Nice October 13 2015

Host's star and habitability

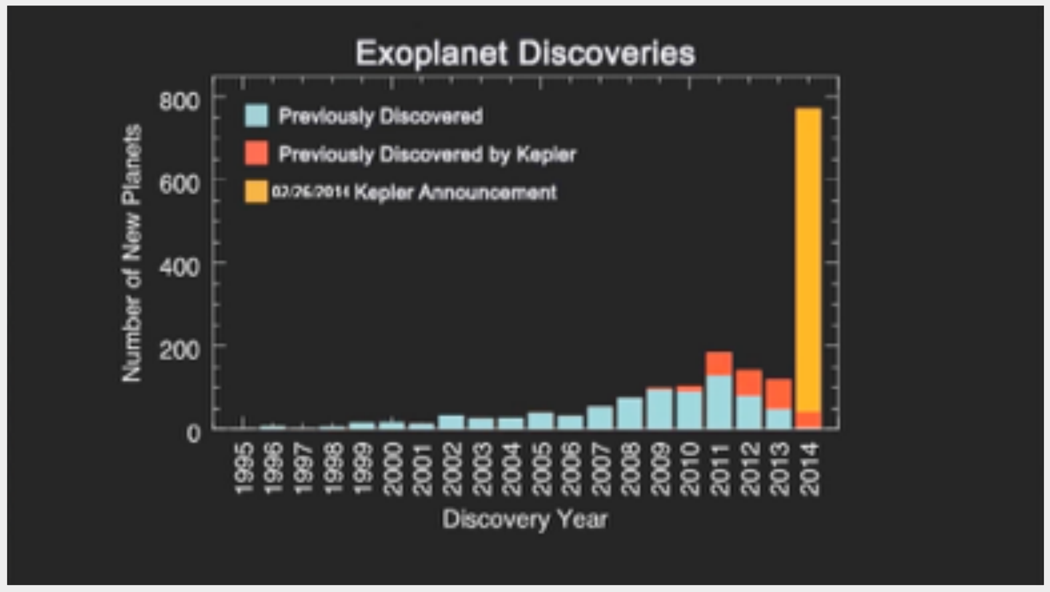
Florian Gallet - Corinne Charbonnel

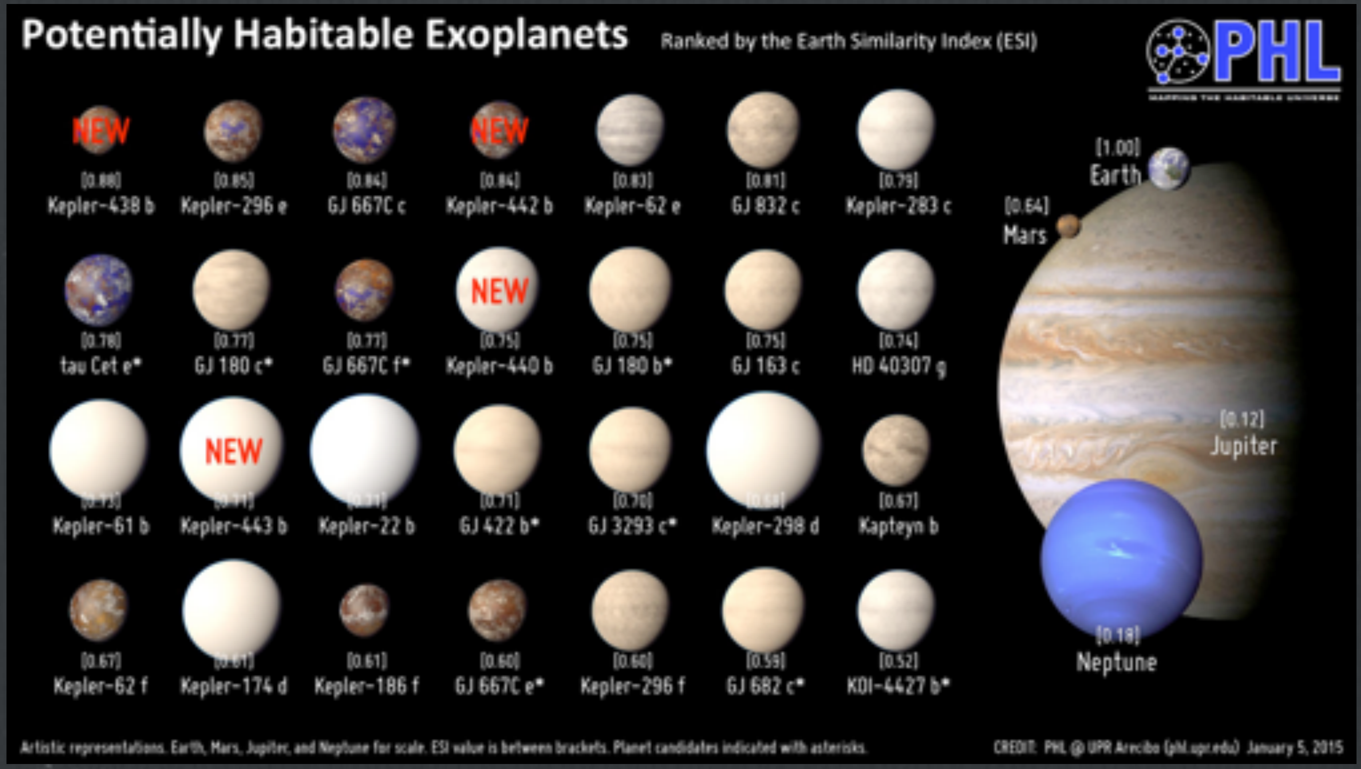
Ana Palacios (LUPM), Louis Amard (LUPM/Geneva), Sacha Brun (AIM Paris-Saclay), Stephane Mathis (AIM Paris-Saclay)

This work results within the collaboration of the COST Action TD 1308

brief Context

- 1642 planets confirmed
- ~30 in the habitable zone
- => need to understand these objects and their behavior in such interesting regions





Ref : exoplanets.org

Literature

Not exhaustif

- 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 = T_{eff}/L_{*} + S_{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...

... = snapshot?

- No!
  - follow intrinsic evolution of star
  - previous evolution?
- Need stellar models!
- Require precise
  - mass
  - metallicity
  - age

...sorry

Reference grid

STAREVOL

α_c = 1.7020
Y = 0.2689
Z = 0.0134

Non-grey atmosphere

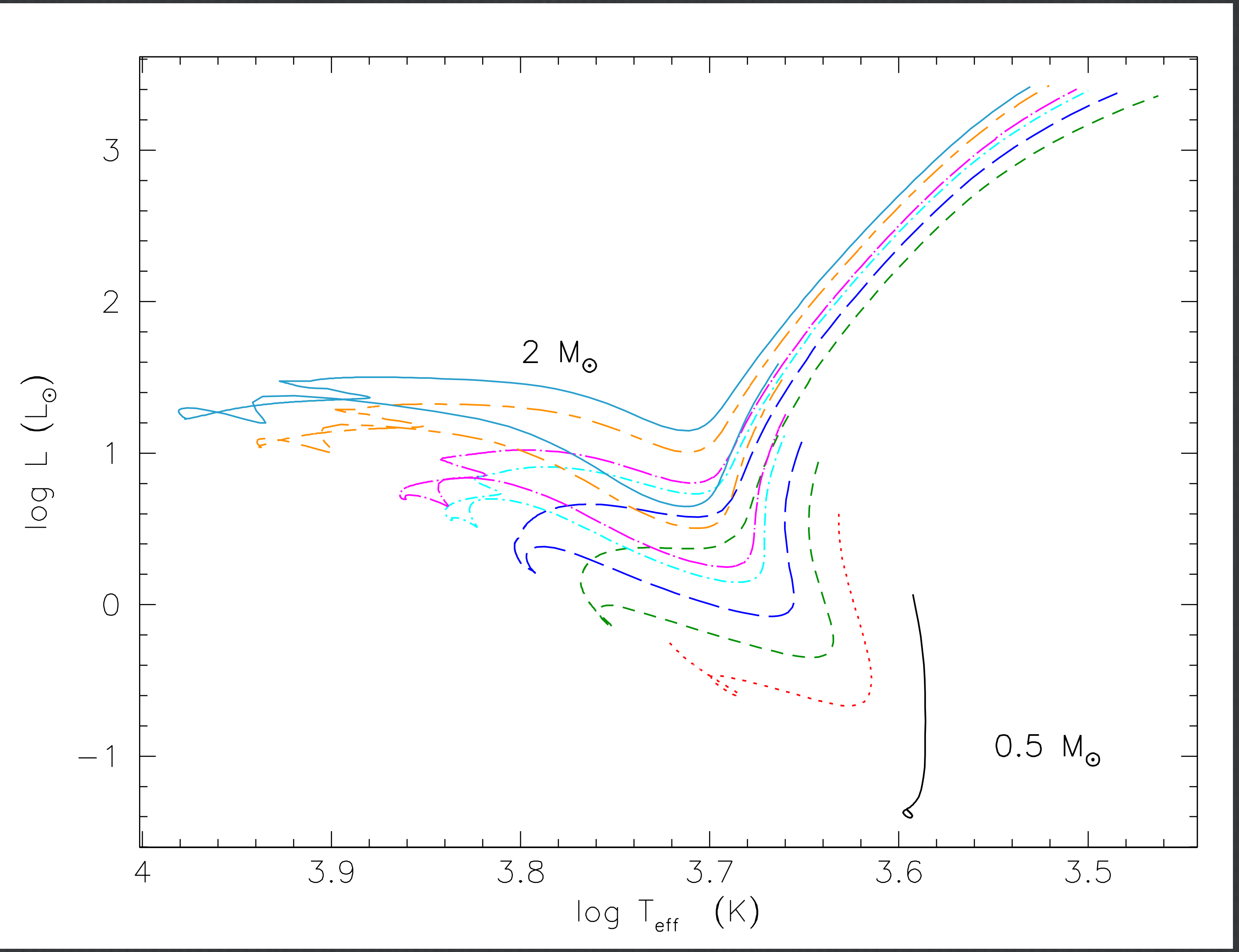
Internal transport of AM

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)

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

$2600\ K \leq T_{eff} \leq 7200\ K$

$S_{eff\odot}$, a, b, c = f(planet atmosphere)

$$S_{eff} = \frac{F_{IR}}{F_{inc}}$$

$$d = \left(\frac{L/L_\odot}{S_{eff}}\right)^{0.5} AU$$

Kasting et al. (1993)

S_{eff} = effective stellar flux = F_{out}/F_{in}

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

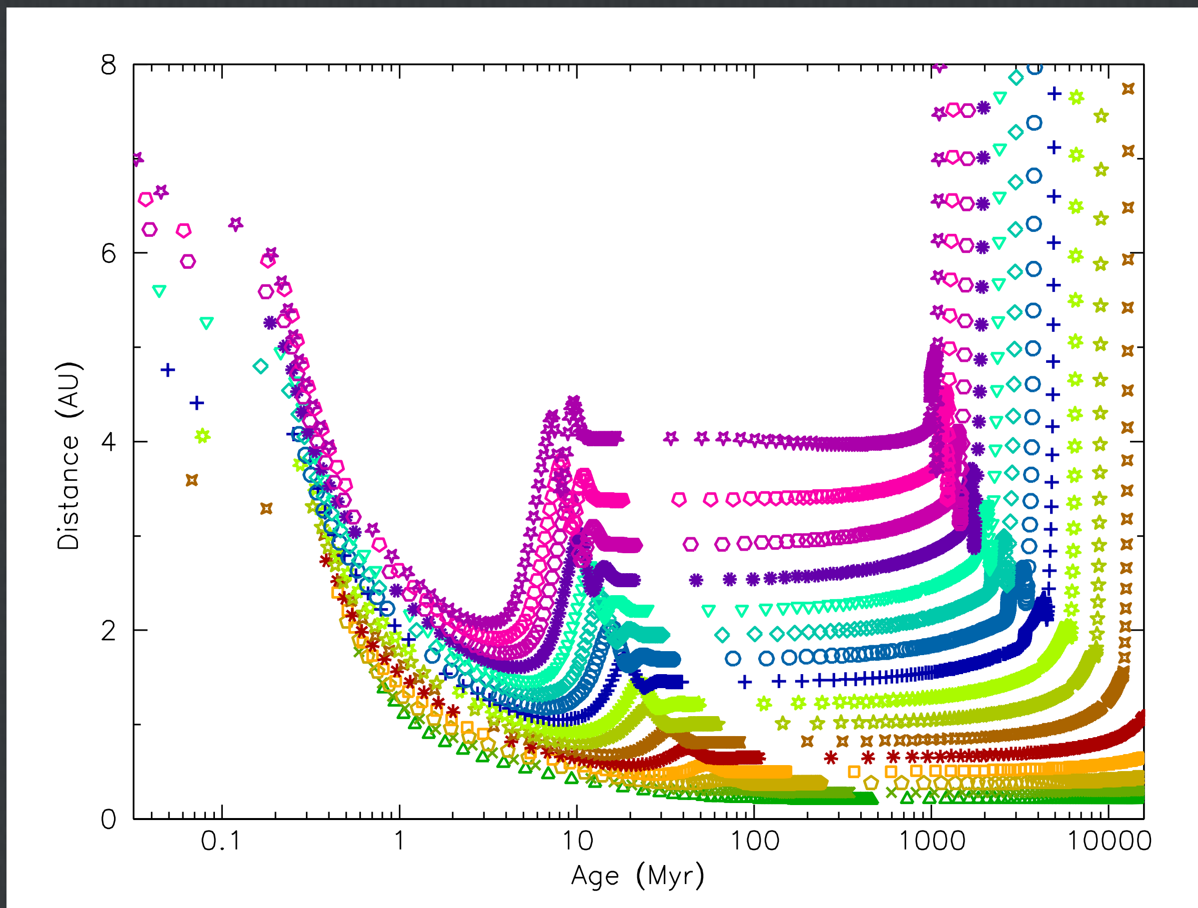
To compute the effective stellar flux, a model for the outgoing IR flux of the planet is needed

→ 1-D radiative-convective climate models

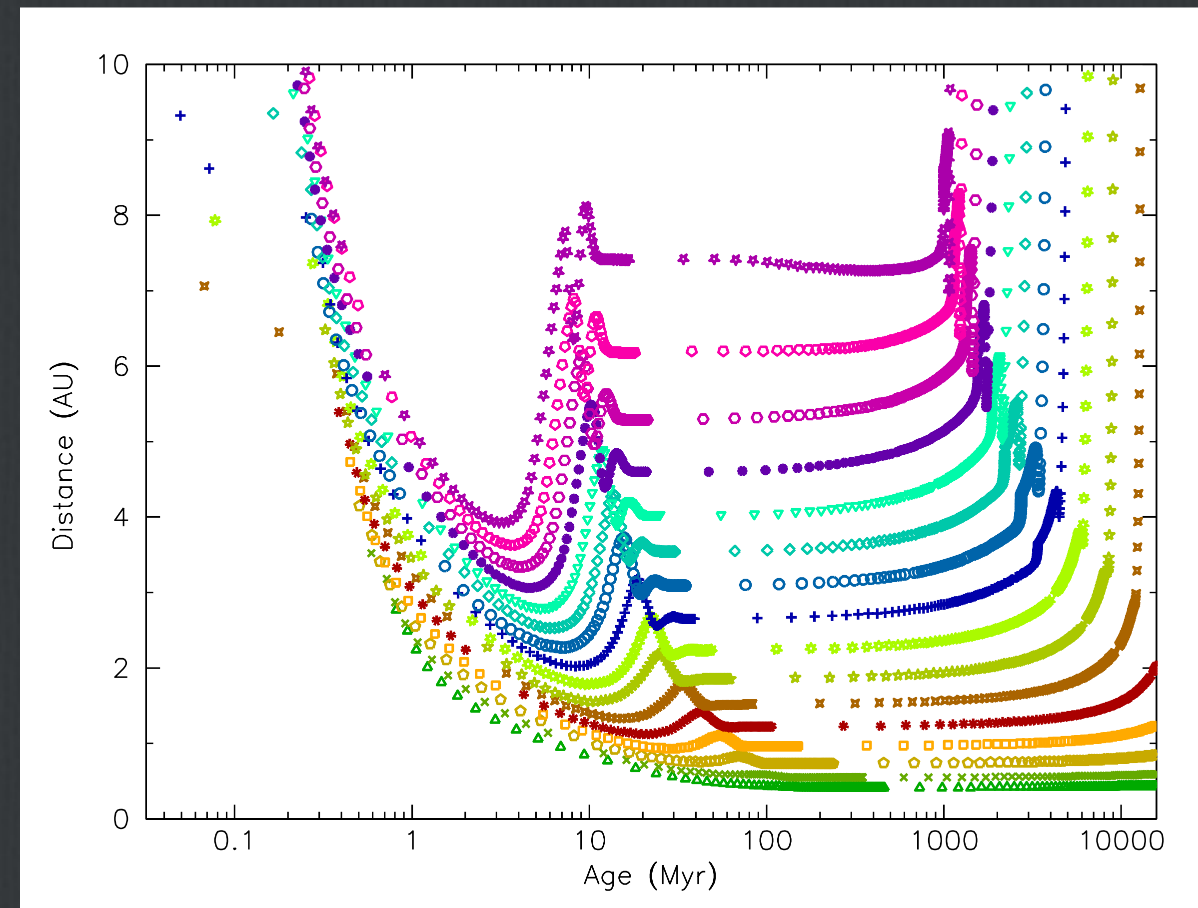
- Habitable region limits
  - R_{in} = Runaway greenhouse : net positif feedback of GH effect (T_{surf} > 647 K), ocean evaporate entirely
  - R_{out} = Maximum greenhouse : Rayleigh scattering by CO_2 reduce GH (T_{surf} = 273 K)

Habitable zone

Impact of mass 0.5-2 $M_\odot$ $Z_\odot$ No rotation 1 $M_\oplus$



HZ_{in}



HZ_{out}

- 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.

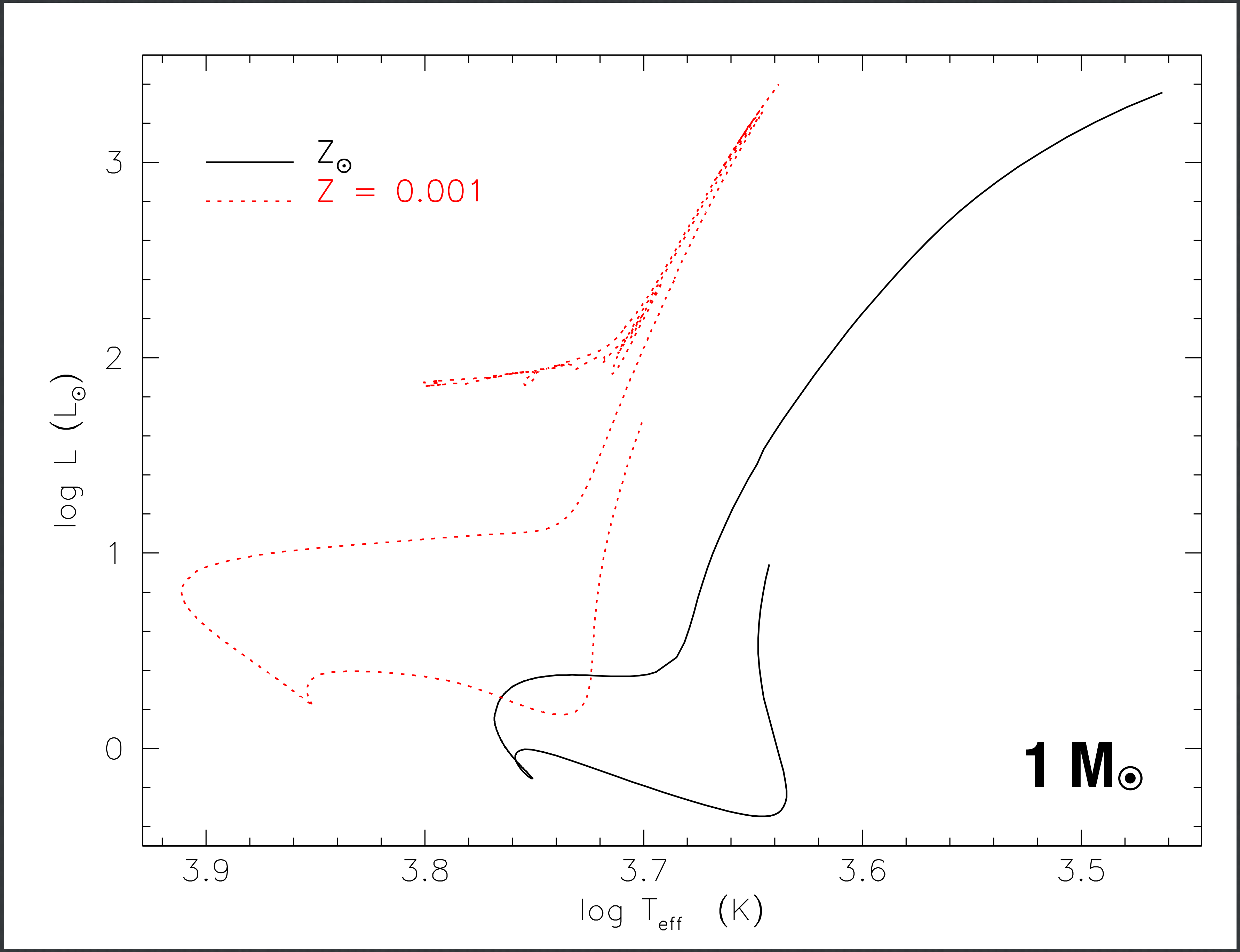
ΔHZ	0.5 $M_\odot$	1 $M_\odot$	1.5 $M_\odot$	2 $M_\odot$
ΔHZ_{mean} (AU)	0.27	0.86	2.05	3.25
ΔHZ_{min} (AU)	0.2	0.65	1.2	1.85
ΔHZ_{max} (AU)	1.39	3.46	5.9	6.63

Habitable zone

Metallicity

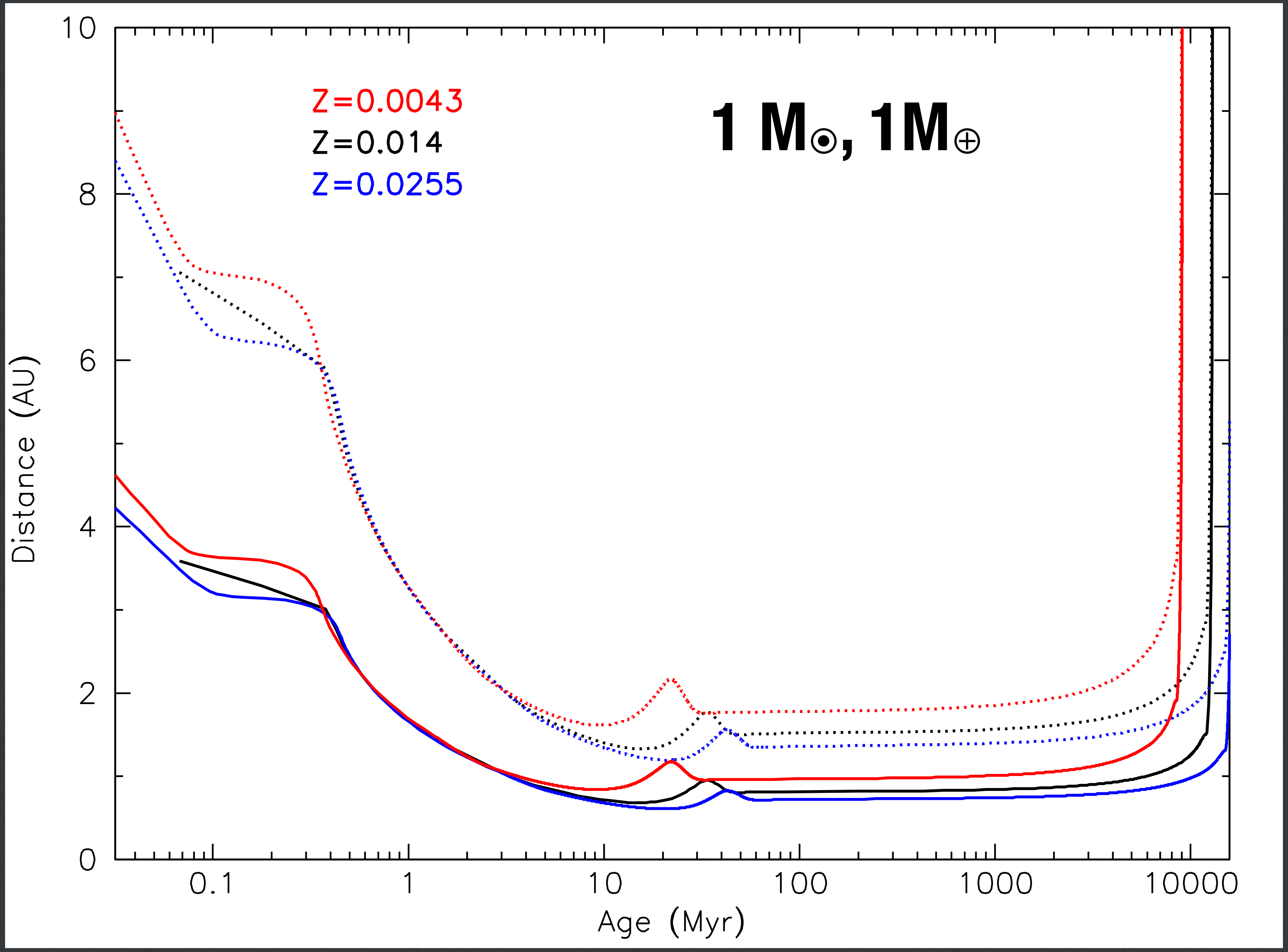
shift in T_{eff} and L_* due to opacity effects

strong impact on HZ



Habitable zone

Metallicity



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

Habitable zone

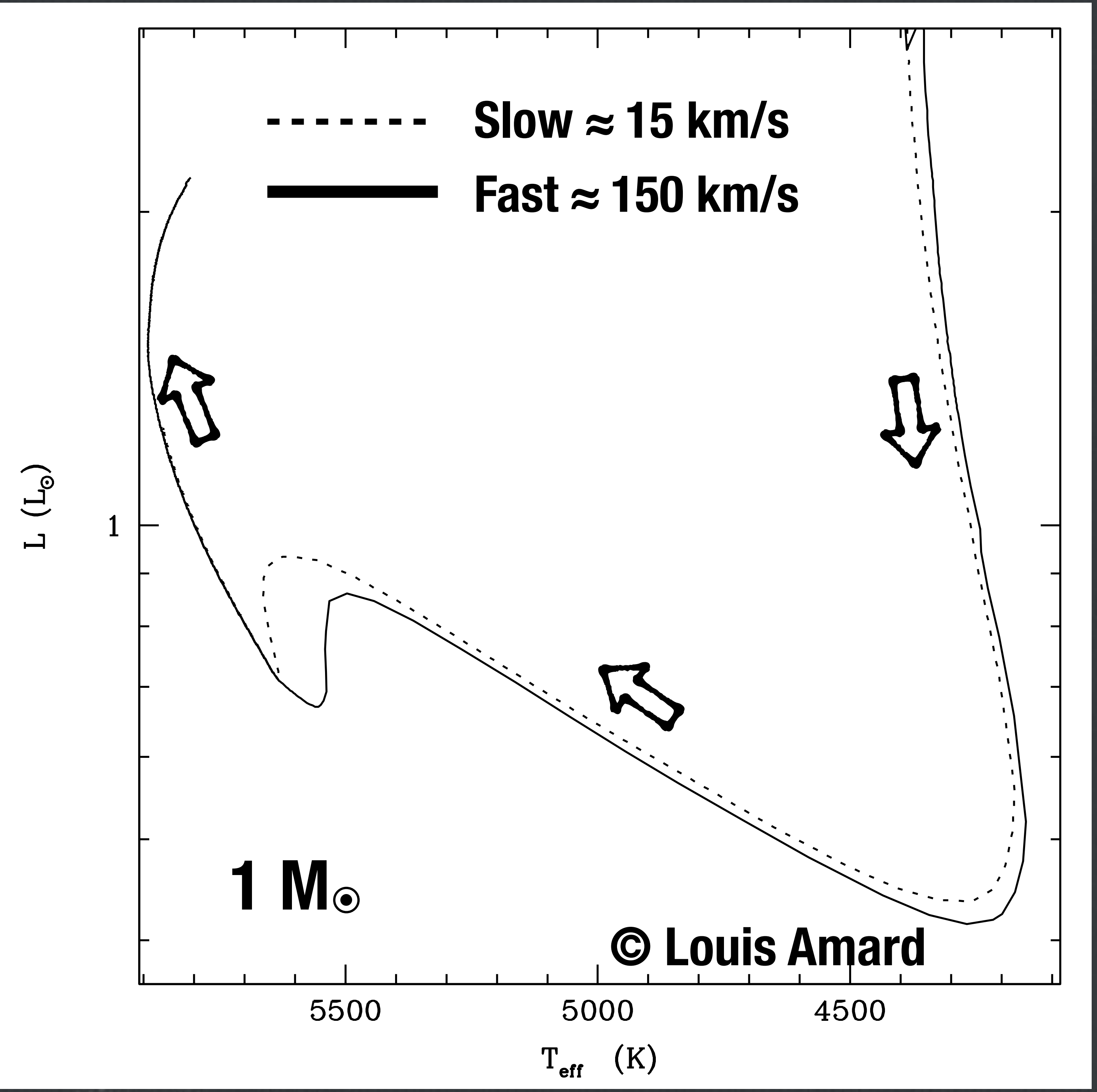
Impact of rotation

Centrifugal effect

$R_* \nearrow \rightarrow T_{eff} \searrow$

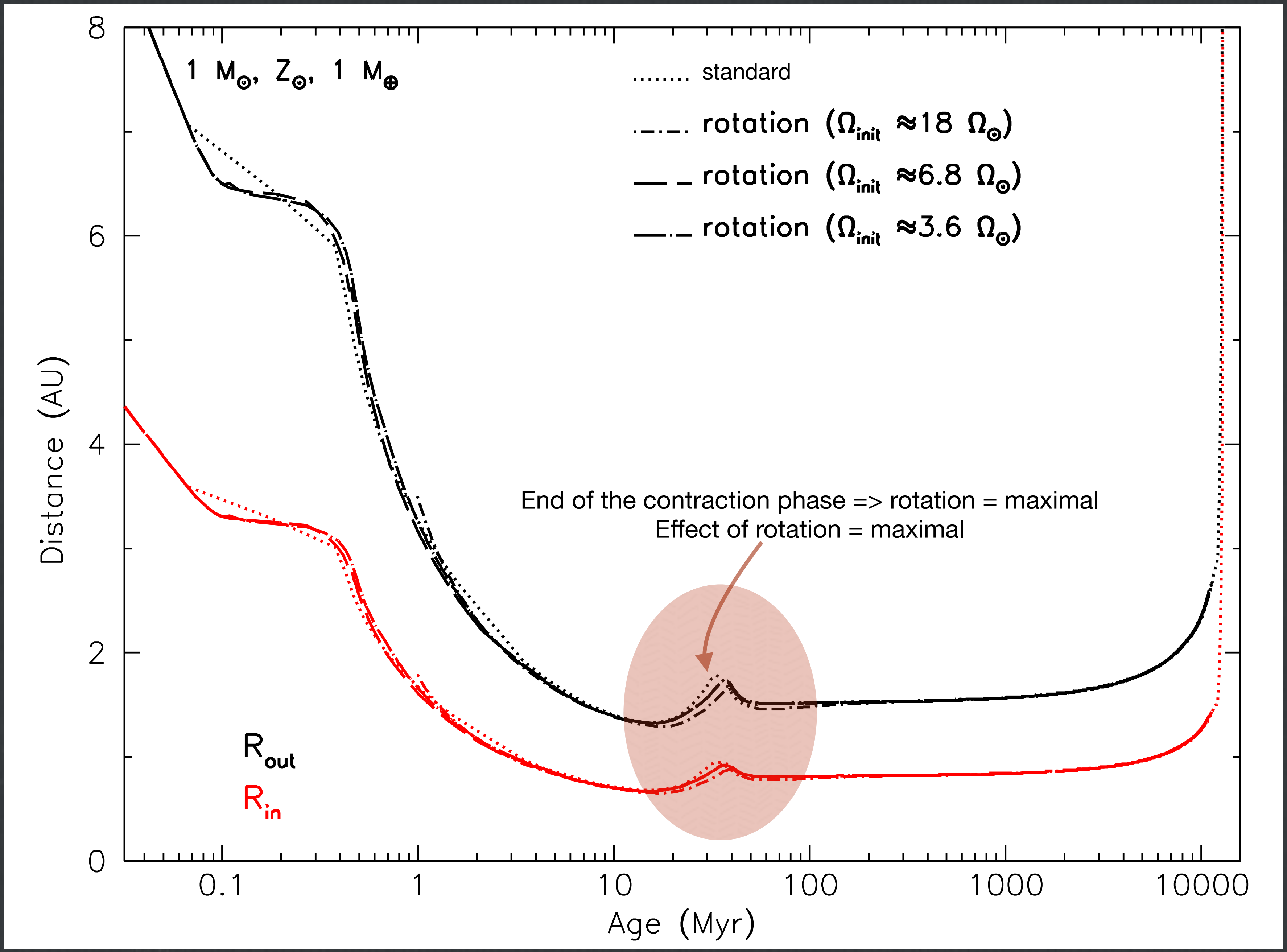
shift of 150 K in T_{eff}
but
L_* almost the same

small impact on HZ



Habitable zone

Impact of rotation



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

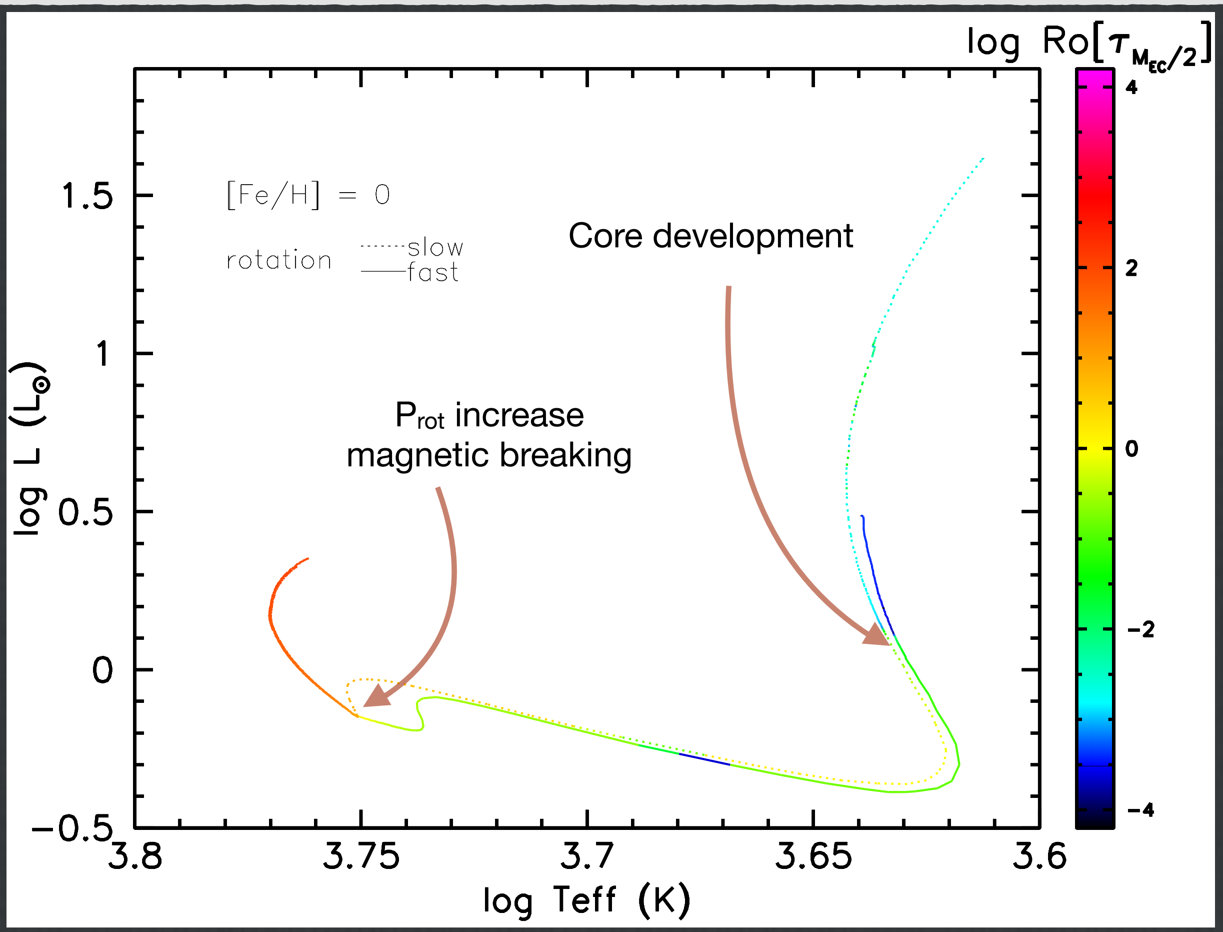
Habitable zone

Stellar activity

Z⊙ 1 M⊙ Rotation

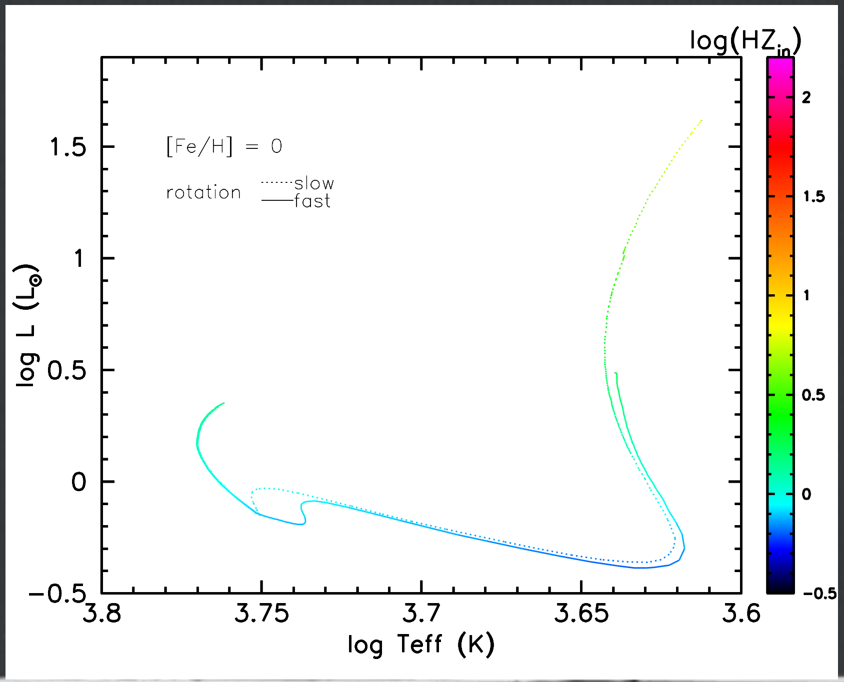
$$Ro = \frac{P_{rot}}{\tau_{conv}}$$

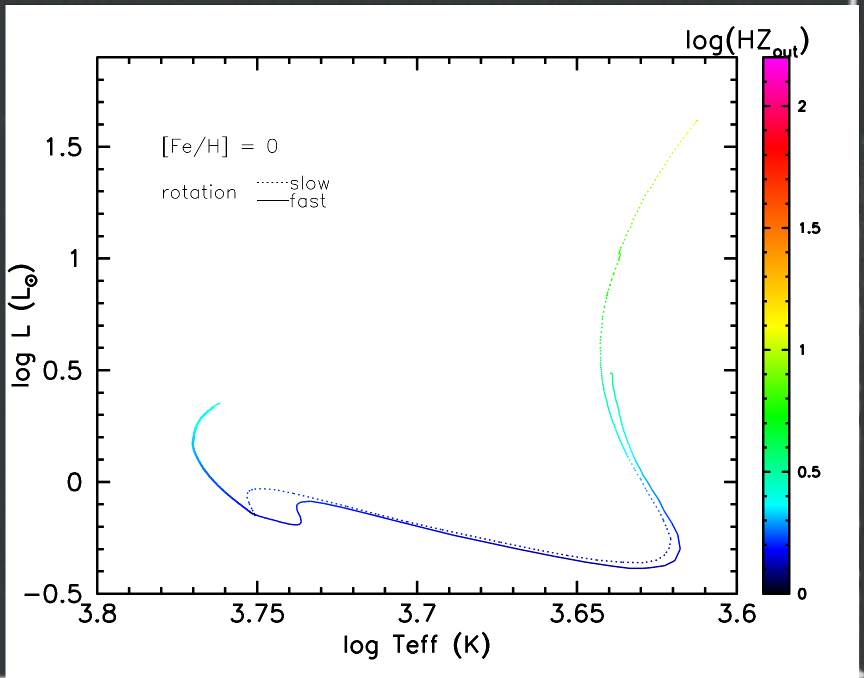
Ro < 1 = stellar activity



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

Impact on emergence/ complexification of life?

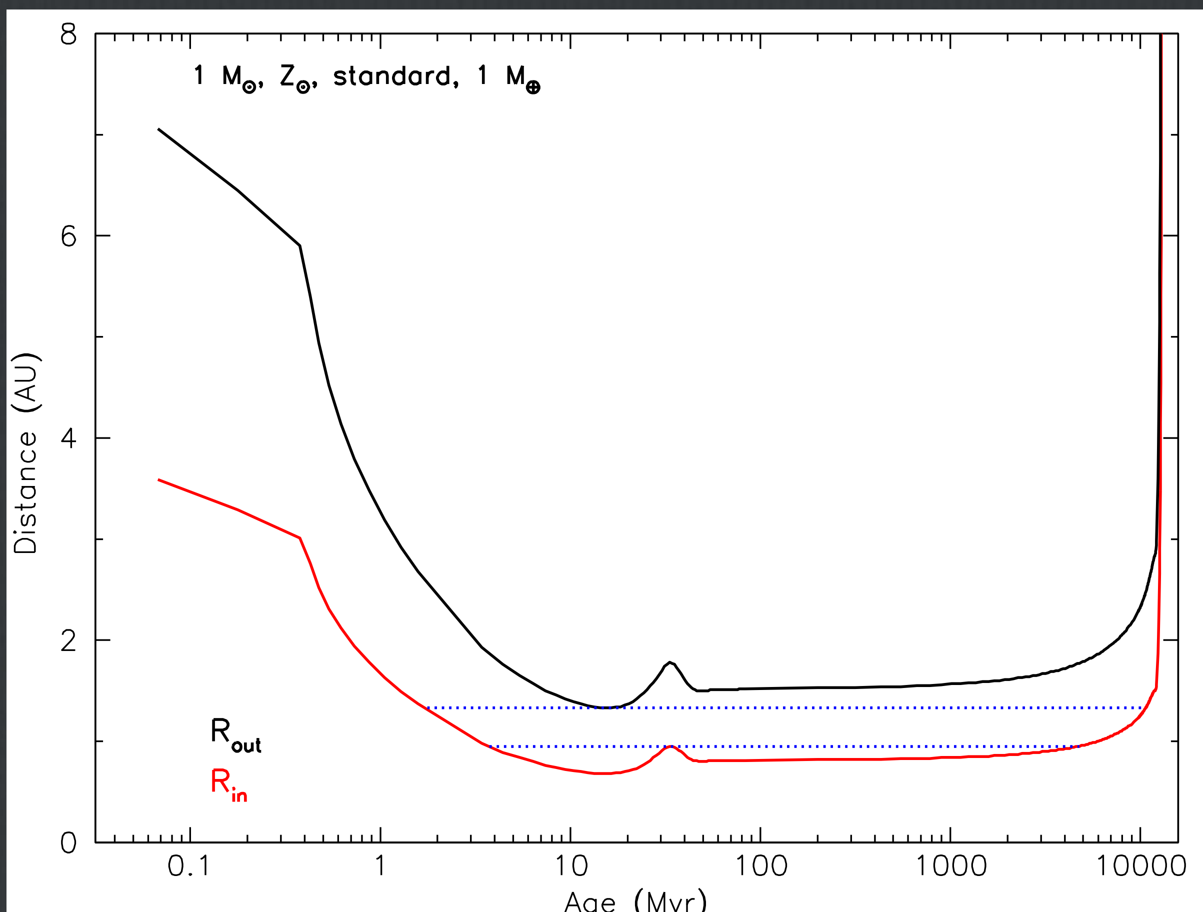




Habitable zone

CHZ

Gallet et al. (in prep.)



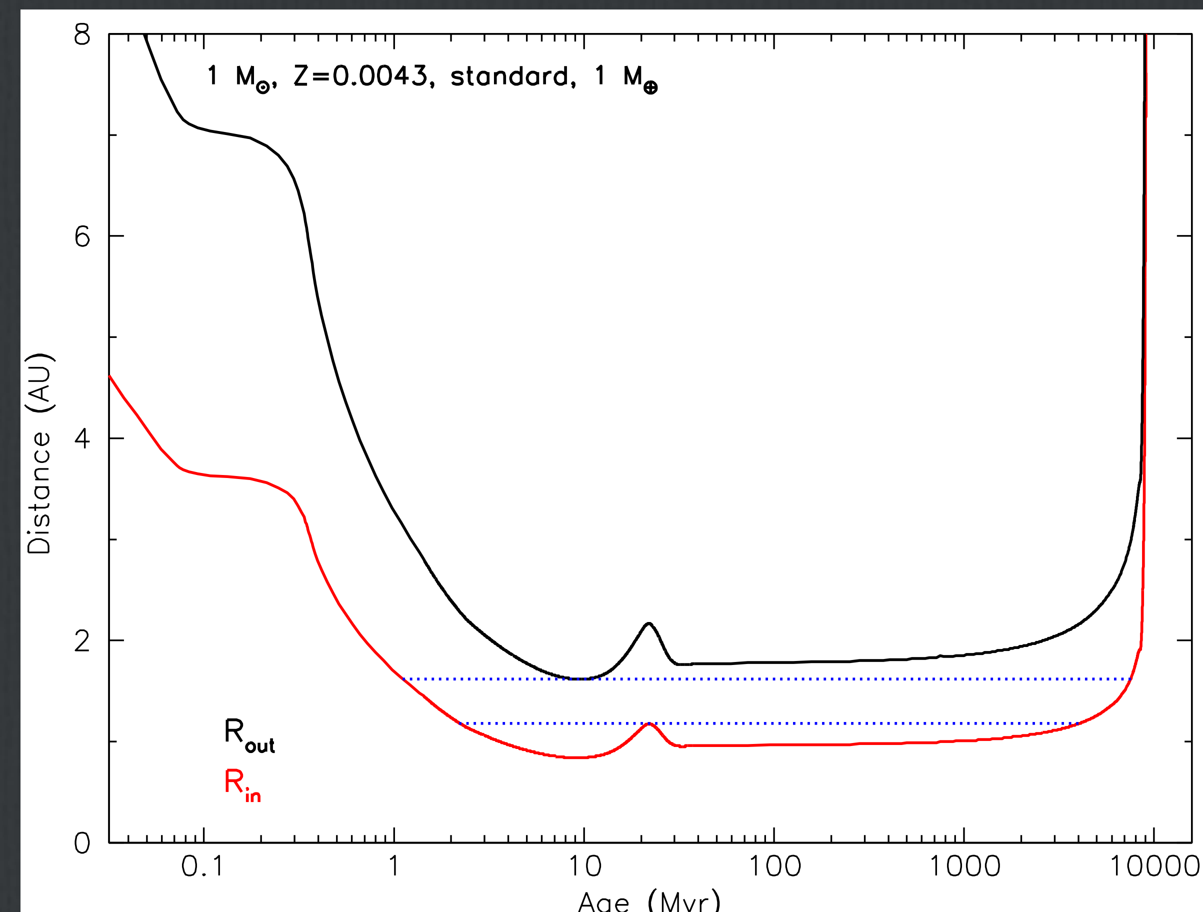
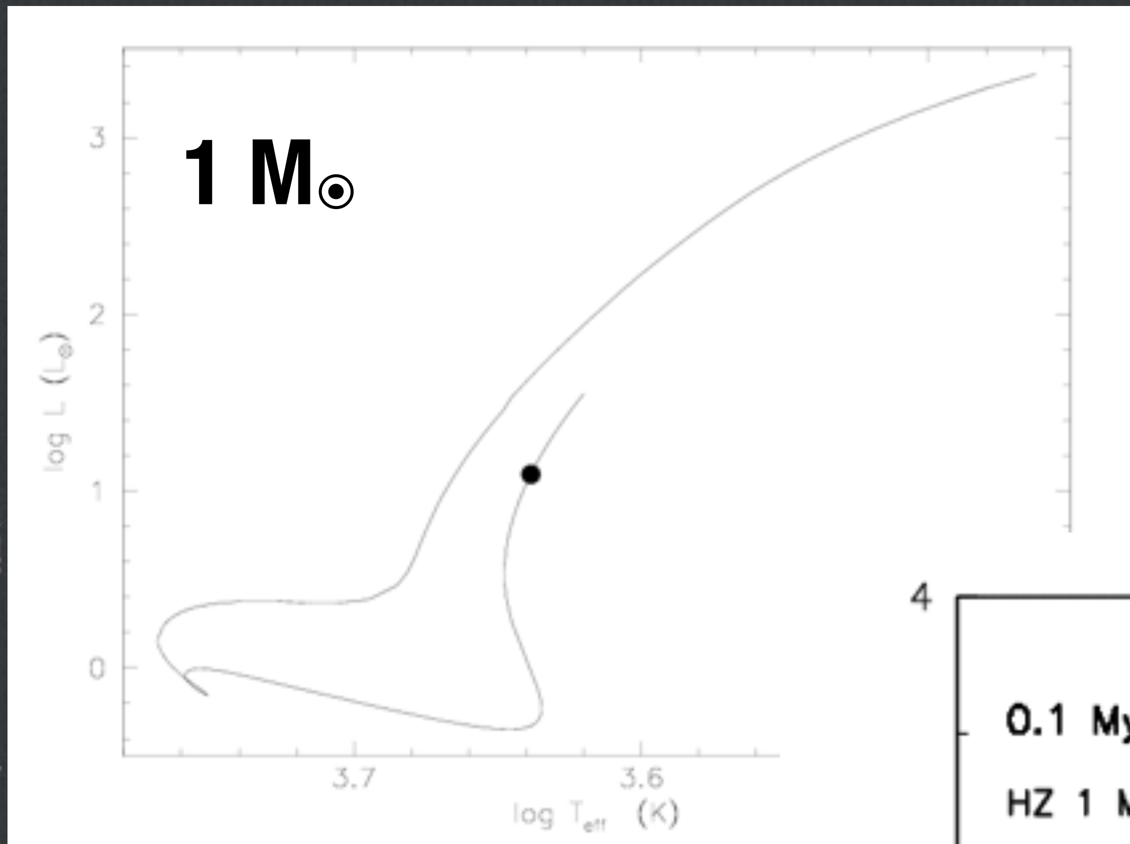


Table 2. Size of the CHZ as a function of stellar mass for solar metallicity.

Mass	HZ_{in} (AU)	Start (Myr)	Time (Gyr)	HZ_{out} (AU)	Start (Myr)	Time (Gyr)
0.5 $M_\odot$	0.22	79.5	19.35	0.41	10.80	19.41
1 $M_\odot$	0.95	3.74	4.77	1.33	1.76	10.67
1.5 $M_\odot$	2.34	0.917	1.87	2.53	0.721	2.19

Start (Myr) = starting age of the CHZ, Time (Gyr) = duration of the CHZ

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

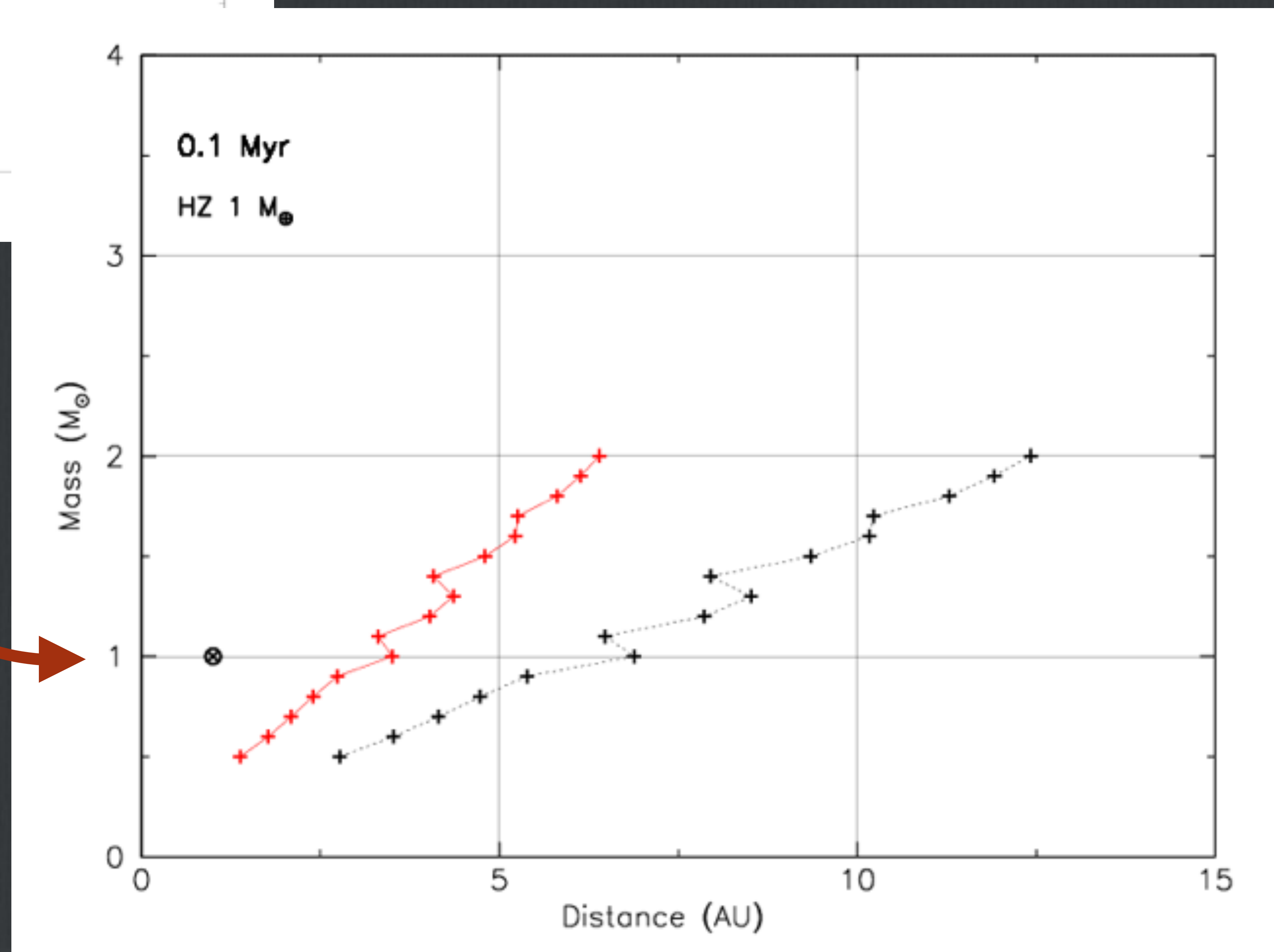


Z⊙ 0.5-2 M⊙ No rotation

Kopparapu et al. (2014) + STAREVOL

Sun's age

0.95 - 1.76 AU

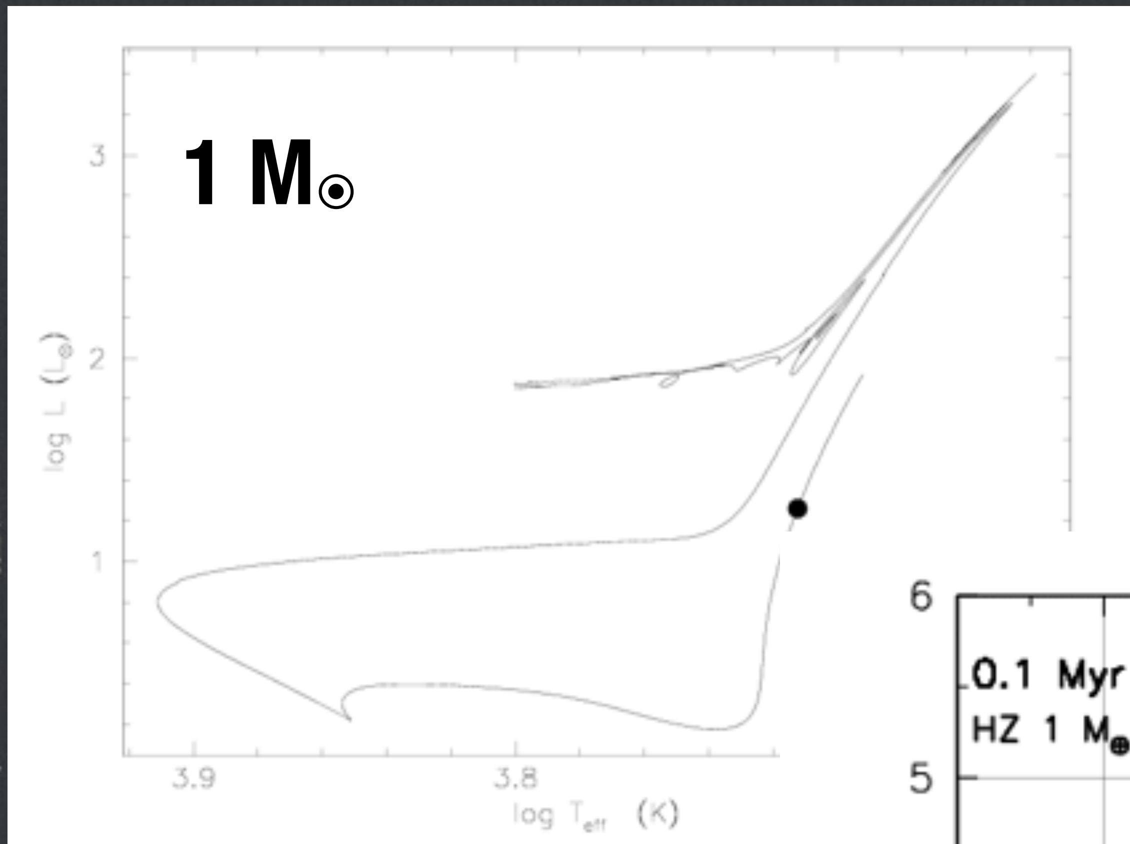


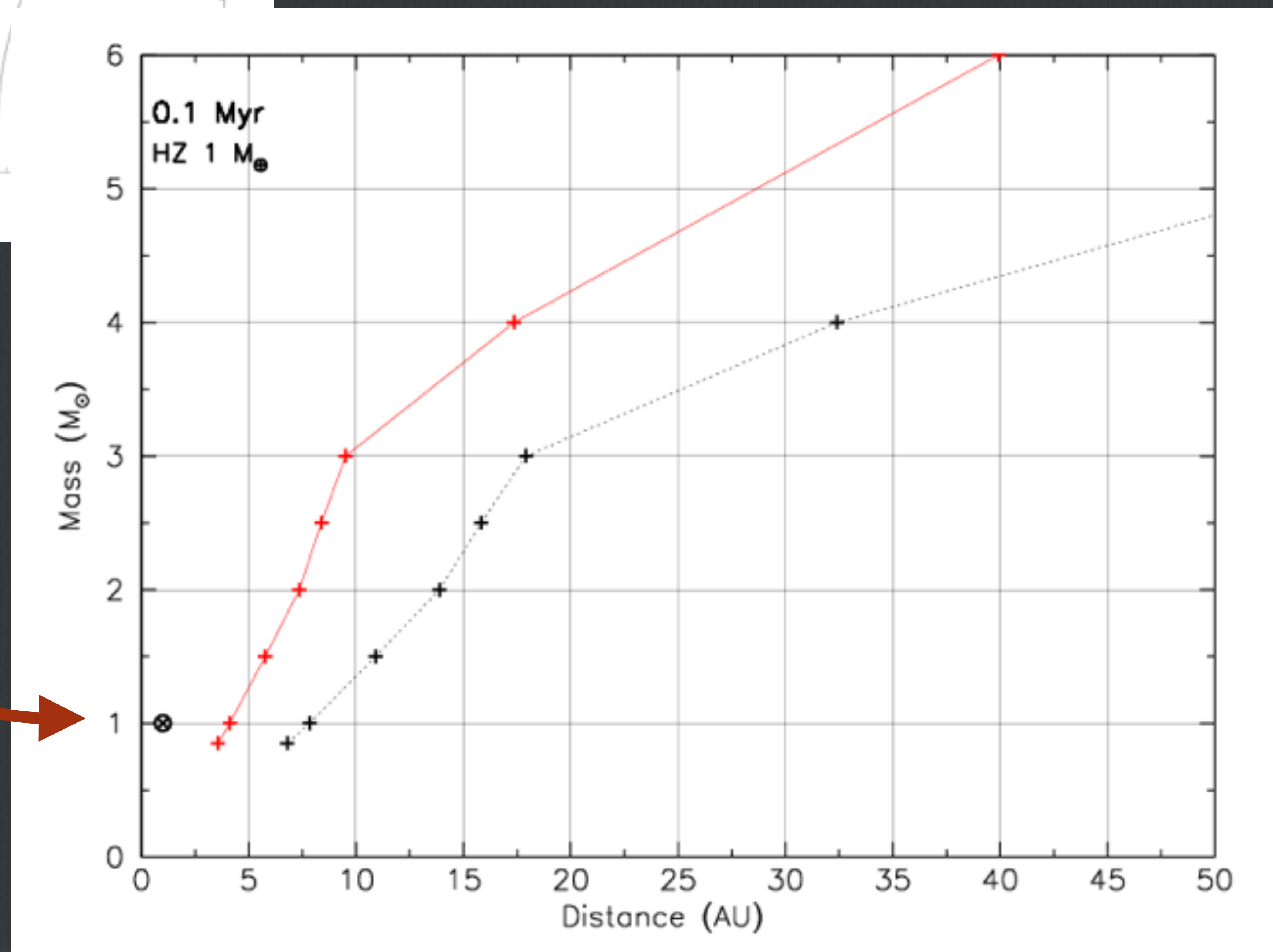
Earth Habitability

3 Myr - 6 Gyr

Z=0.001 0.8-6 M⊙ No rotation

Kopparapu et al. (2014) + STAREVOL



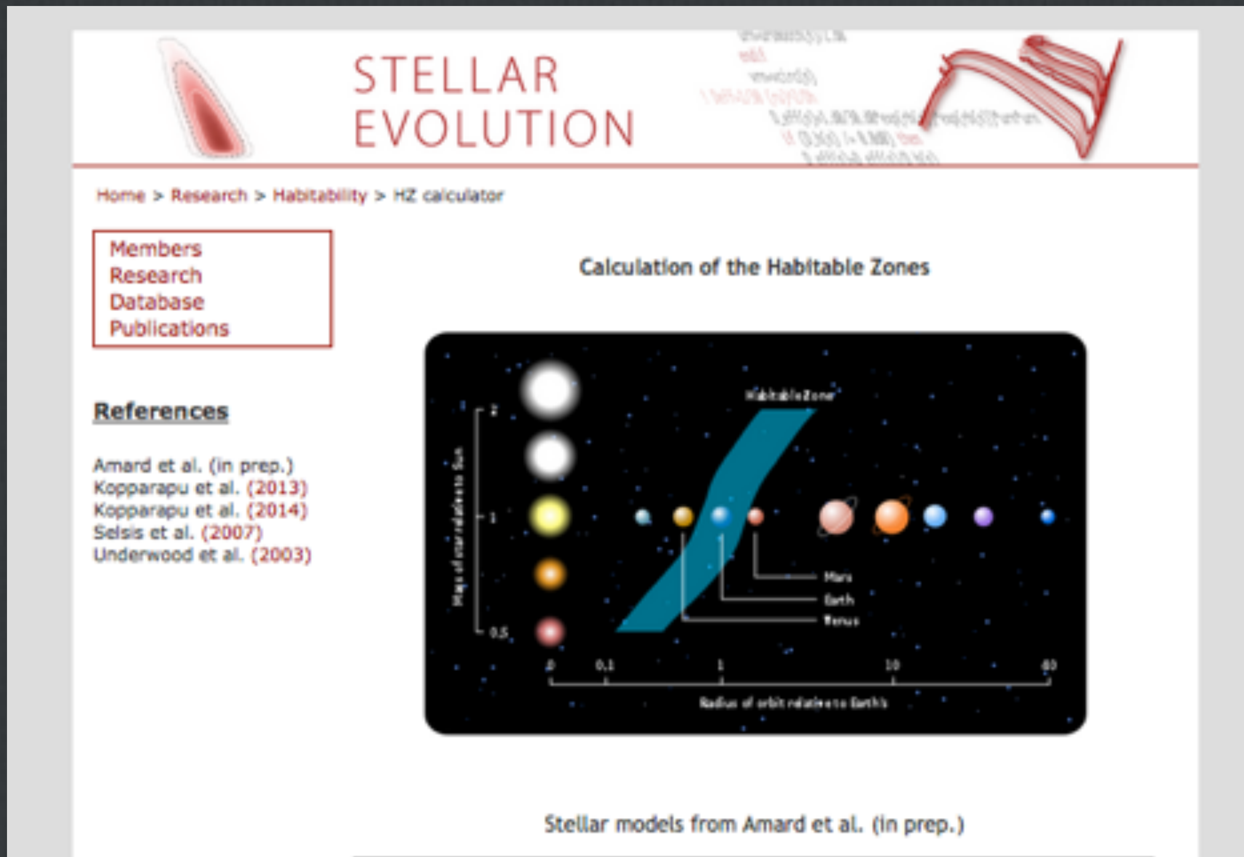


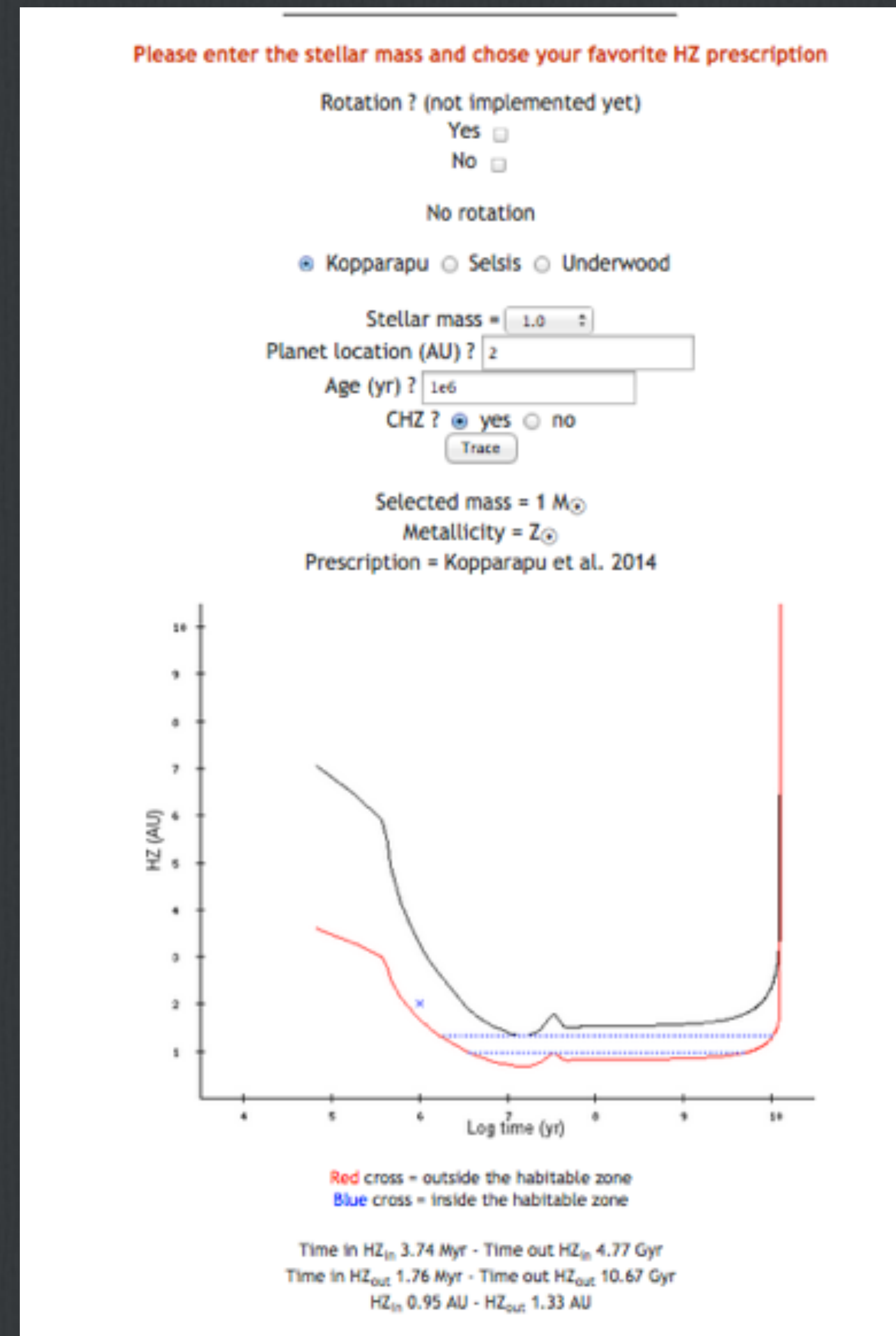
Conclusion/Perspective

- Mass and metallicity control HZ evolution
  - => require precise estimation of M_* 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

obswww.unige.ch/Recherche/evol/starevol/HZcalculator.php





Online tool already available

we will provide stellar grids and other visualisation tools

→ stay tuned