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The M31 and the Milky Way: Evolutionary History of a Galaxy Pair

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Abstract

The possibility of attaining a velocity of 110 km/s through the mutual gravitational acceleration of M31 and the Milky Way is examined. It appears that they could not achieve this mutual velocity at their current separation if the total mass is less than 1.1 trillion solar masses. The maximum stellar mass of the galaxies appears to be no more than 200 billion solar masses, which is insufficient; therefore, the concept of "dark matter mass" is traditionally invoked. It is noted that the estimated dark matter mass for the Milky Way is significantly higher than that for M31. This is interpreted as an indication that the estimated dark matter mass increases as the stellar component deviates further from an equilibrium state. This also suggests that the Milky Way is younger than M31, which in turn supports the idea that the blueshift of M31 is of an evolutionary nature. Consequently, a hypothesis is proposed: the pair of galaxies may have formed through the "budding" of the Milky Way from the core of M31. To support this hypothesis, the authors present evidence and cite the HST-1 knot within the jet of M87 as an example of this process occurring during the early stages of evolution.

Keywords: *Dark energy, Local Group of galaxies, Andromeda galaxy: blueshift, evolution of matter, formation scenario.*

1. Introduction

The Andromeda Nebula has long served as a primary cosmic laboratory for testing cosmogonic concepts in extragalactic astronomy. Its relatively short distance—by cosmological standards—has allowed for detailed study and comparison with the Milky Way. Their similar morphological class makes direct comparison of their physical characteristics easy. Furthermore, the general empirical finding that, in binary galaxy systems, approximately 75 percent of the components share the same morphological class (Karachentsev, 1972) provides a useful framework for studying this local pair.

The observed blueshift of M31 is traditionally interpreted as a Doppler effect, implying that this neighboring galaxy is moving toward us. We have recently proposed an alternative, evolutionary explanation for this blueshift (Harutyunian & Torosyan, 2024). This issue involves two aspects. The first concerns how plausible it is that this galaxy is approaching the Milky Way at 110 km/s and how this fits the standard Big Bang scenario. The second concerns the observational and theoretical foundations of matter evolution —specifically, our conclusion that the Andromeda galaxy has undergone a longer evolutionary process than the Milky Way.

Thus far, we have focused primarily on the second aspect, seeking to substantiate our perspective by comparing facts about the components of this pair. In this discussion, we will also examine the conventional model of this approach and its internal consistency.

2. The hypothesis of approach

Let us consider the hypothesis that the observed blueshift manifests actual motion. In this context, we can consider several possible scenarios for the origin of the observed configuration. For instance, one could assume these galaxies formed independently at some distance apart and later moved closer together. At the time of their formation, these protogalaxies might—or might not—have possessed an initial relative velocity.

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In another version, they could have formed simultaneously within the same volume of space, moved apart to a distance determined by their initial kinetic energy, and then approached each other again.

To select an appropriate scenario, all data relevant to the formation of this configuration must be examined in detail. Dynamic, kinematic, and configurational features are all significant. We shall therefore begin with a simple distance calculation: the Andromeda Galaxy—initially at rest—could have attained a speed of 110 km/s at a separation of 775 kpc under the influence of gravitational acceleration (within the Milky Way's reference frame). Let R_0 denote the initial distance, while M_A and M_{MW} are the masses of the Andromeda Galaxy and Milky Way, respectively. The law of conservation of energy then yields:

$$\frac{v_1^2}{2} = G(M_A + M_{MW})\left(\frac{1}{R_1} - \frac{1}{R_0}\right), \tag{1}$$

where $v_1 = 110km/s$, and $R_1 \sim 775kpc = 2.39 \times 10^{19}km$.

From the relation (1), one can find

$$\frac{1}{R_0} = \frac{4.18}{10^{23}}\left(1 - \frac{10.8}{a+b}\right), \tag{2}$$

where $R_0$is given in meters, and $M_A(M_{MW}) = 10^{11}M_\odot a(b)$. It is evident from (2) that R_0has a real value only if $a+b > 10.8$or $M_A + M_{MW} > 1.08 \times 10^{12}M_\odot$. If we consider only the baryonic mass of these galaxies, it is significantly lower. The stellar mass of the M31 galaxy is estimated at approximately $10 \div 15 \times 10^{10}M_\odot$, while our galaxy's mass is about half that, at $4.0 \div 6.0 \times 10^{10}M_\odot$. This estimate is also roughly consistent with the ratio of the galaxies' linear dimensions.

On the other hand, the situation changes radically if one compares the mass of the hypothetical dark matter within the galaxies under consideration. Estimates based on the assumption that these galaxies are in equilibrium indicate that the mass of dark matter in the M31 galaxy ranges from $0.8 \div 1.1 \times 10^{12}M_\odot$, whereas in the Milky Way, it is between $0.9 \div 1.4 \times 10^{12}M_\odot$. In other words, the concentration of dark matter per unit volume in our Galaxy is approximately an order of magnitude higher than in M31. Let us examine this in more detail. The answer is clear: the Milky Way is further from equilibrium than the M31 galaxy. This is consistent with our assertion that the activity in our Galaxy is higher than in M31. Indeed, given the higher activity, we previously concluded that our Galaxy is younger than the Andromeda galaxy (Harutyunian & Torosyan, 2024).

We recently showed that dark energy eliminates the need for dark matter as an adjustable free parameter (Harutyunian, 2024). Systems of cosmic objects cannot remain in equilibrium in the presence of dark energy; instead, they all undergo expansion. This explanation is physically sound and self-consistent. The carrier of dark energy, which interacts with baryonic matter, continuously transfers energy to any given baryonic configuration, a consequence of the laws of thermodynamics. This also sheds light on why the search for dark matter particles has been so exhaustive yet unsuccessful. The failures of this endeavor are not due to technical or methodological limitations; rather, they stem from the fact that dark matter does not exist.

Indeed, analysis of the Milky Way's observational data reveals that it is expanding. While similar data for M31 are not yet available, its interaction with dark energy is identical. Obviously, evidence of its expansion will emerge as observational technology and methods are refined to the necessary precision.

Returning to the issue at hand, we point to another discrepancy connected with the configuration of their satellite systems. Over the last decade and a half, details have emerged regarding the anisotropic distribution of satellite systems around both the Andromeda Galaxy and the Milky Way. The planes in which these satellites move have been reliably determined. Roughly half of the known M31 satellites lie in a thin, coherent plane called the Great Plane of Andromeda (GPoA) (Conn et al., 2013, Ibata et al., 2013). The classical dwarf satellites of the Milky Way are distributed in a thin plane called the Vast Polar Structure (VPOS) (Pawlowski & Kroupa, 2013, 2020). In both galaxies, the satellites' planes are oriented nearly perpendicular to the galactic disk.

However, the most striking fact is that the satellite planes of the Milky Way and M31 are themselves not randomly oriented inside the Local Group. Another remarkable result concerns the line joining the centers of the Milky Way and Andromeda. The connecting line lies almost within the GPoA plane. This picture suggests that the formation of this plane was, to one degree or another, determined by both galaxies acting together.

3. Evolution of matter

Our approach differs fundamentally from the conventional one. Some studies on the interaction between the dark energy carrier and baryonic matter suggest that this interaction accumulates energy within baryonic objects. This excess energy drives the evolution of baryonic objects at all hierarchical levels—affecting everything from atomic nuclei and baryons to elementary particles. Such evolution can manifest in various observable ways, including nuclear fission, the ejection of elementary particles, and cluster decay. In this context, we are primarily interested in the increase in atomic nuclei's mass, which in turn results in a spectral blueshift.

The same interaction and energy accumulation within mega-objects drive fission and the ejection of matter—much like processes observed in radioactive nuclei. Furthermore, since massive objects must exhibit a negative gradient in the evolutionary age of their baryonic matter (Harutyunian, 2024), the ejected clumps of matter are at a more advanced stage of evolution than the parent galaxy. Consequently, the parent's spectrum should be blueshifted for an observer located in the daughter object. In our view, this is how our own Galaxy was formed. Figuratively speaking, it "budded off" from the Andromeda Galaxy as a result of matter ejection from the parent's nucleus.

Let's consider this scenario in the light of the relevant observational data. We have previously noted that the Milky Way is more active than the Andromeda Galaxy (M31): it has more intense star formation and more frequent nova events (Harutyunian & Torosyan, 2024). Furthermore, the estimated dark matter mass, normalized to the observed stellar mass, is three times higher in the Milky Way than in M31. If our conclusions are correct—namely, that the estimated mass of dark matter increases as a galaxy deviates further from equilibrium—then this result also suggests that the Milky Way is younger than the Andromeda Galaxy. This is further supported by the lower specific frequency of the Milky Way globular clusters (0.5, compared to 0.86–1.2).

In the above scenario, the observed configuration of the satellite galaxies' planes also becomes natural. If the Milky Way was indeed "budded off" from the nucleus of M31 and is moving away from it, then the line connecting the two galaxies takes on special significance. Even without a precise understanding of the mechanism behind the ejection of the clumps of matter from which these satellites form, it is reasonable to suggest that the most likely direction for such ejections would be along the path of the original, "budded-off" clump as it moves away. In other words, the ejection of the clump that formed the Milky Way triggered—and likely continues to trigger—a chain process involving the ejection of smaller clumps.

Over the last few decades, following the discovery of polar (or near-polar) planes of satellite galaxies in M87 and the Milky Way, searches for similar configurations have been conducted in other spiral galaxies. As a result, in other galaxies where observational data allow such investigations, highly flattened satellite systems have been revealed. A nearly orthogonal (polar) to dust lane system was revealed in Centaurus A (Kanehisa et al., 2023, Müller et al., 2021). In M81, a flattened, asymmetric (lopsided) distribution of satellite galaxies was confirmed, although kinematical coherence remains disputable (Müller et al., 2024). Other examples could also be cited. This line of research is still new, and the search continues. However, there is no longer any doubt that such structures are quite widespread and will, in time, be discovered in many galaxies. Finding thin, co-rotating planes around other galaxies, where simulation analogs occur less than 0.5 percent of the time, shows that the Local Group is not an isolated anomaly. Available data lead to another question: what drives their formation?

The formation of a satellite system for any given galaxy is traditionally attributed to the infall of matter onto a larger concentration—the central galaxy itself. In other words, gravitational forces are assumed to drive galaxy formation, shaping the system from the inhomogeneous post-Big Bang Universe. As time has passed and observational data have accumulated, this approach consistently meets fundamental difficulties—problems that cannot be overcome without introducing new, arbitrary parameters chosen to fit the data.

Let's now consider the " budding-off " concept again based on observational data provided by the M87 jet, beginning immediately from the galaxy nucleus. The common interpretation of this jet involves synchrotron radiation, particle acceleration, magnetic-field structures, and shocks. Small knots within the broader jet exhibit superluminal speeds. One such knot, designated HST-1 and located at a projected distance of approximately 70 pc from the core, underwent a striking flare in 2005 (Madrid, 2009). At the maximum brightness—in the X-ray range (April 2005) and the near-ultraviolet range (May 2005)—the object became, respectively, more than 50 and 90 times brighter than it was in its quiescent state. During this same period, the nucleus brightness increased fourfold.

It is worth noting that the configuration of the entire complex remains unchanged. That is, the HST-1 ejection velocity remained the same. Yet the components that make up this knot are moving at relativistic speeds. Indeed, high-resolution Very Long Baseline Interferometry (VLBI) and optical/X-ray studies have resolved HST-1 into distinct subcomponents with vastly different apparent velocities relative to the M87 core, and to one another (Thimmappa et al., 2026). In essence, we are observing the disintegration of a structure whose configuration is itself splitting. At the same time, this structure's luminosity increased across various bands of the electromagnetic spectrum.

Within the framework of our concept, this represents the formation of a new galaxy from a clump of matter ejected from the core of a parent galaxy. The knots within the jet are protogalaxies in the early stages of their evolution. In the specific clump of matter under consideration—HST-1—rapid decay processes are occurring at every level of the hierarchical structure. At the nuclear level, these decay products consist of high-energy elementary particles and "embryos" of nuclei. The mass of these particles gradually increases, since the mass defect reduces at the expense of dark energy. Atoms have not yet formed; consequently, this matter exhibits only a continuous spectrum—primarily due to free-free transitions and synchrotron radiation.

Observations of a jet in the galaxy M87 provide insight into the process by which our own Galaxy may have formed from a clump of matter ejected from the nucleus of the galaxy M31. Based on available data, it is impossible to determine precisely how far the matter of the Milky Way lags behind that of M31 along the evolutionary path. Nevertheless, this gap is significantly smaller than the evolutionary distance separating M31 from the HST-1 knot. Even so, given the observed signs of activity and dynamic instability, it is reasonable to conclude that M31 is an older galaxy and its matter is more evolved than in our own Galaxy.

4. Conclusion

An analysis of the physical characteristics of the galactic pair within the Local Group—the Milky Way and the Andromeda Nebula—reveals that the scenario in which they approach each other at a speed of 110 km/s does not withstand critical scrutiny. We conclude that, given a total mass of less than 1.1 trillion solar masses, this scenario is entirely unfeasible. The stellar mass of both galaxies combined does not exceed 200 billion solar masses. Extremely high mass values arise only when accounting for hypothetical dark matter—a concept that, despite its widespread use, remains little more than a free parameter employed to reconcile traditional cosmogonic theory with observational data.

On the other hand, when the laws of physics are applied in a self-consistent way —accounting for the presence of dark energy—the need for dark matter vanishes (Harutyunian, 2024). Historically, Zwicky (Zwicky, 1937) introduced dark matter into the physics toolkit to satisfy the virial theorem within galaxy clusters. However, the discovery of dark energy—which interacts with baryonic matter—suggests that balanced systems of cosmic objects cannot exist in the observable universe; rather, everything is undergoing expansion. Analysis of observational data further indicates that our own Galaxy is expanding (see, for example, Karapetian et al. (2026) and the references therein).

In this paper, we continue to develop a new concept. Under the influence of dark energy, the nuclear binding energy within atomic nuclei decreases, thus increasing nuclear mass. This, in turn, changes the atoms' spectral properties. An increase in nuclear mass shifts the corresponding atom's spectrum toward the blue end. Consequently, if one measures the spectral shift of a significantly evolved object, one will observe a blueshifted spectrum. We conclude that the M31 galaxy was more extensively evolved than our own galaxy, and that its spectrum is therefore blueshifted.

Based on observational data, we hypothesize that the Milky Way "budded off" from the M31 galaxy as a result of the ejection of pre-stellar matter—specifically, the requisite quantity of baryonic "seeds"—from its nucleus. This is supported by the blueshift of M31 (indicating that this galaxy is more evolved) and the fact that the direction toward M31 aligns with the plane in which its satellite galaxies are situated (their ejection direction). We also draw an analogy to the jet emanating from the nucleus of the galaxy M87, which experienced an outburst in the HST-1 knot in 2006.

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