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An exoplanet in orbit around τ^1 Gruis

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ABSTRACT

We report the detection of a new candidate exoplanet around the metal-rich star τ^1 Gruis. With $M \sin i = 1.26 \pm 0.18$ $\mathrm{M_{Jup}}$, a period of 1391 ± 300 d and an orbit with an eccentricity of 0.14 ± 0.14 it adds to the growing population of long-period exoplanets with low-eccentricity orbits. This population now comprises more than 20 per cent of known exoplanets.

When the companion to τ^1 Gruis is plotted together with all exoplanets found by radial velocity searches we find evidence for a peak in the number of short-period exoplanets, followed by a minimum of planets between approximately 5 and 50 d and then an apparent rise in the number of planets per unit radius that seems to set in by 100 d, indicating more planets further from the host star. This is very different from the Gaussian-like period distribution found for stellar companions. This lends support to the idea that once a clearing in the inner protoplanetary disc develops, it halts the inward migration of planets. In particular, the smooth distribution of exoplanets arising from planetary migration through a disc is altered by an accumulation of exoplanets at the point where the disc has been cleared out.

Key words: stars: individual: HD216435 – stars: low-mass, brown dwarfs – planetary systems.

1 INTRODUCTION

The Anglo-Australian Planet Search (AAPS) is a long-term planet detection programme that aims to perform exoplanet 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 (Vogt et al. 2000; Fischer et al. 2002), it provides all-sky planet search coverage for inactive F, G, K and M dwarfs down to a magnitude limit of $V = 7.5$. So far the AAPS has published data for 17 exoplanets. (Butler et al. 2001, 2002a; Tinney et al. 2001, 2002a, 2003; Jones et al. 2002a,b).

The AAPS is carried out on the 3.9-m Anglo-Australian Telescope (AAT) using the University College London Echelle Spectrograph (UCLES), operated in its 31 line $\mathrm{mm^{-1}}$ mode together with an $\mathrm{I_2}$ absorption cell. UCLES now uses the EEV 2048 × 4096 13.5-μm pixel charge-coupled device, which provides excellent quantum efficiency across the 500–620 nm $\mathrm{I_2}$ absorption-line region. Despite this search taking place on a common-user telescope with frequent changes of instrument, we achieve a 3 m $\mathrm{s^{-1}}$ precision down to the $V = 7.5$-mag limit of the survey (Butler et al. 2001; fig. 1, Jones et al. 2002a), for suitably stable stars.

Our target sample, which we have observed since 1998, is given in Jones et al. (2002b). It includes 178 F, G and K dwarfs of luminosity class IV or V with declinations below $\sim -20°$ and is complete to $V < 7.5$. We also observe subsamples of 16 metal-rich ([Fe/H] > 0.3) stars with $V < 9.5$ and seven M dwarfs with $V < 7.5$ and declinations below $\sim -20°$. The sample is being increased to approximately 300 solar-type stars to be complete to a magnitude limit of $V = 8$. Where age/activity information are available from log R'(HK) indices (Henry et al. 1996; Tinney et al. 2002b) we require target stars to have log $R'(\mathrm{HK}) < -4.5$ corresponding to ages greater than 3 Gyr. Stars with known stellar companions within 2 arcsec are removed from the observing list, as it is operationally difficult to obtain an uncontaminated spectrum of a star with a nearby companion. Spectroscopic binaries discovered during the programme have also been removed and will be reported elsewhere (Blundell et al. 2003). Otherwise there is no bias against observing multiple stars. The programme is also not expected to have any bias against brown dwarf companions. The observing and data processing procedures follow those described by Butler et al. (1996, 2001).

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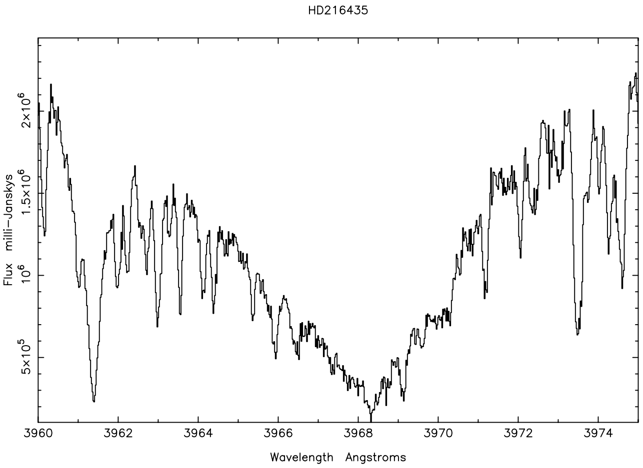

Figure 1. The figure shows the Ca II H line core in τ^1 Gruis. No emission is evident confirming the low activity index, log R'(HK)= −5.00, measured by Henry et al. (1996). The activity of the entire AAPS sample will be assessed in forthcoming papers by Tinney et al. (in preparation) and Blundell et al. (in preparation).

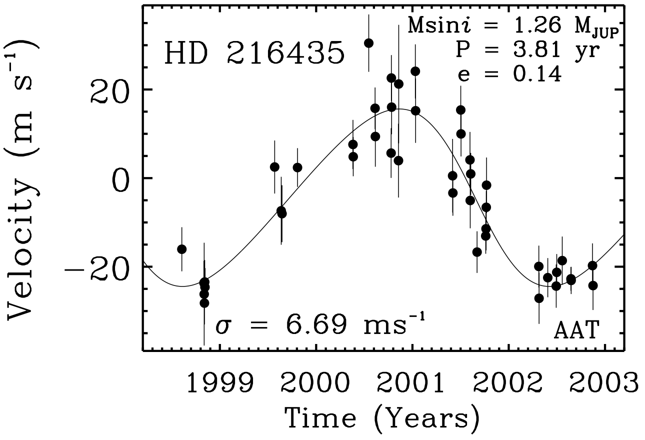

Figure 2. Doppler velocities obtained for τ^1 Gruis from 1998 August to 2002 November. The solid line is a best-fitting Keplerian to the parameters shown in Table 1. The rms of the velocities about the fit is 6.83 m s^{-1}. Assuming 1.25 M$_\odot$ for the primary, the minimum (M sin i) mass of the companion is 1.26 $M_{\rm Jup}$ and the semimajor axis is 2.5 au.

2 STELLAR CHARACTERISTICS OF τ^1 GRUIS

The Michigan Spectral Survey (Houk 1978) assigns τ^1 Gruis a spectral type of G0V, compared with the *Hipparcos* spectral type of G3IV. Its parallax of 30.0 ± 0.7 mas (ESA 1997) together with a V magnitude of 6.03 implies an absolute magnitude of $M_V = 3.42 \pm 0.03$ and $M_{\rm bol} = 3.20 \pm 0.05$ (Cayrel de Strobel et al. 1997). This absolute magnitude puts τ^1 Gruis a magnitude above the main sequence and explains the discrepancy between the literature-assigned spectral types G0V and G3IV.

Fig. 1 shows the Ca II H line for τ^1 Gruis (HD 216435, HIP113044, HR8700) and indicates that it is chromospherically inactive, confirming the activity index log R'(HK)= −5.00 found by Henry et al. (1996). Furthermore, there is no evidence for significant photometric variability in the 121 measurements made by the *Hipparcos* satellite. Combining *Hipparcos* astrometry of τ^1 Gruis with its SIMBAD radial velocity yields a space velocity with respect to the local standard of rest: $U, V, W = -27.5, -21.7, -10.5$. Its inferred age is 5 Gyr (Gonzalez 1999). Favata, Micela & Sciortino (1996) report an equivalent width Li detection of 70 mÅ, equating to an abundance of lithium $N(\,\mathrm{Li}) = 2.44$, consistent with τ^1 Gruis being a metal-rich subgiant (Randich et al. 1999). di Benedetto (1998) calculated the effective temperature of τ^1 Gruis to be 5943 ± 60 K as part of a substantial programme to apply the infrared flux method and angular diameters from interferometry experiments to *ISO* standard stars with $V - K$ measurements. Similarly to many of the stars found to have extrasolar planets, τ^1 Gruis is metal-rich with [Fe/H] derived from high-resolution spectroscopic analysis of Fe lines being +0.15 ± 0.04 (Favata et al. 1996). Interpolation between the tracks of Fuhrmann, Pfeiffer & Bernkopf (1998) and Girardi et al. (2000) indicates a mass of 1.25 ± 0.10 M$_\odot$.

3 ORBITAL SOLUTION FOR τ^1 GRUIS

The 44 Doppler velocity measurements of τ^1 Gruis, obtained between 1998 August and 2002 November, are shown graphically in Fig. 2 and listed in Table 1. The third column labelled 'error' is the velocity uncertainty produced by our least-squares fitting. This uncertainty includes the effects of photon-counting uncertainties, residual errors in the spectrograph point spread function 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.

The data are well-fitted by a Keplerian curve that yields an orbital period of 1391 ± 300 d, a velocity amplitude of 20 ± 2 m s^{-1}, and an eccentricity of 0.14 ± 0.14. The minimum (M sin i) mass of the planet is 1.26 ± 0.18 M$_{\rm Jup}$, and the semimajor axis is 2.5 ± 0.6 au. The rms to the Keplerian fit is 6.69 m s^{-1}, yielding a reduced chi-squared value of 1.18. Since τ^1 Gruis is relatively bright ($V = 6.03$) and inactive, the measured rms seems a little high. At spectral type, G0V, our precision is limited by the smaller equivalent widths of stellar lines relative to later spectral types. Thus with our observing exposures adjusted to give a signal-to-noise (S/N) ratio of 200 per exposure, our precision is probably limited to approximately 4 rather than 3 m s^{-1}. We have investigated our data and we find that the internal velocity errors correlate well with the number of photons per pixel. The velocity errors vary nearly as $1/\sqrt{(\mathrm{photons})}$, as expected from our stable stars (e.g. Butler et al. 2001). We consider that our median measurement for this star is 5 m s^{-1}, which is probably rather high because of an inadequate S/N ratio in our template measurement. Although a new template has been of high priority for a number of recent observing runs, suitable weather conditions have not prevailed. As a G0 star, HD 216435 is especially susceptible to chromospheric activity (Saar, Butler & Marcy 1998; Saar & Fischer 2000). In this case, the S value is 0.15. Our internal estimate for the 'jitter' of a G0 star with this S value is 4 m s^{-1}. Adding to the 5 m s^{-1} of internal measurement uncertainty yields an expected uncertainty of 6.4 m s^{-1}, which is consistent with the rms to the Keplerian fit. The lack of any observed chromospheric activity or photometric variation gives us confidence that the radial velocity signature arises from an exoplanet rather than from long-period star-spots or chromospherically active regions. The properties of the candidate extrasolar planet in orbit around τ^1 Gruis are summarized in Table 2.

4 DISCUSSION

The companion to τ^1 Gruis announced here serves to further reinforce the predominantly metal-rich nature of stars with exoplanets. It also adds to the growing population of long-period exoplanets

Table 1. Velocities for τ^1 Gruis. Julian dates (JD) are heliocentric. Radial velocities (RV) are barycentric but have an arbitrary zero-point determined by the radial velocity of the template.

JD −2 451 000	RV ($\mathrm{m\,s^{-1}}$)	Error ($\mathrm{m\,s^{-1}}$)
34.2105	−9.1	5.0
118.0436	−16.7	5.0
118.9557	−19.2	11.6
119.9400	−21.2	4.8
120.9997	−16.4	4.9
121.9209	−17.6	4.3
386.3182	9.5	6.0
411.1493	−0.4	7.7
414.2635	−1.0	6.4
472.9492	9.4	4.4
683.3180	14.6	5.5
684.3245	11.8	4.4
743.2420	37.5	6.5
767.1997	22.8	4.7
768.2187	16.4	6.8
828.0383	12.6	5.6
828.9589	29.6	5.2
829.9527	23.0	6.1
856.0436	10.9	8.3
856.9123	28.2	13.4
919.9251	31.1	6.1
920.9303	22.2	7.2
1061.2803	7.5	8.3
1062.3446	3.6	5.1
1092.2145	22.4	5.5
1093.2415	17.0	5.1
1127.1922	11.1	6.3
1128.1475	2.0	6.3
1130.1052	8.0	4.7
1154.0982	−9.7	4.7
1186.9518	−6.1	4.0
1188.0403	−4.4	4.9
1188.9741	0.4	3.7
1189.9808	5.4	6.3
1388.3132	−12.9	4.7
1389.3008	−20.1	5.8
1422.3045	−15.5	4.4
1454.3375	−17.4	4.9
1456.2765	−14.3	4.1
1477.1981	−11.6	5.4
1510.2434	−15.7	2.7
1511.0244	−16.1	3.1
1591.9722	−12.7	5.0
1593.9626	−17.3	5.5

Table 2. Orbital parameters for the companion to τ^1 Gruis.

Parameter	τ^1 Gruis b
Orbital period (d)	1391 ± 300
Eccentricity	0.14 ± 0.14
ω (°)	94 ± 60
Velocity amplitude K ($\mathrm{m\,s^{-1}}$)	20 ± 2
Periastron time (JD)	50 765 ± 300
$M \sin i$ ($\mathrm{M_{Jup}}$)	1.26 ± 0.18
a (au)	2.5 ± 0.6
rms to Fit	6.69

with low-eccentricity orbits. Now more than 20 per cent of exoplanets have orbital parameters within those of the Solar system (e.g. Table 3, Jones et al. 2002a). It is notable that as the Anglo-Australian Planet Search becomes sensitive to longer periods, we are continuing to find objects with longer periods, but remain limited by the time-span of our observations. τ^1 Gruis is a pleasing example. Within the errors its velocity amplitude is nearly as low as any long-period single exoplanet announced by radial velocity searches and the error on its period is dominated by the relatively short time-span of our observations. Thus the detection of an exoplanet around τ^1 Gruis together with our long-term stable stars (e.g. Butler et al. 2001) gives us confidence in the stability of our search as we move to longer periods and the possibility of detecting Jupiter analogues.

The radial velocity signal we measure for τ^1 Gruis suggests a planet with a minimum mass of approximately that of Jupiter. τ^1 Gruis b becomes the fifth exoplanet to be found with a mass of approximately that of Jupiter with a period of greater than 3 yr and indicates that radial velocity surveys now have significant sensitivity to Jupiter mass planets out to relatively large periods. It is thus intriguing to look at the period distribution of exoplanets found by the AAPS and other radial velocity searches. In Butler et al. (2003), we plotted a histogram of semimajor axes for exoplanets from the Lick, Keck and AAT searches. This showed a relatively large number of exoplanets at very short orbits and a tail of objects with longer orbits. The detection of long-period planets and long-term stable stars indicated that the peak at short periods was a real feature. 2 years later, with twice as many exoplanets known, Fig. 3 shows the exoplanets announced based on exoplanets.org by 2002 August 21. The bulk of exoplanets lie at relatively long periods. The AAPS has been operating for less time than other successful searches, though the exoplanets published by the AAPS are dominated by companions at longer periods such as τ^1 Gruis b. Fig. 3 plots the period distribution for all exoplanets. Interestingly, there appears to be a dip in the distribution between periods of approximately 5 and 50 d. The evidence for this dip is relatively poor when considering the AAT planets alone, although it is striking when all exoplanets are considered.

The relative lack of exoplanet candidates from approximately 0.2 to 0.6 au was noted by Cumming, Marcy & Butler (1999) and Butler et al. (2002b) and is also evident in fig. 2 of Heacox (1999), fig. 5 of Tabachnik & Tremaine 2001, fig. 4 of Lineweaver & Grether (2002) and fig. 7 of Armitage et al. (2002). Armitage et al. interpret this feature as a slight excess of exoplanets at the shortest periods and attribute it to the completeness of radial velocity surveys falling off towards longer periods. However, the observed period distribution actually appears to rise towards longer periods where the incompleteness of the radial velocity surveys falls rapidly. To allow for this incompleteness introduced by including lots of low-mass short-period exoplanets we follow Armitage et al. (2002) and consider planets in a restricted mass and period range where the surveys can be judged to be more complete. Following the analysis of Cummings et al. (1999), Armitage et al. consider the known exoplanets to be complete in the mass range 0.6–10 $M_{\mathrm{Jup}} \sin i$ for periods of less than 3 au. In the top plot of Fig. 3 we show the period distribution for a 0.6–10 M_{Jup} mass cut-off and all announced planets. The removal of the lowest-mass exoplanets reduces the peak of very short-period planets, however, the peak at short periods remains an

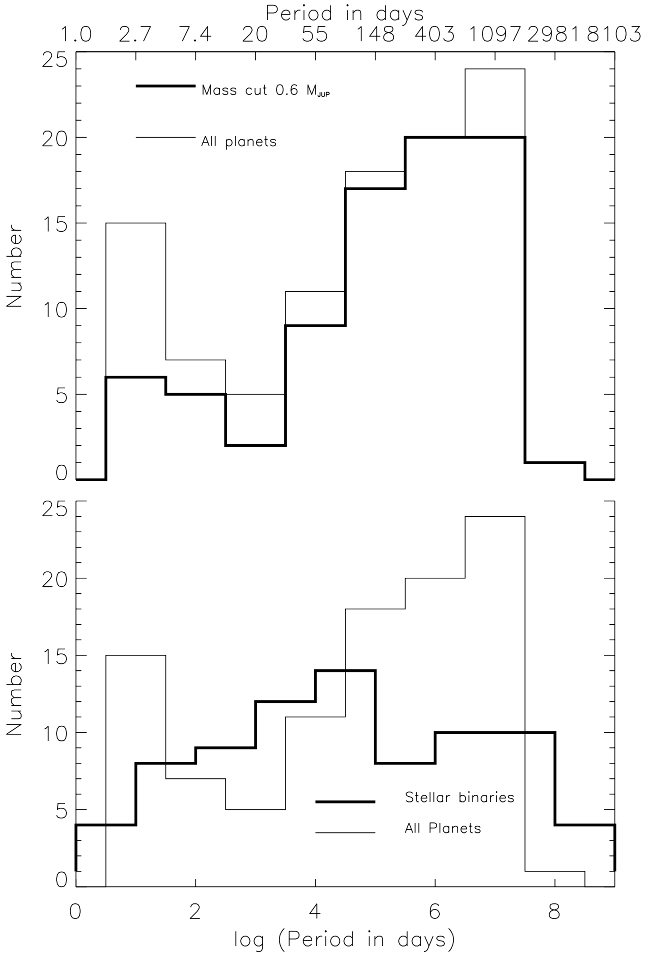

Figure 3. The number of exoplanets discovered within natural logarithm period bins is shown. The top part of the figure compares all radial velocity planets announced based on exoplanets.org/planet_table.shtml (2002 August 21) with those with masses less than 10 $M_{\rm Jup}/\sin i$ and greater than 0.6 $M_{\rm Jup}/\sin i$. The bottom part compares all published planets with the stellar binaries as found by Duquennoy & Mayor (1991).

order of magnitude higher than would be expected from an extension of counts at longer periods. We have also looked at the CORALIE, Keck and Lick surveys in the same manner as for the AAPS. Despite different radial velocity surveys operating with different samples, sensitivities, instruments, scheduling, strategies and techniques we do find evidence for the dip in each of the major surveys. We might expect to find an observational selection effect against periods of approximately one lunar month because of a tendency to schedule such surveys during bright time. For the AAPS, observing runs fall reasonably evenly across all lunar phases other than 'dark' and cover a wide range of time intervals between a week and many months. The floating-mean periodogram analysis of the Lick survey data by Cumming et al. (1999) do not suggest any strong bias against periods of approximately a lunar month. As mentioned above, this dip is evident in a number of works by other authors, although it is relatively less pronounced because of the substantially smaller number of exoplanets announced when those plots were made. The pronounced nature of this peak leads us to consider that Fig. 3 shows evidence for two (or more) populations of exoplanets. That is, a population of exoplanets spanning a small range of short periods (3–7 d) and a separate population increasing with number towards larger periods.

From the lower part of Fig. 3, it can be seen that there is no evidence for such a dip in the stellar binary distribution. The stellar companion period distribution plotted was determined by Duquennoy & Mayor (1991) using the same general radial velocity method to discover binary stars as used to discover the exoplanets. Duquennoy & Mayor find it necessary to make corrections to the stellar binary period distribution for incompleteness at longer periods; however, no such corrections are necessary for shorter periods and they find no dip in short-period stellar binaries. Overall Duquennoy & Mayor find that the period distribution of stellar binaries is well fitted by a Gaussian. Since stellar companions are expected to form via large-scale gravitational instabilities in collapsing cloud fragments or massive discs, whereas planets are expected to form by accretion in dissipative circumstellar discs it is not surprising that stellar and planetary companions should have different period distributions.

The period distribution for exoplanets has been investigated a number of times as the number of radial velocity exoplanets has grown. The existence of a peak at very short periods has been an important motivation in the development of migration theories for exoplanets (Ward 1997; Murray et al. 1998; Trilling et al. 1998; Trilling, Lunine & Benz 2002; Lin et al. 1999; Armitage et al. 2002). The trend towards finding an increasing number of exoplanets with large orbital separation runs counter to the selection effects inherent in radial velocity searches and has been well reproduced by migration theories (Armitage et al. 2002; Trilling et al. 2002). Whilst selection effects start to play an increasingly important role beyond approximately a few hundred days (e.g. Duquennoy & Mayor 1991; Cumming et al. 1999; Butler et al. 2002b), we do not consider them to be significant between 5 and 50 d and thus consider the 'dip' in exoplanet periods to be a feature of the period distribution not currently predicted by migration theories. It is interesting to speculate on the origin of the possible dip in the exoplanet period distribution.

The onset of the stellar wind in young stars and the magnetic clearing of a hole at the centre of the disc will lead to the evacuation of the circumstellar disc and prevent migration of planets. This is expected to happen sooner in stars of higher mass and suggests that the exoplanets of stars with higher mass will lie at greater radii. So far the range of stellar masses yielding significant numbers of exoplanets is rather small and we find no clear difference in exoplanet properties for stars of different mass. Even without such evidence, migration theory does provide an attractive explanation for a range of exoplanet properties. Migration theory can already reasonably explain the progressively larger number of exoplanets at larger radii and with the inclusion of appropriate stopping mechanisms (e.g. Lin, Bodenhimer & Richardson 1996; Kuchner & Lecar 2002) may also be able to consistently produce the peak in the period distribution of short-period planets.

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REFERENCES

Armitage P.J., Livio M., Lubow S.H., Pringle J.E., 2002, MNRAS, 334, 248

Blundell J. et al., 2003, MNRAS, submitted

Butler R.P., Marcy G.W., Williams E., McCarthy C., Dosanjh P., Vogt S.S., 1996, PASP, 108, 500

Butler R.P., Tinney C.G., Marcy G.W., Jones H.R.A., Penny A.J., Apps K., 2001, ApJ, 555, 410

Butler R.P. et al., 2002a, ApJ, 578, 565

Butler R.P., Marcy G.W., Vogt S.S., Fischer D.A., Henry G.W., Laughlin G., Wright J., 2002b, ApJ, 582, 455

Butler R.P., Marcy G.W., Fischer D.A., Vogt S.S., Tinney C.G., Jones H.R.A., Penny A.J., Apps K., 2003, in Penny A., Artymowicz P., Lagrange A.-M., Russell S., eds, ASP Conf. Ser. Planetary Systems in the Universe. Astron. Soc. Pac., San Francisco, in press

Cayrel de Strobel G., Soubiran C., Friel E.D., Ralite N., Francois P., 1997, A&AS, 124, 299

Cumming A., Marcy G.W., Butler R.P., 1999, ApJ, 526, 896

di Benedetto G.P., 1998, A&A, 339, 858

Duquennoy A., Mayor M., 1991, A&A, 248, 485

ESA, 1997, ESA SP-1200, The *Hipparcos* and Tycho Catalogues. ESA Publications, Noordwijk

Favata F., Micela G., Sciortino S., 1996, A&A, 311, 951

Fischer D.A., Marcy G.W., Butler R.P., Laughlin G.P., Vogt S.S., 2002, ApJ, 564, 1028

Fuhrmann K., Pfeiffer M.J., Bernkopf J., 1998, A&A, 336, 942

Girardi L., Bressan A., Bertelli G., Chiosi C., 2000, A&AS, 141, 371

Gonzalez G., 1999, MNRAS, 308, 447

Heacox W.D., 1999, ApJ, 526, 928

Henry T.J., Soderblom D.R., Donahue R.A., Baliunas S.L., 1996, AJ, 111, 439

Houk N., 1978, Michigan Catalogue of two-dimensional spectral types for the HD stars, Department of Astronomy, Univ. Michigan, Univ. Microfilms International

Jones H.R.A., Butler R.P., Tinney C.G., Marcy G.W., Penny A.J., McCarthy C., Carter B.D., Pourbaix D., 2002a, MNRAS, 333, 871

Jones H.R.A., Butler R.P., Tinney C.G., Marcy G.W., Penny A.J., McCarthy C., Carter B.D., 2002b, MNRAS, 337, 1170

Kuchner N., Lecar M., 2002, ApJ, 574, 87

Lin D.N.C., Bodenhimer P., Richardson D.C., 1996, Nat, 380, 606 574, 87

Lin D.N.C., Papaloizou J.C.B., Terquem C., Bryden G., Ida S., 1999, in Manning V., Boss A., Russell S., Manning V., Boss A., Russell S., eds, Protostars and Planets IV. Univ. Arizona Press, Tucson, p. 1111

Lineweaver C.H., Grether D., 2002, Astrobiology, 2, 325

Murray N., Hansen B., Homan M., Tremaine S., 1998, Sci, 279, 69

Randich S., Gratton R., Pallavicini R., Pasquini L., Carretta E., 1999, A&A, 348, 487

Saar S.H., Fischer D., 2000, ApJ, 534, 105

Saar S.H., Butler R.P., Marcy G.W., 1998, ApJ, 498, 153

Tabachnik S., Tremaine S., 2002, MNRAS, 335, 151

Tinney C.G., Butler R.P., Marcy G.W., Jones H.R.A., Penny A.J., Vogt S.S., Apps K., Henry G.W., 2001, ApJ, 551, 507

Tinney C.G., Butler R.P., Marcy G.W., Jones H.R.A., Penny A.J., McCarthy C., Carter B.D., 2002a, ApJ, 571, 528

Tinney C.G., McCarthy C., Jones H.R.A., Butler R.P., Marcy G.W., Penny A.J., 2002b, MNRAS, 332, 759

Tinney C.G., Butler R.P., Marcy G.W., Jones H.R.A., Penny A.J., McCarthy C., Carter B.D., Bond J., 2003, ApJ, in press

Trilling D., Benz W., Guillot T., Lunine J.I., Hubbard W.B., Burrows A., 1998, ApJ, 500, 428

Trilling D., Lunine J.I., Benz W., 2002, A&A, 394, 241

Udry S. et al., 2000, A&A, 356, 590, 2000

Vogt S.S., Marcy G.W., Butler R.P., Apps K., 2000, ApJ, 536, 902

Ward W.R., 1997, ApJ, 482, 211

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