Publications of the Astronomical Society of the Pacific, **114**:529–535, 2002 May

Planetary Companions to HD 136118, HD 50554, and HD 106252[1]

Debra A. Fischer,[2] Geoffrey W. Marcy,[2] R. Paul Butler,[3] Steven S. Vogt,[4] Bernie Walp,[2] and Kevin Apps[5]
Received 2002 February 2; accepted 2002 February 8; published 2002 March 25

ABSTRACT. Precise Doppler observations at Lick Observatory have revealed a substellar companion orbiting the F9 V star HD 136118 with an orbital period $P = 1209 \pm 24$ days, velocity semiamplitude $K = 212 \pm 6$ m s^{-1}, and eccentricity of 0.37 ± 0.025. The assumed stellar mass of 1.24 $M_\odot$ yields a Keplerian companion with $M \sin i = 11.9$ M_J and semimajor axis of 2.3 AU. We also confirm the orbital solutions for two previously announced planets, one orbiting the F8 V star HD 50554 and one orbiting the G0 V star HD 106252. Our orbital solution for HD 50554 yields $P = 1254 \pm 34$ days, $K = 78.5 \pm 6.7$ m s^{-1}, and $e = 0.51 \pm 0.06$. The assumed stellar mass of 1.065 $M_\odot$ implies a companion mass $M \sin i = 3.7$ M_J and semimajor axis of 2.2 AU. For HD 106252, we find $P = 1503.3 \pm 62$ days, $K = 150.9 \pm 25$ m s^{-1}, and eccentricity $e = 0.57 \pm 0.11$. The assumed stellar mass of 0.96 $M_\odot$ implies $M \sin i = 6.96$ M_J and semimajor axis of 2.42 AU.

1. INTRODUCTION

High-precision Doppler techniques have detected about 80 extrasolar planets as companions to F, G, K, and M type main-sequence or subgiant stars (Butler, Marcy, & Vogt 1998; Butler et al. 1997, 1999, 2000, 2001; Butler & Marcy 1996; Cochran et al. 1997; Delfosse et al. 1998; Fischer et al. 1999, 2001, 2002; Hatzes et al. 2000; Henry et al. 2000; Jones et al. 2002; Korzennik et al. 2000; Kürster et al. 2000; Marcy & Butler 1996; Marcy, Butler, & Vogt 1999; Marcy et al. 1998, 2000, 2001a, 2001b; Mayor & Queloz 1995; Mazeh et al. 2000; Naef et al. 2001; Noyes et al. 1997; Queloz et al. 2000; Santos et al. 2001; Tinney et al. 2001, 2002; Udry et al. 2000; Vogt et al. 2000, 2002; Zucker et al. 2002). This technique is sensitive to companions that induce reflex stellar velocities, $K > 10$ m s^{-1}, and exhibit orbital periods ranging from a few days to several years, with the maximum detectable orbital period set by the time baseline of Doppler observations.

The mass distribution of known extrasolar planets rises rapidly toward the low-mass detection threshold of the Doppler technique (Vogt et al. 2002), suggesting that lower mass objects are predominant among gas giant planets. There is essentially no observational incompleteness for companions with $M \sin i > 10$ M_J and orbital separations less than 3 AU. Marcy & Butler (2000) estimate that less than 0.5% of ≈500 stars on their Keck planet search survey have substellar companions at separations less than a few AU with $M \sin i$ between 10 and 80 M_J. Halbwachs et al. (2000) likewise find a minimum in the distribution of close substellar companions between 10 and 80 M_J. The paucity of these companions, a so-called brown dwarf desert, apparently applies to companions at semimajor axes of tens to hundreds of AU (McCarthy 2001). At separations wider than 1000 AU, Gizis et al. (2001) suggest that brown dwarf companions may be as common as stellar companions in that same separation range.

2. OBSERVATIONS

We are carrying out a Doppler survey of about 350 stars at Lick Observatory and about 600 stars at the Keck Observatory. The Hamilton spectrograph at Lick (Vogt 1987) has a resolution $R \approx 50{,}000$ and is fed with light from either the Shane 3 m telescope or the 0.6 m Coudé auxiliary telescope (CAT). The typical signal-to-noise ratio (S/N) for $V = 7$ stars is 140 pixel^{-1} for either a single 10 minute observation with the 3 m telescope or for two 40 minute observations with the CAT telescope.

The Keck project uses the HIRES spectrograph (Vogt et al. 1994) with a resolution $R \approx 80{,}000$. Exposure times for stars brighter than $V = 7$ are typically 1 minute and yield S/N better than 200. To increase phase coverage, stars showing velocity variation at Lick are often added to the Keck project. The higher S/N observations at Keck result in velocity precision that is almost uniformly a few m s^{-1} for chromospherically inactive stars.

The Hamilton spectral format spans a wavelength range of 3700–9000 Å, and the Keck spectral format spans a wavelength range of 3700–6200 Å. Both projects employ an iodine cell to impose a grid of sharp reference lines between 5000 and 6000 Å on the stellar spectrum. In the analysis, a high S/N template spectrum without iodine is combined with a Fourier transform

---

[1] Based on observations obtained at Lick and Keck Observatories, which are operated by the University of California.

[2] Department of Astronomy, University of California, Berkeley, CA 94720; fischer@serpens.berkeley.edu.

[3] Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road NW, Washington, DC 20015-1305.

[4] UCO/Lick Observatory, University of California at Santa Cruz, Santa Cruz, CA 95064.

[5] Physics and Astronomy, University of Sussex, Falmer, Brighton BN1 9QJ, UK.

TABLE 1
Stellar Characteristics

Characteristic	HD 136118	HD 50554	HD 106252
V	6.9	6.84	7.41
$B-V$	0.553	0.582	0.635
Spectral type	F9 V	F8 V	G0 V
Distance (pc)	52.3	31.2	37.4
[Fe/H]	−0.065	−0.057	−0.078
$T_{\rm eff}$ (K)	6003	5844	5753
$v \sin i$ (km s^{-1})	7.0	3.88	2.9
$M_\odot$	1.24	1.065	0.96
$R_\odot$	1.58	1.096	1.096
$S_{\rm HK}$	0.173	0.164	0.162
$\log R'_{\rm HK}$	−4.88	−4.94	−4.97
$P_{\rm rot}$ (days)	12.2	16.1	22.8

TABLE 2
Radial Velocities for HD 136118 from Lick Observatory

JD (+2,450,000)	Radial Velocity (m s^{-1})	Uncertainties (m s^{-1})
10832.069	135.81	35.54
11004.749	−119.48	28.04
11005.735	−69.47	29.15
11026.698	−108.79	20.65
11027.687	−90.31	18.74
11243.013	−176.49	15.29
11298.905	−178.86	19.04
11299.820	−176.55	14.10
11303.868	−195.51	14.79
11304.818	−204.86	13.67
11305.833	−195.43	13.48
11337.758	−233.27	16.75
11362.751	−224.54	17.06
11541.094	−231.26	15.88
11608.004	−181.42	17.22
11627.902	−177.43	13.61
11629.891	−159.88	15.45
11733.725	0.00	13.18
11751.729	20.19	12.21
11752.682	41.09	13.69
11914.096	178.88	16.57
11928.092	157.62	14.03
11946.039	168.71	11.30
11976.046	122.18	14.46
11998.970	112.86	12.71
11999.933	95.87	14.10
12000.978	62.76	17.96
12033.907	63.71	11.86
12040.850	59.74	11.86
12056.870	62.32	15.66
12103.734	−1.48	14.83
12121.686	8.29	12.56
12157.646	−33.19	16.20

spectrometer iodine observation to model instrumental broadening and to derive differential radial velocities in the observations of the star with iodine (Butler et al. 1996). The velocities for all three stars in this paper made use of a high-resolution, high-S/N template spectrum from Keck.

2.1. HD 136118

HD 136118 (=HIP 74948) is a $V = 6.9$, F9 V star with $B-V = 0.553$ and a *Hipparcos*-based distance (ESA 1997) of 52.27 pc. The spectral types for HD 136118, HD 50554, and HD 106252 were all taken from the *Hipparcos* database. The absolute visual magnitude of this star, $M_V = 3.61$, indicates that this star is beginning to evolve away from the main sequence. From spectral synthesis modeling we derive $[{\rm Fe/H}] = -0.065 \pm 0.05$, $T_{\rm eff} = 6003$, and $v \sin i = 7$ km s^{-1}. Together with the absolute magnitude and color, the metallicity provides a mass estimate of 1.18 $M_\odot$ for HD 136118. We note that this mass estimate differs somewhat from Allende Prieto & Lambert (1999), who derive a stellar mass of 1.31 $M_\odot$ and stellar radius $R = 1.58\ R_\odot$. For Keplerian modeling, we adopt an average from these two mass estimates of $1.24 \pm 0.07\ M_\odot$. The stellar characteristics of all three stars in this paper are summarized in Table 1.

It is important to monitor chromospheric activity in stars on Doppler surveys because the correlated magnetic fields can produce an astrophysical source of velocity noise. In extreme cases, strong magnetic fields can produce stellar spots in young active stars, causing changes in line asymmetries that masquerade as dynamical Doppler variations (Queloz et al. 2002). As a chromospheric indicator, we measure an average core emission in the two Ca II H and K lines, calibrated to the Mount Wilson scale (Noyes et al. 1984). The Lick spectral format was extended at the blue end from 4200 to 3700 Å in mid-2000. The time series Ca infrared triplet lines served as a measurement of variations in the chromospheric activity for those observations where the Ca II H and K lines were unavailable.

The Ca II H line for HD 136118 (and the other two stars discussed in this paper) is plotted against the solar Ca II H line in Figure 1 and does not show any overt emission. The emission index for HD 136118 is $S_{\rm HK} = 0.173$. We derive a ratio of $S_{\rm HK}$ to the bolometric flux, $\log R'_{\rm HK} = -4.88$, indicating modest chromospheric activity for this star. The H and K index has been shown to correlate well with stellar rotation (Noyes et al. 1984) and age (Baliunas et al. 1995), providing an estimate for the rotation period $P = 12.2$ days and stellar age ~3 Gyr.

Adopting the stellar rotation period of 12.2 days and stellar radius $R = 1.58\ R_\odot$, the $v \sin i$ of 7 km s^{-1} that we measure in our spectrum suggests that we are observing the rotation axis close to equator-on. If the orbital plane is perpendicular to the spin axis of the star, then our Doppler-derived $M \sin i$ will be close to the absolute mass of the companion.

The moderate rotational velocity of HD 136118 results in spectral lines that are slightly broadened. Because the centroid of broader lines cannot be as sharply defined, the velocity precision is slightly degraded for this star relative to slowly rotating and chromospherically inactive stars. Table 2 lists 33 velocity measurements of HD 136118 obtained over the last 3 yr. The

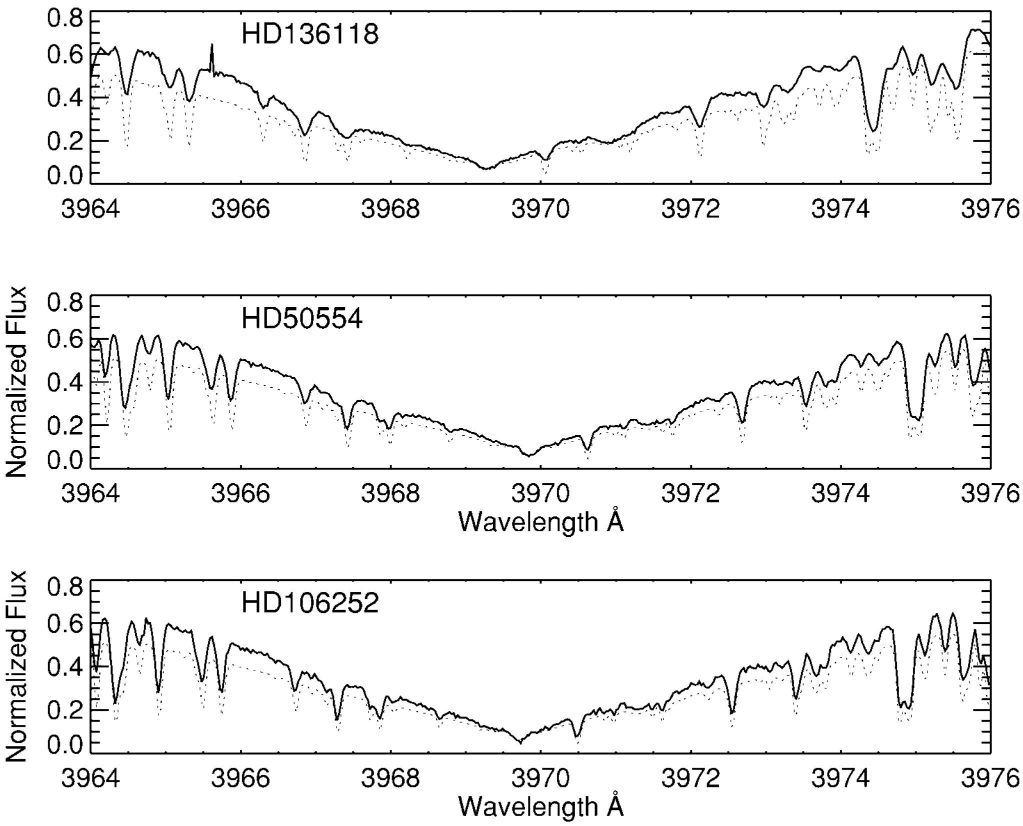

FIG. 1.—Spectral window containing the Ca K line is plotted in three panels for each of the stars HD 136118, HD 50554, and HD 106252. The stellar spectra are plotted as solid lines, and, for comparison, the National Solar Observatory solar spectrum is plotted in each panel as a dotted line.

radial velocity data are well fitted by a Keplerian model with rms $= 22.1$ m s^{-1} and $\chi_\nu^2 = 1.04$. This fit is consistent with the mean velocity error of 16.4 m s^{-1}. The Keplerian fit (Fig. 2) yields a velocity semiamplitude $K = 212.9 \pm 6$ m s^{-1}, orbital period $P = 1209 \pm 24$ days, and eccentricity $e = 0.37 \pm 0.025$. The assumed mass of 1.24 $M_\odot$ implies a companion mass $M \sin i = 11.9$ M_J and semimajor axis of 2.3 AU, or 0$''$.04 at a distance of 52 pc. The range in the assumed stellar masses noted above result in a range for $M \sin i$ between 11.5 and 12.4 M_J. The orbital solutions for HD 136118 and the other two extrasolar planets discussed in this paper are listed in Table 3.

2.2. HD 50554

The Geneva team has announced but not yet published the detection of a planet with $M \sin i = 4.9$ M_J, orbital period $P = 1279$ days, and eccentricity $e = 0.42$ orbiting HD 50554 (ESO press release 07/01, 2001 April 4). This star has also been on the Lick program since 1998. Velocity variations observed in the Lick data prompted us to add this star to the Keck project in 1999. Here, we present our independent observations for this system.

HD 50554 (=HIP 33212) is a $V = 6.84$, F8 V star with

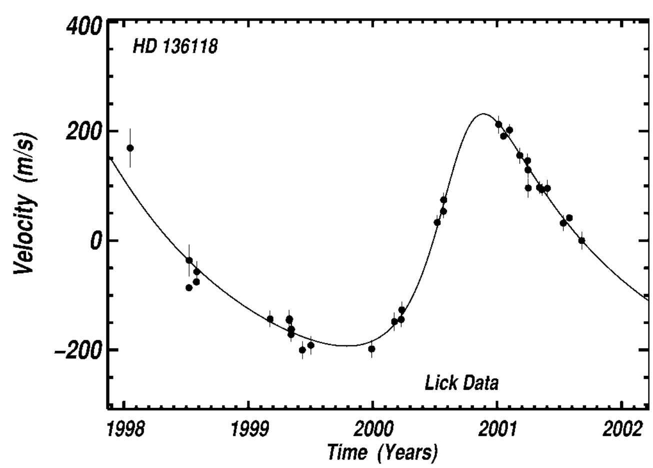

FIG. 2.—Keplerian fit to the radial velocities of HD 136118 reveals a companion with $M \sin i = 11.9$ M_J, $P = 1209$ in an eccentric orbit, $e = 0.37$. The rms to this fit is 22.1 m s^{-1} with $\chi_\nu^2 = 1.04$. The data are from Lick Observatory.

TABLE 3
ORBITAL PARAMETERS

Parameter	HD 136118	HD 50554	HD 106252
P (days)	1209.6 (24.0)	1254.6 (34)	1503.3 (32.0)
T_p (JD)	2,451,800.6 (36.6)	2,451,926 (56.3)	2,451,896.6 (58.6)
e	0.366 (0.025)	0.51 (0.06)	0.57 (0.11)
ω (deg)	315.0 (4.5)	18.3 (7.6)	293.0 (10.5)
K_1 (m s^{-1})	212.9 (6.0)	78.5 (6.7)	150.9 (25.0)
a (AU)	2.335	2.22	2.42
$a_1 \sin i$ (AU)	2.23×10^{-2}	7.77×10^{-3}	0.17×10^{-2}
$f_1(m)$ ($M_\odot$)	9.57×10^{-7}	3.96×10^{-8}	2.93×10^{-7}
$M \sin i$ (M_J)	11.9[a]	3.7	7.0
N_{obs}[a]	33	26	15
rms (m s^{-1})	22.1	11.3	9.34
Reduced χ^2	1.04	1.82	0.83

[a] Range in the mass estimate for HD 136118 is discussed in the text and leads to range of 11.5 $M_J < M \sin i < 12.4$ M_J.

$B-V = 0.582$ and *Hipparcos*-based distance of 31.2 pc. We derive [Fe/H] $= -0.057 \pm 0.05$, $T_{eff} = 5844$, and $v \sin i = 3.88$ km s^{-1} from spectral synthesis modeling. The stellar characteristics are summarized in Table 1. With the derived metallicity, we estimate the stellar mass to be 1.09 $M_\odot$. Allende Prieto & Lambert (1999) derive a stellar mass of 1.04 $M_\odot$ and radius of 1.096 $R_\odot$. We adopt an average mass of 1.065 $M_\odot$ for the mass of HD 50554.

The Ca II H core emission is plotted in Figure 1. Our measurement of core emission in the H and K lines yields $S_{HK} = 0.164$ and sets $\log R'_{HK} = -4.94$, implying a rotation period of 16.1 days.

Twenty-six velocities (Table 4) have been measured for HD 50554 over the last 4 yr. Fifteen of these velocities are from Lick Observatory and 11 are from Keck. The velocities from the two observatories have been combined with an arbitrary offset to minimize residuals to the Keplerian fit. The data are plotted in Figure 3, with diamonds representing the Keck observations and dots representing Lick velocities. The best-fit Keplerian for the combined data set has $\chi^2_\nu = 1.82$ and residuals with rms $= 11.3$ m s^{-1}. We measure an orbital period $P = 1254 \pm 34$ days, a velocity semiamplitude $K = 78.5 \pm 9.7$ m s^{-1}, and an orbital eccentricity of 0.51 ± 0.06. The assumed stellar mass of 1.065 $M_\odot$ yields $M \sin i = 3.72$ M_J and separation of 2.22 AU or 0.″07.

The velocity semiamplitude that we measure is slightly lower than $K = 95.0$ m s^{-1}, the value announced by the Geneva team, perhaps because our phase coverage near the peak of the velocity amplitude is modest. Our higher eccentricity also disagrees slightly with the value announced by the Geneva team. These differences in measured orbital elements explain the slightly lower $M \sin i$ that we derive for the companion.

The rms fit for our orbital solution is consistent with the average errors from Lick (12.6 m s^{-1}) but greater than the mean Keck errors (4.4 m s^{-1}). The relatively poor χ^2 fit to the combined data set suggests that there is an additional source of velocity jitter above the internal errors measured at Keck. One likely source is photospheric noise, which we find typically introduces 5–10 m s^{-1} jitter in the velocities of F8 V stars. The Keck residual velocities have an rms of about 9 m s^{-1}. However, a periodogram of these residual velocities does not reveal significant power at any frequency. We also plotted the residual velocities against the individual measurements of S_{HK} for the higher precision Keck observations, but no correlation between these two parameters was observed.

TABLE 4
RADIAL VELOCITIES FOR HD 50554

JD (+2,450,000)	Radial Velocity (m s^{-1})	Uncertainties (m s^{-1})	Observatory
10831.805	20.23	16.44	Lick
10854.777	26.67	16.24	Lick
11131.003	15.39	16.15	Lick
11154.447	−7.72	10.59	Lick
11171.062	−5.56	4.06	Keck
11171.955	0.00	4.18	Keck
11172.903	−4.59	4.24	Keck
11174.113	−6.74	5.01	Keck
11200.007	6.73	4.60	Keck
11242.710	−7.81	15.83	Lick
11299.528	−12.57	6.47	Lick
11536.884	24.31	9.68	Lick
11540.400	11.93	7.48	Lick
11915.884	156.74	8.31	Lick
11946.739	125.98	8.78	Lick
12007.845	75.27	4.36	Keck
12033.691	64.33	6.85	Lick
12158.523	14.10	8.79	Lick
12219.141	−11.78	4.51	Keck
12220.111	−19.77	5.22	Keck
12235.969	12.16	3.70	Keck
12238.914	10.84	3.89	Keck
12243.018	−7.18	4.29	Keck
12256.951	−22.70	13.06	Lick
12293.715	−1.97	6.17	Lick
12294.897	−7.77	13.05	Lick

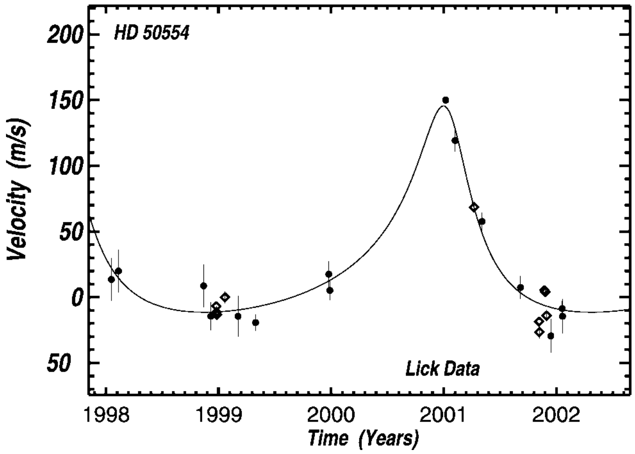

FIG. 3.—Keplerian fit to the radial velocities of HD 50554 confirm a companion announced by the Geneva team. We derive $M \sin i = 3.7\ M_J$ in an orbit with $P = 1254$ days and eccentricity $e = 0.51$. The rms to this fit is 11.3 m s^{-1} with $\chi_\nu^2 = 1.82$. The data are a combined data set from Lick and Keck Observatories and the Keck velocities are plotted as diamonds.

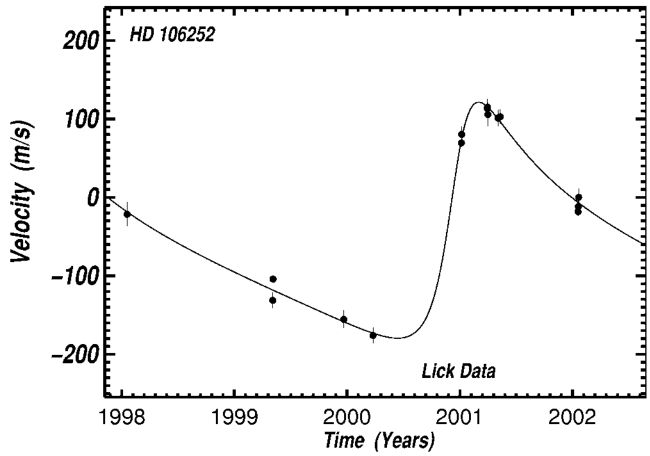

FIG. 4.—Keplerian fit to the radial velocities of HD 106252 confirm a $M \sin i = 6.96\ M_J$ companion announced by the Geneva team. We measure $P = 1503$ days in an eccentric orbit $e = 0.57$. The rms to this fit is 9.34 m s^{-1} with $\chi_\nu^2 = 0.83$. The data are from Lick Observatory.

2.3. HD 106252

The G0 V star HD 106252 has been on the Lick program since 1998. The Geneva team has announced the detection of a planet with $M \sin i = 6.8\ M_J$, orbital period $P = 1500$ days, and eccentricity $e = 0.54$ (ESO Press Release 07/01, 2001 April 4) for this star. We present our independent velocities and orbital solution.

HD 106252 (=HIP 59610) is a $V = 7.41$, G0 V star with $B-V = 0.635$ and *Hipparcos*-based distance of 37.4 pc. Our estimate of the stellar mass agrees with the value published by Allende Prieto & Lambert (1999). They derive a stellar mass of 0.96 $M_\odot$ and stellar radius of 1.096 $R_\odot$ for HD 106252. From spectral synthesis modeling, we derive [Fe/H] $= -0.078 \pm 0.05$, $T_{\rm eff} = 5753$, and $v \sin i = 2.9$ km s^{-1}. We measure the Ca II H and K core emission, $S_{\rm HK} = 0.162$, with a corresponding $\log R'_{\rm HK} = -4.97$ and implied rotation period of 22.8 days. The lack of emission is apparent in the plot of the Ca II H line shown in Figure 1.

Fifteen velocities (Table 5) have been measured for HD 106252 since January 1998. The best-fit Keplerian, shown in Figure 4, has $\chi_\nu^2 = 0.83$ and rms $= 9.34$ m s^{-1}. The orbital period is $P = 1503.3 \pm 32$ days. The velocity semiamplitude is $K = 150.9 \pm 25$ m s^{-1}, and the orbital eccentricity is 0.57 ± 0.11. The assumed stellar mass of 0.96 $M_\odot$ yields a companion mass of 6.96 M_J and separation of 2.42 AU or 0.″065. This result is in excellent agreement with the parameters announced by the Geneva team.

3. DISCUSSION

We have detected an $M \sin i = 12\ M_J$ companion in a 3.3 yr orbit orbiting the star HD 136118. We also present data confirming two detections (around HD 50554 and HD 106252) announced in 2001 April by the Geneva team. For HD 50554, we detect a companion with $M \sin i = 3.7\ M_J$ in a 3.5 yr orbit. For HD 106252, we detect an $M \sin i = 6.96\ M_J$ companion in a 4.1 yr orbit. The differences between our results and those of the Geneva team for HD 50554 arise primarily because we measure a smaller velocity amplitude. However, we have sparse observations at the velocity maximum, so this difference is not compelling. Our results for HD 106252 are in good agreement with the orbital elements announced by the Geneva team.

The three companions presented in this paper all have orbital periods longer than 3 yr. Since the maximum detectable orbital period is set by the time baseline of the Doppler observations, and since all of these stars were added to the Lick project in 1998, it is not surprising that orbital periods of 3–4 yr are being reported in the year 2002. One point worth noting is that most

TABLE 5
RADIAL VELOCITIES FOR HD 106252 FROM LICK OBSERVATORY

JD (+2,450,000)	Radial Velocity (m s^{-1})	Uncertainties (m s^{-1})
10831.984 ……	−31.11	15.67
11303.785 ……	−140.93	10.28
11304.748 ……	−113.73	9.83
11534.094 ……	−165.01	11.37
11628.817 ……	−185.69	10.45
11915.096 ……	59.74	9.58
11916.070 ……	70.63	10.54
11998.900 ……	103.87	11.95
11999.871 ……	105.26	10.97
12000.916 ……	96.04	14.98
12033.833 ……	91.41	10.59
12040.835 ……	93.13	9.46
12293.063 ……	−27.81	15.33
12294.055 ……	−21.29	11.70
12295.022 ……	−9.58	11.55

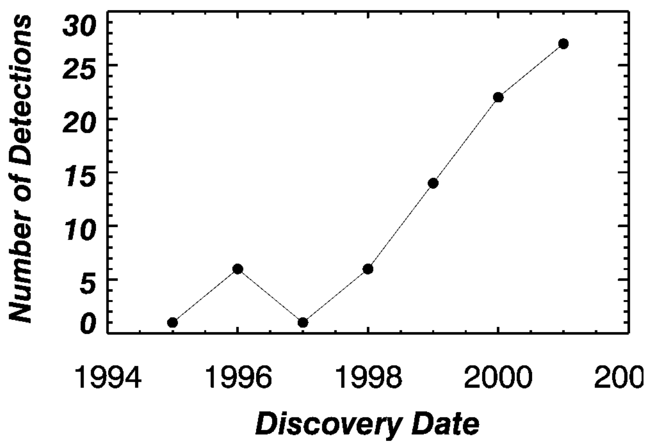

FIG. 5.—Number of $M \sin i < 17\ M_J$ companions detected by all planet-search teams with Doppler observations. The discovery date is the year of publication, or the year in which a press release was issued if the detection has not appeared in a peer-reviewed paper.

of the companions with orbital periods shorter than 1 yr and velocity amplitudes greater than 30 m s^{-1} have probably been detected in the current Lick sample. All five planets that were discovered during 2002 using Lick data (or Lick data combined with Keck data) had orbital periods longer than 1 yr.

Figure 5 shows that the number of published or announced extrasolar planets is increasing each year. Through the year 2000, $\frac{3}{4}$ of these detected planets had orbital periods shorter than 1 yr. However, in the year 2001, only $\frac{1}{3}$ of the extrasolar planet detections had orbital periods shorter than 1 yr. The typical orbital period of extrasolar planets is shifting toward longer periods, reflecting the advancing time baseline of Doppler observations for all planet survey projects. Indeed, it may be the case that nature has conspired to make planets more plentiful in the low-mass and long-period parameter regimes where they are most challenging to detect with Doppler observations. If so, then the productivity of Doppler searches will increase as velocity precision improves and survey duration lengthens.

The tendency for planet-bearing stars to have supersolar metallicities has been widely discussed (Gonzalez 1997; Laughlin 2000; Murray et al. 2001). The 18 stars with $B-V$ less than 0.6 (i.e., approximately G0 V or earlier spectral types) and companions less massive than 5 M_J have a mean [Fe/H] of 0.1. However, the five stars in this same $B-V$ bin that have companions more massive than 5 M_J have a mean [Fe/H] of -0.08, almost 0.2 dex lower. This difference may be insignificant due to small number statistics, but if it continues then this may be a clue to the early conditions and formation mechanisms associated with these different mass ranges of extrasolar planets.

The companion orbiting HD 136118 is somewhat unusual in that it has a mass that probably exceeds the deuterium-burning threshold of 12 M_J, often used to define a brown dwarf. Only three out of 350 stars surveyed at Lick have $M \sin i$ greater than 5 M_J: 70 Vir with $M \sin i = 7.42$ (Marcy & Butler 1996), HD 89744 with $M \sin i = 7.17$ (Korzennik et al. 2000), and HD 136118 (this paper). From statistical arguments, we expect that $M \sin i$ from Doppler detected planets will be within a factor of 2 of the true planet mass. Therefore, these three objects represent the most likely cases where the true mass places them above the deuterium-burning limit. Thus, an upper limit on the rate of occurrence of brown companions in the Lick sample is approximately 0.8%, in keeping with other suggestions that fewer than 1% of solar-type stars appear to have brown dwarf companions at separations less than a few AU (Marcy & Butler 2000; Vogt et al. 2002).

We gratefully acknowledge the dedication of the Lick Observatory staff, particularly Tony Misch, Keith Baker, Wayne Earthman, Kostas Chloros, John Morey, and Andy Tullis. We acknowledge support by NASA grant NAG 5-75005 (to G. W. M.) and by NSF grant AST 99-88358 and NASA grant NAG 5-4445 (to S. S. V.) and by Sun Microsystems. We thank the NASA and UC Telescope assignment committees for allocations of telescope time. This research has made use of the Simbad database, operated at CDS, Strasbourg, France.

REFERENCES

Allende Prieto, C., & Lambert, D. L. 1999, A&A, 352, 555
Baliunas, S. L., et al. 1995, ApJ, 438, 269
Butler, R. P., & Marcy, G. W. 1996, ApJ, 464, L153
Butler, R. P., Marcy, G. W., Fischer, D. A., Brown, T. M., Contos, A. R., Korzennik, S. G., Nisenson, P., & Noyes, R. W. 1999, ApJ, 526, 916
Butler, R. P., Marcy, G. W., & Vogt, S. S. 1998, PASP, 110, 1389
Butler, R. P., Marcy, G. W., Williams, E., Hauser, H., & Shirts, P. 1997, ApJ, 474, L115
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., Vogt, S. S., Marcy, G. W., Fischer, D. A., Henry, G. W., & Apps, K. 2000, ApJ, 545, 504
Cochran, W. D., Hatzes, A. P., Butler, R. P., & Marcy, G. W. 1997, ApJ, 483, 457
Delfosse, X., Forveille, T., Mayor, M., Perrier, C., Naef, D., & Queloz, D. 1998, A&A, 338, 67
ESA. 1997, The Hipparcos and Tycho Catalogues (ESA-SP 1200; Noordwijk: ESA)
Fischer, D. A., Marcy, G. W., Butler, R. P., Laughlin, G. P., & Vogt, S. S. 2002, ApJ, 564, 1028
Fischer, D. A., Marcy, G. W., Butler, R. P., Vogt, S. S., & Apps, K. 1999, PASP, 111, 50
Fischer, D. A., Marcy, G. W., Butler, R. P., Vogt, S. S., Frink, S., & Apps, K. 2001, ApJ, 551, 1107
Gizis, J. E., Kirkpatrick, J. D., Burgasser, A., Reid, I. N., Monet, D. G., Liebert, J., & Wilson, J. C. 2001, ApJ, 551, L163
Gonzalez, G. 1997, MNRAS, 285, 403

Halbwachs, J. L., Arenou, F., Mayor, M., Udry, S., & Queloz, D. 2000, A&A, 355, 581
Hatzes, A. P., et al. 2000, ApJ, 544, L145
Henry, G. W., Marcy, G. W., Butler, R. P., & Vogt, S. S. 2000, ApJ, 529, L41
Jones, H. R. A., Butler, R. P., Tinney, C. G., Marcy, G. W., Penny, A. J., McCarthy, C., Carter, B. D., & Pourbaix, D. 2002, MNRAS, in press
Korzennik, S., Brown, T., Fischer, D., Nisenson, P., & Noyes, R. W. 2000, ApJ, 533, L147
Kürster, M., Endl, M., Els, S., Hatzes, A. P., Cochran, W. D., Döbereiner, S., & Dennerl, K. 2000, A&A, 353, L33
Laughlin, G. P. 2000, ApJ, 545, 1064
Marcy, G. W., & Butler R. P. 1996, ApJ, 464, L147
———. 2000, PASP, 112, 137
Marcy, G. W., Butler, R. P., Fischer, D. A., Vogt, S. S., Lissauer, J. J., & Rivera, E. J. 2001a, ApJ, 556, 296
Marcy, G. W., Butler, R. P., & Vogt, S. S. 2000, ApJ, 536, L43
Marcy, G. W., Butler, R. P., Vogt, S. S., Fischer, D. A., & Lissauer, J. 1998, ApJ, 505, L147
Marcy, G. W., Butler, R. P., Vogt, S. S., Fischer, D. A., & Liu, M. C. 1999, ApJ, 520, 239
Marcy, G. W., et al. 2001b, ApJ, 555, 418
Mayor, M., & Queloz, D. 1995, Nature, 378, 355
Mazeh, T., et al. 2000, ApJ, 532, L55
McCarthy, C. 2001, Ph.D. thesis, UCLA
Murray, N., Chaboyer, B., Arras, P., Hansen, B., & Noyes, R. W. 2001, ApJ, 555, 801
Naef, D., Mayor, M., Pepe, F., Queloz, D., Santos, N. C., Udry, S., & Burnet, M. 2001, A&A, 375, 205
Noyes, R. W., Hartmann, L., Baliunas, S. L., Duncan, D. K., & Vaughan, A. H. 1984, ApJ, 279, 763
Noyes, R. W., Jha, S., Korzennik, S. G., Krockenberger, M., Nisenson, P., Brown, T. M., Kennelly, E. J., & Horner, S. D. 1997, ApJ, 487, L195
Queloz, D., et al. 2000, A&A, 354, 99
———. 2002, A&A, in press
Santos, N. C., Mayor, M., Naef, D., Pepe, F., Queloz, D., Udry, S., & Burnet, M. 2001, A&A, 379, 999
Tinney, C. G., Butler, R. P., Marcy, G. W., Jones, H. R. A., Penny, A. J., McCarthy, C., & Carter, B. D. 2002, ApJ, 571, 528
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
Udry, S., et al. 2000, A&A, 356, 590
Vogt, S. S. 1987, PASP, 99, 1214
Vogt, S. S., Butler, R. P., Marcy, G. W., Fischer, D. A., Pourbaix, D., Apps, K., & Laughlin, G. P. 2002, ApJ, 568, 352
Vogt, S. S., Marcy, G. W., Butler, R. P., & Apps, K. 2000, ApJ, 536, 902
Vogt, S. S., et al. 1994, Proc. Soc. Photo-opt. Instrum. Eng., 2198, 362
Zucker, S., et al. 2002, ApJ, 568, 363