Observational Astronomy - Lecture 13
Evolution of the Universe and Final Review

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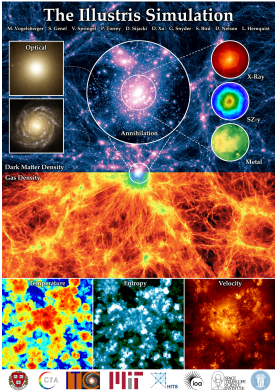
Remaining course logistics

1. Today's lecture - Evolution of the Universe and Final Review
2. Final exam - Monday 5/19 4:00-5:50 PM, Meyer 102
   - Format similar to midterm and homework.
   - Mixture of short answers and calculations.
   - All formulae and constants needed will be provided.
   - All topics covered are "fair game".
   - Will accomodate requests for an early final on Wednesday 5/14 - contact me.
3. All homework solutions are now posted.
4. Tentatively planning an optional Saturn lab week of 5/12.
   - 10:00-11:00 PM tonight - weather permitting.
   - If tonight is not clear, I'll just keep watching the weather each day.
   - Details will follow by E-Mail.

Evolution of the Universe
The Illustris Simulation



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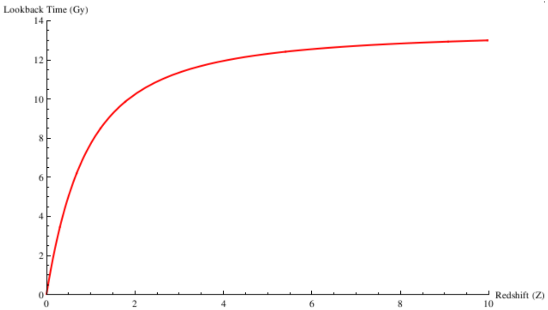
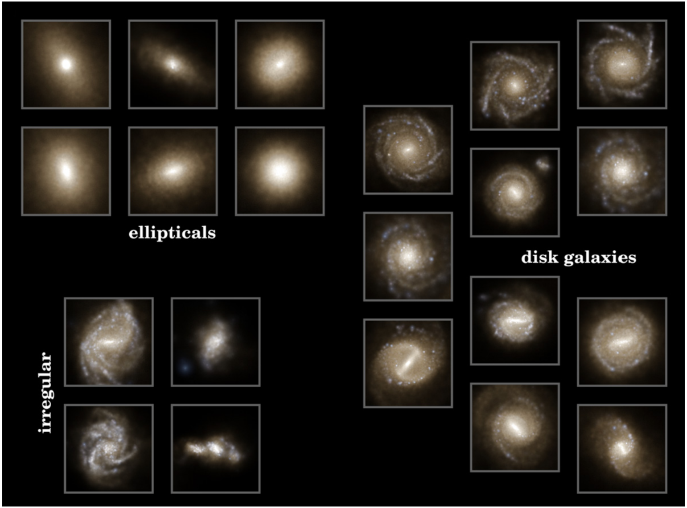
- http://www.illustris-project.org
- 16 million CPU-hours on 8192 CPU's.
- This implies the whole simulation took about 3 months.

Evolution of the Universe
The Illustris Simulation



- For small z, $\mathrm{LBT} \approx 10 \times \mathrm{z}$.
- $\mathrm{z} = 1 \Rightarrow \mathrm{LBT} \approx 8\,\mathrm{Gy}$
- $\mathrm{z} = 2 \Rightarrow \mathrm{LBT} \approx 10\,\mathrm{Gy}$
- $\mathrm{z} = 5 \Rightarrow \mathrm{LBT} \approx 12\,\mathrm{Gy}$
- $\mathrm{z} = \infty \Rightarrow \mathrm{LBT} \approx 13.7\,\mathrm{Gy}$

Illustris Hubble Diagram

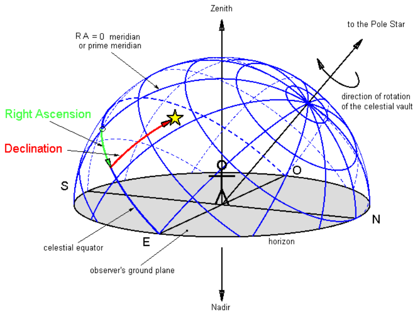


- Let's look at the videos!

Final Review Topics - (Disclaimer)

1. Celestial coordinate systems.
2. Concepts of transit and transit time calculations.
3. Relation between size, distance, and angular extent.
4. Telescope resolution.
5. The electromagnetic spectrum.
6. Magnitudes and luminosities.
7. Apparent and absolute magnitudes.
8. Orbits and Kepler's laws.
9. Moon phases and eclipses.
10. Types of objects in the solar system.
11. Basics properties of stars and the Color-Magnitude diagram.
12. Basics of stellar evolution and types of stellar remnants.
13. Basics of blackbody spectrum.
14. Basics of galaxy structure and galaxy types.
15. Relation between velocity and redshift.
16. Hubble diagram and relation between distance and recession velocity.

Stellar Coordinates



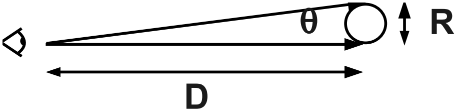
- While standing on the Earth, the stars seem to rotate about the celestial pole.
- We see only 1/2 of the sky at any given time.
- We can only see as far south as $\mathrm{Dec} = -90^\circ + \mathrm{Latitude}$.

Estimating Transit Times: Example

When will Rigel transit on Feb 3?

- Rigel - $\mathrm{RA} = 5^{\mathrm{h}}14^{\mathrm{m}}$
- $\mathrm{RA} = 0^{\mathrm{h}}$ transits at noon on Mar 21.
- Number of days between Feb 3 and Mar 21 = 25 + 21 = 46.
- Transit time shift at 4 min/day = 4 * 46 = 184 min = $3^{\mathrm{h}}4^{\mathrm{m}}$.
- On Feb 3, $\mathrm{RA} = 0^{\mathrm{h}}$ transits at $12^{\mathrm{h}} + (3^{\mathrm{h}}4^{\mathrm{m}})$ = 15:04 = 3:04 PM.
- $\mathrm{RA} = 5^{\mathrm{h}}14^{\mathrm{m}}$ transits at $15^{\mathrm{h}}04^{\mathrm{m}} + 5^{\mathrm{h}}14^{\mathrm{m}} = 20^{\mathrm{h}}18^{\mathrm{m}}$ = 8:18 PM.
- Stellarium gives 8:14 PM.
- These calculations will only be within $\approx 10^{\mathrm{m}}$ or so due to:
  - We are not at the center of the time zone.
  - 4 min/day is a little off (actually $3^{\mathrm{m}}56^{\mathrm{s}}$).

Distance and Angular Size



- The distance and angular size of an object are related as follows:

$$\tan(\theta) = \frac{\mathrm{R}}{\mathrm{D}}$$

- For small angles, and θ measured in radians.

$$\theta(\mathrm{radians}) = \frac{\mathrm{R}}{\mathrm{D}}$$

Resolution Example

- Example 1 - Human Eye in visible light:

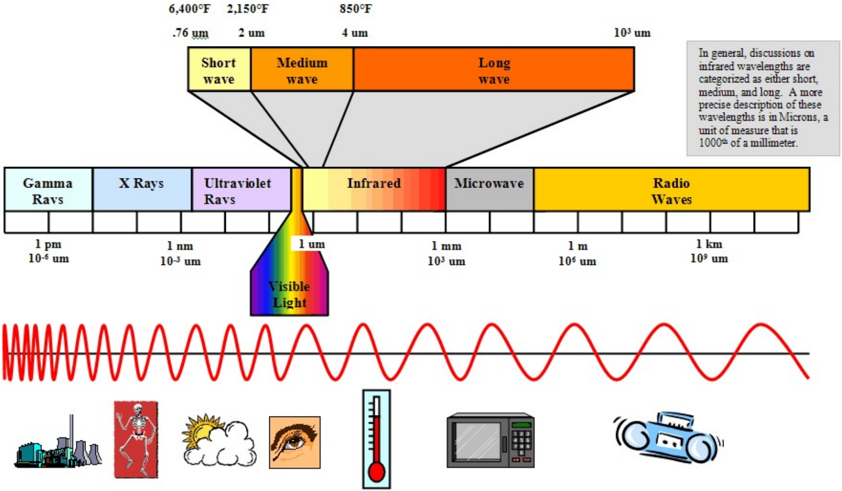
$$\theta(\text{radians}) = 1.22\frac{\lambda}{\text{D}}$$

  - λ is the wavelength of visible light = 500 nm = $5.0 \times 10^{-7} m$
  - D is the diameter of the eye = 7 mm = $7.0 \times 10^{-3} m$

$$\theta = 1.22\frac{5.0 \times 10^{-7}\text{m}}{7.0 \times 10^{-3}\text{m}} = 8.7 \times 10^{-5} \text{ radians}$$

$$\theta = 8.7 \times 10^{-5} \text{ radians} \times \frac{360}{2\pi} \times 60 \times 60 = 18 \text{ arcseconds}$$

The Electromagnetic Spectrum



Magnitude Example

Polaris is 132 pc away and has apparent magnitude +1.95. What is its absolute magnitude, and how much brighter than the sun is it?

- m = +1.95, D = 132 pc
- $\mathrm{m} = \mathrm{M} - 5 + 5\log_{10}(\mathrm{D})$
- $\mathrm{M} = \mathrm{m} + 5 - 5\log_{10}(\mathrm{D})$
- $\mathrm{M} = 1.95 + 5 - 5\log_{10}(132) = -3.65$

$$\frac{\mathrm{L_{Polaris}}}{\mathrm{L_{Sun}}} = 10^{0.4(\mathrm{M_{Sun}} - \mathrm{M_{Polaris}})}$$

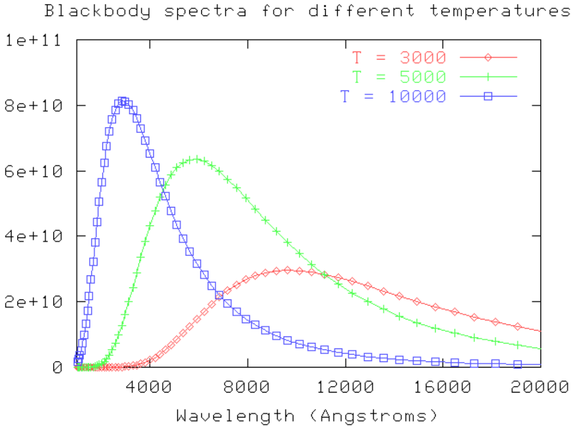
$$\frac{\mathrm{L_{Polaris}}}{\mathrm{L_{Sun}}} = 10^{0.4(4.83-(-3.65))} = 10^{3.39} = 2466$$

Kepler's Laws of Planetary Motion

Johannes Kepler ca. 1610

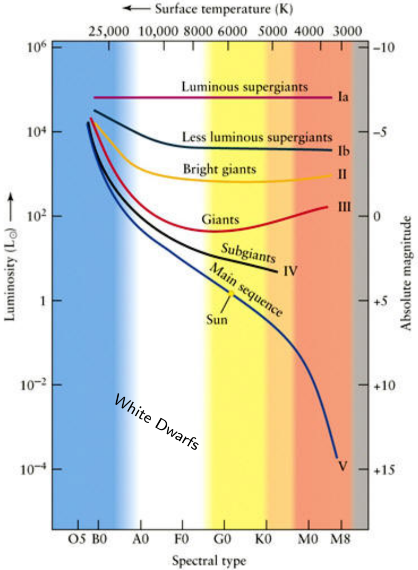
1. The orbit of every planet is an ellipse with the Sun at one of the two foci.
2. A line joining a planet and the Sun sweeps out equal areas during equal intervals of time.
3. The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit.
   - $a^3 \propto T^2$

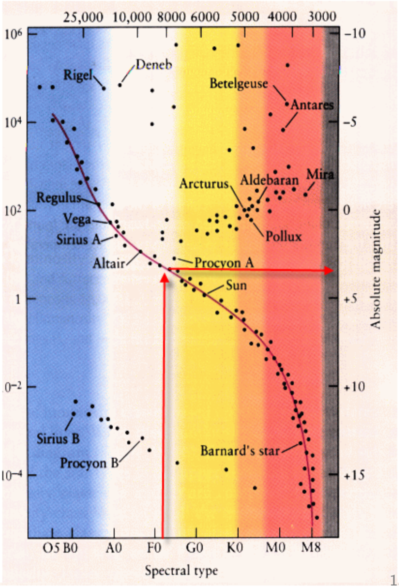
Blackbody Spectra



- Cooler bodies are redder, hotter bodies bluer.
- $\lambda_{\text{Peak}} \times \mathrm{T} = 3.0\mathrm{mm\,K}$

The Color-Magnitude or Hertzsprung-Russell (H-R) diagram.

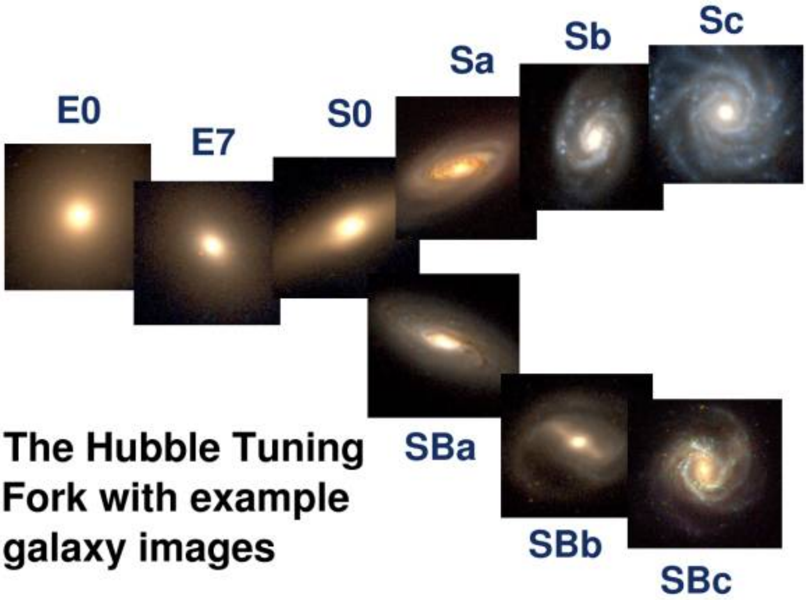




Endpoints of Stellar Evolution - Compact Objects

1. White dwarfs - end point of sun-like stars.
   - White dwarfs have about the mass of the sun, but are about the size of the Earth.
   - A teaspoonful of white dwarf material would weigh approximately 1 ton.
2. Neutron stars - end point of massive stars.
   - Neutron stars have about the mass of the sun, but are about the size of Manhattan.
   - A teaspoonful of neutron star material would weigh approximately 100 million tons.
3. Black holes - end point of massive stars.
   - A black hole curves space so strongly that nothing, not even light, can escape.
   - A black hole the mass of the sun has a radius of 3 km.

The Hubble Tuning Fork Diagram



Calculating Velocities from the Doppler Shift

- Since most objects are moving away from us, astronomers use the symbol z to denote the redshift.

$$z = \frac{\lambda observed - \lambda emitted}{\lambda emitted} = \frac{\Delta\lambda}{\lambda emitted}$$

- The redshift and the velocity of recession are related by:

$$1 + z = \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}}$$

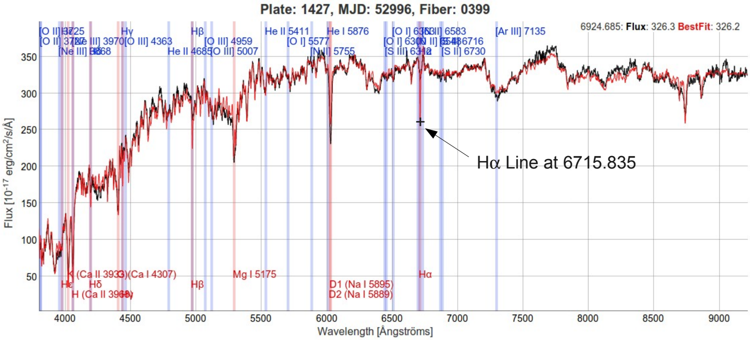
- Solving for v:

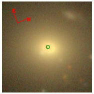
$$\frac{v}{c} = \frac{(1+z)^2 - 1}{(1+z)^2 + 1}$$

- For small v:

$$\frac{v}{c} = z$$

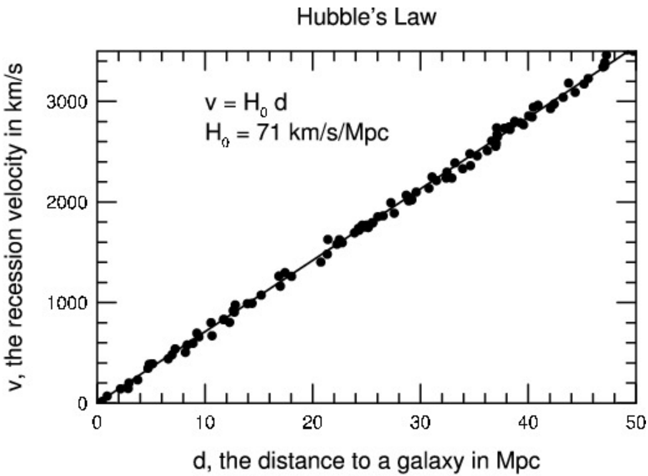
Redshift Example - Sloan Digital Sky Survey





- Measured wavelength of H_α line = 6715.835 Angstroms.
- Lab wavelength of H_α line = 6562.81 Angstroms.
- $\Delta\lambda = 6715.83 - 6562.81 = 153.0$ Angstroms.
- $z = \Delta\lambda/\lambda = 153.0/6562.81 = 0.023$
- $V = 0.023 * c = 0.023 * 299,792 \text{km/sec} = 6895 \text{km/sec}$

Hubble's Law and the Expansion of the Universe



Today's best value - 68 km/sec/Mpc

Calculating Distance from Hubble's Law

- Suppose a galaxy is measured to have a redshift $z = 0.01$.
- Since this is a small redshift, we can write:

$$V = z \times c = 0.01 \times 3.0 \times 10^5 \, km/sec = 3,000 \, km/sec$$

- Now we apply Hubble's Law ($\mathrm{v} = \mathrm{H}_0 \times \mathrm{D}$), assuming a Hubble constant of 70 km/sec/Mpc. The distance of the galaxy is just the speed of recession divided by the Hubble constant:

$$D = \frac{v}{H_0} = \frac{3,000 \frac{km}{sec}}{70 \frac{km}{sec \, Mpc}} = 43 Mpc$$

- You can compare this to the graph of Hubble's law and see that they agree.

Good Luck!

- I am available for questions - E-Mail me or 10:00 AM Friday office hours.
- I hope you enjoyed the class and learned some things.
- Don't forget the online evaluations.