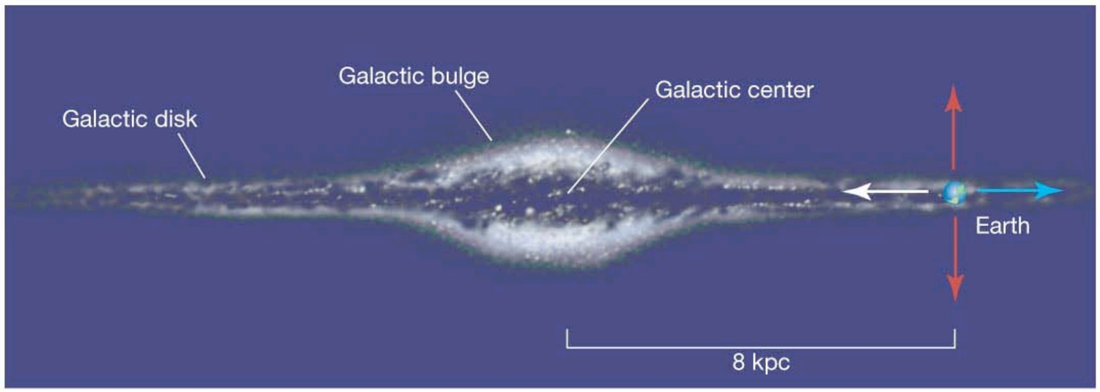
# Chapter 23
# The Milky Way Galaxy

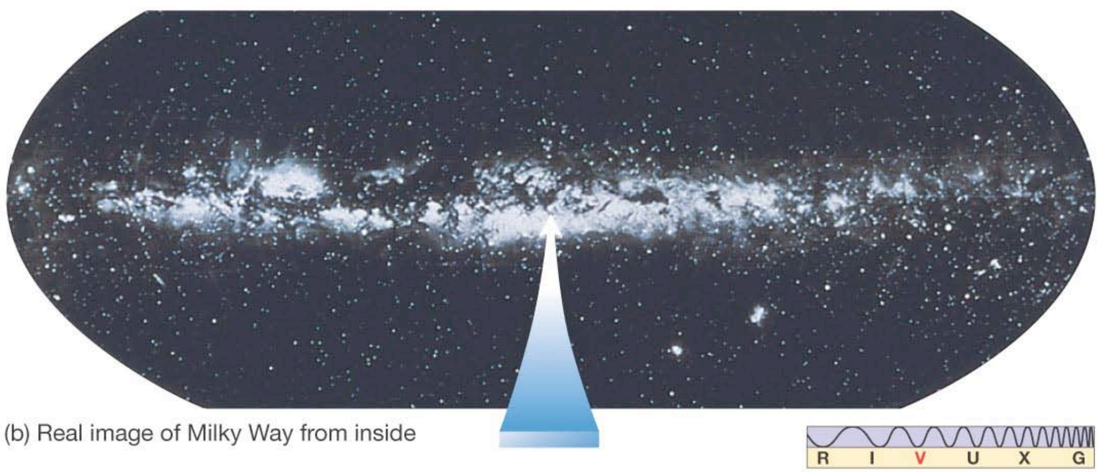
# Units of Chapter 23

# 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.**



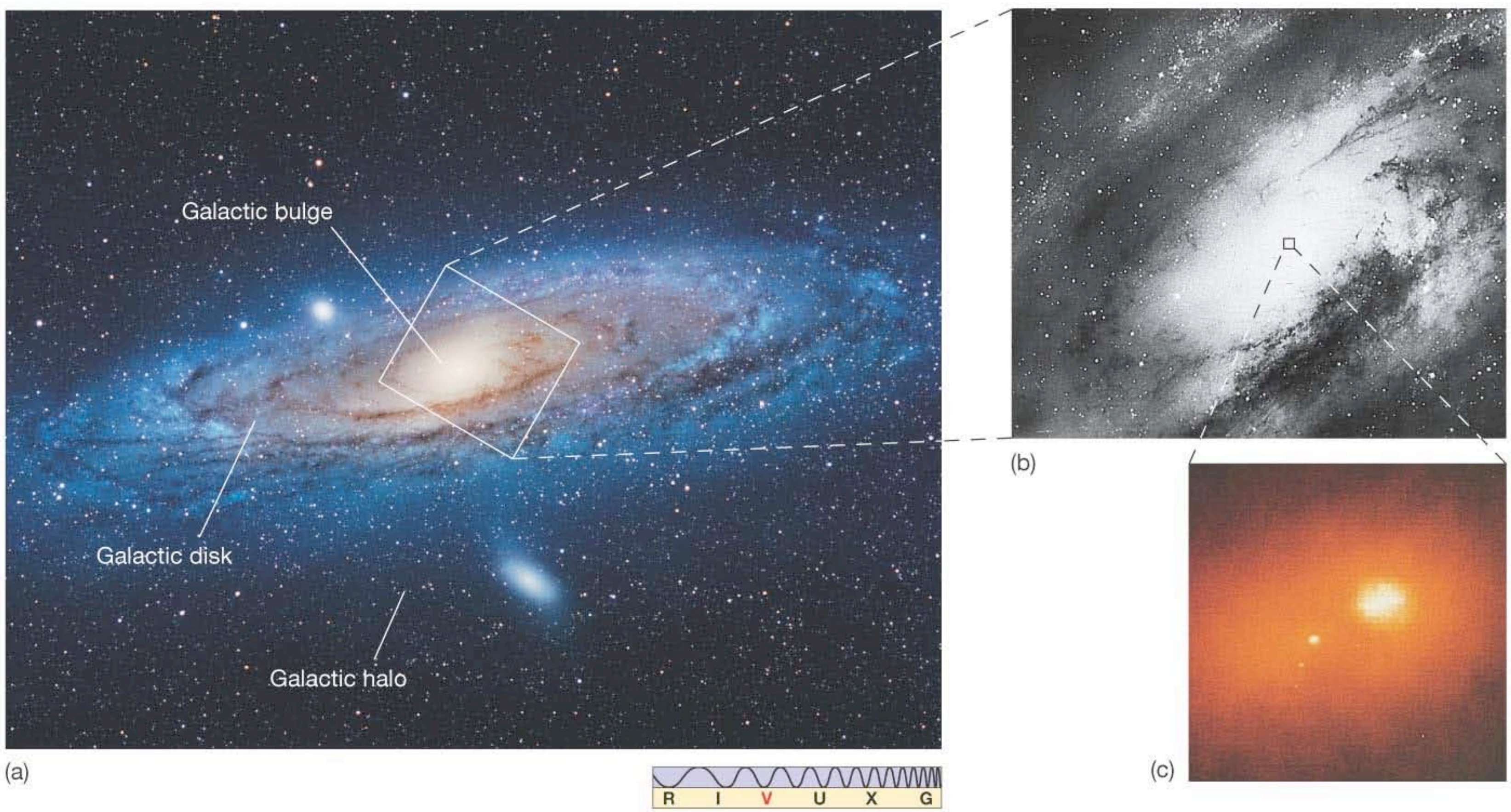

(a) Artist's view of Milky Way from afar




(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.**

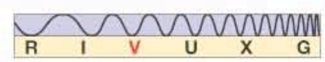


# 23.1 Our Parent Galaxy

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

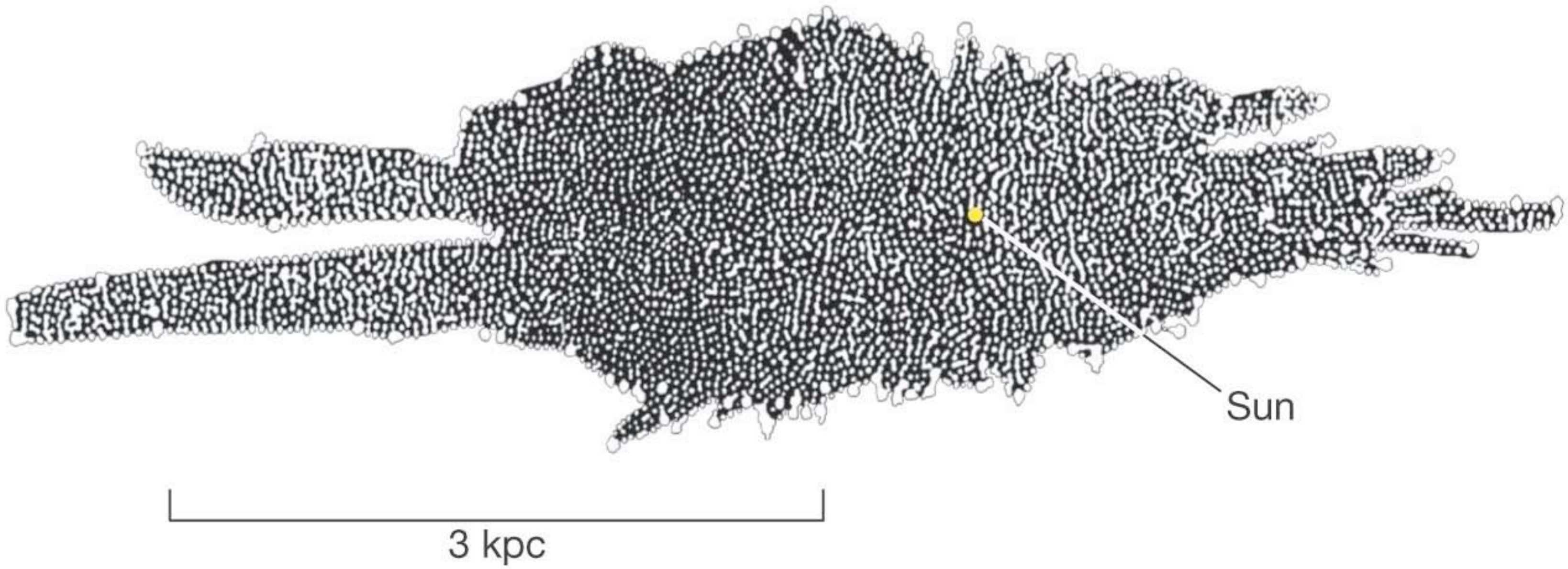
(a)

(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

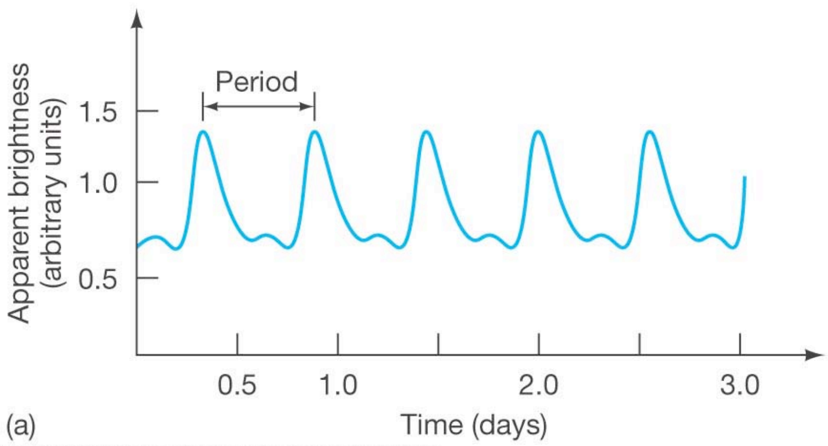
We have already encountered **variable stars**—novae, supernovae, and related phenomena.

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

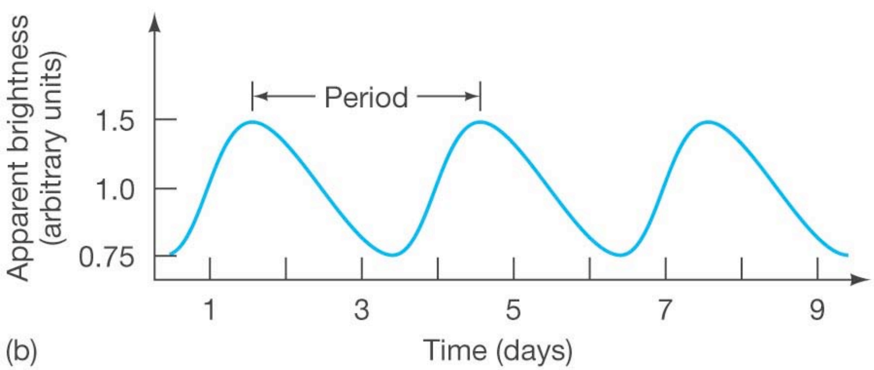
Two types of intrinsic variables have been found: **RR Lyrae** stars and **Cepheids**.

# 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.

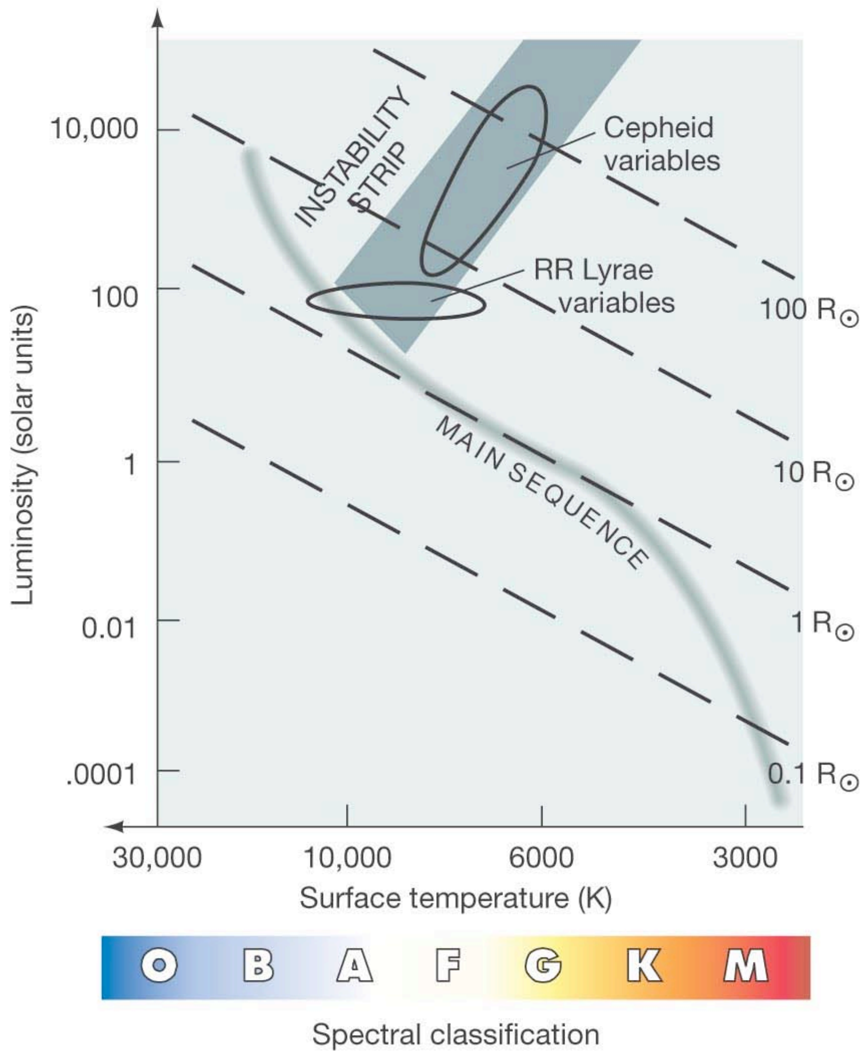



The lower plot is a **Cepheid** variable; Cepheid periods range from about **1** to **100** days.



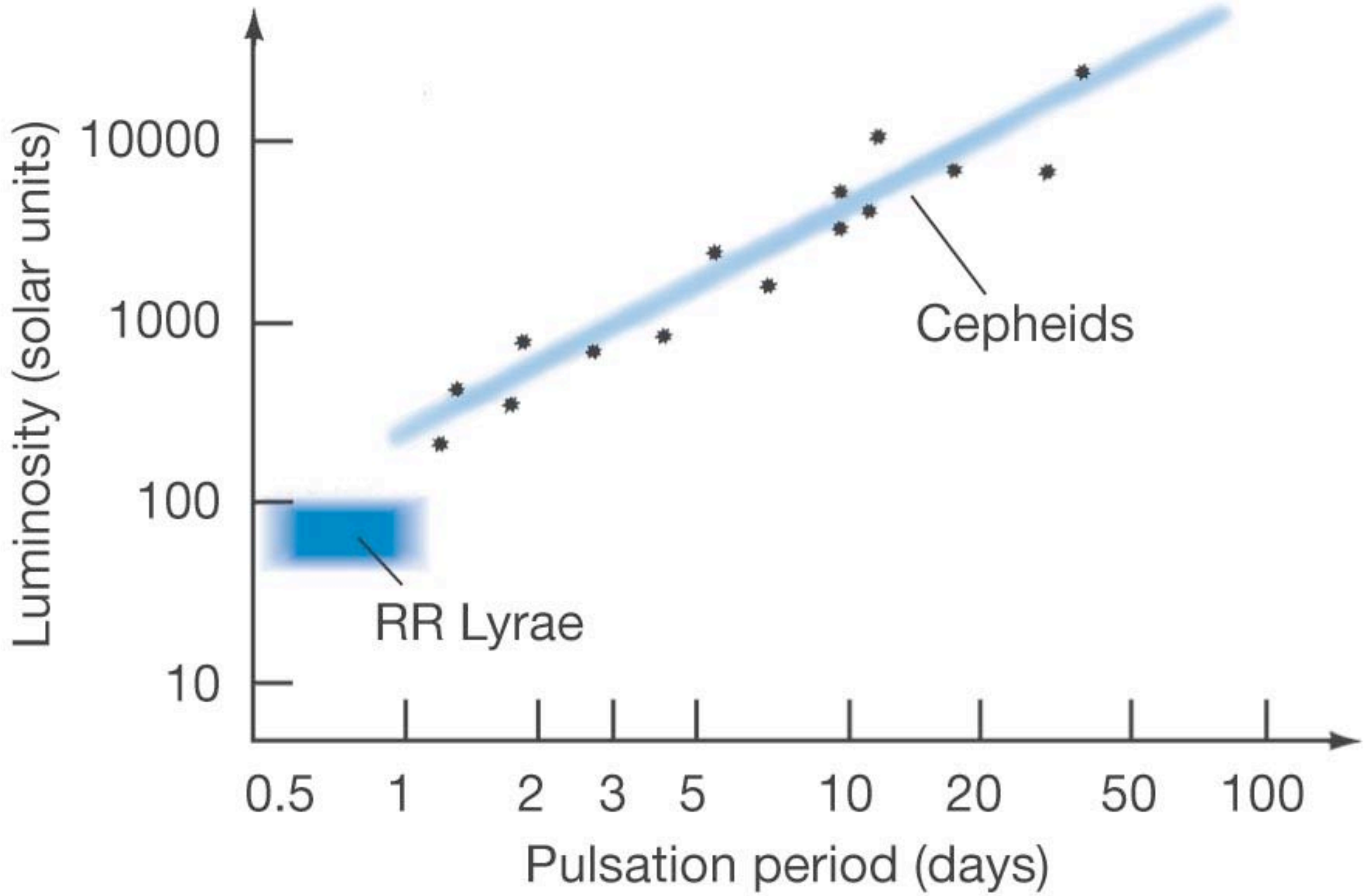
# 23.2 Measuring the Milky Way

**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

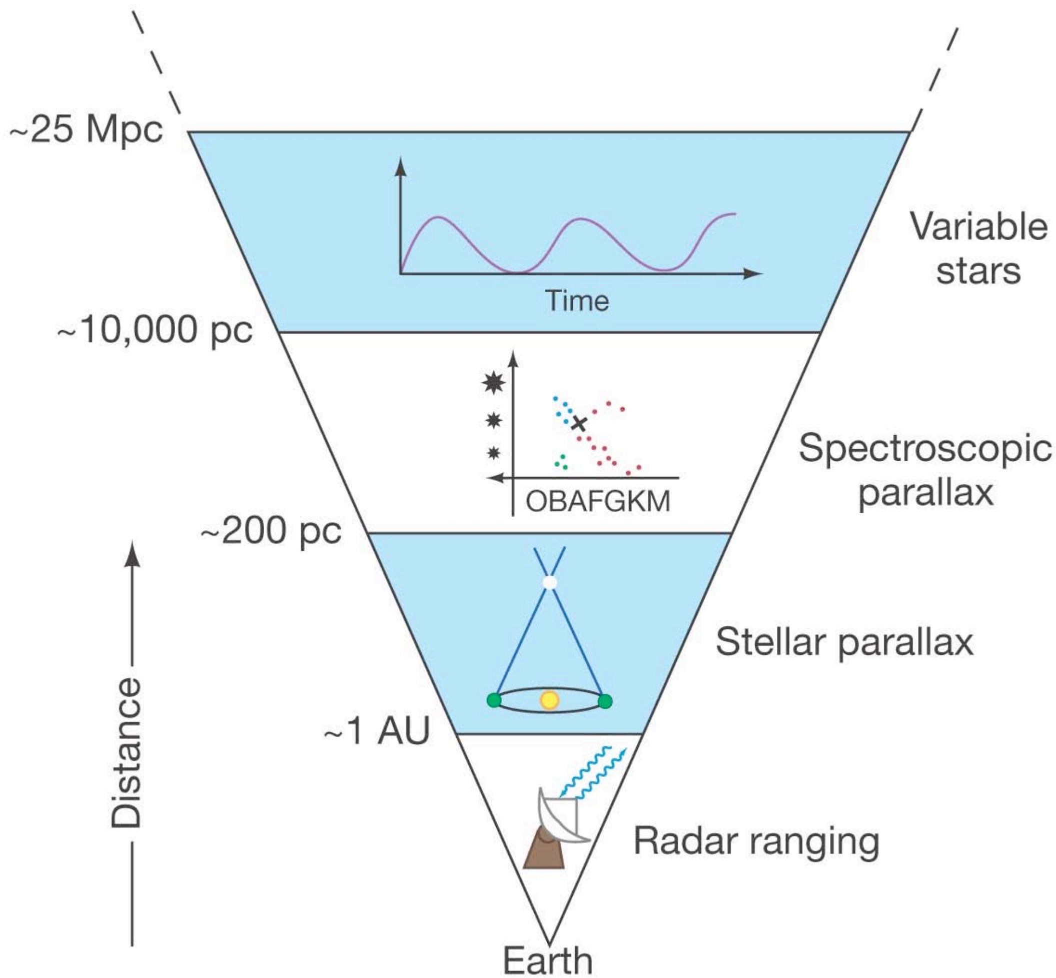
This allows us to measure the distances to these stars:

- 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

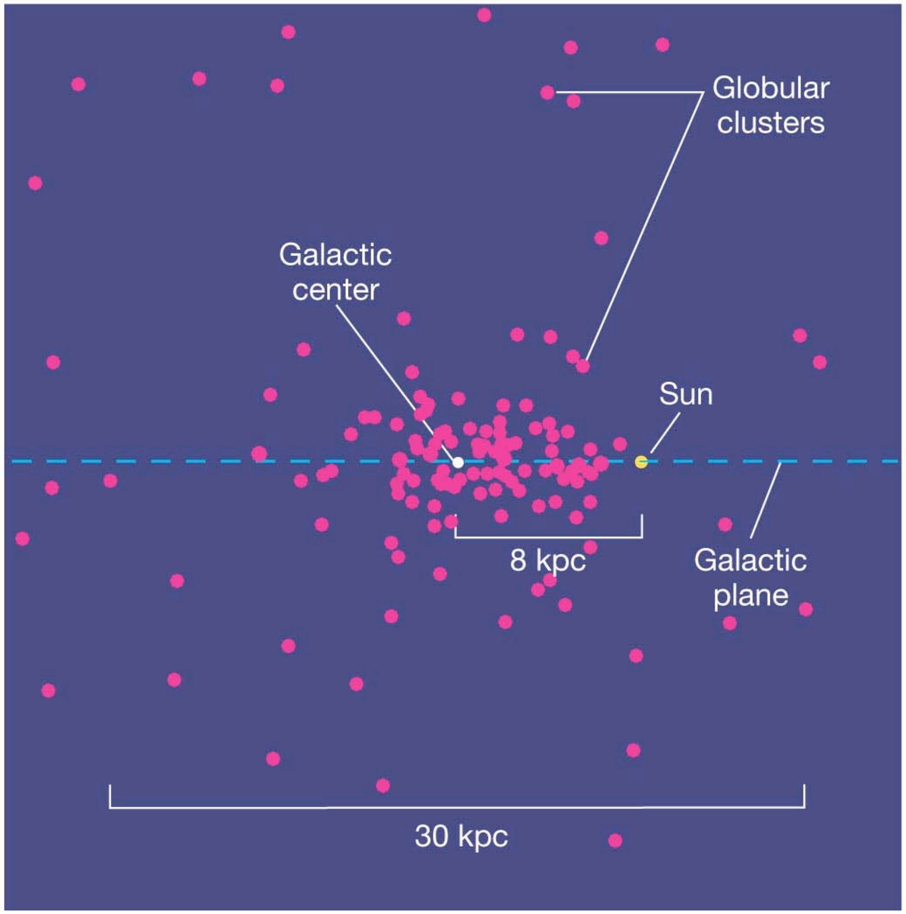
**We have now expanded our cosmic distance ladder one more step:**



# 23.2 Measuring the Milky Way

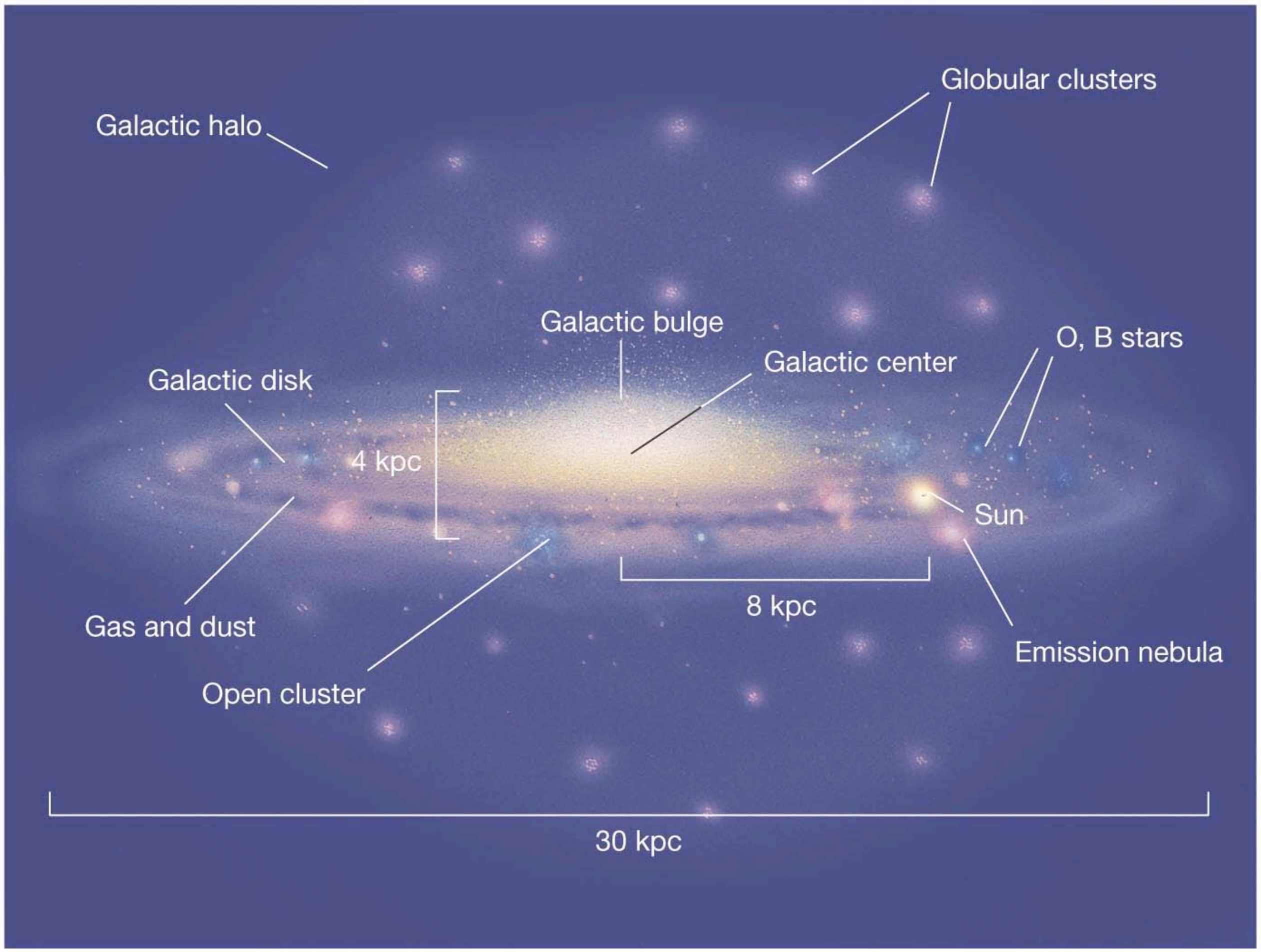
Many RR Lyrae stars are found in **globular clusters**. These clusters are not all in the **plane** of the galaxy, so they are not **obscured** by dust and can be measured.

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

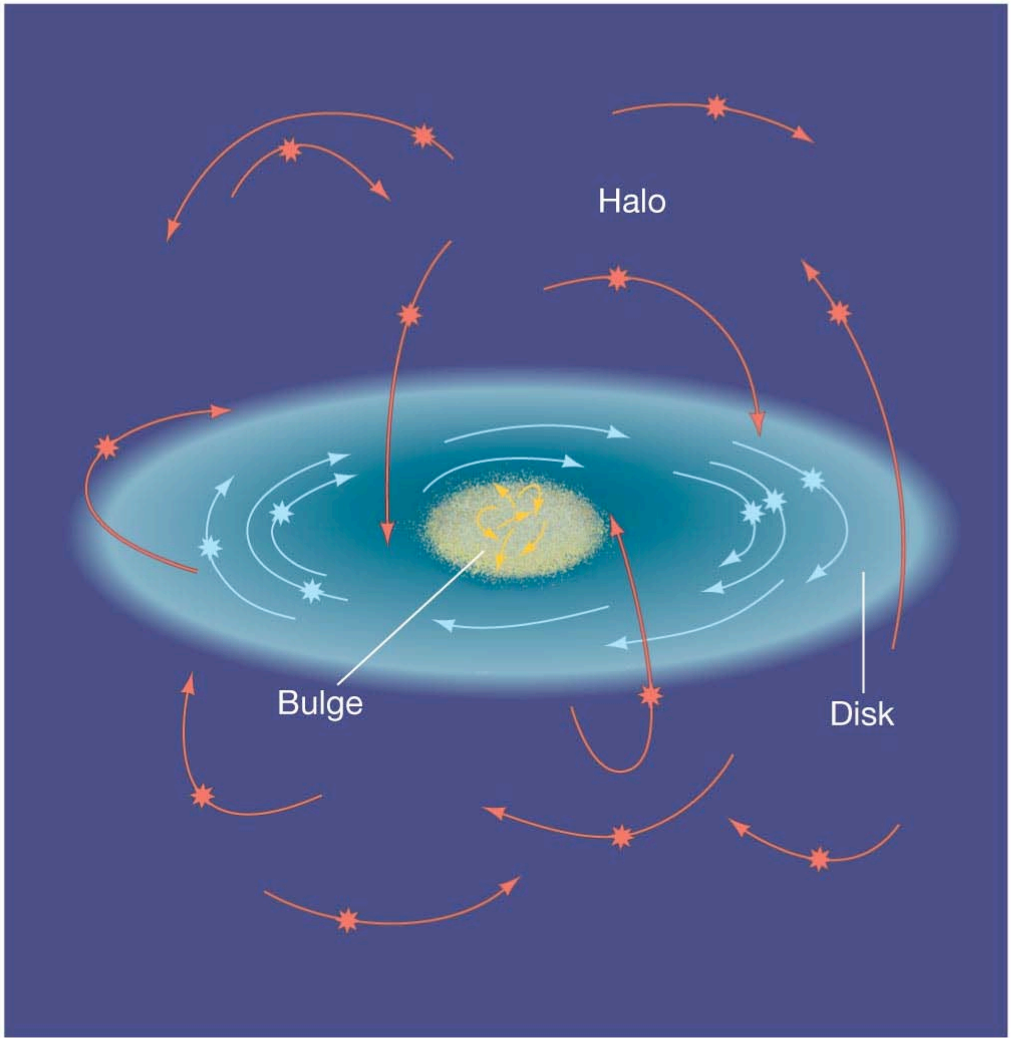
The **galactic halo** and **globular clusters** formed very early; the halo is essentially spherical. All the stars in the halo are very **old**, and there is no gas and dust.

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

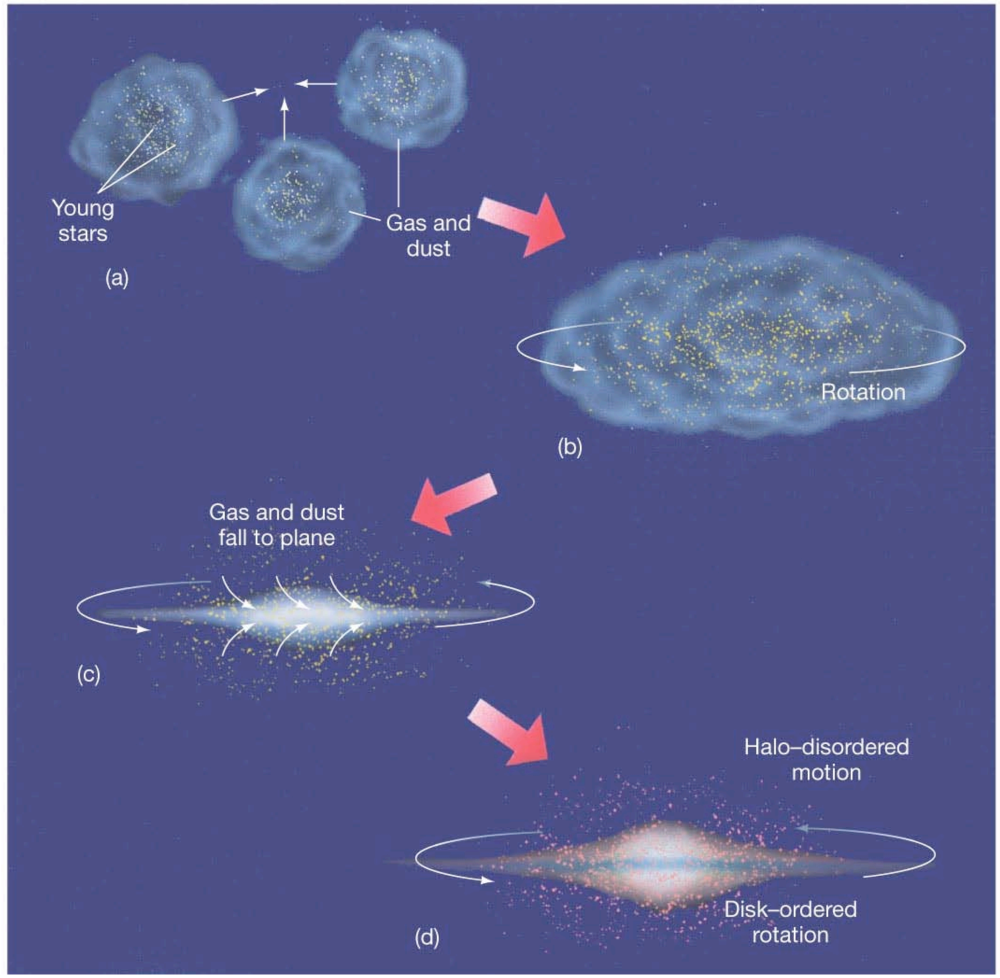
**Any theory of galaxy formation should be able to account for all the properties below:**

**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 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 |

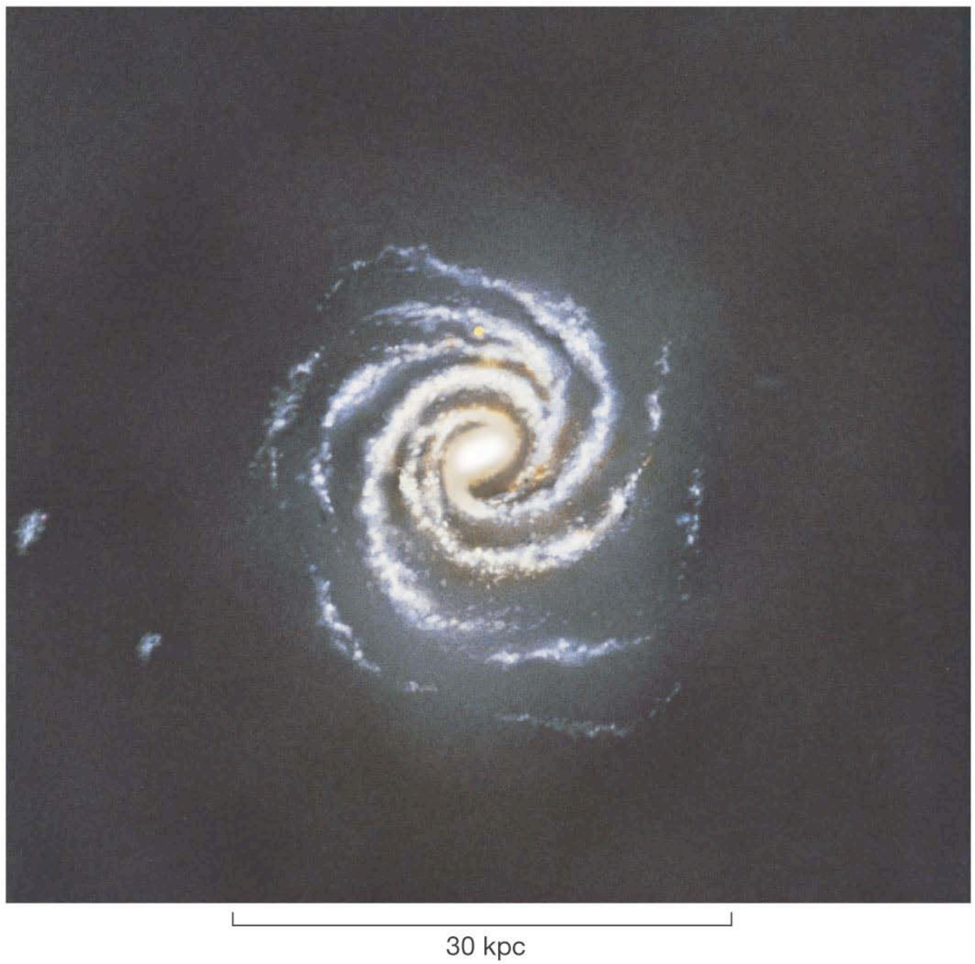
# 23.4 The Formation of the Milky Way

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



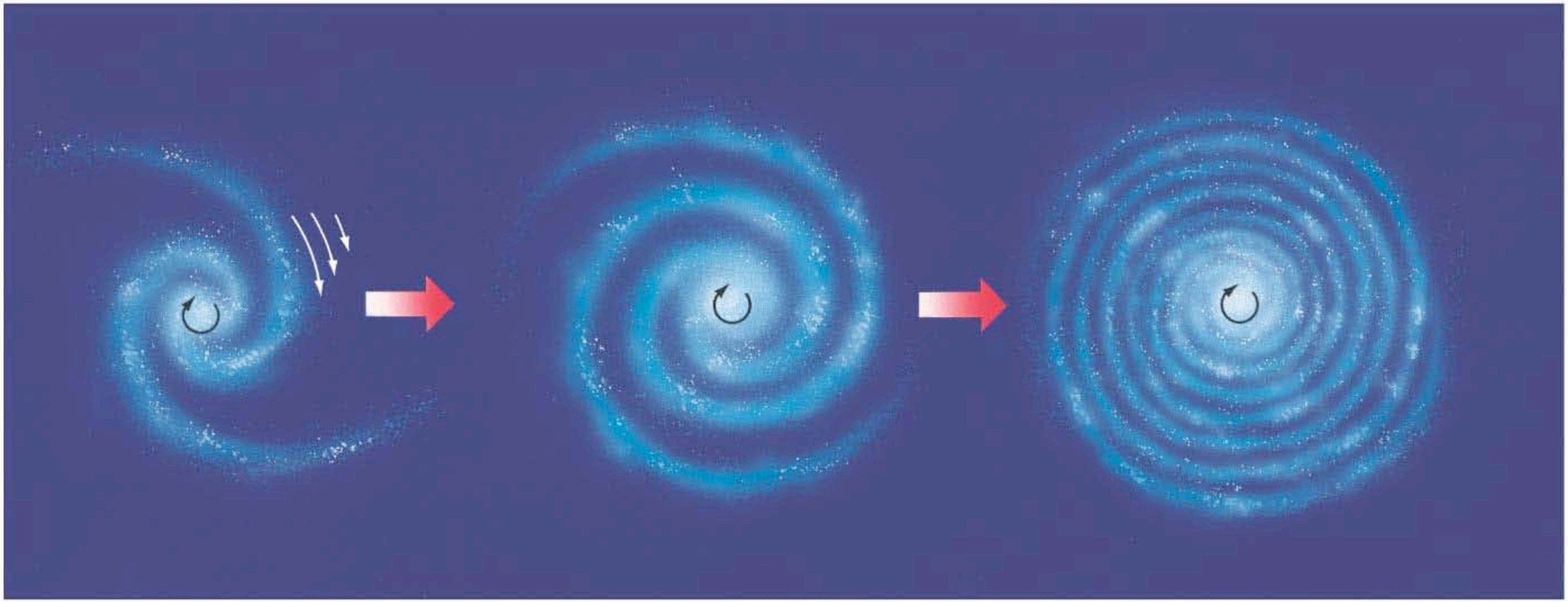
# 23.5 Galactic Spiral Arms

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



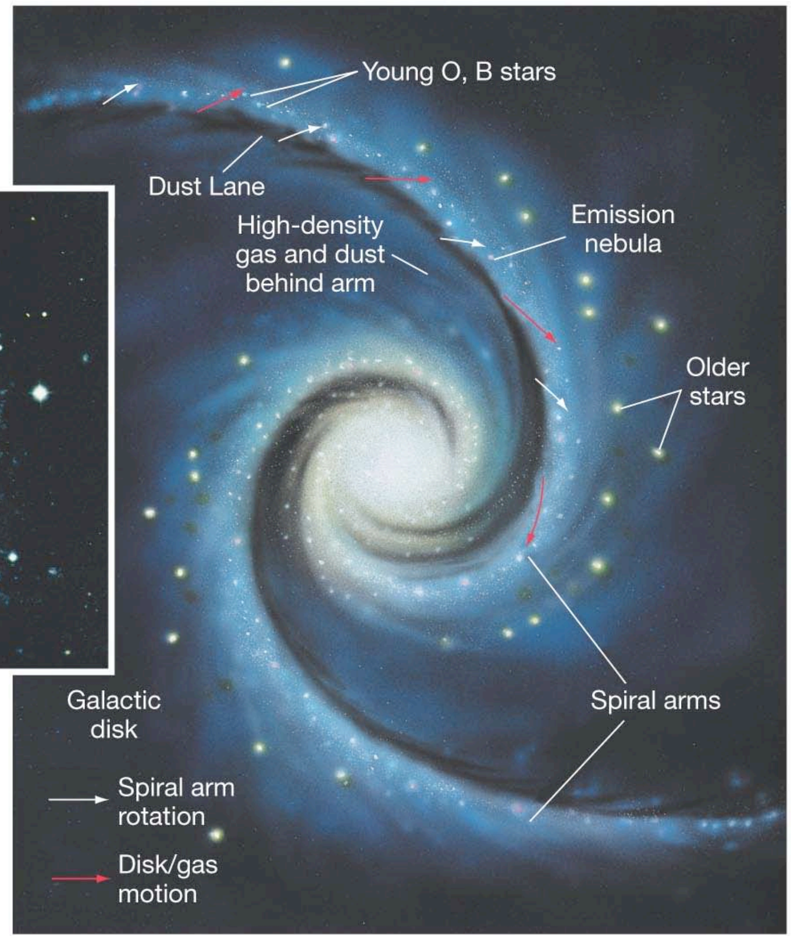
# 23.5 Galactic Spiral Arms

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



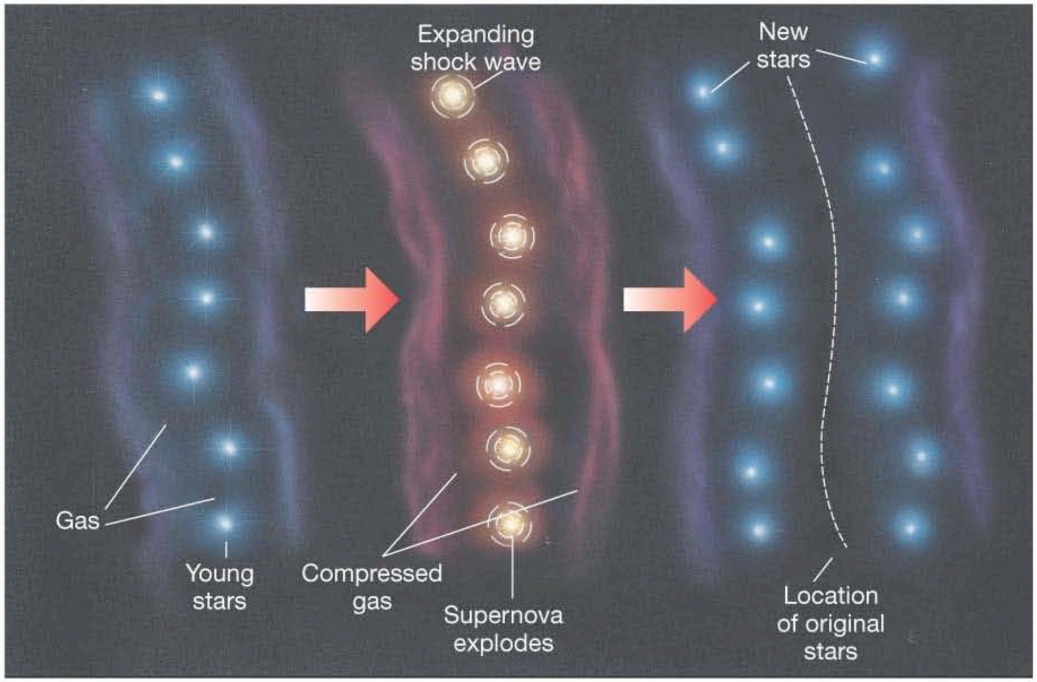
# 23.5 Galactic Spiral Arms

**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:**

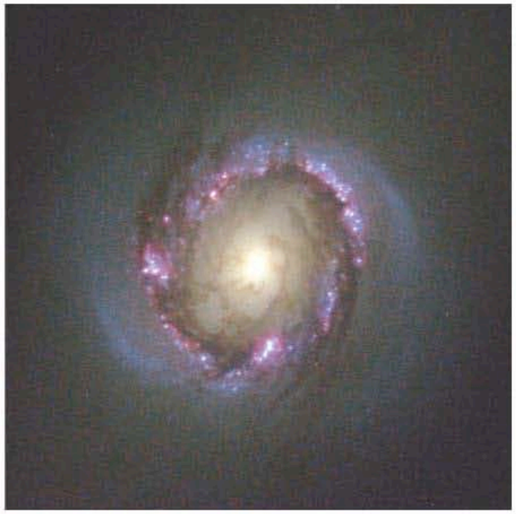



# 23.5 Galactic Spiral Arms

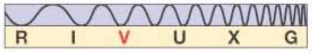
As clouds of gas and dust move through the spiral arms, the increased density triggers star formation. This may contribute to propagation of the arms. The origin of the spiral arms is not yet understood.




(a)

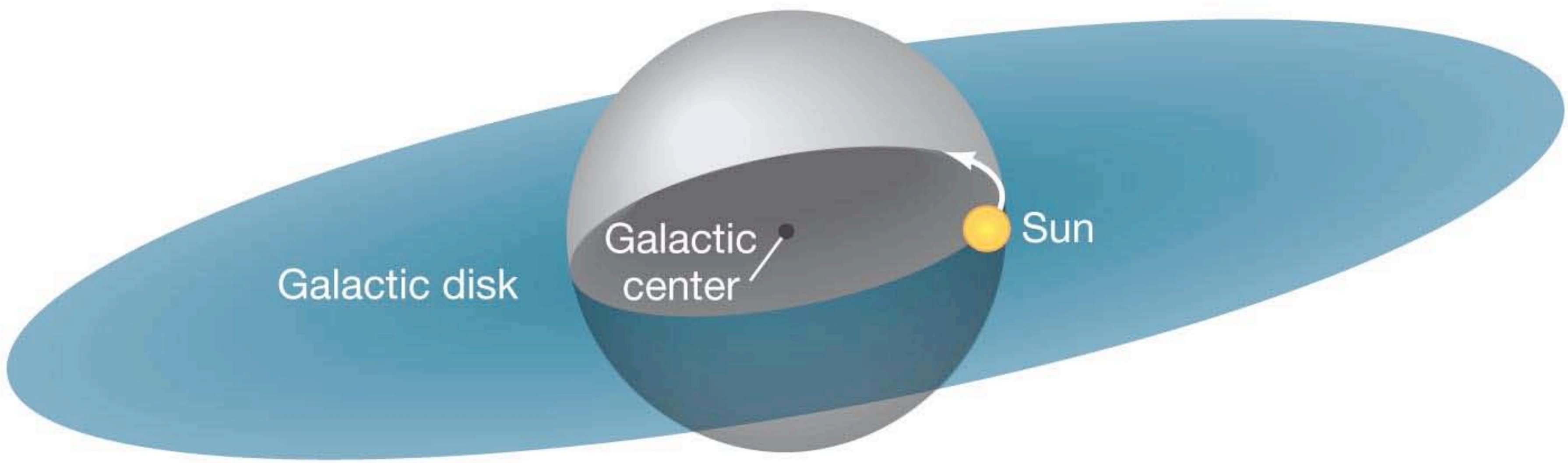


(b)



# 23.6 The Mass of the Milky Way Galaxy

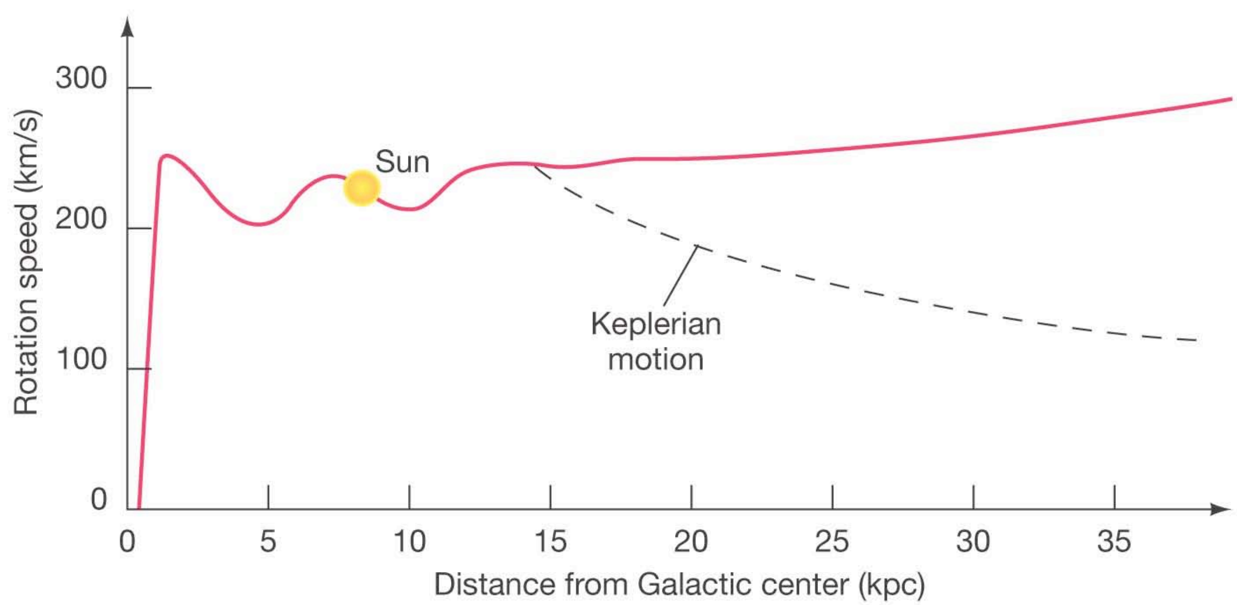
**The orbital speed of an object depends only on the amount of mass between it and the galactic center:**



# 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**?

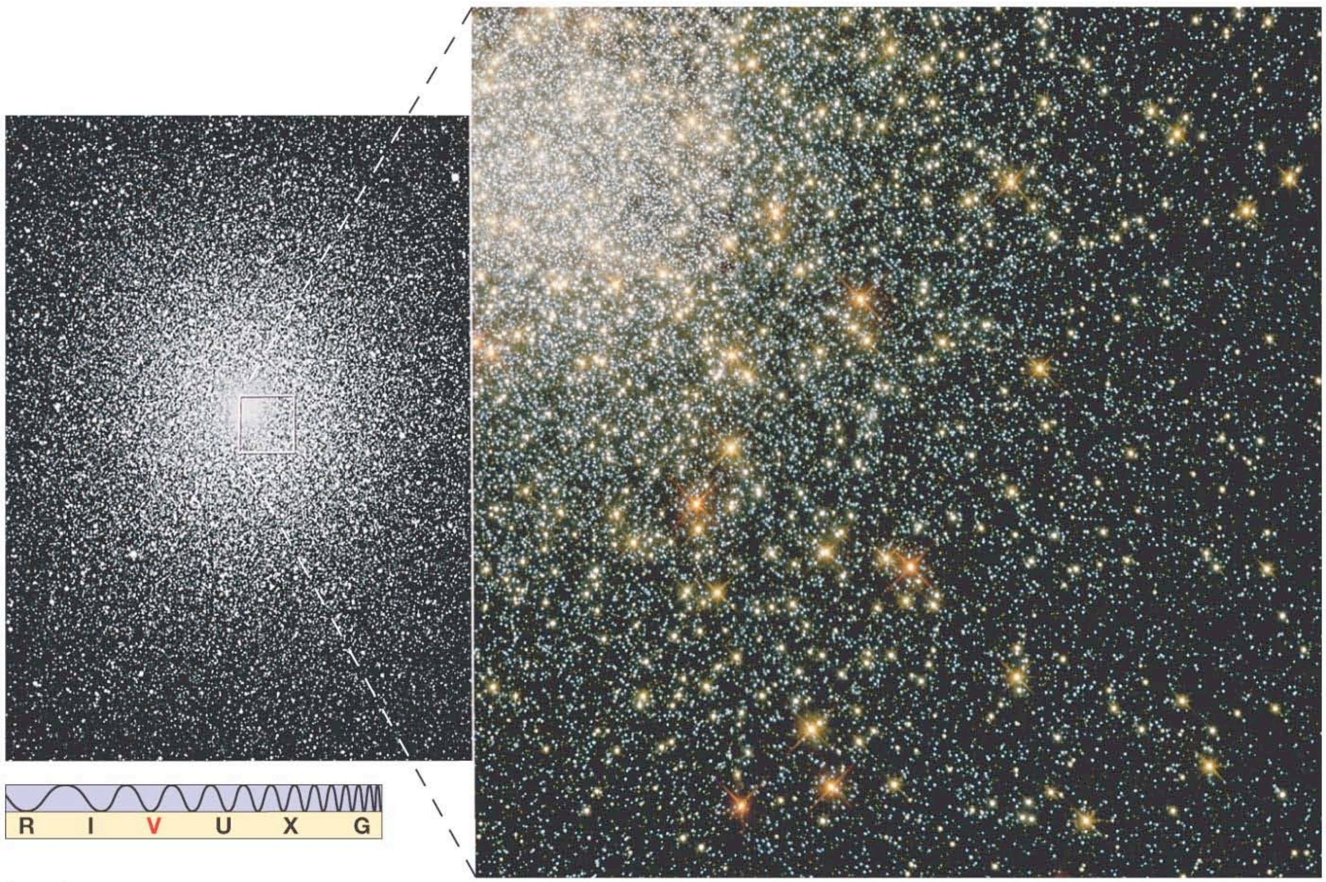
•Recall the solution to the "solar neutrino problem", that neutrinos have a tiny bit of mass. **Neutrinos** turn out to be the most abundant particle in the universe (more than even photons). But falls short by an order of magnitude.

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.**

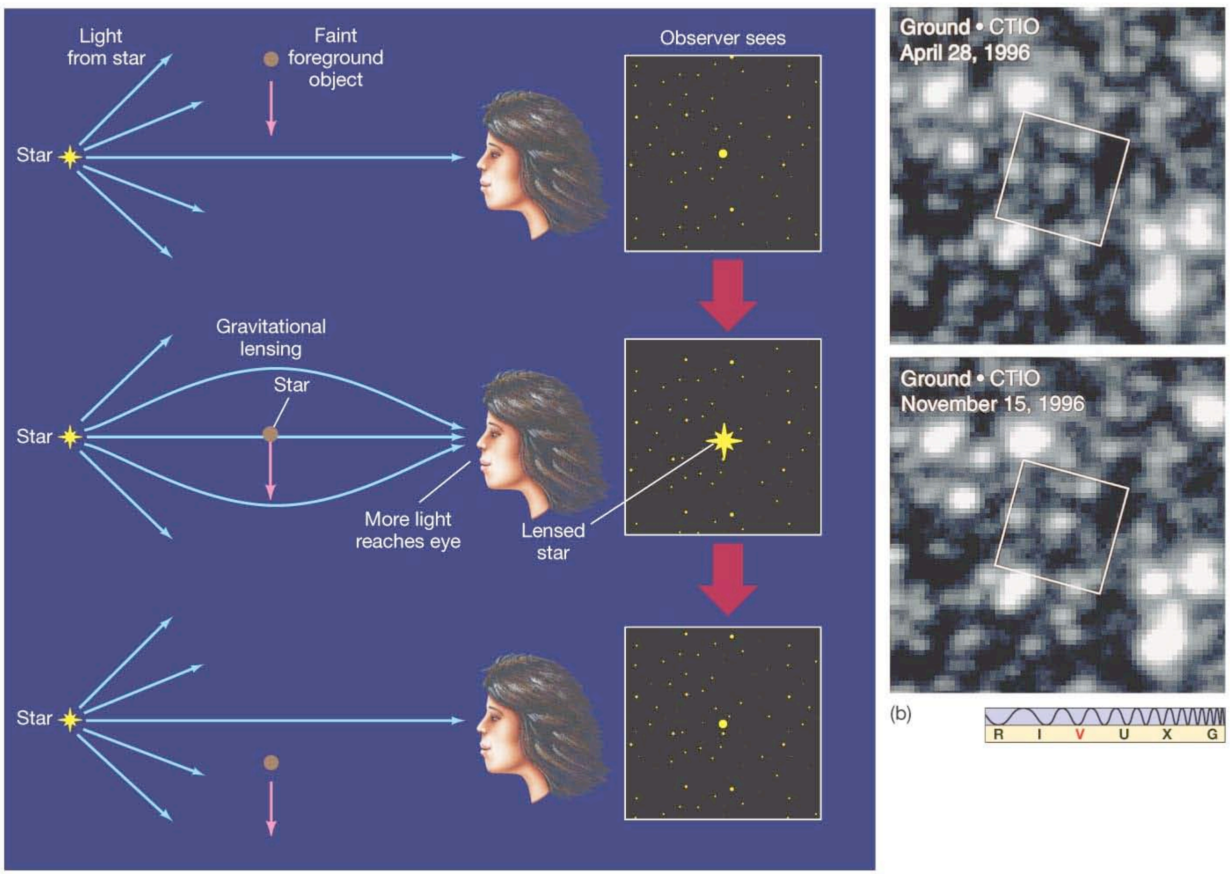
# 23.6 The Mass of the Milky Way Galaxy

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.




(a)

(b)

# 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