Astr 1050 Fri., Feb. 24, 2017

Chapter 7 & 8: Overview & Formation of the Solar System

Reading: Chapters 7 on Solar System

Chapter 8: Earth & Terrestrial Planets

Reminders: New homework on MA up this afternoon, due by midnight on Fri., Mar. 3

Chapter 16: Formation of the Solar System

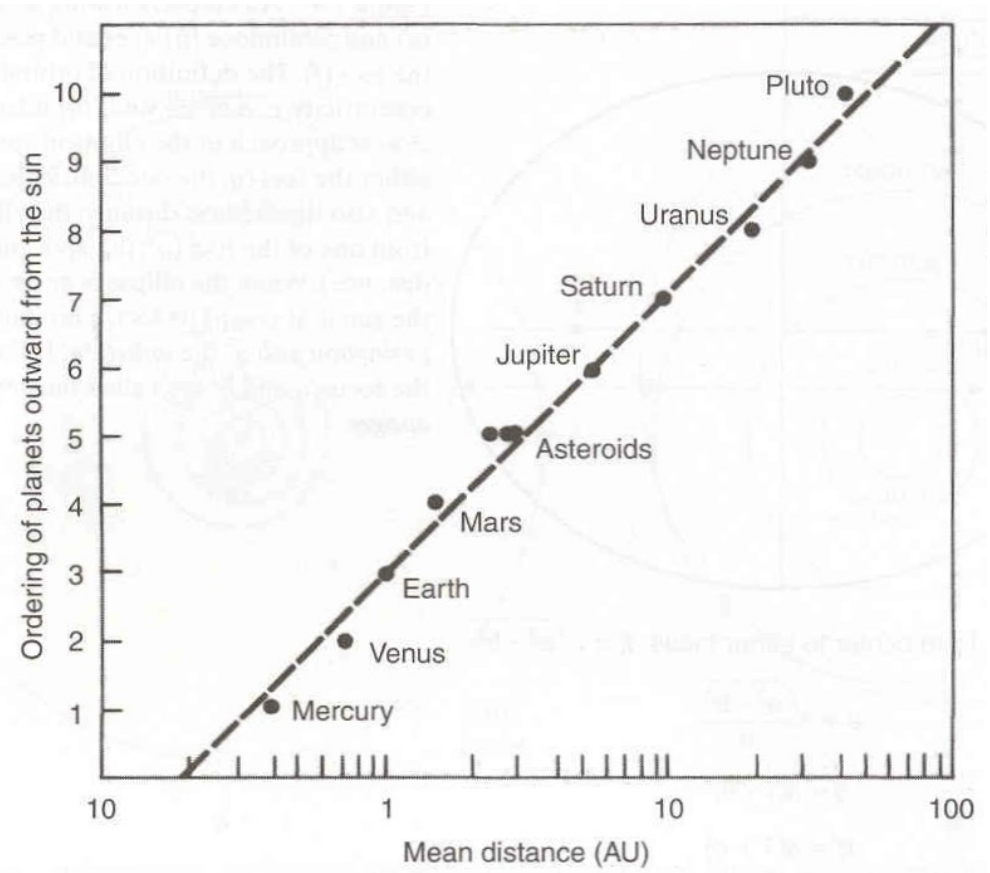
- **Solar Nebula Hypothesis**
  - **Context for Understanding Solar System**
- **Extrasolar Planets**
  - **Dust Disks, Doppler Shifts, Transits and Eclipses**
- **Survey of the Solar System**
  - **Terrestrial Planets**
  - **Jovian Planets**
  - **Other "Stuff" including apparent patterns with application to the nebular hypothesis**

Patterns in Motion

- **All planets orbit in almost the same plane (ecliptic, AKA Zodiac)**
- **Almost all motion is counterclockwise as seen from the north:**
  - **All planets orbit in this direction**
  - ***Almost* all planets spin in same direction**
    - **with axes more-or-less perpendicular to ecliptic**
  - **Regular moons (like Galilean satellites and our own moon) orbit in this direction too**
- **Planets are regularly spaced**
  - **steps increasing as we go outward**

Spacing of Planets

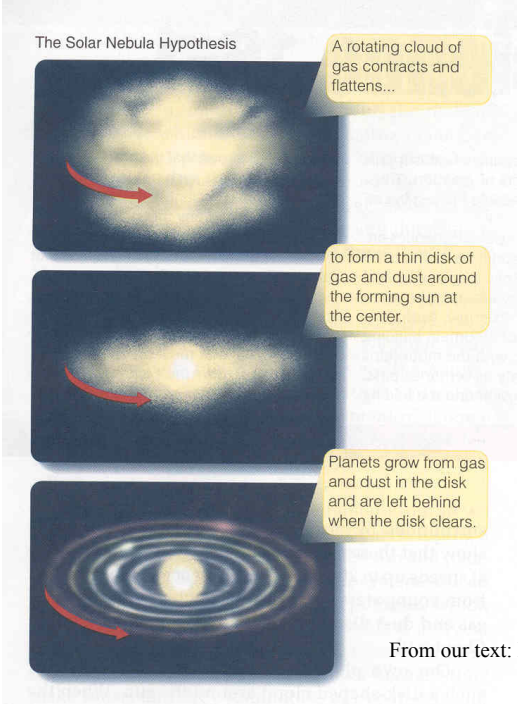
- **Regular spacing of planets on a logarithmic scale**
- **Each orbit is ~75% larger than the previous one**
- **Need to include the asteroids as a "planet"**



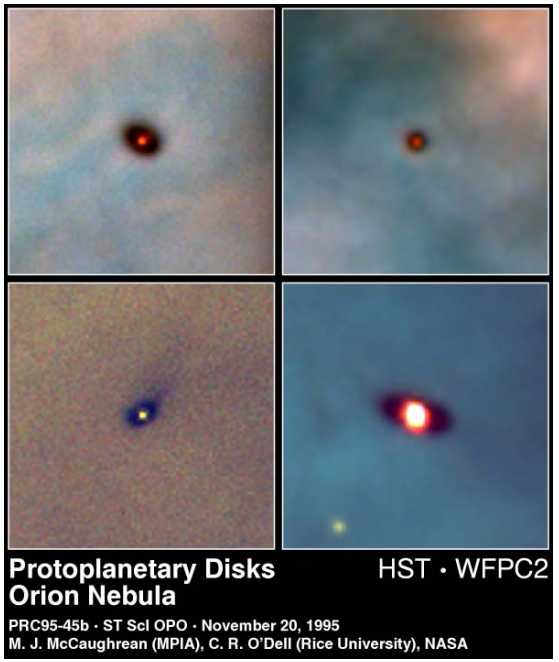
From "The Solar System" by John A. Wood

Solar Nebula Model

- **Planets form from disk of gas surrounding the young sun**
  - **Disk formation expected given angular momentum in collapsing cloud**
  - **Naturally explains the regular (counterclockwise) motion**
- **Makes additional explicit predictions**
  - **Should expect planets as a regular part of the star formation process**
  - **Should see trends in composition with distance from sun**
  - **Should see "fossil" evidence of early steps of planet formation**

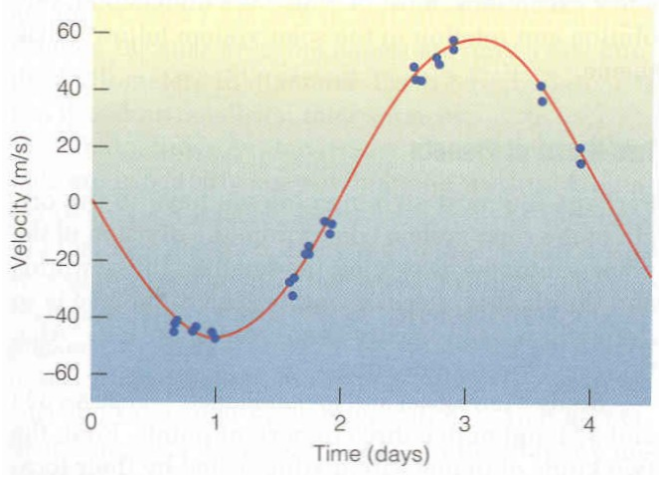


From our text: Horizons, by Seeds



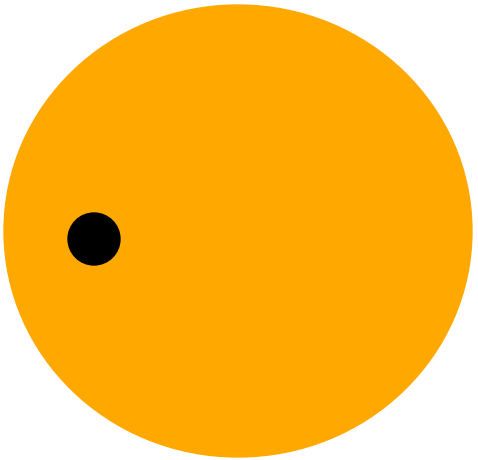
Extra-Solar Planets

- **Hard to see faint planet right next to very bright star**
- **Two indirect techniques available**
  (Like a binary star system but where 2nd "star" has extremely low mass)
  - **Watch for Doppler "wobble" in position/spectrum of star**
  - **Watch for "transit" of planet which slightly dims light from star**



From our text: Horizons, by Seeds

51 Peg – the first extra-solar planet discovered

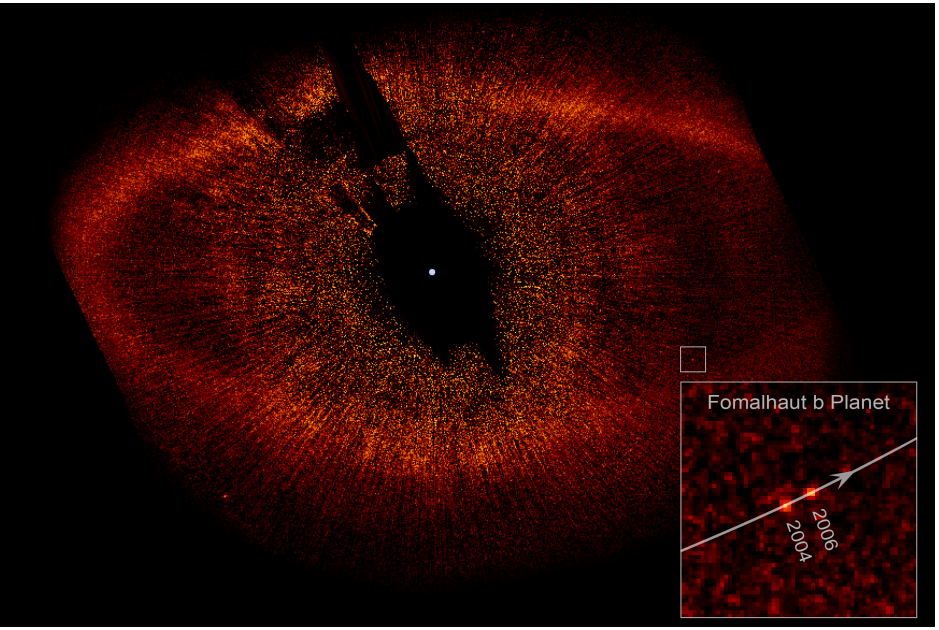


HD 209458 – Transit of planet across star

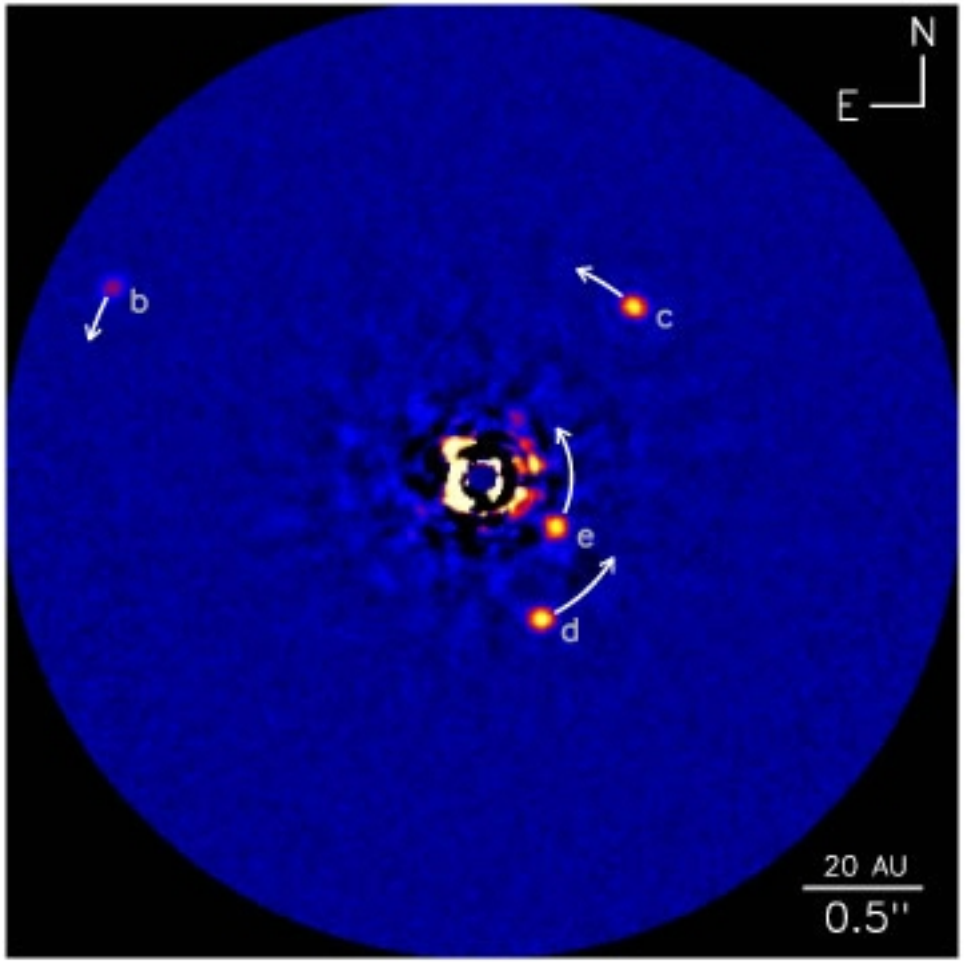
- **About 100 planets discovered since 1996 See http://exoplanets.org/**
- **Tend to be big (≥Jupiter) and very close to star (easier to see)**

Extra-Solar Planets-II

- **Hard to see faint planet right next to very bright star**
- **Some suppression of bight star is possible and reveals planets**



Formalhaut



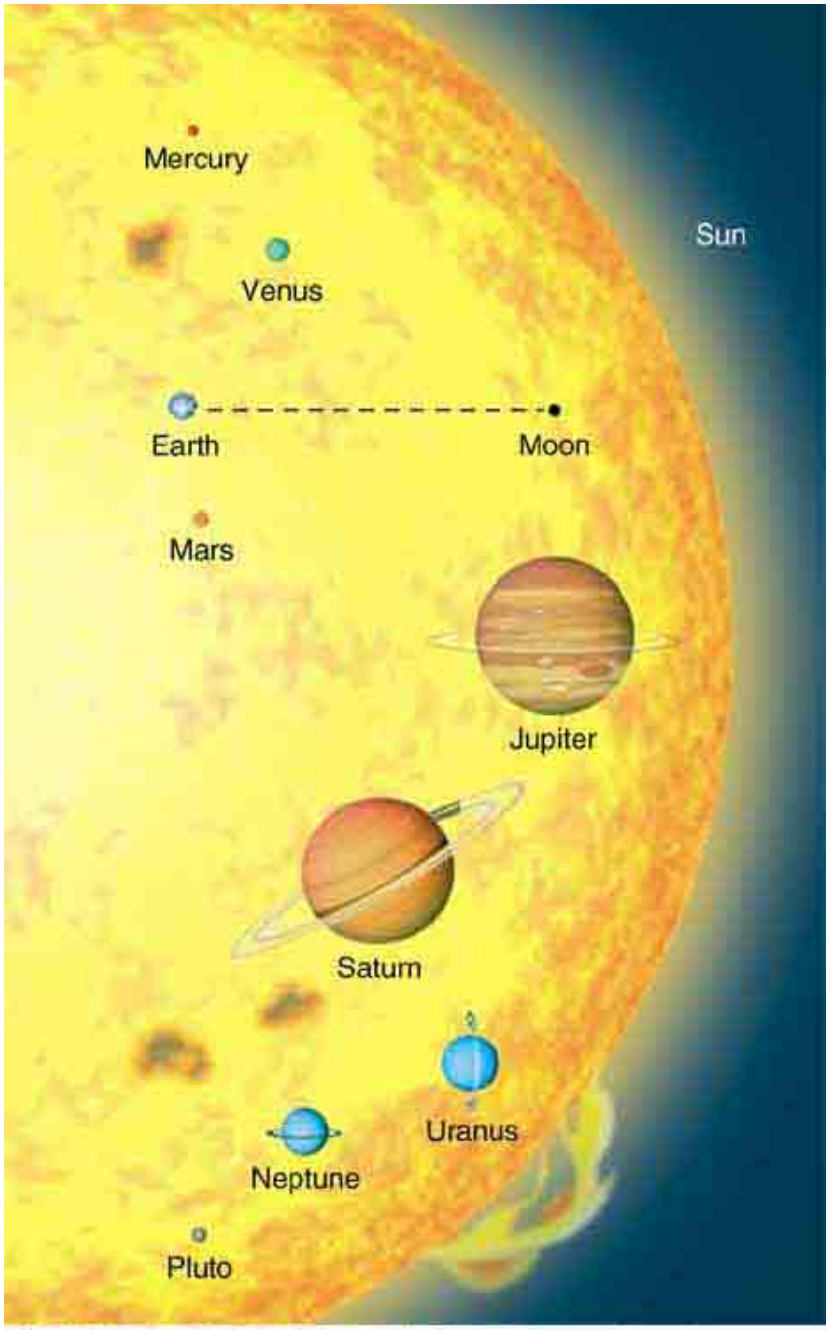
HR 8799

Next Generation Surveys (Kepler & TESS) will Reveal Thousands of Planetary Systems

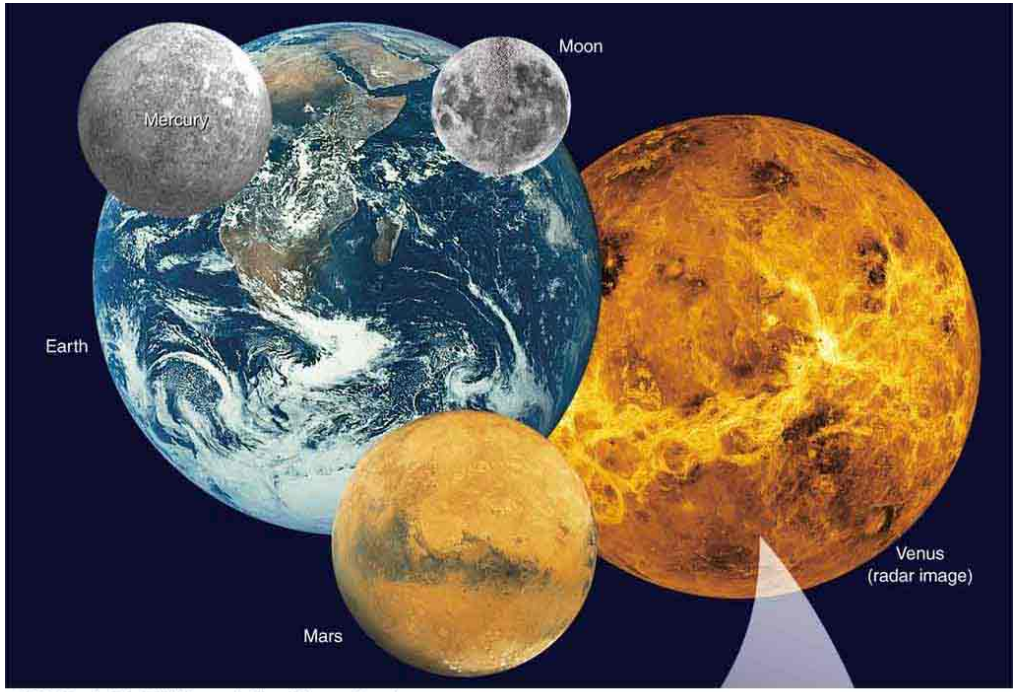
Characteristics of "Planets"

- **Two types of planets**
  - **Terrestrial Planets: small, rocky material: inner solar system**
  - **Jovian Planets: large, H, He gas outer solar system**

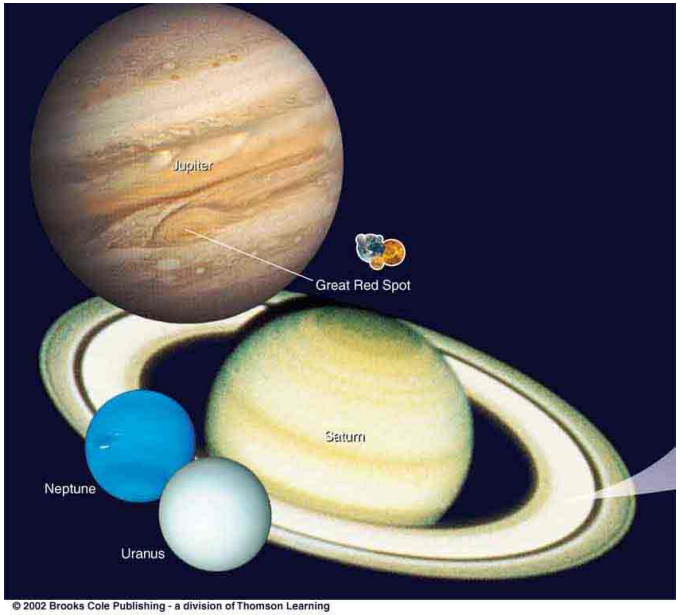
- **Small left-over material provides "fossil" record of early conditions**
  - **Asteroids – mostly between orbits of Mars and Jupiter**
  - **Comets – mostly in outermost part of solar system**
  - **Meteorites – material which falls to earth**



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Patterns in Composition

- **Terrestrial Planets**
  - **Relatively small**
  - **Made primarily of rocky material:**
    - **Si, O, Fe, Mg perhaps with Fe cores**
      (Note – for earth H_2O is only a very small fraction of the total)

- **Jovian Planets**
  - **Relatively large**
  - **Atmospheres made of H_2, He, with traces of CH_4, NH_3, H_2O, ...**
  - **Surrounded by satellites covered with frozen H_2O**

- **Within terrestrial planets inner ones tend to have higher densities (when corrected for compression due to gravity)**

Planet	Density (gm/cm^3)	Uncompressed Density (gm/cm^3)
Mercury	5.44	5.30
Venus	5.24	3.96
Earth	5.50	4.07
Mars	3.94	3.73
(Moon)	3.36	3.40

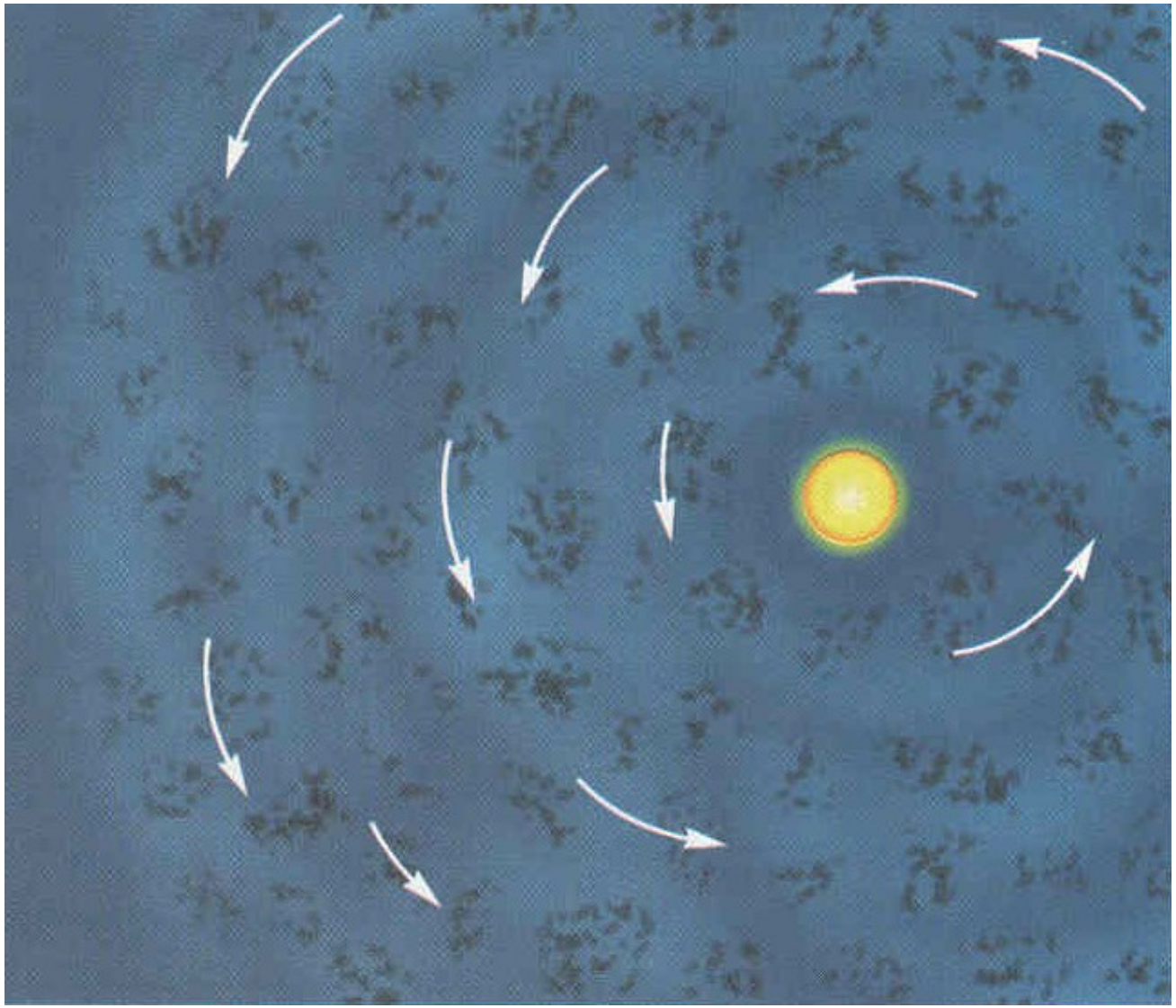
Equilibrium Condensation Model

- **Start with material of solar composition material**
  - **(H, He, C, N, O, Ne, Mg, Si, S, Fe ...)**
- **Material starts out hot enough that everything is a gas**
  - **May not be exactly true but is simplest starting point**

- **As gas cools, different chemicals condense**
  - **First high temperature chemicals, then intermediate ones, then ices**
- **Solids begin to stick together or accrete**
  - **snowflakes ⇒ snowballs ("Velcro Effect")**
- **Once large enough gravity pulls solids together into planetesimals**
  - **planetesimals grow with size**

- **At some point wind from sun expels all the gas from the system**
  - **Only the solid planetesimals remain to build planets**
  - **Composition depends on temperature at that point (in time and space)**
  - **Gas can only remain if trapped in the gravity of a large enough planet**

Growth of the Planetisimals



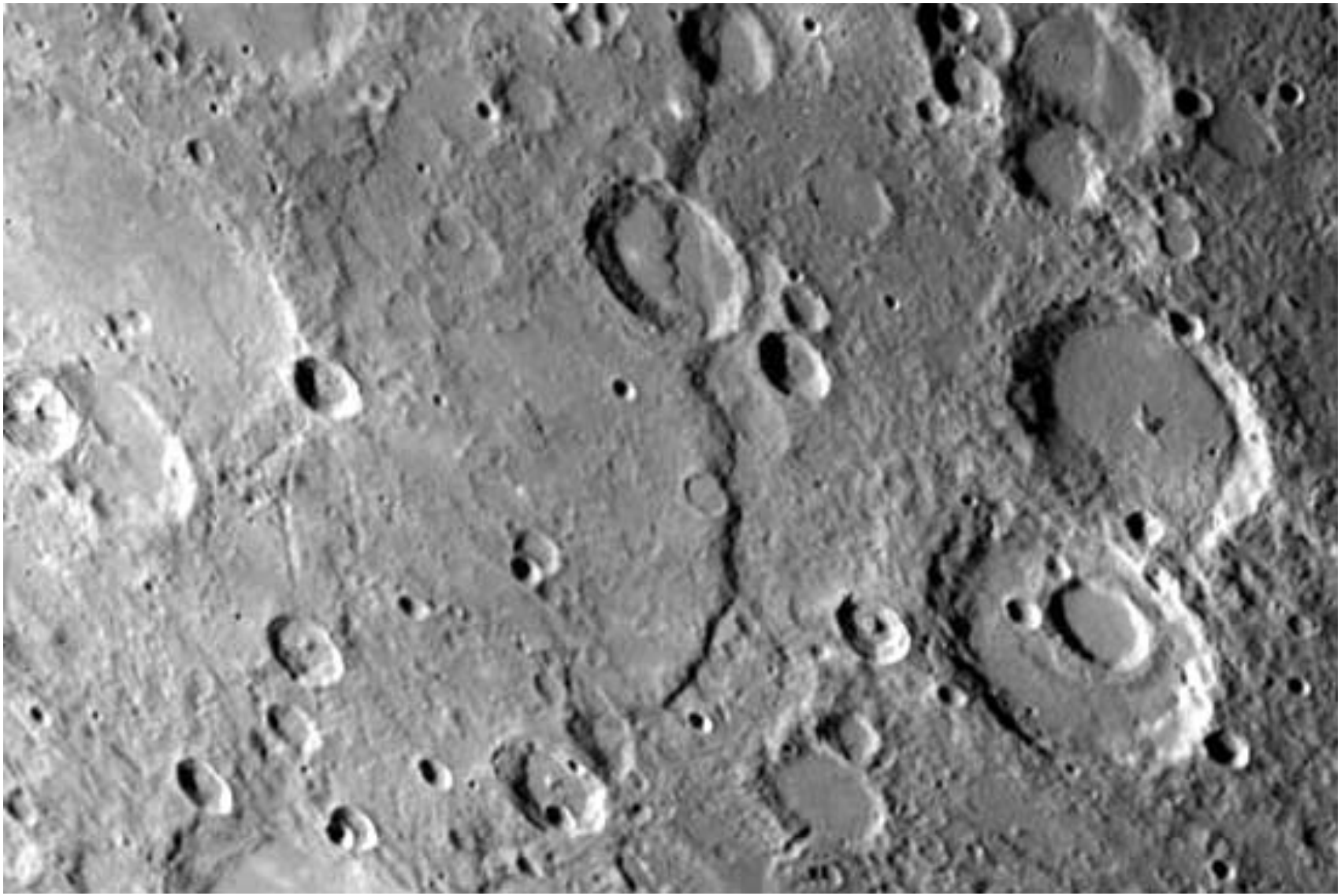
- **Once a planetisimal reaches critical size gravity takes over**

From our text: Horizons by Seeds

Evidence of Assembly Process? Craters



Craters evident on almost all small “planets”



Mercury

Clearing of the Nebula

- **Radiation pressure (pressure of light)**
  - **Will see present day effects in comets**
- **Solar Wind**
  - **Strong solar winds from young T Tauri stars**
  - **Will see present day effects in comets**
- **Sweeping up of debris into planets**
  - **Late Heavy Bombardment**
- **Ejection of material by near misses with planets**
  - **Like "gravity assist maneuvers" with spacecraft**
  - **Origin of the comets**

Patterns and Predictions

- **Why do different planets have different levels of geologic activity?**
- **Why do different planets have different atmospheres?**
- **What are ages of old "unaltered" planetary surfaces?**
  - **Should be similar, and agree roughly with age of Sun**
- **Does composition of asteroids match predictions?**
  - **Lower temperature than Mars region: Hydrated silicates, etc.**
- **What types of minerals do we see in meteorites?**
- **What types of ices and minerals do we see in comets?**

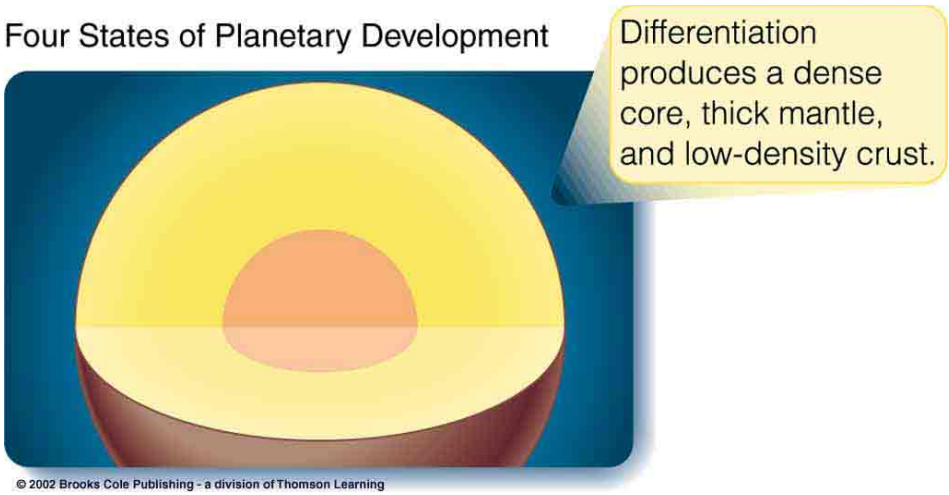
Chapter 9: Planetary Geology of Earth & the Terrestrial Planets

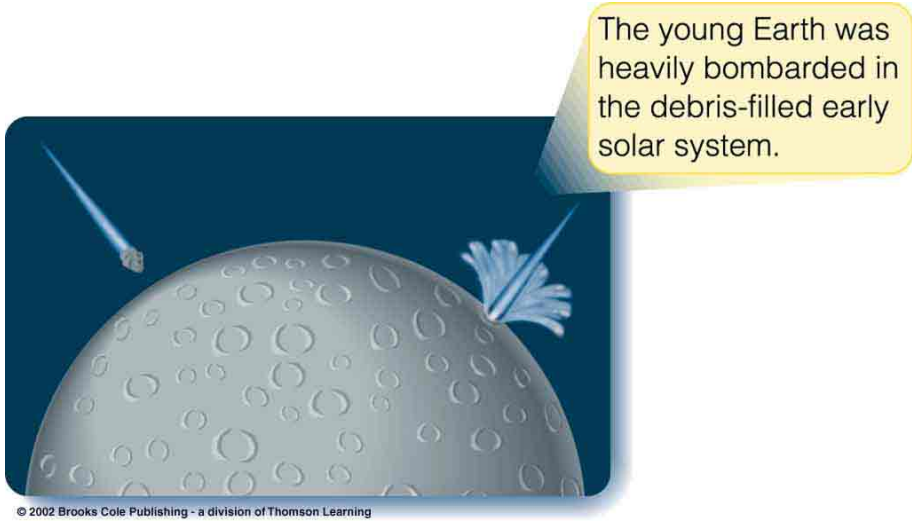
- **Earth**
  - **History, Interior, Crust, Atmosphere**
- **The Moon**
  - **In particular origin**
- **Mercury**
- **Venus**
- **Mars**
  - **Including water (and life ?)**

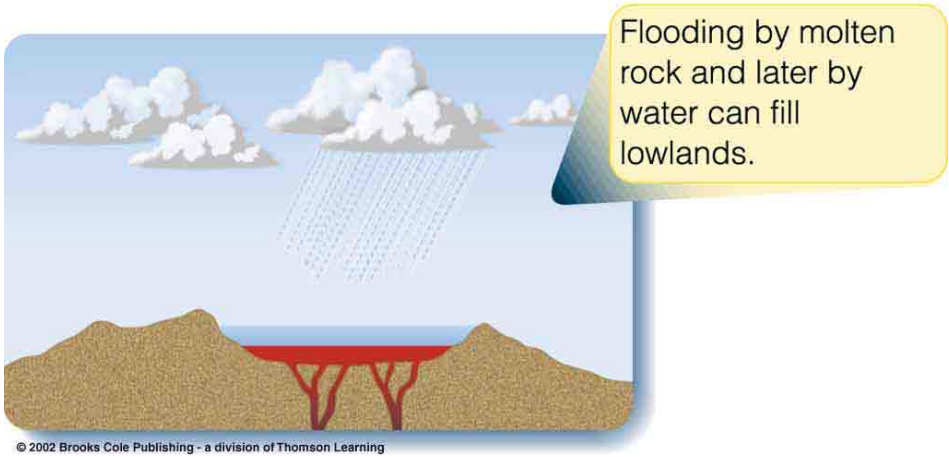
"Comparative Planetology"

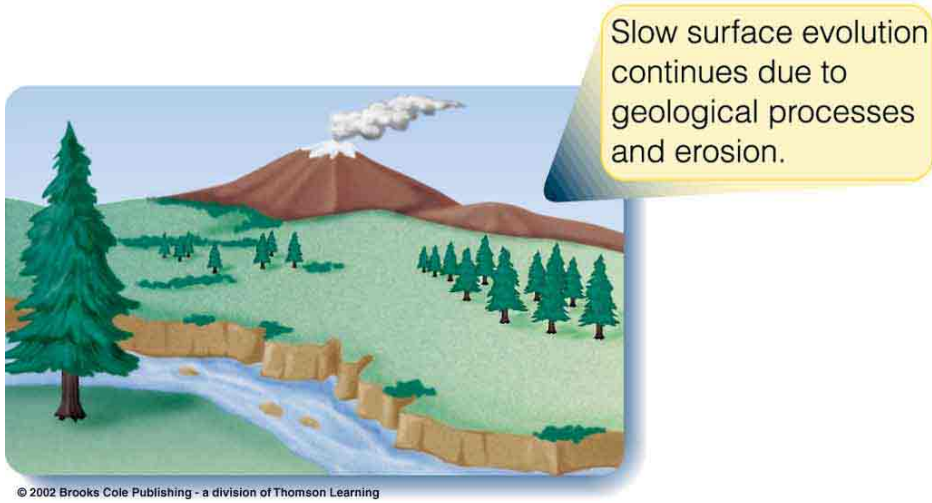
- **Basis for comparisons is Earth**
- **Properties of Earth**
- **Similarities and differences with Mars and Venus help us understand Earth better (e.g., life, greenhouse effect, etc.)**
- **Won't spend much class time on basic properties (size, gravity, orbital period, length of day, etc.) but you should have some relative ideas about these (see "Data Files" in text). There will be a few exam questions!!!**

Four Stages of Planetary Development

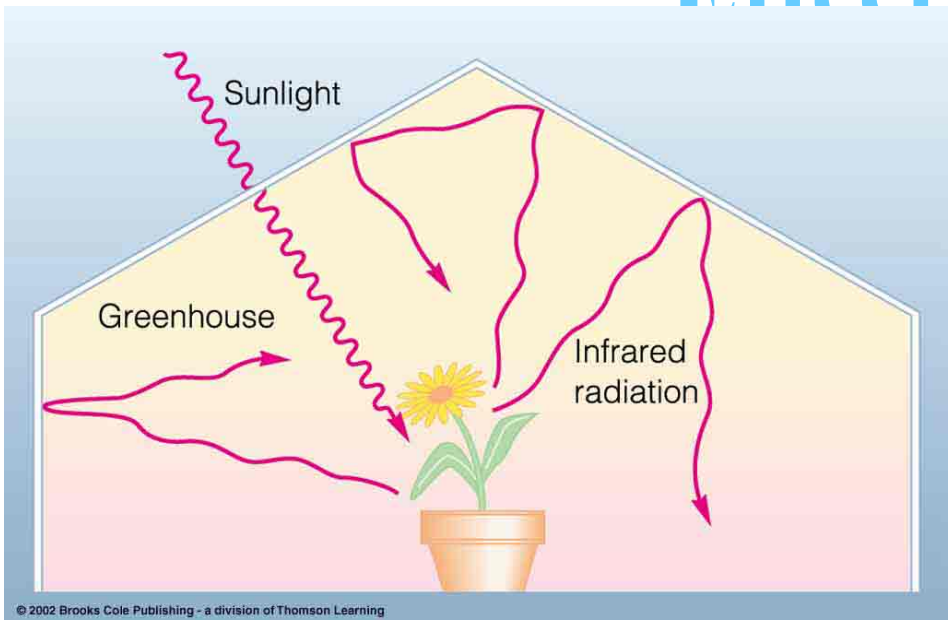


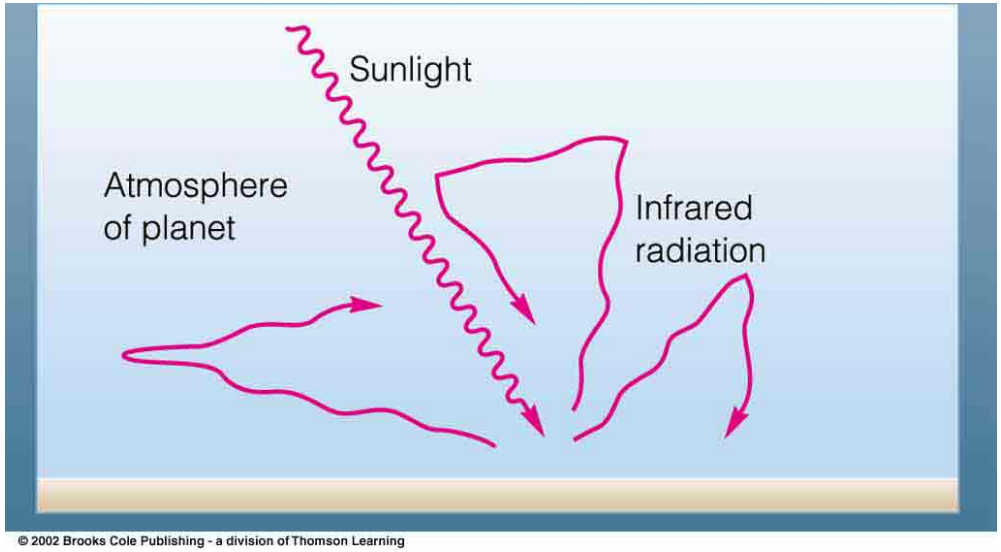






Earth's Atmosphere: Greenhouse Effect





Earth's atmosphere was originally devoid of oxygen, but life changed that. Current make-up is mostly nitrogen, then oxygen, and trace gases like carbon dioxide, methane, etc., which are GREENHOUSE gasses. Earth is already warmed by this effect.

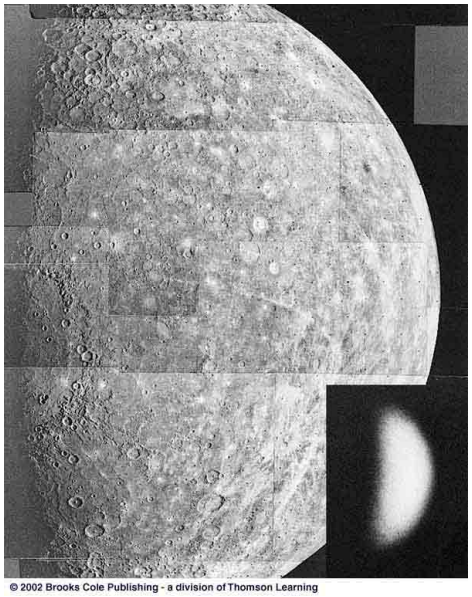
More about this when we discuss Mars and Venus.

The Moon and Mercury

- **No atmosphere**

- **Cratering is evidence of final planet assembly – lots to be learned from craters**





Patterns in Geologic Activity

- **Judge age of surface by amount of craters:**
  more craters ⇒ more ancient surface
  (for some objects, have radioactive age dates)
  - **Moon "dead" after about 1 billion years**
  - **Mercury "dead" early in its lifetime**
  - **Mars active through ~1/2 of its lifetime**
  - **Venus active till "recent" times**
  - **Earth still active**

- **Big objects cool off slower**
  - **Amount of heat (stored or generated) proportional to Volume (so R^3)**
  - **Rate of heat loss proportional (roughly) to Surface Area (so R^2)**
  - **Heat/(Unit Area) ∝ $R^3/R^2 = R$ so activity roughly proportional to R**

- **Same reason that big things taken out of oven cool slower than small things (cake cools slower than cookies)**

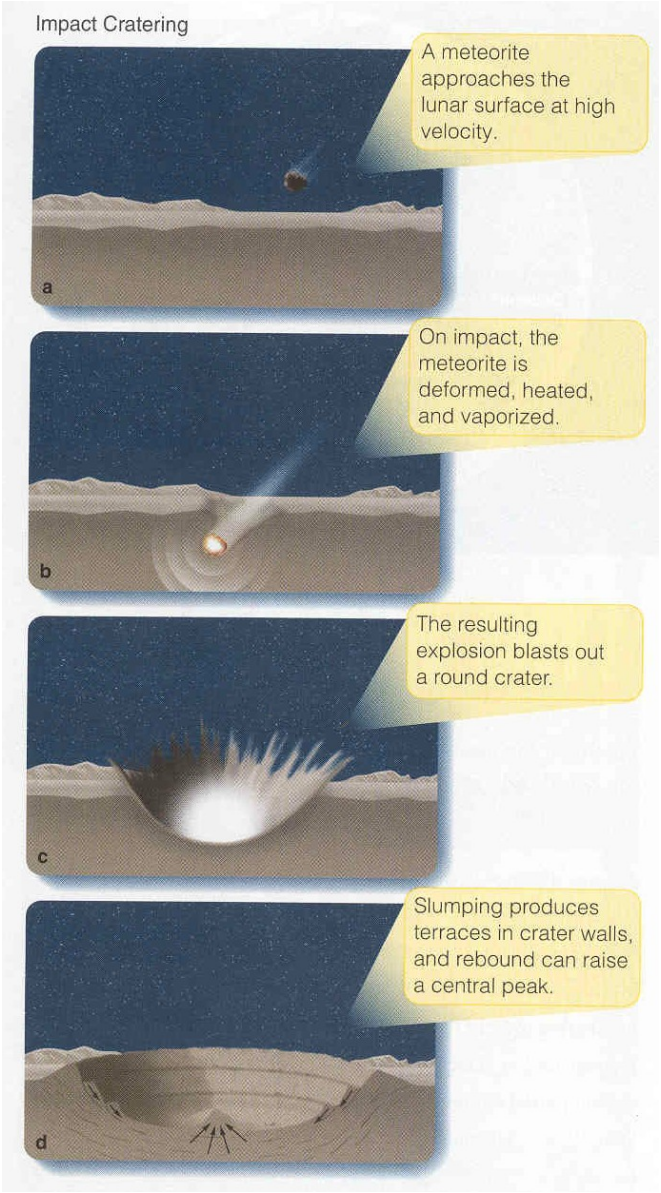
What is a crater?

- **Must think of them as caused by very large explosions from release of kinetic energy of impactor**
  - **Like a mortar shell – it isn't the size of the shell which matters, its how much energy you get out of the explosion**
  - **DO NOT think of them as just holes drilled into surface – think <u>EXPLOSION</u>**
  - **Kinetic Energy $E = \frac{1}{2}\, m\, v^2$**
  - ***v* is roughly escape speed of earth** $v_{\text{Escape}} = \sqrt{\frac{2GM}{R}} = 11\ \text{km/s}\ (= 25{,}000\ \text{MPH})$
  - ***m* = mass = volume * density (Consider a 1 km asteroid)**

$$= \tfrac{4}{3}\pi\, R^3 \rho = \tfrac{4}{3}\pi\, (1000\ \text{m})^3\ 3500\ \text{kg/m}^3 = 1.5 \times 10^{13}\ \text{kg}$$

  - $E = \frac{1}{2}\, m\, v^2 = 9 \times 10^{20}\ \text{kg m}^2/\text{s}^2 = 9 \times 10^{20}\ \text{joules}$
    $= 9 \times 10^{20}\ \text{joules} \ /\ (4 \times 10^{15}\ \text{joules/Megaton})$
    $= 230{,}000\ \text{Megatons}$
  - **This is ~4500 × the size of the largest (~50 Mt) hydrogen bombs ever built and this is for a relatively small size asteroid**

Formation of an impact crater



From our text: Horizons by Seeds

- **Crater caused by the explosion**
  - **Impactor is melted, perhaps vaporized by the kinetic energy released**
- **Temporary "transient" crater is round**
- **Gravity causes walls to slump inward forming "terraces"**
- **Movement of material inward from all sides (trying to fill in the hole) may push up central peak in the middle.**
- **Final crater is typically ~10 times the size of the impactor**

Examples of craters on the moon



- Images on line at
  The Lunar and Planetary Institute:
  http://www.lpi.usra.edu/expmoon/lunar_missions.html

- Detailed record of Apollo work at:
  http://www.hq.nasa.gov/office/pao/History/alsj/frame.html

Effects of late impacts

- H_2O from comets and "wet" asteroids mixed later?

- Lunar origin
  - Bulk composition of moon like earth's mantle
  - Isotopic composition also very similar
  - But is missing all the volatile elements (H in H_2O, etc.)
  - Dynamics of orbit also unusual compared to other moons
  - Giant Impact Origin Theory

- Higher Mercury density also due to giant impact?

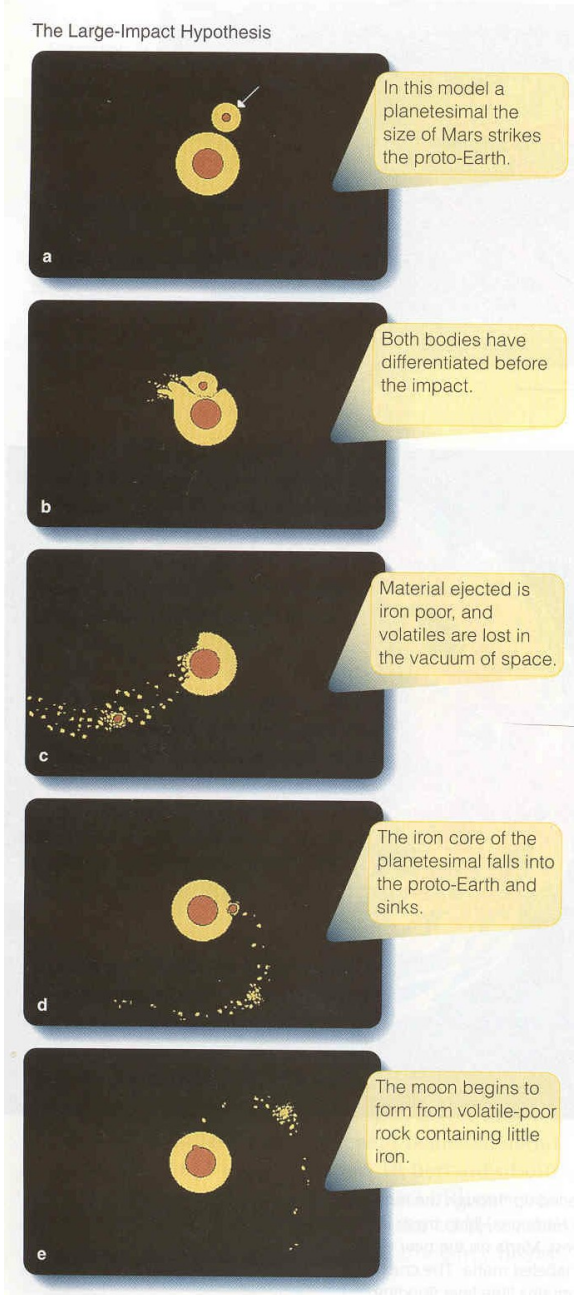


Figure 17-8
Computer simulations of impacts between differentiated bodies suggest Earth's low-density, iron-poor moon might have formed from such an event.

Moon: Giant Impact Hypothesis

- **Explains lack of large iron core**
- **Explains lack of "volatile" elements**

- **Explains why moon looks a lot like earth's mantle, minus the volatiles**

- **Explains large angular momentum in the earth-moon system**

From our text: Horizons by Seeds

Venus



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