Statistics of giant planets around M Dwarfs

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Introduction and Motivation

With the highest planet-to-star mass ratio of any type of planetary systems, giant planets around M dwarfs are extreme cases that serve as **sensitive probes of planet formation and bridges between theories for star and planet formation**. However, only few of them were detected even if M stars are abundant in our Milky Way[1,2,3]. The TESS mission has been enlarging this sample, enabling statistical studies similar to FGK-host analogues.

Our program, named **GPASS** (Giant Planet Around Small Stars), aims to paint a comprehensive picture of such systems including orbital architecture, occurrence rate, dynamical history and stellar properties, and conduct a comparison with FGK counterparts.

Occurrence Rate

Based on the TESS Primary Mission , we built a magnitude-limited M dwarf sample of 60,819 stars with $0.45 \leq M_* \leq 0.65\ M_\odot$ according to information from TESS Input Catalog[4]. We conducted a systematic transit search + an injection & recovery test, and obtained an occurrence rate of 0.27±0.09 % for hot Jupiters around M dwarfs[5]. Compared with previous studies, we found a trend that **the occurrence rate of hot Jupiters has a peak at G stars and falls toward hotter and cooler stars** (Fig. 1).

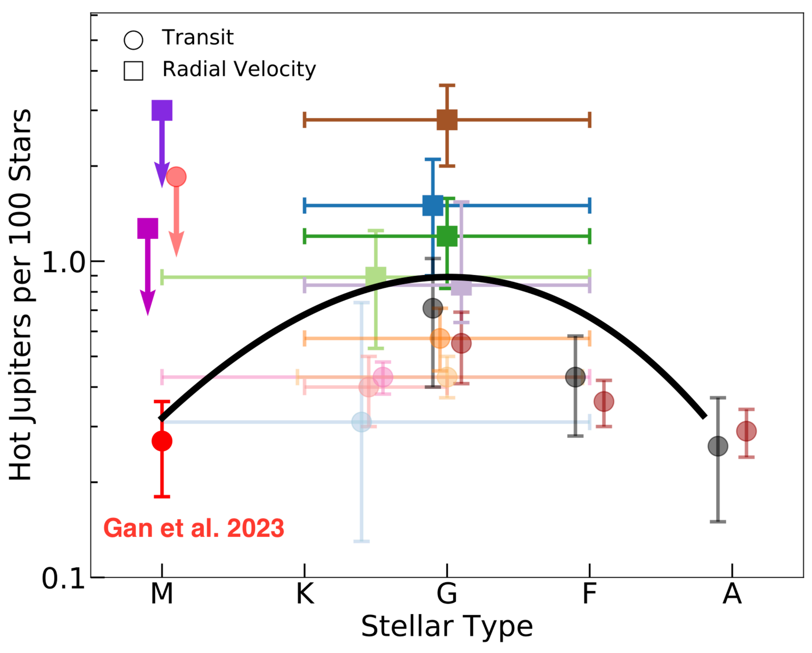

Fig. 1. Occurrence rates of hot Jupiters as a function of stellar type. Results from transit and RV surveys are shown as circles and squares. The horizontal uncertainties mark the range of stellar type used in each work. Small random shift are added to the horizontal coordinates for clarity. A potential parabola-shaped occurrence rate trend (black curve) can be seen.

Relative Occurrence Rate

We proposed a statistical parameter, the relative occurrence rate between hot and cold Jupiters ($\varepsilon = \eta_{HJ}/\eta_{CJ}$), to probe the giant planet migration. By comparing the occurrence rates of hot Jupiters (η_{HJ}) from TESS[6,7] and cold Jupiters (η_{CJ}) from California Legacy Survey (CLS)[8], we found a tentative trend that **ε drops with increasing stellar mass** (Fig. 2) that could be explained by different giant planet formation and migration timescales[9]. **Classical core accretion + disk migration simulations** (planetesimal and pebble model) can reproduce the observational results.

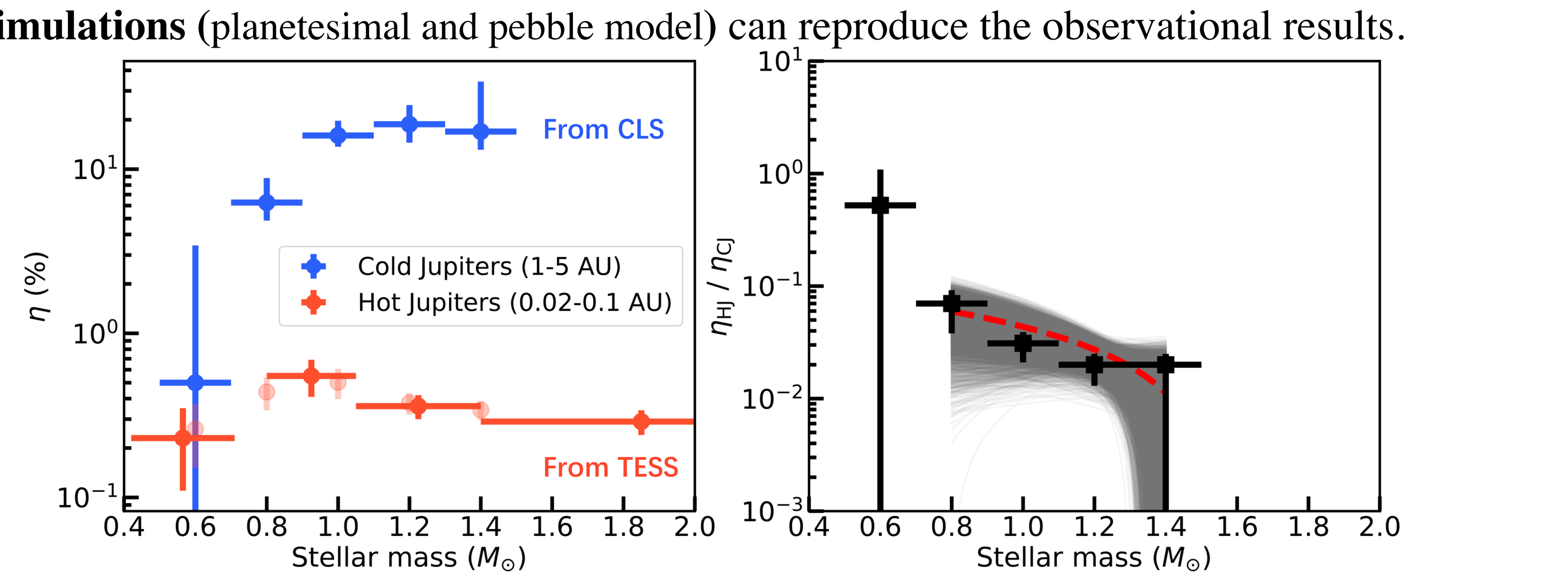

Fig. 2. Left: Observed occurrence rates of hot Jupiters (red, from TESS) and cold Jupiters (blue, from CLS) vs. stellar mass. Right: The derived relative occurrence rate of giant planets. A possible decreasing trend of ε can be seen, following $\varepsilon = [-0.08 \pm 0.04]\frac{M_*}{M_\odot} + [0.12 \pm 0.05]$.

Planet-to-Star Mass Ratio

We studied all known giant planets ($M_p \geq 0.3\ M_J$) around M dwarfs detected by different methods in the planet-to-star mass ratio and semi-major axis space (Fig. 3). We find that:

- Microlensing and RV systems show a wide and similar mass ratio distribution ($q \leq 10^{-2}$), indicating **warm/cold Jupiters around M dwarfs are common and diverse**;
- There is **a paucity of massive hot Jupiters around M dwarfs**[10].

This feature could be linked to (1) **planet formation**. It might be difficult to form massive giant planets close to the host M dwarf; or (2) **planet migration**. The migration of massive cold Jupiters may stops farther away in the disk compared with hot Jupiters.

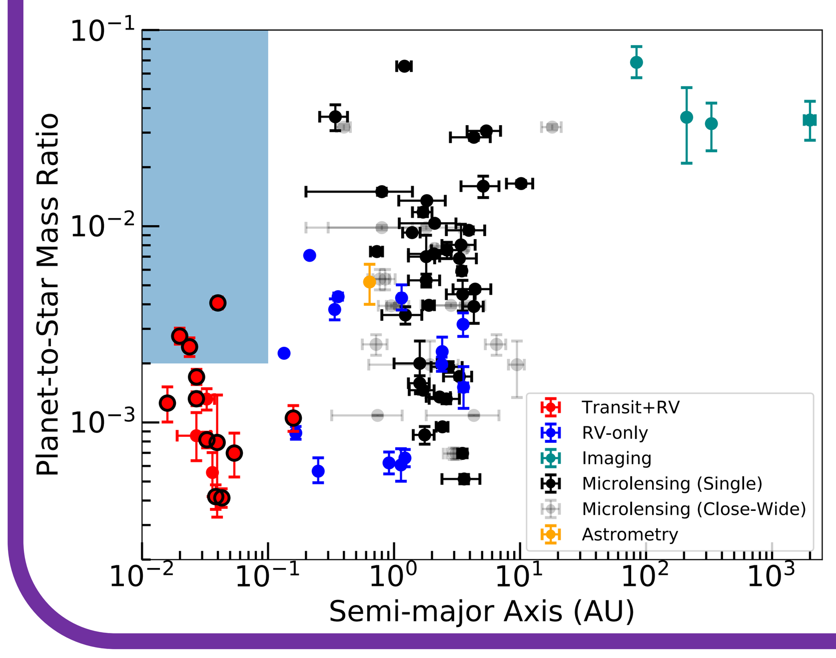

Fig. 3. Planet-to-star mass ratio of known giant planets around M dwarfs as a function of semi-major axis. The TESS detections are red dots with black circles, which have increased the sample of hot Jupiters around M dwarfs by a factor of five. The blue shaded region marks the paucity of massive hot Jupiters around M dwarfs.

Stellar Obliquity

With the observations from the Gemini/MAROON-X, we report the **first** detection of the Rossiter Mclaughlin effect for an M dwarf with a hot Jupiter TOI-4201b[11]. The host star is well-aligned with the planet orbit with a sky-projected obliquity of $\lambda = -3.0^{+2.7}_{-4.2}$ deg, indicating **dynamically quiet formation** or **tidal obliquity damping**.

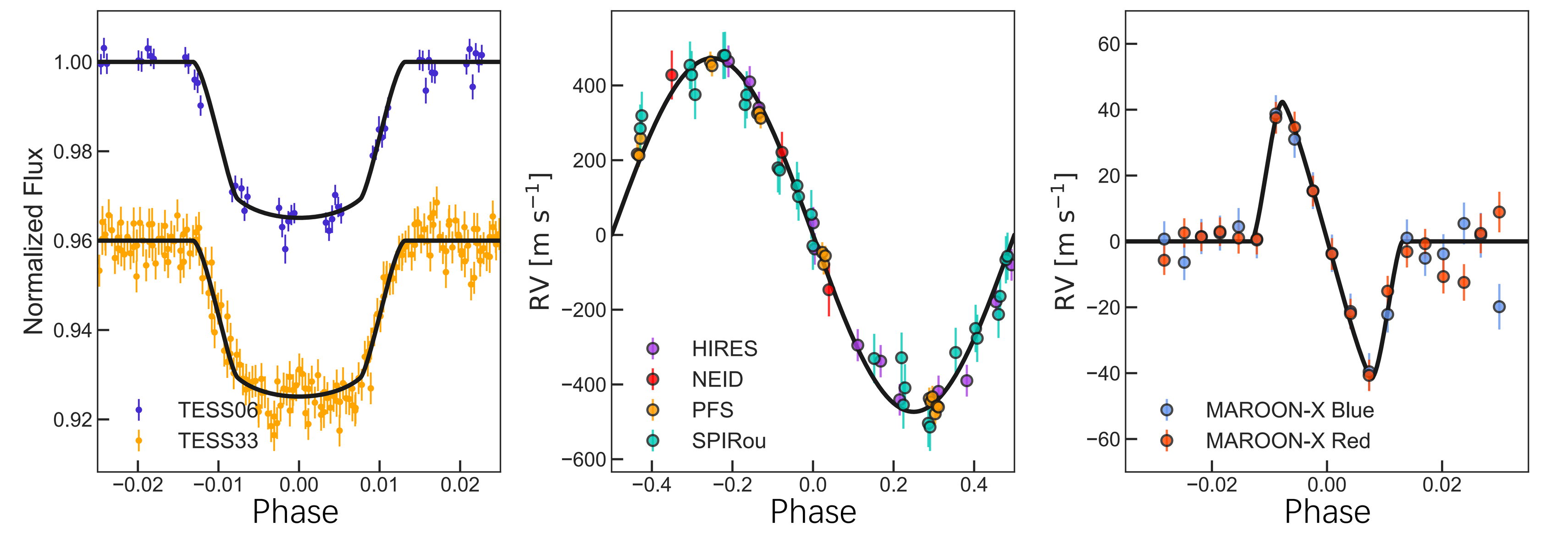

Fig. 4. TESS light curve (left), out-of-transit RVs (middle) and RM measurements (right).

We studied TOI-4201 in the context of systems with measured obliquities, and we find:

- It is consistent with previous findings that **hot-Jupiter hosts with Teff < 6,250 K (i.e., thick convective envelopes) tend to have low obliquities** (Fig. 5 left);
- **Planetary systems with high mass ratio are likely to be well-aligned** (Fig. 5 right);.

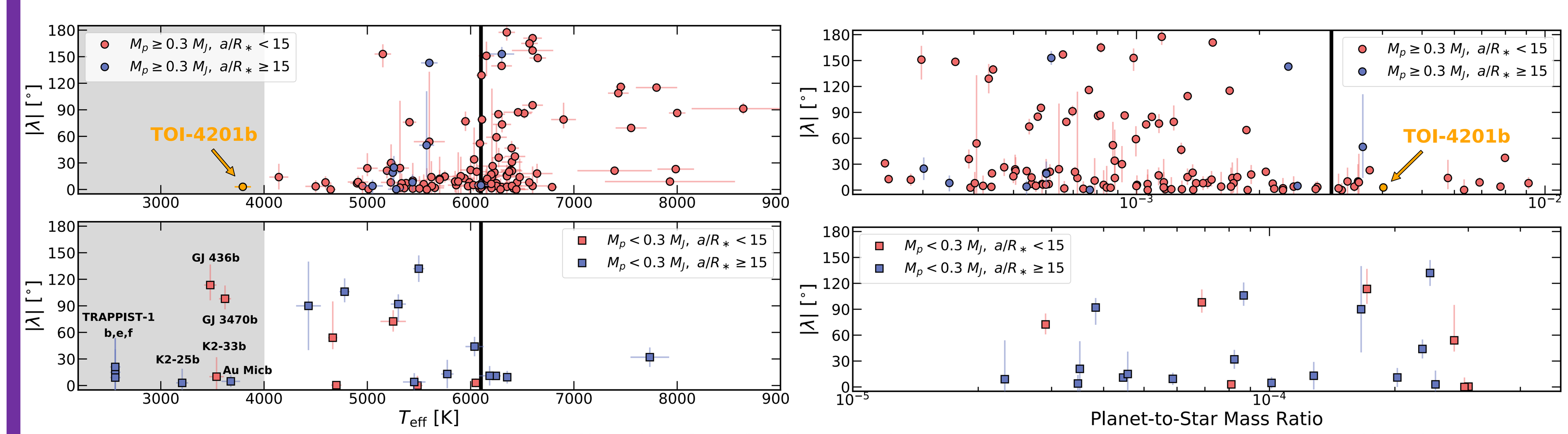

Fig. 5. Left: Projected stellar obliquity λ of giant-planet systems (top) and small-planet systems (bottom) vs. host star effective temperature. Right: Similar as the left panel but for planet-to-star mass ratio. Systems with mass ratio over 3×10^{-3} *tend to be aligned.*

Stellar Metallicity Dependence

Stellar metallicity ([Fe/H]) is a crucial indicator of planet formation. Metal-rich FGK stars are more likely to host giant planets[12], supporting core accretion scenario. Based on all confirmed giant planets orbiting M dwarfs from literature, we found that (1) hot Jupiters ($a/R_* < 20$) also prefer metal-rich M stars; (2) warm Jupiters ($a/R_* > 20$) show a weaker dependence (Fig. 6 left)[13].

We further carried out a **homogeneous stellar characterization** for a sample of **20** systems using IRTF/SpeX (Fig. 6 right)[14]. Compared with field M dwarfs observed by SpeX, we find that:

- **The formation of giant planets prefers metal-rich M dwarfs (3.5σ confidence);**
- **Hot and warm Jupiters around M dwarfs do not show a significant difference on the stellar metallicity preference.**

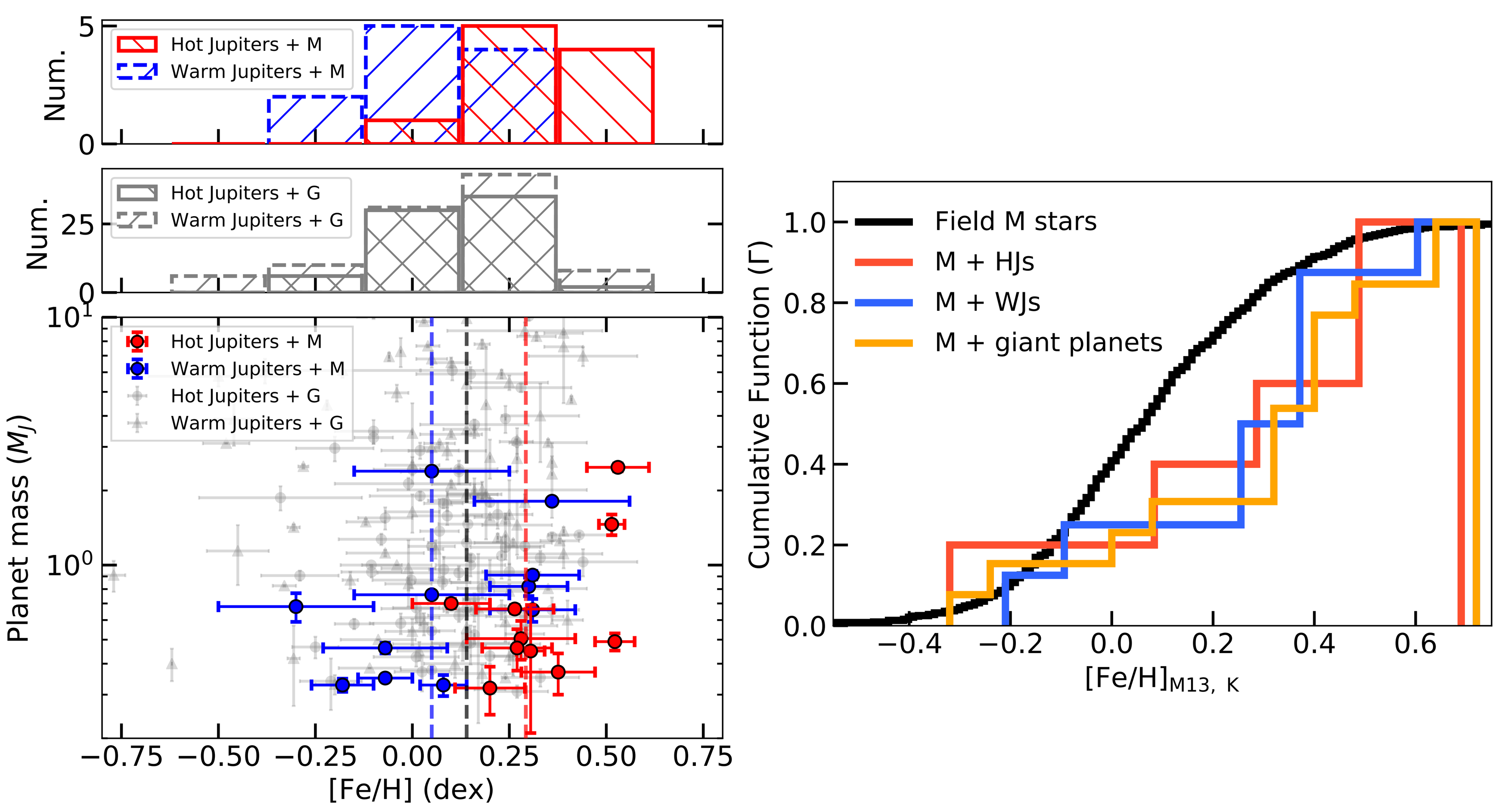

Fig. 6. Left: Planet mass vs. host star metallicity of four groups from literature.. Right: The cumulative function of metallicity of our SpeX M dwarf giant planet sample (red: hot, blue: warm, orange: hot+warm) compared with field M dwarfs (black).

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