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National Aeronautics and
Space Administration

John B. Taylor
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Marshall Space Flight Center
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MARSHALL SPACE FLIGHT CENTER / HUNTSVILLE, ALABAMA
WEDNESDAY, JUNE 20, 1990 / 2:00 P.M.

THANK YOU, DICK [TRULY]. I CAN'T TELL YOU HOW LUCKY WE ARE HAVING THIS MAN LEAD NASA THROUGH THESE EXCITING TIMES. AND I'M PLEASED TO BE HERE WITH GOVERNOR GUY HUNT, WHO IS DOING SUCH AN OUTSTANDING JOB FOR THE GREAT STATE OF ALABAMA. AND I ALSO WANT TO THANK JACK LEE, THE DIRECTOR OF THIS CENTER AND MY TOUR GUIDE TODAY. VERY EDUCATIONAL, BELIEVE ME.

(SORRY WE WERE A LITTLE LATE GETTING STARTED. BUT YOU KNOW HOW THESE ARRANGEMENTS AFFECT EVERYTHING. TODAY EVEN I COULDN'T FIND A PARKING PLACE.) \\\

(WHENEVER I'M IN WEATHER THIS HOT IT REMINDS ME OF MY BASEBALL DAYS IN COLLEGE. THE PLAYERS USED TO GATHER AROUND HOME PLATE SO THEY COULD FEEL THE BREEZE AS I STRUCK OUT!) \\\

BUT IT'S GREAT TO BE BACK IN ALABAMA, AND GREAT TO BE BACK IN HUNTSVILLE. I'M VERY PROUD OF THIS STATE, AND THIS FACILITY. THE MARSHALL SPACE FLIGHT CENTER IS THE BIRTHPLACE OF AMERICA'S FIRST SATELLITE, AMERICA'S FIRST SPACE STATION -- AND THE WORLD'S FIRST MOON ROCKET. IT WAS HERE, WITH THE SATURN FIVE, THAT HUMANKIND BEGAN ITS HISTORIC JOURNEY TO THE STARS. \\\

BECAUSE OF THESE TRADITIONS, HUNTSVILLE HAS A SPECIAL IMPORTANCE TO AMERICA AND TO THE WORLD.

AND IT HAS A SPECIAL IMPORTANCE TO ME, AS WELL. IT WAS TO HUNTSVILLE THAT I JOURNEYED IN THE FALL OF 1987, TO GIVE THE CAMPAIGN'S FIRST MAJOR ADDRESS ON SPACE.

ON THAT OCTOBER DAY, TWO AND A HALF YEARS AGO, I PROMISED TO CREATE A NATIONAL SPACE COUNCIL, CHAIRED BY THE VICE PRESIDENT. I PLEDGED TO UNDERWRITE MISSION TO PLANET EARTH, TO BOOST SPACE SCIENCE, AND TO LAUNCH A DYNAMIC NEW PROGRAM OF BOTH MANNED AND UNMANNED EXPLORATION OF THE SOLAR SYSTEM.

AND TODAY I'M PLEASED TO RETURN TO MARSHALL TO REPORT THAT MY ADMINISTRATION HAS MADE GOOD THESE PROMISES. AND WE'VE DONE IT THE OLD-FASHIONED WAY -- THE AMERICAN WAY -- STEP-BY-STEP, PROGRAM-BY-PROGRAM, ALL ADDING UP TO THE MOST AMBITIOUS AND FAR-REACHING EFFORT SINCE MARSHALL AND APOLLO TOOK AMERICA TO THE MOON. \\\

THE SPACE COUNCIL I PROPOSED IS NOT ONLY UP AND RUNNING, BUT -- UNDER THE DYNAMIC LEADERSHIP OF AMERICA'S OUTSTANDING VICE PRESIDENT -- LEADING THE WAY INTO THE 21ST CENTURY. MISSION TO PLANET EARTH -- A BOLD AND UNPRECEDENTED INITIATIVE TO PRESERVE OUR PRECIOUS ENVIRONMENTAL HERITAGE -- HAS BEEN PLUCKED OFF THE DRAWING BOARD AND PLACED IN THE HANDS OF THE SCIENTISTS WHO WILL MAKE IT HAPPEN.

AND NOW THAT THE SHUTTLE PROGRAM HAS PUT AMERICA BACK IN SPACE, WE STAND AT THE DAWN OF A NEW ERA IN SPACE SCIENCE, WITH WONDERS LIKE THE HUBBLE SPACE TELESCOPE, AND THE FANTASTIC VOYAGE OF GALILEO TO JUPITER.

EXACTLY 11 MONTHS AGO, I STOOD BEFORE THE AIR AND SPACE MUSEUM IN WASHINGTON TO COMMEMORATE A SPECIAL ANNIVERSARY FOR YOU WHO WORK AT THE MARSHALL SPACE FLIGHT CENTER -- THE 20TH ANNIVERSARY OF APOLLO 11'S THUNDEROUS JOURNEY TO THE MOON.

AND STANDING WITH NEIL ARMSTRONG AND DOZENS OF OTHER ASTRONAUTS, I ANNOUNCED THREE MAJOR SPACE POLICY OBJECTIVES: FIRST, TO HAVE SPACE STATION FREEDOM <u>UP</u> BEFORE THE CENTURY IS <u>OUT</u>. SECOND, FOR THE NEW CENTURY, A PERMANENT LUNAR BASE. WE'RE GOING "BACK TO THE MOON, BACK TO THE FUTURE -- AND THIS TIME -- BACK TO <u>STAY</u>."

THE THIRD OBJECTIVE WAS REFINED LAST MONTH IN TEXAS, WHERE I WENT TO ANNOUNCE A NEW AGE OF EXPLORATION, WITH NOT ONLY A GOAL, BUT A 30-YEAR TIMETABLE. I DECLARED THAT: "BEFORE APOLLO CELEBRATES THE 50TH ANNIVERSARY OF ITS LANDING ON THE MOON -- THE AMERICAN FLAG SHOULD BE PLANTED ON MARS." \\\

BEING FIRST IN SPACE IS NOT JUST AMERICA'S DREAM -- IT IS AMERICA'S DESTINY. AND TO SEE THIS HAPPEN, WE'VE MATCHED RHETORIC WITH RESOURCES.

OUR BUDGET PROPOSES $15.2 BILLION FOR NASA -- AN INCREASE OF NEARLY 25 PERCENT -- AND THE LARGEST INCREASE FOR ANY MAJOR AGENCY OF THE GOVERNMENT.

UNFORTUNATELY, NOT EVERYONE ON CAPITOL HILL SHARES THIS COMMITMENT TO INVESTING IN AMERICA'S FUTURE. LAST WEEK, THE HOUSE APPROPRIATIONS SUB-COMMITTEE FOR SPACE VOTED TO PULL THE PLUG ON THIS HISTORIC UNDERTAKING, COMPLETELY GUTTING THE SEED MONEY WE PROPOSED FOR THE MOON/MARS MISSION.

BUT YOU KNOW, SPACE USED TO BE A BI-PARTISAN EFFORT -- AN AMERICAN EFFORT. THE LAST TIME A PRESIDENT VISITED MARSHALL, JOHN F. KENNEDY COMPARED THOSE WHO WERE UNCERTAIN ABOUT AMERICA'S LEADERSHIP IN SPACE TO THOSE IN QUEEN ISABELLA'S COURT WHO COUNSELED, IN EFFECT, "TURN BACK! LEAVE THE RICHES AND REWARDS FOR OTHER NATIONS AND BRAVER HEARTS!"

SOME SAY THE SPACE PROGRAM SHOULD WAIT -- THAT WE SHOULD ONLY GO FORWARD ONCE THE SOCIAL PROBLEMS OF TODAY ARE COMPLETELY SOLVED.

BUT HISTORY PROVES THAT ATTITUDE IS SELF-DEFEATING. HAD COLUMBUS WAITED UNTIL ALL THE PROBLEMS OF HIS TIME WERE SOLVED -- THE TIMBERS OF THE SANTA MARIA WOULD BE ROTTING ON THE SPANISH COAST TO THIS DAY. INSTEAD HE VENTURED FORTH -- AND HIS TRAVELS BROUGHT SPAIN TO THE ZENITH OF HER STATURE AS A NATION. \\\

MANY AN AMERICAN SCHOOLKID HAS READ THE STORY OF COLUMBUS'S DOUBTERS, AND SHOOK THEIR HEADS IN DISBELIEF THAT THESE NAYSAYERS COULD HAVE BEEN SO SHORT-SIGHTED.

MY FRIENDS, WE MUST NOT LET THE CHILDREN OF THE FUTURE SHAKE THEIR HEADS AT OUR BEHAVIOR. RIGHT NOW, IN THE FUNDING WARS IN CONGRESS, WE FACE A CENTRAL QUESTION -- THE QUESTION OF WHETHER AMERICA WILL CONTINUE TO BE A PIONEERING NATION.

WHEN JOHN F. KENNEDY STOOD BEFORE THE CONGRESS IN 1961 AND SPOKE ABOUT THE MOON, HE SPOKE TO A NATION OF PIONEERS.

NOW SOME IN CONGRESS APPEAR READY TO <u>GIVE UP</u> ON THAT PIONEERING SPIRIT -- TO TURN THEIR SIGHTS INWARD, TO CONCEDE THAT AMERICA'S DAYS AS A LEADER IN SPACE HAVE PASSED.

I, FOR ONE, AM NOT READY TO GIVE UP. AMERICA HAS ALWAYS BEEN, AND <u>WILL ALWAYS BE</u>, A NATION OF PIONEERS. I MAY NOT BE HERE IN 2019 -- BUT SOME OF YOU YOUNG PEOPLE IN THE AUDIENCE WILL BE.

AND ON THAT SPECIAL DAY 30 YEARS FROM NOW, I WANT YOU TO THINK BACK TO THE COMMITMENT WE MADE HERE TODAY, AS YOU LOOK AT THE T.V. MONITORS -- MAYBE RIGHT HERE AT MARSHALL SPACE CENTER -- AND WATCH THE FIRST AMERICAN PLANT HIS FEET ON MARS.

DURING THE APOLLO ERA, AMERICA'S SPACE EFFORTS GREW AT UNPRECEDENTED RATES, THE GOVERNMENT HIRED THE BIGGEST AND THE BEST SCIENTIFIC FORCE IN HISTORY, AND COLLEGES AND UNIVERSITIES SWELLED WITH APPLICANTS AND GRADUATES IN SCIENCE AND ENGINEERING.

IT PRODUCED A GOLDEN AGE OF AMERICAN TECHNOLOGY ADVANCEMENT -- AN AGE THAT, TODAY, WE CAN RECAPTURE AND BEGIN ANEW.

WERNHER VON BRAUN WAS THE GIANT WHO PUT HUNTSVILLE ON THE MAP. WHEN SOMEONE ASKED HIM WHAT IT WOULD TAKE TO BUILD A ROCKET TO REACH THE MOON, VON BRAUN REPLIED SIMPLY: "THE WILL TO DO IT." \\\

AND SO I STAND TODAY AT THIS MONUMENT TO DARING AND IMAGINATION THAT VON BRAUN BUILT -- AND CALL ON THE AMERICAN CONGRESS TO STEP FORWARD WITH THE WILL THAT THE MOMENT REQUIRES.

DON'T POSTPONE GREATNESS. HISTORY TELLS US WHAT HAPPENS TO NATIONS THAT FORGET HOW TO DREAM. THE AMERICAN PEOPLE WANT US IN SPACE. SO LET US CONTINUE THE DREAM -- FOR OUR STUDENTS, FOR OURSELVES, AND FOR ALL HUMANKIND. \\\

THANK YOU. GOD BLESS YOU. AND GOD BLESS THE UNITED STATES OF AMERICA.

# # #

Preliminary Results of House Mark-up
NASA Portion of FY 1991 Exploration Initiative
($$$s in millions)

NASA:	1990 Program	FY 1991 Total Request	FY 1991 SEI Increm	House Mark Total Mark	House Mark Amount Cut
National Aerospace Plane	59.0	119.0	0.0	114.0	5.0
Space Research and Technology	124.6	314.9	88.0	115.9	199.0
R&T Base	35.2	36.3		36.3	
Exploration Mission Studies	5.0	0.0		0.0	
Exploration Tech (Pathfinder)	21.9	179.4	88.0	25.4	154.0
Civil Space Technology (CSTI)	57.1	92.3		47.3	45.0
In-Space Experiments	5.4	6.9		6.9	
Exploration Mission Studies	(15.0)	37.0	0.0	0.0	37.0
Space Transportation Cap Dev	21.2	64.3	50.0	14.3	50.0
ALS Civil Systems	0.0	3.9		3.9	
ALS Propulsion	0.0	40.0	40.0	0.0	40.0
Exploration Studies	5.0	0.0		0.0	
Advanced Transportation (base)	5.7	10.4		10.4	
Shutt-C PhB/Heavy Lift	10.5	10.0	10.0	0.0	10.0
Life Sciences	50.4	80.0	0.0	72.0	8.0
Extended Duration (SSF)	0.4	10.0		10.0	
Lifesat Def./Centrifuge/SBI	7.8	16.2		8.2	8.0
Research & Analy/Spacelab	42.2	53.8		53.8	
Space Station	5.7	30.8	20.0	30.8	0.0
Solar Dynamics	5.7	10.8	0.0	10.8	
Exploration	0.0	20.0	20.0	20.0	
Planetary	186.9	227.6	30.0	212.6	15.0
Mars Observer	98.9	83.9	15.0	83.9	
MO Launch Vehicle/TOS	73.2	124.2		124.2	
Mars Balloon Relay	4.4	2.0		2.0	
Exploration Studies	5.0	0.0		0.0	
Lunar Observer Phase B	2.5	15.0	15.0	0.0	15.0
Other (MRSR/Network)	2.9	2.5		2.5	
Facilities	0.0	32.3	0.0	32.3	0.0
Research & Program Mgmt	55.0	56.9	0.0	56.9	0.0
Total, NASA	502.8	962.8	188.0	648.8	314.0
Other Agencies:					
Department of Defense	323.0	263.0			
National Aerospace Plane	192.0	158.0			
SP-100	20.0	20.0			
Advanced Launch System	111.0	85.0			
Department of Energy	30.0	51.0			
SP-100	30.0	51.0			
Total, Other Agencies	353.0	314.0			
TOTAL, SPACE EXPLORATION	**855.8**	**1,276.8**			

06/13/90

McNally/Simon
June 15, 1990
Draft Two (B:MARSHALL)

PRESIDENTIAL REMARKS: MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA
WEDNESDAY, JUNE 20, 1990, 1:45 P.M.

Truly

Thank you, Jack ~~[[LEE, DIRECTOR OF THE CENTER]]~~. And I'm pleased to be here with Governor Guy Hunt, who is doing such an outstanding job for the ~~great~~ State of Alabama.

Peggy Hazelrigg

[[ADD'L ACKNOWLEDGEMENTS: KEY "SPACE" CONGRESSMEN, ETC.]]

(Sorry we were a little late getting started. But you know how these arrangements affect everything. [[EVENT IS IN THEIR PARKING LOT]] **Today even I couldn't find a parking place.**) \\\

(Whenever I'm in weather this hot it reminds me of my baseball days in college. **The players used to gather around home plate so they could feel the breeze as I struck out!**) \\\

But it's great to be back in Alabama, and great to be back in Huntsville. I'm very proud of this state, and this facility. **The Marshall Space Flight Center is the birthplace of America's first satellite, America's first space station -- and the world's first Moon rocket. It was here, with the Saturn Five, that humankind began its historic journey to the stars.** \\\

NASA pamphlet
IRE speech 9-8-60

Because of these traditions, Huntsville has a special importance to America and to the world. And it has a special importance to me, as well. It was to Huntsville that I journeyed in the fall of 1987, to give the campaign's first major address on space.

speech 10-29-87
p. 118 Leadership on the issues

On that October day, two and a half years ago, I promised to create a National Space Council, chaired by the Vice President.

I pledged to underwrite Mission to Planet Earth, to boost space science, and to launch a dynamic new program of both manned and unmanned exploration of the Solar System.

And today I'm pleased to return to Marshall to report that my Administration has made good these promises. **And we've done it the old-fashioned way -- the <u>American</u> way -- step-by-step, program-by-program, all adding up to the most ambitious and far-reaching effort since Marshall and Apollo took America to the Moon.** \\\

The Space Council I proposed is not only up and running, but -- under the dynamic leadership of America's outstanding Vice President -- leading the way into the 21st Century. Mission to Planet Earth -- a bold and unprecedented initiative to preserve our precious environmental heritage -- has been plucked off the drawing board and placed in the hands of the scientists who will make it happen. And now that the Shuttle program has put America back in space, we stand at the dawn of a new era in space science, with wonders like the Hubble Space Telescope, and the fantastic voyage of Galileo to Jupiter ~~and beyond~~.

apollo speech 7-20-89

Exactly 11 months ago, I stood before the Air and Space Museum in Washington to commemorate a special anniversary for you who work at the Marshall Space Flight Center -- the 20th anniversary of Apollo 11's thunderous journey to the Moon. And standing with Neil Armstrong and dozens of other astronauts, I announced three major space policy objectives: First, to have Space Station Freedom <u>up</u> before the century is <u>out</u>. Second, for

the new century, a permanent lunar base. We're going **"back to the Moon, back to the future -- and this time -- back to stay."**

Texas A&I speech 5-11-90

The third objective was refined last month in Texas, where I went to announce a new Age of Exploration, with not only a goal, but a 30-year timetable. I declared that: **"Before Apollo celebrates the 50th anniversary of its landing on the Moon -- the American flag should be planted on Mars."** \\\

Being first in space is not just America's dream -- it is America's destiny. And to see this happen, we've matched rhetoric with resources. Our budget proposes $15.2 billion for NASA -- an increase of nearly 25 percent -- and the largest increase for any major agency of the government.

FY 91 Budget p. 50-51

Unfortunately, not everyone on Capitol Hill shares this commitment to investing in America's future. Last week, the House Appropriations Sub-Committee for Space voted to pull the plug on this historic undertaking, completely gutting the seed money we proposed for the Moon/Mars mission.

Mark Albrecht, Nat'l. Space Council

But you know, space used to be a bi-partisan effort -- an American effort. The last time a President visited Marshall, John F. Kennedy compared those who were uncertain about America's leadership in space to those in Queen Isabella's Court who counseled, in effect, "Turn back! Leave the riches and rewards for other nations and braver hearts!"

JFK speech 5-18-63

Some say the space program should wait -- that we should only go forward once the social problems of today are completely solved. But history proves that that attitude is self-defeating.

Had Columbus waited until all the problems of Spain were solved -- the timbers of the Santa Maria would be rotting in Barcelona to this day. Instead he ventured forth -- and his travels made Spain rich beyond all dreams, the zenith of her stature as a nation. \\\

Many an American schoolkid has read the story of Columbus' doubters, and shook their heads in wonder that they could have been so short-sighted. Well, next week the House Appropriations Committee gets its own crack at the history books. **And I say to them that the future is NOW. Don't postpone greatness. Twenty years is long enough. And history tells us what happens to nations that forget how to dream.** \\\\

During the Apollo era, America's space efforts grew at unprecedented rates, the government hired the biggest and the best scientific force in history, and colleges and universities swelled with applicants and graduates in science and engineering. It produced a golden age of American technology advancement -- an age that, today, we can recapture and begin anew.

Wernher Von Braun was the giant who put Huntsville on the map. When someone asked him what it would take to build a rocket to reach the Moon, Von Braun replied simply: **"The will to do it."** \\\

And so I stand today at the temple Von Braun built -- and call on the American Congress to step forward with the will that the moment requires. **The American people want us in space. Let**

us continue the dream -- for our students, for ourselves, and for all humankind. \\\

Thank you. God bless you. And God bless the United States of America.

# # #

Neph

STATUS AND PERSPECTIVES ON THE PRESIDENT'S SPACE EXPLORATION INITIATIVE

- On December 14, 1972 Gene Cernan left man's last footprint on the moon. The Apollo program cost $100B (1990 dollars) and took eight years. During that time other, non-Apollo space efforts grew at unprecedented rates, the government hired the largest scientific force in history (and the best), and colleges and universities swelled with applicants and graduates in science and engineering. It is widely regarded as the golden age of American technology advancement.

- President Nixon later in 1972 decided against a follow-on exploration initiative to include a space station, a return to the moon and a manned journey to Mars.

- President Nixon, instead started the space shuttle program as a "stepping stone", but made no commitments beyond that development.

- President Reagan in 1984 initiated the space station program as a means of "assuring for the United States preeminence in the utilization and exploration of space".

- Early congressional criticism of the space station focused on the lack of an overall plan and strategy. In 1985 President Reagan established a national commission to provide a long range strategy.

- In January of 1986, the space shuttle Challenger exploded during launch, killing seven people.

- The national commission reported later in 1986 and was followed by the Ride report to NASA on America's future in space, both cited a lack of long term focus as a critical defect in our space program.

- The National Academy of Sciences wrote President-elect Bush in December, 1988 urging him to provide a long term focus for our space efforts, a durable framework to establish priorities.

- On July 20, 1989 President Bush announced a long term goal for space exploration, completion of Space Station Freedom before the end of the nineties, a return to the moon to stay, and a human exploration of Mars.

- The exploration initiative was enthusiastically received by the space community, and immediately attacked by Congressional Democrats as an unaffordable pipe dream on the one hand and too vague, without firm timetables and cost estimates on the other. The general public reception was mixed and low key.

• In the late Winter of 1990, President Bush further defined the initiative as a focused technology development program for the next few years with an objective of developing alternate approaches which promised lower costs and better performance, and he invited international cooperation. He also set a target of a manned mission to Mars no later than 2019.

• The FY 91 NASA budget request included $952M for the Space Exploration Initiative (SEI). Roughly $764M of ongoing programs and $188M of new money.

• In March, 1990 the President met with Congressional leaders to discuss space and his exploration initiative.

• On Tuesday, the House subcommittee on NASA appropriations funded the bulk of the President's overall space request, but specifically and purposefully zeroed the SEI.

6/12

ISSUE:

How hard should the Administration fight for the exploration initiative within the Congress?

PRO's:

• This initiative has been the galvanizing focus of the President's thrust in space. Failure to rally about it now will show weakness and lack of commitment to the entire program.

• Having thrust the exploration gauntlet down, the entire manned effort hangs in the balance. For example, the space station is designed to provide the life science data required for manned flight beyond low earth orbit. The station is to be permanently manned. Both of these capabilities would be threatened by a rejection of long term space exploration goals. The Space Shuttle itself would come under attack as expensive and dangerous with no central purpose.

• With Japan and Europe moving out on their own manned programs, this would undermine our leadership role.

• Ultimately, the question is, if not us, who? If not now, when? Having started this, the President has to finish it.

CON's:

• The initiative has not generated a groundswell of support on the Hill. A lot of work would be required to make a floor issue of this.

- We could always do our spadework over the coming year and take it up next year, perhaps winning more popular support.

RECOMMENDATIONS:

1. The President's speech in Huntsville, AL on Jun 21 should reinforce the President's commitment to space exploration and take strong issue with the House Committee action.

2. OMB should issue a forceful reclama to the House Appropriations Committee concerning the exploration program.

3. The Administration should work, at the summit level, to obtain the largest possible allocation for NASA.

4. The Administration position should be that money for the SEI is a requirement at any level of NASA funding.

5. The Vice President should personally contact House and Senate appropriations committee senior members to express the Administrations commitment to a strong exploration program.

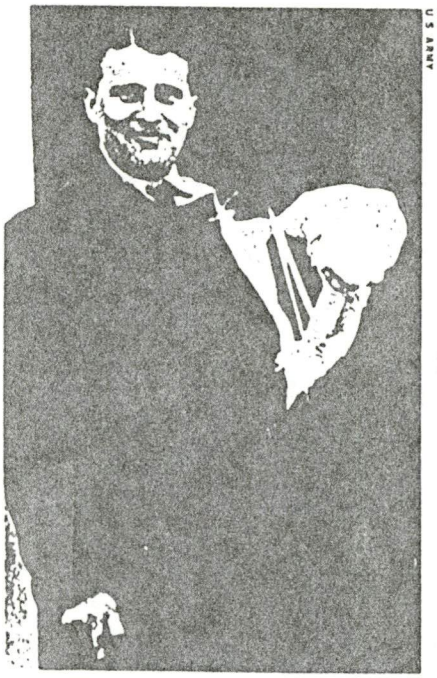
6. Senior White House and OMB leadership should undertake vigorous efforts to ensure the Senate Appropriations allocation and subcommittee mark contain SEI funds.

The Will to Do It

His first rocket—pressurized with a bicycle pump and launched from a local dump—failed to fly. Some of his later models flew only too well, taking off from sites in Germany and occupied Holland to impact on London with horrifying effect. But if Wernher von Braun, who died of cancer last week at 65, is remembered by future generations, it will probably be for his postwar achievements. As one of the most valuable war trophies carried home by the U.S., he headed the team that developed the Jupiter C rocket that put the U.S. into the space race by launching the Explorer 1 satellite in 1958. His team pioneered the development of the Redstone, which carried America's first astronaut aloft in 1961. Most important, he designed and developed the huge Saturn 5 rocket, which opened a new era of space exploration in 1969 when it carried the Apollo 11 astronauts to the surface of the moon. "Wernher von Braun's name was inextricably linked to our exploration of space," said President Carter. "Not just the people of our nation, but all the people of the world have profited from his work."

Born in Germany, where his father was a baron, Von Braun showed a precocious interest in rocketry; at the age of twelve he managed to construct a rocket-powered wagon, and by the time he was 21 he had outlined the design for a moon rocket. His genius led the German army to employ him in 1932 to develop liquid-fueled rockets; by 1937 it had moved him to the Baltic Sea port of Peenemünde, where began the work that led to Hitler's dreaded V-2 rocket. As the war drew to a close, Von Braun was considering a missile that could reach New York City.

In early 1945, as Russian armies approached Peenemünde, Von Braun and many of his staff fled to Bavaria and surrendered to U.S. troops. The Americans recognized the value of their prisoner. Within a few months, he was working under contract to the U.S. Army at the White Sands Proving Grounds in New Mexico. By 1950, he was placed in charge of guided missile development at the Redstone Arsenal near Huntsville, Ala. In 1960, Von Braun, who had since become an American citizen, was named director of NASA's Marshall Space Flight Center at Huntsville and charged with building the rockets that would eventually carry U.S. astronauts to the moon.



VON BRAUN SURRENDERING IN 1945
A 20th century Columbus.

Von Braun's readiness to work for a new master and single-minded dedication to rocketry won him some critics. Satirist Tom Lehrer skewered Von Braun in a mocking song (Sample verse: "Once the rockets are up/ Who cares where they come down/ That's not my department/ Says Wernher von Braun"). Even some Von Braun admirers admitted that their hero was not always easy to like.

But most of those who worked with Von Braun felt that he was a genius. Alan Lovelace, acting director of NASA, described the handsome German as "a 20th century Columbus who pushed back the new frontiers of outer space with efforts that enabled his adopted country to achieve pre-eminence in space exploration." Colleague Ernst Stuhlinger considered him an excellent engineer with an almost uncanny ability to visualize both a problem and its solutions, and a brilliant leader who could transmit his enthusiasm to others. Stuhlinger's admiration is understandable. When someone asked Von Braun what it would take to build a rocket to reach the moon, Von Braun replied simply: "The will to do it."

Von Braun ignored both the criticism and the praise, concentrating on his goal of turning the space race into a vehicle for international cooperation. He once said: "I look forward to the day when mankind will join hands to apply the combined technological ingenuity of all nations to the exploration and utilization of outer space for peaceful uses." That day has not yet arrived, but Von Braun's work has certainly helped to bring it closer.

McNally/Simon
June 14, 1990
Draft One (B:MARSHALL)

PRESIDENTIAL REMARKS: MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA
WEDNESDAY, JUNE 20, 1990, 1:45 P.M.

Thank you, _____. And I'm pleased to be here with Governor Guy Hunt, who is doing such an outstanding job for the great State of Alabama. (Also here today -- Congressmen _____ _____, etc., etc.)

(Sorry we were a little late getting started. But you know how these arrangements affect everything. [[EVENT IS IN THEIR PARKING LOT]] **Today even I couldn't find a parking place.**) \\\

(Whenever I'm in weather this hot it reminds me of my baseball days in college. **The players used to gather around home plate so they could feel the breeze as I struck out!**) \\\

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On that October day, two and a half years ago, I promised to create a National Space Council, chaired by the Vice President.

I pledged to underwrite Mission to Planet Earth, to boost space science, and to launch a dynamic new program of both manned and unmanned exploration of the Solar System.

And today I'm pleased to return to Marshall to report that my Administration has made good these promises. **And we've done it the old-fashioned way -- the <u>American</u> way -- step-by-step, program-by-program, all adding up to the most ambitious and far-reaching effort since Marshall and Apollo took America to the Moon.**

The Space Council I proposed is not only up and running, but -- under the dynamic leadership of America's outstanding Vice President -- leading the way into the 21st Century. Mission to Planet Earth -- a bold and unprecedented initiative to preserve our precious environmental heritage -- has been plucked off the drawing board and placed in the hands of the scientists who will make it happen. And now that the Shuttle program has put America back in space, we stand at the dawn of a new era in space science, with wonders like the Hubble Space Telescope, and the fantastic voyage of Galileo.

Exactly 11 months ago, I stood before the Air and Space Museum in Washington to commemorate a special anniversary for you who work at the Marshall Space Flight Center -- the 20th anniversary of Apollo 11's thunderous journey to the Moon. And standing with Neil Armstrong and dozens of other astronauts, I announced three major space policy objectives: First, to have Space Station Freedom <u>up</u> before the century is <u>out</u>. Second, for

the new century, a permanent lunar base. We're going **"back to the Moon, back to the future -- and this time -- back to stay."**

The third objective was refined last month in Texas, where I went to announce a new Age of Exploration, with not only a goal, but a 30-year timetable. I declared that: **"Before Apollo celebrates the 50th anniversary of its landing on the Moon -- the American flag should be planted on Mars."** \\\

Being first in space is not just America's dream -- it is America's destiny. And to see this happen, we've matched rhetoric with resources. Our budget proposes $15.2 billion for NASA -- an increase of nearly 25 percent -- and the largest increase for any major agency of the government.

Unfortunately, not everyone on Capitol Hill shares this commitment to investing in America's future. Last week, the House sub-committee on space voted to pull the plug on this historic undertaking, completely gutting the seed money we proposed for the Moon/Mars mission.

But you know, space used to be a bi-partisan effort -- an American effort. The last time a President visited Huntsville, John F. Kennedy compared those who were uncertain about America's leadership in space to those in Queen Isabella's Court who counseled, in effect, "Turn back! Leave the riches and rewards for other nations and braver hearts!"

Some say the space program should wait -- that we should only go forward once the social problems of today are completely solved. But history proves that that attitude is self-defeating

-- and that that day will never come. **Had Columbus waited until all the problems of Spain were solved -- the timbers of the Santa Maria would be rotting in Barcelona to this day. Instead he ventured forth -- and his travels made Spain rich beyond all dreams, the zenith of her stature as a nation.**

Knowing what we do today, many an American schoolkid has read the story of Columbus' doubters, and shook their heads in wonder that such influential leaders could have been so short-sighted. Well, next week the House appropriations committee gets its own crack at the history books. **And I say to them that the future is NOW. Don't postpone greatness. Twenty years is long enough. And history tells us what happens to nations that forget how to dream.**

During the Apollo era, America's space efforts grew at unprecedented rates, the government hired the biggest and the best scientific force in history, and colleges and universities swelled with applicants and graduates in science and engineering. It produced a golden age of American technology advancement -- an age that, today, we can recapture and begin anew.

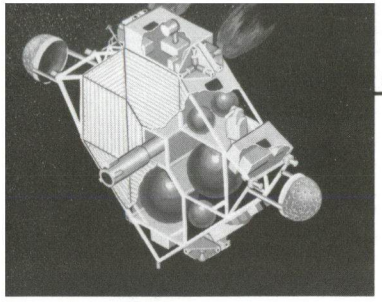
Werner Von Braun was the giant who put Huntsville on the map. When someone asked him what it would take to build a rocket to reach the Moon, Von Braun replied simply: **"The will to do it."** \\\

And so I stand today at the temple Von Braun built -- and call on the American Congress to step forward with the will that the moment requires. **The American people want us in space. Let**

us continue the dream -- for our students, for ourselves, and for all humankind.

Thank you. God bless you. And God bless the United States of America.

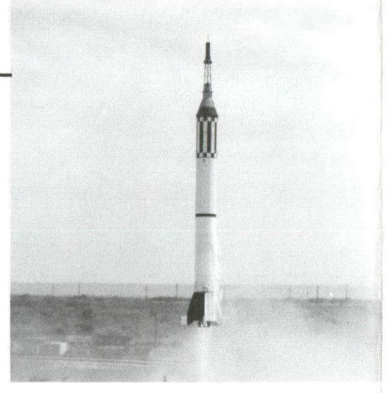
# # #



OMV

Marshall is also responsible for the **Orbital Maneuvering Vehicle,** or "OMV" as it is sometimes called. This unmanned robotic vehicle will be carried into orbit by the Shuttle and perform a number of activities, such as moving satellites from one orbit to another. It is expected to extend the range of Shuttle on-orbit operations by about 1,500 miles and will play an important role in the Space Station program. Its rendezvous and berthing, or docking, with satellites or other spacecraft will be accomplished remotely by human pilots at work stations on Earth. The first flight of the vehicle is planned for 1991. Eventually it will be based at the Space Station, which will have servicing capability for one or two maneuvering vehicles.

Mercury-Redstone



The Center's Beginnings

The Marshall Center was formed July 1, 1960, by the transfer to NASA of buildings and personnel comprising part of the U.S. Army Ballistic Missile Agency. Named for the famous soldier and statesman, General of the Army George C. Marshall, it was officially dedicated by President Dwight D. Eisenhower on September 8, 1960.

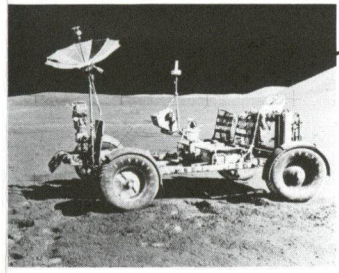
Mr. James R.(J.R.) Thompson Jr. has served as director of the Marshall Center since September 1986. Previous directors were the founding director, Dr. Wernher von Braun, who served from 1960 to 1970; Dr. Eberhard Rees from 1970 to 1973; Dr. Rocco A. Petrone from January 1973 to June 1974; and Dr. William R. Lucas from June 1974 until June 1986.

Marshall's Historic Successes

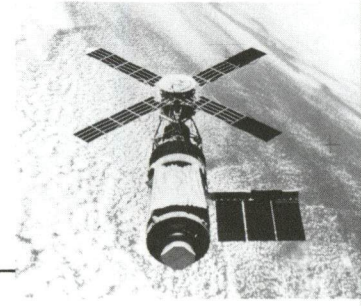
The Center's major mission from its inception to 1969 was the development of the Saturn family of heavy space rockets. The largest of these, the Saturn V, was used in landing the first man on the Moon on July 20, 1969.

Six additional Saturn V's were used in the Apollo Program of manned expeditions to the Moon, and all of the stages performed flawlessly.

Lunar Roving Vehicles, developed by Marshall to carry two astronauts over the surface of the Moon for a distance of several miles from the landing site, accompanied the last three Apollo missions to the Moon.



Lunar Roving Vehicle

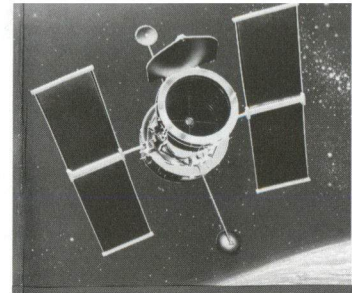


Skylab

The Marshall Center played a significant role in the success of Skylab, man's first Space Station. Skylab's three different three-man crews spent up to 84 days in Earth orbit and performed a variety of more than 100 experiments. The Marshall Center provided the four Saturn launch vehicles and most of the Skylab hardware. The Center was also responsible for the direction of many of the experiments in Skylab.

The Apollo-Soyuz Test Project was an international space mission in which the Soviet Soyuz and American Apollo space vehicles remained docked in orbit for two days. Marshall provided the Saturn 1B launch vehicle for the Apollo spacecraft and managed certain assigned experiments, as well as participating in mission planning.

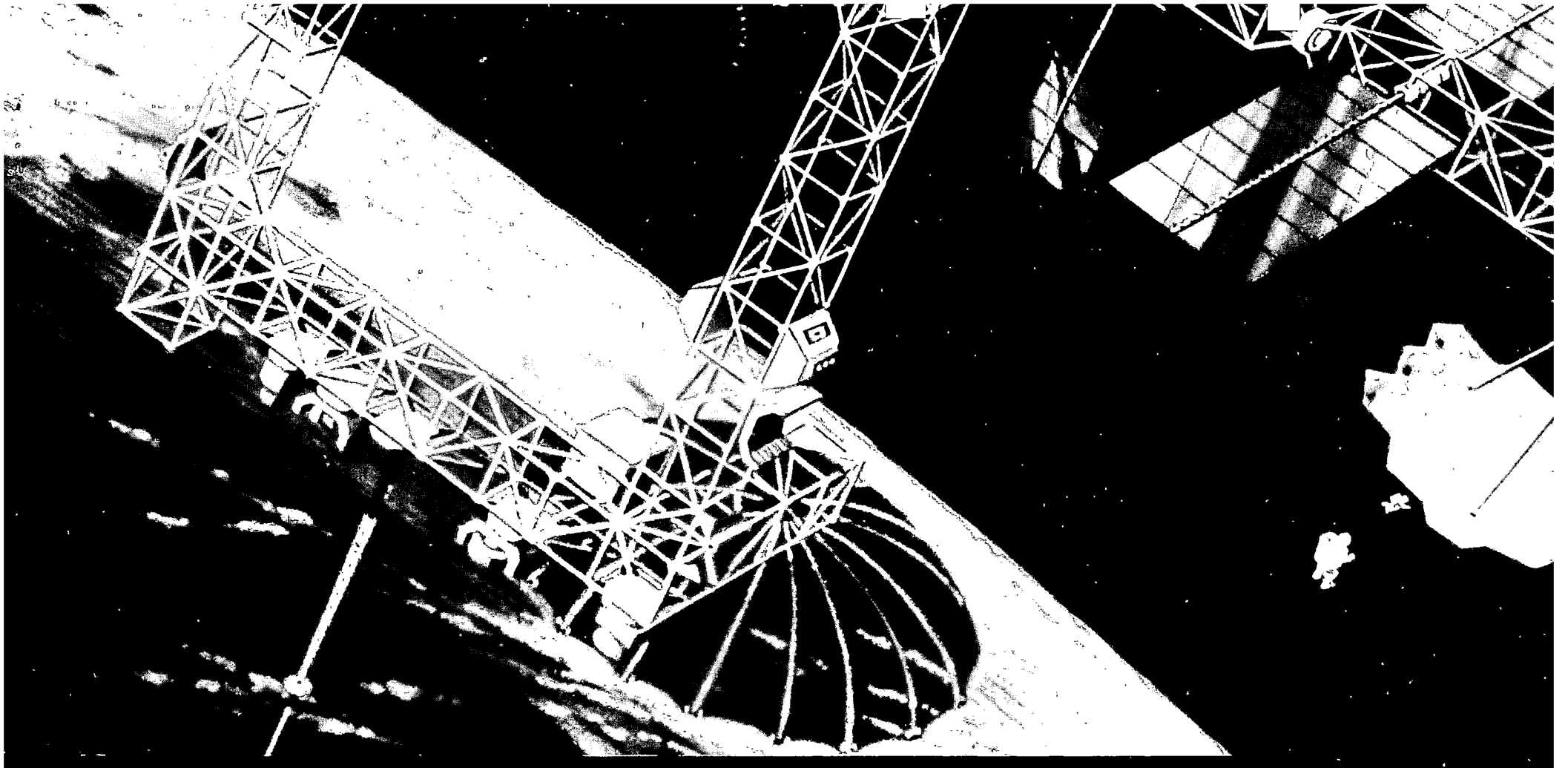
For a number of years in the late 1970s and early '80s, the Marshall Center managed a famed series of orbiting instruments known as the High Energy Astronomy Observatories. The entire family of three HEAO satellites, designed to study high energy radiation in the universe such as X-rays and cosmic rays, returned significant data to scientists over a period of several years. All three of the High Energy Astronomy Observatories were regarded as highly successful.



Marshall Space Flight Center

Huntsville, Alabama

NASA



Looking to the Future

In other areas of study, the Marshall Center is examining ways to lift heavier amounts of material into space. Eventually, larger payload capability than the 65,000 pounds provided by the Shuttle will be required as mankind extends itself into the further reaches of space. Marshall has been looking into designs of cargo vehicles to be used in the next decade and beyond, some of which may carry as much as 250,000 pounds of payload. Evolving from components of the Shuttle into completely new versions called **heavy-lift launch vehicles,** or "HLLVs", these cargo carriers are proposed for the late 1990s and the early years of the 21st century.

Also under study at the Marshall Center are a variety of other possible programs. These include:

*The **Orbital Transfer Vehicle,** which would carry Shuttle payloads to higher orbits than the Shuttle is capable of doing, including geosynchronous orbit 22,300 miles above the equator, and would retrieve payloads from higher orbits and return them to the Shuttle.

*Gravity Probe-B, a module in low Earth orbit and employing super-accurate gyroscopes, that would test a portion of Einstein's theory of general relativity and provide data to resolve conflicting gravitational theories.

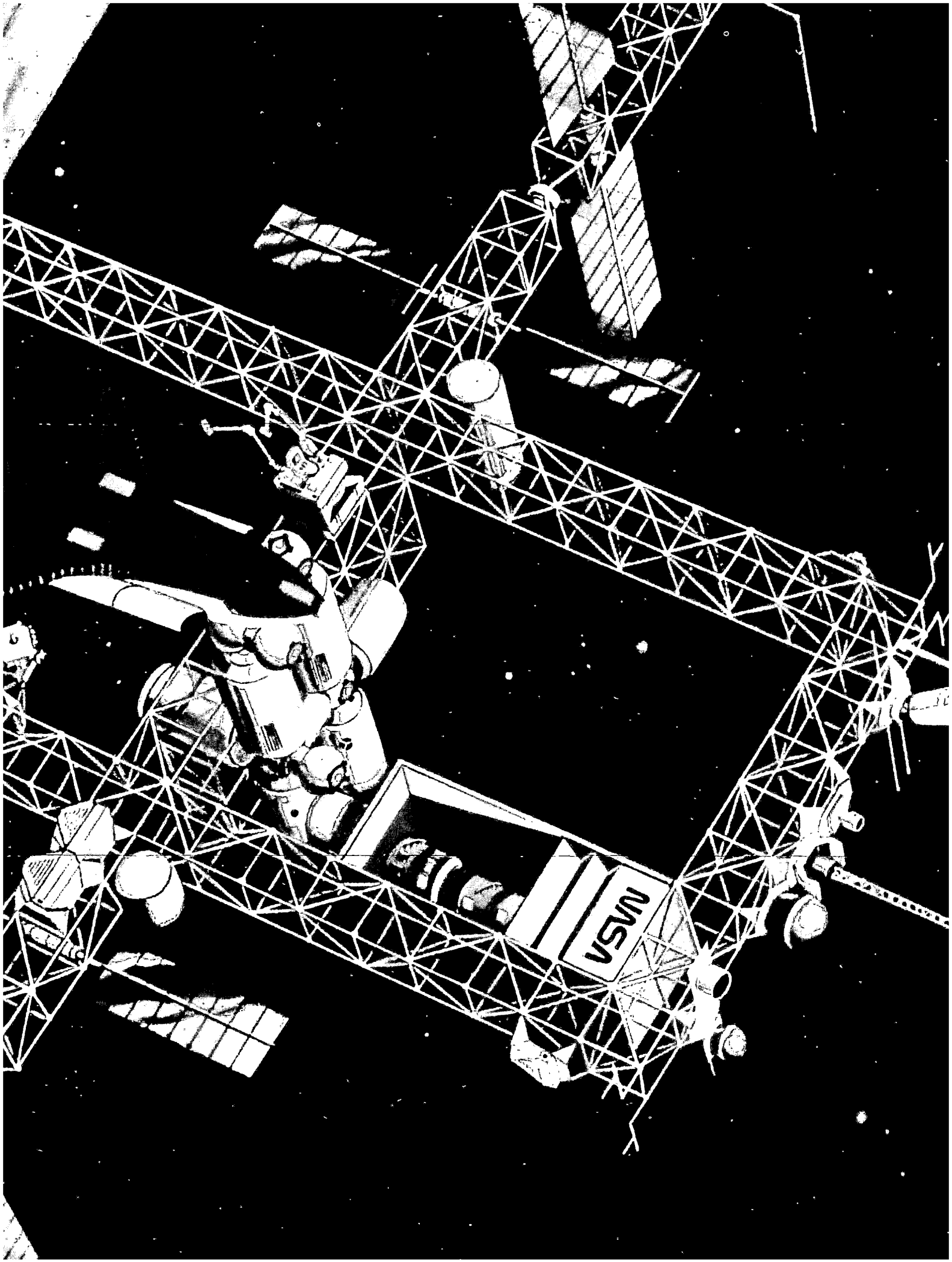
*The **Advanced X-Ray Astrophysics Facility,** an orbiting X-ray observatory proposed for launch later in the decade, that would be many times more sensitive than its predecessors and would peer into space for X-ray sources toward the very edge of the observable universe.

*The **Advanced Solar Observatory,** a combination of instruments — possibly as an attached payload to the Space Station — that would study the full spectral range of electromagnetic radiation from the sun.

Broad Range of Research

The Marshall Center now conducts a broad range of supporting research in many scientific and engineering disciplines including propulsion, electronics, materials (including processing in space), solar energy conversion, structures, dynamics, testing, data management and others.

The concrete and steel structures, the swift computers and the laboratories with sensitive equipment here are valued at over 400 million dollars.


USN

A Primary NASA Center

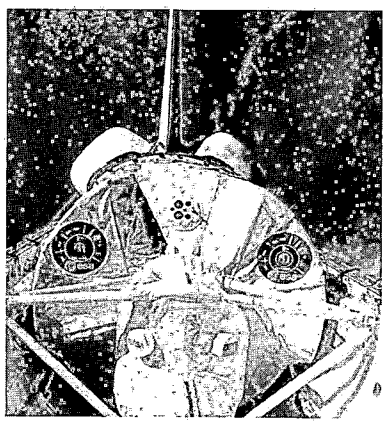
The Marshall Space Flight Center, located on 1,800 acres inside Redstone Arsenal at Huntsville, Ala., is a part of the U.S. National Aeronautics and Space Administration.

The Center has about 3,300 civil service employees. Of this number, about 58 percent are scientists and engineers and 16 percent are business professionals. The remainder consists of technicians and administrative and clerical personnel.

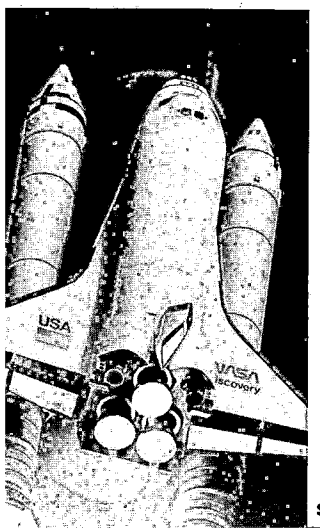
Two other sites are managed by Marshall: the Michoud Assembly Facility, New Orleans, used for manufacturing the External Tank; and the Slidell Computer Complex, Slidell, La., which provides computer services to the Michoud facility.

In the past, the Center has been identified most often as NASA's launch vehicle development center. While this accurately describes part of the Center's activities, it does not tell the whole story.

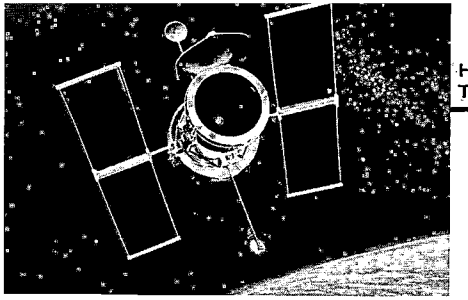
Today, the Marshall Center is a multi-project management, scientific and engineering establishment, with a great deal more emphasis on projects involving scientific investigation and the application of space technology to the solution of problems on Earth. This is the Center's new image, one that will be reflected in the projects of the future.



Spacelab



Shuttle Launch



Hubble Space Telescope

Marshall's Many Assignments

In helping to reach the nation's goals in space, the Center is working on more projects today than at any time in history.

Marshall has a significant role in the development of the **Space Shuttle.** NASA's largest development program, the Shuttle is a reusable launch vehicle system with the capacity to orbit, repair, service, retrieve and replace many different types of space payloads. The Marshall Center is providing the orbiter's engines, the expendable external tank that carries liquid hydrogen and liquid oxygen for those engines, and the solid rocket boosters that assist in lifting the orbiter off the launch pad.

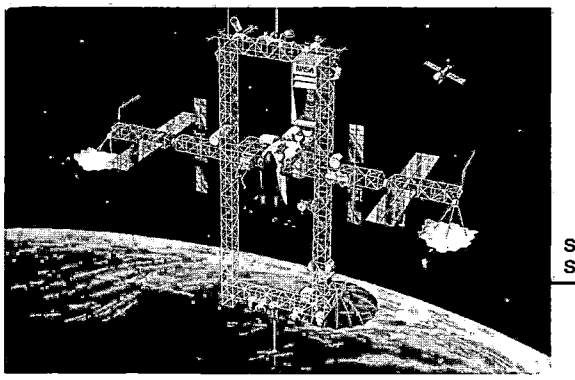
The Center is also playing a key role in development of payloads that are flown aboard the Shuttle.

One such payload is **Spacelab,** a reusable, modular scientific research facility that is carried in the cargo bay of the Shuttle orbiter.

Spacelab is composed of modules in which non-astronaut scientists work and unpressurized pallets to which experiment equipment requiring direct exposure to space is mounted. The facility was designed, tested and provided to NASA by the European Space Agency (ESA). Marshall is responsible for technical and programmatic monitoring of development activities and for development of selected hardware. The Center is also responsible for managing many of the future Spacelab missions.

The **Hubble Space Telescope,** for which Marshall has been assigned management responsibility, is planned as an optical telescope that would be placed in orbit above the Earth's hazy, turbulent atmosphere, enabling scientists to see deep into space — farther than is now possible, perhaps to the outer edges of the universe. The Space Shuttle will place the telescope in orbit in the late 1980s and serve as a base from which astronauts can make repairs and replace instrument packages or add new experiments.

The Marshall Center has been given a substantial role toward the development of a **Space Station,** a permanent manned facility proposed by President Reagan to be in orbit by 1994. The station would offer the capabilities of scientific research and technology



Space Station

development by both government and industry; the commercial use of space in such areas as the manufacture of critical materials and pharmaceuticals not available on Earth; the assembly, servicing and repair of satellites and other large structures in space; and research focused on extending a human being's staying time in space as a first step toward even more ambitious manned space programs. International participation in the Space Station program has been invited by the president.

As now envisioned the Station will be modular in design, with four pressurized modules much like the current Spacelab facility to provide living and working areas, plus a logistics module containing replenishables — air, food, water, clothing, etc. The elements would be carried into low-Earth orbit by the Shuttle and assembled there. The station would be manned by a crew of six to eight people who would rotate about every three to six months. The Marshall Center is responsible for the design of all of the pressurized modules provided by the United States (two other modules will be provided by ESA and Japan).

The **Tethered Satellite System,** the "satellite on a string" expected to be flown in 1990, is also under Marshall management. Scheduled to be carried into orbit by the Space Shuttle, the satellite would be suspended either downward or upward from the Shuttle's cargo bay on a tether — a super-strong synthetic cord about a sixteenth of an inch thick and up to 60 miles in length. When deployed upward, as it will be for its maiden mission in 1990, the satellite will study electrodynamic and other scientific phenomena. Deployed downward, as it will be for later missions, the satellite will troll the Earth's upper atmosphere for magnetospheric, atmospheric and gravitational data.

was honored by having the opportunity last May to act as host for the Sixth Annual Meeting of the SEATO Council of Ministers in Washington. On that occasion I had the great honor and pleasure of greeting personally the Council members, their senior civil and military advisers, the Secretary-General and the Chief of the Military Planning Office of SEATO. At the Sixth Annual Meeting, the member nations renewed their pledges to insure mutual security, reaffirmed their determination to resist Communist aggression and subversion and further developed their plans to foster and support the economic and social advancement of the Treaty Area. On this occasion, I am happy to reaffirm United States support for these solemn pledges.

DWIGHT D. EISENHOWER

287 ¶ Remarks at the Dedication of the George C. Marshall Space Flight Center, Huntsville, Alabama. *September* 8, 1960

Governor Patterson, Mrs. Marshall, Mayor Searcy, Dr. Glennan, Dr. Von Braun, Members of the Congress here present, other distinguished guests, and my fellow Americans—all of you:

It is always good to come back to our Southland, this region of traditional hospitality and friendliness. I thank you, Governor, for making me feel so much at home, and so welcome in your State.

I have long looked forward to visiting this spot. I know that, for an old foot soldier, it will be a revelation to see at firsthand the efforts here under way to probe into the mysteries of the universe millions of miles from our earth.

Already, in brief visits with your distinguished men of rocketry, I have made a significant discovery of my own.

I find that the leaders of the new space science feel as if Venus and Mars are more accessible to them than a regimental headquarters was to me more than 40 years ago, when I was a platoon commander.

To move conceptually, in one generation, from the hundreds of yards that once bounded my tactical world to the unending millions of miles that beckon these men forward, is a startling transformation.

Now I freely admit to sentimentality in my contemplation of these

advances, because so much of this dramatic accomplishment was pioneered in the United States Army, which until recently was my home and my life.

Here, under Army guidance, Redstone and Jupiter and a whole family of missiles have taken form. Here, too, was created Explorer I, America's first earth satellite. I share with the Army its gratification in these trail-blazing achievements, which have their counterparts in other services. These achievements have thrilled the American people and won plaudits throughout the world.

The momentum thus gained accelerates today under the civilian management of the new National Aeronautics and Space Administration, guided by Dr. Glennan, and his Deputy, Dr. Dryden. The gifted scien tists, engineers, and technicians who splendidly served the Army are now eagerly developing, for this new organization, the gigantic launch vehicle Saturn.

No doubt this mighty rocket system makes its presence known loudly—possibly too loudly—in Huntsville. But it is a significant forward step in our conquest of space and for growth in human comprehension.

Already we have improved our understanding of matter, energy, motion, and life processes through our early efforts in space.

The characteristics of the radiation belts girdling the earth—the true nature of our space environment, including solar storms—the appearance of the earth's total cloud cover—the feasibility of a worldwide communications system utilizing satellites—these and other space ventures have opened new vistas of thought, of understanding, and of opportunity.

These, of course, are only beginnings. This past month new milestones in space exploration have been headlined throughout the world. As the months go by we shall see many more.

But marvel as we will at these technical achievements, we must not overlook this truth:

All that we have already accomplished, and all in the future that we shall achieve, is the outgrowth not of a soulless, barren technology, nor of a grasping state imperialism. Rather, it is the product of unrestrained human talent and energy restlessly probing for the betterment of humanity. We are propelled in these efforts by ingenuity and industry, by courage to overcome disappointment and failure, by free-ranging imagination, by insistence upon excellence—with none of this imposed by fiat, none of it ordered by a domineering bureaucracy. In this fact is proof

once again that hard work, toughness of spirit, and self-reliant enterprise are not mere catchwords of an era dead and gone. They remain the imperatives for the fulfillment of America's dream.

Not pushbuttons nor electronic devices, therefore, but superlative human qualities have brought success and fame to this place. These qualities I mention because they typify a distinguished American, George Catlett Marshall, in whose name we carry forward this activity.

General Marshall was supremely endowed. He was a man of war, yet a builder of peace—forceful and dynamic as a leader, calculating and prudent in judgment, yet warmly regarded by his associates. He was selfless, indeed self-effacing, yet known and admired throughout the world. Though dominating in personal force, in action and thought he was humble and considerate.

Northern born and Southern schooled, all-American through military service, he ultimately became a citizen of the world. I, of course, knew him best during the prosecution of World War II. I found him immune to discouragement, relentless in carrying the war to the enemy, and unsparing of himself in his leadership of the great forces he directed. But so profound was his devotion to the constructive works of peace, so outspokenly was he their advocate as Secretary of State, that he later became the symbol of renewed hope for scores of millions of suffering people through his great plan for Europe that will forever bear his name. He became, in consequence, the only professional soldier ever to be honored with the Nobel Peace Prize.

During his final 20 years he lived with, he counselled and influenced, the greatest men and movements of his time. Through it all he remained unaffected, reserved, completely disinterested in self, and dedicated to our Nation's highest ideals.

We, participating in this brief ceremony, agree with Sir Winston Churchill, who said that succeeding generations must not be allowed to forget General Marshall's achievements and his example.

There are ways to do this that General Marshall would have prized far more than what we do here today. It is not enough that we rest with praise of his name.

But we can newly resolve to work ceaselessly, with all our hearts and with such talents as we may possess, as he did throughout his life, for the good of this land and its freedoms.

Thus we shall carry forward the noble mission of our Republic, ever

60295—61——47

striving to strengthen peace, ever advancing the cause of human liberty, ever doing our best to build a better life for all.

That is what George Marshall would wish from us today.

In this spirit, and with deep satisfaction in having shared in this tribute to a revered friend, I dedicate this, the George C. Marshall Space Flight Center.

May this great Center be ever worthy of its honored name.

Now, Governor Patterson and friends, I have an additional comment that is especially meaningful to me. With us is Katherine Marshall, General Marshall's constant helpmeet during the world events of which I have spoken. Without her inspiration, loyal support, and companionship, the great American whom we honor here today could not have hoped to achieve the heights I have briefly outlined.

I salute this distinguished lady. I am, with all of you, delighted that she could be with us today, as we permanently enshrine a bust of her husband which will serve as an inspiration to all who work and visit here.

Mrs. Marshall, I would be deeply grateful if you would step forward with me and unveil this sculpture of General George C. Marshall.

NOTE: The President spoke at 10:35 a.m. in the Administration Building. His opening words referred to John Patterson, Governor of Alabama, Mrs. George C. Marshall, R. B. Searcy, Mayor of Huntsville, T. Keith Glennan, Administrator, National Aeronautics and Space Administration, and Wernher von Braun, Director of the George C. Marshall Space Flight Center.

288 ¶ Memorandum of Disapproval of Bill for the Relief of Raymond Baurkot. *September* 9, 1960

[Released September 9, 1960. Dated September 8, 1960]

I HAVE WITHHELD my approval from H.R. 6767, "For the relief of Raymond Baurkot."

This bill would permit the filing of a tax refund claim that was in fact filed after the deadline date set by law.

Public Law 85–859 provided for the refund of internal revenue taxes paid on certain liquors lost as the result of a major disaster occurring prior to the date of enactment, September 2, 1958. It required that claims be filed on or before March 2, 1959. The claimant filed on March 16, 1959

194 Remarks at Redstone Arsenal, Huntsville, Alabama. *May* 18, 1963

Senator Sparkman, Governor Wallace, Senator Hill, Congressman Elliott, Senator Kefauver, Chairman Wagner of the TVA, Congressman Jones, Congressman Albert Rains, Dr. Von Braun, distinguished guests, ladies and gentlemen:

I want to express a very warm sense of appreciation to you for coming out and joining us. We flew this morning from Washington to Nashville in about an hour and 45 minutes. One hundred years ago or so, 130 years ago, it took Andrew Jackson 30 days to go from Washington, D.C., the White House, to his house, the Hermitage, in Nashville. I don't know whether the world is better off than it was then, but at least we move around more. Whether we accomplish much is going to depend on the judgment of other generations, but I will say as we move faster, there is no place in the world in this decade that is going to play a more significant role in that motion than this community right here in the center of Alabama.

I wonder how many of the people here, now that we have all been introduced—we would like to know something more about you. How many of you here are either in the Armed Forces of the United States, the wife of a member of the Armed Forces of the United States, or the child of a member? Could you hold up your hands? Well, you have just convinced Senator Sparkman and Senator Hill to vote for that pay raise, and I am glad we all came down here.

Then I wonder how many of you work in one way or another for the space agency. Would you hold up your hands? And then I wonder how many of you are taxpayers that are supporting all the rest of us? And what about the Arsenal? All right.

In any case, all of us, whether we are doing one thing or the other, whether we are in Huntsville, Washington, D.C., wherever we may be, all of us are committed to a great objective, and that is to see the United States of America, of which we are proud, not only meet its responsibilites here at home, not only provide a better life for its people, but also continue to be, as it has since 1945, the keystone of the arch of freedom all around the world. There are 11,000 Americans serving today in defending the freedom of Viet-Nam, and they stretch, either in service themselves, or by the guarantees which are maintained by the Armed Forces of the United States—they maintain the freedom of countries stretching all the way around from South Korea in a great half-circle to Berlin. Without the United States there are literally dozens of countries that would not now be free, and with the United States, and with our determination, and with our strong look forward, not only shall they be free, but also the people who come after them.

I know there are lots of people now who say, "Why go any further in space?" When Columbus was halfway through his voyage, the same people said, "Why go on any further? What will we possibly find? What good will it be?" And they want to stop now.

I believe the United States of America is committed in this decade to be first in space. And the only way we are going to be first in space is to work as hard as we can here and all across the country, and support not only Major Cooper but all those who come after him.

So, ladies and gentlemen, we depend on you, either you in the Armed Forces of the United States who help defend the freedom, even here, of countries thousands of miles away, you who are building these missiles which not only raised an American into space but raised the prestige and reputation of this country. I am proud to be here.

I leave this valley, this State, this region, in which I arrived only a few hours ago,

PROPOSED AGENDA FOR PRESIDENT BUSH VISIT TO MARSHALL SPACE FLIGHT CENTER, JUNE 20, 1990

* Motorcade arrives at Marshall Center building 4663, West End marked HOSC (Huntsville Operations Support Center).

* Presidential party is met by Jack Lee, Director, and is escorted into the facility.

* Party goes up one-flight of stairs to second floor and east along hallway to the HUBBLE SPACE TELESCOPE CHECKOUT AREA.

  All engineering data from the new telescope is downlinked to this facility where teams of engineers from NASA, Lockheed, Hughes, Allied Signal and the European Space Agency analyze the state of the HST's health and solve problems that occur. Brief discussion with engineers on success of initial checkout.

  Viewing window for pre-positioned press.

  5 MINUTES

* Party proceeds to east end of hallway, turns right (south) down hallway to the SPACELAB MISSION OPERATIONS CONTROL.

  This new Spacelab control facility is the science command center for the Astro-1 Spacelab mission. On the day of the visit, the control team and all mission scientists will be conducting a 24-hour dress rehearsal of this astronomy mission.

  The President will enter this colorful command center, which features high-tech video animated Shuttle views on the wall, and meet several members of the control team. The President will be seated at the "Capcom" station to make a brief call to the astronaut crew working elsewhere in a spacelab simulator. Bush: "Astro this is Huntsville." Crew: "Go ahead Huntsville." Bush: "This is George Bush sitting in for Debbie Underwood here in Spacelab Control; it sure looks like you folks are ready to go." Crew response: etc. This room has major press support facilities built in.

  Both CBS and CNN have standup locations already in place. Pre-positioned press will view from the hallway viewing area. NASA has overhead robot cameras.

  10 MINUTES.

* The party then exits the command center thru the south door, taking a stairway to the first floor, entering the SCIENCE WORKING AREA from the south.

  Directly below the main control center, this area is occupied with scientists from Johns Hopkins, University of Wisconsin and other institutions surrounded by electronic astronomy equipment. From here they work with the astronomers in the Spacelab, send commands to their telescopes in space, etc. The President will greet the scientists from the south end of this room. Lots of university banners.

  Press will be positioned at the north end of the room, and/or pre-positioned to the President's left side in a viewing room.

  3 MINUTES.

* The party turns to the right, through a doorway, and enters the Astro SPACE CLASSROOM.

  Located right in the control center complex, this is a special classroom where 12 seventh and eighth graders from Huntsville and other major cities in the Southeast (Atlanta, Memphis, Birmingham, Montgomery, Nashville, etc) will participate in this Astro-1 mission. The astronauts in the Spacelab will teach a lesson on the electromagnetic spectrum, after which local science teacher Karen Widenhofer will lead the students through demonstrations and experiments dealing with the spectrum and astronomy. Then the students will discuss what they learned with the astronauts in orbit. Very visual classroom. Students will be in the room preparing for the mission.

  The President will meet them and will have the opportunity to talk with them about their role in the mission.

  Press will be pre-positioned positioned to view the interaction.

  10 MINUTES.

* PRESS AVAILABILITY IN CLASSROOM IF DESIRED.

  5 minutes.

* Party will proceed pass the press to a stop in the north end of the room where a explanatory exhibit on SEI will be stationed detailing the Marshall Center role in support of the President's initiative.

* The party exits through the north door, proceeds through a hallway to the northeast exit to the building.

Interior holding rooms are located here.

* The party exits the building, facing the LASER (Learning About Science, Engineering, and Research) van, a 40-foot tractor-trailer.

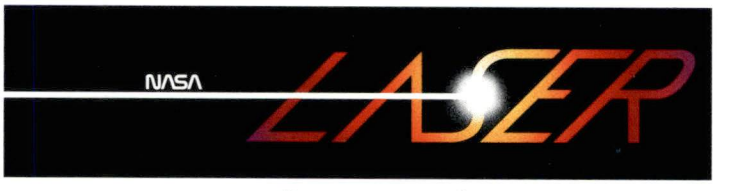
  This tractor-trailer van is a fully equipped teacher resource center that will be crisscrossing the country helping teachers prepare lessons about science and math. The President can meet teachers from all over the country who will be on board using this facility (teachers will be at the Marshall Center participating in our NEWMAST teacher training program conducted jointly with the National Science Teachers Association). Van is set up with a long row of "captains chairs" facing a wall of computers and video equipment that the teachers use to gather materials.

  5 MINUTES

* The party turns right, east, to a location on the East wall of the building for an address to Marshall Center employees.

* Depart

Project



Learning About Science, Engineering, and Research

NASA reaches out to help rebuild America's science and technology workforce

Introduction

The American people expect and deserve leadership in the international community now and as we move into the 21st century. This nation pioneered the world's standards of living and many of the technologies which have allowed the human race to burst the limits of imagination and capability in the decades since World War II.

But the "educational pipeline" which produced scientists and engineers of the 1950's through the '70's is drying up. Fewer students are entering science and engineering careers because they decide science and math are too hard, dull, or "nerdy." The shocking statistic is that this decision is not made when they enter college, but in third or fourth grade—long before they are aware of the excitement the future can hold. Recent international math achievement tests rank U.S. students on a par with Thailand and Hungary—and far behind other nations (Hong Kong and Japan ranked 1 and 2). U.S. rankings in physics, chemistry and biology ranged from abysmal to mediocre compared with other nations.

Goal 1

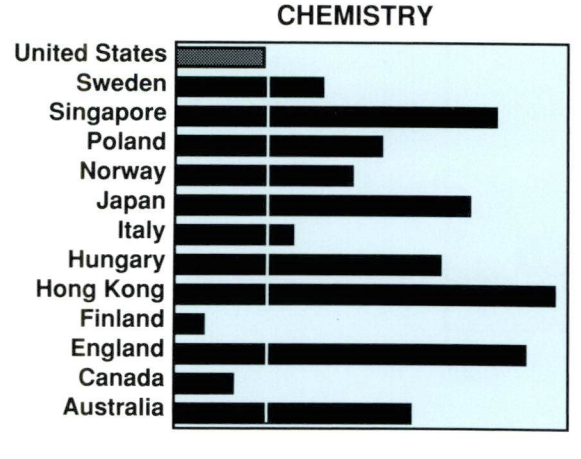
All children, from all backgrounds, must have a quality education which includes science and mathematics, and an equal opportunity to become a vital part of our science and engineering workforce—as workers, beneficiaries, taxpayers, and voters.

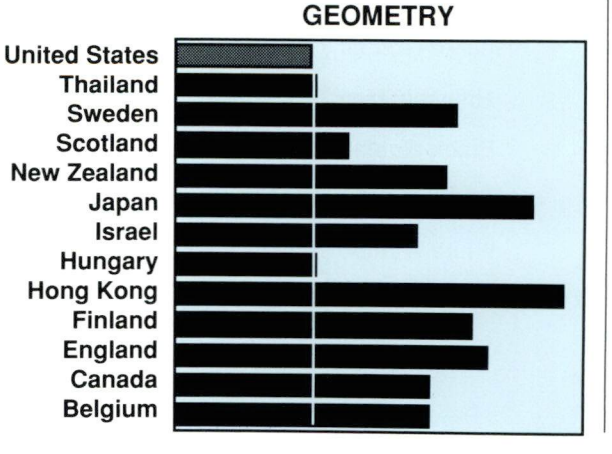
This decline has alarmed Congress which, in 1987, established a Task Force on Women, Minorities, and the Handicapped in Science and Technology (P.L. 99-383) to define the problem and find solutions. If left unchanged, the Task Force has warned, "the prospects for maintaining an advanced industrial society will diminish." [1]

NASA is supportive of the six goals outlined by the Task Force—and which are paraphrased on these pages—and is carefully assessing its education programs to identify those

HOW AMERICA SCORED

Graphs below are typical of how students from 13 countries, including America, fared on International Science and Math Achievement Tests. (Source: International Association for Evaluation of Educational Achievement)





offering the greatest potential for achieving the Task Force objectives with a reasonable range of resources. A major initiative is under way on behalf of NASA at its Marshall Space Flight Center in Huntsville, Alabama, where highly effective features of several NASA education programs along with innovations are being integrated into a comprehensive pilot program. This program, dubbed Project LASER, is discussed presently.

"It is obvious that if this trend is not corrected, the Buck Rogers of the 1990s will be living in Seoul, not Chattanooga, Los Angeles, or Chicago.

University of Tennessee President Lamar Alexander[5]

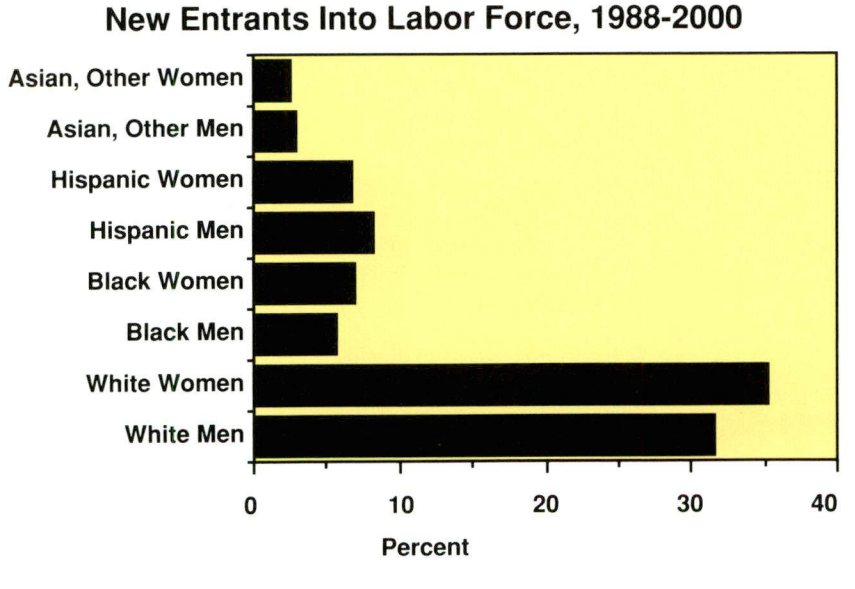
Finding new minds

What made America great was not manifest destiny, but the hunger of immigrants who were willing to sacrifice, to perform harder and learn more. When Leo Durocher said that "Nice guys finish last," he meant that the hungry ones hustle to finish first. Today that hunger and hustle are found throughout the world in nations that are outperforming America in the marketplace, and which have recognized, as Japan did almost three decades ago, that "Economic competition is technical competition, and technical competition has become educational competition."

Goal 2

Education must be reformed to allow American students—from pre-kindergarten to grade 12—to enter college as future competitors in the international marketplace.

It can also be found and nurtured in America's inner cities and impoverished citizens if we provide the opportunities to learn and grow. In the year 2000, 85 percent of the new workers will be members of minority groups, women, and the disabled. Further, the nation will be short some 560,000 science and engineering professionals at that time. As expressed by the Task Force, "The Nation can meet future potential shortfalls of scientists and engineers only by reaching out and bringing



THE CHANGING WORKFORCE
Changing demographics will markedly affect the composition of the future workforce. Of the new workers entering the labor force between 1988 and the year 2000, less than a third will be the white males traditionally sought by most employers. (Source: U.S. Bureau of Labor Statistics)

members of these underrepresented groups into science and engineering. America's standing and competitiveness depend on it."

For years it has been easier to deal with the students who were readily available in the schools near the factory and around the executives' neighborhoods. But assuring America's vitality and competitiveness requires that business and government reach outside their "comfort zones" to capture the imaginations of minority and disadvantaged students. Simply stated, it is folly to ignore large segments of any manpower pool.

Goal 3

By the year 2000 the number and diversity of American science and engineering graduates must expand to meet the demands for faculty, industry, and government.

If left untrained, the poor and disadvantaged children of today will become the poor and disadvantaged parents of tomorrow and the pattern will repeat. They will also become a terrible burden on the economy and keep the nation from reaching its full potential. If tapped, they can become the greatest resource for building the economy and regaining stature and economic power in the world marketplace. In the words of the Task Force:

BASIC SPACE TECH
Students from Bob Jones High School receive a lecture on basic rocket propulsion as part of the Space Science and Technology pilot course. (NASA photo)

AFTER SCHOOL
Students who stay at the public library to study or just read after regular school hours will be offered introductions to science through space. (NASA photo)

"We should commit to the task of producing a world-class science and engineering workforce not only because science and technology happen to be the coin of international power. We should take action not just because Japanese students score higher in international tests. We should take action not only because the opportunity costs of not acting—school dropouts, welfare, and prisons, for example—are staggering.

"One, every American citizen, regardless of background, gender, physical disability or race, should receive the educational and economic opportunity to develop to his or her fullest potential.

"Two, we should extend rights not only in the name of social justice, but as a test of a modern, well-functioning society. This is the standard by which we should continue to stand and be measured."

Goal 4

Because Federal R&D resources strongly influence national science and engineering work, they must be used to help leverage the world's best science and engineering workforce by the year 2000.

From the stars to the Earth

NASA can and will play a vital role in this effort. Because the Space Act directs NASA to expand human knowledge of space and to disseminate information to the widest audience, NASA is a type of education agency, well-suited to capture a child's imagination. Edward Mabley, president of the Society of Automotive Engineers, observed, "Have you ever seen a kid who

didn't like a car or airplane?"[2] Or a spaceship? Nothing fires the imagination as space does. But for many students, that becomes limited in elementary school.

NASA does not entertain the notion that all students it contacts will want to become astronauts or space scientists. Most will move on to other career interests, many of them outside of science and engineering. However, NASA does know that unless the nation provides itself a large enough pool of scientists and engineers, and taxpayers who appreciate their importance, then the agency will find itself in an intense competition for the few skilled people who are available. Through their natural interest in space, students can be stimulated to develop skills in science and mathematics that will serve all disciplines. And the best environment for expanding man's presence in space is a nation with a vibrant economy driven by first-rate technical capabilities in all fields, and supported by a citizenry which is functionally literate in science and mathematics.

"Education is a way of life. And educational reform is an urgent responsibility for every parent, every student, every community. And those who do not advance the cause of education hinder it."

President George Bush[10]

Goal 5

The Federal government will continue to set the pace in providing accessible, equitable, and favorable workplaces for under-represented groups in science and engineering.

Although all levels of education must be addressed, studies have identified the first four years of primary school education as the most crucial. Young people are naturally curious and eager to learn. However, as they reach the third to fourth grade, there is a general tendency for their interest in the more difficult concepts of mathematics and science to give way to less difficult and entertaining activities. This is markedly true for minorities, girls, and children from socially and economically deprived situations. This problem is caused by a lack of "hands-on" experiences that cultivate and stimulate a child's natural curiosity, and in rote learning that appears to have no immediate application or reward.

As noted by Philip and Phylis Morrison—a noted MIT physics professor and a specialist in elementary science education—one of the problems with today's metropolitan society is that many children are not exposed to the same learning experiences as 100 years ago.[3] Children who grew up in small towns and on the farm "knew intimately many things that are not in the experience of children coming to school today ... the rhythm of the moon in the sky. They knew many of the serious steps to keep alive animals for whom they had responsibility and on whom they depended.... They knew a good bit about machinery and how it worked, how it could be mended, what you could do with it that was not exactly what it was intended

"Fortunately, producing an adequate supply of scientists and giving scientific literacy to the non-scientists can be accomplished by the same means—teaching excellent science to every child at the elementary school level."

Educator Daniel Koshland[7]

for." Today, few children build their own radios—a Walkman is cheaper than a kit—or comprehend its workings beyond the face of the volume control.

"Elementary teachers are often regarded as the best science teachers because they are quick to admit to not knowing."

Educator Robert Yager[6]

A LASER to light the way

Project LASER, a major initiative being undertaken by Marshall Space Flight Center on behalf of NASA, will provide hands-on experiences that challenge children to continue science and math studies.[4] "Laser" was selected because it is a readily recognized high-tech device. (Significantly, most people cannot tell what the acronym means or how a laser works.) As adopted by the Marshall Center's education outreach program, LASER means Learning About Science, Engineering, and Research. The brightly-colored logo depicts a laser etching its own name.

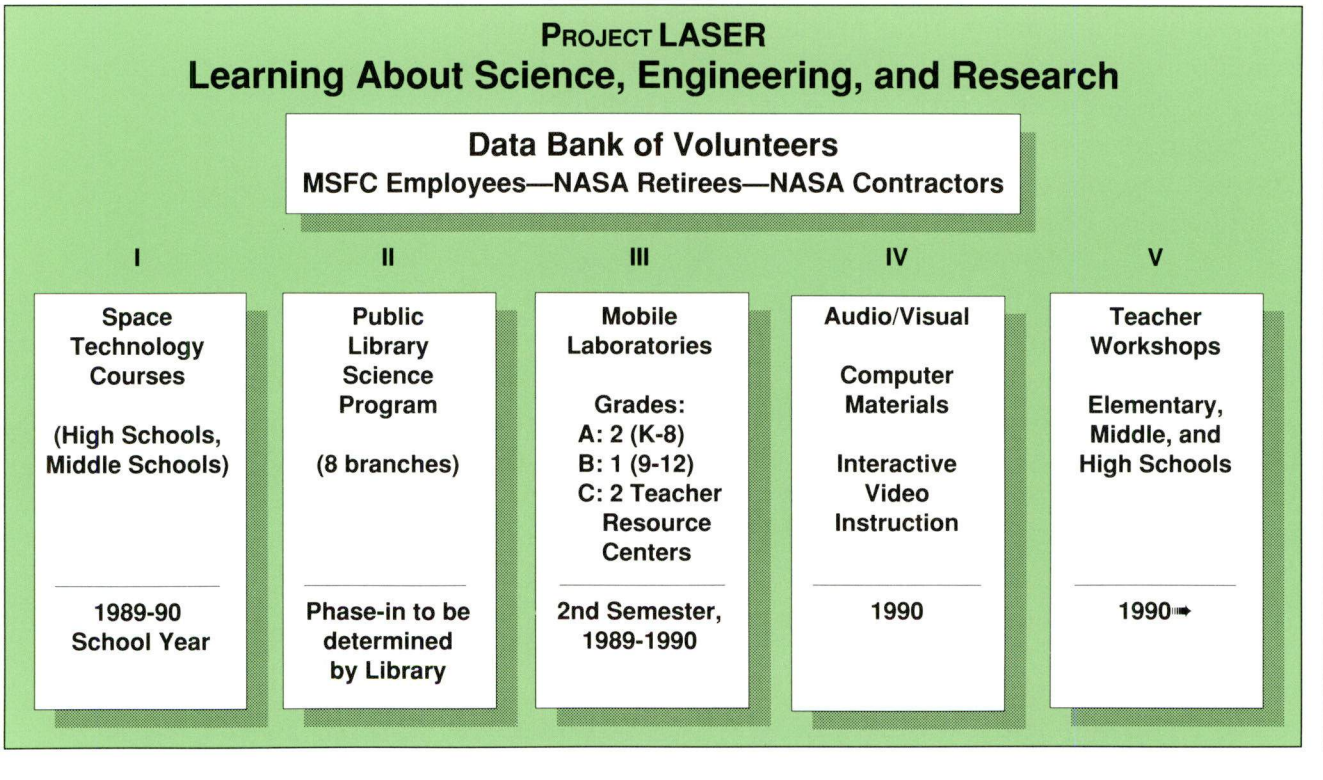
Goal 6

American culture must change.
News and entertainment media, businesses and communities are needed to reverse negative images:

- **"Mad" scientists portrayed in entertainment media.**
- **Science and math are "too tough" or "for nerds."**
- **"Only geniuses need apply."**

There are several areas of focussed effort designed into Project LASER. Although the project includes all teachers and students in elementary through high schools, there will be an intense focus of effort, technology, and reinforcement designed to draw underprivileged and underrepresented children into the mainstream of the educational process and to keep them there.

PROJECT LASER ELEMENTS
Major elements of Project LASER, and their development schedules, are depected below. The Space Science and Technology Course is outlined at right. (NASA diagrams)



SCIENCE DAY
A Marshall Center volunteer supporting Project LASER introduces elementary students to physics experiments. Such an outreach will be possible for more schools through Mobile Discovery Labs. (NASA photos)

In addition, NASA believes special attention is required in three areas:

First, assisting teachers in ways which facilitate and enrich science and mathematics education without adding to the teaching burden.

Second, developing practical applications and interesting "hands-on" activities that attract children to put forth the effort necessary for understanding mathematics and science.

Third, expending a greater effort in grades 3 through 8 to create and maintain the necessary interest through positive reinforcement to sustain the students' desire to learn algebra, geometry, calculus, biology, chemistry, and physics.

"Einstein didn't learn about atoms from lectures."

Education ad, ca. 1988 [8]

Space Science and Technology Course

I. Introduction and overview: Why explore space?

II. Astronomy: Heavenly bodies in space as an environment.

III. History: Man's venture to the sky and beyond.

IV. Getting there: Technology required to go from idea to spaceflight.

V. Space flight: Man's accomplishments and plans.

VI. Experiments in space: What we test and observe.

"We are unique in our ability to capture the interest of children and young adults. No program of any other agency, public or private, can inspire kids more than our activities on the cutting edge of space or aeronautics research."

NASA Administrator Richard Truly[11]

Within Project LASER are five major elements; others may be added as our understanding of educational needs and capabilities is refined. The Marshall Center is using the Huntsville and Madison County School Systems and its own facilities as the laboratory in which LASER programs are developed. As the elements mature they will be "spun off" to other NASA centers, Federal agencies, school systems, and businesses—anyone, in short, who has the need and the interest.

"The essence of science is curiosity. We must instill in our children the curiosity about their everyday world that will always lead to discovery."

Michael S. Brown, 1985 Nobel laureate in physiology and medicine [9]

The major program elements within LASER are:

Volunteer Databank: Current and retired employees of Marshall Center have been asked to volunteer to support space activities at various city and county schools. "Job categories" include tutors for students and small groups; instructors at schools or field trips; consultants for teachers; science fair judges; and volunteers providing other assistance as needed. An important element will be a Discovery Lab at the Marshall Center which will provide specific laboratory capabilities for the schools.

Space Technology Course: This course is being developed by a team of certified teachers and Marshall Center scientists and engineers. Implementation is under way at Bob Jones High School in Madison County and will continue as a full-time course of instruction throughout the 1989-90 school year. Students who attend must arrive an hour before regular classes, but will receive one elective credit. Development of a space technology textbook is being considered as an extension of this program. Marshall Center earlier "adopted" Johnson High School and is helping it develop space science studies integrated with traditional courses.

"At a time when the need for strong math and science programs in our schools has never been greater, we recognize that government agencies and industry can and must make important contributions to education."

MSFC Director Jack Lee

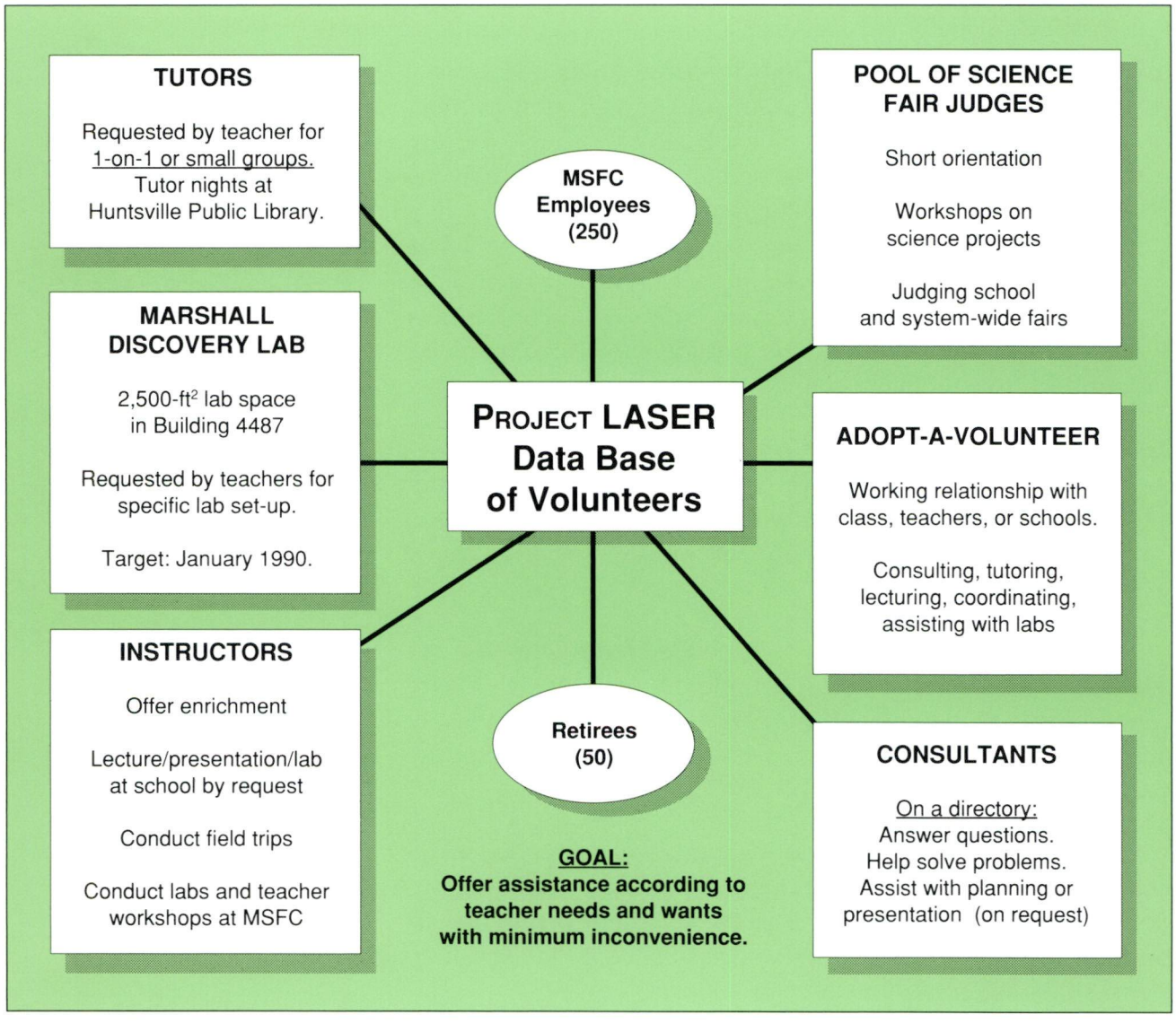
Public Library Science Program: The Huntsville Public Library's main branch has discovered that many children from nearby housing projects "hang out" at the library until their parents return home from work. This provides a natural environment in which science and math programs can be presented as an adjunct to classroom learning. The library may also host weekend, evening, and summer programs to help teach children. The library management has agreed to furnish space in the facility for the Marshall Center to engage the children in learning with NASA-provided materials.

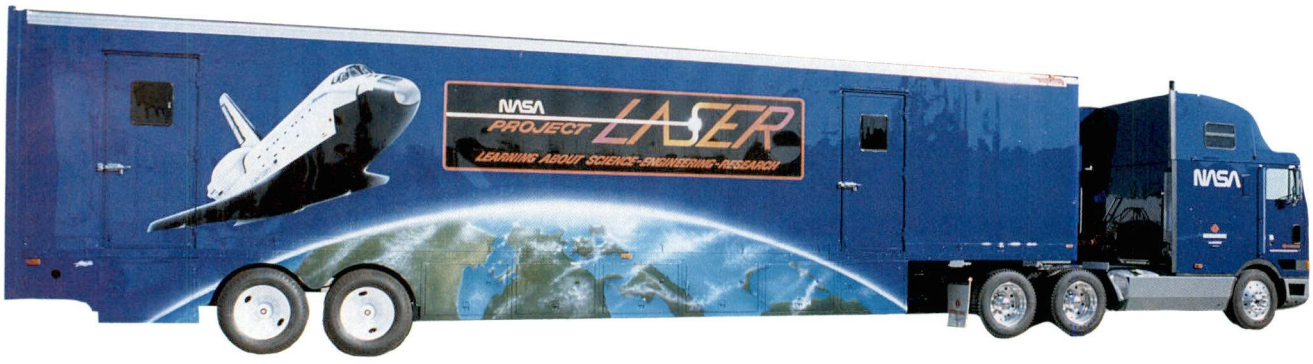
Mobile Discovery Laboratories: This is derived from the Spacemobile familiar to many Americans. The Mobile Labs will carry simple lab equipment and computers to provide

hands-on activities and demonstrations for students, and provide teachers with classroom activities. There will be two for grades K-5, and one for 6-8. At work stations in the mobile labs, teams of two to five students will use prepackaged materials that will show them practical applications of principles being taught in the classroom.

Mobile Teacher Resource Centers: The greatest potential in terms of resources invested in LASER may be offered by the development of Mobile Teacher Resource Centers. Mobile facilities, built on the highly successful NASA-wide system of Teacher Resource Centers (at NASA centers and regional locations), can reach teachers all over the nation, especially those that would otherwise not have the opportunity to avail themselves of this valuable resource. Initially, the vans would visit the six-state region served by the Marshall Center to prove the concept. This would be followed by expansion

LASER WORKERS
LASER's various activities will be staffed by volunteers who have a variety of options for helping the program. (NASA diagram)





to each of the other NASA centers with at least two mobile units per center. The first center is to debut in early 1990.

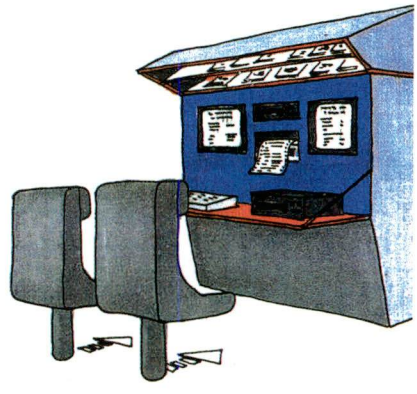
Computer and A/V Materials: The potential of computer-aided learning cannot be underestimated, nor should it be oversold. Not all school systems can afford machines that provide "hypermedia" and other advanced systems. Nevertheless, the potential is great and must be explored to develop affordable systems. The proliferation of VCR's make videotapes a natural medium for presenting educational material, but not simply by taping old movies; new production values and techniques must be used to provide presentations that children want to see and hear. An initiative is under way to join the Alabama University System's audio-video network which is now delivering live interactive instruction by highly-skilled educators in high school classrooms in such subjects as anatomy. NASA would use its new Space Technology Course as a pilot effort to expand its outreach into as many school systems as possible.

Teacher Workshops: "Hands-on" activities are equally important for teachers at all levels. NASA and the Marshall Center will incorporate summer workshops and other related activities into LASER to share the program with as many teachers as possible.

LASER's programs will not be produced overnight. The database, for example, is being completed, and the Discovery Laboratory is to be opened in 1990. Other activities will be initiated during the 1989-90 school year, then refined over the years as experience is gained.

Assistance from industry and academia will be needed in developing these programs. Although NASA has a multi-billion-dollar budget, its monies are largely obligated to fulfilling its primary charter: expanding aerospace science and technology for the national good.

FOR TEACHERS
The Mobile Teachers' Resource Center (above) will be highly visible on the nation's highways as it carries a set of six work stations (below) plus other facilities to teachers at their schools. (NASA photos)



And despite the marvels which NASA has developed, it is not a "know-it-all agency." Neither is it a factory. NASA is an R&D agency. The help of the education community will be needed as NASA brings its expertise and facilities to bear. Most important, the support of the business community will be needed to develop and distribute new educational tools, either by corporate sponsorships, cost-sharing, donations, or other means. Non-profit professional institutions (many of whom have struggled with the education problem for years) are needed to act as receiving agents to make sure that industry receives proper tax credits and to help maintain a proper separation between business and government. Already, several aerospace firms have expressed interest in helping NASA. Education programs and materials which support the overall goals of Project LASER will also be distributed through the Mobile Teacher Resource Centers and Discovery Laboratories.

The support of the entire business community will be needed in what will become the most important investment that any company can make. The return will not come quickly or easily. But the price of not investing is too high to bear.

To my mind, the main task is how generally to improve the education of the young. [You] can do no greater work than help make better the elementary school system throughout the world.

Albert Einstein
(to the League of Nations Committee on International Cooperation, ca. 1924)

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For more information about Project LASER,
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January 1990

Seeing in a New Light

Teacher's Guide With Activities

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Scientists, teachers, and others who gave their time and creativity in recognition of the importance of the space program in inspiring and educating students.

Special thanks to the Astro Team and to Essex Corporation for their creativity in making this document a reality.

Astro-1 Teacher's Guide With Activities

Seeing in a New Light

January 1990

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Space Administration

Astro-1 Teacher's Guide With Activities

Seeing in a New Light

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Astro-1 Crew

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Guy Gardner
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Mike Lounge
Mission Specialist

Jeff Hoffman
Mission Specialist

Robert Parker
Mission Specialist

Sam Durrance
Payload Specialist

Ron Parise
Payload Specialist

Ken Nordsieck
Payload Specialist

Preface

We, the crew of the Astro-1 Observatory mission, invite you to join us on a special adventure: NASA's first Shuttle mission dedicated to astrophysics. Astrophysics is the branch of astronomy that investigates the physical characteristics of celestial objects such as their size, mass, temperature, and chemistry. On this mission, the Space Shuttle Columbia will lift three ultraviolet telescopes and one X-ray telescope above the scattering and absorbing effects of Earth's atmosphere so that astronomers in the Shuttle and on the ground can observe some of the Universe's most fascinating objects. Together, we will use complex computers and pointing systems to turn huge telescopes on the stars and analyze their light for information about their structure and chemistry.

We can hardly wait to share the excitement of astronomy in orbit with students and teachers alike.

This Teacher's Guide concentrates on the electromagnetic spectrum, a subject that was chosen because it is part of the middle school curriculum and because an understanding of the different ranges of energy is crucial to an understanding of the high-energy astronomy performed by the Astro-1 telescopes. Other information about the Astro-1 mission is available through the various NASA Educational Resources listed on page 53 of this Teacher's Guide.

This is only the beginning. There will be other science missions in the months to come. We hope you will make us and future Shuttle crews a part of your classrooms as we explain how science is done in orbit.

Come join us in space.

Vance Brand
Commander

Guy Gardner
Pilot

Mike Lounge
Mission Specialist

Jeff Hoffman
Mission Specialist

Robert Parker
Mission Specialist

Sam Durrance
Payload Specialist

Ron Parise
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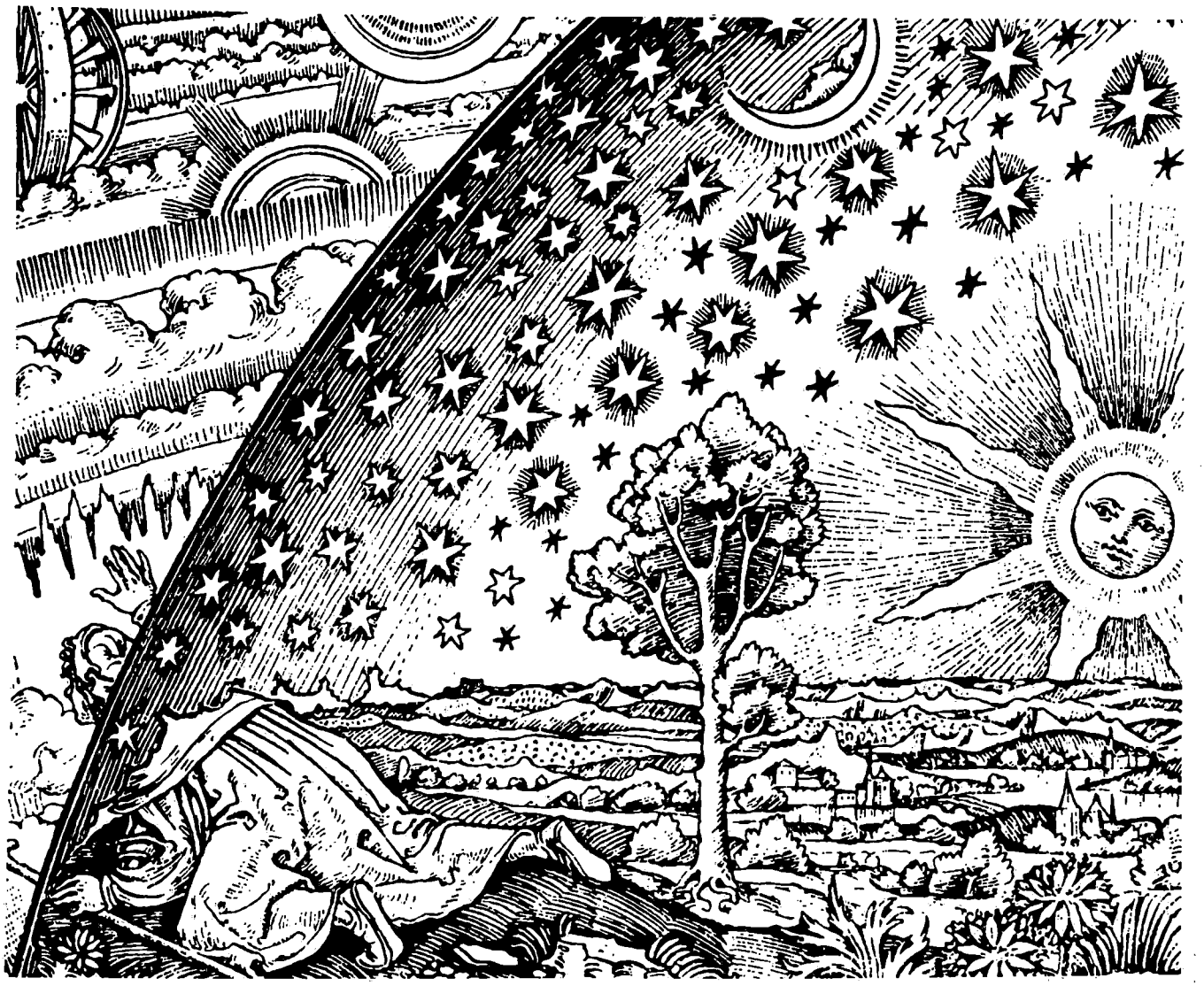


Introduction

For as long as people have walked the Earth, they have looked to the stars. Besides exciting the imagination and inspiring songs and poetry, the stars have provided guidance for many of the advances of civilization. Farmers have sown and harvested crops according to the phases of the Moon and the positions of heavenly bodies. Explorers and sailors have charted their courses across deserts, forests, and open seas with the aid of the stars. Those who studied the stars were sometimes pictured as magical and wise — wizards who tried to understand the remote and beautiful night skies; even today, astronomy embodies both the practical and the romantic, the understandable and the mysterious.

Almost every culture has studied the skies. The Babylonians first grouped the stars into constellations; the Chaldeans and Egyptians used astronomical observations to calculate the length of the year as 365-1/4 days; the Greeks determined the circumference of Earth and catalogued 1,080 stars, grouping them by their brightness. The Greeks also may have been the first to teach that the Sun was the center of the solar system. During the Middle Ages, many of the sciences experienced setbacks, but astronomy was kept alive by the Arabs who translated and preserved the works of the Greeks and improved astronomical instruments. In 1543, Copernicus, a Polish researcher, again advanced the theory that the Sun was the center of the solar system. Kepler, a German mathematician, calculated the movements of the planets and proved Copernicus right. With Galileo's use of a primitive telescope in the 1600s, the science of astronomy took a giant leap forward as more of the Universe was brought into view.

Today's astronomers use giant telescopes, Earth-orbiting satellites, and sophisticated instruments that operate above the atmosphere to explore the Universe. So that progress will continue, students must be made aware of the fascination of astronomy. The goal of this guide is to excite the imagination of students in grades 6, 7, and 8 and encourage them to pursue the study of science, particularly astronomy. To do this, they will be introduced first to the basic scientific principle of the electromagnetic spectrum and to related concepts. As the guide progresses, the concepts become more complex, encompassing the ideas of light waves, their lengths, frequencies, and relationship to color; the effect of the atmosphere on light waves; and the relationship of these concepts to astronomy.

Then, students will be introduced to the Astro Program, a series of Space Shuttle flights that will lift a complement of telescopes above the distorting and absorbing effects of Earth's atmosphere. Astro-1 is scheduled to fly in the spring of 1990.

Astro-1 will carry 4 instruments during its 10-day mission. Three are ultraviolet instruments: the Hopkins Ultraviolet Telescope (HUT) developed at The Johns Hopkins University, the Ultraviolet Imaging Telescope (UIT) developed at Goddard Space Flight Center, and the Wisconsin Ultraviolet Photo-Polarimeter Experiment (WUPPE) developed at the University of Wisconsin. The fourth instrument is the Broad Band X-Ray Telescope (BBXRT), also developed at Goddard Space Flight Center. With these instruments, astronomers will investigate celestial bodies that emit ultraviolet and X-ray radiation impossible to detect with Earthbound telescopes. Some of these objects are hot, young stars; old, dying stars; quasars; neutron stars; supernova remnants; binary star systems; active galaxies; and maybe even black holes.

This expanding and fascinating world of high-energy astronomy awaits your students: a world of ultraviolet and X-ray spectrometers and telescopes that explore stars, nebulae, and phenomena like quasars and black holes, which were unknown to the ancients and are new even to your students' parents.

This Teacher's Guide may be used to introduce and summarize the lessons that will be taught from space by Astro-1 crew members. It is also a practical source of lesson plans and student activities that may be used by itself to teach scientific principles and to interest students in the field of astronomy. It can supplement sections of texts in Earth science, physical science, or social studies. Many activities are designed to extend into the realms of literature, mathematics, art, and history.

The National Aeronautics and Space Administration (NASA) has chosen a wizard as the logo for this Teacher's Guide in the hope that today's students and teachers, like their ancestors, will discover the mystery, excitement, and importance of astronomy and that students will look to the stars to learn about the Universe.

Instructions for Using the Teacher's Guide

This Teacher's Guide is designed to be used with classes of varied sizes and abilities and can be adapted to different time schedules. It is written for middle school students (grades 6, 7, and 8), but many activities will appeal to younger and older students.

Six basic concepts are taught:

Concept 1: Visible light demonstrates the existence of the spectrum.

Concept 2: Radiation exists above and below the visible portion of the electromagnetic spectrum.

Concept 3: Light and other kinds of radiation consist of photons that travel in waves.

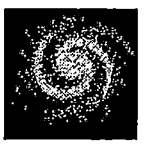
Concept 4: Certain celestial objects give off radiation other than visible light, and we must study them in other energy ranges.

Concept 5: Certain waves of radiation are blocked by Earth's atmosphere.

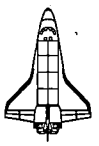
Concept 6: Astronomers need to place telescopes above Earth's atmosphere to perform astronomical observations in several regions of the spectrum.

These concepts are arranged so that the simpler ideas are presented first. If students are not prepared to work on wavelengths, for example, you may want to cover only Concepts 1 and 2. If your students are well along in studying the electromagnetic spectrum, you may want to begin with Concept 5.

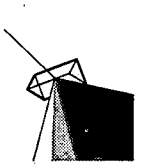
All answers and suggestions for the teacher are printed at the end of each concept, before the Student Activity pages.



Background
This information introduces each concept. Interested students may be referred to some of the references given in the back of this guide.



Classroom Activities
You may choose from several classroom activities to teach each concept, depending on the interests and needs of your students. You also may duplicate these and use them as task cards for students working as individuals or in groups.

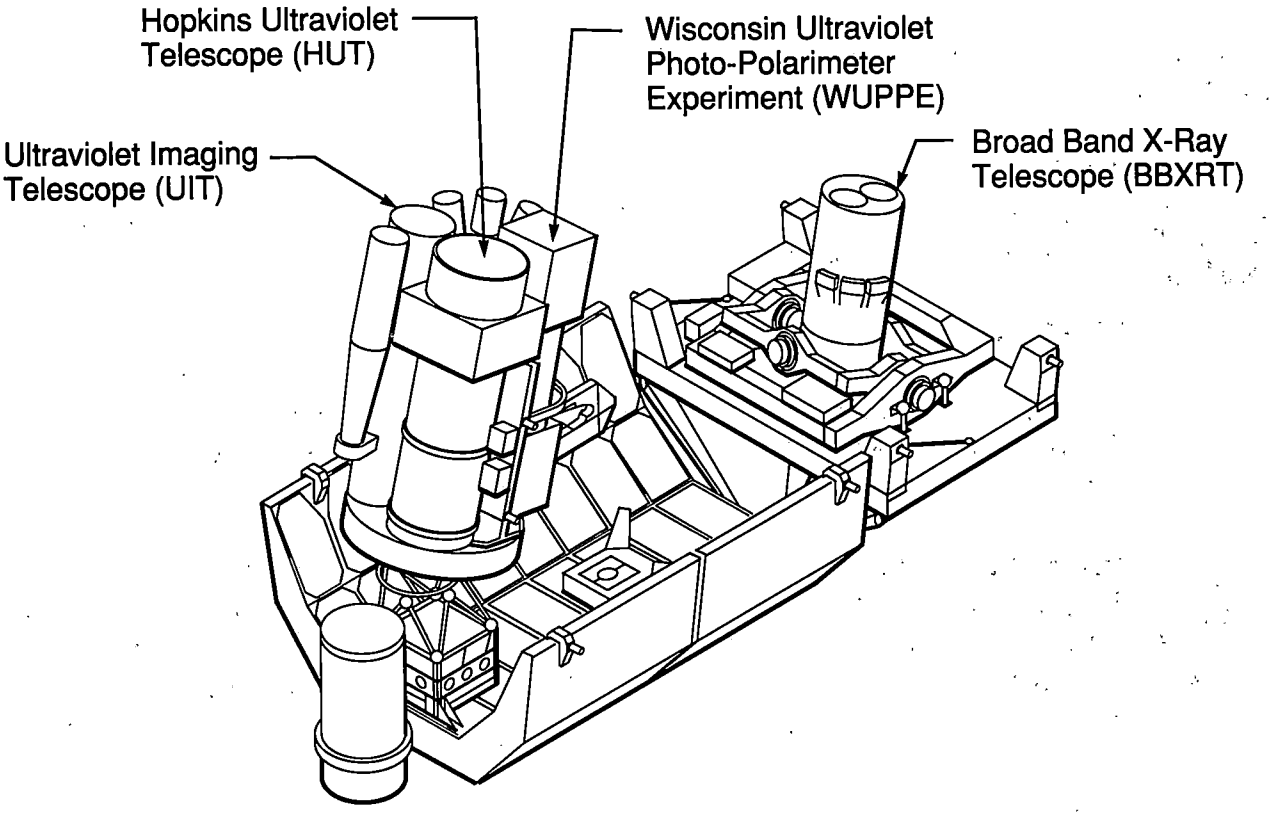


Options for Extending the Lesson Across the Curriculum
These activities are included to reflect the current emphasis on interdisciplinary learning. They are suggestions, and teachers should use them according to the time available for study, the ability of other teachers to help in team teaching, and student interest.

Home Activities
Assign these lesson extensions after Classroom and Student Activities have been completed. They help students remember what has been learned, are enjoyable supplements to homework, and provide an opportunity for parents to participate.

Student Activities
These are intended to be reproduced for independent individual or small-group work.

Your Career in Astronomy
One of the goals of the Astro-1 Teacher's Guide is to encourage students to take an interest in astronomy and perhaps pursue it as a career. This section may be copied for students to read and used for classroom discussion.

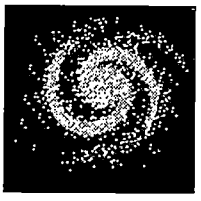


Astro-1 Payload

Seeing the Colors in Light

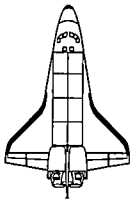
Concept 1
Visible light demonstrates the existence of the spectrum.

Objective
Students observe a visible spectrum.



Background

We often think of rainbows as magical — the subject of charming legends of leprechauns and pots of gold. This makes the rainbow an exciting starting point for the study of the **electromagnetic spectrum**. Think about the colors of the rainbow: red, orange, yellow, green, blue, indigo, and violet. Raindrops break **white light** into its component colors, producing rainbows. This process can be duplicated with a **prism** or a **diffraction grating** or even a pan of water and a mirror.



Activity 1: Producing a Spectrum

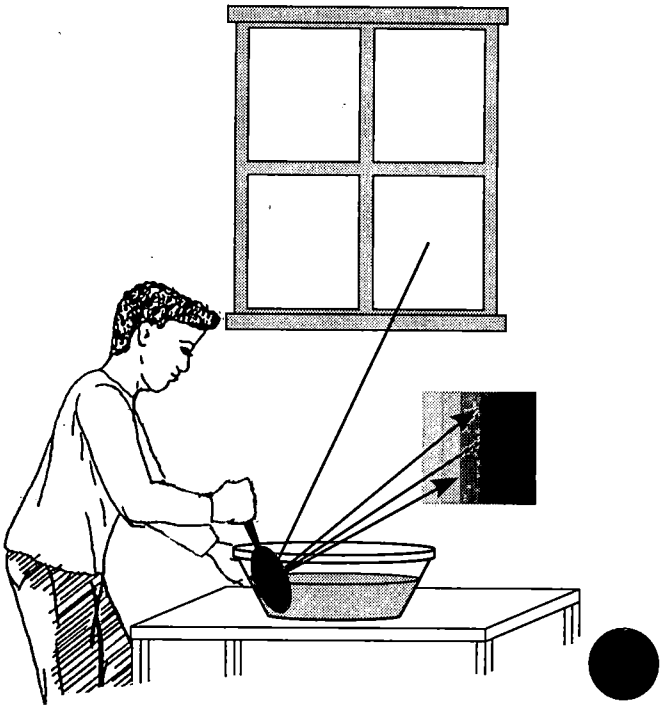
Materials Needed

- pan of water and a small mirror or
- a prism or
- diffraction grating (You may be able to borrow a diffraction grating from a high school physics teacher or remove one from an inexpensive spectroscope.)
- light source, such as sunlight, or
- 1 or 2 straight filament lights with sockets

If you are using the pan of water, set the tray of water in bright sunlight. Lean the mirror against an inside edge of the pan and adjust it so that a spectrum appears on the wall.

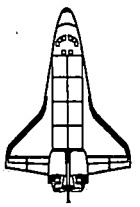
If you are using a prism, turn the prism at various angles until a spectrum appears. Adjust carefully until the spectrum is spread out as much as possible.

If you are using a diffraction grating, turn the grating so that the colors are to the right and left of the bulb.



Questions

1. What colors in the spectrum can you name?
2. Are the spectra produced by different diffraction devices the same?
3. What do you think the word "diffraction" means?



Activity 2: "Bubble-ology"

Materials Needed

The colors of visible light can also be seen in an enjoyable experiment with "bubble-ology."

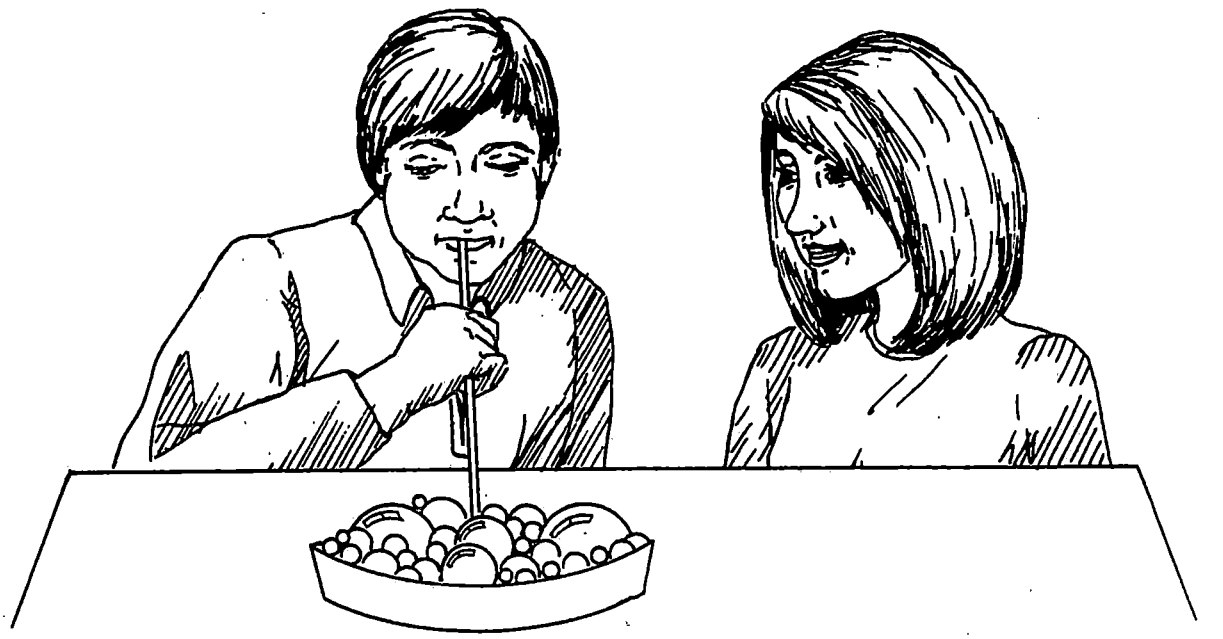
- 1 gal (4 ℓ) of cold water in a pan or bowl
- 1 C (0.25 ℓ) of liquid dishwashing detergent
- several straws
- light source, such as sunlight, or
- 1 or 2 straight filament lights with sockets

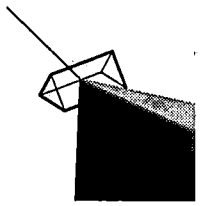
Step 1: In a shallow bowl or pan, gently mix the water and detergent. Use the straws to blow large bubbles in the water.

Step 2: Put the bowl in sunlight and examine the colors appearing on the surface of the bubbles.

When light hits the thin film of a bubble, it is reflected off both the top and bottom surfaces. These two different reflections cross and run into one another. When this happens, the reflected light separates into rainbow colors, also known as "interference color."

As the bubbles grow thinner and their "skin" is stretched out, the colors become redder. Later lessons will help you understand why.





Options for Extending the Lesson Across the Curriculum

Language

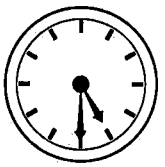
Look up the word **spectrum**. The plural used in the questions for Activity 1 is **spectra.** Why would the plural be formed this way? Spectrum is a Latin word and so forms its plural differently. Are there other words that form their plurals this way? What is the origin (etymology) of these words?

Creative Writing

Make up your own rainbow legend and share it with a younger child.

Art

Different colors of light and different colors of paint can both be mixed; however, red, green, and blue combine to form **white light**, while the primary colors of paint (red, yellow, and blue) combine to make **black**. Set up three projectors. Put a red filter on one, a blue filter on another, and a green filter on the last. Project these onto the same area. Where the colors overlap, white light will appear. Now, experiment with red, yellow, and blue paints. Paints have color because they absorb certain frequencies of light and reflect others. Why does black result when all three primary paint colors are mixed?



Home Activities

1. Early in the morning or late in the afternoon, use a hose with a sprayer attachment to create a rainbow in your yard. Use dark trees, bushes, or grass as a background for greater visibility.

2. With a magnifying glass, examine the screen of a television or a color picture from a magazine to see how color is achieved.

3. On a clear, dark night, look carefully at the stars. Color can be found here, too. If you look closely, some stars are noticeably red in color and some are blue-white. The blue-white stars are hotter, and red stars are cooler.

Activity 1 Answers: 1. Because there are no clear divisions between the colors, answers will differ here. This helps introduce the concept of a **continuous spectrum** that has no lines or well-defined boundaries. 2.Yes, basically they are the same. 3. Accept any reasonable answer here: breaking up, bending, splitting, and so on.
Note to Teacher: For science supplies such as prisms and diffraction gratings, see "Where to Obtain Materials," page 56.
Answers for Options for Extending the Lesson Across the Curriculum: Language — Some other words are medium (media), memorandum (memoranda), curriculum (curricula). These words come from the Latin, which does not use "s" to form plurals. Art — Black results because all colors are being absorbed; none are being reflected.
Student Activity Answers: What Color is Black?: All pigment colors are found in black ink.

Concept 1

Visible light demonstrates the existence of the spectrum.

Student Activity

What Color is Black?

Materials needed

- black felt-tip pen
- strips of coffee filters or clean newsprint
- glass jar
- water
- pencil or tongue depressor
- tape

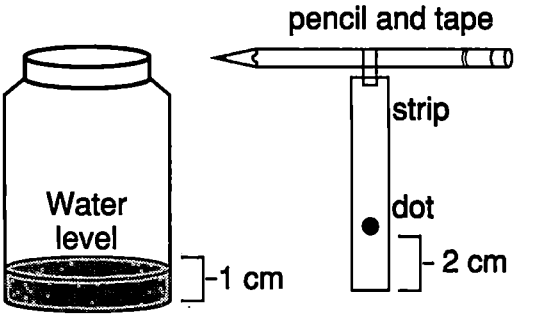
Step 1: Place a dot of black ink from the pen about 1 in. (2 cm) from one end of the paper strip.

Step 2: Tape the other end of the strip to the center of the pencil or tongue depressor.

Step 3: Put water into the jar so that about 0.5 in. (1 cm) of the paper strip will be under water when the pencil is placed on top.

Step 4: What colors do you think will be in the ink? Place a check next to those colors.

Color	Predicted	Actual
black		
red		
green		
blue		
yellow		
orange		
indigo		
violet		



Step 5: Rest the pencil on top of the jar so that the paper is in the water. The dot should **not** be under water.

Step 6: Observe carefully for 5 minutes. Check the colors that actually appear on the strip.

Results

What can be said about the colors in black ink?

Concept 1

Visible light demonstrates the existence of the spectrum.

Student Activity

Colors and Your Mind

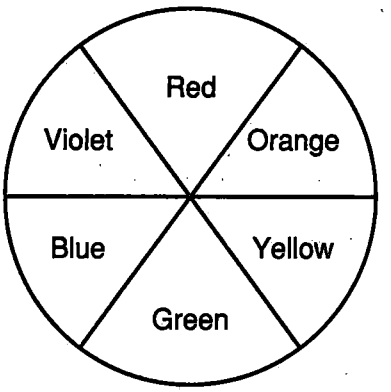
Colors play an important role in our lives, and we make color decisions every day. What color shirt should I put on? What color slacks should I buy?

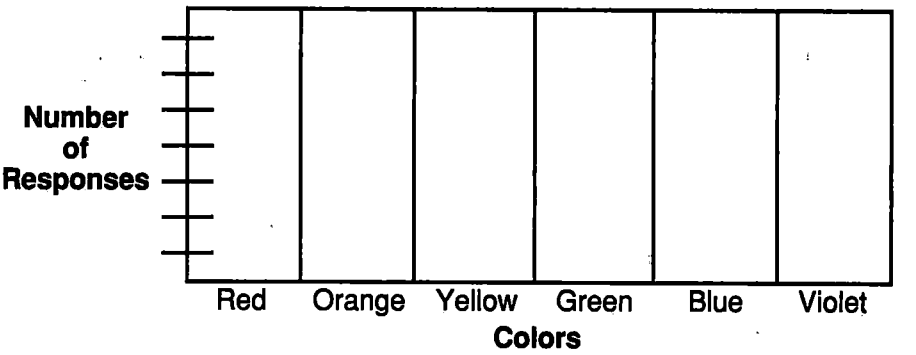
Different people have different color preferences. Do you like the warm reds and oranges or the cool greens and blues? Do color choices change? Do males and females tend to like different colors?

Try doing a survey.

Step 1: Color the wheel below according to the labels. Make the colors as similar as possible in intensity (felt-tip markers are good for this). Make the colors as "true" as possible; that is, make the red a "true red" rather than an orange-red or a blue-red, and so on with the other colors.

Step 2: Ask your friends and teachers to choose a favorite color. Keep track of the results.





Step 3: Fill in the number of responses vertically on the left side of the graph. Remember to use consistent steps: 0, 5, 10, 15 . . . or 0, 10, 20 . . . and so on.

Step 4: You can plot your graph as a line graph or a bar graph. The bar graph might be clearest because you could color your bars accordingly.

Step 5: Share the results with your class. An interesting variation might be to make two or more copies of the graph and survey males and females separately. Is there a difference? Try it again with individuals in different age groups; for example, people under 20 and those over 20. How do these compare?

Concept 1

Visible light demonstrates the existence of the spectrum.

Student Activity

Color Wheels

Color wheels show how our eyes and our brain mix colors. Our eyes receive the reflected colors, but because the colors are changing rapidly, our brain cannot distinguish them, and we see some intermediate color.

Step 1: Using this circle as a guide, trace and cut another circle out of poster board or heavy construction paper.

Step 2: Paint one side yellow and the other side blue.

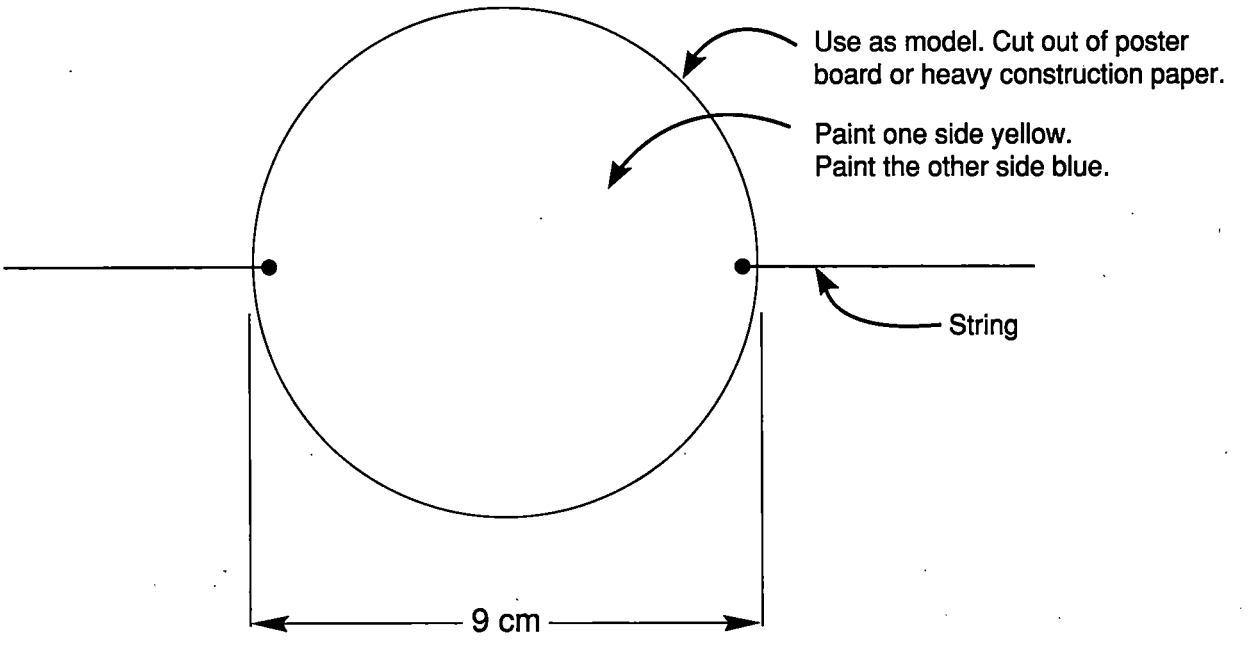
Step 3: Attach strings to opposite sides of the circle.

Step 4: Twirl string so the circle flips rapidly.

Step 5: Try this experiment again with different colors and keep track of the resulting colors.

Results

What colors result?



Twirl disk strings between fingers and thumb.

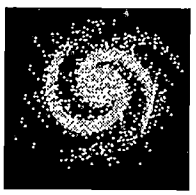
Seeing the Invisible

Concept 2

Radiation exists above and below the visible portion of the electromagnetic spectrum.

Objective

Students see evidence of the existence of radiant energy above and below the visible spectrum.

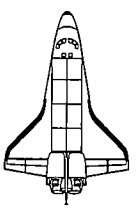


Background

While creating a spectrum is enjoyable, the exciting part is still to come: exploring the spectrum that is invisible.

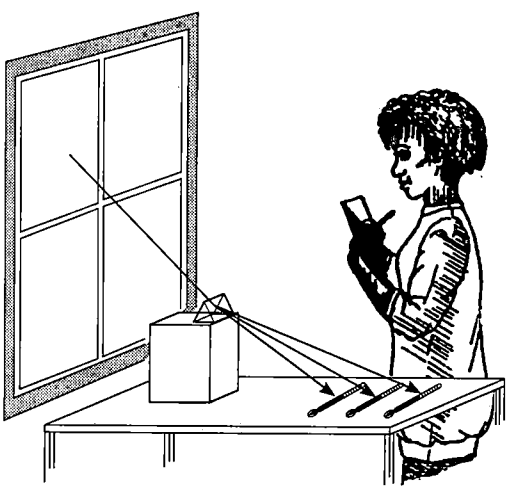
Have you ever had X-rays taken? What did they look like? What could you see? Did you see the X-rays coming out of the machine? How did you know they were there?

X-rays are part of the spectrum but are invisible. Today, you will prove the existence of invisible radiation. Remember, radiation means energy. These invisible rays are beyond both the red and violet ends of the visible spectrum and were discovered when Johann Ritter proved the existence of **ultraviolet rays** and William Herschel did the same with **infrared radiation**. These activities use almost exactly the same methods that were used in the 1800s when these discoveries were made.



Activity 1: Herschel's Experiment

To demonstrate the existence of infrared radiation, duplicate Herschel's experiment.



Materials Needed

- prism
- light source
- three weather thermometers
- pencil and paper

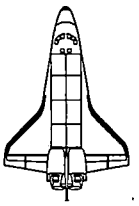
Step 1: Allow the three thermometers to register the temperature of the air where the experiment will be done — about 5 minutes. Take careful note of the temperatures.

Step 2: Create a spectrum using sunlight as the light source. (See Concept 1.)

Step 3: Place thermometers at several points in the spectrum: one in the violet range, one in the center, and one just barely beyond the red end. Leave the thermometers in the spectrum for at least 5 minutes, moving carefully as the sunlight moves the spectrum. Temperature changes may be very slight, so observe carefully.

Questions

1. What were the final readings on each of the three thermometers?
2. Why would there be an increase in temperature beyond the red end of the spectrum?
3. What does this tell us about what exists beyond the visible red?

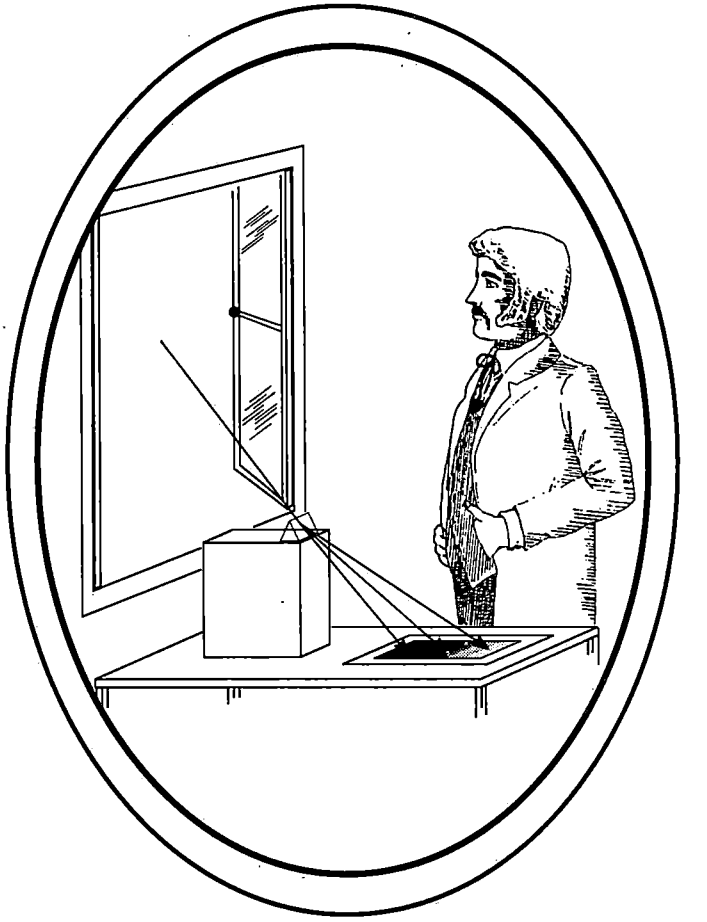


Activity 2: Ritter's Experiment

To demonstrate the existence of ultraviolet radiation, duplicate Ritter's experiment. In 1801, Johann Ritter performed an experiment using paper treated with silver chloride, which decomposes in the presence of light. He found that the silver chloride deteriorated even more rapidly when exposed to the previously unknown radiation beyond the violet end of the spectrum, which the human eye cannot detect.

Materials Needed

- several sheets of blueprint paper
- 1 qt (about 1 ℓ) of household ammonia
- flat pan
- prism or mirror in pan of water
- light source



Step 1: Using a prism or a pan of water, create a spectrum on a horizontal surface, such as a table. Use sunlight from an open window, as glass blocks most ultraviolet radiation. The prism should be resting on a stable object so that the spectrum does not move.

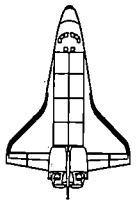
Step 2: Working quickly to prevent exposure of the paper to too much light, cut a piece of blueprint paper about four times larger than the spectrum. Place blueprint paper, which behaves the same way that Ritter's silver chloride paper did, underneath the spectrum. Quickly outline the area covered by the spectrum with a felt-tip pen. Label the violet end.

NOTE: Depending on the sensitivity of the paper, different exposure times will be needed. Most exposure times will be fairly brief, however: about 15 to 20 seconds.

Step 3: Put just enough ammonia in the pan to cover the bottom to a depth of about 0.5 in. (1 cm). In front of an open window or beneath a vent fan, hold the paper over the pan of ammonia so that the fumes will process the paper. Notice the changes in the area outlined and the area just beyond the violet end. You may have noticed that this area began to change even before processing with the ammonia.

Questions

1. What happened to the part of the paper lying where you can see violet?
2. What happened to the part of the paper lying just beyond that violet section?
3. What does this demonstrate about the area beyond the violet end of the spectrum?



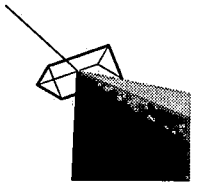
Activity 3: Astro-1 Experiments

Look at the Astro-1 illustrations and Astro-1 Facts your teacher has given you and/or projected onto the wall or a screen.

A NASA mission, named Astro-1, will carry instruments into space that will look at the stars and other objects in invisible energy ranges. Astro-1 instruments will be detecting the ultraviolet and X-ray ranges of the spectrum. Objects in the Universe emit energy in different wavelengths: visible light, infrared rays, ultraviolet waves, and others. The only way scientists can study many of these objects, particularly ones that are billions of light-years away, is to study the energy they give off in different wavelengths.

Question

Why would astronomers want to study ultraviolet radiation and X-rays from far-away objects?



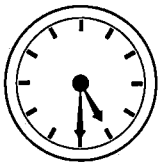
Options for Extending the Lesson Across the Curriculum

Language Arts

Look up the prefix **infra.** What does it mean? Why would **infrared** be called **"below"** red? What does **ultra** mean? What other words can you find or do you know that begin with **ultra**?

Art

Draw or paint your own portrait as your dog or cat would see you, using only combinations of black and white.



Home Activities

Look through your clothes at home. Remember what you learned with the colored cloths and the ice cubes? If you had to select clothes for a trip to the Sahara Desert, what colors would keep you cool? What colors would keep you warm on a trip to the Arctic?

Activity 1 Answers: 1. Answers will vary. 2. Heat must be there. 3. Invisible energy is there that produces heat.
Activity 2 Answers: 1. It shows signs of exposure. 2. It should be even more exposed than the violet section, probably appearing as a lighter area. 3. It demonstrates that radiation is there, but it is not visible to the human eye.
Activity 3 Answer: Because interesting, very energetic processes create this invisible radiation, and we can learn more about the Universe by studying it.
Note to Teacher: Illustrations of Astro-1 instruments can be found on page 41 of this guide. Paragraphs on the back of that page provide additional information.
Answers for Options for Extending the Lesson Across the Curriculum: Language Arts — Infra means below. Maybe it's called "below" red because it is a range of wavelengths whose frequencies are longer than red, and it is sometimes shown below red on the electromagnetic spectrum. Ultra means beyond. Ultra-modern is another word.
Art — **Note to Teacher:** See Student Activity, page 14.
Home Activities: Note to Teacher: See Student Activity, page 13.
Student Activity Answers: The Great Ice Race: 1. Ice cubes covered with darker cloths should melt more quickly. 2. Darker colors absorb heat; lighter ones reflect heat. 3. Dark colors should keep the wearer warm; light colors should help the wearer stay cool. 4. Space suits are white to reflect the Sun's heat.
Student Activity Answers: Pot-of-Gold Word Search: 1. Electromagnetic 2. Red, blue 3. Invisible 4. Filter 5. UV 6. Light, spectrum 7. Violet 8. Rainbow 9. Colors 10. Bulb 11. Bubble

Concept 2

Radiation exists above and below the visible portion of the electromagnetic spectrum.

Student Activity

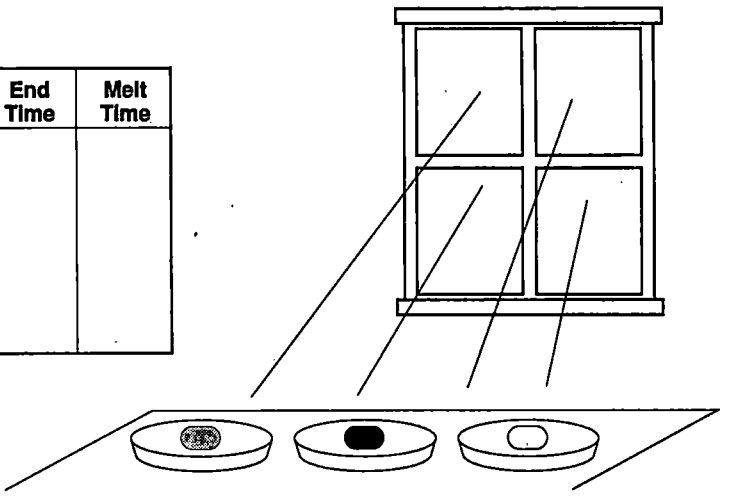
The Great Ice Race

Infrared radiation is heat. Certain colors absorb infrared radiation better than others. Try this experiment to see which colors absorb infrared radiation and which colors reflect it.

Materials Needed

- 3 or more ice cubes of about the same size
- the same number of flat dishes, all the same color
- pieces of cloth, each of a different color
- clock
- light source, preferably sunlight

Color	Start Time	End Time	Melt Time
1.			
2.			
3.			
4.			



Step 1: Put ice cubes in separate, flat dishes or containers in sunlight.

Step 2: Cover each cube completely with a different color cloth. Use a variety: ranging from very light to very dark.

Step 3: Write down starting time for experiment (start time).

Step 4: When ice cubes are completely gone, write down the time (end time).

Step 5: Subtract the start time from the end time to get the melt time.

Results

1. Which ice cube melted fastest?
2. Based on your results, which colors seem to absorb the most heat?
3. What colors should you wear when you want to stay warm? When you want to stay cool?
4. From what you have seen, can you guess why space suits are white?

Concept 2

Radiation exists above and below the visible portion of the electromagnetic spectrum.

Student Activity

A Black-and-White Vision

Try to imagine a world of black and white: no rainbows, charcoal-colored grass, pale-gray skies, black lakes and rivers, butterflies in shades of gray. A world like this sounds cold and unattractive to humans, but few people realize that the world appears just this way to many animals. Most mammals, except for apes and humans, have little color vision; some humans, too, are color-blind. Bees and butterflies, on the other hand, not only have color vision but can see into the ultraviolet region, and fruit flies can see almost up to the X-ray range. Fish, reptiles, and birds possess some color vision, but animals like dogs, cats, and horses see very little color at all. With this in mind, describe your room or your yard as your dog or cat might see it.

Concept 2

Radiation exists above and below the visible portion of the electromagnetic spectrum.

Student Activity

Pot-of-Gold Word Search

D P E O M R E Z B U L B M F S
A C S U A L V C A W T L U B P
F O W O N X I Y I K X U D E E
E L E C T R O M A G N E T I C
R O S E Q T L U V T L S L J T
A R A O B R E D U B R Y O U R
C S C N M F T W I Q U P A C U
R A R I D L G S X S O B J K M
G E G H R A I N B O W B B U E
P S P E F V G G I D I G M L N
Q V Q H N O I P H J H T U O E
F R F I L T E R L T K I A V Z

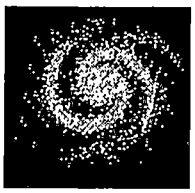
Fill in the blanks in the questions below by finding the correct words in the puzzle. The words run horizontally, vertically, and diagonally. Circle the words when you find them.

1. The whole range of energy waves from the longest to the shortest is called the _____ spectrum.
2. _____, green, and _____ are primary colors of light.
3. X-rays are_____ to the human eye.
4. Looking at a red apple through a green _____ will cause it to appear black.
5. _____ stands for ultraviolet.
6. White _____ is broken into a _____ by a prism.
7. The color of visible light that is closest to the invisible higher frequencies is _____.
8. A _____ is produced when white light is refracted by raindrops.
9. There are seven _____ found in visible light.
10. An ordinary light _____ will not produce a complete spectrum when its light passes through a prism.
11. Interference color can be seen on the surface of a _____.

Seeing Waves Everywhere

Concept 3
Light and other kinds of radiation consist of photons that travel in waves.

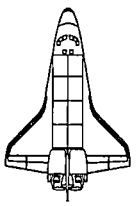
Objective
Students observe changes in wave motion created with different amounts of force.



Background

Try to visualize colors as having form and personality. Red waves are long and have little energy; green is a little shorter and more active; violet waves are short but energetic. Colors are found in visible light, and light is a kind of radiation. Radiation can be thought of as packets of energy called **photons** that travel in waves. Long waves travel with less **frequency** while short waves travel at the same speed but with greater frequencies.

Think about ocean waves. Light waves have high points, or **crests**, and low points, or **troughs**, just as ocean waves do. At the beach, do the gentle swells move your body? No, they just pick you up and set you down again. This is the nature of waves: energy traveling through things, rather than moving things.



Activity 1: Waves on a Rope

Wave action can be demonstrated easily with a piece of rope.

Materials Needed

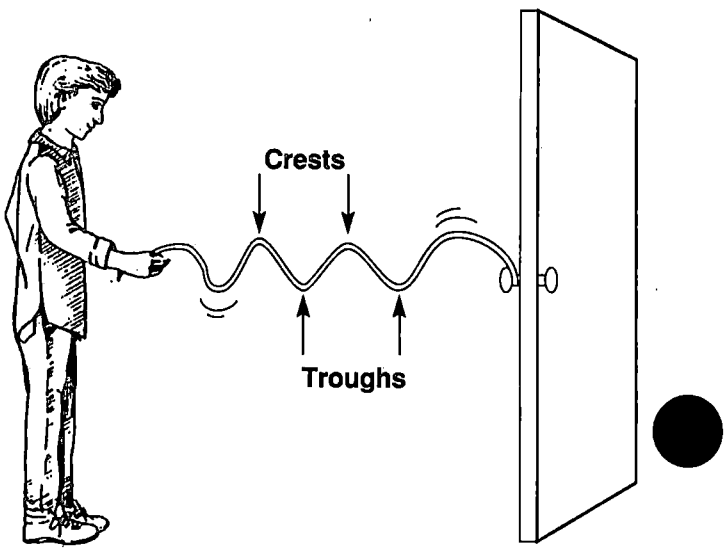
- piece of lightweight rope, approximately 4.5 ft (1.5 m) long

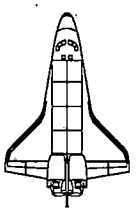
Step 1: Tie one end of the rope to a doorknob or desk and move the other end up and down.

Step 2: Move the rope up and down, slowly at first, and then with more energy.

Questions

1. What happens when the rope is moved slowly?
2. What happens when it is moved quickly?
3. What does this tell us about the energy of the source of the wave? Are long waves likely to be produced by a low-energy source or a high-energy source? What about short waves?
4. Exploding stars give off much energy. What kinds of waves would result?





Activity 2: Waves in Water

Visible light is just a small part of the electromagnetic spectrum, the range of radiation from radio waves to gamma rays. These electromagnetic waves are usually identified by their frequencies because all waves travel at the same **speed** but have different wave frequencies. Radio waves travel at low frequencies; gamma rays, at the other end of the spectrum, travel at very high frequencies. To observe wave frequency, try this experiment. **Because this experiment involves water and electrical equipment, it should be done by the TEACHER ONLY.**

Materials Needed

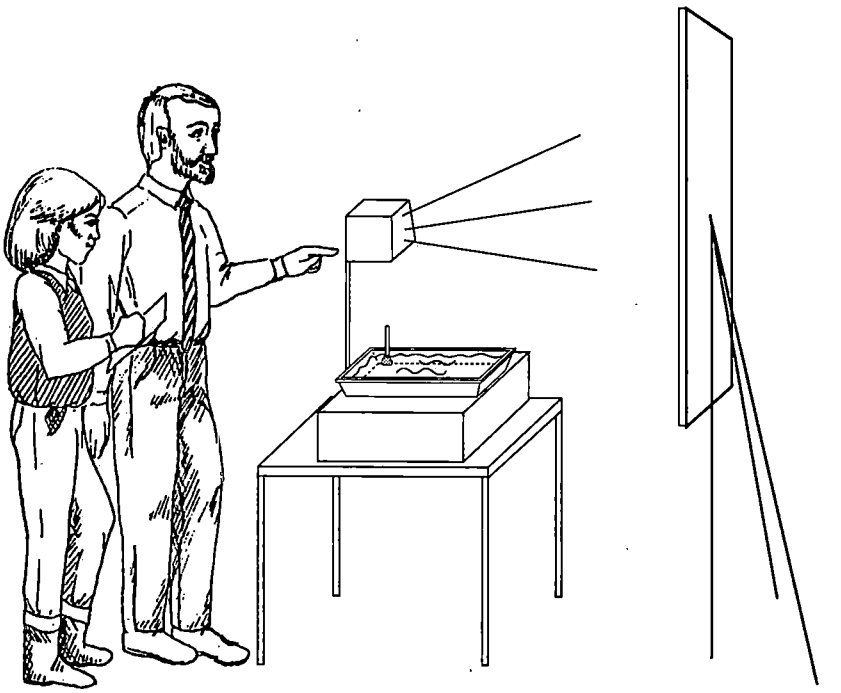
- clear glass pan, approximately 9 in. x 13 in., filled to a depth of about 1 in. (2 cm) with water
- tongue depressor
- putty or clay
- overhead projector

Step 1: Soften a piece of clay or putty and place it on the bottom of the pan near the end. Stand the tongue depressor with the clay.

Step 2: Fill the pan with water.

Step 3: Place the pan on the overhead projector surface.

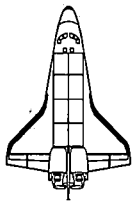
Step 4: Using the side of your hand, slowly strike the water's surface at the end opposite the stick. Waves will appear on the projector screen. Note how many waves pass the stick in 5 seconds. You may count by observing either wave crests or troughs passing the stick.



Step 5: Strike the water more quickly and again note the number of waves passing the stick in 5 seconds. You are seeing variations in wave **frequency.**

Questions

1. Which action produces more frequent waves?
2. Think about what you have observed. Can you write your own definition of frequency?



Activity 3: Looking at the Spectrum

It is important to study the different frequencies that make up the electromagnetic spectrum.

Materials Needed

- chart of the electromagnetic spectrum

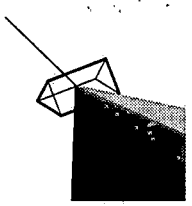
Look at the chart of the spectrum your teacher has given you or projected onto a screen or wall.

There are seven wavelength ranges. On this chart, the less energetic frequencies are on the left, the more energetic frequencies on the right. Those that were investigated in Concept 2 are beyond the visible spectrum. (The infrared and the ultraviolet.)

Astro-1 instruments are used in high-energy astronomy; they observe objects in the ultraviolet and X-ray ranges. These waves are shorter than visible light waves, but they are more energetic.

Questions

1. How do waves at the red end of the spectrum compare in length to the waves at the violet end?
2. Which waves probably are more energetic?



Options for Extending the Lesson Across the Curriculum

Language Arts

Did you know that you can speak Latin? In a dictionary that gives word origins, look up the prefix **astro**. What does it mean? Can you think of any other words that begin with this prefix? **Astro** is a Latin prefix. What does the fact that the Romans, who spoke Latin, had a word for "star" tell you about them? Their word for "sailor" was **nauta**. What word do **astro** and **nauta** make together?

Creative Writing

"Once upon a time, long, long ago, people could see ultraviolet radiation and X-rays . . . ." Write a legend that explains what happened to this imaginary ability.

Activity 1 Answers: 1. Long waves are produced. 2. Short waves are produced. 3. It tells us that the length of the wave is related to the energy of the source. Long waves are likely to be produced by a low-energy source. Short waves are likely to be produced by a high-energy source. 4. Short waves
Activity 2 Answers: 1. Striking the water quickly 2. Frequency is the number of crests or troughs passing a point in a unit of time. **Note to Teacher:** To do this as a student activity, suspend a clear light bulb over a glass pan set on a white surface. When other room lights are turned off, wave shadows can be seen clearly.
Activity 3 Answers: 1. Waves at the red end are longer than the waves at the violet end. 2. The waves at the violet end
Note to Teacher: See page 47 for electromagnetic spectrum.
Answers for Options for Extending the Lesson Across the Curriculum: Astro comes from the Latin word **astra**, meaning "star." The fact that the Romans had a word for star tells us that they were interested in the stars. Roman sailors navigated by the stars, and **astronaut** means "star sailor."
Student Activity Answers: Metric Math Challenge — Making Long Numbers Short: 1. 6.5×10^{-7} m 2. 5.0×10^{-7} m 3. 2.2×10^{19} km 4. 4.0×10^{7} km 5. 1.0×10^{-5} or 10^{-5} cm
Student Activity Answers: The Spectrum and You: 1. Visible light 2. Ultraviolet rays 3. Radio waves 4. X-rays 5. Infrared 6. Microwaves
Student Activity Answers: The Long and Short of It: 1. Atom - X-ray waves 2. Statue of Liberty - radio waves 3. Dime - microwaves 4. Pinhead - infrared waves 5. Nucleus of an atom - gamma ray waves 6. White blood cells - ultraviolet light waves 7. Dust specks - visible light waves

Concept 3

Light and other kinds of radiation consist of photons that travel in waves.

Student Activity

Metric Math Challenge — Making Long Numbers Short

Now that you have a good idea of the sizes of wavelengths across the spectrum, let's work on writing the sizes as astronomers do. Scientists working with very large or very small numbers use a system called **scientific notation.** This shortens numbers by substituting powers of 10 for long strings of zeros. For example, the star nearest to us outside the solar system is Proxima Centauri, which is 4.3 light-years away. A **light-year,** the distance light can travel in a year, is almost 10 trillion kilometers, or 10,000,000,000,000 km. Proxima Centauri is 43,000,000,000,000 km away. Writing numbers this way would take a lot of time and paper, so instead astronomers move the decimal enough places to the left to leave the 4 by itself (4.3). Then, they multiply 10 by itself enough times to supply all the zeros: 10,000,000,000,000 or 10^{13}. Now, Proxima Centauri can be said to be 4.3×10^{13} km away.

Very small numbers can also be written this way. An X-ray is about 0.000000001 meter long. Now, however, the power of 10 is given as a negative exponent, 10^{-9}, and X-rays are said to be 1.0×10^{-9} m long or simply 10^{-9} m. More examples are given below. Can you figure out how to write these other wavelengths in scientific notation?

1. Red light is 0.00000065 m. Write in scientific notation. _____

2. Green light is 0.00000050 m. Write in scientific notation. _____

3. The nearest large galaxy, Andromeda, is 2.2 million light-years, or 22,000,000,000,000,000,000 km away. Write this in scientific notation. _____

4. Venus is 40,000,000 km from Earth. That is _____ km in scientific notation.

5. Written as _____ in scientific notation, a white blood cell is about 0.00001 cm long.

$10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 10^{13}$ (10,000,000,000,000)

Number	Move Decimal	Powers of Ten	+/–	Scientific Notation
43,000,000,000,000.00	4.3 (13 places)	10x10x10x10x 10x10x10x10x 10x10x10x10x 10 = 10^{13}	+ >1	4.3×10^{13}
0.000000781	7.81 (7 places)	10x10x10x10x 10x10x10 = 10^{7}	– <1	7.81×10^{-7}

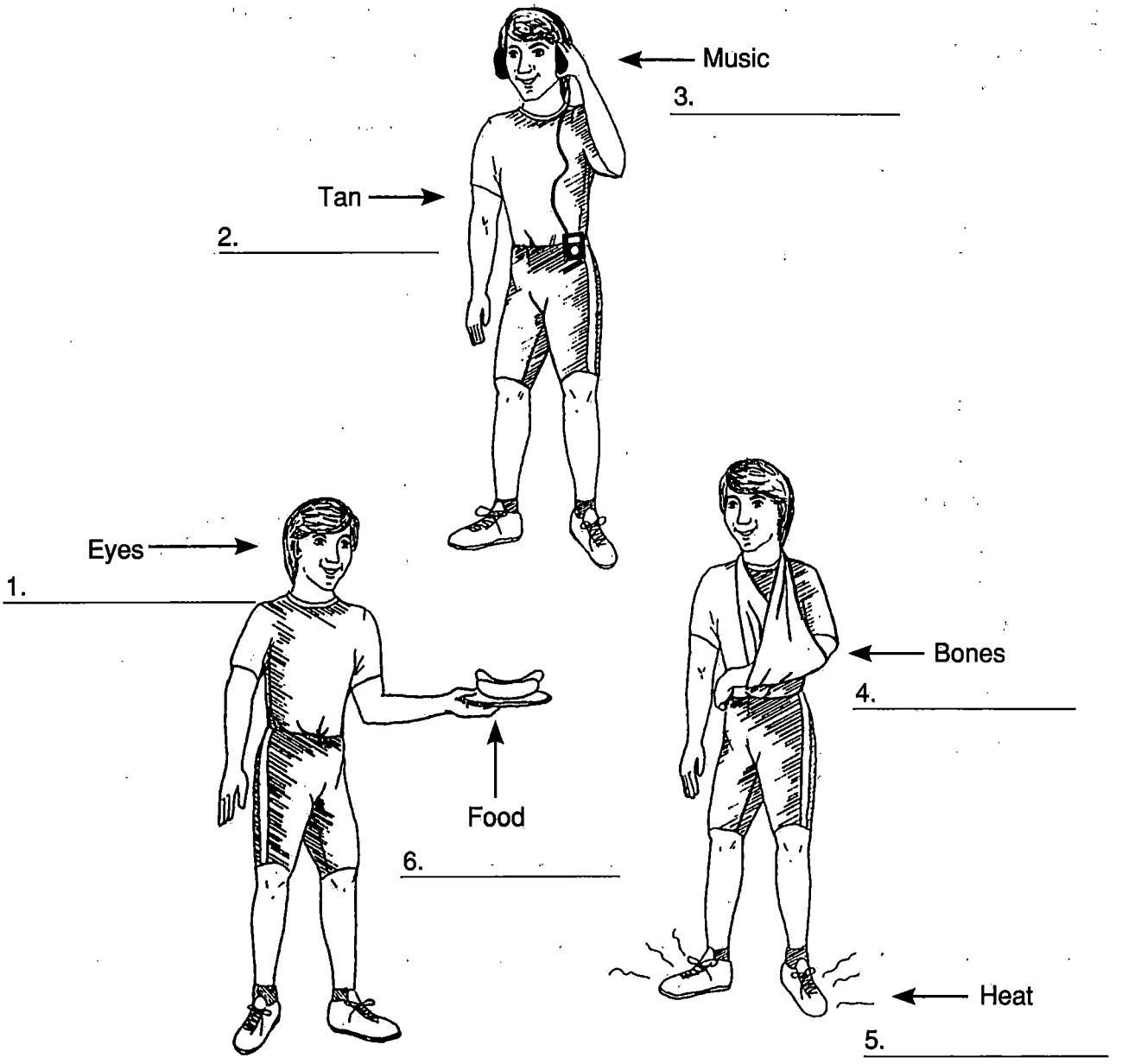
Concept 3

Light and other kinds of radiation consist of photons that travel in waves.

Student Activity

The Spectrum and You

Different radiation wavelengths are part of your everyday life. Write the name of the wavelength in the blank below the way that it affects your life.



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microwaves	radio waves
infrared	ultraviolet rays
visible light	X-rays

Concept 3

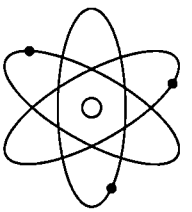
Light and other kinds of radiation consist of photons that travel in waves.

Student Activity

The Long and Short of It

Although the range of energy in the electromagnetic spectrum is continuous, it has been divided into seven categories of energy, distinguished by their wavelengths (the distance between their crests or troughs). Below are some objects approximately the same size as the wavelengths. Can you match the length of the wave with the size of the object? Write the name of the wavelength next to the object that is approximately the same size.

Objects



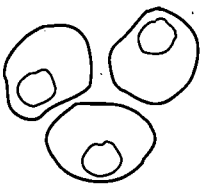
1. Atom _____

2. Statue of Liberty _____

3. Dime _____

4. Pinhead _____

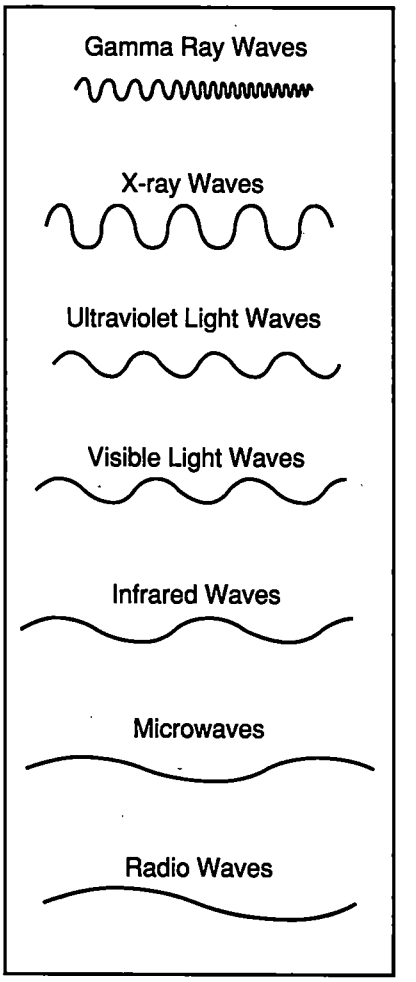
5. Nucleus of an Atom _____



6. White Blood Cells _____

7. Dust Specks _____

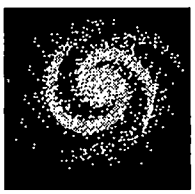
Type of Radiation



Seeing Into the Universe

Concept 4:
Certain celestial objects give off radiation other than visible light, and we must study them in other energy ranges.

Objective:
Students will identify some celestial objects that are studied in other energy ranges.



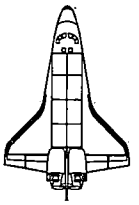
Background

Can you name the star nearest Earth? Did you remember that the Sun is a star? The Universe holds an incredible variety of objects. The twinkling stars and dusty Milky Way that we see in the night sky are only a small portion of what is actually there; many of the most fascinating objects in the Universe give off much of their energy as the invisible wavelengths that you have been studying: radio waves, infrared waves, ultraviolet rays, X-rays, and gamma rays.

Objects that give off a lot of energy emit short wavelengths, while objects that give off less energy emit longer wavelengths. Many of the objects we see by visible light, such as planets, are relatively cool; hotter objects, such as very new **stars** or old stars give off ultraviolet radiation. **White dwarfs**, which are small stars in the last stages of their lives, emit much of their energy as ultraviolet radiation and are sometimes in **binary star systems**, pairs of stars attracted to each other by gravity. In this star combination, the white dwarf may pull matter from a larger star, forming an **accretion disk,** the hot matter that connects the two stars.

Young **galaxies** give off large amounts of ultraviolet and X-ray radiation in their **spiral arms** where new stars are born and in their centers where high-energy processes take place. Galaxies come in several different shapes. Our galaxy, the Milky Way, is a spiral galaxy and has a pinwheel shape. Mysterious **black holes**, possibly the remains of collapsed giant stars, swallow even light. X-rays are given off as they consume everything close to them. **Neutron stars**, the tiniest and densest stars known, are also sources of X-ray radiation. Neutron stars may be found in the centers of **supernova remnants**, also called **nebulae**, the remains of giant exploded stars. The **interstellar medium**, the term given to the shapeless clouds of dust and gas between the stars, actually absorbs ultraviolet radiation and distorts astronomers' views.

These are just a few of the hundreds of kinds of intriguing objects in the Universe, but they are millions and millions of miles away, and we can learn about them only by studying the light messages they send through space. They exist in a Universe mostly hidden from the naked eye but visible to astronomers studying them with ultraviolet and X-ray instruments, such as those on Astro-1.

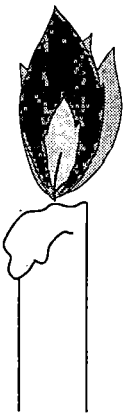


Activity 1: Color and Temperature

Stars, like everything around us, come in different colors of visible light and also give off invisible radiation, such as radio waves, infrared waves, ultraviolet waves, X-rays, and gamma rays. You can see color differences with your naked eye. Cool, red stars can be picked out on a clear, dark night. How do astronomers know that red stars are cool?

Materials Needed

- wax candle
- matches

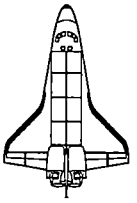


Step 1: Turn room lights down or off.

Step 2: Light the candle. Without getting too close, look carefully at the candle flame.

Questions

1. What colors do you see there?
2. Where are the different colors found? Describe their location in the flames.
3. Where would you guess that the hottest part of the flame would be?
4. What color would the hottest stars probably be?
5. The cooler stars?



Activity 2: How Far the Stars?

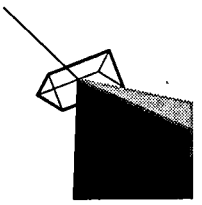
When you were growing up, you probably asked your parents lots of questions: Why is the sky blue? Why do dogs bark and cats meow? Why do stars twinkle? All of us are curious about the world around us. Astronomers try to answer questions about the Sun, the solar system, the Milky Way Galaxy, and the endless reaches of deep space. The incredible distances of the objects they study provide a real challenge.

To give you some idea of the distances, consider this: light travels about 186,000 mi (300,000 km) per second. It could travel the distance from New York City to Los Angeles in 1/100 of a second.

See if you can calculate the time it takes for light to travel to Earth from some of the objects closest to us. Remember, distance equals rate multiplied by time (D = RT), and light's rate of travel is 186,000 mi (300,000 km) per second.

Questions

1. The Moon is about 239,000 mi (384,000 km) from Earth. How long does it take sunlight reflected off the Moon to reach Earth?
2. The Sun is about 93,000,000 mi (150,000,000 km) away. When you are standing in the sunlight, how long did the light that falls on you have to travel?
3. The closest star to us, other than the Sun, is Proxima Centauri, which is about 26,000,000,000,000 mi (43,000,000,000,000 km) away. If your spaceship could travel at the speed of light, how long would the trip take?



Options for Extending the Lesson Across the Curriculum

Art

Use colored pencils or pastels to color the stars in the Hertzsprung-Russell Diagram of the main sequence, page 25. The colors should reflect the colors that are filled in at the bottom.

Creative Writing

Research black holes, then use your imagination to describe a trip into a black hole. How does it feel? How long does it take? What do you see? What is on the other side?

Music

Listen to "Thus Spake Zarathustra," the theme music from "2001: A Space Odyssey." Why do you think it was selected for this movie? Another selection is "Neptune" from Holsts' "Planets." What imagery does it convey?

Home Activities

Look at a 3-D book with special glasses, then without. Describe the differences between the two images that your special glasses make. Do these special glasses make it possible to see more clearly and completely? Is this similar to the way astronomers use special instruments to observe celestial objects?

If you have access to a VCR, rent a "space movie" such as "2001: A Space Odyssey," "Star Wars," or others. What kinds of music were used? Was the story based on any scientific principles?

Activity 1 Answers: 1. White, blue, orange, and red 2. The center of the flame is white, with blue at the top. Outer parts are reddish-orange. 3. The hottest part, which is blue, is just above the center. 4. The hottest stars would be blue. 5. Cooler stars are reddish-orange.

Activity 2 Answers: 1. 1.28 seconds 2. Approximately 8 minutes 3. About 4.3 years

Student Activity Answers: The Hertzsprung-Russell Diagram: Temperatures (left to right): 20,500°; 10,000°; 7,000°; 5,500°; 5,000°; 3,500°. Colors (left to right): violet, indigo, blue, white, yellow, orange, red. 1. Mass increases also. 2. Blue 3. Red 4. White

Student Activity Answers: Scrambled Eggs-tra Galactics: Note to teacher: It may be necessary to discuss the shapes and processes of these objects before assigning this activity to students. See Concept 4, Background, page 22.
1. Black hole 2. Supernova remnant 3. Neutron star 4. Galaxy 5. Spiral arm 6. Binary star system 7. White dwarf 8. Accretion disk 9. Interstellar medium 10. Star

Concept 4

Certain celestial objects give off radiation other than visible light, and we must study them in other energy ranges.

Student Activity

The Hertzsprung-Russell Diagram

Astronomers need to study all ages and types of stars. This is what the Astro-1 mission will do. Astro-1 telescopes will observe young stars, middle-aged stars like our Sun, and older stars near their death.

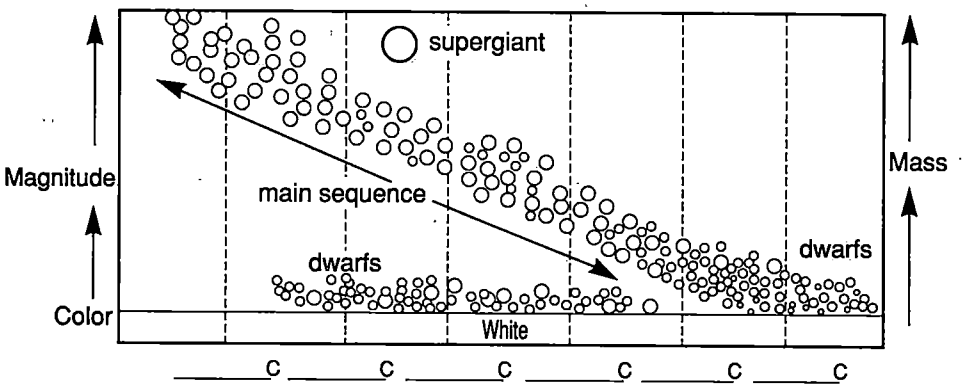
Two astronomers, Ejnar Hertzsprung and Henry Russell, studied the lives of stars in the early part of this century. Though they did not work together, both found that there is a relationship between the brightness, or **magnitude**, of a star and its temperature: as the temperature increases, the brightness increases, unless the star appears bright just because it is close. This relationship forms a pattern, shown on the **Hertzsprung-Russell (H-R) Diagram**. This pattern runs from the upper left to the lower right of the diagram. The stars in this area are called **main sequence stars**.

Later, scientists discovered that there is a relationship between a star's temperature and mass. Mass is the amount of matter in an object. Stars with more mass burn differently and have higher temperatures than stars with less mass. This is shown on the H-R Diagram. The diagram also reveals the relationship between star temperature and color: hotter, more massive stars are blue, while cooler, less massive stars are red.

Step 1: Fill in the temperatures in the spaces at the bottom of the chart. Remember that the stars in the upper left corner are the hottest. Where will the highest temperature go?

Step 2: Some of the colors are missing from the chart. Use what you have learned about star colors (colors in the shorter frequencies, like ultraviolet, are from hotter objects) to fill in the missing colors. Read carefully.

The Hertzsprung-Russell Diagram



Temperatures
5,000°, 7,000°, 3,500°, 20,500°, 5,500°, 10,000°

Colors
red, indigo, yellow, violet, orange, blue

Questions

1. As magnitude increases, what happens to mass?
2. What color will the supergiant in the upper left be?
3. What color will the dwarfs in the lower right be?
4. What color will the dwarfs in the center be?

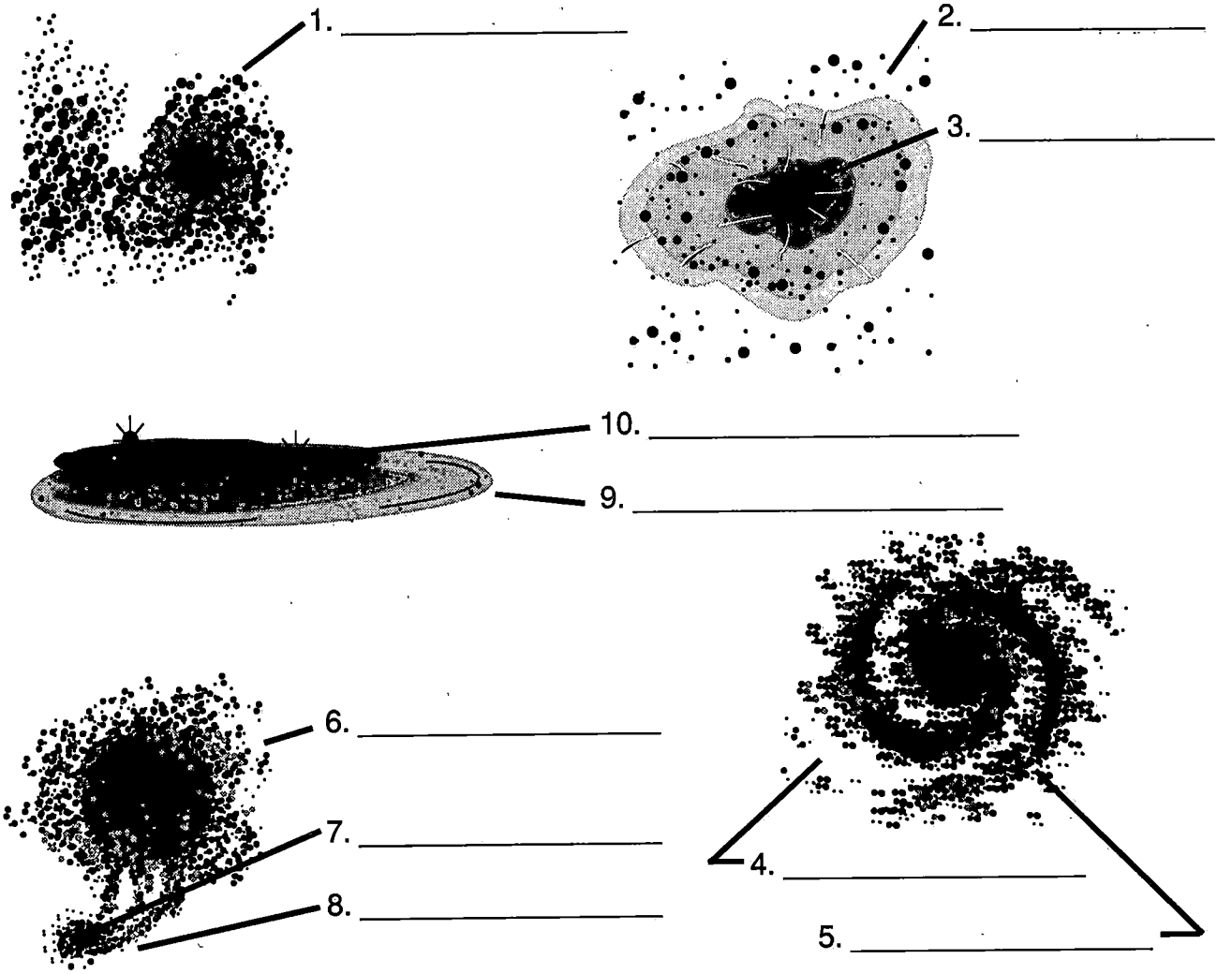
Concept 4

Certain celestial objects give off radiation other than visible light, and we must study them in other energy ranges.

Student Activity

Scrambled Eggs-tra Galactics

Shown below are some of the objects that will be observed by the Astro-1 telescopes. Astronomers have never seen black holes; this drawing just suggests what they may be like. Unscramble the names below. Then match them with the objects or parts of objects by writing the names on the blank next to the object.



lcakb ohel _____

aibrny srta tyssme _____

hteiw radwf _____

narcciteo skid _____

rats _____

sarlip rma _____

lyaaxg _____

psroavneu rtnneam _____

tnuroen rats _____

leitsalerrtn uidmme _____

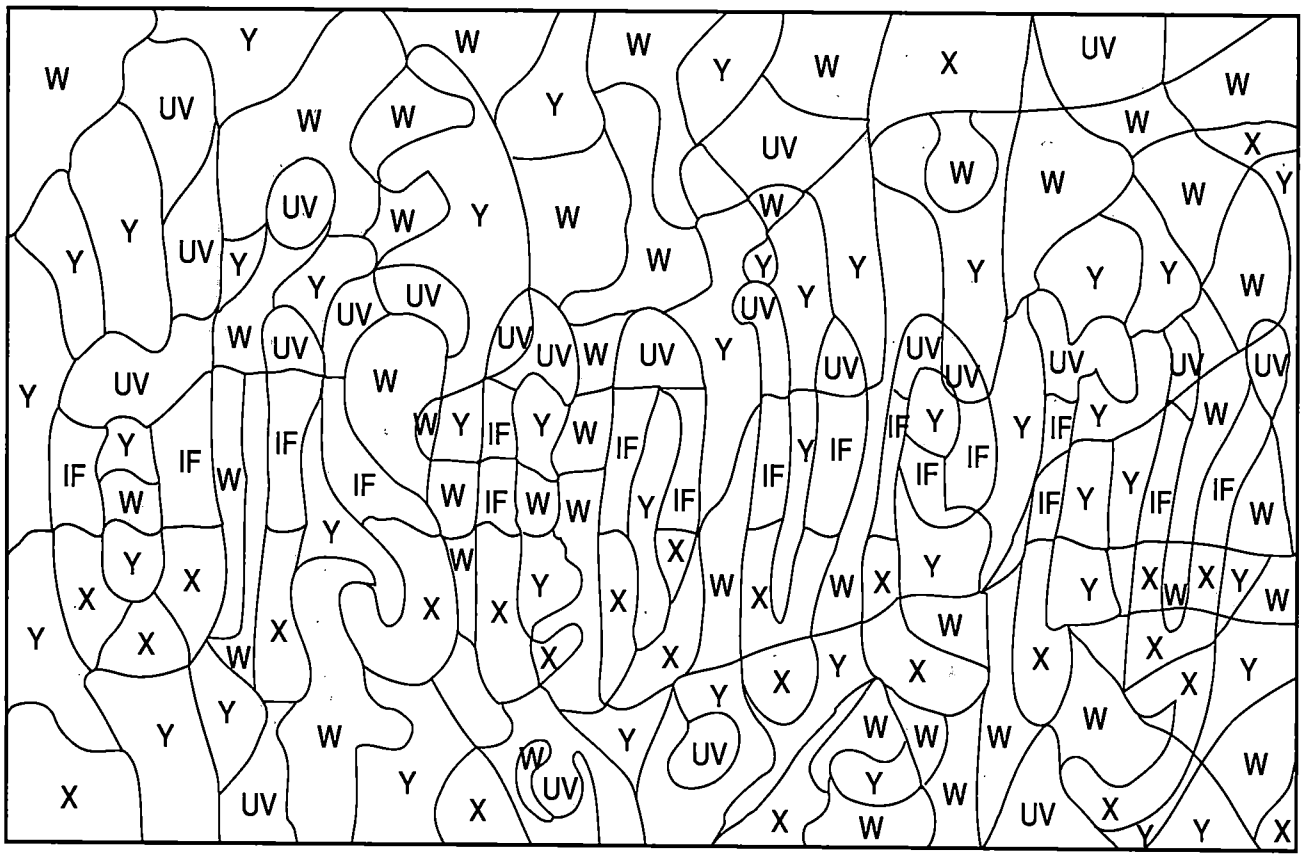
Concept 4

Certain celestial objects give off radiation other than visible light, and we must study them in other energy ranges.

Student Activity

Getting the Whole Picture

If we could view the Universe in only one wavelength, we would miss some very important things. Wavelengths other than visible light are needed to see certain objects in space: ultraviolet (UV), infrared (IF), and X-rays (X). Use colored pencils to fill in the coded blanks. First, color the UV pieces purple. Can you see what it is? Leave W white, but color Y pieces light yellow. Color IF blanks red. Now can you tell? Make the X pieces black. Now you're seeing in several wavelengths. What could you have missed?



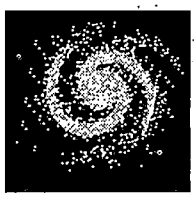
Seeing Through a Filter

Concept 5

Certain waves of radiation are blocked by Earth's atmosphere.

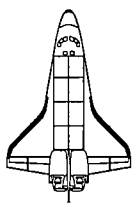
Objective

Students participate in an experiment that demonstrates how Earth's atmosphere blocks certain wavelengths.



Background

Think of Earth's atmosphere as a pair sunglasses — a barrier that repels some forms of radiation while allowing others through. Sunglasses allow visible light to pass through but block certain other rays. Like sunglasses, the atmosphere absorbs or scatters certain waves of radiation coming from the Sun, stars, and other objects in space. Most ultraviolet waves, X-rays, and short, highly energetic **gamma rays** from space do not reach Earth's surface nor do some wavelengths in the longer infrared and **microwave** ranges. The atmosphere protects animal and plant life from harmful radiation that can cause skin cancer in humans and affect plant photosynthesis. At the same time, the atmosphere blocks the infrared, ultraviolet, X-ray, and gamma-ray radiation that allow us to "see" objects in the Universe in other energy ranges.



Activity 1: Refraction

Use a jar of cloudy water and a flashlight to demonstrate refraction. The bending of the light wave demonstrates one of the ways that the atmosphere affects light waves.

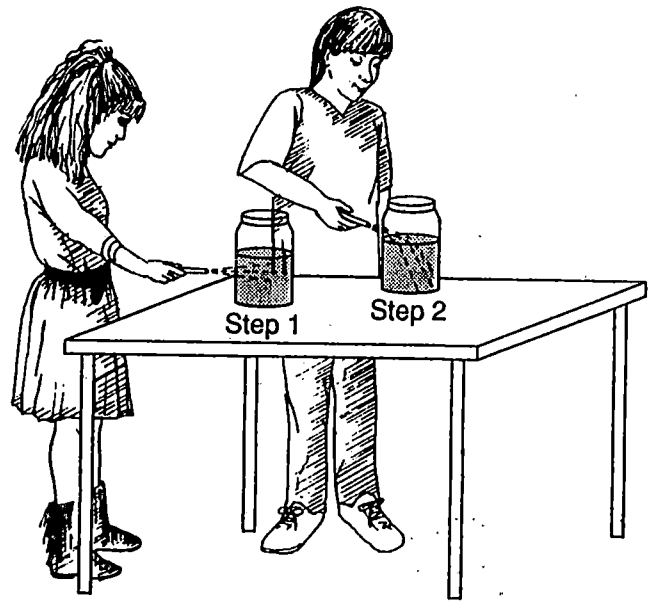
Materials Needed

- 1-qt (1- ℓ) jar (clear glass)
- small flashlight with narrow beam
- water
- few drops of milk

Step 1: Fill the jar with water. Add a few drops of milk to make the water cloudy.

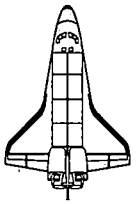
Step 2: Shine the flashlight into the water below the surface.

Step 3: Move the flashlight up to the water's surface.



Questions

1. What happens when the light beam shines through the water below the surface?
2. When the light beam travels from air into water, what happens?
3. If Earth's atmosphere contains particles of dust and water vapor, what do you think happens to radiation coming into the atmosphere?

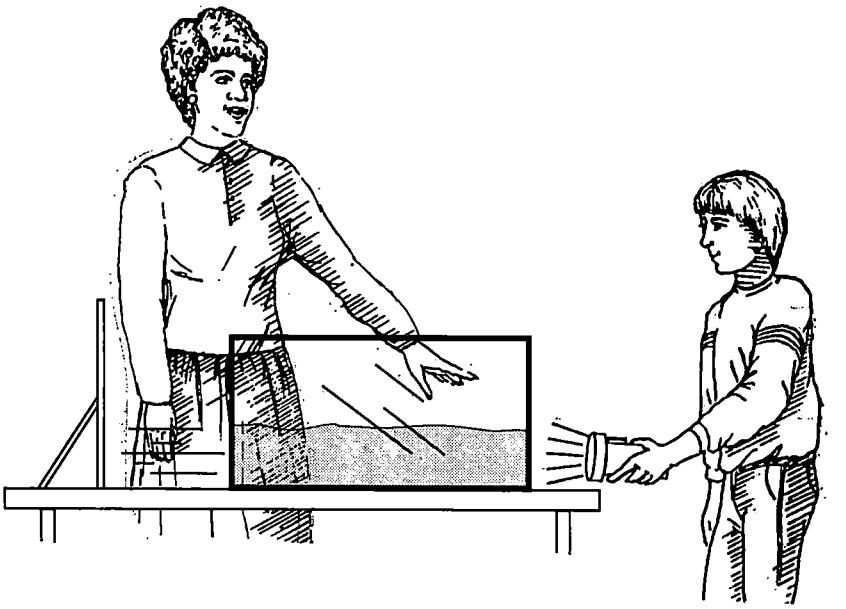


Activity 2: The Atmosphere and Color

To show the effect of the atmosphere on the Sun's rays, try this experiment. Use only diluted acid. **This should be done by the TEACHER ONLY, even though the acid listed is very diluted.** The aquarium may be used for other purposes if washed thoroughly after this experiment.

Materials Needed

- 5-gal (20- ℓ) rectangular aquarium (clear glass)
- 1 gal (4 ℓ) water
- 10 g sodium thiosulfate or sodium hyposulfite (photographic fix)
- 160 ml 0.5N solution of sulfuric acid
- flashlight
- white screen



Step 1: Mix thiosulfate and water (this amount is not critical) in the aquarium.

Step 2: Add 160 ml of diluted sulfuric acid and stir with glass rod.

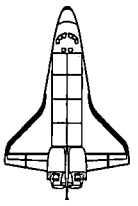
Step 3: Project light through aquarium to screen.

Questions

1. At the beginning, what color is the water when the flashlight shines through it?
2. What color is the light of the flashlight when viewed directly?
3. How does the color of the water change as time goes on?
4. What causes the water to change color?
5. What is the final color of the light?
6. Why? Have you seen anything like this in nature?

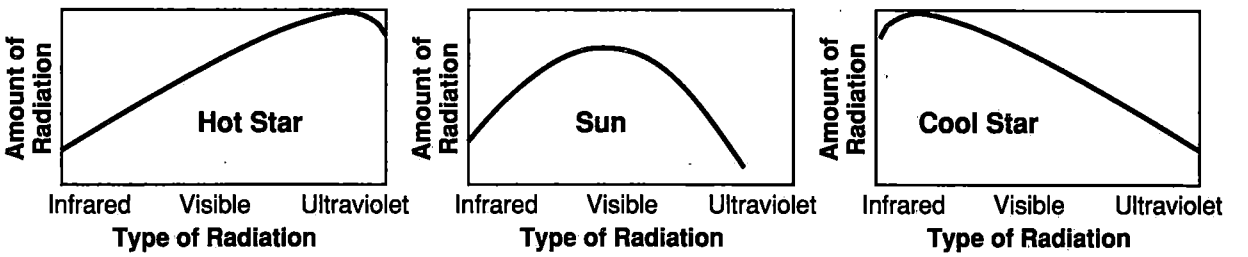
More Help

This demonstration helps explain the scattering effects of Earth's atmosphere on different wavelengths. Think of the water in the aquarium as Earth's atmosphere and the flashlight as the Sun. The reaction of the acid on the sodium thiosulfate creates very fine particles, and very fine particles in the atmosphere cause the sunlight to scatter. The scattering effect first removes the violet and blue end of the spectrum (the shorter waves) and later the red end (the longer waves) as the particles grow larger. Short waves are scattered more than long waves and are scattered by smaller particles than are long waves.



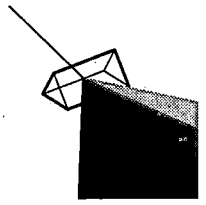
Activity 3: A Picture of a Different Color

Most high-energy radiation, such as ultraviolet, X-ray, and gamma-ray emissions, does not penetrate Earth's atmosphere. Many objects in space, however, give off much of their energy in these ranges. Therefore, scientists must go above the atmosphere to study these objects. Look at these diagrams of star energies.



Questions

1. Hot stars emit most of their radiation in what range?
2. Cool stars emit most of their radiation in what range?
3. Would any of these three stars be invisible to a traveler passing in a spaceship?
4. Would it be correct to say that Earthbound astronomers are, in a way, "color-blind" because their instruments cannot detect all the wavelengths?



Options for Extending the Lesson Across the Curriculum

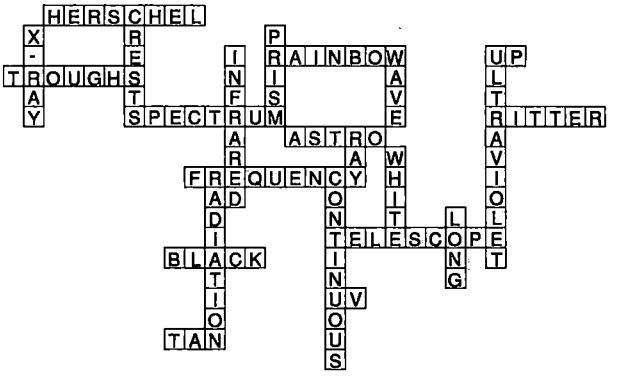
Creative Writing

Ultraviolet rays cause suntans. If we are not careful, they can also cause sunburns. Use your imagination to write a description of what X-rays would do if not blocked by the atmosphere. What effect would X-rays have on plants? Animals? Use lots of descriptive words.

Home Activities

Observe sky color differences at sunrise, noon, and sunset. How is this like the classroom experiment?

Activity 1 Answers: 1. The beam appears to widen slightly but doesn't bend. 2. The beam bends when it hits the water. 3. Radiation entering Earth's atmosphere is absorbed, reflected, or transmitted.
Activity 2 Answers: 1. A blue-violet color 2. White 3. Goes from blue to yellow-green, to orange, and then red 4. The size of the particles increases, and so different wavelengths of light are scattered. The larger the particle, the longer the wavelength that is scattered. 5. No light comes through. 6. There is no light at the end because all wavelengths are being scattered. A similar situation occurs at sunset.
Activity 3 Answers: 1. Ultraviolet 2. Infrared 3. No. All three give off at least some of their radiation in the form of visible light. 4. Yes. Astronomers could be considered color-blind because they must look through the filters of Earth's atmosphere.
Student Activity Answers: Surfing on Math Waves: (a) 50 (b) 4 (c) 50 (d) 0.4 (e) 0.15 (f) 0.6
Student Activity Answers: Crosswords and Colors:
Student Activity Answers: Atmospheric Sunglasses: 1. Radio waves 2. Microwaves 3. Infrared waves 4. Visible light (given) 5. Ultraviolet waves 6. X-rays 7. Gamma rays



Concept 5

Certain waves of radiation are blocked by Earth's atmosphere.

Student Activity

Surfing on Math Waves

You have learned that waves have **lengths**, which is the distance between two neighboring **crests** (high parts) or between neighboring **troughs** (low parts). They also have **frequencies.** The frequency of a water wave, for instance, can be described as the number of crests of a water wave passing a particular point in 1 second. The number of complete waves passing during 1 second is the frequency (f) of that wave. Frequency is measured in **Hertz (Hz)**, named after Heinrich Hertz, who was one of the first to study light waves. One complete wave passing a point each second is a frequency of 1 Hz.

Photons, the packets of energy that make up light and other forms of radiation, also have **velocity.** In space, all energy waves travel at the same velocity.

The relationship between wavelength, velocity, and frequency of waves is expressed this way:

$$\text{wavelength} = \frac{\text{velocity}}{\text{frequency}} \qquad w = \frac{v}{f}$$

You can use different forms of the same expression to find velocity and frequency:

$$\text{frequency} = \frac{\text{velocity}}{\text{wavelength}} \qquad f = \frac{v}{w}$$

and

$$\text{velocity} = \text{frequency} \times \text{wavelength} \qquad v = f \times w$$

Below is a chart with velocity, frequency, and wavelength. Use the equations given above to figure out the missing figures. Happy surfing.

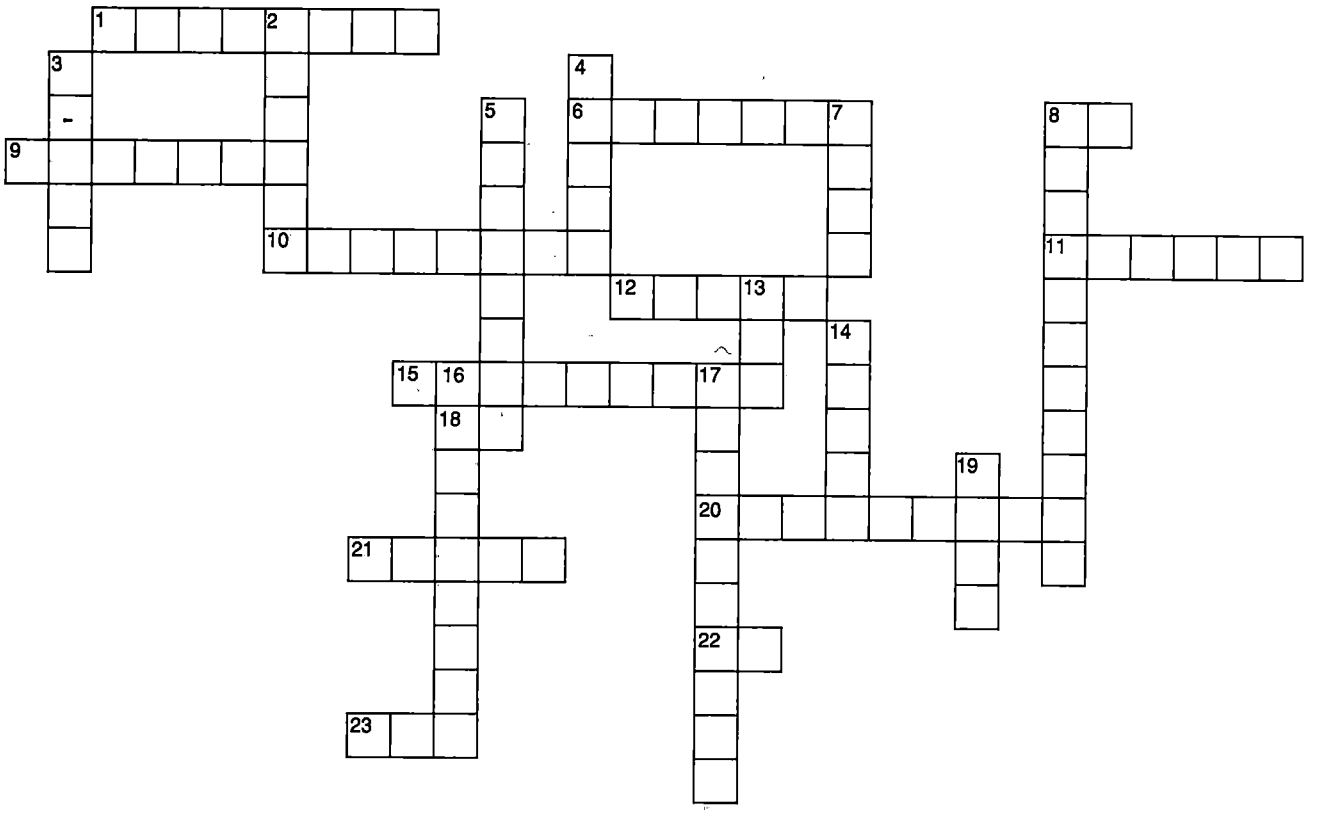
Wavelength (meters)	Frequency (Hertz)	Velocity (meters per second)
(a)_____	3	150
(b)_____	2	8
0.5	(c)_____	25
4.0	(d)_____	1.6
0.5	0.3	(e)_____
0.4	1.5	(f)_____

Concept 5

Certain waves of radiation are blocked by Earth's atmosphere.

Student Activity

Crosswords and Colors



Across

1. The man who proved the existence of infrared radiation.
6. Produced when sunlight hits raindrops.
8. The opposite of down.
9. The low parts of waves.
10. Continuous range of energy.
11. The man who discovered ultraviolet rays.
12. One Space Shuttle program that will put telescopes in space.
15. How often a complete wave occurs.
18. The ancient Greeks studied the stars B.C. We study the stars ____.____.
20. Instrument that can be used to view distant objects.
21. The color of paint that absorbs all colors.
22. Abbreviation for ultraviolet.
23. What ultraviolet rays can do to your skin.

Down

2. The tops of waves.
3. The kind of radiation that reveals broken bones.
4. Transparent object with triangular sides that can be used to produce a spectrum.
5. The kind of radiation that warms us.
7. Shape of radiation paths. Has crests and troughs.
8. The frequency above violet.
13. A narrow beam of radiation (X-_____).
14. The color of light that can be spread out into a spectrum with a prism.
16. Another name for energy.
17. Unending.
19. In terms of length, gamma ray waves are short; infrared waves are _____.

Concept 5

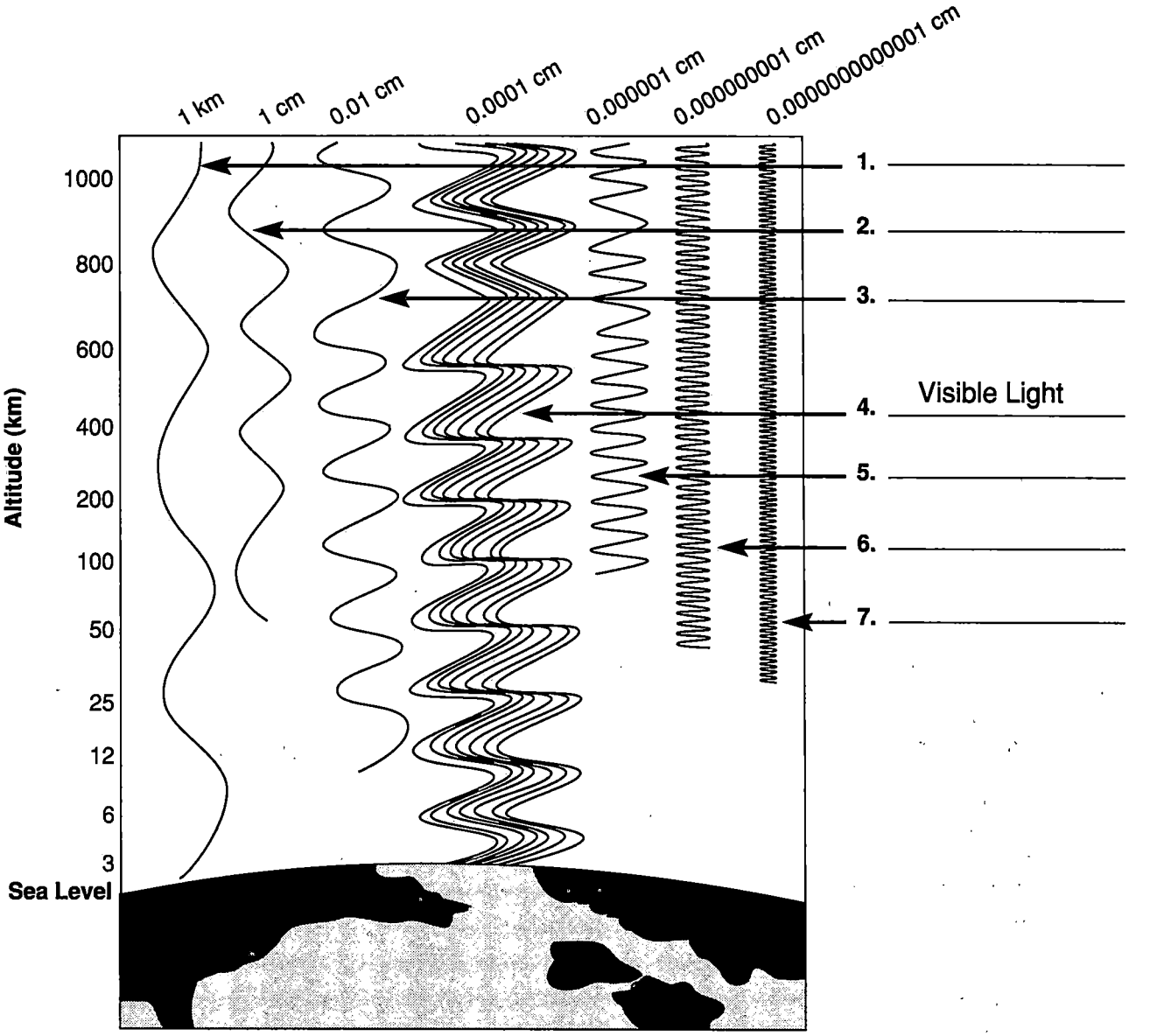
Certain waves of radiation are blocked by Earth's atmosphere.

Student Activity

Atmospheric Sunglasses

This chart will give you an idea of how Earth's atmosphere, its "sunglasses," works to filter harmful wavelengths, such as X-rays and gamma rays, while admitting visible light. The altitude is given on the left, and the approximate length of the wave in centimeters is given at the top.

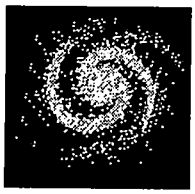
Write in the names of the wavelengths at the correct places. Remember that the shorter, more energetic wavelengths are absorbed by the atmosphere. Visible light is shown for you.



Seeing Above the Atmosphere

Concept 6
Astronomers need to place telescopes above Earth's atmosphere to perform astronomical observations in several regions of the spectrum.

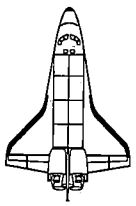
Objectives
Students learn what a telescope is. Students learn about Astro-1 instruments.



Background

The study of the skies is an ancient one: the earliest farmers sowed and reaped crops according to the phases of the Moon; sailors and explorers steered their courses by the stars; many, like the wizards of the Middle Ages, have tried to understand the present and foretell the future by studying the stars.

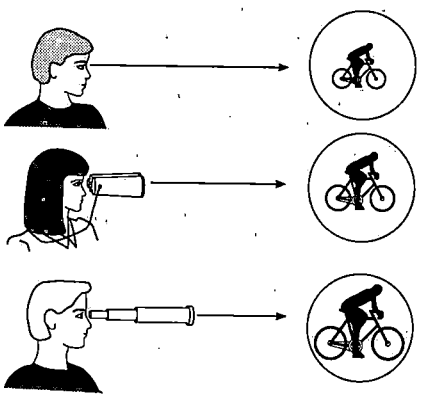
Have you ever looked through a **telescope**? Simple telescopes, made of lenses, mirrors, and a tube, have been used to examine distant objects for hundreds of years. More recently, larger and more complex telescopes have evolved but have been Earthbound. With the coming of the space age, astronomers have been able to place instruments above the dust and glare of the atmosphere to study the size, shape, and structure of the stars, galaxies, and other objects.



Activity 1: Seeing Farther

Astronomers use large telescopes to collect as much light as possible from celestial objects. By examining that light, they can determine what elements, such as iron or calcium, are in the object. They can also learn much about the object's shape. Try this experiment with some simple instruments. Note: Some telescopes can give an inverted image. Does yours?

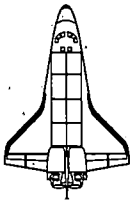
Materials Needed
- binoculars
- telescope



Step 1: Go outside or look through the window at some distant object. How big does the object look?

Step 2: Look at the same object with a pair of binoculars. Now, how big does the object look?

Step 3: Look at the same object with a simple **telescope**. How big does it look now? For years, telescopes like this one, which collects visible light, were the main sources of information about the stars. Many stars and other objects give off radiation in forms other than visible light, but the atmosphere blocks most of the higher energy waves. Astronomers have been sending satellites with telescopes above the atmosphere for many years. Now, they are sending Astro-1 on the Space Shuttle with four telescopes that detect ultraviolet waves and X-rays.



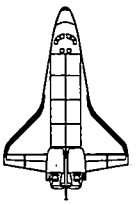
Activity 2: The Astro-1 Telescopes

Materials Needed
- illustrations of Astro-1 instruments

Look at the illustrations of the Astro-1 instruments your teacher has given you or projected onto the wall.

The **Hopkins Ultraviolet Telescope (HUT)** will use an instrument called a spectrograph to study the spectra of galaxies and other objects. Astronomers can determine what elements a particular object contains because each element creates a definite pattern in the spectrum. For example, hydrogen has a unique signature that always appears in certain places on the spectrum. The **Ultraviolet Imaging Telescope (UIT)** will take ultraviolet pictures of hot stars and other objects to reveal their structure and brightness. The **Wisconsin Photo-Polarimeter Experiment (WUPPE)** [pronounced "whoopee"] will examine the shape of stars and the dust that floats in space by seeing how these objects polarize, or direct, light. The **Broad Band X-Ray Telescope (BBXRT)** will study X-rays from different sources in the Universe, including quasars, the most distant objects in the Universe.

Questions
1. What two energy ranges do these instruments explore?
2. From what you know about Earth's atmosphere, why do you think it is important to take these telescopes and other instruments into space?



Activity 3: Polarization

One of the Astro-1 telescopes, the Wisconsin Ultraviolet Photo-Polarimeter Experiment (WUPPE), uses special instruments to study light from celestial objects. Try this experiment to examine the direction of light waves.

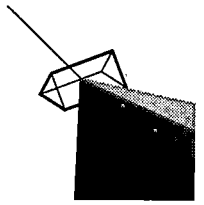
Materials Needed
- polarized filter or
- polarized sunglasses
- light source, preferably sunlight
- shiny, horizontal surface, such as a mirror

Step 1: Put the sunglasses on.

Step 2: Look through the lenses at the shiny surface.

Step 3: With the sunglasses still in place, tilt your head to the right or left about 90°.

Questions
1. A horizontal surface reflects **horizontal** light waves. Which way did the sunglasses block more light?
2. Polarized sunglasses are made from a material that blocks light waves coming from certain directions but not from others. Which way do you think the blocked light waves are moving — vertically or horizontally?
3. If **photo** means "light," and **polar** refers to "direction," what do you think a photo-polarimeter experiment will measure?



Options for Extending the Lesson Across the Curriculum

History

Research Ptolemy's concept of the solar system (Earth-centered, or geocentric) and Copernicus' concept of the solar system (Sun-centered, or heliocentric) and report to the class on what you find.

Art

Look up Ptolemy's Earth-centered concept of the solar system and Copernicus' concept of the solar system. Draw these same concepts for the class.

Literature

You may want to read E.A. Robinson's poem, "Merlin," or T.H. White's *The Book of Merlin*, which is the final chapter of *The Once and Future King*. You also may enjoy listening to "Camelot," which is the musical version of White's book. All of these deal with King Arthur and the Knights of the Round Table and contain references to an early wizard — Merlin.

Archaeology

If you are interested in archaeology or early astronomy, you may want to research Stonehenge in England. From your research, write a report, draw a picture and present an oral report, or build a model of Stonehenge. If you would like to work in a small group, get several classmates to work with you on this.

Home Activities

Watch for newspaper articles about the Astro-1 mission, scheduled to fly in the spring of 1990. Bring these to class and share them. Also be sure to watch for information about Astro-1 on TV.

Activity 2 Answers: Note to Teacher: Illustrations of Astro-1 instruments are found on page 41.
1. Ultraviolet and X-ray 2. These instruments will have to be above the scattering and absorbing effects of Earth's atmosphere to collect ultraviolet and X-ray radiation from celestial objects.
Activity 3 Answers: 1. They block more light in normal wearing position. 2. The blocked light waves are those moving from side-to-side (horizontally). Those that move through the sunglasses are moving up and down (vertically) 3. It will measure the direction of light from an object.
Options for Extending the Lesson Across the Curriculum: Note to the Teacher: See Study Print of Stonehenge, page 43.
Student Activity Answer: Room With A View: Note to Teacher: See Study Print of Whipple Observatory Telescope, page 45. 3. Early rockets - 100 km; later rockets - 200 km; Space Shuttle - 350 km; scientific satellites - 1,000 km
Student Activity Answer: SNAC (Students Need Acronyms for Comprehension): 1. ultraviolet 2. rest in peace 3. National Football League 4. North Atlantic Treaty Organization 5. Federal Bureau of Investigation 6. radio detecting and ranging 7. General Motors 8. Volkswagen 9. National Association for the Advancement of Colored People 10. sound navigation ranging 11. Internal Revenue Service 12. University of California at Los Angeles 13. Wisconsin Ultraviolet Photo-Polarimeter Experiment 14. personal computer 15. Broad Band X-Ray Telescope 16. Massachusetts Institute of Technology 17. United Nations 18. Bavarian Motor Works 19. American Federation of Labor - Congress of Industrial Organizations 20. Atlantic & Pacific (Tea Company) 21. intelligence quotient 22. Union of Soviet Socialist Republics 23. General Electric 24. Students Against Drunk Driving 25. American Telephone and Telegraph 26. National Aeronautics and Space Administration 27. light amplification by stimulated emission of radiation 28. American Football League 29. Young Urban Professional 30. Ultraviolet Imaging Telescope

Concept 6

Astronomers need to place telescopes above Earth's atmosphere to perform astronomical observations in several regions of the spectrum.

Student Activity

Room With A View

If you wanted a good view of the Moon and stars, where would you put your telescope? At the top of a building or on your front porch? In a city or in the country? Where would you be able to see the stars best?

Since Galileo first turned a telescope to the stars, astronomers have been trying to see farther and more clearly. It was not until 200 years after the first telescope was invented, however, that it occurred to astronomers to put telescopes on the tops of mountains. There, higher in the atmosphere and above the dust and lights of the cities, the view was better.

The first mountaintop observatory was the Lick Observatory, built in California in 1887. It held a **refractor** telescope with a 36-in. (91-cm) lens. As time went on, astronomers built bigger and bigger telescopes. Larger telescopes collect more light and enable astronomers to see fainter and more distant objects. In 1904, a large **reflector** telescope with a 4.9-ft (1.5-m) mirror was built on Mt. Wilson, and in the 1940s, an even bigger reflector telescope with a 16.6-ft (5.08-m) mirror was built on Mt. Palomar.

After World War II, scientists began to use captured German rockets to explore up to 62 mi (100 km) above the Earth; later rockets soared up to 124 mi (200 km) to take pictures of astronomical objects from above the atmosphere. The Space Shuttle will carry the Astro-1 telescopes about 218 mi (352 km) above Earth. Scientific satellites can travel 621 mi (1,000 km) above Earth or even higher. For a better understanding of astronomy on Earth and above, try these activities:

1. Research **refractor** telescopes. Describe these briefly and sketch one on the back of this sheet. Be sure to show light paths and label the parts.

2. Read about **reflector** telescopes. Describe these briefly and sketch one on the back of this sheet.

3. Write in the name of the following instruments next to the appropriate altitude shown on the Atmospheric Sunglasses Chart, Concept 5, page 33: early rockets, later rockets, Space Shuttle, scientific satellites.

Concept 6

Astronomers need to place telescopes above Earth's atmosphere to perform astronomical observations in several regions of the spectrum.

Student Activity

Who Invented It?

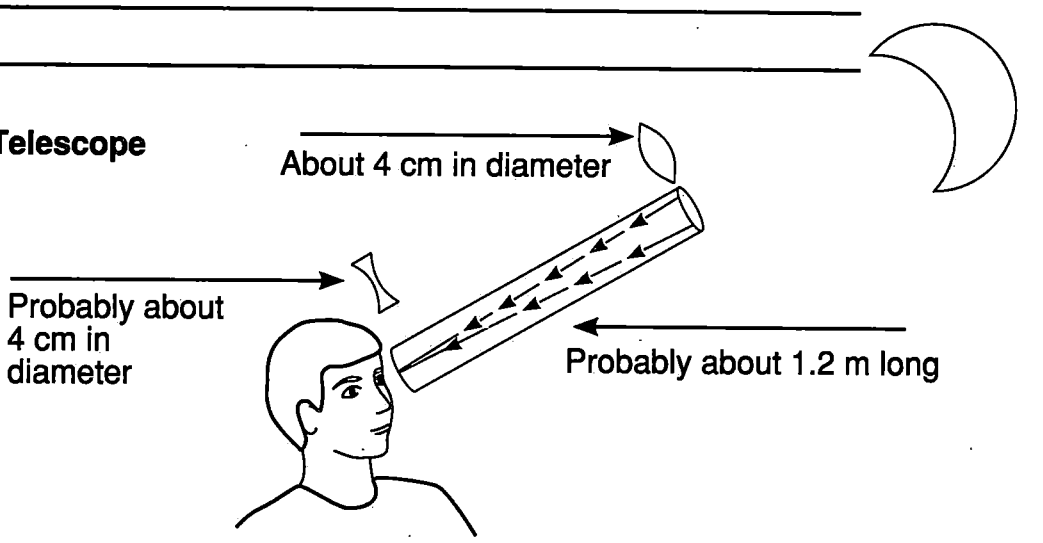
You have probably heard that Galileo invented the telescope. Actually, he probably did not invent it but was the first person to use the telescope to observe planets and stars. It is possible that the person who invented the telescope was Hans Lippershey (lip'-per-shee) who lived in Holland about 1600. The story is that two children were in Lippershey's spectacle (eyeglasses) shop, playing with the lenses. They put two lenses together and then looked through both at the same time at a distant weather vane on top of the town church's steeple. It was magnified. Lippershey looked through the children's invention and began making telescopes himself. After that, many people tried to claim that they had invented the telescope. Galileo himself wrote, "The first inventor of the telescope was a simple spectacle-maker," and did not claim credit for the discovery.

Below is a drawing of what early telescopes probably looked like. Label the **eyepiece** (the **concave** lens), the **objective** (the **convex** lens), and the **tube**. Look up **concave** and **convex** to do this activity.

Concave means _____

Convex means _____

An Early Telescope



The lines in the telescope trace the path of the light in this **refracting** telescope. In a few sentences, describe the light's journey from the Moon to the eye.

_____

_____

_____

_____

Concept 6

Astronomers need to place telescopes above Earth's atmosphere to perform astronomical observations in several regions of the spectrum.

Student Activity

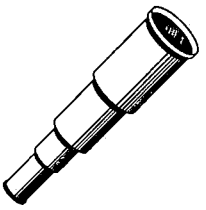
SNAC (Students Need Acronyms for Comprehension)

An acronym is a word or word-like group of letters made from letters of a phrase. HUT, for example, comes from the name Hopkins Ultraviolet Telescope, one of the instruments aboard the Astro-1 mission.

Below are some other acronyms. Some are from the space program, while others are from government, sports, business, and science.

See how many you can identify. Many can be found in the dictionary. Good Luck.

1. UV _____
2. RIP _____
3. NFL _____
4. NATO _____
5. FBI _____
6. radar _____
7. GM _____
8. VW _____
9. NAACP _____
10. sonar _____
11. IRS _____
12. UCLA _____
13. WUPPE _____
14. PC _____
15. BBXRT _____
16. MIT _____
17. UN _____
18. BMW _____
19. AFL-CIO _____
20. A & P _____
21. IQ _____
22. USSR _____
23. GE _____
24. SADD _____
25. AT&T _____
26. NASA _____
27. laser _____
28. AFL _____
29. yuppie _____
30. UIT _____



Your Career in Astronomy

It was early in the morning on a cold mountaintop in Chile. Twenty-nine-year-old Ian Shelton was developing pictures taken through his simple, 10-in. refractor telescope. The pictures were of the Large Magellanic Cloud, or LMC, the nearest galaxy to our own, just 170,000 light-years away. As he developed the photographic plates, he suddenly noticed something strange: a bright star near the center, one that was not there 2 days earlier. Shelton walked outside to look for himself, and sure enough, there was a something new in the sky. Shelton had become the first person to photograph the supernova, the huge, violent explosion marking the death of a star. This star explosion was named Supernova 1987A, the first of 1987, but also the first in 383 years near enough to be seen with the naked eye.

Few astronomers are lucky enough to be the first to see a supernova, but all of them study fascinating objects: clusters of millions of stars, mysterious black holes, tiny, dense neutron stars, and vast, brilliant galaxies. Astronomers study these using a variety of Earthbound instruments: telescopes that detect visible light, radio, infrared, and ultraviolet radiation. They use spectrometers to study the chemistry of celestial objects and polarimeters to study their geometry. Many astronomers now make observations with instruments aboard satellites. Some astronomers, like those crew members flying on Astro-1, will even go into space themselves to study these distant objects in different ranges of the spectrum. Over the next 10 years, NASA will send several new telescopes, such as the Hubble Space Telescope, the Gamma-Ray Observatory, the Advanced X-Ray Astrophysics Facility, and the Space Infrared Telescope Facility into orbit. These huge instruments will open incredible new vistas for astronomers.

What kind of person becomes an astronomer?

Are you curious? Do you wonder how things work or what they are made of? Are you interested in where things come from and how they began? Do you work well both alone and in groups? Do you enjoy math? Are you willing to work at something that is interesting to you? Astronomers often have these qualities.

What do astronomers do?

Many astronomers teach and do research in colleges and universities, like the astronomers who developed the Astro-1 instruments; some astronomers teach in high schools. Others work in observatories, museum planetariums, and government and private research organizations.

How can you become an astronomer?

Middle School

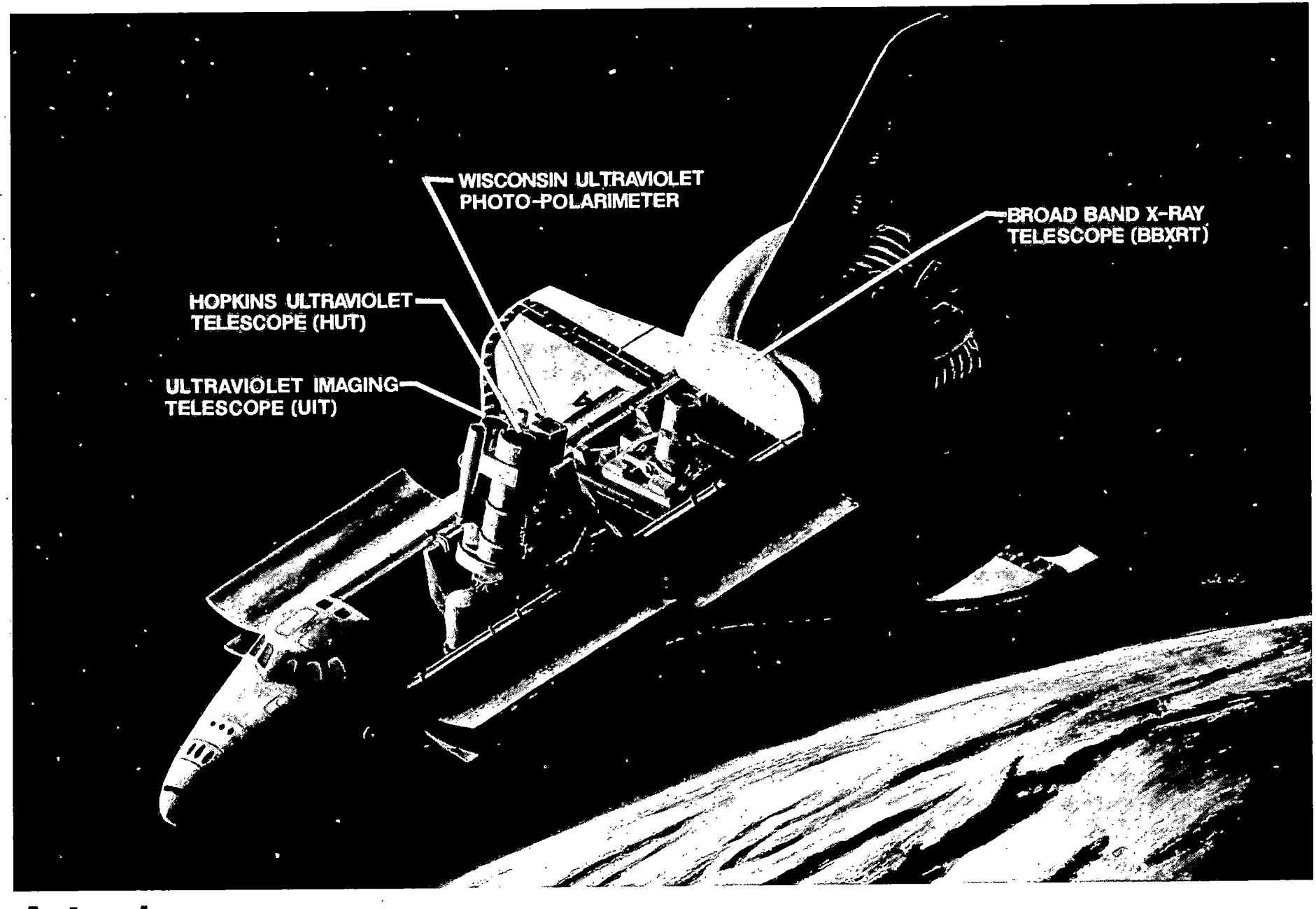
Middle school students should study mathematics and science and work on developing good communication skills, which astronomers need in order to share information and discoveries. You can also do things outside school: build a telescope, join or start an astronomy club, and visit a planetarium or observatory near you.

High School

You will need to take more mathematics and plenty of science courses such as physics, chemistry, and Earth science. Continue your studies in the language arts as well. Computer courses at both the middle school and high school levels are very helpful.

College

You would work for a bachelor's degree in astronomy, mathematics, or physics and probably go to graduate school.


WISCONSIN ULTRAVIOLET
PHOTO-POLARIMETER
BROAD BAND X-RAY
TELESCOPE (BBXRT)
HOPKINS ULTRAVIOLET
TELESCOPE (HUT)
ULTRAVIOLET IMAGING
TELESCOPE (UIT)

Astro-1

Astro-1 Facts

To see ultraviolet radiation and X-rays from astronomical objects, telescopes must be placed above the lower atmosphere, which absorbs most types of radiation before they reach telescopes on Earth.

Astro-1 is the first Shuttle mission dedicated completely to astrophysics, the branch of astronomy that investigates the physical characteristics of celestial objects, such as their size, mass, temperature, and chemistry. Three ultraviolet telescopes and one X-ray telescope will observe a variety of celestial objects. The observations will emphasize hot and energetic sources, some of the most dynamic objects in the Universe.

The Astro-1 Instruments

Hopkins Ultraviolet Telescope (HUT)
The Johns Hopkins University, Baltimore, MD; Principal Investigator: Arthur F. Davidsen
The telescope probes the most energetic part of the ultraviolet spectrum, an almost unexplored region that holds secrets about the chemistry and structure of stars and galaxies. Ultraviolet radiation focused on a mirror is reflected to a spectrometer that records the evidence of hydrogen, helium, carbon, and many other elements.

Ultraviolet Imaging Telescope (UIT)

Goddard Space Flight Center, Greenbelt, MD; Principal Investigator: Theodore P. Stecher
UIT takes the first extensive set of detailed ultraviolet photographs of the Universe, most of which has never been imaged in the ultraviolet. Light enters the telescope and is reflected by a primary mirror to a secondary mirror to a camera, which records images on film.

Wisconsin Ultraviolet Photo-Polarimeter Experiment (WUPPE)

The University of Wisconsin, Madison, WI; Principal Investigator: Arthur D. Code
The telescope observes the polarization (direction), photometry (brightness), and spectra of ultraviolet light from celestial objects. Light entering the telescope is focused by mirrors through polarizers and then onto a spectrometer and detectors that record data to give scientists clues about the shape and size of objects, the strength of magnetic fields, and the nature of gas and dust between the stars.

Broad Band X-Ray Telescope (BBXRT)

Goddard Space Flight Center, Greenbelt, MD; Principal Investigator: Peter J. Serlemitsos
BBXRT explores violent events such as exploding stars or matter and light being consumed by a black hole. Black holes may exist in the centers of galaxies. Two telescope mirrors focus X-rays onto detectors that record evidence of iron, oxygen, silicon, and other heavy elements found in the objects.

On-Orbit Crew

Commander: Vance D. Brand
Pilot: Guy S. Gardner
Mission Specialists: John M. (Mike) Lounge
Jeffrey A. Hoffman
Robert A.R. Parker
Payload Specialists: Samuel T. Durrance
Ronald A. Parise

Mission Parameters

Launch Date: April 1990
Mission Duration: 10 days
Altitude: 190 n.mi. (354 km)
Payload Weight: 30,948 lb (14,038 kg)

Photo Credit: Dr. E.C. Krupp, Griffith Observatory

Stonehenge

Stonehenge

Astronomy is an ancient science practiced since the earliest recorded times. Evidence of these studies can be found in many parts of the world. **Stonehenge**, in Wiltshire, England, may have been an observatory or calendar built by early astronomers during three periods ranging from about 2500 B.C. to about 1700 B.C.

The monument consists of a complicated arrangement of stones, trenches, and holes arranged in concentric circles. Some of the stones are aligned with the directions of the Sun during its rising and setting at the vernal (spring) and autumnal (fall) **equinoxes.**

The Whipple Observatory

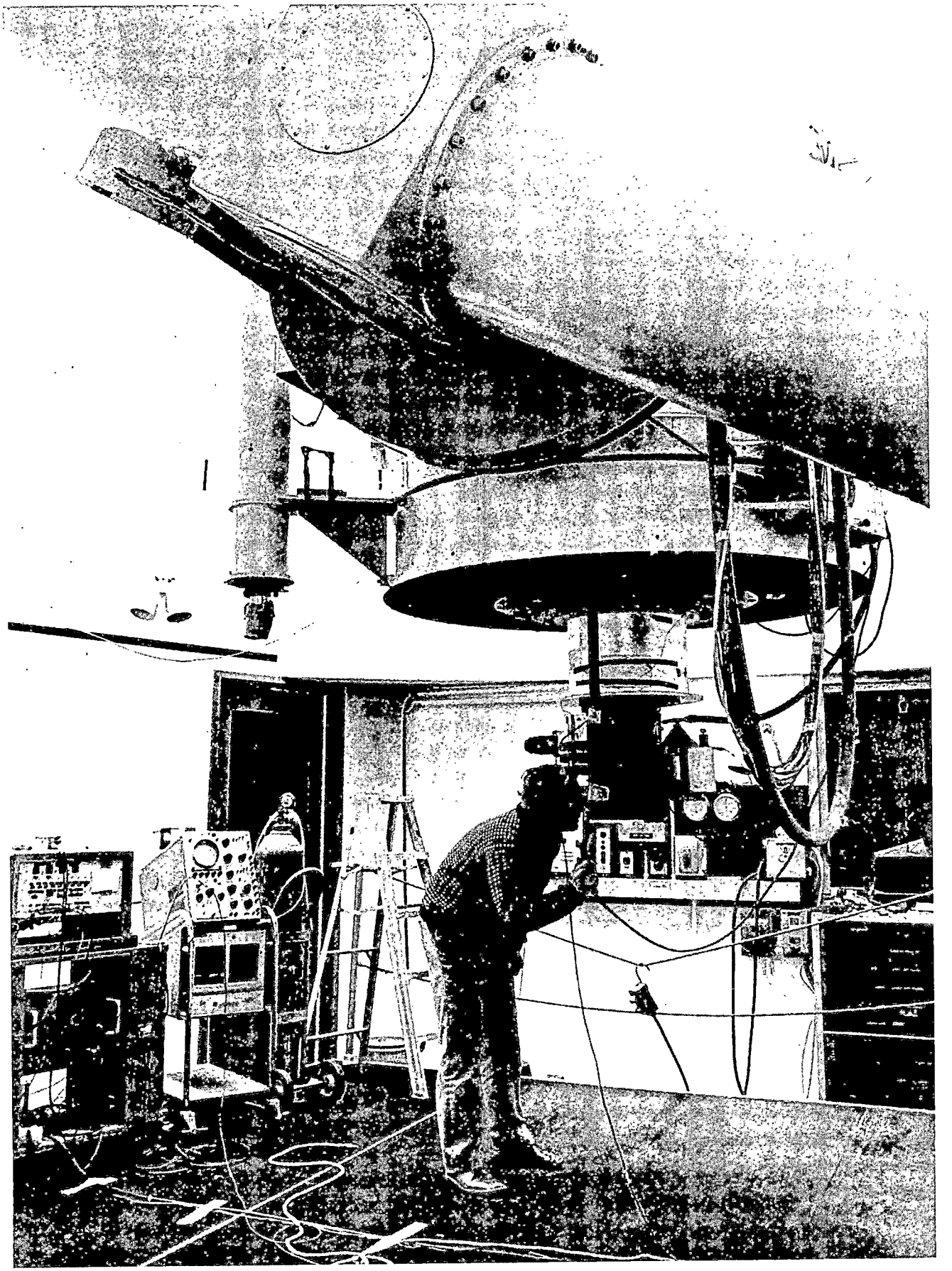


Photo Credit: Smithsonian Astrophysical Observatory

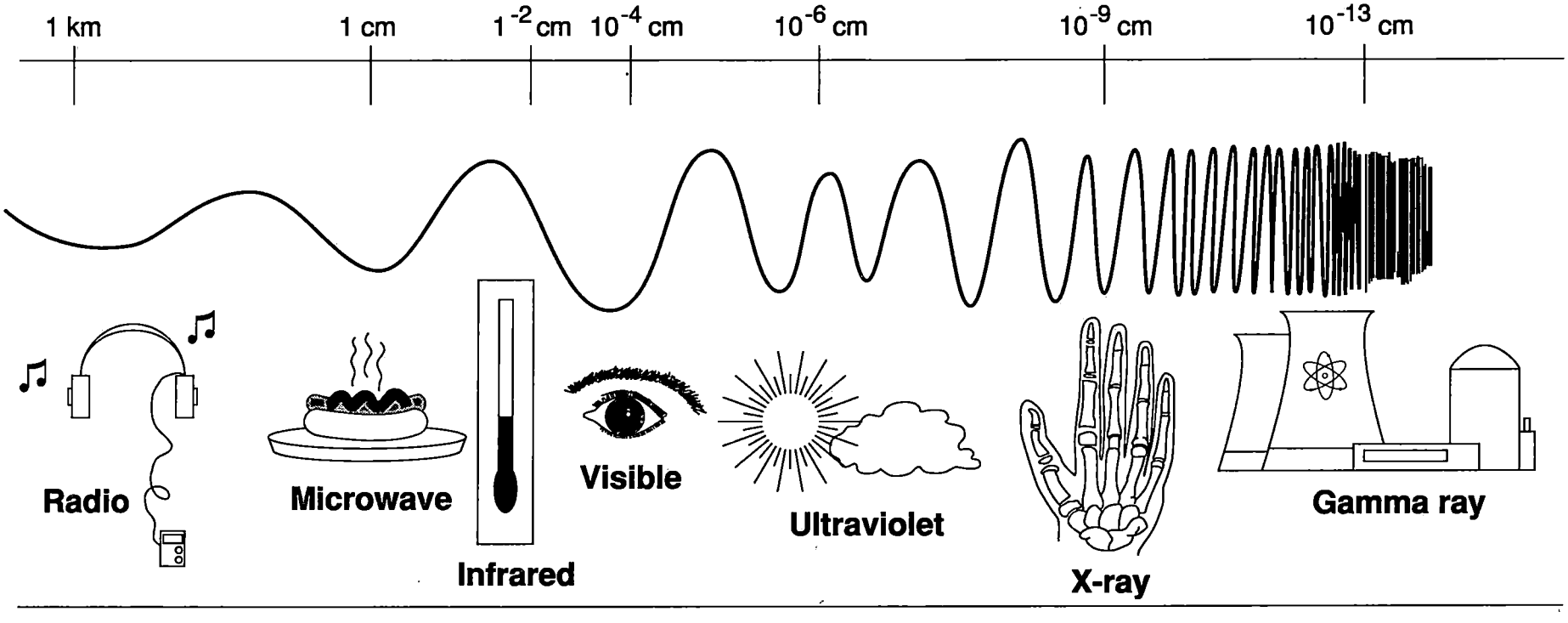
The Whipple Observatory

Over thousands of years, astronomers have progressed from searching the skies with the naked eye to using giant telescopes on mountaintops. They have transcended the atmosphere with instruments in balloons, rockets, satellites, and the Space Shuttle.

Whether on Earth or in space, all these scientists use instruments to collect light from celestial objects. By analyzing this light, they learn more about the size, shape, and chemical makeup of the targets being observed.

The photograph shown here is of an optical telescope at the Whipple Observatory, located on Mt. Hopkins, near Tucson, Arizona. Whipple Observatory is named after planetary expert Fred Lawrence Whipple and is part of the Smithsonian Astrophysical Observatory in Cambridge, Massachussetts. Astronomers at Whipple Observatory use a variety of instruments to research stars, planets, and objects beyond the Milky Way Galaxy. In addition, they study the Sun and monitor the health of Earth and its atmosphere.

The Electromagnetic Spectrum



The Electromagnetic Spectrum

For hundreds of years, scientists believed that light energy was made up of tiny particles which they called "corpuscles." In the 1600s, researchers observed that light energy also had many characteristics of waves. Modern scientists know that all energy is both particles, which they call **photons**, and waves.

Photons travel in **electromagnetic waves.** These waves travel at different **frequencies**, but all travel at the speed of light. The **electromagnetic spectrum** is the range of wave frequencies from low frequencies (below visible light) to high frequencies (above visible light).

The **radio wave** category includes radio and television waves. These low-energy waves bounce off many materials. AM waves bounce off the ionosphere and are reflected back to Earth. FM and television waves bounce off satellites for long-distance transmission.

Microwaves pass through some materials but are absorbed by others. In a microwave oven, the energy passes through the glass and is absorbed by the moisture in the food. The food cooks, but the glass container is not affected.

Like other wavelengths, **infrared** or heat waves are more readily absorbed by some materials than by others. Dark materials absorb infrared waves while light materials reflect them. The Sun emits infrared waves, heating the Earth and making plant and animal life possible.

Visible light waves are the very smallest part of the spectrum and are the only frequencies visible to the human eye. Colors are different frequencies within this category, ranging from the red wavelengths, which are just above the invisible infrared, to violet. Most of the Sun's energy is emitted as visible light.

The Sun also emits many **ultraviolet** waves. High-frequency ultraviolet wavelengths from the Sun cause sunburn.

X-rays can penetrate muscle and tissue but are blocked by bone, making medical and dental X-ray photographs possible.

Gamma-ray waves, the highest frequency waves, are more powerful than X-rays and are used to kill cancerous cells.

The atmosphere protects Earth from dangerous ultraviolet, X-ray, and gamma-ray radiation.

Why They Became Astronomers

Jeff Hoffman

I've been interested in astronomy as long as I can remember. When I was growing up in New York City, I went to the planetarium and learned all I could about the stars and planets. There was something intriguing about researching things too far away to touch. You could only use powerful telescopes to look at the light coming from them. We dreamed that we might someday travel into space, at least to the moon and planets, but that was the 1950s, and satellites hadn't been launched into space, much less people. As I went through high school and college, I studied a lot of mathematics and science, especially physics. Before becoming an astronaut, my work in astronomy involved putting telescopes into space to look at X-rays, gamma rays, and other radiation that doesn't penetrate the atmosphere. We put these telescopes up in high-flying balloons, rockets, and satellites, which intrigued me.

It was exciting because we were studying radiation that human beings had never seen before. Each new telescope put into space was almost guaranteed to make exciting new discoveries. Eventually, scientists were able to work on the Space Shuttle, and I was lucky enough to be selected to become an astronaut. I made one spaceflight in 1985, and I'm looking forward to flying on Astro-1.

Ron Parise

I have always been interested in spaceflight and astronomy. As a child, I followed the early space program closely; I read books on stars and planets. Astronomy was fascinating to me because of the questions it brought to mind: "Does the Universe go on forever?" "If it doesn't go forever, what's on the other side of it?"

As a teenager, I was involved with an amateur astronomy group and made astronomical observations myself. When you make observations, you find that the seemingly unchanging, fixed objects in the sky are actually quite dynamic: their intensities change, their spectra change, their positions change – it's not a static Universe at all.

Another interesting thing is that astronomy is not an experimental science like physics, chemistry, or biology, in which you can perform an experiment to prove a theory. You can't do that because the astronomical objects are at such vast distances. We have to be content with observing the electromagnetic radiation that they emit.

That brings another challenge into the subject – trying to develop new ways of observing things. On the ground, if you want to know what's on the other side of a wall, you go and look. In astronomy, you may come up against dust or gas floating around the stars that prevents you from seeing something. You have to develop ways to see around or through that barrier. It is a challenge to develop techniques that we can use to put the puzzle together.

"How did the Universe actually get here in the first place?" "What was there before it?" "How do all of these stars, planets, and galaxies work?" These questions brought me into astronomy, and the Space Shuttle gives me the opportunity to go into space and look at wavelengths that have rarely been observed.

Sam Durrance

I don't know for certain why I became an astronomer. I was always curious about how things work, but I was not always interested in astronomy. In high school and shortly after, I preferred things like building sports racing cars.

I was always interested in the space program, however; and on July 20, 1969, when men landed on the moon, I decided that I wanted to be part of that excitement. I went to college and earned my bachelor's and master's degrees in physics. I went to graduate school to study astronomy and became involved in a number of space projects, such as launching a rocket-borne telescope to look at Venus and using the Pioneer Venus-orbiting spacecraft to study that planet. After that, I went to The Johns Hopkins University, where I work today, to develop space astronomy hardware.

My primary interest in astronomy is studying the formation of planets in our own solar system, and the formation of planets around other stars. One of Astro's objectives is to study planets in our solar system, so I feel fortunate to be a part of Astro-1.

I have helped develop one of the Astro-1 telescopes and get it ready for flight, and now I look forward to doing the observations in space.

Robert Parker

I don't remember ever making a conscious decision to become an astronomer. Early influences may have been related to a simple book on the myths associated with constellations that I received in the second or third grade and a much more involved book a couple of years later. In any case, by junior high school I had become fascinated by the books of Sir James Jeans who at that time was probably similar to Carl Sagan as a popularizer of astronomy.

The fact that my father was a physicist (astronomy is, after all, just a branch of physics) was also clearly a background influence; my twin brother is a nuclear physicist.

Resources

Audiovisual Materials and Kits

Adventures in Science: Light
Activity cards and supplies
Educational Insights
Dominguez Hills, CA 90220

Astronomy Overhead Transparencies
Hubbard Scientific
1946 Raymond Drive
North Brook, IL 60062 Phone: 1-800-323-8368

Astronomy Study Prints
Hubbard Scientific
1946 Raymond Drive
North Brook, IL 60062 Phone: 1-800-323-8368

Glow-in-the-Dark Celestial Chart. #298505
The Nature Company
P.O. Box 2310
Berkeley, CA 94702

Our Universe Spacekit
National Geographic Society, 1980
Accompanies *Our Universe* text.

"Seven Days in Space." Video. Available with Teacher's Guide, audio supplement (crew interviews), computer software.
Halcyon Films and Video
110 Beach Road
Kings Point, NY 11024
Phone: 1-800-426-0582

3-D Star Maps. Book and two sets of 3-D glasses #300582
The Nature Company
P.O. Box 2310
Berkeley, CA 94702

Star Chart
Hubbard Scientific
1946 Raymond Drive
North Brook, IL 60062
Phone: 1-800-323-8368

Star Finder/Zodiac Dial
Hubbard Scientific
1946 Raymond Drive
North Brook, IL 60062
Phone: 1-800-323-8368

Games

"Sky Challenger"
Hubbard Scientific
1946 Raymond Drive
North Brook, IL 60062
Phone: 1-800-323-8368

"Stellar 23"
Hubbard Scientific
1946 Raymond Drive
North Brook, IL 60062
Phone: 1-800-323-8368

Organizations

American Astronomical Society
2000 Florida Avenue, NW
Washington, DC 20009
Phone: 202-328-2010

Aerospace Educational Development Program
6991 South Madison Way
Littleton, CO 80122
Phone: 303-694-6836

American Astronautical Society
6212 Old Keene Mill Court
Springfield, VA 22152
Phone: 703-866-0020

Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112
Phone: 415-337-1100

The Planetary Society
65 North Catalina Avenue
Pasadena, CA 91106
Phone: 818-793-5100

Planetariums and Observatories

Griffith Observatory
2800 East Observatory Road
Los Angeles, CA 90027
Phone: 213-664-1181

Hansen Planetarium
15 S. State Street
Salt Lake City, UT 84111
Phone: 801-538-2098
Catalog and orders: 1-800-321-2369

Harvard-Smithsonian Center for Astrophysics
60 Garden Street
Cambridge, MA 02138
Phone: 617-495-7000

National Optical Astronomy Observatories
P.O. Box 26732
Tucson, AZ 85726-6732
Phone: 602-325-9204

Publications

Books

Apfel, Necia H. *Astronomy Projects for Young Scientists.* New York: Arco Publishing, Inc., 1984.

Baker, David. *Believe It Or Not — Space Facts.* Vero Beach, FL: Rourke Enterprises, 1988.

Bova, Ben. *Starflight and Other Improbabilities.* Philadelphia: Westminster Press, 1973.

Chaple, Glenn F., Jr. *Exploring With A Telescope.* New York: Venture Books, 1988.

Chartrand, Mark R. *Skyguide: A Field Guide for Amateur Astronomers.* Racine, WI: Golden Press, 1982.

Gallant, Roy A. *The Macmillan Book of Astronomy.* New York: Macmillan, 1986.

Jespersen, James, and Jane Fitz-Randolph. *From Quarks to Quasars.* New York: Atheneum Press, 1987.

Mitton, Jacqueline, and Simon Mitton. *Discovering Astronomy.* London: Stonehenge Press, 1982.

Byron Preiss, Ed. *The Universe.* New York: Bantam Books, 1987.

Provenzo, Eugene F., Jr., and Asterie Baker Provenzo. *Rediscovering Astronomy.* La Jolla, CA: Oak Tree Publications, Inc., 1980.

Rossie, John P. *Handbook for Aerospace Education.* Littleton, CO: Aerospace Educational Development Program, 1988.

Taylor, Ron. *The Invisible World.* New York: Facts on File Publications, 1985.

Zim, Herbert S. *Waves.* New York: Morrow, 1967.

Periodicals

Air and Space Magazine
Smithsonian Institution
P.O. Box 51244
Boulder, CO 80321-1244
Phone: 303-449-9609

Astronomy Magazine and *Astronomy Educator*
Kalmbach Publishing
21027 Crossroads Circle
P.O. Box 1612
Waukesha, WI 53187
Phone: 1-800-446-5489

Odyssey: Space Exploration and Astronomy for Young People
Astro Media Division
Kalmbach Publishing
21027 Crossroads Circle
P.O. Box 1612
Waukesha, WI 53187
Phone: 1-800-446-5489

Sky and Telescope
Sky Publishing Corporation
49 Bay State Road
Cambridge, MA 02138
Phone: 617-864-7360

NASA Educational Resources

NASA Spacelink: An Electronic Information System

NASA Spacelink is an information access system that allows individuals to log on and receive news about current NASA programs and activities and other space-related information, including historical and astronaut data, lesson plans and classroom activities, and even entire publications. Although primarily intended as a resource for teachers, anyone with a personal computer and modem can access the network.

Use the instructions that come with your modem and communications software when calling NASA Spacelink. The computer access number is 205-895-0028. The data word format is 8 bits, no parity, and 1 stop bit. Your computer may send carriage returns or line feeds, but not both. To log on as a first-time caller, enter the Username NEWUSER and the Password NEWUSER. The service is free, but you may have to pay long-distance phone charges. For more information, contact:

Spacelink Administrator
NASA Marshall Space Flight Center
Mail Code CA20
MSFC, AL 35812
Phone: 205-544-6527

NASA Educational Satellite Videoconferences

During the school year, a series of educational programs is delivered by satellite to teachers across the country. The content of each video conference varies, but all cover aeronautics or space science topics of interest to the educational community. The broadcasts are interactive; a number is flashed across the bottom of the screen, and viewers can call collect to ask questions or take part in a discussion. For further information, contact:

Videoconference Coordinator
NASA Aerospace Education Services Program
300 North Cordell
Oklahoma State University
Stillwater, OK 74078-0422
Phone: 405-744-7015

Mr. William D. Nixon
Educational Technology Branch
Educational Affairs Division
Code XE
NASA Headquarters
Washington, DC 20546
Phone: 202-453-8388

Central Operation of Resources for Educators (CORE)

CORE is a centralized mail-order audiovisual library for educators; no printed materials are available. Submit a written request on your school letterhead for a catalogue and order forms. Orders are processed for a small fee that includes the cost of the media. For more information, contact:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
Phone: 216-774-1051, Ext. 293 or 294

Teacher Resource Center Network

To make information available to the educational community, the Educational Affairs Division has created the NASA Teacher Resource Center Network. Teacher Resource Centers (TRCs) contain a wealth of information for educators: publications, reference books, slides, audio cassettes, videocassettes, telelecture programs, computer programs, lesson plans and activities, and lists of publications available from government and nongovernment sources.

Because each NASA field center has its own areas of expertise, no two TRCs are exactly alike. Phone calls are welcome if you are unable to visit the TRC that serves your geographic area. The chart on the next page delineates the geographic regions and provides addresses.

For more information about Elementary and Secondary Programs

If you live in:	Center Education Programs Officer	Teacher Resource Center
Alaska Arizona California Hawaii Idaho Montana Nevada Oregon Utah Washington Wyoming	Mr. Garth A. Hull Chief, Educational Programs Branch Mail Stop T025 NASA Ames Research Center Moffett Field, CA 94035 Phone: 415-694-5543	NASA Ames Research Center Attn: Teacher Resource Center Mail Stop T025 Moffett Field, CA 94035 Phone: 415-694-3574
Connecticut Delaware District of Columbia Maine Maryland Massachusetts New Hampshire New Jersey New York Pennsylvania Rhode Island Vermont	Mr. Elva Bailey Chief, Educational Programs Public Affairs Office (130) NASA Goddard Space Flight Center Greenbelt, MD 20771 Phone: 301-286-7207	NASA Goddard Space Flight Center Attn: Teacher Resource Laboratory Mail Code 130.3 Greenbelt, MD 20771 Phone: 301-286-8570
Colorado Kansas Nebraska New Mexico North Dakota Oklahoma South Dakota Texas	Mr. James D. Poindexter Educational Specialist Public Affairs Office (AP4) NASA Johnson Space Center Houston, TX 77058 Phone: 713-483-8624	NASA Johnson Space Center Attn: Teacher Resource Room Mail Code AP-4 Houston, TX 77058 Phone: 713-483-8696
Florida Georgia Puerto Rico Virgin Islands	Mr. Raymond R. Corey Chief, Education and Awareness Branch Mail Code PA-EAB NASA Kennedy Space Center Kennedy Space Center, FL 32899 Phone: 407-867-4444	NASA Kennedy Space Center Attn: Educators Resources Laboratory Mail Code ERL Kennedy Space Center, FL 32899 Phone: 407-867-4090

Kentucky North Carolina South Carolina Virginia West Virginia	Mr. Roger Hathaway Education Specialist Mail Stop 154 NASA Langley Research Center Hampton, VA 23665-5225 Phone: 804-864-3312	NASA Langley Research Center Attn: Teacher Resource Center Mail Stop 146 Hampton, VA 23665-5225 Phone: 804-864-3293
Illinois Indiana Michigan Minnesota Ohio Wisconsin	Dr. Lynn Bondurant Chief, Educational Services Office Mail Stop 7-4 NASA Lewis Research Center 21100 Brookpark Road Cleveland, OH 44135 Phone: 216-433-5583	NASA Lewis Research Center Attn: Teacher Resource Center Mail Stop 8-1 21100 Brookpark Road Cleveland, OH 44135 Phone: 216-433-2016 or 2017
Alabama Arkansas Iowa Louisiana Missouri Tennessee	Mr. Jeffrey Ehmen Education Officer Public Affairs Office (CA20) NASA Marshall Space Flight Center MSFC, AL 35812 Phone: 205-544-6531	Alabama Space and Rocket Center Attn: NASA Teacher Resource Center Huntsville, AL 35807 Phone: 205-544-5812
Mississippi	Education Officer Public Affairs Office NASA John C. Stennis Space Center Stennis Space Center, MS 39529 Phone: 601-688-3341	NASA John C. Stennis Space Center Attn: Teacher Resource Center Building 1200 Stennis Space Center, MS 39529 Phone: 601-688-3338
The Jet Propulsion Laboratory serves inquiries related to space and planetary exploration and other JPL activities.	Mr. Philipp D. Neuhauser Manager, Education Mail Code 180-205 Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, CA 91109 Phone: 818-354-8592	Jet Propulsion Laboratory Attn: Teacher Resource Center JPL Educational Outreach Mail Stop CS-530 Pasadena, CA 91109 Phone: 818-354-6916

Where to Obtain Materials

Concept 1

prism or diffraction grating:

FSC Educational
905 Hickory Lane
P.O. Box 8101
Mansfield, OH 44905
Phone: 1-800-225-FREY

Sargent-Welch
7400 N. Linder Avenue
P.O. Box 1026
Skokie, IL 60077-1026
Phone: 1-800-SARGENT

Concept 2

blueprint paper:

local print shop

Concept 3

color filters:

Colored plastic wrap or cellophane or color filters from local camera shop

Optical kits containing color filters may be obtained from scientific suppliers listed above.

Concept 5

dilute sulfuric acid:

Sargent-Welch
7400 N. Linder Avenue
P.O. Box 1026
Skokie, IL 60077-1026
1-800-SARGENT

sodium thiosulfate or sodium hyposulfite:
local camera shop or scientific supply listed above

Glossary

accretion disk - a rapidly spinning disk of matter that has been drawn from a primary star in a close binary star system. The matter does not fall directly onto the compact companion, which may be a neutron star, white dwarf, or black hole, but swirls down onto the smaller body in the form of a disk. Gradually the matter in the disk heats up and spirals onto the smaller body emitting large quantities of X-ray and ultraviolet radiation.

binary star system - two bodies revolving around a common center of gravity. Usually consists of a primary star and a compact companion, such as a white dwarf, neutron star, or black hole.

black hole - a point in space where scientists believe that gravitational forces are so intense that neither matter nor light escapes. Possibly the result of the collapse of a massive star.

Broad Band X-Ray Telescope (BBXRT) - an X-ray telescope developed at Goddard Space Flight Center. Uses mirrors and advanced solid-state detectors as spectrometers to examine the chemistry, structure, and dynamics of a source. BBXRT will fly on the Astro-1 mission scheduled for spring of 1990.

concave - curving inward.

continuous spectrum - a spectrum of radiation in which there are no lines of emission or absorption. Emissions from hot, dense matter will produce a continuous spectrum.

convex - bulging outward.

crest - the highest point, e.g., the highest point of a wave.

diffraction grating - a plate etched or ruled with a large number of grooves. Acts to disperse light into different wavelengths, thus producing a visible spectrum.

electromagnetic spectrum - the full range of electromagnetic radiation from the longest to the shortest wavelengths. Usually divided into seven sections: radio, microwave, infrared, visible, ultraviolet, X-ray, and gamma-ray radiation.

frequency - the number of wave crests or troughs passing a set point in a unit of time.

gamma rays - shortest, most energetic form of electromagnetic radiation.

galaxy - collections of millions of stars mixed with gas and dust. Galaxies have three basic forms: spiral, elliptical, and irregular.

Hertz (Hz) - a measure of frequency equalling one cycle per second.

Hertzsprung-Russell Diagram (H-R Diagram) - a diagram showing the relationship between the temperature, magnitude, mass, and color of stars.

Hopkins Ultraviolet Telescope (HUT) - a telescope and spectroscope developed at The Johns Hopkins University. Studies the ultraviolet spectra of faint astronomical objects. HUT, along with two other ultraviolet instruments and one X-ray instrument, will fly on the Astro-1 mission.

infra - prefix from the Latin meaning "below," especially as in a scale or series.

infrared radiation - radiation just beyond the red end of the visible portion of the electromagnetic spectrum. Most infrared radiation is blocked by the atmosphere, but enough solar infrared penetrates to heat Earth's surface. Infrared radiation is used to make maps of Earth's surface.

interstellar medium - matter existing between the stars, consisting mainly of hydrogen and flecks of dust. Helium may also be a major component.

light-year - the distance that light or any form of electromagnetic radiation can travel in 1 year, approximately 5.9×10^{12} mi (9.5×10^{12} km).

magnitude - the brightness of stars and other celestial objects. The greater the brightness, the lower the magnitude.

main sequence stars - the band on the Hertzsprung-Russell Diagram where most stars are found. It runs from the hot, blue stars in the upper left to the cool, red stars on the lower right.

mass - the amount of matter in an object.

microwave radiation - radiation less energetic than infrared and more energetic than radio waves. Used for radar and to cook food.

neutron star - a star that has undergone gravitational collapse, forming the tiniest, densest object known. A neutron star has a mass comparable to the Sun but is collapsed into an object about 12.4 mi (20 km) in diameter, resulting in matter so dense that a teaspoonful could weigh a billion tons.

photon - a packet of electromagnetic radiation.

prism - a transparent object with five sides and triangular ends that can be used to break visible light into its component colors.

radiation - a flow of energy, usually defined as photons, or packets of energy, traveling in waves.

radio waves - the longest and least energetic form of energy on the electromagnetic spectrum.

reflector telescope - a telescope that collects and focuses light with a mirror. Also called a reflecting telescope.

refractor telescope - a telescope that collects and focuses light by means of a lens. Also called a refracting telescope.

scientific notation - a way to write very large or very small numbers. Substitutes powers of 10 for strings of zeros. For example, 561,000,000,000 = 5.61×10^{11} and 0.0000000079 = 7.9×10^{-9}.

spectra - plural form of spectrum.

spectrum - the range of electromagnetic energy emitted or absorbed by a substance.

spiral arms - the parts of a spiral galaxy where new stars are most likely to be formed. The arms are concentrated areas of gas and dust.

star - a celestial object that generates energy by means of nuclear fusion reactions.

supernova - the explosion of a giant star; its last stage of evolution.

supernova remnant - the expanding shell of gas and matter blown off in a supernova. Frequently are strong sources of X-ray and ultraviolet emissions.

ultra - prefix meaning "beyond."

Ultraviolet Imaging Telescope (UIT) - a combination telescope and camera developed at Goddard Space Flight Center. Takes ultraviolet pictures of celestial objects. Will fly on the Astro-1 mission in the spring of 1990.

ultraviolet radiation - the energy range just beyond the violet end of the visible spectrum. Most ultraviolet radiation is blocked by Earth's atmosphere, but some solar ultraviolet penetrates and aids in plant photosynthesis. Ultraviolet radiation has both positive and negative effects on humans: some ultraviolet helps produce vitamin D; too much can burn skin.

white dwarfs - faint stars that have undergone gravitational collapse in their final stages of evolution. White dwarfs, which emit most of their radiation in the ultraviolet, are sometimes found as companions to larger stars in binary star systems.

white light - radiation in the electromagnetic spectrum that is visible to human beings.

Wisconsin Photo-Polarimeter Experiment (WUPPE) - an ultraviolet instrument developed at the University of Wisconsin. Measures the polarization and intensity of ultraviolet radiation from celestial objects and the interstellar medium. Will fly on the Astro-1 mission.

X-rays - energetic form of radiation between ultraviolet radiation and gamma rays. Because they are energetic enough to penetrate muscle and tissue but not bone, X-rays are used to examine bones and teeth.

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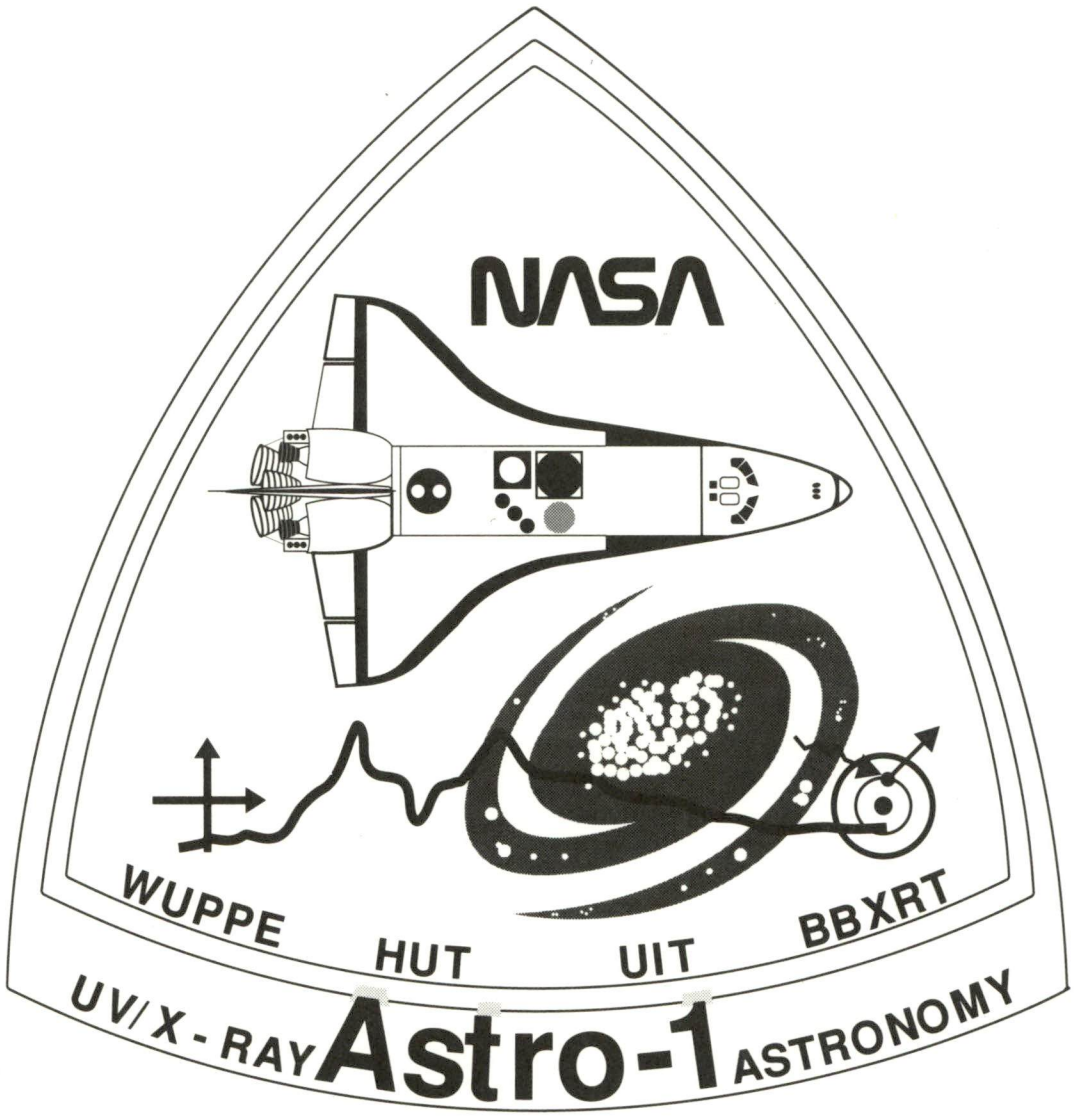

Astro-1 Teacher's Guide: Seeing in a New Light

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Von Braun Seeks to Stir Up Sagging Space Interest

Wernher von Braun, master rocket builder for America's space program, has emerged from the low profile he maintained after quitting the National Aeronautics and Space Administration in 1972 and now, at the age of 64, is trying to get off the ground with his latest vehicle, the National Space Institute (NSI).

In two recent press conferences von Braun said that his outfit is different from existing space organizations, which spend all their time talking to themselves. The purposes of the NSI are twofold: one is to start a grass-roots movement to get the American public space-minded again. The other is to acquaint private industry with the benefits to be gained from utilizing government space-related research and development.

Von Braun feels that interest in space has lagged among a fickle public just at the point where the real returns for the investments of the 1960's should be rolling in. He likens the country to a farmer who has carefully sown and tended his orchard and who, now that the fruit is ripening, says he can't afford to hire pickers.

Von Braun believes all the earth's problems can be tackled with the aid of space technology—from new manufacturing activities made possible in zero gravity, to satellite communications and earth resources monitoring, to the construction of planetary colonies and orbiting habitats. "Space takes the lid off the pressure cooker called earth," says he.

The NSI has a small staff quartered in Arlington, Virginia, an estimated annual budget of $300,000, and a starry board of directors including broadcaster, author, and all-around enthusiast Hugh Downs, now cast as NSI vice president; Boy Scout executive Alden G. Barber; Fulton J. Sheen; Barry Goldwater; Jacques Cousteau; Shirley Temple Black; Issac Asimov; James Van Allen; and Bob Hope.—C.H.

million, Williams pointed out, in deciding what chance they would accept of a rocket landing in a populated area. Why not use that?

Gilruth thought that was unrealistic. "You ought to say what you honestly want," he reasoned. "In the long run, that's a better way than to try to kid yourself. It's like setting your clock up when you know you're going to be late." They compromised. The probability of getting the crew back safely was set at three nines (.999), or 999 times in a thousand. The probability of completing the assigned mission was set at two nines, 99 times in a hundred.

And that, Johnson recalled, is how it happened, in a ten-minute talk. "We wrote those numbers down, and they had a most profound effect on the cost of the program. If you took one decimal point off of that thing, in theory you could probably cut the program cost in half. If we'd added one more, there's no way in the world we could ever have done it —there's not enough money in the world to do it."*

But having set the requirements for the spacecraft's reliability in getting to the moon and back did not help to answer the deeper question: How the hell were they actually going to do it?

* The joke that made the rounds of NASA was that the Saturn V had a reliability rating of .9999. In the story, a group from headquarters goes down to Marshall and asks Wernher von Braun how reliable the Saturn is going to be. Von Braun turns to four of his lieutenants and asks, "Is there any reason why it won't work?" to which they answer: *"Nein."* *"Nein."* *"Nein."* *"Nein."* Von Braun then says to the men from headquarters, "Gentlemen, I have a reliability of four nines."

From the Book
Apollo the Race to the Moon.
pg. 102

went quite right. The preparation and launching of spacecraft at the dawn of the space age turned out to be a laborious business, and the participants were still amateurs sitting at the bottom of the learning curve. "We were green as thumbs," Merritt Preston used to say.

1

Two months after the flight of Big Joe, on November 2, 1959, President Eisenhower signed an executive order transferring Wernher von Braun's rocket engineers at the Army Ballistic Missile Agency in Huntsville to NASA. It was the indispensable step for making NASA legitimate, giving that young and uncertain agency an infusion of talent it could have gotten nowhere else.

The division of responsibility was clean: The Space Task Group had jurisdiction over the spacecraft while the people at Marshall had jurisdiction over the launch vehicle.* The development of the working relationship took time, and there would always be rivalry. But with the addition of the Germans, it became possible to go to the moon.

By 1959, von Braun's rocket team had been in the United States for thirteen years following their surrender to the U.S. Army at the end of World War II. At first they had been sent to White Sands in New Mexico, where they were put to work showing the Americans how the V-2 worked. Then in 1950 the Army decided that an inland site was too confining, a decision prompted in part by an unfortunate occasion when the German team put a V-2 into a cemetery south of Juarez. From then

* Here, in one place, are the genealogies and official nomenclature of the NASA centers principally involved in the space program: (1) For the spacecraft: The manned space program began at Langley Research Center, where the Space Task Group was an organizationally independent entity. In November 1961, the Space Task Group became the Manned Spacecraft Center (M.S.C.) located at Houston, Texas. In 1973, M.S.C. was renamed the Lyndon B. Johnson Space Center (Johnson, or J.S.C.). (2) For the launch vehicle: In the 1950s, von Braun's group was part of the Army Ballistic Missile Agency located at Redstone Arsenal in Huntsville, Alabama. In 1959, when von Braun joined NASA, it became the nucleus of the newly named George C. Marshall Space Flight Center (Marshall, or M.S.F.C.). (3) For launch operations: The area around Cape Canaveral served as a launch area for all of the armed forces during the 1950s. The initial launch group from Huntsville was called the Missile Firing Laboratory. In 1959, when Redstone Arsenal became Marshall, the Missile Firing Laboratory became the Launch Operations Directorate, still administratively under von Braun. In 1962, the Launch Operations Directorate became an independent center, the Launch Operations Center. It was renamed the John F. Kennedy Space Center (Kennedy, or K.S.C.) at the end of 1963, immediately after Kennedy's assassination.

on, the larger rockets were launched out over the ocean from Cape Canaveral. The von Braun team itself was moved to Huntsville, Alabama, where the Germans used the facilities of the Redstone Arsenal.

In contrast to the uneasy relationship between the engineers at Langley and the local Virginians, the Germans and the Alabamians got along fine from the beginning. The Germans were delighted to be out of the arid Southwest and in a wooded, hilly area that reminded many of them of the German countryside. The Alabamians were intrigued by these foreigners and entertained by their eccentricities. The assimilation was extraordinarily fast. By 1952, only two years after the Germans had arrived in Huntsville, former Luftwaffe sergeant Walter Wiesman was president of the Huntsville Junior Chamber of Commerce, elected by a membership that was 70 percent World War II veterans ("So am I!" Wiesman pointed out). As time went on, Huntsville became intensely proud of its Germans, and especially of its most famous German of all, Wernher von Braun.

Von Braun was the only non-astronaut in the space program who became a household name. In Congress, his prestige was enormous. Movie-star handsome, with an expansive smile and European charm to which he added a touch of Alabama folksiness, he could dominate a congressional hearing as easily as he dominated the media. Other senior people in NASA envied him and in some cases resented him ("That damned Nazi," one was known to mutter when he had had several drinks), intimating that von Braun spent too much time worrying about his public image and that the real work at Marshall was done by others. What was hard for some of his NASA peers to swallow was that von Braun was a natural. He was exceptionally good at being a public person, and none of the other engineers of Apollo could compete.

With the fame came a price. In some circles, von Braun was assumed to be a Nazi who had escaped judgment only because of his value to the United States. No such charges were substantiated. On the contrary, his history reveals a man who from his teens had a passion for rockets and space travel, as oblivious to politics in the 1930s as America's Apollo engineers were oblivious to politics during the 1960s. During the height of the war, von Braun was briefly jailed by the Gestapo for insufficient ardor in making weapons. But even among those who bore him no ill will, jokes were inevitable, given the contrast between von Braun's activities during the war and his transformation into an American hero.

When a movie about von Braun was entitled *I Aim at the Stars*, the underground version of the title quickly became *I Aim at the Stars but Sometimes I Hit London.**

Von Braun was not a creative genius—to that extent, the public image misrepresented him. It is not possible to think of "von Braun concepts" that changed the development of rocketry in the same way that "Faget concepts" changed the development of spacecraft. Instead, he was a natural leader and technical manager. Karl Heimburg, chief of the Testing Lab, explained how von Braun went around looking for new ideas, which he would then take to his associates. Heimburg would listen unimpressed and explain to von Braun why something wouldn't work. And then Heimburg would find himself saying, "But we could do it in this other way," and an innovation that he had not considered would have opened up before him.

In general, von Braun seems by the testimony of people who worked for him, ranging from senior colleagues to technicians on the pad, to have been just about as good as his publicity made him out to be. He won from them loyalty and affection as well as professional respect. "He was a noble type of man," said one American at Huntsville. "That's the only word I can think of to describe him."

Ultimately, von Braun won admiration, though sometimes grudging, even from his peers in the other centers. Robert Gilruth, who got far less attention from the press and who in the early days had to struggle to keep the Space Task Group from being eclipsed when von Braun was brought into NASA, had ambivalent feelings about his counterpart at Marshall. But once, after von Braun died in 1977, Gilruth was listening to another senior NASA official talk about a technical problem on the shuttle. "I wish Wernher were still around to ask about this," Gilruth broke in suddenly. "You know," the NASA official reflected, "that was probably the greatest tribute von Braun ever got." And then the NASA official proceeded to give von Braun the only compliment that really counted in the Apollo fraternity. When you ignored all the P.R. stuff, he said, "von Braun was actually a pretty good engineer."

* It was an awkward situation to which the Germans remained sensitive long after they had become naturalized American citizens. During the early years of racial integration, an American engineer once overheard someone asking Hans Gruene, head of Launch Vehicle Operations at the Cape, how he felt about having a black live on his block. "I have no problem," Gruene replied. "I wonder what he thinks of an ex-Nazi living on his?" By that time, many of the Germans had become more American than the Americans. Ray Clark, Kurt Debus's deputy for administration at the Cape, recalled gatherings after work at which Gruene and Debus would get into conversations about America's heritage and its future that more than once went on until dawn—they knew more about the United States than he did, Clark often thought.

FROM the Book: Apollo, The Race to the Moon

The working end of the rocket team at Redstone Arsenal was divided into eight laboratories, and a German headed each of them. Another German, Kurt Debus, headed the Missile Firing Laboratory at the Cape. They ran these labs in a way that often seemed to caricature the precise, methodical rocket scientist of the popular imagination. Their colleagues were "Mister ——" or "Doctor ——," rarely "Chuck" or "Bill," even when they had been working together for years. Everything had to be done with a meticulous exactness and order. Debus, for example, was known for making the rounds of his subordinates' offices after hours, sweeping papers and books from desks that didn't meet his standard of neatness.

The Germans were extraordinarily conservative in their designs, with margins that were lavish even by aerospace standards—every component had to be able to bear far more weight, tolerate far higher temperatures, withstand far higher dynamic pressures than the rated performance of the vehicle required.* When preparing the hardware, the Germans for many years had no separate inspection function. Each engineer inspected the work of his own technicians, and he was expected to be a good enough machinist or electrician or hydraulics mechanic in his own right to be able to know whether the work was done correctly. The Germans' testing programs were excruciatingly thorough, "to the point of being ridiculous," said one American observer with both exasperation and envy.

What made this Germanic conservatism and precision remarkable was that by the late 1950s most of the people from Huntsville who were behaving this way weren't Germans at all, but the Americans who had been hired to work with them. Most of them were men from the small towns of the deep South, graduates of nearby engineering schools like Auburn and the University of Mississippi and Georgia Tech. The result was a combination of Germans like Eberhard Rees or Karl Heimburg or Walter Haeussermann—distinguished and courtly, talking about "ze vay ve do sings," very models of the rocket scientist—and Americans like Alexander A. McCool of Vicksburg, Mississippi, an esteemed propulsion

* When during Apollo the spacecraft kept exceeding its weight limits, NASA officials from headquarters went down to Huntsville to find out whether there was any way that von Braun's people could cut some weight from the launch vehicle and thereby raise its performance beyond its original rating. Sure, one American remembered them saying—"We can cut three thousand pounds, four thousand pounds—it won't make any difference." This was at a time when the spacecraft people were trying to shave ounces. The German margins also let them uprate the performance of the engines of the first stage of the Saturn V from 7,500,000 pounds of thrust to 7,650,000. This reservoir of extra performance that the Germans built into the launch vehicle came to the program's rescue more than once during Apollo.

(LOX), stood 46 feet high, and weighed 14 tons. The nose was packed with a metric ton of high explosive.

At liftoff the V-2 had climbed slowly, with just enough acceleration to compensate for the force of gravity. But as the missile arched on its trajectory and more fuel was consumed, it began to move faster. Sixty-three seconds later, the V-2 was on the fringe of space, 23 miles high, moving at one mile per second. Automatic timers closed the propellant valves, and the pulsing rocket flame snuffed out. Far above the atmosphere, the V-2 continued climbing to the top of its arched trajectory, 60 miles above the Thames estuary. Then the flight path curved down toward London.[1]

When the V-2 hit it was moving at over 2,000 miles per hour, faster than a rifle bullet and far too fast to be seen overhead. And the missile's speed was too great for accurate radar tracking. The mysterious second blast in the sky reported from Chiswick was a sonic boom. The thirteen people killed and injured by the explosion in Chiswick were the first casualties of a space weapon. Over the next six months, 1,114 more V-2s fell on England, killing almost 3,000 men, women, and children.[2] Even worse was the damage done to the Allies' cross-channel debarkation port at Antwerp: over 2,000 V-2s struck that city, shattering the waterfront. After the war, Supreme Allied Commander General Dwight Eisenhower admitted that D-Day would not have been possible had this rocket bombardment begun earlier and been directed at the Allied invaders on the south coast of England or the Normandy beachhead itself.[3]

The V-2 had been designed by a team of German scientists and engineers under the leadership of a young East Prussian aristocrat named Wernher von Braun. He was to become one of the undisputed giants of spaceflight, a man who combined profound intelligence, startling creativity, and unparalleled managerial skill within a personality that has been described as nothing short of charismatic by those who knew him.

Wernher von Braun was an eighteen-year-old technical school student in 1930 (coincidentally the same year I was born) when he met Professor Hermann Oberth, a German from Rumania who had written widely on the future use of rockets for interplanetary spaceflight. After reading Oberth's work, von Braun was convinced that liquid-fueled rockets could be perfected and that one day they could be made large enough to

carry humans to the moon and beyond. Von Braun fell in with a group of like-minded, often eccentric young men who also believed in the possibilities of spaceflight. They formed an amateur rocketry club, the Verein für Raumschiffahrt (VfR), and began testing their tiny missiles in the weedy field of a disused army storage depot outside Berlin. Over the next two years, they slowly developed a crude rocket engine that burned a mixture of LOX and gasoline.[4]

The VfR's labors at the suburban *Raketenflugplatz* were noticed by Colonel Walter Dornberger of the German army's ordnance ballistic section. Dornberger had been ordered by the general staff to develop long-range bombardment weapons that would be in accordance with the stringent disarmament requirements the Allies had imposed on Germany in the Treaty of Versailles. Rockets weren't on that list because, in 1919, they weren't considered serious weapons.

Impressed by the VfR's work, Dornberger became the group's official sponsor. He urged von Braun to complete his education, so that he could better assist the progress of German rocketry. Von Braun received his bachelor's degree in aeronautical engineering in 1932 and his Ph.D. in physics from the University of Berlin only two years later. Dornberger's stewardship is obvious because von Braun's thesis on rocket engines was immediately classified a military secret.

After the Nazis took power in 1933, von Braun's "rocket team" continued their research (though with a relatively small budget compared with the total funds devoted to the massive Nazi rearmament of the 1930s), and under Hermann Goering, the Luftwaffe funded a joint service rocket research center on the Baltic peninsula of Peenemünde. But even after the Germans invaded Poland in 1939, the work of von Braun's rocket team was still neglected by Hitler's general staff.

Von Braun's team continued to grow, however, and was developing larger, longer-range liquid-fueled missiles. Despite repeated failures, the team doggedly overcame the multiple problems of modern rocket engineering: flight stability, fuel management, steady combustion pressure, engine cooling, and guidance. Finally, Field Marshal Walther von Brauchitsch, the Wehrmacht commander, came to the aid of the Peenemünde effort with personnel and funds. Germany's considerable academic talent pool was canvassed for potential rocket experts, who were then sent to work at Peenemünde. The enlarged rocket team's goal was to design a prototype operational missile, the A-4, that would carry a

The history of VonBraun

full ton of explosives accurately to a target 180 miles away. By the summer of 1942, von Braun's team had their prototype. They successfully fired it from Peenemünde on October 3, 1942. As the missile roared aloft and climbed on a steady arch to pierce high scattered clouds, Dornberger (now a general) turned to von Braun. "Do you realize what we have accomplished today? Today a spaceship was born!"[5]

Then events moved more quickly. On June 28, 1943, SS Reichsfuhrer Heinrich Himmler visited Peenemünde on Hitler's behalf to assess the potential of long-range rocket weapons. A first demonstration launch of the A-4 was a catastrophic failure, but the second was a near-perfect flight. Himmler was impressed. Von Braun and General Dornberger were brought to Hitler's headquarters in East Prussia where they showed the Führer films of successful A-4 launches. Hitler immediately ordered the rocket into mass production, which meant that the machine Dornberger and von Braun had envisioned as a spaceship was to become the world's first ballistic missile. The night of August 17, 1943, however, almost 600 RAF heavy bombers struck Peenemünde, badly damaging the rocket laboratories and production facilities and killing hundreds of workers and technicians.

After this air raid, Hitler ordered that rocket production be taken out of the hands of the von Braun team and placed under the control of the SS. Von Braun's prototype A-4 was replicated and mass produced as the V-2. The task fell to SS Brigadier Hans Kammler, who used thousands of concentration camp laborers to build an underground production facility in abandoned mine shafts near Nordhausen in the Harz mountains. Kammler was a relentless slave driver; by 1945, the Mittelwerk underground V-2 factory had reached a peak production level of 900 V-2s per month. But the human cost was horrible. In the final weeks of the war, 150 slave laborers a day were dying of starvation in the nearby Dora concentration camp.[6]

By the end of 1943, von Braun's team could concentrate on more advanced projects. Since the VfR days in Berlin, they had been interested in rockets as spaceflight boosters, not as missiles. They also designed enlarged V-2s with greater range and heavier warheads and even larger classes of rockets that were much more than mere offshoots of the single-stage V-2. These larger boosters would have multiple stages to transport winged space-bomber gliders to near-orbital speed. The

A-12 they planned was a true monster, capable of orbiting 30-ton payloads.

This visionary planning soon caught the attention of the SS, and a Gestapo spy denounced von Braun for "sabotage" because he had once mentioned at a cocktail party that the V-2's real purpose was spaceflight, not bombardment. He was arrested with two of his engineers, Klaus Riedel and Helmut Gröttrup. Only the swift intervention of General Dornberger saved them from a firing squad.[7]

By January 1945, it was clear to von Braun and his men that Germany had lost the war and that they should take their expertise to one of the Allied victors. Von Braun called a secret meeting and tried to rally his key personnel. "Let's not forget that it was our team that first succeeded in reaching outer space," he told them. "We have never stopped believing in satellites, voyages to the moon, and interplanetary travel." He directly asked them which Allied power should receive the incredible technical heritage of the rocket team.[8]

They immediately decided that the rocket team would somehow find a way to surrender to the Americans.

With typical organizational skill and energy, von Braun's team packed up the entire Peenemünde technical archives: blueprints, test reports, patents, and enough other essential documents to fill several boxcars. Von Braun created a bogus "Project for Special Dispositions," and with Peenemünde's priority status he commandeered vehicles and fuel to transport the rocket team and their families south and west toward the advancing American forces. In the spring of 1945, he somehow managed to lead 525 people out of the chaos of the collapsing Third Reich, eventually reaching Oberammergau in the Bavarian Alps. Key members of the team took the archives to Dörnten in the Harz mountains, where they buried tons of documents deep in an abandoned mine.

Von Braun and his close associates knew they were still in danger: they had learned of SS plans to liquidate them in order to prevent their capture by the Allies. But on the evening of May 2, 1945, GIs from an antitank company of the 44th Infantry Division were manning a roadblock in a valley beneath the Bavarian ski resort of Oberjoch. A "shabby young German" in a patched leather jacket rode up on a bicycle. "My name is Magnus von Braun," he said. "My brother invented the V-2. We want to surrender."

PFC Fred Schneikert leveled his rifle at the German's chest. "I think you're nuts," the soldier said. In those days, when the war was coming to an end, all kinds of oddball German civilians were trying to climb on the Allied bandwagon. But luckily the GIs did report the incident, and later that night von Braun and Dornberger officially surrendered.[9]

Army Ordnance Colonel Holger Toftoy soon began a secret effort to bring German scientists to America, known as Operation Paper Clip. American ordnance teams rescued the hidden Peenemünde technical archives and assorted parts for 100 V-2 rockets at Nordhausen from the approaching Soviet occupation forces. This material was dispatched to the Army's White Sands Proving Grounds in New Mexico. While waiting for transport to America, von Braun regaled American intelligence officers with details of the rocket team's plans for multistage rockets and space stations.

To the Americans in the summer of 1945, this kind of talk bordered on delusion. But von Braun's enthusiasm was not dampened. On their way west across the Atlantic to the New Mexican desert test ranges, he told his colleagues how fortunate they were to be working for the Americans. This was a country, he stated with conviction, where spaceflight would take root and flourish.[10] But von Braun could not assess the true nature of the American wilderness that awaited them.

West Point, 1947–1951

When I entered West Point in the summer of 1947, spaceflight was still a fantasy to the men who shaped America's military and scientific policy. Postwar America was more enthralled with jet aviation in Earth's atmosphere than with flying above it. Von Braun's team had by this time been relocated to Fort Bliss, Texas, where they conducted unimportant test flights with the captured V-2s in an underfunded and largely neglected program directed by the US Army Ordnance Corps.

Hiroshima and Nagasaki had demonstrated to President Harry Truman's key advisers in the Pentagon that the ability to drop a ton of high explosives on a city was puny compared to the power of the atomic bomb. For that reason they didn't see any immediate practical military application for ballistic missiles. (Atomic weapons then were very cumbersome fission devices, much too heavy to be delivered by any of the missiles of that day.)

but most important, America's postwar priorities just did not include government funding of a grandiose spaceflight program.

We had a lot more serious things to worry about. By now it was clear that the Soviet Union was no longer our ally. Stalin's occupation forces remained in place, installing satellite governments throughout Eastern Europe, and Winston Churchill alerted the world to the situation with his famous "Iron Curtain" speech. The hot war with fascism that my father had fought in was over; the Cold War with communism had begun. Our small nuclear arsenal had become our single most important deterrent to further communist expansion, a counterpoint to the huge conventional forces of the Soviet Union.

Even as a plebe at West Point, it was clear to me that I would end up fighting the Soviets or their surrogates someplace in the world sooner or later, probably sooner. I was just a young man then, learning the mysteries and rituals of military life in a service academy. It was a hard revelation. I decided that if I had to go to war, I wanted to do it as a jet fighter pilot. I didn't have anything particular against the infantry, but I knew my own talents lay more in the field of science and technology, and jet aviation was then the most advanced field around.

The problem was that my dad and I didn't always agree on what direction I should take in my career. Since I was his only son and namesake—"Buzz" is a childhood nickname that stuck—he'd been pleased when I told him I wanted to attend a service academy. Both my parents had military backgrounds. Dad had been an Army Air Corps pilot and an aide to General Billy Mitchell in the Philippines in the 1920s. It was there that he met my mother, Marion Moon, the daughter of a Methodist Army chaplain. But Dad left the Air Corps after Billy Mitchell was court-martialed for his visionary—but outspoken—views on the future of airpower. My father became an executive with Standard Oil of New Jersey and developed their aviation fuel program. He believed that that was the way I should go: first service in the military, leading to a civilian business career.

His years in the Army had given him a definite feeling about that branch of service. That was why he wanted me to attend the Naval Academy at Annapolis, instead of West Point. He said the Navy really prepared a young man for a career in business. As an executive, he'd seen a lot more ex-Navy officers in the boardrooms than Army generals. He also said that Annapolis men took care of their own in a way that the

the war. He was a disciple of Konstantin Tsiolkovsky, who, in his brilliant theoretical book *Exploration of Cosmic Space with Reactive Devices*, written at the turn of the century, envisioned large multistage boosters fueled by liquid hydrogen and oxygen, space stations, lunar bases, and eventually permanent space colonies ringing Earth. Tsiolkovsky was also the first to calculate the velocities and energy levels that later became the routine mathematical language of spaceflight.[14]

Korolev shared Tsiolkovsky's visions of interplanetary travel. But Korolev was obliged to meet Stalin's military requirements while secretly harboring grandiose plans for spaceflight, just as von Braun had been during the war. And the parallel between the two runs deeper. Korolev was arrested along with thousands of other scientists and technicians by the NKVD secret police in the "great terror" of the late 1930s and was imprisoned for seven years as a gulag convict, several months of which he spent at the notorious Kolyma gold mine in the Arctic. For the rest of his captivity during the war he worked as an engineer under aircraft designer A. N. Tupolev in a "special" prison camp. When he was freed after the war, Korolev quickly rose in the new Soviet missile hierarchy. Although he lacked von Braun's charisma, he was every bit as much a wily survivor.

By the late 1940s, Korolev had recognized that the Soviets had learned all they were going to from their captive German scientists. It was time to strike out on his own. He first modified the basic V-2 propulsion technology into a much larger and more powerful engine. Working within the limits of Soviet metallurgy, he solved the overheating problems inherent to high-energy rocket thrust by creating an engine that had four small, thick-walled combustion chambers. Korolev's RD-107 rocket engine was fueled by a mixture of kerosene and LOX and produced an amazing thrust of almost 225,000 pounds.[15]

Even though Korolev now had the principal building block for a huge rocket that could serve as either an intercontinental ballistic missile or a spacecraft booster, he still faced major technical hurdles. The key to a long-distance missile lay in Tsiolkovsky's pioneering concept of multiple vertical stages; the heavy first stage would break the bonds of gravity, allowing the lighter upper stages to accelerate to the speeds needed for an intercontinental warhead trajectory or orbital flight. It would of course be preferable for the engines of these upper stages to be both

lighter and more powerful than the first-stage engines—that is, with a better thrust-to-weight ratio, generating more energy to accelerate less weight.

Practically, this concept required engine technology that was beyond the reach of the Soviets at the time. So Korolev's innovative compromise was to design a composite rocket that clustered four strap-on boosters around a central core unit known as the "sustainer." Thus the rocket's stages were parallel rather than vertical. The Soviets used two variants of the original basic engine, the RD-107 and the RD-108, an upgraded version of Korolev's earlier design. The strap-on boosters were tapered, wider at the bottom than at the top, giving the base of the rocket the appearance of a flared skirt. The central core was powered by an RD-107 engine with much larger propellant tanks. At liftoff, all the engines fired simultaneously; the "staging" occurred when the strap-on boosters' fuel was expended. The boosters then fell away, leaving the central core's engine to sustain the flight.[16]

Working with this concept, Korolev's team began designing a large, yet simple missile that would eventually become the most durable spaceflight booster in history. Whenever I see pictures of *new* Soviet space boosters these days, I'm amazed at their flared-skirt strap-on boosters: they are obviously direct descendants of Korolev's first ICBM. The Soviets simply do not throw away useful technology. They improve it. We can learn an important lesson from them.

Huntsville, Alabama, 1950–1953

In the beginning, Wernher von Braun and his rocket team didn't find in America the fertile ground for rocketry that Gröttrup's engineers had found in the Soviet Union. Von Braun's key designers had surrendered Germany's human and technical rocket legacy to the US Army because they thought of America as the world's future leader in spaceflight, the nation, they said, that was "most able to provide the resources required for interplanetary travel."[17] But their early years in America had been a long exercise in frustration.

Colonel Holger Toftoy remained the team's sponsor after they were settled at Fort Bliss in the west Texas desert outside of El Paso in 1945. Toftoy was already committed to the cause of missiles and rocketry, but

the Pentagon ignored him. The Germans slowly grew accustomed to the alien culture and climate, but language remained a problem for years. By 1947, they had been joined by their families, and most had become US citizens by 1950.

The rocket team's biggest problem was that they were given low-priority assignments. Their postwar work with V-2s, assembled from the parts Army Ordnance had spirited away from Nordhausen under the noses of the Soviets, was limited to upper-atmosphere probes and minor adaptations of existing German missile technology.

Probably the only excitement the scientists had during this period was the night they accidentally bombed Mexico. Just after 8:45 PM on May 28, 1947, the rocket team fired an unarmed V-2 from the White Sands Proving Ground north of El Paso. The missile veered off course and plunged south toward the Rio Grande, the Mexican border, where it exploded near the Tepeyac cemetery in Ciudad Juárez. When a large Army contingent of engineers arrived in Juárez the next morning, enterprising children tried to sell them twisted shards of the missile.

As someone who can well remember the postwar inflation, I understand why President Harry Truman's priorities were to turn America's economy away from the military and back to civilian production. But this meant American rocketry was eclipsed. Also, the 1947 reorganization of the armed services, which created the Department of Defense, resulted in an interservice rivalry that made Toftoy's German rocket experts even more irrelevant. The newly independent US Air Force made a strong bid for a massive strategic bomber force, and their main competitor for scarce funds, the Navy, wanted "super" aircraft carriers. To enhance its competitive position with the Navy, the Air Force abandoned its tentative preliminary research into a revolutionary intercontinental missile project called the Atlas. This weapon would have used high-pressure rocket engines to boost a huge, heat-shielded nuclear warhead high into space to coast on a ballistic trajectory halfway around the world before reentering the atmosphere. Building the Atlas in the late 1940s would have required an explosion of new technology and a financial investment the Air Force was unwilling to make.

With no American interest in long-range ballistic missiles, von Braun's team simply had no viable work. And they had no sponsor among defense contractors, nor did they have a political patron in Washington. Von Braun learned during these years that such a constituency and patronage would be vital to his future plans, especially because he had not forgotten his dreams of spaceflight.

Von Braun spent his evenings in painstaking research, slowly developing a practical proposal for an international expedition to Mars. By 1948, this became a book manuscript, *Mars Project*, which eighteen US publishers rejected as "too fantastic." Von Braun envisioned a large international interplanetary expedition that would be assembled from a space station in Earth orbit. In essence, von Braun wrote a practical handbook for interplanetary travel, including our Apollo flights of the 1960s.

Von Braun's team was able to advance rocket engine and guidance technology, however, when they were ordered to upgrade the basic V-2 into a tactical nuclear missile for the Army, following the explosion of the first Soviet atomic bomb in 1949. Toftoy, now a general, was dispatched to Huntsville, Alabama, where he acquired and then combined the Redstone and Huntsville arsenals into a single sprawling Army reservation in the red clay hills of the Appalachian Piedmont. He brought von Braun and his team from Texas to the new Redstone Arsenal, home of the Army Ordnance Missile Command. They began work on the long-delayed successor to the V-2, which would become the reliable Redstone missile, the rocket that eventually would put America into space.

Korea, 1952–1953

I was a West Point cadet on a summer study junket in Japan the day the North Korean Army invaded South Korea, June 25, 1950. The Cold War had just turned hot. My trip was cut short. America was at war with a communist army, very well equipped by the Soviet Union. By that December, the Chinese communists had joined the war, and America was bogged down in a bloody stalemate on the Asian mainland.

I graduated from West Point in June 1951, number three in a class of 475 cadets. This academic rating guaranteed that I could enter Air Force flight training, but I still had to face intense competition to earn my wings and win an assignment as a jet fighter pilot. The cadets' code at West Point was "Duty, Honor, Country." Unofficially there was a fourth tenet to the creed: "Work your ass off." And this stood me in good stead during flight training, where the competition for the coveted jet fighter assignments was stiff. By November 1952, I'd managed to stay

list, even without White House support. The plan called for spacecraft and booster technology that would send men on circumlunar flights by 1968 and possibly a manned lunar landing sometime after 1975. NASA estimated that the first phase of the program would cost around $2 billion. George Low told the press that America stood a chance to "win more gold medals in the space Olympics than any other nation."[12]

NASA realized a circumlunar flight would require a spacecraft that could provide life support for more than one astronaut and be capable of reaching a velocity of 25,000 miles per hour in order to escape from Earth's gravitational field. It would also have to shield the crew from radiation while traveling to the moon and be able to withstand reentry to Earth's atmosphere at this speed, which was much greater than the 17,500-mile-per-hour orbital reentry. The big spacecraft would be far heavier than the booster capacity of any planned military missile.

Von Braun's Huntsville team already had a class of large boosters on the drawing board. Called the Saturn (after Jupiter's neighboring planet in the solar system), the first generation of large boosters incorporated a cluster of Jupiter-type engines as the first stage, to produce 1.5 million pounds of thrust. Von Braun also envisioned a second-generation superbooster he called the Nova, whose first stage would cluster the big F-1 engines that were then being studied by the Defense Department. *Each* F-1 produced a thrust of 1.5 million pounds.

In December 1959, Abe Silverstein and his advanced development group went even further than von Braun's ambitious initial plans for the Saturn class of rockets. Following conventional design philosophy, the first stage of the new boosters would use proven kerosene and LOX propellants. Silverstein, however, knew that the upper stages of any eventual moon booster would require a much higher thrust-to-weight capability than LOX-kerosene technology could provide. His group recommended fueling the upper stages with supercold ("cryogenic") liquid hydrogen and LOX, a high-energy combination whose use was fraught with technical problems. This was the technology that the rocket pioneers Tsiolkovsky, Oberth, and Goddard said offered the most efficient and lightweight conversion of fuel to thrust. Von Braun knew this, of course, but was hesitant to embrace this unconventional propellant technology. His years of trying unsuccessfully to interest America in spaceflight had taught him to be cautious in his recommendations. Now that senior NASA officials were backing this method of fueling the boosters, he was more than happy to follow.[13]

Silverstein's insistence on the high-energy cryogenic upper stages for NASA's eventual Saturn rockets would become the key that would unlock the door to the first moon landing. After the fall of 1959, Wernher von Braun began participating to an even greater extent in both NASA's Project Mercury and ambitious advanced spaceflight plans. Eisenhower, recognizing that if America was going to compete with the Soviets it would need large civilian boosters, finally gave in to Glennan's repeated requests and transferred von Braun's Development Operations Division of the Army Ballistic Missile Agency to NASA, effective July 1, 1960. On that date, Wernher von Braun became director of NASA's new Marshall Space Flight Center (named for Ike's wartime colleague General George C. Marshall) in Huntsville, Alabama. Eisenhower even attended the dedication ceremonies on September 1, 1960. NASA had acquired the Army-funded Jet Propulsion Laboratory (JPL), the nation's preeminent satellite laboratory, the year before. This was part of a White House compromise designed to appease both Glennan and the Pentagon, but actually satisfying neither because NASA didn't get the von Braun team and the Army lost the JPL.

Von Braun's Huntsville center had an in-house industrial capacity unlike anything seen before. His policy, from Peenemünde days, was to have his team actually build their own prototypes, rather than farming out the work to industry. So Marshall was actually a booster factory, not simply an R&D laboratory.[14] JPL had the same type of operation for the construction of prototype satellites and spacecraft systems. NASA now had the ability to begin practical work on a manned lunar landing program. All they lacked was White House approval.

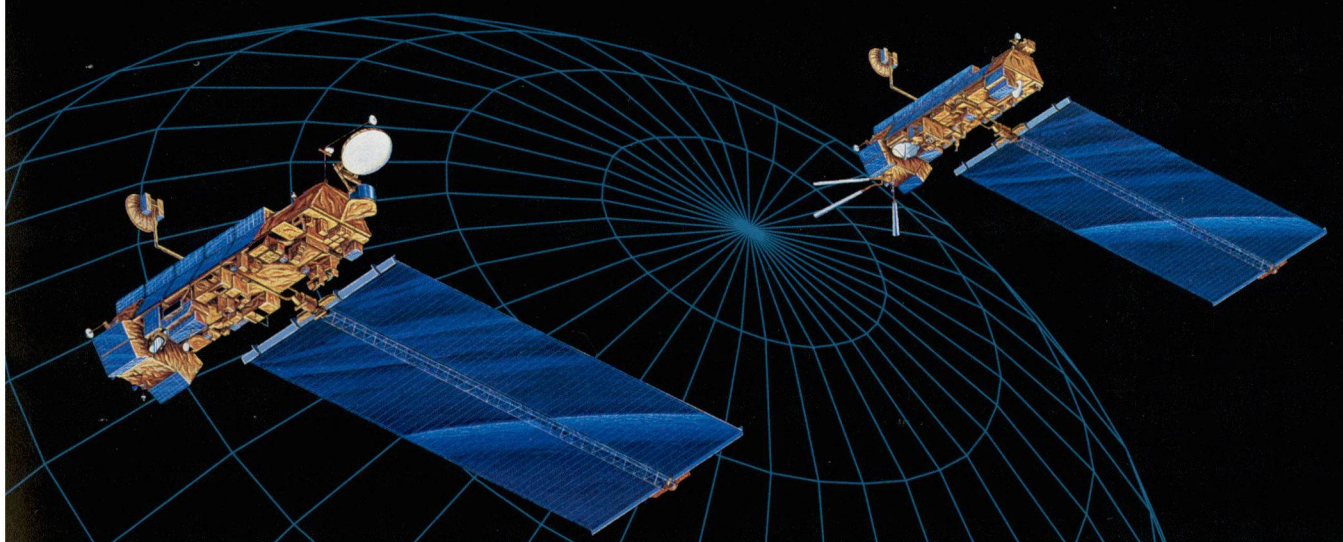
Abe Silverstein again drew on his knowledge of mythology for the name of NASA's post-Mercury manned spaceflight project. "Apollo," the name of the sun god who rode his flaming chariot across the sky, was suitably evocative for this exciting program. Administrator Glennan agreed on the name, but Project Apollo, George Low quickly admitted, had as yet "no official standing." That was probably the understatement of that year.

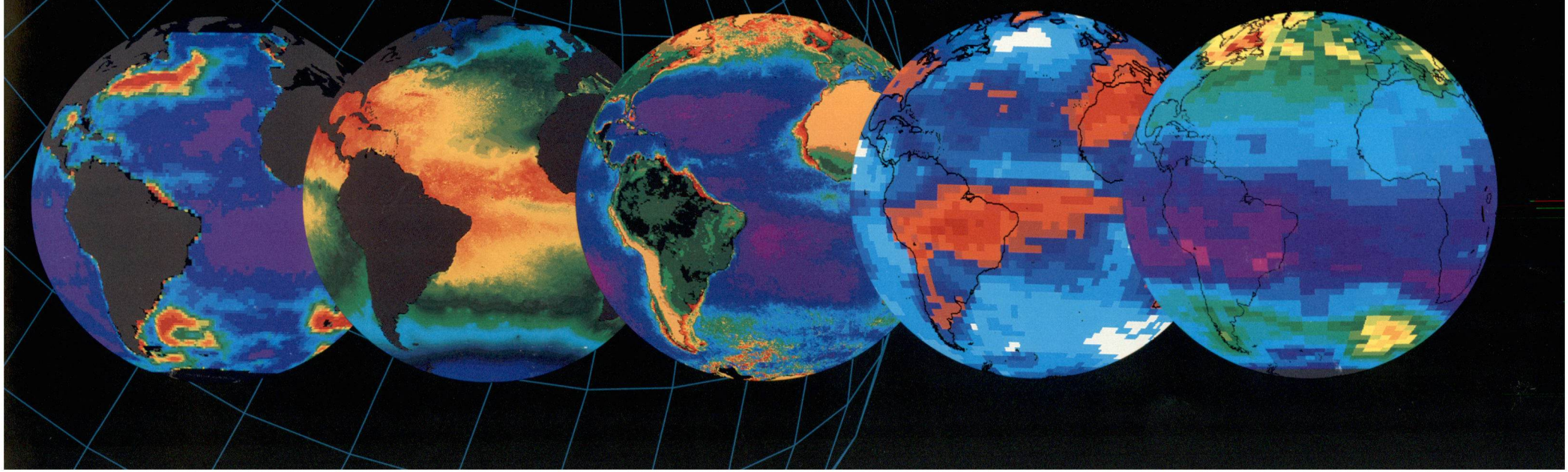
Eisenhower may have supported unmanned scientific and military reconnaissance satellites, but he only grudgingly approved Project

THE EARTH OBSERVING SYSTEM

EOS

A Mission To Planet Earth





Funding for the U.S. Global Change Research Program will increase by nearly 60 percent, to over $1 billion [in FY 1991]. That commitment, by far the largest ever made by any nation, reflects our determination to improve our understanding of the science of climate change.... Our program allows NASA and her sister agencies and all our international partners to move forward with the "Mission to Planet Earth". That will initiate the U.S. Earth Observing System.

President George Bush
February 5, 1990

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EOS: The Earth Observing System

To understand global change and the increasing demands of human activity, it is essential that we document and comprehend how the Earth works as a system. The international scientific community is organizing research efforts to advance our knowledge of both natural and human-induced global change. The U.S. Global Change Research Program, a consensus interagency plan, defines the U.S. element of those efforts.

Mission to Planet Earth, the central NASA contribution to the U.S. Global Change Research Program, includes two proposed initiatives in the FY 1991 Federal budget: the Earth Observing System (EOS) and Earth Probes.

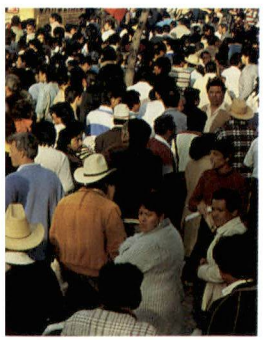
EOS consists of a space-based observing system, a Data and Information System (EOSDIS), and a scientific research program. It represents the initiation of a comprehensive, global observing system with broad and high-resolution spectral and spatial, as well as long-term temporal, coverage of the Earth. The space component will consist of two series of polar-orbiting platforms, with launch of the first platform in FY 1998. EOS will be supplemented by companion European and Japanese platforms, as well as the continuing operational environmental satellites.

EOS will continue and integrate the measurements now being taken by short-term research missions. It will provide the first coordinated simultaneous measurements of the interactions of the atmosphere, oceans, solid earth, and hydrologic and biogeochemical cycles.

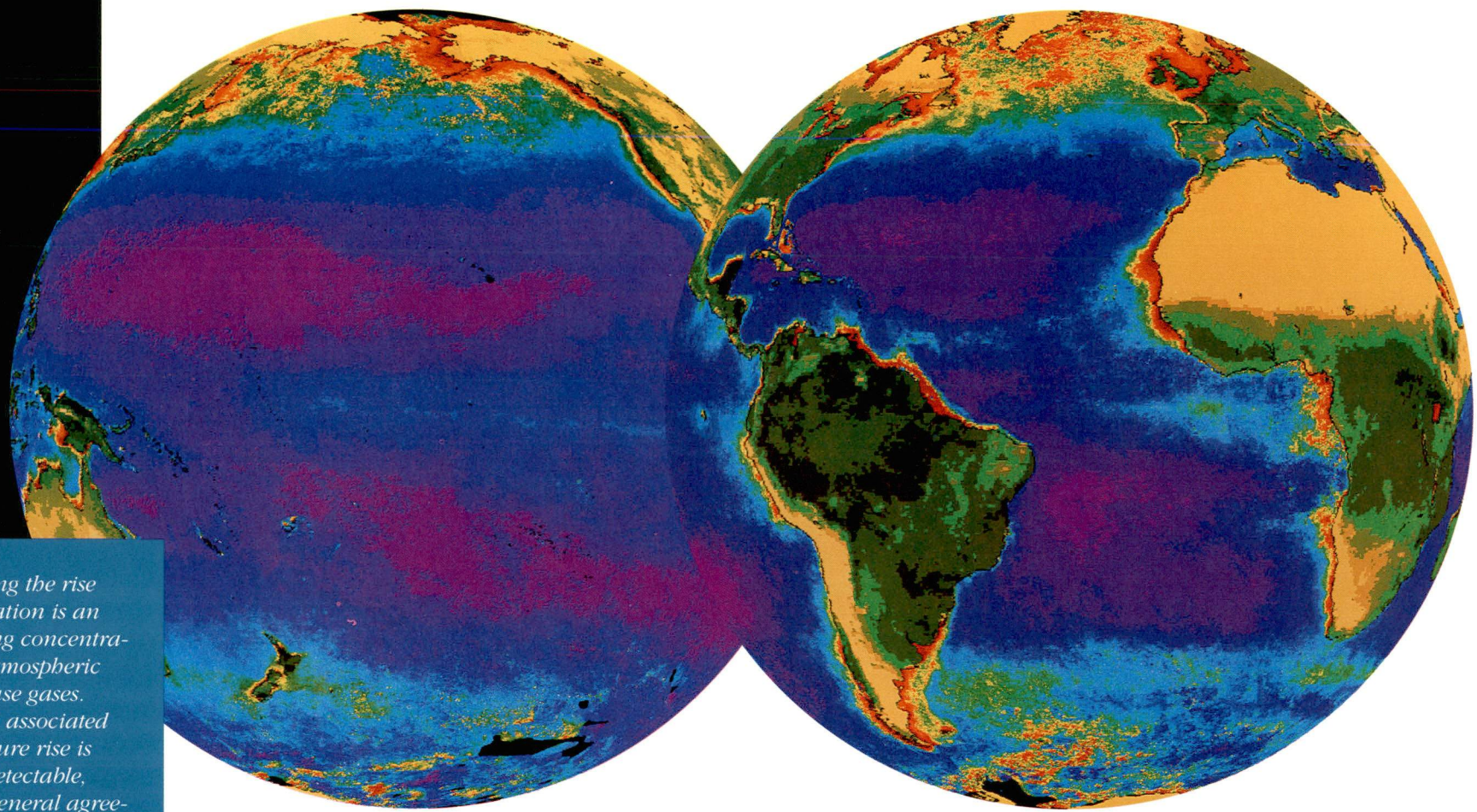
Earth Probes will provide a focus on observing specific Earth processes where smaller platforms and/or different orbits from EOS are required. In addition to complementing EOS, Earth Probes will provide critical near-term observations.

Development of EOSDIS will begin immediately to support the research and analysis of both existing data and those to come from the near-term missions. EOSDIS will be a state-of-the-art information system to foster rapid and easy access for users.

This document presents EOS, Earth Probes, and related precursor research missions—all in the context of supporting the U.S. Global Change Research Program. For additional information, Pre-EOS and EOS Reference Handbooks are available which provide in-depth information on candidate instruments, their measurements, and the Data and Information System.



On the cover: the EOS-A (left) and -B (right) polar platforms. The five discs show (left to right): variable sea-surface topography, sea-surface temperature, a composite of ocean chlorophyll concentration and terrestrial vegetation index, mean cloud cover, and stratospheric ozone.



Paralleling the rise in population is an increasing concentration of atmospheric greenhouse gases. While an associated temperature rise is not yet detectable, there is general agreement that it will occur; the open question regards its rate and magnitude.

Understanding The Earth As A System

We live on a planet of extraordinary complexity; the presence of an atmosphere and oceans with the right chemical composition on a solid planet has supported the development of an abundant diversity of life. Throughout geologic history, the atmosphere, oceans, and land have interacted to produce global environmental change to which life has contributed and adapted. Today, one species of life, humankind, through increasing population and quest for improved quality of life, has developed the capability of changing our global environment in ways that we are only beginning to perceive, but do not fully understand.

In some cases, such as the depletion of the Earth's energy and mineral resources, the effects of human activity are obvious. In other cases, such as the alteration of atmospheric chemical composition, the processes of change are difficult to document, and their consequences harder to foresee. Moreover, the effects of many human-induced changes cannot readily be distinguished from the results of natural change over time periods of decades to centuries.

We now know that we have embarked on a global experiment, but we do not know the consequences. Model predictions suggest that the Earth should be warming in response to increasing carbon dioxide and other gases in the atmosphere, but observations are ambiguous. Is the signal lost in the noise of natural climate variability, or are there other processes at work? Until we more completely understand the Earth system, we will not be able to answer such crucial questions.

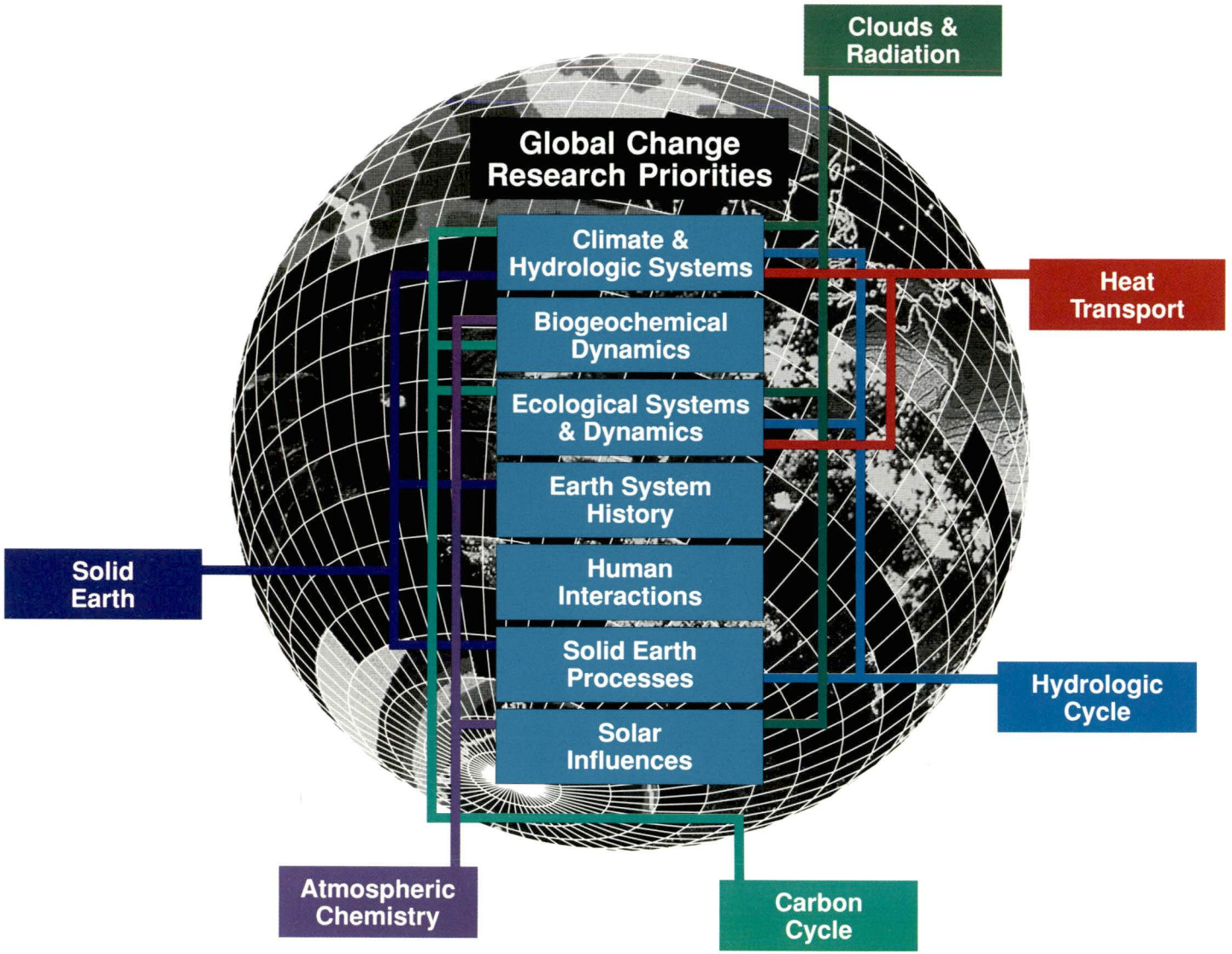
The oceans, atmosphere, and ice-covered regions of the globe are now recognized to be closely coupled in shaping the Earth's weather and climate. Both terrestrial and oceanic biota are recognized as exerting a major influence on global climate and the chemical cycles important to life. But the fundamental questions about how the Earth system works remain unanswered.

Over the past 40 years, our view of the solid Earth has been dramatically transformed. The earlier notion of a placid, static globe has been replaced by the dynamism of plate tectonics. Patterns of mountain-building, volcanism, and earthquake activity all fit consistently into this new view.

It is essential that we understand how components of this system interact—from the short time scales of weather systems to the millennia of geological time—and how we affect these interactions. Until we have that understanding, we will not be able to predict how human activities will change the environment.

A global view of the Earth's biosphere. Shown are three-year composite images of ocean chlorophyll concentration (increasing from purple to red) and land vegetation index (increasing from tan to green), derived from NASA's Nimbus-7 Coastal Zone Color Scanner and the NOAA-7 Advanced Very High Resolution Radiometer, respectively.

Recognizing the potential for global change, the international community is organizing research efforts to understand the Earth system. The Global Change Research Program, resulting from interagency consensus, defines the US contribution to those international efforts.



A Plan For Action

The demonstrated human role in global change requires that we develop a comprehensive program of Earth studies that transcends traditional disciplinary boundaries. Our goal is to obtain a scientific understanding of the Earth as a system, from which we hope to develop a capability to predict future change.

The key to understanding is accurate observations and modelling of the crucial interacting processes. Such observations of the state of the Earth are critical for providing a system for early warnings of change. To obtain that basic information, we need appropriate instruments deployed both on the Earth's surface and in space. Satellite remote sensing provides global and long-term continuous measurements for monitoring the entire planet. Surface-based measurements are required both to validate the space-based observations, to provide more detailed studies, and to observe those processes not accessible from space.

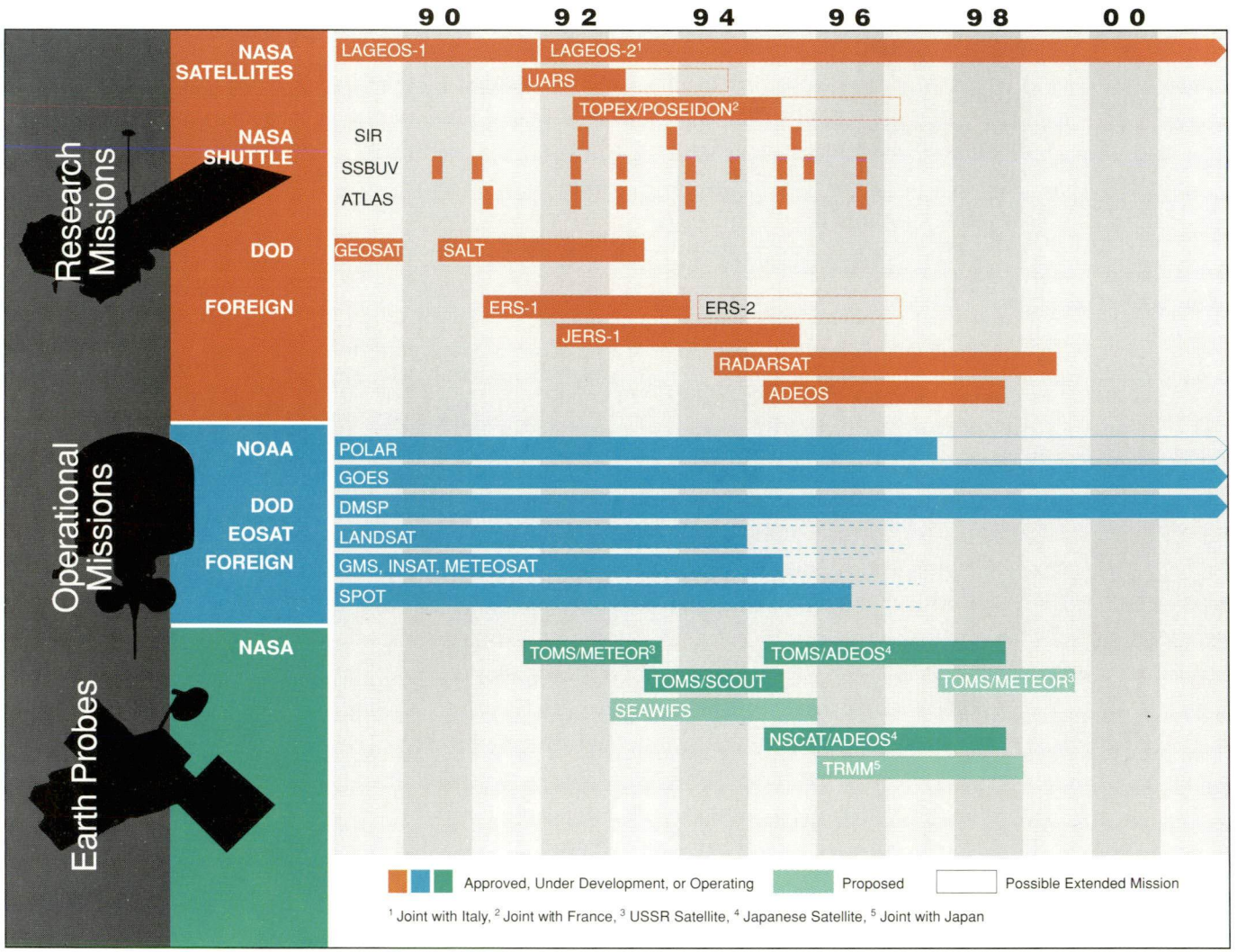
The international scientific community is developing programs to address global change. The World Climate Research Programme, sponsored by the International Council of Scientific Unions (ICSU) and the World Meteorological Organization, focuses on physical aspects of climate systems: the role of clouds and radiation, ocean circulation, air-sea interaction, and the effects of global water and energy budgets on climate. ICSU has established the International Geosphere-Biosphere Programme to describe and understand the interactive chemical and biological processes that regulate the total Earth system.

In response to the scientific challenge and a national perception that the U.S. must take a leadership role in global change research, a federal interagency Committee on Earth Sciences was formed under the President's Science Advisor to develop a plan for action. With remarkable agreement and clear consensus, representatives of thirteen federal agencies have produced the first U.S. Strategy for Global Change Research.

The integrating priorities of this program are to document change in the Earth System using observational programs and data management systems, to carry out focused studies on controlling processes to improve our understanding, and to develop integrated conceptual and predictive models.

For the first half of the 1990s, space-borne contributions to the Global Change Research Program will come from the missions described below. These include the initiation of NASA's Earth Probes as well as the EOS Data and Information System (EOSDIS) which will support study of available satellite data. The launch of the first of NASA's EOS polar platforms is in FY 1998 and will mark the beginning of a comprehensive and long-term measurement system.

Schematic representation showing how interdisciplinary components of NASA's EOS science program relate to the corresponding science priorities of the U.S. Global Change Research Program.



NASA's traditional focus on discipline-specific missions has emphasized the development of improved sensors, placing lower priority on data systems. While the utility of remote sensing has been demonstrated, the full potential of satellites has yet to be realized in Earth science.

Focused Near-Term Observations

arth remote sensing has evolved from developing and demonstrating technology to focusing on specific research and operational topics. For example, NASA's Seasat and the series of Nimbus satellites have demonstrated the utility of active and passive microwave systems for characterizing the oceans and atmosphere.

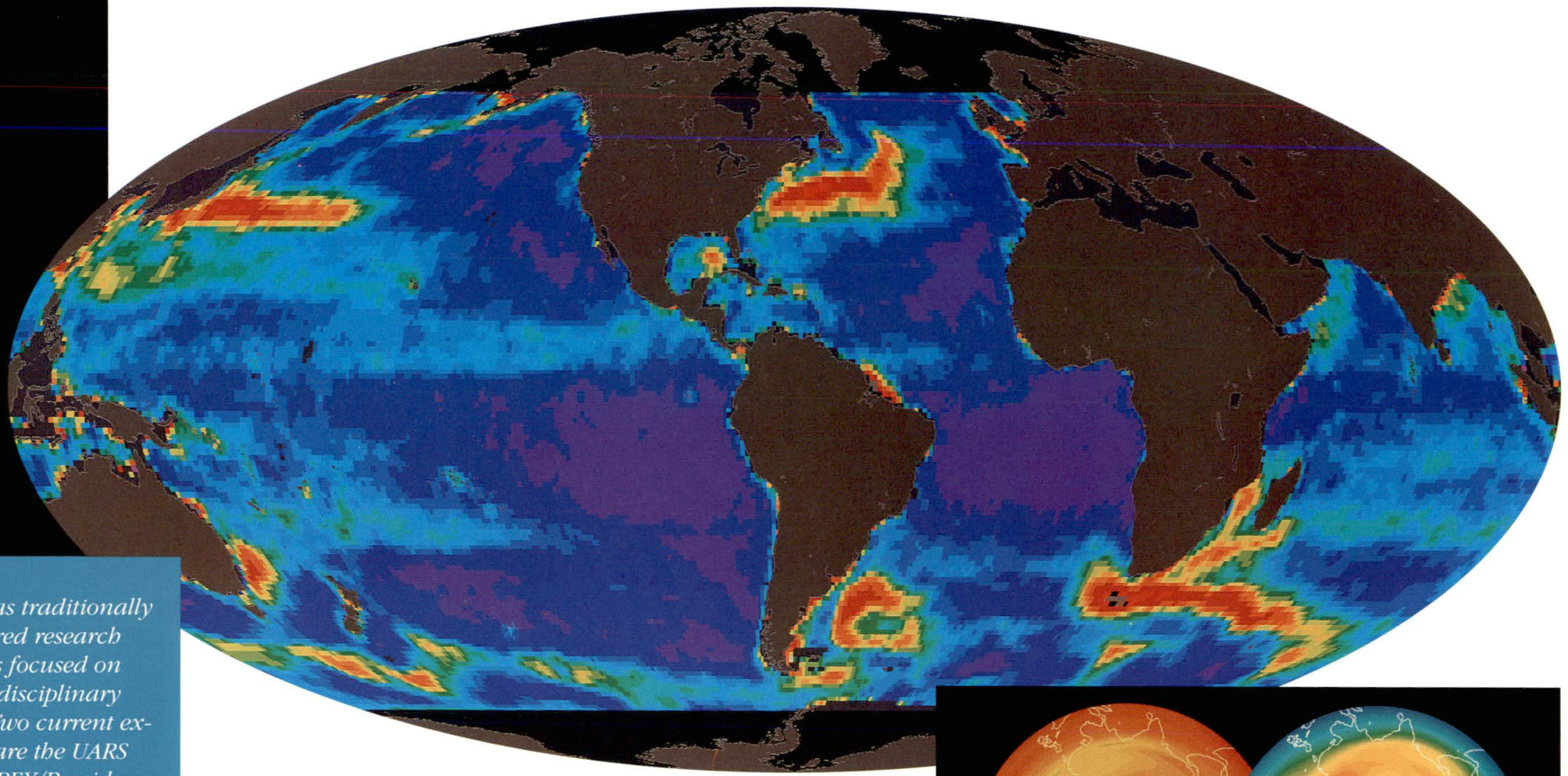
Building on the lessons learned, two research missions under development are the Upper Atmosphere Research Satellite (UARS) and TOPEX/Poseidon, focused on atmospheric chemistry and oceanic circulation, respectively. There are also sensors for short-term deployment from the Space Shuttle: Shuttle Imaging Radar (SIR), Shuttle Solar Backscatter Ultraviolet sensor (SSBUV), and Atmospheric Laboratory for Applications and Science (ATLAS). These address the development and utilization of synthetic aperture radar, accurate measurements of ozone in the upper atmosphere for cross-calibration purposes, and observations of solar influences on atmospheric chemistry. Finally, accurate tracking of the two laser geodynamics satellites (LAGEOS-1, -2) provides gravity and geodetic data.

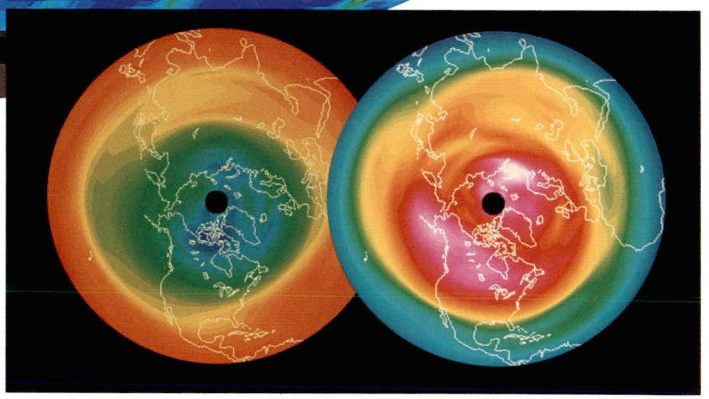
In addition, the U.S. Department of Defense has flown an altimetric satellite, GEOSAT, and plans another, SALT, for observing oceanic circulation. Foreign missions include the European Remote Sensing satellite (ERS-1), for ocean observations; Japanese Earth Resources Satellite (JERS-1), for global mapping of resources; Canadian Radarsat, for sea-ice mapping; and Japanese Advanced Earth Observing Satellite (ADEOS), which will include two of NASA's proposed Earth Probe sensors.

Included in NASA's proposed Earth Probes are sensors destined for flights of opportunity: Total Ozone Mapping Sensor (TOMS) to provide interim ozone observations until the flight of EOS, Sea-viewing Wide-Field Sensor (SeaWiFS) to provide improved observations of oceanic chlorophyll, and Scatterometer (NSCAT) to provide marine surface winds. The Tropical Rainfall Measuring Mission (TRMM) will provide the first spaceborne measurements of low-latitude rainfall.

Throughout the first half of the 1990s, the research missions discussed below will provide remotely sensed data for the Global Change Research Program. They will be complemented by operational missions currently consisting of geosynchronous and polar-orbiting satellites for weather forecasting and land measurements. Simultaneously, the EOS Data and Information System will provide a means for accessing data from these missions and integrating them in global change studies—all in preparation for the comprehensive Earth Observing System of the second half of the 1990s.

This table shows the distribution of Earth-related missions in the pre-EOS era. Included are those proposed Earth Probes which have been defined.





NASA has traditionally configured research missions focused on specific disciplinary topics. Two current examples are the UARS and TOPEX/Poseidon missions, addressing stratospheric chemistry and ocean circulation, respectively.

Oceanic Circulation, Atmospheric Chemistry

Two major missions, each addressing a specific question relating to global change, are under development for launch in the early 1990s. TOPEX/Poseidon is focused on oceanic circulation and the Upper Atmosphere Research Satellite (UARS) on atmospheric chemistry.

TOPEX/Poseidon. The large-scale movement of water in the ocean affects climate by transporting heat from the equator to the poles. This oceanic circulation is one of the weak links in our understanding of the physical climate system. Surface and deep currents, upwelling, and bottom-water formation are involved. But to observe this complex system has proved extraordinarily difficult with conventional means. To achieve a global synoptic view of the circulation will require satellite measurements as well as *in situ* studies. NASA and France's Centre National D'Etudes Spatiales have designed a joint mission, TOPEX/Poseidon, that will use a radar altimeter system deployed in an orbit specifically designed for precise measurements of broad-scale ocean surface currents unobtainable via shipboard observations. It will be launched in 1992 on an Ariane rocket.

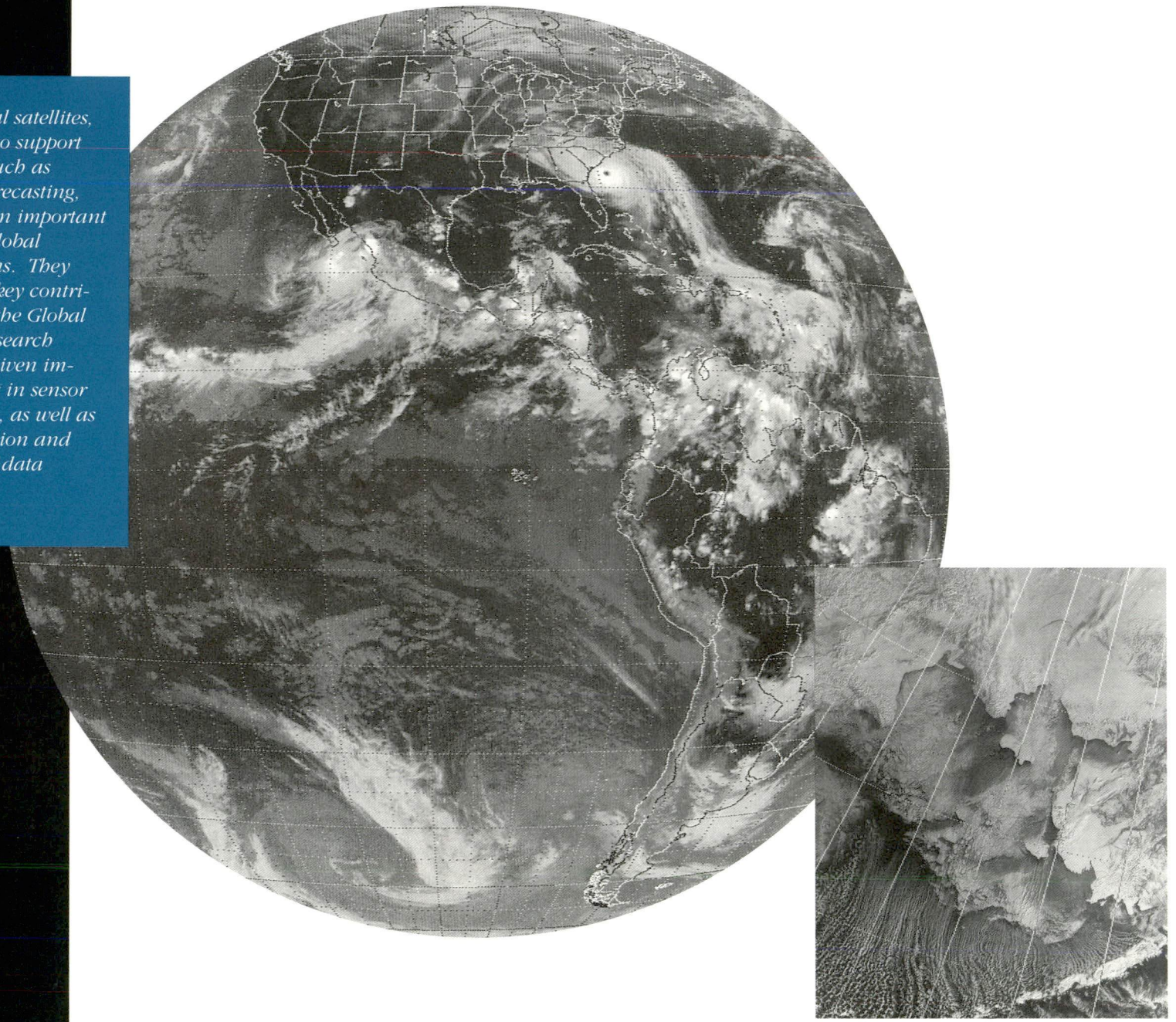
TOPEX/Poseidon will give accurate measurements of currents and tides, but with only a single altimeter, it cannot resolve the smaller-scale ocean eddies which are also important in ocean heat transport and biological processes. With at least two altimeters flying on different satellites in the EOS era, the broad spectrum of oceanic circulation can be monitored.

UARS. Major questions of atmospheric chemistry remain unanswered despite having received much attention in recent years: What causes ozone variations? How are the chemical, radiative, and dynamic processes of the stratosphere coupled? UARS, planned for launch in 1991, will gather data related to the chemistry, dynamics, and energetics of the ozone layer. UARS data will be used to study energy input, stratospheric photochemistry, and upper atmospheric circulation. UARS will help us understand and predict how the nitrogen and chlorine cycles—and the nitrous oxides and halocarbons which maintain them—relate to ozone balance. It will also observe diurnal variations in short-lived stratospheric chemical species important to ozone destruction.

UARS, primarily focused on the upper atmosphere, will only provide a very limited set of companion measurements in the troposphere. Moreover, UARS, like most research missions, has a relatively short (two to five years) lifetime. EOS will provide continuing measurements, as well as more complete coverage of chemical species in both the stratosphere and troposphere.

Sea-level variability measured by the U.S. Navy's GEOSAT over a two-year period revealing fluctuations in the western boundary currents and Antarctic Circumpolar Current (increasing to red-yellow). The smaller images show two atmospheric constituents that were measured by the LIMS sensor aboard Nimbus-7 during the winter of 1979: left, nitrogen dioxide; right, nitric acid (increasing from blue to red).

Operational satellites, developed to support activities such as weather forecasting, represent an important source of global observations. They can make key contributions to the Global Change Research Program, given improvements in sensor calibration, as well as the generation and archival of data products.



Research Use Of Operational Data

Initial pictures of weather from space were produced from a U.S. TIROS satellite in 1960. Today, the polar-orbiting and geostationary environmental satellites of the National Oceanic and Atmospheric Administration, the Defense Meteorological Satellite Program (DMSP), the commercial venture Eosat, and their counterparts around the world provide valuable, real-time information about the changes in the world's weather and land surface. In addition, the operational satellites yield information on climate variables, including surface temperatures, wind velocities, land cover and usage patterns, snow cover and sea ice, cloudiness, global precipitation, and the Earth's radiation budget. This operational system works well: the real-time data provide continual warning of short-term weather hazards such as hurricanes, storms, and other extreme events.

These data have provided a tantalizing first view of the workings of the components of the Earth system. Moreover, the data collected by the operational systems have the potential for providing useful information on global change. They constitute a record, now over a decade long, of baseline information against which global change can be measured. In addition, new data products are being developed to exploit the data for use in longer-term climate studies.

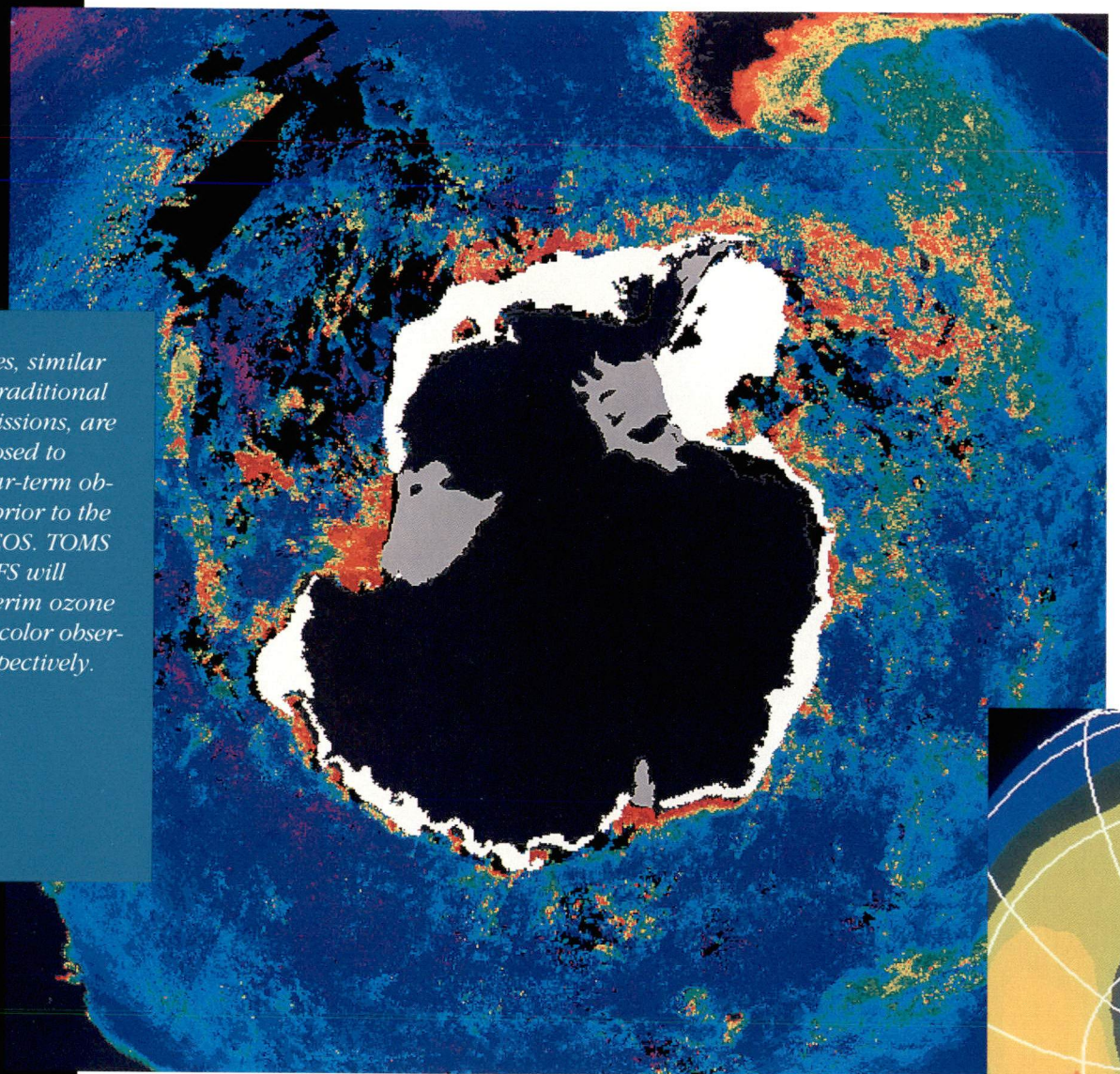
At the same time, since the systems are driven by operational and commercial requirements, the full use of the data for research on global change has been limited. The spectral coverage of the environmental and Landsat systems is limited, the repeat coverage of Landsat is infrequent and the commercial viability and hence continuity of Landsat is in doubt. It has not been easy for researchers to access data, either for reasons of cost or because data do not exist or are not available in formats that can be easily used.

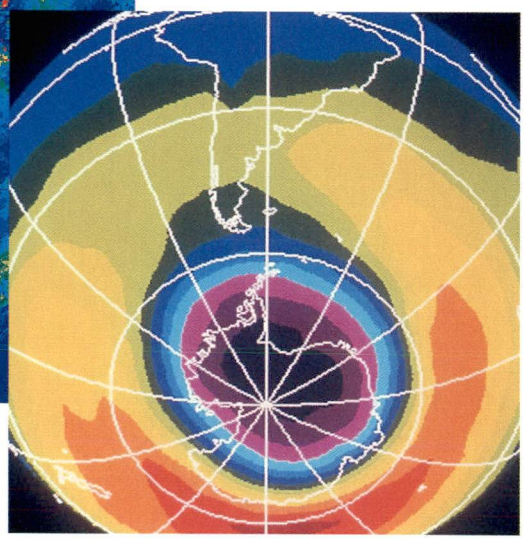
The next logical step for these systems is to address long-term calibration and validation issues, generate research quality products, and make these products available to a wide variety of users in a manner compatible with the EOS Data and Information System. In this way, the research community will have a means to work with large data sets as it prepares for the new research missions and EOS itself.

It is essential that the operational satellite observations extend into the future in order that the baseline information continue. With the generation of research quality products and easy access to archives, the operational systems can significantly complement the research missions, Earth Probes, and EOS to provide the comprehensive data set necessary to document and understand global change.

The larger image from NOAA's GOES shows cloud patterns on September 22, 1989; note Hurricane Hugo off the coast of South Carolina. The smaller visible image from DOD's DMSP shows prominent sea-ice features and wind rows in the Bering Sea on March 2, 1988.

Earth Probes, similar to smaller traditional research missions, are being proposed to provide near-term observations prior to the launch of EOS. TOMS and SeaWiFS will provide interim ozone and ocean color observations, respectively.





The Ozone Hole, Ocean Productivity

Earth Probes are being proposed to obtain near-term observations of specific Earth processes prior to EOS, as well as to complement EOS in those cases where smaller platforms and/or orbits other than EOS are required. Earth Probes are scheduled to begin flying in 1991 with a satellite launch every two to three years.

TOMS. The Total Ozone Mapping Spectrometer (TOMS), the first Earth Probe, will measure atmospheric ozone. The habitability of the Earth depends on maintaining the ozone layer, which absorbs harmful ultraviolet light. We now know that ozone depletion is caused by complex, coupled chemical reactions. In the early 1970s, a warning was sounded that the chlorofluorocarbons used in widespread applications could cause depletion of the ozone layer. The TOMS sensor on Nimbus-7 has provided a continuous global record of ozone over the full depth of the atmosphere since 1978, but the instrument is now reaching the end of its useful life. To continue these measurements, NASA has made arrangements for a TOMS instrument to fly on a Soviet Meteor-3 Satellite and on the Japanese Advanced Earth Observation satellite; a low-cost U.S. satellite to carry a TOMS payload is also being designed. Thereafter, instruments to monitor ozone will be carried on future NOAA satellites.

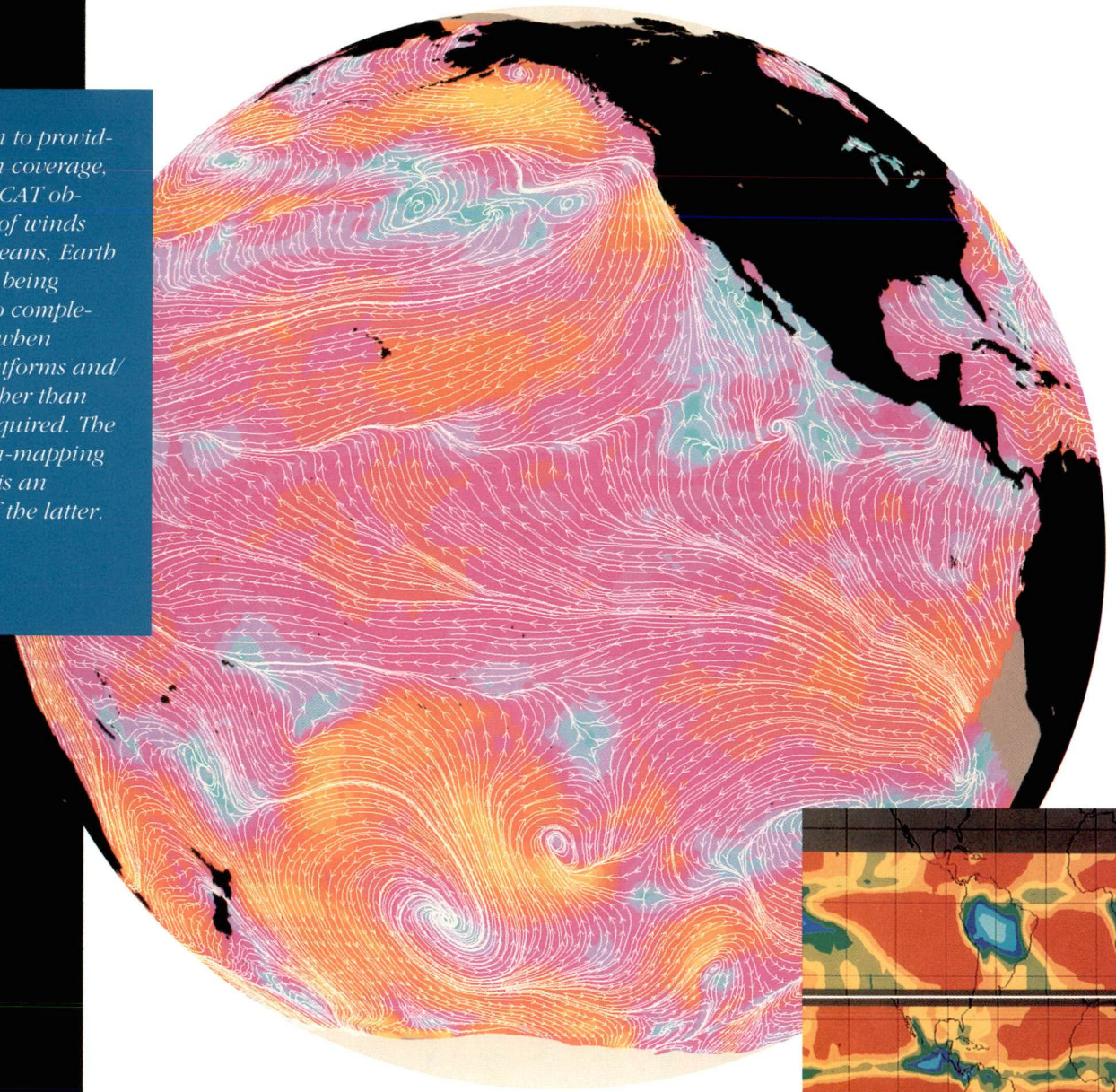
SeaWiFS. One of the next Earth Probes is the Sea-viewing Wide-Field Sensor (SeaWiFS), an ocean color scanner. Biological processes in the ocean are critical to biogeochemical cycles. In the upper ocean, primary production by phytoplankton is a key parameter in regulating carbon flux in the sea. Thus, it is essential to understand its magnitude and variability. However, present uncertainties in estimates of oceanic primary production are larger than the annual rate of atmospheric carbon dioxide increase.

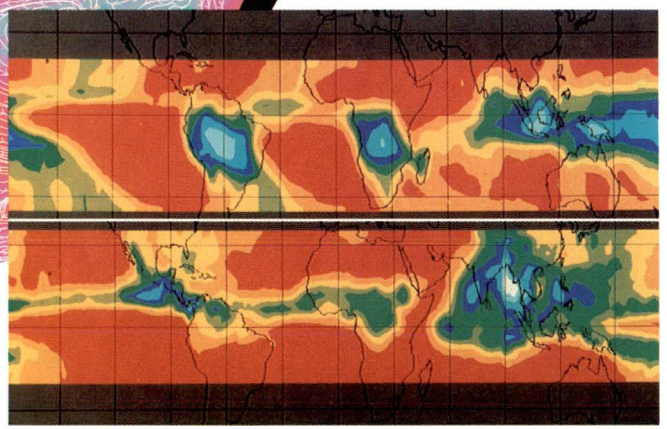
To address this need, NASA has defined performance specifications for the SeaWiFS sensor which will measure ocean color related to phytoplankton chlorophyll. SeaWiFS will be able to measure chlorophyll in the open ocean where the signal is low, distinguish between phytoplankton pigments and sediment in coastal water, and make the necessary atmospheric corrections. These data will provide the first estimates of the mean and variable rates of primary production in the world oceans.

Instruments planned for EOS will continue previous ocean color time series. In addition, with their higher spectral resolution, they will have important new capabilities that will accurately resolve photosynthetic potential and plankton types, thus increasing our capability to study the interactions of marine ecosystems and global change.

Ozone concentration (smaller image) from TOMS showing the ozone hole for October 1989 (increasing from purple-blue to yellow-red). Four-year composite of chlorophyll concentration (larger) from CZCS (increasing from purple-green to yellow-red); also shown is the typical minimal extent of sea ice in summer (white).

In addition to providing interim coverage, such as NSCAT observations of winds over the oceans, Earth Probes are being proposed to complement EOS when smaller platforms and/or orbits other than EOS are required. The TRMM rain-mapping capability is an example of the latter.





Marine Winds, Tropical Rain

In the tropical Pacific Ocean, the changing winds, rainfall, and heat from the ocean are the signals and drivers of El Niño, the periodic climate anomaly that has global implications. Accordingly, NASA is developing systems to measure marine surface winds and rain as part of its Earth Probes program.

NSCAT. Winds drive ocean currents and modulate the fluxes of heat, moisture, gases, and particulates between the air and the sea. Thus, knowledge of ocean surface winds is crucial for understanding the ocean-atmosphere coupling. A better understanding of the marine boundary layer and troposphere will also improve numerical weather predictions.

At present, most wind observations over the oceans come from ships, and the data are often inaccurate and geographically sparse. The NASA Scatterometer (NSCAT), an active radar system in a sun-synchronous orbit, can measure both wind speed and direction over at least 90 percent of the ice-free global oceans every two days. NSCAT is now being developed for space flight on the Japanese ADEOS satellite with launch in 1995. This flight schedule will allow an overlap with the extended mission of TOPEX/Poseidon, thus providing an estimate of the wind forcing and ocean current response.

The absence of a co-located microwave radiometer on ADEOS precludes correction of NSCAT data for contamination by atmospheric water or the identification of rain-induced errors, thus leading to subtle inaccuracies and geographical biases. EOS instrumentation will remedy these deficiencies, as well as continue the measurement series begun by NSCAT.

TRMM. The Tropical Rainfall Measuring Mission (TRMM), a joint effort between the U.S. and Japan, is being proposed to test the feasibility of using active and passive microwave data, together with visible and infrared, to derive rainfall amount and distribution between 35 degrees north and south latitude. In addition, some information about the vertical distribution of rain in thunderstorms will be obtained. TRMM seeks at least a three-year data set of monthly averaged rainfall. As part of EOS, an additional TRMM package is proposed for the Space Station in order to provide a decade of continuous observations.

TRMM data will be used directly in climate models that are critical to understanding global change. However, TRMM will not measure precipitation outside the tropics and subtropics, and it will have relatively large sampling errors over land. These problems will be partially alleviated by using the TRMM package on Space Station in conjunction with complementary sensors on the EOS polar platforms.

The larger image shows surface streamlines (white lines with arrows) and wind speeds (increasing from blue-purple to red-yellow) from the Seasat Scatterometer on September 14, 1978. The smaller shows 1988 Northern Hemisphere winter (top) and summer (bottom) estimates of total rainfall based on infrared observations from the geostationary weather satellites (increasing from red-yellow, through green-dark blue, to light-blue).

Integrated, Long-term Observations

Understanding global environmental change requires knowledge of the entire Earth system. A new concept, Earth System Science, has developed to describe how its components and their interactions have evolved, how they function, and how they may be expected to continue to evolve.

The ultimate goal of Earth System Science is to develop the capability to predict environmental changes, both natural and human-induced, that will occur in the future. Meeting this challenge for the next decade to century requires the integration of knowledge from the traditional disciplines and information from many different sources into a coherent view of the Earth system.

Earth remote sensing has matured as a result of technology development and utility demonstrations. But even as this has occurred, Earth science has continued to be organized along traditional disciplinary lines. With the understanding and experience which has grown within these disciplines, with new technology, and with the challenge of understanding Earth as a system, we are now ready to pursue Earth System Science.

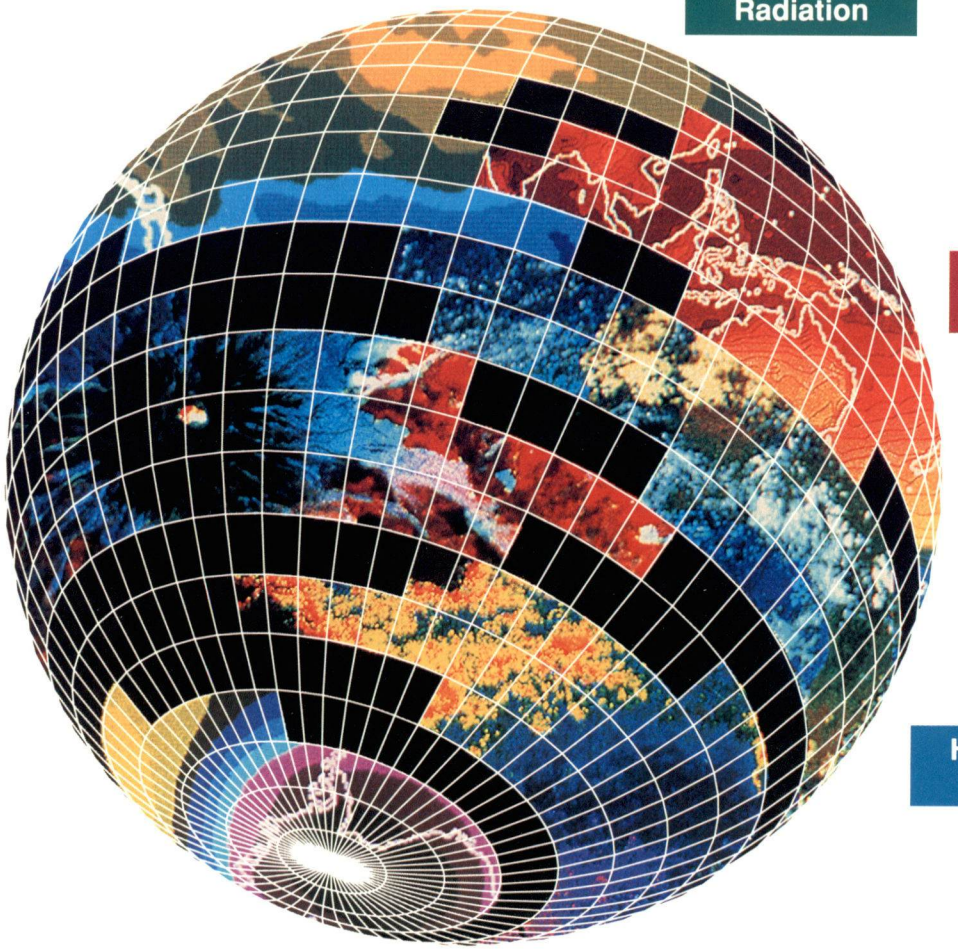
We can now shift our focus from traditional disciplines toward interdisciplinary components of the Earth system as discussed in the following pages: the influence of clouds and radiation balance, role of oceans and atmosphere in heat transport, hydrologic and carbon cycles, changing composition of the atmosphere, and geological and geophysical processes.

EOS has been designed to meet observational needs of Earth System Science. It will operate for 15 years, a time period which encompasses a large span of major environmental change, ranging from several atmospheric biennial oscillations, three to five El Niños, and an entire solar cycle. It will provide a sufficiently large platform to accommodate appropriate suites of sensors so that multiple views of the same location on Earth at the same time will avoid atmospheric-induced uncertainties. It will provide broad and high-resolution spectral and spatial coverage. It will feature a fixed payload for the duration, so that it can provide a consistent set of observations.

One particular strength of EOS is that it will provide, for the first time, a long-term, simultaneous set of observations of the same phenomena on ever-increasing spatial scales (local, regional, global) that can be used to integrate and extrapolate our understanding of ecological and hydrological processes.

The EOS Data and Information System (EOSDIS) will not only provide access to EOS and appropriate complementary ground-based data, but will also support the research and analysis of data which exist today and which will come from pre-EOS missions.

Schematic representation of interdisciplinary components of NASA's EOS science program.



Given the maturity of remote sensing and advances in computer technology, the traditional approach can now give way to one more appropriate to understanding the Earth as a system. The potential now exists to specify — and collect — integrated, long-term, consistent Earth science data sets.

What Is The Influence Of Clouds?

The energy balance of the Earth's climate system is determined by the balance between absorbed and emitted radiation. For the Earth as a whole, and over long time periods, there is a near balance of net radiation at the top of the atmosphere. On shorter time scales, the variable distribution of heating and cooling provides the sources and sinks of energy which drive the circulation of the atmosphere and oceans.

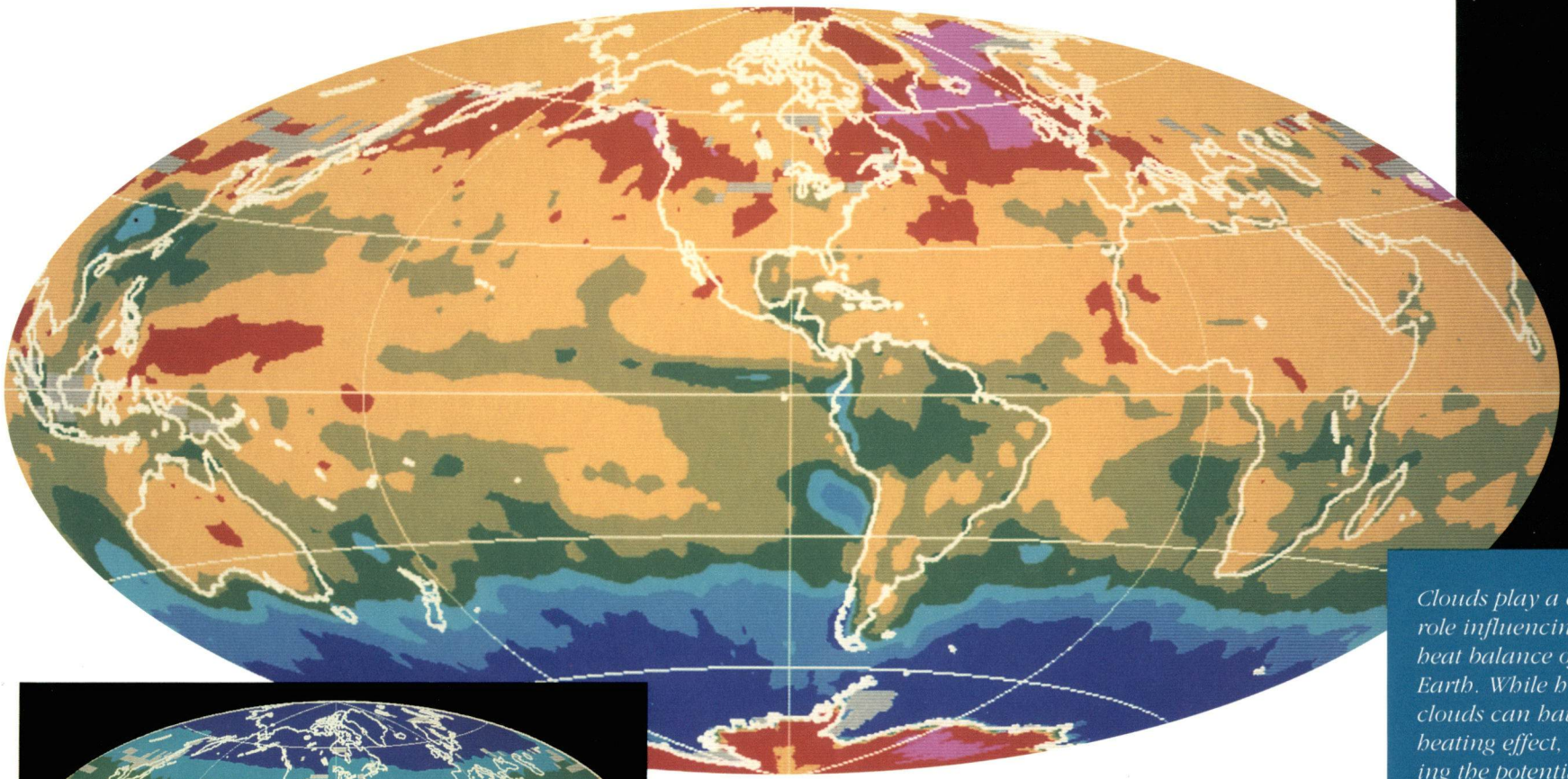
Throughout the atmosphere, radiative heating and cooling compete with other processes such as evaporative cooling or latent heat release to determine the temperature. Radiation is also important in partitioning energy between the atmosphere and the continental surface and between the atmosphere and the oceans, thereby determining the extent to which the oceans moderate climate change. Over land, the solar flux received at the surface has a strong influence on the hydrologic cycle and the biosphere. To understand all of these processes we must monitor the parameters that govern the radiation balance.

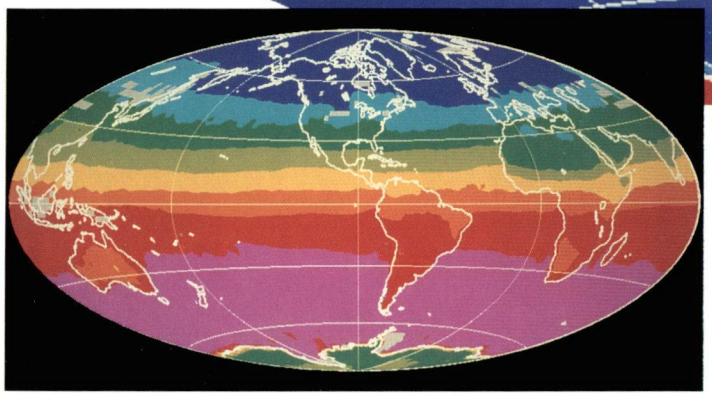
The incoming solar radiation heats the atmosphere and the Earth's surface. The Earth and atmosphere cool by re-radiating a portion of the energy at much longer wavelengths. The difference in radiation at the top of the atmosphere and at the surface is the net radiative heating or cooling of the atmosphere. This difference can be monitored best from space.

The principal attributes of the atmosphere that affect the radiative fluxes must also be monitored to determine the processes that cause changes in the radiative balance. Such measurements have been made from space through the use of operational satellites and the Earth Radiation Budget Experiment. The results from these studies, only recently available, tend to confirm that low level clouds cause cooling through reflection of solar radiation whereas high level clouds cause heating through absorption and reflection of surface radiation. Further long-term measurements will be required to establish the validity of these initial conclusions.

EOS instruments will provide improved spatial resolution and high spectral resolution observations of clouds and more accurate profiles of atmospheric temperature and water vapor. They will also monitor cloud water vapor and precipitation. All of these observations contribute to improved measurement of surface temperature and moisture. Other EOS instruments will provide complete hemispherical coverage of the radiance pattern to provide data for new angular distribution models, improved fluxes and daily, global observations of stratospheric and tropospheric aerosol optical thicknesses.

These figures show results from the Earth Radiation Budget Experiment for January 1986 and include the combined effect of sunlight and infrared radiation. The smaller figure shows the net radiation for clear-sky conditions, where blue (magenta) represents the net heat loss (gain) corresponding to the Northern (Southern) Hemisphere winter (summer). In the larger figure, clouds have a net cooling (heating) effect in the blue-green (yellow-red-magenta) regions.





Clouds play a critical role influencing the heat balance of the Earth. While high clouds can have a net heating effect, increasing the potential greenhouse effect, low clouds can do just the opposite. The study of clouds will thus be a central element in the Global Change Research Program.

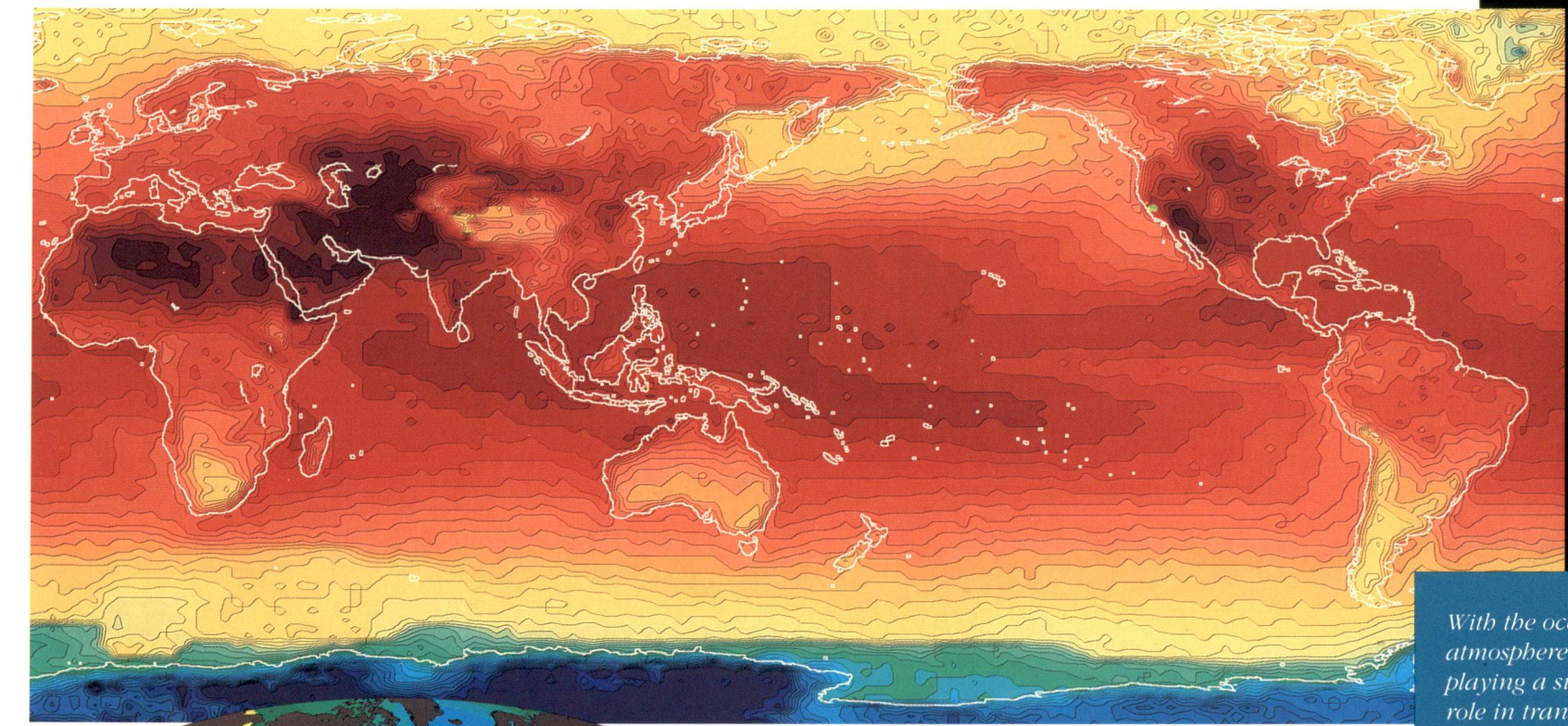
How Is Heat Transported?

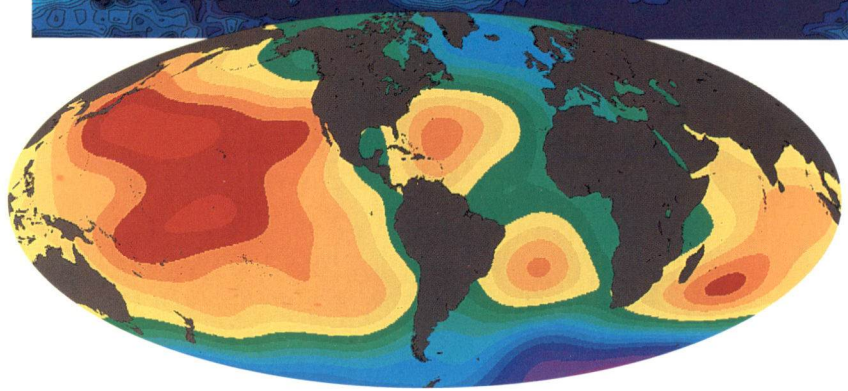
Atmospheric and oceanic circulations play a central role in the climate of the Earth. The atmosphere is driven by the radiation from the sun. The surface winds drive the oceanic circulation and influence the exchange of heat between the oceans and the atmosphere. The result is a complex interacting system of winds and currents which are a part of the climate system. As we try to understand and predict changing climate, improving our knowledge about the interaction between oceanic and atmospheric circulation is essential. For example, the heat content and time scales of motion in the oceans are larger than in the atmosphere. Thus, changing the storage of heat or the rate of formation of cold deep water in the oceans could substantially lessen the impact of a greenhouse effect. Similarly, the formation of sea ice in the polar regions can lead to changes in heat transport and deep-water formation which can have significant impacts on climate.

The best estimates of the heat flux by the atmosphere and oceans have been obtained by inference from the global radiation budget and atmospheric heat transport. Using these estimates, the oceans and atmosphere are found to transport roughly equal amounts of heat poleward. However, attempts to measure the oceanic heat transport directly have not succeeded in providing an accurate estimate. For many parts of the globe, particularly in the Southern Hemisphere, neither the magnitude nor the direction of the directly estimated heat transport is consistent with the inferred transport.

EOS, together with *in situ* measurements, will provide for the first time the necessary simultaneous observations for accurate estimation on a global scale of both the circulation and heat transport of the atmosphere and oceans. While operational satellites have given profiles of atmospheric temperature for almost two decades, EOS will provide the first simultaneous wind profiles on a global basis, which will improve estimates of the atmospheric heat transport. Similarly, the sea-surface temperature, sea-ice coverage, and surface oceanic circulation will be observed simultaneously by the radiometers and altimeters on EOS, leading to improved estimates of the heat exchange between the oceans and the atmosphere. By combining simultaneous observations from several EOS sensors, a better description of the complex interaction between the oceans and the atmosphere will be achieved. Coupled with numerical models, these measurements should greatly improve our ability to understand and predict the role of oceanic and atmospheric circulation in our changing climate.

The mean surface temperature (top) for June 1988 as obtained from the infrared and microwave radiometers (HIRS/MSU) aboard the NOAA series of meteorological satellites (increasing from blue-yellow to red). In the lower figure, the mean dynamic topography obtained from the Geosat satellite shows the large-scale average ocean circulation; streamlines are clockwise around the higher elevations (yellow-red) in the Northern Hemisphere.





With the oceans and atmosphere each playing a significant role in transporting heat from low to high latitudes, it is important to understand the nature of their circulations, as well as how they are driven and interact, so that their influence on regional and global climate can be assessed.

What Governs Rainfall Patterns?

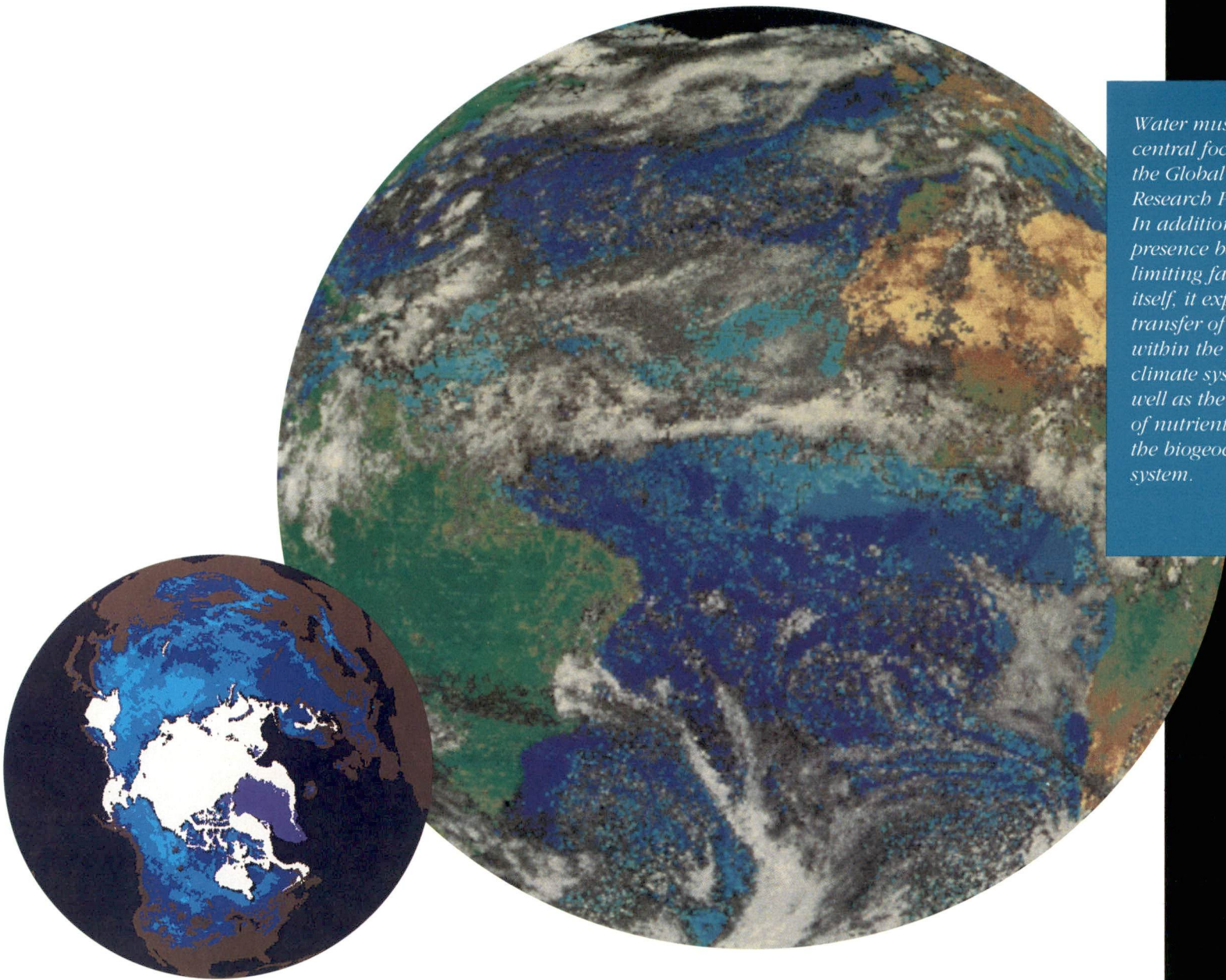
The existence of abundant water, an essential ingredient for life, is a primary difference between Earth and the other planets. Through the hydrologic cycle, water is an essential element of most processes that determine global climate change. The redistribution of heat that governs the Earth's climate depends largely on the transport, evaporation, condensation, and freezing of water, as well as the role of clouds and water vapor in the Earth's radiation balance. Water is a primary agent in shaping the landscape and in transporting sediments and nutrients. It is an essential part of all biogeochemical cycles and interacts strongly with vegetation. In the form of ice and snow cover, water affects the Earth's radiation balance, polar oceans, and sea level. Water supply governs the distribution and level of agriculture, energy production, and industry. Drought and floods are evident examples of the impact of water on societies. Despite the significance of water, our knowledge of the hydrologic cycle as part of the global, interacting system is meager.

In tropical and subtropical regions, clouds and precipitation are a major driving force for the circulation of the atmosphere. The Tropical Rainfall Measuring Mission (TRMM) and the efforts to establish a global precipitation climatology are the first steps in investigating one of the least known and most crucial elements of the global hydrologic cycle. But we are far from understanding how the hydrologic cycle will respond to a changing Earth system, or how water will influence the other components of the system.

Precipitation, soil moisture, atmospheric water vapor, clouds, snow pack, sea ice, polar glaciers, vegetation, temperature, and winds are each critical quantities needed to characterize the climate and hydrologic system. The very diversity of the effects of water in the Earth system have limited the development of a unified understanding of water. EOS will provide the first long-term, consistent global measurements of many of these key physical variables. The most important contribution of EOS will be the capability for simultaneous measurements necessary to investigate the processes which define the interactions and feedbacks within the hydrologic cycle.

A variety of EOS instruments will each contribute different components to our knowledge of physical climate and the hydrologic cycle. The global measurements and the process studies based on the simultaneous combination of EOS measurements are critical to understanding the central role of water in the Earth system.

This composite view (top) in the visible portion of the spectrum is based on data from NOAA's GOES-5 and European Meteosat-2 on July 4, 1983. Clouds are shown in greys, oceans blue, and land green to tan. Nimbus-7 microwave radiometer-derived estimates (bottom) of sea ice and snow cover for February 1983. Sea ice is white, permanent ice sheets purple, and depth of snow cover shades of blue.



Water must be a central focus in the Global Change Research Program. In addition to its presence being a limiting factor for life itself, it expedites the transfer of energy within the physical climate system, as well as the transport of nutrients within the biogeochemical system.

What Controls Atmospheric CO_2?

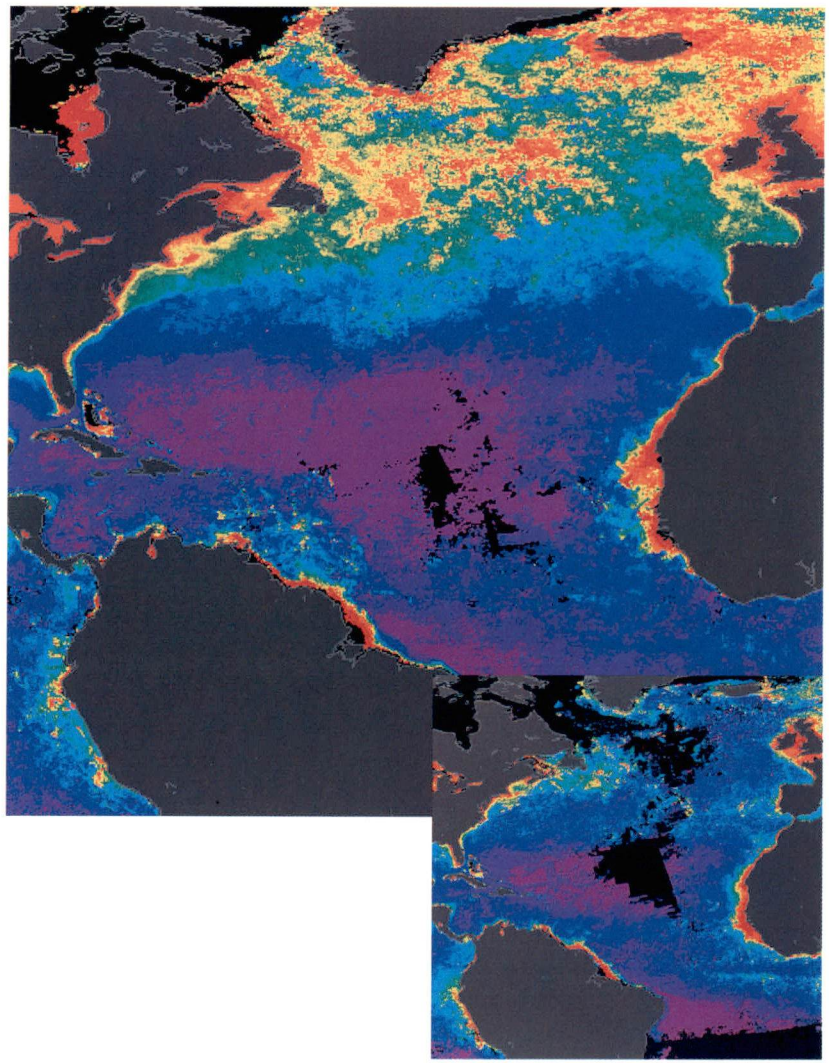
Since 1850, atmospheric carbon dioxide has increased by 25 percent and atmospheric methane by more than 100 percent. Though the changing carbon cycle has been studied for a long time, we remain uncertain about many of the controlling processes and the relative role of the terrestrial ecosystem versus the oceans in sequestering carbon. Hence we cannot predict future trends and effects. The exchange of carbon between the atmosphere, terrestrial biosphere, and oceans as well as the magnitude of the major carbon reservoirs are central issues in understanding the global carbon cycle. If climate changes, how will these exchanges be affected? Will the oceans take up less carbon dioxide or more? Will the terrestrial feedbacks be positive or negative? What will happen to the major storage reservoirs of carbon? These are vital issues for society.

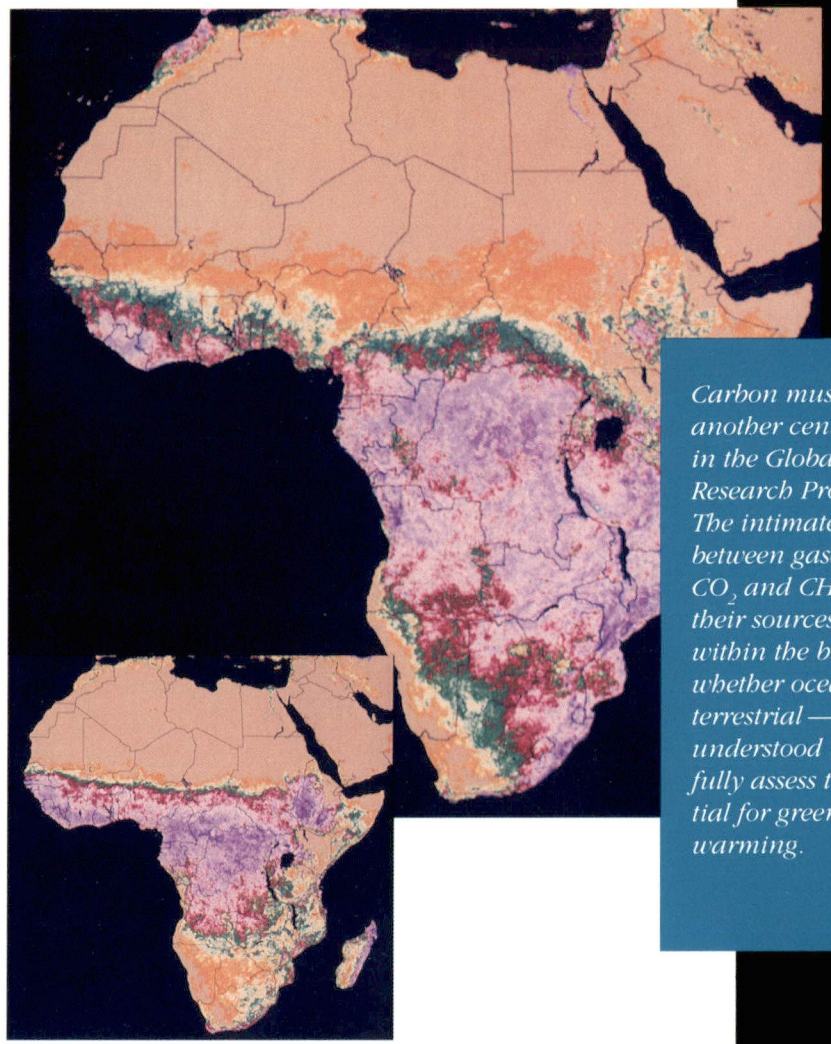
Large uncertainties in our understanding of the carbon cycle are related to questions such as: How much carbon dioxide is being released from vegetation and soils as a result of natural changes and deforestation? How much carbon dioxide is being taken up by the oceans? What is the rate of carbon transfer between the atmosphere and terrestrial ecosystems? The sources for increased methane emissions to the atmosphere need to be identified and quantified.

Current operational observing systems can provide estimates of the rate of deforestation, but coverage is incomplete because of cloud cover problems in the tropics. These systems have extremely restricted spectral resolution and cannot discriminate subtle changes in disturbed ecosystems. EOS instruments will provide needed global coverage of ecosystem states. The synthetic aperture radar, planned to fly on a separate spacecraft, will have the ability to penetrate clouds and forest canopies to characterize forest biomass and moisture status with high resolution maps. This information will be used to infer global productivity patterns, both on the land and in the ocean, another important aspect of the global carbon cycle.

The net flux of atmospheric carbon dioxide into the oceans remains uncertain. The rate of carbon uptake by the oceans is controlled by a complex interaction of ocean biology, chemistry, and circulation. Over 99 percent of all biologically incorporated carbon is buried in ocean sediments. Thus, small changes in oceanic primary productivity can have a major impact on the partitioning of carbon dioxide in the global carbon cycle. EOS instruments will allow dramatically improved estimates of biological activity in the upper ocean, the sea-surface state, and the circulation. The data will be used to make improved models of the carbon cycle.

The figures on the right compare 1989 March (top) and October (bottom) vegetation index patterns (increasing from tan to purple) based on data from the NOAA AVHRR. The figures on the left compare 1979 spring (top) and winter (bottom) phytoplankton chlorophyll concentrations (increasing from purple to yellow-red) based on data from the Nimbus-7 CZCS.





Carbon must be another central focus in the Global Change Research Program. The intimate linkages between gases, such as CO_2 and CH_4, and their sources/sinks within the biosphere — whether oceanic or terrestrial — must be understood in order to fully assess the potential for greenhouse warming.

How Is The Atmosphere Changing?

The changing chemical composition of the atmosphere in recent years has been a dramatic signal of global change. The principal changes observed have been the reduction of stratospheric ozone by chlorofluorocarbons and the buildup of greenhouse gases in the lower atmosphere.

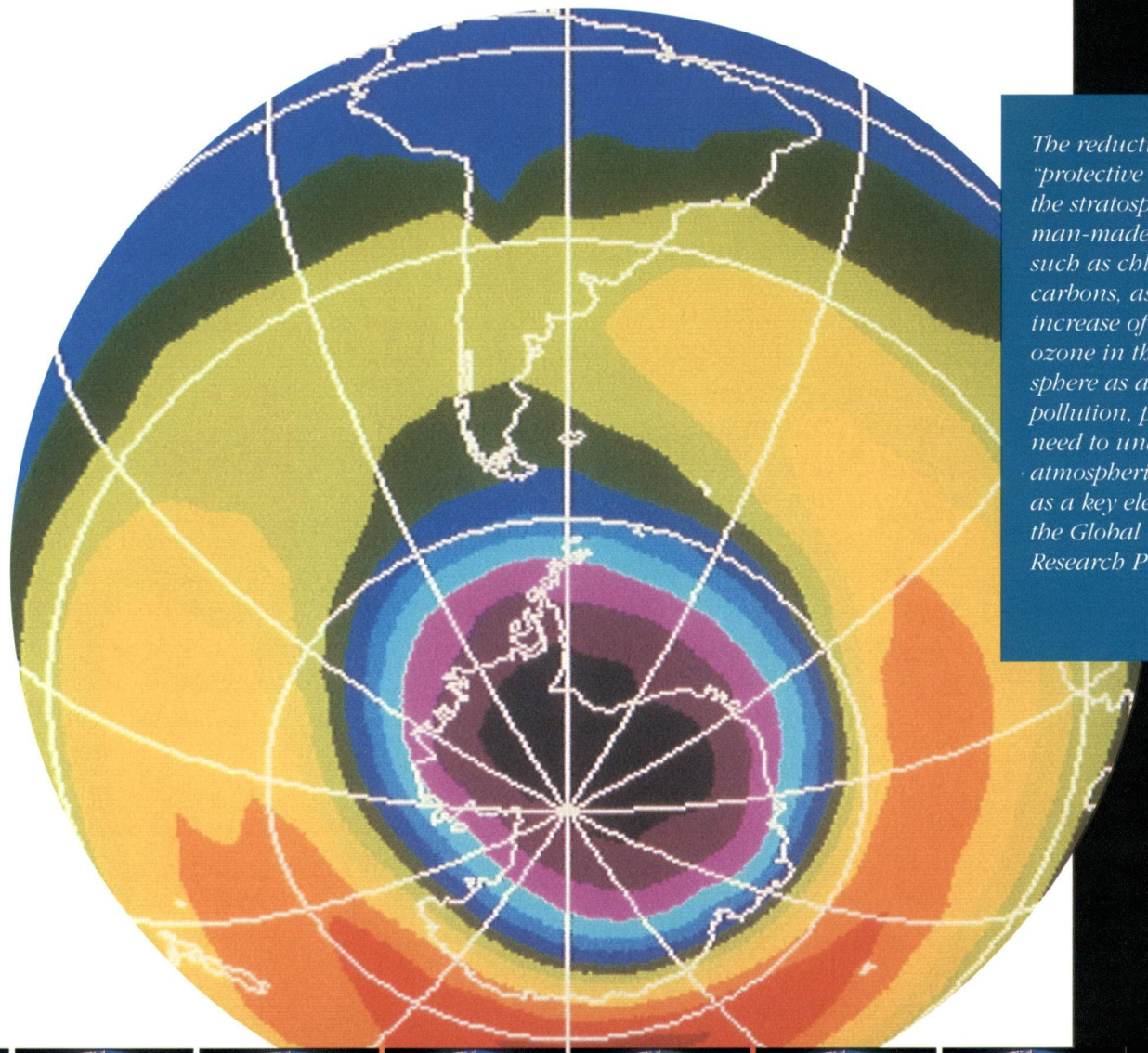
The chemistry of the atmosphere is central to understanding these critical environmental processes, and ozone is at the center of atmospheric chemistry. Ozone is a protective shield in the stratosphere and it is being depleted by reactions with chemicals, such as chlorofluorocarbons, which are released at the surface and transported to the stratosphere. In the troposphere, ozone is a pollutant gas from fossil fuel and biomass burning and from industrial activity. As global air quality degrades, the ability of the atmosphere to cleanse itself chemically is reduced. This in turn could enhance the greenhouse effect by increasing the accumulation of greenhouse gases.

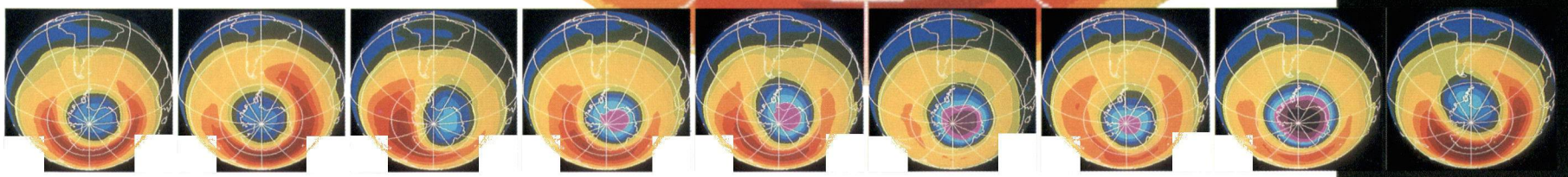
Monitoring ozone depletion in the stratosphere and increase in the troposphere are key requirements of a Global Change Research Program. Measurements of global ozone concentrations as a function of altitude are required along with measurements of the global distribution of the atmospheric chemicals, dynamic processes, and solar energy input that control ozone concentrations. Global-scale models that couple chemistry and dynamics must be used to put the observations into a coherent picture of the atmosphere that allows confident projections of ozone depletion and greenhouse gas buildup for realistic emission scenarios.

UARS will provide focused data on stratospheric chemistry and dynamics in the early 1990s. The Total Ozone Mapping Spectrometer (TOMS), flown as an Earth Probe, will provide data on total ozone to the mid- to late-1990s. After that time, instruments on EOS and NOAA satellites will continue to watch stratospheric ozone depletion and to provide direct global-scale measurements of ozone and greenhouse gases.

EOS includes with its payloads the instruments necessary to study the global processes which control the stratospheric ozone layer and to monitor changes in tropospheric gases. The 15-year life of EOS will allow measurement over a sufficiently large number of annual cycles, biennial oscillations, and ozone changes, to greatly improve our understanding of the ozone layer. It will have the capability to monitor the long- and intermediate-lived chemical components of the troposphere and their long-term changes. The EOS instruments will thus address the central problems of the relation of climate to changing atmospheric chemistry.

This time series of stratospheric ozone for the month of October begins in 1980 (far left) and ends in 1989 (the large image). The data, collected by the Nimbus-7 LIMS sensor, show the evolution of the "ozone hole" near Antarctica (increasing from purple-blue to green-red).





The reduction of "protective" ozone in the stratosphere via man-made chemicals such as chlorofluoro-carbons, as well as the increase of "harmful" ozone in the tropo-sphere as a result of pollution, point to the need to understand atmospheric chemistry as a key element of the Global Change Research Program.

What is the Role Of The Solid Earth?

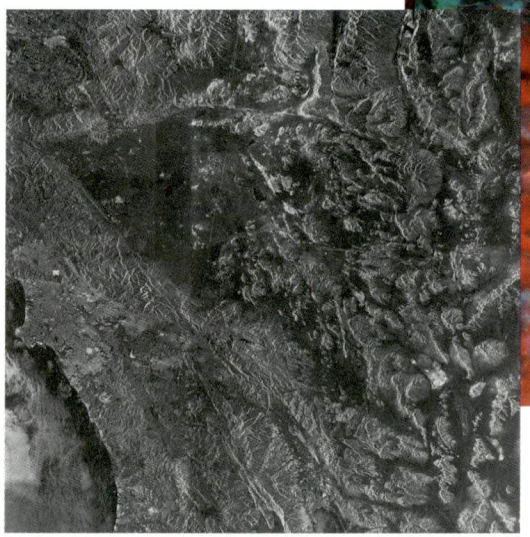
Geological and geophysical processes vitally affect life on Earth. The spectacular hazards of volcanic eruption, earthquakes, floods, and landslides are familiar to all who follow the world news. Volcanoes introduce chemicals and aerosols into the atmosphere. Crustal movement results in earthquakes, regional sea-level variations, and potential flood hazards. Changes in the massive amounts of ice now stored in glaciers and polar ice caps could lead to significant changes in sea level and oceanic circulation. Desertification and erosion of large tracts of land affect the global hydrologic cycle and Earth's productivity. The motion of material deep in the core and mantle causes subtle changes in Earth's rotation and length-of-day in ways that are not yet well understood.

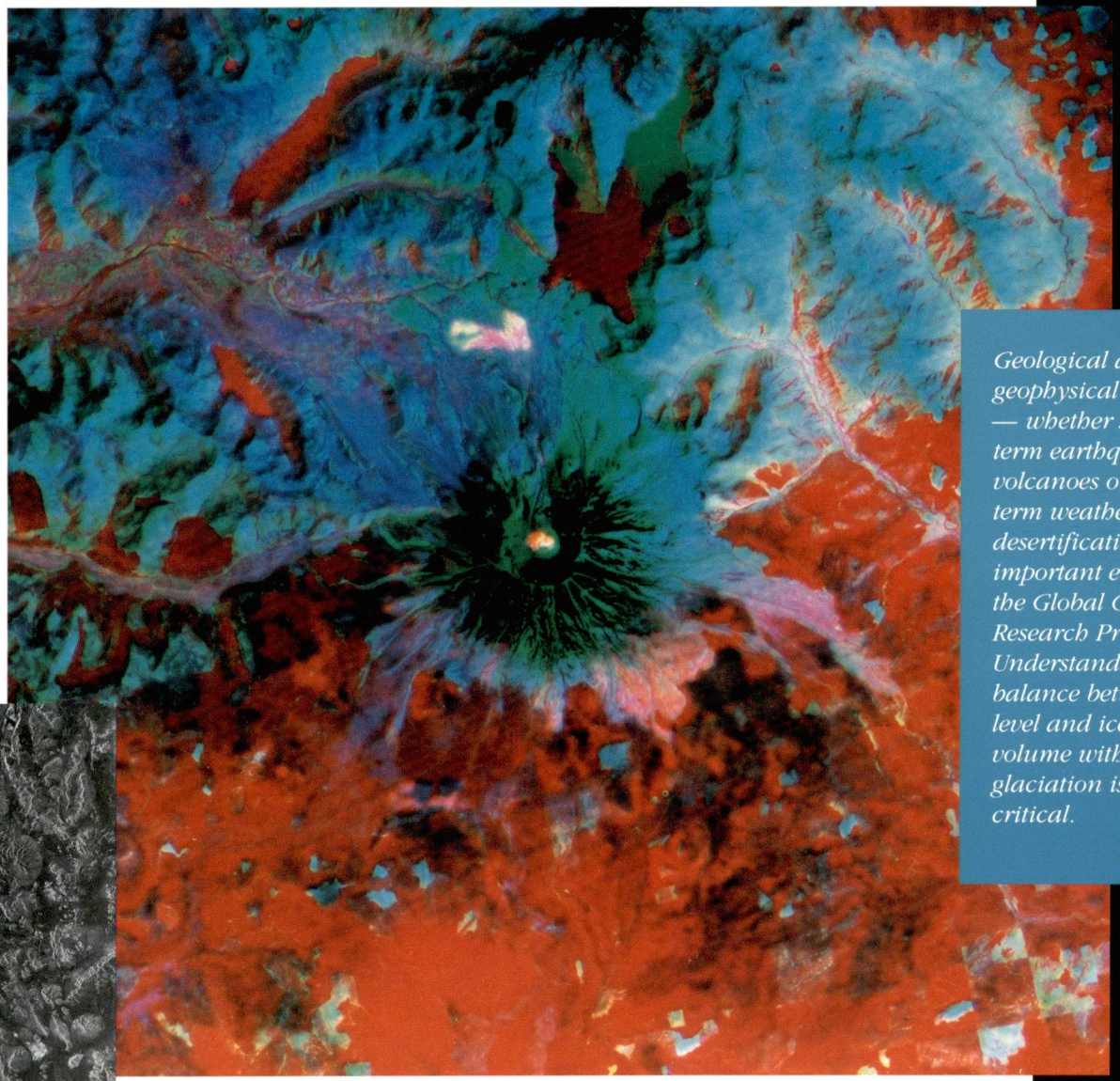
Understanding these processes requires a diversity of observations. We need to monitor the gaseous effusion and thermal productivity of volcanoes to gauge atmospheric effects and to assess the likelihood of eruption and potential of resultant hazards. EOS atmospheric and land-surface sensors will be used to characterize the composition and nature of volcanoes. Altimeters and positioning systems will be used to detect expansion of probable hazardous volcanoes.

We need to monitor the mechanisms of plate motion over long periods and during short, drastic events. Densely spaced, high resolution geodetic measurement on a frequent basis is the most likely technique to achieve timely earthquake prediction. High resolution geodetic observation and altimetry are also the keys to understanding regional uplift, subsidence, and associated hazards in coastal areas, as well as change in the shape and volume of polar ice caps. Changes in the Earth's rotation and length-of-day are best monitored using high resolution geodetic techniques, while the deep-seated processes in the Earth which cause these changes are best understood by study of the Earth's magnetic field. We must be able to detect areas of current or potential desertification and erosion, which requires large-scale observation and detailed characterization, and the ability to continually update the observations.

EOS will provide the sensors required to document and understand the interactions between geological and geophysical processes and other components of the Earth system. The diversity of simultaneous observations which will be possible from the EOS platforms will allow timely responses to situations which would not have been possible with earlier techniques. The remote sensing aspects minimize risk of human life in documenting extreme events.

Mineralogical and thermal features in the vicinity of Mt. St. Helens based on data from Landsat Thematic Mapper in July 1984, four years after its last eruption; note the "hot spot" in the crater, as well as on the flank of the volcano. The black and white image (315 km square) from Seasat's synthetic aperture radar in 1978 shows surface features in Southern California, including the area where the San Andreas and Garlock Fault Zones converge.





Geological and geophysical processes — whether shorter term earthquakes and volcanoes or longer term weathering and desertification — are important elements in the Global Change Research Program. Understanding the balance between sea level and ice-sheet volume with changing glaciation is also critical.

Gathering Comprehensive Global Observations

A new start is proposed for EOS in NASA's FY 1991 budget submission to Congress, with development to be initiated in October 1990. NASA began conceptual studies for EOS in 1982; coordination with the European Space Agency (ESA), Japan, and Canada was initiated in 1986. Present plans call for two series of polar-orbiting platforms: EOS-A and EOS-B. The 15-year observational period will be achieved using three identical satellites per series, each with a five-year design lifetime.

ESA is planning two series of polar platforms with a climatological and terrestrial focus, respectively, and Japan is planning one polar platform. Both NASA and NOAA sensors are planned for inclusion on these platforms. Additionally, NASA is planning to provide sensors as attached payloads for the Space Station.

A group of 41 sensors from the U.S., Canada, Japan, and Europe has been selected as candidates for flight on EOS. The EOS-A series is tentatively planned to focus on atmospheric sounding and surface imaging; selection of specific sensors will be in October 1990. The EOS-B series is planned to include sensors capable of extending observations made by the UARS and TOPEX/Poseidon missions; sensor selection for EOS-B will occur one year later.

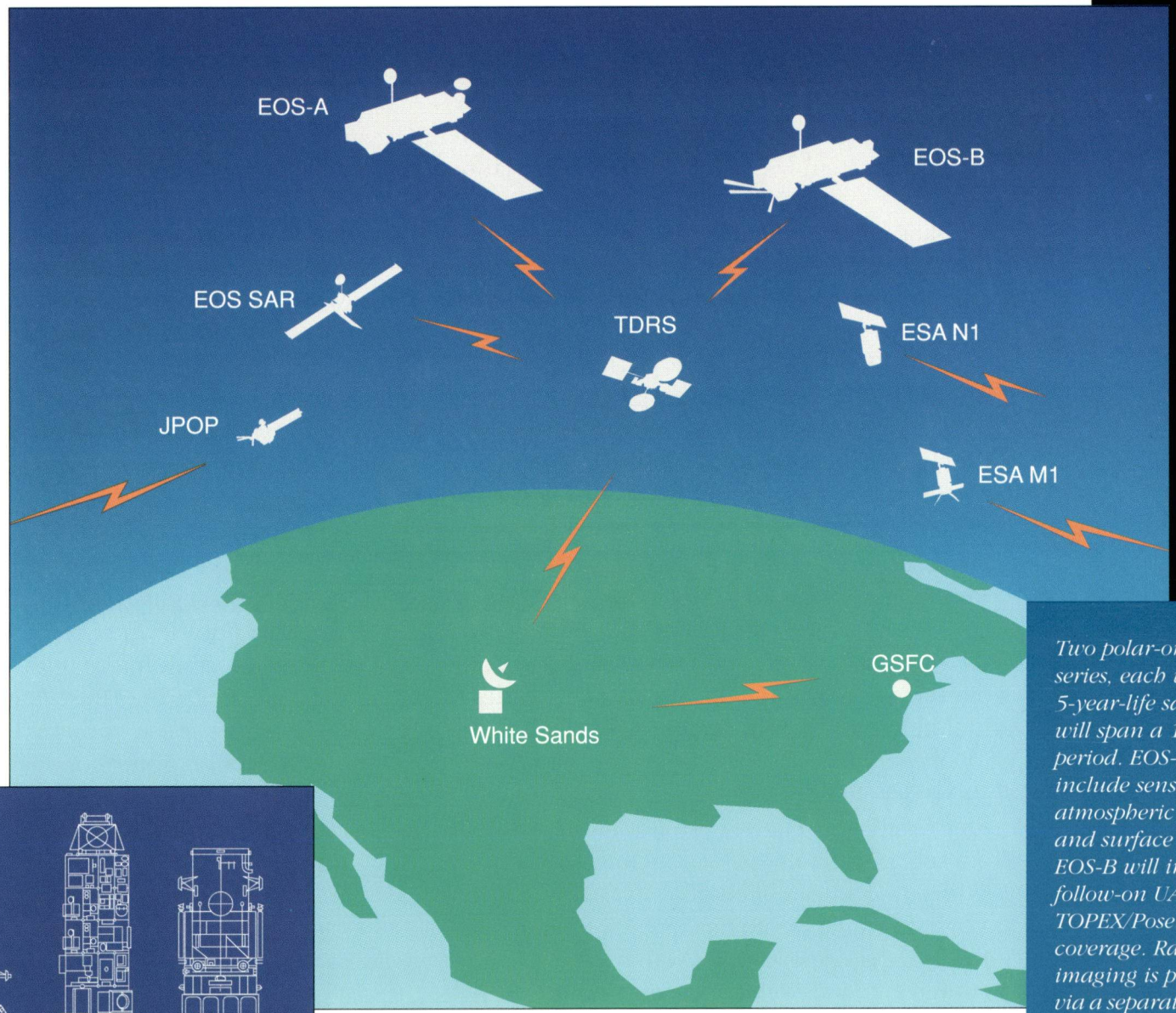
Platform size for EOS has been chosen to accommodate atmospheric sounding and surface imaging sensors, a grouping which maximizes the synergistic use of coincident observations, as well as minimizes atmospheric induced uncertainties. The satellites will be launched into polar orbit from Vandenberg Air Force Base on Titan-IV rockets.

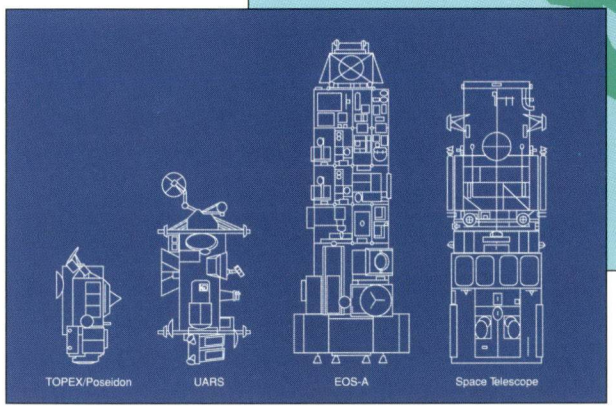
An EOS platform will accommodate a payload up to 3500 kilograms and can supply up to 3.2 kilowatts of power to the payload. This platform is twice the size of UARS and can supply about four times the power; it will accommodate two to four instruments more than the 10 aboard UARS. Because of the wider spectral range of the instruments, its data system will manage more than 10,000 times the data of UARS.

The need for global coverage every one to three days dictates a sun-synchronous orbit with a quasi-two-day repeat; a 705-kilometer altitude, 98.2-degree inclination orbit meets this need. It will have a 1:30 p.m. local equatorial-crossing time.

The Synthetic Aperture Radar (SAR), not able to be efficiently accommodated on the EOS series of platforms, is planned for flight on a dedicated satellite in 1999. Its orbit will have a 620-kilometer altitude and similar equatorial-crossing time; this will provide frequent opportunities for coincident observation of the same locations as sensors on EOS platforms.

NASA's Mission to Planet Earth includes the EOS-A and -B series of polar platforms, a separate EOS SAR mission, and the TDRS communication link; not shown are the Space Station attached payloads and Earth Probes; related foreign polar platforms include the ESA M-1 and N-1 series, as well as the Japanese JPOP. The smaller image shows a comparison of launch-configuration sizes with EOS-A at a 14.8-meter height.





Two polar-orbiting series, each with three 5-year-life satellites, will span a 15-year period. EOS-A will include sensors for atmospheric sounding and surface imaging; EOS-B will include follow-on UARS and TOPEX/Poseidon coverage. Radar imaging is planned via a separate EOS SAR.

Providing Easy Access To Data

The EOS Program has put a major emphasis on the Data and Information System (EOSDIS). EOSDIS is planned to acquire a comprehensive, global, 15-year data set; to maximize the utility of this data set for scientific purposes; and to facilitate its easy access by the research community. In addition to data processing, archival, and distribution facilities, EOSDIS includes the necessary capabilities for command and control of the spacecraft.

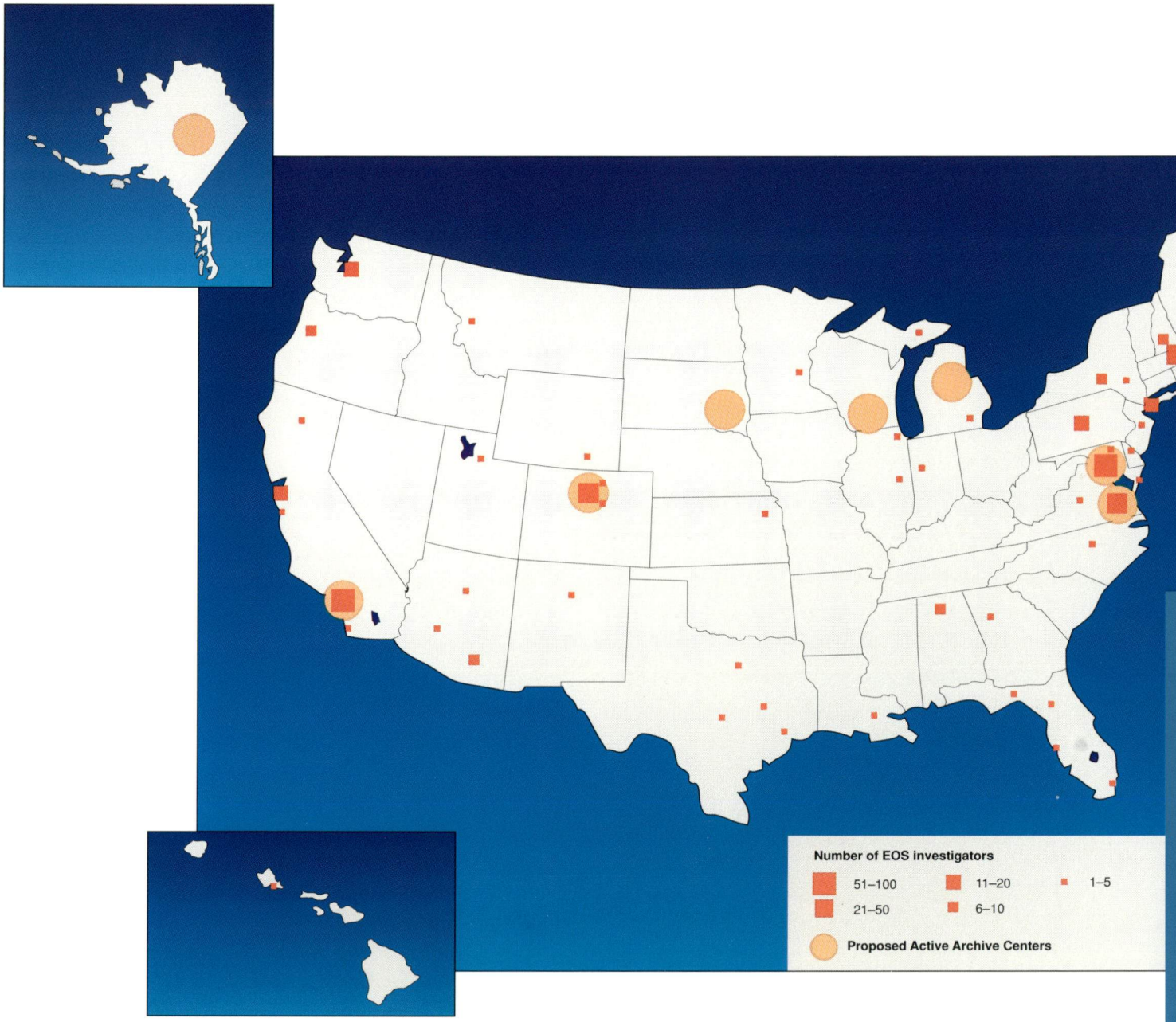
The development of EOSDIS will be initiated immediately by building on the existing infrastructure within the research community. It will implement an architecture which is open and distributed, so that it can evolve with advances in computing and networking technology. The near-term objectives are to support the research and analysis of data which both exist and will come from the near-term pre-EOS missions. In this way, the research community can gain valuable early experience in preparation for the future large EOS data volume.

Archived data sets, in addition to those from the EOS satellites, will include complementary *in situ* and satellite data. EOSDIS will also involve the U.S. Geological Survey, National Oceanic and Atmospheric Administration, the National Science Foundation and other agencies.

There will be two types of data products: standard and specialized. Standard products will be generated and archived at Active Archive Centers; the target time for the availability of engineering-level products is within 48 hours of collection; the target for derived geophysical products is within 96 hours. Specialized products will be generated by individual investigators and made available to EOSDIS for archiving and distribution, as appropriate.

The EOSDIS policy specifies that all data and derived products be available to all users, with no preference given to EOS investigators. Research users in the U.S. and participating countries will pay only the nominal cost of data reproduction and delivery; they will be required to agree to publish their results and to make available supporting information, including methods for analyzing data. Research users in other countries may propose cooperative projects and associated "in kind" contributions (i.e., provide similar access to appropriate satellite, aircraft, and surface-based data) in exchange for access to EOS data on similar terms. Access to the raw data stream will be provided to operational agencies for forecasting purposes. NASA will provide for the commercial distribution of data on a non-discriminatory basis to all other users.

The distribution of the U.S. EOS investigators, shown along with proposed sites under consideration as EOSDIS Active Archive Centers (Goddard Space Flight Center, Jet Propulsion Laboratory, Langley Research Center, National Snow and Ice Data Center, National Center for Atmospheric Research, University of Alaska, University of Wisconsin, and Michigan Consortium for International Earth Science Information Network).



EOSDIS represents a concerted effort to make available to the research community a capability to access in a timely manner data from the EOS mission. EOSDIS will build on and evolve from the existing efforts in the community. All data will be available to all users.

Predicting Global Change

Our planet is experiencing profound environmental changes; the economic and social consequences of global change have received attention at the highest governmental levels. To document, understand, and predict global change is a major scientific challenge; but up to now we have lacked the ability to provide the necessary comprehensive information for key policy decisions. Modern technology and new insights offer hope for early warning of change and accurate predictions of future change, and thus major societal benefits.

Mission to Planet Earth, building on precursor research missions and encompassing the proposed Earth Probes and the Earth Observing System, is a major NASA contribution to the U.S. Global Change Research Program. It will provide the necessary comprehensive global observations of Earth which will reveal how the processes that govern global change interact as part of the Earth System. This understanding is critical to the development of models for predicting future environmental change. With a continuing, comprehensive data set from EOS, it will be possible to update and enhance the models so that they can provide the vital information needed about environmental change on local, regional, and global scales.

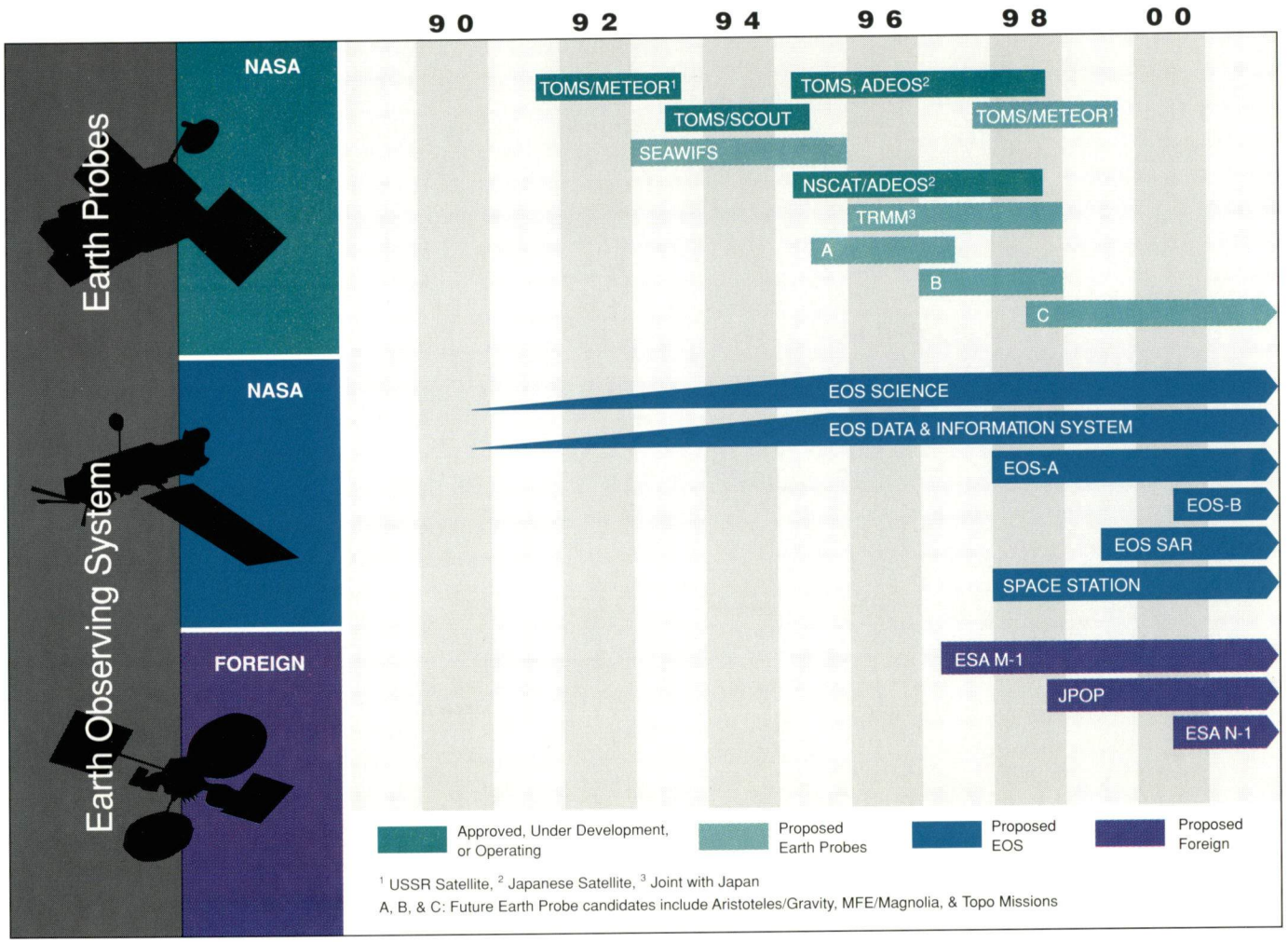
Our nation must take the lead in providing sustained observations of the Earth. We have the scientific and technical capability; our national aspirations and spirit demand that we rise to this challenge.

The total cost of EOS is estimated to be 17 billion dollars through the year 2000. The cost of EOS platforms and payloads is commensurate with other large observing programs, such as the four Great Observatories of NASA's Astrophysics Program.

Typically with flight programs, NASA has allocated about 70 percent of the funding for spacecraft hardware and 30 percent for ground-based activities. For EOS, in recognition of the large data volume and the need for a comprehensive science program, NASA will allocate 40 percent for spacecraft hardware and 60 percent for ground-based activities, including EOSDIS and science.

Although the cost of such an observing and data system is large, it is small compared to that of taking no action or acting on incomplete information. Considering the consequences of global change for humankind, we cannot afford to do less. Mission to Planet Earth will enable us to observe, understand, and predict change on Planet Earth.

This table shows the distribution of the proposed Earth Probes, EOS, and related foreign missions. Near-term activities include the initiation of the EOS science and Data and Information System activities.



Given the long-term, comprehensive data set from EOS, as well as complementary in situ observations, it should be possible to document global change, understand relevant processes, and build improved models. The ultimate goal is the development of realistic predictive models.

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Credits: *Front Cover:* (left to right) Chet Koblinsky, NASA Goddard Space Flight Center (GSFC); Otis Brown, University of Miami; Gene Feldman & Compton Tucker, GSFC; William Rossow, NASA Goddard Institute for Space Studies (GISS); Arlin Krueger, GSFC; Standard projection plotting by Gene Feldman, GSFC. *Inside Front & Back Cover:* All photographs © Payson R. Stevens. *Page 2:* Gene Feldman & Compton Tucker, GSFC. *Pages 4 & 6:* InterNetwork, Inc. *Page 8:* (top) Chet Koblinsky, GSFC; (bottom) James Russell, Langley Research Center (LaRC) and John Gille, National Center for Atmospheric Research. *Page 10:* (top) NOAA/NESDIS; (bottom) Defense Meteorological Satellite Program, NOAA/NESDIS, & University of Colorado/CIRES. *Page 12:* (top) Donald Cavalieri & Gene Feldman, GSFC; (bottom) Mark Schoeberl, GSFC. *Page 14:* (top) Peter Woiceshyn, Jet Propulsion Laboratory (JPL), Morton Wuretle, University of California Los Angeles, & Steven Peteherych, Atmospheric Environment Service of Canada; (bottom) William Rossow, GISS & NOAA/CAC. *Page 17:* InterNetwork, Inc. *Page 19:* ERBE Research Team, LaRC. *Page 21:* (top) Moustafa Chahine, JPL, & Joel Susskind, GSFC; (bottom) Byron Tapley, University of Texas at Austin & Steve Nehrem, GSFC. Page 23: (top) William Rossow, GISS & WCRP/ISCCP; (bottom) Dorothy Hall & Donald Cavalieri, GSFC. *Page 25:* (Africa) Compton Tucker, GSFC; (Atlantic) Gene Feldman, GSFC. *Page 27:* Mark Schoeberl, GSFC. *Page 29:* (top) Locke Stuart, GSFC; (bottom) John Curlander, JPL. *Pages 31, 33, & 35:* InterNetwork, Inc. *Back Cover:* NASA.

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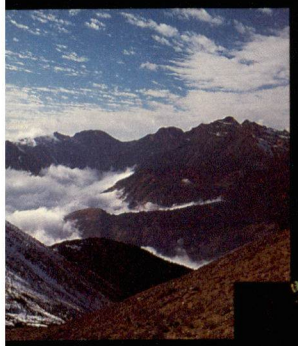
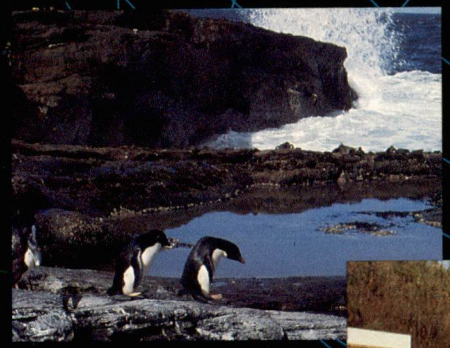




For further information and additional copies, write:

EOS Program Office
NASA Headquarters (Code EE)
Washington, D.C. 20546

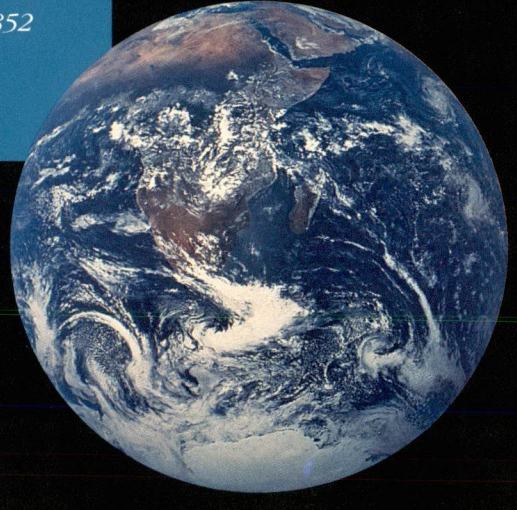
Global change poses monumental policy issues, with enormous economic and social consequences. The development of realistic predictive models requires data and insight that EOS and Earth Probes will provide. We cannot afford to do less, especially considering what is at stake.

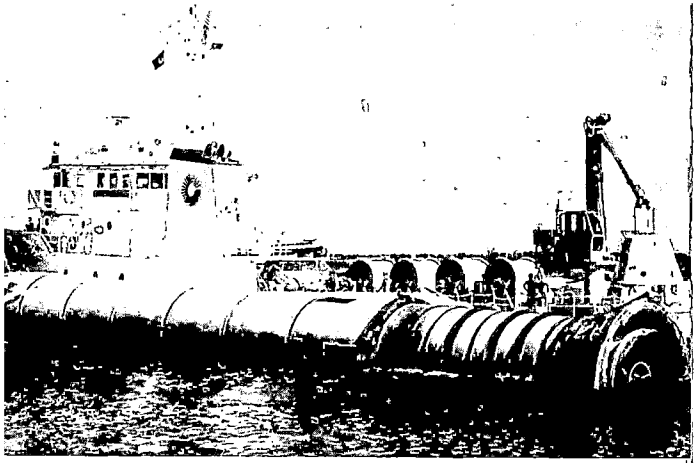
NASA

National Aeronautics and
Space Administration

"This we know: the Earth does not belong to man, man belongs to the Earth. All things are connected like the blood that unites us all. Man did not weave the web of life, he is merely a strand in it. Whatever he does to the web, he does to himself."

Chief Seattle, 1852





Solid Rocket Boosters

Prior to launch, the entire weight of the Space Shuttle is supported on the launch pad by two solid rocket boosters. Each booster is attached to the pad by four large bolts.

The heart of each booster is the motor, the largest solid rocket ever to be flown and the first designed for reuse. It is made of four factory prepared segments filled with propellant at the manufacturer's facility and assembled at the launch site. The segmented design permits ease of fabrication, transportation and handling.

The motor segments are loaded in pairs from one batch of propellant ingredients to minimize any thrust imbalances between boosters used for a single Shuttle flight. Propellant loading is also done in such a manner as to cause a reduction in thrust 55 seconds into the Shuttle flight to prevent overstressing the Shuttle vehicle during its critical phase of flight, the period of maximum dynamic pressure. Each booster develops approximately 11.8 million Newtons (2.65 million pounds) of thrust.

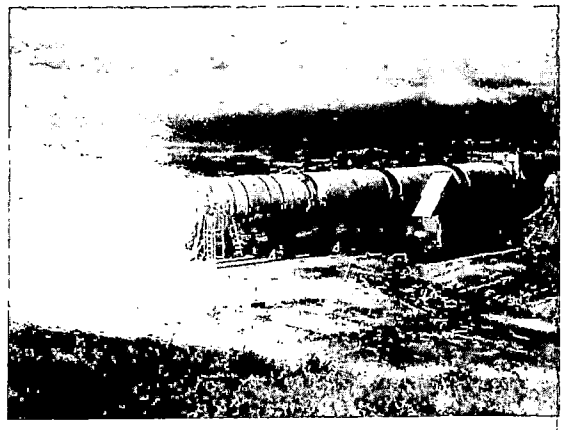
The exhaust nozzle in the aft segment of each motor, in conjunction with the orbiter main engines, steers the Shuttle during flight. It can be moved up to eight degrees by the booster thrust vector control system which is controlled by the orbiter guidance and control computer.

At burnout the two solid rocket boosters are separated from the external tank by pyrotechnic

(explosive) devices and moved away from the Shuttle vehicle by eight separation motors — four housed in the forward compartment and four mounted on the aft skirt. The separation motors are fired by a command from the orbiter.

The recovery system, in the forward section of the booster, consists of parachutes and a homing device. Following separation — at about 5.8 kilometers (19,000 feet) — the booster is slowed by a drogue parachute and finally by three main parachutes to impact water at a speed of about 25 meters/second (85 feet/sec), aft end first. By entering the water this way, the air in the empty booster is trapped and compressed, causing the booster to float with the forward end out of the water. After divers insert a nozzle closure and force the water from the booster using air pumps, the booster is towed to shore.

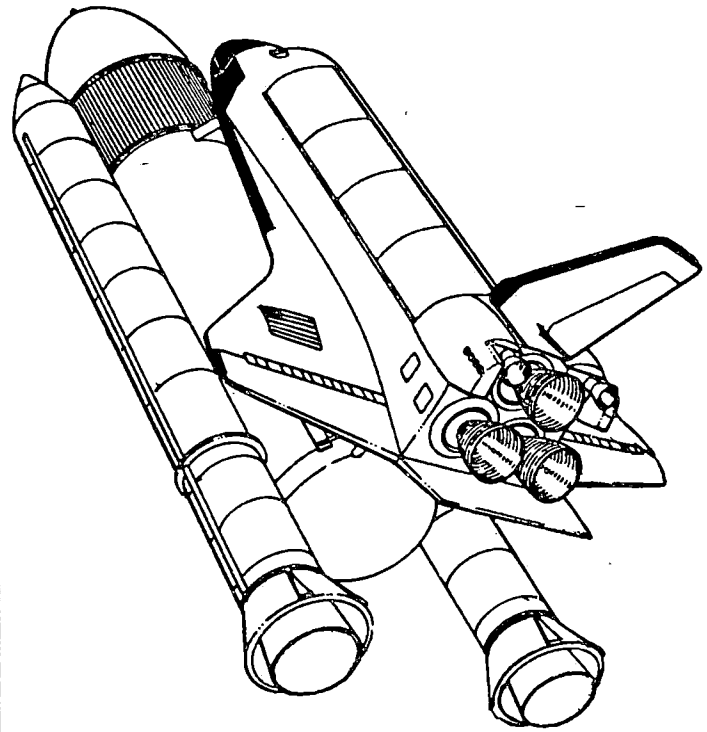
After recovery, the booster is disassembled and refurbished. The motor segments are shipped to the manufacturer for reload for another Shuttle flight. The other systems are refurbished either at the launch site or at the respective manufacturers' locations.



Solid Rocket Motor Test in Utah

MCX-009

Shuttle Propulsion System



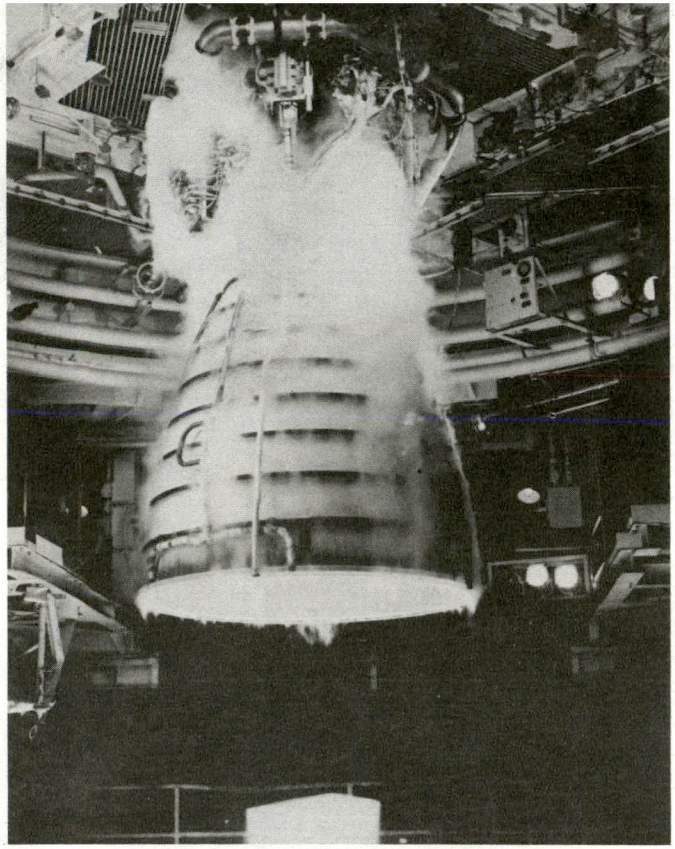
NASA
National Aeronautics and Space Administration

Marshall Space Flight Center
Huntsville, Alabama 35812

NASA's Space Shuttle opened a new era of space transportation when it was launched for the first time in 1981. Essentially a reusable space vehicle, the Shuttle permits greater participation in space by the world-wide scientific community than ever before.

The Shuttle is composed of an orbiter — a winged spacecraft — and a propulsion system. The Shuttle propulsion system, consisting of three main engines, an external tank, and two solid rocket boosters, is one of the most advanced propulsion systems currently in existence. The external tank is theonly major component that is used once.

The two solid rocket boosters and three main engines mounted on the orbiter provide the initial ascent thrust to lift the Shuttle and its payload off the launch pad. During a normal mission, the boosters provide thrust for approximately 2 minutes after lift-off, then are separated from the vehicle. The engines provide thrust for a total of 8 minutes after lift-off. The Marshall Space Flight Center in Huntsville, Ala., is responsible for management of the Shuttle propulsion elements.



Shuttle Main Engine Test

Space Shuttle Main Engines

The Space Shuttle main engine is the most advanced liquid-fueled rocket engine ever built. Its main features are variable thrust, high performance, reusability, total redundancy, and a fully integrated controller. The performance of the engine is the highest thrust for its weight of any engine yet developed.

Three main engines are mounted on the orbiter aft fuselage in a triangular pattern. The engines are spaced so that they are moveable during flight and, in conjunction with the two solid rocket boosters, are used to steer the Shuttle vehicle during flights as well as provide thrust for launch.

Fuel for the engines, liquid hydrogen and liquid oxygen, is contained in the external tank, the largest element of the Shuttle. Fuel is supplied from the tank at a rate of about 178,000 liters (47,000 gallons) per minute of hydrogen and 64,000 liters (17,000 gallons) per minute of oxygen.

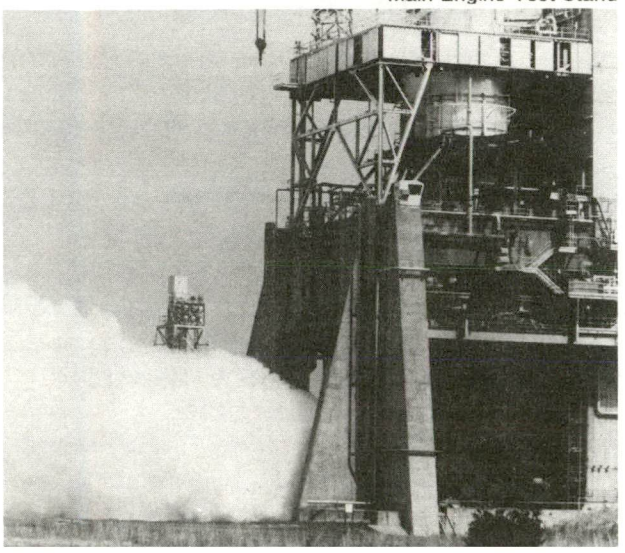
The main engines use a staged combustion cycle in which all propellants entering the engines are used to produce thrust more efficiently than any rocket engine developed previously. In the staged combustion cycle, propellants are burned partially at high pressure and relatively low temperature, and then burned completely at high temperature and high pressure in the main combustion chamber. The rapid mixing of the propellants under these conditions is so complete that a combustion efficiency of about 99 percent is attainable.

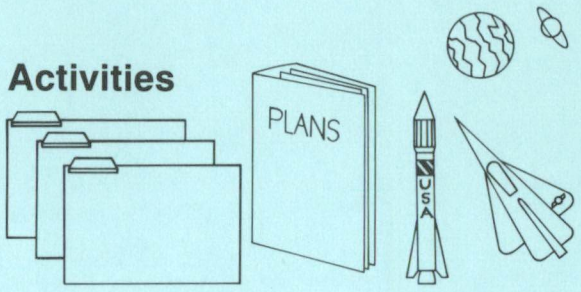
Each engine has three primary levels of thrust or power —minimum, rated and full power. Engine thrust, however, can be varied throughout the range from minimum to full power level depending on mission needs. Shuttle payloads will be sized to be compatible with launch-to-orbit at a maximum of 104 percent of rated power level, with each engine developing 2,174,286 Newtons (488,000 pounds) of thrust, 1,734,803 Newtons (390,000 pounds) at sea level. Full power level (109 percent of rated power) will be available for use in emergency situations. During the latter part of ascent, engine thrust will be reduced to insure that an acceleration force of no more than three times that of Earth's gravity is reached. This acceleration level, permitted by the throttleable Shuttle engines, is about one-third the acceleration experienced on previous manned space flights and is well under the physical stress limits of non-astronaut scientists who fly aboard the Shuttle. The lowest thrust throttle setting — minimum power level — equals 65 percent of rated power.

The Shuttle main engine is the first rocket engine to use a built-in electronic digital controller. The controller will accept commands from the orbiter for engine start, shutdown and change in throttle setting, and also will monitor engine operation. In the event of a failure, the controller takes action automatically to correct the problem or shutdown the engine safely.

Shuttle main engines are thoroughly inspected and tested between flights to assure acceptable operation during subsequent flights. The design goal is to operate for 7.5 accumulated hours.

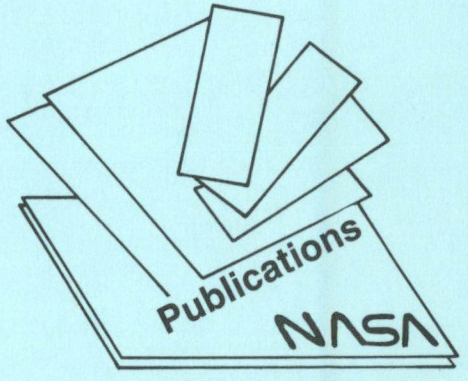
Main Engine Test Stand





Free Handout Materials

Classroom activities suitable for grades K–12 are available for preview in the TRC. A limit of one handout per activity is available free to each educator.



NASA Literature and Educational Publications

A large assortment of informational publications and lithographs (upon availability) is free to educators visiting the TRC.

Preview Site for CORE

Preview the slide/audio programs, filmstrips, and videotape programs available by mail order through CORE.

Central Operation of Resources for Educators (CORE)

CORE was designed for the national and international distribution of aerospace educational materials to enhance the NASA Teacher Resource Center Network. CORE provides educators with another source for NASA educational audiovisual materials. CORE will process teacher requests by mail for a minimal fee. On school letterhead, educators can write for a free catalog and order form to

NASA CORE
Lorain County JVS
15181 *Route* 58 *South*
Oberlin, Ohio 44074

Phone: (216) 774–1051 *Ext.* 293 *or* 294

Regional Teacher Resource Centers (RTRC's)

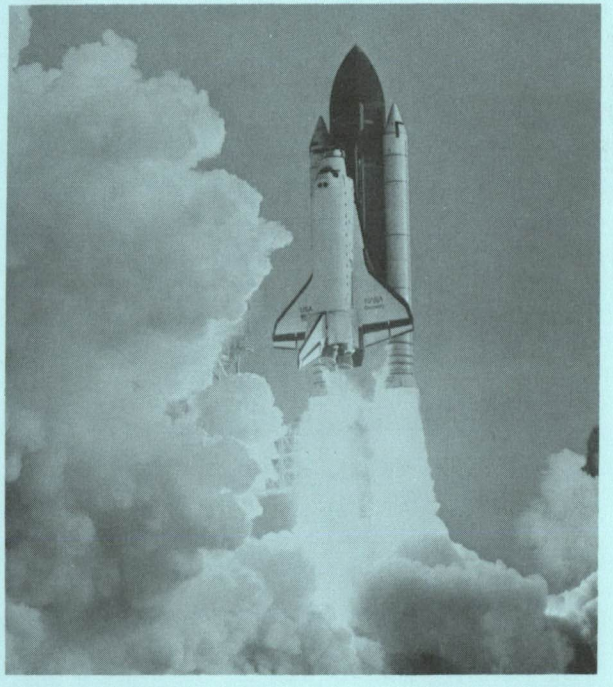
To expand the outreach of the NASA Teacher Resource Center Network, NASA forms partnerships with universities and museums to serve as RTRC's, and plans to have an RTRC in each state. At the RTRC, teachers preview and make copies of NASA materials, or request audiovisual materials from CORE.

B–0198
Mar 89

Teacher Resource Center

at the Lewis

VISITOR CENTER



NASA

National Aeronautics and Space Administration

Lewis Research Center
Cleveland, Ohio 44135

Teachers need immediate access to information generated by NASA programs, technologies, and discoveries so that students can learn how NASA's aerospace efforts and contributions are benefiting humankind.

As a service to educators, the Teacher Resource Center Network has been established to help disseminate aerospace materials that can be easily incorporated into the classroom at all grade levels but that are generally not included in current textbooks. The network comprises Teacher Resource Centers (TRC's), Regional Teacher Resource Centers (RTRC's), and the Central Operation of Resources for Educators (CORE).

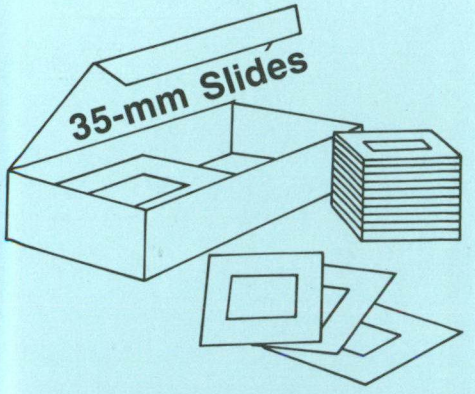
Teacher Resource Centers (TRC's)

Classroom teachers and other educators in the six-state area that the ***NASA LEWIS RESEARCH CENTER*** serves (Ohio, Indiana, Illinois, Minnesota, Wisconsin, and Michigan) can avail themselves of various resources by ***MAKING AN APPOINTMENT*** to visit the ***TEACHER RESOURCE CENTER***.

Teacher Resource Center
Mail Stop 8-1
NASA Lewis Research Center
21000 *Brookpark Road*
Cleveland, Ohio 44135

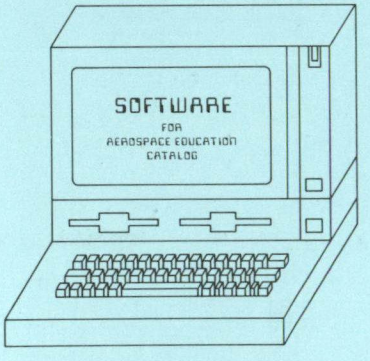
Phone: (216) 433-2016 *or* 2017

As a special service to educators who visit the ***NASA LEWIS TEACHER RESOURCE CENTER*** on an ***APPOINTMENT BASIS***, the following services will be offered:



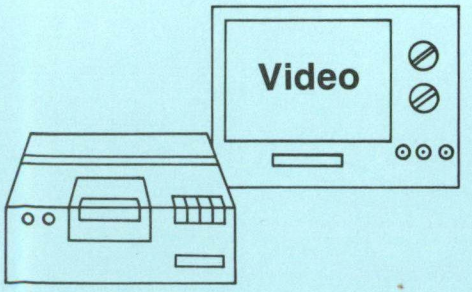
35-mm Slide Duplication

The TRC maintains a slide file on aerospace topics. More than 4000 slides are on file for viewing and duplicating. The current price is $5.50 per 36 slides. The educator receives the processed and mounted slides and, if desired, descriptions for each selected view. A two-week processing time is required for completion of all slide orders. (Slides will be duplicated by TRC personnel.)



Apple IIE Software

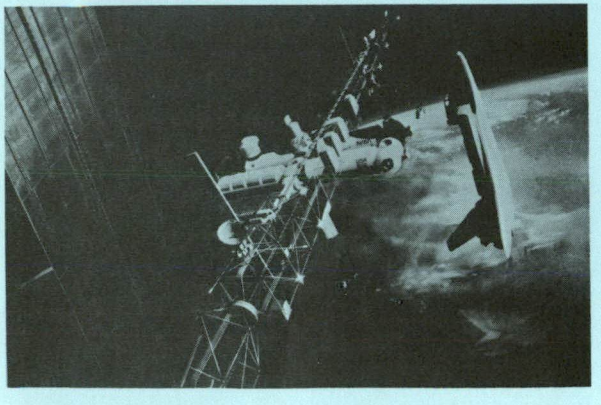
Educators can duplicate aerospace software programs designed for the Apple IIE. Educators must supply their own computer disks and will have access to an Apple IIE computer for previewing and duplicating disks.



Videotape NASA Programs

Educators can duplicate NASA programs onto their own blank cassette(s). Educators bring blank videocassette(s) to the TRC and duplicate NASA programs using one of the following formats. (The educator is responsible for duplicating—real time.)

FORMAT	SPEED	SIZE	LENGTH OF TAPE, hr
VHS	SP-MODE	T-120	2
BETA	BETA II	L-750	3
BETA	BETA II	L-500	1
3/4''	U-MATIC	60 min	1



SPACE
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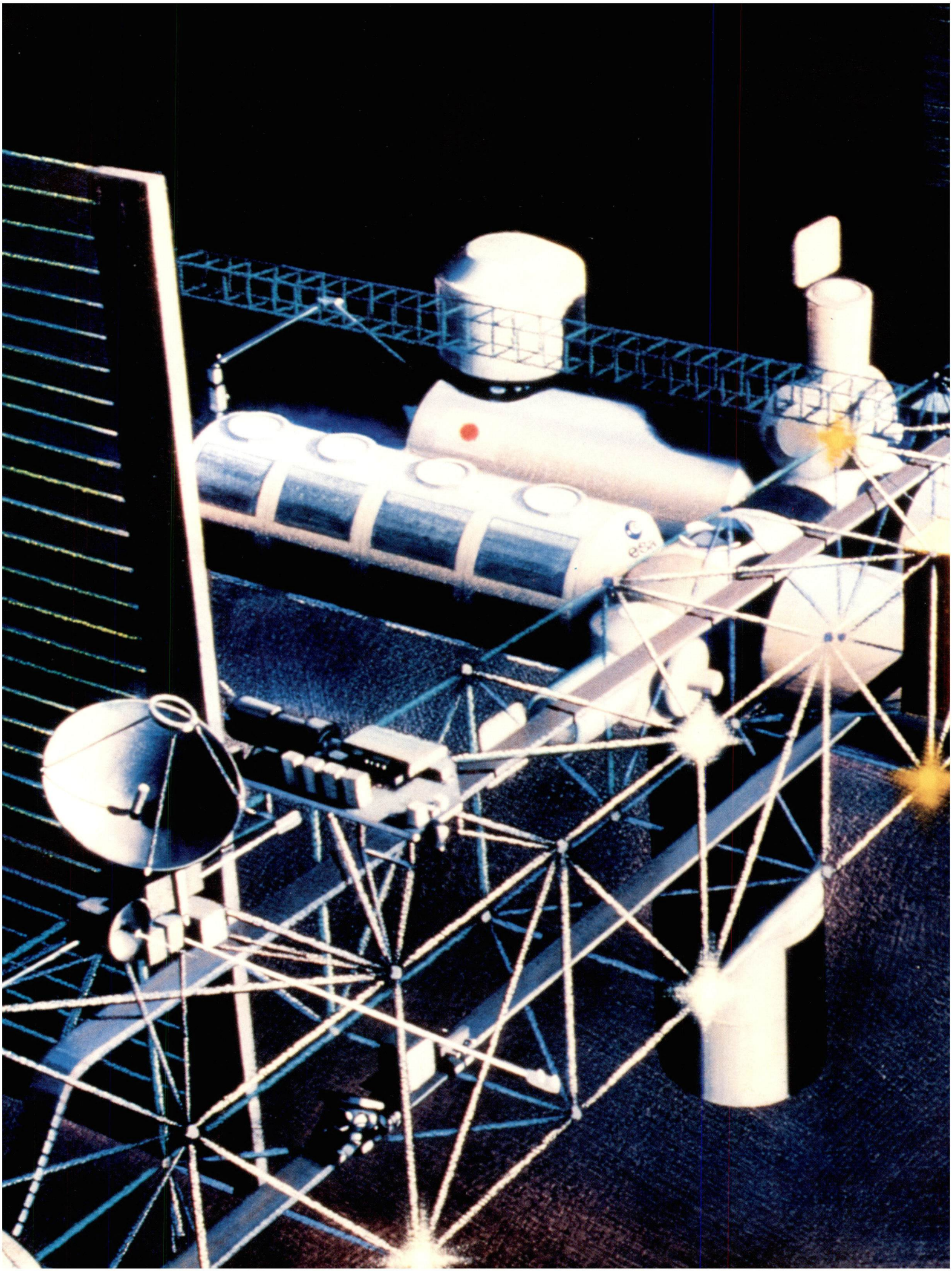
FREEDOM
A Foothold
on the Future
USA
NASA



SPACE STATION FREEDOM

A FOOTHOLD ON THE FUTURE

by Leonard David

for the

National Aeronautics and Space Administration

Office of Space Station

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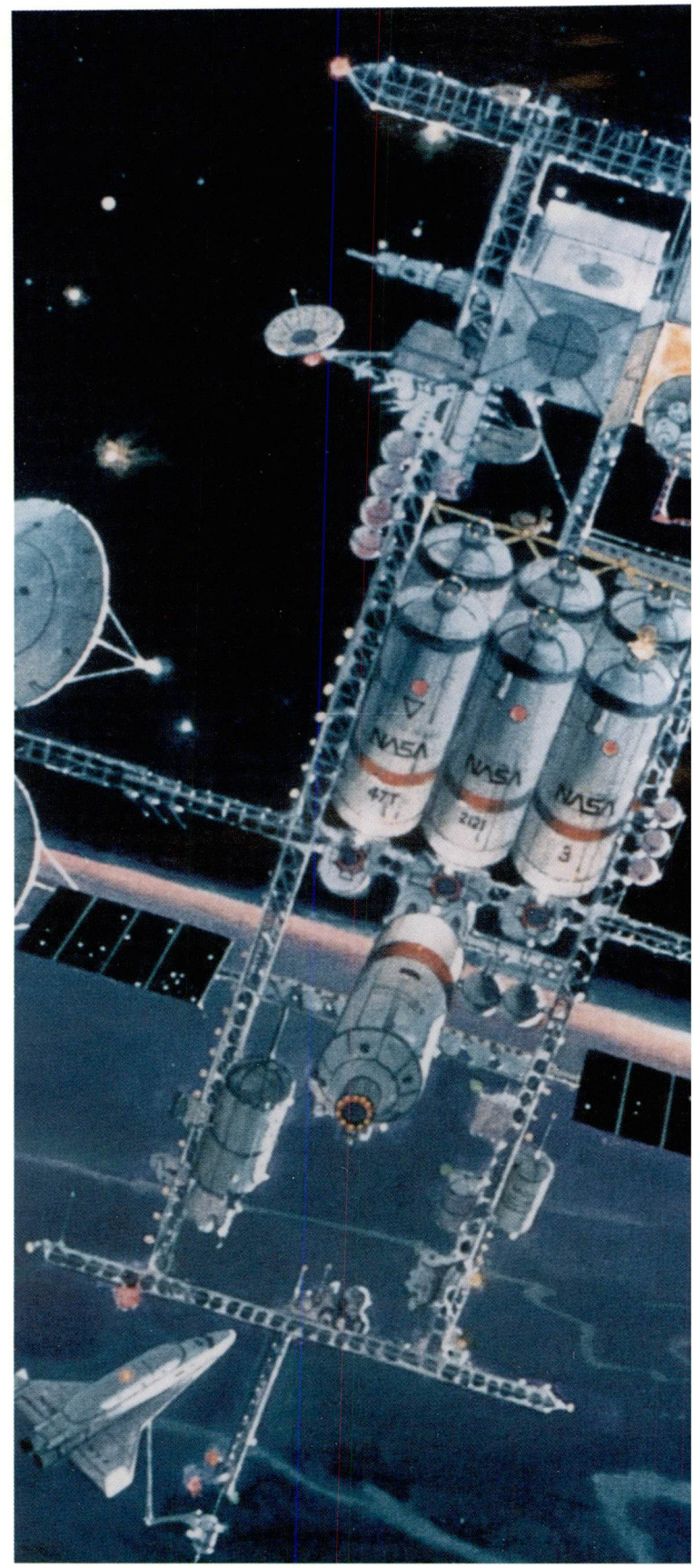
Freedom will be an international research center in space, and an orbital base for future missions to extend human presence out of Earth orbit and into the Solar System.

INTRODUCTION

Throughout the long sweep of history, the quest to push back frontiers on Earth has started with discovery and exploration, followed by settlement and economic development. Indeed this is how the length and breadth of our country was developed. In a sense, therefore, Space Station Freedom signals the early stage of our permanent settlement in low-earth orbit. Backed by over three decades of scientific data gleaned by space satellites and human space voyagers, this new international laboratory, anchored in Earth orbit and inhabited and tended by humans, will help us master and develop the space frontier.

The United States is not alone in its attempts to tame space. Many nations see a bright future in exploring and exploiting the space frontier for world prominence, national strength, and commercial profit. Japanese, German, and French industry-government teams are currently formulating space-based programs in microgravity research and other space services, including remote sensing of Earth. And since 1971 Soviet cosmonauts have been regularly departing to and from Earth to operate stations in space, achievements that lead many experts to expect bolder Soviet missions in the future, perhaps a mission to Mars.

During the early planning years, experts called a space station the next logical step for America's space program. Today, that space station, christened Freedom by President Reagan in 1988, is becoming part of America's foothold on the future. If America is to demonstrate



An artist's view of an evolutionary space station serving as a "Spaceport" in low Earth orbit.

(Copyright 1986, Bantam Books, Inc.)

UNITED STATES OF AMERICA
NASA

Conducting Science in Space

Once assembly of Freedom is complete, eight crew members — the commander, operators, payload specialists, and mission scientists from the United States and space-partner countries — will be on board. Floating free inside Freedom's pressurized modules or tethered outside to its truss, they will work as integrated teams in 9-hour shifts, 5 days a week.

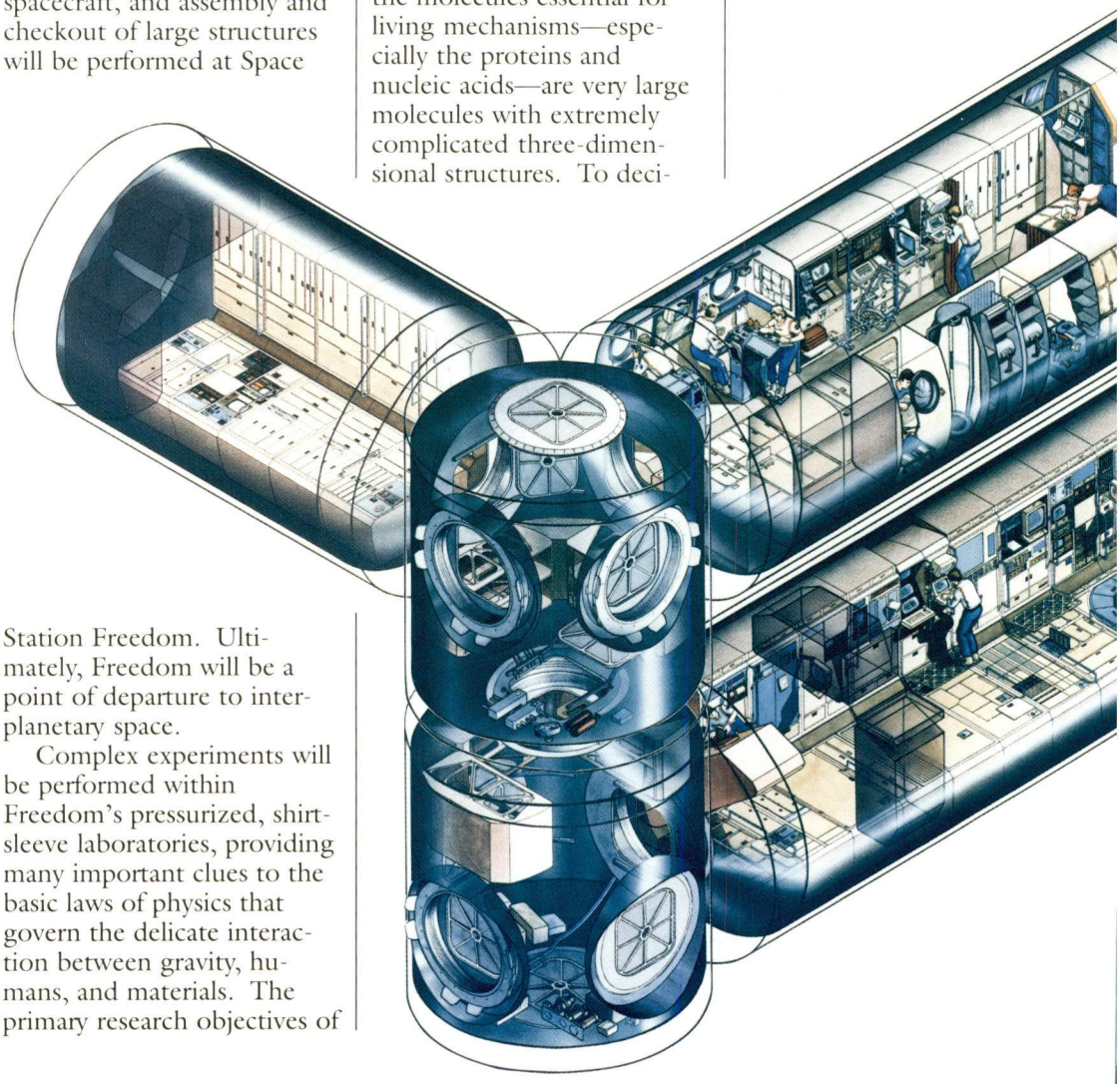
Outfitted with a diverse set of hardware and elaborate instrumentation, Freedom will be an upward-, downward-, and inward-looking international research base. It will be a site for conducting basic research in physics, chemistry, and life sciences, for processing materials, for monitoring Earth's fragile environment, and for developing new technologies. Servicing of attached instruments and reusable spacecraft, and assembly and checkout of large structures will be performed at Space Station Freedom. Ultimately, Freedom will be a point of departure to interplanetary space.

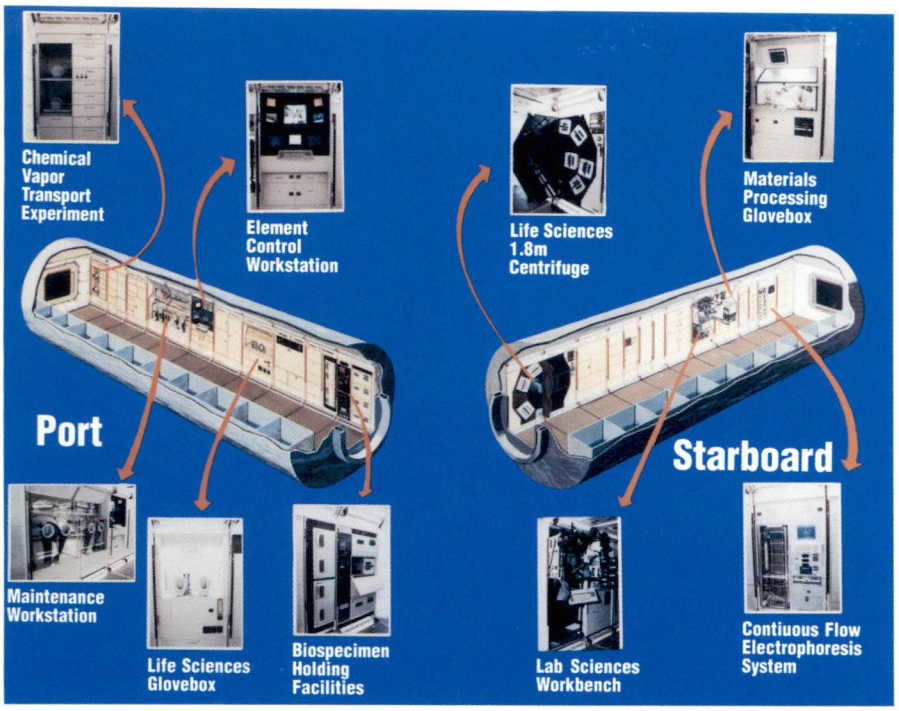
Complex experiments will be performed within Freedom's pressurized, shirtsleeve laboratories, providing many important clues to the basic laws of physics that govern the delicate interaction between gravity, humans, and materials. The primary research objectives of the permanently manned facility are advances in materials science and life sciences. These are the scientific areas that can most benefit from Freedom's extensive capabilities and from human supervision and interaction.

One important research activity to be conducted aboard Freedom will concentrate on the basic structure of protein molecules, the building blocks of life. Protein crystallography, a technique to be implemented using devices in the U.S. laboratory module, is a relatively new and exciting discipline that will be further stimulated by space-borne experiments. Crystallography is a powerful way to determine the three-dimensional structures of large molecules. Knowledge of structure provides a key to understanding the basic mechanisms of life. Many of the molecules essential for living mechanisms—especially the proteins and nucleic acids—are very large molecules with extremely complicated three-dimensional structures. To decipher these structures, crystallographers coax biological molecules to organize symetrically into crystals big enough to study. They bombard these molecular crystals with X-rays to create diffraction patterns, which computers analyze.

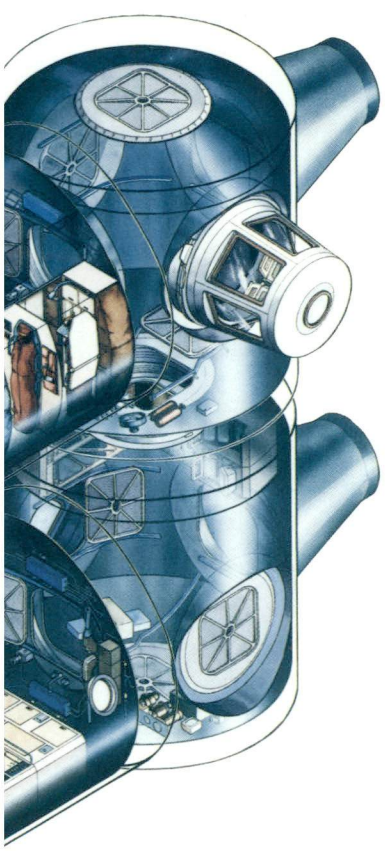
Growing protein crystals good enough to study is extremely difficult. Despite tremendous efforts, researchers have crystallized relatively few proteins successfully, and imperfections often mar the rare large crystals grown under normal circumstances. However, space experiments suggest that larger and more perfect crystals form in the absence of gravity.

Previous experiments have demonstrated the feasibility of growing large protein crystals in microgravity without the formation of multiple seeds, which produce numerous small crystallites that would





The U.S.-built laboratory module will house hardware designed to conduct materials and life sciences investigations. Equipment will be similar to devices found in well-equipped ground-based laboratories.



Configuration of U.S. modules shows the habitat module (top center); laboratory module (below habitat module); logistics module (far left) for storage and transport of supplies and experiments; and resource nodes which interconnect the modules and house command and control systems.

(Courtesy of Boeing Aerospace)

Protein crystals, like these...

may prove to be of major benefit to medical technology.

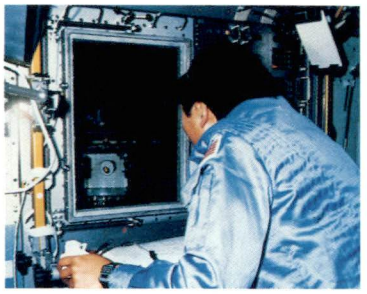
preclude study by X-ray diffraction techniques. Protein crystals grown aboard Freedom will be large enough, and of sufficient quality, to be studied by conventional crystallography. Once their three-dimensional molecular structure has been determined, these new products may be synthesized on Earth through bioengineering techniques, and steps can be taken to alter, enhance, or eliminate the protein effects in the human body. There are potential applications to the treatment of human diseases and disorders, and to organ transplants and implants.

Other fundamental areas of investigation to be explored within Freedom's laboratory module include properties of pure metals, segregation effects in alloy solidification, the microstructure of castings, nucleation and growth phenomena in the absence of container-wall effects, and the process of rapid solidification of highly undercooled melts. For example, the formation of dendrites—whisker-like growths similar to structures found in snowflakes—may be studied in detail. Dendritic growth is an important feature of solidification, with implications for the strength of castings. The high vacuum of space also may be utilized in metallurgical studies. In combination with containerless processing, a vacuum system offers unique opportunities to study metal purification and the basic properties of ultrapure or high corrosive materials.

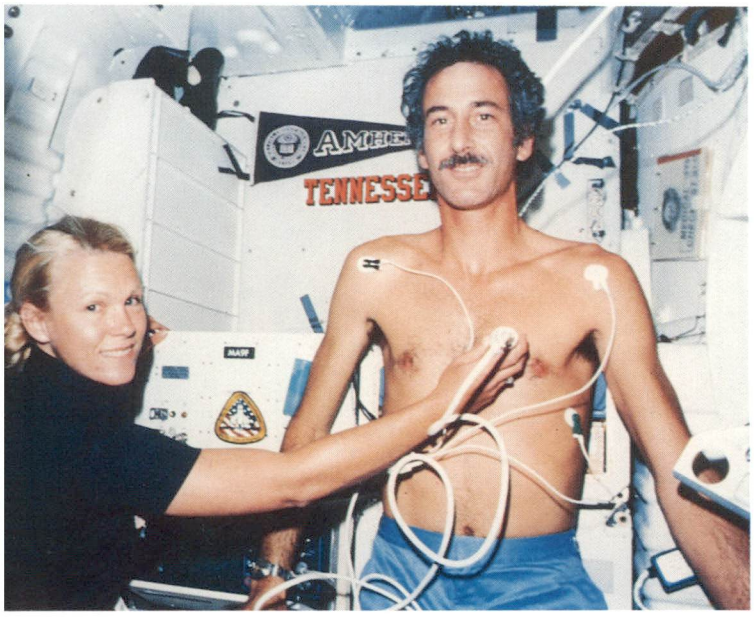
The understanding of room-temperature and cryogenic fluid behavior is a key to microgravity research generally, since nearly all materials are processed in their fluid state. Specific experiments performed aboard Freedom could examine processes and phenomena related to droplet and bubble dynamics, phase transitions, capil-

Ability to perform materials sciences investigations, similar to those performed here by Byron Lichtenberg on the Spacelab 1 mission, will be dramatically enhanced by Space Station Freedom.

Right: Spacelab 3 payload specialist Taylor Wang manipulates sphere in a device which served as a forerunner to a containerless processing facility being developed for Freedom.



Below: Life sciences investigations, like this heart-monitoring echocardiograph being connected by Dr. Rhea Seddon to Jeffrey Hoffman during a Shuttle mission, will study the effect of microgravity on plant, animal and human organisms.



lary processes, forced multiphase flows, nucleation and cluster phenomena, and electrohydrodynamic effects. Additional fundamental research will provide improvements in measurements of thermophysical properties and furnish data relevant to a wide variety of applications, including liquid propellant storage and transfer, microencapsulation of biomedical materials, meteorology, and the study of planetary interiors.

Space Station Freedom will give researchers a powerful facility for conducting research in the microgravity sciences. Microgravity research presents opportunities for fundamental research advances, some of which could have landmark impacts on science and technology. Six microgravity facilities planned for Freedom Station's laboratory module are:

Biotechnology Facility to study the microgravity effects on biological processes and living organisms at the cellular level. This facility would permit a detailed study of the response of various cells to microgravity under carefully controlled conditions.

Advanced Protein Crystal Growth Facility to grow high-quality crystals, to obtain the highest degree of long range order in the crystalline lattice, which determines the precision with which X-ray crystallographers can determine the structures of these complex biologically active molecules.

Modular Containerless Processing Facility to provide basic support for a wide range of experiments that require the positioning and manipulation of samples without physical contact. Acoustic, electromagnetic and electrostatic fields will provide the forces to manipulate the sample. Experiments to be performed in this facility will range from tests of theories that describe the behavior of liquid drops to the processing of molten materials at high temperatures.

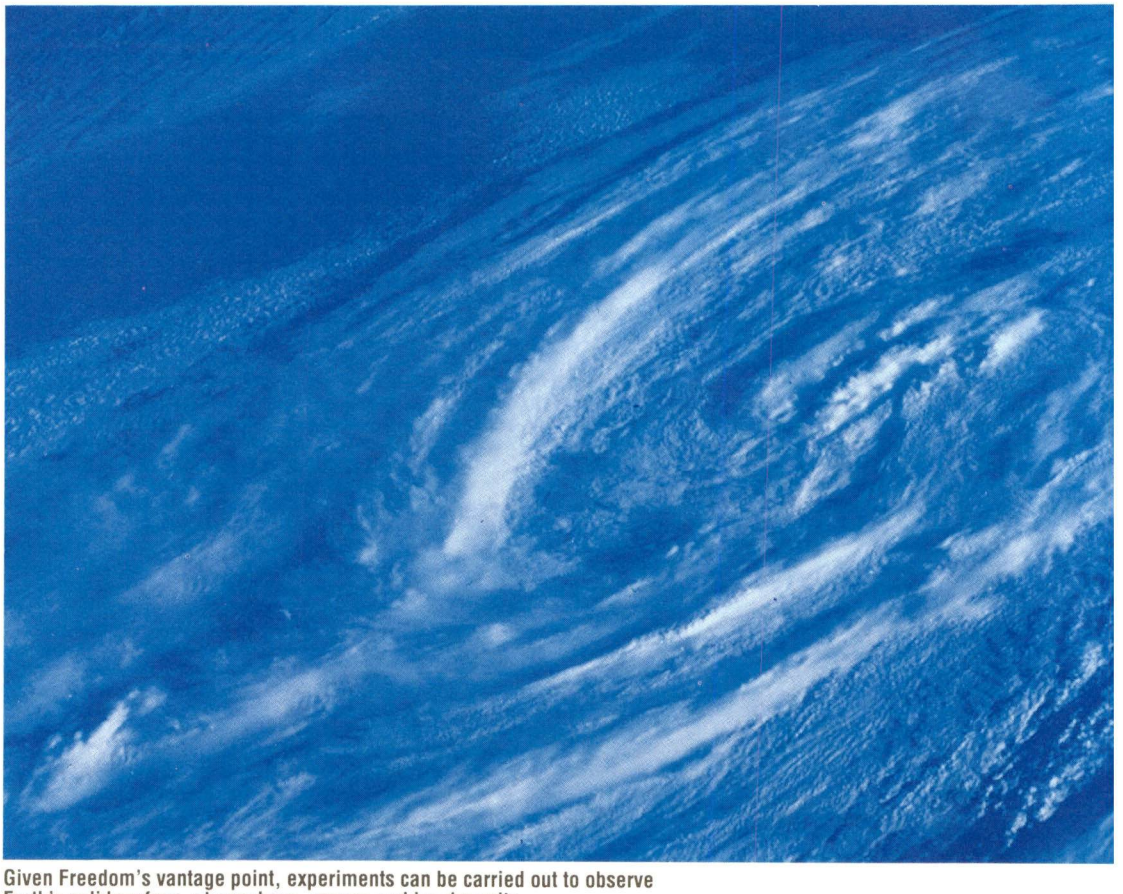
Space Station Furnace Facility for study of metal and alloy solidification and crystal growth with applications to electronic devices and development of materials with unique or improved properties.

Modular Combustion Facility to study fundamental combustion processes and phenomena and provide data for combustion-related applications such as fire safety and control and advanced furnaces.

Fluid Physics/Dynamics Facility to provide a better understanding of fundamental fluid behavior which is essential to developing processes that take full advantage of the microgravity environment.

Equally important are detailed studies in life sciences. Life on Earth, from microbe to man, has been shaped by gravitational forces in ways that are only now beginning to be revealed by space investigations. Previous space missions have confirmed a complex interaction between gravity and life, but these have been too limited or constrained to permit authoritative biological research. Space Station Freedom—offering controlled examination of a variety of species in long-duration microgravity under the skilled supervision of a resident crew—will present research opportunities unparalleled in the history of life sciences.

Freedom's laboratory module will permit extraordinary advances in biology. Variable-gravity research conducted aboard Freedom will seek to advance our knowledge of fundamental biological processes. A major objective of this



Given Freedom's vantage point, experiments can be carried out to observe Earth's solid surface, atmosphere, oceans and ice deposits.

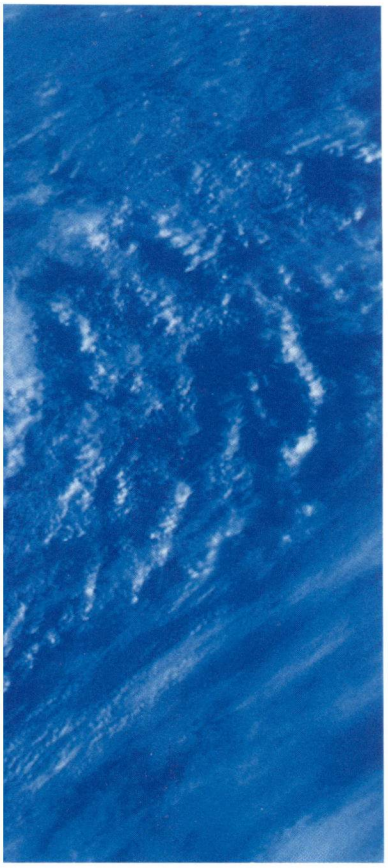
research is a deeper understanding of the relationship between gravity and life, as revealed through synergistic experimentation across a suite of species ranging from single-cell organisms to human beings.

In the area of space physiology, researchers will exploit the ambient microgravity environment, together with the variable gravity produced by specially designed research centrifuges, to examine the physiological effects of gravity on mammalian systems, especially human systems. Experiments will focus on the mechanisms by which gravity influences bone and muscle, fluid and hydrostatic systems, orientation in space, homeostatic control, and response to environment. Data gleaned from these experiments will help lift the veil of mystery surrounding human adaptation to space flight, a necessary feat before extending the human presence further into the solar system, and are expected to have wide-ranging clinical applications on Earth, such as in the treatment of bone-degrading diseases such as osteoporosis.

Gravity plays a key role in the development of most, if not all, biological systems. The opportunity to examine microorganisms, plants, and animal species throughout multiple life cycles in a microgravity environment is unprecedented in the history of biology. Experiments will focus on identifying the organ or site of gravity reception; determining the effect of gravity on reproduction, development and maturation; and investigating physiological responses. In particular, this program will sponsor scientific studies of life born and raised beyond Earth. Research in this field may have practical applications for computer scientists. The discovery that gravity-sensing cells in mammals also act as parallel processors gives scientists a simple device to study. Experimenters now hope to produce a dynamic model of a mammal's neural network, which could be used as a model to design machines capable of artificial intelligence.

Experimental modeling of gas-grain interactions can also be carried out in

Mockup of 1.8 meter centrifuge for life sciences investigations.



Freedom's laboratories, with applications to the origin of life, particularly the cosmic history of organic molecules from the formation of biogenic elements to their incorporation into living organisms.

Research on Freedom will promote the development of a bioregenerative life-support technology for use within the spacecraft. This research will investigate the use of plants and microorganisms to perform in space the same functions performed on Earth—production of oxygen, potable water, and food from biological wastes. One of the practical benefits of designing agricultural systems for use in space is that it could contribute to developing new intensive farming practices in extreme environments on Earth. The design of small, efficient plant growth chambers may also have practical value in urban areas, in regions where growing conditions are not right for a particular crop, or in extreme environments such as the Antarctic or deserts. And, aside from its importance in food production, closed ecological life support system research may provide a model of other closed environments, such as modern insulated houses, where plants could act as natural "scrubbers" to remove air pollutants.

Making use of the Freedom—its crew and high sensitive instruments—Earth's star, the Sun, can be continuously observed. Dynamic Sun-Earth relationships, studied from the Station, may yield valuable clues about the effects of solar phenomena on the Earth.

Freedom's expansive horizontal truss will provide attachment points for payloads designed to study the Earth and its environment, the sun, other bodies in the solar system and cosmic objects. Attachment to Freedom Station offers a number of advantages, including provision of electrical power, communications and some pointing capabilities furnished by Freedom itself, together with opportunities for resupply of consumables and instrument exchange by Freedom's resident crew.

NASA has already identified many promising candidate payloads that can benefit from Freedom's orbit, configuration and operation. One exciting experiment under study is Astromag, which would use a powerful superconducting magnet for unravelling aspects of mysterious cosmic rays and begin an unprecedented study of the origin and evolution of matter in the galaxy by direct sampling of galactic material. The experiment will produce a magnetic field one thousand times the strength of Earth's magnetic field. To achieve its superconductivity, the device will be cooled by liquid helium brought up by the Shuttle and resupplied periodically by Freedom's crew.

Freedom will also support exobiology and solar system research. Freedom provides an unprecedented opportunity to collect intact fragments of interplanetary dust particles, the "fossils" of early solar system development, and possibly interstellar particles for post-flight analysis. For example, a Cosmic Dust Collector, attached to Freedom's truss, will snag the finely divided solid matter—a substance that may offer clues to the origin of the universe. A high-resolution, Astrometric Telescope Facility, designed to peer deep into the surrounding universe with superior pointing accuracy, may also be mounted to Freedom's frame. This device will look for planets around other stars.

We are just beginning to appreciate the complex and highly volatile Sun-Earth relationships. Equipment fitted outside Freedom's pressurized modules, such as the Solar Terrestrial Observatory, promises to advance our understanding of solar features and properties and of the ebb and flow of electrical plasma, the solar wind cast off from the Sun before interacting with Earth. Other prospective attached payloads include a Large Area Modular Array of Reflectors for surveys of cosmic X-ray sources at low resolution and high sensitivity, and a Pinhole Occulter Facility for mapping of solar X-rays.

Although the manned base is only a few hundred

DREAMS FULFILLED

For hundreds of years the idea of an orbiting facility in space has fueled the fantasies of writers, scientists, and engineers. Not until the great burst of scientific activity marking the turn of the 20th century, however, did the first truly thoughtful, provocative concepts for a space station emerge. Penned mostly by scientists and engineers, not one postulated a station in space as an end in itself.

Instead, the visionaries saw space stations as serving enduring purposes: enlarging our understanding of the cosmos, servicing Earth, and providing a way station to worlds beyond. In Russia, scientist Konstantin Tsiolkovsky clearly spelled out the possibility of orbital stations forming the heart of a program of space conquest that would eventually lead to "cities in space." To this day, Soviet exploits have kept alive Tsiolkovsky's assertion that "the planet is the cradle of mankind, but one cannot spend one's life in a cradle."

The Space Era is Launched

On October 4, 1957, when the Soviet's *Sputnik* I rumbled skyward to give birth to the Space Age, the stuff of science fiction moved a notch closer to becoming science fact. With the creation of the National Aeronautics and Space Administration in 1958, American civilian space planning efforts were centralized, and the United States set out to become the lead space-faring nation in the

The Apollo program achieved the goal of landing a man on the Moon and returning him safely to Earth. Twelve men walked on the Moon during Apollo. One of the last to visit the Moon was Apollo 17 scientist-astronaut Harrison Schmitt shown here next to a deployed U.S. flag. The Earth, 240,000 miles away, is visible in the background.

Astronaut Edward White conducts the first American space walk June 1965 during a Gemini IV mission. Rendezvous and docking techniques, mandatory for the Apollo lunar landing effort, were developed during the Gemini program.

world. One year later, an embryonic space industry, coupled with NASA, began design studies of a manned space laboratory, soon to become popularly known as a space station.

The Challenge of Apollo

On May 25, 1961, President John F. Kennedy launched the Apollo program, calling on the nation to "commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth."

Kennedy's call also galvanized strong support for an Earth-orbit rendezvous, that is, using a space station as a staging base for a flight to the Moon. As an added bonus, the station was to remain in place after the lunar landing. Within 10 years, every major new program being proposed for space was dependent on a space station.

Numerous designs were offered. They ranged from very large stations placed in orbit by giant boosters to inflatable balloon-like structures, retrofitted rocket stages, and cannisters arranged in a spoke configuration that were then spun to create artificial gravity inside.

Eventually, limited funds and the President's deadline led to an alternative approach for the Apollo program: a take-off from Earth to be followed by a lunar-orbit rendezvous, with one astronaut orbiting the Moon as two others landed on the Moon and explored it.

The Legacy of Skylab

Skylab was the first American experimental space station to be built. Furnishing a wealth of experience between 1973 and 1974, Skylab achieved its fundamental objective, to determine human ability to adapt to prolonged weightlessness. Over 270 multidisciplinary investigations conducted by Skylab also provided un-

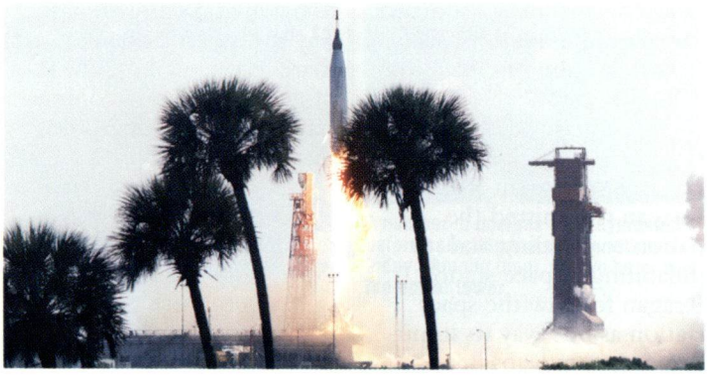
Original Mercury astronauts were announced on May 8, 1961. Left to right: Donald Slayton, Walter Schirra, Gordon Cooper, Scott Carpenter, Virgil Grissom, John Glenn and Alan Shepard.

Dr. Wernher von Braun contemplated use of large space stations in the 1950's to support exploratory treks to the Moon and to help send off spaceships to Mars.

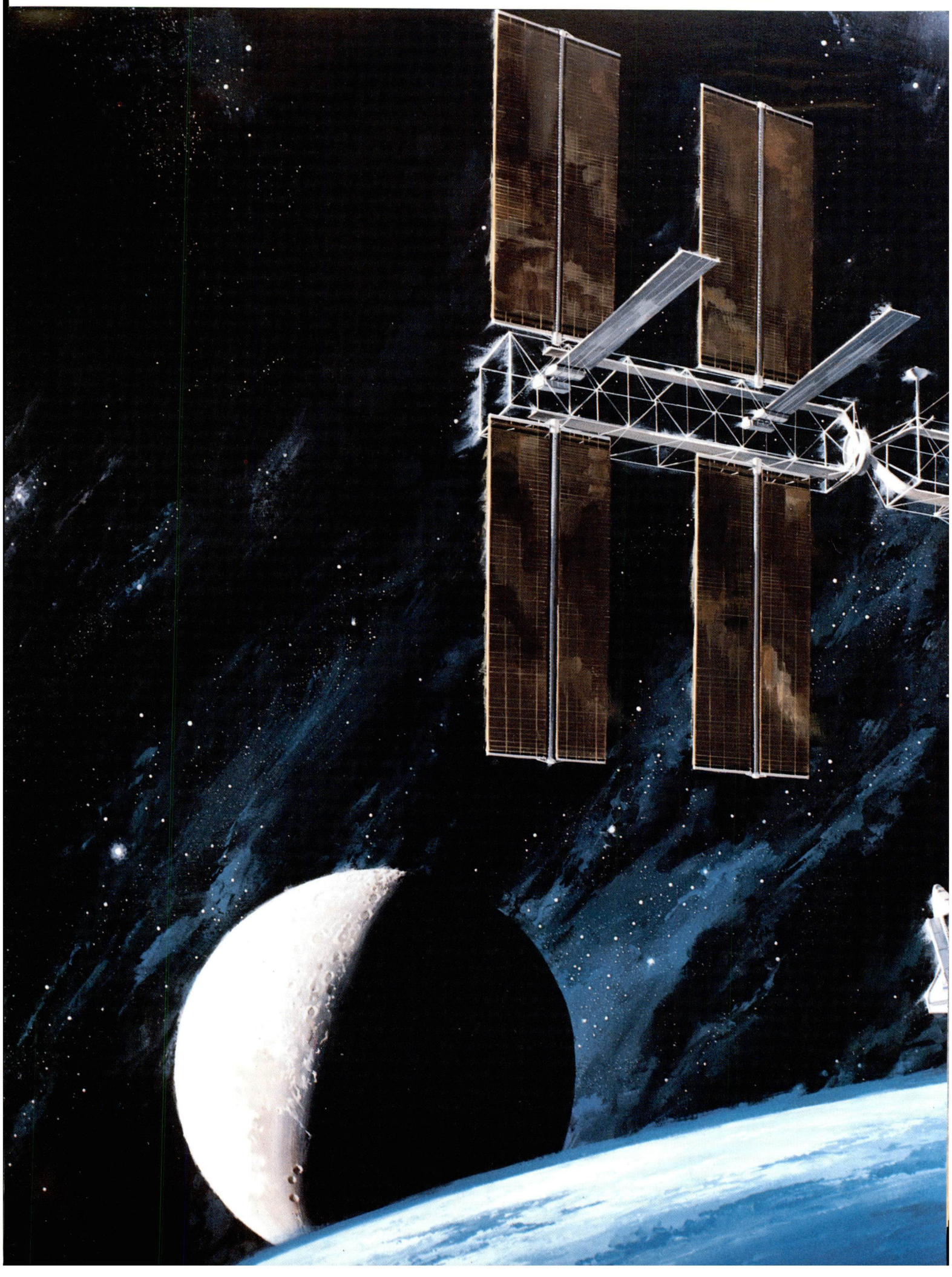
(Courtesy of NSI Archives)

precedented solar observations, Earth resource studies, and tests of space manufacturing techniques.

Far removed from the versatile Station now under way, this modest orbital workshop was actually a converted, left-over, Saturn V third stage used to launch the Apollo astronauts to the Moon. Astronauts were flown to and from the 91,000-kilogram (100 ton) orbiting laboratory, the size of a three-room house, in a small Apollo spacecraft, a transportation system limited to single up-and-down trips. To this day, Skylab's dimensions, which encompassed 353 cubic meters (12,700



An Atlas booster roars off its Florida launch pad carrying Scott Carpenter on Mercury-Atlas 9. The Mercury program opened wide the doors to space exploration by humans.



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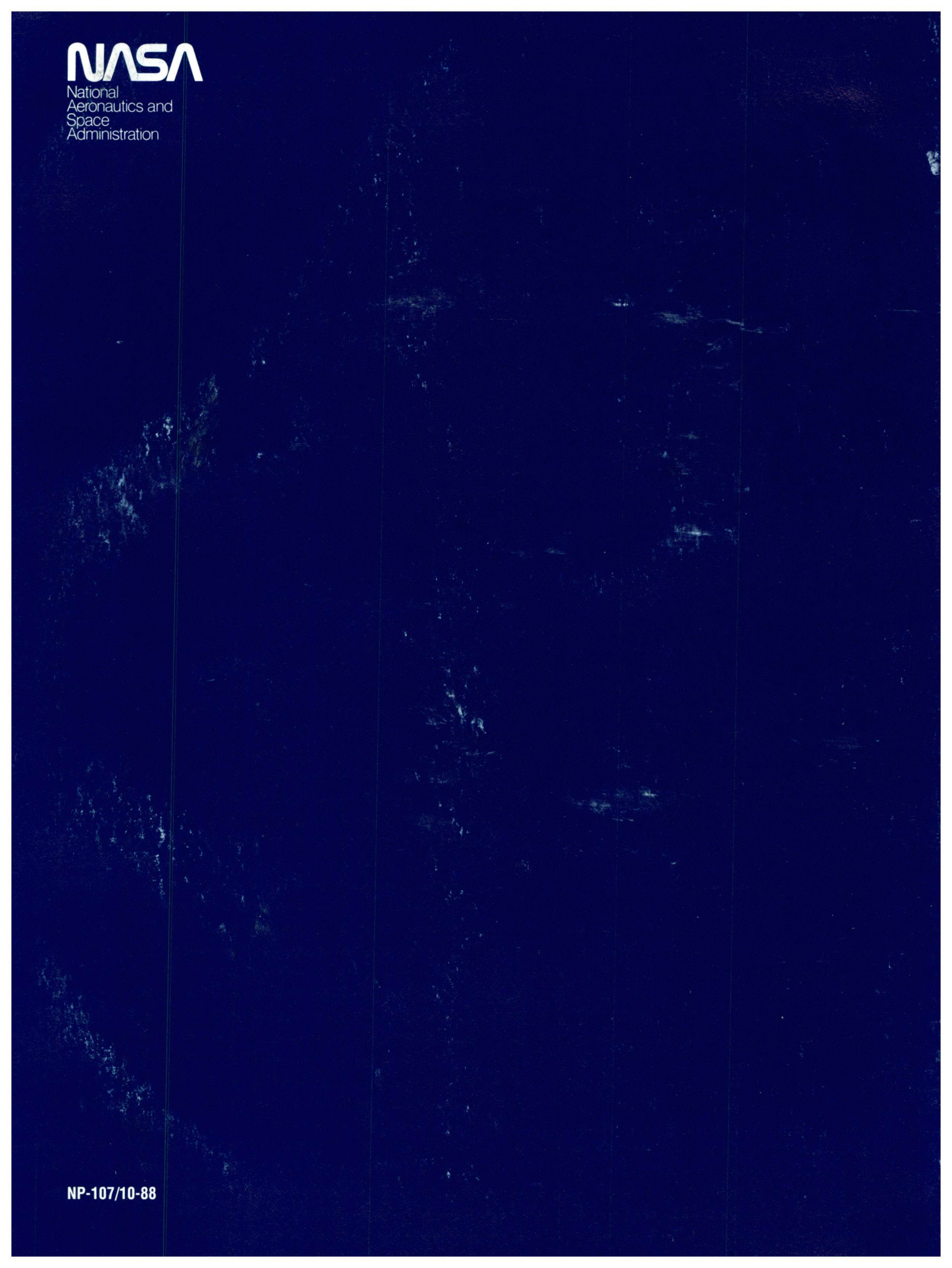

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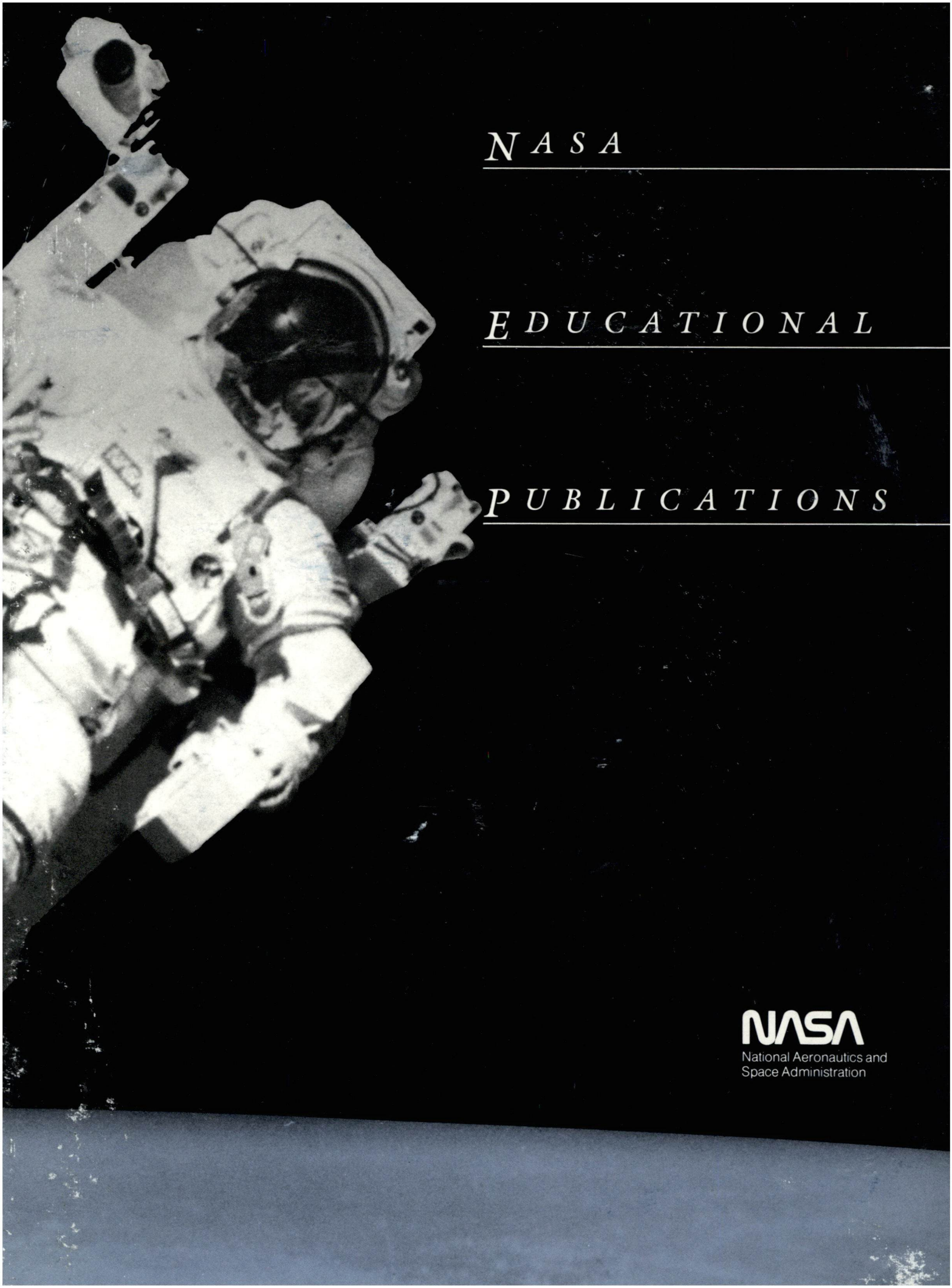

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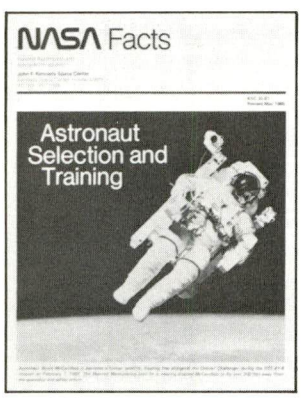
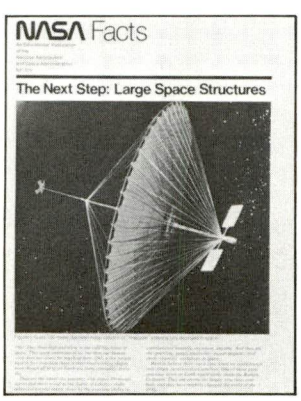
NASA Facts

The following listing of numbered NASA Facts are identified according to their intended educational audiences. When a publication number starts the entry, an "e" in the parentheses following the publication number indicates elementary; an "m," middleschool; an "s," secondary school; and a "u," university.



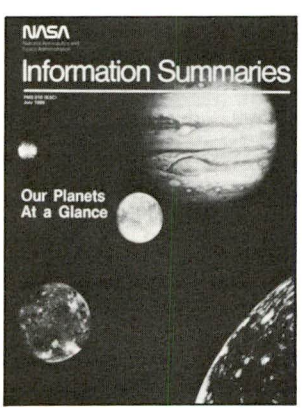
NF-89 (s) **The Voyager Mission**
Presents information on Jupiter gathered from the Voyager mission. The origin of Jupiter, its magnetosphere and great red spot are discussed in detail. Illustrated in color. 8 pages. 1979.
Stock No. 033-000-00753-1. $2.00

NF-121 (s) **Astronaut Selection and Training**
Outlines qualifications and training required for astronauts in earlier space missions and the present Space Shuttle program. Illustrated. 6 pages. 1981.
Stock No. 033-000-00823-6. $2.00



NF-127 (s) **The Shuttle Era**
Describes the Space Shuttle system, presents a mission profile, and explains why the Shuttle has ushered in a new era for America's space program. Illustrated. 8 pages. 1981.
Stock No. 033-000-00822-8. $2.00

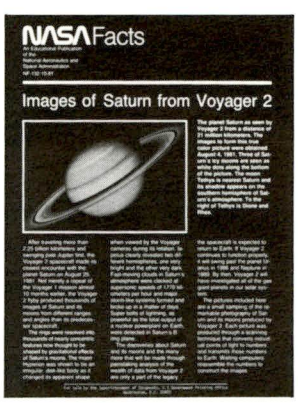
NF-129 (s) **The Next Step: Large Space Structures**
Explains how giant antennas and platforms will be built in space in the coming decades. Discusses construction techniques and materials for such structures, and includes suggestions for classroom activities. Illustrated. 8 pages. 1982.
Stock No. 033-000-00853-8. $2.00

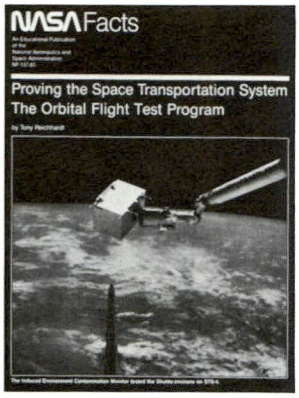


NF-132 (s) **Images of Saturn from Voyager 2**
Describes images of Saturn returned by the Voyager 2 spacecraft. Illustrated in color. 4 pages. 1982.
Stock No. 033-000-00837-6. $2.00

NF-134 (s) **Our Planets at a Glance**
Guide to current knowledge about the celestial bodies of our solar system, based on the interplanetary explorations of Viking, Voyager, Pioneer, and Mariner spacecraft. Illustrated. 16 pages. 1982.
Stock No. 033-000-00859-7. $2.75

NF-135 (s) **General Aviation**
Summary of NASA research in general aviation aircraft technology, including new ideas on increasing safety, engine performance, fuel efficiency, and instrument-flying techniques. Illustrated. 8 pages. 1982.
Stock No. 033-000-00858-9. $2.00





NF-137 (s) **Proving the Space Transportation System: The Orbital Flight Test Program**
Describes the Space Shuttle test flight program in nontechnical language, explaining how Columbia's different systems were tested during its first four flights, and why. Illustrated. 20 pages. 1983.
Stock No. 033-000-00884-8. $2.50

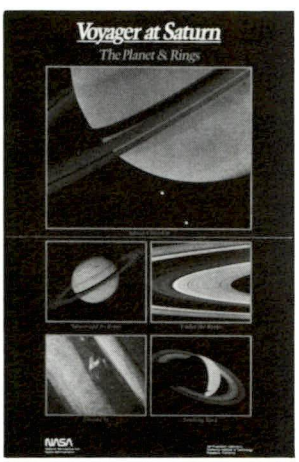
NF-138 (s) **Planet Earth Through the Eyes of Landsat 4**
Explains how pictures taken from Earth orbit reveal surface features such as deserts, areas of vegetation, urban development, and bodies of water. Illustrated in color. 12 pages. 1983.
Stock No. 033-000-00875-9. $2.25

NF-140 (s) **A New Dimension in Space Exploration: LDEF**
Explains purpose of the Long Duration Exposure Facility (LDEF), an unmanned structure launched by the Space Shuttle in which 53 experiments took place to test the effects of space on different materials. Illustrated. 12 pages. 1984.
Stock No. 033-000-00914-3. $1.00

NF-144 (s) **Space Shuttle: NASA's Answer to Operations in Near Earth Orbit**
Describes technological development and uses of the Space Shuttle. Illustrated. 6 pages. 1985.
Stock No. 033-000-00968-2. $1.00

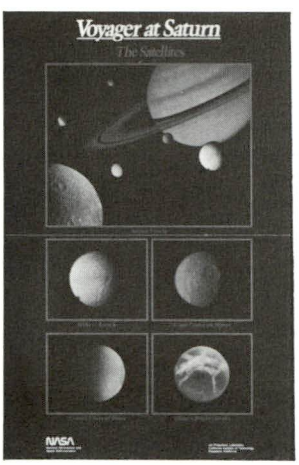
Posters and Wallsheets

The following listing of numbered posters and wallsheets generally contain materials appropriate for use in secondary school and university classrooms, but may also provide motivational images and instruction for younger audiences.



WAL-33/34 **Voyager at Saturn: The Planet and Rings and The Satellites**
Two posters. Printed in color. 17x11 inches. Folded. 1981.
Stock No. 033-000-00827-9. $3.75

WAL-58 **Comparing the Planets**
Introduces comparative planetology (a "Teacher's Guide" accompanies the wallsheet) by presenting information gathered from NASA space missions. In addition to size and distance from the Sun, planets are described in terms of composition, density, atmosphere, and geology. Printed in color. 32x56 inches. 1979.
Stock No. 033-000-00744-2. $3.75



WAL-81 **Space Shuttle**
Space Shuttle with "skin" removed to show skeletal structure and interior. Includes statistics on the orbiter and brief account of its nature and uses. Printed in color. 30x42 inches. Folded. 1978.
Stock No. 033-000-00743-4. $3.50

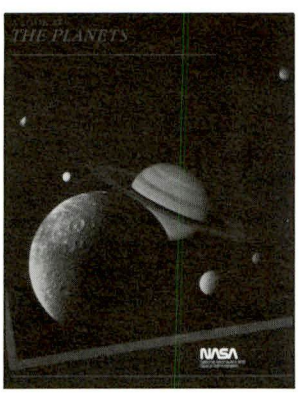
WAL-102 **Spacelab Wallsheet**
Spacelab and Space Shuttle orbiter during hypothetical mission. Inserts show "life cycle" of spacelab from assembly to launch, different Spacelab configurations and parts of the vehicle. Printed in color. 43x44 inches. 1983.
Stock No. 033-000-00903-8. $3.75

WAL-109 **Ten Years of Planetary Exploration**
Highlights of NASA planetary research from 1972 through 1981, when all planets out to Saturn were explored by spacecraft. Shows spacecraft trajectories and describes major discoveries about each planet. Printed in color. 39x49 inches. 1982.
Stock No. 033-000-00861-9. $3.75

WAL-118 **International Cometary Explorer Wallsheet**
Depicts comet and International Cometary Explorer (ICE) spacecraft, and lists mission details (a "Teacher's Guide" accompanies the ICE Wallsheet). Printed in color. 37x41 inches. 1985.
Stock No. 033-000-00958-5. Wallsheet $4.00; Teacher's Guide, $1.00

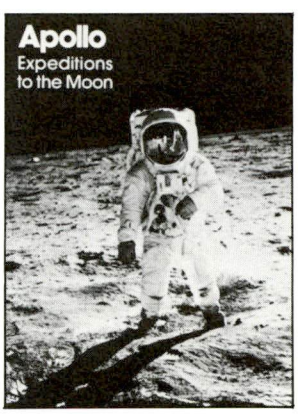
Voyager's Encounter with Jupiter and its Moons
Images taken from Voyager 1 and 2 flybys of Jupiter in spring and summer of 1979. Includes Jupiter's Great Red Spot, various views of four Jupiter's moons: Europa, Ganymede, Io, and Callisto, and an intense volcanic eruption on the surface of Io. Printed in color. Six posters 23½x35 inches (each). 1980.
Stock No. 033-000-00791-4. $10.00

Other Publications of Interest to Educators



A Look at the Planets
Results of NASA planetary exploration including a list of spacecraft, description of each planet, and chart of facts and size comparisons. Illustrated in color. 8 pages. 1985.
Stock No. 033-000-00964-0. $1.00

Apollo Expeditions to the Moon (SP-350)
Photographic presentation of Apollo as told by the Apollo astronauts and NASA executives. Illustrated in color. 313 pages. 1975.
Stock No. 033-000-00630-6. $13.00



Atlas of Mercury (SP-423)
Background and results of three Mariner 10 fly-bys of planet Mercury. Illustrated. 128 pages. 1978.
Stock No. 033-000-00695-1. $21.00

Beyond The Atmosphere: Early Years of Space Science (SP-4211)
History of early years of space science. Illustrated. 515 pages. 1980.
Stock No. 033-000-00798-1. $12.00

Chariots for Apollo: A History of Manned Lunar Spacecraft (SP-4205)
Survey of Apollo lunar exploration program focusing on spacecraft hardware and how it was developed. Illustrated. 538 pages. 1979.
Stock No. 033-000-00768-0. $12.00

Evolution of the Solar System (SP-345)
A highly technical summary of the analysis of the origin and evolution of the solar system. Illustrated. 599 pages. 1976.
Stock No. 033-000-00613-6. $17.00

Far Travelers: The Exploring Machines (SP-480)
Overview of NASA's unmanned spacecraft from early development through completion of the Pioneer program in the late 1970s. Illustrated. Clothbound. 267 pages. 1985.
Stock No. 033-000-00957-7. $17.00

Galileo to Jupiter: Probing the Planet and Mapping Its Moons
Describes mid-1980s project named for scientist who discovered Jupiter's four largest moons. Discusses purpose, spacecraft design, the planet and its satellites. Illustrated in color. 20 pages. 1979.
Stock No. 033-000-00763-9. $2.75

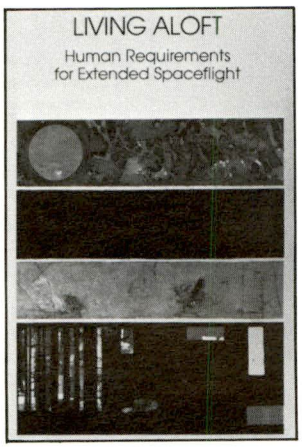
Global Geodynamics
Describes in nontechnical terms what NASA's Geodynamics Program involves. Areas discussed include geodynamics, geodesy, global dynamics, satellites, and geophysics. Illustrated. 14 pages. 1983.
Stock No. 033-000-00865-1. $2.75

Halley's Comet: A Bibliography
References to publications on Halley's Comet, its history, orbital motion, and physical characteristics. Also included are preparations for space missions that studied Halley's Comet in 1986. Illustrated. Clothbound. 585 pages. 1984.
Stock No. 030-000-00158-3. $26.00

High-Density Digital Recording (RP-1111)
History, background, and perspective of high-density digital recording from a user's viewpoint. Also includes information on state-of-the-art, high-density digital recording (HDDR), discussing magnetic, optical and bit error correction technologies. Illustrated. 320 pages. 1985.
Stock No. 033-000-00967-4. $11.00

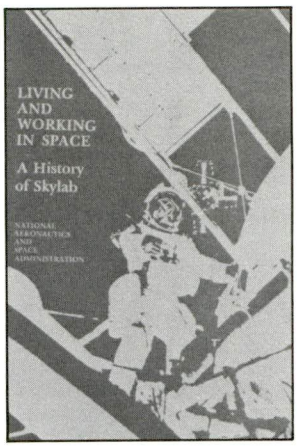
Images of Mars: The Viking Extended Mission (SP-444)
Data on Mars gathered by Viking's orbiters and landers during the period from summer 1976 to late 1979. Shows changes that took place on the Martian surface during that time. Illustrated. 32 pages. 1980.
Stock No. 033-000-00793-1. $3.25

Impact of Science on Society (SP-482)
Edited versions of speeches made in 1983 by James Burke, Jules Bergman, and Isaac Asimov at the College of William and Mary, commemorating NASA's 25th anniversary. Illustrated. 101 pages. 1985.
Stock No. 033-000-00943-7. $4.50



Living Aloft: Human Requirements for Extended Spaceflight (SP-483)
Identifies psychological and social problems that may be associated with future space missions, and explores possible solutions. Illustrated. 432 pages. 1985.
Stock No. 033-000-00949-6. $14.00

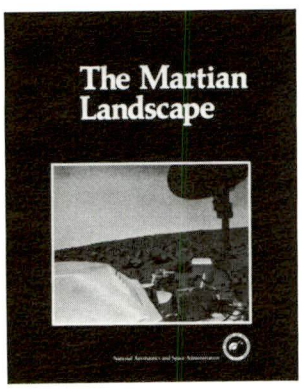
Living and Working in Space: A History of Skylab (SP-4208)
Built from a modified Apollo Saturn rocket, Skylab is considered by many to be the first Space Station. It was during the Skylab mission that we learned many of the effects of living and working in space, as well as what advantages are to be gained from a permanent space base. Illustrated in color. 462 pages. 1983.
Stock No. 033-000-00847-3. $20.00



Literature of Aeronautics, Astronautics and Air Power
Bibliographical essay providing guidance to various publications in aeronautics, astronautics, and air power. Illustrated. 66 pages. 1985.
Stock No. 008-070-00523-9. $2.50

Lunar Impact: A History of Project Ranger (SP-4210)
History of Project Ranger, the first successful American Moon exploration project, from its authorization to 1965. Illustrated. 450 pages. 1977.
Stock No. 033-000-00699-3. $10.00

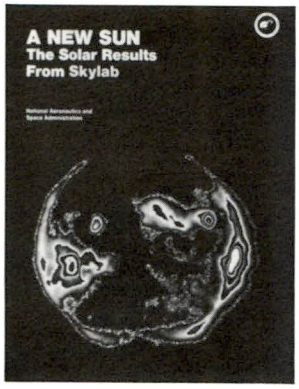
Marshall Space Flight Center, 1960–1985: Twenty-Fifth Anniversary Report
Review of Marshall Space Center's major achievements over the past twenty-five years. Presentation is topical, and focuses on propulsion and launch vehicles, space science and technology, and manned space systems. Past achievements, present projects, and future endeavors of the center are discussed, and a 4-page chronology is provided at the end of the publication. Illustrated. 86 pages. 1986.
Stock No. 033-000-00965-8. $6.00



The Martian Landscape (SP-425)
Genesis, planning, and fruition of the Viking missions to Mars. Includes sections devoted to Viking 1 and 2 lander pictures. Illustrated. Clothbound. 160 pages. 1978.
Stock No. 033-000-00716-7. $17.00

Mission to Earth: Landsat Views the World (SP-360)
Interpretations of information gathered by Landsat, originally called Earth Resources Technology Satellite (ERTS). Presents 400 plates, worldwide, most are in color. Clothbound. 469 pages. 1976.
Stock No. 033-000-00659-4. $34.00
(A "Teacher's Guide" accompanies *Mission to Earth.* It is sold separately and has a separate GPO Stock Number.)

This Island Earth (SP-250)
Presents Earth as the "island" in space that it is. Includes chapters on North America, Earth's atmosphere, lands and waters, humanity's impact on Earth, and the Sun and solar system. Illustrated. Clothbound. 192 pages. 1970.
Stock No. 033-000-00321-8. $12.00



A New Sun: The Solar Results from Skylab (SP-402)

Tells of the great harvest of information about the Sun gathered by the Apollo Telescope Mount on Skylab. Illustrated in color. Clothbound. 217 pages. 1979.
Stock No. 033-000-00742-6. $21.00

On the Frontier: Flight Research at Dryden, 1946-1981 (SP-4303)

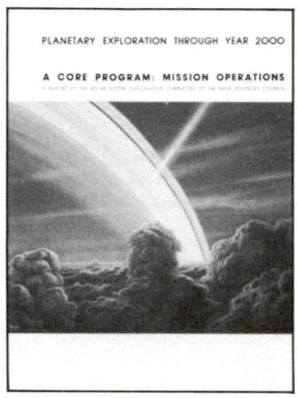
Traces development of Hugh L. Dryden Space Flight Research center as NACA High-Speed Flight Research Station, a division of Langley Laboratory, through use as a landing site for the Space Shuttle Columbia. Illustrated. 399 pages. 1984.
Stock No. 033-000-00893-7. $15.00

Photographic Catalog of Selected Planetary Size Comparisons

Size comparisons of moons and planets. Both global views and prominent geographical features are depicted at the same scale. Illustrated. 138 pages. 1985.
Stock No. 033-000-00961-5. $5.00

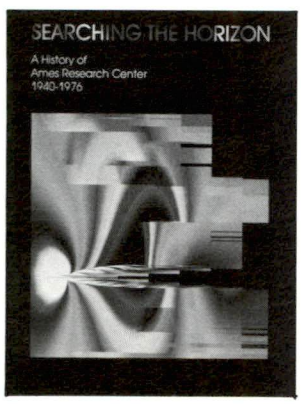
Planetary Exploration Through the Year 2000: A Core Program, Mission Operations

Describes the application of cost control techniques to the planetary exploration program of the Jet Propulsion Laboratory's Core Program. Mission Operations areas of emphasis include the need to develop unique operations and information systems for each planetary mission, gradual elimination of labor-intensive operations, and changing insufficient end-to-end analysis of deep space mission operations. Illustrated. 55 pages. 1986.
Stock No. 033-000-00993-3. $4.00



Project Galileo: A Return to Jupiter

Describes goals of the Galileo mission scheduled to be launched toward Jupiter and its moons in the late 1980s. Illustrated. 8 pages. 1980.
Stock No. 033-000-00815-5. $1.75

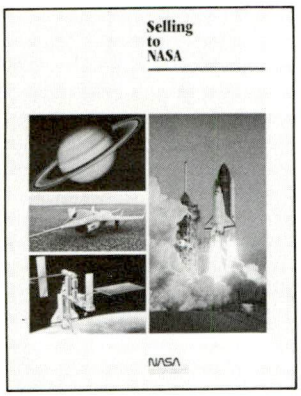


Searching the Horizon: A History of Ames Research Center, 1940-1976 (SP-4304)

Broad, chronological outline of technological achievements at the Ames Research Center within the context of its operational and managerial developments. Topics discussed include plasma studies conducted using data from the Pioneer spacecraft; the development of fighter aircraft during World War II; the blunt-body concept used on the Mercury, Gemini, and Apollo spacecraft; and a reusable thermal protection system for the Space Shuttle. Illustrated. 316 pages. 1985.
Stock No. 033-000-00966-6. $13.00

Selections from the NASA Art Collection

Portfolio of 12 lithographs of artworks by well-known artists that participate in the NASA Art Program. Subjects include Shuttle launches and landings, flight tests of experimental aircraft, space science satellites, deep-space probes, and other key activities of the U.S. space program. Printed in color. 11x14 inches (each).
Stock No. 033-000-00998-4. $6.00

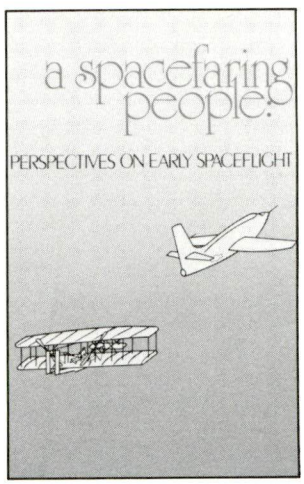


Selling to NASA
Prepared to assist potential contractors in the process of doing business with NASA. The procurement process is explained and advice is offered for marketing products. Illustrated in color. 44 pages. 1986.
Stock No. 033-000-00995-0. $3.25

Skylab, Classroom in Space (SP-401)
Results of Skylab experiments proposed by talented high school students through Skylab Student Project administered by the National Science Teacher's Association. Illustrated in color. Clothbound. 182 pages. 1977.
Stock No. 033-000-00678-1. $11.00

Skylab, Our First Space Station (SP-400)
Complete story of Skylab, America's first manned Earth-orbital space station. Illustrated. Clothbound. 176 pages. 1977.
Stock No. 033-000-00670-5. $11.00

A Spacefaring People: Perspectives on Early Spaceflight (SP-4405)
Essays presented at a conference on the history of space activity, held at Yale University. Topics discussed include space history, domestic and international ramifications of space activity, technology, management and the space program, and rationale for space exploration. Also included are biographies on each participant. Illustrated. 164 pages. 1985.
Stock No. 033-000-00933-0. $3.50

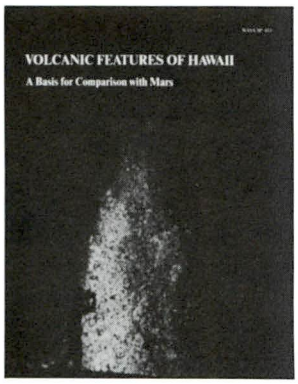


Space Shuttle Lithographs
Four photographic lithographs of the Space Shuttle. Printed in color. 8x10 inches (each). 1981.
Stock No. 033-000-00828-7. $4.00

Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles (SP-4206)
Technological history of the Apollo/Saturn lunar landing program. Illustrated. 511 pages. 1981.
Stock No. 033-000-00794-9. $12.00

Supersonic Cruise Technology (SP-472)
History of supersonic cruise technology from the early research efforts of the National Advisory Committee for Aeronautics (NACA) in 1920 through the NASA Variable Cycle Engine program completed in 1981. Illustrated. 199 pages. 1985.
Stock No. 033-000-00944-5. $6.50

Telescopes and Space Exploration
Account of the uses of different kinds of telescopes for astronomical research on such subjects as solar flares, interstellar gas, black holes, and the nature of the universe. Illustrated in color. 16 pages. 1976.
Stock No. 033-000-00647-1. $2.00



Viking Orbiter Views of Mars (SP-441)
Collection of Mars images including polar regions, moons, atmosphere, craters, and channels. Stereo viewer enclosed. Illustrated in color and black and white. Clothbound. 182 pages. 1980.
Stock No. 033-000-00795-7. $11.00

Volcanic Features of Hawaii: A Basis for Comparison With Mars (SP-403)
Compares and contrasts Earth's largest volcanoes with the larger ones NASA found on Mars. Illustrated. Clothbound. 216 pages. 1980.
Stock No. 033-000-00788-4. $15.50

Voyager Encounters Jupiter
Nontechnical discussions of discoveries by Voyager 1 and Voyager 2 about the planet Jupiter and several of its satellites. Illustrated in color. 48 pages. 1979.
Stock No. 033-000-00772-8. $3.50

Voyager 1 Encounters Saturn
Preliminary photographic results of Voyager 1's encounter with Saturn and its major satellites, with easy-to-understand captions. Illustrated in color. 40 pages. 1980.
Stock No. 033-000-00817-1. $3.25

Scientific and Technical Publications

NASA Scientific and Technical Publications are aimed at providing scientists and technicians with in-depth information on highly technical subject areas. Some of these books have educational benefits and are often used in high-level university courses. Those books listed here concentrate on individual topics and require some familiarity with the particular subject area. (For a complete listing of the most current titles available from the Superintendent of Documents, contact the U.S. Government Printing Office and ask for Subject Bibliography SB-257, "NASA Scientific and Technical Publications.")

Fuel Economy in Aviation (SP-462)
Provides an account of the Aircraft Energy Efficiency Program (ACEE), a joint venture between NASA and the private sector to develop energy-efficient technologies for present and future aircraft. Chapters include Engine Component Improvement, Energy Efficient Engine, Advanced Turboprops, Composite Structures, Energy Efficient Transport, and Laminar Flow Control. Illustrated. Clothbound. 120 pages. 1983.
Stock No. 033-000-00899-6. $15.00

Geology of the Terrestrial Planets (SP-469)

Outlines geologic history of the terrestrial planets, the Earth, Mercury, Venus, and Mars in light of recent exploration and changes in geological thought. Geological features of the Moon, asteroids, and Comets are also discussed. Illustrated. Clothbound. 325 pages. 1984.
Stock No. 033-000-00900-3. $16.00

International Halley Watch Amateur Observer's Manual

Two-volume set written for the advanced amateur astronomer. Part one details general observing techniques and data for tracking Halley's Comet during its reappearance in 1985–86. Part two has ephemeris and star charts. Illustrated. 97 and 86 pages. 1983.
Part 1: Stock No. 033-000-00888-1. Part 2: Stock No. 033-000-00889-9. $4.50 (each).

Laser Technology: A Survey (SP-5116)

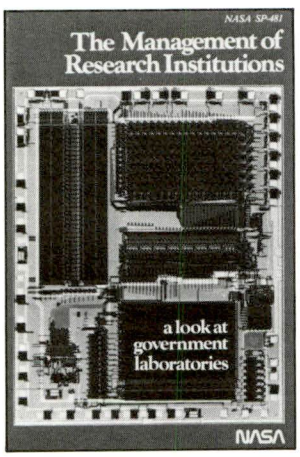
A survey of lasers, extremely powerful new tools, developed in the last few decades. Lasers may be used increasingly in industry, medicine and dentistry, communications systems, and many kinds of scientific research. This survey includes both background information and suggestions regarding potential uses for lasers. Illustrated. 48 pages. 1973.
Stock No. 033-000-00537-7. $4.50

Life in the Universe: Proceedings of a Conference Held at NASA Ames Research Center (CP-2156)

Contains 31 papers presented on exploring the prospects for research into nature and distribution of life in the universe. Discusses the origin of life, life-supporting environments, evolution of complex life, detectability of technically advanced civilizations, and plans and rationale for trying to locate extraterrestrial intelligence. Illustrated. 468 pages. 1982.
Stock No. 033-000-00841-4. $8.00

Magnetic Tape Recording for the Eighties (RP-1075)

Deals with both the practical and theoretical aspects of state-of-the-art magnetic tape recording technology. Topics include tape and head wear; wear testing; magnetic tape certification; care, handling, and management of magnetic tape; cleaning packing and winding of magnetic tape, tape reels, bands, and packaging; coding techniques, and tradeoffs of coding techniques. Devoted to detailed discussion and analysis. Illustrated. 176 pages. 1982.
Stock No. 033-000-00855-4. $6.50



Management of Research Institutions: A Look at Government Laboratories (SP-481)

Describes how technology development laboratories operate, identifies conditions in favor or against the performance of a laboratory's mission, and draws certain conclusions as to how such laboratories should be managed. Illustrated. 318 pages. 1984.
Stock No. 033-000-00937-2. $9.00

Managing NASA in the Apollo Era (SP-4102)

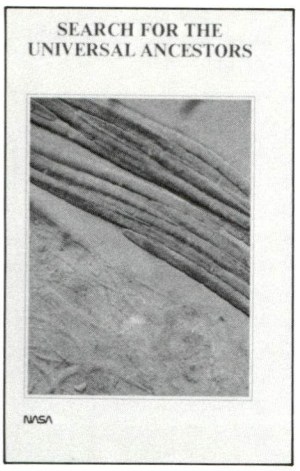
Historical account of the development of NASA during the 1960s. Topics covered include key administrative decisions in the early history of NASA, a narrative account of NASA

from its origins through 1969, contracting, manpower, the budgetary process, headquarters organization, relations with the Department of Defense, and long-range planning. Illustrated. 364 pages. 1982.
Stock No. 033-000-00844-9. $10.00

Model Research: The National Advisory Committee for Aeronautics, 1915-1958 (SP-4103)
Examines the National Advisory Committee for Aeronautics (NACA) as an institution, explains its purpose, and evaluates it as a research organization. Primary emphasis is placed on political and institutional history. Illustrated. 2 volumes. 772 pages. 1985.
Stock No. 033-000-00894-5. $26.00

Modern Observational Techniques for Comets
Proceedings of a workshop held at Goddard Space Flight Center. Includes papers on theory and needs, astrometry, photometry, infrared observations, radio observations, spectroscopy, imaging of coma and tail, image processing, space telescope and shuttle observation, laboratory input, and plans for Halley's Comet. Illustrated. 325 pages. 1981.
Stock No. 033-000-00835-0. $16.00

NASA and General Aviation (SP-485)
Overview of private aviation functions and the latest NASA developments in technology for general aviation. Aerodynamics, internal combustion engines and turbine engines are discussed in detail. Other topics include safety, electronics, and the future of general aviation. Illustrated. 141 pages. 1986.
Stock No. 033-000-00984-4. $6.50



Search for the Universal Ancestors (SP-477)
Introductory analysis of chemical evolution and the origins of life as defined by astronomers, biologists, chemists, and physicists. Illustrated. 146 pages. 1985.
Stock No. 033-000-00953-4. $3.75

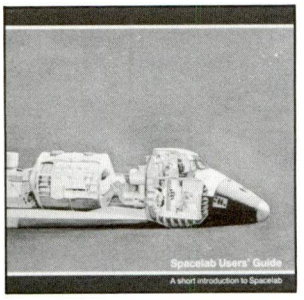
Significant NASA Inventions Available for Licensing in Foreign Countries (SP-7038)
Abstracts of various NASA-owned inventions available for foreign licensing. Illustrated. 180 pages. 1986.
Stock No. 033-000-00986-1. $5.00

Skylab Explores the Earth (SP-380)
Review of the Skylab experiment for determining the astronaut's role in observing Earth on future orbital missions. Covers subjects for study such as vegetation, cultural features, geology, hydrology, oceanography, and meteorology. 536 pages. Heavily illustrated. 1977.
Stock No. 033-000-00674-8. $16.50

Small Transport Aircraft Technology (SP-460)
Results of a NASA study on technical improvements in commuter aircraft and how these improvements might help to increase public acceptance and use of small planes. Illustrated. 111 pages. 1983.
Stock No. 033-000-00872-4. $5.00

Space Physiology and Medicine (SP-447)
General reference manual for persons engaged in or concerned with the practice of space medicine, this book discusses space flight, space environment, space flight systems and procedures, physiological adaptation to space flight, health maintenance of space crewmembers, and medical problems of space flight. Illustrated. Clothbound. 335 pages. 1982.
Stock No. 033-000-00864-3. $15.00

Space Resources and Space Settlements (SP-428)
Technical papers from a 1977 study of space settlements and industrialization using nonterrestrial materials and conducted at NASA Ames Research Center. The subjects considered were research needs for regenerative life-support systems, habitat design, dynamics and design of electromagnetic mass drivers, asteroids as resources for space manufacturing, and processing of nonterrestrial materials. 300 pages. 1979.
Stock No. 033-000-00765-5. $9.00



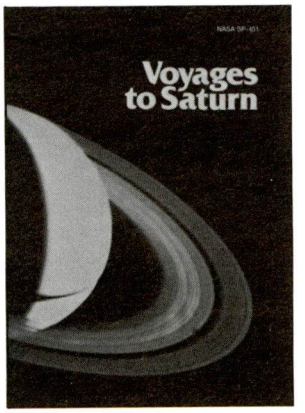
Spacelab Users' Guide: A Short Introduction to Spacelab
Briefly describes Spacelab, its configurations, and uses. Published jointly by NASA and the European Space Agency. Illustrated. 23 pages. 1983.
Stock No. 033-000-00897-0. $3.50

Sun As a Star (SP-450)
Essays on observations and diagnostics of the Sun, and on theoretical interpretations of solar phenomena. The summary (resume) of the book is in French and English; the rest of the text is in English. Illustrated. 571 pages. 1981.
Stock No. 033-000-00747-7. $11.00

Sun, Weather, and Climate (SP-426)
Overall view of the present status of new field of investigating the effects of the sun on weather and climate. Illustrated. 360 pages. 1978.
Stock No. 033-000-00747-7. $7.50

Voyage to Jupiter (SP-439)
Authoritative account of the Voyager Jupiter encounter, including flybys of the planet in 1979. Illustrated. 211 pages. 1980.
Stock No. 033-000-00797-3. $9.00

Voyages to Saturn (SP-451)
A member of the Voyager science team tells the story of the Voyager 1 and 2 encounters with Saturn and its moons. Includes behind-the-scenes anecdotes about the scientists who shared the excitement of the Voyager discoveries. Illustrated in color. 227 pages. 1982.
Stock No. 033-000-00842-2. $9.50



Wind Tunnels of NASA (SP-440)
Details history, development, and importance of wind tunnels to aeronautical research. Illustrated. 164 pages. 1981.
Stock No. 033-000-00832-5. $13.00

Educational Materials From Regional Service Centers

Some publications not available from GPO may be obtained from NASA Regional Service Centers. Materials may vary slightly from center to center. For a listing of available publications, films, and other services, contact the Educational Services Office at the NASA field center that serves your state. Some Regional Service Centers also have materials and classroom aids unique to the centers. For a listing of publications available exclusively from a selected center, please contact the center nearest you.

NASA Ames Research Center
Moffet Field, CA 94035
Serves Alaska, Arizona, California, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming.

NASA Goddard Space Flight Center
Greenbelt, MD 20771
Serves Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.

NASA Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
Serves inquiries related to space exploration and other JPL activities.

NASA Johnson Space Center
Houston, TX 77058
Serves Colorado, Kansas, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, and Texas.

NASA Kennedy Space Center
Kennedy Space Center, FL 32899
Serves Florida, Georgia, Puerto Rico, and the Virgin Islands.

NASA Langley Research Center
Hampton, VA 23665
Serves Kentucky, North Carolina, South Carolina, Virginia, and West Virginia.

NASA Lewis Research Center
Cleveland, OH 44135
Serves Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin.

NASA Marshall Space Flight Center
Tranquility Base
Huntsville, AL 35812
Serves Alabama, Arkansas, Iowa, Louisiana, Missouri, and Tennessee.

National Space Technology Laboratories
NSTL, MS 39529
Serves Mississippi.

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NASA

National Aeronautics and
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PAM-101/7-87

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NASA News
National Aeronautics and
Space Administration

Marshall Space Flight Center
Huntsville, Alabama 35812

Space Celebration '89

Bill Anderson
Marshall Space Flight Center
Huntsville, Ala.
(Phone: 205/544-0038)

July 21, 1989

RELEASE NO: 89-154

LOCAL TEACHER ATTENDS NASA EDUCATORS' WORKSHOP

Ms. Lynne F. Zielinski of Long Grove, a teacher at Glenbrook North High School, recently attended the two-week NASA Educational Workshop for Math and Science Teachers (NEWMAST) at the Marshall Space Flight Center, Huntsville, Ala.

Ms. Zielinski was one of 100 teachers selected by the National Science Teachers Association from over 400 applicants from schools throughout the nation. Marshall was host to 25 teachers representing schools in Ohio, Michigan, Arkansas, Tennessee, Iowa, Texas, Wisconsin, Oklahoma, Missouri, Indiana, Minnesota, Illinois, and South Carolina.

The purpose of the workshop is to assist teachers in updating and enhancing their knowledge of space science and technology. Marshall is a multi-project management, scientific and engineering establishment, with emphasis on launch vehicle development, scientific investigation, and the application of space technology to the solution of problems on Earth.

Highlights of the workshop included visits to the seven research and development laboratories in the Center's Science and Engineering Directorate. The teachers received detailed briefings on the development of such projects as the Space Shuttle, Hubble Space Telescope, Space Station, Spacelab, and other current and future programs.

NEWMAST is sponsored by the National Science Teachers Association and NASA.

-30-

....Photo caption: Ms. Lynne F. Zielinski examines Space Shuttle aft flight deck mockup in Payload Crew Training Complex at NASA Marshall Space Flight Center in Huntsville, Alabama.

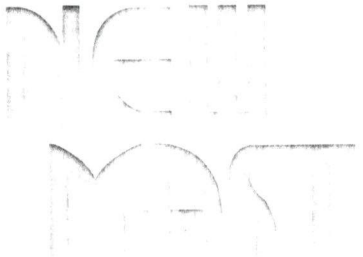
AN EXCITING OPPORTUNITY FOR TOP TEACHERS

The **NASA Educational Workshop for Math, Science, and Technology Teachers (NEWMAST)** gives outstanding educators the chance to personally experience NASA's aerospace activities. **NEWMAST** teachers update their knowledge of aerospace research and technology, develop new teaching strategies, and bring the U.S. aerospace program back to their classrooms and communities.

Workshop participants will spend two weeks at a NASA center, witness its inner workings, learn the latest technological information directly from NASA scientists and engineers, and bring back a wealth of materials for classroom use.

Each **NEWMAST** workshop includes:

- Seminars conducted by NASA scientists and engineers
- Field trips within and outside the NASA center
- Resource sharing sessions with other teachers
- Hands-on resource and materials field-testing



*The **NEWMAST** program is cosponsored by the National Aeronautics and Space Administration (NASA) and National Science Teachers Association (NSTA) in cooperation with the National Council of Teachers of Mathematics (NCTM), and the International Technology Educational Association (ITEA).*

IMMERSE YOURSELF IN NASA'S LATEST AEROSPACE ACTIVITIES

Winners of the **NEWMAST** award will return from the workshop with resources and ideas that will enrich the science, math, and precollege technology programs in their schools and provide inspiration for a new generation of scientifically literate citizens. As a **NEWMAST** participant, you will be able to:

- Observe current state-of-the-art research and development activities in space science and technology at NASA centers
- Interact directly with NASA scientists and engineers concerning specific projects in their research laboratories
- Receive NASA resources to share with your peers and students
- Update your knowledge of new technology and developments in aeronautics, astronomy, and aerospace science
- Review the wealth of materials in the NASA Teacher Resource Center

NEWMAST workshops will be held between June 17 and August 18, 1990 at the following NASA centers:

- Ames Research Center, Moffett Field, California
- Goddard Space Flight Center, Greenbelt, Maryland
- Marshall Space Flight Center, Huntsville, Alabama
- Jet Propulsion Laboratory, Pasadena, Cailfornia

NOMINATE TALENTED TEACHERS FOR NEWMAST NOW!

ELIGIBILITY:

Nominees must be full-time outstanding teachers of math, science, or pre-college technology, grades 7-12, in public and private schools in the U.S. and the U.S. territories, Department of Defense dependent schools, Department of State overseas schools, and Bureau of Indian Affairs schools.

Nominees must have a minimum of five (5) years teaching experience and hold certification in science, mathematics, or pre-college technology.

NOMINATION GUIDELINES:

The nominee has established a reputation among peers for motivating and encouraging students to reach a standard of excellence.

The nominee has significantly improved student understanding of science, mathematics, or precollege technology.

The nominee has continued to grow and show professional involvement in his/her discipline, and in the science and artistry of teaching.

The nominee reaches students in particular need of educational resources and innovative or motivational approaches to interdisciplinary learning, such as rural populations, gifted and talented students, and underrepresented minority groups.

Nomination of outstanding teachers from underrepresented minority groups is especially encouraged. The sponsors and cooperators of the **NEWMAST program are committed to eliminating barriers to educational opportunities for all students and educators.*

DEADLINE:

Completed nomination packages must be postmarked no later than March 9, 1990.

NASA FactSheet

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

April 1990

"SPACE CLASSROOM ASSIGNMENT: THE STARS"

BACKGROUND

"Space Classroom" is a new NASA educational effort designed to involve students and teachers in the excitement of Space Shuttle science missions. This new program joins more than 160 other educational programs being conducted by NASA that use the agency's missions and unique facilities to help educators prepare students to meet the nation's growing need for a globally competitive workforce of skilled scientists and engineers.

The first Space Classroom project, called Assignment: The Stars, will capitalize on the May 1990 flight of Astro-1, a Space Shuttle astronomy mission. The project is designed to spark the interest of middle school students, encouraging them to pursue studies in mathematics, science and technology. It will offer educators an alternative approach to teaching their students about the electromagnetic spectrum -- a science concept that is required instruction in many classrooms in the United States.

Space Classroom, Assignment: The Stars, involves several educational elements. They include a lesson on the electromagnetic spectrum to be taught live by the Astro-1 crew from the cabin of the Space Shuttle Columbia during the flight; a supporting lesson to be taught from the Astro-1 control center in Huntsville, Ala.; an Astro-1 teachers guide; an Astro-1 slide presentation; a NASA educational satellite video conference next fall; and post-flight video products suitable for classroom use.

THE EDUCATIONAL ELEMENTS

A Lesson From Orbit

The major component of Assignment: The Stars will be a lesson taught by members of the Astro-1 science crew from the Space Shuttle as they orbit the Earth during the mission. This 15-20 minute presentation will focus on the electromagnetic

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spectrum and its relationship to the high-energy astronomy mission.

The crew presentation will be followed by demonstrations and discussions of the concepts introduced by the crew from a classroom in the Astro-1 control center at Marshall Space Flight Center.

The lesson will conclude with an opportunity for some students participating in the lesson from Marshall and from the Goddard Space Flight Center, Greenbelt, Md., to ask questions of the crew in orbit. Students at both centers will also participate in additional workshops, tours and laboratory sessions.

The lesson by the crew, the follow-up lesson from the Astro-1 control center, and the question-answer session will be carried live on NASA Select TV, Satcom satellite F2R, transponder 13, 3960 megahertz, 72 degrees West longitude. NASA Select will carry continuous programming of all mission events as well.

The lesson is tentatively scheduled for the fifth day of the mission. However, because launch dates and the actual lesson date and time are subject to change, teachers may want to arrange to videotape the lesson off NASA Select for subsequent classroom use. Many local cable companies carry NASA Select TV coverage of missions. Teachers may wish to check this possible resource if they do not have access to satellite receivers. All NASA Select mission programming may be used freely for non-commercial purposes.

In the fall of 1990, tapes of the lesson will be available for a small fee from NASA CORE, Lorain County Joint Vocational School, 15181 Route 58 South, Oberlin, Ohio, 44074, phone: (216) 774-1051.

A Guide For Teachers

Seeing in a New Light, the Astro-1 teachers guide with activities, is a practical source of lesson plans and student activities on the electromagnetic spectrum. Intended for middle school use, the concepts range in difficulty from basic instruction on the electromagnetic spectrum to information on interesting astronomical objects and telescopes. The guide is interdisciplinary, with projects in math, literature, social studies, and art, and is easily reproduced for individual and small-group assignments.

The teachers guide is available at no charge from all NASA Teacher Resource Centers.

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A Slide Presentation

Astro-1: Seeing the Hidden Cosmos slide presentation, is a scripted set of 24 slides. The presentation describes the Astro-1 mission and basic concepts on the electromagnetic spectrum and astronomy. The slides include X-ray, ultraviolet, visible and infrared images of interesting astronomical objects.

Reproductions of the slide set and script are available from NASA CORE or by visiting one of NASA's Teacher Resource Centers.

A Post-flight Video Conference

A NASA Educational Satellite Video Conference on the Astro-1 mission science results is scheduled for October 1990. The interactive conference will feature NASA scientists and specialists in aerospace education and will be broadcast by satellite.

Further information will be available from Video Conference Series, Aerospace Education Services Project, Oklahoma State University, Stillwater, OK, 74078-0422; phone: (405) 744-8131.

An Experiment in Amateur Radio

The Shuttle Amateur Radio Experiment (SAREX-II) is another element of the Astro-1 mission that offers educational value. Payload Specialist Dr. Ron Parise, a Spacelab science astronaut, will use a ham radio aboard the Shuttle to communicate with amateur radio operators on Earth. Parise's call sign is WA4SIR.

Additional information is contained in Amateur Radio in Space, NASA EB-89-1, available from NASA Spacelink or from a NASA Teacher Resource Center.

KEEPING CURRENT

NASA Spacelink

NASA Spacelink is a computerized information service for educators. It is accessible from most computers through a modem by dialing (205) 895-0028. It includes a variety of information on the Astro-1 mission. During the flight, it will be updated daily.

Spacelink information can be obtained by writing the Spacelink Administrator, Mail Code CA20, Marshall Space Flight Center, Huntsville, Ala., 35812, or by phoning (205) 544-0038. Spacelink is a free service, but your telephone company makes normal charges for the long distance call.

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Telephone Hotline

Beginning approximately one week before launch, Astro-1 Update, a recorded bulletin on the status of the Astro-1 mission and information about Space Classroom activities, will be available by dialing (205) 544-8504.

Today in Space

Although not an element of the Space Classroom program, NASA will air a half-hour daily summary of Astro-1 mission activities at approximately 2:30 p.m. CDT on NASA Select during the mission. Teachers may wish to record and view the program as a source of up-to-date information on mission progress.

NASA TEACHER RESOURCE CENTERS

Further information about NASA's Astro-1 Space Classroom project can be obtained from the following Teacher Resoure Centers:

Teacher Resource Center
NASA AMES RESEARCH CENTER
Mail Stop 204-7
Moffett Field, CA 94035
415/694-6077

Teacher Resource Ctr./Mail Stop: CS 530
JET PROPULSION LABORATORY
4747 New York Avenue
La Crescenta, CA 91214
818/354-6916

Teacher Resource Center
NASA JOHN F. KENNEDY SPACE CENTER
Mail Code ERL
John F. Kennedy Space Center, FL 32899
305/867-4090

Teacher Resource Center, Mail Stop 8-1
NASA LEWIS RESEARCH CENTER
21000 Brookpark Road
Cleveland, OH 44135
216/433-2016/2017

Teacher Resource Center
Stennis Space Center
Building 1200
Stennis Space Center, MS 39529
601/688-3338

Teacher Resource Center
NASA GODDARD SPACE FLIGHT CENTEI
Mail Code 130.3
Greenbelt, MD 20771
301/286-8570

Teacher Resource Center
NASA JOHNSON SPACE CTR.
Mail Code AP-4
Houston, TX 77058
713/483-8696

Teacher Resource Center
NASA LANGLEY RESEARCH CENTER
Mail Stop 146
Hampton, VA 23665
804/865-4468

NASA/MSFC Teacher Resource Ctr.
ALABAMA SPACE AND ROCKET CENTER
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Huntsville, AL 35807
205/544-5812

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MONTGOMERY, AL 36104
(205) 265-8507

☐ 105 MAIN STREET
P.O. BOX 228
TUSCUMBIA, AL 35674
(205) 381-7060

April 19, 1990

Dear Colleague:

A premiere prototype NASA Mobile Teacher Resource Center called Project LASER (Learning About Science, Engineering and Research) will be parked on the Capitol East Front Plaza on April 26 - 27, from 10:00 AM - 6:00 PM.

All MEMBERS are invited to visit this 48-foot-long van-style trailer. It is designed and outfitted with advanced electronic work stations for grades K - 12 teachers to receive a broad range of information and educational materials to enhance their classroom presentations in the areas of mathematics, and science. The 6 work stations, for 12 teachers, are equipped with a computer, an electronic information system, videotape recorder, and a monitoring system so that teachers can copy from a large library of NASA educational videotapes and documents. The van also contains a laser printer, photocopy and photographic equipment to allow teachers to copy lesson plans, slides related to aeronautics, astronomy and space exploration.

Senate staff who have assignments in education and space are also invited to visit the Mobile Teacher Resource Center.

This pilot program has been developed by NASA's Marshall Space Flight Center and numerous corporate sponsorships. It is in response to White House and Congressional requests that Federal R & D Agencies and industry join forces to reach America's teachers and students in a major educational outreach program.

The walk through, with NASA education staffers on board, will be an educational experience. It should take about 10 - 15 minutes.

Richard Shelby

Howell Heflin

Barbara Mikulski

18

JUN 8 '90 15:08 FROM MSFC DIRECTOR OFC PAGE.004

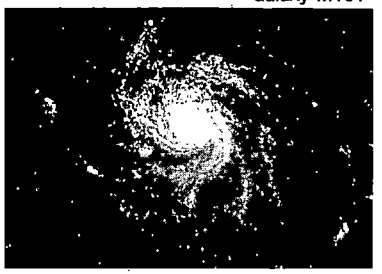
Observatory Operations in the Space Age

The Hubble Space Telescope was developed by the National Aeronautics and Space Administration, and its partners in space, under the Office of Space Science and Applications at NASA Headquarters in Washington, D. C. The Marshall Space Flight Center in Huntsville, Alabama, has been responsible for the design and development of the telescope. Goddard Space Flight Center in Greenbelt, Maryland, developed the science instruments; it will operate the telescope and manage the Space Telescope Science Institute. The European Space Agency has played a major role in development of the telescope by providing the power producing solar arrays and one of the science instruments. The Johnson Space Center in Houston, Texas, is training crews for the launch, deployment, and maintenance of the Hubble Space Telescope and will be in charge of Shuttle mission operations. The Kennedy Space Center in Cape Canaveral, Florida, will ready the telescope for launch aboard the Shuttle.

After NASA deploys the telescope in space, Marshall personnel will verify that the telescope and ground support systems work, and Goddard personnel will check out the science instruments. Because the telescope is so sophisticated and complex, checkout will take time. It will be many months before it is ready for full-time research. The Space Telescope Operations Control Center at the Goddard Center will be in charge of day to day telescope operations. Ultimately, the operations center will be able to complete more than 200 observational programs a year, providing about 3,500 hours of observing time annually.

The Space Telescope Science Institute, operated by the Association of Universities for Research in Astronomy (AURA) and located at The Johns Hopkins University in Baltimore, Maryland, will be responsible for the telescope's observing agenda. In response to requests from scientists all over the world, astronomers associated with the institute are generating the telescope's observing plan. The institute scientists engage in their own research and distribute telescope data to other scientists.

Galaxy M101



The Hubble Space Telescope and The Great Observatories

Progress occurs in science as information is gained through many channels. NASA's strategy for astrophysics research in the rest of this century relies on a set of complementary observatories in space, each dedicated to view the universe through a different window in the spectrum:

- Hubble Space Telescope (HST) - infrared radiation, visible light, ultraviolet radiation
- Gamma Ray Observatory (GRO) - gamma rays
- Advanced X-Ray Astrophysics Facility (AXAF)- x - rays
- Space Infrared Telescope Facility (SIRTF) - infrared radiation

With improvements in sensitivity and resolution much beyond their predecessors, the Great Observatories will enable us to study astronomical objects in more detail than we ever have. Together, they will produce a golden age of astronomy.

The Hubble Space Telescope is a crucial member of this family of Great Observatories, the only one designed to study the universe in visible and ultraviolet light. Maximum scientific benefit will be achieved when all of these observatories operate simultaneously, each complementing the others. Just as we depend on all of our senses to perceive the world around us, so we need all of the Great Observatories working together to better know the universe.

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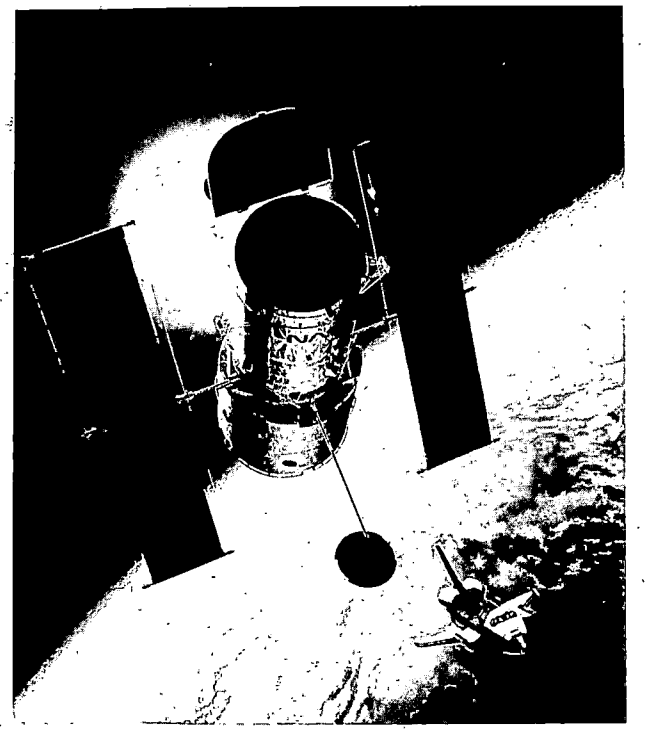
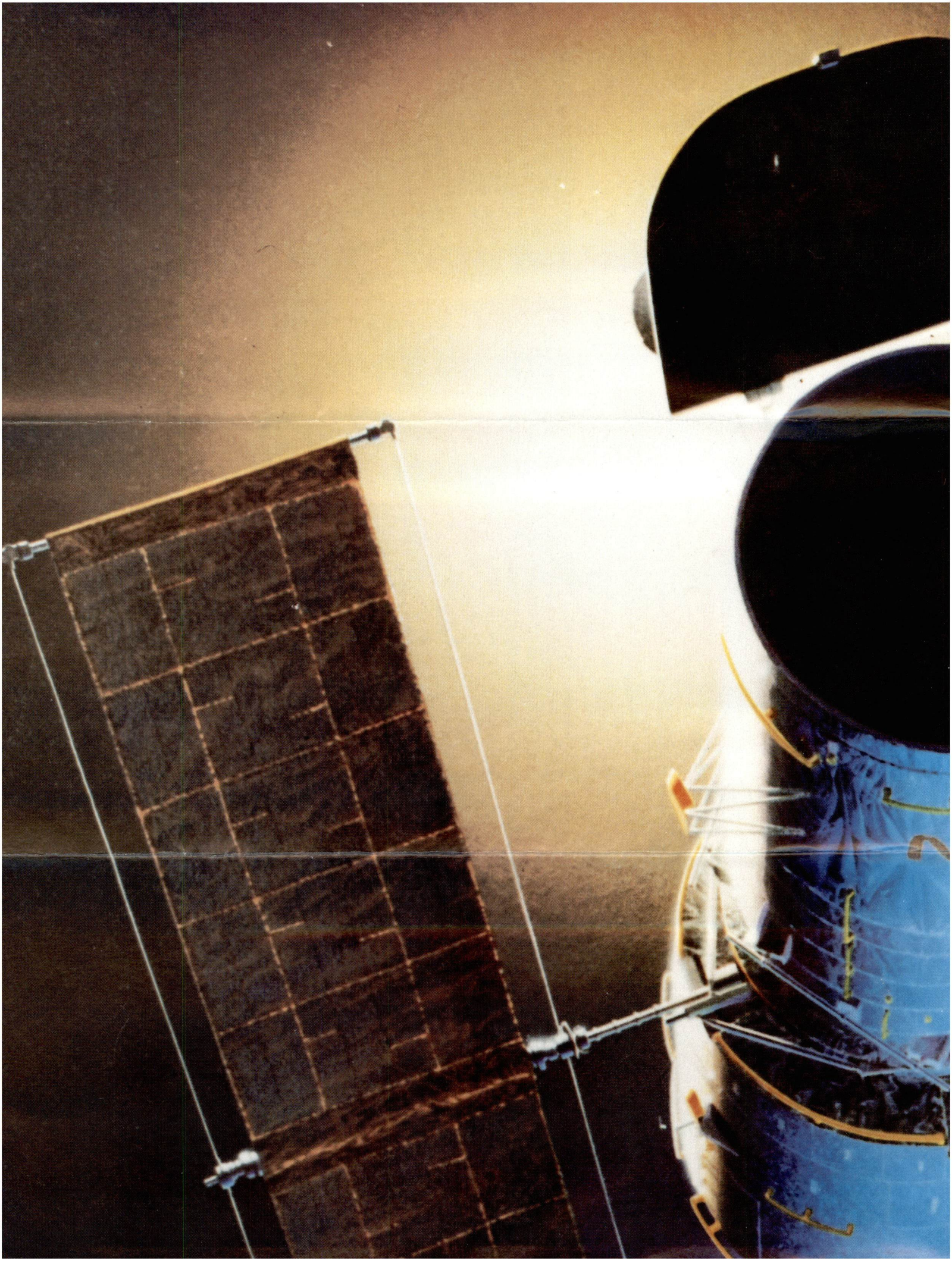
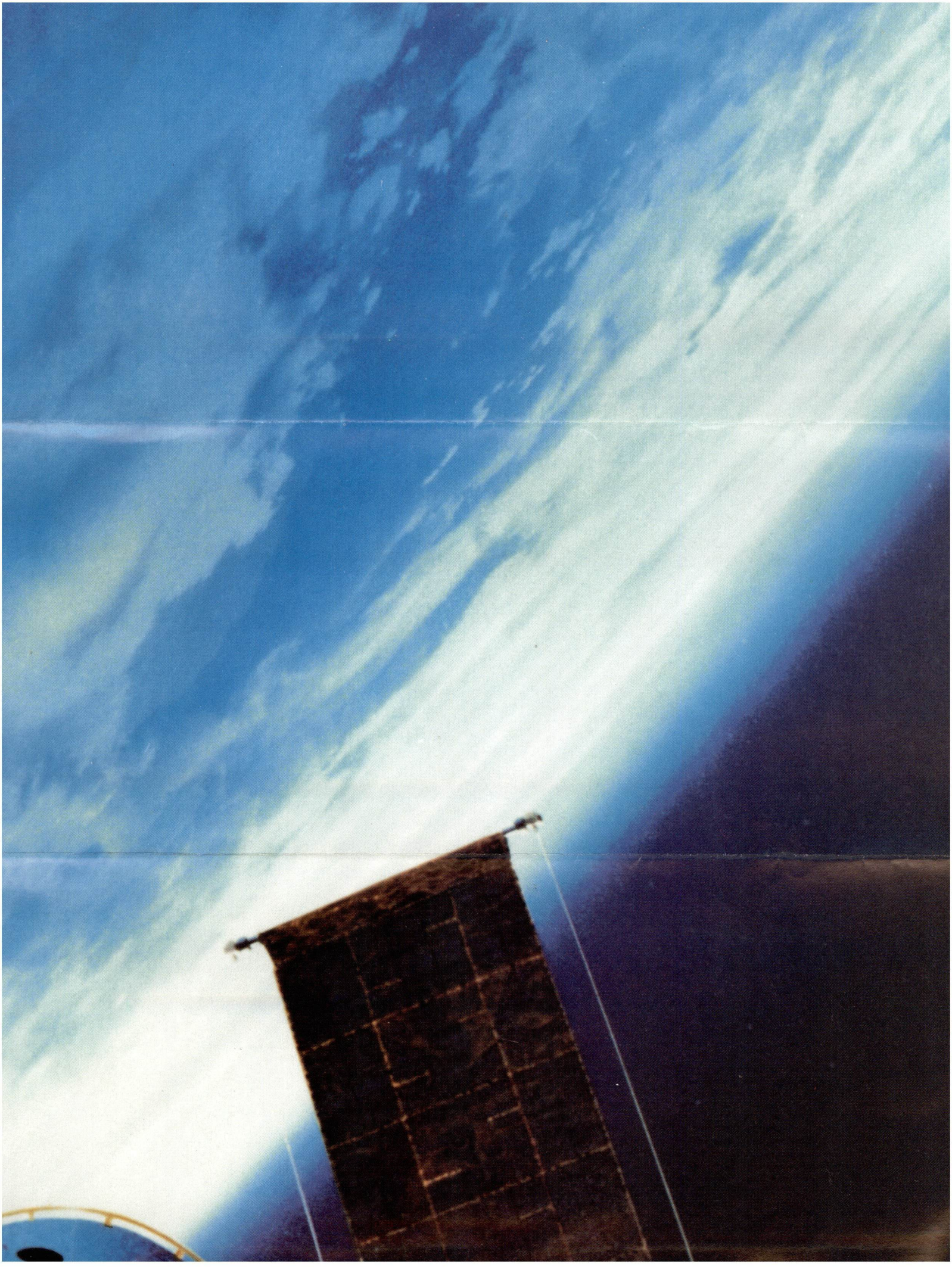
Hubble Space Telescope



NASA

National Aeronautics and Space Administration



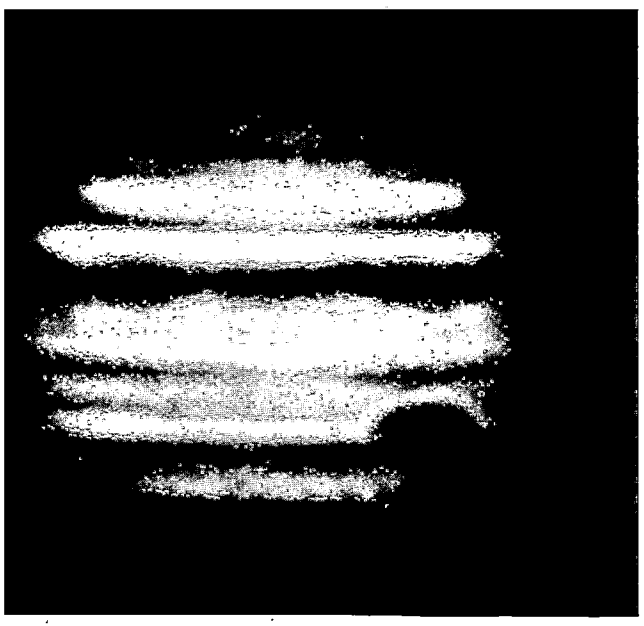


The Telescope's Senses

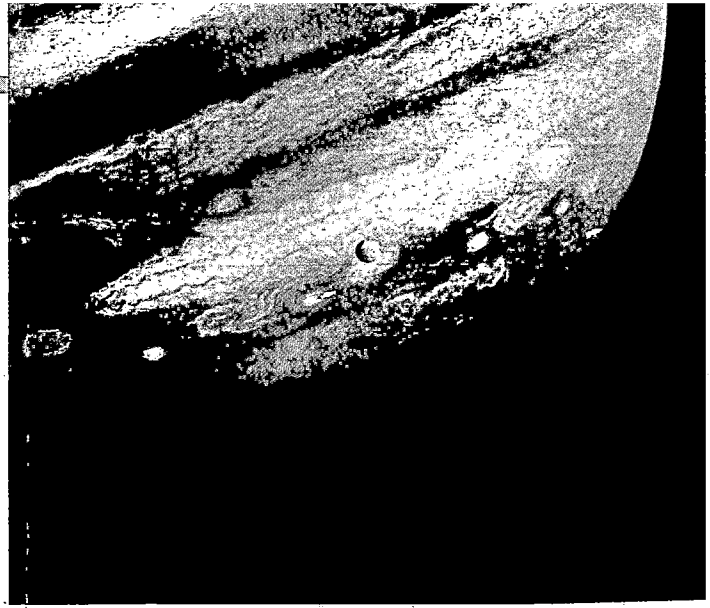
Just as we have eyes that sense light and a brain that translates it into visible images, the Hubble Space Telescope has instruments that sense light and computers that convert it into images and other forms of information. The telescope's "eyes" are in space, but much of its" brain" is on the ground.

The telescope's electronic light collectors, which are so sensitive that they could detect light from a flashlight a quarter of a million miles away, record energy as electrical signals. These signals are sent to powerful onboard computers and then to a computer network on the ground where the data analysis takes place. Astronomers use computers to display the signals as photographs, spectra and other types of data.

For each observation, the pointing system aims the telescope at a planet, star, galaxy or other object. Light from the object enters the telescope and strikes the primary mirror which



Jupiter as seen by a telescope on Earth



The spectrograph with the highest resolution is able to detect objects 1,000 times dimmer than those observed by previous space instruments.

The photometer, a light meter, records the total light from an object in space and notes any changes in brightness in fractions of a second. Using the data, astronomers can determine the relation of stars to each other and their distances from Earth. Spikes of hot energy erupting from sources also can be identified.

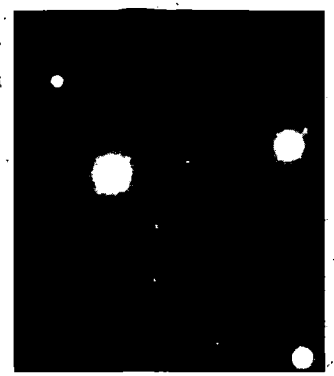
The telescope's pointing system also collects scientific information by pinpointing the positions of objects five times more accurately than we can from Earth.

The Universe Beyond

Twinkling like diamonds in the night, stars enchant us. All our knowledge about the universe is a result of what we observe, yet with the naked eye we can see only about 6,000 of the hundred billion stars in our own galaxy, almost every problem in astronomy, especially issues involving the origin, age, and fate of the universe. The Hubble Space Telescope will measure distances five times more accurately than current estimates.

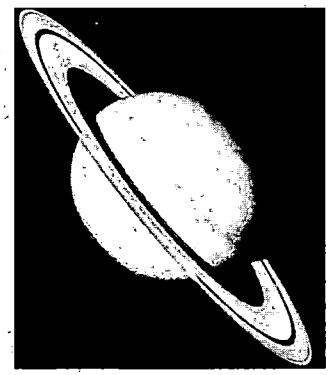
What are quasars and other exotic objects?

Among the most intriguing celestial objects are quasars and other compact objects that produce intense radiation for their size. Because these objects are small and distant, we cannot see exactly what they are from Earth. With the Hubble Space Telescope, astronomers may discover what these objects really are.



Quasars

Saturn



What are the other planets in our solar system like? The Hubble Space Telescope will give us our first close look at the outermost planet in our solar system, Pluto. Pictures of closer planets will be almost comparable to images from the Voyager spacecraft; while the Voyagers gave us passing glimpses of the planets, the Hubble Telescope will view the planets over longer periods to reveal seasonal or other cyclic changes.

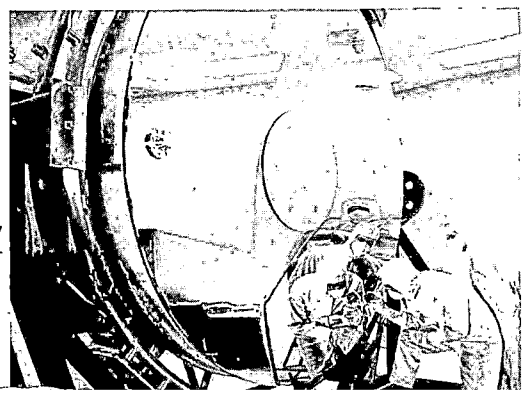
Do other planets exist?

It is unlikely that of all the stars in the universe, our sun is the only one with a family of planets. The Hubble Space Telescope probably will not observe planets around another star directly, for they would be small and hidden by the star's light. The telescope may detect wobbles in a star's motion caused by an orbiting body. The telescope also may see swirling dust around a young star where a planetary system may be forming.

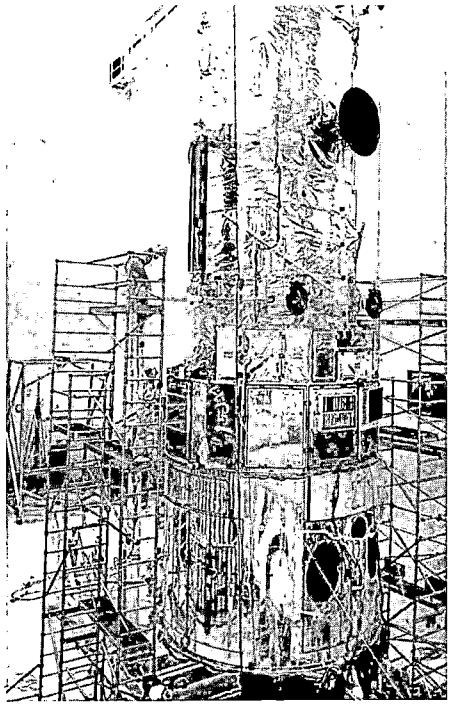
scientific instruments, electrical systems and batteries, and the pointing and control mechanisms. Solar arrays for generating electricity and antennas for communicating with operators on the ground extend from the telescope. Doors allow astronauts to remove parts for repair or replacement without bringing the telescope home.

Building the telescope has presented many tough engineering challenges. To collect the faint light from sources trillions of miles away, the Hubble Space Telescope's eight-foot primary mirror had to be almost perfectly smooth. No telescope mirror has ever been more finely polished. If the surface of Earth were as smooth, the highest peak and the deepest valley would deviate from the surface by less than three inches.

Another challenge was to provide a way to point the telescope with precision. The telescope must be able to locate a position in the sky to within 0.01 second of arc. This is equivalent to pointing a needle at a human hair located two blocks away. The pointing system is so accurate that it is actually used as one of the scientific instruments.



The primary mirror



Preparing the telescope for launch

reflects it to a second smaller mirror. This mirror directs the light into selected scientific instruments located behind the primary mirror. The Hubble Space Telescope uses five scientific instruments to study the universe: two cameras, two spectrographs, and one photometer.

The two cameras record light that is translated into pictures of the universe. A wide field camera photographs large areas; it can photograph hundreds of galaxies at once or the entire face of each planet in our solar system (except Mercury which is too close to the sun). A faint object camera can cover only one-tenth the area of the wide field camera, but it makes more detailed images of dimmer objects. Astronomers can choose the best camera for their observations.

In additon to pictures, other types of information are valuable for studying the universe. Atoms emit and absorb light in packages of energy called photons. Each element, composed of atoms such as hydrogen or oxygen, has a unique signature associated with specific energies. Spectrographs can separate radiation by energy in much the same manner that raindrops split visible light into the spectrum of colors in a rainbow. By studying the intensity and distribution of radiation, scientists can determine an object's chemistry, temperature, and density.

The Hubble Telescope spectrographs will reveal details of objects that we ordinarily cannot see. They will study both the visible and ultraviolet radiation emitted by objects.

Jupiter as seen by Voyager

the Milky Way. Our largest ground-based telescopes have extended our vision to reveal a universe with an estimated hundred billion galaxies, each populated by several hundred billion stars.

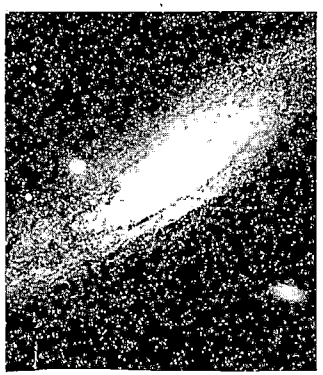
Radiation in the form of light, brings us the information needed to understand the past. Light travels very fast, but space is so vast that much time passes before the light from distant objects reaches us. When it is collected by the Hubble Space Telescope this information will tell us about the conditions which prevailed at the source when that light was emitted. So in effect, we are "looking back in time." The Hubble Space Telescope will extend our vision by detecting light that started its journey 14 billion years ago when the universe was young. Imagine what wonders we will discover.

Questions about the Universe

The Hubble Space Telescope will help answer key questions in astronomy and astrophysics.

How do stars and galaxies form and evolve?

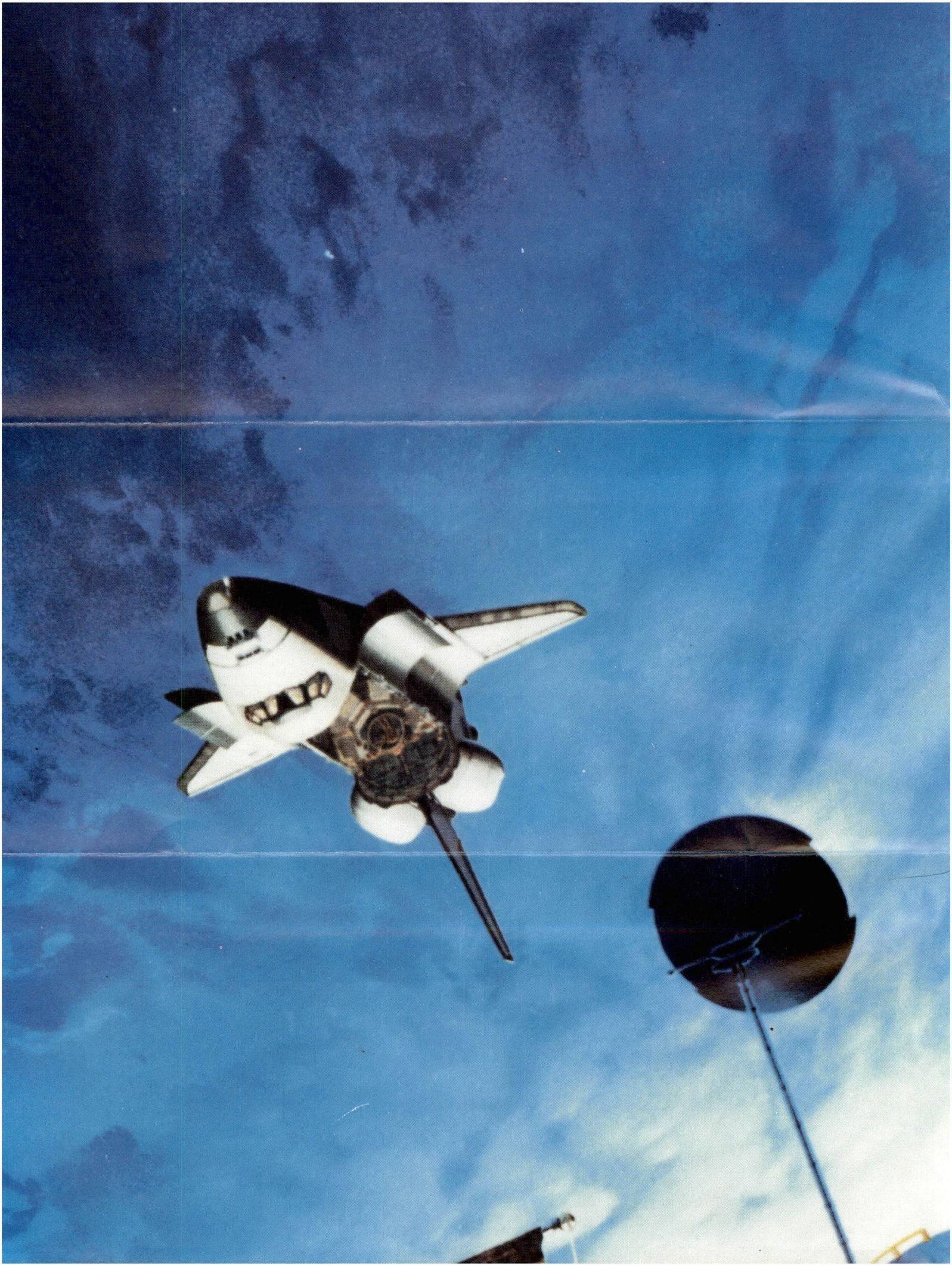
A variety of stars exist. Today, we see evidence of stars being born and dying. Stars and other objects come together to form galaxies of varied shapes and sizes. To understand the universe, astronomers need to get acquainted with stars and galaxies of all ages and types. With the Hubble Space Telescope, astronomers will view billions of stars and galaxies with new clarity to obtain a large statistical survey of their characteristics.

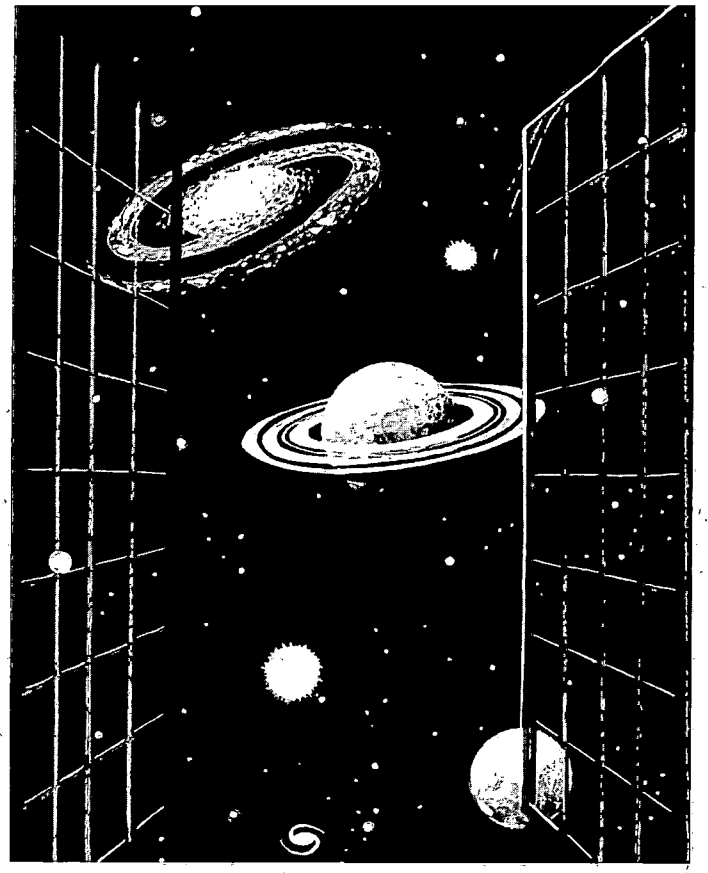


Andromeda Galaxy

How big is the universe?

We have never accurately measured distances to stars and galaxies well beyond the Milky Way. Current estimates are so uncertain that distant galaxies may be twice as far away or only half as far away as we think. Distance is





A Picture Window View

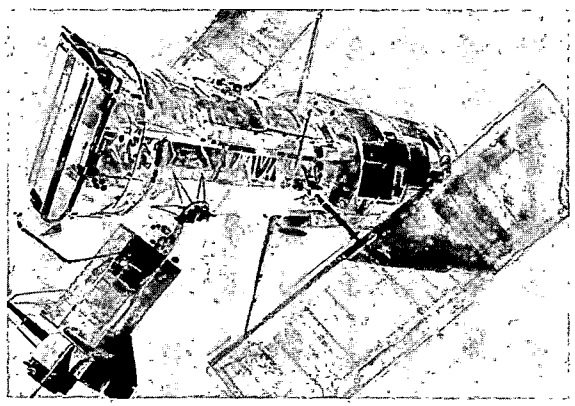
Imagine seeing the universe as if it were just outside your window. Clouds and lightning form as a storm brews on Jupiter. An icy moon revolves nearby. In the distance, you see billions of stars. Still farther away, quasars shine.

NASA's Hubble Space Telescope will give us this picture window view of the universe. The telescope will see planets, stars, and other objects about 10 times better than we now can with our best optical telescopes on Earth. It will show us the most distant planets in our solar system and monitor seasonal changes on nearby ones. It may detect evidence of new worlds, planets revolving around other stars, raising the possibility of extraterrestrial life. The Hubble Space Telescope will alter our perceptions of the universe — perhaps as dramatically as Galileo's telescope revolutionized thought almost 400 years ago.

Unlike most observatories, the Hubble Space Telescope will be in space outside our atmosphere. Looking at the heavens through the best telescope from the highest mountain on Earth is still much like trying to identify someone at poolside when you are sitting on the bottom of a swimming pool. Our vision is blurred. The atmosphere masks much of the detail of objects in the universe. From orbit, the telescope can detect light before it is absorbed or distorted by the atmosphere. It can "see" stars that release infrared and ultraviolet light that, because of the atmosphere, never reaches telescopes on Earth.

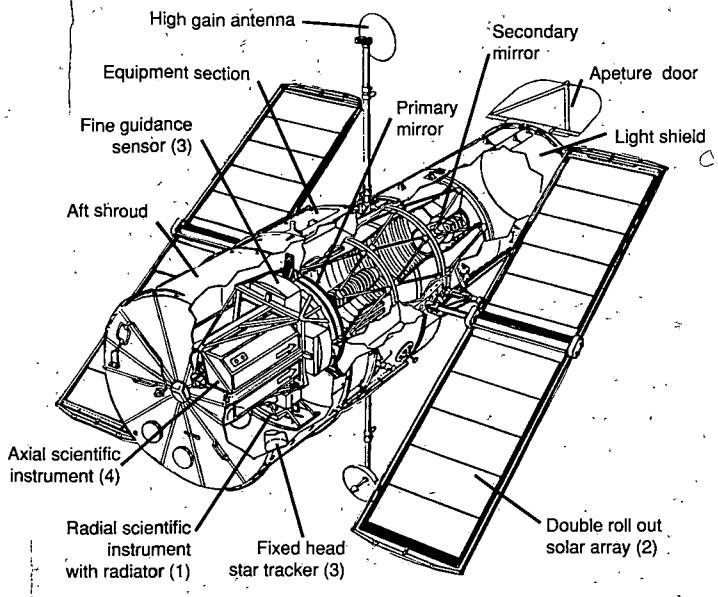
For many years, astronomers have dreamed of placing a large observatory in orbit to make high-quality observations. The Hubble Space Telescope is the realization of that dream.

Placing the telescope in orbit



A Great Space Observatory

The 43-foot Hubble Space Telescope will be the largest astronomical observatory ever placed in orbit. This great observatory was named the Hubble Space Telescope in honor of the American astronomer, Edwin P. Hubble. Before Hubble's work in the 1920s, no one knew with certainty that the universe extended far beyond the Milky Way. His observations of other galaxies led to his discovery that the universe is expanding.



The Space Shuttle will carry the telescope into orbit some 370 miles above Earth. Then, the Shuttle will come home, leaving the telescope to observe the universe for 15 years or longer. The Hubble Space Telescope is a major scientific resource that will be shared by scientists around the world. To keep it in top-notch condition, every few years, astronauts will visit it to do routine repairs and to replace scientific instruments and other equipment as technology improves.

The 25,000-pound observatory is about the size of a bus and looks like a tower of stacked silver canisters. Each section houses important telescope components: the mirrors, the