

Planetary companions around the K giant stars 11 Ursae Minoris and HD 32518[★]

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Received 22 January 2009 / Accepted 10 August 2009

ABSTRACT

Context. 11 UMi and HD 32518 belong to a sample of 62 K giant stars that has been observed since February 2004 using the 2m Alfred Jensch telescope of the Thüringer Landessternwarte (TLS) to measure precise radial velocities (RVs).

Aims. The aim of this survey is to investigate the dependence of planet formation on the mass of the host star by searching for planetary companions around intermediate-mass giants.

Methods. An iodine absorption cell was used to obtain accurate RVs for this study.

Results. Our measurements reveal that the RVs of 11 UMi show a periodic variation of 516.22 days with a semiamplitude of $K = 189.70 \text{ m s}^{-1}$. An orbital solution yields a mass function of $f(m) = (3.608 \pm 0.441) \times 10^{-7}$ solar masses (M_{\odot}) and an eccentricity of $e = 0.083 \pm 0.03$. The RV curve of HD 32518 shows sinusoidal variations with a period of 157.54 days and a semiamplitude of $K = 115.83 \text{ m s}^{-1}$. An orbital solution yields an eccentricity, $e = 0.008 \pm 0.03$ and a mass function, $f(m) = (2.199 \pm 0.235) \times 10^{-8} M_{\odot}$. The *HIPPARCOS* photometry as well as our $H\alpha$ core flux measurements reveal no variability with the RV period. Thus, Keplerian motion is the most likely explanation for the observed RV variations for both giant stars.

Conclusions. An exoplanet with a “minimum mass” of $m \sin i = 10.50 \pm 2.47$ Jupiter masses (M_{Jup}) orbits the K giant 11 UMi. The K1 III giant HD 32518 hosts a planetary companion with a “minimum mass” of $m \sin i = 3.04 \pm 0.68 M_{\text{Jup}}$ in a nearly circular orbit. These are the 4th and 5th planets published from this TLS survey.

Key words. stars: individual: 11 Ursae Minoris – stars: variables: general – stars: individual: HD 32518 – stars: late-type – techniques: radial velocities – stars: planetary systems

1. Introduction

To date around 350 exoplanets have been detected mostly via the RV technique. However, these surveys are giving us a very biased view of the process of planet formation because less than 10% of the planets orbit host stars with masses $> 1.25 M_{\odot}$. In the search for planets over a wider range of stellar masses an increasing number of RV searches are looking for planets around low- and intermediate-mass stars that have evolved off the main sequence (MS) and up the giant branch. Hatzes & Cochran (1993) found first indications of substellar companions around giants. The first extrasolar planet around the K giant HD 137759 (ι Dra) was discovered by Frink et al. (2002). Other exoplanets around HD 13189 and β Gem were detected by Hatzes et al. (2005, 2006). The last planet was independently announced by Reffert et al. (2006).

Starting in 1998 Setiawan et al. (2003a) began to search for planets around 83 giants with *FEROS*. This programme detected two giant exoplanets around HD 47536 (Setiawan et al. 2003b), one around HD 11977 (Setiawan et al. 2005), and more recently one around HD 110014 (de Medeiros et al. 2009). We started a similar survey in February 2004 (Döllinger 2008) monitoring a sample of 62 K giant stars using higher RV accuracy at TLS. During this survey planets around the K giants 4 UMa (Döllinger et al. 2007), 42 Dra and HD 139357 (Döllinger et al. 2009) were

discovered. In this paper we present precise stellar RVs for two other programme stars, 11 UMi and HD 32518, which most likely host extrasolar planets in almost circular orbits.

Moreover several other surveys are actively searching for planets around giant stars. Sato started in 2001 a precise Doppler survey of about 300 G–K giants (Sato et al. 2005) using a 1.88 m telescope at Okayama Astrophysical Observatory. From this survey planetary companions around HD 104985 (Sato et al. 2003), the Hyades giant ϵ Tau (Sato et al. 2007), 18 Del, ξ Aql, and HD 81688 (Sato et al. 2008) were detected. Furthermore, this survey discovered planetary companions around 14 And and 81 Cet (Sato et al. 2008). In the same paper the detection of exoplanets orbiting the subgiants 6 Lyn and HD 167042 were reported. Niedzielski et al. (2007) discovered an exoplanet to the K0 giant HD 17092 using observations taken with the Hobby-Eberly Telescope (*HET*) between 2004 January and 2007 March. Johnson et al. (2007) published exoplanets around the three intermediate-mass subgiants HD 192699, HD 210702, and HD 175541. Planetary companions around two other subgiants HD 167042 and HD 142091 were discovered monitoring a sample of 159 evolved stars at Lick and Keck Observatories for the past 3.5 years by Johnson et al. (2008).

Until now five main, yet preliminary results have emerged from the TLS survey:

- 1) giant planets around giants are fairly common (about 10%). This is in contrast to a frequency of $\approx 5\%$ for solar-type MS stars;

[★] Tables 2 and 5 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/505/1311>

- 2) planets around giant stars do not favour metal-rich stars (e.g. Pasquini et al. 2007; Hekker & Melendez 2007; Hekker et al. 2008; Takeda et al. 2008). A spectral analysis of the Tautenburg sample showed that the planet-hosting stars tend to be metal-poor (Döllinger 2008). This is in contrast to planet-hosting solar-type MS stars which tend to be metal-rich (e.g. Santos et al. 2004);
- 3) planets around giant stars tend to be super planets with masses of 3–10 M_{Jup} . For solar-type MS stars over half of the planets have masses less than 3 M_{Jup} . For giant stars (intermediate stellar mass) over half of the planets have masses more than 3–5 M_{Jup} ;
- 4) planets around giants have periods larger than ~ 150 days;
- 5) inner planets with orbital semimajor axes, $a \leq 0.7$ AU are not present (Johnson et al. 2007; Sato et al. 2008).

Giants are well suited to search for long-period planets around massive stars, but there are limitations on the possibility to detect short-period planets due to the fact that giants have large radii and they thus would have swallowed up any close-in planets. This region of the planetary orbital parameter space ($P < 20$ days) is thus inaccessible. In short, the results for planets around giant stars show different characteristics to those found around solar-type (and presumably less massive) MS stars.

2. Data acquisition and analysis

Observations are described in Döllinger et al. (2007) and summarised here: The data were acquired using the coude échelle spectrograph of the 2m Alfred Jensch telescope, with a resolving power of $R = 67\,000$. The wavelength coverage was 4700–7400 Å and the resulting signal-to-noise (S/N) ratio typically greater than 150. Standard CCD data reduction (bias-subtraction, flat-fielding and spectral extraction) was performed using *IRAF* routines. An iodine absorption cell placed in the optical path provided the wavelength reference for the velocity measurements.

The RVs were computed using standard procedures for measuring precise stellar RVs using an iodine absorption cell (see Butler et al. 1996; and Endl et al. 2006). Our spectral data was also used to derive important stellar parameters such as Fe abundance, surface gravity, and effective temperature. For these a high S/N stellar spectrum taken without the iodine cell was used. Stellar masses were derived using the online tool from Girardi (<http://stevoapd.inaf.it/cgi-bin/param>) which is based on theoretical isochrones (Girardi et al. 2000) and a modified version of Jørgensen & Lindegren’s (2005) method (see da Silva et al. 2006, for a description). In a forthcoming paper (Döllinger 2009) we will present in more detail the chemical analysis and stellar parameter determination of all stars in our programme including 11 UMi and HD 32518.

3. Results

3.1. 11 UMi

The stellar parameters of the K4 III star 11 UMi (= HD 136726=HR 5714 = HIP 74793) are summarised in Table 1. The stellar parameters like effective temperature, T_{eff} , Fe abundance, [Fe/H], logarithmic surface gravity, $\log g$, and microturbulent velocity, ξ were derived from our spectral observations. Some of them like the stellar mass and radius comes from the Girardi isochrones. All other quantities were obtained from the *SIMBAD* database.

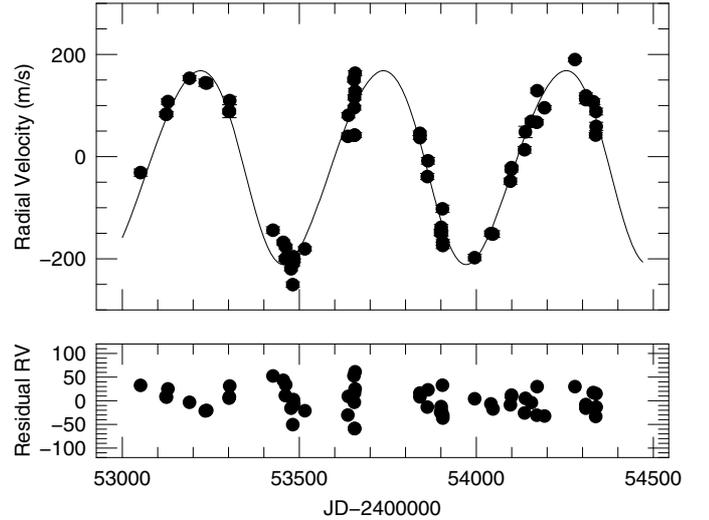


Fig. 1. (Radial velocity measurements for 11 UMi. The solid line is the orbital solution (top). RV residuals after subtracting the orbital solution (bottom).

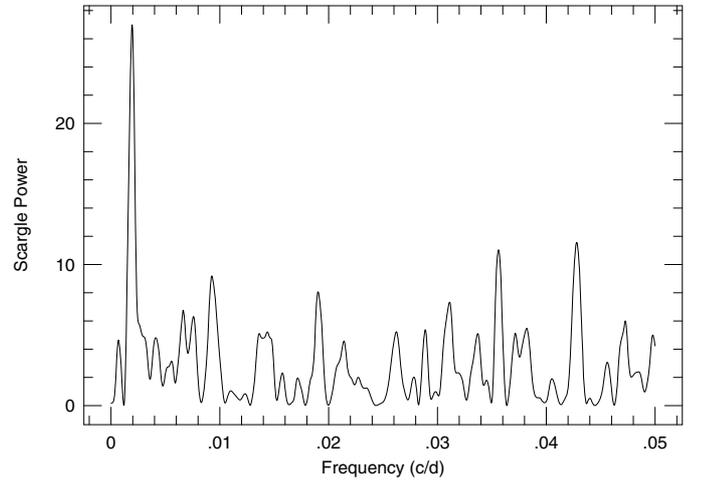


Fig. 2. Scargle periodogram for 11 UMi. The high peak at Scargle power ≈ 23 is at a frequency $\nu = 0.00194 \text{ c d}^{-1}$ corresponding to a period of 518.18 days.

A total of 58 spectra with the iodine cell were obtained for 11 UMi. These values are listed in Table 2. The time series of the corresponding RV measurements is shown in Fig. 1.

A Scargle periodogram (Scargle 1982) was used to get an estimate of the RV period that was used as an initial guess in the subsequent orbit fitting. Figure 2 shows the Scargle periodogram of the 11 UMi RV measurements. There is highly significant power (“False Alarm Probability”, $\text{FAP} \approx 10^{-10}$) at a frequency of $\nu = 0.00194 \text{ c d}^{-1}$ corresponding to a period of $P = 515$ days.

The parameters for the orbital solution to the RV data for 11 UMi are listed in Table 3. The orbital fit to the data is shown as a solid line in Fig. 1. The orbit is nearly circular. The phase folded data and solution are shown in Fig. 3. Using our derived stellar mass of $1.80 \pm 0.245 M_{\odot}$ results in a minimum mass, $m \sin i = 11.20 \pm 2.47 M_{\text{Jup}}$.

Figure 4 shows the periodogram of the RV residuals (see lower panel Fig. 1) after subtracting the orbital solution. There are no significant peaks present out to a frequency of 0.05 c d^{-1} . A periodogram analysis out to a higher frequency of 0.5 c d^{-1} also reveals no significant short-term variability that might be

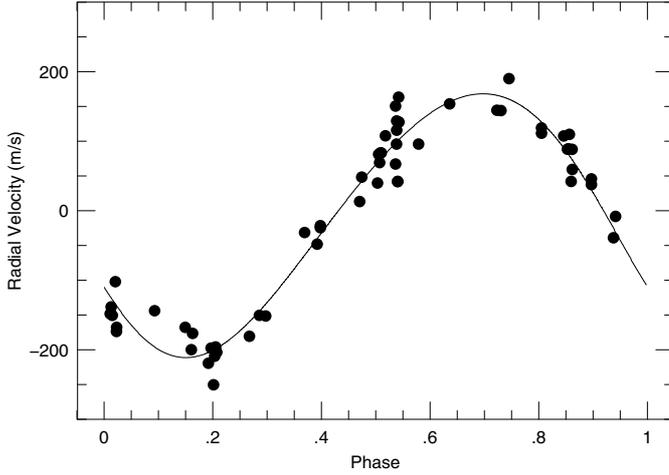


Fig. 3. Radial velocity measurements for 11 UMi phased to the orbital period.

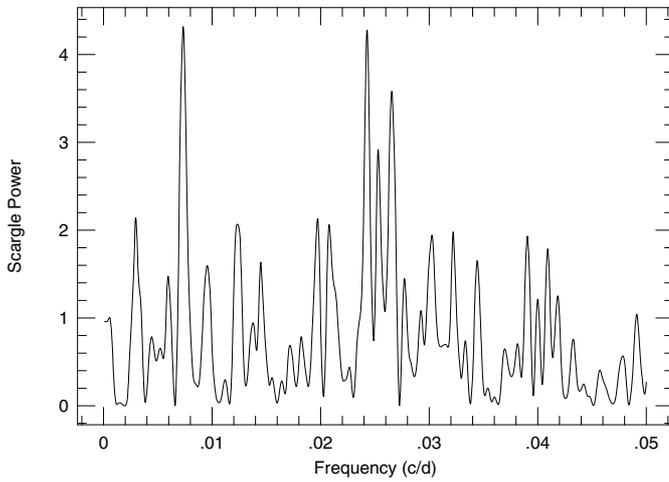


Fig. 4. Scargle periodogram of the RV residuals of 11 UMi. There are no significant peaks in the residual RVs.

due to oscillations. This result is not surprising since our sparse data sampling is inadequate for detecting such short-period variability.

The rms scatter of the RV measurements about the orbital solution is 28 m s^{-1} , or a factor of 5 greater than the estimated measurement error. This scatter most likely arises from stellar oscillations. We can use the scaling relations of Kjeldsen & Bedding (1995) for p-mode oscillations to estimate the velocity amplitude of such stellar oscillations. Their Eq. (7) and the stellar parameters listed in Table 1 results in a RV amplitude of 27 m s^{-1} , comparable to our observed scatter.

As with all giant stars we must be cautious about attributing any RV variability to planetary companions. Such observed variability can also arise from stellar surface structure as well. However, spots should produce variability in other quantities.

To test whether rotational modulation could account for the observed RV variability, we examined the *HIPPARCOS* photometry. Figure 5 shows the periodogram of the *HIPPARCOS* photometry after removing outliers and taking daily averages. There is no significant power at the observed orbital frequency. Figure 6 shows the *HIPPARCOS* photometry phase folded to the orbital period. There is no significant variability to a level of about 0.01 mag.

Table 1. Stellar parameters of 11 UMi.

Spectral type	K4III	<i>HIPPARCOS</i>
m_V	5.024 ± 0.005	[mag]
M_V	-0.37 ± 0.12	[mag]
$B - V$	1.395 ± 0.005	[mag]
Parallax	8.37 ± 0.46	[mas]
Distance	119.50 ± 6.60	[pc]
M_*^a	1.80 ± 0.25	$[M_\odot]$
R_*^a	24.08 ± 1.84	$[R_\odot]$
Age ^a	1.56 ± 0.54	[Gyr]
T_{eff}^a	4340 ± 70	[K]
$[\text{Fe}/\text{H}]^a$	$+0.04 \pm 0.04$	[dex]
$\log g^a$	1.60 ± 0.15	[dex]
micro turbulence ^a	1.6 ± 0.8	$[\text{km s}^{-1}]$

^a Döllinger (2008, 2009).

Table 3. Orbital parameters for the companion to 11 UMi.

Period[days]	516.22 ± 3.25
$T_{\text{periastron}}[\text{JD}]$	52861.04 ± 2.06
$K[\text{m s}^{-1}]$	189.70 ± 7.15
$\sigma(\text{O} - \text{C})[\text{m s}^{-1}]$	27.50
e	0.08 ± 0.03
$\omega[\text{deg}]$	117.63 ± 21.06
$f(m)[M_\odot]$	$(3.61 \pm 0.44) \times 10^{-7}$
$a[\text{AU}]$	1.54 ± 0.07

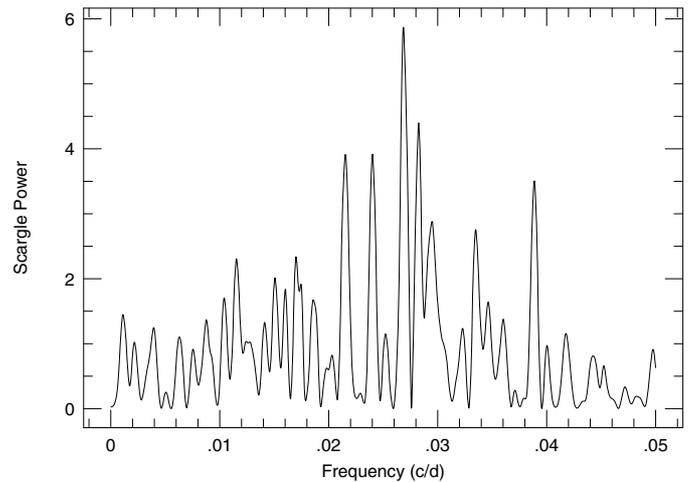


Fig. 5. Scargle periodogram of the *HIPPARCOS* photometry for 11 UMi.

As an additional test we looked for variations in the $\text{H}\alpha$, which can be an indicator of stellar activity. We measured the line strength using a band pass of $\pm 0.6 \text{ \AA}$ centered on the core of the line, and two additional ones at $\pm 50 \text{ \AA}$ that provided a measurement of the continuum level (see Döllinger 2008) for a more detailed description of how the $\text{H}\alpha$ was measured.

Figure 7 shows the Scargle periodogram of the $\text{H}\alpha$ variations. There is no significant peak at the orbital frequency. In addition, Fig. 8 shows the $\text{H}\alpha$ indices as a function of time. However, there is also no significant feature in Fig. 8.

The rotational period estimated by the projected rotational velocity, $v \sin i = 1.5 \text{ km s}^{-1}$ published by de Medeiros & Mayor (1999), and the stellar radius, R_* listed in Table 1, is $P_{\text{rot}} \leq 2\pi R_*/(v \sin i) \sim 813 \pm 61$ days, which is incompatible with the observed period of the planetary companion with a value of 516.22 days.

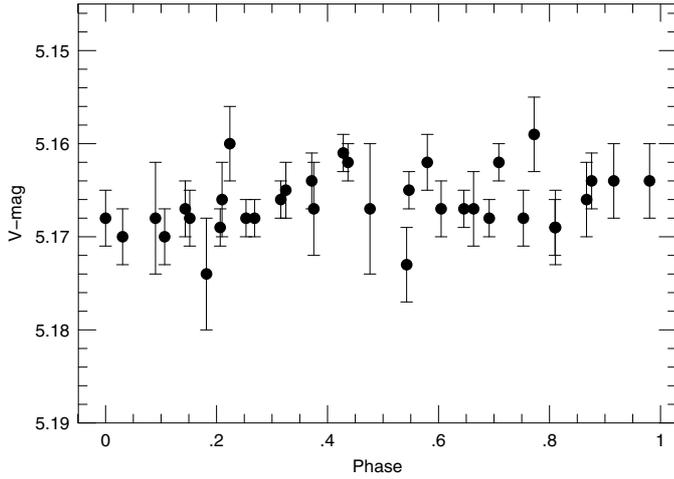


Fig. 6. *HIPPARCOS* photometry phased to the orbital period for 11 UMi.

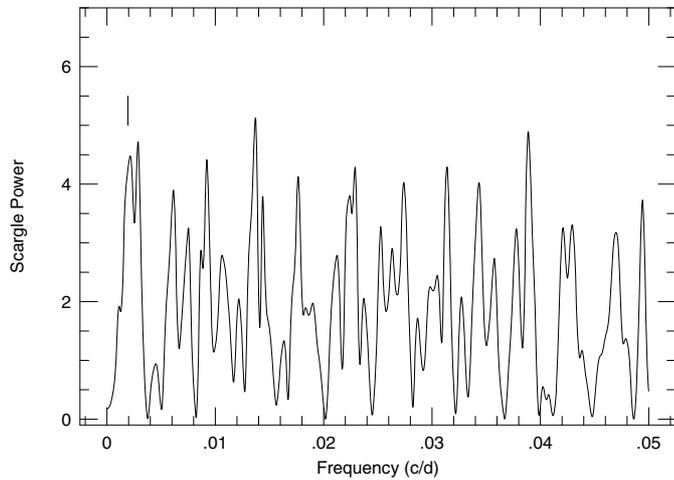


Fig. 7. Scargle periodogram of the 11 UMi $H\alpha$ variations. There are no significant frequencies in the data.

The lack of variability of photometric and $H\alpha$ data along with the exclusion of rotational modulation due to the incompatibility of orbital and rotational period strongly suggests that the RV variations are due to Keplerian motion of a companion.

3.2. HD 32518

The stellar parameters for the K1 III giant HD 32518 (=HR 1636 = HIP 24003) are listed in Table 4.

A total of 58 observations for this star were made with the iodine cell. These are listed in Table 5. The top panel of Fig. 9 shows the time series of the RV measurements. The Scargle periodogram of the RV measurements is shown in Fig. 10. There is a significant power with $FAP \approx 10^{-9}$ at a frequency of $\nu = 0.00634 \text{ c d}^{-1}$ corresponding to a period $P = 157$ days.

An orbital solution to the RV data yields a period, $P = 157.54 \pm 0.38$ days and a circular orbit, $e = 0.008 \pm 0.032$. The orbital solution is shown as a line in Fig. 9. All of the orbital parameters are listed in Table 6. Figure 11 shows the RV variations phase-folded to the orbital period.

Our stellar mass estimate of $1.13 \pm 0.18 M_{\odot}$ for HD 32518 results in a minimum companion mass of $3.04 \pm 0.68 M_{\text{Jup}}$.

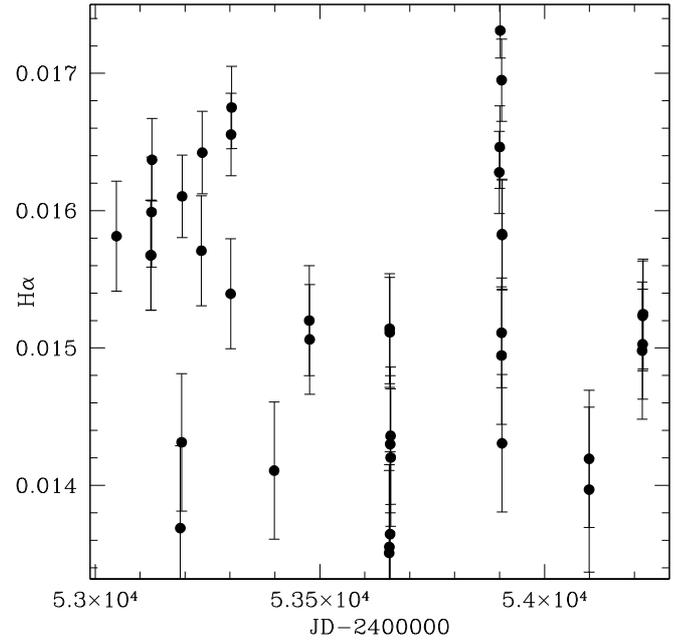


Fig. 8. $H\alpha$ indices of 11 UMi as a function of time which show no significant feature.

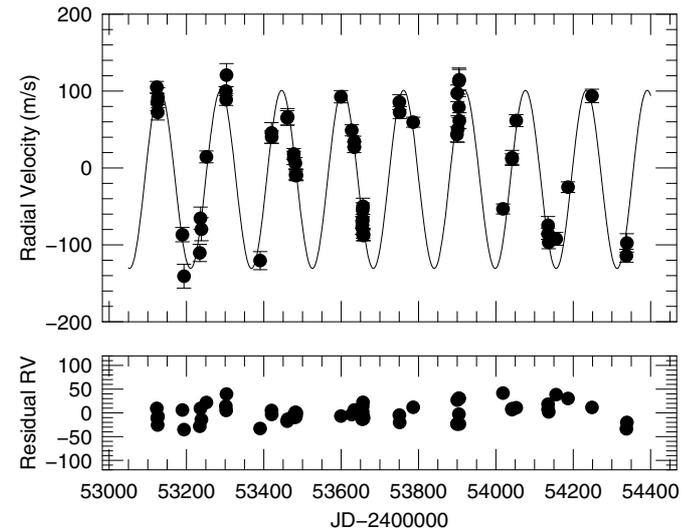


Fig. 9. Radial velocity measurements for HD 32518. The solid line represents the orbital solution (*top*). RV residuals after subtracting the orbital solution (*bottom*).

Table 4. Stellar parameters of HD 32518.

Spectral type	K1III	HIPPARCOS
m_V	6.436 ± 0.005	[mag]
M_V	1.08 ± 0.20	[mag]
$B - V$	1.107 ± 0.005	[mag]
Parallax	8.52 ± 0.78	[mas]
Distance	117.40 ± 10.70	[pc]
M_*^a	1.13 ± 0.18	$[M_{\odot}]$
R_*^a	10.22 ± 0.87	$[R_{\odot}]$
Age ^a	5.83 ± 2.58	[Gyr]
T_{eff}^a	4580 ± 70	[K]
$[\text{Fe}/\text{H}]^a$	-0.15 ± 0.04	[dex]
$\log g^a$	2.10 ± 0.15	[dex]
micro turbulence ^a	1.2 ± 0.8	$[\text{km s}^{-1}]$

^a Döllinger (2008, 2009).

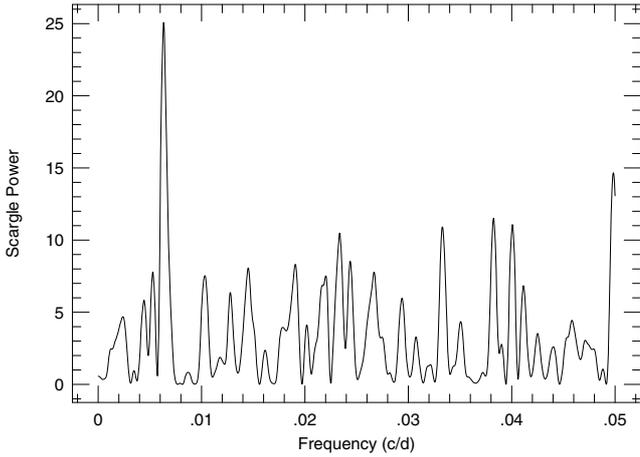


Fig. 10. Scargle periodogram for HD 32518. The high peak at a frequency of $\nu = 0.00634 \text{ c d}^{-1}$ corresponds to a period of 157.73 days.

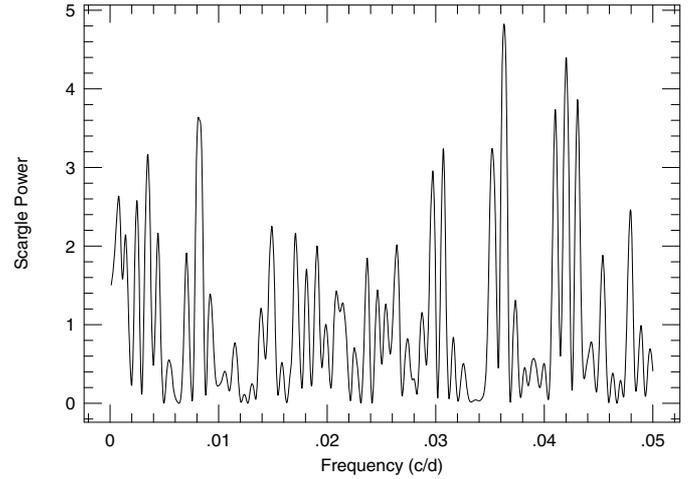


Fig. 12. Scargle periodogram of the RV residuals of HD 32518. There is no significant peak in the RV residuals.

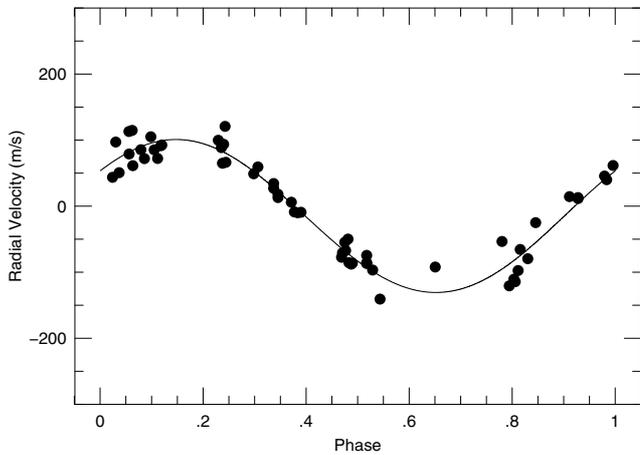


Fig. 11. Radial velocity measurements for HD 32518 phased to the orbital period. The line represents the orbital solution.

Once again, the rms scatter of about 18 m s^{-1} can largely be explained by stellar oscillations. Using the Kjeldsen & Bedding (1995) scaling relations results in a RV amplitude of about 27 m s^{-1} for the predicted stellar oscillations in HD 32518.

Figure 12 shows the periodogram of the RV residuals (lower panel of Fig. 9) after subtracting the orbital solution. There are no significant peaks present out to a frequency of 0.05 c d^{-1} . An extension of the periodogram out to higher frequencies (0.5 c d^{-1}) also reveals no additional periodic RV variations.

To determine the nature of the RV variations, we again examined the *HIPPARCOS* photometry (see Fig. 13) and our $H\alpha$ measurements. Figure 14 shows the Scargle periodogram of the daily averages of the *HIPPARCOS* photometry with outliers removed. There are no significant peaks near the orbital frequency marked by the vertical line.

The Scargle periodogram of the $H\alpha$ variability is shown in Fig. 15. There is no significant peak at the orbital frequency. Figure 16 shows the $H\alpha$ indices of HD 32518 as a function of time.

From the projected rotational velocity, $v \sin i = 1.2 \text{ km s}^{-1}$ published by de Medeiros & Mayor (1999), and the adopted stellar radius (see Table 4) we have estimated the upper limit of the rotational period. This calculated value of 430 ± 40 days is different from the orbital period (see Table 6).

Table 6. Orbital parameters for the companion to HD 32518.

Period[days]	157.54 ± 0.38
$T_{\text{periastron}}$ [JD]	52950.29 ± 13.66
K [m s^{-1}]	115.83 ± 4.67
$\sigma(\text{O} - \text{C})$ [m s^{-1}]	18.33
e	0.01 ± 0.03
ω [deg]	306.11 ± 126.71
$f(m)$ [M_{\odot}]	$(2.20 \pm 0.24) \times 10^{-8}$
a [AU]	0.59 ± 0.03

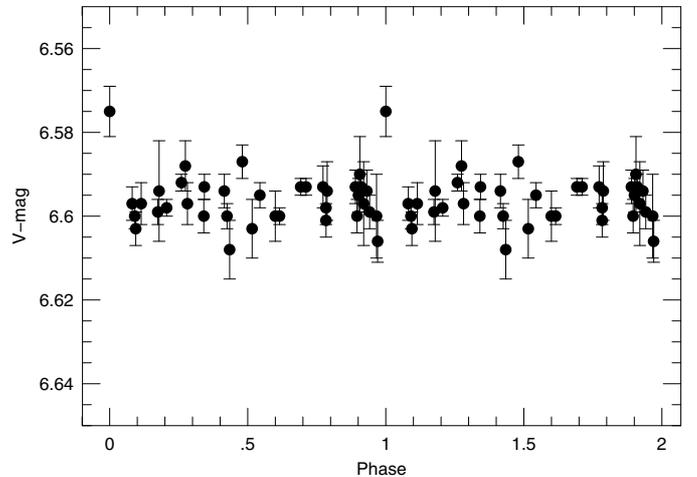


Fig. 13. *HIPPARCOS* photometry for HD 32518 phased to the orbital period.

The lack of photometric and $H\alpha$ variability with the RV period and the different rotational period suggests that the RV variations for this star are due to a planetary companion.

4. Discussion

Since the discovery of 51 Peg b in 1995, we know about the presence of exoplanets around solar-type stars. In the meantime the detected number of extrasolar planets has increased tremendously. At the moment more than 350 have been discovered mostly using the RV method which is currently the method of choice for planet-hunting.

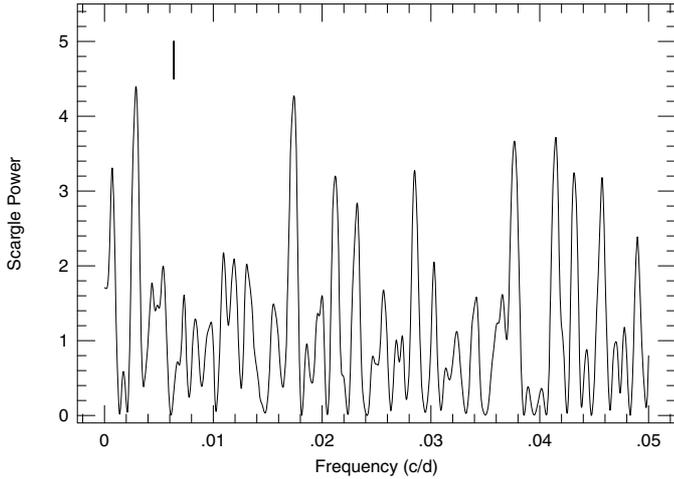


Fig. 14. Scargle periodogram of the *HIPPARCOS* photometry for HD 32518. The vertical line marks the orbital frequency. The *HIPPARCOS* photometry shows no significant peak at this frequency.

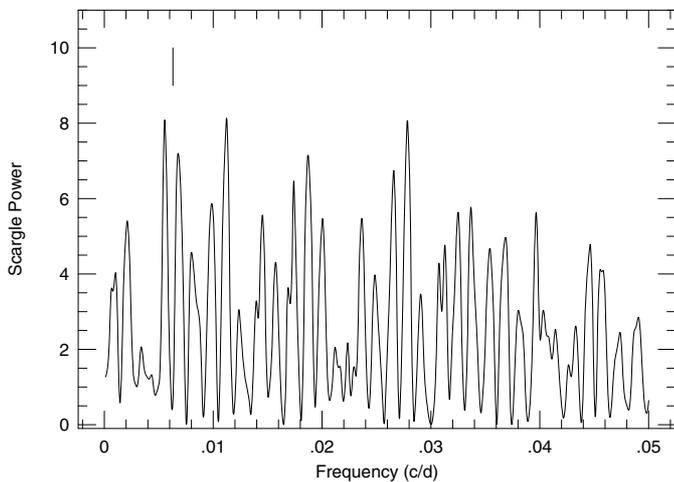


Fig. 15. Scargle periodogram of HD 32518 $H\alpha$ variations. The vertical line marks again the orbital frequency. The $H\alpha$ variations show no significant peak at the orbital frequency of the planetary companion.

In the past solar-type MS stars were favoured targets for planet searches, and consequently most of the published planets orbit this type of host star. Very famous in this context are the so-called “hot Jupiters”, Jupiter-like planets which are in very close orbits around their parent stars. Their existence was a big surprise and is still a puzzle. In contrast to MS stars this kind of exoplanet will normally not be present around evolved stars with their enlarged envelope because the planetary companions would be swallowed up. Therefore planets around giants have periods larger than ~ 150 days with exception of ξ Aql (Sato et al. 2008) which shows an orbital period of 136.75 days.

The planet of HD 32518 with a period of 157.24 days is slightly above this limit. HD 32518 b and 11 UMi b have a nearly circular orbit. In this case the variations in the RV curves can be mimicked by surface structures like starspots. However, the lack of variability in the *HIPPARCOS* and the $H\alpha$ data for both giants is more consistent with the planet hypothesis. We caution the reader that the *HIPPARCOS* photometry was not simultaneous with our RV measurements. Thus, we cannot exclude that spots were not present when *HIPPARCOS* observed these stars, but are present now and are causing the RV variations. However,

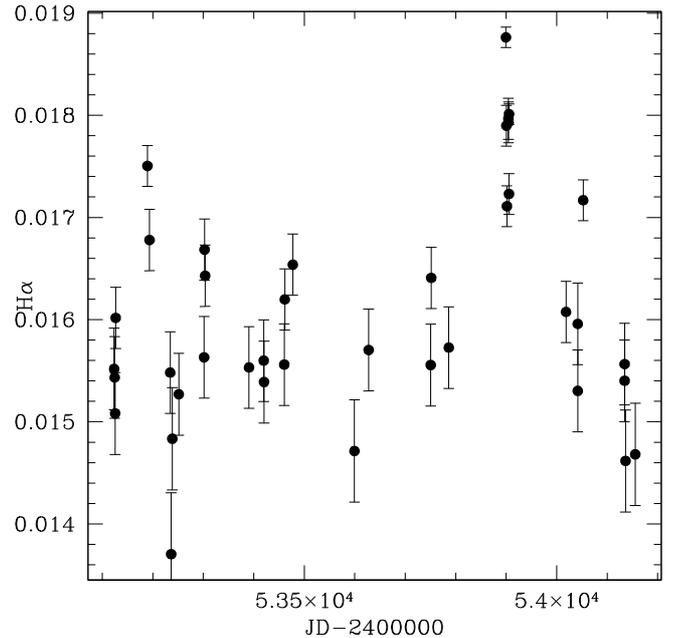


Fig. 16. $H\alpha$ indices of HD 32518 as a function of time.

our $H\alpha$ measurements were made simultaneously to the RV data. We therefore believe that the detected periods of several hundred days in both stars are not due to rotational modulation, but rather to planetary companions.

During the *TLS* programme we have found at least 6 planetary companion candidates. This corresponds to an occurrence rate of around 10% for giant stars, which is in opposite to around 5% for MS stars. More recently 3 additional objects are found, which would bring the percentage to 15%. This higher frequency of planet occurrence around evolved stars seems to be consistent with recent theoretical predictions. Kennedy & Kenyon (2008) used semi-analytical disk models to show that the probability of a star having at least one giant planet rises linearly from 0.4 to 3 M_{\odot} . They predict that the frequency of giant planets is about 10% for 1.5 M_{\odot} stars, consistent with our initial estimate.

11 UMi has a nearly solar metal abundance, $[Fe/H] = +0.04 \pm 0.04$ dex while HD 32518 is slightly metal-poor with a value of -0.15 ± 0.04 dex. However, both stars are relatively “metal-poor” compared to previous results of planet-hosting MS stars which tend to be metal-rich (Santos et al. 2004), but of higher abundance compared to other planet-hosting giant stars which tend to be metal-poor (Schuler et al. 2005; Pasquini et al. 2007).

Our stellar mass determinations indicate that the MS progenitor to HD 32518 was most likely a late F-type star. More interesting is 11 UMi whose stellar mass suggests a progenitor that was an early A-type star. Intriguingly, the more massive star of the two has the more massive substellar companion ($m \sin i = 10.5 M_{Jup}$ compared to 3.04 M_{Jup}). This is consistent with the observed trend that more massive stars tend to have more massive planets, but more statistics are needed to confirm this. Comparing the results of other searches for planets around giant stars Johnson et al. (2007) as well as Lovis & Mayor (2007) also found that more massive stars seem to harbour more massive planetary systems (see their Fig. 11). A possible explanation for this behaviour can maybe delivered by model predictions (Laughlin et al. 2004; Ida & Lin 2005). According to them giant planet formation depends on the mass and surface density of

the protoplanetary disc besides the metallicity. For these parameters the mass of the star plays a key role in the sense that more massive stars will have more massive disks and higher surface densities, which enables to accrete larger amounts of material.

Acknowledgements. We are grateful to the user support group of the Alfred Jensch telescope: B. Fuhrmann, J. Haupt, Chr. Högner, U. Laux, M. Pluto, J. Schiller, and J. Winkler. This research made use of the *SIMBAD* database, operated at CDS, Strasbourg, France.

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