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Host Star Metallicity Across Different Exoplanet Populations: A Statistical Analysis Using LAMOST Spectroscopic Data

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Sihan He is a student of The Experimental High School Attached to Beijing Normal University, and he is interested in astrophysics, especially exoplanets, and the statistical analysis of astronomical survey data. His research mainly focuses on exoplanets, their host stars and stellar spectroscopy.

ABSTRACT

The formation and diversity of exoplanets are influenced by both physical and chemical properties of their host stars, making statistical comparisons of host stars an important approach to understanding how planetary systems differ. In this study, we combine medium-resolution spectroscopic data from the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) with confirmed exoplanet information from the NASA Exoplanet Archive to construct samples of exoplanet host stars and a matched control sample of stars without known planets. Using uniform data selection and statistical analysis, we examine stellar parameters with particular emphasis on metallicity and compare host stars associated with different types of exoplanets. We find that host stars and control stars are generally similar in effective temperature and evolutionary stage, indicating that they belong to comparable stellar populations, but they show differences in metallicity distributions. Gas giant planets are preferentially found around metal-rich stars, while terrestrial planets and sub-Neptunes occur over a much broader range of metallicities. For the low-mass planet sample, planetary mass and radius exhibit a weak positive trend with host star metallicity, although this result is limited by small sample size and should be interpreted with caution. Overall, this work provides statistical observational evidence that host star metallicity is related to exoplanet type, particularly for massive planets, and demonstrates that medium-resolution spectroscopic surveys such as LAMOST are valuable resources for large-sample studies of exoplanet host stars.
Keywords: exoplanets, host stars, metallicity, planet formation, planetary populations, spectroscopy, LAMOST, NASA Exoplanet Archive, statistical analysis

Keywords: *pied-à-terre, housing financialization, gentrification, super-gentrification, social dead space, luxury real estate, vacancy rates, expropriation*

INTRODUCTION

Over the past two decades, thousands of exoplanets have been discovered through space-based missions such as Kepler and TESS, primarily using high-precision photometric observations. Statistical results from these missions show that the majority of known exoplanets are super-Earths and sub-Neptunes, with radii between approximately one and four times that of Earth (Batalha, 2014). These planets exhibit a wide diversity in physical properties, orbital configurations, and potential compositions, reflecting the complexity of planetary systems beyond the Solar System.

At the same time, the host stars of these exoplanets also span a broad range of stellar properties, including mass, temperature, age, and chemical composition (Mulders, 2018). As the number of confirmed exoplanets has continued to grow, understanding how host star characteristics relate to planet type has become an increasingly important topic in exoplanet research. Statistical comparisons between different planetary systems provide a useful way to explore how stellar environments may influence the formation and diversity of planets (Batalha, 2014).

Among various stellar properties, metallicity—commonly defined as the abundance of elements heavier than hydrogen and helium—is of particular interest. Stellar metallicity can be measured from stellar spectra by analyzing absorption features produced by different chemical elements. Because metallicity reflects the chemical composition of the protoplanetary disk from which planets form, it is widely regarded as a key parameter in studies of planet formation and evolution (Jiang et al., 2021).

LITERATURE REVIEW

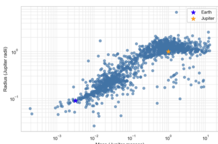
Previous observational studies have shown that stellar metallicity plays an important role in shaping planetary populations. Early high-resolution spectroscopic surveys demonstrated that stars hosting giant planets tend to have higher metallicities than stars without detected planets (Fischer & Valenti, 2005). Subsequent studies confirmed a strong correlation between the occurrence rate of gas giant planets and host star metallicity (Jiang et al., 2021). These findings are commonly interpreted within the framework of the core accretion model, in which metal-rich disks promote faster growth of planetary cores.

In contrast, smaller planets with radii below approximately 4 $R_{\oplus}$ are observed around stars spanning a much wider range of metallicities, often close to the solar value (Buchhave et al., 2012). More recent statistical analyses combining data from LAMOST, Kepler, and Gaia indicate that the correlation between stellar metallicity and planet radius becomes weaker for small planets, while host stars of larger planets still show a tendency toward metal enrichment (Chen et al., 2025). Overall, these studies suggest that while high metallicity favors the formation of massive planets, smaller planets also form around stars with a wide range of metallicities (Buchhave et al., 2012).

RESEARCH GOAL OF THE STUDY

The distributions shown below (Fig. 1) highlight the wide range of planetary types and physical properties observed in current exoplanet surveys, motivating further classification and comparative studies.

Figure 1. *Mass–radius distribution of known exoplanets on logarithmic scales, illustrating the broad diversity of planetary sizes and masses and their approximate relationships. Earth and Jupiter are marked as reference points.*



Based on the background and previous research discussed above, the primary goal of this study is to investigate whether host stars associated with different types of exoplanets exhibit systematic differences in metallicity. By combining large-sample spectroscopic data with confirmed exoplanet catalogs, this work aims to

provide a statistical comparison of host star metallicity across different planet categories, offering insight into how stellar chemical environments may be related to planetary diversity.

DATA AND RESEARCH METHOD

Exoplanet Data

Confirmed exoplanet data used in this study are obtained from the NASA Exoplanet Archive, which serves as a comprehensive and publicly accessible database of exoplanets discovered by major space missions such as Kepler, K2, and TESS, as well as ground-based surveys including KELT and SuperWASP (NASA Exoplanet Archive, n.d.). The archive provides a wide range of planetary parameters, including planet mass, radius, and orbital properties, along with basic information about their host stars.

In this study, we extract a sample of confirmed exoplanets and record the corresponding host star parameters. Planetary radius and mass are used to classify planets into different categories, allowing statistical comparisons between host stars associated with different planet types. Because the NASA Exoplanet Archive compiles data that have been vetted through the literature, the exoplanet sample used here is based on reliable and widely accepted observational results (NASA Exoplanet Archive, n.d.).

Stellar Spectroscopic Data

Stellar spectroscopic data are obtained from the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), using its medium-resolution spectroscopic survey. The LAMOST stellar catalog provides homogeneous measurements of stellar parameters for a large number of stars across the sky.

For each star in the sample, we extract fundamental stellar parameters including right ascension (RA), declination (Dec), signal-to-noise ratio (S/N), effective temperature (Teff), surface gravity (log g), and metallicity ([Fe/H]). These parameters are derived using standard LAMOST data reduction and calibration pipelines, ensuring consistency across the sample.

DATA SELECTION AND CROSS-MATCHING

To associate exoplanet host stars with LAMOST spectroscopic observations, we perform celestial coordinate cross-matching between the NASA Exoplanet Archive host star catalog and the LAMOST stellar catalog using a matching radius of 3 arcseconds. When multiple spectroscopic observations are available for a single star, the spectrum with the highest signal-to-noise ratio is selected to ensure data quality.

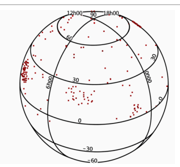


Figure 2. *Sky distribution of exoplanet host stars cross-matched with the LAMOST spectroscopic catalog. The red points represent exoplanet host stars with available LAMOST spectra. The non-uniform sky coverage reflects the observational footprint of the LAMOST survey and does not indicate any intrinsic spatial clustering of planetary systems.*

After cross-matching, spectra with low data quality are removed. Specifically, spectra with signal-to-noise ratios below 10 are excluded, and stars with unusually large uncertainties in Teff, log g, or [Fe/H] are filtered out. These selection steps help ensure that the statistical analysis is based on reliable stellar parameters.

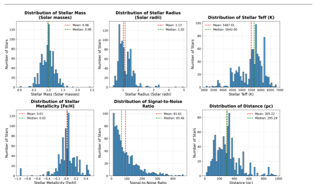


Figure 3. *Distributions of the principal stellar properties in the final exoplanet host-star sample, including stellar mass, stellar radius, effective temperature, metallicity [Fe/H], spectral signal-to-noise ratio, and distance. Dashed red and green lines indicate the mean and median of each distribution, respectively.*

The majority of host stars have masses and radii close to solar values, with effective temperatures mainly concentrated between 5000 K and 6000 K. The metallicity distribution is also dominated by values near the solar level, indicating that the sample primarily consists of Sun-like stars (Fig. 3). This makes the dataset well suited for statistical studies of planetary systems around solar-type stars.

PLANET CLASSIFICATION AND ANALYSIS STRATEGY

Planet Categories

Exoplanets are commonly classified using their observed radius or mass as proxies for their internal structure and composition. In this study, planets are grouped into three broad categories based on planetary radius: terrestrial planets, sub-Neptunes, and gas giant planets. Terrestrial planets are typically interpreted as predominantly rocky bodies with little or no gaseous envelope, while sub-Neptunes are thought to consist of

rocky cores surrounded by substantial volatile-rich or hydrogen–helium envelopes (Weiss & Marcy, 2014; Rogers, 2015; Fulton et al., 2017). Gas giant planets possess massive gaseous envelopes and are frequently associated with metal-rich host stars, consistent with expectations from the core accretion model (Fischer & Valenti, 2005).

This classification scheme is adopted to enable statistical comparisons of host star metallicity across different planet types. It should be noted that these categories are based on observational parameters and do not imply precise compositional boundaries.

STATISTICAL ANALYSIS APPROACH

The primary goal of this study is to compare host star metallicity across different categories of exoplanets. After constructing the final host star sample and classifying planets by type, we perform statistical analyses of stellar metallicity and related planetary parameters for each category to examine potential differences among host star populations.

The analysis focuses on comparing the distributions of host star metallicity for different planet types and exploring how planetary mass and radius vary with stellar metallicity within the low-mass planet sample. These comparisons are designed to identify statistical trends rather than to establish causal relationships, and all results are interpreted with appropriate caution given sample size limitations and observational biases.

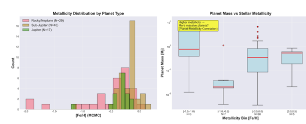
During the data inspection process, a small number of host stars are also found to exhibit emission-line features in their spectra. These cases are treated as an additional observational finding and are discussed separately from the main statistical analysis.

RESULTS

Host Star Metallicity Across Different Planet Types

The primary goal of this study is to examine whether host stars associated with different types of exoplanets exhibit systematic differences in metallicity. To address this question, we compare the metallicity distributions of host stars for different planet categories, as shown in Figure 4.

Figure 4. Comparison of host-star metallicity and planetary mass across different exoplanet populations. The left panel shows the metallicity distributions of rocky/Neptune-size, sub-Jupiter, and Jupiter-size planets. The right panel presents planetary-mass distributions within different stellar-metallicity bins.



A clear difference is observed among the planet categories (Fig. 4). Host stars of gas giant planets are predominantly concentrated at higher metallicities, while host stars of sub-Neptunes and terrestrial planets span a much broader metallicity range and extend toward lower metallicities. This result indicates that metal-rich stellar environments are more commonly associated with the formation of massive planets, whereas lower-mass planets can form around stars with a wider range of chemical compositions.

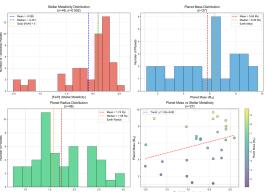
In the low-metallicity regime ([Fe/H] < −0.5), planets tend to have lower masses and a relatively narrow mass distribution (Fig. 4). In contrast, at near-solar and slightly metal-rich metallicities, both the median planet mass and the spread of the mass distribution increase, and higher-mass planets are more frequently observed. Although the sample sizes in individual metallicity bins are uneven, this pattern suggests a possible association between host star metallicity and planet mass.

However, due to the limited sample size—especially at the extremes of the metallicity distribution—these trends should be interpreted as indicative rather than conclusive, and they do not by themselves establish a causal relationship.

Metallicity, Mass, and Radius of Low-Mass Planets

To further investigate the relationship between host star metallicity and planetary properties, we focus on the subsample of low-mass planets.

Figure 5. *Metallicity, mass, and radius distributions of the low-mass planet sample. The panels show the host-star metallicity distribution (upper left), planetary-mass distribution for 27 planets with measured masses (upper right), planetary-radius distribution for 48 planets (lower left), and the relationship between planetary mass and host-star metallicity with a linear regression fit (lower right).*



The distribution peaks around [Fe/H] ≈ −0.4 to −0.5 dex, with a mean value of −0.585 dex and a median value of −0.401 dex. This result suggests that low-mass planets are commonly found around stars with mildly sub-solar metallicities, indicating that extremely high metallicity is not a necessary condition for their formation.

Of the 27 low-mass planets with measured masses, planet masses are primarily concentrated in the range of 5–7 $M_{\oplus}$, corresponding to super-Earths and sub-Neptunes. The radius distribution of 48 low-mass planets indicates that most radii fall between 1 and 2 $R_{\oplus}$. When considered together, these mass and radius distributions suggest that many low-mass planets may retain modest gaseous envelopes or reflect a diversity of formation and evolutionary pathways.

The relationship between planet mass and host star metallicity has a linear fit given by

$$M_p = 1.33\,[Fe/H] + 6.80\,M_{\oplus}. \quad (1)$$

Although the statistical significance of this trend is limited by the small sample size, it suggests that planet mass may increase weakly with host star metallicity. This behavior is broadly consistent with previous statistical studies and with expectations from the core accretion model, in which higher metallicity environments provide more solid material for planetary growth.

Taken together, while low-mass planets form across a wide range of metallicities, host star metallicity may still influence their mass and radius distributions.

ADDITIONAL FINDING: EMISSION-LINE FEATURES IN HOST STAR SPECTRA

In addition to the primary statistical analysis, we identify a small number of host stars whose spectra exhibit clear emission-line features. These cases were identified during data inspection using a dedicated emission-line detection procedure.

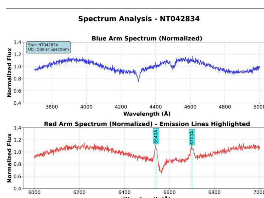


Figure 6. *Normalized blue- and red-arm LAMOST spectra of the exoplanet host star NT042834. Candidate emission-line features identified near 6540 Å and 6700 Å are highlighted in the red-arm spectrum.*

The emission lines may be associated with enhanced stellar activity, such as flare events or chromospheric emission. Although only three such cases are identified in this sample, their presence is noteworthy because stellar activity can influence the physical and chemical evolution of nearby planets, particularly for close-in systems.

Stellar flare activity may affect planetary atmospheres through enhanced radiation and particle fluxes, potentially leading to atmospheric erosion or changes in climate conditions. While the small number of detected emission-line host stars prevents any statistical conclusions, this finding highlights a potentially interesting connection between stellar activity and planetary environments and motivates further investigation with larger samples and time-domain observations.

DISCUSSION

Summary of Main Results

In this study, we performed a statistical analysis of exoplanet host stars using medium-resolution spectroscopic data from the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) combined with confirmed exoplanet information from the NASA Exoplanet Archive. By constructing samples of exoplanet host stars and a comparison sample of stars without known planets, we investigated how host star metallicity varies across different types of exoplanets.

The results indicate that host stars of gas giant planets are, on average, more metal-rich than stars hosting low-mass planets, while terrestrial planets and sub-Neptunes are found around stars spanning a much broader range of metallicities. Although host stars and comparison stars largely overlap in metallicity, statistical trends suggest that higher stellar metallicity is associated with a higher likelihood of forming massive planets. Within the low-mass planet sample, weak trends indicate that planet mass may increase with host star metallicity, although this result is limited by sample size.

Overall, these findings support the view that stellar metallicity plays an important role in shaping planet populations, particularly for massive planets, while low-mass planets can form efficiently in a wide range of chemical environments.

CONSISTENCY WITH PREVIOUS STUDIES

The trends identified in this study are broadly consistent with results reported in previous observational work. Earlier high-resolution spectroscopic studies found that gas giant planets preferentially form around metal-rich stars, while smaller planets are distributed over a wider metallicity range. The results presented here reinforce these conclusions using an independent dataset based on large-sample, medium-resolution spectroscopy.

Compared with many previous studies that rely on relatively small samples of high-resolution spectra, this work uses LAMOST-MRS data to construct a more homogeneous and statistically consistent sample of host star parameters. Although the precision of medium-resolution spectra is lower than that of high-resolution observations, the advantage of LAMOST lies in its large sample size and uniform data processing. As such, this study provides complementary evidence and demonstrates the value of medium-resolution surveys for statistical studies of exoplanet host stars.

LIMITATIONS OF THE STUDY

Several limitations should be considered when interpreting the results of this study.

First, the effective sample size is limited, particularly for terrestrial planets and for planets with well-measured masses and radii. This constraint reduces the statistical significance of some observed trends and highlights the need for larger samples in future studies.

Second, observational selection effects influence the exoplanet sample. Different detection methods have different sensitivities: the transit method favors short-period and large-radius planets, while the radial velocity method is more sensitive to massive planets. In addition, the sky coverage and signal-to-noise limitations of the LAMOST survey affect which host stars are included. As a result, the observed distributions may not fully represent the true underlying planet population.

Third, this study is based on statistical correlations and does not attempt to establish causal relationships. Planet formation and evolution are influenced by many factors, including protoplanetary disk mass, stellar age, and dynamical interactions, which are not explicitly modeled here. Therefore, the results should be interpreted as statistical associations rather than direct evidence of physical causation.

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