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Gravitational Black-Body Radiation

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Abstract

Analogous to a black body, the empty space surrounding a massive body is theoretically envisioned to radiate thermal gravitational energy in accordance with Planck's radiation law. Gravitational black-body radiation offers a remarkably compelling solution to the deep, long-standing questions concerning galaxy rotation curves and strong gravitational lensing by large astrophysical systems, without the need to impose a dark matter or massive graviton hypothesis. As with the quantized orbits of the electron in the atom and the classical physics of Maxwell's theory of electromagnetism, gravitational black-body radiation represents a truly profound break from the classical physics of Einstein's general theory of relativity and the emergence of the fundamental quantum nature of gravity.

Keywords

Black Body, Graviton, Milky Way, Rotation Curve

1. Introduction

It is well known since the 1930s, that the observed rotational velocity of matter and energy in the outer arms of flat spiral (disc) galaxies, such as our own Milky Way galaxy, is greater than that predicted by the inverse square law of Newton's law of universal gravitation (1729). This mysterious phenomenon suggests, in general, that the visible (Newtonian) mass of a flat spiral galaxy alone cannot be the total source of the gravitational force holding a massive system of stars, planets, gas, and dust together.

Generally, a parcel of energy produces a gravitational field. Hypothetical *massless* quanta of the gravitational field are called gravitons [1], and their energy, such as photons, which are quanta of the electromagnetic field[1] generate packets of coherent temporal oscillations within the Planck lattice [2] [3]. How-

[1]The notion of light quanta was first conceived by Einstein in a paper where he proposed an explanation for the photoelectric effect in 1905.

ever, because gravitons are essentially particles of spacetime itself, then unlike photons, gravitons not only travel at the speed of light but also oscillate along with the internal oscillations of the Planck lattice. As is known from Maxwell's work on electromagnetism, a moving electric charge radiates electromagnetic waves. Similarly, Einstein's work on gravity showed that a moving gravitational charge radiates a gravitational wave. Thus, we imagine an empty space near parcels (or distributions) of energy to be full of gravitons jiggling about, coupled to localized standing waves of the Planck lattice. Suppose that each standing wave mode of curved spacetime is coupled to a graviton that oscillates at the same frequency as the standing wave. Each graviton has two degrees of freedom, one for kinetic energy and one for potential energy, so it has an average energy of $k_B T$ according to the equipartition theorem. In thermal equilibrium, the average oscillation energy of the graviton and the standing wave mode of curved spacetime must be the same for the two to be in thermal equilibrium. Hence, each mode of oscillation of the gravitational field has an energy $k_B T$ and can be considered as having a temperature T, which is the basis of the Rayleigh-Jeans theory (1900) for the spectral radiance of electromagnetic radiation.

2. Rotation Curves of Spiral Galaxies

As in the case of oscillating electrons in a material radiating electromagnetic energy, we have oscillating gravitons radiating gravitational energy in a similar manner. Because oscillating gravitons increase the energy of a gravitational field, which increases the frequency of graviton oscillations, the resulting strength (or energy) of any gravitational field should be infinite. However, this does not agree with the observations. Therefore, we propose that the gravitational energy spectrum be discrete. In accordance with Planck's (black-body) radiation law [4], which has proven to be adequate thus far, we conjecture that for a given increase in the curvature of spacetime, the oscillation frequency of the gravitons may increase if the increase in the gravitational field energy is greater than or equal to the fundamental unit of energy, as defined by the Planck-Einstein relation, for that particular frequency. This assumption is essential to prevent the energy of the gravitational field from becoming infinite.

Now, we proceed under the general assumption that the gravitational field of a spiral galaxy consists of a familiar classical Newtonian component $\overline{\mathrm{g}}_N$ that includes all forms of matter and energy that are not made of spacetime, and a hypothetical gravitational black-body radiation (GBR) component $\overline{\mathrm{g}}_{\mathrm{gr}}$, which is due to the (finite) energy of the oscillating gravitons of a Newtonian gravitational field. The GBR component of the gravitational field is presumed to be vanishingly small, except in the case of large mass-energy[2] distributions such as galaxies or clusters of galaxies. Therefore, in general, the gravitational field $\overline{\mathrm{g}}$ of an arbitrary energy distribution is defined by the following expression:

$$\overline{\mathrm{g}} \equiv \overline{\mathrm{g}}_N + \overline{\mathrm{g}}_{\mathrm{gr}} . \tag{1}$$

[2]In accordance with relativity theory which has sufficiently established the equivalence of mass and energy, we shall refer to mass as energy in this study.

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Let us assume that the radiation energy E_{gr} produced by the Newtonian gravitational field of a spiral galaxy is equivalent to the difference in kinetic energy between the observed (empirical) rotation speed and the Newtonian rotation speed. Thus, we may write

$$E_{\text{gr}} = M_{\text{gr}} c^2 = \frac{1}{2} M_N \left(\mathrm{v}^2 - \mathrm{v}_N^2 \right), \tag{2}$$

where $M_N = E/c^2$ is the visible (Newtonian) relativistic mass of the system, M_{gr} is the relativistic mass of the GBR, v is the observed rotational speed of the galaxy, and $\mathrm{v}_N = \sqrt{GM_N/r}$ is the rotational speed of the galaxy, as predicted by Newton's law of gravity for a spherical (symmetric) energy distribution. It follows that the rotational velocity of the system is suitably determined by

$$\mathrm{v} = \sqrt{\frac{GM_N}{r} + \frac{4GM_{\text{gr}}}{r_s}}, \tag{3}$$

where r is the radial distance from the center of rotation of the system, $r_s = 2GM_N/c^2$ is the Schwarzschild radius of the Newtonian gravitational source, and G is Newton's universal gravitational constant.

From the equation for circular motion, we obtain an expression for the gravitational field, as follows:

$$\mathrm{g}_r = -\frac{GM}{r^2} = -\frac{\mathrm{v}^2}{r}, \tag{4}$$

which gives

$$\overline{\mathrm{g}} = \mathrm{g}_r \hat{r} = -\frac{1}{r}\left(\frac{GM_N}{r} + \frac{4GM_{\text{gr}}}{r_s} \right)\hat{r} = -\left(\frac{GM_N}{r^2} + \frac{4GM_{\text{gr}}}{r_s r} \right)\hat{r}. \tag{5}$$

Hence, the Newtonian and GBR components of the gravitational field are, respectively:

$$\mathrm{g}_N = -\frac{GM_N}{r^2} \quad \text{and} \quad \mathrm{g}_{\text{gr}} = -\frac{4GM_{\text{gr}}}{r_s r}. \tag{6}$$

From the famous radiation law of Max Planck (1900), the relation for the spectral density of an electromagnetic black body in thermal equilibrium is given by:

$$S_{\text{em}}(\lambda) = \frac{8\pi hc}{\lambda^5 \left(\mathrm{e}^{hc/\lambda k_B T} - 1 \right)}. \tag{7}$$

Hence, with some foresight, we presume that, in general, the radial distribution of the GBR energy density of a spiral galaxy has the following form:

$$u_{\text{gr}}(r) = \frac{8\pi}{3} \frac{A}{r^3 \left(\mathrm{e}^{B/r^{3/4}} - 1 \right)}. \tag{8}$$

The constant parameters A and B are to be determined such that the computed rotation speed of the galaxy due to the energy density distribution of the GBR, as prescribed by the relation above, equals the observed rotation speed of the galaxy

$$\mathrm{v} = \sqrt{\frac{GM_N}{r} + \frac{4GM_{\mathrm{gr}}}{r_s}}, \tag{9}$$

which corresponds to the expression developed earlier. The values of A and B were computed for a few example galaxies and are listed in **Table 1**.

The GBR energy is related to the energy density by the following equation:

$$E_{\mathrm{gr}} = M_{\mathrm{gr}} c^2 = u_{\mathrm{gr}} \mathcal{V}_{\mathrm{gr}}, \tag{10}$$

where $\mathcal{V}_{\mathrm{gr}} = \mathcal{V}_{tot} - \mathcal{V}_N = \mathcal{V}_{tot}\left(1 - M_N / M_{tot}\right)$ is the approximate volume of empty (interstellar) space, as determined from the Newtonian (non-gravitational) energy content[3] of the galaxy; $\mathcal{V}_{tot} = \pi r^2 t_{disc}$ is the total volume of a disc with radius r and approximate average thickness t_{disc}, and $M_{tot} = \mathrm{v}^2 r / G$ is the total gravitational energy of the system, as determined from the rotational speed v of the system.

Table 1. Galaxy properties.

Galaxy	A (J)	B ($\mathrm{m}^{3/4}$)	t_{disc} (ly)
Milky Way	3.84E+52	4.35E+15	1004
NGC 3198	8.26E+51	4.06E+15	821
NGC 1560	1.33E+52	2.69E+15	379
NGC 2403	3.72E+51	3.94E+15	806

Note: The values for A and B were determined from observational rotation curve data provided in Refs. [5] [6]. The approximate average thickness of the galactic disc t_{disc} is determined by scaling the thickness to diameter ratio of the Milky Way by the ratio of maximum angular speed of the Milky Way to the maximum angular speed of a given spiral galaxy, that is, $\left(t_{disc}/D\right) = \left(t_{disc}/D\right)_{MW}\left(\omega_{Mw}/\omega\right)_{\max}$, where $\omega = \mathrm{v}_{rot}/R$ and $R = D/2$ are the usual relations for angular speed and radius of a rotating object, respectively. This relationship suggests in general, that as the angular velocity of a rotating system increases, it tends to spread out, which causes its thickness to diameter ratio to decrease.

From these relations, it immediately follows that

$$M_{\mathrm{gr}} = \frac{8\pi}{3} \frac{A \mathcal{V}_{\mathrm{gr}}}{c^2 r^3 \left(\mathrm{e}^{B/r^{3/4}} - 1\right)}. \tag{11}$$

Applying these theoretical considerations to the Milky Way, one can readily observe that as the volume of space filled with GBR increases, the number of allowed energy states increases as well, which increases the gravitational radiation component of the interstellar gravitational field and subsequently causes the rotation curve of the Milky Way to flatten[4]. Although this empirical result mani-

[3]For ease of evaluation, we shall not restrict generality by assuming that the energy distribution of the systems under consideration are approximately uniform (homogeneous and isotropic).

[4]This mysterious phenomenon is part of the more general dark matter problem [7], which in principle can be achieved in the framework of extended gravity [8].

festly contradicts the "behavior" of the typical rotation curve as predicted by Newton's well-known classical theory of gravitation, it is in complete agreement with the predictions of our nonclassical (Planckian) theory of gravity as presented here in this paper.

By differentiating $u_{\mathrm{gr}}(r)$ with respect to r, to find the location r_m of the maximum energy density, we obtain the following equation:

$$\frac{B}{r_m^{3/4}} = 4\left(1 - \mathrm{e}^{-B/r_m^{3/4}}\right), \tag{12}$$

which can be iteratively solved. After a few iterations, we obtain the following simple equation:

$$\frac{B}{r_m^{3/4}} = 3.921. \tag{13}$$

Once B is determined from observational (rotation curve) data, it is straightforward to compute the location of the peak energy density of the GBR distribution. We found that the peak energy density of the GBR of the Milky Way is approximately 4.28 nJ/m^3 and is located 3.72 kpc from the center of the galaxy, as illustrated in **Figure 1**.

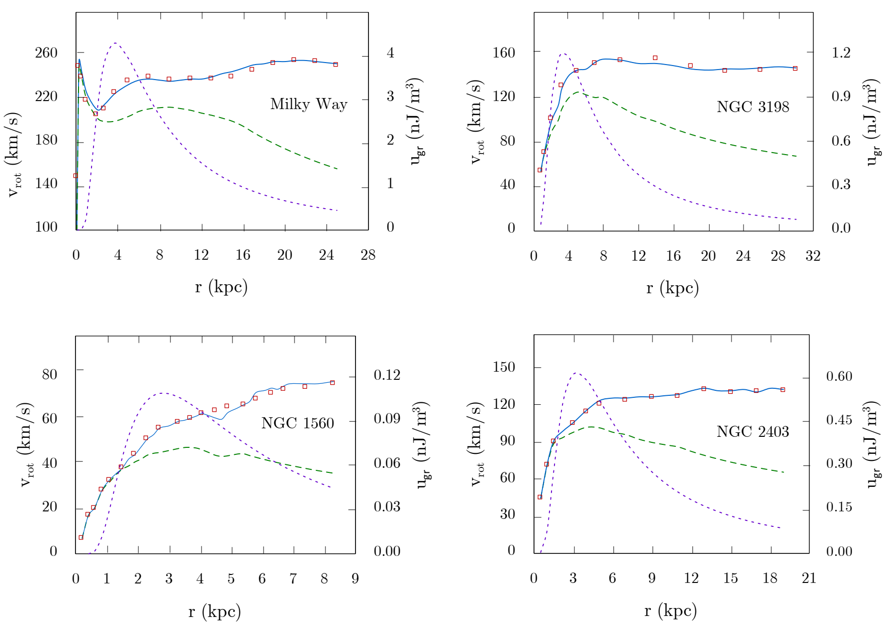

Figure 1. The rotation curves of four spiral galaxies calculated by assuming the gravitons of the local Newtonian gravitational field oscillate and radiate thermal gravitational energy. The Newtonian rotation curve for light traces mass is shown by the dashed line, and the rotation curve observed in the 21-cm line of neutral hydrogen is shown by the solid line, which extends far beyond the bright galactic center. The squares lie along the theoretical rotation curve of the galaxy due to GBR, and the dotted (short dashed) curve is the corresponding GBR energy density profile. The theoretical rotation speeds agree well with the observational (experimental) data[5].

[5]The plotted curves were generated from galaxy rotation curve data obtained from Refs. [5] [6] and the computed galaxy properties listed in Table 1.

3. Black-Body Temperature of Curved Spacetime

The GBR of a spiral galaxy consists of gravitational radiation in thermal equilibrium with the interstellar gravitational field. When they are in thermal equilibrium, the average rate of emission of radiation by the gravitational field equals the average rate of absorption of gravitational radiation. At thermal equilibrium, the temperature of the interstellar gravitational field is equal to the temperature of the radiation, which consists of gravitationally charged gravitons oscillating in phase along the local time coordinate axis of the corresponding unit cells of the Planck lattice [3].

Hawking radiation (1974) is caused by the energy fluctuations of the quantum vacuum near the event horizon of a black hole. In general, the oscillating gravitons of GBR are harmonic temporal fluctuations of the Planck lattice near a massive body; therefore, let us suppose that the thermal equilibrium (black-body) temperature T of the GBR and the gravitational field (curved spacetime) follows from Hawking's radiation formula:

$$T = T_H = \frac{\hbar c}{4\pi k_B r_s} = \frac{\hbar c^5}{8\pi k_B G A}, \tag{14}$$

where T_H is the Hawking temperature [9] and A is the equilibrium energy[6] of the GBR for the mass distribution under consideration. It follows from **Table 1**, that the blackbody temperature of the Milky Way's gravitational field is 0.29 pK.

By equating the exponents in the denominators of equations $S_{\text{em}}(\lambda)$ and $u_{\text{gr}}(r)$ for electromagnetic and gravitational blackbody radiation, respectively, we obtain:

$$\frac{B}{r^{3/4}} = \frac{hc}{\lambda k_B T}. \tag{15}$$

Since $r^3 = \left(\frac{B\lambda}{\lambda_H}\right)^4$, the GBR energy density $u_{\text{gr}}(r)$ may be written as

$$u_{\text{gr}}(\lambda) = n_{\text{gr}}(\lambda) U(\lambda, \lambda_H) = \frac{8\pi\Omega_{\text{gr},o} hc}{3\lambda^4 \left(e^{\lambda_H/\lambda} - 1\right)}, \tag{16}$$

where $\lambda_H = hc/k_B T_H$ is the Hawking wavelength, $\Omega_{\text{gr},o} = A\lambda_H^4 / B^4 hc$ is the ratio of the equilibrium energy density of the radiation to the kinetic or Hawking energy density of the oscillating gravitons, $n_{\text{gr}}(\lambda) = 8\pi\Omega_{\text{gr},o} / 3\lambda^3$ is the number of states per unit volume, and the average energy per "mode" or "quantum" is given by

$$U(\lambda, \lambda_H) = \frac{hc}{\lambda\left(e^{\lambda_H/\lambda} - 1\right)}, \tag{17}$$

where $h\nu = hc/\lambda$ is the energy of the quantum and $\left(e^{\lambda_H/\lambda} - 1\right)^{-1}$ is the Bose-Einstein distribution function, which provides the probability that a given energy level will be occupied.

[6]Computed values of the A for several spiral galaxies are provided in **Table 1**.

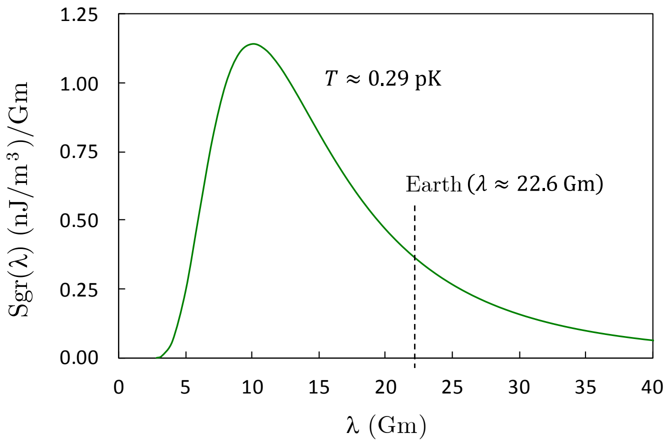

Figure 2. The spectral density of gravitational radiation emitted by the Milky Way galaxy. The energy of the GBR emitted by the interstellar Newtonian gravitational field of the Milky Way near Earth is estimated to be slightly over twenty trillion (~10^{13}) times smaller than the lowest frequency (~300 GHz) of electromagnetic radiation emitted by the Sun, which is approximately 750 times smaller than the lowest frequency (~10 Hz) that can be detected by LIGO[7] [10].

In general, the GBR spectral energy density, which is plotted in **Figure 2** for the Milky Way galaxy, has the form.

$$S_{\mathrm{gr}}(\lambda) = \rho_{\mathrm{gr}}(\lambda) U(\lambda, \lambda_H) = \frac{8\pi\Omega_{\mathrm{gr},o} hc}{\lambda^5 \left(\mathrm{e}^{\lambda_H/\lambda} - 1\right)}, \tag{18}$$

where $\rho_{\mathrm{gr}}(\lambda) = \left|\mathrm{d}n_{\mathrm{gr}}/\mathrm{d}\lambda\right| = 8\pi\Omega_{\mathrm{gr},o}/\lambda^4$ is the density of states per unit wavelength. Similar to electromagnetic black-body radiation, the total energy density for GBR

$$u_{\mathrm{gr},tot} = \int S_{\mathrm{gr}}(\lambda)\mathrm{d}\lambda, \tag{19}$$

is finite and proportional to the equilibrium energy density of the radiation

$$u_{\mathrm{gr},tot} \propto u_{\mathrm{gr},o} = A/B^4, \tag{20}$$

which, according to the data provided in **Table 1**, gives us a value of 0.107 nJ/m^3 for the equilibrium energy density of the GBR in the Milky way [11].

4. Interesting Theoretical Results

The distance R from the Earth to the Moon is approximately 3.84×10^8 m. The computed energy density of the GBR that fills the empty space throughout the Solar System is approximately[8] 2.63 nJ/m^3. The strength of the gravitational field produced by local interstellar GBR that slowly pulls the Moon toward the Earth is approximately:

$$\left|g_{\mathrm{gr}}\right| = \frac{4GM_{\mathrm{gr}}}{r_{s,E}R} = \frac{2M_{\mathrm{gr}}c^2}{M_E R} \approx 5.45 \times 10^{-16}\ \mathrm{m/s^2},$$

[7]The plotted curve and gravitational temperature of the Milky Way were derived from galaxy rotation curve data obtained from Ref. [5] and the computed galaxy properties listed in **Table 1**.
[8]Estimated energy density is computed with rotation curve data for the Milky Way in Ref. [5].

$$M_{\text{gr}} = \frac{u_{\text{gr}} \mathcal{V}_{\text{gr}}}{c^2} \approx 6.95 \text{ kg},$$

$$\mathcal{V}_{\text{gr}} = \frac{4\pi}{3} R^3 \approx 2.38 \times 10^{26} \text{ m}^3,$$

$$M_E = 5.972 \times 10^{24} \text{ kg},$$

$$^{9}\, c = 3.00 \times 10^{8} \text{ m/s},$$

which is 13 orders of magnitude smaller than the Newtonian gravitational field of Earth pulling on the Moon ~2.70 mm/s^2. Here, M_{gr} is the relativistic mass of the gravitational radiation energy contained within a spherical volume centered on Earth with a radius equal to the distance between Earth and Moon. This outcome confirms our earlier claim that the gravitational field generated by GBR is indeed extremely small, except in the case of large astrophysical structures, such as galaxies and clusters of galaxies.

At the edge of the Solar System, a distance of 143.7 billion kilometers[10] from the Sun, where the gravitational force of our Sun fades, the additional increase in the Sun's gravitational acceleration due to local interstellar GBR is approximate:

$$|g_{\text{gr}}| = \frac{2M_{\text{gr}} c^2}{M_{\odot} R} \approx 2.29 \times 10^{-10} \text{ m/s}^2,$$

$$M_{\text{gr}} = \frac{u_{\text{gr}} \mathcal{V}_{\text{gr}}}{c^2} \approx 3.63 \times 10^{17} \text{ kg},$$

$$\mathcal{V}_{\text{gr}} = \frac{4\pi}{3} R^3 \approx 1.24 \times 10^{43} \text{ m}^3,$$

$$^{11}\, M_{\odot} = 1.988 \times 10^{30} \text{ kg},$$

which is comparable in magnitude to the anomalous acceleration 8.74 × 10^{-10} m/s^2 towards the Sun experienced by the Pioneer spacecraft [12] (launched in 1972 and 1973) as they moved beyond the orbit of Uranus (approximately 2.8 billion km from the Sun) on their way out of the Solar System.

Conflicts of Interest

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

References

[1] Schwinger, J. (1968) Sources and Gravitons. *Physical Review Journals Archive*, **173**, 1264-1272. https://doi.org/10.1103/PhysRev.173.1264

[2] Cacciatori, S., Preparata, G., Rovelli, S., Spagnolatti, I. and Xue, S.-S. (1998) On the Ground State of Quantum Gravity. *Physics Letters B*, **427**, 254-260. https://doi.org/10.1016/S0370-2693(98)00349-9

[3] Nash, L. (2022) On the Dynamics of Euclidean Space-Time at the Planck Scale. *Re-*

[9] The speed of light in vacuum.

[10] This value is based upon Sedna the most distant observable object known in our Solar System.

[11] The mass of the Sun.

ports in Advances of Physical Sciences, **6**, 2250002.

[4] Planck, M. (1901) Ueber das Gesetz der Energieverteilung im Normalspectrum [On the Law of Energy Distribution in the Normal Spectrum]. *Annalen der Physik*, **4**, 553-563. https://doi.org/10.1002/andp.19013090310

[5] Sofue, Y. (2015) Dark Halos of M31 and the Milky Way. *Publications of the Astronomical Society of Japan*, **67**, 75. https://doi.org/10.1093/pasj/psv042

[6] Brownstein, J.R. and Moffat J.W. (2006) Galaxy Rotation Curves without Non-Baryonic Dark Matter. *The Astrophysical Journal*, **636**, 721-741. https://doi.org/10.1086/498208

[7] Sanders, R. (2010) The Dark Matter Problem: A Historical Perspective. Cambridge University Press. https://doi.org/10.1017/CBO9781139192309

[8] Capozziello, S. and De Laurentis, M. (2011) Extended Theories of Gravity. *Physics Reports*, **509**, 167-321. https://doi.org/10.1016/j.physrep.2011.09.003

[9] Hawking, S.W. (1975) Particle Creation by Black Holes. *Communications in Mathematical Physics*, **43**, 199-220. https://doi.org/10.1007/bf02345020

[10] Barish, B. & Weiss, R. (1999) LIGO and the Detection of Gravitational Waves. *Physics Today*, **52**, 44-50. https://doi.org/10.1063/1.882861

[11] Parikh, M., Wilczek, F. and Zahariade, G. (2020) The Noise of Gravitons. *International Journal of Modern Physics D*, **29**, Article No. 2042001. https://doi.org/10.1142/S0218271820420018

[12] Anderson, J., Laing, P., Lau, E., Liu, A., Nieto, M., *et al.* (2002) Study of the Anomalous Acceleration of Pioneer 10 and 11. *Physical Review D*, **65**, Article No. 082004. https://doi.org/10.1103/PhysRevD.65.082004