**Lecture 10: Moons in the Solar System**

* 1. Generalities
     1. Our Moon is not the only moon in the solar system
     2. the outer planets all have moons, some comparable in size to Earth!
     3. rarer in the smaller, inner planets, but Mars does have two small moons
     4. the Galilean moons around Jupiter were the first to be found (by Galileo)
     5. important in his adoption of heliocentrism
     6. Saturn, Uranus, Neptune all have moons too
  2. Mars moons
     1. discovered in 1877 by Asaph Hall at the USNO
     2. relatively small things: Phobos 22km, Deimos 13 km
     3. close orbits to Mars: Phobos is about 8hr, Deimos further out at 30 hr
     4. both, like our moon, are tidally locked
     5. Mars Opportunity has actually witnessed a transit of the Sun by Phobos!
     6. they look in many ways like asteroids, and it is possible they are “captured” asteroids
     7. also possible that they are products of ejecta from Mars after an impact
     8. because Mars is smaller than Earth and has little atmosphere
     9. impacts stand a chance of launching ejecta into space
     10. some stuff falls back
     11. some stuff is known to actually escape Mars (some has eventually made its way to us!)
     12. possible that Phobos and Deimos were big pieces stuck in between
  3. Galilean moons
     1. Galileo discovered the moons of Jupiter using telescopic observations
     2. Jan 1610
     3. his diagrams are readily recognizable if you have seen the moons
     4. named Io, Europa, Ganymede & Callisto
     5. Galileo himself called the Medician satellites, to get back in the favor of the Medicis
     6. Europa is the smallest, at 3100 km diameter
     7. Ganymede is the largest at 5100 km diameter
     8. **How large is the Earth? compare to Earth’s 12,000 km diameter**
     9. Io’s orbit is 1.8 days, Callisto is 17 days
     10. the largest of about 60 moons of Jupiter
     11. others are much smaller: no more were discovered until Almathea in 1892
     12. that one is 170 km in diameter
     13. they are really quite bright: would be naked eye visible in good conditions
     14. except Jupiter is so bright!
     15. again in good conditions, a decent pair of binoculars and you can see them
     16. duck soup with a moderate telescope like ours
     17. they are worth a closer look
     18. the Voyager spacecraft gave us spectacular views of these guys
     19. since then they have been the subject of the Galileo space mission
  4. Galileo mission
     1. launched in 1989, and reached Jupiter in 1996
     2. antenna malfunction: high gain antenna never deployed properly
     3. perhaps due to lubricant evaporation during delay due to the Challenger accident
     4. but low gain antenna worked
     5. made data transfer back to Earth difficult and slower than should have been
     6. nevertheless, a transformative look at Jupiter and moons
     7. at the end of its lifetime, arranged to plunge it into Jupiter in 2003
  5. Io
     1. among the things Galileo gave us was this beautiful image of Io
     2. looking very much like pizza
     3. **How old is the surface of Io?**
     4. the first thing you should conclude about Io is that its surface is YOUNG
     5. it is not heavily cratered
     6. why is that? it turns out that Io is very volcanic
     7. and why is that?
     8. **Why is it volcanic?**
     9. the Earth is volcanic because radioisotope decay is heating our interior
     10. also, we are large, so cooling is relatively slow --- Earth is still warm from early times
     11. Io is small, should have cooled by now
     12. however, TIDES are keeping it hot
     13. Io’s orbit, unlike the Moon’s, is elliptical enough that changing distance changes tides
     14. kept elliptical because of other moons: Europa & Ganymede
     15. means that it keeps getting squeezed by the tides
     16. like bending a fork over and over again: makes it warm
     17. this was in fact PREDICTED based on knowledge of the orbit
     18. published a few \*days\* before the Voyager fly by and subsequent discovery of volcanos
     19. good timing...
  6. Europa
     1. the other more interesting moon of Jupiter is Europa
     2. also remarkable for a rather “young” looking surface
     3. evident geologic activity
     4. clearest ones are the lineae (lines)
     5. these are analogous to the oceanic ridges on the Earth
     6. plates moving apart, warm material below bubbling up
     7. but in this case, all of this material is not rock and lava, but ICE
     8. Europa is dense, so must have a rocky interior
     9. **Wait, how do we know its density?**
     10. but is covered by a 100 km thick “ocean” of slush or possibly water
     11. tides are also what keeps this from freezing
     12. it has the fun aspect of being one of the few places life could be hiding in Solar system
     13. if warm enough ...
     14. in fact it was this possibility that led to Galileo being crashed into Jupiter
     15. wanted no chance of contaminating Europa’s surface with Earth-life
     16. which might confuse future explorers
  7. Ganymede & Callisto
     1. for another day
     2. **But briefly: how old are their surfaces?**
     3. but note that they have OLDER surfaces, more heavily cratered
     4. though Ganymede has some geologic activity
  8. Saturn’s rings and moons
     1. Moving on to Saturn
     2. the most obvious feature Saturn has are its rings
     3. also has about 60 moons known as well
     4. again, Galileo was the first to note them
     5. but he didn’t understand what they were
     6. at first he thought they were two moons
     7. then they disappeared (edge-on, hard to see)
     8. then he saw them as two half-circles
     9. hard to see how he didn’t connect the dots to make them a ring, but he didn’t
     10. it wasn’t until 45 years later that Huygens did that
     11. and concluded that they were a ring
     12. now, clearly Voyager got much better views
     13. here you see the many divisions between individual rings
     14. most prominently the Cassini gap between the A (outer) and B (inner) rings
     15. discovered by Cassini in 1676
     16. and there is currently a space craft orbiting Saturn studying it called Cassini
  9. Rings
     1. what are the rings made of?
     2. mostly small bits of ice: cm to meters across
     3. **How do we know that?**
     4. if all the ice were gathered together into one body, would be a few 100 m across
     5. unclear how they formed: story has changed over the years
     6. makes sense that in fact they were once part of a moon, that collided with something
     7. and shattered
     8. question is: how long could they last?
     9. their gravitational dynamics naturally drives the rings outwards on 100 Myr timescale
     10. but it turns out that the presence of moons of Saturn can slow this down considerable
     11. maybe could last billions of years
     12. note creationists have locked onto this topic ...
     13. tons of structure in the rings
     14. mostly created by interactions with planets many moons
     15. e.g. F-ring on outside kept in place by Prometheus (inside) and Pandora (outside)
  10. Moons
      1. Saturn, like Jupiter, has about 60 moons
      2. largest one is (appropriately) called Titan
      3. discovered by Huygens same year as rings, 1655
      4. 5000 km diameter, bigger than our Moon or mercury
      5. next biggest is Rhea, which is about 1500 km
      6. about six easily visible in telescopes, discovered by Cassini (1670s, 80s) and Herschel (1780s)
      7. note Enceledus
      8. looks a bit like Europa?
      9. also covered in water ice
      10. tidally heated, like Io
      11. **What do you think this makes it do?**
      12. actually has Geysers!
      13. even more interesting is Titan
      14. Titan has been explored by a lander (Huygens) that Cassini dropped
      15. Very organic-molecule filled atmosphere
      16. Lakes of pure methane
      17. Perhaps water/ammonia molecules
  11. Really only scratched the surface!
      1. Uranus has rings
      2. Neptune has 14 known moons (like Triton)
      3. Pluto has a big moon, Charon
      4. Too much for one course!!