The chemistry of the planet host star

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Objectives of ARIEL:

What are the conditions for planet formation and the emergence of life?

Key science objectives:

- Detect planetary atmospheres, and identify their composition and structure
- Determine vertical and horizontal temperature structure, and diurnal and seasonal variations
- Identify chemical processes at work (thermochemistry, photochemistry, transport quenching)
- Constrain planetary interiors (breaking the radius-mass degeneracy)
- Quantify the energy budget (albedo, temperature)
- Constrain formation and evolution models (evidence for migration)
- Detect secondary atmospheres around terrestrial planets (evolution)
- **Investigate the impact of stellar and planetary environment on exoplanet properties**

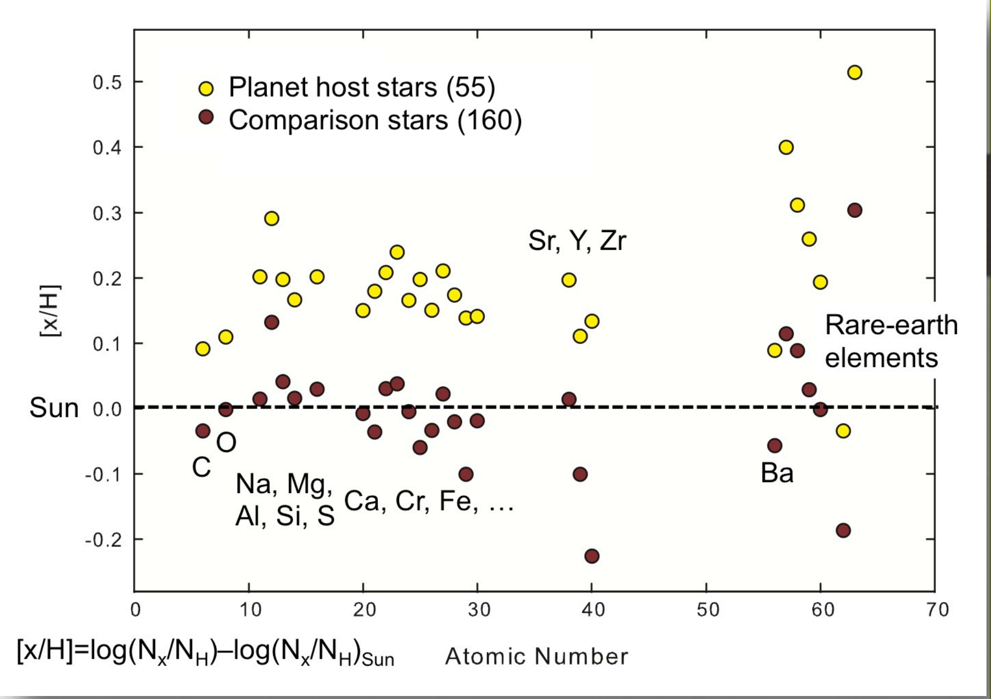
The mission will thus provide a truly representative picture of the chemical nature of the exoplanets studied, and relate this directly to the type and **chemical environment of their host stars.**

The relationship between the presence of planets and the chemistry of the host star:

- FIRST RESULTS: Stars with planets are systematically more metal rich than field stars of the same mass (e.g., Laughlin & Adams, 1997). The planet-metallicity correlation was quantified by Fischer & Valenti (2005).
- MORE RECENTLY (from Adibekyan et al. 2015):
  - **Giant planet formation** is more efficient around metal rich stars (e.g. Gonzalez 1997 ; Santos et al. 2004 ; Johnson et al. 2010; Mortier et al. 2013)
  - The planet–metallicity correlation probably **does not hold for lower-mass/small-size planets** (e.g. Sousa et al. 2011b ; Mayor et al. 2011 ; Buchhave et al. 2012).

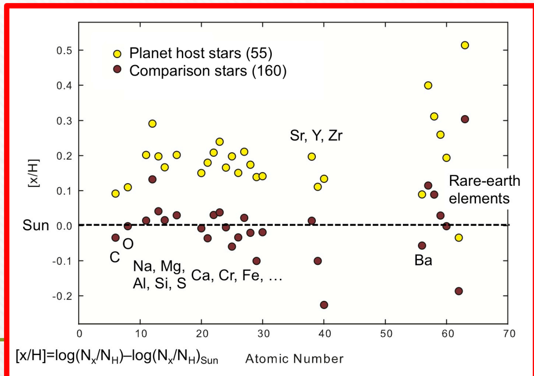
The relationship between the presence of planets and the chemistry of the host star:

- The planet-metallicity correlation is due to the intrinsically higher metallicity of the molecular clouds from which the majority of the planetary systems have formed

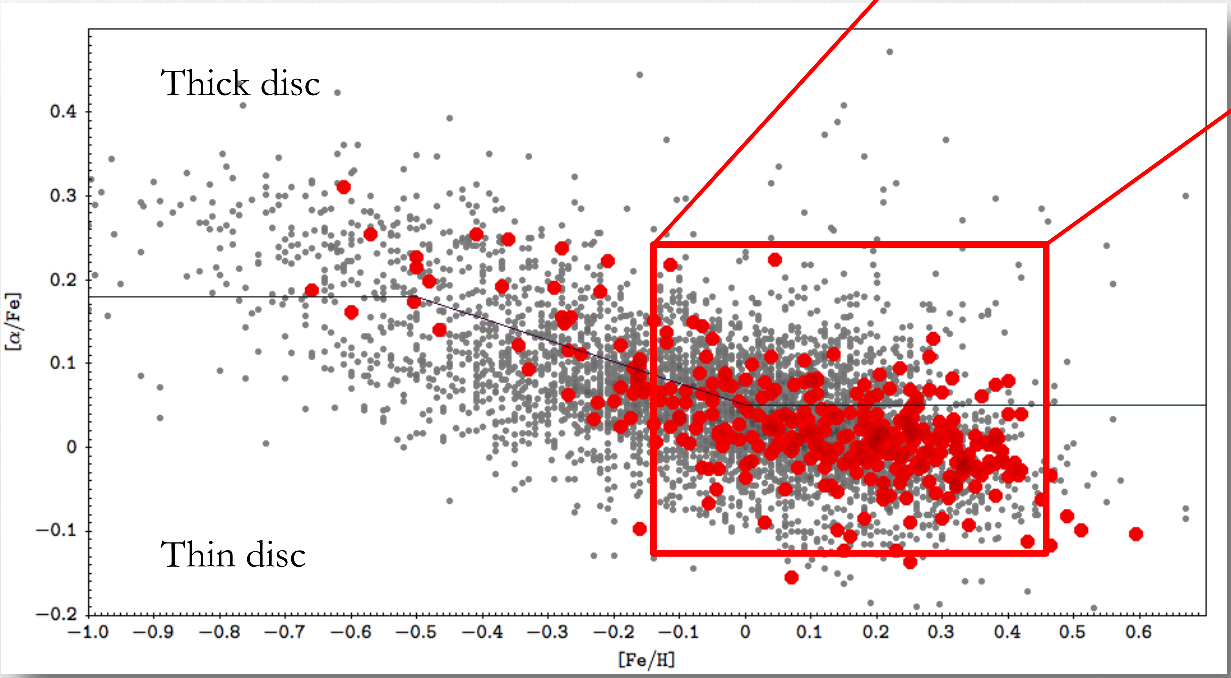


The abundances of chemical elements in planet host stars, adapted from Luck & Heiter (2006, AJ 131, 3069).

From the Hypatia catalog



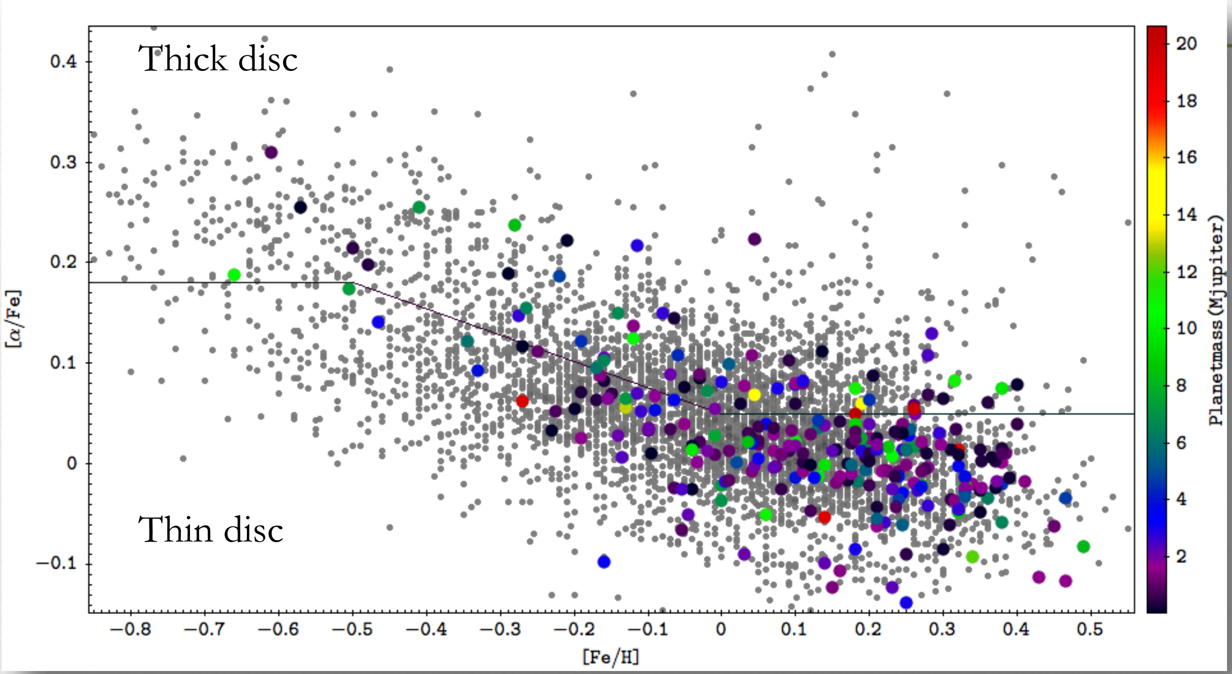
The enhancement of α-elements of iron-poor planet hosts was shown to be robust (Haywood 2008 ; Adibekyan et al. 2012a ,b).



Distribution of the stars with planets (red) and without planets (grey) in the [α/Fe] vs. [Fe/H] plane.

- Planets are more frequent around high metallicity thin disc stars
- At relatively low metallicity [Fe/H]<-0.2, planets are more frequent in **<u>thick disc stars.</u>**

From the Hypatia catalog

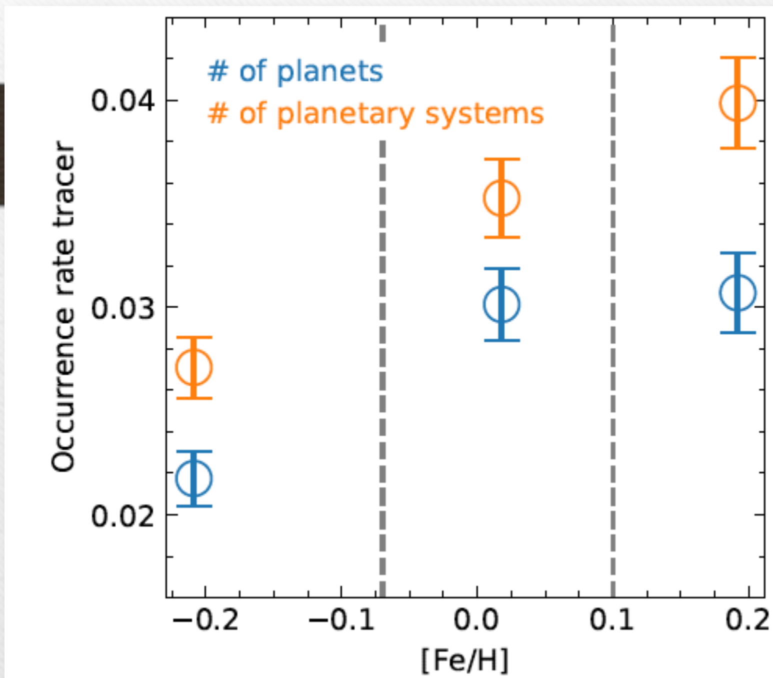


Distribution of the stars with planets, colour-coded by planet mass

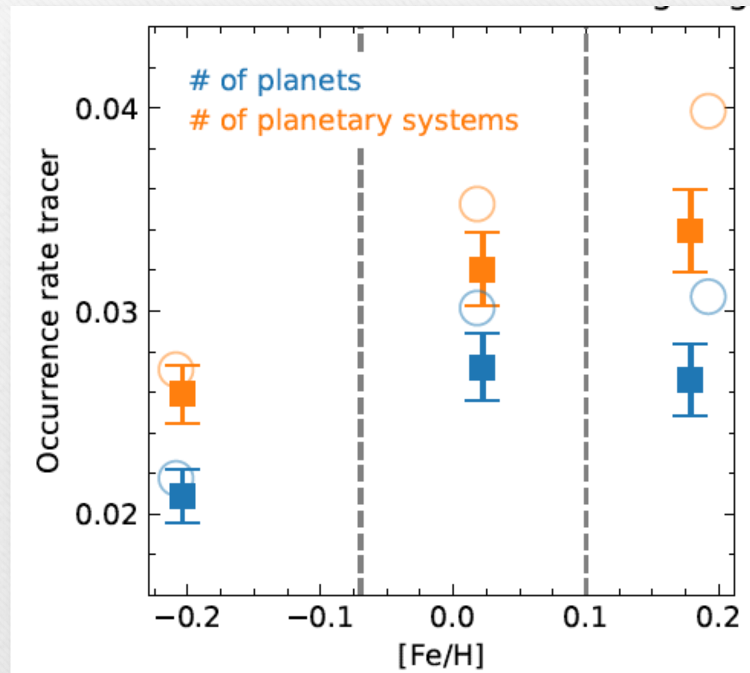
The relationship between the presence of planets and the chemistry of the host star:

- LAMOST-Kepler observations (Zhu 2018)

Stars with giant planets



Stars with rocky planets



Important constraints on mechanisms of planet formation

Which constraints to planet formation models: **Giant planets**

- The giant planet metallicity correlation supports the core-accretion scenario for the formation of planets (Pollack et al. 1996; Ida & Lin 2004; Mordasini et al. 2009) in which it is assumed that planetesimals are formed by the condensation of heavy elements.
- It is in agreement with Nayakshin (2015)'s theory of Tidal downsizing
- **These works show how important the study of stellar metallicities of planet hosts is to constrain the planet formation theories.**

Which constraints to planet formation models:
Rocky planets

Different theoretical studies on planet formation have shown that **Fe, Si, Mg and O** are the most important elements forming the bulk composition of rocky planets together with **Ni and S**.

- Adibekyan et al (2015) found **that low-mass planets are more prevalent around stars with high [Mg/Si].**
- Thiabaud et al. (2015) modelled the abundance ratios in planets, finding that Mg/Si and Fe/Si in planets are essentially identical to those in the star. Some deviations are shown for planets that formed in specific regions of the disc. The **C/O ratio in the planet atmosphere ratio** shows instead only a very weak dependence on the stellar value.

Missing information: how does this translate in the composition of the planets and of their atmospheres ?

Missing observations out from the Solar System

Which constraints to planet formation models:
Rocky planets

There are two main hypotheses for the rocky composition of exoplanets.

- The solid planets formed in equilibrium from the material of the solar nebula (Elser et al. 2012; Madhusudhan et al. 2012; Thiabaud et al. 2014), so that **equilibrium chemistry can be used as a constraint for model**
- The elemental ratios Fe/Si and Mg/Si have **stellar values** (e.g., Valencia et al. 2010; Wang et al. 2013) and these values are then used to model the planetary structure.

→OK for Mars (Khan & Connolly 2008) and Earth (Javoy et al 2010) but not that of present-day Mercury, which has elemental ratios that are not solar, possibly due to its collisional history (Benz et al. 2007) or peculiar formation (Lewis 1972, 1988).

→**More planetary systems are necessary, with the study of the composition of their atmospheres**

The relationship between the stellar parameter and the habitable zone:

- Stellar parameters such as surface temperature and gravity determine the region around a star in which water can remain in its liquid state.

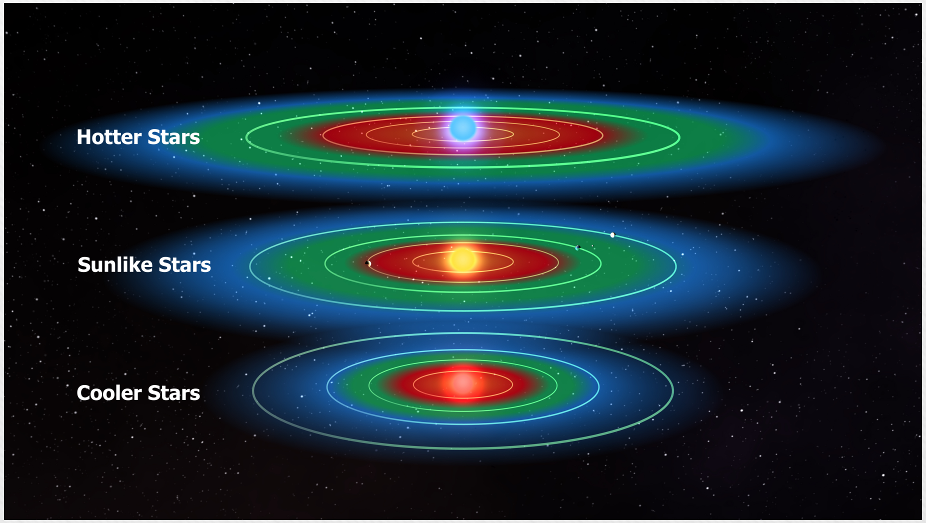


Fig. 1: Schematic of habitable zones around different stars. The green region is at the proper distance from the star where water can remain in its liquid state on the surface of a planet. The red region is too warm, and the blue region is too cool. **Image:** NASA/Kepler Mission/Dana Berry.

How can we contribute in this phase?

- **Inputs to the target list** – to be observed will be solicited from the wider community (e.g. through whitepapers, meetings, and other mechanisms)
- ARIEL will thus provide a representative picture of the chemical nature of the exoplanets and relate this directly to the type and chemical environment of the host star.
- **Characterization of the possible targets:**
  - Stellar parameters (T_{eff}, logg, [Fe/H])
  - Individual element abundances
  - Ages (see Germano's talk)

How can we contribute in this phase?

- → **select host stars in a wide range of metallicities and with different abundance ratios to put strong constraints to planet formation (rocky vs gaseous, single vs multiple)**
- → collect literature high-resolution spectra for the selected stars or make new observation proposal
- **→ perform a homogeneous analysis of them to derive stellar parameters and global metallicity, but moreover individual abundances from light (e.g. C,N,O) to heavy (e.g. Ba, Eu) elements.**

The expertise of the ***stellar*** group in Arcetri

- Co-Leadership of Gaia-ESO, the largest spectroscopy survey on an 8-m telescope
- Expertise in data reduction pipelines (G. Sacco, M. Rainer, N. Sanna, F. Massi)
- Spectral analysis and abundance determination of large sample of high-resolution spectra (L. Magrini)
- Age determination (G. Sacco, L. Magrini, G. Casali)→ see Germano’s talk
- Involvement in present and future spectrographs (MOONS, WEAVE, HIRES)→ See Nicoletta’s talk for HIRES