Investigating stellar-age and planet-mass correlation using Galactic Chemical Evolution

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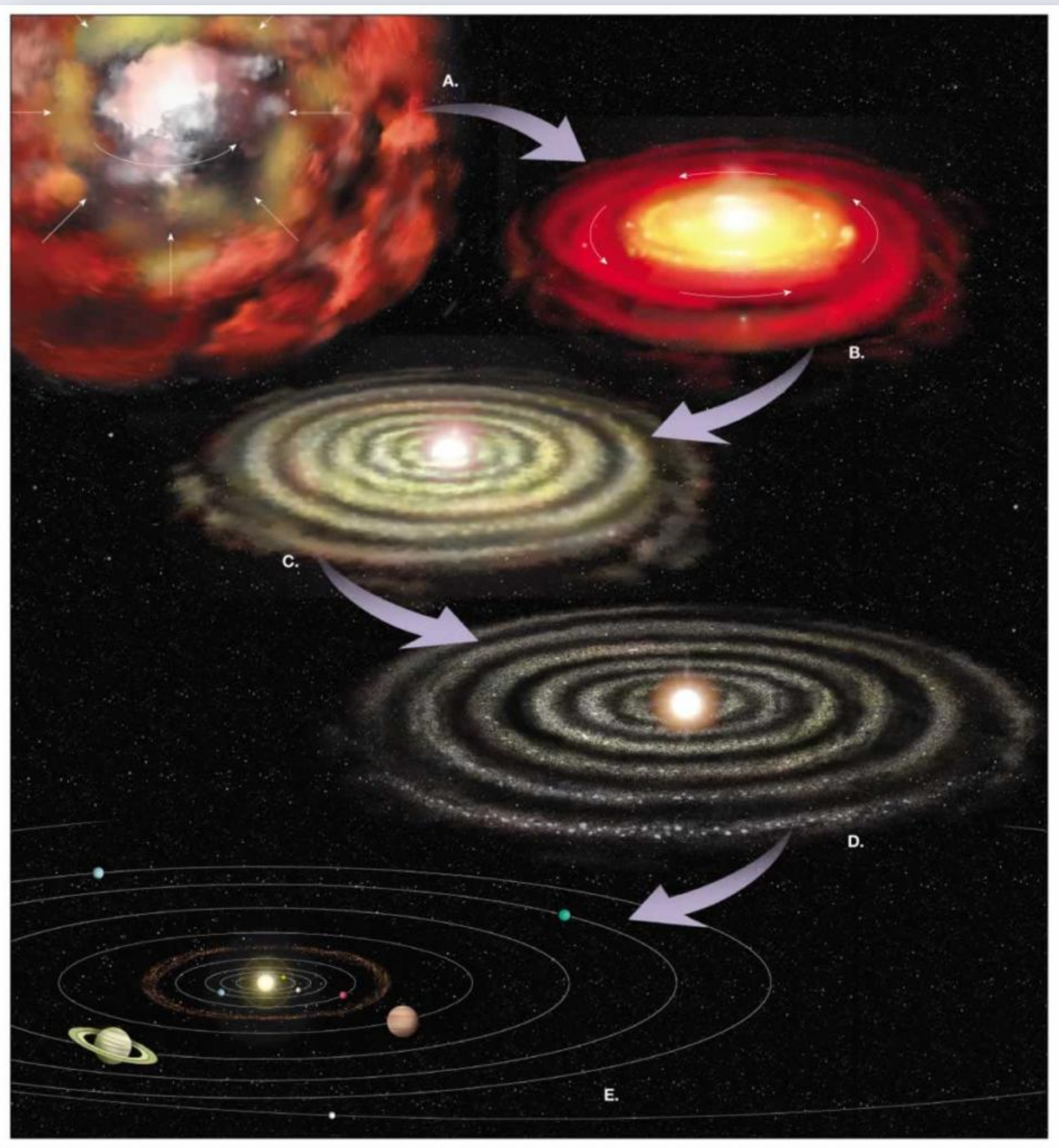
Motivation

- Chemical properties of star, protoplanetary disks and planets are interrelated.
- Chemical composition of molecular cloud determines the types of planets formed around the star.
- Jupiter-like planets tend to form around metal-rich stars while the low-mass planets are common around stars having wide range of metallicity [1,2].
- The signature of chemical evolution of the Milky Way are imprinted in the iron-peak and α-elements abundance of stars belonging to different stellar populations.
- To understand the role of Galactic Chemical Evolution in forming different kinds of planetary systems, in this work:
  - we study the iron-peak (Mn, Cr, Ni) and α-element (Mg, Si, Ca, Ti) abundances of several hundreds of exoplanet host stars.
  - correlate the abundance patterns of planet hosting stars with the planets' mass.
  - analyze the host stars ages determined from the isochrone fitting.



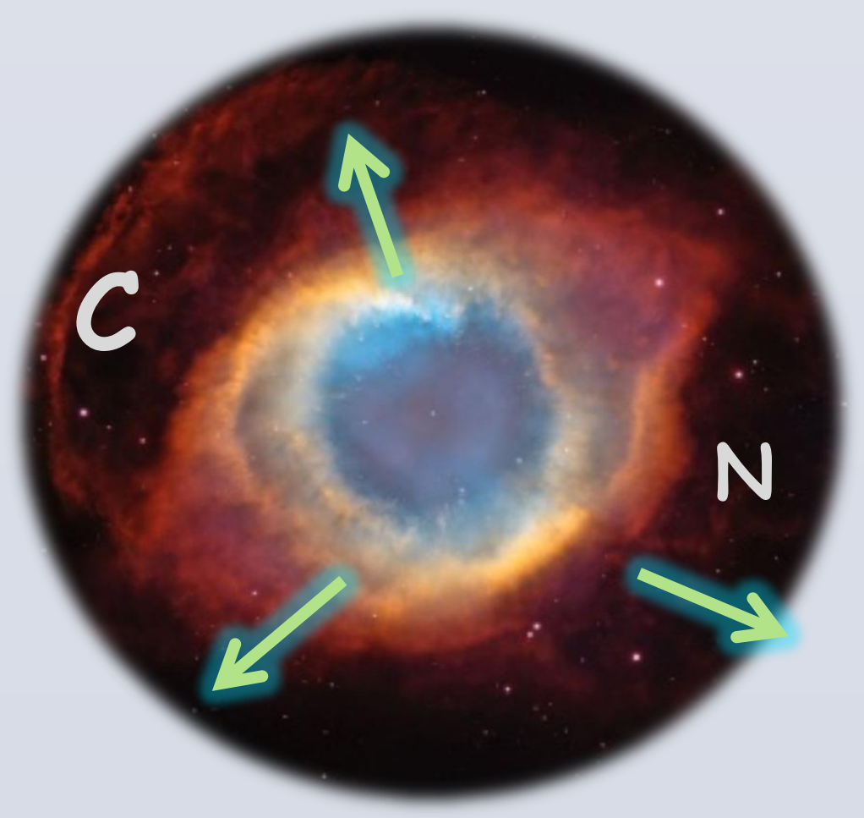
Star and planets are formed from same molecular cloud and hence share same chemical composition

Galactic Chemical Evolution (GCE)

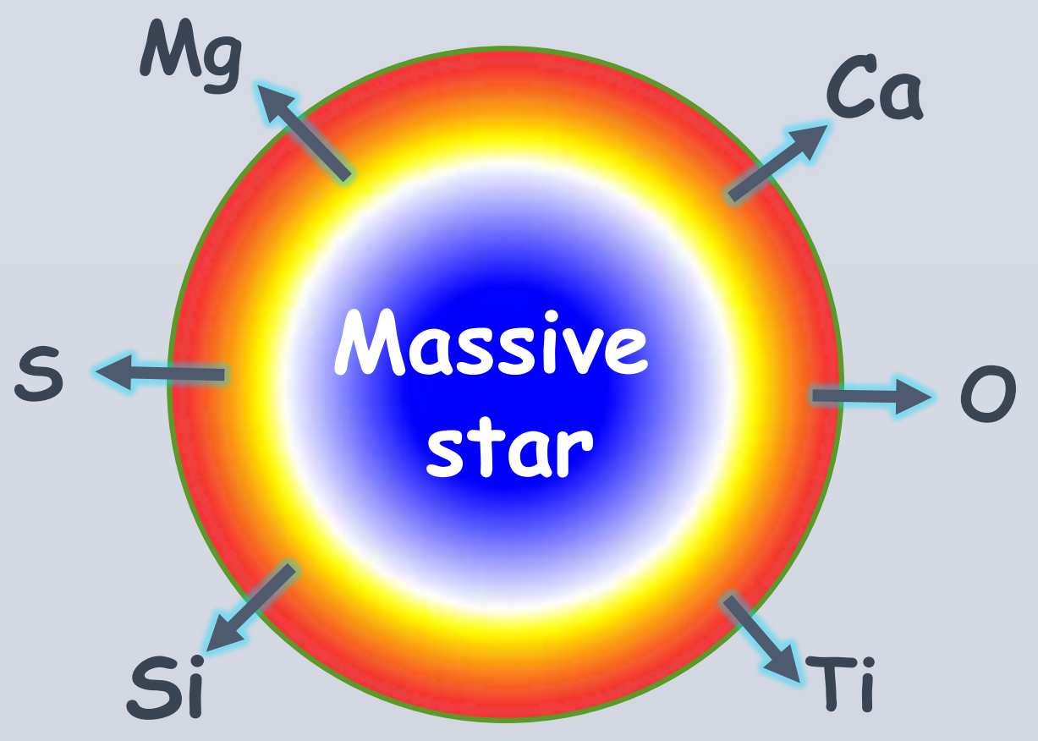
Bulk of the chemical elements in interstellar medium (ISM) are produced in three astrophysical processes

1. Planetary nebulae

- End stage of low- and intermediate-mass stars, such as our Sun
- Red giant forming planetary nebula
- Elements to ISM: notably C, N
- Time scale ~ Gyr



Planetary nebula formed by red giant



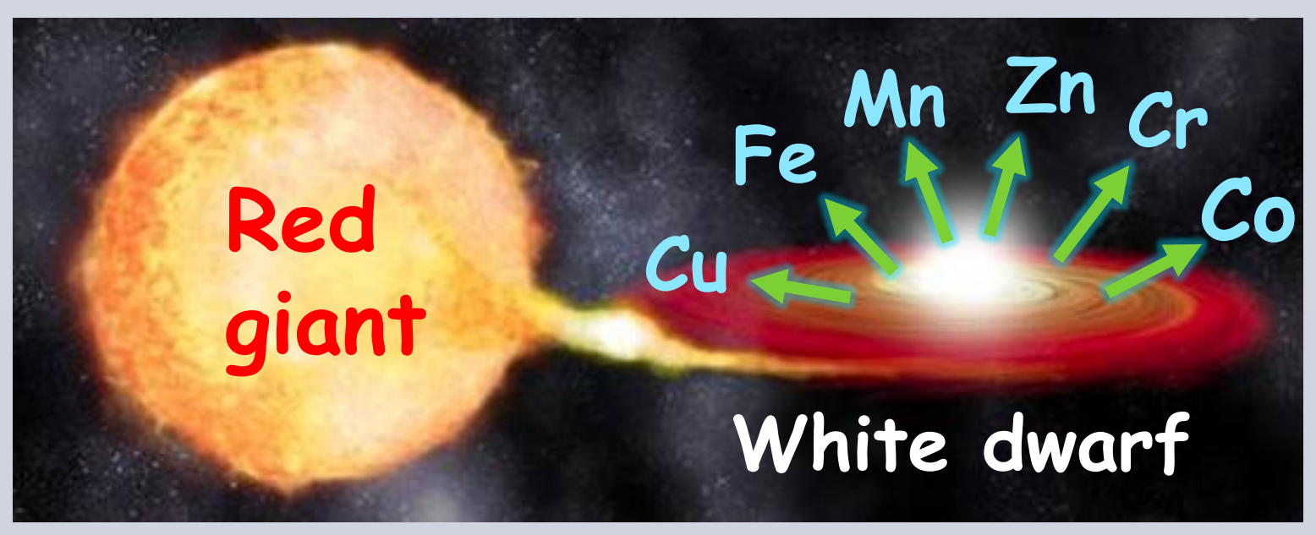
Type II supernova

2. Type II supernovae

- Explosive end of massive stars
- Production site for α-elements
- Time scale ~ 10-100s Myr
- More high-mass stars were formed when the galaxy was young
- Old stars, richer in α-elements

3. Type Ia supernovae

- A binary system with white dwarf accreting material from red giant
- Seeded galaxy with several Fe-peak and trace elements
- Time scale ~ a few Gyr
- Young stars, richer in Fe-peak elements



Type Ia supernova
Fe-peak + trace elements

Sample Selection

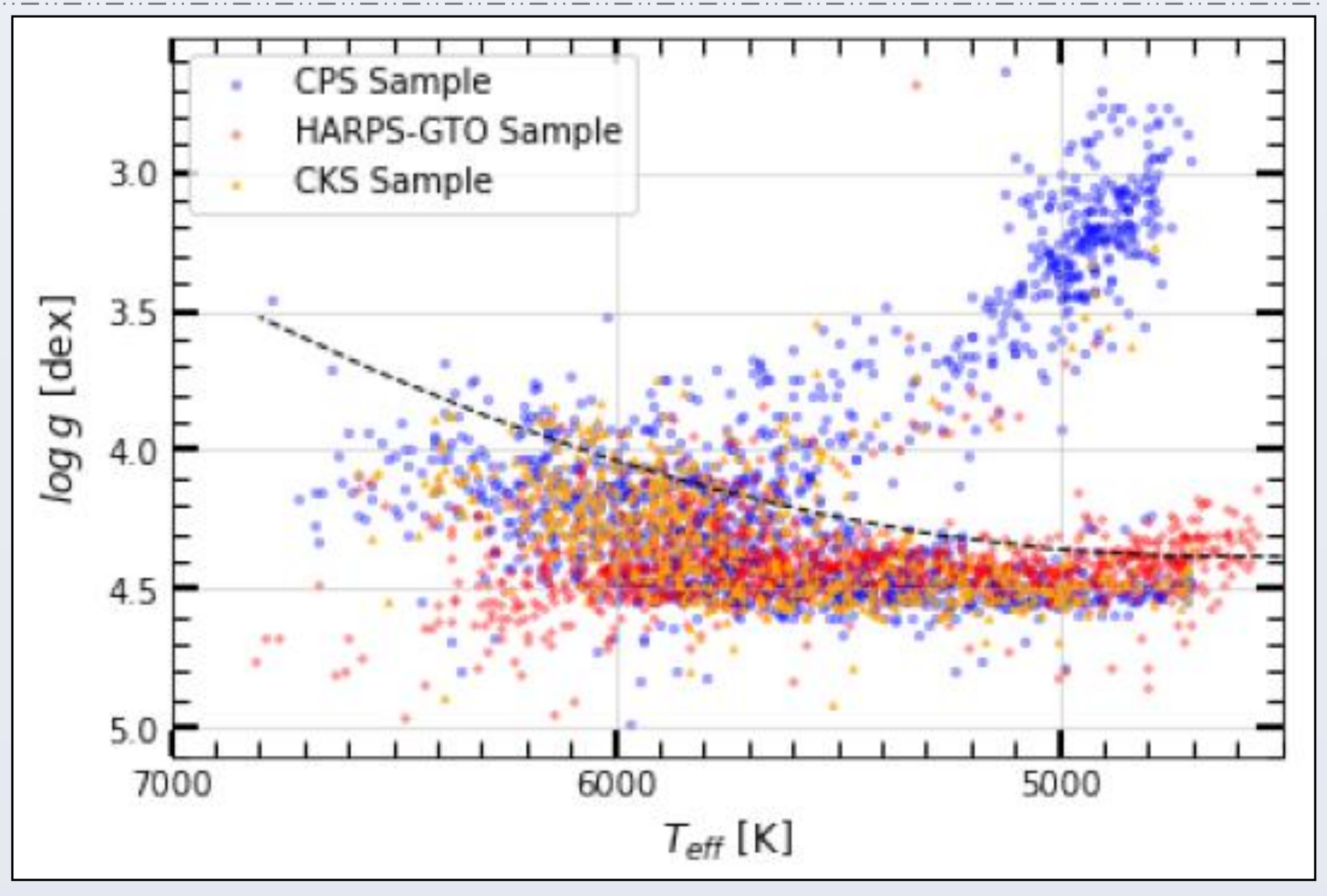
Sample for this study came from three well known planet search programes, namely;

1. **HARPS-GTO** [3,4]
   - Radial Velocity targets (1111 stars)
   - Spectroscopic observations: ESO/HARPS
2. **California Kepler Survey (CKS)** [5]
   - Follow up of Kepler targets (1127 stars)
   - Spectroscopic observations : Keck/HIRES
3. **California Planet Survey (CPS)** [6]
   - RV targets (1615 stars)
   - Spectroscopic observations: Keck/HIRES

Small planets: $M_P \leq 0.3\ M_J$
Giant planets: $0.3\ M_J < M_P \leq 4\ M_J$
Super Jupiters: $4\ M_J < M_P \leq 13\ M_J$

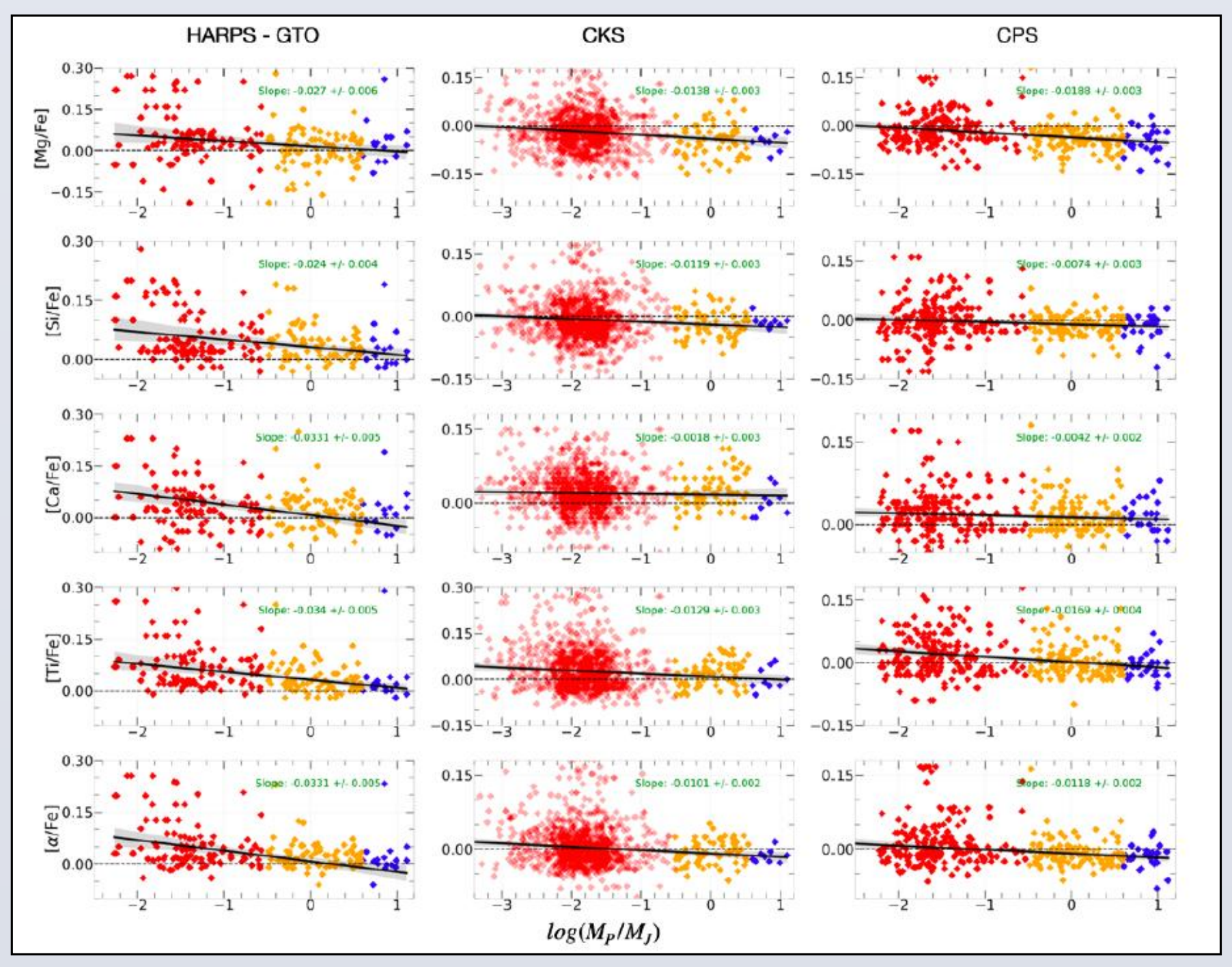
Small Planets	Giant Planets	Super Jupiters
119	81	17
206	103	19
935	65	9

Our final sample consists of 981 planet hosting main sequence stars. Planet mass was taken from NASA's Exoplanet archive.

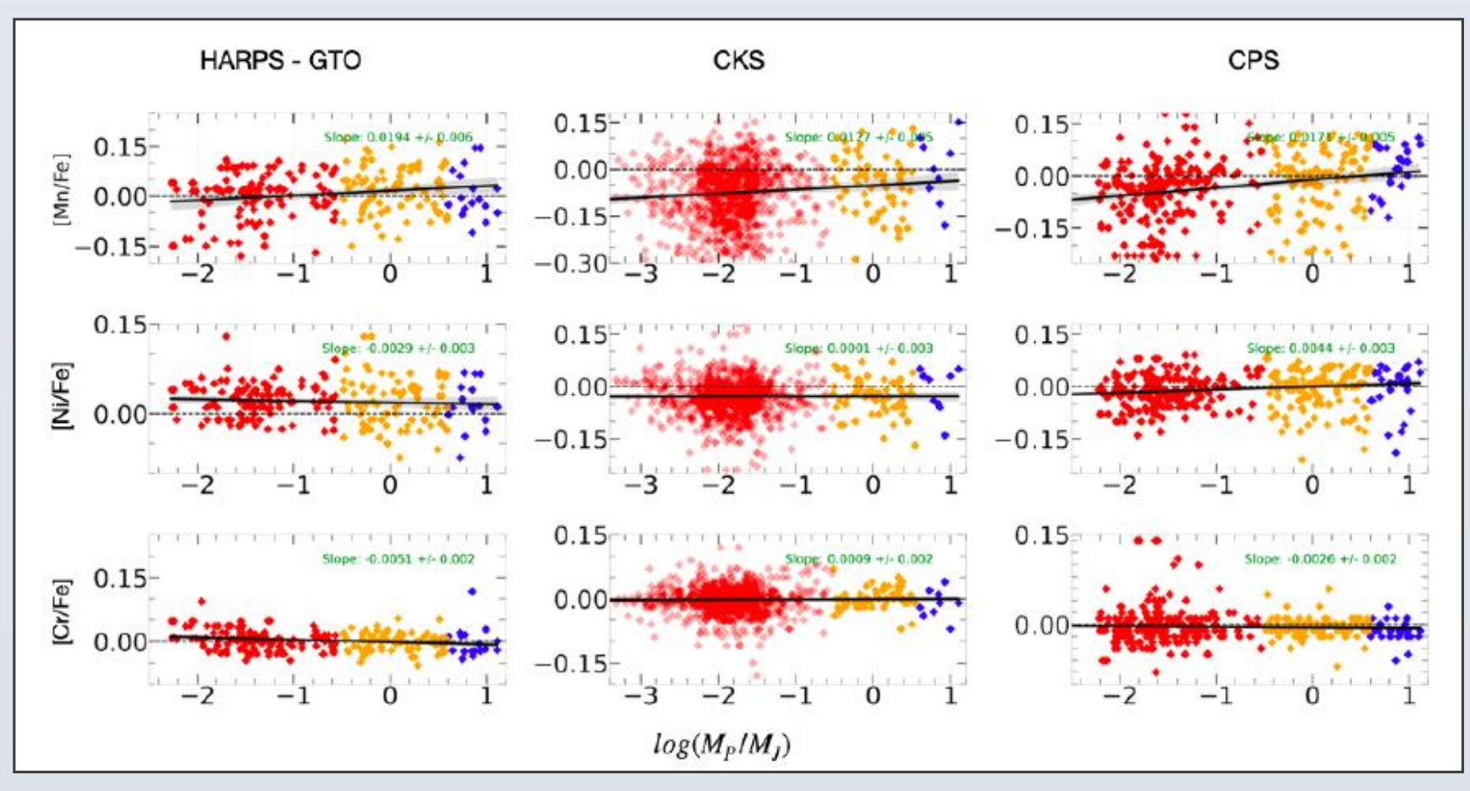


Combined sample HARPS, CKS and CPS stars. Main sequence stars below the black dotted line were chosen for this study.

Main Results & Conclusions



Observed trends for α-element abundances of host stars With planet mass for the HARPS-GTO, CKS and CPS sample. The black line shows the linear fit and the grey shaded region represents the 95 percentile confidence interval.

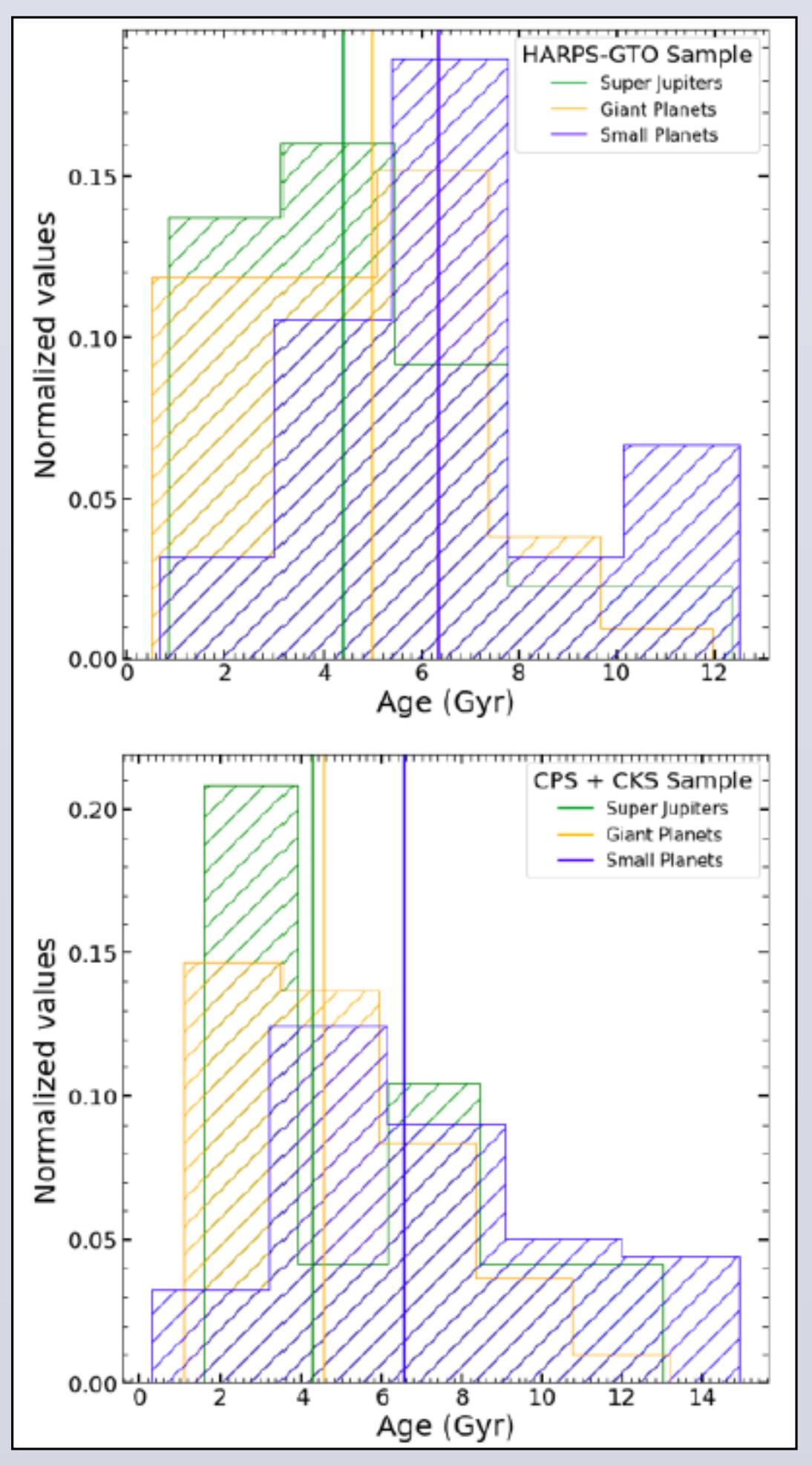


Fe-peak [X/Fe] abundances as a function of planet mass for HARPS-GTO, CKS and CPS sample. The black line shows the linear fit. Red, orange and blue dots represents small planets, giants planets and super jupiters, respectively. Near-zero slope indicates Fe-peak elements followed the same scaling as iron.

◈ The [α/Fe] abundances correlates negatively with planet mass. This is the consequence of enrichment of Galaxy with [Fe/H] over time. Since the formation of high-mass planets (core accretion process) requires high metallicity material, our results, therefore, suggests that stars hosting giant planets and super Jupiters could be younger.

◈ Also, from the isochrone age estimates (figure on right) we find that stars hosting low-mass planets are indeed older compared to the Jupiter and super Jupiter hosts.

◈ These findings are also independently validated by Stellar Kinematics Studies. *See the ASI poster by Mayank et al (ID: ASI2022_304).*



Age distribution of our sample from isochrone fitting. Vertical solid lines show the median age of planets in three mass bins.

References:

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2. Swastik, et al. AJ, 2021.
3. Adibekyan, et al, A&A, 2011.
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5. Brewer, et al. ApJS, 2018.
6. Brewer, et al. ApJS, 2016.

Acknowledgement:

This research has used the data from NASA Exoplanet database, HARPS-GTO, CKS and CPS archives. Authors gratefully acknowledge the service provided by these public archives. C. Swastik also thanks E. Delgado Mena and P. Goswami for fruitful discussions.