**Lecture 9: the planets**

* 1. Generalities
     1. Our solar system has 8 or 9 planets depending on how you count
     2. We aren’t unique (planets have been discovered around other stars)
     3. But boy are these planets very well understood
     4. Most have had close fly-bys or been quite thoroughly studied or landed upon
     5. Really cannot do this subject justice in a lecture
     6. But first I’ll describe the observable things about the planets and their motions
     7. **What is the difference between the inner and outer planets?**
     8. Briefly, there are 4 rocky inner planets and 4 gaseous, much larger, outer planets
     9. asteroid belt in between
     10. **Which are easily seen with the naked eye?** all of these except Uranus and Neptune
     11. Pluto is the furthest thing we have called a planet; but now it is called a dwarf planet.
     12. **What is a dwarf planet?**
     13. a very important property they have is that they move with respect to the stars
     14. Planet is from the greek for wanderer
     15. so let’s discuss that first
  2. Geocentrism
     1. there a revolution in astronomy in the 1500s and 1600s
     2. was the correct explanation of the motions of the planets
     3. part of this revolution was that the Earth and planets revolved around Sun
     4. overthrough geocentrism **what is that?**
     5. astronomers in this time period had inherited a very successful model from the ancients
     6. in particular credited to Ptolemy: the geocentric model
     7. now, Ptolemy was a very smart guy: he mapped the world!
     8. used longitude and latitude
     9. so don’t get the wrong idea
     10. his model with the Earth at the center was a VERY good model
     11. it predicted lots about the motions of the planets correctly
     12. however, it was, shall we say, quite complicated
     13. there isn’t a lot to learn from the details of the models
     14. but it is clear they are going to be complex because the planets are moving around the Sun!
     15. key ingredient: epicycles (but it isn’t quite that simple ...)
  3. Heliocentrism
     1. **what does heliocentric mean?**
     2. among the first to suggest a Sun-centered, or heliocentric, model was Copernicus
     3. famous for “on the revolution of the celestials spheres”
     4. which had an explanation of the sun-centered model
     5. championed a few decades later by Galileo, in another famous book
     6. in order to account for motions of planets as was as Ptolemy, needed epicycles too
     7. planets moved in circles, but circles around those circles
     8. but more naturally accounted for the phases of Venus
     9. now, we should keep one thing straight
     10. either Earth- or Sun-centered systems can in principle do equally well, if set up correctly
     11. from the purely experimental point of view, only stellar parallax really seals the deal
     12. in fact, back in the 300s B.C. this was Aristotle’s objection to heliocentrism
     13. that stars should not be “fixed” in the sky if the Earth is moving
     14. wasn’t discovered until 1838 by Friedrich Bessel
     15. more than 2000 yrs for experimental confirmation of this prediction!!
     16. even for that observation, you could IMAGINE a geocentric model accounting for it
     17. it REALLY is the THEORETICAL picture of gravity tells us that the Sun is close to stationary
     18. so all of these clever arguments in these old books were in many ways besides the point in the end!
     19. they simply didn’t have the tools to tell geo from heliocentrism
  4. Orbits and Kepler’s laws
     1. Kepler made the greatest leap by moving from circles to ellipses
     2. **What are ellipses?**
     3. this GREATLY simplified everything in Copernicus’s model
     4. and is worth describing in detail
     5. first, planets move in ellipses: squashed circles
     6. second, they sweep out equal area in equal time
     7. **What does that mean for how fast velocity is between A&B vs C&D?**
     8. so faster near perihelion, slower near apohelion
     9. and the period grows with size of orbit
     10. so period is short for mercery: 88 days
     11. long for outer planets: Pluto discovered 80 years ago, only 1/3 of full orbit since!
     12. note eccentricities: mostly small, but large for Mercury, Pluto
     13. ecliptic angles are small: all in about same plane (except Pluto)
     14. maybe not surprisingly, speeds also are slower in outer solar system
     15. as we’ll see, the consequence of these laws are that mars, venus and mercury execute motions on the sky month to month relative to the stars
     16. but saturn and jupiter march more slowly
     17. you have lived through not even 2 orbits of jupiter
     18. and not even one orbit of saturn
  5. Opposition/Conjunction
     1. there is some simple terminology that is useful to know regarding how we view these orbits
     2. let’s look at the possible positions of the planets w.r.t. the Earth
     3. there are basically two very interesting positions
     4. conjunction and opposition
     5. conjunction is when the planet is in the same direction as the Sun
     6. opposition is when it is in the opposite direction
     7. objects interior to the Earth can only be in conjunction of course (inferior & superior)
     8. objects outside Earth’s orbit can be in opposition or conjunction
     9. **What planets can experience inferior conjunction?**
     10. **What will the phase of the planet be: at opposition? inferior conjunction? conjunction? What about to east and west?**
     11. opposition is the time that planets are easiest to observe: closest to us and brightest
     12. conjunction for Mars, Jupiter, Saturn make them impossible to see
     13. for Venus and Mercury, inferior conjunction is a VERY interesting time
     14. there is the possibility that they TRANSIT the Sun
  6. Synodic period
     1. What is time between each opposition?
     2. recall the Moon had a sidereal period, which had to do with its absolute motion
     3. and a synodic period, which had to do with its relative position w.r.t the Sun as viewed from Earth
     4. similarly, the orbital periods I showed above are the SIDEREAL periods
     5. but they also have SYNODIC periods, which are the times between conjunctions (or oppositions)
     6. e.g. start out Earth, and another outer planet at the same time in opposition
     7. one year later, we will have gotten to (3)
     8. Earth moves faster, so will catch up at (4)
     9. next opposition is a little longer than a year later
     10. the closer the planet, the smaller the difference in period
     11. so the longer it takes for earth to catch up
     12. outer planets move very little during an earth year --- synodic periods are just over a year; Mars synodic period is 2.2 years
     13. thinking is exactly the same for inner planets, but now EARTH is outer planet
     14. so Venus, which isn’t much further in, has a very long synodic period
     15. Mercury’s is only a month longer than its actual period
     16. Synodic periods are important because they tell you roughly how long it will be ...
     17. until you see the planet again
     18. Mercury recurs every 3-4 months
     19. Venus about 19-20 months
     20. Mars every 2.2 years
     21. outer planets almost the same from year to year
     22. but Jupiter slowly creeps forward (month per year)
     23. so synodic periods are useful
  7. Mars Favorable Opposition
     1. there is a particular configuration, favorable opposition, that is relevant to Mars
     2. the Mars orbit is somewhat eccentric, so how close we are in opposition depend on when it occurs
     3. it so happens that the ORBITS are closest at Aug 29 (current solar calendar)
     4. **What is interesting about that?**
     5. so when opposition happens around then, mars is much bigger than other oppositions
     6. happens every 15 years or so, but actually 2003 was closer than most
     7. next Mars opposition is this May 22. July 2018 there will be a very favorable opposition (94% of maximum size of Mars)
  8. Retrograde motion
     1. another interesting thing about Mars is the so-called “retrograde motion”
     2. happens for all outer planets but most pronounced for Mars
     3. usually outer planets go East from night to night
     4. but as opposition occurs, Earth is “catching up” to them
     5. makes them appear to move West for a while
     6. explaining this motion was a great triumph of Ptolemy’s geocentric model
     7. but it is even easier to understand in a heliocentric system
  9. Phases
     1. as they undergo these motions, the planets experience “phases”
     2. just precisely like the moon’s phases, but of course not as easily seen
     3. **What phases can you see for inner planets? Outer planets?**
     4. for inner planets, can see quarter, crescent, etc
     5. of course Venus you’ll see in crescent only during day or VERY close to sunrise/set
     6. I’ve seen this, it is quite nice
     7. harder even to see it full! and it is of course smaller
     8. phases of the outer planets are variations on gibbous of course!
     9. basically we always have the light source behind us
  10. Transits
      1. another interesting thing about the inner planets are the TRANSITS
      2. **What phase of orbit do transits happen at?**
      3. **Why don't transits happen at every inferior conjunction?**
      4. this are essentially eclipses of the Sun by venus and mercury
      5. but very very tiny eclipses
      6. must happen at very specific times during year
  11. Transit of Venus
      1. Historically, measuring the transit of Venus was a major goal of astronomers
      2. purpose was to establish the DISTANCE to the Sun
      3. the orbits of the planets was enough to deduce their relative distances
      4. but not the absolute distance
      5. it turns out that if you observe a transit at two places on earth you can do that
      6. basically, you get the side of a triangle
      7. people knew Re/Rv but not Re itself
      8. knowing the distance on the Earth would do it
      9. this is a punishing task: you have to wait 100 ish years, and hope to get everything right!
      10. Kepler predicted the 1631/1639 pair: but for 1631 his calculations were off -- oops!
      11. Luckily for the 1639 observations, a fellow in England Jeremiah Horrocks corrected Kepler’s calculations, actually saw it
      12. according to his notes he was quite lucky: cloudy until a few minutes before transit
      13. the pair in 1761 and 1769 was well-observed: established distance within about 2%
      14. There was substantial effort for astronomers to observe this from various places
      15. some were luckier than others, in terms of weather and other factors
      16. Guillaume Le Gentil (discoverer of Messier 32)
      17. traveled to India in 1760, redirected his observing site due to France and Britain being at war
      18. because of the war, he did not reach his site on time
      19. was on a boat during transit --- really terrible way to take observations
      20. he figured he would stay in India until the next of the pair, 8 years later in 1769
      21. did some geographical work, built an observatory in India
      22. waited eight years
      23. it was cloudy
      24. after getting dysentery and being otherwise delayed on trip home
      25. arrived in Paris in 1771, having been declared dead, his wife had remarried
      26. etc. this is what astronomy is like!
  12. Too much known to talk about all planets in detail!!
  13. But one more thing you should be able to answer: why is Pluto not counted as a planet anymore? Basically, because it is too much like a type of object that fills the outer solar system -- the Kuiper belt objects! Like a big version of one of those.