TWO EXTRA-SOLAR PLANETS FROM THE ANGLO-AUSTRALIAN PLANET SEARCH

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ABSTRACT

We report the detection of two new extra-solar planets from the Anglo-Australian Planet Search within one year, while that orbiting HD 23079 has a period of just under two years. HD 142 falls into the class of "eccentric" gas giants. HD 23079 lies in the recently uncovered class of "Ret-like" planets - extra-solar gas giant planets with near-circular orbits outside 0.1 a.u. 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 (HD142, HD23079)

1. THE ANGLO-AUSTRALIAN PLANET SEARCH

The Anglo-Australian Planet Search (AAPS) is a long-term planet detection program which aims to perform extra-solar planet detection and measurement at the highest possible precision. Together with programmes 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 of this programme demonstrate that AAPS achieves long-term, systematic velocity precisions of 3 m s\(^{-1}\) or better (Tinney et al. 2001; Butler et al. 2001).

AAPS is being carried out on the 3.92 m Anglo-Australian Telescope (AAT), using the University College London Échelle Spectrograph (UCLES) and an I\(_{2}\) absorption cell. UCLES is operated in its 31 lines mm\(^{-1}\) mode. Prior to 2001 September, it was used with a MIT/LL 2048×4096 15\(\mu\)m pixel CCD, and since then has been used with an EEV 2048×4096 13.5\(\mu\)m pixel CCD.

Our target sample includes 178 FGK stars with \(\delta < -20^\circ\) and V<7.5, and a further 23 M and metal-rich stars with V<11.5. Where age/activity information is available from R\(_{\text{HK}}\) indices (see e.g., Henry et al. (1996); Tinney et al. (2002)) we require target stars to have R\(_{\text{HK}}\)<4.5 (corresponding to ages greater than 3 Gyr). The observing and data processing procedure follows that described in Butler et al. (1996) and Butler et al. (2001).

2. CHARACTERISTICS OF HD 142 & HD 23079

HD 142 (HR 6, HIP 522, GJ 4.2A, LHS 1020) is a chromospherically inactive (R\(_{\text{HK}}\)=-4.92) G1IV star (Houck 1978; Tinney et al. 2002). Its Hipparcos parallax of 39.0±0.6 mas implies absolute magnitudes of M\(_V\)=3.66±0.03 (ESA 1997) and M\(_{bol}\)=5.55±0.05 (Alonso, Arribas & Martínez-Roger 1995). The fundamental parameters of HD 142 have been examined via spectroscopy (Favata et al. 1997) and Strömgren ubvy photometry (see the compilation of Eggen (1998)). Spectroscopy derives [Fe/H]=+0.04±0.15 and T\(_{eff}\)=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 et al. (1998, 1997), 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 R\(_{\text{HK}}\)=-4.96 (Tinney et al. 2002; Henry et al. 1996). Houck & Cowley (1975) classify it as F8/G0V (i.e. intermediate between F8 and G0). Its Hipparcos parallax is 28.9±0.6 mas, giving it M\(_V\)=4.42±0.05 and M\(_{bol}\)=4.25±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. (1998, 1997) 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±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 magnitudes (ESA 1997).

3. RADIAL VELOCITY OBSERVATIONS AND ORBITAL SOLUTIONS

Twenty-seven observations of HD 142 are listed in Table 1. The column labelled “Uncertainty” is the velocity uncertainty
uncertainty produced by our least-squares fitting. This fit simultaneously determines the Doppler shift and the spectrograph 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 four hundred 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 is within the typical range seen in even inactive stars. The thirteen 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 of only 3.08 m s$^{-1}$ demonstrates the extra-ordinary control over long term systematics which 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.

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 inhomogeneties, stellar activity and stellar rotation.

Together with the extra-solar planetary companions to ε Ret (Butler et al. 2001), HD 4208 (Vogt et al. 2002), 47 UMa b & c (Fischer et al. 2002), and possibly the companions to HD 114783 and HD 10697 (Vogt et al. 2002, 2000), HD 23079 forms a new class of extra-solar planets, which we name after the prototype object ε Ret. The region of the Log(ε) versus Log(a$_{\text{maj}}$) diagram these “ε Ret-like” planets occupy is highlighted in Fig. 4. It is worth remembering that prior to about 12 months ago the highlighted region of this plot was empty – though many extra-solar planets had been discovered, none shared orbital properties with the planets of our own Solar System. The “ε Ret-like” planets, therefore, join with the “51 Peg-like” and eccentric giant planets in filling out the bestiary of extra-solar planets. Prior to their detection, it was unclear whether giant planets in circular, or near-circular, orbits outside 0.1 a.u. would be found at all outside the Solar System. 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 year periods.

5. CONCLUSIONS

We present results for the detection and characterisation for two new extra-solar planets with orbital periods of one year 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 a.u. The continued detection by high precision Doppler searches of these gas giants, in Solar System-like orbits, gives added impetus that the continuation of these searches to the 10-12 year periods where analogs of the gas giants in our own Solar System may become detectable around other stars.

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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).
Fig. 2.— AAT Doppler velocities for HD 142 from 1998 January to 2001 October. The 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.
Fig. 3.— AAT Doppler velocities for HD 23079 from 1998 January to 2001 October. The solid line is a best fit Keplerian with the parameters shown in Table 2. The rms of the velocities about the fit is $3.08 \text{ m s}^{-1}$. Assuming a 1.1 $M_\odot$ for the primary, the minimum ($M \sin i$) mass of the companion is $2.5 \pm 0.3 \, M_{\text{JUP}}$, and the semimajor axis is $1.5 \pm 0.2 \, \text{au}$. 
Fig. 4.— Log(e) versus Log(a) for extra-solar planets reported as of 2001 September, plus the 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 “$\epsilon$ Ret-like” planets is highlighted.
### Table 1

**Velocities for HD 142**

| JD\(^a\) (-2450000) | RV\(^a\) (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 (RV) are barycentric, but have an arbitrary zero-point determined by the radial velocity of the template, as described in Section 3.
Table 2
Orbital Parameters

| Parameter                  | HD 142     | HD 23079  |
|----------------------------|------------|-----------|
| Orbital period $P$ (d)     | 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 |
| $\omega$ (°)              | 71±36      | 202±50    |
| $a_1 \sin i$ (km)          | (0.1280±0.0066)×10$^6$ | (0.482±0.019)×10$^6$ |
| Periastron Time (JD-2450000) | 1752±22  | 1680±90   |
| $M \sin i$ ($M_{JUP}$)     | 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      |

Table 3
Velocities for HD 23079

| JD$^a$ (-2450000) | RV$^a$ (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