The Milky Way

The Milky Way

The Milky Way is a continuous band of diffuse light. The band is thicker and brighter in one part of the sky and 180^o away it is thinner and fainter. The band is tilted about 60^o with respect to the Celestial Equator.

The Milky Way

Telescopic observations show the band is composed of millions of stars.

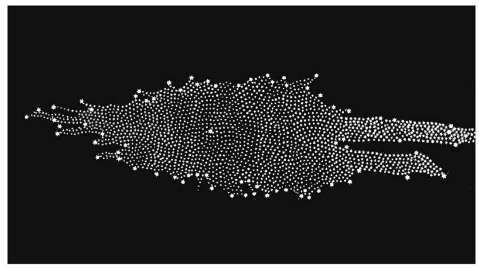
What is this collection of stars of which the Sun is a member?

It is the **Milky Way Galaxy** or just **The Galaxy**.

Where Are We Located?

William Herschel (late 1700s) counted stars in 683 regions on the sky. He reasoned he should see the greatest number of stars toward the Galaxy's center and a lesser number toward the Galaxy's edge.

But, he found about the same density of stars all along the Milky Way. Therefore, he concluded that we are at the center of the Galaxy. Later, Jacobus Kapteyn came to the same conclusion and that the diameter is 17 kiloparsecs (17 kpc).



Universe by Freedman, Geller, and Kaufmann

Interstellar Extinction

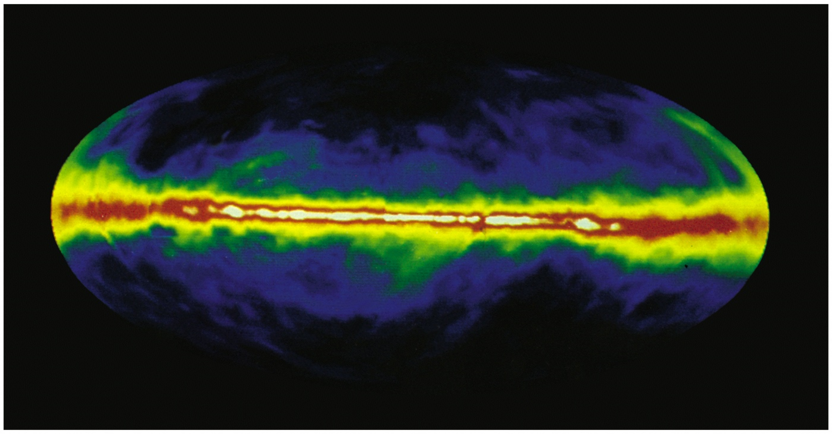
Both Herschel and Kapteyn were wrong about the Sun being at the center of the Galaxy. The reason for their mistake was finally discerned in 1930 by Robert Trumpler. While studying star clusters, Trumpler discovered that the more remote clusters appear unusually dim – more so than would be expected from their distances alone.

He concluded that interstellar space contains **dust** that absorbs or scatters light from distant stars. (Like looking through a fog.)

Because of **interstellar extinction**, Herschel and Kapteyn were only seeing the nearest stars.

Dust and Gas

Most of the gas and dust is in the *plane* of the Milky Way.



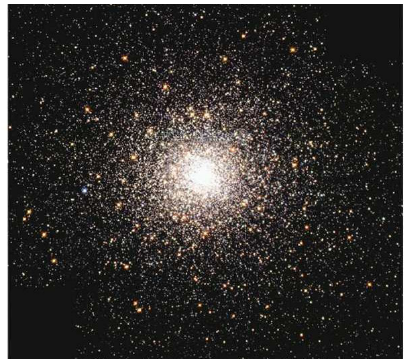
Jones and Forman, Harvard-Smithsonian Center for Astrophysics

The Solution – Where We Are

While interstellar dust in the plane of the Galaxy hides the sky covered by the Milky Way, we have an almost ***unobscured view out of the plane***.

To find our location in the Galaxy, we need to locate bright objects that (a) are part of the Galaxy but lie outside its plane in unobscured regions of the sky and (b) are surrounding the center of The Galaxy.

Globular Clusters are such objects.



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Star Clusters

Open Cluster

Globular Cluster

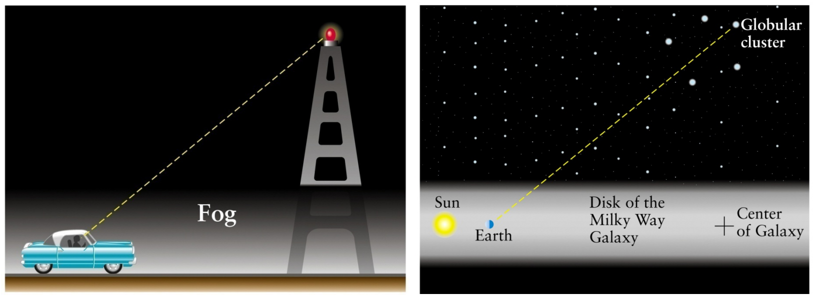
Universe by Freedman, Geller, and Kaufmann

Distribution of Globular Clusters

Open Clusters are rather uniformly spread along the Milky Way band. However, the majority of the **Globular Clusters** are located in one-half of the sky.

(Although this picture covers only 2% of the sky, it contains about one-fifth of the known globular clusters, which are circled.)

Finding the Center of the Galaxy



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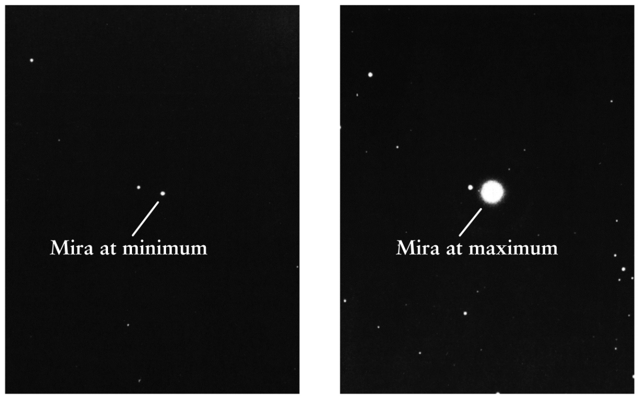
Getting Distances

However, to use globular clusters to determine our location in the Galaxy, we must first determine the distances from the Earth to these clusters.

This is done with Variable Stars! In particular, the **RR Lyrae** stars.

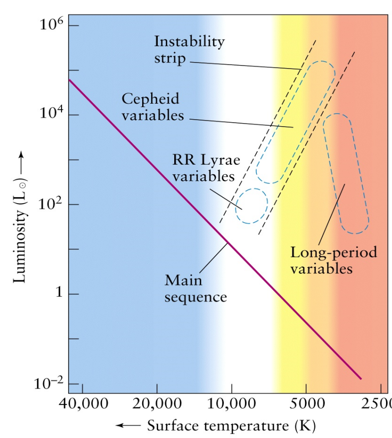
Pulsating (Variable) Stars



Instability Strips

Why do some stars pulsate?

The structure of any star is determined in large part by how easily radiation can travel from the core to the photosphere – that is, by the opacity, the degree to which the gas hinders the passage of light through it.



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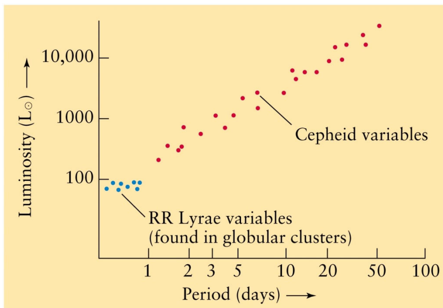
Period-Luminosity Relationship



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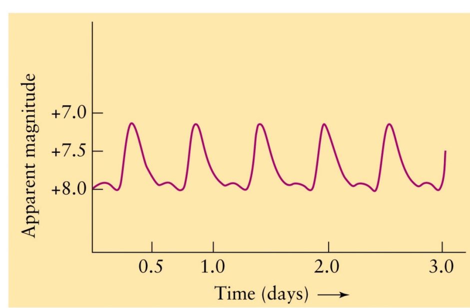
The period-luminosity law can be used to determine distances. By using photometry to determine the period, one can deduce the star's average luminosity, and therefore get its absolute magnitude.

With the apparent magnitude (also from the photometry), one can now compute the star's distance.

$$\mathbf{m - M = 5 \log (d/10)}$$

RR Lyrae Stars

Shortly after Leavitt's discovery, Harlow Shapley began studying a family of pulsating stars related to the Cepheids called **RR Lyrae** variables. The light curve of an RR Lyrae variable is similar to that of a Cepheid, and their period-luminosity relationship is similar to that of the short-period Cepheids.



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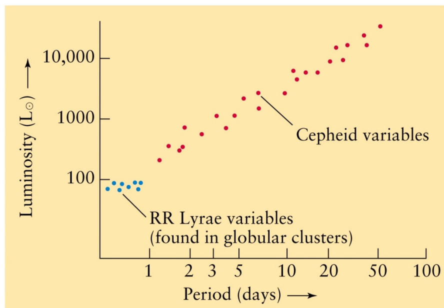
Obtaining Distances

Most globular clusters contain at least a few RR Lyrae variable stars, whose absolute magnitudes are known. The distance to an RR Lyrae star in a globular cluster, and hence to the cluster itself, can therefore be calculated from its observed apparent magnitude. Shapely used this technique to obtain distances to the globular clusters.



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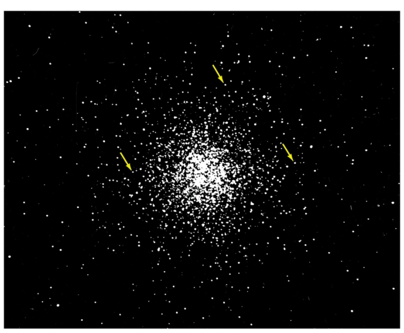
Obtaining Distances



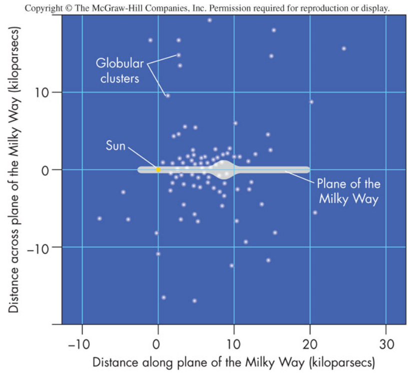
RR Lyrae variables are commonly found in globular clusters. Using the period-luminosity relationship, Shapley determined the distances to 93 globular clusters. He found that some are as far away as 100,000 light years (~33 kpc).

Distribution of Globular Clusters

Open clusters are rather uniformly spread along the Milky Way band. However, the majority of the 93 **globular clusters** that Shapley studied are located in one-half of the sky.

(Although this picture covers only 2% of the sky, it contains about one-fifth of the known globular clusters, which are circled.)

Distribution of Globular Clusters



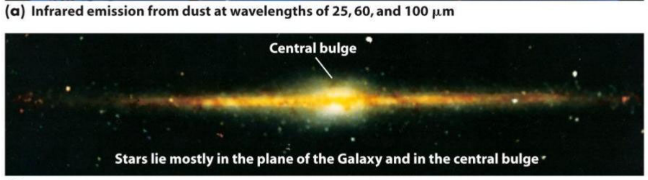
From the directions and distances to the 93 globular clusters, Shapley mapped out their 3D distribution. He concluded that the clusters form a huge spherical distribution centered about a point **~8 kpc away**.

Shapley reasoned this point must coincide with the center of our Galaxy because of the gravitational forces between the disk and the "halo" of globular clusters.

Side View of the Structure

The Galaxy is a thin, circular **disk** of luminous matter distributed across about 50,000 pc (160,000 LY) in diameter, with a thickness of 600 pc (2000 LY). Dust and gas are closely confined to the galactic plane.

(a) Infrared emission from dust at wavelengths of 25, 60, and 100 μm



(b) Infrared emission from dust at wavelengths of 1.2, 2.2, and 3.4 μm

Universe by Freedman, Geller, and Kaufmann

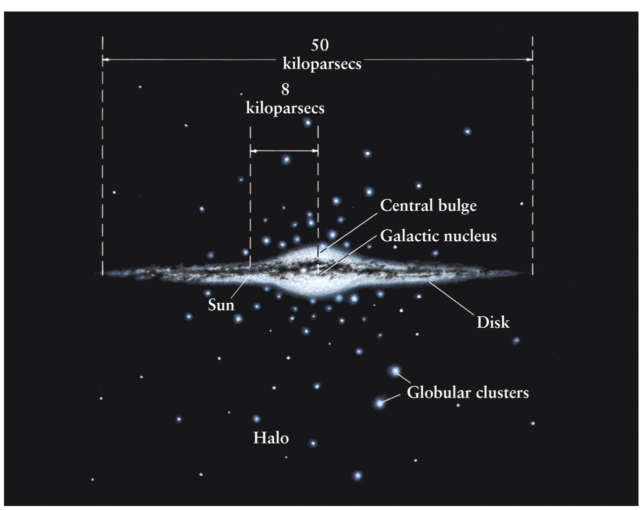
Side View of the Structure

The disk is embedded in a **halo** of largely non-luminous or dark matter that extends to a distance of at least 50,000 pc from the galactic center. The globular clusters are also distributed in a much larger spherical halo around the galactic center.

Within 1000 pc of the galactic center, the stars are no longer confined to the disk but rather form a spheroidal **nuclear bulge** of old stars.

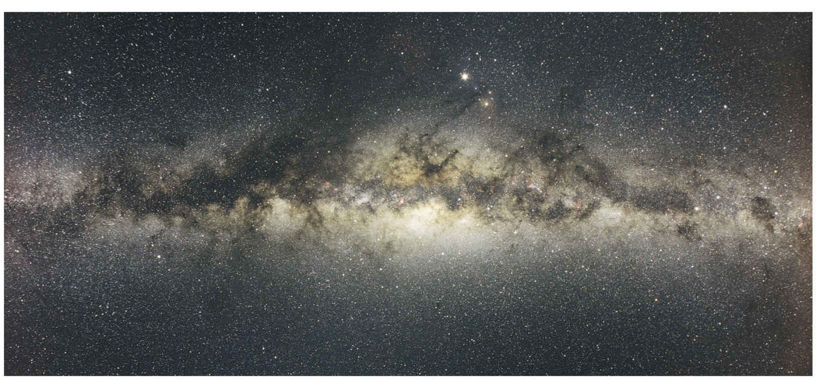
The following slide shows a side view of The Galaxy. The one after that is an image of a galaxy we think is similar to the Milky Way.

Side View



Universe by Freedman, Geller, and Kaufmann

The Milky Way



Components of the ISM

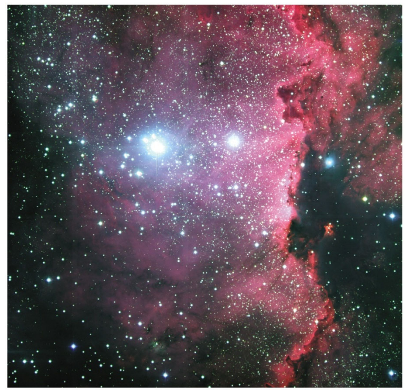
Interstellar Gas

- H II Regions
- H I Regions
- Cold Clouds

Interstellar Dust

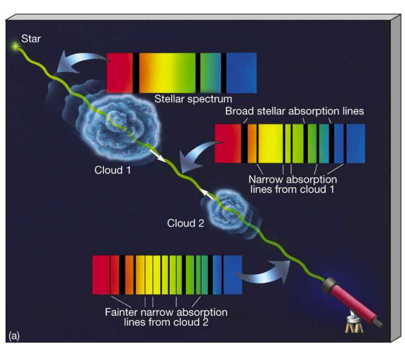
- Reflection Nebulae
- Dark Nebulae
- Reddening

Giant Molecular Clouds



European Southern Observatory

H I Regions & Cold Clouds



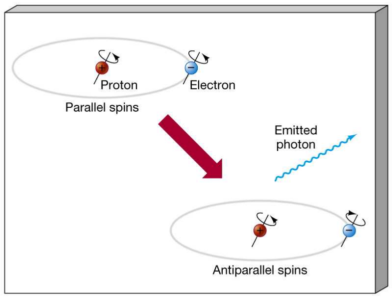
Astronomy Today, Chaisson and McMillan

Interstellar matter located at large distances from stars does not produce the strong emission lines that make H II regions visible.

A cold cloud of gas will, however, produce dark absorption lines in the spectrum of light from a star that lies behind it.

This was first seen in spectroscopic binaries, for the interstellar line does not change wavelength.

21-cm Radiation

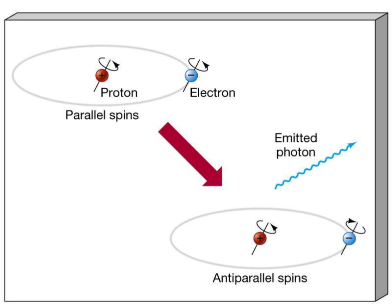


Astronomy Today, Chaisson and McMillan

A hydrogen atom possesses a tiny amount of angular momentum by virtue of the electron's spin and orbital motion.

In addition, the proton has a spin, too. If the spins are in opposite directions, the atom has a very slightly lower energy than if the two spins are aligned.

21-cm Radiation



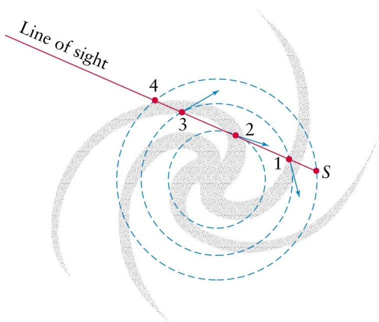
Astronomy Today, Chaisson and McMillan

If a spin-opposed atom acquires a small amount of energy, the spins of the proton and electron can be aligned, leaving the atom in a slightly excited state.

If it then loses that energy, it returns to its ground state.

The amount of energy involved is that associated with a photon of **21-cm** wavelength.

Mapping the Galaxy

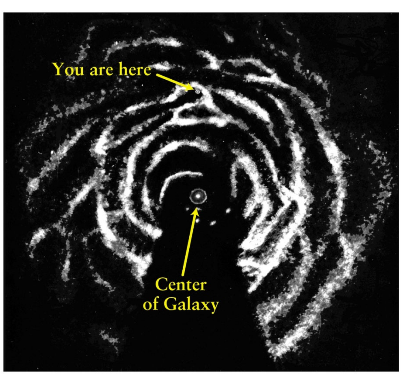


Universe by Freedman, Geller, and Kaufmann

Looking within the plane of the Galaxy from our position at S, the H clouds at different locations (shown as 1, 2, 3, and 4) along our line of sight are moving at slightly different speeds.

As a result, radio waves from these various gas clouds are subjected to slightly different Doppler shifts. This permits astronomers to sort out the gas clouds and thus map the Galaxy.

Neutral Hydrogen Map

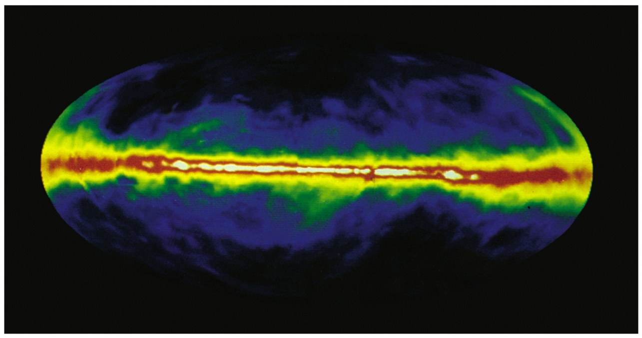


This map shows the distribution of hydrogen gas in a face-on view of the Galaxy. The map suggests a **spiral structure**.

Details in the blank, wedge-shaped region are unknown. Cool gas in this part of the Galaxy is moving perpendicular to our line of sight and thus does not exhibit a detectable Doppler shift.

Interstellar Gas in the Disk

Observations at 21 cm show that the neutral atomic hydrogen is confined to an extremely flat layer. It extends to 25,000 pc from the center. At the position of the Sun, the layer is only about 125 pc thick.



Jones and Forman, Harvard-Smithsonian Center for Astrophysics

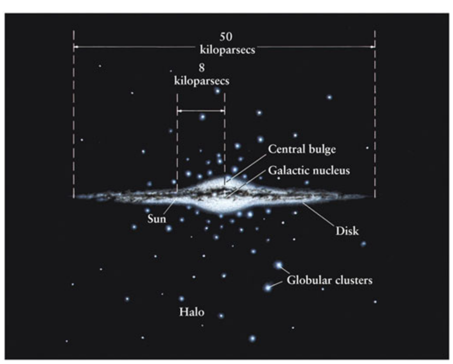
Interstellar Dust

In the inner regions of the Galaxy, dust is typically found in the same places as neutral hydrogen. The thickness is also about 125 pc, and there is very little emission from dust lying outside the Sun's orbit.

Galactic Disk

Although the Sun lies far from the galactic center (about **8.5 kpc**), the main disk of the Galaxy extends a nearly equal distance beyond the Sun.

The young stars in the disk of the Galaxy are concentrated in a series of **spiral arms**. The disk is at least **50,000 pc** (160,000 LY) in diameter.

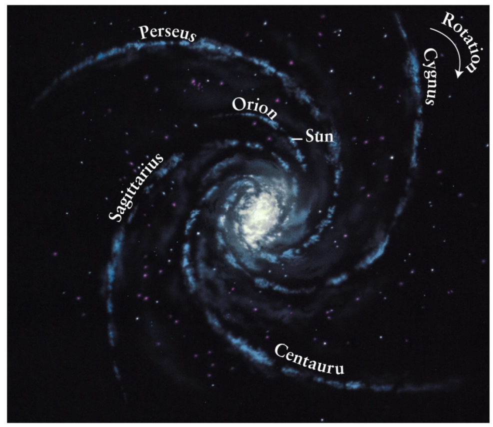


Spiral Arms

The Galaxy has four spiral arms.

The Sun appears to be near the inner edge of a spur called the Orion spur, which is about 5000 pc long.

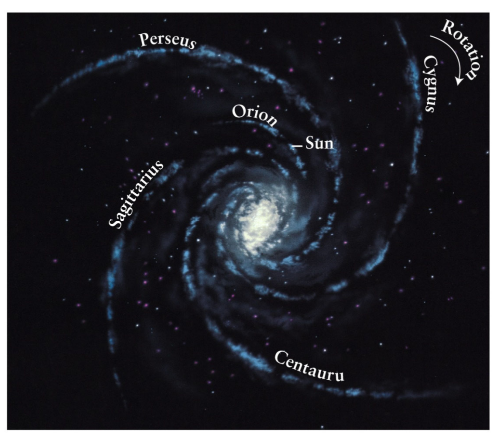
More distant are the Sagittarius-Carina and Perseus arms, located about 2000 pc inside/outside the Sun's position with respect to the galactic center.

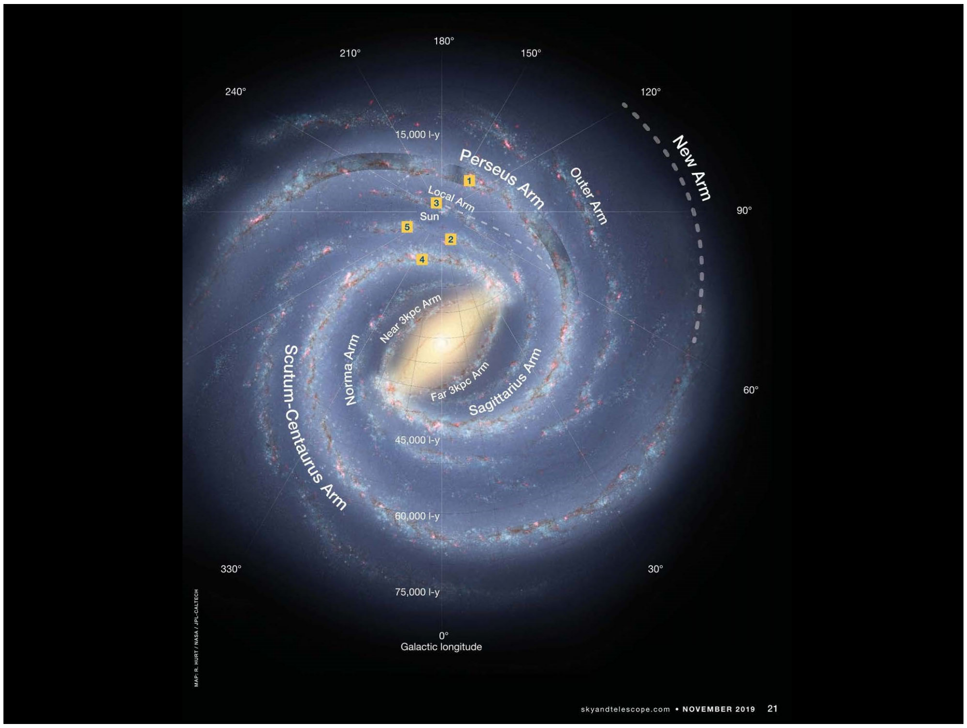


Spiral Arms

Those arms, and the Cygnus arm, are about 25,000 pc long.

The fourth arm, Centaurus, is difficult to detect because emission from it is confused with strong emission from the central regions of the Galaxy.





Galactic Halo

The globular clusters are distributed in a sphere centered on the Galaxy. A sparse "haze" of individual stars – not members of clusters but far outnumbering the cluster stars – also exists in this region.

This haze of stars and clusters forms the **galactic halo**, a region whose volume exceeds that of the main disk of the Galaxy by many times.

Individual RR Lyrae stars have been found as far away as 10,000 to 15,000 pc on either side of the galactic plane. A few globular clusters are as far as 80,000 pc.

Galactic Corona

There is also gas in the halo, and some of it emits X-ray radiation. In order to do this, the gas must be very hot – about 1 million K – too hot to produce the emission lines seen in ordinary H II regions.

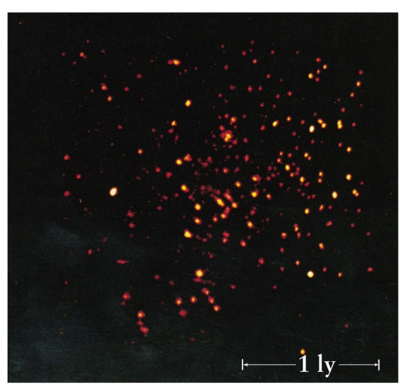
The gas is probably heated by supernova shells and/or stellar winds. It extends only into the inner part of the halo and defines a region now usually referred to as the **galactic corona**.

Galactic Center

Because of the severe interstellar absorption, most information about the galactic center comes from IR and radio observations.

The strongest IR emission comes from Sagittarius A, which is a group of several powerful radio sources.

One of these sources, **Sgr A***, is thought to be the galactic nucleus. Hundreds of stars are crowded within 1 light years of Sgr A*.



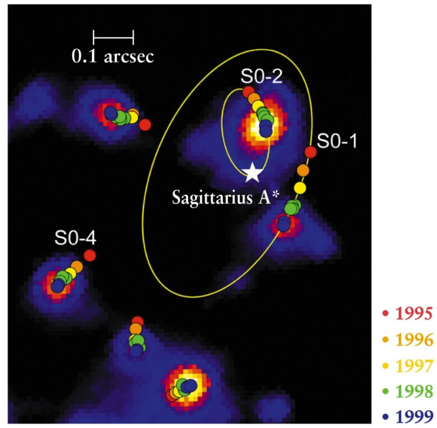
What is Sgr A*

The strongest evidence comes from recent IR observations of the motions of stars in the vicinity of Sgr A*. Stars are orbiting around Sgr A* at speeds in excess of 1500 km/s.

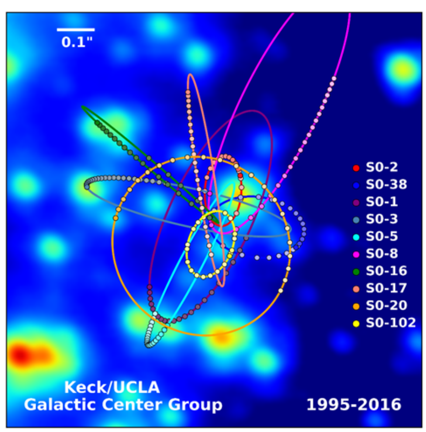
A source of gravity must be keeping these stars in orbit about the galactic center. Using Kepler's Third Law, this source must have a mass of

~3 x 10^6 solar masses.

All of this is contained in a volume no larger than our Solar System.



Movie of Stellar Orbits



Orbits Around Galactic Center