

Chapter 23

The Milky Way Galaxy



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23.5 Galactic Spiral Arms

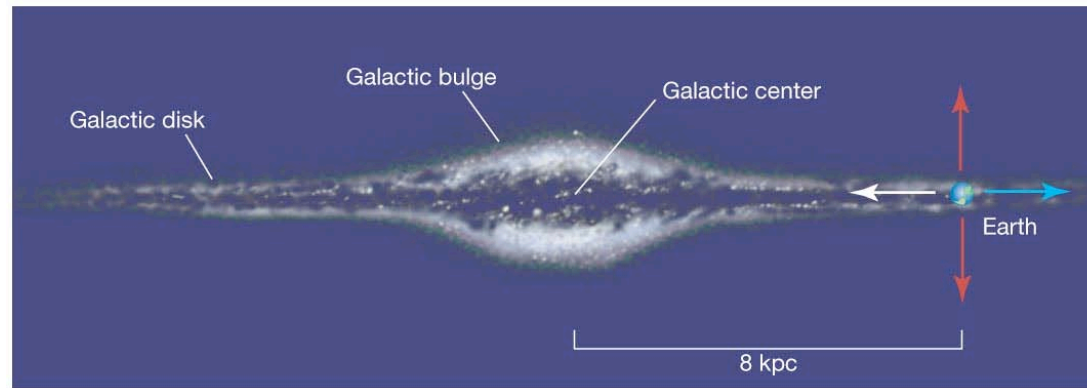
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23.6 The Mass of the Milky Way Galaxy

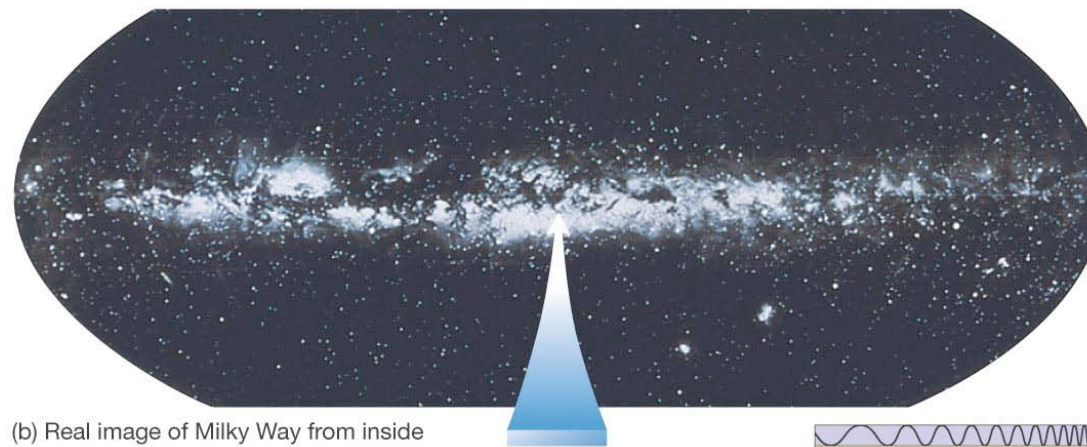
23.7 ~~XX~~The Galactic Center

23.1 Our Parent Galaxy

From Earth, we see few stars when looking **out** of our galaxy (red arrows) and many stars when looking **in** (blue arrows). **Milky Way** is what our galaxy appears as in the night sky.



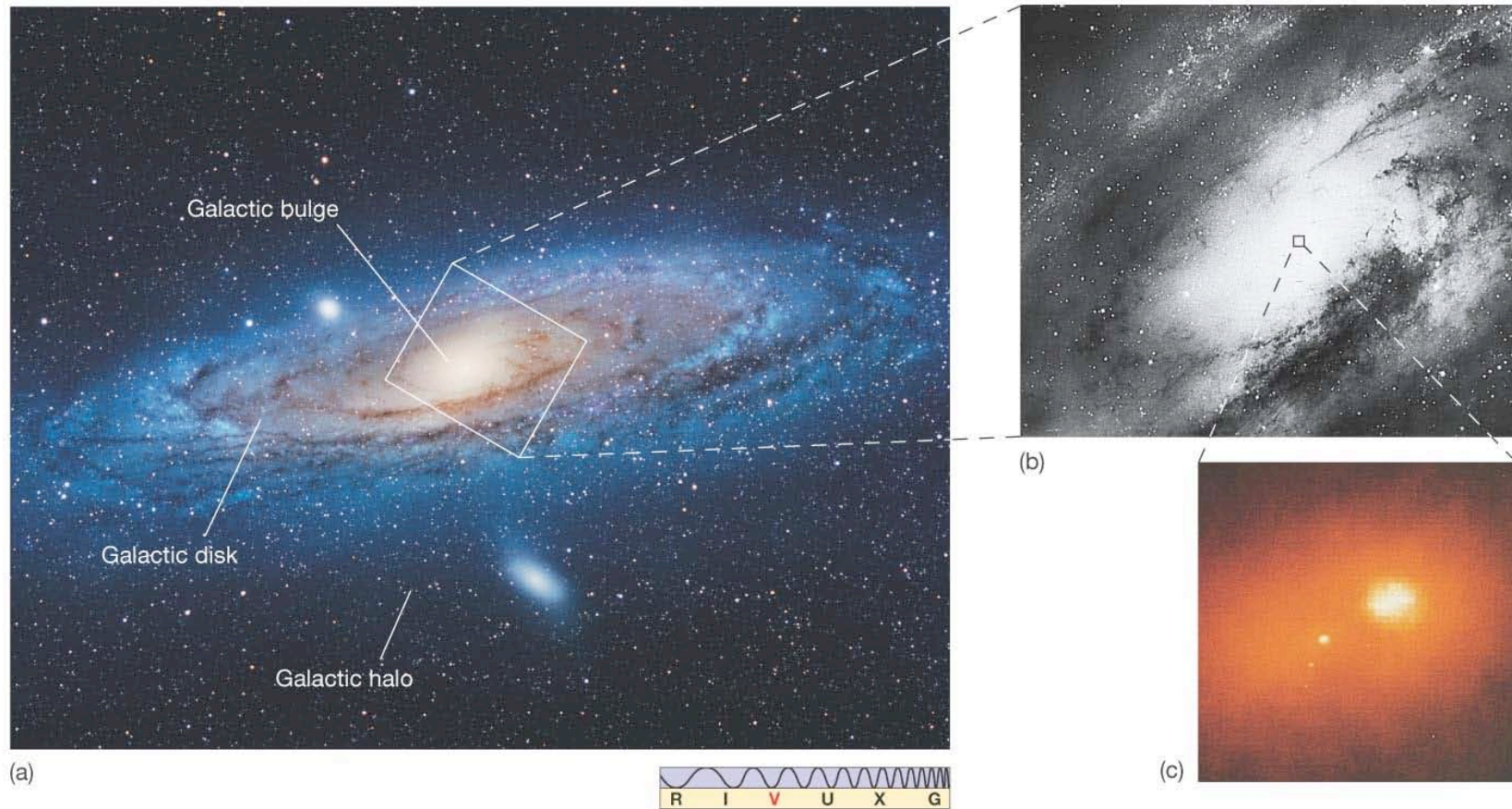
(a) Artist's view of Milky Way from afar



(b) Real image of Milky Way from inside

23.1 Our Parent Galaxy

Our galaxy is a **spiral galaxy**. The Andromeda Galaxy, our closest spiral neighbor, probably resembles the Milky Way fairly closely.

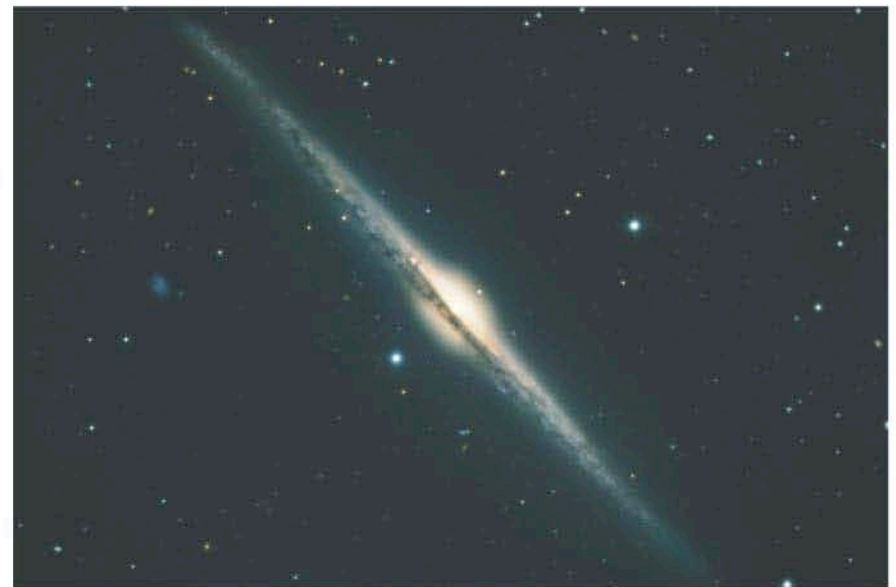


23.1 Our Parent Galaxy

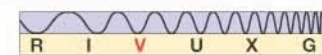
Here are two other spiral galaxies, one viewed from the **side** and the other from the **top**:



(a)

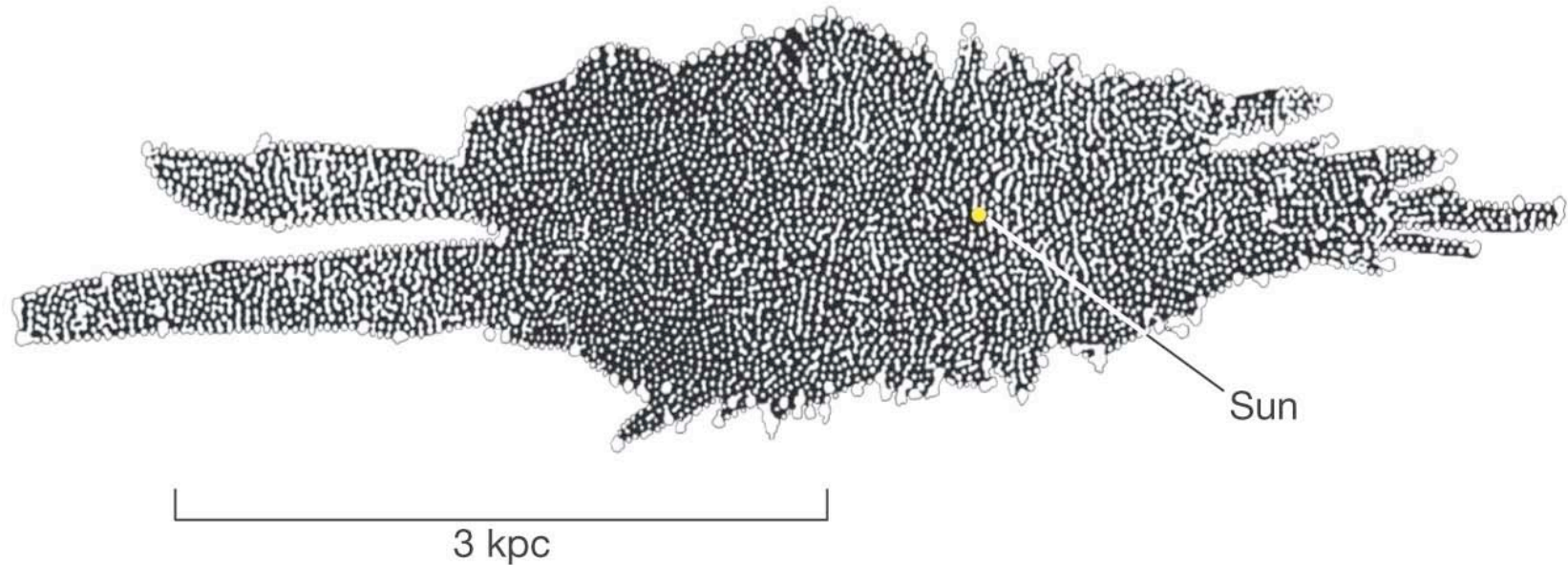


(b)



23.2 Measuring the Milky Way

One of the first attempts to **measure** the Milky Way was done by Herschel using visible stars.



Unfortunately, he was not aware that most of the galaxy, particularly the center, is blocked from view by vast clouds of **gas and dust**.

23.2 Measuring the Milky Way

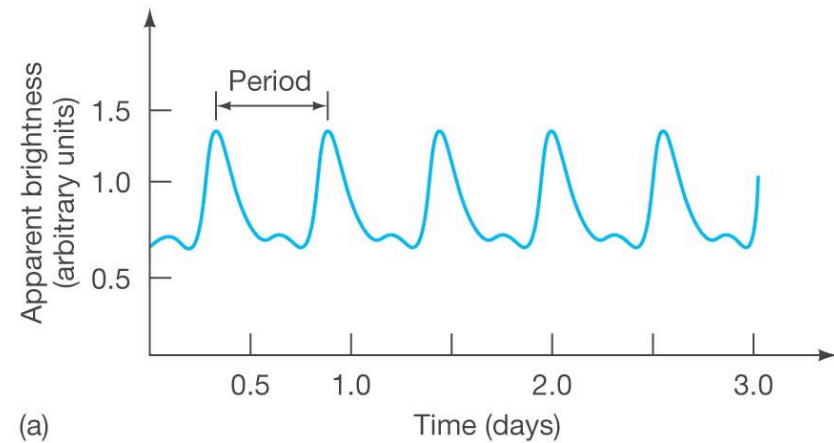
We have already encountered **variable stars**—novae, supernovae, and related phenomena.

There are other stars whose luminosity varies in a regular way, but much more subtly. These are called **intrinsic variable stars**.

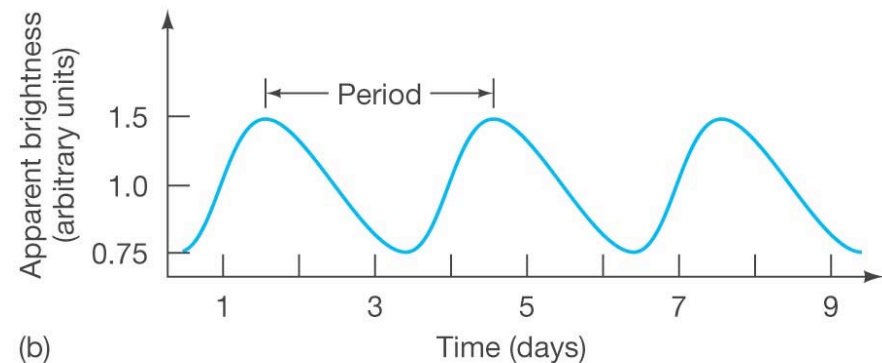
Two types of intrinsic variables have been found: **RR Lyrae stars** and **Cepheids**.

23.2 Measuring the Milky Way

The upper plot is an **RR Lyrae star**. All such stars have essentially the same luminosity curve with periods from **0.5 to 1 day**.

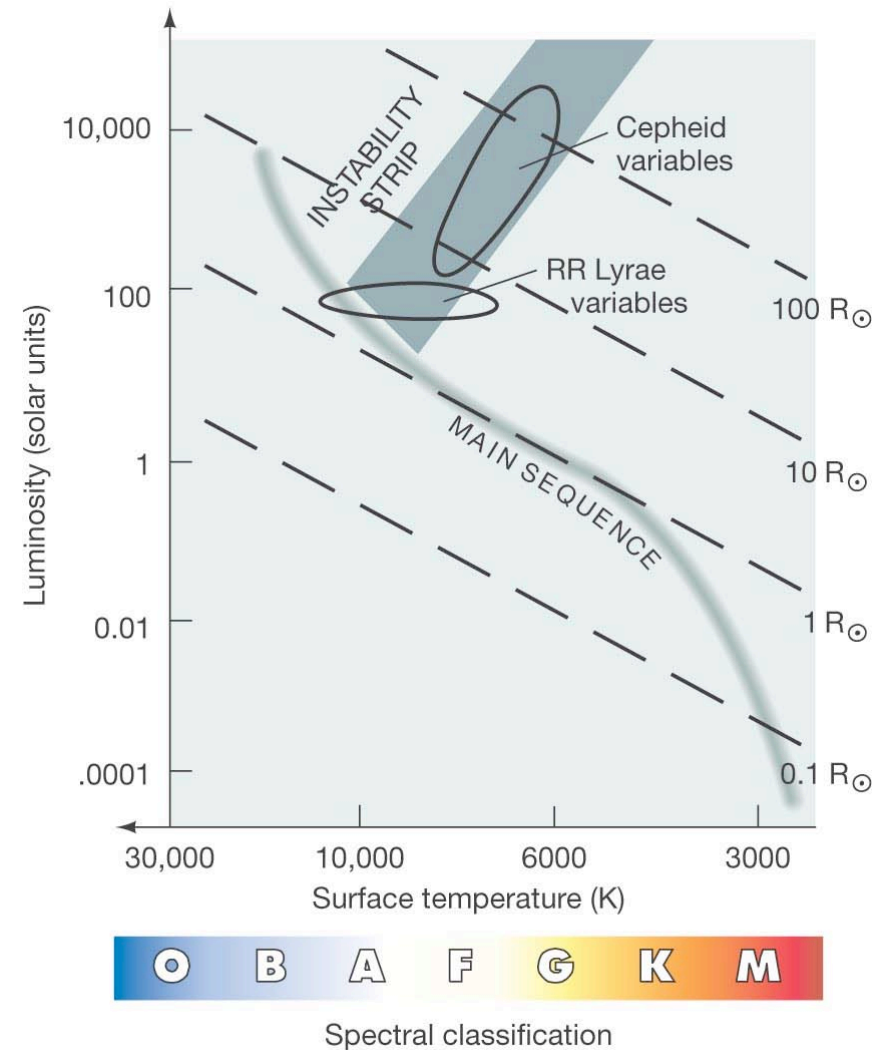


The lower plot is a **Cepheid variable**; Cepheid periods range from about **1 to 100 days**.



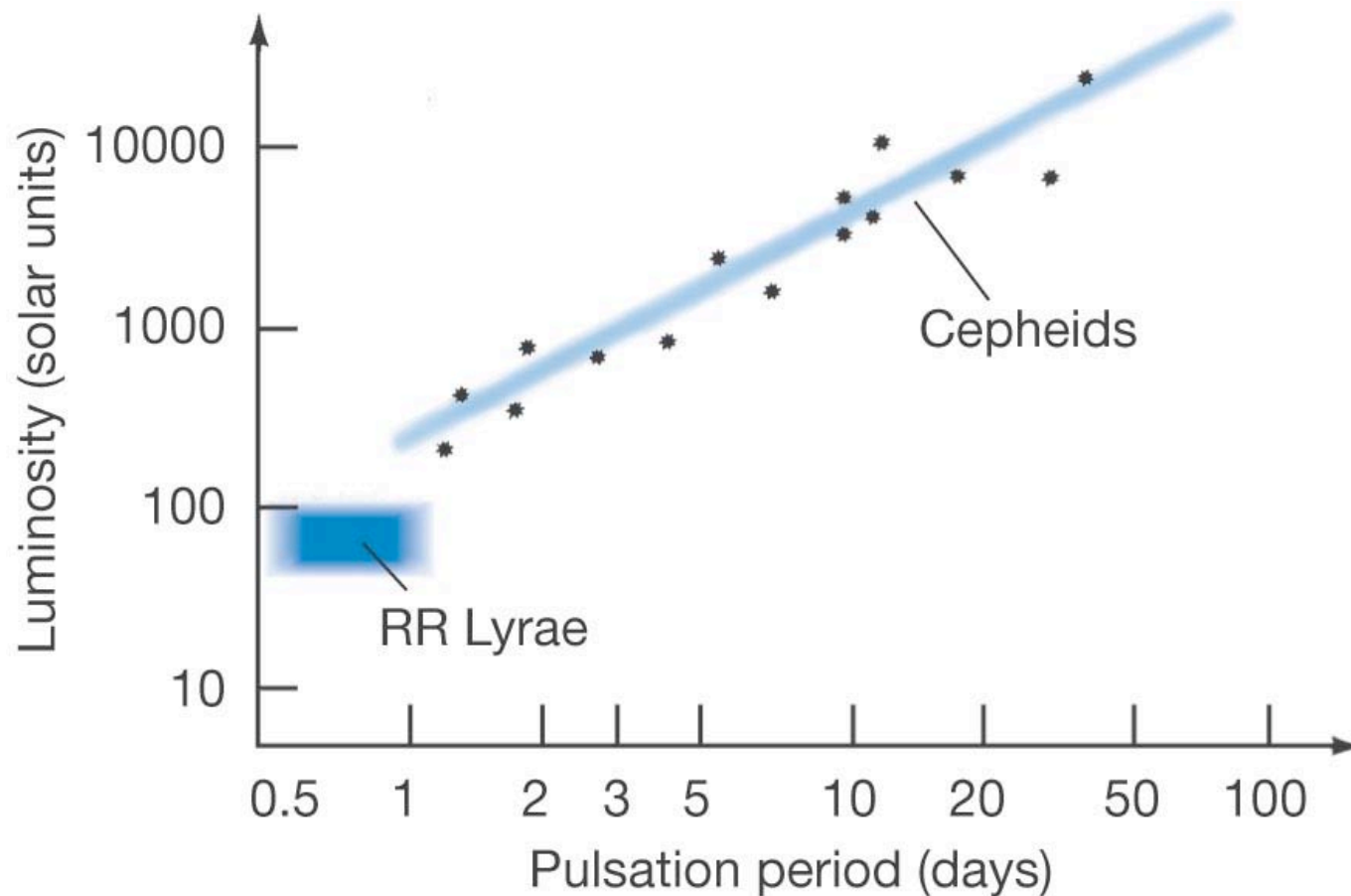
23.2 Measuring the Milky Way

The variability of these stars comes from a dynamic balance between gravity and pressure—they have large oscillations around stability.



23.2 Measuring the Milky Way

The usefulness of these stars comes from their **period–luminosity relation**:



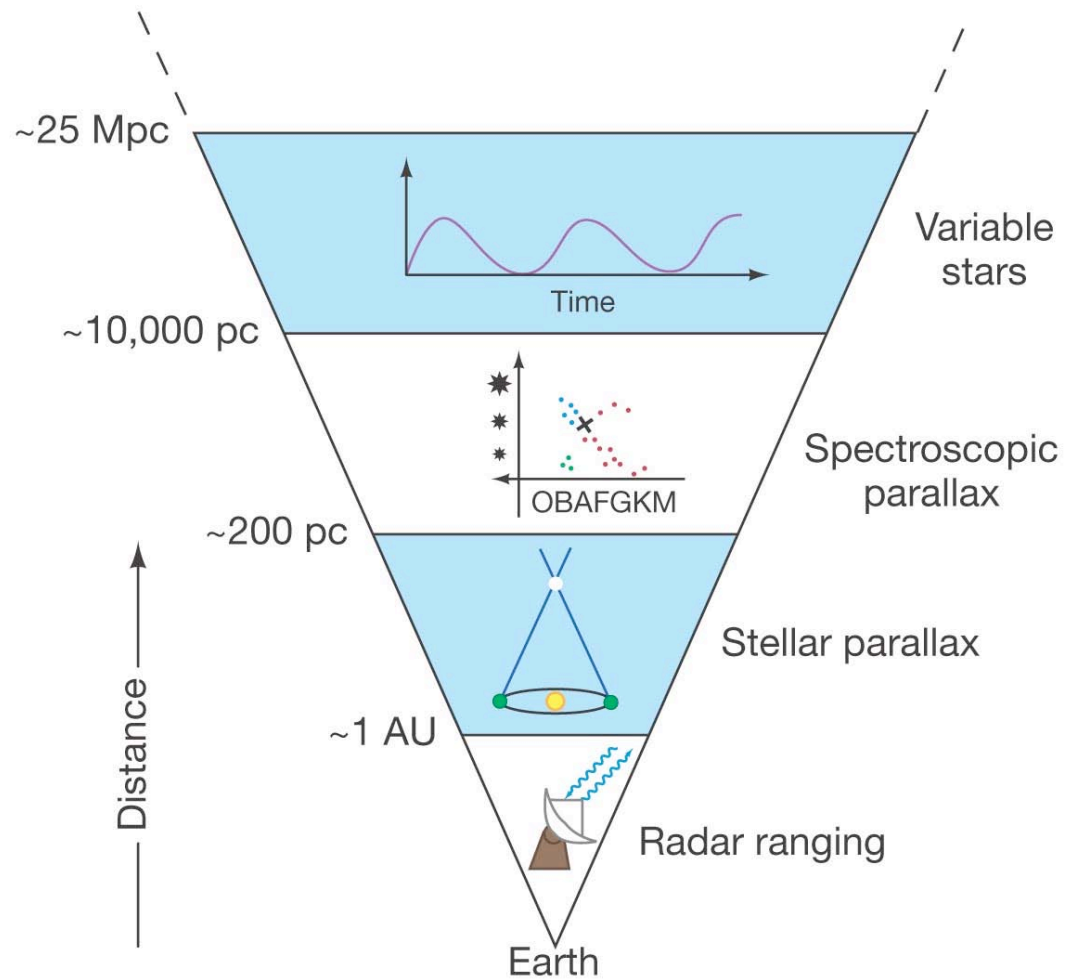
23.2 Measuring the Milky Way

This allows us to measure the **distances to these stars:**

- **RR Lyrae stars all have about the same luminosity; knowing their apparent magnitude allows us to calculate the distance.**
- **Cepheids have a luminosity that is strongly correlated with the period of their oscillations; once the period is measured, the luminosity is known and we can proceed as above.**

23.2 Measuring the Milky Way

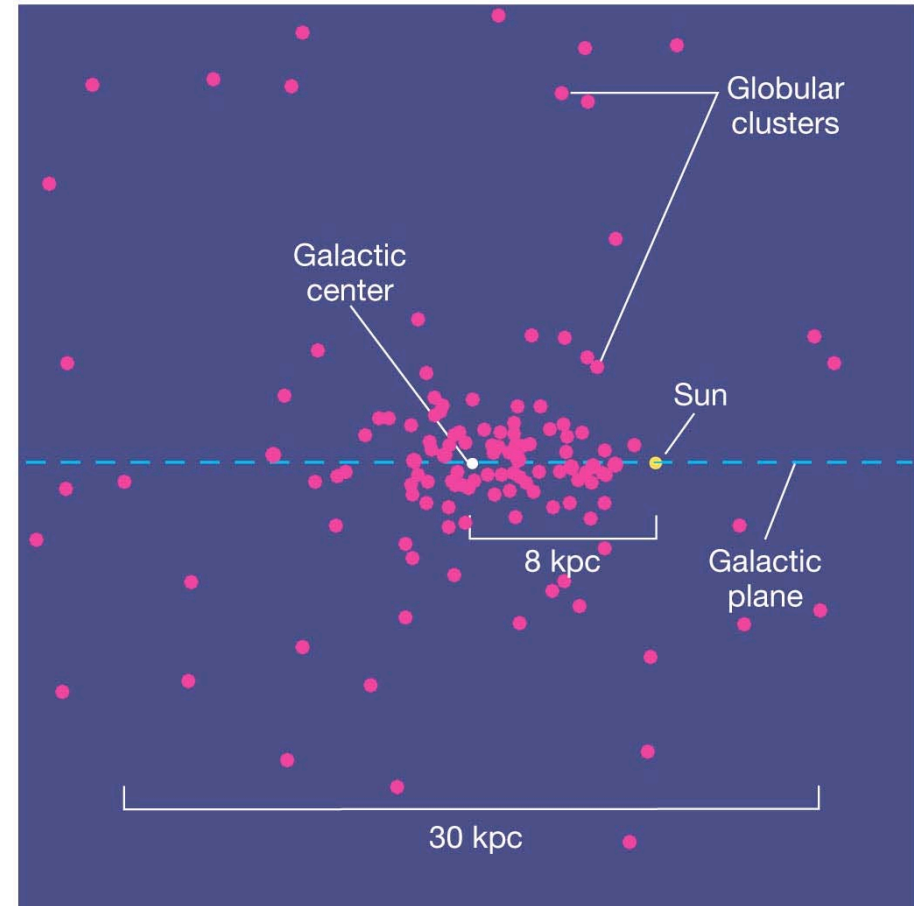
We have now expanded our cosmic distance ladder one more step:



23.2 Measuring the Milky Way

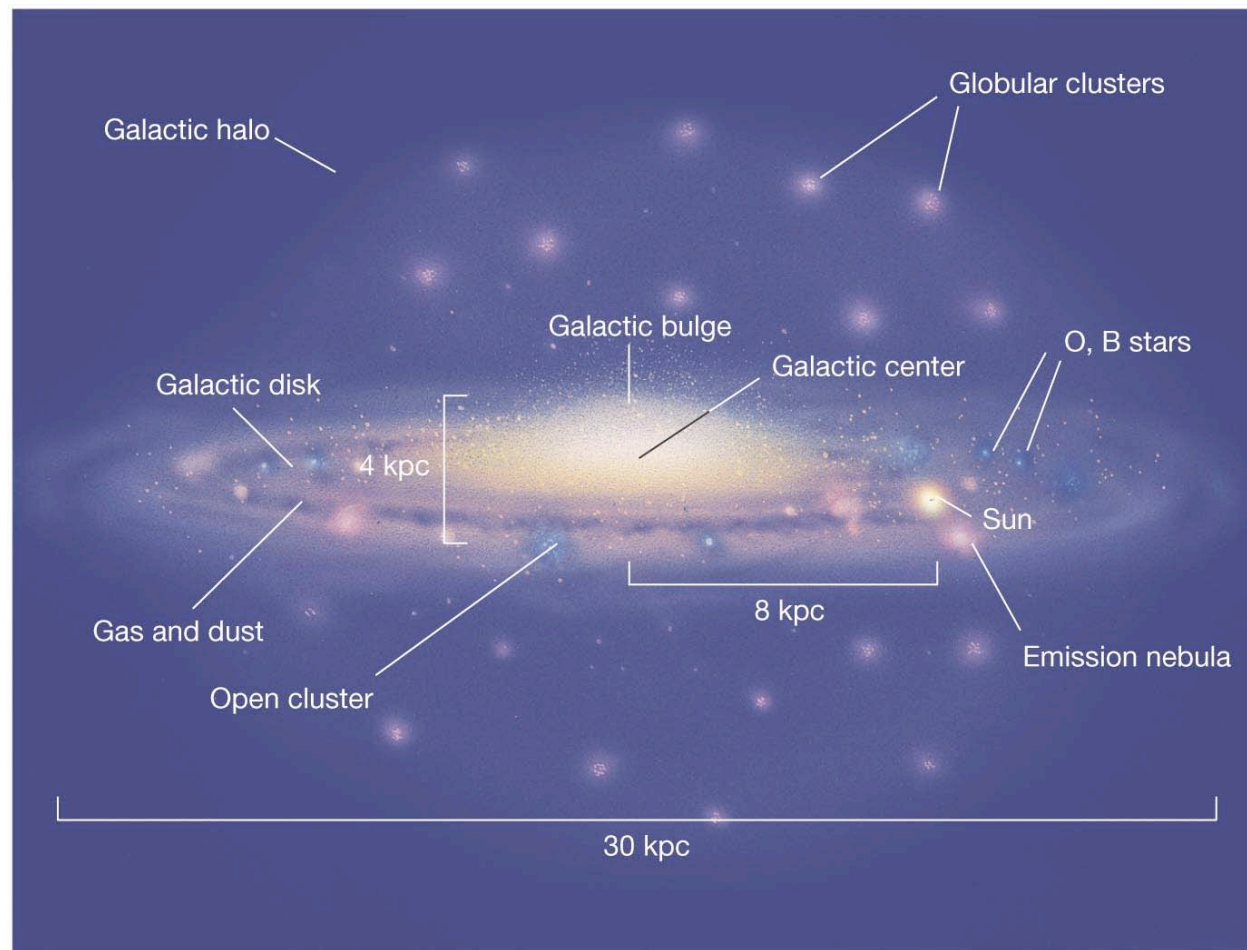
Many RR Lyrae stars are found in **globular clusters**. These clusters are not all in the **plane of the galaxy**, so they are **not obscured by dust** and can be measured.

This yields a much more **accurate picture of the extent of our galaxy and our place within it.**



23.3 Galactic Structure

This artist's conception shows the various parts of our galaxy, and the position of our Sun:



23.3 Galactic Structure

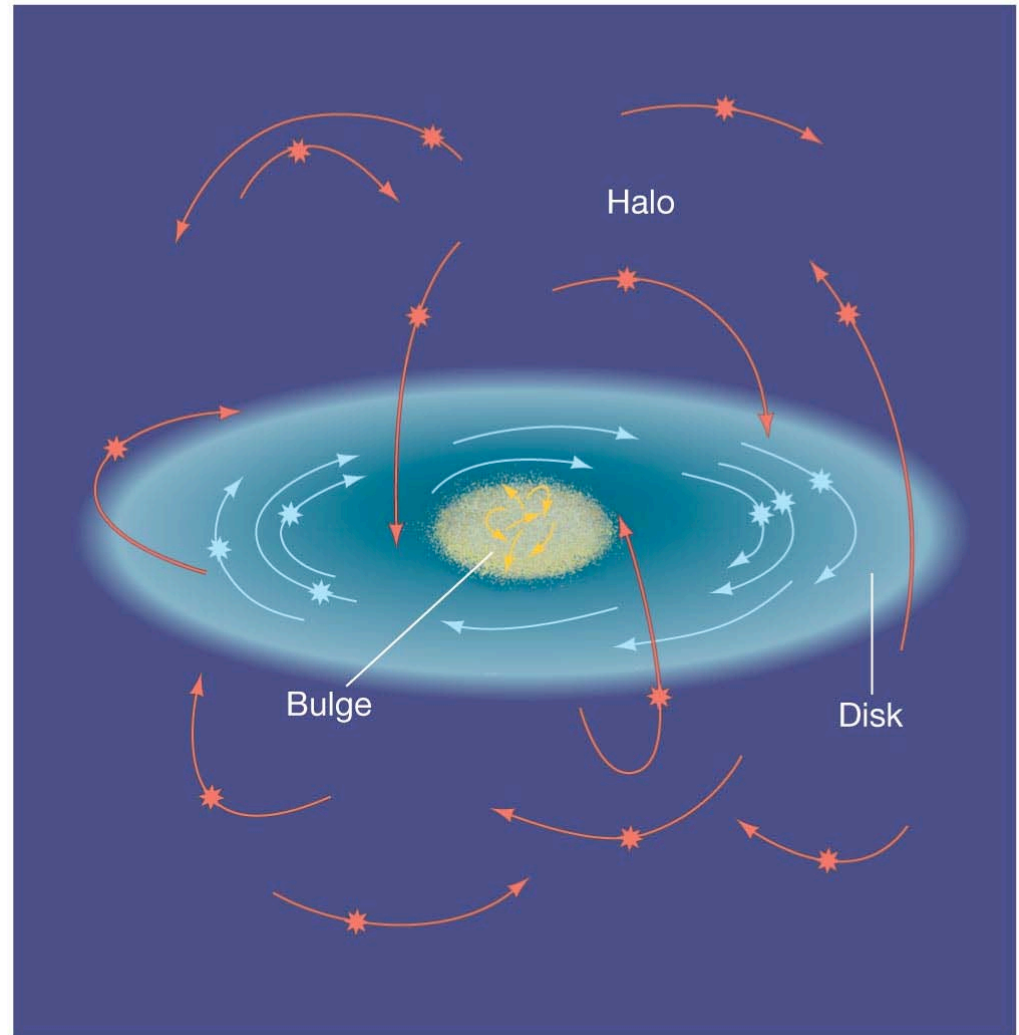
The galactic halo and globular clusters formed very early; the halo is essentially spherical. All the stars in the halo are very old, and there is no gas and dust.

The galactic disk is where the youngest stars are, as well as star formation regions—emission nebulae and large clouds of gas and dust.

Surrounding the galactic center is the galactic bulge, which contains a mix of older and younger stars.

23.3 Galactic Structure

Stellar orbits in the disk move on a plane and in the same direction; orbits in the halo and bulge are much more random.



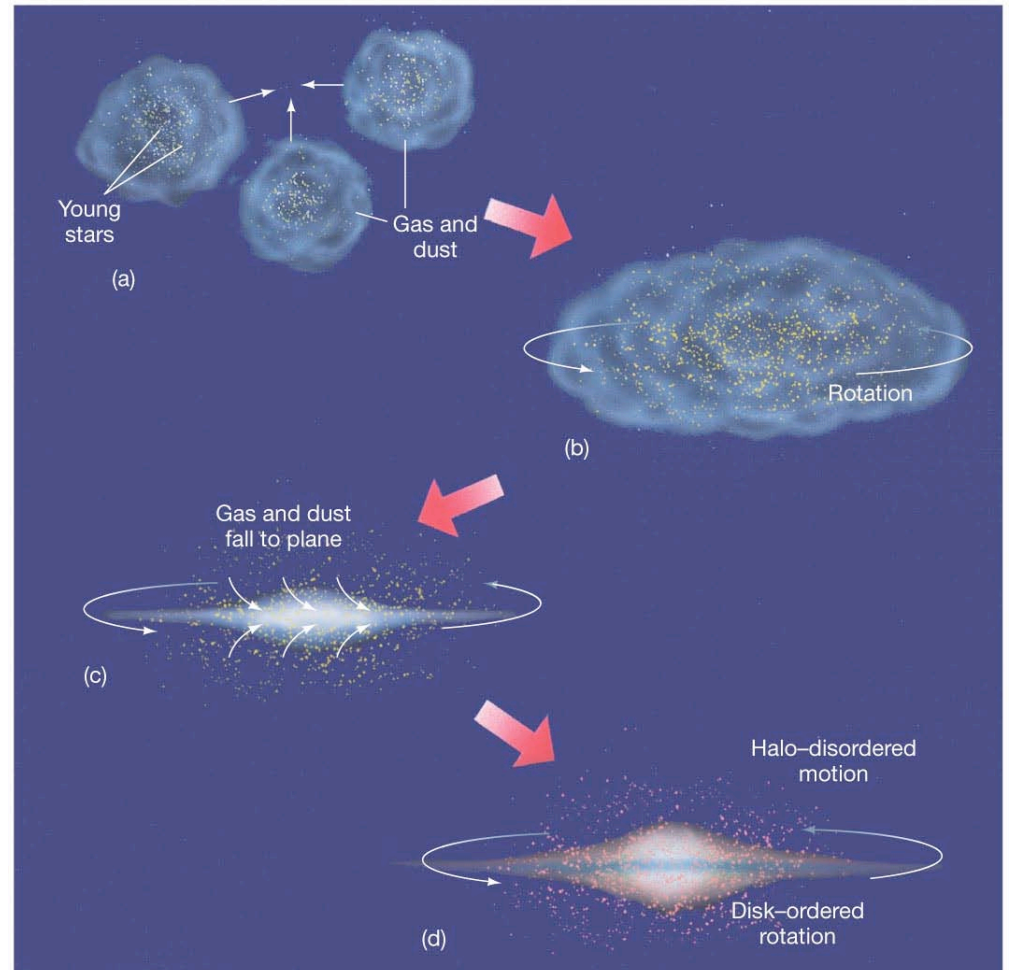
23.4 The Formation of the Milky Way

Any theory of galaxy formation should be able to account for all the **properties below**:

Galactic Disk	Galactic Halo	Galactic Bulge
highly flattened	roughly spherical—mildly flattened	somewhat flattened and elongated in the plane of the disk (“football shaped”)
contains both young and old stars	contains old stars only	contains both young and old stars; more old stars at greater distances from the center
contains gas and dust	contains no gas and dust	contains gas and dust, especially in the inner regions
site of ongoing star formation	no star formation during the last 10 billion years	ongoing star formation in the inner regions
gas and stars move in circular orbits in the Galactic plane	stars have random orbits in three dimensions	stars have largely random orbits, but with some net rotation about the Galactic center
spiral arms	no obvious substructure	central regions probably elongated into a bar; ring of gas and dust near center
overall white coloration, with blue spiral arms	reddish in color	yellow-white

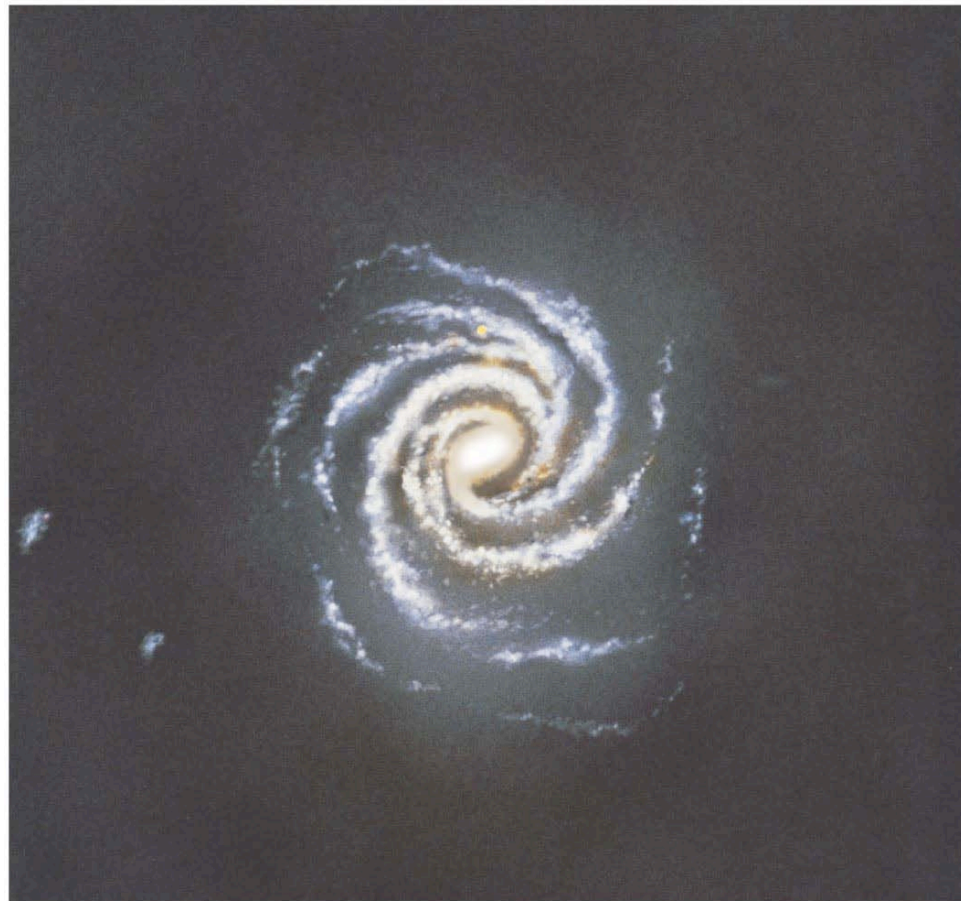
23.4 The Formation of the Milky Way

The formation of the galaxy is believed to be similar to the formation of the solar system, but on a much larger scale:



23.5 Galactic Spiral Arms

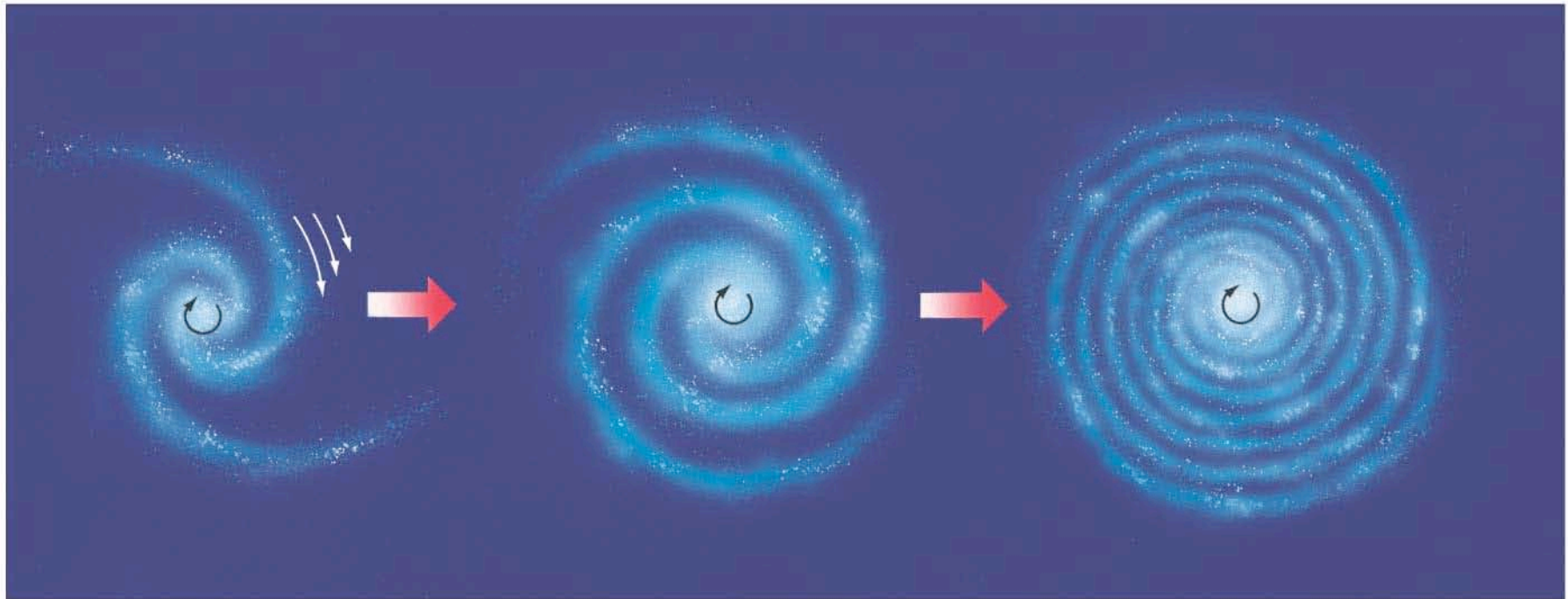
Measurement of the **position and motion of gas clouds** shows that the Milky Way has a spiral form:



30 kpc

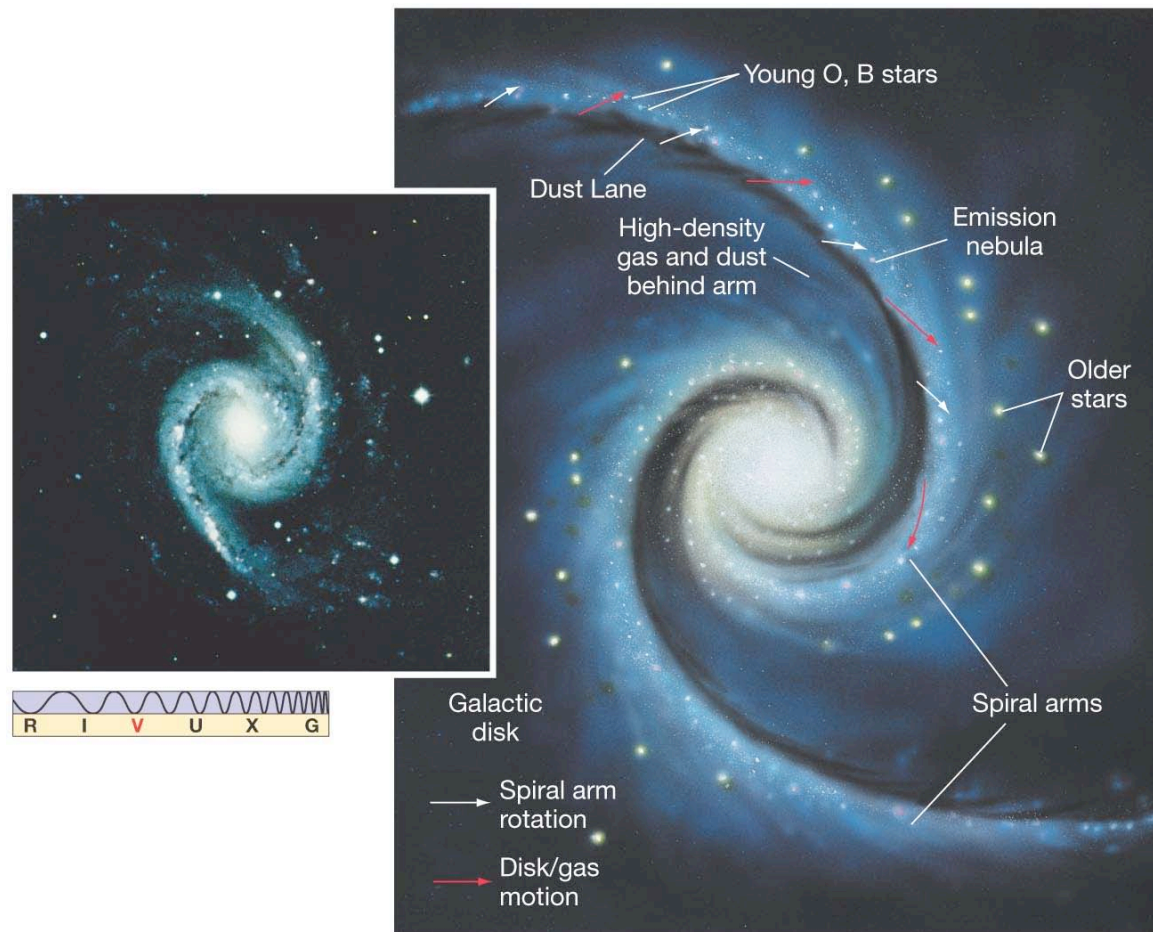
23.5 Galactic Spiral Arms

The **spiral arms cannot rotate at the same speed as the galaxy; they would “curl up”.**



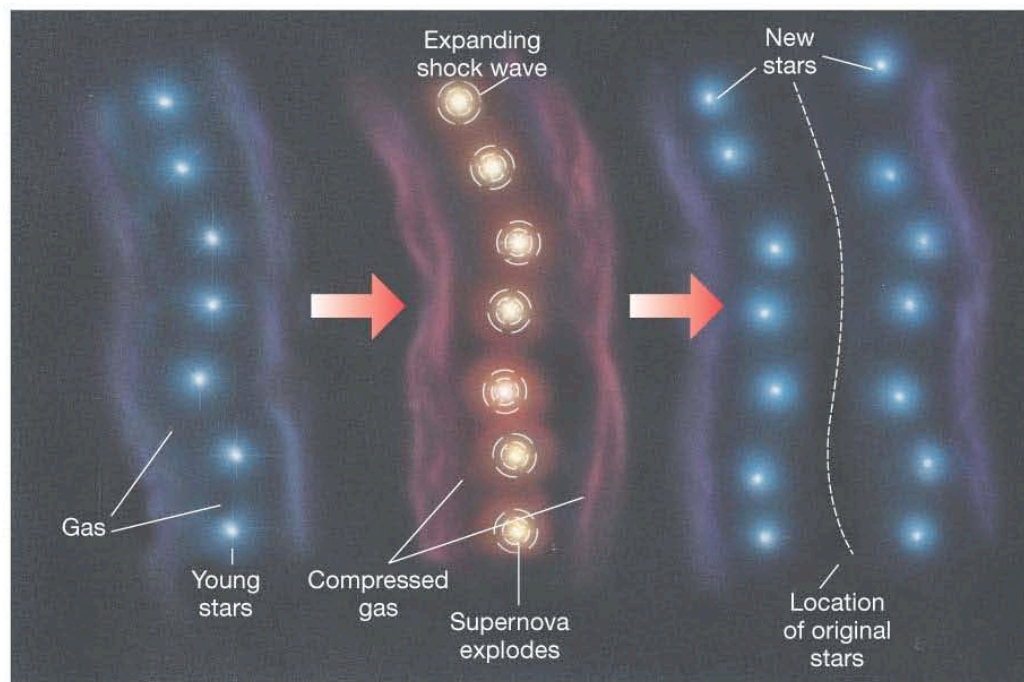
23.5 Galactic Spiral Arms

Rather, they appear to be **density waves**, with stars moving in and out of them such as cars move in and out of a traffic jam:

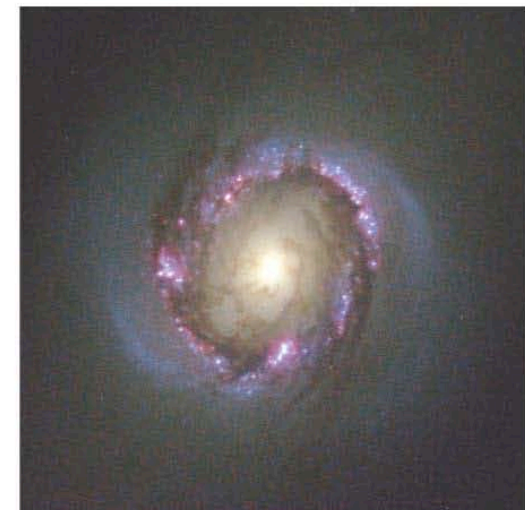


23.5 Galactic Spiral Arms

As clouds of **gas** and **dust** move through the spiral arms, the increased **density** triggers **star formation**. This may contribute to propagation of the arms. The origin of the spiral arms is not yet understood.



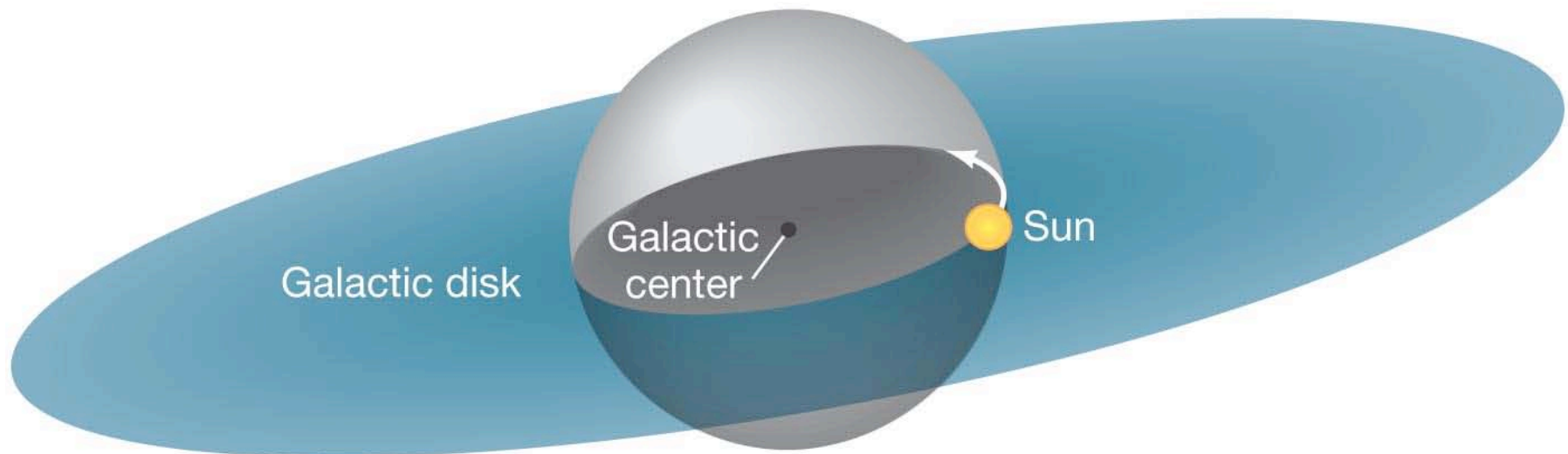
(a)



(b)

23.6 The Mass of the Milky Way Galaxy

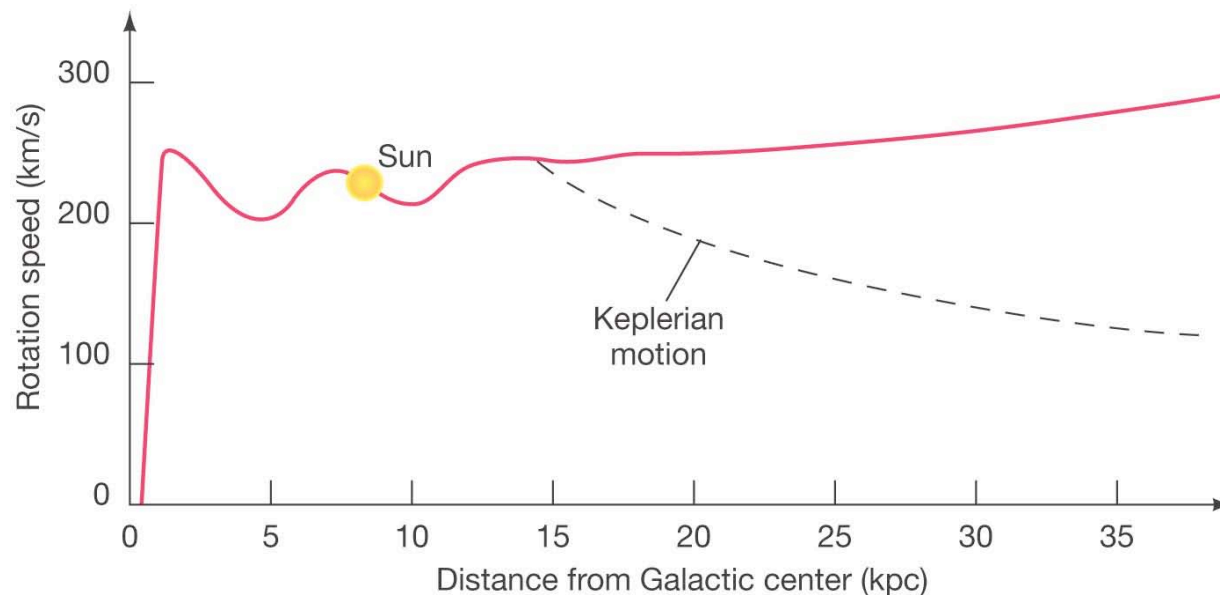
The **orbital speed** of an object depends only on the **amount of mass** between it and the **galactic center**:



23.6 The Mass of the Milky Way Galaxy

Once all the galaxy is within an orbit, the velocity should **diminish** with distance, as the dashed curve shows.

It doesn't; more than **twice** the mass of the galaxy would have to be outside the visible part to reproduce the observed curve.



23.6 The Mass of the Milky Way Galaxy

What could this “dark matter” be? It is dark at all wavelengths, not just the visible.

- **Stellar-mass black holes?**

Probably no way enough of them could have been created

- **Brown dwarfs, faint white dwarfs, and red dwarfs?**

This was the best star-like option, but comes up short by a significant margin.

- **Subatomic particles?**

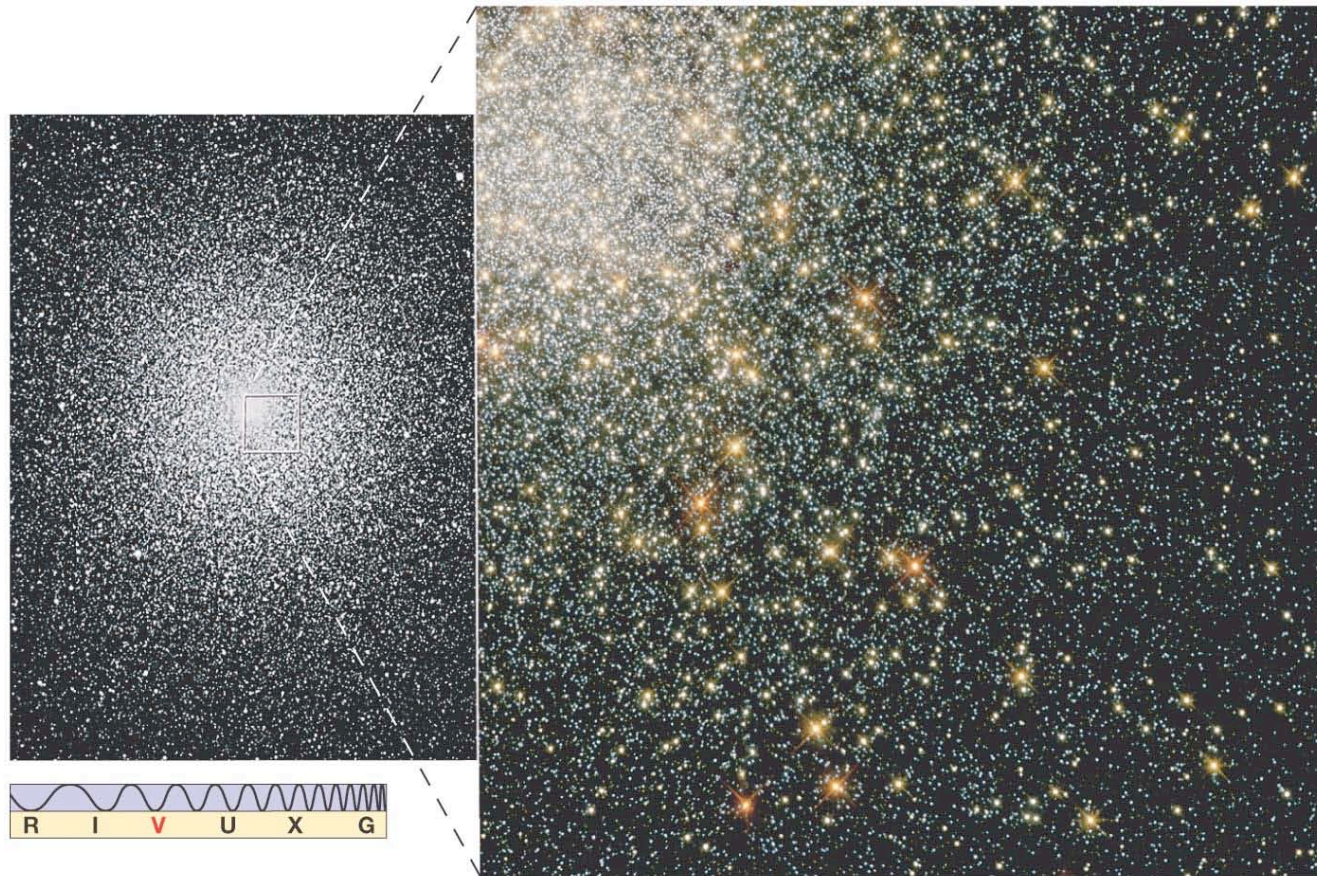
• Recall the solution to the “solar neutrino problem”, that neutrinos have a tiny bit of mass. Neutrinos turn out to be the most abundant particle in the universe (more than even photons). But falls short by an order of magnitude.

A “weird subatomic particle” is the most (only?) favored candidate. But whatever they are, they are too massive to observe in present-day particle accelerators (takes too much energy to create them).

Conclusion: Our galaxy (and others) consist mostly of “dark matter,” but we have no idea what that is, other than it exerts a gravitational force.

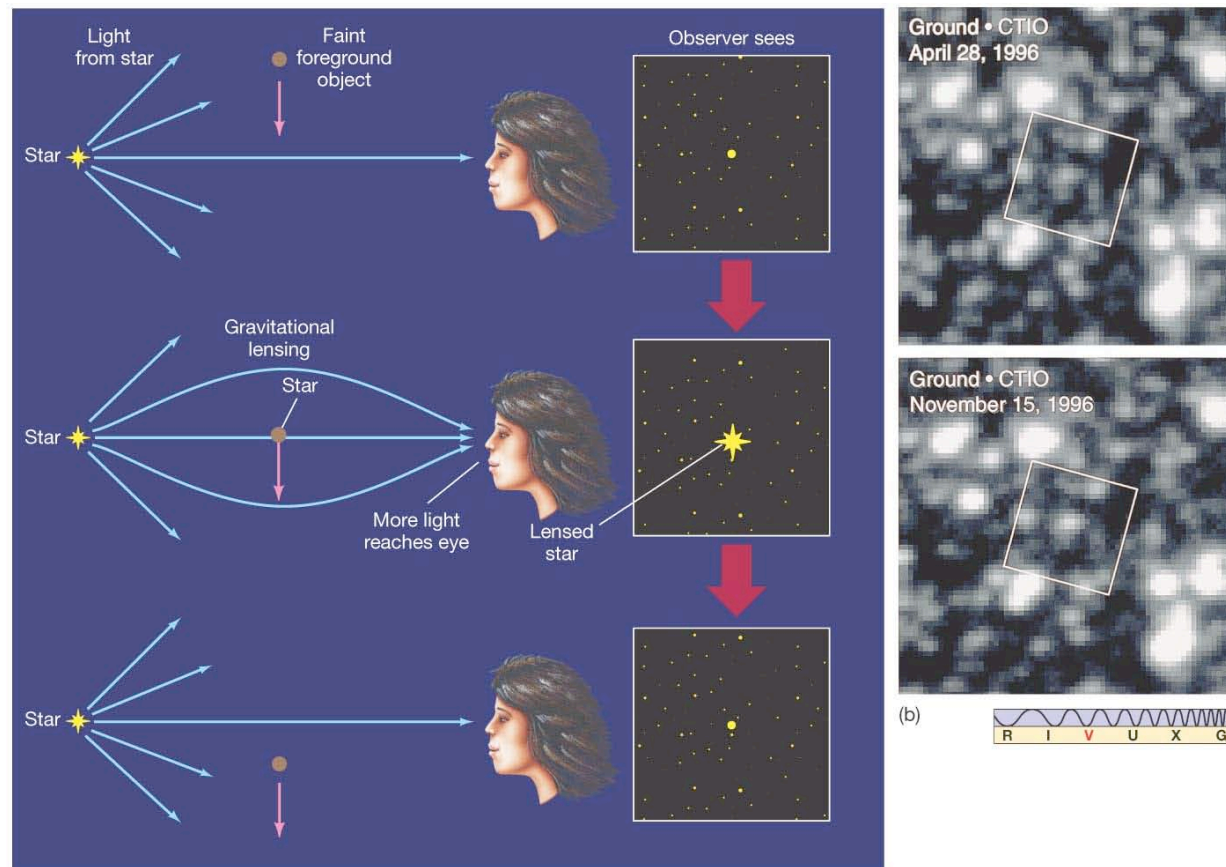
23.6 The Mass of the Milky Way Galaxy

A Hubble search for **red dwarfs** turned up too few to account for dark matter; if enough existed, they should have been detected.



23.6 The Mass of the Milky Way Galaxy

The bending of spacetime can allow a large mass to act as a **gravitational lens**. Observation of such events suggests that **low-mass white dwarfs** could account for as much as 20% of the mass needed. The rest is still a mystery.



Summary of Chapter 23

- **A galaxy is stellar and interstellar matter bound by its own gravity.**
- **Our galaxy is spiral.**
- **Variable stars can be used for distance measurement through the period–luminosity relationship.**
- **The true extent of the galaxy can be mapped out using globular clusters.**
- **Star formation occurs in the disk, but not in the halo or bulge.**

Summary of Chapter 23 (cont.)

- **Spiral arms may be density waves.**
- **The galactic rotation curve shows large amounts of undetectable mass at large radii called dark matter.**
- **Activity near galactic center suggests presence of a 2 to 3 million solar-mass black hole**