Chapter 21 - The Milky Way Galaxy: Our Cosmic Neighborhood

Chapter Preview

- The Universe is composed of billions of galaxies; each galaxy in turn contains billions of individual stars.
- The Milky Way, a band of faint stars that stretches across the dark night sky, is the galaxy in which we live.
- Until the early part of the twentieth century it wasn’t clear that our own Milky Way wasn’t our entire Universe.
- One of the major scientific and cultural advances of this century is the development of a clear picture as to the size and content of our Universe.
- We will begin by studying the Milky Way which we can use as a model for studying
other galaxies in the same way that we use the Sun, our nearest star, as a basis for studying other stars.

Key Physical Concepts to Understand: *structure of the Milky Way and other spiral galaxies, imaging galaxies at different wavelengths, mass determination of the Milky Way, density wave theory of spiral structure, self-propagating star formation*

I. Structure of the Milky Way

**Figure 1.** A drawing of the Milky Way made under the direction of Knut Lundmark of the Lund Observatory, Sweden. This drawing contains over
seven thousand stars. P 512-29.16 & APOD.
In about 400 BC, the Greek philosopher Democritus first attributed the Milky Way to unresolved stars (and was also the first to hypothesize the existence of the atom (Chapter 14, Section IV)).

In 1610 Galileo, among his other pioneering efforts with the telescope, first resolved the Milky Way as a band of countless faint stars (Figure 1).

In the 1780s, the German composer and musician William Herschel built a 1.2-meter telescope, the largest telescope in the world until the 1840s (Figure 2).

He probed the three-dimensional structure of the distribution of stars in the sky by assuming that faint stars were the same as brighter stars, only more distant.

From this evidence he deduced that the Sun is at the center of a disk of stars (Figure 3).

In 1930, the American astronomer R.J. Trumpler determined from analysis of H-R
diagrams of open star clusters that the stars in some distant clusters were fainter than he thought they should be, based on the apparent size of the cluster.

- He concluded that there must be obscuring dust concentrated in the disk of the galaxy. Indeed patches of obscuration are seen in wide-field photos of the Milky Way (Figure 4).
- In 1912, Harvard astronomer Henrietta Leavitt published a paper on the relationship between the period of variation of brightness and the luminosity of RR Lyrae variable stars (see also Chapter 24, Section IV).
- In 1981 Harvard astronomer Harlow Shapley used the period-luminosity relationship of RR Lyrae stars to determine the distance to 93 globular clusters. (Figure 5).
- Shapley concluded that the Earth, which was shown by Copernicus and others not to be at the center of our Solar System, was now evidently not at the center of our galaxy either.
Figure 2. Herschel’s 1.2 m (49.5 inches in diameter, 40 feet in length) telescope.
Figure 3. A schematic of the Milky Way showing the disk, bulge, position of the Sun, and the halo composed of globular clusters. P 505-29.6.

Figure 4. A wide-angle photograph of the Milky Way toward the galactic center. This photograph shows 50&deg; of sky. The dark vertical region is a result of dust absorption in the disk of the galaxy. FMW 491-24.13.
Figure 5. A halo of globular clusters outlines the Milky Way. This diagram shows the distribution of globular clusters in the Milky Way along with the position of the Sun and the assumed galactic center. FMW 483-24.4.
II. A Roadmap of the Milky Way

- In the 1930s, Karl Jansky worked for Bell Telephone Laboratory trying to track the origin of radio noise that interfered with telephone communications. In building and using an antenna that is credited as the first
radio telescope, he discovered a strong signal from the Milky Way (Figure 6).

- The advent of radio astronomy was of great importance in studying our own galaxy. The study of the Milky Way is perhaps the only case in astronomy where the study of an object is made more difficult by our proximity to it.
- The Milky Way is transparent to long wavelength electromagnetic radiation, including radio and infrared wavelengths.
- Radio mapping of our galaxy has been used to determine our distance to the nucleus by measuring the Doppler shifts of radio emission from orbiting clouds of hydrogen gas.
- The distance of Sun to the galactic center is about 8,500 parsecs or 28,000 light years. While the interstellar dust is too opaque to allow us to view the center of our galaxy at visible wavelengths, long wavelength radiation allows us to directly view clouds of
hydrogen even on the other side of the Milky Way (Figure 7).

- Toward the center of the Galaxy stars are seen to be distributed to greater distances above and below the plane of the Milky Way in a nuclear bulge, a flattened sphere of stars some 20,000 light years in diameter (Figure 3).

*Figure 6. Photo of Karl Jansky and his telescope.*
Figure 7. A 21-cm map of the sky shows the distribution of cold hydrogen in the Milky Way. This false color map shows the most intense emission corresponding to the lightest colors in the plane of the Milky Way and the least intense emission corresponding to the darkest colors in the directions perpendicular to the plane of our galaxy. 

**FMW 485-24.8 & APOD.**

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An Inventory of our Galaxy
• Radio mapping of gas clouds in the Milky Way has shown that our galaxy has at least several spiral arms, including the arm containing the Sun and it’s neighbors.
• The volume of the Milky Way is outlined by a 100,000 light year diameter spherical halo defined by its globular clusters.
• The Milky Way also contains a disk of stars and gas, approximately 100,000 light years in diameter and 2,000 light years thick, centered in the galactic halo (Figure 3).

• The galactic disk contains open star clusters, OB associations, and unassociated stars, also called field stars.
• Filling the void in between these stars is the so-called interstellar medium, dust and gas; the latter exists in both atomic and molecular form.
The evidence of gas and dust in the Milky Way are the infrared emission and the emission lines from atomic gas seen in hot, star-illuminated dust and gas clouds, and the gas absorption lines and dust obscuration imposed on stars in the Milky Way by intervening gas and dust (Figure 8).

Figure 8. An infrared image of the sky from the Cosmic Background Explorer satellite. This false-color image shows the infrared emission from the disk and bulge of our own Milky Way. NASA. APOD.
Figure 9. Multi-wavelength images of the Milky Way (the sky). **Panel A:** A 408 Mhz radio image of the sky shows synchrotron emission from high-energy electrons spiraling along magnetic field lines. The sources for much of this emission are supernova remnants which produce the high arcs of material above the galactic disk. **APOD.** **Panel B:** This false-color map shows emission from carbon monoxide on the sky, an easy molecule to detect. Carbon monoxide is found in giant molecular clouds, which are shown here to be concentrated in the disk of the Milky Way. **APOD.** **Panel C:** A drawing of the Milky Way made under the direction of Knut Lundmark. This
drawing shows the distribution of over 7,000 bright stars and the dust clouds which obscure starlight. **Panel D:** A map of the X-ray emission from the sky. Most of this emission comes from white dwarfs, neutron stars, and black holes in the Milky Way. **APOD.**
"Galaxies are complex systems composed of many different components, including high and low mass stars, star clusters and associations, gaseous nebulae, and dust. These components are not all uniquely detected from observations in the same part
of the electromagnetic spectrum (Table 21.1, Figure 9).

- Hα image of the Whirlpool Galaxy (Figure 10).
Figure 10a. Multi-wavelength images of the Whirlpool Galaxy. Upper **Panel A:** A false color image of 21-cm radio emission from hydrogen gas. **Arny. Panel B:** A visible image color image. **Panel C:** An ISO (Infrared Space Observatory) infrared image showing the locations of warm dust illuminated by starlight. **Panel D:** A false-color radio telescope image of M51 at a wavelength that captures emission from carbon monoxide molecules in giant molecular clouds. **P-546-33.3.**
Figure 10b. Composite image of the Whirlpool Galaxy, much like our own.

Table 21.1: Galactic Components
### Table 21.2: Stellar Temperature Classes

<table>
<thead>
<tr>
<th>Typical Object</th>
<th>Temperature</th>
<th>$\lambda_{\text{max}}$</th>
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<tbody>
<tr>
<td>High mass star</td>
<td>~10,000 K</td>
<td>350 nm</td>
</tr>
<tr>
<td>1 solar mass star</td>
<td>5,800 K</td>
<td>550 nm</td>
</tr>
<tr>
<td>Low mass star</td>
<td>~2,500 K</td>
<td>1000 nm (1 micron)</td>
</tr>
<tr>
<td>Cold dust</td>
<td>~25 K</td>
<td>100 microns</td>
</tr>
<tr>
<td>Neutral H gas</td>
<td>--</td>
<td>21 cm</td>
</tr>
<tr>
<td>Ionized H</td>
<td>--</td>
<td>H$\alpha$</td>
</tr>
<tr>
<td>Class</td>
<td>Temperature</td>
<td>$\lambda_{\text{max}}$</td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>O</td>
<td>25,000 K</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>B</td>
<td>11,000 – 25,000 K</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>A</td>
<td>7,5000 – 11,000 K</td>
<td>Blue</td>
</tr>
<tr>
<td>F</td>
<td>6,000 – 7,500 K</td>
<td>White to blue</td>
</tr>
<tr>
<td>G</td>
<td>5,000 – 6,000 K</td>
<td>Yellow to white</td>
</tr>
<tr>
<td>K</td>
<td>3,500 – 5,000 K</td>
<td>Red to orange</td>
</tr>
<tr>
<td>M</td>
<td>&lt; 3,500 K</td>
<td>Infrared to red</td>
</tr>
</tbody>
</table>

**Webnote: Mapping Populations in M51**

*Figure 11. 21-cm emission from the electron spin-flip in hydrogen. When the electron orbiting the nucleus of a*
hydrogen atom flips, from spinning in the same direction as the nucleus to spinning in the opposite direction, the atom gives off a low-energy photon with a wavelength of 21 centimeters. *P 526-30.11, top half only.*

IV. Radio Observations and Spiral Structure

- Radio observations not only allow astronomers to "look around" the dust, but also allow them to construct three-dimensional maps of the concentrations of gas that form the spiral arms.
One of the most useful radio wavelengths for mapping the Milky Way is 21-centimeters, the wavelength at which cold unionized (or "neutral") hydrogen emits.

If the electron flips from one state to the other it can emit or absorb a tiny amount of energy (Figure 11). This energy has a wavelength of 21-centimeters.

Because hydrogen is found everywhere in the galaxy and dust clouds are transparent to 21-centimeter radiation, this wavelength is the staple of the radio astronomer.

If hydrogen gas in the disk of the Milky Way is orbiting the center of the Milky Way in circular orbits which obey Kepler’s 3\textsuperscript{rd} law (the more distant the gas, the slower it orbits), then the astronomer can determine its distance from how fast it is moving away from or toward the Sun (us) (Figure 12). Different Doppler shifts correspond to different distances.

Once a 3-dimensional map of hydrogen emission is constructed, what does it show?
Maps show a number of arcs of neutral hydrogen giving us a suggestion of spiral structure (Figure 13).

- In other galaxies we see spiral arms that are outlined by bright blue young stars and emission nebulae, giant molecular clouds, and OB associations, places where massive stars are forming (Figure 10d).
- Our Sun is located on the inner edge in a short arm segment including the Orion nebula, called the Orion arm (Figure 14).

**Figure 13.** Different Doppler shifts of hydrogen emission at 21-cm enable radio astronomers to piece together a 3d map of the Milky Way.
Figure 13. Mapping the structure of the Milky Way with 21-cm hydrogen emission. The distance to a hydrogen cloud orbiting the center of the Milky Way can be determined from the Doppler shift of its 21-cm emission, which is determined by its velocity along the line of sight. Cloud C is moving away from the Sun in its orbit, and so it appears red shifted. Cloud...
A appears to be moving toward the Sun so its emission is blue shifted. Objects in line with the galactic center, $B_1$ and $B_2$, have no line of sight velocity with respect to the Sun and thus no Doppler shift. The closer a hydrogen cloud is to the Milky Way nucleus the greater its orbital velocity. This information can be used to piece together a three-dimensional hydrogen emission map of the galaxy. P 528-30.13.
Figure 14. Artist’s concept of the Milky Way.
V. Spiral Structure

Figure 15. Schematic of spiral arms in the Milky Way. Modify. Hartmann and Impey.
Spiral arms are outlined by HII regions and the luminous blue stars in OB associations. Spiral galaxies are usually divided into two classes, flocculent and grand-design.

What causes this spiral structure? The cause of spiral arms has been a great mystery of astronomy until the 1960s. Simplistic ideas based on the formation of a linear arm that is
stretched into a spiral arm as a result of differential rotation fail.

- The reason for the failure of simple rotation models is the problem with spiral arms "winding up" in a relatively short time (Figure 16).
- In the 5 billion-year lifetime of the Sun, it has orbited the Milky Way nucleus about 25 times.
- The Sun is part of the Orion spiral arm. This spiral arm would have wound up so tightly in 5 billion years as to be totally unrecognizable as a spiral arm. Arms in galaxies are not tightly wound but are relaxed gently curving arms.
- We only see spiral arms because of the blue massive stars strung along them. Surprisingly, the spiral arms contain only 5% more stars than the regions between the arms.
- There are two theories used to explain the enhanced star formation along spiral arms: density wave theory and self-propagating star formation.
Figure 16. The windup problem in spiral arm formation. This imaginary time sequence shows how large molecular clouds would become elongated due to the differential rotation of the galaxy. The inner parts rotate the fastest, eventually winding up the clouds through many rotations into arms that are so tightly wound that they would not be recognizable. FMW 486-24.10 modified.

Density Wave Theory
In the 1920s the Swedish Astronomer, Bertil Linblad, suggested that compression waves traveling through a rotating disk are the cause of spiral arms (Figure 17).
American astronomers C.C. Lin and Frank Shu refined this theory in the 1960s with the aid of modern computers. Ripples in a rotating galaxy, much like ripples in a rotating pan of water, would be spiral shaped. As spiral compression waves move through a galaxy, material at the wave crests is compressed and becomes locally more dense. The waves are not associated with any particular stars or giant molecular clouds, but move through them as a sound wave moves through air or a ripple moves through water in a pond. As the compression wave moves through giant molecular clouds it compresses them, seeding their collapse and initiating star formation.

- Why don’t the spiral arms wind-up in the density wave model?
- As the spiral density wave moves slowly through the galaxy, luminous high-mass stars are born when the crest of the density wave piles into a giant molecular cloud.
• By the time the density wave moves on, the high-mass star has already died.

• HII regions, OB associations, and short-lived stars will be seen only at the crest of the density wave. Other more long-lived objects are left behind the crest and live their lives long after the spiral wave has passed.

• In this model a spiral arm is an arm of recent star formation.

• What is the mechanism for starting a compression wave? It could be the gravitational interaction with a nearby or companion galaxy.

Self-propagating Star-formation Theory

• As in the density-wave theory, the self-propagating star formation theory perceives
spiral arms to be the sites of high-mass star formation (Figure 18).

• Instead, the previous generation of star formation spurs the current generation of star formation. Star formation is seen as a self-propagating chain reaction (also see Chapter 18, Section III). Hot massive stars form from collapsing knots in giant molecular clouds.

• As clouds are compressed, a cluster of new, 2nd generation stars is formed, in some tens of millions of years after the birth of the previous generation.

• Differential rotation will stretch and shear these regions of star formation.

Figure 18. Self-propagating star formation in a molecular cloud. A bright open cluster is seen on the left. Intense light originating from this cluster as well as compression waves from supernovae in this cluster serve to compress the rest of the molecular cloud. The result is the formation of protostars on the right hand side of the cloud. P 535-30.24 modified.
Webnote: Spiral Arm Formation

What are the pros and cons of each model? In the self-propagating star-formation model, random bursts of star formation would result in the appearance and disappearance of short arm segments, of the type seen in flocculent spiral galaxies. The grand-design spirals are more
satisfactorily explained by density wave theory, which can account for the longer more distinct spiral arms. Perhaps the difference in the appearance of these two types of galaxies can be accounted for by whether or not a galaxy has had a close encounter with a neighboring galaxy in the recent past.

VI. Mass of the Milky Way

Orbital motion of stars and gas about the center of mass of the Milky Way has kept them from falling into its center billions of years ago just as the Moon’s circular orbit about the Earth has kept it from falling into our planet. Their motion, as has been determined by Doppler shift measurements, indicates that the Milky Way does not rotate like a rigid body, like a phonograph record on a turntable, but by differential rotation, much as the planets orbit the Sun.
The Sun travels around the center of the galaxy at 828,000 km/hour (225 km/s), but because of the enormous size of the Milky Way it takes about 230 million years to orbit the galaxy once. Kepler’s third law can be used to estimate the mass of the Milky Way. This method is based on the fact that when observing a low-mass object orbiting an object of much higher mass, the force of gravity between the central object and its satellite must be balanced by the centripetal acceleration of the satellite. The faster a satellite moves (and accelerates) the more massive the central object. This method gives the relationship between the Sun’s period about the nucleus of the galaxy (or alternatively the Sun’s velocity) and the mass of the galaxy. One catch is that the stars outside of the Sun’s radius from the center have no influence on its orbital properties. So all that can be determined from the Sun’s velocity is that there are about 100 billion solar masses inside the orbit of the Sun. But the velocities of stars further out are even greater, in conflict with Kepler’s 3rd law, unless there is a great deal of mass outside the Sun’s orbit (Figure 19). From an analysis of the motion of stars and gas outside the orbit of the Sun it has been shown that in
excluding mass exterior to the orbit of the Sun, perhaps 90% of the mass of the Galaxy has not been accounted for. The mass of the Galaxy could exceed $10^{12}$ solar masses. This mass of nearly $10^{12}$ suns doesn’t appear in the conventional inventories of the Milky Way from visible stars, X-ray emission from black holes, radio emission from gas, or infrared emission from dust. This is the so-called **missing mass** of the galaxy. Astronomers commonly refer to the source of missing mass as **dark matter**, because it hasn’t been seen from any detected electromagnetic waves.
Figure 19. Calculation of the mass of the Milky Way using a modified form of Kepler's 3rd Law. The lower curve shows the expected velocity of stars and gas about the nucleus of the Milky Way vs. distance from the galactic center, using an estimate of the mass of the Milky Way from visible matter (stars, gas clouds, and dust). The lower curve represents the measured velocity vs. radial distance curve for the Milky Way. The displacement between the two curves indicates a substantial unseen or "missing" mass in the Milky Way. Modify. Nick Stroebel's Web site.
VII. Stellar Populations and Star Clusters

The Milky Way contains two different kinds of stars, called Population I stars and Population II stars, based on their compositions, as determined from their spectra, and their orbital properties (Figure 20).

Table 21.3: Properties of Stellar Populations

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Population I</th>
<th>Population II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution</td>
<td>In spiral arms, patchy</td>
<td>Smooth distribution in halo</td>
</tr>
<tr>
<td></td>
<td>distribution</td>
<td></td>
</tr>
<tr>
<td>Heavy Element</td>
<td>2-4%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Abundance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ages</td>
<td>$0 – 10^{10}$ years</td>
<td>$10^{10}$ years</td>
</tr>
<tr>
<td>Orbits</td>
<td>Circular</td>
<td>Elliptical</td>
</tr>
<tr>
<td>Objects</td>
<td>Open clusters, OB associations, star formation regions</td>
<td>Globular clusters</td>
</tr>
</tbody>
</table>

IIIX. Origin of the Milky Way Galaxy
• It is thought that the Milky Way formed from a rotating, fragmenting cloud of self-gravitating gas, similar to the way that individual stars and star clusters are thought to have formed, but on a much larger scale (Figure 21).
• Originally the cloud that formed our galaxy was composed of 75% hydrogen and 25% helium, by mass, with no significant contribution from heavier elements.
• The volume of the cloud is presumed to match the volume currently occupied by globular clusters.
• About 15 billion years ago, the age of the oldest globular clusters, the galactic gas cloud began to collapse and fragment, forming stars throughout the entire galactic volume.
• The globular clusters maintained orbits about the center of mass of the galaxy while the gas collapsed into a rotating disk, much as a collapsing presolar cloud collapsed into a Sun surrounded by a spinning dust disk (Chapter 12, Section V).
• The stars that formed prior to galactic disk collapse are the Population II stars in the Galaxy. (Remember: Population II stars formed first.)

• In the second phase of the formation of the Galaxy, a spinning disk of gas formed and Population I stars began to form in the disk.
• The first generation of stars started brewing heavier elements in their interiors with thermonuclear fusion.

• As these stars died they began to recycle heavier elements back into the interstellar medium, out of which the newer stellar generations would form.
• Recycling into the interstellar medium then took place via planetary nebulae, supernovae, stellar winds, and binary mass exchange (Chapter 19, Section III).
• Subsequently, newer generations of stars came and went, enhancing the heavy elements in the interstellar medium.
The proposed scenario, while it explains the gross properties of our galaxy, isn’t perfect. There are problems with some of the details. For example, the predicted free-fall time for the collapse of the galactic gas cloud is several hundred million years. However, this doesn’t match the 3 billion-year spread in globular cluster ages as determined from their H-R diagrams. It will take a more complex and comprehensive model to explain more of the observed details of our galaxy.

Figure 21. Formation of the Milky Way. In a simple model, the Galaxy is formed by the collapse of a giant gas cloud (1). The first objects to condense out of the collapsing protogalactic cloud are globular clusters (2). The underlying gas continues to collapse to a disk (3). Star formation continues in the disk from gas that had been enriched with metals from the stars that had already formed in the halo (4). FMW 494-24.17.
IX. The Nucleus

The density of stars at the center of the Milky Way is so great that if you lived on a planet orbiting a star at the center of the Galaxy you would see 1 million stars as bright as Sirius, one of the brightest stars in
our sky. It would never really get dark at night. But the nucleus of our galaxy is unusually luminous in the radio and infrared regions of the spectrum as well. The visible dust between the galactic nucleus and the Sun totally prevents us from seeing any of the stars at the nucleus of the galaxy. With infrared light and radio radiation we can see an exposed galactic center (Figure 22).

![Figure 22. Schematic of the Milky Way nucleus. Arny. Modify.](image)

Strong infrared emission comes from a group of several powerful radio emitters at the galactic center,
called Sagittarius A (Figure 23). Sagittarius A is one of the brightest sources of synchrotron emission in the sky. Synchrotron emission is the emission of electromagnetic radiation from electrons spiraling in a magnetic field, the same kind of emission that produces the Earth’s aurorae.

Figure 23. A Chandra X-ray image of the center of the Milky Way.
The most luminous of the Sagittarius A radio sources is called Sagittarius A*, thought to be the nucleus of our galaxy. Two arms of hydrogen gas have been detected by 21-cm emission that originate in the nucleus; one is approaching us at 53 km/s and another receding at 135 km/s. The length and velocity of these arms indicate that they were blown out of the galactic core about 10 million years ago.

In addition to these arms, there is a ring of gas orbiting the galactic center. Doppler shifts of broadened neon gas indicate that gas is orbiting the nucleus at up to 200 km/s. From this Kepler’s 3rd law indicates 1 million solar masses of matter in a region smaller than a few light-years across. Most think that this mass is contained in a supermassive black hole with a hot accretion disk causing emission in the radio and infrared. This kind of black hole-like activity is seen in other galaxy nuclei as well. Matter is expected to fall to the center of the Galaxy as it collapses and forms stars, and would naturally form a supermassive black hole at the Galaxy nucleus.
The Milky Way, like other spiral galaxies, is a dense disk of stars, about 100,000 light years in diameter, surrounded by a spherical halo of globular clusters. Luminous, blue stars outline a spiral pattern in the disk. The Sun is embedded in such a spiral arm, about two-thirds the distance from the center of the Galaxy to the edge of the disk. One of the most useful methods of mapping the structure of the Milky Way uses the 21-cm emission line of hydrogen, due to the spin-flip of the single hydrogen electron. The disk of the Milky Way consists of stars and gas clouds independently orbiting the galactic center. Use of Kepler’s 3rd law allows us to estimate the mass of the Milky Way from measurements of their velocities about the nucleus. There are two theories of spiral arm formation in galaxies like the Milky Way. The first is the density wave theory, in which spiral waves of mass density propagate through the disk, compressing gas clouds and
instigating star formation. The second is the self-propagating star formation theory in which a high mass star evolves and supernovas; the resulting compression wave collapses gas clouds and initiates star formation in them. The resulting pattern of star formation in a rotating galaxy is spiral. The Milky Way and other spirals contain two populations of stars, old Population II stars and younger Population I stars. Population I stars fill the disk including the spiral arms. Population II stars are seen in the galaxy halo and central bulge. The nucleus of the Milky Way is a source of energetic activity indicating the likely existence of a black hole and high temperature accretion disk.