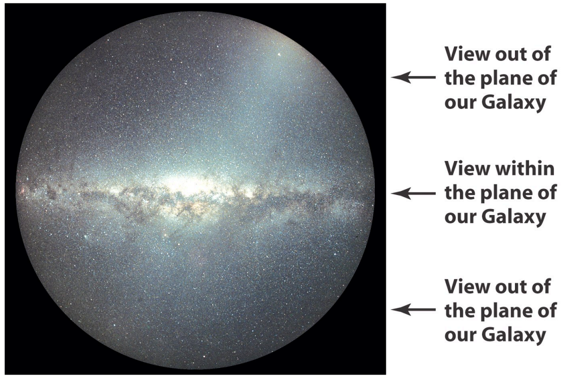
Lecture 12: Galaxies

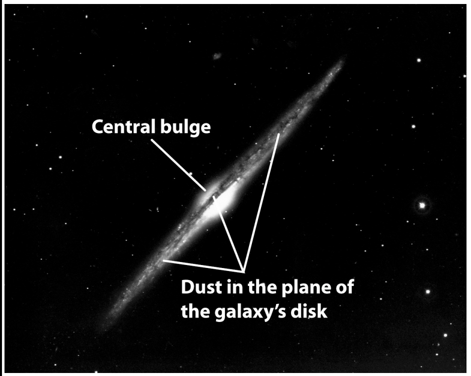
- The Milky Way galaxy
- Rotation curves and dark matter
- External galaxies and the Hubble classification scheme

View of the Galaxy from within



- Plotting the sky brightness in galactic coordinates, we see that the stars form a band across the sky, suggesting that we are embedded within a stellar disk.
- Interstellar dust absorbs light in the plane of the galactic disk.

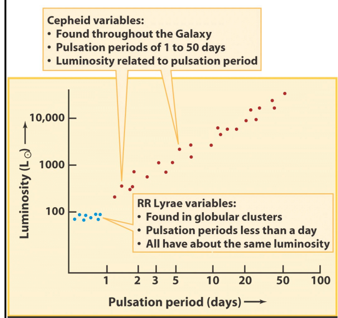
Comparison to an external disk galaxy

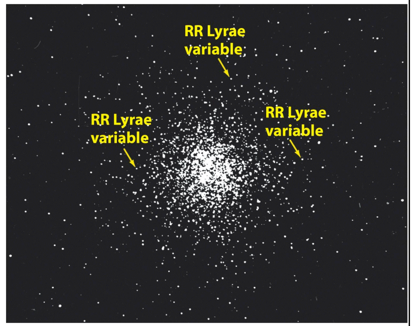


NGC 4565 - an edge-on disk galaxy

- An edge-on disk galaxy like NGC 4565 looks very similar.
- Most stars are located in a central bulge and a dusty surrounding disk.
- There is also a more extended, roughly spherical halo of old stars and globular clusters.

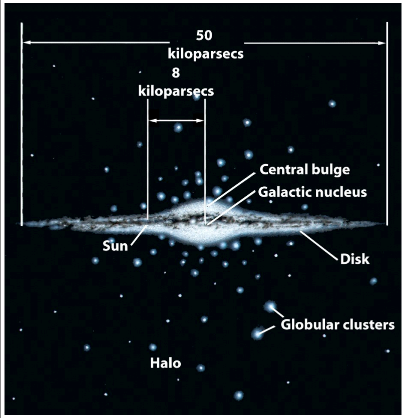
Where do we lie in our Galaxy?





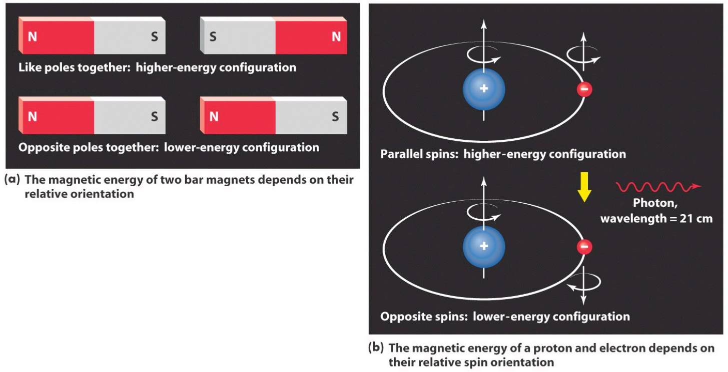
- By plotting the distances of globular clusters (estimated using regular variable stars) we can determine the sun's location relative to the stellar halo of the Galaxy.
- We conclude that our Sun lies within the galactic disk, some 8000 pc (26,000 ly) from the Galactic centre.

The structure of our Galaxy



- Our Galaxy contains around 2×10^{11} stars.
- It has a disk about 25 kpc (80,000 ly) in radius and about 600 pc thick, with interstellar dust and gas strongly concentrated in the disk plane.
- The Sun orbits around the Galactic centre at a speed of about 220 km s^{-1}.
- It takes about 220 million years to complete one orbit

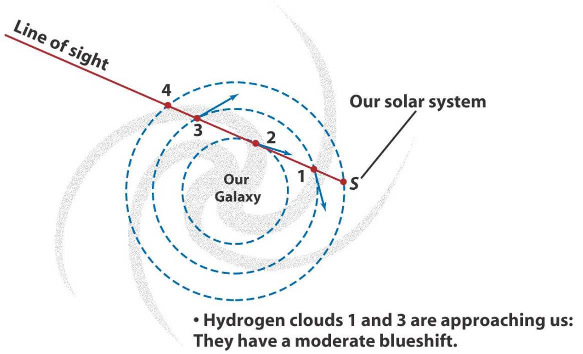
The spin-flip transition in neutral hydrogen emits 21 cm radio waves



(a) The magnetic energy of two bar magnets depends on their relative orientation

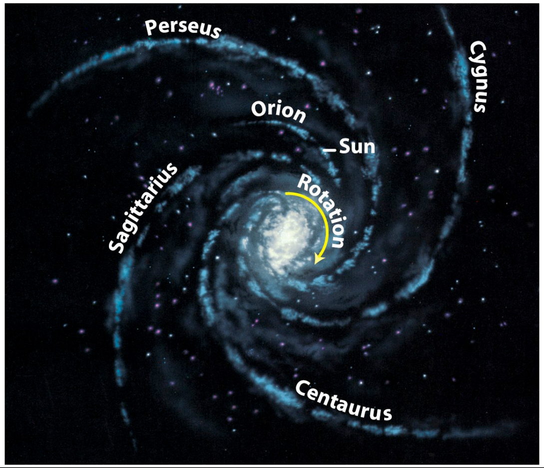
(b) The magnetic energy of a proton and electron depends on their relative spin orientation

Spiral arms can be traced from the positions of clouds of atomic hydrogen



- Hydrogen clouds 1 and 3 are approaching us: They have a moderate blueshift.
- Hydrogen cloud 2 is approaching us at a faster speed: It has a larger blueshift.
- Hydrogen cloud 4 is neither approaching nor receding: It has no redshift or blueshift.

OB associations, H II regions, and molecular clouds in the galactic disk outline the spiral arms

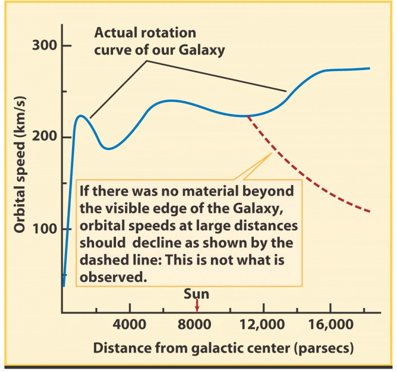


The rotation of our Galaxy reveals the presence of dark matter

From studies of the rotation of the Galaxy, astronomers estimate that the total mass of the Galaxy is about $10^{12}\ M_{\odot}$

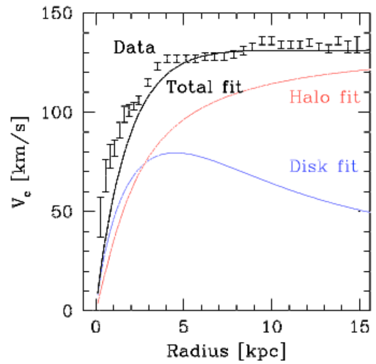
$$M = \frac{rv^2}{G}$$

Where
M is the mass within radius *r*,
v is the circular velocity at radius *r*



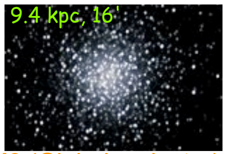
Rotation curves of other galaxies

- It is actually easier to derive rotation curves for external galaxies.
- These can then be fitted by combining the expected gravitational effects due to the mass of the stars in the disk and bulge of the galaxy, plus a hypothetical halo of dark matter.
- Such studies show that the total mass of a galaxy is *dominated* by dark matter.



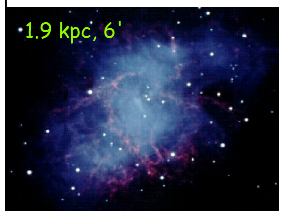
Rotation curve for NGC 2403, with fitted model

Fuzzy objects in the sky

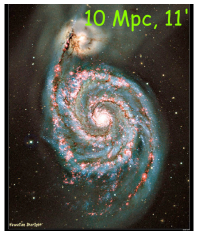


M3 (Globular cluster)

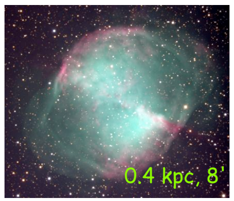
Charles Messier
(1730-1817)



M1 (Crab)



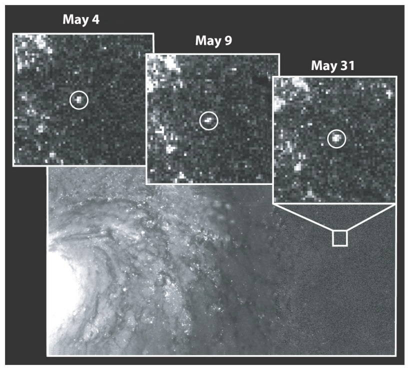
M51 (galaxy)



M27 (Planetary nebula)

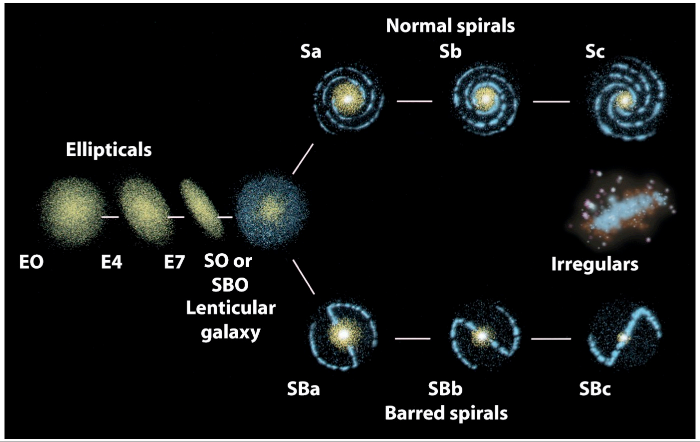
Very different objects!

Hubble showed that the spiral nebulae are far beyond the Milky Way



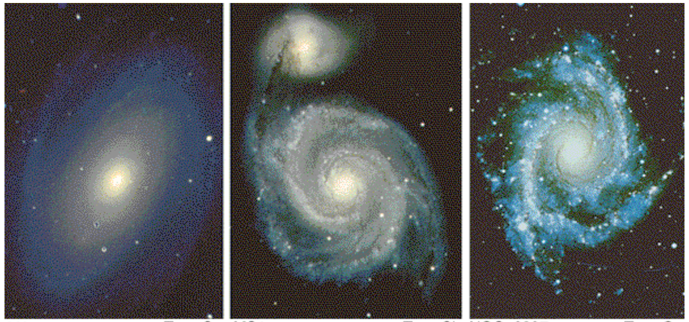
- Edwin Hubble used Cepheid variables to show, in the 1920s, that the “spiral nebulae” were actually distant star systems, similar in size to our own Galaxy.

The Hubble "tuning fork" classification of galaxies



Spiral Galaxies: Sa, Sb, and Sc

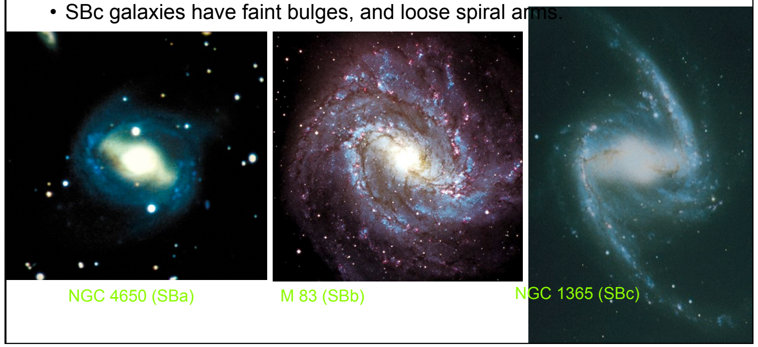
Spiral galaxies have a bulge, a disk, spiral arms, and a halo.
- Sa galaxies have a bright bulge with tightly wound spiral arms.
- Sb galaxies have fainter bulges and more loosely wound spiral arms.
- Sc galaxies have faint bulges, and blue, loosely wound spiral arms.



M81 Type Sa MS1 Type Sb NGC 2997 Type Sc

Barred Spiral Galaxies: SBa, SBb, and SBc

Barred spiral galaxies have a bulge, a bar through the galactic center, and spiral arms which start at the ends of the bar.
- SBa galaxies have a bright bulge and bar with faint, tightly wound spiral arms.
- SBb galaxies have fainter bulges and looser spiral arms.
- SBc galaxies have faint bulges, and loose spiral arms.



NGC 4650 (SBa) M 83 (SBb) NGC 1365 (SBc)

Galaxies can be grouped into four major categories: spirals, barred spirals, ellipticals, and irregulars

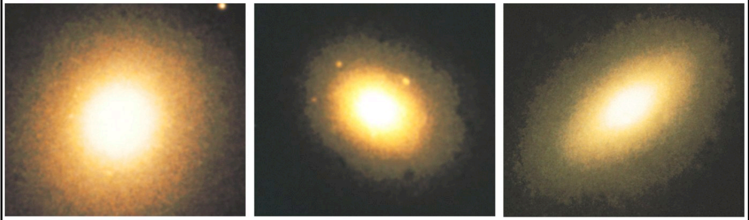
table 26-1 Some Properties of Galaxies

	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	Spiral arms: young Population I Nucleus and throughout disk: 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.*

- In addition, there are lenticular (S0) galaxies, which are intermediate between spirals and ellipticals.
- Note that "Population I" and "Population II" refer to young and old stellar populations, respectively.

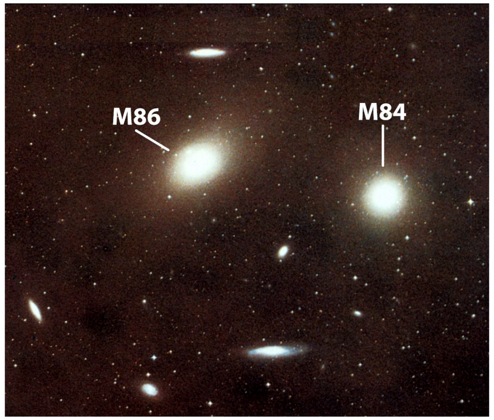
Elliptical galaxies are nearly devoid of interstellar gas and dust, and so have little star formation



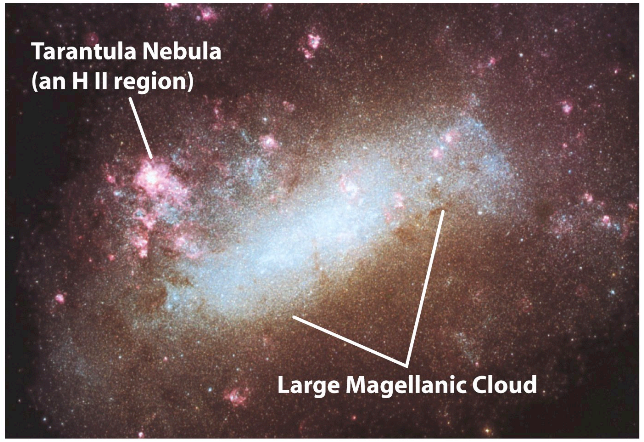
(a) E0 (M105) (b) E3 (NGC 4365) (c) E6 (NGC 3377)

- Due to the lack of recent star formation, elliptical galaxies contain mostly old, rather red stars (population II).
- They do not have spiral arms, but are usually rather featureless spheroidal systems, with shapes classified along a scale from E0 (spherical) to E7 (highly elongated).

Giant elliptical galaxies are found in galaxy clusters like the Virgo cluster

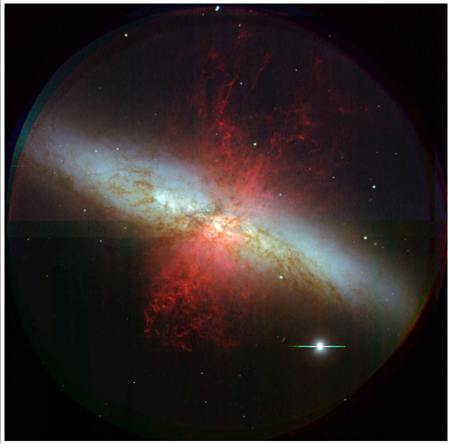


Irregular galaxies have ill-defined, asymmetrical shapes



They are often disturbed in some way.

The irregular galaxy M82



M82 is a well known irregular galaxy full of hot stars and emission nebulae.

The galaxy is experiencing a violent central burst of star formation. It is called a starburst galaxy.

The resulting supernovae heat the interstellar gas, which then escapes from the galaxy in a hot wind (red filaments).