Characterization of planet host stars for HWO: the case of Ariel

Maria Tsantaki
& the Ariel stellar characterization group

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

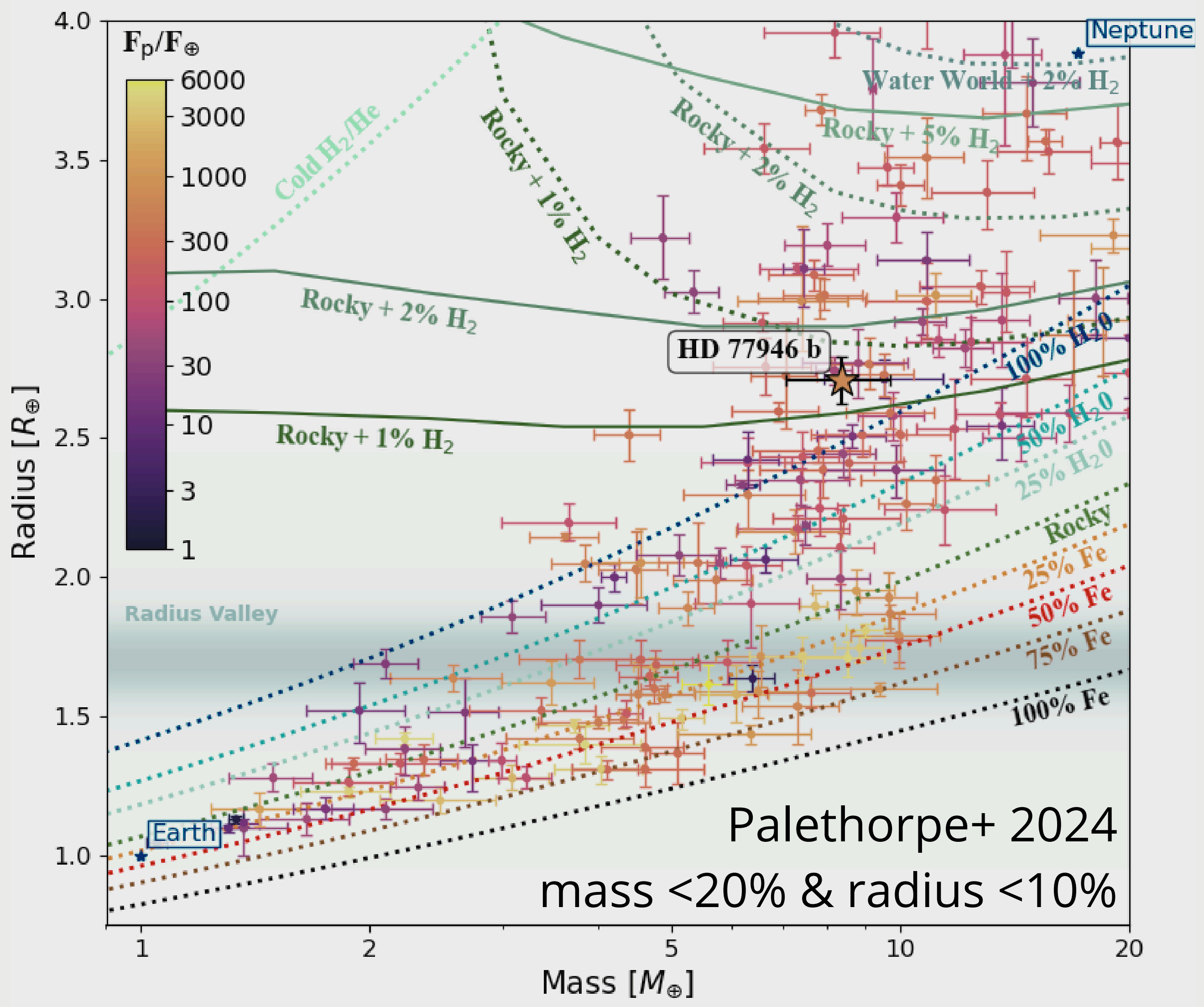
OSSERVATORIO ASTROFISICO DI ARCETRI

Know the star, know the *small* planet

Moving beyond the correlations between iron metallicity & planet presence, stellar composition can be used more directly for planet formation & composition.

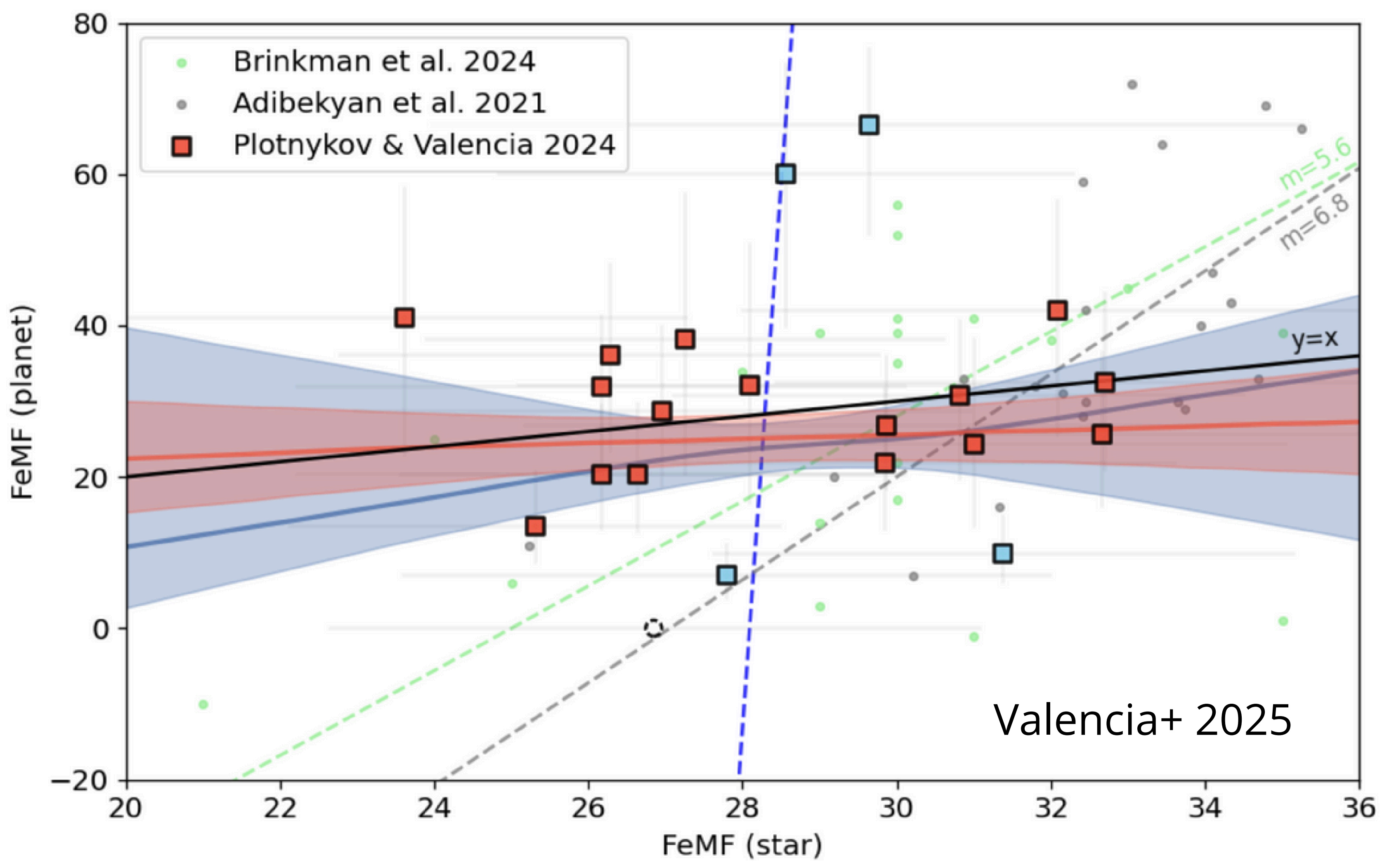
Modelling interior structure

- Planet Mass & Radius → directly dependent on stellar M, R
- Uncertainties in planet mass & radius are still a limiting factor for rocky composition & structure (e.g. Otegi+ 2020)
- Stellar Fe/Si, Mg/Si with low uncertainties (<3%) can improve models (e.g. Valencia+ 2013, Dorn+ 2015)



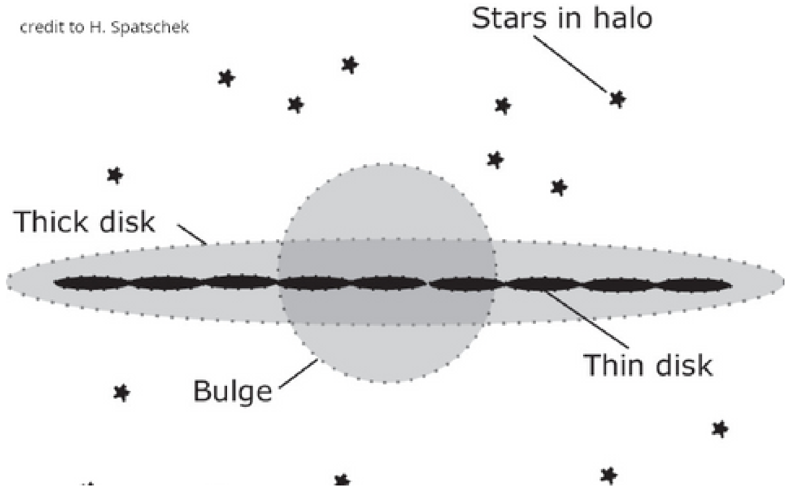
What is the compositional link between stars & planets?

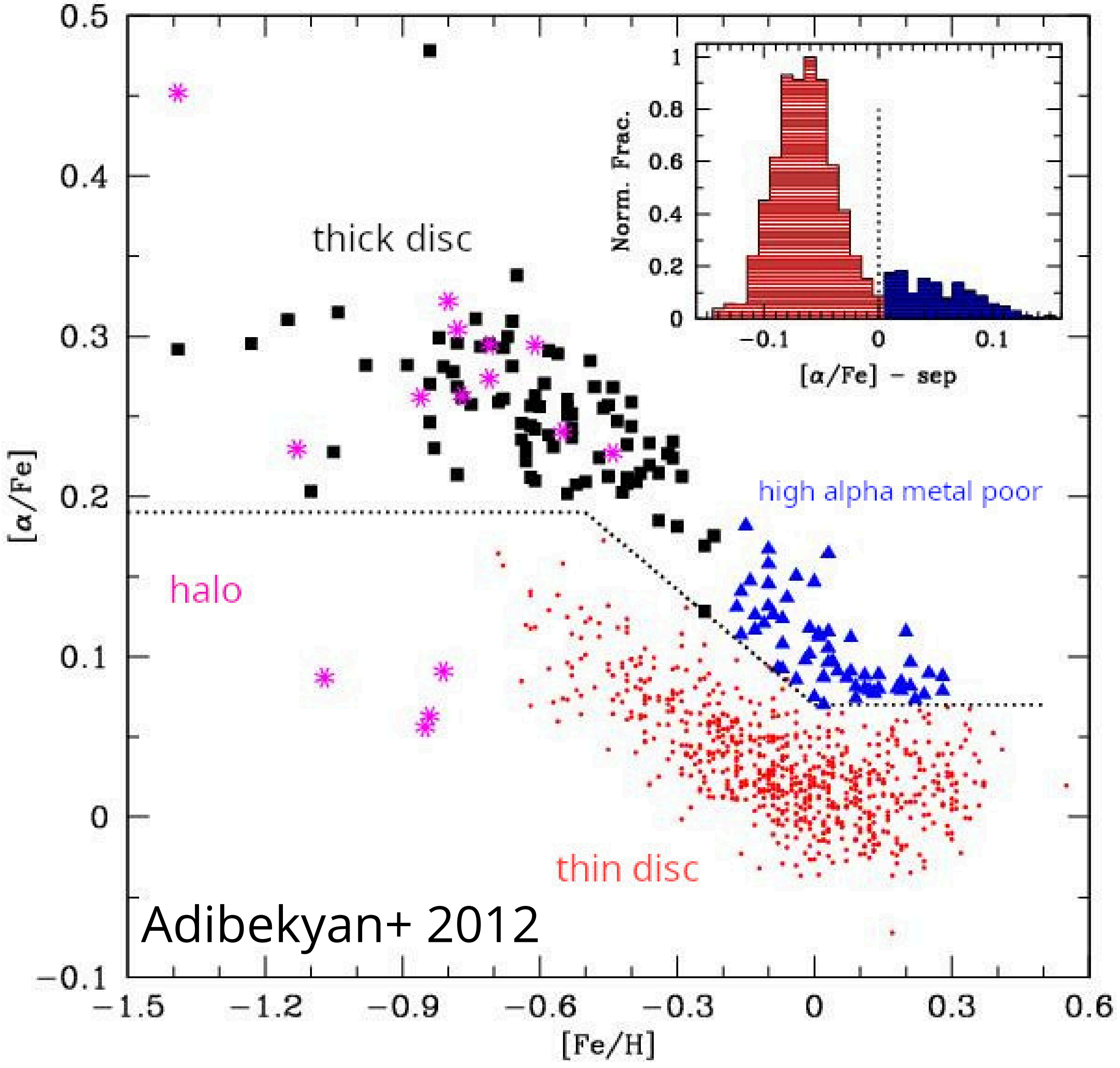
- Star composition (iron mass fraction) →? planet composition
- Not enough **precise & uniform** planetary masses (errors <25%)
- Limiting **precision** on stellar abundances (Fe, Ni, Si, Mg, O)



Where are *small* planets formed in the Galaxy?

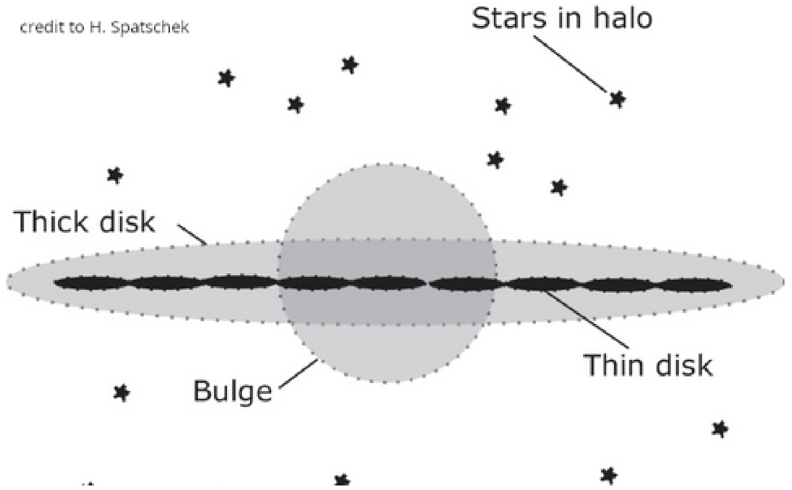
Different Galactic components have different chemistry/age/kinematics

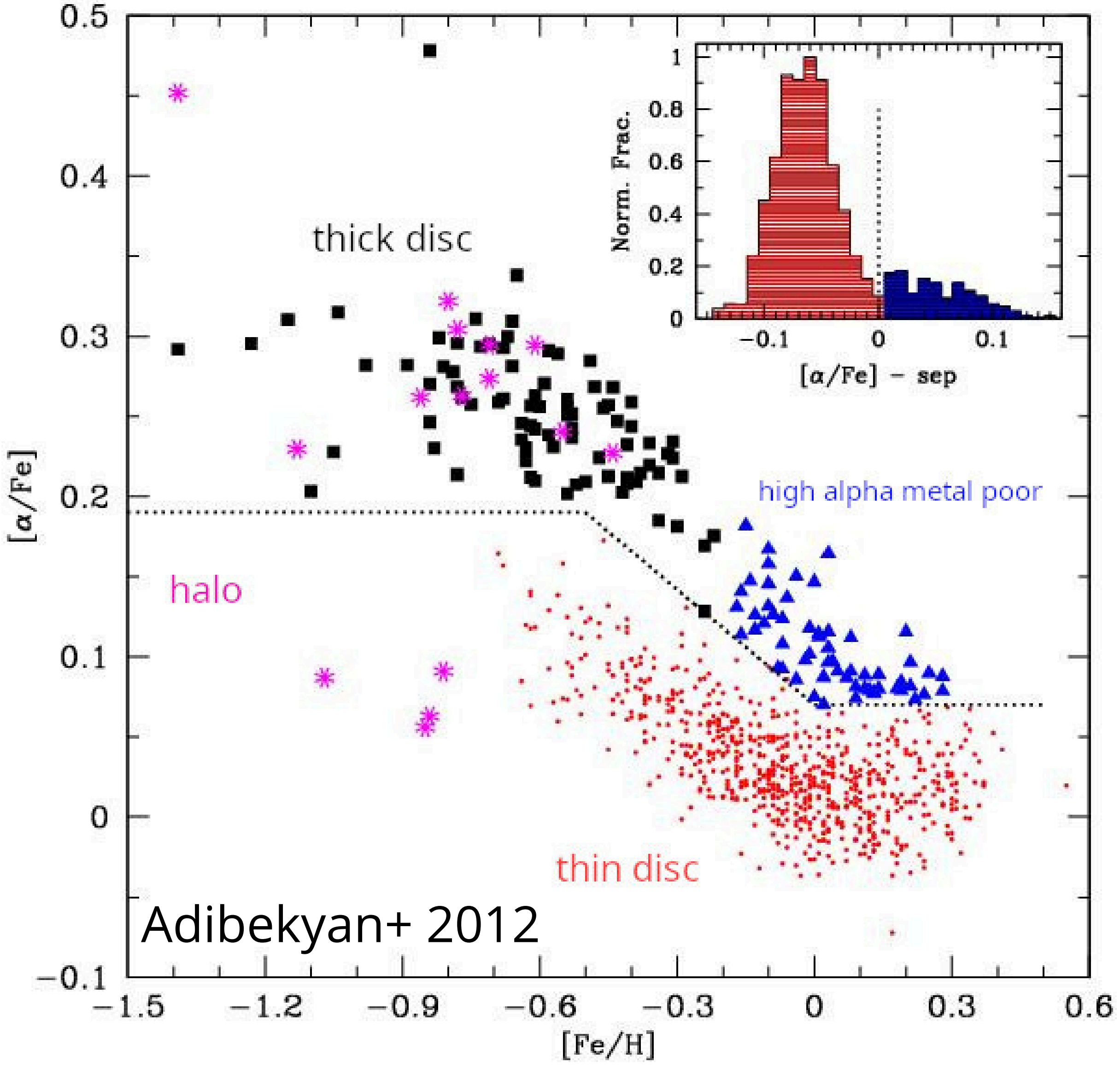


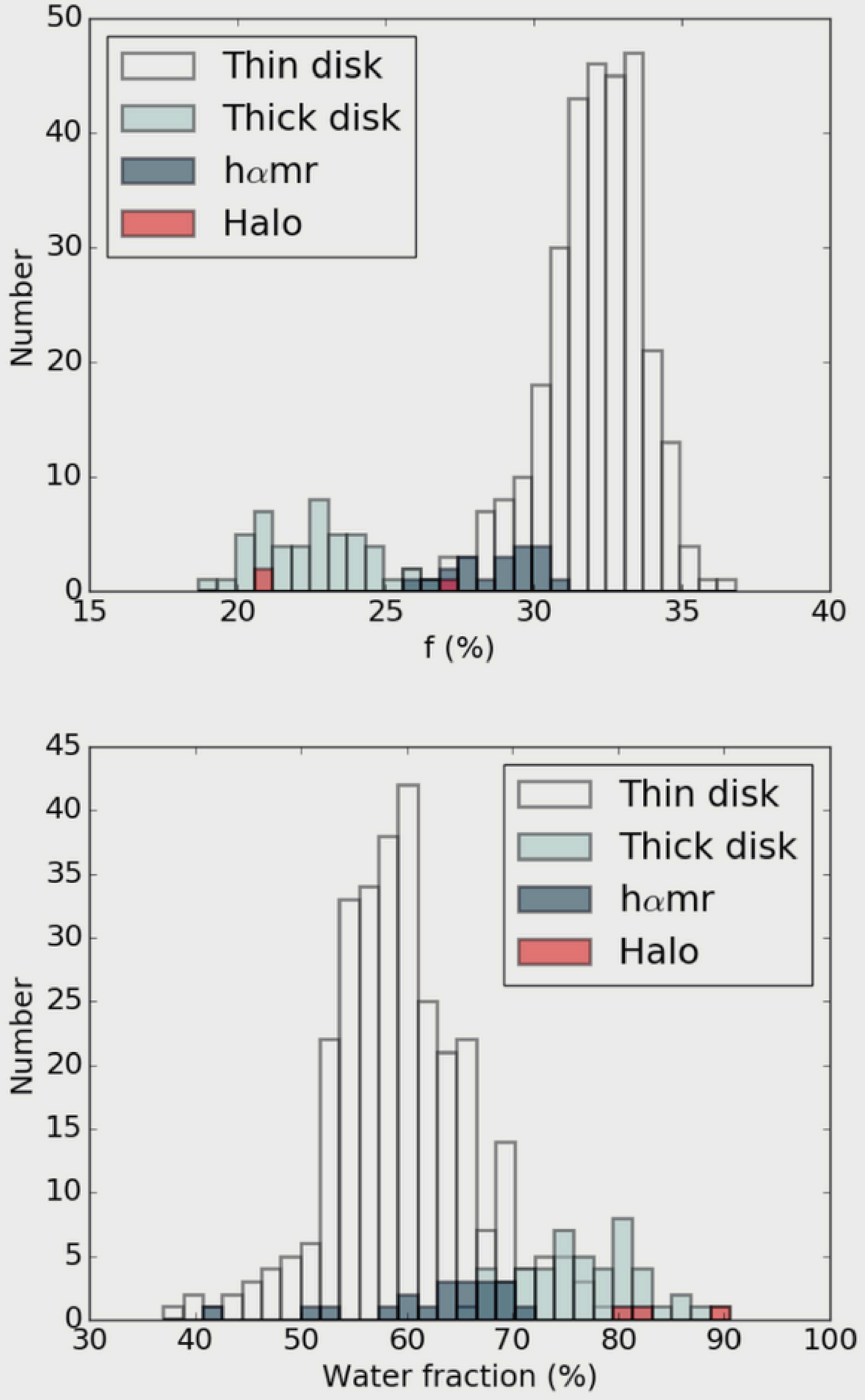


Where are *small* planets formed in the Galaxy?

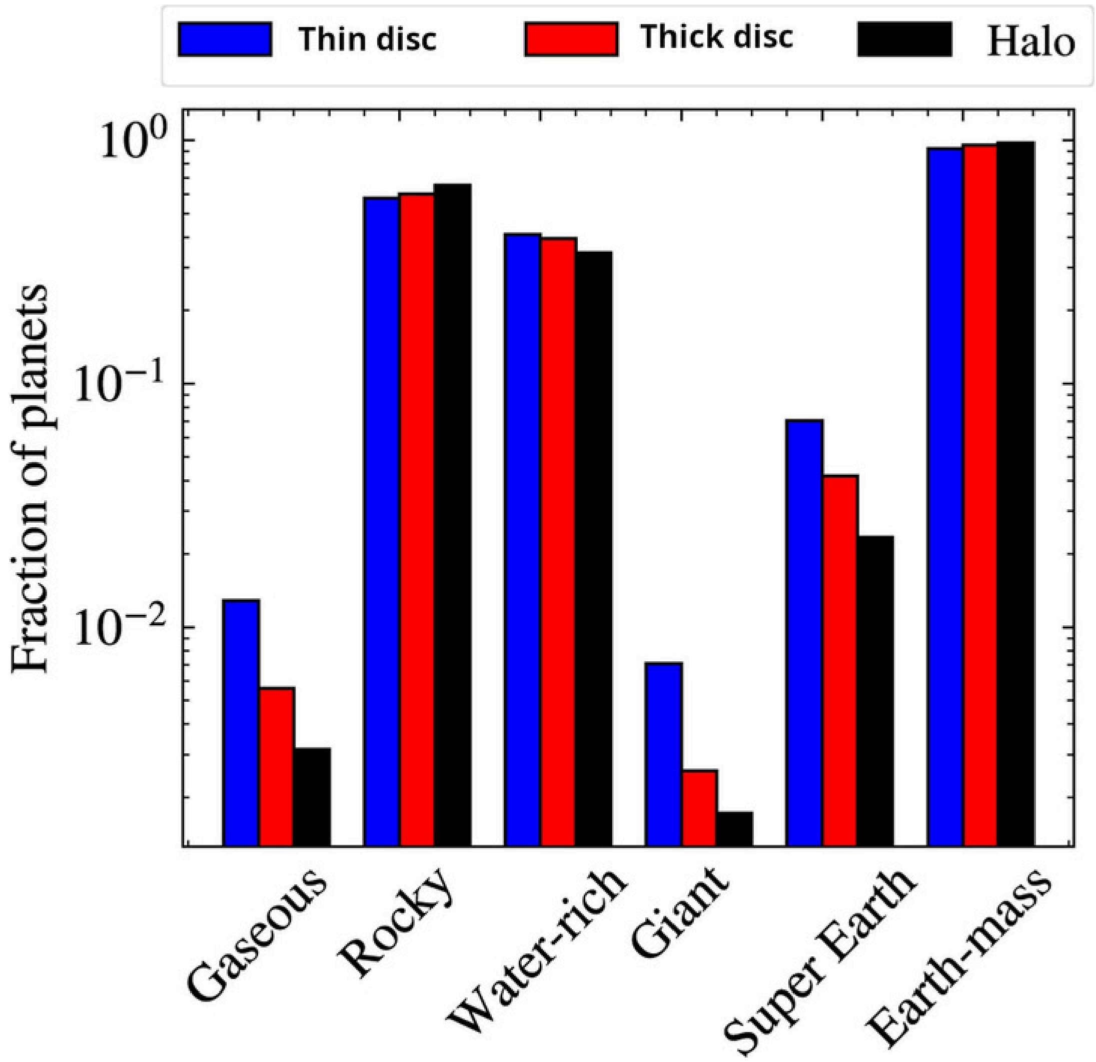
Different Galactic components have different chemistry/age/kinematics







Stars from different Galactic populations are expected to form rocky planets with significantly different iron-to-silicate mass & water mass fractions (Santos+ 2017).

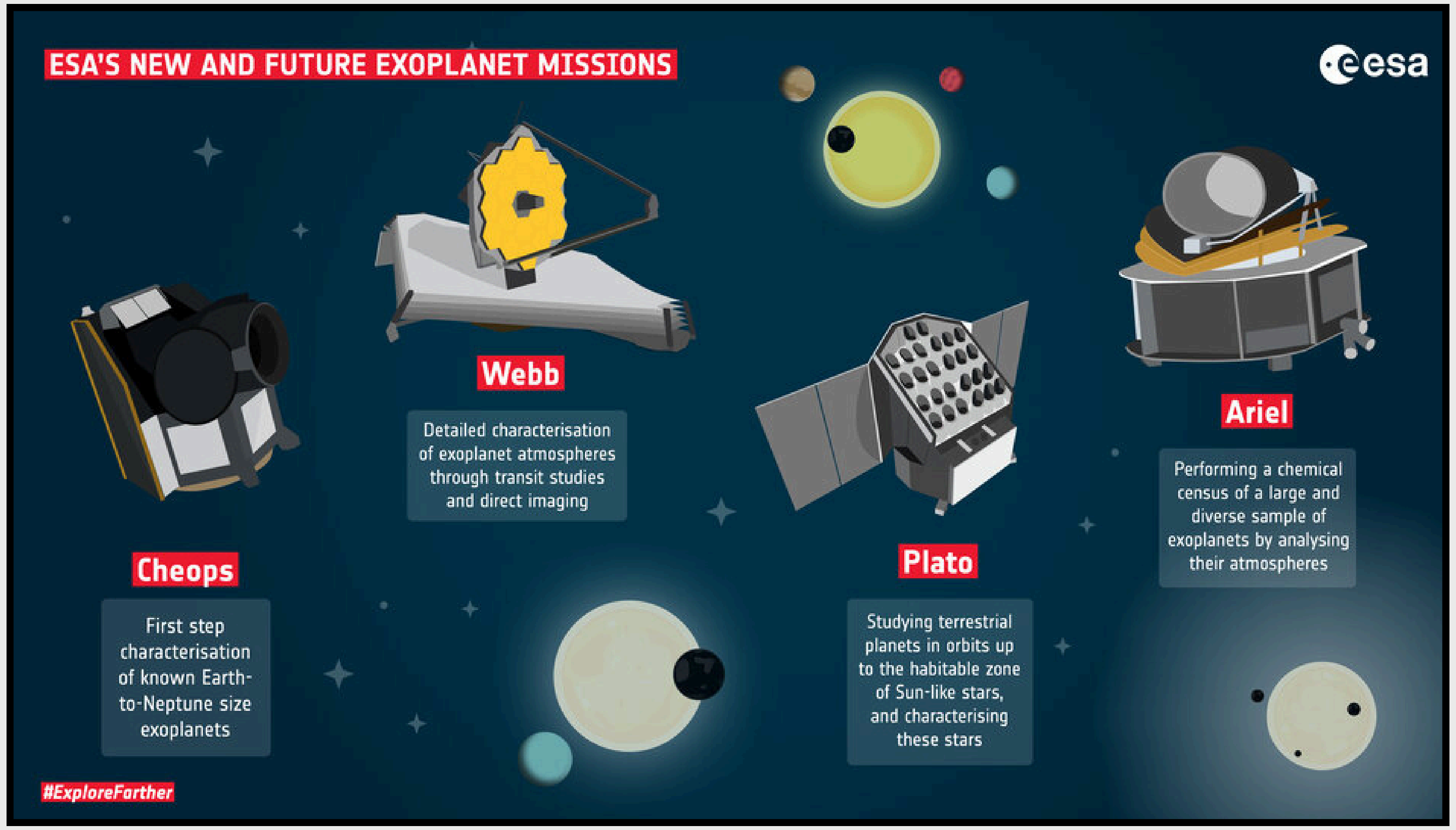


- Theory predicts that planetary mass & composition depend on [Fe/H] & a-elements (adopted Nielsen+ 2023).
- Planets formed within different parts of the galaxy have inherently different mass & compositions.

The Ariel mission

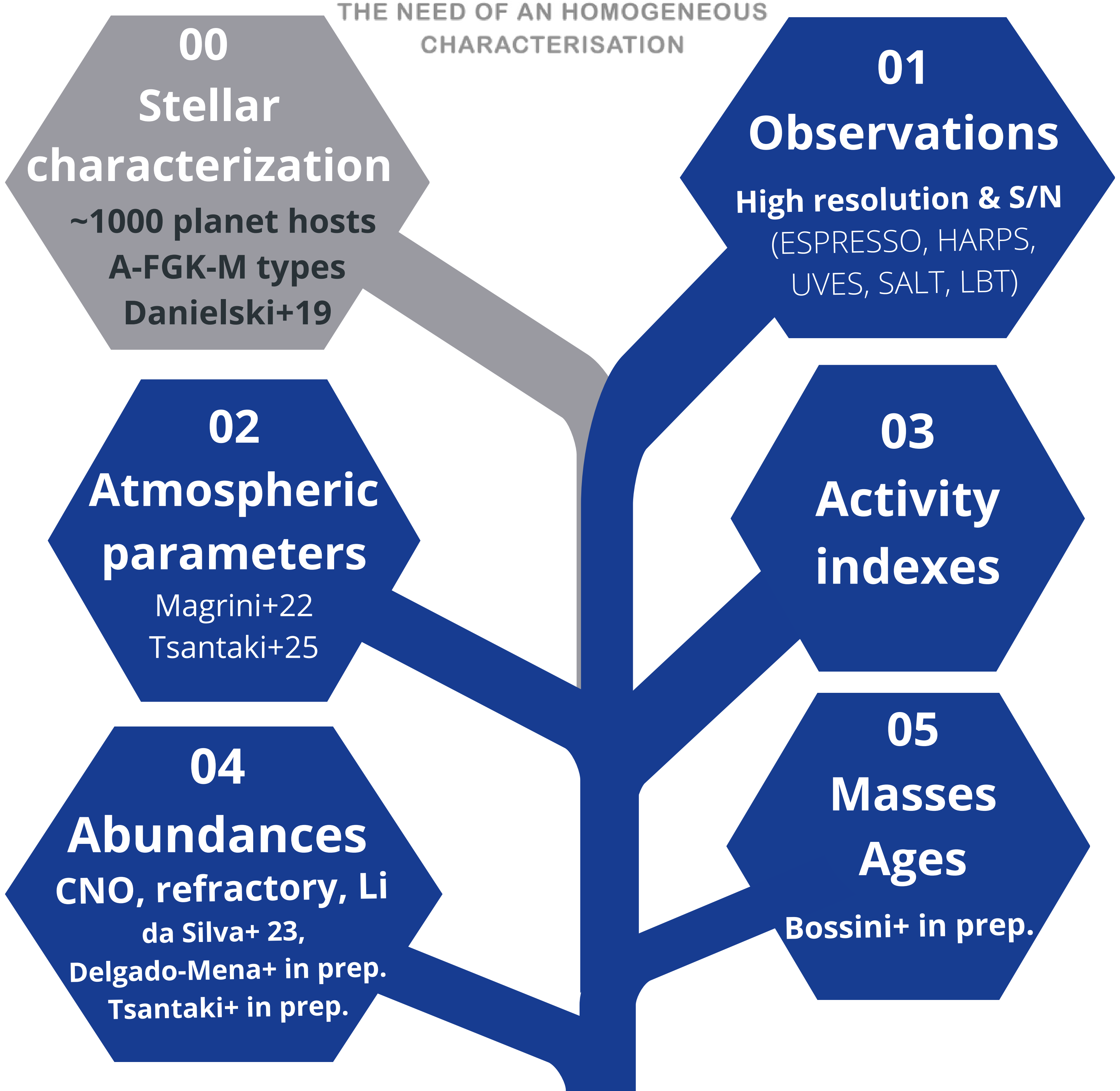
Planned launch: 2029

Mission theme: Ariel will study the composition of **1000 exoplanets** from rocky to giants & provide a chemical census by **analysing their atmospheres.**



https://sites.google.com/inaf.it/arielstellarcatalogue

THE NEED OF AN HOMOGENEOUS CHARACTERISATION



Homogeneous stellar parameters for 358 FGK planet hosts with high resolution spectroscopy

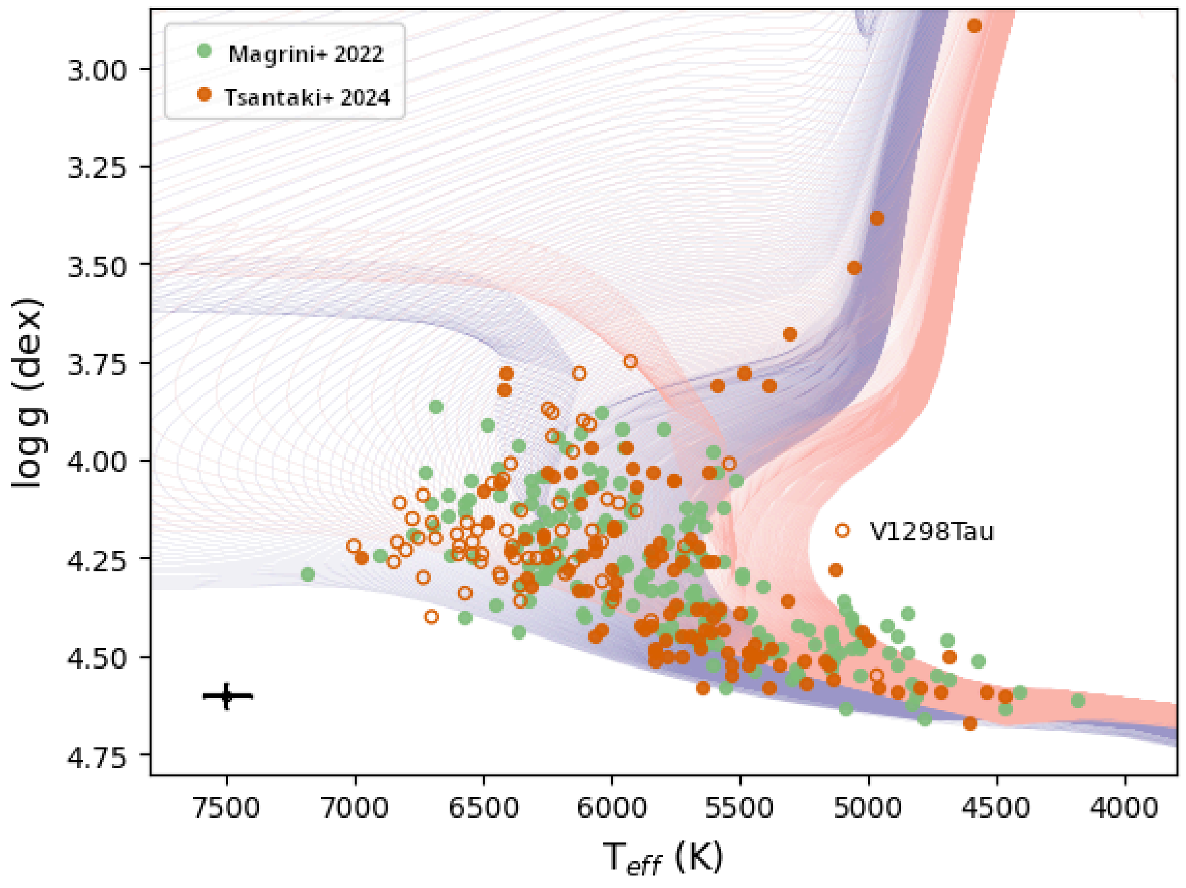
Methods:

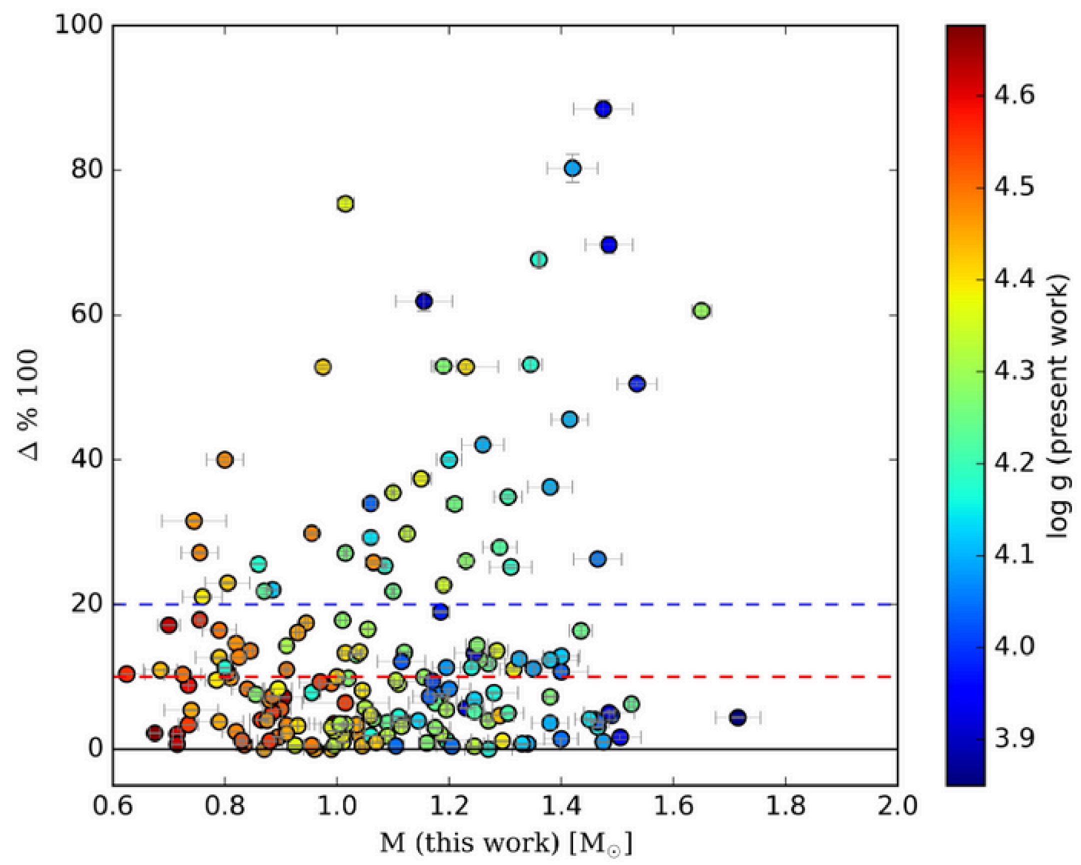
1. **Equivalent Widths of Fe Lines** (Magrini+ 22)
2. **Spectral Synthesis Technique** for Fast Rotators (Tsantaki+ 25)

To ensure consistency, the same ingredients were utilized: radiative transfer, atomic data, model atmospheres & logg from spectro-photometry.

Combined dataset: **358 FGK-type stars & 446 planets**:

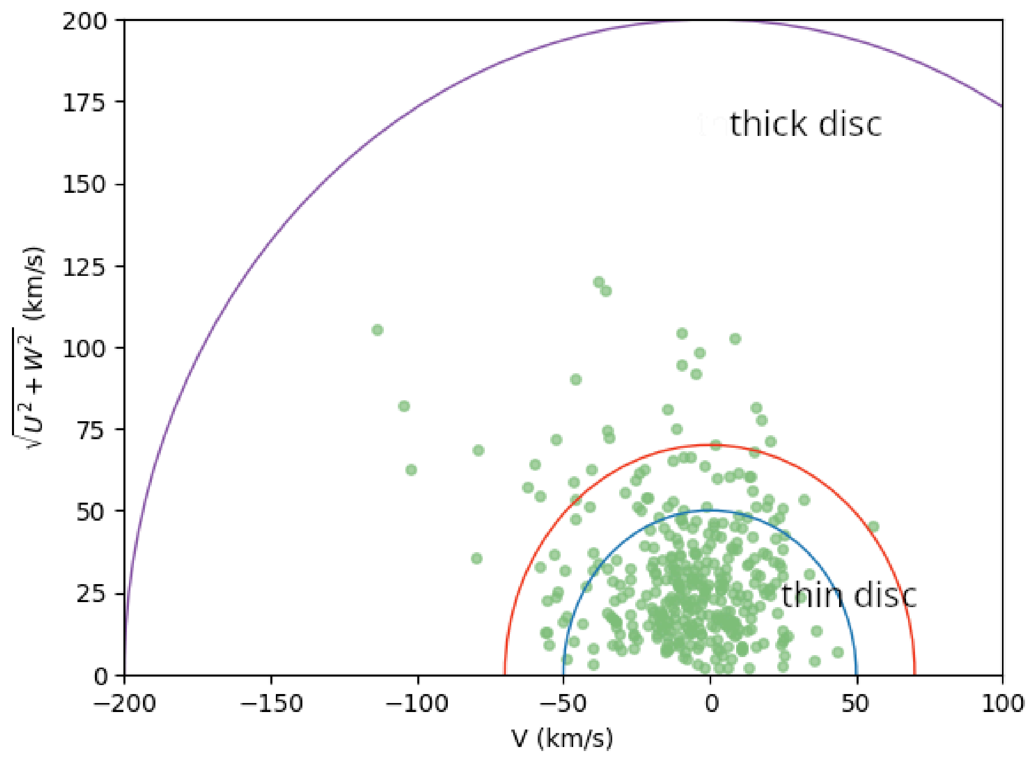
- 4200 ≤ Teff ≤ 7100 K
- 2.90 ≤ log g ≤ 4.60 dex
- -0.60 ≤ [Fe/H] ≤ 0.50 dex
- 0.6 ≤ M⋆ ≤ 1.8 Msolar

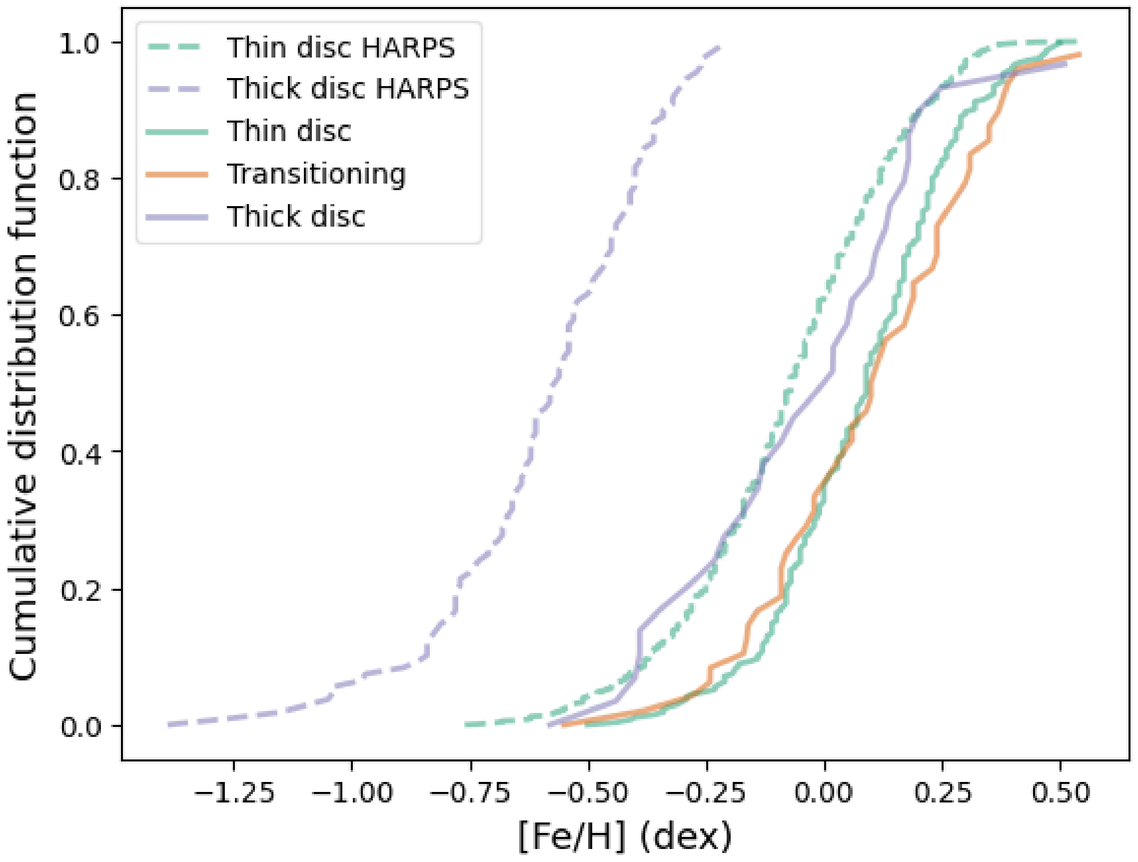




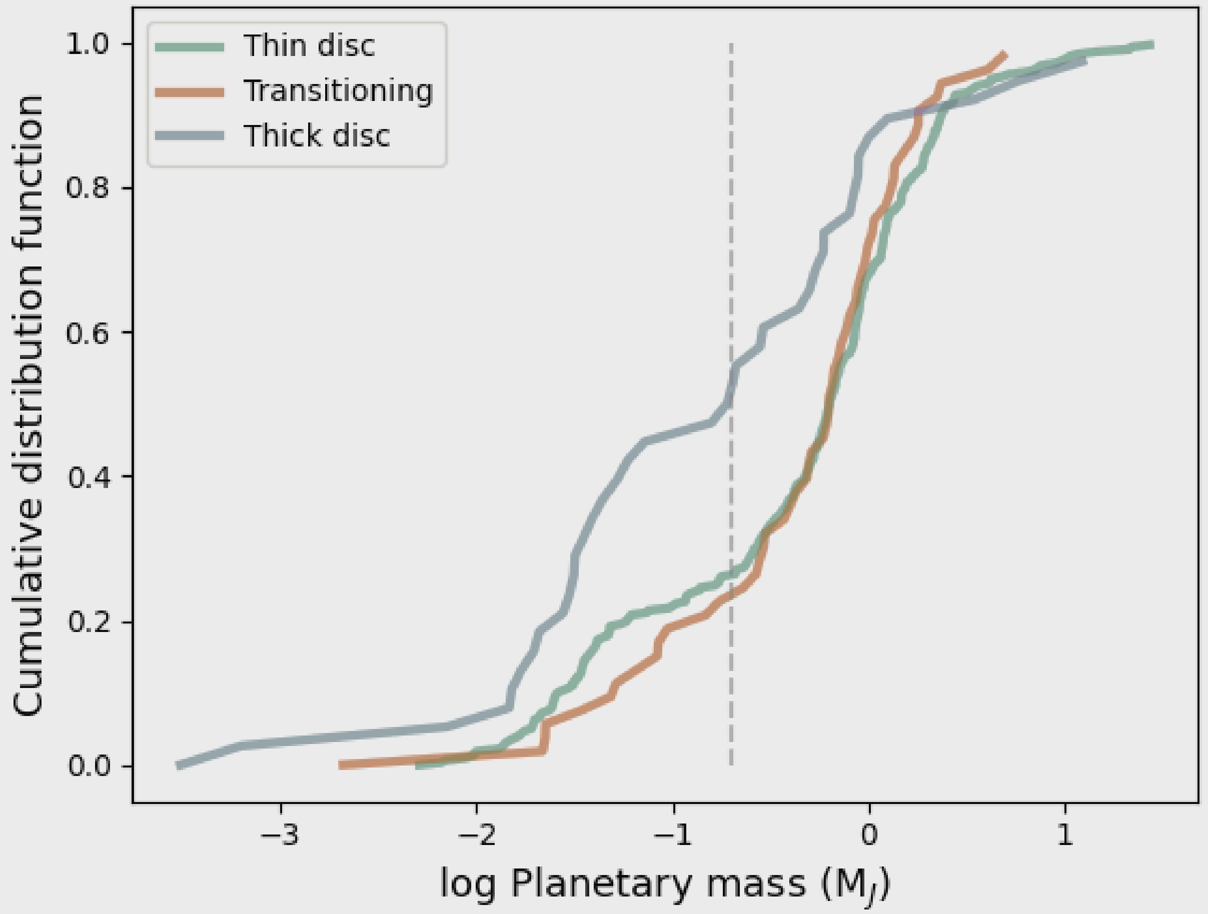
Improved & homogeneous masses based on isochrone fits (Magrini+2022, Tsantaki+2025, Bossini+ in prep.)

The Ariel Mission Candidate Sample so far





Planet hosts do not follow the metallicity distribution of their populations.



More massive planets are formed predominantly around [Fe/H]-rich stars and are mainly located in the **thin** disc.

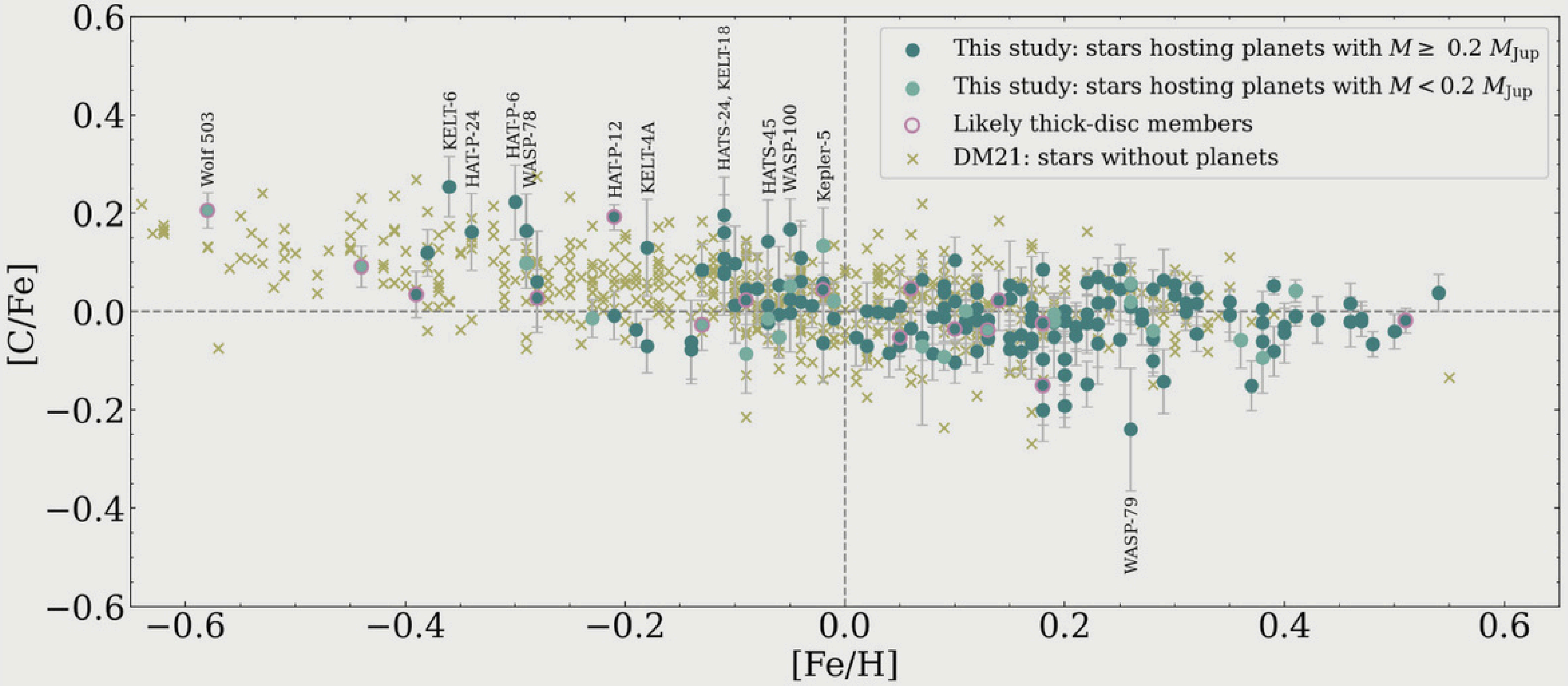
- **Thin** disc stars are metal rich and should also be the **youngest**.
- As stars get more chemically enriched over time, the formation of more massive planets is also enhanced.

(see also Adibekyan+ 2012; Biazzo+ 2022; Swastik+ 2022)

Caution on the detection biases of low-mass planets.

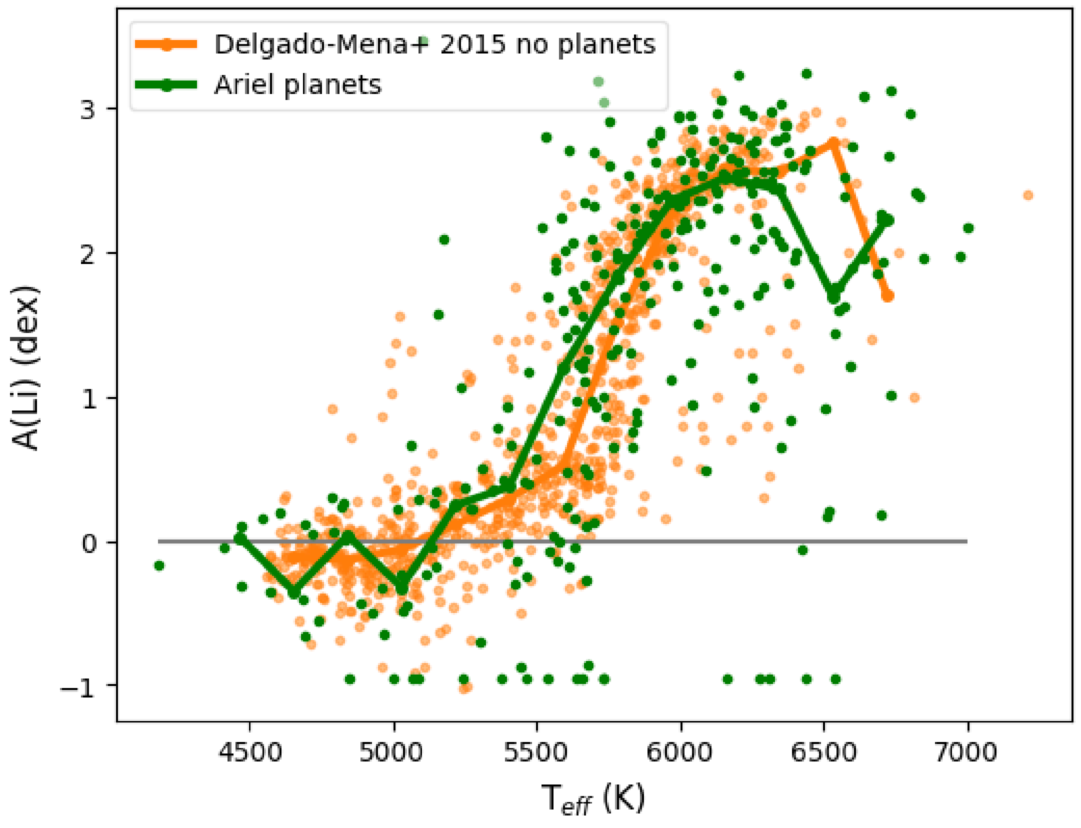
The Ariel Mission Candidate Sample so far

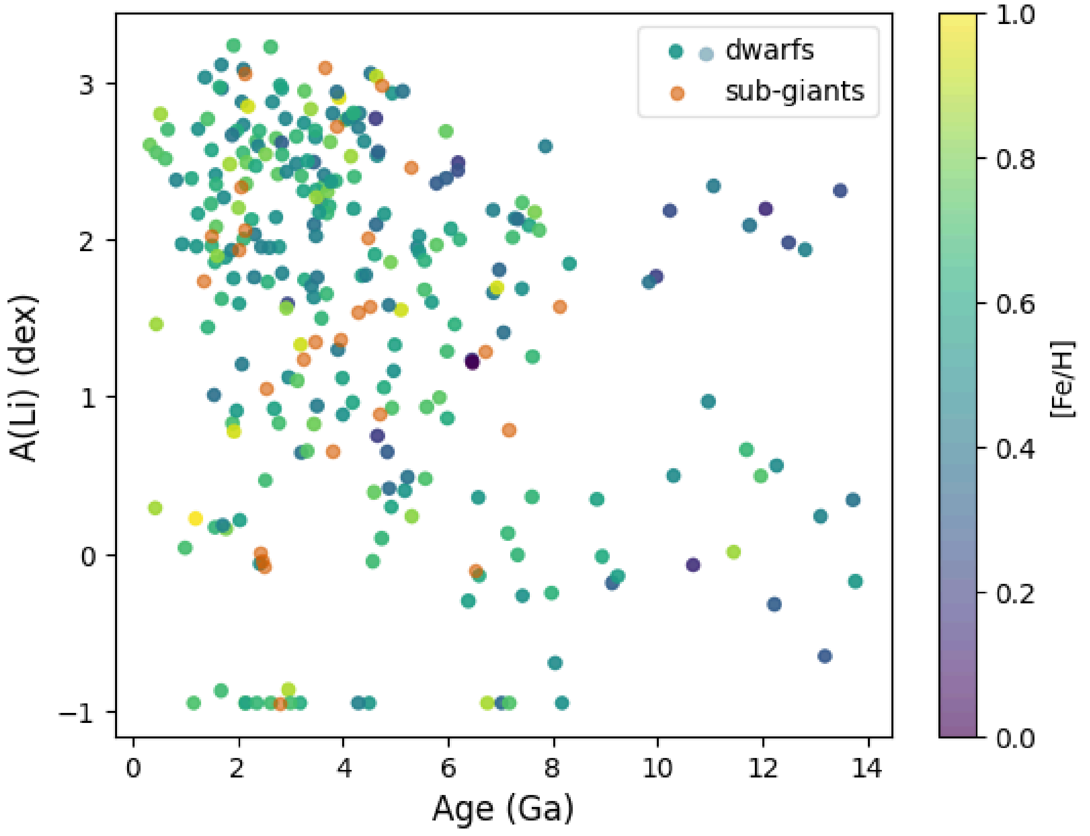
1) *Are hosts still chemically enriched after removing the effects of GCE?*



Ariel CNO abundances (daSilva+2024):
Our sample basically follows the typical trends with metallicity expected for the [C/Fe], [N/Fe], and [O/Fe] abundance ratios.

2) Are stars with planets Li depleted?





Does the presence of planets cause additional mixing in the external layers of planet host stars?
(see Ghezzi+2009, Delgado-Mena 2014, 2015)

Preliminary results
Tsantaki+ in prep. 2025

The HWO stars: Exploration Program Mission Star List

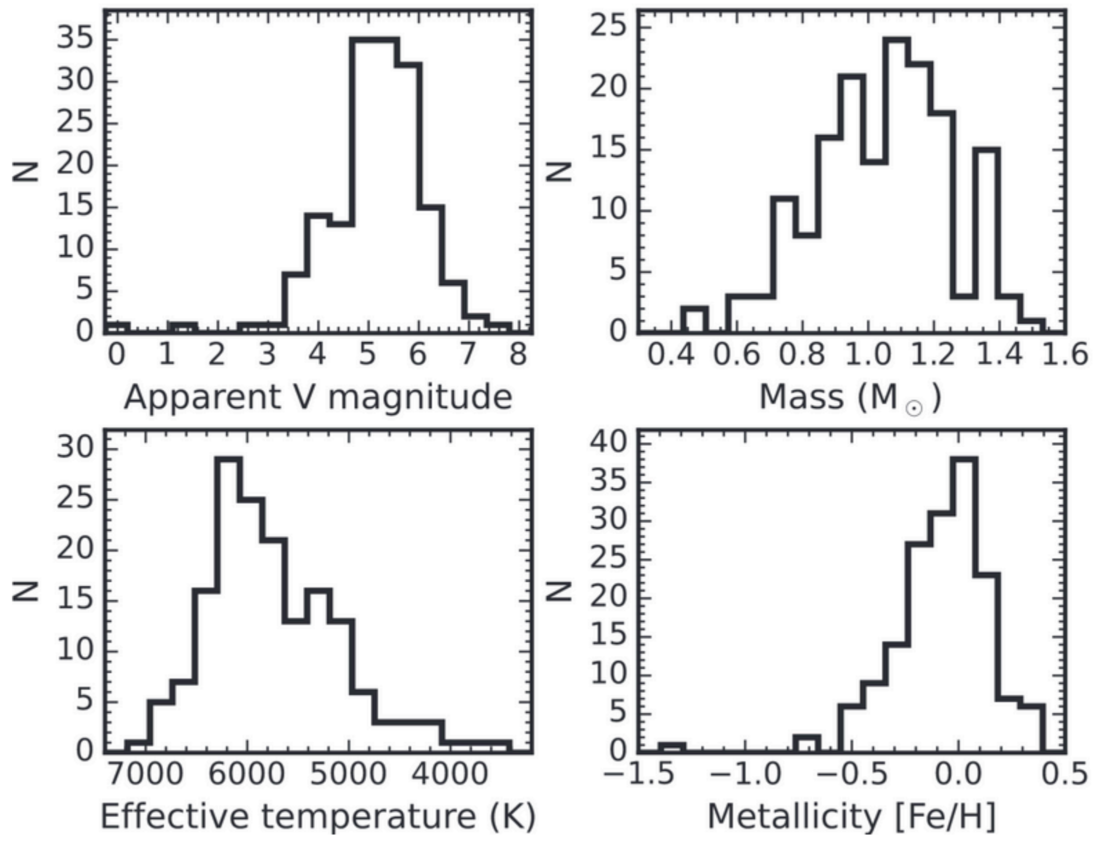
Living Worlds – WG Target Stars & Systems

Goal to “constrain important properties of host stars & their planetary systems”.

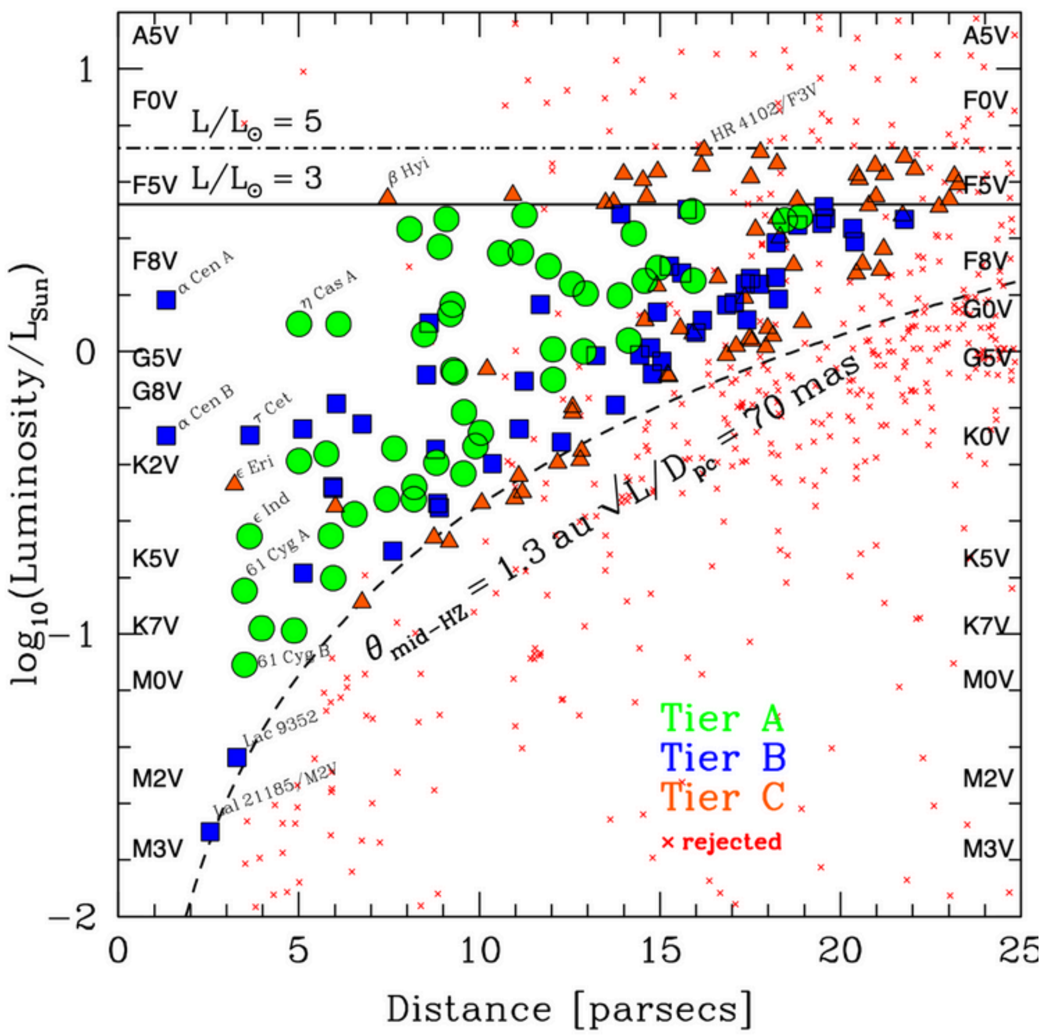
Target Stars for preparatory science

- 164 nearby (d<25pc) FGKM types
- the most accessible for habitable exoplanets
- Prioritization can change depending on various stellar parameters:

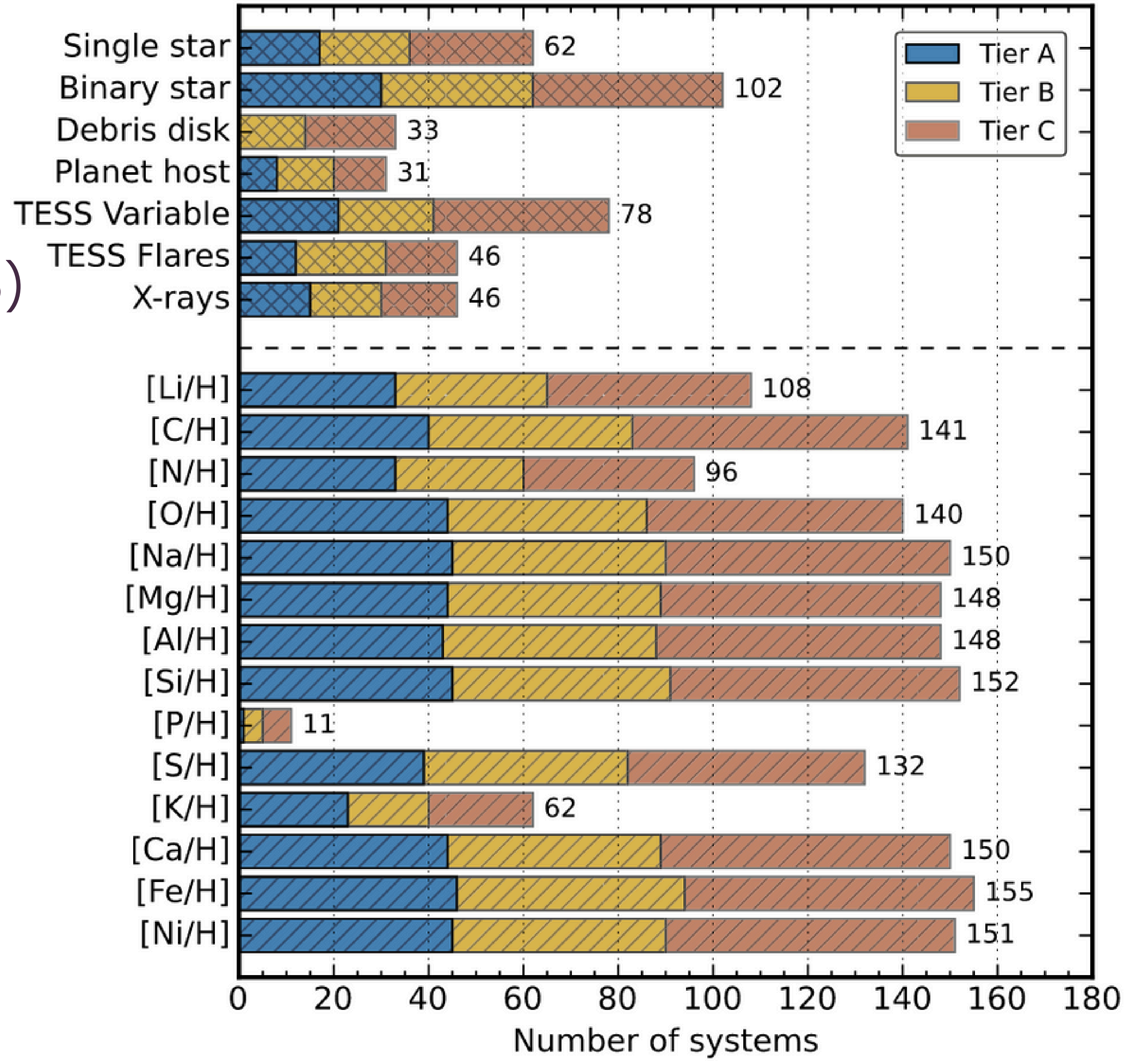
stellar energy spectrum, stellar chemistry, definition of HZ (Ware+ 2025)



Harada+ 2024



Mamajek & Stapelfeldt 2023



Harada+ 2024

The HWO stars: Exploration Program Mission Star List

Living Worlds – WG Target Stars & Systems

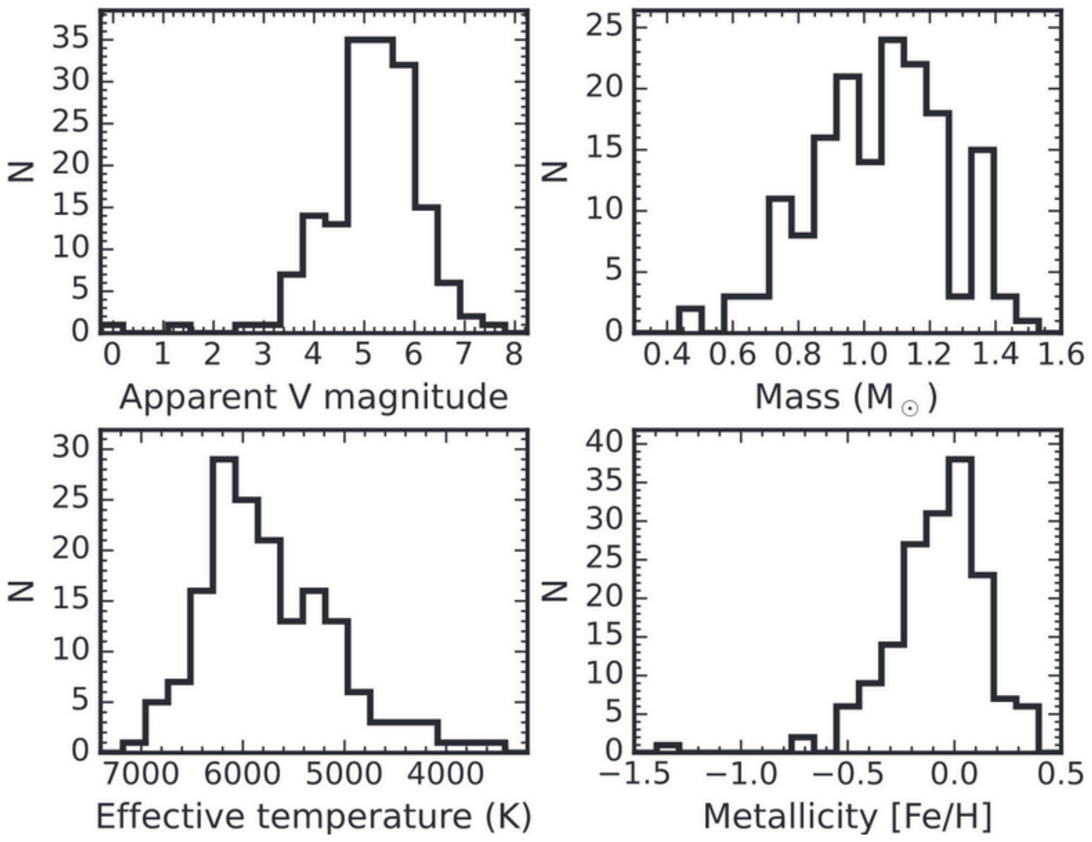
Goal to “constrain important properties of host stars & their planetary systems”.

Target Stars for preparatory science

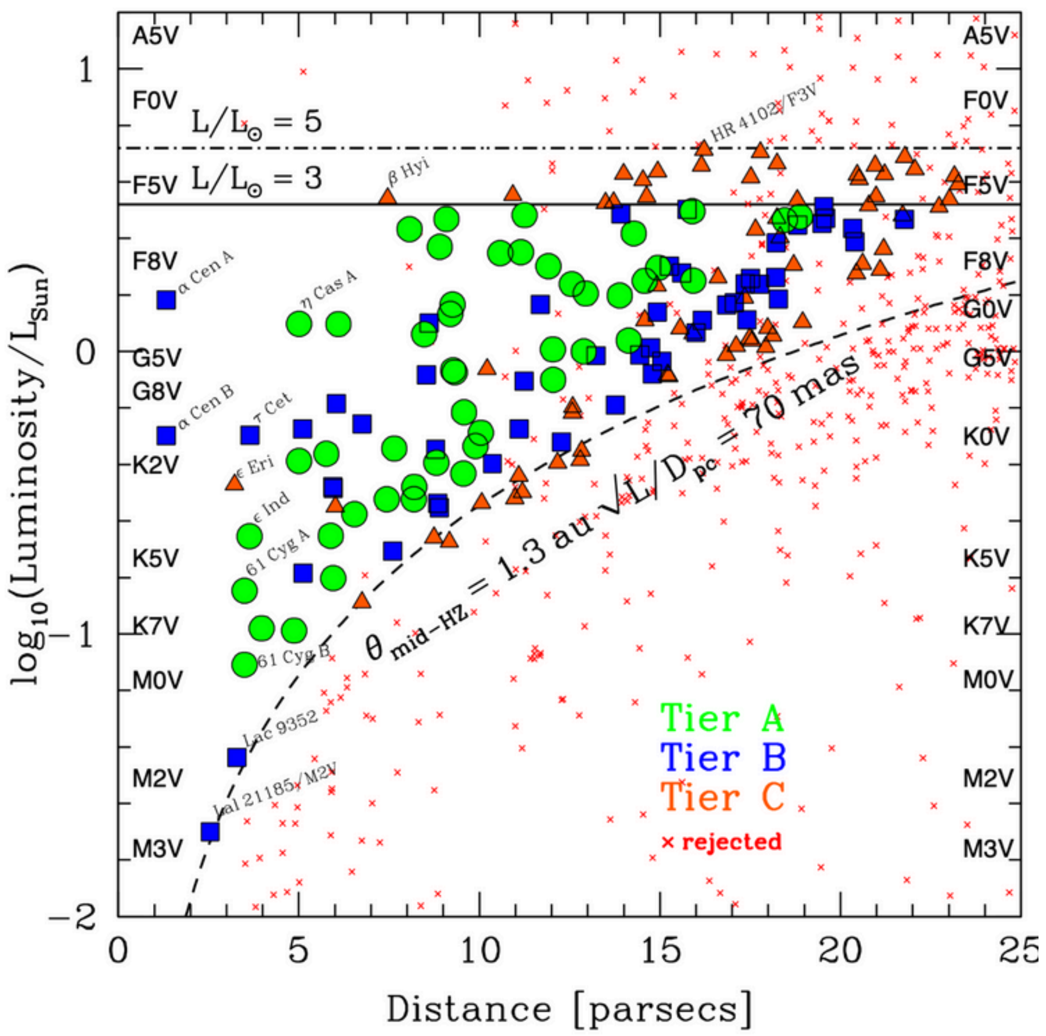
- 164 nearby (d<25pc) FGKM types
- the most accessible for habitable exoplanets
- Prioritization can change depending on various stellar parameters

stellar energy spectrum, stellar chemistry, definition of HZ (Ware+ 20

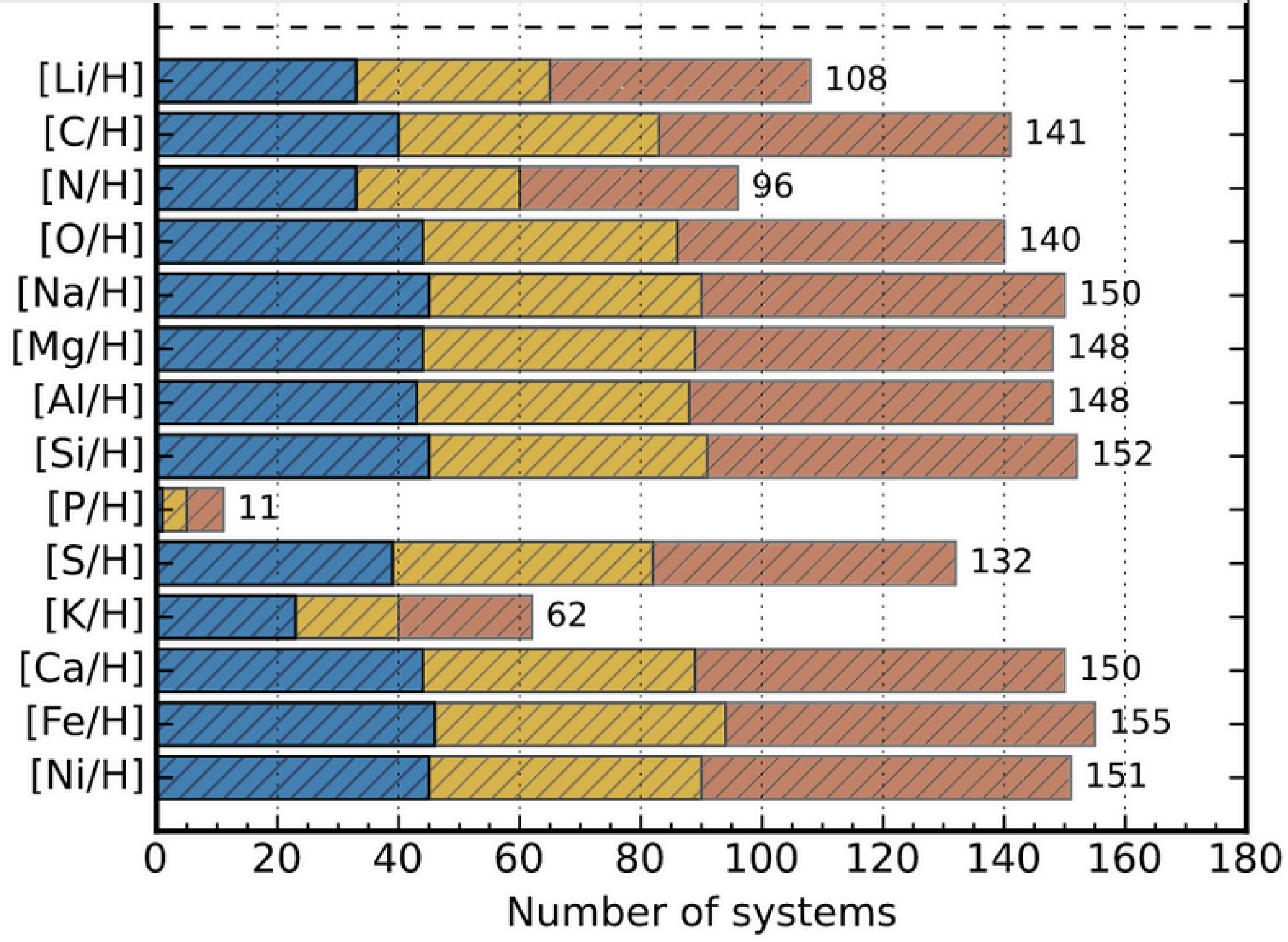
- **Large discrepancies in some elements**
- **Need for homogenous analysis**
- **Lack of important elements**



Harada+ 2024



Mamajek & Stapelfeldt 2023



Harada+ 2024

Precursor science for HWO: benchmarking the host stars

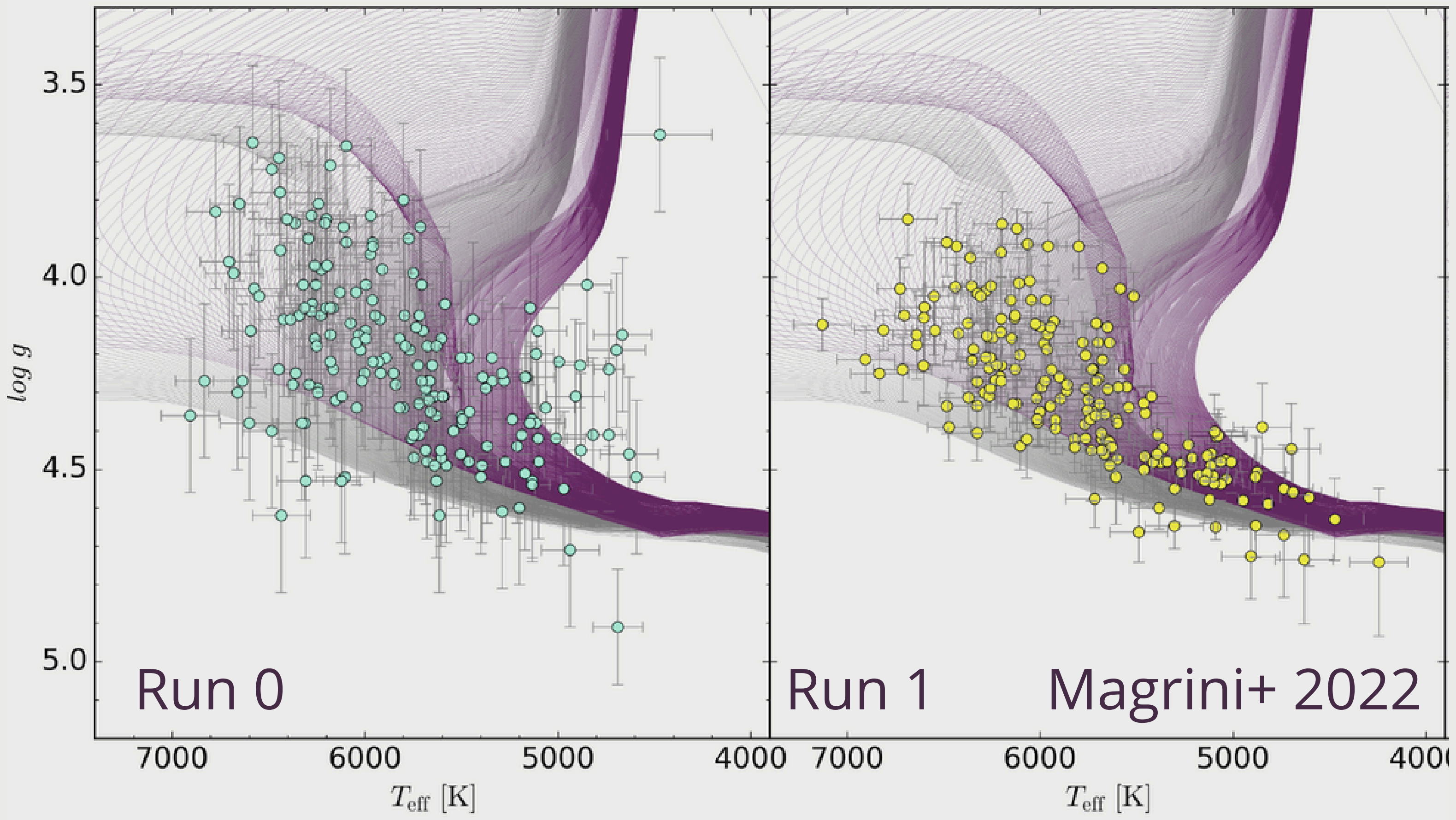
Teff
- Spectroscopy
- Photometry (e.g. IRFM)
- Interferometry

Metallicity
- Spectroscopy

Mass, Radius, Age
- Asteroseismology (input of Teff, [M/H])
- Spectroscopy+isochrone fitting
- Interferometry (only Radius)

Rotation, Activity

High resolution spectroscopy is key! But a holistic approach on the characterization can be beneficial.



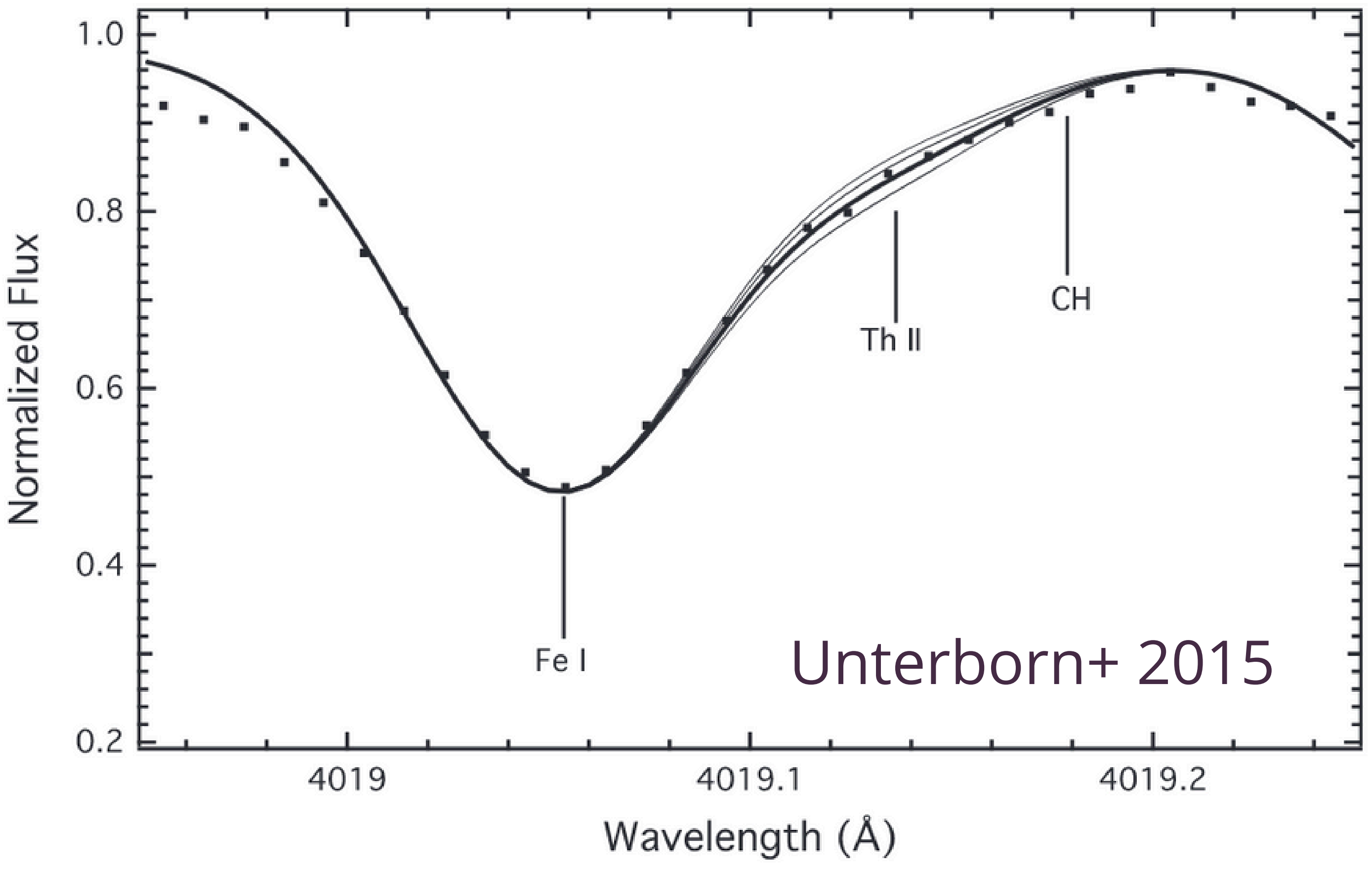
Communication between stellar astrophysicists, planetologists & astrobiologists

Experience from Ariel using a combination of data from spectroscopy, photometry & astrometry for better constraints of the target list.

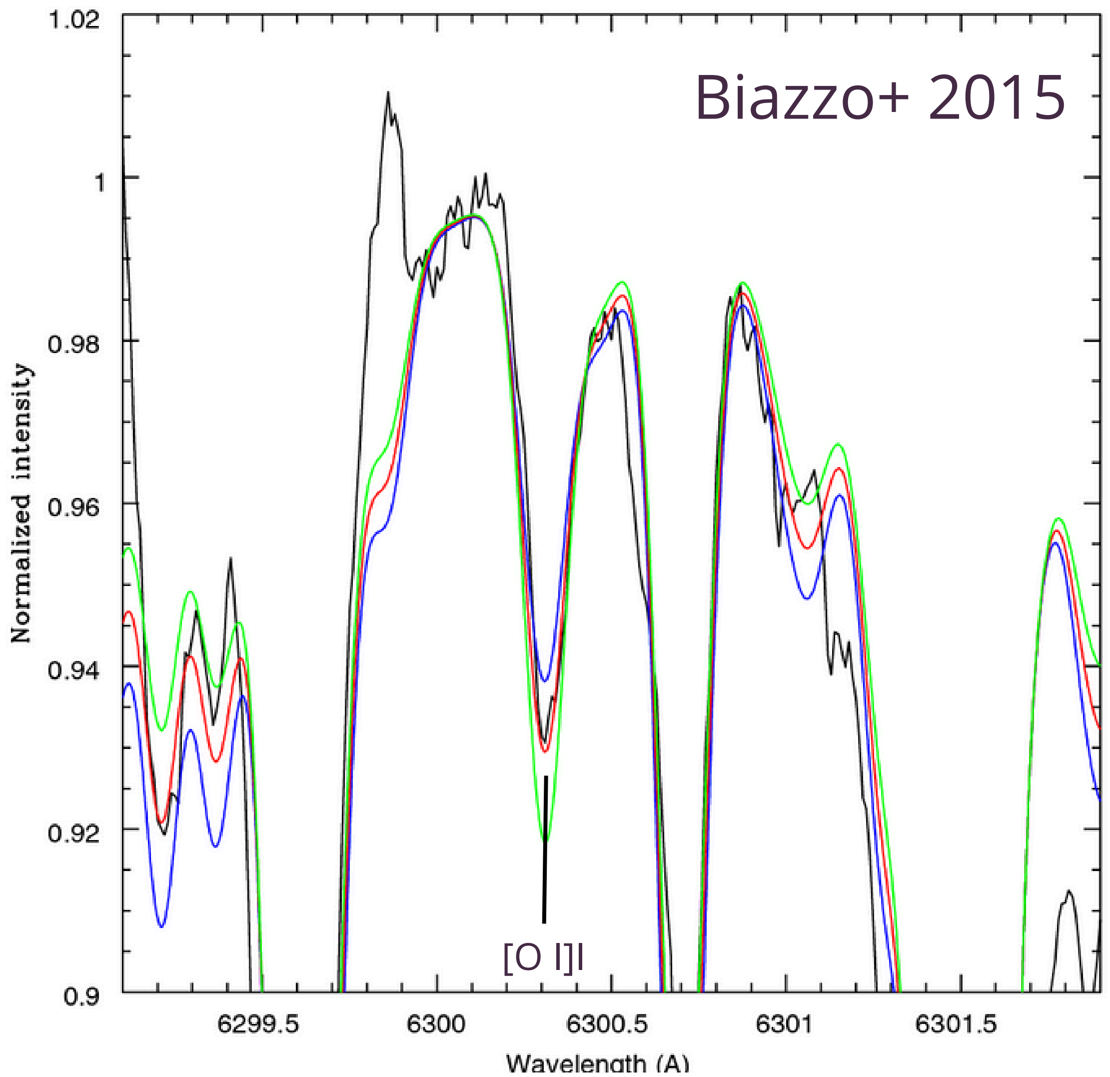
see also Gaia benchmark stars (Heiter+ 2015)

Stellar charactetization: observational challenges

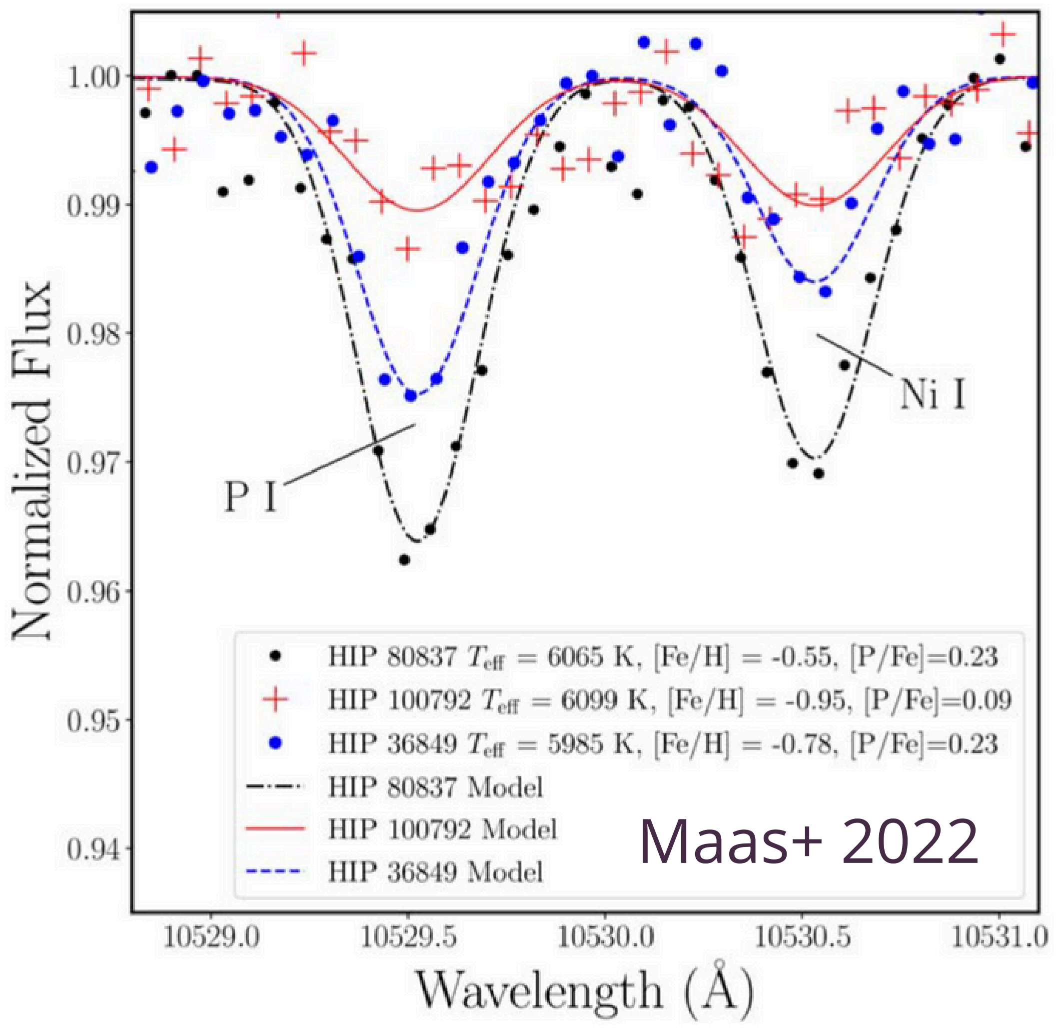
- Deriving precise & accurate abundances for key elements is extremely difficult:
  only very high resolution & very high S/N spectra
- Some elements are not fully explored (e.g. blending)
- Some elements are not easily observationally accessible (e.g. nIR, UV)



Thorium:
radionuclide abundances → volcanism
blended line, lack of measurements in the literature



Oxygen: very often weak, airglow contamination



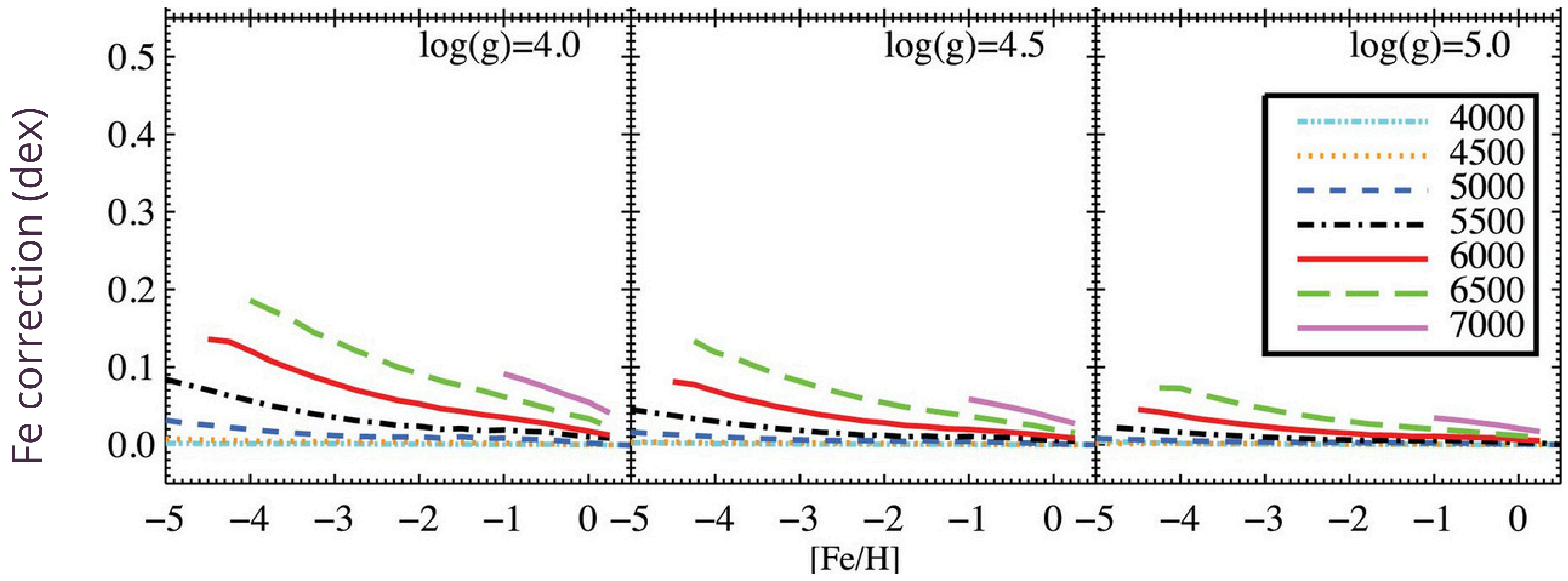
Phosphorus: key element for biology
line in the nIR, lack of measurements

Stellar characterization: modelling challenges

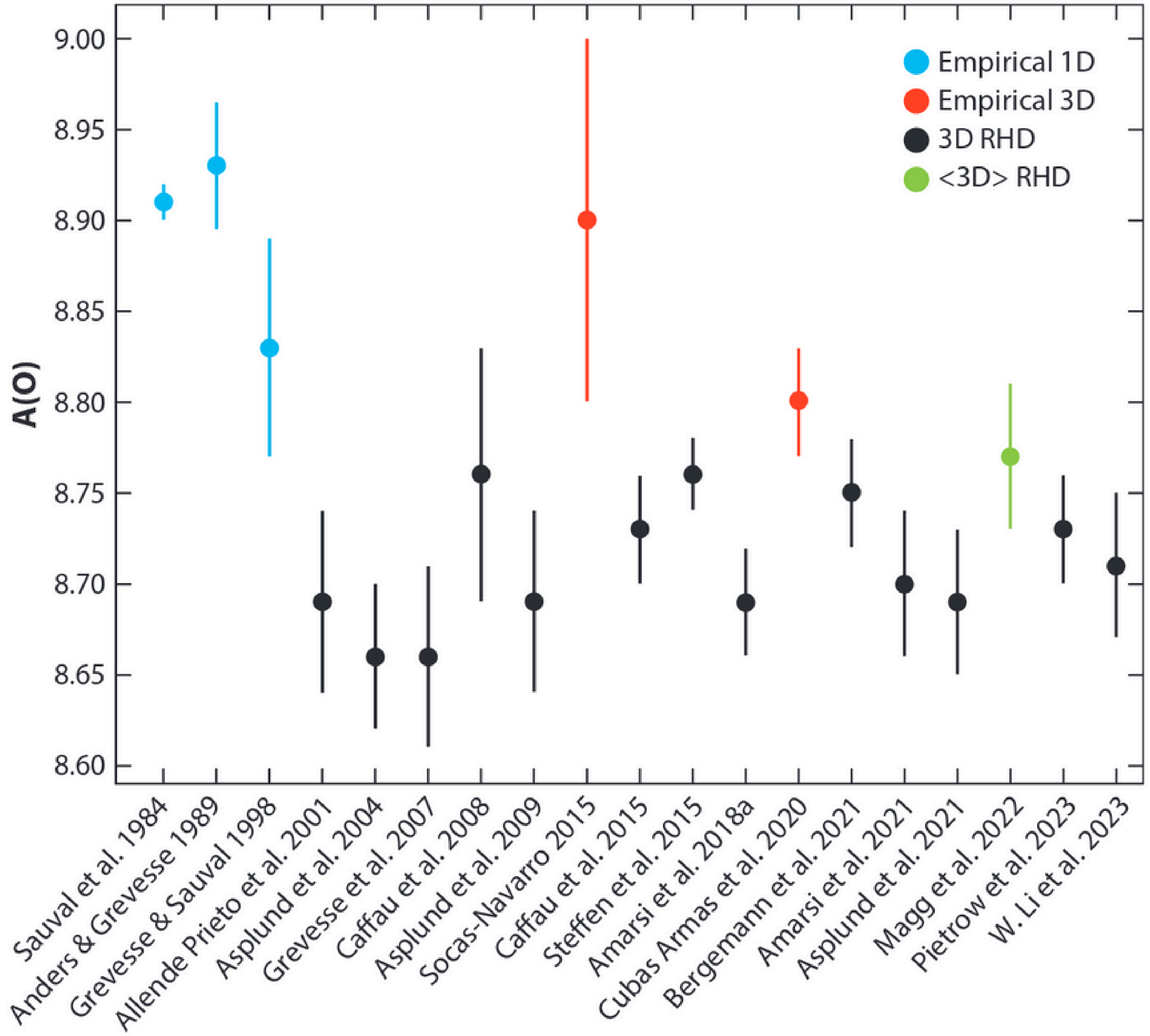
Spectroscopy is model dependent!
Need to update our analysis methods for the elements most affected:

- non-LTE effects apply
- 3D model atmospheres

Non-LTE abundance correction of unsaturated Fe I lines
(Lind+ 2012)



Evolution of Solar O over 40 years
Lind+ (2024)



SUMMARY

- The Ariel stellar characterization WG has provided an online catalog with ***homogeneous*** stellar parameters & chemical abundances.

- **The Galactic environment plays a very important role in shaping the planetary system. These effects on planet demographics have so far been unexplored observationally.**

- We can apply similar methodologies to characterize the HWO stars and we can plan in advance the challenges.

THANK YOU

ARIEL STARS

Ministero dell'Università e della Ricerca
Finanziato dall'Unione europea
NextGenerationEU
Italiadomani
COSMIC POT
EPOCH
Beyond metallicity: Exploiting the full POtential of CHemical elements