On the Cosmological Nature of ``PIONEERS'' Anomalous Acceleration

© A.A. Raikov[1] and V.V. Orlov[2]

[1] Main (Pulkovo) Astronomical Observatory of RAS, St.-Petersburg, Russia
[2] St. Petersburg State University, St.-Petersburg, Russia

Abstract: We suggest an explanation of anomalous accelerations of spacecrafts ``Pioneer 10'' and ``Pioneer 11'' due to gravitational action of fractal matter distribution with dimension $D=2$. This ``fractal acceleration'' has to be directed along the tangent to trajectory in direction opposite to the spacecraft velocity vector. The value of the acceleration is equal to the product of two fundamental constants - Hubble constant H and speed of light c: $a=Hc \approx 8 \cdot 10^{-8}$ cm/s^2. We predict the behaviour of anomalous acceleration of spacecraft ``New Horizons'' in frame of the Earth.

1. Introduction

The spacecrafts Pioneer 10 and Pioneer 11 have started on March 2, 1972 and April 5, 1973. After flyby near Jupiter (Pioneer 10) and two flybys near Jupiter and Saturn (Pioneer 11), both spacecrafts have reached the hyperbolic orbits and escaped from the solar system. Now we have no connection with both spacecrafts. Last telemetric data from Pioneer 10 were received on April 27, 2002 when it was at the distance of 80 AU from the sun. Last contacts with Pioneer 11 were in November 1995 at the heliocentric distance of 40 AU. The details of observations of these spacecrafts are given by Anderson et al. [1]. Let's note that escapes of both spacecrafts take place in approximately opposite directions near the ecliptic.

In 1979, NASA has formulated a task to measure the acceleration of spacecraft Pioneer 10 with the purpose to reveal any additional accelerations, e.g. perturbations from other bodies of the solar system which have not been detected at the time. As a result, two series of telemetric information were received (about 60,000 points for Pioneer 10 and 50,000 points for Pioneer 11). For both spacecrafts, the anomalous accelerations were found. The methods of measurements and data processing are described by Turyshev et al. [2]. The averaged acceleration for both spacecrafts is

$$a_p = (8.74 \pm 1.33) \cdot 10^{-8} cm/s^2 \approx 2.8 cm/s/yr. \tag{1}$$

The dependences of accelerations on heliocentric distance are shown in Fig. 1. We can see that the anomalous acceleration of Pioneer 11 has significantly increased after its flyby near Saturn. Then the spacecraft has reached the velocity more than the escape velocity from the solar system. The measurements of the spacecraft Pioneer 10 were started after its flyby near Jupiter.

In the literature, various effects are discussed which can serve as a reason for these anomalous accelerations. A critical review of these effects was given by Anderson et al. [1]. The upper estimations of accelerations connected with these effects were found. Those are included in the uncertainty of Eq. 1. After taking into account the random errors and systematic effects, the anomalous acceleration is significant at the level of 6.6σ.

As a result, different attempts were made to explain this anomalous acceleration by various modifications of gravity theory, hidden mass, dust action etc. The discussion of these attempts is given by Anderson et al. [1]. However, none of the suggested proposals has given a satisfactory explanation of anomalous acceleration that did not contradict the data on other objects of the solar system or artificial bodies. Thus, an interpretation of anomalous accelerations of the spacecrafts Pioneer 10 and Pioneer 11 is of interest. Below we suggest one more version to explain such effect.

2. New explanation

Before we discuss the anomalous acceleration, we would like to note one important circumstance. We can see an approximate equality of the anomalous acceleration a_p and the Hubble acceleration a_H

$$a_p \approx a_H = Hc \approx 8 \cdot 10^{-8} cm/s^2, \tag{2}$$
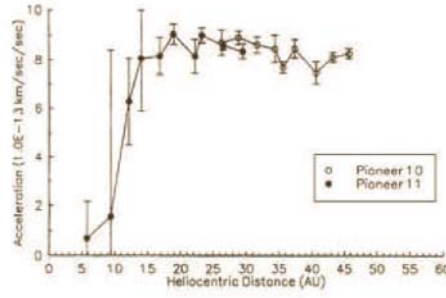
Fig. 1. The dependences of anomalous accelerations of the spacecrafts Pioneer 10 and Pioneer 11 on heliocentric distance [3].

where c is the speed of light, H is the Hubble constant. This coincidence is noted by many authors, however there is no satisfactory explanation of cosmological nature of this effect.

The question of the direction of this anomalous acceleration vector is also open. Nieto et al. [3] have discussed four possible orientations of this vector: 1) to the Sun; 2) to the Earth; 3) along the trajectory of the spacecraft; 4) along the axis of rotation of the spacecraft. The dependences on time are different in each case. One cannot choose between these versions for the spacecrafts Pioneer 10 and Pioneer 11, because of low accuracy of observations. It is possible that we could make this for future flights, e.g. New Horizons (see below).

Here we propose one more explanation of the anomalous spacecraft accelerations. This is the gravitational action of the matter distributed as a fractal. It is well-known that large-scale distribution of the matter in the Universe has the signs of fractal with a dimension $D \approx 2$ up ~ 100 Mpc (see, e.g. [4, 5]).

If the matter distribution is a fractal of dimension D then the average mass of the matter inside the sphere of radius R is proportional to R^D. When a photon moves inside such fractal with the dimension $D \approx 2$ the gravitational redshift appears [6]

$$z_g = \frac{\Delta\varphi}{c^2} = \frac{4\pi}{3} \frac{G\rho_0 r_0}{c} \frac{r}{c} = \frac{H_g}{c} r, \tag{3}$$

where $\Delta\varphi$ is the difference of potentials, the density ρ_0 and distance scale r_0 correspond to the lower boundary of the fractal, H_g is the 'gravitational' Hubble constant. Here one assumes that there is a center of distribution ("fractal sphere"). Actually a fractal distribution is not required for such formula. The same is valid when the density distribution is smooth and has a form $\rho(r) \propto r^{-1}$.

However, in the Local Group of galaxies (see [7]) the huge mass of $\sim 10^3$ galaxies within the sphere of radius 1 Mpc is required to save the gravitational nature of the observed redshift of the Hubble flow in vicinity of the group. Therefore usually the authors (see, e.g. [8-10]) analyze only ΛCDM models. At the same time, the observed values of redshifts would be explained if the dissipation of energy is connected with non-local action of gravitating matter that has a fractal distribution with dimension $D \approx 2$. This non-local nature of gravitational action from the fractal mass could be connected with the gravity transmitters which fill space. This argumentation is similar to that by Dicke [11] who has considered the Mach principle. Probably, this effect has a non-local cosmological character, i.e. we have an action of gravitating matter that is distributed on the Hubble scales and acts on the local phenomena (e.g., inertial mass and gravitational redshift of a photon).

When we consider a massive particle, we can also formally introduce an acceleration of the particle due to the difference of potentials [12]. Analogically to [6], we can write $M \propto r^2$, $\varphi \propto r$.

If the particle is moving inside the self-gravitating fractal structure, it is subject to, generally speaking, variable acceleration a_F directed along the tangent to trajectory against the velocity vector. When $D = 2$, this acceleration is constant: $a_F = const$.

The absolute value of this acceleration is proportional to

$$\frac{d\mathrm{v}}{dt} \propto G\rho_0 r_0. \tag{4}$$

If the upper boundary of fractal distribution is near the Hubble radius

$$R_H = \frac{c}{H}, \tag{5}$$

then

$$a_F = a_H \cong \frac{GM_H}{R_H^2} \cong Hc. \tag{6}$$

The equation of motion of the particle inside the fractal structure with dimension $D = 2$ has a form

$$\frac{d\mathbf{v}}{dt} = \mathbf{a}_{Holts} - H_g c \frac{\mathbf{v}}{|\mathbf{v}|}, \tag{7}$$

where a_{Holts} is the vector of acceleration for the Holtsmark distribution.

If the fractal acceleration has a dissipative character, then we can estimate in order of magnitude the variation of kinetic energy of the particle with the mass m that moves through fractal cluster with velocity v:

$$\frac{dE}{dt} \cong mva_H = mvHc = mc^2 H \frac{\mathbf{v}}{c} = mc^2 \frac{\mathbf{v}}{R_H} \cong \frac{c^5}{G} \frac{m}{M_H} \frac{\mathbf{v}}{c}. \tag{8}$$

Let's note that the expression

$$\frac{c^5}{G} = L_{Plank} \tag{9}$$

is maximum possible luminosity [13].

We can also consider the photon that has the energy

$$E = h\nu = \frac{hc}{\lambda}, \tag{10}$$

where h is the Planck constant, ν is frequency, and λ is the wavelength. The typical rate of energy loss for the photon is

$$\frac{dE}{dt} \cong \frac{E}{T_H} \cong \frac{hc}{\lambda} = hH \frac{c}{\lambda}, \tag{11}$$

where $T_H = H^{-1}$ is the Hubble time.

Introducing the de Broglie wavelength,

$$\lambda = \frac{h}{mv}, \tag{12}$$

we find Eq. 8 from Eq. 11. This fact leads to the thought that the processes of the energy loss by massive particle and photon have the same dissipative nature. When a photon or massive particle goes the distance λ, it loses the energy hH. The photon decreases its frequency (increases its wavelength, i.e., "reddens"), and the massive particle loses its kinetic energy.

Let's note a significant difference between the behavior of a particle or photon in local gravitational field (e.g. on the Earth) and on the Hubble scales. When there is a local condensation of gravitating matter (the Earth, Galaxy, galaxy cluster etc.), a free particle can "know" the direction to the center of mass of gravitating object under consideration. The force lines of such field have the divergent structure. In this case, the density of energy is similar to the density of energy of electrostatic filed around the charged particle

$$\rho_e = \frac{1}{8\pi}(\nabla\varphi_e)^2 = \frac{e^2}{8\pi R^4}, \tag{13}$$

where φ_e is the potential, e is the charge, R is the distance from the charge to the point of the field.

When we consider the stochastic fractal with $D = 2$, the density of energy of the gravitational field is

$$\rho_G = \frac{(\nabla \varphi)^2}{8\pi G c^2} \cong \frac{(Hc)^2}{8\pi G c^2} = \frac{H^2}{8\pi G} \cong 3 \times 10^{-30} \, g \cdot cm^{-3}. \tag{14}$$

It gives in each point of fractal structure the scalar a^2. This explains partially that the vector a is directed along the tangent to the trajectory, because the attracting center does not exist.

One more important question is "Why do we observe no signs of fractal acceleration in motions of planets, satellites of planets and other objects of the solar system?" In this connection, we can consider three possibilities:

1. The particle is gravitationally connected with some system.

2. The particle flies freely through the fractal.

3. The particle loses a gravitational connection with the system of lower hierarchy level (e.g., with the solar system) and temporally hits in the "fractal wind".

In each of these situations, the behavior of the particle may be different. In the first case, the particle is gravitationally "connected" with the center of mass of the system, and one cannot separate the acceleration of the particle from the acceleration of the system. In the second case, a "fractal wind blows" on the system. This wind drags the particle (for the photon this effect leads to the gravitational redshift). In the third case, the following effect can take place: the "fractal wind" acts on the particle during a finite time until the particle has no gravitationally connected with the system of the higher hierarchy level (in our case, with the Galactic regular field). Thus, we can explain "why the objects connected with the solar system do not feel the fractal acceleration", as well as why the objects losing the gravitational connection with the solar system feel it.

Let's note that the analysis of possible manifestations of the anomalous acceleration in the motions of major planets has been carried out in several papers (see, e.g. Iorio [14] and references therein). In particular, the effect of this acceleration on apsidal motions of Jupiter and Saturn has been estimated. However, the authors of these studies did not reveal any signs of anomalous accelerations in motions of natural bodies of the solar system within 20 < r < 70 AU [14]. As for additional motions of perihelia, connected with anomalous acceleration, such estimations were made by Iorio [14] and have been compared with the ephemeredes EPM 2004 [15]. These estimates are in agreement with the ephemeredes within the uncertainties. However, the uncertainties are rather large and do not allow to extract the effect of anomalous acceleration. At the same time, if we compare the ratio of predicted apsidal motions for Jupiter and Saturn with the ephemeredes [14], then those differ strongly (at level of *15σ*). Thus, the data of recent ephemeredes contradict the predictions of the anomalous accelerations for Jupiter and Saturn. This bears evidences to the lack of their effect to the connected objects in the solar system.

Let's note that such effects may take place in other gravitating systems, in particular in galaxy groups. Recently, a series of papers by Chernin et al. [8-10] has been published. Here the authors consider the Local Group of galaxies, as well as two other loose groups (M81 group and Cen A/M83 group). The authors construct the dependences between separations of galaxies from the center of the group and radial velocities of the galaxies from the centers of the groups. They observe an increasing trend (increase of velocities) with the distance of the galaxy from the center of the group, beginning from 1-1.5 Mpc. The authors explain this result as the pressure of dark energy that pushes the galaxies of the group. We will observe a "dispersal" of the galaxies after crossing the surface of "zero gravity".

The velocity dispersion in the Hubble flows for all three groups is almost constant and equal to about 30 km/s. This value is comparable with the uncertainties of radial velocities, i.e. actual velocity dispersions in the flows can be even lower. This anomalous "coldness" of the galaxy flows in the periphery of the groups can be explained by the fractal acceleration that acts on the galaxies escaping from the groups along the hyperbolic orbits. The fractal acceleration will drag the galaxies and form the outer regions of galaxy groups where the velocity dispersion is rather low. Then the redshifts of galaxies in the flows has a gravity nature because the photons are moving in the gravitational field of the matter distributed as a fractal with dimension of $D \approx 2$.

Let's note that introduction of pushing ("heating") dark energy leads to definite difficulties in thermodynamic description of some processes. We do not meet such difficulties when we consider the dissipative drag process inside the fractal structure.

Therefore, the fractal acceleration may serve as an explanation of the anomalous accelerations of the spacecrafts Pioneer 10 and Pioneer 11, as well as the "coldness" of coronae in the galaxy groups.

3. Perspectives

Let's emphasize that in the framework of our proposal, the anomalous acceleration of the Pioneers spacecrafts is not connected with any hidden mass in the solar system or its neighborhood. This has to have a global character. So it must show itself in the motions of other objects escaping from the solar system. Such unique object was recently created. This is a spacecraft "New Horizons". It flies to the Pluto and other objects of the Kuiper-Edgewort Belt. Recently it has reached Jupiter and after flyby has escaped to in the hyperbolic heliocentric orbit. Now it is rather difficult to reveal anomalous acceleration because of closeness of spacecraft to the Sun, effect of light pressure, and trajectory corrections. However, soon the solar light pressure will become weaker, and it will be possible extract the anomalous acceleration more reliably, if it exists. Therefore a regular telemetry is strongly desirable (see Nieto [16]).

We can make a prediction of the observed dependences of the anomalous acceleration projections for the "New Horizons" in two cases: 1) the acceleration is directed along the trajectory against the velocity vector; 2) it is directed to the Sun. The results are shown in Fig. 2.
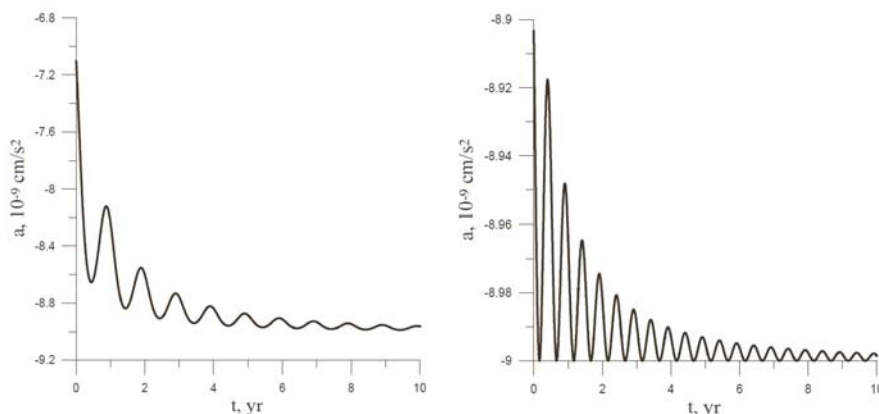

Fig. 2. The dependences on time of the anomalous acceleration projections of the spacecraft New Horizons to the vector Earth-spacecraft in two cases: left panel – the acceleration vector is oriented along trajectory against the velocity vector; right panel – it is directed to the Sun.

Let's note that the damping oscillations take place in both cases. The period of oscillations is equal to one year in the first case, and it is twice shorter in the second case. Therefore, we have a principal possibility to separate two directions of the acceleration vector.

We can suggest one more cosmic experiment to test the existence and some details of the anomalous acceleration. We suggest to consider the objects which have escaped from the gravitational Earth's field for a short time. The idea is to measure the anomalous acceleration if it exists. The purpose of such experiment is to find a dependence of this acceleration on time. We may consider several possibilities: 1) absence of such acceleration at all; 2) an instant switching on and instant switching off of the acceleration; 3) an instant switching on and smooth switching off the acceleration; 4) a smooth switching on and instant switching off the acceleration; 5) a smooth switching on and smooth switching off the acceleration. It is of interest to carry out similar experiment on the lunar orbit and try to measure the accelerations. This is necessary in order to give the escape velocities with respect to the Earth. We think that this is possible due to the blow in the orbit. However, we need to use the reliable detectors (such as transmitters, as reflectors). We do not analyze here the technical details. However it seems that such experiment may be carried out.

References

1. Anderson J.D., Laing P.A., Lau E.L., Liu A.S., Nieto M.M., Turyshev S.G. // Phys. Rev. D. 65, 082004 (2002).
2. Turyshev S.G., Toth V.T., Kellogg L.R., Lau E.L., Lee K.J. // ArXiv: gr-qc/0512121v2 (2006).
3. Nieto M.M., Turyshev S.G., Anderson J.D. // ArXiv: gr-qc/0411077v2 (2004).
4. Best J.S. // Astrophys. J. 541, 519 (2000).
5. Seshadri T.R. // Bull. Astr. Soc. India. 33, 1 (2005).
6. Baryshev Yu.V. // Astron. Astrophys. Trans. 5, 15 (1994).
7. Baryshev Yu.V., Teerikorpi P. Fractal structure of the Universe / Nizhnij Arkhyz: SAO RAN 2005 (In Russian).
8. Chernin A.D., Karachentsev I.D., Makarov D.I., Kashibadze O.G., Teerikorpi P., Valtonen M.J., Dolgachev V.P., Domozhilova L.M. // ArXiv: 0704.2753v1 (2007).

9. Chernin A.D., Karachentsev I.D., Teerikorpi P., Valtonen M.J., Byrd G.G., Efremov Yu.N., Dolgachev V.P., Domozhilova L.M., Makarov D.I., Baryshev Yu.V. // ArXiv: 0706.4068v1 (2007).

10. Chernin A.D., Karachentsev I.D., Kashibadze O.G., Makarov D.I., Teerikorpi P., Valtonen M.J., Dolgachev V.P., Domozhilova L.M. // Astrophys. 50, 405 (2007).

11. Дикке Р. In collection ``Gravity and relativity'' / Moscow: Mir 1965 (In Russian).

12. Raikov A.A. // Proceed. Intern. Conf. ``Dynamics of galaxies'', St. Petersburg, August, 6-10, 2007, in press (2008).

13. Baryshev Yu.V., Raikov A.A. // Astrofizika. 28, 689 (1988).

14. Iorio L. // ArXiv: 0712.1273v1 (2007).

15. Pitjeva E.V. // Solar System Res. 39, 176 (2005).

16. Nieto M.M. // ArXiv: 0710.5135v1 (2007).