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LETTERS

A planetary companion orbiting the intermediate-mass G Giant HD 173416 *

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Abstract The discovery of a planetary companion to the intermediate-mass late-type giant star HD173416 from precise Doppler surveys of G and K giants at Xinglong station and Okayama Astrophysical Observatory (OAO) is presented in this letter. The planet has a minimum mass of 2.7 $M_{\rm J}$, an eccentricity of 0.21, a semimajor axis of 1.16 AU and an orbital period of 324 days.

Key words: planetary systems — stars: individual: HD173416 — stars: Planetary Systems — techniques: radial velocities

1 INTRODUCTION

Since the first planet was discovered around the solar-like star 51 Peg (Mayor & Queloz 1995), planet hunters have unveiled more than 300 extrasolar planets by precise radial velocity monitoring. Statistical properties of planets around solar-like stars as well as their host stars have been widely investigated (e.g., Udry et al. 2003; Santos et al. 2004). In general, the planetary companions are quite different from those in our solar system. The planets have minimum masses that range from 5 Earth masses to 20 Jupiter masses (here after $M_{\rm J}$) and are distributed in the range of orbital radii from 0.02 to 6 AU with orbital eccentricities of 0 to 0.9 (e.g. Butler et al. 2006) and the period distribution shows a peak at 3 days. Despite that radial velocity method is more sensitive to massive companions, the frequency of the discovered planets increases with increasing mass (Johnson et al. 2007a).

After the first detection of a planet around a giant star by Frink et al. (2002), hunting for extrasolar planets around giants and subgiants has gradually become a new frontier in extrasolar planet searches during recent years. By now, more than 20 planets and a few brown dwarfs have been discovered around such evolved stars. The growing number of planets is now allowing us to preliminarily unveil their properties. Researchers find that they show different properties from those in solar-like stars: high frequency of massive planets (Lovis & Mayor 2007; Johnson et al. 2007a) and a lack of inner planets (Johnson et al. 2007b; Sato et al. 2008).

It is well known that planet-harboring main-sequence stars are, on average, metal-rich compared with stars that do not harbor Doppler-detected planets. On the other hand, preliminary statistics show that planet-harboring giant stars tend to be metal-poor (e.g. Sadakane et al. 2005; Pasquini et al. 2007;

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Takeda et al. 2008). Hekker et al. (2007) found metallicity enhancement based on 20 reported giants with substellar companions by shifting the zero-points of metallicity for their study as compared with those in the literature. Thus, metallicities of giants accompanied by planets have not yet been well understood, probably due to the limited number of samples. More planets around giants are required to characterize their properties.

In this paper, we announce a new discovery of a planetary companion to the intermediate-mass giant HD 173416 from precise Doppler planet search programs conducted at Xinglong station and Okayama Astrophysical Observatory (OAO).

2 STELLAR PROPERTIES

HD173416 (=HIP91852, HR7043) is a G8 giant star with visual magnitude $m_V = 6.057$, a color index B-$V = 1.04$, and a precise astrometric parallax π = 7.41±0.53 (ESA 1997), which yields a distance of 135 pc from the sun and absolute magnitude of $M_V = 0.406$. Effective temperature $T_{\rm eff} = 4683 \pm 100\,$K was derived from the B–V and [Fe/H] using the empirical calibration of Alonso et al. (2001), and a bolometric correction $\mathrm{B.C.} = -0.388$ was derived from the calibration of Alonso et al. (1999) with temperature and metallicity. Subsequently, the stellar luminosity was estimated to be $L = 78 \pm 10\,L_\odot$, with a radius of $R = 13.5 \pm 0.9\,R_\odot$. The stellar mass $M = 2.0 \pm 0.3\,M_\odot$ was estimated from the star's position on the theoretical H-R diagram by interpolating the evolutionary tracks of Yonsei-Yale (Yi et al. 2003). Surface gravity $\log g = 2.48 \pm 0.10$ was determined using the relation between the temperature, mass, luminosity and gravity. Iron abundance was determined from the equivalent widths measured from a high resolution spectrum (3720–4940, 4981–6242 and 6255–7474 Å), which was taken with the HIDES spectrograph (see Sect. 3) at OAO, based on the model atmosphere (Kurucz 1993). We iterated the whole procedure described above until the value of the overall metallicity of the model converged. Finally, we obtained $[\mathrm{Fe/H}] = -0.22 \pm 0.09$ and a microturbulent velocity $v_t = 1.5 \pm 0.2$ km s^{-1}.

3 RADIAL VELOCITIES AND ORBITAL SOLUTION

Precise radial velocity measurements for HD 173416 were carried out using the Coude Echelle Spectrograph (CES) at Xinglong and the High Dispersion Echelle Spectrograph (HIDES) at OAO. The resolving power ($\lambda/\Delta\lambda$) was set to 40 000 by two pixel sampling for CES and 67000 by about 3.3 pixel sampling for HIDES, and a waveband of 5000–5800 Å was used for radial velocity measurements (only $\Delta \sim 470\,$Å is available for CES because of the small format of the current CCD). An iodine absorption cell installed in each spectrograph was used for precise wavelength calibration. Details about the

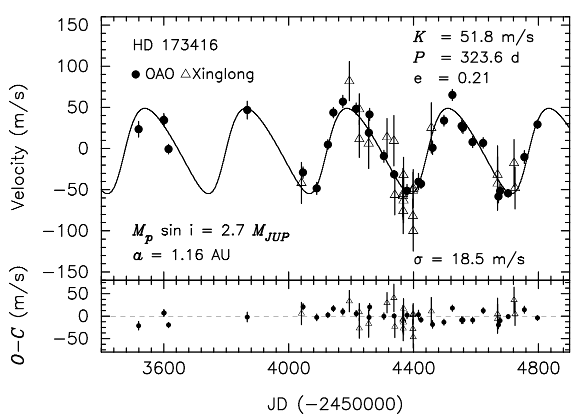

Fig. 1 Top: Radial velocities of HD 173416 observed at Xinglong (triangles) and OAO (circles). The Keplerian orbit (solid line) is determined using both the Xinglong and OAO data. Bottom: Residuals of the Keplerian fit.

settings of the spectrographs and the analysis technique are described in Liu et al. (2008). We gathered a total of 22 and 30 data points of the star at Xinglong and OAO in 2005–2008, respectively, and their typical signal-to-noise ratio (S/N) was 130–200 with exposure times of 1800 s with CES, and 200 with 1200 s exposure with HIDES. Typical measurement precision with CES and HIDES was 25 and 7 m s^{-1}, respectively.

The observed radial velocities are shown in Figure 1 and listed in Table 1 together with their estimated uncertainties. The best-fit Keplerian orbit was derived using both the OAO and Xinglong data. An offset of -119 m s^{-1} was applied to the Xinglong radial velocities in order to minimize χ^2 when fitting a Keplerian model to the combined OAO and Xinglong velocities. The resulting orbit is shown in Figure 1 overplotted on the velocities, and its parameters are listed in Table 2. The uncertainty of each parameter was estimated using a Monte Carlo approach. When we determined the Keplerian orbits using only OAO data, the rms scatter of the residuals in the Keplerian fit was 13.3 m s^{-1}. This is comparable to that of typical G giants with similar B-V values (Sato et al. 2005) and no significant periodicity was found in the residuals at this stage. Adopting a stellar mass of 2.0±0.3 $M_\odot$, for the companion, we obtained a mass of $m_2 \sin i = 2.7 \pm 0.3\ M_{\rm J}$ and a semimajor axis $a = 1.16 \pm 0.06$ AU. The uncertainties mostly come from that in the host star's mass. We performed line shape analysis for the star with

Table 1 Radial Velocities of HD 173416

JD (−2450000)	Radial Velocity (m s^{-1})	Uncertainty (m s^{-1})	Observatory	JD (−2450000)	Radial Velocity (m s^{-1})	Uncertainty (m s^{-1})	Observatory
3519.2335	23.4	9.5	OAO	4367.9836	−63.0	27.1	Xinglong
3600.1055	34.8	7.6	OAO	4367.9999	−32.1	21.5	Xinglong
3601.1862	34.3	6.4	OAO	4379.0718	−51.1	7.7	OAO
3615.1874	−0.7	5.8	OAO	4397.9655	−81.9	20.9	Xinglong
3867.2492	46.7	10.8	OAO	4397.9764	−51.0	22.0	Xinglong
4041.0323	−41.8	24.9	Xinglong	4398.9529	−48.7	23.0	Xinglong
4045.9804	−29.2	6.8	OAO	4398.9640	−100.0	24.5	Xinglong
4089.8885	−48.3	7.4	OAO	4415.9137	−40.1	10.0	OAO
4125.3635	4.9	5.9	OAO	4423.9496	−42.9	5.6	OAO
4143.3342	43.6	6.3	OAO	4456.9602	25.1	30.5	Xinglong
4173.3054	57.1	7.5	OAO	4460.8747	0.9	8.2	OAO
4194.3156	81.8	23.7	Xinglong	4497.3354	33.9	6.6	OAO
4216.2644	48.2	7.1	OAO	4524.3322	65.0	6.7	OAO
4226.2513	47.8	18.8	Xinglong	4554.3106	27.5	7.5	OAO
4226.2730	11.6	22.3	Xinglong	4558.3003	25.5	7.4	OAO
4256.2437	6.1	30.3	Xinglong	4589.2615	7.9	6.9	OAO
4257.2401	19.4	6.5	OAO	4623.1193	6.9	6.3	OAO
4259.2447	41.4	7.4	OAO	4669.0668	−42.4	32.5	Xinglong
4305.0945	−9.3	7.3	OAO	4669.0895	−31.7	35.0	Xinglong
4315.1139	13.8	22.6	Xinglong	4672.0946	−58.1	7.7	OAO
4337.0554	9.5	30.6	Xinglong	4677.0142	−51.5	8.4	OAO
4338.1045	−31.5	4.8	OAO	4703.0579	−54.4	4.5	OAO
4340.0567	−56.3	24.3	Xinglong	4722.0206	−17.5	28.3	Xinglong
4365.9894	−57.7	25.7	Xinglong	4725.0446	−47.9	25.4	Xinglong
4366.0117	−55.3	31.0	Xinglong	4755.0042	−10.4	7.7	OAO
4366.9771	−75.9	27.6	Xinglong	4796.9111	29.4	5.2	OAO

Table 2 Orbital Parameters of HD 173416 determined from both the Xinglong and OAO data.

Parameter	Value	Parameter	Value
P (days)	323.6±2.2	$f_1(m)$ ($10^{-5}\ M_\odot$)	4.38±0.51
K_1 (m s^{-1})	51.8±2.0	$m_2 \sin i$ ($M_{\rm J}$)	2.7±0.3
e	0.21±0.04	a (AU)	1.16±0.06
ω (deg)	254±11	N	52
T_p (JD−2 450 000)	3465.8±8.3	rms (m s^{-1})	18.5
$a_1 \sin i$ (10^{-3} AU)	1.510±0.061	Reduced $\sqrt{\chi^2}$	1.5

the same method as that adopted in Liu et al. (2008) and found no significant variations in them. This supports the orbital motion hypothesis as the cause of the observed radial velocity variability.

4 SUMMARY

Here, we reported the discovery of a $2.7M_{\rm J}$ planet around the evolved intermediate-mass star HD 173416. This is the first planet candidate discovered from the Xinglong-Okayama Planet Search Program.

All of the currently known substellar companions around intermediate-mass giants and subgiants reside in orbits with $a \geq 0.6$ AU. The new planet reported here fits this pattern well, with $a = 1.16$ AU. Since many planets exist within 0.6 AU around low-mass dwarfs, the lack of inner planets around evolved intermediate-mass stars may reflect different histories of formation and evolutions of the planetary systems around them.

It is well established that giant planets are preferentially found around metal-rich solar-type stars (e.g. Zhao et al. 2002, Santos et al. 2004, Fischer & Valenti 2005) and stars with planets are on average about 0.25 dex more metal-rich than those without planets (Santos et al. 2004). On the other hand, this tendency does not appear in giants with planets (Pasquini et al. 2007, Takeda et al. 2008). HD173416 fits this pattern, with sub-solar metallicity $[\rm Fe/H] = -0.22$. It should be noted, however, that super-metal-rich giants with $[\rm Fe/H] > 0.2$ were originally rare in the samples of planet searches (e.g. Takeda et al 2008; da Silver et al. 2006). A larger scale survey of giants, including more metal-rich ones, is required for a better understanding of the planet-metallicity correlation in giants.

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