The Diversity of Chemical Composition:

The Impact of Stellar Abundances on the Evolution of Stars and Habitable Zones

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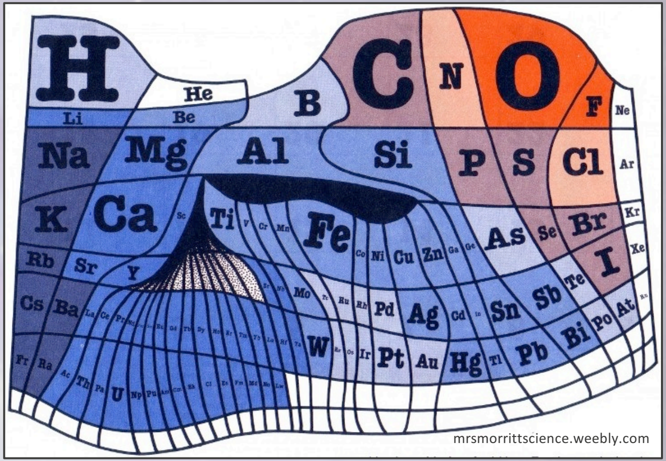
Motivating Questions

- How do stars of different masses and compositions evolve?
- How does this impact the location of a **"habitable" zone**?
- How do habitable zones **co-evolve** with their parent star?
- How will utilizing this knowledge apply to the search for habitable Earth-like planets in the future?

Elemental Abundances

- Usually only **<u>iron (Fe)</u>** is measured in stars – other elements assumed to scale in same proportion as measured in the Sun

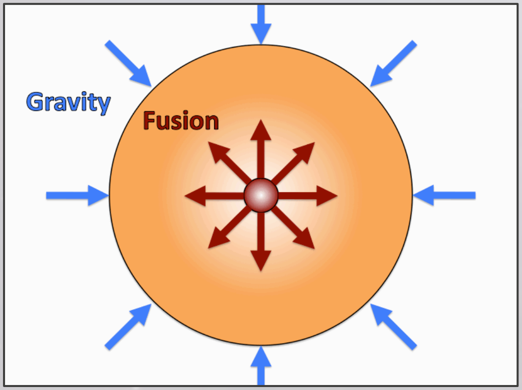


- BUT **specific chemical abundances** can vary significantly (e.g. Hinkel+2014)
  - Previous work (Young+2012) has shown <u>oxygen</u> particularly impacts the stellar evolution

Stellar Evolution: measurable physical parameters

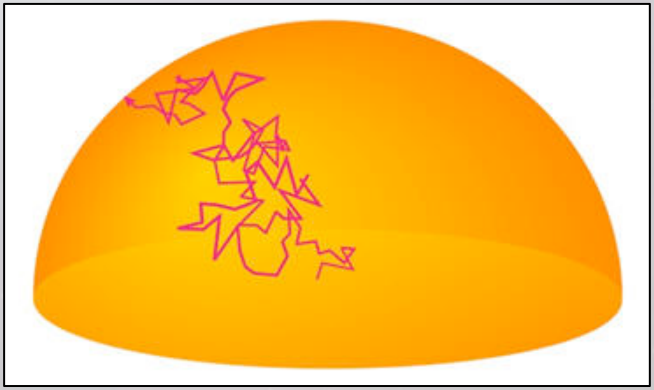
- Mass → Rate of hydrogen fusion
  - Higher mass = shorter main sequence lifetime
- Composition → Opacity, energy transport
  - Lower opacity = more efficient energy escape
  - Shorter MS lifetime than star of equal mass

http://large.stanford.edu/courses/2011/ph241/olson1/



Hydrostatic Equilibrium

http://cse.ssl.berkeley.edu/bmendez/ay10/2002/notes/lec12.html



Photon mean free path becomes short in dense material

Modeling Stellar Evolution

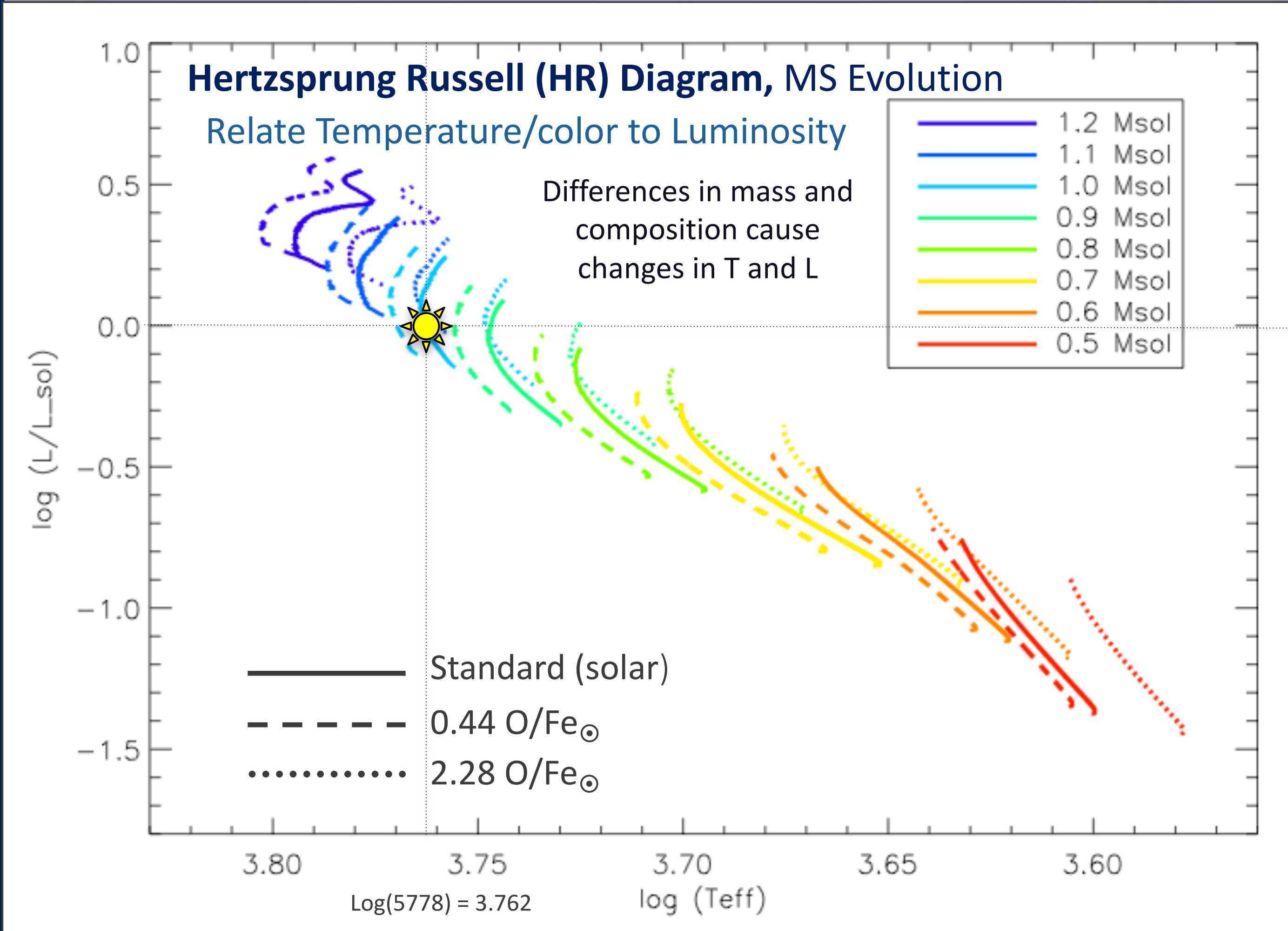
- **TYCHO** (Young & Arnett 2005)
  - **1D spherically symmetric, hydrodynamical code**
    - OPAL opacity tables & equations of state
    - Outputs **stellar surface quantities** for each time-step
- **MS Evolution**
  - ZAMS = H burning begins in core (L min on HRD)
  - TAMS = H exhaustion in core ($X_H < 10^{-6}$)

Database of Stellar Evolution Tracks:

✧ **Abundance ranges from observations of nearby stars**

- Truitt+2015 discussed grid of **376 stellar models**:
  - Mass range (FGKM):……………… $0.5 – 1.2\ M_{\odot}$
  - Scaled metallicity:…………………. $0.1 – 1.5\ Z_{\odot}$
  - **Oxygen**:………………………………. $0.44 – 2.28\ O/Fe_{\odot}$
- Truitt & Young (2017) – additional **528 models**:
  - Carbon:………………………………… $0.58 – 1.72\ C/Fe_{\odot}$
  - Magnesium:…………………………… $0.54 – 1.84\ Mg/Fe_{\odot}$
  - Neon*: (artificial range) ………… $0.5 – 2.0\ Ne/Fe_{\odot}$

*difficult to accurately measure


Hertzsprung Russell (HR) Diagram, MS Evolution
Relate Temperature/color to Luminosity
Differences in mass and composition cause changes in T and L
1.2 Msol
1.1 Msol
1.0 Msol
0.9 Msol
0.8 Msol
0.7 Msol
0.6 Msol
0.5 Msol
Standard (solar)
0.44 O/Fe⊙
2.28 O/Fe⊙
1.0
0.5
0.0
−0.5
−1.0
−1.5
log (L/L_sol)
3.80
3.75
3.70
3.65
3.60
log (Teff)
Log(5778) = 3.762

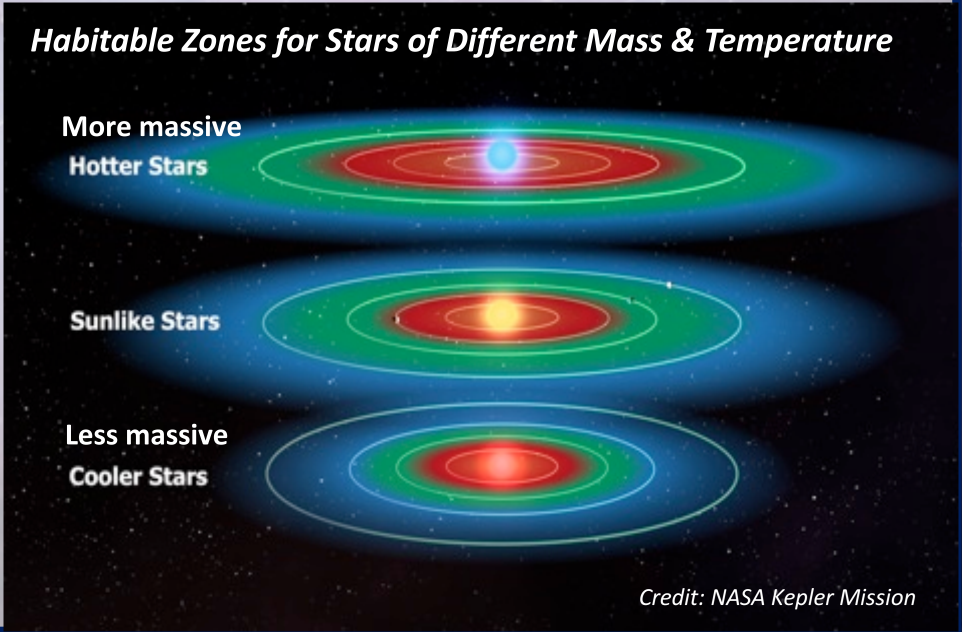
Habitable Zone (HZ)

- Region where a planet could support surface liquid water
- Stellar temperature and luminosity determine boundaries
- ***Kepler* mission: evidence for Earth-like planets in the HZ**

20% of Sun-like stars
(Petigura+2013)

50% of M-type stars
(Batalha+2013)

For different masses, the HZ is located at varying distances, AND expands outward at **different rates**



HZ Limit Equations

- **CHAD**: **C**alculating **HA**bitable **D**istances
  - ✧ Upgradable for use with other HZ prescriptions
- **Equations**: Kopparapu et al. 2013

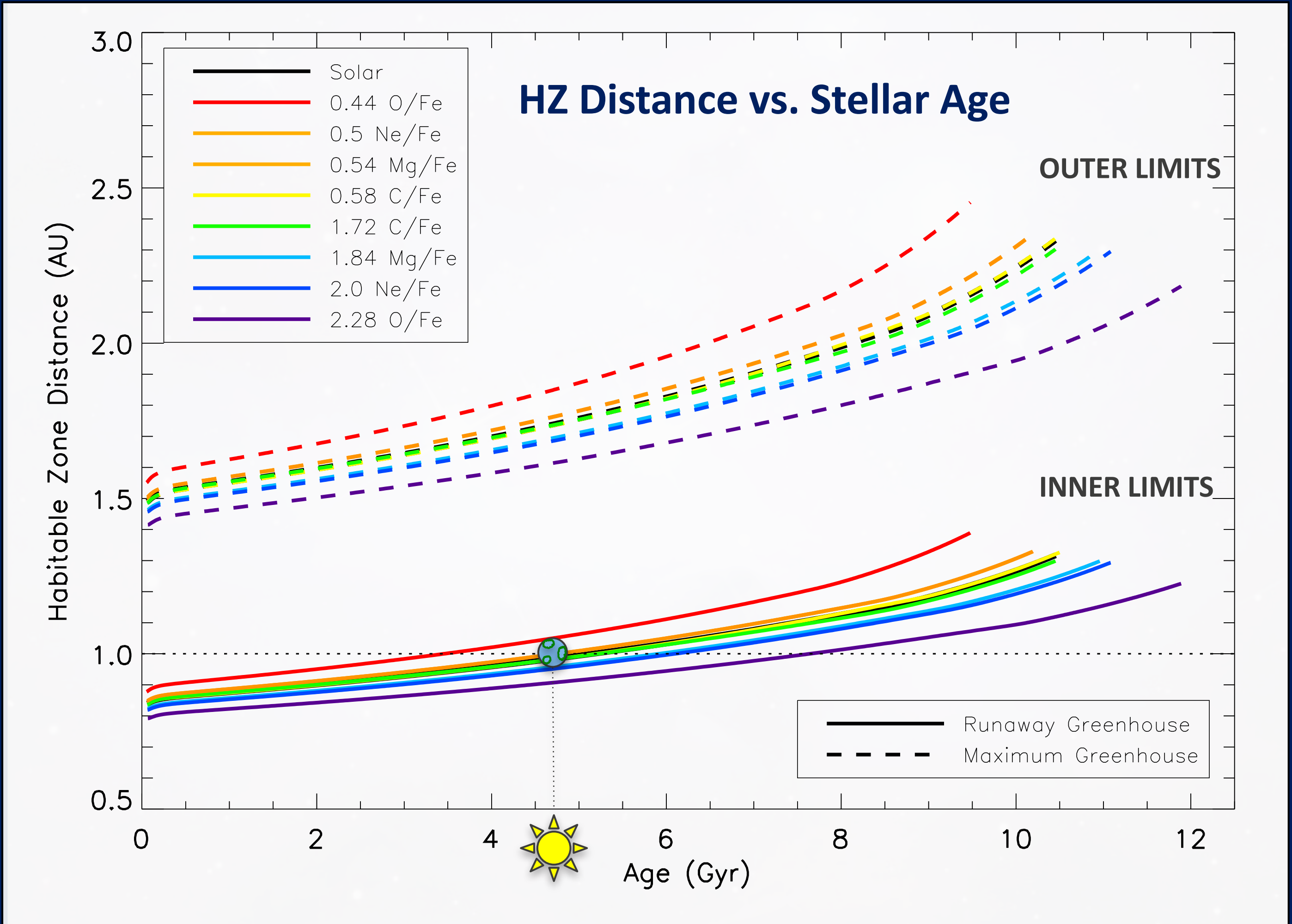
$$S_{\rm eff} = S_{\rm eff\odot} + aT_\star + bT_\star^2 + cT_\star^3 + dT_\star^4,$$

$$T_\star = T_{\rm eff} - 5780\ {\rm K}$$

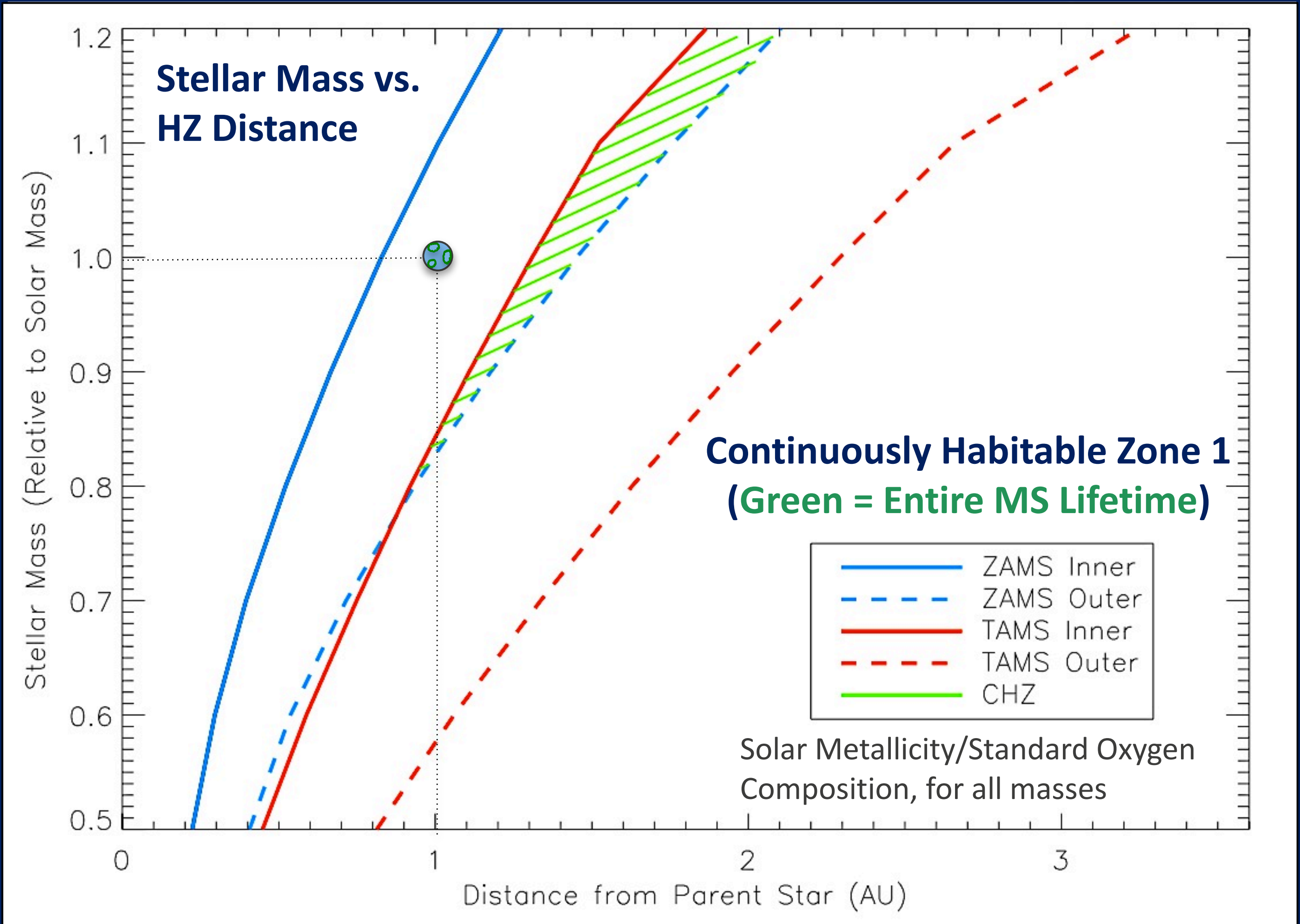
$$d = \left(\frac{L/L_\odot}{S_{\rm eff}}\right)^{0.5} {\rm AU},$$

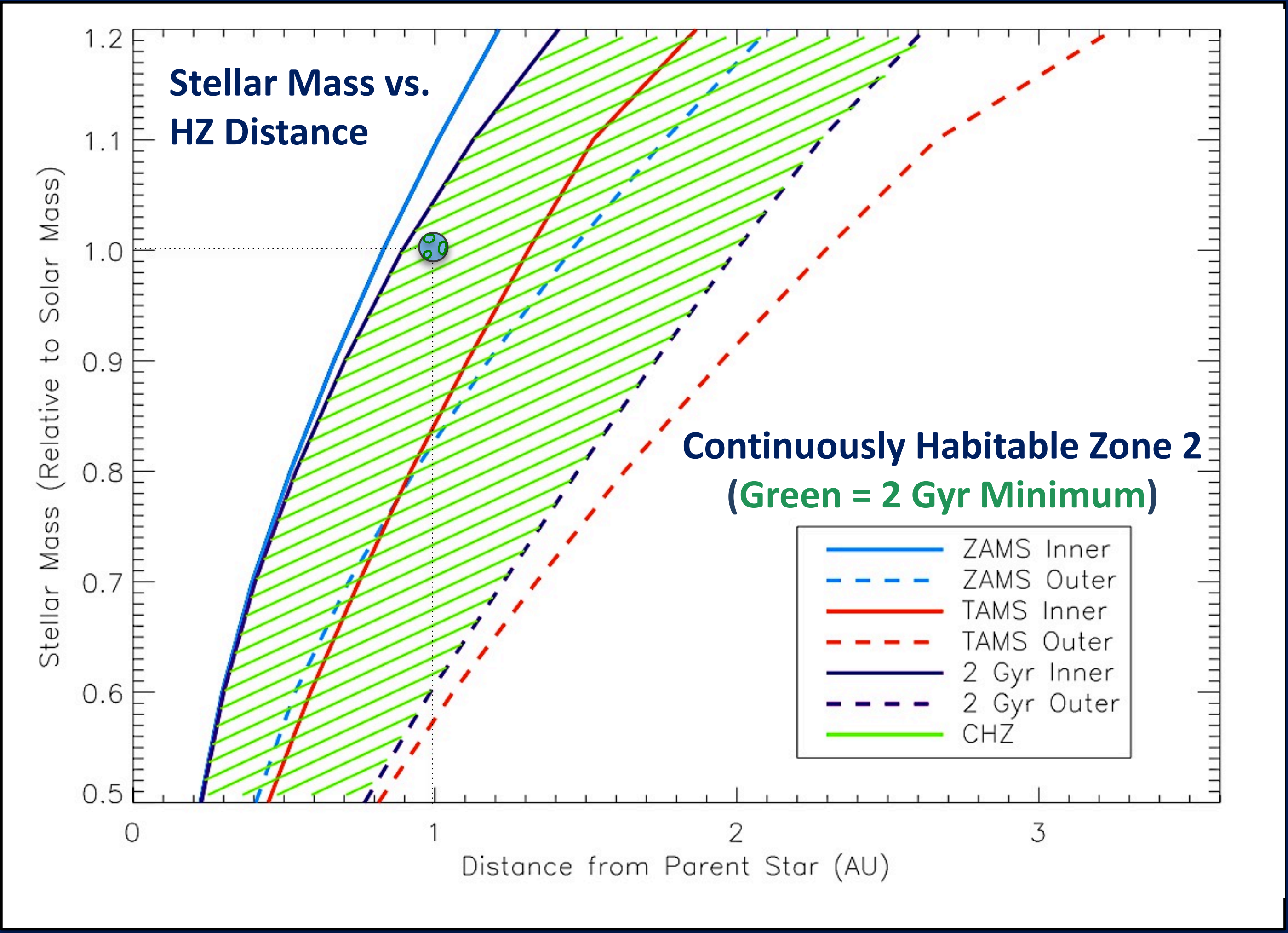
- **Limits**: Kopparapu et al. 2014
  - ✧ **Conservative** cases: Runaway Greenhouse (**RGH**) to Maximum Greenhouse (**MaxGH**)

Calculating Habitable Zones

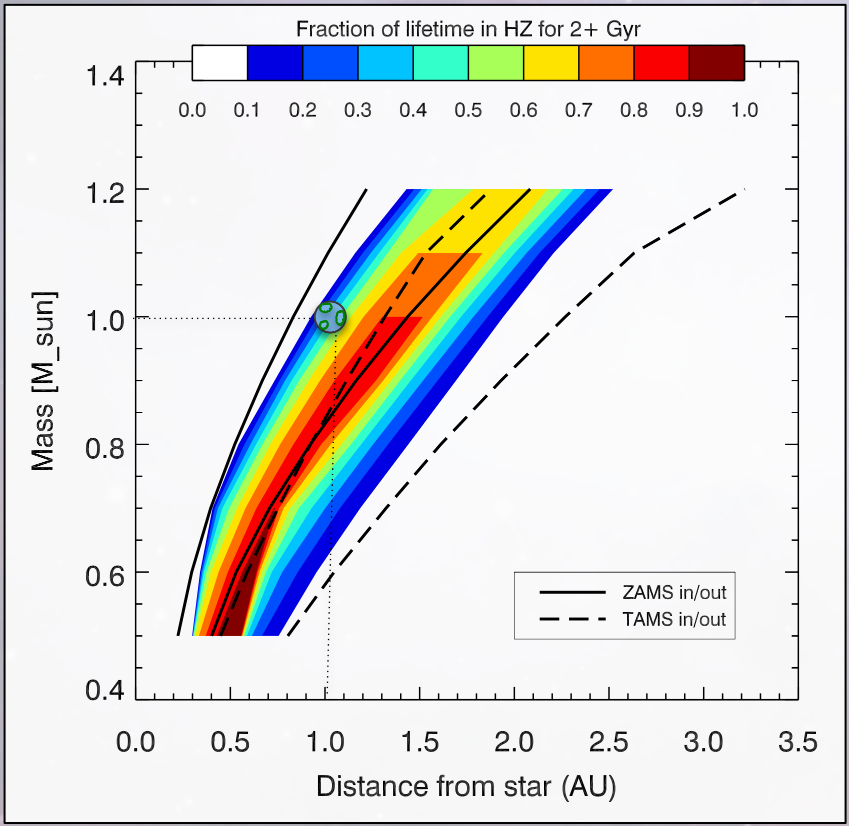


"Continuous" Habitability




Stellar Mass vs.
HZ Distance
Continuously Habitable Zone 2
(Green = 2 Gyr Minimum)
ZAMS Inner
ZAMS Outer
TAMS Inner
TAMS Outer
2 Gyr Inner
2 Gyr Outer
CHZ
Stellar Mass (Relative to Solar Mass)
Distance from Parent Star (AU)
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
0
1
2
3

Stellar Mass vs. HZ distance (AU)



If we don't know **stellar age**, what is the likelihood that at any given time we observe a star (with known planets) it would have a planet in the 2 Gyr CHZ?

All masses, at 1 Zsol

Take Home Points

- ✧ **The concept of planetary habitability is complex**; I approach the problem from the astrophysical (and statistical) perspective
- ✧ I have considered how **stellar evolution directly influences the time-dependent location of the HZ** around stars
- ✧ Specific **abundance ratios** and the **overall scaled metallicity** (Z) both influence the MS evolution of stars (differences in opacity)
- ✧ Given the classical HZ definition, characterizing a host star is extremely important in order to evaluate **long-term habitability potential** of a system

Thank You!