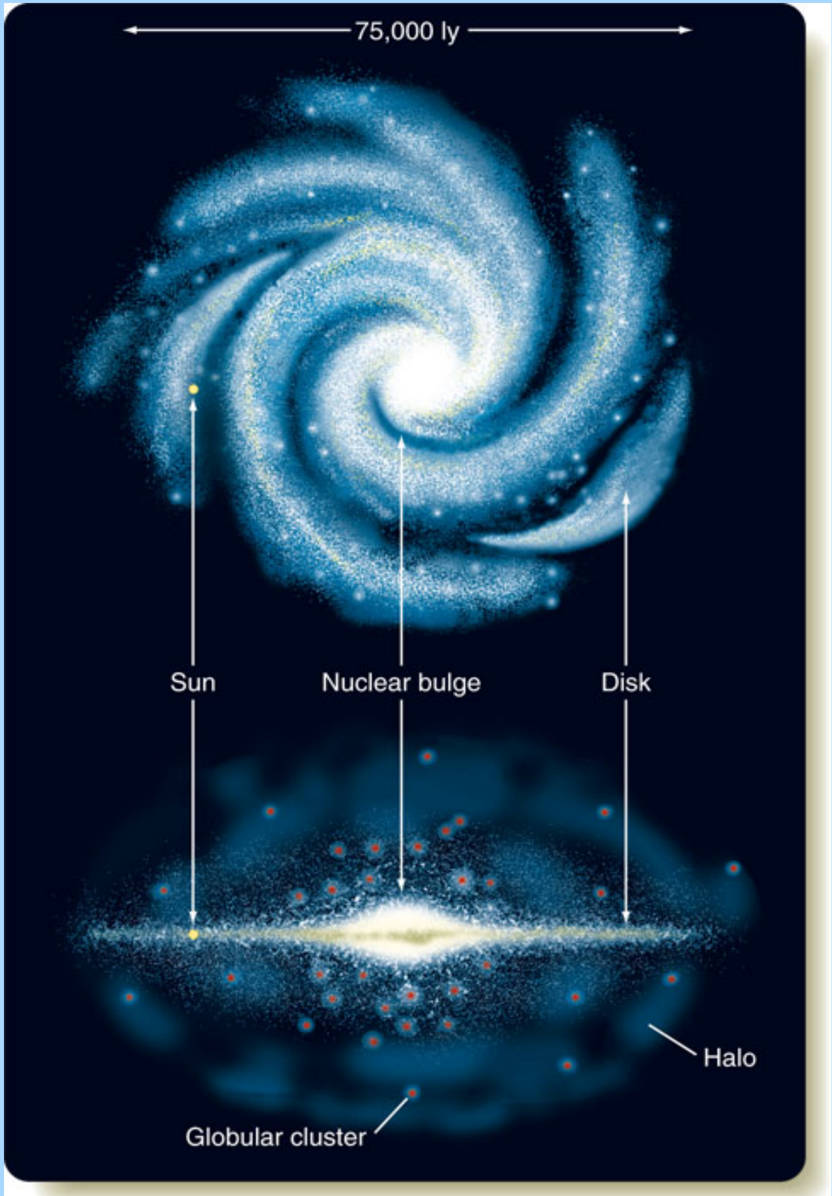
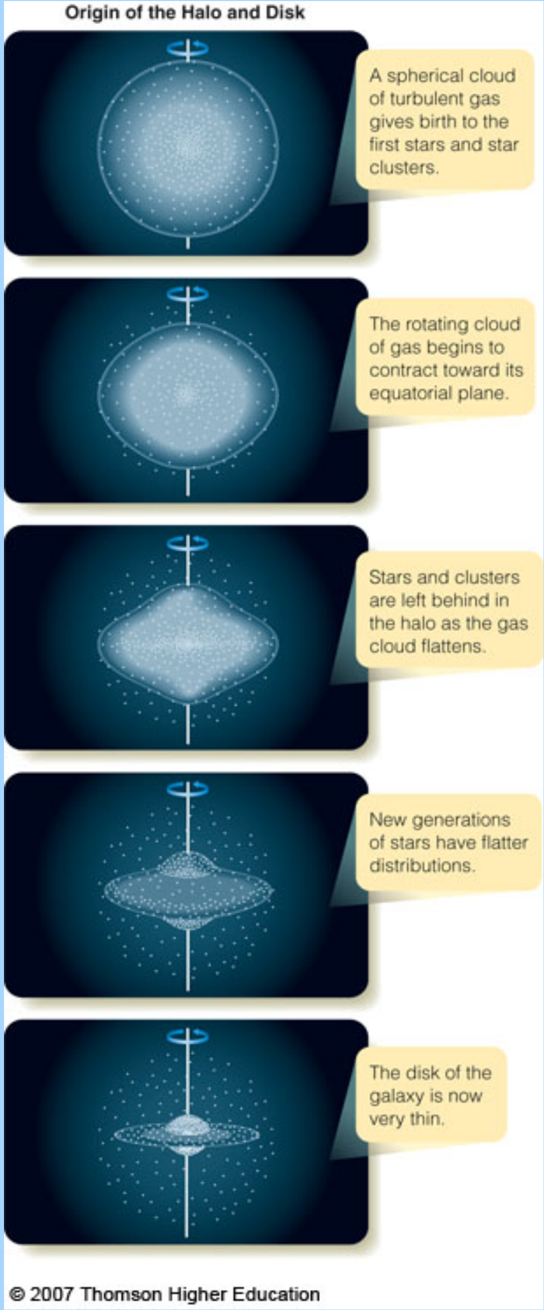
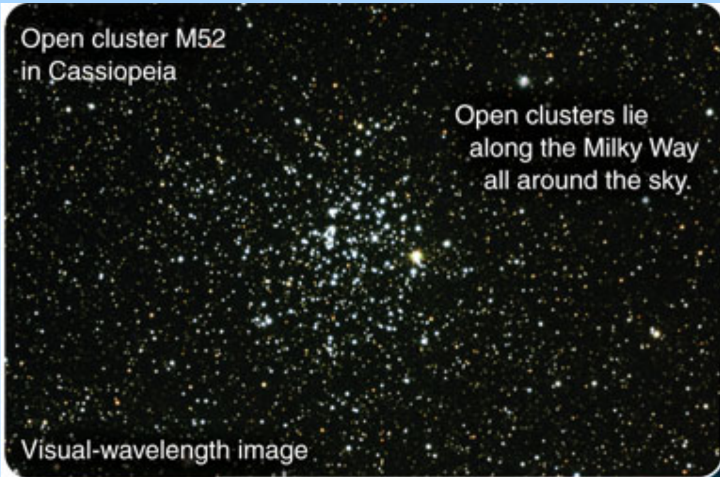
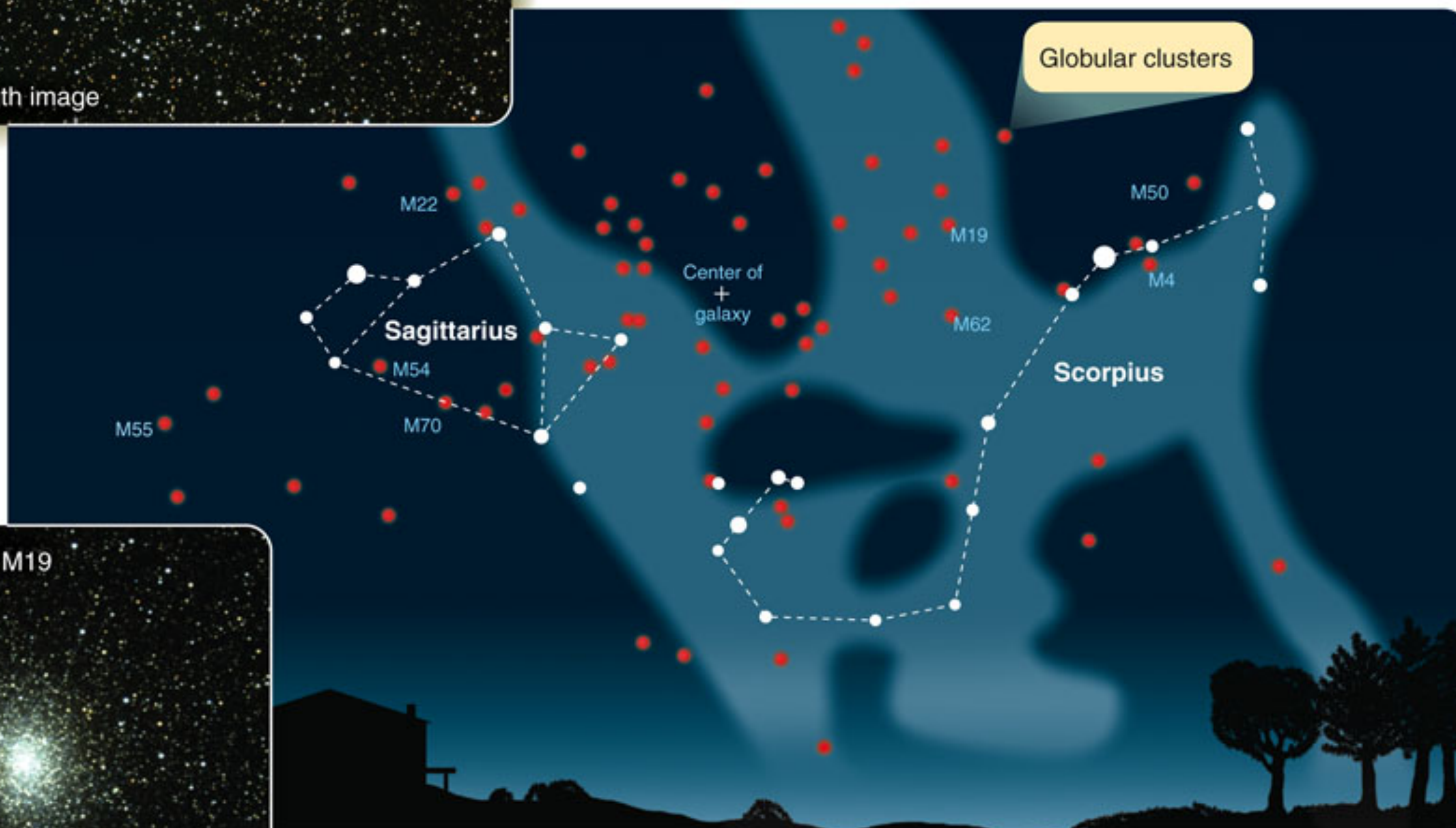


The Milky Way Galaxy



The first description of the formation of the Galaxy was published by the German philosopher Immanuel Kant (1724-1804) in his 1755 book, the *Allgemeine Natur-geschichte und Theorie des Himmels*. The graphic in our book shows the same basic idea.



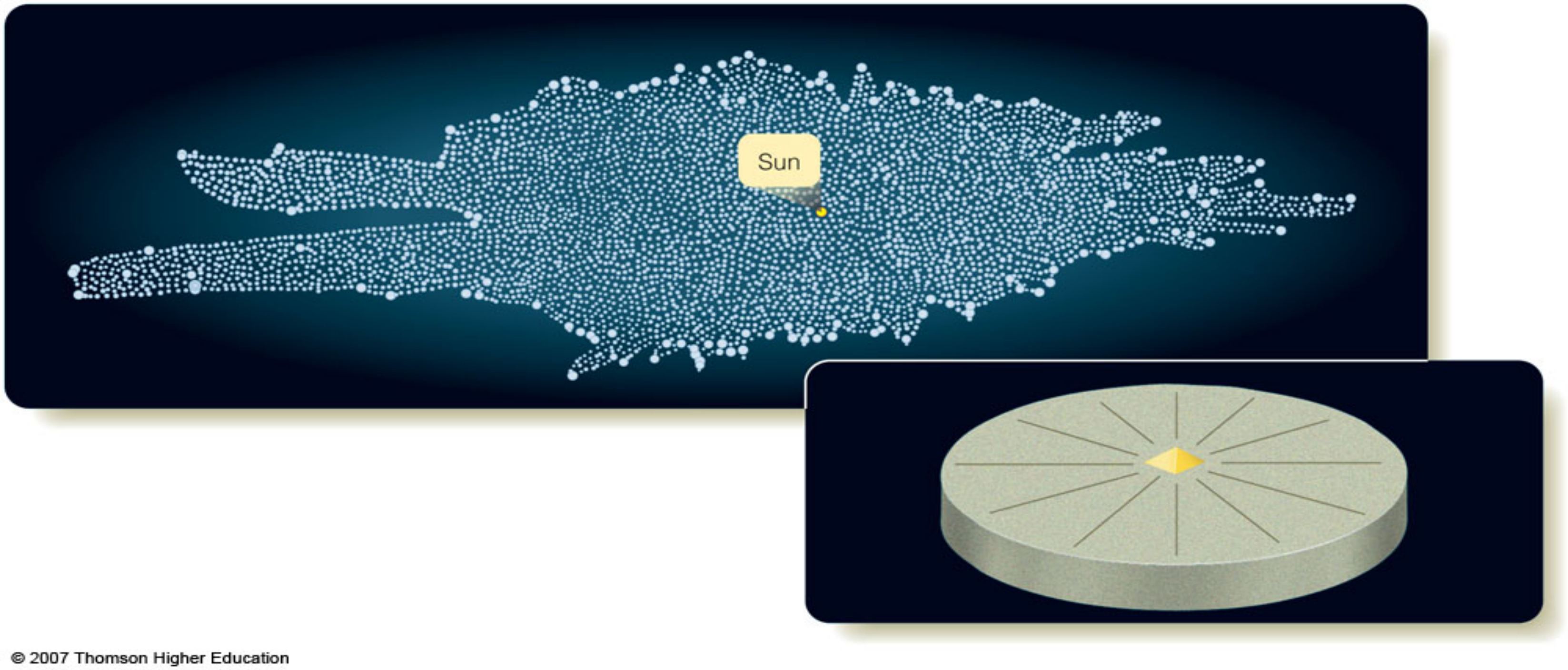


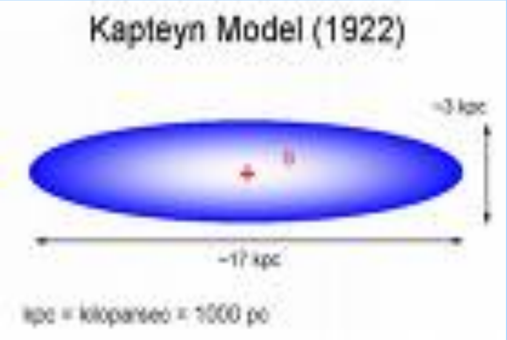
Globular clusters are scattered over the entire sky but are strongly concentrated toward Sagittarius.

Because the Sun in situated in the plane of the Milky Way, as we scan around the sky, we see a band of light. Perpendicular to the plane of the Milky Way there are many fewer stars. Some constellations have lots of star clusters, like Sagittarius, Scutum, Scorpius, and Cygnus. Other constellations such as Coma Berenices cover the North Galactic Pole. We see few Galactic star clusters here but many external galaxies.

Wm. Herschel (1738-1822) and his sister Caroline (1750-1848)

William Herschel's 1785 model of the Galaxy placed us close to the center of flattened system of stars. But he did not know about the effect of interstellar dust on his star gauges.





In the early part of the 20th century J. C. Kapteyn (1851-1922) produced a very similar model of the Galaxy to that of Herschel. He too did not take into account the effect of interstellar dust.

Why are Cepheids so important?

a. We know their luminosities, so we can determine their distances.
b. They produce pulsars.
c. They are about to explode as supernovae.
d. They generate most heavy elements.

What type of star makes a Type II supernova?

a. A neutron star in a mass-transfer binary.
b. A black hole.
c. A pulsar.
d. A single massive star.

Rank these associations of stars from those with the fewest stars to those with the most stars:

a. globular clusters, galaxies, open star clusters
b. open star clusters, globular clusters, galaxies
c. open star clusters, galaxies, globular clusters
d. galaxies, globular clusters, open star clusters

Meanwhile, a very important tool for Galactic astronomy was being exploited by a young astronomer from Missouri. In 1912 the Harvard astronomer Henrietta Leavitt (1868-1921) discovered that the brighter Cepheid variable stars in the Large Magellanic Cloud had longer periods than the Cepheids with shorter periods. This is the famous period-luminosity law.

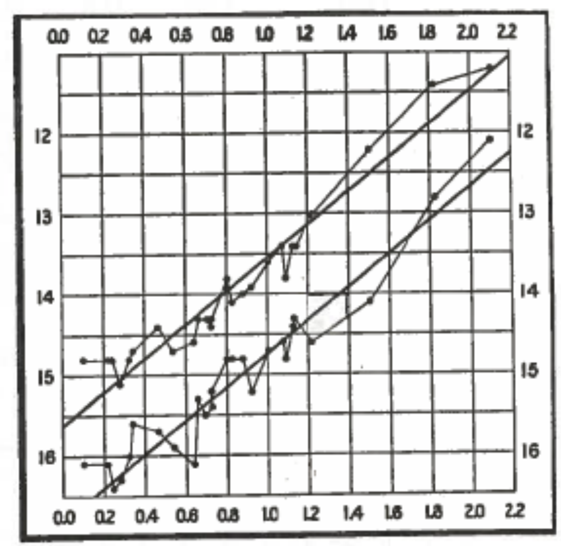
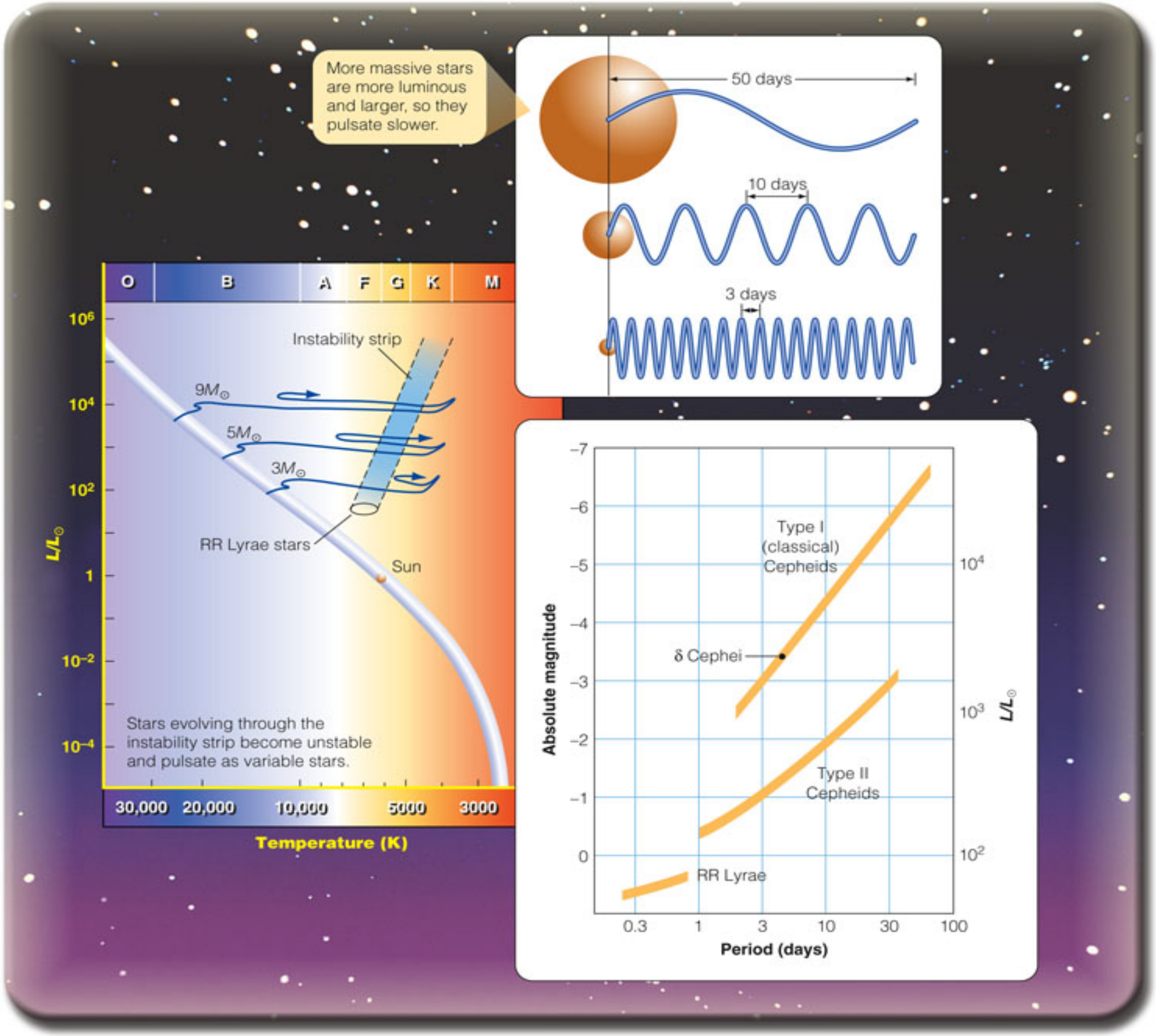


Fig. 2. Magnitudes and logarithms of the periods.

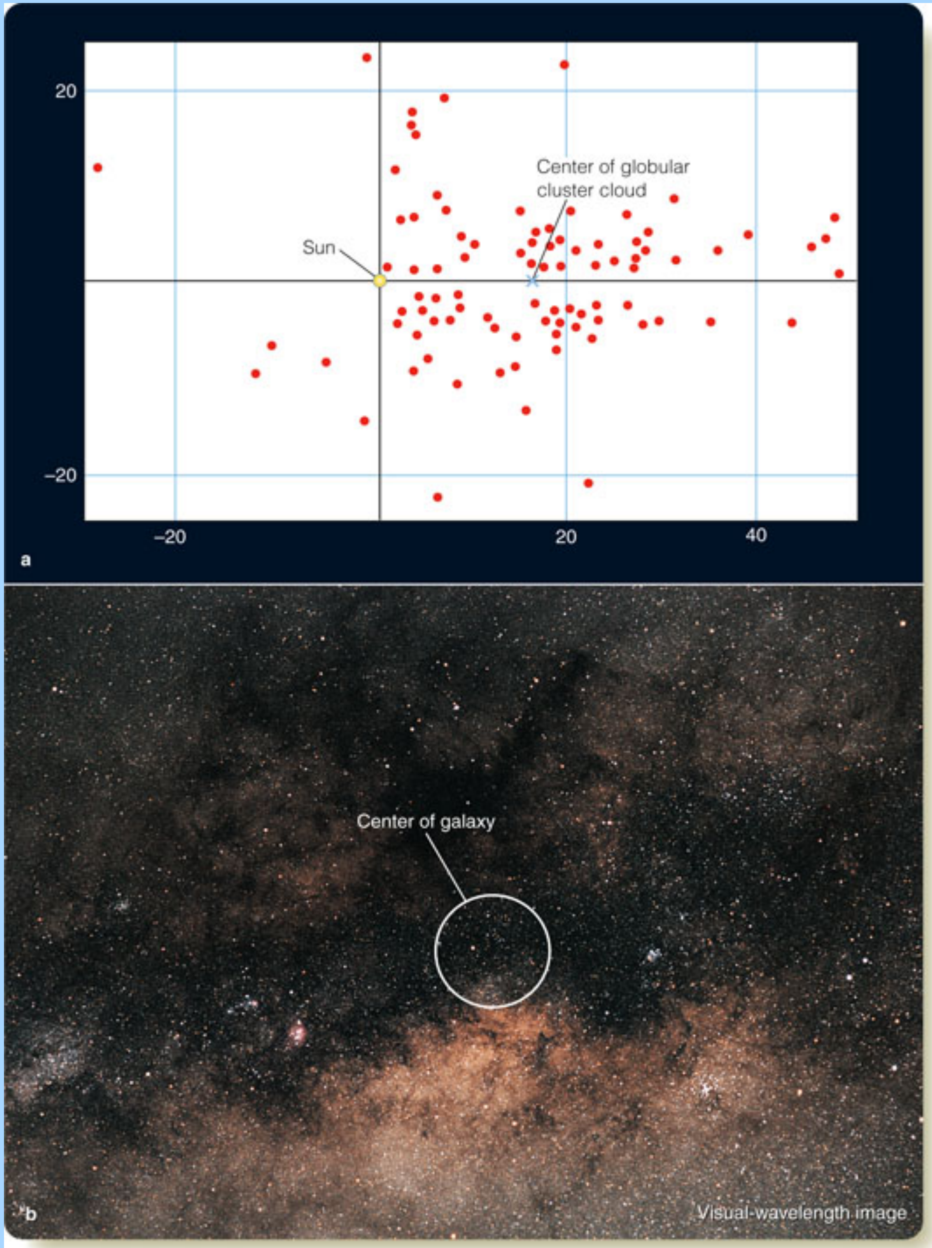


More massive stars are more luminous and larger, so they pulsate slower.
50 days
10 days
3 days
O
B
A
F
G
K
M
Instability strip
$9M_{\odot}$
$5M_{\odot}$
$3M_{\odot}$
RR Lyrae stars
Sun
10^6
10^4
10^2
1
10^{-2}
10^{-4}
$L/L_{\odot}$
Stars evolving through the instability strip become unstable and pulsate as variable stars.
30,000
20,000
10,000
5000
3000
Temperature (K)
Absolute magnitude
−7
−6
−5
−4
−3
−2
−1
0
Type I (classical) Cepheids
δ Cephei
Type II Cepheids
RR Lyrae
10^4
10^3
10^2
$L/L_{\odot}$
0.3
1
3
10
30
100
Period (days)

Since the stars in the Large Magellanic Cloud are all at approximately the same distance from us, a relationship between their apparent magnitudes and periods implied a relationship between their intrinsic luminosities (i.e. absolute magnitudes) and periods.

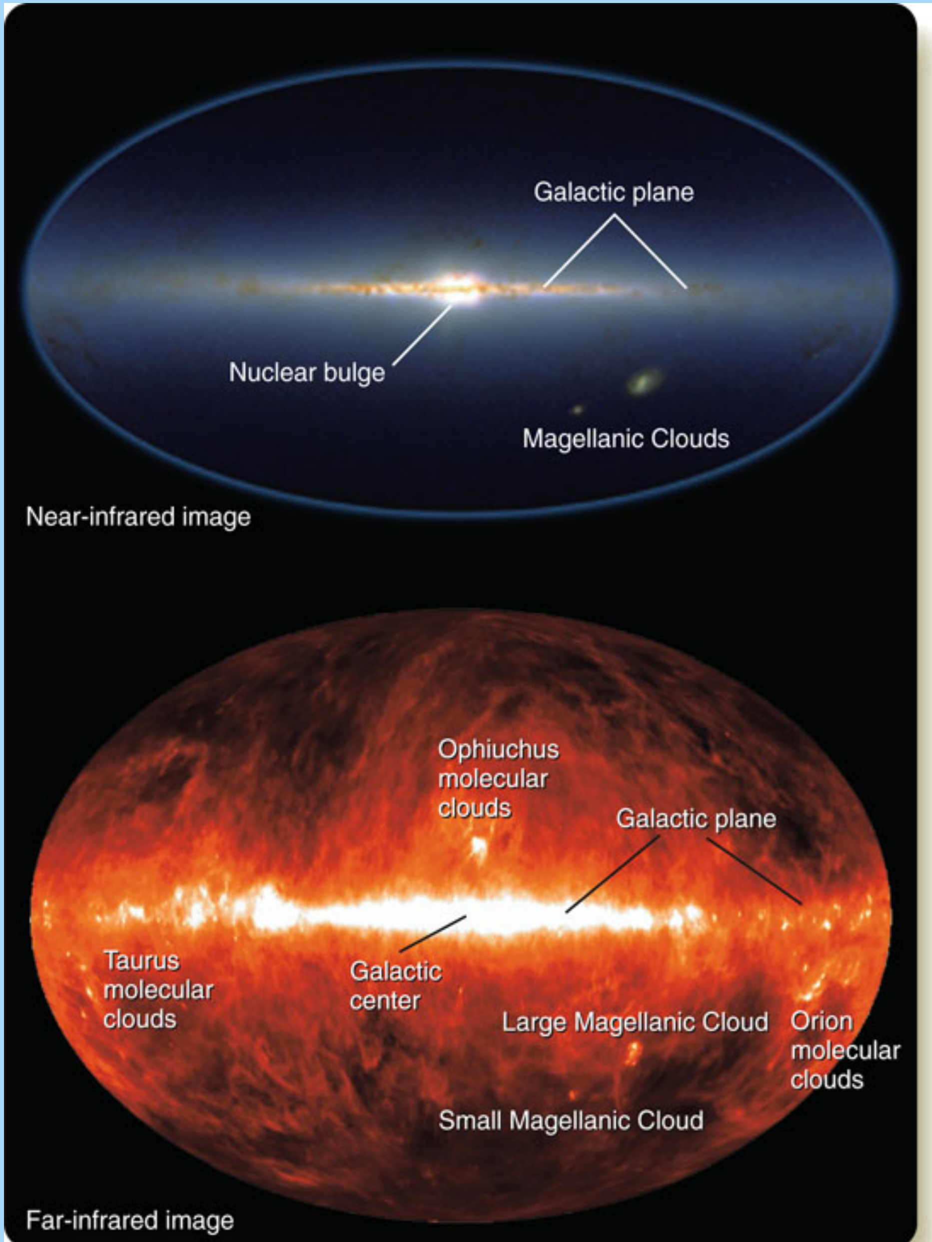
Harlow Shapley (1885-1972) noticed that most of the globular clusters in the sky were situated in the constellations Scorpius and Sagittarius. He wondered: "Is the center of the Galaxy the same as the center of the globular cluster system?"

Shapley determined the distances to a number of globular clusters using the period-luminosity law for Cepheids. He noted that most globular clusters had linear diameters of about 25 pc. He could then use their angular diameters to get approximate distance for clusters whose stars were too faint to study individually. He discovered that the center of the globular cluster system was situated in Sagittarius at a distance of some 50,000 light years. However, he did not take extinction by interstellar dust into account. Modern determinations of the distance to the center of the Galaxy place it at a distance of about 25,000 light-years, or about 8000 parsecs.

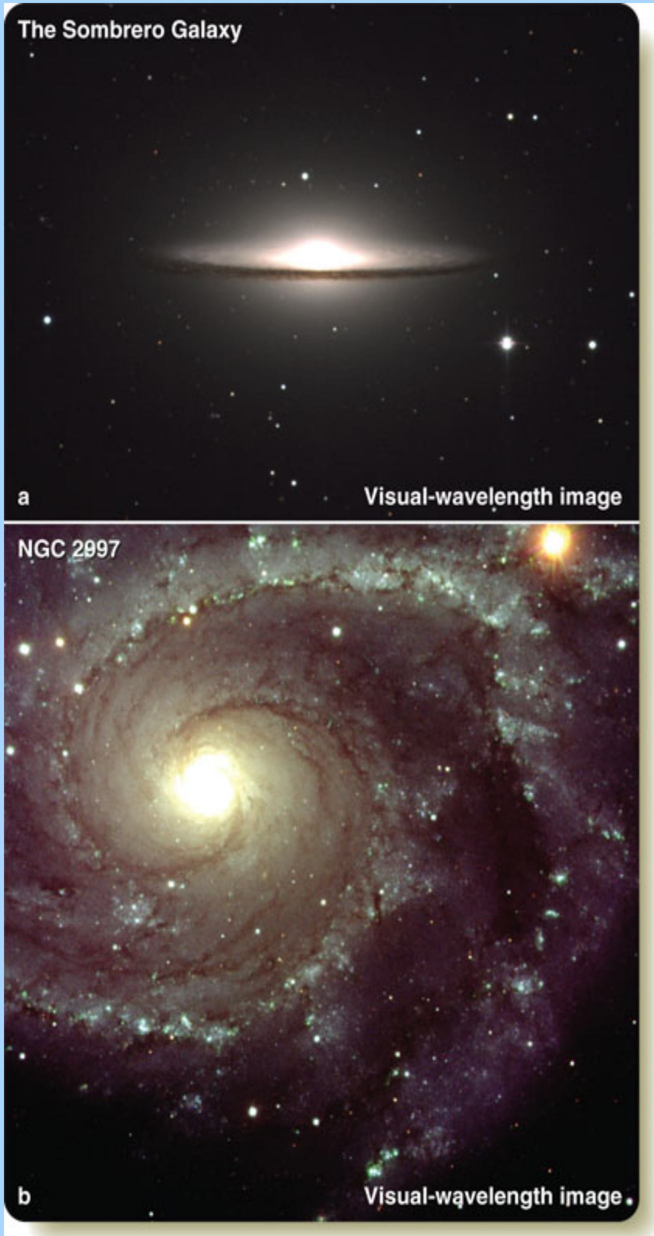


After Copernicus moved the Earth from the center of the solar system, Shapley moved the Sun from the center of the Galaxy.

Looking ahead, it appears that no matter what direction you look, distant galaxies are receding from us.
Is our Galaxy at the center of the universe?

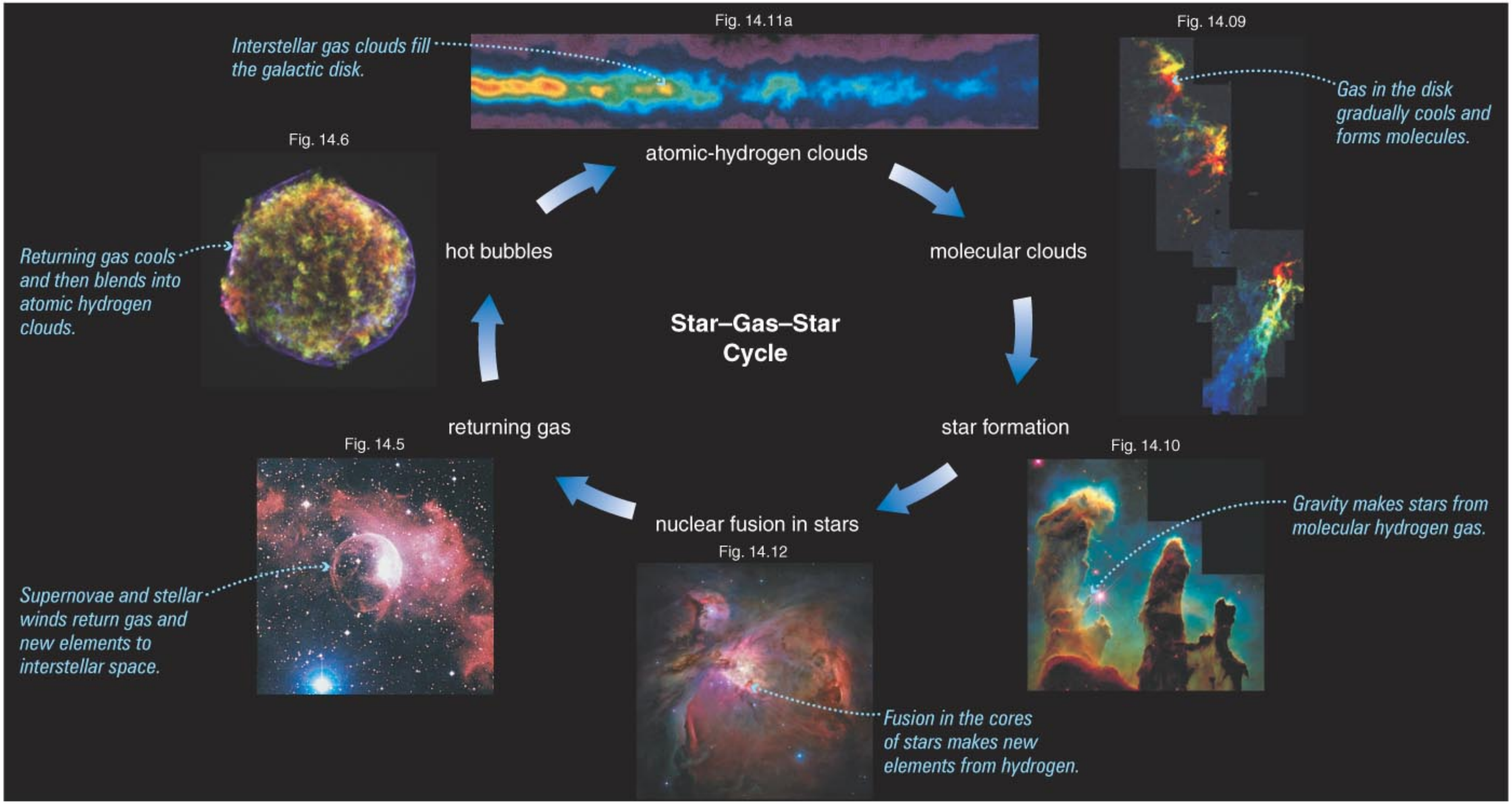


Essentially all of the gas, and all of the bright blue stars are found in the plane of the Galaxy.



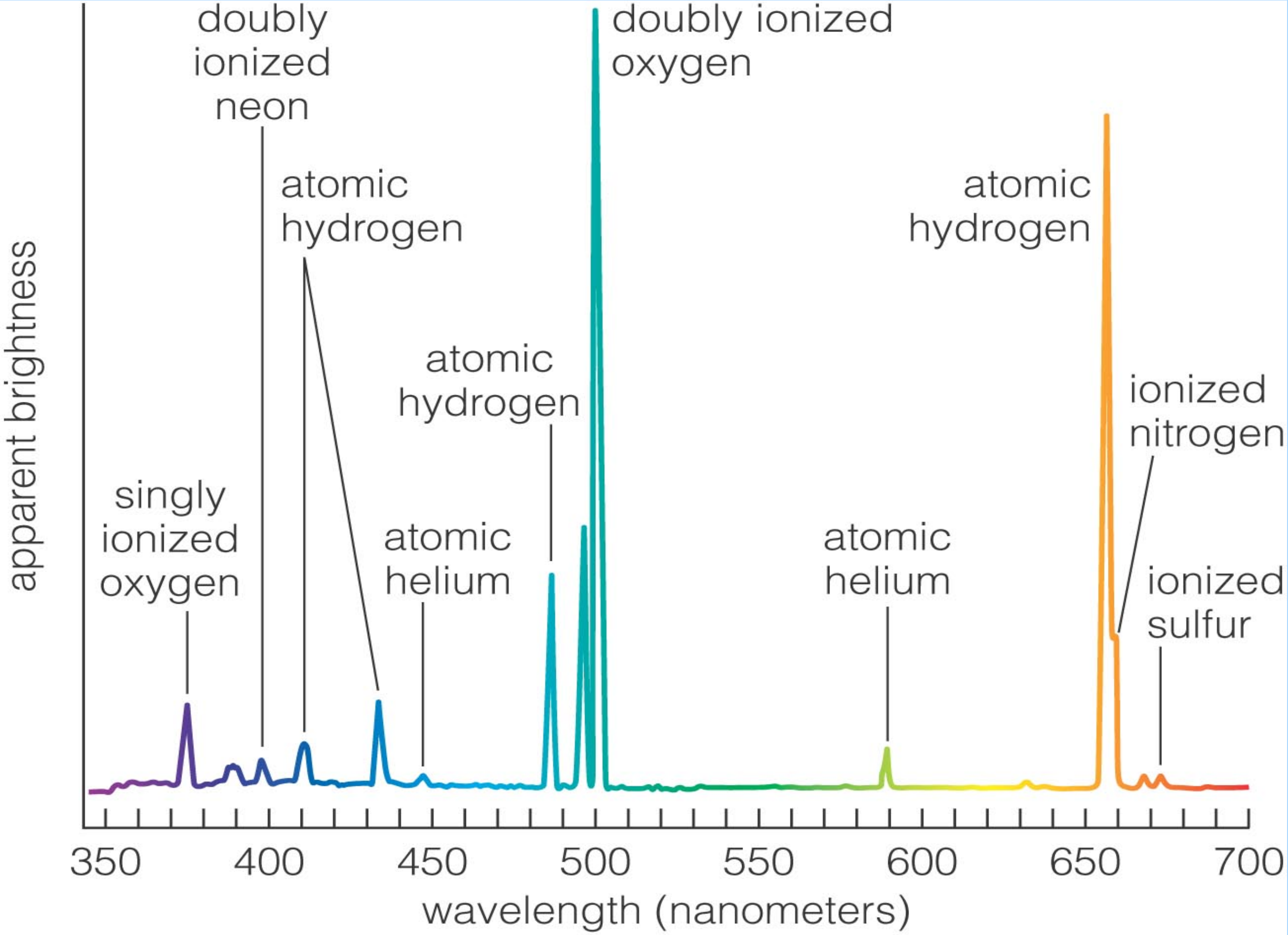
Because we are situated inside the Milky Way Galaxy, and optical light is extinguished by interstellar dust so much, it is difficult to get a picture of our galaxy. But we feel confident that the side-on and face-on views must be similar to these two other galaxies.

The star-gas-star cycle of the Galaxy

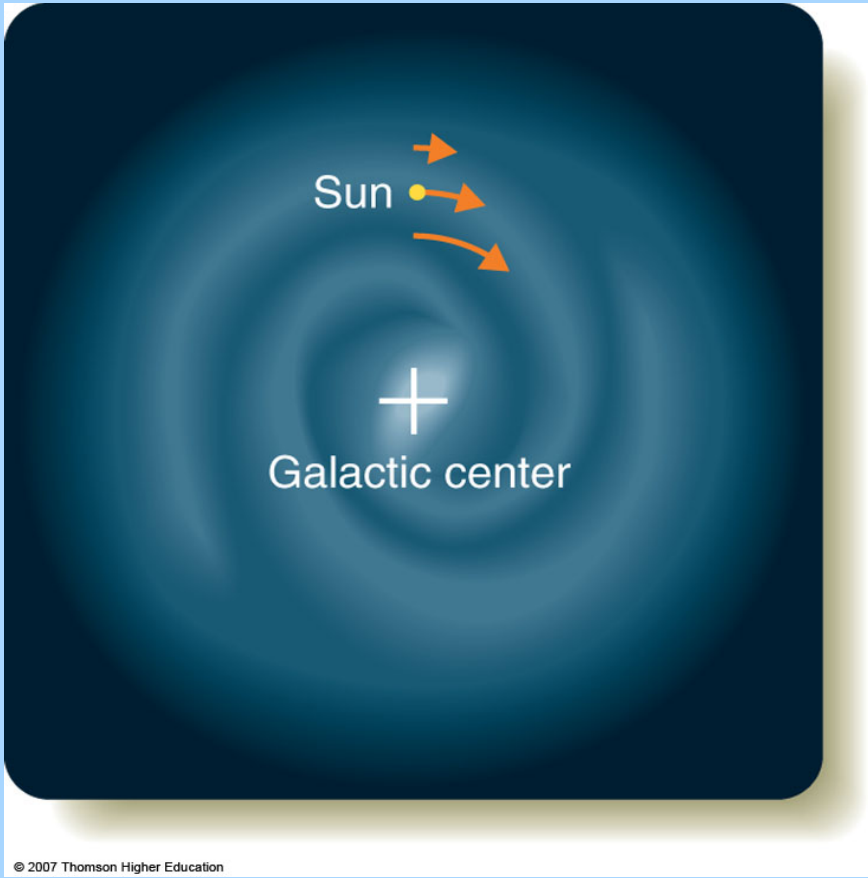


So, as new generations of stars are formed, the fraction of elements heavier than helium in the new stars

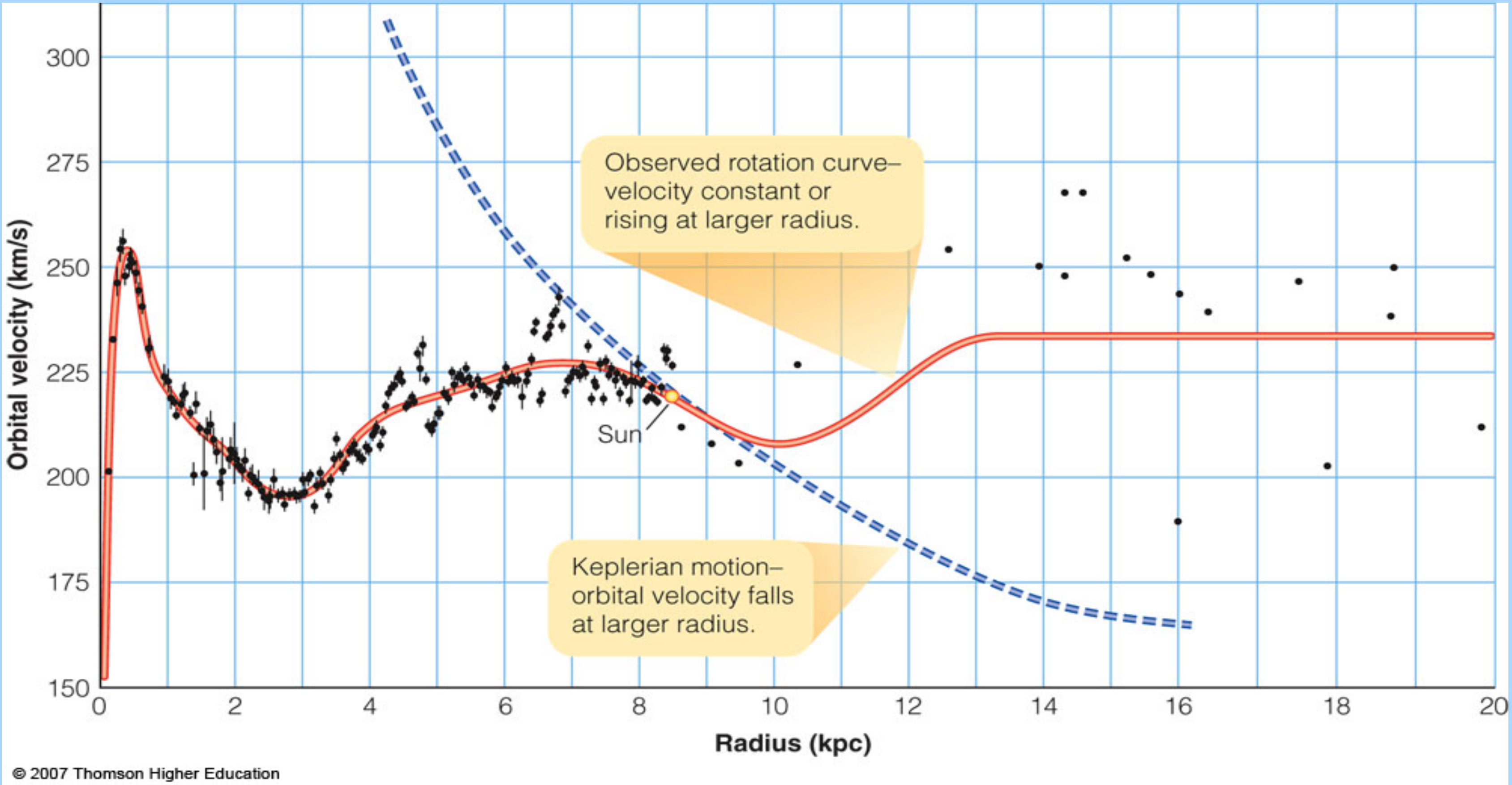
A. stays about the same
B. decreases
C. definitely increases



A spectrum of the Orion Nebula reveals many *emission* lines.



Just like the planets in the solar system, stars further out in the Galaxy orbit the Galactic center more slowly. The Sun is moving 220 km/sec toward Cygnus and orbits the center every 240 million years.



Unlike the solar system, however, the circular speeds around the center do not decrease nicely in accord with Kepler's Third Law.

Your book gives estimates of the mass of the Galaxy from 1 to 4 X 10^{11} solar masses. A more recent determination of the mass of the Galaxy is even larger, ~1.5 X 10^{12} solar masses. This is on the basis of the motions of globular clusters (Watkins et al., 2019, *ApJ*. **873**, 18) absolute magnitude called horizontal branch stars.
The visible Galaxy that gives off most of the light is embedded in a halo of invisible **Dark Matter**.

What could this dark matter be? Relic particles from the Big Bang? Lots of 3 solar mass black holes? This is one of the biggest mysteries in modern astronomy.

Different Stellar Populations

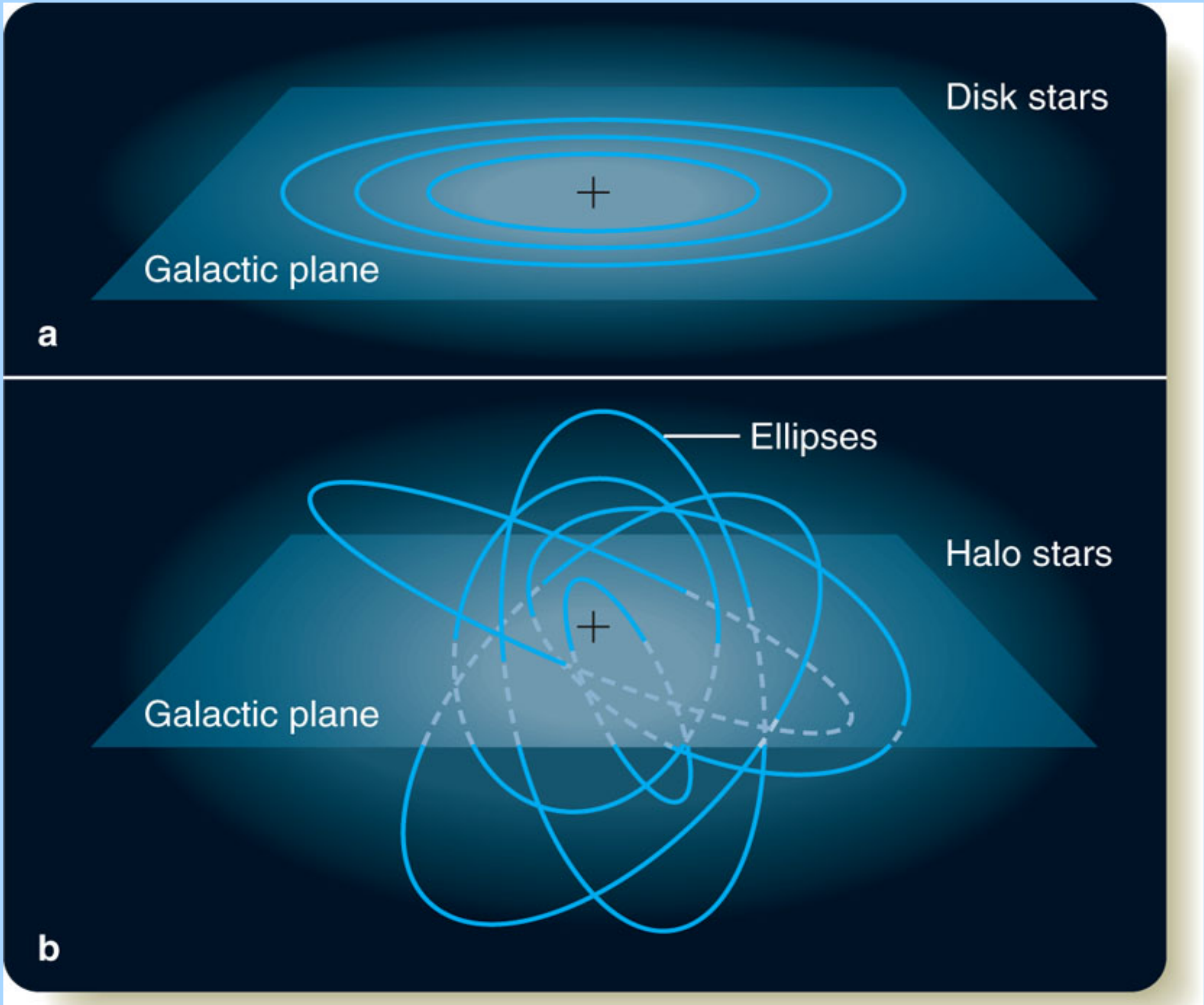
Table 15-1 | Stellar Populations

	Population I		Population II	
	Extreme	*Intermediate*	*Intermediate*	*Extreme*
Location	Spiral arms	Disk	Nuclear bulge	Halo
Metals (%)	3	1.6	0.8	Less than 0.8
Shape of orbit	Circular	Slightly elliptical	Moderately elliptical	Highly elliptical
Average age (yr)	100 million and younger	0.2–10 billion	2–10 billion	10–13 billion

Gas is confined to the Galactic plane, with a thickness of only 100 pc. This is where the most recent stars are being formed.

Perturbations of stars' motion by giant molecular clouds and star clusters has elongated the orbits of other stars over time.

Stars formed in the halo can have highly elliptical orbits around the Galactic Center. These orbits are not confined to the plane of the Galaxy.



Know this for final exam!

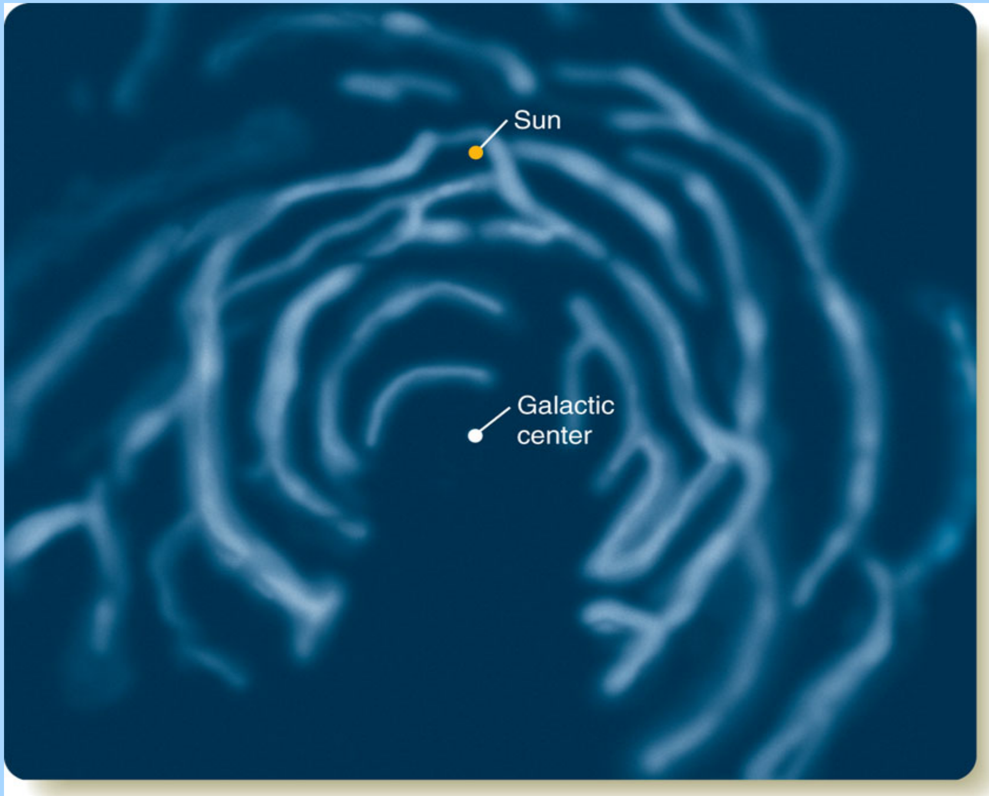
The Sun is found in the plane of the Galaxy.

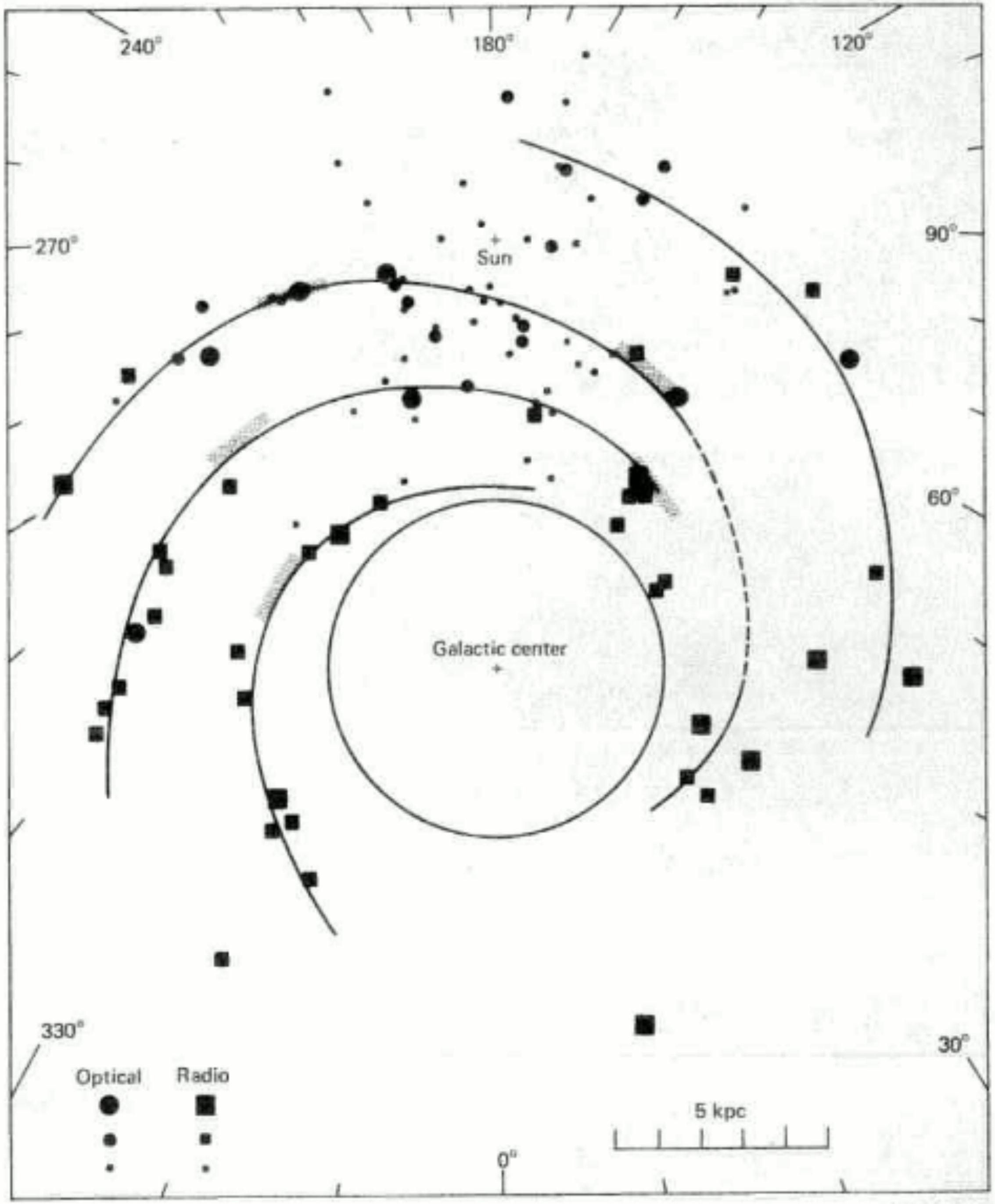
It moves on a nice circular orbit around the center of the Galaxy along with other stars formed in the plane.

If a halo star is passing through the plane, it will have a large relative velocity with respect to the Sun. So this is one way to identify a star that is likely to have a different composition (much lower abundance of elements heavier than helium) – it is a "high velocity star" that is just passing through the plane on an elliptical orbit toward the halo or toward the center of the Galaxy

Globular clusters were formed when the Galaxy was young. They have ages up to 10 to 13 billions years. Also, the oldest white dwarfs in the plane are now sort of orange in color. We can estimate that they may be 9 to 10 billion years old. This is how we can get an estimate of the age of the Galaxy.

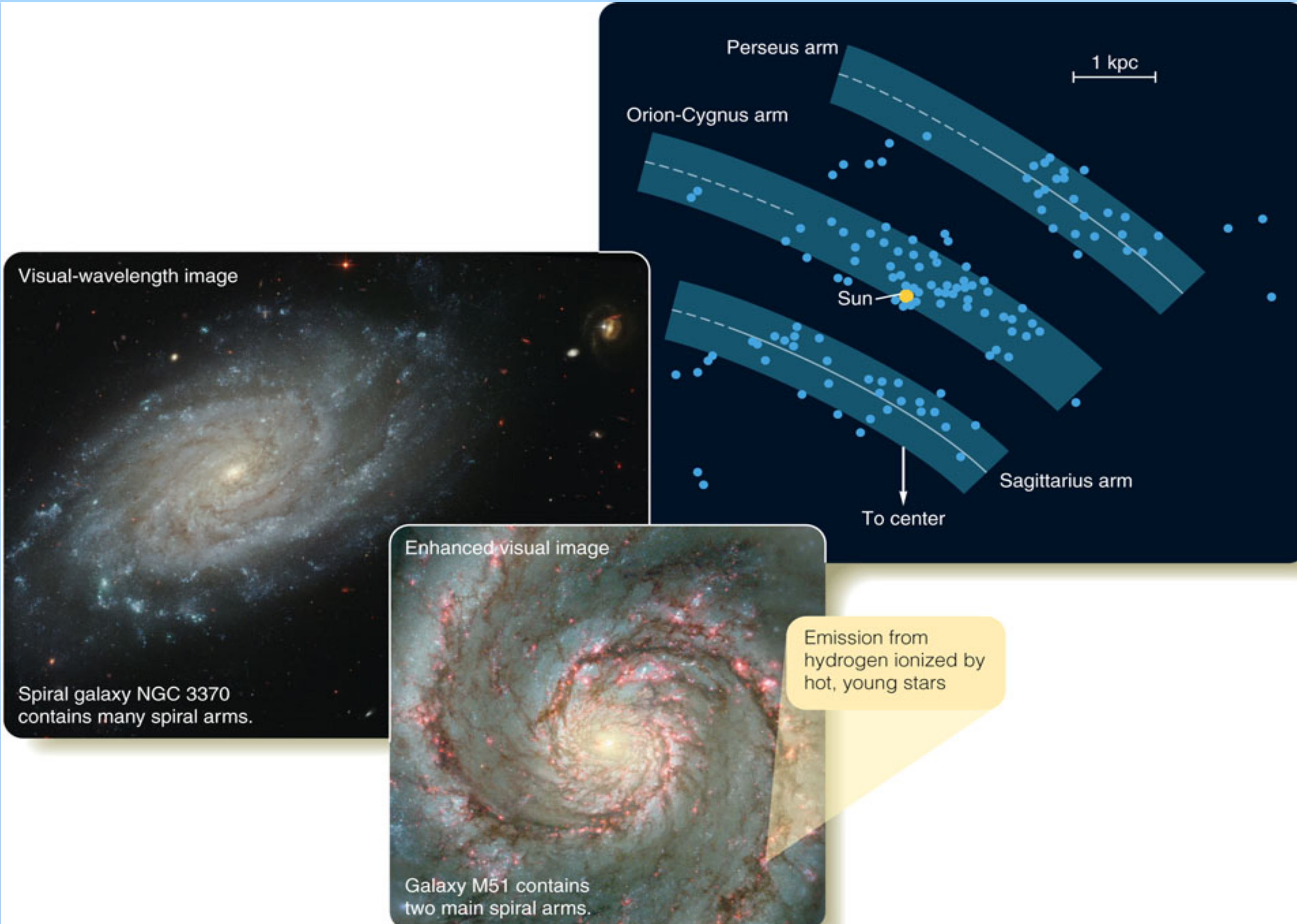
Evidence for the spiral structure of the Galaxy comes from nearby associations of hot, new stars. Also from observations of neutral hydrogen gas.

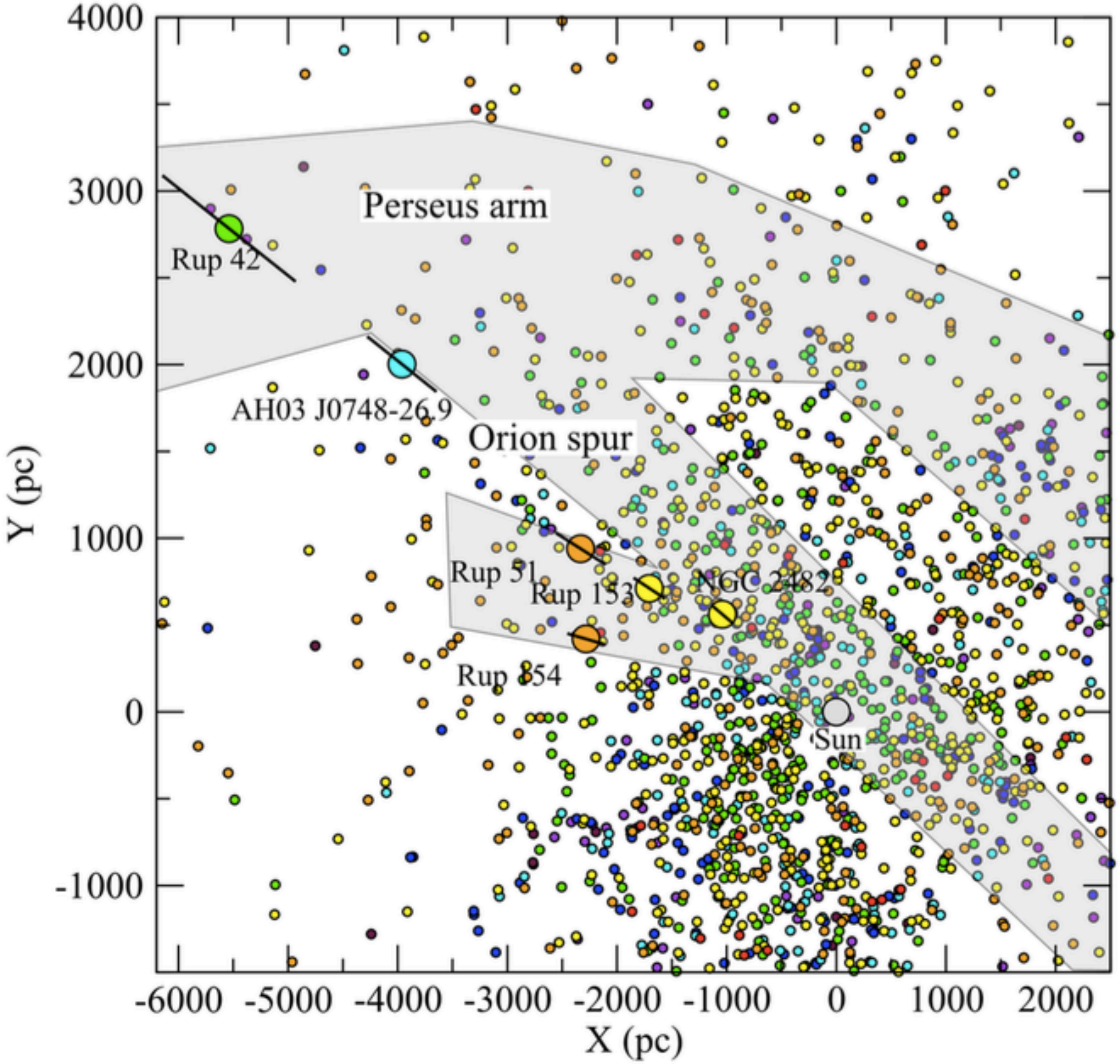




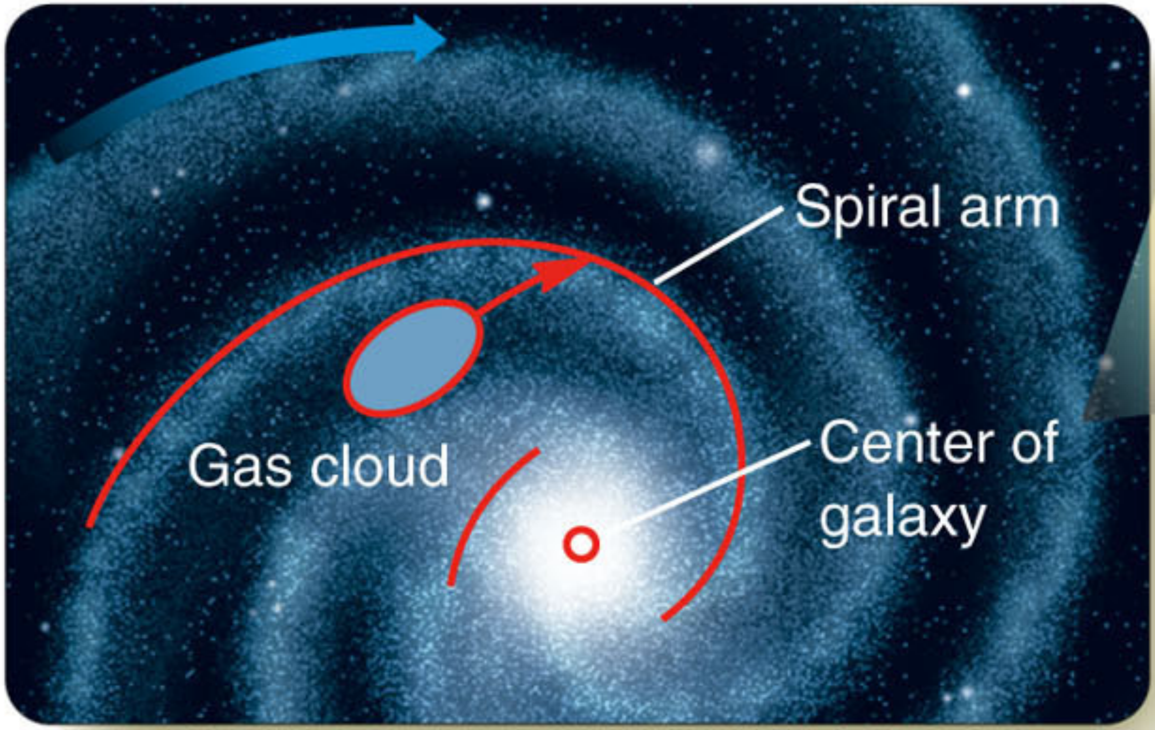
Spiral structure of our Galaxy, as determined from ionized hydrogen regions

Georgelin & Georgelin (1976)

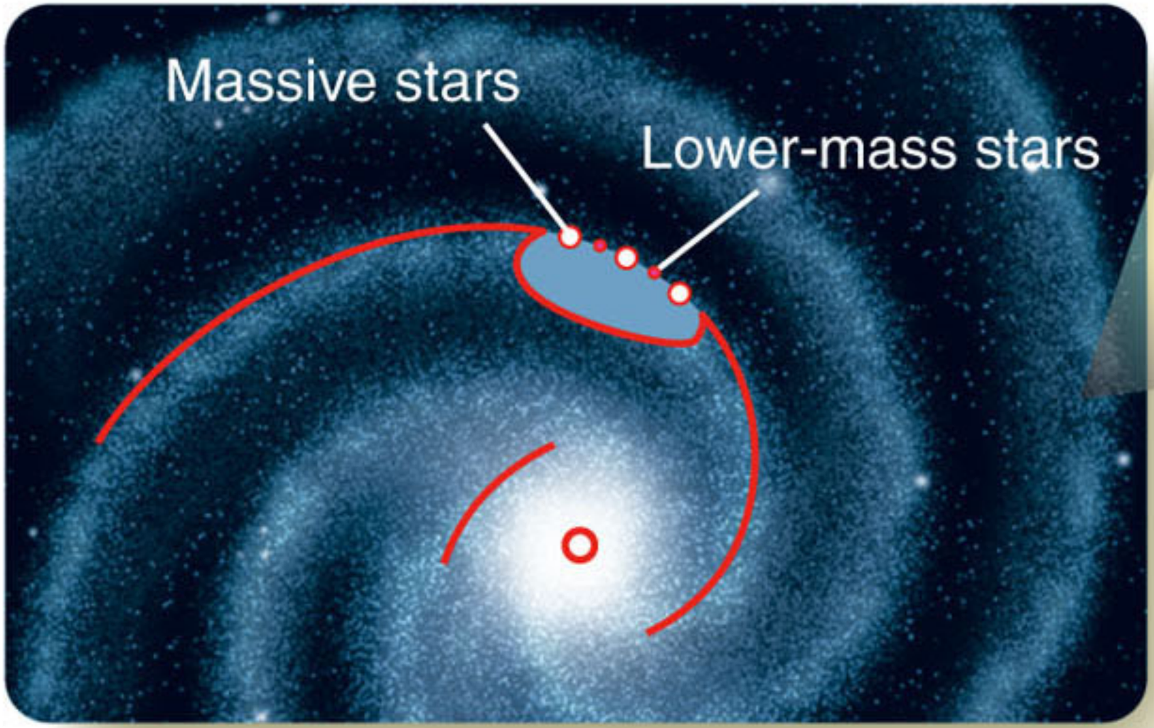

Perseus arm
1 kpc
Orion-Cygnus arm
Sun
Sagittarius arm
To center
Visual-wavelength image
Spiral galaxy NGC 3370
contains many spiral arms.
Enhanced visual image
Galaxy M51 contains
two main spiral arms.
Emission from
hydrogen ionized by
hot, young stars


4000
3000
2000
1000
0
-1000
Y (pc)
-6000
-5000
-4000
-3000
-2000
-1000
0
1000
2000
X (pc)
Perseus arm
Rup 42
AH03 J0748-26.9
Orion spur
Rup 51
Rup 153
NGC 2482
Rup 54
Sun

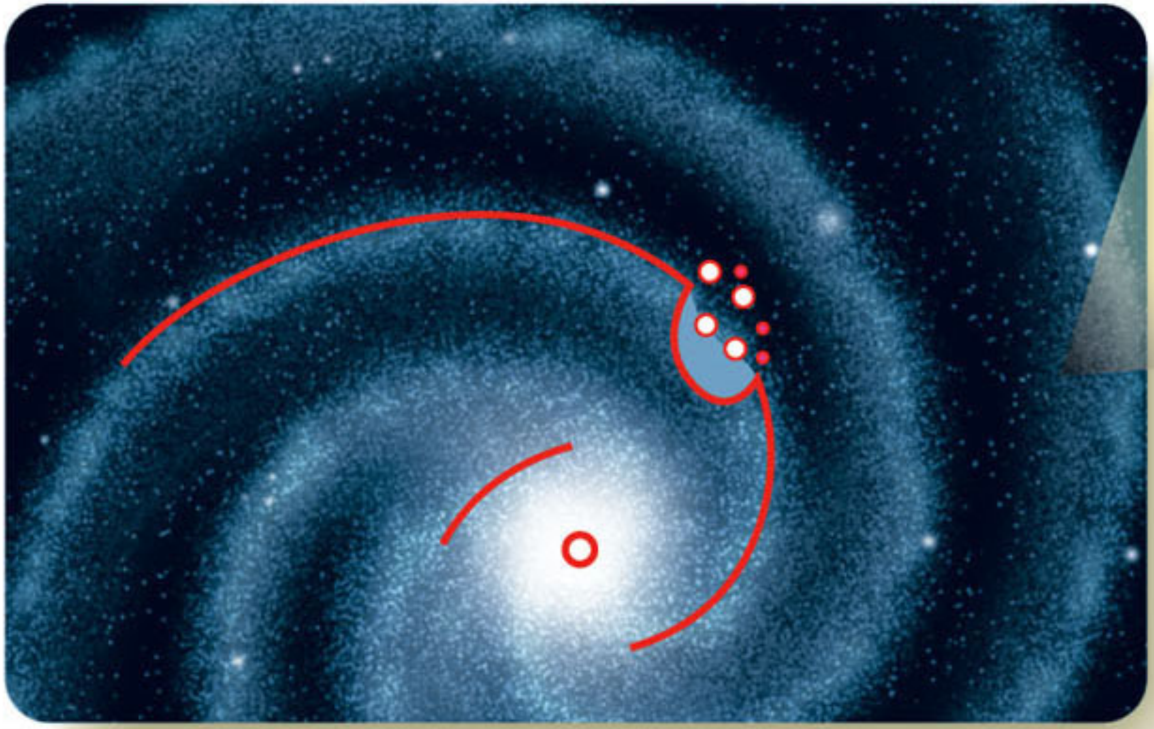
The Spiral Density Wave



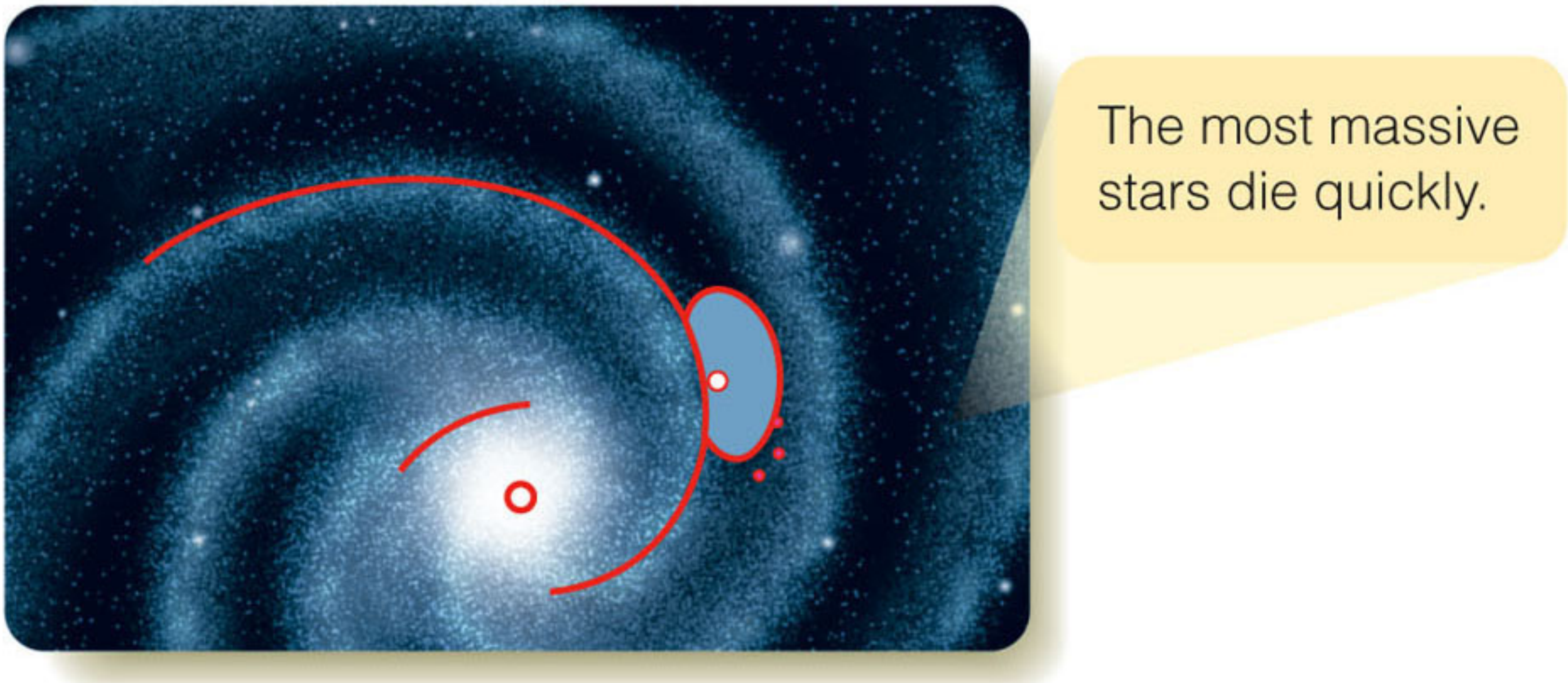
Orbiting gas clouds overtake the spiral arm from behind.

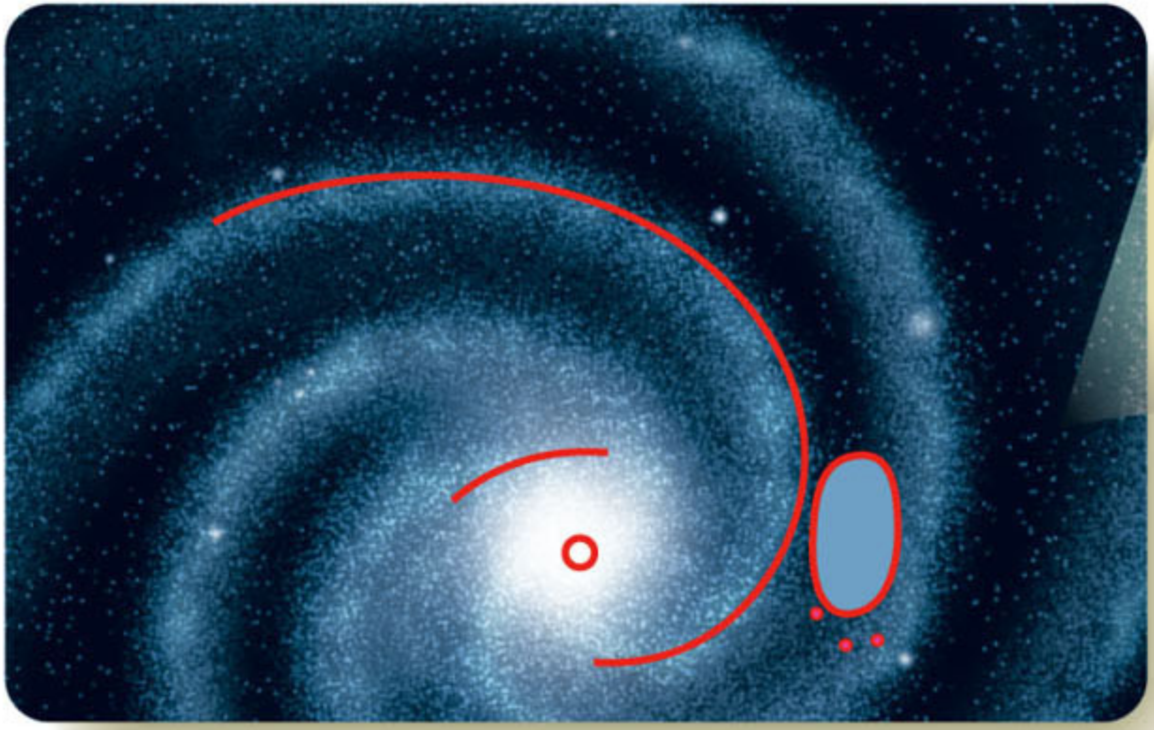


The compression of a gas cloud triggers star formation.



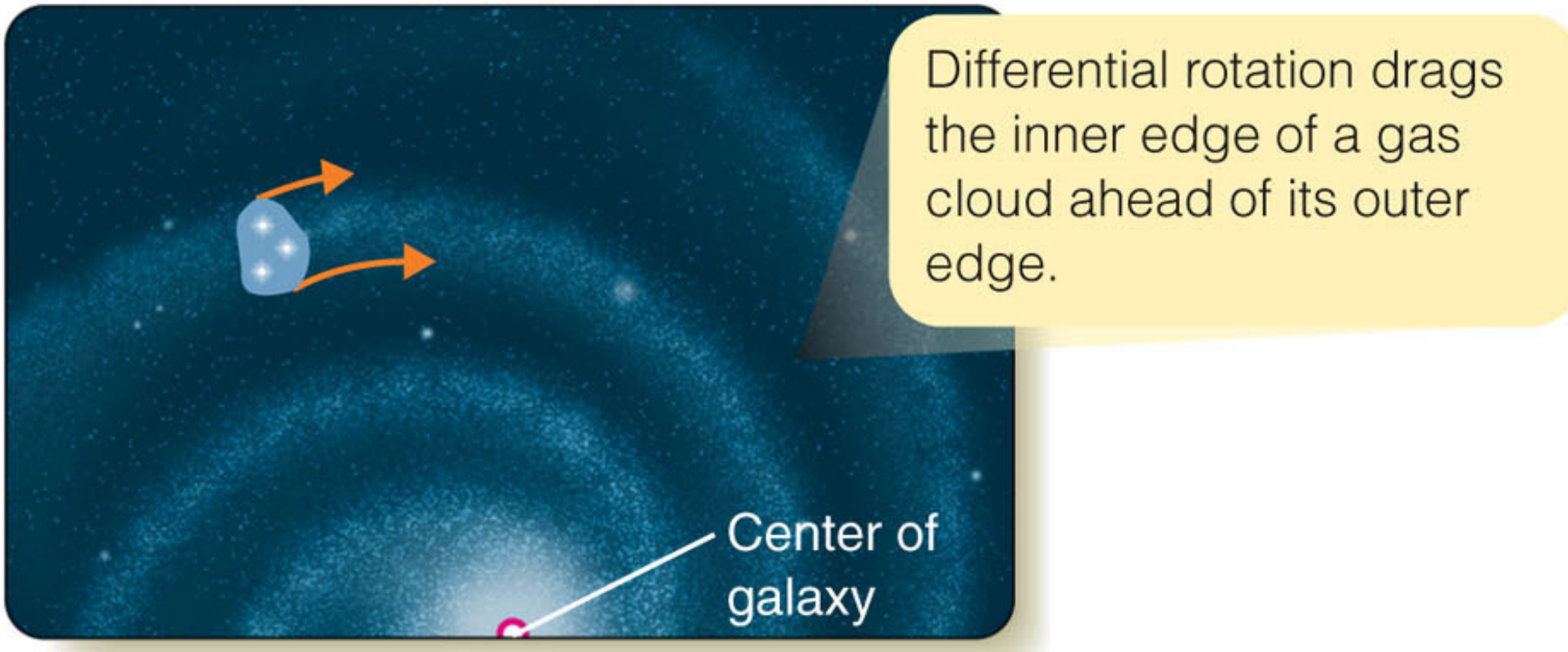
Massive stars are highly luminous and light up the spiral arm.

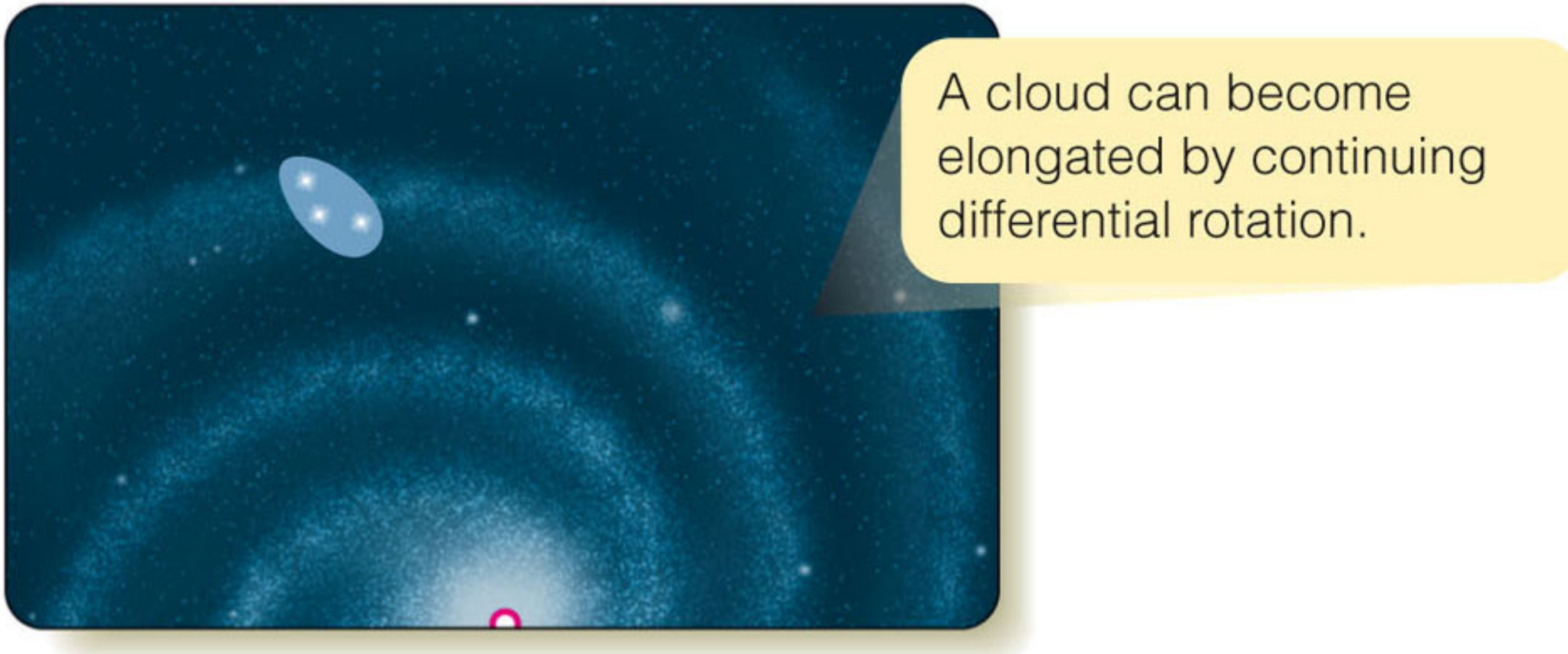

The most massive
stars die quickly.

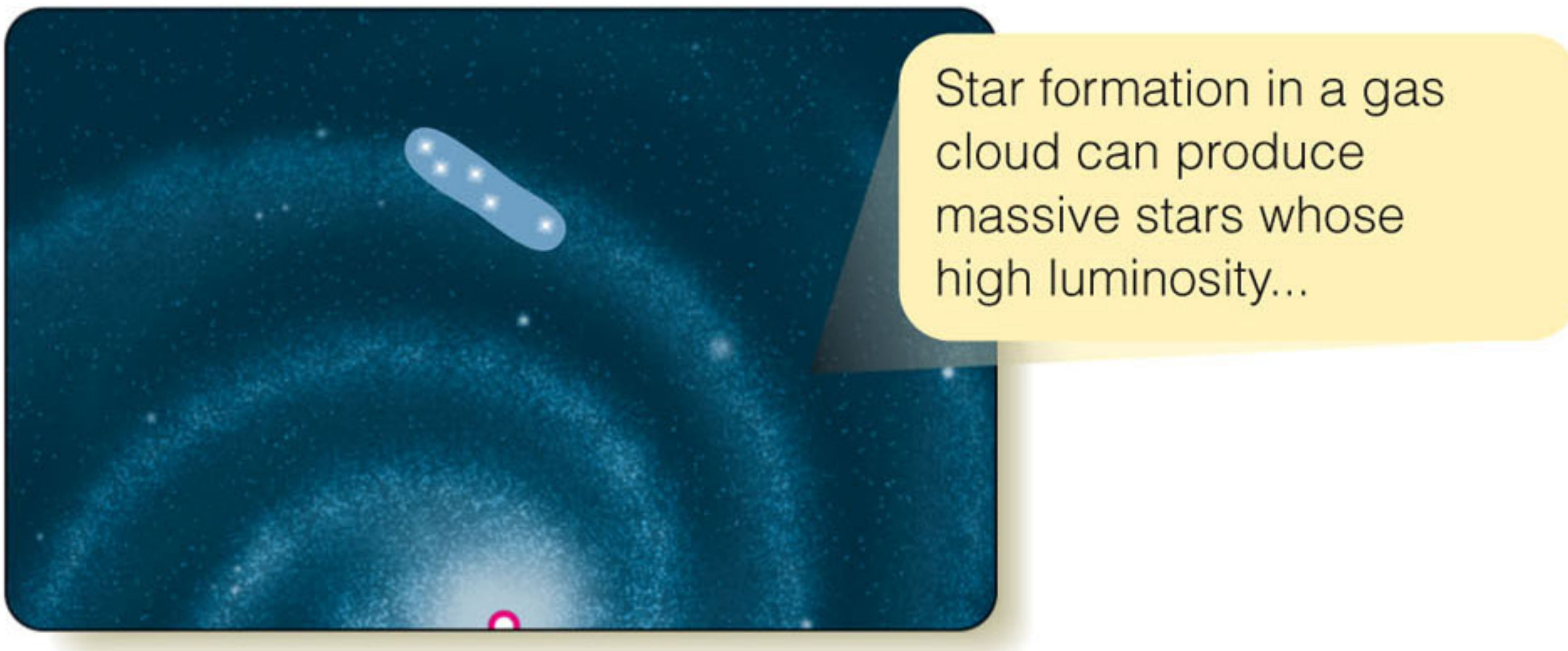


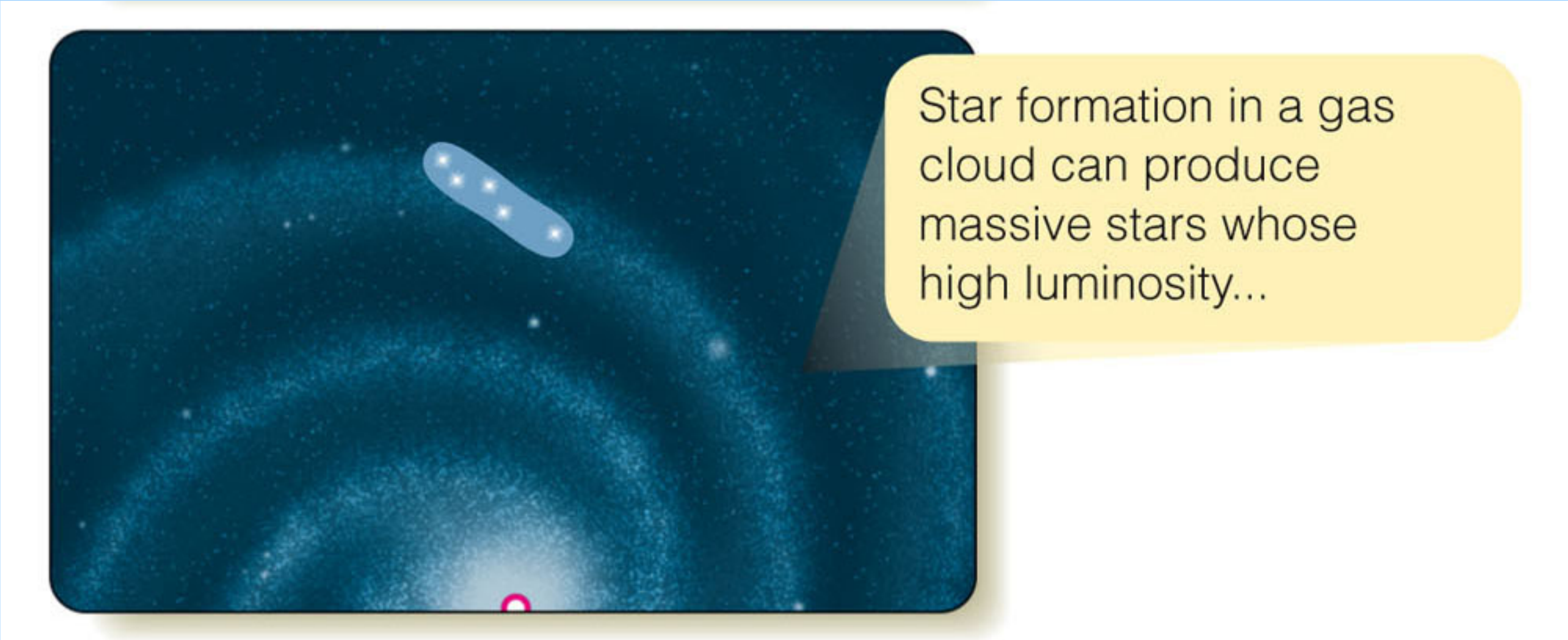
Low-mass stars live long lives but are not highly luminous.

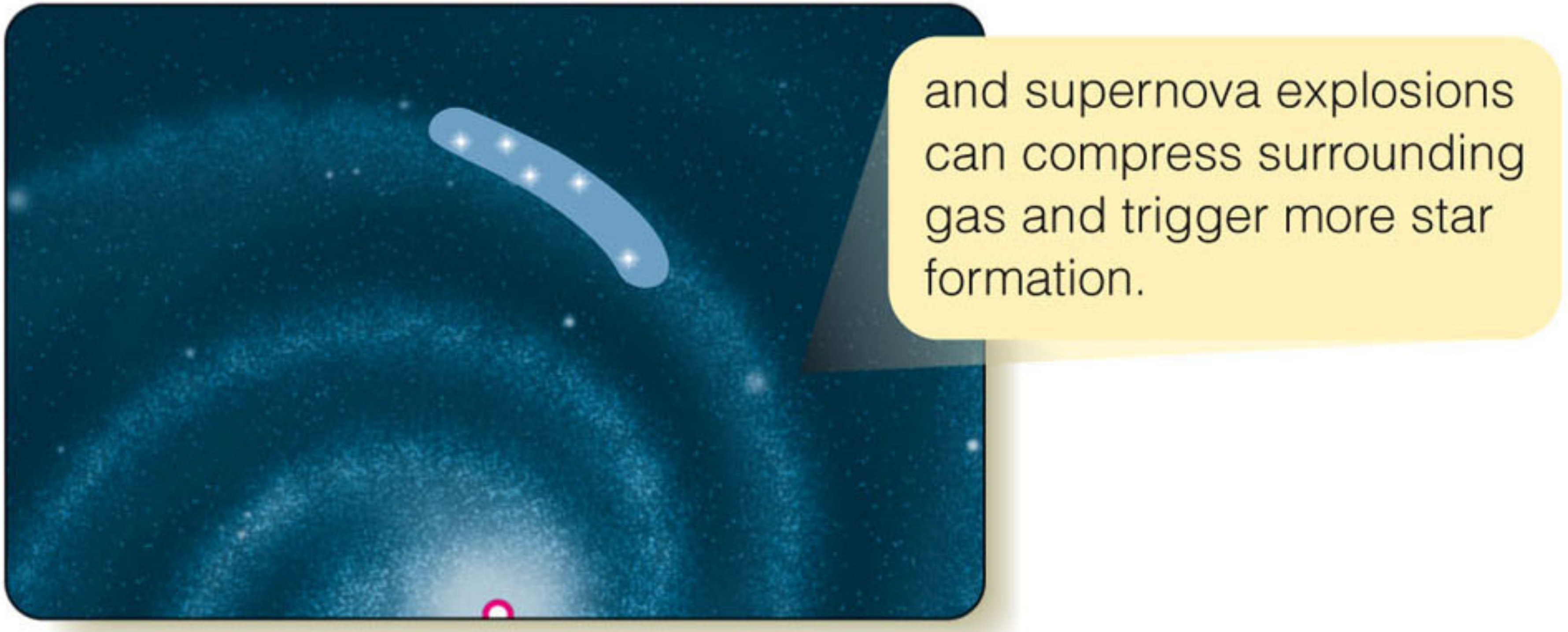
Self-Sustaining Star Formation

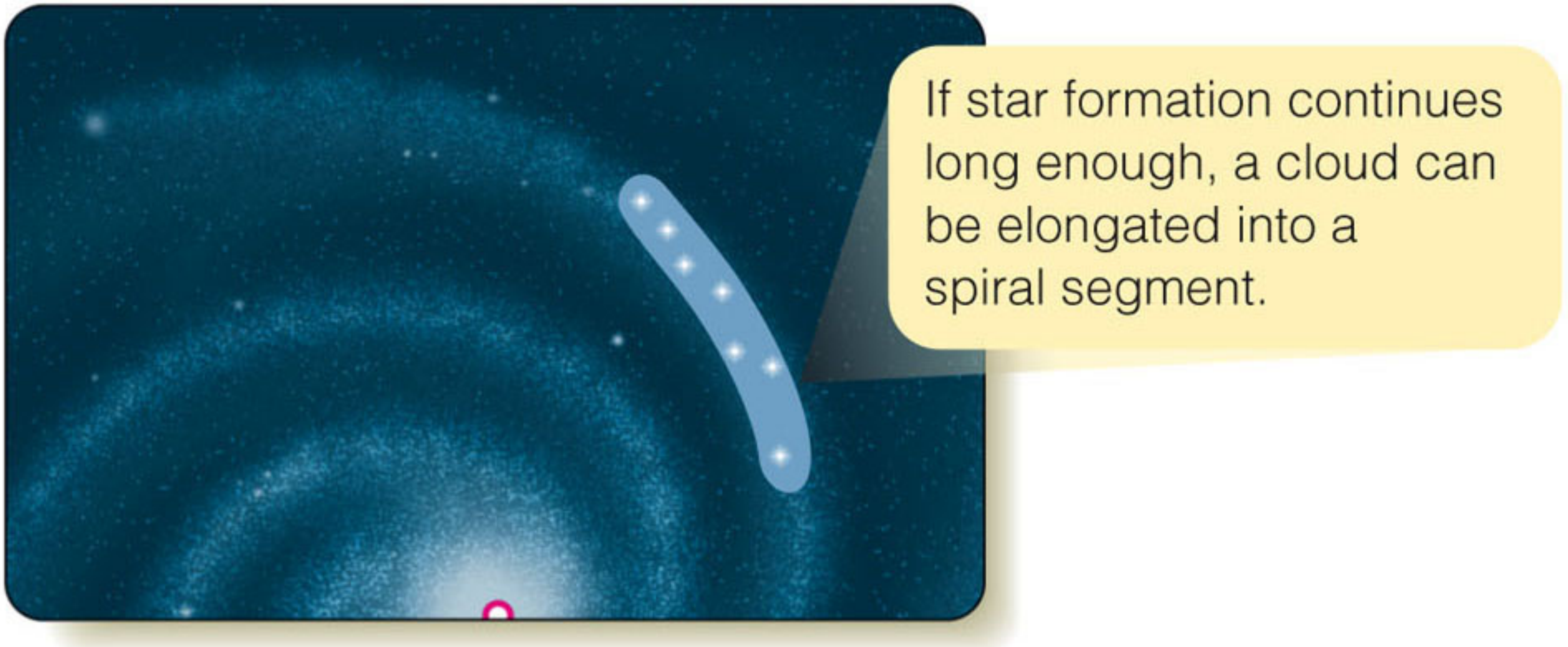



A cloud can become elongated by continuing differential rotation.


Star formation in a gas cloud can produce massive stars whose high luminosity...


Star formation in a gas cloud can produce massive stars whose high luminosity...


and supernova explosions can compress surrounding gas and trigger more star formation.


If star formation continues long enough, a cloud can be elongated into a spiral segment.

We can map out the distribution of cold atomic hydrogen in our Galaxy by using

a. an optical telescope to obtain spectra of hydrogen emission nebulae
b. a radio telescope tuned to a wavelength of 21 cm
c. an infrared telescope, because IR light is less affected by interstellar dust

The Sun and most of the stars near it are moving

a. at all angles and velocities with respect to the plane of the Galaxy
b. on nearly circular orbits around the center of the Galaxy
c. inevitably toward the black hole at the center of the Galaxy

Most of the mass of the Galaxy is in what form?

a. main sequence stars
b. giant stars
c. white dwarfs
d. Dark Matter
e. black holes