Astronomy & Astrophysics manuscript no. 2850 April 3, 2005
(DOI: will be inserted by hand later)

A giant planet around the massive giant star HD 13189*

A.P. Hatzes[1], E.W. Guenther[1], M. Endl[2], W.D. Cochran[2], M.P. Döllinger[3], and A. Bedalov[4]

[1] Thüringer Landessternwarte Tautenburg, Sternwarte 5, D-07778 Tautenburg, Germany
[2] McDonald Observatory, The University of Texas at Austin, Austin, TX 78712
[3] European Southern Observatory, Karl-Schwarzschild-Straße 2, D-85748 Garching bei München, Germany
[4] Astrophysikalisches Institut und Universitäts-Sternwarte Jena, Schillergäßchen, 2-3, D-07745, Germany

Received; accepted

Abstract. Most extrasolar planet discoveries using radial velocity measurements have been for solar-like G-stars. In order to understand better the role stellar mass for the formation of planets we must learn more about the frequency of planetary companions around both high- and low-mass stars. Radial velocity searches for planets around high mass main-sequence stars are difficult due to the paucity of lines and often rapid rotation of these early-type stars. On the other hand, evolved stars that have moved off the main sequence offer us the possibility of searching for planets around higher mass stars by means of precise radial velocity measurements. Here we present radial velocity measurements for the star HD 13189 using measurements taken at the Thüringer Landessternwarte Tautenburg, the Harlan J. Smith Telescope at McDonald Observatory, and the Hobby-Eberly Telescope. We classify the spectral type of this star as K2 with luminosity class II. The radial velocity measurements show long-period variations with a period of 472 days and an amplitude of 173 $\mathrm{m\,s^{-1}}$. The Ca II S-index is consistent with an inactive star and this shows no variations with the radial velocity period. We also investigated possible changes in the line shapes by measuring spectral line bisectors. These show no variations with the radial velocity period. We interpret the 472-day period as being caused by a sub-stellar companion. Based on the estimated absolute magnitude and a comparison to evolutionary tracks we estimate the mass of the progenitor star between 2 and 7 $M_\odot$ which results in a projected mass of the companion of $m \sin i = 8 - 20\ M_J$. HD 13189 may be the most massive star known to possess an extrasolar planet. This suggests that the formation of giant planets can also occur around early-type stars. HD 13189 also shows significant short term radial velocity variability on time scales of days that is most likely due to stellar oscillations. This behavior is typical for K giant stars.

Key words. individual star: HD13189, binaries, radial velocity monitoring

1. Introduction

Precise measurements of the radial velocity (RV) of stars have lead to the discovery of more than 100 extrasolar planets. While the exact processes that leads to the formation of planets are still being investigated, there is a general agreement that planets are formed from the circumstellar disk in the early stages of the evolution. Two different scenarios have been proposed: disk instability and core-accretion. In the disk instability picture (e.g. Boss 1997; Mayer et al. 2002), gravitational instabilities of a sufficiently massive disk causes it to fragment into clumps out of which planets form. The process is presumably very fast, but possibly does not allow the formation of planets with mass $\leq 1\ M_J$. In the core-accretion scenario (e.g. Wuchterl et al. 2000) the coagulation of dust grains ultimately leads to the formation of planetesimals that collide with one another to form planetary cores. When a core reaches a critical mass of about 10 M_{Earth}, gas around the protoplanet quickly accretes onto it forming a giant planet. This mechanism was thought to be quite slow with a time scale for the formation of giant planets possibly exceeding the disk-life time (Pollack et al. 1996). However, recent work suggests that planet formation in a few million years is possible if one includes migration, disk evolution, and gap formation (Alibert et al. 2004). Planets can form ten times faster by letting the cores migrate to new "feeding grounds". The fact that frequency of planets is higher for metal rich stars than for metal poor stars can be taken

Send offprint requests to: Artie Hatzes, e-mail: `artie@tls-tautenburg.de`

∗ Based on observations obtained at the 2-m-Alfred Jensch telescope at the Thüringer Landessternwarte Tautenburg, the Harlan J. Smith 2.7m telescope of McDonald Observatory, and the Hobby-Eberly Telescope (HET). The HET is a joint project of the University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maximilians-Universität München and Georg-August-Universität Göttingen.

as evidence for the core-accretion scenario (Santos et al. 2004, Kornet et al. 2005).

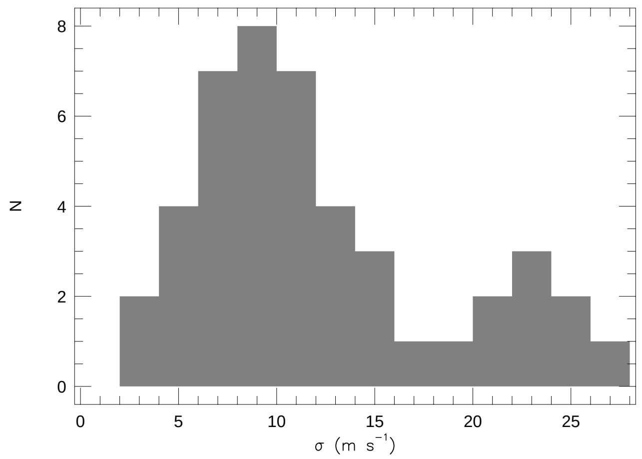

Fig. 1. Histogram of the standard deviations (σ) of RV measurements for stars in the TLS sample. The σ was computed after removing any obvious long term trends in the data that were due to stellar or substellar companions.

It is still not known how this picture changes with the mass of the central object. In the context of the disk instability model, the crucial parameter is the disk-to-stellar mass ratio. Since more massive stars presumably have a more massive disk, the planet frequency should not strongly depend on the mass of the star. For the core accretion scenario Laughlin et al. (2004) argue that for a star of 0.4 $M_{\odot}$ the surface density of the disk is so low that the formation of massive planets is not possible. A few surveys for planets around M-stars have now begun and these may provide an answer to this question (Endl et al. 2003). Planets of 0.6 M_J and 1.9 M_J orbiting the M4V-star Gl 876 have already been found (Marcy et al. 1998; Delfosse et al. 1998). However, even in these programs most of the stars are early M-stars, and an M0V-star still has 0.5 $M_{\odot}$. Thus, the influence of the mass of the central object on planet formation would have to be dramatic in order to produce the so-far null results found for M-dwarf surveys. Guenther & Wuchterl (2003) initiated a survey for detecting planets of very-low-mass stars and brown dwarfs but found only one object showed significant RV-variations that might be caused by an orbiting planet. Additional observations are needed to establish if these variations are indeed caused by a planet or not.

Detecting planets of high mass main-sequence stars is difficult because at spectral types earlier than about F6V the stars tend to have high rotation rates and few spectral features. One possibility is simply to observe more massive stars after they have evolved from the main sequence stars when they have lower effective temperatures (i.e. more spectral lines) and slower rotation rates. However, giant stars often show RV-variations due to oscillations and it is difficult to estimate the mass of these evolved stars. Nevertheless, precise RV-measurements of giant stars are relatively easy and may provide us with knowledge about planets around more massive stars.

Three planets around giant stars have already been found. Frink et al. (2002) reported the detection of a planet with $m \sin i$ = 8.9 M_J orbiting the K2III star ι Dra (M = 1.05 $M_{\odot}$). Sato et al. (2003) discovered a planet with $m \sin i$ = 6.3 to 9.6 M_J orbiting the G9III star HD 104985 (M = 1.5 to 3.0 $M_{\odot}$). Substellar companions have been discovered around HD 47536 ($m \sin i$ = 5.0-9.7 M_J, Setiawan et al. 2003), and HD 11977 ($m \sin i$ = 2.5–3 M_J, Setiawan et al. 2005). Here we report on the detection of a planet orbiting a giant star of luminosity class II.

2. Observations

In 2001 the Thüringer Landessternwarte Tautenburg (TLS) started a program to search for extrasolar planets using precise stellar radial velocity (RV) measurements. The goal of the Tautenburg Observatory Planet Search (TOPS) program was to contribute to our knowledge of extrasolar planets by extending planet searches to classes of objects typically not covered by other programs such as young active stars and stars more massive than G-type stars. HD 13189 was one of the stars monitored.

Precise radial velocity measurements for the TOPS program are made using the high resolution coude echelle spectrometer of the Alfred-Jensch 2m telescope and an iodine absorption cell placed in the optical path. The echelle spectrometer has a resolving power R ($\lambda/\Delta\lambda$) = 67,000 and a choice of three different grisms provides the cross-dispersion for different wavelength regions. The RV program uses the so-called VISUAL grism that covers the wavelength region 4630–7370 Å. The spectrometer sits in a temperature stabilized room in the cellar of the observatory and is fed using a train of 5 flat mirrors. The spectrometer itself has few moving parts and the CCD detector is dedicated to the instrument and is thus never moved. All of these factors should result in excellent RV precision.

Precise stellar radial velocities are achieved by using a temperature regulated iodine absorption cell placed in the optical path of the telescope. Iodine has suitable absorption lines in the wavelength range 5000–6000 Å, ideally placed for the VISUAL grism. The RV analysis takes into account possible temporal and spatial changes in the instrumental profile (Valenti et al. 1995, Butler et al. 1996, Endl et al. 2000).

Figure 1 shows the rms scatter (σ) of our RV measurements for 45 of our target stars. Half of our current sample of stars consists of young active stars which show large intrinsic RV variations due to activity "jitter". These

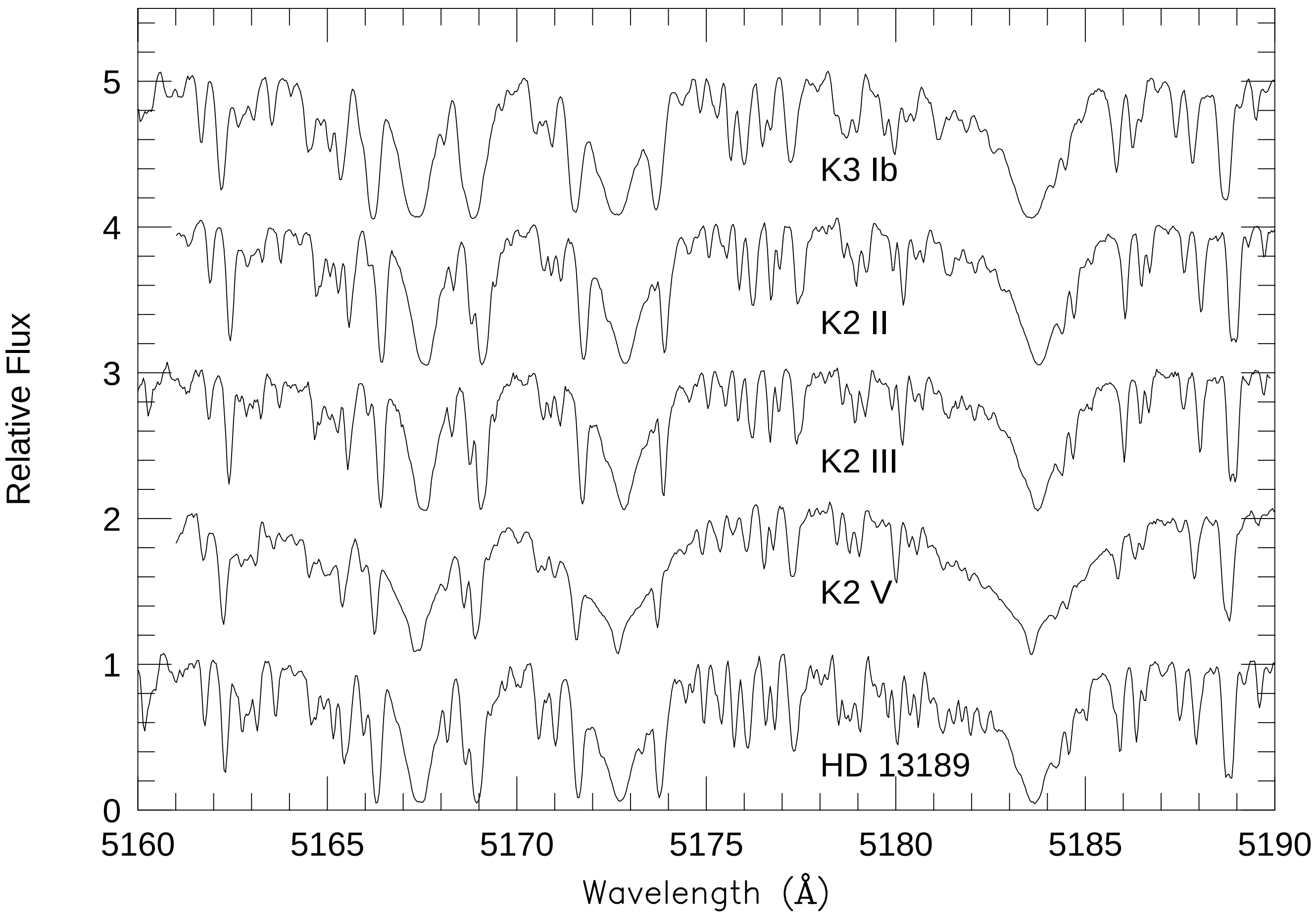

Fig. 2. The spectral region of HD 13189 around 5170 Å (bottom) compared to K-type stars of luminosity class I–V. The strong absorption features are the Mg I lines at 5167.3 Å, 5172.3 Å, and 5183.6 Å.

were excluded from Fig. 1 as we are interested in assessing the working RV precision of our survey separate from any intrinsic variability of the stars. In computing the σ obvious long-term trends in the data due to stellar and possibly sub-stellar companions were removed. In a few instances we monitored stars with known extrasolar planets. For these the σ was computed after subtracting the orbital solution.

The peak of the distribution is at 9 $\mathrm{m\,s^{-1}}$. About half of the sample (47%) shows RV scatter less than 10 $\mathrm{m\,s^{-1}}$. Our most constant stars (13% of the sample) have rms scatter less than 5 $\mathrm{m\,s^{-1}}$. The precision of the TOPS program is thus comparable to other RV planet search programs.

Sixty-eight observations were made of HD 13189 at TLS between June 2001 and October 2004. Once it became apparent that this star showed significant RV variations it was added to the McDonald Observatory Planet Search Program. A total of 13 observations of this star were made at McDonald Observatory using the 2.7m Harlan J. Smith Telescope (HJS). The details of the instrumental setup and data reduction can be found in Hatzes et al. (2000).

An additional 16 observations of HD 13189 were made between November 2003 and December 2004 using the High Resolution Spectrograph (HRS) of the Hobby-Eberly Telescope (HET). The details of the instrumental setup and data reduction for these can be found in Cochran et al. (2004).

3. The properties of HD 13189

HD 13189 has a visual magnitude of $V = 7.57$ and is classified in SIMBAD as K2-star, but with an unknown luminosity class. The upper limit to the Hipparcos parallax is 0.54 ± 0.93 mas and this implies an absolute magnitude brighter than −1.6 mag. Since a K2III-star has M_v = −0.11, HD 13189 must have luminosity class I or II.

To determine a more precise spectral type of HD 13189 spectra were acquired at TLS of K-type stars spanning a range of luminosity classes. Figure 2 shows the spectral region centered on the Mg I lines at 5167.3 Å, 5172.3 Å, and 5183.6 Å for HD 13189 and four K-type stars of luminosity class Ib, II, III, and V.

The spectrum of HD 13189 seems most similar to the that of the K2 III or II star. The Mg I lines of the supergiant star are clearly broader in the core than the same features for HD 13189. We can be confident that HD 13189 is not a supergiant. The spectrum of the K2 III also seems to be consistent with that of HD 13189. Based on the stellar spectrum we cannot exclude the possibility that this star has luminosity class III. However, a luminosity class II is more consistent with our Hipparcos-based estimate of the absolute magnitude. We therefore conclude that HD 13189 is most likely a K2 II star.

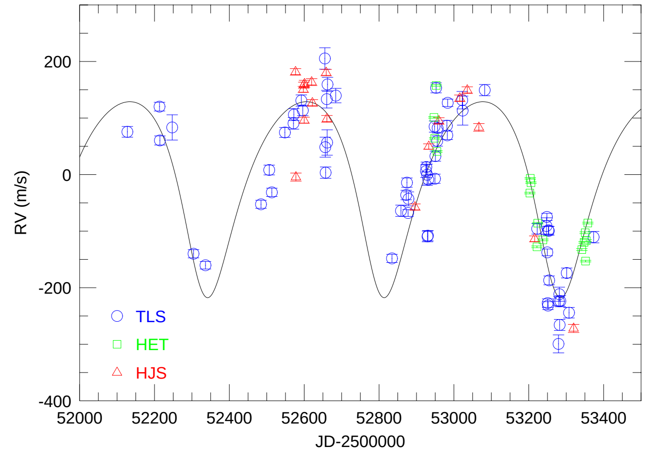

Fig. 3. The radial velocity measurements for HD 13189 from TLS (circles), the Harlan J. Smith Telescope (HJS) of McDonald Observatory (triangles), and the Hobby-Eberly Telescope (HET, squares). The solid line represents the orbital solution.

4. Radial velocity Variations

4.1. Long-period Variability

Figure 3 shows the time series of the RV measurements from TLS, the HJS telescope, and the HET. Each data set has its own zero point offset that was determined by the orbit fitting procedure described below. There is an obvious long-period variations as well as significant variations that occur on much smaller time scales.

Figure 4 shows the Lomb-Scargle periodogram (Lomb 1976, Scargle 1982) of the TLS only, and TLS + McDonald HJS measurements, and the full data set. There is significant peak at a frequency near ν = 0.002 c d^{-1} (Period ∼ 500 d) whose power significantly increases upon adding each data set. The false alarm probability (FAP) of the TLS data only, using expressions in Scargle (1982), is FAP ≈ 2×10^{-10}. The FAP was also estimated using the bootstrap randomization technique (Murdoch et al. 1993; Kürster et al. 1997). The measured RV values were randomly shuffled keeping the observed times fixed. A periodogram was then computed. The fraction of the random periodograms having power higher than the data periodogram in the range $0.0005 < \nu < 0.05$ c d^{-1} is the false alarm probability that noise would create the detected signal. After 2×10^5 "shuffles" there was no instance where the random periodogram had more Lomb-Scargle power. The bootstrap randomization procedure confirms the very low FAP of the detected signal.

An orbital solution was made to the combined data sets. This is also shown in Fig. 3. Since each data set has its own zero point offset these were varied until the best least-squares fit to the measurements was achieved. These individual zero points in the velocity were subtracted from each data set before plotting in Fig. 3. The orbital parameters are listed in Table 1. Fig. 5 shows all the RV data phased to the orbital period.

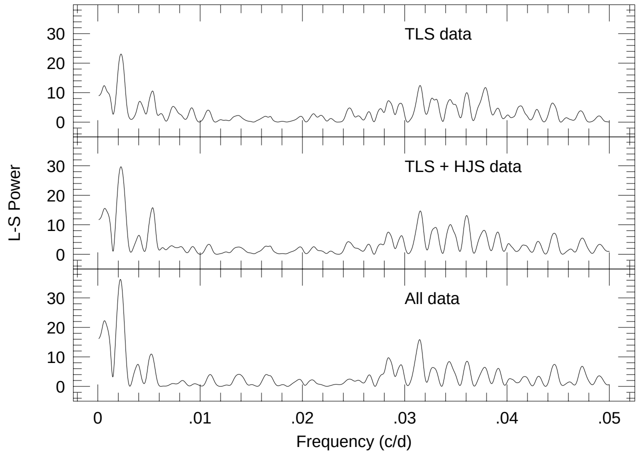

Fig. 4. Lomb-Scargle Periodogram of the RV measurements for HD 13189 for the TLS only data (top panel), the TLS + HJS data (bottom panel), and the combined data sets. The Lomb-Scargle (L-S) power is in arbitrary units that are a measure of the statistical significance of the peak.

Parameter	Value
Period [days]	471.6 ± 6.0
$T_{periastron}$ [JD]	52327.9 ± 20.2
K [m s^{-1}]	173.3 ± 9.8
e	0.27 ± 0.06
ω [deg]	160.7 ± 12.0
$f(m)$ [solar masses]	(2.26 ± 0.37) $\times 10^{-7}$
rms_{TLS} [m s^{-1}]	57.2
rms_{McD} [m s^{-1}]	54.5
rms_{HET} [m s^{-1}]	41.9

Table 1. Orbital Parameters for Companion to HD 13189

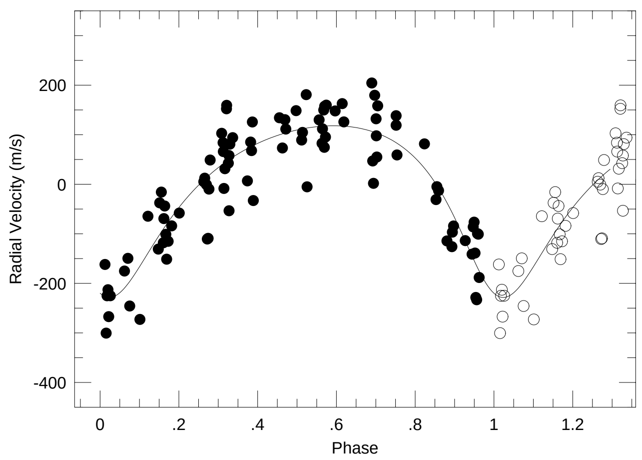

Fig. 5. The combined RV measurements for HD 13189 phased to the orbital period. The solid line is the orbital solution. Open circles represent repeated points plotted for the second cycle.

4.2. Short-term Variability

All data sets have a large rms scatter about the orbital solution (Table 1) that is about a factor of 10 higher than the expected RV precision for our measurements. HD 13189 is clearly an intrinsic variable on time scales much shorter than the orbital period of the presumed planetary companion. A periodogram analysis of the residual RV measurements after subtracting the orbital solution revealed no significant periods in the frequency range $0.01 < \nu < 1.0$ c d^{-1}.

We suspect that HD 13189 exhibits short-term variations that are periodic, but that do not persist for the entire time span of our observations. Figure 6 shows the RV measurements of HD 13189 taken at TLS over 8 consecutive nights. There is clear evidence of periodic variability. The solid line represents a least squares sine fit

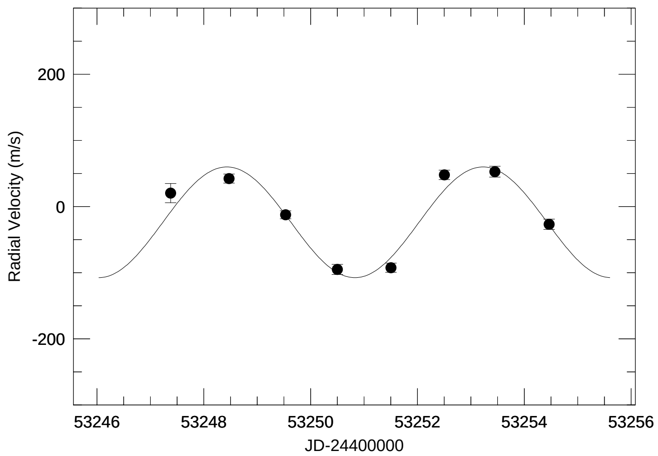

Fig. 6. RV measurements of HD 13189 make on eight consecutive nights on the TLS 2m telescope. The curve represents a least-squares sine fit with a period of 4.79 days and a full amplitude (K) of 168 m s^{-1}.

with a period of 4.8 days and a peak-to-peak amplitude of 168 m s^{-1}. Since no significant power was found at ≈ 0.2 c d^{-1} in the periodogram of the RV residuals such short period variability may indeed be short-lived. A more detailed analysis of the short term variability for this star will be presented in a future paper.

5. The Nature of the RV Variations

The giant status of HD 13189 forces us to be cautious in interpreting the RV variations in HD 13189. Rotational modulation by surface features or pulsations could also cause periodic RV variability. The former is particularly worrisome since the rotation periods of giant stars are of order several hundreds of days. Furthermore, long period variations seem to be a common occurrence among giant stars. Hatzes & Cochran (1993) found long-period RV variability in Arcturus (231 days), Aldebaran (654 d), and β Gem (554 d). A 613-d period was found in the RV variations of the K giant π Her by Hatzes & Cochran (1999). The nature of the long-period variations in these stars is still not known.

Many giant stars also show other forms of variability with the RV period which casts doubt on the companion hypothesis. Lambert (1987) found a 233-day variation in the equivalent width of Arcturus. Larson et al. (1993) found marginal variability in the equivalent width of Ca II 8662 line in β Gem with the RV period. On the other hand Aldebaran showed no variations in the spectral line shapes with the RV period which supports the companion hypothesis (Hatzes & Cochran 1998a).

5.1. Ca II S-index variations

A search for variations in activity indicators may help establish if the radial velocity variations are due to rotational modulation. Setiawan (private communication) has found at least one instance where the Ca II K emission varied in step with the radial velocity measurements. In another giant star, HD 47536, the lack of significant Ca II K variations was strong evidence that the 712-day RV period was due to a sub-stellar companion (Setiawan et al. 2003). The instrumental setup of the McDonald data simultaneously records the Ca II H & K emission lines. Although these data are much sparser than the TLS data, they have adequate phase coverage to enable us to search for variations of Ca II emission with the orbital period.

The mean McDonald S-index (SMcD) for HD 13189 is 0.164 (see §2.3 in Paulson et al. 2002 for a detailed description of how the McDonald S-index for the Ca II K line core emission is obtained). HD 13189 is not a particularly active star having a comparable emission level to the well-known inactive star τ Ceti (SMcD = 0.166±0.008). Figure 7 shows the Lomb-Scargle periodogram of the McDonald S-index measurements. One measurement had a value of SMcD = 0.228 which is about 2σ higher than the mean value. This may be an indication of short term chromospheric activity, but because of the larger error bar this measurement could still be consistent with the others made at this orbital phase. This measurement was not included in the periodogram analysis. There is no power at the orbital frequency shown by the vertical line.

Figure 8 shows the S-index measurements phased to the orbital period (including the outlyer excluded from the periodogram analysis). There are no convincing sinusoidal variations with an amplitude above the measurement error. Figure 9 shows the S-index plotted versus the RV value. The two quantities are clearly uncorrelated. The correlation coefficient, excluding the outlyer, is −0.0245 with the probability of 0.93 that the two quantities are uncorrelated. The McDonald S-index measurements do not support rotational modulation as a cause for the RV variations.

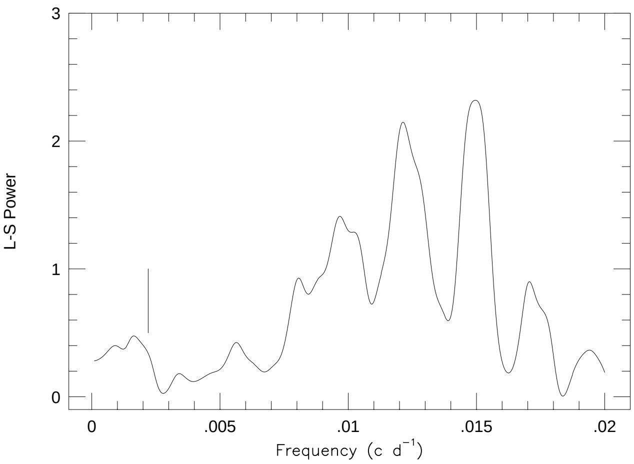

Fig. 7. The Lomb-Scargle periodogram of the McDonald Ca II S-index measurements. The vertical line marks the orbital frequency.

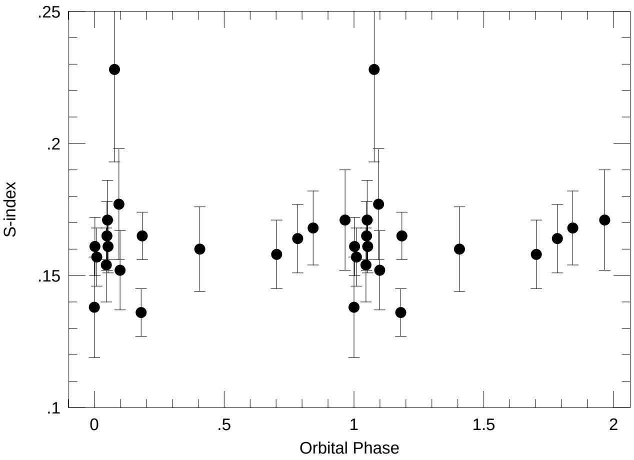

Fig. 8. The McDonald S-index measurements phased to the orbital period.

5.2. Spectral Line Bisector Variations

Radial velocity variations caused by surface features or nonradial pulsations should be accompanied by variations in the shapes of the spectral line profiles. On the other hand, a companion should not produce changes in the shapes of the spectral lines. The analysis of the shapes of spectral lines via line bisectors has proved to be an effective technique for confirming that RV variations are due to substellar companions. The lack of spectral line bisectors variations helped to confirm the companion nature of the RV variations of the main sequence stars 51 Peg (Hatzes, Cochran & Johns-Krull 1997; Hatzes, Cochran, & Bakker 1998) and τ Boo (Hatzes & Cochran 1998b) and the giant stars HD 47536 (Setiawan et al. 2003) and possibly Aldebaran (Hatzes & Cochran 1998a). Line bisector variations helped establish that surface features were the cause of the RV variations in the main sequence star HD 166435 (Queloz et al. 2001) and the K giant HD 78647 (Setiawan et al. 2004).

To search for variations in the spectral line shapes, line bisectors were computed for 8 strong, unblended spectral features with wavelengths longer than about 6500 Å.

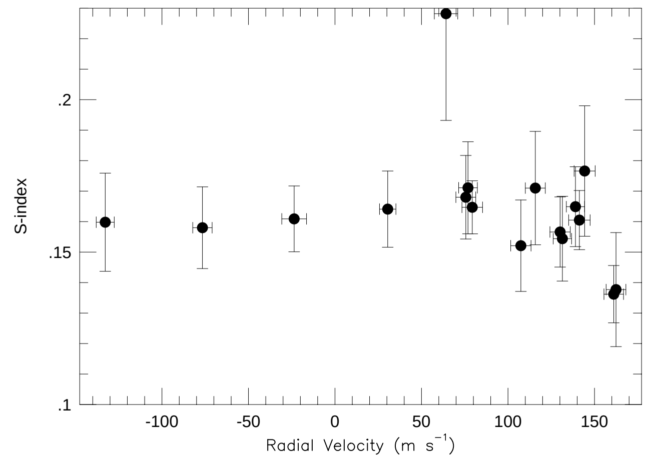

Fig. 9. The S-index measurements versus RV measurements from the McDonald data.

The TLS iodine cell has negligible absorption lines beyond 6600 Å so these should not affect our bisector measurements. For our bisector measurements we chose the spectral lines Ni I 6643.7, Ca I 6717.7, Ti I 6742.6, Fe I 6750.2, Ni I 6767.8, Co I 6770.0. Two bisector quantities were measured: the velocity span which is the velocity difference between two endpoints of the bisector and the curvature which is the difference of the velocity span of the upper half of the bisector minus the lower half. We examined both quantities because it is possible for a star to show variations in one quantity but not the other. For our span measurements we chose a flux levels of 0.52 and 0.85 of the continuum. These avoided the cores and wings of the spectral lines where the error of the bisector measurements are large. The average velocity span and curvature was computed using the bisector measurements of all 8 spectral lines after subtracting the mean value for each spectral line.

Figure 10 shows the Lomb-Scargle periodogram of our bisector measurements. There are no significant variations at the orbital frequency. Figure 11 shows the phase-binned averages of the bisector span and velocity measurements phased to the orbital period. The error bars represent the mean rms scatter of the bisector measurements used in the phase-binned average. There are no obvious sinusoidal variations in either quantity. The least squares sine-fit to the span measurements yields an amplitude of 40.5 ± 24.1 m s^{-1}. This value is reduced to 31.4 ± 21.3 m s^{-1} when one eliminates the point with the large error bar at phase 0.98.

A least squares fit to the curvature measurements amplitude yields an amplitude of 20.5 ± 5.5 m s^{-1}. To the eye there does seem to be a hint of sinusoidal variations in the bisector curvature; however, this is largely driven by the point with the large error. Indeed, after eliminating this point the least-squares amplitude is reduced to 12.0 ± 10.2 m s^{-1}. We conclude that to within the errors the bisector span and curvature measurements are consistent with no variations with the orbital period. There are most certainly short term variations in the bisector quantities and the larger scatter of the span measurements probably indicate a higher intrinsic variability of this quantity

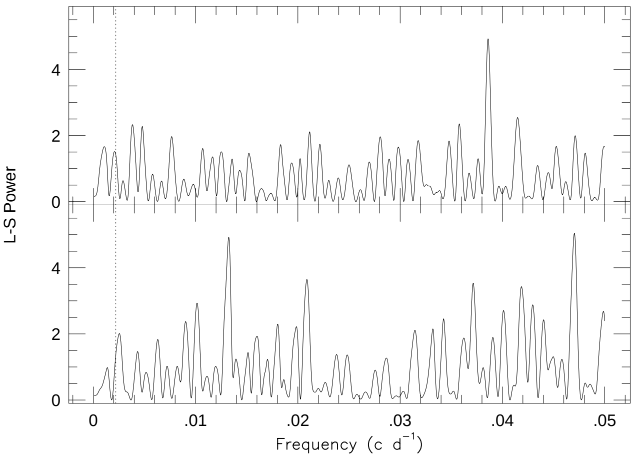

Fig. 10. Lomb-Scargle periodogram of the mean bisector span (top) and curvature (bottom) measurements. The vertical dashed line marks the location of the orbital frequency.

5.3. Hipparcos Photometry

The Hipparcos photometry for HD 13189 was also analyzed to see if variations with the 472-day period was present. Figure 12 shows the Lomb-Scargle periodogram of the Hipparcos photometry. There is no power at the orbital frequency. A sine fit to the photometry using the orbital period yields an amplitude of 3.03 ± 3.12 mmag for any long term photometric variations of HD 13189 during the Hipparcos measurements. We caution the reader that the Hipparcos measurements were not contemporaneous to our RV measurements. It could be that during the Hipparcos mission that HD 13189 also exhibited no RV variations. However, if the long period RV variations for HD 13189 prove to be long-lived then they seem to not be accompanied with photometric variability.

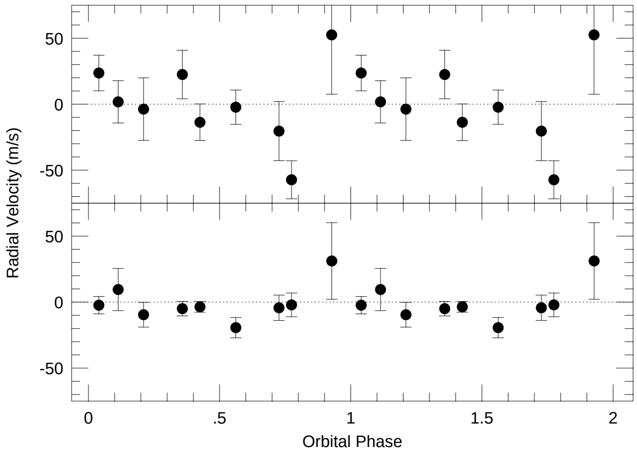

Fig. 11. The phase-binned averages of the bisector span (top) and curvature measurements (bottom) phased to the orbital period.

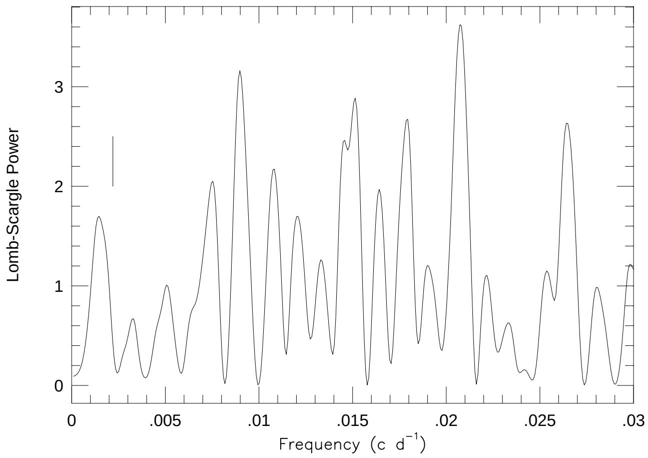

Fig. 12. Lomb-Scargle Periodogram of the Hipparcos photometry for HD 13189. The vertical line marks the orbital frequency.

6. Discussion

There is no question that a 472-day periodic signal is present in our RV measurements for the K2 II star HD 13189. The false alarm probability for this signal is extremely low (ll 10^{-6}) and measurements made with three different telescopes are consistent with its presence. The signal is real, the only debate concerns the nature of these variations. We have carefully examined all ancillary data available to us: Ca II S-index, spectral line bisectors, and Hipparcos photometry (albeit this is not contemporaneous with our measurements). None of these shows convincing variations with the RV period. At face value this supports the hypothesis that the long-period variations are due to the presence of a companion.

Could these long period variations still be due to cool spots? We think that this is unlikely. Hatzes (2002) using numerical simulations derived expressions relating the RV and bisector variations to the spot filling factor on the stellar surface, all as functions of the projected rotational velocity of the star.

Using the TLS spectra we measured the projected rotational velocity, $v \sin i$, for HD 13189 using 6 spectral lines. Each spectral line was fit using a disk integration scheme that included the contribution of macroturbulence. A macroturbulent velocity of 6 km s^{-1} was adopted. This is comparable to values measured for K-type stars with luminosity class II (Smith & Dominy 1979; Gray & Toner 1986; Gray 1992). The mean value for the measured $v \sin i$ was 2.4 $\pm$ 0.5 km s^{-1}. We note that at such a low projected rotational velocity there is a trade-off between rotational and macroturbulent velocities. Decreasing the macroturbulent velocity to zero requires a rotational velocity of $\approx$ 4 km s^{-1} to fit the line widths. Likewise, decreasing the rotational velocity to zero requires a macroturbulent velocity $\approx$ 8 km s^{-1} to match the line width. In both extremes the fits to the line profiles were not as good when using our nominal values for $v \sin i$ and the macroturbulent velocity.

Such a low $v \sin i$ requires a very large filling factor to produce the observed RV K-amplitude with spots. Using the expressions in Hatzes (2002) this filling factor is approximately 10%. This is not supported by the Hipparcos photometry. Since the Hipparcos photometry were acquired several years before our measurements were made we cannot exclude the possibility that spots were not present on this star during the Hipparcos mission. However, such a large spot filling factor is not supported by the Ca II S-index measurements that show this star to be relatively inactive and with S-index variability that is uncorrelated with the RV variations. It is difficult to reconcile the requirement of a high spot filling factor needed to produce the RV variations with the apparent lack of any significant chromospheric activity.

Although the apparent lack of bisector variability seems to exclude the presence of a spots, this result is not conclusive given the low rotational velocity of the star. According to the expressions of Hatzes (2002) a spot filling factor of 10% should produce bisector span variations with an amplitude of about 20 m s^{-1}, lower than the rms scatter of the phase-binned span measurements (σ = 50 m s^{-1}). We note, however, that due to the very low v sin i for HD 13189 it would take very large surface structures to produce the observed RV amplitude of 173 m s^{-1}.

Of course we cannot exclude the possibility that the RV variations could be due to surface structure of an unknown nature. After all, we have very little knowledge about the surface structure on K giant stars. One possibility is that such surface structure is in the form of "macroturbulence spots", regions on the star where the macroturbulent velocity due to convection is reduced, possibly due to weak magnetic fields. These spots would also produce observed RV variations, but with a lack of significant photometric and Ca II variations in this star. Hatzes & Cochran (2000) in their study of the RV variations in the low-amplitude Cepheid-type star Polaris, investigated whether macroturbulent spots could explain the variations of the residual RVs for this star after subtracting the contribution due to the pulsation. They considered spots that had a macroturbulent velocity of zero compared to the "photospheric value" of 8 $\mathrm{km\,s^{-1}}$. Such spots could produce a maximum RV amplitude of 150 $\mathrm{m\,s^{-1}}$ but these were accompanied with bisector span variations with approximately the same amplitude. It is unlikely that macroturbulent spots could produce as high an RV amplitude in HD 13189. The rotational velocity of Polaris is 13 $\mathrm{km\,s^{-1}}$, considerably larger than for HD 13189 and this results in an "amplification effect" for the spectral line distortions. The same spot features on HD 13189 with its much narrower lines would produce a much smaller RV amplitude. Any such macroturbulent spots on HD 13189 must have a much higher velocity difference than Polaris as well as a very large filling factor. The line profiles of HD 13189 were well fit using a macroturbulent velocity of 6 $\mathrm{km\,s^{-1}}$. Attempts to model the line profiles of HD 13189 with higher values of the macroturbulent velocity produced noticeably poorer fits. Furthermore, the measured macroturbulent velocity of HD 13189 did not vary with time. We conclude that it is unlikely that the observed long-period variations are due to macroturbulent velocity spots.

The companion hypothesis for the long-period RV variations in HD 13189 is reasonable. After all, sub-stellar companions have been found around other the K giants. In the case of ι Dra the planet hypothesis was accepted mostly on the basis of the highly eccentric orbit. It is reasonable to expect that not all sub-stellar companions to K giants are in highly eccentric orbits. The presence of short-term, high amplitude, often periodic variability in many K giant stars is also well established. It is therefore reasonable to expect that some K giants showing this short term variability could also possess sub-stellar companions. We thus cannot use the presence of the short term variability in HD 13189 to cast doubt on the companion hypothesis.

It is difficult to estimate the companion mass owing to the uncertainty in the mass of the central star. Using the nominal Hipparcos parallax results in a luminosity of HD 13189 of $log\ L/L_{\odot} = 3.6$. The evolutionary tracks of Girardi et al. (1996) imply a progenitor mass anywhere between 2 and 7 $M_{\odot}$. This yields a companion mass between about 8 and 20 M_J and a semi-major axis between 1.5 and 2.2 AU. Clearly if HD 13189 has a companion it is sub-stellar in nature.

The short-term variations in HD 13189 are most likely due to p-mode oscillations. It is unlikely that these are due to rotational modulation since observations of this star taken on 8 consecutive nights show a periodic variations with an approximately 4.8 day period. The very low $v \sin i$ makes it highly unlikely that this is due to rotational modulation. Both the time scales ($\sim$ days) and the RV amplitudes ($\sim 100\ \mathrm{m\,s^{-1}}$) are comparable to those found for the p-mode oscillations in Arcturus (Hatzes & Cochran 1994). The fact that no significant period is found in the residual RVs for HD 13189, yet on successive nights this star shows clear short term periodic variations implies that either the pulsations are short-lived, or there are several modes beating against one another which masks the detection of any periods in the full data set. Data with better temporal resolution is needed to distinguish between these two hypotheses. If this star indeed shows many pulsation modes then this opens the possibility of using asteroseismic techniques to derive the stellar mass. We are continuing to monitor this star in order to derive the oscillation spectrum.

Although the present evidence favors the companion hypothesis for the long term RV variability for HD 13189, this evidence is still not unequivocal. Additional evidence can put this hypothesis on firmer ground. These include: 1) Continued monitoring to show that the long period RV variations are long-lived and coherent. Any change in the amplitude and phase of the variability will immediately exclude the companion hypothesis. 2) Photometric measurements to establish that no light variations accompany the 472-day period. The Hipparcos photometry excludes this, but these measurements were made several years before our RV measurements. Contemporaneous photometric measurements would be useful. 3) Line bisector measurements made at high resolution. The very low $v \sin i$ for this star implies that any line bisector variability due to surface structure may have a very low amplitude. Our bisector measurements used spectral data taken at a resolving power of 67,000. If the bisector variations have an amplitude of order of several $\mathrm{m\,s^{-1}}$ then these may require measurements made with $R = 100{,}000$–$200{,}000$.

Since the main sequence progenitor star of K giants are often early-type stars, K giants represent a unique opportunity to probe planet formation around higher mass stars. Radial velocity measurements for main sequence stars earlier than about spectral type F6 are not particularly suited for finding sub-stellar companions for these stars. Early-type stars rotate much faster and have fewer spectral lines. When these stars are evolved K giants they have much lower effective temperatures and rotate slowly. There are two problems associated with planet searches around K giants. First the stellar masses are poorly determined. If one can place the star accurately in the H-R diagram then one could use evolutionary tracks, but these are model dependent. If one can find stellar oscillations in the K giants, then these might also be used to get mass estimates.

The second problem is that K giant stars show large intrinsic RV variability on short-time scales and have expected rotation periods of several hundreds of days. Extracting a possible planet RV signal from a star that is pulsating is more difficult, and when we do that signal may just be rotational modulation disguised as a planet. Choosing only "constant" K giants for RV planet searches may introduce biases in the sample. Likewise, using orbital characteristics, e.g. eccentricity to choose the companion hypothesis as the cause of long period variability would also introduce a severe bias in the orbital properties of planets around evolved stars. Giant stars may be an effective means of studying planet formation around high mass stars, but their confirmation requires an investigation of other possible forms of variability (e.g. Ca II emission, line shapes, and light variations).

In summary, our precise RV measurements for HD 13189 have established the presence of variations with a 472 day period. These RV variations are not accompanied by variability in Ca II emission, line shapes, or photometry. A companion is the most probable explanation for these RV variations. From our spectral observations for this star we were able to classify its spectral type as K2 II. Due to the uncertainty in the mass of the central star the companion mass can range from 8–20 M_J with a semi-major axis of 1.5–2.2 AU. With an estimated progenitor mass of 2–7 $M_\odot$ HD 13189 may be the most massive star to host a giant extrasolar planet.

Acknowledgements. We are grateful to the user support group of the Alfred-Jensch telescope: B. Fuhrmann, J. Haupt, Chr. Högner, M. Pluto, J. Schiller, and J. Winkler. ME and WDC acknowledge the support of NASA grant NNG04G141G. This research made use of the SIMBAD database, operated at CDS, Strasbourg, France. The Hobby-Eberly Telescope (HET) is a joint project of the University of Texas at Austin, the Pennsylvania State University, Stanford University, Ludwig-Maximilians-Universität München, and Georg-August-Universität Göttingen. The HET is named in honor of its principal benefactors, William P. Hobby and Robert E. Eberly.

References

Alibert, Y., Mordasini, C., & Benz, W. 2004, A&A, 417, L25,
Boss, A.P. 1997, Science, 276, 1836
Butler, R. P., Marcy, G.W., Williams, E., McCarthy, C., Dosanjh, P., & Vogt, S.S., 1996, PASP 108, 500
Cochran, W.D. and 15 co-authors, 2004, ApJ, 611, L133.
Delfosse, X., Forveille, T., Mayor, M., Perrier, C., Naef, D., & Queloz, D. 1998, A&A 338, L67
Endl, M., Kürster, M., & Els, S. 2000, A&A, 362, 585
Endl, M., Cochran, W.D., Tull, R.G., & MacQueen, P.J. 2003, AJ, 126, 3099
Frink, S., Mitchell, D.S., Quirrenbach, A., Fischer, D.A., Marcy, G.W., & Butler, R.P. 2002, ApJ 576, 478
Girardi, L., Bressan, A., Chiosi, C., Bertelli, G., & Nasi, E. 1996, A&AS, 117, 113
Gray, D.F. & Toner, C.G. 1986, 310, 277
Gray, D.F. 1992, *The Observation and Analysis of Stellar Photospheres*, Cambridge Astrophysics Series, Cambridge, Cambridge University Press.
Guenther, E.W. & Wuchterl, G. 2003, A&A 401, 677
Hatzes, A.P. & Cochran, W.D. 1993, ApJ, 413, 339
Hatzes A. P., & Cochran, W. D. 1994, ApJ, 422, 366
Hatzes, A.P., Cochran, W.D., & Johns-Krull, C.M. 1997, ApJ, 478, 374
Hatzes, A.P., Cochran, W.D., & Bakker, E.J. 1998, Nature, 391, 154
Hatzes, A.P., & Cochran, W.D. 1998a, MNRAS, 293, 469
Hatzes, A. P., & Cochran, W. D. 1998b, ApJ, 502, 944
Hatzes, A.P., & Cochran, W.D. 1999, MNRAS, 304, 109
Hatzes, A.P., & Cochran, W.D. 2000, AJ, 120, 979
Hatzes, A. P., and 13 co-authors, 2000, ApJ, 544, L145
Hatzes, A.P. 2002, AN, 323, 392
Kornet, K., Bodenheimer, P., Różyczka, & Stepinski, T.F., A&A, in press
Kürster, M., Schmitt, J.H.M.M., Cutispoto, G. & Dennerl, K. 1997, A&A, 320, 831
Lambert, D.L. 1987, ApJS, 65, 255
Larson, A.M., Irwin, A.W., Yang, S.L.S., Goodenough, C., Walker, G.A.H., Walker, A.R., & Bohlender, D.A. 1993, PASP, 105, 332
Laughlin, G., Bodenheimer, P., & Adams, F.C., 2004, ApJ, 612, L73
Lomb, N.R. 1976, Ap&SS, 39, 477
Marcy, G.W., Butler, R.P., Vogt, S.S., Fischer, D., & Lissauer, J.J. 1998, ApJ 505, L147
Mayer, L., Quinn, Th., Wadsley, J., & Stadel, J. 2002, Science 298, 1756
Murdoch, K.A., Hearnshaw, J.B., & Clark, M. 1993, ApJ, 413, 349
Paulson, D. B., Saar, S. H., Cochran, W. D., & Hatzes, A. P. 2002, AJ, 124, 572
Pollack, J.B., Hubickyj, O., Bodenheimer, P., Lissauer, J.J., Podolak, M., & Greenzweig, Y. 1996, Icarus 165, 428
Queloz, D., Henry, W., Sivan, J. P., et al. 2001, A&A, 379, 279
Santos, N. C., Israelian, G., Mayor, M. 2004, A&A 415, 1153
Sato, B., Ando, H., Kambe, E., Takeda, Y., Izumiura, H., Masuda, S., Watanabe, E., Noguchi, K., Wada, S., et al. 2003, ApJ 597, L157
Scargle, J.D. 1982, ApJ, 263, 835
Setiawan, J., Pasquini, L., da Silva, L., Hatzes, A. P., von der Lühe, O., Girardi, L., de Medeiros, J.R. & Guenther, E. 2004, A&A, 421, 241
Setiawan, J., Hatzes, A. P., von der Lühe, O., Pasquini, L., Naef, D., da Silva, L., Udry, S., Queloz, D., Girardi, L. 2003, A&A 398, L19
Setiawan, J., Rodman, J., da Silva, L., Hatzes, A.P., Pasquini, L., von der Lühe, Medeiros, J.R., & Döllinger, M.P. 2005, A&A, submitted.
Smith, M.A. & Dominy, J.F. 1979, ApJ, 231, 477
Valenti, J.A., Butler, R.P., & Marcy, G.W., 1995, PASP 107, 966
Wuchterl, G., Guillot, T., & Lissauer, J. J. 2000, Protostars and Planets IV, 1081