CONFERENCES AND SYMPOSIA

Advances in astronomy
(Scientific session of the Physical Sciences Division of the Russian Academy of Sciences, 27 February 2013)

A scientific session of the Division of Physical Sciences of the Russian Academy of Sciences (RAS), entitled ''Advances in Astronomy,'' was held on 27 February 2013 at the conference hall of the Lebedev Physical Institute, RAS.

The following reports were put on the session agenda posted on the website www.gpad.ac.ru of the RAS Physical Sciences Division:

(1) **Chernin A D** (Sternberg Astronomical Institute, Moscow State University, Moscow) ''Dark energy in the local Universe: HST data, nonlinear theory, and computer simulations'';

(2) **Gnedin Yu N** (Main (Pulkovo) Astronomical Observatory, RAS, St. Petersburg) ''A new method of supermassive black hole studies based on polarimetric observations of active galactic nuclei'';

(3) **Efremov Yu N** (Sternberg Astronomical Institute, Moscow State University, Moscow) ''Our Galaxy: grand design and a moderately active nucleus'';

(4) **Gilfanov M R** (Space Research Institute, RAS, Moscow) ''X-ray binaries, star formation, and type-Ia supernova progenitors'';

(5) **Balega Yu Yu** (Special Astrophysical Observatory, RAS, Nizhnii Arkhyz, Karachaevo-Cherkessia Republic) ''The nearest 'star factory' in the Orion Nebula'';

(6) **Bisikalo D V** (Institute of Astronomy, RAS, Moscow) ''Atmospheres of giant exoplanets'';

(7) **Korablev O I** (Space Research Institute, RAS, Moscow) ''Spectroscopy of the atmospheres of Venus and Mars: new methods and new results'';

(8) **Ipatov A V** (Institute of Applied Astronomy, RAS, St. Petersburg) ''A new-generation radio interferometer for fundamental and applied research.''

Summaries of the papers based on reports 1, 2, 4, 7, 8 are given below.

Dark energy in the nearby Universe: HST data, nonlinear theory, and computer simulations

A D Chernin

1. Introduction

Dark energy is an invisible cosmic substance of unknown physical nature and microscopic structure. Its existence was recognized 15 years ago from astronomical observations of objects at large distances, near the cosmological horizon [1, 2] (the 2011 Nobel prize in physics). This medium does not gravitate as all previously known forms of matter do, but instead induces antigravity. This antigravity dominates in the observed Universe as a whole. Due to the antigravity, recession motion of galaxies occurs with acceleration, which was registered by astronomers using the Hubble Space Telescope (HST) and other large instruments [1, 2]. It was established that the phenomenon of cosmic antigravity can be described well by general relativity (GR), created by Einstein about 100 years ago [3].

General relativity, if speaking in the language of Newtonian mechanics, states that in nature, along with the Newtonian universal gravity inverse-square law

$$F_N = -\frac{GM}{R^2},\qquad(1)$$

there is also a universal antigravity with the force proportional to the distance:

$$F_E = \frac{c^2}{3}\Lambda R.\qquad(2)$$

Here, G is the universal gravitational constant and Λ is Einstein's cosmological constant [1]. The forces are given per mass of a particle, i.e., these are accelerations acting on the

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particle. Formula (1) can be applied to the motion of a light (test) particle around a heavy mass M, and then R is the distance to the center of the mass. Einstein's formula (2) describes the repulsion between two particles separated by the distance R. For a positive cosmological constant, force (2) is directed oppositely to (1). Force (1) is formed by the masses of bodies, while force (2) does not depend on the masses of bodies and is due to the presence of an invisible ideal homogeneous cosmic medium that fills the space. This medium is identified with dark energy, discovered by astronomers. The dark energy density ρ_V is expressed in terms of the cosmological constant as $\rho_V = c^2 \Lambda/(8\pi G)$. The cosmological density of dark energy is now measured [4] with a several percent accuracy: $\rho_V = (0.721 \pm 0.025) \times 10^{-29} \, \mathrm{g\,cm^{-3}}$. In the observed Universe, the dark energy density dominates and constitutes 72% of the total energy density of the world.

An interpretation of the cosmological constant in terms of an antigravitating medium with constant density was suggested by Gliner [5] in 1965. Now it is widely accepted and underlies the modern standard cosmological model (the ΛCDM model, with CDM standing for cold dark matter). Dark energy as a macroscopic medium has several very specific features [5–8]: (1) its density is positive and pressure is negative, and its absolute value is equal to the energy density $P_V = -\rho_V c^2$; (2) it creates antigravity because its effective gravitating density is negative: $\rho_V^{\mathrm{eff}} = \rho_V + 3P_V/c^2 = -2\rho_V < 0$; (3) it represents a vacuum, because, similarly to the trivial vacuum, it cannot serve as a reference frame.

Soon after the discovery of dark energy, it was suggested that the antigravity due to dark energy can manifest itself not only near the cosmological horizon but also in the local Universe around the Milky Way [9, 10]. Local dark energy effects have been studied at the Sternberg Astronomical Institute (SAI) of Moscow State University (MSU) in cooperation with astronomers from the Special Astrophysical Observatory of the RAS (SAO RAS), St. Petersburg State University, the University of Turku (Finland), and the University of Alabama (USA). This study uses very precise data recently obtained by the HST, BTA SAO RAS, and the 'Aresibo-Dish' radio telescope.

In this paper, we briefly present our new results obtained in studying local dynamical effects of dark energy on scales $\sim 1–10$ Mpc.

2. The Local Group and Local Flow

Galaxies are distributed homogeneously in global cosmic volumes with a size of 300 Mpc and larger. Within these volumes, the standard ΛCDM model is applicable. At relatively small scales, the Universe has a highly inhomogeneous distribution of galaxies. Most galaxies are collected in massive groups (with a size of ~ 1 Mpc) and clusters (~ 10 Mpc). The space between these mass concentrations is almost empty.

We first consider our close vicinity. The Galaxy (Milky Way) and a similarly large galaxy in Andromeda (M31) form the Local Group of galaxies, which also includes about fifty smaller galaxies.

The Local Group is a gravitationally bound quasi-stationary system with the total mass $M = (2–3) \times 10^{12} M_\odot$. This mass includes 'ordinary' (baryonic) matter from stars and the interstellar medium, as well as dark matter, which is five times as massive and is mainly contained in extended halos of the two giant galaxies of the group. The group has a
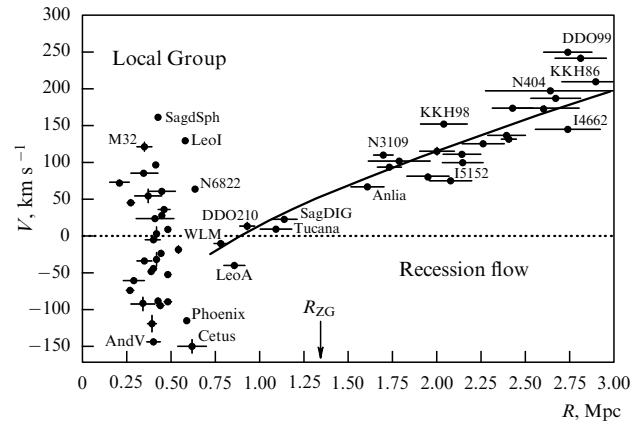

Figure 1. The velocity–distance diagram for the Local Group of galaxies and the recession flow around it. Each point corresponds to a galaxy with measured distance and radial velocity [11] in the reference frame related to the Local Group center. Velocities are positive if they are directed away from the group center. In the vicinity of the group ($R < R_{\mathrm{ZG}}$), gravitation dominates; outside the group ($R > R_{\mathrm{ZG}}$), in the flow region, antigravity prevails.

size of about 2 Mpc across. At a distance of 1–3 Mpc from the group center, 24 dwarf galaxies are observed. All of them move away from the group center, and the larger the distance from the center is, the higher the velocities. This is the local flow of galaxy recession.

Each galaxy of the group and the flow have been studied in detail by Karachentsev and colleagues using the HST and other big telescopes mentioned in Section 1 (see [11] and the references therein). In particular, distances to Local Group galaxies and galaxies in the recession flow have been measured with a record accuracy of 10%. Velocities of the galaxies have been measured with an accuracy better than 5–10 km s^{-1}. The results of observations are presented in Fig. 1, taken from [11].

The group-flow system can be essentially described by a nonlinear spherically symmetric theoretical model [12, 13] in which the group is represented by a spherical mass M and the flow is treated as a collection of 'test particles' (the total mass of dwarfs in the flow is less than a few percent of the total mass of the group). The group and flow are embedded in the cosmic dark energy background with the local energy density ρ_X. In general, we do not set it equal to the global density ρ_V, unless specially stated. Newton's force of attraction (1) to the group and Einstein's force of repulsion (2) (in which ρ_V now stays instead of ρ_X) act on each test particle. The first force decreases with distance, while the second one increases. The absolute values of both forces become equal at the distance

$$R = R_{\mathrm{ZG}} = \left(\frac{3M}{8\pi\rho_X} \right)^{1/3}, \tag{3}$$

where R_{ZG} is the zero-gravitation radius [12, 13]. Gravitation dominates at $R < R_{\mathrm{ZG}}$, while antigravity prevails at $R > R_{\mathrm{ZG}}$. We assume that the local dark energy density ρ_X is equal to its global value $\rho_V = 0.72 \times 10^{-29}$ g cm^{-3} as inferred from cosmological observations. Then the zero-gravitation radius is

$$R_{\mathrm{ZG}} = 1.1 \left(\frac{M}{10^{12} M_\odot} \right)^{1/3} \mathrm{Mpc}. \tag{4}$$

Substituting the Local Group mass $M = (2-3) \times 10^{12} M_\odot$ in (4), we obtain the critical radius R_{ZG} about 1.3–1.4 Mpc (see Fig. 1).

We see that for the assumed local dark energy density, the zero-gravitation radius R_{ZG} is very close to the radial size of the Local Group, $R_0 \simeq 1$ Mpc, found from observations. Obviously, the size of a quasistationary gravitationally bound system cannot be larger than the critical radius where antigravity dominates. Remarkable, however, is the fact that this theoretical upper limit on the size of the group almost coincides with the actually observed system size.

As regards the recession flow, it is located entirely at distances $R > R_{ZG}$, where antigravity dominates (see Fig. 1). This is the nearest space region where the dynamical effect of antigravity due to dark energy is as strong as at the cosmological horizon. This region is confined within concentric spheres with the radii $R_{ZG} = 1.4$ and 3 Mpc.

3. Regions of antigravity

In searching for other antigravity-dominated regions, we consider the "Catalog of nearby galaxies" by Karachentsev [14] and papers [11, 15–18]. They contain data on velocities and distances for about 200 galaxies at distances up to 7–8 Mpc, which have been studied by the HST over 200 orbital periods of the instrument. According to these data, one of the nearby galaxy groups is located at a distance of 4.0 ± 0.4 Mpc from the center of the Local Group. It includes the giant galaxy Cen A and the massive galaxy M83. The group fills an elongated volume with a cross size of about 4 Mpc. There are 50 dwarf galaxies around it; distances and velocities for 21 of them have been accurately measured. Within the distance range 2–3 Mpc, all velocities of galaxies are positive, with the highest velocity 250 km s^{-1} at a distance of about 3 Mpc in this recession flow.

Two more groups from the local volume have a similar structure. One of them includes the main galaxies M81 and M82 and has a volume 2 Mpc in diameter. Outside this group, a recession flow is observed; it includes 22 galaxies for which distances and velocities have been accurately measured with the HST. Velocities of the flow (relative to the group center) lie in the range from zero to 220 km s^{-1}. The center of another group (called Canes Venatici I cloud, CVIc) is located near the giant spiral galaxy M94 (NGC 4736) at a distance of 6 Mpc from the Milky Way. CVIc has a volume about 2 Mpc in diameter, and a recession flow with velocities from 10 to 200 km s^{-1} is observed around it. For all four groups/flows considered above, the antigravity region has the shape of a spherical layer with the inner radius $\simeq 1$–2 Mpc and the outer radius $\simeq 3$–4 Mpc [19–21].

New data obtained by Karachentsev's group [22, 23] allows searching for antigravity regions around galaxy clusters. Two nearby clusters in Virgo and Fornax are located at a distance of about 20 Mpc. Recession flows on the scale of 10–25 Mpc were discovered around these clusters [22, 23]. Velocities in these flows attain 500–1500 km s^{-1} in the reference frame connected with the cluster center. By applying the model described in Section 2 to the cluster flow system, we see [24, 25] that the flows around two clusters are located at distances exceeding the corresponding zero-gravity radius ($R > R_{ZG}$), i.e., in the antigravity-dominated regions, which can be represented as a spherical layer between the inner sphere with the radius $\simeq 7$–10 Mpc and the outer sphere with the radius $\simeq 20$–25 Mpc.

Based on observations of six nearby group/cluster-flow systems, we can assume [25–28] that the sizes of many, if not all, groups and clusters of galaxies everywhere in the Universe never exceed the zero-gravity radius. Around groups and clusters of galaxies, at a distance of 2–3 zero-gravity radii from their centers, there must be antigravity-dominated regions (even if no recession flows are observed there).

4. Phase attractor

We return to the theoretical model in Section 2 and consider radial trajectories of test particles of a typical flow in the force field determined by Eqns (1) and (2). The equation of radial motion of an individual particle

$$\ddot{R} = F_N + F_E = -\frac{GM}{R^2} + \frac{8\pi}{3} G\rho_X R \qquad (5)$$

can be easily integrated to obtain the mechanical energy conservation law

$$E = \frac{1}{2} \dot{R}^2 - \frac{GM}{R} - \frac{4\pi}{3} G\rho_X R^2, \qquad (6)$$

where $E = $ const is the total mechanical energy of the particle per unit mass.

Equations (5) and (6) are valid in the flow region ($R \geqslant R_{ZG}$) dominated by dark energy. Equation (6) determines the phase trajectories of recessing particles in the velocity–distance space. This equation implies that in the limit of large distances ($R \to \infty$), the dark-energy antigravity is the only dynamical factor, and in this limit, phase trajectories therefore follow a linear velocity–distance dependence known as the Hubble law, $V = \dot{R} = H_X R$. Here,

$$H_X = \left(\frac{8\pi}{3} G\rho_X \right)^{1/2} \qquad (7)$$

is a constant determined only by the local dark energy density. If this density is equal to the global dark energy density, then $H_X = H_V = 60$ km s^{-1} Mpc^{-1}. The straight line $V = H_X R$ in the phase space of the flow represents a dynamical attractor: all possible phase trajectories of flow particles tend to it as the distance increases. The quantity H_X is the parameter of the attractor.

Do real dwarf galaxies of the local flow follow trajectories of the theoretical model? The answer can be obtained from Fig. 2, which shows trajectories in the velocity–distance space by assuming the Local Group mass $M = 3 \times 10^{12} M_\odot$. The
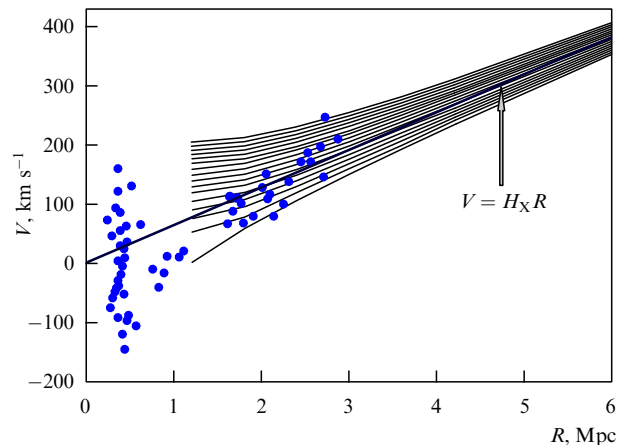

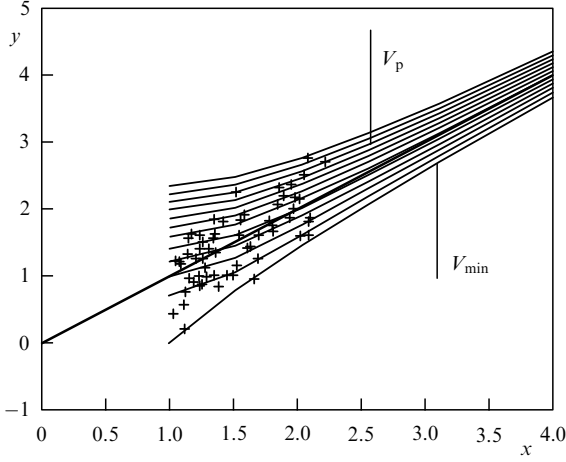**Figure 2.** Phase trajectories and phase attractor.

Figure 3. Synthetic velocity–distance diagram in dimensionless variables for four recession flows around nearby galaxy groups.
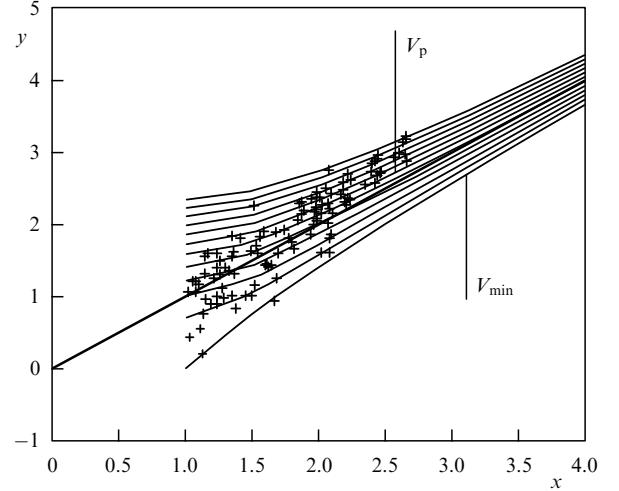

Figure 4. Synthetic diagram for six nearby recession flows.

observed galaxies of the flow comprise a moderately wide bundle of trajectories, which then converges to a linear attractor. The parameter of the attractor determined by this bundle of trajectories is $H_X = 63$ km s^{-1} Mpc^{-1}, which differs from the global value of H_V by less than 5%.

A synthetic phase diagram for four flows around galaxy groups is shown in Fig. 3 using the dimensionless variables $x = R/R_{ZG}$ and $y = V/V_V$, where $V_V = H_X R_{ZG}$ [29]. Figure 4 presents a synthetic diagram for all six flows described above. We note that the flows in Figs 2–4 look almost similar and the points comprise (almost) the same bundle of phase trajectories converging to the attractor $y = x$. This means that the flows have a universal self-similar structure [25] independent of the physical space scale, which can differ by almost an order of magnitude around groups and clusters of galaxies.

The attractor parameter H_X and the zero-gravity radius R_{ZG} can be used to express the acceleration of particles [see Eqn (5)] in the dimensionless form

$$Q(R) = \frac{\ddot{R}}{V_V H_X} = x - x^{-2}. \tag{8}$$

The acceleration parameter Q is equal to zero at $x = 1$ and increases with distance up to $Q = 2.9$ at $x = 3$ (the maximum distance in the empirical diagrams); $Q = 1$ at the intermediate distance $x = 1.5$. We see that the local galaxy recession flows accelerate with increasing acceleration. As a function of the dimensionless distance from the center, the acceleration parameter is the same for all flows. This supports the conclusion about the universal self-similar structure of the flows accelerated by dark energy.

The existence of an attractor in the phase space of a flow can be used to empirically determine the local density of dark energy from the observed velocity–distance plots. Indeed, if the observed points (galaxies) on such a plot single out a specific bundle of trajectories from many theoretically admissible trajectories, the geometry of the bundle can be used to find the phase attractor as the ray emanating from the origin to which all trajectories converge with distance (see Fig. 2). The equation for the ray gives the value of the attractor parameter H_X and hence the value of the local dark energy density:

$$\rho_X = \frac{3H_X^2}{8\pi G}. \tag{9}$$

For example, in the nearby flow around the Local Group of galaxies, we find $H_X = 63$ km s^{-1} Mpc^{-1} (see above); from Eqn (9), we then obtain the density of dark energy in the local Universe as almost equal to the global dark energy density ρ_V. The accuracy of this estimate with all uncertainties taken into account is 20–30%. To within this accuracy, other flows (see above) yield the same result.

We see that flows around galaxy groups and clusters can serve (and are actually used) as a convenient natural tool to measure the local dark energy in the nearby Universe (also see [29–31]).

5. Numerical experiments

The origin and evolution of groups of galaxies surrounded by recession flows can be studied in the ΛCDM model using numerical simulations [32, 33] that reproduce the formation of cosmic structures in the process of hierarchical clustering of first subgalactic objects. In the numerical simulations in [32] using supercomputers at CSF (Finnish IT Center for Science), a many-body problem was solved, with the mass of each body equal to $10^6 M_\odot$, on a dark-energy background in a cubic volume 20 Mpc in size. The resulting synthetic velocity–distance diagram (in dimensionless variables) for galaxy groups with masses $\sim 10^{12} M_\odot$ is shown in Fig. 5.

Groups ($x < 1$) and flows ($x > 1$) can be clearly distinguished in Fig. 5. In the region occupied by the flow, all points turn out to cover a fairly narrow bundle of phase trajectories limited by two characteristic trajectories. The lower boundary corresponds to the minimal flow velocity

$$V_{\min}(R) = H_X R \left(1 + 2x^{-3} - 3x^{-2} \right)^{1/2}. \tag{10}$$

This trajectory corresponds to the minimum energy E_{esc} that is required for a particle to escape from the gravitational well of the group. It is known that in systems without dark energy, the minimal energy of an escaping particle is zero. But Eqn (9) involves both gravitational attraction of mass M and the antigravity due to dark energy comprised within the group volume ($R \leqslant R_{ZG}$). As a result, the threshold energy is negative:

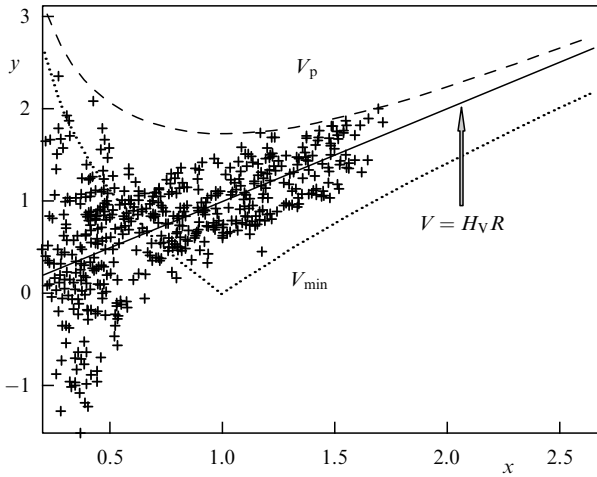$$E_{esc} = -\frac{3}{2} \frac{GM}{R_{ZG}} < 0. \tag{11}$$

Figure 5. Computer simulation of a synthetic diagram for galaxy groups and recession flows around them.

The decrease in the threshold energy in the presence of dark energy facilitates 'evaporation' of particles from a gravitationally bound system: the antigravitational force, which is directed outward from the system, stimulates the escape of particles beyond the critical surface with the radius $R = R_{ZG}$. This effect can be responsible for the formation of the observed flows [34–37].

The upper boundary of the model trajectory bundle corresponds to the trajectory of parabolic motion with zero mechanical energy ($E = 0$):

$$V_{\mathrm{p}}(R) = H_{\mathrm{X}} R \left(1 + x^{-1/2}\right). \tag{12}$$

A comparison of Fig. 5 and Figs 1–4 shows that both model and real recession flows strictly correspond to theoretical lower bound (10) on the flow velocity; most of the real trajectories and all the model ones do not cross characteristic trajectory (12).

Formulas (10) and (12) show that both limiting trajectories (as well as all trajectories of the flow in general) are pulled to the attractor $V = H_{\mathrm{X}} R$. The best agreement between model calculations and empirical plots (see Figs 1–4) is reached in the case where the local dark energy density is assumed to be equal to its global value (Fig. 5), such that $H_{\mathrm{X}} = H_{\mathrm{V}}$. Thus, the numerical experiments confirm the empirical "phase attractor method" (9), which is used to determine the local dark energy density.

6. Flows in the homogeneity cell

The theory of flows accelerated by dark energy antigravity (see Section 2) can be extended to a collection of groups (or even clusters) of galaxies on different space scales up to the size of the cosmic homogeneity cell (300–1000 Mpc) [37–39]. We consider a simple example: two groups of galaxies with masses M_1 and M_2 separated by a distance R recess with acceleration if the absolute value of Newton's gravitational attraction force, $-G(M_1 + M_2)/R^2$, is smaller than that of Einstein's repulsion force, $(8\pi/3)\rho_{\mathrm{V}} R$. This condition is satisfied when

$$R > R_{ZG} = \left[\frac{3}{8\pi\rho_{\mathrm{V}}}(M_1 + M_2)\right]^{1/3}. \tag{13}$$

Let the masses of the groups be $M_1 = M_2 = 3 \times 10^{12} M_{\odot}$. Then $R_{ZG} = 2$ Mpc. The nearby groups of galaxies are found at a distance of 3–4 Mpc from the Local Group center, and hence for any pair including the Local Group and one of the nearby groups of galaxies, condition (13) is satisfied. This suggests that two groups separated by 3–4 Mpc cannot be gravitationally bound, and their barycenters must recess with the (dimensionless) acceleration

$$Q(R) = \frac{\ddot{R}}{V_{\mathrm{V}} H_{\mathrm{X}}} = x - x^{-2} \simeq 1-2. \tag{14}$$

Similar accelerations were obtained in Section 4 for the Local flow of dwarf galaxies.

The treatment of two groups can be applied to triplets and higher multiplets of galaxies, for which acceleration criterion (13) can be rewritten in the form $\langle \rho_{\mathrm{M}} \rangle < 2\rho_{\mathrm{V}}$, where $\langle \rho_{\mathrm{M}} \rangle = (3/4\pi R^3) M_{\mathrm{tot}}$ is the mean density of dark matter and baryons inside the sphere with radius R comprising all systems of a given ensemble with a total mass M_{tot}. In the case of the largest ensembles with sizes comparable to that of the homogeneity cell, $\langle \rho_{\mathrm{M}} \rangle = 0.4\rho_{\mathrm{V}}$. Here, we have taken into account that the average density of dark matter and baryons on scales of 300 Mpc and beyond is about 28%, and the remaining 72% is the dark energy density. For these limit scales, the acceleration condition is well satisfied.

Observers have noticed for a long time that flows of galaxies on different scales have similar structures and properties within the homogeneity cell. According to [40], HST observations suggest that recession flows follow the Hubble law $V = H_{\mathrm{S}} R$ with $H_{\mathrm{S}} = 64 \pm 6$ km s^{-1} Mpc^{-1} on scales of 4–200 Mpc. Until recently, this fact looked enigmatic [40]. However, the presence of dominating dark energy solves this puzzle: dark energy antigravity controls the flow on almost all scales and tends to make them universal and correspond to a common phase attractor. When commenting on this result, the authors of [41] noted that "presently, this approach appears to have no viable alternative."

The argument about the universal phase attractor can be applied to the global expansion of the Universe. On long time scales, the cosmological expansion following the Hubble law $V = H(t) R$ tends to the asymptotic regime $H \to H_{\mathrm{V}}$. This suggests that the global flow has the same attractor as local flows. The modern value of the Hubble parameter $H_0 = 69 \pm 1$ km s^{-1} Mpc^{-1} [4] suggests that the observed state of the global flow differs from the asymptotic value H_{V} by only 15%.

The similarity of the global and local flows is also confirmed by the acceleration parameter. For the global flow, the dimensionless quantity

$$Q(t) = \frac{\ddot{a}}{V_{\mathrm{V}} H_{\mathrm{V}}} = \frac{1 + z_{ZG}}{1 + z} - \left(\frac{1 + z}{1 + z_{ZG}}\right)^{-2} \tag{15}$$

is a function of the time t or the redshift z. The redshift z_{ZG} at which the cosmological expansion changes from accelerating to decelerating is the analog of the zero-gravitation radius $R_{ZG} = 0.7$. The modern value ($z = 0$) of the cosmological acceleration parameter $Q(z = 0) = 1.4$ is close to the mean value of the acceleration parameter in local flows (see Section 4).

7. Conclusions

The discovery of dark energy in the local Universe and its local density estimation using highly precise observational data are the main result of our studies.

We predicted and discovered (using the same data) local space volumes in which Einstein's antigravity due to dark energy is stronger than Newton's gravity from dark energy and baryons; the nearest such region is located at a distance of 1–3 Mpc from the Milky Way.

A new type of cosmic motion — local recession flows accelerated by dark energy — has been discovered in the antigravity regions.

The local dark energy density measured in these volumes turned out to be equal (within measurement errors) to the global dark energy density. This provides a new independent empirical argument in favor of Einstein's antigravity as a universal phenomenon, in the same sense as Newton's gravity is universal. This result is in contradiction with theories of modified gravity, which treat dark energy as an effect that is possible only at large distances.

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Investigating supermassive black holes: a new method based on the polarimetric observations of active galactic nuclei

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1. Introduction

Presently, the existence of supermassive black holes (SMBHs) in active galactic nuclei (AGNs) is widely recognized. Rotating supermassive black holes are powerful engines responsible for energetic physical processes operating on a giant scale of the order of $10^{22}-10^{25}$ cm in galaxies. The characteristic phenomena related to SMBHs include radiation from the narrow emission line region ($\sim 10^{20}-10^{22}$ cm), broad emission line region ($\sim 10^{18}-10^{21}$ cm), region of nonthermal radiation ($\sim 10^{18}-10^{19}$ cm), and rapid X-ray variability region ($\sim 10^{13}$ cm). It is the central black hole that generates radiation in these space regions.

Active galactic nuclei hosting such SMBHs form a sufficiently homogeneous class of astronomical objects. The brightest AGNs have the bolometric luminosity $L_{bol} > 10^{47}$ erg s^{-1} and their masses can be as high as $\sim 10^{10} M_{\odot}$. Many AGNs demonstrate highly collimated outflows (jets) of matter moving with relativistic velocities normal to the disk. The size of the jets reach several dozen kiloparsecs, which exceeds the size of a galaxy.

Black holes are predicted by Einstein's General Relativity (GR). By definition, a black hole is a region of space from which no signal can escape. In other words, the escape velocity for a black hole is equal to the speed of light in the vacuum. The boundary of such a region is called the event horizon, R_{h}.

The characteristic size of a black hole is determined by the gravitational radius

$$R_{g} = \frac{GM}{c^{2}},$$

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