Lecture 8: the Moon

* 1. Generalities
     1. The Moon is probably the most familiar object on the sky
     2. Responsible for the tides and interesting for eclipses
     3. More about that in a later lecture
     4. Today we will describe the Moon itself, its orbit, and its observable features
  2. Formation of the Moon
     1. As I described earlier, when stars form a disk of gas and dust forms around them
     2. It is out of this gas and dust that the planets, moons, and asteroids formed
     3. Little particles glob together and somehow over time form huge objects
     4. **How long ago did this formation occur? (4.6 Gyrs)**
     5. When the planets were first formed there were a lot of other small bodies in the Solar System
     6. Imagine the asteroid belt actually filling the solar system
     7. an important consequence is that everything at that time was being pelted by asteroids
     8. however, because there were only so many asteroids, this didn’t last forever
     9. basically about 500 Myrs
     10. during that time, there was most likely a Mars sized object near Earths orbit
     11. collided with Earth, but neither was destroyed
     12. resulting pair of objects was Moon & Earth system
     13. The Moon started out very close to the Earth in its orbit
     14. The effects of the tides has tended to push the Moon away: more on that later
     15. The Moon since then has cooled down; as you can tell, continued to be pelted for a while
     16. Basically inert today: unlike Earth, no plate tectonics reforming surface all the time
     17. There are moonquakes, due to tidal effects and slow continued cooling, but mild
  3. Orbit of the Moon
     1. We’ve talked about the Earth’s orbit around the Sun
     2. The Moon, meanwhile, is orbiting around the Earth
     3. The sidereal period of the orbit is 27.3 days
     4. While the Earth’s orbit is nearly circular, the Moon’s is quite elliptical
     5. We’ll talk later about orbits in more generality
     6. But to introduce some terminology, perigee is distance of closest approach
     7. apogee is furthest distance
     8. about 10% difference between the two, so angular size of the Moon changes over time
     9. **By how much does angular radius of Moon change? "Solid angle" or area on the sky?**
     10. (Though it isn’t trivial to estimate just by looking at the Moon by eye!)
     11. As we’ll discuss later, that change does affect the tides
     12. The orbit is not quite in the plane of the Ecliptic
     13. about 5 deg off (this is typical of the planets)
     14. That fact will become important when we discuss eclipses
     15. A final important point about the Moon is that it is rotating
     16. with a period equal to the siderial period
     17. for this reason, the same side always faces us
     18. again, this is a consequence of the tides: known as “tidal locking”
     19. we’ll talk more about that later too
     20. the distant side of the moon, the far side, is not always “dark” of course
     21. so don’t get confused by that
  4. APOLLO project
     1. For obvious reasons, the details of the motion of the Moon have been known for a long time
     2. The Moon has been important to human culture for so long that its patterns have been studied carefully
     3. Newton’s thinking about the orbit of the Moon led to his theory of gravity
     4. It turns out that the distance to the Moon and its orbit is now known extraordinarily well
     5. Thanks in part to the Apollo space program,
     6. These measurements are testing General Relativity (Einstein’s theory of gravity, which replaced Newton’s a century ago)
     7. These folks (and some Soviet robots) placed special reflectors on lunar surface
     8. a telescope on Earth is used to blast one 10 billionth of a second laser pulses at them
     9. some tiny number are reflected back, some tiny number of which actually hit the telescope
     10. a detector on the telescope can detect the 1-5 or so photons that make it back each time
     11. provides measurement of light travel time: distance to the moon to few inches
     12. with many pulses, can know distance to the moon to mm
     13. of course, the telescope is moving on Earth, the Moon is vibrating
     14. lots of things contributing to motion at mm precision!
     15. but ultimate goal is to understand all of those and test gravity
     16. already one of the most precise tests known
     17. From this an other information we know the Moon's orbit is receding at 3.8 cm/year
     18. This is because of the tides: again, more when we discuss tides and eclipses!
  5. Phases of the Moon
     1. What is the consequence of the orbit for the phases of the moon?
     2. Let’s just remind you of what the phases ARE
     3. new moon, crescent, 1st quarter, gibbous, full and back
     4. waxing vs waning
     5. **what causes this?** obviously, the position of the Sun with respect to the Moon
     6. New Moon is when the Sun is in the same direction as the Moon, so it is “backlit”
     7. Full Moon it is lit from behind us
     8. Quarter moons are in between
     9. **Now, if new moon is when Moon and Sun aligned, why not a solar eclipse every month?**
     10. because of the ecliptic angle of the Moon’s orbit
     11. only sometimes is it new moon AND the moon is in the ecliptic
     12. same for Full Moon --- that’s why there isn’t always a lunar eclipse
     13. More on that later!!
     14. getting back to the phases: there is clearly a relationship between the phase and time of day the moon transits
     15. A new moon transits at noon, with the sun
     16. Therefore generally waxing crescent moons are visible right after sunset
     17. waning crescent moons are visible right before sunrise
     18. similarly, at sunset a first quarter moon will be transiting
     19. at sunrise a third quarter moon will be transiting
     20. and a full moon rises as the sun sets and transits at midnight
  6. Synodic period of the Moon
     1. The sidereal period of the orbit is 27.3 days
     2. However, that is not the period of the phases
     3. **Why do sidereal and synodic periods differ?**
     4. The period of the phases is called the synodic orbit
     5. It is affected by the orbit of the Earth around the Sun
     6. after all, during a month the Earth travels 1/12 of the way around the Sun
     7. this has a substantial effect on the phases
     8. how does this happen?
     9. a sidereal period is how long it takes the moon to go around once
     10. but after those 27.3 d the Earth has moved, in the same sense
     11. so the Moon is not (in this case) Full again yet
     12. It is 2.2 d before it catches up (not surprisingly, about 1/12 of 27.3 d)
     13. thus the synodic period is about 29.5 d
     14. similar to the difference between a sidereal day and solar day on Earth
     15. note that the sign of the effect would differ if Moon orbited the OTHER way
  7. Librations
     1. Now, as I stated before, the same side of the moon is always facing us
     2. however, we can see little bits of the other side, through effects known as librations
     3. these are beloved of moon-watchers, and are instructive to understand at least a little
     4. largest libration effect is the libration in latitude
     5. the Moon rotates about an axis that is not QUITE aligned with its orbit
     6. off by about 6.5 deg
     7. so tipped toward us in during one part of its orbit, and away at other parts
     8. so we see a little bit over the poles
     9. second largest effect is the libration in longitude
     10. happens because the orbit is nonuniform but the rotation is uniform
     11. so don’t quite get the same side
     12. easier to see in exaggerated view
     13. finally, there is the diurnal libration
     14. due to change in parallax during the day
     15. a small effect
  8. Craters
     1. Let’s talk for a bit about the visible features on the moon
     2. Basically, the moon has two types of areas: bright areas and dark areas
     3. the bright areas are dominated by craters, others are not
     4. **Are the cratered areas older or younger than the other areas?**
     5. Craters are the oldest areas on the moon, they have not been perturbed since the heavy bombardment of the early solar system
     6. that is one way we know there is no plate tectonic activity on the moon
     7. there are several famous craters with distinctive rays coming of them
     8. material spewed during the event
     9. these are YOUNG craters of recent origin: previous rays have been erased by subsequent cratering
     10. e.g. Tycho is 100 Myrs old
     11. a closer look at the craters reveals interesting structure
     12. an impact crater, with a high ridge or wall on the outside
     13. the larger ones have a central peak resulting from the impact
     14. often a smooth floor (pockmarked with subsequent cratering)
  9. Maria
     1. On this side of the moon we can see, there are also the dark patches: the maria
     2. These may have been from the last few large impacts after most of the cratering had ceased; or something else
     3. so large that they released huge amounts of lava, which spread out into large flows
     4. smooth dark basaltic areas (similar to oceanic crust on the earth)
     5. these are mostly young areas, since otherwise they would have been cratered over
     6. But by young we mean ~ 3 billion years old
  10. Lunar Reconnaissance Orbiter
      1. It is worth pointing out that from LRO we have EXTREMELY good images of the Moon now.
      2. incredibly high resolution images
      3. including of the back side of the moon: note no maria (as known since 1960s)!
      4. Still functioning