STARDRIVES AND SPINOZA

By: LOUIS CRANE, KSU MATH DEPARTMENT, FQXi GRANT BG0522,

I. PHYSICS AND LIMITS

There are several senses in which one may speak of limits in relation to Physics.

For the purposes of this essay, it is most useful to begin with the technological limitations of practical human activity. In this context, Physics both provides positive and negative information. Physical laws tell us how to achieve some goals, and informs us that others are forever out of reach.

An excellent historical example is the science of thermodynamics. On the one hand, it tells us how to construct heat engines, on the other, it provides us with the Carnotic limit on efficiency, and rules out perpetual motion machines of both kinds.

So Physics both extends our limits and helps us to understand them. Despite the annoying tendency of popular authors to tell us that anything is possible, the laws of Physics act as negative limits, and this is one of the great services of science to humanity.

One may also ask about the limits of our knowledge, i.e. of physical theory. Is it almost finished, as Feynman insisted, does it end in a non-predictive theory, as we sometimes hear from string theorists, or is there a final theory yet to be discovered?

Finally, we can discuss the limits of Science in relationship to other intellectual disciplines, such as Philosophy and Theology.

In this essay, we shall present possible end results of Physics in the different senses we discussed above: our practical possibilities, our understanding of nature, and the role of Physics in our intellectual and (for want of a better phrase) spiritual life; and show that they are closely interwoven.

We shall outline this network of ideas here, then discuss them in detail in the rest of the essay.

We begin by discussing a family of potential practical applications of Theoretical Physics, namely the creation of artificial black holes (ABH's), and their use as powerplants and stardrives [1]. This is suggested by classical general relativity and quantum field theory, but in order to see if it is truly possible, we will need a quantum theory of gravity, and moreover, one which can be put in a certain form, as we shall discuss below.

Black holes, according to Hawking, are not really black. They radiate a thermal bath because of quantum field effects on the boundary [2]. For astronomical black holes the power is minuscule, but for microscopic ones it can be enormous. We have investigated whether there is a size range which is both useful and possible to produce, and found that the answer is a qualified yes.

This proposal is extremely difficult technically. However, it seems that it is actually the least difficult possible approach to transporting human beings to the stars. Of the other suggestions, some are vastly larger and more difficult, others seem to be excluded by physical laws much like perpetual motion machines.

The ABH proposal seems just at the edge of possibility. There are physical effects we have not carefully considered yet which seem likely to make it less difficult.

An ABH embedded in a power plant and transported to a near earth orbit could provide a permanent solution to our energy problems, provided ABH's can be fed efficiently. Even if it took a few centuries to implement the ABH proposal it would be highly desirable for this reason, as stocks of coal and uranium will run out sooner or later. An ABH is the ultimate renewable energy source.

Because of the importance of quantum corrections, this potential application of Physics, which would extend the range of human activity to interstellar space, is connected to discovering a new level of physical theory, which very likely will be the final one.

So the last key opens the last door.

The creation of ABH's would also be the ultimate physical experiment, in that careful examination of the Hawking radiation as the ABH evaporated and heated, would reveal to us all the fundamental particles and forces all the way to the Planck scale. Thus it would allow us to reach the limit of knowledge of matter.

Lastly, we shall discuss issues of the role of intelligence in the universe, and the question of ultimate purpose as applied to humanity at large. These questions have generally been regarded as beyond the sphere of science; belonging either to Philosophy and Theology, or to the category of pseudoquestions, better not pursued at all.

We shall argue that the human production of ABH's, opens the possibility of an approach to these questions from Physics itself, what we have referred to elsewhere as the meduso-anthropic principle [3]. Thus, in reaching its terminus, Physics will transcend its current bounds in the sphere of human thought.

The matters under discussion here are extrapolations beyond the bounds of what is currently known. They can only have the status of a plausible forecast whose substantiation or refutation will take a long time.

II. THE PATH TO THE STARS? ON THE FEASIBILITY OF ARTIFICIAL BLACK HOLE APPLICATIONS

In this section we want to discuss whether the Physics of black holes, together with the laws of Physics of matter as we know them, make it possible to produce artificial BHs which would be useful, either as power plants or as starships.

Since the mass of a black hole decreases with its radius, while its energy output increases and its life expectancy decreases (see [2]), this is a delicate question.

List of criteria: *We need a black hole which*

1. has a long enough lifespan to be useful, *2. is powerful enough to accelerate itself up to a reasonable fraction of the speed of light in a reasonable amount of time,*

3. is small enough that we can access the energy to make it,

4. is large enough that we can focus the energy to make it,

5. has mass comparable to a starship,or is smaller but can be fed very efficiently.

We could easily imagine that this would be impossible. Somewhat surprisingly, it turns out that there is a range of BH radii, which according to the semiclassical approximation, fit these criteria.

Using the formulae discussed in [1] or [2], we find that a black hole with a radius of a few attometers at least roughly meets the list of criteria. Such BHs would have mass of the order of 1,000,000 tonnes, and lifetimes ranging from decades to centuries. A high-efficiency square solar panel a few hundred km on each side, in a circular orbit about the sun at a distance of 1,000,000 km, would absorb enough energy in a year to produce one such BH.

A BH with a life span on the order of a century would emit enough energy to accelerate itself to relativistic velocity in a period of decades. If we could let it get smaller and hotter before feeding matter into it, we could get a better performance.

In Section III below, we discuss the plausibility of creating ABHs with a very large spherically converging gamma ray laser. A radius of 1 attometer corresponds to the wavelength of a gamma ray with an energy of about 1.24 TeV. Since the wavelength of the Hawking radiation is $8\pi^2$ times the radius of the BH, the Hawking temperature of a BH with this radius is on the order of 16 GeV, within the limit of what we could hope to achieve in a nuclear laser.

Now the idea that the wavelength of the radiation should match the radius of the BH created is very likely pessimistic. The collapsing sphere of radiation would gain energy from its self-gravitation as it converged, and there is likely to be a gravitational self-focussing.

Thus it seems that making an artificial black hole and using it to drive a starship is just possible, because the family of BH solutions has a "sweet spot." This has not been remarked before in the literature, except for the earlier work of the author [3].

We cannot fully trust this result, in that we do not know how to take corrections from quantum gravity into account.

III. FOUR MACHINES

Now we discuss how our proposal could be implemented technically. The devices we propose are far beyond current technology, but we do not see why they would be impossible if an advanced future industrial society were determined to make them.

A. The black hole generator

In a previous paper by the author [3], it was proposed that an ABH could be artificially created by firing a huge number of gamma rays from a spherically converging laser. The idea is to pack so much energy into such a small space that a BH will form. An advantage of using photons is that, since they are bosons, there is no Pauli exclusion principle to worry about. Although a laser-powered black hole generator presents huge engineering challenges, the concept is physically sound according to classical general relativity. The Vaidya-Papapetrou metric shows that an imploding spherically symmetric shell of "null dust" can form a black hole (see, e.g., [2], p. 187, or Joshi [4] for further details).

Since photons have null stress energy just like null dust, a black hole should form if a large aggregate of photons interacts classically with the gravitational field. As long as we are discussing regions of spacetime that are many orders of magnitude larger than the Planck length, we should be outside of the regime of quantum gravity and classical theory should be appropriate.

Since a nuclear laser can convert on the order of 10^{-3} of its rest mass to radiation, we would need a lasing mass of order 10^9 tonnes to produce the pulse. This should correspond to a mass of order 10^{10} tonnes for the whole structure (the size of a small asteroid). Such a structure would be assembled in space near the sun by an army of robots and built out of space-based materials. It is not enormously larger than some structures human beings have already built. The precision required to focus the collapsing electromagnetic wave would be of an order already possible using interferometric methods, but on a truly massive scale.

This is clearly extremely ambitious, but we do not see why it should be impossible. Given the enormous advantages it could bring to humanity, it should be approached as optimistically as the facts permit.

B. The drive

Now we would like to discuss how to use an ABH to drive a starship. We need to accomplish 3 things.

Design requirements for a BH starship

1. *use the Hawking radiation to drive the vessel*

2. *drive the BH at the same acceleration*

3. *feed the BH to maintain its temperature*

Item 3 is not absolutely necessary. We could manufacture an ABH, use it to drive a ship one way, and release the remnant at the destination. However this would limit us greatly as to performance, and be very disappointing in the powerplant application discussed below.

We shall discuss these three problems in outline only here; at the level of engineering they will require years of study.

It is not hard to see how to approach requirement 1. We position the ABH at the focus of a parabolic reflector attached to the body of the ship. Since the ABH will radiate gamma rays and a mix of particles and antiparticles, it is not clear how to construct the reflector. It has already been proposed to make a gamma ray reflector out of an electron gas in the closely related case of an antimatter rocket [5].

It is not clear if this is feasible (e.g., [6]).

A more detailed discussion of the drive design appears in [1].

The most optimistic approach is to solve requirements 2 and 3 together by attaching particle beams to the body of the ship behind the ABH and beaming in matter. This would both accelerate the ABH, since BHs "move when you push them"(see [2] p270), and add mass to the ABH, extending its lifetime.

The delicate thing here is the absorption cross section for a particle going into a BH. If simply aiming the beam at the ABH doesn't work, we can try forming an accretion disk near the ABH and rely on particles to tunnel into it. Alternatively, we could use a small cluster of ABHs instead of just one to create a larger effective target, charge the ABH etc. It is also possible that because of quantum effects ABHs have larger than classical radii, due to the analog of zero point energy.

There are some physical considerations which we are still investigating, which make us optimistic on this point. Nevertheless it must remain as a challenge for the future.

C. The powerplant

This has already been proposed by Hawking (see [8] pp. 108 - 109). We simply surround the ABH with a spherical shield, and use it to drive heat engines. (Or possibly use gamma ray solar cells, if such things be.) This would have an enormous advantage over solar electric power in that the energy would be dense and hence cheaper to accumulate.

The 3 machines here really form a tool set. Without the drive, getting the powerplant near Earth where we need it would be very difficult. Without the generator, it would require the good fortune to find a primordial ABH to implement the proposal.

D. The self-driven generator

The industry formed by our first 3 machines would not yet be really mature. To fully tap the possibilities we would need a fourth machine, a generator coupled to a family of ABHs which could be used to charge its laser. Assuming we can feed a ABH as discussed above, we would then have a perpetual source of ABHs, which could run indefinitely on water or dust or whatever matter was most convenient.

A civilization equipped with our four machine tool set would be almost unimaginably energy rich. It could settle the galaxy at will.

IV.THE ONLY PATH?

The technical program we have outlined is extremely difficult. Why even consider it? Because the goal of interstellar flight is so profoundly important to our future, and because the alternatives are either much more difficult and much larger, or actually impossible barring a major surprise in Physics.

Also, a long term solution to our energy problems is not yet clearly at hand. ABH technology would provide us with energy resources beyond even fusion power, and not use anything except waste matter.

A. Shielding

The dreams of manned spaceflight of the fifties and sixties have largely gone unrealized. This is to an important degree because it has been discovered that cosmic radiation has much more serious medical consequences than was originally believed [9].

Substantial human presence in space has only occurred in low Earth orbit near the equator, where the earth's magnetic field shields us from the cosmic radiation.

Our visits to the moon were brief, and it is known that a prolonged human presence there would have to be underground, necessitating the transport of massive "earth" moving equipment [9].

It is now known that any prolonged human presence deeper in space would need to be behind a shield of the effective strength of two feet of lead, which would weigh 400 tonnes for a small capsule [9].

It therefore becomes more economical to think of a larger vessel, weighing many thousands of tonnes, in which a group of people could live indefinitely. This possibility has not been very widely explored, particularly not in a practical direction, because of the enormous energies involved in accelerating such a body.

B. Specific impulse

The distances between the stars are so great that practical travel between them would require us to reach speeds comparable to the speed of light. This is extremely difficult to do because very few processes known to us release energies comparable to the masses of the matter involved. Nuclear reactions, for example, release only a fraction of a percent of the rest masses of the nucleii, so that an interstellar vehicle powered by fission or fusion would have to carry many thousands of times the mass of its payload in fuel.

Coupled with the shielding problem discussed in Section A above, this means an interstellar voyage using nuclear energy would deplete the Earth's resources of fissile or fusile materials to an intolerable degree.

Other than black hole radiation the only process we know of which is sufficiently energetic for interstellar flight is matter-antimatter annihilation. This has been proposed, but there are two severe obstacles.

The first is that the efficiency of antimatter production in current accelerators is well below 10^{-7} (very few collisions produce a trappable antiparticle) [6]. Thus, making enough antimatter to propel a starship would use up ten million times as much energy as our proposal. The most optimistic projections of antimatter enthusiasts do not produce an efficiency above 10^{-4}, so that at best our proposal is still ten thousand times more efficient.

The second obstacle is containment. A microscopic particle of ordinary matter which drifted into the antimatter would cause an explosion, scattering the antimatter into contact with the ship, and destroying everything for millions of miles around. Any electromagnetic force which held the antimatter in would also drive normal matter in. One hears the suggestion that this could be solved by "magnetic bottles," but magnetism is a force which acts perpendicularly to the motion of a charged particle, and therefore does not in any simple way form a bottle. Experiments in the magnetic confinement of plasma for millisecond intervals have been very frustrating.

Paramagnetic forces can repel matter, but they are extremely weak, and treat matter and antimatter identically. So they would force normal matter in as much as antimatter.

For these reasons an antimatter starship seems out of reach given Physics as we know it. We could imagine surprises in future Physics which would change this picture, but they seem remote. Dark matter, for example, interacts neither with normal matter nor antimatter.

Let us briefly contrast the idea of using antimatter with the ABH proposal. It is currently possible to produce antimatter in extremely small quantities, while a synthetic black hole would necessarily be very massive. On the other hand, the process of generating an ABH from collapse is naturally efficient, so it would require millions of times less energy than a comparable amount of antimatter or at least tens of thousands of times given some optimistic future antimatter generator.

As to confinement, a BH confines itself. We would need to avoid colliding with it or losing it, but it won't explode. Matter striking a BH would fall into it and add to its mass. So making a BH is extremely difficult, but it would not be as dangerous or hard to handle as a massive quantity of antimatter.

Although the process of generating an ABH is extremely massive, it does not require any new Physics. Also, if an ABH, once created, absorbs new matter, it will radiate it, thus acting as a new energy source; while antimatter can only act as a storage mechanism for energy which has been collected elsewhere and converted at extremely low efficiency.

None of the other ideas suggested for interstellar flight seem viable either. The proposal for an interstellar ramjet turns out to produce more drag than thrust [10], while the idea of propelling a ship with a laser beam runs into the problem that the beam spreads too fast.

At this point, we do not even have a viable method for sending very small probes to other stars. Sending human beings is much harder, but in some sense it is what we really want, being what we are.

C. Wormholes and Warpdrives

The mere fact that wormholes or warpdrives are discussed in the context of interstellar flight shows how difficult a goal it is, and how strongly we desire it.

Both suggestions are forbidden by the positive energy condition. It is true that it is possible to produce negative energy densities between the plates of a capacitor via the Casimir effect, but they are extremely small, and could never remotely equal the masses of the plates. Starting from positive energy matter, which is all we have ever seen, there is no method anyone knows to produce the enormous negative energy densities a warp drive or wormhole would require.

It is by far the most probable case that they are simply impossible.

V. CHALLENGES TO QUANTUM GRAVITY IN THE ABH PROPOSAL

If a theory of quantum gravity is to allow us to find the necessary corrections to see if the ABH proposal is feasible, it must allow us to describe quantum effects in a small highly energetic region whose surroundings can be treated classically and well approximated by flat spacetime. A quantum theory of the whole universe would need profound reinterpretation to be used for this purpose.

This suggests a version of quantum gravity which is defined relative to an observer, which is treated as classical. It is widely believed that the information which can pass from a bounded region of spacetime to an external observer is finite, limited by the Bekenstein bound [11]. Creation of a theory of quantum gravity which includes the Bekenstein bound in its structure is therefore strongly suggested by the ABH proposal [12].

A quantum theory of gravity would also have to describe the relationship between spacetime and matter, in order to improve on the semiclassical picture which led us to the prediction of Hawking radiation. Since Hawking radiation is generated from transplanckian modes near the horizon of the BH which are then redshifted, it is highly unlikely that the semiclassical calculations would be accurate enough for the starship designers of the future.

Such a theory would have to be a unified field theory, if it were to fully describe the interactions of quantum gravity with all forms of matter. In all likelihood, it would be a final theory.

VI. THE MEDUSO-ANTHROPIC PRINCIPLE

The origin of the ABH proposal is very peculiar. The author was reviewing the work of Lee Smolin, which was later published in a book entitled *The Life of the Cosmos* [13]. Professor Smolin proposed that the universe we see was only one of many universes, and that new universes arise from old ones whenever a black hole is produced. This then leads to an evolutionary process for universes in which universes with an unusually high number of stars are selected for.

The author proposed that the evolutionary process of universes should include life. This is possible if successful industrial civilizations eventually produce black holes, and therefore baby universes.

Note that if successful industrial civilizations only trapped already existing BHs, it would not alter the number of baby universes a universe produced, so that no evolutionary loop would result.

This led us to consider the possibility of producing ABHs, and to explore how they might be useful.

The meduso-anthropic principle (as this proposal was named) is at least falsifiable, in the sense that if ABHs prove to be completely impossible or useless then the evolutionary cycle universes-civilizations-black holes -baby universes could never happen.

The result of our feasibility calculation is much too tenuous to be considered evidence for the meduso-anthropic principle. It is not in fact certain that black holes create baby universes, although the maximal analytic continuations of the standard BH solutions to Einstein's equation suggest that they do.

Nevertheless, only through this line of thought did we consider the possibility of synthetic BH creation. We are the first and almost the only author to our knowledge to consider this. The only other author we are aware of is Semiz [7], who wrote: "...we would have to either find small black holes, possibly primordial, or manufacture them by means as yet unknown," in a rather popular discussion on BH powerplants and stardrives, which appeared after our first paper.

VII. THE ROLE OF SCIENCE IN HUMAN LIFE. SCIENCE AND RELIGION

The construction of ABH technology would be preceded by a long period in which space based industries were constructed and expanded. Armies of sophisticated automatic machines would be assembled, sources of raw materials hunted for, and laser technologies advanced.

A society that decided to build the laser and other machinery to implement the ABH proposal would have to allocate resources comparable to building the pyramids over a timescale comparable to building the cathedrals. The work would have its fruition only long after the initial builders' lifespans were over.

If the meduso-anthropic hypothesis turns out to be valid, the builders would understand their work as part of the eternal recreation of the universe, having purpose in the sense that the organs of animals develop purpose as the result of an evolutionary process. Their entire lives would have a higher purpose in that they result in the creation of new universes and new life, as well as spreading their descendants throughout the universe. It would also imply that our own universe is fine tuned because it is the result of the activity of earlier intelligence.

It is impossible to consider these things and not be reminded of religious ideas. Spinoza's pantheistic idea of God as identical to the creative power of the universe would take on a much richer interpretation in such a future. Christian ideas about the unity of God and man, and Buddhist or Hindu ideas about the eternal return could find a home within Science in such a future; although in a very new sense.

So possibly the quantum theory of gravity will give us the tools to reach the stars, solve our energy problem forever, teach us we really have purpose in the cosmos, and compel us to organize ourselves around a common purpose which extends beyond ourselves. Our limits in space and time will be expanded as the structure of our social consciousness transforms and unifies itself. Religion will fuse into Science.

Many observers have felt that Western civilisation is experiencing a time of aimlessness and confusion as its traditional spiritual ideas fall into apparently hopeless contradiction with the discoveries of modern Science. Deep social and emotional needs seem irreconcilable with hard, undeniable facts.

We have outlined a plausible future where a central project for the whole world gives us an almost infinite extension of our range as a result of an immense collective effort. Depending on subtle points of interpretation of general relativity, this could come with a new understanding of our place in the universe, in which we play a role in its cycle of creation.

Will this mean that the time of alienation and aimlessness will end, if we simply have the courage to persevere? Will we find a different sense of meaning and belonging in the vast group effort to settle the universe, recreating the multiiverse itself in the effort?

We do not really know. I can say that for myself no other focus than research into quantum gravity is thinkable any more.

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References

[1] L. Crane and S. Westmoreland “are Black Hole Starships Possible?” gr-qc preprint 0908.1803

[2] V. P. Frolov and I. D. Novikov, *Black Hole Physics: Basic Concepts and New Developments*, Kluwer, Dordrecht, (1998).

[3] L. Crane, “Possible implications of the quantum theory of gravity,” arXiv:hep-th/9402104, to appear in Foundations of Science.

[4] P. S. Joshi, “Gravitational Collapse,” arXiv:gr-qc/9702036, also appears in *Singularities, Black Holes and Cosmic Censorship*, (On the fortieth anniversary of the Raychaudhuri Equation), IUCAA publication, Pune, India, (1996).

[5] E. Sanger, “Photon Propulsion” Chapter 21.4 in Handbook of Astronautical Engineering, First Edition H. H. Koelle (ed) McGraw Hill, New York (1961).

[6] R. Forward, “Antiproton Annihilation Propulsion,” Journal of Propulsion and Power, Vol. 1, No. 5, pp. 370 - 374, (1985).

[7] İ. Semiz, “Black hole as the ultimate energy source,” American Journal of Physics, Vol. 63, No. 2, pp. 151 - 156, (February 1995).

[8] S. W. Hawking, *A Brief History of Time*, Bantam Books, New York, (1988).

[9] E. N. Parker, “Shielding Space Travelers,” Scientific American, (March 2006).

[10] ”The Interstellar Conundrum” A Survey of Concepts and Proposed Solutions” PAUL A. GILSTER, Annals of the New York Academy of Sciences, Volume 1065, Issue New Trends in Astrodynamics and Applications (pp. 462-470)

[11] J. Bekenstein, Holographic Bound from the Second Law of Thermodynamics Phys. Lett. B 481 (2000) p334-345.

[12] L. Crane Model Categories and Quantum Gravity gr-qc preprint 0810.4492

[13] L. Smolin, *The Life of the Cosmos*, Oxford University Press, New York, (1997).