Search for hot Jupiters in the Pleiades open cluster with radial velocity method

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Abstract

Since 2017, we have been conducting a planet survey in the Pleiades open cluster (~140 Myr) with radial velocity (RV) method. So far, 47 stars are observed with Subaru telescope/HDS and 30 stars are observed with Okayama 188cm telescope/HIDES-F. Although no significant RV modulation by planets was detected from our sample, our survey provide strong constraints on the frequency of HJs in the Pleiades open cluster. By combining the HDS sample with the HIDES ones, we determine the upper limit of HJ frequency to be less than 4.7%. We also estimate a typical stellar RV jitter to be ~50 m/, which is consistent with other young stars whose ages are same as Pleiades.

1. Introduction

The formation process of Hot Jupiters (HJs) is still unclear despite of large number of detection. Two leading scenarios have been proposed for such processes(Fig.1); one is disk-driven migration (DDM) and the other is High-eccentricity migration (HEM). One of the crucial factors to discriminate between the two scenarios is the time scale on which the processes occur. While the DDM takes an order of 10 Myr to form HJs, HEM does hundreds Myr. Thus, studying planets around young stars (< a few hundreds Myr) can give us direct clues for the HJs formation process.

To confirm the time-scale of the HJ formation, we are conduction a precise Doppler survey of solar-type stars in Pleiades open cluster using the HDS/Subaru and HIDES-F/Okayama 188cm tel. The age of Pleiades cluster, ~140Myr, can distinguish DDM and HEM.

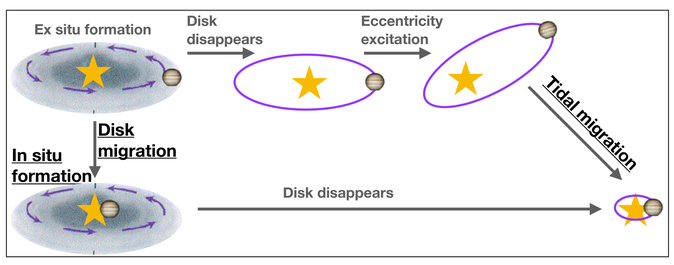

Fig.1: Two major path for the formation process of HJs.
(from Dawson R.I+2018, ARA&A, 56, 175.)

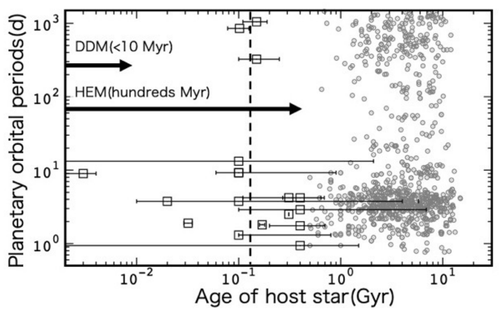

Fig.2: Age of exoplanet host stars vs planetary orbital periods. The age of Pleiades is show by dotted line.

2. Observation and Analysis

● Sample Selection

129 GK–type stars in Pleiades selected with following criteria:
i) High membership probability (>70%) [1], ii) V mag 9.5–12.5, iii) B-V>0.6, iv) v sin i, < 20 km/s (if known)
v) not identified as spectroscopic binary.

● Observation

We used Subaru/HDS and Okayama 188cm tel./HIDES-F with I2Cell for radial velocity (RV) measurements. Among our samples, 30 stars which are brighter than 10.5 mag are observed with HIDES-F ([2]). 47 stars fainter than 10.5 mag are observed with HDS. (Since 2023, we start follow-up and additional observations with Seimei/GAOES-RV.)
To search HJs with minimum observation, we obtain 3-days-consequence data and 2 data with several-days interval.

● Analysis

RVs are derived by the method of Sato+2002 [3]. To check the origin of RV modulations, we also perform stellar activity analysis; Line profile analysis and activity sensitive lines (Ca H and Hα lines).
Once significant correlations between RVs and any activity indicators is confirmed, we subtract it to reduce stellar jitter.

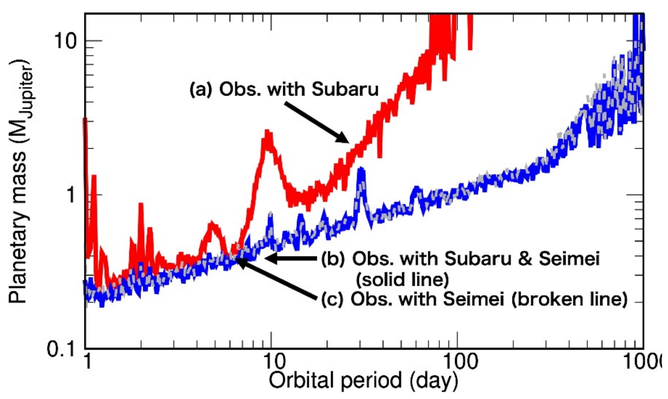

Fig.3: Expected detection limit by our obs. plan. Red, blue and gray lines are observation with Subaru (5 data), Subaru+Seimei observation (12 data in total), and Seimei observation (20 data), resp.

References: [1] Kharchenko et al. 2004, Astronomische Nachrichten, 325, 740, [2] Takarada T et al. 2020, PASJ, 72, 104. [3] Sato B et al. 2002, PASJ, 54, 873. [4] Paulson, D. B., & Yelda, S. 2006, PASP, 118, 706 [5] Bailey, J. I. et al. 2018, MNRAS, 475, 1609 [6] Wright, J. T., et al. 2012, ApJ, 753, 160 [7] Quinn S.~N., et al., 2014, ApJ, 787, 27. [8] Brucalassi, A., et al. 2017, A&A, 603, A85

3. Result

● RVs modulation

Several stars show significant RV modulation compared to RV errors (Fig.4 black dots). After stellar activity correction, most of them get close to measurement errors (Fig4. red dots). While some targets still exhibit large RV modulations, no periodicity is detected due to insufficient RV data. We need additional observations.
Assuming std. of RVs consist with root mean squares of stellar RV jitter and RV measurement error, stellar RV jitters are estimated to be ~50 m/s.

Fig.4:Median RV error vs Std of RVs. Black and red points are RVs before and after activity correction. Black solid line is 1:1 line.

● Detection limit and survey completeness

Fig.5 shows planet detection limits for HDS sample (red), and HIDES-F sample (magenta) compared with two other surveys targeting young (40-300Myr) clusters (green [4], blue [5]).
We derived survey completeness for HDS sample (Fig.6). 40 samples out of 47 samples can rule out > 0.5MJUP planets.

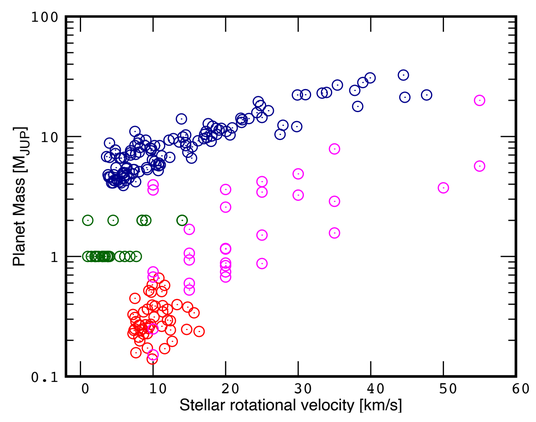

Fig.5: Detection limit as a function of stellar rotational velocity. Red and magenta are Pleiades stars observed with HDS and HIDES-F. Green is IC 2391 (30–50 Myr) and Ursa Major moving group (300 Myr) [4].Blue is NGC 2516 (141 Myr) and NGC 2422 (73 Myr) [5].

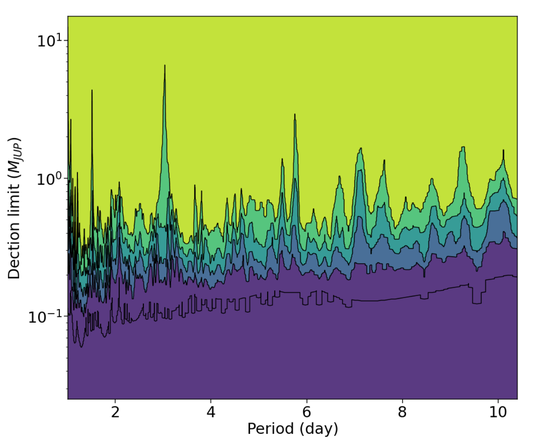

Fig.6: Survey completeness for HDS sample.

● HJs frequency

By combining HDS and HIDES-F sample, the upper limit of HJs frequency in Pleiades are estimated to be 4.7%. Currently, the comparison with frequency of field stars and Hyades+Praesepe is difficult. HJs frequency in Pleiades would be less than M67.

Target	HJs freq.
Pleiades, HDS	< 7.5%
Pleiades, HDS+HIDES	< 4.7%
Field stars [6]	~1.2%
Hyades+Praesepe [7]	$0.99^{+0.96}_{-0.54}$%
M67 [8]	$5.7^{+5.5}_{-3.0}$%

4. Discussion and Future plan

Our sample yields 1 sigma upper limit of HJs occurrence rate to be 4.7%. This enables us to refute high frequency of HJs as confirmed in M67, which indicate that the cluster environment does not affect HJs formation in Pleiades unlike M67.
Aiming to set more stringent occurrence rate of HJs, another coeval OCs and stellar stream are planned to be observed. OCs under considerations include Mellote 20 (~70 Myr), ASCC123 (130 Myr), and Pisces-Eridanus stellar stream (120Myr). From these OCs, another >150 GK-type stars would be added to our sample, from which we can set the upper limit of HJs occurrence rate to be less than 1% even in the case of null detection.