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OA/ID Number: 13715
Folder ID Number: 13715-007

Folder Title:
National Academy of Sciences 4/24/90 [OA 8311] [1]

Stack:	Row:	Section:	Shelf:	Position:
G	26	20	5	3

p.1 : + Adm. Watkins ✓

p.3: Manuf. Forum – announced ✓

p.8: $19B for space station ✓

p.7: Carlson – room over a pub ✓

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p.7 - NIH

Carolyn

(Lange/Cawley)
April 20, 1990
9:30 P.M.
[SCI.DOC]

PRESIDENTIAL ADDRESS: NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.
MONDAY, APRIL 23, 1990
2:00 P.M.

Adm. Watkins

Distinguished members of the National Academy, Dr. Press, Dr. Ebert, Dr. Raven, Dr. Gordon, Dr. Blout, Dr. Bromley, ladies and gentlemen: It's an honor to be with you today. The advice and counsel of this Academy has been crucial to American Presidents for well over a century. I'm proud to be the latest to thank you.

We stand at a moment of wondrous prosperity. But our wealth goes far beyond the merely material. Ours is an **intellectual** prosperity, unprecedented in history. For that, and the health and security it affords this nation and the world, gratitude is owed to the men and women who have committed their minds and lives to science.

Those devoted to such work -- its patient searching, its passionate struggles -- have engaged themselves in mankind's most exalted mission, and the mind's manifest destiny: the search for understanding.

N.A.S.: A New Era in Svce to the Nation

President Abraham Lincoln established this great institution in the dark hours of our nation's greatest crisis -- which testifies to the enduring importance of scientific knowledge. In the years that followed your academy has responded to urgent national needs in times of war and peace.

NAS Historical Booklet, p. 3 + + text of Coolidge speech

top of p. 2

p. 3 - announced Manuf. Forum
p. 1 - Adm. Watkins
p 8 - $19B

text of Coolidge speech

When this magnificent building was dedicated, Calvin Coolidge predicted "a new day in scientific research. A new sun is rising," he said. He was right. The awesome scientific advances of this century, many of which you've brought about, bring us ever closer to understanding the universe, its origins, and our own. And science has told us a stranger and more wondrous story than myth might ever have written for us.

NY Times - National Section 1-4-90

Fourscore and ten or twenty billion years ago, the theory goes, it all began -- with a universe of energy and mass unimaginably hot and compressed, containing everything that would become what we now see in the heavens. And then, science tells us -- in one incomprehensibly powerful instant -- energy and matter of every kind exploded in every direction. [[Or as a layman might explain it, somebody hit that cosmic baseball right out of the park.]]

But while the pace of **cosmic** change may have begun with blinding speed and slowed down since, the pace of our **scientific** evolution has been accelerating rapidly. Growing in intensity like a series of chain reactions in a critical mass of highly-trained American grey matter -- touching off scientific and technical revolutions in every direction.

Today, I want to outline the role this Administration is playing to advance those revolutions. Because as the pace of science accelerates, I believe that **government must keep pace -- and <u>will</u> keep pace.**

First, we've moved to better integrate science and technology into the policy process. We have created a White House Working Group that will more closely link science and technology considerations into the policy-making process of the Economic and Domestic Policy Councils.

My Assistant for Science and Technology, Dr. Allan Bromley, is also an active participant in those Councils, advising them on matters related to science and technology -- as well as serving on the National Space Council.

And we're also committed to greater cross-fertilization with talent from the private sector -- on issues ranging from pure research to manufacturing performance. So this year we created a President's Council of Advisors on Science and Technology -- experts whose guidance I value and depend on. We'll also be looking for counsel from this Academy's new Manufacturing Forum, just established this month.

We want to advance America's tradition of innovation -- and we intend to get the biggest bang for the Federal buck. So in January, we sent a budget to Congress that includes a **record $71 billion for research and development** -- an investment in a stronger economy, a more secure nation, and a brighter future.

To improve the international competitiveness of American industry, and our overall standard of living, we've called for a permanent extension of the research and experimentation tax credit. And we're working to lower the cost

of capital and clear away regulatory burdens, so that industry can make the kinds of investments the future demands.

Along with the applied, market-driven knowledge so crucial to this country's competitive future, let me reaffirm two other priorities:

First, **math and science education.** We understand that only with a new generation of scientists and engineers will your work, and America's preeminence, be assured. So we're engaged in a broad initiative of reform and restructuring, in cooperation with the states. It is an effort that began with our first-ever Education Summit with the nation's governors last fall. Our goal is to make American students first in the world in science and math achievement by the end of this century -- and to convince more women and minorities to study science.

We're providing a number of new incentives for students, like the National Science Scholars program I've proposed. We're opening the doors of Federal laboratories, facilities, and agencies to students and teachers. Our budget increases funding to **over one billion dollars** for science, math, and engineering education -- through the Departments of Education, Energy, Interior and others, as well as the National Science Foundation and NASA. We are committed to ensuring that **America has the brainpower to remain at the forefront.**

A second priority of this administration is **basic research**

-- the historical wellspring of this nation's well-being. Science must be able to continue seeking answers to our most fundamental questions.

That's one reason our budget calls for increasing funding for the U.S. Global Change Research Program by 57 percent -- to over one billion dollars. And earlier this year, I reiterated my commitment to double the National Science Foundation budget by 1993. **Today, I want to call on Congress: Put our money where our future is. Put an increased National Science Foundation budget back on track.**

Today, science and technology are assuming a broader and more interrelated role in human life than ever before. They are becoming forces for historical change.

Satellites already help us study the earth's natural systems and assess environmental threats -- and the Mission to Planet Earth will further our work of global stewardship.

But this past year, in the Revolution of '89, we have also seen communications satellites, along with video cameras, VCR's and FAX machines, becoming a potent force for peace -- both a product of science and a source of conscience -- **bringing the actions of nations before the eyes of the world.**

Pictures from Poland and South Africa, scenes on the Berlin Wall... the eye of technology has proved more powerful than chisels for breaking down barriers -- etching the idea of freedom on the psyche of humanity -- and setting off a wondrous, hopeful, **political** chain reaction, worldwide.

It's no accident that many of the individuals at the center of today's worldwide political revolutions share a vision of the future based on personal freedom, openness, and freedom of inquiry. These values are shared by our political system and by science alike. Science, like any field of endeavor, relies on freedom of inquiry. And one of the hallmarks of that freedom is objectivity.

Now more than ever -- on issues ranging from climate change, to A.I.D.S. research, to genetic engineering, to food additives -- government relies on the impartial perspective of science for guidance. And as the frontiers of knowledge are increasingly distant from the understanding of the many, it is ever more important that we can turn to the few for straightforward advice.

The National Academy of Sciences is **renowned** for objectivity and immunity to partisan pressures. Your impartial guidance has been invaluable to American Presidents, and the American people, for well over a century. So I am confident that the members of this body -- the most distinguished scientists in America -- will continue the tradition that has been the Academy's hallmark.

On this I know we agree -- because so many of our technical and scientific achievements have been the products of independent minds. And if the earth-moving events of 1989 reminded us of anything, it's that complex bureaucracies and centralized planning don't work well in the governance of societies. **We will not try to impose them on science.**

Just as entrepreneurs and small businesses fuel the growth of the American economy, the backbone of American science is its brilliant array of individual investigators, spread across the nation.

Among so many, think of Chester Carlson, who invented the photocopy machine in a little room behind a beauty parlor. Or Barbara McClintock, working alone, who made monumental discoveries in genetics nearly 50 years ago that the world began to understand only in the last decade.

[[Of course, I can't claim to comprehend how science does its work. Like many, my scientific understanding has been influenced by those Gary Larson cartoons. Like the one where, after detailed calculations, Einstein discovers that Time is actually Money.]]

One of the **best** things government can do to support the magnificent creativity and energy of the American technical community is to locate individual scientists with talent, and furnish them with adequate resources and state-of-the-art instrumentation -- through agencies like the National Institutes of Health, the National Science Foundation, the Departments of Defense and Energy, and others -- to help these investigators make progress.

But there are **also** scientific challenges that, because of their unprecedented scope and importance, demand unusual support -- and international cooperation. Already, the European Space Agency, Japan, and Canada are making hardware contributions

valued at more than seven billion dollars for **Space Station Freedom**. Combined with our total investment of about 16 billion dollars, this will be the largest international R & D project ever undertaken.

We're exploring new ways to encourage international cooperation on other big science projects -- like mapping the human genome [GEE-nome], global change research, and the Superconducting Super Collider -- a technological giant that will recreate the fireball of our origins, and allow us to study forms of matter that haven't existed since the birth of the universe.

There's a vote coming up in Congress this week on that Super Collider -- so I'd like to call on the members to fully fund that project, as well as our NASA budget. Only by doing so will we keep America on the leading edge of advancing human knowledge, and pushing the limits of space exploration.

Tomorrow morning, the Space Shuttle is scheduled to lift into the heavens the most sophisticated celestial object that mankind has ever built -- with the power to see to the ends of the universe, and back to the birth of time. [[I understand it's half a billion times more sensitive than the human eye. Talk about the vision thing...]]

On the southwest grounds of this great Academy rests a bronze memorial to a scientist who helped redefine mankind's understanding of time and space, of matter and energy. Among the engravings on that memorial are words of wonder -- about the "joy

and amazement" Einstein felt, "at the beauty and grandeur of this world, of which man can just form a faint notion."

Your work, the work of science, daily brings that beauty and grandeur into sharper focus.

As President I can assure you of this: my administration is committed to supporting you, as you pursue the knowledge that illuminates the world. Knowledge that will surely, ceaselessly continue to bring benefit to all mankind.

Thank you. God bless you. And God bless this great Academy.

# # #

THE WHITE HOUSE

WASHINGTON

April 19, 1990

NOTE FOR CAROLYN CAWLEY

FROM: JOHN SCHALL JAS

RE: Math/Science Education

As we discussed, attached are materials explaining the Department of Energy's Math/Science Education Initiative, and proposed language to include in the President's speech to the National Academy of Sciences on Monday.

If you have any questions, please feel free to call me on extension 7090 or Peggy DuFour at the Department of Energy on 586-7970.

PROPOSED INSERT FOR SPEECH TO NATIONAL ACADEMY OF SCIENCES
ON APRIL 23, 1990

As we approach the 21st century, we face great scientific challenges and opportunities. Today's children are the scientific leadership of tomorrow.

In January, the nation's Governors and I declared six National Education Goals. The fourth of these is: "By the year 2000, U.S. students will be first in the world in science and mathematics achievement." To maintain American leadership in world technology, we can accept no less. We must increase the numbers of mathematicians, scientists, engineers and technicians in the United States, and create a more scientifically informed and literate citizenry. This must be a truly national undertaking, every individual, every community, and every organization -- both public and private -- has a role to play.

Therefore, today, as but one element of a far broader set of activities that we all must undertake in the years to come, I am charging all Federal agencies with a new mission. On behalf of our nation's young people, Federal agencies must assume a new role as instruments of science education. We must open wide the doors of our Federal laboratories to bring in more students and teachers. We must send our Federal scientists and engineers out into the community as volunteer teachers and mentors to excite and enlighten. Through the Departments of Education, Energy, Interior and others, the National Science Foundation and NASA, we are already reaching thousands of youngsters. If the nation is to reach its goal, we must do our best to assist in reaching hundreds of thousands.

We are targeting younger students -- to spark and hold their interest in the sciences. We must especially target women and minorities, who have fallen out of the science pipeline too soon and too frequently. And we must work in tandem with the States, the education communities, and with business and industry to create science alliances that fully mobilize the great scientific and technical resources of our Nation. I look to my Domestic Policy Council and to the Federal Coordinating Council on Science, Engineering, and Technology to coordinate this important effort.

I know the agencies have other responsibilities: cleaning up the environment, ensuring a drug-free America, and helping the poor and disadvantaged -- and certainly would not want to distract them from these important activities. Moreover, Federal math and science activities alone cannot possibly achieve this important national goal. But the stakes are too high and the long-term effects too important for continued competitiveness of American business. So today, I am also asking that American business pitch in and assist in these programs.

OFFICE OF THE SECRETARY

FACSIMILE TRANSMITTAL SHEET

DATE 4-18-90

TO John Schall

FAX NUMBER 456-7734 2223

OFFICE NUMBER 456-7090

COMMENTS

FROM Peggy Dufour

FAX NUMBER

OFFICE NUMBER 586-7970

NUMBER OF PAGES INCLUDING COVER 2

Talking points for National Academy speech 4/24

(to follow material on major scientific issues facing Nation/world)

As we approach the 21st Century, we face many great scientific challenges and opportunities.

Today's children are the scientific leadership of tomorrow.

In January, the nation's Governors and I declared six National Education Goals. The fourth of these is "By the year 2000, U.S. students will be the first in the world in science and mathematics achievement." To maintain American leadership in world technology, we can accept no less. We must increase the numbers of mathematicians, scientists, engineers and technicians in the United States, and (create) actualize a more scientifically informed and literate citizenry. This must be a truly national undertaking.

Therefore, today I am charging (all) Federal agencies with a new mission. On behalf of our nation's young people, they must assume a new role as instruments of science education. We must open wide the doors of our laboratories to bring in more students and teachers. We must send our scientists and engineers out into the community as volunteer teachers and mentors to excite and enlighten. We must target women and minorities, who have fallen out of the science pipeline too soon and too frequently. And we must work in tandem with the States, the education communities, and with business and industry to create science alliances that fully mobilize the great scientific and technical resources of our Nation.

(that's the gist of it -- if you want a very short para on specifics, using DOE, I can do that, but I know you have a 3:00 meeting. Call me. 586-7970. Peggy)

additional thoughts

We are targeting younger students--to spark and hold their interest.

Through the Department of Education, Energy, Interior and others, the National Science Foundation and the NASA, we are reaching thousands of youngsters. If we are to reach our goal, we must reach hundreds of thousands.

As we work to accomplish this goal, each of the other National Education goals is advanced.

DRAFT

CLOSE HOLD

February 15, 1990

THE BUSH ADMINISTRATION'S COMMITMENT TO SCIENCE AND MATHEMATICS EDUCATION

NATIONAL EDUCATION GOAL IN SCIENCE AND MATHEMATICS EDUCATION

In this State of the Union Address, President Bush announced six national education goals, including one related to science and mathematics education: "By the year 2000, U.S. students will be first in the world in science and mathematics achievement."

The six goals represent the first phase in realizing commitments made at the President's Education Summit with Governors. They will be extended and adopted by the Nation's governors at the National Governors' Association Winter Meeting on February 25-27, 1990.

Reaching the ambitious goals of being first in science and mathematics education will require the concerted effort of all sectors of society, including the education community, the private sector, the mathematics and scientific communities, all levels of Government, as well as each individual citizen.

The Administration will work with appropriate agencies and organizations to ensure that appropriate and constructive measurements are developed to track progress. The President has requested a 50% increase in the Department of Education's statistics budget.

THE DEPARTMENT OF ENERGY INITIATIVE

The Department of Energy (DOE) has launched an agency-wide initiative to expand the use of its unique scientific facilities and personnel to help make American students the best in the world in mathematics and science. The Secretary of Energy's prototype utilizes partnerships and expert outreach to improve student and teacher knowledge, and provides a model that other Federal agencies with scientific laboratories, equipment, and expertise can replicate.

Specifically, the Secretary has directed the National Laboratories and other DOE scientific facilities programs to:

- Clarify their mission to identify education as a fundamental part of their activities.

- Open their doors to provide access to hands-on science experiences to students and teachers in surrounding communities.

- Broaden their educational programs or initiate additional ones to encompass the elementary and middle grades, to reach "average" students, and to increase participation by minority and female students.

- Collaborate with businesses, school districts, universities, museums, public libraries, community groups, and other partners to develop or expand education programs.

- Encourage scientists, engineers, technicians, and other experts to go into their communities and work with students and teachers.

The goals for this initiative parallel those of the Education Summit and focus on the year 2000. The major goals are as follows:

- Each year 10% of the Nation's mathematics and science teachers will be provided with high-quality teacher enrichment programs in hands-on science in Federal and private sector facilities;

- In numbers equaling at least 10% of the teaching force, scientists, engineers, and mathematicians will serve as volunteer expert teaching partners, bringing cutting-edge science into the classroom; and

- In 10% of the Nation's school districts, science alliances will be established, over the next 24 months, that include partners from the Federal government and the education and business communities.

Attaining these goals will require the involvement of all Federal agencies with mathematical and scientific facilities and expertise. Toward this end, the Department of Energy is compiling a list of existing Federal mathematics and science education programs and gathering information about the capacity of these programs to serve more teachers and students. In addition, Secretary Watkins has contacted chief executive officers of 10,000 corporations and is compiling similar information on private sector programs.

EXAMPLES OF OTHER COMMITMENTS IN THE FY91 BUDGET

The Bush Administration's commitment to strengthening science and mathematics education in elementary, secondary, and post-secondary education already extends across many Cabinet Departments and agencies.

The President's request for the FY1991 budget proposes over $1 billion in direct spending on science, mathematics, and engineering education by Energy, Education, the National Science Foundation, the National Aeronautical and Space Administration, and the National Institutes of Health, an overall increase of more than 27 percent above 1990.

Investing in Science, Mathematics, and Engineering Education
(in millions of dollars)

Department or Agency	Budget Authority 1990 Enacted	1991 Proposed	Dollar Change	Percent Change
NSF	$ 357	$ 463	+106	+39
Dept. of Ed.	180	292	+112	+62
NASA	42	51	+8	+21
Energy	17	25	+8	+47
NIH	287	292	+5	+2
	$ 883	$1,123	+239	+27

- The President has proposed the National Science Scholars program in the "Educational Excellence Act of 1989," originally sent to Congress last year. The program would provide scholarships of up to $10,000 each year for four years to talented high school seniors interested in pursuing a degree in science, mathematics or engineering at the institution of their choice.

- **The Department of Education - $292 million (up 62%).** The President has requested a 70 percent increase in the Dwight D. Eisenhower Mathematics and Science Education programs, from $136 to $230 million, for elementary and secondary programs that provide grants to states to enhance the abilities of math and science teachers.

Department programs such as the **National Research and Development Centers for Science and Mathematics, Science Improvement Programs** for minorities, and others develop and implement improved programs for teaching science and mathematics.

Often overlooked is that an estimated $1.5 billion of the $4.0 billion Chapter 1 budget goes to improve mathematics education for the disadvantaged.

- **Department of Energy - $25 million (up 47%).** The Department supports a variety of internships, research opportunities, and semester programs in state-of-the-art laboratories for secondary and post-secondary students.

- **National Science Foundation math and science education programs - $463 million (up 28%).** NSF will provide increased support of programs designed to improve education and human resources for science and engineering. NSF will expand the focus of precollege math and science programs on teacher preparation and enhancement, instructional materials development, educational technologies, the young scholars program, informal science education, and a new initiative (a systemic statewide math and science education activity).

  In addition, funds will support an increased number of the NSF sponsored **Career Access Centers** that serve to enhance the participation of minorities in mathematics, science, and engineering education at both the precollege and undergraduate levels.

  At the undergraduate level, the NSF supports research experiences for undergraduate students. NSF has initiated a program to support a major revision of courses and curricula in all fields of science, engineering and mathematics. NSF also provides support for laboratory improvements at all types of institutions and continues efforts to double the number of NSF graduate fellowships in science and engineering.

- **National Aeronautics and Space Administration - $51 million (up 21%).** NASA's activities include presentations and workshops around the country, grants for undergraduate and graduate student research, and special efforts to ensure minority participation in science and engineering education.

  In particular, **"Scientific Literacy for the 21st Century"** informs and involves students, teachers, universities, and the general public in space education. Teacher internships, scholarships, space science competitions, private sector partnerships, and pilot teacher programs with education colleges are included.

NASA's new space grant college and fellowship program will expand the network of postsecondary institutions and industrial partnerships involved in space education, research, and training.

- National Institutes of Health - $292 million (up 2%). NIH will support 12,000 graduate trainees in research laboratories throughout the nation in FY91.

OTHER PROGRAMS

Other programs exist in the Departments of Agriculture, Commerce, and Interior, Defense, as well as the Environmental Protection Agency and others.

For instance, the Department of Defense sponsors a number of precollege programs, the largest of which provides high school students with research-related work experiences in DOD laboratories through a DOD cooperative education program. Universities receive DOD research and development grants to support some 8,000 graduate assistants and about 660 fellows.

Recognizing the need to attract more minorities into the field, the Army, Navy, and Air Force have expanded a long tradition of support for research activities, scholarships, and assistantships at Historically Black Colleges and Universities as well as other minority institutions.

The Smithsonian Institution and the National Academy of Sciences have established the National Science Resources Center to improve the teaching of science and mathematics in the nation's schools. The NSRC is developing and disseminating resources materials for science and mathematics teachers, maintaining a curriculum database, and offering teachers, school administrators, and scientists a program of outreach and leadership development activities.

FEDERAL COORDINATION

The Domestic Policy Council Working Group on Education Policy is working to provide coordination across agencies.

The President's Science Advisor chairs the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) which, through its committees, provides the policy-making bodies of the Administration with accurate, timely, objective information on Federal science and technology.

The FCCSET Committee on Education and Human Resources will focus on mathematics, science, engineering, and technology education and the development of a scientific and technological workforce.

The President recently announced the President's Council of Advisors on Science and Technology (PCAST). PCAST and its ad hoc panels of private sector executives, researchers, and academics provide science and technology advice for the President.

Math/Science Education Action Conference

Lawrence Hall of Science
October 9-10, 1989

CHAIRMEN'S STATEMENT

STATEMENT OF ADMIRAL JAMES D. WATKINS AND DR. GLENN T. SEABORG
CO-CHAIRMEN, MATH/SCIENCE EDUCATION ACTION CONFERENCE

[On October 8-10, 1989, the U.S. Department of Energy, the Lawrence Hall of Science, and the Lawrence Berkeley Laboratory sponsored a Math/Science Education Action Conference in Berkeley, California. Nearly 250 scientists, educators, business executives, and government leaders came together to develop a concrete plan of action for restructuring and revitalizing mathematics and science education. Their target was to improve education for an entire cohort of children--the Class of 2007, the children born this school year--and their governing principle was one of public and private sector collaboration.]

PART I: OVERARCHING PRINCIPLES

OUR MOTIVE

The primary mission of the U.S. Department of Energy is to supply the Nation with the energy resources, technologies, and information needed for economic progress and national security. To fulfill that responsibility, the Secretary of Energy must be able to staff the Department with highly qualified mathematicians, scientists, engineers, and technicians. Just as important, the Secretary must be able to rely upon a scientifically and technologically informed citizenry to help chart a course for public energy policy.

On both counts, the mission of the Department is in jeopardy.

By every measure, our schools are failing to produce scientifically literate graduates. Student achievement in mathematics and science is unacceptably low, especially compared with that of our international counterparts. Too many young people--particularly female and minority students who represent a largely untapped resource--lack the preparation they need to advance to higher education and careers in scientific and technical fields. Too few teachers receive training of the depth and currency required to deliver mathematics and science instruction in a way that sparks student interest. Public knowledge of scientific and technical subjects is alarmingly inadequate in light of the complex issues our Nation faces.

The Department of Energy has a direct stake in the quality and distribution of mathematics and science education in the Nation. We convened this Conference because the problem cannot be solved without the collaborative efforts of all the key public and private parties and because the Department of Energy can make a unique contribution of facilities and human resources to the cause.

In preparing for this conference, we realized that the children born today will graduate from high school in the year 2007, the fiftieth anniversary of the launch of Sputnik, the event which began a post-war revolution in mathematics and science education in America. To reach this unique cohort of students, in addition to the millions of children already in school, we have established the year 2000 as the target for accomplishing the goals outlined in this document, so that our efforts will move in conjunction with those of the President and the Governors. We consider this the near-term time frame in which to take the actions necessary to sustain lasting change.

OUR GOALS

We endorse the following goals, to be achieved by the year 2000:

1. Students. American elementary and secondary students will receive excellent preparation in mathematics and science in every grade.

   A. Performance. American students will be the best in the world in their knowledge of mathematics and science.

   B. Curriculum. The Nation will have in place an integrated, interdisciplinary core curriculum for mathematics and science in pre-school through high school.

2. Teachers. The Nation's mathematics and science teaching professionals will attain their rightful place as full-share partners in the scientific community and will become empowered to prepare this generation of children for lives of discovery in the 21st Century.

   A. Enrichment. Each year 10% of the Nation's teachers will be provided with high-quality teacher enhancement programs in hands-on science.

   B. Partners. Scientists, engineers, and mathematicians will serve as volunteer expert education partners to bring cutting-edge science into the Nation's classrooms, in numbers equaling 10% of the teaching force.

3. Underrepresented Groups. Significantly greater numbers of female, minority, disabled, and disadvantaged students will complete a K-12 education program, advance to the highest levels of mathematics and science education, enter careers in mathematics and science, and complete teaching programs in these fields.

4. Public Literacy. Citizens will understand and derive excitement from confronting new frontiers in science, mathematics, and technology and will appreciate their potential for bettering our society and our world.

   A. Science Alliances. Mathematics and science community alliances, including partners from government, education, and business, will be established or significantly expanded in 10% of the Nation's school districts over the next 24 months.

5. Competitive Work Force. The Nation will have a diversified work force, competent in mathematics and science and equipped to meet the technological demands of the 21st Century.

OUR STRATEGY

We believe that the Department of Energy, with its unparalleled collection of scientific laboratories, facilities, and experts, has the potential to set a highly visible and creative example of educational collaboration for the entire Federal Government and the private sector. DOE has kept these resources secret for too long. It is time to move these programs out of the shadows and in doing so, inspire others Federal agencies and the private sector to develop similar models of cooperation.

As Co-Chairmen of the Math/Science Education Action Conference, we will initiate and support a series of vigorous and immediate steps to use the Department's resources to help strengthen mathematics and science education in the Nation. Specifically, we are asking the Department's laboratories and headquarters to:

- Open their doors to the surrounding schools and the community.
- Develop programs for students and teachers that will be models for the entire Federal government.
- Collaborate with the business sector, universities, school districts, other laboratories, science-technology centers, and community groups.
- Encourage volunteerism and community service from their employees.

We are not suggesting that the Department of Energy can replace the schools or the State and local educational agencies as the primary providers of instruction. In carrying out model programs, DOE will respect the knowledge and leadership of those with the chief responsibility for education and will build on the many excellent Federal, State and local efforts already underway.

We will also forge linkages with other entities with a stake in mathematics and science education, including the Department of Education (ED), the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA) and other Federal agencies, the White House, the Congress, the Governors, State legislatures, State education departments, higher education institutions, school boards, administrators, principals, teachers, scientists, science-technology centers, museums, public libraries, corporate leaders, foundations, parents, and the general public.

Part II of this document spells out our recommendations and strategies for achieving the aforementioned goals. These goals are closely aligned with the National Goals announced in the President's State of the Union address and were produced with an awareness of the results-oriented model for reforming education that emerged from the President's Education Summit with the Governors in Charlottesville, Virginia.

Part III describes the roles of the DOE National Laboratories and leadership in implementing a model of educational collaboration, and Part IV sets forth a blueprint for a Federal interagency effort to improve mathematics and science education.

PART II

RECOMMENDATIONS AND STRATEGIES

For each of the goals listed in Part I, conference participants proposed recommendations and strategies for its achievement.

Implementing these recommendations and strategies below will require action from all the partners represented at the Berkeley Conference--too many to name--and will require concerted Federal effort and leadership from the White House, the Department of Education, the National Science Foundation, the National Aeronautics and Space Administration, and the Department of Energy.

GOAL #1: STUDENTS

BY 2000, AMERICAN ELEMENTARY AND SECONDARY STUDENTS WILL RECEIVE EXCELLENT PREPARATION IN MATHEMATICS AND SCIENCE IN EVERY GRADE.

A. PERFORMANCE. AMERICAN STUDENTS WILL BE THE BEST IN THE WORLD IN THEIR KNOWLEDGE OF MATHEMATICS AND SCIENCE.

B. CURRICULUM. THE NATION WILL HAVE IN PLACE AN INTEGRATED, INTERDISCIPLINARY CORE CURRICULUM FOR MATHEMATICS AND SCIENCE IN PRE-SCHOOL THROUGH HIGH SCHOOL.

Recommendations/Strategies:

A. We affirm the principle that every student must and can study mathematics and science every year, pre-school through high school, as a part of the core curriculum.

B. The Department of Energy (DOE), the National Science Foundation (NSF), the Department of Education (ED), the National Aeronautics and Space Administration (NASA) and other Federal agencies will support the efforts of the President and the Governors to establish a consensus on what students need to learn in mathematics and science and by what ages they should know it.

C. We believe that this consensus must be built upon the recent work of the American Association for the Advancement of Science, the National Council of Teachers of Mathematics, the National Science Teachers Association, the National Academy of Sciences, the National Academy of Engineering, the National Research Council, the Mathematical Sciences Education Board, the National Science Resources Center, and other relevant research.

D. We recommend establishing a national goal of increasing the number of students taking chemistry, physics, life sciences, and advanced mathematics courses by 10% each year between now and the year 2000.

E. We encourage attention to new concepts and curricula for inspiring "average" students to continue in the mathematics and science pipeline.

GOAL #2: TEACHERS

BY 2000, THE NATION'S MATHEMATICS AND SCIENCE TEACHING PROFESSIONALS WILL ATTAIN THEIR RIGHTFUL PLACE AS FULL-SHARE PARTNERS IN THE SCIENTIFIC COMMUNITY AND WILL BECOME EMPOWERED TO PREPARE THIS GENERATION OF CHILDREN FOR LIVES OF DISCOVERY IN THE 21ST CENTURY.

A. ENRICHMENT. EACH YEAR 10% OF THE NATION'S TEACHERS WILL BE PROVIDED WITH HIGH-QUALITY TEACHER ENHANCEMENT PROGRAMS IN HANDS-ON SCIENCE.

B. PARTNERS. SCIENTISTS, ENGINEERS, AND MATHEMATICIANS WILL SERVE AS VOLUNTEER EXPERT EDUCATION PARTNERS TO BRING CUTTING-EDGE SCIENCE INTO THE NATION'S CLASSROOMS, IN NUMBERS EQUALING 10% OF THE TEACHING FORCE.

Recommendations/Strategies:

A. Working with the President's Science Advisor, DOE will propose a model for integrated Federal/private sector action to provide high-quality teacher enhancement in mathematics and science to 10% of the Nation's teachers annually, so that by the turn of the century. development programs will have touched all K-12 teachers.

This program will initially target teachers of elementary and middle school students, and expand to include greater numbers of high school teachers in ensuing years. The program will build on existing DOE, NASA, and private sector models to offer teachers a chance to participate in real world research, and will ensure that training is attentive to equity issues.

B. We endorse recent successful efforts to increase the number of highly qualified mathematicians, scientists, and engineers entering the precollege mathematics and science teaching profession by streamlining or revamping credentialing and certification.

Through its National Laboratories, DOE will work with teacher associations and state and local education agencies to develop or assist model credentialing programs to encourage persons from mathematical and scientific fields who have or are willing to secure the credentials needed to become teachers, emphasizing both skills and subject matter knowledge.

C. We encourage qualified scientists, business people, retired professionals, and others with appropriate backgrounds and skills to serve as unique cost-free teaching resources in the schools, to assist and supplement the mathematics and science teaching force, and to bring cutting-edge science into the classroom, in numbers equaling 10% of the total teaching force.

DOE will work with ED, the Office of National Service, the American Federation of Teachers, industry, higher education institutions, the elementary and secondary education community, and parents, to create a model that coordinates these volunteers and provides them with the necessary preparation to enable them to

GOAL #3: THE UNDERREPRESENTED

BY 2000, SIGNIFICANT NUMBERS OF FEMALE, MINORITY, DISABLED, AND DISADVANTAGED STUDENTS WILL COMPLETE A K-12 EDUCATION PROGRAM, ADVANCE TO THE HIGHEST LEVELS OF MATHEMATICS AND SCIENCE EDUCATION, ENTER CAREERS IN MATHEMATICS AND SCIENCE, AND COMPLETE TEACHING PROGRAMS IN THESE FIELDS.

Recommendations/Strategies:

A. We support a national target of increasing the number of minority and female students enrolled in mathematics and science courses at all grade levels by 10% annually, until enrollments are commensurate with representation in the population.

B. We recommend that Federal laboratories and other scientific facilities located in areas with large minority populations develop model outreach programs for providing hands-on science experiences, education, mentoring, residential academies, and other activities, on a long-term, sustained basis, to students from underrepresented groups.

C. DOE will expand its alliances with Historically Black Colleges and Universities, primarily Hispanic colleges and universities, and other minority institutions to increase the number and range of programs aimed at pre-college minority children.

D. We believe that DOE and other Federal agencies must work with women's and minority professional societies, such as, but not limited to, the National Action Council for Minorities in Engineering, the Society of Hispanic Professional Engineers, the American Indian Science and Engineering Society, and Women in Science and Engineering, to develop strategies for increasing the number of female, minority, disabled, and disadvantaged students in mathematics and science.

These strategies might include developing mentor and role model relationships, spreading positive messages about mathematics and science through the media and community organizations, helping students understand the education required for scientific and technical careers, and actively promoting mathematics and science as a viable, rewarding career choice for female and minority students.

E. We encourage every Federal agency to examine ways to build upon the work of the Task Force on Women, Minorities, and Handicapped in Science and Technology and to incorporate the Task Force's recommendations into their programs.

F. We encourage Federal laboratories to develop programs that use hands-on mathematics and science, mentoring, peer tutoring, and other techniques to help prevent students from dropping out.

G. We support the expansion and replication of exemplary collaborative programs for underrepresented students, such as the Mathematics, Engineering, Science Achievements (MESA) program.

GOAL #4: PUBLIC MATH/SCIENCE LITERACY

BY 2000, CITIZENS WILL BE ABLE TO UNDERSTAND AND DERIVE EXCITEMENT FROM NEW FRONTIERS IN MATHEMATICS, SCIENCE, AND TECHNOLOGY AND WILL APPRECIATE THEIR POTENTIAL FOR BETTERING OUR SOCIETY AND OUR WORLD.

Recommendations/Strategies:

A. As Secretary of Energy and Chairman of the Lawrence Hall of Science, we will undertake an effort with the Advertising Council of America to develop a coordinated media plan to reach the general population and the Nation's young people with the message that the mastery of mathematics and science is a fun and achievable goal and is vital for understanding the technological society of the 21st Century.

B. We further encourage the adoption by all Federal agencies of NASA's Mission to Mars initiative as a rallying point around which to build exciting science education and awareness programs.

C. We recommend that Federal agencies increase their work with the education community, the mass media, science-technology centers, museums, public libraries, the private sector, parents and the public to improve mathematics, science, and technological literacy of "average" and low-achieving students, not just for the brightest students.

D. We encourage the leaders of Federal facilities to reach out to surrounding communities and provide opportunities for students, teachers, parents, and other community people to come into their facilities to participate in exciting and highly visible scientific projects designed especially for a lay audience.

E. We urge the development of a network of science and mathematics professionals from DOE and other Federal agencies and the private sector who will volunteer in their communities to promote public literacy programs in and out of school.

F. We advocate a national outreach campaign to convey the message that knowledge of science is needed to understand our society and our world and to make wise public policy choices.

G. We propose that public and private agencies, institutions, and organizations build public literacy programs around events such as Earth Day and National Science and Technology Week to illustrate how science and technology can help solve environmental problems.

H. DOE will develop a minimum of 10 pilot programs that deliver intergenerational mathematics and science experiences to children and parents in an integrated fashion and in conjunction with Head Start and other early childhood programs.

GOAL #5: A COMPETITIVE WORK FORCE

BY 2000, THE NATION WILL HAVE A DIVERSIFIED WORK FORCE, COMPETENT IN MATHEMATICS AND SCIENCE AND EQUIPPED TO MEET THE TECHNOLOGICAL DEMANDS OF THE 21ST CENTURY.

Recommendations/Strategies:

A. We believe that improving pre-college education, beginning at the earliest grade levels, is the only way that the United States can increase the future supply of well-trained scientists and engineers.

B. DOE will undertake a program of outreach in its laboratories to educate people in the surrounding communities, especially young people, about scientific and technical career options and the preparation required to pursue these careers.

C. We urge the Federal government and the private sector to use their scientific facilities and personnel to offer summer and academic year internships, apprenticeships, worksite programs, and other appropriate outreach activities to encourage and expose students in mathematics, science, and technology careers.

D. We encourage governmental and private agencies and institutions to remove administrative obstacles that may impede science and engineering personnel from working with students and teachers to bring current science to the future work force.

E. We believe that the Federal government should work with the business community to help strengthen relationships between the private sector and vocational and technical training institutions.

F. DOE and the Department of Labor will collaborate on a project to create a profile of future jobs, based on Workforce 2000, that describes the mathematics and science skills those jobs require. This profile will be aimed at children in grades K-8 and will be disseminated to schools.

G. We encourage professional scientific and mathematical societies to help convey to students more precisely what preparation is needed for scientific and technical careers, to stress the need for a solid background in mathematics and science education in non-scientific careers, and to work to stimulate student interest in these careers.

H. We recommend that education and training institutions highlight their preparation programs for the jobs of the future, in such critical areas as waste management, environmental restoration, and alternative energy.

PART III

BUILDING A DOE MODEL

The Role of the DOE Laboratories

The Secretary of Energy has challenged the DOE Laboratories and headquarters to come up with detailed plans for helping to strengthen mathematics and science education in the schools. Many DOE laboratories already have exciting projects underway for teachers and students. Our intent is to build upon these excellent efforts and use them to guide the rest of the Department and eventually offer a model for the other Federal departments and agencies that have scientific laboratories, equipment, and expertise.

As we envision it, the DOE model would include:

- Long-term, sustained partnerships with selected urban and rural districts and communities.
- Strong collaboration with teachers, administrators, universities, the business sector and other appropriate partners at all stages.
- Volunteerism and sharing of knowledge by scientists, engineers, and other staff.
- Elimination of administrative obstacles to forging partnerships among laboratories, schools, business, and community groups.

Building on the results of the first year of implementation, DOE will increase the number of partnership programs each year.

The model does not involve large amounts of new money. The multi-million dollar network of laboratories is already there; the people are already in place. For example, physics equipment can be turned into physics and educational equipment.

Specifically, the National Laboratories will carry out the following programs:

Chicago: Through Argonne National Laboratory and the Fermi National Accelerator Laboratory, DOE will work with ED, NSF, the Chicago Public Schools, and the Chicago business community to implement two national models to improve mathematics and science education and upgrade the skills of teachers in urban school districts: the Chicago Science Explorers Program and the development of a prototype for a specialized mathematics and science teacher development academy.

California Bay Area: Through the Lawrence Berkeley Laboratory, the Lawrence Livermore National Laboratory, the Sandia National Laboratories and the Stanford Linear Accelerator Center, DOE will establish an urban partnership program targeted on the Oakland Public Schools and other Bay Area schools, in cooperation with the Lawrence Hall of Science, the University of California at Berkeley, other higher education institutions, and the business community.

to create and strengthen private sector partnerships to implement the education initiatives in this report.

Streamlined Credentialing. The Secretary will work with the Department of Education, the Governors, State boards of education, State education departments, teacher associations, institutions of higher education, and other appropriate bodies to develop ways to streamline credentialing so that mathematics and science experts can become educational resource people or assume new careers as credentialed teachers without delay and with an emphasis on teaching and learning expertise.

Teacher Employment. As an adjunct to ongoing programs, the Secretary will expand summer employment opportunities for teachers in Federal and private sector laboratories to make teachers full-share partners in the Nation's scientific community, to provide needed augmentation of their salaries, and to upgrade their skills.

Teacher Demonstration Laboratory. DOE will establish one model teacher demonstration laboratory at a DOE National Laboratory to provide low-cost, effective, and hands-on learning experiences for teachers and students and to offer experiments that cannot be conducted in school laboratories. In subsequent years, expand the program to additional sites, until all DOE National Laboratories are involved.

Science Alliances. The Secretary will work with the Office of National Service to establish local mathematics and science community alliances or significantly expand existing alliances, in 10% of the Nation's school districts over the next 24 months. These alliances will involve DOE facilities, other government facilities, the education community, and industry and will meet with local teachers, administrators, elected officials, and representatives of science-technology centers, PTAs, churches, civic organizations, foundations, and businesses; together, they will identify local needs, set local goals, identify successful programs, adapt these programs to local conditions, and develop plans that use schools, communities, and home as places to learn mathematics and science.

Partnership Register. The Secretary will take the lead in assembling an inventory of successful mathematics and science education partnership programs involving Federal agencies working with other public, private and community partners, to provide successful instruction to students, parents, and teachers.

Inventory of Hands-On Projects. By the start of school year 1990-91, the Secretary will have mechanisms in place for conducting an inventory of its Laboratories and programs as well as those of other Federal agencies for existing hands-on science programs for students, parents, and teachers. Upon completion, this inventory will be disseminated to the White House, other Federal agencies, the Governors, State legislators, State education departments, corporate leaders, the public, and national associations representing administrators, school boards, principals, teachers, and science-technology centers. This information will be also included in an existing on-line data system to provide dial-up linkage from any location in the country.

PART IV

FEDERAL INTERAGENCY EFFORT

Office of Science and Technology Policy

The implementation of the national goals and the government-wide acceptance of successful practices from the DOE model will require the full and active participation of all appropriate Federal departments and agencies. The President's Science Advisor is the appropriate person to coordinate this effort, through the White House Office of Science and Technology Policy. We have pledged to support and assist the President's Science Advisor as he takes the following actions:

- Convenes ~~and chairs~~ an interagency committee under ~~the Federal Coordinating Council on Science, Engineering and Technology (FCCSET)~~, FCCSET in coordination with ongoing Presidential Cabinet Council working group activities, to produce agreements among the Federal departments and agencies for major, national public and private mathematics, science and technology education partnerships, building upon the DOE model and other successful initiatives and working with the Nation's Governors and State legislators.

- Directs this interagency committee to work with all appropriate Federal agencies, including ED and NSF, and with the Governors, to refine and disseminate the national consensus on mathematics and science curricula; and further charges this committee to develop procedures for annually measuring the Nation's progress in meeting our overarching goals for mathematics and science education improvement.

- To the extent that consensus can be developed, takes these initiatives forward to the President and requests an Executive Order directing all appropriate Federal departments and agencies with research and development missions to add mathematics and science education as a core part of their formal missions.

Office of National Service

The work of the President's Youth Entering Service to America initiative is an essential component in the attainment of mathematics and science literacy. The Science Advisor's interagency committee will work with the White House Office of National Service to develop a plan to increase the numbers of students participating in community service projects in science, by encouraging students to tutor and mentor.

- The Office of National Service will designate mathematics and science education as a priority for community service. For example, mentoring of elementary and middle school students by college and high school students is an effective way to harness community service to improve mathematics and science skills.

DEPARTMENT OF ENERGY
Washington, DC 20585

April 9, 1990

OFFICE OF THE SECRETARY

Dr. Ken Yale
Special Assistant to
the President
The White House
Washington, D.C. 20500

Dear Dr. Yale:

Enclosed are the seven copies of the Chairmen's Statement from the Berkeley Math/Science Education Action Conference that you requested. Please be aware that changes were made to Part IV, "The Federal Interagency Effort," as marked on the galley proof also enclosed. We will send you a clean copy of this text when it becomes available.

Sincerely,

Christopher Hanus

Christopher Hanus
Staff Assistant

Enclosures

and communications technology to link teachers and students directly to mathematics and science research.

State Task Force. The Secretary will serve as a member of the Education Commission of the States task force on improving mathematics and science education through State actions. This task force will link States to national and Federal resources, suggest strategies and policy options to States to restructure their education system, and improve mathematics and science education.

National Science Day. In cooperation with ~~site laboratories~~, NSF, NASA, other Federal agencies, and higher education institutions, the Secretary will establish a national science project for hands-on scientific data collection that directs students nationwide to make measurements on the same day.

Instructional Materials. The Secretary will ask DOE laboratories to work in cooperation with NSF and other appropriate partners to assess the quality of available instructional materials and hands-on experiments and to create new ones where existing ones are inadequate.

Science Equipment for Schools. The Secretary will revise policies that restrict the direct transfer of excess mathematics and science equipment to schools and institute mechanisms to make equipment available.

Monitoring and Assessment. This model is being developed with the goal of replication and will be most effective if it can be replicated. Therefore, the Secretary will establish effective assessment and monitoring procedures for evaluating progress toward meeting the Conference goals. These procedures will include a peer review component in which all significant partners in science and education will participate. The Secretary will report the results to participants in the action items.

PART IV

FEDERAL INTERAGENCY EFFORT

Office of Science and Technology Policy

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- Convenes ~~and chairs~~ an interagency committee under ~~the Federal Coordinating Council on Science, Engineering and Technology~~ (FCCSET), in coordination with ongoing Presidential Cabinet Council working group activities, to produce agreements among the Federal departments and agencies for major, national public and private mathematics, science and technology education partnerships, building upon the DOE model and other successful initiatives and working with the Nation's Governors and State legislators.

- Directs this interagency committee to work with all appropriate Federal agencies, including ED and NSF, and the Governors, to refine and disseminate the national consensus on mathematics and science curricula; and further charges this committee to develop procedures for annually measuring the Nation's progress in meeting

INS 1

The President's Assistant for Science and Technology chairs the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET), and has the responsibility for coordinating the development of a strategy to improve mathematics, science and engineering education in the Nation. We have pledged to support the President's Assistant as he takes the following actions:

(Lange/Cawley)
April 19, 1990
3:15 P.M.
[SCI.DOC]

PRESIDENTIAL ADDRESS: NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.
MONDAY, APRIL 23, 1990
2:00 P.M.

Thank you, Frank [Press]. Distinguished members of the National Academy, Dr. Press, Dr. Bromley, ladies and gentlemen: It's an honor to be with you today. The advice and counsel of this Academy has been crucial to American Presidents for well over a century. I'm proud to be the latest to thank you.

We stand at a moment of wondrous prosperity. But our wealth goes far beyond the merely material. Ours is an **intellectual** prosperity, unprecedented in history. For that, and the health and security it affords this nation and the world, gratitude is owed to the men and women who have committed their minds and lives to science.

Those devoted to such work -- its patient searching, its passionate struggles -- have engaged themselves in mankind's exalted mission, and the mind's manifest destiny: the search for understanding.

President Abraham Lincoln established this great institution in the dark hours of our nation's greatest crisis -- which testifies to the enduring importance of scientific knowledge. And when this magnificent building was finally dedicated, Calvin Coolidge predicted "a new day in scientific research. A new sun is rising," he said.

He was right. The awesome scientific advances of this century, many of which you've brought about, bring us ever closer to understanding the universe, its origins, and our own. And science has told us a stranger and more wondrous story than myth might ever have written for us.

NYT-Not'l 1-14-90

Fourscore and ten or twenty billion years ago, it all began. With a quantity of energy and mass unimaginably hot and dense, about the size of a baseball, containing everything that would become the universe, they say. And then, in one incomprehensibly powerful instant, energy and matter of every kind exploded in at least four dimensions. Or in a layman's terms, somebody hit that cosmic baseball right out of the park.

But while the pace of **universal** change may have begun with blinding speed and slowed down since, the pace of our **scientific** evolution has been accelerating rapidly. Growing in intensity throughout this century like a series of chain reactions in a critical mass of highly-trained American grey matter -- touching off revolutions in every direction.

Today, I want to outline the role this Administration is playing to fuel those revolutions. Because as the pace of science accelerates, I believe that **government must keep pace -- and <u>will</u> keep pace -- with science.**

Suggested insert from OSTP

First, we've moved to better integrate science and technology into the policy process. My assistant for Science and Technology, Dr. Allan Bromley, is an active member of the Economic Policy Council, and chairs a White House Working Group

that advises the Domestic Policy Council. And we're already working to better integrate our science and technology efforts across the spectrum -- to get the "biggest bang" out of those big bucks.

But beyond the Federal role, we're committed to greater cross-fertilization with talent from the private sector -- on issues ranging from pure research to manufacturing performance.

So this year we created a President's Council of Science and Technology Advisors -- experts whose guidance has already been invaluable. We'll also be looking for counsel from this Academy's new Manufacturing Forum, just established this month.

We're committed to advancing America's tradition of innovation -- so our '91 budget called for a substantial increase in civilian research and development, and a permanent extension of the research and experimentation tax credit. But along with the applied, market-driven knowledge so crucial to this country's competitive future, let me reaffirm two priorities.

First, **math and science education** -- where we're engaged in a broad effort of reform and restructuring in cooperation with the states that began with our first-ever Education Summit with the nation's governors last fall. Our goal is to make American students first in the world in science and math achievement by the end of this century.

Today, I call on <u>all</u> Federal laboratories, facilities, and agencies to open their doors to students and teachers -- and get involved with education at the local level. And I ask our

industrial and business communities to create new alliances for education, mobilizing more of this nation's great technical resources, for the sake of the future.

The second priority I'd reaffirm is **basic research** -- the historical wellspring of this nation's well-being. Science must be able to continue seeking answers to our most fundamental questions. But here, some vigilance is needed. Earlier this year, I proposed to double the National Science Foundation budget. **Today, I want to call on Congress: Put our money where our future is. Put the National Science Foundation budget back on track.**

Without strong science we are blind: unable to grasp the real parameters of the present, or the future. But with the past as prologue, we know that **the investments we make in science are some of mankind's most promising.**

Satellites already help us study the earth's natural systems and assess environmental threats. And they've become a unifying force for peace, combined with video cameras, as both a product of science and a source of conscience -- **bringing the actions of nations before the eyes of the world.**

Pictures from Poland, scenes on the Berlin Wall... the eye of technology has proved more powerful than chisels for breaking down barriers -- etching the idea of freedom on the psyche of humanity -- and setting off a wondrous, hopeful, **political** chain reaction, worldwide.

Molecular biology, already responsible for agricultural advances that help feed the world, is tackling the challenge and promise of mapping the genome [GEE-nome] -- breaking the code of human life that might allow us to isolate and conquer such diseases as A.I.D.S., and cancer.

And just this month -- while one group of scientists pulled strands of D.N.A. from a 17 million-year-old magnolia leaf buried at the bottom of an ancient lake in northern Utah -- another group in San Jose managed to see and manipulate single **atoms** under a new scanning microscope -- bringing us a step closer to the creation of man-made molecules, new generations of tailored materials with undreamed-of properties, and computers with inconceivable power.

[[Of course, I can't claim to comprehend all of this. Like many, I've gain my scientific understanding from those Gary Larson cartoons. Like the one where, after detailed calculations, Einstein discovers that Time is actually Money.]]

While this administration is convinced that science is a priority investment -- and we're **committed** to keeping pace with science, as partner and catalyst -- we will not attempt to direct the course of science, any more than we would dictate the work of art, music, or literature.

Now more than ever -- on issues ranging from climate change, to A.I.D.S. research, to genetic engineering, to food additives -- we rely on the objective perspective of science for guidance. And as the frontiers of knowledge are increasingly distant from

the understanding of the <u>many</u>, it is ever more important that we can turn to the <u>few</u> for straightforward advice.

The National Academy of Sciences is **renowned** for objectivity and immunity to partisan pressures. So it is essential that the members of this body -- the most distinguished scientists in America -- <u>preserve</u> the objectivity that has been the Academy's hallmark.

On this I know we agree -- because so many of our technical and scientific achievements have been the products of independent minds. And if the earth-moving events of 1989 reminded us of anything, it's that complex bureaucracies and centralized planning don't work well in the governance of societies. **We will not try to impose them on science.**

Just as entrepreneurs and small businesses fuel the growth of the American economy, the backbone of American science is its brilliant array of individual investigators, spread across the nation, well, like a thousand points of enlightenment.

Among so many, think of two physicists who worked in secret because their firm wouldn't approve it, and discovered low-temperature superconductivity. Or Chester Carlson, who invented the Xerox machine in a little room behind a beauty parlor. Or Barbara McClintock, working alone, who made monumental discoveries in genetics 40 years ago that the world began to understand only in the last decade.

One of the **best** things government can do to support the magnificent creativity and energy of the American technical

community is to locate individual scientists with talent, and through agencies like N.I.H., N.S.F., and others, furnish them with the equivalent of venture capital. But there are **also** scientific challenges that demand more coordination.

'91 Budget p. 67

So we maintain a balanced commitment to projects like Space Station Freedom. And the new Supercollider -- so critical to retaining our scientific talent -- that will re-create the unimaginable fireball of our origins in miniature, allowing us to study matter that hasn't existed since the birth of the universe.

Leading-edge technologies often help us find what we aren't even looking for -- whether it's breaking the genetic code of life, or getting a new look at the most ancient forms of light.

NYT 4-10-90 p. C-1

The Hubble telescope is such a tool -- the most sophisticated celestial object mankind has ever tried to lift into the heavens, with the power to see to the ends of the universe, and back to the birth of time. [[I understand it's half a billion times more sensitive than the human eye. Talk about the vision thing...]]

USA Today 4-6-90 p1A

Nat'l Academy of Sciences Historical Booklet, p. 36

On the southwest grounds of this great Academy rests a bronze memorial to a scientist who helped redefine mankind's understanding of time and space, of matter and energy. Among the engravings on that memorial are words of wonder -- about the "joy and amazement" Einstein felt, "at the beauty and grandeur of this world, of which man can just form a faint notion." Your work, the work of science, daily brings that beauty and grandeur into sharper focus.

Still, if Nature were a goddess, she would be a clever and imaginative one, with an endlessly amusing habit of resting just beyond anticipation... but not quite beyond the reach of imagination.

We count on you to ask the questions that confound us, and to struggle, that solutions might not manage forever to evade us. Because for those whose hearts are as open as their minds, the answers will surely, ceaselessly, enlighten and amaze us.

Thank you. And God bless you.

# # #

(Lange/Cawley)
April 20, 1990
7:15 P.M.
[SCI.DOC]

PRESIDENTIAL ADDRESS: NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.
MONDAY, APRIL 23, 1990
2:00 P.M.

Distinguished members of the National Academy, Dr. Press, Dr. Ebert, Dr. Raven, Dr. Gordon, Dr. Blout, Dr. Bromley, ladies and gentlemen: It's an honor to be with you today. The advice and counsel of this Academy has been crucial to American Presidents for well over a century. I'm proud to be the latest to thank you.

We stand at a moment of wondrous prosperity. But our wealth goes far beyond the merely material. Ours is an **intellectual** prosperity, unprecedented in history. For that, and the health and security it affords this nation and the world, gratitude is owed to the men and women who have committed their minds and lives to science.

Those devoted to such work -- its patient searching, its passionate struggles -- have engaged themselves in mankind's most exalted mission, and the mind's manifest destiny: the search for understanding.

President Abraham Lincoln established this great institution in the dark hours of our nation's greatest crisis -- which testifies to the enduring importance of scientific knowledge. In the years that followed your academy has responded to urgent national needs in war and in peace.

When this magnificent building was finally dedicated, Calvin Coolidge predicted "a new day in scientific research. A new sun is rising," he said. He was right. The awesome scientific advances of this century, many of which you've brought about, bring us ever closer to understanding the universe, its origins, and our own. And science has told us a stranger and more wondrous story than myth might ever have written for us.

Fourscore and ten or twenty billion years ago, the theory goes, it all began -- with a universe of energy and mass unimaginably hot and compressed, containing everything that would become what we now see in the heavens. And then, they say -- in one incomprehensibly powerful instant -- energy and matter of every kind exploded in every direction. [[Or as a layman might explain it, somebody hit that cosmic baseball right out of the park.]]

But while the pace of **cosmic** change may have begun with blinding speed and slowed down since, the pace of our **scientific** evolution has been accelerating rapidly. Growing in intensity throughout this century like a series of chain reactions in a critical mass of highly-trained American grey matter -- touching off scientific and technical revolutions in every direction.

Today, I want to outline the role this Administration is playing to advance those revolutions. Because as the pace of science accelerates, I believe that **government must keep pace -- and <u>will</u> keep pace.**

First, we've moved to better integrate science and technology into the policy process. My Assistant for Science and Technology, Dr. Allan Bromley, is an active participant of the Economic and Domestic Policy Councils, as well as serving on the National Space Council, and chairs a White House Working Group that is going to pull together and coordinate Federal programs in areas like education, computing, and high technology -- **so that America remains at the forefront.**

We're committed to greater cross-fertilization with talent from the private sector -- on issues ranging from pure research to manufacturing performance. So this year we created a President's Council of Advisors on Science and Technology -- experts whose guidance I value and depend on. We'll also be looking for counsel from this Academy's new Manufacturing Forum, just established this month.

We want to advance America's tradition of innovation -- and we intend to get the biggest bang for the Federal buck. So in January we sent a budget to Congress that includes a **record $71 billion for research and development** -- an investment in a stronger economy, a more secure nation, and a brighter future.

Our budget calls for increasing funding for the U.S. Global Change Research Program by 57 percent -- to over one billion dollars.

To improve the international competitiveness of American industry, and our overall standard of living, we've

called for a permanent extension of the research and experimentation tax credit. And we're working to lower the cost of capital and clear away regulatory burdens, so that industry can make the kinds of investments the future demands.

But along with the applied, market-driven knowledge so crucial to this country's competitive future, let me reaffirm two priorities:

First, **math and science education** -- where we're engaged in a broad initiative of reform and restructuring, in cooperation with the states. It is an effort that began with our first-ever Education Summit with the nation's governors last fall. Our goal is to make American students first in the world in science and math achievement by the end of this century -- and to convince more women and minorities to study science.

So we're providing new incentives for students, like the National Science Scholars program I've proposed. We're opening the doors of Federal laboratories, facilities, and agencies to students and teachers. Our budget increases funding to **over one billion dollars** for science, math, and engineering education -- through the Departments of Education, Energy, Interior and others, as well as the National Science Foundation and NASA.

A second priority I'd reaffirm is **basic research** -- the historical wellspring of this nation's well-being. Science must be able to continue seeking answers to our most fundamental questions. Earlier this year, I reiterated my commitment to <u>double</u> the National Science Foundation budget by 1993. **Today, I**

want to call on Congress: Put our money where our future is. Put an increased National Science Foundation budget back on track.

Today science and technology are assuming a broader and more interrelated role in human life than ever before. They are becoming forces for historical change.

Satellites already help us study the earth's natural systems and assess environmental threats -- and the Mission to Planet Earth will further our work of global stewardship. Combined with video cameras, communications satellites have become a potent force for peace -- both a product of science and a source of conscience -- **bringing the actions of nations before the eyes of the world.**

Pictures from Poland and South Africa, scenes on the Berlin Wall... the eye of technology has proved more powerful than chisels for breaking down barriers -- etching the idea of freedom on the psyche of humanity -- and setting off a wondrous, hopeful, **political** chain reaction, worldwide.

It's no accident that many of the individuals at the center of today's worldwide political revolutions share a vision of the future based on personal freedom, openness, and freedom of inquiry. These values are shared by our political system and by science alike.

Now more than ever -- on issues ranging from climate change, to A.I.D.S. research, to genetic engineering, to food additives

-- government relies on the objective perspective of science for guidance. And as the frontiers of knowledge are increasingly distant from the understanding of the many, it is ever more important that we can turn to the few for straightforward advice.

The National Academy of Sciences is **renowned** for objectivity and immunity to partisan pressures. Your impartial guidance has been invaluable to American Presidents, and the American people, for well over a century. So I am quite confident that the members of this body -- the most distinguished scientists in America -- will continue the tradition of objectivity that has been the Academy's hallmark.

On this I know we agree -- because so many of our technical and scientific achievements have been the products of independent minds. And if the earth-moving events of 1989 reminded us of anything, it's that complex bureaucracies and centralized planning don't work well in the governance of societies. **We will not try to impose them on science.**

Just as entrepreneurs and small businesses fuel the growth of the American economy, the backbone of American science is its brilliant array of individual investigators, spread across the nation like, well, "a thousand points of enlightenment."

Among so many, think of Chester Carlson, who invented the photocopy machine in a little room behind a beauty parlor. Or Barbara McClintock, working alone, who made monumental discoveries in genetics nearly 50 years ago that the world began to understand only in the last decade.

[[Of course, I can't claim to comprehend how science does its work. Like many, my scientific understanding has been influenced by those Gary Larson cartoons. Like the one where, after detailed calculations, Einstein discovers that Time is actually Money.]]

One of the **best** things government can do to support the magnificent creativity and energy of the American technical community is to locate individual scientists with talent, and furnish them with adequate resources and state-of-the-art instrumentation -- through agencies like the National Institutes of Health, the National Science Foundation, the Departments of Defense and Energy, and others -- to help these investigators make progress.

But there are **also** scientific challenges that, because of their unprecedented scope and importance, demand unusual support -- and international cooperation. Already, the European Space Agency, Japan, and Canada are making hardware contributions valued at more than seven billion dollars for **Space Station Freedom**. Combined with our total investment of about 16 billion dollars, this will be the largest international R & D project ever undertaken.

We're exploring new ways to encourage international cooperation on other big science projects -- like mapping the human genome [GEE-nome], global change research, and the Superconducting Super Collider.

There's a vote coming up in Congress this week on that Super Collider -- so I'd like to call on the members to fully fund that project, as well as our NASA budget. Only by doing so will we keep America on the leading edge of advancing human knowledge, and pushing the limits of space exploration.

Tomorrow morning the Space Shuttle is scheduled to lift into the heavens the most sophisticated celestial object that mankind has ever built -- with the power to see to the ends of the universe, and back to the birth of time. [[I understand it's half a billion times more sensitive than the human eye. Talk about the vision thing...]]

On the southwest grounds of this great Academy rests a bronze memorial to a scientist who helped redefine mankind's understanding of time and space, of matter and energy. Among the engravings on that memorial are words of wonder -- about the "joy and amazement" Einstein felt, "at the beauty and grandeur of this world, of which man can just form a faint notion."

Your work, the work of science, daily brings that beauty and grandeur into sharper focus.

As President I can assure you of this: my administration is committed to supporting you, as you pursue the knowledge that illuminates the world. Knowledge that will surely, ceaselessly continue to bring benefit to all mankind.

Thank you. God bless you. And God bless this great Academy.

# # #

INCORPORATING CAWLES
JASPECW

(Lange/Cawley)
April 19, 1990
3:15 P.M.
[SCI.DOC]

PRESIDENTIAL ADDRESS: NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.
MONDAY, APRIL 23, 1990
2:00 P.M.

~~Thank you, Frank [Press].~~ Distinguished members of the National Academy, Dr. Press, Dr. Bromley, ladies and gentlemen: It's an honor to be with you today. The advice and counsel of this Academy has been crucial to American Presidents for well over a century. I'm proud to be the latest to thank you.

We stand at a moment of wondrous prosperity. But our wealth goes far beyond the merely material. Ours is an **intellectual** prosperity, unprecedented in history. For that, and the health and security it affords this nation and the world, gratitude is owed to the men and women who have committed their minds and lives to science.

Those devoted to such work -- its patient searching, its passionate struggles -- have engaged themselves in mankind's most exalted mission, and the mind's manifest destiny: the search for understanding.

President Abraham Lincoln established this great institution in the dark hours of our nation's greatest crisis -- which testifies to the enduring importance of scientific knowledge. And when this magnificent building was finally dedicated, Calvin Coolidge predicted "a new day in scientific research. A new sun is rising," he said.

He was right. The awesome scientific advances of this century, many of which you've brought about, bring us ever closer to understanding the universe, its origins, and our own. And science has told us a stranger and more wondrous story than myth might ever have written for us.

Fourscore and ten or twenty billion years ago, it all began. ~~With a quantity of energy and mass~~ A universe of energy and mass unimaginably hot and dense, ~~about the size of a baseball,~~ containing everything that would become ~~the universe, they say.~~ we know. And then, in one incomprehensibly powerful instant, energy and matter of every kind exploded in ~~at least four dimensions. Or in a layman's terms, somebody hit that cosmic baseball right out of the park.~~ every direction.

But while the pace of ~~universal~~ cosmic change may have begun with blinding speed and slowed down since, the pace of our **scientific** evolution has been accelerating rapidly. Growing in intensity throughout this century like a series of chain reactions in a critical mass of highly-trained American grey matter -- touching off scientific/technological revolutions in every direction.

Today, I want to outline the role this Administration is playing to fuel advancing those revolutions. Because as the pace of science accelerates, I believe that **government must keep pace -- and <u>will</u> keep pace -- with science.**

First, we've moved to better integrate science and technology into the policy process. My Assistant for Science and Technology, Dr. Allan Bromley, is an active member of the Economic Policy Council, and chairs a White House Working Group

that advises the Domestic Policy Council. And we're already working to better integrate our science and technology efforts across the spectrum -- to get the "biggest bang" out of those big bucks.

But beyond the Federal role, we're committed to greater cross-fertilization with talent from the private sector -- on issues ranging from pure research to manufacturing performance.

So this year we created a President's Council of Science and Technology ~~Advisors~~ -- experts ~~whose~~ guidance ~~has already been invaluable.~~ We'll also be looking for counsel from this Academy's new Manufacturing Forum, just established this month.

We're committed to advancing America's tradition of innovation -- so our '91 budget called for a substantial increase in civilian research and development, and a permanent extension of the research and experimentation tax credit. But along with the applied, market-driven knowledge so crucial to this country's competitive future, let me reaffirm two priorities.

First, **math and science education** -- where we're engaged in a broad effort of reform and restructuring in cooperation with the states that began with our first-ever Education Summit with the nation's governors last fall. Our goal is to make American students first in the world in science and math achievement by the end of this century.

Today, I call on <u>all</u> Federal laboratories, facilities, and agencies to open their doors to students and teachers -- and get involved with education at the local level. And I ask our

industrial and business communities to create new alliances for education, mobilizing more of this nation's great technical resources, for the sake of the future.

The second priority I'd reaffirm is **basic research** -- the historical wellspring of this nation's well-being. Science must be able to continue seeking answers to our most fundamental questions. But here, some vigilance is needed. Earlier this year, I proposed to double the National Science Foundation budget. **Today, I want to call on Congress: Put our money where our future is. Put the National Science Foundation budget back on track.**

Without strong science we are blind: unable to grasp the real parameters of the present, or real potential of the future. But with the past as prologue, we know that **the investments we make in science are some of mankind's most promising.**

Satellites already help us study the earth's natural systems and assess environmental threats. And combined with video cameras they've become a potent force for peace -- both a product of science and a source of conscience -- **bringing the actions of nations before the eyes of the world.**

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Molecular biology, already responsible for agricultural advances that help feed the world, is tackling the challenge and promise of mapping the genome [GEE-nome] -- breaking the code of human life that might allow us to isolate and conquer such diseases as ~~A.I.D.S.~~, and cancer. Alzheimer's?

And just this month -- while one group of scientists pulled strands of D.N.A. from a 17 million-year-old magnolia leaf buried at the bottom of an ancient lake in northern Utah -- another group in San Jose managed to see and manipulate single **atoms** under a new scanning microscope -- bringing us a step closer to the creation of ~~man-made molecules~~, new generations of tailored materials with undreamed-of properties, and computers with inconceivable power.

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Astrom Sawfed out loud !t!

While this administration is convinced that science is a priority investment -- and we're **committed** to keeping pace with science, as partner and catalyst -- we will not attempt to <u>direct</u> the course of science, any more than we would dictate the work of art, music, or literature.

Now more than ever -- on issues ranging from climate change, to A.I.D.S. research, to genetic engineering, to food additives -- we rely on the objective perspective of science for guidance. And as the frontiers of knowledge are increasingly distant from

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Just as entrepreneurs and small businesses fuel the growth of the American economy, the backbone of American science is its brilliant array of individual investigators, spread across the nation, well, like a thousand points of enlightenment.

Among so many, think of two physicists who worked in secret because their ~~firm wouldn't approve it~~ project wasn't part of the management plan, and discovered low-temperature superconductivity. Or Chester Carlson, who invented the Xerox machine in a little room behind a beauty parlor. Or Barbara McClintock, working alone, who made monumental discoveries in genetics ~~40~~ nearly 50 years ago that the world began to understand only in the last decade.

One of the **best** things government can do to support the magnificent creativity and energy of the American technical

community is to locate individual scientists with talent, and through agencies like N.I.H., N.S.F., and others, furnish them with the equivalent of venture capital. But there are **also** scientific challenges that, because of their unprecedented scope, demand unusual support.

So we maintain a balanced commitment to projects like Space Station Freedom. And the new Supercollider -- so critical to retaining our scientific talent -- that will re-create the unimaginable fireball of our origins in miniature, allowing us to study matter that hasn't existed since the birth of the universe.

Leading-edge technologies often help us find what we aren't even looking for -- whether it's breaking the genetic code of life, or getting a new look at the most ancient forms of ~~light~~.

Our space program is a leading example -- as is the Hubble telescope -- the most sophisticated ~~celestial~~ object mankind has ever tried to lift into the heavens, with the power to see to the ends of the universe, and back to the birth of time.

[[I understand it's half a billion times more sensitive than the human eye. Talk about the vision thing...]]

On the southwest grounds of this great Academy rests a bronze memorial to a scientist who helped redefine mankind's understanding of time and space, of matter and energy. Among the engravings on that memorial are words of wonder -- about the "joy and amazement" Einstein felt, "at the beauty and grandeur of this world, of which man can just form a faint notion." Your work,

the work of science, daily brings that beauty and grandeur into sharper focus.

Still, if Nature ~~were~~ seems to have the endless power to surprise us, she would be a clever and imaginative one, with an endlessly amusing habit of resting just beyond anticipation... but not quite beyond the reach of imagination.

We count on you to ask the questions that confound us -- and to struggle, that solutions might not manage forever to evade us. Because for those whose hearts are as open as their minds, the answers will surely, ceaselessly, enlighten and amaze us.

Thank you. ~~And~~ God bless you. And God bless this great Academy.

# # #

(Lange/Cawley)
April 20, 1990
9:30 P.M.
[SCI.DOC]

PRESIDENTIAL ADDRESS: NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.
MONDAY, APRIL 23, 1990
2:00 P.M.

Distinguished members of the National Academy, Dr. Press, Dr. Ebert, Dr. Raven, Dr. Gordon, Dr. Blout, Dr. Bromley, ladies and gentlemen: It's an honor to be with you today. The advice and counsel of this Academy has been crucial to American Presidents for well over a century. I'm proud to be the latest to thank you.

We stand at a moment of wondrous prosperity. But our wealth goes far beyond the merely material. Ours is an **intellectual** prosperity, unprecedented in history. For that, and the health and security it affords this nation and the world, gratitude is owed to the men and women who have committed their minds and lives to science.

Those devoted to such work -- its patient searching, its passionate struggles -- have engaged themselves in mankind's most exalted mission, and the mind's manifest destiny: the search for understanding.

President Abraham Lincoln established this great institution in the dark hours of our nation's greatest crisis -- which testifies to the enduring importance of scientific knowledge. In the years that followed your academy has responded to urgent national needs in times of war and peace.

When this magnificent building was dedicated, Calvin Coolidge predicted "a new day in scientific research. A new sun is rising," he said. He was right. The awesome scientific advances of this century, many of which you've brought about, bring us ever closer to understanding the universe, its origins, and our own. And science has told us a stranger and more wondrous story than myth might ever have written for us.

Fourscore and ten or twenty billion years ago, the theory goes, it all began -- with a universe of energy and mass unimaginably hot and compressed, containing everything that would become what we now see in the heavens. And then, science tells us -- in one incomprehensibly powerful instant -- energy and matter of every kind exploded in every direction. [[Or as a layman might explain it, somebody hit that cosmic baseball right out of the park.]]

But while the pace of **cosmic** change may have begun with blinding speed and slowed down since, the pace of our **scientific** evolution has been accelerating rapidly. Growing in intensity like a series of chain reactions in a critical mass of highly-trained American grey matter -- touching off scientific and technical revolutions in every direction.

Today, I want to outline the role this Administration is playing to advance those revolutions. Because as the pace of science accelerates, I believe that **government must keep pace -- and <u>will</u> keep pace.**

First, we've moved to better integrate science and technology into the policy process. We have created a White House Working Group that will more closely link science and technology considerations into the policy-making process of the Economic and Domestic Policy Councils.

My Assistant for Science and Technology, Dr. Allan Bromley, is also an active participant in those Councils, advising them on matters related to science and technology -- as well as serving on the National Space Council.

And we're also committed to greater cross-fertilization with talent from the private sector -- on issues ranging from pure research to manufacturing performance. So this year we created a President's Council of Advisors on Science and Technology -- experts whose guidance I value and depend on. We'll also be looking for counsel from this Academy's new Manufacturing Forum, just established this month.

We want to advance America's tradition of innovation -- and we intend to get the biggest bang for the Federal buck. So in January, we sent a budget to Congress that includes a **record $71 billion for research and development** -- an investment in a stronger economy, a more secure nation, and a brighter future.

To improve the international competitiveness of American industry, and our overall standard of living, we've called for a permanent extension of the research and experimentation tax credit. And we're working to lower the cost

of capital and clear away regulatory burdens, so that industry can make the kinds of investments the future demands.

Along with the applied, market-driven knowledge so crucial to this country's competitive future, let me reaffirm two other priorities:

First, **math and science education.** We understand that only with a new generation of scientists and engineers will your work, and America's preeminence, be assured. So we're engaged in a broad initiative of reform and restructuring, in cooperation with the states. It is an effort that began with our first-ever Education Summit with the nation's governors last fall. Our goal is to make American students first in the world in science and math achievement by the end of this century -- and to convince more women and minorities to study science.

We're providing a number of new incentives for students, like the National Science Scholars program I've proposed. We're opening the doors of Federal laboratories, facilities, and agencies to students and teachers. Our budget increases funding to **over one billion dollars** for science, math, and engineering education -- through the Departments of Education, Energy, Interior and others, as well as the National Science Foundation and NASA. We are committed to ensuring that **America has the brainpower to remain at the forefront.**

A second priority of this administration is **basic research**

-- the historical wellspring of this nation's well-being. Science must be able to continue seeking answers to our most fundamental questions.

That's one reason our budget calls for increasing funding for the U.S. Global Change Research Program by 57 percent -- to over one billion dollars. And earlier this year, I reiterated my commitment to double the National Science Foundation budget by 1993. **Today, I want to call on Congress: Put our money where our future is. Put an increased National Science Foundation budget back on track.**

Today, science and technology are assuming a broader and more interrelated role in human life than ever before. They are becoming forces for historical change.

Satellites already help us study the earth's natural systems and assess environmental threats -- and the Mission to Planet Earth will further our work of global stewardship.

But this past year, in the Revolution of '89, we have also seen communications satellites, along with video cameras, VCR's and FAX machines, becoming a potent force for peace -- both a product of science and a source of conscience -- **bringing the actions of nations before the eyes of the world.**

Pictures from Poland and South Africa, scenes on the Berlin Wall... the eye of technology has proved more powerful than chisels for breaking down barriers -- etching the idea of freedom on the psyche of humanity -- and setting off a wondrous, hopeful, **political** chain reaction, worldwide.

It's no accident that many of the individuals at the center of today's worldwide political revolutions share a vision of the future based on personal freedom, openness, and freedom of inquiry. These values are shared by our political system and by science alike. Science, like any field of endeavor, relies on freedom of inquiry. And one of the hallmarks of that freedom is objectivity.

Now more than ever -- on issues ranging from climate change, to A.I.D.S. research, to genetic engineering, to food additives -- government relies on the impartial perspective of science for guidance. And as the frontiers of knowledge are increasingly distant from the understanding of the many, it is ever more important that we can turn to the few for straightforward advice.

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On this I know we agree -- because so many of our technical and scientific achievements have been the products of independent minds. And if the earth-moving events of 1989 reminded us of anything, it's that complex bureaucracies and centralized planning don't work well in the governance of societies. **We will not try to impose them on science.**

Just as entrepreneurs and small businesses fuel the growth of the American economy, the backbone of American science is its brilliant array of individual investigators, spread across the nation.

Among so many, think of Chester Carlson, who invented the photocopy machine in a little room behind a beauty parlor. Or Barbara McClintock, working alone, who made monumental discoveries in genetics nearly 50 years ago that the world began to understand only in the last decade.

[[Of course, I can't claim to comprehend how science does its work. Like many, my scientific understanding has been influenced by those Gary Larson cartoons. Like the one where, after detailed calculations, Einstein discovers that Time is actually Money.]]

One of the **best** things government can do to support the magnificent creativity and energy of the American technical community is to locate individual scientists with talent, and furnish them with adequate resources and state-of-the-art instrumentation -- through agencies like the National Institutes of Health, the National Science Foundation, the Departments of Defense and Energy, and others -- to help these investigators make progress.

But there are **also** scientific challenges that, because of their unprecedented scope and importance, demand unusual support -- and international cooperation. Already, the European Space Agency, Japan, and Canada are making hardware contributions

valued at more than seven billion dollars for **Space Station Freedom**. Combined with our total investment of about 16 billion dollars, this will be the largest international R & D project ever undertaken.

We're exploring new ways to encourage international cooperation on other big science projects -- like mapping the human genome [GEE-nome], global change research, and the Superconducting Super Collider -- a technological giant that will recreate the fireball of our origins, and allow us to study forms of matter that haven't existed since the birth of the universe.

There's a vote coming up in Congress this week on that Super Collider -- so I'd like to call on the members to fully fund that project, as well as our NASA budget. Only by doing so will we keep America on the leading edge of advancing human knowledge, and pushing the limits of space exploration.

Tomorrow morning, the Space Shuttle is scheduled to lift into the heavens the most sophisticated celestial object that mankind has ever built -- with the power to see to the ends of the universe, and back to the birth of time. [[I understand it's half a billion times more sensitive than the human eye. Talk about the vision thing...]]

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Thank you. God bless you. And God bless this great Academy.

# # #

(Lange/Cawley)
April 19, 1990
1:30 P.M.
[SCI.DOC]

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WASHINGTON, D.C.
MONDAY, APRIL 23, 1990
2:00 P.M.

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Today, I want to outline the role this Administration is playing to fuel those revolutions. Because as the pace of science accelerates, I believe that **government must keep pace -- and <u>will</u> keep pace -- with science.**

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Today I call on all Federal laboratories, facilities, and agencies to open their doors to students and teachers -- and get involved with education at the local level. And I ask our

industrial and business communities to create new alliances for education, mobilizing more of this nation's great technical resources, for the sake of the future.

The second priority I'd reaffirm is **basic research** -- the wellspring of this nation's well-being. Science must be able to continue seeking answers to our most fundamental questions. But here, some vigilance is needed. Earlier this year, I proposed to double the National Science Foundation budget. **Today, I want to call on Congress: Put our money where our future is. Put the National Science Foundation budget back on track.**

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with the equivalent of venture capital. But there are **also** scientific challenges that demand more coordination.

So we maintain a balanced commitment to projects like Space Station Freedom. And the new Supercollider -- so critical to retaining our scientific talent -- that will re-create the unimaginable fireball of our origins in miniature, allowing us to study matter that hasn't existed since the birth of the universe.

Leading-edge technologies often help us find what we aren't even looking for -- whether it's breaking the genetic code of life, or getting a new look at the most ancient forms of light.

Our space program is certainly a perfect example.

The Hubble telescope is also such a tool -- the most sophisticated celestial object mankind has ever tried to lift into the heavens, with the power to see to the ends of the universe, and back to the birth of time. [[I understand it's half a billion times more sensitive than the human eye. Talk about the vision thing...]]

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(Lange/Cawley)
April 18, 1990
11:45 P.M.
[SCI.DOC]

PRESIDENTIAL ADDRESS: NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.
MONDAY, APRIL 23, 1990
2:00 P.M.

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We stand at a moment of wondrous prosperity. But our wealth goes far beyond the merely material. Ours is an **intellectual** prosperity, unprecedented in history. For that, and the health and security it affords the nation and the world, gratitude is owed to the men and women who have committed their minds and lives to science.

Those devoted to such work -- its patient searching, its passionate struggles -- have engaged themselves in mankind's exalted mission, and the mind's manifest destiny: the search for understanding.

President Abraham Lincoln established this great institution in the dark hours of our nation's greatest crisis -- which testifies to

the enduring importance of scientific knowledge. And when this magnificent building was finally dedicated, Calvin Coolidge predicted "a new day in scientific research. A new sun is rising," he said.

He was right. The awesome scientific advances of this century, many of which you've brought about, bring us ever closer to understanding the universe, its origins, and our own. And science has told us a stranger and more wondrous story than myth might ever have written for us.

Fourscore and ten or twenty billion years ago, it all began. With a quantity of energy and mass unimaginably hot and dense, about the size of a baseball, containing everything that would become the universe, they say. And then, in one incomprehensibly powerful instant, energy and matter of every kind exploded in at least four dimensions. In a layman's terms, somebody hit that cosmic baseball right out of the park. ~~[[The Rangers ought to sign the guy up.]]~~

But while the pace of **universal** change may have begun with blinding speed and slowed down since, the pace of our **scientific** evolution has been accelerating, exponentially. Growing in intensity throughout this century like a series of chain reactions in a critical mass of highly-trained American grey matter -- touching off revolutions in every direction.

Today I want to outline the role this administration is ~~taking~~ to catalyze those revolutions. Because as the pace of

science accelerates, I believe that **government and policy must keep pace -- and <u>will</u> keep pace -- with science.**

First, we've moved to better integrate science and technology into the policy process. My assistant for Science and Technology is an active member of the Economic Policy Council, and chairs a White House Working Group that advises the Domestic Policy Council. And we're already working to better integrate our science and technology efforts across the spectrum -- to get the biggest bang out of those big bucks.

But beyond the Federal role, we're committed to greater cross-fertilization with talent from the private sector -- on issues ranging from pure research to manufacturing performance.

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And second, **basic research** -- because it is the wellspring of this nation's well-being. Science must be able to continue seeking answers to our most fundamental questions. But here, some vigilance is needed. In our budget, I proposed to double the National Science Foundation budget. **Today I want to call on Congress: Put our money where our future is. Put the National Science Foundation budget back on track.**

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Satellites already help us study the earth's natural systems and assess environmental threats -- and they've become a force for peace, creating a communications network that makes remote wars more difficult. Handheld cameras are also both a product of science and a source of conscience -- **bringing the actions of nations before the eyes of the world.**

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[[Of course, I can't claim to comprehend all of this. Like many, I've gain my scientific understanding from those Gary Larson cartoons. Like the one where, after detailed calculations, Einstein discovers that Time is actually Money.]]

While this administration is convinced that science is a priority investment -- and we're committed to keeping pace with science, as partner and catalyst -- we will not attempt to direct the course of science, any more than we would dictate the work of art, music, or literature.

Now more than ever -- on issues ranging from climate change, to A.I.D.S. research, to genetic engineering, to food additives -- we rely on the objective perspective of science for guidance. And as the frontiers of knowledge are increasingly distant from the understanding of the many, it is ever more important that we can turn to the few for straightforward advice.

The National Academy of Sciences is **renowned** for objectivity and immunity to partisan pressures. So it is essential that the members of this body -- the most distinguished scientists in America -- preserve the objectivity that has been the Academy's hallmark.

On this I know we agree -- because so many of our technical

and scientific achievements have been the products of independent minds. And if the earth-moving events of 1989 reminded us of anything, it's that complex bureaucracies and centralized planning don't work well in the governance of societies. **We will not try to impose them on science.**

Just as entrepreneurs and small businesses fuel the growth of the American economy, the backbone of American science is its brilliant array of individual investigators, spread across the nation, well, like a thousand points of enlightenment.

Among so many, think of two physicists who worked in secret because their firm wouldn't approve it, and discovered low-temperature superconductivity. Or Chester Carlson, who invented the Xerox machine in a little room behind a beauty parlor. Or Barbara McClintock, working alone, who made monumental discoveries in genetics 40 years ago that the world only ~~caught onto~~ began to understand in the last decade.

One of the **best** things government can do to support the magnificent creativity and energy of the American technical community is to locate individual scientists with talent, and furnish them with the equivalent of venture capital. But there are **also** scientific challenges that demand more coordination.

So we are committed to ~~those~~ projects like Space Station Freedom. And the new Supercollider -- so critical to retaining our scientific talent -- that will re-create the unimaginable fireball of our origins in miniature, allowing us to study matter that hasn't existed since the birth of the universe.

Leading-edge technologies often help us find what we aren't even looking for. As ~~if, after walking into a library, the book you need is missing, but the one next to it tells you more than you were able to imagine.~~ Whether it's breaking the genetic code of life -- or getting a new look at the most ancient forms of light.

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You know, a year after Galileo first pointed a telescope to the heavens in 1609, Shakespeare wrote an earthbound drama where, for a moment, Hamlet exulted in mankind's greater qualities. "How noble in reason," he wondered. "How infinite in faculty... In action how like an angel, in apprehension how like a god... The paragon of animals! And yet," he paused, "What is this quintessence of dust?"

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It is computing power, of course, that makes our exponential growth in scientic understanding possible. Vast quantities of information are now mediated through integrated circuits: conceptual spectacles that enable us to see, or model with the mind's eye, phenomena we'd otherwise miss or couldn't comprehend -- from the diffusion of charge in a single semiconductor, to collisions between galaxies.

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Some say the universe will contract -- others, that it will expand forever. We can be that mankind's intellectual capacity and curiosity will continue to expand -- and that the singular, unifying force that rules our nature, will remain the desire for understanding.

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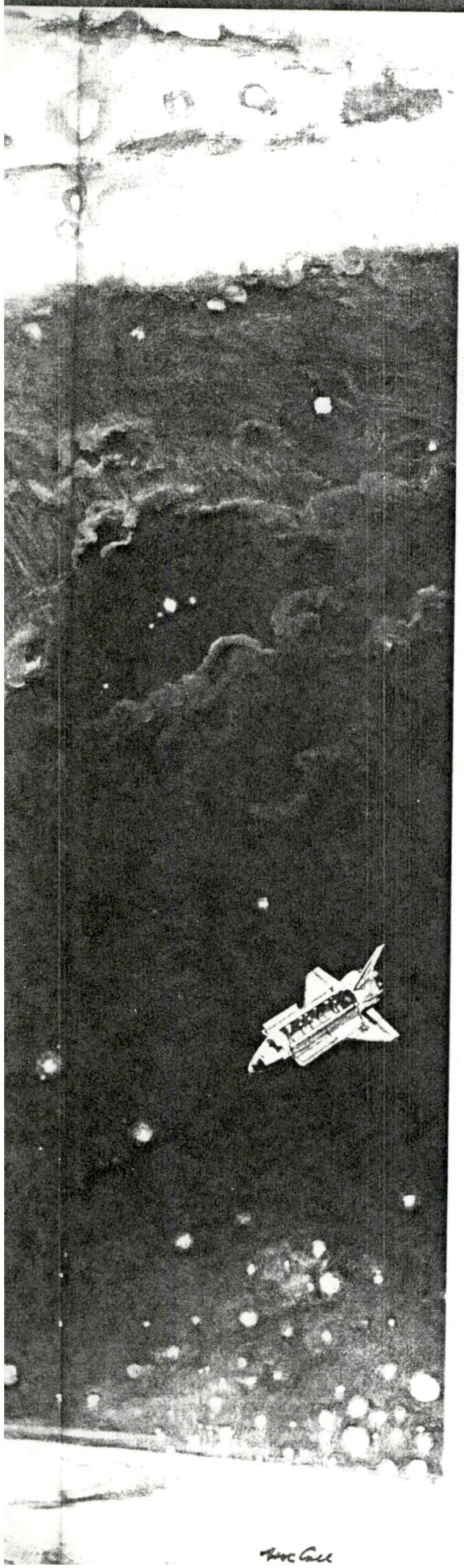
The New York Times Magazine / FEBRUARY 11, 1990

THE SEARCH FOR THE BEGINNING OF TIME



ROBERT McCALL

BY JOHN NOBLE WILFORD

ANY SPACECRAFT THAT inspires allusions to Alice of Wonderland cannot be meant for some ordinary excursion through the heavens. The Hubble Space Telescope is, indeed, not just any spacecraft. Scheduled for launching this spring, after five years of delays, the spacecraft and its exquisitely polished 94½-inch-wide telescopic mirror should enable astronomers to see farther and 10 times more clearly than they have before, out tantalizingly close to the edge of the universe and toward the very beginning of time. Excited astronomers can hardly believe their good fortune to be living at a moment so rich in the promise of revolutionary discovery. One of them likens the anticipated adventures in astronomy to Alice stepping into Wonderland.

Malcolm Longair, the Astronomer Royal of Scotland, has written, with respectful apologies to Lewis Carroll, a whimsical (though highly technical) book about the "world's most extraordinary looking glass" and titled it "Alice and the Space Telescope." His Alice encounters Humpty Dumpty, who has been put together again by the people at the National Aeronautics and Space Administration. She asks him why the telescope will revolutionize mankind's understanding of the universe. "The answer is very short," Humpty Dumpty replies. "Space Telescope will revolutionize mankind's understanding of the Universe because it cost a billion dollars."

Actually, since construction began in 1977, one and a half billion have been spent on the space telescope, mostly by the United States, but with some critical help from the 13-nation European Space Agency. (By contrast, the bill for the Keck Telescope, the most powerful ground-based instrument, nearing completion in Hawaii, will come to $100 million.) Hubble's costs escalated, in large part, because of early development difficulties and the four-year launching delay necessitated by the explosion of the space shuttle Challenger in January 1986. Just operating the Hubble, once it gets into space, will run $200 million more a year.

But astronomers reckon the value of their expensive eye in the sky not by cost, the cynical Humpty Dumpty notwithstanding, but by their own vision of impending discovery. Over the next 15 years or more, the Hubble's designed lifetime, the

John Noble Wilford writes about science and space for The New York Times. His newest book, "Mars Beckons," will be published in May.

THE HUBBLE SPACE TELESCOPE, SCHEDULED FOR LAUNCH THIS SPRING, MAY PROVIDE CLUES TO HOW THE UNIVERSE BEGAN—AND HOW IT MAY END.

DAN BORRIS/OUTLINE

Rodger Doxsey of the Space Telescope Science Institute says the delays in launching, paradoxically, have been beneficial.

THE SPACE TELESCOPE WILL LET ASTRONOMERS SEE ALMOST TO THE END OF THE UNIVERSE.

breadth and depth of view from the telescope's 380-mile-high orbit should open their minds to realms of knowledge once denied mere mortals. With it they expect to learn the age and size of the universe, and to probe its origin, evolution and ultimate fate.

The telescope will search for planets around other stars, a key to the quest for extraterrestrial life, and examine interstellar dust and gases out of which stars are born. It will contribute to the heated dispute over the rate of the universe's expansion — and thus over its age — one of the most important measurements to be undertaken by astronomers operating the telescope. "In Wonderland, you get prizes for asking the questions, not for giving the answers," says Longair's Mad Hatter. "It's just like extragalactic astronomy."

With the spirit of Alice leading the way, I set out on my own wide-eyed adventure, which landed me in Baltimore. Now, astrophysicists applying Einstein's general theory of relativity to three-dimensional space believe that the universe is curved and has no center. But try telling that to the engineers and scientists established in a beige brick building on a wooded hillside on the campus of Johns Hopkins University. This is the Space Telescope Science Institute, financed by NASA and operated by the Association of Universities for Research in Astronomy, a consortium of 20 institutions that also runs major observatories at Kitt Peak in Arizona and Cerro Tololo in Chile. Here astronomers are putting the finishing touches on mission plans and will be directing, by remote control, what the telescope looks at. If this does not exactly make Baltimore the center of the universe, it insures that it will be a center of cosmic exploration well into the next century.

OVERSEEING THIS AMBITIOUS UNdertaking is Riccardo Giacconi, an Italian-born astronomer and the institute's director. He was a professor of astronomy at Harvard and led the international scientific teams that developed and successfully operated the Uhuru and Einstein X-ray astronomy satellites in the 1970's. For the last eight years he has been planning how to make the most of the Hubble telescope's abilities. He has also become an articulate and enthusiastic spokesman for modern astronomy.

The windows of his spacious office look out on the earthly delight of a brook flowing through Wyman Park, but in response to a question, he seems to see, from behind the thick lenses of his glasses, only the panorama of astronomy's history. Yes, he agrees, we have reached a point of mind-stretching revelation unlike anything since Galileo gazed through the first telescope in 1609 and, seeing the four moons orbiting Jupiter, glimpsed the truth of the Copernican concept of worlds circling the Sun. That was the beginning of the end of belief in an Earth-centered universe.

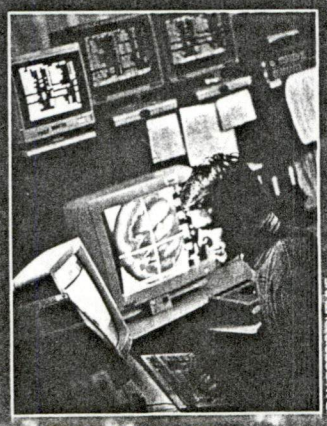
"We are in a period of revolution in astronomy," Giacconi says with a heavy Italian accent. "Anything you really want to know about the universe we've found out in the last 50 or so years. If you want to know how stars form, produce their energy and then die — that was unknown until the theory of general relativity and the discovery of nuclear fusion in this century. If you want to know how big the universe is, and how old — we started learning that in 1930."

It was the American astronomer Edwin P. Hubble who laid the groundwork for studying the age of the universe. In the 1920's, he made two startling discoveries — that the universe is organized into galaxies of many sizes and shapes, and that the galaxies are rushing away from one another. Moreover, the more distant galaxies are moving away from Earth faster than those closer by. This relationship between distance and recessional velocity became known as Hubble's law. The most distant objects, according to this law, represent conditions in the early universe, close to the beginning of time. It thus became conceivable that the age of the universe could be calculated.

It is altogether appropriate that the new telescope bears Hubble's name. His discovery of an expanding universe not only made sense in terms of Newton's theory of gravity and Einstein's relativity; it also proved to be the wellspring for the idea of the Big Bang, now the reigning theory of how the universe began.

The Hubble telescope alone will not bring a fuller knowledge of the birth and evolution of the universe, as Giacconi readily acknowledges. Visible light, which conventional optical telescopes magnify, tells only a small part of the cosmic story. Radio, infrared and ultraviolet waves, X-rays and gamma rays carry messages of an incredibly violent universe, which were unsuspected as long

NATIONAL OPTICAL ASTRONOMY OBSERVATORIES



DAN BORRIS/OUTLINE

THE BIG QUESTIONS

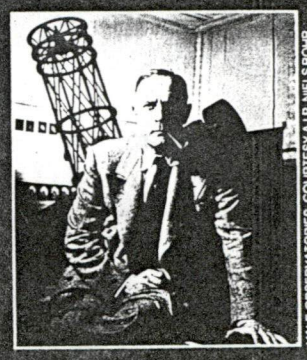
Astronomers think that the Hubble telescope may deliver answers to three of the most challenging questions in cosmology:

- How fast is the universe expanding? Observations of certain stars could determine the speed at which galaxies are receding and pin down the expansion rate to an accuracy of 10 percent.
- How old is the universe? Estimates range from 10 to 20 billion years. Examining extremely old and faint stars could yield a more precise answer.
- What is the fate of the universe? By learning the rate at which the universe is decelerating, scientists may be able to determine its mass, or density. These observations should give scientists important insights into whether the universe will continue to expand forever or collapse in on itself.

THE BETTMAN ARCHIVE

GALILEO

The Italian astronomer was the first to look at the heavens through a telescope, in 1609. His observation of four moons orbiting Jupiter supported Copernicus's belief that the Earth was not the center of the universe but was actually a satellite of the Sun.



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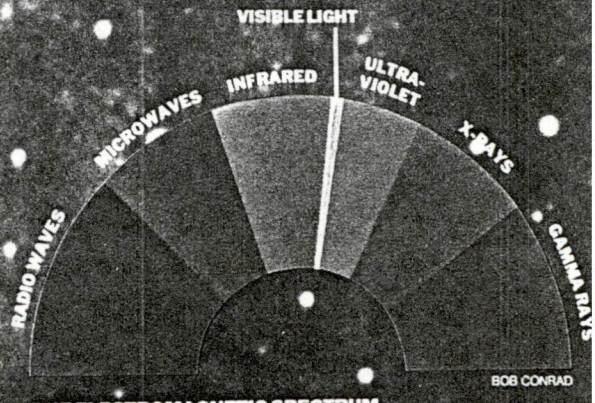
EDWIN P. HUBBLE

The space telescope is named after an American who made two discoveries in the 1920's that transformed astronomy. He recognized that the universe is organized into galaxies, and that they are all hurtling away from one another. His discovery of an expanding universe led to the Big Bang theory of cosmic creation.



BOB CONRAD

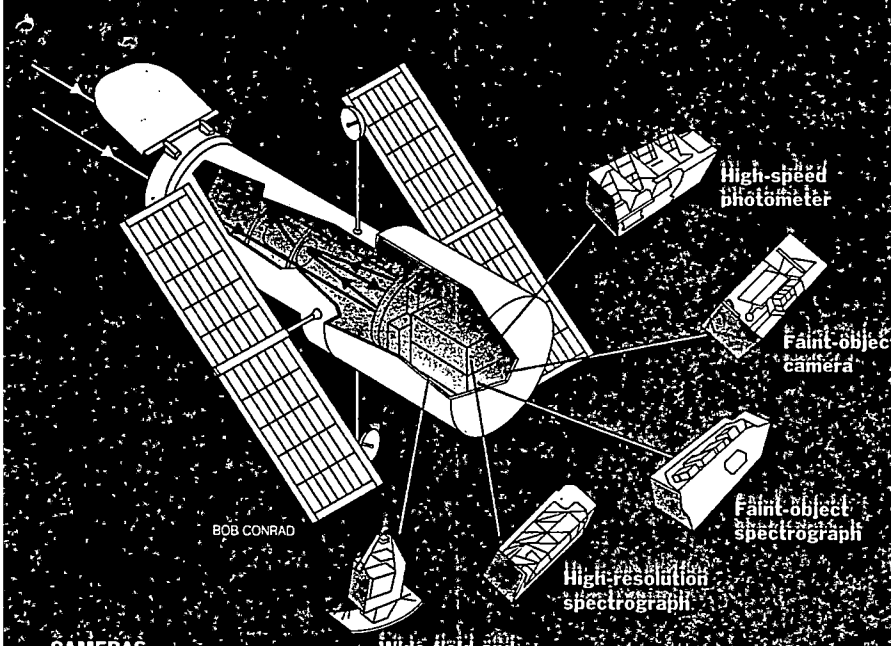
THE ELECTROMAGNETIC SPECTRUM

The violent forces created by stars, galaxies and other cosmic objects result in electromagnetic vibrations that spread out into space like ripples in a pond where a pebble has been tossed. These electromagnetic waves come in different forms of radiation, varying in frequency and wavelength. Only a narrow band of the spectrum (visible light) is observable by the human eye. The Hubble telescope will not only see visible wavelengths more clearly but also penetrate more deeply into ultraviolet and some infrared wavelengths.

SCANNING THE GALAXIES

M83, 10 million light-years away, a spiral galaxy in the constellation Hydra.

INSIDE THE TELESCOPE



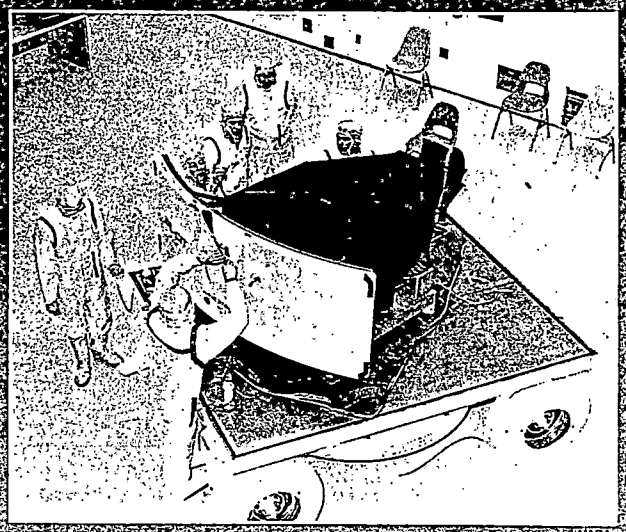
BOB CONRAD

DETECTORS

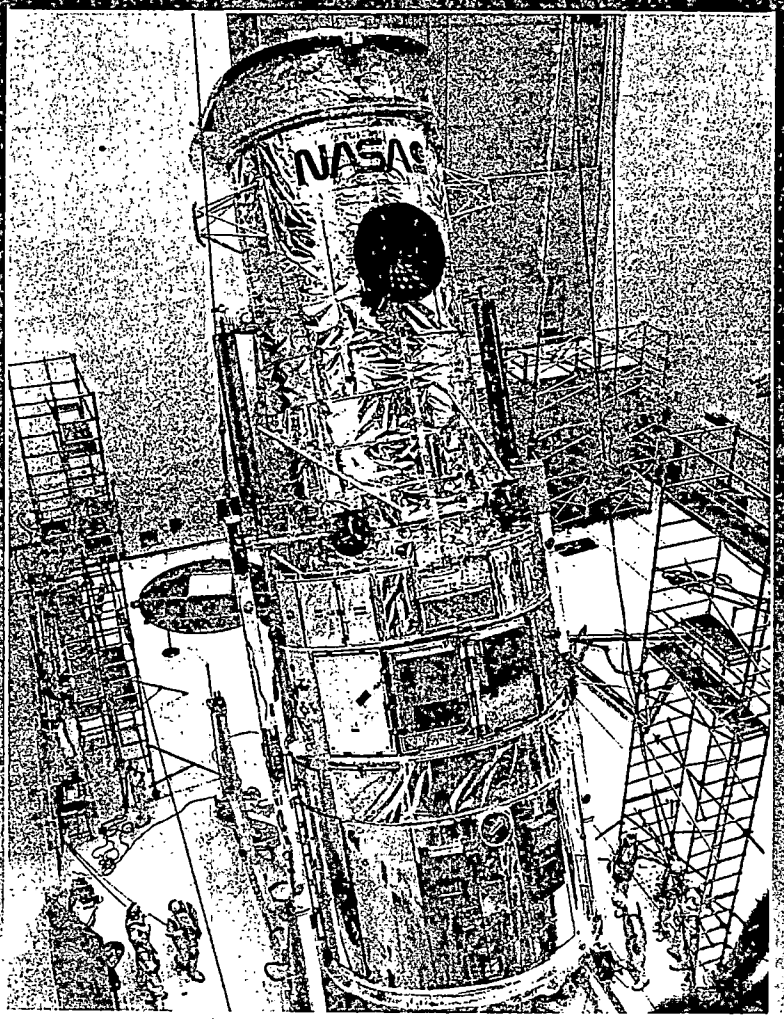
The space telescope will carry two spectrographs, optical devices that spread out the light gathered by the telescope, dividing it according to wavelength. Also aboard will be a high-speed photometer, a very sensitive light meter that measures the intensity and frequency of the light, as well as other properties. The path of light is shown by arrows.

CAMERAS

The space telescope's cameras will produce the mission's most tangible results. The wide-field-and-planetary camera will photograph galaxies 10 times more clearly than any ground-based telescope has. The faint-object camera will see celestial bodies 50 times as faint as any seen so far from Earth.



NASA



NASA

COUNTDOWN TO LAUNCH

The wide-field-and-planetary camera, above, being prepared for installation in the Hubble telescope. Right: The telescope being readied for launch.

Riccardo Giacconi, director of the Space Telescope Science Institute, holding a scale model of the Hubble telescope.

DAN BORRIS/OUTLINE

as human vision reached only as far as the apparent serenity of the night sky. Since Hubble's day, astronomy has developed an amazing variety of tools for observing wavelengths of radiation invisible to the eye.

In the 1960's, huge dish antennas first detected radio waves emitted by gases being sucked into enormous gravitational sinks in space known as black holes. In 1967, similar telescopes picked up radio waves emanating from neutron stars, or pulsars, which are stars that have collapsed into rapidly spinning dense objects. Two years earlier, radio antennas had detected the faint radiation left over from the Big Bang itself. Gamma and X-ray detectors borne by spacecraft have revealed the fantastically powerful forces at the core of galaxies and in quasars, those brilliant enigmatic starlike objects, each presumably associated with the core of a galaxy, billions of light-years away. Spacecraft with ultraviolet telescopes have defined much of the structure and composition of the vast regions between galaxies. And an infrared telescope, also operating from orbit, has detected stars in birth as well as disks of dust surrounding other stars, where planetary systems may be evolving.

One of the most liberating influences on astronomy has been the ability to rise above Earth's murky and turbulent atmosphere, which either blocks or attenuates radiation in all wavelengths, including visible light. The Hubble telescope's surpassing utility will derive from its orbital vantage point. Thus, though its mirror is less than half the size of that of the 200-inch Hale telescope on Mount Palomar in California, which has been astronomy's premier optical telescope since 1948, the Hubble should have 50 times the sensitivity.

NOTHING DEFINES THE HUBBLE'S potential for discovery better than the big questions that scientists, with an audacity bordering on hubris, are asking it to address. Colin A. Norman, a lanky Australian and former Rhodes Scholar, is a theoretical astrophysicist at the institute. He strides to the chalkboard in his office and poses the three big questions in the cryptic symbols of his profession.

H_0, he scratches on the board, pronouncing it H (for Hubble) naught. This stands for the present rate of the universe's expansion. The trouble is that no one can be sure what the rate is. Some estimates are twice that of others, resulting in uncertainty about what scale to apply in measuring cosmic distances and, hence, about whether the universe is as little as 10 or as many as 20 billion years old.

"This is one question we're really going after," Norman says. By observing stars of the Cepheid class, especially the luminous giants that serve as beacons for surveying astronomers, Hubble should accurately determine distances to remote galaxies, much farther away than any measured before. Analysis of these distances and of the speed at which the galaxies are receding, Norman predicts, should determine, once and for all, the rate of expansion of the universe to an accuracy of about 10 percent.

T_0 is the symbol for the second question, which has to do with the age of faraway globular clusters — dense accumulations of some of the oldest stars that can be observed. T stands for time. Current estimates range from 12 to 17 billion years old. Hubble's cameras and spectrographs, which spread out the light gathered by the telescope, dividing it into separate beams according to wavelength, should be able to resolve the colors and magnitude of these extremely old and faint stars and thereby fix an age for them and the distant clusters they inhabit.

"The first two questions I think we'll handle very well," Norman says, before writing the symbol for the third and more difficult question on the board: Ω_0. Omega naught, he explains, is the measure of the universe's density. (Omega, the last letter of the Greek alphabet, refers to the end of the universe.) Scientists believe the universe is still expanding but at an ever slower rate. If they learn the scale of distances and ages of the oldest stars, then they can, with other careful observations of galactic motion, determine the rate of deceleration of the expansion of the universe. That rate is a function of the mass, or density, of the universe.

Scientists may discover that the density is such that the universe should eventually cease expanding and collapse in on itself. Or they may discover that the universe will expand forever, growing more and more tenuous. A third possibility is that the universe *(Continued on Page 56)*

IN ASTRONOMY, A POINT OF MIND-STRETCHING REVELATION IS AT HAND.

TELESCOPE

Continued from Page 33

is closer to a state of equilibrium, expanding still, but in what scientists describe as a "coasting phase."

THE ADVANTAGES OF ORBITAL telescopes were prophesied in the 1920's by Hermann Oberth, an innovative thinker who influenced the German rocket team led by Wernher von Braun. Lyman Spitzer Jr., a professor of astronomy at Princeton University, began promoting the idea after World War II and, soon after space flight was inaugurated in 1957, gained an important ally in the National Academy of Sciences. The academy's strong recommendation moved NASA to begin designing the Hubble telescope in 1972.

But those were lean years for the space agency. Budget cuts and rising costs of building the reusable space shuttles left the cupboard bare. Only a herculean lobbying effort led by Spitzer and John N. Bahcall, an astrophysicist at the Institute for Advanced Study in Princeton, N.J., saved the project from extinction. In 1975, the astronomers finally struck a deal with NASA and Congress. The telescope would use the shuttle for launching and servicing, which meant it had to be reduced in size, down to a 94½-inch mirror from the originally planned 120-inch version. This compromise, and the promise from Europeans to assume 15 percent of the costs, cleared the way for work to begin in earnest.

Some 60 scientists from 38 institutions were selected by NASA to design and develop the telescope. Under the guidance of C. Robert O'Dell, the former director of the Yerkes Observatory in Williams Bay, Wis., who was chief project scientist, they decided on six instruments to be operated in conjunction with the telescope, each capable of making different but somewhat overlapping observations.

Two of these will be cameras, which will produce the mission's most tangible results. The wide-field-and-planetary camera developed at the California Institute of Technology and NASA's Jet Propulsion Laboratory, is actually two cameras in one. Operating in the wide-field mode, it will survey entire galaxies at a resolution about 10 times better than any ground-based telescope. In the planetary mode, the camera's field of view is narrower, but big enough to display the whole disk of Jupiter; it should be sensitive enough to see Uranus and Neptune better than ground-based telescopes do.

The faint-object camera, built by the European Space Agency, complements the other camera, but is specially designed to detect distant objects; it will see celestial bodies 50 times as faint as any so far seen from the ground, according to O'Dell.

Two spectrographs break up the light into the spectrum, allowing scientists to analyze the chemical composition, temperatures and magnetic fields of celestial objects.

The simplest instrument on board will be the high-speed photometer, a very sensitive light meter that measures the intensity, wavelength and other properties of the light. The sixth of these instruments, a set of fine guidance sensors (which have three "pickle shaped" segments, according to Longair's description), points the telescope at its target. They will measure star positions 10 times more accurately than has been done, findings that should be invaluable in establishing distance scales in the universe. All of the instruments are sensitive to ultraviolet light, a part of the electromagnetic spectrum that is especially obscured by the atmosphere. The telescope itself is also sensitive to a portion of the infrared wavelength, which could be measured by instruments installed in the future.

Sitting in his Princeton office one morning recently, John Bahcall let his thoughts drift back to the early planning days and to one colleague in particular, Robert Danielson, a professor of planetary science at Princeton who did preliminary design studies for the telescope's cameras.

"Bob had a blood disease he knew to be terminal, and was in great pain," Bahcall says. "I carried his briefcase for him to meetings, and once, toward the end, I asked him why he kept on. He told me, because it was the most important thing he could do with the time left him. I think we all felt that way. We were excited, eager, absolutely hyper about the telescope. You know you have a chance to play a role in making history."

While the astronomers designed their instruments, engineers at Lockheed Missiles and Space Company in Sunnyvale, Calif., started on the spacecraft. The company was awarded the contract because of its experience building complex photographic surveillance satellites for the Air Force (although the Hubble's tracking system and light sensitivity preclude it from observing features on Earth). The spacecraft looks like a log wrapped in silvery insulating material, 43 feet long and 14 feet wide; with the telescope fitted inside, it weighs 12 tons. Once the telescope is released from the cargo bay of the space shuttle, the craft's antennas will be deployed, as will two wide solar panels, which will supply electric power for all operations.

The Perkin-Elmer Corporation in Danbury, Conn., a company knowl-

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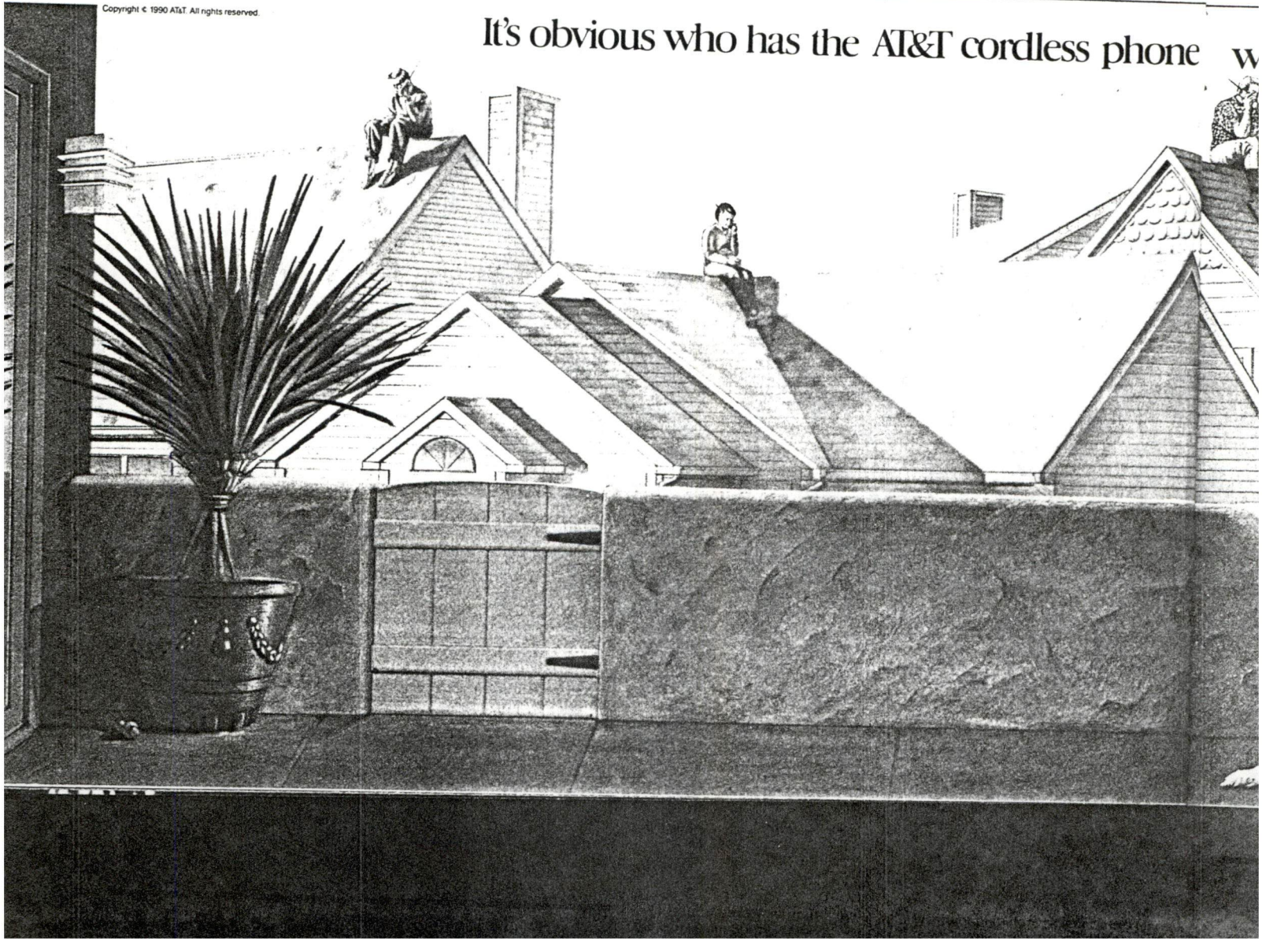

edgeable in military optics, won the contract to supply the electro-optical systems. Technicians started with a one-foot-thick circular "blank," a honeycomb structure sandwiched between glass plates, which had been prepared by the Corning Glass Works to specifications prepared by the Marshall Space Flight Center in Huntsville, Ala. Guided by laser blemish-spotting detectors, they polished the main surface 20 times and coated it with aluminum overlaid with magnesium fluoride, a covering one-thousandth the thickness of a human hair.

I remember a snowy January day in 1982 when the primary mirror was finished and ready for installation in the telescope. Visiting a "clean room" (free of dust and other pollutants), at the Perkin-Elmer plant, I found the mirror on loving display, like an objet d'art — or the elemental wheel in modern gloss. Up close, I could see myself as large as life. Stepping back, I saw my reflection explode larger than life, but without any funhouse distortion. The concave mirror is so smooth that no point on its surface deviates more than a millionth of an inch from an ideally perfect surface, Perkin-Elmer engineers say with understandable pride. (The division is now called Hughes Danbury Optical Systems.) The full telescope assembly includes two mirrors, which collect and condense the light detected and magnify it on the image plane, which has its own scientific instruments attached.

At that time, scientists were aiming for a 1985 launching, but because so much of the technology related to secret military systems, the Pentagon dictated that only 116 managers in the project could have access to the contractors' plans. "This lack of manpower came back to haunt us many times," Robert O'Dell, who now teaches at Rice University, wrote in Sky & Telescope magazine last July. "It kept NASA from closely following the contractors' work and made it very difficult for us to know what was happening at any given time."

Costs soared and deadlines were missed. The system that controls the telescope's directional pointing encountered difficulties, which made matters worse. Only after a management reshuffling at Marshall Space Center, and the addition of more overseers, did the project finally get back on track, but with launching delayed until late 1986.

Then the Challenger exploded and all shuttles were grounded indefinitely. The Hubble was put in storage, where maintenance and testing continued, at a cost of $7 million a month.

Linking the telescope to the shuttle has always seemed a mixed blessing to astronomers. "That's one of our sins for which we're paying now," Bahcall says. On the positive side was a promise that shuttle astronauts would service the Hubble every two

The telescope will be put in orbit 380 miles above the Earth, not the 22,300 miles that astronomers would have preferred.

years. The Hubble, unlike other, smaller telescopes to be put in orbit, is designed for such regular maintenance. Faulty components would be replaced, and new instruments could be added. The entire spacecraft would be returned to Earth every five years for a complete overhaul. (That idea was deemed impractical as early as 1984.) Now, with few illusions about shuttle reliability, project leaders plan for astronauts to visit the telescope only every five years, to replace instruments and nudge it back to an altitude safely above Earth's grasping atmosphere.

From the beginning, astronomers complained that the shuttle could not put the Hubble in the orbit they would prefer, 22,300 miles above Earth's Equator, where it would give an almost unobstructed view of the heavens. At an orbit of only several hundred miles, the telescope's view of the sky will always be half blocked by the Earth — and a different part of the sky will be blocked out at any given moment in the spacecraft's 90-minute circuit of Earth. This has given mission planners a monumental scheduling headache.

Rodger Doxsey, chief of engineering support for the space telescope institute, concedes that the delay caused by the Challenger disaster was not all bad: "We were not ready to operate the telescope in 1986. There would have been a big scramble just to get it operating. But that's a route history didn't take."

The biggest problem was in developing the computer software to control the constantly orbiting telescope: slewing it into position, pointing it to targets and keeping them in the field of view, making adjustments dictated by the interference of Earth and the need to avoid looking at the Sun. (To prevent damaging glare to the optics, the telescope cannot point within 20 degrees of the bright limb of Earth or within 50 degrees of the Sun.) Computers also instruct the telescope about which cameras or sensors to operate for a particular observation, and which of the many camera filters it should use. The computer must then schedule a time when the resulting data can be radioed to Earth

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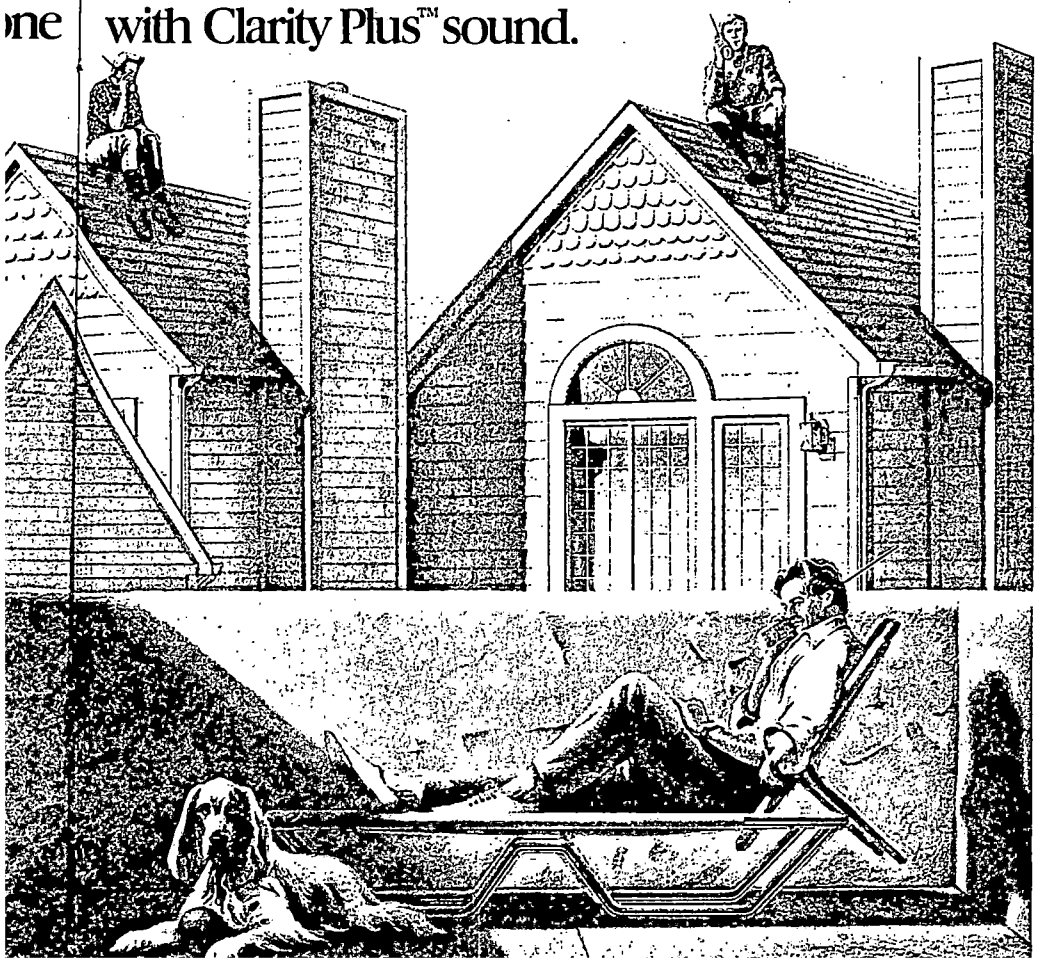

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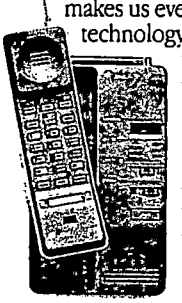

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through the two tracking and data relay satellites, which are not always available, because of commitments to shuttle missions and various spy satellites. Each observation, whether for a few hours or several days, must be meticulously planned down to the second. "The entire architecture for this software has had to be very much redefined in the last four years," Doxsey says.

The delays also have given astronomers time to complete a star catalogue and map giving the precise location and brightness of 18,819,291 celestial objects — everything from planets and stars to quasars, galaxies and clusters of galaxies. Previous catalogues inventoried a mere 250,000 objects. The Hubble will lock on targets by using nearby charted stars as landmarks, or skymarks.

Because all the operations are computerized and monitored by flight controllers, there is no necessity for the astronomers who planned an observation to be in the institute's control room. The data are recorded on tape, which can be viewed later. But, says Eric Chaisson, an astrophysicist who is director of educational programs for the institute, "If I were an observer, I would certainly be here." By monitoring the TV screen in the control room, "You're going to be looking at the universe in real time."

The Hubble is already booked up for observations in its initial year. F. Duccio Macchetto, an astronomer from the European Space Agency and chief of science programs at the institute, says more than 1,500 astronomers in 30 countries submitted a total of 600 proposals for observations — "10 times as many as we could accept and fit into operations the first year." An international committee of scientists makes recommendations to the institute for assigning telescope time.

Proposals fall into five categories: observations of planets in the solar system and the search for planetary systems around other stars, observations of stars and stellar systems, of the areas between stars, of galaxies, and of quasars, those distant energetic objects that may lie at the core of the universe's earliest galaxies. Every effort has been made to give equal observing time to each category. Six or seven projects can be fitted into each week's operations.

"The first science is tailored to things you know you want to investigate," Macchetto says. Astronomers will study dust storms on Mars and the atmosphere of Jupiter, two outstanding mysteries in astronomy. They will search for planetary systems, starting with Beta Pictoris, a star 53 light-years away, and four or five other likely candidates. They will try to confirm the existence of black holes, to observe stars being born, to look in the intergalactic medium for evidence of what scientists refer to as the universe's "missing mass" and to see if the powerful energies of quasars emanate from the heart of distant galaxies. Above all, they will be asking the instruments to answer the three big questions about the universe: its rate of expansion, its age and its destiny.

> With abiding faith in nature's capacity for surprise, scientists believe the telescope will reward them with discoveries they never anticipated.

AT LAST, BOTH THE HUBBLE telescope and the space shuttle are ready. Launching at Cape Canaveral may be as early as the middle of April. Mission officials believe they have finally worked out the bugs in the computer software. So much money and hope have been invested in the telescope over the years. Will it be a disappointment? Will the images measure up to our fantasies of the promised cosmic discoveries?

Robert A. Brown, an astronomer at the institute, concedes that claims for the telescope may be impossible to fulfill entirely. The search for other planetary systems "is the Holy Grail of planetary astronomy," he says, noting that his generation of scientists has made this discovery its goal. He doubts the telescope will see objects even as large as Jupiter around other stars. "Hubble might very well identify young stars with surrounding disks of material, including young planets. But we do not really expect to pick out individual planets."

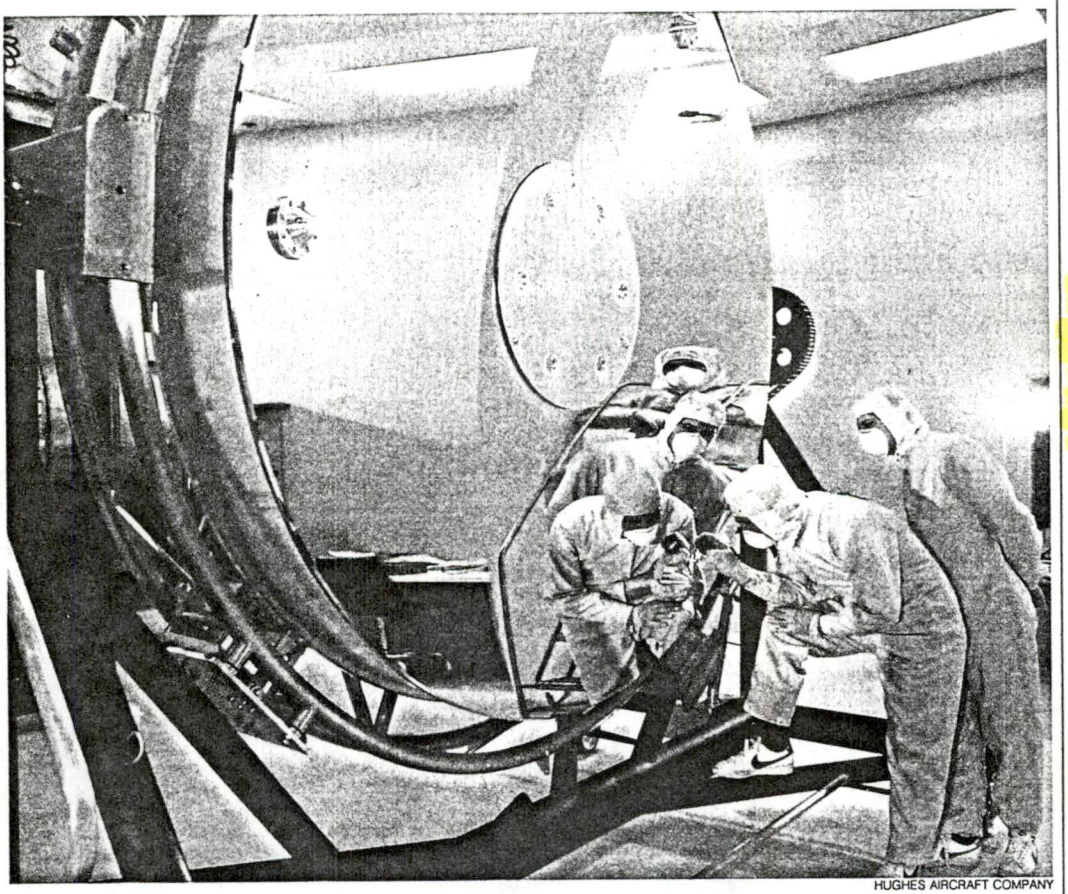
Astronomers also caution the public not to expect the same kind of spectacular vistas that the two Voyager spacecraft transmitted of the outer planets. Discovery is not likely to be as visually dramatic as the rings of Saturn or the volcanoes of Jupiter's moon Io or Neptune's icy Triton. Revelation will spring more slowly and only after bringing to bear the accumulated knowledge of Newton, Einstein, Hubble and today's architects of astrophysical theory.

Still, scientists are confident that they will succeed in getting the first accurate distance measurements to nearby galaxies and in determining the age of the universe. Even if that is all they accomplish, Duccio Macchetto says, he will not be disappointed. "If we can define the expansion velocity of the universe, that's enough, and I'm sure we'll do much more."

They also expect to confirm the existence of black holes. And, with their abiding faith in the telescope and in nature's capacity for surprise, they believe they will be rewarded with discoveries they never even anticipated, including insights into the beginning of time. Galileo, after all, did not know that his little telescope would give him a glimpse of those moons around Jupiter.

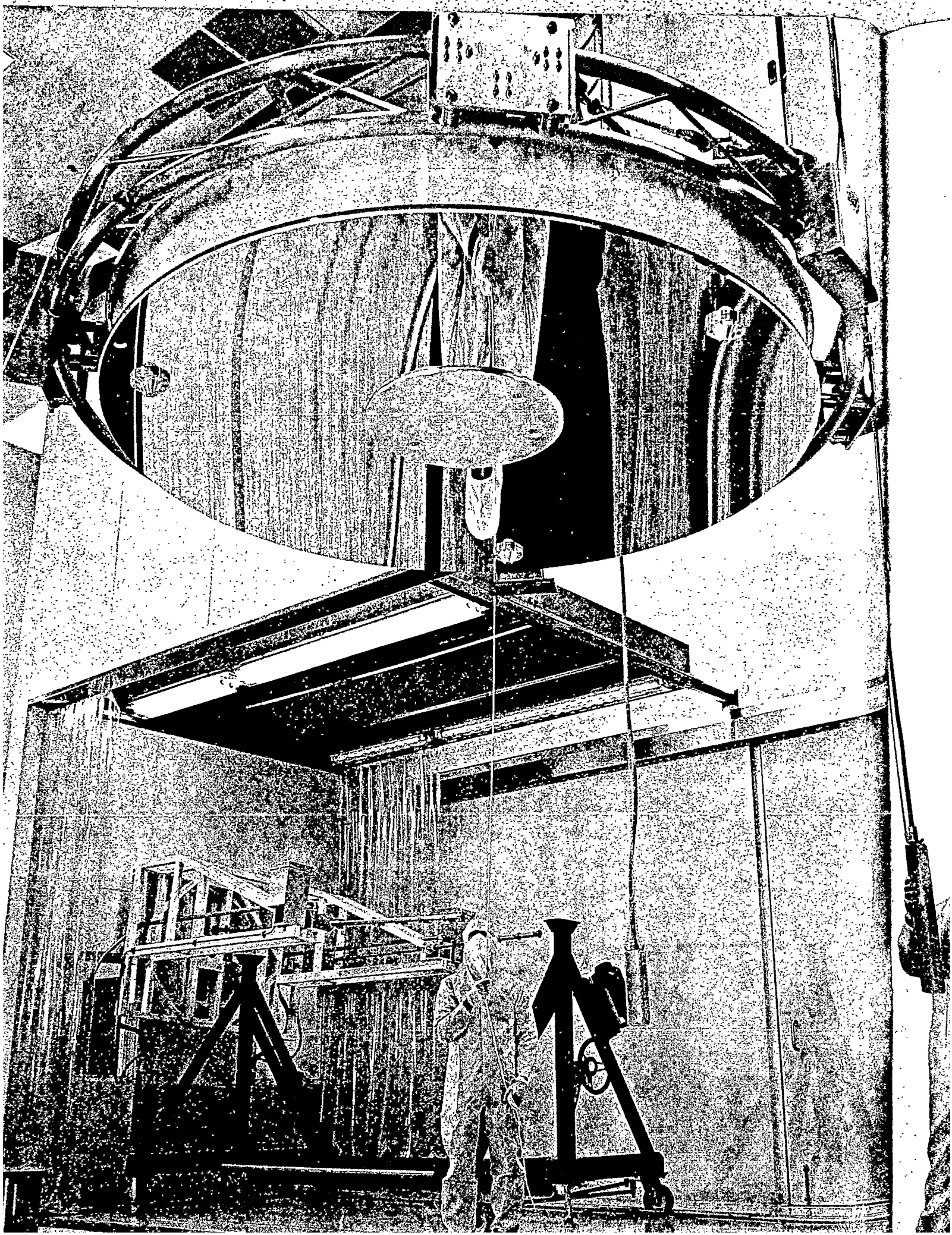
John Bahcall expects that the telescope will not fail to do its part. "If we are disappointed," he says, "it's not the telescope's fault or our fault. It will be because of a lack of imagination on the part of God. What we will see will depend on what nature has in store."

The Hubble telescope's most enduring and reassuring achievement may be nothing less than its affirmation of the spirit motivating our species to seek knowledge. Asking the big questions, the Mad Hatter would be pleased to hear, may well surpass in cultural significance any answers they elicit. "It's not how big the universe is that's impressive," Giacconi says. "It's the power of human reason. We can sit here with our little one kilogram of brain and figure out what this universe is all about." ■



HUGHES AIRCRAFT COMPANY

The telescope's 94½-inch concave mirror: its magnesium fluoride coating is a thousandth the thickness of a human hair.



THE BIG GLASS

The craftsmen working on the Hubble Space Telescope were going for the smoothest and brightest mirror ever. They succeeded—and the view from Earth will never be the same.

BY TERRY DUNKLE

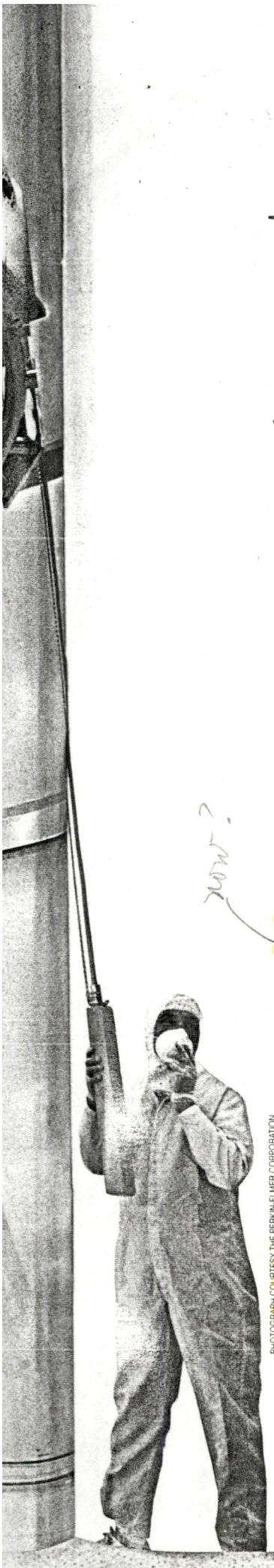
Since November 1, 1984, the Hubble Space Telescope has been sitting in a clean room at a Lockheed plant in California, where it has been cared for at an average cost of $10 million a month. That, inarguably, is a high price to pay for a piece of hardware. But this piece of hardware may soon profoundly change our view of the universe. After years of delays—most recently as a result of the Challenger explosion—it looks as if the Space Telescope will finally be launched from the shuttle next spring.

The rationale for putting a telescope in orbit has long been plain. Earth's atmosphere is the bane of astronomers. Thick, dusty, and turbulent, it either blocks or smears much of the light from stars before the light can reach telescopes on Earth. In particular, the atmosphere blocks almost all the ultraviolet light, which, because of its short wavelength, could be focused into much sharper images than visible light—if it could be collected.

Orbiting 370 miles above Earth's surface, the Space Telescope will be awash in light of all wavelengths. From that privileged position it will enable astronomers to see five to ten times farther and more clearly than they have ever seen before. Distant galaxies, now fuzzy and indistinct, will resolve into multitudes of stars. Quasars, blue pinpoints of light that are the most remote and energetic objects we know, may reveal themselves as galaxies—specifically, as galaxies in the boisterous flamboyance of youth. For in looking farther out through space, astronomers will be seeing further back in time, more than halfway to the creation of the universe 10 to 20 billion years ago.

It is impossible, of course, to predict all the things that they will see. "The most exciting are likely to be objects we can't even imagine today," says Lyman Spitzer, a Princeton University astronomer who may fairly be called the father of the Hubble Space Telescope. "Quasars were unheard of before the two-hundred-inch telescope at Palomar, and before Edwin Hubble's work with the one-hundred-inch on Mount Wilson—only sixty years ago—most of us thought the Milky Way was the whole universe. The Hubble Telescope represents a bigger leap in performance than either of these—a leap just as great, in fact, as Galileo's telescope."

There are many stories one could tell about so complex a project. DISCOVER has chosen one: the story of the making of the telescope's primary mirror. Massive as a buffalo yet delicate as fine porcelain, the mirror is the key to the telescope's performance. If the Space Telescope lives up to the expectations of astronomers, it will be in no small measure due to the efforts of engineers at the Perkin-Elmer Corporation in Connecticut, where the mirror was ground, polished, and coated. Those engineers built a mirror closer to perfection than anyone had a right to expect.



PHOTOGRAPH COURTESY THE PERKIN-ELMER CORPORATION

Shortly after the 94-inch primary mirror of the Hubble Space Telescope was completed in December 1981, technicians at the Perkin-Elmer Corporation hoisted it out of the vacuum chamber where it had received its brilliant aluminum coating.

One afternoon in the late fall of 1981, two dozen men in ice-blue jumpsuits and surgical masks stood in a cavernous room at a factory in Wilton, Connecticut, watching as a stainless steel canister 16 feet tall had its interior pumped to a vacuum nearly as empty as interplanetary space. Inside was a $15 million glass disk, almost eight feet in diameter, which Jack Kurdock and his crew were about to coat with aluminum. This disk was the primary mirror for the Hubble Space Telescope, and in a technical sense, it was the most finely crafted object ever made. Five years of nerve-wracking labor had gone into casting, grinding, and polishing it. Now, in the course of just five minutes, Kurdock was going to give the mirror its final touch. Never had he felt so nervous. If he succeeded, astronomers would be able to see almost to the beginning of the universe. If he failed, the Perkin-Elmer Corporation stood to lose tens of millions of dollars in NASA contracts, and a chance at the aerospace big time.

Although Perkin-Elmer had made telescope mirrors before, the company was still known primarily as a manufacturer of laboratory instruments and machines for printing microchips. It saw the Hubble project, for which it was building the telescope proper (Lockheed had the contract for the spacecraft as a whole) as a stepping-stone to more lucrative contracts. In particular, it had its eye on the Solar Optical Telescope, a $60-million orbiter NASA planned to launch four years after the Hubble. "We'd like very much to build that," said Perkin-Elmer president Horace McDonell. "It'll prove we can handle an entire spacecraft on our own."

To get the Hubble contract Perkin-Elmer had pulled out all the stops, devoting an army of engineers to the project. They had designed an 18-foot telescope tube that could orbit from the sunlit to the shadowed side of Earth without expanding or shrinking more than 150-millionths of an inch. They had designed sensors that could lock the telescope onto a target as small as a fly at 170 miles. Finally, they had declared they could build the whole thing for $70 million. "They had a superior technical proposal," recalls James Beggs, then head of NASA, "and a very attractive price tag."

But they also had a few spots on their record. In 1968 four Perkin-Elmer technicians had dropped a $1 million mirror for Copernicus, a small orbiting telescope. More recently, in preparing for the bidding on this project, Perkin-Elmer had sunk $1 million in NASA funds into polishing a 60-inch demonstration mirror. "It turned out okay in the end," says a source close to the work, "but at the time we submitted our proposal it looked like a total abortion. They had scratched it and turned the edge so badly it looked like the heel of an old shoe."

NASA could not afford that kind of failure with the Hubble's 94-inch primary. Shaped like a pineapple ring, with a 26-inch hole at its center, the mirror was the very heart of the telescope. Incoming starlight would fall on its subtly dished face, bounce to a 13-inch secondary mirror in the front of the tube, and be thrown back through the hole in the primary to a bank of spectrographs and cameras. If the telescope was to do its job—if it was to transmute distant pinpoints of light into turbulent suns or even entire galaxies—then the primary would have to make good use of the light it collected, bringing it into tight focus and scattering as little as possible.

"Forget the Teacup! By the time we're finished, it'll be like a mole on the shoulder of a beautiful woman."

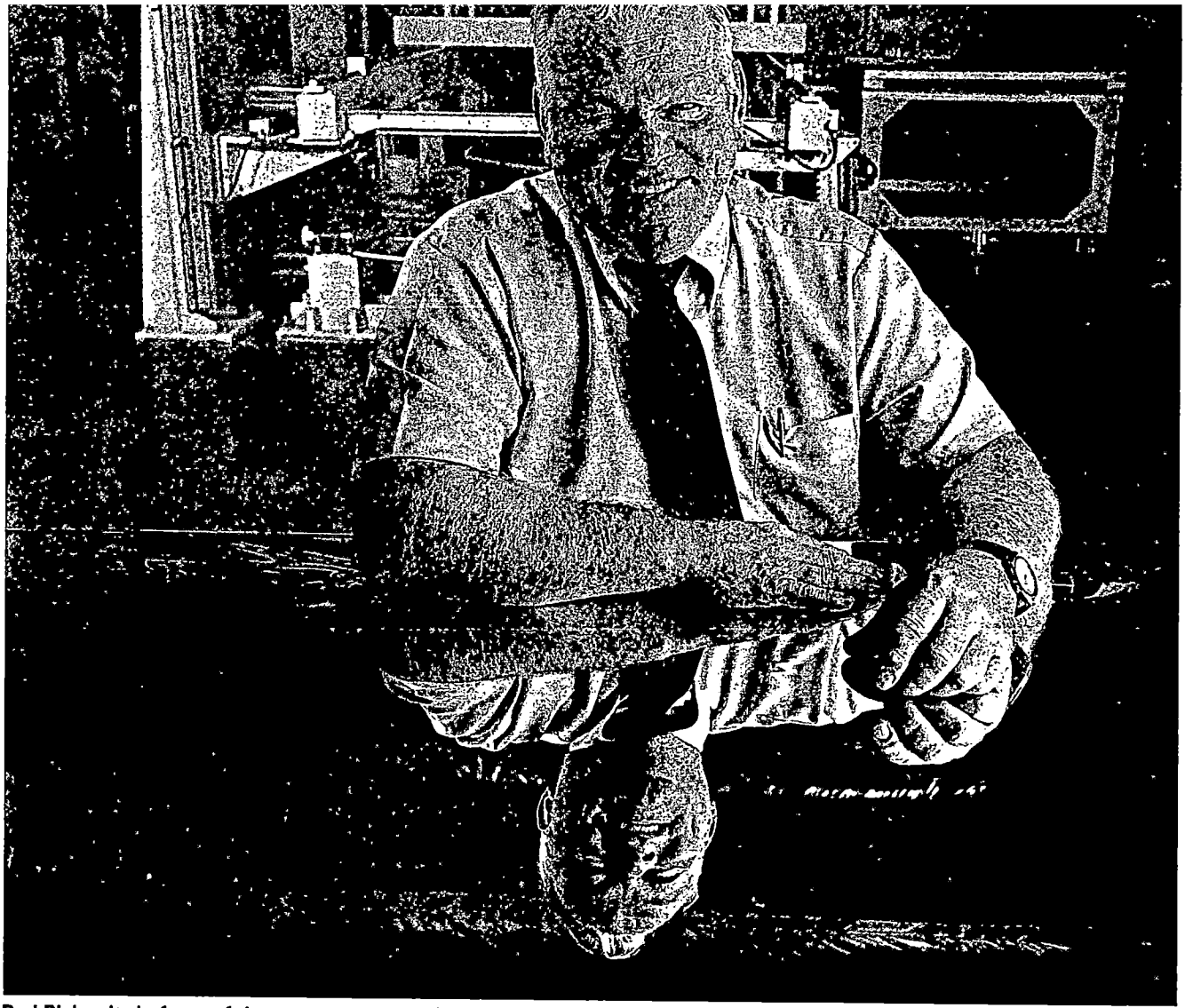
And to do that, the mirror would not only have to be unusually reflective—something Kurdock's aluminum coating was supposed to ensure—but also extraordinarily smooth. NASA's main specification was "lambda by 64," meaning that the surface of the mirror could not deviate from a perfect shape by more than one sixty-fourth the wavelength of neon light, or half a millionth of an inch. Blown up to the diameter of the Gulf of Mexico, the mirror could have waves averaging no more than a quarter of an inch high. On that scale a typical eyeglass lens would have 50-foot swells.

No one had ever built such a mirror; yet the success of the entire project depended on it. So when NASA awarded Perkin-Elmer the contract in July 1977, it hedged its bets: it commissioned a spare mirror from the company's chief rival, Eastman Kodak, and reserved the right to fly the spare if it should prove superior. "From then on," said a Perkin-Elmer employee, "the word around here was, 'Our mirror must fly.' "

Thus it was that on a gray December day in 1981, as Kurdock prepared to put the gloss on Perkin-Elmer's mirror, he held many hopes in his hands: those of astronomers, eager to get a quasar in their sights; those of Perkin-Elmer executives, who had great dreams for their company; and, not least, those of dozens of optical engineers and technicians, who had devoted much of their waking hours over the past five years to the pursuit of perfect smoothness.

Listen," said Ronald Roy Rigby Jr., also known as "R-Cubed" or "Bud," "there isn't one of us on this team whose whole life—whose *personal* life, okay?—hasn't been seriously impacted by the making of this optic." Rigby had just finished his work on the glass and had delivered it to Kurdock for coating. One might have thought he would be unwinding. But Rigby—a florid-faced man in his fifties with a pushed-up nose and yellowish-white hair—is not the unwinding type. When he stripped off his jacket, he revealed shirt pockets crammed with Maalox tablets and True menthols, along with the more predictable pens and calculator. Bud Rigby, as his colleagues know, is many things: brash, vain, and cantankerous are adjectives that come to mind. Relaxed he is not.

He was, however, a natural choice to run the mirror team. A veteran of the division that makes Perkin-Elmer's microchip-printing machine (which uses a highly accurate 20-inch mirror to focus pictures of electric circuits onto tiny plates), Rigby already knew how to meet Hubble Telescope specs on small areas, and he had 25 years of experience making larger, though less accurate, mirrors for satellites. "He's also one of the few optical engineers in the company who



Bud Rigby sits in front of the computer-controlled device that he used to polish the primary mirror's concave surface.

PHOTOGRAPH BY KIMBERLY BUTLER

could stand the stress," said one of his superiors. "Bud's not an introvert, like most of these glass people. Put them on a job like this and they go to pieces." Mirror-makers speak darkly of George Willis Ritchey, the brooding genius who polished the 100-inch mirror that Edwin Hubble used to discover the expansion of the universe; Ritchey is said to have been driven insane by the task. "Bud's already insane," said a colleague of his, "so it didn't make any difference."

Like most of his team, Rigby had started work on the Hubble project years before. First, back in 1977, he had overseen the manufacture of the mirror blank at Corning Glass. To save launch weight, the blank was cast not as a solid disk, but as two thin plates sandwiching an "egg crate" interior made of slender glass slats. It was 90 percent air. To get it to approximately the right curve, the entire blank had been heated and "sagged" over a mushroom-shaped mold.

At this point the glass was transferred to Perkin-Elmer. There the front plate—the one that would be given a reflective coating—was sculpted into its required form, a concave figure called a hyperboloid. Using spinning disks and powdered abrasives, Rigby's team ground away the irregularities left by the mold, leaving a satiny surface that would later be polished to fit the curve exactly. From casting to fine grinding, this preliminary work lasted more than two years.

It did not proceed without incident. There was, for example, the Teacup Affair.

The episode was one of the most frightening in the mirror's five-year history. It began during a routine inspection one morning late in the fine grinding, when an inspector smeared kerosene on the frosty surface of the glass to look inside. Just beneath the surface, not far from the mirror's edge, he found a tiny crack radiating white tips into a shape like the bowl of a teacup, one-quarter inch in diameter.

Panic ensued. In a really large piece of glass the tiniest nick or chip can spell disaster, because the stresses inside the glass always concentrate at the sharpest point. Mirrors smaller than this had been shattered by even a slight temperature change. A few had burst while opticians were home in bed sleeping. If the Teacup wasn't removed and the wound safely rounded, the crack might grow.

An argument broke out between Rigby's group and others on the project. Rigby wanted to cut into the mirror's flank with a dental drill, angle the drill upward, and clean out the Teacup from below. Another engineer, a stress analyst charged with predicting whether the mirror could survive a space shuttle launch, complained that the re-

pair hole's irregular shape would make the mathematics too difficult and unreliable. His group preferred lifting out the Teacup with a coring tool, coming in through the front.

"Our mirror is *not* going to have a hole in its face!" protested some of Perkin-Elmer's top managers.

"That's not the point," Rigby told them. "A hole that small won't affect the light-gathering power significantly. The problem is, the coring tool will apply pressure in the same direction the crack wants to grow. If one of those tips opens up, it's going to run all over the place. I work with glass. I know."

"The tips can't open—they're sealed," replied one of those in the coring camp.

"You don't know that. *I* don't know that," said Rigby.

The fracture tips would be sealed only if the crack had developed at Corning before the mirror blank was annealed. Nobody was sure it had.

For the moment, Rigby seemed to have the upper hand. Then someone realized that drilling through the side of the mirror would pollute its interior with glass dust. The egg crate had 144 cells, each larger than a half-gallon milk carton, communicating with one another through a single quarter-inch hole in each cell wall. Wash water would drain out of the mirror about as readily as from a Tabasco bottle. In space, leftover dust grains would float into the telescope's optical path, scattering the light. Coring, it seemed, was the only alternative.

So after three weeks of fearing a disaster, Rigby's group found themselves doing the one thing they knew might bring one on. They held their breath as the spinning tool touched down, and gritted their teeth as it chewed its way into the glass. But the earsplitting crash never came.

Afterward the Teacup, in a frosty-sided plug about the size of a bottle cap, was sent to a NASA laboratory for analysis. Months later word came back that the crack's tips were sealed and inactive. The Teacup could have safely remained. The unnecessary hole galled many members of the mirror team, but not Rigby. By then he was too busy preparing for the critical polishing stage to worry about anything else. "Forget the Teacup!" he told his colleagues. "By the time we're finished, it'll be like a mole on the shoulder of a beautiful woman."

Before they could begin polishing, Rigby's opticians had to design their tools. For starters, they needed a way of supporting the glass so it wouldn't sag under its own weight (nearly a ton) during polishing. If it did, by even a millionth of an inch, it would relax into a different shape in the weightlessness of space. "You'd get star images like big, fuzzy cotton balls," Rigby explained. To prevent this, the engineers built a "bed of nails" with 134 titanium push-rods, each bearing on a sapphire glued to the mirror's back and mounted on a delicate leaf spring that could be adjusted as finely as a pharmacist's scale. On this device the mirror would float almost as freely as in space. The cost: $2 million.

The aluminum coating was so thin that if it were peeled off and flung into air, it would remain suspended for days, like smoke.

A bigger problem was finding a way to gauge the mirror's accuracy. After each step in the polishing, the team needed to know precisely where and how much the surface deviated from the ideal hyperboloid so they could design the next polishing run. Rigby's assistant Lou Montagnino solved the problem with a $5 million device that bounced a pair of laser beams off the surface, producing a pattern of dark, wavy interference bands like those seen in overlapping window screens. By analyzing these interferograms with a computer, he was able to generate contour maps showing bumps and hollows as shallow as ten-billionths of an inch. So sensitive was the device that traffic on Route 7, half a mile from the plant, shook the basement too violently to permit measurements except in the wee hours of the morning. "We had to polish all day and measure all night," said Rigby.

Finally, Rigby's team had to devise the polishing tool itself. Since Isaac Newton invented the reflector telescope in 1668, the standard polishing tool has been a glass disk, about the size of the mirror, coated with pitch laced with jeweler's rouge. Rubbed back and forth on the mirror, it polishes faster in some zones than others, depending on the length and shape of the stroke. The chief drawback of this method is that each type of stroke has multiple effects. A long *W* stroke, for example, will scoop out the middle nicely, but not without also wearing down the very edge.

The optician can switch to a smaller tool for localized polishing, but then he runs into a different problem: that of a cabinetmaker trying to sand a tabletop with his pinkie instead of a block. No matter how hard he tries to work the zones evenly, he ends up getting little bumps and hollows all over the place, and must return to the large tool for a "smoothing run." For these reasons, the optician who can drive a large mirror directly toward his goal is regarded as something of an artist. "Part of our mission," said Rigby, "was to turn the art into a science."

What he and his group did was to figure out how to use the pinkie method and get away with it. Their polishing machine, controlled by a computer reading the contour maps, would drive a spinning, poker-chip-size tool over the surface of the glass, dwelling longer on the hills than the valleys; each run would take several hours to a couple of days, depending on the amount of glass to be removed. When polishing finally began in August 1980, the machine worked beautifully. At the end of each run the interferograms showed a surface much closer to the perfect hyperboloid. But by November, as the runs grew shorter and the remaining hills more subtle, the vagaries of pitch and polishing compound began to play a larger role. Surprises kept popping up: a deep, arcing canyon, a turned edge, a mysterious scratch, a little bump that shifted from run to run. Progress slowed: "We had to adopt the carpenter's adage: Measure twice; cut once," said Rigby. "It

PHOTOGRAPH COURTESY THE PERKIN-ELMER CORPORATION

was horrible. Work all day, work all night . . . "

". . . And then be at our desks the next morning to explain why we still weren't finished," said his assistant Jim Smith. "It's one thing to do a good job. It's another thing to *have* to do a good job, and it's still another to have to do it with people standing over you all the time."

By mid-November Perkin-Elmer's top managers were under intense pressure from NASA. Ronald Reagan had just been elected president, deep budget cuts were predicted, and the Hubble Telescope was gaining a spendthrift's reputation in the press. Four years into the program, the cost estimate for the entire telescope had risen from $435 million to $1.1 billion, and yet not a single major component had actually been built. With double-digit inflation prevailing, every delay hurt NASA's budget severely. And NASA had two effective ways of getting at Perkin-Elmer: the ever-present threat that it might fly Kodak's mirror if Kodak finished first; and the contract for the Solar Optical Telescope, which Perkin-Elmer was to bid on the following March. Perkin-Elmer's management desperately wanted Rigby to deliver the Hubble mirror by then.

Rigby did not take kindly to the pressure. In fact, he vehemently resisted it. And as winter deepened, his progress became painfully slow. Sometimes he took more than a week to remove a few millionths of an inch of glass.

By the beginning of March, half a year behind schedule, Rigby was almost finished. The mirror's overall shape, its "figure," was nearly perfect. All it needed was a bit of edge work with the smallest of tools. Carefully the team designed and executed a single polishing run. When they saw the interferograms, they rejoiced: the figure had passed spec by a comfortable margin. Superimposed on the figure were a myriad of tiny peaks and valleys, but with a large tool they also could be eliminated in what Rigby hoped would be a final smoothing run.

"So we smoothed it," Rigby said wryly, "and what we did was, we wrecked the figure."

The smoothing run had slightly flattened the edge, and extra runs would be needed to scoop the middle to the right depth again. But the correction would take weeks and cost up to a million more dollars. Total expenditures, originally forecast at $6 million, had already passed the $9 million mark. NASA was appalled.

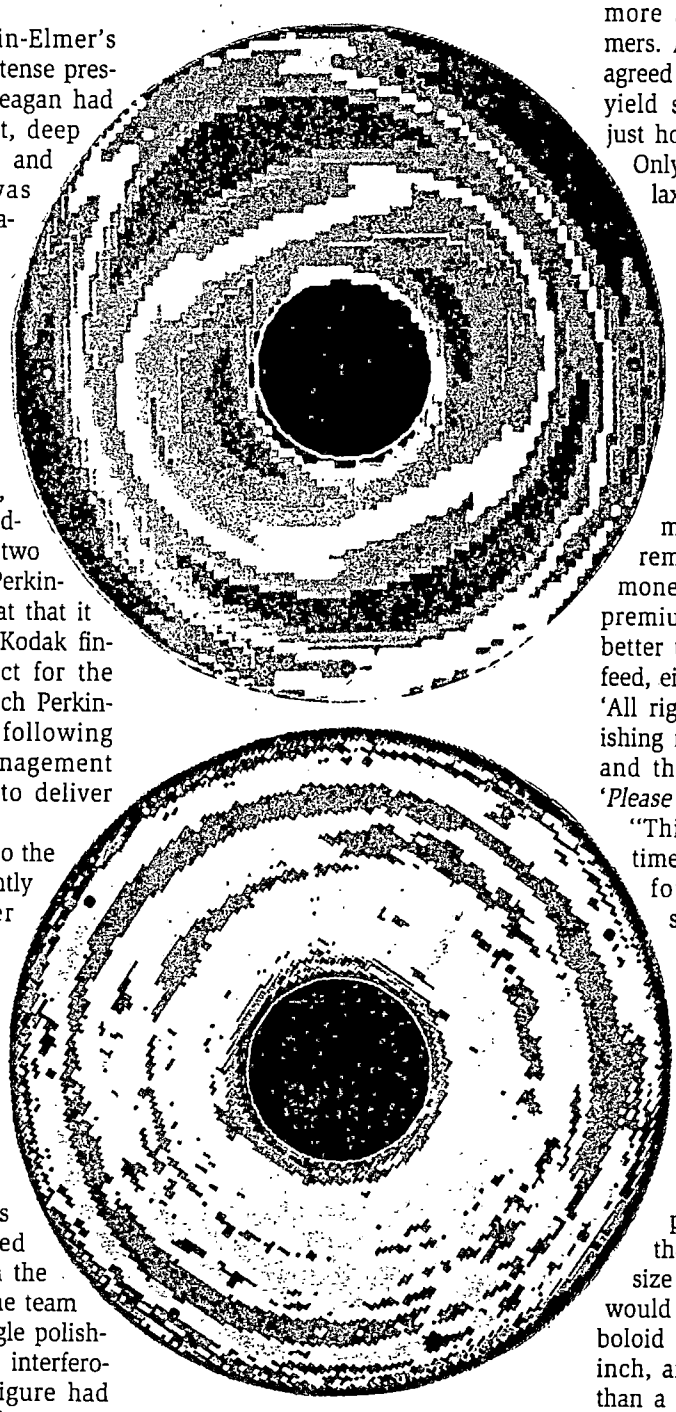
Rigby's superiors began to consider taking the mirror away from him before he reached his spec of lambda by 64. NASA was willing to accept lambda by 50; it had never guaranteed the more stringent number to astronomers. After all, even though everyone agreed that greater smoothness would yield sharper images, nobody knew just how smooth was smooth enough. Only Rigby stood in the way of relaxing the spec.

But Rigby preferred not to compromise. He had spent 30 years climbing to the top of his profession, and he knew he would never see another mirror as challenging as this one. And besides, his own contract with Perkin-Elmer specified lambda by 64.

"I told them I wasn't violating my contract," said Rigby. "And I reminded them that we get extra money from NASA—a performance premium—if the telescope performs better than expected. It's not chicken feed, either—it's millions. So they said, 'All right, you can have another polishing run.' And we took another run, and the mirror *still* wasn't finished. '*Please* stop,' they said.

"This went on for weeks. By the time we finally finished—on April fourteenth—we'd made such skunks of ourselves that hardly anyone would speak to us. We ended up with one hell of a mirror, though. You're gonna live a good many lifetimes before you see another one like it."

In the end, Rigby had achieved an accuracy of lambda by 78—better than planned by 20 percent. Now if the mirror were enlarged to the size of the Gulf of Mexico, its figure would deviate from a perfect hyperboloid by no more than a fifth of an inch, and its wavelets would be less than a millimeter high. In June NASA telescope scientist William Fastie pronounced the big glass "easily the finest mirror ever made. I have no doubt," he said, "that we're going to see perfect star images very deep into the ultravio-



"Interferograms" of the mirror surface guided the polishing. Before: Hills (blue) and valleys (red) mar the shape. After: The mirror is less than a millionth of an inch from perfection (white).

PHOTOGRAPH COURTESY THE PERKIN-ELMER CORPORATION

let. Thanks to Rigby, we'll be able to reach hundreds of millions of light-years farther than we ever expected."

The pronouncement was fair, but premature. Rigby's exquisite piece of glass wasn't a mirror yet. The rest of the job had fallen to a very different sort of man: Jack Kurdock.

Kurdock had never taken the mirror quite as seriously as Rigby had. "I've got other things to worry about," he told me one morning early in September 1981. We were sitting on the unopened mirror crate, a large wooden box bearing a number of empty coffee cups and a red tag reading NASA—CRITICAL HARDWARE. Kurdock, a broad-faced young man with dark brown hair, was head of Perkin-Elmer's mirror-coating department. His chief responsibility was coating the 20-inch mirrors that went into the company's Micralign chip-printing machines. Because of the recent boom in the microcomputer industry, his work load had become frightfully heavy. "The guys in production are throwing glass at me faster than I can coat it," he said. "I'm already six months behind." His main interest in the Hubble Telescope, he confessed, had been the excuse it provided—and the $1.5 million in NASA funds—to build the world's largest vacuum coating chamber. "I can fit eight Micralign mirrors in there at once, as soon as I get rid of this baby," he said, knocking on the wooden crate.

He led me across the room to the vacuum chamber: a gleaming steel canister, nearly two stories tall and as broad as a house, with walls three-quarters of an inch thick. A rubber gasket went *pfup!* as Kurdock opened the quarter-ton door.

The interior was gloomy, lit mainly by a large, open slot near the ceiling. "That's where the mirror will come in," said Kurdock, his voice echoing. On the ceiling was a giant toothed metal ring, from which the mirror would hang face down. Near the floor, spaced evenly around the circumference, were eight crucibles: copper pans about the size of bottle caps. Each crucible sat on an electron gun: a metal box attached to the wall, trailing an electric cable.

After the mirror was installed in the chamber, the door and the slot would be sealed. For a week a set of powerful pumps would exhaust the interior, until the pressure was 1,000 times lower than what the telescope would encounter 370 miles above Earth. On Coating Day, Kurdock's team would first start the mirror rotating slowly, to help ensure a uniform thickness to the coating. Then, at the appointed hour, four of the guns would begin shooting streams of high-energy electrons at lumps of pure aluminum sitting in the crucibles. As the aluminum vaporized, its atoms would rise toward the ceiling and cling to the glass. If the guns, the rotation, and the vacuum held steady, in about three minutes the glass would gain a brilliant and smooth veneer. Finally, the film would be sealed against oxidation by a transparent overcoating of magnesium fluoride, to be applied by the remaining four guns. The overcoating would take about a minute and a half. When it was over, the Hubble Telescope mirror would be complete—provided it passed all NASA's tests.

Kurdock's eyes were glued to the voltmeters. A look of panic invaded his face. Something was wrong with Gun One—and the clock was ticking.

The specifications for this coating were the most demanding Kurdock had ever faced. First, it had to be incredibly thin: three-millionths of an inch of aluminum and one-millionth of an inch of magnesium fluoride. This was so thin that if the coating were peeled off and flung into air, it would remain suspended for days, like smoke. Second, it had to be uniform in thickness, to within 3 percent. And finally, it had to be almost impossibly bright—especially in the ultraviolet, where the telescope would make its most important observations. (One reason the mirror had to be coated with aluminum rather than silver was that silver absorbs ultraviolet light.) "It's got to reflect at least seventy percent of the light in the ultraviolet," said Kurdock. "I don't know of anyone who's ever done that with aluminum. Theoretically *perfect* is only eighty-four percent. We've been practicing on small mirrors for months, and we still haven't gotten above sixty-seven percent."

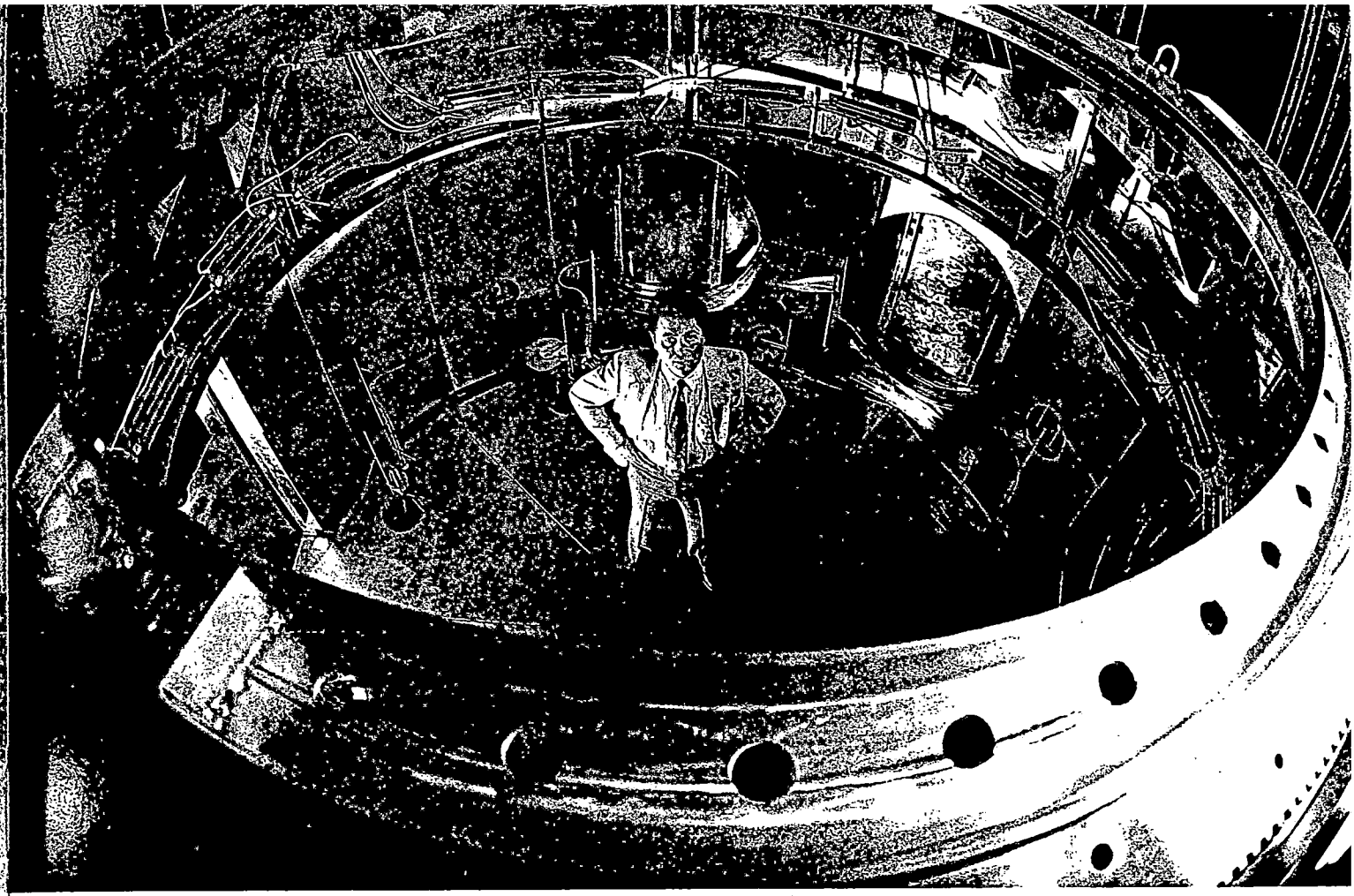
Kurdock's biggest difficulty lay with the electron guns. The guns had to vaporize the coating materials rapidly and steadily. Speed was required because even the deepest vacuum would contain quadrillions of oxygen atoms. "These are attacking the aluminum at the same time you're laying it down," explained Kurdock. "If you don't get the aluminum on quickly and seal it up right away with the mag fluoride, you'll end up with a layer of aluminum oxide on the coating. It may be only a couple of molecules thick; you'll never notice it in visual light, but in the ultraviolet the mirror will be as black as fresh asphalt."

Steadiness, too, was important, especially in the sealing stage. The magnesium fluoride overcoating had to be exactly the right thickness. A sudden drop or surge in a gun's output could leave a "dark" spot on the mirror.

Unfortunately, the guns were neither speedy nor steady. During practice runs the guns' power sources, a quartet of 16,000-watt transformers, had a habit of "slumping": their output voltage would climb into a danger zone, boil the cooling water in the guns, and suddenly drop to zero. The result was an inferior coating, a burned-out gun, and a frustrated coating team. "We've got to have six perfect test runs in a row before we're allowed to coat," Kurdock explained. "So far, we haven't made it past three."

Kurdock's other hurdle was to convince NASA that his team could safely open the crate and begin handling the mirror. Moving it from the crate to the chamber was a major problem in itself, mainly because the glass had to be washed before the coating. If the surface bore even the tiniest trace of dust or grease—a single thumbprint, say—the foreign matter would vaporize in the chamber and precoat the glass with a thin film of hydrocarbon molecules. These would have the same effect as oxidation: a coating nearly dead black in the ultraviolet.

The easiest way to ensure that no impurities were left on the mirror was to stand it up and rinse it with distilled water until the surface began draining in perfect sheets. But the mirror was too



Jack Kurdock stands in the vacuum chamber he used to coat the mirror. On the floor are the electron guns.

heavy to stand on its edge; it would crack immediately.

Foreseeing this dilemma, Perkin-Elmer had designed the mirror to be hung by three toggle bolts passing all the way through it from front to back. The heads of the bolts would bear all the weight when the mirror hung face down; their shafts would bear *most* of the weight when it hung vertically. The rest would bear on the inside of a half-million-dollar space frame made of welded steel tubing, which would fit over the mirror like an upside-down cake pan. Thus distributed, the forces would neither crack the mirror nor craze its delicate coating.

Before the coating could begin, then, Kurdock's team had to unpack the mirror, slip the space frame over it, bolt the two together, turn the resulting assembly on edge, wash it, dry it, turn it face down again, lift it onto the trestle leading into the chamber slot, and finally draw it safely inside.

PHOTOGRAPH BY KIMBERLY BUTLER

None of these operations could be hurried. The simplest mistake—dropping a bolt, or losing one's grip on a wrench—might crack the glass. To guard against such accidents, every one of the 1,500 steps in Kurdock's job had been meticulously laid out in a special book, *Space Telescope Operational Procedure and Testing Procedure O.P. 679-5088,* which the team was expected to study and obey as a fundamentalist obeys the Bible. The book was two inches thick and in places devoted whole paragraphs to the tightening of a single bolt. Every step had to be performed under the watchful eyes of two quality-assurance inspectors, one from the government and one from Perkin-Elmer.

"Those guys can make your life miserable," said Kurdock. "Professional nitpickers is what they are. They report to no one, they don't have to justify the cost of anything they demand, and their powers are almost dictatorial."

On September 29 a dozen engineers from NASA's Marshall Space Flight Center in Alabama visited Kurdock for an "operational readiness inspection." The delegation was headed by Charlie Brooks, chief of quality assurance. They spent most of the morning in a windowless conference room, grilling Kurdock and Rigby on the safety of the handling equipment.

"What about this space frame?" Brooks asked. "Has it been stress-tested?"

Kurdock told him that the space frame had supported a test weight more than twice as heavy as the mirror, without breaking.

"Was that after you welded in the extra struts, or before?" someone asked.

"Before. But of course the struts have made it even stronger."

"Not necessarily," said someone else. "Suppose you've got a crack in one of the strut welds. It lets loose, there's a sudden strain on the rest of the welds, and they all go."

"There aren't any cracks," Kurdock said.

"How do you know? Did you X-ray?"

"All right," said Kurdock. "If it'll make you guys happy, we'll test the frame again with *ten* times the load."

"Fine."

"Action Item?" asked the recording secretary.

Brooks nodded, and pencils began scratching in the margins of *5088.*

They argued their way through a dozen other details, adding an Action Item for each. Finally they came to the limit switch—a device that was supposed to shut off the electric motor that drew the mirror into the chamber, in time to prevent the mirror from crashing into the chamber wall.

"I think you should open up that switch and inspect the wiring," said one of the quality men. "Suppose your man's got it wired up backward. I've seen things like that happen."

"Naw," said Kurdock. "He's a very careful guy. Besides, if you look at paragraph 15.6.2A, you'll see we have a man up there on the ladder, watching. If the mirror doesn't stop, there'll be plenty of time to shut the motor down manually."

"Suppose the guy falls off the ladder," said a quality man. "Then you're in a failure mode without a backup."

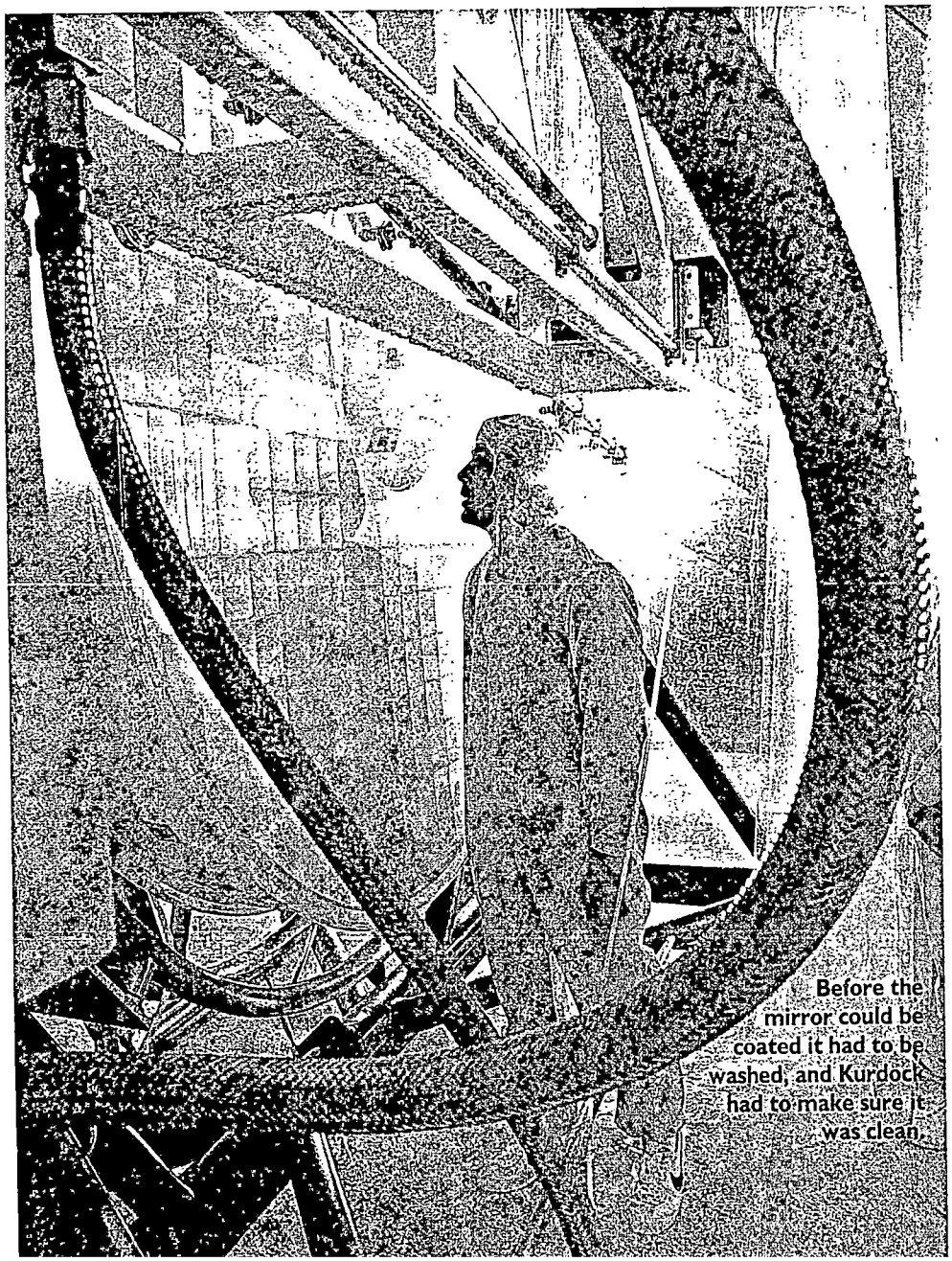
The quality men spent the rest of that day, and all of the next, examining the equipment and watching a dress rehearsal. They were especially interested in Kurdock's technicians: Martin Geyselaer, a serious and soft-spoken 42-year-old Dutch immigrant who had worked with Kurdock for ten years; Bill McCullock, a shy 24-year-old with a profound Scottish brogue; Karl George, a strapping 37-year-old who wore designer jeans and a gold chain around his neck; and Rick Gagliardi, 26, who favored black T-shirts and roared to work on a motorcycle. Each man's role in the coating had been carefully defined, and his movements choreographed to an extreme: how to hold a nut while twirling it onto a bolt, which wrench to use for tightening it, where to lay the wrench afterward. "We've practiced every step so many times, we can do it without thinking," Gagliardi told me. Sure enough, the rehearsal offered no surprises.

Afterward I asked Kurdock why NASA had ridden him so hard on the handling procedures. "We've been known to break mirrors," he replied. "Not that we're careless or anything. In this business, crap like that happens all the time. The worst one was probably Copernicus, another NASA job. It was a thirty-six-inch mirror, weighed maybe three hundred pounds. Four guys were carrying it, and one of them trips over a two-by-four somebody left on the floor. Bang! No more mirror! When you work with glass, you learn to expect stuff like that. No matter how much you plan, there's always a few stupid events you can't foresee. Things just *happen.*"

NASA's two-day inspection left Kurdock with 18 Action Items—enough to push Coating Day back to at least mid-November. It was the third time the date had slipped since he received the mirror. NASA was not happy. The mirror was now a year behind schedule.

Perkin-Elmer had a more immediate worry. It had failed to complete the Hubble mirror before submitting its bid for the Solar Optical Telescope; now it at least wanted to finish the job before it had to defend that bid in front of a NASA panel. That meeting was scheduled for November 19. Perkin-Elmer needed the Solar Optical contract more than ever: it had just been forced to lay off 50 workers in its optical division, many of them high-level engineers. A hundred more had taken early retirement. The mood at the company was black.

Kurdock and his team spent most of October working on the Action Items. The worst item was completing six flawless test runs. Time and again, they watched the voltage needles climb into the danger zone and heard the sickening rattle of the coolant boiling in the guns. The team soon found itself working double shifts. Kurdock was exhausted: besides wrestling with the Hubble Telescope, he was trying desperately to get a new wing built for



Before the mirror could be coated it had to be washed, and Kurdock had to make sure it was clean.

coating Micralign mirrors.

It was the end of October before the coating team reached Test Run Number 6. They were too tired to celebrate. On Tuesday, November 3, Kurdock finally got permission to open the mirror crate. After looking at the glass, he suddenly told his team he wasn't feeling well, and went home. His wife called the next morning to say he was down with the flu and a temperature of 105.

At the coating-room door a few mornings later, I met Rick Gagliardi, who had agreed to let me have my first look at the mirror. He handed me a jumpsuit, a surgeon's mask, a hood, and a pair of white booties with tacky soles, meant to prevent me from kicking up dust. "We're going into a Class Ten Thousand environment," he said. The previous weekend, a cleaning crew had scrubbed every square inch of the room, including its 24-foot-high ceiling. An electronic monitor had been set up to make sure the air contained no more than 10,000 dust particles per cubic meter—1,000 times fewer than in a hospital operating room. Gagliardi handed me a ballpoint to replace the pencil I was using to take notes. "NASA doesn't like pencil dust," he explained.

He punched a secret code, and the coating-room door slid open. We entered an "air shower," where stray particles were stripped from our clothes by a deafening blast from the ceiling and a strong suction through the floor.

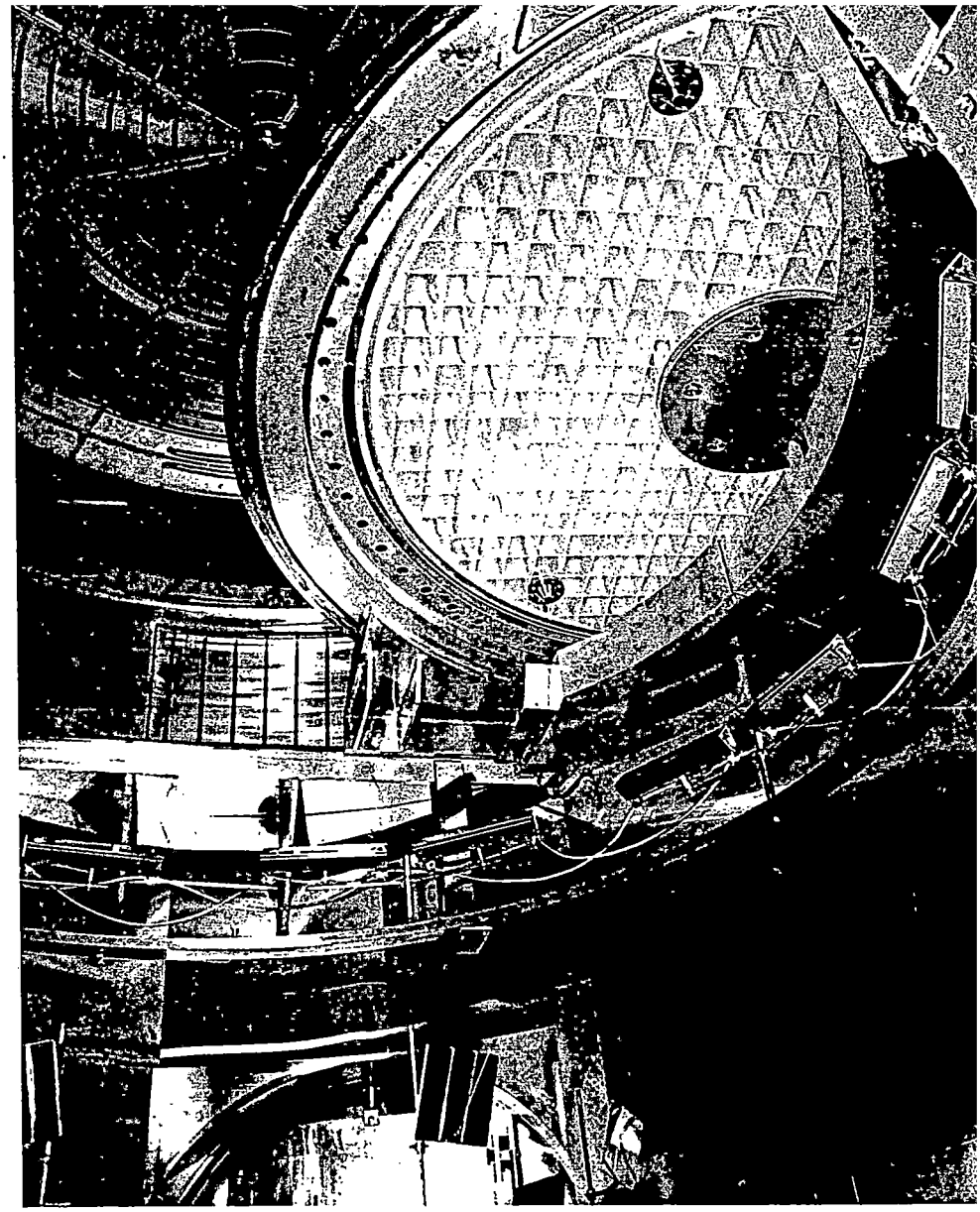
We stepped out and walked past the coating chamber. Up ahead, in the middle of the floor, was the mirror, lying face down on a ruffle of white lens tissue. It looked like a gigantic Life Saver. An optical inspector, kneeling at the far side, was scanning its slightly convex, polished back with a loupe, comparing it with a map of all the blemishes that had been recorded before it left Rigby's shop. Moving closer, I saw the glass slats that divided the hollow interior.

"Okay if I feel the mirror?" I asked. Today was one of the last days anyone would be allowed to touch even the back with his bare hand.

A quality man nodded, and I began bending over.

"Wait!" he shouted. "Your glasses!" Gagliardi brought over a length of wire, and the quality man tied the stems of my spectacles behind my head.

PHOTOGRAPHS COURTESY THE PERKIN-ELMER CORPORATION



The uncoated mirror, its "egg crate" structure still visible under its surface, was fed into the top of the vacuum chamber like a coin into a slot.

The mirror felt strangely cold, as though it had been cast in metal. I removed my hand and watched the moist print evaporate into a frosty archipelago of fingertips, then vanish.

"I've found something," said the optical inspector. He had quit moving the loupe and was motioning to the quality man. Everybody crowded around. Under the loupe was a short, curving crack, blunt at one end and sharp at the other. "It's not on the map," the inspector said gravely.

"Wait a minute," said one of the technicians. He knelt beside the mirror, lifted the loupe, and blew on the crack—causing it to skitter across the surface. The onlookers guffawed. The "crack" was only an eyelash.

A few days later, on Saturday, November 14, I returned to watch the space frame get lifted onto the mirror.

"Who let you in?" barked a man I had never seen before. His name, I later learned, was Mike Vagnone. He was a government inspector, assigned to oversee the lifting operation.

I explained that I had cleared my visit with corporate.

"You're not on the authorized personnel list," said Vagnone. "I don't know you. How do I know you aren't some nut with a gun?"

The question was not academic. A few months earlier, Kurdock had come to the plant early one morning and found the glass door shattered and a .38-caliber bullet lodged in the wall behind the reception desk—the work, perhaps, of a laid-off employee. Everyone knew about the drunken technician who had emptied a Smith & Wesson

automatic into a 103-inch NASA mirror in Texas a few years back; and everyone knew about the bullet craters found in the Palomar mirror's armor after its cross-country train trip in 1936. (Some Perkin-Elmer quality men had wanted their own mirror to have sandbags for its 17-mile trip from the main plant to the coating facility, but Rigby had snorted at this. "Just put the goddamned thing on the truck and get it out of here," he said.)

Fortunately, Gagliardi was there to vouch for my character, and Vagnone grudgingly agreed to tolerate my presence. He turned his attention to the preparations under way. Geyselaer was testing the crane, while the other technicians were fastening cables to the space frame, which sat 15 feet from the mirror. The frame was to be lifted 8 feet into the air, swung over the mirror, then lowered. When Vagnone and Tom Dubos, a Perkin-Elmer quality inspector, were satisfied that the cables had been properly attached, they stamped their copies of *5088* and told Geyselaer to go ahead.

Geyselaer pushed a button in the control paddle, which hung from the ceiling. With nine pairs of eyes watching, the cables tightened, and the space frame slowly began rising. Dubos and Vagnone began circling, heads up and eyes darting.

Just as the load reached a height of seven feet, Vagnone shouted, "Hold it!" There was a loud clunk as Geyselaer hit the STOP button. The space frame hung in midair, wobbling like a giant chandelier.

"There's something on top of that Hydra-Set," said Vagnone. The Hydra-Set was a boxy-looking weight scale, interposed between the lift cable and the space frame; its purpose was to enable Geyselaer to lower the 1,281-pound frame over the mirror with exacting gentleness, by observing how the weight was gradually being transferred from the cable to the floor.

Something was peeking over the edge of the Hydra-Set. Swiftly, Geyselaer lowered the space frame, stopping it a foot from the floor and well to one side of the mirror. Vagnone picked off the object. It was a metal bracket. Geyselaer had removed it from a pair of valve handles while preparing the Hydra-Set for operation. He had no pockets in his jumpsuit, and *5088* did not specify where he was to put the bracket. Not thinking, he had left it on the Hydra-Set. "I had a friggin' feeling, I don't know why," said Vagnone proudly. He tossed the bracket onto the tool table, where it gave a resounding clang. The technicians were silent.

After work, when frame and mirror had been successfully joined, I found Geyselaer sitting on a bench, staring blankly into his locker. I asked him what would have happened if the bracket had fallen on the mirror. "It might've made a nick in the glass," he said. "It would've taken months just to decide what to do about it. The schedule would've been wrecked, for sure."

At the last minute the pen turned upward and hit the target at an incredible 81 percent—only three points shy of theoretical perfection.

The Bracket Incident was a low point for Kurdock as well. "Maybe I shouldn't have been putting all that time into the new Micralign wing," he told me guiltily. "Maybe I wouldn't have gotten sick. Maybe I would've been there and seen the bracket before the lift." Back from the flu at last, he was full of resolve. "From now on," he said, "I'm spending all my time on the telescope mirror."

By then Perkin-Elmer had already had to face NASA on the Solar Optical Telescope without good news on the Hubble. And NASA chief James Beggs had been phoning Perkin-Elmer president Horace McDonell frequently to check on Kurdock's progress. McDonell, in turn, had taken to dropping in on Kurdock several times a week. "He's awfully nice," Kurdock told me, "but I wish he'd—well, frankly, he gives me the heebie-jeebies. I like to have my work noticed now and then, but I don't need *that* kind of attention." On McDonell's mind was Perkin-Elmer's next quarterly review by NASA; several million dollars would be at stake. Kurdock's new deadline was the date of the review: 9 A.M., Wednesday, December 9.

By Thanksgiving Kurdock began to think he might actually meet the deadline. The big glass was clean and ready. It had been cranked upright in the space frame and wheeled into a large shower stall, where a pair of rotating wash wands had sprayed the surface all day with a soap solution. Then it had been rinsed with ultrapure, deionized water. No one knew exactly how long the rinse would last; the team simply shut off the water every few hours to see how the mirror was draining. At 3 A.M. on Saturday, November 28, Kurdock was delighted to see a perfect, single sheet thinning itself on the surface, indicating that all traces of grease had been removed. Under the floodlights the sheet exhibited interference effects like those seen on the surface of a bubble: waves of crimson, yellow, green, and violet cascaded over the surface.

Coating Day dawned cold and gray and windy. When Kurdock reached his office that morning, he found the place crawling with onlookers. NASA had put half a dozen quality men on a plane from Alabama the night before. There were a number of company vice presidents as well, thanks to a hint from McDonell that it wouldn't be fair to keep them away.

The air was festive at first. After watching a few tests and preliminary procedures, the group moved to the conference room. Somebody ordered pizzas. Soon, the room was full of greasy napkins and soft-drink cans, and 20 men cracking jokes. "You guys wanna move this pizza over to the coating room?" Kurdock asked. "I'm sure NASA wouldn't mind."

Finally, it was time. As we stepped out of the air shower, looking like a convention of surgeons in our jumpsuits, cowls, and booties, a deep chugging sound filled our ears: the "roughing" pumps on the chamber. "Pressure looks good," said Kurdock, stepping to the control panel. Red numerals indicated 2.4×10^{-8} torr, which meant that the space inside the chamber contained less

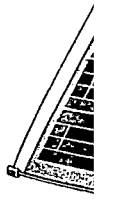
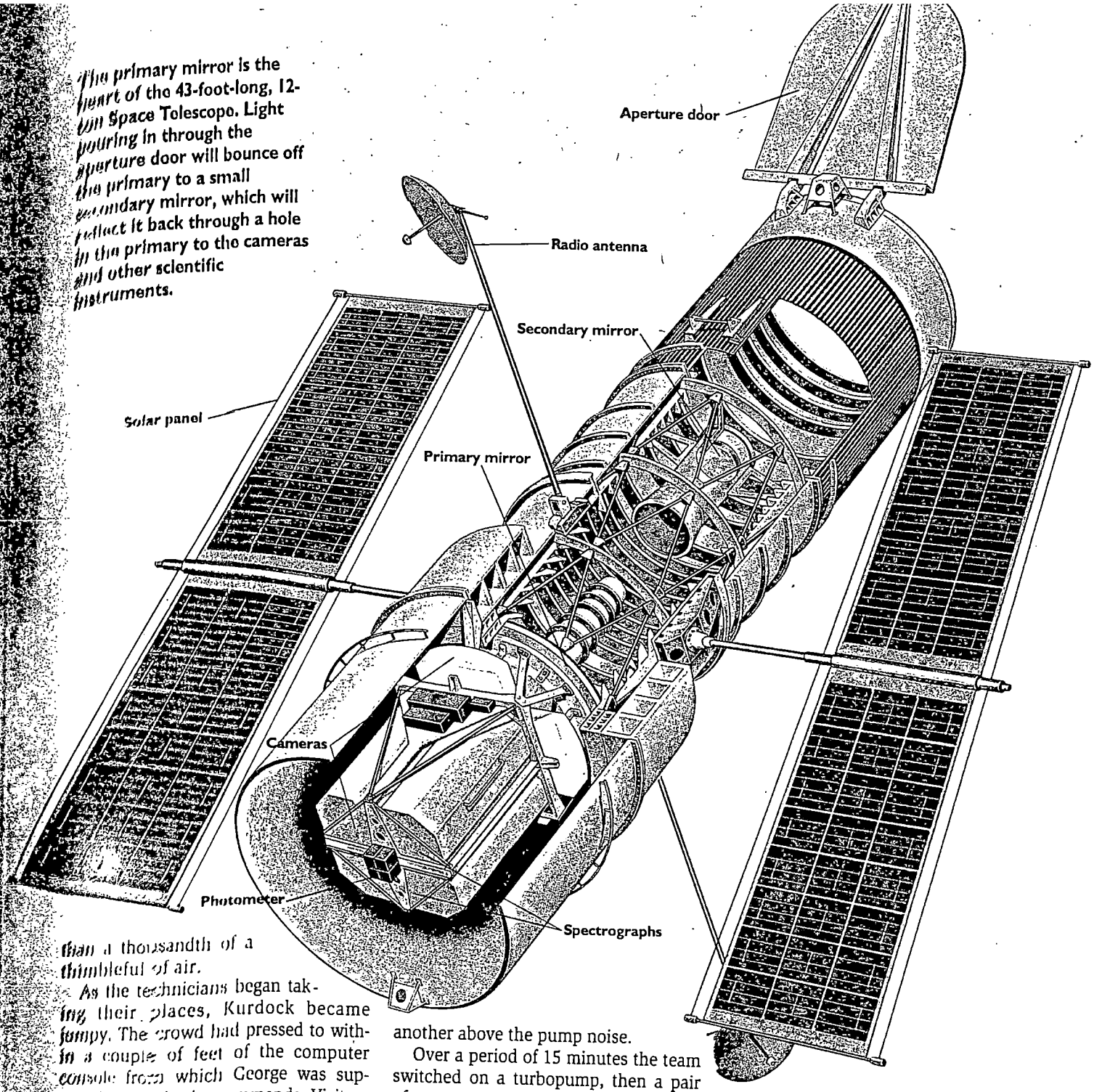


ILLUSTRATION BY MARK MCCANDLISH



The primary mirror is the heart of the 43-foot-long, 12-ton Space Telescope. Light pouring in through the aperture door will bounce off the primary to a small secondary mirror, which will reflect it back through a hole in the primary to the cameras and other scientific instruments.

than a thousandth of a thimbleful of air.

As the technicians began taking their places, Kurdock became jumpy. The crowd had pressed to within a couple of feet of the computer console from which George was supposed to key in the commands. Visitors were leaning against the adjoining control panel, leaving no room for Geyselaer. "Everybody back behind the table!" Kurdock barked. He and Mike Vagnone pushed a white Formica table away from the console, clearing a space about ten feet square. Vagnone plopped his copy of *5088* on the table and took out his rubber stamp and red ink pad. Gagliardi and McCullock moved to the tiny viewing ports in the side of the chamber. All four technicians donned headphones to hear one another above the pump noise.

Over a period of 15 minutes the team switched on a turbopump, then a pair of cryopumps, and finally a titanium pump that drew out most of the remaining oxygen by means of a chemical reaction. Through it all, Kurdock sat on a stool, staring at the control panel and rubbing his chin. His face seemed to drain. At last the pressure in the chamber was low enough.

"Initiate rotation!" called Vagnone, reading from *5088*.

George punched a few keys on the computer. There was a loud clunk, and from inside the chamber came the noise of dozens of steel balls clacking together as the ring gear, with the mirror nested inside it, began turning. It sounded as if we were standing outside a busy billiard parlor.

"Rotation established," said Geyselaer. The control panel indicated three revolutions per minute.

"Rotation established," repeated Vagnone. He marked the step in *5088* with his stamp, which made a picture of an eagle with three stars under it.

Now it was time for the coating itself. First, four of the electron guns would be powered up. If their voltages looked

good, four metal shutters would then be opened to let the vaporized aluminum out. As the aluminum built up on the mirror, Karl George would see a vertical line growing on his computer screen, indicating the film's thickness. The line would inch toward a horizontal bar marking the target thickness. The moment it touched, George would close the shutters and the aluminum layer would be complete. Then would come the critical stage: In less than two minutes, the team would have to power up the other four guns and open the shutters on the magnesium fluoride. If they took any longer, the aluminum would be oxidized before it was sealed, and the mirror's reflectivity would suffer.

"You guys ready?" asked Kurdock.

The technicians nodded.

"All right. Aluminum guns!"

The guns made a roaring sound in the chamber. Kurdock's eyes were on the control panel, watching the voltage needles on the power supplies. All four needles had jumped to 9,000 volts and were holding steady. A flicker of relief passed over his face. "Open the shutters!" he said.

The roar suddenly deepened, and a white line sprouted on George's computer screen. Peeking through one of the viewing ports, I saw the inside of the chamber bathed in a golden light, like a late summer afternoon. In the nearest crucible a lump of aluminum glowed pink where the electron beam was boring into it. The vaporizing metal did not make a visible cloud, but as I watched the mirror rotating overhead I could see a grayness blooming on its surface, as if it were being spray-painted by someone standing far off. Gradually the gray clarified and took on a marvelous brilliance. I saw features of the upper chamber wall reflected in the mirror's edge zones, magnified as if in a giant shaving mirror.

Abruptly the roar changed pitch again as the shutters closed.

"Okay, let's seal 'er up!" said Kurdock, clapping his hands.

Everything seemed to happen faster now. George's fingers flew over the keyboard. Geyselaer leapt for switches on the control panel. Gagliardi talked excitedly on the intercom to Bill McCullock, who had his nose pressed to the nearest port.

Meanwhile Kurdock's eyes were glued to the voltmeters. A look of panic invaded his face. The needle on the power supply for Gun Number One was still on zero. All the others had leveled off at 9,000. Something was wrong. The clock was ticking: 20 seconds, 25.

"What's going on, Bill?" Kurdock said into his intercom mike. "Can you see anything?"

McCullock, at the viewing port, shook his head. Thirty seconds had passed. Inside the chamber, oxygen atoms would already be attacking the aluminum.

George looked at Kurdock, his eyes pleading for permission to open the shutters. It was possible to meet spec with only three guns—but not if the team waited the whole two minutes.

"They got ten percent more light coming through the telescope than they paid for! That's probably a billion light-years added to its reach."

"Come *on*, Gun One!" Kurdock urged, glowering at the voltmeter. "Come *on*!"

Still the needle wouldn't budge.

"Go without it!" said George. "There isn't time!"

Kurdock held up a hand to shush him. The clock passed 80 seconds. McCullock and Gagliardi were jabbering on the intercom. Geyselaer had turned his back on the panel and was staring at Kurdock.

"Go!" Kurdock blurted. His face bore a look of pain and disgust.

Then a miracle happened. The instant the shutters opened, Gun One seemed to awaken. Its needle hopped to 9,000 volts and immediately began flickering in perfect unison with the others.

Kurdock let out a whoop that set the spectators laughing.

"Aw *right*!" said George.

At 53 minutes and 11 seconds after one o'clock, the heart of the Hubble Telescope was complete. Rigby, hearing the shutters close, shouted and jabbed a fist into the air. While the crowd applauded, he warmly shook Kurdock's hand. "Good show!" he said.

"Hey, what'd you expect?" replied Kurdock. All the color had returned to his face.

Soon the room was full of the sound of popping champagne corks. The men drank Korbel out of plastic cups. The work of five years now completed, they engaged in bittersweet reminiscence.

The reflectivity test was scheduled for Monday afternoon. In the morning Kurdock's team vented the chamber and opened the door. They knelt on the top step and aimed a floodlight at the ceiling. For an instant Kurdock thought someone had stolen the mirror—nothing was visible up there, only an inexplicably high ceiling. Then he realized that he was looking at a reflection of the chamber floor in an extraordinarily bright mirror. "God, that's pretty!" he cried. He switched off the light. "Course, that doesn't mean anything. For all we know, it's dead black in the ultraviolet."

"A buck says it's seventy-six percent," said Gagliardi. Spec was 70.

"I hope not," said Kurdock. "If it's that high, they'll try to make us recoat the secondary." The 13-inch secondary mirror, coated two weeks earlier in a much smaller chamber, had come in at 73 percent reflectivity.

For the test, the team removed from the chamber three sample mirrors, each about the size of a checker, that had been coated along with the main one. In a laboratory near the coating room, Gagliardi installed the first checker in a vacuum spectrophotometer—a small chamber in which a light beam of gradually changing color is bounced off the sample while a photocell measures the percentage of light reflected at each wavelength. Gagliardi had hooked the machine to a chart recorder, so that he and the others could see the results immediately. They watched silently as the pen traced a squiggle of green ink across the page, beginning at the red end of the spectrum and advancing toward the ultraviolet. As the pen neared the target wavelength,

PHOTOGRAPH COURTESY NASA

the line began dipping and diving steeply, drawing cries from the technicians. But at the last minute it turned upward and hit the target at an incredible 81 percent—only three points shy of theoretical perfection.

"That can't be," said George. "There's something wrong with the machine."

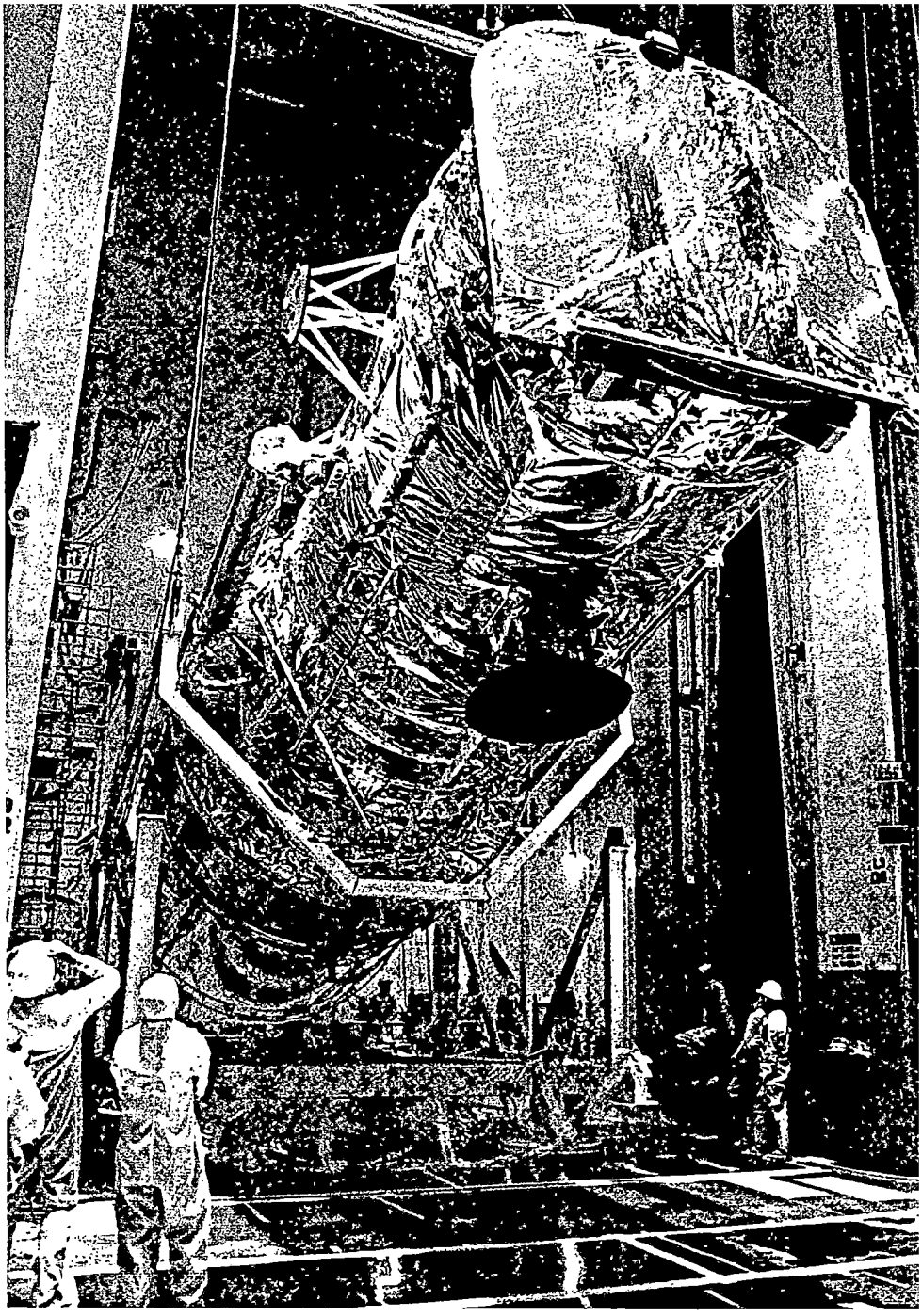
Gagliardi shook his head. "I just calibrated it."

Kurdock came into the room and looked at the chart. "I can't believe that," he said. Within the hour, though, the second and third samples confirmed the ultraviolet reflectivity at 80 percent. The technicians whooped and hollered. "Best in the world!" said Gagliardi, tapping his chest.

Kurdock had mixed feelings. "Engineers don't like surprises," he told me. "Not even *good* surprises." In the end he insisted on reporting the reflectivity to NASA as only 78 percent. "It'll give us a little room down the road," he said, "in case we get some mysterious tarnishing or something." That afternoon, when Kurdock reported the result to Charlie Jones, chief of the optical branch at Marshall Space Flight Center, Jones gave a loud, lingering whistle. "Man, that's *in* there," he said.

Later I sat with Kurdock in his office, reviewing the day's events. "Jones seemed pretty happy," I said.

"*Pretty* happy? You don't know Charlie. The man was ecstatic," said Kurdock. "Look—look at what we did for him." He grabbed pencil and paper and began calculating. "To get the amount of light coming through the telescope, you multiply the reflectivity of the primary mirror times the reflectivity of the secondary, right? Okay, the specs were seventy percent times sixty-seven percent, which equals forty-seven percent. So, they expected forty-seven percent of the light entering the telescope to get through to the cameras. Now, look at what they actually got: seventy-*eight* percent on the primary times seventy-*three* on the secondary—fifty-seven percent. They asked for forty-seven, we delivered *fifty*-seven. They got ten percent more light coming through the telescope than they paid for! What the hell—that's probably a billion light-years added to the telescope's reach—and it didn't cost 'em a cent." He tossed the pencil down and leaned back in his swivel chair, his hands folded behind his head. "Yeah, you'd better believe they're happy," he said.



PHOTOGRAPH COURTESY NASA

On January 28, 1986, the day *Challenger* exploded, Lockheed engineers tested the Space Telescope's ability to withstand the vibrations of a shuttle launch.

"They're *deliriously* happy."

Apparently he was right. On Wednesday morning, at the quarterly review, NASA officials gave Perkin-Elmer representatives a standing ovation. Six months later, Perkin-Elmer got the contract to build the Solar Optical Telescope.

Since completing the big glass, Rigby and Kurdock have both been promoted. Kurdock is now head of Perkin-Elmer's optical operations directorate. Rigby, the company's senior technical consultant for large optics, is overseeing production of the mirrors for an orbiting X-ray telescope called the Advanced X-Ray Astrophysical Facility. Now almost 60, he is thinking of retiring before he finishes the project; it's less of a challenge than the Hubble. Whenever he thinks of his work on the big glass, he still sighs and shakes his head. "I'll never see another mirror like that one," he says.

Kurdock just laughs and says, "I hope I never do!" ❑

Terry Dunkle is a senior editor at Reader's Digest. *As an amateur astronomer during his teens, he built his own eight-inch telescope, grinding and polishing the mirror in his basement.*

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plate tectonics

2ND STORY of Level 1 printed in FULL format.

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July, 1988

SECTION: Vol. 259; No. 1; Pg. 72

LENGTH: 4694 words

HEADLINE: The supercontinent cycle: several times in earth history the continents have joined to form one body, which later broke apart. The process seems to be cyclic; It may shape geology and climate and thereby influence biological evolution

BYLINE: Nance, R. Damian; Worsley, Thomas R.; Moody, Judith B.

BODY:

The Supercontinent Cycle

Is plate tectonics a random process or is it orderly? According to the theory of plate tectonics, the earth's rigid outer layer, called the lithosphere, is a mosaic of slablike plates that move with respect to one another at speeds averaging a few centimeters per year. The plates float on a hot, plastic layer of the earth's mantle called the asthenosphere. Most of the plate movements are driven by a process known as sea-floor spreading, in which molten material from the asthenosphere rises through the lithosphere at high ridges on the ocean floor, where it cools to become the crust that makes up the ocean bottom. Newly created oceanic crust moves steadily away from the mid-ocean ridges toward the continents. If the sea floor and the adjacent continent are on the same lithospheric plate, the continent is carried along by the conveyor belt of oceanic crust. Alternatively, the oceanic crust may sink under the continent to rejoin the mantle, in a process known as subduction.

The continents are generally viewed as passive objects that are ferried about by sea-floor spreading. They are not entirely unchanged by the processes of plate tectonics, however. Separate blocks of continental crust can collide and merge, forming new, larger continents. Conversely, continents can be torn apart by deep rifts that eventually become the centers of new ocean basins. Indeed, there is evidence that several times in the history of the earth the continents have undergone these processes on a grand scale: several times most or all of the continents have gathered to form a single supercontinent, which has later split into many smaller continents only to rejoin and form a supercontinent again.

What governs the formation and destruction of supercontinents? Do they appear and disappear simply by chance, because of the random shifting of continental plates? Various regularities in the geologic record have led the three of us to believe that a much more orderly, even cyclic, process must be at work. Drawing on the ideas of Don L. Anderson of the California Institute of Technology and on the prescient observations of the Dutch geologist J. Umgrove (set out in his 1947 book The Pulse of the Earth), we have devised a theoretical framework that describes what may be the underlying mechanisms of such a "supercontinent cycle."

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In our theory the dominant force comes from heat. It is generally understood that tectonic plates are driven by convective motions in the underlying mantle, which are powered by heat from the decay of radioactive elements. The radioactive decay (and the resulting production of heat) is a continuous process whose rate has declined smoothly with time, and so the production of heat cannot in itself account for the episodicity inherent in an alternation between continental assembly and continental breakup.

The key phenomenon, we think, is not the production of heat but rather its conduction and loss through the earth's crust. Continental crust is only half as efficient as oceanic crust at conducting heat. Consequently, as Anderson has pointed out, if a stationary supercontinent covers some part of the earth's surface, heat from the mantle should accumulate under the supercontinent, causing it to dome upward and eventually break apart. As fragments of the supercontinent disperse, heat can be transferred through the new ocean basins created between them. After a certain amount of heat has escaped, the continental fragments may be driven back together.

In other words, we think the surface of the earth is like a coffee percolator. As in a coffee percolator, the input of heat is essentially continuous. Because of poor conduction through the continents, however, the heat is released in relatively sudden bursts.

This theoretical framework and its corollaries make it possible to tie together a number of observations in widely disparate fields. They make it possible, for example, to understand the timing of the extreme changes in sea level that have taken place in the past 570 million years. The framework also helps to explain and link many other events of the past 2,500 million years, such as periods of intense mountain building, episodes of glaciation and changes in the nature of life on the earth. The supercontinent cycle, in our view, is a major driving process that has provided the impetus for many of the most important developments in the earth's history.

The Opening Oceans

Our model builds on an earlier description of episodic plate motions known as the Wilson cycle. Named for J. Tuzo Wilson of the Ontario Science Center, the Wilson cycle is the process by which continents rift to form ocean basins and the ocean basins later close to reassemble the continents. In the first stage of the Wilson cycle volcanic not spots" form in a continent's interior; the hot spots are then connected by rift valleys, along which the continent eventually splits. When the continent fragments, the rift valleys grow to become a new ocean as hot mantle material wells up through the rifts to form the sea floor. The continental fragments move apart, sliding away from these elevated " spreading centers" as mantle material wells up.

As the material making up the ocean floor ages, it cools, becomes denser and subsides, increasing the depth of the ocean. Eventually, about 200 million years after the first rift formed, the oldest part of the new ocean floor (the part directly adjacent to the continental fragments) becomes so dense that it sinks under the continental crust: it is subducted. The processes of subduction then close the ocean, bringing the continents back together. Eventually the continents collide and rejoin, and the compressive forces of collision create mountain belts.

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When viewed in terms of Wilson cycles, there is a striking contrast between the evolution of the continental margins surrounding the North Atlantic and the margins of the Pacific. The margins of the North Atlantic have undergone a series of Wilson cycles during the past billion years; the regions bordering the Pacific have apparently undergone none. In other words, oceans have repeatedly opened and closed in the vicinity of the present-day North Atlantic, while a single ocean has been maintained continuously in the vicinity of the Pacific.

In our model, then, the Pacific is the descendant of the oceanic hemisphere that has surrounded each incarnation of the supercontinent; each of the Wilson cycles that took place in what is now the North Atlantic region occurred as part of the breakup and reassembly of a supercontinent. The Atlantic should therefore be expected to close again, once more reuniting the continents in a supercontinent surrounded by a single superocean.

At present the sea-floor crust of the Pacific is being subducted under all the continents that surround it, whereas the floor of the Atlantic generally butts up against surrounding continental blocks. In our fraemwork this means that the continents are still in the process of dispersing after the breakup about 200 million years ago of the most recent supercontinent, which Alfred Wegener, the father of the theory of continental drift, christened Pangaea, or "all earth" [see "The Breakup of Pangaea," by Robert S. Dietz and John C. Holden; SCIENTIFIC AMERICAN, October, 1970]. The continents are now approaching their maximum dispersal. Soon (on a geologic time scale) the crust of the Atlantic will become old and dense enough to sink under the surrounding continents, beginning the process that will close the Atlantic ocean basin.

Surprising Regularity

A second underpinning of our supercontinent-cycle hypothesis is the timing of various episodes of mountain building and episodes of rifting. The ages of mountain ranges that could have been produced by the compressive forces that accompany continental collisions reveal a surprising regularity. This kind of mountain building was particularly intense, occurring in several parts of the world, during six distinct periods. The periods were broadly centered on dates about 2,600 million years ago, 2,100 million years ago, a time between 1,800 and 1,600 million years ago, 1,100 million years ago, 650 million years ago and 250 million years ago. The timing shows a certain periodicity: the interval between any two of these periods of intense compressive mountain building was about 400 to 500 million years.

What is more, about 100 million years after each of these periods of mountain building there appears to have been a period of rifting. Large numbers of mantle-derived rocks--rocks that may have been produced when magma welled up into cracks created by rifting--date from times broadly centered on 2,500 million years ago, 2,000 million years ago, a time between 1,700 and 1,500 million years ago, 1,000 million years ago and 600 million years ago. The mountain building of 250 million years ago, of course, was followed by the rifting and eventual breakup of Pangaea.

These regularities indicate to us that supercontinents are created in a cyclic process, in which one complete cycle takes about 500 million years. By examining these geologic records and others, and by taking into account such factors as the rate at which sea-floor spreading takes place in present-day oceans, we have calculated a more precise timetable for the supercontinent

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cycle. After the fragments of a supercontinent first separate--probably some 40 million years or so after rifting begins--we estimate that it should take about 160 million years for the fragments to reach their greatest dispersal and for subduction to begin in the new oceans. After the continents begin to move back together, another 160 million years or so should elapse before they re-form a supercontinent. The supercontinent should survive for about 80 million years before enough heat accumulates under it to cause rifts to form. Forty million years later that rifting will lead to another breakup, 440 million years after the previous one.

Effects on Sea Level

How can one test whether the supercontinent cycle proceeds as we have described? The cycle is likely to have striking effects on sea level, for which there are clear geologic records covering the past 570 million years. Assuming a constant amount of water in the world oceans, sea level (in relation to continental mass) is largely determined by two factors: the total volume of the world's ocean basins, which depends in part on the average depth of the sea floor, and the relative elevation of continents. The supercontinent cycle would involve the creation and destruction of ocean basins and the thermal uplifting of continents, and so it should have a profound influence on both factors.

As the material making up the ocean floor moves away from mid-ocean ridges during sea-floor spreading, it cools and subsides, its depth increasing as the square root of its age. Wolfgang H. Berger and Edward L. Winterer of the Scripps Institution of Oceanography have calculated how the average age of the world ocean floor should change during the breakup of a supercontinent. Before the breakup the average age of the ocean should remain constant, because in the superocean surrounding the supercontinent new sea floor is created at about the same rate as old sea floor is destroyed by subduction under the landmass. During the breakup, the subducting, "Pacific type" superocean will be replaced by an increasing proportion of non-subducting, "Atlantic type" oceans. Later, when the supercontinent begins to reunite, these "interior" oceans will be destroyed by subduction and replaced by Pacific-type ocean again. These processes affect the average age of the world ocean floor.

Immediately after the breakup of a supercontinent the world ocean floor should, on the average, become progressively younger and shallower as young, Atlantic-type oceans begin to replace the older, Pacific-type ocean. When the Atlantic-type oceans reach the same average age as the Pacific-type ocean, the trend should reverse: the growth of increasingly old Atlantic-type oceans should cause the world ocean floor to age and deepen. The maximum average depth should occur when Atlantic-type oceans reach their greatest average age, just before they begin to be subducted. Then, as the oldest areas of the Atlantic-type oceans are subducted and the oceans close, the world ocean floor should become younger and shallower again.

Calculations of sea level based on these parameters alone suggest that a supercontinent's continental shelves should be flooded, because the ocean basin surrounding a supercontinent is younger and shallower than, for example, the floor of today's world ocean. A second factor, however, must be added to the analysis: the degree to which a supercontinent would be uplifted by the heat that would accumulate under it. If the supercontinent is lifted high enough, sea level in relation to the continental mass could still be low even if the sea floor is comparatively shallow.

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One way to estimate how much a supercontinent might be uplifted thermally is to consider present-day Africa. Africa has remained essentially stationary for at least the past 200 million years, during which time a good deal of heat from the mantle has accumulated under it. (Some of that heat is being released in the rift valleys now forming in various areas of the continent.) By comparing the height relative to sea level of Africa's shelf break (the true edge of the continent) with the height of the shelf breaks of other continents, we can estimate that thermal uplifting has buoyed Africa by about 400 meters. As a lower limit, then, one can expect that a supercontinent would be thermally uplifted by at least 400 meters.

Other factors should also cause the supercontinent to be emergent (elevated in relation to sea level). For example, the collisions that take place during the assembly of the supercontinent should compress and thicken continental crust, decreasing the earth's total land area. This would add to the total area of the ocean basins and thereby lower sea level. Conversely, the stretching and extension of crust that accompanies the breakup of a supercontinent should lower the total area of the world ocean basin, thereby raising sea level.

By adding together all these components, it is possible to determine how sea level should change in the course of every phase of the supercontinent cycle. As we have noted, during the existence of a supercontinent sea level should be relatively low. As the supercontinent breaks up, sea level should rise, both because the continental fragments will stretch and subside thermally and because the breakup will replace old, Pacific-type ocean with young, Atlantic-type ocean. Sea level should continue to rise for about 80 million years, as the younger oceans make up a greater fraction of the world ocean. Then, as the Atlantic-type oceans age and expand, sea level should decline for another 80 million years or so, until the Atlantic-type oceans begin to be subducted.

When the continents begin to come together, sea level should rise, as older Atlantic-type crust is subducted. That rise in sea level should continue for another 80 million years, until the supercontinent begins to be reassembled. Then, as continents collide and the growing supercontinent is uplifted thermally, sea level should decline for about 80 million years. Once the supercontinent has been formed, sea level should reamin static for another 120 million years, until the supercontinent breaks up again.

These predictions of changes in sea level match the geologic record of the past 570 million years, which is as far back as sea level can be determined with any reliability. In particular, the timing and the relative magnitudes of sea-level changes predicted by the model match the preserved record. The absolute values, of course, always vary from continent to continent, the model gives only global averages.

Testing the Model

Evidence for the supercontinent cycle can also be found by examining the isotopes of sulfur and carbon found in certain marine sediments. (Isotopes are atoms of the same element that have different atomic weights.)

During the early stages of breakup, a supercontinent is likely to include a number of marine rifts that, like the modern Red Sea, are weakly connected to the world ocean. These rifts can undergo a continuous process of partial evaporation, in which certain elements, such as sulfur, precipitate out of the

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seawater to form minerals. When seawater containing sulfur is evaporated, heavy sulfur (which has an atomic weight of 34) precipitates out more readily than light sulfur (which has an atomic weight of 32).

If an evaporating marine rift continues to mix with the world ocean, it should act as a sink for heavy sulfur: it should tend to pull heavy sulfur from the ocean as a whole and bury it in evaporitic sediments. Then the world ocean should become relatively depleted in heavy sulfur and enriched in light sulfur. Hence in sediments derived from the world ocean as a whole during the period of the supercontinent, we should expect to see relatively high levels of light sulfur and low levels of heavy su lfur. This is indeed what is found in open marine sediments formed about 200 and 600 million years ago--that is, during the past two instances of the supercontinent.

Carbon isotopes also give evidence of supercontinents. The lighter isotope of carbon (carbon 12) diffuses in solution faster than a heavier isotope (carbon 13). As a result light carbon is more likely to be taken up by organisms and incorporated into their biomass. Organisms are therefore a sink for light carbon. During periods of low sea level the rate of organic productivity in the world ocean should be high, because greater amounts of nutrients such as phosphorus and nitrogen--eroded from continental crust and carried to the sea by rivers--will be available when more continental crust is exposed.

Thus when sea level is low, more carbon (particularly light carbon) will be incorporated into organisms, and the water of the world ocean will be comparatively depleted in light carbon and enriched in heavy carbon. When examining such seawater-derived sediments as limestone (calcium carbonate), then, we should expect to find relatively high levels of heavy carbon and low levels of light carbon if the sediments were produced during a period of low sea level. In similar sediments produced during a period of high sea level, we should expect to find relatively more light carbon and less heavy carbon. And indeed, the ratio of heavy carbon to light carbon in such sediments closely matches the predictions of our model for the past 600 million years.

Climate and Life

Perhaps the most important effects of the supercontinent cycle are its influences on climate and life. What should those effects be? Most of the climatological effects of the supercontinent cycle will be driven by the changes in sea level that are caused by the processes of continental breakup, dispersal and reassembly.

When sea level is low--that is, when the world is dominated by a single emergent supercontinent or when individual continents are widely dispersed (as they are now) and the world ocean floor is at its oldest--large amounts of silicate minerals in the continental crust, such as calcium silicates, are exposed to weathering and erosion; they are dissolved in rivers and carried into the world ocean. When these dissolved silicates are mixed into seawater, they combine with dissolved carbon dioxide to produce solid precipitates [see "How Climate Evolved on the Terrestrial Planets," by James F. Kasting, Owen B. Toon and James B. Pollack; SCIENTIFIC AMERICAN, February]. For example, calcium silicates may combine with carbon dioxide to produce calcite (limestone) and quartz. This process draws down carbon dioxide from the atmosphere.

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Carbon dioxide in the atmosphere helps the earth to retain the heat it gains from solar radiation. When carbon dioxide is drawn down into oceanic deposits, this "greenhouse" warming effect is diminished, and the world climate becomes colder. If there is an emergent continental landmass near enough to the pole, glaciers will form (as they have on modern-day Antarctica and Greenland).

Glaciation has several important effects on the global climate. For one thing, it removes water from the ocean basins, causing sea level to drop still lower. Glaciation also amplifies circulation and mixing in the world ocean. Much of the ocean circulation of the present-day earth, for example, is driven by a global "heat engine," in which warm, salty water from the Tropics and the subtropics flows toward the pole, where it gives up its heat, sinks to the bottom and flows back toward the Equator [see "Polynyas in the Southern Ocean," by Arnold L. Gordon and Josefino C. Comiso; SCIENTIFIC AMERICAN, June]. By mixing surface water into the deep water, the heat engine distributes oxygen and other nutrients throughout the ocean. Ice at the pole keeps the polar waters cold, helping to maintain the temperature difference that drives the heat engine.

Such vertical circulation combines with the increased supply of continent-derived nutrients to raise the level of biological productivity at times of low sea level. High productivity should trap still more carbon in organic matter, further lowering levels of atmospheric carbon dioxide.

The environments that are most hospitable to marine life are the continental shelves, where continent-derived nutrients are abundant and shallow depths allows sunlight to penetrate to the sea floor. When biological productivity is high, however, these shelf environments are unavailable, exposed by the low sea level. As a result many established species will become extinct, and new, innovative species will be favored. This does not mean, however, that life will be particularly divers. On the contrary, such conditions--high nutrient levels but few available environmental niches--lead to ecosystems in which a large amount of biomass is concentrated in relatively few successful species.

Climate after Breakup

Thus the effects of low sea level include a propensity toward glaciation, strong vertical circulation in the world ocean, high biological productivity, biological innovation and a low degree of biological diversity. What should be the effects of high sea level, which would be expected just after a supercontinent breaks up or just before it is reassembled?

When continents are drowned, a relatively small amount of silicates will be available to sequester atmospheric carbon dioxide in sea-floor deposits. Meanwhile carbon dioxide will be released into the ocean and from there into the atmosphere by the hot mantle material that wells up at sea-floor spreading centers. Also, the subduction of oceanic crust and the resulting melting of limestone deposits in the subducted sediments will release still more carbon dioxide into the atmosphere at the volcanoes that mark subduction zones.

Atmospheric levels of carbon dioxide will therefore rise and the earth's climate will become warmer. Polar ice caps should melt, raising sea level still higher and further drowning the continents. The absence of polar ice will reduce vertical and horizontal circulation of the world ocean, causing it to begin to stagnate: oxygen and nutrient levels in ocean waters will decline,

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and with them biological productivity. On the other hand, the drowned continental crust will provide a large area for the shallow seas that are most hospitable to life. The resulting ecosystems will resemble those of the present-day Tropics, where the climate is warm, nutrient levels are low and a relatively large number of environmental niches are available. Like today's Tropics, these ecosystems would be characterized by low productivity and great species diversity.

How well does the record of past climates and life forms bear out these predictions? One of the most impressive confirmations of our model is found in records of glaciation. All the known episodes of glaciation in the history of the earth took place at times when according to our model sea levels should have been low. The converse is not true. That is, not every period when sea levels should have been low had an episode of glaciation: probability dictates that in some periods there would not have been an emergent continent near the pole.

Biological Evidence

The biological record is a little more ambiguous, for a variety of reasons. Perhaps most important, the fossil record is not unfirom throughout time. The record is based mainly on deposits buried on continental crust--buried when sea levels were high. When sea levels are low, marine organisms will generally live offshore, beyond the exposed continental shelves. Deposits recording these periods are rare: such deposits are likely to have been destroyed later, by subduction of the ocean floor. Nevertheless, the available evidence tends to confirm our hypothesis.

For example, the few geologic records of marine life during the existence of the most recent supercontinent, Pangaea, indicate low diversity of species, as we would expect when sea levels are low. In addition, the period of drowning that followed the breakup of Pangaea was characterized by high levels of species diversity.

Looking further back in time, the breakup of the previous supercontinent about 600 million years ago was marked by the first recorded appearance of shelled animals. During the period following this breakup there was what has been called an explosion of diversity [see "The Emergence of Animals," by Mark A. S. McMenamin; SCIENTIFIC AMERICAN, April, 1987]. In particular, shelled animals radiated into a highly diverse array.

Looking back still further, the first recorded multicellular animals are found in marine sediments that are about a billion years old. These sediments would have been deposited, according to our model, right after the breakup of a supercontinent. It is quite possible that this biological innovation occurred during the existence of the supercontinent but was not recorded until the continent broke up and sea levels rose, drowing the continental shelves.

A still older innovation may also be linked to the supercontinent cycle. About 2,100 million years ago, just prior to an assumed supercontinental breakup, blue-green algae first developed heterocysts, the organelles that make it possible to fix nitrogen (to crack apart nitrogen molecules and bind the constituent atoms to carbon in organic matter) even in the presence of atmospheric oxygen. Without heterocysts or similar organelles, the chemical reactions of nitrogen fixation can be interrupted by oxgen atoms that bind to the nitrogen atoms. The atmosphere was then just beginning to contain oxygen;

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the innovation made it possible for many later organisms--the predecessors of today's photosynthetic plants--tyo survive in the new, oxygen-bearing atmosphere, which otherwise could have been poisonous to them.

A New Framework

The supercontinent-cycle hypothesis represents a new framework, a new way to understand the geologic history of the earth. It suggests that the processes of plate tectonics on the largest scale are primarily governed not by chance but by a regular, cyclic process.

The supercontinent cycle also represents a new way of understanding the history of life on the earth. The large-scale climatological effects brought about by various phases of the supercontinent cycle--continental drowning or emergence, glaciation and ocean circualtion, stagnation in the world ocean and other effects--drove many of the important biological innovations that have directed the later course of evolution. In a sense, then, the supercontinent cycle is indeed the pulse of the earth with every beat the earth's climate, geology and population of living organisms are advanced and renewed.

GRAPHIC: Map; Chart; Caption: Breakup of Pangaea.; Continental block and fragment dynamics.; Supercontinent cycle is depicted schematically

SUBJECT: Sea-floor spreading, research; Continental drift, research; Plate tectonics, research; Paleogeography, research

LOAD-DATE-MDC: August 30, 1988

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30TH STORY of Level 1 printed in FULL format.

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April, 1988

SECTION: Vol. 258; No. 4; Pg. 69

LENGTH: 5579 words

black holes

HEADLINE: The membrane paradigm for black holes

BYLINE: Price, Richard H.; Thorne, Kip S.

BODY:

The Membrane Paradigm for Black Holes

Can one understand black holes in simple, physical terms? Can these offspring of general relativity, which trap light, curve space and slow time, be added to the astrophysical catalogue of objects with intuitively clear behaviors? It is now widely accepted that black holes exist and have an astrophysical role, in particular as the likely power source of quasars: distant, pointlike beacons of light that shine as brightly as an entire galaxy. To understand this role with ease, we and our colleagues have developed a new paradigm for black holes --a new way to picture, thik about and describe them. As far as possible it treats black holes as ordinary astrophysical objects, made of real material. A black hole, in our description, is a spherical or oblate surface made of a thin, electrically conducting membrane.

As theoretical entities black holes have a long history. Two hundred years ago the English physicist John Michell, and independently the French mathematician Pierre-Simon Laplace, predicted the existence of "dark bodies": astronomical objects with a gravitational pull so strong that light could not escape them. The prediction, based on Newton's corpuscular theory of light and his action-at-a-distance theory of gravity, did not survive for long. In the early 19th century, experiments revealed that light consists of waves rather than Newtonian corpuscles and set the stage for James Clerk Maxwell's wave theory of light. Laplace, seeing the foundation of his prediction crumble, retracted it.

In 1917, however, with the introduction of general relativity, Newton's description of gravity was displaced by Einstein's. Physicists then realized that even though Maxwell's light waves were immune to Newtonian gravity, they could be trapped by Einsteinian gravity. The first observational hints of this trapping came in 1919 during an eclipse, when astronomers saw that light rays from distant stars are deflected ever so slightly by the sun. From the equations of general relativity it was straightforward to deduce that if the sun were compressed while its mass stayed fixed, starlight grazing its surface would be deflected ever more sharply. Ultimately, when the sun's circumference reached 18.5 kilometers, the starlight would be trapped, as would any light emitted by the sun. The sun would become a dark body, superficially similar to the dark bodies of Michell and Laplace.

The physical structure of general relativity's dark bodies is radically different from that of the 18th-century dark bodies, however, and wonderfully richer. They are not made of matter, although they have mass and might be

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created from stellar matter by a process of gravitational collapse. Once formed they consist of curved spacetime, wrapped up on itself so tightly that it holds in light--a structure that was impossible to imagine before Einstein. In 1968 John Archibald Wheeler of PRinceton University coined the name black holes for these objects.

It has taken more than four decades for theoretical physicists to accept black holes as a serious prediction of general relativity, a prediction worth searching for in the real universe. Astronomers were even more resistant to the idea. Until the mid-1960's many astronomers regarded the universe as a tidy place in which most phenomena were known and understood--an environment in which there was no place for something as bizarre as a black hole.

This view was shaken, however, by the discovery of quasars in 1963. Their enormous outputs of energy meant that a titanic mass would be needed to power them, but their rapid fluctuations in luminosity suggested that their central power source had to the very compact. Large mas and small size implied the existence of an intense gravitational field, and suspicions began to focus on black holes. Then, in 1967, came the discovery of pulsars, objects that emitted pulses of radio waves with apparently inexplicable regularity. Within a year they were understood as rotating neutron stars, fantastically dense objects with about the mass of the sun but with a circumference of only about 60 kilometers. That is just three times the size of a black hole with the same mass: squeeze a neutron star by a factor of three, general relativity insisted, and it would become a black hole.

Since then further surprises and puzzles have beamed their strange signals into telescopes, radio dishes and other detectors at a rate that keeps astronomers from feeling secure in their preconceptions. Black holes, created by the gravitational collapse of one or many stars, have become a possibility astronomers routinely consider in trying to explain their observations. In particular, it is now just short of establishment doctrine that a black hole with the mass of at least 100 million suns is the prime mover in a quasar.

An astrophysical role for black holes creates some awkwardness, the nature of which is brought out by Thomas S. Kuhn's concept of a paradigm. Kuhn, a physicist turned philosopher and historian of science, introduced the term in the mid-1960's to describe the full set of tools a community of scientists uses to study a specific topic. The paradigms of theoretical physics, for example, encompass equations embodying the relevant laws of physics, many specific problems that have been solved with those equations and--most important for our purposes--a set of pictures or diagrams with a matching vocabulary, expressing some of the mathematics in a powerful and heuristic way. The pictures, diagrams and vocabulary are the key to physical intuition, and the intuition makes possible the sudden leaps of insight that quickly advance the frontiers of knowledge. The mathematics, of course, is the ultimate arbiter; only it can say whether the leaps of insight are correct.

In the 1960's and 1970's physicists developed an elegant and powerful paradigm for black holes: the curved-spacetime paradigm. Its mathematics is that of general relativity, which describes space and time as a single four-dimensional entity. Its characteristic picutres are spacetime diagrams, which span time and two of the three dimensions of space. Curves known as world lines trace the trajectories of particles such as photons (packets of light) through spacetime.

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A black hole, in such a spacetime diagram, is represented by a cylindrical surface called the horizon, where spacetime is curved so sharphy by intense gravity that photons are trapped on or inside the surface. The horizon marks a point of no return: photons and every other kind of particle can fall through the horizon into the interior of the hole but none can emerge. The horizon cuts off all communication between the hole and the rest of the universe.

These diagrams and the other tools of the curved-spacetime paradigm have yielded deep insight into the physical nature of black holes that live in isolation, away from the influence of the external universe. Such insight was not enough for astrophysicists, however. Understanding a black hole as an astrophysical object--as the pwoer source in a quasar, for example--requires understanding how the hole interacts with the gas and magnetic fields in its surroundings. Unfortunately those interactions cannot be studied with any ease in the curved-spacetime paradigm. Curved spacetime is fundamentally incompatible with the mental images on which astrophysicists base their insights about magnetized plasmas (hot, ionized gases). It is couched in the language of unified, four-dimensional spacetime, whereas descriptions of magnetized plasmas are in the more familiar language of three-dimensional space, with time completely separate.

How, then, have black holes been treated by astrophysical theorists seeking to explain quasars? Until the late 1970's workers generally dodged the incompatibility of language and images by avoiding the curved-spacetime paradigm. Instead of viewing gravity as a curvature of spacetime they went back to the Newtonian paradigm of gravity as an attractive force. Where gravity is weak, as it is far from the horizon, the predictions of Newtonian and Einsteinian gravity agree to high precision; where the agreement breaks down, as it does close to the horizon, the theorists artificially cut off their calculations.

Early models of quasars applied this approach to describe how the accretion of matter could provide a power source. A black hole in a region of dense interstellar gas will draw in material by its gravity; the inflow will be spherical if the gas has little angular momentum but will become concentrated in a disk in the more typical case of rotating material. As the gas flows inward it will be compressed and heated, and like any hot gas it will emit radiation in such forms as radio waves, light and X rays. In calculating the emission of energy, theorists included radiation from a region extending almost to the point at which Einsteinian gravity would produce a horizon; there the calculations were cut off by fiat.

This approach might seem rather crude, but the errors it introduced were modest compared with the uncertainties about physical processes in the turbulent, hot accreting gas. Attempts (by the authors and others) to model the same process in the more accurate curved-spacetime paradigm were hardly worth the effort. In dealing with the gravitational pull of a black hole, then, the astrophysical failings of the curved-spacetime paradigm could be avoided.

Yet gravitational pull is not a black hole's only source of energy. As Roger Penrose of the University of Cambridge showed in 1969, a black hole can store enormous amounts of energy in the form of rotation. James M. Bardeen of the University of Washington pointed out soon afterward that black holes are likely to spin rapidly in the real universe: as matter rotating at typical rates collapses to form a black hole or accretes onto an existing hole, it

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will whirl faster and faster as it moves inward, driving the hole into rapid rotation. A hole's rotational energy offered an intriguing alternative possibility for powering a quasar.

Numerical estimates made rotation seem particularly attractive as a power source. A black hole of a given mass has a maximum rotation rate: if the imploding or accreting matter rotates too fast, centrifugal forces counteract the inward pull of gravity and prevent the matter from falling into the hole and further amplifying its spin. Most black holes probably spin at just about their maximum rate, which makes it possible to estimate the amount of energy stored in their rotation. The rotational energy in a black hole as massive as 100 million suns (about 3 X 10.sup.48 kilowatt-hours) would be about right to keep a typical quasar shining at its observed luminosity for its longest plausible lifetime, several billion years.

Until 1977, however, no one could find an astrophysically believable mechanism for extracting that rotational energy. The Newtonian picture of black holes offered no clues to a mechanism: in Newtonian physics a gravitational field behaves exactly the same way when its source is rotating as it does when the source is stationary. There is a rotationally induced component of a gravitational field that is a purely Einsteinian, relativistic phenomenon, one that cannot be simulated in any way with Newtonian gravity.

The search for an energy-extraction scheme continued, however, and in 1977 Roger D. Blandford of Cambridge and his graduate student Roman Znajek managed to use the mathematics of general relativity to show that magnetic fields threading the horizon of a black hole can tap its rotational energy. When we studied the mathematical analysis, we had to agree. The mathematics was clear. But for us the physical, intuitive picture was fuzzy: we had no simple images or language to describe the interaction of the rotating hole and the magnetic field.

It was our quest to understand the Blandford-Znajek process intuitively that led us to create the membrane paradigm. Our strategy was to translate the general-relativistic mathematics of black holes into the same language of three-dimensional space that is used for magnetized plasmas and to create a new set of black-hole diagrams and pictures to go along with the language. The translation was undertaken in the early 1980's by a group of investigators who were then at the California Institute of Technology but are now scattered over the U.S. and Europe. The Caltech Paradigm Society, as it came to call itself, included Douglas A. MacDonald, Wai Mo Suen, Ian H. Redmount, Xiao-He Zhang, Ronald J. Crowley, Wojciech H. Zurek and us.

The membrane paradigm seeks to treat a black hole as a simple, three-dimensional object that is not greatly different from its closes cousin, a neutron star. A rotating neutron star energizes a pulsar by way of magnetic fields. The standard description of the pulsar mechanism was a model for the kind of picture we hoped to develop for understanding energy extraction in quasars, and so it is worth reviewing here.

In spite of its name a neutron star, formed by the collapse of a massive star's core, contains not only neutrons but also protons and electrons, which make it highly conducting, even superconducting. Electric currents persist almost indefinitely in a neutron star, as do the magnetic fields they create. In appropriately pictorial, paradigmatic language, these magnetic fields are

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described as being "frozen" into the highly conducting material.

The neutron star, then, resembles a permanent magnet; it can be imagined as having magnetic field lines emerging from a north-polar region, looping out through space and swinging back into the star at a south-polar region. This astrophysical magnet spins. The normal stars from which neutron stars are created always rotate, at least a little, and the collapse that forms the neutron star amplifies the rotation. Hence most neutron stars are expected to be born spinning quite rapidly, with a period of between a thousandth of a second and one second. Since a neutron star's magnetic field is frozen into its electrically conducting interior, the magnetic field lines must also rotate.

The mental image of magnetic field lines suggests an important consequence of the rotation: even if the neutron star is turning slowly, at a sufficiently large remove these imaginary lines will be whirling through space at a speed greater than that of light. Charged particles (plasma) in the neighborhood of the neutron star are frozen to the field lines just as the field lines are frozen in the neutron star's interior. But since the particles cannot move faster than light, they resist the lines' rotation by bending them backward and sliding outward along them at velocities just under the speed of light. The field lines thereby act as levers for transferring the energy of the star's rotation to outflowing plasma.

The details of how this energy is transformed into pulsed radio emission and other phenomena typical of pulsars are complicated and are not at all the point here. The point is that one can get a good general grasp of the nature of pulsars and their influence on their surroundings with simple intuitive aids (magnetic field lines) and rules of thumb (the freezing together of field lines and conductors). These are the kinds of thought tools we should like to have for understanding how a magnetic field might extract the rotational energy of a black hole.

Our first order of business was to take black holes out of four-dimensional spacetime and describe them in three-dimensional space. We did so not only to make black holes easier to picture but also because in spacetime magnetic fields do not exist as distinct entities. Rather, they lose their separate identity and merge with electric fields in a single, unified electromagnetic field, which wreaks havoc with ordinary physical intuition. In order to divide the unified field into separate magnetic and electric fields, we had to reestablish a three-dimensional space consistent with the mathematics of unified spacetime.

To do so we needed a set of observers. An observer, in Einstein's theories, can be thought of as a being who carries a small framework of aligned measuring rods and a set of synchronized clocks for marking the location of events and measuring velocities, accelerations and so on. Relativity theory insists that two observers at the same point who are moving with respect to each other will measure different values for many physical quantities. Perhaps more shocking is the insistence that the observers will differ in their definition of three-dimensional space. They will disagree about which points in spacetime occur at the same time--which points make up three-dimensional space at that moment.

Three-dimensional space and with it an independent magnetic field, then, can be defined only in terms of a specific observer. In the membrane paradigm we

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recover an independent magnetic field, and the ability to imagine magnetic field lines around a black hole, by choosing a specific observer in each region of spacetime. The result is a family of observers who make a three-dimensional "slice" through spacetime and thereby define which part of the electromagnetic field is electric and which part is magnetic. We call these observers FIDO's, for fiducial observers. It is from their point of view that we examine the physics near the hole. Having chosen our FIDO's, we can begin talking about black holes in familiar, three-dimensional language.

To give the membrane paradigm simplicity and power, the FIDO's must be chosen according to strick mathematical rules. As it happens, these rules appear quite natural when they are translated into words and pictures. Each FIDO must retain at the same distance from the black hole and at the same latitude with respect to the hole's axis of rotation. The FIDO's also have a specific state of orbital motion: they are all, in a very special sense, at rest in three-dimensional space.

Does "at rest" mean that each FIDO, at any distance from the hole, is at rest with respect to distant stars? No: a rotating gravitational field tugs "absolute space" along with it. Near the earth the effect is expected to be minute, but it is dramatic near a rotating black hole: the hole drags space, and with it the FIDO's, into motion just as a golf ball spinning in maple syrup would drag along nearby syrup. The FIDO's, in this analogy, are at rest in the syrup (absolute space), but the syrup rotates with respect to the walls of the kitchen (the distant stars). Close to the horizon the FIDO's and the space they inhabit rotate nearly as fast as the hole itself (once every 90 minutes for a rapidly rotating black hole of 100 million solar masses); far from the horizon they are almost stationary with respect to distant stars.

Speaking of rotation rates in this way suggests a universal standard of time. But to an observer watching from afar, the FIDO clocks appear to tick at different rates. The closer a FIDO is to the horizon, the slower his clock will appear to run. Clocks belonging to FIDO's arbitrarily close to the horizon tick arbitrarily slowly. This phenomenon, called gravitational time dilation, also occurs in the earth's gravitational field, but there it is tiny: a difference of one part in a billion between the ticking rate of a clock on the earth and one on a geosynchronous satellite.

The clock time of a specific FIDO can serve for describing physics at a point. But in order to enable the membrane paradigm to cope with large-scale physical processes that involve an extended region of space we define a second kind of time. We imagine at each point a clock adjusted in rate and starting time so that clocks close to the horizon keep time with clocks farther away in spite of the strong gravitational field. These adjusted clocks, then, define a "universal" time that ticks at the same rate everywhere, like the time of classical physics and our (nonrelativistic) intuition.

Our family of FIDO's suffers one major embarrassment: no FIDO can possibly reside at or inside the horizon. At the horizon the gravitational field is so strong that only photons, which move at the speed of light, can hover there. FIDO's, being physical observers, must move more slowly than light. If any FIDO were to find himself at or inside the horizon, he would fall toward the center of the hole. His distance to the horizon would necessarily change, and so he would violate our rules for the choice of FIDO's. Because we cannot place a FIDO at the horizon, the membrane paradigm's absolute space must stop just

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short of it.

This omission seems less distressing when one examines physics arbitrarily close to the horizon. As seen from afar, physics clocks tick progressively slower as they approach the horizon. Correspondingly, every physical process slows to an infinitesimal pace there. For example, if a marble is dropped into the hole and its fall is timed by a distant FIDO, the marble falls rapidly at first but then slows as it nears the horizon. It gets plastered onto the horizon, moving inward at an exponentially dying rate but orbiting the hole in lockstep with the hole's rotation.

As seen by a FIDO hovering near the horizon, in contrast, the falling marble is accelerating to nearly the speed of light, and it undergoes the "Lorentz-FitzGerald contraction" that affects objects moving at relativistic speeds. The FIDO sees the marble become compressed to arbitrary thinness as it falls past him. (From the point of view of a third observer, who falls into the hole together with the marble, it plunges through the horizon without slowing or contracting. Such is the peculiarity of time and space in general relativity!)

In this way, according to the FIDO-based membrane paradigm, the horizon becomes cluttered with remants of the past, accumulating in infinitesimally thin layers like sediments on the ocean floor. This layered structure, doomed to sink exponentially closer to the horizon, has no bearing on the rest of the universe. Since the membrane paradigm is designed for astrophysical intuition, its inability to offer insight into processes at or inside the horizon is not a handicap. Indeed, we sweep them under the rug in the membrane paradigm by constructing a new, "stretched horizon" just outside the true horizon and ignoring everything inside it.

If we are to abandon the study of all matter and fields inside the stretched horizon, the influence of the hole on its environment must be expressed in terms of this new surface. Specifically, the interplay of FIDO-observed magnetic and electric fields on the stretched horizon must mimic the effect of the actual horizon on the electromagnetic field, an effect we have deduced from the old, curved-spacetime paradigm. Hence we define the properties of the new paradigm's stretched horizon so that it influences the FIDO-measured fields in a way that is consistent with the predictions of curved spacetime.

Znajek and, independently, Thibaut Damour of the University of Paris showed in 1978 that there is a resemblance between the equations describing the electromagnetic field at the horizon and those relating electric and magnetic fields in conducting material. In the membrane paradigm we exploit this resemblance. We treat the stretched horizon as a spherical or (if the hole is rotating) oblate membrane of electrically conducting material.

Like every other conductor, this stretched-horizon membrane develops surface charge in response to an external, perpendicular electric field, and specifically just the right distribution and concentration of charge to terminate the perpendicular electric field lines and prevent them from penetrating its interior. This shielding accords with Gauss's law, which states that electric field lines can only start and end on electric charges. The membrane also develops a surface current it response to a parallel magnetic field, in keeping with Ampere's law, which relates magnetic fields to electric currents. In the membrane the surface current has just the right value to shield the interior from the parallel magnetic field.

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It turns out that general relativity's description of the electromagnetic field at the horizon is beautifully and simply expressed in terms of membrane charges and currents. One aspect of the description is fulfilled by regarding the membrane as obeying the law of conservation of charge. Whenever real electric charge, carried for example by electrons or positrons, falls into the hole, the charge can be regarded as changing into membrane surface charge as it hits the stretched horizon. The charge then moves from place to place on the membrane in the form of membrane surface currents. Charge is neither created nor destroyed, from this point of view. The sum of the real charge in the black hole's environment and the fictitious (but intuitively powerful) charge accumulated on the membrane remains constant.

A second aspect of the description takes the form of an equally simple stipulation, a variant of Ohm's law, which relates currents to the electric fields that drive them. Nearly every conductor offers some resistance to the flow of current; for a thin sheet of conductor the resistance is quantified as surface resisitivity. The mathematics of general relativity, translated into the membrane paradigm, specifies a precise value for the surface resistivity of the membrane. It is 377 ohms, which is to say that an electric field of 377 volts would be needed to drive one ampere of current across a square patch of membrane material. This resistivity is quite high compared with that of, say, a copper sheet (a copper sheet one millimeter thick has a surface resistivity of .000018 ohm), and it has a special significance: it is the surface resistivity of a perfect absorber of electromagnetic radiation. The 377-ohm resistivity is the manifestation in the membrane paradigm of the fact that radiation can flow only into and not out of the hole.

In the context of astrophsics our main concern is not how a black hole interacts with radiation (rapidly oscillating electromagnetic fields) but how it interacts with large-scale magnetic fields that change relatively slowly. To see how viewing the hole as a conducting membrane is an aid in picturing such interactions, consider a simple thought problem. An intense magnetic field, like that in the gap of a laboratory magnet, exists somewhere in a galaxy far, far away. A black hole enters the intense field on a path perpendicular to the field lines. How does the hole influence the field, and how does the field affect the hole's motion?

The membrane paradigm suggests that the hole will interact with the field in roughly the same way as would a spheroidal membrane of conducting material with the same circumference as the horizon and a surface resistivity of 377 ohms. When a conducting surface enters a magnetic field, according to electromagnetic theory, the surface currents ("eddy currents") that are induced contribute a new component to the magnetic field, thereby distorting the original field lines. At the same time the external field exerts a force on the induced currents, retarding the conductor's passage.

The membrane paradigm thus provides a picture in which the field lines are distorted slightly as they brush over the stretched horizon. At the same time the hole experiences a modest drag, whose precise value can be calculated by solving the equations of the membrane paradigm. It is worth emphasizing that the mathematics of the curved-spacetime paradigm yields exactly the same result. The advantage of the membrane paradigm is that the picture is obvious and intuitive; before any calculations are done it gives a feel for the nature and amount of distortion and drag.

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It does so in party by hiding irrelevancies. If we put aside the membrane viewpoint for a moment and take a peek inside the stretched horizon, we find that, because of gravitational time dilation, the field lines never cross the horizon. Instead lengths of field line become wrapped around the black hole and eventually pinch off, forming loops that shrink inward toward the horizon. These tightly wrapped lines are an example of the layered remnants of the past that are shrouded by the stretched horizon. Only the modest distortion of the lines is astrophysically important, and only it is visible outside the stretched horizon.

How does the membrane paradigm help us to understand the more complex interaction of a rotating black hole and a magnetic field that may power a quasar? The paradigm emphasizes that black holes cannot maintain a magnetic field on their own, as the magnetized neutron stars that drive pulsars do. The resistance-free flow of current in the interior of a neutron star can sustain a magnetic field almost indefinitely, but the black-hole membrane's high resistivity means that similar currents there would be dissipated within a few minutes, and the magnetic field would die out. To have a role in powering a quasar, a magnetic field would have to thread the stretched horizon for the quasar's full lifetime.

There is an external source for such a field: the interstellar gas being drawn into the hole. All interstellar gas harbors magnetic fields, and the field lines become frozen into the gas as it is heated and ionized near the hole. rotation and turbulence in this accreting plasma drive the field lines into a chaotic tangle, parts of which are deposited onto the stretched horizon by infalling clumps of plasma. Eddy currents flowing through the membrane continually dissipate the energy of the chaotic field, leaving orderly, "cleaned" field lines threading into the membrane at a south-polar region and out again at a north-polar region. Once an orderly line has been deposited on the hole, it cannot be dissipated; the accretion disk's plasma and magnetic field hold it in as long as the disk is not blown away or swallowed by the hole. In this way the hole acquires a magnetic field of perhaps 10,000 gauss (more than 10,000 times stronger than the earth's magnetic field).

How does this orderly field rotate?

If, like a neutron star, the membrane had an electrical resistivity of zero, the field lines would be frozen into the membrane and would be forced to rotate at the same rate. If its resistivity were infinite, the lines could slip freely across the membrane and so avoid rotating. The actual resistivity of 377 ohms suggests that the lines will tend to rotate along with the membrane, but with some slippage. The image for energy transfer in pulsars, then, applies equally to quasars: the lines, whirling even though they slip, act as levers to fling plasma outward at great speeds, transforming the hole's rotation into a rapid outflow of gas.

The membrane paradigm suggests a second and equally valid way of thinking about this same process, a way that offers quantitative as well as qualitative insight into the energy transfer. The motion of any magnetic field generates an electric field. In the case of a rapidly rotating, magnetized black hole, the electric field generated near the stretched horizon can produce an enormous voltage difference between the poles of the membrane and its equatorial region: as much as 10.sup.20 volts. It is as though the stretched horizon were a huge battery.

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The magnetic field lines carry current driven by the voltage difference to distant parts of the quasar, linking the membrane with its environment in a gigantic direct-current circuit. Positive charge flows up field lines from the equatorial region of the membrane, in the form of an excess of negatively charged particles falling into the hole; it flows back down other field lines to the polar regions, in the form of an excess of positively charged particles. Current flows from polar to equatorial regions on the stretched horizon, completing the circuit at one end. At the other end, far from the hole, current crosses from equatorial to polar field lines through the intervening plasma.

The resistivity of this distant load region is probably similar to that of the membrane. As in any earthbound circuit, such "impedance matching" of the generator and the load region leads to the greatest possible transfer of power. About half of the energy in the circuit is deposited in the distant plasma and half is dissinated in the form of "waste heating" of the stretched horizon.

The net result is that the plasma in the load region is accelerated outward, in keeping with Blandford and Znajek's original calculations. Though complex processes of plasma physics some of the plasma's kinetic energy may then be transformed into the intense radiation of a quasar. The accelerated plasma may also feed the focused jets of ionized gas that are seen emerging from the nuclei of many quasars, often stretching out into space for many light-years [see "Cosmic Jets," by Roger D. Blandford, Mitchell C. Begelman and Martin J. Rees; SCIENTIFIC AMERICAN, May, 1982]. It is likely--but far from certain--that many quasars are powered in this way. The membrane paradigm has thus enabled us to picture some of the processes that link a black hole with the rest of the universe.

GRAPHIC: Chart; Caption: Electric generator is analogous to black holes powering quasars. ; Images of a black hole differ in curved-spacetime & membrane paradigms.; Schematic of pulsar's power output.; Time and space are affected by the horizon of a black hole; Stretched horizon is black hole's true boundary in membrane paradigm.; Thought experiment

SUBJECT: Black holes (Astronomy), models; Gravitation, research; Pulsars, models

LOAD-DATE-MDC: June 14, 1988

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(1)

BILL WELLS (CW) 994-6678
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Just over a year ago I ~~stated~~ clearly stated several basic principles aimed at strengthening ~~federal~~ federal science and technology policy. These principles had guided the promises I made during my presidential campaign; they have guided the promises I have kept as President. I believe:

~~PRINCIPLES~~

- Science and technology are increasingly critical to the Nation's national security and economic health.
- Many government policies and programs have an important scientific and technological component. Informed judgements on these issues are crucial to ~~the President~~ me, and thus, the science and technology advisor to the President warrants an elevated status in the White House.
- ~~The President believes~~ that the Federal science and technology process must be better coordinated with the private sector. Scientists, engineers, and executives from industry and academia should also be actively involved in the development of Federal science and technology policy.

(1)

Today's scientific and technical issues reach deeper into areas of social and economic concern and are more closely bound up with them. ~~Few matters that come to me~~ Certainly this is repleted in the decisions coming into my office.

To help me ~~in~~ with the more effective use of science and technology in developing our Federal strategies and policies, I have, as I said I would,

(2.)

"~~I will~~ upgrade the President's Science Advisor to Assistant to the President and ~~make~~ him an active member of the Economic Policy Council and our national security planning processes. And I ~~will create~~ a President's Council of Science and Technology Advisors, composed of leading scientists, engineers and distinguished executives from the private sector." Recently I attended their first meeting.

George Bush

Last month, on March 21, I appointed D. Allan Bromley, my Assistant for S&T, as Chairman of the White House Working Group on Science and Technology. The Working Group reports to the Economic Policy Council. It also will develop all science and technology issues related to domestic and social policy for consideration by the Domestic Policy Council.

(3)

While I have been ~~strengthening~~ strengthening the ways we develop Federal S+T policy within the government, I ~~also~~ want to reinforce another basic principle:

The Administration believes that the private sector should also have an important role in providing science and technology advice. Science and technology form the foundation of economic power. It is the combination of dedicated, skilled people and technological advancement that can improve our standard of living and our competitive position in the global marketplace.

BUILDING BETTER AMERICA

For such reasons, we have been turning to you and your ~~distinguished~~ predecessors ~~at the Academy~~ for more than one hundred and twenty-five years. Your record of distinguished service and advice has ~~served~~ served the Nation well -- in war and in peace. ~~Let me say~~ "We are grateful!"

(4)

Thank you, too, for your most recent venture: the ~~undertaken by~~ Manufacturing Forum & I fully agree with the remarks of Forum Chairman, Ruben F. Mettler, in saying that

"manufacturing is America's economic foundation. World-class manufacturing ~~capabilities~~, especially in key industries, are necessary to sustain a strong service sector and to generate the jobs and economic resources needed for economic growth and national security."

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DRAFT TEXT OF PRESS RELEASE

ON S&T WORKING GROUP AND FCCSET REORGANIZATION:

WHITE HOUSE POLICY APPARATUS

FOR SCIENCE AND TECHNOLOGY

For Immediate Release

March 21, 1990

The White House today announced the appointment of D. Allan Bromley, Assistant to the President for Science and Technology and Director of the Office of Science and Technology Policy, as chairman of the White House Working Group on Science and Technology. The Working Group currently reports to the Economic Policy Council and assists in the formulation, coordination, and implementation of Administration policies involving science and technology. The Working Group will also develop all science and technology issues related to domestic and social policy for consideration by the Domestic Policy Council. Members will include White House officials and senior representatives from all Federal agencies and departments with substantial involvement in scientific and technological issues.

The Working Group will analyze the scientific and technological components of economic and domestic policy issues, including Federal encouragement of investment research and development by the private sector; cooperation among government laboratories, university laboratories, and business; and access by American firms to international research and technology.

In addition, the Working Group will act as a conduit through which the deliberations and actions of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) that relate to policy issues broader than science and technology can be considered by the Economic Policy Council or the Domestic Policy Council.

In a related action, Dr. Bromley announced a substantial restructuring of the Federal Coordinating Council for Science, Engineering, and Technology, which is charged with reviewing and coordinating Federal activities in science and technology that cut across the missions of more than one Federal agency. Dr. Bromley is the chairman of FCCSET, and a list of the new FCCSET membership is attached. Other agencies may be requested to participate in meetings of the FCCSET concerned with matters of interest to those agencies.

FCCSET is in the process of forming seven umbrella committees, each chaired by a high-level official of a Federal agency or department, to oversee broad areas of science and technology. Subcommittees and working groups will work within each of these umbrella committees to examine, coordinate, and integrate Federal activities in selected areas of science and technology.

The Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) was originally established in 1976 by Public Law 94-282, the National Science and Technology Policy Organization and Priorities Act, which also established the Office of Science and Technology Policy. FCCSET is charged with:

- Providing for more effective planning, coordination, and administration of Federal scientific and technological programs.
- Identifying research and development needs, including areas requiring additional emphasis.
- Achieving more effective use of the scientific and technological resources of Federal agencies.
- Developing and reviewing, in close cooperation with the Office of Management and Budget, annual and long-range Federal budget plans in selected cross-cutting areas of science and technology.
- Furthering international cooperation in science and technology.

FCCSET is also charged with identifying scientific and technological issues of importance to the nation and with developing authoritative scientific and technological expertise and advice for the Executive Branch.

FCCSET also expects to receive information and advice on issues of science and technology from the President's Council of Advisers on Science and Technology, which the President established on February 2. PCAST consists of 12 distinguished

scientists and engineers from academia and industry; it reports directly to the President and is chaired by Dr. Bromley. PCAST members will chair panels on specific areas of science and technology that in some cases will parallel the committee structure of FCCSET, allowing private sector input into high-level government policy making.

FEDERAL COORDINATING COUNCIL FOR SCIENCE, ENGINEERING & TECHNOLOGY MEMBERSHIP

March 1990

Chairman: D. Allan Bromley
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy

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Clayton Yeutter
Secretary of Agriculture

Louis Sullivan
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Environmental Protection Agency

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WASHINGTON -- In an effort to help U.S. companies compete more effectively in world markets, the National Academy of Engineering and the National Academy of Sciences have convened the Manufacturing Forum, a new, standing committee that will assess public policies and programs and private-sector actions affecting U.S. manufacturing performance.

The Forum is composed of senior government officials and leaders from the private sector with corporate, labor, and academic experience. Frank Press, president of the National Academy of Sciences (NAS), and Robert White, president of the National Academy of Engineering (NAE), serve as ex-officio members.

"Manufacturing is America's economic foundation," said Forum chairman Ruben F. Mettler. "World-class manufacturing capabilities, especially in key industries, are necessary to sustain a strong service sector and to generate the jobs and economic resources needed for economic growth and national security. The forum will discuss ways U.S. industries can achieve sustainable excellence and competitiveness in manufacturing."

Mettler is retired chairman and chief executive officer of TRW Inc., Cleveland, Ohio, and current chairman of the board of the California Institute of

B: Bromley

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These principles had guided the promises I made during my Presidential campaign. They have guided the promises I have kept as President.

I believe:

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--Many government policies and programs have an important scientific and technological component. Informed judgments on these issues are crucial to me and thus, the Science and Technology Advisor to the President warrants an elevated status in the White House.

--That the Federal science and technology process must be better coordinated with the private sector. Scientists, engineers, and executives from industry and academia should also be actively involved in the development of Federal science and technology policy.

Today's scientific and technical issues reach deeper into areas of social and economic concern and are more closely bound up with them. Certainly this is reflected in the decisions coming into my office.

To help me with the more effective use of science and technology in developing our Federal strategies and policies, I have, as I said I would, upgraded the President's Science Advisor to Assistant to the President and made him an active member of the Economic Policy Council and our national security planning processes. And I created a President's Council of Science and Technology Advisors, composed of leading scientists, engineers, and distinguished executives from the private sector. Recently I attended their first meeting.

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While I have been strengthening the ways we develop Federal Science and Technology policy within the government, I wish to reinforce another basic principle.

The Administration believes that the private sector should also have an important role in providing science and technology advice. Science and technology form the foundation of economic power. It is the combination of dedicated, skilled people and technological advancement that can improve our standard of living and our competitive position in the global marketplace.

For such reasons, we have been turning to you and your predecessors for more than one hundred and twenty five years. Your record of distinguished service and advice has served the Nation well -- in war and in peace. "We are grateful!"

Thank you, too, for your most recent venture: the Manufacturing Forum. I fully agree with the remarks of Forum Chairman, Ruben F. Mettler, in saying that "manufacturing is America's economic foundation. World-class manufacturing capabilities, especially in key industries, are necessary to sustain a strong service and to generate the jobs and economic resources needed for economic growth and national security."

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(3)

While I have been ~~strengthening~~ strengthening the ways we develop Federal S+T policy within the government, I want to reinforce another basic principle.

The Administration believes that the private sector should also have an important role in providing science and technology advice. Science and technology form the foundation of economic power. It is the combination of dedicated, skilled people and technological advancement that can improve our standard of living and our competitive position in the global marketplace.

BOLD, BEST Am

For such reasons, we have been turning to you and your ~~distinguished~~ predecessors ~~at the Academy~~ for more than one hundred and twenty-five years. Your record of distinguished service and advice has ~~always~~ served the Nation well -- in war and in peace. ~~Let me say~~ "We are grateful!"

(4)

Thank you, too, for your most recent venture: the ~~of industry~~ Manufacturing Forum. I fully agree with the remarks of Forum Chairman, Ruben F. Mettler, in saying that "manufacturing is America's economic foundation. World-class manufacturing capabilities, especially in key industries, are necessary to sustain a strong service sector and to generate the jobs and economic resources needed for economic growth, and national security."

TO MARK LANGE / FROM BILL WELLS (OSTP)

456 - ~~0972~~ 2734

-OR- 994-7375 (His office now)

Additional Points for Bush Academy Address

1. Refer to 1939 threshold in the relationship (CHANGED) of S&T and modern society -- the global shaping and transformation effects arising from stunning scientific and technological advances in which many of you have participated led to:

- o the tremendously decisive impact on the outcome of World War II and the continuing vitality and strength of our national security in meeting new challenges

- o the exploration of space and the building of new multi-billion dollar industries, and the creation of entirely new modes of communications and thousands of jobs

- o the outpouring of innovations by our industrial and service sectors that helped to power vast economic growth here and abroad along with a dramatic growth in international trade during the past four decades -- the kinds of growth connected by Dr. Robert Solow to investment in science and technology for which he so deservingly was awarded the Nobel Prize in Economics in 1988.

- o the generous sharing of the fruits of our scientific knowledge and our technological advances with international partners on a scale unparalleled in human history.

2. We may well be crossing another threshold in the evolving relationship between science and technology and society. It seems to be no accident that a consensus is emerging around the world about the centrality of S&T to economic development and industrial revitalization, IN HEALTH, IN THE ENVIRONMENT

- o among the Governors of our States and

- o among the leaders of nations large and small, developed and developing

The attractiveness of Western technology -- including our own -- is part and parcel of the attractiveness of our open, market-oriented economic systems to those making radical changes from centrally planned economies in Eastern Europe.

But even in those economies where change is underway more cautiously, the acquisition of Western technology has high

priority and is seen as a major component of economic revitalization and growth.

3. Science and technology policy has -- in light of such trends -- arisen to the top of political agendas, worldwide. As a guiding principle, for us and others as well, it is essential for leaders to create and nuture an environment for innovation and effective resource investment. Complex bureaucracies and rigid rules are not the way to go as dozens of nations are finding out.

RATHER, My Administration's policies are aimed at:

- Encouraging higher levels of overall investment
- Seeking a less adversarial, more cooperative set of relationships between government and the private sector
- Supporting a wide range of increases in investment in research and development -- federal and private -- including a continuing focus on basic research
- Encouraging and supporting a broad set of activities in science and mathematics education in cooperation with the States. The Education Summit with the Governors last July was only the beginning; this will be a high priority during my Presidency.

EXCERPTS OF REMARKS FOR
VICE PRESIDENT GEORGE BUSH
OHIO ASSOCIATION OF BROADCASTERS
COLUMBUS, OHIO
TUESDAY, OCTOBER 25, 1988

We have grown accustomed in the political arena to speaking in the language of economics. We talk of Gross National Product, the consumer price index and the leading economic indicators. The economists sift and tally their numbers and present us with the facts of our economic existence.

But I want to talk today about another kind of economic fact, one that is often overlooked by those numbers, but one that is, in many ways, more fundamental.

Imagine a computer the size of a room, shrunk down to a size that will fit comfortably on your lap. Imagine today's super-computer shrunk down so that it fits on a single silicon chip -- this is the kind of dramatic improvment the experts now predict. This is the computer revolution -- the positive explosion of productivity at the heart of our economy.

It is accelerating the process of discovery, of innovation and change and has helped give America, in these last eight years, one of the most remarkable periods of creativity our economy has ever known.

But the fundamental point I want to make today is this -- these dramatic breakthroughs don't only effect silicon valley or other high-tech centers, its effects are spreading throughout our economy.

It is a mistake to segregate in one's mind "high tech" from the rest of our industrial base. In fact, one of the most profound effects of this technological revolution is the revitalization of our traditional industries -- not replacement, but revitalization -- making our products more competitive in global markets. Technology is America's economic fountain of youth.

We are in a new era of American industry, where the "service sector" melds with the industrial sector to create modern manufacturing. Americans are taking America's high-tech advantage and putting it to work reshaping our factories to be more competitive in the new information age. Some of the most dramatic examples are right here in Ohio.

-more-

There are so many successes here in Ohio, its hard to pick just a few. For example, take American Steel and Wire Corporation in Cleveland, which bought several of United States Steel's "moth balled" facilities and remodeled them with the latest steel technology. They are also paving the way to the future with an ambitious Employee Stock Ownership Plan -- in my view, some of the best labor relations are when employees become owners.

Take the Castite Corporation, also of Cleveland, whose President, Joan Lamson, personifies American entrepreneurship. Utilizing a new technology that makes metal castings pressure-tight, she decided to start her own company -- and she took it to an inner-city community, hiring half of her employees from one of the roughest parts of town.

Mead Corporation in Dayton, a maker of paper products, is also utilizing new technology in their paper mills, as well as diversifying into, among other things, information services, with their dramatically successful "Lexis" and "Nexis." Employment at their information division has gone from roughly 490 employees in 1980 to over 2,400 today.

It's this kind of restructuring that is putting new strength in the heartland's rebound and making the term "rustbelt" obsolete. A few numbers: unemployment, a painful 12.5 percent in Ohio during the recession, is now 5.9 percent -- still too high, but moving dramatically in the right direction. Throughout our nation's heartland, in almost every state, service sector and manufacturing employment has jumped. In Iowa, manufacturing employment is up 5 percent over last year, 10 percent over two years ago. Wisconsin's industrial employment is up four percent, Minnesota's 3.7 percent, Indiana's three percent. 26,000 new businesses sprang up in Ohio last year alone, creating many of the new jobs.

I think we sometimes make the mistake of thinking of the high-tech, "service sectors" of our economy as being in competition with the industrial sectors. But the industrial revolution didn't replace agriculture. Its inventions, from John Deere's steel plow and Cyrus McCormick's reaper to the steam combine and now to today's most modern farm machinery only made agriculture hugely more productive and created new markets for its products -- and, not incidentally, raised living standards for all. In the same way, the high-tech revolution isn't replacing basic manufacturing, it's creating new markets and, by playing to America's greatest strengths -- entrepreneurship and innovation -- it's making American industry more competitive abroad.

I have spent this campaign trying to delineate as clearly as I possibly can the profound differences between me and my opponent. On no issue are our two approaches more profoundly opposed, than on the question of how America must respond to this historic transformation as we enter the new information age in a truly global economy. These next four to eight years are crucial. To a great extent they will determine whether the United States continues to lead the world through openness and innovation -- or falls behind, retreating into isolation, economic provincialism, and destructive policies that protect special interests.

Let me take a moment to outline some of the principles and proposals a Bush administration will adopt to make sure America remains the world's high-tech leader.

The federal investment in research and development should focus on basic research and allow the private sector -- also a tremendous source of basic R&D -- to decide which technologies will have the most potential in the marketplace. Centralized planning leads only to centralized stagnation. Entrepreneurs, not bureaucrats, are going to blaze America's trail to the future.

Despite the extraordinary pressures on the budget, the Reagan/Bush administration has increased basic research funding by over 50 percent after adjusting for inflation. I will continue our strong support of federal investments in basic research, and I will make the Research and Development tax credit permanent. At the same time, I will seek government R&D authorizations for five years and appropriations for two years at a time -- so that researchers in our businesses and universities have a more stable, consistent environment in which to plan.

Improved commercialization is also vital. I will enhance the commercialization of new technologies by encouraging cooperation between laboratories and business.

A Bush Administration will vigorously move to protect intellectual property in the world marketplace and see that American companies have just as much access to foreign research projects as foreign companies have to ours.

I will upgrade the President's science advisor to Assistant to the President and make him an active member of the Economic Policy Council and our national security planning processes. And I will create a President's Council of Science and Technology Advisors, composed of leading scientists, engineers and distinguished executives from the private sector.

I will urge states and school boards to focus on science and math education from elementary grades to graduate school. Today, the United States awards about half the number of engineering

degrees as Japan, per capita. It's estimated that by 1995, we will need 300,000 additional secondary-school math and science teachers.

I've said before that I will call a conference of the nation's Governors to discuss the most urgent problems facing our schools, including curricula and achievement levels. One of our tasks will be to set goals and timetables for improving Math and Science Education -- and I will encourage states to adopt Alternate Certification for Teachers, ACT, so that science and technology professionals, among others, can share their crucial knowledge with our nation's students.

Finally, the United States government shouldn't, through misguided policies, put United States industry at a disadvantage.

We must realize that American industry faces global competition. We need vigorous enforcement of our anti-trust laws to ensure fair play, but when we consider the range of competition, we must take into account that the marketplace has expanded enormously and that American business is in a race with foreign competitors. A Bush Administration will conduct a thorough review of anti-competitive laws and regulations and work with Congress to rewrite them as need be to give ourselves a level playing field -- while still protecting the American consumer.

Perhaps most important of all, a Bush Administration will seek to cut the Capital Gains tax from 28 to 15 percent.

Let's learn from history -- there is nothing more crucial than cutting the capital gains tax if we want to spur investment, innovation and jobs.

My opponent says he wants American industry to be competitive -- yet most of our major competitors don't even have a capital gains tax. Japan doesn't have one. Neither do Hong Kong, South Korea, Taiwan or Singapore. Perhaps my opponent can explain why he wants to shackle America's entrepreneurs and businesses with a tax many of our foreign competitors don't have to contend with.

Does my opponent really want to put American business at a disadvantage against its foreign competitors? He's the one that would prevent American industry from competing on a level playing field -- in fact, he's the one who would tip it in favor of our foreign competition.

I have wondered if there is any rhyme or reason behind my opponent's fierce opposition to the capital gains tax cut. Every time we've cut it in the past, we've actually brought in more revenue because of increased investment and economic activity. That's history. That's fact. It's estimated that our cut would have zero revenue loss. So its not the effect on the deficit.

I have come to the conclusion -- it is my belief -- that my opponent's economic polices cannot be understood as a rational approach to economic growth and the creation of jobs. He clings, despite all the evidence of the last two decades, to the discredited polices of high taxes and big government spending.

It is my belief that my opponent is far outside the mainstream of economic thinking, and has broken with the American traditions of entrepreneurship and free enterprise.

He advocates what is called an "industrial policy" -- which means having bureaucrats in Washington pick the winners and the losers, and that would simply make us all losers.

Perhaps twenty or thirty years ago, I understand some people considered it reasonable to believe such things. Today, it is quite simply irrational. Those policies have been tried, and they have failed. Dramatically. Across the Atlantic, the stagnation and high unemployment caused by high taxation and over-regulation was called the "European Disease." Here at home, I seem to remember, when we were moving that direction last time a tax-and-spend Governor was in the White House, we called it "malaise."

Around the world, governments are abandoning socialism, in all its various guises and degrees, and embracing the American model of low taxation, entrepreneurship and individual initiative. Now is not the time to throw America's gears full speed in reverse back to the 1970s with policies that would stymie the competitive transformation of American industry taking place in America's heartland.

I spoke of irrationality. I must say that I've been disturbed, as I've witnessed my opponent's campaign over the last several weeks, at the increasing appeals to class conflict. In my view, there is no place in American public life for philosophies that divide Americans one from another and that excite conflict among them.

America will move forward together, or not at all. America will find her future by keeping with the traditions of her past -- traditions of openness, generosity and cooperation. We will move forward, not by succumbing to the base temptations of fear and envy, but by following, as Abraham Lincoln said, those "better Angels of our nature."

The world today is in the midst of a profound transformation -- one so far-reaching in its consequences that past revolutions -- political, economic or scientific -- will all be dwarfed by comparison.

Because this transformation encompasses all three. We are entering the information age at a time of sweeping change in the economic and political spheres, the decline of communism as an economic philosophy, and the tide of democratic governments that is changing the face of the world -- all based on the right of the individual to be, in Milton Friedman's resounding phrase, Free to Choose.

America is uniquely suited to lead this world revolution to a new era of peace and prosperity. Founded in freedom, our nation is imbued with the spirit of enterprise, the torch of creativity that will light our way.

As I said earlier, these next four to eight years will be watershed years when we decide whether America goes forward as a leader, or slips back into the past. I am dedicated to expanding our economic freedom and unleashing the creativity of our entrepreneurs that is revitalizing American industry. I believe that America must lead the world in every field -- economic, political and scientific, or we will fall behind in all.

I am proud to have worked with our great President and had the experience of helping to create six years of record setting economic growth, technological innovation and record setting employment. I have an optimistic faith in America and the limitless capabilities of its people who will carry those policies on to the future.

Thank you all very much and God bless you.

# # # #

Marla Lange
1/6

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

PRESS STATEMENT

FOR IMMEDIATE RELEASE JANUARY 29, 1990

SCIENCE AND TECHNOLOGY IN THE PRESIDENT'S FY 1991 BUDGET

The President's 1991 budget proposes a substantial increase of 12 percent in civilian R&D. The Administration proposal would increase civilian R&D from the $23.8 billion that was enacted in FY 1990 to $26.7 billion in FY 1991. Conduct of defense R&D would increase by 4 percent, from $39.9 billion to $41.4 billion.

Total funding for basic research fares well in the 1991 budget. Funding for both civilian and defense basic research is set at $12.4 billion in FY 1991, an increase of about $1 billion or 8 percent above the level enacted in 1990. Basic research thus represents about 17 percent of the total 1991 R&D budget. Civilian basic research would go up about 9 percent, while defense basic research goes up about 6 percent.

Altogether, the total conduct of R&D, both civilian and defense, would rise 7 percent, to $68.1 billion. Adding $3.06 billion for the construction, repair, and modernization of R&D facilities brings the total proposed federal support for R&D to $71.2 billion. This amount is 5.1 percent of the total budget for FY 1991 and 1.3 percent of the U.S. gross national product. In FY 1990, the corresponding percentages were 5.0 percent of the total budget and 1.2 percent of GNP.

This year's budget will continue the change in the proportions of civilian and defense R&D funded by the federal government. During the 1980s, defense R&D rose much faster than civilian R&D, reaching a peak of 69 percent in 1986. This year, civilian R&D will total 39 percent and defense 61 percent of total conduct of federal R&D.

Components of the Budget

At an aggregate level, federal R&D funding can be divided into several categories, involving both the continued support of previous commitments and funding for new initiatives. As in previous years, the major portion of the total R&D budget is made up of:

- Multiyear commitments already made by the Administration. Important examples include doubling the budget of the National Science Foundation by 1993 from a base year of 1987 (a 14.3 percent increase in FY 1991 to $2.38 billion), Space Station Freedom (up 36 percent to $2.63 billion), research to bring HIV infection and AIDS under control (a 7 percent increase to $1.25 billion, with an additional $2.21 billion for HIV/AIDS treatment, prevention, and income support), and continued support for the construction of the Superconducting Supercollider (up 46 percent to $318 million in FY 1991).

- Commitment to continued real growth for basic research, a long-term investment that has consistently yielded very high returns to society. Growth in real terms is essential both to cover the ever increasing capital and supporting costs required to do basic research (which have been increasing faster than the overall cost of living) and to foster an environment where sufficient funding is available for imaginative new ideas.

- Continuation of multiyear programs directly supporting existing agency missions and the broader public good. Examples include research in the life sciences and medicine, energy research, and research in the earth and space sciences.

- Defense R&D. Most of this R&D is directly tied to weapons systems and their supporting systems. These funds support a wide range of activities, ranging from support of basic research to full-scale development of hardware and its testing and evaluation. In 1991, defense R&D is up by 4 percent, whereas the total defense budget is up by 1.7 percent. Furthermore, defense basic research is only up by 5.9 percent.

- New initiatives. This includes new R&D activities, or significant increases in ongoing programs, reflecting changes in emphasis. Examples are provided in the following section.

Areas of Emphasis in the Budget

The budget includes several areas of emphasis originating from agency proposals, the White House, and Congress. These areas include:

- Science, mathematics, and engineering education. The Administration is proposing an increase of 26 percent in FY 1991 for science and mathematics education supported by the National Science Foundation, the Department of Education, the Department of Energy, NASA, and the National Institutes of Health. Funding in these five agencies would rise from $841 million to $1.06 billion. These funds support new and existing agency programs that target revitalization of mathematics, science, and engineering education to produce the technological workforce and scientifically literate population needed to maintain a globally competitive economy.

- Global change. To gain the information and knowledge base needed to assess and help predict the magnitude of global change due to man-made and natural causes, the FY 1991 budget calls for an increase of support for the interagency U.S. Global Change Research Program (USGSRP) of 57 percent. This increased funding, from $659 million to over $1 billion, includes a commitment to build and deploy the Earth Observing System (EOS) satellites and the necessary ground-based support and further supports the United States' leading position in research on global change. Prior to beginning full-scale development of EOS, the National Academy of Sciences will undertake an independent review of EOS as part of an overall review of the USGSRP.

- Agricultural research. To expand research in plant science, animal science, nutrition, and natural resources, the budget proposes the first step in a National Research Initiative that will double the size of the U.S. Department of Agriculture's competitive grants program to $100 million in 1991. Funding will be increased by $50 million annually in subsequent years so long as the funds are awarded competitively.

- The Human Genome. To capitalize on recent technological advances in the manipulation of DNA, an initiative has been launched to map and sequence the entire human genome. This will entail determining the precise structure and order of the 3 billion pairs of genetic building blocks that distinguish a human being from other living organisms. The two key federal agencies involved in this effort are the National Institutes of Health and the Department of Energy. Together, they will commit $154 million to genome research in FY 1991, an increase of $68 million or 56 percent. Plans for the allocation of these funds are described in a joint DOE/NIH five-year plan. Other agencies contributing to this effort include the National Science Foundation and The Department of

Agriculture. In addition to studying the human genome, investigations on other animal and plant model systems will provide important insights into the evolution and conservation of key genetic elements. Technological developments will be encouraged under this initiative, many of which will have applications in other areas of science and in the commercial sector.

- Exploration beyond the Earth to the Moon and Mars. Space is truly a frontier that will never end; it represents a challenge to the human spirit. On the twentieth anniversary of Apollo 11 last July 20, the President called for manned exploration and ultimately a permanent manned presence beyond the Earth. The 1991 budget for this initiative shows an increase of nearly 50 percent to about $1.27 billion (primarily in NASA but including important efforts in the Departments of Energy and Defense). This increase includes a major new initiative to developing the new technologies needed for future manned exploration of the Moon and Mars.

Many of the Administration's priorities and areas of emphasis that influence the budget cannot be easily expressed in a budget figure for a program. For example, the Administration is proposing to make the research and experimentation (R&E) tax credit permanent and to enhance its availability to companies that perform R&D. This may briefly decrease tax revenues from business in the short term but will significantly help our industrial base in the longer term. The R&E tax credit is an important investment for the future. The Administration also plans to improve international protection of intellectual property, encourage R&D investments by transnational companies, and endorse changes in product liability laws to promote U.S. competitiveness.

Selected OSTP Policy Highlights

The Office of Science and Technology Policy is charged with coordinating federal R&D that cuts across the missions of more than one federal agency and with providing advice to the President on issues of science and technology policy that affect national and international policy. In light of these responsibilities, OSTP has established several areas that will receive major emphasis in the coming year.

Basic Research

Basic research is the wellspring of fundamental knowledge, and federal support for basic research is an essential investment in the nation's scientific and technological future. Our country is unique in the extent to which our universities conduct the research that expands the base of fundamental scientific knowledge and simultaneously train future generations of scientists and engineers. The federal

government supports basic research not only through individual research grants but also through construction of the large, expensive research facilities that are essential to progress in areas ranging from space sciences to particle physics to materials engineering. Large facilities are important not only for academic research but also for industry-oriented research.

As we prepare to extend our scientific horizons by constructing new facilities, we must take care to ensure the health and vitality of the university-based individual investigator enterprise that is the backbone of our system.

Science and Technology for Economic Growth

Our ability as a nation to commercialize scientific and technological innovations effectively is a major factor in assuring our long-term economic growth and industrial competitiveness. The United States spends more on research and development than any other country in the world. We must continually assess the role of government and industry in the technology commercialization process to ensure that we realize the full potential of this public and private investment. Indeed, improving relationships between the public and private sectors to achieve this goal will be a major challenge of the 1990s. Specific concerns on which OSTP will focus are:

- o Catalyzing state and local activities in industrial competitiveness to obtain maximum leverage for federal funds.
- o Improving the technology transfer process from federal laboratories to the private sector.
- o Encouraging the development and application by the private sector of critical technologies that exert strong leverage on the U.S. manufacturing sector and other sectors of the U.S. economy.
- o Refining our technology policy to establish guidelines for future federal R&D investments.

A prerequisite for our future national well-being is a strong manufacturing sector; our national policy toward technology has the primary underlying objective of encouraging this necessary base--particularly in the high technology end. In addition, the nation needs a better working relationship between government and industry and an improved climate for the formation of business consortia. The sophistication and capital-intensive nature of modern technology require new ways of increasing cooperation between government and industry and of fostering communication on long-term technology goals. SEMATECH is an important example of such government-industry cooperation.

OSTP plans to focus attention on several broad areas of advanced technology including: information technology, biotechnology, and materials science and engineering. These "enabling" technologies will be discussed separately in following sections.

Science and Engineering and Advanced Technologies

While this area covers the spectrum from basic research to engineering development in a broad range of fields, the above areas of information technology and materials science and engineering will be highlighted.

Information technology covers all aspects of computing, computer networks, and computer-aided design, engineering, and manufacturing. High-performance computing, while still a relatively small component of the overall industry, holds particular promise as a high-leverage technology that could expand dramatically in the future. A national computing network, ultimately linking research institutions, businesses, schools, and homes, will have a strong leverage on the rest of our economy.

Materials include the basic components of our industrial civilization, from ceramics, semiconductors, superconductors, and metals to polymers and composites. Important new insights into the nature of materials and new abilities to create materials, in some cases on an atom-by-atom basis, are ushering in an age of "tailored" materials that will have a wealth of everyday applications. OSTP intends to raise the visibility of this critical area of R&D and technology, particularly in encouraging greater effectiveness in commercializing materials R&D.

One major category of federally supported materials-related R&D, including support of manufacturing processes, is semiconductors. The largest single program is Defense funding for SEMATECH. The federal goal is to encourage cooperation among businesses to help bridge the current divide between R&D and timely commercialization of semiconductor chips.

Science and Technology for National Security

We could not provide for the security of our nation or our allies were it not for America's tremendous scientific and technological strength providing the qualitative edge that has long ensured our deterrent and helped preserve the peace. The Strategic Defense Initiative is a leading example of technological innovations that promise paths to greater security and stability. OSTP will continue close interaction with the Department of Defense in providing advice to further advances in defense technology.

Particularly in times of international uncertainty, a strong research and technology base is critical to enable investigation into promising new technologies and to guard against technological surprise from potential adversaries. OSTP is keenly interested in ensuring healthy levels of investment in critical and cutting-edge technologies central to tomorrow's defense. Many of these technologies also have commercial applications. One example is the National Aerospace Plane, an aircraft that could take off and land on a normal runway and fly through the atmosphere and into orbit at hypersonic speeds. The NASP program has already achieved important advances in composite materials and fluid dynamics, and OSTP will continue to provide support to the NASP effort.

The dramatic changes under way in Eastern Europe presage changes in the international environment and in the security needs of the West. The development and application of technology to support changing defense and foreign policy requirements in such areas as arms control verification technologies, intelligence collection, analysis and protection, and command, control, and communication capabilities are key OSTP concerns.

Life Sciences

The life sciences have made enormous progress during the last decade, yet they still represent a frontier with major advances on the horizon that will dramatically enhance our quality of life. While research into diseases such as AIDS captures a great deal of attention, many other areas of investigation will also have a sweeping impact on our population, such as efforts to understand and ameliorate the effects of aging.

The 1990s have been designated the Decade of the Brain to focus needed public and scientific attention on the multidisciplinary efforts required to continue our progress in understanding mental illness, addictive disorders, and treatments for diseases that affect the brain. OSTP will be coordinating an interagency response on the Decade of the Brain.

Biotechnology entails the use of living systems to produce goods or provide services, from the biological production of organic molecules to improved plants and animals for agriculture. Biotechnology is not an end in itself but merely a tool to be applied to problems that extend across the spectrum of life sciences research. For instance, improvements in food crop nutrition content or disease-resistance will have positive effects on public health and on economic growth.

In the coming year the Office of Science and Technology Policy plans to examine the federal investment in biotechnology to identify those areas in need of attention. One such area is generic applied research that can benefit all sectors of the industry, such as scale-up technology, large-scale culture systems, and protein

design. Another very important issue is the need for training the next generation of biotechnologists. These are issues that will be addressed at the highest levels of government in the President's Council of Advisors on Science and Technology and in the Vice President's Competitiveness Council Biotechnology Working Group. The biotechnology industry has reached a critical stage when the proper encouragement can sustain our leadership in the world market while disincentives to commercialization can force the United States from the lead.

Global Change and Other Cross-Cutting Issues

Global change is one of several issues that demonstrate the increasingly interdisciplinary nature of science. At the federal level, this interconnectedness leads to more cross-cutting programs involving different agencies and scientific specialties. The degree of success of the global change R&D program in predicting atmospheric temperatures, for example, will depend on effective communication between these specialties. At a more fundamental level, the age of scientific specialization is giving way to a world where progress depends more and more on the pooling of expertise of many different investigators and nations.

As our depth of knowledge increases, effective communication among scientists in different disciplines becomes ever more critical. OSTP will play an important role in facilitating the necessary cross-fertilization among scientific communities.

International Science and Technology

The results of basic research are a global resource adding to the knowledge base and ultimately to the economic prosperity of all nations. While the social rate of return on investment in basic research is very high, benefits do not accrue just to sponsoring countries or governments but rather to the world at large. This being the case, where possible, nations need to coordinate planning and support for basic research, especially for megaprojects that require large financial commitments and involve science and engineering talent from many nations.

OSTP is developing a framework for dealing effectively and comprehensively with the challenges of coordinating science and technology on a global scale. This comprehensive approach will be addressed within the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET). Existing bilateral science and technology relations with countries and regions such as Japan and the European Community will play an important role in this effort, as will emerging cooperation with the Soviet Union, Eastern Europe, and developing countries.

There is a special need for applying an equitable and broadly based approach to international cooperation (e.g., on megaprojects) in the basic sciences. One result

of this effort will be a more comprehensive approach to seeking increased international cooperation in such fields as high energy physics, astronomy, space, the life sciences, and controlled thermonuclear fusion.

Science, Mathematics, and Engineering Education

Education at all levels needs to be revitalized. This revitalization involves not only the training of our scientists, engineers, and technical workforce but also the education of a population sufficiently literate in science and technology to deal with the social issues arising from rapid scientific and technical change. Achieving such a goal will require a broad-based approach involving businesses, academia, educational organizations, and State and local governments. For example, businesses are playing an increasingly important role in the training and retraining of our workforce. Junior colleges and technical schools provide a means of upgrading the skills of our youth and workforce. And last but not least, the precollege level is where life-long interests in science and mathematics are aroused, if they are to be aroused at all.

Through the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), OSTP is developing a framework for interagency coordination and collaboration for mathematics, science, engineering, and technology education. The goal is to develop an effective and appropriate role for the federal government in support of the states, localities, and universities as they reform science and technology education.

CONCLUSION

Though the FY 1991 budget covers a wide range of R&D activities, several underlying themes unify the Administration's science and technology policy:

- The first is to preserve the initiative, independence, and creativity of American scientists through a stable multiyear pattern of funding for basic research and continued real growth in federal R&D funding.

- The second is to foster a more efficient and effective interchange between R&D and commercial production. SOUNDS LIKE INDUSTRIAL POLICY

- The third is to ensure that the best scientific advice is an integral part of all policy decisions on the environment.

- The fourth is to contribute to international cooperation through international support of large science projects such as the Superconducting Supercollider and the Space Station, along with international cooperation on a wide range of other scientific endeavors.

- **Finally, a key goal is to improve national literacy in science and mathematics and meet future requirements for trained people in science and engineering. This is essential for our future economic prosperity in an increasingly technological and competitive world.**

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL

Executive Office

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NATIONAL ACADEMY OF SCIENCES
2101 Constitution Avenue Washington, D C 20418

ADMINISTRATION GUESTS
ADDRESS BY PRESIDENT BUSH
April 23, 1990

The Honorable Donald J. Atwood, Jr.*
Deputy Secretary, Department of Defense

The Honorable Erich Bloch
Director, National Science Foundation

Dr. Charles M. Herzfeld
Director of Defense Research and Engineering
Department of Defense

The Honorable Charles E. Hess
Assistant Secretary for Science and Education
Department of Agriculture

The Honorable James O. Mason
Assistant Secretary for Health
Department of Health and Human Services

The Honorable Thomas J. Murrin
Deputy Secretary, Department of Commerce

The Honorable Louis W. Sullivan*
Secretary, Department of Health and Human Services

Vice Admiral Richard H. Truly
Administrator, National Aeronautics and Space Administration

Admiral James D. Watkins (with Dr. Glenn Seaborg)
Secretary, Department of Energy

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*Invited; unconfirmed.

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Data Communications

February, 1988

SECTION: EOT; Pg. 252

LENGTH: 770 words

HEADLINE: Don't discourage innovation. Here's a plan

BYLINE: Jerome Lemelson and Eric Lemelson; Jerome is president and Eric is vice president of Licensing Management Corp., a patent and technology-licensing firm in New York City.

HIGHLIGHT:

A potpourri of commentary on data communications

BODY:

Typical of most U.S. industries, data communications has felt the sting of foreign competition. Yet many leaders in this industry have become reluctant to pioneer new products. This reluctance has contributed in large part to reduced sales of products made in America, and subsequently to the increased trade deficit.

A key element in America's search to overcome its economic dilemmas is innovation. Innovation drives the nation's economic engine.

Every schoolchild learns about the inventions of Thomas Edison, Alexander Graham Bell, Henry Ford, and others throughout U.S. history whose accomplishments provided much of the impetus behind our nation's past economic success. More recent examples of the contributions from individual American innovators are the laser (Gordon Gould), instant photography (Edwin Land), and xerography (Chester Carlson) .

But the reality behind these success stories is often complex. Chester Carlson, for example, approached all the manufacturers in the photocopying industry. He offered them, individually, exclusive patent rights to his invention, without success.

Still, the fact that his idea did eventually make it to the marketplace is evidence of Carlson's persistence. The outstanding success of his exrographic copier revolutionized the office world.

New industries were eventually created as a result of the perseverance of Carlson, Gould, and Land. Still, the resistance encountered added years to the time between when the original idea was conceived and the eventual marketing of the inventions.

Two of the major causes of the decline of American innovation are the NIH (not invented here -- meaning inhouse) syndrome, and the unwillingness of many corporate executives to take risks. Too many of these executives have a tendency to "let George do it first," and then attempt to compete with George -- or buy out George's company.

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Today there are many new product ideas available to industry that are covered by patents owned by private inventors, universities, and research organizations. Unfortunately, the product-implementation mechanism often functions in a way that decreases industry's chances to utilize ideas from these sources.

This is due in part to the risk associated with developing new products that are based on licenses offered from sources outside the manufacturing company. Company groups that are set up to seek and evaluate new products often are hamstrung by the lack of management support -- and the NIH syndrome.

In general, foreign firms are more willing to acknowledge the role of outside inventors in formulating newproduct ideas, and they are less hesitant to negotiate with these individuals. This accounts, in large part, for the success of the Japanese in producing high-technology products.

We believe that the U.S. government can take positive steps to make it more attractive for businesses to seek outside ideas. Incentives, in the form of tax credits, would be a logical first step in this process.

Tax credits might take the form of the following:

* A faster write-off of the costs of development and production tooling for products manufactured under license.

* An extra tax deduction on profits made from the sale or lease of licensed products

* An extra tax deduction from profits derived from an invention's increasing a company's productivity.

* An extra tax deduction on profits from the sale of licensed products made in the United States and sold in foreign markets. This would also reduce the trade deficit.

* An extra tax deduction from corporate profits if the licensed products result in a net loss and are discontinued. This would partially compensate for the risk. Wise use of our tax laws is an important and necessary step in encouraging innovation in networking or any field. But tax credits are only part of the solution.

Patenting and the protection it affords private inventors and manufacturers should be streamlined. The time now required to reach decisions relating to patent validity and infringement needs to be reduced, since very few individuals can afford to participate in legal processes that can last literally decades and cost hundreds of thousands of dollars in the course of defending a patent.

Finally, we need leadership that recognizes the value of innovation and is willing to encourage the work of the next generation of Thomas Edisons. The American economic success story is, after all, the story of individual contributions to produce a greater whole. If we forget this simple fact, then we will have lost the economic battle by default.

GRAPHIC: Illustration, no caption

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12TH STORY of Level 2 printed in FULL format.

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August 21, 1985, Wednesday, Final Edition

SECTION: Style; B1

LENGTH: 1593 words

HEADLINE: The Deans of Duplication;
Celebrating 25 Years of Xerox Originals

BYLINE: By Michael Kernan, Washington Post Staff Writer

BODY:

You never saw so many blue suits.

The Xerox 914 Copier, the original, is 25 years old, and yesterday Xerox Corp. gave a 914 to the Smithsonian.

It wasn't your usual executive lunch: The room was filled with the very men who put that pioneering machine together, designed it, and manufactured and sold it.

This is one of the more hair-raising sagas of American industry, about a modest firm in Rochester, N.Y., named the Haloid Co., with 500 employes and a president named Joseph C. Wilson who was willing to spend -- in perfecting and producing an invention that nobody knew for sure was really wanted -- more than the firm made for an entire decade.

In the most literal sense, he bet his company on it.

"Joe Wilson found himself," said David T. Kearns, the present chairman of Xerox, "in the position of having spent money he didn't have to build a machine he couldn't sell."

He did, however, think of a way to sell it. And created a $27 billion industry. And also made it economically feasible, for the first time in history, to print, just like that, a single copy of anything you wanted on paper.

And when Kearns called the copier "a marvelously free expression of a free society," he wasn't just waving his teeth. For, as one Xerox veteran pointed out, in the Soviet Union, where every sheet from every copier has to be logged, tagged and accounted for, underground literature is reproduced with carbon paper . . .

In the beginning, there was this inventor.

His name was Chester Carlson, and he was a 29-year-old patent attorney who spent his weekends in a small room over a bar in Astoria, on Long Island, trying to build a copying machine. It was 1938.

Since the word xerography didn't exist, Carlson went to the public library and looked up articles on the ways that light affects matter. Seeking techniques that the big photographic companies probably wouldn't have bothered to explore, he hit upon electrostatics as a means of picking up an image and putting it

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down somewhere else.

But he was no good at lab work. How do you spread melted sulfur on a metal plate while preventing the substance from bursting into flame? Once you get it there, how do you give it an electric charge? Things like that.

Carlson's solution was radically simple: From a job ad in a technical magazine, he hired an unemployed physicist named Otto Kornei to work as long as Carlson could afford him. Within three weeks, on Oct. 22, 1938, Kornei had produced a glass plate with "10-22-38 Astoria" inked on it. He rubbed it with a silk handkerchief, giving it an electrostatic charge, then shone light through it.

The light neutralized the charge except where the inked marks were. When Kornei dusted the plate with powder, grains stuck to the charged areas, and when he laid waxed paper on the plate, the powdered image was transferred.

That historic device is already at the Smithsonian.

Other people had made paper transfers, of course. There were the wet-paper techniques -- Thermofax by 3M, Verifax by Kodak -- and there was carbon paper, which smudged your fingers. The great thing about Carlson's copies was that they were on ordinary paper . . . and they were dry. That's where the word Xerox comes from, in fact: the Greek xeros means dry.

Carbon paper, the workhorse of the office, was about to become -- like the horse -- obsolete. But it would take awhile.

For inventor Carlson, all thumbs in the lab, also was no salesman.

"He never came directly to Haloid," said Horace W. Becker, the engineer who helped bring the idea to the production line. "Tried to sell it to several large corporations, but they weren't interested. Then finally, the Haloid people saw something about it in a magazine, and in 1944 Wilson bought limited rights in it."

What did Haloid, a manufacturer of photocopy paper with sales of $5 million a year -- and particularly Wilson, its driving force -- see in a dry-copy machine? This is the fascinating part: Whatever he saw, it wasn't in sharp outline. It was hazy -- a potential, a dream, a hunch. Yet Wilson had absolute, total, out-the-window faith in it: a machine that could make clear, dry copies on ordinary paper must be useful to somebody.

"When I got there in 1959," Becker recalled, "Wilson asked me to estimate what it would cost Haloid to produce this machine; he'd never done any market research himself. I gave my estimate, and the room went very quiet. The company had already spent several times earnings on the thing. So they tried to find someone else to build it."

Bell and Howell said the idea would never fly; the image would blur. IBM called for an Arthur D. Little survey. The survey showed that very little copying was done in the American office, not enough to warrant building more than, say, 5,000 machines.

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"What they didn't ask," Becker said, "was: 'Why?' "

Why so little copying was done was that wet-sheet copies were a nuisance and cost 19 to 25 cents each.

"What they really researched was the carbon paper market. Nobody was looking at the possibility of copies being made at point of receipt."

Nobody, in other words, realized that the people who received a memo might want to copy it. In those far-off days, offices were tyrannized by the buck slip, a memo with various names on it that was initialed and passed along. A buck slip could take weeks to circulate through a large office staff.

Wilson pressed on. Over 12 years, Haloid spent $75 million to develop the machine, more than the firm had spent on all of its products in its 40-year history, and twice its earnings from all of its operations in sensitized papers.

When at last Wilson had his product ready to sell, he found himself pitted against Kodak's Verifax and 3M's Thermofax, both selling for under $400 and small enough to fit on a desk top. His new machine sold for $29,500 and was as big as a desk, weighing 648 pounds.

Wilson's solution was almost as ingenious as the Xerox machine itself: He offered to lease it for a mere $95 a month, with the first 2,000 copies free and additional copies costing 5 cents each. Plus, he would make repairs himself. Plus, the user could cancel within 15 days.

"Nobody bought it at first," Becker said. "But there weren't many cancellations, and few repairs. It ran pretty good. We could have done a better job if we'd had two more years, but then there wouldn't have been a company anymore."

In 1960, Haloid Xerox Inc. changed its name to Xerox Corp. and sold its first 914 to Standard Pressed Steel of Boston. From the first day, the machine was mobbed by users. In the first month it made more than 100,000 copies.

Xerox had stumbled on an astonishing fact: A vast, unsuspected market was sitting right under everybody's nose. It was thought that 5,000 machines would saturate the market. Within two years, Xerox had produced twice that many; by the end of the 1960s, production passed 200,000. And copies: Xerox had figured maybe 10,000 copies a month from an average machine. Right from the start, machines were turning out more than 10 times that number. People in offices all over America were lining up to make copies. Some machines made 5,000 copies a day, and 120,000 a month was nothing special.

Even before the company went on the New York Stock Exchange in 1961, some of the faithful had bought stock. But the engineers, as Becker says, though they believed in the product, "saw only the problems; we weren't sure the company knew what it was getting into. The thing wouldn't feed, the motors wouldn't work, the relays didn't relay, and anyway, we were only going to make 5,000 of them."

As everyone knows, the stock split and split and zoomed out of sight. A share of Haloid Xerox bought over the counter in 1959 for about $100 would be worth something like $3,150 today.

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Said Becker: "I didn't buy any, but my wife Gloria bought some on her own, without telling me. I'm very polite to her now."

Incidentally, the 914, named for the 9-by-14-inch paper it could take, ran somewhat better than pretty good. "There are still about 1,600 of them flailing away," Becker said. Of course, at seven copies a minute they are a mite slow compared with the 120 copies a minute the Xerox 9200 is capable of churning out; and the gray-scale reproduction has been improved since the 914, as well as paper-handling ability. Today, Xerox copies can be made for 2.5 cents a click. But the 914 is still around.

Paul A. Strassmann, a former Xerox vice president, is considered the philosopher of copying and has written a book about it. "One way of measuring the evolution of mankind," he said, "is through communication. Gutenberg was a watershed in western civilization. He made everybody a reader. Before, only priests and a few others had books. But it didn't come for free; printing was costly. Five hundred years after Gutenberg there were only 200,000 printers in the world.

"The significance of the late Chester Carlson is that he made everybody a printer. He brought printing to the masses, as Gutenberg brought reading. Suddenly you have 20 million printers in the world. This is an enormous democratization. Until recently, information was a privileged possession, but after Carlson -- and Wilson's principle of transaction pricing -- information becomes a commodity. Xerography makes information a commodity. Suddenly you can buy and sell information."

And the computer, he says, has taken the process one giant step further. In the next stage, Strassmann says, beyond Gutenberg and Carlson, everybody will be an author. The prospect is numbing.

GRAPHIC: Picture 1, The first Xerox 914, sold to a Boston firm in 1960; Picture 2, The Xerox 9200, which can make two copies a second.

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Big Sci/small sci ((drop a small store)):

And while we praise and admire the accomplishments of our great technical enterprises in Big Science let's not forget Small Science. Just As entrepeneurs and small businesses have fueled the growth of the American economy, it is the individual scientist who is not part of a big team -- the two physicists who, working by themselves, discovered low-temperature superconductivity in an IBM laboratory in Zurich; Fleming, the discoverer of penicillin; Chester Carlson, who invented the xerox machine ~~working~~ in a little room behind a beauty ~~salon~~ parlor; and others -- who have created many of the great advances in science that propel us to new achievements in economic progress and the betterment of the health and well being of men and women. ~~across~~ throughout the world

spread across the nation like a thousand points of enlightenment.

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Familiar Quotations

A collection of passages, phrases and proverbs traced to their sources in ancient and modern literature

by JOHN BARTLETT

Fourteenth Edition
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EMILY MORISON BECK, *Editor*

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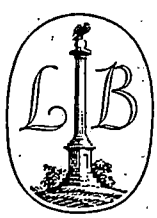

Little, Brown and Company · Boston · Toronto

Which well the reach of their high wits record.

Sonnets to Delia. Sonnet: I Must Not Grieve

These are the arks, the trophies, I erect,
That fortify thy name against old age.

Ib.

And for the few that only lend their ear,
That few is all the world.

Musophilus [1599], *st.* 97

This is the thing that I was born to do. *Ib. st.* 100

Unless above himself he can
Erect himself, how poor a thing is man!

To the Countess of Cumberland [*c.* 1600], *st.* 12

Love is a sickness full of woes,
All remedies refusing.

Hymen's Triumph [1615]

LOPE DE VEGA
1562–1632

Harmony is pure love, for love is complete agreement.

Fuente Ovejuna,[1] *act I, l.* 381

Except for God, the King's our only lord. *Ib.* 1701

MICHAEL DRAYTON
1563–1631

Fair stood the wind for France.

The Ballad of Agincourt [1606], *st.* 1

O, when shall Englishmen
With such acts fill a pen,
Or England breed again
Such a King Harry? *Ib.* 15

Since there's no help, come let us kiss and part —
Nay, I have done: you get no more of me,
And I am glad, yea glad with all my heart,
That thus so cleanly I myself can free.
Shake hands forever, cancel all our vows,
And when we meet at any time again,
Be it not seen in either of our brows
That we one jot of former love retain.
Now at the last gasp of love's latest breath,
When his pulse failing, Passion speechless lies,
When Faith is kneeling by his bed of death,
And Innocence is closing up his eyes,
Now if thou wouldst, when all have given him over,
From death to life thou might'st him yet recover.

Poems [1619]. *Idea*

The coast was clear.

Nymphidia [1627]

Had in him those brave translunary things
That the first poets had.

Said of MARLOWE. *To Henry Reynolds, Of Poets and Poesy* [1627]

For that fine madness still he did retain
Which rightly should possess a poet's brain. *Ib.*

GALILEO GALILEI
1564–1642

Philosophy is written in this grand book — I mean the universe — which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering about in a dark labyrinth.

Il Saggiatore [1623][1]

[1] Translated by ANGEL FORES and MURIEL KITTEL. From *Spanish Drama* [1962].

[1] *The Assayer* in *The Controversy on the Comets of 1618* [1960], translated by STILLMAN DRAKE and C. D. O'MALLEY.

PN6081
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WH

PETER'S QUOTATIONS

IDEAS FOR OUR TIME

By

LAURENCE J. PETER

WILLIAM MORROW AND COMPANY, INC.

NEW YORK 1977

To be ignorant of one's ignorance is the malady of the ignorant.
—A. B. Alcott (1799–1888)

Not ignorance, but ignorance of ignorance, is the death of knowledge. —Alfred North Whitehead

* *

Nothing is so firmly believed as that which is least known.
—Francis Jeffrey (1773–1850)

The more ignorant the authority, the more dogmatic it is. In the fields where no real knowledge is even possible, the authorities are the fiercest and most assured and punish non-belief with the severest of penalties. —Abraham Myerson

* *

Wise men learn more from fools than fools from wise men.
—Marcus Porcius Cato (234–149 B.C.)

I have never met a man so ignorant that I couldn't learn something from him. —Galileo Galilei (1564–1642)

It is impossible to defeat an ignorant man in argument.
—William G. McAdoo

Ignorance once dispelled is difficult to reestablish.
—Laurence J. Peter

* *

Your ignorance cramps my conversation. —Anthony Hope

Ignorance is no excuse—it's the real thing. —Irene Peter

IMMORTALITY

Immortality—a fate worse than death. —Edgar A. Shoaff

To desire immortality is to desire the eternal perpetuation of a great mistake. —Arthur Schopenhauer (1788–1860)

Our existence is but a brief crack of light between two eternities of darkness. —Vladimir Nabokov

The chief problem about death . . . is the fear that there may be no afterlife, a depressing thought, particularly for those who have bothered to shave . . . I do not believe in an afterlife, although I am bringing a change of underwear. —Woody Allen

I don't want to achieve immortality t
achieve it through not dying. —

Spring—an experience in immortality.
—Henry I

A man has only one way of being imm
forget he is mortal. —Jean Girau

As to posterity, I may ask what has it
—

Posterity is just around the corner.

We are made to be immortal, and yet
be taken seriously. —Eugène Io

You lose your immortality when you

When we are planning for posterity,
virtue is not hereditary. —Thom

Us, the most transient./Everyone onc
more. —Rainer Maria Rilke

Neither can I believe that the indivi
body, although feeble souls harbor s
ridiculous egotism. —Albert Ei

One of the proofs of the immortalit
have believed it—they also believed

Infinity converts that which is possib

Up, sluggard, and waste not life;
enough. —Benjamin Franklin

Suns may rise and set; we, when c
sleep on during one perpetual night.

*

When I die I shall be content to va
show, however good, could conceiva
not believe in immortality, and have

In all things that are purely social we can be as separate as the fingers, yet one as the hand in all things essential to mutual progress.
—Booker T. Washington

I am in favor of integration but not solely for the purpose of busing.
—Irene Peter

INTELLIGENCE / INTELLECTUALS

An intellectual is a man who takes more words than necessary to tell more than he knows. —Dwight D. Eisenhower

If an animal does something, we call it instinct; if we do the same thing for the same reason, we call it intelligence.
—Will Cuppy

We forgot to make ourselves intelligent when we made ourselves sovereign. —Will Durant

An "egghead" is a person who stands firmly on both feet in mid-air on both sides of an issue. —Senator Homer Ferguson

Eggheads, unite! You have nothing to lose but your yolks.
—Adlai Stevenson

It would take only one generation of forgetfulness to put us back intellectually several thousand years. —Dean Tollefson

If the Aborigine drafted an IQ test, all of Western civilization would presumably flunk it. —Stanley Garn (An intelligence test sometimes shows a man how smart he would have been not to have taken it.)

I do not feel obliged to believe that that same God who has endowed us with sense, reason, and intellect has intended us to forego their use. —Galileo Galilei (1564–1642)

Intellect . . . is the critical, creative, and contemplative side of mind . . . intelligence seeks to grasp, manipulate, re-order, adjust; intellect examines, ponders, wonders, theorizes, criticizes, imagines . . . —Richard Hofstadter

Intellect distinguishes between the possible and the impossible; reason distinguishes between the sensible and the senseless. Even the possible can be senseless. —Max Born

Recent discoveries in the physiology of the brain suggest that there may be two different kinds of intelligence—analytic, conceptual, verbal intelligence, located in the left hemisphere of the brain, and intuitive, artistic intelligence in the right hemisphere.
—*Newsweek* magazine

not the verses of Homer continued twenty-five hundred years or more, without the loss of a syllable or letter; during which time infinite palaces, temples, castles, cities have been decayed and demolished? —Francis Bacon (1561–1626)

I am defeated, and know it, if I meet any human being from whom I find myself unable to learn anything.

—George Herbert Palmer

If a little knowledge is dangerous, where is a man who has so much as to be out of danger?

—Thomas Henry Huxley (1825–1895)

A little learning is not a dangerous thing to one who does not mistake it for a great deal. —William Allen White

* *

It is surely harmful to souls to make it a heresy to believe what is proved. —Galileo Galilei (1564–1642)

By identifying the new learning with heresy, you make orthodoxy synonymous with ignorance.

—Desiderius Erasmus (1465–1536)

A little learning is a dangerous thing;/Drink deep, or taste not the Pierian spring. —Alexander Pope (1688–1744)

A little learning is a dangerous thing, but a lot of ignorance is just as bad. —Bob Edwards

* *

All that I know I learned after I was thirty.

—Georges Clemenceau

The second half of a man's life is made up of nothing but the habits he has acquired during the first half.

—Feodor Dostoevski (1821–1881)

LEISURE AND RETIREMENT

Increased means and increased leisure are the two civilizers of man.

—Benjamin Disraeli (1804–1881)

Liberty is being free from the things we don't like in order to be slaves of the things we do like. —Ernest Benn (The best intelligence test is what we do with our leisure.)

Who knows whether in retirement I s
infirmity of mundane minds, which is

A society that gives to one class all t
and to another all the burdens of w
spiritual sterility. —Lewis Mumfc

The thing that I should wish to obtain f
with security. —Bertrand Russell
is not wasted time.)

Some men are so selfish that they reac
for their own sinister pleasure, instead
conditions, as the good citizen does
playing bridge. —Jacques Barzun

It is seldom that an American retires
fortune in comfort . . . He works bec
and knows no other way. —Tho
the time when you never do all the thir
you'd have the time.)

Few women and fewer men have enou

The end of labor is to gain leisure.
(So that you can drink coffee on your

A perpetual holiday is a good working

Let me give a word of advice to you y
looking forward to retirement: Have n
it's like this. Have you ever been out f
closing part of the afternoon, and su
that the leaves have practically all gon
the day gone before you knew it—and
across the landscape? That's retireme

If we are dreamers who laud the self-ir
we really wish we could buckle down
work, however, we must anticipate th
lazy life we left behind. —Harve

Retired is being tired twice, I've thoug
Then tired of not. —Richard Ar

* *

Ref.
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WH

THE NEW INTERNATIONAL DICTIONARY OF QUOTATIONS

Selected by

Hugh Rawson

and

Margaret Miner

E. P. DUTTON

One religion is as true as another.
—Robert Burton, *Anatomy of Melancholy*

Wonder is the basis of worship.
—Thomas Carlyle, *Sartor Resartus*

Religion is by no means a proper subject of conversation in mixed company. —Earl of Chesterfield, letter to his godson, #112, undated

The all-male religions have produced no religious imagery. . . . The great religious art of the world is deeply involved with the female principle. —Sir Kenneth Clark, *Civilization*

In my religion, there would be no exclusive doctrine; all would be love, poetry, and doubt. —Cyril Connolly, *The Unquiet Grave*

Science without religion is lame; religion without science is blind.
—Albert Einstein, quoted in *The Reader's Digest*, Nov. 1973

I like the silent church before the service begins, better than any preaching. —Ralph Waldo Emerson, *Self-Reliance*

God builds his temple in the heart on the ruins of churches and religions. —Ralph Waldo Emerson, *Worship*

Religion is an illusion and it derives its strength from the fact that it falls in with our instinctual desires.
—Freud, *A Philosophy of Life* in *Lectures in Psychoanalysis*

The Bible shows the way to go to heaven, not the way the heavens go. —Galileo, fragment

All religions are ancient monuments to superstitions, ignorance, ferocity; and modern religions are only ancient follies rejuvenated.
—Baron d'Holbach, *Le bons sens . . .*

Writing for a penny a word is ridiculous. If a man really wants to make a million dollars, the best way would be to start his own religion. —L. Ronald Hubbard, the founder of Scientology, lecture 1949, quoted in *The New York Times*, July 11, 1984

It does me no injury for my r
Gods, or no God.

The church must be reminded
servant of the state, but rather the
—Martin L

Here I stand, I cannot do otherw
—Martin Lut

Religion is the sign of the oppr
heartless world, and the soul of s
of the people. —Karl Mar
of Right

What mean and cruel things me
—W. Somerset

We must respect the other fello
and to the extent that we respect h
and his children smart. —

Fear of death and fear of life bo

A nation must have a religion, ar
control of the government.
—Napoleon I
June 6, 1801

I want nothing to do with any
the masses satisfied to live in hunge
—Jawaharl
Journey to

Dogma has been the fundament
Religion, as mere sentiment, is to n
—Cardinal

Any system of religion that ha
mind of a child, cannot be a true s
—T

Men despise religion; they hate i

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THE HOME BOOK OF QUOTATIONS

Classical and Modern

SELECTED AND ARRANGED BY

BURTON STEVENSON
Editor *The Home Book of Verse*

I can tell thee where that saying was born
SHAKESPEARE, *Twelfth Night*
Act i, sc. 5, l. 9

TENTH EDITION

DODD, MEAD & COMPANY
NEW YORK

1
Without, or with, offence to friends or foes,
I sketch your world exactly as it goes.
BYRON, *Don Juan*. Canto viii, st. 89.

2
I value not the world a button.
SUSANNAH CENTLIVRE, *The Wonder*. Act i, sc. 1.

3
A world where nothing is had for nothing.
ARTHUR HUGH CLOUGH, *The Bothie of Tober-na-Vuolich*. Sec. 8, l. 5.

4
The world, like an accomplished hostess, pays most attention to those whom it will soonest forget.
CHURTON COLLINS, *Aphorisms*.

5
Such stuff the world is made of.
COWPER, *Hope*, l. 211.

'Tis pleasant through the loop-holes of retreat
To peep at such a world; to see the stir
Of the great Babel, and not feel the crowd.
COWPER, *The Task*. Bk. iv, l. 88.

6
And for the few that only lend their ear,
That few is all the world.
SAMUEL DANIEL, *Musophilus*. St. 97.

There was all the world and his wife.
SWIFT, *Polite Conversation*. Dial. iii. (1738)

How he welcomes at once all the world and his wife,
And how civil to folk he ne'er saw in his life!
CHRIS. ANSTEY, *New Bath Guide*, 130. (1766)

7
Come, follow me, and leave the world to its babblings. (Vien retro a me, e lascia dir le genti.)
DANTE, *Purgatorio*. Canto v, l. 13.

8
Behold the world, how it is whirlèd round,
And for it is so whirl'd is named so.
SIR JOHN DAVIES, *Orchestra*. St. 34.

9
What a world of gammon and spinnage it is, though, ain't it?
DICKENS, *David Copperfield*. Ch. 22.

10
I am a citizen of the world.
DIOGENES. (DIOGENES LAERTIUS, *Socrates*. Bk. vi, sec. 63.) *See under* COSMOPOLITANISM.

11
We must see that the world is rough and surly.
EMERSON, *Conduct of Life: Fate*.

The world is always equal to itself.
EMERSON, *Social Aims: Progress of Culture*.

12
The world is too narrow for two fools a quarrelling.
THOMAS FULLER, *Gnomologia*. No. 4844.

This world surely is wide enough to hold both thee and me.
LAURENCE STERNE, *Tristram Shandy*. Bk. ii, ch. 12

I have my beauty,—you your Art—
Nay, do not start:

13
It moves, nevertheless! (E pur si muove!)
GALILEO. A phrase which he is said to have whispered to a friend as he rose from signing his recantation of his theory that "the sun is the centre of the universe, and immovable, and that the earth moves." (1615) Von Gebler (*Galileo Galilei and the Roman Curia*) doubts that he ever uttered them.

Does the world go round?
SHAKESPEARE, *Cymbeline*. Act v, sc. 5, l. 232.

Roll on, thou ball, roll on
Through pathless realms of space,
Roll on! [It rolls on.]
W. S. GILBERT, *To the Terrestrial Globe*.

Gyrate, old Top, and let who will be clever;
The mess we 're in is much too deep to solve.
Me for a quiet li e while you, as ever,
Continue to revolve.
BERT LESTON TAYLOR, *To a Well-Known Globe*.

Long and long has the grass been growing,
Long and long has the rain been falling,
Long has the globe been rolling round.
WALT WHITMAN, *Song of the Exposition*. Pt. i.

14
Creation's heir, the world, the world is mine!
GOLDSMITH, *The Traveller*, l. 50.

15
If the world were good for nothing else, it is a fine subject for speculation.
WILLIAM HAZLITT, *Characteristics*. No. 302.

To understand the world, and to like it, are two things not easily to be reconciled.
LORD HALIFAX, *Works*, p. 230.

16
The world runneth on wheels.
JOHN HEYWOOD, *Proverbs*. Pt. ii, ch. 7. (1546)

They were wont to say, the world doth run on wheels.
BARNABE RICH, *Honestie of This Age*, p. 30. (1614)

17
The world belongs to those who think and act with it, who keep a finger on its pulse.
DEAN W. R. INGE. (MARCHANT, *Wit and Wisdom of Dean Inge*. No. 171.)

18
World without end.
Old Testament: Isaiah, xlv, 17.

19
It takes all sorts of people to make a world.
DOUGLAS JERROLD, *Story of a Feather*. Ch. 28. (1844)

In the world there must be of all sorts.
JOHN SKELTON, *Quixote*. Pt. ii, ch. 6. (1620)

The world has people of all sorts.
JOHN LOCKE. Quoted by Samuel Johnson. (BOSWELL, *Life*, 17 Nov., 1767.)

20
This world, where much is to be done and little to be known.
SAMUEL JOHNSON, *Prayers and Meditations: Against Inquisitive and Perplexing Thoughts*.

21