Laser boost of a small interstellar ram jet to obtain operational velocity. Implications for the DM rocket/ram jet model

Andrew Walcott Beckwith

American Institute of Beam Energy propulsion (life member)
abeckwith@uh.edu, beckwith@aibep.org

Abstract .In other conference research papers, Beckwith obtained a maximum DM mass/ energy value of up to 5 TeV, as opposed to 400 GeV for DM, which may mean more convertible power for a dark matter ram jet. The consequences are from assuming that axions are CDM, and KK gravitons are for WDM, then up to a point, $\rho_{Warm-Dark-Matter}$ would dominate not only structure formation in early universe formation , but would also influence the viability of the DM ram jet applications for interstellar travel. The increase in convertible DM mass makes the ram jet a conceivable option. This paper in addition to describing the scientific issues leading to that 5 TeV mass for DM also what are necessary and sufficient laser boost systems which would permit a ram net to become operational.

Key words: Graviton, DM, ram jet
PACs: 98.80.Cq, 95.35.+d, 95.30.Sf, 65.40.gd, 11.25.Uv

Introduction

When at the 12 Marcell Grossman meeting, July 2009 17th , the author talked with Leszek Roszkowski, at the Paris Observatory as to what would happen to DM if hot and cold DM models were mixed together.., Dr. Roszkowsk stated there would be no structural changes which would occur in galaxy formation, if two cold DM candidates would be partially mixed. Conversely, Roszkowsk referred to significant formation and density fluctuation changes if warm and cold DM candidates were mixed together. We assume a mix of DM types, as far as the interstellar mix, which will have consequences for the DM ram jet. Next. having settled upon looking at the KK graviton as a dark matter candidate, the author settled upon using $m_n(Graviton) = \frac{n}{L} + 10^{-65}$ grams, with the lowest rest mass being determined with n equal to zero, and the highest version of graviton mass as of 5 TeV. This increased mass will factor into our discussion of the ram jet. But for now, let us Let us now review different models as to how to obtain proper velocity for a space craft.

First the rocket eqn. I.e. why boost to near earth orbit are expensive with chemical rockets, plus light sails for propulsion purposes

The rocket equationand the low exhaust velocity of chemical fuels are at the root of the high cost. Laser boosting of space crafts are a way about this problem.In a different context, laser boosting will be done to obtain up to 1 / 20th of the speed of light, as a pre cursor to having the DM ram jet kick in.

$$\Delta v = v_e \ln \frac{m_0}{m_1} \quad (1)$$

This can be presented as having m_0 as the initial total mass, including propellant. Qne also can have m_1 as the final total mass., and having as a stated given v_e as the effective exhaust velocity.

$$v_e = I_{sp} \cdot g_0 \quad (2)$$

Δv is the delta-v. where as m_0/m_1 is the mass ratio.

table 1 mass delta ratio V
(multiple of exhaust velocity)

1	0
2	0.693
3	1.098
4	1.386
5	1.609
6	1.791
...	
33	3.496

It is obvious from inspection as to why laser boost to Earth orbit have been considered. The AIBEP meeting will bring up what can be said about such technology. For the authors demonstration, it is appropriate to consider the problem of laser assists for boosting a space craft in the regions in near space conditions, and to obtain conditions for up to 1/20 th the speed of light velocity being reached , so a DM ram jet can begin to operate. The reason why laser assisted ram jets have been considered as a way to have space crafts go to other near by stars is because the best current rocket technology can do is about 30 km/s - 0.01% of light speed. That's 10,000 years per light-year in travel time, about the average speed of stars passing each other in the galaxy. For use of a photon assisted drive to get to another star, say 4 light years away, using low boost technology, up to a million years would be needed. Clearly, if one wants to have interstellar probes going to another star in say a century of travel time, different engineering technologies need to be used.

table 2 - getting there

System	Velocity (km/s)	Velocity (lightspeed = 1.0)	years per light-year	to Alpha Centauri (years)
Current rockets	30	0.0001	10,000	44,000
VASIMR	300	0.001	1,000	4,400
solar sail MAX	1,000	0.0033	300	1,320
Orion	10,000	0.033	30	132

But, Orion has largely been ruled out. One of the reasons being that the amount of fusion bombs . Secondly, if one wishes to begin effective acceleration, one could use either ground or space based laser systems hitting a light sail. Note that Space vehicles can be made much lighter and smaller if they do not have to carry their source of power. Power can be supplied through lasers projected on structures called 'light sails.' The sail material could be some form of Mylar – both thin and strong. Steering the sail and aiming the huge lasers, however, are not trivial problems. By huge lasers, think 10 gigawatts shining on a 1 kilometer in diameter sail just to send a 16 gram payload to the closest star. The laser must be precisely aimed on target for as long as possible to get the desired velocities.

Realistically though, the lasers would only work hitting a light sail within a small fraction of a light year. It would then be appropriate to think of how to obtain up to 1/20th the speed of light, via this method, and then perhaps employing a DM ram jet.

Breaking up portions of the trip into three states

(1) Moving from Earth orbit to Mars orbit

The author views either a ground based laser system hitting a light sail, or using VASMIR, as a plasma rocket boost to Mars orbit, as optimal. The lasers would have to be based upon Earth itself; and five to six of them roughly spaced along the equatorial regions would be enough to supply a powered light pressure venue to push the space craft. The preferred venue would be perhaps to use Yb: YAG 200 kW laser system as outlined by Sherstobitov, et al. as of (2004). As indicated in Sherstobitov, et. al. (2004), figure 5, relative beam size spreading is not a serious problem, as well as atmospheric turbulence would for an Earth to Mars trip be a not insurmountable problem as far power transfer to a Earth to Mars orbit trip. The problem would be in getting five to six coordinated laser sites to be effectively administered by a scientific body. IMO, politics, not scientific feasibility is the limiting factor If Earth bound lasers would be impacted by politics as a significant administrative issue, and then the VASMIR boost system to Mars would perhaps be the preferred venue.

(2) Traveling from Mars, to the Kuiper belt

Use of lasers placed in the Lagrange points about the Earth-Moon system. Note that Lagrange points L4 and L5 constitute stable equilibrium points, so that an object placed there would be in a stable orbit with respect to the Earth and Moon. With small departures from L4 or L5, there would be an effective restoring force to bring a satellite back to the stable point. The L4 and L5 points make equilateral triangles with the Earth and Moon.

(3) Post Kuiper belt travel, i.e. time to employ the DM rocket

Getting first to Mars orbit, alternate procedures, before using laser at the L4 and L5 lagrange points powering a light sail

First would be to use VASMIR, as a way to get a space craft to Mars Orbit. For those who wish to know what VASMIR is, the following engine diagram suffices to make the point. Secondly, would be to use Earth bound lasers as far as a source of power for a significant light sail, from the beginning.

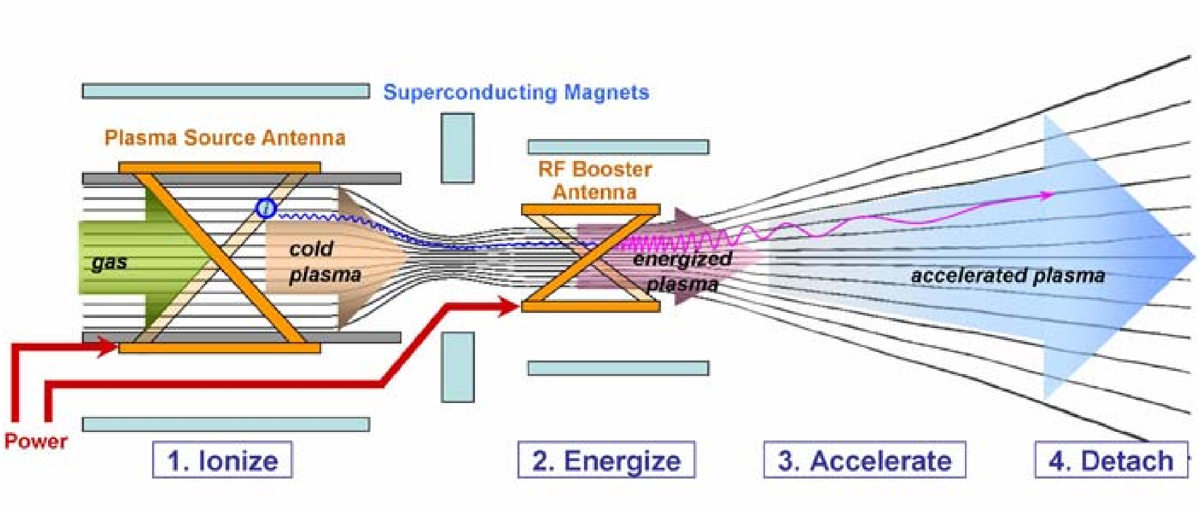

Figure 1

Force equation considerations, and the light sail.

From Millis (2009), the following variations, with P pressure from a laser hitting a light sail of area A, and with a fudge factor of δ put in, in the case of real Radiometers, taking into account what could be expected in terms of sail material properties, and sail geometry, plus the degree energy impinging upon the sail has been locally altered , reciprocally across the front and back of the sail. As Millis writes it, for force upon the sail

$$F \equiv \frac{P}{A} - Differntial - Sail: \text{Analogous to an ideal Radiometer vane} \quad (3a)$$

$$F \equiv \left(\frac{\delta^2 - 1}{\delta}\right) \cdot \frac{P}{A} - Induction - Sail: \text{ Analogous to a real Radiometer vane} \quad (3b)$$

$$F \equiv 2 \cdot \frac{P}{A} - Diode - Sail: \text{ Analogous to a one way mirror} \quad (3c)$$

Details as to the fudge factor of δ being put in can only be resolved via space vacuum tests of a laser- sail system in near earth orbit.

Getting to a 10 gigawatts laser (note the real laser system at the L4 and L5 Lagrange points would have to be considerably more powerful)

The Gigawatt Laser, as described by Yu. Satov, et al (2004) is a CO_2 "SKATE" and its output would appear to be able to approach ten gigawatts. The problem is that the laser system for hitting a space craft would have to be operational for quite a long time, enough so that the space craft would be able to get out to the Kuiper belt. The Kuiper Belt is a disk-shaped region past the orbit of Neptune extending roughly from 30 to 50 AU. One would likely need a system like a High Power Nd:YAG Laser, with a variant of the YAG laser , and that would lead to considerable engineering challenges. One of them would be to develop seed lasers for the Yag Laser. Note that highly stable low power seed laser plays a crucial role in these systems by keeping the high power, Q-switched, Nd:YAG laser at a fixed wavelength and single mode. In addition, the seed laser reduces shot-to-shot intensity fluctuations due to mode beating in the YAG laser, which cause damage to internal optics and reduce the lasers lifetime. Current seed lasers are large, expensive, and suffer under vibration and field use.

The problem would be in obtaining and developing a seed laser which combined optical Bragg waveguide structures and new semiconductor laser technology to create a narrow linewidth laser at the precise wavelength. After the seed laser development would be the even bigger problem.

Secondly, if the lasers were to be put to the Lagrange L4 and L5 point, would be the support and logistics problems

A full accounting of what would be required for appropriate seed laser for a variant of a stable powerful Yag Laser awaits engineering development work. The detail of finding an appropriate seed laser is brought up as a concept to be developed which requires specific laser R and D work. I.e. sufficiently stable YAG lasers capable of a boost of a space craft up to the KUIPER belt requires break through technology as far as appropriate seed lasers, which would probably be the source of a DARPA style initiative.

Hierarchy of engineering and real life deployment issues for getting lasers operational and ready for show time

First of all, is finding an appropriate seed laser system which would help stabilize a YAG style laser system for long term usage. Philip Battle of Bozeman, Montana has filed for patents as far as stabilizing YAG laser systems. The author is of the opinion that his proposal is currently very crude, but promising and needs considerable expansion and development. Secondly, if a ground based system, as opposed to getting VASMIR to boost a space craft to MARS orbit is to be used, again assuming a YAG style system of the form discussed by Sherstobitov et al (2004), one needs near orbit space tests to determine the δ for a real induction sail. I.e. theorizing about it will not work.

I.e. the author will contact Philip Battle, of MSU, and others of a similar background to begin the hard task of finding appropriate seed lasers for stabilization of a candidate YAG laser system, of sufficient power.

Now for the DM rocket / ram jet problem, as proposed a year ago, a brief review.

As put in , in a discussion by Beckwith, 2009, as referenced for SPESIF, 2009

Quoting from the 2009 conference paper by A.W. Beckwith (2009) : ". So, we can only talk about perhaps a ram jet engineering construction, I.e., scooping up Axions /DM from the interstellar void and using that as a fuel source. So how do we get around this ?

As can be inferred from P. Sikivie (1983), "Every axion which is converted to a photon with the same total energy and going in the same direction produces a momentum kick of

$$\Delta p = mc \times \gamma \cdot (1 - \beta) \tag{4}$$

where m is the axion rest mass." What is the rest mass of a KK DM graviton candidate ? It is up to a mass of 5 TeV. The conversion factor to be considered is 5 TeV versus the upper limit of 13.5 MeV , tops, for an axion (it is usually a lot LESS) as reported by A. Bischoff-Kim, M. H. Montgomery and D. E. Winget (2008) wrote, "our analysis yields strong limits on the DFSZ axion mass. Our thin hydrogen solutions place an upper limit of 13.5 meV on the axion, while our thick hydrogen solutions relaxes that limit to 26.5 meV". For this result, I am picking the 13.5 meV as the upper limit for axion mass analysis. I.e. values as low as 1 eV have been figured as to axion mass, 5 TeV corresponds to 5.0×10^{12} electron volts, Whereas 13.5 MeV is = 13 500 000 electron volts At the high of the energy scale for axions, there is still roughly $10^5 - 10^6$ times more energy in a DM from KK gravitons, as opposed to axions,. Contrasting this with the 400 GeV value for WIMPS specified as of being 400 000 000 000 eV, then it is that the KK graviton would yield a far higher amount of energy ~ mass value than the WIMP**.** The implication may be that Eqn (4) has a stronger change in momentum contribution as to the DM ram jet / rocket problem, than expected.

Now that the preliminary discussion of the DM ram jet has been brought up, we need to discuss as to what is the space environment as to the ram jet. What would be the DM concentration we could expect? That is not so simple as people think. Key to getting to it would be determing if the present local group of galaxies and star clusters we are in is a local void, or that DM plays the role we hope it does in galaxy formation.

Controversies of DM/ DE applications to cosmology.

What to consider is the'cosmic void hypothesis'. See Timothy Clifton, Pedro G. Ferreira and Kate Land . I.e. Clifton raises the following question- can HFGW and detectors permit cosmologist to get to the bottom of this ? "Solving Einstein's equations for an averaged matter distribution is NOT the same as solving for the real matter distribution and then averaging the resultant geometry"("We average, then solve when in effect we should solve, then average") .Next, let us look at a recently emerging conundrum of DM feeding into the structure of new galaxies and their far earlier than expected development, i.e. 5 billion years after the big bang. What could cause the earlier clumping? . First of all, note the formula of variation of DM density which exists has a Hubble parameter *H*, and also the 2nd derivative of the gravitational potential $\nabla^2 \Phi$, where ρ_0, a_0 are today's values for density and 'distance.' Note that if $H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \left[\left(\frac{\rho}{3M_4^2} + \frac{\Lambda_4}{3} + \frac{\rho^2}{36M_{Planck}^2}\right) - \frac{\kappa}{a^2} + \frac{C}{a^4}\right] \xrightarrow[\Lambda_4 \to 0]{\kappa \to 0,} \left[\frac{\rho}{3M_4^2} + \frac{\rho^2}{36M_{Planck}^2} + \frac{C}{a^4}\right]$, as well as $\rho \to \rho(z) \equiv \rho_0 \cdot (1+z)^3 - \left[\frac{m_g}{8\pi G}\right] \cdot \left(\frac{a_0^4}{14 \cdot (1+z)^4} + \frac{2a_0^2}{5 \cdot (1+z)^2} - \frac{1}{2}\right)$, and $1 + z = a_0 / a$, then the contribution of large z , i.e. large contributions from red shift, that a significant early contributions will be for non zero contributions from $1/\rho^\beta$ terms, for [**large number]** $> \beta \geq 1$ in the DM density variation parameters. So long as $m_{graviton} \neq 0$, even if $m_{graviton}$ is very small. In addition, if the following is true

$\Phi \equiv \Phi_L + f_{NL} \cdot \left[\Phi_L^2 - \left\langle \Phi_L^2 \right\rangle\right] + g_{NL} \cdot \Phi_L^3$ then. when using the formula, $\nabla^2 \Phi$ consider the contributions to the expression f_{NL} . To do this consider what Licia Verde (2000) put up about Φ considered to be the gravitational potential, and Φ_L its linear Gaussian contribution. P. Chingabam, C. Park

(2009)) used $-4 < f_{NL} < 80$ at a confidence level of 95%. Now for some sort of bounds as to what may be acceptable bounds in error, based upon CMB data

$$\left| f_{NL} \cdot \left[\Phi_L^2 - \left\langle \Phi_L^2 \right\rangle \right] \right| \leq 10^{-5} \cdot \left| f_{NL} \right| < ?up \quad to \quad 10^{-3} \tag{5}$$

Depending upon which model is used for describing Φ_L i.e. as a perturbation of a gravitational potential, this eqn. (24) may allow us to obtain a good guess as to what dimensions are crucial for the formation of a graviton, i.e. how much spread may be permitted. Also, White and Hu (1996), also have a way to link the gravitational potential Φ to temperature fluctuations, and do it as

$$\left.\frac{\Delta T}{T}\right|_{Final} - \left.\frac{\Delta T}{T}\right|_{Initial} = -\Phi_{Initial} \tag{6}$$

A simple way to understand eqn (6) is to consider if it is linkable to the Sach-Wolfe effect. Here, the Sachs–Wolfe effect (ISW) occurs when the Universe is dominated in density by something other than matter. If the Universe is dominated by matter, then large-scale gravitational potential wells and hills do not evolve significantly. If the Universe is dominated by radiation, or by dark energy, , those potentials do evolve, subtly changing the energy of photons passing through them. If so is there a difference in the initial and final ratios $\Delta T / T$ of temperature variations are for different red shift values ? Look at then

$$(\delta T / T) \cong (1/3) \cdot \left[\Phi_L + f_{NL} \cdot \left(\Phi_L^2 - \left\langle \Phi_L \right\rangle^2 \right) \right] \tag{7}$$

The choice of temperature variations would impact structure formation, and perhaps upon the level of DM contributions to structure even as locally expected for travel to different stars. Beckwith(2009) has written how this issue impacts galaxy formation, but it may have enormous consequences as to DM concentration about our star as well. . On the local stellar level Let us now consider what would be high level DM masses which may be appropriate for the DM ram jet. This is important for two reasons. First of all is the supposition that masses above the traditional WIMP mass for DM may contribute to more efficient

The following figure 2 is a KK tower for gravitons, with the zeroth KK mode being the 4 dimensionalgraviton. **The modified KK tower for gravitons will be our candidate for DM**

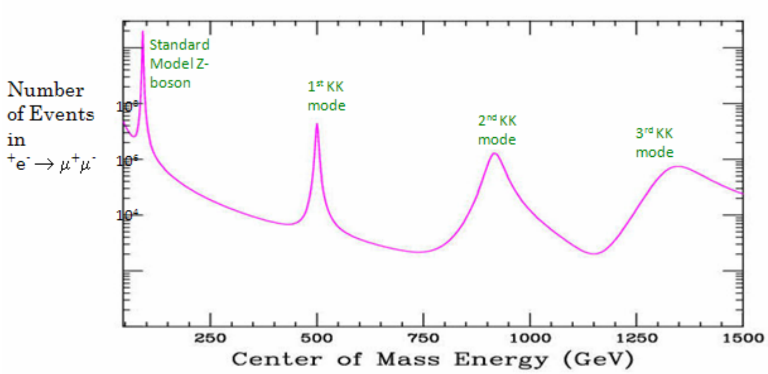

Figure 2: *Number of Events in e+e- $\to \mu+\mu$- For a conventional braneworld model with a single curved extra dimension of size ~ 10-17 cm Numbers range from* 10^4 *to about* 10^8 *for the number of events in scattering. First peak is for KK zero mode, a.k.a. the standard Z boson, ending with the 4th peak for the 3rd KK mode,*

Unanswered questions, and suggestions for future research endeavors

First of all, what can researchers expect if KK gravitons exist, and exist in inter stellar space with axions ? Cembranos, Jose A. R.; Feng, Jonathan L.; Strigari, Louis E. (2007) give a partial answer. It is not just the gamma ray spectrum which may be altered. I.e. Alexey Boyarsky, Julien Lesgourgues, Oleg Ruchayskiy and Matteo Viel (2009) have strict Baysian s tatistical limits as to what sort of warm to cold dark matter mixes are allowed. One of their basic result, which is put here,

$\rho_{Baryons}, \rho_{Cold-Dark-Matter}, \rho_{Warm-Dark-Matter}$ refer to density profiles, of the respective baryons, CDM, and WDM candidates, whereas, the density fluctuations $\delta_{Baryons}, \delta_{Cold-Dark-Matter}, \delta_{Warm-Dark-Matter}$ are with regards to the fluctuations of these density values. So

$$\left(\frac{\delta\rho}{\rho}\right) \equiv \frac{\rho_{Baryons}\delta_{Baryons} + \rho_{Cold-Dark-Matter}\delta_{Cold-Dark-Matter} + \rho_{Warm-Dark-Matter}\delta_{Warm-Dark-Matter}}{\rho_{Baryons} + \rho_{Cold-Dark-Matter} + \rho_{Warm-Dark-Matter}} \quad (8)$$

If axions are CDM, and KK gravitons are for WDM, then up to a point, $\rho_{Warm-Dark-Matter}$ would dominate Eqn. (40) in earlier times, ie. Up to Z~1000. However, Boyarsky, et al (2009) also stress that as of the recent era, i.e. probably for Z~.55 to Z~0 today , they would expect to see the following limiting behavior

$$\begin{aligned} &\delta_{Baryons} \equiv \delta_{CDM}, \\ &\delta_{WDM} << \delta_{CDM} \end{aligned} \quad (9)$$

In earlier times, what is put in, with regards to eqn. (8) would be probably far different . However, up in the present era, the denominator of Eqn (8) would be dominated by KK DM, whereas there would be rough equality in the contributions $\rho_{Cold-Dark-Matter}\delta_{Cold-Dark-Matter}, \rho_{Warm-Dark-Matter}\delta_{Warm-Dark-Matter}$, with the baryon contribution to the numerator being ignorable, due to how small baryon values would be for Z~.55 to Z~0 today. Somehow, contributions as to eqn (8) should be compared with.

$$\left(\frac{\delta\rho}{\rho}\right)_{Horizon} \cong \frac{k^{3/2}|\delta_k|}{\sqrt{2}\pi} \propto \frac{k^{(3/2)+3\alpha-3/2}}{\sqrt{2}\pi} \approx \left(1/\sqrt{2}\pi\right)\cdot k^{3\alpha} \quad (10)$$

where $-.1 < \alpha < 0.2$, and $\alpha \equiv 0 \Leftrightarrow n_s \equiv 1$ and to first order, $k \cong Ha$. The values, typically of $n_s \neq 1$ If working with $H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \left[\left(\frac{\rho}{3M_4^2} + \frac{\rho^2}{36M_{Planck}^2}\right) + \frac{C}{a^4}\right]$, and with a density value $\rho \equiv \rho_0 \cdot \left(\frac{a_0}{a}\right)^3 - \left[\frac{m_g c^6}{8\pi G\hbar^2}\right]\cdot\left(\frac{a^4}{14} + \frac{2a^2}{5} - \frac{1}{2}\right)$ where $m_g \approx 10^{-65}$ grams, and $\alpha < 0.2$ is usually picked to avoid over production of black holes, a complex picture emerges. Furthermore, $\alpha < 0.2$ and $\alpha \neq 0$. The following limits as of eqn. (8) in early and later times should be reconciled with.

$$\left(\frac{\delta\rho}{\rho}\right)_{Horizon} \cong \left(1/\sqrt{2}\pi\right)\cdot k^{3\alpha} \sim \frac{H^2}{\dot{\phi}} \propto 10^{-4} - 10^{-5} \quad (11)$$

The above equation gives inter relationships between the time evolution of a pop up inflaton field ϕ , and a Hubble expansion parameter H , and a wave length parameter $\lambda = (2\pi/k)\cdot a(t)$ for a mode given as δ_k . What should be considered is the inter relation ship of eqn (11) and $\lambda \leq H^{-1}$. What Beckwith thinks is

$$\left(\frac{\delta\rho}{\rho}\right) \cong Ak^{\left(\frac{n_S-1}{2}\right)} \propto 10^{-4} - 10^{-5} \quad (12)$$

Understanding eqn.(8) to Eqn. (12) may allow us to ujnderstand how to map out concentrations of DM which would be appropriate for our usage once we get to at least the Kuiper belt of the frontiers of the solar system.

Conclusion

Looking at the KK graviton as a enabler to adding more momentum kick to eqn (4) seems to be a reasonable thought experiment. Of greater concern is the relative distribution of mass/ DM distributions as presented in Eqns (8) That has huge implications as to what concentration of DM/ energy scoop up could be configured as to an interstellar probe. Left unsaid here is the necessary datum of a suitable power boost of a ram net, to sufficient speed to work at all. Ultimately, that involves lasers In addition, the density profile of DM and of fuel to the rocket engine has to be mapped out. WMAP techniques will not get that for us. Unfortunately, like many scientific endeavors, it will require test flights in the solar system itself, and not just theory to obtain realistic data as to what to expect.

Acknowledgements

First is to thank Andrew Pakhomov, for allowing me to join and partake of AIBEP.org. Many thanks, Andrew and I hope to in the years ahead to make his investment in my participation worth while to all concerned. Secondly , is to thank both Amara Angelica and also H. Keith Henson, Founder, L5 Society for a back ground briefing as of surface to earth orbit physics boosts via lasers , a subject I am very interested in, as well. Also, Eric Davis whom over the years has corrected many of my initial assumptions and pointed me in more nuanced and focused /'fruitful venues of scientific inquiry.

BIBLIOGRAPHY

Babich ,D,., P, and Zaldarriaga; M."The shape of non – Gaussianities", CAP 0408:009,2004; http://arxiv.org/abs/astro-ph/0405356

Barcelo, C. Luis J. Garay,"Quantum fields in Anti-De Sitter Wordholes", http://arxiv.org/PS_cache/gr-qc/pdf/9703/9703028v2.pdf

Beckwith,A.W. "Entropy growth in the early universe and confirmation of initial big bang conditions (Wheeler De Witt eqn. results vs. String theory ?)", http://vixra.org/abs/0908.0109

Beckwith,A.W." Hypothetical Dark Matter/Axion rockets: What can be said about Dark Matter in terms of space physics propulsion". AIP Conf.Proc.1103:276-284,2009

Beckwith, A. W. "Relic High Frequency Gravitational waves from the Big Bang, and How to Detect Them", http://arxiv.org/abs/0809.1454 (2009), AIP Conf.Proc.1103:571-581,2009 (SPESIF)

Bischoff-Kim, M. H. Montgomery and D. E. Winget, "Strong Limits on the DFSZ Axion Mass with G117-B15A",

Cembranos, J..; Feng, J. .; S. ;"Dark matter decaying now", report S15-369, ABS-S15-006 ; Contributed to XXIII International Symposium on Lepton and Photon Interactions at High Energy, Aug 13-18, 2007, Daegu, Korea; http://arxiv.org/abs/0708.0247

Durrer ,R ,and Rinaldi, M. , "Graviton production in non-inflationary cosmology", Phys.Rev.D79:063507,2009, http://arxiv.org/abs/0901.0650

Jedamzik, K., Lemoine M., and Moultaka, G,." Gravitino, axino, and Kaluza–Klein graviton warm and mixed dark matter and reionization", JCAP 0607 (2006) 010; http://arxiv.org/abs/astro-ph/0508141

Kahniashvili ,.T. "Relic Gravitational Waves as a Test of the Early Universe",arXiv:0705.1733 [astro-ph], (2007)

Kolb, E., and Turner, S. "The Early Universe", Westview Press, Chicago, USA, 1994

Jean-Luc Lehners, Paul J. Steinhardt, 'Non-Gaussian Density Fluctuations from Entropically Generated Curvature Perturbations in Ekpyrotic Models', Phys.Rev.D77:063533,2008; http://arxiv.org/abs/0712.3779

Linder, E., , "Exploring the Expansion History of the Universe", Phys. Rev. Lett. 90, 091301 (2003)

Maartens, R., , "Brane-World Gravity (2004)", http://www.livingreviews.org/lrr-2004-7

Martin, J., "Inflationary Perturbations:The cosmological Schwinger effect",pages 193-241, Lecture notes in Physics, 738, editors M. Lemonine, J. Martin, P. Peters, Springer - Verlag (2008), Berlin

Roszkowski, Leszek discussions with A.Beckwith at 12 Marcel Grossman meeting, July 17th, 2009, in Paris observatory, during the Dark matter section of the conference, in Parallel section run by Dr. Chardin.Satov, Y., Sharkov, Y., Smakovski, Y., Makarov, K. et al. ," The "SKATE" CO_2 Gigawatt Laser for a Laser-Plasma Generator of Ions and Nuclei", The Russsian journal of Laser physics research,,Volume 25, Number 6 / November, 2004

Sherstobitov, V., Kaliteevskiy, N. Kuprenyup, V, et al. , " Computer simulations of a solid state Laser System for Propulsion of a Space "Tugboat" from LEO to GEO" pages , AIP Conference proceedings 766, 2004 , pp 347-351