Rotation as a Source of Accelerating Expansion of the Universe

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ROTATION AS A SOURCE OF ACCELERATING EXPANSION OF THE UNIVERSE

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Abstract

Assuming a hypothesis, that the universe is rotating from the very beginning – as soon as it appeared- creates new possibilities to explain accelerating expansion of the universe. A spinning universe is under the action of two enormous forces: gravitational force and centrifugal force. The difference between the two forces has been shown to give the resultant force that causes the expansion of the universe to accelerate. Applying classical mechanics as a method, I calculated the magnitude of this acceleration, the time when it appeared and how it changes over time. By applying only recognized cosmological parameters, interesting results were obtained that can be checked with astronomical observations. The presence of acceleration of expansion causes the rate of expansion of the universe to continue to increase, which is consistent with astronomical observations. However, the speed of this increase in the rate of expansion becomes slower over time.

Introduction

The main objective of this work was to analyze the impact of rotation on the accelerating expansion of the universe. Astronomial observations have shown that the expansion of the universe is such, that galaxies are moving away from one another at an accelerated rate (Nobel Prize in Physics 2011, for the discovery of the accelerating expansion of the Universe through observations of distant supernovae) [1]). These observations clearly show that the expansion of the universe appears to be accelerating, but the reason is a complete mystery. An attempt to explain this mystery is to hypothesize that dark energy is the cause. However what that dark energy is remains an enigma, which also needs to be clarified, "The dark energy evinced by the accelerating cosmic expansion grants us almost no clues to its, identity" [2]. In physical cosmology and astronomy it is assumed that dark energy is an unknown, hypothetical form of energy that permeates all space, is constant, has negative pressure (repulsive action) that opposes gravity and causes the accelerating expansion of the universe [2-6]. One of the proposed forms of dark energy is a cosmological constant (Λ-Lambda), representing a constant energy density filling space homogeneously [7]. However, there is a disagreement between the observed small value of the cosmological constant and its theoretical large value (called the cosmological constant problem).

From the last two decades, there have been active areas of cosmological research aimed at understanding the fundamental nature of dark energy [8].

On the other hand, the centrifugal force connected with the kinetic energy of the rotating universe, seems to provide a reasonable explanation for the accelerating expansion of the universe.

All objects in the observable universe rotate: planets, stars, galaxies, and groups of galaxies. Why not the whole universe? There are no contraindications to assume a hypothesis that the universe was rotating from the very beginning [9]. The primordial matter of the universe at the time of creation [10,11] could have not only high temperature but also high velocity of rotation. Adopting this hypothesis introduces a new form of energy into the universe - the kinetic energy of rotation of the universe. Without introducing a new form of energy, it was impossible to explain how an accelerating universe could be measured [12-17]. This hypothesis creates new opportunities to explain accelerating expansion of the universe.

Using classical mechanics as a method (stars and galaxies are macroscopic objects and therefore obey the laws of classical mechanics) I made calculations: - the angular velocity of the rotation of the universe; - the magnitude of the acceleration of the expansion of the universe; - the time when the acceleration of expansion began; - of how the acceleration of expansion changes when the radius of the universe increases, that is, over time. Only recognized cosmological parameters were used in these calculations. The obtained results provide new data that can be used in astronomical observations.

Results

1. Rotational kinetic energy of the universe

A body rotating about any axis, going through the center of mass, has rotational kinetic energy E_R, which is the sum of the kinetic energies of its moving parts, and is given by equation (1) [18]:

$$E_R = \frac{1}{2} I \omega^2 \tag{1}$$

Where: ω - is the body's angular velocity. I - is the body's moment of inertia.

The shape of the closed [19], rotating and expanding universe is significantly influenced by the centrifugal force related to its rotation. Assuming that the shape of the universe is a flat disk, which is most likely in this case, its moment of inertia is given by a formula (2) [18]:

$$I = \frac{1}{2} M R^2 \tag{2}$$

Where: M - mass of the universe. R - radius of the universe.

Substituting this formula into equation (1), the equation of kinetic energy of the rotating universe is given by:

$$E_R = \frac{1}{4} M R^2 \omega^2 \tag{3}$$

According to the law of conservation of energy the total energy of an isolated system remains constant - it is said to be conserved over time [20]. This law means that energy can neither be created nor destroyed, it can only be transformed or transferred from one form to another.

Thus, the kinetic energy E_R does not change with increasing radius R of the rotating universe, which expands due to the action of centrifugal force. Today, this kinetic energy of the universe is the same as in the time of inflation. An increase in the radius R, causes an increase in the moment of inertia I of the universe (equation (2)). Simultaneously, the angular velocity ω decreases, so that the kinetic energy of the rotating and expanding universe remains constant (equation (3)).

This interrelation between the angular velocity and the moment of inertia is seen clearly in an ice skater performing a pirouette. When he keeps his hands close to the body, he rotates fast, but when he spreads them out the rotation becomes slow [21].

According to the European Space Agency's Planck Telescope [22], the critical density of the universe equals approximately 0.85 x 10^{-26} kg/m^3. Critical density is the energy/mass density in which the universe is flat. In a flat universe Euclidean geometry applies at the largest scale. This means that parallel lines will never meet, and the internal angles of a triangle always add up to exactly 180 degrees. These conditions also meet the assumption made in this paper that the rotating universe is shaped like a flat disk. This density includes three significant types of energy and mass: ordinary matter (baryonic) (4.9%), cold dark matter (26.8%), and dark energy (68.3%). The mass of ordinary matter is estimated to be equal [22]:

$$M = 1.5 \times 10^{53} \quad [kg] \tag{4}$$

Let us convert this mass to energy using Albert Einstein's formula:

$$E_{OM} = Mc^2 \tag{5}$$

Where: E_{OM} energy of the ordinary matter. M – mass of ordinary matter; c – speed of light = 2.9983*10^8 (ms-1):

$$E_{OM} = 1.5 \times 10^{53} \times 8.99 \times 10^{16} = 1.35 \times 10^{70} \quad [J = kgm^2s^{-2}] \tag{6}$$

Let us calculate the energy of dark matter E_{DM} and the dark energy E_{DE}:

$$E_{DM} = \frac{E_{OM}}{4.9} \times 26.8 = 7.38 \times 10^{70} \quad [J] \tag{7}$$

$$E_{DE} = \frac{E_{OM}}{4.9} \times 68.3 = 1.88 \times 10^{71} \quad [J] \tag{8}$$

Accepting the hypothesis of the rotation of the universe, and assuming, in the first approximation, that dark energy E_{DE} is equal to the kinetic energy E_R of the rotating universe [12], we can write:

$$E_{DE} = E_R \tag{9}$$

$$E_R = \frac{1}{4} M R^2 \omega^2 = 1.88 \times 10^{71} \quad [J] \tag{10}$$

2. Determination of angular velocity ω of the rotating universe

From equation (10) we can calculate the present angular velocity ω of the rotation of the universe:

$$\omega^2 = \frac{4E_R}{MR^2} \tag{11}$$

Substituting to the equation (11) the kinetic energy E_R =1.88*10^{71} [J], the mass of ordinary matter M = 1.5*10^{53} [kg], and the present radius of the universe R = 4.4*10^{26} [m] [23], we obtain:

$$\omega^2 = 0.2590 \times 10^{-34} \tag{12}$$

$$\omega = R^{-1}\sqrt{4E_R M^{-1}} = 0.51 \times 10^{-17} \quad [rad\ \ s^{-1}] \tag{13}$$

The angular velocity ω of the universe is a function of the variable radius *R* of the universe. As this radius increases, on account of the expansion of the universe, the angular velocity decreases (equation (13)).

The present value of the angular velocity, calculated in this paper, - equal ω =0.51*10^{-17} [rad s^{-1}], appeared to be exactly of the same order, as the angular velocity determined by Su & Chu [24], who applied an entirely different method – analysis of the cosmic microwave background anisotropy (CMBA) data. These authors constrain the angular velocity of the rotation of the universe to be less than:

ω =10^{-9} [rad*yr^{-1}]; (1yr = 0.31536*10^8 [sec]), ω =3.171*10^{-17} [rad s^{-1}].

The compatibility between these two results (underlined), may be yet another, indirect, proof that the universe is rotating.

3. Centrifugal force

Centrifugal force acts on every point of the universe rotating about an axis, going through the center of mass. Determining the position of a given point on a plane perpendicular to the axis of rotation, the value of centrifugal force is given by equation (14) [25]:

$$Fc = M\omega^2 R \tag{14}$$

Where: Fc - centrifugal force. M - mass of the universe ($1.5*10^{53}$) [kg]). ω - angular velocity ($0.51*10^{-17}$ [rad s^{-1}]). R - present radius of the universe ($4.4*10^{26}$ [m]). Substituting these data to the equation (14) we get:

$$Fc = 1.7094 *10^{45} \text{ [N]}.$$

Centrifugal force, resulting from the rotation of the universe, is directly opposite to gravitational force and is responsible for the current expansion of the universe. While the gravitational force together with the centrifugal force causes the rotating universe to keep the shape of a disk, as is the case with rotating spiral galaxies, for example.

4. Determination of acceleration with which the universe expands.

Let us consider a galaxy that has the same mass as the Milky Way [26] but is located at a distance equal to the radius of the universe from the axis of rotation. This galaxy is under the action of two forces: centrifugal force Fc (equation (15)), and gravitational force Fg (equation (16)) [27], which act on this galaxy in opposite directions:

$$Fc = m\,\omega^2 R \;= m\frac{4E_R}{MR} \tag{15}$$

$$Fg = G\frac{m\,M}{R^2}\ ,\tag{16}$$

Where: E_R = 1.88 X 10^{71}[J]; M - mass of the universe = 1.5 x 10^{53} [kg];

ω - angular velocity = 0.51x 10^{-17} [rad s^{-1}]; R - present radius of the universe = 4.4 x 10^{26}[m]; G - gravitational constant = 6.67 x10^{-11} [N m^2 kg^{-2}] [27]; m - mass of Milky Way = 3 x 10^{42} [kg]

Substituting the above data into equations (15) and (16), we obtain:

$$Fc = 3.416 \times 10^{34} \qquad [N]\tag{17}$$

$$Fg = 1.55 \times 10^{32} \qquad [N]\tag{18}$$

As one can see from equations (17) and (18), the centrifugal force, for our galaxy under consideration, is greater than the gravitational force that acts on this galaxy:

$$\Delta F = Fc - Fg = 3.404 \times 10^{34} \quad [N]\tag{19}$$

ΔF - is the force that brings about the accelerating expansion.

According to Newton's second law of motion [27], for an object of mass m, the net force ΔF on the object is equal to the mass m times the object's acceleration A:

$$\Delta F = m\,A\tag{20}$$

How large is the acceleration of expansion for our galaxy under consideration?

$$A = \frac{\Delta F}{m} = \frac{3.404 \times 10^{34}}{3 \times 10^{42}} = 1.1347 \times 10^{-8} \qquad \left[\frac{m}{s^2}\right]\tag{21}$$

Let us present the acceleration of expansion as a function of the variable radius R of the universe:

$$\Delta F = Fc - Fg = \ m\,\frac{4E_R}{MR} - \ G\,\frac{mM}{R^2} = mA\tag{22}$$

$$A = \frac{4E_R}{MR} - G\ \frac{M}{R^2} \tag{23}$$

Equation (23) indicates that the acceleration of expansion A does not depend on the mass m of the object that is accelerated. As radius R increases, acceleration decreases. But the gravitational force Fg decreases faster than the centrifugal force Fc. In equation (23), the second negative term, expressing gravitational force, is inversely proportional to the second power of the radius of the universe R. On the other hand, the first positive term of this equation, expressing centrifugal force, is inversely proportional to the first power of R. As a result, as the radius R increases, the centrifugal force decreases more slowly than the gravitational force.

This causes the centrifugal force Fc to be constantly greater than the gravitational force Fg, as the radius R increases (Tab .1, Fig. 1). Therefore, the expansion of a rotating universe is accelerated. This conclusion shows that the source of the accelerating expansion of the universe is its rotation.

Table 1. The values of centrifugal force and gravitational force (divided by the mass of the selected object m) for different sizes of the radius of the universe R, on a normal and logarithmic scale.

R [m]	$6.50*10^{23}$	$1.996*10^{24}$ min	$3.99*10^{24}$	$4.40*10^{25}$	$4.40*10^{26}$	$4.40*10^{27}$
Fc/m [N/m]	$7.71*10^{-6}$	$2.51*10^{-6}$	$1.26*10^{-6}$	$1.14*10^{-7}$	$1.14*10^{-8}$	$1.14*10^{-9}$
Fg/m [N/m]	$2.37*10^{-5}$	$2.51*10^{-6}$	$6.28*10^{-7}$	$5.17*10^{-9}$	$5.17*10^{-11}$	$5.17*10^{-13}$
$log\,R$	23.81	24.30 min	24.60	25.64	26.64	27.64

log Fc/m	-5.11	-5.60	-5.90	-6.94	-7.94	-8.94
log Fg/m	-4.63	-5.60	-6.20	-8.29	-10.29	-12.29

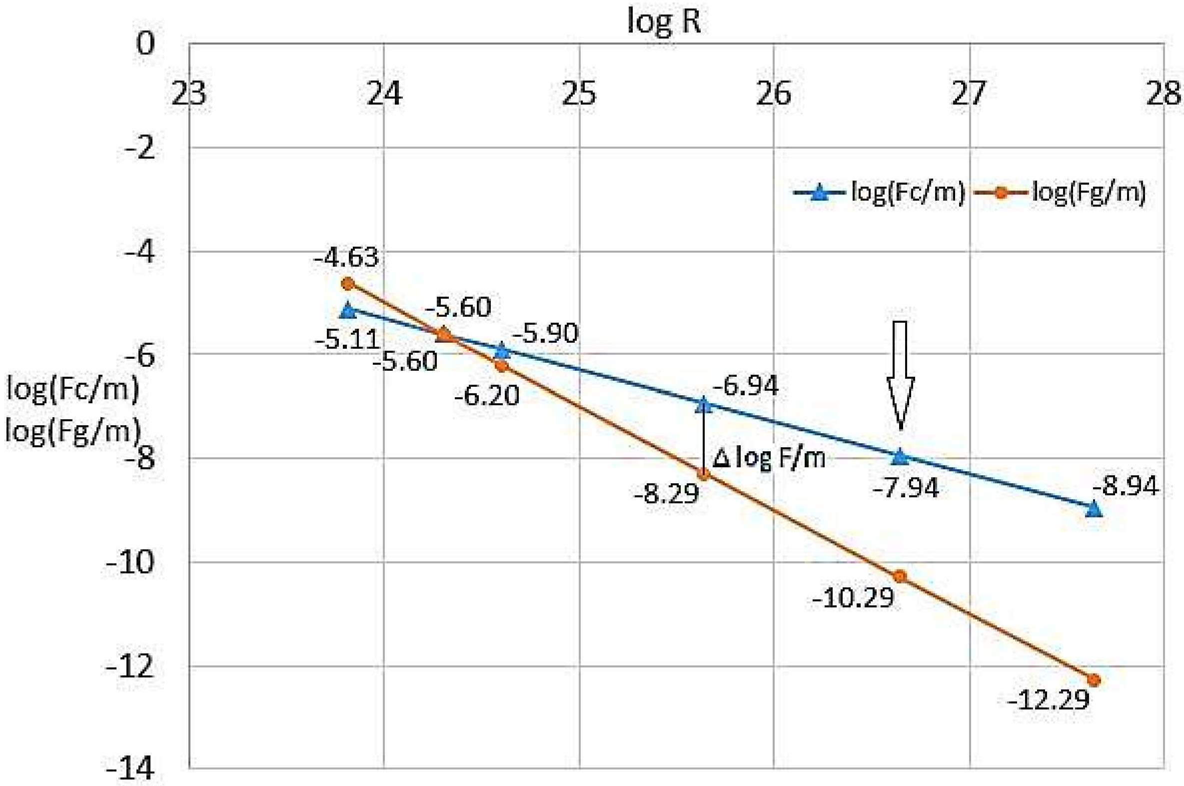

Fig. 1. The dependence of the centrifugal force *Fc* and the gravitational force *Fg* (divided by the mass of the selected object *m*) on the radius *R* of the universe in a logarithmic scale. With increasing radius, the gravitational force decreases faster than the centrifugal force. The difference between *Fc* and *Fg* is the force (ΔF) that accelerates the expansion of the universe. The acceleration of the expansion started at R_{min}, that is, when the centrifugal force was equal to the gravitational force. The arrow in the diagram indicates the present radius of the universe.

For the expansion of the universe to occur with acceleration, in equation (23) this acceleration must be positive. Therefore, the condition that the centrifugal force *Fc* should be greater than the gravitational force *Fg*, must be met:

$$Fc > Fg \tag{24}$$

$$\frac{4E_R}{MR} > \frac{GM}{R^2} \tag{25}$$

$$R > \frac{GM^2}{4\ E_R} \tag{26}$$

To ensure a positive acceleration of expansion, the radius R must meet equation (26). It is the smallest radius $R = R_{minimum}$ below which the acceleration will be negative.

$$Rmin > \frac{6.67 \times 10^{-11} \times 2.25 \times 10^{106}}{4 \times 1.88 \times 10^{71}} = 1.996 \times 10^{24} \quad [m] \tag{27}$$

Comparing the radius of the universe equal R_{min} = 1.996 x 10^{24} [m] (when the centrifugal force is equal to the gravitational force (equation 25)), and the current radius of the universe R = 4.4 x 10^{26} [m], allows us to determine when the accelerating expansion of the universe began:

$$\frac{R}{t_0} = \frac{Rmin}{t} \tag{28}$$

where: t_0 – age of the universe – 13.8 billion years [28]; t – age, after the big bang, when the accelerated expansion began

$$t = \frac{Rmin}{R} t_0 = \frac{1.996 \times 10^{24}}{4.4 \times 10^{26}} \times 13.8 \times 10^9 = 6.26 \times 10^7 \cong \ 63 \times 10^6 \quad [yr] \tag{29}$$

The accelerating expansion of the universe, caused by the rotation of the universe, began approximately sixty- three million years (63*10^6 [yr]) after the big bang, i.e., 13.737 billion years ago. The first stars and galaxies already existed at this time [29]. This result shows that the accelerating expansion started much earlier than determined by Frieman, J.A., Turner, M.S., and Huterer,D. [30]. Using astronomical observations, these authors estimated that the accelerating expansion of the universe began much later, approximately ten billion years after the big bang (i.e., roughly four billion years ago). For a more detailed comparison, it is necessary to know the magnitude of this acceleration.

Let us calculate the acceleration of the expansion of the universe for the present radius of the universe.

For R = 4.4 x 10^{26} [m], we get:

$$\omega^2 = \frac{4E_R}{MR^2} = 0.259 \times 10^{-34} \quad \left[\frac{rad}{s^2}\right] \tag{12}$$

$$A = \omega^2 R - \frac{GM}{R^2} = \frac{4E_r}{MR^2} R - \frac{GM}{R^2} \tag{30}$$

$$A = 1.136 \times 10^{-8} \quad \left[\frac{m}{s^2}\right]; \quad (cf. equation\ (21)) \tag{31}$$

Let us compare the present magnitude of the acceleration of the expansion of the universe with the magnitude of accelerations in the future when the radius of the universe is greater.

For R = 4.4 x 10^{27} [m], we will get:

$$\omega^2 = \frac{4 \times 1.88 \times 10^{71}}{1.5 \times 10^{53} \times 19.36 \times 10^{54}} = 0.259 \times 10^{-36} \quad \left[\frac{rad}{s^2}\right] \tag{32}$$

$$A \cong 1.14 \times 10^{-9} \quad \left[\frac{m}{s^2}\right] \tag{33}$$

As one can see from equations (31) and (33), the magnitude of acceleration of expansion, for the larger radius of the universe, is smaller because the moment of inertia I (equation (2)) increases, reducing the angular rotation velocity ω. This means that the universe constantly expands with acceleration, but this acceleration decreases over time. As a result of the existence of acceleration, the rate of expansion of the universe constantly increases. The speed of this increase in the rate of expansion also becomes slower over time (because acceleration of expansion decreases over time). The continuous increase in the rate of expansion means, that in the past this rate was smaller.

5. Analysis of the expansion acceleration equation *A(R)*

The acceleration equation *A(R)* is a square equation (23) that has an extremum:

$$A = \frac{4E_R}{MR} - \frac{GM}{R^2} \tag{23}$$

$$A = 4E_R M^{-1} R^{-1} - GMR^{-2} \tag{34}$$

To determine this extremum, let us differentiate equation (34) and set it equal to 0:

$$f'(A) = 4E_R M^{-1}(-1)R^{-2} - GM(-2)R^{-3} = 0 \tag{35}$$

$$f'(A) = R^{-2}(-4E_R M^{-1} + 2GMR^{-1}) = 0 \tag{36}$$

Let us designate the roots R_1 and R_2 of equation (36):

$$R_1 = 0$$

$$\left(-4E_R M^{-1} + 2GM{R_2}^{-1}\right) = 0$$

$$R_2 = \frac{2GM^2}{4E_R} = 3.9875 \times 10^{24} \qquad [m] \tag{37}$$

R_2 specifies the position of the maximum of function *A(R)*.

$$A(\max) = A(R_2) = \frac{4E_R}{MR_2} - \frac{GM}{R_2^2} = 0.6281 \times 10^{-6} \qquad \left[\frac{m}{s^2}\right] \tag{38}$$

The maximum function *A(R)* (equation (38)) is located (equation (37)) near R_{min} equal to $1.996 * 10^{24}$ [m] (equation (27)). (Fig. 2).

A set of results of the function *A(R)*, containing the selected magnitudes of the radius of the universe *R*, and the calculated values of the acceleration *A*, is shown in Table 2.

Table 2. Expansion acceleration values for different magnitudes of the radius of the universe *(R)*, on a normal and logarithmic scale.

R [m]	$1.996*10^{24}$ min	$2.00*10^{24}$	$2.50*10^{24}$	$3.99*10^{24}$	$9,00*10^{24}$	$4.4*10^{26}$	$4.4*10^{27}$
A [m/s²]	$4.05*10^{-10}$	$5.42*10^{-9}$	$4.05*10^{-7}$	$6.28*10^{-7}$ max.	$4.34*10^{-7}$	$1.13*10^{-8}$	$1.14*10^{-9}$
log R	24.3002 min	24.3010	24.3979	24.6011	24.9542	26.6435	27.6435
log A	-9.39	-8.27	-6.39	-6.20 max.	-6.36	-7.95	-8.94

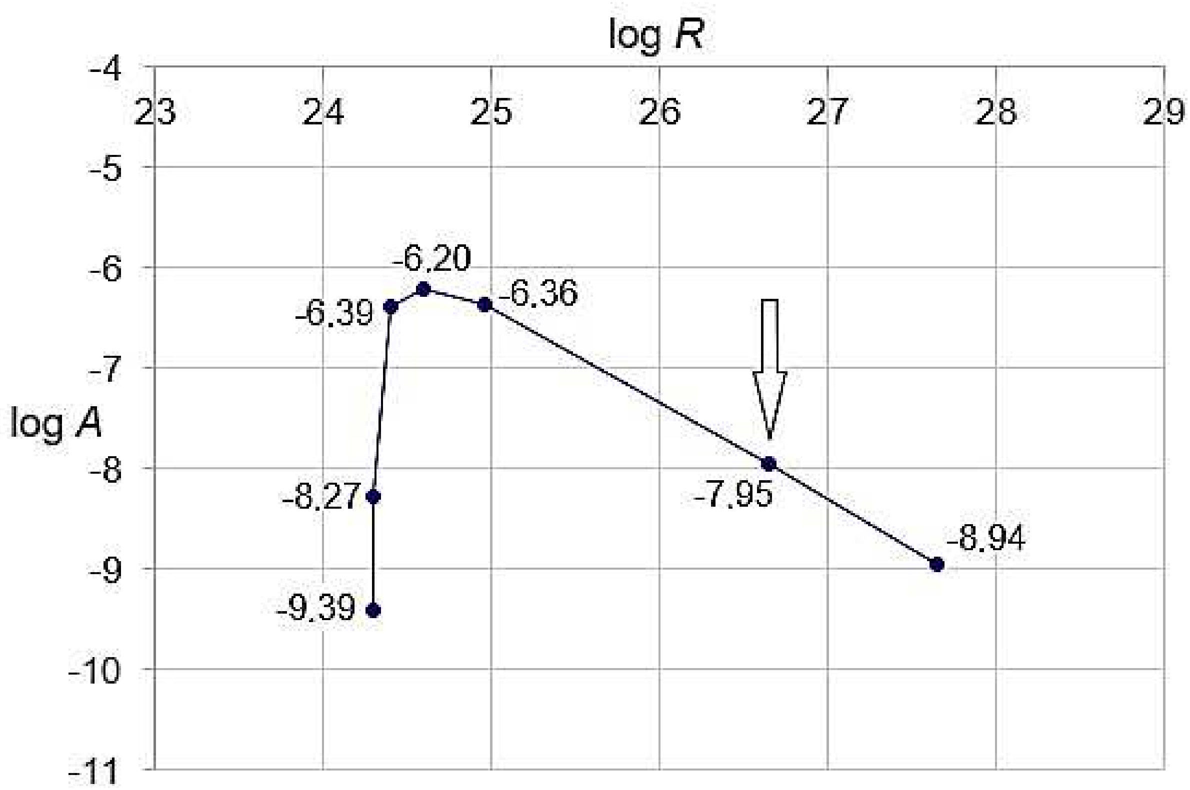

Fig. 2. Diagram of the interrelation between the acceleration of expansion A and the radius of universe R (that is function $A(R)$), on a logarithmic scale. An arrow in the diagram shows the present radius of the universe.

This diagram (Fig. 2) was calculated for the value of the kinetic energy of rotation E_R equal to dark energy E_{DE}, equal to 1.88*10^{71} [J]. The results presented in Table 2 and in Fig. 2 indicate that in the rotating universe, the acceleration of expansion was larger when the radius of the universe was smaller, that is, when the universe was younger. The larger acceleration of expansion in the early universe (Fig. 2) means only that the speed of increase in the rate of expansion was greater, but the magnitude of this rate was smaller than now. The existence of acceleration causes the rate of expansion to constantly increase. This is compatible with astrophysical observations [2,31].

Discussion

Rotation of the universe is not directly observed because the observer on Earth is rotating together with the entire universe and there is no point of reference. However, the rotation of the universe can be inferred, and confirmed by direct astronomical observations of the rotation of the galaxies and of the accelerating motion of the galaxies.

The rotation of galaxies is significant proof that the universe rotates, as their rotation is the result of the rotation of the universe. The global rotation of the universe has been found to be the natural beginning of galaxy rotation [32]. Because galaxies formed in a rotating universe, they rotated from the very beginning and some of the kinetic energy of the universe's rotation was transferred to them.

Fig. 2 shows that in the early universe, the acceleration of expansion was greater (but the rate of expansion was smaller), whereas in the late universe the acceleration of expansion was smaller (but the rate of expansion was greater). The compatibility of astronomical observations with the diagram in Fig. 2 may be evidence, that the universe is rotating.

The kinetic energy of the rotating and expanding universe does not change with the increasing size of the universe and similarly to dark energy, remains constant. Other features attributed to dark energy such as permeation of the entire universe, opposition to gravitational force, and acceleration of the expansion of the universe, are also features of the kinetic energy of rotation. Considering the cause of the accelerating expansion of the universe, the kinetic energy of rotation can successfully replace dark energy.

Methods

Classical mechanics

Classical mechanics (Newtonian mechanics) is a physical theory describing the motion of macroscopic objects, from projectiles to parts of machinery, and astronomical objects, such as spacecraft, planets, stars, and galaxies. For objects governed by classic mechanics, if the present state is known, it is possible to predict how it will move in the future and how it has moved in the past.

The earliest development of classical mechanics is often referred to as Newton mechanics. It consists of the physical concepts employed and the mathematical methods invented by Isaac Newton, Gottfried Wilhelm Leibniz, and others in the 17th century to describe the motion of bodies under the influence of a system of forces [1,2].

Newtonian kinetic energy

In classical mechanics the kinetic energy of the nonrotating rigid body depends on the mass of the body as well as its speed. The kinetic energy is equal to ½ the product of the mass and the square of the speed in formula form:

$$\boldsymbol{E}_k = \frac{1}{2}\boldsymbol{m}\boldsymbol{v}^2$$

where $\boldsymbol{m}$ is the mass, $\boldsymbol{v}$ is the speed (or the velocity) of the body in SI units, mass is measured in kilograms, speed in meters per second, and the resulting kinetic energy is in joules.

For the translational kinetic energy, that is the kinetic energy associated with rectilinear motion of a rigid body with constant mass $\boldsymbol{m}$, whose center of mass is moving in a straight line with speed $\boldsymbol{v}$, as seen above is equal to:

$$\boldsymbol{E}_t = \frac{1}{2}\boldsymbol{m}\boldsymbol{v}^2$$

where $\boldsymbol{m}$ is the mass of the body, $\boldsymbol{v}$ is the speed of the center of mass of the body [1,2].

Kinetic energy of rotation

The kinetic energy of rotation or rotational energy is kinetic energy due to rotation of an object and is part of its total kinetic energy. Looking at rotational energy separately around an object's axis of rotation, the following dependence is observed:

$$\boldsymbol{E}_R = \frac{1}{2}\boldsymbol{I}\boldsymbol{\omega}^2$$

where: $\boldsymbol{\omega}$ is the angular velocity, $\boldsymbol{I}$ is the moment of inertia around the axis of rotation, and $\boldsymbol{E}_R$ is the kinetic energy of rotation. For free-floating (unattached) objects, the axis of rotation is commonly around its center of mass.

Note the close relationship between the result for rotational energy and the energy held by linear (or translational) motion:

$$E_{translational} = \frac{1}{2}mv^2$$

In the rotating system, the moment of inertia, I, takes the role of the mass, m, and the angular velocity, w, takes the role of the linear velocity, v [1,2].

Centrifugal force

In classical mechanics the centrifugal force is an inertial force that appears to act on all objects when viewed in a rotating frame of reference. A rotating frame of reference is a special case of a noninertial reference frame that is rotating relative to an inertial reference frame. (An everyday example of a rotating reference frame is the surface of the Earth). Determining the position of a given point on a plane perpendicular to the axis of rotation the magnitude of centrifugal force is given by the following formula:

$$F = m\omega^2 r$$

where F is the centrifugal force, m is an object mass, and r is the distance from the origin of a frame of reference rotating with angular velocity w. The concept of centrifugal force can be applied in many rotating devices as well as in planetary orbits. [1,3,4].

Newton's second law of motion

There are three Newton's laws of motion that describe the relationship between the motion of an object and the forces acting on it. The second law states that the rate of change of momentum p of a body over time is directly proportional to the force applied and occurs in the same direction as the applied force:

$$\boldsymbol{F} = \frac{\boldsymbol{dp}}{\boldsymbol{dt}}$$

For objects and systems with constant mass, the second law can be restated in terms of an object's acceleration:

$$\boldsymbol{F} = \frac{\boldsymbol{d(mv)}}{\boldsymbol{dt}} = \boldsymbol{m}\frac{\boldsymbol{dv}}{\boldsymbol{dt}} = \boldsymbol{ma}$$

where $\boldsymbol{F}$ is the net force applied, $\boldsymbol{m}$ is the mass of the body, and $\boldsymbol{a}$ is the body's acceleration. Thus, the net force applied to a body produces a proportional acceleration. [1,2].

The Gravitational force

All objects in the universe exert a force of attraction upon each other by virtue of their masses. This is called the gravitational force. According to Newton's Universal Law of Gravitation: "Everybody in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them". Thus, if two bodies of masses $\boldsymbol{m_1}$, and $\boldsymbol{m_2}$ are separated by a distance $\boldsymbol{r}$, then the gravitational force of attraction between them has the magnitude:

$$\boldsymbol{F} = \boldsymbol{G}\left(\frac{\boldsymbol{m_1 m_2}}{\boldsymbol{r^2}}\right)$$

where $\boldsymbol{G}$ is a constant called the universal gravitational constant. Its value in SI units is: $\boldsymbol{G}$=6.67*10^{-11} [Nm^2/kg^2]. The force on $\boldsymbol{m_1}$ is towards $\boldsymbol{m_2}$ and vice versa. Thus, the force is along the line joining the two bodies.

It is clear, that the law of gravitation is strictly true for point objects. However, if the bodies are far apart, i.e., the distance between them is much greater than their sizes, then a good approximation r may be taken to be the distance between their centers, even if their separation is not large.

The gravitational force is a long-range force, though the magnitude of the force, being inversely proportional to the square of the distance, decreases sharply with the distance. It is the weakest of all four fundamental forces. A small value of G indicates that the force is negligible between elementary particles and even between other objects of ordinary size. The gravitational force becomes significant only if at least one of the masses is large. In fact, it plays a major role in the large-scale phenomena in the universe such as the formation, evolution and motion of galaxies, stars, and planets. It governs the motion of the moon and artificial satellites around the earth and the motion of objects falling towards the earth. [1,5].

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Figure Legends

Fig. 1. The dependence of the centrifugal force Fc and the gravitational force Fg (divided by the mass of the selected object m) on the radius R of the universe on a logarithmic scale. With increasing radius, the gravitational force decreases faster than the centrifugal force. The difference between Fc and Fg (ΔF) is the force that accelerates the expansion of the universe. The acceleration of the expansion started at R_{min}, that is, when the centrifugal force was equal to the gravitational force. The arrow in the diagram indicates the present radius of the universe.

Fig. 2. Diagram of the interrelation between the acceleration of expansion A and the radius of universe R (that is function A (R) on a logarithmic scale. An arrow in the diagram shows the present radius of the universe.

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Figures

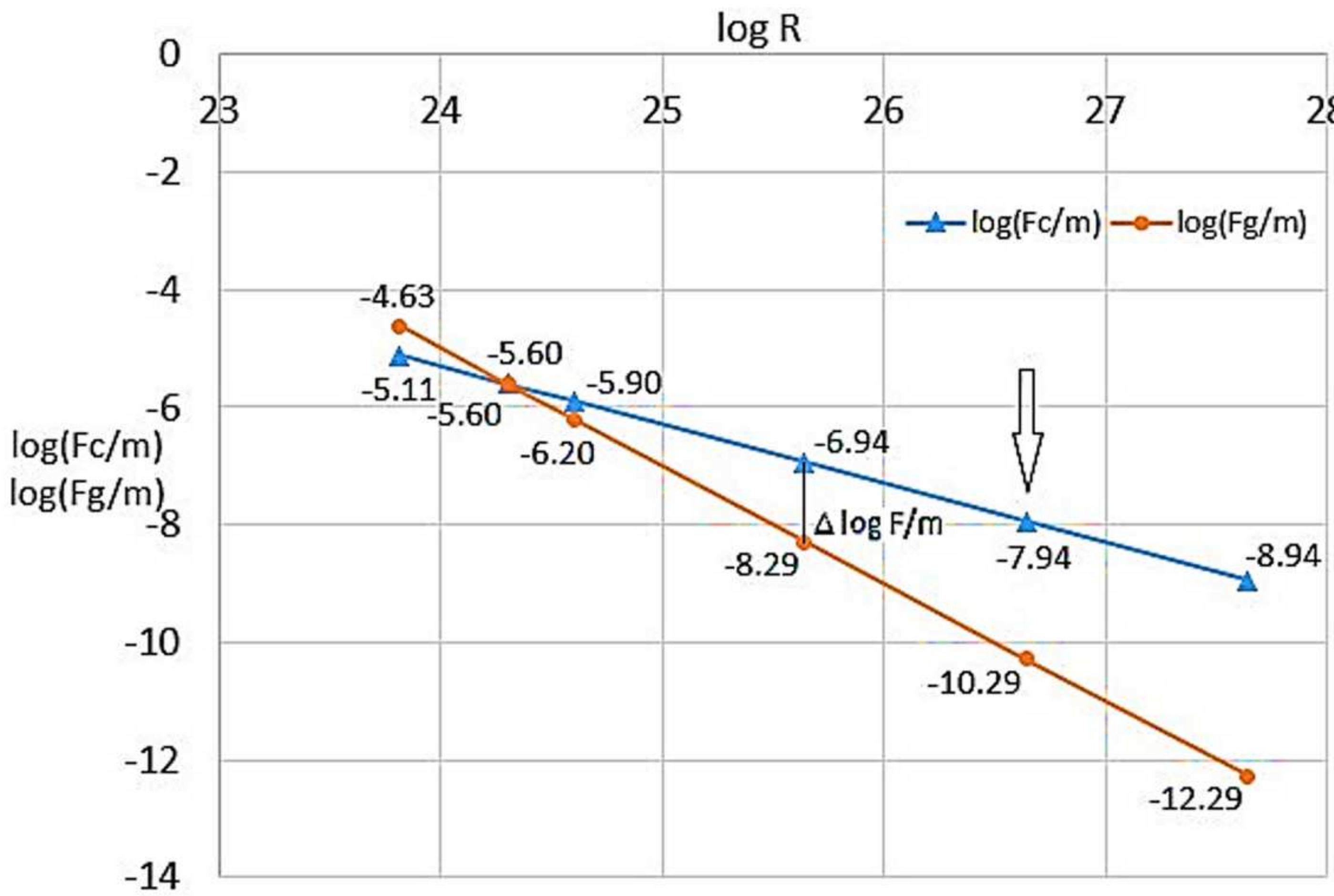

Figure 1

The dependence of the centrifugal force Fc and the gravitational force Fg (divided by the mass of the selected object m) on the radius R of the universe in a logarithmic scale. With increasing radius, the gravitational force decreases faster than the centrifugal force. The difference between Fc and Fg is the force (ΔF) that accelerates the expansion of the universe. The acceleration of the expansion started at R min, that is, when the centrifugal force was equal to the gravitational force. The arrow in the diagram indicates the present radius of the universe.

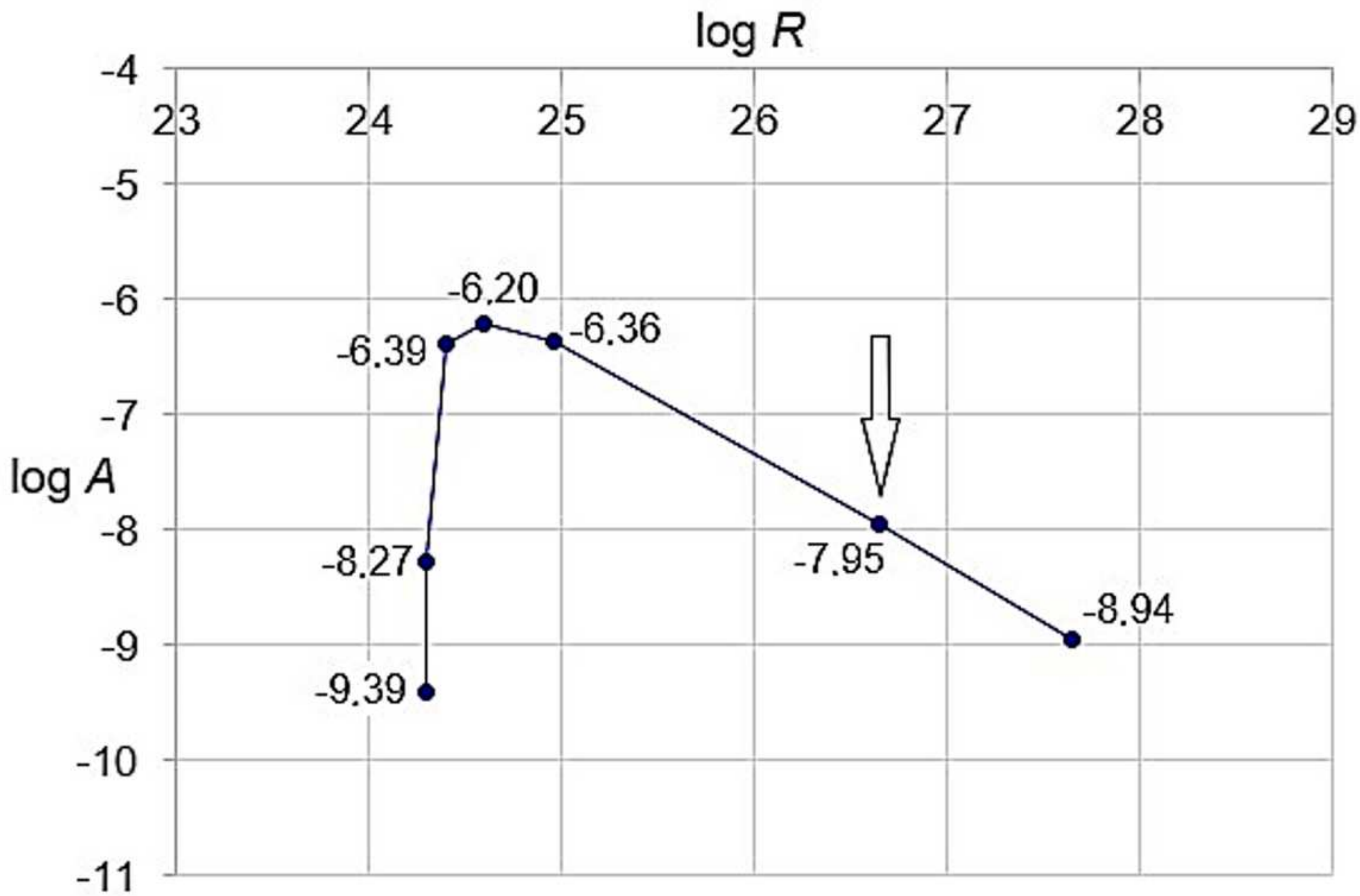

Figure 2

Diagram of the interrelation between the acceleration of expansion A and the radius of universe R (that is function A(R)), on a logarithmic scale. An arrow in the diagram shows the present radius of the universe.