Organics and Life

An important focus for the future of planetary science and the Outer Solar System in particular.
The search for a second genesis of life

⇒ comparative biochemistry (life 2.0)

step to understanding the origin of life

⇒ life is common in the universe (yeah!)

"The Tree of Life"
defines Earth Life

From Woese, 1967
Where to look for life?

Mars: past liquid water, no organics (yet), current surface destroys organics

Europa: has ocean, No direct evidence of N or organics

Enceladus: has icy jet, liquid water, organics, nitrogen

Titan: liquid - not water, organics

Increasing chance of life not related to Earth life
Organics

No evidence of organics.

Organics present in the plume.

Organics present in the atmosphere and surface.
Figure 22.18 Mass spectrum of the Enceladus plume from the October 9th 2008 flyby (Waite et al. 2009). The colors show contributions from various species and their breakdown products using the composition shown in Table 22.3.
Enceladus Organics

• Is H$_2$ present, redox?

• Diagnostic compounds:
  C$_2$H$_2$ stable energetic compound
  CO unstable energetic compound
  HCN important source of N
  C$_2$H$_4$ not in comets, FFT and thermal

• Simultaneous CH$_4$ and NH$_3$ usually from decaying biomass.

• Are amino acids present?
Titan Organics

Even with Cassini/Huygens our knowledge of the organics processes on Titan, especially the surface is rudimentary.

- $\text{C}_2\text{H}_6$ surface mixing ratio
- C:H:N ratio in the haze
- Surface processing of solid organics
- Solutions & residues seen in receding lakes
- Any curious depletions of $\text{H}_2$
Habitability

Water, and presumably nutrients and energy

Water, organics, N, probably redox energy

Liquid (not water) redox energy ($H_2 + C_2H_2$), organics (lots)
Examples of ecologically isolated microbial ecosystems
(no O₂, no light, no organic input)

Only three examples are known:
Two are based on H₂ from rock reactions
(H₂ + CO₂ → CH₄ + H₂O)

One based on radioactive decay
4H₂ + H⁺ + SO₄²⁻ $\xrightarrow{\text{SRB}}$ H₂S + 2H₂O + 2OH⁻

Desulfoprofundis tokoloshe

Lin et al. 2006, slide courtesy of T. Kieft
Surface material

Liquid water reservoir

Biology: $\text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O}$

Thermal processing, $T>500^\circ\text{C}$: $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{CO}_2$

McKay et al. 2008
The only fact we have about the origin of life is that it happened more than 3.5 Gyr ago.

We do not know where, when, how it happened, or how long it took.

The view that it occurred on Earth and/or took a long time is unsupported by any evidence.
“As with all fields where significant data are still sparse and where the most important breakthroughs probably lie well in the future, many books now claim to have completely solved the problem or to have at least opened the field sufficiently so that no other approach than the author’s is significant.”

Greenberg 1994 book review in Phys Today

The history of science suggests that the important breakthroughs will come not from theory but from observations in a new domain.
OK for Europa & Enceladus
Life Wanted: Dead or Alive

• The search for life is **not** a search for something alive.
  - No microscopes for motion
  - No Viking-like metabolism experiments
• At the scale of microorganisms, structure is not convincing.
• The best evidence of life is dead
  - biomolecular structures

[life: 1) a phenomenon, 2) a state variable, 3) a path integral]
Biomarkers

Organic
- Lipids
- Nucleic Acids
- Proteins
- Amino acid
- Amino acid selection
- Special molecules
  - (quinones, porphyrins, etc)

Inorganic
- Trace fossils
- Isotopes
- Mineralogy
- Cell-like shapes
- Magnetite chains

Red = could be convincing evidence
Blue = possibly convincing
Grey = context information only
Amino acids are in meteorites & comets
- Even without life they are likely to be present in plumes.
- Relevant to understanding sources and processing of organics.

Murchison

Glavin et al. 2011

<table>
<thead>
<tr>
<th>Peak</th>
<th>Amino acid</th>
<th>#C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>d-aspatic acid</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>l-aspatic acid</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>l-glutamic acid</td>
<td></td>
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<tr>
<td>4</td>
<td>d-glutamic acid</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>l-serine</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>l-serine</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>d-threonine</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>l-threonine</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Glycine</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>β-alanine (BALA)</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>d-alanine</td>
<td>3</td>
</tr>
<tr>
<td>12</td>
<td>l-alanine</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>γ-amino-β-butyric acid (γ-ABA)</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>d-β-amino-β-butyric acid (d-β-ABA)</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>l-β-amino-β-butyric acid (l-β-ABA)</td>
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</tr>
<tr>
<td>16</td>
<td>α-aminoisobutyric acid (α-AIB)</td>
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</tr>
<tr>
<td>17</td>
<td>d, l-α-amino-β-butyric acid (d,l-α-ABA)</td>
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</tr>
<tr>
<td>18</td>
<td>3-amino-2,2-dimethylpropanoic acid (3-a,2,2-dmpa)</td>
<td>5</td>
</tr>
<tr>
<td>19</td>
<td>d,l-4-aminopentanoic acid (d,l-4-apa)</td>
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<tr>
<td>20</td>
<td>d,l-4-aminopentanoic acid (d,l-4-apa)</td>
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<tr>
<td>21</td>
<td>d,l-3-amino-2-methylbutanoic acid (d,l-3-a-2-mba)</td>
<td>5</td>
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<td>22</td>
<td>d,l-3-amino-2-ethylpropanoic acid (d,l-3-a-2-epa)</td>
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<td>23</td>
<td>5-aminopentanoic acid (5-apa)</td>
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<td>25</td>
<td>3-amino-3-methylbutanoic acid (3-a-3-mba)</td>
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<td>26</td>
<td>d-2-amino-2-methylbutanoic acid (d-isovaline)</td>
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<td>27</td>
<td>l-3-aminopentanoic acid (l-3-apa)</td>
<td>5</td>
</tr>
<tr>
<td>28</td>
<td>l-2-amino-2-methylbutanoic acid (l-isovaline)</td>
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<td>29</td>
<td>l-2-amino-3-methylbutanoic acid (l-valine)</td>
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<td>31</td>
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<tr>
<td>32</td>
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</tr>
<tr>
<td>33</td>
<td>ε-amino-n-caproic acid (EACA)</td>
<td>6</td>
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<tr>
<td>34</td>
<td>d,l-isoleucine</td>
<td>6</td>
</tr>
<tr>
<td>35</td>
<td>d,l-leucine</td>
<td>6</td>
</tr>
<tr>
<td>L.S.</td>
<td>d,l-norleucine (internal standard)</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 1. Peak identification numbers and abbreviations for amino acids detected in the chromatograms of the standards, procedural blanks, and meteorite extracts. The number of carbons (#C) for the aliphatic amino acids is also shown.
L - amino acids used in proteins

D - amino acids not in proteins
A specific proposal:

All possible amino acids

- Stranger biology
- Earth's 10/20
- Strange biology
Why Sample Return

• If Nature conforms to our expectations and life elsewhere uses amino acids and these are present in a plume as a distinct group and of definite chirality then there is no need to sample return at this time.

• Nature does not have a good record of conforming to our expectations (eg. perchlorate on Mars).

• If life elsewhere has unexpected biochemistry then understanding this will require iterative investigations – virtually impossible in-situ methods.

• We need to learn to do astrobiology sample return.
We need to develop the requirements and technology for sample return from habitable environments.

This is current a show-stopper.
Could there be methane life on Titan? 😊

Table 1. Free Energies of Hydrogenation on Titan

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$\Delta G$ (kcal/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{C}_2\text{H}_2 + 3\text{H}_2 = 2\text{CH}_4$</td>
<td>80</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_6 + \text{H}_2 = 2\text{CH}_4$</td>
<td>15</td>
</tr>
<tr>
<td>$\text{R-CH}_2 + \text{H}_2 = \text{R} + \text{CH}_4$</td>
<td>13</td>
</tr>
<tr>
<td>Earth</td>
<td></td>
</tr>
<tr>
<td>$\text{CO}_2 + \text{H}_2 = \text{CH}_4 + \text{H}_2\text{O}$</td>
<td>$&gt;10$</td>
</tr>
</tbody>
</table>

$$\Delta G = \Delta H - T\Delta S + RT \ln(Q)$$

McKay and Smith, Icarus, 2005
Possibilities for Widespread Life on Titan

**Earth**
- Carbon based
- Liquid H$_2$O
- Widespread
- Global pollution (O$_2$)

**Titan**
- Carbon based
- Liquid CH$_4$
- If widespread then
- H$_2$ depletion
Opinions*

• The strongest support for outer Solar System missions beyond science comes from interest in life. Our planned missions do not adequately reflect this.

• We need to push harder for small innovative missions and technology demo. (eg. Mars Pathfinder, Philae)

*Not the opinion of the US gov’t, NASA HQ, Ames, my Division, my colleagues or me.
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