Chapter 04: The Solar System

Notes and Sketches

4.1: An Inventory of the Solar System

Planetary Properties

- The solar system is big: Earth is 1AU from sun, comets as far as 180AU from sun
- The solar system is flat: Planets orbit in the plane of the ecliptic with small deviations
- The solar system is spinning: Planets orbit CCW around sun, spin on their axes CCW (few notable exceptions), same direction as the sun spins
- The solar system is differentiated: Planet densities are not the same, and follow a pattern of decreasing density with increasing distance from sun

Terrestrial and Jovian Planets

- Terrestrial = rocky: Mercury, Venus, Earth, Mars are dense rockballs
- Jovian = gaseous: Jupiter, Saturn, Uranus, Neptune are giant gasballs

Solar System Debris

- There's a surprising amount of junk out there in empty space
- By "junk" we mean the leftover tidbits that date back to the formation of the solar system
- Studying the junk is useful, because it's really, really old junk that has not changed in literally billions of years

4.2 Interplanetary Matter

Not So Empty

- The empty space between the planets is not completely empty
- Rocky bits and icy chunks, ranging in size from tiny to tons
- Total mass is tiny compared to the sun, but certainly more than you could eat at one meal
- What you call them depends on their composition and where you find them

Asteroids, Meteoroid, and Dwarfs

- Asteroids have rocky composition (they are dense) and large size (diameter > 100 meters, mass > 10,000 tons)
- Meteoroids = asteroids < 100m diameter
- Dwarf planet: Massive enough to be spherical, but not massive enough to clear its orbit

Asteroid Orbits

- Look for them between Mars and Jupiter: typically low e
- Trojan Asteroids: Gravitationally locked in Jupiter's La-Grange points
- Earth-crossing: Orbits can be disturbed if an asteroid gets too close to Mars of Jupiter (gravity)

Asteroid Properties

- The more massive, the more spherically shaped (gravity...again)
- Smaller ones are just giant Space Potatoes (not literally edible...you knew that)
- Composition can be inferred spectrographically and by examining reflectivity (albedo)
- From what we have seen, most look like they have spent 4.5 billion years bumping into each other (wait...they have)

What Killed the Dinosaurs?

- Probably more than one answer to this question, but an asteroid strike certainly didn't help matters
- Asteroid impact about 65 million years ago
- Impact crater located off the Yucatan in the Gulf of Mexico
- Iridium layer is evidence of impact

Why Would A Space Rock Landing in the Ocean Kill the Dinosaurs?

- It's all about the energy: Estimated release equivalent to 50 million megatons of TNT
- Global tsunami, rain of fire, earth-blanketing ash
- Kind of amazing that anything came out the other side alive

Comets

- Imagine an Oreo Blizzard: Mostly cold, creamy vanilla, but gritty with those tiny bits of delicious cookie
- Obviously there are no Dairy Queens in space, so comets are not literally soft serve and sandwich cookies
- Mostly water ice with rocky bits
- Nucleus: The dirty snowball itself
- Coma: Surrounds nucleus as ice evaporates and dust gets loosened
- Dust Tail: Curves backwards along orbit
- Ion Tail: Ionized gas blown away from the sun by the solar wind

Comet Orbits

- Extremely eccentric: Perihelion inside Mercury's orbit, aphelion out past Pluto (sometimes WAY past Pluto)
- Can be at any angle to the ecliptic: Imagine a sphere
- Can be prograde (around sun in the same direction as planets) or retrograde (opposite direction)
- Kuiper Belt: Comet neighborhood located between about 30 and 100 AU
- Oort Cloud: More distant neighborhood as far as 50,000 AU

How Does An Oreo Blizzard 50,000 AU From Earth Become a Comet?

- Gravity: You will notice that it's the explanation for almost everything
- A larger body disturbs the orbit, sends the comet speeding towards the sun
- Neptune can mess with Kuiper Belt objects
- Other stars can disturb Oort Cloud objects

Meteoroids

- Meteoroid: A chunk of rocky space debris
- Meteor: A chunk that enters the atmosphere
- Meteorite: A chunk that manages not to get completely burned up in the atmosphere and lands on the ground

Meteor Showers

- Every time a comet orbits, more ice gets evaporated, leaving more bits of rocky debris behind along its orbit
- Occasionally (but predictably) the Earth's orbit crosses the orbit of a comet
- When that happens, the debris enters the atmosphere and burns up (friction)
- We see "shooting stars"

When Earth + Debris = Disaster!

- If the Earth and large debris happen to intersect at the same place and time, the Earth will win
- Tunguska: Siberia, 1908
- Huge impact, but no circular crater: debris completely vaporized
- A lot of damage because of the enormous amount of energy released by vaporizing

Notes and Sketches

4.3 The Formation of the Solar System

Notes and Sketches

Model Requirements

- You have to be able to explain all of the following:
- Each planet has its own orbit (you don't see three planets sharing the same orbit)
- Orbits have low eccentricity
- Plane of orbits is nearly flat
- Planets orbit sun in same direction sun spins
- Planets spin on axis same direction sun spins (noted exceptions)
- Moons orbit planets same direction as spin (noted exceptions) Density depends on distance: Differentiation between terrestrial and gas giant planets
- Asteroids
- Kuiper belt
- Oort Cloud

The Concept of Angular Momentum

- You need this to explain observations related to spin
- angular momentum = tendency of an object to keep spinning
- Depends on mass of object: More mass, more angular momentum
- Depends on speed of object: Faster rotation, more angular momentum
- Depends on size of object: Larger object, more angular momentum
- Depends on location of object: Farther from axis, more angular momentum

Keplers #2 and 3 Are All About Angular Momentum

- Kepler #2: Perihelion = closer = planet moves faster, aphelion = farther = planet slows down
- Kepler #3: Planets nearer sun (smaller r) move faster around the sun (bigger speed)
- Conservation of angular momentum

Nebular Contraction

- Cloud of interstellar gas and dust, just minding its own business
- Something causes a disturbance: Passing object, collision with another object
- Contraction, rotation: More contraction, more rotation
- More rotation means equatorial bulge, ultimately sphere becomes disk in equatorial plane

Gravity vs Pressure: Who Will Win?

- Cloud wants to collapse because of gravity
- Cloud wants to expand because of thermal pressure (hot gas will expand)
- Dust grains: Tiny, icy bits help cool the cloud so that it can contract

Planet Formation

- Dust grains become accretion nuclei: bits start to stick together
- The more bits that stick in a clump, the bigger the clump, the easier it is to attract more bits...and so on
- Pretty soon (well, millions of years) you have a disk of rocks instead of a disk of dust
- The rocks start sticking together: bigger rocks, until you have chunks the size of mountains
- The bigger the chunk, the more gravity: it pulls in other pieces
- Big enough chunks, collisions can cause them to break apart instead of stick together
- The solar system was a very violent place in its infancy and youth

Making the Jovian Planets

- We do not know for sure exactly how large gas giants form
- Accretion: Same gradual method as described above, followed by a rapid accretion of gas
- Contraction: Gas giants formed rapidly from localized collapse of nebula
- We can figure this out better by looking for developing solar systems (extrasolar planets)

Differentiation of the Solar System

- First the obvious: Sun at the center means it's hottest at the center of the disk
- Too hot to allow lighter elements to condense
- Closer to sun: Denser (terrestrial) planets
- As you get farther from sun, lighter elements and compounds can condense
- Notice also that it's cooler farther out, so you can accrete (or condense) more material sooner...gives the gas giants a head start accumulating mass

Asteroids and Comets

- Once the planets get to forming, they act like gravitational vacuum sweepers, hoovering up debris
- The space between the planets is relatively clean
- Most of the rocky pieces have been accreted, most icy pieces have been flung
- Asteroid belt: Rocky pieces too small to pull themselves together into a planet (sun to the left, Jupiter to the right: no place to go)
- Comets: Icy pieces get tossed, but Jupiter & sun's gravity keep them from escaping entirely

Solar System Regularities and Irregularities

- Violence inherent in the system results in what looks like random deviations
- Why is the Earth's moon so big?
- Why does Venus have retrograde rotation?
- Explain that rotational axis of Uranus!

4.4 Planets Beyond the Solar System

Detecting Extra-Solar Planets

- Direct detection is difficult: Really tiny, really dim object really, really far away
- Every method will always find the closest, biggest planets before the smaller and/or farther planets
- Indirect detection using gravity: Examine star for wobble (planet pulling on it)
- Indirect detection using luminosity: Examine brightness (if a planet transits a star, it gets briefly dimmer)

Exoplanet Properties

- Over 1500 confirmed planets, 5600 candidates
- More than 450 multiple planet systems
- None are like Earth, most are like Jupiter

Exoplanet Composition

- We are reaching the point where we can spectroscopically determine the composition of an exoplanet atmosphere
- Exciting fact: stars with composition similar to the sun are statistically more likely to have planetary systems

Is Our Solar System Unusual?

- We don't know enough to know yet; 450 planetary systems sounds like a lot, but it represents a tiny fraction of stars
- Small planets are (by definition) hard to find
- None of the systems we have seen contradict the current condensation mechanism for system formation
- My personal speculation: We will find an earth-like system within the next 3-5 years
- That's just my *guess*; we could find one tomorrow

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