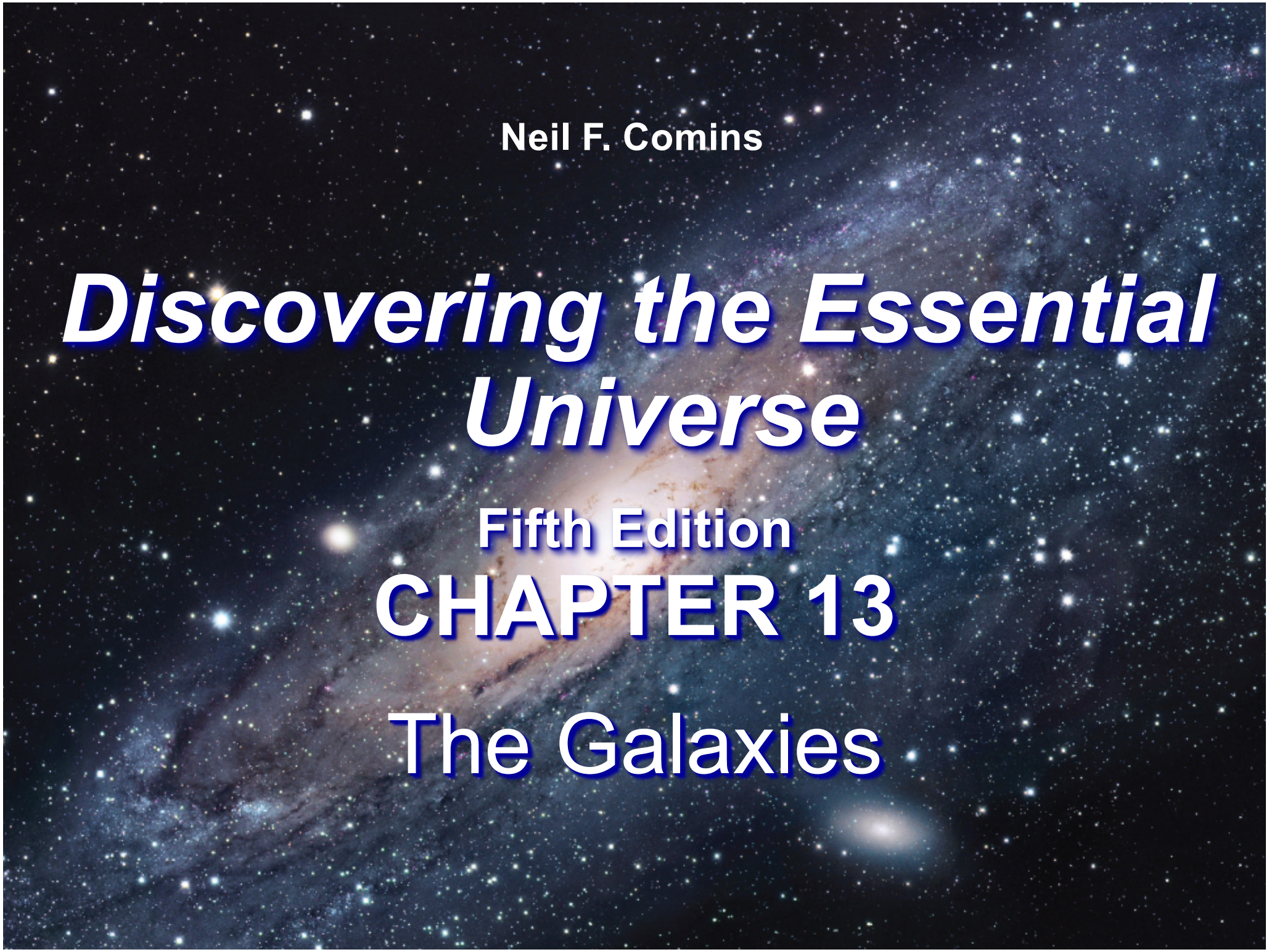
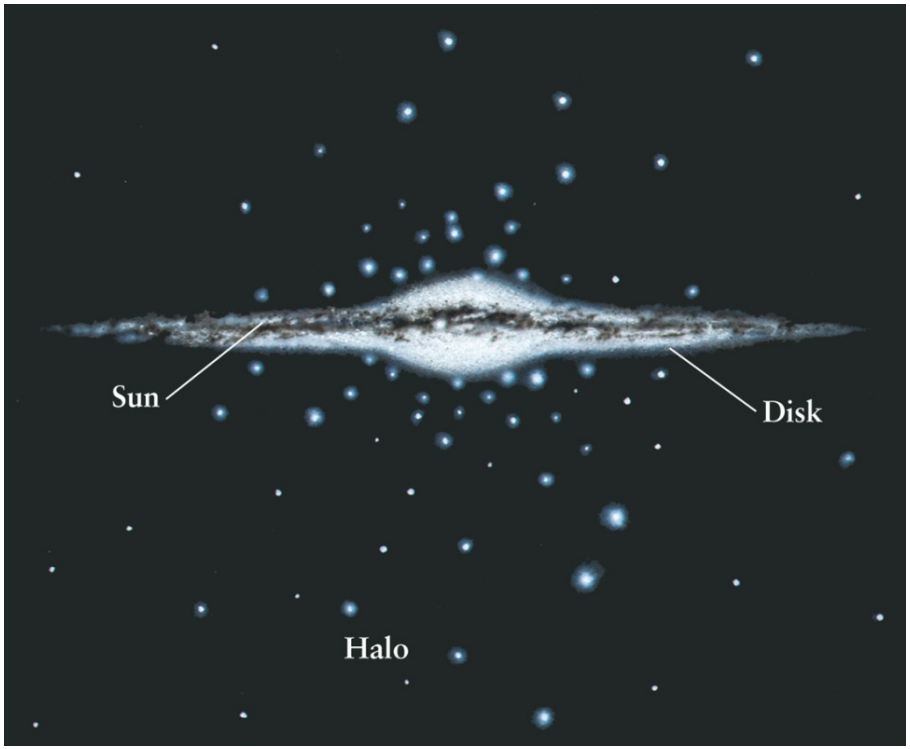
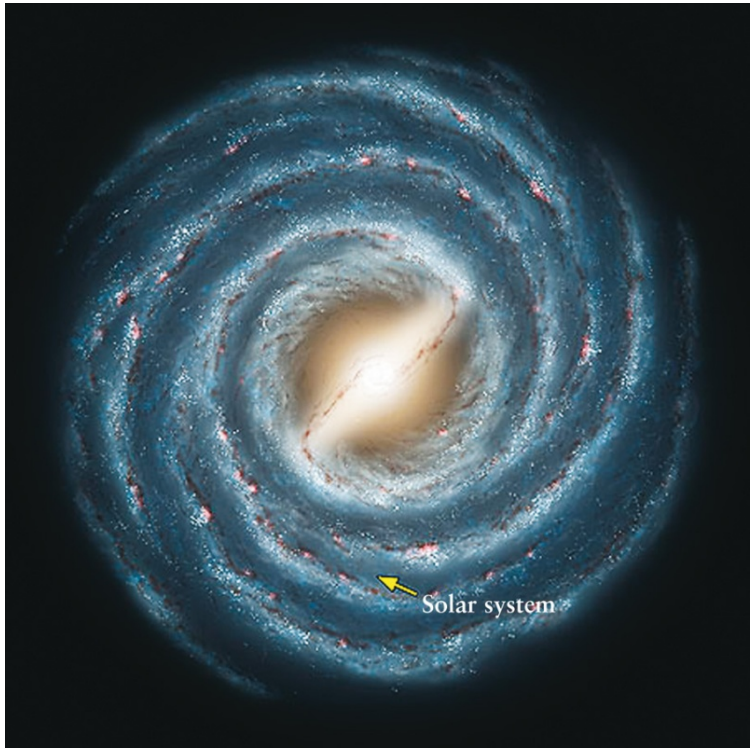

Neil F. Comins
Discovering the Essential Universe
Fifth Edition
CHAPTER 13
The Galaxies

In this chapter you will discover…

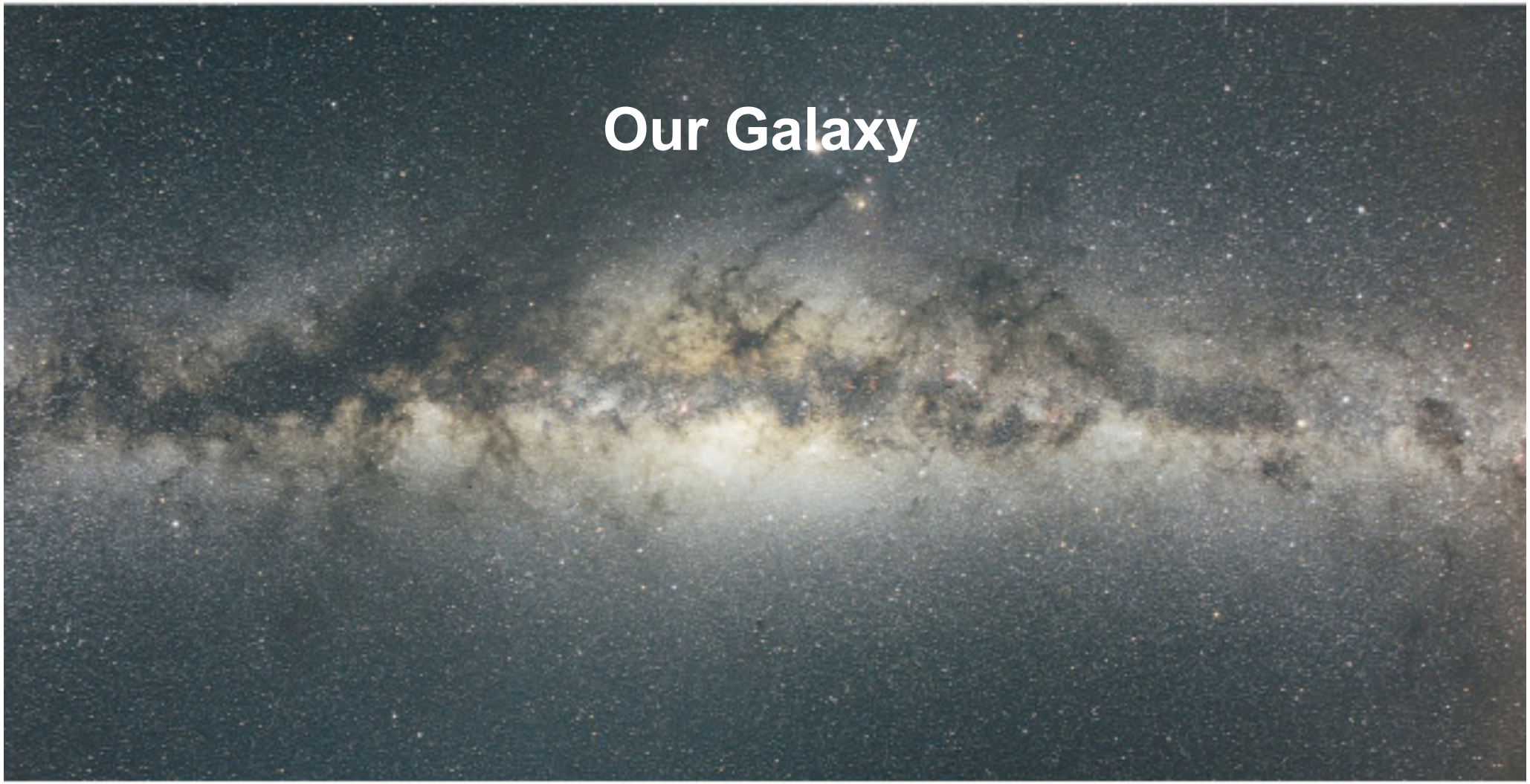
- the structure of our Milky Way Galaxy and Earth's location in it
- how galaxies are categorized by their shapes
- that galaxies are found in clusters that contain huge amounts of dark matter and why clusters of galaxies form in superclusters
- that the universe is expanding

Schematic Diagrams of the Milky Way



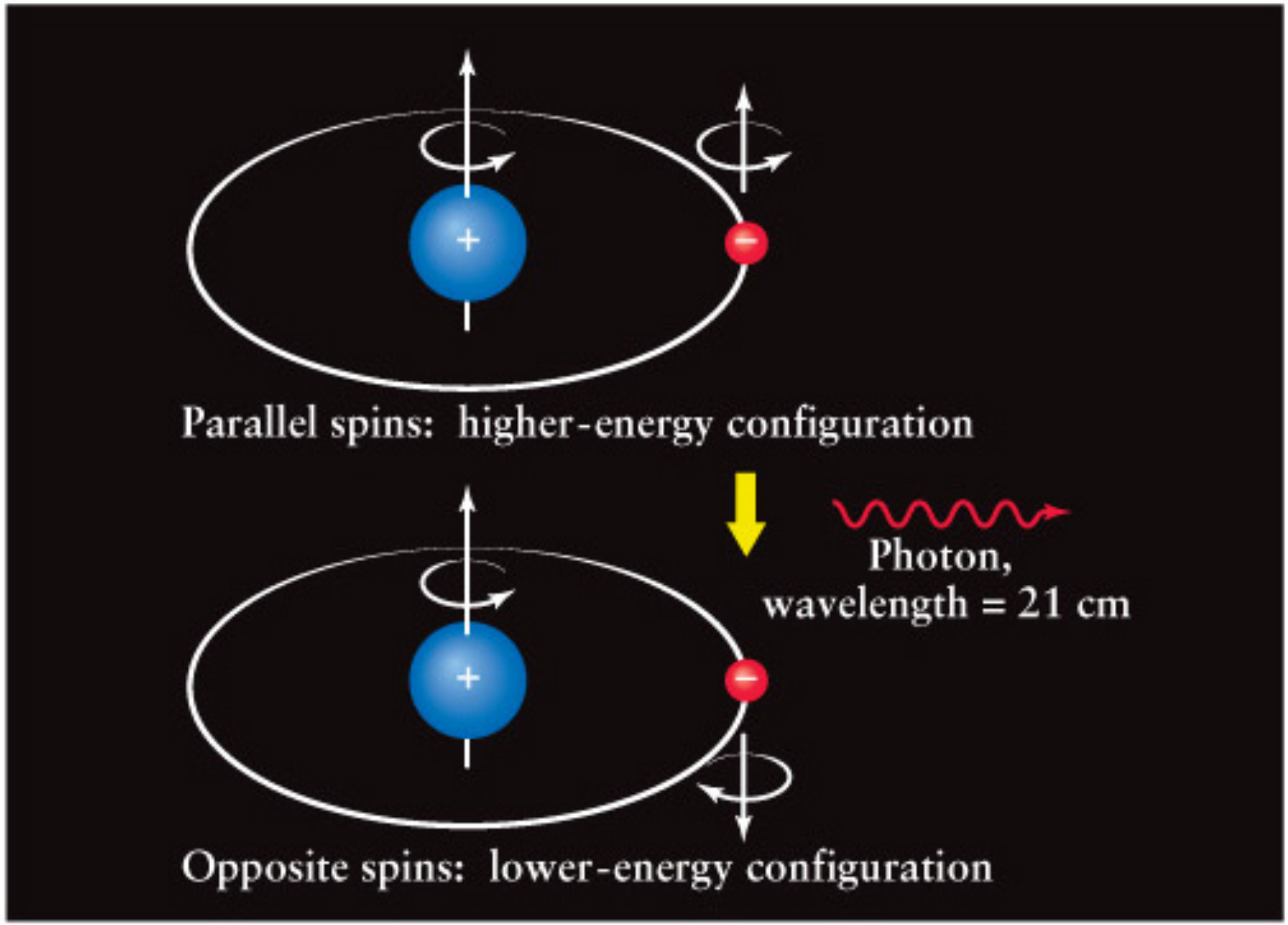


Our Galaxy

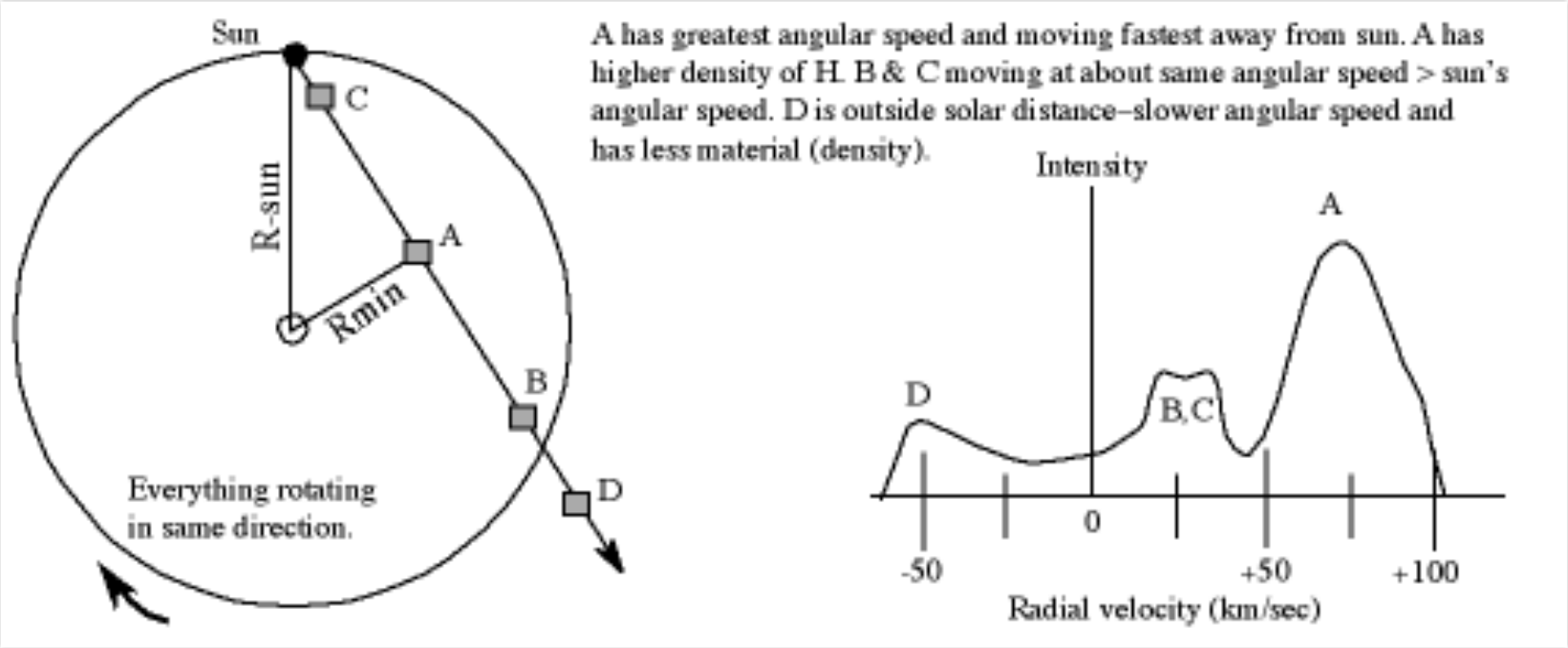


This wide-angle photograph spans half the Milky Way. The Northern Cross is at the left and the Southern Cross is at the right. The center of the Galaxy is in the constellation Sagittarius, in the middle of this photograph. The dark lines and blotches are caused by hundreds of interstellar clouds of gas and dust that obscure the light from background stars, rather than by a lack of stars.

Electron Spin and the Hydrogen Atom

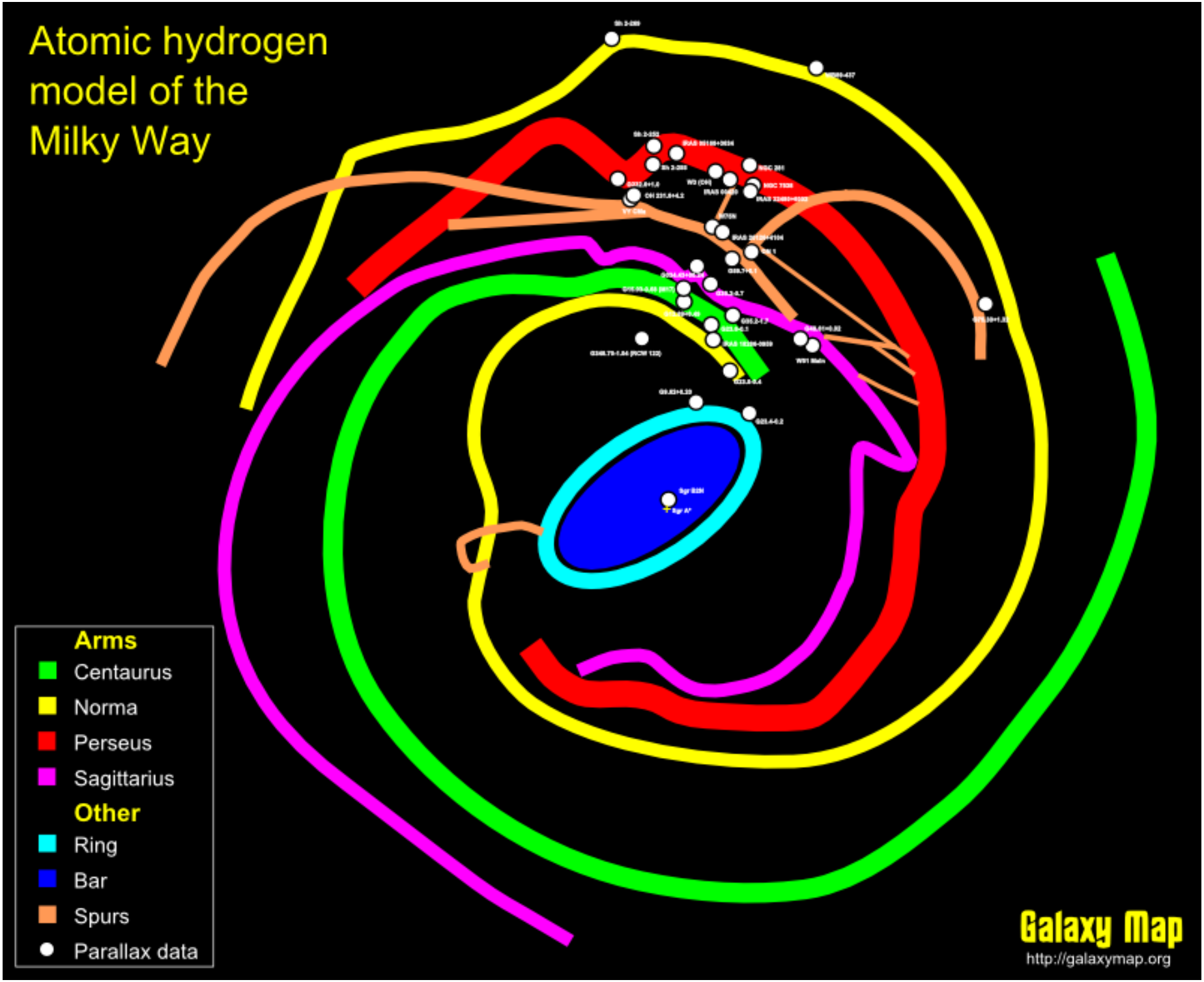


Mapping the spiral structure of the Galaxy

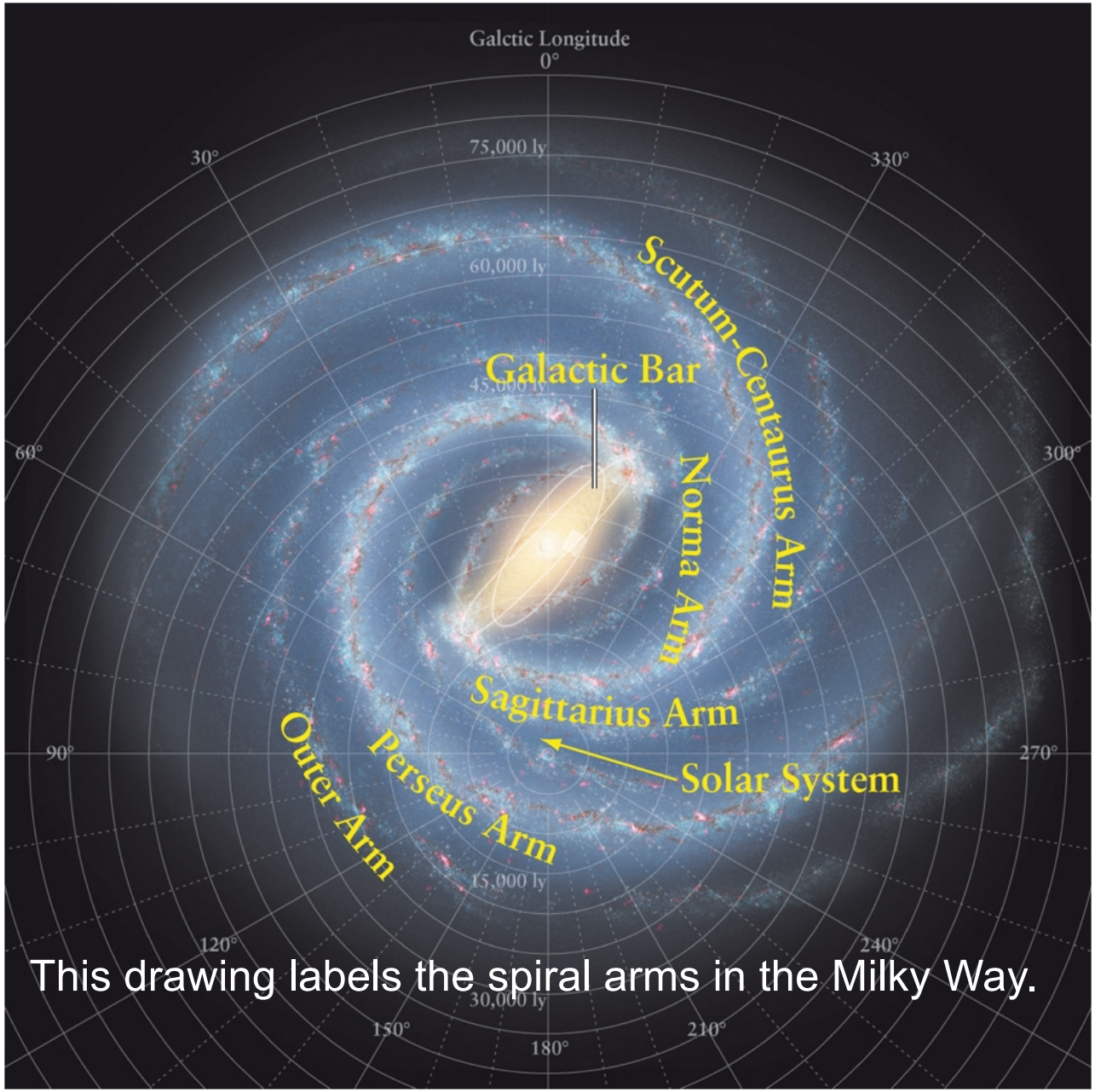


Four clouds all in the same direction. Use doppler shifts to distinguish one cloud from the other. Use the rotation curve to convert the doppler shifts of each cloud to distances from the center of the Galaxy. Do this for other directions to build up a map of the Galaxy strip by strip.

Spiral structure of Galaxy


Atomic hydrogen model of the Milky Way
Arms
Centaurus
Norma
Perseus
Sagittarius
Other
Ring
Bar
Spurs
Parallax data
Galaxy Map
http://galaxymap.org

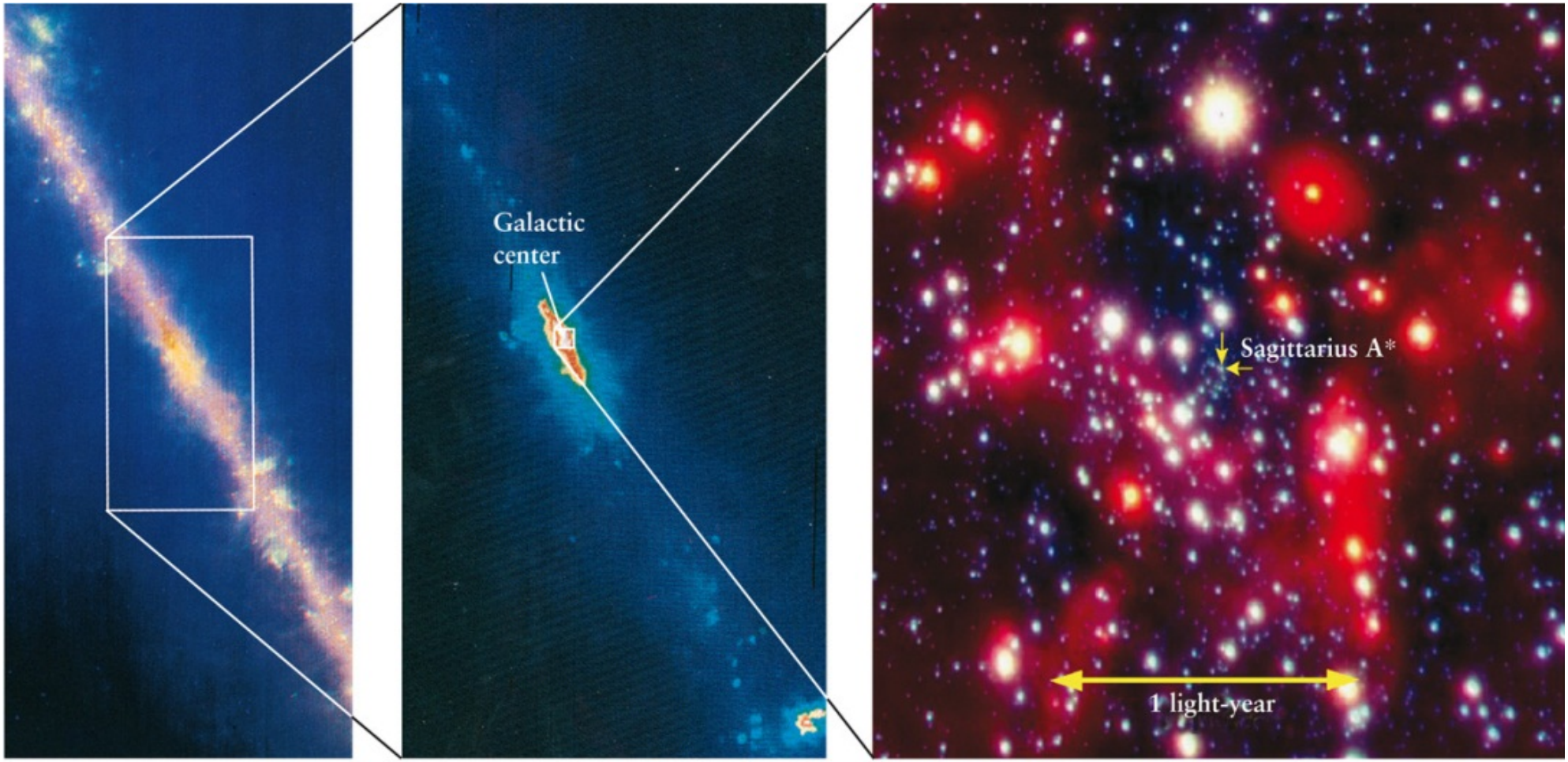
A Map of the Galaxy



This drawing labels the spiral arms in the Milky Way.

b

The Galactic Center

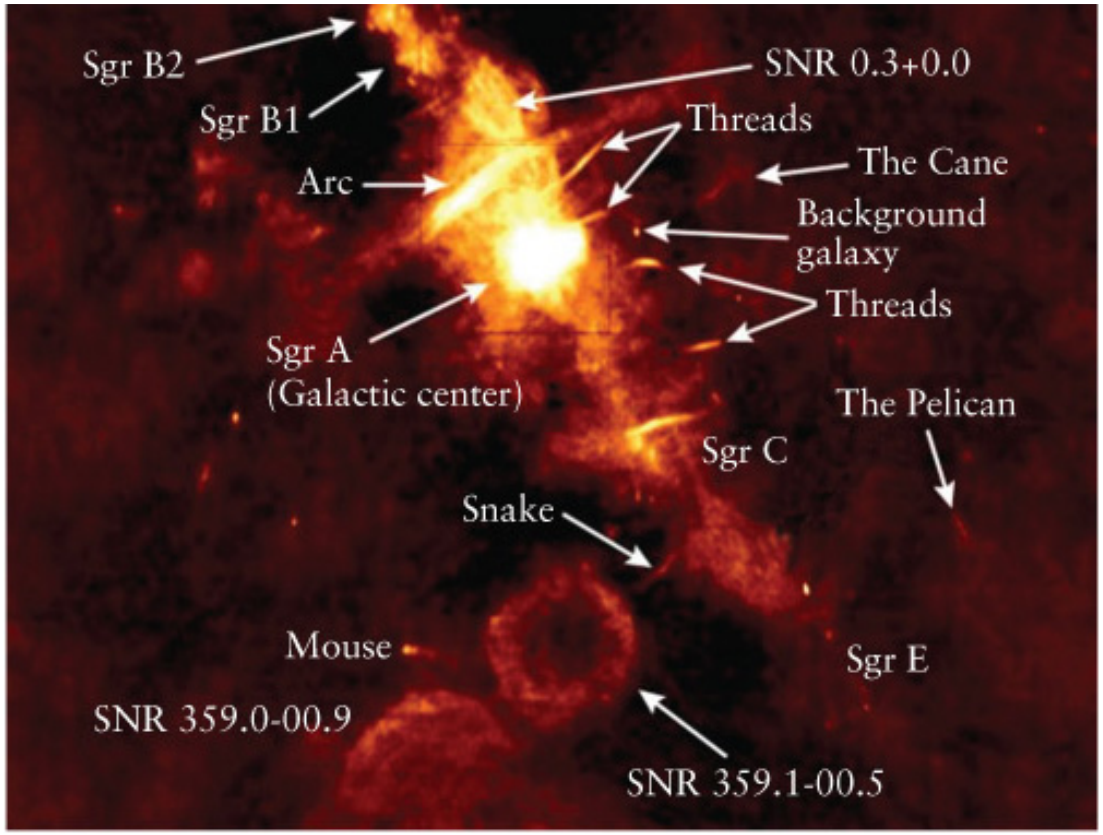


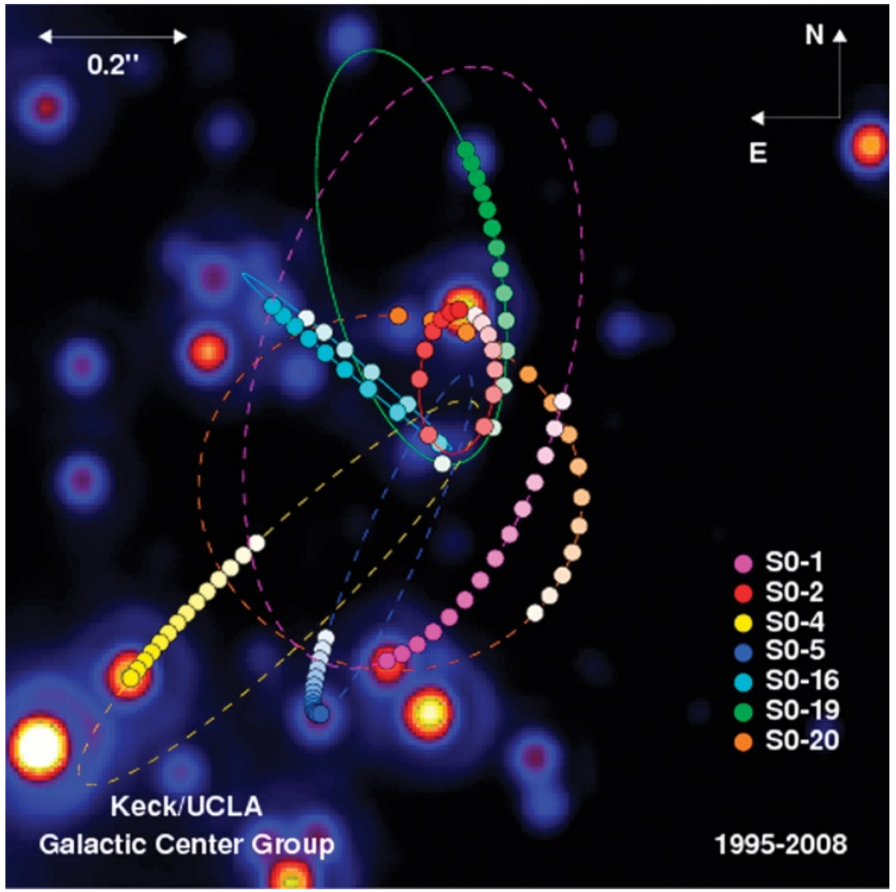
a A wide-angle (50°) infrared view.

b A close-up view shows a more luminous region at the galactic center.

c An extreme close-up view centered on Sagittarius A*, a radio source at the very center of the Milky Way Galaxy, shows hundreds of stars within 1 ly (0.3 pc).

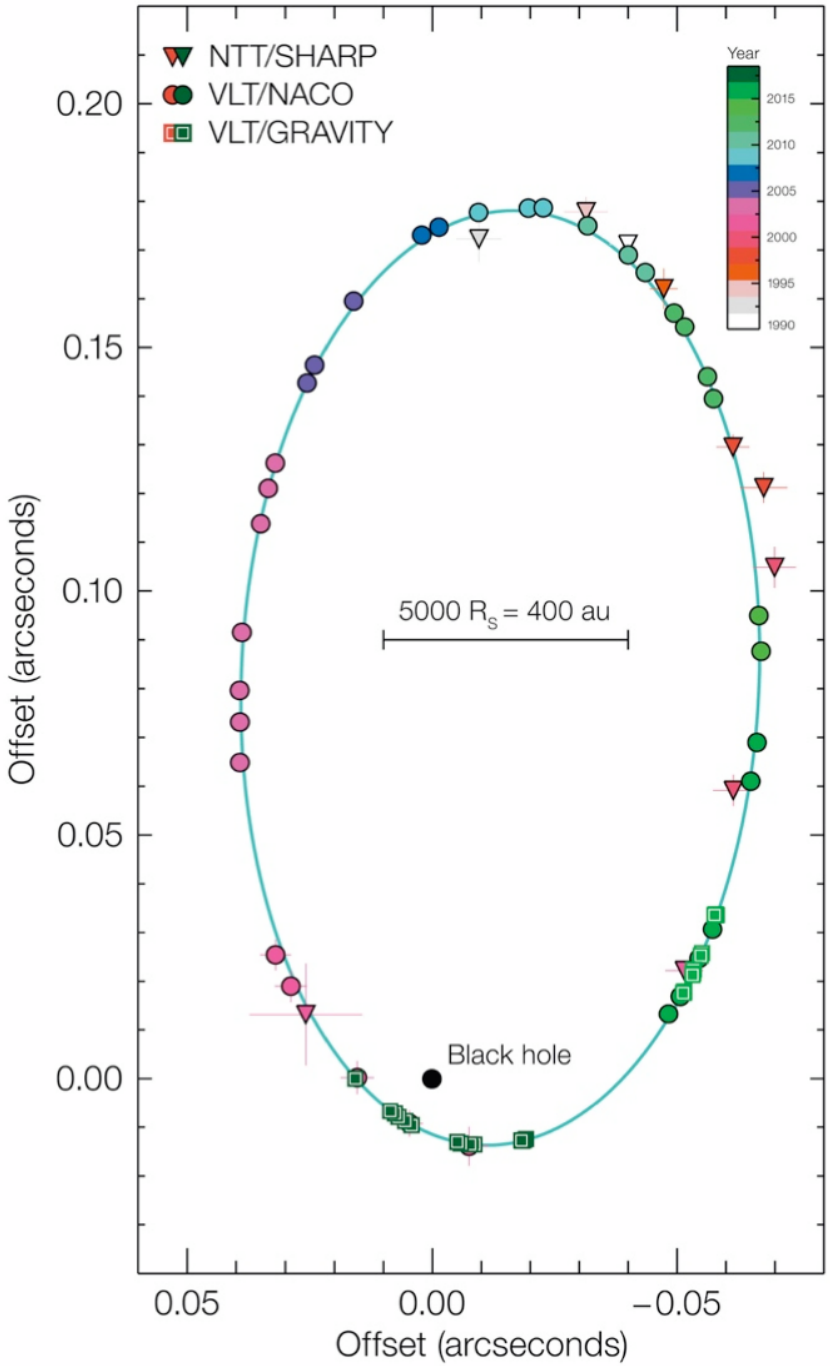
Two Views of the Galactic Nucleus





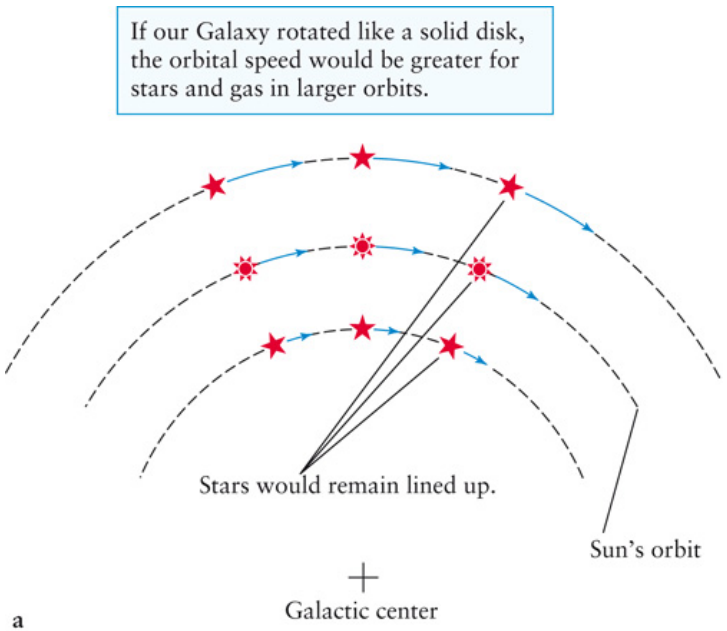
Radio image

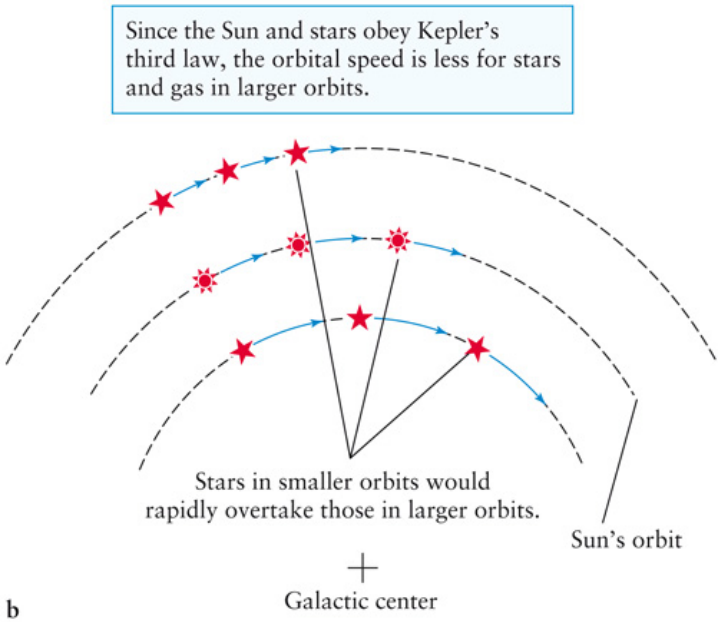
Infrared image
with motions of seven stars



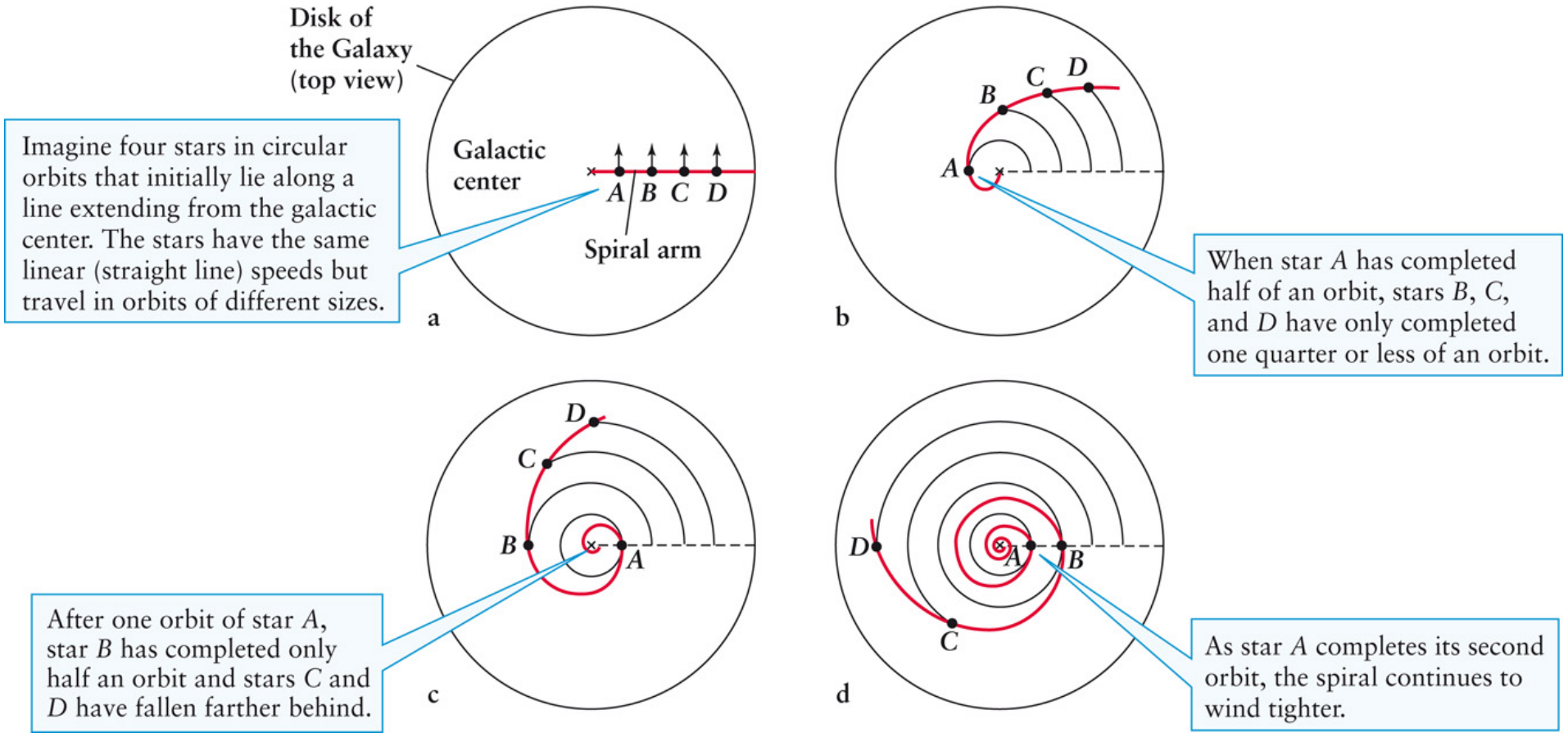
Star S2 orbiting
the black hole
in the Galactic Centre

Differential Rotation of the Galaxy



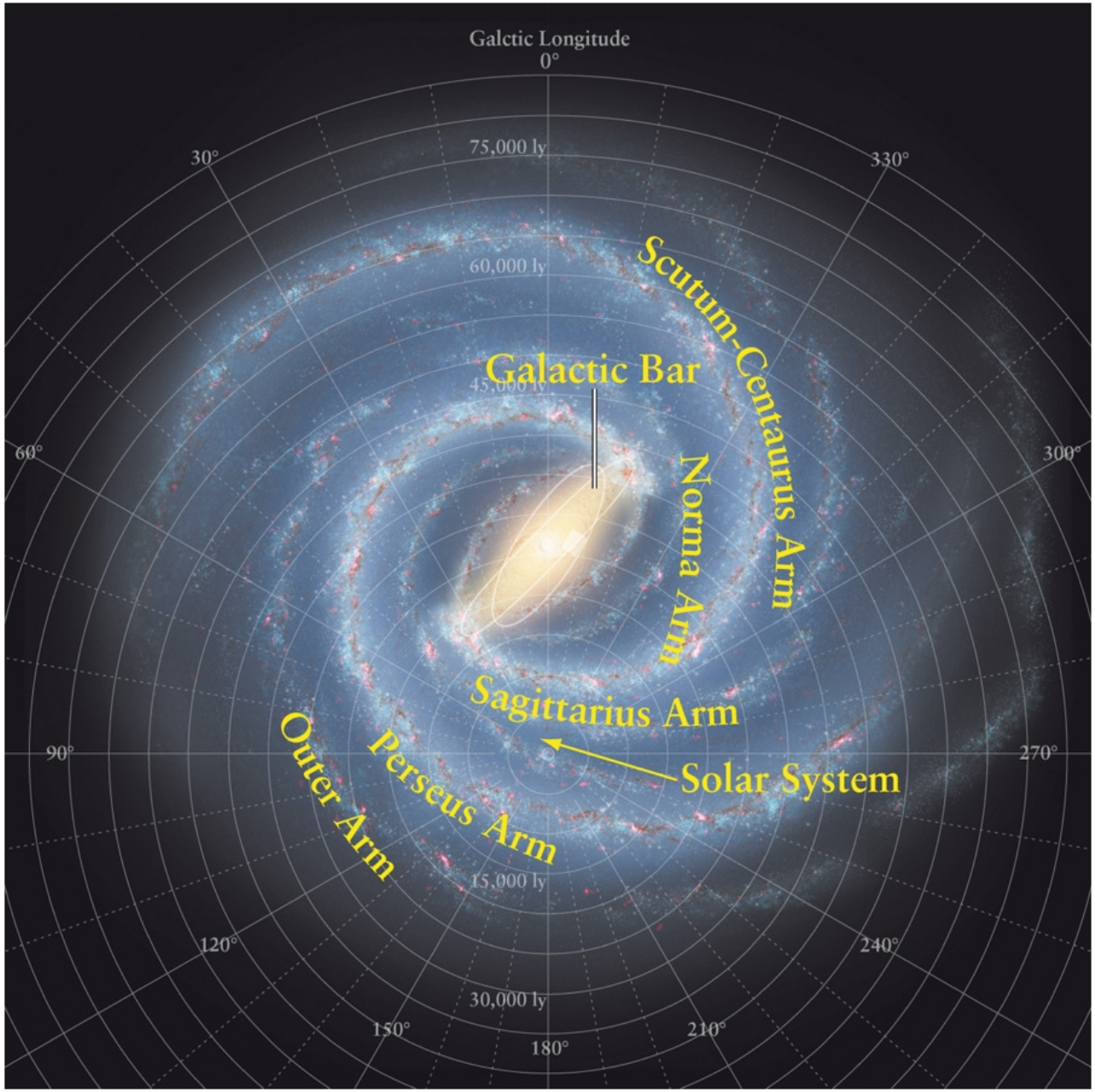


The Winding Dilemma



The rotation curve of the disk stars in our Galaxy indicates that most of them have the same linear (straight-line) speed. If the spirals were due to these stars, tightening would occur. However, such tightening is not observed in our Galaxy or in other galaxies. ➔ density wave

The spiral structure is due to density waves



b

Density wave in traffic

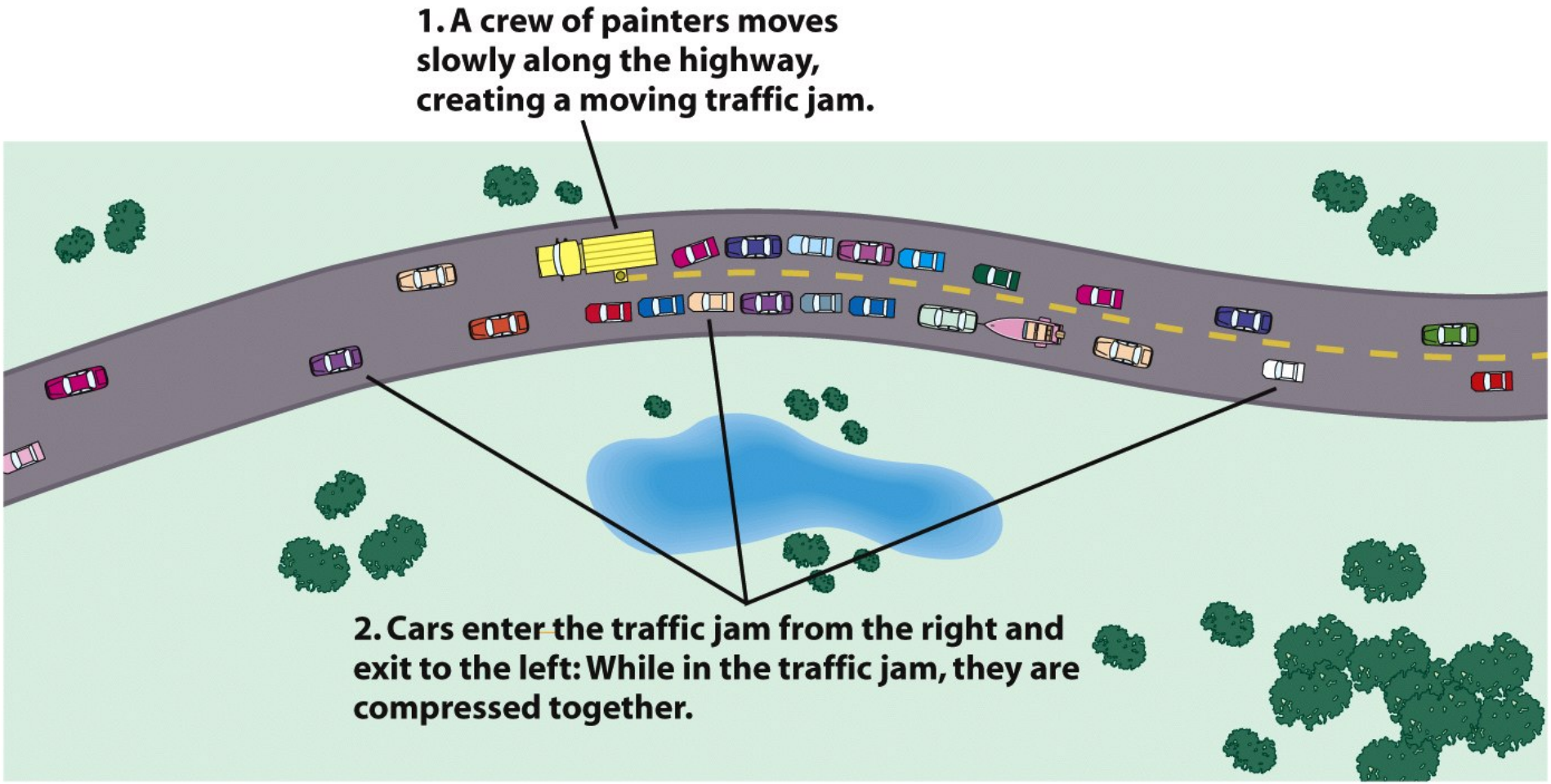
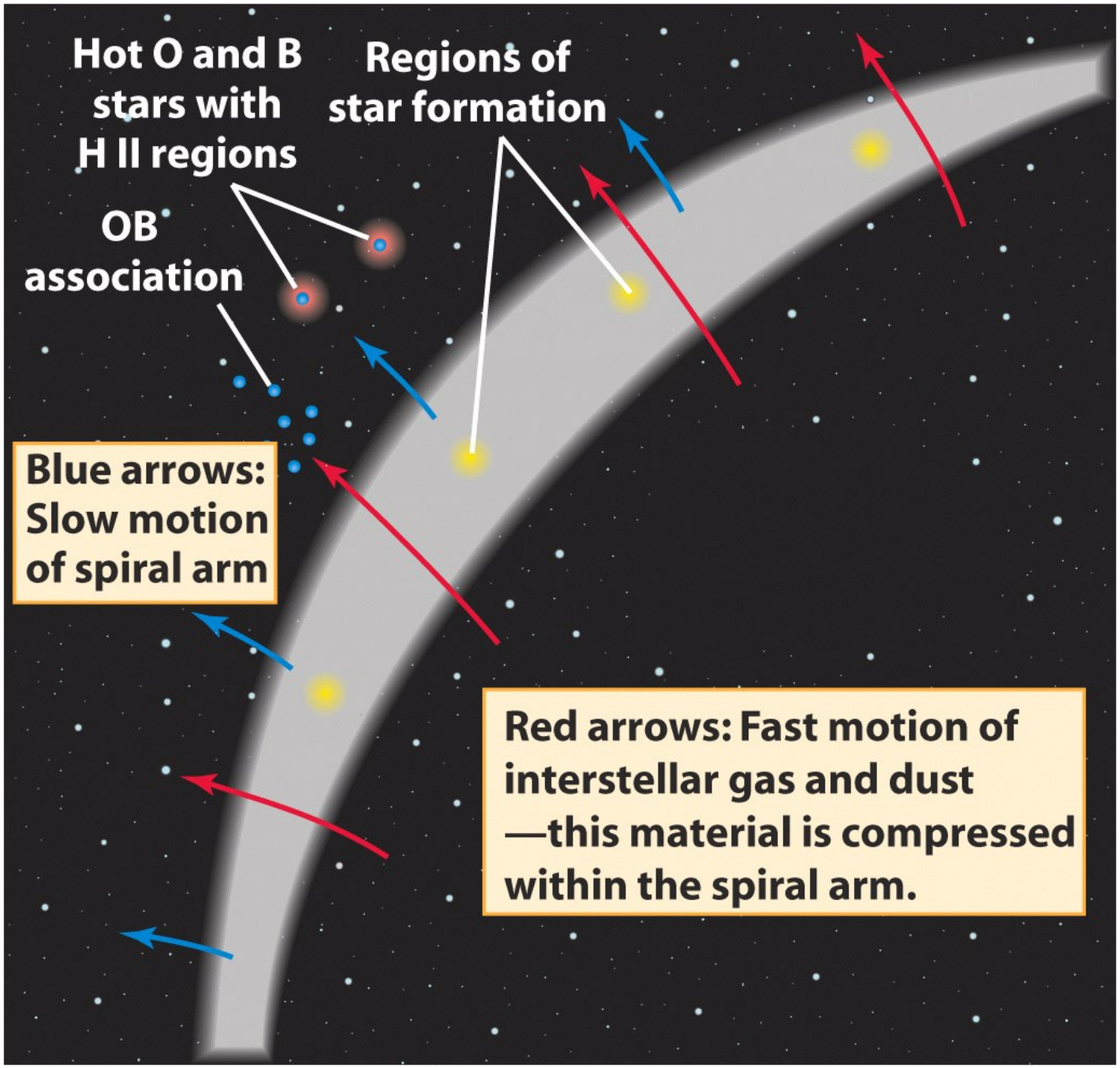
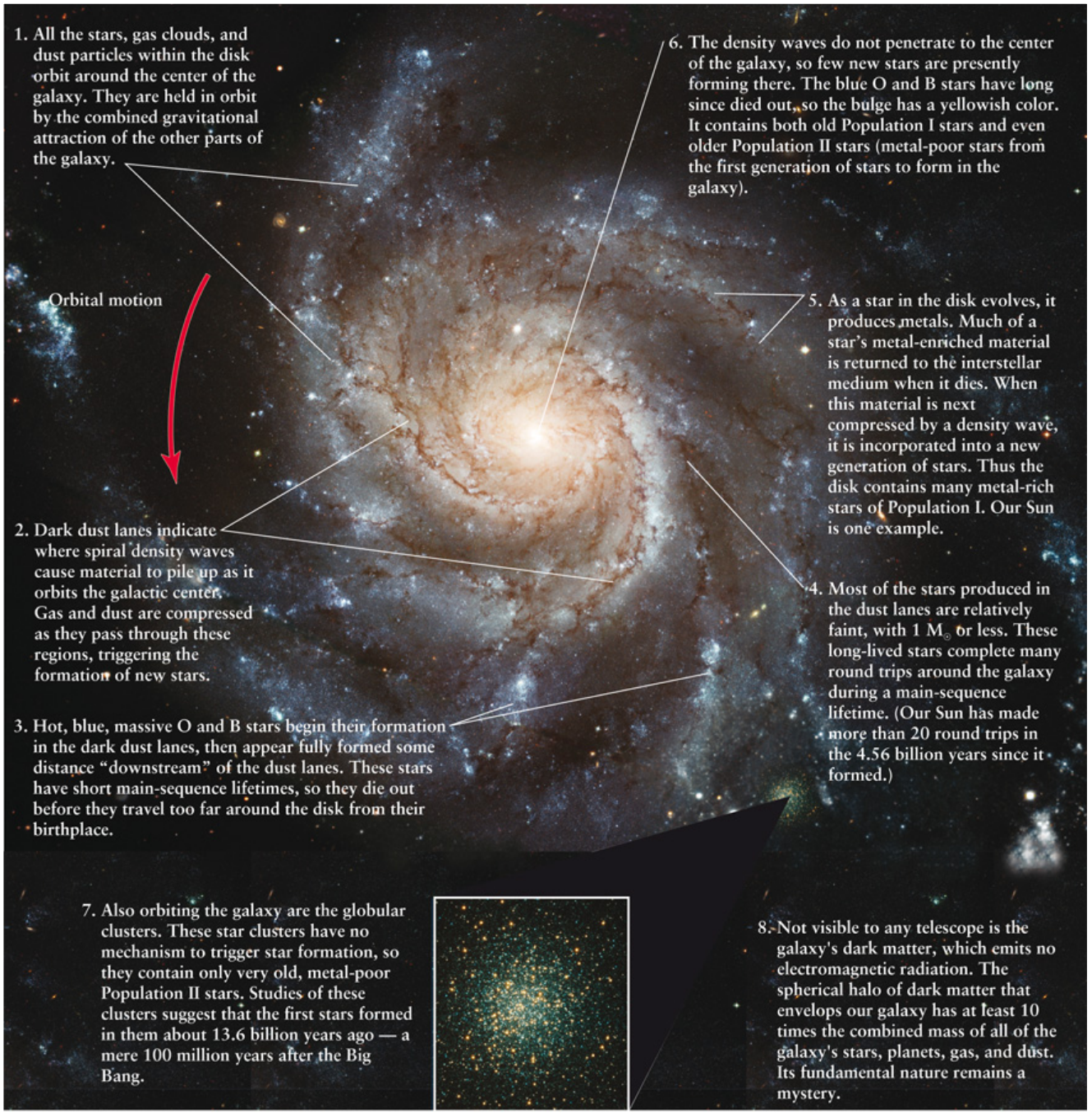


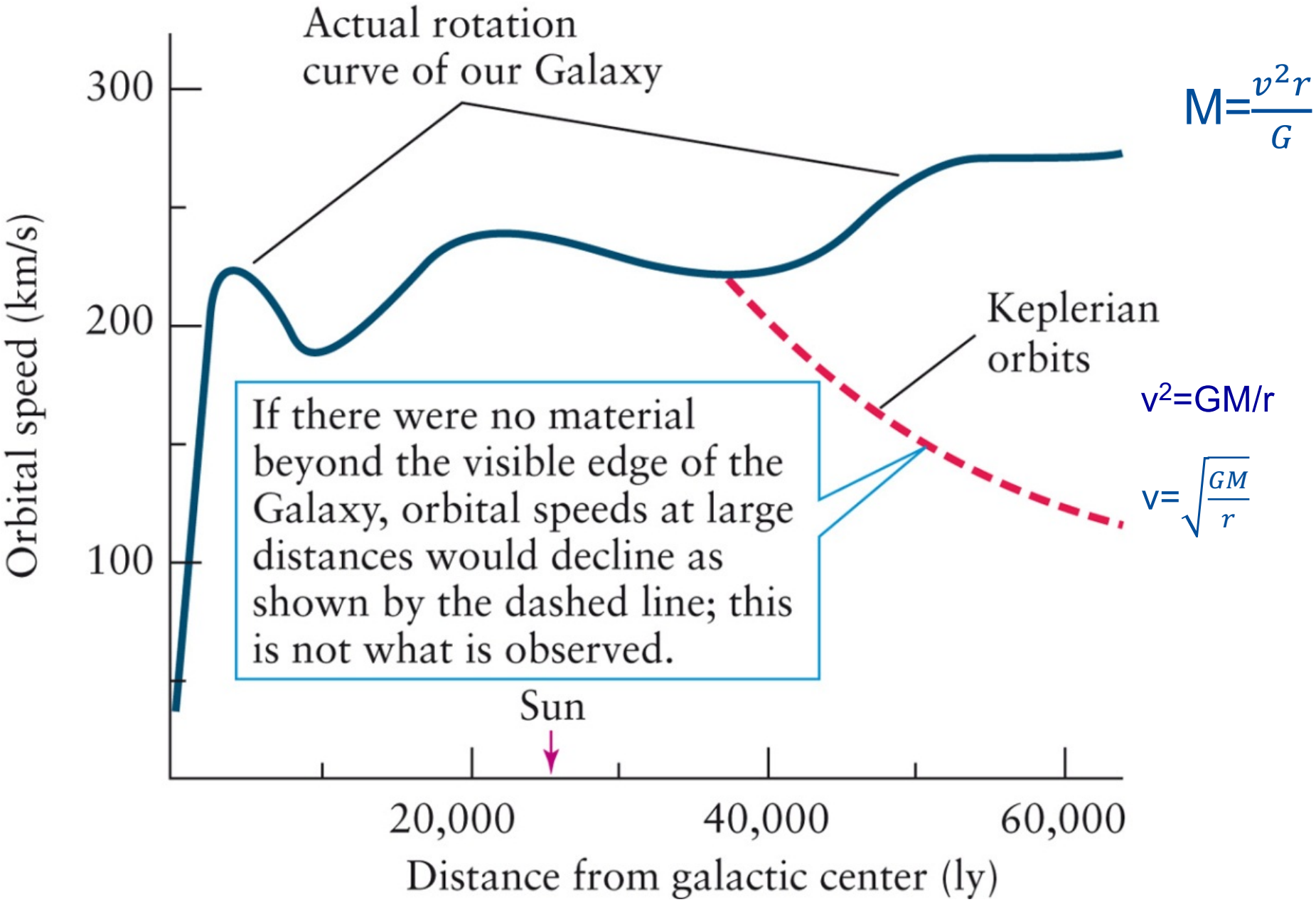
Figure 23-22
Universe, Eighth Edition


Hot O and B stars with H II regions
Regions of star formation
OB association
Blue arrows: Slow motion of spiral arm
Red arrows: Fast motion of interstellar gas and dust —this material is compressed within the spiral arm.

Dynamics of a Grand-Design Spiral Galaxy



The Galaxy's Rotation Curve

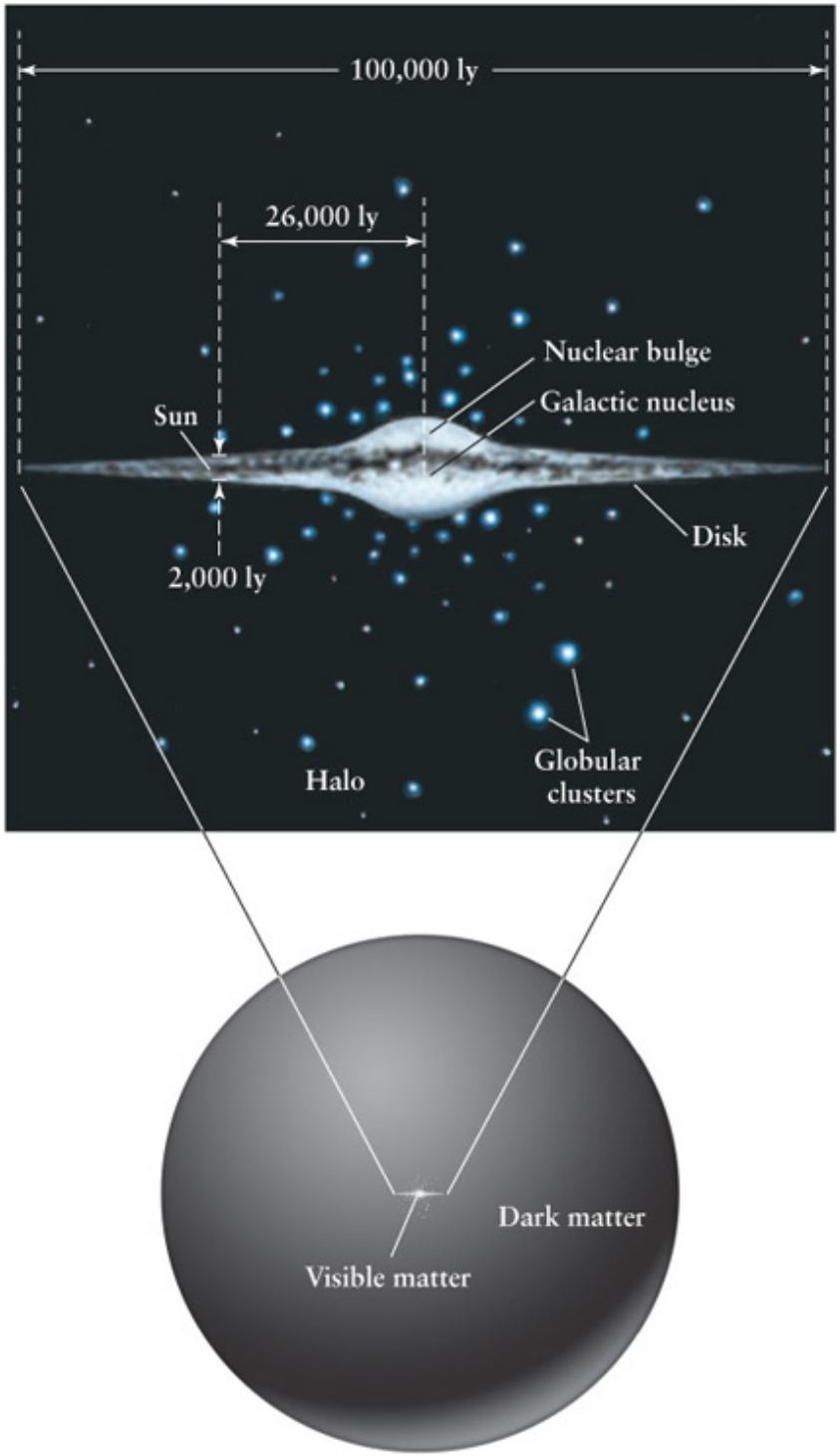


$M=\frac{v^2 r}{G}$

$v^2=GM/r$

$v=\sqrt{\frac{GM}{r}}$

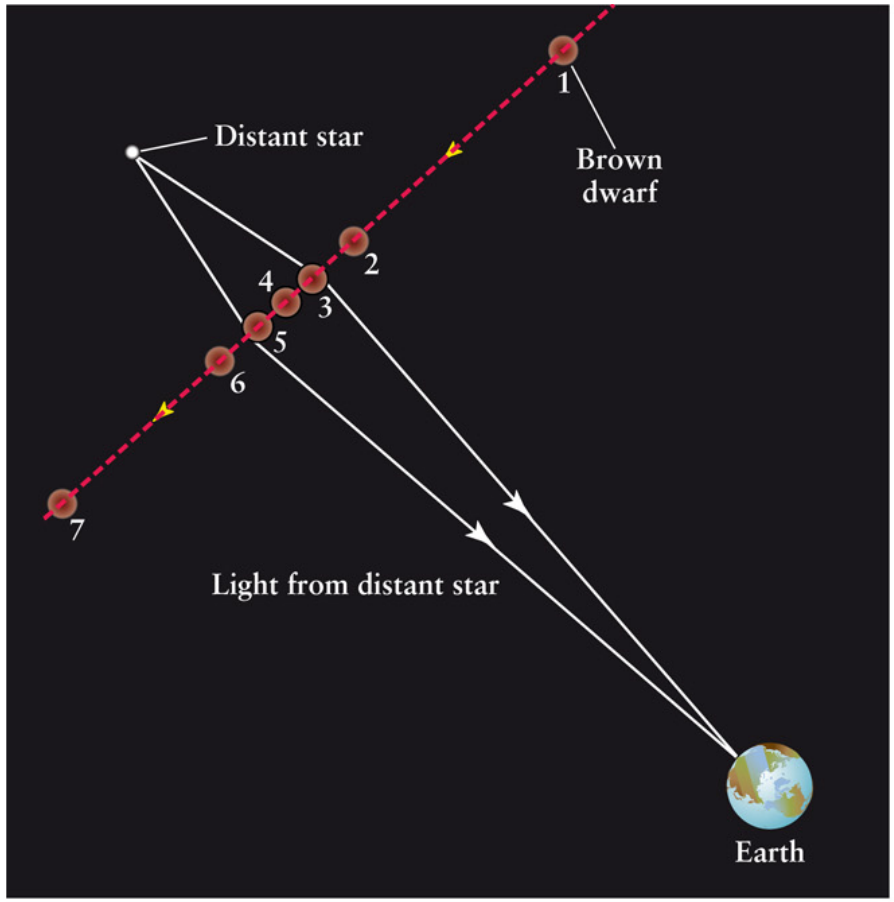
Our Galaxy



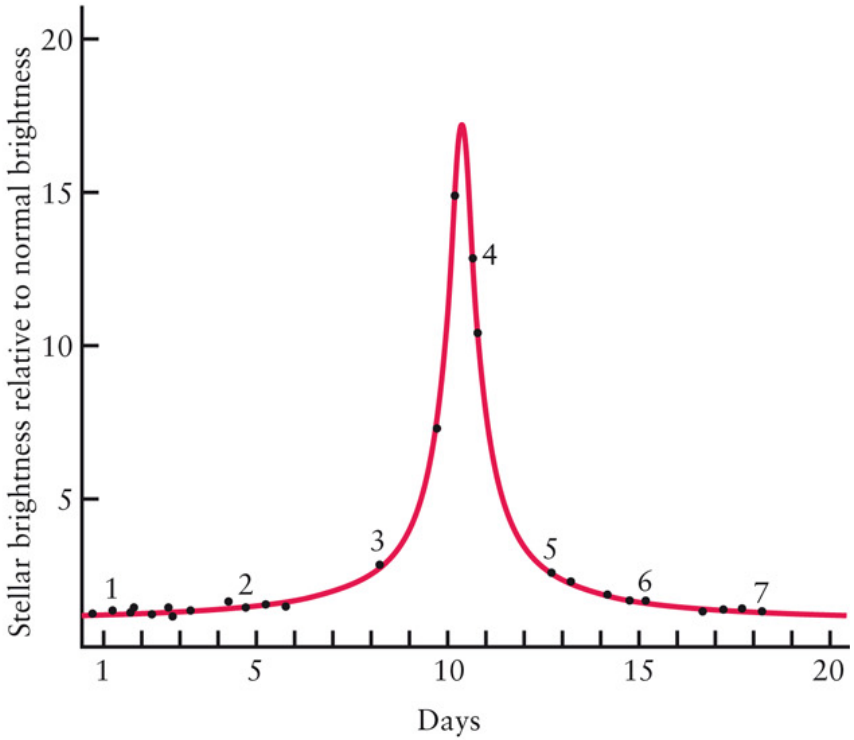
Most of the Galaxy is Dark matter

Together with dark matter the mass of the galaxy is 1 Trill M_{sol}

Microlensing by Dark Matter in the Galactic Halo



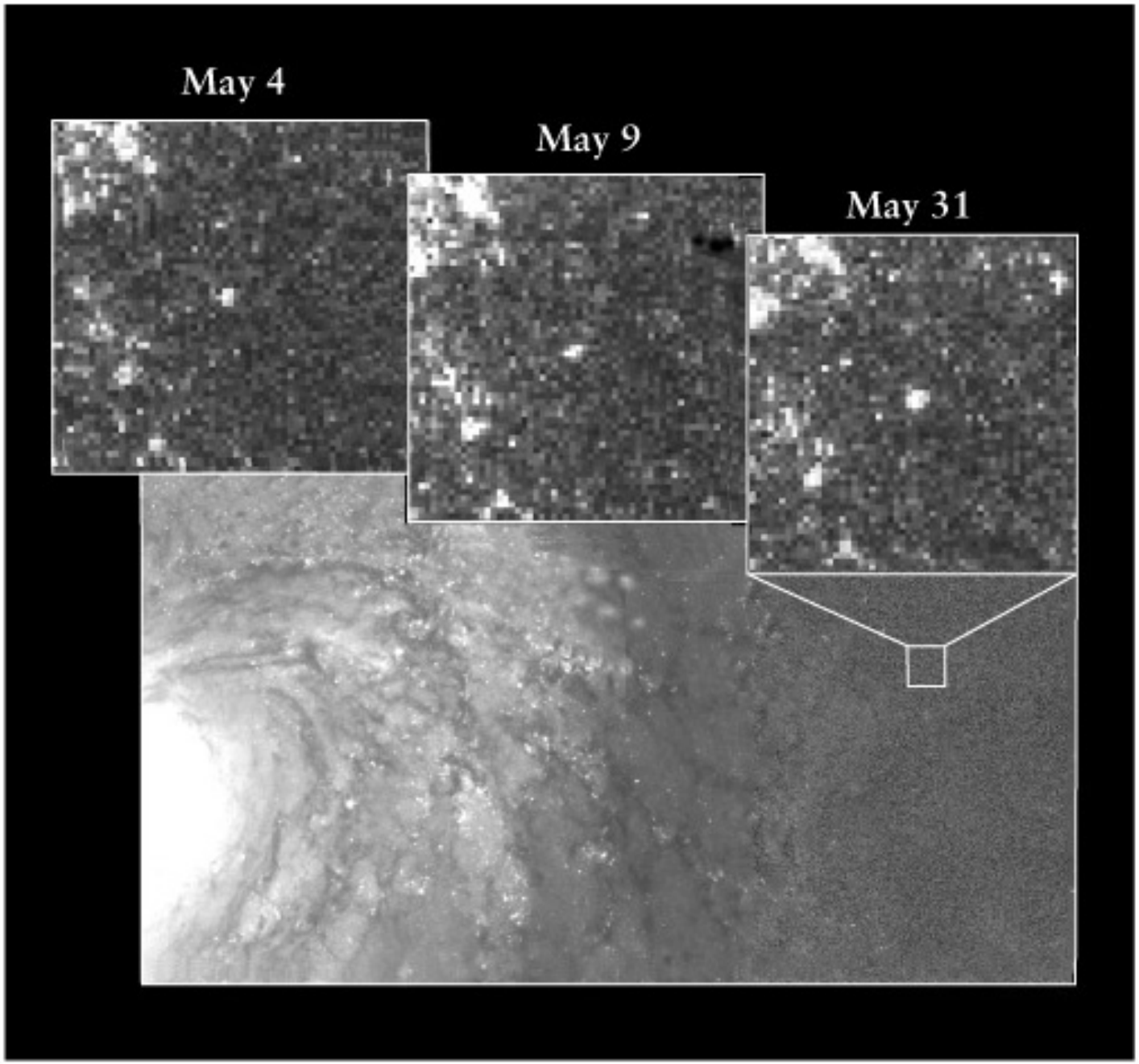
a



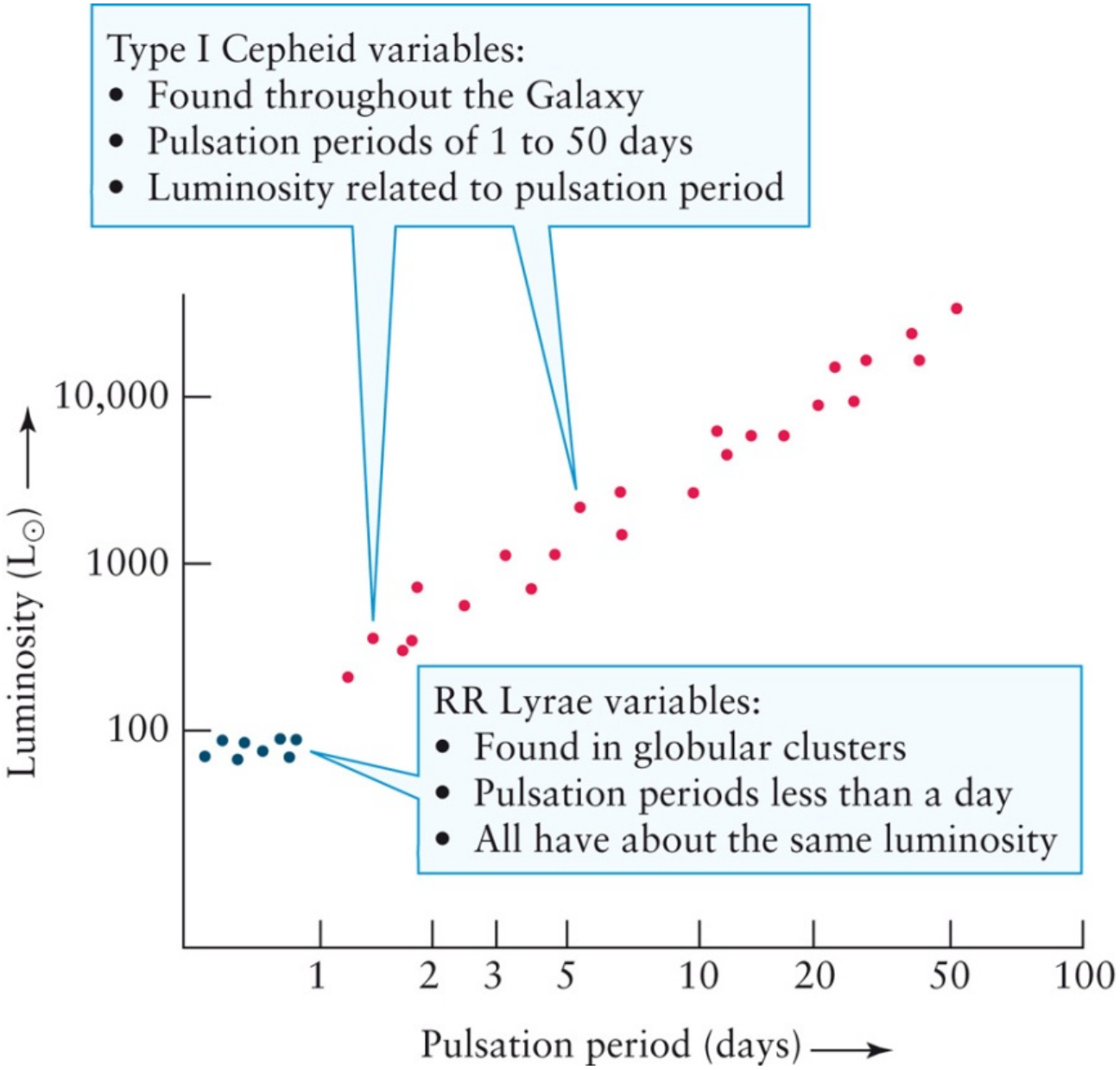
b


Andromeda nebula

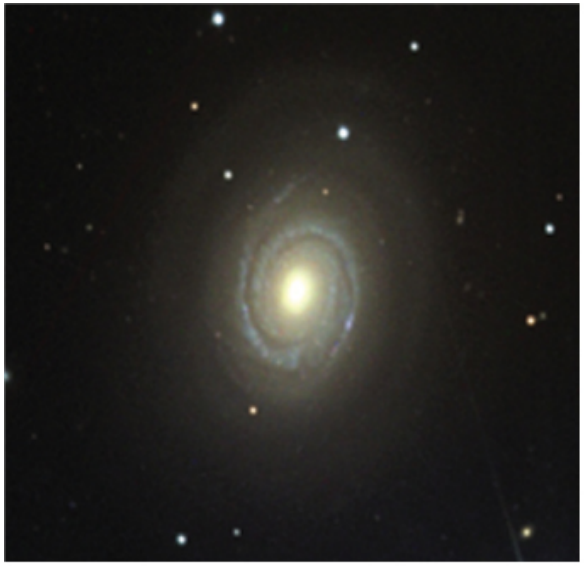
A Cepheid Variable Star in Galaxy M100



The Period-Luminosity Relation

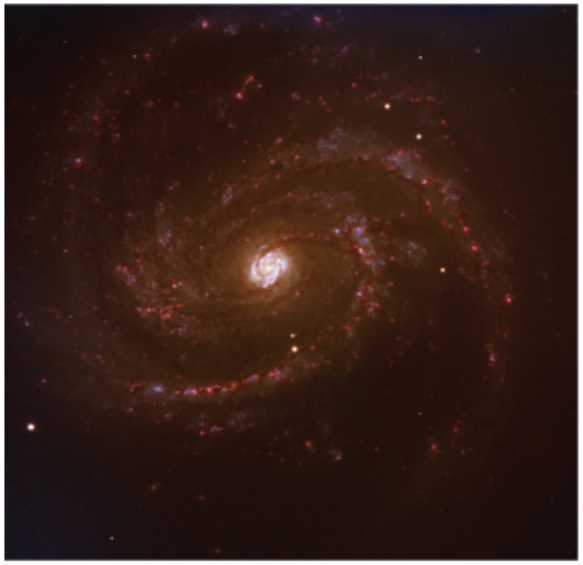


Spiral Galaxies



a Sa (NGC 1357) R I V U X G

c Sb (M81) R I V U X G



e Sc (NGC 4321) R I V U X G

b M104; an Sa galaxy R I V U X G

d NGC 891: an Sb galaxy R I V U X G

f NGC 5907: an Sc galaxy R I V U X G

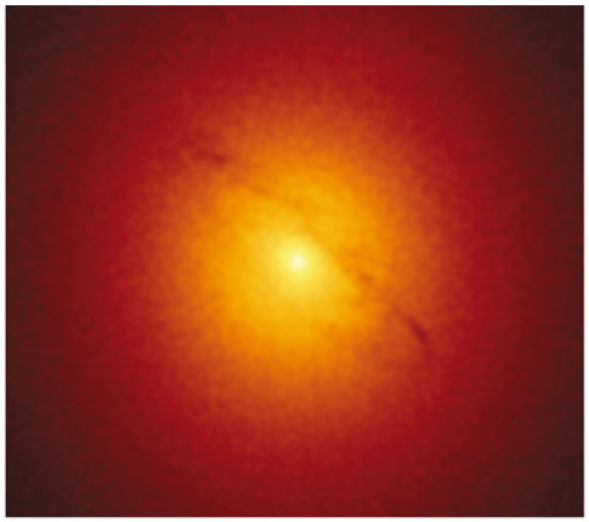
Barred Spiral Galaxies

a M58: an SBa galaxy

b M83: an SBb galaxy

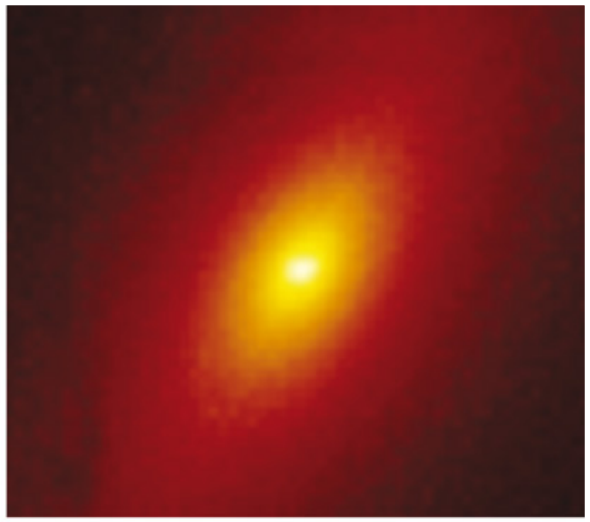
c NGC 1365: an SBc galaxy

Elliptical Galaxies



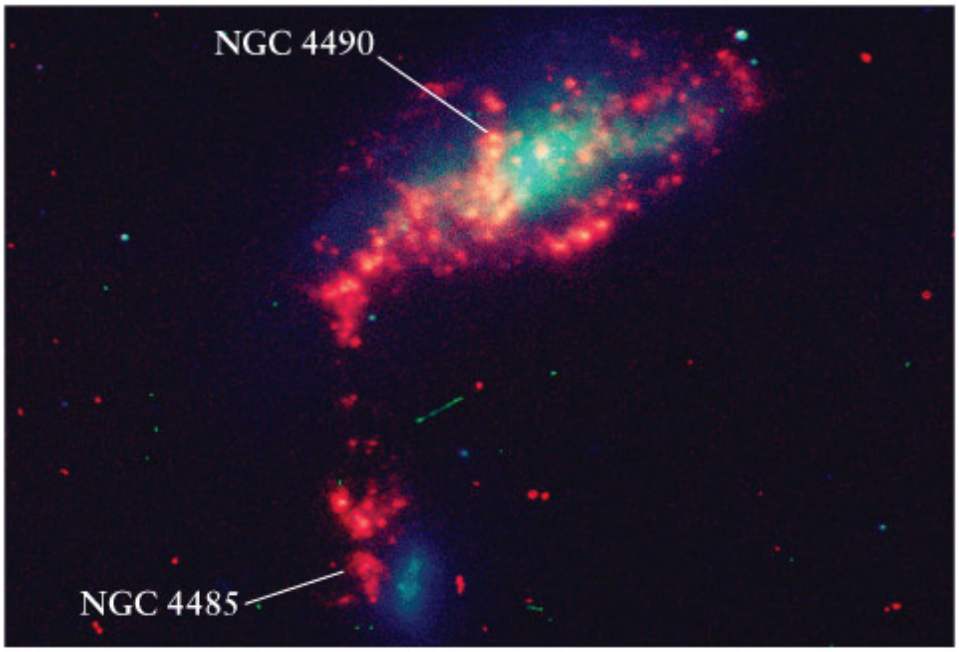
a E0 (M105)

b E3 (NGC 4406)



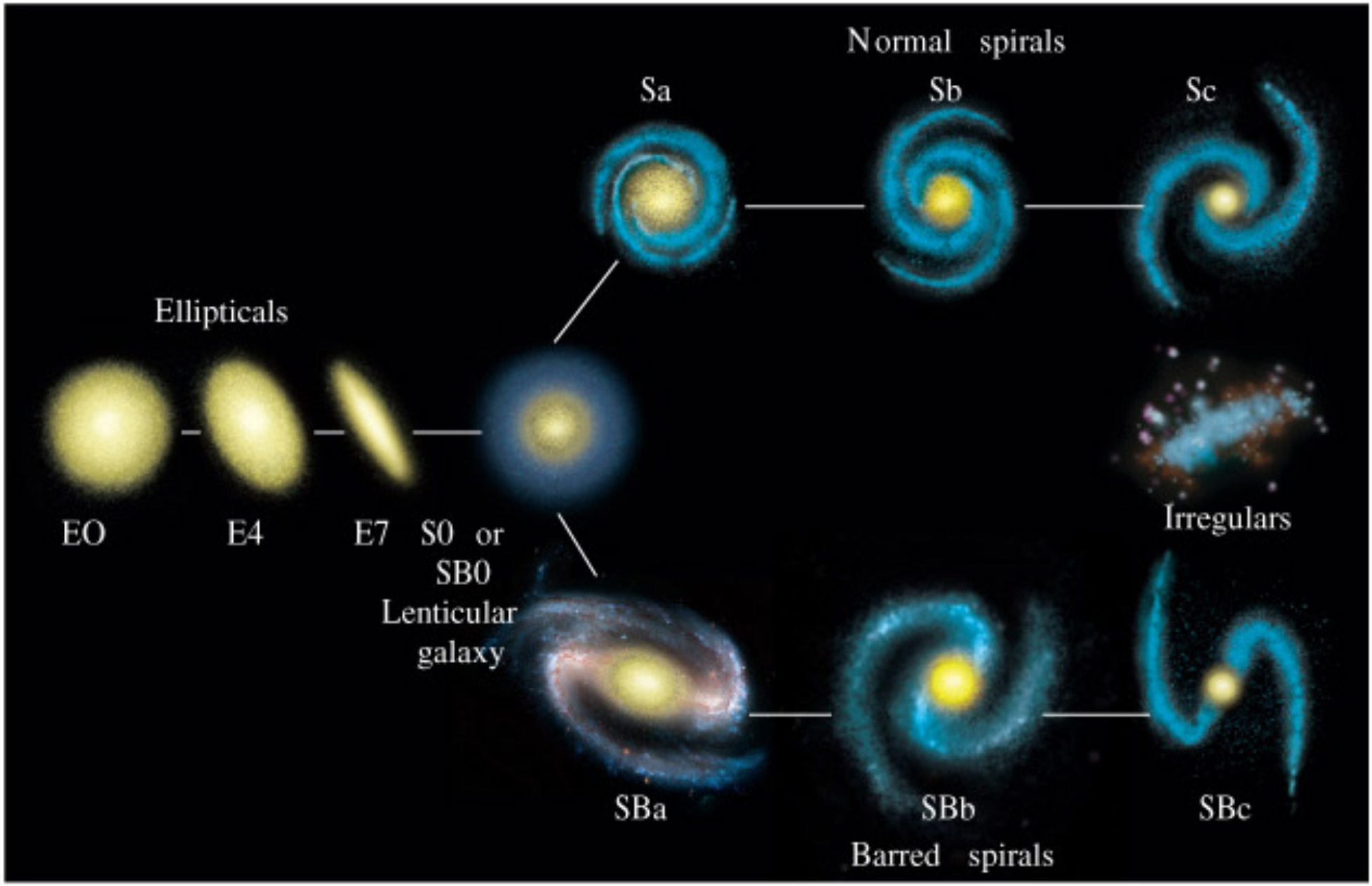
c E6 (NGC 3377)

Irregular Galaxies

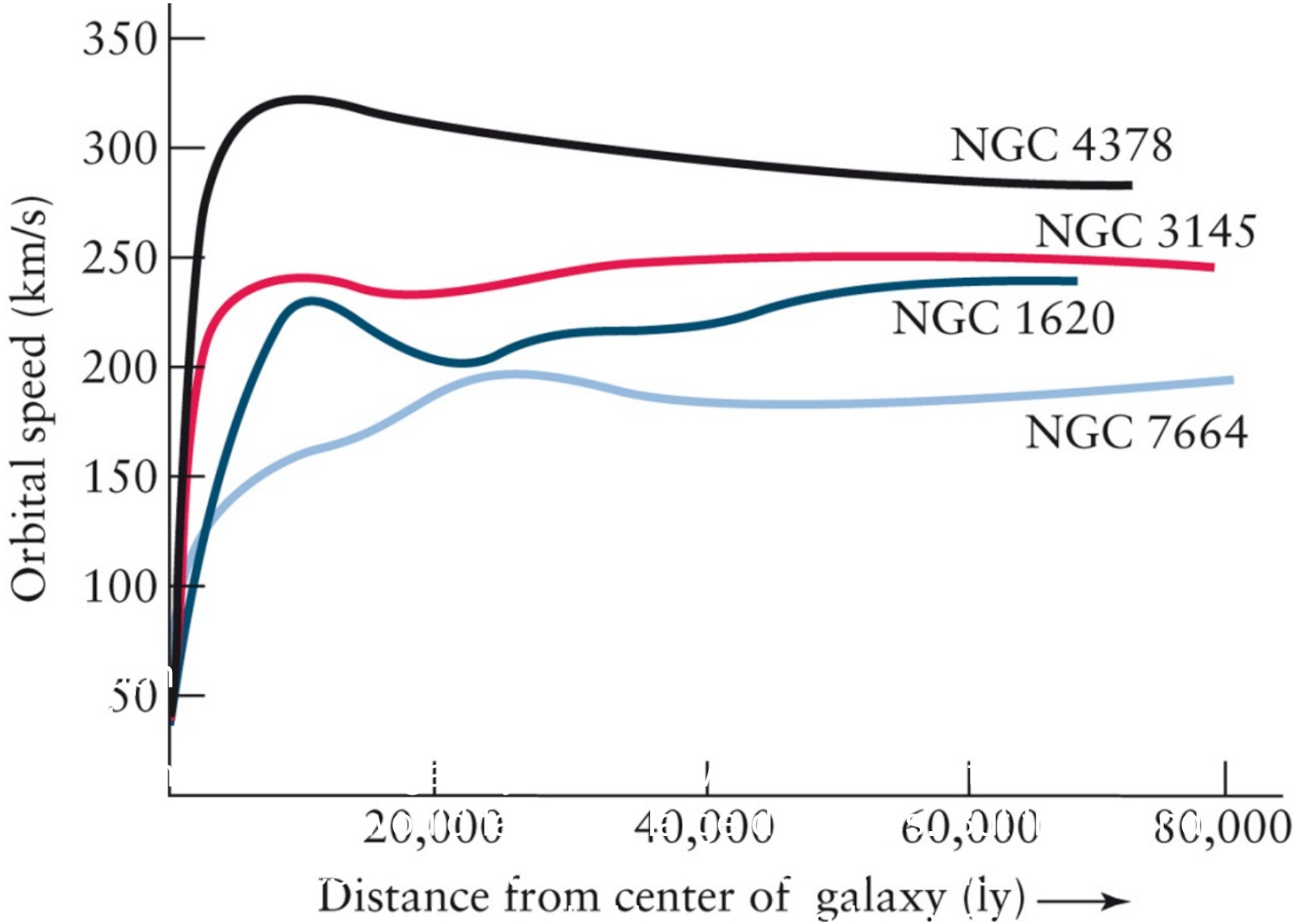


b NGC 4485 (Irr II) and NGC 4490 (Sc) galaxies

Hubble's Tuning Fork Diagram



The Rotation Curves of Four Spiral Galaxies



Dark Matter everywhere

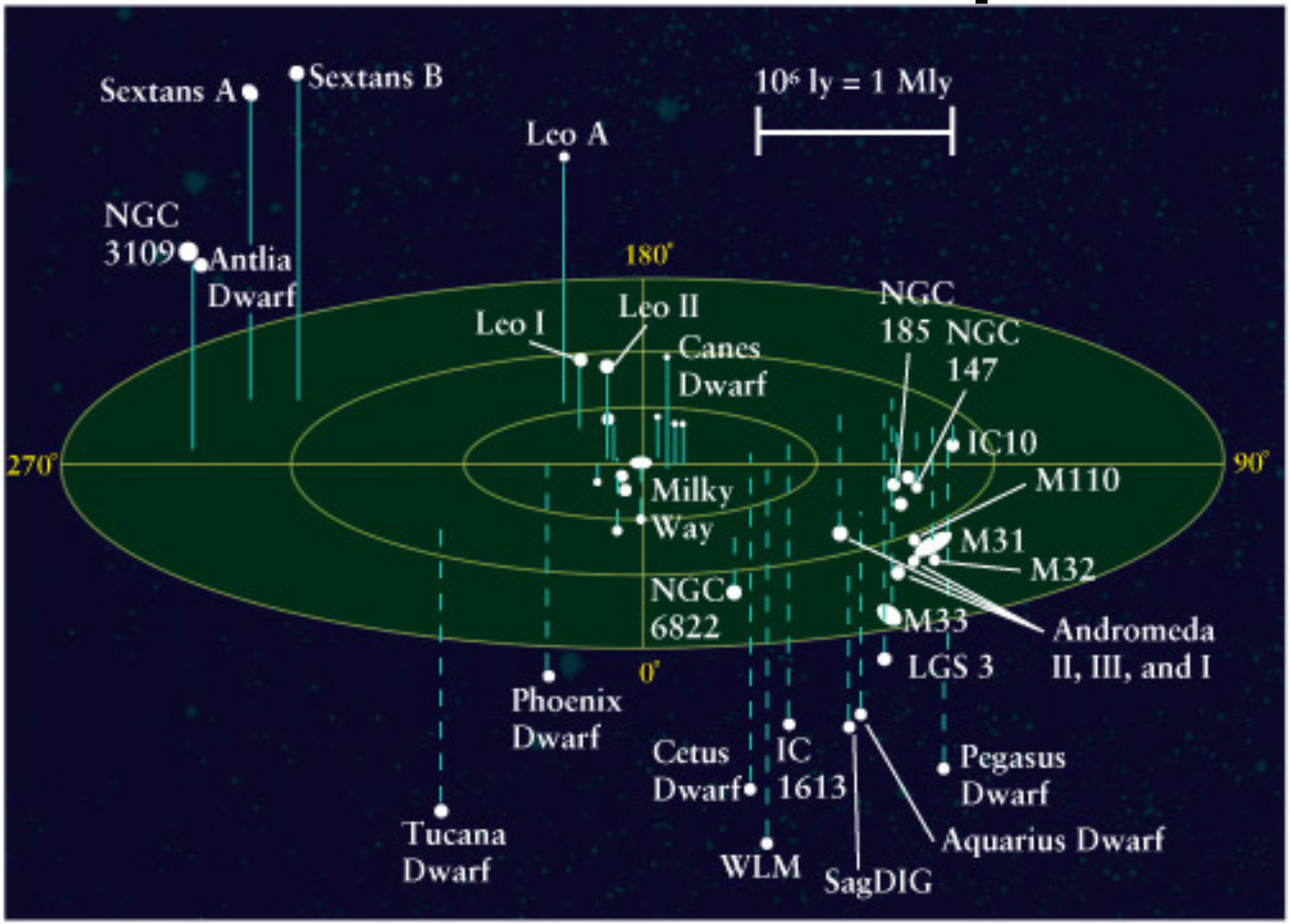
TABLE 12-1 Some Properties of Galaxies

	Spiral (S) and barred spiral (SB) galaxies	Elliptical galaxies (E)	Irregular galaxies (Irr)
Mass ($M_\odot$)	10^9 to 4×10^{11}	10^7 to 10^{13}	10^8 to 3×10^{10}
Luminosity ($L_\odot$)	10^8 to 2×10^{10}	3×10^5 to 10^{11}	10^7 to 10^9
Diameter (ly)	1.6×10^4 to 8×10^5	3×10^3 to 6.5×10^5	3×10^3 to 3×10^4
Stellar populations	Disk: young Population I central bulge; halo: Population II and old Population I	Population II and old Population I	Mostly Population I
Percentage of observed galaxies	77%	*20%	3%

*This percentage does not include dwarf elliptical galaxies that are as yet too dim and distant to detect. Hence, the actual percentage of galaxies that are ellipticals is likely to be higher than shown here.

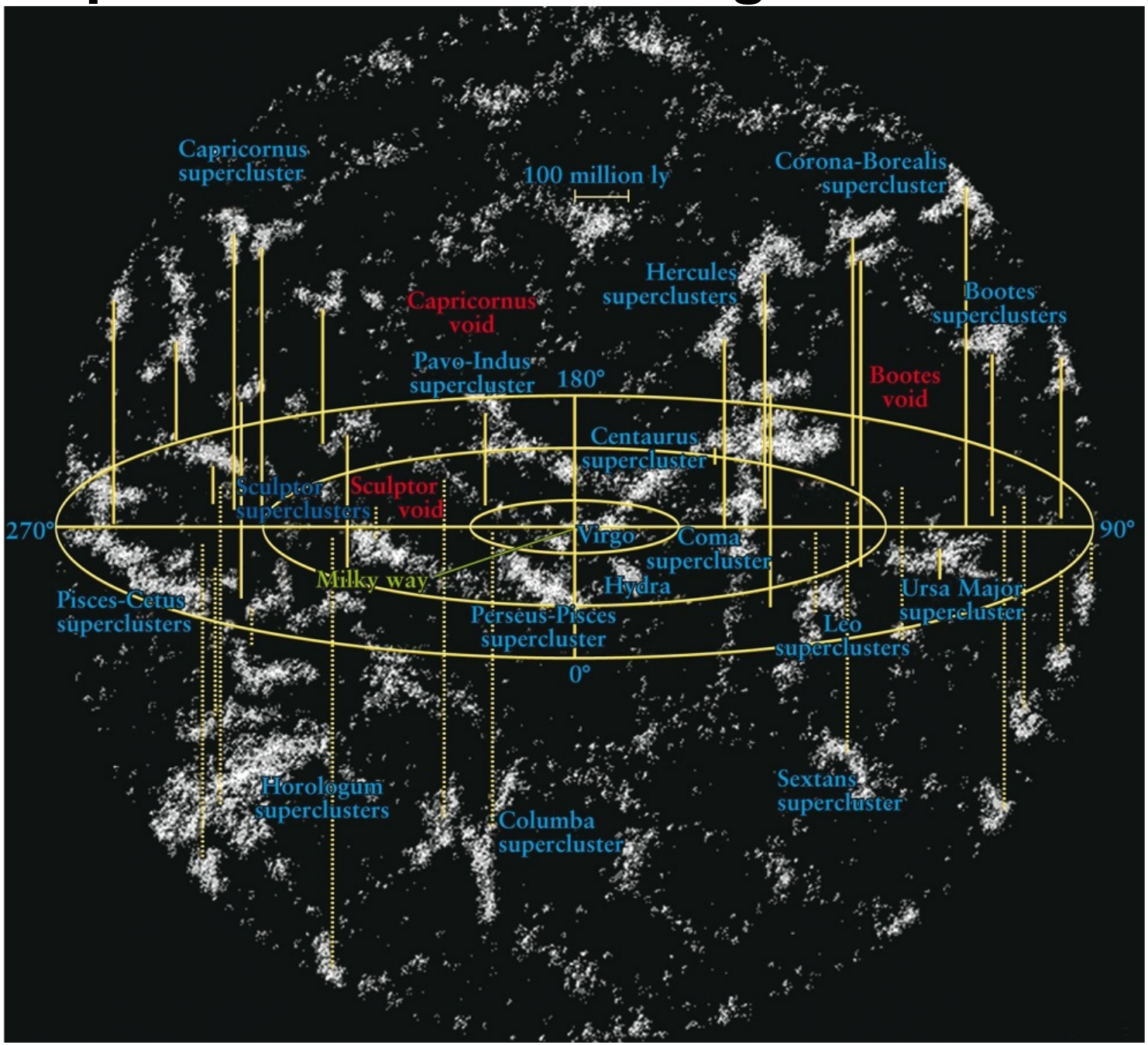
Population I: metal-rich stars
Population II: metal-poor stars

The Local Group



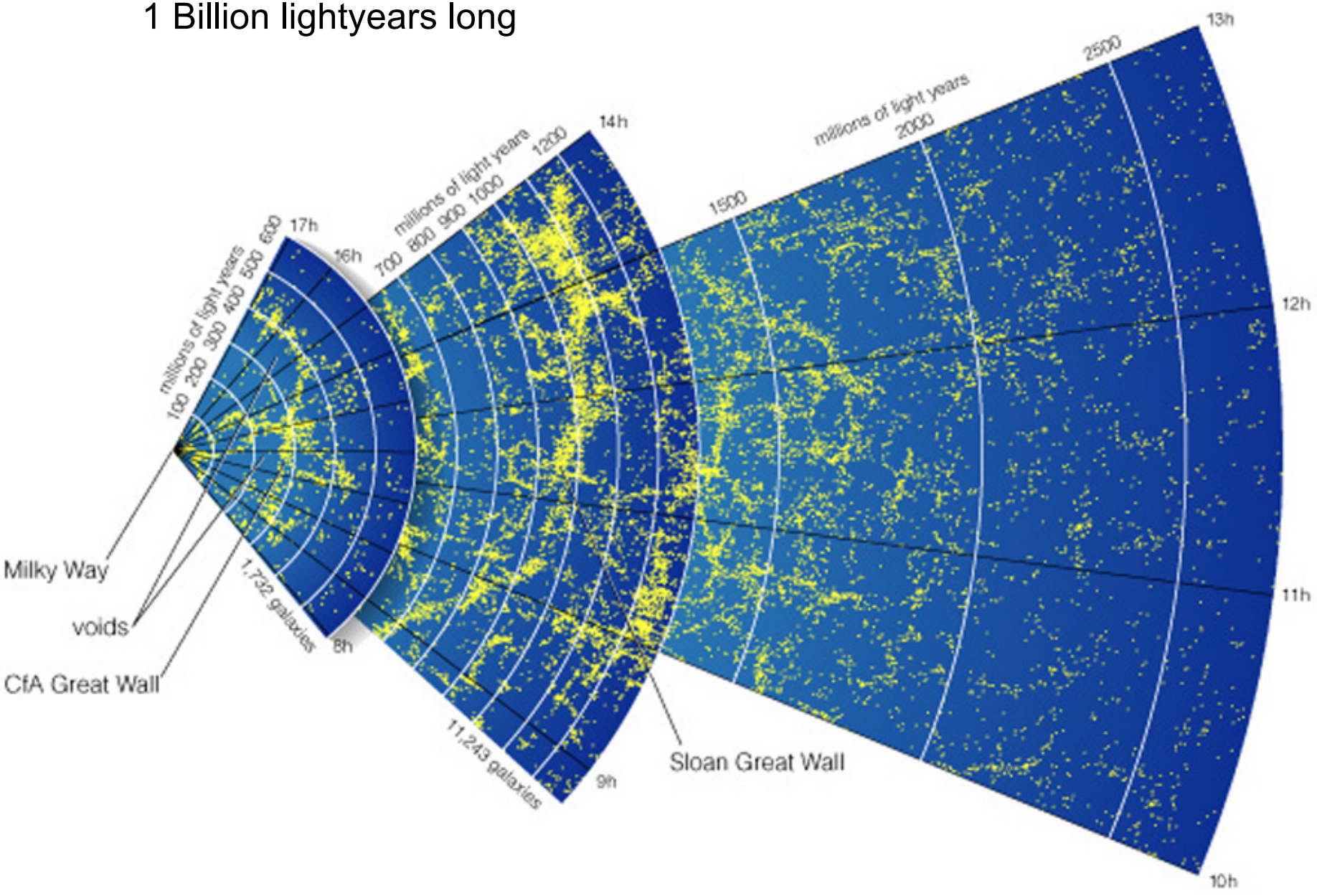
A Cluster of Galaxies

Superclusters in Our Neighborhood

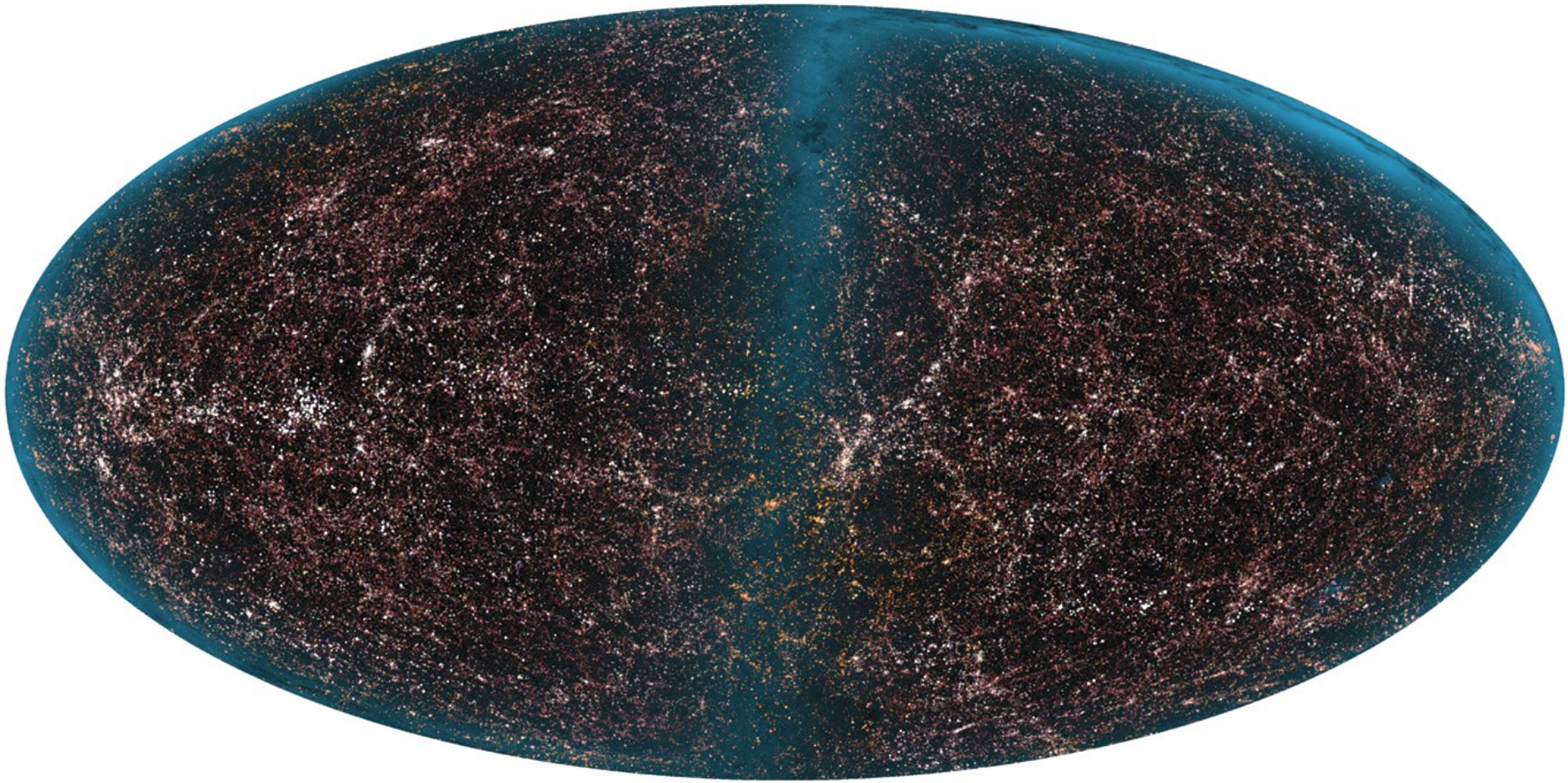


The largest structure in the universe:

1 Billion lightyears long

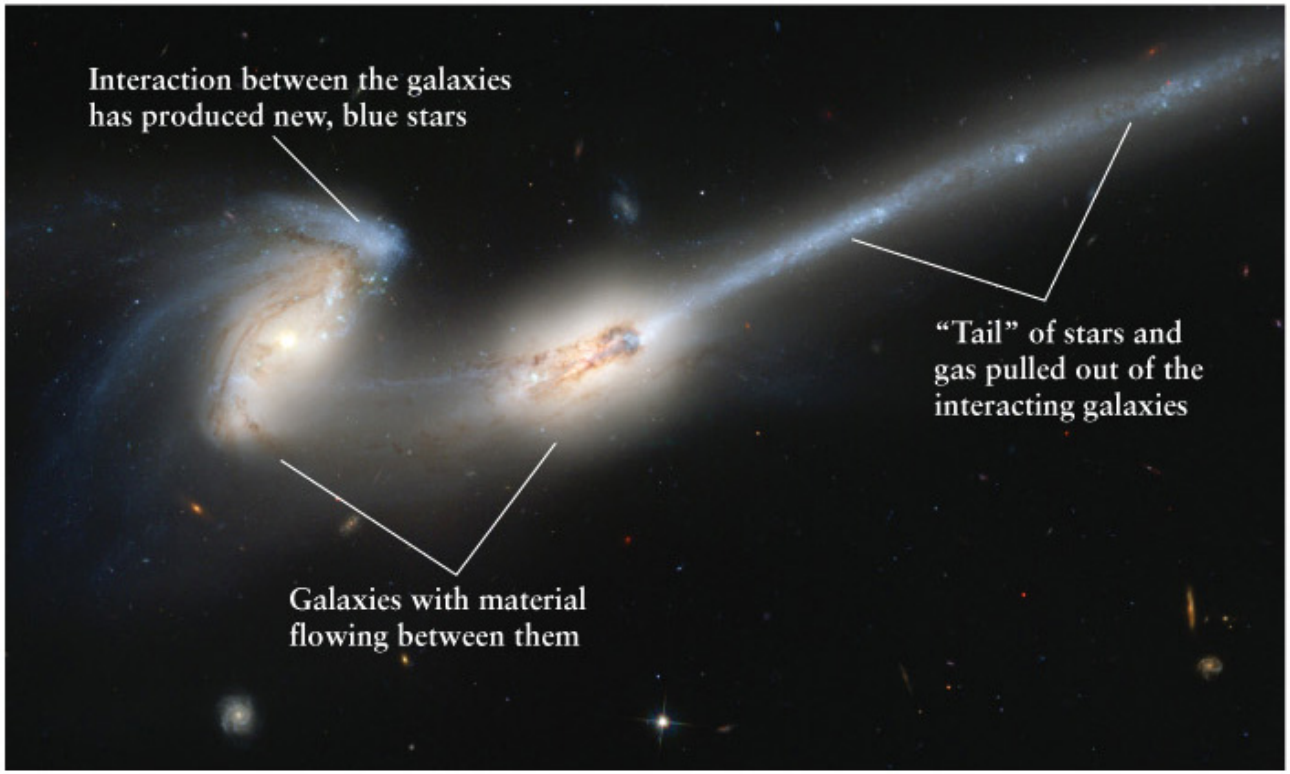


Structure in the nearby universe
1.6 million galaxies



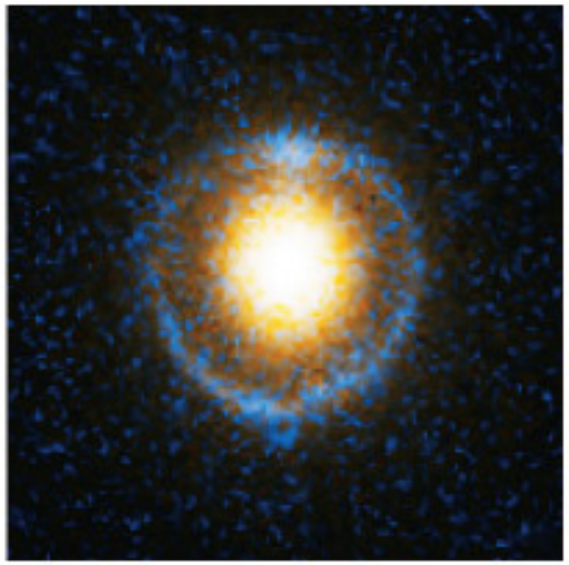

Infrared (24 microns)

Interacting and Colliding Galaxies

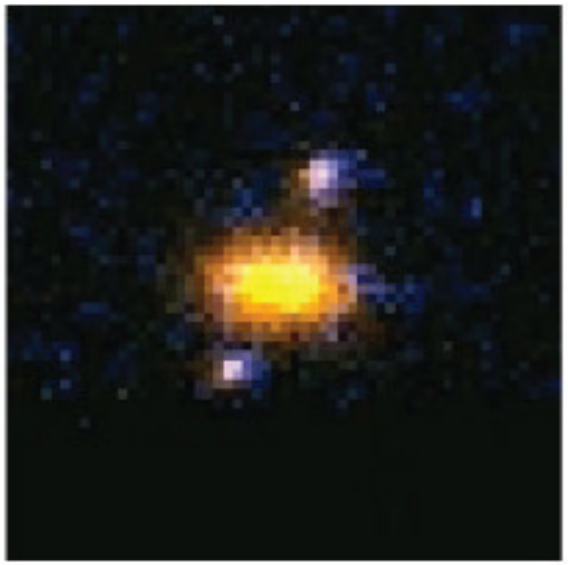


Gravitational Lensing of Extremely Distant Galaxies

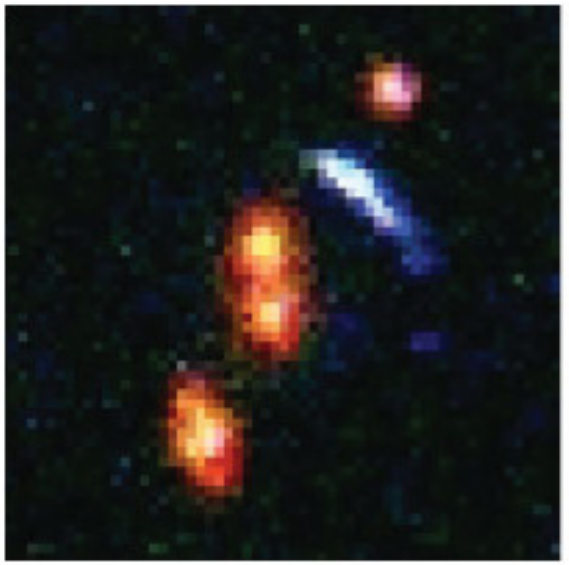
1



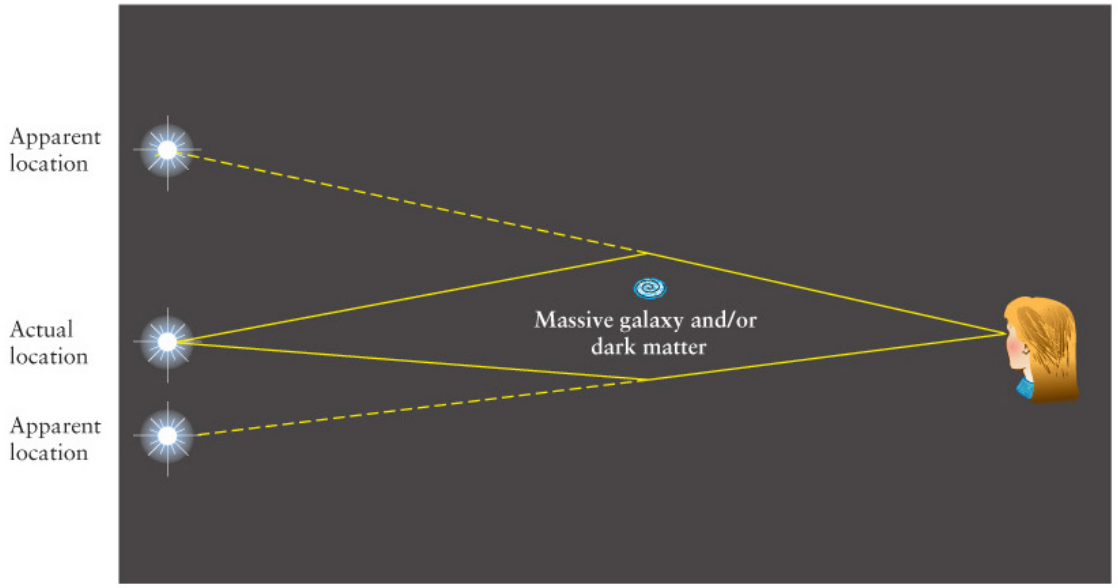
2



3

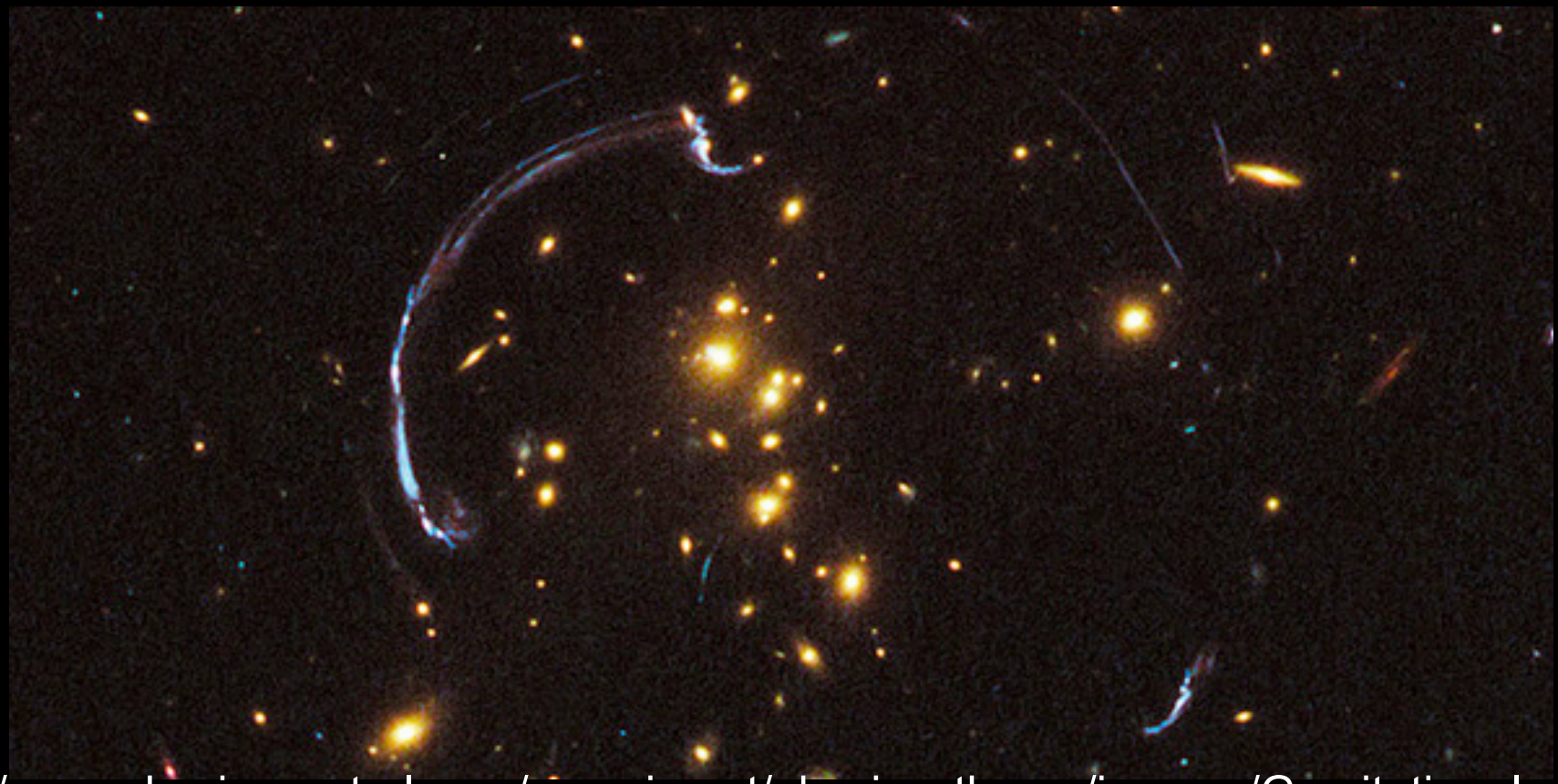


b



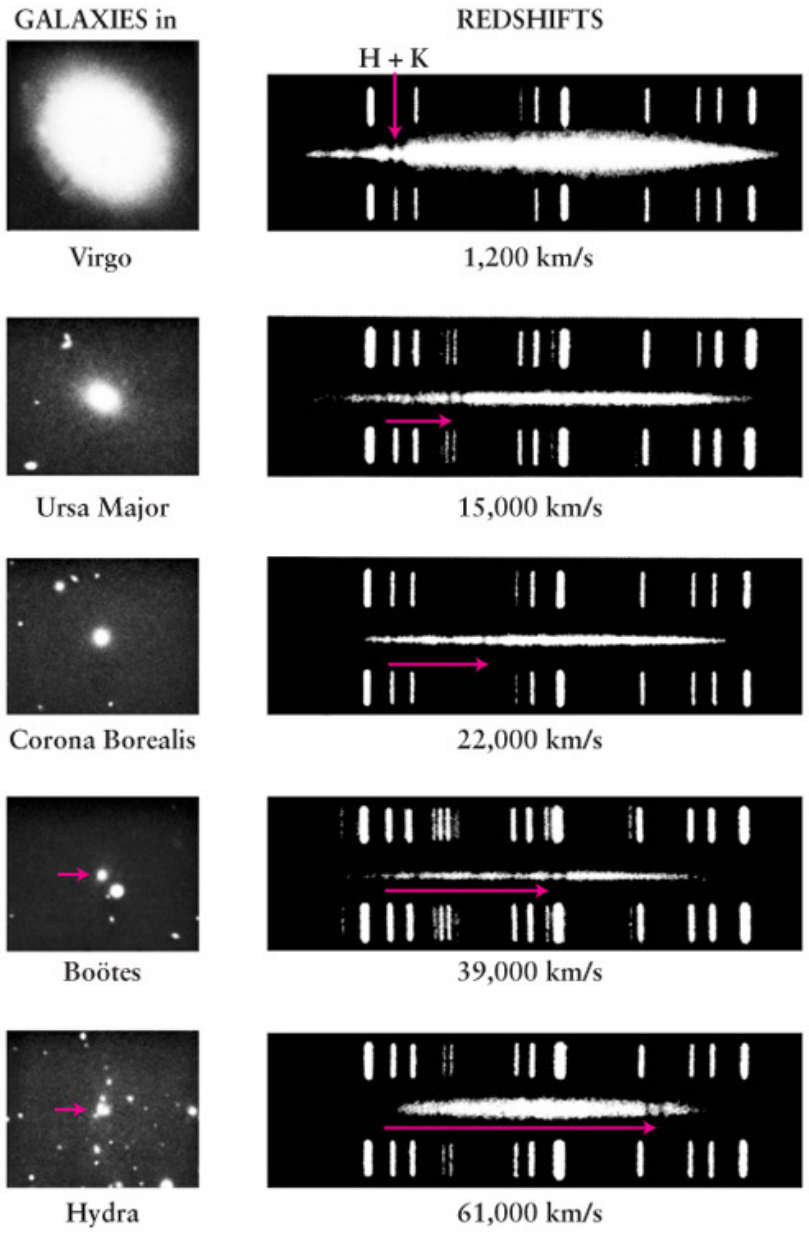
a

Gravitational lensing of a galaxy

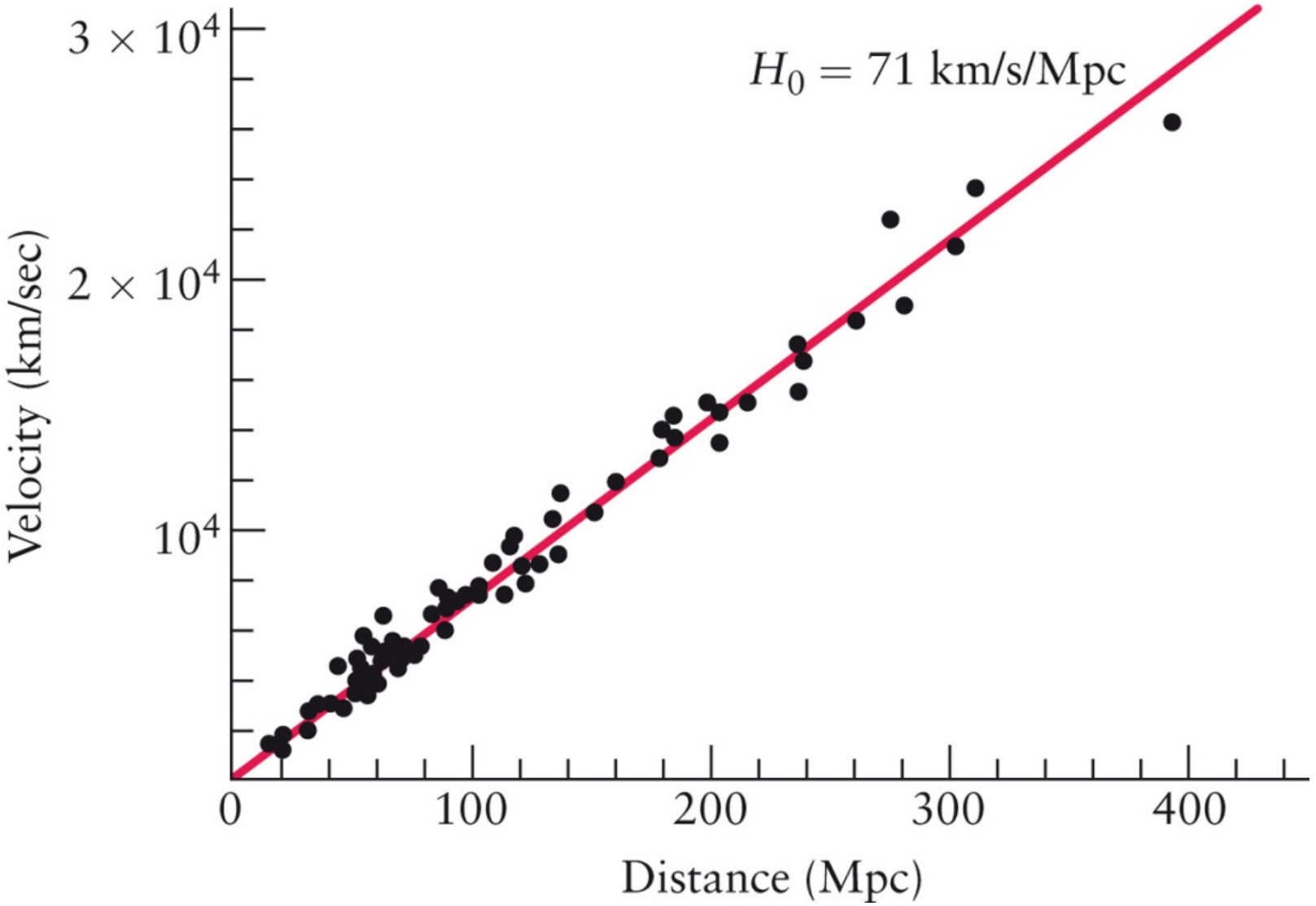


http://www.physicscentral.com/experiment/physicsathome/images/Gravitational-Lensing-001.jpg

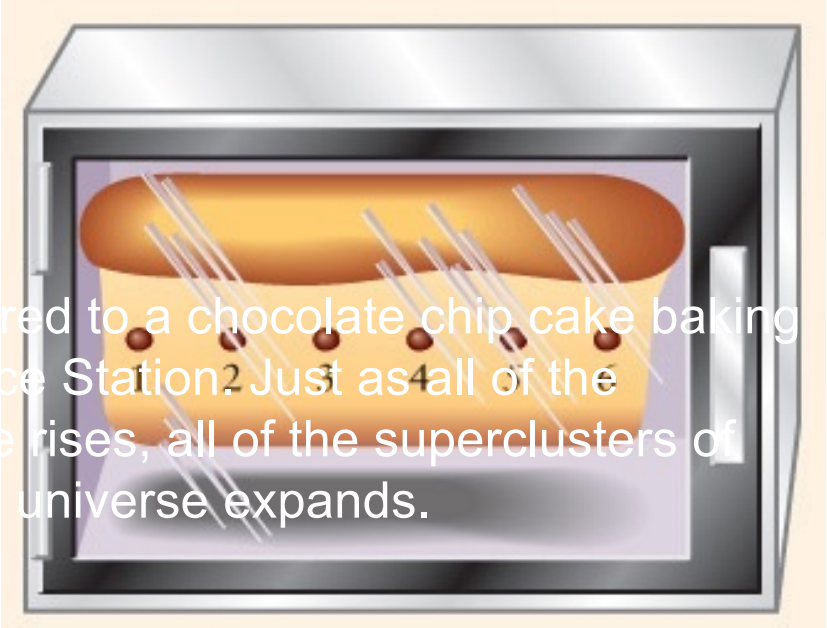
Five Galaxies and Their Spectra



The Hubble Law

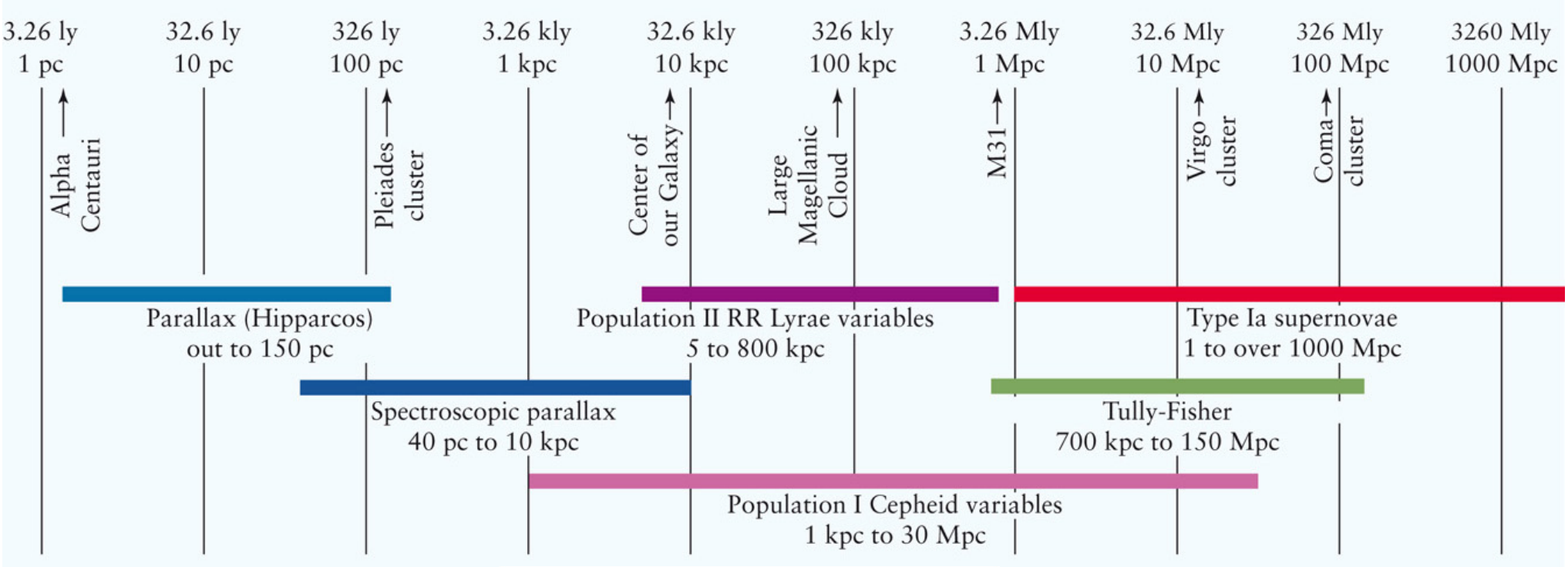


The Expanding universe
and the Expanding Chocolate Chip Cake Analogy



The expanding universe can be com red to a chocolate chip cake baking and expanding in the International S ce Station. Just as all of the chocolate chips move apart as the ca e rises, all of the superclusters of galaxies recede from each other as t universe expands.

Techniques for Measuring Cosmological Distances



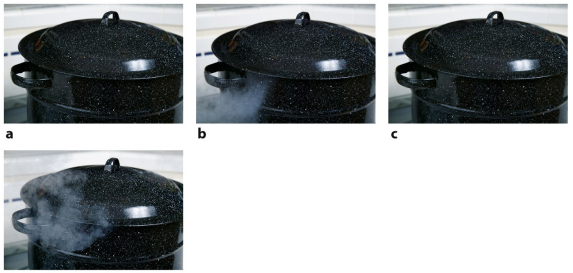


Figure 12-26
Discovering the Universe, Eighth Edition
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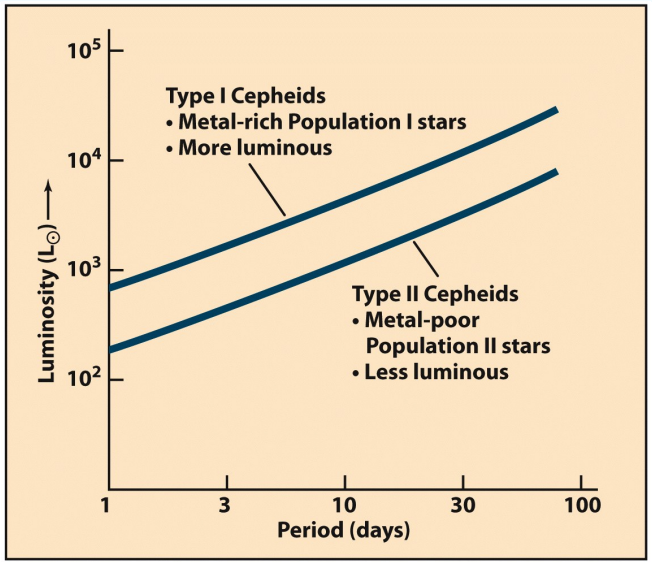
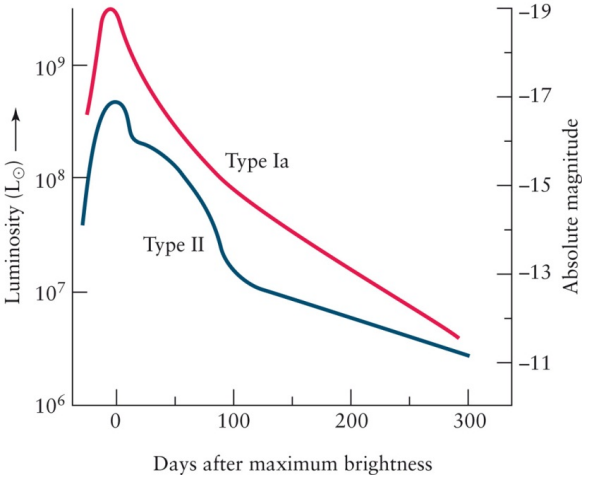
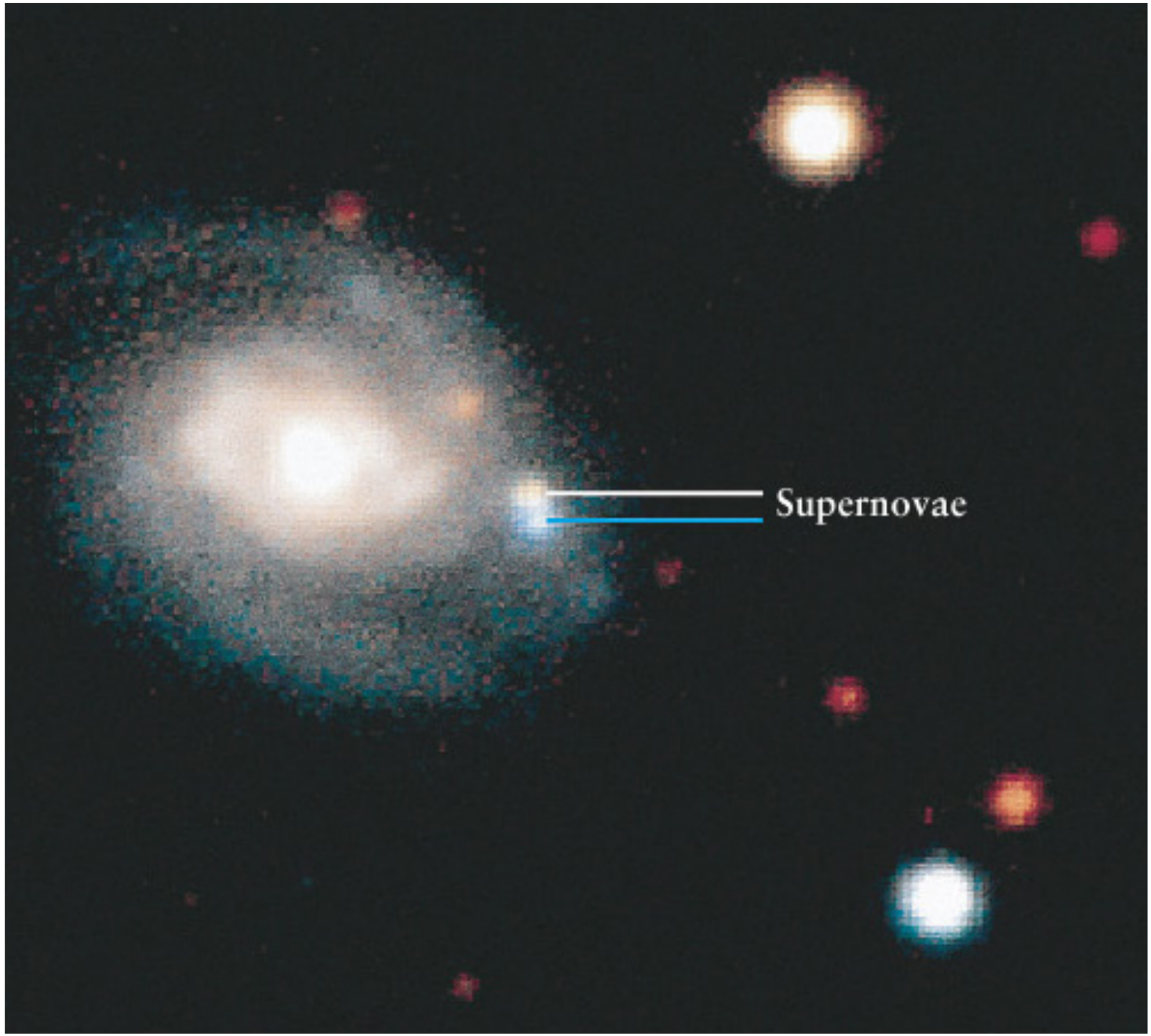


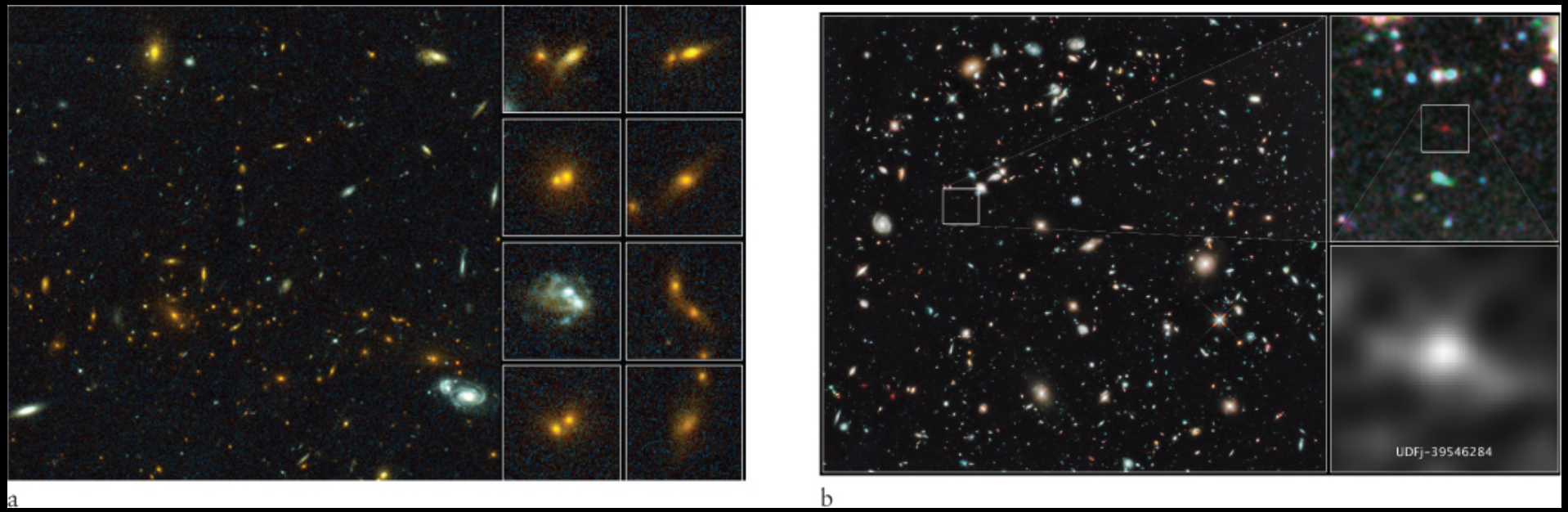
Figure 12-27



Two Supernovae in NGC 664



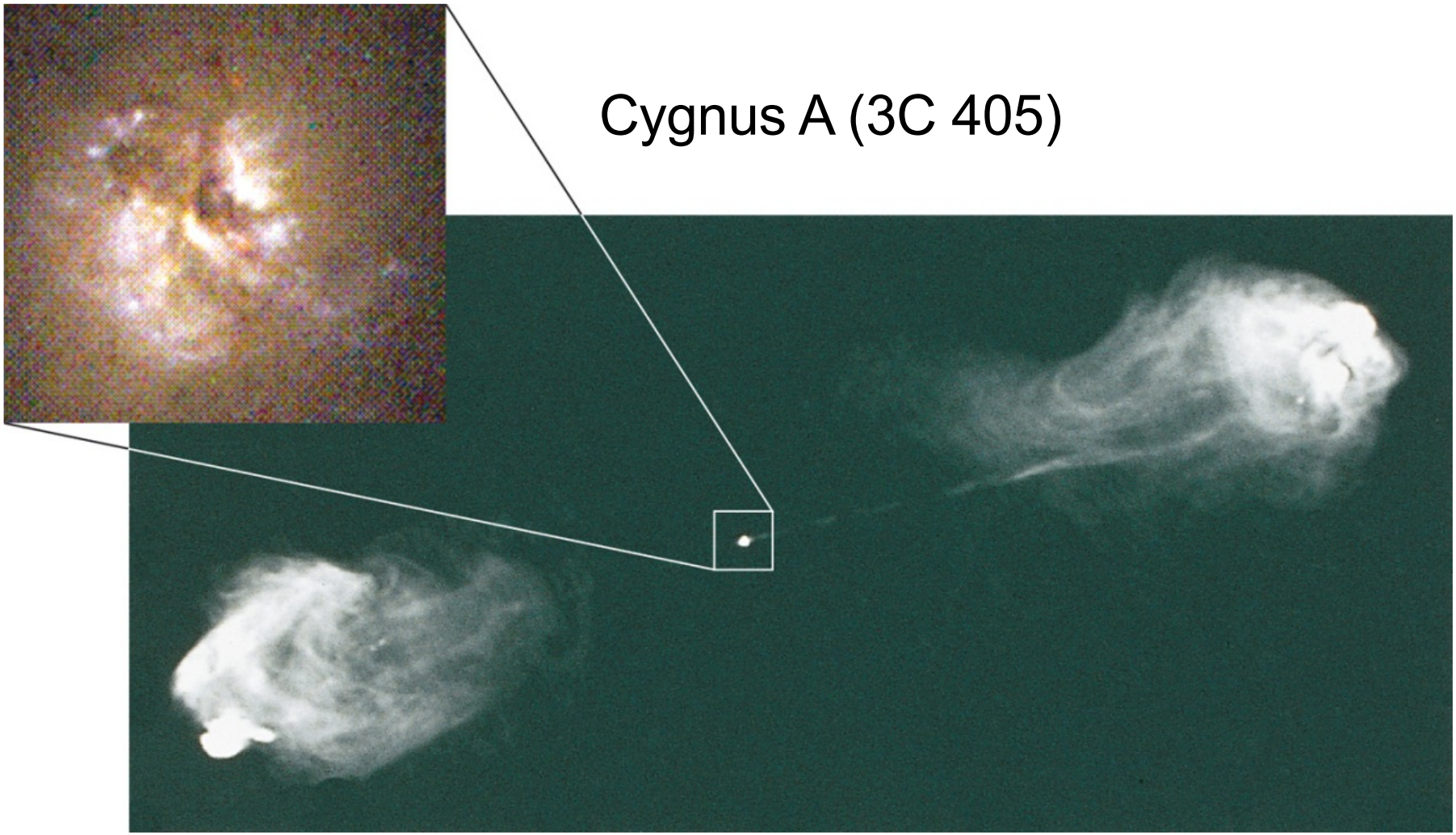
Distant Galaxies



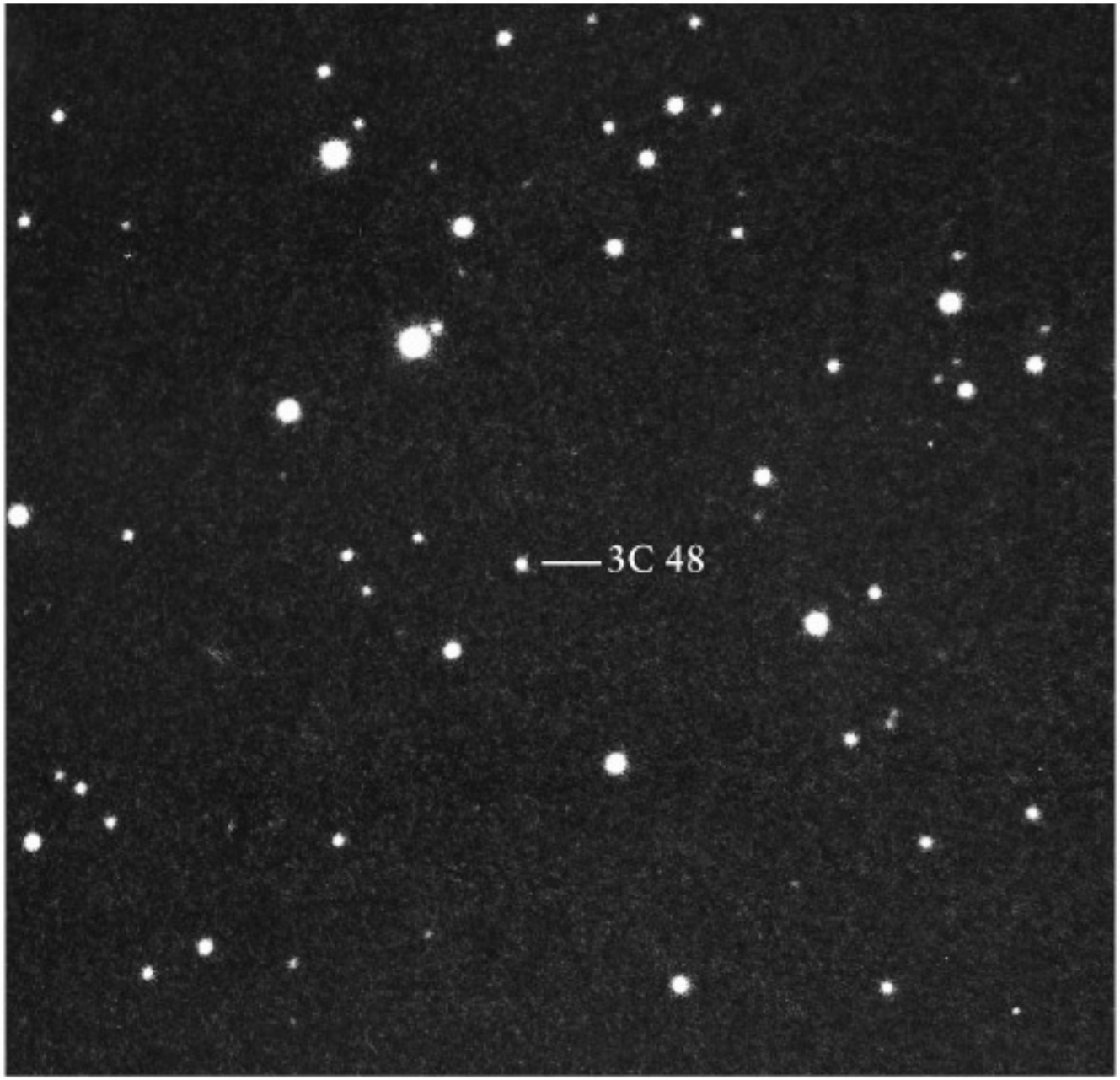
(a) The young cluster of galaxies MS1054-03, shown on the left, contains many orbiting pairs of galaxies, as well as remnants of recent galaxy collisions. Several of these systems are shown at the right. This cluster is located 8 billion ly away from Earth. (b) The farthest known galaxy, shown in the lower- right inset, is 13.2 billion light-years from Earth. It is in the constellation Fornax, in the southern hemisphere.

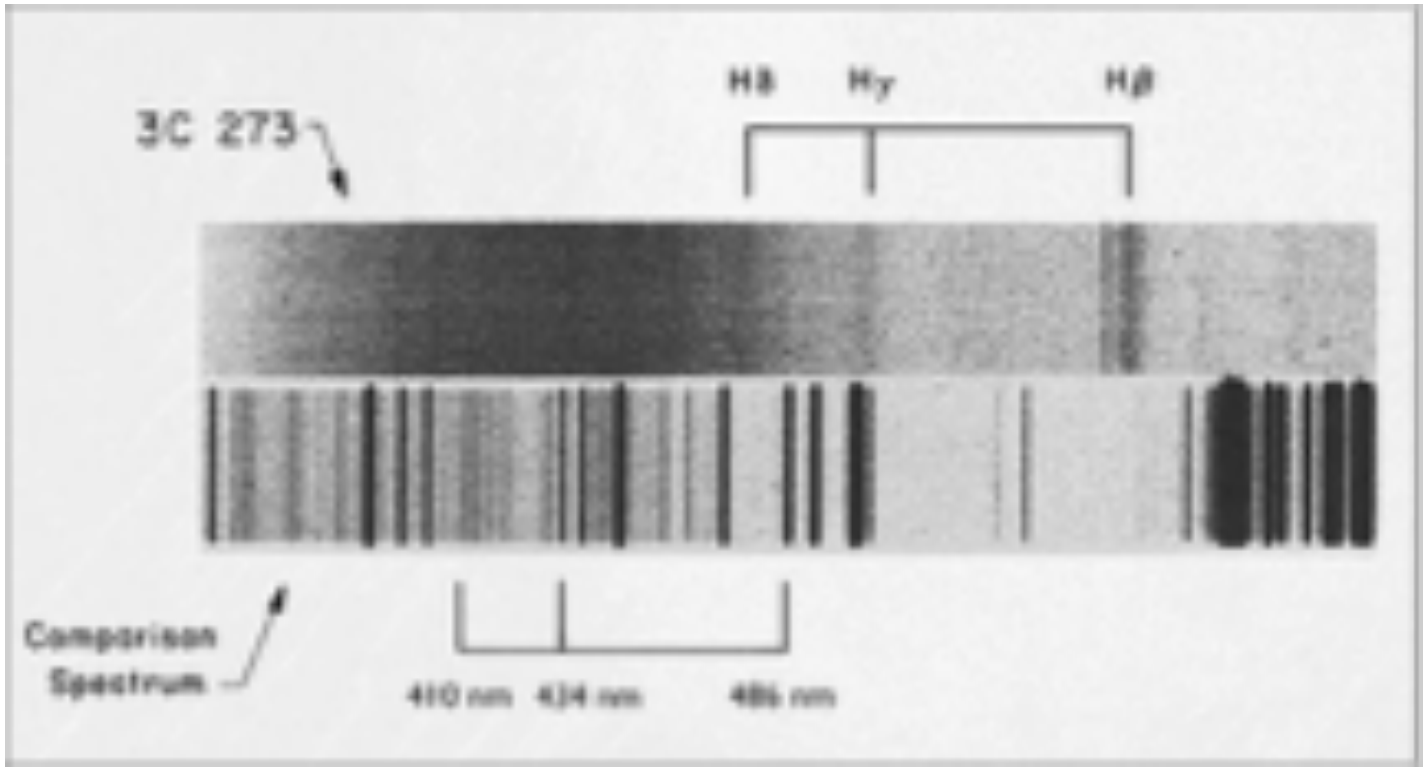
Active Galaxies

Radio galaxies and quasars



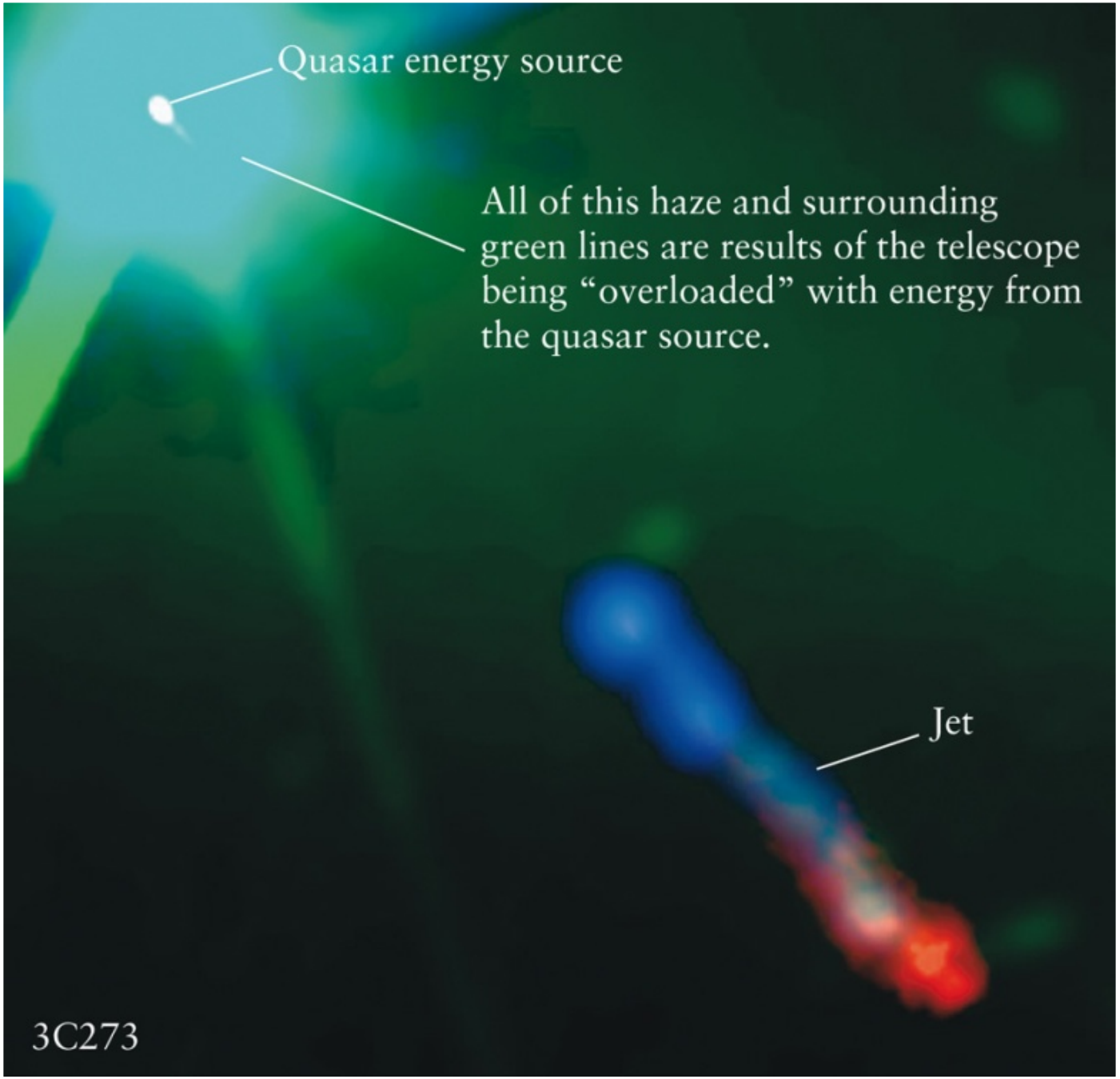
Quasar 3C 48



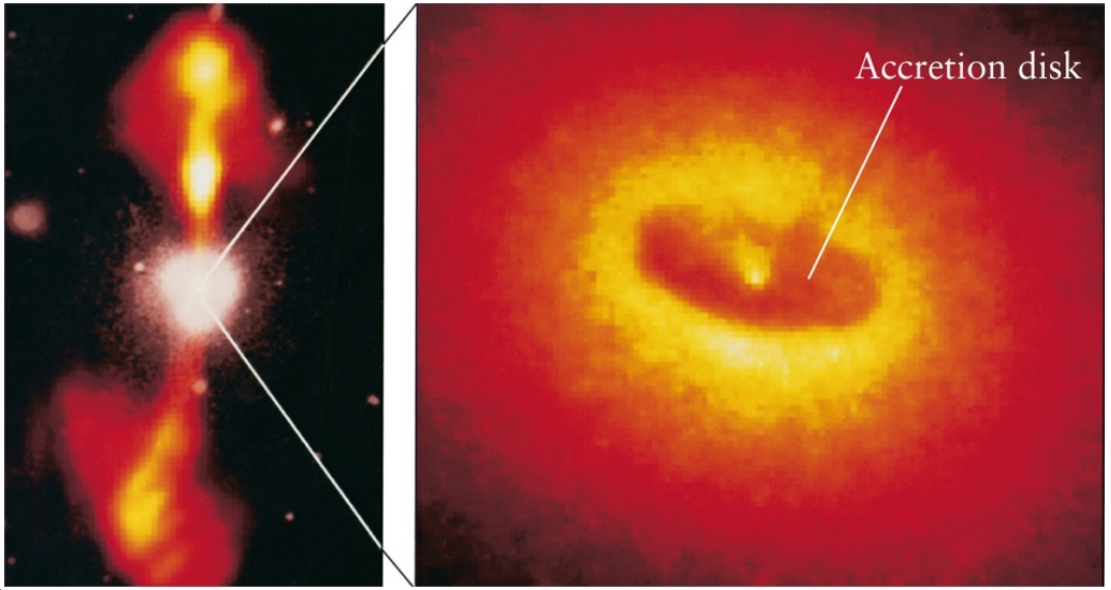


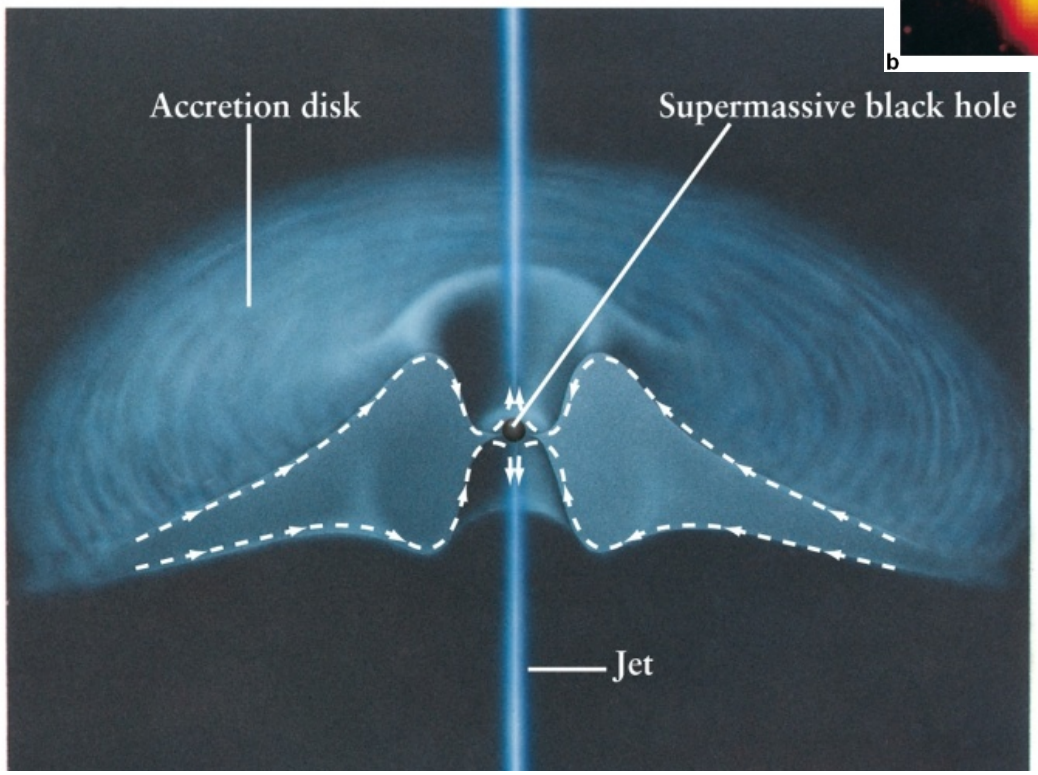
M. Schmidt

Quasar 3C 273

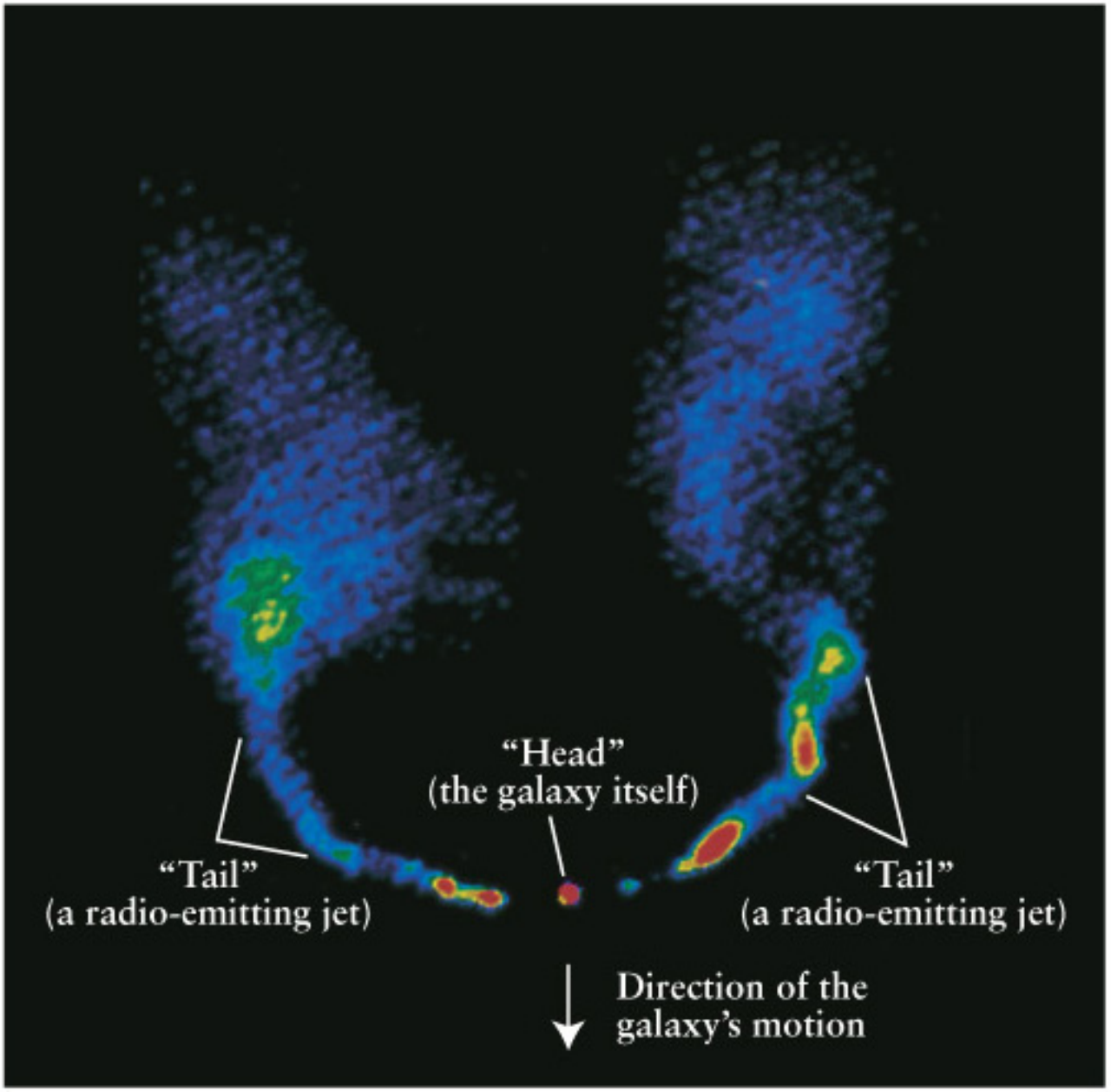


Supermassive Black Holes as Engines for Galactic Activity

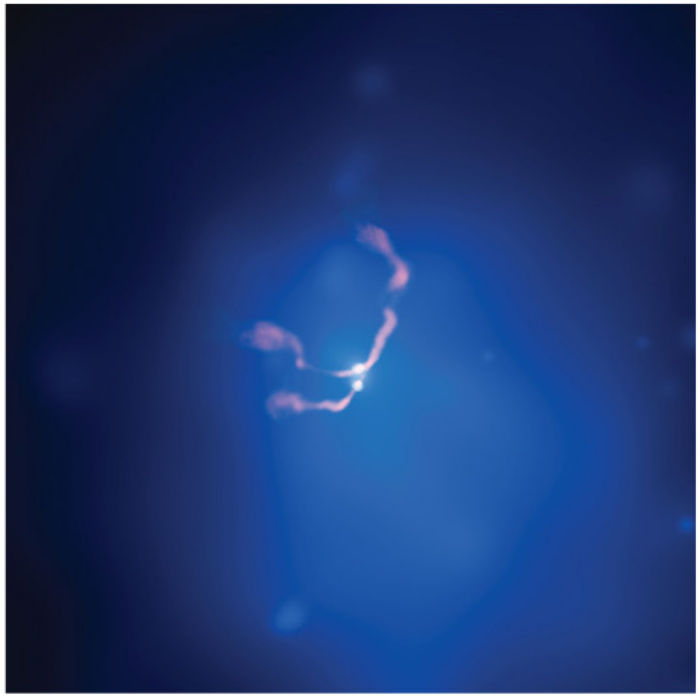




Head-Tail Source NGC 1265



3C 75



Light fluctuation of quasar 3C 279

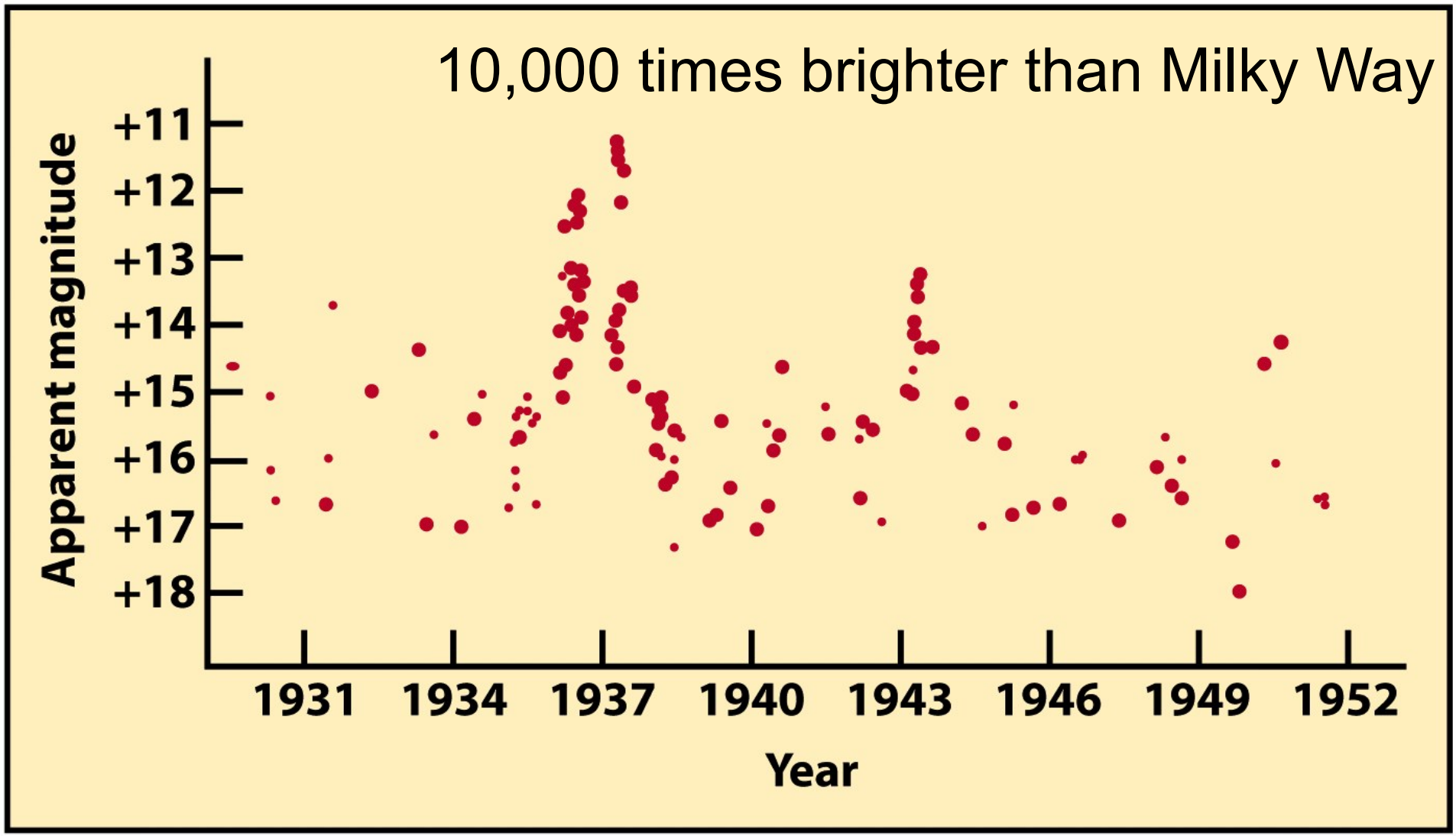


Figure 17-7
Discovering the Universe, Eighth Edition

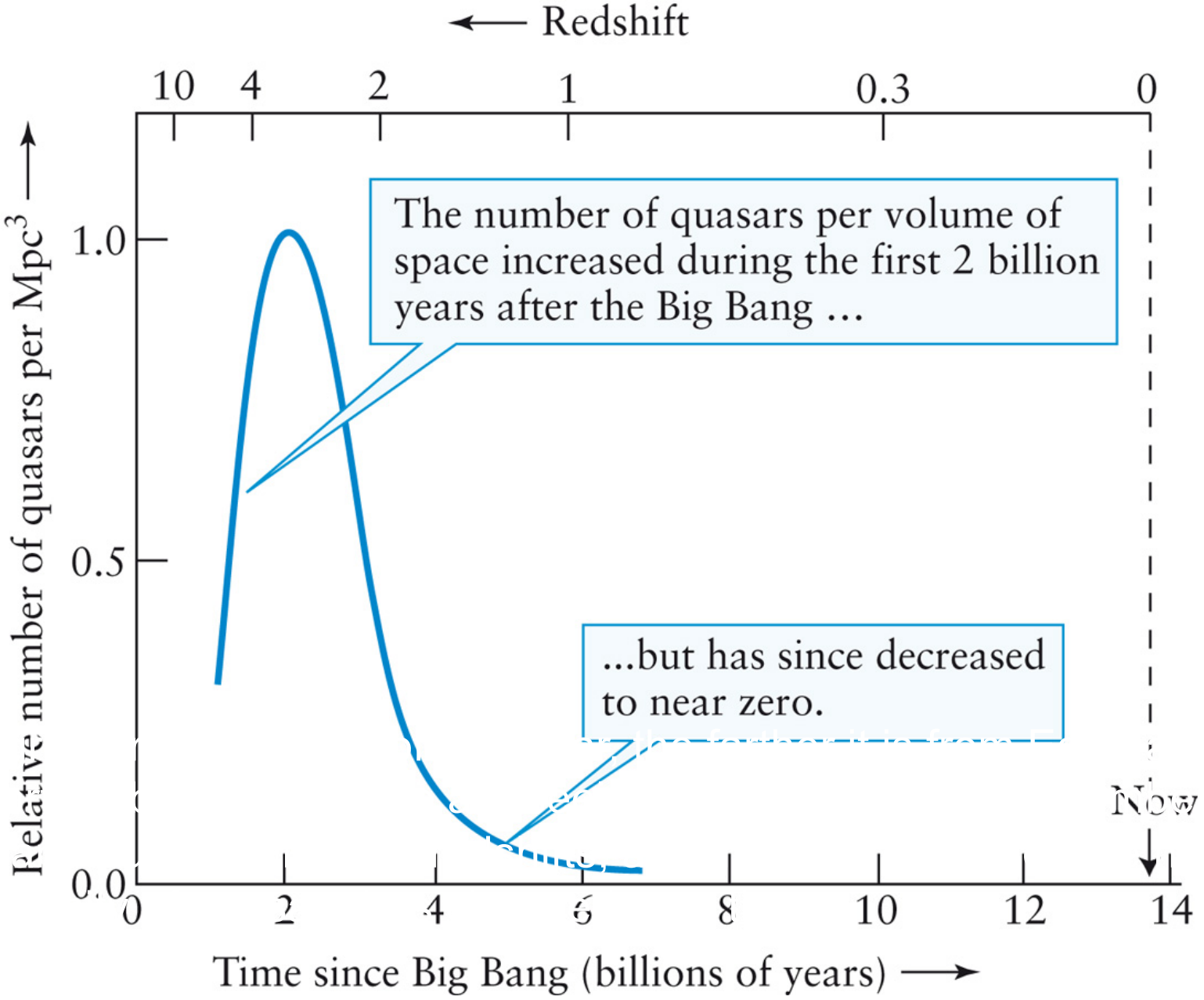
Some quasars flare up and down in less than a day. $R < c\Delta t$

==> Energy source is smaller than a light day!

TABLE 12-2 Galaxy and Quasar Luminosities

Object	Luminosity (watts)
Sun	4×10^{26}
Milky Way Galaxy	10^{37}
Seyfert galaxies	$10^{36}-10^{38}$
Radio galaxies	$10^{36}-10^{38}$
Quasars	$10^{38}-10^{42}$

History of Quasar Formation



Sombrero Galaxy (M104)

Hawking radiation

Black holes evaporate

The process happens because black holes can convert their mass into energy through virtual particle production in the vicinity of the event horizon.

Virtual particle pairs (e^+ e^- or photon photon) appear and disappear within 10^{-21}s.

Tidal forces could pull them apart where one Particle disappears beyond the event horizon and the other particle becomes real.

The particles that leave the vicinity of the black hole are called Hawking radiation.

The result is that black holes loose mass and evaporate.

The timescale of evaporation is for
$M_{BH}=5M_{sol}$ ➔ 10^{62} yr
$M_{BH}=10^{10}$kg ➔15 Bill yr