ICCUB Winter meeting 2024

The Galactic Habitable Zone

Chloé Padois

PhD supervisors: Friedrich Anders & Daniel del Ser

MWGaiaDN

This project is a Horizon Europe Marie Skłodowska-Curie Actions Doctoral Network funded under grant agreement no. 101072454.

Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA

Summary

1) Overview of current knowledge on exoplanet population

2) Galactic habitability: the Galactic Habitable Zone (GHZ)

3) PhD work & goals

1) Overview of current knowledge on exoplanet population

- First detection of an exoplanet around a Sun-like star: Nobel Prize 2019

ARTICLES

A Jupiter-mass companion to a solar-type star

Michel Mayor & Didier Queloz

Geneva Observatory, 51 Chemin des Maillettes, CH-1290 Sauverny, Switzerland

The presence of a Jupiter-mass companion to the star 51 Pegasi is inferred from observations of periodic variations in the star's radial velocity. The companion lies only about eight million kilometres from the star, which would be well inside the orbit of Mercury in our Solar System. This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.

NATURE · VOL 378 · 23 NOVEMBER 1995

- 5572 confirmed detections since 1995 (https://exoplanetarchive.ipac.caltech.edu/)

1) Overview of current knowledge on exoplanet population

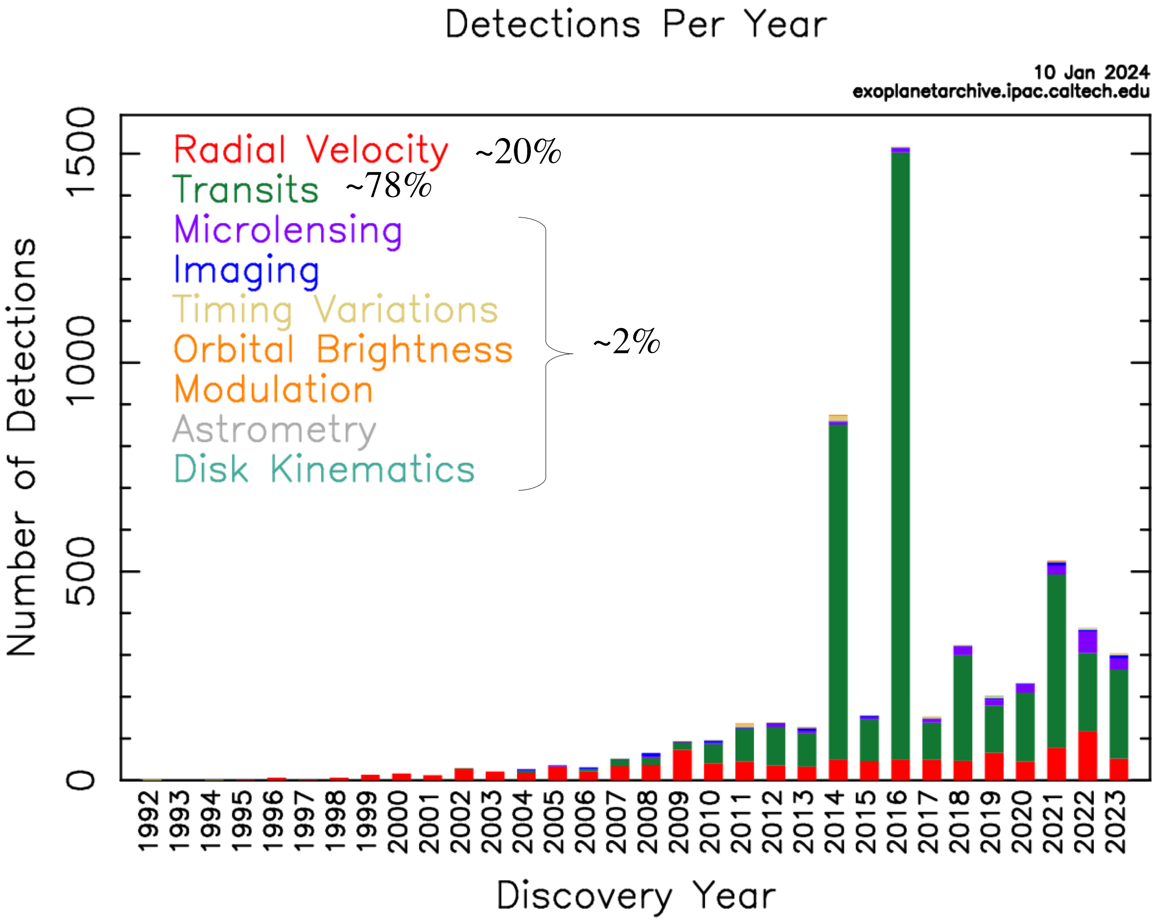
- Different methods of detection:

2006-2013

2009-2018

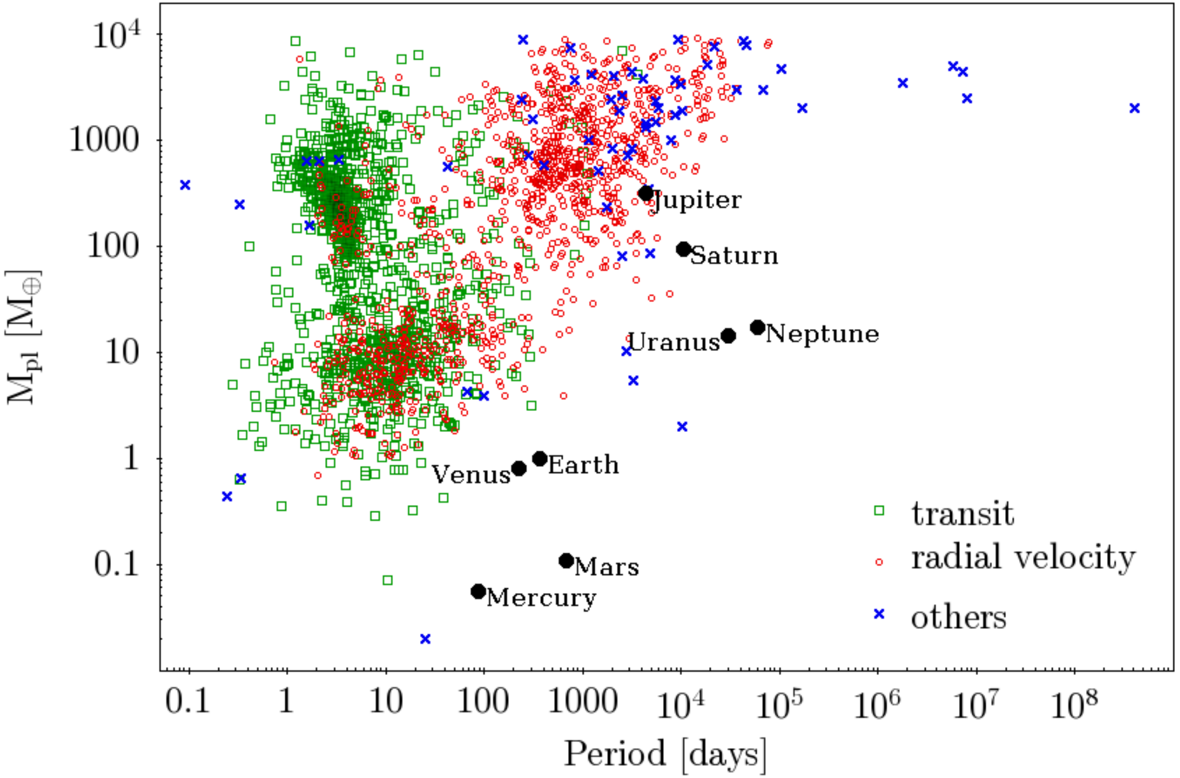
2018-

2026-



1) Overview of current knowledge on exoplanet population

- Classified in ≠ categories:
  - super-Earths
  - hot / cold Jupiters
  - and others…



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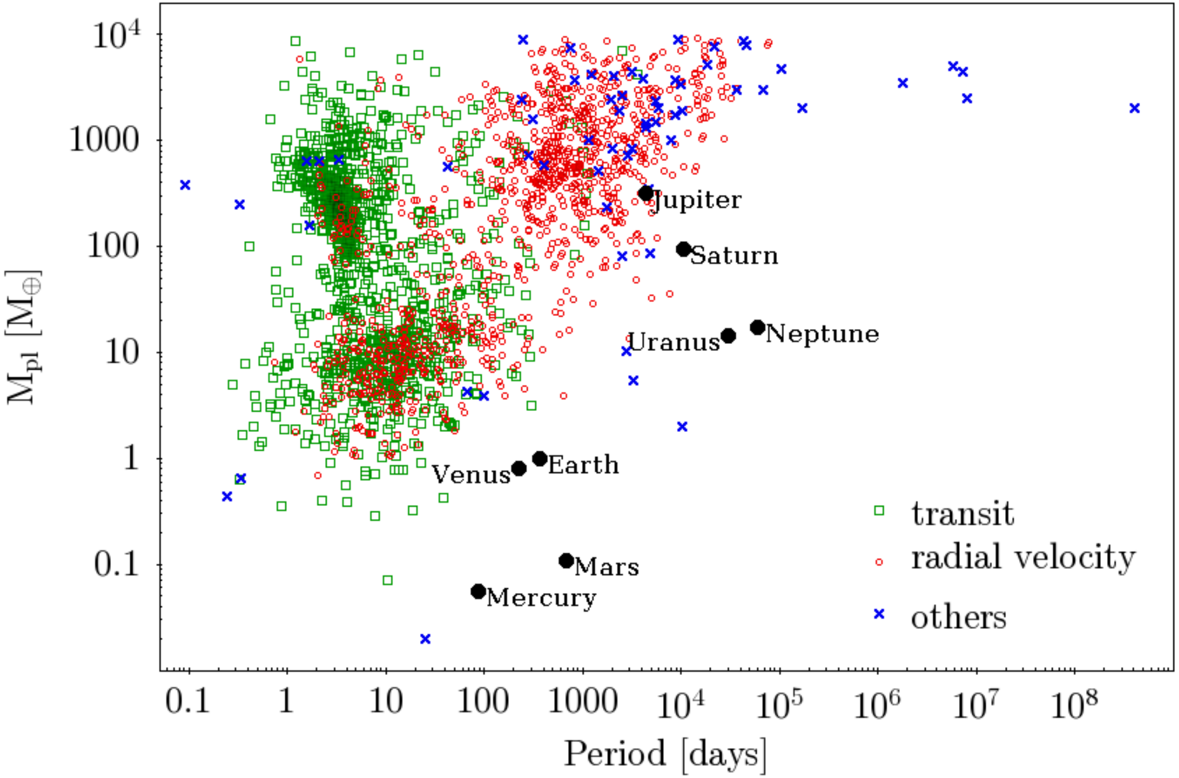
- Detection of only a small fraction of all exoplanets:
  - Instrumental limitations
  - Systems configuration



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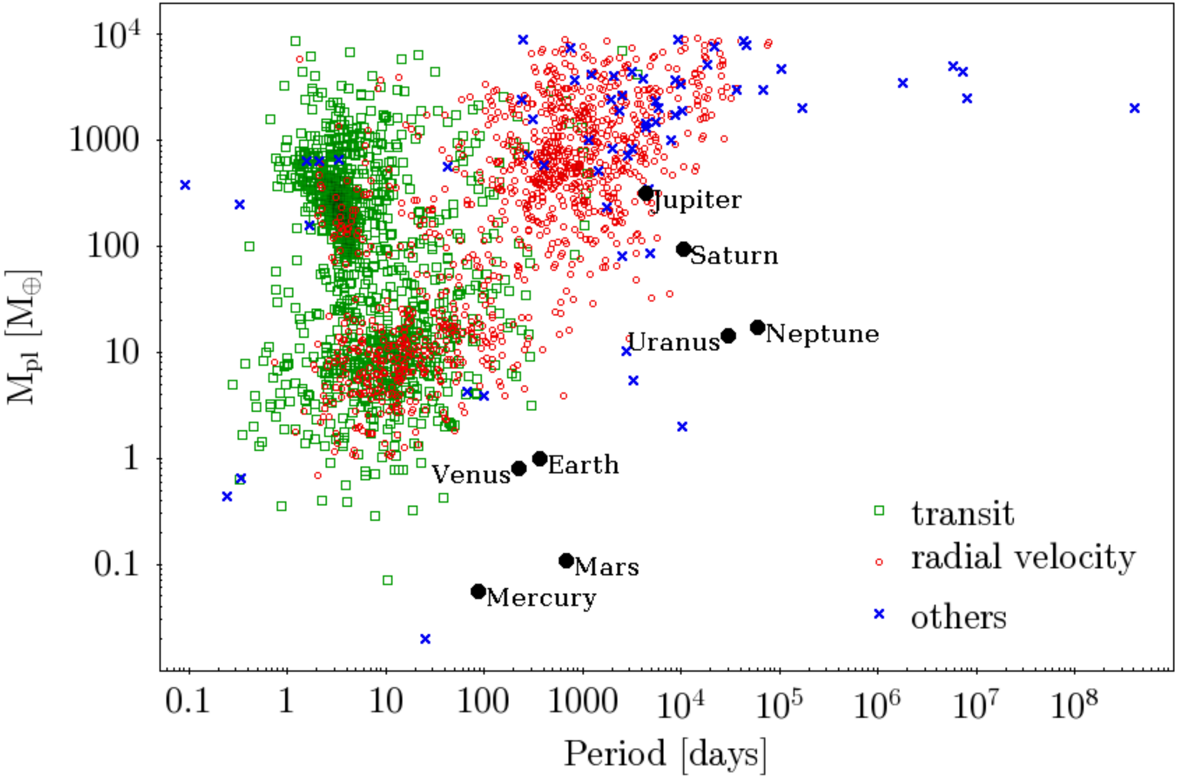
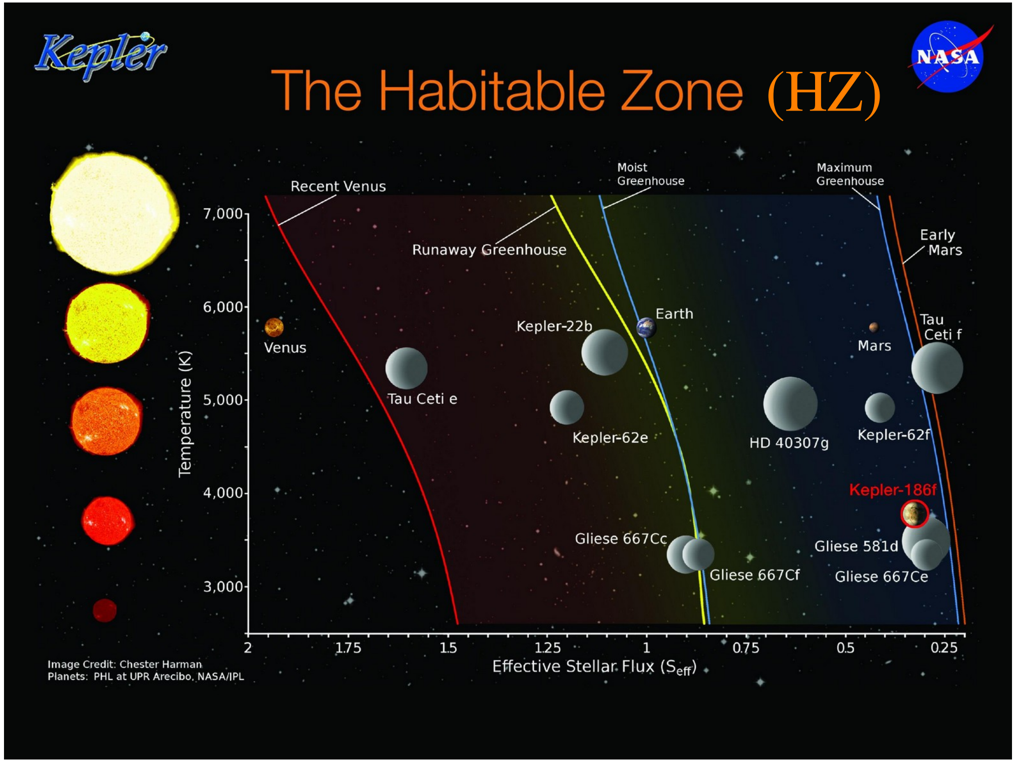
- Where are habitable planets?



1) Overview of current knowledge on exoplanet population

- Definition of an "habitable" planet:
  - rocky planet
  - can host liquid water (depend on star's properties and distance)
  - definition of the HZ, atmosphere, etc...



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- Definition of an "habitable" planet:
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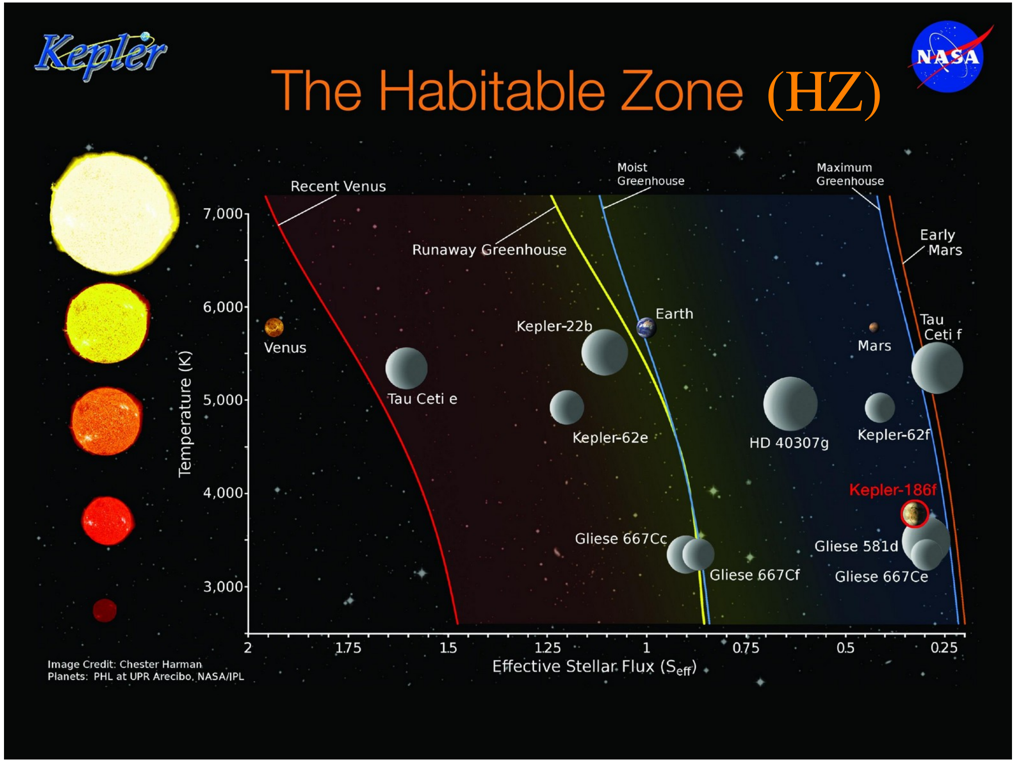
- Can rocky planets appear around all types of stars?
  - new criteria: the hoststar **metallicity**



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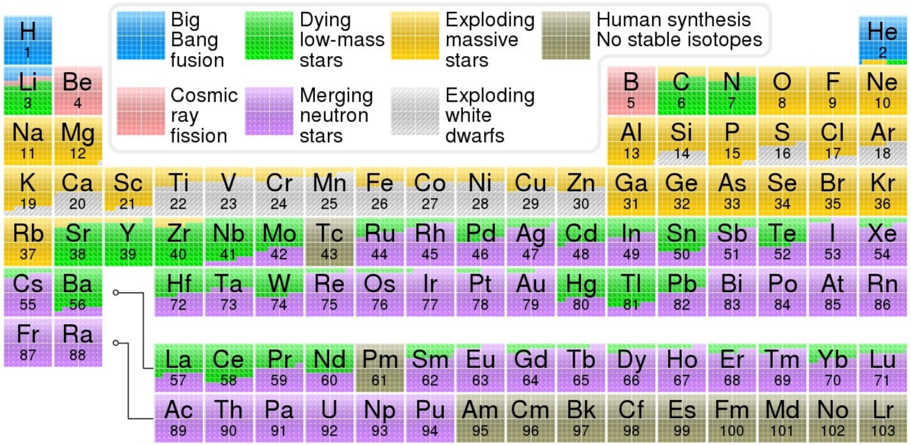

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$$X + Y + Z = 1$$

$$[\mathrm{Fe/H}] = \log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\star} - \log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\odot}$$

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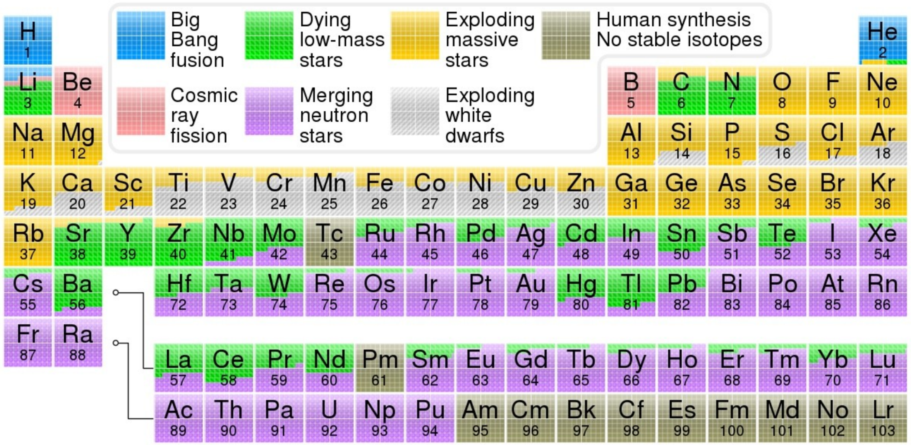

Hypothesis: minimal amount of metals needed to form rocky planets

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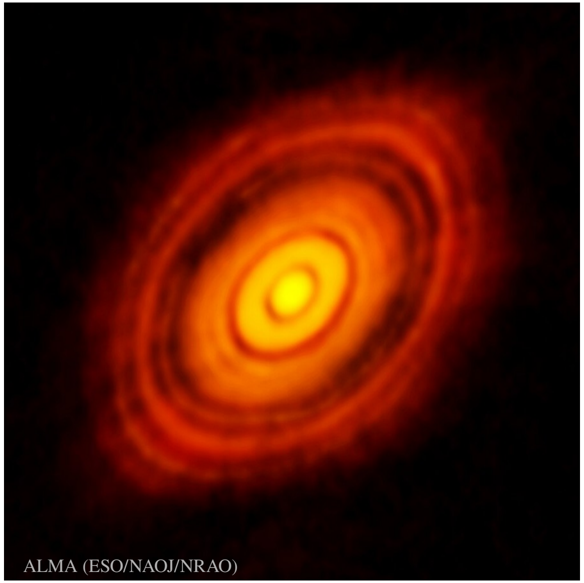

Probability of forming rocky planets related to the star metallicity.

↑

Hypothesis: minimal amount of metals needed to form rocky planets

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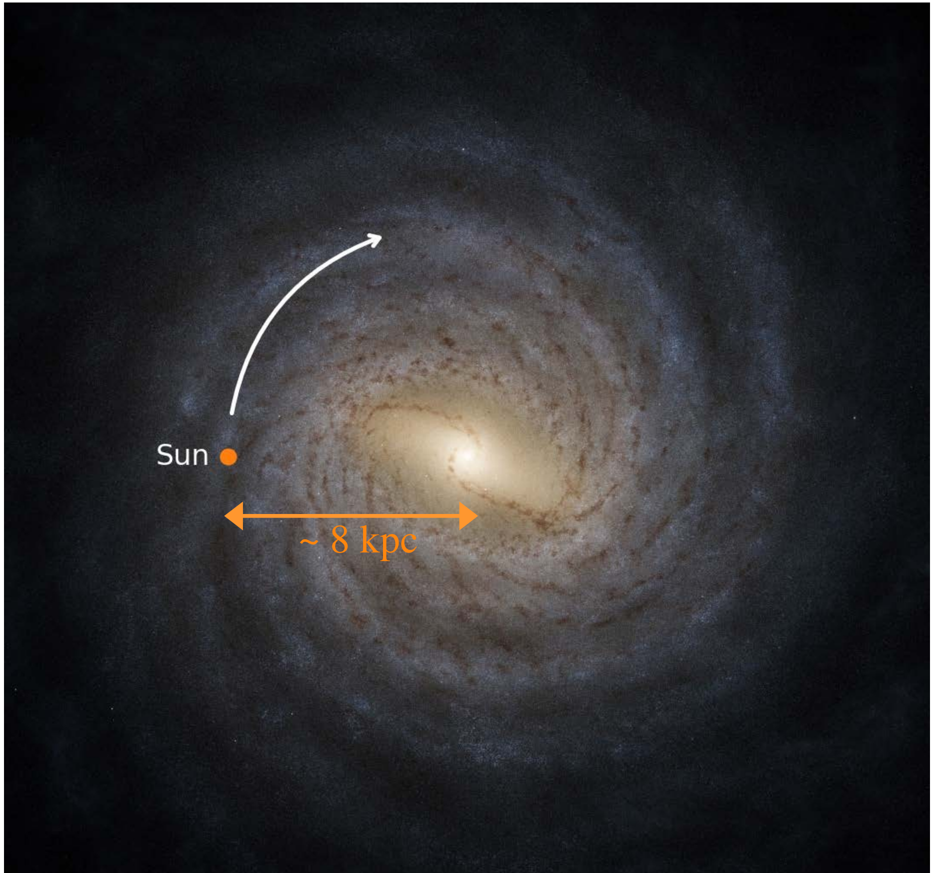
- Can we find rocky planets everywhere in the galaxy?
  - Metallicity is not uniform in the MW



From ESA/Gaia/DPAC; CC BY-SA 3.0 IGO, Stefan Payne-Wardenaar/MPIA.

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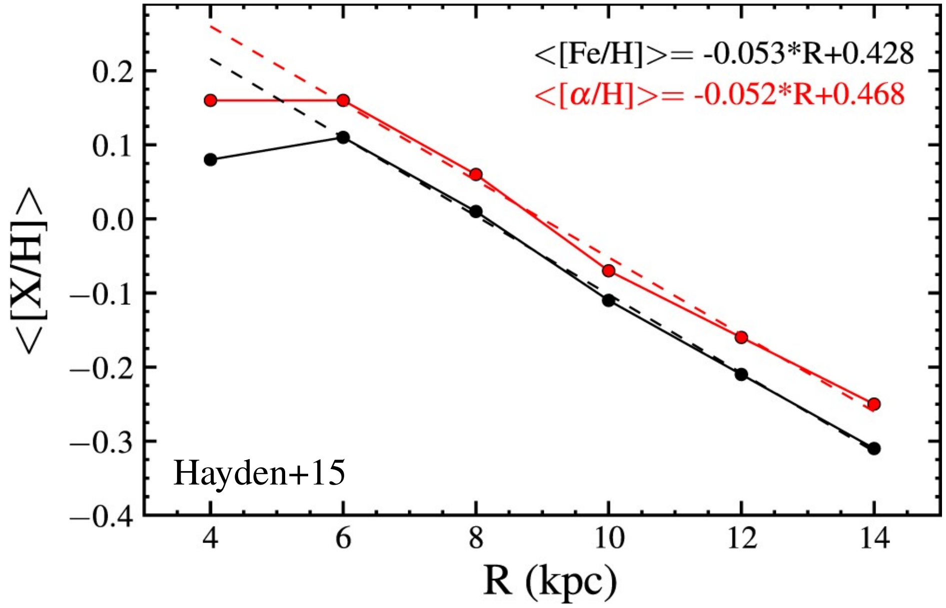
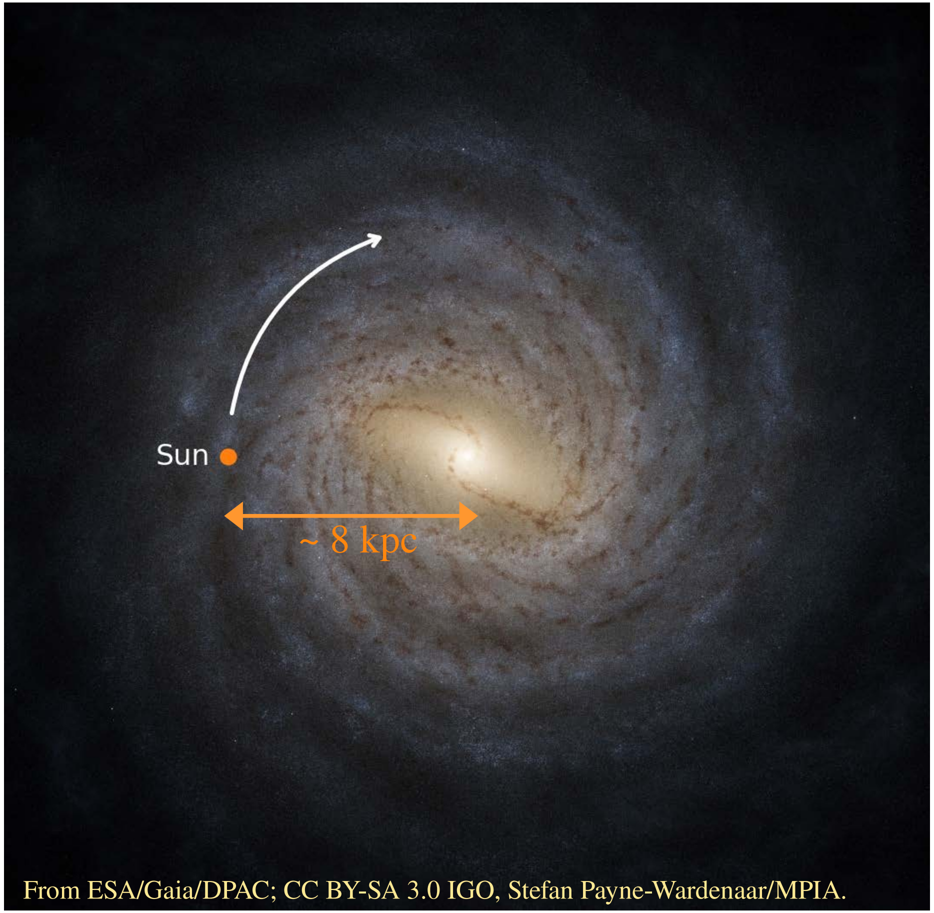
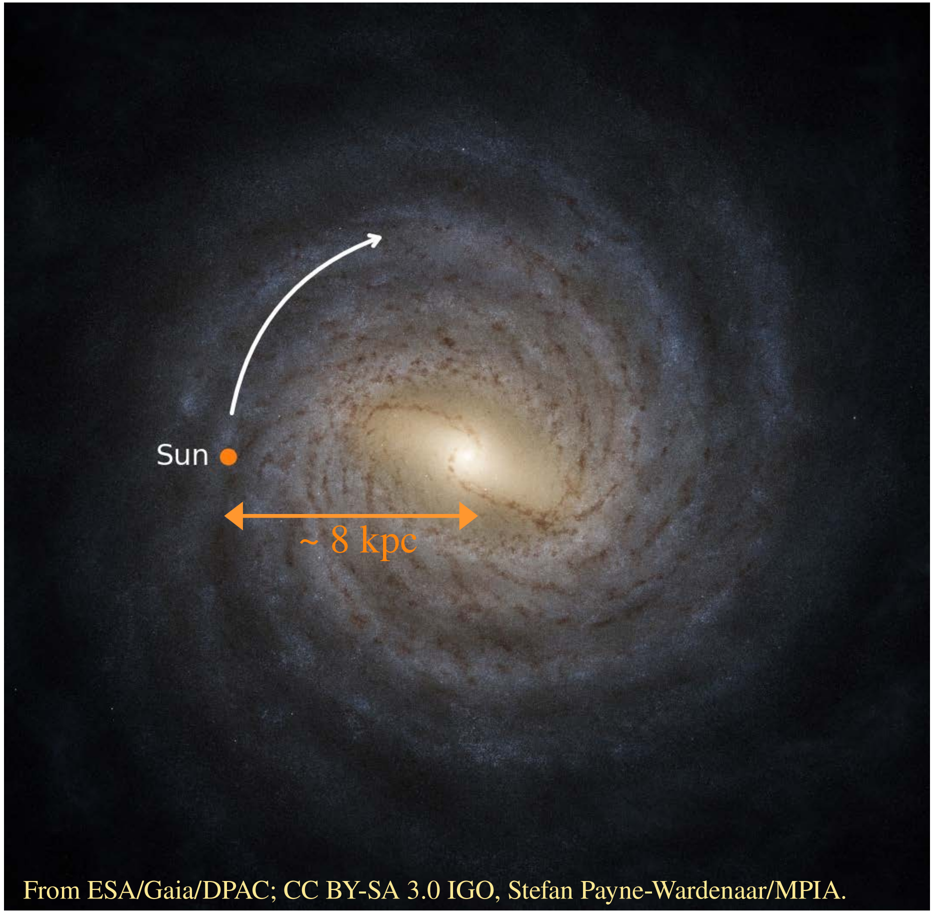


GHZ: the Galactic Habitable Zone



2) The Galactic Habitable Zone (GHZ)

$$P_{\text{GHZ}} \sim \text{SFR} \times P_{\text{metals}} \times P_{\text{SN}}$$



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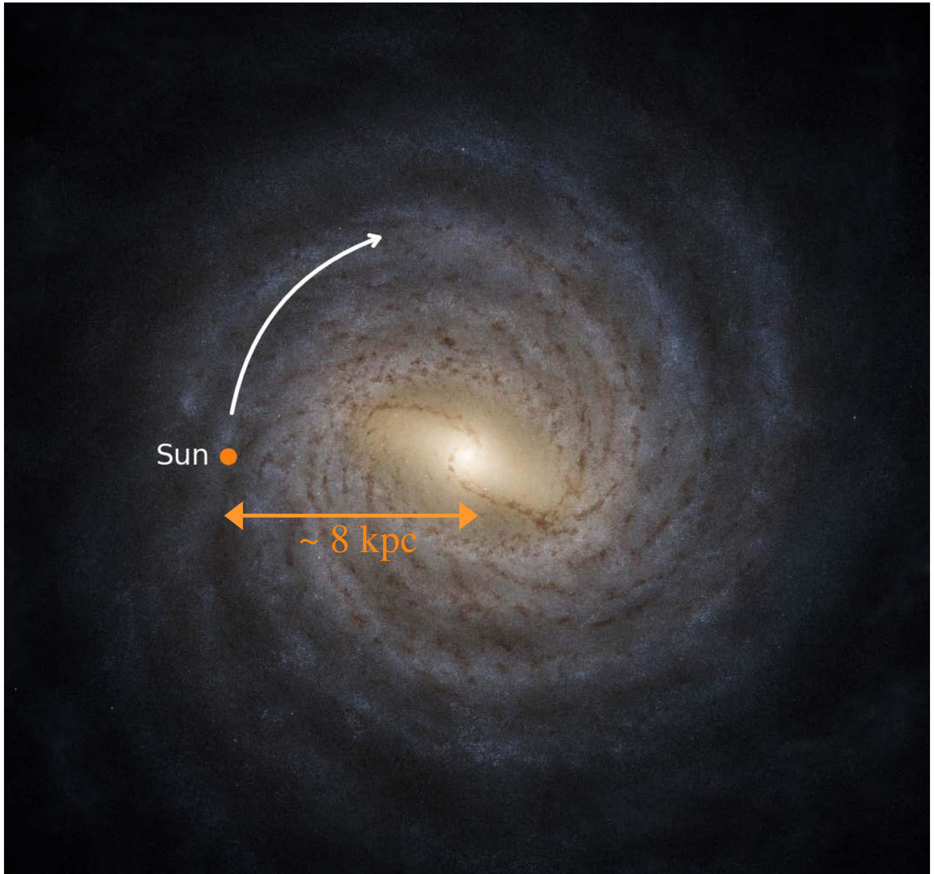
2) The Galactic Habitable Zone (GHZ)

$$P_{GHZ} \sim SFR \times P_{metals} \times P_{SN}$$

SFR: Star Formation Rate

$M_\odot \cdot yr^{-1}$



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2) The Galactic Habitable Zone (GHZ)

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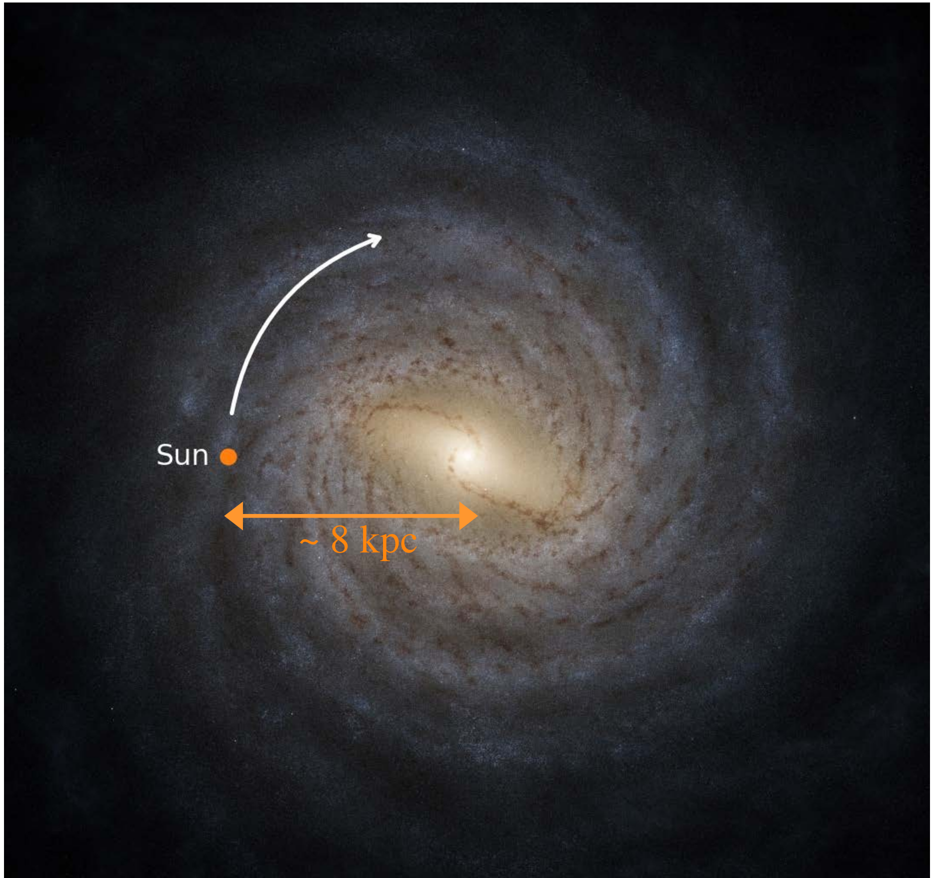
P_metal = probability of having a rocky planet around a star given its metallicity



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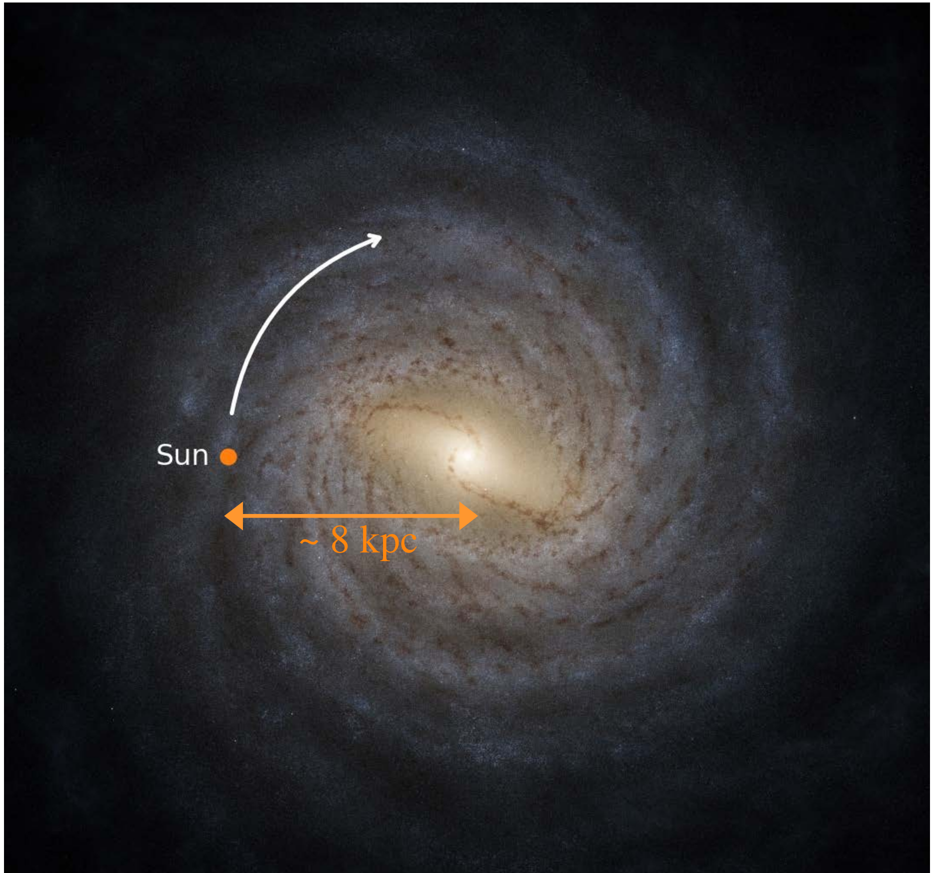
2) The Galactic Habitable Zone (GHZ)

$$P_{GHZ} \sim SFR \times P_{metals} \times P_{SN}$$

P_SN = survival probability of life given the local SN rate



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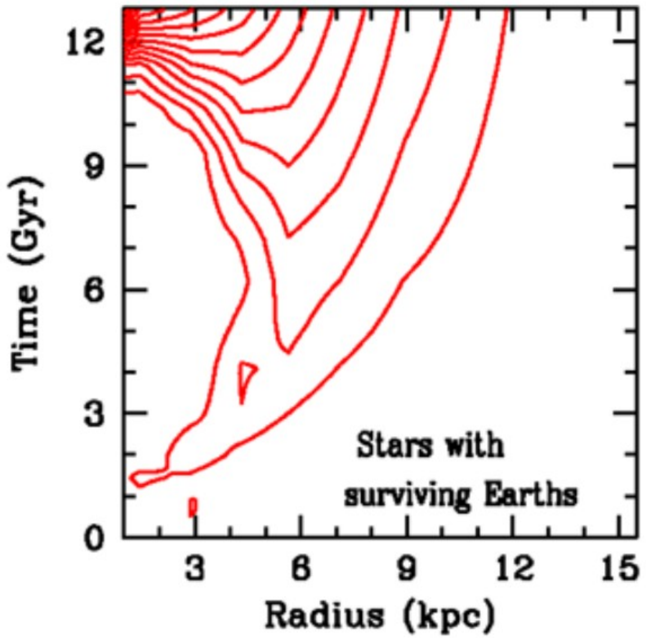
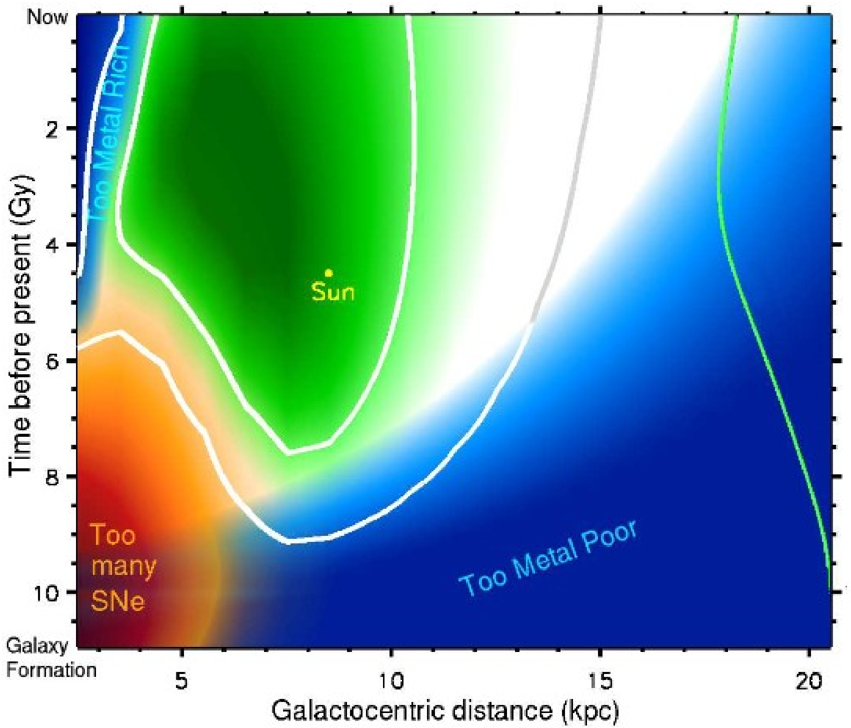
Prantzos+08



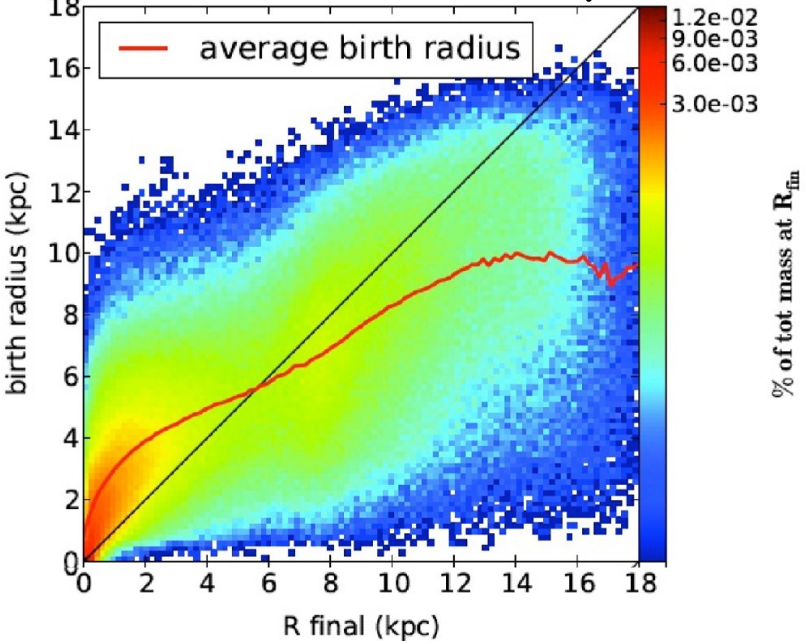
Lineweaver+04



2) The Galactic Habitable Zone (GHZ)

- Challenges: **radial mixing** induces a blurring of the GHZ boundaries

Kubryk+13



➜ simulations needed to integrate radial migration in the GHZ study

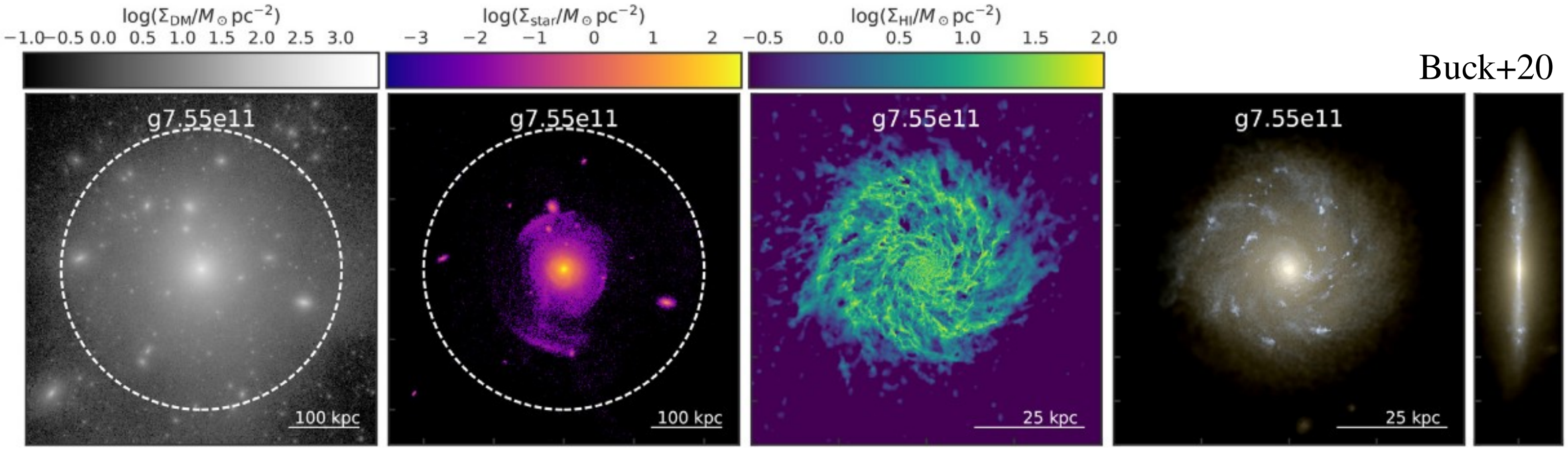
3) PhD work & goals

- Simulate a realistic exoplanet population (ongoing)
  - Solar neighbourhood
  - Kepler's field
  - entire Galaxy...
- Compare with actual observations (future)
- Study the radial mixing influence (future)

3) PhD work & goals

- Simulate the Solar neighbourhood exoplanet population
  - Simulation of a Galaxy similar to the MW

Buck+20



Dark matter Stars Gas Optical

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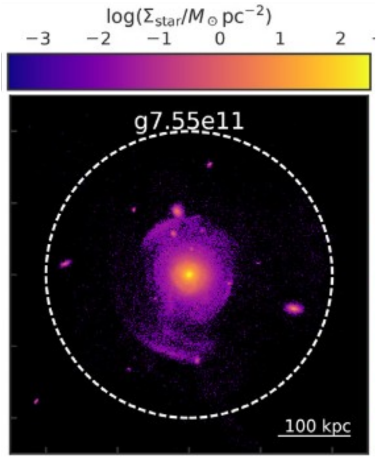
4.556.857
"stellar particles"



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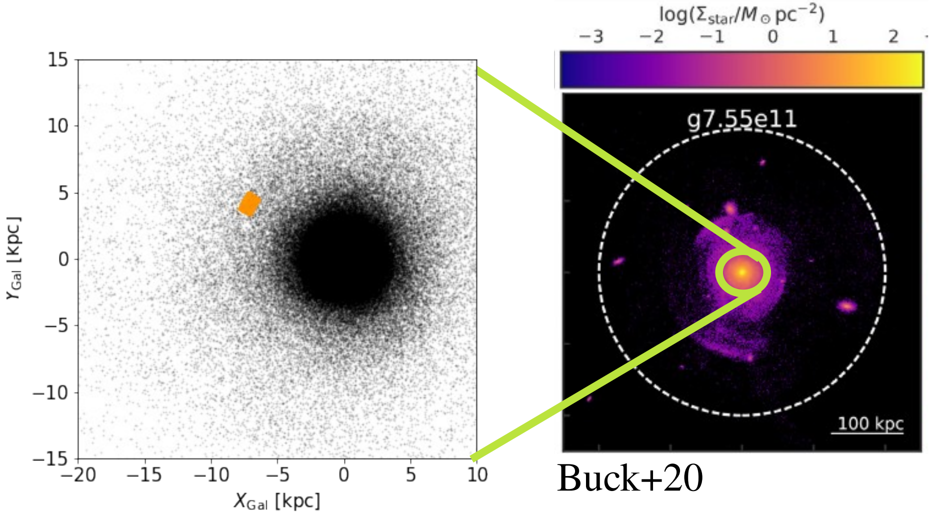

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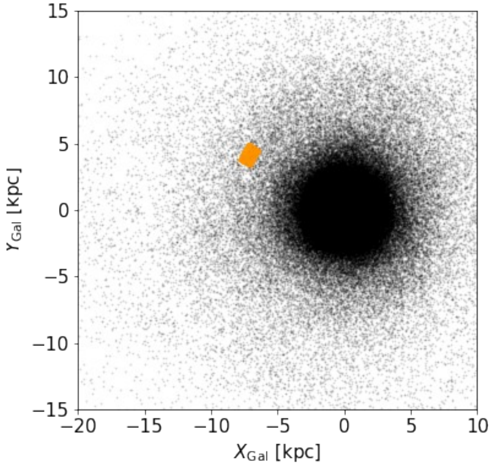

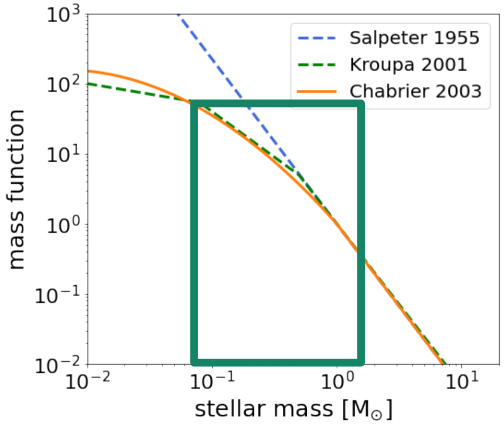

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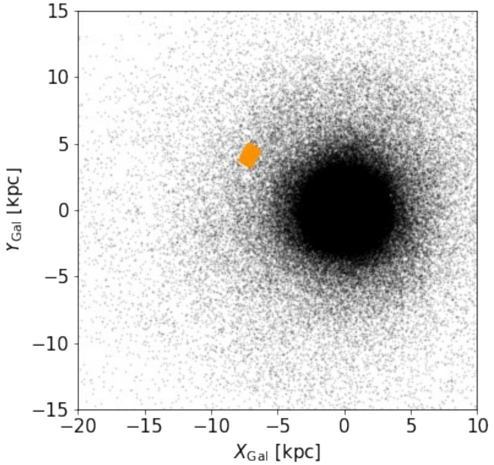

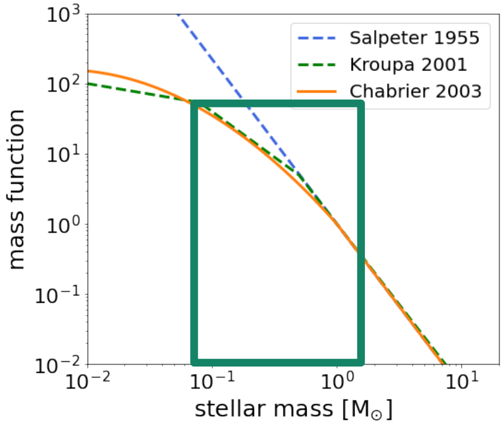

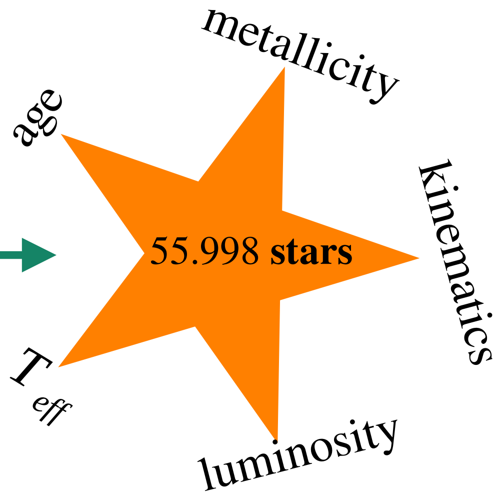

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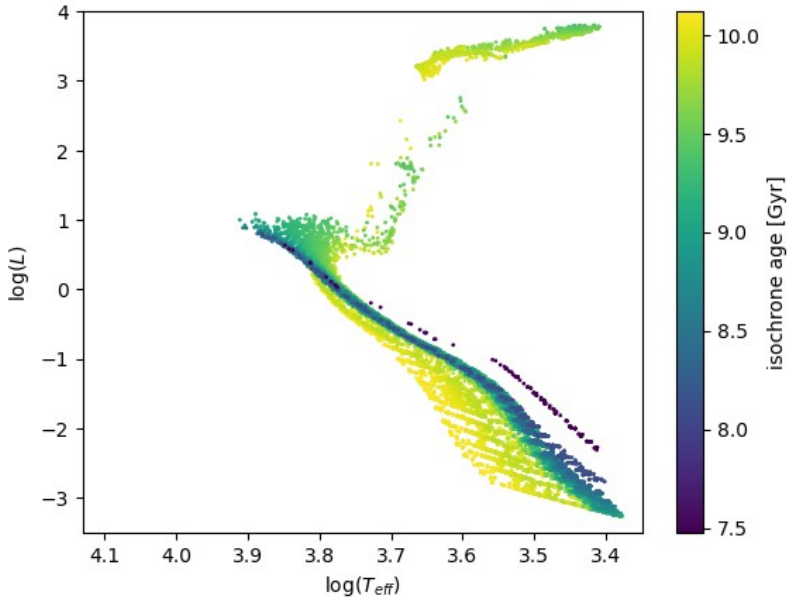

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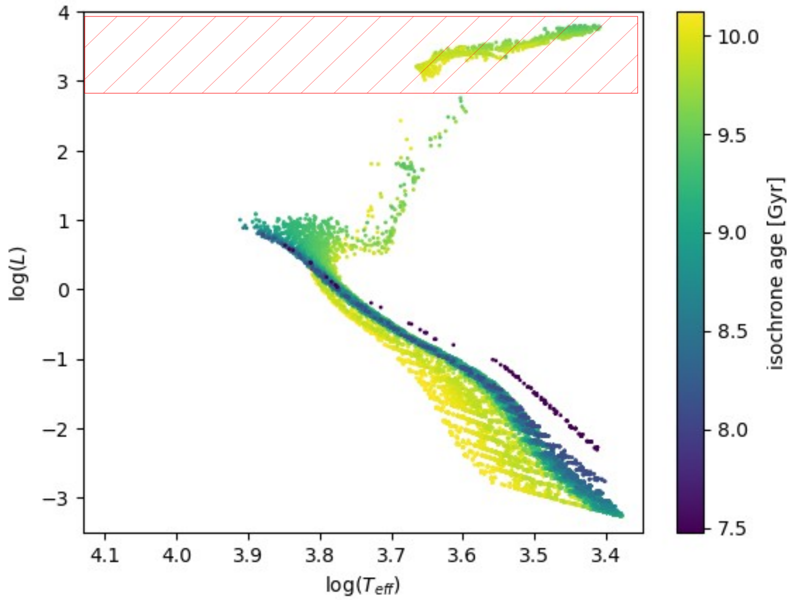

- Exclusion of stars too young/old

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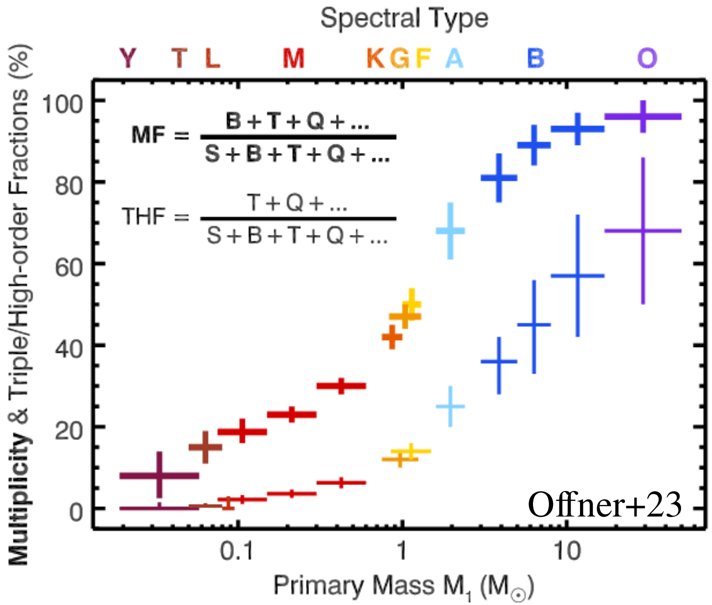

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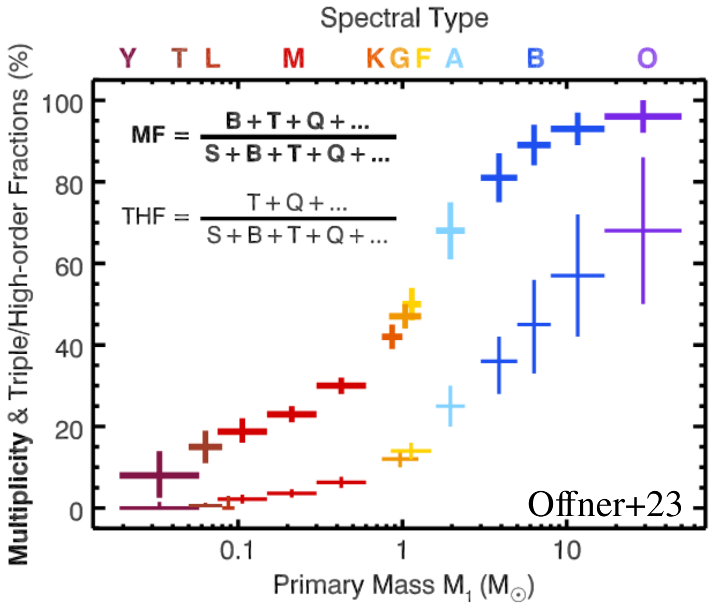

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40.605
stars

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- Simulate the Solar neighbourhood exoplanet population
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  - “creation” of a population of stars
  - “creation” of 1 exoplanet per star

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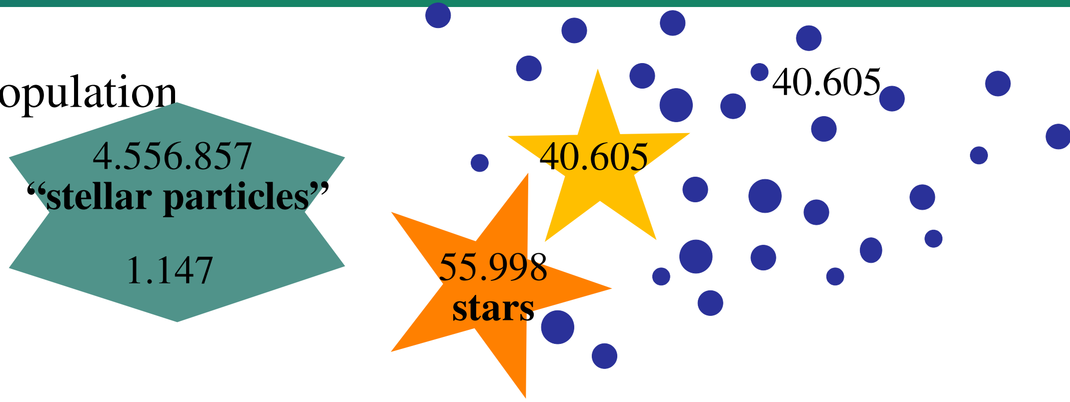

  - “creation” of 1 exoplanet per star:
    - Semi-mayor axis: uniform distribution from relative a_{Mercury} to a_{Jupiter}
    - Radius: uniform distributions from $0.4\ \mathrm{R}_{\oplus}$ to $2\ \mathrm{R}_{\oplus}$

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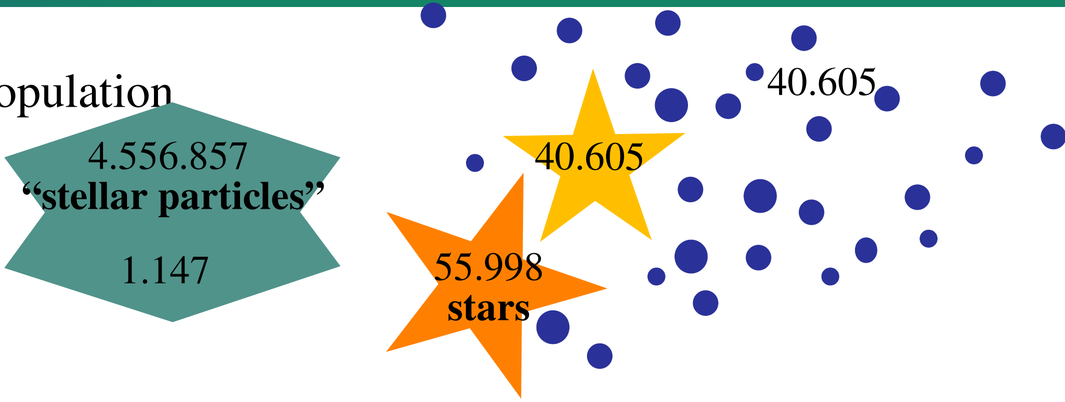

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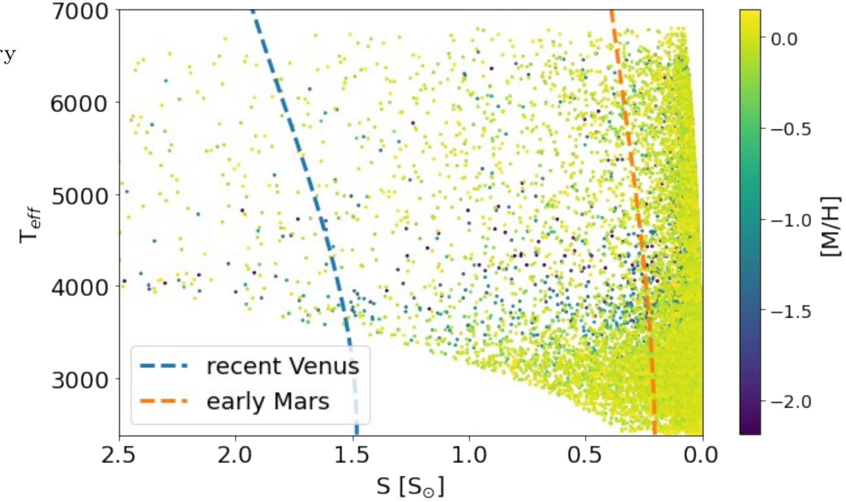

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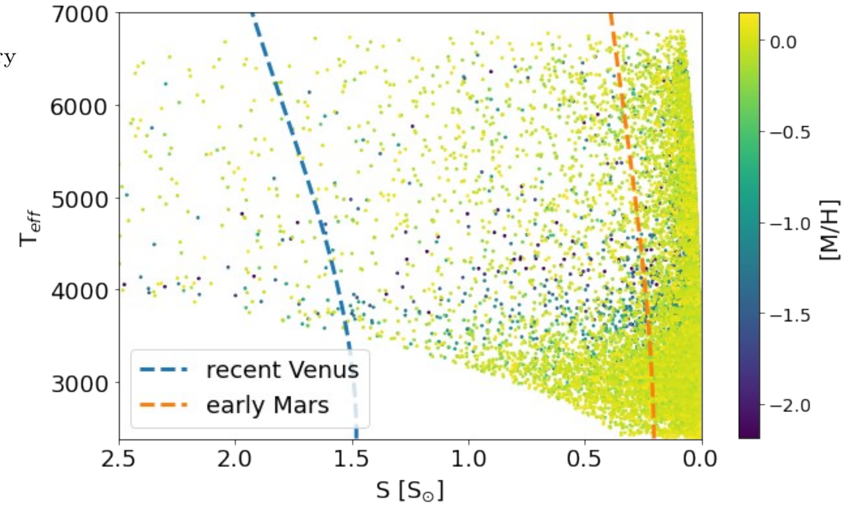
3437
planets ∈ HZ



Conclusion

Main goals:

- Complexify exoplanet simulation
  - more realistic radius and distance distributions
  - multi-planetary systems
  - others: include all types of exoplanets, include binaries, ...

- Apply an observational selection function to the simulated exoplanet population: compare the result with actually observed population

- Extend the simulation to the entire galaxy

- Study stellar migration and its influence on the (past & present) GHZ boundaries

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The Galactic Habitable Zone

moltes gràcies!

Chloé Padois

PhD supervisors: Friedrich Anders & Daniel del Ser

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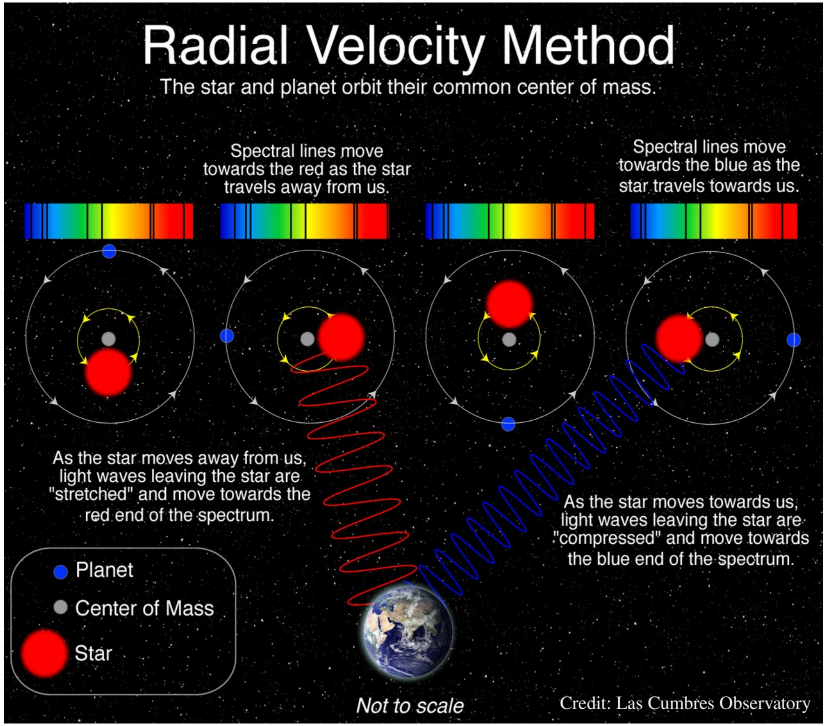
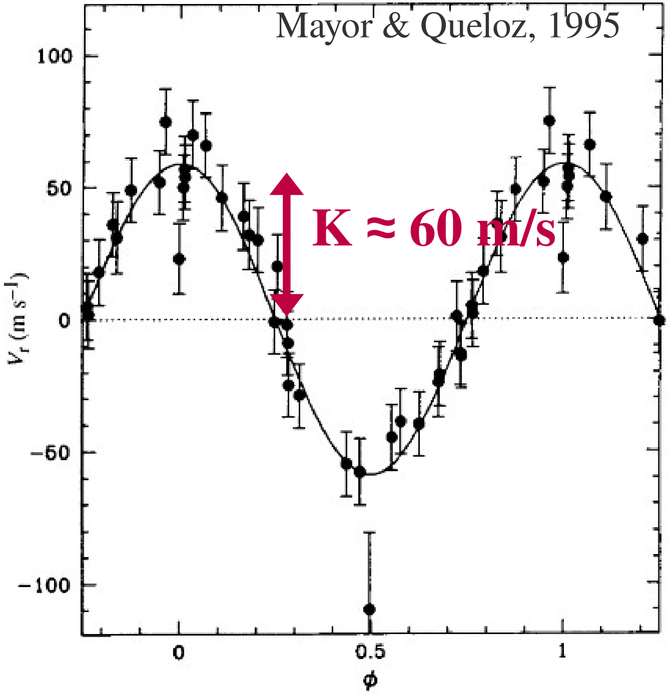
Radial Velocity (RV)

Spectroscopy: ELODIE (OHP), HARPS (ESO), etc.





$K_{\mathrm{Jupiter}} \simeq 12.5$ m/s
$K_{\mathrm{Earth}} \simeq 0.09$ m/s

$$\mathbf{M_{pl}} \cdot \sin i \propto \mathbf{K}\ \mathrm{P}^{1/3}\,(\mathrm{M}_s + \cancel{\mathrm{M_{pl}}})^{2/3}$$

The Habitable Zone

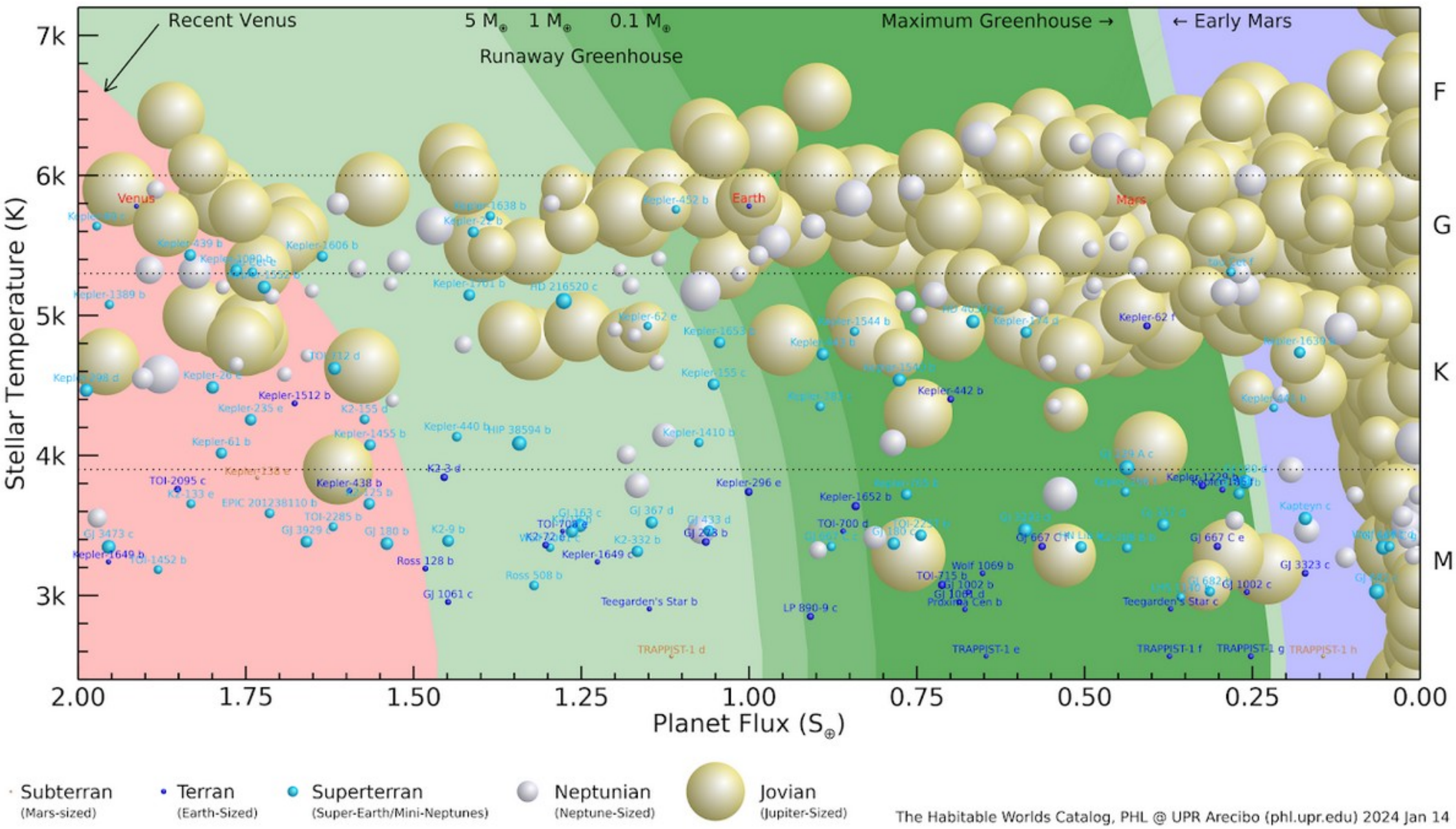
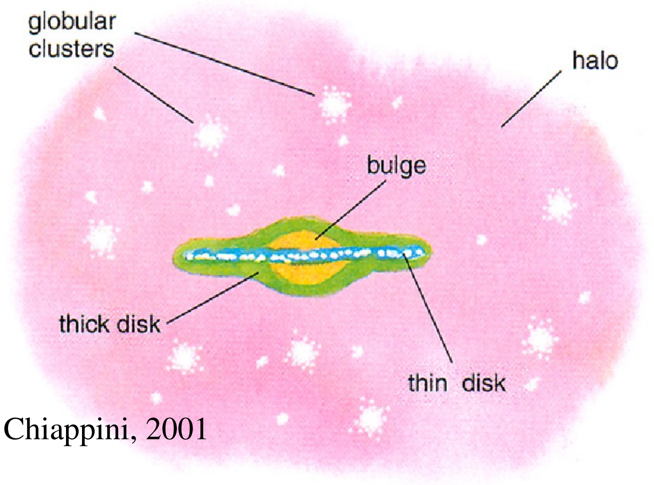
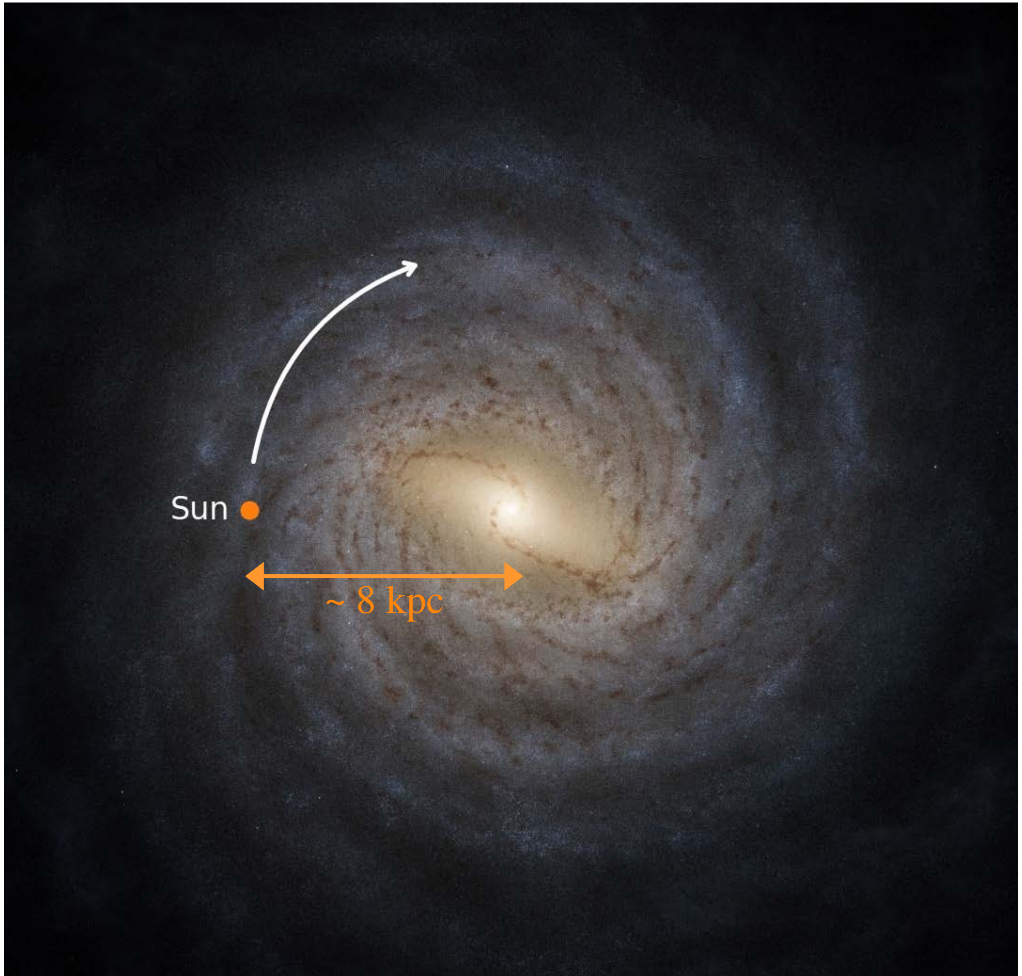


Figure 2. All planets near the habitable zone (the darker green shade is the conservative habitable zone, and the lighter green shade is the optimistic habitable zone). Only those planets with less than 10 Earth masses or 2.5 Earth radii are labeled. Credit: PHL @ UPR Arecibo.

additional



Chiappini, 2001



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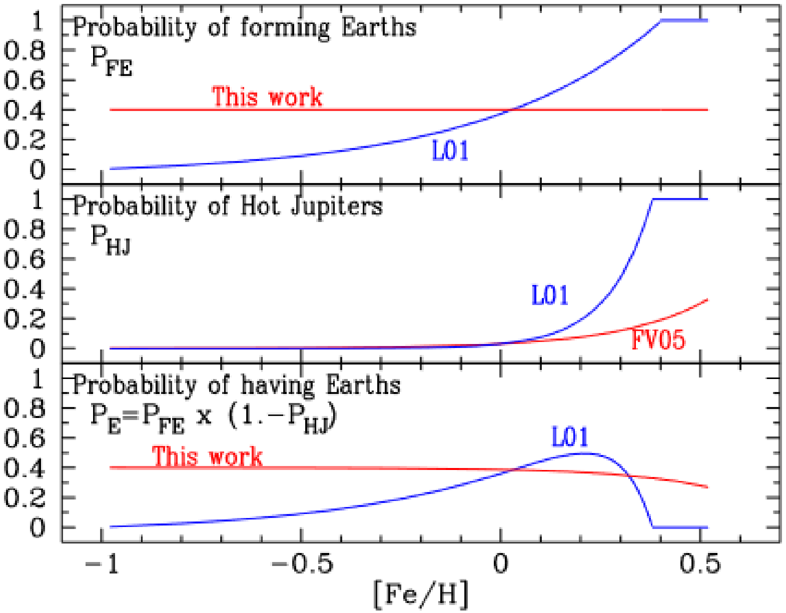
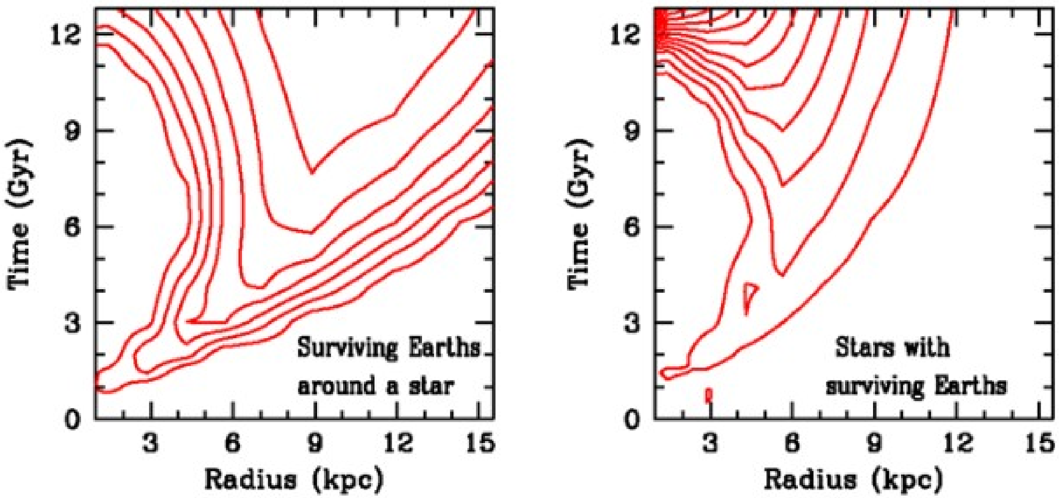
additional

Prantzos+08





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