Biosignatures
Generations of stars
Current strategies
Methane + Oxygen = ?

A. Water
B. Carbon dioxide
C. All of the above

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]
Lect. 3: Biosignatures from space

A search for life on Earth from the Galileo spacecraft

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A search for life on Earth from the Galileo spacecraft

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Near-infrared

RGS, p.268, Fig. 8.7
Both methane and ozone!

- Methane: absorption around 7 – 8 μm
- Carbon dioxide: absorption around 15 μm
- Lots of water lines

\[
\lambda = \frac{c}{v} = \frac{3 \times 10^8 \text{ m/s}}{4 \times 10^{13} \text{ s}^{-1}} = 0.75 \times 10^{-5} \text{ m} = 7.5 \times 10^{-6} \text{ m} = 7.5 \mu \text{m}
\]
Why this 276 K for Earth?

A. Surface temperature of the Earth
B. Temperature higher in the atmosphere
C. Contributions from oceans
D. Caused by chlorophyll
Match?

- Yes, a few km
- Think of IR telescopes
Why this 276K for Earth?

A. Surface temperature of the Earth
B. Temperature higher in the atmosphere
C. Contributions from oceans
D. Caused by chlorophyll
Examples: Infrared telescope: Sofia

- 4–12 km above the ground
Comparison: other atmospheres

- Galileo
- Massive payload: fly-by on Earth
- Near infrared spectrometer (NIMS)
- O₂ difficult, but large amount of O₃
- Hard to explain abiologically
- Also CH₄: this, together with O₃, important
- Readily oxidized to give…
How to find biospheres

- No CH$_4$ reservoir on warm Earth
- Only 1 molecule in ever 600,000
- Enough for case beyond reasonable doubt
Reflectance spectrum

• Sharp rise in reflectance
• Red-edge
• Chlorophyll
• Figs 8.7, 8, 9, 12
• Also from Galileo: radio signals
- Sharp rise in reflectance
- Red-edge
- Chlorophyll
- Figs 8.7, 8, 9, 12
- Also from Galileo: radio signals
Potential habitats

• Focus on carbon-based life & water
  – Complex compounds, diverse, versatile

• Habitable zones (HZ)
  – If ok for 3% of planets: next one 20 ly
  – one planet every 6 ly, \((33*6^3)^{1/3}=20\)

• HZ excludes icy worlds, but water worlds?

• Also: atmosphere, not too many impacts
  – Jupiter shields us from many impacts
Carbon comes from nuclear fusion in stars during the late stages of a star's evolution.
Older stars: iron fraction?

A. More Fe than younger stars
B. The same
C. Less
Example of Kepler 444: born when 20% age of the Universe

- Fewer stellar generations
- But only of massive stars
- Interstellar medium has less Fe
- Resulting stars have less Fe
Older stars: iron fraction?

A. More than younger stars
B. The same
C. Less
Older stars: iron fraction?

of its planetary and orbital parameters based on an analysis of the transit photometry. Kepler-444 is the densest star with detected solar-like oscillations. We use asteroseismology to directly measure a precise age of 11.2 ± 1.0 Gyr for the host star, indicating that Kepler-444 formed when the universe was less than 20% of its current age and making it the oldest known system of terrestrial-size planets. We thus show that Earth-size planets have formed throughout most of the universe’s 13.8 billion year history, leaving open the possibility for the existence of ancient life in the Galaxy. The age of Kepler-444 not only suggests that thick-disk stars were among the hosts to the first Galactic planets, but may also help to pinpoint the beginning of the era of planet formation.

### Details

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Mass</strong></td>
<td>0.758 (± 0.043) (M_\odot)</td>
</tr>
<tr>
<td><strong>Radius</strong></td>
<td>0.752 (± 0.014) (R_\odot)</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>5040 (± 74.0) K</td>
</tr>
<tr>
<td><strong>Metallicity [Fe/H]</strong></td>
<td>-0.55 (± 0.07) dex</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>11.23 (± 0.99) Gyr</td>
</tr>
</tbody>
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10\(^{-0.55}\) = 0.28 times solar = 28% solar Fe abundance

Other aspects

- Kepler-444?
- Ancient life?
But \([\mathrm{Fe/H}]\) perhaps not important


Metallcity, planetary formation and migration

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Accepted 2003 October 21. Received 2003 October 16; in original form 2003 September 25

\textbf{ABSTRACT}

Recent observations show a clear correlation between the probability of hosting a planet and the metallicity of the parent star. As radial velocity surveys are biased, however, towards detecting planets with short orbital periods, the probability–metallicity correlation could merely reflect a dependence of migration rates on metallicity. We investigated the possibility, but find no basis to suggest that the migration process is sensitive to the metallicity. The indication is, therefore, that a higher metallicity results in a higher probability for planet formation.

\[ \Rightarrow \text{[Fe/H] matters for making Jovian planets, not for terrestrial ones} \]
Next time

- Finding more planets (& in future)
- Other methods
- Planets around binaries
- Tidally locked planets

- BS: 370 – 414
- RGS: 235 – 260
- Lon: 339 – 342