Host’s star and habitability

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This work results within the collaboration of the COST Action TD 1308
1642 planets confirmed

~30 in the habitable zone

=> need to understand these objects and their behavior in such interesting regions

Ref: exoplanets.org
Linsenmeier et al. 2015

« Commonly, a planet is considered habitable if its surface conditions allow for the existence of liquid water. »

Torres et al. 2015

« Public curiosity and scientific interest have motivated efforts in the last few years to find and confirm rocky planets similar in size to the Earth that are orbiting in the so-called habitable zone (HZ) of their parent stars, usually taken in this context to be the region in which water on the surface can be in a liquid state. »

Bolmont et al. 2014 (SF2A)

« We define here the habitable zone (HZ) as the region around a star where a planet with the right atmosphere can potentially sustain surface liquid water (Kasting et al. 1993; Selsis et al. 2007). »

Kasting et al. 2013/2014

« The habitable zone (HZ) around a star is typically defined as the region where a rocky planet can maintain liquid water on its surface. That definition is appropriate, because this allows for the possibility that carbon-based, photosynthetic life exists on the planet in sufficient abundance to modify the planet’s atmosphere in a way that might be remotely detected »

The region where a rocky planet can maintain liquid water on its surface.
Habitability

Habitable zone $+$ « life’s ingredients »

- Habitable zone $= \frac{T_{\text{eff}}}{L_{\bullet}} + S_{\text{eff}}$ (given planet atmosphere)
  - stellar point of view

- « ingredients » $= $ tidal interaction, magnetic field, volcanic activity …
  - ingredients required to host « life »
  - planetary point of view
Habitable zone...

No!
- follow intrinsic evolution of star
- previous evolution?

Need stellar models!

Require precise
- mass
- metallicity
- age

... = snapshot?

...sorry
STAREVOL

\[ \alpha_c = 1.7020 \]
\[ Y = 0.2689 \]
\[ Z = 0.0134 \]

- Non-grey atmosphere
- Internal transport of AM
- Rotation
- AM and mass loss
- Impact of centrifugal effect on effective gravity

\[ 0.5 < M_*/M_\odot < 2 \]

See Lagarde et al. (2012) and Amard et al. (submitted) for more details
Habitable Zone

Kopparapu et al. (2013)

\[ S_{\text{eff}} = S_{\text{eff}}^\odot + aT_* + bT_*^2 + cT_*^3 + \ldots \]

2600 K ≤ \( T_{\text{eff}} \) ≤ 7200 K

\( S_{\text{eff}} = \) effective stellar flux = \( F_{\text{out}}/F_{\text{in}} \)

→ ratio between the outgoing IR flux from the planet and the net incident stellar flux

To compute the effective stellar flux, a model for the outgoing IR flux of the planet is needed

→ 1-D radiative-convective climate models

□ Habitable region limits

□ \( R_{\text{in}} = \) Runaway greenhouse: net positive feedback of GH effect (\( T_{\text{surf}} > 647 \) K), ocean evaporate entirely

□ \( R_{\text{out}} = \) Maximum greenhouse: Rayleigh scattering by CO\(_2\) reduce GH (\( T_{\text{surf}} = 273 \) K)
**Habitable zone**

**Impact of mass**

<table>
<thead>
<tr>
<th>0.5-2 M☉</th>
<th>Z☉</th>
<th>No rotation</th>
<th>1 M⊕</th>
</tr>
</thead>
<tbody>
<tr>
<td>HZ_in</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HZ_out</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Increases** towards higher masses
- **Shape** depends on the stellar mass
- **Correct estimation of mass** = crucial

Table 1. Size of the HZ as a function of stellar mass.

<table>
<thead>
<tr>
<th>ΔHZ</th>
<th>0.5 M☉</th>
<th>1 M☉</th>
<th>1.5 M☉</th>
<th>2 M☉</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔHZ_{mean} (AU)</td>
<td>0.27</td>
<td>0.86</td>
<td>2.05</td>
<td>3.25</td>
</tr>
<tr>
<td>ΔHZ_{min} (AU)</td>
<td>0.2</td>
<td>0.65</td>
<td>1.2</td>
<td>1.85</td>
</tr>
<tr>
<td>ΔHZ_{max} (AU)</td>
<td>1.39</td>
<td>3.46</td>
<td>5.9</td>
<td>6.63</td>
</tr>
</tbody>
</table>
Habitable zone

Metallicity

shift in $T_{\text{eff}}$ and $L_*$
due to opacity effects

strong impact on HZ
Habitable zone

Metallicity

- Increases towards lower metallicities
- Correct estimation of metallicity = crucial
Habitable zone

Impact of rotation

Centrifugal effect

\[ R_\ast \uparrow \rightarrow T_{\text{eff}} \downarrow \]

shift of 150 K in \( T_{\text{eff}} \)

but

\( L_\ast \) almost the same

small impact on HZ
Habitable zone

Impact of rotation

Rotating model from Amard et al. (in prep.)
Habitable zone

Stellar activity

\[ \frac{Ro}{\tau_{\text{conv}}} = \frac{P_{\text{rot}}}{\tau_{\text{conv}}} \]

\( Ro < 1 \) = stellar activity

High stellar activity during the PMS when HZL closest for from the star

Impact on emergence/complexification of life?
Habitable zone

CHZ

Gallet et al. (in prep.)

Table 2. Size of the CHZ as a function of stellar mass for solar metallicity.

<table>
<thead>
<tr>
<th>Mass</th>
<th>( HZ_{in} ) (AU)</th>
<th>Start (Myr)</th>
<th>Time (Gyr)</th>
<th>( HZ_{out} ) (AU)</th>
<th>Start (Myr)</th>
<th>Time (Gyr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 M(_\odot)</td>
<td>0.22</td>
<td>79.5</td>
<td>19.35</td>
<td>0.41</td>
<td>10.80</td>
<td>19.41</td>
</tr>
<tr>
<td>1 M(_\odot)</td>
<td>0.95</td>
<td>3.74</td>
<td>4.77</td>
<td>1.33</td>
<td>1.76</td>
<td>10.67</td>
</tr>
<tr>
<td>1.5 M(_\odot)</td>
<td>2.34</td>
<td>0.917</td>
<td>1.87</td>
<td>2.53</td>
<td>0.721</td>
<td>2.19</td>
</tr>
</tbody>
</table>

- Longer for planet close to the outer edge
- Decrease towards lower metallicity
- Longer for lower mass stars

Start (Myr) = starting age of the CHZ, Time (Gyr) = duration of the CHZ
Sun’s age: 0.95 - 1.76 AU

Earth Habitability: 3 Myr - 6 Gyr

Kopparapu et al. (2014) + STAREVOL

Z\odot: 0.5-2 M\odot, No rotation
$Z=0.001 \quad 0.8-6 \, M_\odot \quad$ No rotation

Kopparapu et al. (2014) + STAREVOL
Conclusion/Perspective

- Mass and metallicity control HZ evolution
  - => require precise estimation of $M_\star$ and Fe/H
- Stellar models should be used to get HZ evolution
  - estimation of CHZ / duration of planet inside HZ?

- Provide the community with an online tool to estimate habitability
- Couple atmospheric model to STAREVOL to directly get the flux receive by planet
- Include tidal interaction/dissipation in STAREVOL => Stéphane Mathis @ CEA Saclay
- Magnetic interaction? => Aline Vidotto @ Geneva
Online tool already available

we will provide stellar grids and other visualisation tools

stay tuned