The Milky Way - Our Home in the Universe

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Abstract : *Aakasha Ganga, Via Lactea or the Milky Way is our home in the Universe. The discovery of the telescope by Galileo Galilei had facilitated the sky watchers to notice a variety of geometrical forms in the sky. The use of photographic techniques have expanded our knowledge about galaxies. Galaxies can be grossly put into one of the 3 types: elliptical, spiral and irregular galaxies. Milky way is one among billions of galaxies present in the universe and it is spiral galaxy. Newtons law of gravitation explains the planetary motions in solar system. But to explain the motion of sun and other stars in galaxy one has to modify Newtonian gravity dynamics. Development of quantum mechanics, particle physics and the measurement of stellar velocities at unprecedented accuracies would help to unravel the mystery of the formation of Milky Way in near future.*

Key Words : *Galaxy, Telescope, Nebulae, Milky Way, Newtonian Dynamics, constellaction.*

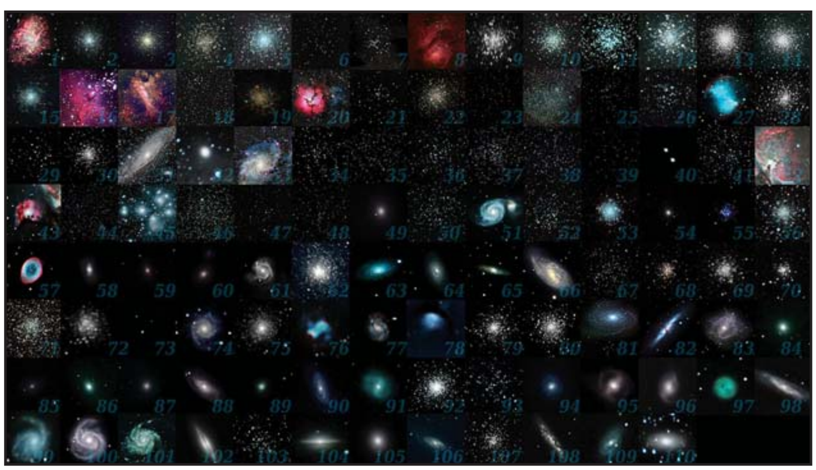
Figure 1 : The Milky Way

Credits: Astronomy Picture of the Day

Aakasha Ganga, *Via Lactea* or the Milky Way — all mean the same thing — the name given to our home in the Universe by different ancient civilizations. Who can miss the dark and white patchy band passing over our head in the summer skies? Some imagined it as a band of milk while the others related it to a river. After millennia of pondering over what it is, it is only around a century ago that a clear picture of this band has emerged, thanks to a new generation of astronomers, powerful telescopes and progress in the theoretical physics. The band constitutes neither milk nor a river, but light from millions of stars that are scattered by the intervening dust particles. This understanding marked the birth of modern astronomy.

The discovery of the telescope by Galileo Galilei (1610) had facilitated the sky watchers to notice a variety of geometrical forms in the sky. It was the French comet hunter Charles Messier (1730-1817) who catalogued for the first time 110 objects that always remained in the same constellation. He had no interest in these catalogued objects, but compiling these "nuisance" objects into a catalogue helped him to identify the comets. Unlike the objects he catalogued, comets moved from one constellation to the other in a matter of days. Little did he realize at that time that his catalogue would turn out to be an important collection of objects for future generations. More than a 100

Figure 2 :



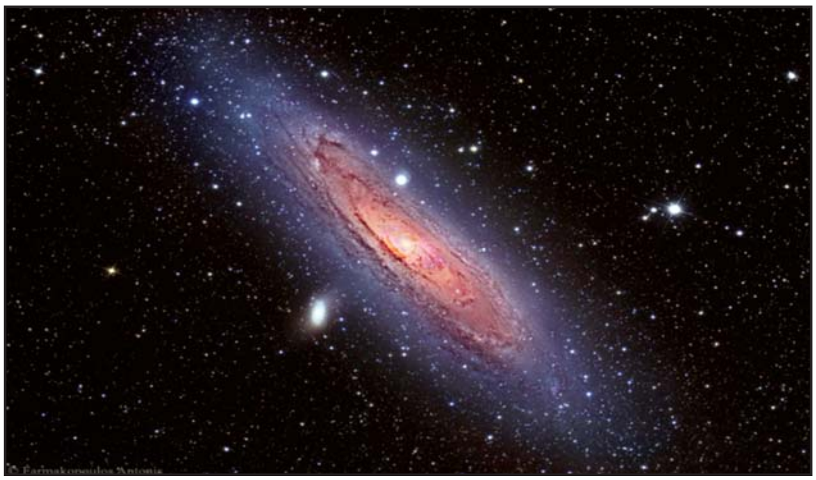
year later, Edwin Hubble (1889-1953) and other astronomers realized that the catalogue contains several kinds of nebulae - planetary nebulae (e.g. M57 – ring nebula), star-forming nebulae (M42 - Orion nebula), supernova remnants (M1 - Crab nebula), stellar clusters (M45 - the Pleiades), spiral (e.g. M31 - Andromeda), elliptical (M104 – Sombrero) and irregular-shaped (M82 – Cigar galaxy) nebulae.

Development of photographing techniques at the focal plane of large telescopes such as the 100-inch Hooker telescope at the Palomar observatory allowed Hubble to distinguish the spiral, elliptical and irregular-shaped nebulae from the rest of the Messier objects. Of great interest were the so-called spiral nebulae; Andromeda being the best example. Hubble could see several individual stars in the images of this galaxy, and some of these stars seemed to vary in strength in different photographic plates. He soon established that these stars are variable in intensity and the variability is periodic, similar to the stars known as Cepheid variables. From studies of these stars in the Large Magellanic Cloud (LMC), it was known that the larger the period, brighter is the star when it is in its maximum. These variable stars paved the way to determine the distances, for the first time, to faraway stars. All Cepheids in Andromeda were fainter than those in the LMC immediately suggesting that Andromeda is at a farther distance than the LMC.

The idea prevailing at that time was that the Milky Way constituted the whole Universe; i.e. everything that we see, including the objects such as Andromeda and the LMC, belonged to the Milky Way. The basic problem was the complete ignorance of the size scale of the Milky Way. Thus, inspite of knowing the distances to Andromeda and the LMC, it wasn't possible to consider them as separate entities, each by its own right a galaxy like the Milky Way. Finally, the issue was settled in a "great debate" (1920) between Harlow Shapley and Heber Curtis, the latter challenging the prevailing idea of Milky Way constituting the whole Universe. As the arguments of the debate reached the wider astronomical community, efforts were made to put to test the different arguments without prejudice

As the arguments of the debate reached the wider astronomical community, efforts were made to put to test the different arguments without prejudice. These tests conclusively showed that the Milky Way is just one among the so called spiral nebulae, and each one of these objects are called galaxies. Thus our home, the Milky Way is a galaxy, one among the millions of galaxies that are present in the Universe.

Figure 3 :

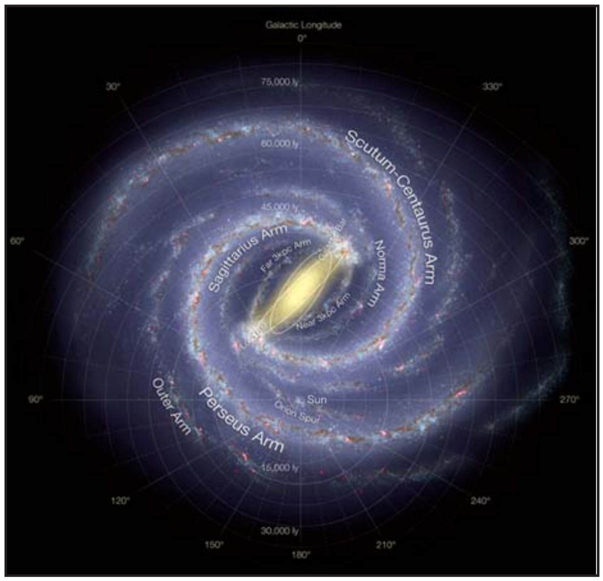


Though there exist millions of galaxies, every one of these can be grossly put into one of the 3 types; elliptical, spiral and irregular galaxies. Elliptical galaxies are spherical systems somewhat similar to inflated balloons, whereas the latter two classes are flat systems dominated by a thin disc. The dark and white patchy band that characterized the Milky Way from the ancient times is the disc seen edge-on. Actually, the Milky Way galaxy is not just the patchy band but instead contains every star that we see by naked eye in the night sky. In addition to stars, the Milky Way contains gas and dust particles, which are the raw material from which stars that illuminate the nebulae such as that seen in the constellation of Orion are formed. At the center of the flat disc resides a dense spherical bulge and the whole disc is surrounded by a sparsely populated large spherical halo. Both the bulge and halo contain some of the oldest stars in the Universe. At the very center of the bulge, there lies a black hole that weighs around 4 million times the mass of the sun. The Milky Way is estimated to contain around 100 billion stars similar to the Sun.

Figure 4 :

Where are we located in the Milky Way? The Sun is located in the Galactic disc at about halfway between the center and the edge. The Sun rotates around the center of the Milky Way, very much similar to how the Earth rotates around the Sun in the solar system. However, the orbit of the Sun is around 2 billion times larger than the orbit of the Earth (27000 light years vs 8 light minutes), and takes around 200 million years to go around once compared to one year that the earth takes to come back to the same position in its orbit. Both systems are governed by the Newton's law of gravitation. However, there seems to be a fundamental difference between the solar system and the Galactic disk; while in the Solar system almost the entire mass is concentrated in the Sun, in the Galaxy it is more smoothly distributed in its disc. Painstaking observations over several decades have revealed that the gravitational force exerted by the stars in the Milky Way is not strong enough to maintain the Sun and the stars in their orbits. There seems to exist a matter, known as dark matter, that contributes to gravitational force but do not emit any electromagnetic radiation. All known fundamental particles interact with other particles and emit electromagnetic radiation, and hence the dark matter should be made up of a yet-to-be discovered Weakly Interacting Massive Particle (WIMP). Powerful accelerators of particles such as the Large Hadron Collider (LHC) at the CERN (Europe) are presently searching for the existence of such a particle.

Figure 5 :



The failure to detect any candidate for dark matter has prompted some groups of astronomers to question the validity of Newton's gravitational law at astronomical scales. It should be remembered that the gravitational law has been tested only at the scale of the Solar system, but is assumed to hold over much larger scales following the fundamental principle of physics namely "The Physical Laws are Universal''. So going against this fundamental principle is like undoing all that has been learnt over the last few centuries. Thus, the wider astronomical community is skeptical over this seemingly outrageous suggestion. This new theory of gravitation is being called as the Modified Newtonian Dynamics (MOND), wherein beyond a certain scale, the gravitational force falls as the inverse of the distance, rather than the inverse of the square of the distance. At the scale of the Solar system, the MOND recovers the Newton's gravitational law. With MOND, observed rotational velocities of the Sun and stars can be perfectly explained without invoking any dark matter. It is very well established that all spiral galaxies have rotational patterns very similar to that of the Milky Way, and hence require dark matter under Newton's gravitational law, and no dark matter with MOND. This new law is awaiting to be tested by rigorous experiments in the near future.

Do the millions of galaxies that we see today have similar structure as the Milky Way? How are these galaxies formed? These are some of the fundamental questions that are being addressed by the current astronomers and astrophysicists. There are two competing theories to explain the formation of galaxies. The traditional idea put forth by the English astrophysicist Donald Linden-Bell (1935) and collaborators 55 years ago was that the Milky Way formed from a huge cloud of gas, that slowly evolved into the current structure almost without getting affected by its neighbours. This theory is losing ground to a competing theory, in which galaxies grow in time by snatching gas and stars from their neighbours. The Milky Way is caught in the act of looting gas from what was once upon a time a little galaxy like the companion galaxy of Andromeda, but now seen as a large loop in the sky in the Sagittarius constellation.

Figure 6 :

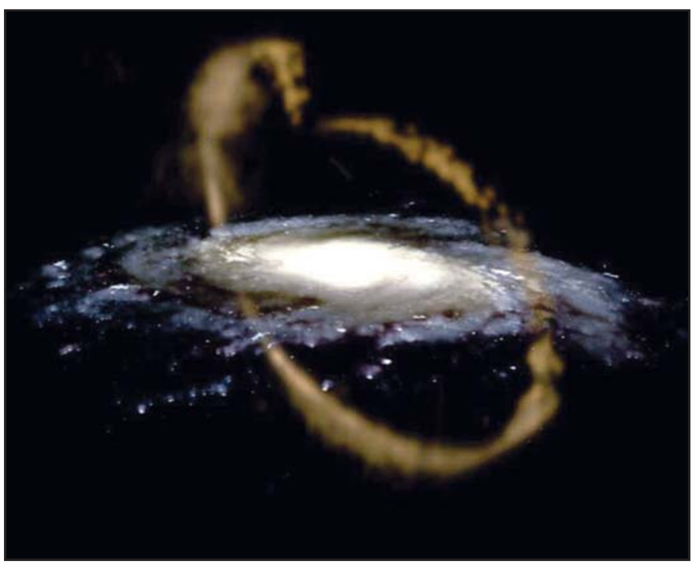
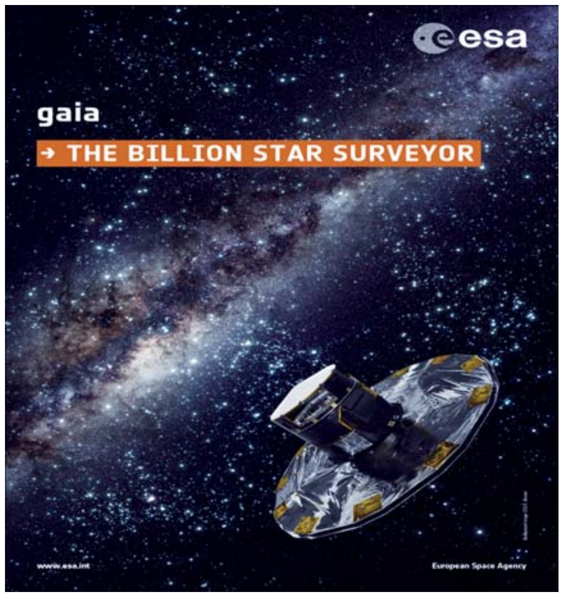


Figure 7 :

Whether galaxies formed stars quietly from the gas that they always had right from the beginning, or whether stars and gas are violently looted from the neighbouring smaller galaxies could be checked by analyzing the motions of the stars. Stars are expected to move around the Galactic center in regular orbits in the former picture, whereas the random motions would have importance in the latter scenario. Ever since the humanity started looking up at the sky, stars have hardly moved with respect to each other, i.e. the constellations have retained the same form since they were named by the Greeks. For example, the Orion constellation looks like a hunter even today. However, comparing the positions of stars in photographs taken today with those taken around 50 years ago, astronomers were able to measure minute movements that suggest non-negligible random motions of stars.

However, techniques of comparing current photographs of the sky with ancient photographs could detect motions of stars that are in the vicinity of the Solar system. Two years ago, European astronomers launched a satellite, known as GAIA, to measure the stellar movements with an unprecedented accuracy even at the outer edges of the Milky Way. After the completion of the mission in 5 years, motions of 1 billion stars in the Milky Way would be known. These data would allow to discover the complete story of the formation of the Milky Way, and would also put to test the alternative theory of gravitation.

Figure 8 :



The ancient observers couldn't understand the Universe due to their inability to interpret the dark bands in the sky. A century after the nature of the dark band was understood, we are now confronted with a mysterious dark matter whose nature is completely unknown. Development of quantum mechanics nearly a century ago, paved the way for understanding the nature of stars. We hope that the developments in particle physics and the measurement of stellar velocities at unprecedented accuracies would help to unravel the mystery of the formation of Milky Way in near future.

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