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TWO EXTRASOLAR PLANETS FROM THE ANGLO-AUSTRALIAN PLANET SEARCH[1]

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ABSTRACT

We report the detection of two new extrasolar planets from the Anglo-Australian Planet Search around the stars HD 142 and HD 23079. The planet orbiting HD 142 has an orbital period of just under 1 yr, while that orbiting HD 23079 has a period of just under 2 yr. HD 142 falls into the class of "eccentric" gas giants. HD 23079 joins the group of "ϵ Ret-like" gas giant planets, with near-circular orbits outside a radius of 0.1 AU. The recent discovery of several more members of this class provides new impetus for the extension of existing planet searches to longer periods in the search for Jupiter-like planets in Jupiter-like orbits.

Subject headings: planetary systems — stars: individual (HD 142, HD 23079)

1. THE ANGLO-AUSTRALIAN PLANET SEARCH

The Anglo-Australian Planet Search (AAPS) is a long-term planet detection program which aims to perform extrasolar planet detection and measurement at the highest radial velocity precision currently possible. Together with programs using similar techniques on the Lick 3 m and Keck I 10 m telescopes (Fischer et al. 2001; Vogt et al. 2000), it provides all-sky planet search coverage for inactive F, G, K, and M dwarfs down to a magnitude limit of $V = 7.5$. Initial results from this program demonstrate that AAPS achieves long-term, systematic velocity precisions of 3 m s^{-1} or better (Tinney et al. 2001; Butler et al. 2001a, hereafter Paper II).

AAPS is being carried out on the 3.92 m Anglo-Australian Telescope (AAT), using the University College of London Echelle Spectrograph (UCLES) and an I_2 absorption cell. UCLES is operated in its 31 line mm^{-1} mode. Prior to 2001 September, it was used with an MIT/LL 2048 × 4096 15 μm pixel CCD and since then has been used with an EEV 2048 × 4096 13.5μm pixel CCD. Our target sample includes 178 F, G, and K stars with $\delta < -20°$ and $V < 7.5$ and a further 23 M-type and metal-enriched stars with $V < 11.5$. Where age/activity information is available from $R'_{\rm HK}$ indices (see, e.g., Henry et al. 1996; Tinney et al. 2002), we require target stars to have $\log(R'_{\rm HK}) < -4.5$ (corresponding to ages greater than 3 Gyr). The observing and data processing procedure follows that described in Butler et al. (1996) and Paper II.

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2. CHARACTERISTICS OF HD 142 AND HD 23079

HD 142 (HR 6, HIP 522, GJ 4.2A, LHS 1020) is a chromospherically inactive [$\log(R'_{\rm HK}) = -4.92$] G1 IV star (Houck 1978; Tinney et al. 2002). Its *Hipparcos* parallax of 39.0 ± 0.6 mas implies absolute magnitudes of $M_V = 3.66 \pm 0.03$ (ESA 1997) and $M_{\rm bol} = 5.55 \pm 0.05$ (Alonso, Arribas, & Martínez-Roger 1995).

The fundamental parameters of HD 142 have been examined via spectroscopy (Favata, Micela, & Sciortino 1997) and Strömgren *ubvy* photometry (see the compilation of Eggen 1998). The spectroscopy derives [Fe/H] = $+0.04 \pm 0.15$ and $T_{\rm eff} = 6025$ K, while the photometry suggests [Fe/H] = -0.04, which is in agreement with the spectroscopy to within uncertainties.

Based on interpolation between the evolutionary tracks of Fuhrmann, Pfeiffer, & Bernkopf (1997, 1998), the mass of HD 142 is estimated to be 1.15 ± 0.1 $M_\odot$. Figure 1 shows the Ca II H line region for HD 142 together with the quiet Sun and HD 23079. The absence of significant emission confirms that this star is chromospherically inactive.

HD 23079 (HIP 17096, LTT 1739) is an inactive dwarf with a $\log(R'_{\rm HK}) = -4.96$ (Tinney et al. 2002; Henry et al. 1996). Houck & Cowley (1975) classify it as F8/G0 V (i.e., intermediate between F8 and G0). Its *Hipparcos* parallax is 28.9 ± 0.6 mas, giving it $M_V = 4.42 \pm 0.05$ and $M_{\rm bol} = 4.25 \pm 0.05$ (ESA 1997; Lang 1992).

No metallicity information is available for this star, so mass estimation will be less precise. At [Fe/H] = +0.25, 0.0, and −0.25, the models of Fuhrmann et al. (1997, 1998) would indicate $M = 1.25$, 1.10 and 1.0 $M_\odot$, respectively. For the most likely metallicity range of this F/G dwarf, its mass lies in the range 1.0–1.25 $M_\odot$, and we therefore adopt $M = 1.10 \pm 0.15$ $M_\odot$. Both HD 142 and HD 23079 were seen to be photometrically stable over the life of the *Hipparcos* mission at a 95% confidence level of <0.018 mag (ESA 1997).

3. RADIAL VELOCITY OBSERVATIONS AND ORBITAL SOLUTIONS

Twenty-seven observations of HD 142 are listed in Table 1. The column labeled "Uncertainty" is the velocity uncertainty produced by our least-squares fitting. This fit simultaneously determines the Doppler shift and the spec-

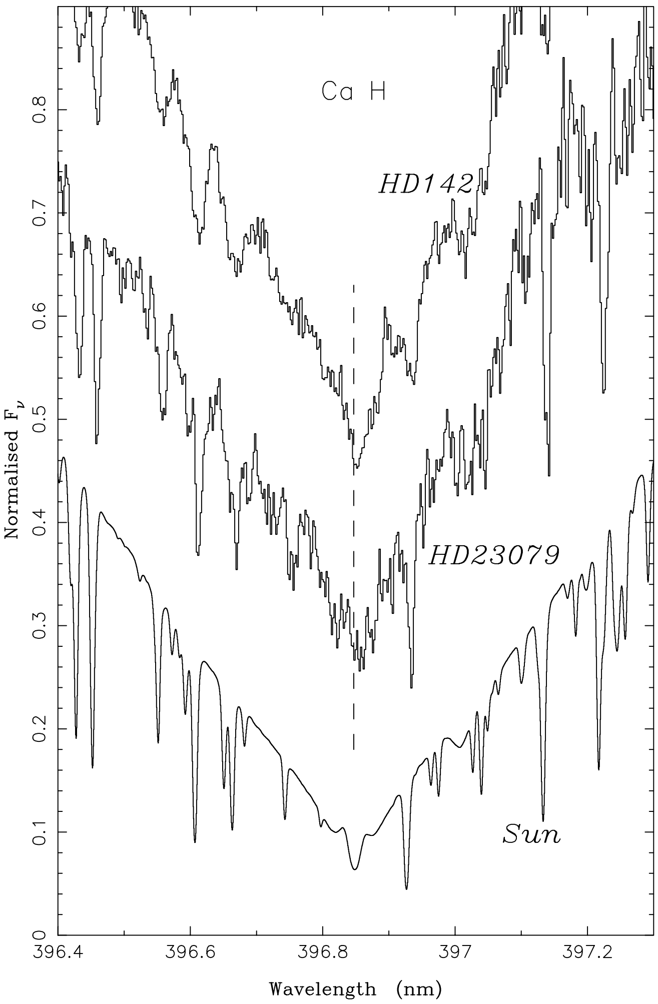

FIG. 1.—Comparison of the Ca II H line core in the Sun (*lower line*), HD 23079 (*middle line*), and HD 142 (*upper line*). Solar spectrum is from Kurucz et al. (1984), and other spectra are from Tinney et al. (2002).

trograph point spread function (PSF) for each observation made though the iodine cell, given an iodine absorption spectrum and an iodine-free template spectrum of the object (Butler et al. 1996). The uncertainty is derived from the ensemble of velocities from each of 400 useful spectral regions (each 2 Å long) in every exposure. This uncertainty includes the effects of photon-counting uncertainties, residual errors in the spectrograph PSF model, and variation in the underlying spectrum between the template and iodine epochs. All velocities are measured relative to the zero point defined by the template observation. Only observations where the uncertainty is less than twice the median uncertainty are listed. These data are shown in Figure 2. The figure shows the best-fit Keplerian model for the data, with the resultant orbital parameters listed in Table 2.

The residuals about the fit are slightly higher than the 3–4 m s^{-1} average level of "jitter" expected in a G1 star with HD 142's level of activity (Saar et al. 1998) but are within the typical range seen even in inactive stars.[9]

TABLE 1
VELOCITIES FOR HD 142

Julian Date[a] (−2450000)	Radial Velocity[a] (m s^{-1})	Uncertainty (m s^{-1})
830.9587.........	−13.1	7.5
1121.0194.......	−16.0	7.5
1385.3105.......	42.6	14.5
1411.2025.......	13.0	15.8
1473.0850.......	−15.2	7.9
1683.3314.......	36.1	8.1
1743.2765.......	41.0	7.5
1745.2642.......	24.0	10.4
1767.2699.......	0.1	9.0
1768.2542.......	1.3	7.1
1828.0607.......	−16.4	8.9
1856.0643.......	−5.9	10.7
1856.9250.......	−12.5	12.9
1918.9407.......	−4.1	9.3
2061.2963.......	32.7	8.0
2092.2683.......	19.8	7.5
2093.2876.......	11.4	8.1
2127.2230.......	−20.0	9.4
2128.1545.......	−4.0	9.0
2130.2433.......	−16.0	8.0
2151.2113.......	−21.9	7.4
2152.0786.......	−12.0	7.8
2154.1541.......	−29.5	6.9
2187.1000.......	−15.2	7.0
2188.0360.......	−9.4	7.2
2189.0199.......	−23.9	7.0
2190.0032.......	−12.0	6.4

[a] Radial velocities are barycentric but have an arbitrary zero point determined by the radial velocity of the template, as described in § 3.

The 13 observations of HD 23079 are listed in Table 3, and they are shown in Figure 3 along with a Keplerian fit to the data with the orbital parameters listed in Table 2. The rms scatter about this fit is consistent with velocity scatter seen in stable stars from the AAPS (Paper II). These results

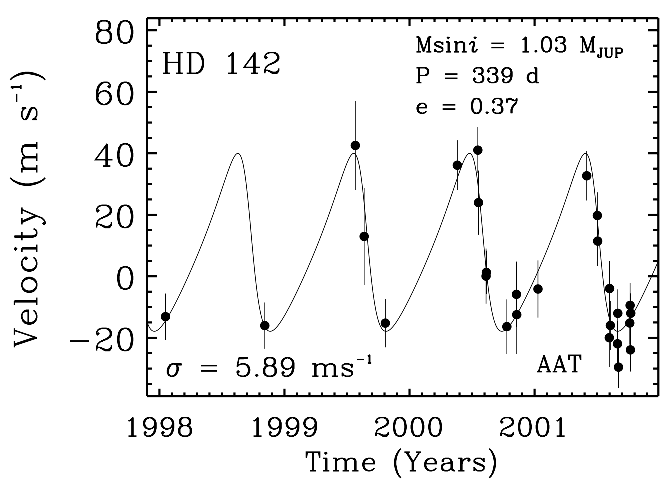

FIG. 2.—AAT Doppler velocities for HD 142 from 1998 January to 2001 October. Solid line is a best-fit Keplerian with the parameters shown in Table 2. The rms of the velocities about the fit is 5.89 m s^{-1}. Assuming 1.15 $M_\odot$ for the primary, the minimum ($M \sin i$) mass of the companion is 1.03 ± 0.19 M_{JUP}, and the semimajor axis is 1.0 ± 0.1 AU.

[9] "Jitter" here is used to refer to the scatter in the observed velocity about a mean value in systems observed over the long term to have no Keplerian Doppler shifts, or about a fitted Keplerian in systems known to have a planetary mass companion. It is thought to be due to the combined effects of surface inhomogeneities, stellar activity, and stellar rotation.

TABLE 2
ORBITAL PARAMETERS

Parameter	HD 142	HD 23079
Orbital period P (days)	339 ± 6	626 ± 24
Velocity amp. K (m s^{-1})	29.6 ± 5	56 ± 5
Eccentricity e	0.37 ± 0.1	0.02 ± 0.12
ω (deg)	71 ± 36	262 ± 50
$a_1 \sin i$ (km)	$(0.1280 \pm 0.0066) \times 10^6$	$(0.482 \pm 0.019) \times 10^6$
Periastron time (JD$-$2450000)	1752 ± 22	1680 ± 90
$M \sin i$ ($M_{\rm JUP}$)	1.03 ± 0.19	2.5 ± 0.3
a (AU)	1.0 ± 0.1	1.5 ± 0.2
RMS about fit (m s^{-1})	5.89	3.08

demonstrate the extraordinary control over long-term systematics that the iodine cell technique can deliver for stars with suitable intrinsic velocity stability. It also demonstrates the suitability of the UCLES spectrograph at the AAT for radial velocities at the highest precisions, even for a $V = 7.1$ star near our $V = 7.5$ current survey limit.

4. DISCUSSION

The resultant minimum companion mass for HD 142 is $M \sin i = 1.03 \pm 0.19 M_{\rm JUP}$, with an orbital semimajor axis $a = 1.0 \pm 0.1$ AU at an eccentricity of $e = 0.37 \pm 0.1$, a roughly Jupiter-mass giant planet in an Earthlike but eccentric orbit. It has been argued that extrasolar planets preferentially orbit metal-enriched stars. (See Gonzalez et al. 2001; Santos et al. 2001a and references therein for discussion of these observations and possible mechanisms.) It is interesting, then, that HD 142 is only marginally enriched over solar metallicity.

The minimum companion mass and orbital parameters derived for HD 23079 ($M \sin i = 2.5 \pm 1.1$ $M_{\rm JUP}$, $a = 1.5 \pm 0.2$ AU, $e = 0.04 \pm 0.18$) indicate the presence of a planet with significantly larger mass than Jupiter in a Mars-like orbit with eccentricity consistent with zero. HD 23079 joins a growing list of stars with recently discovered planets in circular or near-circular orbits outside 0.1 AU (ϵ Ret, HD 4208, 47 UMa, all three companions to 47 UMa, HD 28185 and possibly HD 114783 and HD 10697 in Vogt et al. 2000, 2002; Fischer et al. 2002; Santos et al. 2001b). The region of the log(e) versus log($a_{\rm maj}$) diagram occupied by this group of planets (which we will call the ϵ Ret-like group, after the first such planet found) is highlighted in Figure 4. It is worth remembering that prior to about 12 months ago, this highlighted region of orbital phase space was empty (Butler et al. 2001b), though many extrasolar planets had been discovered. Though the ϵ Ret-like systems are clearly not solar system analogs, they take us one step closer in our search for such systems. Their discovery points the way to the detection of solar system analogs (in the form of Jupiter-like planets in Jupiter-like orbits) once data sequences at better than 2–3 m s^{-1} span the necessary 10–12 yr periods.

TABLE 3
VELOCITIES FOR HD 23079

Julian Date[a] (−2450000)	Radial Velocity[a] (m s^{-1})	Uncertainty (m s^{-1})
831.0689	−42.1	5.3
1121.1268	27.7	12.0
1157.0594	33.6	11.0
1473.2492	−54.6	5.6
1828.1399	51.0	5.8
1920.0142	35.7	6.0
1983.8858	4.4	7.8
2092.3211	−44.2	4.7
2127.2797	−58.5	7.3
2151.2764	−57.9	5.0
2152.2093	−65.5	5.4
2187.1679	−59.2	5.0
2188.1270	−62.1	4.7
2189.1418	−58.3	5.2

[a] As for Table 1.

5. CONCLUSIONS

We present results for the detection and characterization of two new extrasolar planets with orbital periods of 1 yr or greater around the stars HD 142 and HD 23079. The planet around HD 23079 is particularly interesting. It represents the detection of a new member of the class of ϵ Ret-like giant planets in near-circular orbits outside 0.1 AU. The continued detection by high precision Doppler searches of these gas giants in solar system-like orbits gives added impetus to

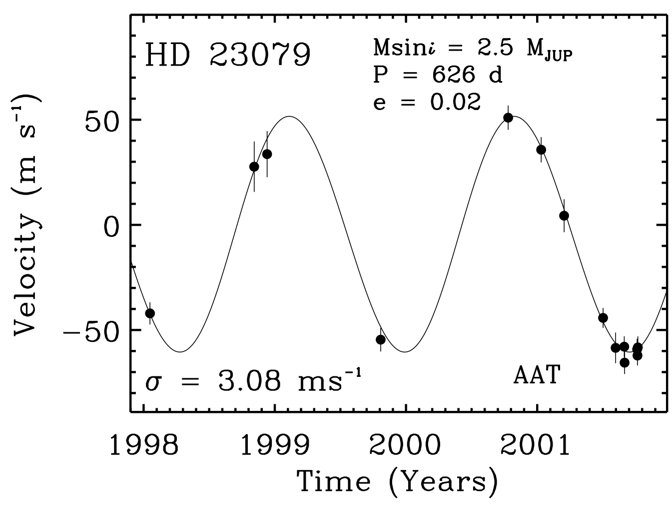

FIG. 3.—AAT Doppler velocities for HD 23079 from 1998 January to 2001 October. Solid line is a best fit Keplerian with the parameters shown in Table 2. The rms of the velocities about the fit is 3.08 m s^{-1}. Assuming a 1.1 $M_\odot$ for the primary, the minimum ($M \sin i$) mass of the companion is 2.5 ± 0.3 $M_{\rm JUP}$, and the semimajor axis is 1.5 ± 0.2 AU.

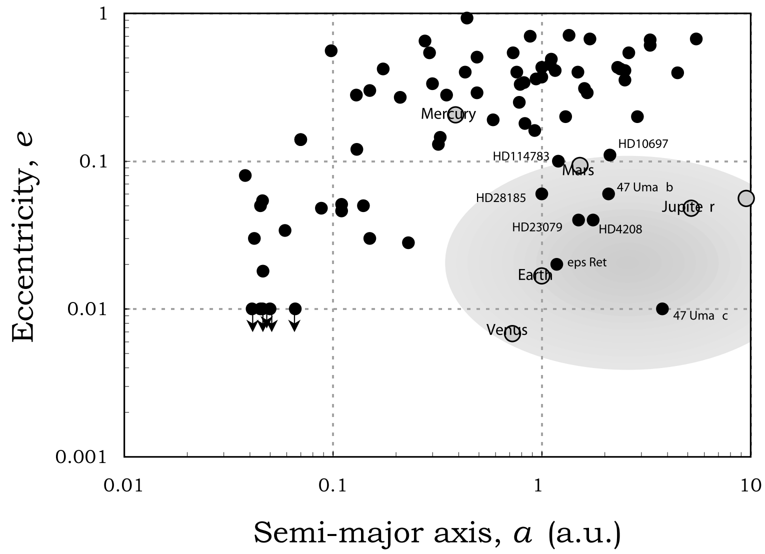

FIG. 4.—log(e) vs. log(a) for extrasolar planets reported as of 2001 September, plus new planets reported in this paper and by Vogt et al. (2002; *solid circles*), together with the inner planets of the solar system *(shaded circles)*. Planets with measured eccentricities $e < 0.01$ are shown as upper limits at $e = 0.01$. The region of the log(e)-log(a) occupied by the planets of the solar system and its similarity to those of the ϵ Ret-like planets is highlighted.

the continuation of these searches to the 10–12 yr period, in which analogs of the gas giants in our own solar system may become detectable around other stars.

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