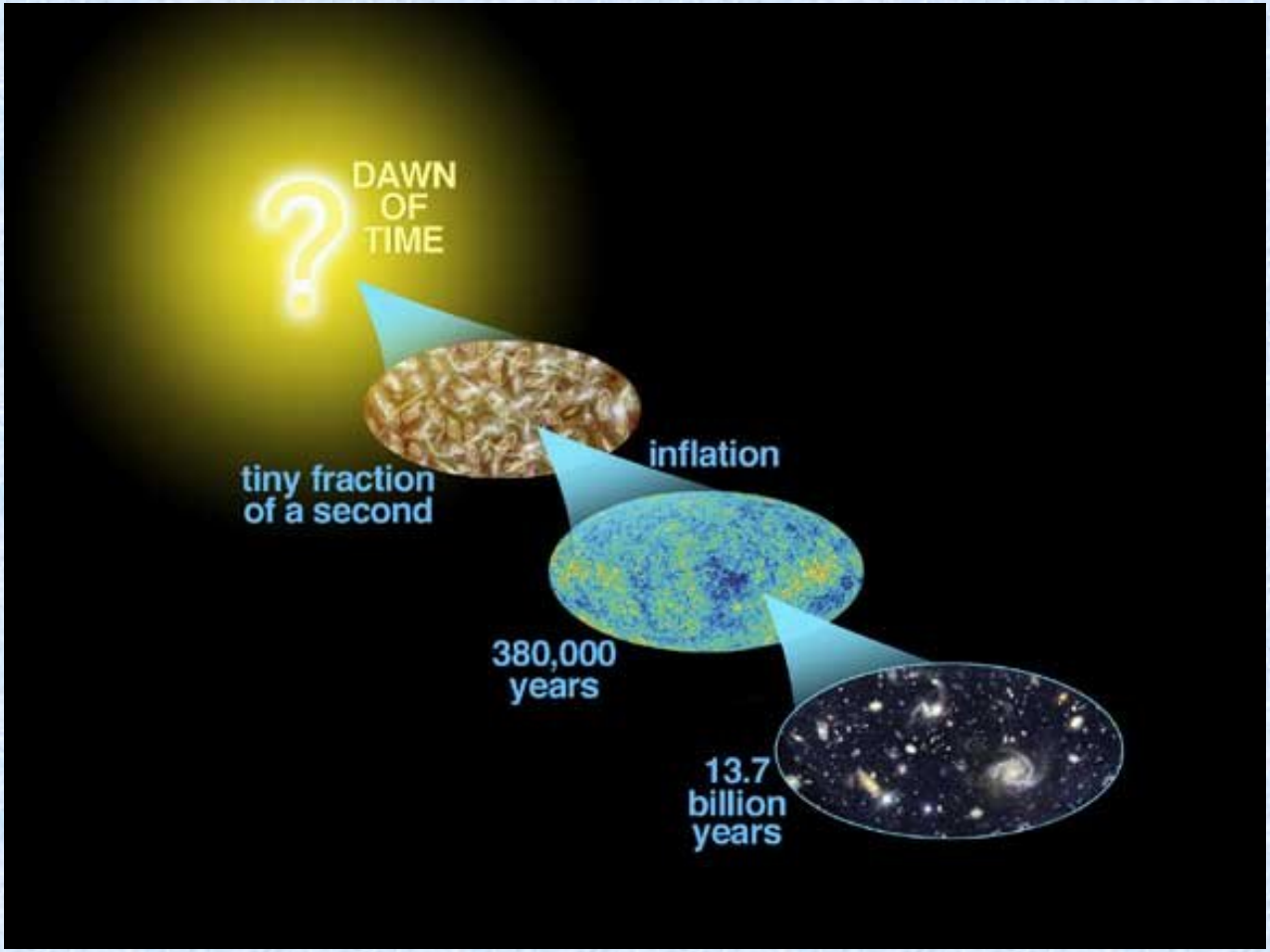
Astro-2: History of the Universe



Lecture 2; April 9 2013

Previously.. On Astro-2

- The goal of cosmology is to understand how the universe formed and evolved.
- How can we build a theory of the universe valid at all times in every place?
- We have to assume that the view of the universe from Earth now is as good as from any other place and time.
- You had a nice introduction to Big Bang cosmology from Neil DeGrasse-Tyson

Previously.. On Astro-2

- Cosmological Principle
- Universe is homogenous and isotropic.
- VERIFIED BY OBSERVATIONS
- Perfect Cosmological Principle
- Universe is homogenous, isotropic, and time-invariant. But..
- FALSE, NOT VERIFIED BY OBSERVATIONS, THE UNIVERSE EVOLVES!

Today.. On Astro-2

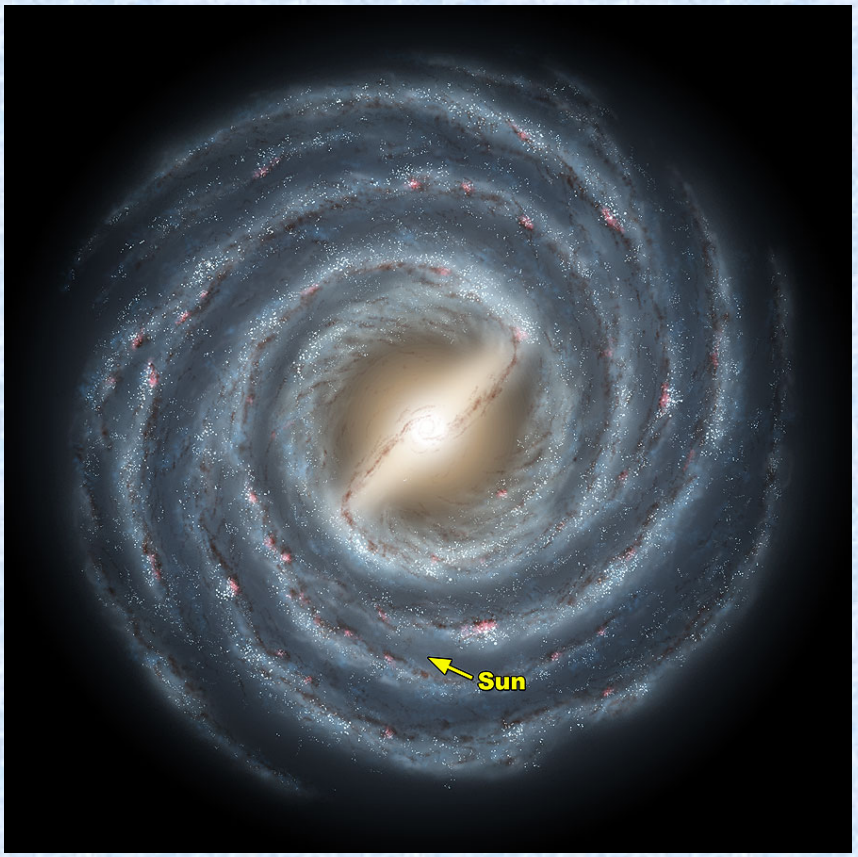
1. How big is the universe?
2. What kind of stuff is in it?
3. How do we find out how big is the universe?

Assignments.
Due on Monday 15 4PM

1. To TA: Universe 24.34 - 24.37 - 24.41
2. On your own: 24.1 thru 24.16

How big? The birth of Modern Cosmology

- What is this?
- The Milky Way!
- In the past people called other galaxies Nebulae.
- Nebula=cloud in Latin
- In modern times Nebulae (galaxies) were studied and catalogued by Messier (M catalog) and Herschel in the XVIII and XIX century



How big? The birth of Modern Cosmology

- What are "nebulae"?
- Are they part of our own galaxy, the Milky Way?
- Are they galaxies themselves?
- Is the Milky Way all there is, or is the Universe much bigger and our galaxy is only one of the many?

The closest big galaxy:
Andromeda (M31)
Visible with the naked eye!

How big? The birth of Modern Cosmology

- We know how big is the Milky Way
- 50 kpc = 4,000 billion times around the globe (universe chapter 23)
- How big are the “nebulae”?
- Do they fit in the Milky Way?

How big? "Island universes"?

- How big are "nebulae"?
- This was the subject of a heated debate in the early 1920s:
  - Harlow Shapley (galactic=small)
  - Heber D. Curtis (extragalactic=big)
- By looking at them, we do not know if they are small objects nearby or big objects very far.
- How do we figure this out?

How big is M31?

How big? 1923 comes Hubble…

- In 1923 Edwin Hubble finds the solution measuring the distance to M31.
- Discovers Cepheids in M31(what are Cepheids? Universe chapter 21)
- Cepheids are “standard candles”. By measuring their period, we know the intrinsic brightness. From that and observed brightness we infer distance.

How big is M31?

Cepheid distance. Example:

- A Cepheid in IC4182 has a period of 42 days and an apparent magnitude of m=22.0 in the V band
- From the period luminosity relation we know that the absolute luminosity M=-6.5 in the V band
- The relation between distance (in parsec) apparent and absolute magnitude is:
  - $m=M+5 \log (d/pc) -5$
- Hence $d=10^{0.2(m-M+5)}$pc, i.e. $5\ 10^6$ pc

How big? Hubble discovers the "realm of the nebulae"

- Using the Cepheid distance Hubble concludes that M31 is 750 kpc away (15 times the size of the Milky Way)
- Thus, the size of M31 is 70 kpc, larger than our own Milky Way.
- The same is true for billions of galaxies that populate the universe! Our Milky Way is just and "average Joe" galaxy
- Overnight people realized that the universe was thousands of times bigger than they thought

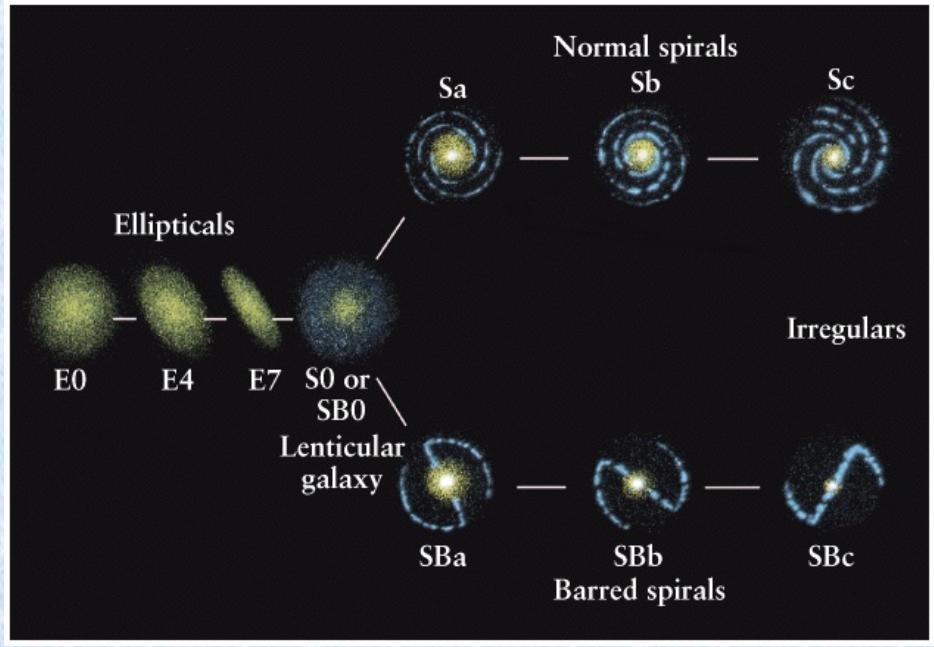
How big is M31? 70 kpc

How big? Answers

- The universe is much bigger than the Milky Way
- It contains billions of galaxies, each one tens of kpc in size.
- The size of the visible universe is of order Giga (Giga=billion) pc, i.e. millions of times that of the Milky Way
- It could be infinite…

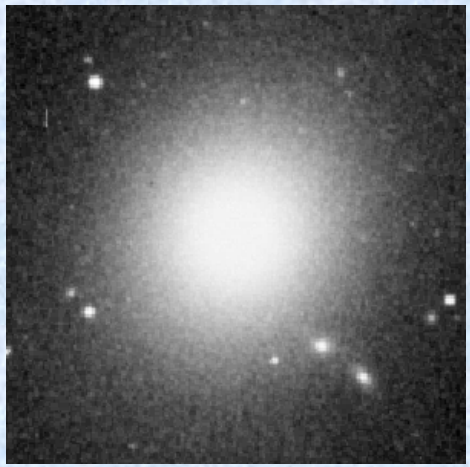
What kind of stuff? The Hubble "tuning fork" diagram

- Hubble classified the variety of galaxies according to their "morphology", i.e. their appearance.
- Most galaxies belong to one of these four main types:
  1. Ellipticals
  2. Lenticulars
  3. Spirals. Barred and non Barred
  4. Irregulars



What kind of stuff: Elliptical galaxies

- Elliptical galaxies appear elliptical in the sky.
- Sub-Classified based on the **apparent** (what does this mean?) elongation.
- If a and b are the major and minor axis, then the galaxy is classifed as En with n = (1-b/a)*10



M87
E0
b/a=?

N3377
E6
b/a=?

What kind of stuff? After shape, color, or spectrum

- When you want to describe something you generally say the shape and then the color
- The same things with galaxies:
- First morphology, then color
- A precise measurement of color is a “spectrum”
- A spectrum contains lots of physical information

What kind of stuff? The age of Elliptical galaxies.

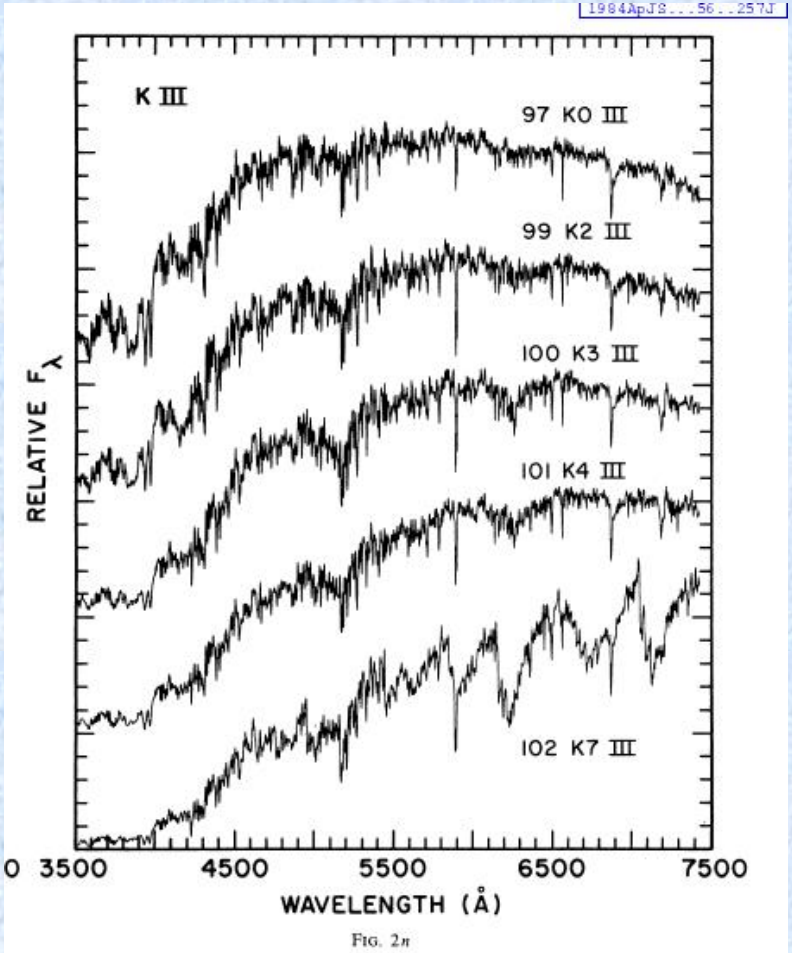


FIG. 2n

Old stars

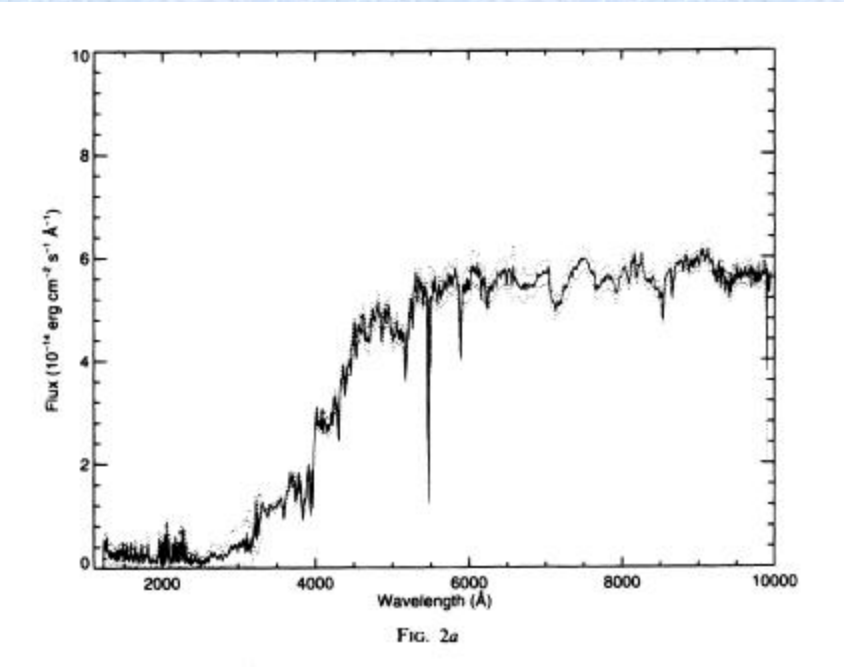


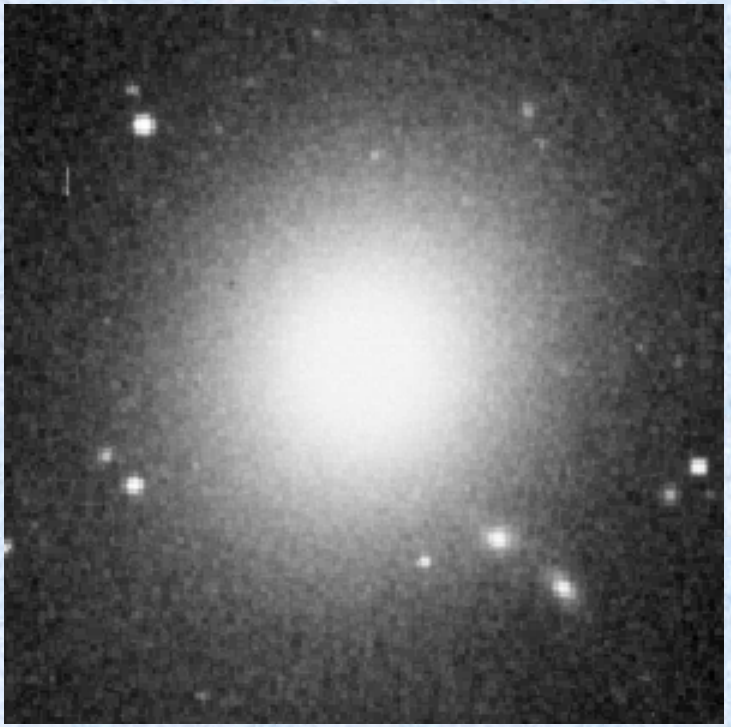
FIG. 2a

Elliptical Galaxy

Can you tell the difference?

What kind of stuff? Elliptical galaxies contain old stars

- Ellipticals are made of OLD stars, older than our own star (4.5 billion years old)
- They contain very little gas or grains of solid materials (that astronomers call “dust”)

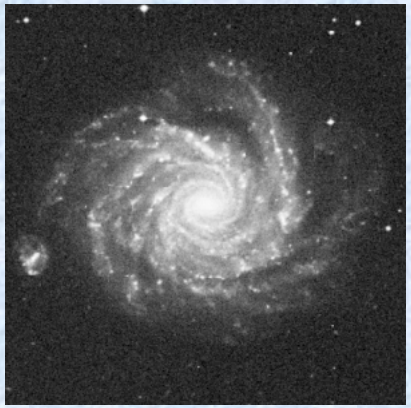


What kind of stuff? Spiral galaxies

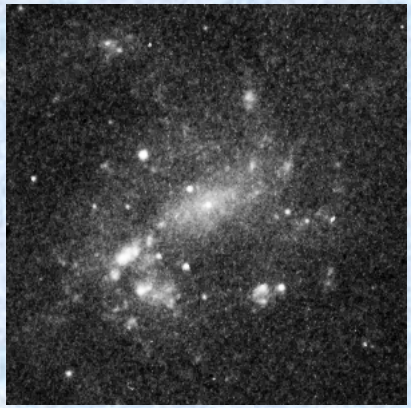
- Spirals are characterized by spiral arms. Sub-classified based on the relative size of the "bulge" and the "disk"
- Sa have big bulges.. Sd have no bulge

Sa

Sb



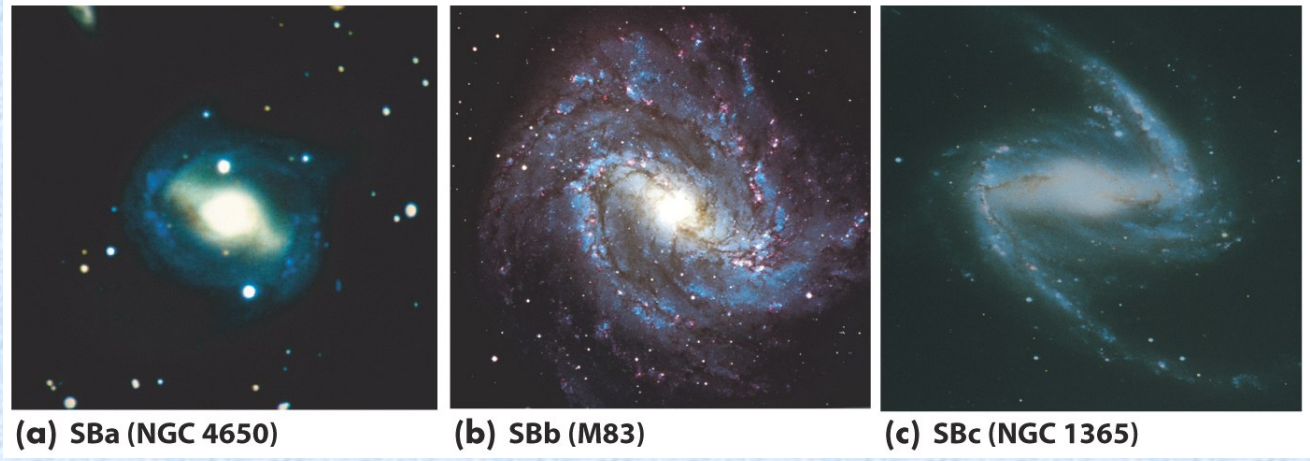
Sc



Sd

What kind of stuff?
Barred spiral galaxies

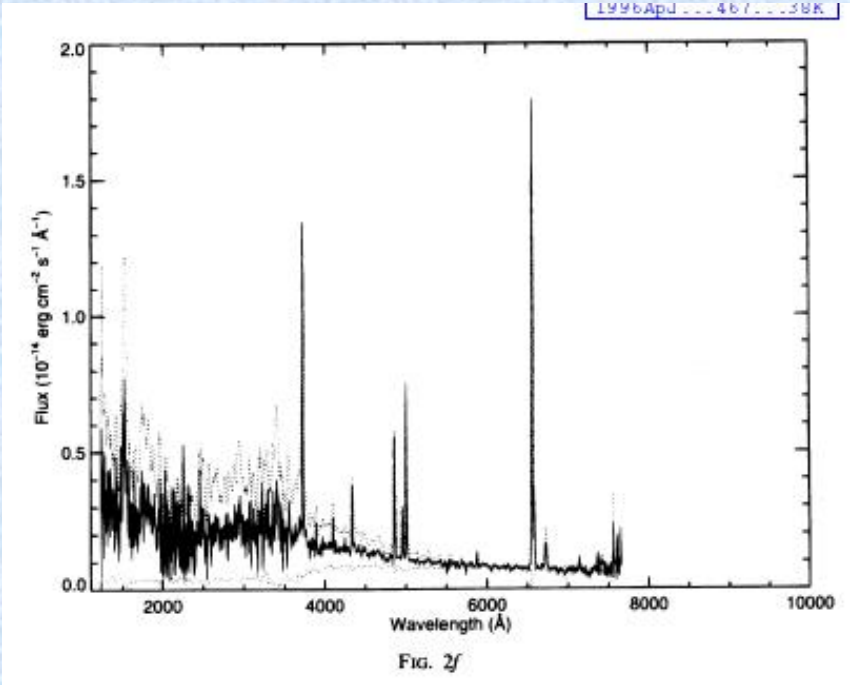
- Barred galaxies are similar to spirals but with a boxy central feature called bar.
- Bars are found in ¾ of spirals and are thought to arise from instabilities
- It is unclear exactly why not all spiral galaxies are barred…



(a) SBa (NGC 4650) (b) SBb (M83) (c) SBc (NGC 1365)

What kind of stuff?
Spiral galaxies have young stars

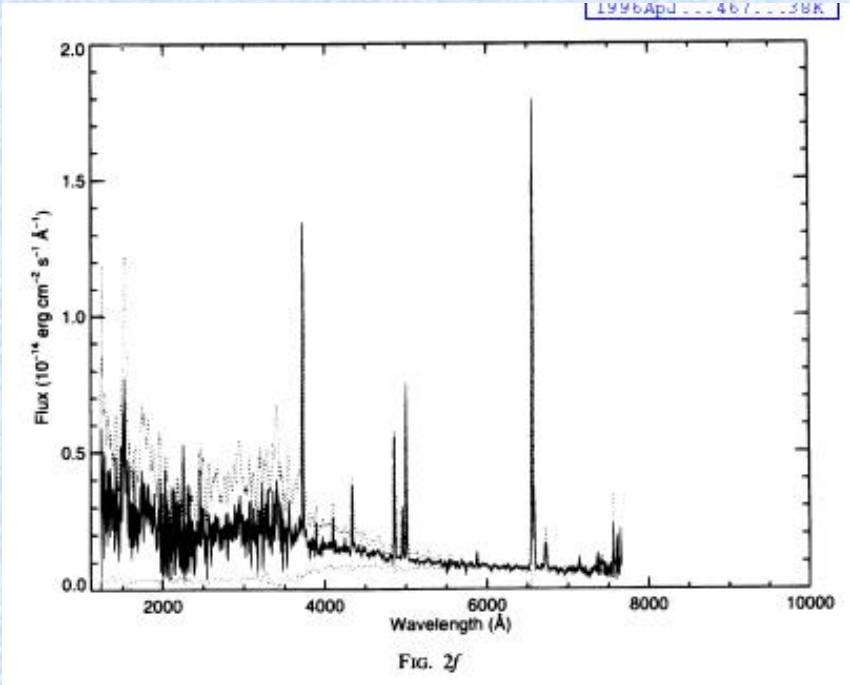
- The typical spectrum of a spiral galaxy is different from that of a star.
- There are prominent emission lines (Universe Chapter 5).



Sc Galaxy

What kind of stuff?
Spiral galaxies have young stars

- Emission lines arise from gas "ionized" by very energetic radiation
- Such high energy radiation is NOT produced by cold old stars, implying that very young stars (10 million years old) are present.
- They also contain vast amounts of gas and dust



Sc Galaxy

What kind of stuff?
Lenticular (S0) galaxies

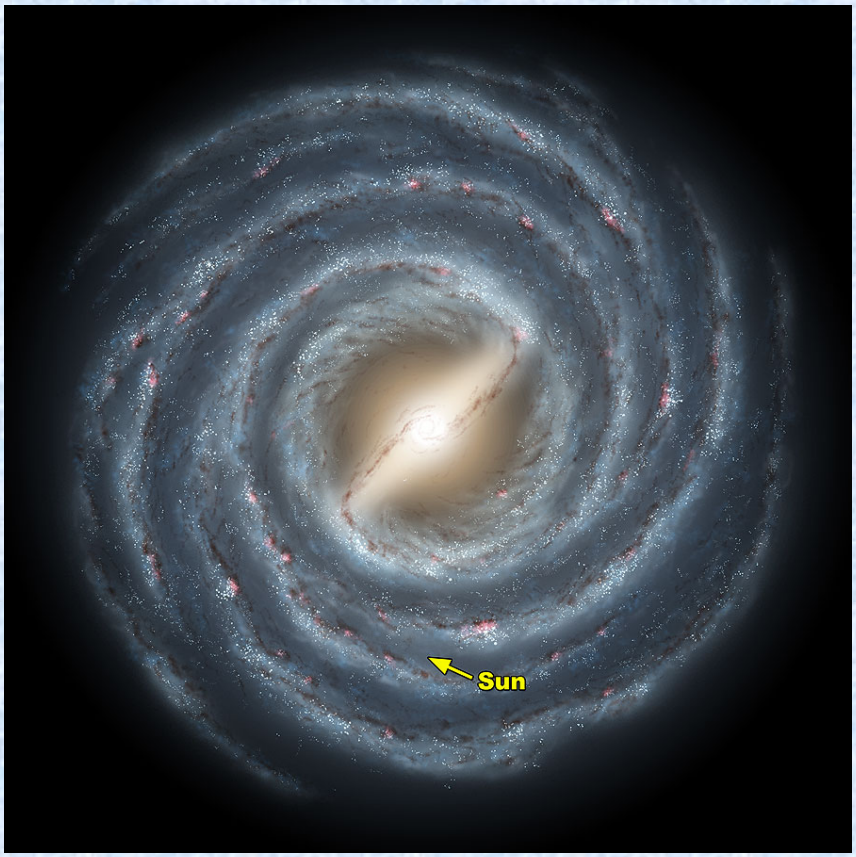
- Lenticulars, like spirals, have a bulge and disk component, buy they have no spiral arms
- Spectra are very similar to those of elliptical galaxies, i.e. only old stars.

What kind of stuff? Answers

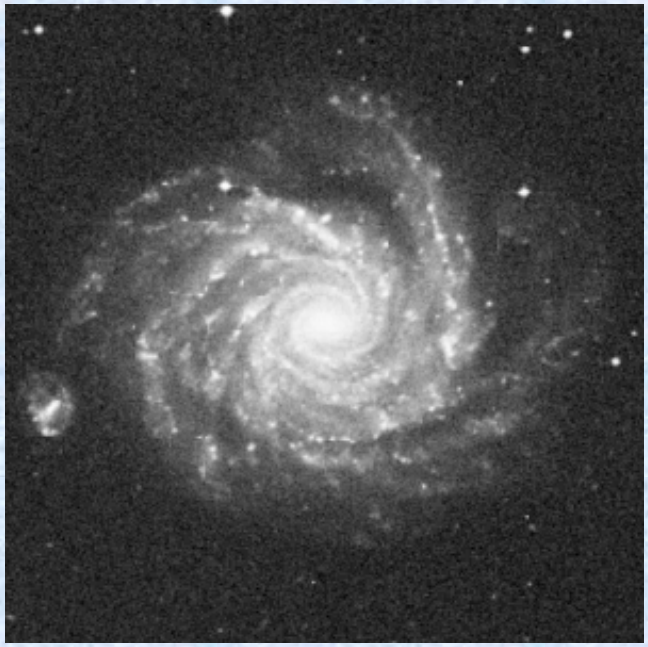
- Galaxies do not take any possible form or shape.
- Most galaxies belong to one of these types:
  - Elliptical
  - Lenticular
  - Spiral
  - Irregular
- Ellipticals and lenticulars have stars older than the sun
- Spirals and irregulars have stars younger than the sun

What kind of stuff? Discussion

- Are there stars younger than the sun in the Milky Way
- Yes!!
- Why?

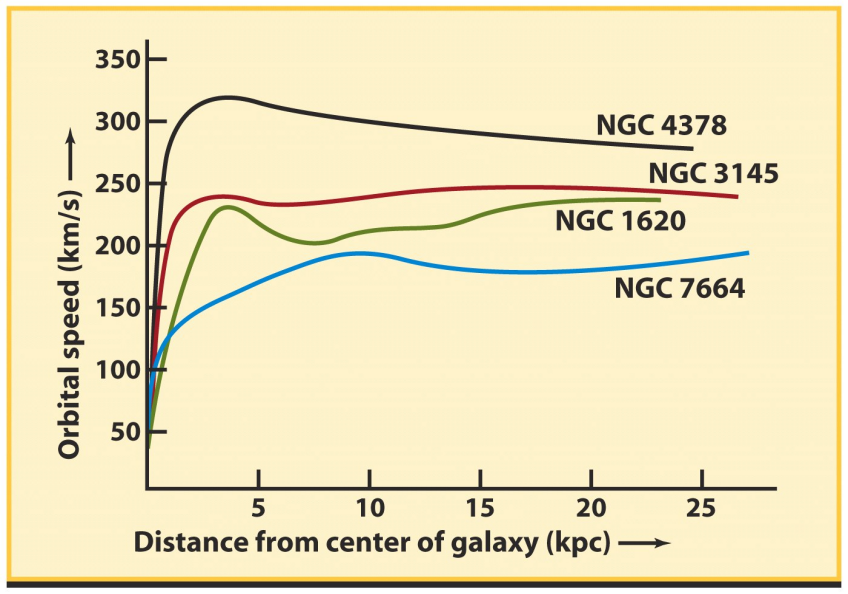


How “heavy”? Apples fall, why not stars in galaxies?



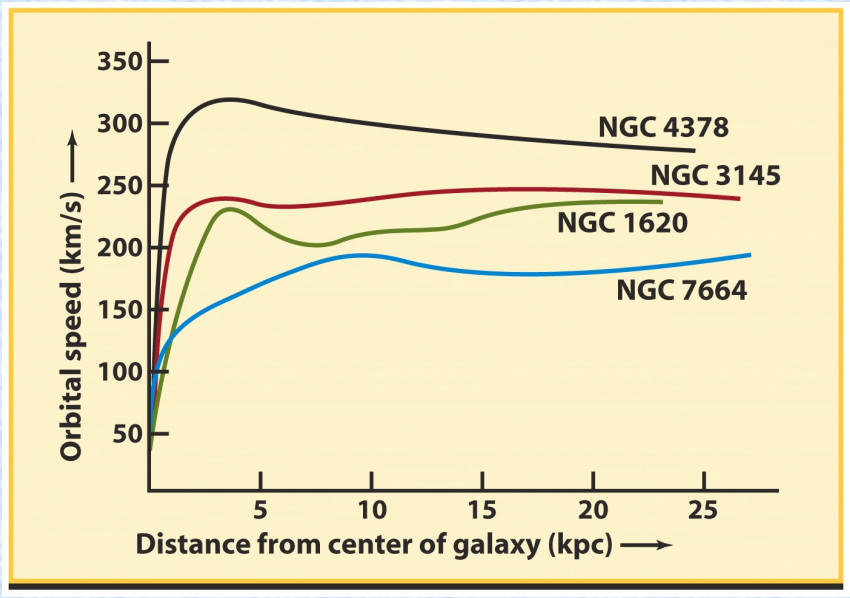
How heavy?
Spirals are supported by rotation

- Like planets around the sun, stars rotate around the center of spiral galaxies.
- Rotation prevents them from falling: rotational support!

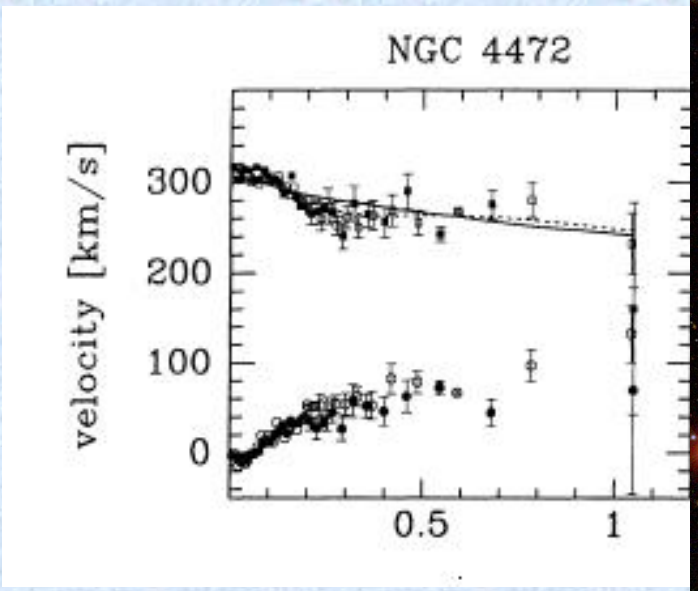


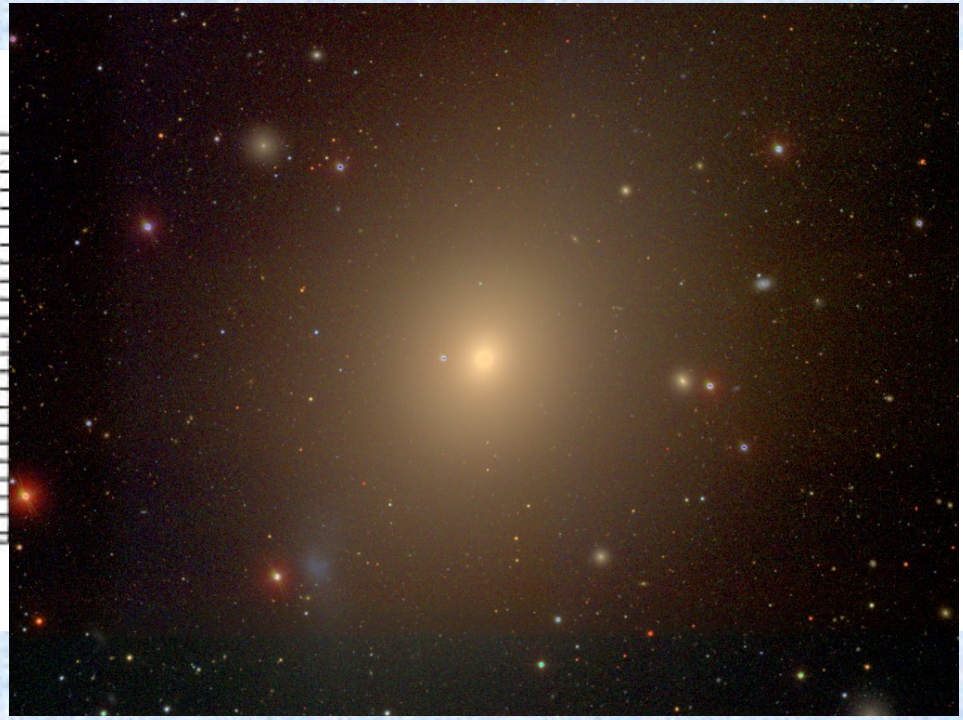
How heavy are spirals?

- We can use rotation to measure a galaxy's mass ("weight")
- In Equilibrium, gravity provides just the right amount of centripetal acceleration:
- $GM/R^2=V^2/R$
- We can use the rotation speed to infer the mass of the galaxy:
- $M(<R)=V^2R/G$

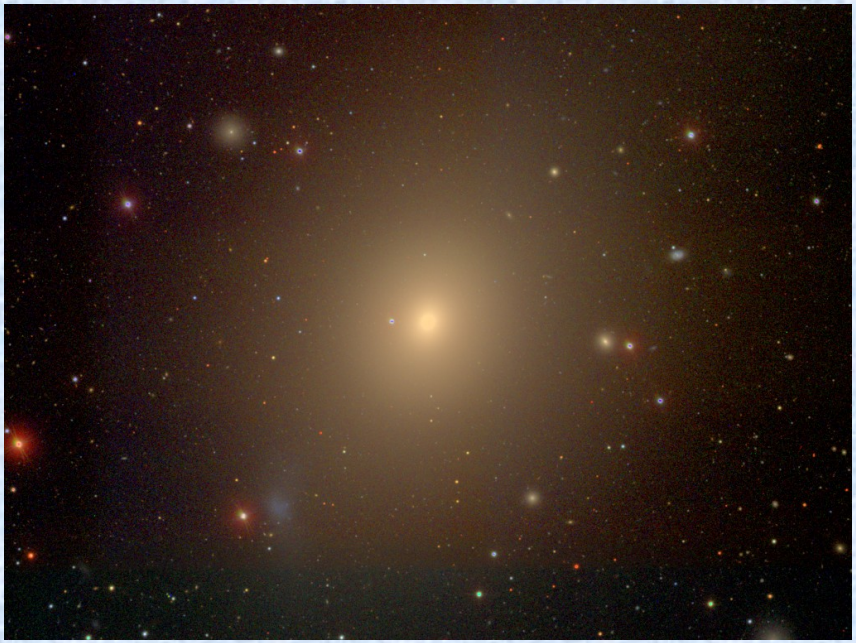


How heavy?
Ellipticals do not rotate!



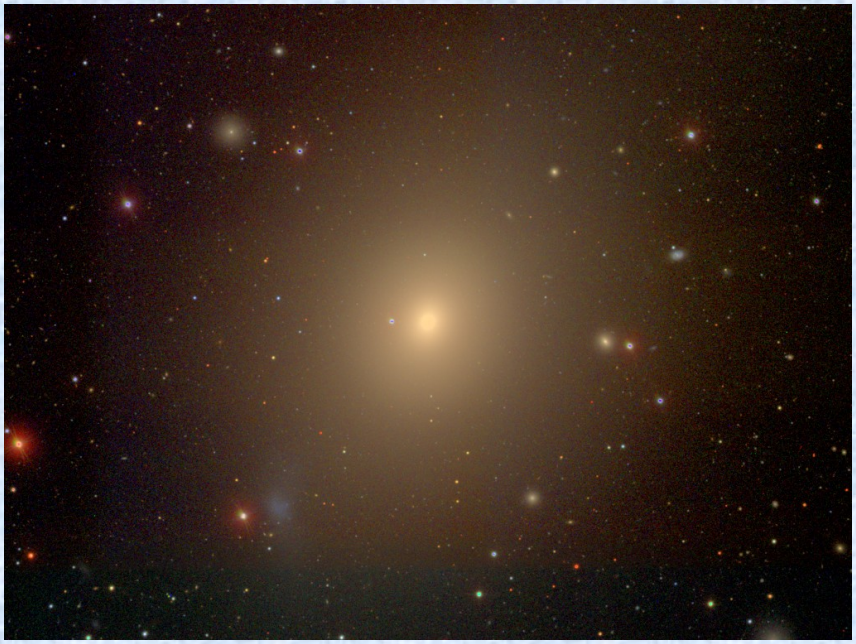


How heavy? Ellipticals do not collapse because of pressure, like a balloon



How heavy? Measuring their pressure and size, we infer their mass

- From a spectrum we measure pressure σ
- From the distance we infer the size R
- From a physics theorem called the "virial theorem" we obtain the mass M:
- $M = k \sigma^2 R / G$



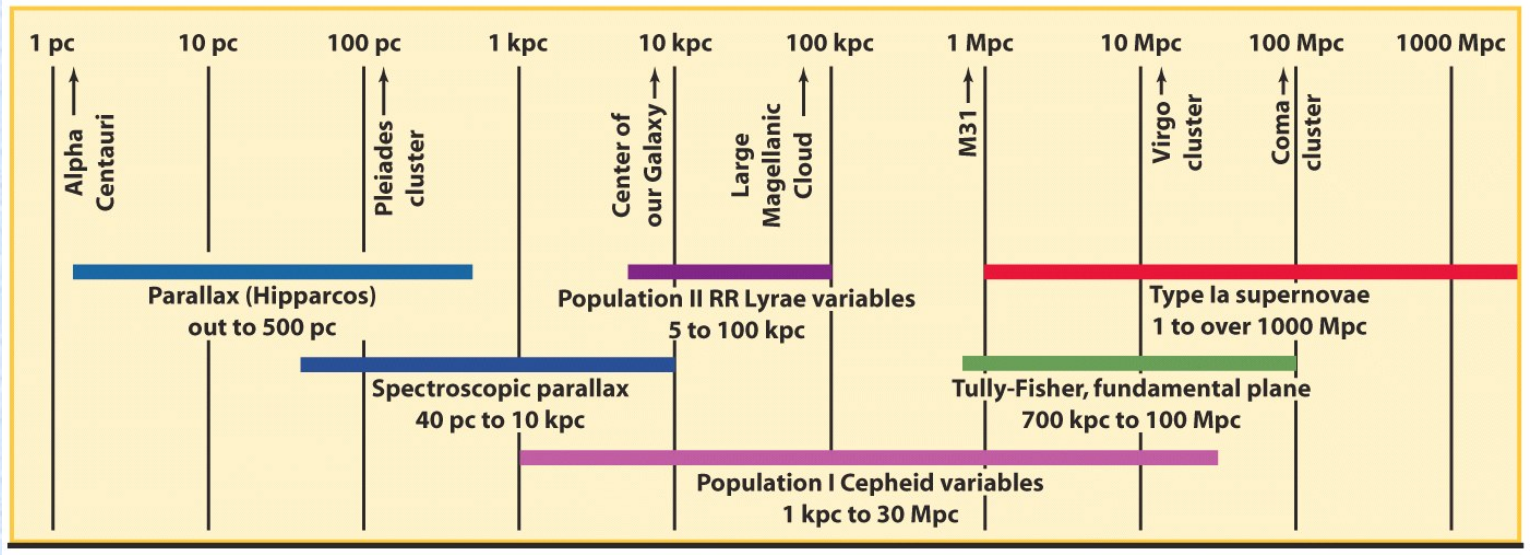
How heavy are galaxies?
We need size to measure masses..

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.*

How far? So we are back to square 1. The distance scale..



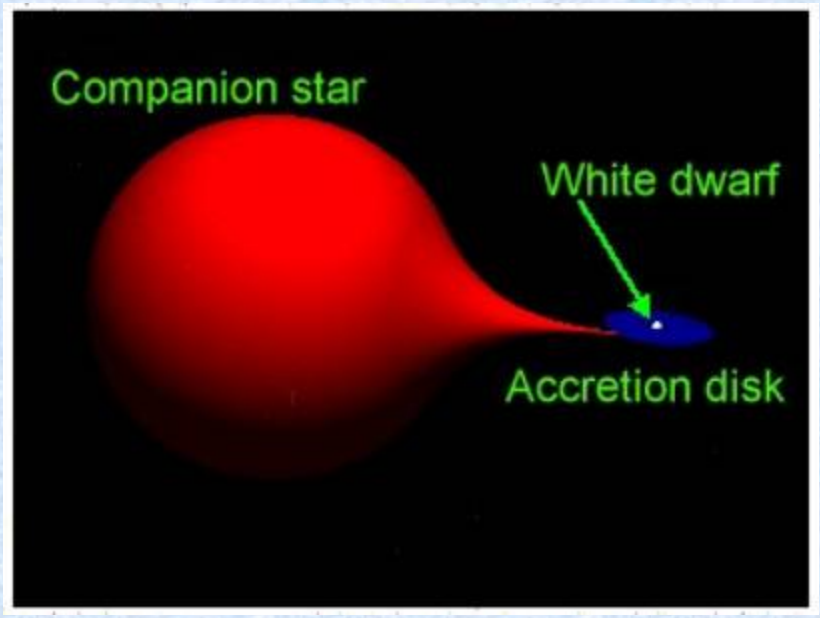
- Parallax (Universe Chapter 17;Big Bang Chapter 3) and variable stars can only measure distances up to a few kpc.
- We need some method that can extend to longer distances! Typically a standard candle, or a standard ruler..

How far? The distance scale standard candles/rulers

- If we know the intrinsic luminosity L (size R) of an object and we measure the apparent flux F (angular size θ) we obtain the distance from the expressions $F=L/4\pi d^2$ or $d=R\theta$

How far? Examples of standard candles/rulers

- Cepheids (as discussed earlier)
- Supernovae
- Tully-Fisher (See Universe Chapter 24)
- Fundamental-Plane (Universe Chapter 24)
- Gravitational time delays (discussed later..)



How far? Summary

- Measuring distances is essential to learn how big is the universe and how much stuff there is in it
- To measure distances of far away objects, more than 100kpc or so, astronomers use “standard candles” such as Supernovae
- Using Supernovae or other standard candles, astronomers have been able to find a general method to measure distances.
- Next, on astro-2: In the process they also discovered that the universe is expanding.

The End

See you on thursday!