OPEN CLUSTER SCIENCE WITH HRMOS

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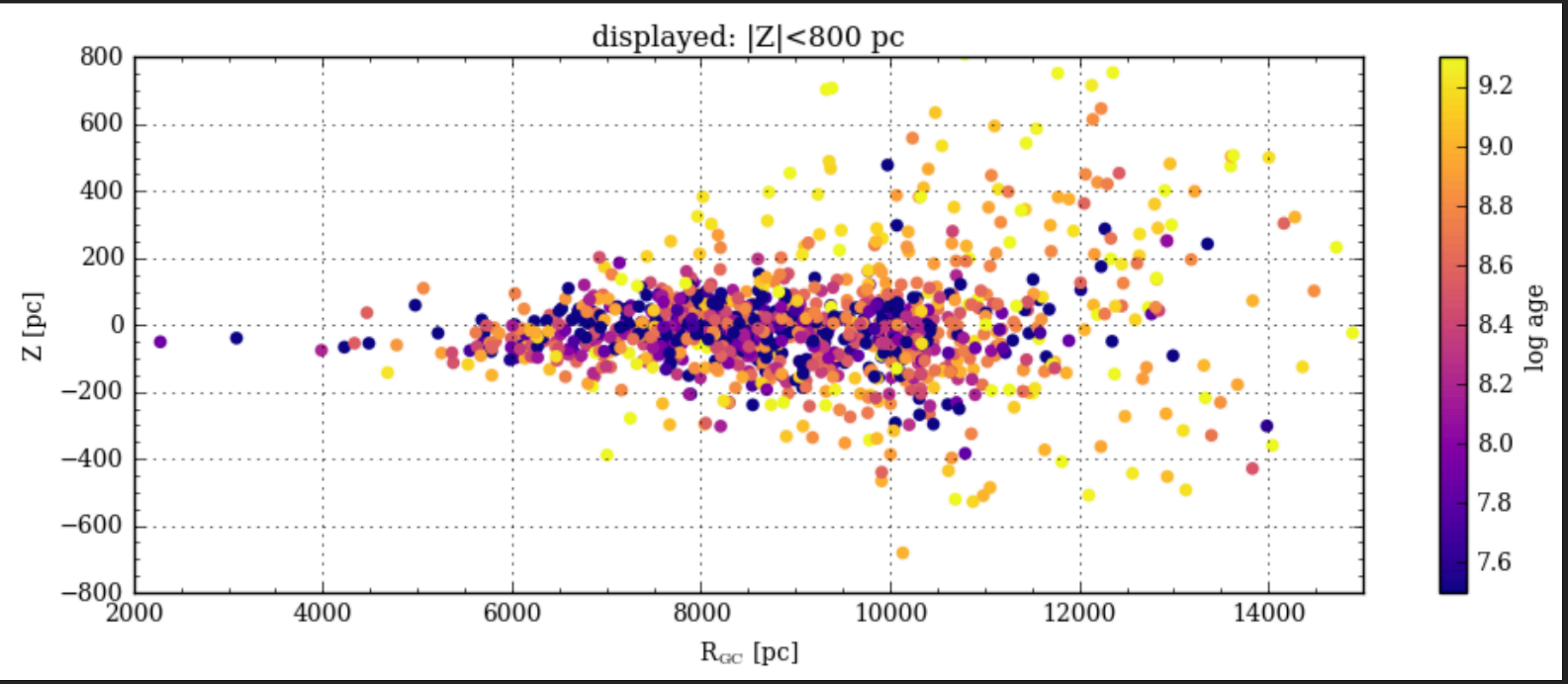
OSSERVATORIO ASTRONOMICO DI PADOVA

HRMOS Science Workshop - 2021

THE OPEN CLUSTER POPULATION

Open Clusters' **ages**, **masses**, **distances**, and **chemical composition** can be estimated in a relatively simple way and with extremely high precision.

Cantat-Gaudin et al. (2018)



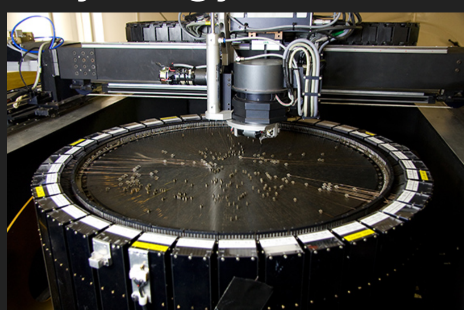
How is the Milky Way disk structured? How does it evolve with time? Where are stars primarily produced in our Galaxy? Is it possible to trace stars back to the location where they have formed? How are chemical elements synthesised in stars and then recycled throughout the Galaxy?

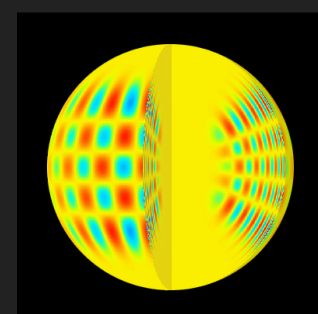
SPECTROSCOPY OF OPEN CLUSTERS BEFORE 2030s

The Galactic revolution in 2010s

...and many others.

In synergy with...





Information on kinematics, chemical and global properties for a very large number of open clusters (e.g., Magrini et al. 2018, Donor et al. 2020, Spina et al. 2021)

2020s will be even brighter:

...and others.

A large spectroscopic surveys at high-resolution (>60 000) and with a broad spectral window is still missing in the current observational context.

A new high-resolution multi-object spectrograph could fill the gaps in knowledge left by the current and future surveys.

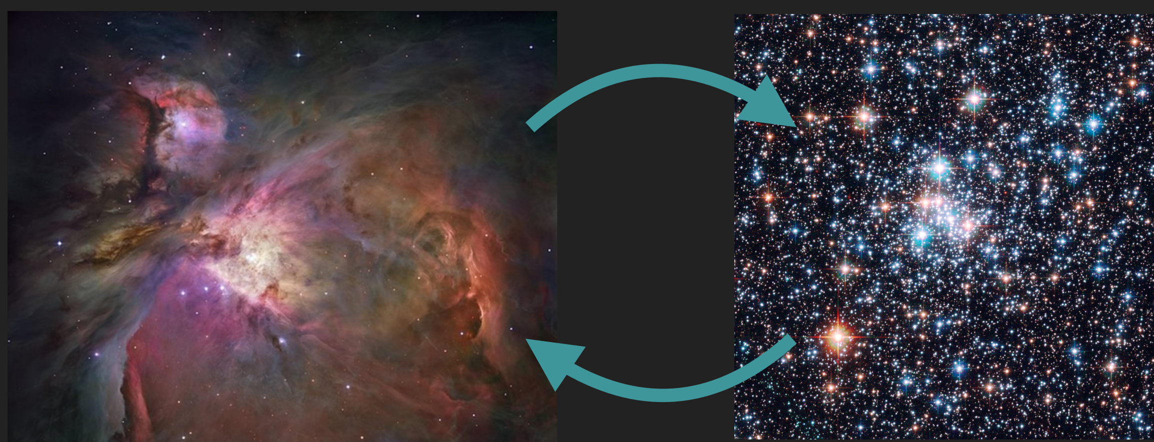
THE AIM OF THIS TALK

- I am not going to cover all the possible topics
- I can't predict the future
- I am biassed

The topics of my talk: **Young Stars**, **Chemical Tagging**, **Nucleocosmochronometry**, and **Star-Planet Chemical Connections**

My aim is to trigger **interesting discussion**

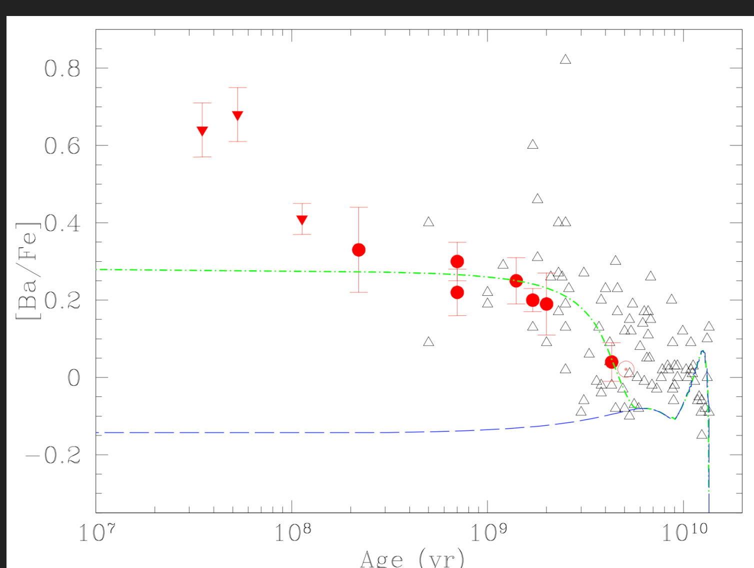
ODDITIES IN YOUNG CLUSTERS



Cosmology
Nuclear physics
Galactic evolution
Stellar formation
Stellar evolution

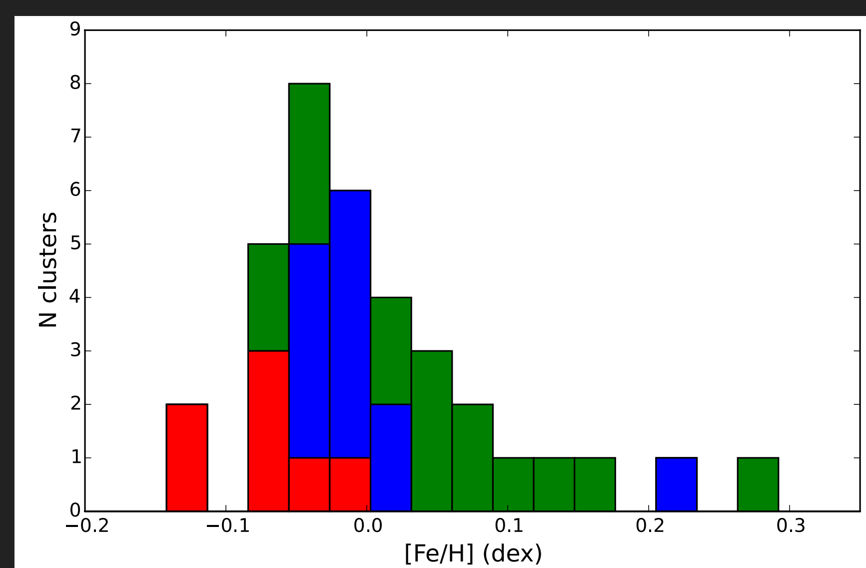
- Young OCs (age≤100 Myr) are the latest products of the Milky Way. Essential to put strong constraints on models of Galaxy evolution.
- Young OCs did not have time to migrate along the Galactic disk. Their chemical composition is representative of the chemical makeup of the ISM at the exact location where they are observed now.

Anomalously **high Ba abundances** in young OCs



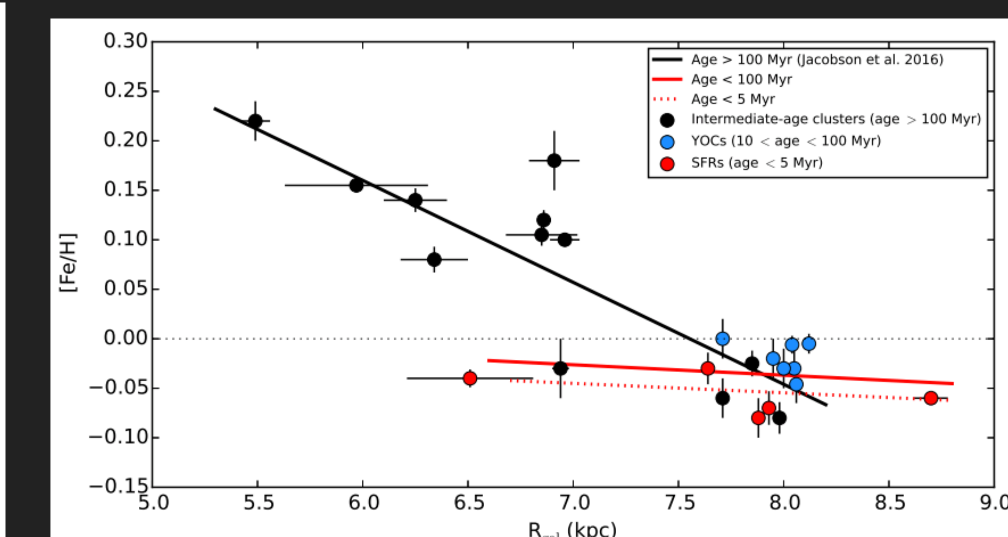
D'Orazi et al. (2009)

The **anemy** of the local ISM



Spina et al. (2014ab)

...and **beyond**



Spina et al. (2017)

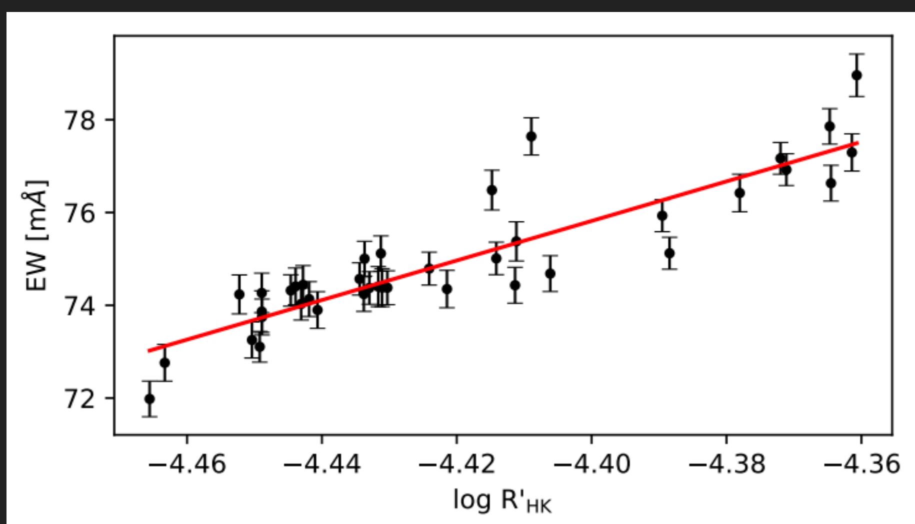
These are artefacts. The real **chemical content of young stars is still unknown**. Huge gap in knowledge.

ODDITIES IN YOUNG CLUSTERS

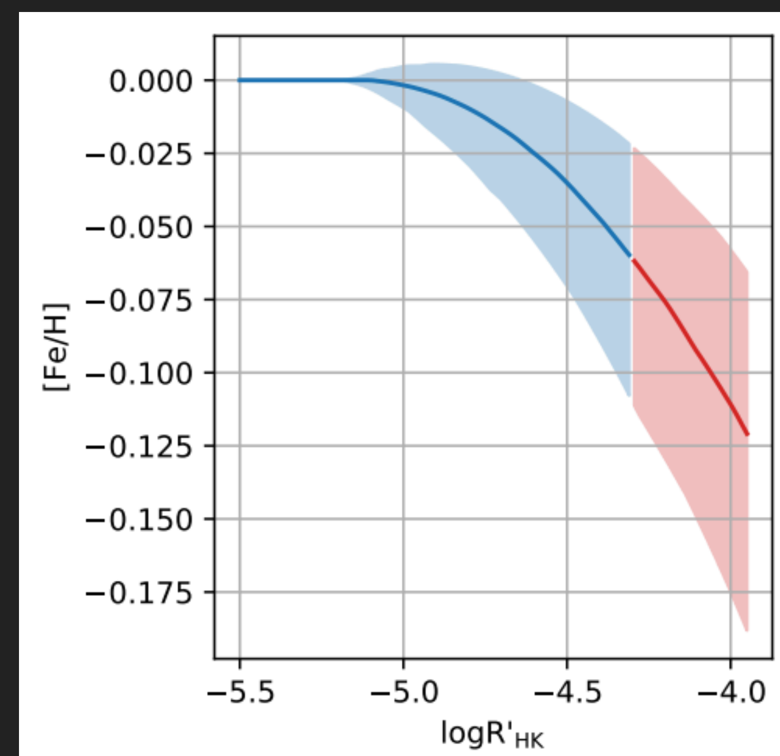
- When the star is young and active: strong **magnetic fields**, significant number of **stellar spots**, **flares**, etc…
- These phenomena shape the spectra, but they are completely neglected in our models.
- It is a **synthetic gap** that strongly affects the analysis of young stars (≤ 1 Gyr).

See Yana-Galarza et al. (2019), Spina et al. (2020), Baratella et al. (2020, 2021)
…and **Baratella's talk**.

Variation of the Ba line @5853Å along the stellar cycle for HD59967 (~400 Myr)



Spina et al. (2020)

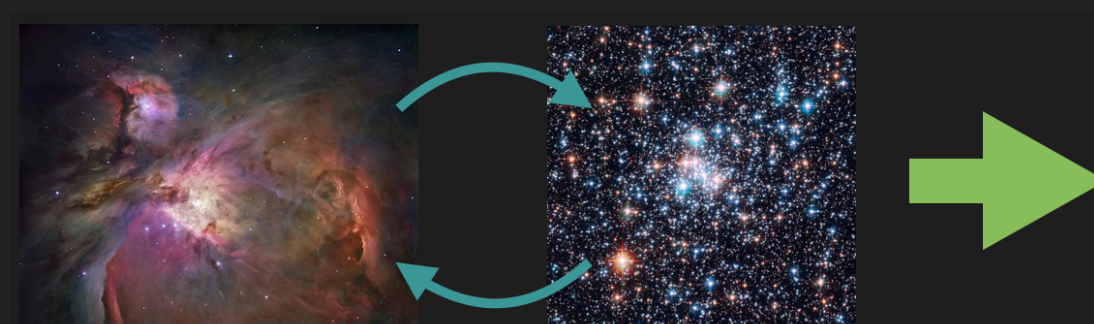


When stellar activity is high, the star appears to be poorer of metals than what it actually is.

Spina et al. (2020)

We have never been able to determine the chemical composition of young stars in an accurate way.

This is a **MAJOR** problem in stellar astrophysics!



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ODDITIES IN YOUNG CLUSTERS

Possible solutions to these "**magnetic horrors**" of young stars?

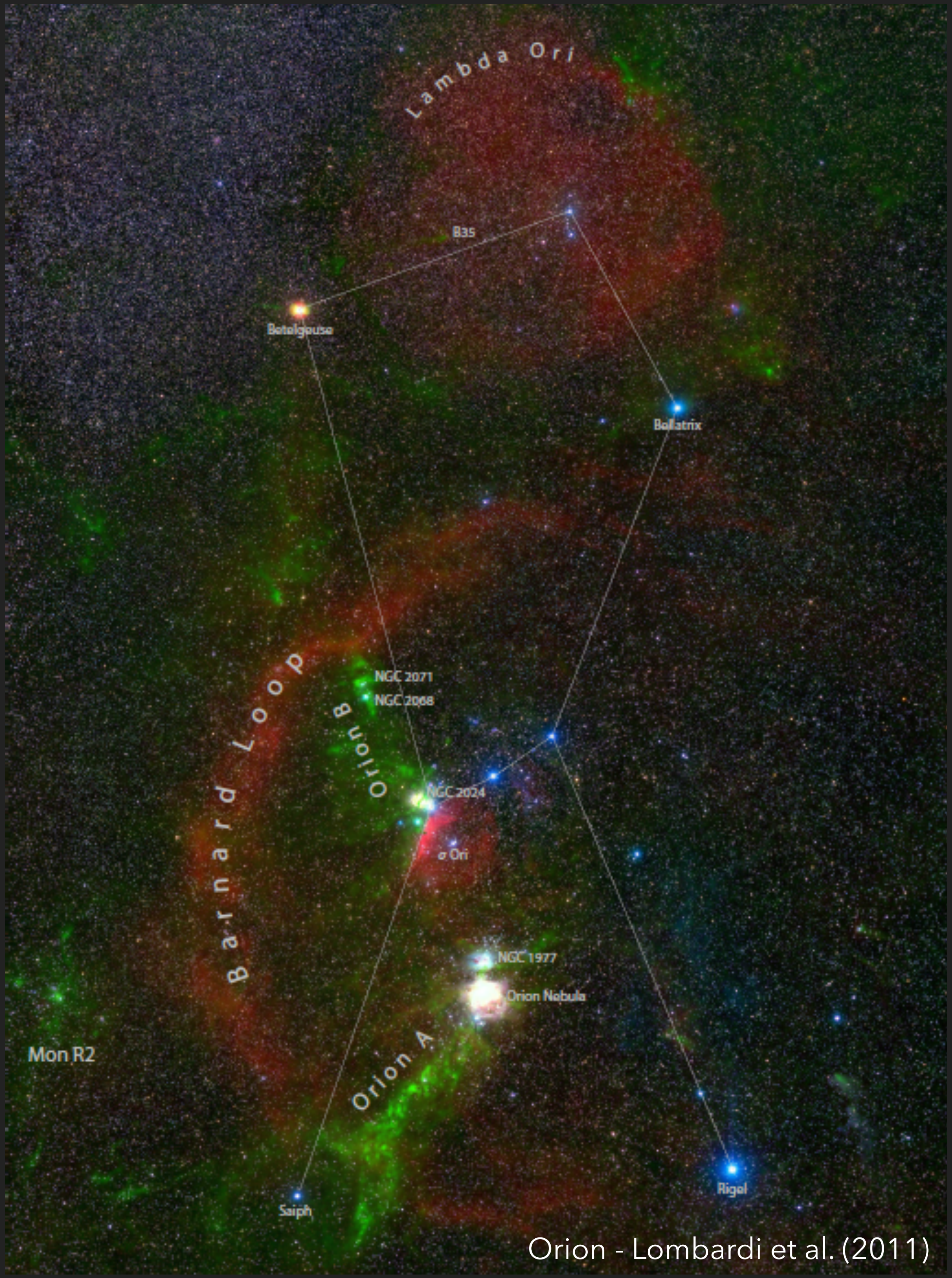
- Baratella et al. (2020,2021) has developed a method to alleviate this problem. See Baratella's talk!
- The actual cause of the synthetic gap is still unknown. We are still unable to model spectra of young stars!

Two possible paths for the future:

- **Model-driven approach**. Develop more accurate models to be used in our analysis.
- **Data-driven approach**. Learn from data which are the features that are not included in our models and use this information to bridge the synthetic gap. See Cycle-Starnet (O'Briain, et al. 2021).

We need **several high-resolution spectra of young stars** with the same age, chemical composition, but at different phases of the activity cycle.

HRMOS and Open Clusters can give a fundamental contribution to fill the synthetic gap.



Orion - Lombardi et al. (2011)

CHEMICAL TAGGING

The chemical makeup of a star is the immutable marker of the environment where it formed (Freeman & Bland-Hawthorn 2002).

Tag stars that formed from the same material through clustering in the chemical space.

Open Clusters are the natural **testbeds** of chemical tagging.

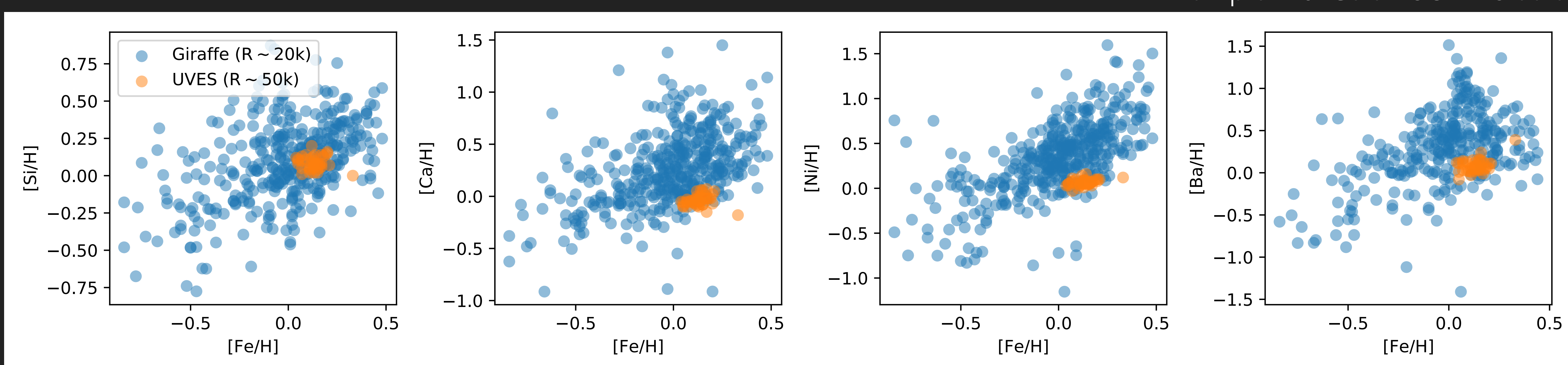
The (im)possibility of strong chemical tagging

L. Casamiquela[1], A. Castro-Ginard[2,3], F. Anders[2], and C. Soubiran[1]

Casamiquela et al. (2021) using data from OCCASO
1 out of 33 OCs is recovered at the 70% of their members.

- We cannot ask too much to clustering algorithms when our **chemical abundances** are **not accurate** (magnetic horrors - the youngest look metal poorer).
- Although clustering in the chemical space seems very complicated in the solar vicinity (R_{Gal} = 8-9 kpc), **it may be easier in the inner and outer disk**.
- Clustering algorithms struggle enormously with noise. We need precise abundance determinations. **We need high-resolution**.

Trumpler 20. Gaia-ESO DR6 data



NUCLEOCOSMOCHRONOMETRY

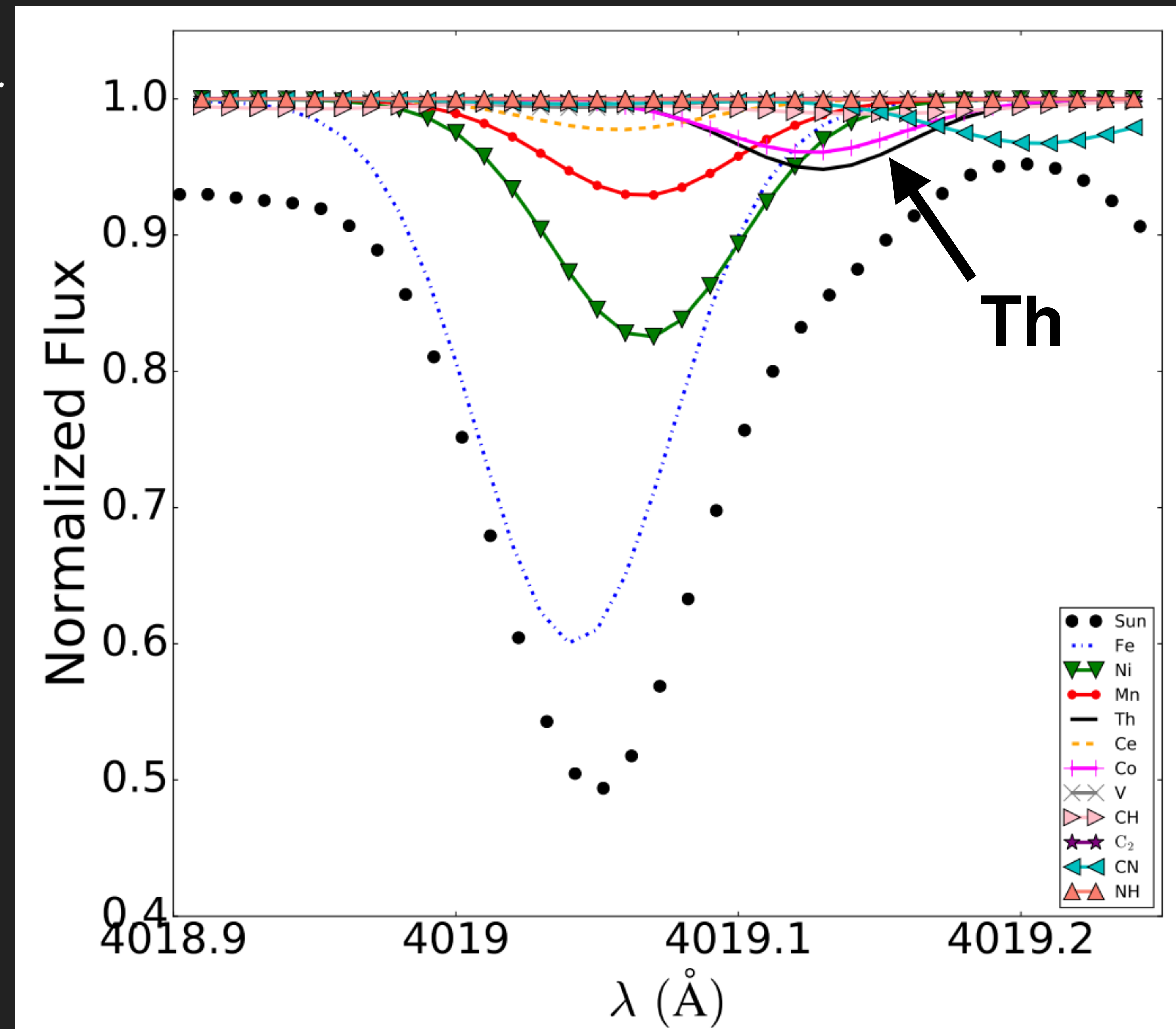
Stellar ages by measuring the decay of long-lived isotopes. **^{238}U** ($\tau_{1/2}$ = 4.47 Gyr), **^{232}Th** ($\tau_{1/2}$ = 14.05 Gyr).

The **Th line is heavily blended**

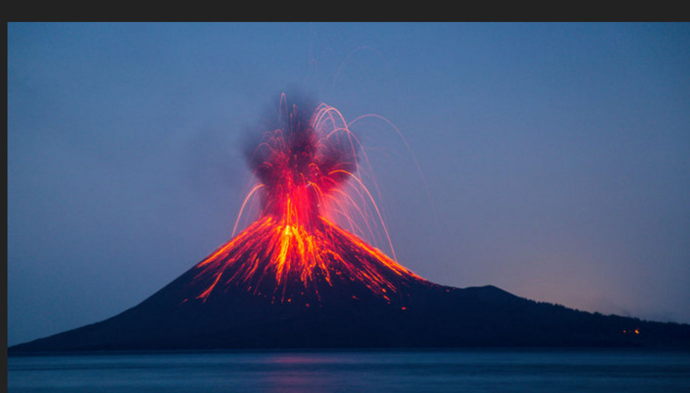
...however...

Chemical abundances can be determined with **very high precision** in Open Clusters. Useful for deblending!

The same idea is valid for many other lines that cannot be deblended under "standard" circumstances.

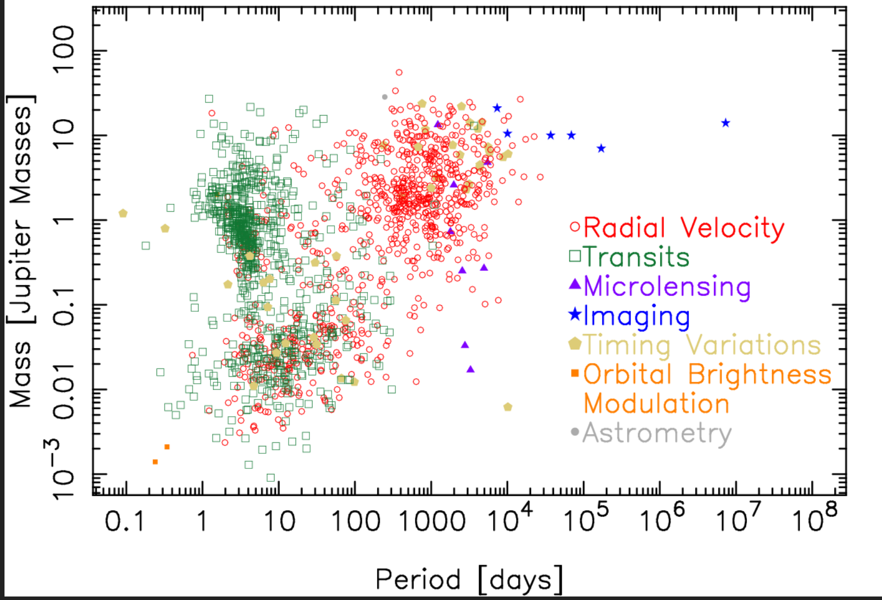


Botelho et al. (2018) - Syntetic spectrum of the Sun



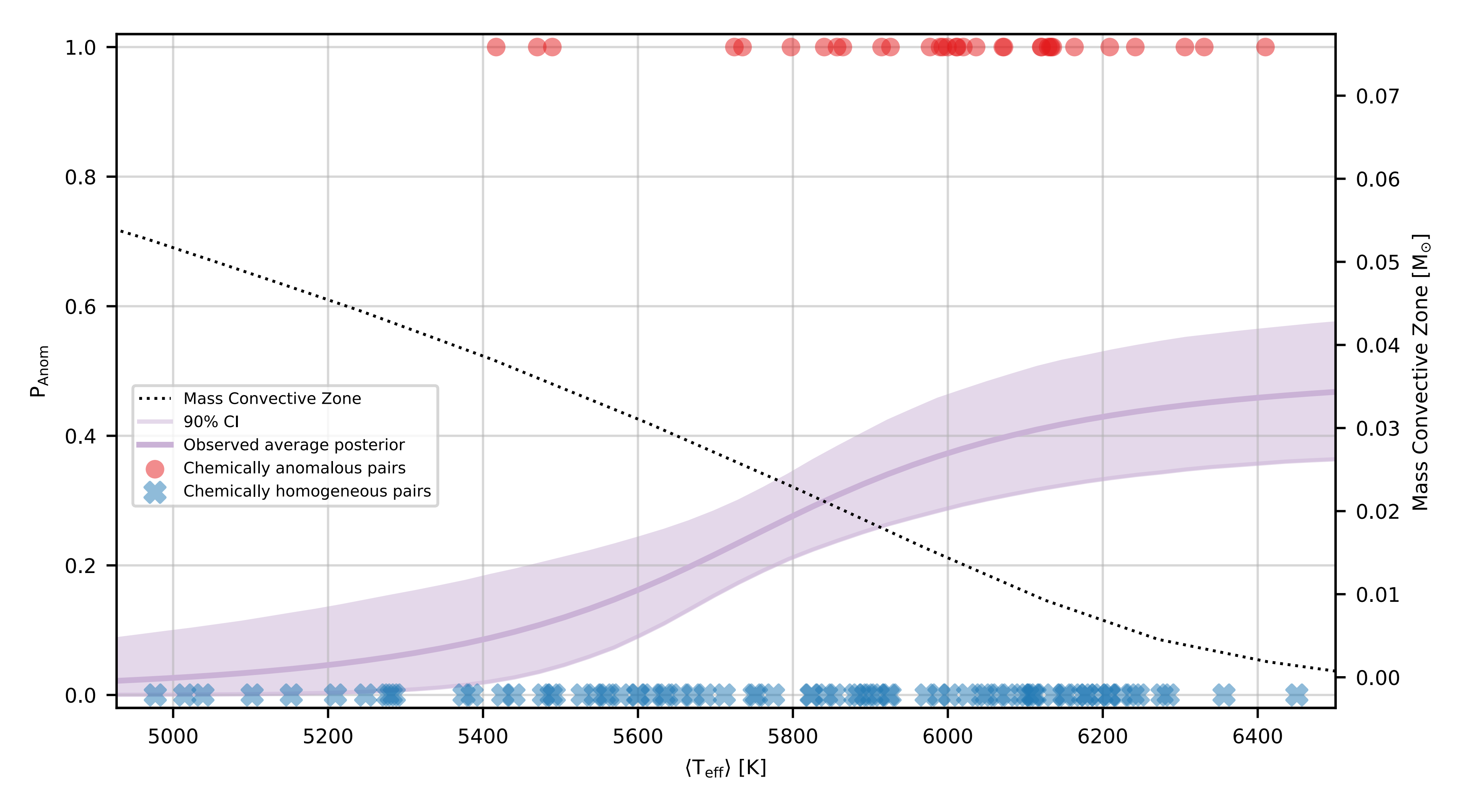
Th is a major **heat source** in rocky planets (mantle tickness, convection inside telluric plates, volcanic activity, recycle of gases between the mantle and the atmosphere)

STAR-PLANET CHEMICAL CONNECTIONS



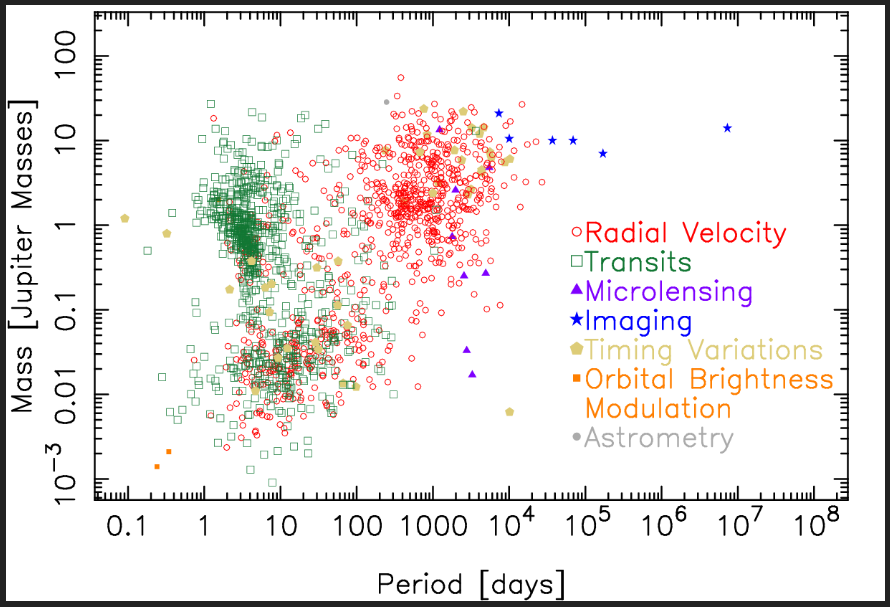
- Big **diversity** among exoplanetary systems.
- The observed diversity is the result of **severe dynamical processess** and strong dependence on initial conditions.
- In the most dynamical systems, part of the planetary material may have **fallen into the hosting star**.
- Do planet engulfment events leave **signatures** in the chemical composition of stars?

The probability of finding anomalous stars increases with T_{eff}. It is external pollution!



Spina et al. (2021, Nature Astronomy, in press)

STAR-PLANET CHEMICAL CONNECTIONS



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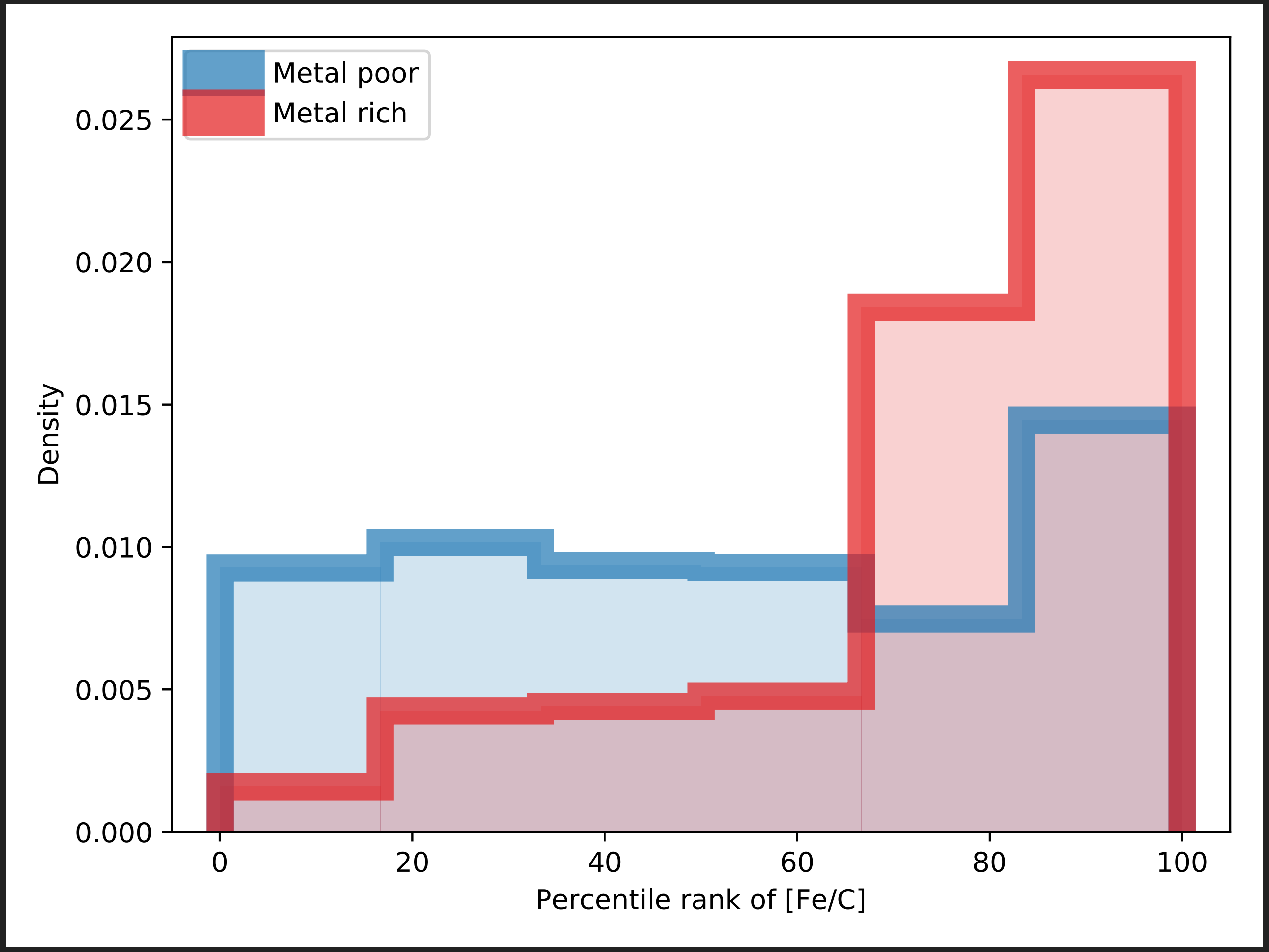
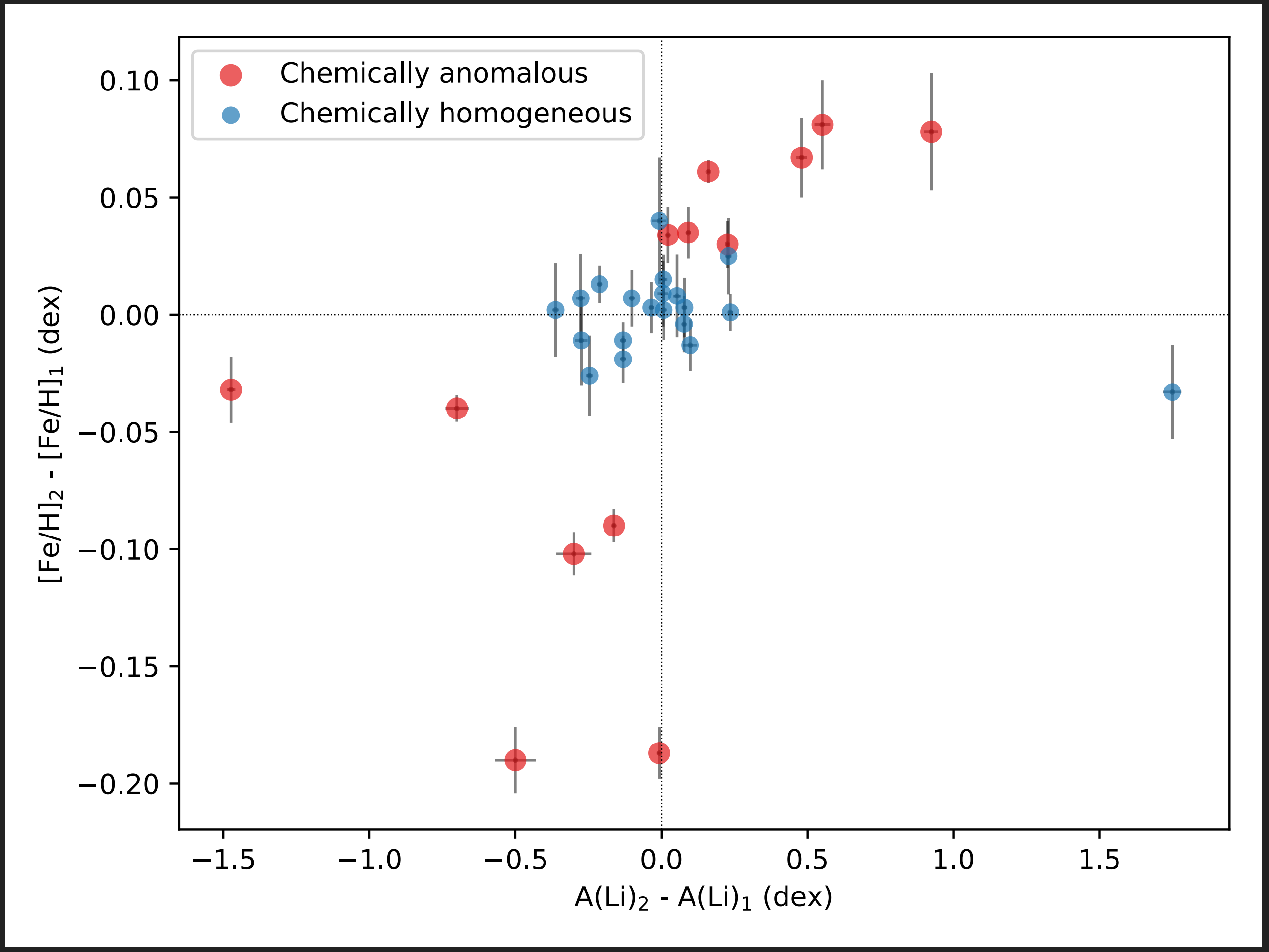
The metal-rich components are anomalous.
The metal-poor components are normal.



The metal-rich components are enriched also in Li.



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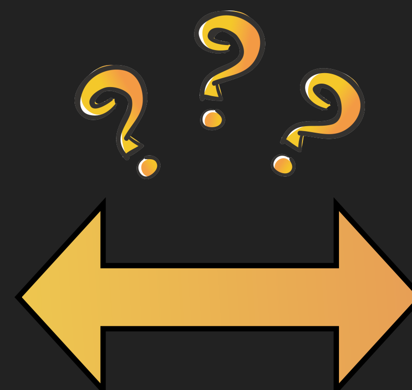
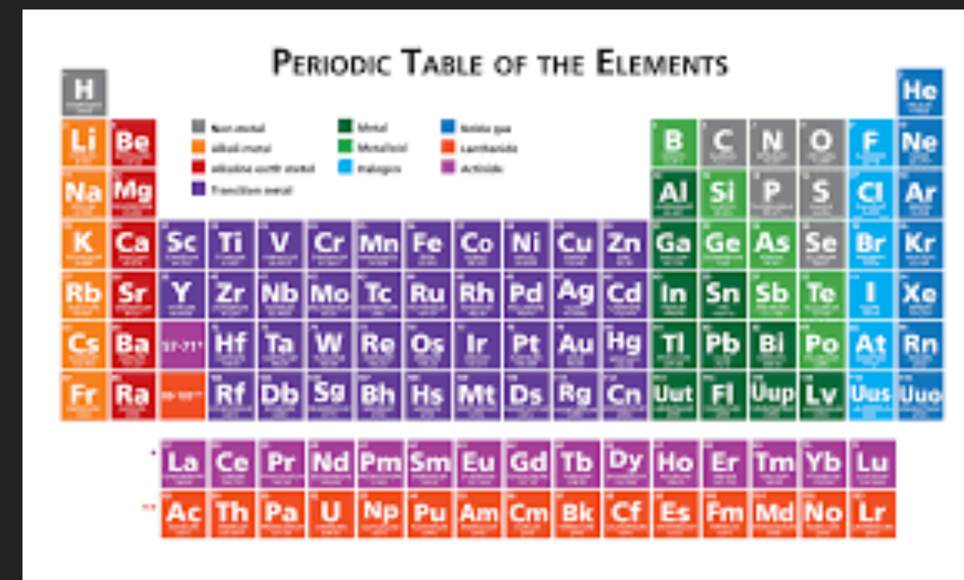
STAR-PLANET CONNECTIONS

- Planet engulfment events leave **chemical signatures** in the atmospheres of Sun-like stars.
- **Stellar associations** are the perfect laboratories to study these signatures.
- Is there any link between the chemical anomalies that stars may or may not have and the **architecture of their planetary systems**?





- HRMOS will be designed for planet hunting (hot jupiters) around Sun-like stars in open clusters.
- With this aim, we will acquire dozens of spectra of the same stars. The stacked spectrum is expected to have very high-SNR.
- Spectra of many members of a single open cluster will be acquired at the same time.

For each open cluster member we will target

Information on the presence/absence of hot-jupiters	Information on the presence/absence of chemical enrichment

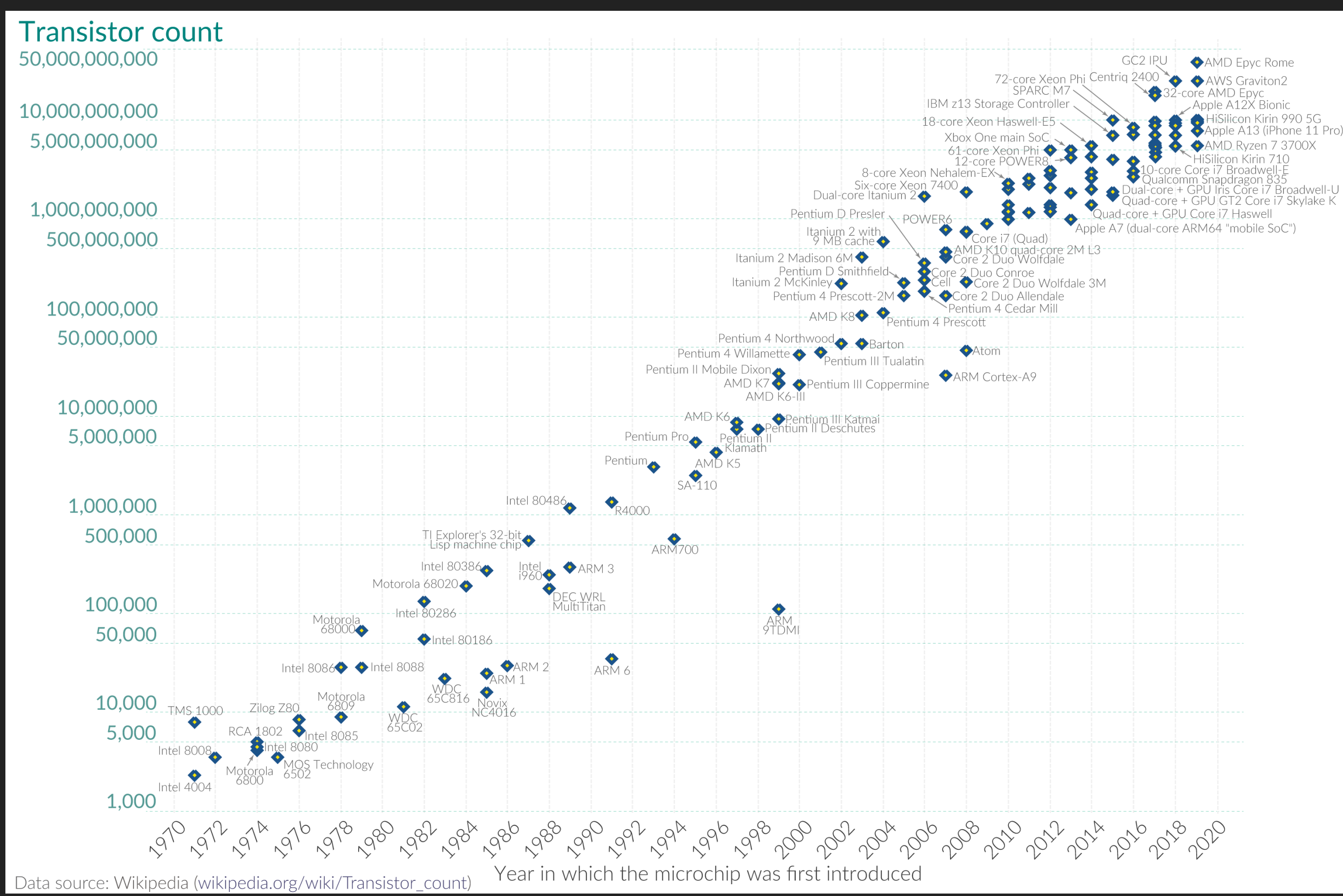
That is exactly the information that we need!

CONCLUSIONS

What can HRMOS do that is not feasible with current/future surveys?
Any synergy with the new datasets that will be produced in the 2020s?
Any synergy with the unique characteristics of Open Clusters?

Quite obvious questions...
...although answers are not obvious

How will stellar spectroscopy look like in 2030?



The processing power of computers doubles every two years

Big data

Growing progress in the research of new algorithms

High-resolution contains a lot of information.

Present: we extract only the information that is present in our models.

Future: can we learn more from data?

In Open Clusters the same information is repeated in different ways across the many members.

Present: we still analyse stars one by one.

Future: can we unlock more information by looking at an Open Cluster as a unique entity?