AST 101
General Astronomy:
Stars & Galaxies
"Hubble's Law"

\[ v = H_0 \times d \]

Velocity of Recession (Doppler Shift) \((km/sec)\)  
Hubble’s Constant \((km/sec/Mpc)\)  
Distance \((Mpc)\)

**Best current values for expansion**

\( H_0 = 71 +/- 4 \) \( \text{km/s/Mpc} \)
What is Hubble’s Law?

A. A law stating that more distant galaxies move away from us faster than closer ones
B. An equation giving the maximum luminosity for a white dwarf supernova
C. The relationship between the period and luminosity of a Cepheid variable star.
D. The law giving the maximum speed that a galaxy can move at.
E. The idea that there are more galaxies outside our own and that the universe contains immense numbers of these “island universes.”
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Balloon analogy for expanding universe

- Each dot on the balloon can be thought of as a galaxy.

As the balloon expands, galaxies move farther away from each other.
A Better Way To Image the Expanding Universe

• **NOT** like an explosion of galaxies THROUGH space from a center place

• The space **BETWEEN** galaxies is expanding, carrying the galaxies away from each other
  – Why don’t galaxies themselves expand? **Gravity!**
No matter which direction we look, we see galaxies moving away from us. Therefore, we must be at the center of the expansion.

A. True
B. False
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A. True

B. False
The Cosmological Principle

*The universe looks about the same no matter where you are within it*

- Matter is *evenly distributed* on very large scales in the universe
- No *center & no edges*
- Not proven but consistent with all observations to date
Since the universe is expanding, light traveling through the universe “feels” the stretch as it travels.

Cosmological Redshift
"Hubble’s Law"

\[ v = H_0 \times d \]

Velocity of Recession (Doppler Shift) 
(\(km/sec\))

Hubble’s Constant 
(\(km/sec/Mpc\))

Distance (\(Mpc\))

Implies the [Expansion of the Universe](#)!
What does the “expansion of the universe” most accurately mean?

A. Galaxies are moving apart through space
B. Space itself is expanding
C. Everything is expanding, including the earth, our bodies, etc
D. The Milky Way is at the center of the universe and all other galaxies are expanding away from us.
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Your friend leaves your house. She later calls you on her cell phone, saying that she’s been driving at 60 mph (miles per hour) directly away from you the whole time and is now 60 miles away. Without looking at your watch, can you tell how long has she been gone?

A. Yes, 1 minute
B. Yes, 30 minutes
C. Yes, 60 minutes
D. Yes, 120 minutes
E. No, not enough information to tell
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Expansion and the Age of the Universe

IF the universe has been expanding at the same speed always:

Distance = velocity × time ⇒ time = distance/velocity

Hubble’s Law: v = H_o × D ⇒ H_o = velocity/distance

**Time (Age) = 1 / H_o**

For 71 km/sec/Mpc: Age ~ 13.7 billion years

For larger H_o, shorter time
For smaller H_o, longer time
Is this anywhere near correct?

- Age of the solar system ~ 4.6 billion years
- Age of the oldest star clusters ~ 13 billion years
- General agreement, but we’ll revisit the assumption of constant expansion soon..
Next: Galaxy Evolution

- Observing galaxies at different redshifts (lookback times)
  - Allows us to assemble a sequence of galaxies showing birth and evolution
  - Check via computer models of gas, gravity and star formation
Some galaxies very young, when the Universe was about a tenth of its current age!
Making of a spiral galaxy

- Start with a fairly uniform cloud of hydrogen
- Gravitational collapse forms protogalactic clouds
- First stars are born in this spheroid (such stars are billions of years old → “fossil record”)
Small variant in spiral making ...

- Several *smaller protogalactic clouds* may have merged to form a single large galaxy

- May explain variations in metallicities in the halo stars
Forming a disk with spiral

- As more material collapses, angular momentum spins it into a disk

- Stars now formed in dense spiral arms – disk stars are younger!

Angular momentum of protogalactic cloud important in spiral galaxy formation
Making **ellipticals**

1. Higher density: *much faster star formation*
   - *Nothing left to make a disk*

   or

2. Lower spin
   - *Gas used up before angular momentum took over*

   • *Now we see a sphere of old stars*
Or perhaps a different scenario....

• **Spiral galaxy collisions** destroy disks, leave behind **elliptical**

• **Burst of star formation** uses up all the gas

• **Leftovers:** **train wreck**

• **Ellipticals** more common in dense galaxy clusters (centers of clusters contain **central dominant galaxies**)

NGC 4038/39 Antennae
Why are collisions between galaxies more likely than between stars within a galaxy?

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C. Relative to their sizes, galaxies are closer together than stars
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1. Encounter Overview
Colliding galaxies – “The Antennae”

HST detail: NGC 4038/39
Colliding Galaxies: NGC 4676

“Mice” with HST Advanced Camera for Surveys
Stephan’s Quintet in HST detail
Many interacting galaxy systems
A mature example: 
Elliptical shape *but with dust lanes*?
It may happen to us in future!

Andromeda (M31) in future
Messages From Galaxy Interactions

1. In dense clusters, galaxy collisions (grazing or even head-on) must have been common
2. With successive passages, spiral galaxies can tumble together to form a big elliptical
3. Vastly increased star birth from shocking the gas and dust (starburst galaxies; coming up next!)
4. Start rapid feeding of supermassive black hole lurking at center of most galaxies (quasars; coming up soon!)
Starburst Galaxies

- Milky Way forms about 1 new star per year
- Starburst galaxies form 100's of stars per year
Vigorous star birth – “The Antennae”

HST detail: NGC 4038/39
Starburst galaxies emit most of their light at infrared wavelengths

- Star formation heats dust to very hot temperatures
  - Hot dust glows strongly in the infrared

- Much evidence for giant supernova-driven galactic winds

- Usually triggered by galaxy collisions or close passages of another galaxy
Starburst galaxy in fine detail

NGC 3310 - HST

Big open two-sided spiral structure
--> tidal interaction
**Active Galactic Nuclei (AGNs):**

- Galaxies with *lots of activity*

- Some galaxies at high redshift (large lookback times) have extremely active centers
  - More than 1000 times the light of the entire Milky Way combined from a *point source at the center*!!
A type of AGNs: Quasars

- **Quasi-Stellar Radio Source**
- **Nuclei so bright (at nearly all wavelengths) that the rest of the galaxy is not easily seen**
- **First discovered as radio sources - then found to have very large redshifts!**
What is the most likely source of the light from bright nuclei (radio, visible, X-rays) in active galaxies?

A. Thermal radiation from a massive star cluster
B. Emission lines from hot gas
C. 21 cm from hydrogen gas
D. H-alpha from hydrogen gas
E. Synchrotron radiation from a black hole
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E. Synchrotron

- Only synchrotron radiation is bright at both radio and X-ray wavelengths (far ends of the spectrum)
Whatever is powering these QSO’s must be very small!!

• Some quasars can double their brightness within a few hours.

• Therefore they cannot be larger than a few light-hours across (solar system size)
  – Why? Think about the time it takes light from the front of the object to get to us compared to the light from the back.
Quasar Central Engines

How do quasars emit so much light in so little space?

- They are powered by accretion disks around supermassive black holes.
- In some quasars, huge jets of material are shot out at the poles. These jets are strong radio sources.