Provisional Rough Draft, March 17, 2009

Hypothetical Dark Matter/Axion rockets: Dark Matter in terms of space physics propulsion

Andrew Beckwith
GravWave®LLC
abeckwith@uh.edu

Keywords: Dark Matter, Photon Rocket, Axions
PACS: 07.87.+v, 95.85.Ry, 95.35.+d

Abstract: Current proposed photon rocket designs include the Nuclear Photonic Rocket and the Antimatter Photonic Rocket (proposed by Eugen Sanger in the 1950s, as reported by Gulevich et al., 2001). In a Nuclear Photonic Rocket, a nuclear fission reactor is used to directly heat tungsten coils or graphite blocks to white heat at the focus of a parabolic reflector. Using a laser to produce the light beam would provide much better collimation, but this is offset by the reduction in efficiency incurred by powering with a laser rather than black-body radiation (a nuclear fission reactor will generally output at least 5 to 10 times more energy as heat than electricity). Then there is the issue of fuel. It would take at least the current energy output of the entire world (1.73×10^{16} watt-hours per year as of 2005, according to the EIA/U.S. Dept. of Energy, 2008) to send a probe to the nearest star. According to Brice N. Cassenti, as quoted by Frisbee (2009), a ramjet would allow for very-high-energy expenditures while avoiding the absurdity of carrying x GW (as of 2008) on board a space craft. Instead, it makes sense to use a ramjet to avoid carrying huge amounts of on-board fuel. So more conversion of matter to energy (via DM candidates, for example) is needed to achieve realistic interstellar travel. To make the prospect of interstellar travel practical, this paper examines the feasibility of improving the thrust of photon-driven ramjet propulsion by using DM rocket propulsion. DM would first be converted to low-mass axions, which would then be converted to photons, hypothetically allowing for greater power and thrust than with currently proposed photon sources. In saying this above, the reader should be aware that axions are a DM candidate, but with insufficient mass to upgrade interstellar propulsion. WIMPs are suggested as a starting point because of their neutral character, as well as their high mass values. The open question the readers and the author need to consider is: would a relatively heavy WIMP, if eventually converted to photons, considerably upgrade the power and thrust of a photon rocket drive, to make interstellar travel a reasonable proposition? Proper analysis of relic conditions, in which both gravitons and DM are to be created could be aided by judicious use of the Li-Baker detector (Li et al., 2008 and Baker et al., 2008).

Which DM candidates are viable?

Taoso, Bertone and Masiero (2008) provide a ten-point test a new particle has to pass to be considered a viable DM candidate: "(I) Does it match the appropriate relic density? (II) Is it cold? (III) Is it neutral? (IV) Is it consistent with BBN? (V) Does it leave stellar evolution unchanged? (VI) Is it compatible with constraints on self-interactions? (VII) Is it consistent with direct DM searches? (VIII) Is it compatible with gamma-ray constraints? (IX) Is it compatible with other astrophysical bounds? (X) Can it be probed experimentally?" It so happens that WIMPs meet all the above tests. Muramaya (2006) gave a mass value of between 100—300 GeV for WIMPs. Furthermore, DM, such as WIMPs, are not thought to be charged particles, so they do not emit electromagnetic radiation at any frequency and thus appear dark. A second theory involving undetected particles is that some dark matter is made of hypothetical subatomic particles called "axions." Axions are many times lighter than electrons and have no electric charge. One of the main differences between WIMPs and axions is their mass. Thus, the difference between the two theories (WIMPs or axions) is that dark matter is either made of a large number of light particles (axions) or a smaller number of heavier particles. A way to link the two states of DM is to note, first of all, that if, as Weinberg (2008) notes, axions were the whole of DM, that there would be $m_{axion} \approx 10^{-5} eV$ for a total DM mass

$M \approx 10^{12}\, GeV$. But if there were WIMPs and axions together, $m_{axion} \approx 10^{-5}\, eV\big|_{no-WIMPS} >> m_a\big|_{WIMPS-exist}$. For most theoreticians, Neutralinos are the preferred SUSY particle of choice for DM. However, in what has startling implications, Meissner and Nicholai (2008) and Beckwith (2008) using Mesissner and Nicholai's parameter space arguments as well as a replay of Muramaya's reference to Boltzmann equation calculations obtained WIMP DM masses of between 300 GeV to 400 GeV as an upper range to WIMP masses. What needs to be obtained, possibly using Dan Hooper and Edward Baltz's (2008) expression for WIMP density from thermal relics of the early universe, and comparing that with models of axion density to fathom a possible interrelationship between axions and WIMPs as far as DM. The preferred method would likely be to use Bayesian methods for comparing the relative fit between WIMP and axion models, i.e., effective Lagrangian methods as explored by Feroz et al. (2008). This is a venue of research actively being investigated by the present author. Axions have been considered as a power source to be scooped up in space because of their estimated thick density in space, and DM candidates for masses considerably above the axion values have been brought up as a way to increase thrust / power for more efficient propulsion. Frisbee (2009) in the AIAA book writes that a typical Daedalus's star ship designed for six light years of travel would require 1.7 million metric tons of fuel, which is unrealistic, and Frisbee states that the photon rocket has a travel time of 42 million years to accelerate to one tenth the speed of light due to acceleration based upon $2 \cdot (1.68 Watt)/(1.5 kg)/c = 2.2 \times 10^{-8}\, m/(\sec)^2$.

Limits to measurement (detection?) of axions

The author claims that in analogy with gravitational waves, low-mass axions are hard to measure. One could use the minimum uncertainty principle of $\Delta E \Delta t \geq \eta$ with $\Delta E \equiv \eta \Delta\omega \Rightarrow \Delta\omega \Delta t \geq 1$ and $(\Delta p)^2 \equiv (m_{axion}/\eta)\Delta\omega$ and $(\Delta p)^2 (\Delta l)^2 \equiv (m_{axion}/\eta)\Delta\omega (\Delta l)^2 \geq \eta^2 \Rightarrow (\Delta l) \geq \sqrt{(\eta^3 / m_{axion}\Delta\omega)}$. In the minimum uncertainty relationship, this is an equality, so that $(\Delta l) \approx \sqrt{(\eta^3 / m_{axion}\Delta\omega)}$. If $\omega \propto f \equiv$ frequency, do we have a linkage with holographic noise? The author claims this is the case. Here is why. In analogy with Laser interferometer measurements of gravitational waves (such as with LIGO), Hogan writes, and the author applies an amplitude variation, *h*, so that if *L* is the length of a 'measurement' device, a variant of holographic noise takes over as far as imprecision as to make reliable axion measurements. As seen in Hogan (2007), at low frequencies, the detected spectrum is independent of frequency *f*

$$h_{\text{rms,det}} \approx h_{H,rms} \approx (l_P/\text{L})^{1/2} L^{1/2}, \quad (f > L^{-1}). \qquad (1)$$

A different situation exists for higher frequencies, and here lies the problem

$$h_{\text{rms,det}} \approx h_{H,rms} \approx (l_P/\text{L})^{1/2} f^{-1/2}, \quad (f < L^{-1}). \qquad (2)$$

The reader should be aware that the author does not claim a 1-1 correspondence with LIGO arm measurements, which is what Hogan's argument was designed for. But even for axion measurements, the above amplitude measurements originally set for GW, implies an imprecision, i.e., a fuzziness with respect to low mass measurements which still carries over to axions. Current axion measurements have yet to confirm their existence, and the above quasi uncertainty argument is to show why precise measurements of axions are so hard to obtain.

If the following mass range is correct, i.e., 10^{-6} eV ≤ G ≤ m(axion) ≤ 10^{-2} eV. Then if Duffy, Sikivie et al. (2006) use the energy value (assuming that the energy of the axion is converted to photonic energy, and that *V* is the speed of an axion traveling in space)

$$E \sim 10^{-4}\text{ eV} \sim E_{axion} = m_{axion} C^2 + (1/2) m_{axion} v^2 = \hbar\omega, \qquad (3)$$

One gets for a low axion mass of 10^{-6} eV, and a low total axion energy E ~ 10^{-4} eV a requirements for a low frequency associated with the axion implying a correspondingly enormous *L* value for a workable detector. I.e., reliable measurements of the axion, and even transferring it to a 'chamber' for eventual photonic conversion to a rocket engine will be a huge challenge. And if frequency dependence is worked in, according to Eq. (2) the resulting axion dark matter so measured will be very unstable in a data sense to measure. Having said that, what can be modeled with respect to axion/DM ramjets?

First Principles of an Axion/DM Ramjet

According to Collar, Miller et al. (2006) in discussions of the applications of their description of the CAST experiment, axions can be changed by the Primakoff effect into photons, which could theoretically be used as a source of thrust (Collar, Miller et al., 2006, and Bernabei, Belli et al., 2001). The power density available from axions depends on their mass, the density of axions in space, and the velocity of the vehicle. At 10^{-5} eV, with a velocity of .001c, assuming 200,000 per cc axions in intergalactic space (an axion has a mass of about 1/400,000,000th of the mass of an electron, so there should be 200,000 per cc in intergalactic space, according to Lakic, 2008).

$$\text{Power} = 3\text{watts}/\text{cm}^2 \times [v/c] / \left(1 - [v/c]^2\right) \qquad (4)$$

The author used a velocity of .001c, assuming a ramjet is used for inserting axions into a chamber from outer space. This value was done after consultation with different people whom the author is in communication with in the AIBEP (American institute of Beamed energy propulsion).

At .999c, the power is nearly 1500 watts/cm^2, which appears to be respectable. However, relativity dictates that the closer to the speed of light, the greater the needed energy intake. These calculations assume a density of half a trillion axions per cubic centimeter the vicinity of Earth, more per cc near the galactic center, and only is also assumed that an axion traveling at .1c, hitting a 1 cm-squared region of space, undergoes an 10^{-5} electron volte value to 10^{-3} eV value for the axion mass. This axion mass would then be directly converted into energy, and that there are roughly up to half a trillion axions per cubic centimeter This is the origins of the 3 watts per square centimeter term above. However, a space ship is not capable of travelling at 99.9 percent the speed of light through interstellar space. MHD dynamics among other things likely would tear a spacecraft apart at speeds appreciably above one tenth the speed of light. Also the massive changes in space time geometry initiated in Bremmsstrahlung effects of particles traveling near the speed of light in order suggest what can go wrong. So how can one obtain a power value of 1500 or so watts per square centimeter at nearly .1c? The reader should know that the 1500 Watt per square centimeter figure is what would be obtained if an axion ramjet were traveling at .99 percent the speed of light. What is being looked for is how to have a far greater energy power equivalent to 1500 Watts per square centimeter for far slower travel. The reason being that the greater the power output at lower speed of light values, the faster a space craft would be able to accelerate to that speed. i -- a more reasonable way to have interstellar travel? To do this, we take into account another datum. Our Dark Matter candidates (WIMPs), instead of being 10^{-3} eV are, instead 100 to 400 GeV, i.e., much more massive than the value of an axion. So a more efficient way is required to reach a power ratio of 1500 or so watts per square centimeter for a rocket. This implies the need for a massive upgrade of power efficiency of a star drive system. The problem of momentum kick is as follows. As can be inferred from Sikivie (1983), "Every axion which is converted to a photon with the same total energy produces a momentum kick of

$$\Delta p = mc \times \gamma \cdot (1 - \beta) \qquad (5)$$

where *m* is the axion rest mass." If one makes a swap between axions and DM, or uses a mass of several hundred GeV as a starting point, based on the calculations referenced above, and avoids the absurdity. Special relativity suggests that a low-power-output space craft would take quite a long time to accelerate to almost the speed of light. A viable DM rocket would allow a rocket to have far more power, permitting a more rapid acceleration to at least ten percent of the speed of light in a reasonable time period. The main point of confirming a viable candidate for the

DM particle, is to design a ship on the order of magnitude of at least an aircraft carrier in bulk to travel at one tenth the speed of light. So one can assume a coupling of axion to matter coupling strength of the value of

$$f_a = \vartheta(10^{15}\, GeV) \qquad (6)$$

Why this is all important? Facing some serious problems in contemporary cosmology (partial list given to the author by Abhas Mitra, Bhabha Atomic Research Centre)

At the EXTREMA of any function: *dx/dt =0*. But for Big-Bang, *dS/dt* =∞ at *S=0*. And then why would one care about entropy in the first place. It so happens as reported by Beckwith (2009) as adapted from Ng (2007, 2008). The fact is that the DM non-SUSY Lagrangian offered by Meissner and Nicolai (2008) may not only give the correct mass value for a useful interstellar propulsion candidate, but it also may tie in with entropy production formalism which may avoid the *dS/dt* =∞ at *S=0* seen in present cosmology, which leads to insuperable problems in modeling contemporary cosmological models of present vacuum energy models, in terms of quantum criticality. Thus, the rethink of DM production can not only figure in with realistic propulsion candidate values of DM masses, but allow us to avoid the absurdity of the *dS/dt* =∞ at *S=0* seen in present cosmology. This means making progress on Ng's treatment of entropy, as due to DM and to either confirm or to falsify it. It is then appropriate to look at the datum raised by Ng, i.e., to consider practical applications of his DM-Entropy linkage, i.e., the entire matter of quantum 'infinite' statistics. Ng (2008) outlines how to get $S \approx N$, which with additional arguments we refine to be $S \approx < n >$ (where <*n*> is a 'DM' density). Begin with a partition function

$$Z_N \sim \left(\frac{1}{N!}\right) \cdot \left(\frac{V}{\lambda^3}\right)^N \qquad (7)$$

This, according to Ng, leads to an entropy of the limiting value of

$$S \approx N \cdot \left(\log\left[V / N\lambda^3\right] + 5/2\right). \qquad (8)$$

But $V \approx R_H^3 \approx \lambda^3$, so unless *N* in Eq. (8) above is about 1, *S* (entropy) would be < 0, which is a contradiction. Now this is where Ng introduces removing the *N!* term in Eq. (7) above, i.e., inside the Log expression we remove the expression of *N* in Eq. (8) above. This is a way to obtain what Ng refers to as Quantum Boltzmann statistics, so then we obtain for sufficiently large *N*

$$S \approx N \qquad (9)$$

The supposition is that the value of *N* is proportional to a numerical DM density referred to as <*n*>. This is to be either confirmed or shot down, and our rocket equation problem may be a way to either confirm or falsify it.

Conclusions

The DM searches so mentioned in this document involve particle physics candidates which have an interface with gravitons, and gravitational wave astronomy, from relic conditions. Proper analysis of relic conditions, in which both gravitons and DM are to be created could be aided by judicious use of the Li-Baker detector (Baker et al., 2008 and Li et al., 2008). We hope that such a program is initiated in the near future. Since early universe conditions, as inferred by CMBR studies infer a preponderance of DM and of relic graviton conditions, use of a HFGW detector would be an optimal, useful application of research tools to enable a proper study and development of our understanding of initial conditions for DM physics. One can state that near-light speeds, the available axion power would be about 3 watts/cm^2 times $\beta \times \gamma^2$, where $\beta = $ (v/c) is the velocity relative to light, and $\gamma^2 = 1/\left[1 - \beta^2\right]$ is the square of the relativistic mass-increase factor. At a velocity of 99.9% c, the available power from axions would be about 1500 watts/cm^2, enough power for a modest energy-efficient space drive (the faster it goes, the more such power becomes available). In principle, a photon rocket may be improved upon, using DM/axion destruction via intense **E** & **B** fields. A full-blown R & D project would be required to determine the feasibility of obtaining axions /DM in the first place.

In IDM 2008, a mass range for DM candidates up to about 400 GeV, per particle was predicted (Beckwith, 2009). Also Hooper and Baltz (2008) argued for a 100—200 GeV range. DM mass values which adds credibility to implementation of a counting algorithm based on Eq. (9). I.e., entropy would then be added due to DM particles which would be produced within the CMBR region of space. I.e., the wave length of DM would be well within the region of space before 380 thousand years after the Big Bang. The reader should be aware that Beckwith (2009) authored a similar argument as to relic graviton production, which would assume a far higher frequency regime, and a correspondingly smaller area of production for relic gravitons. What is needed, to make a linkage between axions and WIMP DM more understood would be application of Bayesian statistics, as Feroz, Allanach et al. (2008) wrote about. A proper experimental program of DM applications to space flight may enable empirical investigations into this issue, and allow for understanding the genesis of entropy in pre CMBR space. Furthermore the additional mass of a DM WIMP has its uses. I.e., additional mass leads to a calculated power increase, if we approach V= ten percent of the speed of light, with a power output of $10^{14} \times 3$ watts/cm^2 times $\beta \times \gamma^2$. The absurdity of the idea of carrying an energy supply of the magnitude of the Earth's entire energy output with the spacecraft for a journey to the stars is therefore avoided. However, the real engineering problems lie ahead in a radical upgrade of the photon rocket ship. Finally, the author claims that the entire exercise as outlined, if developed is a way to either confirm, or deconstruct Ng's radical treatment of entropy, with potential technological spin-offs.

References

Baker, R. M. L., Jr., Stephenson, G. V. and Li, F. (2008). "Proposed Ultra-High Sensitivity HFGW Detector," ed. M. S. El-Genk, after peer review published in the proceedings of *Space Technology and Applications International Forum (STAIF)* **969**: 1045-1054. American Institute of Physics Conference Proceedings, Melville, NY. http://www.gravwave.com/docs/Proposed%20Ultra-High%20Sensitivity%20HFGW%20Detector%2005-15-08.pdf.

Beckwith, A. W. (2009). "Hypothetical Dark Matter/Axion rockets: What can be said about Dark Matter in terms of space physics propulsion," Contributed to SPESIF - 2009, Huntsville, Alabama, 24-27 Feb 2009. arXiv:0810.1493 [physics.gen-ph], http://arxiv.org/abs/0810.1493.

Beckwith, A. W. (January 2009). "Relic High Frequency Gravitational waves from the Big Bang, and How to Detect Them," arXiv:0809.1454v3 [physics.gen-ph], http://arxiv.org/abs/0809.1454.

Bernabei, R., Belli, P., Cerulli, R., Montecchia, F., Nozzoli, F., Incicchitti, A., Prosperi, D., Dai, C. J., He, H. L., Kuang, H. H., Ma, J. M. and Scopel, S. (August 2001). "Search for solar axions by Primakoff effect in NaI crystals," *Physics Letters **B*** **515**(1-2): 6-12.

Collar, J. I., Miller, D., Rasmussen, J. and Vieira, J. (2006). *CAST, The Solar Axion Search at CERN*, Kavli Institute for Cosmological Physics, University of Chicago, http://collargroup.uchicago.edu/projects/axion/index.html.

Duffy, L. D., Sikivie, P., Tanner, D. B., Asztalos, S. J., Hagmann, C., Kinion, D., Rosenberg, L. J., van Bibber, K., Yu, D. B. and Bradley, R. F. (2006). "A High Resolution Search for Dark-Matter Axions," *Physical Review **D*** **74**(012006).

Energy Information Administration (2008). *International Energy Outlook 2008: Electricity*, U.S. Department of Energy, http://www.eia.doe.gov/oiaf/ieo/electricity.html.

Feroz, F., Allanach, B. C., Hobson, M., AbdusSalam, S. S., Trotta, Roberto and Weber, A. M. (July 2008). "Bayesian Selection of sign μ within mSUGRA in Global Fits Including WMAP 5 Results," arXiv:0807.4512v1 [hep-ph], http://arxiv.org/abs/0807.4512v1.

Frisbee, R. H. (2009). "Limits of Intestellar Flight Technology," *Frontiers Propulsion Science*, eds. M. Millis and E. Davis, in *Progress in Atronautics and Aeronautics* **227**:31-126 (AIAA, 2009).

Giromini, P., Happacher, F., Kim, M. J., Kruse, M., Pitts, K., Ptohos, F. and Torre, S. (October 2008) "Phenomenological interpretation of the multi-muon events reported by the CDF collaboration," arXiv:0810.5730v1 [hep-ph], http://arxiv.org/abs/0810.5730v1.

Gulevich, A. V., Ivanov, E. A., Kukharchuk, O. F., Poupko, V. Y. and Zrodnikov, A. V. (2001). "Application of nuclear photon engines for deep-space exploration," *STAIF* **552**: 957-962, AIP Conf. Proc. – February 2, 2001.

Hogan, C. J. (September 2007). "Holographic Indeterminacy, Uncertainty and Noise," arXiv:0709.0611v1 [astro-ph], http://arxiv.org/abs/0709.0611.

Hooper, D. and Baltz, E. (November 2008). "Strategies for Determining the Nature of Dark Matter," *Annual Reviews of Nuclear and Particle Science* **58**: 293-314.

Lakic, B. (2008). "Search for solar axions with the CAST experiment," Proceedings of IDM 2008, Stockholm, Sweden, ID 484

Li, F. Y., Baker R. M. L., Jr., Fang, Z., Stephenson, G.V. and Chen, Z. (July 2008). "Perturbative Photon Fluxes Generated by High-Frequency Gravitational Waves and Their Physical Effects," *European Phys. J.* **C 22**(18-19), http://www.gravwave.com/docs/Li-Baker%206-22-08.pdf.

Meissner, K. A. (April 2008). Personal communication, Bad Honnef meeting on "Quantum gravity, new directions and perspectives," Germany.
Meissner, K. A. and Nicolai, H. (September 2008). "Neutrinos, Axions, and Conformal Symmetry," arXiv:0803.2814v3 [hep-th], http://arxiv.org/abs/0803.2814.
Muramaya, H. (2006). "Physics beyond the Standard Model and Dark matter," Lectures at Les Houches Summer School, Session 86, Particle Physics and Cosmology: the Fabric of Spacetime, 31 July-25 August.
Ng, Y. J. (2008). "Spacetime Foam: From Entropy and Holography to Infinite Statistics and Nonlocality," *Entropy* **10**(4): 441-461.
Ng , Y. J. (2008). "Quantum Foam and Dark Energy," International workshop on the Dark Side of the Universe, http://ctp.bue.edu.eg/workshops/Talks/ Monday/QuntumFoamAndDarkEnergy.pdf.
Sikivie, P. (1983). "Experimental Tests of the 'Invisible' Axion," *Physical Review Letters* **51**(16): 1415-1417.
Taoso, M., Bertone, G. and Masiero, A. (March 2008). "Dark matter candidates: a ten-point test," Journal of Cosmology and Astrophysics **JCAP03**(2008)022.
Weinberg, S. *Cosmology* (New York: Oxford University Press, 2008).