Host-star Metallicity of Directly Imaged Planets

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ABSTRACT

Planets discovered in wider orbits (≥10 AU) by high-contrast imaging belong to a different region of star-planet parameter space. The star-planet properties and their interdependence is well known for a large number of planetary systems discovered by radial velocity and transit methods. However, host-star properties of the directly imaged planets (DIP) are not very well documented in exoplanet literature. In this work we used high-resolution spectra from public archives to uniformly determine the atmospheric parameters and metallicity of 18 DIP hosts. The total 22 DIP hosts (other 4 taken from literature) analyzed in this work show a large scatter in metallicity with median being closer to the Sun. Upon dividing our stellar sample into three mass bins, we noticed a decreasing metallicity trend with increasing mass from Jupiter-type planets ($M_P \leq 5M_J$) to super-Jupiter ($5M_J < M_P \leq 13M_J$) and beyond $M_P > 13$.

References

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Exoplanets: What do we know?

- Number of confirmed exoplanet discoveries till date is 4296.
- Most planetary systems are compact (d < 0.1 AU, and orbital period ∼ 10-12 days).
- Super earth (M ∼ 5M⊕, R∼1.25-2 R⊕) are most commonly occurring planets.
- Different detection methods probe different region of star/planet parameter space.
- Planets are generally found around metal-rich stars. High metallicity stars tend to host high mass planet up to $M \sim 10^3 M_\oplus$

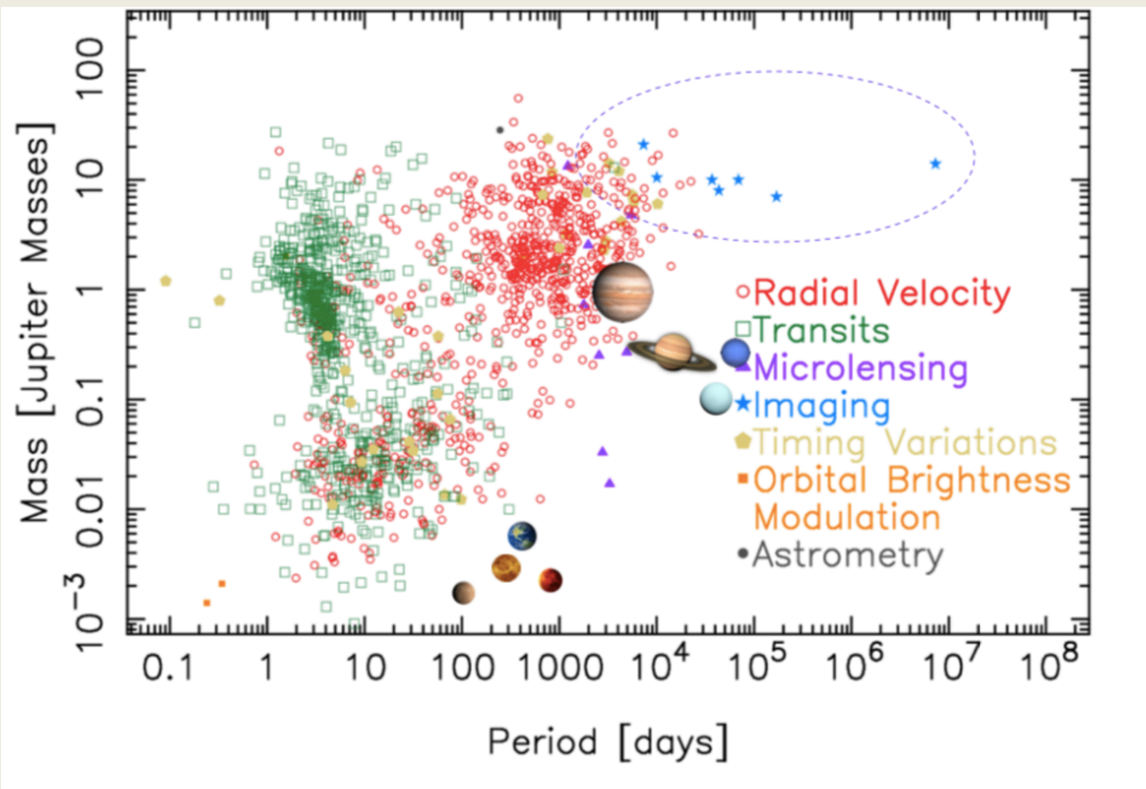

Figure 1: Exoplanet discoveries by different methods and their location in stellar mass -orbital period diagram. The position for solar-system planet is also shown for comparison.

Directly imaged planets

- Young and warm (self-luminous)
- Direct detection at infrared wavelengths.
- Requires : large telescope + adaptive optics + stellar chronograph
- Imaging + spectroscopy is possible for both planet and star
- Total 51 DIPs detection around 45 stars

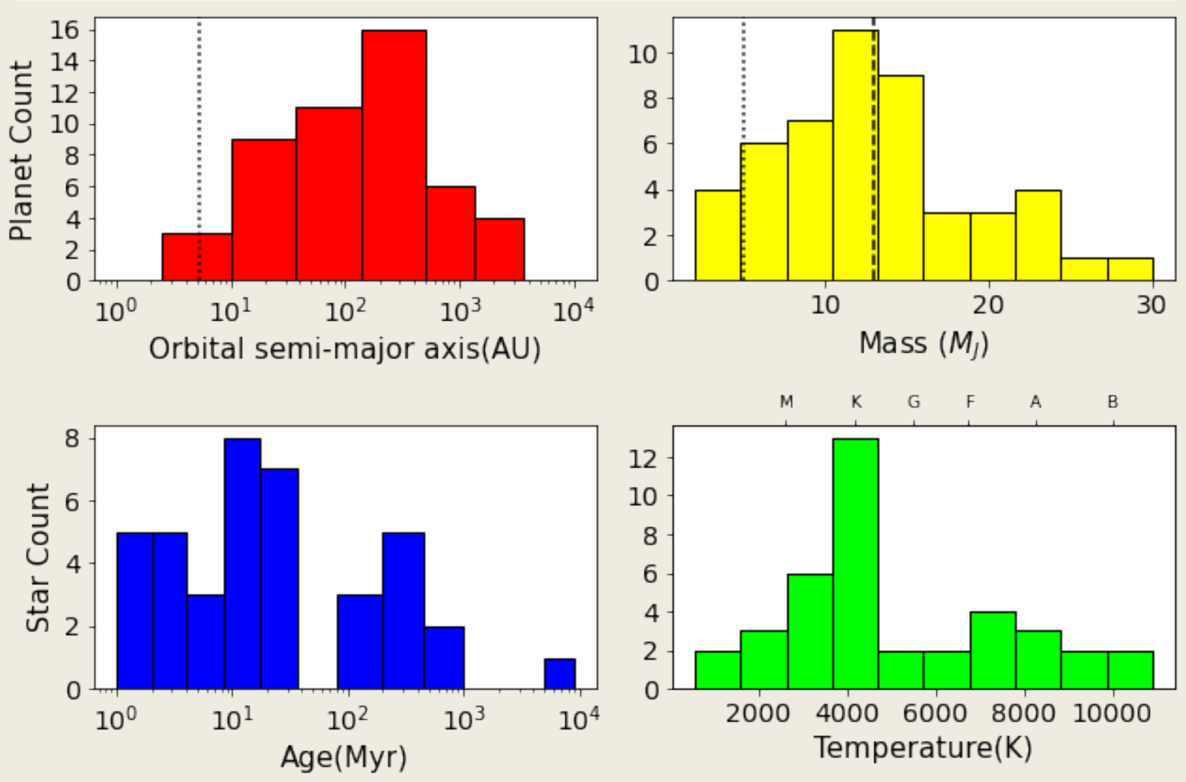

Fig 2:Histograms of orbital distance and mass of directly imaged systems (top panel) with age and temperature distribution of their stellar hosts (bottom-panel).

Objective

- Directly imaged planets (DIP) and their host stars are not well studied together as a separate population, unlike the host stars discovered by other techniques such as radial velocity and transits[1 2].
- The DIP are located at large orbital distances from their host stars. Studying the planetary mass - stellar metallicity correlations will help us to understand the possible formation scenarios of these objects at such large orbital distances[3 4].

Sample selection

- For the present work we analysed 18 DIP host stars for which the spectra was taken the from public archives.
- We obtained high-resolution, high-SNR spectra for 14 targets from ESO science archive facility and for 4 targets from Keck archive.
- For four DIP host stars the metallicity value is taken from the literature.
- For the remaining 23 DIP hosts analysis was not possible because either the spectra was not available or the quality of the data was poor (low-SNR). This group also includes some of the hot and very rapidly rotating stars ($v \cdot \sin i > 160$~Km/s), which do not have clear spectral features and reliable atmospheric models for parameter estimation.

Methodology

We have used iSpec[5] to generate synthetic spectrum together with Bayesian analysis to obtain the posterior distribution of the stellar parameters.

iSpec is a python wrapper which bundles several radiative transfer codes, model atmosphere and line list in single module to obtain the stellar parameters from both synthetic spectral fitting (SSF) and equivalent width (EW) technique.

Radiative Tranfer code	SPECTRUM
Line List	VALD
Solar Abundances	Asplund 2009
Atmosphere Model	Atlas 9 : Castelli
Spectral segment selected	515-520 nm / 600-620 nm/ 590-596.5 nm/ H_α

Results

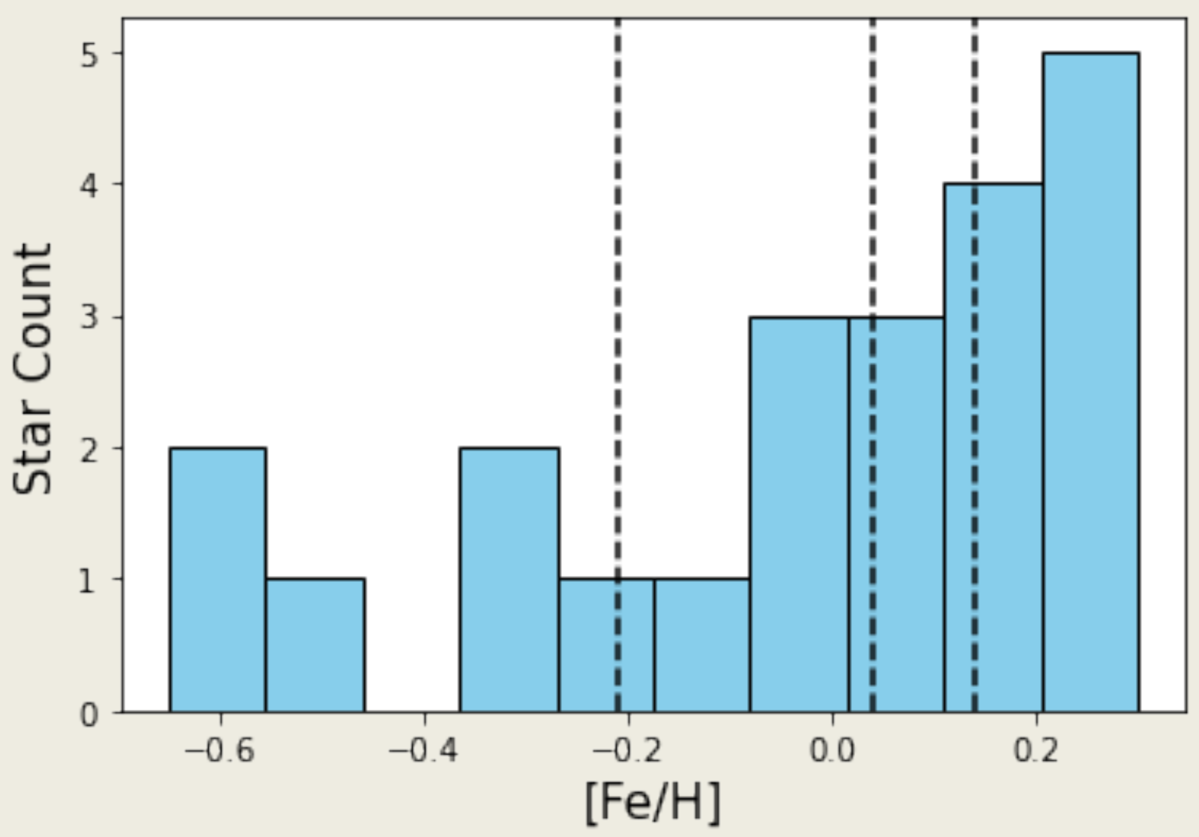

Fig 3 : The observed metallicity [Fe/H] distribution of 22 stars known to host directly imaged planets. The dashed lines represent the median and the 1st and 3rd quartiles of the distribution.

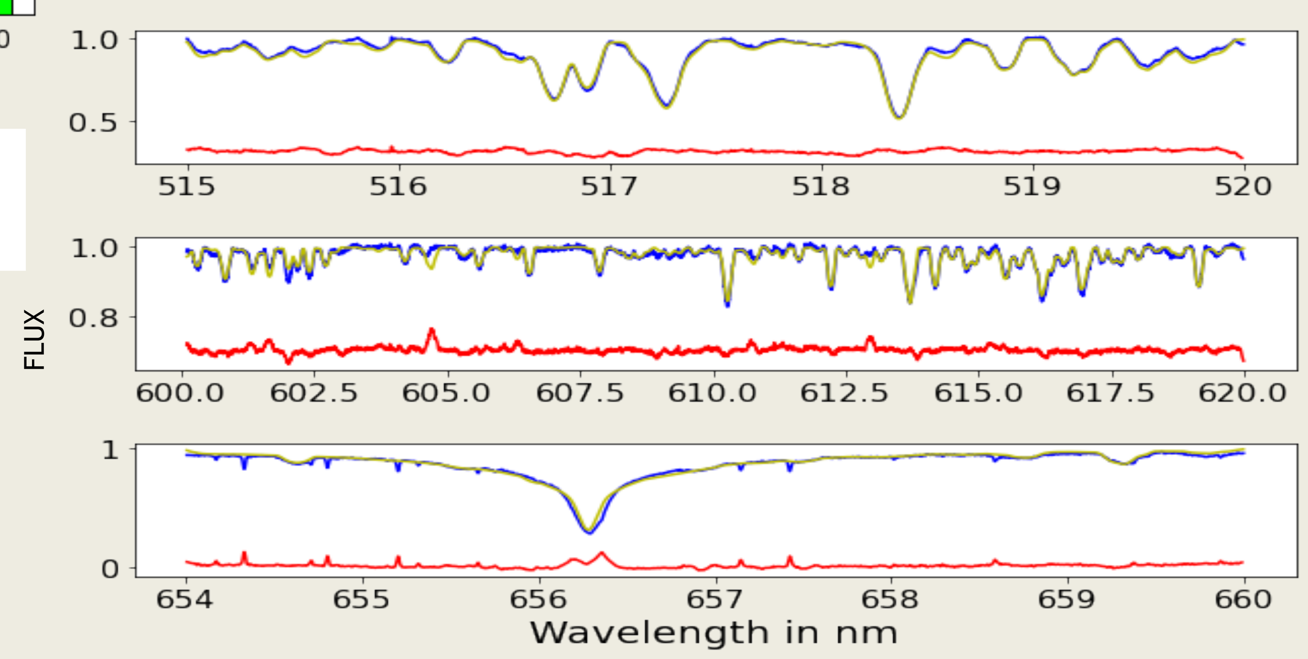

Fig 4 :A narrow slice showing the results of synthetic spectral fitting technique for HR2562. Blue: Original spectra, yellow: Synthetic spectra spectra. Red: Residuals

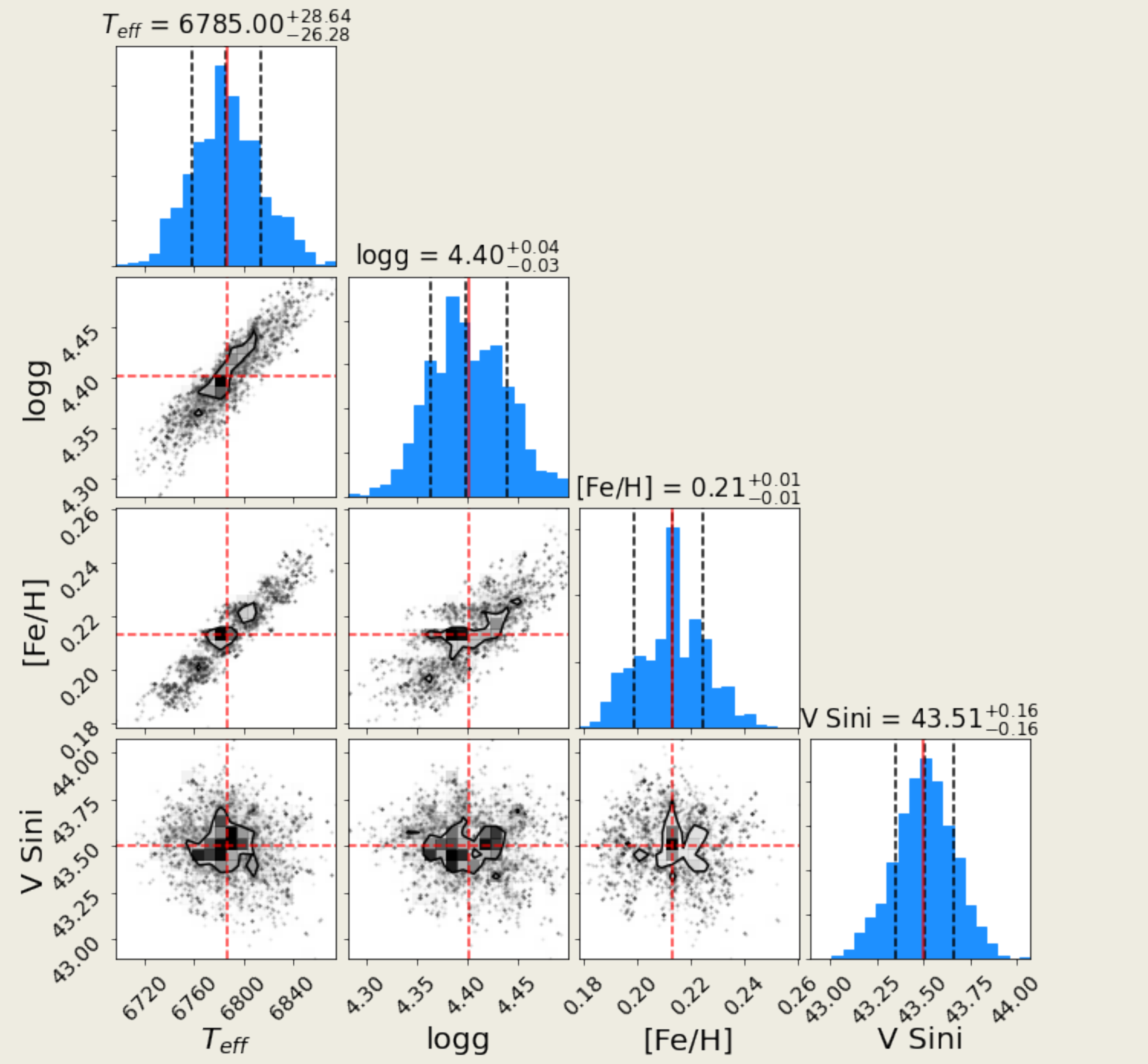

Fig 5: Posterior distributions of stellar parameters for HR2562, obtained from MCMC analysis (40 chains, 300 steps, a burn-in limit at 140 steps).

Metallicity correlation

We have estimated the metallicity using iSpec and MCMC and the planet mass was taken form the Nasa Exoplanet archive to study the correlation between them to investigate the possible clues for planet formation at such large orbital distances.

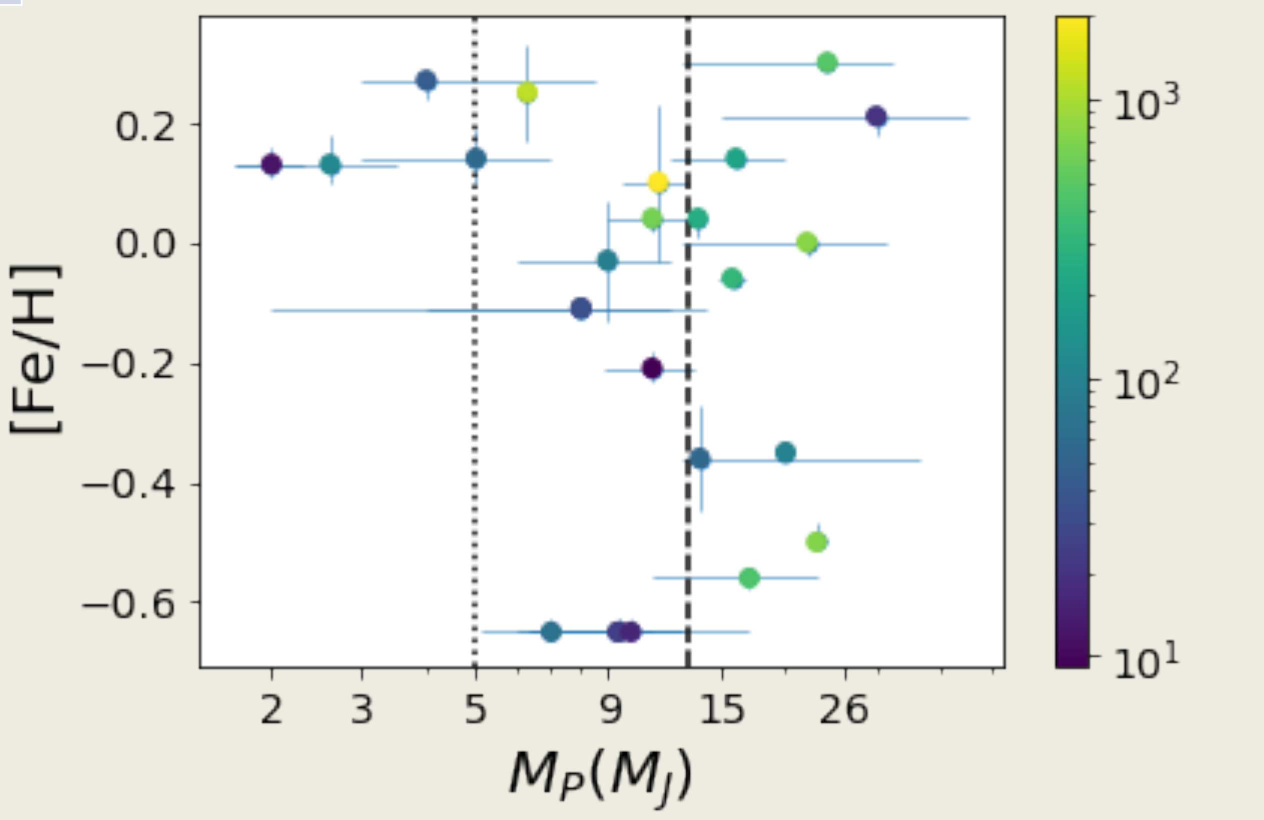

Fig 6 :The distribution of mass of directly imaged planets and the host-star metallicity. The dotted-line indicates $5M_J$ and dashed-line indicates $13M_J$ boundary. The colorbar to the right represents the orbital distance in AU.

Conclusions

Our results suggest that low-mass giant ($M_P \lesssim 5M_J$) planets tend to have metal-rich hosts. This is in line with the predictions of planet formation via core accretion mechanism[6]. As the planet mass increases ($M_P > 5M_J$), we find a more scatter in the distribution of stellar metallicity, suggesting that metallicity might not play a crucial role in the formation of these planets, which is in agreement with the gravitational instability model. Our analysis suggests two planet formation scenarios for DIP host stars, with low-mass giant planets likely formed by core accretion process while the high-mass giant planets are likely formed by disk instability method.

Acknowledgement

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