Water Contents of Habitable Zone Rocky Planets Around M dwarfs

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• Tong Li (Construct Line-by-line RT model)
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• Xianglei Huang
• Yi Huang
• Chuhong Mai
Outline

• Potential Problems on Habitability of M Dwarf Planets

• Biosignature of Exoplanets
To build a habitable planet, you need:

• 1) elements important to life as we know it: CHONPS + metals (Fe, Cu, Ni, Mo, Mn, etc.)
  – Seems to be readily available

• 2) sunlight
  – Underground life is not well understood and hard to find around other stars
  – Seems to be readily available except for rogue planets

• 3) liquid water (universal solvent)
Planets Near the Liquid Water

http://phl.upr.edu/projects/habitable-exoplanets-catalog
Potential Water Problems with D. Apai’s talk this morning: they are not necessarily dry!
Pre-Main Sequence M dwarfs were Brighter!

Figure 15 from Modules for Experiments in Stellar Astrophysics (MESA) by Bill Paxton et al. 2011 ApJS 192 3 doi:10.1088/0067-0049/192/1/3
THE HABITABLE ZONES OF PRE-MAIN-SEQUENCE STARS

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Extreme Water Loss and Abiotic O₂ Buildup on Planets Throughout the Habitable Zones of M Dwarfs

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Water contents of Earth-mass planets around M dwarfs

Feng Tian¹* and Shigeru Ida²
The HZ of M dwarfs migrates inward significantly during PMS phase! -- in danger of losing
Water loss has 3 bottlenecks

Exosphere (Collisionless)

- Exobase
  - 500

- Tropopause
- 10~15 km

Chemistry converts H$_2$O into H

- Overcome the cold trap
- Evaporation from the surface

Troposphere: H$_2$O controlled by T

Particles with enough energy to overcome the gravity can escape
M dwarfs are stronger XUV emitters than the Sun (Sanz-Forcada talk this morning), potentially destabilizing planetary atmospheres.
For Eric:

Even early M dwarfs are...
M dwarfs:
- 0.1%~1% probability to have Earth-twins (0.1-10 M_\text{\text{Earth}} + Water fraction >1e-8 and < 1e-2)

Sun-like Stars:
- 10% probability

Potential problems with too much water:
1) Climate instability (Cowan&Abbot 2014, Abbot+ 2012, see also Kitzmann+ poster in this conference)
2) Limited nutrients for surface life (Dohm & Maruyama 2015)

BTW, the probability for H2-rich atmospheres
Uncertainties

• Late Delivery of Water…
  – Greaves talk
  – How much could be delivered?
  – Impacts = high exozodiacal light? – if so, bad for characterization

• Store water in the interior… why doesn’t Venus have water?
Earth-mass planets in the HZ of M dwarfs are either water worlds or dune planets.
Severe water loss may lead to O2 buildup! Observing rocky planets around PMS M dwarfs could provide key insight on planet evolution.
The Probability of Observing Exoplanets around PMS M dwarfs

Tian (Icarus 2015)
How many nearby PMS M dwarfs are there?

Tian (Icarus 2015)

Biosignature Detection: $\text{O}_2$

Luger & Barnes 2015
Different FUV/NUV ratio changes chemistry
As a result of high FUV/NUV ratio, abiotically produced $O_2$ and $O_3$ could be maintained in the atmosphere.

Tian+EPSL 2014; also see Dogmal-Goldman + 2014, Gao+ 2015, Harman+ 2015
Detectability of CO... but CH$_4$

Wang et al. in prep.

Reflectivity vs. wavelength for various gases, showing detection limits.

R~100
Detectability of CO in the

Wang et al. in prep.

(a) Reflectivity vs. Wavelength (μm)

R~100

(b) Reflectivity vs. Wavelength (μm)

R~1000
So observations in multiple wavelengths will probably be the solution -- even 5 μm can be

Wang et al. in prep.
If stellar light and instrument

\[ \Delta t = t_0 \left( \frac{A}{0.3} \right)^{-1} \left( \frac{r_p}{r_E} \right)^{-2} \left( \frac{F_*}{1367} \right)^{-1} \left( \frac{d}{10 \text{ pc}} \right)^2 \left( \frac{D}{6.5 \text{ m}} \right)^2 \left( \frac{\text{SNR}}{10} \right)^2 \left( \frac{R}{100} \right) \]

\[ t_0 = 6.87 \times 10^{-15} \times \frac{T_*^4}{\lambda^2 B_{\lambda}(T_*)} \text{ hours} \]
For $f_{O_2} \sim 10^{-3}$ on exoplanets with Earth-like climate, the integration time needed for CO detection is as follows:

<table>
<thead>
<tr>
<th>$\lambda$ (μm)</th>
<th>A with $O_2$</th>
<th>A without $O_2$</th>
<th>SNR</th>
<th>$\Delta t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.69</td>
<td>0.274</td>
<td>0.279</td>
<td>112</td>
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<td>0.254</td>
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<td>0.2</td>
</tr>
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<td>4.67</td>
<td>0.03</td>
<td>0.66</td>
<td>3</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Not for imaging! (Wang et al. in prep.)
Conclusions

- Rocky planets in the Liquid Water Habitable Zone of Main Sequence M dwarfs may be **inhabitable** – evolution matters!
  - But these planets offer opportunities to understand the evolution of solar system planets.

- It is possible to distinguish photochemically
Thank you!

• Questions? please email tianfengCO@mail.tsinghua.edu.cn