ASTR 1010–004: significant dates

Wednesday, Dec. 5 beginning: standard course evaluation

Wednesday, Dec. 5: Homework 7 due

Monday, Dec. 10: review session, 7:30 PM, here.

Tuesday, Dec. 11: extra office hours, 4 to 7 PM

Wednesday, Dec. 12: final exam 7:30 PM, here

Additional Brooks Observatory opportunities

Review of Quiz 7

The class average was 10.2 / 20 ...

Here are model answers. Your answers did not have to be this thorough for full credit.

How is Carl Sagan’s statement, “We are star stuff,” supported by evidence from astronomy?

The theory of stars’ life histories (which is supported by evidence about stars) tells us that massive stars build heavy elements, including carbon and oxygen, in their cores, and then eject them into space, where they are eventually able to be part of new stars and planets. This is called the gas-star-gas cycle. These heavy elements are essential to living things.
What is the event horizon of a black hole? What is the singularity?

The event horizon is the sphere around a black hole where the escape speed is equal to the speed of light. It acts as the boundary of the black hole; inside it, nothing can escape. The singularity is the collapsed object at the center.

What is Hubble’s Law? What is Hubble’s Constant?

Hubble’s Law says that the other clusters of galaxies recede from the Local Group at speeds proportional to their distances; or, speed increases with increasing distance. Hubble’s Constant is the number you get when you divide the speed of a galaxy by its distance.
After a supernova explosion, what is left over? In the case of the Crab Nebula, how did we identify the star that exploded?

What is left over are an expanding cloud of gas and a collapsed object (neutron star or black hole). In the Crab Nebula, the collapsed object—a neutron star—is now a pulsar, so we can identify it.
Quasars

“Quasar” stands for “quasi-stellar radio source.”

- Discovered as bright, powerful sources of radio waves
- In visible-light images, they look like stars (points of light).
- But spectra are not starlike: emission-line spectra with very large redshifts.

In recent years, many quasars have been discovered from the large redshift alone.

In fact, most are not radio sources.

Therefore, the more neutral term, “quasi-stellar object (QSO)” is sometimes used instead of “quasar.”
Similarities to active galactic nuclei

• The spectra are very similar.

• The luminosities are similar, but quasars are generally more luminous.

• Similar variations in brightness

• Many quasars are located in the centers of galaxies.

These similarities suggest that quasars are the same type of object as active galactic nuclei, just farther away.

So the same model is applied to both.
Properties of the universe

Expansion of space

- Hubble Relation: clusters of galaxies move apart with speeds proportional to their mutual separations.

- We imagine space itself as a stretchable fabric with clusters of galaxies pasted onto it.

- Mutual recession of clusters of galaxies is caused by expansion of space itself. Hence, “expansion of the universe”

Imagine you are living on the surface of a balloon (Fig. 15.18)
Light waves are “stretched” as they travel through the expanding fabric. (Fig. 15.19)

The farther & longer they travel, the more they are “stretched:” an explanation for Hubble’s Law of redshifts.

Large-scale structure

Clusters of galaxies are the largest gravitationally bound structures.

They are grouped into superclusters.

Superclusters line up in filaments, which are separated by empty spaces or voids.
Looking back in time

• We see galaxies as they were when the light left them.

• The farther away a galaxy is, the farther back in time we are looking.

• For example: in the Hubble Ultra Deep Field, very faint, distant galaxies are seen as they were fairly soon after they formed.
Age of the universe

- Current estimates
  - Based on observed radial velocity of any galaxy and its estimated distance; *assumes this rate has been constant* over time
  - About 14 billion years. Uncertainty 2 billion years.

- Compare with age of oldest known objects: globular star clusters, about 12 to 15 billion years.

But has the expansion rate always been the same as it is now?

The mutual gravitational pull of all the galaxies in the universe could be slowing it down.
Average density of the universe

Estimate the average density in a large volume: reckon up the total mass in the volume, divide by the volume
To determine the mass of a galaxy

- Study *Doppler shifts in outer disk* to learn orbital speeds of stars (rotation of galaxies)
- Study galaxies in clusters to learn their motion in relation to each other

Learn: in most galaxies, this method indicates more mass than the detected stars in the galaxy can account for.

This fact argues that much of the matter in galaxies is *dark.*
The *critical density*

- The average density that would cause the cosmic expansion to slow down continually but never quite stop
- There are good theoretical reasons for thinking that the average density of the universe is equal to the critical density.
Acceleration

A new standard candle for great distances: *white dwarf supernovae*

- A different kind of stellar explosion
- In a binary system, a white dwarf gathers material from its companion until its mass exceeds the maximum for a white dwarf.
- Then it explodes, producing a great burst of light but leaving no collapsed remnant.
• Because the mass and composition of the exploding star are always the same, the luminosity of the explosion is uniform.

• These explosions have been calibrated in nearby galaxies.

• Allow distance estimates to greater distances than ever before.

• The farthest ones are closer than their redshifts would indicate.

This means that the universe expanded more slowly in the past than it does now: the expansion is accelerating.
No one knows for sure what is causing the acceleration, but we give it a name anyway: *dark energy*.

Dark energy is a property of space itself, even in vacuum.

If we assume the dark energy has certain properties, then it has the equivalent of enough mass to bring the average density of the universe up to the critical value. (Remember $E = mc^2$!)
The cosmic background radiation

• Definition & properties
  – An infrared & microwave “glow” from empty sky
  – Thermal radiation at about 3° Kelvin
  – Almost perfectly uniform in brightness

• Interpretation
  – This radiation fills the universe as if we were inside a room with glowing walls.
  – In the past, the waves were less “stretched.”
– Observers then would have measured the temperature of the “walls of the room” to be higher than we do now.

– The farther back in time, the hotter and denser the universe.

– Suggests that the universe originated in an extremely hot, dense state: a *primordial cosmic fireball*.

– The brightness of the background is very slightly nonuniform, so the primordial fireball was too.

– Denser regions in the fireball eventually gave rise to superclusters in the universe today, through gravitational contraction.