The Physics behind the NASA Flyby Anomaly

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Abstract

From 1990 to 2005 NASA did six flybys of Earth in order to boost the energy of each spacecraft, enabling them to go deeper into the solar system. These six flybys showed an unexpected violation in the conservation of energy of up to 100 sigmas, matching a simple physical formula related to the input and output spacecraft velocities relative to the Earth rotational plane. Mysteriously, occasionally the effect was not present. After several years of reviewing the data and evaluating all sources of perturbation known to NASA, no solution was identified. NASA sent the final report to the author above for further review. Independently, the author's firm Optical Physics Company had published research into the vacuum field, finding that it was not constant but varied across the Earth's orbit and was also separately detected being radiated by the Sun. The physics we had learned was applied to the NASA passes, allowing all the anomalies they had encountered to be explained and adding considerably to our understanding of the vacuum field. We hypothesized a radially emitted vacuum field (which controls the rate of time) would couple the radial direction r with time t to add a g_{tr} term in the metric tensor. We then combined the previously published experimental data of the vacuum field radiated by the Sun with the NASA data to develop a formula for the emission of the vacuum field from warm rotating bodies, accurate to about 1%. 25 candidate formulas were evaluated, based on powers of radial acceleration and temperature, and one was definitively selected. This research offers a linkage between the vacuum field whose spectrum is proportional to h and an effect on the metric tensor of gravity. Since both gravity and h control time rates, it seemed credible they could both affect the metric tensor.

1. Introduction

From 1990 to 2005 NASA did six flybys of Earth [1] in order to boost the energy

of each spacecraft relative to the Sun, enabling them to go deeper into the solar system. Each of these fly-bys was carefully monitored from Earth using Doppler radar in order to verify that the encounter went as planned. To their surprise, NASA found that these encounters appeared to violate the NASA models of gravity and even more seriously violated conservation of energy in the center of mass of the Earth, where a spacecraft could leave the Earth with more energy than it came in with—100 sigmas more.

The NEAR mission passed the Earth in 1998 and gained 92.2 joules/kg of energy in the pass with an rms uncertainty of 0.9 joules/kg—about 100 sigmas of violation for energy conservation relative to Earth.

This conclusion of non-conservation of energy in the Earth coordinate system precipitated an in-depth evaluation at NASA of many candidate causes, all of which were discarded as negligible. This paper explores a potential solution to this NASA mystery which eliminates the fundamental issues of non-conservation of energy that the NASA data appeared to show. It explores the possibility that the vacuum field is being radiated by the Earth and Sun. Combining the NASA data with a previous experiment of annual variations in tunnel current on Earth, we found a simple physical model that derives the radiation law for the vacuum field that matches the rather accurate NASA data available.

While variations in the vacuum field may sound unfamiliar, over the past 60 years many scientists have made the vacuum field vary temporally and spatially in our laboratories by factors of 10-100X. This vast research has over 200 confirming experiments with well-developed theory and applications. Thus, the ability of the vacuum field to vary in both time and space is well documented in our laboratories and accepted by our standard model of physics [2] [3].

The vacuum field has its strength based on a parameter h, called Planck's constant. Despite its name suggesting that h is invariant, there is also considerable research supporting Planck's constant h varying across our solar system and across the cosmos. A number of papers [4]-[9], including US, German and Russian national labs, show up to 15 years of annual variations in strong and weak radioactive decay rates—all peaking around January and minimizing around July. The researchers were not able to identify a cause.

The number of time varying radioactive decay reports caught DARPA's interest, so Ref [10] was funded by DARPA to assemble the many experimental results related to time varying radioactive decay in the hope that someone could integrate them into a single theory. DARPA sent that data to this author for his investigation.

Since radioactive decay is exquisitely sensitive to Planck's constant in the denominator of the exponent, we hypothesized that these data could support a model where h varies linearly across the Earth's orbit, maximizing around January and minimizing around July.

To verify that variations in h were the cause, a separate tunnel diode experiment by the author had detected similar annual oscillations in tunnel current

consistent with a gradient in h across the Earth orbit of 231 ppm. The tunneling experiment also detected a radiated form of the vacuum field coming from the Sun with 13 sigma confidence as well as similar radiation aligned with the super red giant Betelgeuse with 7 sigmas of confidence. In those published papers, we have chosen to call the radiated form of the vacuum field Casimir Radiation after the scientist who first proposed that the vacuum field was real and how to verify it [11] [12] [13].

The success of this analysis below to explain the NASA Anomaly opens the possibility that there is a quantitative linkage between the vacuum field and the metric tensor of space.

2. The NASA Fly-By Anomaly

The six fly-bys of Earth were exquisitely measured and modeled by NASA, with accuracies as fine as 0.01 mm/sec for the velocity change in the Earth coordinate system. While the intent of the monitoring was simply to determine how precisely the fly-bys were accomplished, the data showed, by up to 100 sigmas, that energy was not conserved in the fly-by encounters, and in most passes the energy of the spacecraft increased.

In gravity theory, except for effects like atmospheric drag, an object enters and leaves the Earth space with the same energy. Thus, this anomaly led NASA to undertake an in-depth evaluation of all the factors, such as atmospheric drag, relativity effects and tidal acceleration. Nothing explained the data, and getting more energy out than in was considered a serious challenge to physics [1] .

Despite the lack of any identified cause, NASA did find an empirical formula for the energy gain or loss for these fly-by encounters as measured in the Earth coordinate system [1]. The spurious velocity gain or loss in all six passes (ΔV_∞) could be computed within the error bars by a simple formula.

$$\nabla V_\infty = K V_\infty \left(\cos \delta_{in} - \cos \delta_{out} \right) \tag{1}$$

where V_∞ = the incident velocity of the spacecraft far from Earth

K = a dimensionless constant evaluated to be 3.099×10^{-6}.

δ_{in} and δ_{out} were the declination angles relative to the Earth-rotational plane of the incident and outgoing spacecraft trajectory, suggesting that Earth rotation was a significant factor.

This formula fits the data quite well as shown in Figure 1, but the challenge is to find a physical model that matches this effect. NASA was unable to find one in standard physics. This paper presents a model that matches the NASA data, based on a coupling between the Earth's rotation and the gravity metric. Such a coupling is well known for angular momentum [14], but this model represents a potential new form of coupling between the Earth's rotation and the polar angle θ, based on a radial component of the vacuum field radiated by a rotating warm Earth.

This paper derives the radiation equation for the vacuum field, accurate to about 1% based on the accuracy of the NASA data.

The NASA Fly-By Data

The NASA data in Figure 2 is quite complete, including all the parameters needed for precise modeling of the pass. When we look at the NASA data, we realize that:

1) Some effect makes the Earth's gravity look stronger in the direction of the asymptotic spacecraft velocity, proportional to its velocity relative to the Earth.
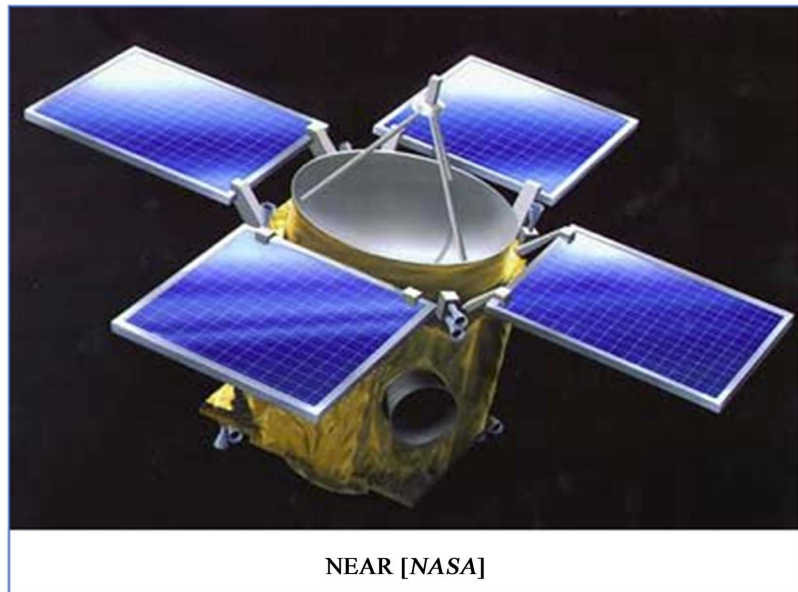

NEAR [*NASA*]

Figure 1. (Color) The NEAR spacecraft showed 100 sigmas of unexplained energy increase when flying past the Earth. The model presented here matches this measurement for radar data backscattered from the gold kapton, which covers the main body. Backscattered energy from dielectric surfaces is not predicted to show this anomaly as shown below. NASA did see a variation in the effect, ON or OFF in some passes.
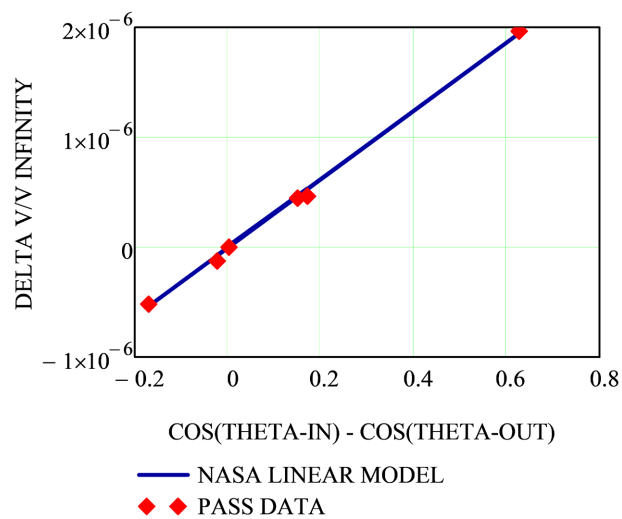

Figure 2. (Color) Here we plot the match between NASA's best fit model and the measured data for six different fly-bys of the Earth. It shows a deviation from conservation of energy up to 100 sigmas, which can be positive or negative. The deviation is linear in the cosine of the asymptotic velocities relative to the rotational plane of the Earth.

2) The increase in velocity is proportional to the magnitude of the velocity and not its sign since both incoming and outgoing portions of the trajectory have the effect of gravity increased.

3) Given that the sign of the velocity makes no difference, we conclude that the direction of Earth's rotation is not a factor.

4) However, since the anomalous gravity effect is aligned with the Earth's rotation axis, the magnitude of Earth's rotation must be a significant causal factor.

3. Developing the Physical Model

First of all, adding additional or modified gravitational interactions to the GR gravity equations of motion fails. The author has applied numerous forms of additional terms with various power laws with distance. They all fail for a fundamental reason. The effect NASA has found is proportional to the asymptotic velocity of the spacecraft at an infinite distance from the Earth. The velocity of any spacecraft increases substantially as the spacecraft approaches Earth, and any Earth-induced gravity effects also increase. Thus, the added velocity when approaching Earth creates effects that depend not just on the incoming velocity but also depend strongly on the distance of the closest approach—quite unable to match the NASA data which only depends on the spacecraft velocities far from Earth.

For this reason, we have concluded that modifications to the gravity equations that change gravity effects as the spacecraft gets closer to the Earth are unlikely to reproduce the effect reported by NASA.

We note that despite the many Casimir-type experiments [3], the vacuum field still offers mystery. Its ability to have no detectable power in one configuration and then to show the pressure of 19 psi (2 terawatts/cm^2) in another configuration has only recently been given a simple physical model [15]. In that publication, the vacuum field is modeled as a complex field with only negative frequencies, and this model is shown to match the theoretical intensity for spontaneous emission, making spontaneous emission into causal emission from the vacuum field.

In this paper, the vacuum field is central to the effects observed by NASA, which have no other identified cause in standard physics. The model [15], where the vacuum field is complex allows this NASA Anomaly to be explained as shown below.

3.1. The Long-Range Doppler Measurements

Now we focus on the NASA measurements themselves, which measure the Doppler shift of radar signals both as the spacecraft approaches the Earth and then leaves the Earth. NASA has, of course, removed the usual Doppler shift due to the Earth's rotation. The asymptotic frequency shift far from the Earth is used to determine the NASA Anomaly.

Since these asymptotic measurements occur when the spacecraft is far from

Earth, it is reasonable to assume that the spacecraft is not being significantly influenced by the Earth. Thus, we need to postulate an effect on Earth at the Doppler radar site that can explain these results.

In this paper, we explore a modified metric tensor, which incorporates the effect of the Earth's rotation. Specifically, we find that a new g_{tr} term for the metric tensor, which couples time and radial distance from the Earth, predicts measurements that exactly match the NASA data. Later in this paper, we explore the source for this new term.

We note that coupling time with another coordinate is not a new concept. The Kerr solution for the metric tensor outside a rotating planet links time and the equatorial angle θ. The exact form of the extra term in the Kerr solution is shown in Equation (2), where θ is the angle of the path relative to the equatorial plane.

$$g_{t\varphi} = \frac{4GJ}{c^3 r}\sin^2\theta \qquad (2)$$

where G = gravitational constant and J = angular momentum of the rotating planet, which for the Earth has $J = 2/5\, m_E R_E^2 \omega_E$. This modification to the metric tensor is many orders of magnitude too small to explain the NASA anomaly and has the wrong dependence on the polar angle, but it shows other research that has coupled time to a spatial coordinate for a rotating planet.

3.2. What are the Physical Consequences of a g_{tr} Modified Metric?

Let's begin by asking what happens to light propagation with this hypothesized extra g_{tr} term from a site on the Earth's equator. In particular, we will compute the Stress-Energy-Momentum tensor for a freely propagating E&M wave with the assumed modification to the metric tensor. We will find that the transmitted beam of known frequency has additional energy stored within it, due to the modified metric tensor and resulting in the NASA-observed frequency shift. Even better, conservation of energy is restored in this model since the anomaly is a measurement effect, not a satellite effect.

We begin by deriving the Stress-Energy-Momentum (SEM) tensor for a beam of light transmitted vertically into the equatorial plane from a site somewhere on the Earth. For convenience, we choose the local lab coordinate system where x and y are parallel to the Earth sphere, and z is the radial vector to space. This model can apply to any latitude once we specify how the g_{tr} term varies with latitude.

Coordinates:

$0 = ct$ = time
$1 = x$ = local θ direction (East)
$2 = y$ = local θ direction (North)
$3 = z = r$ = radial distance from the center of the Earth   (3)

To affect both polarizations of light equally, we hypothesize a coupling between the z (vertical) and time axes. To evaluate its impact, we simply denote it

as ε, where ε is the order of 10^{-6}, and our calculation will only keep the first order in ε, where $g_{\mu\nu}$ and $g^{\mu\nu}$ are identical tensors.

$$g_{\mu\nu} = g^{\mu\nu} = \begin{bmatrix} 1 & 0 & 0 & \varepsilon \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \varepsilon & 0 & 0 & -1 \end{bmatrix} \tag{4}$$

Setting up the Initial Beam Leaving the Transmitter

We begin by launching a beam of light of spatial frequency k in the radial direction. Both polarizations have the same physics since the modification to the metric tensor is in the r direction and thus orthogonal to both polarization axes. For mathematical convenience, we use a purely X polarized beam, which has only an A_1 component. This simple beam of light has only four components in the E & M field tensor $F_{\mu\nu}$, and all are equal in magnitude. Note that we have set all the various physical constants to unity to make the structure of the equations as clear as possible, not unusual for General Relativity derivations. [13]

$$A_1 = A_x \sin(k(r-ct))$$
$$F_{10} = A_{1|0} = A_x \cos(k(r-ct)) = -F_{01} \tag{5}$$
$$F_{13} = A_{1|3} = -A_x \cos(k(r-ct)) = -F_{31} = F_{01}$$

The E&M field tensor is shown in Equation (6).

$$F_{\mu\nu} = \begin{pmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix} A_x \cos(kr-ct) \tag{6}$$

To compute the Stress-Energy-Momentum (SEM) tensor for this E&M field we need to compute various forms of the field tensor and combine them properly.

$$F^{\mu}{}_{\nu} = \begin{bmatrix} 0 & \varepsilon-1 & 0 & 0 \\ -1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & -\varepsilon-1 & 0 & 0 \end{bmatrix} A_x \cos(k(r-ct))$$

$$F^{\mu\nu} = \begin{bmatrix} 0 & 1-\varepsilon & 0 & 0 \\ -1+\varepsilon & 0 & 0 & -1-\varepsilon \\ 0 & 0 & 0 & 0 \\ 0 & 1+\varepsilon & 0 & 0 \end{bmatrix} A_x \cos(k(r-ct)) \tag{7}$$

Now we assemble these terms into the Stress-Energy-Momentum (SEM) Tensor given by:

$$T^{\mu\nu} = F^{\mu}{}_{\alpha}F^{\alpha\nu} + \frac{1}{4}g^{\mu\nu}F^{\alpha\beta}F_{\alpha\beta} \tag{8}$$

The result is a symmetric SEM tensor which multiplies the power density of the E&M wave, where we kept only the terms linear in ε. We see that the T^{00} term (energy density) in Equation (10) has an additional factor of $1 + 2\varepsilon$ which

multiplies the usual power density.

$$T^{\mu\nu} = \left(\begin{bmatrix} (\varepsilon+1)^2 & 0 & 0 & -(\varepsilon^2-1) \\ 0 & -2\varepsilon & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -(\varepsilon^2-1) & 0 & 0 & (\varepsilon-1)^2 \end{bmatrix} - 4\varepsilon \begin{bmatrix} 1 & 0 & 0 & -\varepsilon \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ -\varepsilon & 0 & 0 & -1 \end{bmatrix} \right)$$
$$\cdot A_x^2 \cos^2\left(k(r-ct)\right) \tag{9}$$

$$T^{\mu\nu} = \begin{bmatrix} 1+2\varepsilon & 0 & 0 & 1 \\ 0 & -2\varepsilon & 0 & 0 \\ 0 & 0 & -4\varepsilon & 0 \\ 1 & 0 & 0 & 1-2\varepsilon \end{bmatrix} A_x^2 \cos^2\left(k(r-ct)\right) \tag{10}$$

We note that the rotational acceleration is proportional to the cosine of the polar angle, which will make this effect also proportional to the cosine of the polar angle and match the NASA data.

3.3. The Candidate Model for the NASA Data

In our model, ε is positive from the additional vacuum field radiating in the radial direction, and the power in this transmitted beam is 2ε more than what is expected. In our model, the source of the ε is the additional radiated vacuum field intensity from the Earth, which is a complex form of E&M radiation with zero mean power.

Since complex E&M radiation has zero mean real energy, if we are to see an effect from this complex radiation, something must happen to convert this complex vacuum radiation into a real signal that can affect the backscatter frequency from the satellite.

Fortunately, the many Casimir experiments have given us some practical clues:

If we model the vacuum field as a complex E&M field [14], then its familiar properties can be deduced for Casimir experiments.

- The vacuum field has zero mean energy and is thus invisible for most optical interactions.
- If we set up two mirrors close together (nanometers) and parallel, then the real part of the vacuum field reflects as usual and thus has relatively few modes between the mirrors compared to outside.
- The imaginary component does not interact with the mirror surfaces and simply transmits through the reflective surfaces without alteration.
- The reduced number of real modes between the plates is used to compute the vast pressure density due to the real component of radiation outside the pair of mirrors.

The key principle here is that only the real part of the vacuum field reflects from a mirror in the lab to create observable effects. The imaginary part simply transmits through the mirror. This reflected real part of the vacuum field creates up to 19 psi of pressure—equivalent to 2 gigawatts/cm^2 of reflected light on the outside of the pair of mirrors.

This extreme vacuum pressure was a shock to most scientists when Casimir experiments first began, but is now accepted. The vacuum field has no net energy but can exert 19 psi radiation pressure on two mirrors close together due to the extremely high power in the real part of the vacuum field.

Case 1: Reflecting off a Kapton Surface

Using this observed Casimir result, we hypothesize that the $2\varepsilon(1+i)$ complex field component interacts with the transmitted beam as it exits the Earth's environment to increase its energy by a complex amount. When the beam reflects off a kapton metallic surface, the main beam and the real part of the Casimir term reflect together and in phase while the imaginary component does not reflect as shown in Figure 3.

This reflected beam now has 2ε (~3 ppm) more fractional energy, which could mean either that new photons suddenly appear or that the energy of each photon is increased slightly. Given no obvious mechanism to generate new photons of the same frequency at the reflection surface, we are left with the extra energy being added to the energy of each photon as it reflects from the metallic layer, increasing the frequency of the light in the rest coordinate system of the satellite by the fraction 2ε. This increased frequency is in the center of mass of the satellite and thus increases the return frequency at the NASA tracker by the change in frequency times the usual Doppler shift of $2v/c$ for the satellite. This is exactly what NASA reports.

What NASA observes is the asymptotic frequency shift for the incoming and outgoing spacecraft. According to modern gravity theory, they should be of equal magnitude and oppositely signed, indicating equal incoming and outgoing speeds, but they are shifted by up to 3 ppm according to Equation (1).

Clearly, we don't have field equations yet for such a process, but if we believe that conservation of photons and conservation of energy are relevant here, then we are guided to this conclusion.

Case 2: Scattering off a Dielectric Surface

When a dielectric surface is used, we have E&M backscatter that comes from the roughness of the surface and the change in refractive index, which we assume
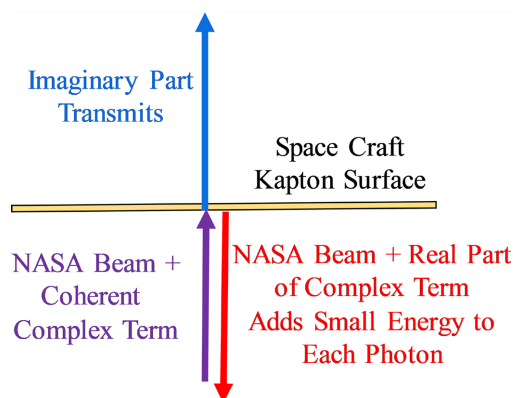

Figure 3. (Color) Only the real part of the NASA radar beam reflects off a Kapton surface since the imaginary part cannot create imaginary reflective currents.

will affect the real and imaginary components equally. In this case, there would be no change in the energy or frequency of the return light.

If ε is proportional to the cosine of the direction relative to the equatorial plane due to the Earth radiation, then we have a model that exactly matches the NASA data with a metallic surface such as kapton. The result is that the vehicle appears to be going faster than expected in proportion to the cosine of the latitude of the direction and in proportion to the speed of the spacecraft divided by c—whether coming in or going out. This frequency shift due to the metric tensor around the Earth applies equally to both the incoming and exiting portions of the engagement, and since both the incoming and outgoing velocities are identical in GR theory, the combined effect is proportional to the difference between their two cosine latitudes.

This is, of course, what NASA has found.

The key point of every Casimir experiment is that the vacuum field exerts no pressure unless you reflect it. The reason behind this observation is that the vacuum field is well modeled as a complex E & M wave of the form $e^{ik(x-ct)}$. [14] As a complex form of electromagnetic radiation, it has zero momentum and zero energy density despite having a field intensity greater than the total power output of the Earth in every square cm. However, when the vacuum field reflects off a mirror surface in a Casimir experiment, only the real part reflects, since the electrons do not have the ability to oscillate in an imaginary direction. The reflection of the real part of the vacuum field creates the massive pressure of 19 psi observed in Casimir experiments even while the vacuum beam itself is invisible.

A single mirror shows no effect when reflecting the ubiquitous vacuum field because the reflected real part is joined by the transmitted imaginary part from the other side. However, Casimir experiments use two mirrors close together so that the internal volume supports only a few wavelengths, making the internal pressure much less. Pressures as much as 19 psi are routinely reported due to reflecting the real part of the Casimir radiation.

We suggest that the same effect is happening when NASA probes a spacecraft going by the Earth. The laser light has an added term in the Stress-Energy-Momentum tensor term T_{00} equal to 2ε in Equation (10), generated by the g_{tr} term in the metric tensor. This term 2ε is complex since the Casimir radiation that generates this term is itself complex. The frequency of the light is thus unaffected until the light reflects off a metalized surface (such as kapton) on the spacecraft. Upon reflection, only the real part of the Casimir light reflects just as in the Casimir lab experiments, so the contribution of the radiation to the energy content of the light is now real and positive—increasing its frequency to match the NASA data. Unlike a usual Casimir experiment, this reflected light is coherent with the reflected laser beam.

In summary, one way we know to make the vacuum field interact physically is to reflect it off a mirror, separating the real from the imaginary component. It works in the many Casimir experiments, and we are proposing it here to explain

the 100 sigmas of apparent violation of conservation of energy in the NASA anomaly. The effect of this process on gravity red shift experiments is discussed later and shown to be negligible.

4. A Physical Model Derivation to Explain This Modified Metric Tensor

Since the new term in the metric tensor is so large in magnitude (~10^{-6}) compared to the usual gravity terms (10^{-9}), it appears not to have any dependence on the mass of the Earth or the gravitational constant, and thus is not caused by any usual gravitational effect. So what would be its source?

We have some clues:

1) The source of this new term is associated with the rotation of the Earth and varies proportional to the cosine of the satellite direction with respect to the Earth's plane of rotation.

2) An added metric tensor term that couples time and radius from the Earth matches the NASA data perfectly.

Uniting all these clues, we have chosen a new direction to explore.

Hypothesis: The effect we are looking for is a modification to a time term (g_{tr}) in the metric tensor created by some form of radiation coming from a rotating body.

There are only two physical processes known to our physics that control time rate:

1) Gravity

2) Casimir radiation (the spectrum characterized by Planck's constant h)

While Casimir radiation is typically specified as a particular spectrum computed from zero-point energy, it has been shown to vary from 10-100:1 in intensity in our labs both spatially and temporally. [3] [4] Approximately 200 Casimir experiments have put two reflecting surfaces close together to reduce the Casimir radiation between the two. [4] The impact is huge, creating up to 19 psi radiation force squeezing the two plates together, and it all comes from a spatial non-uniformity in Casimir radiation. If variations in Casimir radiation exist in our labs, why not in the rest of space?

Adding to the variations in h seen in laboratory Casimir experiments, we have two deep space studies showing with 3.4 and 4.2 sigma certainty that the fine structure constant alpha varies with an apparent cosine distribution in the sky. That constant $\alpha = 2\pi k_e e^2 / hc$ includes h in its denominator, lending support that the same h variations we see in our labs may also be present in the larger universe [15] [16] [17].

A completely different type of research on radioactive decay (strong and weak interactions) shows the fastest decay rates in January and minimum decay rates in July of each year [5]-[10].

The author verified annual variations in tunnel current with a purely electromagnetic test using Schottky tunnel diodes over two and a half years [11] [12].

All of these radiation and tunneling experiments share the common factor that they are exponentially affected by Planck's constant h, and no other physical effect has been found as a probable cause.

4.1. Casimir Radiation Law Derived

We are hypothesizing that radial Casimir radiation from the Earth is coupling into the g_{tr} term of the metric tensor. To explore this hypothesis in more detail, we would like to find a radiation law for the vacuum field. Fortunately, previous papers by the author show how the Schottky tunnel diode experiment detected Casimir radiation coming from the Sun with 13 sigmas of confidence [11] [12]. Using the measured data for the Sun radiation and the observed NASA data, we can search among the candidate radiation laws and see if any match the data for both effects.

To be precise:

- We hypothesize here that Casimir radiation (the vacuum field) is being continually emitted by stars and planets everywhere, and below we derive a candidate emission formula for that rate of Planck radiation, which matches the observed NASA flyby anomaly as well as the detected Casimir radiation from the Sun.
- In searching for a radiation law, we hypothesize that the electromagnetic Planck spectrum can be generated by any warm source similar to the way that thermal light is radiated. However, to be consistent with the NASA anomaly, the rate of Casimir radiation must include a rotation factor, which makes it quite distinct from simple thermal radiation.

4.2. How Is Casimir Radiation Produced?

There is currently no theoretical model available in standard physics for the emission of Casimir radiation, so we were guided by the NASA data and the measured magnitude of the Casimir radiation from the Sun—published data from the author's 2.5-year tunnel diode Planck experiment [11] [12].

We knew the NASA effect varied proportional to the cosine of the direction of the space vehicle velocity relative to the plane of rotation of the Earth. This cosine relationship required rotation of the Earth to be a factor, quite different from standard blackbody emission of E&M light, and is a familiar angular dependence for radiated E&M amplitude from a spinning source. We discuss the physics of this angular dependence more later.

Given both the NASA Earth data [1] and the previously detected Casimir radiation from the Sun [11] [12], we were able to test the candidate formulas to see which one best-matched the variations in the vacuum field radiation for both Earth and Sun data simultaneously.

In searching for a physical formula for Planck radiation, we assumed it would be a simple power-law of local effects involving the temperature T and radial acceleration, and we allowed the temperature to have an exponent in the range 0 -

4 and radial acceleration to have an exponent in the range 0 - 4. With these parameters, this created 5 * 5 = 25 possible power laws, which were scored by how well they predicted the observed ratio between Casimir radiation measured for the Earth and the Sun. The functional form we chose to evaluate was a simple product of a constant times a power of temperature times a power of radial acceleration.

$$\text{Planck Radiation}\left(T, R\omega^2\right) = \text{Const} \cdot hT^{n_1}\left(R\omega^2\right)^{n_2} \tag{11}$$

For the truth value of Earth radiation, we used the metric value derived above (g_{tr} = 1.547 ppm) that best matched the observed data in the NASA analysis discussed above.

4.3. Equation Evaluation

For the Sun, we used the experimentally measured value on Earth for the Casimir radiation from the Sun [11] [12] of 2.31 ppm divided by the estimated gain of the Schottky tunnel diode with respect to h (40.85). Then we scaled that result by $1/r^2$ from the Earth's orbit at 1 AU from the Sun to the surface of the Sun's equator (6.955×10^5 km). This gave us an estimate for the Casimir radiation at the surface of the Sun on its equator. The tilt of the Sun relative to the Earth's orbital plane is 7 deg, so depending on the time of year, there may be a cosine factor in the radiation varying from cos(7 deg) = 0.993 to 1.0, which is a small enough correction to be ignored in this evaluation.

The accuracy of this estimate for solar Casimir radiation was set by our uncertainty in the fractional change in the tunnel diode signal per fractional change in the Planck radiation. We computed this parameter $\text{Gain}_{\text{sensor}}$ = 40.85 with a ±25% uncertainty due to not knowing the exact shape of the barrier voltage profile inside the tunnel diode. [10] The uncertainty in the tunneling gain with variations in h is the main uncertainty in setting the absolute radiation coefficient.

$$\text{Sun Radiation} = h\frac{2.31\,\text{ppm}}{\text{Gain}_{\text{sensor}}}\left(\frac{AU}{R_{\text{SUN}}}\right)^2 = 2.616 \times 10^{-3} \cdot h \tag{12}$$

The metric we used for evaluating various physical models for Casimir radiation was the ratio between the predicted emitted Planck intensity between the Sun and the Earth. The NASA radiance seems quite well determined (<1% rms uncertainty), so our only significant uncertainty is with the Planck data for the sun as measured by our tunnel diode detector.

To find the meaningful candidates, we required the formula to have only locally impactful parameters. This meant that the local temperature T would be a valid parameter as would the rotational acceleration $R\omega^2$, but R by itself or ω by itself would not be a local parameter and would cause a candidate equation to be discarded. Thus, we chose only two local physical parameters, temperature T and the local acceleration $\omega^2 R$ to vary in our physical model of Casimir radiation, and we allowed their powers to vary from 0 - 4 for a total of 25 candidate radiation laws.

We then required that the formulas match the estimated ratio between the Sun and Earth Planck radiation ± 25%, our estimated maximum range of experimental error for that ratio based on uncertainty in the barrier voltage profile across the tunnel diode. The scoring plot for all 25 candidate equations is shown in **Figure 4**, and then zoomed in to examine the more interesting candidates more closely in **Figure 5**.

Expanding the vertical scale in **Figure 4**, we can see how the nearest candidate equations scored more clearly. Only two of our candidate equations (Equations (8) and (19)) scored well (within 3% of the measured Sun-Earth radiation ratio), and all the rest were at least a factor of 4.3 away from the estimated Sun-Earth radiation ratio.
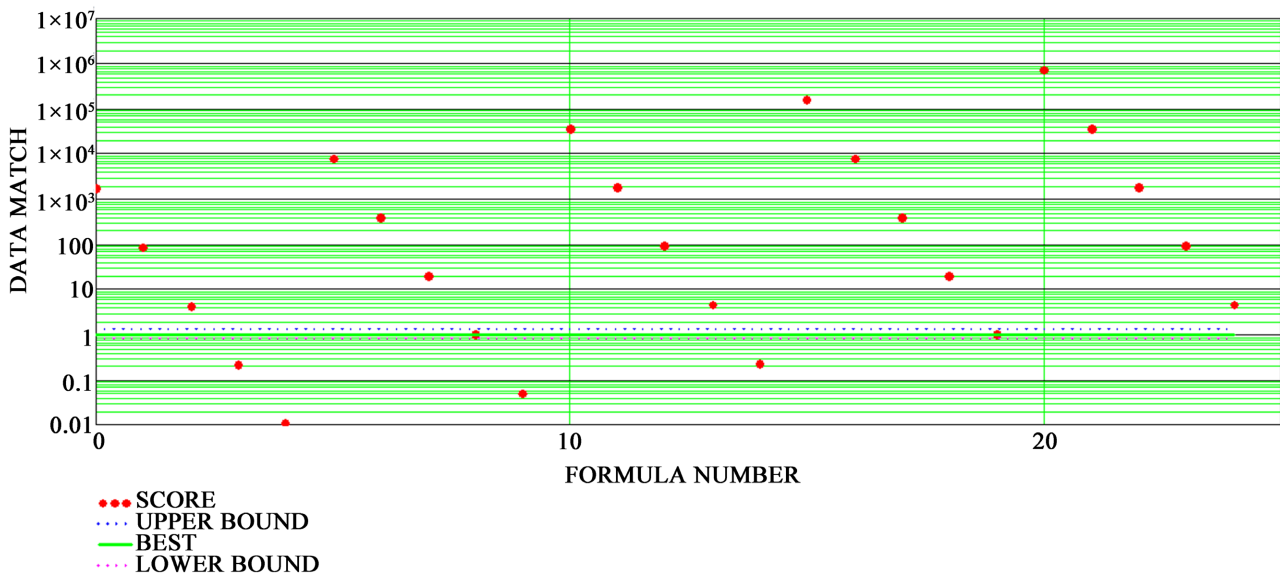

Figure 4. Of the 25 candidate formulas tested for matching the ratio between the measured Earth and Sun Planck radiation, only 2 fell within our ±25% error bounds.

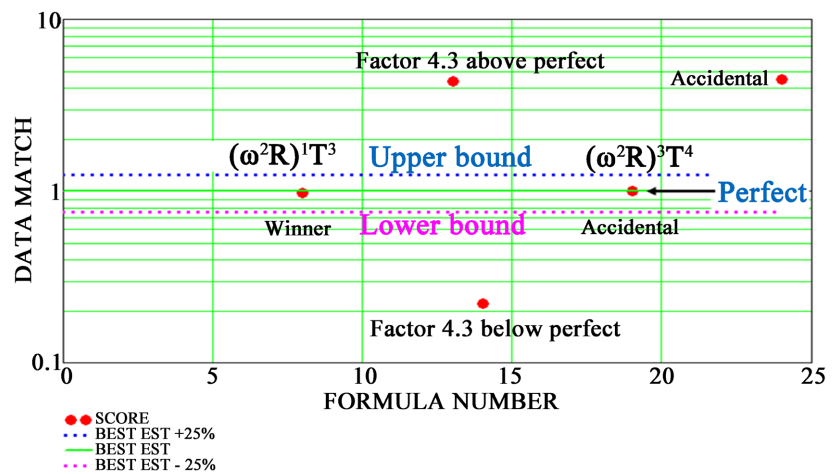**Figure 5.** Only formulas 8 and 19 (accidental pair) fell inside our ±25% error bars. They had an error of only 3% while the next closest formula had an error factor of 4.3, about 130 X worse.

An expanded scale plot (Figure 5) shows the two winning equations in more detail.

4.4. An Accidental Symmetry of Nature

The reader might notice that formula numbers 11 apart are almost identical. This is because of an accidental symmetry in the various parameters of the Earth and Sun as shown below. If you increase the power of the temperature by 1 and the power of the rotation term by 2, the error changes by only 2.2%. When we have an accidental echo pair within our 25% target error, we need to use physical logic to choose between them.

$$\left(\frac{T_{\text{Earth}}}{T_{\text{SUN}}}\right)^1 \left(\frac{\omega_{\text{Earth}}^2 R_{\text{Earth}} \cos\theta_{\text{lat}}}{\omega_{\text{SUN}}^2 R_{\text{SUN}}}\right)^2 = 1.022 \tag{13}$$

Since the NASA-observed effect varies linearly with the cosine of the latitude for the distant spacecraft, we chose the formula that had acceleration to the unit power rather than the echo that required acceleration cubed. This matches our experience with E&M radiation where the amplitude is emitted proportional to radial acceleration and varies linearly with the cosine of the latitude. The rejected formula had acceleration cubed, which would be expected to produce a cosine-cubed angular distribution.

4.5. Result of the Equation Validation

Of the 25 candidate equations, only one and its accidental echo were within our ±25% constraints of the data. The radiation equation that varied linearly with the cosine of the latitude was selected as our radiation model at 2.7% deviation from predictions: $T^3(\omega^2 R_E \cos(\theta_{\text{lat}}))^1$, where θ_{lat} = the latitude of the transmitter (35.24 deg) and T = annual mean temperature for the ground site (291 K).

The next best candidate was a factor of 4.3 from the green expectation line and far outside our estimated error bars. Our final choice for the Casimir radiation equation and the logic used to set the coefficient is summarized in Table 1.

4.6. Is There a Thermal Cutoff to the Emission Frequency?

Since we have modeled Casimir radiation as a form of thermal emission coupled to acceleration, we considered adding an additional term, familiar in the standard blackbody radiation, *i.e.* the thermal exponent—$\exp(-h\nu/k_B T)$, but our frequency range is too small to show much effect. Since the vacuum field has zero real energy, it is expected that this term is not present. This zero real energy was one of the reasons that it took so long to verify the existence of the vacuum field and why Casimir's contribution was so important [2].

4.7. What about the Hotter Interior of the Earth?

If the full Earth volume or the full Sun volume were generating this radiation, then the effective temperatures would be much higher, since the core temperatures

Table 1. The logic to assemble the final equation for Casimir Radiation of the Vacuum Field from a warm rotating sphere.

$\text{Casimir Radiation} = C_{\text{Cas}} h \dfrac{\left(R_{\text{Earth}} \omega_{\text{Earth}}^2 \cos\theta_{\text{lat}} \right) T_{\text{Earth}}^3}{\left(\dfrac{r_{\text{tgt}}}{R_{\text{Earth}}} \right)^2}$	Equation form found to match the measured ratio of Sun and Earth radiation	(14)
$C_{\text{Cas}} = \dfrac{\dfrac{\omega_{\text{Earth}} R_{\text{Earth}}}{c}}{R_{\text{Earth}} \omega_{\text{Earth}}^2 \cos\theta_{\text{lat}} T_{\text{Earth}}^3} = 2.259 \times 10^{-12} \left[\dfrac{s^2}{K^3 \cdot m} \right]$	Solve for coefficient using the very accurate NASA data	(15)
$\dfrac{\Delta h_{\text{radial}}}{h} = C_{\text{Cas}} \dfrac{R \omega^2 T^3}{\left(\dfrac{r}{R} \right)^2} \cos\theta$	Final formula for all Casimir radiation	(16)
$\dfrac{\Delta h_{\text{radial\_Earth}}}{h} = 1.547 \times 10^{-6}$ from formula	Earth Radiation $= 1.547 \times 10^{-6}$ measured	Cross-checks on final equation
$\dfrac{\Delta h_{\text{radial\_SUN}}}{h} = 2.677 \times 10^{-3}$ from formula	SUN Radiation $= 2.616 \times 10^{-3}$ measured	

R = radius of the star or planet, T = Surface temperature, ω = rotation rate (rad/sec), r = distance from the star or planet, θ = polar angle.

are vastly higher than the surface temperatures. Since the surface temperatures of the Sun and Earth provide good agreement with the NASA and Sun data, that would require that Casimir radiation reaches an equilibrium with the local temperature and acceleration just like normal thermal radiation. This in turn would require a mechanism to equilibrate the Casimir radiation coming from a hotter region into a cooler region.

We know from a large number of Casimir lab experiments that Casimir radiation is a form of E&M radiation that reflects off mirrors and very likely behaves like regular E&M energy in scattering off atoms and other particles. Normal thermal light moving from a hotter to a cooler region of matter automatically adjusts itself into local equilibrium, and we expect the same behavior with Casimir radiation. We note that Casimir radiation has zero energy and zero momentum, so it may be quite easy to equilibrate simply by multiple scattering.

4.8. Linkage between the Vacuum Field and the Metric Tensor

Based on the current model showing a g_{tr} coupling between time and radius due to a warm sphere radiating the vacuum field, we point out that the physical process of generating a spatially varying metric tensor has not been offered in physics. We simply say that every mass produces a metric tensor field around it with specific equations.

In the NASA data, we have found a coupling between time and radius which matches the experimental results when we have anisotropic vacuum radiation. If the vacuum radiation was isotropic, then we would have only diagonal couplings into the metric tensor, offering the possible physics that the vacuum field is a potential cause of the metric tensor.

In discussing this conjecture, we point out that the main effect of gravity is variations in the rate of time, affecting the g_{00} term of the metric tensor. Based on the current analysis of the NASA Anomaly, we could also hypothesize that the metric tensor is the physical effect of the vacuum field radiating from a mass body. However, we would immediately point out that the vacuum field radiation requires a warm body while gravity does not, allowing us to definitively conclude that the two effects on time (vacuum field and metric tensor) are independent.

5. Summary

A possible solution to the NASA conundrum is offered in this paper by hypothesizing that the effect is due to a change in the g_{tr} term of the metric tensor, created by Casimir radiation (vacuum field radiation) emitted by the Earth. When a complex g_{tr} term was added to the metric tensor, it had no effects on clocks or orbital dynamics, but had exactly the effect needed to match the NASA data while maintaining conservation of energy, which had appeared to be violated by up to 100 sigmas.

The effect of the added g_{tr} term in the metric tensor is to change the beam energy by a small complex amount when the beam is launched and as it leaves the Earth. When the microwave beam travels to the distant spacecraft and reflects off the surface, its frequency then increases as the real part of the energy stored in the beam is released into the light at the time the light reflects from the satellite. However, if the beam primarily backscatters from a dielectric, no such effect is predicted. A process such as this can fully account for the observed NASA anomaly and restores conservation of energy since there is no actual change in the vehicle velocity.

Once this physical principle had been suggested, we then explored how the extra term was created in the metric tensor. By combining the NASA solution with the previously detected radiation from the Sun we were able to find a candidate radiation law for the Casimir radiation which matched the NASA and Sun data to <3%. All other candidate equations were far away from the observed NASA data except one accidental echo, which was discarded to match the observed cosine distribution with spacecraft elevation.

Given that the NASA data appeared to be accurate to <1%, we have a potential radiation equation for the vacuum field, accurate to that same 1% uncertainty.

6. Discussion

While annually varying strong and weak radioactive decay plus similarly varying electromagnetic tunnel currents strongly pointed to a time-varying Planck constant h on the Earth, there was no basis in our standard model to support Planck's constant is a variable. In fact, there is no theory at all about how the vacuum field is generated since it is hypothesized to be a basic property of nature that can never change.

Since numerous Casimir experiments in labs around the world have proven

that the vacuum field does vary in space and time using mirrors, it is not unreasonable to assume that other factors in the universe besides mirrors may also affect the vacuum field. Thus, a vast amount of data on annual variations in radioactive decay for strong and weak decays from three national labs and other groups combined with similar time variations in tunnel diode current should be considered as strong support that the vacuum field radiation varies spatially and temporally all over the universe just as it has been shown to do in our laboratories.

6.1. What about the NIST Experiment That Showed *h* Was Constant?

On the contrary side, one could then point to a recent experiment from NIST that showed Planck's constant is extremely stable over several years [18]. Such a result is apparently inconsistent with the data from radioactive decays and tunnel diodes [11] [12]. However, the answer is familiar in quantum mechanics. Since every linear physical process runs at a rate proportional to *h*, if *h* is doubled, we would not know it except for the few processes that are nonlinear in *h*. Given that the NIST experiment was entirely linear in *h*, it could not measure a change in *h*, since its clocks would also run faster or slower to cancel any variation.

Radioactive decay and tunneling are highly nonlinear in *h*, and all show a consistent time variation of *h* over a year. It is now reasonable for researchers to consider measuring and analyzing spatially and temporally varying Casimir radiation, perhaps using tunneling sensors, which appear to be both accurate and convenient. Superconducting tunnel junctions may allow for exquisite accuracy.

6.2. Impact on the Hubble Constant

The tunneling research presented above shows Casimir radiation being emitted by the Sun and the Earth, and by similarity all stars and planets. If Casimir radiation is continuously emitted by stars and planets, then Planck's constant h would be increasing with time. This could provide an alternative explanation for the Hubble constant, where the distant galaxies are redder simply because *h* is smaller back in time, making local time move more slowly. In contrast to the expanding model of the universe, we could now consider whether our universe might simply be static, where gravity is everywhere balanced on a large scale. Such a conclusion would end the search for dark energy since such a universe is essentially static while the usual red shift would still be observed.

We note that the Hubble constant would still be important because it would indicate the time constant of the universe as its vacuum field increases. Thus, a Hubble time constant of 16 billion years may simply be the exponential coefficient of a universe constantly speeding up in its time rate, potentially eliminating the big bang model and replacing it with the quiet whisper model. In the quiet whisper model of the universe, it starts with almost nothing, but increases its energy level for all processes as the Casimir radiation increases h. Such a conjectured universe may be trillions of years old.

6.3. Liquid Earth and Mars Conundrum

This model of a time-varying Planck's constant can also address another conundrum. How could our main sequence Sun have been so hot 3 - 4 billion years ago that it melted the ice on Earth and even on Mars, creating vast oceans and rivers on both planets [18] [19]. Currently the average temperatures of the Earth and Mars are 15°C and −63°C respectively. Our model of a main-sequence star like our Sun, says the Sun should be 30% dimmer 4 billion years ago than it is now, making the ancient Earth a block of ice. [18] Yet our Earth and even Mars had liquid oceans back then [19] [20]. Liquid oceans on Mars would require the Sun to be much hotter than it is now. Even if Mars had an atmosphere in the past like present-day Earth (possible), it would have had about 0.70 * (93 × 10^6 miles/142 × 10^6 miles)^2 = 30% of the current Earth's sunlight. Even a 30% reduction of solar flux on Earth would make the Earth into an ice block, so Mars would have no chance for liquid oceans with 70% less solar irradiance than Earth has now. And yet NASA data says ancient oceans existed on Mars in vast amounts.

In considering plausible explanations to the combined Earth/Mars liquid oceans in ancient times, it is important to realize that a star is one of the most sensitive responders to a change in Planck's constant with a gain of about $\ln(10^{28})$ - $\ln(10^{32})$ = 64 - 74, since it takes an estimated 10^{28} - 10^{32} proton-proton collisions to fuse into one deuterium nucleus, and this rate of fusion is controlled by the intensity of the vacuum field at the frequency of the proton barrier. With this sensitivity, a 1.6% increase in the vacuum field would about triple the power output of our Sun and warm Mars in the past to current Earth levels. Could a nearby star in our galaxy have fired up 4 billion years ago, flooding our solar system with 1.6% more Casimir radiation (vacuum field) and heating up our Sun enough to melt Earth and Mars?

No one can say yet, but more research might consider that possibility since currently, we don't have any answer for this well-documented mystery of a warm ancient Earth and even more, a warm and liquid ancient Mars. [19] [20] [21]

Agreement with Gravity Red shift Experiments

Many readers would note that such a large frequency shift would dwarf the usual gravity red shift since this new term is several orders of magnitude larger. However, gravity red shift experiments are not designed to look for complex changes in the metric tensor. For instance, transmitting a narrowband source to a narrow band absorber (*i.e.* Pound and Rebka [22]) is unaffected by a complex component in the photon energy, since the real frequency is unchanged. Also, the time drift of orbiting GPS clocks has no mechanism to be affected. Even a maser transmitted to Earth from space is not a backscattered beam and has no obvious reason to show an effect, especially when the transmission occurred far out in space where the g_{tr} term is much smaller.

Given that the NASA data used in the vacuum field analysis had an SNR up to

100, the effect is verified and quantified to about 1%, matching the theoretical model well, and allowing a radiation equation that matches the separately measured vacuum field emissions of both the Earth and Sun.

How Can There Be Imaginary Field Components?

Physics has traditionally been double-minded about imaginary numbers. They are used throughout our many calculations but we also maintain they have no physical reality. This paper encourages us to consider the option that imaginary numbers are real and physical in our universe. How can we explain the vast pressure in the vacuum field while it has no ability to excite or burn anything?

If we allow ourselves to consider the possibility that imaginary numbers are supported in our space-time coordinate system, then we must assume that those imaginary coordinates are tightly wrapped. And yet they would strongly impact the properties of elementary particles. In particular, elementary particles might actually have complex masses. If so, then the worrisome inconsistencies in the measurement of the gravitational constant G might occur simply because we have neglected the imaginary parts of atomic mass, which would interact in a repulsive manner and confuse the measurements. A more careful gravity measurement design using several different materials in various pairings would potentially be able to detect the effect and verify whether we do indeed have imaginary mass and energy and thus imaginary coordinates hidden within the fabric of our universe.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Anderson, J.D., *et al*. (2008) Anomalous Orbital-Energy Changes Observed during Spacecraft Flybys of Earth. *Physical Review Letters*, **100**, Article ID: 091102. https://doi.org/10.1103/PhysRevLett.100.091102

[2] Casimir, H.B.G. (1948) On the Attraction between Two Perfectly Conducting Plates. *Proceedings of Koninklijke Nederlandse Akademie van Wetenschappen/C*, **51**, 793-795.

[3] Bordag, M., Mohideen, U. and Mostepanenko, V.M. (2001) New Developments in the Casimir Effect. *Physics Reports*, **353**, 1-205. https://doi.org/10.1016/S0370-1573(01)00015-1

[4] Siegert, H., Schrader, H. and Schötzig, U. (1998) Half-Life Measurements of Europium Radionuclides and the Long-Term Stability of Detectors. *Applied Radiation and Isotopes*, **49**, 1397-1401. https://doi.org/10.1016/S0969-8043(97)10082-3

[5] Ellis, K.J. (1990) The Effective Half-Life of a Broad Beam ^{238}Pu/Be Total Body Neutron Radiator. *Physics in Medicine and Biology*, **35**, 1079-1088. https://doi.org/10.1088/0031-9155/35/8/004

[6] Falkenberg, E.D. (2001) Radioactive Decay Caused by Neutrinos? *Apeiron*, **8**, 32-45.

[7] Alburger, D.E., Harbottle, G. and Norton, E.F. (1986) Half-Life of ^{32}Si. *Earth and Planetary Science Letters*, **78**, 168-176.

https://doi.org/10.1016/0012-821X(86)90058-0

[8] Jenkins, J.H., *et al.* (2011) Analysis of Experiments Exhibiting Time-Varying Nuclear Decay Rates: Systematic Effects or New Physics?
https://arxiv.org/abs/1106.1678

[9] Parkhomov, A.G. (2010) Researches of Alpha and Beta Radioactivity at Long-Term Observations. https://arxiv.org/abs/1004.1761

[10] McDuffie, M.H., Graham, P., Eppele, J.L., Gruenwald, J.T., Javorsek II, D., Krause, D.E., Fischbach1, E. (2020) Anomalies in Radioactive Decay Rates: A Bibliography of Measurements and Theory. https://arxiv.org/abs/2012.00153v2

[11] Hutchin, R.A. (2016) Experimental Evidence for Variability in Planck's Constant. *Optics and Photonics Journal*, **6**, 124-137. https://www.scirp.org/journal/opj/

[12] Hutchin, R.A. (2019) Detection of Casimir Radiation from the Sun. Optical Society of America Technical Digest, 2019, paper JTu4A.26.
https://opg.optica.org/abstract.cfm?URI=FiO-2019-JTu4A.26

[13] Hutchin, R.A. (2019) Detection of Casimir Radiation from Our Sun. *Optics and Photonics Journal*, **9**, 141-154. https://doi.org/10.4236/opj.2019.99013

[14] Adler, R., Bazin, M. and Schiffer, M. (1975) Introduction to General Relativity. McGraw Hill, New York.

[15] Hutchin, R.A. (2015) Toward a Local Theory of Light. *Optics and Photonics Journal*, **5**, 247-259. https://doi.org/10.4236/opj.2015.57024

[16] King, J.A. (2010) Searching for Variations in the Fine-Structure Constant and the Proton-to-Electron Mass Ratio Using Quasar Absorption Lines. Ph.D. Thesis, University of South Wales, South Wales. https://doi.org/10.1103/PhysRevA.81.042523

[17] Webb, J.K., Flambaum, V.V., Churchill, C.W., Drinkwater, M.J. and Barrow, J.D. (1998) A Search for Time Variation of the Fine Structure Constant.
https://arxiv.org/abs/astro-ph/9803165

[18] Haddad, D., *et al.* (2017) Measurement of the Planck Constant at the National Institute of Standards and Technology from 2015 to 2017. *Metrologia*, **54**, 633-641.
https://doi.org/10.1088/1681-7575/aa7bf2

[19] https://en.wikipedia.org/wiki/Faint_young_Sun_paradox

[20] https://en.wikipedia.org/wiki/Mars_ocean_hypothesis

[21] https://en.wikipedia.org/wiki/Proton%E2%80%93proton_chain

[22] Pound, R.V. and Rebka Jr., G.A. (1959) Gravitational Red-Shift in Nuclear Resonance. *Physical Review Letters*, **3**, 439-441. https://doi.org/10.1103/PhysRevLett.3.439