Lecture 33: Announcements

1) Pick up graded hwk 5. Good job: Jessica, Jessica, and Elizabeth for a 100% score on hwk 5 and the other 25% of the class with an A.

2) Article and homework 7 were posted on class website on Monday (Apr 18) . Due on Mon Apr 25.

3) Reading Assignment for Quiz Wed Apr 27 Ch 23, Cosmic Perspectives: The Beginning of Time

4) Exam moved to Wed May 4

Lecture 33: Galaxy Formation and Evolution

Several topics for galaxy evolution have already been covered in Lectures 2, 3, 4,14,15,16. you should refer to your in-class notes for these topics which include:

- Types of galaxies (barred spiral, unbarred spirals, ellipticals, irregulars)
- The Local Group of Galaxies, The Virgo and Coma Cluster of galaxies
- How images of distant galaxies allow us to look back in time
- The Hubble Ultra Deep Field (HUDF)
- The Doppler blueshift (Lectures 15-16)
- Tracing stars, dust, gas via observations at different wavelengths (Lecture15-16).

In next lectures, we will cover

- Galaxy Classification. The Hubble Sequence
- Mapping the Distance of Galaxies
- Mapping the Visible Constituents of Galaxies: Stars, Gas, Dust
- Mapping the Dark Matter in Galaxies and in the Universe
- Understanding Galaxy Formation and Evolution
- Galaxy Interactions: Examples and Applications to the Milky Way
- The Big Bang
- Fates of our Universe and Dark Energy

Galaxy Classification

Galaxy: Collection of few times (10^8 to 10^{12}) stars orbiting a common center and bound by gravity. Made of gas, stars, dust, dark matter.

There are many types of galaxies and they can be classfiied according to different criteria. If we classify them according to their structure, sizes, total amounts of gas and star formation, we get the following types:

- à Spiral galaxies, Elliptical galaxies,
- à Irregular galaxies, Dwarf galaxies,
- à Peculiar/Interacting galalxies

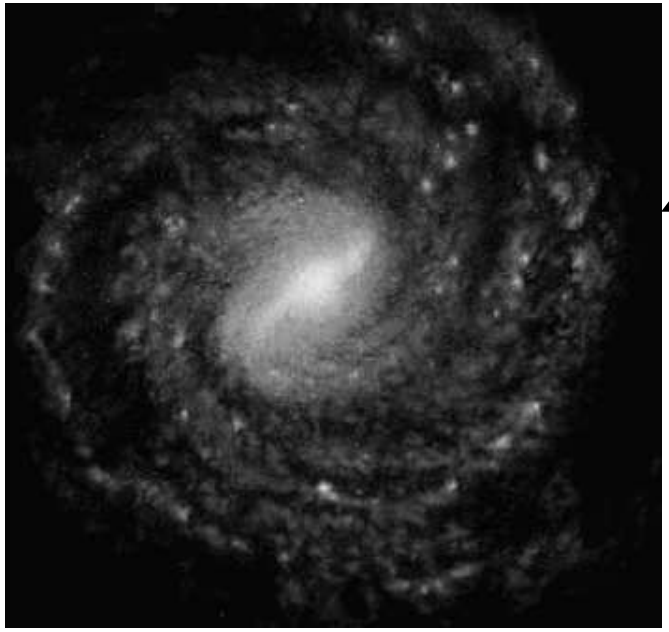
Spiral Galaxies

1) They have a disk component (shaped like a saucer). In the center of the disk, there is sometimes a spheroidal bulge (a melon-shaped component).
2) They contain up to 10^12 stars and lots of gas, dust, ongoing star formation .
3) Most spiral galaxies are barred, meaning that their disk contains an elongated stellar feature called a bar. Bars carry gas from the disk to the center of a spiral galaxy, thus influencing its evolution. Our Milky Way is a barred spiral.

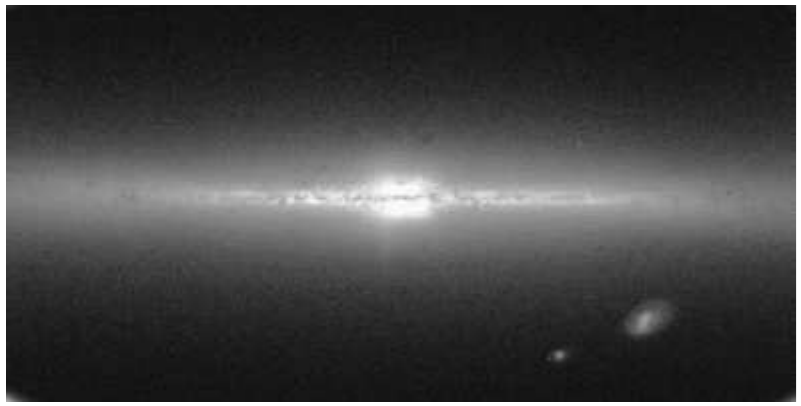
Unbarred spiral (SAab) NGC 4622

Strongly Barred spiral (SBbc) NGC 1300

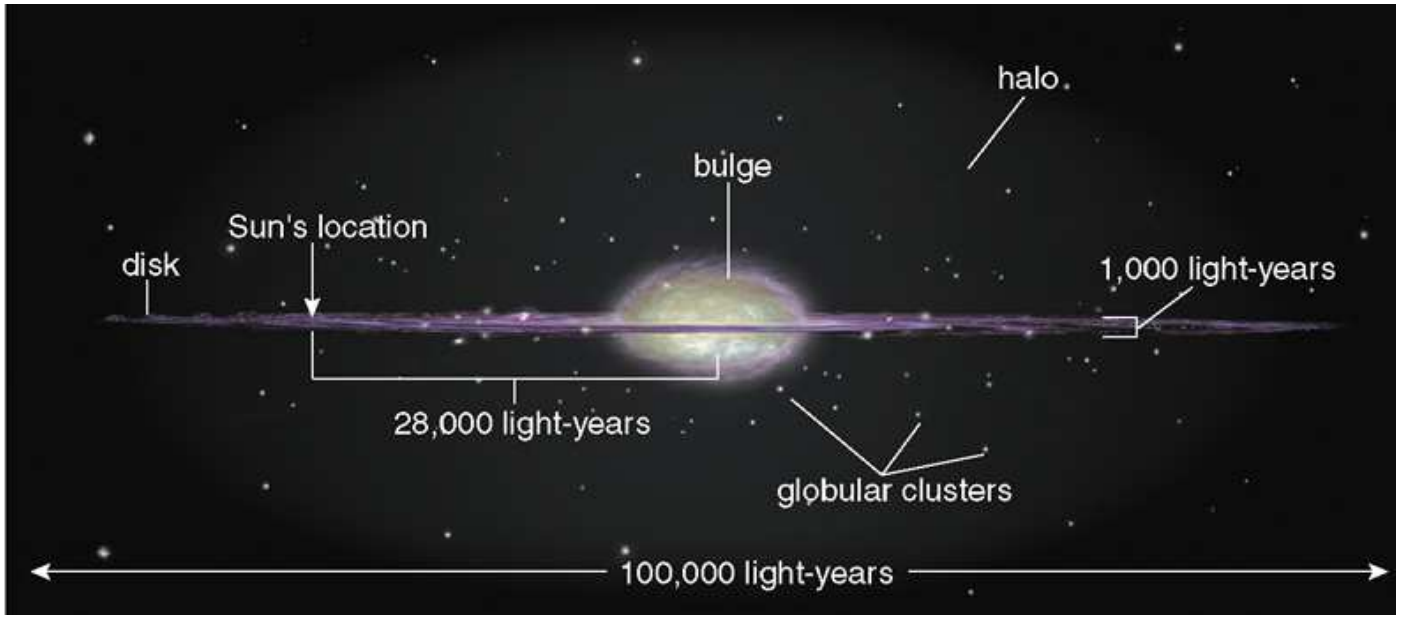
Milky Way = a barred spiral galaxy, hosting our Sun and Solar system



Face-on view
(Artist's conception)



Edge-on view :
Actual infrared image
from COBE satellite



Edge-on view
(Artist's conception)

Spiral Galaxies

NGC 4594 or M104 (Sombrero) ; HST image
Spiral, with a large bulge and a dusty disk, seen edge-on

Weaky barred spiral (SABc) NGC 674

Elliptical Galaxies

1) They are spheroidal systems (shaped like a water melon) and do not have extended disk components. Contain up to up to 10^12 stars.
2) They have a smooth appearance as they are mostly made of old stars, and have little gas, dust, and recent star formation

Giant elliptical M87

Irregular Galaxies

1) They have irregular, peculiar morphologies in terms of gas, dust and star formation.
2) They are low mass gas-rich systems.Typically contain up to a few x 10^9 stars
3) Two of the three closest galaxy neighbors of the Milky Way, the LMC and SMC, are Irr galaxies

LMC; Irr; 30,000 ly across

SMC; Irr ;18,000 ly across

Dwarf Galaxies

1) They are much smaller than spirals or ellipticals, but may be comparable to Irr galaxies. Their optical radius is typically less than 15,000 lyr while that of spirals is greater than 50,000 lyr.
2) They typically contain up to a few x 10^{8} stars (vs 10^{12} in spirals)
3) They come in two types : dwarf ellipticals and dwarf irregulars

Leo I, dwarf elliptical

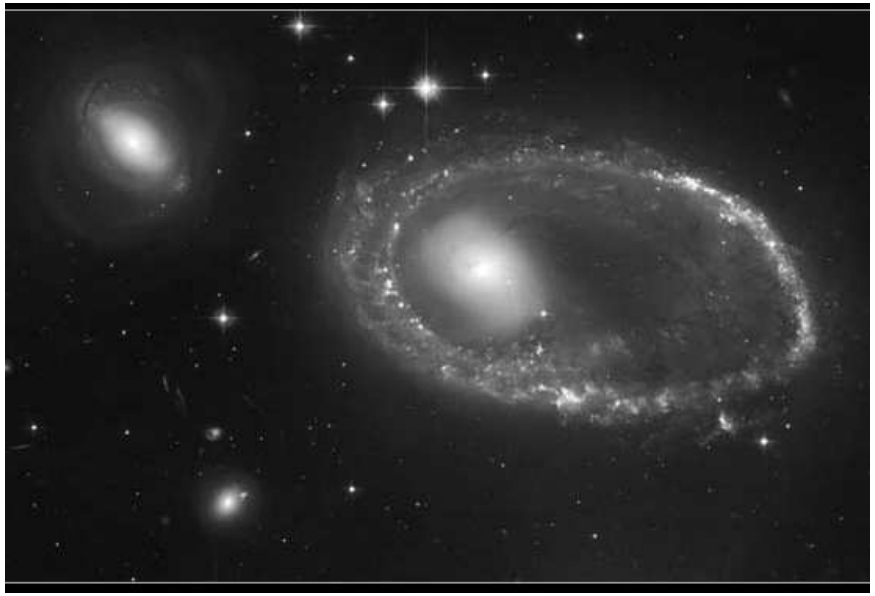
Peculiar/Interacting Galaxies

Galaxies which look peculiar and distorted. They do not fit on the Hubble sequence. These distortions are often caused by interactions with other galaxies.

Polar ring galaxyNGC 4650

Cartwheel galaxy
Head-on collision

Ring galaxy AM 0644-741 50,000 ly across



Peculiar/Interacting Galaxies

A dusty gas-rich warped disk inside an elliptical-like older system

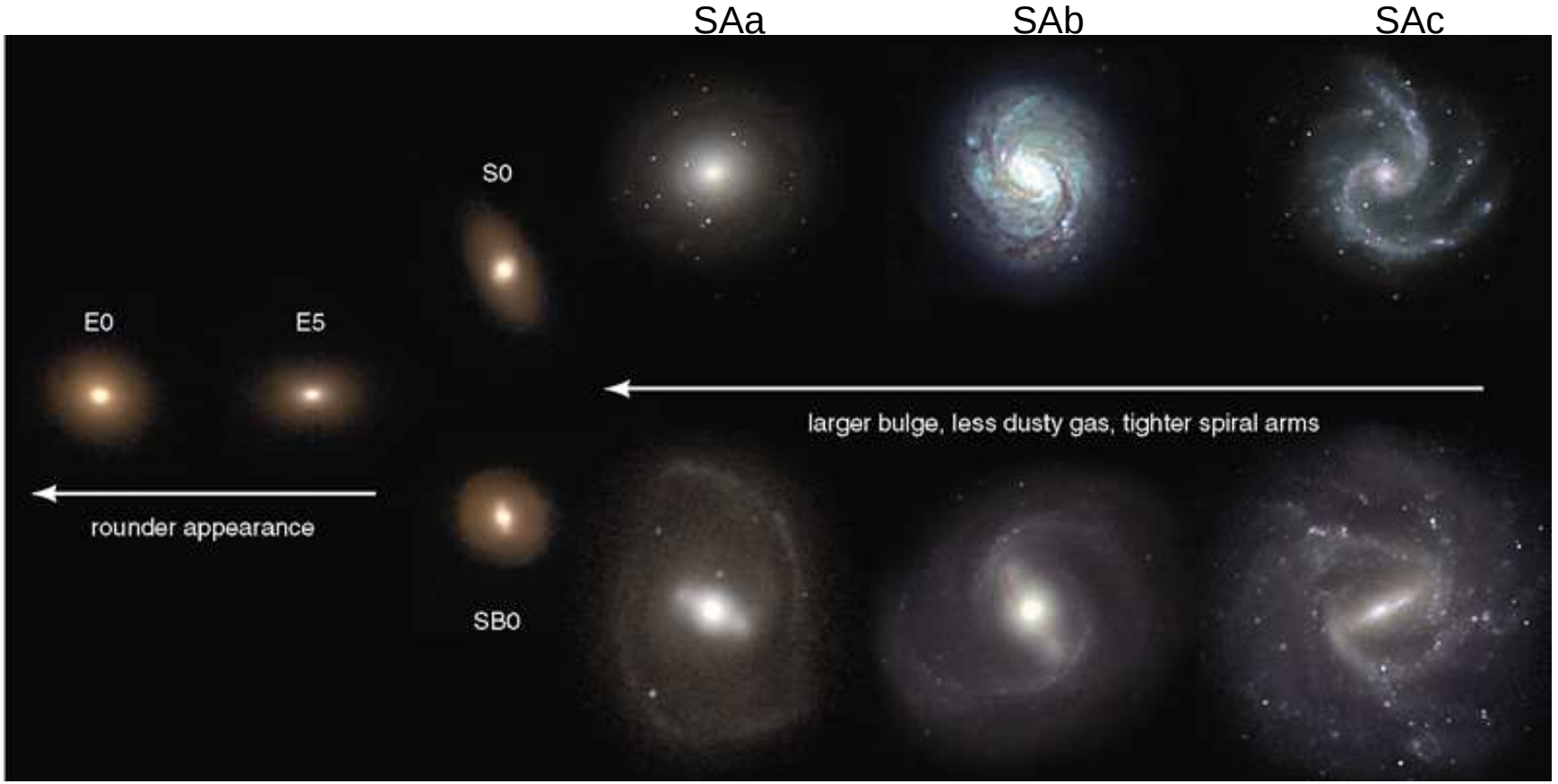
The Hubble Scheme for Galaxy Classification

or

The Hubble Sequence

Hubble's Classification Scheme : The Hubble Sequence or Tuning Fork Diagram

- usually based on visual images of elliptical and spiral galaxies
- Elliptical galaxies become rounder along the sequence E5 E4 E3 E2 E1 E0
- Spirals are divided into two forks for barred spirals (SB) and unbarred spirals (SA).
- The spirals are further divided into sequences "c b a" (SBc, SBb, SBa or SAc, SAb SAa) along which the bulge luminosity, the bulge-to-disk ratio and the tightness of the spiral arms rises, while the relative amounts of gas and dust in the disk falls.



Hubble's classification scheme : What are its limitations?

In-class discussion

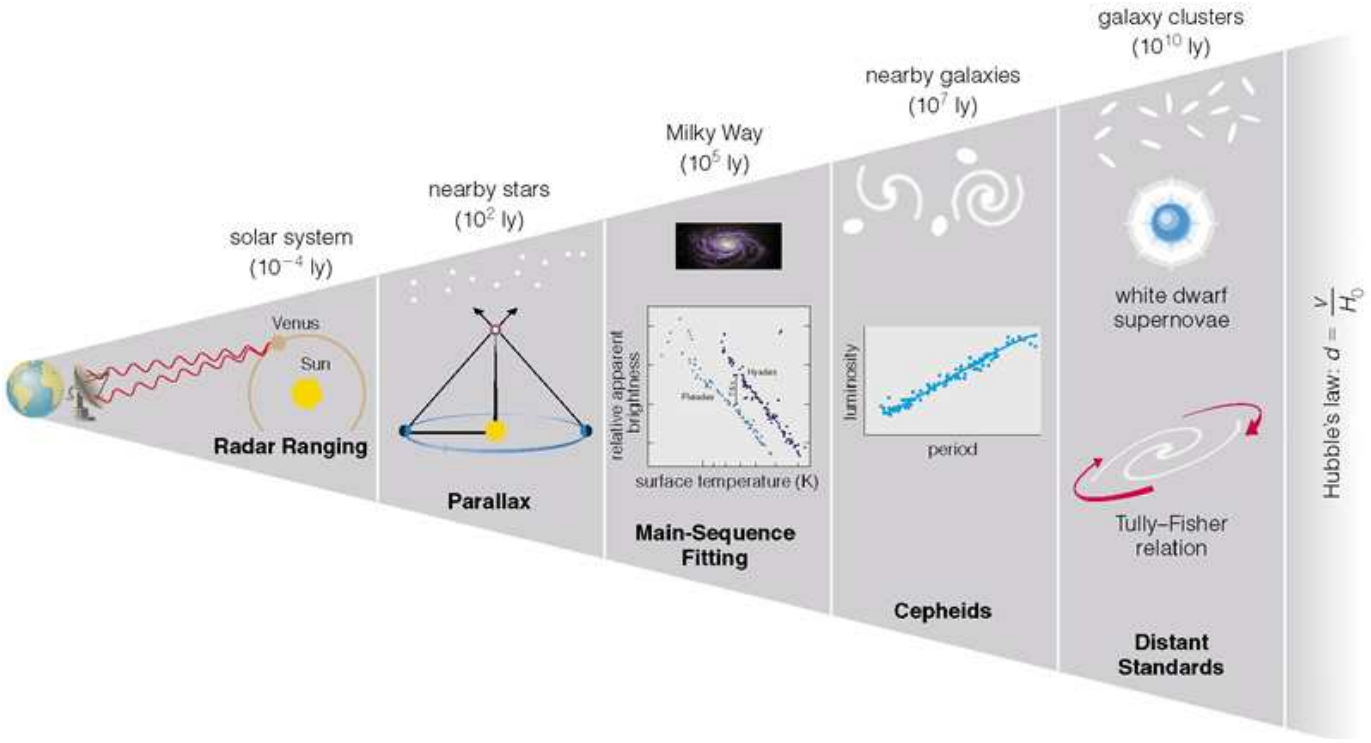
A galaxy looks different at infrared and optical wavelengths

Movie
(NASA/Spitzer)

The optical image of M81 shows intermediate age stars and patchy obscuration.
The infrared observations of M81 from the Spitzer satellite show old stars, but also penetrates the dust and reveal young stars enshrouded in dust

Mapping the Distance of Stars and Galaxies

The distance ladder for stars and galaxies



2) Standard candles are objects whose luminosities L is known or can be determined from some easily observable property. For instance a Cepheid's luminosity can be easily determined by observing its period. Standard candles are used determine distances D, by using the fact that once we know the luminosity L and we measure the flux F, we can trivially calculate D.

$$F = (L) / (4 \pi D^2)$$

3) As we move to larger distances we need brighter standard candles. For instance, we use the main sequence turn off of stellar clusters out to 10^5 lyr in our Milky Way, then brights Cepheids in external galaxies out to 10^7 lyr, then Type Ia supernovae etc