Astronomy 1144 Final Exam Review Sheet

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Observational Astronomy

1. What are constellations?
    - They are collections of stars which are close together on the sky.
2. What is special about the constellations called “the zodiac”?
    - They lie along the ecliptic, so that the Sun passes through them.
3. What is the ecliptic plane?
    - The plane of the Sun’s path along the sky. Since all the planets have low inclination, it is also where they lie, as well as the zodiac.
4. Why is the ecliptic tilted with respect to the celestial equator? How big is this tilt in degrees?
    - Because the Earth’s rotation is tilted with respect to its revolution around the Sun.
    - 23.5 degrees.
5. What are the primary coordinates for finding a place on Earth? What about the celestial sphere?
    - Earth: latitude and longitude.
    - Celestial sphere: declination and right ascension.
6. Why did the ancients keep track of the planets?
    - Because they move with respect to the background stars.
7. What are the two main periods of a planet, and how are they defined?
    - Synodic period: the apparent orbital period of a planet as viewed from Earth. This is the time from conjunction to conjunction, or opposition to opposition. The synodic periods of the outer planets are just over one year.
    - Sidereal periods: the time it takes an object to return to the same place with respect to the background stars; also the true orbital periods of a planet around the Sun.
8. What is the angular size of an object? What is it for the Moon?
    - It is the angle subtended in your field of view by the object.
    - The Moon is about 30’, or 0.5 degrees, in the sky. This is roughly the same size as the Sun.
9. How big is an arcminute? An arcsecond?
    - 1’ = 1/60th of a degree.
    - 1” = 1/60th of 1’ = 1/3600th of a degree.

Greek Astronomy

1. How did Greek astronomers first conclude that the Earth was spherical?
    - The Earth's shadow, as seen during a lunar eclipse, is round.
2. What did Eratosthenes do? How did he do it?
    - Estimated the circumference of the Earth.
    - He measured the length of the shadows cast at noon in two different locations separated by a known North-South distance. The difference in these lengths gave him the angle between the two locations along Earth's surface, allowing him to calculate the circumference of the Earth.
3. What is stellar parallax? Why is it useful?
    - Stellar parallax is the apparent change in the position of stars brought about by the motion of the Earth around the Sun.
    - It can be used to determine the absolute distance to stars.
4. Why did the Greeks reject the heliocentric model?
    - They could not see stellar parallax.
5. Why couldn't they see stellar parallax?
    - Even for the nearest star, the parallax is far too small to see with the naked eye.

The Heliocentric Model

1. In simple terms, what are the geocentric and heliocentric models?
    - Geocentric - the planets and Sun all orbit around the Earth.
    - Heliocentric - the planets, Earth included, all orbit around the Sun.
2. Who was the first major proponent of the heliocentric model? What were the key facets of his model?
    - Copernicus.
    - His model had a central Sun with the planets orbiting it. It also includes epicycles, like Ptolemy's geocentric model, to preserve circular motion.
3. Explain the main observational problem that Mars presented for the geocentric and early heliocentric models.
    - Retrograde motion - Mars would abruptly change its direction of motion on the sky and then flip back periodically.
4. What did Ptolemy add to the geocentric model to explain this problem?
    - By adding epicycles, i.e. circular orbits within circular orbits, to the planets' motion around the Earth.
5. Who correctly solved this problem? How? Using whose data?
    - Johannes Kepler solved this by incorporating elliptical orbits rather than perfectly circular ones, compiled from Tycho Brahe's data.
6. What is the cause of retrograde motion? Where will a superior planet be during this time?

- An inferior planet moves faster in its orbit than one superior to it, and thus laps the outer planet. This causes the outer/superior planet to appear to move backwards in the sky.
- Opposition.

7. Which of Galileo's observations supported the heliocentric model?
    - Phases of Venus.
    - Satellites of Jupiter (something else in the Solar System has objects orbiting it besides the Earth).
8. Define superior planet, inferior planet, conjuction, opposition, quadrature, perihelion, aphelion, and eccentricity.
    - Superior planet - one whose orbit around the Sun is outside that of the Earth's.
    - Inferior planet - one whose orbit around the Sun is internal to that of the Earth's.
    - Conjunction - occurs when the Sun is directly between the Earth and a superior planet (superior conjunction), an inferior planet is between the Earth and the Sun (inferior conjunction), or the Sun is between an inferior planet and the Earth (also superior conjunction).
    - Opposition - occurs when the Earth is directly between the Sun and a superior planet. The superior planet then appears opposite the Sun in the sky (rises at sunset, sets at sunrise), hence the name.
    - Quadrature - occurs when the Sun and a superior planet are 90 degrees apart in the sky.
    - Perihelion - the closest a body comes to the Sun in its orbit.
    - Aphelion - the furthest a body goes from the Sun in its orbit.
    - Eccentricity - a measure of how an orbit deviates from being a perfect circle. Is 0 for a circle, 1 for a parabola. For elliptical orbits, is determined by the ratio of the distance from the center of the ellipse to one focus and the semimajor axis.
9. Explain Kepler's 3 Laws.
    - 1st Law - All the planets are on elliptical orbits, with the Sun at one of the foci.
    - 2nd Law - In their orbits around the Sun, every planet sweeps out equal area in equal time. Equivalently, planets move more slowly when further away from the Sun.
    - 3rd Law - The square of the period, P, of any orbit is proportional to the semimajor axis, a, of said orbit to the third power, or $P^2 \propto a^3$.

Gravity, Galileo, and Newton

1. What are some things Galileo observed through his telescope?
    - The phases of Venus.
    - Sunspots.
    - Lunar mountains and craters.
    - The largest and brightest moons of Jupiter.
    - That the Milky Way is made up of many individual stars.
2. Galileo also studied gravity. How did he do so, and what did he discover?
    - He timed cannonballs rolling down a slope to measure the acceleration of gravity.
    - He found that the acceleration of gravity was the same for any object, no matter its mass.

3. What are Newton's 3 Laws?
   - Law of Inertia: A body either stays at rest or moves in a straight line unless acted upon by an external force. Mass is a measure of this inertia.
   - Law of Acceleration: For a given mass, its acceleration is proportional to the force applied - $F = ma$. More massive objects are more resistant to acceleration.
   - Law of Action equals Reaction: For every action there is an equal and opposite reaction - momentum is conserved.
4. What is meant by "conservation of momentum"?
   - The momentum (mass times velocity) of an object or system is the same, or conserved, before and after an event.
   - Example: If you and a friend stand facing each other on roller skates and you push them, you travel backwards at the same time your friend does.
5. What is Newton's Law of Gravity?
   - The gravitational force between two objects is proportional to the product of their masses, and inversely proportional to the square of the distance between their centers; $F_g = Gm_1m_2/r^2$, where G is a constant.
6. What point do two objects orbiting each other revolve around? Where does it lie?
   - The barycenter, or their mutual center of mass.
   - An orbiting object's distance from the barycenter is inversely proportional to its mass: more massive objects lie closer to the barycenter.
   - For example, in the Earth-Moon system, the barycenter is below Earth's surface, but is not at the center of the Earth.
7. What is the energy associated with your position with respect to a source of gravity called?
   - Gravitational potential energy.

Light and Matter

1. What is light?
   - Light is electromagnetic radiation.
   - It is composed of perpendicular electric and magnetic fields, and interacts with charged particles.
   - Electromagnetic radiation can have many different wavelengths/frequencies, most of which we are not able to see. The visible spectrum runs from 4000-7000 Angstroms in wavelength.
2. How does the electromagnetic spectrum run?
   - From longest wavelength to shortest, it is radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays.
3. How large is an angstrom? What is it often used for?
   - An angstrom (Å) is 10^{-10} m.
   - It is often used to specify the wavelength of visible or ultraviolet light.

4. What is the relationship between an electromagnetic wave's wavelength and frequency? How about between the energy of a photon and its frequency/wavelength?
   - $c = \lambda f$, where c is the speed of light, f is the frequency, and λ is the wavelength.
   - $E = hf$, or $E = hc/\lambda$, where h is Planck's constant.
5. What is the Doppler Effect, and how does it apply to light?
   - The Doppler Effect is a feature of all waves. When an object is moving towards you, any waves it emits "pile up" and their frequency increases. When an object is moving away from you, any waves it emits towards you are more spread out and their frequency decreases.
   - The faster the wave source is moving with respect to you, the larger the effect.
   - With light, this manifests as blueshifts (moving towards) and redshifts (moving away) - i.e., an object moving towards you looks bluer, while an object moving away from you looks redder.
6. What is a spectrum?
   - It is the light from an object arranged according to wavelength or frequency; i.e., light from an object spread out into its constituent colors.
7. What is special about an electron orbiting an atomic nucleus? What are some consequences of this?
   - Electrons *must* be in specific orbits around the nucleus with a specific amount of energy. They cannot be in arbitrary orbits!
   - Since atoms absorb and emit light through their electrons, they may only emit or absorb certain wavelengths which correspond to the gaps between energy levels/orbits.
   - The energy level pattern for each atom is unique; hydrogen has different levels from helium or iron, for example. This makes each atom have a different pattern of spectral lines.
8. What are spectral lines?
   - Spectral lines come in two flavors: emission and absorption.
   - Emission lines are from electrons in atoms jumping down to a lower energy level and emitting light, and are bright lines of color.
   - Absorption lines come from electrons absorbing light and jumping to a higher energy level, and are dark. E.g., the dark lines in the solar spectrum are absorption lines.
   - As long as the change in energy level is the same (e.g., from 2nd to 3rd or 3rd to 2nd), the wavelength of emission and absorption lines are identical.

Relativity

1. What are the two postulates of special relativity?
   - The laws of physics are the same everywhere in the universe.
   - The speed of light, c, is the same in all inertial (non-accelerating) reference frames. No matter how fast you are going, you will always measure the speed of light to be c ($\sim$ 300,000 km/s).
2. What are some consequences of these postulates (i.e., what are some results from special relativity)?
   - It takes an infinite amount of energy for a massive object to travel at c, therefore the speed of light is the maximum speed anything in the universe can travel.

- For fast-moving objects, time moves slower, and distances contract in the direction of motion (to an outside observer, a fast-moving spacecraft would appear shorter).
- The notion of simultaneity changes; two events which are simultaneous according to one observer may not appear to be simultaneous to a different observer.
- $E = mc^2$. Matter and energy are two forms of the same thing, and can be converted into one another.

3. What is the main statement of general relativity, and why do we need GR?
   - GR says that gravity is not a force; instead, it is simply the result of matter curving spacetime.
   - GR is needed because Newtonian gravity does not explain everything we see; instead, it breaks down near large masses and at speeds close to the speed of light.
4. What are some additional predictions general relativity makes over special relativity?
   - Being in freefall is indistinguishable from being in an inertial (non-accelerating) reference frame. Thus astronauts feel weightless.
   - Similarly, an observer standing in a small box cannot tell the difference between them being on the surface of the Earth and being accelerated by a rocket with the same strength as Earth's gravity.
   - Light bends in the gravitational field of a massive object such as the Sun.
5. What are the defining characteristics of a black hole?
   - A black hole is something so dense that not even light can escape from it if its gets too close.
   - A black hole may be completely described with only its mass, electric charge, and spin.
6. What is the event horizon? The singularity?
   - The event horizon is the point of no return. Beyond it, nothing can escape, not even light.
   - It is more rigorously defined as the point at which the escape velocity of the black hole is equal to the speed of light, c.
   - The singularity is the point at the very center of the black hole. All the mass that makes up the hole is compressed into a single point at the center, according to GR.
7. What is the Schwarzchild radius?
   - It is the radius of the event horizon. If an object is compressed to a size smaller than its Schwarzschild radius, it will inevitably collapse to form a black hole.
   - The Schwarzschild radius for the Sun is about 3 km. The Earth's is roughly 1 cm.
8. What is gravitational lensing?
   - Light follows the curvature of spacetime, so it bends as it passes nearby massive objects. This is gravitational lensing: gravity bending light.

Stars and Stellar Classification

1. What is a star's energy source, or how do stars shine?
   - Stars shine by fusing light elements into heavier ones.
   - During fusion, some mass is converted into energy. For example, a Helium-4 nucleus (two protons, two neutrons) is lighter than the four protons that went into making it.

- This energy is radiated as light/heat, causing a star to shine.

2. Nuclear fusion, as happens in stars, requires extremely high temperatures. Why?
   - Atomic nuclei are partially made of charged particles (protons).
   - In order to fuse, two nuclei must be able to overcome the electrical repulsion from their protons.
   - High temperatures = higher particle speeds = more likely to fuse.
3. What is the layer of a star that we are actually able to see? How is it defined?
   - This layer is called the photosphere.
   - The depth of the photosphere is the depth from which the average photon can escape the Sun without hitting a particle before doing so.
4. Why does the Sun appear darker towards its edge?
   - This is called limb-darkening.
   - Photons from the edge of the Sun's disk are reaching us after being emitted by higher, cooler layers of the Sun. A photon from the center of the disk and the limb both travel about the same distance in the photosphere before exiting the Sun.
5. What is the solar corona, and what are some of its characteristics?
   - The corona is a hot plasma atmosphere which surrounds the Sun.
   - It is very tenuous, and heavily affected by the Sun's magnetic field.
   - Sometimes, solar flares or coronal mass ejections can send large amounts of charged particles zooming off into space.
6. How are stars classified?
   - Mainly by temperature/color and spectral line strengths.
   - The spectral classes (OBAFGKML) are defined by the ratios of spectral line strengths.
   - The spectral class sequence is also a temperature sequence, with O & B stars being the hottest, and M & L stars being the coolest.
   - For example, the Sun has a surface temperature of roughly 5800 K and has spectral type G.
7. What is the Hertzsprung-Russell (HR) diagram? What are some of its main features?
   - A plot of luminosity vs. temperature for stars.
   - Stars only fall into certain places on the diagram - they may not have arbitrary properties.
   - Most stars lie on the main sequence, where they burn hydrogen into helium.
8. What is the single most important attribute of a star for determining its properties and evolution?
   - Its mass.
   - More massive stars are more luminous, tend to be larger, tend to be hotter, and live much shorter lives than less massive stars do.
9. What is a star's apparent magnitude? What is its absolute magnitude?
   - A star's apparent magnitude is its apparent brightness, or how bright it looks from Earth. It is affected by both how far away the star is from Earth, as well as the star's actual luminosity.
   - A star's absolute magnitude is defined as what a star's apparent magnitude would be if it were 10 parsecs away from Earth. It is related to the star's luminosity, or how much energy the star actually puts out in a given time. It does not depend on the star's distance from Earth.

Star Formation and the Interstellar Medium

1. How, generally, do stars form?
   - They collapse from clouds of gas, called giant molecular clouds (GMCs).
   - As the clouds collapse, they fragment and heat up, until the cores of the fragments are hot and dense enough for hydrogen to begin fusing.
   - They typically form as a cluster, so that many stars are born in roughly the same area at roughly the same time.
   - The remaining gas left over from star formation remains as nebula. The nebula may glow as a result of the newborn star's radiation ionizing the gas.
2. What is interstellar dust, and how may it be detected?
   - Interstellar dust consists of the heavy elements produced in stars.
   - Its largest components are silicates and graphite-like compounds.
   - It often is not hot enough to significantly glow on its own in visible light, so it is detected by looking at how it absorbs and scatters light coming from behind it.
   - Blue light is scattered more strongly than red by dust, so dust reddens light passing through it.
3. What is a forbidden transition/line? Why are they important?
   - A forbidden transition/line is a spectral line resulting from a transition with a low probability of occurring. They are typically much weaker than ordinary spectral lines such as Hα.
   - They are important in astronomy because such lines are often seen in emission nebulae.

Evolution of Low-Mass Stars

1. Where does a low-mass star like the Sun spend most of its life? What is it doing during this time?
   - Low-mass stars spend most of their lives on the main sequence, where they fuse hydrogen into helium.
   - They typically fuse hydrogen via the proton-proton (p-p) chain, as their cores are not hot enough for CNO fusion.
2. When they exhaust their hydrogen supply, what happens to the low-mass stars?
   - When they exhaust the hydrogen in their cores, they start burning hydrogen in a shell around the core.
   - The outer envelope of the star massively expands and cools as the star grows much more luminous.
   - The star becomes a red giant, and moves up and to the right of the main sequence on the HR diagram.
3. How is core helium burning ignited? What happens to the star after that? By what process is helium fused?
   - Core helium burning begins explosively once the core is hot and dense enough; this is the "helium flash." Once the flash is over, the star stably burns helium.
   - After the helium flash, the star contracts and its surface gets hotter as it settles onto the horizontal branch. The star is still much brighter than it was on the main sequence.

- Helium is fused via the triple-alpha process. Because Beryllium-8 is so unstable, three helium nuclei must come together very quickly to form Carbon-12.
- Helium burning is *highly* temperature sensitive; while p-p fusion goes as T^4, the triple-alpha process goes roughly as T^{40}!

4. What happens after the end of helium burning?
    - These stars fuse hydrogen and helium in shells around the core, and rise up the asymptotic giant branch. The asymptotic giant branch (AGB) is named because it asymptotes to the red giant branch on the HR diagram; i.e., it gets closer and closer, but never touches or crosses it.
    - The star then puffs off its outer layers, as the AGB shell-burning configuration is unstable.
5. What is left of the star at this point?
    - When the star puffs off its outer layers, it generates a planetary nebula.
    - This nebula glows, because it is ionized by the high levels of radiation emitted by the now-exposed hot carbon-oxygen core of the star.
    - The core of the star, no longer able to fuse, cools and collapses to become a white dwarf.
    - Eventually, the white dwarf may crystallize, once it is cold enough to no longer be able to be a gas, and may effectively become a huge diamond/carbon crystal.
6. If white dwarfs cannot fuse, how are they supported against gravity?
    - White dwarfs support themselves against their own gravity through electron degeneracy pressure.
    - Due to the Pauli exclusion principle, electrons cannot be in the same quantum state as their neighbors, and thus cannot be in the same place as their neighbors.
    - This fact creates a pressure which can resist the star's gravity.
    - However, it also means that a white dwarf is very small, only about the size of the Earth.
    - The pressure from electron degeneracy is also not limitless; if, at the end of the star's life, the mass of its core is more than 1.4 solar masses, gravity will overcome the electron degeneracy pressure and the core will collapse further. This is called the Chandrasekhar Limit.

Evolution of Massive Stars

1. How is a massive star's early life different from a lower-mass star's?
    - Massive stars burn through their fuel much more quickly than low-mass stars, and are thus much, much brighter.
    - Because they burn their fuel much faster, they also live much shorter lives, and die relatively quickly. The most massive stars live only a few million years, while the Sun will end up living over 10 billion years in total.
    - Massive stars do not use the p-p chain to fuse hydrogen on the main sequence; instead, the high temperatures in their cores allow them to use the CNO cycle.
2. What happens to a massive star after it moves off the main sequence?
    - Massive stars are able to fuse helium into carbon and oxygen, just like low-mass stars.
    - They are, however, able to go further still, and burn carbon into oxygen, neon, and magnesium. In contrast to burning hydrogen or helium, this process takes about 1000 years maximum.

- If the star is between about 4-8 solar masses, the burning stops there, and the star blows off its outer layers and becomes an oxygen-neon-magnesium white dwarf.
- Above 8 solar masses, the star can burn oxygen, neon, and magnesium into silicon; this stage lasts no more than a few years.
- Once a silicon core has formed, the star begins fusing silicon into even heavier elements, reaching iron and nickel.
- The star's core at this point resembles an onion, with lighter elements burning in shells surrounding the core.

3. What happens to a massive star when it tries to fuse iron?
   - Iron fusion does not generate energy; instead, it consumes it. A star cannot continue to shine via iron fusion.
   - This means that the end of the line has been reached, and a stellar collapse is unavoidable.
   - The same as a white dwarf, however, the core is able to support itself against gravity via electron degeneracy pressure until it hits the Chandrasekhar Limit.
   - Once the core hits the limit, it collapses extremely quickly, becoming only a few kilometers across. The outer shells rush in to fill the void left by the collapsing core.
   - The inrushing material essentially bounces off the collapsed core and rebounds, destroying the star in a huge explosion known as a supernova.
   - The core is left behind and becomes either a neutron star or a black hole, depending on how massive it is.

Supernovae

1. Which stars will go supernova at the end of their lives?
   - Those which begin their lives more massive than about 8 solar masses.
   - Also, white dwarfs which are accreting material from a companion star may also go supernova.
2. What types of supernovae are there? How are they differentiated?
   - There are two main types of supernova, with subclasses: Type I and II.
   - Type I supernovae do not have hydrogen lines in their spectra, while Type II's do.
3. What forms Type II supernovae? Type I?
   - Type II supernovae are all formed by the massive stars exploding following the collapse of their iron cores.
   - Type I's are formed from exploding white dwarfs.
4. What do supernovae leave behind?
   - Type II's leave behind neutron stars or black holes: the remnant of the collapsed core of the star.
   - Type I's involve the total destruction of the white dwarf, and thus leave no central remnant behind.
5. What are neutron stars? Pulsars?
   - Neutron stars are similar to white dwarfs in that they are bodies of degenerate matter left over after the death of a star. Unlike white dwarfs, neutron stars form in supernovae.

- Neutron stars, however, are supported by neutron degeneracy pressure, not electron degeneracy pressure.
- They are also much smaller than white dwarfs, no more than about 10 km across, roughly the size of Manhattan.
- Pulsars are very rapidly spinning neutron stars which emit beams of radiation from their magnetic poles. If the magnetic field axis is aimed towards us, we see pulses of radiation as the beam sweeps over us.

Observatories & Telescopes

1. What is a telescope's main function?
    - To gather light, NOT magnify an image.
    - Astronomical objects are typically very faint, so a lot of light/radiation needs to be gathered together in order to get a good image.
2. What are the main parts of a telescope?
    - The objective, or main mirror/lens, which collects the light.
    - The eyepiece, a small lens/mirror which magnifies the image after it is formed from the light collected by the objective.
3. What are the two main types of telescopes?
    - Reflecting and refracting.
    - Reflecting telescopes (or reflectors) use mirrors to gather light.
    - Refracting telescopes (or refractors) use lenses instead.
4. What are some advantages of reflectors over refractors?
    - Reflectors can be built much larger than refractors, as mirrors may be supported much more effectively against gravity.
    - Reflectors do not suffer from chromatic aberration.
5. How does refraction work?
    - Light travels different speeds in different media.
    - Because of this, light waves bend when entering or leaving different media.
    - The amount by which light slows down and bends in a material compared to a vacuum is called the index of refraction. It is defined as the ratio between the speed of light in a material and the speed of light in vacuum.
    - The refractive index/index of refraction varies with the wavelength/frequency of light. Typically, red light is bent less by a material than blue light.
6. What about reflection?
    - At any interface between two materials of differing refractive indices, at least some light is reflected.
    - What fraction of the incoming light is reflected depends on many factors which can be ignored here.
    - The Law of Reflection states that the angle of incidence is equal to the angle of reflection; i.e., light will reflect off a surface at the angle it came in at.

7. Where are most observatories placed?
    - High, dry places far away from city lights.
    - These places offer good weather/clear skies, and a steady atmosphere.
    - They are also above much of the atmosphere's low level turbulence.
8. What wavelength ranges are available to ground-based telescopes?
    - The visible and near-infrared.
    - Radio waves with wavelengths above $\sim$ 1 mm.
    - All others are blocked by the Earth's atmosphere, and must be observed from space.
9. What is the largest optical telescope in the world? How about the largest radio telescope?
    - The largest optical telescope is the Keck 10 m.
    - The largest radio telescope is the 1000 ft. Arecibo telescope.
    - Radio telescopes are almost universally much larger than their optical counterparts.

Introduction to Cosmology

1. What is Hubble's Law?
    - Hubble's Law is a relationship between a galaxy's distance from us and its redshift or recessional velocity (i.e., how quickly it is moving away from us).
    - Mathematically, $v = H_0 d$. v is the recessional velocity of the galaxy, H_0 is Hubble's constant, and d is the galaxy's distance from us.
    - Therefore, using the galaxy's redshift, we can determine its distance from us.
2. What does Hubble's Law imply?
    - The universe is expanding!
    - The universe had a beginning, what we call the Big Bang.
3. What is the approximate age of the universe?
    - Roughly $1/H_0$. Numerically, this is 13-14 billion years.
4. What is the cosmic Microwave Background (CMB)? What are some of its properties?
    - The CMB is extremely uniform relic radiation from the Big Bang.
    - It is a blackbody to very high precision; in fact it has the purest blackbody spectrum we know of.
    - It is very cold: only 2.73 K (3 degrees above absolute zero).
    - It is almost totally isotropic; i.e., it looks virtually the same in all directions.
    - However, it has some extremely slight deviations generated by matter immediately following the Big Bang.
5. What are the most abundant elements in the universe?
    - Hydrogen and helium.
6. What are three major bieces of evidenc for the Big Bang Theory?
    - That the universe is expanding, based on Hubble's Law.

- The existence of the cosmic microwave background shows that the universe was once hot.
- The observed abundances of hydrogen and helium in old stars and gas clouds agree with that predicted by the theory.

7. Why does the CMB appear the way it does? What formed it?
    - When the universe was very young, it was much hotter and denser than it is today; it cooled as it expanded.
    - In the universe's earliest days, it was dense enough to be opaque.
    - Once it had expanded and cooled enough for neutral atoms to form, the universe became transparent.
    - This released the blackbody/thermal radiation of the gas in the universe, and allowed it to travel across the universe.
    - The CMB is the redshifted and cooled relic of this radiation.
8. Why is the extreme uniformity of the CMB such a problem? What is the current thinking on the solution to this problem?
    - The CMB is extremely uniform across the entire observable universe.
    - This is a problem because two things on opposite ends of the universe are not in causal contact with each other.
    - That is, they have never been able to influence or see the other, because light has never had time to go between them.
    - In order to remedy this, cosmic inflation was proposed.
    - Very early in the universe's history, in first tiny fractions of a second, the universe expanded by many orders of magnitude, then the expansion suddenly slowed.
    - Opposite sides of the universe would have been in contact with each other before the inflation began, but not after.
9. What are the three types of curvature the universe may have?
    - Open: the universe is negatively curved on large scales. In 2D, this is a sort of saddle shape. Parallel lines diverge.
    - Flat: the universe is flat everywhere, like a tabletop or a sheet of paper. Parallel lines always stay the same distance from each other.
    - Closed: the universe is positively curved on large scales - i.e., it curves back on itself like the surface of a sphere. Parallel lines will always meet.
10. What is the cosmological constant?
    - The cosmological constant is a parameter which Einstein added in order to make the universe static. He needed it to counteract the gravity of matter and radiation trying to pull the universe back together.
    - Einstein abandoned it once the universe was shown to be expanding.
    - However, the expansion of the universe is accelerating, and the repulsive force of the cosmological constant is needed again to overpower matter's gravitational pull on large scales.
11. What is the critical density of the universe?
    - The critical density of the universe is the density where the universe would be flat.

- It takes into account all matter, radiation, and the cosmological constant/dark energy.
- The density of the universe is very close to the critical density, and thus the universe is very close to flat, if not exactly flat.
- If the density is less than the critical density, the universe would be open.
- If the density were instead more than the critical density, the universe would be closed.

12. How much of the universe is made up of matter? How much is dark energy?
    - Just 4% of the universe is made up of ordinary matter. Dark matter makes up an additional 26% of the universe, for a total matter content of roughly 30% .
    - Dark energy makes up virtually all the rest, at roughly 70%.

The Cosmic Distance Ladder

1. What are some of the rungs on the cosmic distance ladder?
   - Trigonometric parallax.
   - Spectroscopic parallax.
   - Cepheid and RR Lyrae variables.
   - Tully-Fisher Relation.
   - Type Ia supernovae.
2. How do the above techniques work? What distance ranges do they cover?
   - Trigonometric parallax involves measuring the annual change in position of nearby stars relative to background ones over the course of the year. It is accurate for only the closest objects - no more than 1000 pc away.
   - Spectroscopic parallax works by measuring the apparent brightness, spectral type, and luminosity class of a star, giving an estimate of its luminosity. That then gives a distance estimate. This is good out to about 50 kpc.
   - Cepheids and RR Lyraes are variable stars whose pulsation periods are directly tied to their luminosities - more luminous stars take longer to pulsate. Cepheids are massive stars, while RR Lyraes are low-mass stars. Both have evolved off the main sequence. This method is good out to 30-40 Mpc, beyond which the individual stars cannot be resolved.
   - The Tully-Fisher relation relates how quickly a spiral galaxy is spinning to its luminosity. More massive galaxies rotate more quickly and have more stars, so they are more luminous than less massive galaxies. By looking at a galaxy's rotation curve, you can estimate its mass and thus luminosity, giving a distance. Good out to a few hundred Mpc, but fairly imprecise.
   - Type Ia supernovae have brightnesses which are strongly tied to how quickly they fade away, so they function as "standard candles." They are visible out to several hundred Mpc, and can give relatively precise distances, but are rare for any one galaxy.
3. How is the distance ladder used?
   - The distance ladder is used to set the physical scale of the universe.
   - By using Hubble's Law relating redshift to recessional velocity and distance, and by redshifts to objects of known distance, we can measure changes in the expansion of the universe.

Galactic Dynamics and Classification

1. What are the main constituents of the Milky Way galaxy?
    - The Milky Way has a rotating disk of stars, gas, and dust, a central bulge of old stars, a halo of dark matter and old stars, and a supermassive black hole at its center.
2. Can stars account for all of the mass of the Milky Way? How do we know?
    - No, stars cannot account for all of the Milky Way's mass.
    - The rotation curve (how fast stars orbit at different distances from the center) is flat as you go outward from the center of the galaxy, even far past where the stars mostly stop.
    - Objects out there in the halo orbit at roughly the same speed as the Sun; if the mass were concentrated with the stars, we would expect the stars further out to orbit much more slowly than they do.
3. How can we explain the discrepancy between the visible stars and the flat galactic rotation curves?
    - The best solution astronomers have come up with is dark matter.
    - This is extra matter that interacts very weakly with baryons and photons.
    - 90% of the matter in the universe is dark matter. We still do not know what exactly it is.
4. What are the various Populations of stars? How are they differentiated?
    - Stars are classified into Populations by the amount of metals (in astronomy, elements heavier than hydrogen and helium) they contain.
    - Population I stars are relatively young and metal-rich. In spiral galaxies, they tend to be found in the arms and disk. The Sun is an intermediate Population I star.
    - Population II stars are old, metal-poor stars, and are not found in the disk. Globular clusters and the central bulge are made up of Population II stars; the galactic halo is also largely Population II stars.
    - Population III stars are very metal-poor stars which formed in the very early universe, and have virtually no metals. None have yet been observed.
5. What is at the center of most galaxies?
    - Most galaxies have a supermassive black hole at their centers.
    - The Milky Way is no different. Sagittarius A is a radio source which marks the center of the Milky Way, and is thought to come from such a supermassive black hole.
6. What are some different types of galaxies? What are some of their characteristics?
    - Ellipticals: No disk, dust, or spiral arms. Large elliptical/spherical agglomerations of stars. Further classified by how elongated they appear: E0's are nearly spherical, while E9's are extremely elongated/cigar- or football-shaped.
    - Spirals: Disk galaxies with a central spherical bulge. Arms are often blue and dusty from the formation of new, young stars. Further classified based on the size/prominence of the bulge and how tightly the arms are wound. Sa's have large bulges and more tightly wound/less prominent arms, while Sc's have small bulges and prominent/loosely wound arms. The Milky Way is a spiral galaxy.
    - Barred Spirals: Similar to spirals, except that their bulges are elongated into football-shaped bars. Finer classification is the same, using SBa, SBb, etc. instead of Sa, etc.
    - Irregulars: Galaxies with no regular, defined shape. Often very small satellite galaxies such as the Magellanic clouds.

Active Galactic Nuclei (AGN)

1. What is an active galactic nucleus (AGN)?
    - It is an extremely bright and compact nucleus with non-stellar spectra (i.e., it does not look like it is made of stars).
    - They can sometimes outshine their entire host galaxy. In fact, quasars, a type of AGN, are the most luminous objects in the universe.
2. What is the power source for an AGN?
    - All AGN are powered by the accretion of matter onto the central supermassive black hole of the galaxy.
    - That is, as matter falls onto the black hole, it forms a disk and heats up greatly, causing it to shine very brightly.
    - Some of the infalling material may be ejected along two finely narrowly-focused jets from the poles of the black hole.
3. What are some types of AGN? How are they classified?
    - AGN types include Seyfert galaxies (Type I and II), radio galaxies, quasars, and blazars.
    - It is thought that which type of AGN is seen depends on the viewing angle.
    - Looking straight down the jet produces a blazar, while quasars and Seyferts are seen at more of an angle.
    - The difference between Seyferts and quasars is mainly their luminosity: A Seyfert nucleus may be roughly as bright as the host galaxy, while a quasar may outshine it by a factor of 100 or more.
    - Seyferts are additionally only found in spiral galaxies.
4. Is the Milky Way's nucleus considered active?
    - No, the Milky Way does not have an AGN.

The History of the Universe

1. How has the energy content of the universe evolved over time? What is it currently dominated by?
    - In the very early universe, radiation dominated the energy content of the universe. However, the energy density of radiation falls off very quickly as the universe expands.
    - After that, matter dominated the universe for most of its history.
    - About five billion years ago, the matter had become diluted enough for dark energy to dominate, and the expansion of the universe began to accelerate.
    - Dark energy does not dilute as space expands; it has a constant energy density. Thus, it is able to contribute ever more energy to the total energy content of the universe over time.
2. When did the first stars form? And the galaxies?
    - The first stars began to form several hundred million years after the Big Bang.
    - The first large galaxies were around by 3-4 billion years after the Big Bang, around 10 billion years ago.
3. What is the epoch of reionization?

- After the CMB decoupled from the gas permeating the universe, the universe was dark and filled with neutral gas.
- After the first stars began to form, they emitted ionizing radiation which began to ionize the gas.
- The universe had previously been completely ionized when it was hotter and denser, thus “reionization.”

4. How did the first galaxies begin to form?
    - Quantum fluctuations from the formation of the universe made it so that the universe was not quite uniform.
    - Over time, gravity caused these fluctuations in temperature and density to grow.
    - The material in the overdense fluctuations got denser and denser as more material flowed onto them from the underdense regions, and the large-scale structure of the universe took shape.
    - The first galaxies formed from the further collapse of these overdense fluctuations.

Extrasolar Planets

1. What are exoplanets/extrasolar planets?
    - They are planets which orbit stars other than the Sun.
2. What are some ways we have detected exoplanets? What kind of planets do these methods find?
    - Transits: we observe a dip in the brightness of a star as a planet moves in front of it, blocking some of the light. This method preferentially finds large, close-in planets.
    - Radial velocity: we observe a change in the star’s radial velocity as a planet tugs it to and fro with its gravity, using the Doppler Effect on spectral lines. This method also preferentially finds massive, close-in planets.
    - Direct Imaging: we simply take a picture of a planet orbiting its star. This is the most difficult technique in current use, because planets are extremely faint and difficult to see in the glare of their parent star. This method preferentially finds large, young/warm planets which are far from the glare of their parent star.
    - Microlensing: uses gravitational lensing to find planets, by observing the magnification of light as a star and planet pass in front of another star. This method more easily finds massive planets at distances around their star similar to the size of Earth’s orbit around the Sun.
3. What are the two dominant theories of planetary formation? How do they work?
    - Core Accretion: small rocks/dust particles stick together and collide, growing larger and larger until their own gravity is able to hold them together. At that point, the biggest few rocks sweep up everything else and become planets. Once a rock and ice core is able to reach 10-15 Earth masses, it may sweep up all the gas around it and become a gas giant.
    - Gravitational Instability: In this model, a very massive disk of dust and gas is able to cool itself extremely quickly. When it does so, it can no longer hold itself up and collapses to form several very massive planets.
4. What are Hot Jupiters? What interesting scientific questions do they pose?
    - Hot Jupiters are gas giants which orbit very close to their stars, much closer than the orbit of Mercury in our solar system.

- They present a problem because we do not believe a rocky body could accumulate enough mass to become a gas giant that close to the star.
- Rather, gas giants are thought to form beyond the “snow line”, where solid ices can form and provide enough mass to start the seed of a gas giant.
- Therefore, the question is how hot Jupiters formed and ended up in their present positions. Their existence suggests that our current models of solar system formation need fixing.

Life in the Universe

1. What is the physical definition of life?
    - Life is a self-replicating mechanism; i.e., all living things reproduce.
2. What are the building blocks of all known life? What does it use to replicate itself?
    - The basic building blocks of all known life are organic molecules and water. These molecules are made mostly of carbon, hydrogen, oxygen, and nitrogen (CHON elements).
    - Life uses the chemical deoxyribonucleic acid (DNA) to replicate itself.
3. What was the Miller-Urey experiment? What did it show?
    - The Miller-Urey experiment took a mix of gases (among them water, ammonia, methane, and carbon dioxide) thought to exist in the Earth’s early atmosphere and ran electrical current through it.
    - Many organic molecules, including amino acids and nucleotides, were formed as a result.
    - The experiment showed that the building blocks of life could form out of a primitive atmosphere.
4. What is the Drake Equation?
    - The Drake Equation is an equation giving a back-of-the-envelope estimate for how many technologically advanced civilizations may exist in the Milky Way.
    - It takes into account several properties of the galaxy and occurrence of Sun-like stars and Earth-sized planets.