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Satellite system of M31 and dark energy

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Abstract

The structural features of the Andromeda satellite galaxy system are examined. Their configuration clearly contradicts the assumption that they formed randomly from a uniform distribution of primordial matter. In contrast, we propose a scenario that emerges when the evolutionary role of dark energy is taken into account. The disintegration of a protogalactic baryonic clump of matter is proposed as the primary mechanism for the formation of all Local Group galaxies. M31, from which the Milky Way separated, was most likely the first of the two giant galaxies in the Local Group to form. This is supported by the fact that M31 is larger than our galaxy, the diameter of its satellite system is larger than that of the Milky Way, and the known flattened satellite structures of both galaxies are aligned parallel to the line connecting their parent galaxies. As a supporting argument, the blueshift of the spectra of Andromeda's satellites is shown to be inversely correlated with their luminosity.

Keywords: *Dark energy, Local Group of galaxies, Andromeda galaxy, satellite system: structural features, formation scenario.*

1. Introduction

In our previous work, we examined the blueshift of the neighboring galaxy M31. To this end, we used the results of analyses on the physical consequences of baryonic matter interacting with dark energy carriers. This approach is based on the following well-known observational data and laws of physics—the building blocks upon which the entire paradigm is built. The first building block is the acceleration of the expansion of the Universe and the introduction of the concept of dark energy into science. The second building block is the inevitable recognition of the interaction between the dark energy carrier and baryonic matter, which became the key to their discovery on cosmological scales. The third important link is the laws of thermodynamics, which govern energy exchange processes in interactions among various physical systems. Since all baryonic objects, starting from baryons themselves and atomic nuclei and up to stars and galaxies, exist as a whole due to negative total energy, such interactions lead to the transfer of some non-zero amount of energy to baryonic objects. At the macro and mega levels of the cosmic hierarchy, this additional energy increases the kinetic energy of the corresponding system. This very effect is clearly seen in the universe's expansion behavior. In the microworld, it simply reduces the binding energy, increasing therefore the baryonic and nuclear masses. Mass growth at the nuclear level leads to the spectral blueshift for the corresponding energy terms. The statement formulated here and the linked predictions are based on the interpretation of physical laws. No laboratory experiment can reveal this effect if the process is slow and beyond the possibilities of modern measuring methods. However, cosmic distances and time intervals enable one to trace the predicted effects, if any. It is easy to understand that the rate of the evolutionary change of baryonic matter depends on the ratio of dark energy to the object's maintenance energy. The higher this ratio, the more intensive the evolution process. In our view, the most significant result of the study of the rate of evolution is the conclusion that within a family of physically similar objects, the massive ones evolve more slowly. More precisely, the evolution rate is lower for more massive objects, provided that the average density is constant or at least decreases more slowly than the inverse square root of the mass. This estimate was obtained for spherical objects, but it holds to some accuracy for other configurations as well. Previously, we compared the masses and sizes of our galaxy and M31 to show that M31 is twice the size of the Milky Way with nearly the same mass. This means, according to the criterion above, M31 is evolving faster than our galaxy. Therefore, assuming these two galaxies formed simultaneously or resulted from

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the fragmentation of a parent object, we can conclude that M31 has advanced further in its evolutionary history than our galaxy. M31's longer evolutionary path is also supported by its lower activity, lower rate of star formation, and nova explosions. The physical mechanism presented here explains the blueshift of M31 without involving the Doppler effect and the galaxy's movement toward us. In this paper, we study the satellite system of the Andromeda galaxy to find additional facts backing our concept.

2. The structural features of the Local Group of galaxies.

The bulk of the Local Group of galaxies is concentrated in its two main members, the Milky Way and M31. Traditionally, this group, like other groups and galaxies, is believed to have formed by successive mergers of dwarf galaxies formed immediately after the Big Bang. The observed blueshift in M31's spectrum is interpreted as its motion toward our galaxy, with an inevitable future collision that will form a single supermassive galaxy that will engulf all dwarf galaxies, sooner or later. However, studies show (Harutyunian, 2024) that dark energy radically changes the adopted interpretation. And here, one circumstance comes to the forefront, one that is almost always neglected for some unknown reason. This circumstance is that the carrier of dark energy, whatever it is, interacts with baryonic matter. It is precisely the discovery of Corollary A that, since dark energy is purely positive, during such interactions, baryonic structures, which have negative total energy at all hierarchical levels, gain a non-zero amount of energy. Moreover, since the interaction is continuous and energy is cumulative, it accumulates in these structures over time. It is obvious, from a general physical point of view, that injecting excess energy into any equilibrium baryonic structures renders them nonequilibrium. Adding positive energy to the energy balance of a given structure primarily reduces its binding energy. Gravitational systems, including clusters of galaxies and planetary systems, must expand. At the level of baryons and atomic nuclei, a decrease in binding energy reduces the mass defect and increases the mass. The transformation occurring in the microworld ultimately manifests itself as an increase in the mass of all baryonic objects and the entire baryonic universe. The increase in mass and decrease in binding energy ultimately require energy release by ejecting clumps of matter and/or dividing the object with excess energy into pieces. A similar process continues for each decaying part. Research shows that the satellites of both our Galaxy and the Andromeda Galaxy are not randomly distributed in space, contrary to predictions of the prevailing cosmological theories. Their distribution is highly anisotropic, forming ordered structures. In both cases, dwarf galaxies orbit their parent galaxies synchronously within thin disks (Pawlowski, 2018). A strictly anisotropic distribution of satellites was first discovered in our Galaxy in mid 70s of the last century (Kunkel & Demers, 1976, Lynden-Bell, 1976). The first attempt to model the Milky Way's satellite system using cosmological models was made based on the then-known positions of 11 satellites (Kroupa et al., 2005). The authors concluded that the satellite system is strictly aligned in a narrow plane oriented nearly perpendicular to the Milky Way's disk. After considering the positions of all known satellites, the authors rejected with 99.5 percent confidence the hypothesis that the satellite positions could be derived from an isotropic distribution. The mentioned detailed analysis of the spatial satellites of the Milky Way showed that these galaxies are better understood as precursors of the so-called dark matter configurations (Kroupa et al., 2005). As model calculations show, such well-defined, extensive, and long-lived thin satellite planes are extremely unlikely in standard cosmological simulations of cold dark matter. That is, the authors believe that they cannot be considered dwarf galaxies of cosmological origin, in which dark matter dominates. Moreover, studies of the spatial distribution of all known satellites, including the newly revealed fainter ones, again confirmed a flat distribution (Metz et al., 2007, Pawlowski et al., 2012). In the paper (Ibata et al., 2013), the authors have concluded that a subgroup of Andromeda's satellites, comprising approximately 50 percent of the entire population, forms a flat configuration (99.998 percent significance). The diameter of this formation is approximately 400 kpc, and the thickness is no more than 14.1 kpc (99 percent confidence level). The radial velocities of these satellites have the same direction of rotation relative to their parent galaxy. Remarkably, the revealed plane has a unique orientation relative to the Milky Way. It (approximately) includes the pole of our Galaxy's disk, as well as the Milky Way's position vector relative to Andromeda. Figuratively speaking, it is extremely thin, almost perpendicular to the Milky Way's disk, and extends precisely in its direction. A recent study (Conn et al., 2013) examined the spatial structure of the M31 satellite system. Using a sample of 27 M31 satellites and M31 itself, they concluded that the satellite distribution, when considered as a whole, is no flatter than would be expected from a random distribution of equal sizes. However, the disk consisting of 15 satellites turned out to be very significant and strikingly thin, with a root-mean-square thickness of only 12.3 kpc. This disk is oriented approximately edge-on to the

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Milky Way. It turned out that this disk is also roughly orthogonal to the disk-shaped structure in the Milky Way satellite system and closely corresponds to the giant stellar stream of M31. Analysis of the observed asymmetry in the spatial distribution of M31 satellites shows that it is significantly greater than would be expected from a random distribution. Moreover, 20 of the 27 satellites appear to be on the Milky Way side. This remarkable asymmetry is most pronounced in the subset of satellites that form a thin disk. Since the entire scientific methodology of modern cosmology and cosmogony is built on two well-known hypotheses: the Kant-Laplace concept of the formation of baryon structures and Lemaitre's idea of the primeval atom (dubbed the Big Bang thanks to Fred Hoyle's sarcasm), the interpretation of the formation of any cosmic configuration is inevitably based on them. It is this approach that leads to many paradoxes when considering real cosmic structures and their coexistence at different eras of cosmic history. Each JWST discovery, for example, dating back to the early stages of the universe's evolution, necessitates introducing some new "free parameters" to reconcile prevailing concepts with observational surprises. We observe the same situation in relation to the aforementioned disks and their orientations. There is no doubt that the random formation of such "coordinated" kinematic structures from independently generated fragments within the halos of two massive galaxies is extremely unlikely. It requires a specifically developed scenario. Such structures can form if they are already encoded in the properties of the material they are composed of, which previously had been united within a single body with a strict internal structure. In a previous paper (Harutyunian & Torosyan, 2024), we demonstrated that observational data on the physical parameters of M31 are consistent with the hypothesis of baryonic matter evolution under the influence of dark energy. The most significant conclusion was that M31 may actually exhibit a Doppler redshift relative to the Milky Way due to its removal, and the observed blueshift in its spectrum may be the result of an evolutionary effect superimposed on the Doppler effect. This could occur if the baryonic matter in our neighboring galaxy has undergone a longer evolution path than that of our galaxy. Since M31 is approximately 2.5 million light-years away, we see the evolutionary state of its baryonic matter at that distance. On the other hand, according to Hubble's law, at that distance it should have had a recession velocity of approximately 50 km/sec. Although we believe this value may be reduced, it is nevertheless clear that, in that case, for the observed velocity of -122 km/sec, M31's evolutionary blueshift should be at least -170 km/sec. Considering also that the evolutionary shift per million years is approximately -2 km/sec (see Harutyunian 2021), it turns out that in terms of the evolution of baryonic matter, M31 is 85 million years ahead of our galaxy. This is a relatively small value compared to the ages of M31 and the Milky Way, but its "fingerprints" are nevertheless clearly visible in the spectrum of the neighboring galaxy.

3. Correlation between satellites' stellar magnitudes and their blueshifts.

As noted in the previous paragraph, within the framework of the considered paradigm of the evolution of baryonic matter and the formation of cosmic structures under the influence of dark energy, any group of objects is formed as a result of the decay of a clot of matter, which is a proto-object of a higher hierarchical class. This proposal diametrically contrasts with the generally accepted scenario of object formation through mergers at all levels, beginning with the synthesis of heavy atomic nuclei through fusion, stars, and planets—due to the compression of gas and dust clouds—and galaxies through merging and cannibalism. The decay of baryonic clumps is a consistent process at all hierarchical levels of the universe. As a result of this decay, an object of a higher hierarchical class can form objects of its own class and lower classes. Moreover, the distribution of the decay products across classes is governed by the parent object's structural features. The above, if correct, means that statistically less massive objects are either the same age as more massive ones or younger. This means that their evolutionary path is either the same length as that of massive objects or shorter. However, on the other hand, the rate of evolution is greater for less massive objects since evolution is more difficult at larger values of the following parameter introduced as a measure of stability (MoF, see, for example, (Harutyunian, 2024):

$$\eta \sim \left(M\rho^2\right)^{2/3} \sim \left(\frac{M}{R}\right)^2, \tag{1}$$

where M, ρ and R are mass, density, and radius of an object. Evidently, the MoF gets larger with mass if the mass of an object grows faster than its radius. Let's apply the above-mentioned to the system of the Andromeda galaxy. We previously showed that interaction with a dark energy carrier increases the nuclear mass of atoms. Therefore, one of the most easily detectable evolutionary changes should be a blueshift of

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the object's spectrum, according to the Rydberg relation:

$$\frac{1}{\lambda_{mn}} = RyZ^2\left(\frac{1}{m^2} - \frac{1}{n^2}\right) \tag{2}$$

where

$$Ry = \frac{\mu e^4}{8\varepsilon_0^2 h^3 c} \tag{3}$$

is the Rydberg constant and $\mu$is the derived mass of the atomic nuclei and electron. The remaining designations are also generally accepted. Since, according to relation (1), low-mass galaxies should evolve faster than more massive ones, this effect should be more pronounced for them. However, it should be taken into account that, within this paradigm, satellites form much later than their host galaxies, which, for a host galaxy much more massive than its satellite, provides sufficient time for evolution. However, even in this case, given the enormous difference between masses, we expect the effect to be statistically visible in our small sample. That is, we expected a statistically significant gradient of increasing blueshift with decreasing luminosity (mass) of the galaxies in our sample. For our statistical analysis, we use the richest data on the galaxies of the Local Group, which are presented in the paper published one and a half decades ago (McConnachie, 2012). The data pertain to all galaxies in the Local Group, 33 of which are designated as true members of the M31 family, including the Andromeda Galaxy itself. Of these galaxies, only 22 have the required parameters—absolute magnitudes and galactocentric velocities. Namely, these galaxies were used. We first directly calculated the correlation coefficient between these parameters without any preliminary sample processing. A simple calculation yielded a value of -0.44 for this coefficient, which, as expected, is negative but cannot be considered sufficiently convincing. When M31 is excluded from the sample, the desired coefficient increases up to -0.5. Clearly, there may be a spread in the satellites' ages, which makes it difficult to detect the underlying trend, if any. Therefore, our next step was to average the magnitudes and corresponding velocities over intervals of one magnitude. This immediately revealed a more pronounced correlation. In the first case, when the parent galaxy is taken into account, the correlation coefficient amounts to -0.64. In the second case, it increases to -0.83, which indicates an unconditional correlation. Moreover, the dispersion of velocities increases for the faintest satellites. In the context of the concept we are considering, this means that their evolutionary paths are of completely different lengths, or, in other words, they are of completely different ages. It is noteworthy that the correlation we obtained here repeats the one we had found earlier for the Virgo and Fornax clusters of galaxies (Harutyunian et al., 2019). The analogous analyses for the mentioned clusters have given -0.90 and -0.64, respectively. Interestingly, the correlation coefficient for the mentioned clusters becomes much more significant when calculated only for galaxies with velocities below the cluster's average. It has a very intriguing physical meaning that follows from the applied physical mechanism. The fact that some regularity, which was found for clusters with statistically significant samples of objects, is sharply exhibited in a much smaller sample speaks in favor of the regularity's universal nature.

4. Conclusion and perspectives.

We continue studies of the manifestation of baryonic matter evolution using observational data of objects and systems of various hierarchical levels of the Universe. The Andromeda galaxy satellite system is a baryonic structure, possessing several features unexpected from the traditional viewpoint. This makes this system a suitable "laboratory" for testing theoretical predictions and hypotheses. Many recently discovered structural features pose complex challenges for researchers and are considered unique due to the lack of analogs. They will remain so until other similar structural features are discovered, definitively demonstrating their natural existence within the new paradigm of baryon structure formation. This paper analyzes two features of the Andromeda Galaxy's satellite system. The first has been studied in detail by many researchers. This feature is the flat structure of the satellite system, which is oriented toward the Milky Way. Moreover, most of the satellites are located on the side of our galaxy relative to M31. Clearly, a random distribution of satellites in circumgalactic space cannot explain such a low-entropy structure. Therefore, the researchers who discovered and are studying this still unique structure are developing various intricate scenarios for interpreting it within the framework of traditional extragalactic cosmogony. Our approach to the formation and evolution of cosmic structures is quite different from the prevailing hypothesis. It is based on observational data and a consistent application of the laws of modern physics. This approach inevitably

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leads to the conclusion that, at all hierarchical levels of the universe, baryonic structures interact with the carrier of dark energy, thereby continuously receiving energy, which makes these structures unstable and simultaneously increases their mass. This approach returns us to Ambartsumian's cosmogonic concept (Ambartsumian, 1961), where the main direction of evolution is decay and expansion. This concept has been largely forgotten today for two reasons. The first is the impossibility of the stable existence of superdense matter of the required mass. The second concerns the source of the required energy. In the summary of the Santa Barbara Conference on the "Instability of Systems of Galaxies", devoted to Ambartsumian's hypothesis, it is mentioned: "The first is the mechanism whereby such tremendous amounts of energy can be released - energy equivalent roughly to the total annihilation of a globular cluster, or to the radiation from a million stars over their whole lifetimes" (Neyman et al., 1961). Now, 65 years later, the storage of this energy is widely known. That is dark energy. Within our paradigm, the entire Local Group of galaxies has been formed as a result of the disintegration of a single clump of baryonic matter and the successive ejections of secondary objects (satellites) from the two most massive objects (M31 and our Galaxy). We reached this conclusion (Harutyunian & Torosyan, 2024) by hypothesizing that the blueshift of M31's spectrum is not Doppler-induced but is evolutionary. This would imply that the Andromeda Nebula has undergone a longer evolutionary path than our Galaxy. The data presented in the previous paper, at least, do not contradict our concept. Here, we further develop our idea, arguing that the two main galaxies of the Local Group resulted from the disintegration of a proto-object into two parts. A more probable scenario is that the clump of matter from which the Milky Way formed was ejected from the core of M31. The following facts support this assertion. Not only is M31 twice the size of our galaxy, but the diameter of its satellite system is also at least twice that of the Milky Way. Therefore, it's not surprising that both planes of these systems are aligned with the line connecting the nuclei of the two galaxies. We will discuss this in more detail in a future paper.

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