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Article

Anthropic Principle and the Hubble-Lemaître Constant

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Abstract: According to the weak formulation of the anthropic principle, all fundamental physical constants have just such values that they enabled the origin of life. In this survey paper, we demonstrate also that the current value of the Hubble–Lemaître constant essentially contributed to the existence of humankind. Life on Earth has existed continually for at least 3.5 Gyr, and this requires very stable conditions during this quite long time interval. Nevertheless, as the luminosity of the Sun increases, Earth has receded from the Sun by an appropriate speed such that it received an almost constant solar flux during the last 3.5 Gyr. We introduce several other examples illustrating that the solar system and also our galaxy expand by a speed comparable to the Hubble–Lemaître constant.

Keywords: Hubble parameter; local Hubble expansion; Earth; solar system; gravitational aberration; dark energy; law of conservation of energy and momentum

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1. Introduction

Cosmologists usually claim that the Hubble expansion can manifest itself only on cosmological scales and that the universe expands globally, but not locally. However, this immediately implies various mathematical contradictions (see, e.g., [1] (pp. 243–244), [2] (p. 90)). Thus, the universe must expand somewhere locally. In this survey paper, we first introduce several examples showing that there are also manifestations of the Hubble expansion on local scales such as the solar system.

The value of the gravitational constant G has a significant influence on the interior temperature of a star, its age and size, its luminosity, and many other parameters. The reason is that the product GM is proportional to the pressure inside the star, where M is its mass. If G were to be only one part per thousand smaller or larger than its present value, then all stars, galaxies, and also their clusters would evolve in a different way, and thus Earth could not come into being as it is. Unfortunately, we cannot perform any experiments to test the evolution of the universe for a different value of the gravitational constant G.

Similar statements are also valid for other fundamental physical constants like the speed of light c in a vacuum[1], the mass of the proton m_p, the proton-to-electron mass ratio $m_\mathrm{p}/m_\mathrm{e} \approx 1836.152673$, the elementary charge e (of the electron), Planck's constant h, the vacuum electric permittivity ε_0, the Avogadro constant N_A, the Boltzmann constant k_B, etc., see Novotný [3]. In contrast, the dimensionless constant of fine structure $\alpha = e^2/(2\varepsilon_0 hc) \approx 1/137$, the reduced Planck constant $\hbar = h/(2\pi)$, the vacuum magnetic permeability constant $\mu_0 = 1/(\varepsilon_0 c^2)$, etc., should not be called fundamental, as the right-hand sides of their definition expressions already contain fundamental constants. Another way would be to use a different (but equivalent) set of fundamental constants, where we replace, e.g., ε_0 by α.

Some physical constants that characterize, for instance, ordinary water, also have remarkable values. It is well-known that water has the highest density at 4 °C under normal pressure. As a result, in winter, lakes do not freeze from the bottom. Contrary to other substances, ice has a lower density than liquid water. Thus, ice floats on water, which protects the fish and other aquatic animals from freezing. Water also has the highest heat capacity of all substances, which significantly contributes to a high stability of the temperature of Earth's surface. Nevertheless, particular values of these physical constants are only side effects of the fundamental physical constants. Hence, the values of c, m_p, e, h, ε_0, etc., are so perfectly tuned that they allow water to have such advantageous properties suitable for the existence of life.

The structure of DNA with covalent bonds in both its strands and with hydrogen bonds between adenine and thymine, and cytosine and guanine also essentially depend on the size of the elementary charge e (see Figure 1). This value plays a crucial role in replication and transcription processes [4]. The translation process: RNA → PROTEINS in ribosomes depends on e, also. Other fundamental constants allow a proper forming of the helix shape of DNA as well, although each cell has approximately 2 m of DNA strands that do not tangle during replication and transcription. Note that the total length of DNA in each human is approximately 10^{13} m, which is more than the Earth–Pluto distance.

The two hydrogen bonds between adenine and thymine are contained in the so-called TATA-box that precedes the start codon [4]. Therefore, this box can be more easily split by the enzyme RNA polymerase during transcriptions than three hydrogen bonds between cytosine and guanine, cf. [5] (p. 966).

It is also remarkable that the main components of all organic compounds are the most frequent elements in the universe (except for the inert gas helium). The most frequent element is, of course, hydrogen, oxygen is third, carbon fourth, and nitrogen fifth. They have small nuclei, which support a large variability of organic molecules.

A suitable combination of the aforementioned fundamental constants also guarantees an incredible stability of the Sun for approximately 10 Gyr. The total solar power incident per unit area of 1 m^2 perpendicular to the Sun's rays at the distance of one astronomical unit (1 au = 149,597,870,700 m) is by definition equal to the *solar constant*:

$$L_0 = 1.36\ \mathrm{kW\,m^{-2}}. \tag{1}$$

At present, the value of L_0 changes by less than 0.1% depending on the number and size of sunspots. Therefore, the total solar power is approximately

$$L_\odot = 4\pi R^2 L_0 = 3.825 \times 10^{26}\ \mathrm{W}, \tag{2}$$

where R is one astronomical unit. Hence, by the formula $E = mc^2$, the Sun's mass losses due to nuclear reactions are 4.26×10^9 kg/s. As $M_\odot = 1.989 \times 10^{30}$ kg, we find that $L_\odot / M_\odot = 0.0002$ W/kg on average. Consequently, nuclear reactions inside the Sun are very precisely tuned so that they enabled the origin of humankind.

The *weak formulation* of the anthropic principle states that all fundamental physical constants have just such values that they enabled the origin of life (see [1,6–9]). The expansion speed of the universe is also a very important quantity in the context of the anthropic principle. If it would be too high, galaxies would not appear. If it would be too small, our universe would gravitationally collapse and life would not have enough time to arise. According to the IAU 2018 Resolution B4 in Vienna, the expansion of the universe should be referred to as the *Hubble–Lemaître law.* Therefore, we will call the associated constant:

$$H_0 \approx 70\,\mathrm{km\,s^{-1}Mpc^{-1}}. \tag{3}$$

the *Hubble–Lemaître constant* (formerly the Hubble constant). It corresponds to the current expansion speed of our universe. Hence, H_0 has an essential influence on the formation of galaxy clusters.

In this paper, we show how the Hubble–Lemaître constant significantly contributed to the origin and evolution of life on Earth, even though it is not a fundamental constant. Note that life probably did not arise in one time instant, but it could very slowly evolve during thousands or millions of years in water. Let us emphasize that H_0 represents only some average value over large structures. For example, according to Karachetsev et al. [10] (p. 2032), the local Virgo cluster of galaxies expands anisotropically with rates 81, 62, and 48 km/(s Mpc) in three mutually orthogonal directions in a ball with radius 8 Mpc.

Moreover, the expansion rate of our universe depends on time. It is described by the *Hubble parameter* $H = H(t)$, which decreases with time; see (12) for its definition. In Figure 2 we observe the behavior of the Hubble parameter calculated from the standard Friedmann equation corresponding to 30% of dark and baryonic matter and 70% of dark energy. We see that $H = H(t)$ is almost constant during the last 3.5 Gyr when life existed on Earth. It also remains almost constant in this interval for slightly different values of cosmological parameters. Best fitting solutions are presented, e.g., by Fahr and Heyl [11].

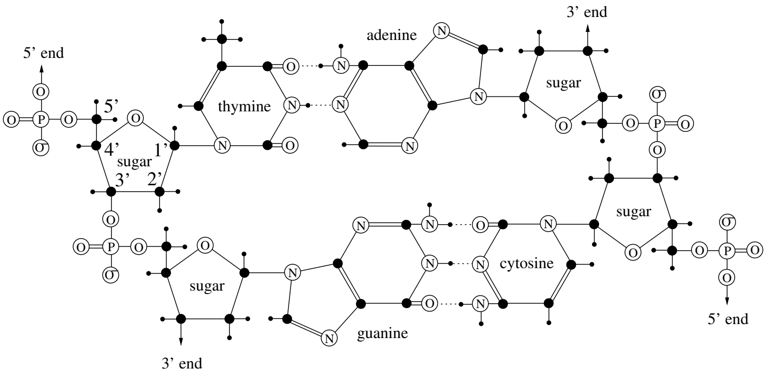

Figure 1. Schematic illustration of DNA: atoms of hydrogen are marked by small black dots, atoms of carbon by large black dots, covalent bonds are shown as solid lines, and hydrogen bonds as dotted lines.

In [1] (Chapt. 16), we also demonstrate that galaxies themselves slightly expand at a speed similar to $H_0 = H(t_0)$, where t_0 is the age of the universe. By [12] (Sect. 8), the observed expansion speed of the radius of the Milky Way is 0.6–1 kpc/Gyr. Taking into account that 1 kpc $= 3.086 \times 10^{16}$ km and 1 Gyr $= 3.156 \times 10^{16}$ s, the expansion speed is approximately 600–1000 m/s. This value perfectly fits to the Hubble–Lemaître constant (3), which is recalculated on the diameter $D \approx 10^5$ ly of our galaxy (see also [1] (p. 241)), namely,

$$H_0 = 2\,\mathrm{km}/(\mathrm{s}D).$$

This observation is supported by the fact that the measured mean density of stars in galaxies with $z > 1$ is much larger than in nearby galaxies, see, e.g., [13–15].

In Section 2, we show that also the solar system slowly expands by a speed similar to the current value of the Hubble–Lemaître constant recalibrated to one astronomical unit. Because light travels the Earth–Sun distance with speed c approximately 500 s and 1 pc = 3.262 ly, we obtain by (3) that:

$$H_0 \approx 20\,\mathrm{km\,s^{-1}Mly^{-1}} = \frac{0.02}{c}\,\mathrm{m\,s^{-1}year^{-1}} = 0.02\frac{500}{\mathrm{au}}\,\mathrm{m\,year^{-1}} = 10\,\mathrm{m\,year^{-1}au^{-1}}. \quad (4)$$

Nevertheless, such a relatively high expansion speed cannot be explained by the decrease of Sun's mass nor by solar wind and radiation pressure nor by tidal forces (see [1] (Sect. 13.7)).

In this paper, we assert that the local Hubble expansion yields tiny discrepancies from exact conservation of energy in the solar system. Some authors claim (see, e.g., [16,17]) that the Hubble constant has no influence on the expansion of the solar system. However, in Section 3, we show why these authors obtained much smaller values for recession speeds and from where we get energy for the local expansion, i.e., what could be the origin of dark energy. In Section 4, we give some concluding remarks.

Finally, note that the proposed local expansion has, of course, some limitations. For instance, an observer is held together by electromagnetic forces and not by gravitational forces, so he/she does not expand. Expansion of the universe is caused by free bodies, which act on each other only by gravity. However, this is not the case in the micro-world, because the electromagnetic force is more than 40 orders of magnitude greater than the gravitational force.

2. Local Hubble Expansion

According to [18,19], the expansion of the Universe accelerates due to repulsive dark energy forces. In [20], we present many examples illustrating that some tiny apparent repulsive forces can be detected locally. Introducing these repulsive forces into the solar system, a number of classical paradoxes can be easily explained, such as the Faint Young Sun Paradox, the slow rotation of Mercury and Venus, the absence of their moons, the Tidal Catastrophe Paradox of the Moon, rivers on Mars, rapid orbital expansion of Titan, the synchronous rotation of Iapetus, the very large orbital momentum of Titan, Triton, Charon and also of the Moon, an unexplained residual in the orbit of Neptune, the formation of Neptune and the Kuiper belt, and migration of planets.

Life on Earth appeared ∼3.8 Gyr ago and there was a hot climate. Nevertheless, at that time the luminosity of the Sun was only ∼75% of its present value, and since then the relative luminosity has increased approximately linearly with time, as shown in Figure 3 (see [21]). Theorem 1 below states that the recession speed

$$\overline{v} = 5.2\,\mathrm{m\,year}^{-1} \tag{5}$$

of Earth from the Sun guarantees an almost constant flux of solar energy during the last 3.5 Gyr. By (4), this value yields the expansion speed $0.52\,H_0$, which represents another argument for the anthropic principle [20]. Hence, the amount of the apparent repulsive forces, which are continually generated by the Earth–Sun system, lies in a narrow interval that enabled the origin of intelligent life [22]. Note that a decrease of the solar luminosity of only 2% caused ice ages, and a long-term decrease greater than 5% would cause total glaciation of Earth. In contrast, a long-term increase of the solar luminosity larger than 5% is also not probable, as mammals' DNA decays at temperatures over 57 °C.

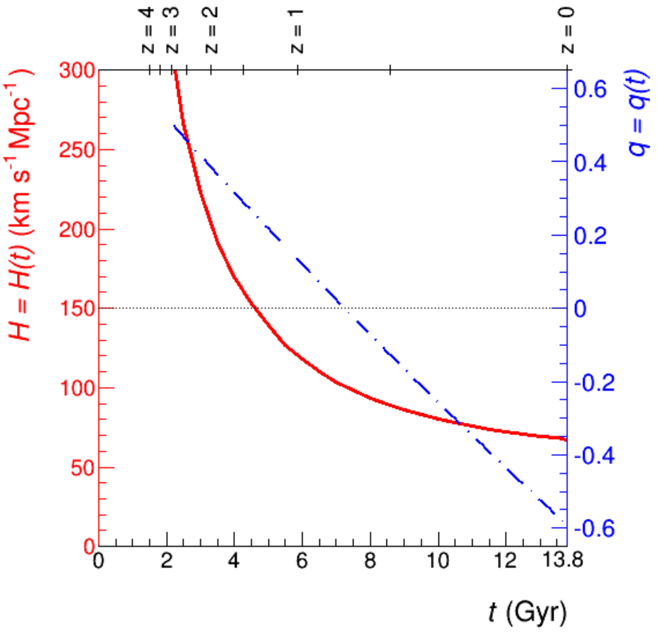

Figure 2. The solid line illustrates the decreasing Hubble parameter $H = H(t)$ in time. The dashed-dotted line shows the behavior of the deceleration parameter defined by $q = -1 - \dot{H}/H^2$. In the lower horizontal axis we see time in Gyr since the Big Bang, and the upper horizontal axis shows the corresponding redshift z.

Put:

$$\tau = -3.5 \text{ Gyr}$$

and let $t = 0$ correspond to the present time. As the luminosity of the Sun increases approximately linearly and it was only about 77% of its present value 3.5 Gyr ago (see Figure 3), we set:

$$L(t) = \left(1 - 0.23\frac{t}{\tau}\right)L_0 \quad \text{for all } t \in [\tau, 0],$$

i.e., $L(\tau) = 0.77\,L_0$ and $L(0) = L_0$. As the luminosity decreases with the square of the distance, we get quite surprising optimal recession speed of Earth from the Sun.

Theorem 1. *Set:*

$$L_{\text{opt}}(t) = \frac{L(t)R^2}{(R + \overline{v}t)^2}, \quad t \in [\tau, 0],$$

where $R = 1$ au *and* $\overline{v}$ *is given by* (5)*. Then:*

$$|L_{\text{opt}}(t) - L_0| < 0.005 \text{ kW m}^{-2} \quad \textit{for all } t \in [\tau, 0].$$

For the proof see [1] (Chapt. 14). Several other two-sided estimates can also be found there.

Zhang, Li, and Lei in [23] (Figures 4 and 5) derived a similar recession speed to (5). Using modern paleontological methods, they proved that the mean orbital expansion of Earth increases approximately at the rate of 0.6 H_0. Their method can be roughly described as follows (for details see [1,23]).

Zhang et al. in [23] examined solar and lunar data of hundreds of fossil corals from the entire world. By a sophisticated analysis of growth patterns they found that during the last 500 Myr the radius of Earth's orbit increased by approximately 3×10^6 km. This leads to the mean recession speed:

$$v = 6 \,\text{m}\,\text{year}^{-1}. \tag{6}$$

By laser measurements, the mean Earth–Moon distance d = 384,402 km increases by approximately 3.84 cm/year (see [24]). However, according to [25], only 55% of this value could be due to tidal forces. The remaining part

$$v = 1.71 \,\text{cm}\,\text{year}^{-1}$$

can be explained by the local Hubble expansion, as this speed is again comparable with the Hubble–Lemaître constant (4) recalibrated to the distance d, in particular,

$$H_0 = 1000 \,\text{cm}\,\text{year}^{-1}\text{au}^{-1} = 2.57 \,\text{cm}\,\text{year}^{-1}\text{d}^{-1}.$$

Thus, the associated expansion rate is:

$$\frac{1.71}{2.57} H_0 = 0.67\,H_0. \tag{7}$$

Similar rates can be found in [26–29].

According to Maeder and Bouvier [30] (p. 88), the orbital expansion of Mars was several meters per year. By [20,25], Mars was also nearer to the Sun 3–4 Gyr ago when a large liquid ocean was in the northern hemisphere and when there were many rivers and lakes within ±50° of Martian latitude. Assume for a moment that Mars was at the current distance 225 million km from the Sun when there was liquid water (see the bold time interval on the horizontal axis of Figure 3). With that assumption, the associated *solar constant for Mars* would be quite small, namely,

$$L_{\text{Mars}} = 0.75 L_0 \frac{150^2}{225^2} = \frac{1}{3} L_0, \tag{8}$$

where L_0 corresponds to the distance 1 au $\approx$ 150 million km (see (1)). The reason is that the solar luminosity decreases with the square of the distance from the Sun. Hence, the remaining enormous decrease of 66.6% excludes the existence of liquid water, if Mars were to have the same orbit as at present.

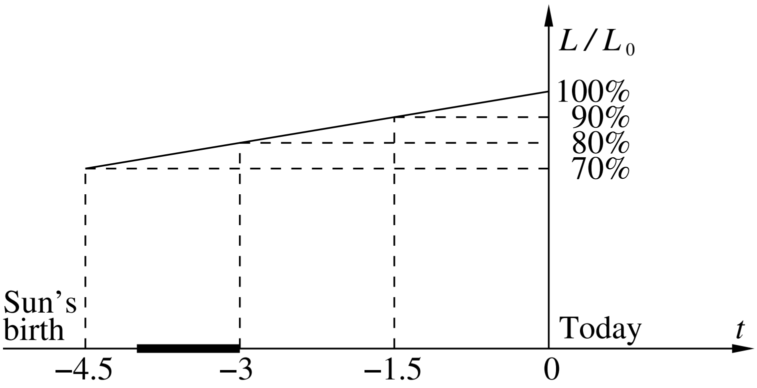

Figure 3. An idealized relative luminosity L/L_0 of the Sun, where L_0 is the solar constant and the time t is given in Gyr. The bold interval on the horizontal axis denotes the time period when life appeared on Earth and when liquid water was present on the surface of Mars.

Using the Stefan–Boltzmann law, we investigate in [1] (p. 174) the average surface temperature on Mars. We found that the corresponding theoretical temperature ≈ -62 °C is in a very good agreement with the overall mean temperature ≈ -60 °C measured by the Vikings, Pathfinder, Spirit, Opportunity, Phoenix, Curiosity, Perseverance, etc. (see [31] (Chapt. 18)). Recall, moreover, that the luminosity of the Sun 3 to 4 Gyr ago was only 75% of its current value (cf. Figure 3). Thus the greenhouse effect cannot guarantee a mean temperature close to the freezing point of water even though Mars had a higher radioactivity, denser atmosphere, and more volcanism. According to [32], the Curiosity rover found the absence of carbonates on Mars. This led to the production of too little carbon dioxide necessary for a greenhouse effect to be present about 3.5 billion years ago to allow the generation of liquid water on Mars. These arguments support the so-called Faint Young Paradox [1,27,33,34].

Further argument that Mars was closer to the Sun 3.5 Gyr ago is as follows. Mars had a larger albedo than at present (and thus a lower mean temperature), because there were water clouds feeding thousands of streams and rivers (see [20]). Finally, let us point out that if Mars were to be, for example, 180 million km rather than 225 million km from the Sun when it originated 4.5 Gyr ago, then its mean recession speed would be just 10 m/year. This value is again similar to the Hubble–Lemaître constant (4).

Another measured value concerns Titan. By two independent methods based on radio waves and astrometry (see [35]), it was derived that the average recession speed of Titan from Saturn is equal to:

$$v = 11.3\ \text{cm/year}. \tag{9}$$

Before this precise measurement, planetologists supposed that this speed should be only 0.1 cm/year, as Saturn is gaseous planet and, therefore, tidal forces are almost negligible. As the Titan–Saturn mean distance is D = 1,221,870 km, the recalibrated value of the Hubble–Lemaître constant (4) is:

$$H_0 = 8.14\,\text{cm}\,\text{year}^{-1}\text{D}^{-1}.$$

Then the corresponding total mean expansion rate is (see [36]):

$$\frac{11.3 - 0.1}{8.14} H_0 = 1.38\, H_0. \tag{10}$$

It is even greater than H_0 due to several other processes (resonances, tides, etc.) that act simultaneously.

Lainey et al. [35] claim that the rapid recession speed v is mainly caused by a resonance locking mechanism of the five inner mid-sized moons of Saturn: Mimas, Enceladus, Tethys, Dione, and Rhea. Nevertheless, their total mass is only 3% of the mass of Titan. Therefore, if the unexplained recession speed of Titan is approximately 0.1 m/year, the inner moons should approach Saturn on average approximately more than 3 m/year (i.e., 3,000,000 km/Gyr) to keep the laws of conservation of energy and momentum valid. Nonetheless, this would contradict the present sizes of their semi-major axes from the interval 185,539–527,108 km and old cratered surfaces [37].

Now we show that some other moons of the planets are affected by repulsive forces as well, namely, the so-called *fast satellites*. They are below the stationary orbit of a given planet, i.e., their orbital periods are smaller than the rotational period of the planet. These satellites should approach their mother planet along spiral trajectories due to tidal forces. From Kepler's third law we can find the following relation for the radius of the stationary orbit:

$$r_i = \left(\frac{Gm_iP_i^2}{4\pi^2}\right)^{1/3}, \tag{11}$$

where m_i stands for the mass of the ith planet and P_i is its sidereal rotational period. Nevertheless, apparent repulsive forces act in the opposite direction. They have similar size as tidal forces. Therefore, orbits of fast satellites are stable for billions of years (see, e.g., [1] (p. 229), [2] (p. 85), [20]). The apparent repulsive forces thus prevent fast satellites from crashing into their mother planets.

It is not known how Neptune could be formed as far away as $R = 30$ au from the Sun, where the original protoplanetary disc was relatively sparse and all motions are very slow (by Kepler's third law its average speed is only 5.4 km/s). Supposing that the mean Neptune–Sun distance increases approximately at the rate of $0.5H_0$ as in previous examples, we obtain from (4) that Neptune could be formed closer to the Sun $t = 4.5$ Gyr ago on the initial orbit with radius R_0. Using the formula $R = R_0 \exp(H_0 t/2)$, we obtain:

$$R_0 = R\exp(-H_0 t/2) = R\exp(-5 \times 4.5/150) = R\mathrm{e}^{-0.15} = 25.82\,\mathrm{au}.$$

This and relations (4)–(10) support our conjecture that the solar system slowly expands by the speed comparable with H_0. More information about the local Hubble expansion can be found in, e.g., [1,26–28,30,38].

3. Hubble Parameter

Currently, most cosmologists believe that the expansion of our universe is accelerating. Their hypothesis is based on a thorough analysis of distant supernovae of type Ia (see [18,19,39]). These supernovae are assumed to be standard candles, which need not be true due to extinction, if they are not on the edge of a particular galaxy [40,41]. It is said that this acceleration is due to dark energy that is distributed everywhere almost uniformly (see [42]). Hence, dark energy should also have an influence on local systems and on the Hubble–Lemaître constant (3) that characterizes the speed of this expansion. Note that the effect of cosmological expansion on local systems has a very rich history. A local expansion was already conjectured by McVittie [43] in 1933. Subsequently, Einstein and Straus [44] connected the static outward Schwarzschild metric with the standard time-dependent FLRW metric to model the local spacetime around stars. Some drawbacks of this concept are explained in Fahr and Siewert [45].

Recall (see, e.g., [46–48]) that the Hubble parameter is defined by the ratio:

$$H = \dot{a}/a, \tag{12}$$

where a stands for the expansion function. For example, if the universe would be modeled by the hypersphere S^3 at some fixed time instant t, then the value of the expansion function $a = a(t)$ is equal to the radius of S^3 at time t. Differentiating $H = H(t)$, one gets:

$$\dot{H} = \frac{\ddot{a}}{a} - H^2 = -qH^2 - H^2.$$

According to the standard cosmological ΛCDM model, $t_0 \approx 13.75$ Gyr is the age of universe. The *deceleration parameter*, which characterizes the expansion rate, is defined by $q = -\ddot{a}/a$ (see Figure 2). Then the Taylor expansion of $a = a(t)$ can be written as follows:

$$\begin{aligned} a(t) &= a(t_0) + \dot{a}(t_0)(t - t_0) + \frac{1}{2}\ddot{a}(t_0)(t - t_0)^2 + \cdots \\ &= a(t_0)(1 + H_0(t - t_0) - \frac{1}{2}q_0 H_0^2 (t - t_0)^2 + \ldots), \end{aligned} \tag{13}$$

where $q_0 = q(t_0) \approx -0.6$.

Carrera and Giulini in [16] derived an extremely small derivative of the Hubble parameter $H = H(t)$ for $t = t_0$ on the scale of the solar system. In particular, they got a tiny outward acceleration of $2 \times 10^{-23}\,\mathrm{m/s^2}$ at Pluto's distance of 40 au. Similar values were obtained in [17] (p. 62) and [49] (p. 5041), which would mean that the effect of dark energy has almost no influence on the expansion of the solar system. These authors assert that the quadratic term in (13) has no effect on the solar system. Nevertheless, the large value of the Hubble–Lemaître constant (4) that is contained in the linear term of the last line of (13) is surprisingly not taken into account in the aforementioned papers.

Remark 1. *Let us emphasize that the quadratic term of (13) is much smaller than the linear term; see [2] (p. 88) for details. The famous cosmological constant Λ is hidden in the quadratic term. However, for the time being, no significant digit of this constant is known, even though there are thousands of papers on Λ.*

Remark 2. *The fact that $H = H(t)$ is a decreasing function (see Figure 2) does not contradict the statement that the expansion of the universe could accelerate, i.e., that the second derivative $\ddot{a} > 0$ on some interval, where a is a strictly convex function. To see this, take, e.g., $a(t) = t^2$ on $I = (0, \infty)$. Then $\dot{a}(t) = 2t$, $\ddot{a}(t) = 2 > 0$, and $H(t) = \dot{a}(t)/a(t) = 2/t$ is a decreasing function on I.*

By [50], the radius of Earth's orbit increases only 15 cm per year. Nevertheless, this statement is obtained under an incorrect supposition that the Newtonian theory of gravitation describes movements of all planets exactly. Moreover, no modeling and discretization errors are assumed, and the existence of apparent repulsive forces is not considered.

Note that Henri Poincaré in 1905 already conjectured that the speed of gravitational waves is equal to the speed of light c in a vacuum (see [51]). This was recently confirmed by LIGO/VIRGO measurements [52]. Hence, gravitational and electromagnetic waves should produce the same aberration effects. However, from Section 2 it seems that the gravitational aberration angle is much smaller than the aberration of light, but it is positive due to causality. It is not clear whether the speed of gravitational waves is the same as the speed of gravitational interaction. Carlip in [53] states under some very strong assumptions that the gravitational interaction yields much smaller aberration effects than does light aberration.

4. Concluding Remarks

Apparent repulsive forces cause secular migration of our planet on the order of meters per year, so that it stays within the expanding ecosphere. If they were not to act, then conditions favorable for the development of life on Earth would exist for only about one billion years. Intelligent life would not have had enough time to develop due to a continual rise in temperatures (cf. Figure 3 and [20,46]). The observed slow expansion of the solar system causes that the law of conservation energy is slightly violated. According to the theorem of Emmy Noether, the energy of each isolated system is conserved if it possesses symmetry with respect to time translations. Nevertheless, this is not true for spiraling trajectories.

Note also that there exist close binary pulsars and black hole mergers whose orbits decay with time (see [52,54]). In this case, strong magnetic and gravitational fields are present and the system loses energy due to electromagnetic and gravitational waves and also due to tidal forces. These effects are stronger than effects coming from apparent repulsive forces or aberration phenomena yielding the local Hubble expansion, which can be then interpreted as dark energy.

Another possibility is to take into account a curved space-time. The proper distance d_{prop} between two point masses m_A and m_B is, in fact, larger than the coordinate distance d_{coor} of their projection into the flat Euclidean space. The sharp inequality $d_{\text{prop}} > d_{\text{coor}}$ could contribute to the local Hubble expansion as well. This hypothesis even has the potential to explain the dark energy mystery [46,55].

Apparent repulsive forces (sometimes called *dark forces*) slightly, but continually generate energy in any system of free bodies that interact gravitationally [47] (p. 276). They increase its total (kinetic + potential) energy and angular momentum [56]. Thus, they contribute to the migration of planets and their moons over long time periods, they explain the Faint Young Sun Paradox first noted in [33], they cause many star clusters to dissipate, they help to reduce the frequency of collisions of galaxies and stars, etc. They stabilize the solar system and have also helped to create suitable habitable conditions on Earth for several billion years [20].

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Conflicts of Interest: The authors declare no conflict of interest.

Note

[1] We can always choose physical units so that $c = 1$, $G = 1$, $\varepsilon_0 = 1$, etc., instead of the standard SI units.

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