Reprise - Comet Origin

• Some comets are "new comets": entering solar system on near-parabolic orbits from all directions.
  – Postulated “Oort Cloud” of small icy bodies 1000-10000 AU from solar system: material that never made it into protoplanetary disk.
  – Occasionally disturbed by nearby star into passing close enough to sun to be perturbed by outer planet (esp Jupiter)
• Others are “Long-period Comets” with periods 1000-20000 years, most in plane of solar system (eg Hale-Bopp).
  – Kuiper Belt of icy planetesimals beyond Neptune.
  – Many become “short-period comets” (eg Halley) by encounters with planets, are swept up by planets or the Sun.
Terrestrial Planet Comparison

<table>
<thead>
<tr>
<th></th>
<th>Mercury</th>
<th>Venus</th>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit Size (AU)</td>
<td>.387</td>
<td>.723</td>
<td>1</td>
<td>1.52</td>
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<tr>
<td>Orbit Period</td>
<td>88</td>
<td>225</td>
<td>365</td>
<td>687</td>
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<tr>
<td>Satellites</td>
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<td>0</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Mass</td>
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<td>.82</td>
<td>1</td>
<td>.11</td>
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<tr>
<td>Density</td>
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<td>5.3</td>
<td>5.5</td>
<td>3.9</td>
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<tr>
<td>Rotate (d)</td>
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<td>117</td>
<td>1</td>
<td>1.03</td>
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<tr>
<td>Tilt (deg)</td>
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<td>177</td>
<td>23.5</td>
<td>24</td>
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<tr>
<td>Atm Comp</td>
<td>None</td>
<td>CO₂ (96%), N₂ (3%)</td>
<td>N₂ (78%), O₂ (21%)</td>
<td>CO₂ (95%), N₂ (3%)</td>
</tr>
<tr>
<td>Atm Press</td>
<td>0</td>
<td>90</td>
<td>1</td>
<td>.007</td>
</tr>
<tr>
<td>Surface</td>
<td>Craters</td>
<td>Volcanoes, lava</td>
<td>Ocean, mountains, volcanoes</td>
<td>Craters, maria</td>
</tr>
</tbody>
</table>

Why are they so different?

- **Orbit position: closer to sun =>**
  - Higher equilibrium surface temperature
  - More formation bombardment
  - Sun’s tides forces synchronous rotation
- **Mass: massive =>**
  - Interior heating -> volcanism
    - retain formation heat
    - more radioactive materials
  - Higher surface gravity -> atmosphere retention
- "Contingency" (eg collisions)
Rotation/ satellites

- Mercury: 3:2 synchronous rotation
- Venus: early collision reverses rotation
- Mercury/ Venus: no satellites due to Sun tides
- Earth: large moon due to early collision
  - large lunar tides possibly important for life
- Mars: two small moons captured from asteroid belt
- Earth/ Mars: non-synchronous rotation + moderate axial tilt => even temperatures; moderate seasons

Interiors/ Surfaces

In order of increasing mass
- Mercury: no vulcanism;
  - retains original cratering
- Mars: Decreasing vulcanism:
  - some early cratering
  - thick crust; few large fixed volcanoes
- Venus: Active vulcanism
  - few craters
- Earth: Active
  - craters rare
  - liquid core; planetary magnetic field
  - thin crust; plate tectonics
Atmospheres: Origin

Origin
- captured gas from solar nebula (probably small): H-rich, ie CH₄, NH₃
- "outgassed" material from vulcanism: CO₂, H₂O, etc
- comets! (Especially during early history of solar system): CO₂, H₂O

Atmospheric Escape

Loss Into Space
- molecule at top of atmosphere attains escape velocity.
  \[ v_{esc} \sim \frac{M}{R^{1/2}} \] (M, R = mass, radius of planet)
- molecular speed depends on temperature and molecular wt:
  - molecule velocity = constant \times \text{Temp}/(mol wt)
- => gas is lost first from
  - low-mass planet/satellite (low escape velocity) (eg Moon):
  - hotter planet (higher molecular velocity) (eg Mercury)
  - low molecular weight (eg H₂, He)
Chemical modification:

- **precipitation/evaporation:**
  \[ \text{H}_2\text{O} \leftrightarrow \text{oceans, polar caps} \]
- **solution/evolution:**
  \[ \text{CO}_2 + \text{liquid H}_2\text{O} \leftrightarrow \text{carbonate rocks} \]
- "photochemistry"
  \[ \text{solar UV} + \text{O}_2 \rightarrow \text{O}_3 \text{ (ozone)} \]
- **life:**
  \[ \text{sunlight} + \text{CO}_2 + \text{photosynthesis} \rightarrow \text{O}_2 \]
  (life is only known O$_2$ producer => good spectroscopic indicator of life!)
- **Chemistry with surface**
  \[ \text{O}_2 + \text{most anything} \rightarrow \text{oxides} \]

Atmosphere Feedback Effects

Temperature \(\leftrightarrow\) Atmospheric composition

- Recall equilibrium temperature.  refine this:
- **Solar input** = Watts/m$^2$ (mostly visible wavelengths)
  - Reflected = Watts/m$^2 \times$ Albedo ("Albedo" = fraction of light reflected)
  - Absorbed = Watts/m$^2 \times (1 - \text{Albedo})$
- **Emitted** = constant $\times$ Temp$^4$ (mostly infrared for T -100-800 K)
- **Equilibrium**: Absorbed (visible) = Emitted (IR)
Comet Origins

- Oort cloud—A swarm of billions of comet nuclei in a huge shell surrounding the Sun and planets.

Kuiper Belt Orbits

- Red—Plutinos
- Blue—CKBO’s
- Black—SKBO’s
Mercury

Venus
Earth

Mars
Mercury Locked Rotation

Mars Volcanoes
Venus Volcanoes

Precipitation- Mars frost