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EVIDENCE FOR A PLANETARY COMPANION AROUND A NEARBY YOUNG STAR

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ABSTRACT

We report evidence for a planetary companion around the nearby young star HD 70573. The star is a G-type dwarf located at a distance of 46 pc. We carried out spectroscopic observations of this star with FEROS at the 2.2 m MPG/ESO telescope at La Silla. Our spectroscopic analysis yields a spectral type of G1–1.5 V and an age of about 100 Myr. Variations in stellar radial velocity (RV) of HD 70573 were monitored from 2003 December until 2007 January. HD 70573 shows an RV variation with a period of 852($\pm$12) days and a semiamplitude of 149($\pm$6) m s^{-1}. The period of this variation is significantly longer than its rotational period. Based on the analysis of the Ca ii K emission line, Hα, and $T_{\rm eff}$ variation as stellar-activity indicators, as well as the lack of a correlation between the bisector velocity span and the RV, we can exclude rotational modulation and nonradial pulsations as the source of the long-period RV variation. Thus, the presence of a low-mass companion provides the best explanation for the observed RV variation. Assuming a primary mass $m_1 = 1.0 \pm 0.1\ M_\odot$, we calculated a minimum mass of the companion $m_2 \sin i$ of 6.1 $M_{\rm Jup}$, which lies in the planetary-mass regime, and an orbital semimajor axis of 1.76 AU. The orbit's eccentricity is $e = 0.4$. The planet discovery around HD 70573 gives an important input for the study of debris disks around young stars and their relation to the presence of planets.

Subject headings: planetary systems — stars: general — stars: individual (HD 70573) — techniques: radial velocities

1. INTRODUCTION

Precise radial velocity (RV) measurements are a well-established technique in detecting extrasolar planets around nonactive stars, such as solar-type stars with masses and ages similar to those of our Sun (see e.g., Butler et al. 2006). This technique was also applied in the late 1980s in planet searches around cool evolved stars (Cochran & Hatzes 1989). However, the number of extrasolar planets around such non-solar-type stars is still very small compared to planets around solar-like stars. The situation for young stars is similar, where practically no convincing case is known so far. Planet detections around young and active stars are indeed much more difficult than those around evolved and quiet solar-like stars.

Many young stars possess high levels of stellar activity and are also known as fast rotators. Spectroscopically this is indicated by strong line broadening and the presence of emission-line features, in particular Hα (λ6536), Ca ii H (λ3967), and K (λ3934). Within the same spectral class the stellar activity of young stars is considerably higher than for older stars. The rotational velocity of F-, G- and K-type young stars can be as high as a few hundred km s^{-1}, which can be observed by strong line broadening. This makes precise RV measurements very difficult. Intrinsic stellar activity, such as nonradial pulsations and rotational modulation, manifests itself in RV variation. In order to distinguish the sources of RV variation in active stars, the stellar spectra have to be investigated carefully, for instance, via bisector analysis (e.g., Hatzes 1996) and stellar-activity indicators such as Ca ii H and K emission lines and variation in the Hα line, to avoid a misinterpretation of the observed RV variation. This kind of analysis is indispensable for planet searches around active young stars.

The search for young planetary systems by the RV technique is indeed limited to young stars that do not show a high activity level. High stellar activity affects the accuracy of the RV method, such as in stars with high rotational velocity ($v \sin i > 20$ km s^{-1}). Nevertheless, in comparison to other young-planet-search methods, such as direct-imaging techniques, the RV method is more sensitive to planetary companions with closer orbits, i.e., less than 10 AU to the parent stars. A further advantage compared to direct imaging is that the RV method is not strongly limited by distance. It can be applied to planet searches in nearby young moving groups (30–70 pc) and star-forming regions at >100 pc (e.g., the Taurus-Auriga region at 140 pc), for which direct-imaging methods are not possible.

This work reports the discovery of a planetary companion around the nearby young star HD 70573. Our RV measurements of HD 70573 show a periodic variation on a timescale that is much longer than the stellar rotational period. This excludes rotational modulation as the source of RV variation. We will show that the bisector technique allows us to distinguish intrinsic stellar activity (nonradial pulsations or stellar rotational modulation due to starspots) from variability due to companions. By measuring the bisector velocity spans we detected rotational modulation in other young stars of our sample (J. Setiawan et al. 2007, in preparation). Planet detection around HD 70573 is concluded by a lack of the correlation between the observed RVs and stellar activity indicators (§ 4).

2. HD 70573: A NEARBY YOUNG STAR

HD 70573 was identified by Jeffries (1995) as a lithium-rich star. He predicted an age of this star substantially younger than 300 Myr. In a study of young stellar kinematic groups by Montes et al. (2001b), HD 70573 has been classified as a member of the Local Association (Pleiades moving group) with an age range between 20 and 150 Myr. Later, Lopéz-Santiago et al. (2006) classified HD 70573 as a member of the Hercules-Lyra association, a group of stars comoving in space toward

TABLE 1
Stellar Parameters of HD 70573

Parameter	Value
Spectral type	G1–1.5 V
M_V	0.4 mag
Distance	45.7 pc
m	$1.0 \pm 0.1\ M_\odot$
T_{eff}	5737 ± 70 K
[Fe/H]	-0.18 ± 0.2 $[Fe/H]_\odot$
log g	4.59 ± 0.1
EW(Li)	156 ± 20 mÅ
Age	78–125 Myr
$v \sin i$	14.7 ± 1.0 km s^{-1}
P_{rot}	3.296 days

the constellation of Hercules. This moving group has an estimated age of ∼200 Myr. By comparing the equivalent width of Li λ6708 versus the spectral-type diagram (Fig. 2 in Montes et al. 2001a), we derived an age within the Pleiades age regime (78–125 Myr).

The stellar parameters of HD 70573 are compiled in Table 1. We measured the equivalent widths (EWs) of neutral and ionized lines as described in Gray (1992). By comparing our EW measurements with the EWs of standard stars adopted from Cayrel de Strobel (2001) and by using the relation between EWs and temperature we derive the spectral type of G1–1.5 V for HD 70573. The stellar parameters T_{eff}, [Fe/H], and log g have been calculated by using the TGV model (Takeda et al. 2002), which computes the stellar parameters from the EWs of Fe I and Fe II.

The absolute visual magnitude has been calculated from the visual brightness $m_V = 8.70$ mag and the distance $d = 45.7$ pc (Lopéz-Santiago et al. 2006). Henry et al. (1995) has measured photometric variations of HD 70573 and found a period of 3.296 days, which corresponds to the rotational period of the star. We measured the projected rotational velocity $v \sin i$ from the spectral lines by using a cross-correlation method (Benz & Mayor 1981) with the instrumental calibration from Setiawan et al. (2004). Our measured value (see Table 1) is slightly higher than the value published by Henry et al. (1995), who derived $v \sin i = 11$ km s^{-1}.

3. OBSERVATIONS AND RESULTS

We are carrying out an RV survey of a sample of young stars with FEROS at the 2.2 m MPG/ESO telescope located at the ESO La Silla Observatory, Chile. The spectrograph has a resolution of $R = 48{,}000$ and a wavelength coverage of 3600–9200 Å (Kaufer et al. 1998).

The data reduction has been performed by using the online pipeline, which produces 39 orders of one-dimensional spectra. The RVs have been measured with the simultaneous calibration mode of FEROS and a cross-correlation technique (Baranne et al. 1996). During a period of 3 years we obtained a long-term stability of FEROS that is about 10 m s^{-1}.

RV measurements of HD 70573 are shown in Figure 1. We observed a long-term RV variation with a period of 852 ± 12 days, which is much longer than the period of the photometric variability. The semiamplitude of the RV variation is 149 ± 16 m s^{-1}. A Lomb-Scargle periodogram (Scargle 1982) (Fig. 2) of the RVs show the highest peak in the power, which corresponds to the long-period RV variation. On a smaller timescale of several days we also detected short-term RV variations. In the Lomb-Scargle periodogram we also found a lower peak in the power, which corresponds to a period of ∼2.6 days. This is comparable to the period in the photometric variation detected by Henry et al. (1995). The false alarm probability (FAP) of the peaks is 1.1×10^{-3} for the long-period RV variation and 3.5×10^{-2} for the short-period one. Additional RV measurements, taken with intervals of a few hours in several consecutive days, may increase the power in the frequency region that corresponds to the period of ∼3 days.

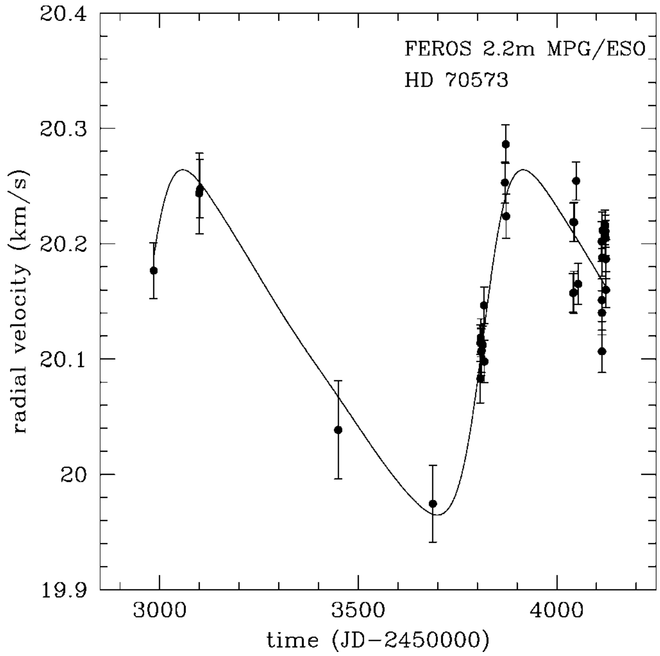

Fig. 1.—RV measurements of HD 70573. We observed a long-period RV variation of 852 days and a short-period variation of a few days (see text).

4. TESTING THE STELLAR ACTIVITY

As detected in many surveys, young stars show high stellar activity, characterized by strong X-ray, Hα, and Ca II H and K emission. In addition, they are also known as fast rotators. For example, large surveys of young stars in star-forming regions such as NGC 2264 (Lamm et al. 2004) show that the

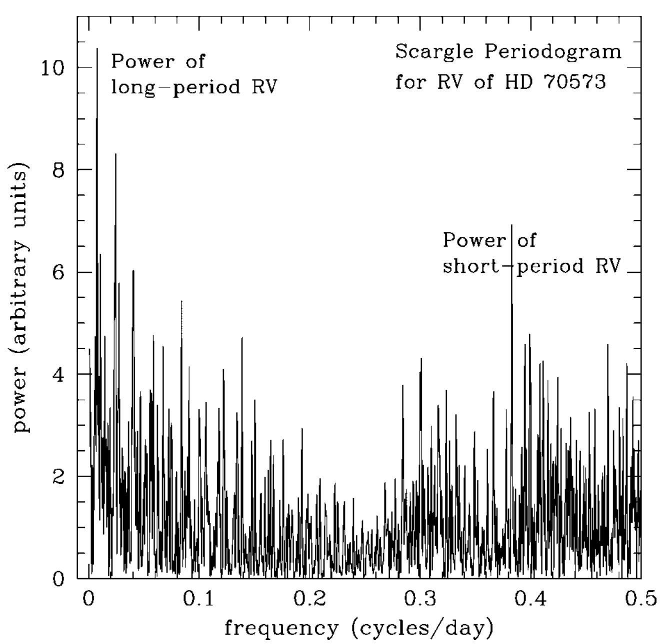

Fig. 2.—Lomb-Scargle periodogram of the RV variation of HD 70573.

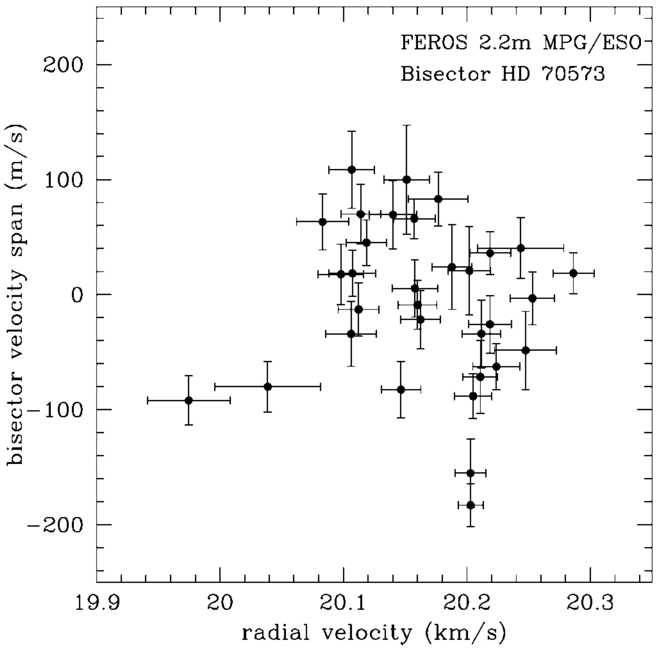

Fig. 3.—Bisector velocity span vs. RV of HD 70573. The figure shows no correlation between the quantities. This favors the presence of a low-mass companion rather than stellar activity as the source of RV variation.

objects are often fast rotators with periods between 0.2 and 15 days. Stellar magnetic activity manifests itself by starspots and granulation, as observed in the Sun. Pulsations have also been observed in young stars (e.g., Marconi et al. 2000).

To measure the stellar activity of HD 70573 we investigated the variation of the Ca II K emission line (λ3934) and Hα. We did not use the Ca II H line (λ3967) to avoid the blend that can be caused by the Hϵ line of the Balmer series. Similar to the method used by Santos et al. (2000), we computed an activity index by measuring the intensity of the Ca II K line relative to the intensities of 2 Å windows located in the blue and red parts of the spectra, which are close to the Ca II K region and do not have strong absorption features. Our measurements do not show any long-period variation that might be correlated with the RV variation. The relative rms of the *S*-index variation is 4.5% of the mean value. In addition, we also measured the EW variation of the Hα line and the $T_{\rm eff}$ variation by using the line-ratio technique (e.g., Catalano et al. 2002) to search for the stellar activity. The EW measurements of the Hα line give a value of 961 ± 45 mÅ. The rms of 45 mÅ corresponds to 4.7% variation in the EW, which is similar to the variation observed in the Ca II K emission line. We observed a short-term $T_{\rm eff}$ variation with a peak-to-peak value of ~220 K and a period of few days, which is close to the stellar rotational period. This result means an approximately 4% variation in $T_{\rm eff}$ (Table 1) and thus in good agreement with other stellar activity indicators. However, we did not find any long-term periodicity. The EW variation of the Hα line also does not show any long-period variation.

The stellar activity will leave imprints on the spectral line profile. Another possibility for characterizing stellar activity in the spectra is by using the bisector or the bisector velocity span (Hatzes 1996), which measures the asymmetry of the spectral line profile. Equivalently, the bisector velocity span method can be applied to the cross-correlation function used for the RV computation (Queloz et al. 2001). A correlation between bisector velocity spans and RVs should be expected, if the activity is responsible for the RV variation. In contrast to non-active solar-like stars, the bisector velocity spans of active stars are not constant. The scatter in the velocity spans may provide information about the activity level of the star.

TABLE 2
Orbital Parameters of HD 70573b

Parameter	Value
P	851.8 ± 11.6 days
K_1	148.5 ± 16.5 m s^{-1}
e	0.4 ± 0.1
ω	269.6° ± 14.3°
$\mathrm{JD}_0 - 2{,}450{,}000$	2106.54 ± 25.72 days
Reduced χ^2	1.34
$O - C$	18.7 m s^{-1}
m_1	1.0 ± 0.1 $M_\odot$
$m_2 \sin i$	6.1 ± 0.4 $M_{\rm Jup}$
a	1.76 ± 0.05 AU

In HD 70573 we found no correlation between the bisector velocity spans and RVs (Fig. 3). Thus, based on the results of our analysis of the Ca II K emission lines, Hα, temperature variation, and bisector velocity spans as stellar activity indicators, we conclude that the observed long-period RV variation of HD 70573 is most likely due to the presence of a low-mass (substellar) companion.

5. DISCUSSION

We computed an orbital solution for the RV data of HD 70573 by using a standard Keplerian fit with χ^2 minimization. The orbital parameters are listed in Table 2. HD 70573b is probably the youngest extrasolar planet detected so far with the RV technique (Fig. 4).

Planet discoveries around young stars provide important constraints for theories of planet formation. An example is the migration process of planets occurring in the gas-rich phases of protoplanetary disks. The detection of young planets will also allow us to study the relation between extrasolar planets and the structure of debris disks (Moro-Martín et al. 2007). Since HD 70573 is part of the young-star sample of the *Spitzer* FEPS legacy program (Meyer et al. 2004), the detection of a planetary companion around this star is of great interest for the study of the relation between debris disks and planets. With a spectral type of G1–1.5 V and an age of only 3%–6% of the

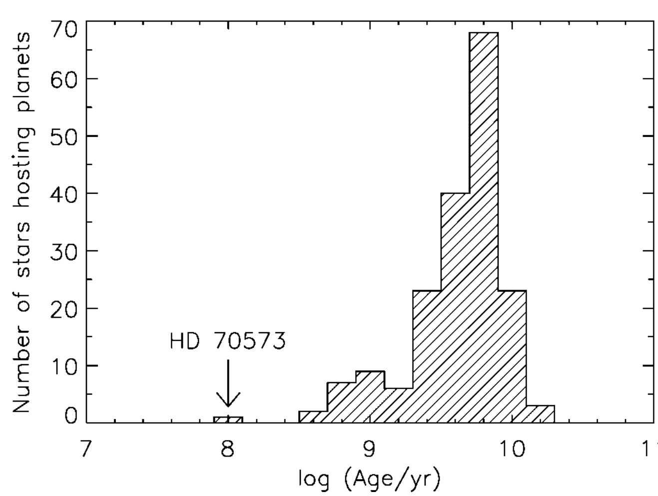

Fig. 4.—Histogram of the ages of exoplanets as of 2006 November. HD 70573b is the youngest planet detected so far by the RV method.

age of the Sun, the planetary system around HD 70573 could resemble the young solar system.

More planet discoveries around young stars will certainly improve our understanding of planetary systems in their early evolutionary stages. Since planet searches around young stars via the RV method are restricted to the visual wavelength region and are strongly affected by stellar activity, other detection techniques such as , e.g., NIR direct imaging or astrometry, are gaining importance and will most likely soon deliver more discoveries. Astrometric measurements with a precision level of few tens of μas, for example, will be able to detect the astrometric signal of the planet around HD 70573, which is ~0.23 mas.

Finally, with the detection of a planetary companion around the young star HD 70573, we have shown that the RV technique is still potentially profitable for planet-search programs.

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Facilities: FEROS, 2.2 m MPG/ESO.

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