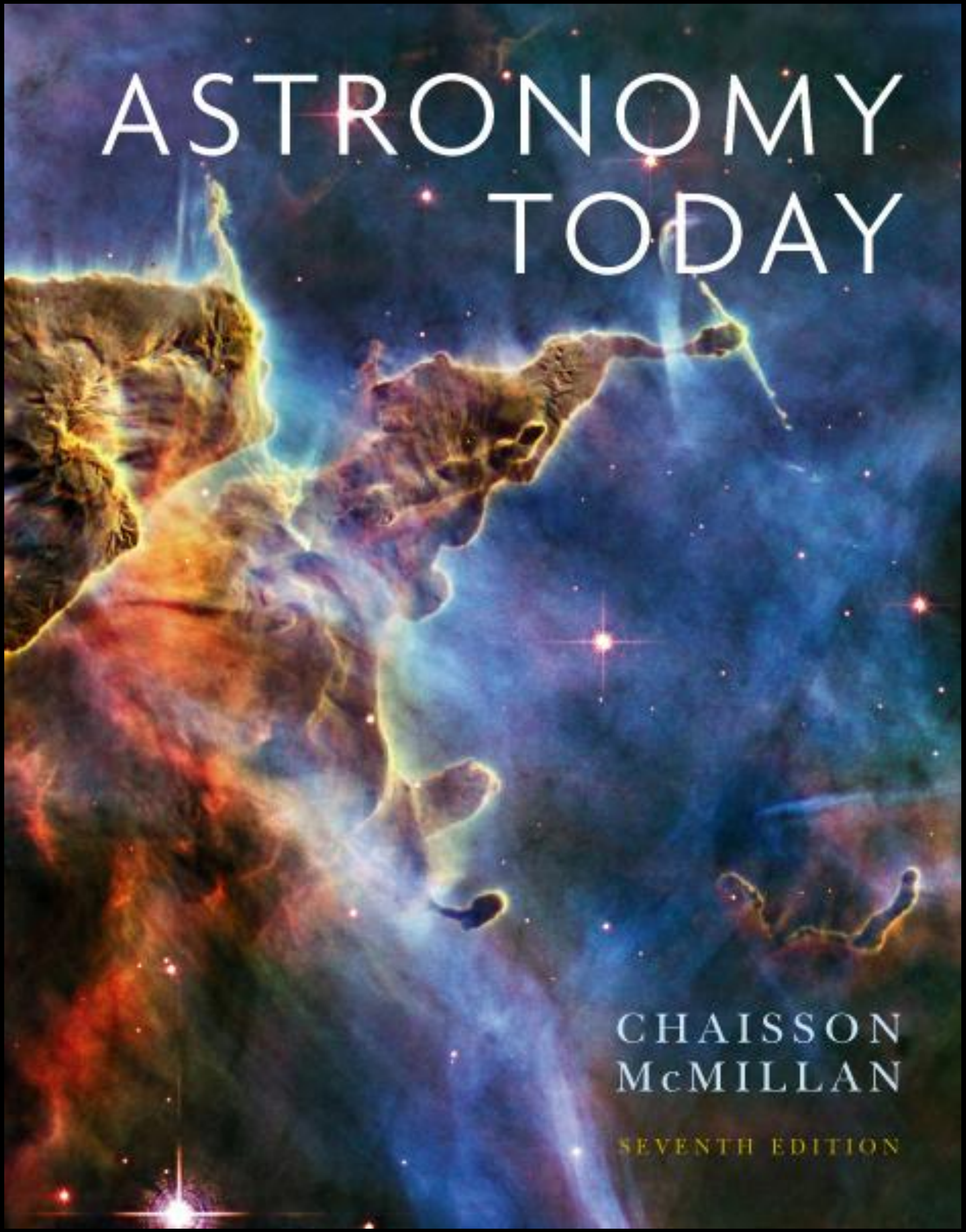


Lecture Outlines

Chapter 23

Astronomy Today

7th Edition

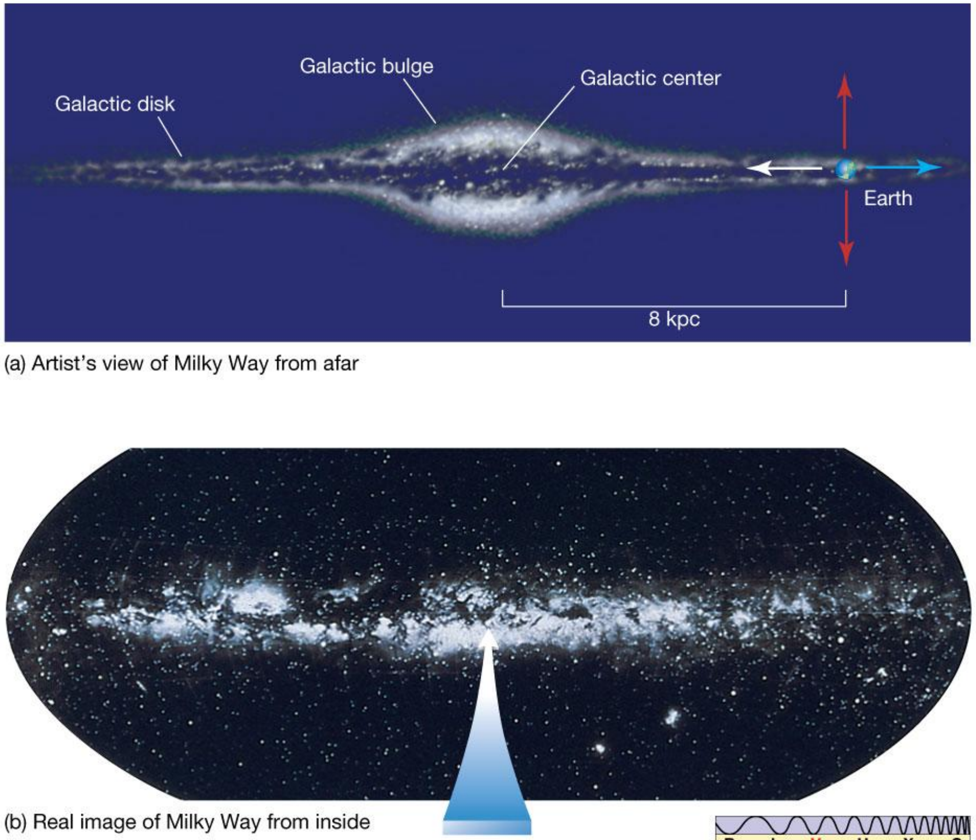
Chaisson/McMillan

Chapter 23
The Milky Way Galaxy

Units of Chapter 23

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.

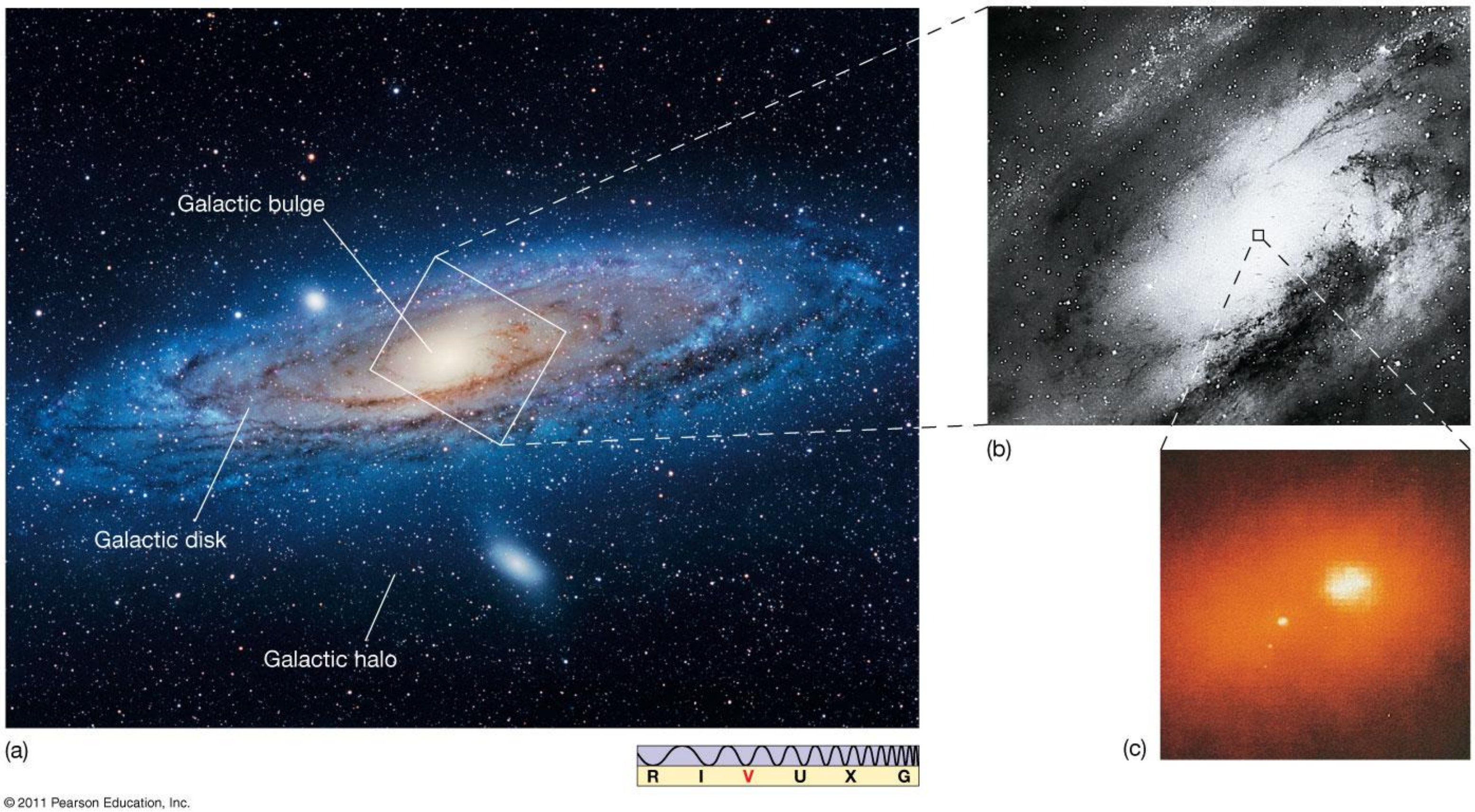


(a) Artist's view of Milky Way from afar

(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

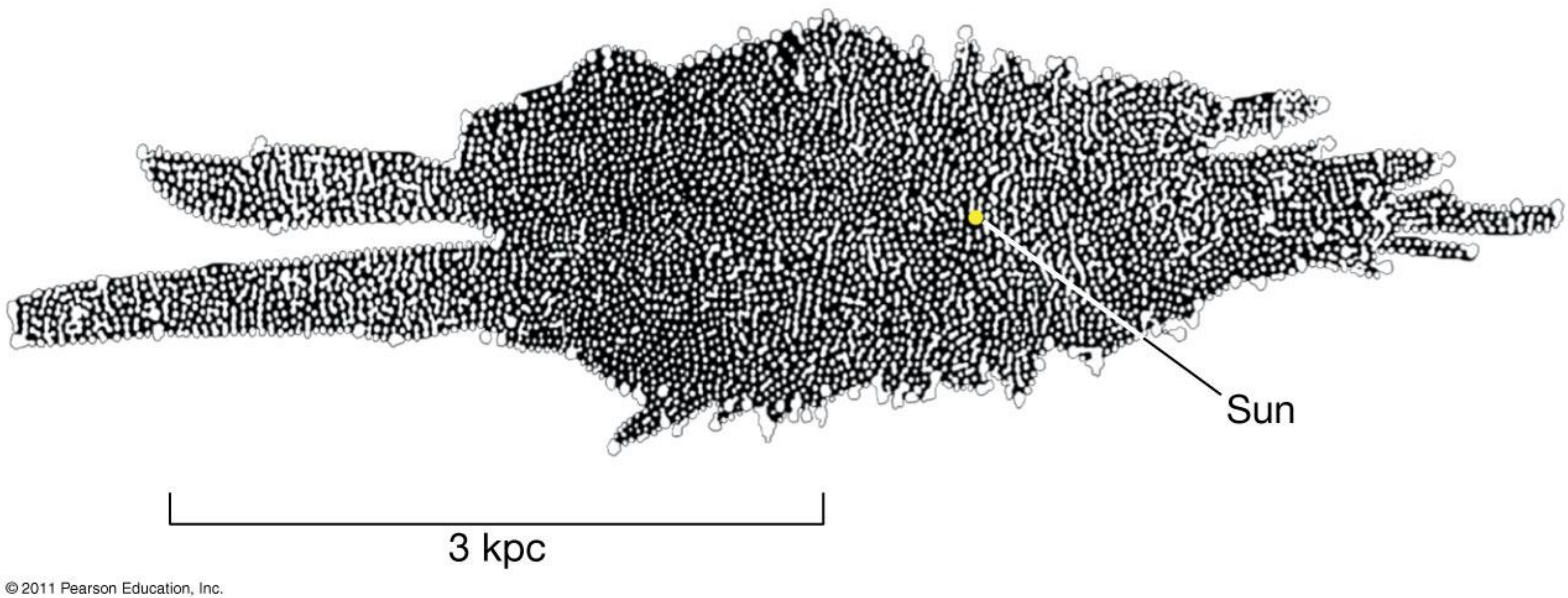
Here are two other spiral galaxies, one viewed from the side and the other from the top:

(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

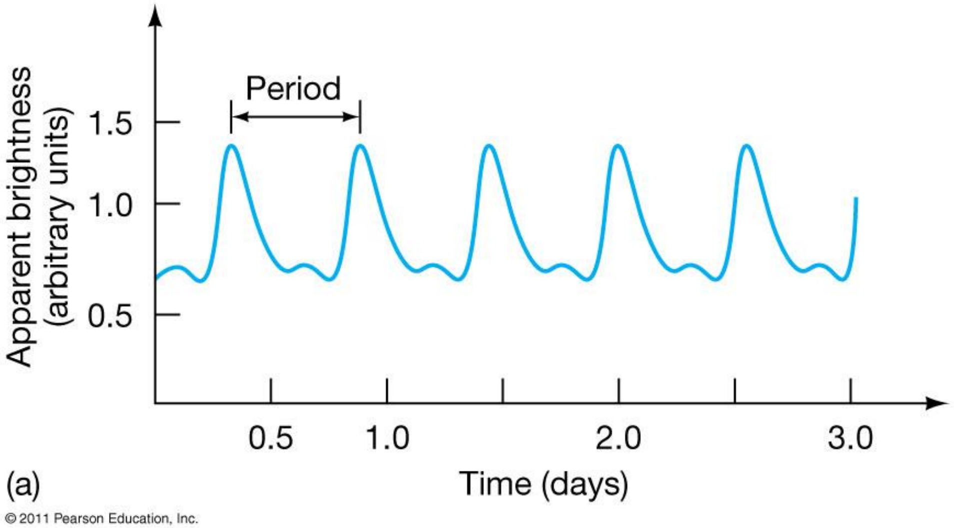
We have already encountered variable stars—novae, supernovae, and related phenomena. These are called cataclysmic variables.

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

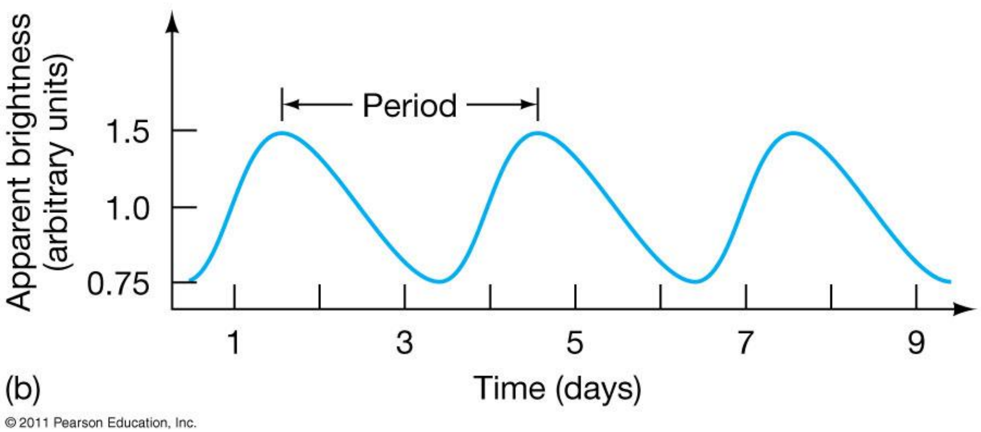
Two types of intrinsic variables have been found: RR Lyrae stars and Cepheids.

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.

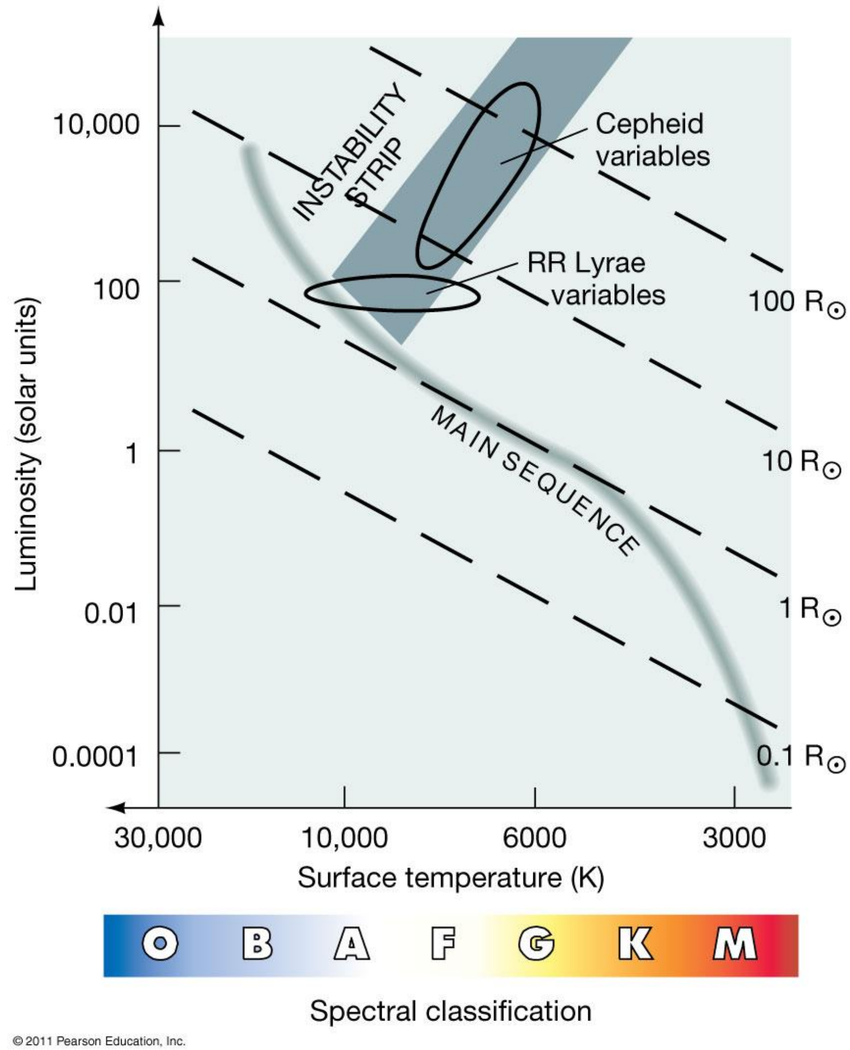


The lower plot is a Cepheid variable; Cepheid periods range from about 1 to 100 days.



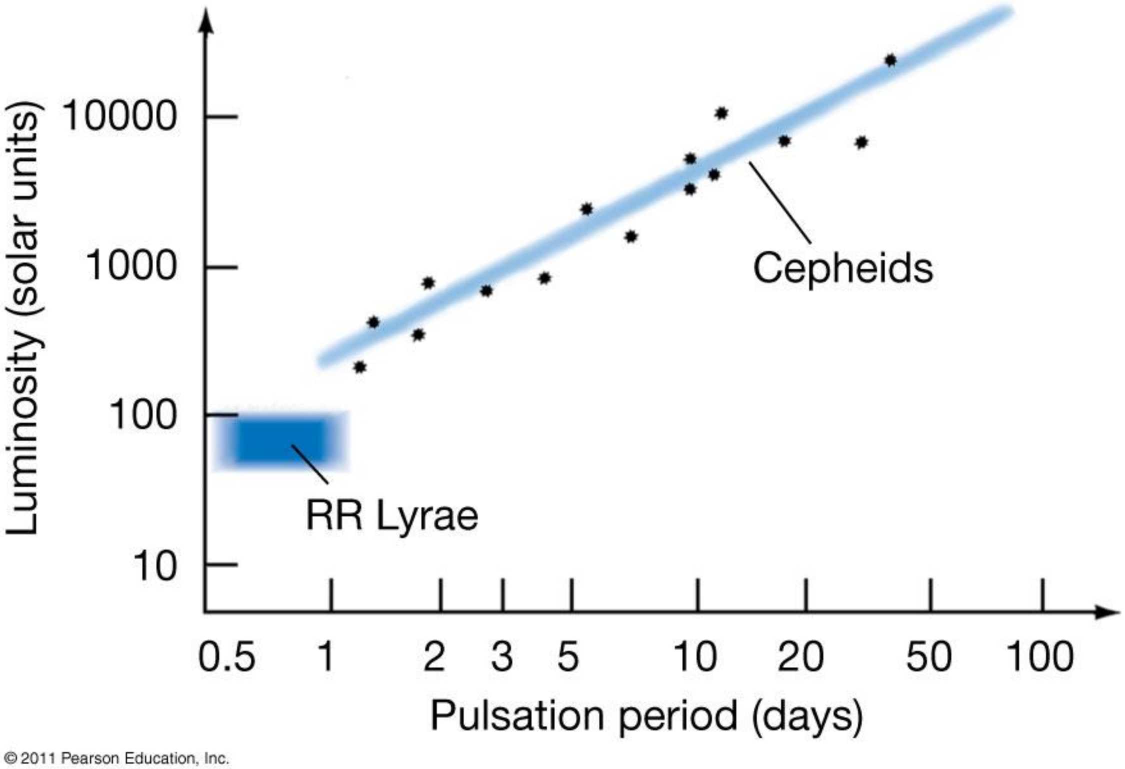
23.2 Measuring the Milky Way

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:



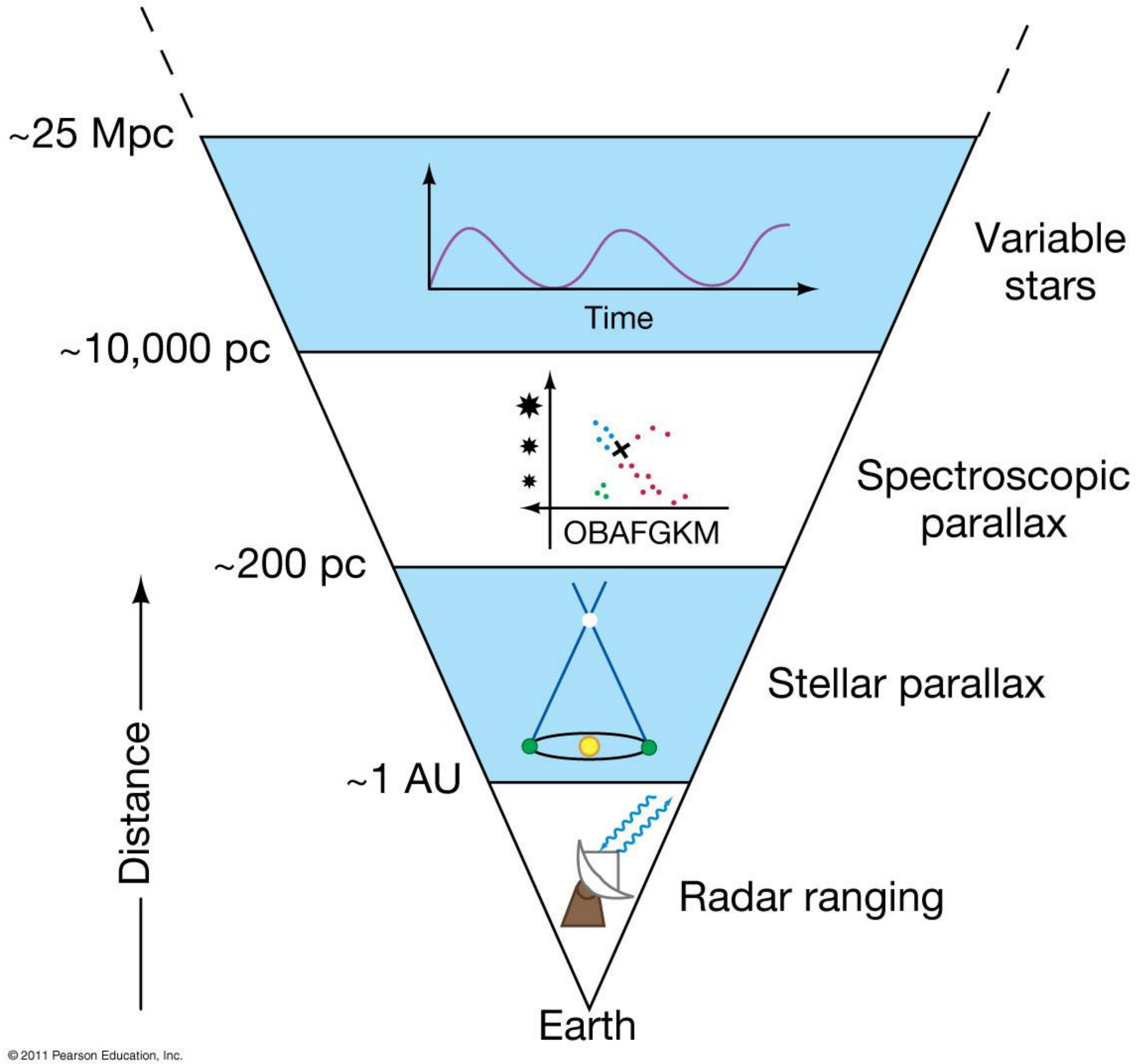
23.2 Measuring the Milky Way

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

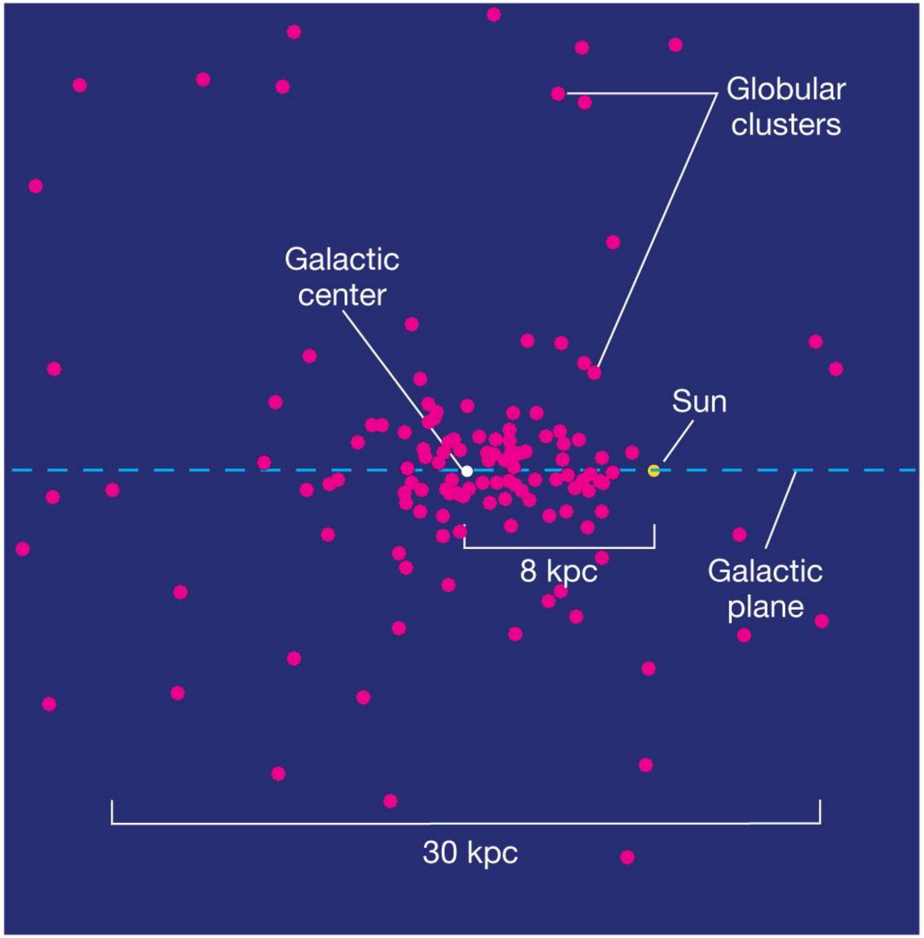
We have now expanded our cosmic distance ladder one more step:



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.



Discovery 23-1: Early “Computers”

Much of the early detailed work in astronomical research was done by analysis of photographs; this work was mostly done by women (called “computers,” as they did computations). Several of these women went on to become well-known astronomers in their own right. Their work enabled the advances made by Shapley as well as Hertzsprung and Russell, among others.

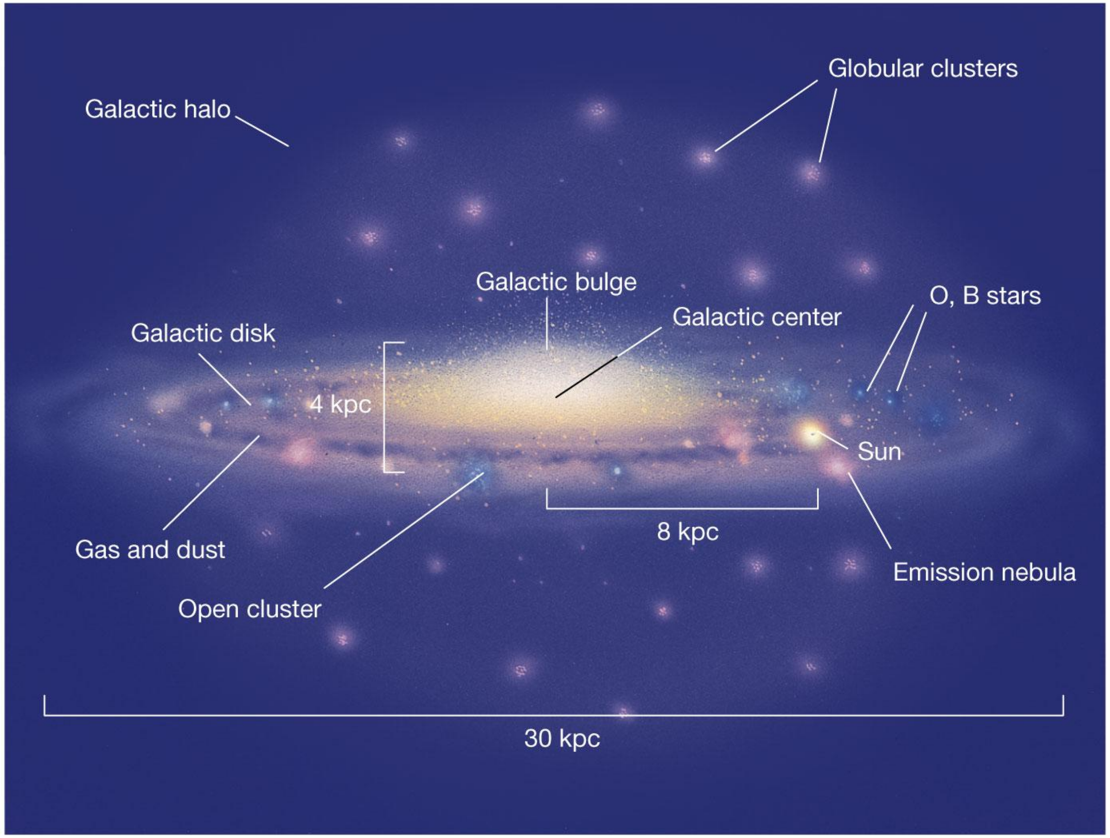
Discovery 23-1: Early “Computers”

Some of the discoveries and innovations made by these women include:

- The spectral classification system (OBAFGKM)
- The period–luminosity relationship of Cepheid variable stars

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

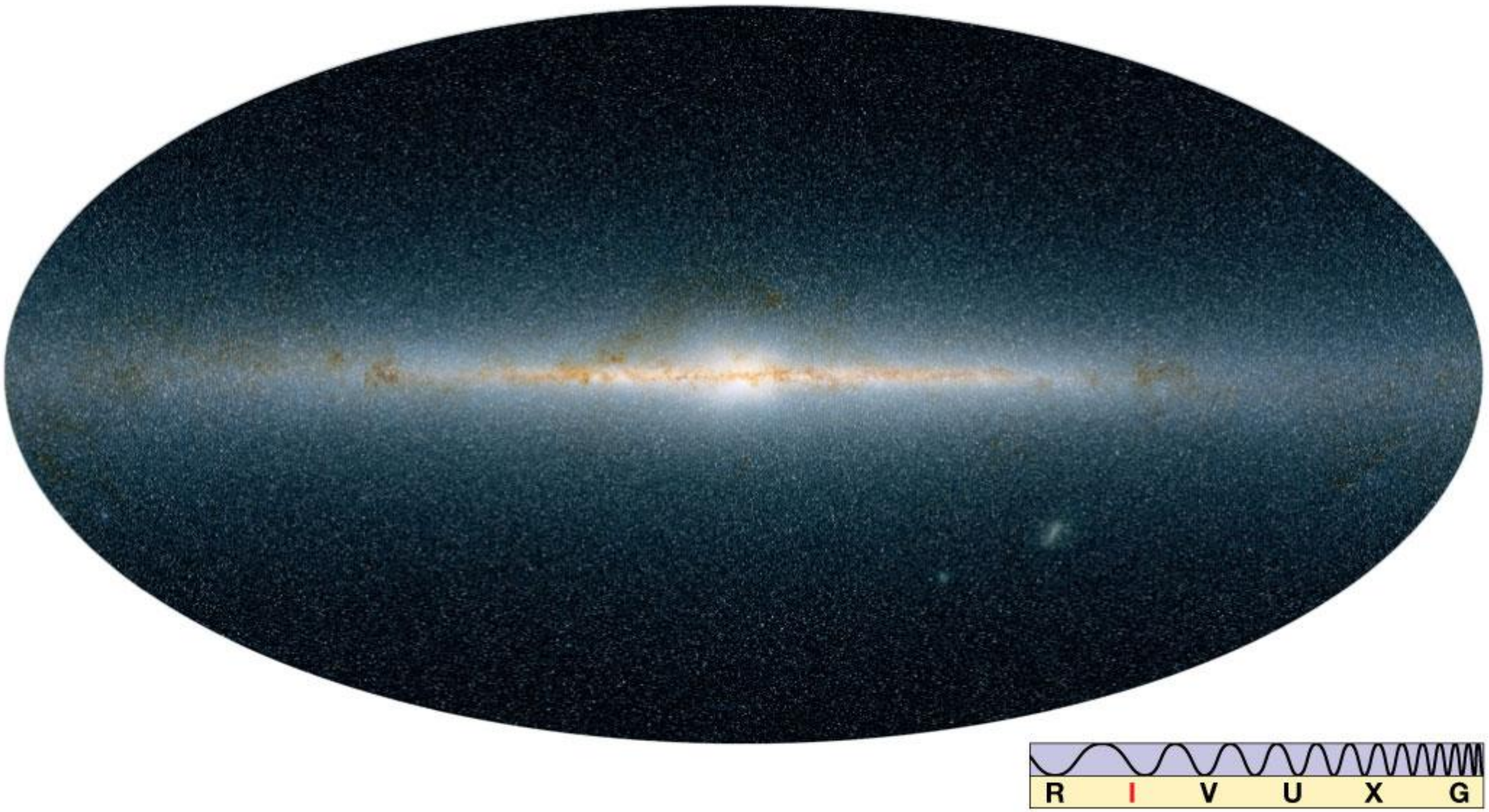
The galactic halo and globular clusters formed very early; the halo is essentially spherical. All the stars in the halo are very old, and there is no gas and dust.

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.

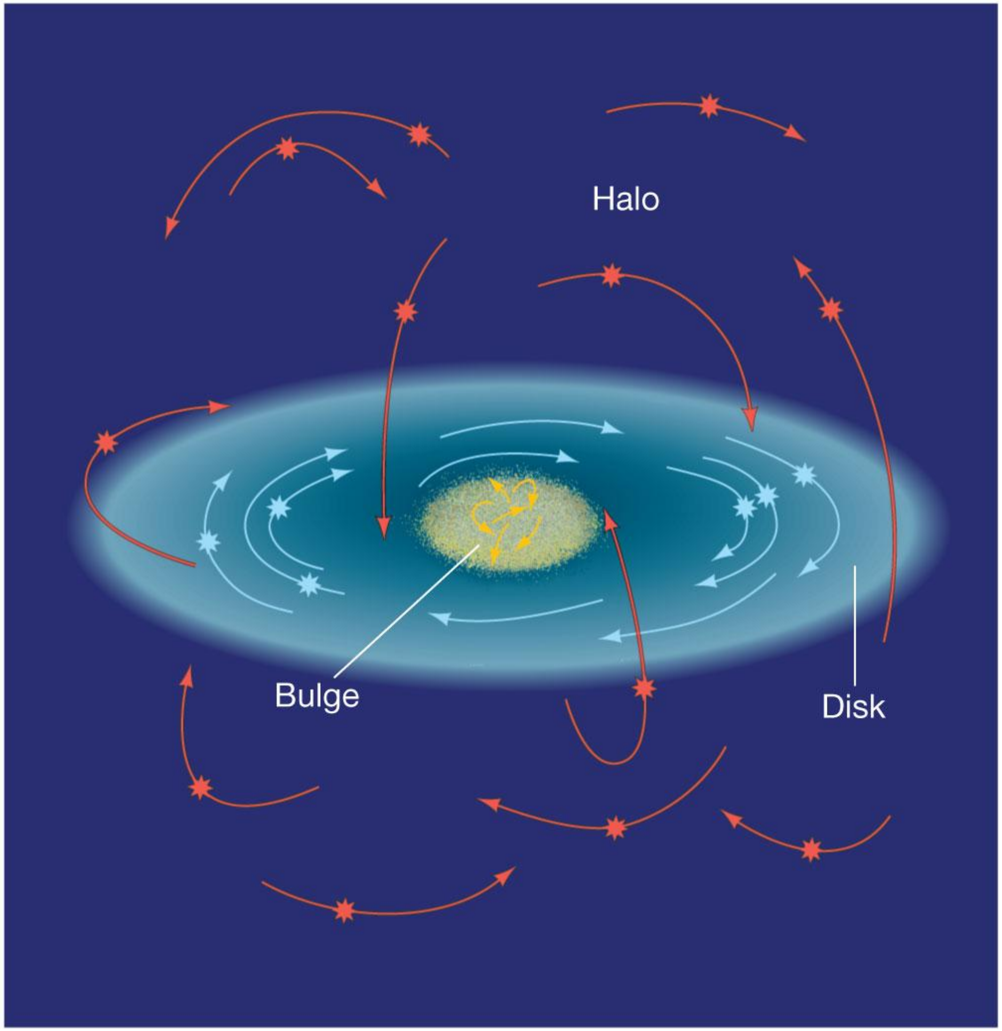
23.3 Galactic Structure

This infrared view of our galaxy shows much more detail of the galactic center than the visible-light view does, as infrared is not absorbed as much by gas and dust.



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.



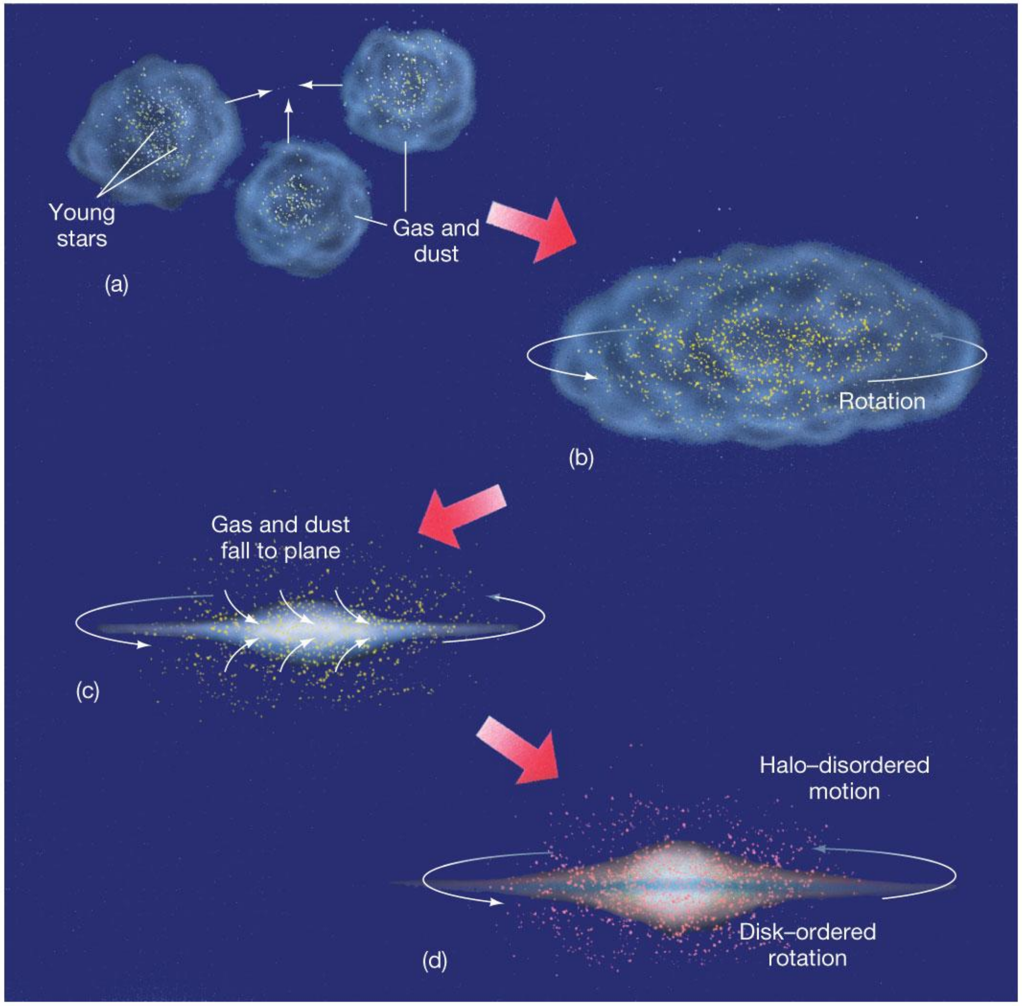
23.4 The Formation of the Milky Way

Any theory of galaxy formation should be able to account for all the properties shown to the right:

TABLE 23.1 Overall Properties of the Galactic Disk, Halo, and Bulge		
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 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 random orbits but 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

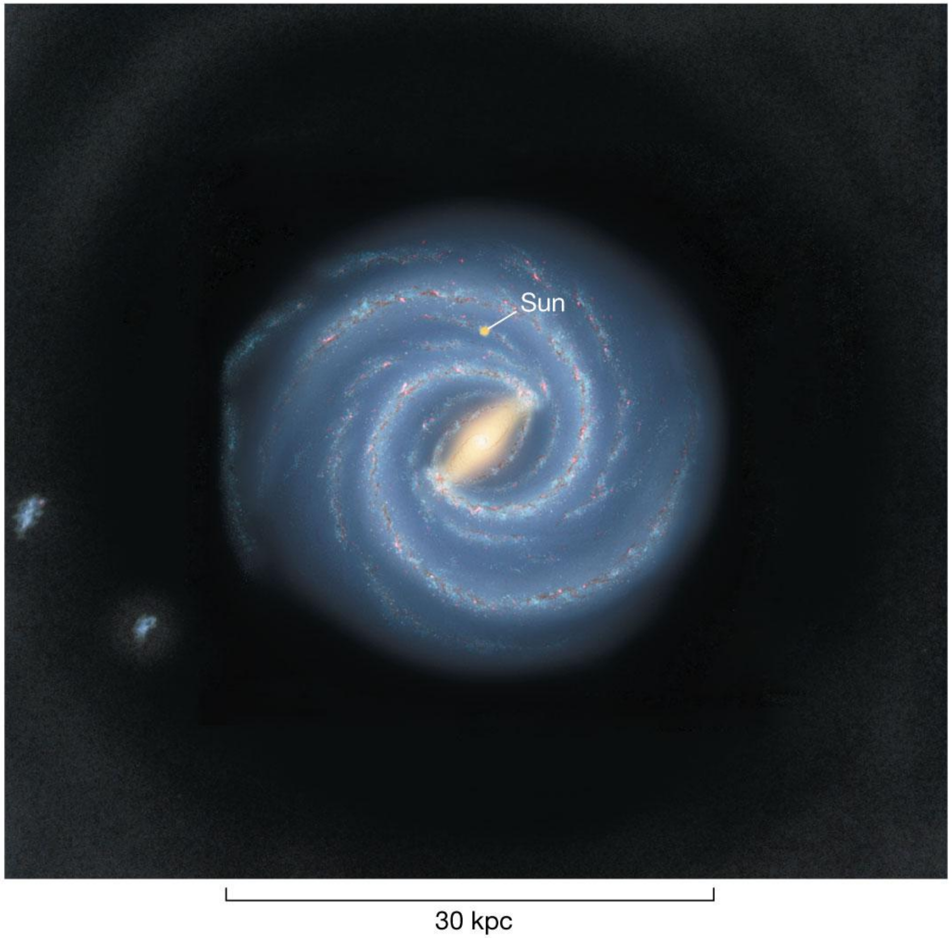
23.4 The Formation of the Milky Way

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



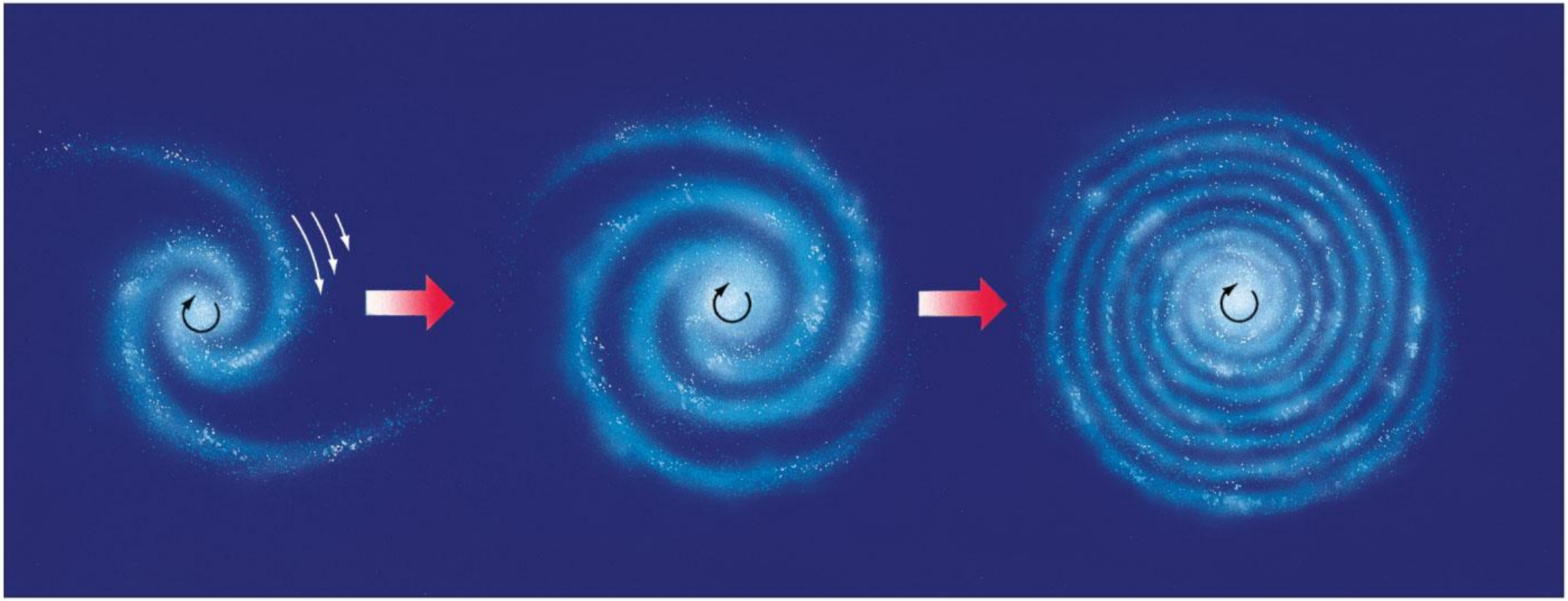
23.5 Galactic Spiral Arms

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



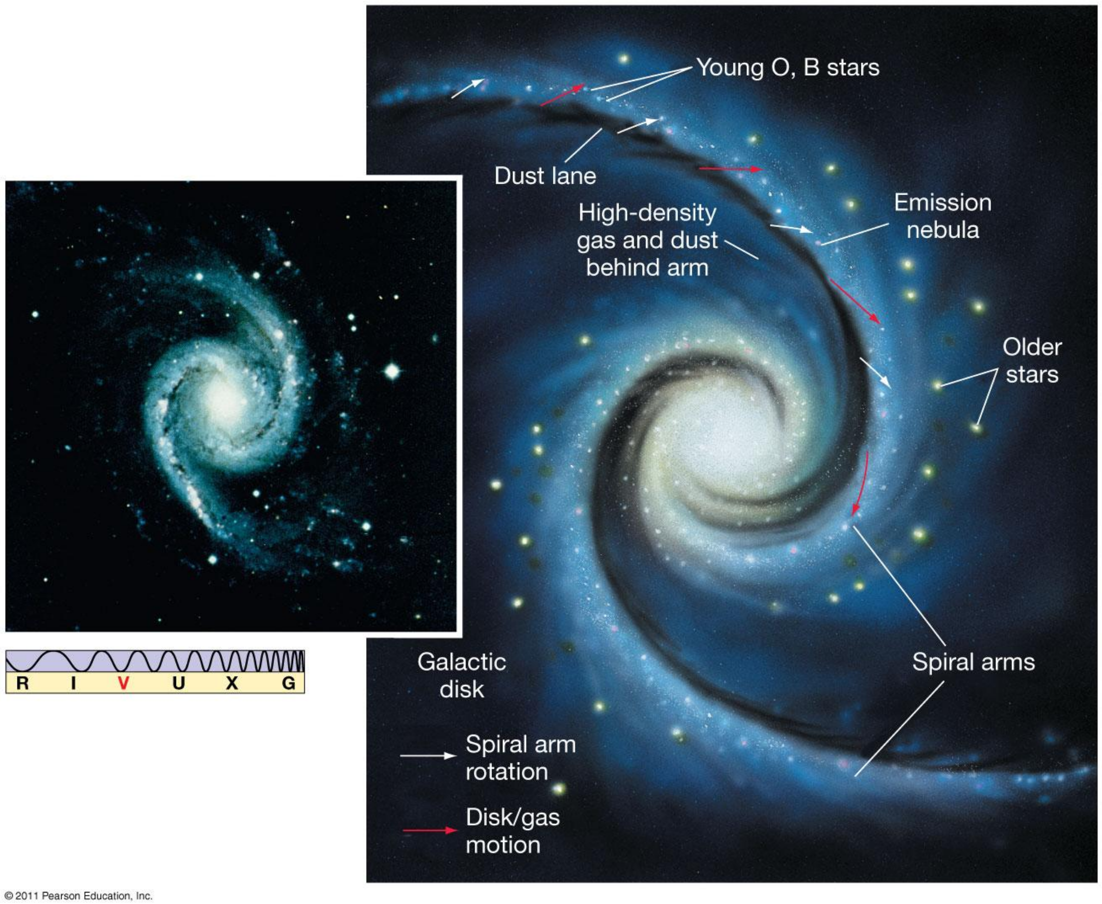
23.5 Galactic Spiral Arms

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



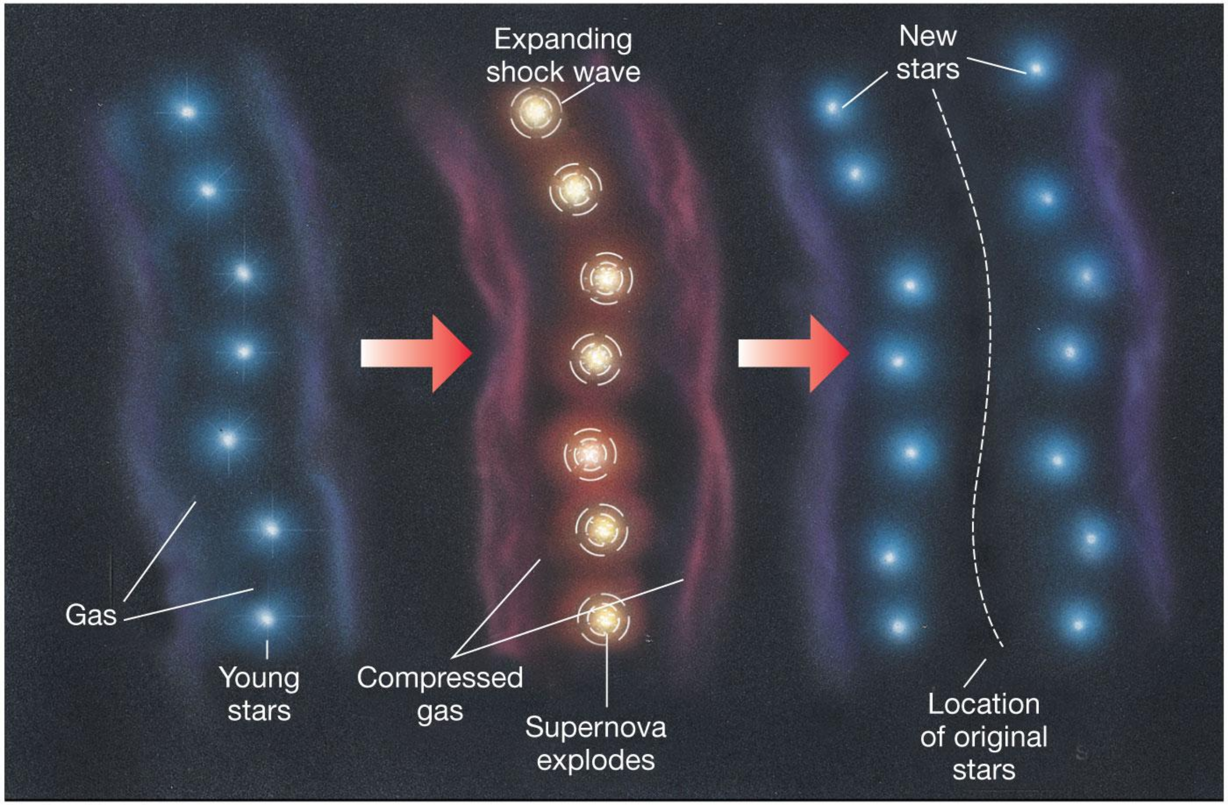
23.5 Galactic Spiral Arms

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:



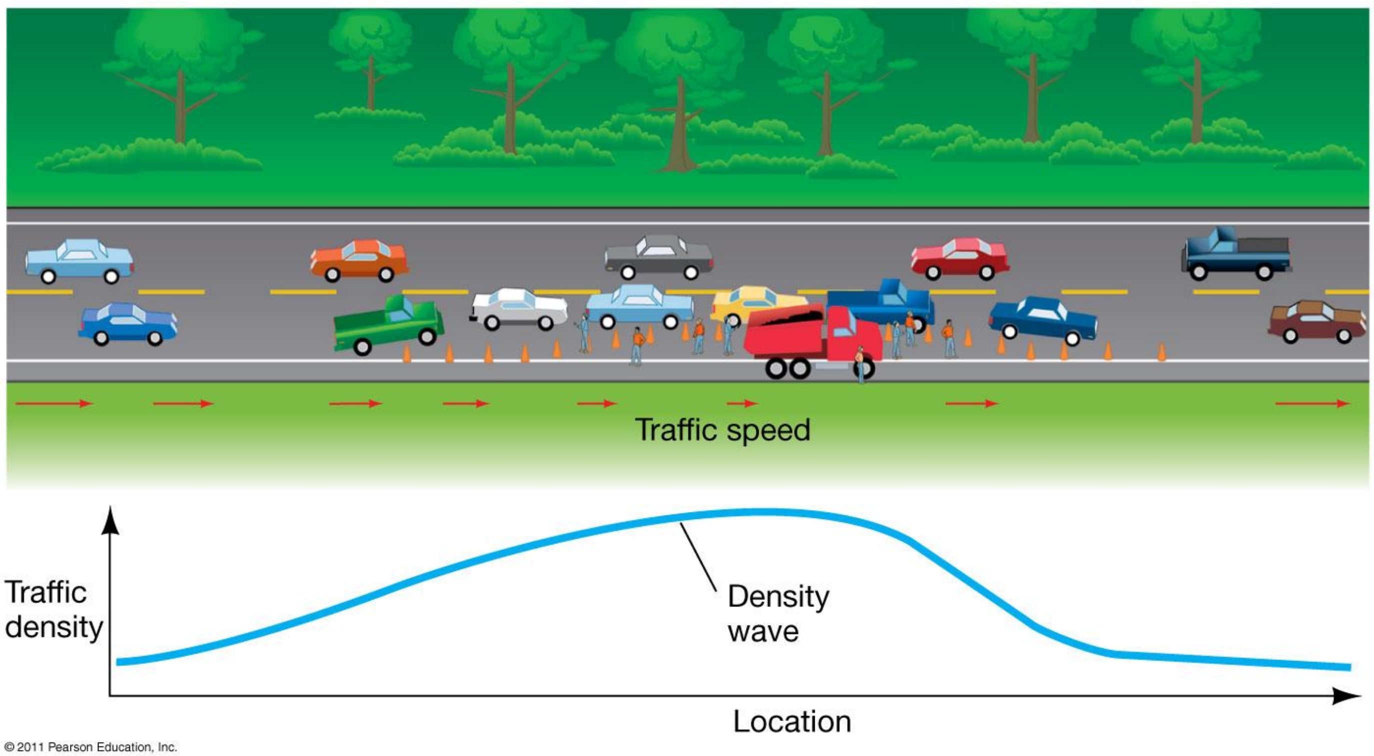
23.5 Galactic Spiral Arms

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.



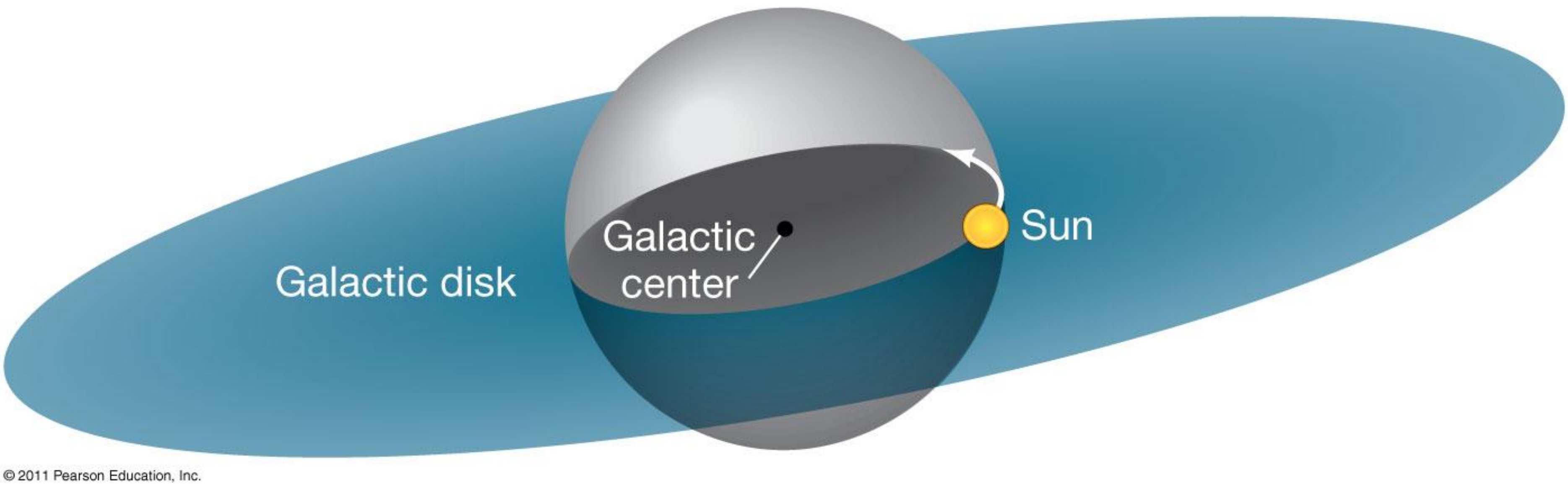
Discovery 23-2: Density Waves

The persistence of the spiral arms as density waves, rather than as structures made up of particular stars, may be understood using a traffic jam as an analogy. The jam persists even though particular cars move in and out of it, and it can persist long after the event that triggered it is over.



23.6 The Mass of the Milky Way Galaxy

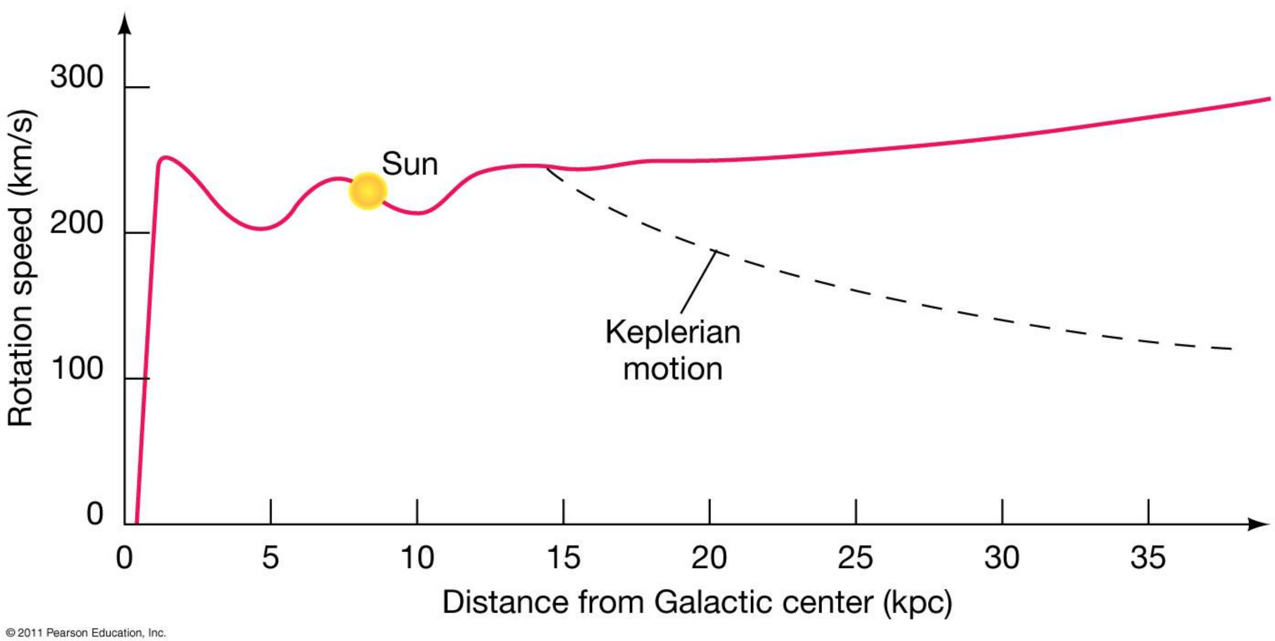
The orbital speed of an object depends only on the amount of mass between it and the galactic center:



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?

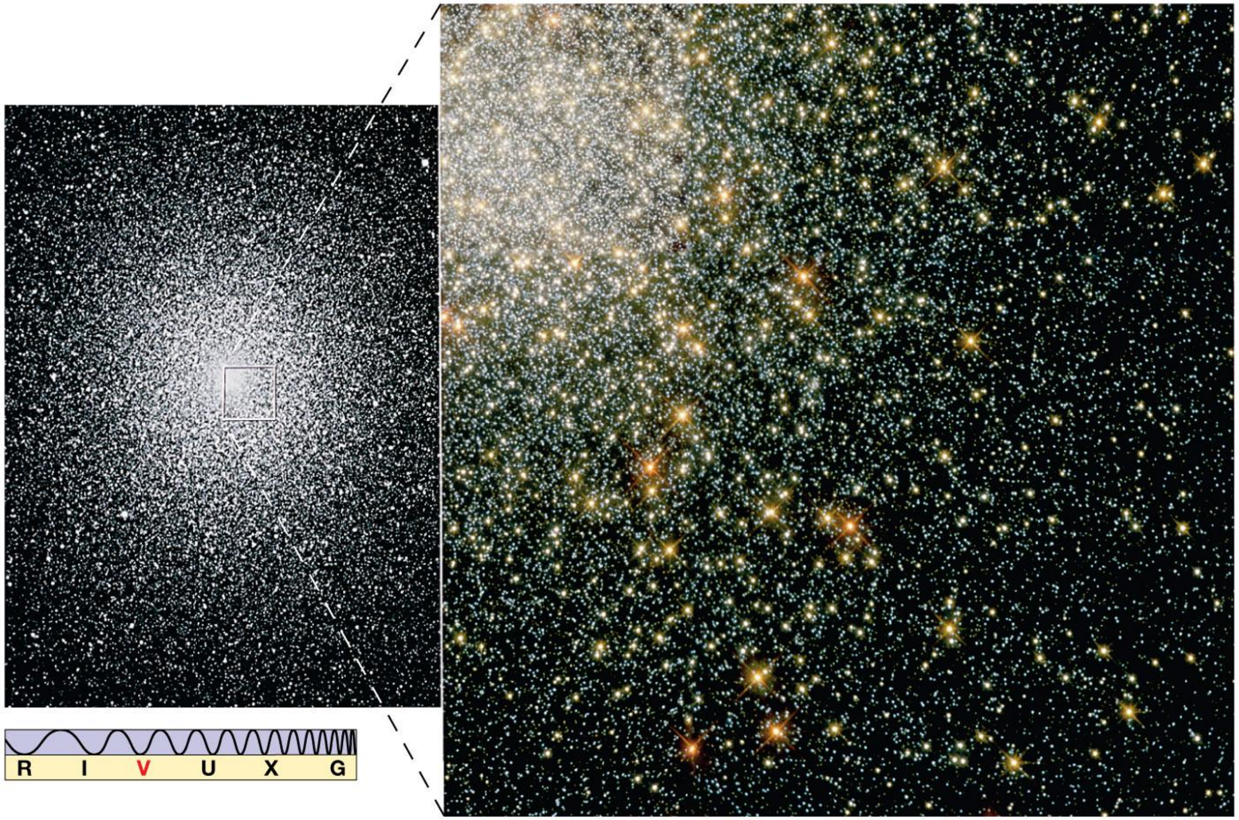
  Currently the best star-like option

- Weird subatomic particles?

  Could be, although no direct evidence so far

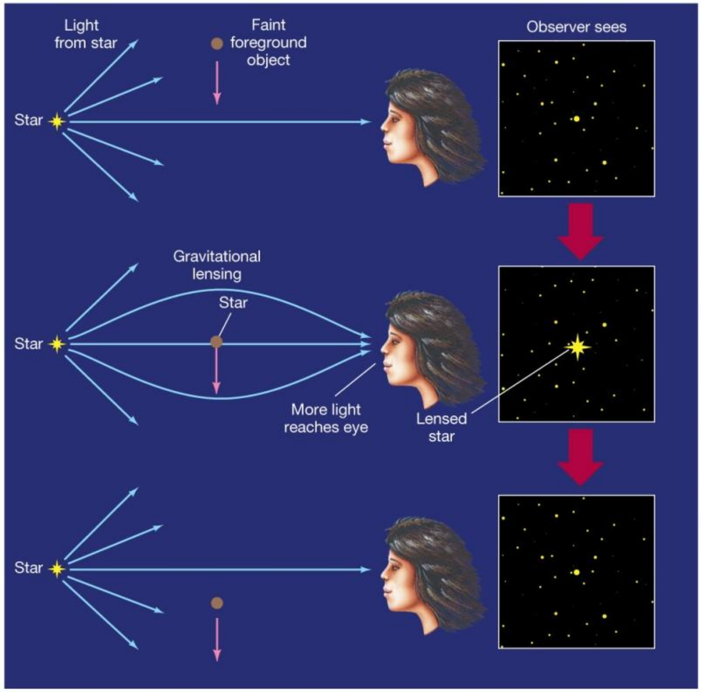
23.6 The Mass of the Milky Way Galaxy

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

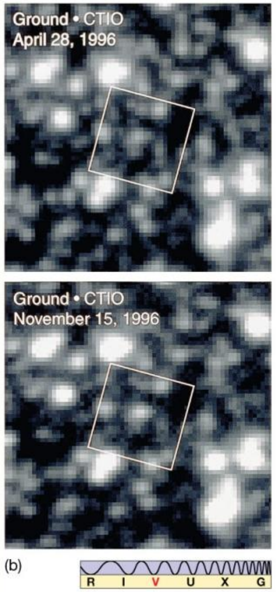


23.6 The Mass of the Milky Way Galaxy

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.



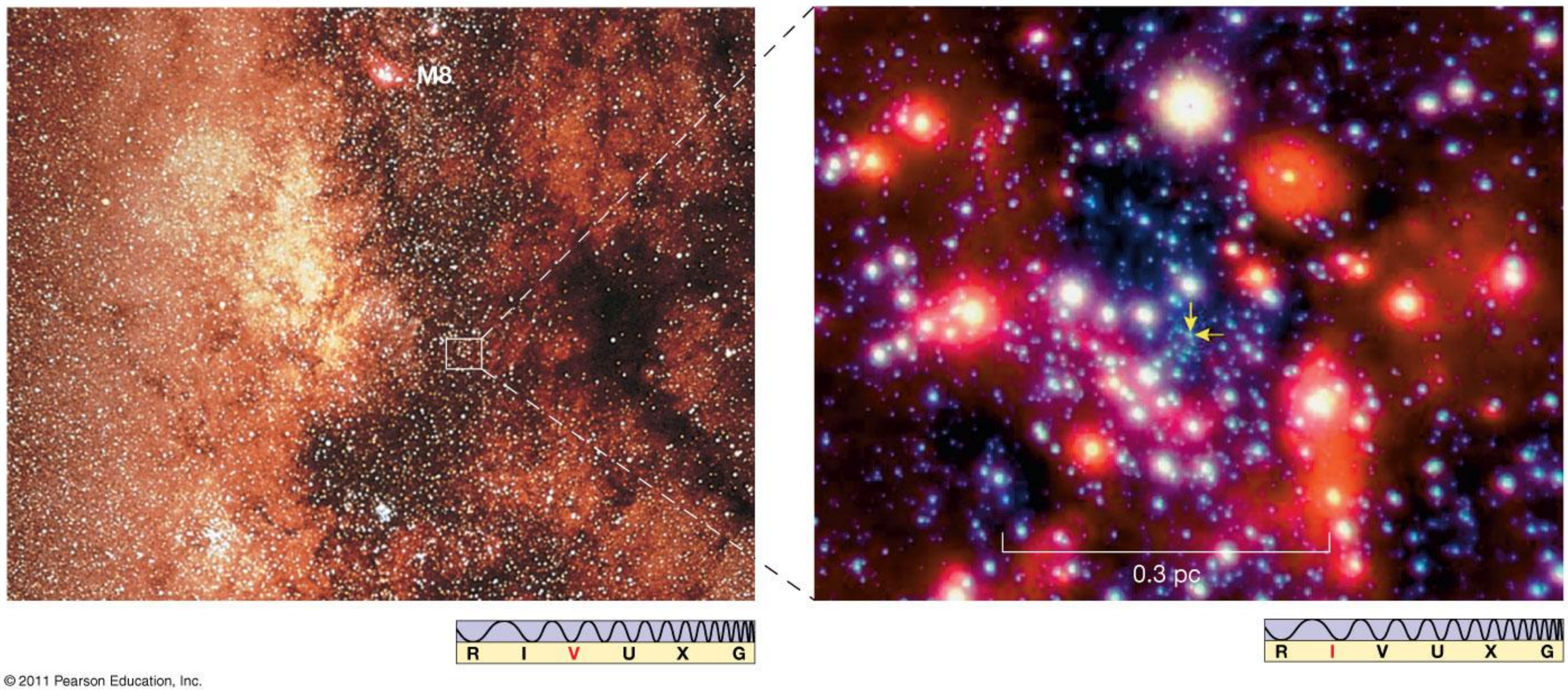
(a)



(b)

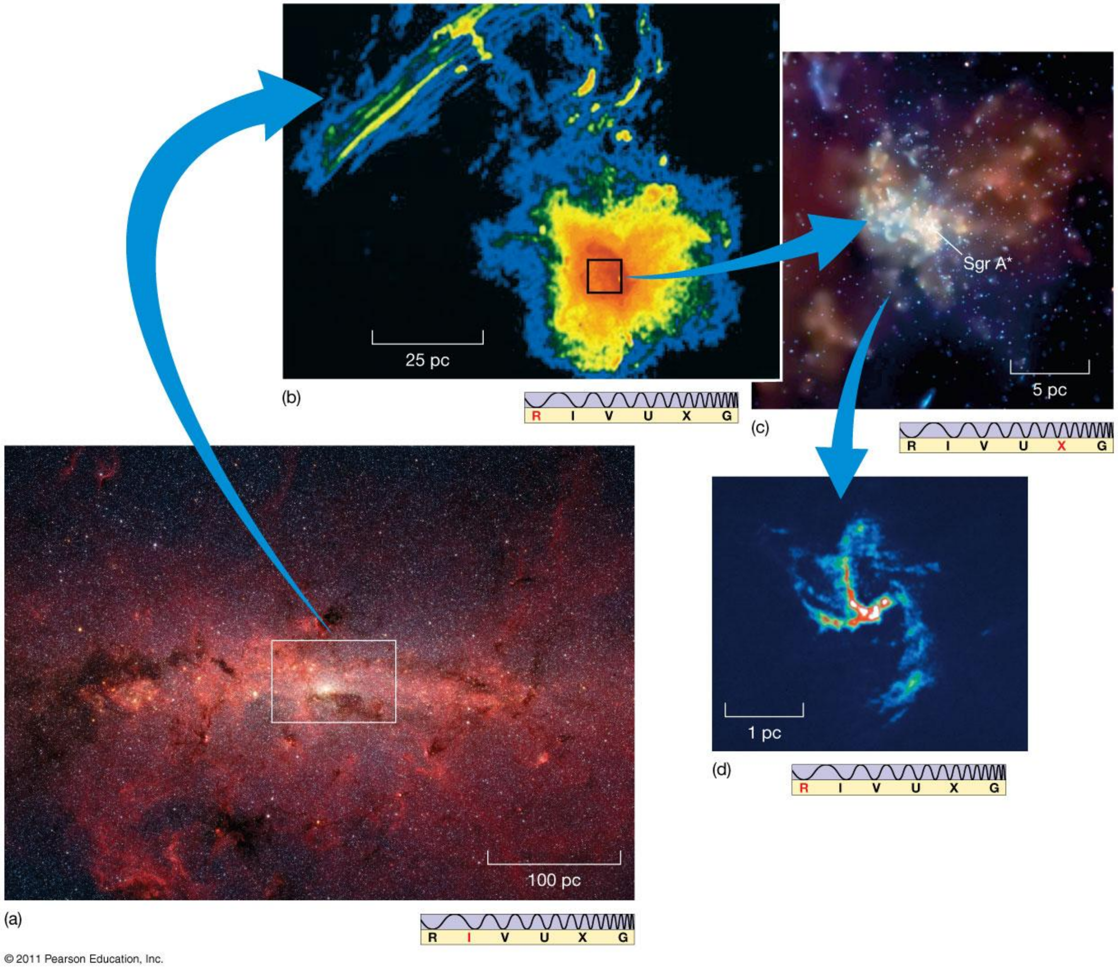
23.7 The Galactic Center

This is a view toward the galactic center, in visible light: the two arrows in the inset indicate the location of the center; it is entirely obscured by dust.



23.7 The Galactic Center

These images—in infrared, radio, and X-ray—offer a different view of the galactic center:



23.7 The Galactic Center

The galactic center appears to have:

- A stellar density a million times higher than near Earth.
- A ring of molecular gas 400 pc across
- Strong magnetic fields
- A rotating ring or disk of matter a few parsecs across
- A strong X-ray source at the center

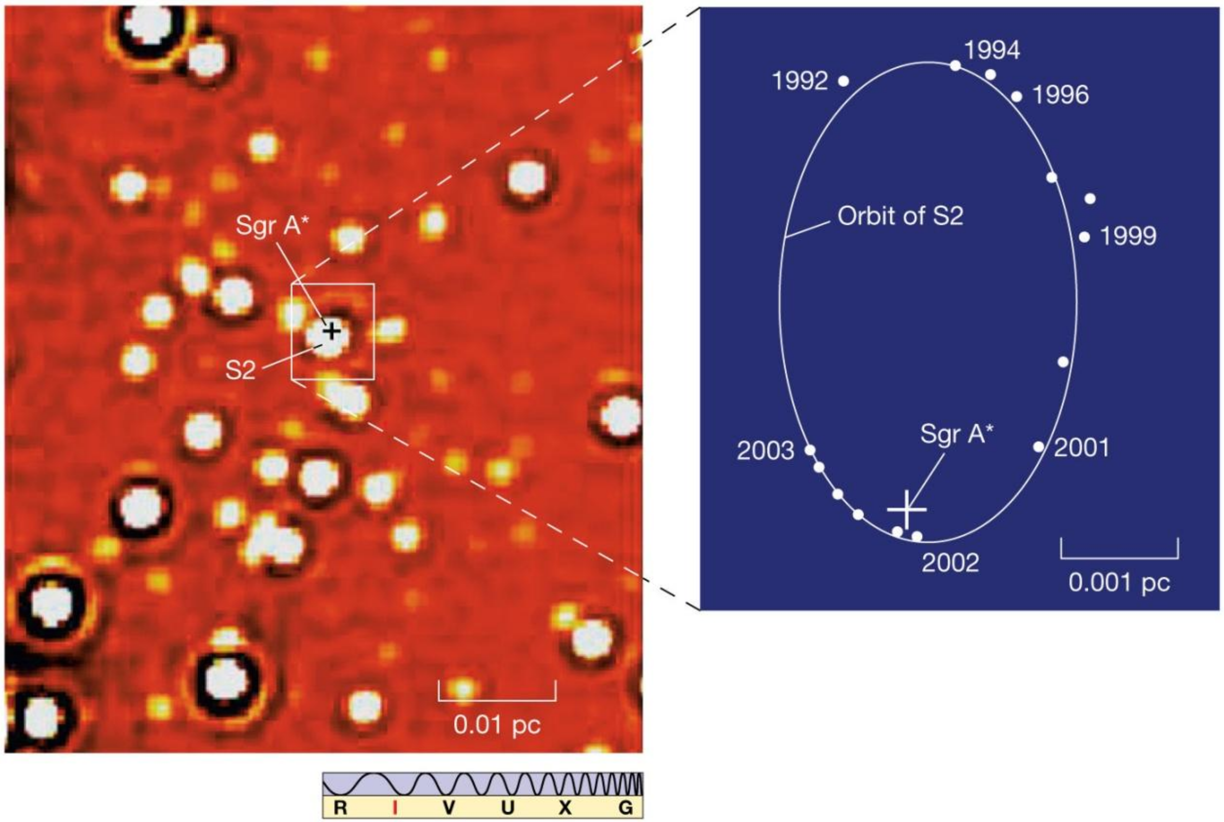
23.7 The Galactic Center

Apparently, there is an enormous black hole at the center of the galaxy, which is the source of these phenomena.

An accretion disk surrounding the black hole emits enormous amounts of radiation.

23.7 The Galactic Center

These objects are very close to the galactic center. The orbit on the right is the best fit; it assumes a central black hole of 3.7 million solar masses.



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