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# Massive Photon as Solution to Anomalous Acceleration of Deep-Space Probes and Some Other Cosmological Anomalies

Mario Ljubičić *

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# Massive Photon as Solution to Anomalous Acceleration of Deep-Space Probes and Some Other Cosmological Anomalies

**Mario Ljubičić**

108. brigade ZNG 43, 35252 Sibinj, Croatia; mljubicic99@gmail.com

**Abstract**

All deep-space probes seem to experience small anomalous acceleration. Although original thermal modelling of Pioneer spacecraft effectively ruled it out, newer modelling suggests that the anomalies do arise from the anisotropic thermal radiation, mainly associated with radioisotope thermoelectric generators. However, although the results are convincing, alternative solutions are not ruled out. Here, it is proposed that the thermal anisotropy is generally only a part of the solution and may not be a dominating part in all cases. The other contribution is hypothesized to come from a non-zero photon mass and its gravitational coupling. The exact solution for the Pioneer anomalies is presented, in remarkable agreement with measurements, and with the original thermal modelling. In addition, the solution provides an alternative explanation for the Schwarzschild radius of the observable universe and could potentially explain different cosmological anomalies, not limited to the anomalous acceleration of deep-space probes.

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## 1. Introduction

The analysis of motion of deep-space probes shows anomalous constant weak long-range acceleration [1] on the order of -$10^{-10}$ m/s$^2$ (deceleration relative to the Sun). A solution has been proposed in the form of anisotropic thermal radiation [2] and it has even been claimed eventually that that this could completely resolve the Pioneer [3] anomaly [4]. However, although convincing, the result is not absolutely definitive. A large uncertainty exists in RTG surface degradation, for example. Although explained within uncertainties, thermal estimate at about 80% of the Doppler-inferred acceleration is not a perfect match. The apparent onset of the anomaly [5] only once the giant planets have been reached [6] (unexplainable by thermal anisotropy) is assumed to be a result of mismodelling of the solar thermal contribution, but this is not certain either. The observed diurnal/annual oscillation [7] in the anomalous acceleration (unexplainable by thermal anisotropy) is also assumed to be the artefact of mismodelling (including that of the spacecraft orientation). The best fit to the original data is a temporally constant anomaly [8], while the thermal anisotropy implies temporal decay of the anomaly. Although the decay cannot be ruled out - especially with the extended Pioneer data sets [9], the obtained marginal signs of decay likely are a result of mismodelled [10] solar radiation pressure [11].

The newer thermal modelling is significantly different from the original modelling (which effectively ruled out thermal anisotropy [7]), and others have criticized [12] it [13] (e.g., for the extensive parametrisation, potential bias, reliance upon an inferior quality extension of the highest quality data set to overturn the consensus view of a [mean] constant anomaly, the fact that only the "acceleration" value is considered, etc.).

Considering the involved assumptions, uncertainties, criticism, and the potential scientific value of a different explanation, alternative solutions [14] should not be easily dismissed. Here, an exact solution in the form of a massive photon is proposed, a solution that could, in addition, explain some other cosmological anomalies.

## 2. The Hypothesis

Assume that the photon is propagating as an expanding spherical wave, with mass concentrated at the expanding sphere surface (spherical shell). As such, the photon is affected by the gravitational potential of the enclosed mass (with the assumption of homogeneous/isotropic distribution, per the shell theorem, the outer mass would have no net effect) - with the gravitational coupling proportional to photon mass. Therefore, its linear momentum is converting to angular momentum, and, upon reaching its range, the photon's linear (radial) velocity becomes equal to zero. Effectively, thus, the photon is experiencing relatively constant negative radial acceleration (or, increasing curvature in the context of General Relativity). This acceleration is the equivalent of inverse free fall, and on a return trip (assuming the photon is not absorbed and *falls back* upon reaching the range) it would be equivalent to free fall. The negative radial acceleration of photons (or, more precisely, the blueshift due to increasing curvature) will then be misinterpreted as a decrease in velocity (Doppler shift) of the moving source of emission if the mass of the photon is assumed to be zero. But in reality, there is no change in velocity of the source, the frequency shift occurs because the photon paths are curved and curvature changes for each new photon emitted. Note that the reference frame of the observer of an photon with the range and radius on the order of the radius of the observable universe would effectively be near an event horizon, as the enclosed mass-energy/density forms a black hole for the photon (although the photon is localized with the absorption).

Thus, the source of anomalous acceleration detected in deep-space probes is here proposed to be the massive photon. With such photon, the *onset* (proper term here would be "inflation") of the anomaly at particular distance can be explained with mass oscillation, settling of photons in higher mass eigenstates.

> The transition to higher eigenstates should be correlated with the transition in coupling - e.g., from the density/pressure of the Solar System to that of the galaxy, or the cosmological vacuum. Interestingly, the anomaly *onset* seems to occur as the spacecraft themselves decouple from the Solar System [15] (pass from an elliptic orbit into an hyperbolic escape trajectory, following a gravity-assist Jupiter/Saturn flyby). In fact, since the hypothesis involves coupling of photons to gravity, the anomalies could occur with changes in gravitational coupling in general. Note that anomalous kinetic energy has been detected in several spacecraft even during gravity-assist Earth flyby [15].

The detected annual periodicity could then be explained by the motion of Earth about the Sun, as this is the place of photon absorption. Since the distance to the spacecraft is oscillating annually due to Earth's motion, the maximal radius the photon can have before absorption is oscillating as well - hence the annual oscillation of the anomaly (this correlation, however, is not further analysed in this paper).

Note that the solution provided here also goes in favour of physical interpretation of the wave-function - the collapse of the wave-function is the collapse (localization) of the mass forming the propagating spherical waveform to the point of photon absorption.

It can be shown easily that, for a spatially flat expanding universe (where the observable radius is a Hubble radius), the observable radius is equal to the Schwarzschild radius of the total mass-energy inside the observable universe, which seems to be the case with our universe [16]. The solution presented here provides an alternative interpretation for the Schwarzschild radius, one that doesn't require expanding universe (note, however, that the two interpretations are not mutually exclusive). If the enclosed mass grows exponentially with the expanding photon radius ($dM/dr \neq const.$) - which is the case for a spherical photon and a large scale homogeneous/isotropic universe, at some point of the photon expansion the enclosed mass will effectively become a black hole for the photon, and as the photon radius becomes equal to the event horizon further expansion becomes impossible - this is the point where its radial velocity is completely converted to angular velocity.

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Of course, on large distances (scales), the blueshift will be cancelled by the redshift due to universe's expansion. The blueshift may also be negligible for the lowest mass eigenstates and may also be limited with the partial localization of photons, constraining their radii - which may be more likely for higher frequencies.

## 3. The Solution and Discussion

In established quantum physics photon is assumed to have zero rest mass, however, this doesn't have to be the case in reality, and there are reasons to believe it is not. Localized photon mass in experiments is on the order of $10^{-50}$ to $10^{-54}$ kg [17]. This is usually interpreted as the upper limit on its rest mass. However, it can also be interpreted as the actual photon mass associated with particular photon scale and correlated density/pressure. If the photon has mass the electro-magnetic potential is a Yukawa potential and the photon also has a range, equal to the [reduced] Compton wavelength, i.e.,:

$$r = \frac{\hbar}{m_p c} \tag{1}$$

where $\hbar$ is the reduced Planck constant, $c$ is the standard vacuum speed of *light*, and $m_p$ is photon mass. This range should be, obviously, equal or larger than the observable universe for cosmological photons, which translates to the upper limit on the order of $\sim 10^{-69}$ kg. Others have calculated this mass, with the assumption of dS vacuum and a Ricci scalar of $4\Lambda$ (where $\Lambda$ is a positive cosmological constant), to be $\approx 2 \times 10^{-69}$ kg [18]. Using matter density and pressure of the Solar System (Sun magnetosphere) in the Ricci scalar instead, and a zero cosmological constant, one obtains photon mass of $\approx 2 \times 10^{-72}$ kg [18]. The author has obtained similar values in a different approach [19], where 3 mass eigenstates of the photon are hypothesized as well. In example, the mass of $6.335 \times 10^{-69}$ kg was obtained as the cosmological photon tau *equivalent* eigenstate, and $1.822 \times 10^{-72}$ kg as the lowest mass eigenstate. Using the higher mass, one obtains the radial acceleration:

$$a = -\frac{1}{2}\frac{c^2}{r} = -\frac{1}{2}c^2\frac{c}{\hbar}M_{\gamma\tau} = -8.093 \times 10^{-10}\frac{m}{s^2} \tag{2}$$

c = standard vacuum speed of *light* = $2.99792458 \times 10^8$ m/s. $\hbar$ = reduced Planck constant = $1.054573 \times 10^{-34}$ Js. $M_{\gamma\tau}$ = tau photon mass = $6.335 \times 10^{-69}$ kg

which is in remarkable agreement with the observed Pioneer 10 anomaly of $-8.09 \pm 0.20 \times 10^{-10}$ m/s$^2$ [1]. Similarly, if one assumes a superposition (sum) of tau and muon photon eigenstates, one obtains:

$$a = -\frac{1}{2}c^2\frac{c}{\hbar}(M_{\gamma\tau} + M_{\gamma\mu}) = -8.574 \times 10^{-10}\frac{m}{s^2} \tag{3}$$

$M_{\gamma\tau}$ = tau photon mass = $6.335 \times 10^{-69}$ kg. $M_{\gamma\mu}$ = muon photon mass = $3.767 \times 10^{-70}$ kg

which is in remarkable agreement with the observed Pioneer 11 anomaly of $-8.56 \pm 0.15 \times 10^{-10}$ m/s$^2$ [1]. The obtained results are also in agreement with the anomalous Galileo acceleration of $-8 \pm 3 \times 10^{-10}$ m/s$^2$ [1].

Note that the ratio of mass between tau photon and muon photon is the same as the ratio of mass between tau electron and muon electron, as the author hypothesises that muon/tau eigenstates are not limited to electrons, rather represent a more general oscillation of particles. Note also that, assuming photons here generally couple to mass/gravity in pairs, an additional eigenstate should be added to the first equation. However, if this is the lowest mass eigenstate, the result wouldn't change significantly. For both photons in lowest mass eigenstates, the acceleration becomes relatively negligible (on the order of $10^{-13}$ m/s$^2$). The *onset* of the anomaly at particular distance is then explained as transition to higher mass eigenstates (which, however, may be more correlated with the decoupling from the Solar System, rather than with the distance itself).

However, even though the results above suggest the thermal anisotropy in Pioneer spacecraft is likely to be negligible (in agreement with the original modelling, where the value of 0.55±0.55 × $10^{-10}$ m/s$^2$ has been obtained for the thermal anisotropy, with reasons given to consider this an upper bound [7]), higher anisotropy of thermal dissipation in the probes generally cannot be ruled out. In fact, thermal anisotropy could dominate over the proposed effect, especially for smaller photon mass eigenstates.

Coupling thermal modelling with the above, one could then obtain solutions in agreement with anomalies of other probes (e.g., detected Ulysses anomaly of 12±3 × $10^{-10}$ m/s$^2$ [1], New Horizons anomaly of 13.2±0.6 × $10^{-10}$ m/s$^2$ [20]).

In any case, at smaller distances gravitational coupling prevails, however, in an expanding universe, at larger distances the deceleration (blueshift) will be counteracted by the acceleration (redshift) due to the expansion. Therefore, if photons are generally propagating by the proposed mechanism, expansion of the universe may be underestimated, however, blueshift can also be limited by smaller mass eigenstates and partial localization of photons during propagation.

Note that the proposed photon nature and mechanism of propagation can potentially explain some other anomalies as well. By the hypothesis, a photon emitted from an celestial object may be reflected back towards the original point of emission upon reaching the range. Since celestial objects are generally in motion, an observer receiving both direct light from the object and *reflected* light will observe two images of the same object at different points in time, which could then be interpreted as two different but highly correlated objects even if they appear far away from each other. This could explain, for example, the alignment of many quasar polarization vectors over extremely large regions of the sky - billions of light-years apart, even though the quasars are not gravitationally bound [21]. Another potential example is the Huge Large Quasar Group [22]. Here, part of the group may be formed by *reflections*, so the actually physical group is smaller. However, the examination of the plausibility of the proposed explanation for these particular cases is beyond the scope of this paper.

### *3.1. Is the Universe Contracting?*

It has been hypothesized that the observed effect depends on the enclosed mass. If the enclosed mass is increasing with each photon emitted, a blueshift is produced. With constant energy density of space, the enclosed mass is increasing with each photon emitted if the source and absorber are moving apart. Thus, a blueshift is expected (although it will be counteracted with the redshift produced with motion of objects, or universe's expansion).

Conversely, if the universe is contracting, without increasing energy density, the enclosed mass should be decreasing with each photon emitted. Thus, a redshift would be produced instead of blueshift, even for otherwise relatively stationary sources. If, however, the contraction of the universe dominates on larger scales (like dark energy), on smaller scales, for two objects moving apart, a blueshift would be produced instead (the effect depends solely on eclosed mass and photon mass/range, so as long as the enclosed mass is increasing with each new photon a blueshift is produced).

Note that, since this is effectively a gravitational frequency shift, it includes other relativistic effects, such as time dilation. If one now assumes there is no partial localization of photons during propagation (affecting enclosed mass), the observed increasing redshift with distance in the observable universe may have been misinterpreted. Instead of expanding, the universe may be actually contracting.

Note that the lowest mass eigenstate of the photon, per the hypothesis, is equal to 1.822 × $10^{-72}$ kg. Per Equation (2), this produces the acceleration of -2.328 × $10^{-13}$ m/s$^2$, or double that value for the sum of two eigenstates. Expressing this in a value analogous to the Hubble constant (which here, being negative, may be interpreted as contraction), one obtains:

$$A_0 = -2.328 \times 10^{-13}\, m/s^2 \sqrt{\frac{2 \times 3.086 \times 10^{22} m}{2.328 \times 10^{-13} m/s^2} \frac{1}{Mpc}} = -119.86\,(km/s)/Mpc \qquad (4)$$

And, for the sum of two eigenstates:

$$B_0 = 2 \times -2.328 \times 10^{-13}\, m/s^2 \sqrt{\frac{2 \times 3.086 \times 10^{22} m}{2 \times 2.328 \times 10^{-13} m/s^2}} \frac{1}{Mpc} = \frac{2}{\sqrt{2}} A_0 = -169.50\,(km/s)/Mpc \quad (5)$$

These values are suspiciously close to the inferred values of the Hubble constant ($H_0$), suggesting that the dark energy may be coupled to a particle of similar mass to photon. Assuming now that the expansion of the universe is actually equal to one of these values (albeit positively signed), one can obtain the Hubble constant as the superposition of expansion and the effective contraction (a product of the proposed nature of the photon [propagation]). Simple addition gives, for the expansion equal to $B_0$ in value:

$$H_0 = -B_0 + A_0 = 49.64\,(km/s)/Mpc \quad (6)$$

Associating the sum of 4 particles with dark energy and 2 with photon coupling, one obtains:

$$H_0 = -\left(\frac{4}{\sqrt{4}} - \frac{2}{\sqrt{2}}\right) A_0 = 70.21\,(km/s)/Mpc \quad (7)$$

A value that is about the average of the measured values, and is in agreement with many measurements/models [23]. Based on the above, one possible solution to the Hubble tension may be in the changing, or the running, gravitational coupling.

## 4. Conclusions

It has been shown that anomalous acceleration of Pioneer probes can be fully explained with massive photons propagating by the proposed mechanism, going in favour of the original thermal modelling of Pioneer spacecraft. Although newer thermal modelling has produced convincing results, it remains questionable whether it is the proper solution of the anomalies. The solution provided here can explain multiple aspects of the anomaly, not limited to the value of "acceleration". It can also explain anomalies in other deep-space probes, but may in some cases represent only a partial solution (the other being thermal recoil). The solution provides an alternative interpretation for the Schwarzschild radius of the observable universe - without excluding the established one. Additionally, it could potentially explain unexpected cosmological correlation and some other cosmological anomalies. In any case, experimental verification of the proposed solution is desirable, as any deviation from conventional physics could have large implications for cosmology, astrophysics and particle physics. A deep-space probe, for example, designed in such way to minimize or rule out anisotropic thermal dissipation could provide an unambiguous confirmation or refutation of alternative solutions, so it would be useful even in the case the solution proposed here doesn't hold up to scrutiny.

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