The Milky Way – Our Galaxy

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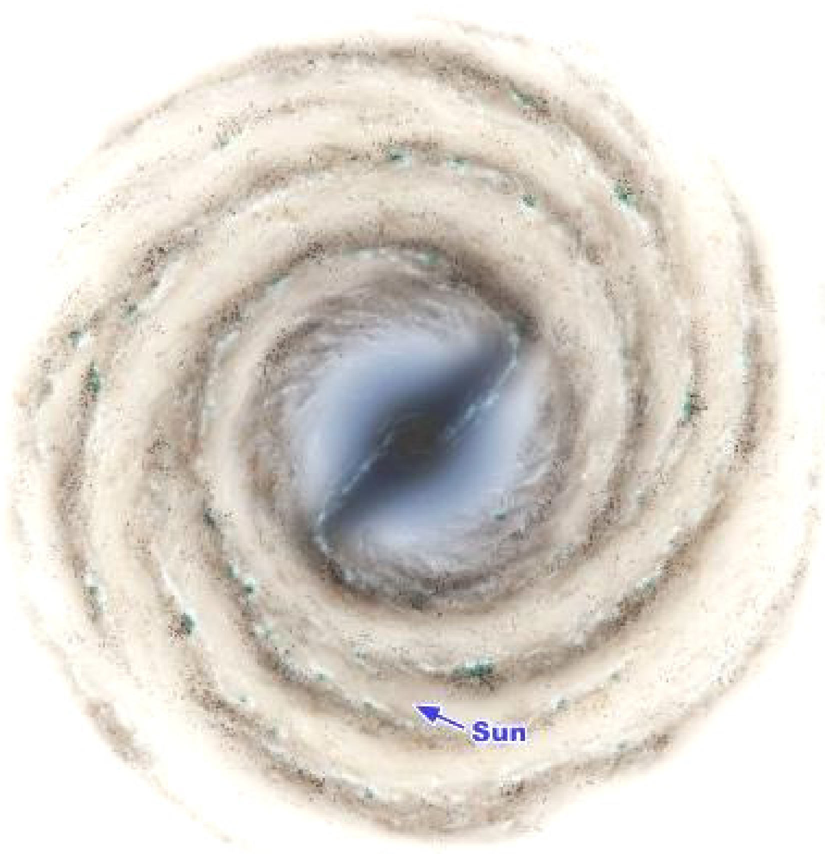


Our Place in the Milky Way

1. **Milky Way in the Night Sky**

All the stars that the eye can distinguish in the night sky are part of the Milky Way Galaxy. The solar system is a part of it. However, what we call as the Milky Way is a hazy band of white light criss-crossing the night sky in different orientations at different times of the night. Apart from stars other material contribute to this band like appearance. There are dark regions within the band, with nick names like the Coalsack ; these are regions where light from distant stars is blocked by dark nebulae. There are bright emission and reflection nebulae too.

The glory of the Milky Way can be appreciated from suburban locations free from light pollution. In spite of millions of stars contributing to it, it is quite dim. This is partly because of matter, mostly invisible, called the interstellar medium. It fills the galactic disk and prevents us from seeing the bright galactic center.

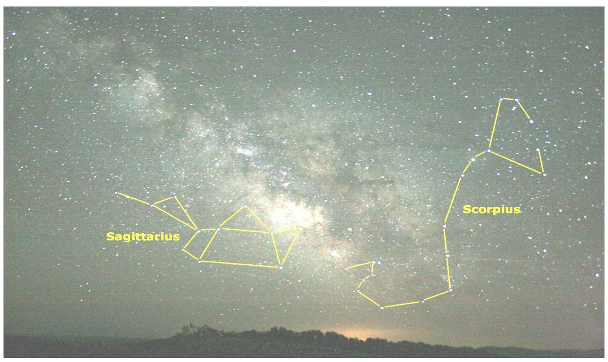


Figure 1. Photograph of the Sagittarius region of Milky Way between the constellations of Sagittarius and Scorpius

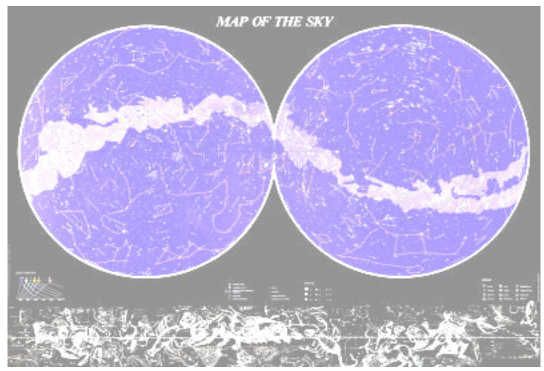


Figure 2 Star maps showing the domain of the Milky Way

The brightest part of the Milky Way is in the direction of Sagittarius, and it is here that center is located. From Sagittarius, the Milky Way branches off in to several streams. It stretches westward through the constellations of Scorpius, Ara, Norma, Triangulum Australe, Circinus, Centaurus, Musca, Crux, Carina, Vela, Puppis, Canis Major, Monoceros, Orion and Gemini, Taurus, Auriga, Perseus, Andromeda, Cassiopeia, Cepheus and Lacerta, Cygnus, Vulpecula, Sagitta, Aquila, Ophiuchus, Scutum, and back to Sagittarius. At any given time we can see only half of this stream; it appears as though it divides the night sky into two roughly equal hemispheres. This idea is interpreted to mean that the Solar System lies close to the plane of the Galaxy.

The plane of the disk of the Galaxy is inclined to the ecliptic (the plane of the Earth's orbit) by about 60 degrees. Therefore, it stretches from the constellation like Sagittarius on the ecliptic to as far north as the constellation of Cassiopeia and as far south as the constellation of Crux, indicating the high inclination to the earth's equatorial plane. In the Galactic Coordinate System (in which the equator corresponds with the galactic plane), the north galactic pole is situated near Beta Comae Berenices, and the south galactic pole is near Alpha Sculptoris.

The river Ganga and the milky way in the heaven are considered to be terrestrial-celestial analogs. The term Kshira (milk) is also used as an alternative name for the milky way in many Hindu texts. So is Mandakini. It is cited as the heavenly bridge in the sky visible during Sharad Ritu (September – October) in the great epic Ramayana.

2. **How vast? - Understanding Structure and Dimensions**

Some of the earliest thoughts about the structure of Milky Way came from the Greek philosophers Anaxagoras (ca. 500–428 BC) and Democritus (450–370 BC) and Aristotle (384-322 BC) who conjectured that the Milky Way consists of a large number of distant stars. It is interesting to note that Democritus stated in his writings that "The Milk of Hera swirls around a centrepoint" and how he arrived at this reference to the movement of the galaxy around the galactic centre is indeed a mystery. We also read statements from Aristotle about the Milky Way to be caused by "the ignition of the fiery exhalation of some stars which were large, numerous and close together" and that the "ignition takes place in the upper part of the atmosphere, in the region of the world which is continuous with the heavenly motions." The Arabian astronomer, Alhazen (965-1037 AD) (his full name was Abū ʿAlī al-Ḥasan ibn al-Ḥasan ibn al-Haytham) refuted this by making the first attempt at observing and measuring the Milky Way's parallax, and he thus "determined that because the Milky Way had no parallax(See box), it was very remote from the earth and did not belong to the atmosphere."

What is parallax?

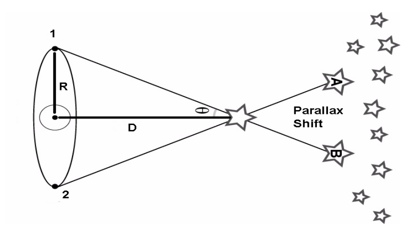


Figure 4 The meaning of parallax

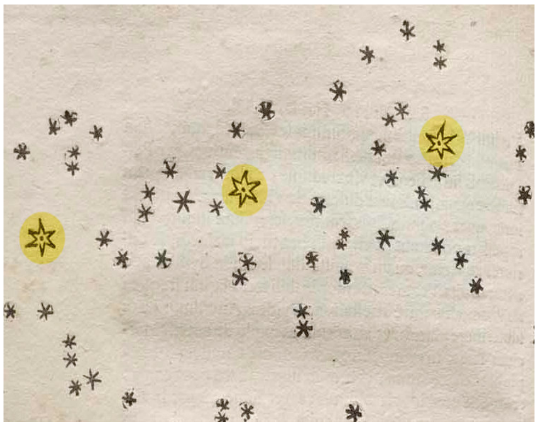
Let us begin with a simple exercise. Take a look out of the window and stretch your hand so that you hold the finger in your line of sight. Watch the scene with one eye closed; without moving the finger view with the other eye. You will notice that the finger appears to shift across the field of view. This apparent shift because of the change in the line of sight can be expressed as an angle subtended by the finger at the eye. It is simple to infer that as the distance of the finger varies this angle also varies. If instead of the finger you have a stick which can be taken to a greater distance the effect diminishes. This is the principle of parallax. You may use it as a tool to find the distance to objects; surveyors employ the technique extensively. It is also be clear from this explanation that you need to have broader baseline (analogous to the separation between the eyes) to measure larger distances. For the moon and planets the diameter of the earth is used as the base line. For stars the orbit of the earth is the base line.

If the angle subtended at the earth's orbit by an object is one arcsecond, the distance is a parsec; *PARar*allax of one arc*SECo*nd.

The Persian astronomer Abū Rayhān al-Bīrūnī (973-1048) who visited India cites that the Milky Way galaxy was referred to as a collection of countless stars. Avempace (d. 1138) brought forth the ideas of physics for the first time when he said that the Milky Way is made up of many stars but appears to be a continuous image due to the effect of refraction in the Earth's atmosphere. Ibn Qayyim Al-Jawziyya (1292–1350) said that the Milky Way galaxy consists of "a myriad of tiny stars packed together in the sphere of the fixed stars" and that that these stars are larger than planets.

It was left for Galileo Galilei to provide the proof that the Milky Way consists of a huge number of stars. He, in 1610, used a telescope to study the Milky Way; he was astonished at the sighting of a huge conglomeration of stars and said “there are stars not seen by the (naked) eye”. His sketches of the region of Orion bear testimony to this.

Figure 5. Galileo’s sketches of the Milky Way region and an image from a small telescope equipped with digital camera



The idea of rotation of the Milky Way was first proposed by Thomas Wright and extended by Immanuel Kant; he rightly conjectured that the Milky Way might be a rotating body of a huge number of stars, held together by gravitational forces akin to the Solar System but on much larger scales. The resulting disk of stars would be seen as a band on the sky from our perspective inside the disk. Kant also was the first to conjecture that some of the nebulae visible in the night sky might be separate "galaxies" themselves, similar to our own.

William Herschel made a very serious effort to deduce the shape of the Milky Way in 1785 by meticulously counting the stars in different regions of the visible sky. This is first attempt to describe the shape of the Milky Way and the position of the Sun within it. He produced a diagram of the shape of the Galaxy and placed the Solar System almost at the center.

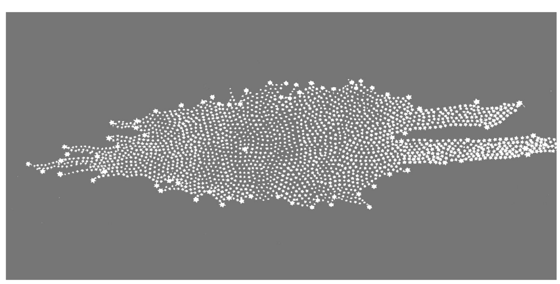


Figure 6. The shape of Milky Way as inferred by William Herschel

In 1845, Lord Rosse identified the elliptical and spiral-shaped nebulae. He also showed that they were indeed made up of dot like stars and corraborated the idea of separate galaxies of the hundred odd year old hypothesis of Kant.

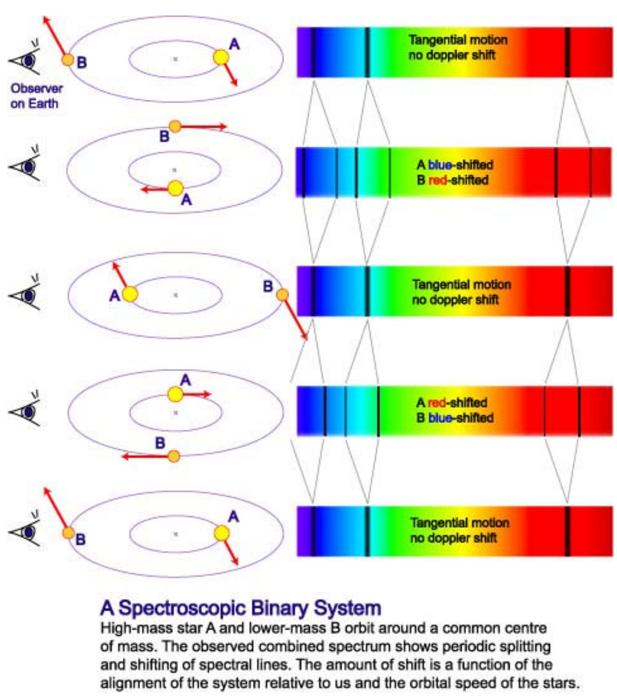
Novae are stars that suddenly brighten up giving a flase impression of a “new star”. In 1917, Heber Curtis had observed a nova in the "Great Andromeda Nebula" (Messier object M31). This is now catalogued as S Andromeda. He scrutinized old photographs and found 11 more novae. He noticed that these novae were, on average, 10 magnitudes fainter than those that occurred in our galaxy. He used this idea to estimate the distance of the nebula as of 150,000 parsecs. He became a proponent of the "island universes" hypothesis, which held that the spiral nebulae were actually independent galaxies.

In 1920 a Great Debate took place between Harlow Shapley and Heber Curtis, concerning the nature of the Milky Way, spiral nebulae, and the dimensions of the universe. This is considered one of the most interesting debates. To support his claim that the Great Andromeda Nebula was an external galaxy, Curtis noted the appearance of dark lanes resembling the dust clouds in the Milky Way, as well as the significant Doppler shift. This technique was applied to not only the binary stars but to derive the structure of the Galaxy as well. Edwin Hubble measured the red shifts of nebulae and those which we now call as galaxies showed no periodicity; instead they all had red shift without even one exception. The remarkable relation between the red shift (or the velocity) with distance is the Hubble's law.

Doppler effect

Doppler effect is the apparent change in the frequency of a wave due to the motion of the source or observer. It is well demonstrated in case of sound waves. For realising it in the case of light, celestial examples like binary stars are needed. As a star moves away from us its recession will be recognisable as a shift in the wavelength of spectral lines towards the longer side; hence the name red shift. On the other hand if the star is approaching us the shift is towards the shorter wavelength side – the blue shift. A periodic variation in the shift is a clear indicator of the binary nature. The shift is directly proportional to the velocity. Thus it provides the direct evidence on the movement of stars.

Figure 7 Doppler Effect as applied to a binary star



The debate went on till the new observations from Edwin Hubble were available. Hubble not only resolved the outer parts of some spiral nebulae as collections of individual stars but also identified some Cepheid variables, which allow precise estimate of the distances to the nebulae. Spiral nebulae turned out to be far too distant to be part of the Milky Way.

Most of the stars in the Galaxy are spread along a disc which is approximately 100,000 light-years (9×10^{17} km) in diameter, and is considered to be about 1,000 ly (9×10^{15} km) thick.

An understanding of the Inter stellar matter (ISM) came up by fusion of results from apparently different avenues. One was the simple count of stars attempted by Herschel. Another avenue was to mark the sizes of the nebulae as seen from the earth. This is a lesser known law of Hubble which relates the illumination of the reflection nebulae to its apparent angular size. Another interesting aspect was the relation between the number of stars in a given angular area with the brightness. These results hinted on the presence of material between the stars.

Figure 8: The open cluster Preasepe (Krittika) is the best example for a young cluster with blue stars.

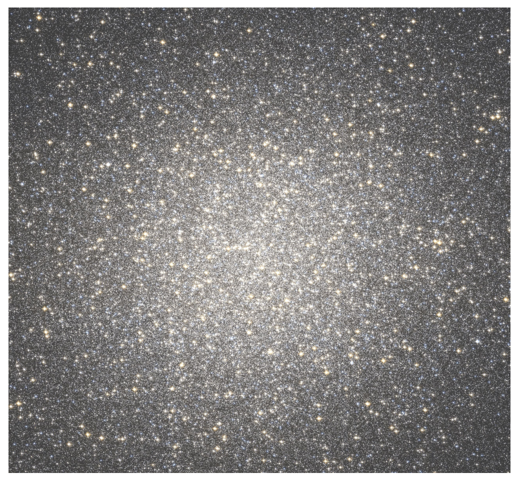


Figure 9: The globular cluster M 13 in Hercules has old yellow stars

A systematic study of the clusters provided yet another approach. Farther the cluster smaller is the angular size. Star clusters can be classified in to two groups – open and globular. Open clusters have young, blue metal rich stars while globulars have yellow and red stars. One of the points which was instrumental in establishing the structure of the Galaxy is the fact that open clusters are mainly seen on the disc along the spiral arms, where as the globulars are seen in the halo of the Galaxy. From our understanding of the stellar evolution the reason for the difference in their properties can be attributed to the age by a simple assumption that all the members of the cluster are formed together. That puts the globulars as the older generation and open clusters with the blue stars as having formed recently. Their metal content (material other than hydrogen and helium) corraborated with this idea. Older (called Population II stars) have lesser metal; while the younger population formed out of ingradients enriched by the supply of heavier elements from supernovae explosions are metal rich.

The study of motion of stars in the solar neighbourhood provided the best answer.

3. **Rotation of the Galaxy**

The first exercise on finding the motion was attempted by Jan Oort (1900-1992). The space velocity of a star can be obtained by adding the two components – one in the line of sight and the other perpendicular to it. This gives an idea of their movement which appears random. However, they can be now resolved in to components with reference to the Galaxy. The apparent peculiar motion was attributed to the motion of the sun itself. This revealed not only the motion of the sun but the motion of all other stars; it disclosed the revolution around the centre.

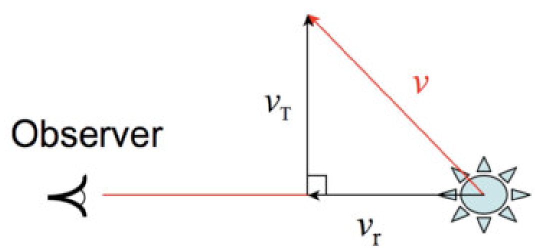
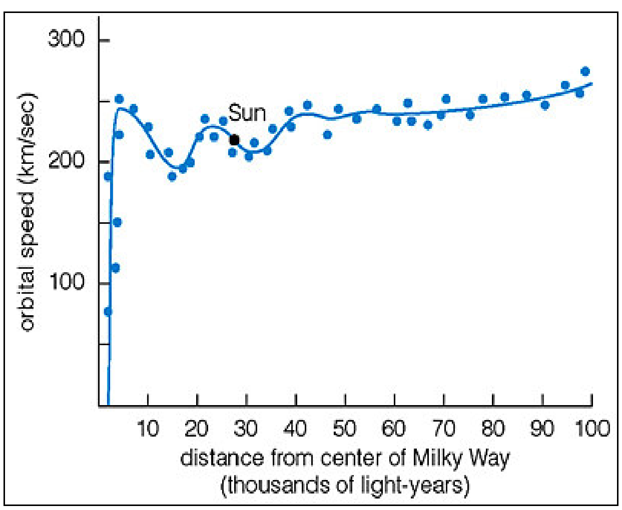


Figure 10 Understanding the motion of stars and deriving the space velocity

The rotation of the Galaxy is still an unsolved problem. The distribution of mass in the Milky Way Galaxy is such that the orbital speed of most stars does not depend strongly on its distance from the center. Away from the central bulge or outer rim, the typical stellar velocity is between 210 and 240 km/s. The orbital period of the typical star is directly proportional only to the distance from centre. This is unlike the situation within the Solar System, where two-body gravitational dynamics dominate and different orbits are expected to have significantly different velocities associated with them. For example, a linear relationship of this kind cannot be sought for the speeds of the planets. In fact, this is the essence of Kepler's law, which was first determined observationally.



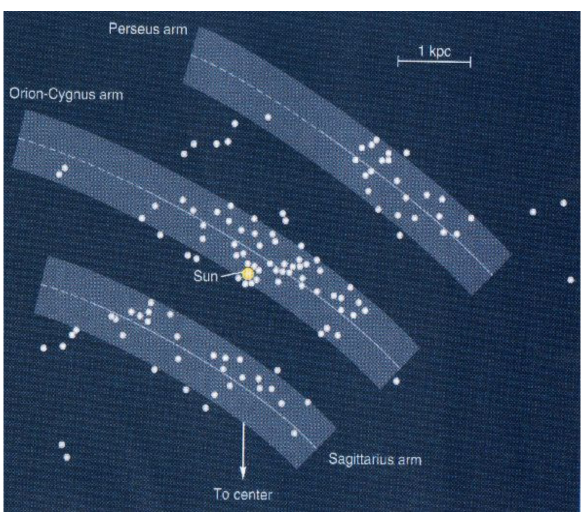


Figure 11. The deduction of spiral arms and the Rotation curve of the Milky Way

The dynamics of the stars in the Galaxy are best understood by considering the motion of the sun itself. The Apex of the Sun's Way, or the solar apex, is the direction that the Sun travels through space in the Milky Way. The general direction of the Sun's galactic motion is towards the star Vega in the constellation of Lyra, at an angle of roughly 60 sky degrees to the direction of the Galactic Center. The Sun's orbit around the Galaxy is expected to be roughly elliptical with the addition of perturbations due to the galactic spiral arms and non-uniform mass distributions. In addition, the Sun oscillates up and down relative to the galactic plane approximately 2.7 times per orbit. This is very similar to how a simple harmonic oscillator works with no drag force (damping) term. These oscillations often coincide with mass extinction periods on Earth; presumably the higher density of stars close to the galactic plane leads to more impact events. One of the recent names to this hypothesis of mass extinction on earth is the “Shiva hypothesis”

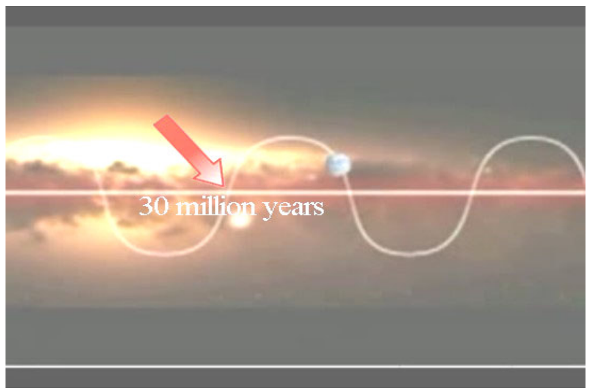


Figure 12. Motion of the sun perpendicular to the plane of Galaxy; Once in 30 million years the Sun passes through the dust lane.

Let us try to represent the Galaxy by scaling it to the dimensions of Bangalore. Every house will then be a star with all the trees constituting the interstellar matter. Just as the heart of the city has densest population of houses, the center of Galaxy also is densest at the center and called the nucleus. However, the scaling demands that the city be closely packed with multi storeyed buildings (at least 50 floors!) at the center.

The scaling cannot be extended to include other entities of the Galaxy. Because extending beyond the stellar disc is a much thicker disc of made up of gas. This gaseous disk of the Milky Way has a thickness of around 12,000 ly (1×10^{17} km). Now let us scale it to the solar system – if the Galaxy were reduced to 10m in diameter, the Solar System, including the hypothesized Oort cloud, would be no more than 0.1mm in width.

The Galactic Halo extends outward, but is limited in size by the orbits of two Milky Way satellites, the Large and the Small Magellanic Clouds, ~180,000 ly (2×10^{18} km) away. At this distance or beyond, the orbits of most halo objects would be disrupted by our nearest neighbour the Magellanic Clouds, and the objects would likely be ejected from the vicinity of the Milky Way.

The galaxy was believed to be consisting a nucleus and spiral arms. Recently a bar-shaped core region surrounded by a disk of gas has been detected. The dust and stars form four distinct arm structures spiralling outward in a logarithmic spiral shape. The mass distribution within the galaxy closely resembles the Sbc Hubble classification, which is a spiral galaxy with relatively loosely wound arms. The Spitzer Space Telescope observations in 2005 showed the galaxy's central bar to be larger than previously suspected.

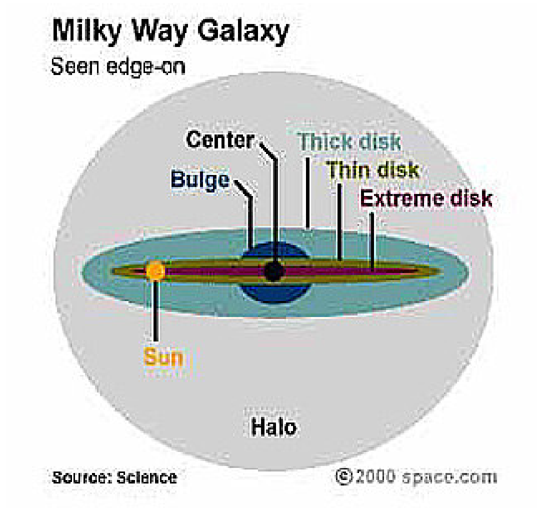


Figure 13. The overall structure of Milky Way

Nucleocosmochronology is a new technique for estimating the ages of celestial objects. In 2007, a star in the Galactic halo, designated HE 1523-0901, was estimated to be about 13.2 billion years old, nearly as old as the Universe. As the oldest known object in the Milky Way at that time, it placed a lower limit on the age of the Milky Way. This estimate was determined using the Echelle Spectrograph of the Very Large Telescope. This is a special spectrograph which uses two gratings perpendicular to each other to achieve high resolution. This was used to measure the relative strengths of spectral lines caused by the presence of Thorium and other elements created by the R-process. The R – process is a mechanism by which elements heavier than iron are formed by capturing a fast moving neutron. (The S process invloves capture of slow moving neutrons). The line strengths yield abundances of different elemental isotopes, from which an estimate of the age of the star can be derived – this is the essence of nucleocosmochronology. The age of stars in the Galactic thin disk yield an estimate that the thin disk formed between 8.8 ± 1.7 billion years ago. There was a gap of almost 5 billion years between the formation of the Galactic halo and the thin disk.

4. **The Mass – How do we estimate?**

It takes the Solar System about 225–250 million years to complete one orbit of the galaxy (a galactic year), so it is thought to have completed 20–25 orbits during the lifetime of the Sun and 1/1250 of a revolution since the origin of humans. The orbital speed of the Solar System about the center of the Galaxy is approximately 220 km/s. At this speed, it takes around 1,400 years for the Solar System to travel a distance of 1 light-year, or 8 days to travel 1 AU (astronomical unit).

The Galaxy is estimated to contain at least 200 billion stars; this number can be arrived at by simple application of universal law of gravitation . However the number may possibly be 400 billion stars, the exact figure depending on the number of very low-mass stars, which is highly uncertain. This can be compared to the one trillion (10^{12}) stars of the neighbouring Andromeda Galaxy. It is difficult to fix the edge of the disc, if we define it as a radius beyond which there are no stars. The number of stars drops smoothly with distance from the centre of the Galaxy. Beyond a radius of roughly 40,000 light-years (4×10^{17} km) the number of stars drops much faster with radius, for reasons that are not yet understood.

Calculation of the mass of the Galaxy – Let us assume that the sun (with its family) revolves around the center of the galaxy in a circular orbit. We may use the familiar equation

$$mv^2 / r = GMm/r^2$$

From the numbers we have derived from observations - the distance (8kpc) and the speed (220km/s) we can estimate the mass as $4x10^{41}$ Kg,or 200 solar masses. This can be interpreted as equivalent of having 200 billion suns.

Estimates for the mass of the Milky Way vary, depending upon the method and data used. Recent estimates at the low end have placed the mass of the Milky Way at 5.8×10^{11} solar masses (M☉), somewhat smaller than the Andromeda Galaxy.

5. **The Spiral structure**

Earliest measurements on the rotation of the Galaxy was based on a systematic estimate of the speeds of stars in the solar neighbourhood. As mentioned earlier, Jan Oort achieved this result and deduced the equations of motion of the stars. If we were to look at the stars they seem to be moving randomly; however a systematic resolution of their speeds towards the Galactic Center and perpendicular to it discloses their revolution around the centre.

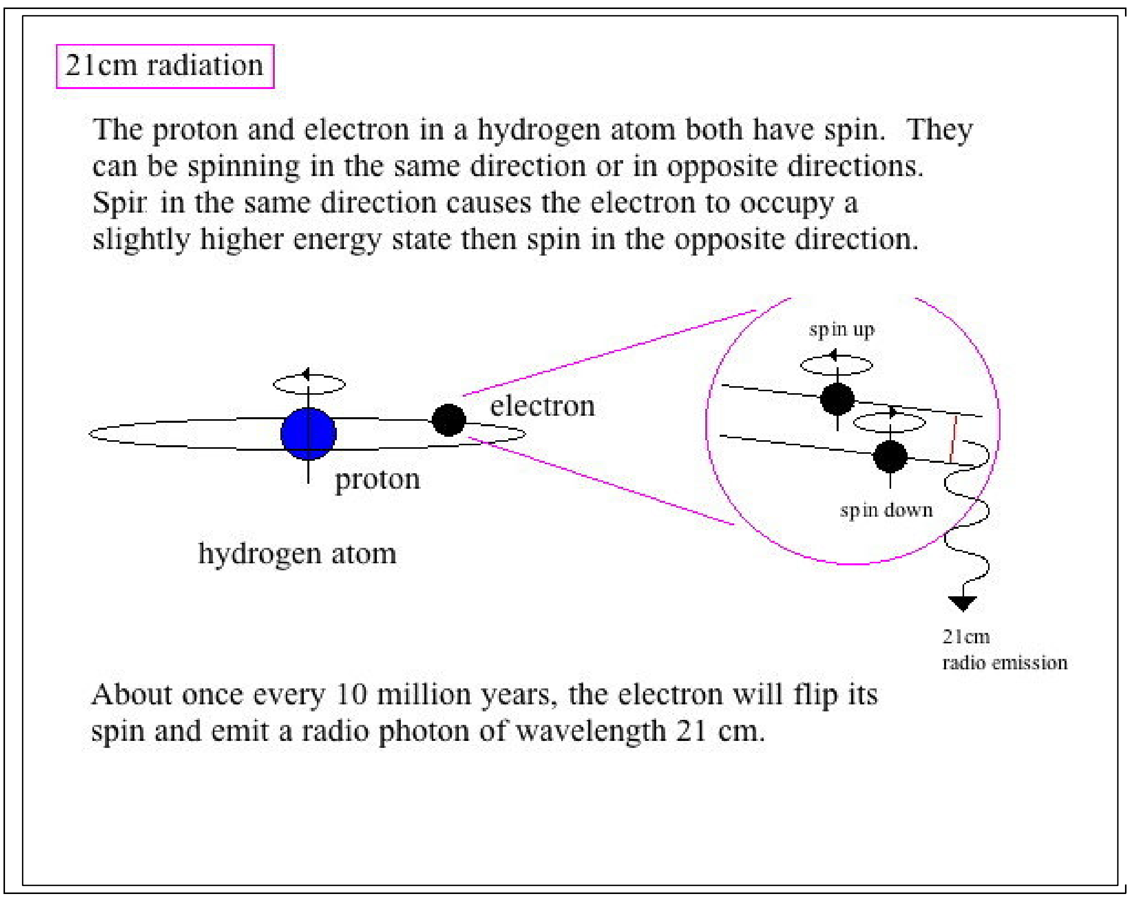


Figure 14 The origin of 21cm radiation

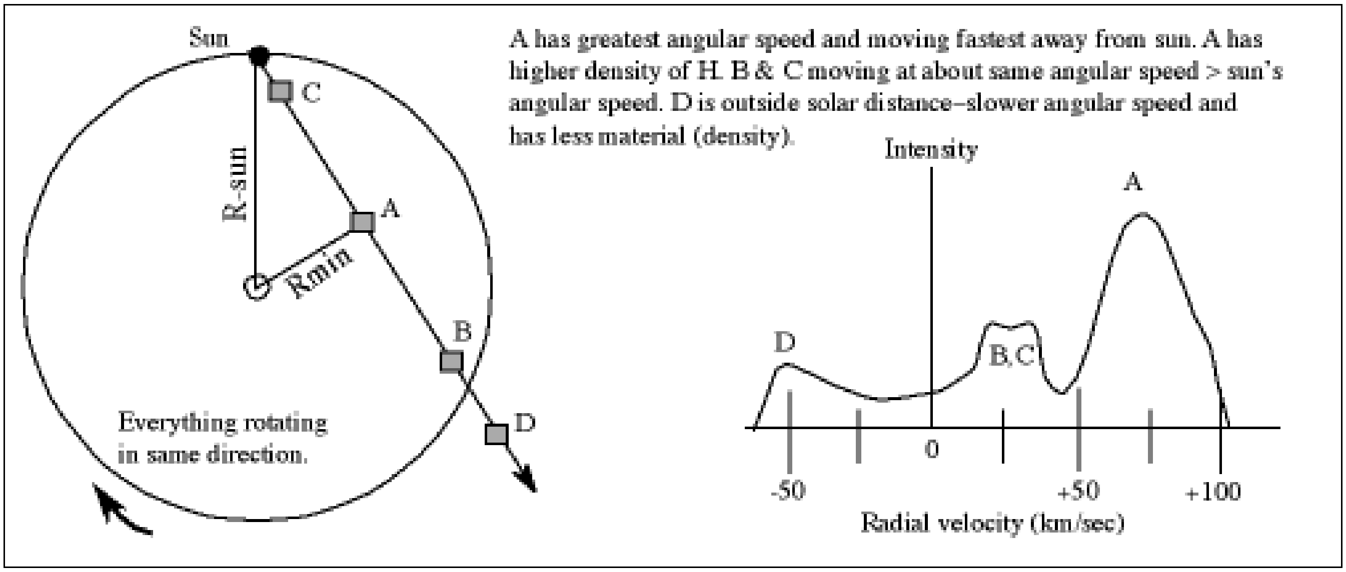


Figure 15: Application of the 21cm line profile for deriving the structure of spiral arms

The measurements of the profiles of the 21cm line from hydrogen in different dirctions in the sky provided the vital information on the spiral structure. Measurements by the Very Long Baseline Array (VLBA) have found velocities as large as 254 km/s for stars at the edge of the Milky Way, higher than the previously accepted value of 220 km/s. Essentially this is a deviation from the well understood laws of Kepler treating the Galaxy to be analogous to the solar system. This led to the concept of the effect of unseen mass or the dark matter. This implies that the Milky Way is more massive, roughly equaling the mass of Andromeda Galaxy at 7×10^{11} solar masses (M☉). A recent measurement of the radial velocity of halo stars finds the mass enclosed within 80 kiloparsecs is 7×10^{11} solar masses. Most of the mass of the Galaxy is perhaps the dark matter, which forms a dark matter halo that is spread out relatively uniformly to a distance beyond one hundred kiloparsecs from the Galactic center. The overall mass of the entire galaxy is estimated at 600–1000 billion M☉ This mass in baryonic matter is estimated to include 200 to 400 billion stars.

Observe the structure of the Milky Way's spiral arms. Our Sun is in the region stretching a little out of the arm called the Local Spur. The galactic disc, which bulges outward at the galactic center, has a diameter of between 70,000 and 100,000 light-years. The distance from the Sun to the galactic center is now estimated at 26,000 ± 1,400 light-years, while older estimates could put the Sun as far as 35,000 light-years from the central bulge.

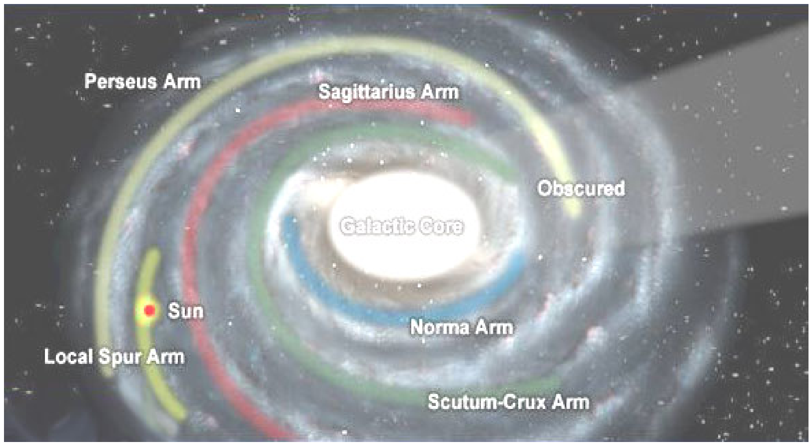


Figure 16 : Diagram showing the disk, halo and spiral arms and the constellations they appear in.

The galactic center harbors a compact object of very large mass as determined by the motion of material around the center. The intense radio source named Sagittarius A, thought to mark the center of the Milky Way, is newly confirmed to be a super-massive black hole.

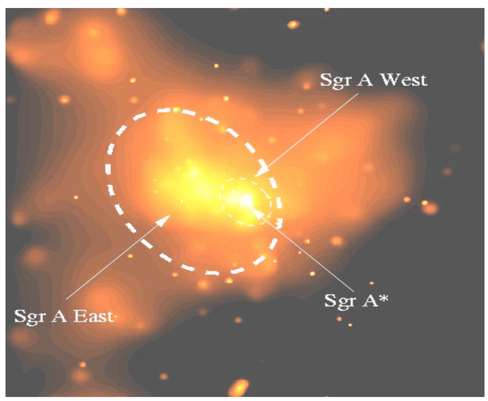


Figure 17: Galactic center as seen by Chandra X-ray Observatory

Most galaxies are believed to have a super-massive black hole at their center.

The Galaxy's bar is thought to be about 27,000 light-years long, running through its center at a 44 ± 10 degree angle to the line between the Sun and the center of the galaxy. It is composed primarily of old red stars. The bar is surrounded by a ring called the "5-kpc ring" that contains a large fraction of the molecular hydrogen present in the galaxy, as well as most of the Milky Way's star formation activity. If we were to view our Galaxy from a star in the Andromeda Galaxy, it would be the brightest feature of our own galaxy.

Currently we understand the observed and extrapolated structure of the spiral arms as Perseus Arm, Norma and Outer arm (along with a newly discovered extension), Crux Arm, Carina and Sagittarius Arm. There are at least two smaller arms or spurs, including Orion-Cygnus arm (which contains the Sun and Solar System). However, observations presented in 2008 suggest that the Milky Way possesses only two major stellar arms: the Perseus arm and the Scutum-Centaurus arm. The rest of the arms are minor or adjunct arms. This would mean that the Milky Way is similar in appearance to NGC 1365.

Figure 18: An example of two armed barred spiral galaxy - NGC 1365

The rotation of the Galaxy is still an unsolved problem. The variation of the speed of revolution of stars is depicted in a "rotation curve". Its deviation from a simple Keplarian curve is the key to the inference on dark matter. The deviation is due to either dark matter or perhaps a modification of the law of gravity.

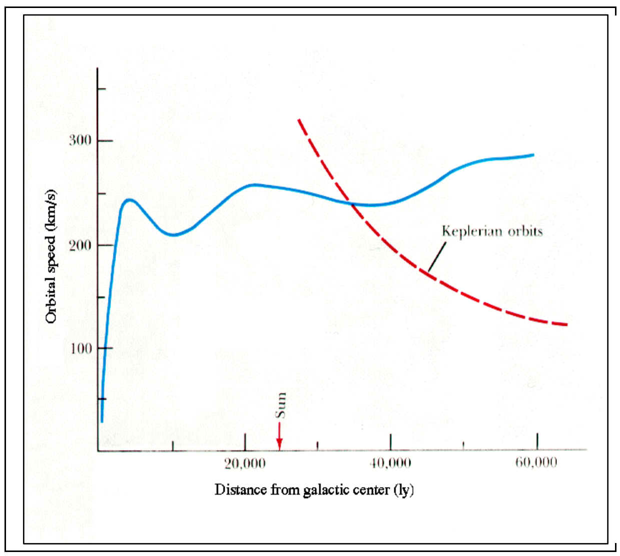


Figure 19: Galaxy rotation curve. Vertical axis is speed of rotation about the galactic center. Horizontal axis is distance from the galactic center in kpcs. The prediction based on Kepler's law is shown as dashed curve.

Let us consider the situation when the inner parts of the arms rotate faster than the outer part. As a consequence the galaxy will wind up so much that the spiral structure will be thinned out. This is the so-called "wind-up problem" of the spiral arms, a problem which is only theoretical since no galaxy is demonstrates this effect.

It has been possible to identify the spiral pattern as the result of a density wave emanating from the galactic center. This is likened to a moving traffic jam on a highway—the cars are all moving, but there is always a region of high density of slow-moving cars. This model also agrees with enhanced star formation in or near spiral arms; the compressional waves increase the density of molecular hydrogen and protostars form as a result.

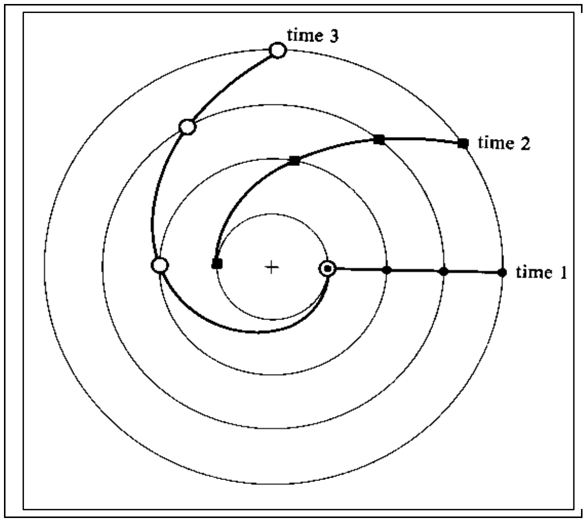


Figure 20: The winding problem – the observed motion of stars should eventually wind up the spiral arms

This aspect is corroborated by the observational evidence of star clusters. Open clusters have young, blue metal rich stars while globulars have yellow and red stars. One of the points which was instrumental in establishing the structure of the Galaxy is the fact that open clusters are mainly seen on the disc along the spiral arms, where as the globulars are seen in the halo of the Galaxy, which envelopes the nucleus. 90% of the globulars lie within 100,000 light-years. However, there are exceptions like PAL 4 and AM1 discovered recently at more than 200,000 light-years away from the galactic center. Quite interestingly about 40% of these clusters are on retrograde orbits; they move in the opposite direction from the Milky Way rotation.

While the disk contains gas and dust which obscure the view in some wavelengths, the spheroid component does not. Active star formation takes place in the disk (especially in the spiral arms, which represent areas of high density), but not in the halo as established by the distribution of open clusters.

Radio telescopes paved way for discoveries in the latter half of 21st century; extending the vastness of our Galaxy to larger limits. Our neighbor Andromeda Galaxy (M31) shows a larger extent of its disc leaving us to explore a similar possibility of the disk of the Milky Way galaxy. That led to the discovery of the Outer Arm extension of the Cygnus Arm. Another stunning discovery was that of a small galaxy called the Sagittarius Dwarf Elliptical Galaxy; and the effect of its interaction with the Milky Way leading to its distortion. Similarly, with the discovery of the Canis Major Dwarf Galaxy, it was found that a ring of galactic debris from its interaction with the Milky Way encircles the galactic disk.

Both galaxies and stars come in small sizes to which the term "*Dwarf*" is applied. A Dwarf galaxy is most commonly irregular in shape but spheroidal, elliptical and compact varieties occur. Such galaxies contain up to 2 billion stars or as few as a few thousand. Most of the stars are young. A Dwarf galaxy is usually located, as a "satellite", around a larger galaxy.

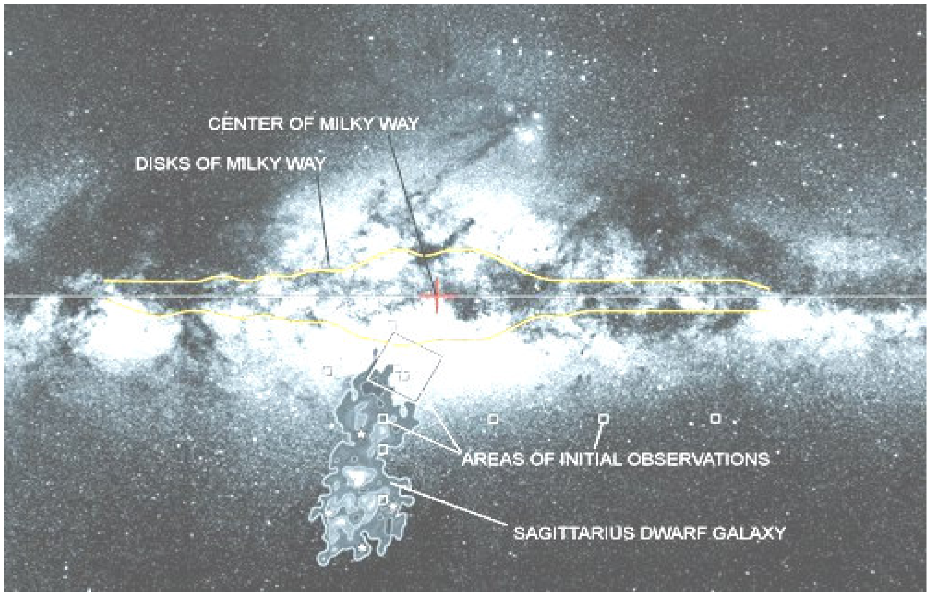


Figure 21: Location of Sagittarius Dwarf galaxy

The radio telescopes established the spiral structure from the 21 cm profiles which showed clumps of hydrogen clouds at different distances and with different velocities. Today we know that they represent the material in the spiral arms. ISM thus participates in the rotation around the center of the Galaxy.The 21cm line of hydrogen discovered in 1951 marked the beginning; subsequently radio telescopes looked at the OH line at 18cm , NH3 line at 1.3cm, H2O line at 1.4 cm and most importantly the CO line at 2.6mm . The list of molecules in the ISM is growing longer and longer.

In 2006 an analysis based on the images of the Sloan Digital Sky Survey of the northern sky showed a huge and diffuse structure (spread out across an area around 5,000 times the size of a full moon) within the Milky Way that does not seem to fit within current models. The collection of stars rises close to perpendicular to the plane of the spiral arms of the galaxy. The proposed likely interpretation is that a dwarf galaxy is merging with the Milky Way. This galaxy is tentatively named the Virgo Stellar Stream and is found in the direction of Virgo about 30,000 light-years away.

6. **Sun's location and neighborhood**

The Sun (and therefore the Earth and the Solar System) lies close to the inner rim of the galaxy's Orion Arm, in the Local Spur inside the Local Bubble, and in the Gould Belt, at a distance of 7.62±0.32 kpc (~25,000±1,000 ly) from the Galactic Center. The Sun is currently 530 parsecs from the central plane of the galactic disc. The distance between the local arm and the next arm out, the Perseus Arm, is about 6,500 light-years. The Sun, and thus the Solar System, is found in the galactic habitable zone, which is defined as the most probable zone for finding planets, that too earth like ones.

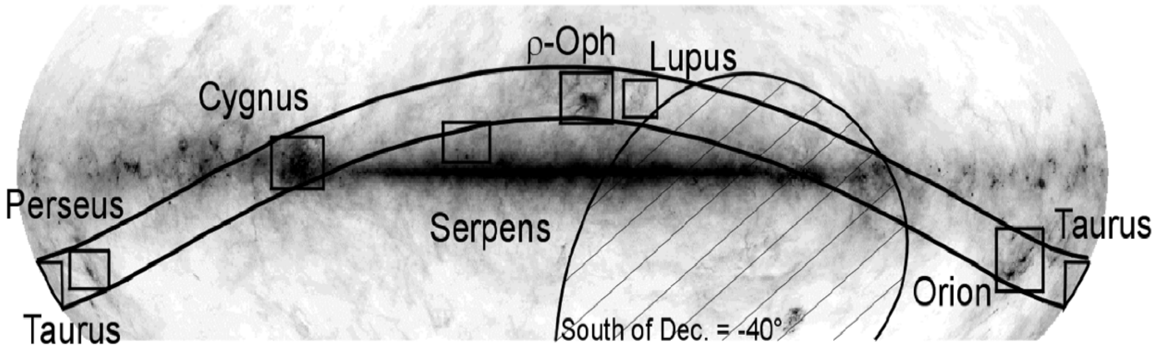


Figure 22: The Gould belt – a simple study of the distribution of stars of Galaxy showed a very interesting result. The stars are distributed in a plane which is slightly tilted to the disc of the Galaxy. This is called the Gould belt. The luminous stars (B and A type) are generally seen at very low Galactic latitudes. Their plane is slightly inclined to the plane of the disc. Lesser luminous stars (type F – M) are seen at slightly higher latitudes also. Many variable stars extend to higher latitudes. The high space velocity stars at still higher latitudes but not as high as the globular clusters which shroud the nucleus like a halo.

Let us consider the density of stars; it suffices to take in to account the most massive which are the most luminous too. There are about 208 stars brighter than absolute magnitude 8.5 within 15 parsecs of the Sun, giving a density of 0.0147 such stars per cubic parsec, or 0.000424 per cubic light-year (from List of nearest bright stars). On the other hand, there are 64 known stars (of any magnitude, not counting 4 brown dwarfs) within 5 parsecs of the Sun, giving a density of 0.122 stars per cubic parsec, or 0.00352 per cubic light-year (from List of nearest stars), illustrating the fact that most stars are less bright than absolute magnitude 8.5.

The estimates show that the Milky Way is moving at approximately 630 km per second. (Recall that moving at 600 km/s, Earth travels 51.84 million km per day, or more than 18.9 billion km per year, about 4.5 times its closest distance from Pluto.) The Milky Way is thought to be moving in the direction of what is named the Great Attractor. The Local Group (a cluster of gravitationally bound galaxies containing, among others, the Milky Way and the Andromeda galaxy) is part of a supercluster called the Local Supercluster, centered near the Virgo Cluster.

Another reference frame is provided by the cosmic microwave background (CMB). The Milky Way is moving at around 552 km/s with respect to the photons of the CMB, toward a point near the center of constellation Hydra. This motion is observed by satellites such as the Cosmic Background Explorer (COBE) and the Wilkinson Microwave Anisotropy Probe (WMAP) .

Cosmic Microwave background radiation

The cosmic microwave background is a thermal relic of a hot, dense phase in the early universe. For the first year after the Big Bang, the temperature and density remained high enough for photon-creating processes (pair creation and double Compton scattering) to proceed rapidly. The matter and radiation in the early universe were thus in thermal equilibrium. The subsequent expansion of the universe shifts the radiation to lower temperatures but does not otherwise change the spectrum: the cosmic microwave background will follow a blackbody spectrum.

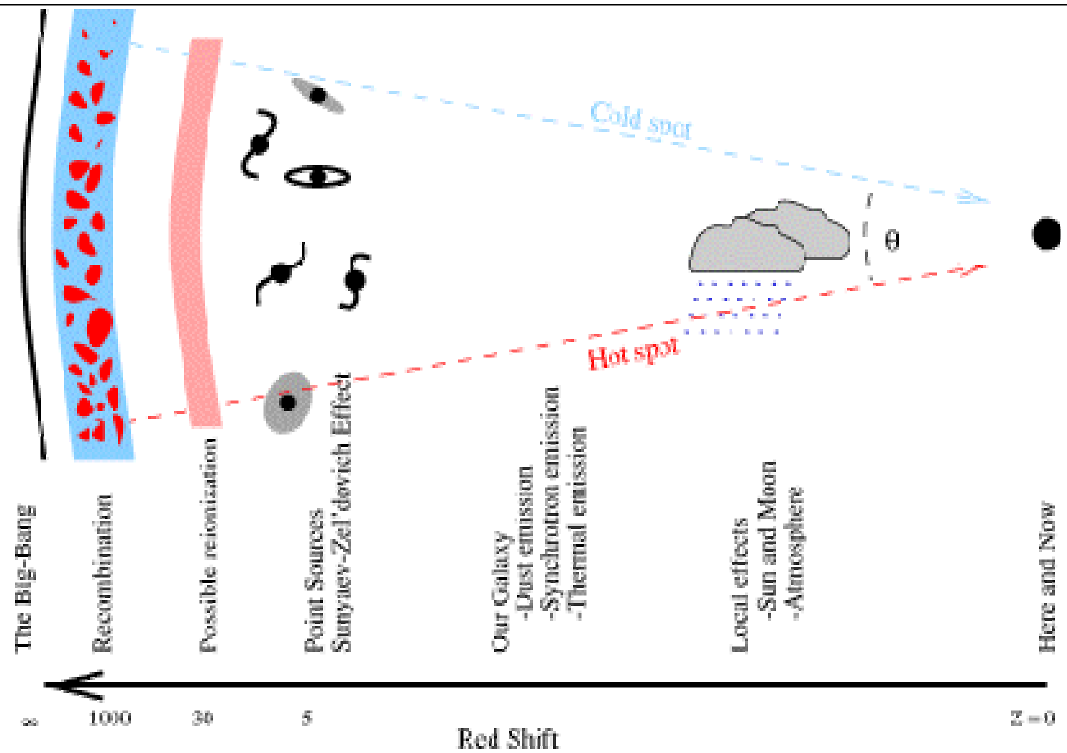


Figure 23: The time line from the origin of universe

7. **Local group ; Andromeda-Milky Way collision?**

We have evidence of interaction with other galaxies in the outside of the major spiral arm as the Monoceros Ring (or Outer Ring); this is a ring of gas and stars perhaps torn from collision or interaction with other galaxies billions of years ago.

The Milky Way and the Andromeda Galaxy appear like a binary system of giant spiral galaxies belonging to a group of 50 closely bound galaxies known as the Local Group, which itself is a part of the Virgo Supercluster. Two smaller galaxies and a number of dwarf galaxies in the Local Group orbit the Milky Way. The largest of these is the Large Magellanic Cloud with a diameter of 20,000 light-years. It has a close companion, the Small Magellanic Cloud. The Magellanic Stream is a peculiar streamer of neutral hydrogen gas connecting these two small galaxies. The stream is thought to have been dragged from the Magellanic Clouds in tidal interactions with the Milky Way.

Some of the dwarf galaxies orbiting the Milky Way are Canis Major Dwarf (the closest), Sagittarius Dwarf Elliptical Galaxy, Ursa Minor Dwarf, Sculptor Dwarf, Sextans Dwarf, Fornax Dwarf, and Leo I Dwarf. The smallest Milky Way dwarf galaxies are only 500 light-years in diameter. These include Carina Dwarf, Draco Dwarf, and Leo II Dwarf.

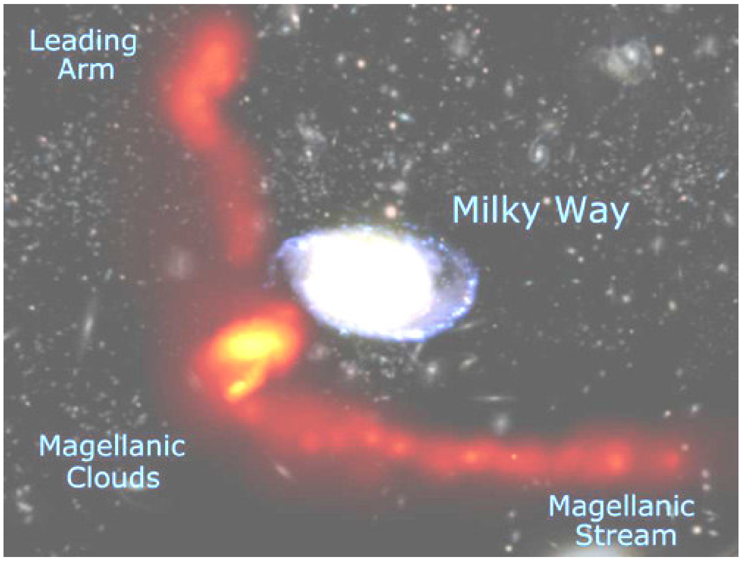


Figure 25: The Magellanic Stream

There may still be undetected dwarf galaxies, which are dynamically bound to the Milky Way, as well as some that have already been absorbed by the Milky Way, such as Omega Centauri. Observations through the zone of avoidance are frequently detecting new distant and nearby galaxies. Some galaxies consisting mostly of gas and dust may also have evaded detection so far.

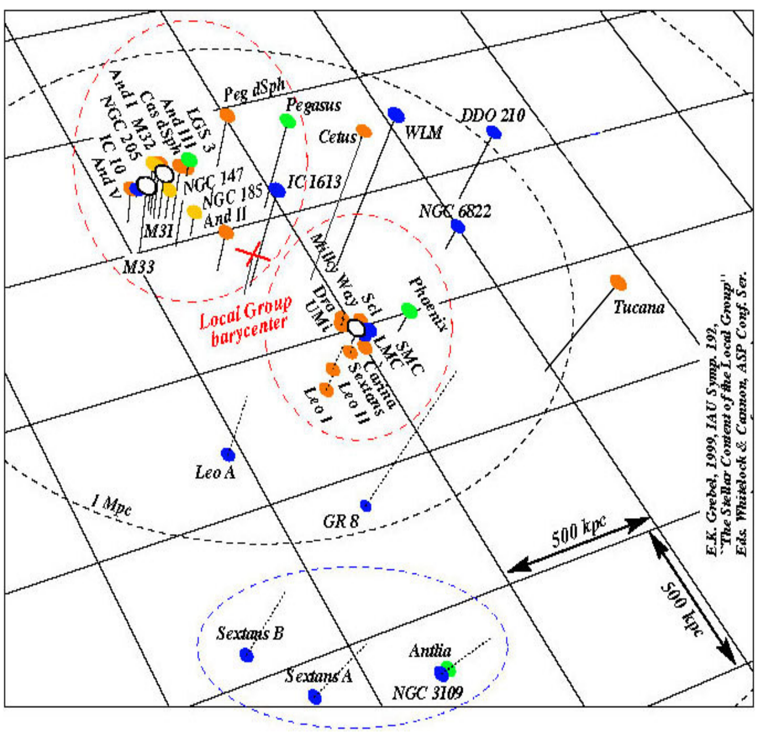


Figure 26: The Local Group of galaxies which includes the Milky Way

In January 2006, researchers reported that the unexplained warp in the disk of the Milky Way has now been mapped and found to be a ripple or vibration set up by the Large and Small Magellanic Clouds as they circle the Galaxy, causing vibrations at certain frequencies when they pass through its edges. Previously, these two galaxies, at around 2% of the mass of the Milky Way, were considered too small to influence the Milky Way. However, by taking into account dark matter, the movement of these two galaxies creates a wake that influences the larger Milky Way. Taking dark matter into account results in an approximately twenty-fold increase in mass for the Galaxy. This calculation is according to a computer model ; the dark matter is spreading out from the galactic disc with the known gas layer. As a result, the model predicts that the gravitational effect of the Magellanic Clouds is amplified as they pass through the Galaxy.

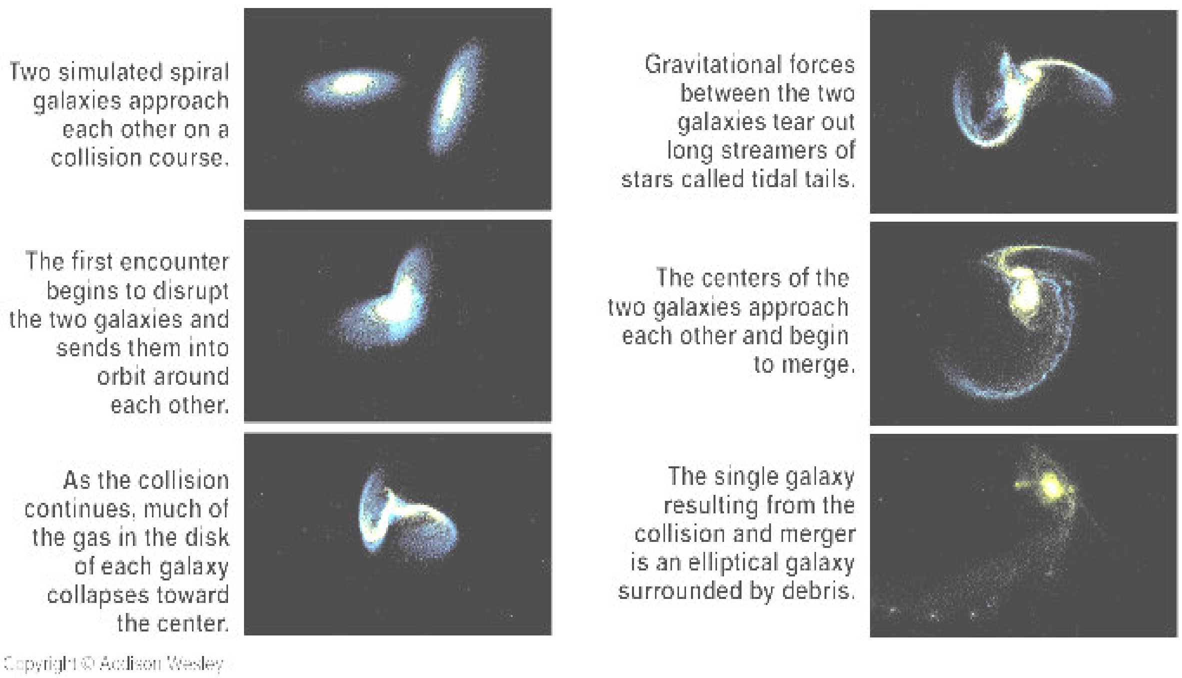


Figure 27: Simulation of collision of the Milky Way Galaxy and Andromeda galaxy

Current measurements suggest the Andromeda Galaxy is approaching us at 100 to 140 kilometers per second. The Milky Way may collide with it in 3 to 4 billion years, depending on the importance of unknown lateral components to the galaxies' relative motion. If they collide, individual stars within the galaxies would not collide, but instead the two galaxies will merge to form a single elliptical galaxy over the course of about a billion years.

That is a long way to go!

Study material prepared by B S Shylaja, Jawaharlal Nehru Planetarium, Bangalore, for "Galaxy Forum, India – Bangalore, Astronomy Education in 21st Century- Our place in the Milky and Beyond" August 9, 2010.

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