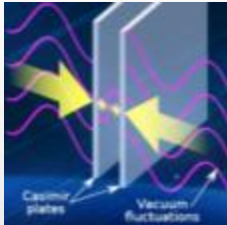




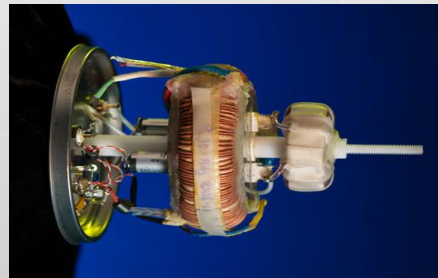
NASA Brief: Q-Thruster Physics

June 2013

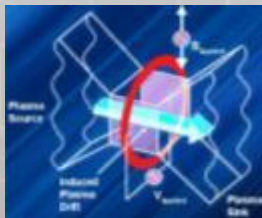
Dr. Harold "Sonny" White



Casimir force



0.4N/kW test article



Quantum
Vacuum
MHD

- Q-thrusters are a low-TRL form of electric propulsion that operates on the principle of pushing off of the quantum vacuum.
- A terrestrial analog to this is to consider how a submarine uses its propeller to push a column of water in one direction, while the sub recoils in the other to conserve momentum – the submarine does not carry a “tank” of sea water to be used as propellant.
- In our case, we use the tools of Magnetohydrodynamics (MHD) to show how the thruster pushes off of the quantum vacuum which can be thought of as a sea of virtual particles - principally electrons and positrons that pop into and out of existence, and where fields are stronger, there are more virtual particles.
- The idea of pushing off the quantum vacuum has been in the technical literature for a few decades, but to date, the obstacle has been the magnitude of the predicted thrust which has been derived analytically to be very small, and therefore not likely to be useful for human spaceflight.
- Our recent theoretical model development and test data suggests that we can greatly increase the magnitude of the negative pressure of the quantum vacuum and generate a specific force such that technology based on this approach can be competitive for in-space propulsion ($\sim 0.1\text{N/kW}$), and possibly for terrestrial applications ($\sim 10\text{N/kW}$).
- As an additional validation of the approach, the theory allows calculation of physics constants from first principles: Gravitational constant, Planck constant, Bohr radius, dark energy fraction, electron mass.

Principles of Q-thruster Operation

- Local mass concentrations, say in the form of a conventional capacitor with a ceramic dielectric, affect vacuum fluctuation density according to equation 1

$$\rho_{v_local} = \rho_v \sqrt{\frac{\rho_{m_local}}{\rho_v}} = \sqrt{\rho_{m_local} \rho_v} \quad (1)$$

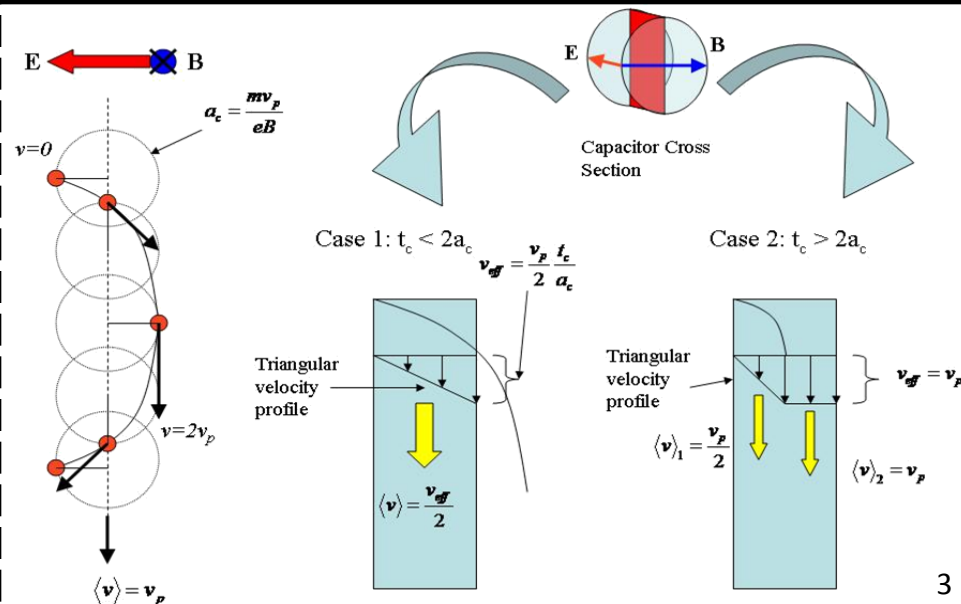
- Just as relativistic acceleration (Unruh radiation) can change the apparent relative density of the vacuum, so too can higher order derivatives according to equation 2.

$$\delta\rho = \frac{1}{4\pi G} \left(-\frac{1}{a^2} \left(\frac{da}{dt} \right)^2 + \frac{1}{a} \frac{d^2 a}{dt^2} \right)$$

$$\delta\rho = \frac{1}{4\pi G} \left(\frac{1}{\phi^2} \left(\frac{d\phi}{dt} \right)^2 - \frac{1}{\phi} \frac{d^2 \phi}{dt^2} \right)$$

$$\vec{a} = -\nabla\phi \quad (2)$$

- The tools of MagnetoHydroDynamics (MHD) can be used to model this modified vacuum fluctuation density analogous to how conventional forms of electric propulsion model propellant behavior.





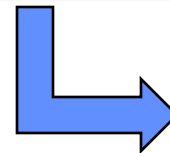
Gravitational Coupling Constant

- Consider the following thought experiment: what would an inertial observer in deep space find if the dark energy density were to be integrated over the light horizon of the observable universe, ~13.7 billion light years?
- Starting with the Friedman Equation (and after some manipulation), the following equation can be derived that formally captures the results of this thought experiment:

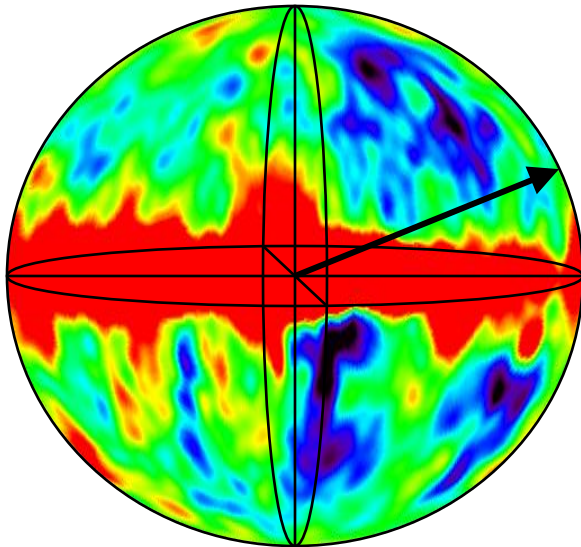
Vacuum Energy
Density

$$\frac{2}{3} \rho_0 c^2 4\pi c^2 t_H^2 = \frac{c^4}{G}$$

Equation can be
rearranged into the
following form



$$G = \frac{1}{4\pi t_H^2 \frac{2}{3} \rho_0}$$



Light horizon

- Using $9.9 \times 10^{-27} \text{ kg/m}^3$ [2] with t_H of 13.7 billion years yields a predicted value for the gravitational constant of $6.45 \times 10^{-11} \text{ m}^3/\text{kg}\cdot\text{s}^2$
- A possible physical meaning to this rearranged equation solved for G is that gravitation is an emergent phenomenon rather than a fundamental force.
- To be specific, the claim could be made that the gravitational coupling constant may be a long wavelength consequence ($\lambda = ct_H$) of dark energy.



Gravitational Coupling Constant

Formal Process

- Start with the Friedmann Equation, and through some manipulation, the gravitational coupling constant, G , can be shown to be a time-independent function of the dark energy density integrated over the spherical light horizon. Recall the Friedmann Equation (1)
- The variables take on their familiar nomenclature: R is the co-moving coordinate; t is time; G is the gravitational constant; ρ_0 is the critical density; k is the curvature; and c is the speed of light. Assume a flat universe, $k=0$, and simplify to get (2)
- This can be solved for R to get the following familiar time-dependent function (t_H is the Hubble time, or rather the age of the universe) (3)
- Going back to equation 2, and set up the integrals again (4); This can be integrated to yield (5); Simplify and rearrange to get (6); G can be isolated to one side (7); Equation 3 can be used to substitute for the co-moving coordinate, R , to get (8); Cancelling terms and multiply both sides by c^4 (9)
- Second, although equation 9 has the Hubble time (current age of the universe) in it, t_H , it is not a function dependent on time and is constant for the duration of the cosmos as the variable time dependency cancelled in equation 8.

$$(1) \quad \left[\left(\frac{1}{R} \frac{dR}{dt} \right)^2 - \frac{8\pi G \rho_0}{3R^3} \right] R^2 = -kc^2$$

$$(2) \quad \left(\frac{dR}{dt} \right)^2 - \frac{8\pi G \rho_0}{3R} = 0$$

$$(3) \quad R = \left(\frac{3}{2} \right)^{2/3} \left(\frac{t}{t_H} \right)^{2/3}$$

$$(4) \quad \int R^{1/2} dR = \int \sqrt{\frac{8\pi G \rho_0}{3}} dt$$

$$(5) \quad \frac{2}{3} R^{3/2} = t \sqrt{\frac{8\pi G \rho_0}{3}}$$

$$(6) \quad \frac{4}{9} R^3 = \frac{8\pi G \rho_0}{3} t^2$$

$$(7) \quad \frac{9}{4} \cdot \frac{2}{3} \cdot \frac{4\pi \rho_0 t^2}{R^3} = \frac{1}{G}$$

$$(8) \quad \frac{9}{4} \cdot \frac{2}{3} \cdot 4\pi \rho_0 t^2 \left(\frac{2}{3} \right)^2 \left(\frac{t_H}{t} \right)^2 = \frac{1}{G}$$

$$(9) \quad 4\pi t_H^2 \cdot \frac{2}{3} \rho_0 c^2 = \frac{c^4}{G}$$

$$(9b) \quad G = \left(4\pi \cdot t_H^2 \cdot \frac{2}{3} \rho_0 \right)^{-1}$$



Planck Constant

- Consider the Einstein Tensor: The Gravitational Coupling Constant equation derived earlier can be substituted for the Planck Force term in the 00th element of the Einstein Tensor, and the dark energy density can be substituted for the T^{00} energy density term. Plugging in the Hubble time, the following relationship is found to be numerically true:

$$\langle 0 | G^{\mu\nu} | 0 \rangle = \frac{-2}{c^2 t_H^2} = \frac{-h}{4\pi t_H} \Re$$

- This equation can be rearranged to solve for the Planck constant, h , which yields a predicted value of 6.46×10^{-34} .

$$h = \frac{8\pi}{c^2 t_H}$$

- This equation suggests that the basic geometry of the cosmos is related to the lowest energy observable photon with same wavelength discussed in the derivation of the gravitational coupling constant.
- These tiny building blocks or “lego” bits of energy may be a phenomenological explanation for the nature of the Heisenberg uncertainty principle.



Perturbation of Quantum Vacuum

- The previous narrative has been focused on things at a cosmological scale. A question can be asked about what happens on a local scale in the presence of a local concentration of matter.
- How does dark energy, or more appropriately the quantum vacuum, respond in the presence of ordinary matter?
- Start by reconsidering the Einstein tensor in the presence of a local concentration of ordinary matter. The $1/t_H$ term on the right side of the Planck equation is replaced by the local conditions imposed by the presence of local matter with a characteristic spacing defined as Δx . Note that the Gravitational Coupling Constant equation has been used to substitute for the Planck force c^4/G :

$$G^{00} = -8\pi \frac{G}{c^4} T^{00} = -8\pi \frac{1}{\frac{2}{3}\rho_0 c^2 4\pi c^2 t_H^2} \rho_{v_local} c^2 = \frac{hc}{4\pi\Delta x}$$

- Equation 1 can be used to redefine the characteristic spacing Δx in terms of the local matter density with the assumption that gravitation is constant at all scales.
- The long wavelength ct_H term is replaced by the maximum wavelength allowed Δx in the presence of local matter density ρ_m :

$$\rho_m c^2 4\pi\Delta x^2 = \frac{c^4}{G} \Rightarrow \Delta x^2 = \frac{c^2}{4\pi G \rho_m}$$

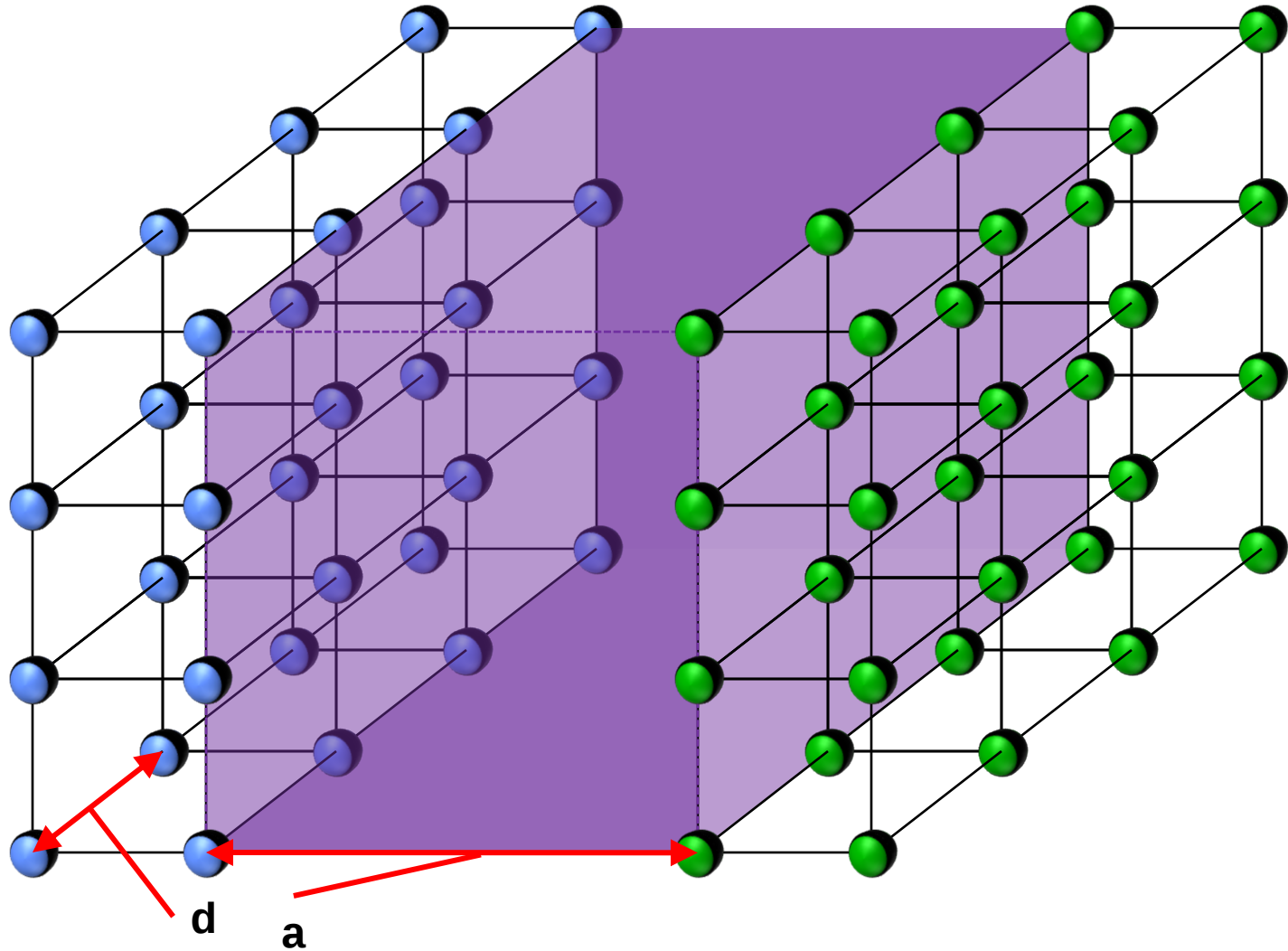
- These two equations can be used together to derive the perturbation of the local quantum vacuum state as a result of the local matter concentration. The ρ_v term has been substituted for the $\frac{2}{3}\rho_0$ term for brevity:

$$\rho_{v_local} = \sqrt{\rho_m \rho_v}$$



What Does This Mean?

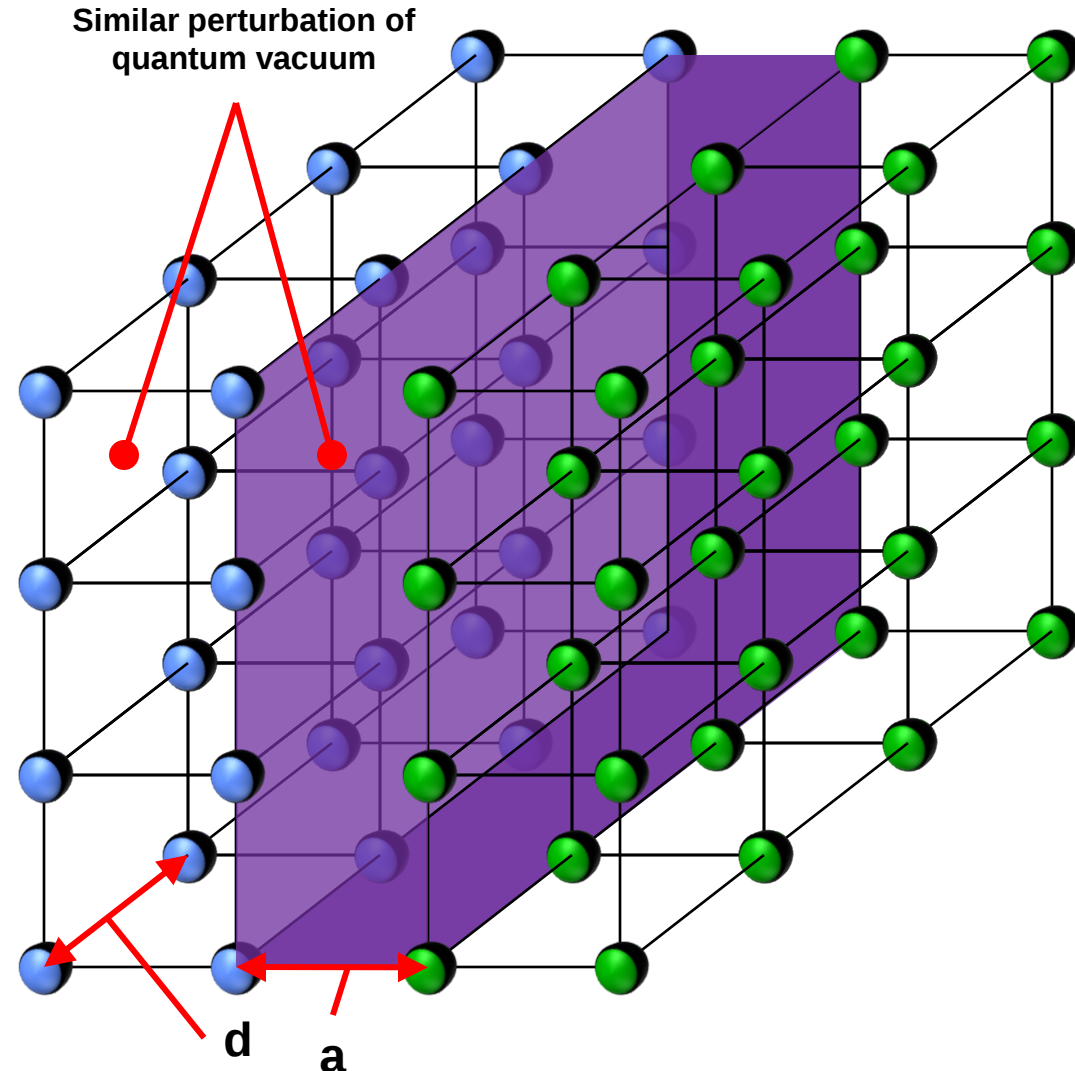
- A possible physical interpretation of the local perturbation of the quantum vacuum in the presence of ordinary matter is provided for consideration.
- In the Casimir cavity scenario, the presence of two conducting plates in very close proximity perturbs the local quantum vacuum state between the plates such that the pressure between the two plates is negative relative to the pressure outside the plates resulting in a force that pushes the plates together.
- As the separation distance between the two plates ' a ' becomes comparable to the inter-atomic spacing in the lattice structure of the plates ' d ', the two plates begin to approximate a single monolithic plate rather than two distinct plates.





What Does This Mean? (cont'd)

- In the limit of this scenario, the Casimir force does not know when to “shut off”, and the perturbed vacuum state will still have a negative pressure when compared to the unperturbed state.
- Similarly within the atomic lattice structure of either plate, there are infinite combinations of virtual Casimir cavities that can be traced out owing to the crystalline structure of the atomic nuclei.
- Said simply using the visualization tools of nuclear engineering, if quasi-classical pressure readings could be made from a miniature “atomic person” peering between the two plates with a quantum vacuum “pressure gauge”, the “atomic person” would find a similar perturbed negative pressure state of the quantum vacuum within the lattice structure of either plate.
- The quantum vacuum responds due to the presence of the two plates creating a distinct Casimir cavity, and similarly the quantum vacuum responds due to the presence of the virtual Casimir cavities defined by the crystalline structure of the local concentration of matter.





Bohr Radius

- The vacuum perturbation equation just derived can be used to evaluate the state of the quantum vacuum in close proximity of the proton at the center of the Hydrogen atom.
- The first step is to calculate a quasi-classical density for the hydrogen nucleus. The radius of the hydrogen atom nucleus is given as $R_0 = 1.2 \times 10^{-15} \text{ m}$ ($R = R_0 \cdot A^{1/3}$ where $R_0 = 1.2 \times 10^{-15} \text{ m}$ and A is the atomic number - these are experimentally determined by electron scattering).
- The radius can be used with the mass of a proton to calculate a quasi-classical density of the hydrogen nucleus:

$$\rho_m = \frac{m_p}{\frac{4}{3}\pi R_0^3} = 2.31 \times 10^{17} \frac{\text{kg}}{\text{m}^3}$$

- Using $\rho_v = 2/3 * 9.9 \times 10^{-27} \text{ kg/m}^3$, along with this quasi-classical density ρ_m , the perturbed negative pressure state of the quantum vacuum around the hydrogen nucleus is calculated to be:

$$\rho_{v_local} = \sqrt{\rho_m \rho_v} = 3.90 \times 10^{-5} \frac{\text{kg}}{\text{m}^3}$$

- The question can be asked how much volume of this perturbed state of the quantum vacuum is needed to have the equivalent energy value as the ground state of Hydrogen (13.6eV or $2.18 \times 10^{-18} \text{ Nm}$)

$$r = \left(\frac{E}{\rho_{v_local} c^2 \frac{4}{3}\pi} \right)^{\frac{1}{3}} = a_0$$

- The calculated radius is $r = 5.29 \times 10^{-11} \text{ m}$, which is an exact match to the given value for the Bohr Radius, $a_0 = 5.29 \times 10^{-11} \text{ m}$.



Electrostatic Force

- The derivation of the gravitational coupling constant included a macroscopic integration of the dark energy density over the light horizon. What happens if an analogous microscopic exercise is performed for the vacuum density present around the hydrogen atom? If the $2/3$ factor is included, the result is the electrostatic force

$$4\pi a_0^2 \frac{2}{3} \rho_{v_local} c^2 = \frac{q^2}{4\pi \epsilon_0 a_0^2}$$

- Similarly, the energy density of the electric field around the atom can be compared to the energy density of the vacuum density. Note that here the equation is exact only if one-third of the vacuum density is used.

$$\frac{1}{3} \rho_{v_local} c^2 = \frac{E \epsilon_0^2}{2}$$

- Both of these equations suggest that some of the tools of MHD can be used to model the behavior of the vacuum around the hydrogen atom, suggesting that some focus also be put on the magnetic field to see if this hypothesis remains consistent



Electron Mass

- Frank Wilczek, Nobel laureate: “We have achieved a beautiful and profound understanding of the origin of most of the mass of ordinary matter, but not of all of it. The value of the electron mass, in particular, remains deeply mysterious...”
- Consider the energy state of the perturbed quantum vacuum field around the proton, and set this equal to the kinetic energy of the orbiting electron at the ground state.

$$\frac{4}{3} \pi a_0^3 \rho_{v_local} c^2 = \frac{1}{2} m_e v^2$$

- We know the speed of the orbiting electron:

$$v = \alpha c = c / 137$$

- We can solve for the electron mass, and using the predicted value for ρ_{v_local} of $3.9 \times 10^{-5} \text{ kg/m}^3$, we get a predicted electron mass of $9.1 \times 10^{-31} \text{ kg}$.

$$m_e = \frac{\frac{8}{3} \pi a_0^3 \rho_{v_local} c^2}{\left(\frac{c}{137} \right)^2}$$



Principles of Q-thruster Operation

- Local mass concentrations, say in the form of a conventional capacitor with a ceramic dielectric, affect vacuum fluctuation density according to equation 1

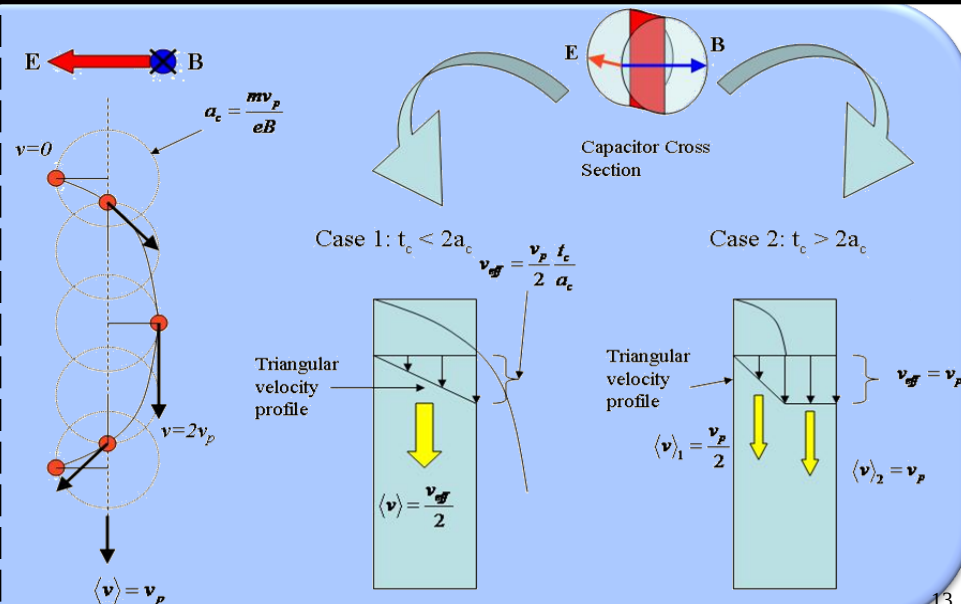
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$$\delta\rho = \frac{1}{4\pi G} \left(\frac{1}{\phi^2} \left(\frac{d\phi}{dt} \right)^2 - \frac{1}{\phi} \frac{d^2 \phi}{dt^2} \right) \quad \vec{a} = -\nabla \phi \quad (2)$$

- The tools of MagnetoHydroDynamics (MHD) can be used to model this modified vacuum fluctuation density analogous to how conventional forms of electric propulsion model propellant behavior.





Venus Sidebar

(Plasma Pressure & Magnetic Pressure illustration)

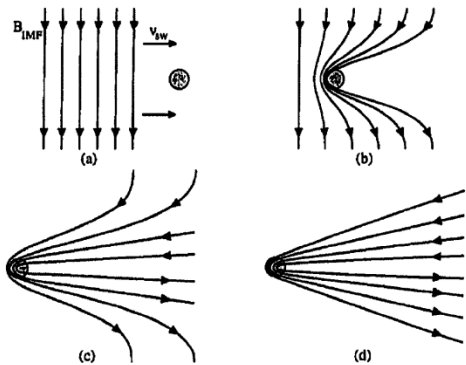
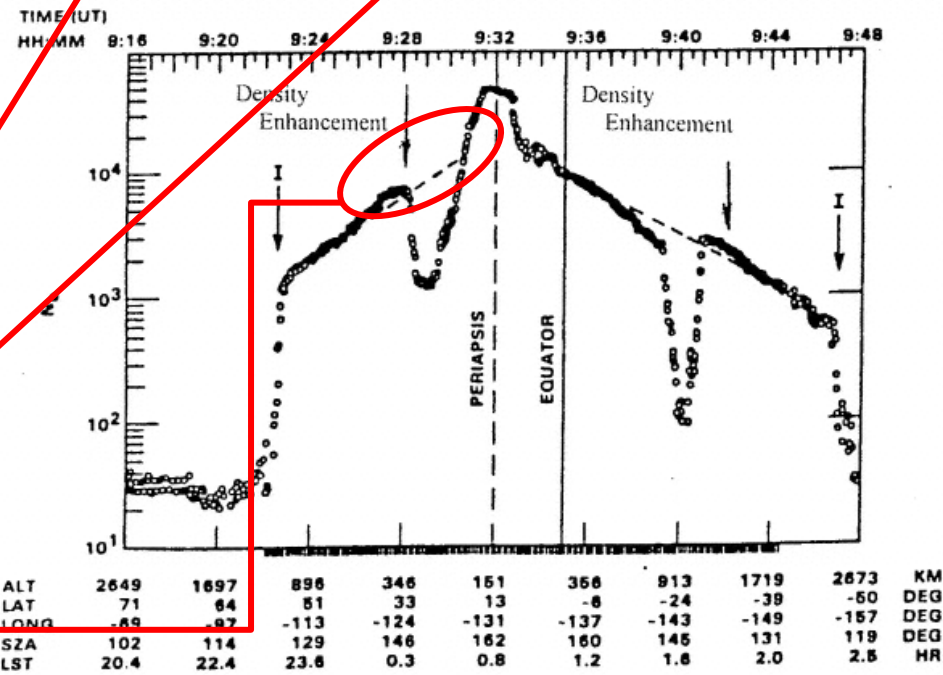
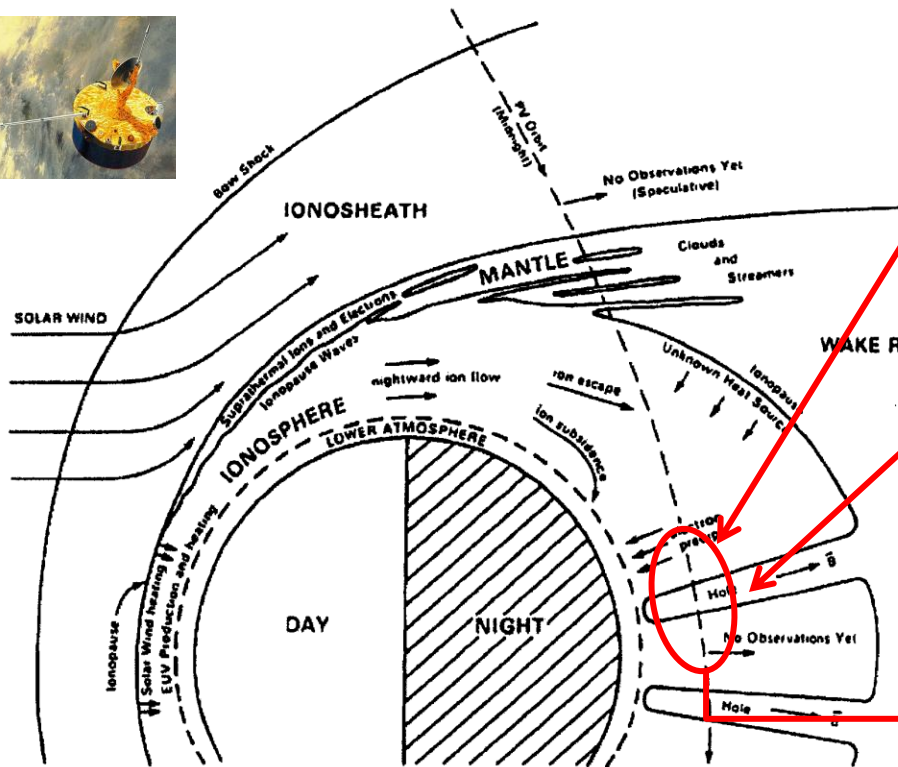


Figure 2.1-3: Depiction of draping of flux tubes to form magnetic tail [Alfvén, 1957]

- Pioneer Venus Orbiter (PVO) routinely traversed regions of extreme low plasma pressure (holes) on the night side of Venus enabled by the presence of enhanced magnetic pressure

$$P = n_e kT \rightarrow \frac{B^2}{2\mu_0} = n_e kT$$





Magnetic Pressure

- **The first step now is to calculate the magnetic pressure around the Hydrogen nucleus.**

The magnetic field as perceived by the electron is given by the following relationship. The speed of the orbiting electron is αc .

$$B = \frac{\mu_0 q v}{4\pi a_0^2}$$

The magnetic pressure is a simple calculation:

$$\frac{B^2}{2\mu_0} = 6.25 \times 10^7 \text{ N/m}^2$$

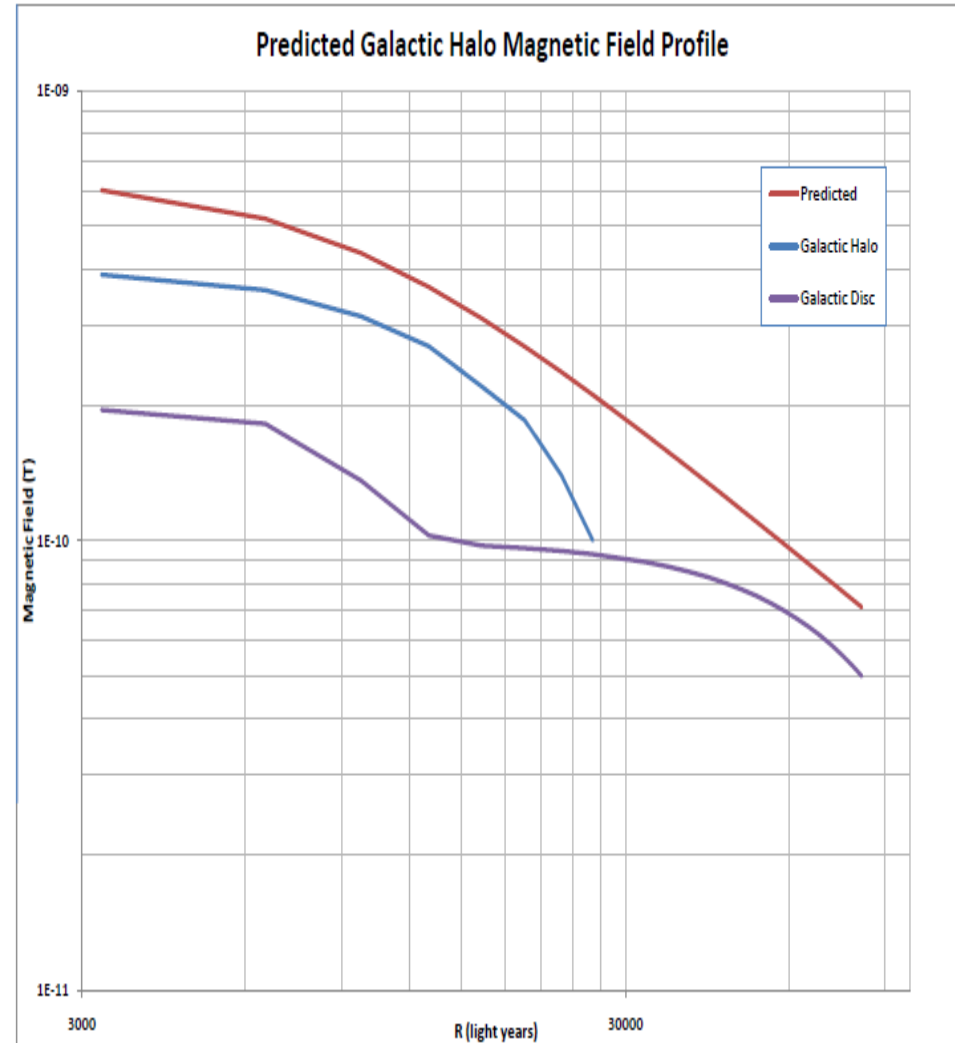
- **The quasi-classical plasma pressure of the perturbed quantum vacuum state around the Hydrogen nucleus can be calculated by converting the electron velocity to temperature using $1/2 m_e v^2 = kT$, and making the assumption that the virtual electron-positron plasma has the same effective temperature as the orbiting electron.**
- **When the plasma pressure calculation makes use of a $2/3$ factor, analogous to the predicted dark energy fraction of $2/3$ picked up during integration to calculate the Gravitational constant, the values are nearly identical:**

$$P = n_e kT = \frac{2}{3} \frac{\rho_{v_local}}{m_e} kT = 6.24 \times 10^7 \text{ N/m}^2$$



Intergalactic & Galactic Magnetic field

- Consider the extragalactic magnetic field which is estimated to be 1×10^{-12} Tesla. If the quantum vacuum can be treated as a virtual plasma, then the magnetic energy density (or pressure) should correlate to the plasma pressure. The magnetic pressure is calculated using the following equation: $P_B = B^2 / (2\mu_0)$, $B = 1 \times 10^{-12} \text{ T}$, $\mu_0 = 1.26 \times 10^{-6} \text{ T}^2 \text{ m}^3 / \text{J}$, $P_B = 3.98 \times 10^{-19} \text{ N/m}^2$. The plasma pressure can be calculated using the following equation: $P_{\text{plasma}} = n_e kT$. The electron-positron density n_e can be found using $n_e = \rho_c / m_e$. The critical density is as stated before, $\rho_c = 9.9 \times 10^{-27} \text{ kg/m}^3$, and the temperature is $T = 2.73 \text{ K}$. Assuming an electron-positron plasma population, the plasma pressure is $P_{\text{plasma}} = 4.09 \times 10^{-19} \text{ N/m}^2$.
- This relationship suggests that in the far field limit, the magnetic field affects the quantum vacuum. This same methodology can be applied to dark matter models for galaxies to see if there is a similar correlations when treating dark matter as a virtual electron-positron plasma. Current dark matter models for galaxies can be used to predict a galactic halo magnetic field as a function of galactic radius, and this magnetic field magnitude distribution can be compared to observation. Although galactic halo magnetic field strength and structure is not fully understood, the predictions can still be compared to the data and models available [8]. Figure 4 shows the comparison. As with the extragalactic magnetic field, there is a very strong correlation for the galactic magnetic field.
- These findings also show that the tools of MHD can successfully be used to model quasi-classical behavior of the vacuum.





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- Local mass concentrations, say in the form of a conventional capacitor with a ceramic dielectric, affect vacuum fluctuation density according to equation 1

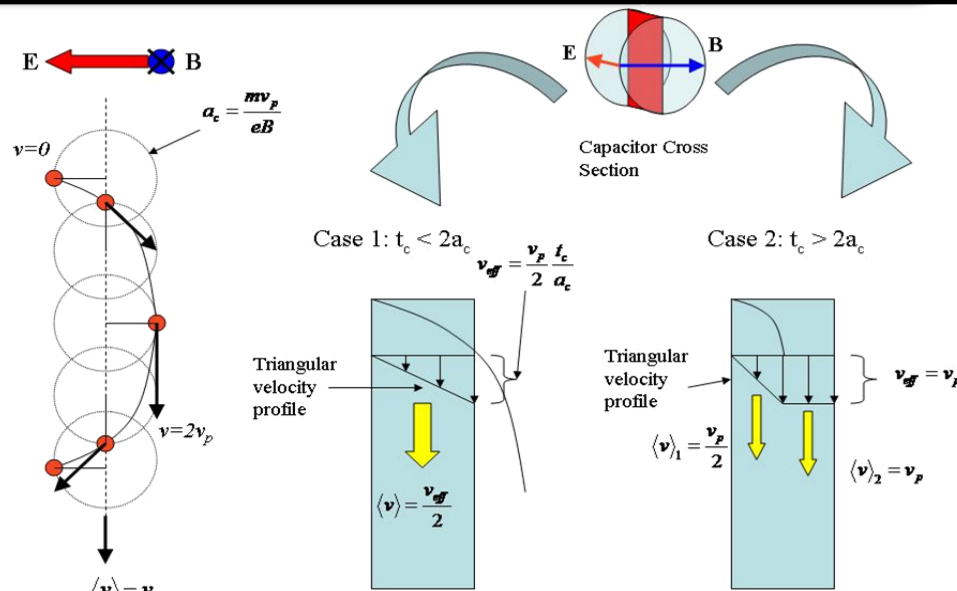
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$$\delta\rho = \frac{1}{4\pi G} \left(-\frac{1}{a^2} \left(\frac{da}{dt} \right)^2 + \frac{1}{a} \frac{d^2 a}{dt^2} \right)$$

$$\delta\rho = \frac{1}{4\pi G} \left(\frac{1}{\phi^2} \left(\frac{d\phi}{dt} \right)^2 - \frac{1}{\phi} \frac{d^2 \phi}{dt^2} \right) \quad \vec{a} = -\nabla\phi \quad (2)$$

- The tools of MagnetoHydroDynamics (MHD) can be used to model this modified vacuum fluctuation density analogous to how conventional forms of electric propulsion model propellant behavior.





What is the dynamic Casimir force?

- The dynamic Casimir force arises as a result of Unruh radiation where an accelerated observer sees the vacuum as a higher temperature photon bath, and is the mechanism that facilitates Hawking radiation around a black hole where relativistic acceleration separates a virtual pair such that one particle goes in the horizon, while the other escapes.
- Recent findings reported earlier in 2011 show that the dynamic Casimir effect may have been detected in the lab: <http://www.technologyreview.com/blog/arxiv/26813/>
- The simplest mechanical construct to help visualize using the dynamic Casimir force to generate thrust is through the use of vibrating mirrors where the mirror trajectory is designed to generate radiation in a preferred direction.
- The magnitude of thrust arising from using the dynamic Casimir force derived numerous times in the literature has been shown to be very small in comparison with conventional propulsion systems, but has been clearly shown to be theoretically possible.



FRW-derived wave equation

- The discussion will now continue on to derive a wave equation that relates perturbation of the quantum vacuum to first and second order time-varying potential terms.

- Start with the Friedmann equation:

$$\frac{1}{R^2} \left(\frac{dR}{dt} \right)^2 = \frac{8\pi G \rho}{3} \quad \underline{\text{A}}$$

- ...then using the fact that RT = constant [1] and incorporating Birkhoff's theorem[1]:

$$\frac{1}{R} \frac{dR}{dt} = - \frac{1}{T} \frac{dT}{dt} \quad \underline{\text{B}}$$

- Take the second derivative and simplify:

$$\frac{1}{R} \frac{d^2 R}{dt^2} = \frac{-1}{T} \left(- \frac{2}{T} \left(\frac{dT}{dt} \right)^2 + \frac{d^2 T}{dt^2} \right) \quad \underline{\text{C}}$$

- Birkhoff's theorem can be restated to facilitate substitution:

$$\frac{1}{R} \frac{d^2 R}{dt^2} = - \frac{4}{3} \pi G \rho \quad \underline{\text{D}}$$

- D can be subtracted from A to yield:

$$\frac{1}{R^2} \left(\frac{dR}{dt} \right)^2 - \frac{1}{R} \frac{d^2 R}{dt^2} = \frac{8\pi G \rho}{3} + \frac{4\pi G \rho}{3} \quad \underline{\text{E}}$$

- B and C can be substituted into E to recast the discussion from R to T :

$$- \frac{1}{T^2} \left(\frac{dT}{dt} \right)^2 + \frac{1}{T} \frac{d^2 T}{dt^2} = 4\pi G \rho \quad \underline{\text{F}}$$



Unruh Radiation

- At this point, let us consider Unruh radiation - Unruh radiation is conjectured thermal radiation emitted by the vacuum as detected by an accelerated observer.
- Said differently, an observer accelerated with respect to the vacuum will see themselves immersed in a thermal bath - the higher their acceleration, the higher the temperature of the thermal radiation. This relationship is defined as:

$$kT = \frac{\hbar a}{2\pi c} \Rightarrow T = \frac{\hbar a}{2\pi c k}$$



- In response to the proper acceleration a , the accelerated observer will see the vacuum take on the temperature, T .
- Taking the first and second time derivatives of $\underline{G}$, and substituting these relationships back into $\underline{E}$:

$$\delta\rho = \frac{1}{4\pi G} \left(-\frac{1}{a^2} \left(\frac{da}{dt} \right)^2 + \frac{1}{a} \frac{d^2 a}{dt^2} \right)$$

$$\delta\rho = \frac{1}{4\pi G} \left(\frac{1}{\phi^2} \left(\frac{d\phi}{dt} \right)^2 - \frac{1}{\phi} \frac{d^2 \phi}{dt^2} \right)$$

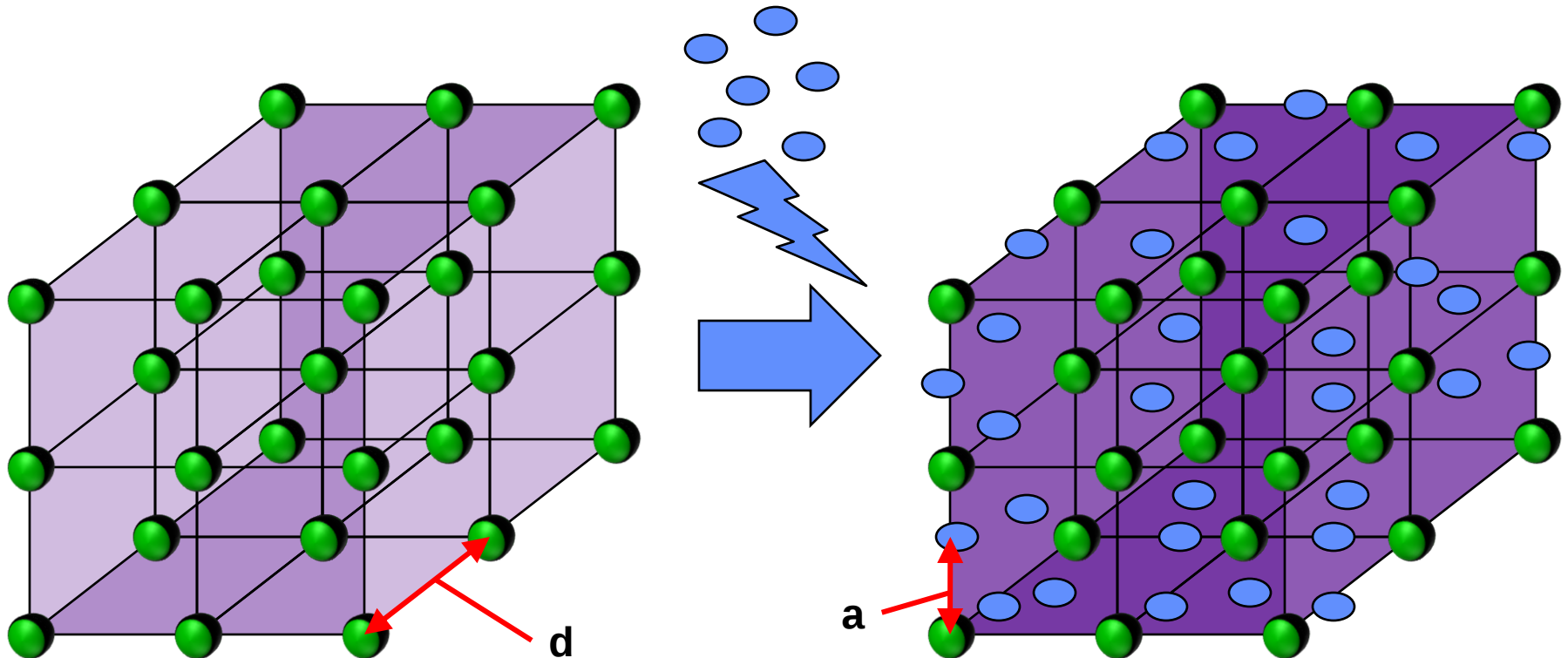
$$\vec{a} = -\nabla \phi$$

- This equation relates perturbation of the quantum vacuum to first and second order time-varying potential terms.



What Does This Mean?

- **Baseline geometry of matter has average lattice spacing.**
- **Addition of photon number density due to application of high power RF radiation decreases average spacing between “boundaries” in quantum vacuum.**
- **This gives the matter the appearance of having more “molecules” per given volume which simulates a higher density, and increases the perturbation of the vacuum to a more negative state.**

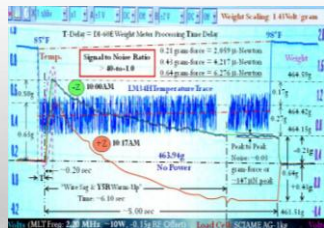




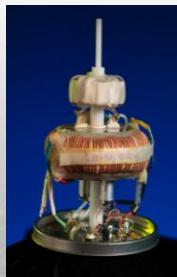
EAGLEWORKS LABORATORIES



2004 Test Article



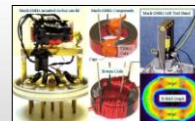
-4 mN Thrust
Specific Force ~0.4N/kW



2005 Test Campaign

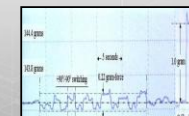
The test unit was run at 2.13 MHz, yielding an AC electric field of ~20kV/m, and an AC magnetic field of ~27 Gauss.

- Based on the input parameters, the QVPT thrust prediction was 0.63 mN
- The observed thrust was +/- 0.89 mN



The test unit was run at 3.8 MHz yielding an AC electric field of ~20kV/m, and an AC magnetic field of ~48 Gauss.

- Based on the input parameters, the QVPT thrust prediction was 2.79 mN
- The observed thrust was +4.91 to -1.96 mN as measured via a 4900 mN (500gf) load cell



As can be seen to the right, the thrust signal is very clear when the unit is excited.

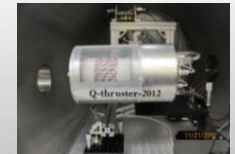
~3 mN Thrust
Specific Force ~0.3N/kW

2012 Test Article

2012 test article tested in November 2012

2012 test article tested -> 98uN predicted, 2-3 uN detected

- Scientifically very significant as vacuum fluctuation density had to be increased from ~1x10-26 to > 1x10-14
- As built quality factor much lower than desired, more engineering work necessary
- Adjustment to power distribution network are in work to address power losses, increase thrust level



~vacuum fluctuation density increased from 1x10-26 to >1x10-14

SFE Test Article at JSC

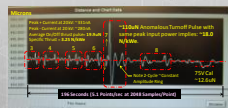
In 2013, Boeing/DARPA sent Eagleworks Lab an SFE test article for testing and evaluation

Evaluation of the test article in and out of a Faraday Shield performed from Feb through June 2013.

- There is a consistent transient thrust at device turn-on and turn-off that is consistent with Q-thruster physics
- The magnitude of the thrust scaled approximately with the cube of the input voltage (20-110uN).
- The magnitude of the thrust is dependent on the AC content of the turn-on and turn-off pulse
- Specific force of transient thrust was in the ~1-20 N/kW range.



SFE Test Article in Faraday Shield



-20-110 uN Thrust Pulses
Specific Force ~1-20N/kW

Microwave Thruster Device

Aviation Week, 5 Dec 2012

Unreal Results?

Chinese academics say they have performed the End-Drive Thruster

End-Drive Thruster

End-Drive Thruster

End-Drive Thruster

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End-Drive Thruster

SPR Ltd. Has produced several Microwave test articles. Claim is they produce thrust with just electric power input.

- Shawyer's theoretical model has been deemed non-viable by scientific community ([cshirley](#))

Thruster assessed against Q-thruster models and analysis suggests this may be a microwave version of a quantum vacuum plasma thruster.

- Tapered shape creates virtual toroid of active volume that can realize net thrust in virtual plasma.
- Microwave Q-thrusters would not be restricted to tapered construction.

Thrust magnitude increased over multiple test devices from 16 to 170mN

If Q-Thruster theory accounts for measured force, then microwave test articles may have ability to reach >10N/kW

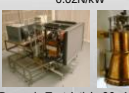
Chinese university claims to have duplicated EM Drive tests, but no way for U.S. to evaluate credibility (so we have ignored it)



16-170 mN Thruster
Specific Force 0.02-0.4N/kW



Prototype 16mN @ 850W, 0.02N/kW



Dynamic Test Article 96mN @ 334W, 0.3N/kW



High fidelity Test Article 170mN @ 450W, 0.4N/kW

Cannae Test Article

At DARPA's request, Eagleworks Lab began discussions with Cannae LLC on hosting a test article

Cannae's "Q-Drive" design is inspired by RF resonant cavity design used in particle linear accelerators

List-Group">

- Utilizes an asymmetric superconductive Niobium-Tin resonant cavity
- Cannae theoretical model is likely non-physical.

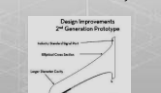
Initial assessment of conditions in thruster during operation indicate it may be a high frequency q-thruster.



First Generation Test Article



Cannae Test Facility



Second Generation Test Article (under development)

-7-10 mN Thruster
Specific Force ~0.75N/kW

What we suspect:

- A variety of industry experiments, for which theory is lacking, may be Q-thrusters including Boeing, Lockheed-Martin, EM Drive, Cannae, etc.
- Low measured thrust but specific power ranges from 0.3 to 10+ N/KW

Q-thruster Roadmap

~10N/kW

High altitude, high speed aircraft

Lox, LCH4 fed turbines power banks of q-thrusters

High thrust, high isp spacelift (2000s effective specific impulse)

In-space
Space-lift
Aero

?N/kW

In-space

~0.1N/kW



Blimp Test



ISS Free Flyer
COTS Free Flyer
Class D Mission



Space Tugs



Deep Space Exploration

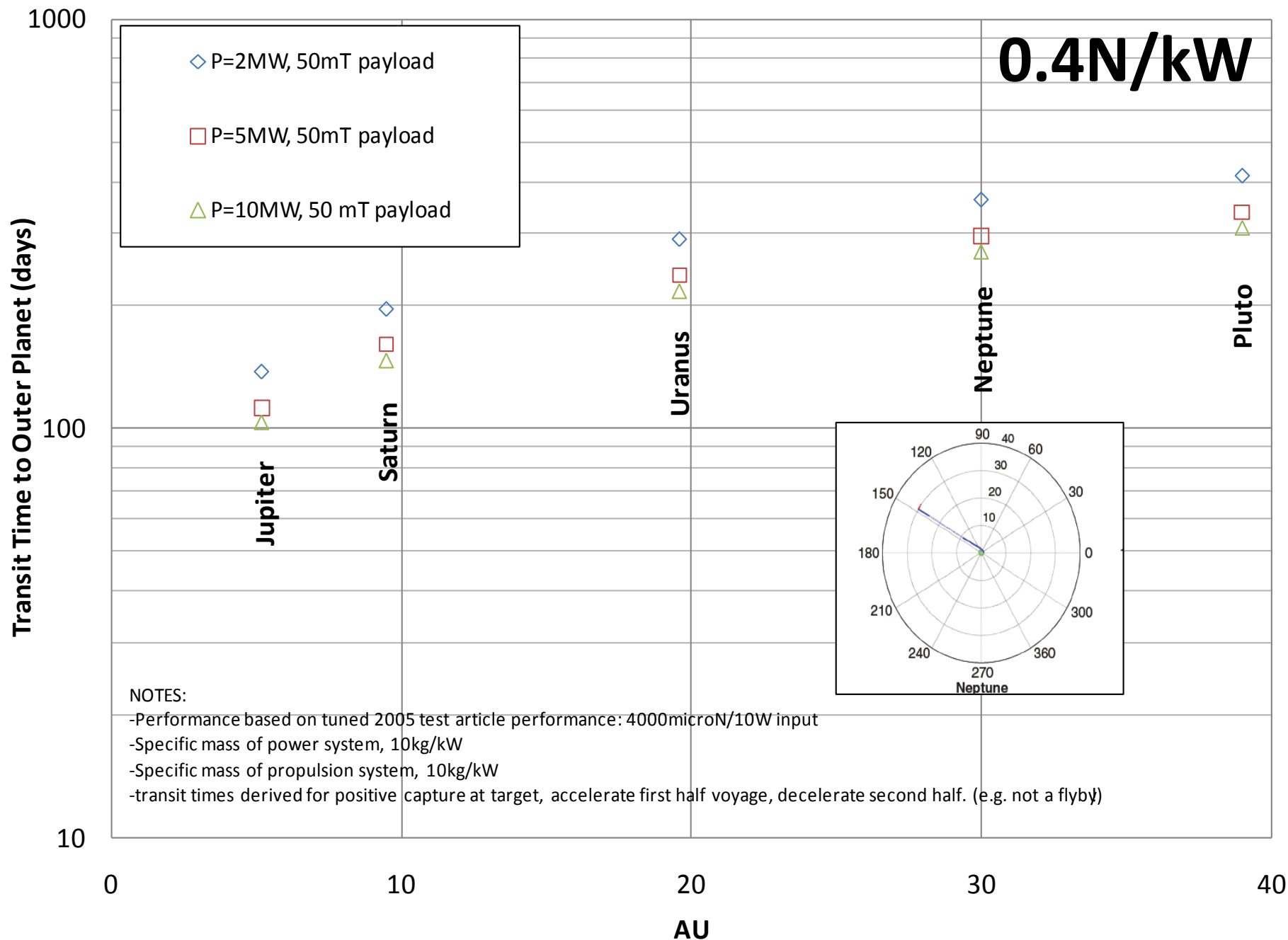


Repetitive powered overflight of ISR targets
(akin to Space UAV)

Outer solar system exploration & beyond

Fast Mars missions

Human Exploration of Outer Planets with Advanced Propulsion (QVPT)





Backups

Are there methods to increase net force?

- Recent models developed by White suggests that there are ways to increase the net force, and these models have been validated against data at both the cosmological scale, the quantum level, and test devices have been fabricated/tested in the lab and found to agree with model predictions:
 - Claim 1: an increase in local matter density correlates to an increase in local quantum vacuum energy density according to the following relationship: $\rho_{v_loc} = (\rho_v * \rho_m)^{0.5}$
 - This claim is substantiated by the fact that it exactly predicts the Bohr radius.
 - Claim 2: the energy density of the quantum vacuum can be amplified by not only acceleration, but by changing acceleration and subsequent derivatives.
 - this claim is substantiated by data from several test articles, but the upper limit of this hypothesis is not known at this time, and will be the subject of parallel scientific efforts.
 - This wave equation is derived using the FRW metric with the Unruh radiation equation. This equation can be shown to derive the relativistic relationship, $\phi=c^2$ developed by Sciamia [1]. A similar equation was previously derived by Woodward using a different approach in the literature [2].
 - Claim 3: the QV can be modeled as electron-positron virtual plasma (Dirac vacuum), and thus the tools of MHD can be successfully used to predict macroscopic behavior.
 - this claim is substantiated by cosmological observation (intergalactic magnetic field, dark matter/magnetic field distribution in galaxies)
 - this claim is substantiated by quantum observation – hydrogen magnetic field energy density exactly equals plasma pressure of vacuum density around proton in hydrogen atom.
 - It was recently shown in the literature [3] how ϵ_0 and μ_0 originate from the polarization and the magnetization of these virtual pairs.

[1] Sciamia, D. W., "On the Origin of Inertia", Monthly Notices of the Royal Astronomical Society, Vol. 113, 1952.

[2] Woodward, J., "Flux Capacitors and the Origin of Inertia", Foundations of Physics Volume 34, Number 10, 2004.

[3] available at < http://xxx.lanl.gov/PS_cache/arxiv/pdf/1106/1106.3996v1.pdf >



MHD Continuity Equations for Virtual Plasma shock // B

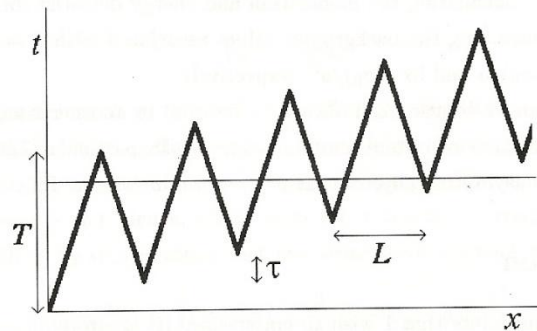
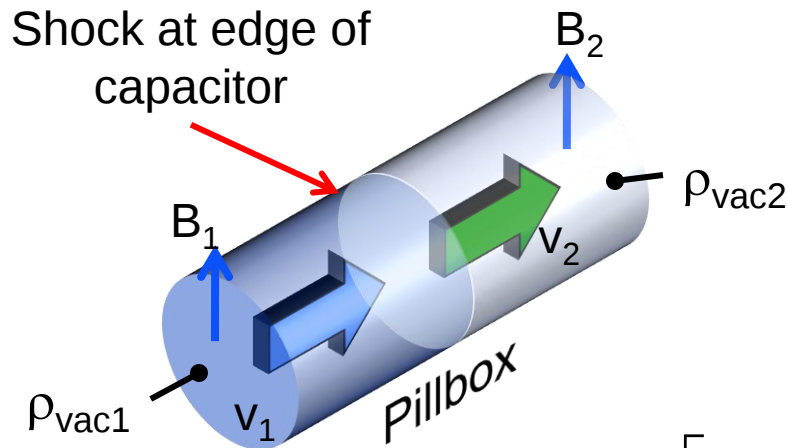


Figure 6: Possible spacetime picture of a superluminal phonon-like excitation. There are multiple pair-creation and pair-annihilation events organized so that the collective motion is fast $L/\tau \gg c$ while the individual particles move slowly ($L/(2T) < c$).

- **Conservation of Mass**

$$\Rightarrow \rho_1 v_1 = \rho_2 v_2$$

- **Momentum Conservation**

$$\rho_1 v_1^2 + P_1 + \frac{B_1^2}{2\mu_0} = \rho_2 v_2^2 + P_2 + \frac{B_2^2}{2\mu_0}$$

- **Energy Conservation**

$$v_1 \left[\frac{1}{2} \rho_1 v_1^2 + \frac{\gamma P_1}{\gamma - 1} + \frac{B_1^2}{\mu_0} \right] = v_2 \left[\frac{1}{2} \rho_2 v_2^2 + \frac{\gamma P_2}{\gamma - 1} + \frac{B_2^2}{\mu_0} \right]$$

Some possible mechanisms to satisfy conservation of mass: false vacuum, superluminal phonons, higher dimensional space-time, ?

$$\frac{dX}{dt} = \frac{ce^{kU}}{a(t)} \sqrt{1 - \frac{dU^2}{c^2 dt^2}}$$

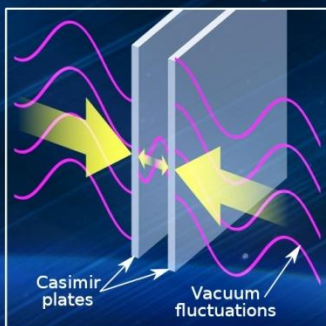


EAGLEWORKS LABORATORIES



Humanity should explore and colonize the Solar System in the next fifty years, while making human-crewed and robotic interstellar flights a real possibility by the end of the 21st Century. To that end, many dedicated teams and individuals are actively working to research and develop both the science and technology (propulsion & power) required to accomplish these goals. Propulsion and Power are the keys to exploration and utilization of the Solar System and beyond. Godspeed!

QUANTUM VACUUM THEORY

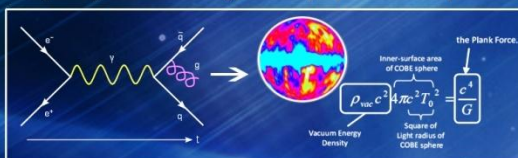


Casimir forces are predicted by the existence of Quantum Vacuum fluctuations

The theoretical calculation for the energy of the absolute zero ground state of the ZPF

$$E_0 = \int_{\omega=0}^{\omega_{cutoff}} \frac{\hbar \omega^3}{2\pi^2 c^3} d\omega$$

Integrating vacuum energy density of the COBE sphere



SUMMARY OF ABSTRACT

The Big Idea:

Use quantum vacuum "virtual plasma" for spacecraft propulsion. Scalable from milli-Newton to multiples of Newtons based on power level

The Approach:

Develop, Integrate, and Demonstrate 0.1-1N quantum vacuum plasma thruster prototype (0.3 - 3kW)

The Concept:

An excited state of the quantum vacuum is achieved by using a high density dielectric and high frequency electric field increasing the available vacuum density within the dielectric from $1 \times 10^{-27} \text{ kg/m}^3$ to $1 \times 10^{-12} \text{ kg/m}^3$

The Goal:

Q thruster prototype for testing on ISS targeting NEO/LI/MFB Reaction Control System (RCS) with force range of 0.1-1N with corresponding input power range of 0.3 - 3kW

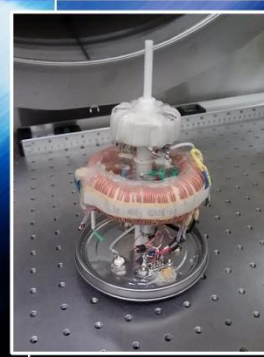
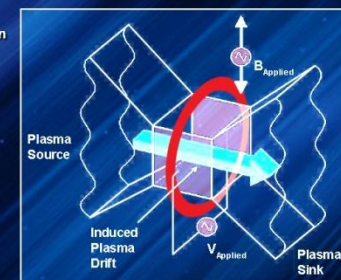


Low Thrust Torsion Pendulum Test-Bed for Model Investigation

PRINCIPLES OF Q-THRUSTER OPERATION

How Does the Q-Thruster Work?

- A Q thruster uses the same principles & equations of motion that a conventional plasma thruster would use, namely Magnetohydrodynamics (MHD), to predict propellant behavior.
- The virtual plasma is exposed to a crossed E and B-field which induces a plasma drift of the entire plasma in the ExB direction which is orthogonal to the applied fields.
- The difference arises in the fact that a QVPT uses quantum vacuum fluctuations as the fuel source, eliminating the need to carry propellant.
- An excited state of the quantum vacuum is achieved by using a high density dielectric and high frequency electric field increasing the available vacuum density within the dielectric from $1 \times 10^{-27} \text{ kg/m}^3$ to $1 \times 10^{-12} \text{ kg/m}^3$
- E field provided by capacitors spaced around ring, integrated into RLC tank circuit
- Frequency is tuned with amplifiers to create maximum plasma excitation



Mars

- To flyby: 30 days
- To capture: 37 days
- 2MW Power System
- 50mT Payload
- 40mT Power/Propulsion
- 90mT Total Mass

Jupiter

- To flyby: 112 days
- To capture: 135 days
- 2MW Power System
- 50mT Payload
- 40mT Power/Propulsion
- 90mT Total Mass

Proxima Centauri

- Realized for: 1,3009 parsecs
- 10MW Power System
- 50mT Payload
- 200mT Power/Propulsion
- 250mT Total Mass



Arrives in 100.28 years