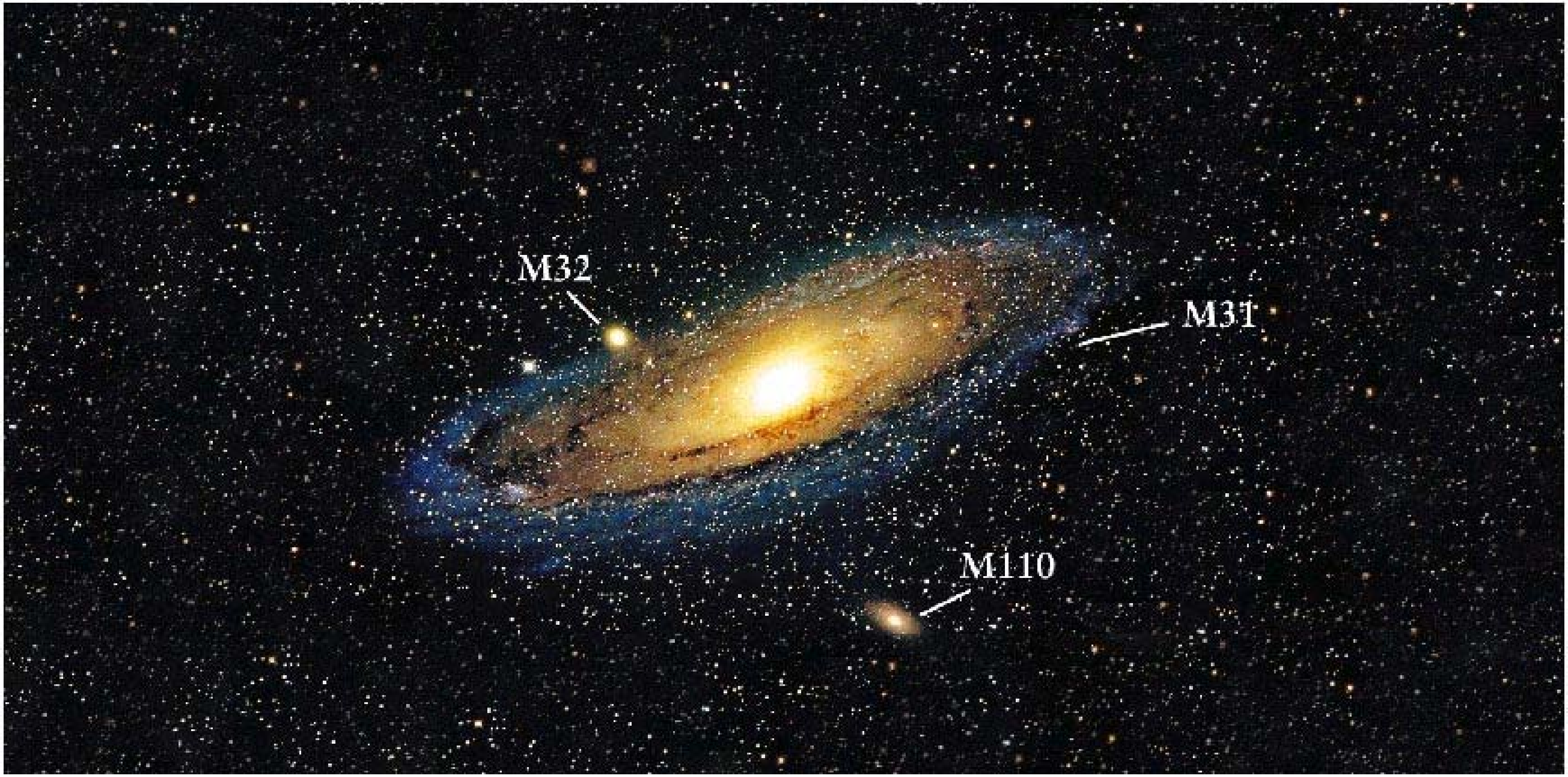
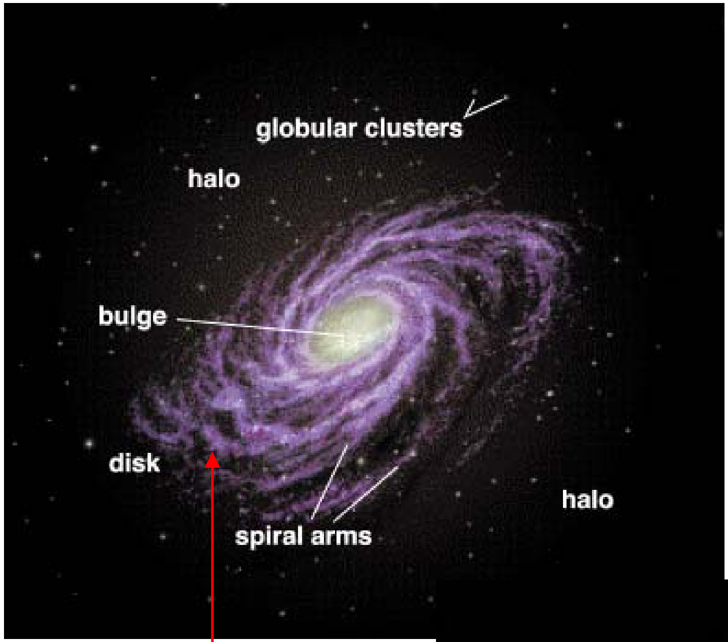
Lecture 5 Galaxies



Regions of the Milky Way Galaxy

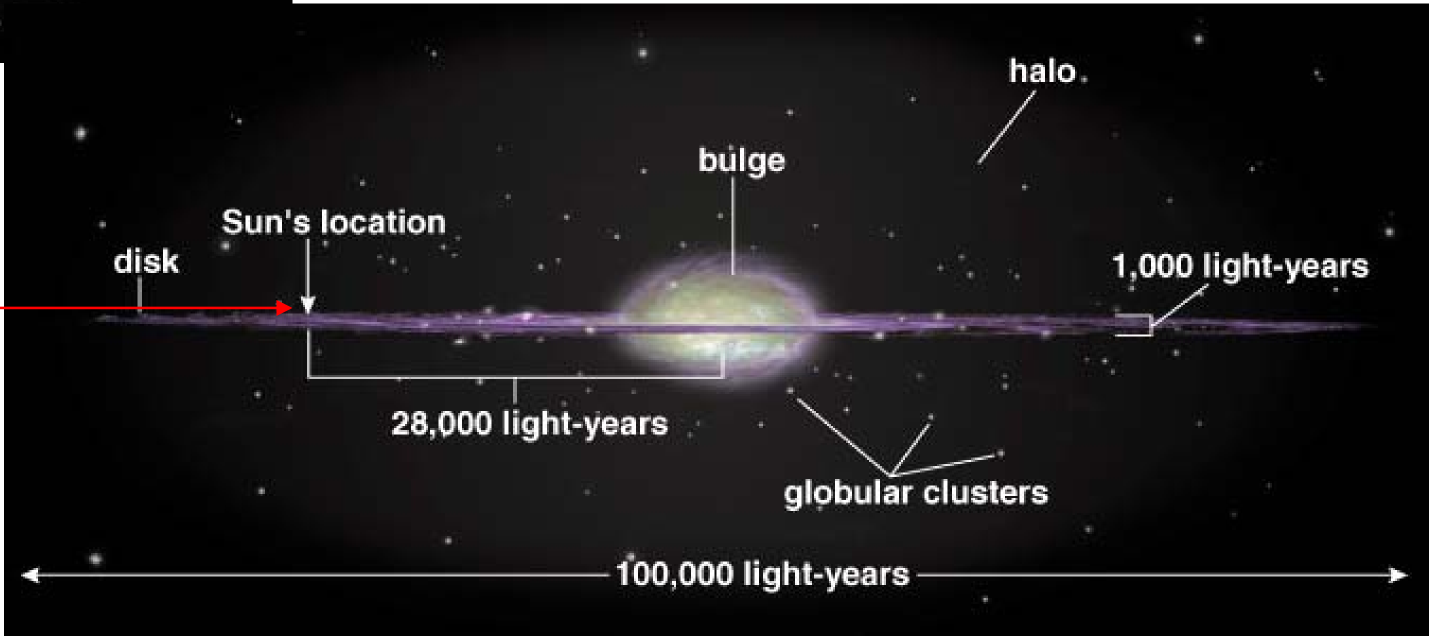


diameter of disk = 100,000 l.y. (30,000 pc)

thickness of disk = 1,000 l.y. (300 pc)

number of stars = 400 billion

Sun is in disk, 28,000 l.y. out from center

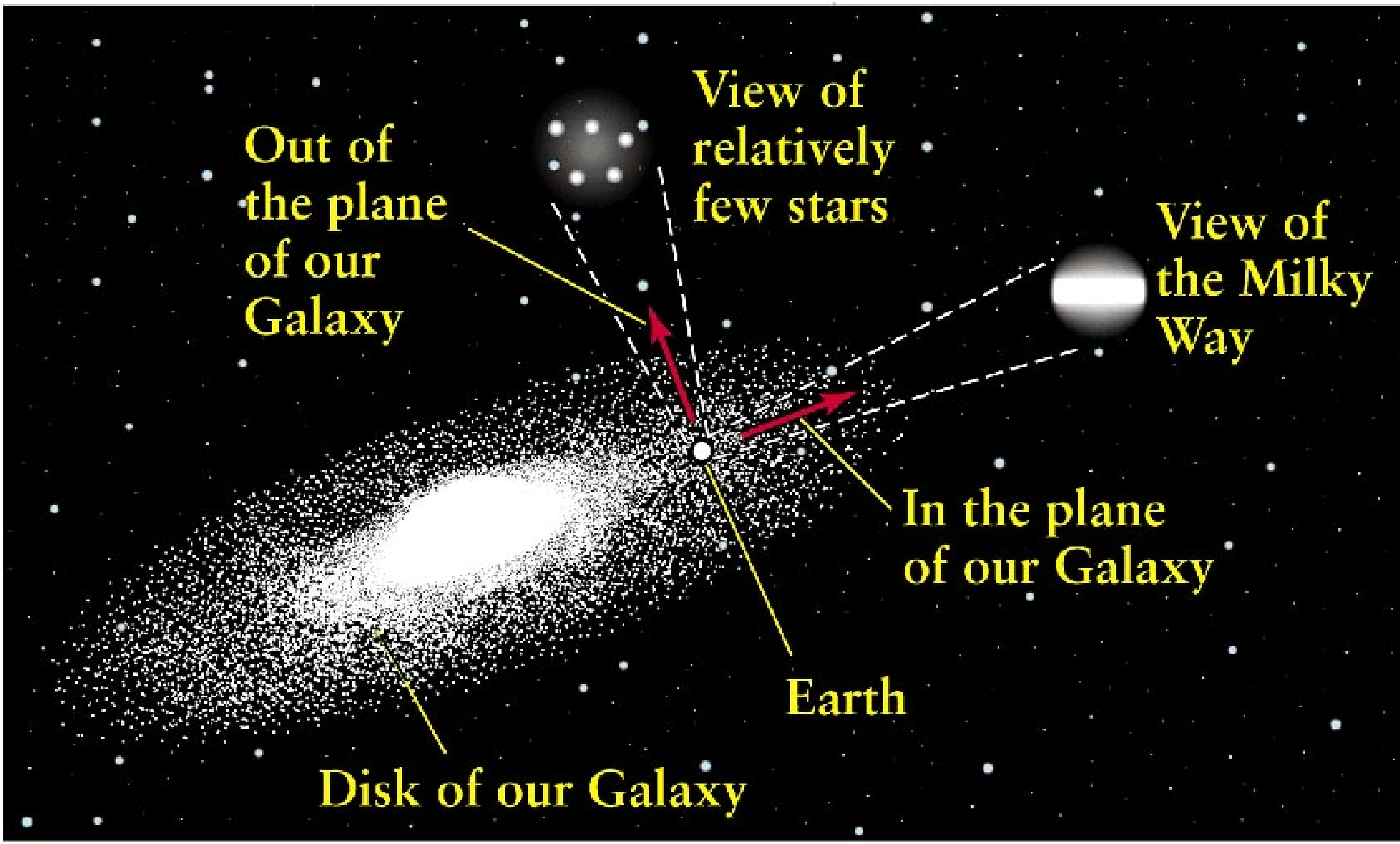


Regions of the Milky Way Galaxy

- Disk
  - younger generation of stars
  - contains gas and dust
  - location of the open clusters
- Bulge
  - mixture of both young and old stars
- Halo
  - older generation of stars
  - contains no gas or dust
  - location of the globular clusters

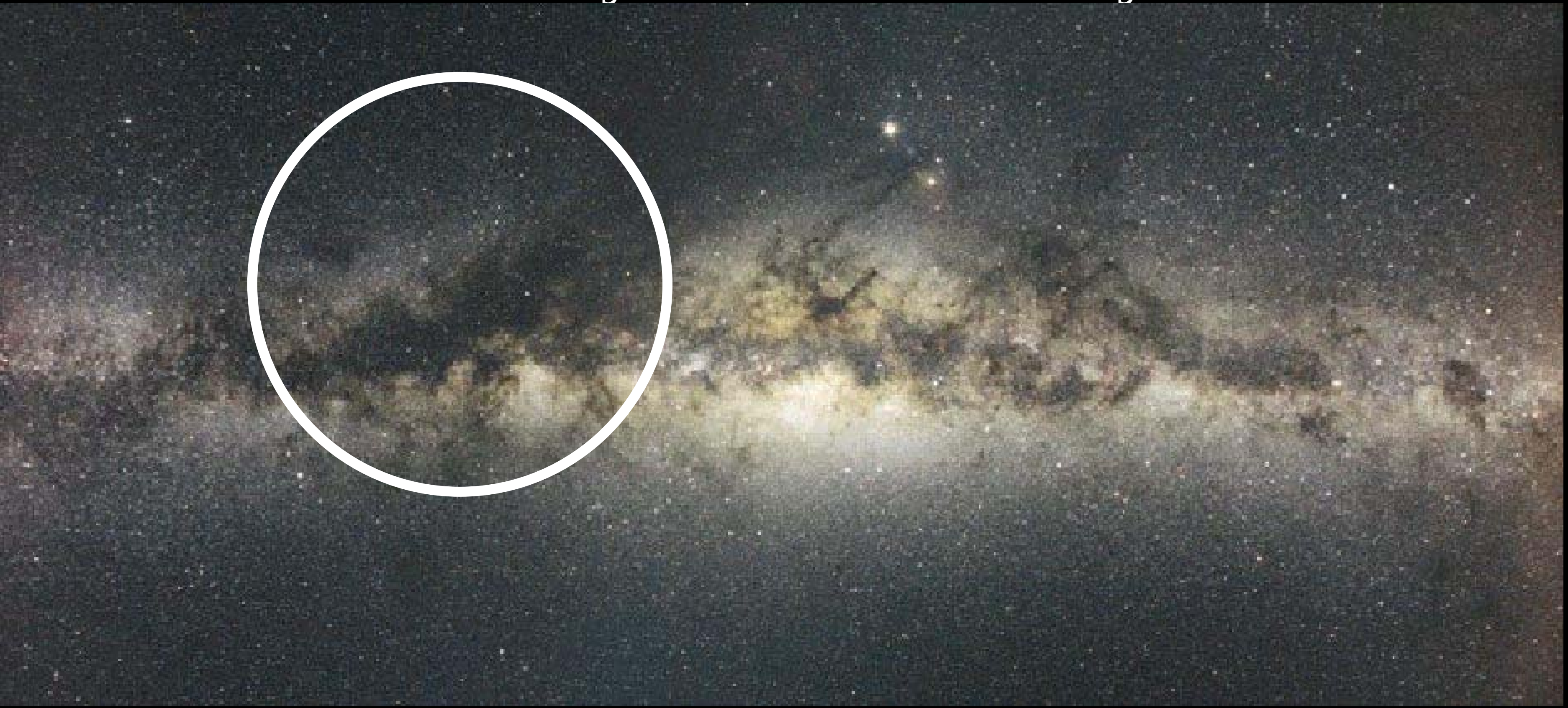
The Interstellar Medium (ISM)

- It is the “stuff” between the stars.
- It is mostly a vacuum (1 atom cm^{-3}).
- It is composed of 90% gas and 10% dust.
  - gas: individual atoms and molecules
  - dust: large grains made of heavier elements
- The ISM effectively absorbs or scatters visible light.
  - it masks most of the Milky Way Galaxy from us
- Radio & infrared light does pass through the ISM.
  - we can study and map the Milk Way Galaxy by making observations at these wavelengths


View of
relatively
few stars
Out of
the plane
of our
Galaxy
View of
the Milky
Way
In the plane
of our Galaxy
Earth
Disk of our Galaxy

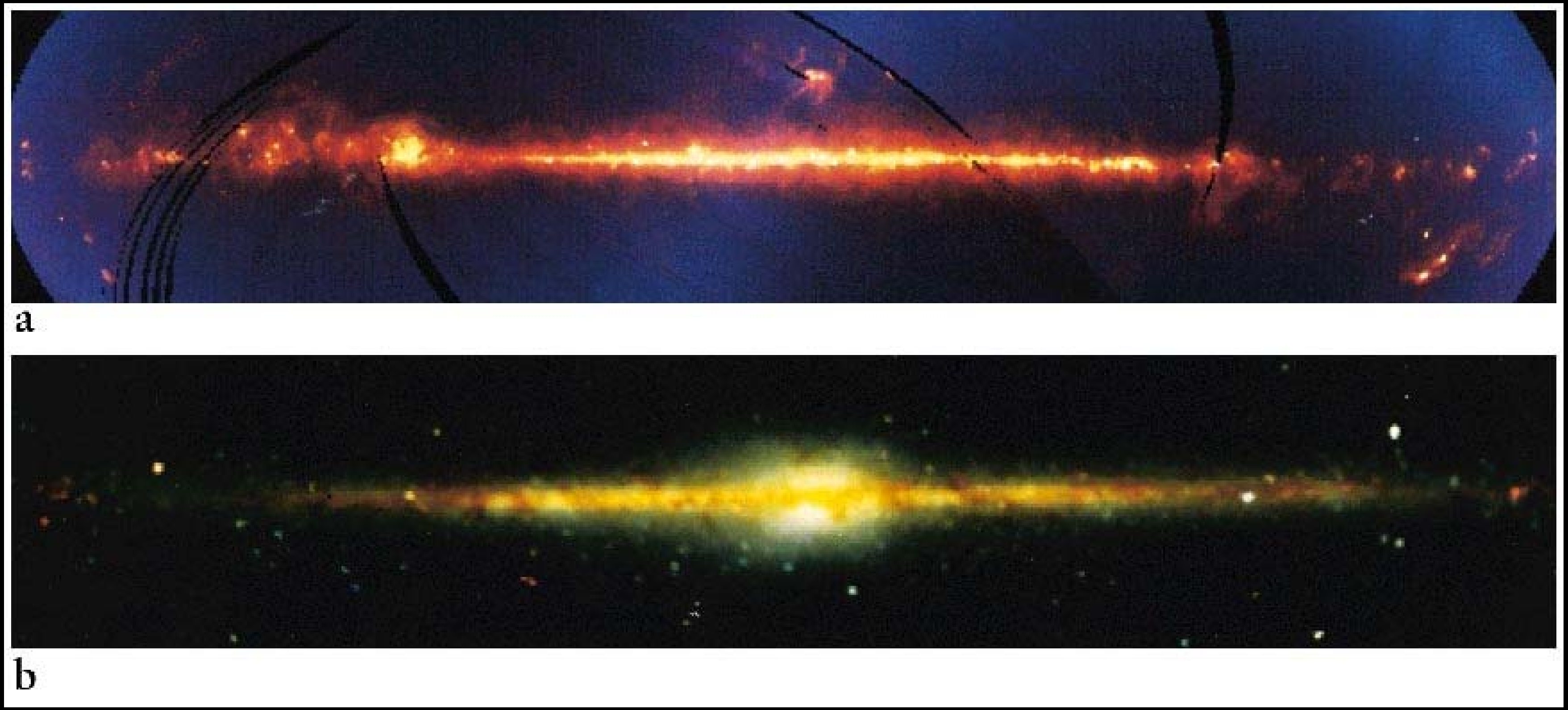
a

The Milky Way is composed of all the stars in our galaxy, nearly 400 billion. All the stars you can see in the sky are in our Galaxy.

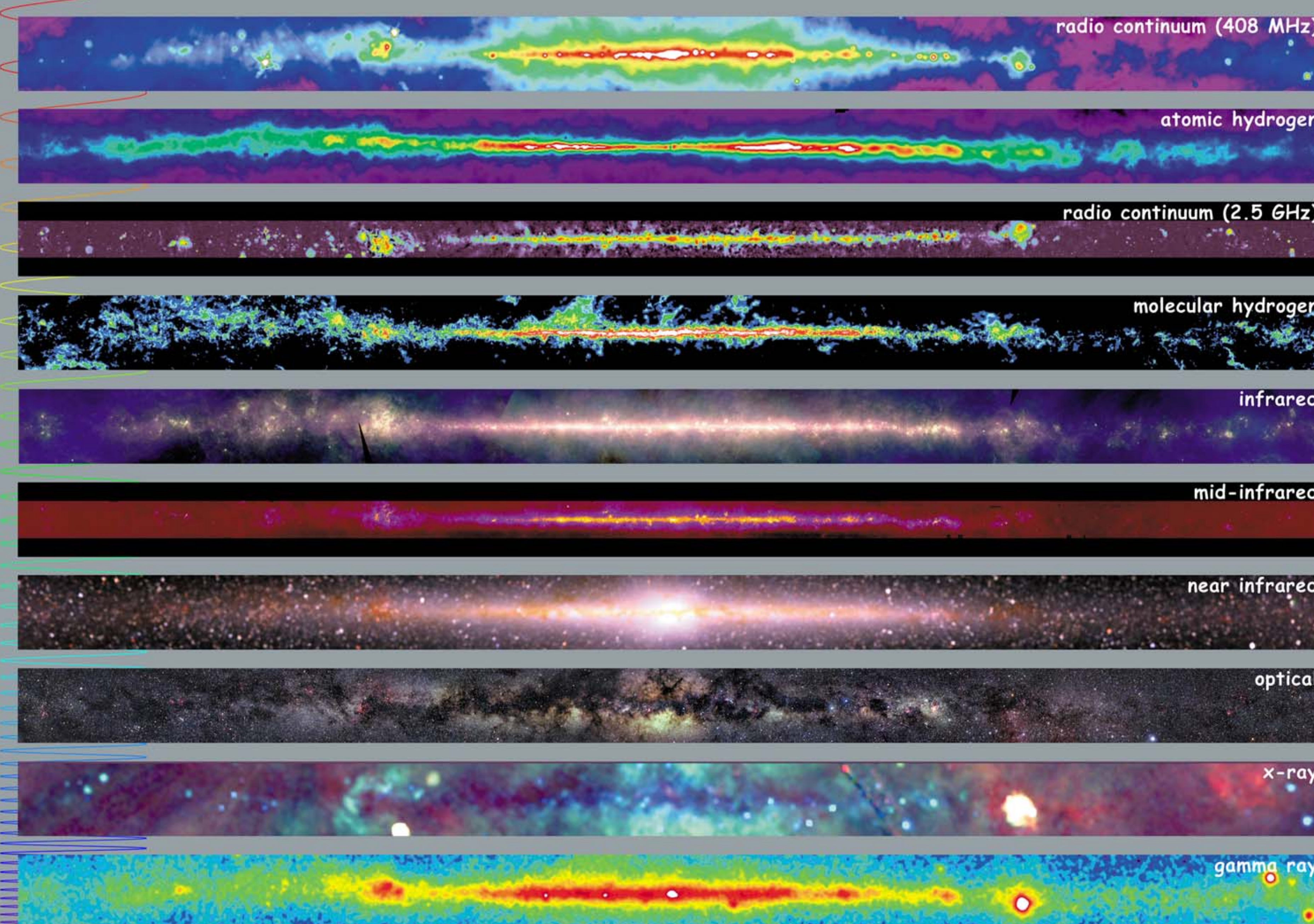


Enormous clouds of dust obscure our view of most of the stars in our Galaxy.

Observations at non-visible wavelengths reveal the shape of the Galaxy.



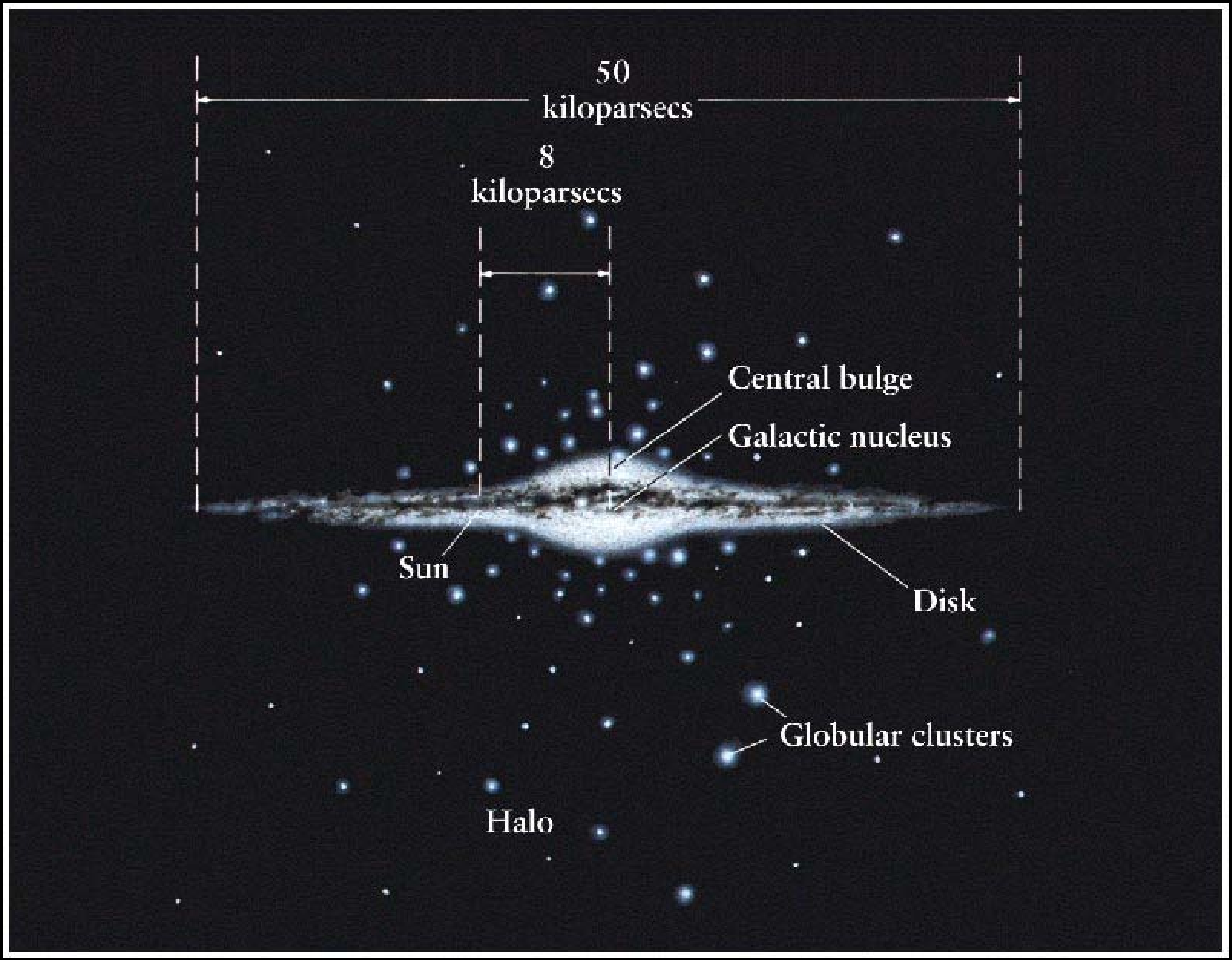
Far-infrared and near-infrared views of the galactic plane.



http://adc.gsfc.nasa.gov/mw

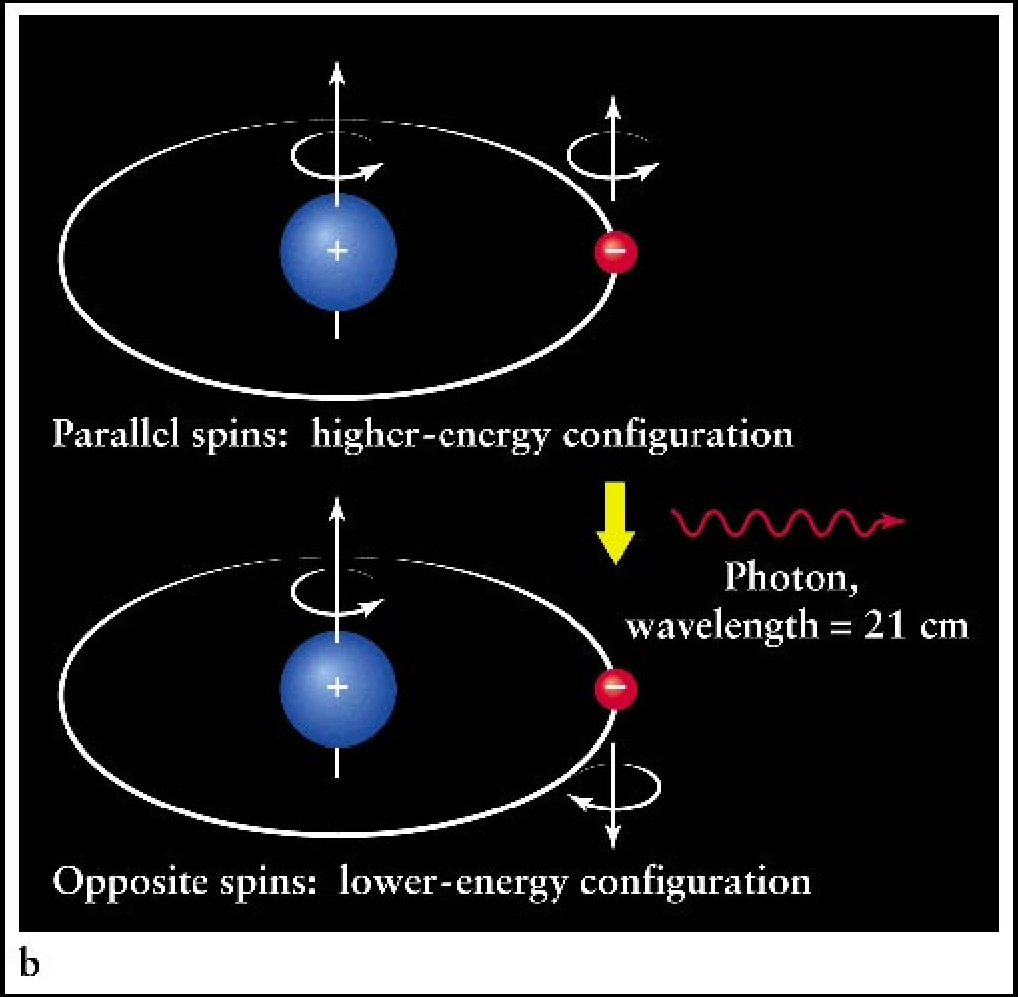
NASA

Multiwavelength Milky Way


50
kiloparsecs
8
kiloparsecs
Central bulge
Galactic nucleus
Sun
Disk
Globular clusters
Halo

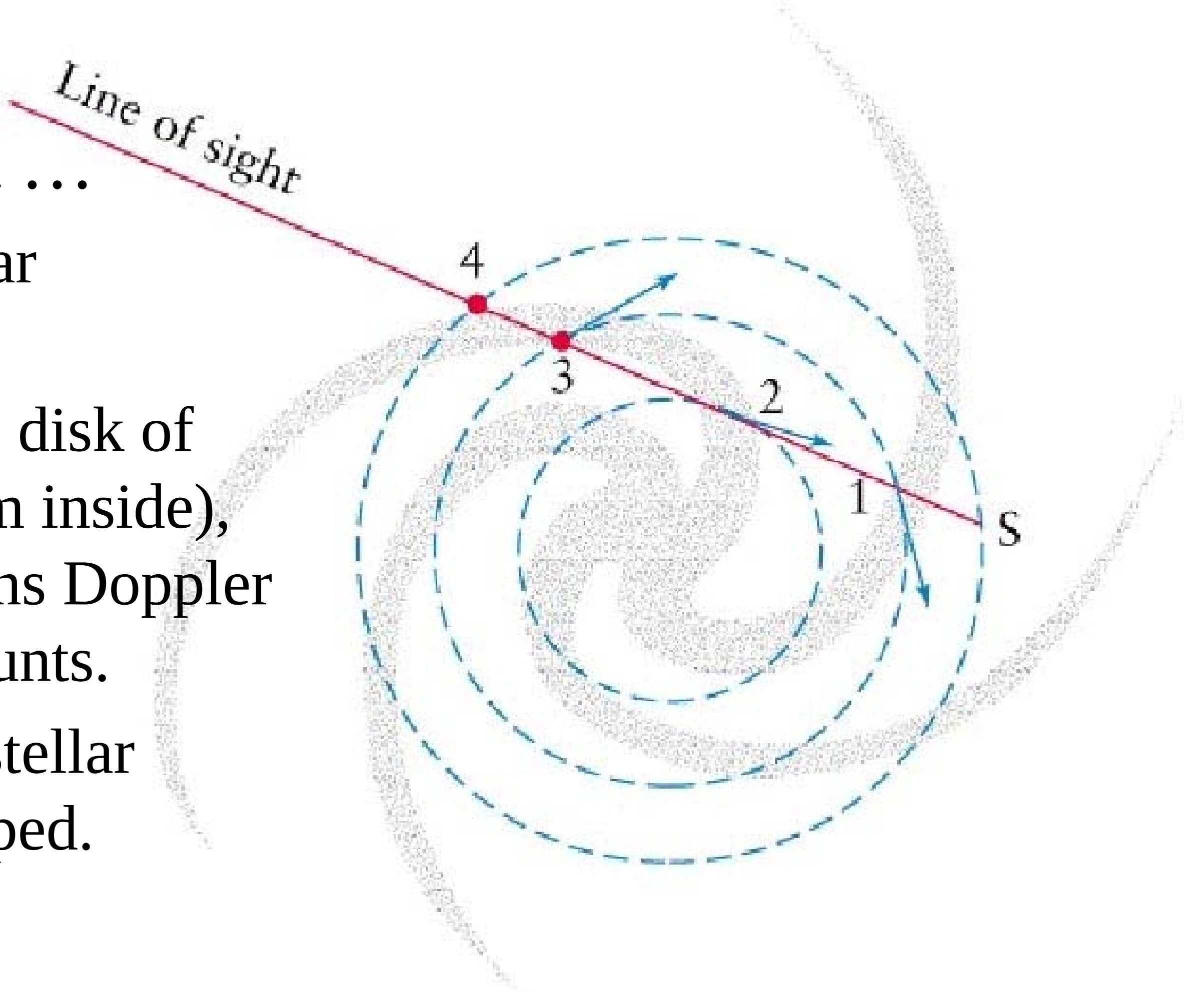
Observations of star-forming regions reveal that our Galaxy has spiral arms.

Electrons in hydrogen atoms emit a photon with 21 cm wavelength if the proton and the electron spontaneously change from spinning in the same sense to the opposite sense.



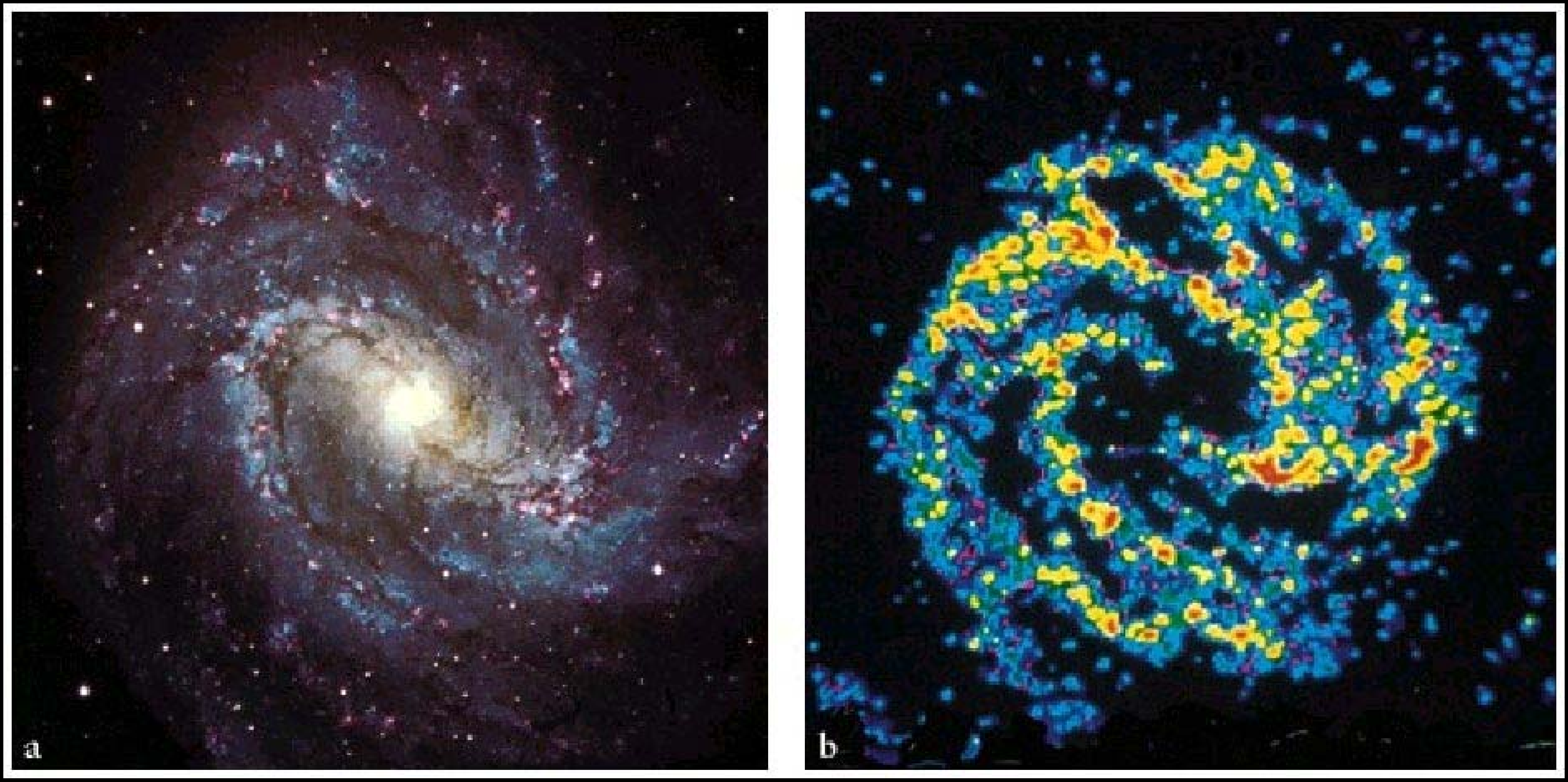
Observations of star-forming regions reveal that our Galaxy has spiral arms.

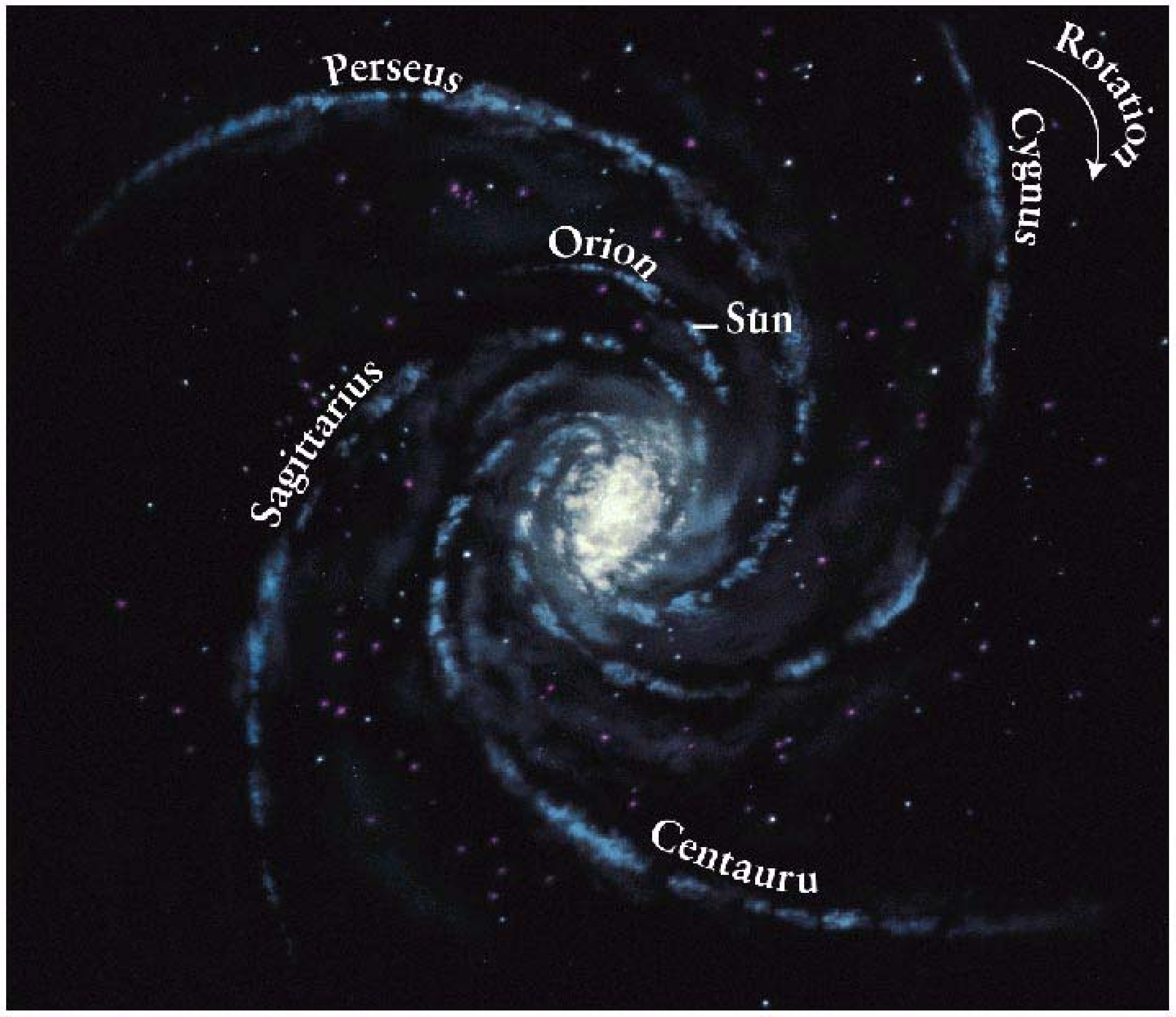
- Looking for 21-cm wavelengths of light …
  - emitted by interstellar hydrogen.
  - as we look along the disk of the Milky Way (from inside), we see 21-cm photons Doppler shifted varying amounts.
  - this allows the interstellar hydrogen to be mapped.



A Map of the Milky Way Based on 21-cm wavelength light mapping.

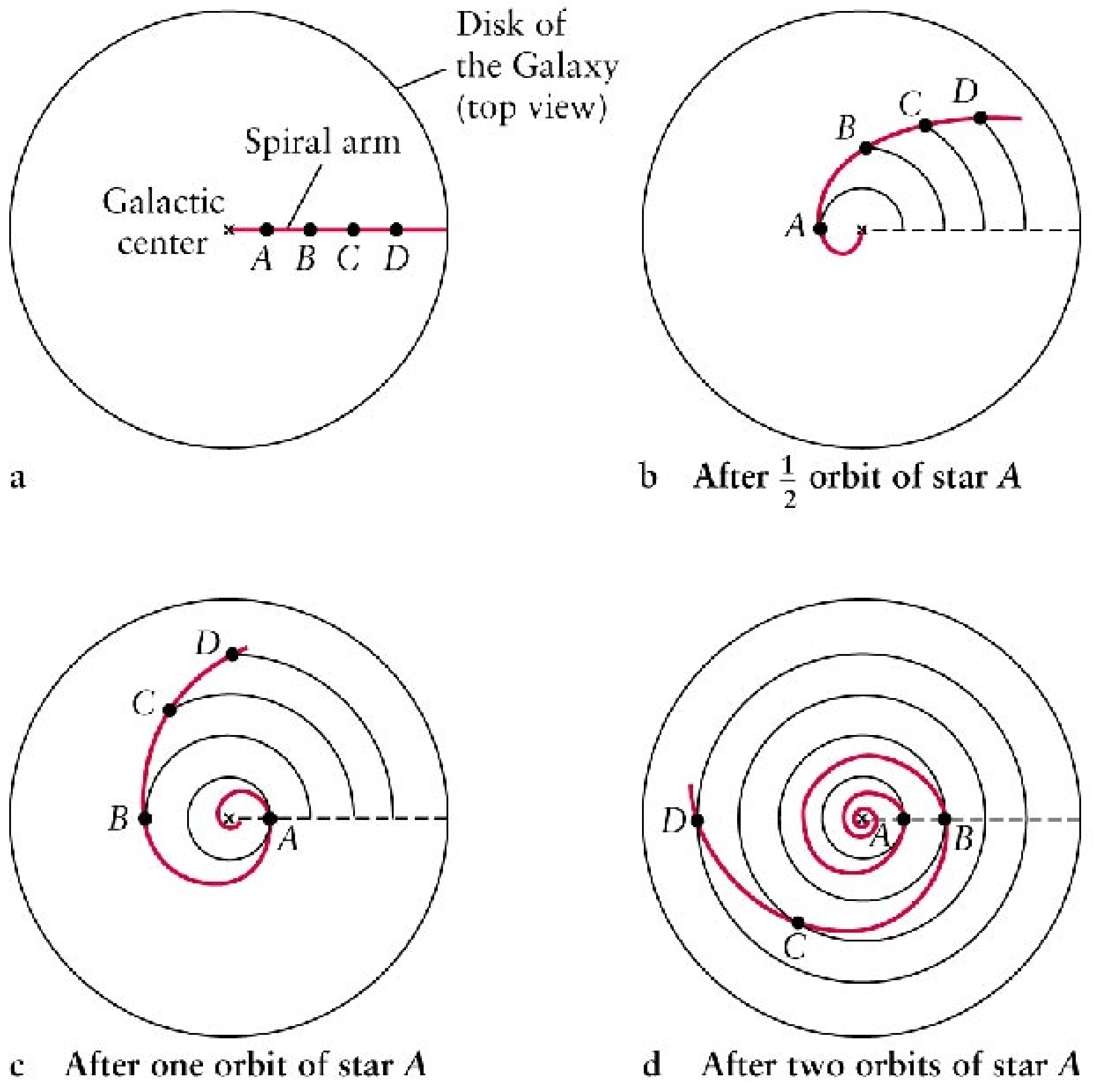
Spiral Galaxy M83 observed in both visible light and radio wavelengths.



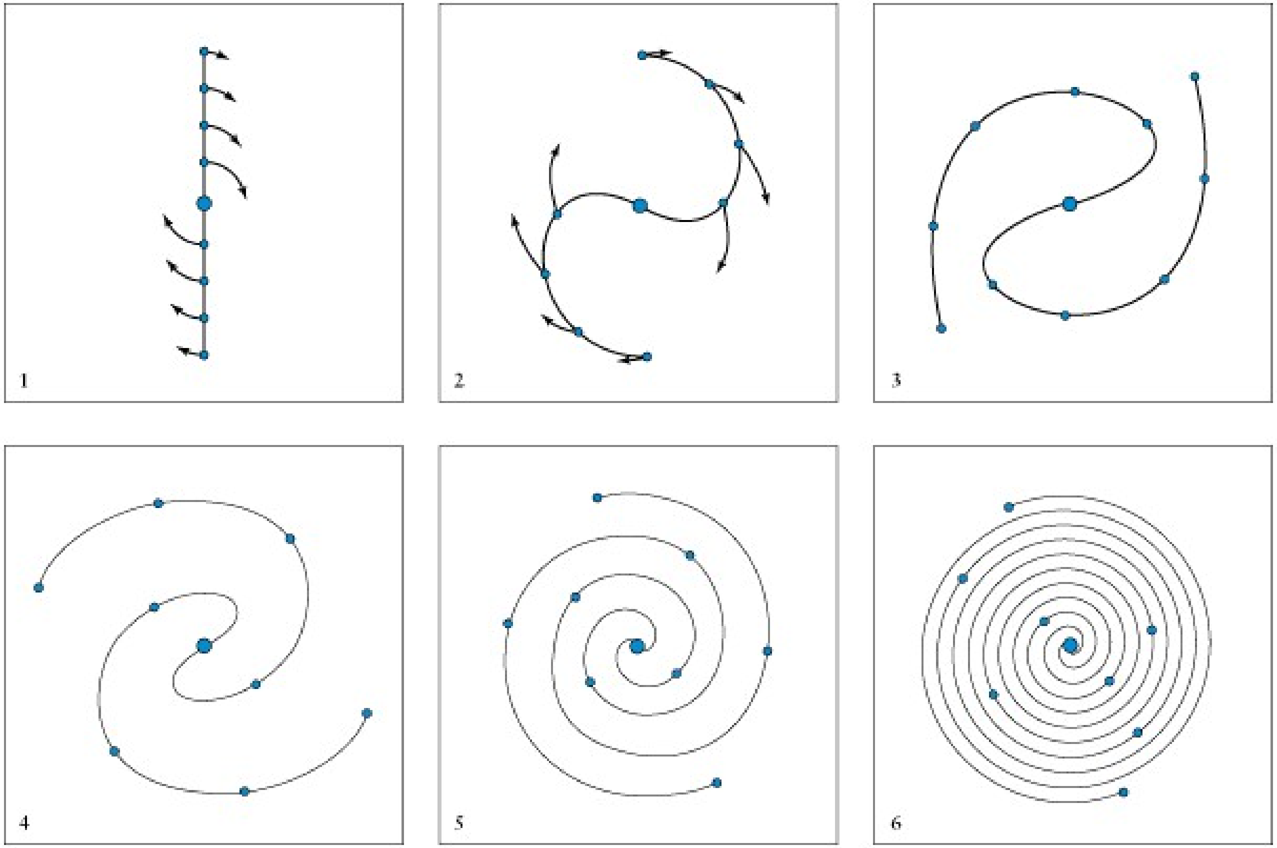

Perseus
Rotation
Cygnus
Orion
Sun
Sagittarius
Centauru

Spiral arms are caused by density waves that sweep around the Galaxy.

The Winding Dilemma is that if galaxies rotated like this, the spiral structure would be quickly erased.



Why don’t the arms wind up?

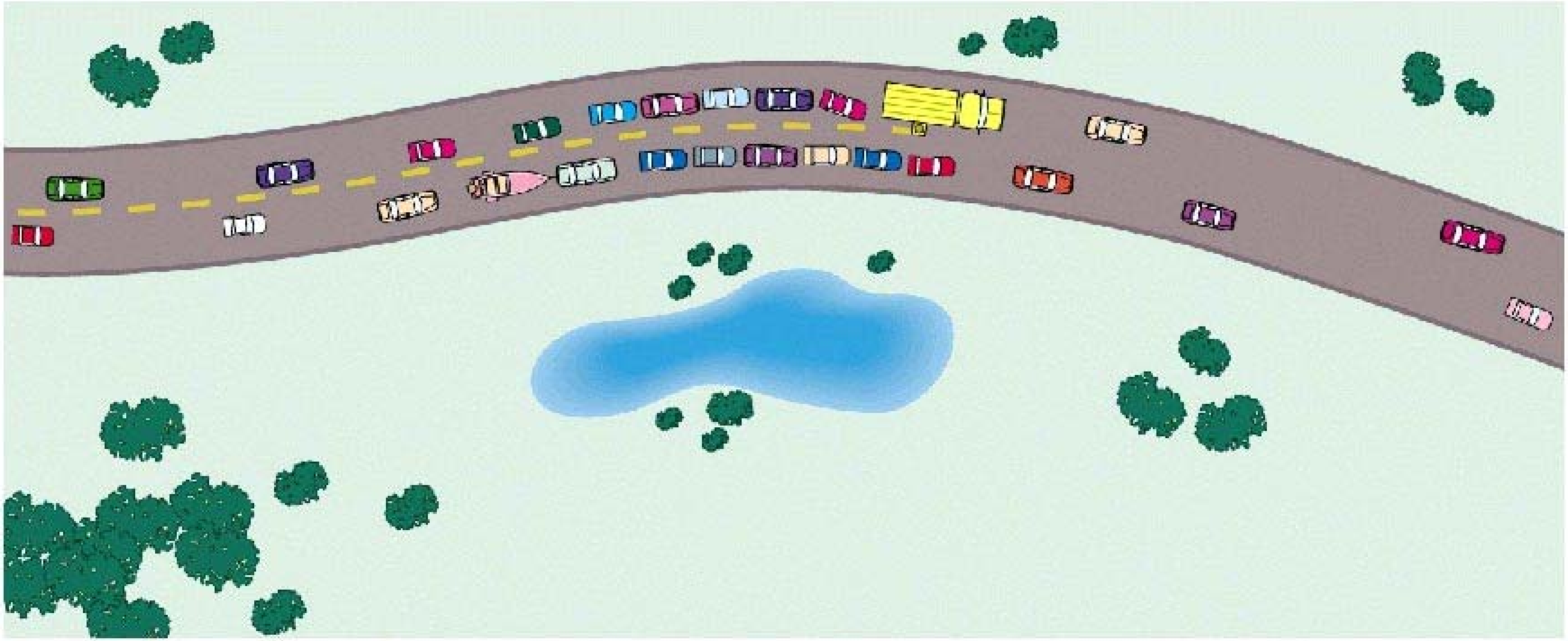


Our Sun orbits with P~200 Myr

The MWG is ~14 Gyr old…..

(G⇒ “giga” =“billion”)

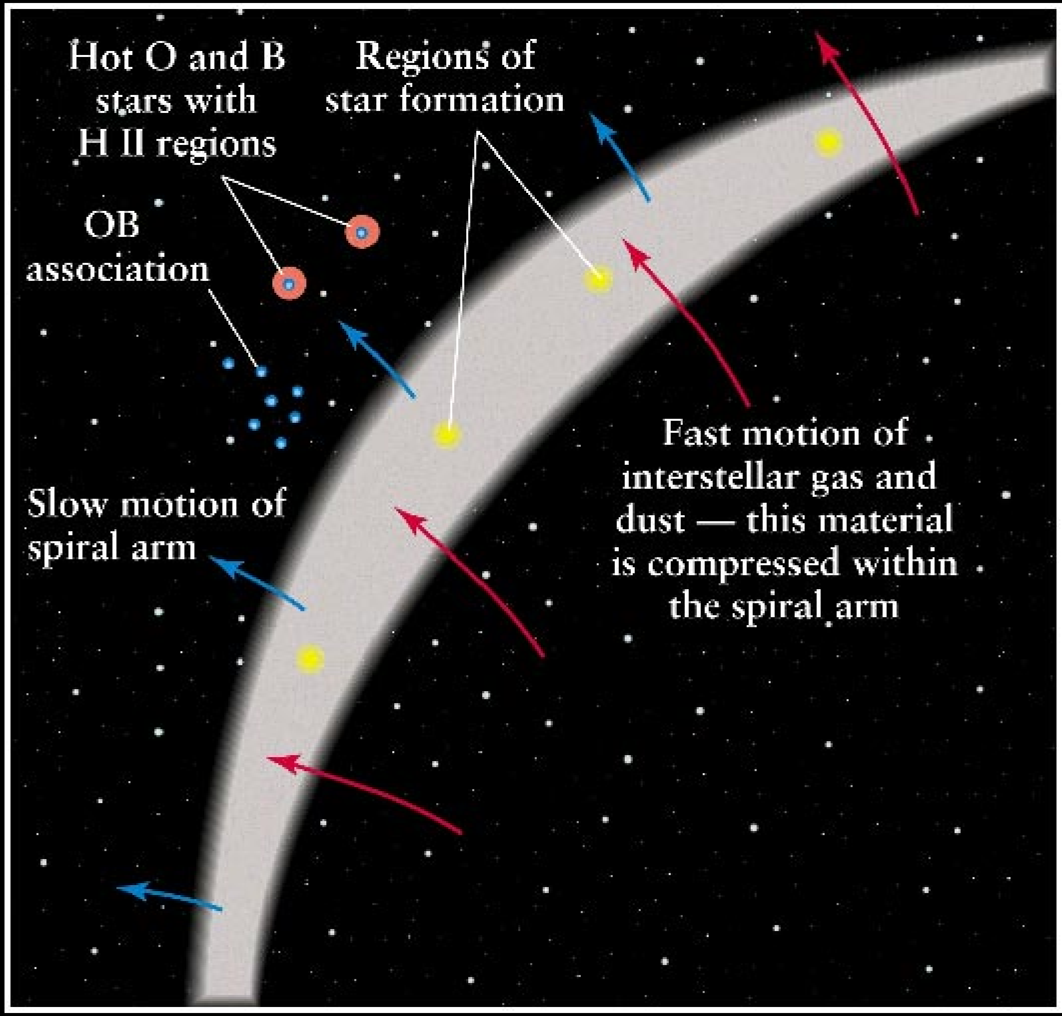
Spiral arms are caused by density waves that sweep around the Galaxy.



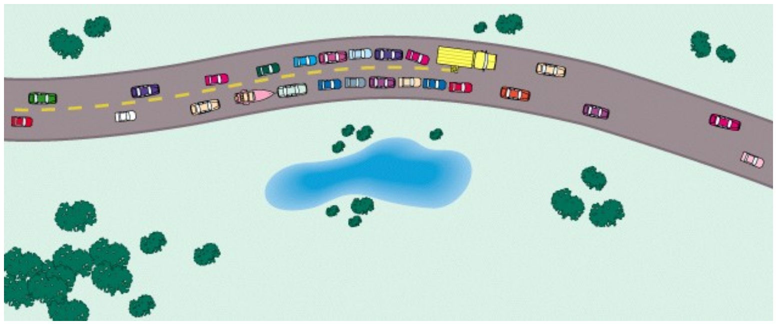
Concept of a "density wave" applied to traffic. Density waves make matter pile up at some places and free it at other places. In our Galaxy, gas and dust piles up "in the spiral arms."

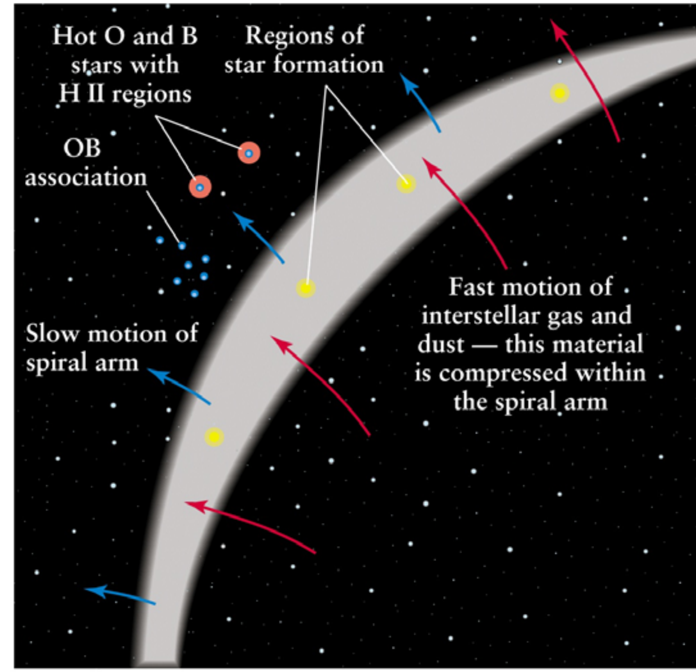
Spiral arms are caused by density waves that sweep around the Galaxy.

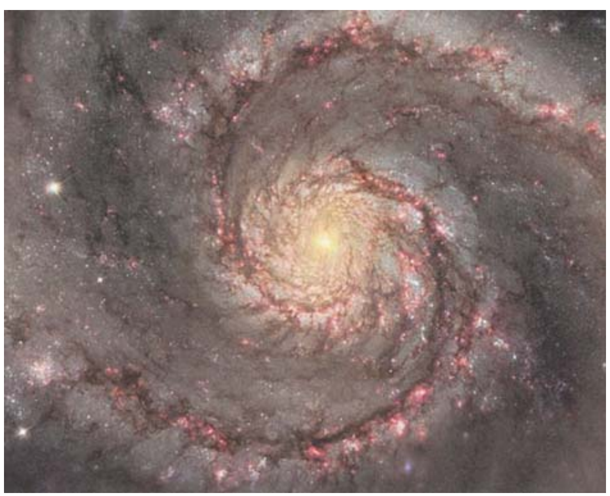
Density waves make matter pile up at some places and free it at other places. In our Galaxy, gas and dust piles up "in the spiral arms" which initiates rapid star formation.



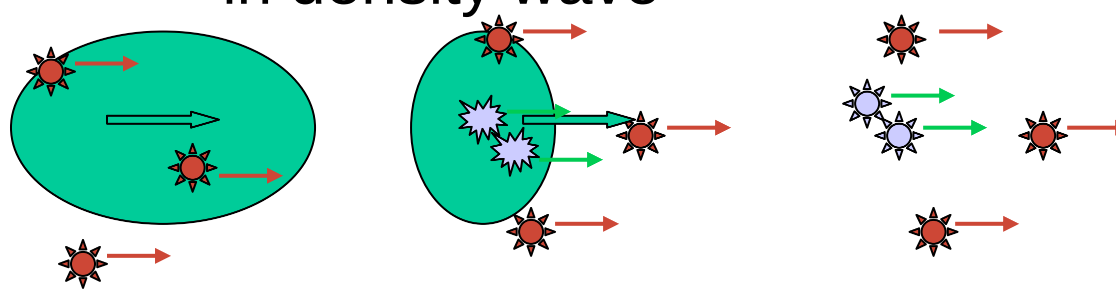
Spiral Density Wave







Gas compression in density wave

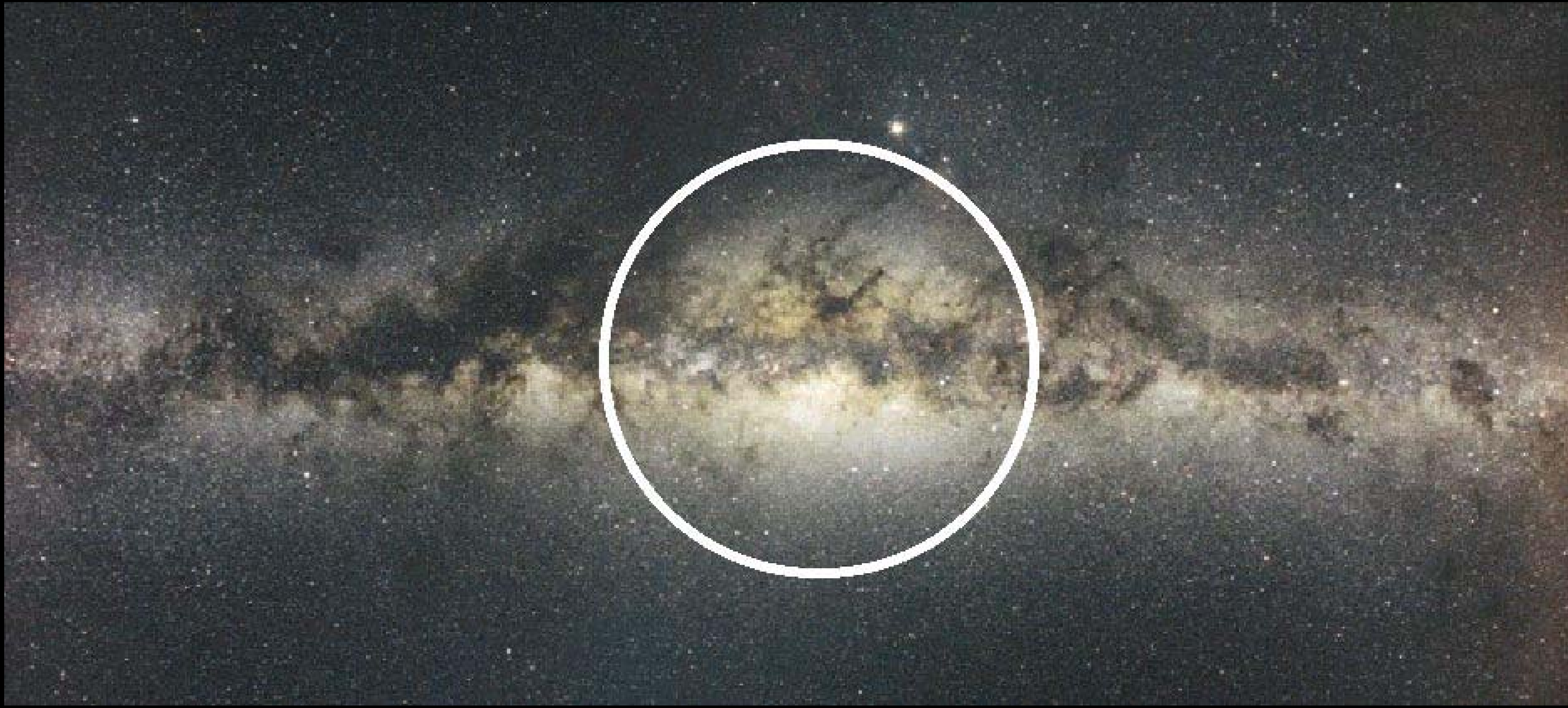


Stars & low density gas

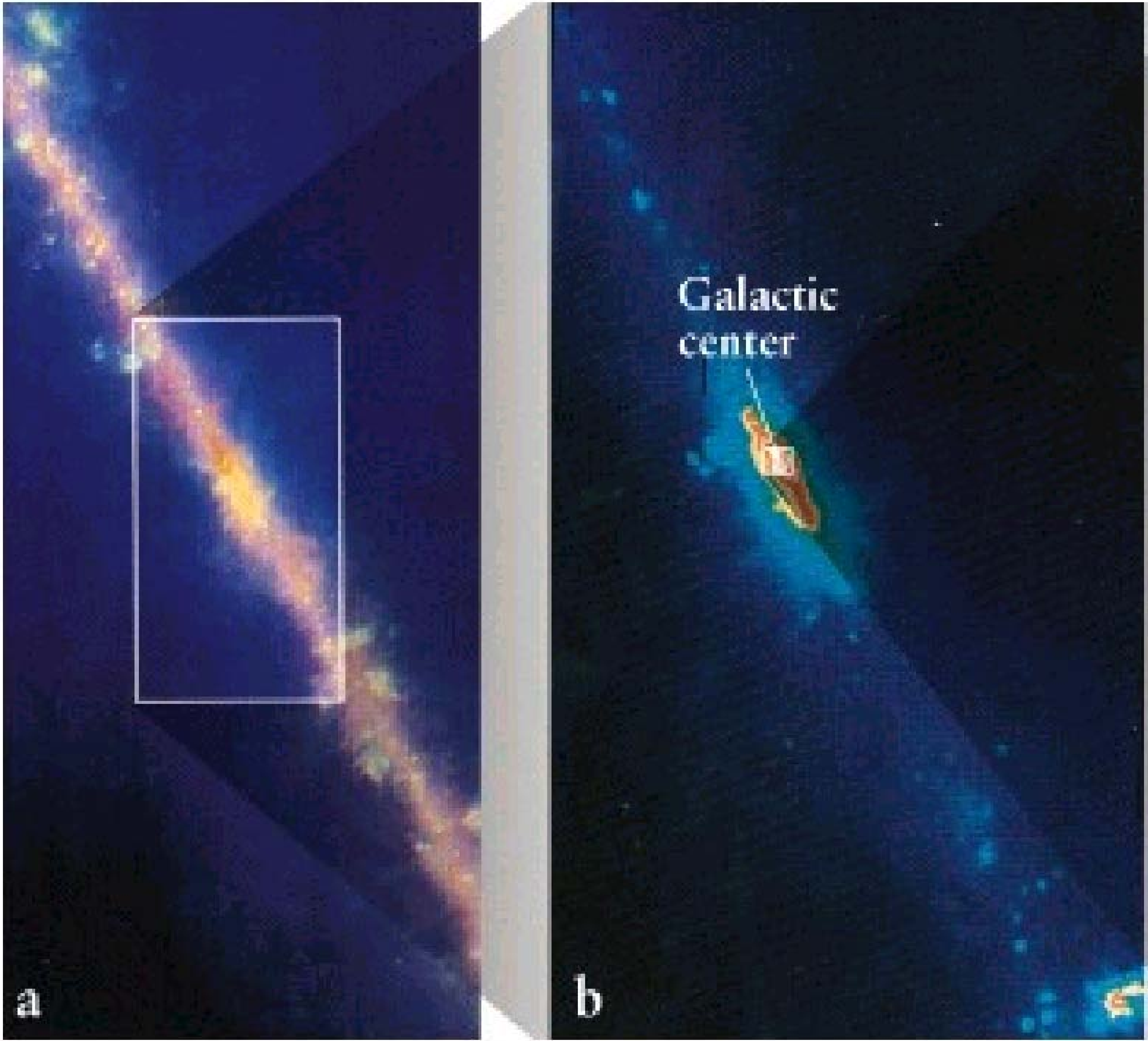
New stars exit with old

Infrared and radio observations are used to probe the galactic nucleus.

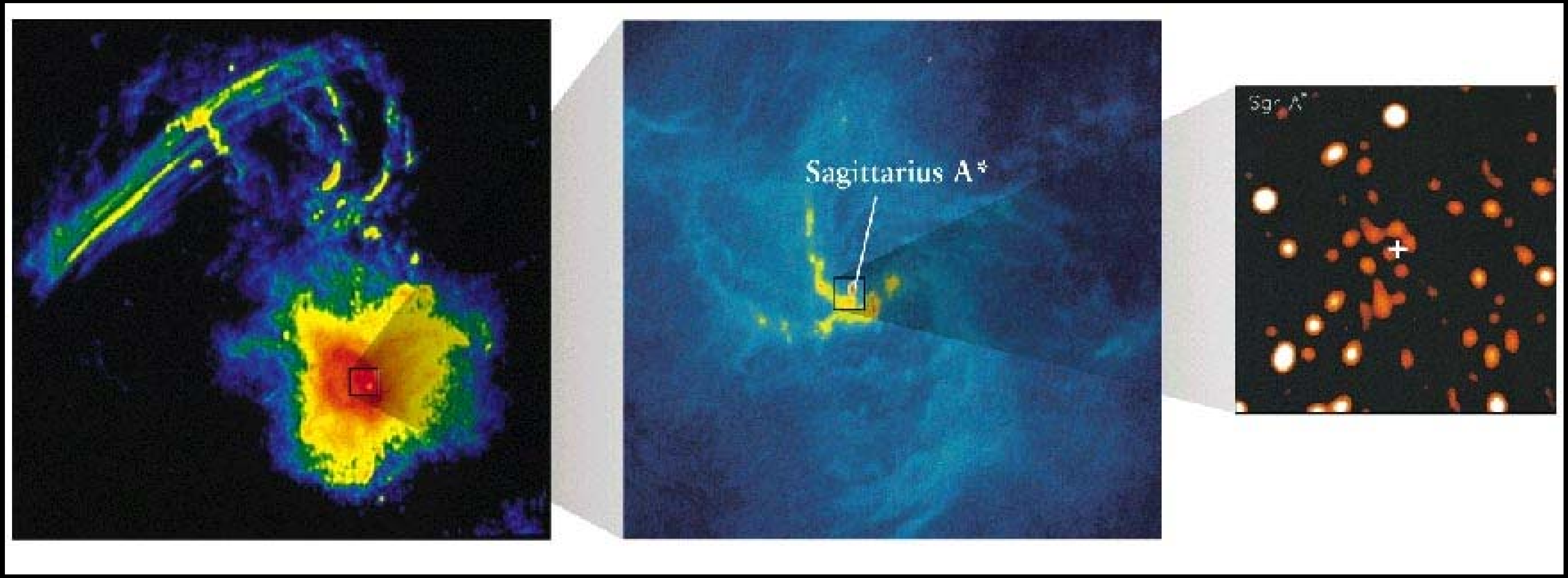
- *The center is located near the constellation of Sagittarius where dust and gas obscures our view.*

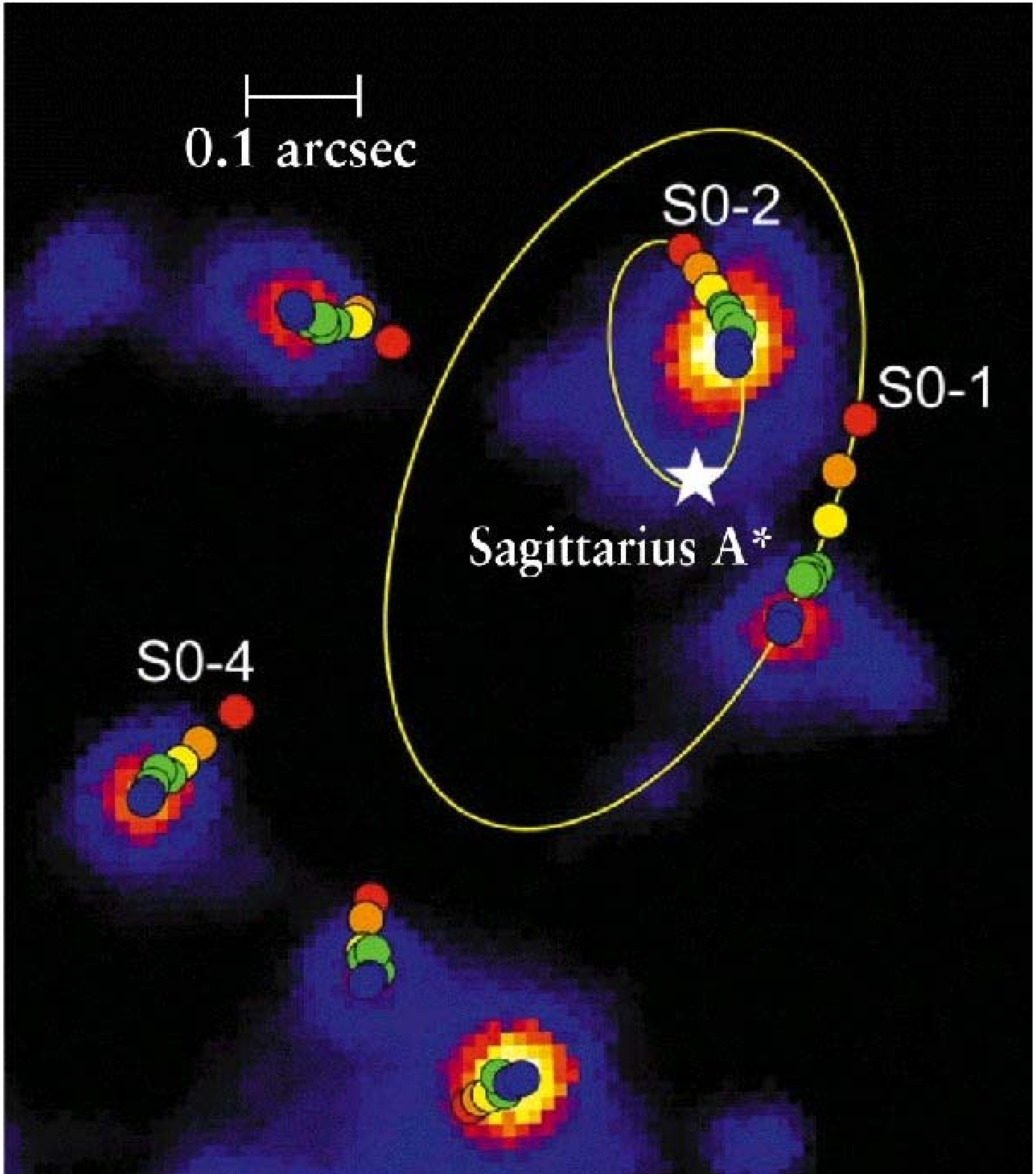


Infrared and radio observation are used to probe the galactic nucleus.



Infrared and radio observations are used to probe the galactic nucleus.





The colored dots superimposed on this infrared image show the rapid motions of stars around the galactic center. These can only be accounted for by *Sag A** being an invisible supermassive black hole.

- 1995
- 1996
- 1997
- 1998
- 1999

Hubble devised a system for classifying galaxies according to their appearance

Spirals

- Barred Spirals
- Ellipticals
- Irregulars

Hubble devised a system for classifying galaxies according to their appearance

Sa NGC 1357

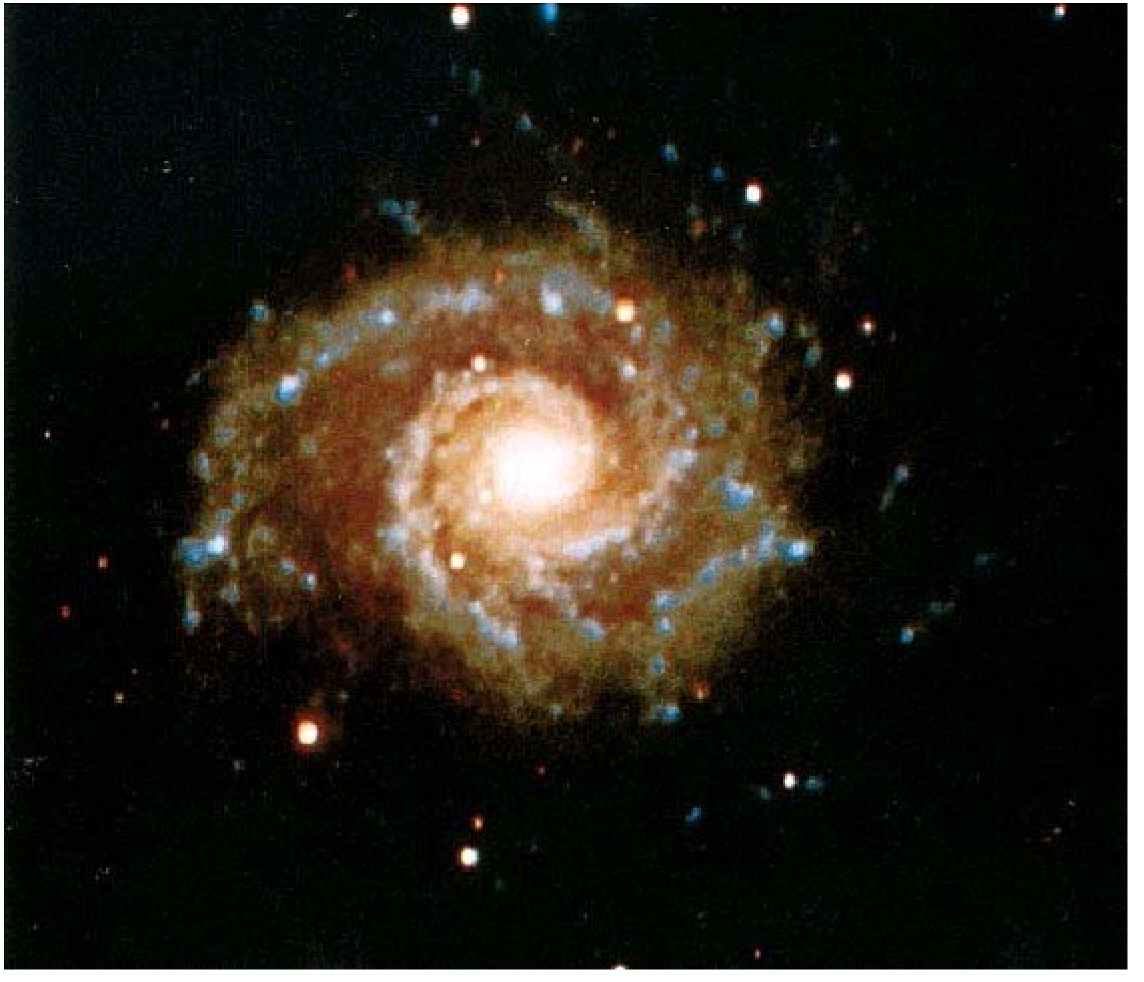
Sb M81

Sc NGC 4321

SPIRALS

We easily see these spiral arms because they contain numerous bright O and B stars which illuminate dust in the arms.

However, stars in total seem to be evenly distributed throughout the disk.



Hubble devised a system for classifying galaxies according to their appearance


SBa NGC 4650


SBb M83


SBc NGC 1365

BARRED SPIRALS

Hubble devised a system for classifying galaxies according to their appearance


E0 M105

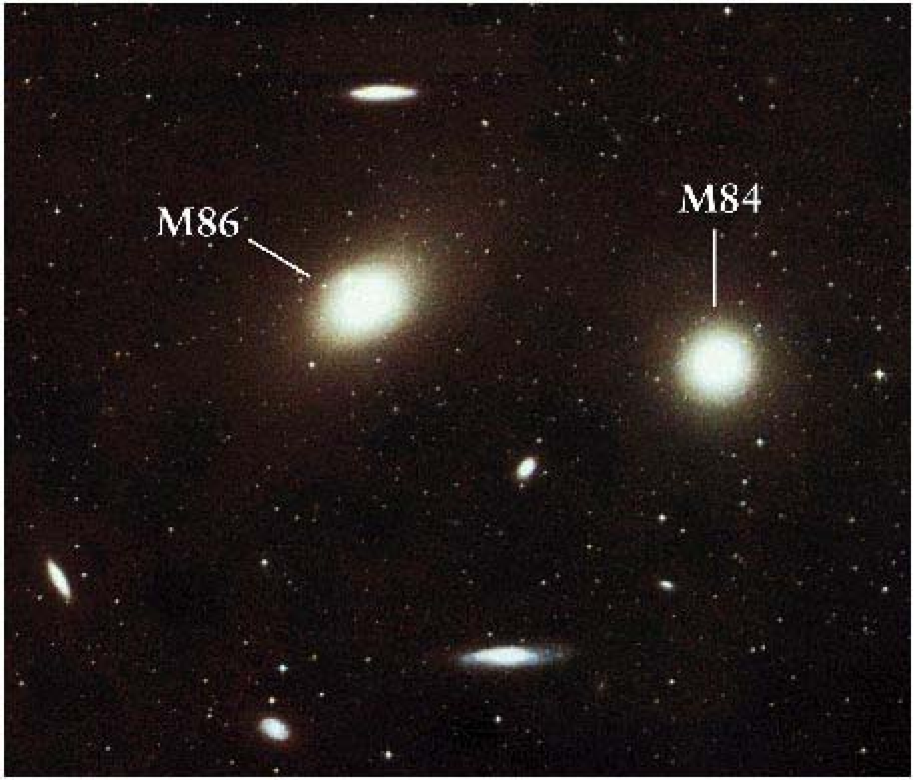

E3 NGC 4365


E6 NGC 3377

ELLIPTICALS

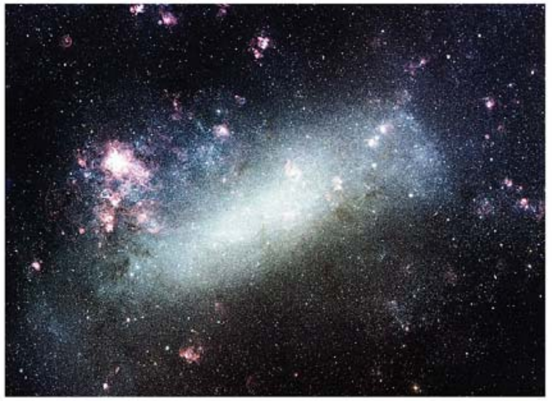
Elliptical galaxies display a variety of sizes and masses.

- ***Giant elliptical galaxies*** can be 20 times larger than the Milky Way.
- ***Dwarf elliptical galaxies*** are extremely common and can contain as few as a million stars.



Irregular Galaxies

- "none of the above" category; neither spiral nor elliptical
- appear white & dusty with ISM
  - have more in common with the disk component of spirals
- distant galaxies are more likely to be irregular
  - they were more common when the Universe was young



Hubble devised a system for classifying galaxies according to their appearance

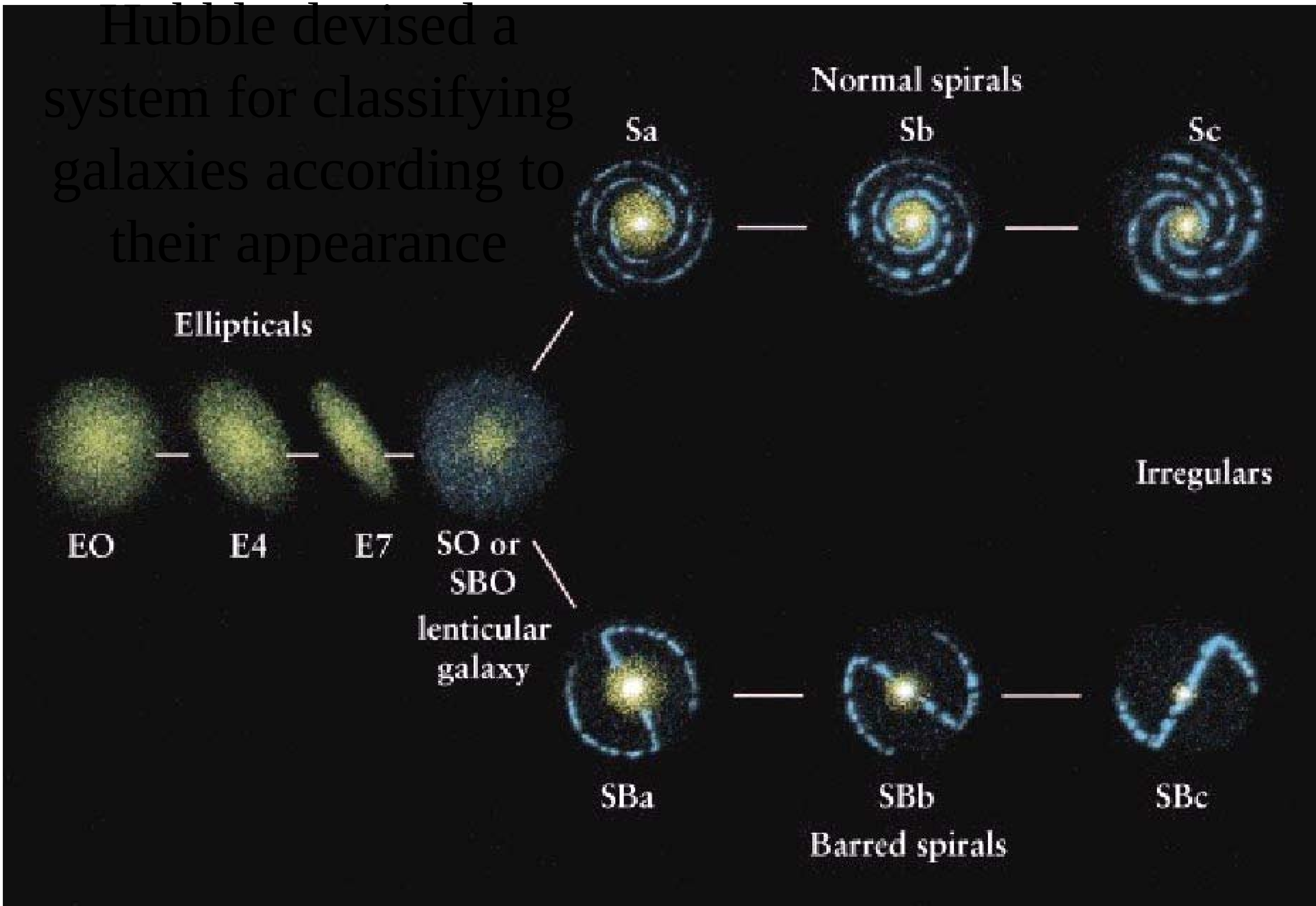


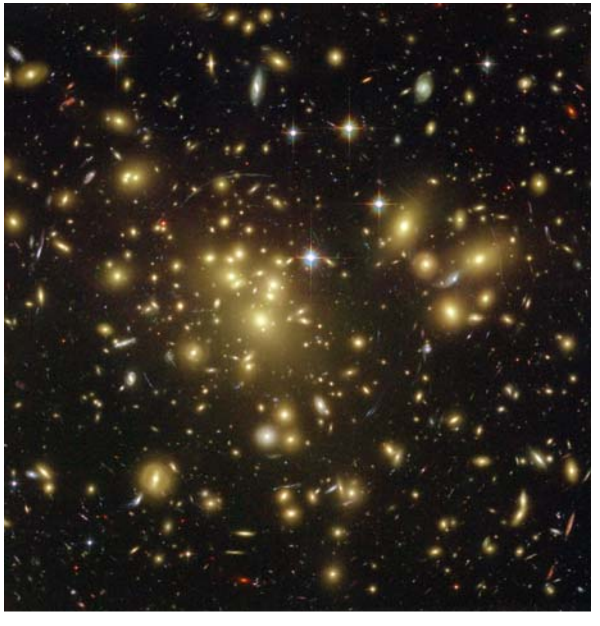
Table 26-1 Some Properties of Galaxies

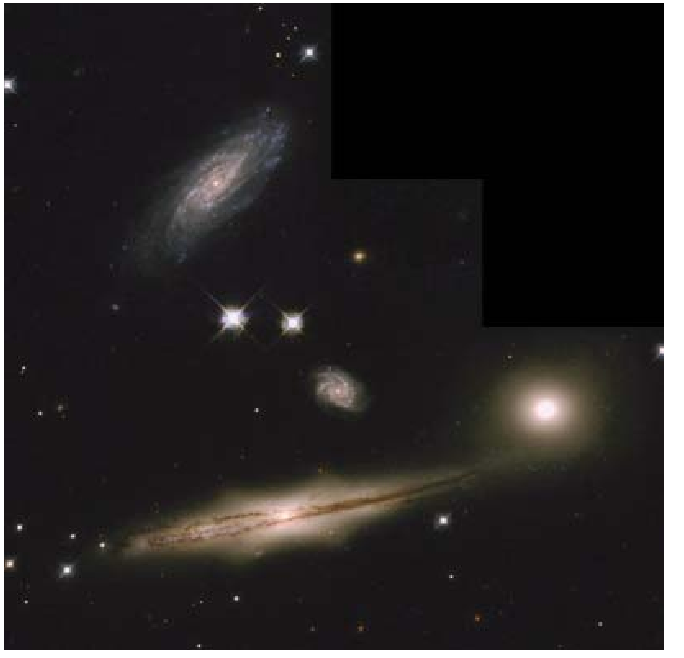
	Spiral (S) and barred spiral (SB) galaxies	Elliptical galaxies (E)	Irregular galaxies (Irr)
Mass ($M_{\odot}$)	10^9 to 4×10^{11}	10^5 to 10^{13}	10^8 to 3×10^{10}
Luminosity ($L_{\odot}$)	10^8 to 2×10^{10}	3×10^5 to 10^{11}	10^7 to 10^9
Diameter (kpc)	5 to 250	1 to 200	1 to 10
Stellar populations	disk: young Population I central bulge and 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 may be higher than shown here.*

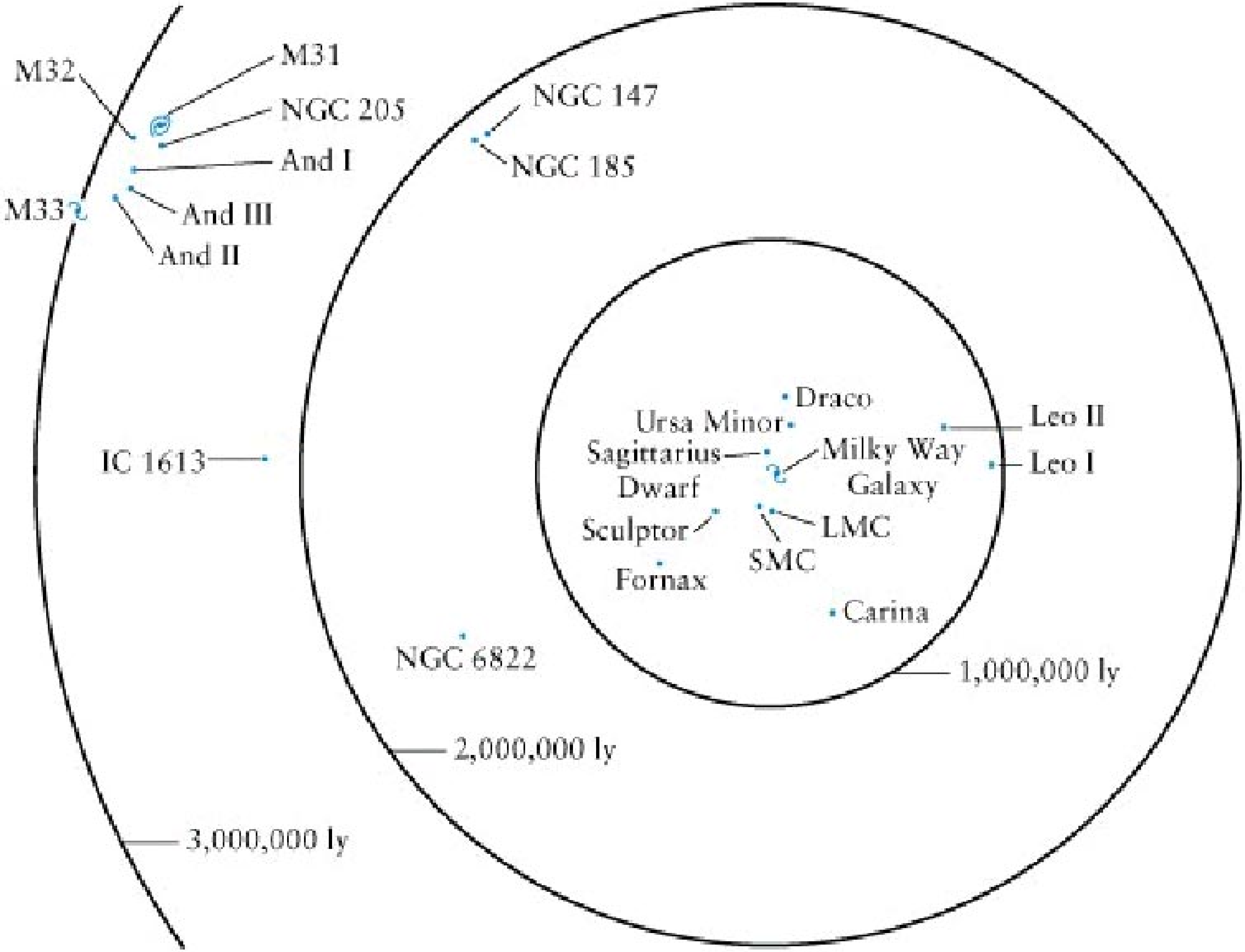
Groups and Clusters

- Among large galaxies…
  - most (75–85%) are spirals
  - they tend to associate in loose **groups** of several galaxies
- Our Local Group is an example
  - dominated by two large spirals
    - the Milky Way
    - Great Galaxy in *Andromeda*

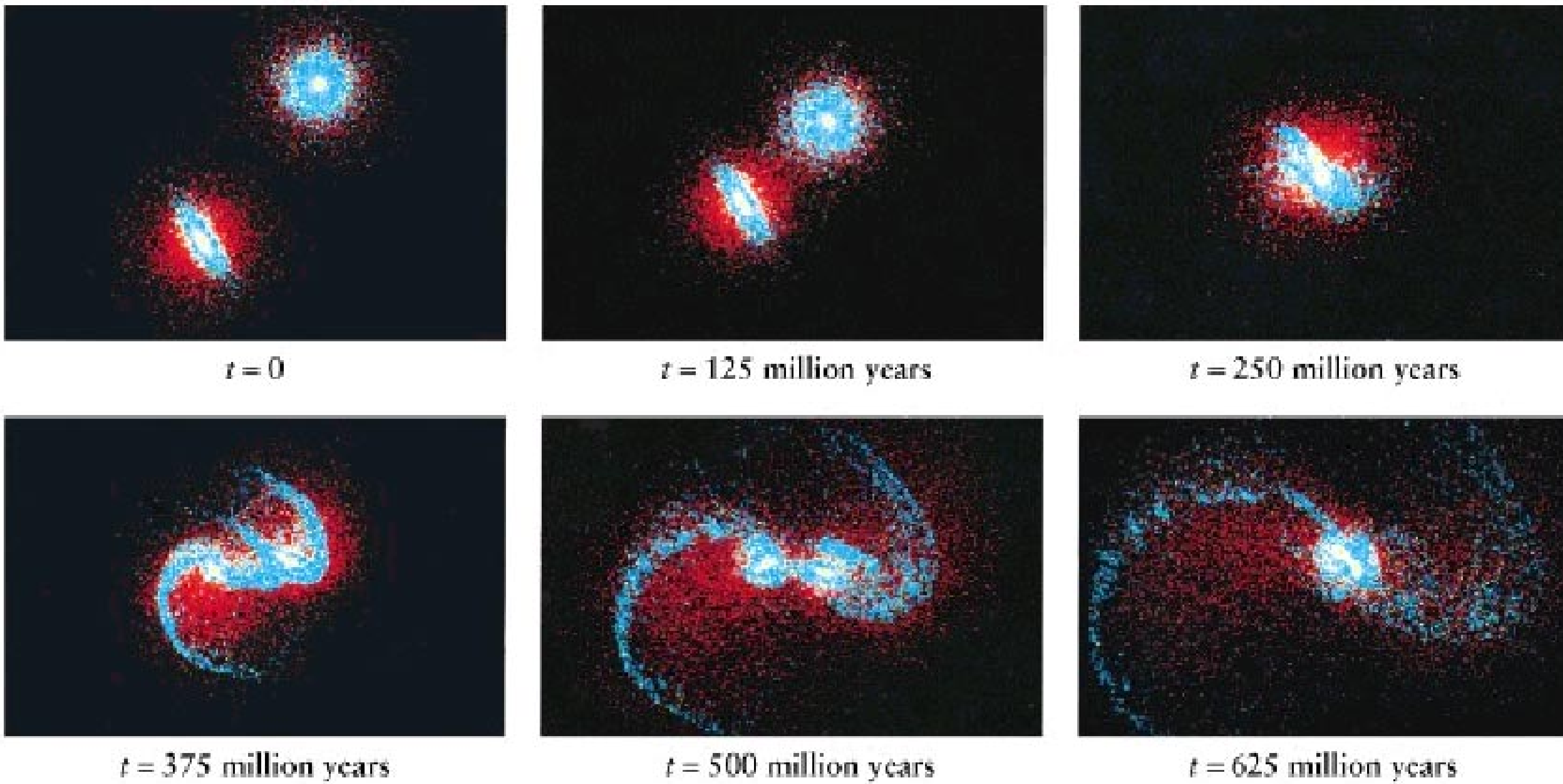




- Some galaxies associate in tightly bound **clusters**.
  - contain hundreds of galaxies
  - half of all large galaxies are elliptical
- Outside of clusters…
  - large ellipticals are rare (15%)
  - most dwarfs are elliptical

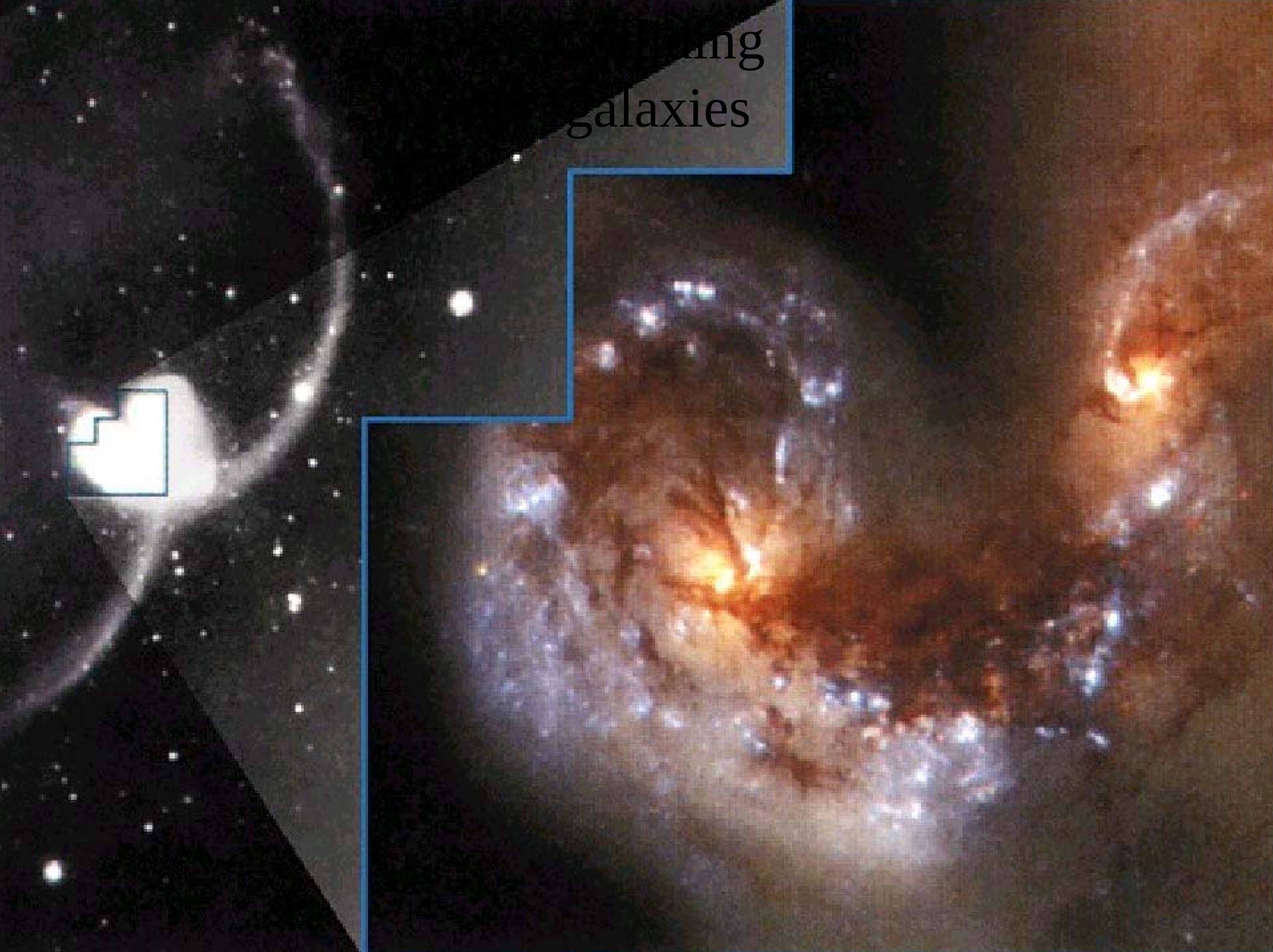

M32
M31
NGC 205
And I
M33
And III
And II
NGC 147
NGC 185
Draco
Ursa Minor
Leo II
Sagittarius Dwarf
Milky Way Galaxy
Leo I
IC 1613
Sculptor
LMC
SMC
Fornax
Carina
NGC 6822
1,000,000 ly
2,000,000 ly
3,000,000 ly

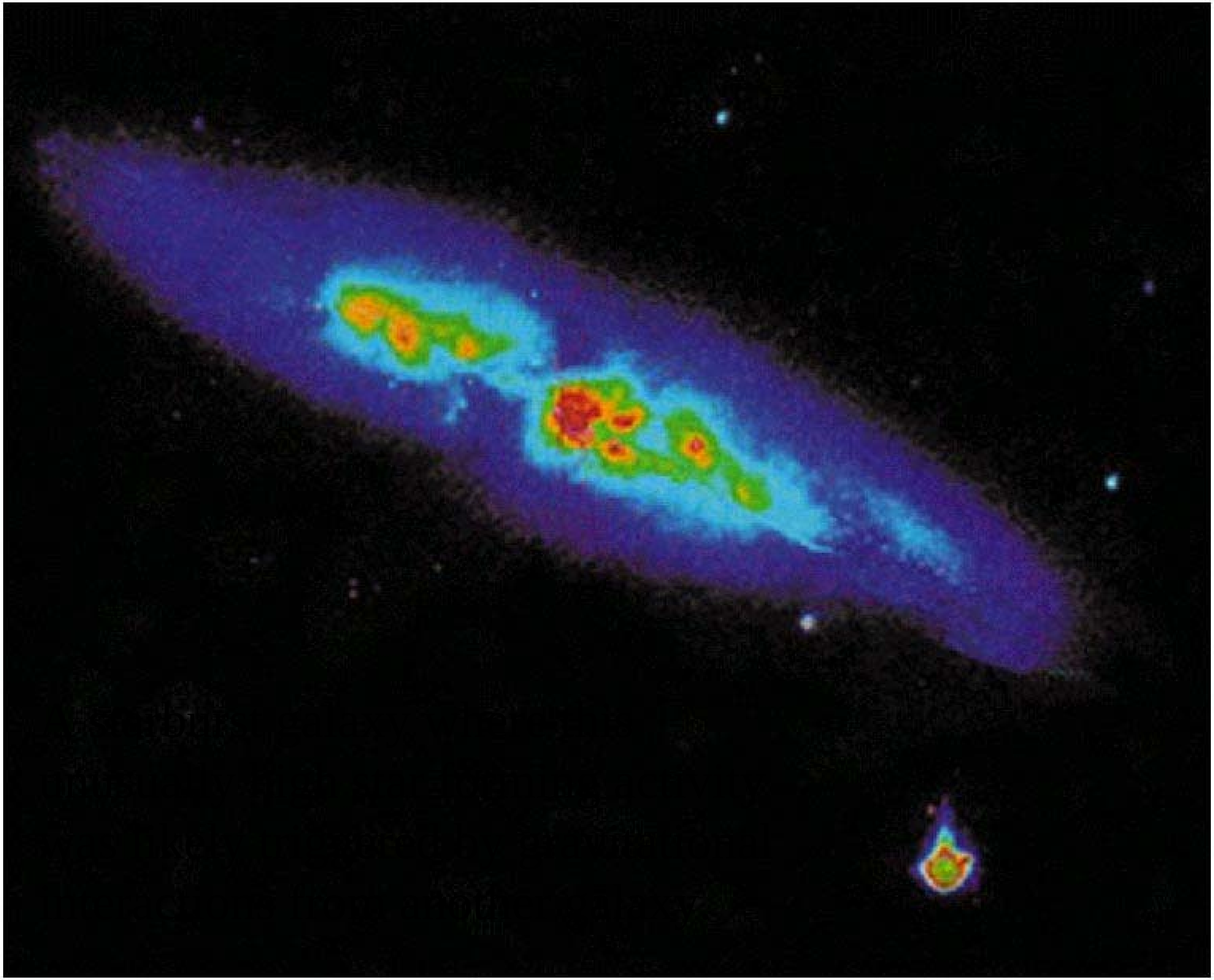
Colliding galaxies produce starbursts, spiral arms, and other spectacular phenomena.



There is so much space between stars in a galaxy that the probability of two stars crashing into each other is extremely small.

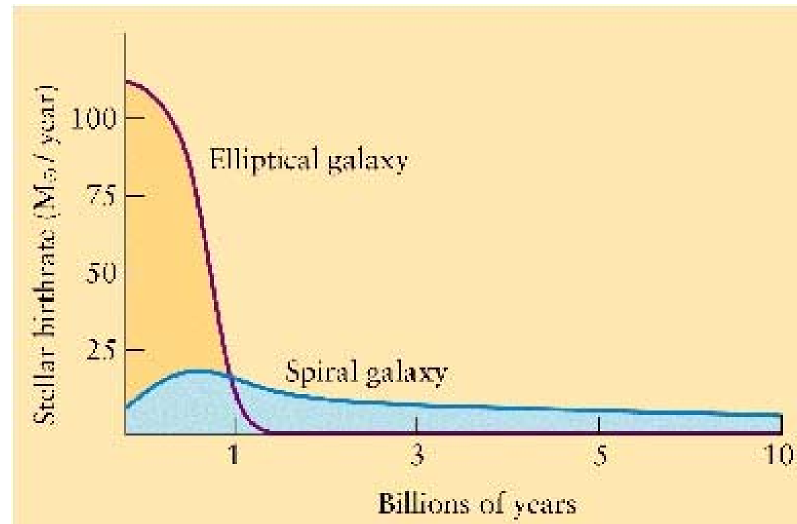
Colliding galaxies





Galaxies may have formed from the merger of smaller objects.

- Galaxies were “bluer” in the past.
- Spiral galaxies were more common in the past.



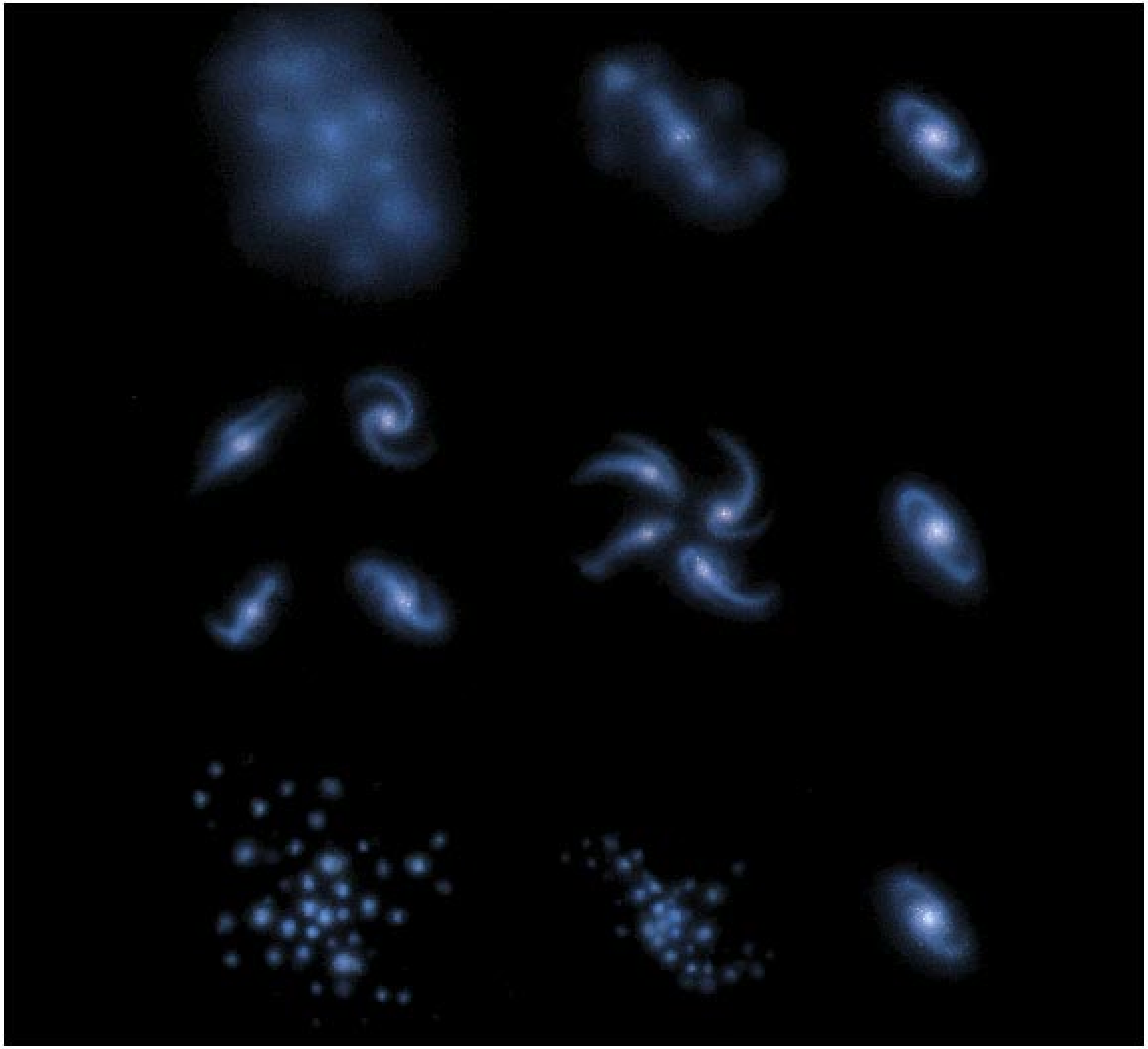
- Galactic collisions and mergers have probably depleted most rich clusters of spiral galaxies leaving dimmer ellipticals behind.

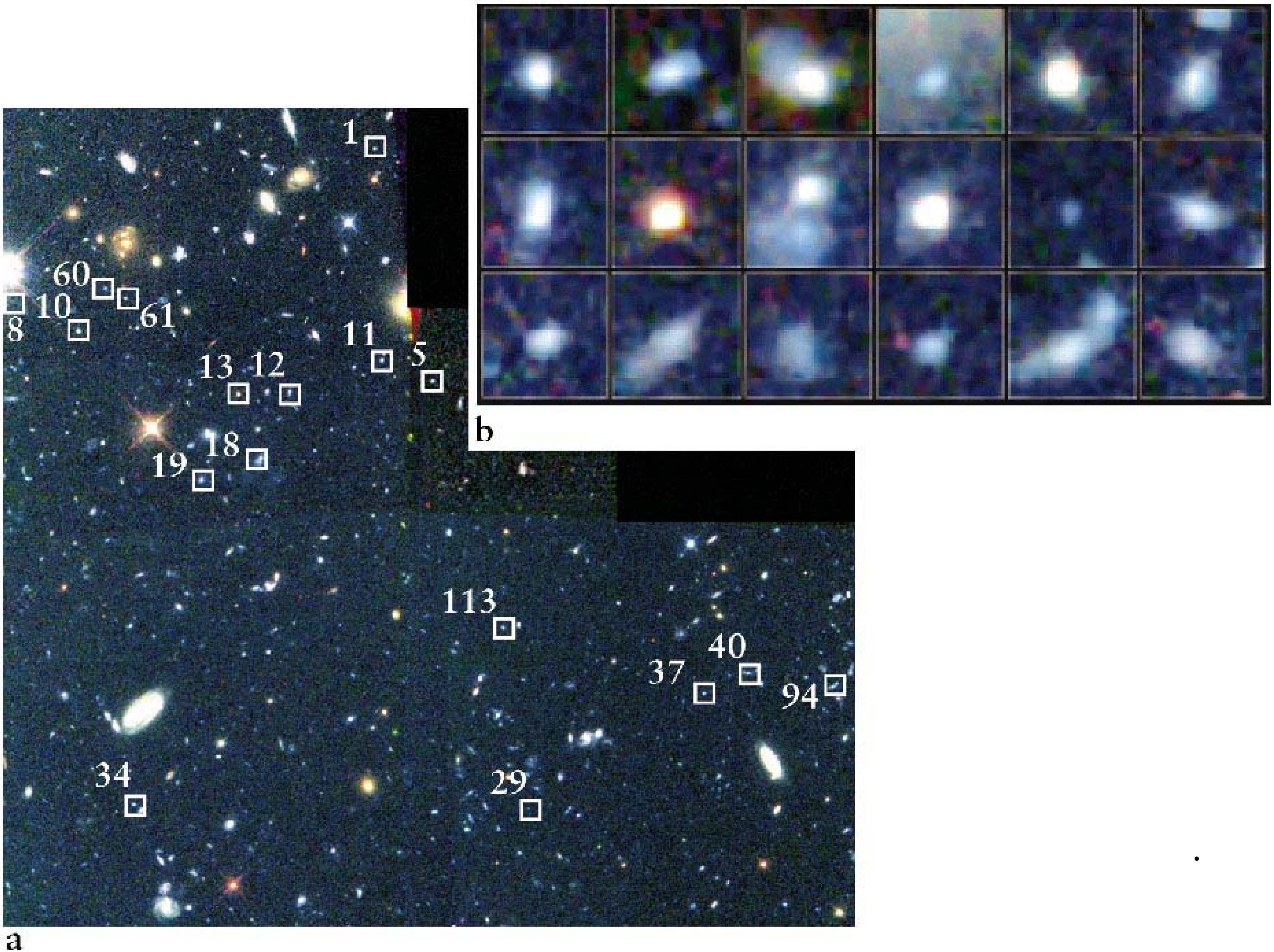
Three separate theories of galaxy formation:

Single, huge cloud condenses.

Several moderate-sized clouds contract to form a single galaxy.

Numerous small clouds condense.




1
60
10
61
8
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13
12
18
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113
40
37
94
34
29
a
b

Galaxy Evolution