Key concepts for Oct 6, 2011 ASTR 100 exam

Note: *everything* in the class up to and including the October 4 lecture is fair game. Thus anything in lecture, discussion, homeworks, or our textbook could be used. The following are key concepts to help you focus your studies.

- Scale of the universe: the Earth is much smaller than the Sun, which is much smaller than the Solar System, which is much smaller than the distance to the nearest star to the Sun, which is much smaller than a galaxy, which is much smaller than the universe.
- The scientific method: hypotheses come from observations or other motivations, but their predictions must be tested against observations or experiments to be scientific. Hence untestable hypotheses (e.g., "The Flying Spaghetti Monster did it") are not scientific. If two models make equally valid predictions, we tend to favor the simpler model ("Ockham's Razor"). Hypotheses can be rejected if they do not make correct predictions (although in practice "hypotheses are tested in bundles", so you have to make sure it isn't one of your ancillary hypotheses that has actually been rejected), but can never be proved (only confirmed by a particular experiment). Enough confirmations elevates a hypothesis to the status of a *theory*; unlike in colloquial usage, "theory" does not mean "my personal guess".
- Seasons on Earth are *not* produced by the Earth being closer to the Sun in summer and farther in winter! If that were the case, the whole Earth would experience the same seasons at the same time, but we know that Southern Hemisphere countries such as Australia have summer when we have winter and vice versa (and actually, during northern winter the Earth is closer to the Sun than it is during northern summer). The main cause is the tilt of the Earth; note, though, that contrary to what some people think this issue is *not* that the tilt brings the northern hemisphere *closer* to the Sun during northern summer. Indeed, the Earth is so small that at a given time all of it is equally distant from the Sun. The main issue is that during summer the Sun is higher in the sky, so we get its rays more directly than the more grazing incidence we have during winter; effectively, when the Sun is low in the sky its warmth is spread over a larger area than when it is high in the sky, and spreading more means colder on average.
- The Moon and the planets shine only by reflected light from the Sun, not by themselves. As a result, half the Moon is always reflecting the Sun unless the Moon is eclipsed. From our perspective, though, we only see the part that is bright *and* in our view. Thus if the Moon is between us and the Sun we see only the dark part; this is a new Moon. If the Moon is on the opposite side of the Earth from the Sun, we can see the whole lit part of the Moon; this is a full Moon. The Moon is very far from the Earth, so phases

are *not* caused by the shadow of the Earth, but are instead just our perspective on the bright part of the Moon. Solar eclipses happen when the Moon's shadow falls on the Earth; this can only happen during new Moon. Lunar eclipses happen when the Earth's shadow falls on the Moon; this can only happen during full Moon.

- To ancient societies, astronomy had many uses: nagivational, for agriculture, and for religious and ceremonial purposes.
- We don't appear to move, distant stars don't show parallax (change of their apparent direction over the year) to the naked eye, and objects seem to orbit around us. These were motivations for the *geocentric* (Earth-centered) cosmology, in which we are at the center. There are several observations that are explained only inelegantly using the geocentric model, including retrograde motion and the fact that Mercury and Venus always are seen close in direction to the Sun.
- Several observations changed people's minds in the 1500s and 1600s. These include Galileo's observation that Venus goes through a full set of phases (not possible in the geocentric model), his discovery of the moons of Jupiter (showing that objects could, in fact, stay with something that is moving), and his observations of mountains on the Moon and spots on the Sun (demonstrating that at least some celestial objects are imperfect).
- In addition, Kepler came up with three laws of planetary motion that described the motion of planets extremely precisely, within the context of a *heliocentric* (Sun-centered) cosmology. His first law is that planets travel in ellipses, with the Sun at one focus. His second is that the line between a planet and the Sun sweeps out equal areas in equal times. His third is $P^2 = a^3$: the square of the orbital period measured in years equals the cube of the orbital semimajor axis measured in AU (Astronomical Unit; the average distance between the Sun and Earth, which is 93 million miles or 149.6 million kilometers). He came up with these laws after many years of study of Tycho Brahe's extremely precise naked-eye observations of the planets over 20 years.
- Later, Newton proposed three laws of motion, which when combined with his law of gravity explained Kepler's laws from a more fundamental perspective. His first law of motion is that an object at rest remains at rest, and an object in uniform straight-line motion remains in that motion, unless the object is acted on by a force. His second law is that force equals mass times acceleration: $F = ma$. His third law is that every action has an equal and opposite reaction: if some object A exerts a force on B, then B exerts a force of exactly the same magnitude but the opposite direction on A.
- Based in part on Newton's laws, and in part on subsequent experiments, we understand that a completely isolated system (which is more often a good approximation than you'd think!) has certain *conserved quantities*, meaning that the value of that quantity will

not change for the system as a whole although it might be transferred from one object to another within the system. Conserved quantities in the realm we explore include mass, energy, linear momentum ($p = mv$, where m is the mass and v is the velocity), and angular momentum ($L = mvr$, where r is the radius of the moment arm). Note that energy can come in many forms (potential, kinetic, thermal, light, ...) and the energy in any *one* of those forms might not be constant, but the *total* over a whole system is.

- Newton's universal law of gravity is that every mass attracts every other mass in the universe. The force is directly proportional to each mass and inversely proportional to the square of the distance between them: $F_g = GM_1M_2/d^2$ if the masses are M_1 and M_2 and the distance between them is d. Note that the constant G is a *universal* constant; it applies as well to galaxies as it does to the Sun and Earth. Incidentally, there is a nice simplification: if you are outside a spherical object of mass M, its gravity acts as if all its mass is concentrated at a point at its center. From this law and Newton's laws of motion, Kepler's laws can be derived and generalized, and other concepts also emerge (e.g., escape speed: if you leave an object of mass M and radius R with a speed $v_{\text{esc}} = \sqrt{2GM/R}$, you will (barely) escape to infinity; we ignore things like air resistance here). Gravity also explains tides: the part of the Earth near the Moon is attracted more by the Moon than the part farthest from the Moon, so water and other parts of the Earth are raised slightly. A similar effect explains why Jupiter's moons Io and Europa are much warmer than they would otherwise be.

- The terrestrial (Earth-like) planets are, in increasing order of distance from the Sun, Mercury, Venus, Earth, and Mars. These are comparatively small and rocky planets. Earth is the biggest, hence it has retained its formation heat the best and thus has active convection in its interior that drives plate tectonics (absent in Mercury and the Moon [sometimes considered a terrestrial], dead now on Mars but active in its early life, and still present but less active on Venus). The surfaces of terrestrials are shaped by a variety of effects, including tectonics, impacts from meteorites, wind, and (on Earth alone!) water and life.

- Greenhouse gases such as carbon dioxide work by letting visible light in but trapping the infrared (heat) radiation that comes off the planet. They thus increase the temperature of the planet; this is a significant societal concern now because of human influence. Venus, the planet with the hottest average surface temperature despite being farther from the Sun than Mercury, has a runaway greenhouse effect and an atmosphere 90x thicker than Earth's.