Characteristics of Our Galaxy

*The Composition, Structure and Evolution of the Milky Way*

**Abstract:** Galaxies are the main constituents of the Universe. On a grand scale, they are like atoms or cells; the things that we who live and operate on smaller scales see as basic constituents. This paper seeks first to introduce galaxies, explain their stellar and interstellar compositions and their structure in general. Then it focuses in on our Galaxy, examining the specific structure and composition of the Milky Way. Finally, a most probable formation scenario for the early stages of the evolution of the Galaxy is proposed.

1. Introduction

The Universe as we know it consists of mostly empty space with intermittent lumps of matter, radiation, and gravitational forces. While 98% of matter is believed to be Dark in nature, 90% of which is believed to be composed of non-baryonic particles, the 2% of all matter in the Universe which we can directly detect, known as Baryonic Luminous Matter, exists almost entirely in the form of galaxies.\(^1\) These fundamental entities contain large groups of bound stars, small non-stellar objects, planets, different amounts of dust and gases, and even black holes held together by mutual gravitational attraction. The galaxies themselves are often clustered together with various clusters interspersed throughout space like the particles in a shaken snow-globe, only much less densely scattered, as on the whole, the boundaries of clusters of galaxies, when extrapolated and summed, are believed to take up only a mere 5% of all space\(^2\).

It is commonly believed that most galaxies formed within the first billion years following the Big Bang. Early quantum fluctuations led to non-homogenous distributions
of gas, which in turn accumulated under mutual gravitational attraction to form many
different galaxies as opposed to just one humongous structure. Some new galaxies form
today out of collisions and interactions between existing galaxies.\(^3\)

Our home, the planet Earth, orbits the Sun along with Mercury, Venus, Mars,
Jupiter, Saturn, Uranus, Neptune, and Pluto. The Sun, the eight major planets, Pluto, and
various small bodies such as dwarf planets, moons, comets, and asteroids locked into
gravitational orbits with the Sun and planets comprise our Solar System. Our Solar
System is centered around the Sun, one of the 200 billion stars that comprises the Milky
Way Galaxy. As we on Earth orbit around the Sun every 365 Earth days, the Sun orbits
around the Galactic Center every 220 million Earth years!

Galaxies are distributed and arranged in aggregates of various sizes. There are
small groups, large clusters, and superclusters. The Milky Way Galaxy is part of the
Virgo supercluster which is comprised of nearly 300 galaxies. Our Local Group consists
of approximately two dozen galaxies. The Andromeda Galaxy is our closest neighbor at
2.5 million light years away, and it like the Milky Way is spiral in nature. Often visible
in the southern sky are the Small and Large Magellanic Clouds—two irregular galaxies
that orbit our own.

Because it is our home, the Milky Way Galaxy is near and dear, and of profound
astrophysical importance. That the Milky Way Galaxy should be studied closely is an
undeniably a priori fact. However, astrophysicists the world over have come to
understand that because of our internal vantage point, the study of our Galaxy is tricky
business. Unlike our birds-eye view of Andromeda, our view of the Milky Way is like
that of a person somewhat lost in a dense forest with no map. Thus, to best understand
the structure, composition, and evolutionary characteristics of the Milky Way it is important to not only conduct ground-based and space-based observations of our Galaxy but it is also to study other galaxies as well.

While the study of the Milky Way Galaxy seems like a specific task, to truly explain its past, present, and future, and to truly understand its essence, requires one to address nearly everything but the question of multiple universes. While this is too much for the present paper, and far more than even the best astronomers can fully grasp, we can layout the basic suggestion of transformative events that ultimately gave rise to the Milky Way Galaxy as we know it today. In the beginning, assuming there to have been a Big Bang, quantum fluctuations during the inflationary epoch created large-scale inhomogeneities throughout the Universe. These low-amplitude irregularities quickly amplified into proto-galactic clumps. The first task is to understand exactly what was formed during the tumultuous beginning of the Universe. For example, how did the non-baryonic dark matter first congeal into galaxy-size entities. The next step is to understand when, how, and in what quantities was baryonic matter—gas and dust—finally formed. What was the temperature of this stuff? What kind of internal, gravitational, and kinematic energy did it possess? Next, given this knowledge, one must figure out how all the random gas and dust accumulated into the massive clumps of matter we call galaxies. What processes, such as star formation, occurred, and at what rates did it occur at the same time the galaxies were still forming? How did the initial conditions of the constituent gas and dust affect what the structure of the Galaxy would become? How did the cosmic transformative processes that occurred at the same time as the Galaxy was
formed affect the structure of the Galaxy? How did nearby accumulating clumps affect the clump in question?

Obviously, these steps involve many variables and years of research in order to make significant progress. As scientists, we look for pieces of the puzzle, and occasionally great minds see ways to assemble them into coherent paradigms of physical reality.

While the set of steps to a “True and Complete” understanding of our Galaxy is beyond painstaking, the same general idea can be followed to produce a very useful and informative result. We must first look at the composition of galaxies to see what they are made of. We then will look at what types of galaxies were sculpted using the generalized composition as clay. We will then get into the specific characteristics of the Milky Way, and finally try to make some inferences and consider some examples that explain how our specific Galaxy may have come to be.

2. The Composition of Galaxies

Galaxies are the main constituents of the Universe. Before understanding what physical processes gave rise to the magnificent and puzzling beasts that galaxies are, it is important to know first and foremost what material existed prior to their formation; the stuff that ultimately became them.

Our Galaxy contains $10^{37}$ tons of interstellar gas, which is just about what we’d need to make 10 billion stars the size of our Sun. The density of atoms in the Galaxy is about 1 atom per cubic centimeter. In the Milky Way Galaxy, each of the 200 billion stars spread over 100,000 light years is like a grain of sand separated from the nearest
grain of sand by 10 km.² Space is as close as you could ever get to a true vacuum. Yet at
the same time, stuff still exists there!

The stuff contained in galaxies falls into four categories: Interstellar matter, stars
and planetary systems, stellar remnants, and dark matter. Here, we will consider only the
interstellar and stellar components.

2.1 The Interstellar Medium

2.1.1 Gas in the ISM

The interstellar medium comprises the space between stars, or simply put, all
interstellar matter. Hydrogen is far and away the most common element in the
interstellar medium. Interstellar Hydrogen exists in three forms in various abundances
and at various temperatures; molecular (H₂), atomic (H⁰ or HI), and ionized (H⁺ or HII).
Molecular Hydrogen is a poor emitter, but can be traced by virtue of the profuse
emissions from interacting CO molecules at mm wavelengths. Atomic Hydrogen, also
known as “neutral Hydrogen” is associated with a 21 cm wavelength spectral line that
allows it to be easily detected throughout the Galaxy. Atomic Hydrogen exists both as a
homogenous expanse of gas and in dense clouds. Ionized gas, especially Hydrogen,
accounts for most of the baryonic mass and occupied volume of the Universe⁵. There are
also other elements in the ISM but they’re quantities are all defined in terms of
Hydrogen; the relative abundance of some element is ratio of the number of atoms of that
gas as compared to the number of atoms of hydrogen in the same volume of space.
Interstellar Helium exists in large abundance throughout space as well. In HII regions
there is approximately one He atom for ever 10 H⁺ atom. One the whole there is
approximately 40% as much Helium in the Universe as Hydrogen.⁶ Heavy elements such
as carbon, nitrogen, oxygen, neon, sulfur, chlorine, and argon are also somewhat abundant in the ISM, although at fractions ranging from one ten-thousandth to one-millionth the amount of Hydrogen. There also exists an extremely hot and thin type of ionized gas in the ISM known as coronal gas. Coronal gas, at 1,000,000 K, is 100 times hotter and no less than 100 times thinner than gas in HII regions. This gas is ionized by collisions among its own constituent particles as opposed to high-energy photons from stars. It is extremely difficult to detect yet could perhaps be the most widespread form of interstellar matter in our Galaxy. Ultimately, gas is extremely useful to astronomers as their emission spectra can be observed and information interpreted in terms of temperature, densities, and relative abundances.

2.1.2 Dust in the ISM

While dust only constitutes fewer than 1% by mass of the ISM, it has a great effect on the flow of electromagnetic radiation throughout galaxies, it is pivotal in the heating of interstellar nebulae, and it plays a major role in star formation. Knowing the dust content of a given galaxy has huge implications on how that galaxy was formed, and what kinds of transformative processes are occurring inside it. Dust grains range from .005 micrometers in size to .1 micrometers, and they range from graphite particles and silicate particles, to various frozen compounds (water, ammonia, etc.), to polycyclic aromatic hydrocarbons or PAHs. PAHs consist of multiple hexagonal benzene rings (C₆H₆) bonded together and assembled into flexible sheets. Usually consisting of 10-50 Carbon atoms total, PAHs are remarkably stable and able to “survive” in interstellar space.

2.1.3 Metals in the ISM
In the process of star formation, the onset of thermonuclear fusion in the dense stellar core marks the beginning of a star’s main sequence life. Massive stars host especially hot and dense cores which are able to undergo successive nuclear fusion reactions forging elements all the way up to iron. When a massive supergiant dies and explodes as a supernova, the explosions are so intense that more fusion goes on and elements as heavy as uranium are created. Thus, in areas with lots of massive stars forming, metallicity is usually quite elevated. The more massive star formation that has transpired in a galaxy or part thereof, the more chemically evolved is that galactic parcel.

2.1.4 Radiation in the ISM

Radiation permeates the ISM in the form of electromagnetic waves that span the entire spectrum, from infrared and radio waves, to higher energy cosmic rays and gamma rays. While the radiation pressure (and thus gravity) of this radiation does add to the kinematics of a galaxy, the greatest impact the radiation has is it’s occasional interaction with gas and dust; photons traveling with 13.6 eV of energy can ionize neutral hydrogen. Lower-energy UV photons can excite molecules (especially PAHs) and can heat up dust grains which will give off IR radiation.

2.2 Stellar Constituents

2.2.1 Stars in the Disk

Stars in the Disks of galaxies tend to have specific recurring characteristics. Disk stars, also known as Population I stars, range from very young spiral arms stars, to young thin-disk stars, to intermediate aged disk stars.

Most of the Galactic gas and dust is located in the spiral arms. Young, spiral arm stars are usually less than 100 million years old. O and B stars, supergiants, Cepheid
variables (useful for judging distances), pre-main sequence stars, T-Tauri stars, Herbig-Haro objects, and even some A stars can be found in the arms. These stars are very metal rich and have highly circular orbits, although they comprise likely less than one percent of Milky Way stars.

Young thin disk stars are generally around one billion years or more in age. They have orbits of low eccentricity. They are mostly A and F stars, A,F,G,and K giants, some main-sequence dwarfs and white dwarfs. They are very metal rich, although less metal rich than those in the spiral arms.⁹

Intermediate-aged stars such as our Sun, most G and some K and M dwarfs, and various subgiants and red giants tend to be scattered throughout the general plane of the disk. The stars are often as old as five billion years and general have metallicities similar to young thin disk stars. They have fairly eccentric orbits.

### 2.2.2 Stars in the Halo

Stars in the Halo are very different than stars in the disk. They are often termed Population II stars. They are old and red, most between 10 and 14 billion years old (close to the age of the Galaxy). They show little if any structured or symmetric movements, and have highly eccentric orbits, although they do orbit at speeds comparable to the speeds at which disk stars at comparable distances from the center rotate. The Halo stars are believed to have formed very early on in the formation of the Milky Way and other galaxies; star formation has likely not occurred there for several billion years. Halo stars are also incredibly metal poor, consisting on average of less than .1% metal, which contrasts the Population I stars that tend to have metallicities of 2-3%. The low metal content of the halo stars is consistent with their old age.
2.2.3 Stars in the Bulge

Stars in the center of our Galaxy, the Bulge, are similar to those in the Halo. They are usually Population II stars, although they are less metal poor than the stars in the Halo. Most of the stars in the Bulge are 5-7 Billion years old, although there are also stars as young as 500 million years old. They tend to have the same type of 3-dimensional, non-planar, strange orbits that the Halo stars have.

3. Galactic Structure

3.1 Basic Overview of Galactic Structure

For many years scientists have tried to estimate the total number of galaxies in the Universe. While the estimates vary, they tend to lie in the range of several hundred billion. In 1999, the Hubble Space Telescope estimated that the total was in the range of 125 Billion.\(^{10}\) For our purposes, whether the number is 125 Billion or 250 Trillion is a moot point. What matters is that we understand the scale. HUGE! Given so many galaxies it is no surprise that galaxy classification is simultaneously complex and imperfect. Nonetheless, standard classifications do exist, and there are several basic constituents of all galaxies.

3.1.1 Basic Constituents of Galaxies

In the same way that different houses are built out of many of the same structural components, different galaxies are composed of similar components with varying characteristics. Galaxies can have 3-dimensional shapes like ellipsoids and spheres, they can be disks, or they can be irregular, lacking any particular specificity to the arrangement of matter. They can contain stellar bars, bulges and arms, and are often
surrounded by a spherical halo of stars, hot gas and dust. The center is often called the nucleus, and like the nucleus of an atom, it is the most dense part of the galaxy.

3.2 Common Galactic Structures

The primary types of galaxies are Elliptical, Lenticular, Irregular, Peculiar, and Spiral, the latter of which includes the Milky Way. To understand what the structure of our home is, first we will discuss what it isn’t.

3.2.1 Elliptical Galaxies

Elliptical Galaxies have a smooth three-dimensional shape, and can range from very eccentric ellipsoids to near spheres. Elliptical galaxies often lack in any large-scale internal structure; except for radial density gradients (which may vary triaxially). The stellar density of elliptical galaxies increases sharply from the edge of the galaxy to the nucleus. There are two main types of ellipticals; boxy and disky. Boxy ellipticals have a rectangular distribution of light in their centers, whereas disky ellipticals have a slower fall-off of brightness and thus greater stellar densities in their outer regions by comparison. Disky ellipticals rotate whereas in Boxy ellipticals rotational motion is kinematically trivial, as there is little net rotation of the galaxies on the whole nor of the matter within them.\(^{11}\) Ellipticals are designated by the letter E, followed by a number ranging from 0 to 7 that relates to how elliptical they actually appear in the sky. E0 ellipticals are nearly circular, while E5 ellipticals have a major axis twice as long as their minor axis. While we designate ellipticals by how eccentric they actually appear in the sky, in actuality we may be missing their true 3-dimensional structure, as the type of elliptical galaxy depends not only on its inherent shape but on its orientation in space relative to our line of sight. For instance, a truly cylindrical galaxy seen on end will look
circular. While this complicates matters in terms of understanding the true nature of a galaxy, in terms of classification all that really matters to us is what we see; given that distances between galaxies are so great it is unlikely that we will ever get a appreciably different vantage point and thus astronomers work with what they can. The sizes of elliptical galaxies and their stellar contents vary widely, ranging from the most common dwarf ellipticals containing fewer than one million stars spread across 1 kiloparsec, to rarer giant ellipticals which can be as much as 10 times more massive than the Milky Way. Ellipticals contain little cool gas and dust, and appear to have stopped undergoing star formation. They contain mostly old, red, low-mass stars that orbit the galactic center in a highly disorderly fashion, without regard to a common plane or direction.

3.2.2 Spiral Galaxies

Spiral Galaxies are among the most lively to study, and the Milky Way is no exception. Spiral galaxies are characterized by the majority of stars organized in a flattened galactic disk with a central bulge. The disk itself is structured into a relatively dense configuration of spiral arms with fewer stars in the interarm region. The arm-interarm density contrast is typically small (a few percent) but is made more prominent by the luminous young OB type stars that adhere closely to the arms. The bulge may or may not contain a bar. A halo of old, dim stars surrounds these elements. The disks are in general thinner than the lens of a lenticular galaxy. The degree to which the arms spiral is defined by their pitch angle (how tightly they are wound), and there is generally a direct relationship between bulge size and pitch angle. What makes Spiral Galaxies so interesting, aside from their pleasing appearance, is that the flat disks are usually full of gas and dust, allowing for rapid and frequent star formation to occur in the arms. Even
more interesting is that the rate of star formation is a near linear function of the density of gaseous material, and has little to do with the actual age of the galaxy itself. Thus, older galaxies like the Milky Way can continue to form new stars as long as they have conserved or acquired a significant store of gas.

Spirals are classified as Type Sa, Type Sb, or Type Sc. Sa spirals have the largest bulges, tightest windings, and the least interstellar gas for star formation. Sc spirals have the opposite qualities; somewhat indistinct, loose arms but lots of star formation. Spirals with bars of stellar and interstellar matter intersecting the bulge and extending to the halo are classified as SBa, SBb, and SBc. The existence of a bar causes the arms to extend from near the ends of the bar as opposed to from the bulge itself.

3.2.3 Lenticular Galaxies

Lenticular galaxies are similar to ellipticals but most of their mass exists in a flattened disk of stars with little structure and no distinct arms. Most lenticulars are comprised of a massive bulge surrounding a central nucleus with a lens (disk) that extends beyond the bulge. Unlike regular ellipticals, they are often characterized by a bar of matter intersecting the bulge, within the plane of the lens. They also have an outer extent, or halo. Like the ellipticals, lenticular galaxies contain low mass stars and little to no gas, consistent with their slow current star formation.

3.2.4 Irregular Galaxies

Irregular Galaxies, also known as dwarf galaxies, are usually much smaller than the giant elliptical or spiral galaxies. They are generally classified as either Type I Irregulars, which are low mass galaxies characterized by slow rotation about a small nucleus with no definite disk structure, or Type II Irregulars, characterized by little
structure and frequent interactions which occasionally results in intense starformation, or *starbursts*. Typically, irregular galaxies contain $10^8$ to $10^{10}$ stars, putting them just above dwarf ellipticals in terms of star content. The most common irregular galaxies are called *dwarf irregulars*. Like the Small and Large Magellanic Clouds, which are large irregulars, they are often located in proximity to parent galaxies, the Milky Way acting as parent to the Magellanic clouds at a distance of about 50 kiloparsecs away. Together, dwarf ellipticals and dwarf irregulars comprise in near equal amounts the majority of galaxies in the known Universe.

### 3.2.5 Peculiar Galaxies

Peculiar galaxies are exactly as they sound; strange. The most studied and important of these galaxies are QUASARS, or Quasi-Stellar Radio Sources. Quasars are extremely bright and can have strong nonthermal emission at radio and optical wavelengths. When observed they represent point sources rather than galaxies. Divided into two categories, Quasars are either QSOs characterized by strong optical emission lines, or QSRs, characterized by strong radio emission lines. It has been thought that Quasars, despite appearing as point sources, are just the extremely bright cores of very active galaxies, and they simply shine so bright as to make it nearly impossible to resolve the galaxy around the core. Today it is accepted that Quasars are in fact extremely compact halos of matter surrounding the central supermassive black holes of young distant galaxies. In fact, Hubble Space Telescope images have now been able to resolve the surrounding galaxies.

### 4. The Structure and Evolution of the Milky Way Galaxy
Advances in technology and observations of other galaxies have given scientists large amounts of information with which to use in order to explain the place that we live. By studying galaxies like Andromeda and NGC 4565 and relating our findings to observations of our own spiral Galaxy we’ve learned quite a lot. Our galaxy consists of approximately 200 billion stars and various interstellar matter confined to a planar disk with a large bulge in the middle. The disk and bulge are surrounded by a spherical shell of dim, old stars, known as the galactic halo. These are the three main regions of our galaxies. There is also the strong possibility that a bar exists rather than a simple bulge.

4.3.1 Disk, Bulge, Bar, and Halo

The disk of the Milky Way Galaxy is approximately 30 kpc in diameter, and varies in thickness. Near our Solar System the stellar disk appears around 300 pc thick. Most star formation is confined to the thin disk, approximately 100 pc thick. While stars and interstellar matter exist beyond the 15 kpc radius and greater than 150 pc above and below, the majority of matter is confined to the above defined region.

The Bulge of the Galaxy is approximately 6 kpc in diameter by 4 kpc thick. Recent measurements of the kinematics of stellar and interstellar matter near the bulge suggest that the bulge is actual shaped more like a football than a diskus; approximately twice as long as it is wide, with the long “side” of the football lying parallel to the disk. This suggest that we may live in an SBB or SBc Type galaxy.

By studying variable stars in globular clusters, 20th century astronomer Harlow Shapley diskovered that the globular clusters were arranged in a spherical halo. His insights led modern astronomers to conclude that the halo has an approximately 30 kpc diameter, centered 8 kpc away from our Solar System, in the direction of the constellation
Sagittarius. While Shapley’s numbers were overestimated, he still realized that the center of the spherical halo was a number of kpc away from our location, and intuition led him to realize that the Globular clusters had indeed mapped out a halo, and that the center of that halo corresponded to the Galactic center, which as stated above we now know to be approximately 8 kiloparsecs away from us, in the direction of Sagittarius. Nowadays this assumption is corroborated with the fact that the center of the distribution of 21-cm atomic hydrogen emission line lies just about where Shapely believed the Galactic center to lie. Furthermore, theory would predict that during the formation of the Milky Way, gas and dust was first spread out over a much larger, more diffuse volume than now. As star formation occurred concurrently with the gravitational accumulation, the first stars were left behind in what is now a halo, with random motions due to the lack of a substantial disk at their birth. By the time the gas and dust collected and due to rotation accumulated as a disk, there was already a halo of aging stars surrounding the Galaxy. Once a dense disk was formed, newly formed stars in the disk would be “locked” into a “structured” orbit as we observe them today.

There are vast differences between the three main components of our Galaxy, not just in structure/appearance but also in makeup. Unlike the disk and bulge, the halo contains very little interstellar matter, only trace amounts of gas and dust, so no star formation occurs there. Whereas the disk appears bright because of bluish-white O and B type blue supergiants, the stars in the halo and bulge, G, K, and M type dwarfs are much redder. All star formation occurs in the disk. Cooler, redder, older stars seem to be spread evenly throughout the three components, whereas young hot stars dominate the disk. At the interior of the bulge and throughout the disk, intense star formation occurs,
thus stars of all ages can be found. The lack of interstellar matter in the halo and the age of the stars that comprise it suggest that no star formation has occurred there for over 10 billion years. Furthermore, the high abundances of metals in the disk versus the relatively low metallicity of the halo indicate that star formation, which by nucleosynthesis leads to an increase in metallicity over time, has stopped in the halo and has stayed that way for quite some time. While the range of stellar ages varies widely as one moves radially outward from the galactic center in any direction, especially along the plane, the types of stars in the Galaxy are generally classified as members of one of two populations. Population I stars are the “young” stars in the disk. Population II stars are the old halo stars.

4.3.2 The Arms of the Milky Way

While the spiral structure of the Galaxy is difficult to discern, especially since one must contend with the absorption and scattering of radiation by interstellar matter when looking towards the plane of the Galaxy, astronomers have succeeded in developing models of what the actual spiral structure of our galaxy is, or, what exactly characterizes our galaxies arms. These models, however, have yet to converge into a common consensus on the Milky Way’s final structure!

Spectroscopic radio astronomy allows us to make precise measurements of gas densities which can in turn give us an idea of the location and arrangement of the arms. Extremely low frequency and hence long wavelength radio waves are able to travel more or less unaltered through the Galactic disk as they are unaffected by interstellar matter. As hydrogen is the most abundant form of interstellar matter in the Galaxy, the 21-cm emission lines corresponding to atomic hydrogen are strong and ubiquitous. Thus, since
different parts of the disk of our galaxy are rotating at different rates, we can create models, discern distances, and ultimately study the Doppler shifts of the 21-cm emission in order to determine the densities and rotation rates of virtually any clumps in the Galactic disk. The “kinematic” distances, however, are prone to large errors, thus making the specification of any spiral configuration highly uncertain.

Studies of the Galactic disk indicate that the spiral arms of our Galaxy are composed of a whole range of different objects: gas, dust, O stars, B stars, emission nebulae, and open clusters. Depending on what sources you use or who you talk to, our Galaxy could have 2, 4, or even 6 spiral arms. While we don’t know how many we have, we know that in our Solar neighborhood, the density is approximately .1 sun-like star per pc$^3$. As one proceeds towards the Galactic center the number drops as we enter an interarm region, then rises again, eventually reaching an unbelievable density of 10 million stars per cubic parsec. The “interarm” region between our arm and the next spiral arm is not incredibly large. Overall, our Galaxy appears to have an arm separation of approximately 1-2 kpc, and a pitch angle of 12 to 25 degrees. Calculations and inferences like this are what give us an idea of how many arms we have and how they are arranged.

One of the big unsolved mysteries of spiral structure is how structure is maintained over time. Over millions of years, because of differential rotation, the pitch angle of the arms should increase, and a spiral should eventually have more and more turns until it looks like a bulls eye. A leading theory to explain this endurance of structure tries to characterize the arms as spiral density waves. These are waves of coiled
gas compression that sweep through the Galactic disk, triggering star formation as they sweep into and “squeeze” interstellar gas clouds.

4.3.3 Formation Scenarios

The Milky Way most likely formed by the merger of several smaller systems of gas, dust, and young stars. As the individual systems accumulated under their mutual gravitational attraction to form an amorphous blob of gas, dust, and young stars, star formation began to take place inside the centers of smaller systems which lived at the edges of the slowly accumulating blob. With time, the irregular shaped galaxy balanced out and gas and dust spread into the plane of our Galaxy while forming a spinning disk which compensates for the conservation of angular momentum. The previously formed stars were left behind in the halo (the “edge of the blob”) with no preferred path in which to move due to no defined center of attraction. New stars forming in the disk inherit the disk’s overall rotation and thus orbit the Galactic center with structured circular orbits. This accounts for the bulge, the disk, the halo, and the division between Population I and Population II stars based on the different epochs at which they were formed. This also leads to the possibility of learning where the several smaller systems emerged from by observing and comparing the old stars in the halo in various nearby galaxies as well as in our own.

3 Ibid
4 Ibid

6 Ibid. P56.
7 Ibid P54.
8 Ibid P76.


12 Elmegreen
13 Ibid
14 Ibid
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