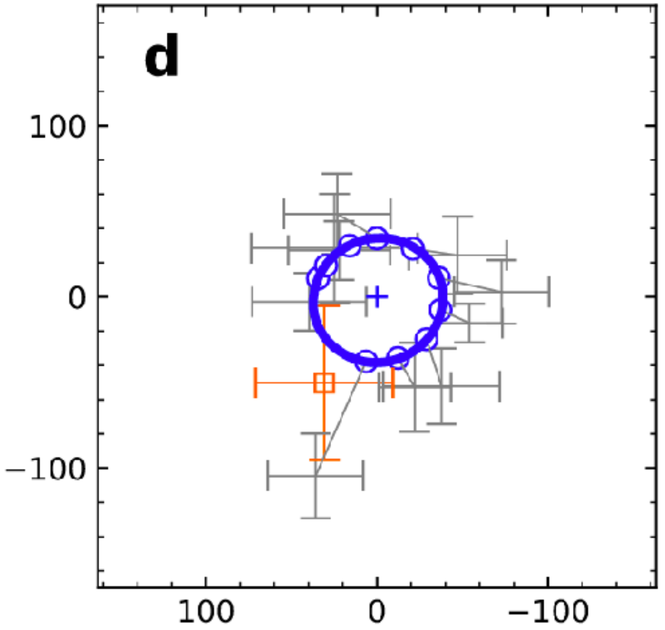
Chapter 14: Measuring Galaxies

Chapter 14 Reading Assignment due now!

Turn in extra credit planetarium and public observing reports up front when complete

Midterm 2 *next* Friday!

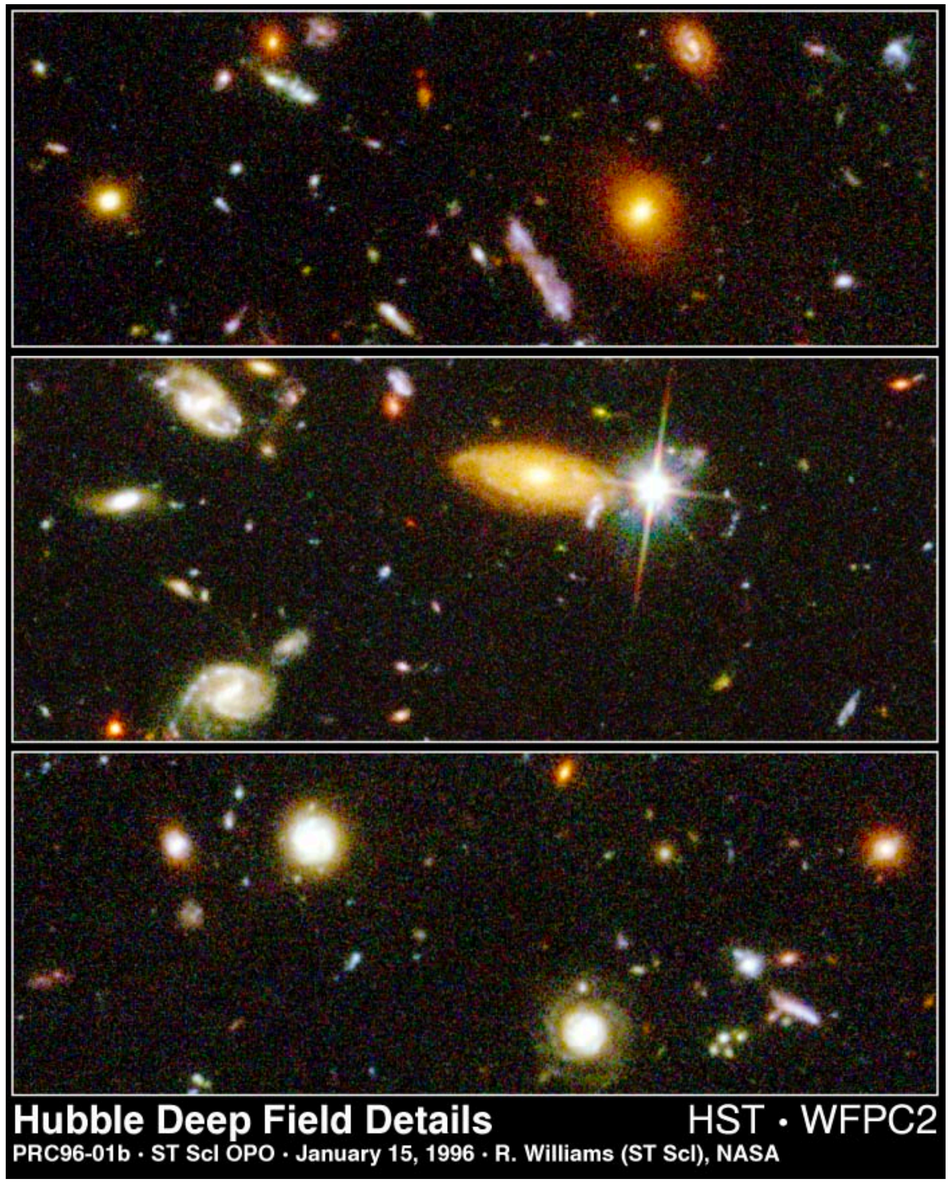


BREAKING NEWS!

Gas cloud orbiting the SMBH in the center of our Galaxy over a half hour — more evidence it must really be a black hole.

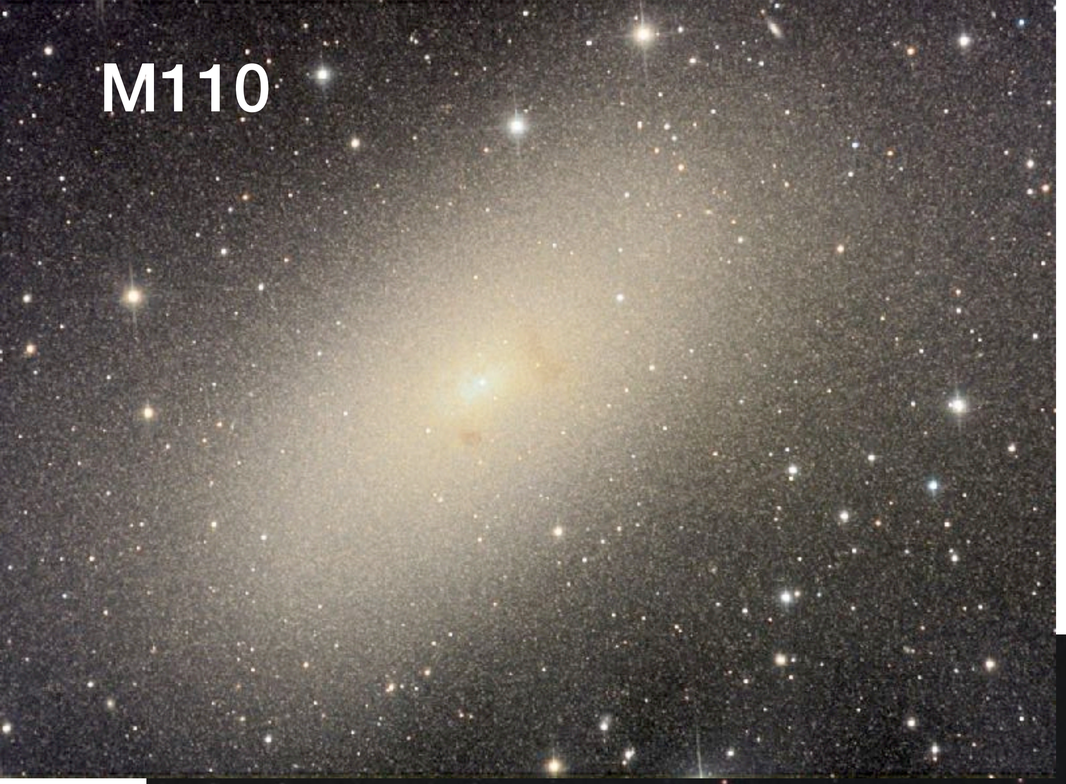
https://www.nytimes.com/2018/10/30/science/black-hole-milky-way.html?action=click&module=Well&pgtype=Homepage&section=Science

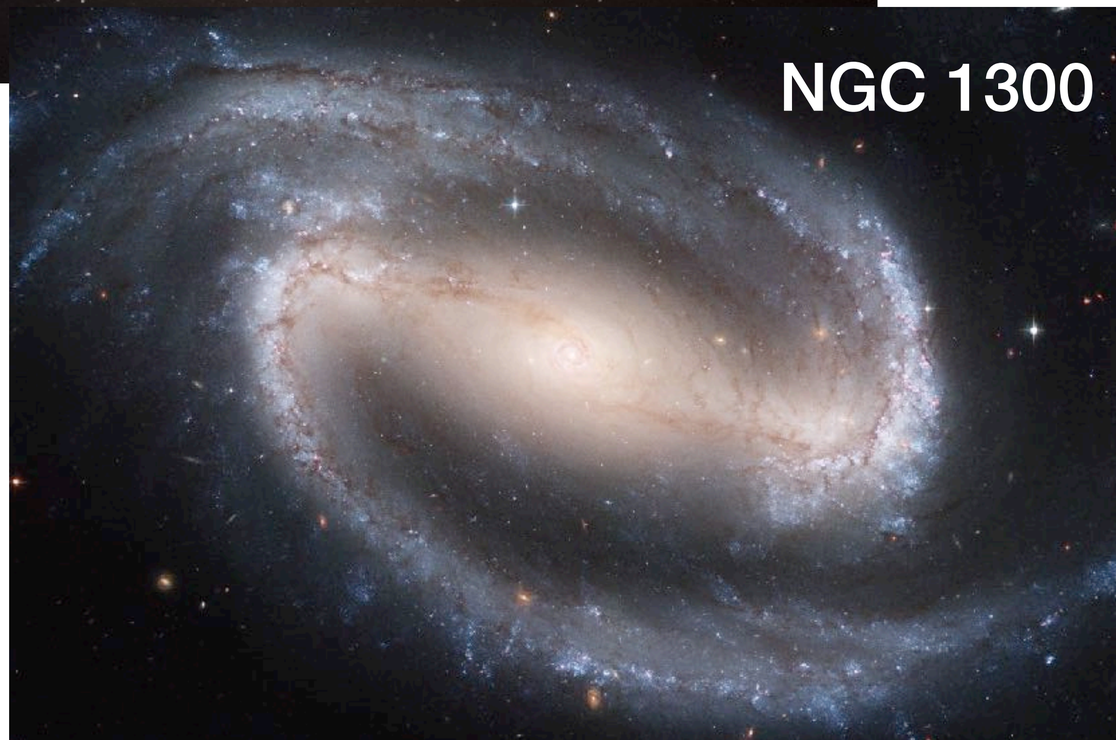
Now on to Galaxies!



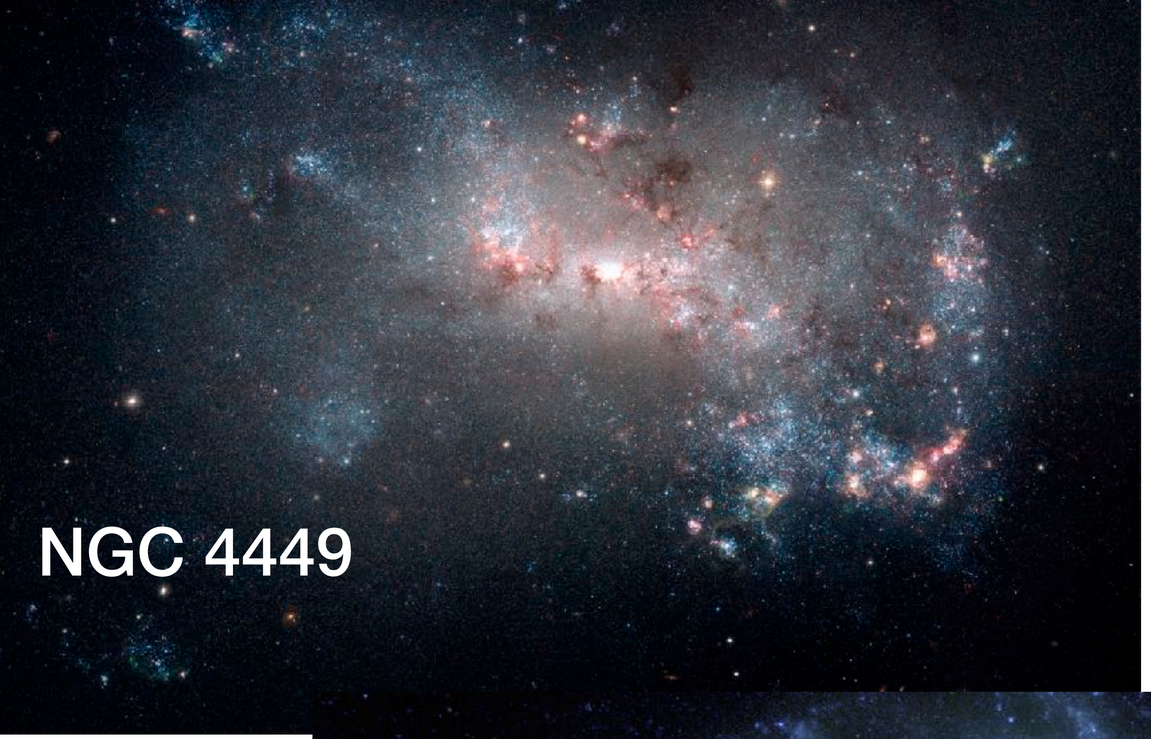
Classifying Galaxies

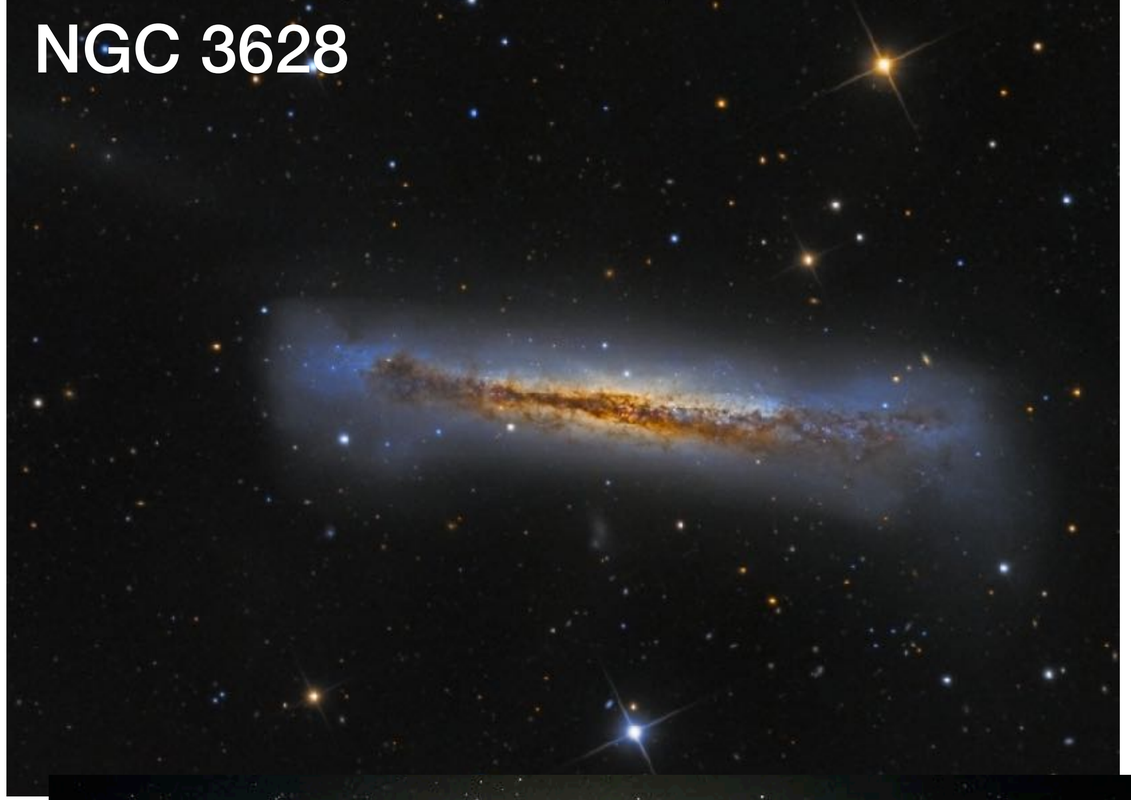
- Groups of 2-4, one sheet per group
- One person from each group raise your hand (so TAs can efficiently pass out dead tree shavings)
- First step: Once I display the 8 galaxies onscreen, begin! What is the overall shape of the galaxy? Is it smooth or mottled? What else do you find notable about it?
- When finished with Questions 1-4, display your ABCD card so I know when you're done.





ASTR


NGC 4449


NGC 3628


NGC 1232


Sombrero

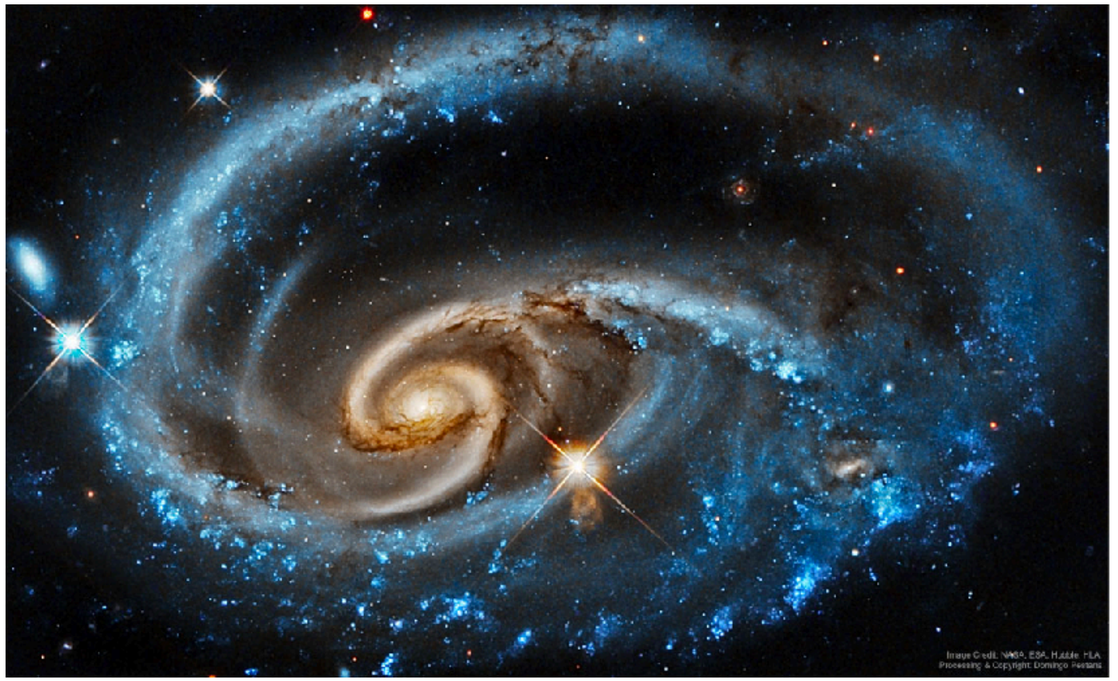
Chapter 14: Measuring Galaxies

Midterm 2 *in one week*!

No office hours today

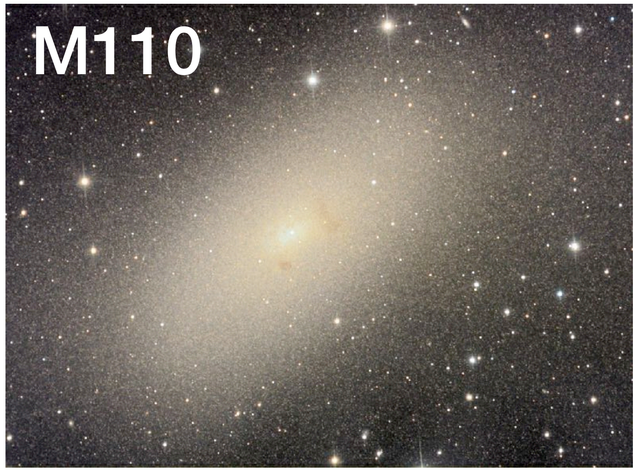
New Galaxy Zoo HW due on Wednesday

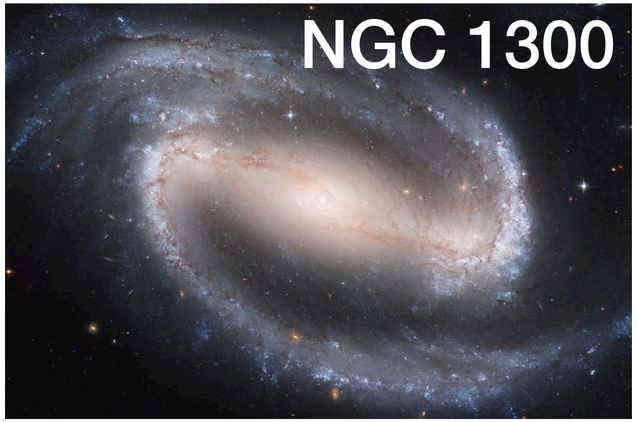
Turn in extra credit planetarium and public observing reports up front when complete

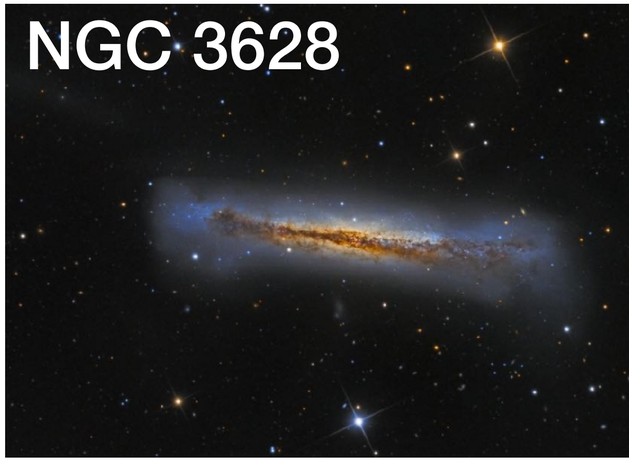


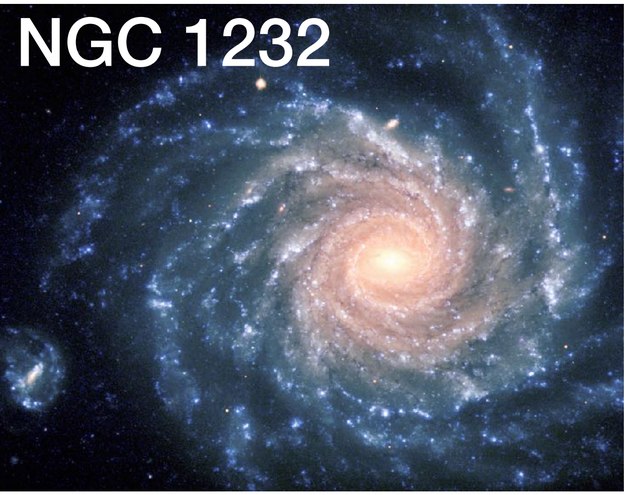
https://apod.nasa.gov/apod/ap170510.html

How did you classify the galaxies?

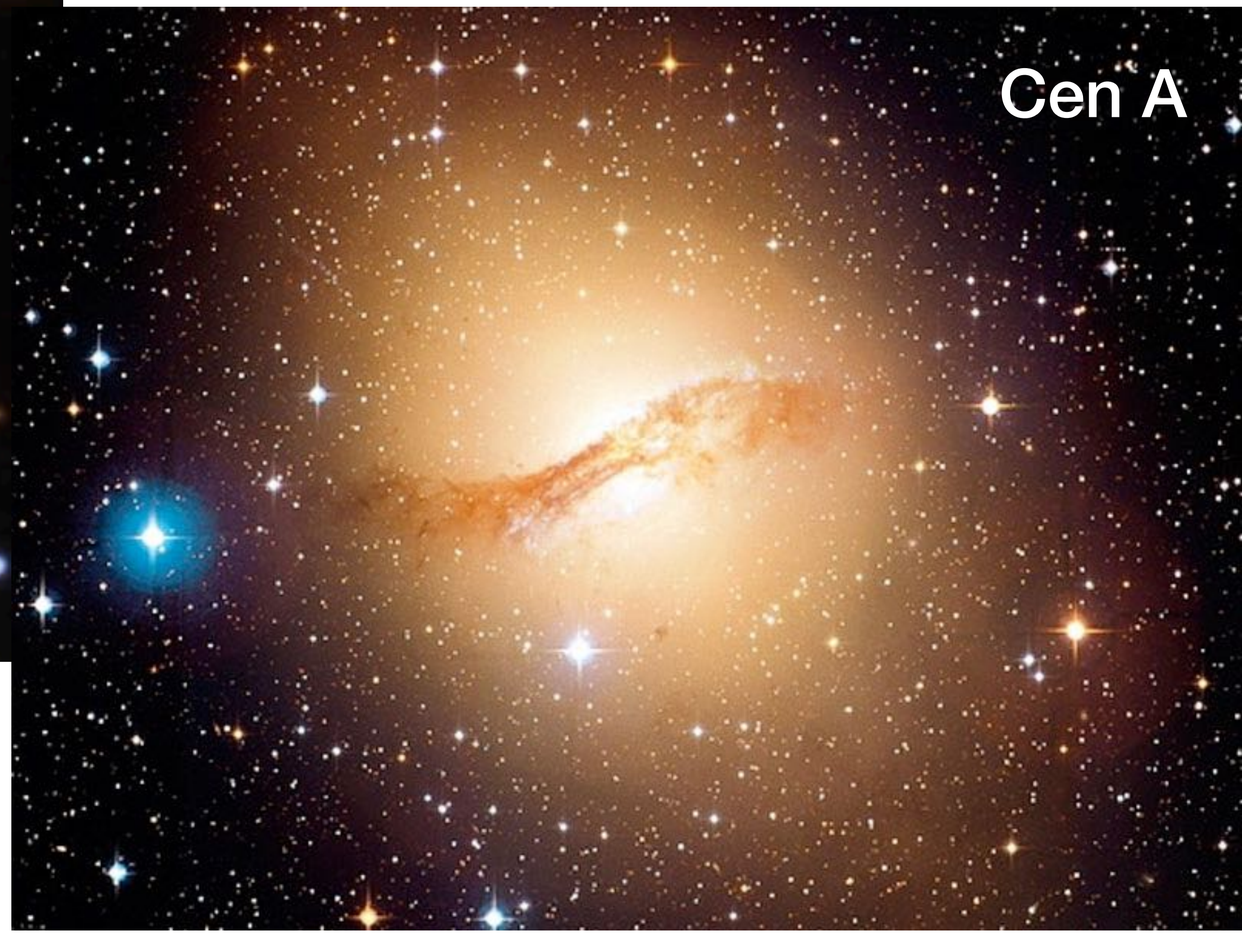




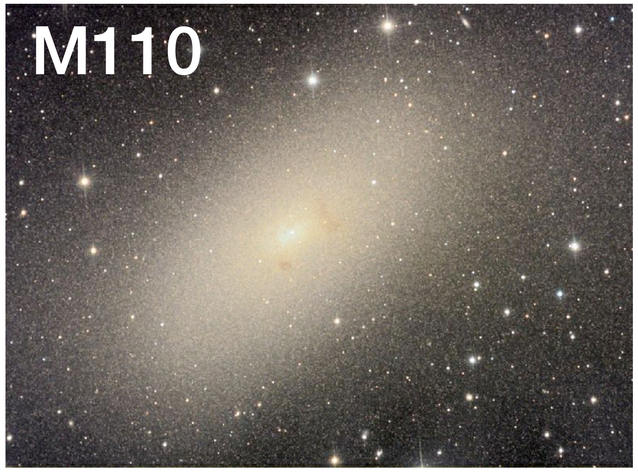


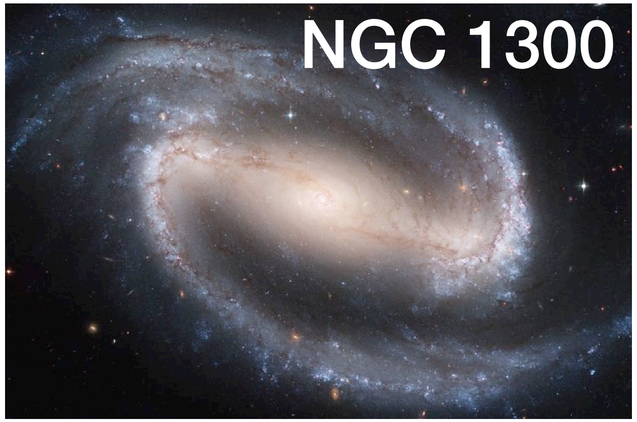


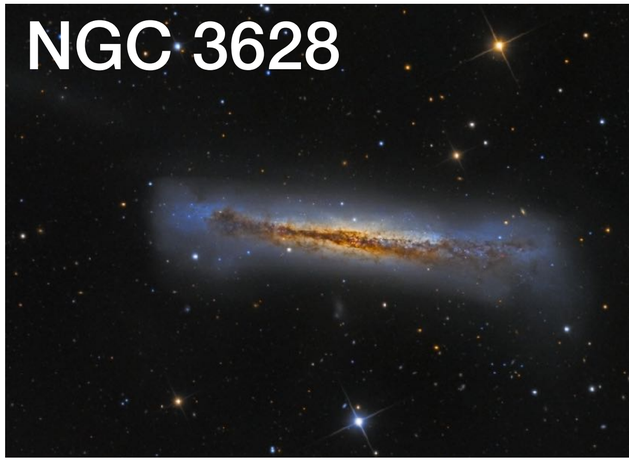
<u>Question 5</u>: Try to incorporate these into your classification. Where would they go?

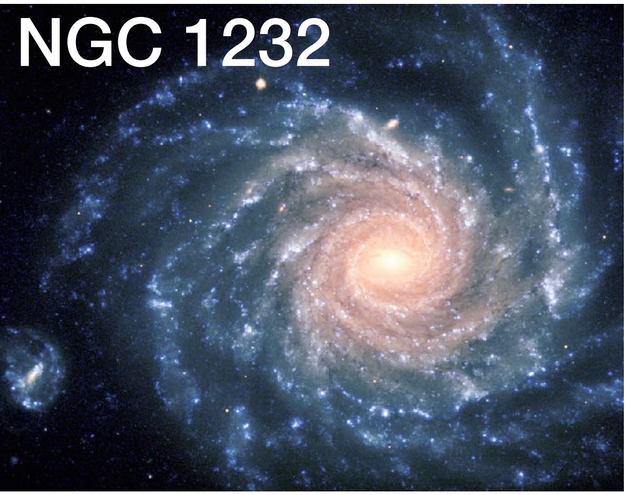


How did you classify the galaxies?

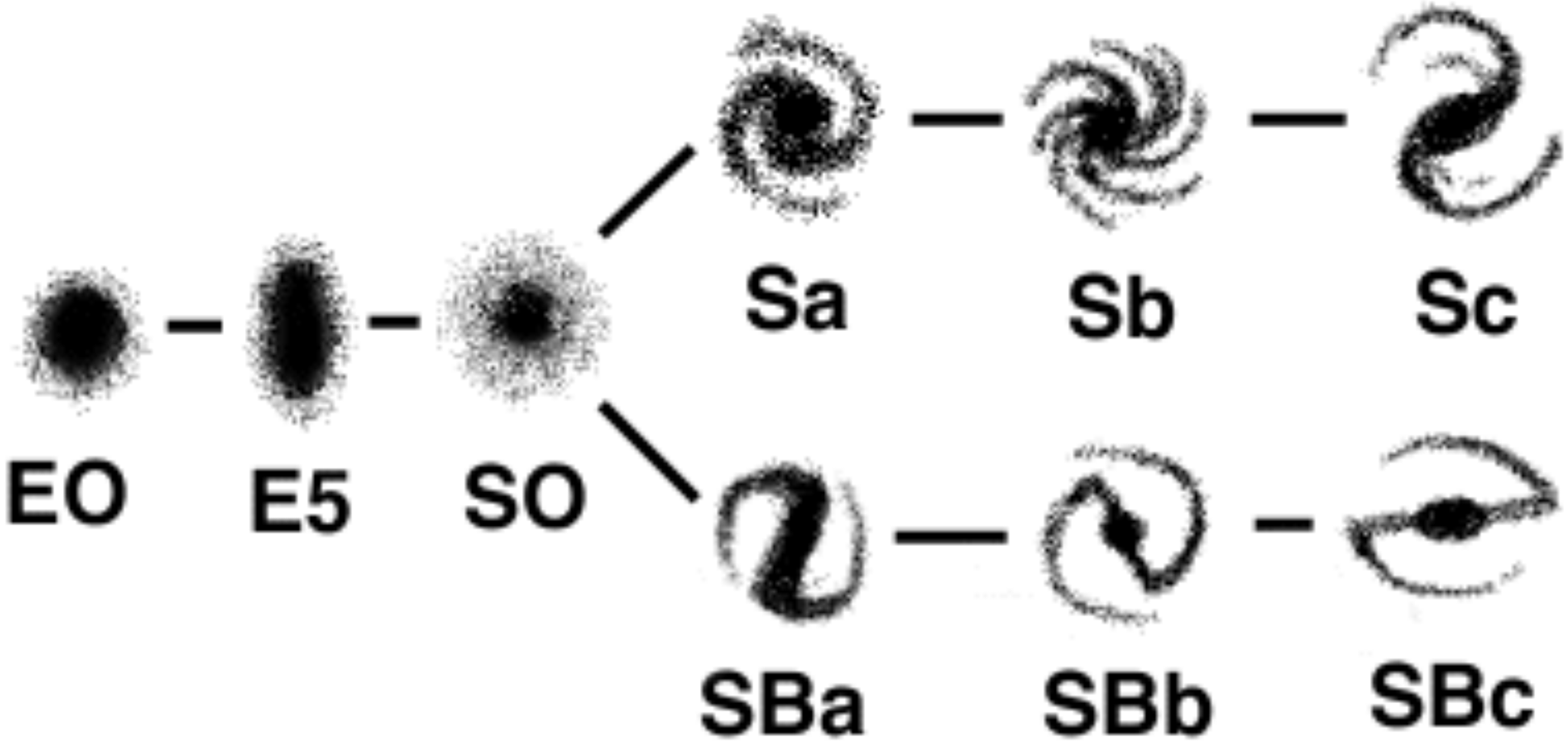


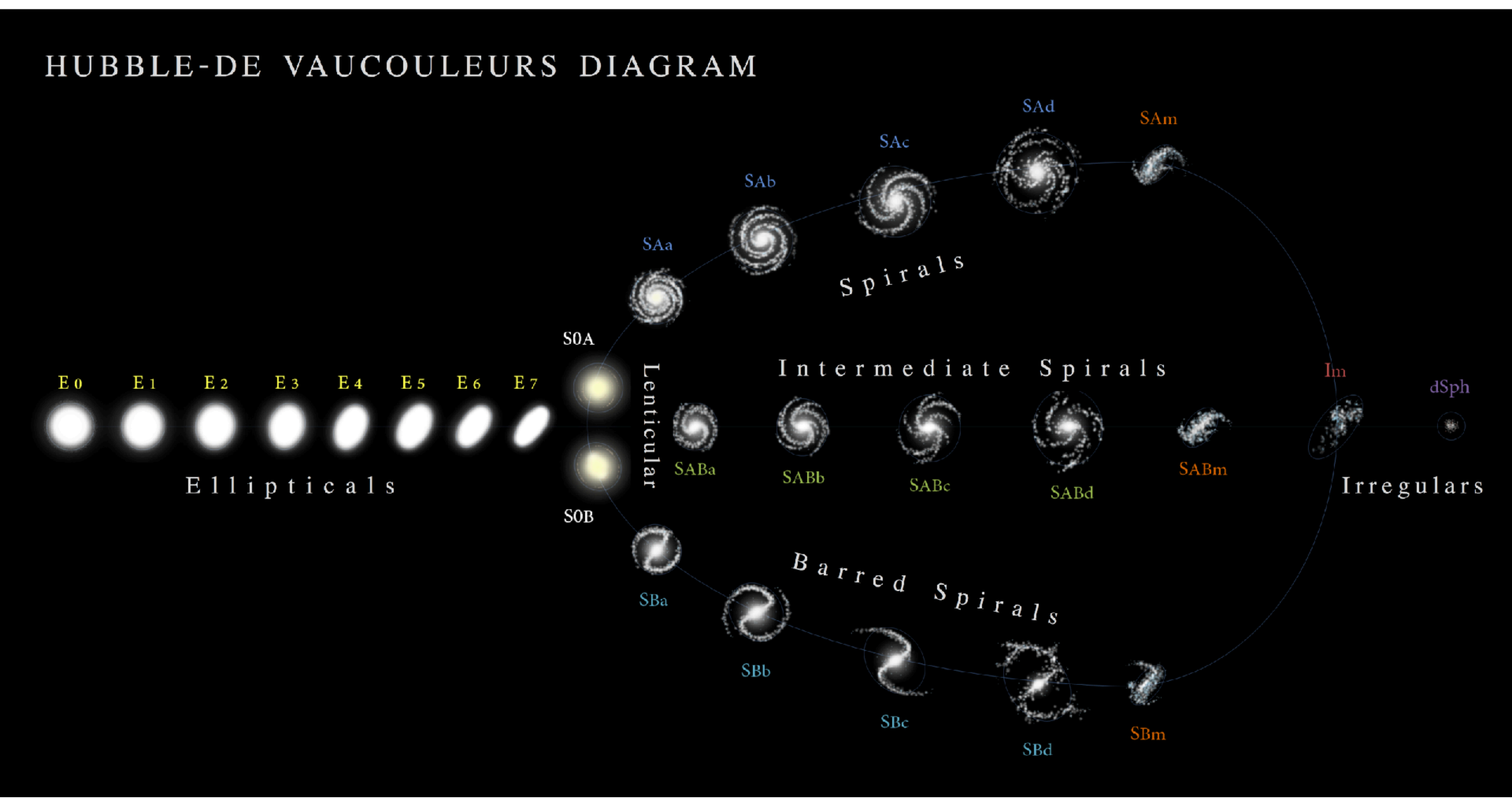




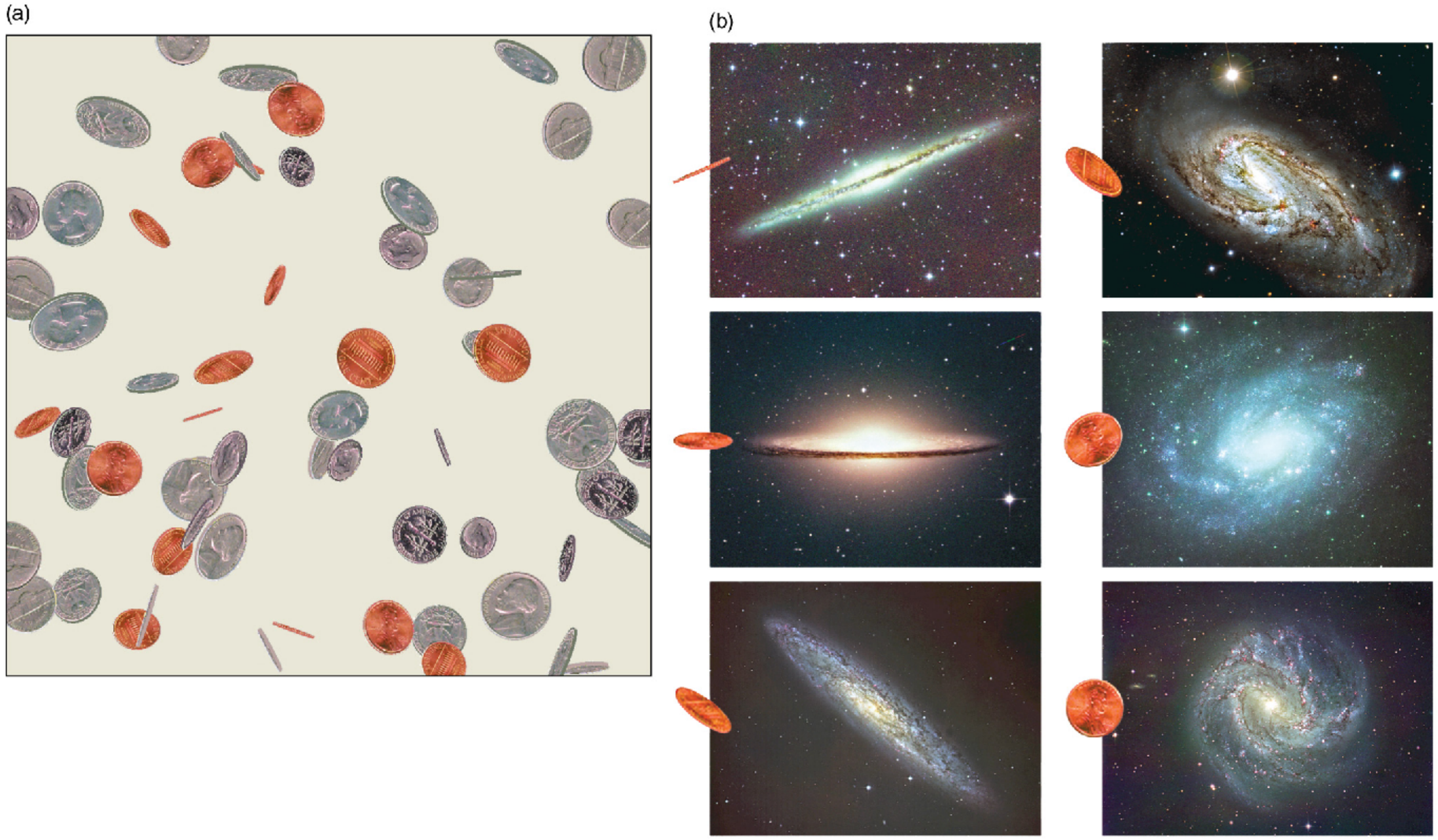


Hubble's Classification Scheme: Tuning Fork Diagram

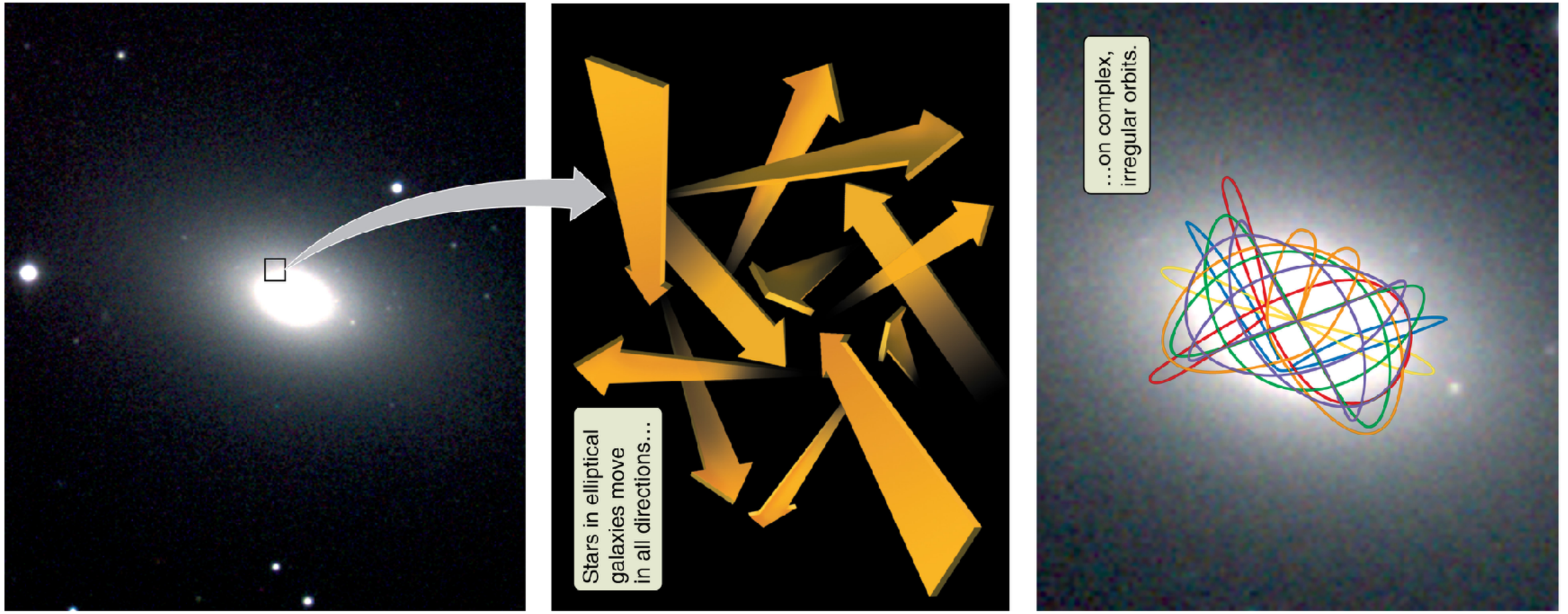



HUBBLE-DE VAUCOULEURS DIAGRAM
E0
E1
E2
E3
E4
E5
E6
E7
Ellipticals
S0A
S0B
Lenticular
SAa
SAb
SAc
SAd
SAm
Spirals
SABa
SABb
SABc
SABd
SABm
Intermediate Spirals
Im
dSph
Irregulars
SBa
SBb
SBc
SBd
SBm
Barred Spirals

Appearance depends on orientation…

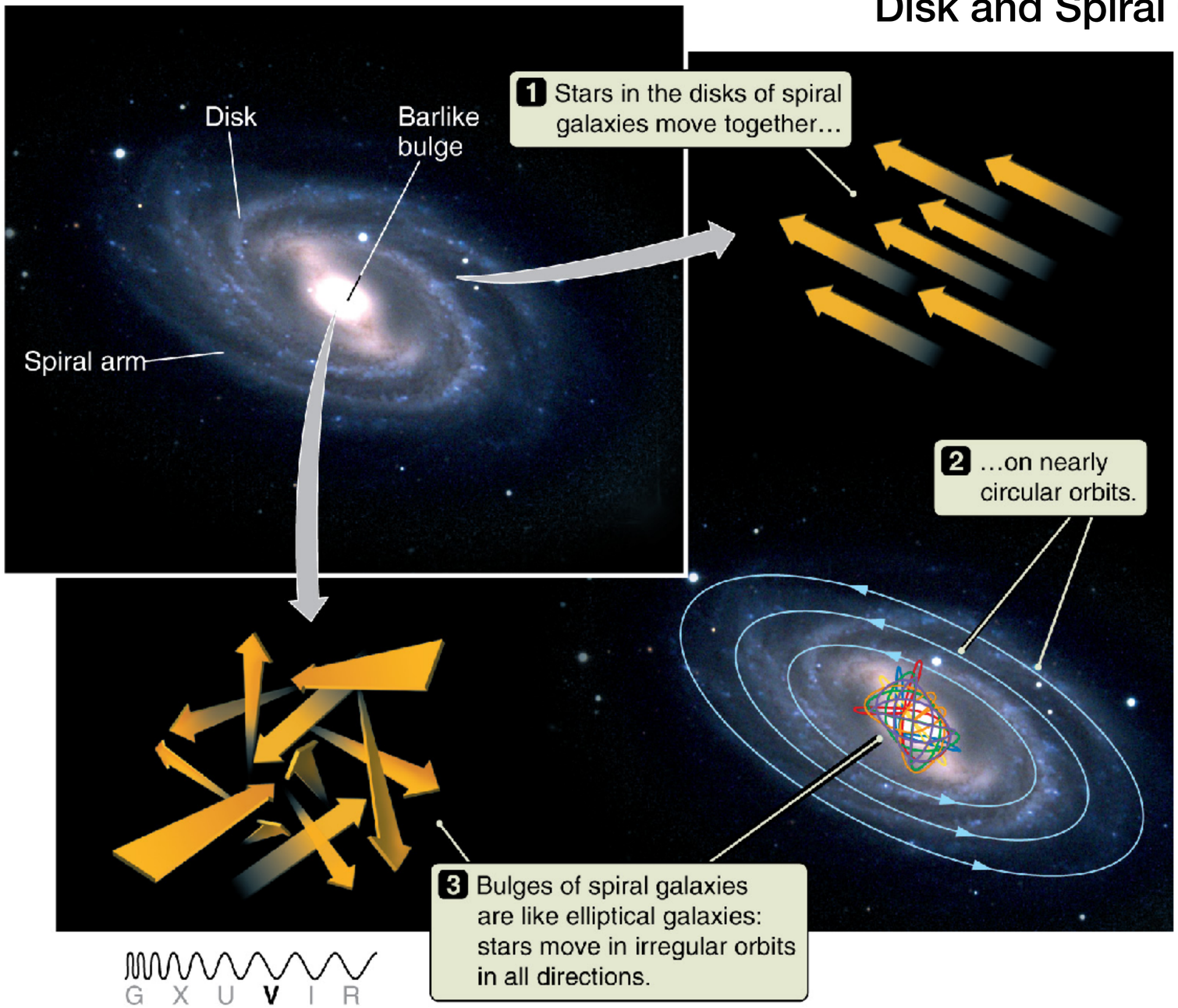


…and the motions of stars



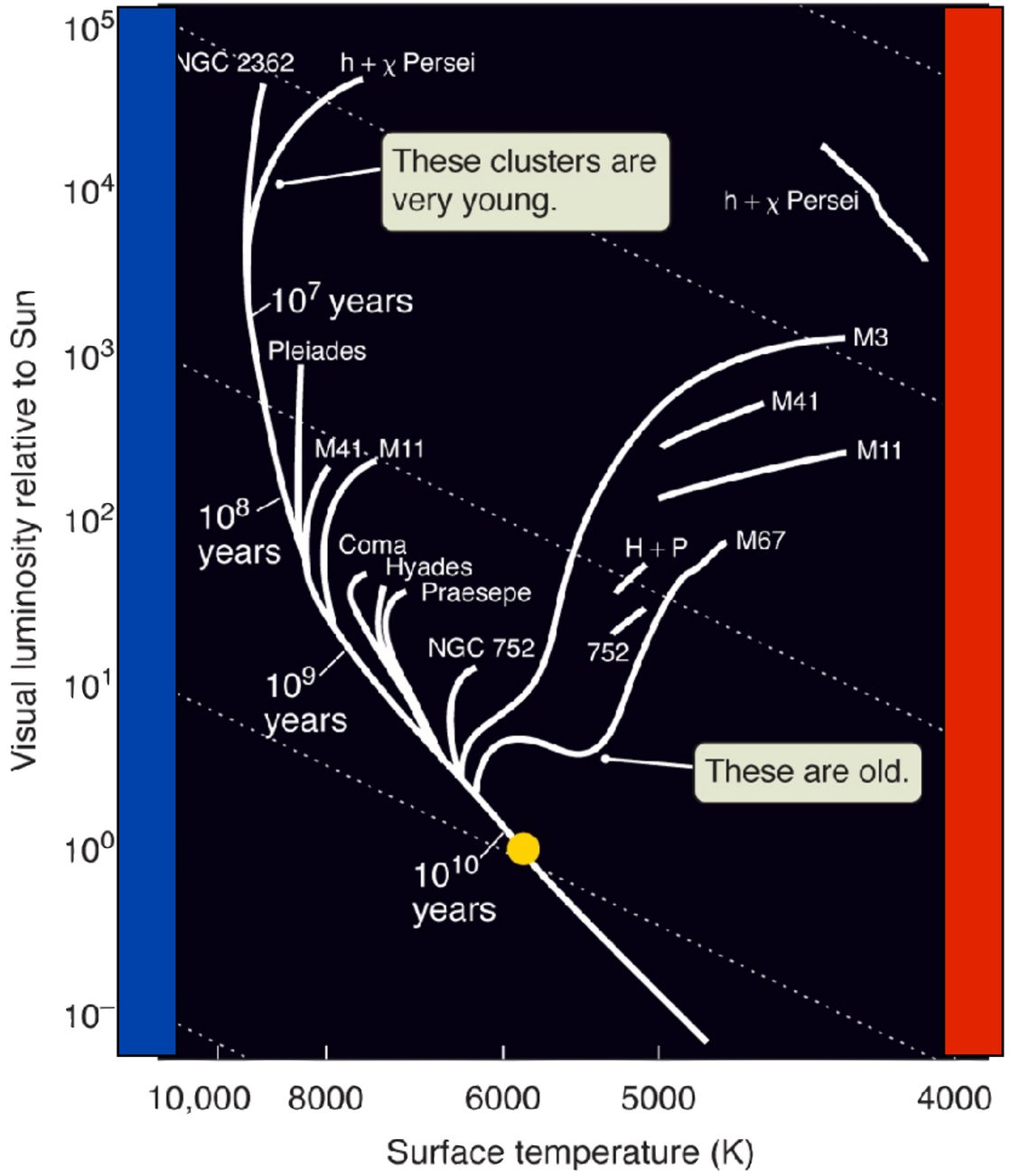
Bulges and Ellipticals

Disk and Spiral Galaxies



Which type of galaxy (Disk or Elliptical) is our galaxy, the Milky Way?

Why do you think so?



Color vs stellar age

A) Older stars have bluer colors

B) Older stars have redder colors

C) Stellar colors do not depend on age

Which galaxy is oldest?

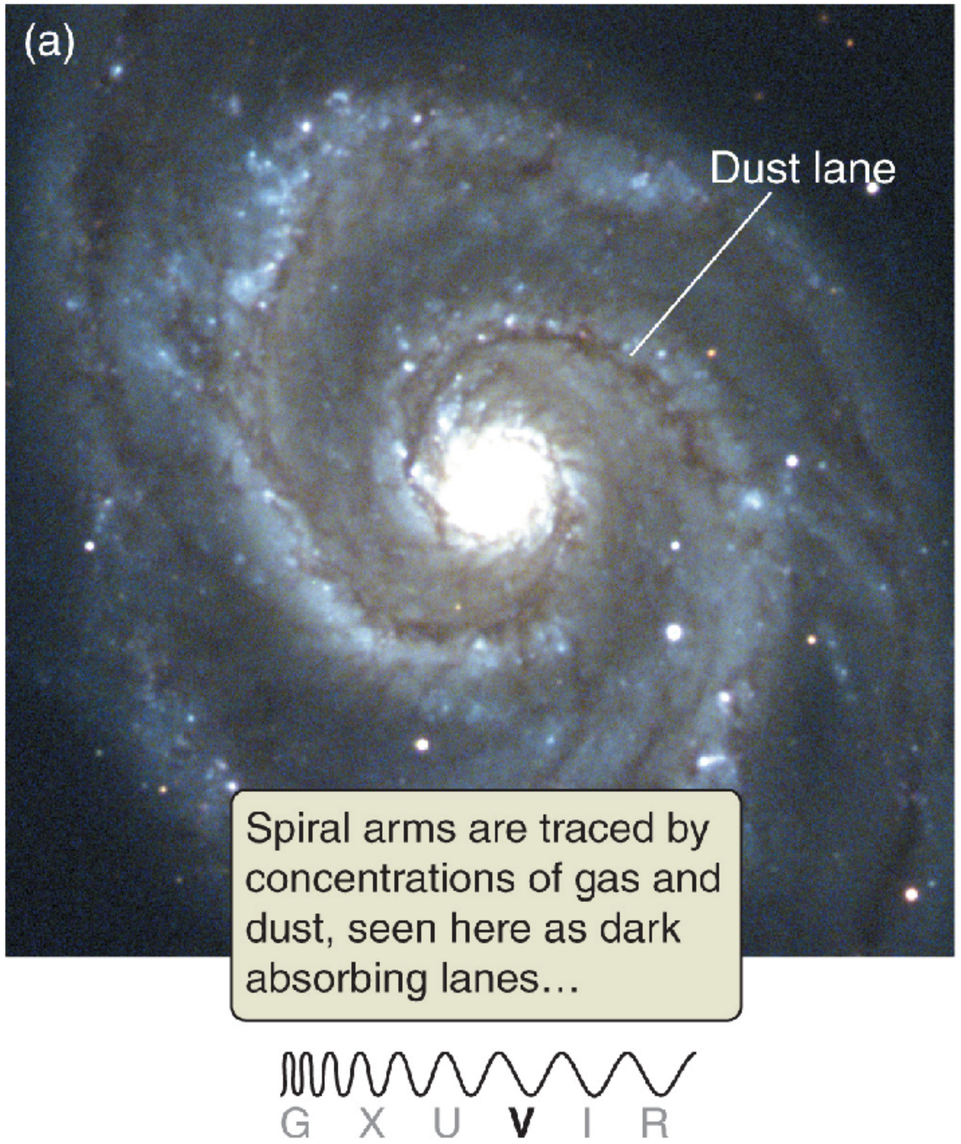
Which galaxy is prettiest?

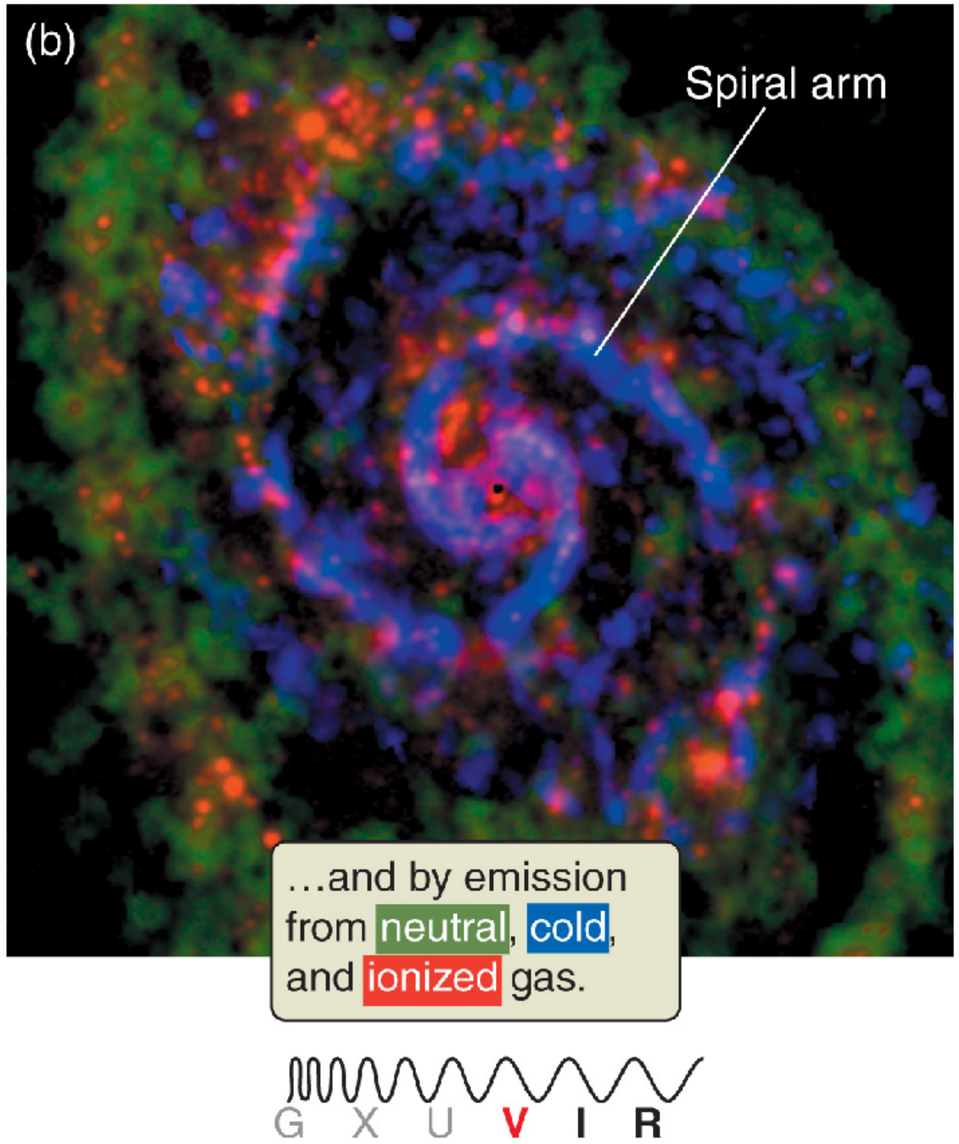
Why is there a connection between shape & stellar age?

Hint: it's analogous to planets in star systems

Stars form from gas — gas settles into a disk due to angular momentum conservation!

Spiral arms are density waves (like sound waves)





Galaxies are not isolated

https://www.youtube.com/watch?v=52k-VryS1hs

Chapter 14: Measuring Galaxies

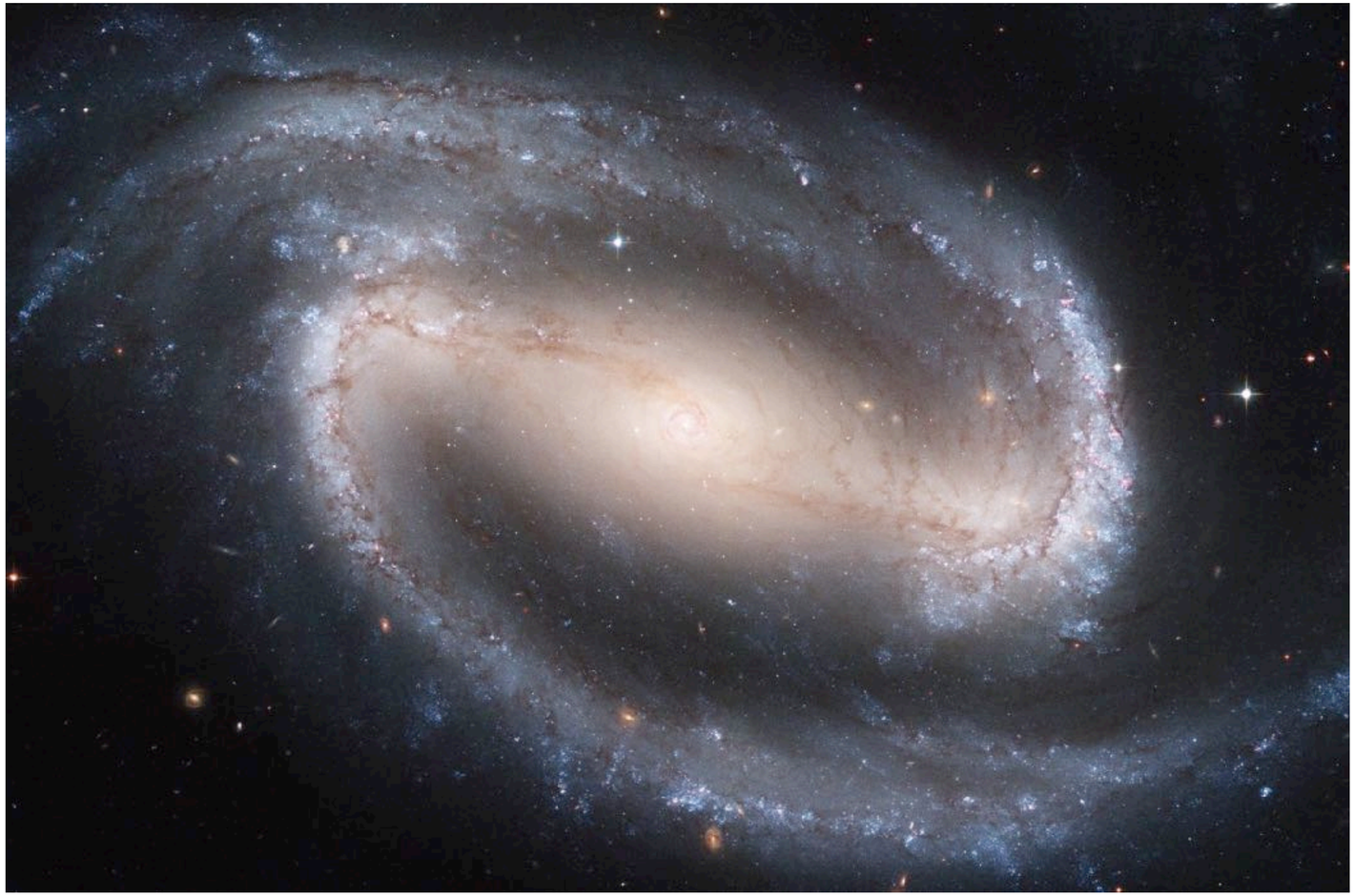
Midterm 2 *this Friday*!

New Galaxy Zoo HW due on Friday
(but preferred by Wednesday)

Turn in extra credit planetarium and public observing reports up front when complete

https://www.youtube.com/watch?v=52k-VryS1hs

What is the dominant factor that determines a galaxies appearance?



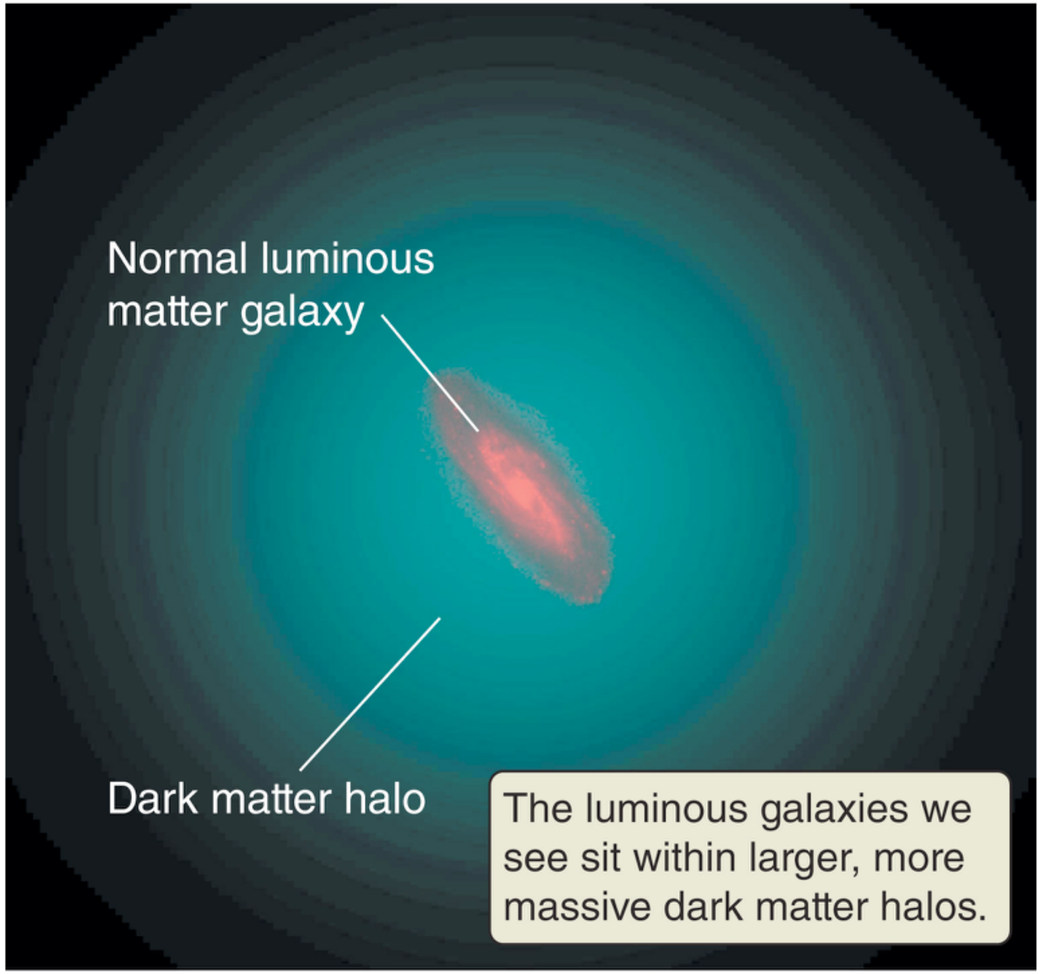
A) Total Mass

B) Age of stars

C) Environment

D) All of the above

What are galaxies mostly made of?



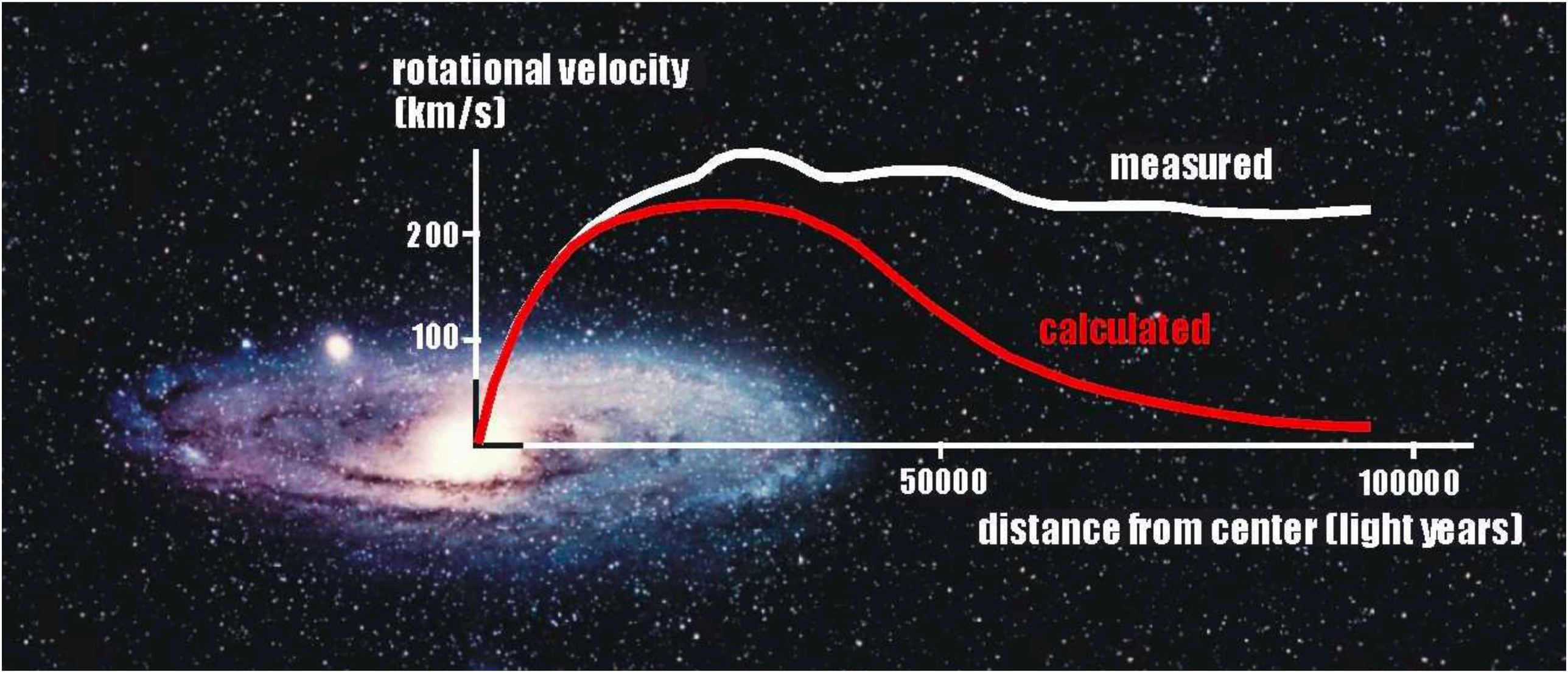
A) Stars

B) Stellar Remnants

C) Gas

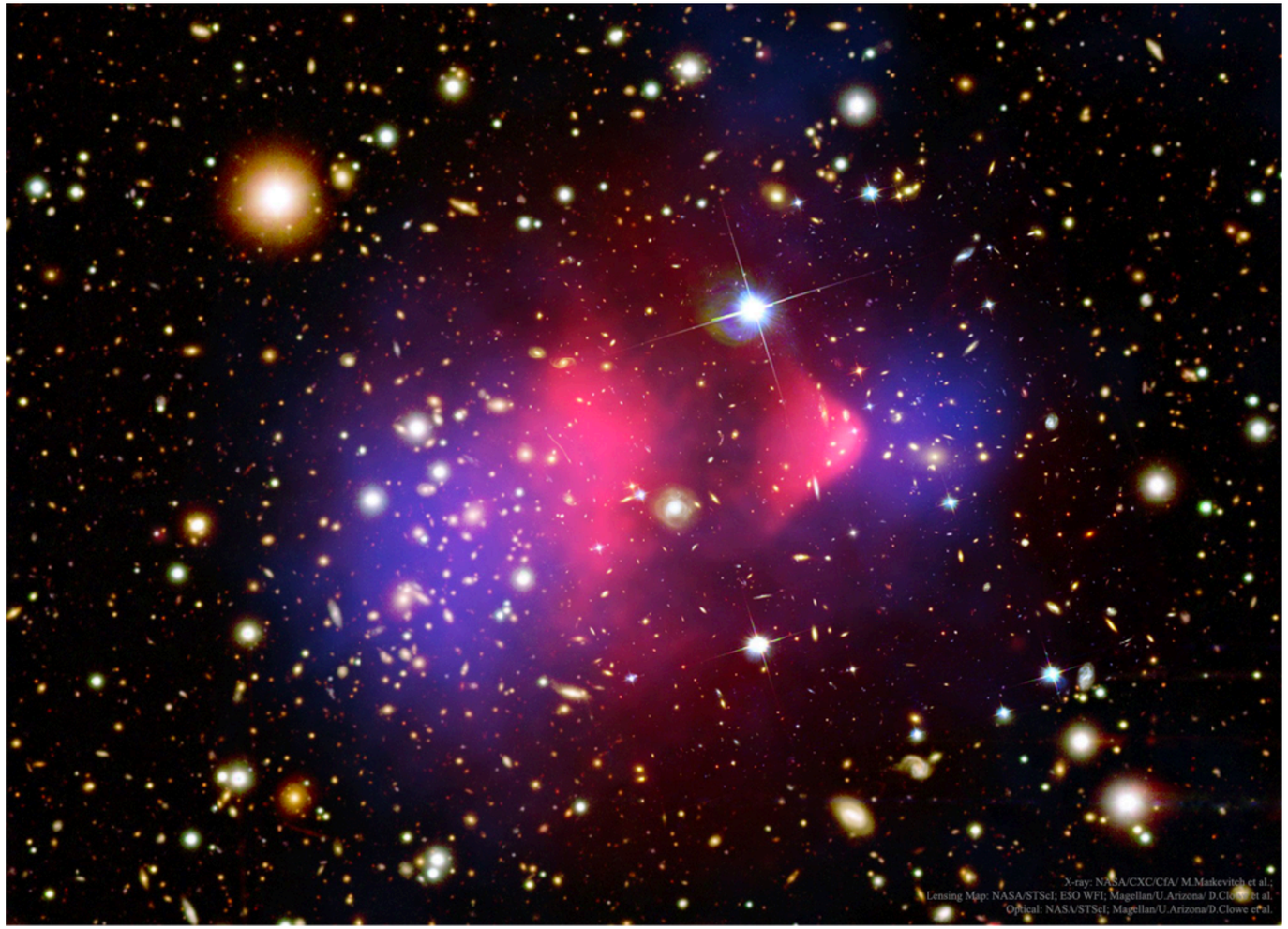
D) Who knows?

What are galaxies mostly made of?



Can estimate the mass of elliptical galaxies from its hot, X-ray emitting gas

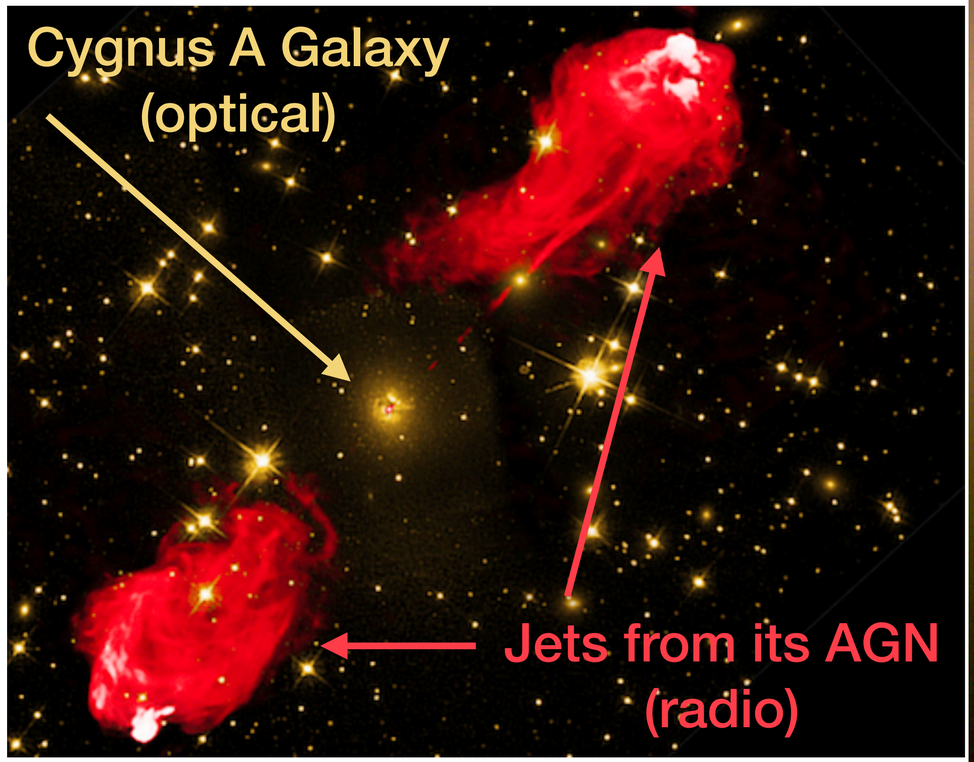
What is dark matter?

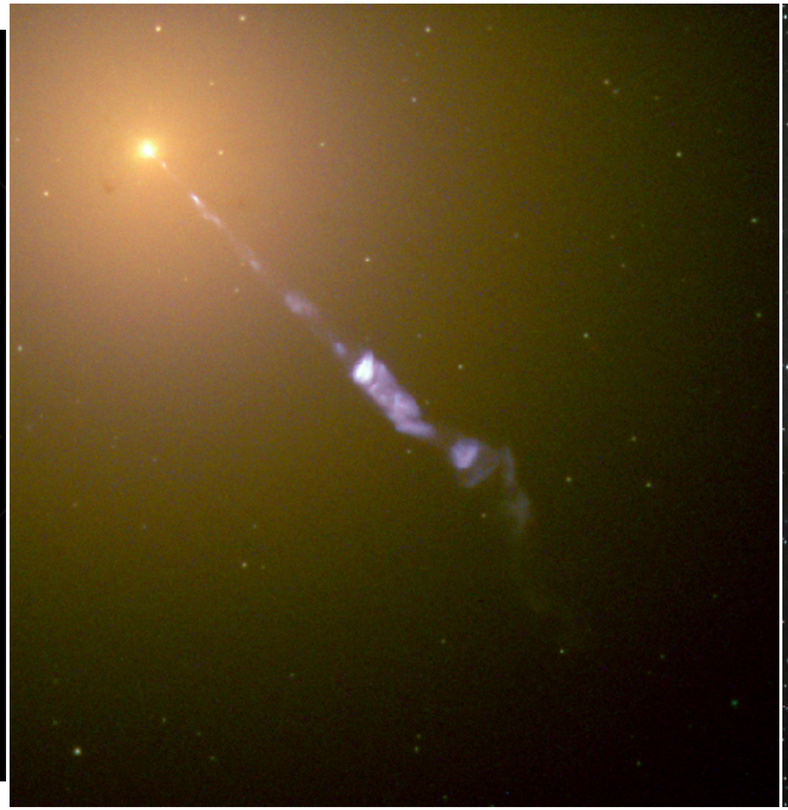


- Most likely a new kind of matter (but possibly a modification to general relativity)
- Does not absorb or emit light
- Interacts very weakly, except through its gravity
- WIMP or MACHO? Axion or sterile neutrino?

Active Galactic Nuclei (AGN) <—> Supermassive Black Holes (SMBHs)

more or less all galaxies have an SMBH, and its mass is proportional to the mass of its bulge

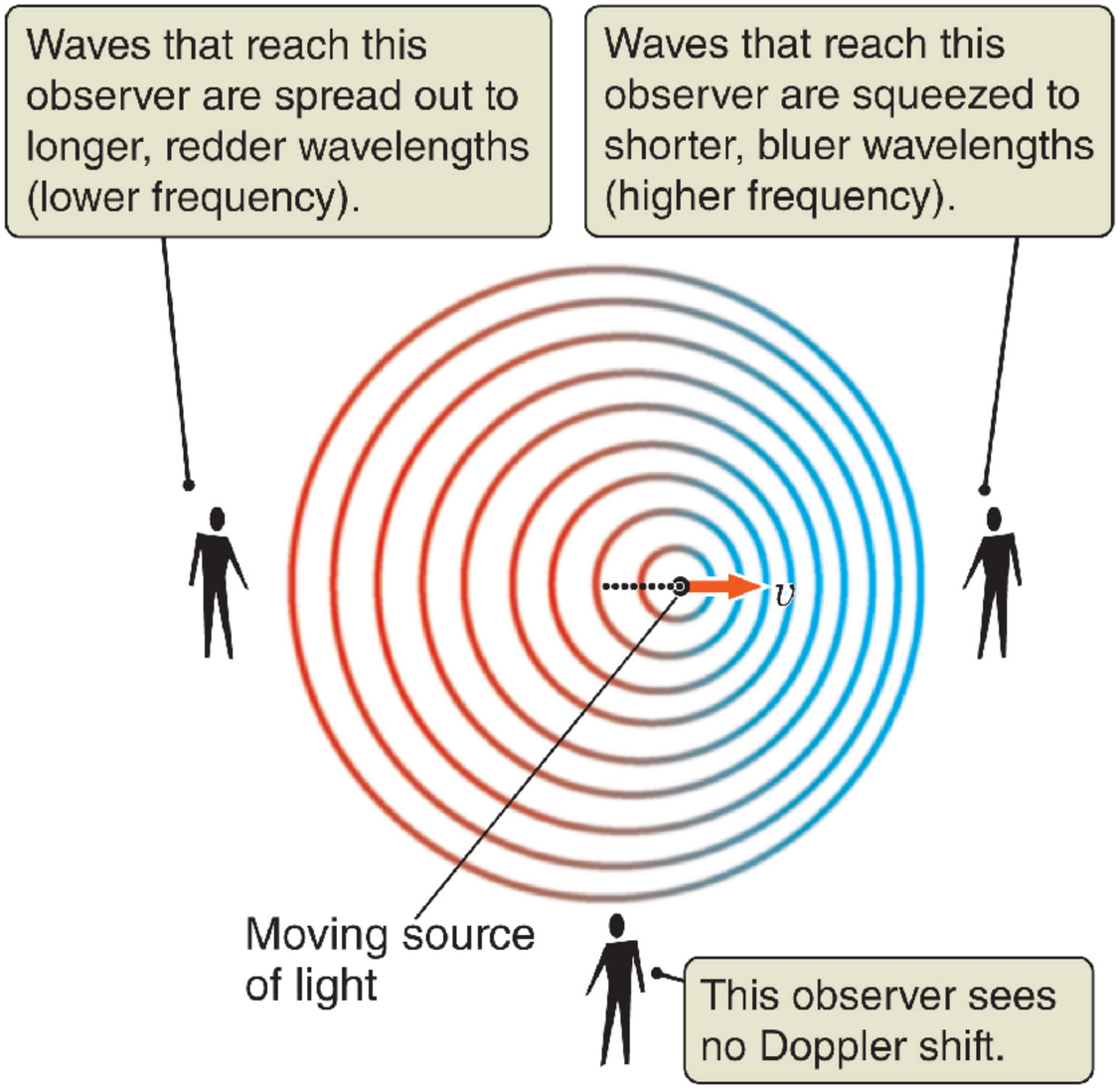




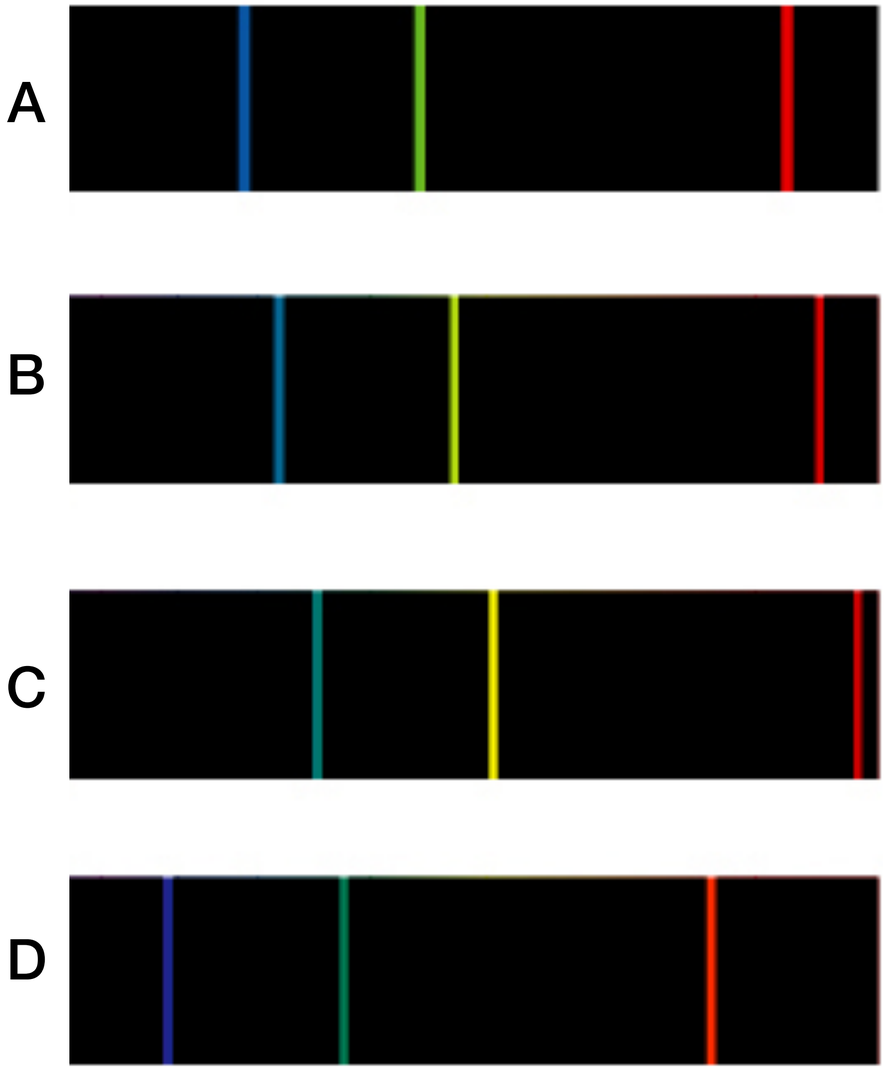
M87

Centaurus A

But how are galaxies moving?



Doppler Shift of Light

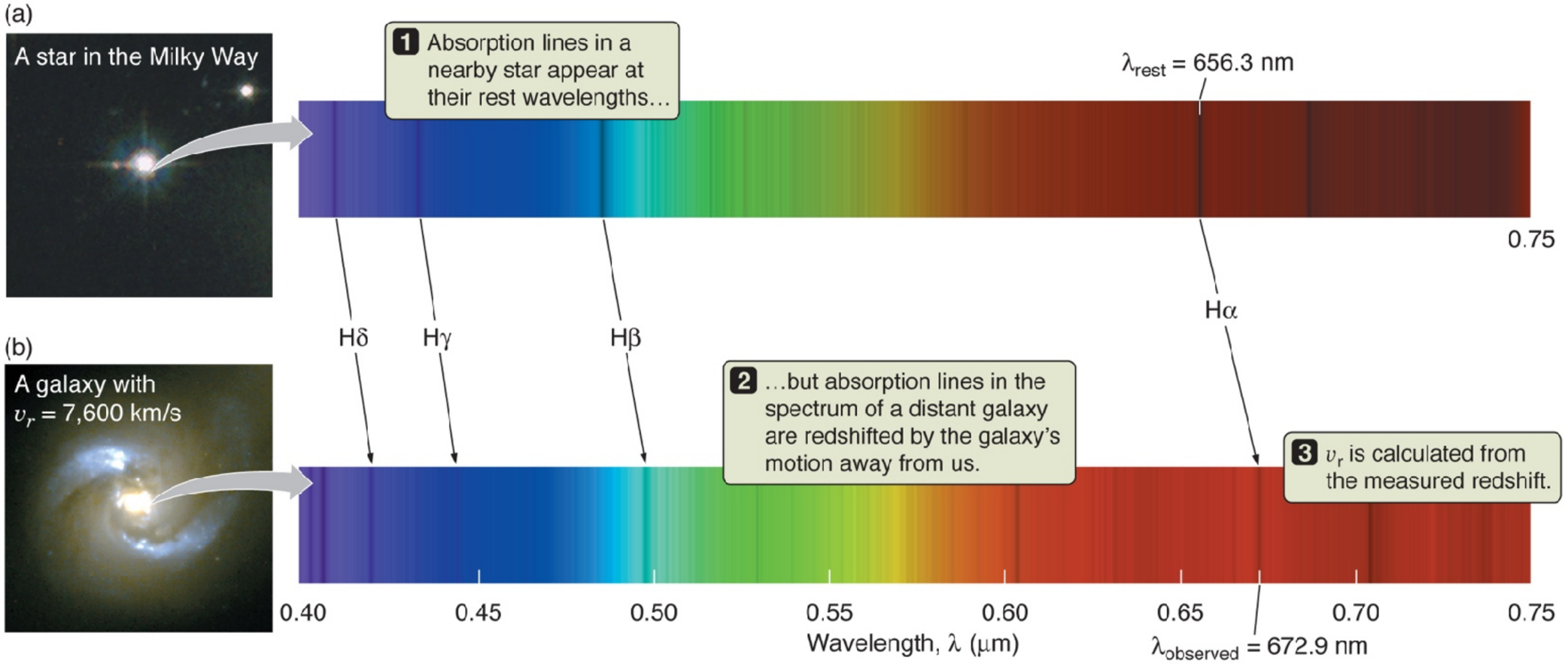


$$\frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}} = \frac{V}{c}$$

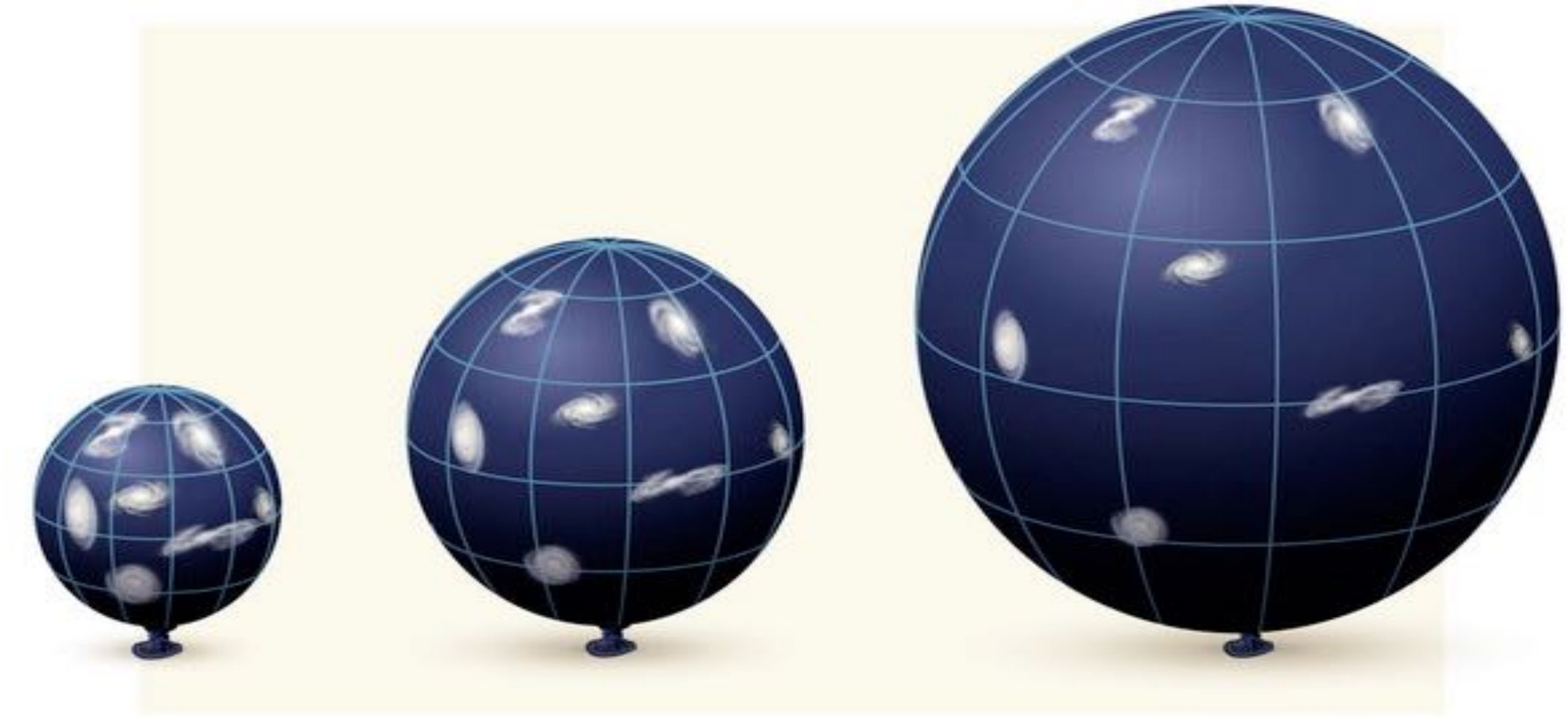
Which spectrum is moving away from us the fastest?

Almost all galaxies are moving away from us.

$$\frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}} = \frac{v}{c}$$



We live in an expanding “balloon universe”



Activity Instructions

- Groups of 3-5 people
- HAND IN ONE SHEET WITH ALL GROUP MEMBERS NAMES
- Materials: Balloon, String, Ruler (or any reference length), Marker, [Stopwatch or clock]
- Roles: Secretary, Balloon Blower, Measurer, Speaker, [Time Keeper]

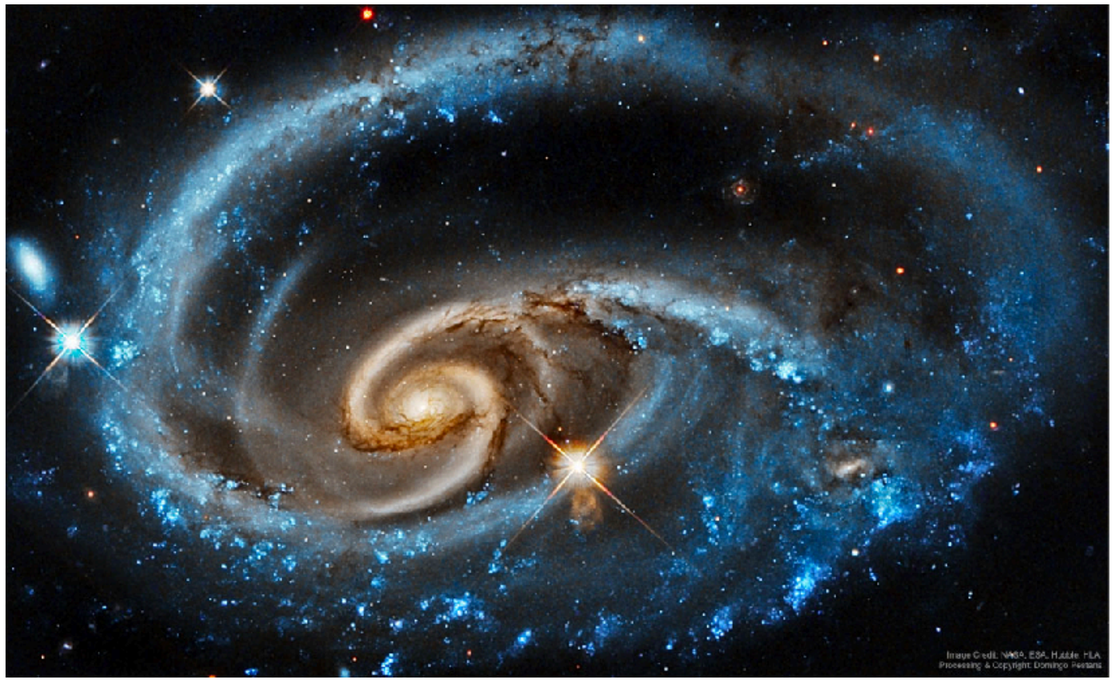
Chapter 14: Measuring Galaxies

Midterm 2 *this Friday*!

Galaxy Zoo HW due Friday

Ch. 15 & 16 Reading Assignments due Monday & Wednesday

TA Office Hour Reviews in JFB 325 today and tomorrow



https://apod.nasa.gov/apod/ap170510.html

Additional discussion questions

- Was there anything special about your reference galaxy? If you had picked a different reference galaxy, would the slope of your line be different?

- Parts of your balloon may have expanded faster than others because they have more or less stretchy balloon stuff. How is this similar to some places in the actual universe?

What are the spiral nebulae?

The great debate of 1920

Harlow Shapley

Herber Curtis

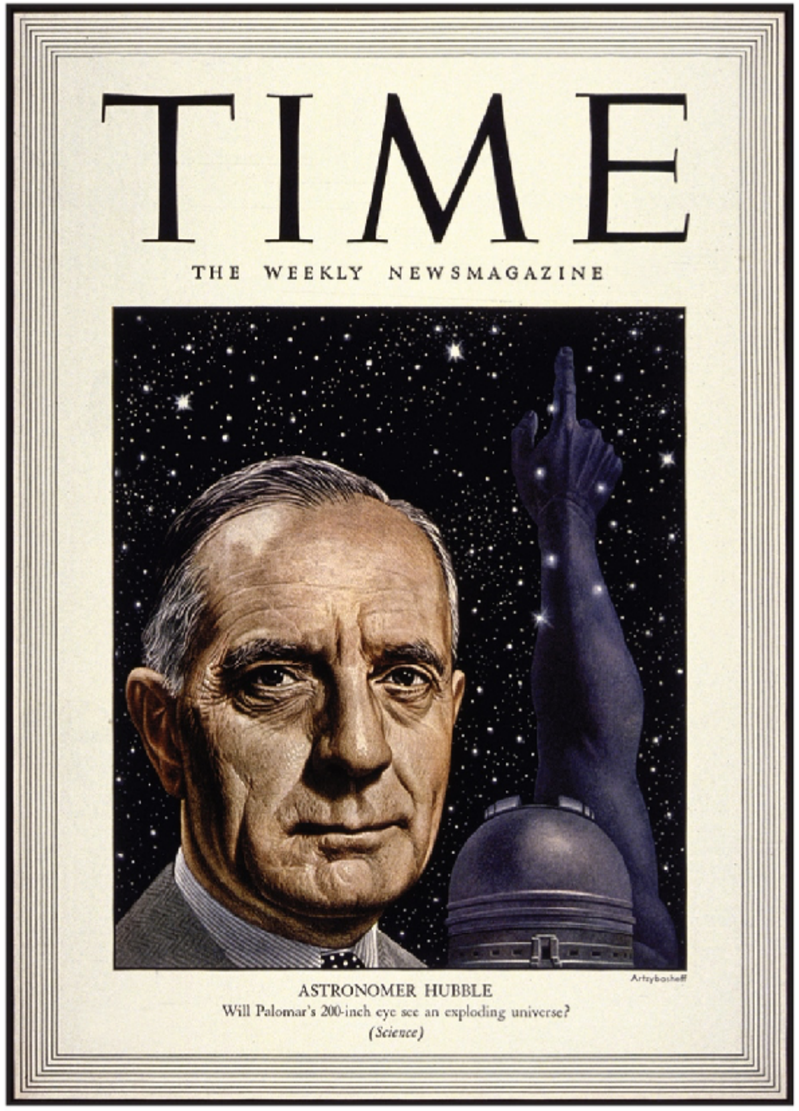
MW is whole Universe

- ✓ Sun is in outer part of the MW
- ✗ M31 would have to be at an insane distance to be similar
- ✗ we can see rotation in the Pinwheel
- ✓✗ this one nova in M31 would have been impossibly bright

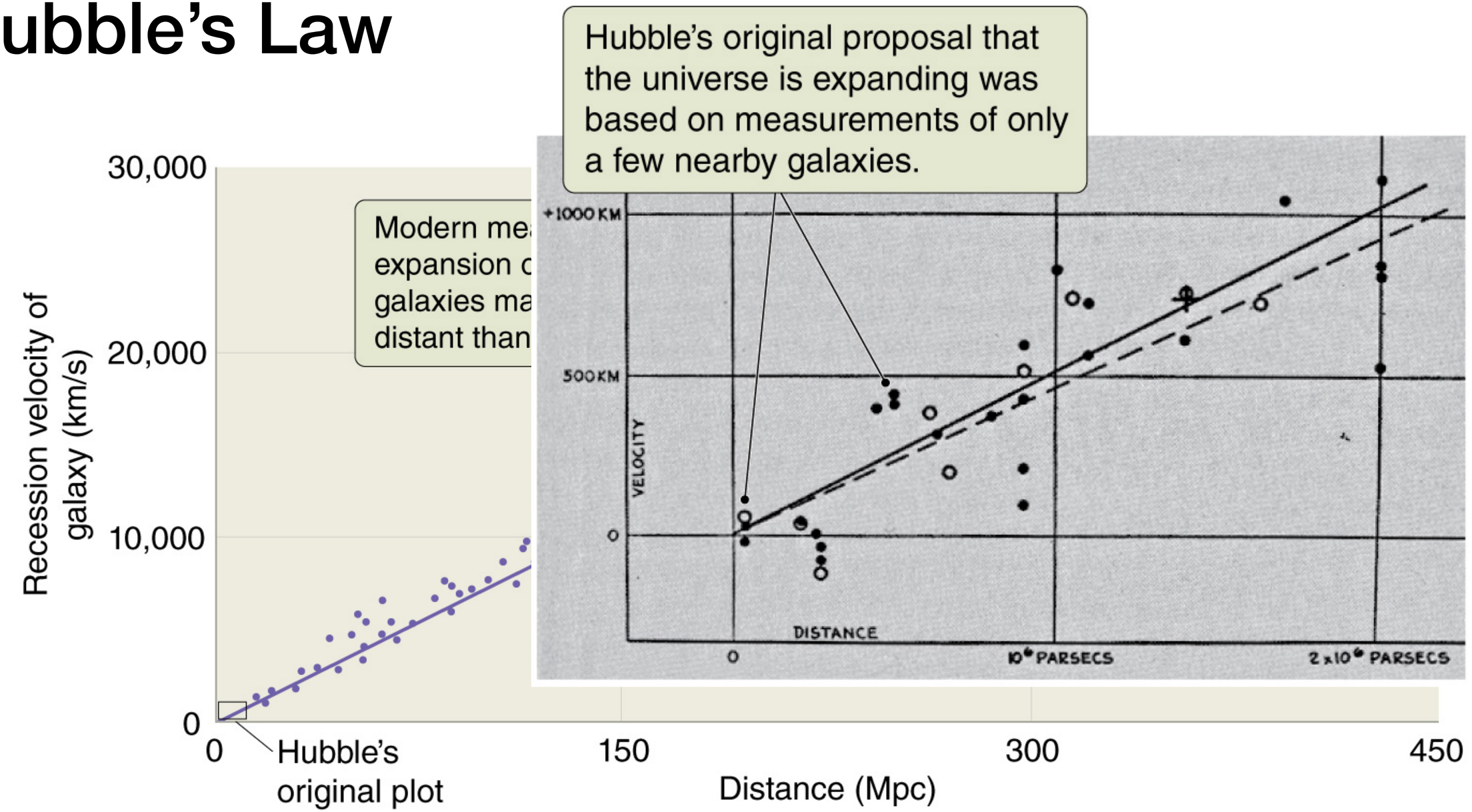
MW is one of many galaxies

- ✗ Sun is at the center of MW
- ✓ M31 has too many novae to be just a galactic nebula
- ✓ we see dust lanes in other nebulae, like the MW's

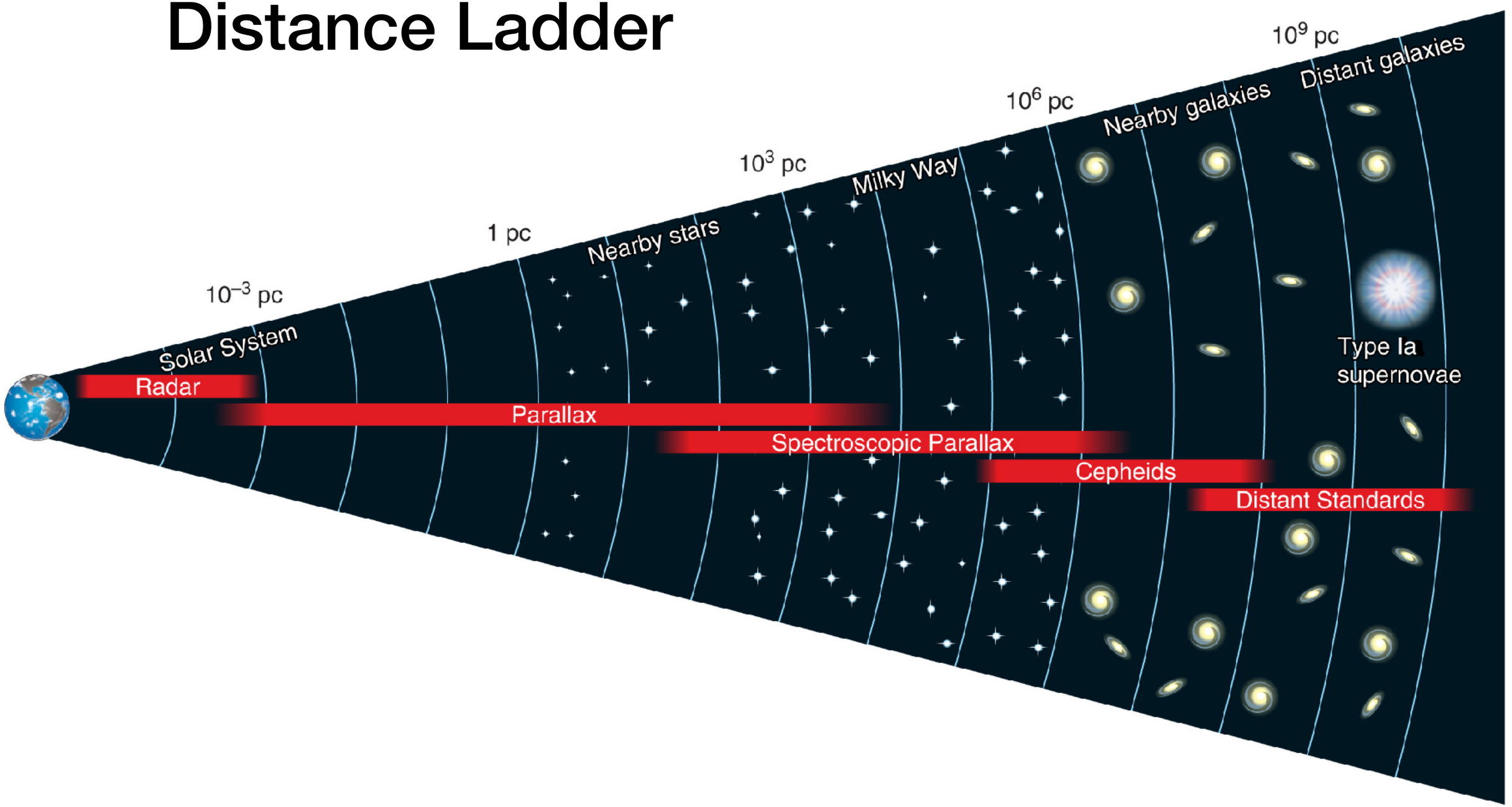
Edwin Hubble settles the debate



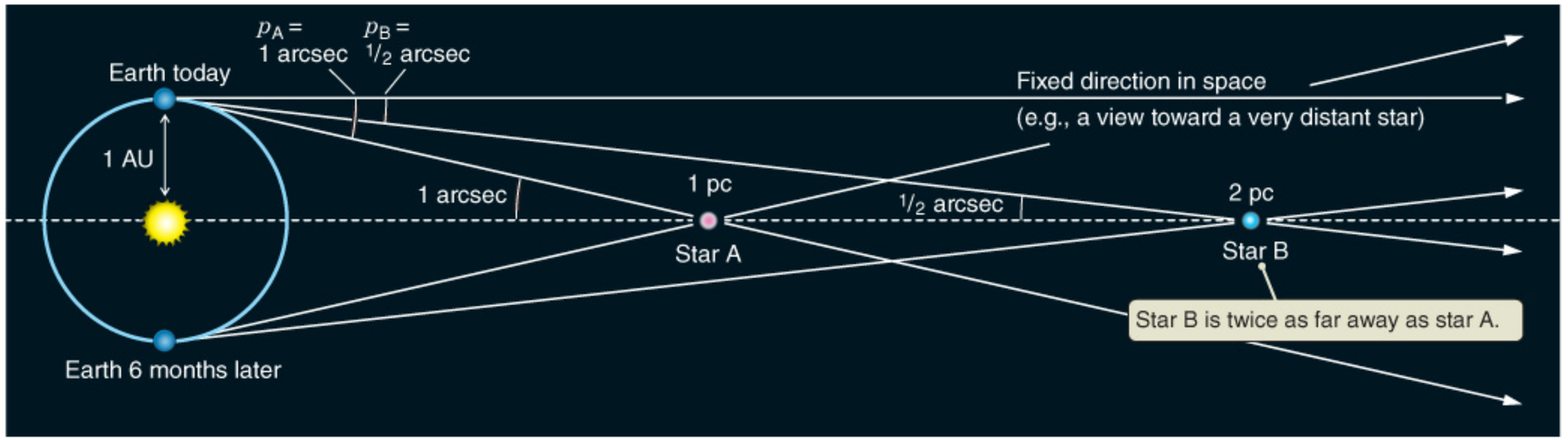
Hubble's Law


Hubble's original proposal that the universe is expanding was based on measurements of only a few nearby galaxies.
Modern me
expansion c
galaxies ma
distant than
Recession velocity of galaxy (km/s)
30,000
20,000
10,000
0
0
150
300
450
Distance (Mpc)
Hubble's original plot
+1000 KM
500 KM
0
VELOCITY
DISTANCE
0
10⁶ PARSECS
2 x 10⁶ PARSECS

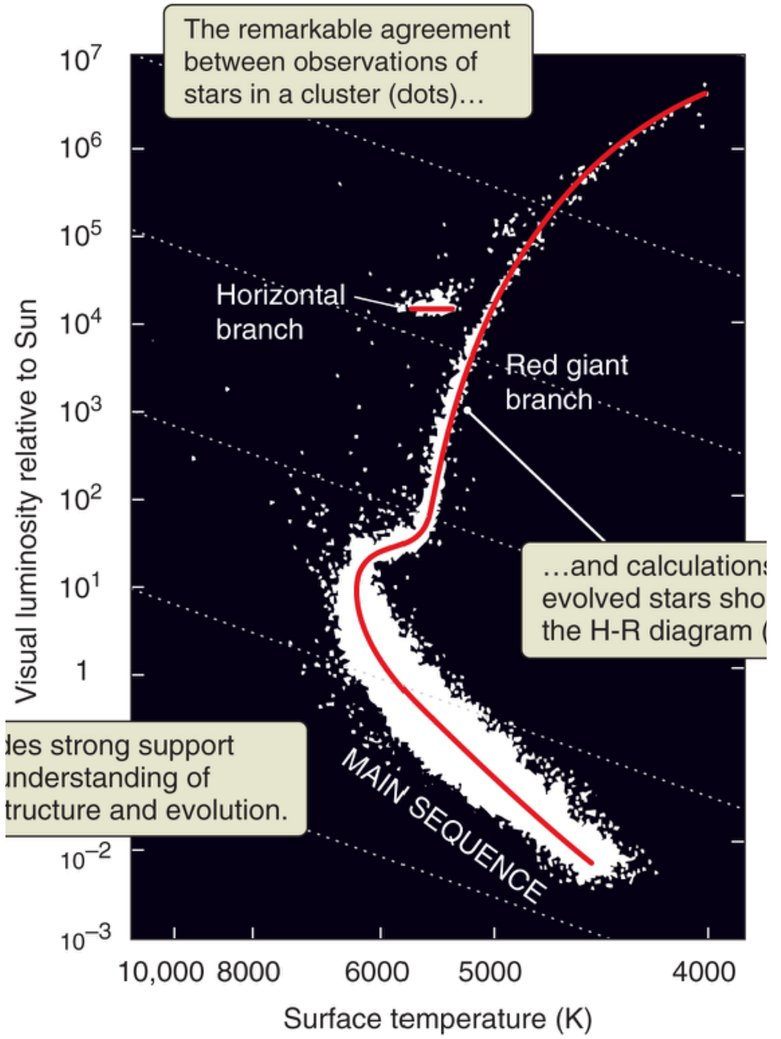
Distance Ladder



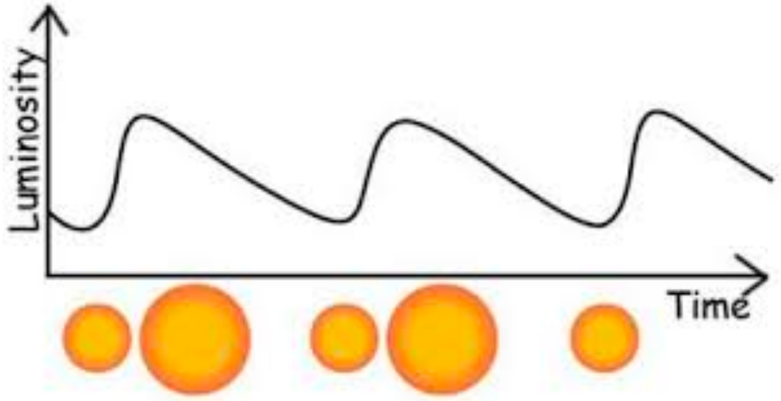
Parallax



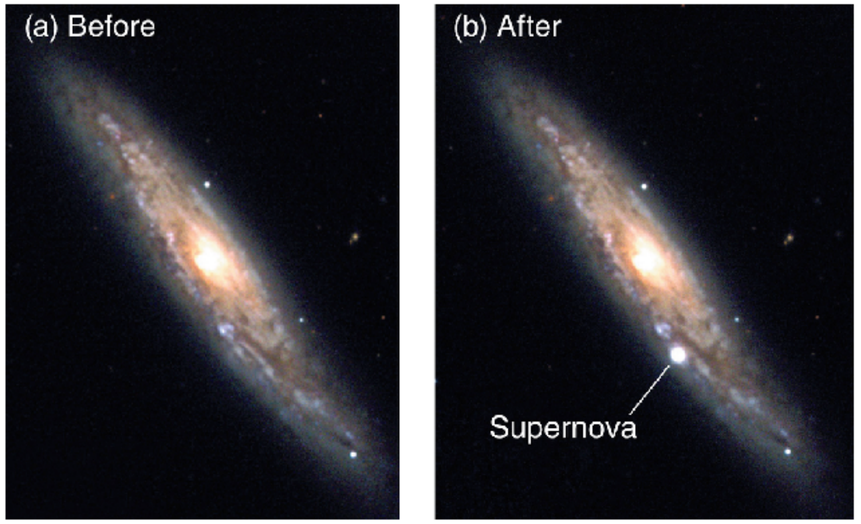
Spectroscopic Parallax



Cepheid Variables



Type Ia SNe



Working It Out 14.1 Redshift: Calculating the Recession Velocity and Distance of Galaxies

The Doppler equation you learned for spectral lines showed that

$$v_r = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}} \times c$$

The fraction in front of the c is equal to z, the redshift. Substituting for the fraction, we get

$$v_r = z \times c$$

(Note: This correspondence works only for velocities much slower than the speed of light.)

Suppose a hydrogen line is seen in the spectrum of a distant galaxy. In the laboratory, this hydrogen line has a measured rest wavelength of 122 nanometers (nm). If the observed wavelength of the hydrogen line is 124 nm, then its redshift is

$$z = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$$

$$z = \frac{124\ \text{nm} - 122\ \text{nm}}{122\ \text{nm}}$$

$$z = 0.016$$

We can now calculate the recession velocity from this redshift:

$$v_r = z \times c = 0.016 \times 300{,}000\ \text{km/s} = 4{,}800\ \text{km/s}$$

How far away, though, is our distant galaxy? This is where Hubble's law and the Hubble constant ($H_0 = 70$ kilometers per second per megaparsec [km/s/Mpc]) come in. Hubble's law relates a galaxy's recession velocity to its distance and can be expressed mathematically as $v_r = H_0 \times d_G$, where d_G is the distance to a galaxy measured in millions of parsecs (that is, megaparsecs). We can divide through by H_0 to get

$$d_G = \frac{v_r}{H_0}$$

$$d_G = \frac{4{,}800\ \text{km/s}}{70\ \text{km/s/Mpc}} = 69\ \text{Mpc}$$

From a measurement of the wavelength of a hydrogen line, we have learned that the distant galaxy is approximately 69 Mpc away.

Midterm 2 Highlight Tour

Emphasize on understanding concepts over memorizing details

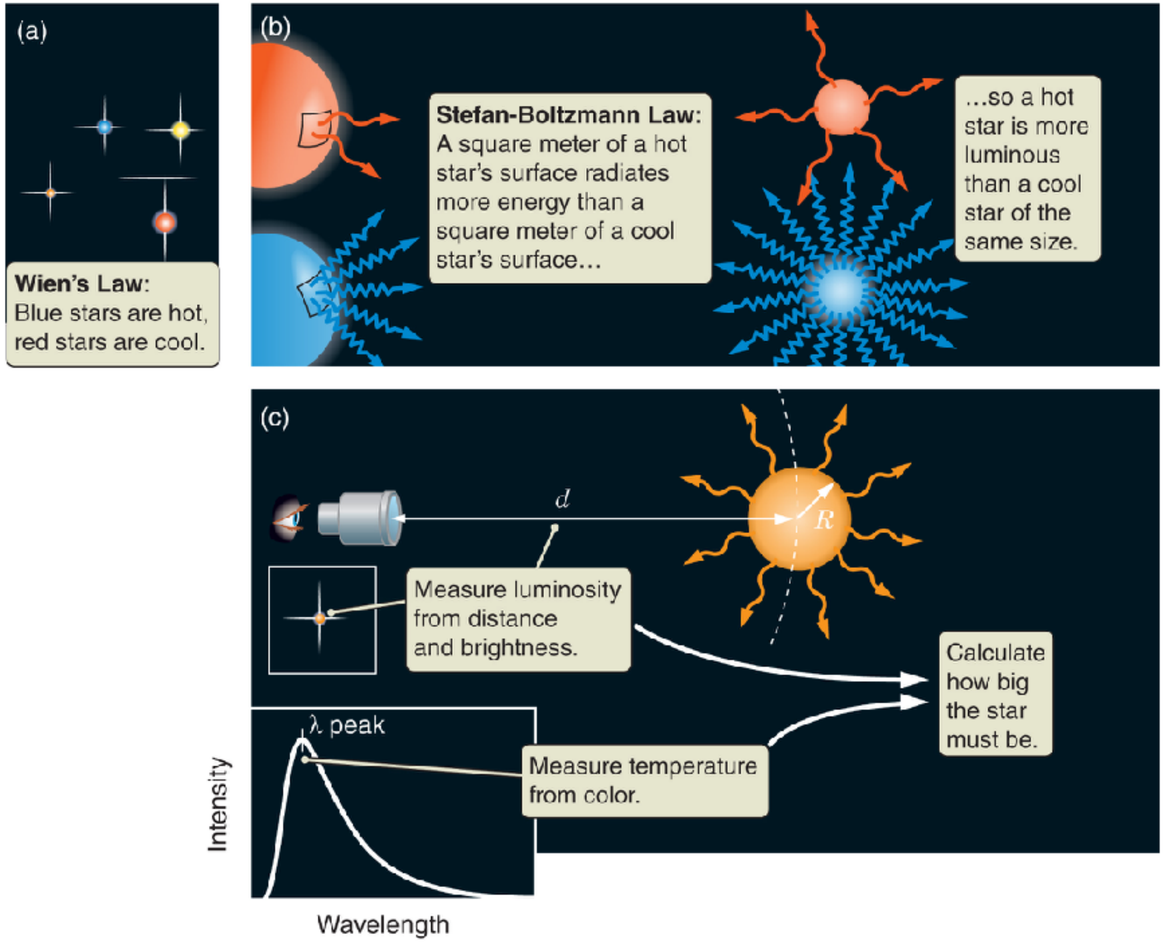
But, need to know what terms mean

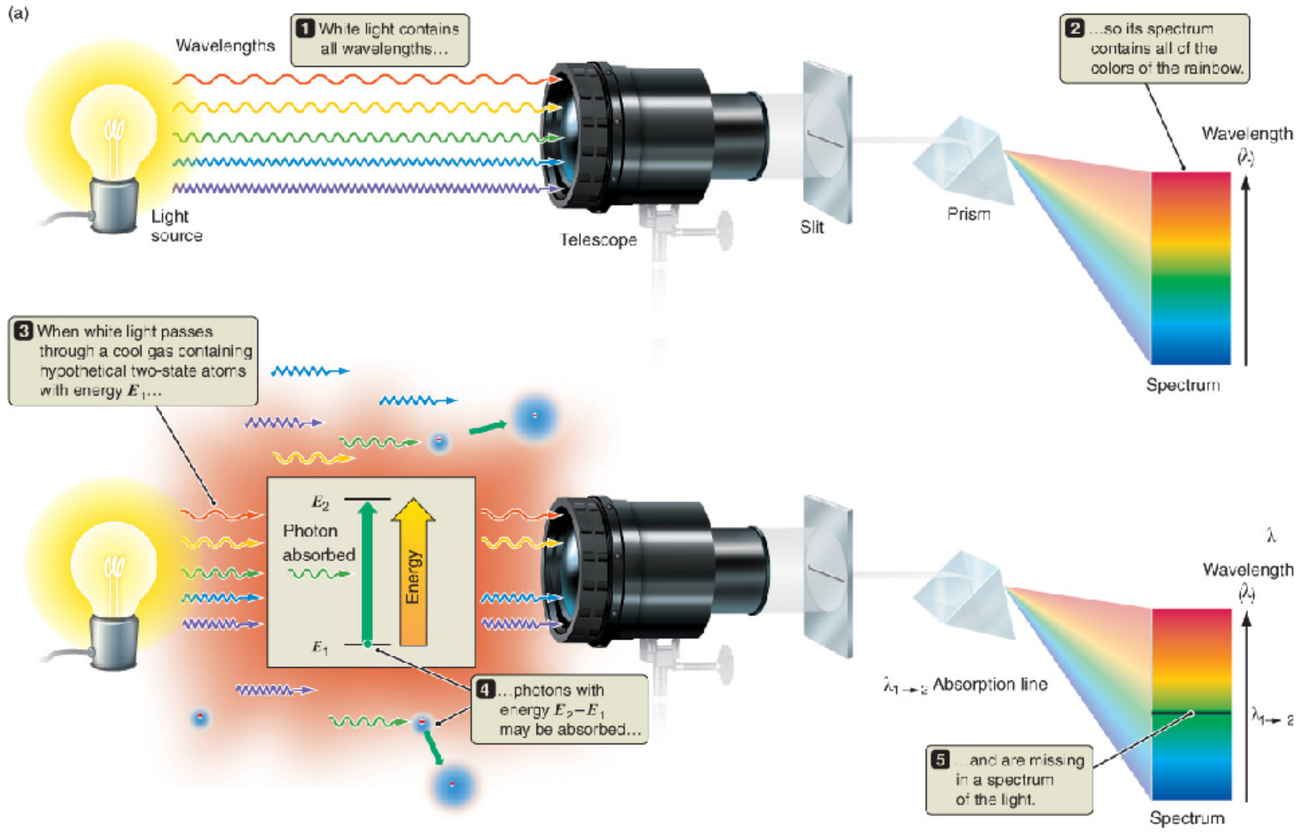
Example:
Should know the inputs and outputs of the p-p chain, but not necessary to know the details of each step

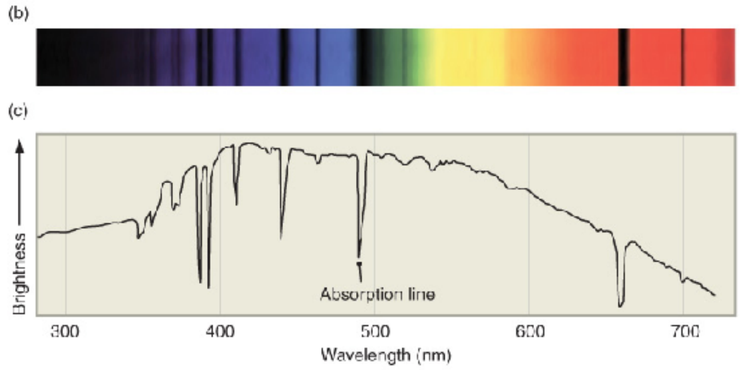
25 multiple choice questions (3 pts each), similar to last time
Several short answer questions (more this time, but still 25 pts total)

TA-led reviews in office hours this afternoon and tomorrow

Luminosity depends on Temperature AND Size

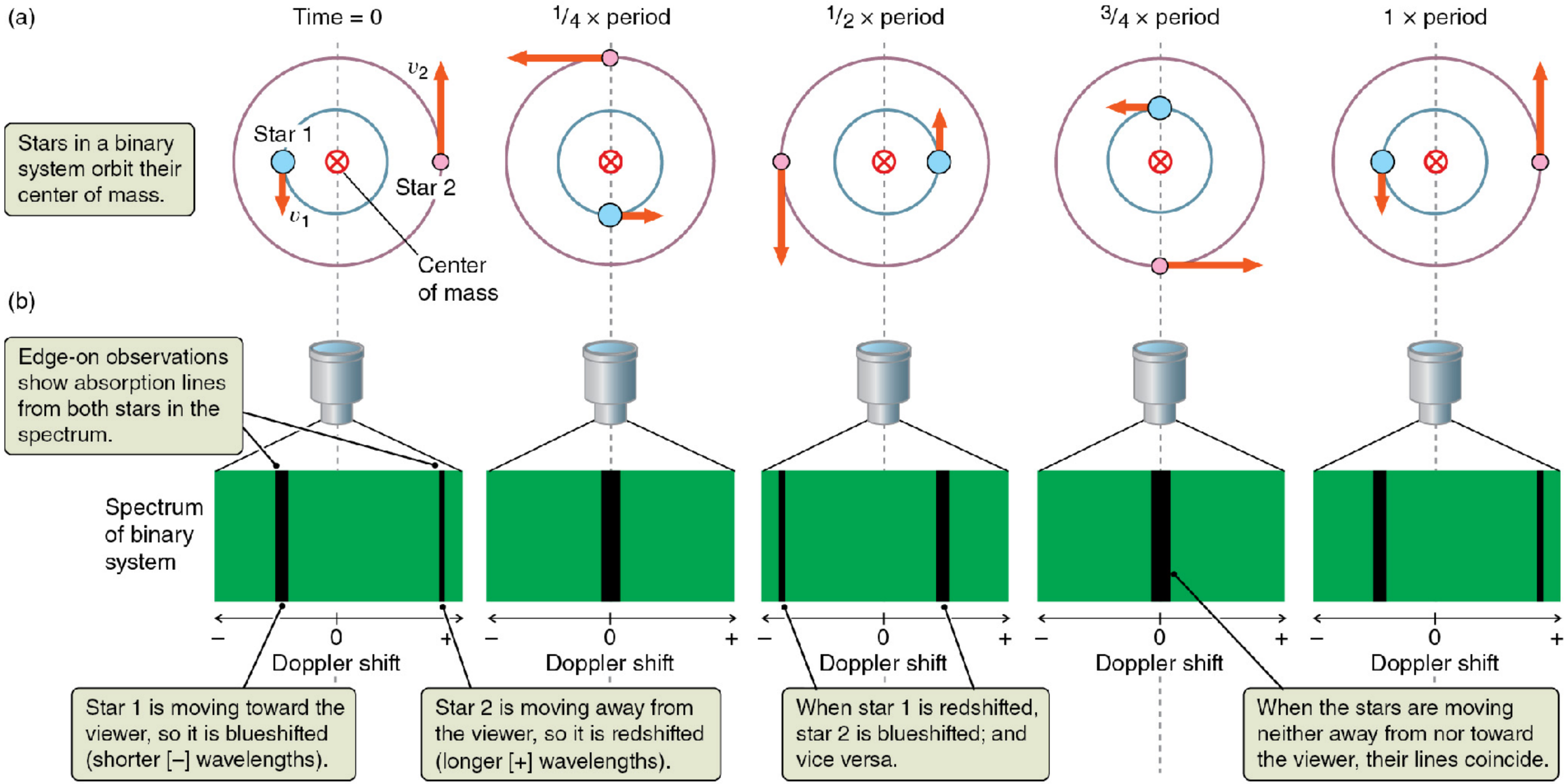




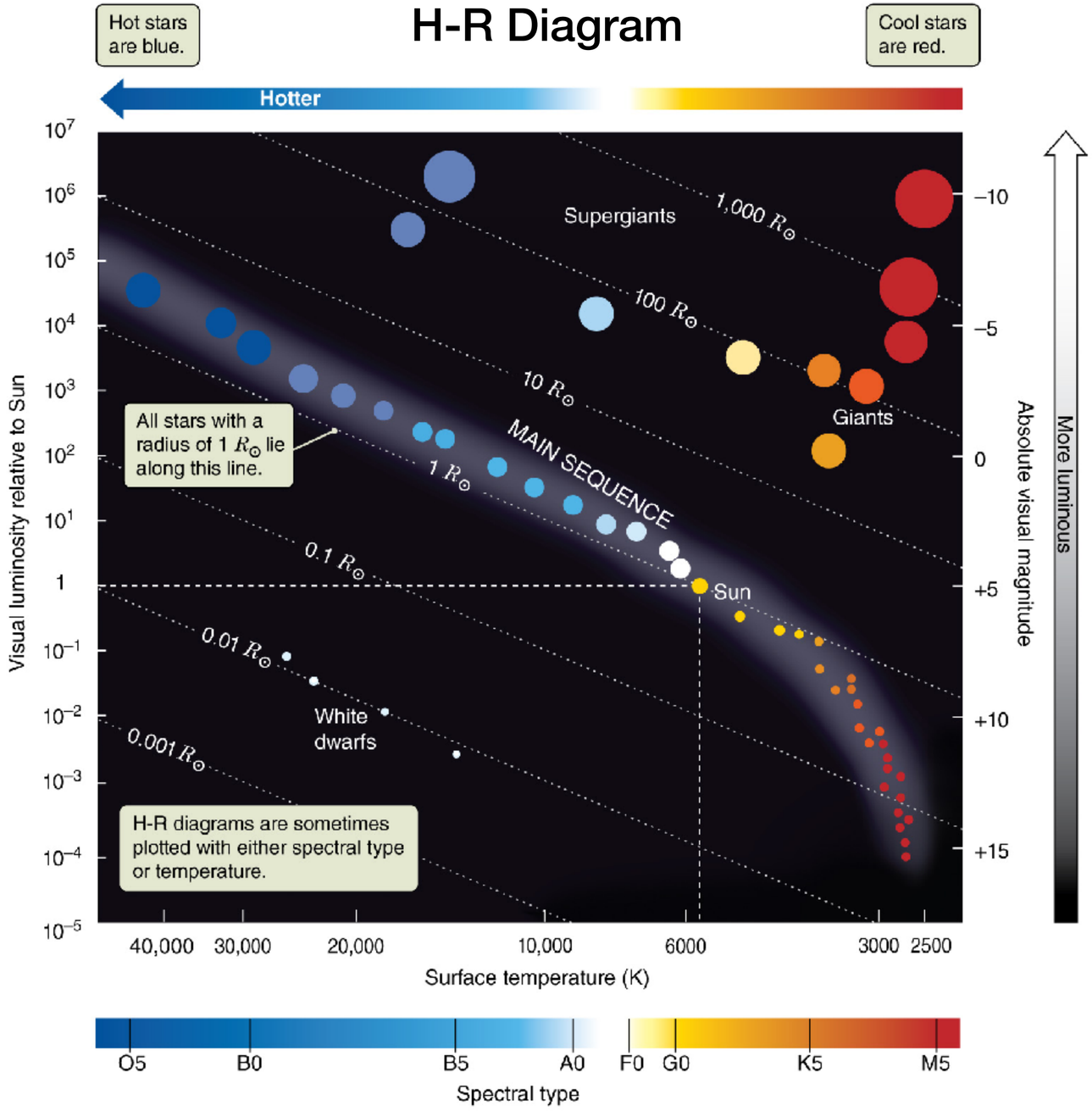


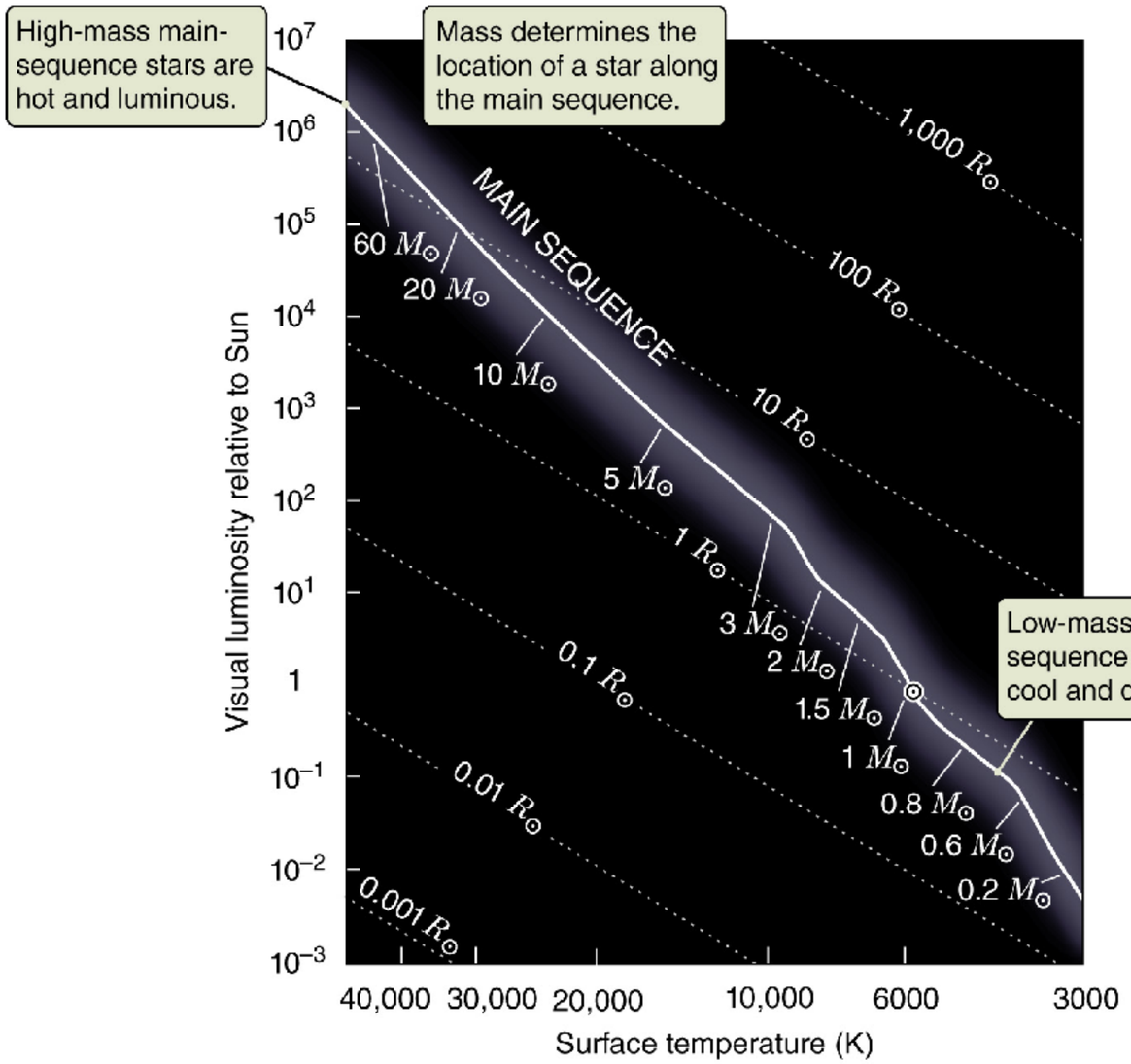
Stellar Spectra: blackbody plus absorption lines

Binary Stars: Doppler shift proportional to velocity, inversely proportional to relative mass

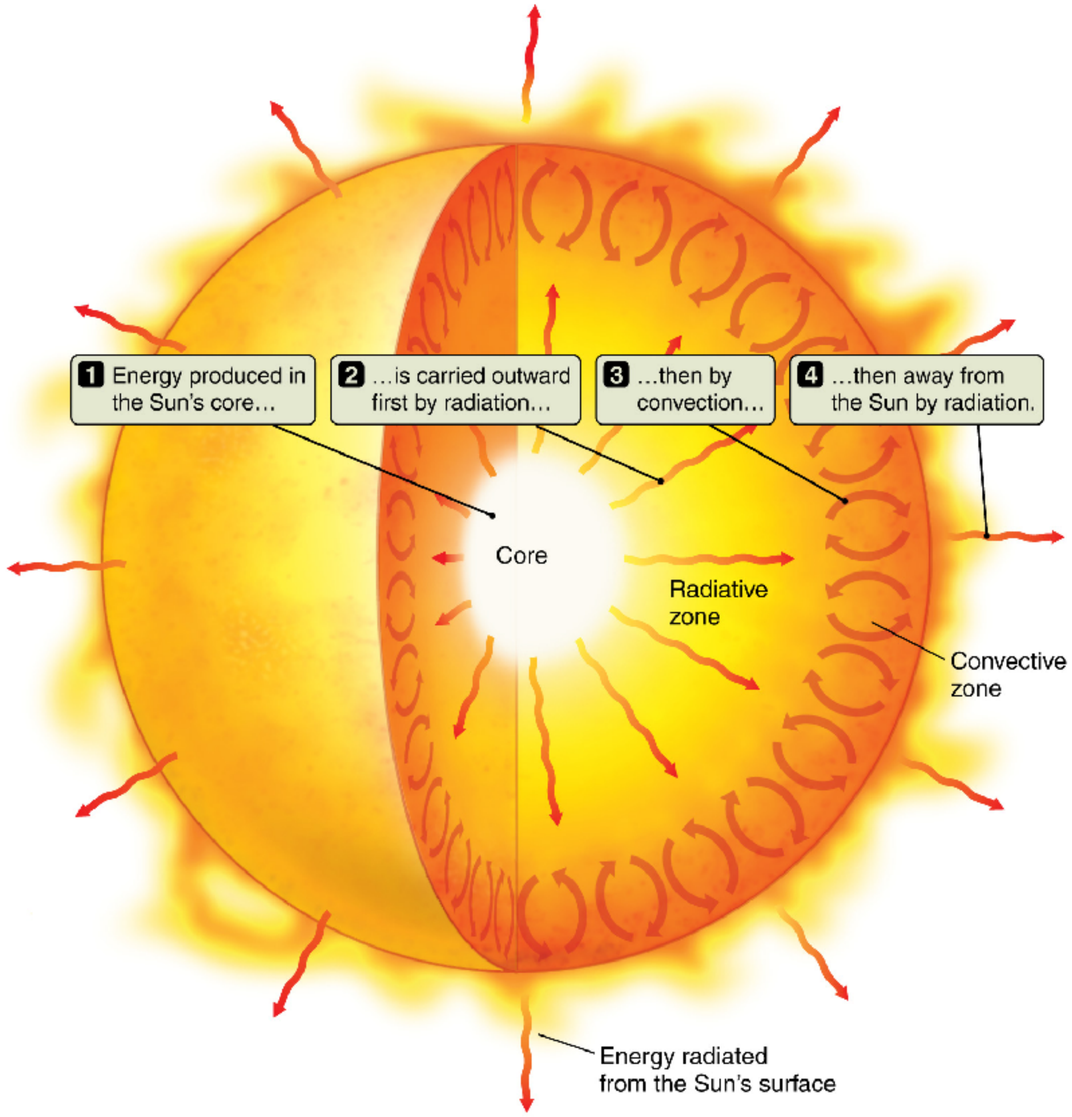


H-R Diagram

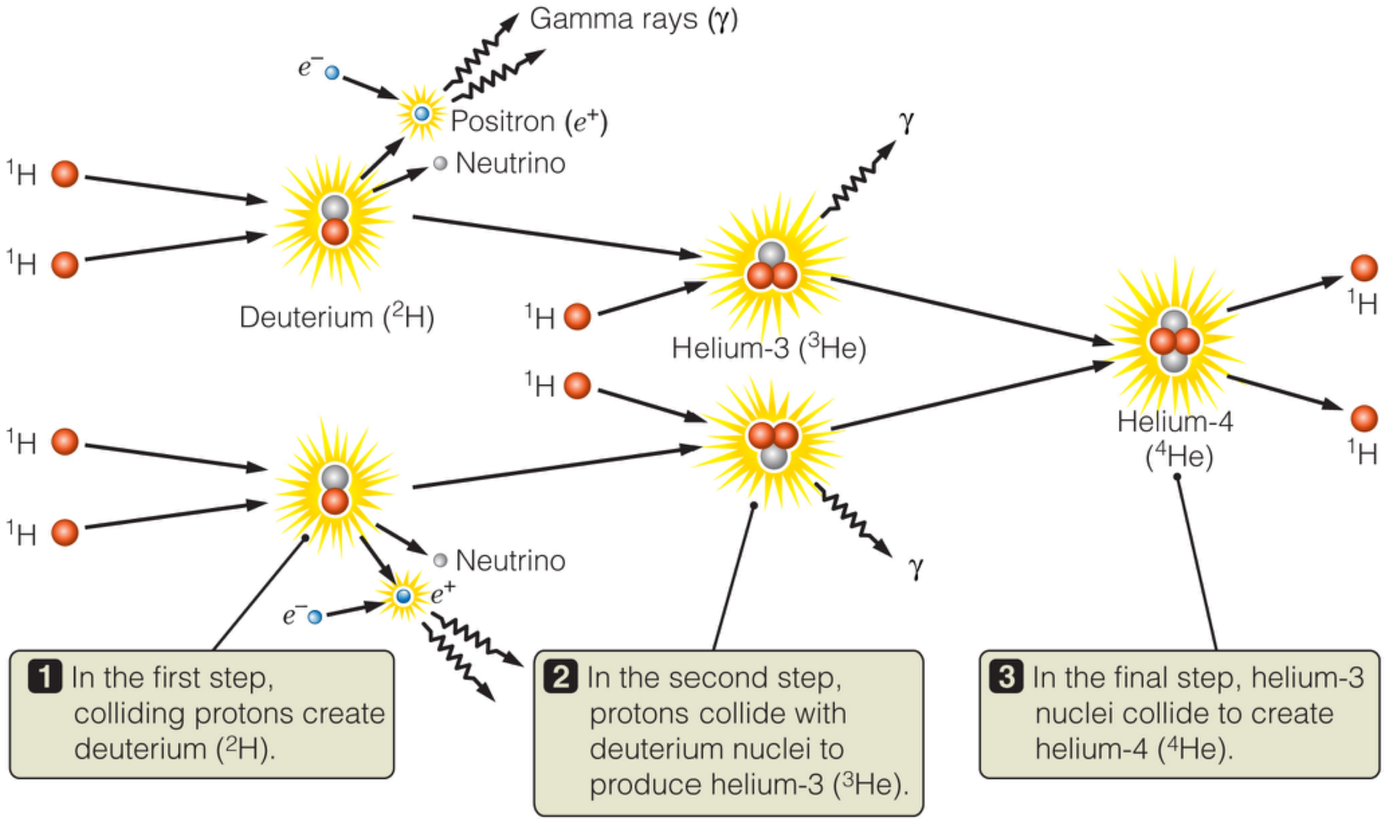

Hot stars are blue.
Cool stars are red.
Hotter
Supergiants
Giants
MAIN SEQUENCE
1,000 $R_\odot$
100 $R_\odot$
10 $R_\odot$
1 $R_\odot$
0.1 $R_\odot$
0.01 $R_\odot$
0.001 $R_\odot$
All stars with a radius of 1 $R_\odot$ lie along this line.
Sun
White dwarfs
H-R diagrams are sometimes plotted with either spectral type or temperature.
Visual luminosity relative to Sun
Absolute visual magnitude
More luminous
Surface temperature (K)
40,000 30,000 20,000 10,000 6000 3000 2500
O5 B0 B5 A0 F0 G0 K5 M5
Spectral type

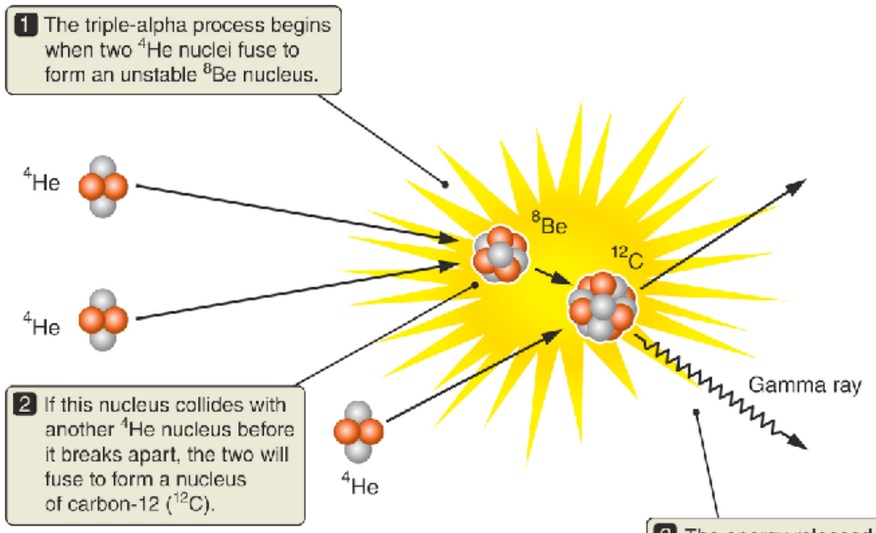

High-mass main-sequence stars are hot and luminous.
Mass determines the location of a star along the main sequence.
MAIN SEQUENCE
60 $M_\odot$
20 $M_\odot$
10 $M_\odot$
5 $M_\odot$
3 $M_\odot$
2 $M_\odot$
1.5 $M_\odot$
1 $M_\odot$
0.8 $M_\odot$
0.6 $M_\odot$
0.2 $M_\odot$
1,000 $R_\odot$
100 $R_\odot$
10 $R_\odot$
1 $R_\odot$
0.1 $R_\odot$
0.01 $R_\odot$
0.001 $R_\odot$
Low-mass m
sequence sta
cool and dim
Visual luminosity relative to Sun
Surface temperature (K)
40,000 30,000 20,000 10,000 6000 3000

Sun has distinct zones, half way through its 10 billion year lifespan

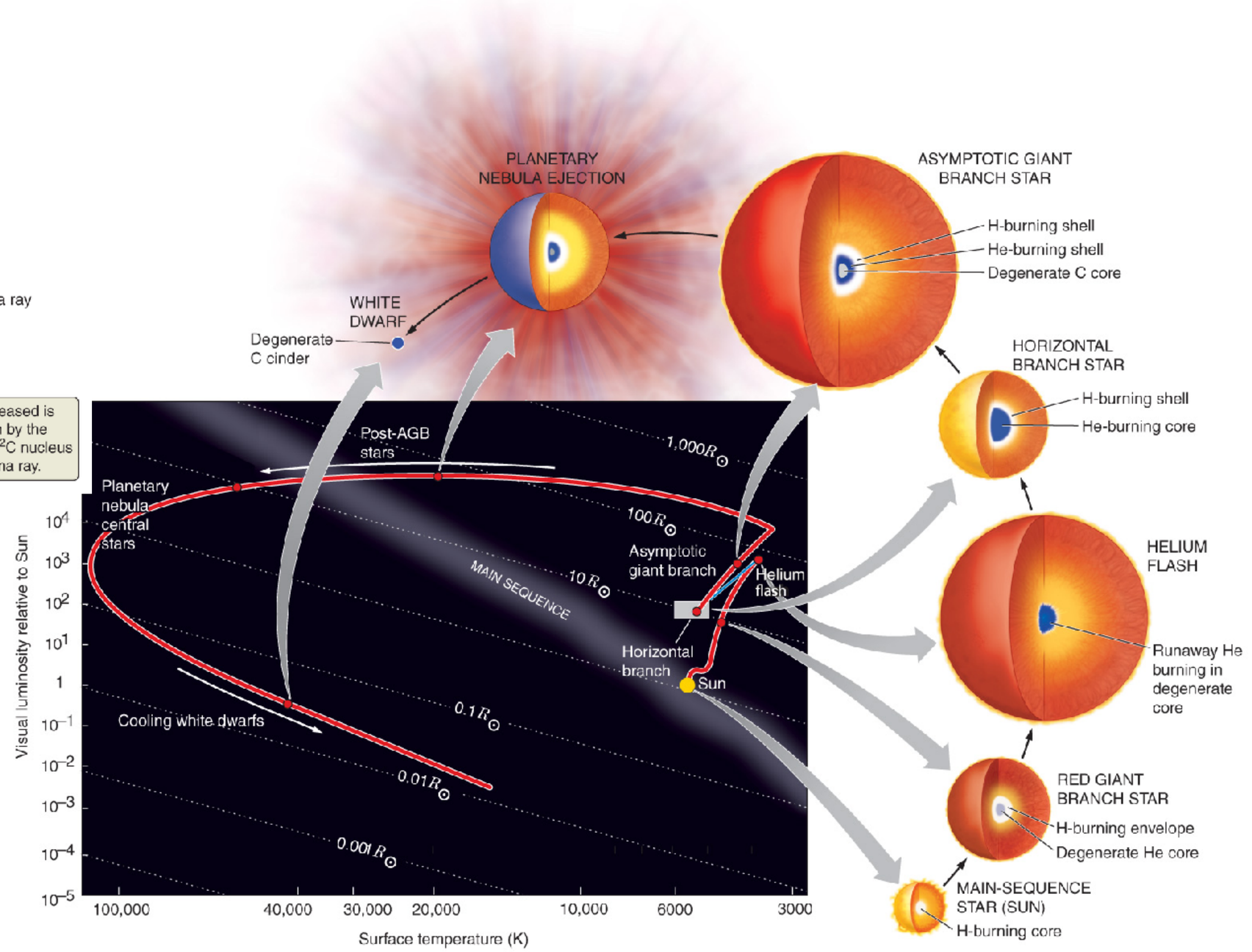


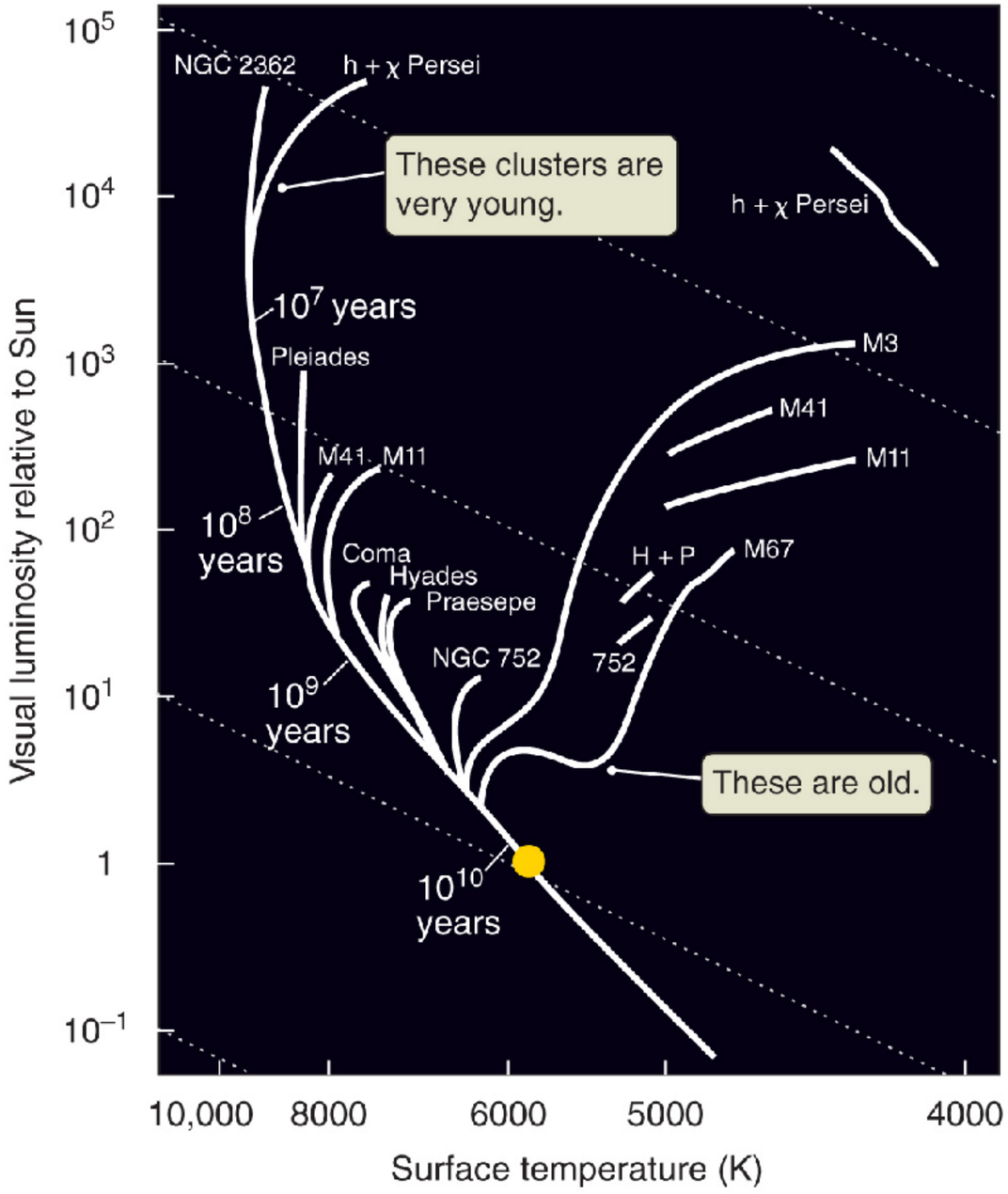
proton-proton chain burns H —> He, releasing neutrinos and positrons (gamma rays)

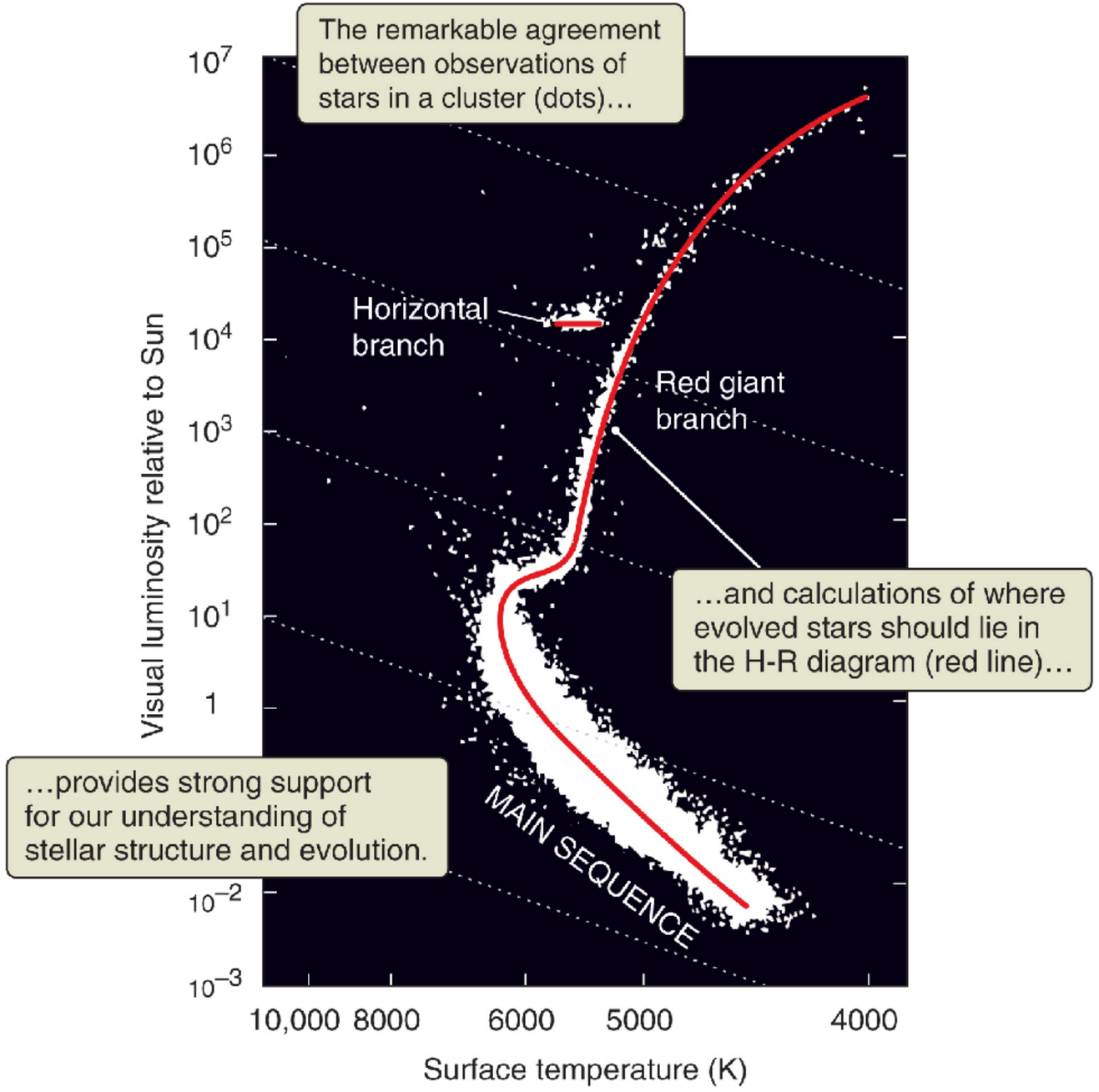


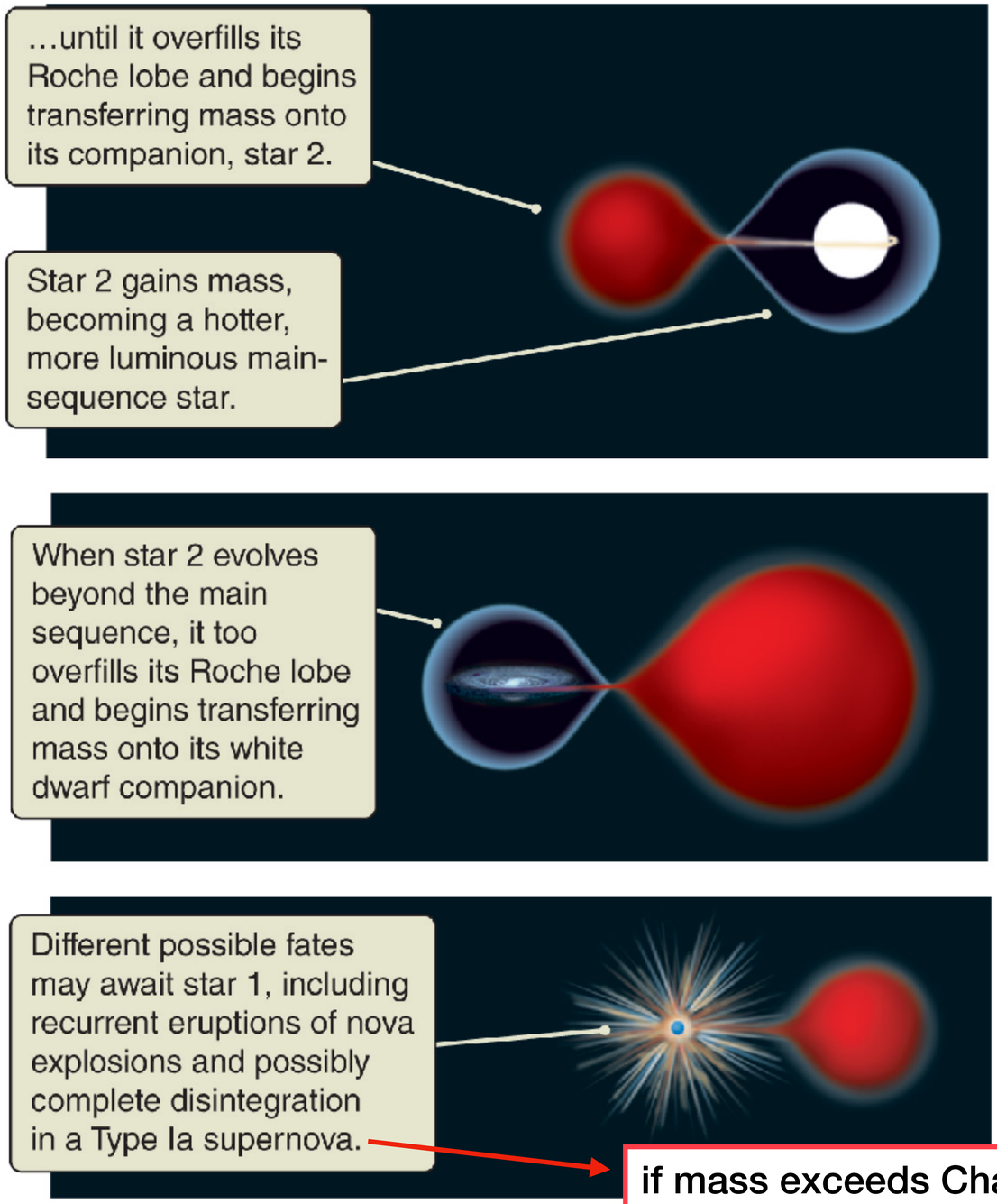


Triple-alpha process, burns He —> C in Horizontal Branch phase



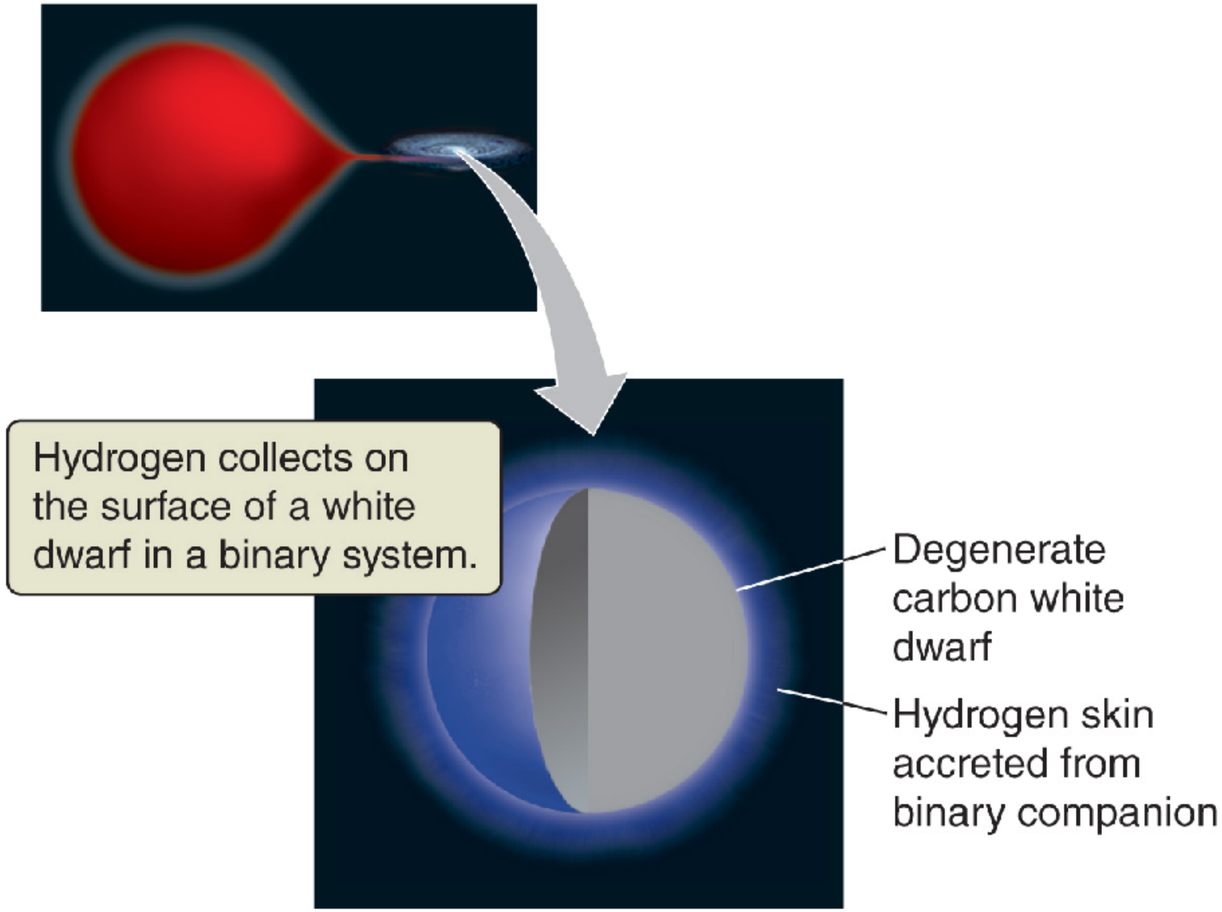

NGC 2362
h + χ Persei
These clusters are very young.
h + χ Persei
10^7 years
Pleiades
M3
M41
M41
M11
M11
10^8 years
Coma
Hyades
Praesepe
H + P
M67
NGC 752
752
10^9 years
These are old.
10^10 years
Visual luminosity relative to Sun
10^5
10^4
10^3
10^2
10^1
1
10^-1
10,000
8000
6000
5000
4000
Surface temperature (K)


The remarkable agreement between observations of stars in a cluster (dots)…
Horizontal branch
Red giant branch
…and calculations of where evolved stars should lie in the H-R diagram (red line)…
…provides strong support for our understanding of stellar structure and evolution.
MAIN SEQUENCE
Visual luminosity relative to Sun
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
10^-2
10^-3
10,000
8000
6000
5000
4000
Surface temperature (K)

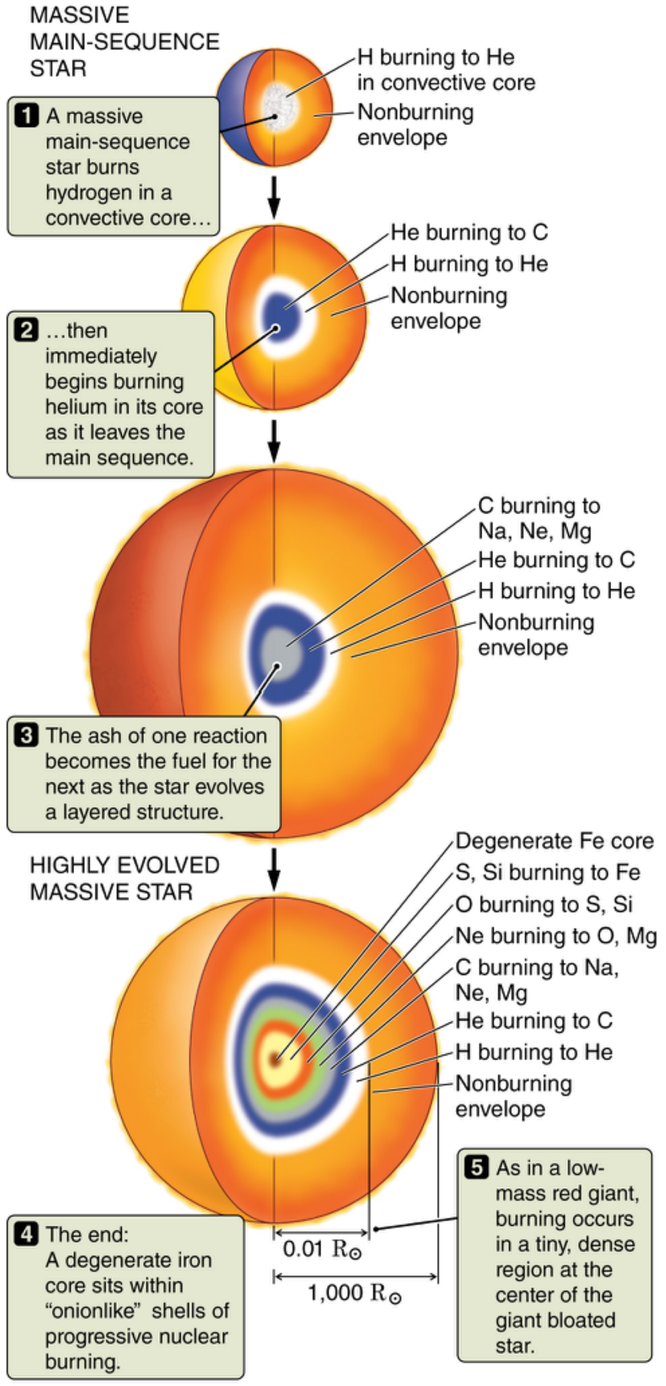


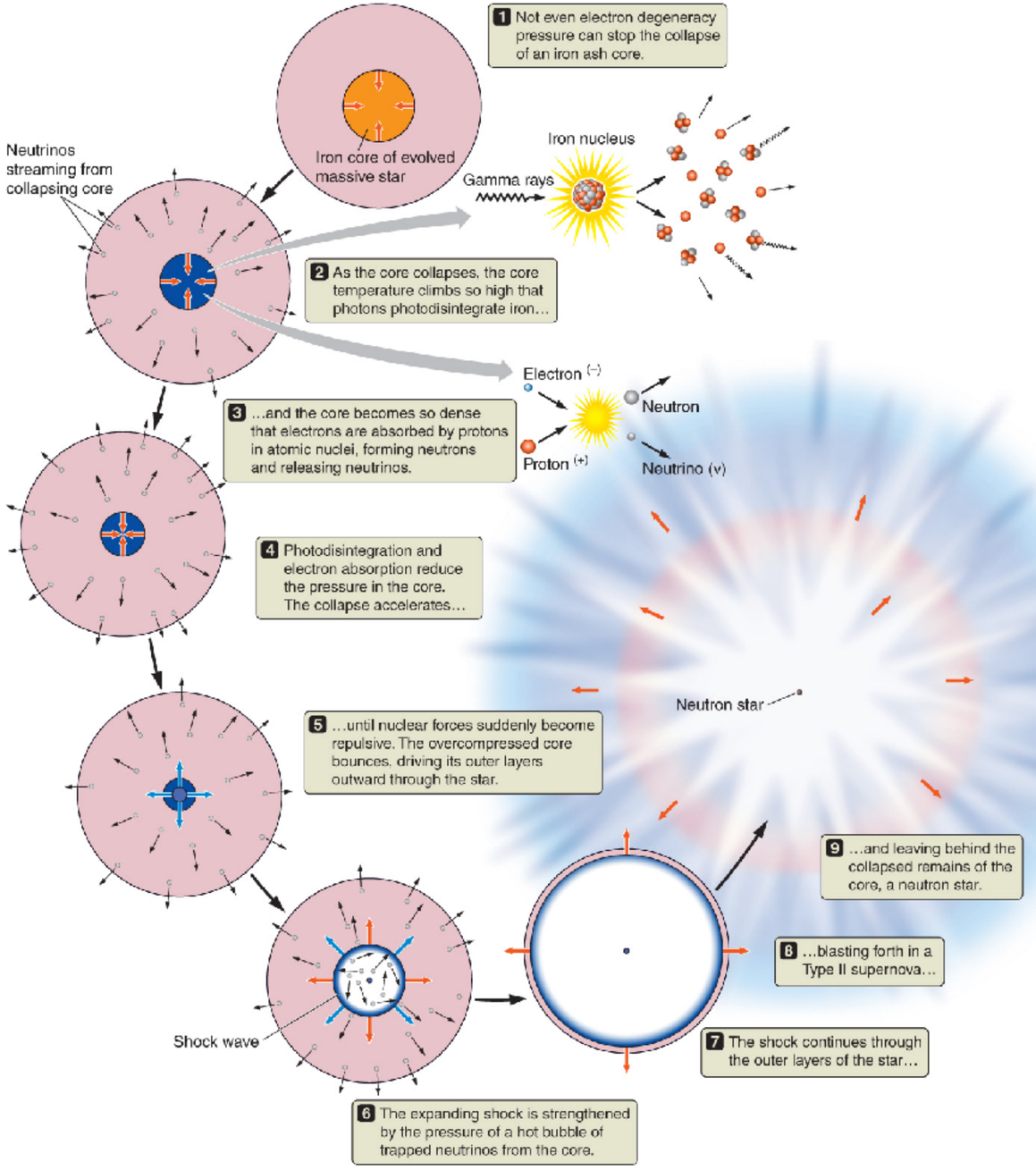
if mass exceeds Chandrasekhar limit (1.4 M_{sun})

White Dwarf <—> electron degeneracy pressure

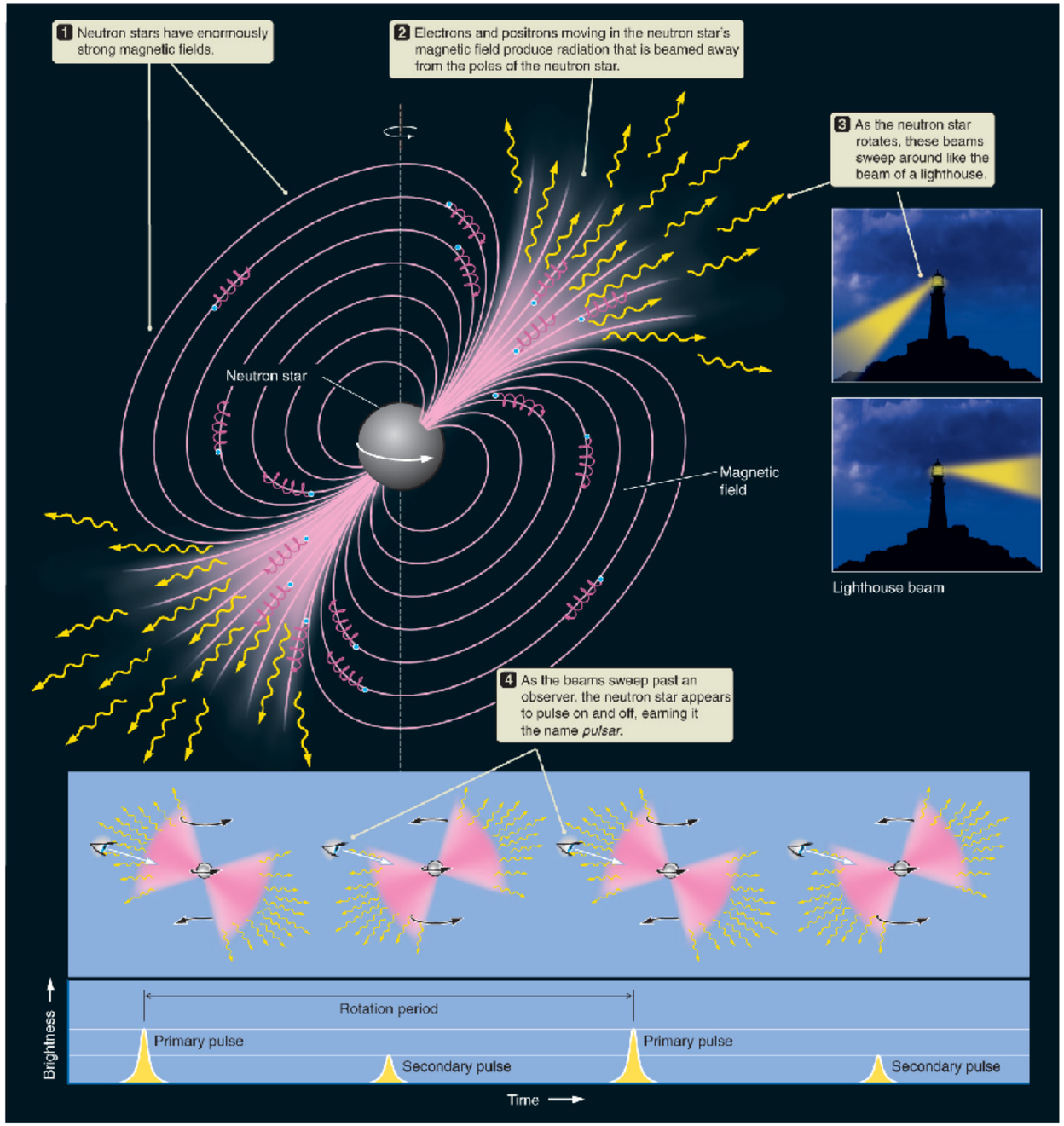


Massive stars burn up to Fe (iron) in its core, then go supernovae (Type II)



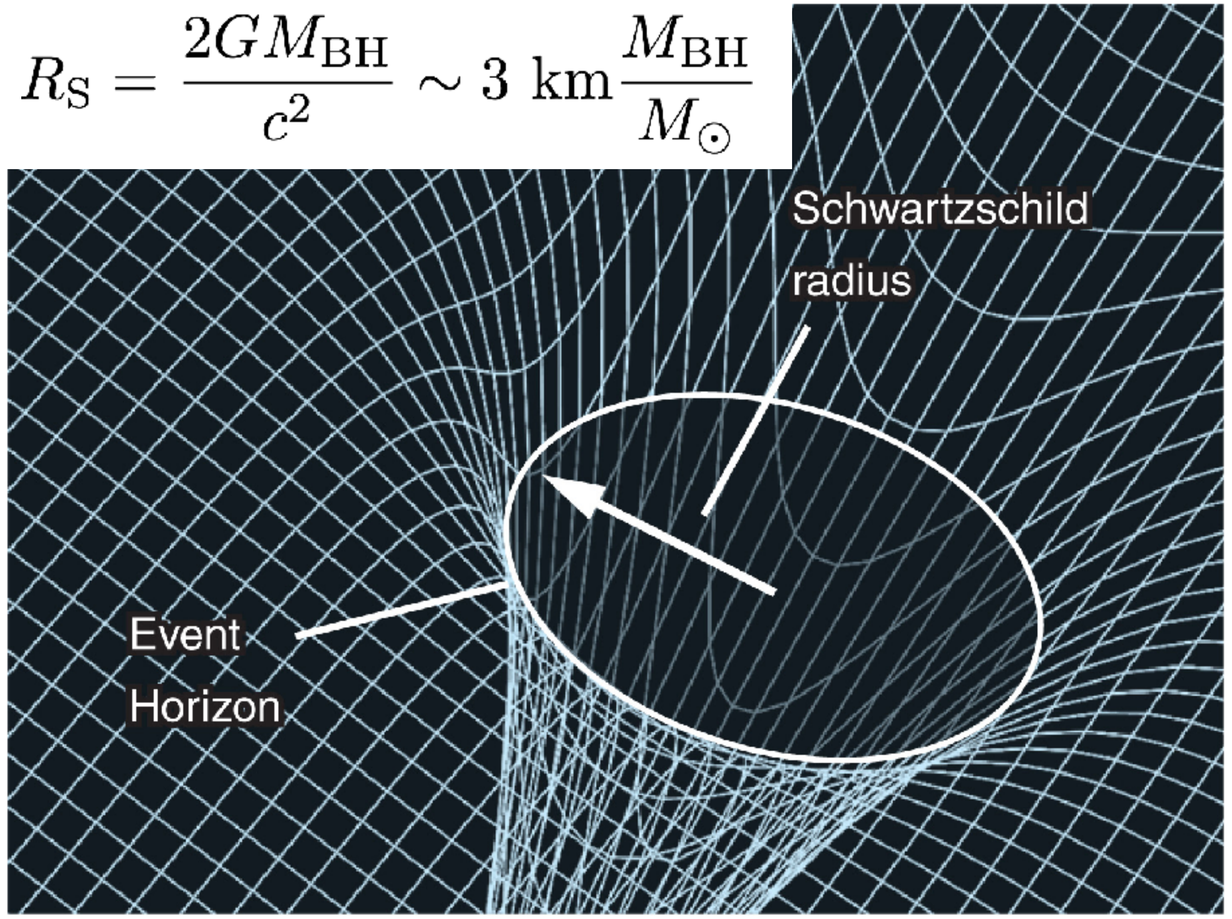


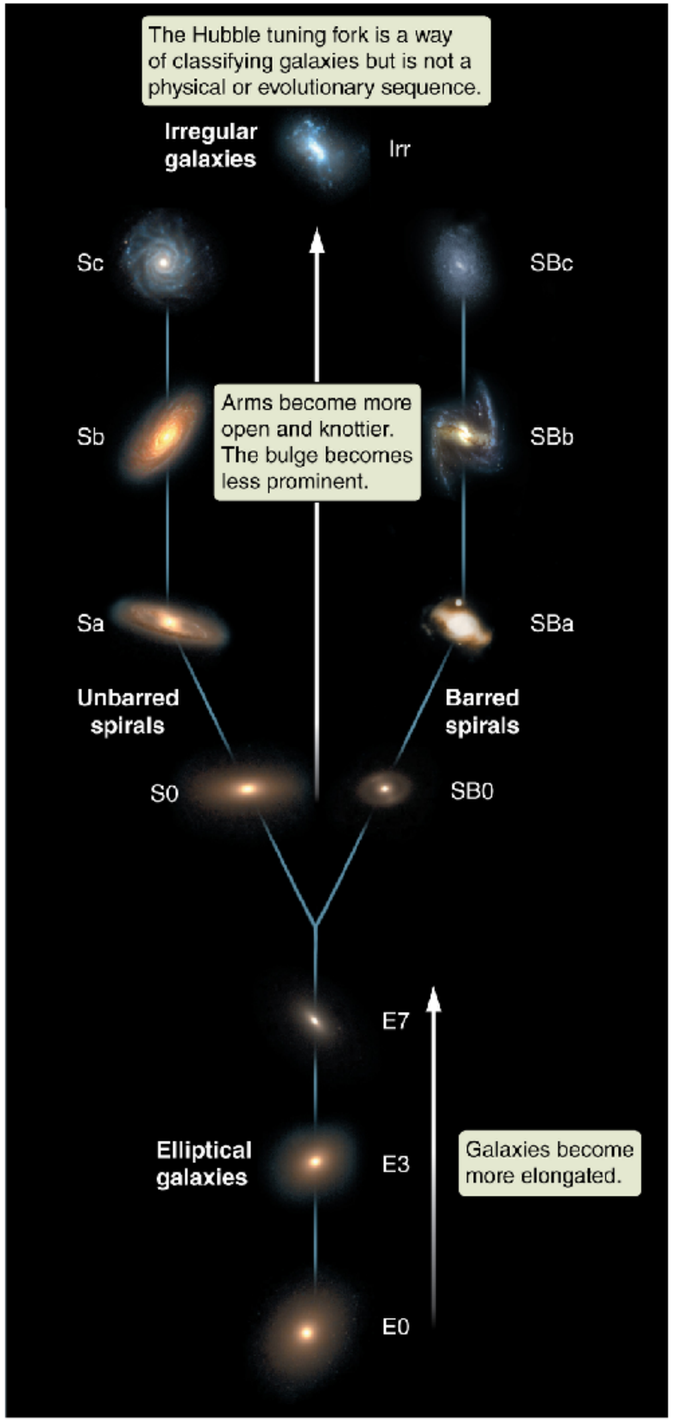
Neutron Stars

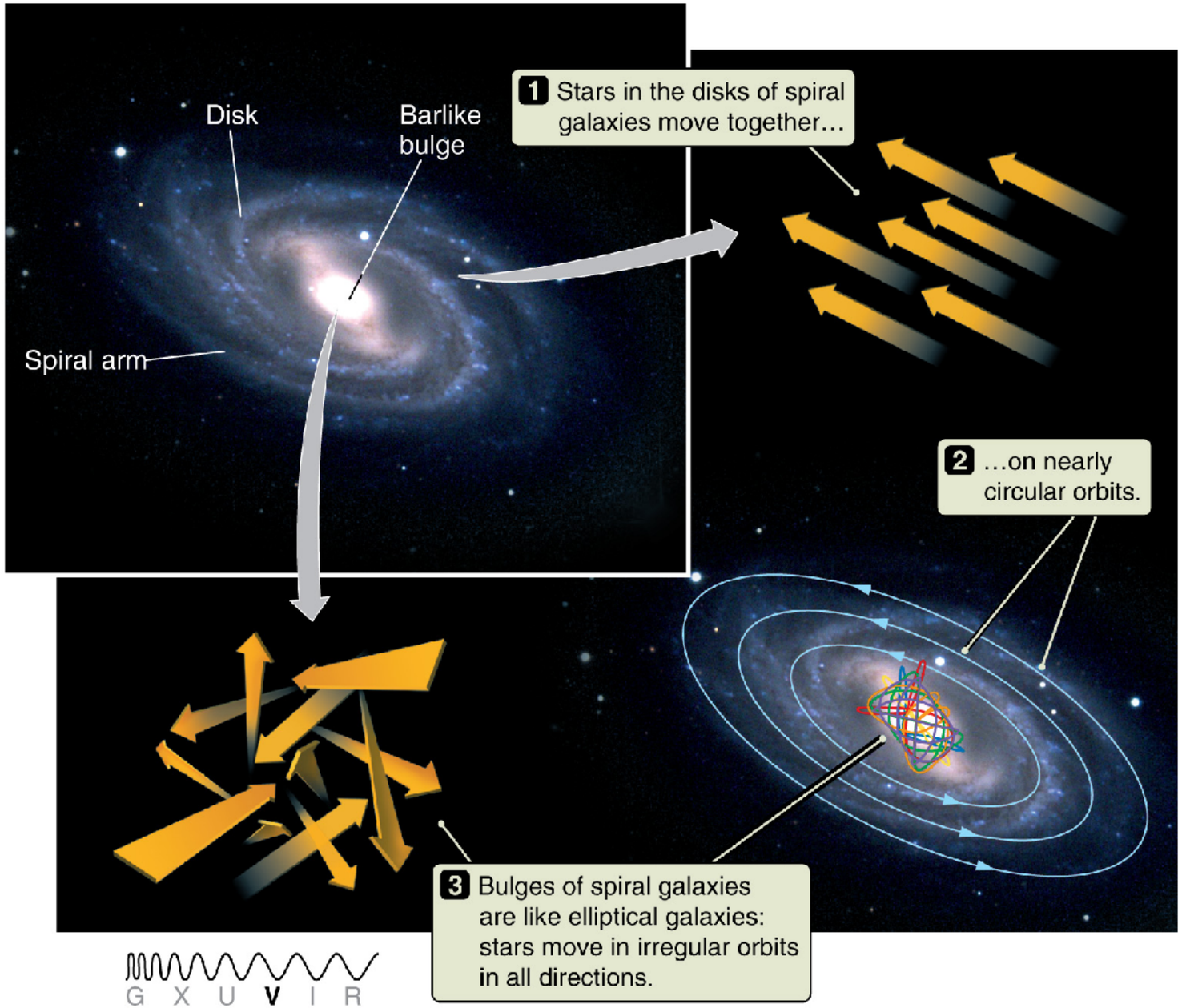


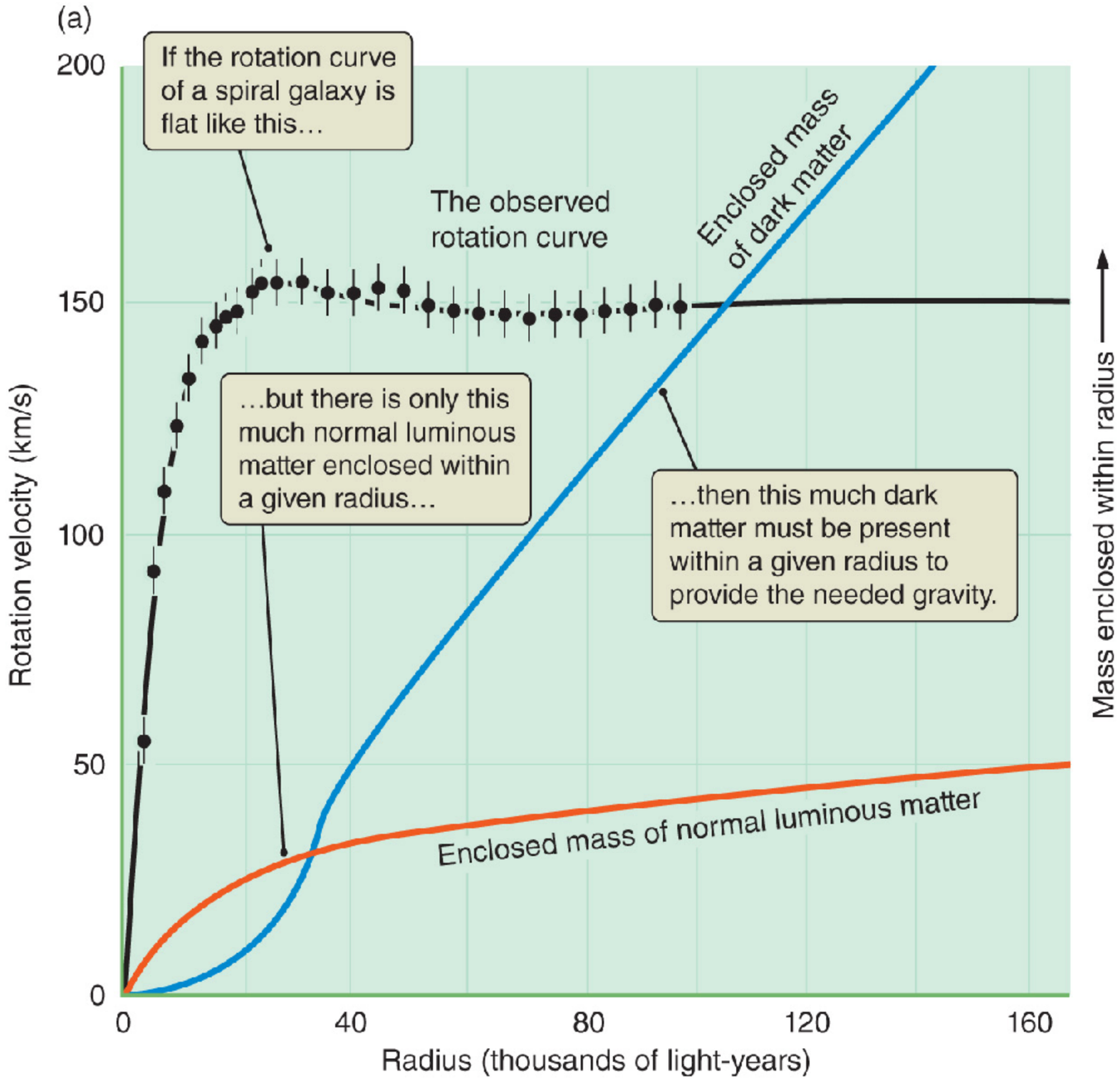
Black Holes

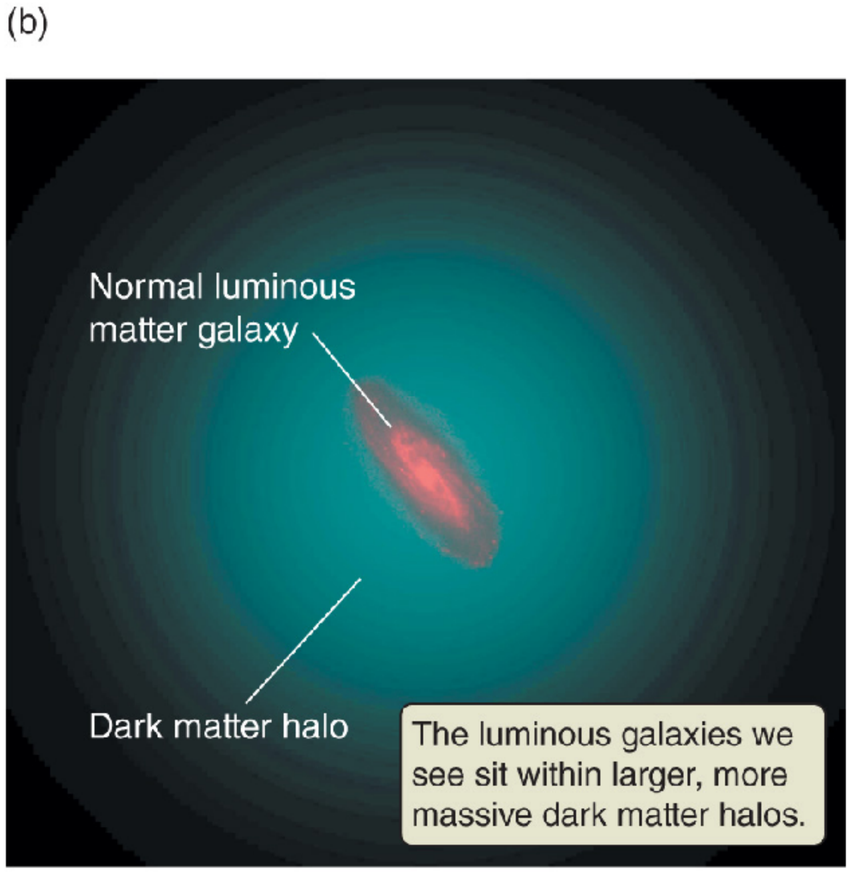
$$R_S = \frac{2GM_{BH}}{c^2} \sim 3 \text{ km} \frac{M_{BH}}{M_\odot}$$




The Hubble tuning fork is a way of classifying galaxies but is not a physical or evolutionary sequence.
Irregular galaxies
Irr
Sc
SBc
Sb
SBb
Arms become more open and knottier. The bulge becomes less prominent.
Sa
SBa
Unbarred spirals
Barred spirals
S0
SB0
E7
Elliptical galaxies
E3
Galaxies become more elongated.
E0

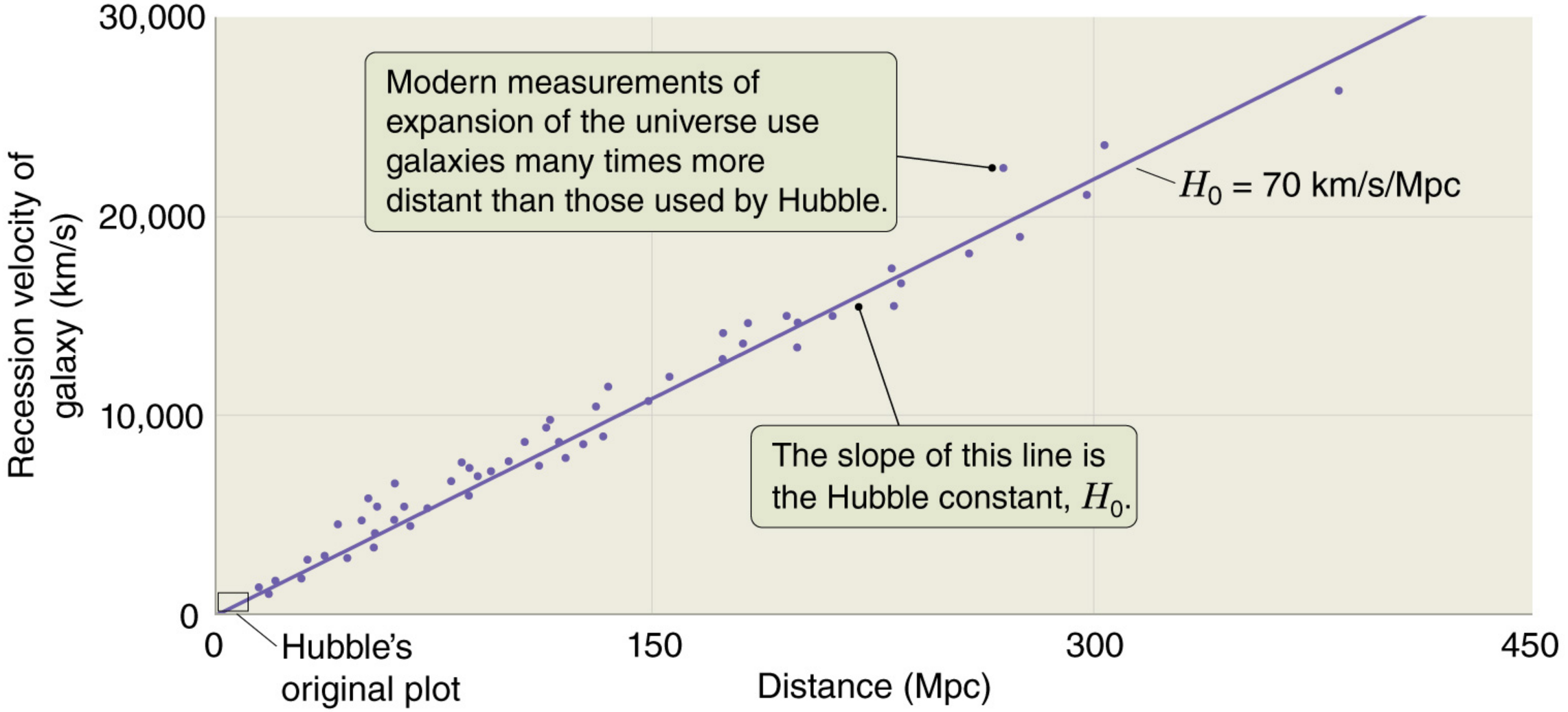

Disk
Barlike bulge
Spiral arm
1 Stars in the disks of spiral galaxies move together…
2 …on nearly circular orbits.
3 Bulges of spiral galaxies are like elliptical galaxies: stars move in irregular orbits in all directions.
G X U V I R



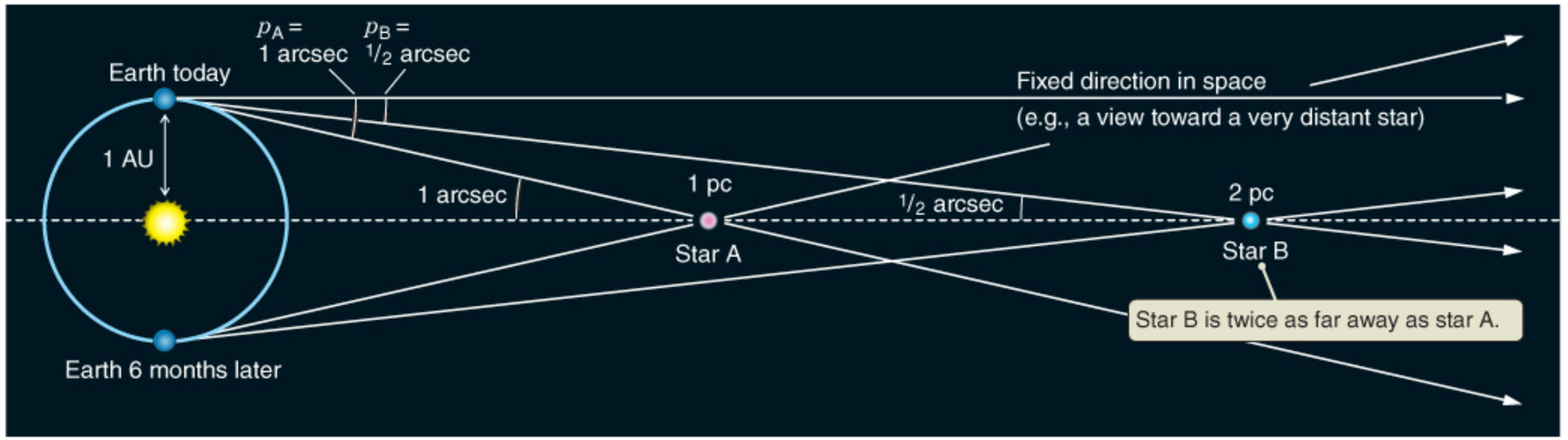


Galaxies seem to have more mass than we can see —> dark matter

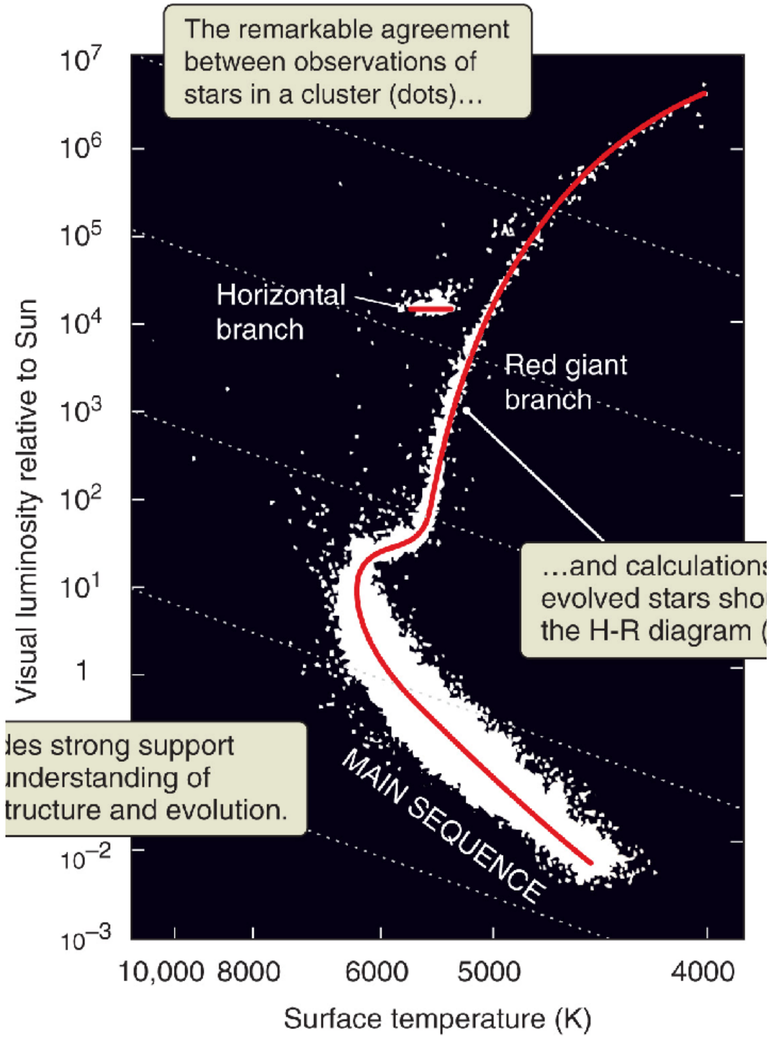
Hubble's law demonstrates that the universe is expanding



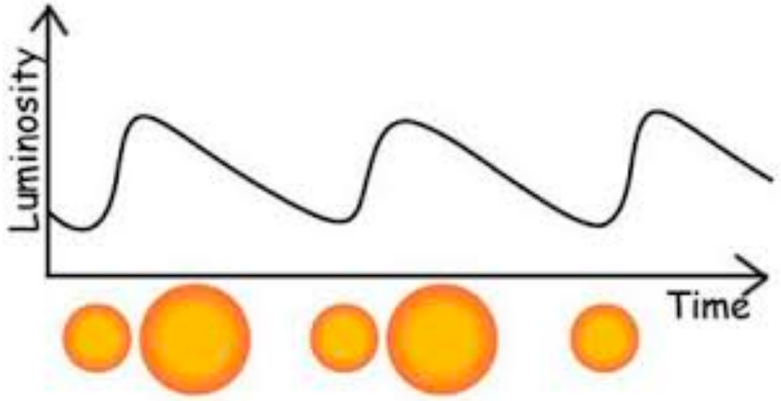
Parallax



Spectroscopic Parallax



Cepheid Variables



Type Ia SNe