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# Antigravity—Its Manifestations and Origin

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## ABSTRACT

Dark energy has been introduced in order to explain the observed acceleration of the expansion of our Universe. It seems to be distributed almost uniformly and it has an essential influence on the present value of the Hubble constant which characterizes the rate of this expansion. The Newtonian theory of gravitation is formulated so that the laws of conservation of energy and momentum hold. However, the Universe is designed so that the total amount of energy is slowly, but continually increasing, since its expansion is accelerating. Our examples show that even the Solar System and also our Galaxy imperceptibly expand thanks to dark energy whose origins are tiny antigravity forces. We claim that these forces appear due to the finite speed of gravitational interaction, which causes gravitational aberration effects. We show that effects of dark energy are observable; they are not only globally, but also in local systems. These effects can be measured and are comparable with the present value of the Hubble constant.

**Keywords:** Hubble Parameter; Dark Energy; Antigravity; Cosmological Constant; Gravitational Aberration; Conservation of Energy and Momentum Law; Solar System

## 1. Introduction

There is a tendency among physicists to state that dark energy can only manifest itself on cosmological scales by definition. However, there is an underlying reality which our model of dark energy tries to capture. In this paper, we provide many examples that give evidence that in reality there are manifestations of dark energy on local scales as small as the Solar System.

The validity of physical laws is verified by measurements. Nevertheless, absolutely exact measurement instruments cannot be constructed. Hence, we are not able to check by measurements whether generally accepted physical laws (such as the conservation of energy law or the conservation of momentum law) are valid for an arbitrary number of decimal digits.

The law of conservation of energy belongs to the basic pillars of current physics. The Newtonian theory of gravitation is formulated in such a way that the law of conservation of energy is valid absolutely and exactly. However, is this law valid also in the real world that is only modeled by Newton's theory or Einstein's theory of general relativity? We will apply a wide interdisciplinary approach to answer this question. We will present more than 10 real-world examples that illustrate why the law of conservation of energy is not valid absolutely and exactly. Firstly we survey a number of astrobiological, astronomical, geometrical, geophysical, geochronometrical, heliophysical, climatological, paleontological, and observational arguments showing that the Solar System slowly expands by a speed of approximately $v = 5\ \mathrm{m{\cdot}yr^{-1}{\cdot}au^{-1}}$. comparable to the present value of the Hubble constant recalibrated to 1 au = 149,597,870,700 m, *i.e.*

$$H_0 = 10\ \mathrm{m \cdot yr^{-1} \cdot au^{-1}}. \quad (1)$$

Such a large expansion rate cannot be explained by the decrease of the solar mass nor by solar wind or by tidal forces (see [1]). This, of course, contradicts Kepler's laws, and thus also the law of conservation of energy taking into account that the Solar System is sufficiently isolated from the gravitational influence of other stars. For instance, the closest star (except for our Sun), Proxima Centauri acts on the Earth with about a million times smaller gravitational force than does Venus.

Dark energy has an essential influence on the expansion of our Universe and there is no reason to assume that dark energy would somehow avoid the Solar System or the interior of our Galaxy. In [2,3] we show that the average recession speed 5.2 m/yr of the Earth from the

Sun guarantees an almost constant solar flux on the Earth during the last 3.5 billion years, since the luminosity of the Sun slowly and continually increases. This would, of course, guarantee very stable conditions for the development of life. Zhang, Li, and Lei in their groundbreaking paper [4] present other independent arguments showing that the Earth-Sun distance increases several meters per year. We give more details on this topic in Section 2.

The repulsive force, which is responsible for the expansion of the Solar System and other gravitationally bounded systems, is called *antigravity*. It is not a new fifth physical force, but only a secondary effect of the gravitational force caused by the finite speed of gravitational interaction producing gravitational aberration effects. (Similarly, the strong force, which holds quarks together, has a secondary effect, which keeps atomic nuclei together.)

In this paper we assert that the presence of dark energy leads to small discrepancies from exact conservation of energy within the Solar System. Some authors claim (see e.g. [5,6]) that dark energy has no influence on the Solar System. In Section 3 we show where these authors fail and from where we get dark energy, *i.e.*, what is the mysterious origin of dark energy?

## 2. Manifestations of Dark Energy

### 2.1. Manifestation of Dark Energy in the Solar System

According to [7,8], the expansion of our Universe accelerates due to dark energy that has a repulsive character. In [1,3,9] we give more than ten examples showing that some tiny antigravity forces can be detected even in the Solar System. Introducing dark energy into the Solar System, a number of classical paradoxes can be explained, such as the Faint Young Sun Paradox, the very large orbital momentum of our Moon and Triton, the formation of Neptune and the Kuiper belt, an unexplained residual in the orbit of Neptune, the existence of Saturn's rings, rivers on Mars, the Tidal Catastrophe Paradox of the Moon, and migration of planets.

A decrease of the solar luminosity of only 2% caused ice ages in the past. Life on Earth originated approximately 3.5 Gyr ago. However, in that time the luminosity of the Sun was about 77% of the current value and since then it has increased approximately linearly (see **Figure 1** and [10]). In [2] it was shown that the recession speed

$$v = 5.2\ \mathrm{m \cdot yr^{-1}} \quad (2)$$

of the Earth from the Sun is just right to enable the almost constant influx of solar energy from the origin of life on Earth up to the present. By (1) this corresponds to the expansion rate 0.52 $H_0$ due to dark energy and

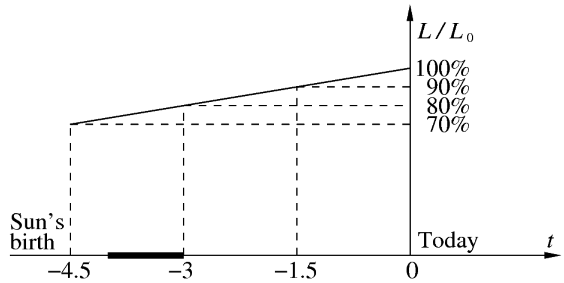


**Figure 1. Relative luminosity $L/L_0$ of the Sun from the origin of the Solar System up to the present. The time $t$ is given in Gyr.**

represents further support for the Anthropic Principle [3]. In other words, the amount of dark energy that is continually produced by the Earth-Sun system lies in a narrow interval that enabled the origin of intelligent life.

A similar recession speed to (2) was independently derived by Zhang *et al.* in [4, Figures 3 and 4]. Using sophisticated paleontological and computational methods, they showed that the average Earth-Sun distance increases very roughly at the rate of $0.5H_0$ (cf. (4) and (6)), where

$$\begin{aligned} H_0 &\approx 20\ \mathrm{km \cdot s^{-1} \cdot Mly^{-1}} \approx 70\ \mathrm{km \cdot s^{-1} \cdot Mpc^{-1}} \\ &\approx 10\ \mathrm{m \cdot yr^{-1} \cdot au^{-1}} \approx 2.3 \times 10^{-18}\ \mathrm{s^{-1}} \end{aligned} \quad (3)$$

is the Hubble constant (1) characterizing the expansion of the Universe at present. By a detailed analysis of growth patterns on many fossil corals they found that during the last 500 million years the Earth-Sun distance increased about 3 million km. This yields an average recession speed

$$v = 6\ \mathrm{m \cdot yr^{-1}} \quad (4)$$

which is of the same order as the above-mentioned Hubble constant (1).

Zhang *et al.* in their seminal paper [4] investigated solar and lunar data (which are independent) of hundreds of fossil patterns from the whole world. To reduce the error in the calculations it is necessary to have at least four consecutive years of data. The main idea of their method can be explained by the following example.

By means of calculating the number of layers deposited during one year in fossil corals Zhang, Li, and Lei found that in the Devonian era (370 million years ago) each year had about 405 days. However, each day was shorter at that time—about 21.3 hours, since the rotation of the Earth slows down due to tidal forces. The Earth's rotational history is known from many papers on paleorotation. In this way we obtain that the length of the sidereal year in the Devonian era was about 31,055,400 seconds, whereas the present value is

$$Y = 31558149.54\ \mathrm{s}. \quad (5)$$

 

Kepler's third law enables us to derive that the semi-major axis of Earth's orbit was only 148.1 million km, *i.e.* shorter than it is now. From this we find an average recession speed

$$v = \frac{(149.6 - 148.1)\cdot 10^9}{370\cdot 10^6 \cdot Y} \approx 4 \text{ m/s}. \quad (6)$$

By [2,3] Mars was also closer to the Sun 3 - 4 Gyr ago when there were rivers on its surface and when it contained a large liquid ocean in the northern hemisphere. Let us take a closer look at situation on Mars by means of the Stefan-Boltzmann law. The intensity of radiation of the black body (Sun) is equal to $\sigma T^4 = L_\odot / (4\pi r^2)$, where $\sigma = 5.669\times 10^{-8}\,\text{Wm}^{-2}\cdot\text{K}^{-4}$ is the Stefan-Boltzmann constant, $T$ is the equilibrium temperature, $L_\odot = 3.846\times 10^{26}$ W is the total solar power and $r$ is the distance from the Sun. Since the surface of Mars is four times larger than its maximal cross section, the surface equilibrium temperature is given by

$$T_{\text{Mars}} = \left(\frac{(1-A)L_\odot}{16\pi\sigma r^2}\right)^{1/4} = 211 \text{ K}, \quad (7)$$

where $A = 0.25$ is the present value of the Bond albedo. In this case the absorbed energy is equal to the emitted energy.

The theoretical value as given in (7) is in good agreement with the overall average temperature $\approx -60$ ˚C that was measured by the Vikings, Pathfinder, etc. It is deeply below the freezing point of water. However, the luminosity of the Sun 3 - 4 Gyr ago was only 75% of its present value (see the emphasized interval in **Figure 1**), since the Sun is a star on the main sequence of the Hertzsprung-Russell diagram. Then by (7) we get only $T_{\text{Mars}} = 197$ K. For such a low temperature the greenhouse effect cannot guarantee an average temperature around the freezing point of water even though Mars had a denser atmosphere, higher radioactivity, and more volcanism. For example, the present greenhouse effect on the Earth increases the average temperature if Earth would not have an atmosphere by about 29 degrees so that the average temperature on the Earth is about 15˚C (see **Figure 2**). Moreover, Mars had a larger albedo (cf. (7)) than now, since there were water clouds feeding hundreds of large rivers (see [1]). We further note that if Mars were to be 180 million km rather than 225 million km from the Sun when it originated, then its average recession speed would be 10 m/yr which is comparable to the value of the Hubble constant given in (1).

If Mars were substantially closer to the Sun, then Jupiter was closer as well, since otherwise Mars would have larger dimensions.

According to measurements by means of laser retroreflectors installed on the Moon, the average distance $D = 384{,}402$ km between Earth and the Moon increases

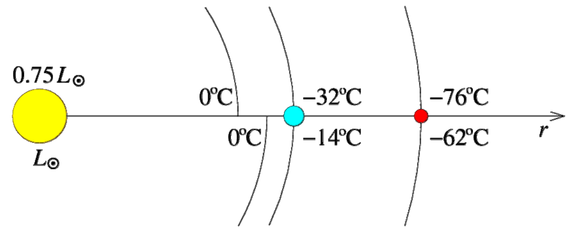


**Figure 2. The equilibrium temperature according to the Stefan-Boltzmann law (7) for the albedo $A = 0.25$. Temperatures in the upper part correspond to the luminosity $0.75L_\odot$ and in the lower part to the present luminosity $L_\odot$. The radii of the circles are respectively 117, 134, 150, and 225 million km. The Sun is yellow, Earth is blue and Mars is red.**

about 3.84 cm/yr. Nonetheless, only 55% of this value can be explained by tidal forces (see [2] for details). The missing part

$$v = 1.71\,\text{cm}\cdot\text{yr}^{-1} \quad (8)$$

could again be due to dark energy. This value is also comparable with the Hubble constant recalibrated to the distance *D*, namely

$$H_0 = 2.56\,\text{cm}\cdot\text{yr}^{-1}\cdot D^{-1}.$$

The corresponding expansion rate due to dark energy is $1.71H_0/2.56 = 0.66H_0$.

Other satellites of the planets are also affected by antigravity forces. In particular, the so-called *fast satellites* that are below the stationary orbit of a planet, where the orbital and rotational periods are equal, should approach their mother planet along spiral trajectories due to tidal forces. By Kepler's third law the radius of the stationary orbit is

$$r_i = \left(\frac{Gm_i P_i^2}{4\pi^2}\right)^{1/3}, \quad (9)$$

where $m_i$ is the mass of the $i$ th planet and $P_i$ is its sidereal rotational period. However, dark energy causes a repulsive force that acts in the opposite direction and has approximately the same size as tidal forces. This makes trajectories of fast satellites stable for billion years (see [3]). Dark energy thus prevents all fast satellites from crashing into their mother planets.

Consider e.g. Neptune's satellite Larissa whose orbit has radius 73,548 km which is close to $r_8 = 83{,}496$ km. Since the rotation of Neptune slows down due to tidal forces by Triton and other satellites, it is not clear where Larissa was 4.5 Gyr ago. At that time the stationary orbit was by (9) much smaller and by the Newtonian theory Larissa is continually approaching Neptune. This shows that Larissa is floating by antigravity forces due to dark energy.

 

It is an open problem 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 mean speed is only 5.4 km/s). Assuming that the average Neptune-Sun distance increases roughly at the rate of $0.5H_0$ due to dark energy (as in previous examples), we find by (1) that Neptune could be formed several astronomical units closer to the Sun $t = 4.5$ Gyr ago on the orbit with radius $R_0$. From the relation $R = R_0 \exp(H_0 t/2)$ we have

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

Another hypothesis states that some star had flown closely to the Solar System which could also contribute to the current distant position of Neptune. Other models, like the Nice model [11], assume that several Gyr ago two giant planets exchanged their orbits to keep the total energy conserved. Nevertheless, this scenario has several drawbacks:

1) It is well known that the classical non-colliding $N$-body problem has a unique global solution and that this problem is not stable in the Lyapunov sense. This means that extremely small variations in initial data cause large errors in the final state after billion of years. Moreover, the backward integration of the current situation does not show that two giant planets would exchange their orbits billion years ago. If the backward integration does not give the initial situation, then the numerical simulation is incorrect due to the Lyapunov instability;

2) The validity of the Newtonian theory of gravity (with infinite speed of gravitational interaction) is supposed over an extremely long time interval of 4.5 Gyr and the influence of dark energy and the finite speed of gravitational interaction are not taken into account;

3) In the Nice model it is not clear what would happen with very rich families of satellites (moons) of giant planets during their close encounter, even though the authors of this model assert that satellite systems survived during their numerical simulation of the exchange.

## 2.2. Do Galaxies Expand Due to Dark Energy?

A positive answer to the above question is based on the following 10 independent observational facts:

1) There is no reason to assume that dark energy would somehow avoid the interior of galaxies, since it is distributed almost uniformly throughout the Universe and it acts also locally in the Solar System as shown in the previous subsection.

2) Recently several observational arguments were published that confirm the expansion of galaxies themselves. For instance, Bouwers *et al.* [12] found that galaxies subtly grow with cosmic time. Also Trujillo *et al.* [13] discovered that the size of massive galaxies increases with time. By [14] superdense massive galaxies were quite common in the early universe with redshift $z > 1.5$ and they are very exceptional in the nearby universe. Also early-type galaxies were smaller and denser at earlier times (see [15]). Based on the above facts (see also [16-18], etc.) we claim that dark energy essentially contributed to the expansion of galaxies. By [19] the density of some galaxies for $z > 1$ is even comparable with the density of present globular clusters, *i.e.*, on average one star in one $\text{pc}^3$.

3) The density distribution of galaxies in space 10 - 13 Gyr ago was much larger than at present, since the Universe was smaller. For instance, for the redshift $z = 2$ (which roughly corresponds to the Hubble Field South), when space was $(z+1)$ times smaller, the density of galaxies in the unit volume is on average $3\times 3\times 3 = 27$ times higher. Since protogalaxies at that time were smaller, this higher accumulation is not observed. They only seem to be larger, since the space for $z = 2$ was three times smaller (see [1] for the time-lens principle or [20, p. 319]).

Suppose to the contrary that galaxies do not change their sizes. The right part of **Figure 3** illustrates what we would see at cosmological distances, provided galaxies would have a constant size. On the left, five galaxies are schematically sketched in the unit volume corresponding to $z = 0$. In the same volume, there is on average $5 \times 3^3 = 135$ crammed galaxies for $z = 2$ and $5 \times 5^3 = 625$ tightly crammed galaxies for $z = 4$. However, this is not observed, since galaxies were smaller at that time.

4) According to [21], the measured stellar mass density in galaxies with $z \approx 3$ is up to eight times higher than for galaxies in our neighborhood. These very distant galaxies cca 11 Gly far away are seen to have been roughly a factor two times smaller than they are seen now. They have grown from some smaller protogalaxies.

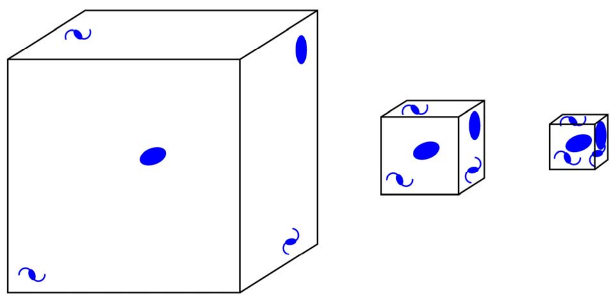

**Figure 3. On the left: Schematic illustration of distribution of galaxies in our neighborhood for $z \approx 0$. If galaxies would not expand, then their distribution in cosmological distances for $z = 2$ is sketched in the middle and for $z = 4$ on the right. Such a picture is not observed.**

 

Consider now our Galaxy whose diameter is about $D = 10^5$ ly. Let us show that its current size $D$ is attainable by the Hubble expansion rate. Assume that the Galaxy expanded from some smaller protogalaxy with diameter $d = D/2$ during the last $T = 11$ Gyr. From (3) we find that the present value of the Hubble constant recalibrated to $D$ is $H_0 = 2\ \mathrm{km\cdot s^{-1}\cdot}D^{-1}$. Then the present size of our Galaxy could be extrapolated as follows

$$d\exp(H_0T) = d\exp\left(\frac{2\times11\times10^9}{300{,}000\times10^5}\right) = d\,\mathrm{e}^{11/15} \approx 1.04D,$$

which is indeed comparable with its actual diameter $D$. Taking into account that the Hubble parameter $H = H(t)$ was larger than $H_0$, we could even get a size comparable with $D$ at the rate $H/2$. The present expansion rate of our Galaxy is thus comparable with $H_0$ even though it is probably smaller.

5) According to [12,22], the observed rate of star formation in galaxies at cosmological distances is proportional to $(1+z)^{1.9\pm0.1}$. For instance, if $z \approx 2.3$ it is ten times higher than in our neighborhood. This extremely high rate can again be explained by higher mass density inside galaxies at large $z$ than there is now for $z \approx 0$.

6) According to [23], the observed activity of galactic nuclei at cosmological distances is larger than in our neighborhood. This may again be explained by higher mass density inside galaxies for large $z$, even though central massive black holes were on average smaller.

7) There exist several dwarf galaxies around our Galaxy (e.g. LEO IV) that were formed 13 Gyr ago. However, their star formation stopped after 300 Myr. Dark energy could again reduce the critical mass density necessary for star formation.

8) The mean radial component of velocities of all 150 globular clusters in our Galaxy indicates that globular clusters on average slowly move away from the Galactic center. This mean speed (normal or weighted by distances) is comparable with $H_0$ (see [24]). It is even higher than $H_0$, but of the same order.

9) Almost all open or globular star clusters seem to be unstable as observed e.g. by [25]. It is again dark energy that very slowly, but continually increases the total energy (kinetic + potential) of each system of free bodies, and thus each star cluster slightly expands. Due to dark energy the frequency of escape of stars from clusters is higher than predicted by the classical Virial Theorem, which does not take into account the influence of dark energy. Dark energy thus contributes to the evaporation of star clusters and acts against the so-called gravothermal catastrophe (cf. [26]).

10) The exoplanet WASP-18b revolves around its mother star with mass $1.25M_\odot$ once per 0.94 day. Its orbit is almost circular with radius 3 million km. Since the rotational period of the star is 5.64 days, by Kepler's third law the stationary orbit has radius 10 million km, *i.e.* the exoplanet is below the stationary orbit (cf. (9)). Due to tidal forces WASP-18b should approach its mother planet along a spiral trajectory within less than one million years. However, the star exists already for 700 Myr (see [27]). Astronomers do not know, how this exoplanet with 10 Jupiter masses could appear in this current position below the stationary orbit and why it would not fall down onto its mother planet in such a short geological period. This paradox can again be explained by antigravity forces. WASP-18 does not quickly spiral into its mother star, since the repulsive force due to dark energy acts in the opposite direction than the tidal forces for more than 700 Myr of its existence. From the evolution of all orbital parameters we could estimate within the next 10 years how large is the repulsive force that prevents the extrasolar planet from crashing onto its mother star.

The points 1)-10) justify us in asserting that dark energy acts also inside galaxies (see **Figure 4**). Dark energy thus may slowly expand habitable zones (as in the case of the Earth) when the luminosity of the corresponding mother star increases. In this way habitable zones are more stable and exist for a longer time.

## 3. The Origin of Dark Energy

### 3.1. Dark Energy Mystery

In Section 2 we surveyed results showing that the influence of dark energy can be observed not only among galaxies, but also inside galaxies including our Galaxy and in the Solar System, too, *i.e.* dark energy acts not only globally, but also locally.

By [3] dark energy has an essential influence on the present value of the Hubble constant. To demonstrate its influence in the Solar System we must either measure very precisely (e.g. the Earth-Moon distance), or we have to consider extremely long time intervals, where all small deviations from the Newtonian theory of gravitation are usually not cancelled, but accumulated and then possibly

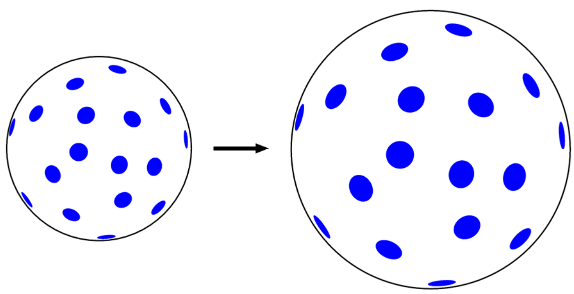

**Figure 4. A two-dimensional model of an expanding Universe of positive curvature with expanding galaxies. In [20, p. 72] galaxies do not expand.**

observed. An extremely small deviation $\varepsilon > 0$ during one year may cause after one billion years a quite large and detectable value of $10^9\varepsilon$ which is then interpreted as dark energy. For instance, in the case of our Moon, $\varepsilon = 1.71\ \mathrm{cm/yr}$ (see (8)) and in the case of our Earth $\varepsilon \approx 5$ m/yr due to (2), (4), and (6). Thus, we should never identify any physical model with reality, since the above argument can be applied to any non-Newtonian model as well.

Let us estimate by means of classical physics how much dark energy is generated by the Earth-Sun system within one year. Assume for simplicity that the Earth has a circular orbit with radius $R$. From Kepler's third law $R^3/Y^2 = GM/4\pi^2$ the total energy (kinetic + potential) of the Earth is equal to

$$E(R) = \frac{1}{2}m\left(\frac{2\pi R}{Y}\right)^2 - \frac{GmM}{R} = -\frac{GmM}{2R},$$

where $m = 5.97\times10^{24}$ kg is the mass of the Earth, $M = 1.989\times10^{30}$ kg is the mass of the Sun, $G$ is the gravitational constant, and $Y$ is the sidereal year as given in (5). Then for $\Delta R = 5.2$ m (cf. (2)) we find that the annual increase of dark energy is

$$E(R+\Delta R) - E(R) = 9.4\times10^{22}\ \mathrm{J},$$

which is about a ten orders of magnitude lower value than the kinetic energy of the Earth, *i.e.* $|E(R)| = 2.69\times10^{32}$ J. By (5) this corresponds to a permanent power of almost 3000 TW for free. Therefore, the classical laws of conservation of energy and momentum do not hold.

According to Krasinsky and Brumberg [28], the increase of the Earth-Sun distance is only 15 cm per year. However, their conclusion is derived under a nonrealistic supposition that the Newtonian theory of gravitation describes movements in the Solar System absolutely exactly. They solve an algebraic system for 62 unknown Keplerian elements of all planets and some large asteroids. No modeling error is assumed, no discretization error analysis is done, and the influence of dark energy is not taken into account.

It is said that the source of dark energy that accelerates the expansion of the Universe is unknown for the time being. This is often termed the Dark Energy Mystery. Several possible hypotheses of the origin of dark energy are surveyed in [29]. These hypotheses include quintessence, energy of the vacuum, variable fundamental constants, etc.

Another hypothesis was introduced in [2]. This is the hypothesis we will concentrate on in the next Subsection 3.2. Since the speed of gravitational interaction is finite, it causes aberration effects [30] between any two (or more) free bodies that interact gravitationally. In [2] we showed that gravitational aberration could contribute to dark energy and consequently to the accelerated expansion of the whole Universe. This hypothesis even has the potential to substantially explain the dark energy mystery.

### 3.2. Gravitational Aberration

Consider two bodies $A$ and $B$ of equal masses that orbit symmetrically with respect to their midpoint. Since the speed of their mutual gravitational interaction is **finite**, $B$ is attracted by $A$ towards its previous position $A'$ as indicated in **Figure 5**. Similarly $A$ is attracted by $B$ in the direction of its previous position $B'$. Then a couple of non-equilibrium forces arises which acts permanently and thus, slowly increases the angular momentum and also the total energy of this system which is then interpreted as dark energy. This simple example indicates why the classical law of conservation of energy cannot be valid. If it would be valid, then the trajectories would be circles of constant radii for appropriate initial conditions.

Our Galaxy and the Solar System provide us with a unique laboratory to study a finite speed of gravitational interaction and its product: *dark energy*. Gravitational waves were already predicted by Henri Poincaré. He conjectured that their speed is the same as the speed of light *c* (see [31]). However, by the results of Section 2 it seems that gravitational aberration angle is probably much smaller than that due to the aberration of light, but it is positive due to causality. Otherwise, the Solar System would be not so stable (see [3]).

According to Carlip [32], the gravitational interaction

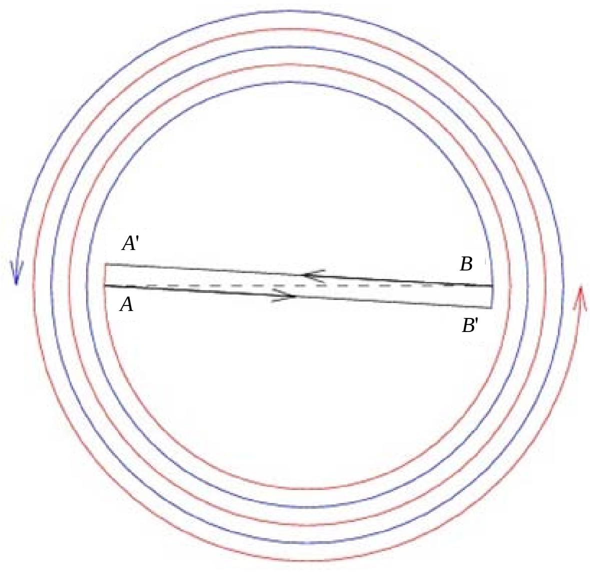


**Figure 5. Trajectories corresponding to two interacting bodies of equal masses constitute a double spiral. The aberration angles $ABA'$ and $BAB'$ are extremely small but positive.**

 

in general relativity produces almost no aberration effects contrary to known relatively large aberration effects in the electromagnetic interaction. However, Carlip assumes that the cosmological constant is zero and neglects some nonlinear terms to make calculations easier. He also assumes that the laws of conservation of energy and momentum are valid and thus he cannot get spiraling trajectories as schematically illustrated in **Figure 5**.

The gravitational aberration effects can be modeled by a nonautonomous system of differential equations with delay, where the aberration is a free parameter (see [2] and [30]). For the two-body problem the above system with delays yields slightly spiraling trajectories (see **Figure 5**) that describe reality (cf. Section 2) much better than the Newtonian theory of gravitation. As a result the two bodies are drifting apart. Also a system of $N$ free bodies slightly expands on average due to gravitational aberration effects. This mechanism contributes to the expansion of the Universe and it can explain the Dark Energy Mystery.

## 3.3. Cosmological Constant

Is the cosmological constant a fundamental physical constant? We claim it is not. Since the gravitational aberration has a continual influence of the expansion rate of our Universe (at least partly), as shown in the previous subsection, the cosmological constant appearing in the standard cosmological model [20] should depend on time, *i.e.*, $\Lambda = \Lambda(t)$. It should also depend locally on many other quantities (mass distribution, velocities, distances, etc.). In other words, $\Lambda$ is probably not a fundamental physical constant like the speed of light $c$ or the gravitational constant $G$, but it represents only some average value due to gravitational aberration effects of all free bodies in the Universe. Its present value $\Lambda(t_0)$ is roughly of order $10^{-52}\ \mathrm{m}^{-2}$, but in the future it can became smaller. Note that the Hubble constant $H = H(t)$ depends on time, too.

The corresponding expansion rate cca $0.5H_0$ due to dark energy provides further support for the Anthropic Principle [3]. In other words, the amount of dark energy that is continually produced by the Earth-Sun system lies in a narrow interval that enabled the origin of intelligent life on the Earth. On the other hand, dark energy and the loss of atmosphere destroyed the habitable zone with liquid water on Mars (cf. (7)).

## 3.4. The Hubble Parameter

Knowledge of the effect of cosmological expansion on local systems (such as the Solar System) has a long history dating back to the paper [33]. At present we know that the expansion of our Universe accelerates. This fact is based on the 10% - 15% lower luminosity of very distant supernovae of type Ia that shine into a larger volume than if the expansion were to be decelerating, see [7, 8,34]. The observed acceleration is due to dark energy that is distributed almost uniformly in the Universe [35]. Therefore, dark energy has an essential influence on the present value of the Hubble constant (3) which characterizes the speed of this expansion.

For very distant cosmological objects with redshift $z > 1$ it was found by [35] that a decelerating expansion of the Universe turned into an accelerating one approximately eight billion years after the Big Bang. In [3], the Hubble parameter $H = H(t)$ is split into two terms $H = H_M + H_\Lambda$, where $H_M \approx 1/t$ is a decreasing function due to the Big Bang and the subsequent gravitational interaction that slows the expansion of the Universe and $H_\Lambda$ is a positive (and probably increasing) function that corresponds to dark energy which accelerates this expansion. The present value of $H_\Lambda$ is so large that the impact of dark energy can also be detected in the Solar System as we have seen in Subsection 2.1.

An extremely small time derivative of $H(t)$ for the present time $t$ on the scale of the Solar System is derived in [5] yielding a tiny outward acceleration of $2\times 10^{-23}\ \mathrm{m/s^2}$ at Pluto's distance of 40 au. Similar very small values are given in [6, p. 62] and [36, p. 5041]. However, the large value of the Hubble constant itself $H_0 = H_M + H_\Lambda = 10\ \mathrm{km\cdot yr^{-1}\cdot au^{-1}}$ is surprisingly not considered in these papers. On the other hand, a more realistic expansion rate of $0.57H_0$ in the Solar System derived from growth patterns on fossil corals is proposed in [4].

The Hubble parameter is usually defined by the relation $H = a'/a$, where $a$ is the scaling parameter (for instance, if the Universe would have a constant positive curvature in all directions at time $t$, then the scaling parameter $a = a(t)$ is equal to the radius of the Universe at time $t$). Differentiating $H = H(t)$ with respect to time, we find that

$$H' = \frac{a''}{a} - H^2 = -qH^2 - H^2, \tag{10}$$

where $t_0 = 13.75\ \mathrm{Gyr}$ is the age of Universe and $q$ is the so-called *deceleration parameter*, which characterizes the expansion of the Universe. The Taylor expansion of the scaling parameter reads

$$a(t) = a(t_0)\left(1 + H_0(t-t_0) - \frac{1}{2}q_0H_0^2(t-t_0)^2 + \cdots\right). \tag{11}$$

where $q_0 = q(t_0) \approx -0.6$ is the actual value of the scaling parameter. (Its negative value $q_0 < -1$ was predicted by Beatrice Tinsley already in 1978, see [37]. In this case, $H'(t_0) > 0$ by (10).)

By [5,6], the effect of dark energy has no influence on the dynamics of the Solar System. Their authors claim that the quadratic term in the above Taylor expansion has almost no effect on the acceleration expansion of the Solar System which is true, but they do not take into account the large value of the Hubble constant (1) which appears in the linear term in (11).

## 4. Conclusions

Note that there exist close binary pulsars whose orbits do not expand with time, but decay. In this case, strong magnetic and gravitational fields are present and the system loses energy due to tidal forces, electromagnetic and gravitational waves. These effects are much stronger than weak effects coming from dark energy. Also various resonances may be significantly larger in comparison with dark energy effects.

The classical *N*-body problem is usually solved by symplectic methods that are designed in such a way that the energy is conserved. However, for numerical solution of long-term evolution problems (including aberration effects) these methods are not suitable, since they do not take into account dark energy and assume the infinite speed of gravitational interaction. Also various modifications of the Newtonian theory, known as MOND, assume the infinite speed of gravitational interaction, *i.e.*, they do not produce aberration effects.

Dark energy is slightly, but continually generated by any system of free bodies that interact gravitationally. It increases its total (kinetic + potential) energy. Thus, it contributes to the migration of planets and their moons over long time periods, it causes that many star clusters dissipate [25], it helps reduce the frequency of collisions of galaxies and stars, etc. It stabilizes the Solar System and has also helped create suitable habitable conditions on the Earth for several billion years [3].

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