The iron metallicity content of planet hosts: the Ariel sample

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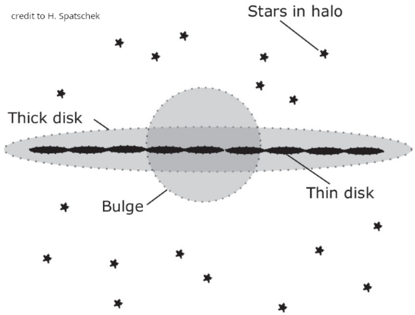
Molecules & planets in the outer Galaxy
12 November 2024

Where do planets live in our Galaxy?



Stellar populations are distinguished by chemical composition, kinematics & age:

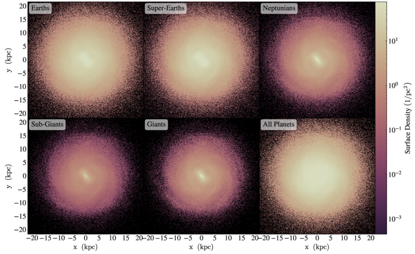
- Thin disc stars have lower orbital velocity and higher velocity dispersion compared to thick disc stars.
- Thick disc stars are older, [Fe/H] poor and α-rich relative to thin-disc stars.
- Halo stars have even larger velocity dispersion and are [Fe/H] poor.
- Bulge stars have high velocity dispersion and a wide range of [Fe/H] ([–1.5-0.5] dex).

$\Rightarrow$ Galactic chemical evolution could profoundly affect planet demographics throughout the Galaxy.

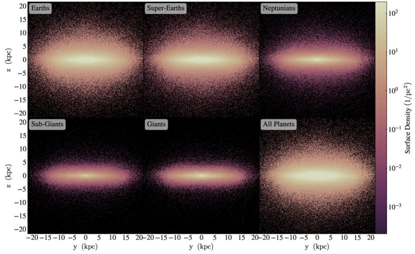
Where do planets live in our Galaxy?

I. From the theoretical point of view

Where do planets live in our Galaxy?

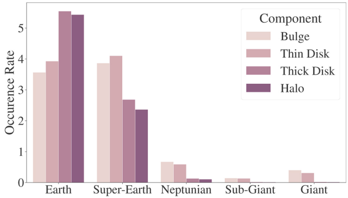


(a) Face-on view.



(b) Side-on view.

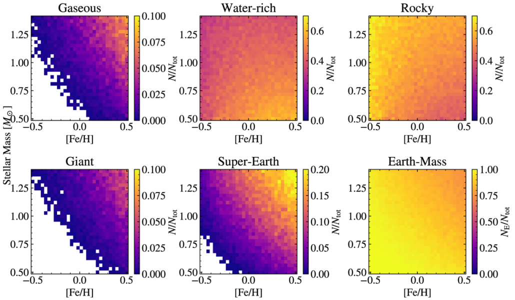
- Planet model + MW analog (at $1M_\odot$)
- Planets in [bulge & thin disc], [thick disc & halo] are very similar but with different ages
- Giant planets are more common around thin disc stars & Earth-mass planets around thick disc stars.
- Giant planets (90%) are concentrated in the center of the MW due to high metallicity dependence.

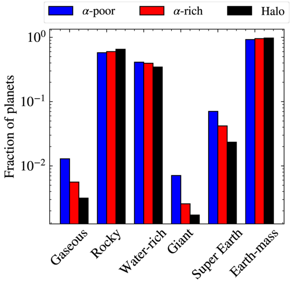


(Boettner et al. 2023)

Where do planets live in our Galaxy?

- Protoplanetary disc model + a chemical model (using also observations) to infer planet composition around stars in different populations
- Stellar $M_\star$ and [Fe/H] affect the formation of giants & super-Earths.
- Super-Earths, giants, gaseous, & water-rich planets are more common around α-poor (thin disc) stars compared to α-rich (thick disc).





Nielsen+ (2023)

see also Bitsch & Battistini (2020), Cabral+ (2023)

Where do planets live in our Galaxy?

II. From the observational point of view

The Ariel mission reference sample

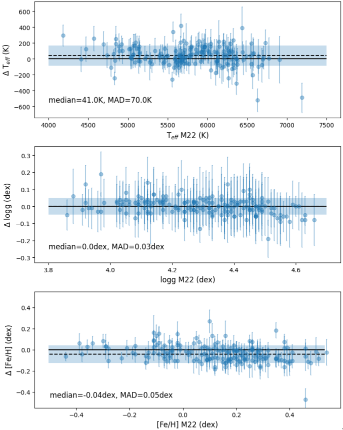
THE NEED OF AN HOMOGENEOUS CHARACTERISATION

Characterization of ∼1000 planets around AFGKM stars

- Chemical composition & atmospheric thermal properties of exoplanets
- to be launched in 2029

Uniform analysis of Ariel planet hosts with high resolution spectroscopy

1. Equivalent Widths of Fe
   - 187 FGK-type (Magrini+ 2022; M22)
   - 169 FGK-type (Tsantaki+ 2024 subm.)
2. Spectral synthesis
   - 36 fast rotators & hot stars (Tsantaki+ 2024 subm.)



Used the same ingredients to guarantee homogeneity: radiative transfer, atomic data, model atmospheres, fixed log g

The Ariel mission reference sample

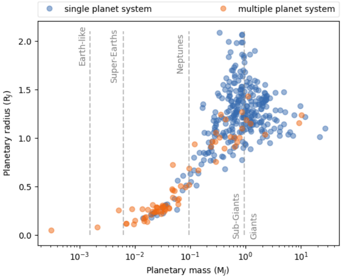
Combined sample of **354 FGK-type stars** hosting 446 planets detected by RV & transit methods:

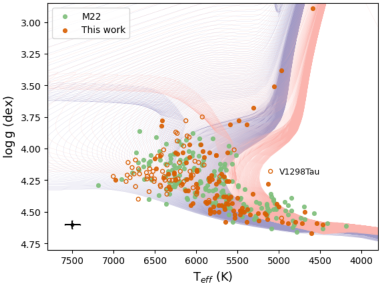
$$4184 \leq T_{eff} \leq 7003 \text{ K}$$

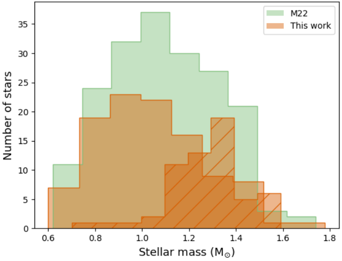
$$2.89 \leq \log g \leq 4.57 \text{ dex}$$

$$-0.58 \leq [Fe/H] \leq 0.54 \text{ sex}$$

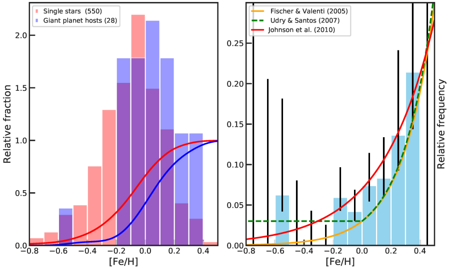
$$0.60 \leq M_{\star} \leq 1.78 \text{ M}_{\odot}$$





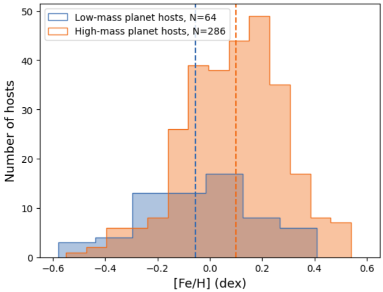


The Ariel reference sample: metallicity & planetary mass



extensive literature,

see review Adibekyan 2019

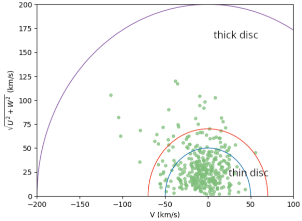


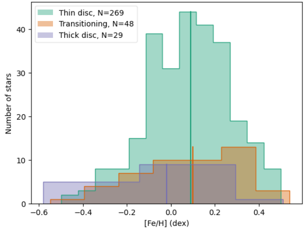
$<[\mathrm{Fe/H}]_{lowmass}> = -0.06 \pm 0.03$ dex
$<[\mathrm{Fe/H}]_{highmass}> = 0.10 \pm 0.01$ dex

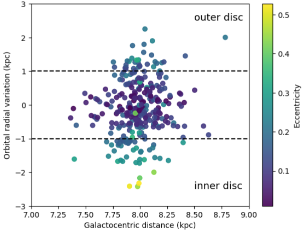
Low-mass planets are found in a wider range of [Fe/H].

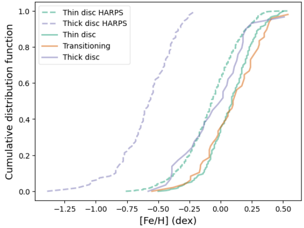
The Ariel reference sample

Kinematic separation for the thin & thick disc stars using Gaia DR3 data





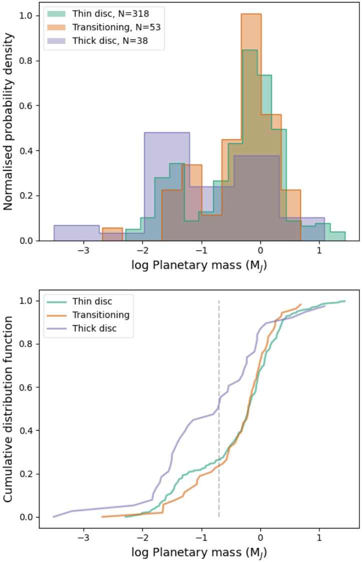




Planet hosts do not follow the metallicity distribution of their populations.

Caution on the low number of detections around thick disc stars.

The Ariel reference sample: metallicity & planetary mass

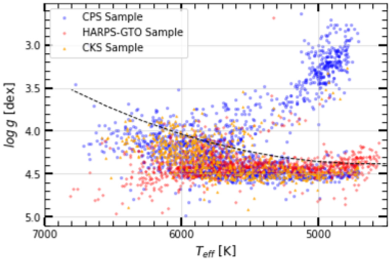


- More massive planets are formed predominantly around [Fe/H]-rich stars and are mainly located in the thin disc.
- Thin-disc stars are younger, and due to the relationship between age and metallicity, those richest in metals should also be the youngest.
- As stars get more chemically enriched over time, the formation of more massive planets is enhanced as well.

(see Adibekyan+ 2012; Biazzo+ 2022)

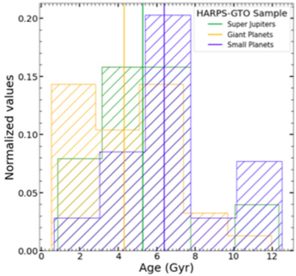
Caution on the detection biases of low-mass planets around young stars.

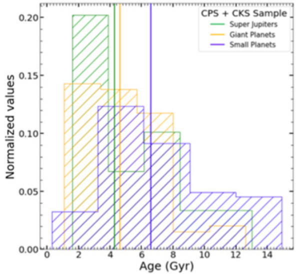
Are High-mass Planetary Systems Young?



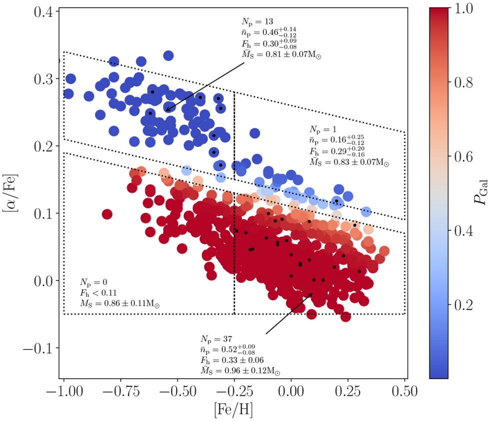
Low-mass planets may have been formed during all epochs of star formation, while giant planets are formed around chemically enriched stars that are relatively young.

(Swastik+ 2022)





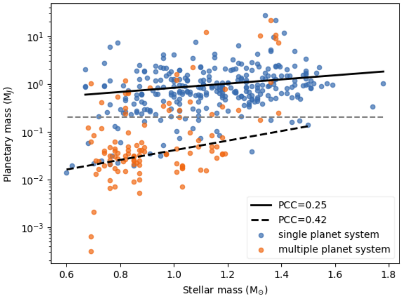
Occurence rates of low-mass planets at the Galactic discs

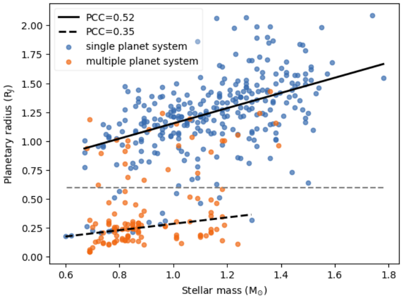


HARPS GTO planet search sample (Adibekyan+ 2012; Bashi+ 2022)

- Chemical separation of the discs is more robust than kinematic (talk of Delgado-Mena)
- The occurrence rates of small planets in the thin and thick disks are compatible.
- For iron-poor stars, a significantly higher small-planet occurrence rate among thick-disk stars as compared to thin-disk stars.

Planetary mass & radius vs stellar mass

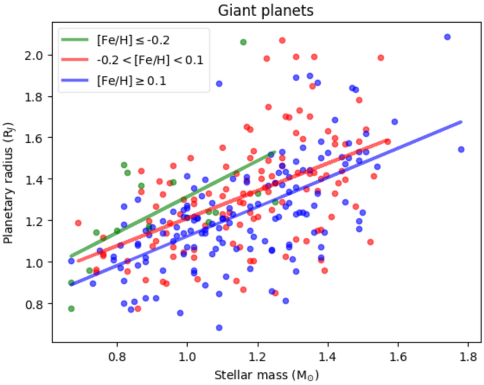




- More massive planets are around more massive stars.
- The planetary M_{pl} does not shift linearly with the stellar $M_\star$.
- More ejected planets occur for higher stellar $M_\star$ because of the growth of giant planets (Burn+ 2021).

- Larger planets are around more massive stars.
- Small planets forming around more massive stars tend to accrete H-He atmospheres more efficiently (Lozovsky+ 2021).

Planetary radius vs stellar mass & [Fe/H]

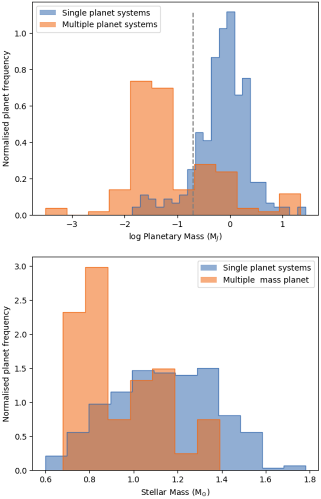


At a given stellar $M_\star$, larger planets orbit more metal-poor stars.

(Magrini+ 2022; Tsantaki+ subm. 2024)

- Giant planets accreted larger amounts of heavy elements around higher [Fe/H] stars during their formation and migration (e.g. Turrini+ 2022, 2021).
- These planets have higher densities and more compact radii than those of similar planets formed in lower [Fe/H] environments.
- Giant planets formed in lower [Fe/H] ⇒ richer in light elements (H and He) ⇒ have larger radii.

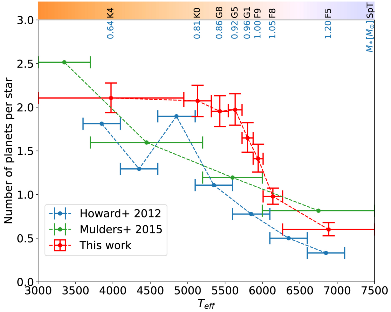
The Ariel reference sample: multiplicity



Tsantaki+ subm. (2024)

Most (76%) low-mass planets in our sample belong to multiple systems orbiting lower-mass stars.

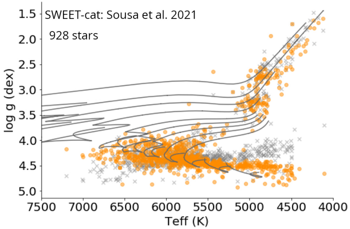
Planet multiplicity ↓ with ↑ stellar $M_\star$

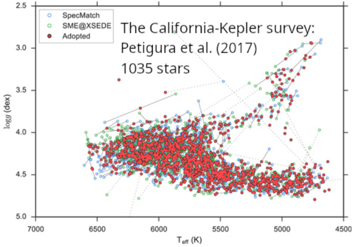


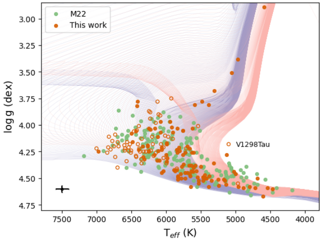
Kepler Data

Yang+ (2020)

The need for homogeneous planet-host catalogs







Other catalogues in high resolution:

- Hypatia (Hinkel+ 2014)
- PASTEL (Soubiran+ 2021)
- 1111 HARPS (Adibekyan+ 2012)
- SPOCS (Valenti+ 2005)

The need for volume-limited samples

Requirements

Resolving power

R=80 000

Spectral range

Three windows from blue to red, with varying ranges from about 15.0 nm (blue) to 30.0 nm (red)

Radial velocity stability

10 m/s

Multiplexing

From 40 to 100 fibers

Fiber size

From 1 to 1.2 arcsec

- How do the incidence, orbital and physical properties of giant exoplanets change with age, mass and composition of their host star?
- Which are the characteristics that differentiate stars with planets and without planets when both are part of the same cluster?
- What is the influence of environmental effects on the frequency and properties of exoplanets?

see white paper (Magrini+ 2023) in the arxiv

Conclusions

- High-mass planets orbit more [Fe/H]-rich stars which belong to the thin disc. The lower-mass planets can be found in more [Fe/H]-poor environments and are more likely to be hosted in the thick disc.
- **The Galactic environment plays a very important role in shaping the planetary system.**
- Larger planets orbit around more massive stars and larger planets around more [Fe/H]-poor stars, at a given stellar $M_{\star}$.
- **Homogeneity is key.**

Thank you!