Elemental abundances in planet host stars

(and their use as chemical clocks)

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on behalf

of the GAPS project (Biazzo et al. 2022) & of the Ariel sub-WG for Stellar Parameters (see Laura Magrini's talk)

The Context

Accurate, precise, and **homogeneous** determination of stellar parameters and elemental abundances of planet host stars is crucial for a comprehensive characterization of planetary systems:

- ❑ To derive absolute planetary masses (and radii), which depend on precise determination of exoplanet-hosting stellar masses (and radii)
- ❑ To derive precise stellar ages
- ❑ To measure stellar abundances (e.g., Fe, Mg, Si, C, O, N, S) and correlate them with planetary abundances (e.g., to study the formation/migration/evolution mechanisms)
- ❑ To distinguish features from stellar and planetary atmospheres

The GAPS Sample

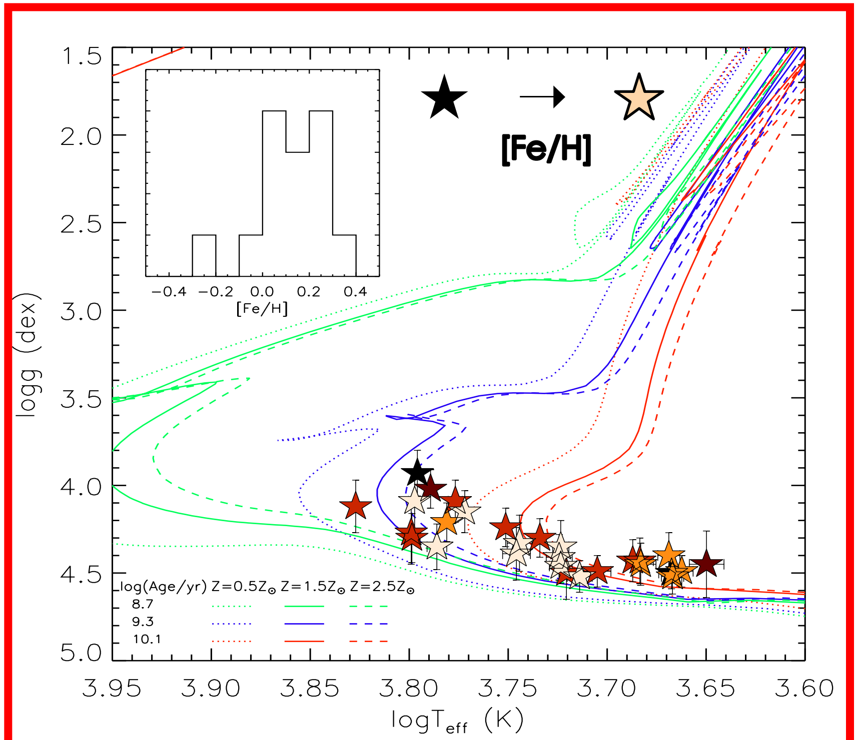
- ❑ **Known Planets with transiting planets (e.g. RML, ATMO) → benchmark targets/study (Biazzo et al. 2022)**
- ❑ Known Planets with long period planets
- ❑ Metal-Poor stars
- ❑ M-type stars
- ❑ Oper Clusters
- ❑ Young Objects
- ❑ Stars with Neptunian candidates
- ❑ Other (asteroseismology, SPI, etc.)

The Method
Chemical and Kinematic analysis

- Approach to measure **precise** chemical properties (MOOG code+ATLAS models+HFS+NLTE):
  - Line equivalent widths (T_{eff}, logg, ξ, [Fe/H], [X/H])
  - Spectral synthesis (vsini, Li, CNO)

Kiel diagram

- 4400 < T_{eff} (K) < 6750
- -0.3 < [Fe/H] < +0.4
- Abundance of 26 elements (e.g., C for 26/28, O for 18/28, Mg & Si for all stars)
- vsini < 10 km/s
- Lithium detected in 7/28 stars



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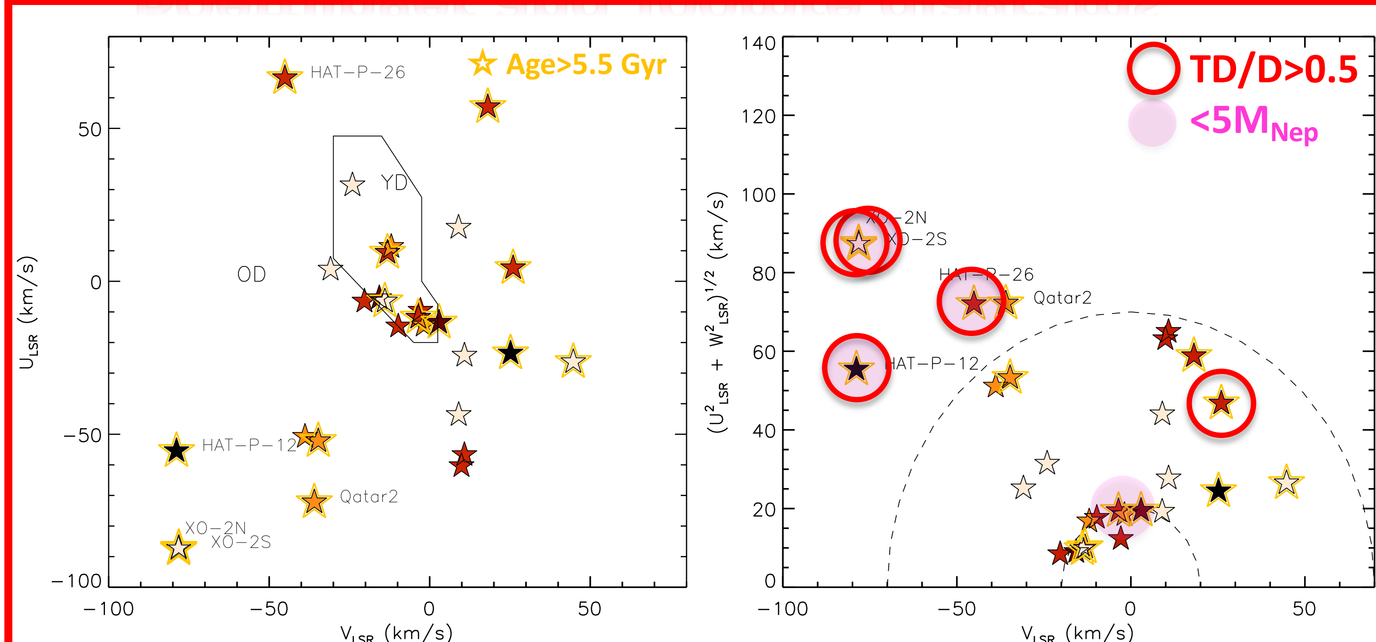
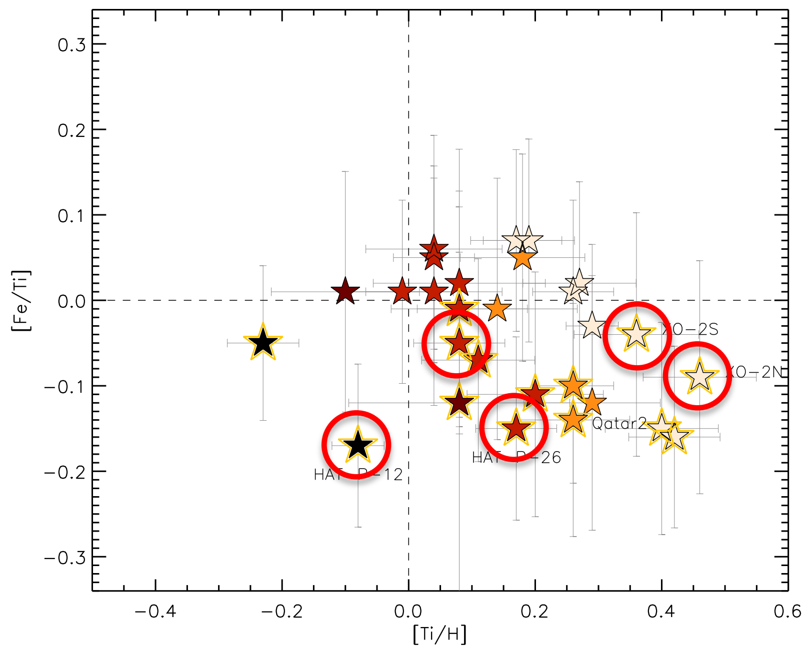
  - ❑ Line equivalent widths (T_{eff}, logg, ξ, [Fe/H], [X/H])
  - ❑ Spectral synthesis (vsini, Li, CNO)
- ❑ Kinematic procedure:
  - ❑ Space velocity components: Gaia parallaxes/proper motions and HARPS-N V_{rad}
  - ❑ TD/D probabilities (Bensby prescriptions)
  - ❑ Z_{max}, e_G, R_{peri}, R_{apo}, R_{GC} (`galpy` package)

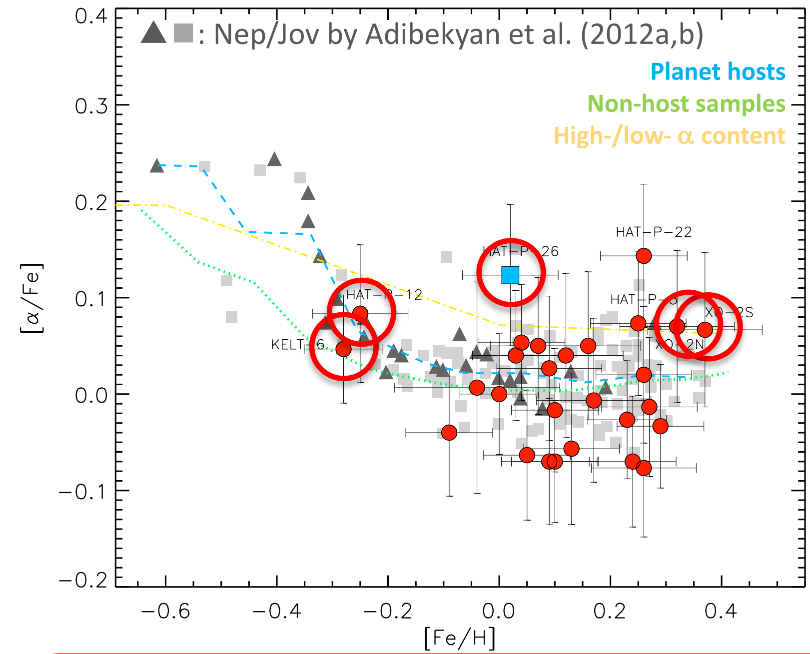
- ❑ YD/OD stars
- ❑ No evident trend with [Fe/H]
- ❑ 4 stars with v_{rot}>70 km/s (thick disk?)
- ❑ 5 (old) stars with TD/D>0.5 ($|\Delta R_{mean}-R_{GC}|>1$)
- ❑ Stars with <5M_{Nep} higher e_G and older

Boettlinger and Toomre diagrams



Chemical and Kinematic properties





- All 5 targets with TD/D>0.5 show [Fe/Ti]<0.0
- All older (age>5.5 Gyr) targets show [Fe/Ti]<0.0
- Mean v_{tot}>20 km/s for targets with [Fe/Ti]<0.0

- [Fe/H]<-0.2: slight α–enhancement but different kinematics
- solar [Fe/H]: highest-[α/Fe] value for the star with the lowest-mass planet
- [Fe/H]>0.2: α–enhancement for the most metal-rich stars

→ Kinematically hot stars, older, and α-enhanced
→ Kinematically cold stars, younger, and less α-enhanced

GAPS
GLOBAL ARCHITECTURE OF PLANETARY SYSTEMS

Abundances as “Chemical clocks”

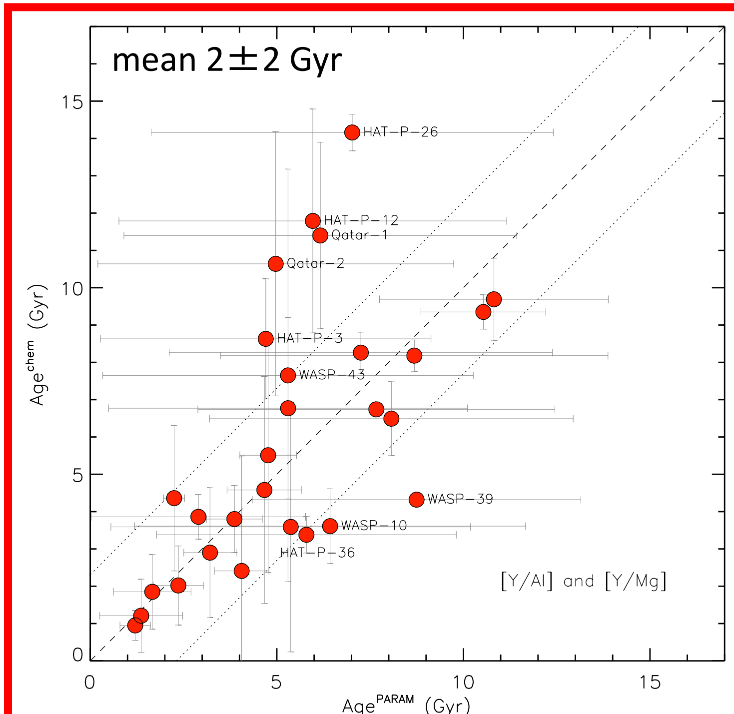
[X/Fe] versus Age:

- α-elements (e.g., Mg) over Fe have positive slopes with ages in agreement with their production over shorter timescale with respect to iron
- s-process elements (e.g., Y, Zr) over Fe have negative slope due to their delayed production from successive captures of neutrons by iron-peak elements in low-mass AGB stars with respect to the early contribution of SNIa/SNII that produce iron

$\Longrightarrow$ abundance ratios of pairs of elements produced over different timescales can be used as "**chemical clocks**" (e.g., Nissen 2015, Casali et al. 2020)

First attempt done in exoplanet hosting stars

Comparison with isochronal ages (PARSEC models; Bressan et al. 2012)



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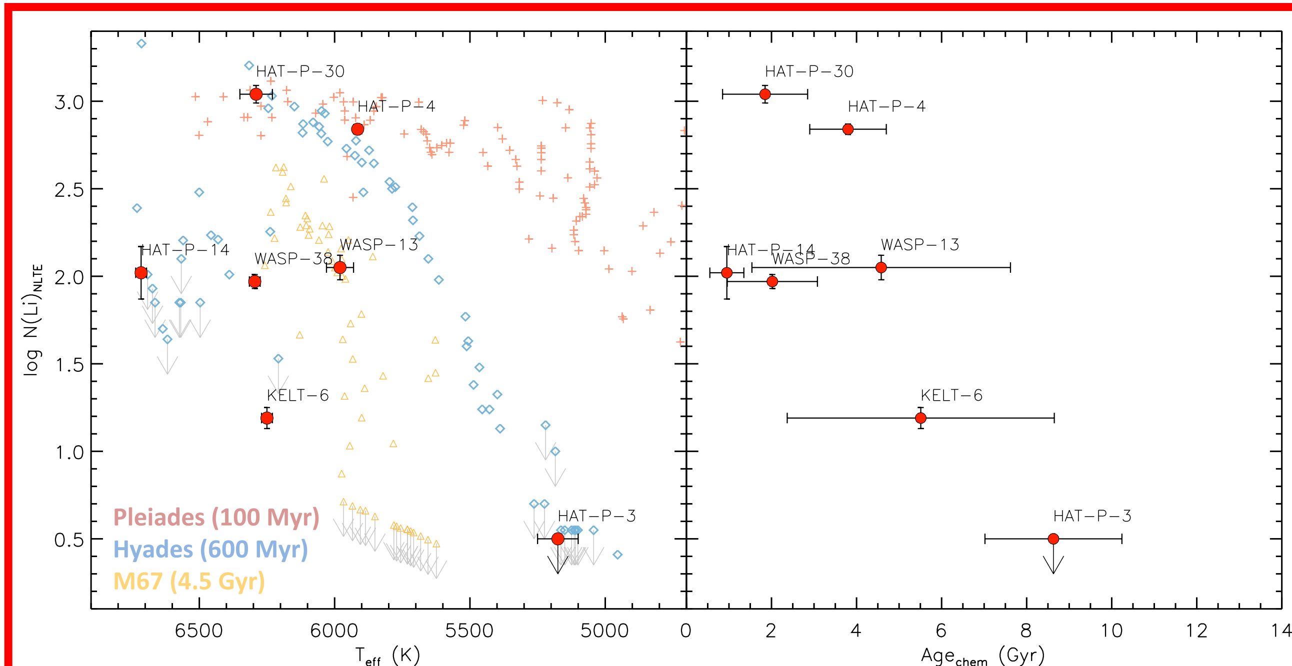
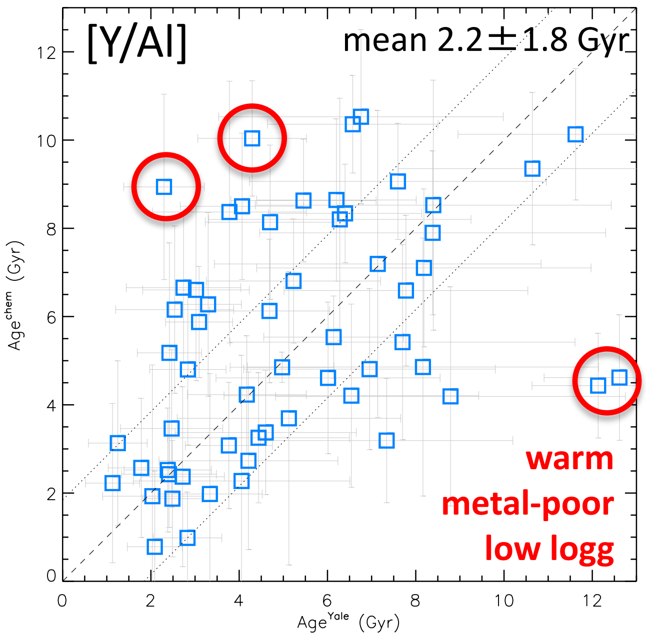
Lithium abundance and “chemical age”



Ariel targets: first tests



- Errors in [X/H] < 0.2 dex
- 5000 < T_{eff} < 6500 K
- -0.5 <[Fe/H]< 0.3 dex

Tot ≈ 60 stars

Comparison with isochronal ages (Yonsei-Yale models; Han et al. 2009)

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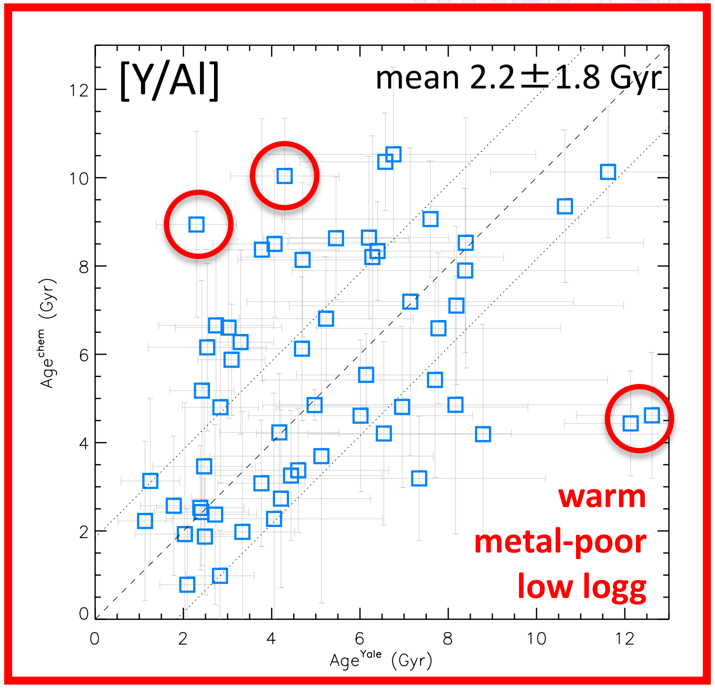

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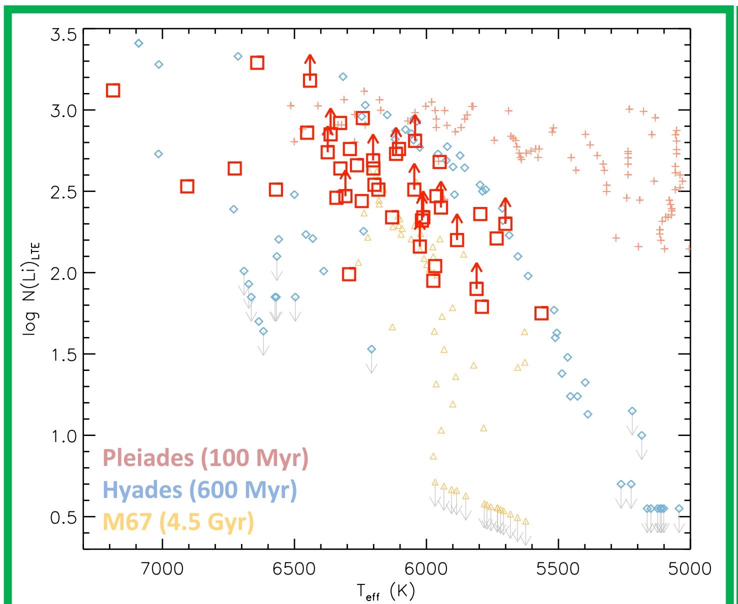
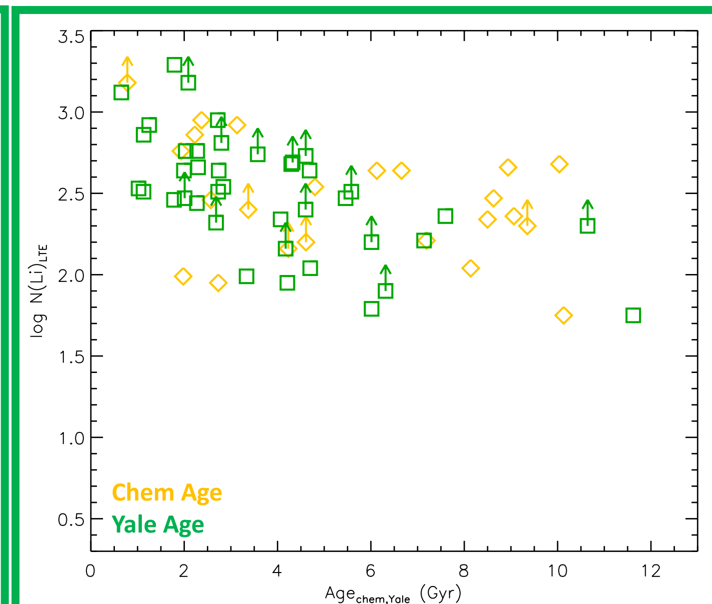
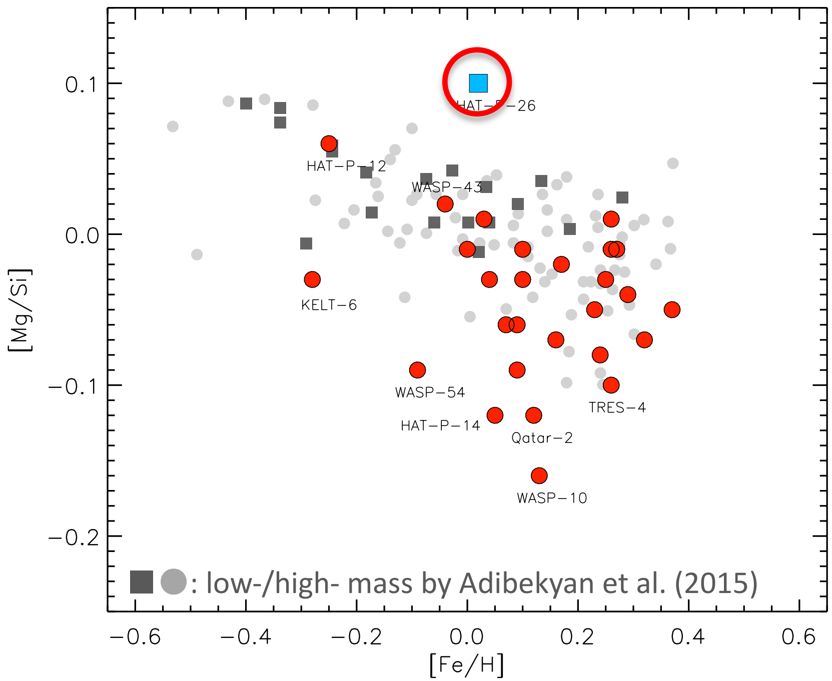
Lithium abundance

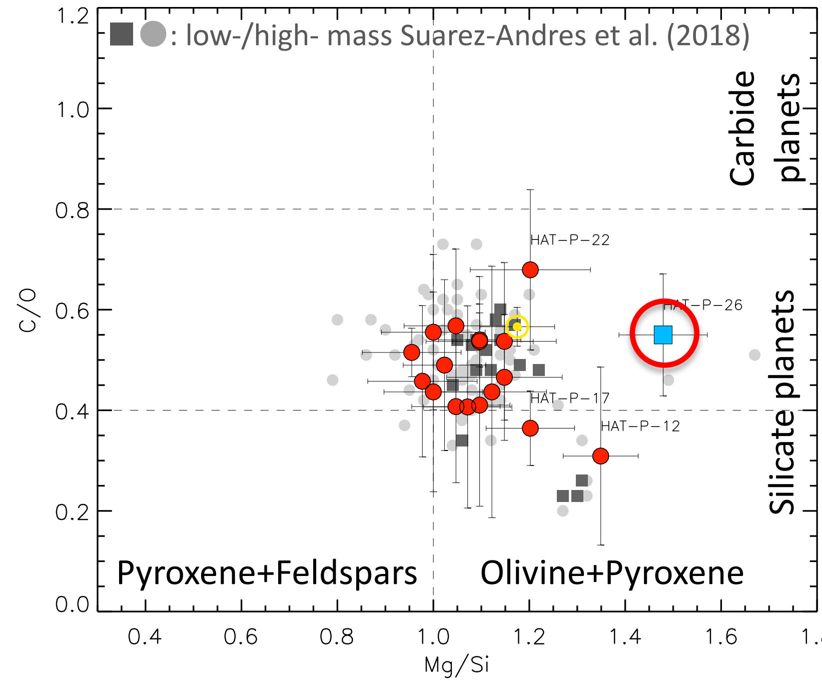
Tot ≈ 40 stars





The importance of Mg, Si, C, O





Lower-mass planet hosting star shows higher [Mg/Si] ratio

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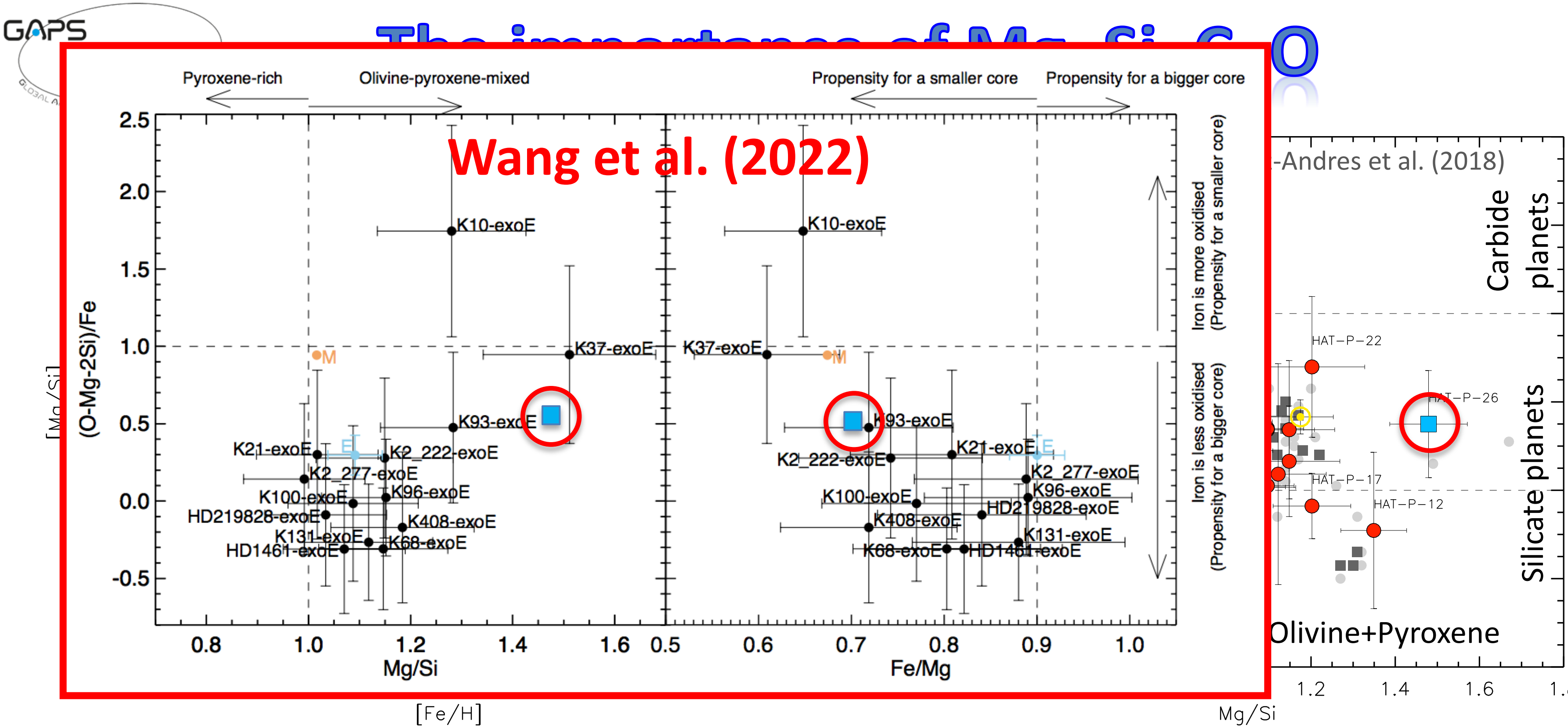
→ Mg,Si,C,O play important role in the formation/migration of exo-planets
→ Importance of the Galactic chemical evolution
→ Mg/Si, C/O, (O-Mg-2Si)/Fe of the lowest-mass planet compatible with olivine-rich mantle and large (iron) core



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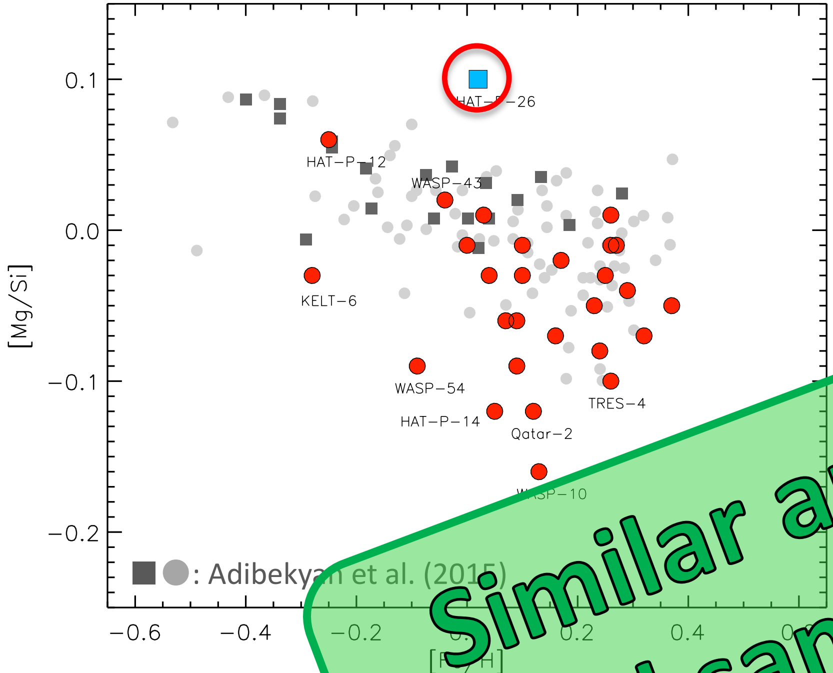

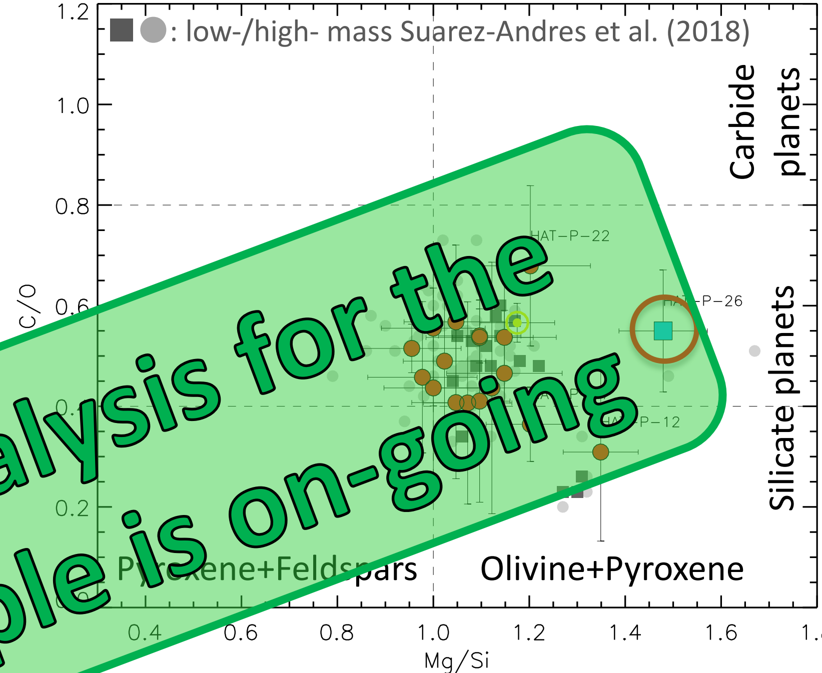

Similar analysis for the Ariel sample is on-going

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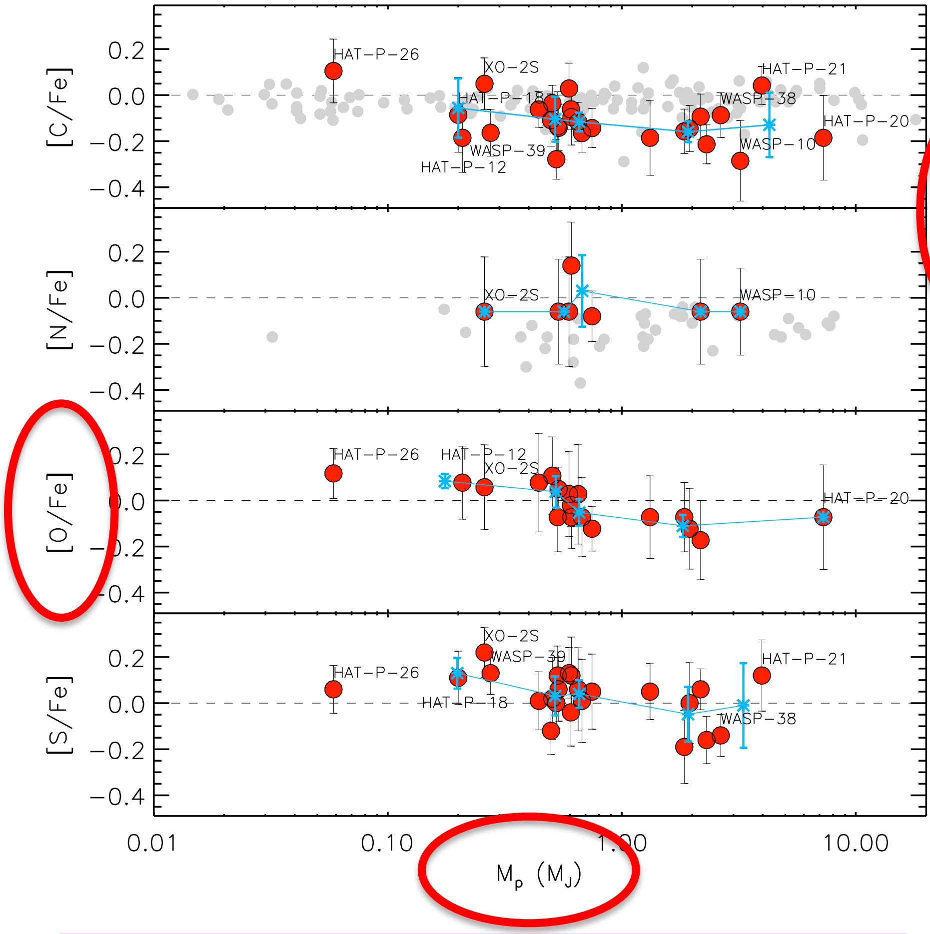
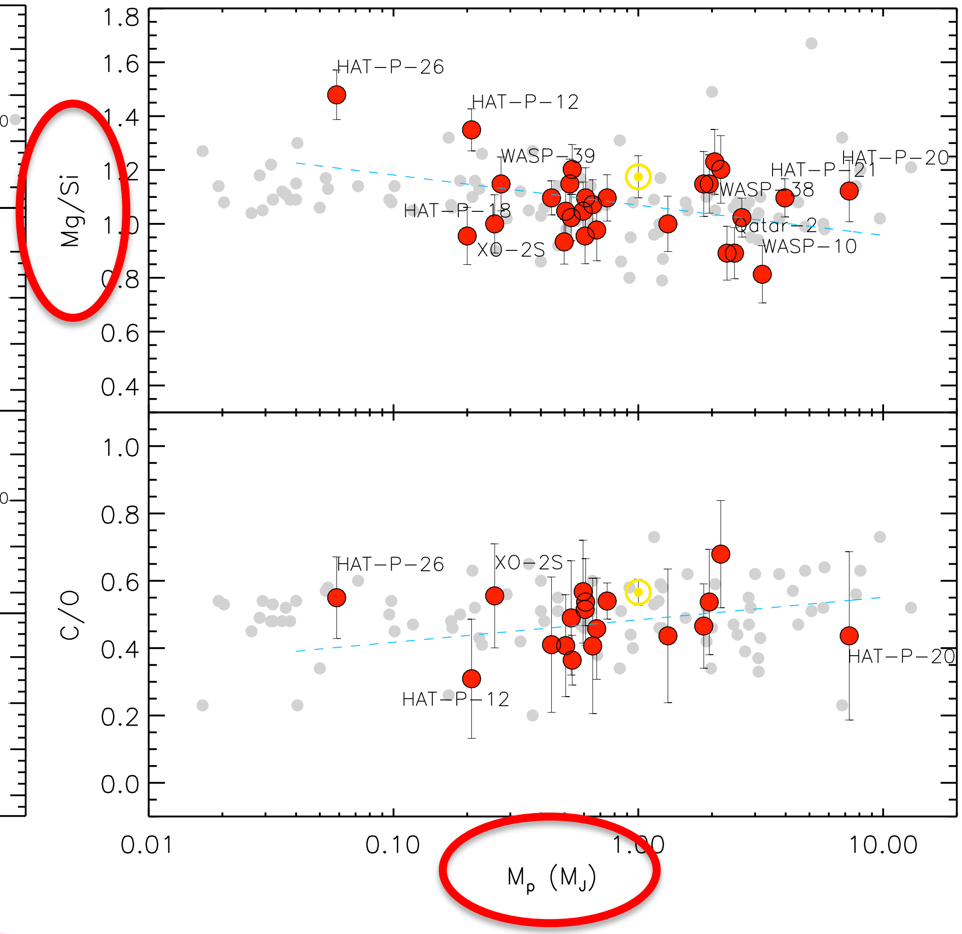
Stellar abundances vs Planetary masses

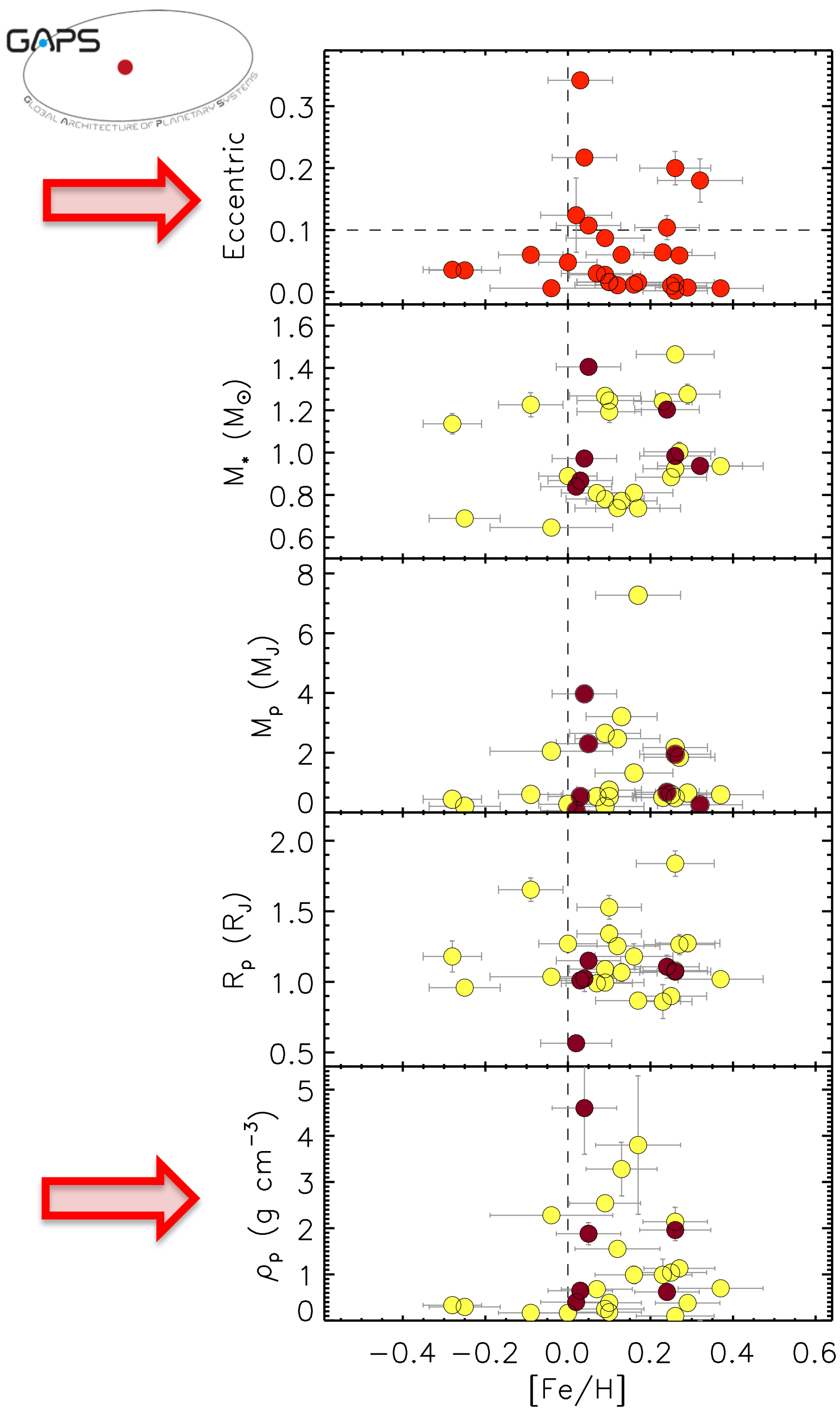




Is the most significant correlation ([O/Fe]-M_P) consequence of the planetary formation scenario and/or location in the Galactic disk?

Hints of trend between Mg/Si and M_P possibly related to the planetary composition and/or location in the Galactic disk?

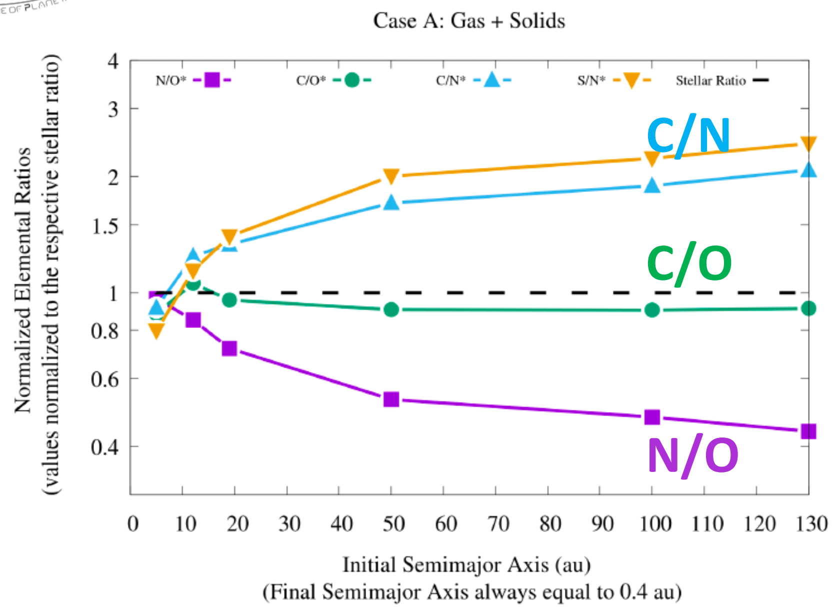
Stellar Iron abundances vs Planetary properties

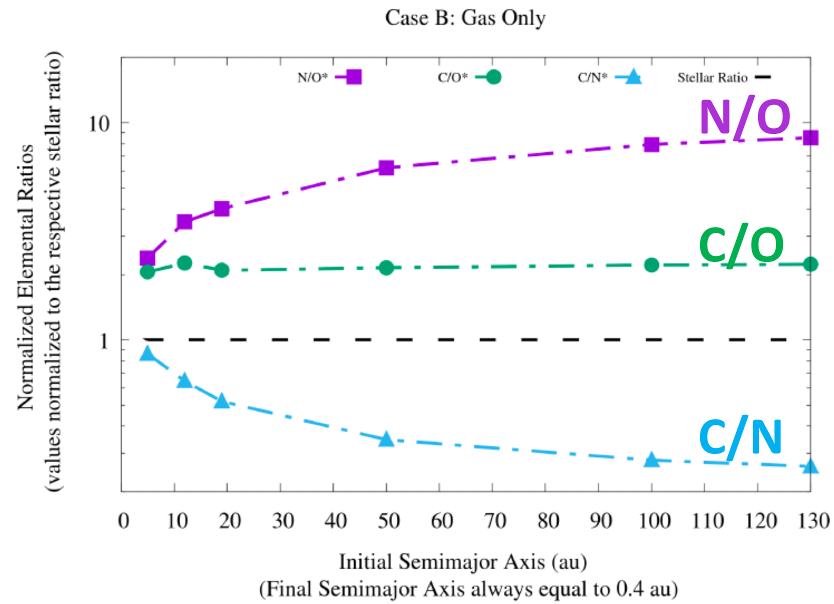


- Tendency for high-eccentricity planets to be around more metal-rich stars
- Denser planets around stars with higher [Fe/H] (and therefore in more eccentric orbits)

Similar analysis will be possible with Ariel

Tracing the Planet Formation Scenario…





Turrini et al. (2021)

- ❑ C/N*>C/O*>N/O* heavy elements dominated by the accretion of solids
- ❑ N/O*>C/O*>C/N* accretion from the disk gas

Name	$C/N_\star$	$C/O_\star$	$N/O_\star$	C/N_p	C/O_p	N/O_p	C/N*	C/O*	N/O*
HAT-P-12	2.09±0.16	0.31±0.18	0.15±0.16	5.33±0.18	0.80±0.15	0.15±0.10	2.55±0.24	2.58±0.23	1.00±0.19
WASP-10	2.00±0.21	0.37±0.18	0.19±0.18	6.31±0.32	0.82±0.30	0.13±0.10	3.16±0.38	2.22±0.35	0.68±0.21
HAT-P-26	3.80±0.15	0.55±0.12	0.14±0.12	1.79±0.16	0.25±0.13	0.14±0.10	0.47±0.22	0.45±0.18	1.00±0.16
WASP-39	3.73±0.12	0.51±0.12	0.14±0.14	1.73±0.16	0.26±0.12	0.15±0.10	0.46±0.20	0.51±0.17	1.07±0.17

See also talks by *Diego Turrini, Elenia Pacetti*

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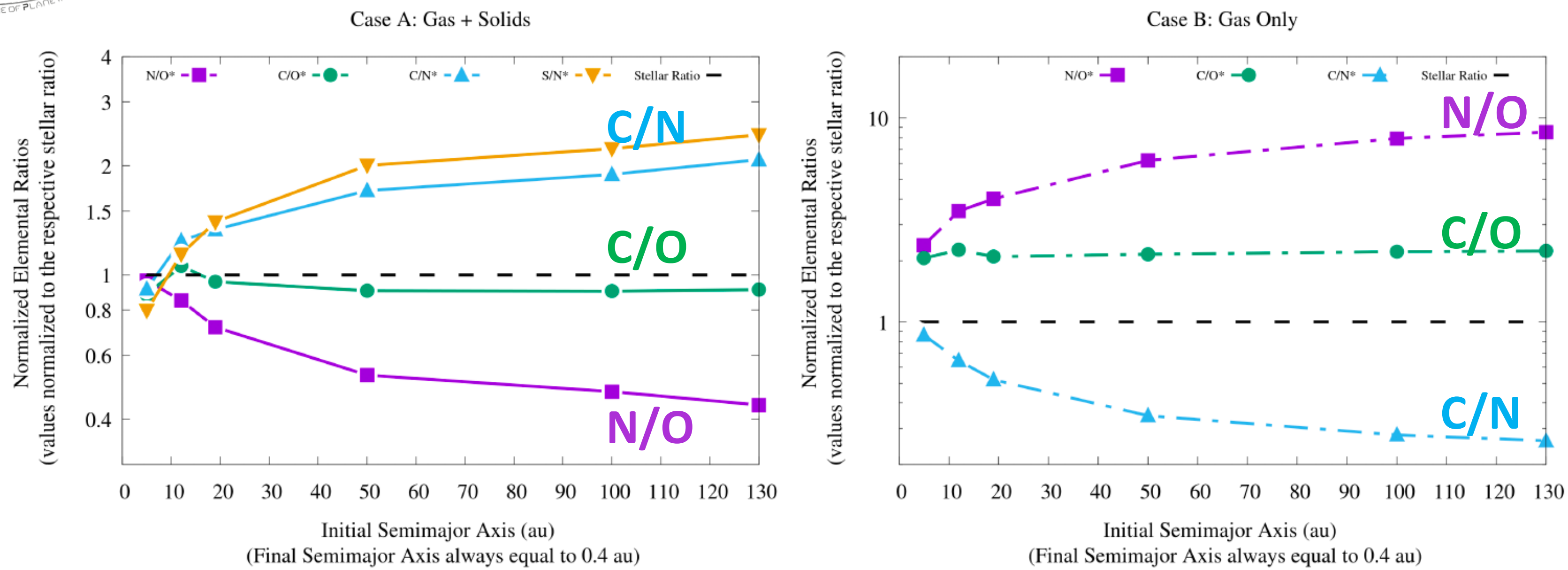

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S: Biazzo et al. 2022 **P: Kawashima & Min 2021** **P/S**

- ❑ Accretion of solids + N-rich gas between N_2 and CO_2 snowlines (HAT-P-12), C-enriched gas between CO_2-CH4 snowlines (WASP-10)
- ❑ Formation outside the CO_2 snowline and accretion of gas (HAT-P-26 & WASP-39)

Next-coming perspectives for Ariel targets

Stellar Characterization WG
(PI Camilla Danielski)

Spectroscopic method & Gaia astrometry/photometry
Stellar Parameters sub-WG (INAF)

see talk by *Laura Magrini*

Elemental abundance determination
Stellar Abundances sub-WG (CAUP)

Stellar Ages/Masses
(IA)

Alternative age determination from chemical clocks?

Homogeneous Approach
→ to correlate Stellar-Planetary Properties
→ to study Planetary Formation/Evolution