• Delivery of C and H$_2$O via comets & asteroids
• Seeding of life
Cassini dead since 5:55 this morning
Today

- Electrolysis experiment
  \[ 2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2 \]
- Delivery by comets
- Panspermia Reading:
  - RGS pp. 22-24, 28-29
  - Lon pp. 383-384
  - BS pp. 121-125
  - also: BS pp. 210-212
Power input?

- 200 Volts
- 0.1 Amps
- Power: 200V * 0.1A = 20 W
  = 20 Joule/sec

Comparison

- 2500 calories/day = 10^7 J/day
  = 10^7 J/(24*3600s) = 120 W
Solar energy: 10 W from 13x10 inches

- Power per square meter?
- \[ 10W / [(13 \times 0.0254\text{m}) \times (10 \times 0.0254\text{m})] = 120 \text{ W/m}^2 \]
How many Joules per year?

- 1 yr = 3x10^7 sec

So 120 W = 120 J/s in 1 yr gives:

120*3x10^7 J = 360x10^7 J = 3.6x10^9 J

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy /J m^{-2} yr^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>total radiation from the Sun</td>
<td>1 090 000.0</td>
</tr>
<tr>
<td>ultraviolet light</td>
<td>1 680.0</td>
</tr>
<tr>
<td>electric discharges (lightning)</td>
<td>1.68</td>
</tr>
<tr>
<td>cosmic rays</td>
<td>0.0006</td>
</tr>
<tr>
<td>radioactivity (to 1 km depth)</td>
<td>0.33</td>
</tr>
<tr>
<td>volcanoes</td>
<td>0.05</td>
</tr>
<tr>
<td>shock waves (atmospheric entry)</td>
<td>0.46</td>
</tr>
</tbody>
</table>
Corrected in 2011 issue of RGS

Table 1.4 Present-day sources of energy averaged over the Earth.

<table>
<thead>
<tr>
<th>Source</th>
<th>Power/W m(^{-2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>total solar radiation</td>
<td>360</td>
</tr>
<tr>
<td>geothermal heat flow</td>
<td>(8.1 \times 10^{-2})</td>
</tr>
<tr>
<td>electrical discharges (lightning)</td>
<td>(5.4 \times 10^{-8})</td>
</tr>
<tr>
<td>cosmic rays</td>
<td>(2 \times 10^{-11})</td>
</tr>
<tr>
<td>shock waves (atmospheric entry)</td>
<td>(1.5 \times 10^{-8})</td>
</tr>
</tbody>
</table>

- Efficiency of solar panels with 120 W/m\(^2\)?
  
  \[ \frac{1}{3} \text{ or } \sim 0.3 = 30\% \]
Other numbers were ok

<table>
<thead>
<tr>
<th>Source</th>
<th>J m(^{-2}) s(^{-1})</th>
<th>Energy / J m(^{-2}) yr(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>total radiation from the Sun</td>
<td>1.1 \times 10^{10}</td>
<td>1.09 \times 10^{9}</td>
</tr>
<tr>
<td>ultraviolet light</td>
<td></td>
<td>1.68</td>
</tr>
<tr>
<td>electric discharges (lightning)</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>cosmic rays</td>
<td></td>
<td>0.0006</td>
</tr>
<tr>
<td>radioactivity (to 1 km depth)</td>
<td>6.3 \times 10^{-4}</td>
<td></td>
</tr>
<tr>
<td>volcanoes</td>
<td></td>
<td>0.33</td>
</tr>
<tr>
<td>shock waves (atmospheric entry)</td>
<td></td>
<td>0.47</td>
</tr>
</tbody>
</table>
### Putting the right molecules together

- Need to produce order
  - drive away from equilibrium
- Energy required to generate & sustain order

<table>
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</table>
Conclusion from this

- Electrolysis experiment turned electric energy into chemical energy
- Hydrogen can be stored & used later
- Energy much higher than other non-solar energy sources
- Some biological metabolisms operate at much lower energies
Where in the solar system did it start?

- Where is the carbon?
- Where is the water?
Enough carbon in inner parts?

Noticed in 1961 (J. Oro)
Puzzle

• Not much Carbon where liquid water
• A lot of carbon where water is frozen

What is the reason?
# Carbon delivery (present rates)

## Table 1.7: Accretion rates on Earth today.

<table>
<thead>
<tr>
<th>Sources</th>
<th>Mass range /kg</th>
<th>Mass accretion rate (estimated) /10^6 kg yr⁻¹</th>
<th>Carbon %</th>
<th>Carbon accretion rate /10^6 kg yr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>meteoritic matter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>meteors (from comets)</td>
<td>10⁻¹⁷ to 10⁻¹</td>
<td>16.0</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>meteorites</td>
<td>10⁻² to 10⁵</td>
<td>0.058</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>crater-forming bodies</td>
<td>10⁵ to 10¹⁵</td>
<td>62.0</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>unmelted material contributing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>organic matter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>meteors (from comets)</td>
<td>10⁻¹⁵ to 10⁻⁹</td>
<td>3.2</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>meteorites, non-carbonaceous</td>
<td>10⁻² to 10⁵</td>
<td>2.9 × 10⁻³</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>meteorites, carbonaceous</td>
<td>10⁻² to 10⁵</td>
<td>1.9 × 10⁻⁴</td>
<td>2.5</td>
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- Which type is the greatest C source?
Which type is the greatest C source?
- Crater-forming bodies
- Arrive intermittently
**Carbon delivery (present rates)**

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<td>meteorites</td>
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<td>0.058</td>
<td>1.3</td>
<td>&lt;0.001</td>
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- Greatest organic C source?
- Compare with C of biomass: \(6 \times 10^{14}\) kg
  - \(6 \times 10^{14}\) kg / \(0.3 \times 10^6\) kg/yr = \(20 \times 10^8\) yr = 2Gyr
Carbon delivery

• Somewhat more anorganic than organic C
  – Organic C delivery continuous

• Enough to produce all C in biomass
  – Early rates likely much higher; see moon
Also water is volatile

• Not much water during formation
  – temperatures too high \(\rightarrow\) dry accretion

• Possible solution:
  – Late delivery from beyond "snowline"
  – Evidence: depletion wrt meteorites

• Low K/U (potassium to uranium ratio)
  – Indicator of relative depletion of volatiles
Is wet accretion possible?

• Yes, by later inward migration
  – Need to look at orbital dynamics

• Many body problem
  – Can easily become unstable
Water on terrestrial planets

• Not much on Venus and Mars
  – either acquired less than Earth,
  – or lost more

• Earth: much is in the mantle (2-10 times)
  – Venus: unclear (losses by impact & sol wind)
  – Mars: loss by solar wind (MAVEN)
Alternative: late delivery

- Also known as: late veneer
  - comets & asteroids
  - Formed beyond snow line
- Potential problem D/H $\sim 3 \times 10^{-4}$
  - Ocean water D/H = $1.56 \times 10^{-4}$
- But 103P/Hartley 2 (IR): comp. w/ Earth
- For the coma: core could be enriched
Different types of comets

LETTER

doi:10.1038/nature10564

Ocean-like water in the Jupiter-family comet 103P/Hartley 2

Paul Hartogh\(^1\), Dariusz C. Lis\(^2\), Dominique Bockelée-Morvan\(^3\), Miguel de Val-Borro\(^1\), Nicolas Biver\(^3\), Michael Küppers\(^4\), Martin Emprechtinger\(^2\), Edwin A. Bergin\(^5\), Jacques Crovisier\(^3\), Miriam Rengel\(^1\), Raphael Moreno\(^3\), Slawomira Szutowicz\(^6\) & Geoffrey A. Blake\(^2\)

For decades, the source of Earth’s volatiles, especially water with a deuterium-to-hydrogen ratio (D/H) of \((1.558 ± 0.001) \times 10^{-4}\), has been a subject of debate. The similarity of Earth’s bulk composition to that of meteorites known as enstatite chondrites\(^1\) suggests a dry proto-Earth\(^2\) with subsequent delivery of volatiles\(^3\) by local accre-
Panspermia

- Arrhenius (1859-1927): spores survived
- Lord Kelvin (1824-1907): via meteorites
- Allan Hills meteorite (ALH 84001)
  - 4.5 Gyr: crystallized magma from Mars
  - 4.0 Gyr: battered, but not ejected
  - 3.6-1.8 Gyr: altered by water
  - 1984: discovered in Antarctica
  - 1996: NASA press conference
Why not Panspermia Earth → Mars?

A. Because of Earth’s atmosphere
B. Because Earth is too massive
C. Because Earth is closer to the Sun
D. Because of either B or C
E. Because of both B and C

There are several good answers!
Why not Panspermia Earth → Mars?

A. Because of Earth’s atmosphere
B. Because Earth is too massive
C. Because Earth is closer to the Sun
D. Because of either B or C
E. Because of both B and C
Panspermia

• Not a hypothesis for origin of life
  – We could be related to Martian life (think)
  – Other way unlikely (against Sun, heavier)

• Bacteria $\rightarrow$ suspended animation
  – Virtually no metabolism (bact spores)
  – Hardy to heat, desiccation, radiation, chem.

• Record so far 250 Myr (Lon 384)
  – Isolated bubbles, lake bed Salado in NM
Next week’s material

• Domains of life & extremophiles
  – Bacteria in antarctica survived -50 C (-58 F)
  – LUCA, the last common ancestor

• RNA world
  – It can also act as catalyst
  – No proteins necessary
Preparation for quiz #1

- Next week Thursday
- Check all lectures: def of life, order/disorder,
- Away from equilibrium
- Natural selection
- Carbon & Water, polar molecules
- Lipids and other building blocks
- Genetic code, A-T, G-C
- Biomarkers, meteorites, Miller/Urey, ...