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GRAVITY-ANTIGRAVITY INTERPLAY ON Mpc SCALE

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ABSTRACT. It is demonstrated that the major physical features of the local expansion flows of galaxies are due to antigravity domination in the dynamics of the systems.

Keywords: Cosmology: dark energy, local expansion flows.

1. Introduction

In 1998-99, the discovery of dark energy (Riess et al., 1998, Perlmutter et al. 1999) opened new wide prospectives in cosmology (see, for instance, Byrd et al. 2012, and references therein). With dark energy, a new "antigravity" force has entered the cosmic scene, and it has been soon realized that the gravity-antigravity interplay is the major dynamical factor that controls the global cosmological expansion at distances of 1 000 Mpc and more. The astronomical findings made near the cosmic horizon have provided us as well with new reliable grounds for better understanding of astronomical phenomena at relatively small, non-cosmological distances. In this way, it was found that the local expansion motions of galaxies at distances of the order of $\sim$1 Mpc are also ruled by gravity-antigravity interplay (Chernin 2001, 2008, 2013 and references therein). Local dynamical effects of dark energy are in the focus of our discussion here.

2. Local dark energy

Due to the cosmological discoveries (Riess et al., 1998, Perlmutter et al. 1999), we know now that dark matter and dark energy are the basic components of the present-day Universe. The fractions of dark energy and dark matter in the entire mass/energy balance of the observed Universe are about 70 and 26%, respectively. The usual (baryonic) matter constitutes about 4%. Dark matter and dark energy do not emit, absorb, or scatter light. They manifest themselves only by their gravity and antigravity, correspondingly. Antigravity was predicted theoretically by Einstein in 1917, when he introduced the cosmological constant Λ to the equations of General Relativity. This constant represents dark energy and antigravity produced by dark energy in physics and cosmology. In 1922-24, the possible existence of Einstein's antigravity was taken into account in Friedmann's cosmological model where Λ was treated as a theory empirical parameter which should be measured in astronomical observations.

The modern cosmological data show that antigravity is stronger than gravity in the observable Universe as a whole. Because of the antigravity domination the global expansion proceeds with acceleration: the relative velocities of receding galaxies increase with time. Antigravity dominates at present and during the last 7 Gyr of the cosmic evolution; in the unlimited future, antigravity domination will be even stronger than now.

Do dark energy and Einstein's antigravity exist not only at the global distances where it was initially discovered, but also at relatively small distances around the Milky Way Galaxy?

It comes from General Relativity that Einstein's antigravity is a universal (in the same sense as Newton's gravity) physical factor acting actually everywhere in space, on both global and local astronomical scales. The density of dark energy is the same everywhere in the Universe and it is given by Einstein's cosmological constant alone: $\rho_\Lambda = \Lambda/(8\pi G)$, where G is the Newtonian gravitational constant; the speed of light $c = 1$ here; the dark energy density ρ_Λ is positive and its currently adopted value $\rho_\Lambda \simeq 0.7 \times 10^{-29}$ g/cm^3.

On these physical grounds and with the use of the recent most precise observational data on the local expansion flows and their environments (Karachentsev 2005, Karachentsev et al. 2003, 2006, 2007) , we worked out a theory model which is a local counterpart of Friedmann's cosmological model. For our model, we adopt from General Relativity the macroscopic description (Gliner 1965) of dark energy as a vacuum-like continuous medium of perfectly uniform constant density with the equation of state

$$p_\Lambda = -\rho_\Lambda. \quad (1)$$

Here p_Λ is the dark energy pressure.

We take from General Relativity also an indication that the "effective gravitating density" is determined by both density and pressure of the medium:

$$\rho_{eff} = \rho + 3p. \quad (2)$$

The effective density of dark energy, $\rho_\Lambda + 3p_\Lambda = -2\rho_\Lambda < 0$, is negative, and it is because of this sign minus that dark energy produces not attraction, but repulsion, or antigravity.

Finally, we borrow from General Relativity the Köttler exact solution for a spherically-symmetrical spacetime (known also as the Schwarzschild-de Sitter spacetime). The solution gives the metric outside a spherical matter mass M imbedded in the dark energy of the density ρ_Λ. We use the solution in the weak field approximation, when deviations from the Galilean metric are small; correspondingly, the velocities of the local motions are small compared to the speed of light and the spatial differences of the gravity-antigravity potential are small (in absolute value) compared to the speed of light squared. Then the Köttler solution is reduced to the Newtonian description in terms of the gravity-antigravity potential U:

$$Y^{1/2} \simeq 1 + U, \quad U(R) = -\frac{GM}{R} - \frac{4\pi G}{3}\rho_\Lambda R^2. \quad (3)$$

In this approximation, the force (per unit mass) comes from Eq.6:

$$F(R) = -\frac{dU}{dR} = -\frac{GM}{R^2} + \frac{8\pi G}{3}\rho_\Lambda R. \quad (4)$$

We see in the rhs here the sum of the Newtonian force of gravity produced by the mass M and Einstein's force of antigravity produced by dark energy (the forces are for unit mass, i.e. acceleration). It is also seen from Eq.4 that gravity dominates at small distances from the mass M, while antigravity is stronger than gravity at large distances. Gravity and antigravity balance at the distance

$$R = R_\Lambda = (\frac{M}{\frac{8\pi}{3}\rho_\Lambda})^{1/3} \quad (5)$$

which is the radius of the "zero-gravity sphere" (Chernin 2001).

The zero-gravity radius R_Λ appears as the local spatial counterpart of the "zero-gravity moment" in the global expansion of the Universe which occurred about 7 Gyr ago.

3. Very Local Flow: a model

The nearest flow of galaxies is observed at the distances of 1-3 Mpc from the barycenter of the Local Group. This "Very Local Flow" (hereafter VLF) has been well studied in the recent observations (Karachentsev et al. 2003, 2006, 2007, and references therein). Basing on these data and the theory relations of Sec. 2, we suggest a model of gravity-antigravity interplay which controls the dynamics of local flows of expansion (Chernin 2001, 2008, 2013). In application to the VLF, our model treats the Local Group as a spherical mass $M = (3 \div 4) \times 10^{12} M_\odot$ with a radius $\simeq 1$ Mpc. According to Eq.5, the zero-gravity radius of the group proves to be $R_\Lambda = 1.1 - 1.3$ Mpc which is near its observed radial size. The model treats galaxies (dwarfs) of the expansion flow around the group as "light (test) particles" moving along radial trajectories in the force field produced by the matter mass M of the group and the dark energy uniform background in which both group and outflow are imbedded.

In the volume of the group, $R < R_\Lambda$, the gravity of the matter mass M is stronger than the antigravity produced by the dark energy background in the same volume. Because of this, the group is quasi-stationary and gravitationally bound. Outside the group, in the VLF area, $R > R_\Lambda$, the antigravity of dark energy dominates. Consequently, the VLF particles are unbound and moving with acceleration away from the group. The particle dynamics is ruled by the equation of motion which follows from Eq.4:

$$\ddot{R}(t) = -\frac{GM}{R^2} + \frac{8\pi G}{3}\rho_\Lambda R. \quad (6)$$

The sum in the rhs of Eq.10 is positive and growing with the distance at $R > R_\Lambda$, so that the acceleration of the particles is increasing with the distance.

The first integral of the equation of motion is the mechanical energy conservation law:

$$\frac{1}{2}\dot{R}^2 = \frac{GM}{R} + \frac{4\pi G}{3}\rho_\Lambda R^2 + E, \quad (7)$$

where $\dot{R} = V$ is the particle radial velocity, E is a constant which is the total mechanical energy of the particle.

Eq.7 gives the radial phase trajectories of the accelerating flow in the velocity-distance space. As we may see, the model is completely compatible with the data by Karachentsev et al. (2006, 2006, 2007). It may also be seen from Eq.7 that the phase trajectories of the flow converge to the phase attractor of the system which is the straight line $V = \dot{R} = H_\Lambda R$. Here $H_\Lambda = (\frac{8\pi}{3}G\rho_\Lambda)^{1/2}$ is the "asymptotic Hubble factor" which is a universal constant given by the dark energy density only: $H_\Lambda = 61$ km/s/Mpc. The attractor indicates the evolutionary trend of the system: the flow gains its nearly linear kinematic structure with the growing distance.

Note that the asymptotic expansion rate $H_\Lambda = (\frac{8\pi}{3}G\rho_\Lambda)^{1/2}$ is the same for both global cosmology and our local theory model.

Accelerating expansion flows of galaxies which are similar to the Very Local Flow are also found around several nearby groups and clusters of galaxies

(Karachentsev et al. 2007, Chernin 2013). Their spatial physical scales differ in an order of magnitude, from ~ 1 to ~ 10 Mpc. Nevertheless they all reveal the same nearly linear velocity-distance kinematic structure with time-rates about the Hubble's global factor. They constitute a new and rich class of extragalactic systems whose observational appearance, kinematic structure and evolution are completely due to the antigravity domination in their internal dynamics.

4. Conclusion

The world of galaxies is a grandiose expansion flow studied first by Vesto Slipher, Ernst Öpik, George Lemaître and Edwin Hubble in 1910-20s. The most impressive discovery of that times is the linear velocity-distance relation, $V = HR$, known as Hubble's law of cosmic expansion, where V is the receding velocity of galaxies at the distance R and H is the "Hubble's factor" which is the expansion time-rate. Found at local distances of 1-30 Mpc, Hubble's law was widely interpreted as the major property of the whole Universe. Meanwhile cosmological implications based on Friedmann's uniform model are valid only for global distances of the order of 1 000 Mpc and larger where the spatial distribution of galaxies is statistically uniform. This important point was made by Sandage et al. (1972, 2006) and Zeldovich (1978, 1993) who seen Hubble's law at local distances "mysterious" and "surprising".

In this paper, the physics which is behind these systems is clarified. We show that the structure and evolution of the local flows are due to the gravity-antigravity interplay in their dynamics.

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References

Byrd G.G., Chernin A.D., Teerikorpi P., Valtonen M.J.: 2012, *Paths to Dark Energy.* De Gruyter Pubs., Berlin/Boston.
Chernin A.D.: 2001, *Physics-Uspekhi,* **44,** 1099.
Chernin A.D.: 2008, *Physics-Uspekhi,* **51,** 253.
Chernin A.D.: 2013, *Physics-Uspekhi,* **56,** 741.
Gliner E.B.: 1965, *JETP,* **49,** 542.
Karachentsev I.D.: 2005, *Astron. J.,* **129,** 178.
Karachentsev I.D., Chernin A.D., Teerikorpi P.: 2003, *Astrophysics,* **46,** 491.
Karachentsev I.D., Tully R.B., Dolphin A., et al.: 2007, *Astron. J.,* **133,** 504
Karachentsev I.D., Dolphin A., Tully R.B., et al.: 2006, *Astron. J.,* **131,** 1361.
Perlmuter S., Aldering G., Goldhaber G., et al.: 1999, *ApJ,* **517,** 565.
Riess A.G., Filippenko A.V., Challis P., et al.: 1998, *AJ,* **116,** 1009.
Sandage A., et al.: 1972, *Astrophys. J.,* **172,** 253.
Sandage A. et al.: 2006, *Astrophys. J.,* bf 653, 843.
Zeldovich Ya.B.: 1978, in *"The Large Scale Structure of the Universe"*, eds. M. Longair and J. Einasto, *IAU,* p.409
Zeldovich Ya.B.:1993, *Selected Works,* **vol.2,** *Particles, Nuclei, and the Universe,* Princeton Univ. Press, p. 123