The ELODIE survey for northern extra-solar planets

IV. HD 196885, a close binary star with a 3.7-year planet

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ABSTRACT

Aims. A major goal of our survey is to significantly increase the number of detected extra-solar planets in a magnitude-limited sample to improve our knowledge of their orbital elements distributions and thus obtain better constraints for planet-formation models.

Methods. Radial-velocity data were taken at Haute-Provence Observatory (OHP, France) with the ELODIE echelle spectrograph.

Results. We report the presence of a planet orbiting HD 196885 A, with an orbital period of 1349 days. This star was previously suggested to host a 386-day planet, but we cannot confirm its existence. We also detect the presence of a stellar companion, HD 196885 B, and give some constraints on its orbit.

Key words. stars: individual: HD 196885 A – stars: individual: HD 196885 B – stars: binaries: visual – stars: planetary systems – techniques: radial velocities – methods: observational

1. Introduction

The ELODIE Planet Search Survey was an extensive radial-velocity northern survey of dwarf stars at the Haute-Provence Observatory (OHP, France) using the ELODIE high-precision fiber-fed echelle spectrograph (Baranne et al. 1996) mounted on the Cassegrain focus of the 1.93-m telescope. It started to operate at the end of 1993 and acquired data until the summer of 2006, when it was replaced by the new echelle spectrograph SOPHIE (Bouchy & The Sophie Team 2006).

This survey is part of a large effort aiming at an extra-solar planet search through radial-velocity measurements, in order to characterize the zoo of exoplanets and to bring strong constraints on their processes of formation and evolution. ELODIE was responsible for the findings of many extra-solar planets, among them the first hot Jupiter, 51 Peg b (Mayor & Queloz 1995). The original sample consisted of 142 stars, but a new sample of 330 stars was defined in 1997. Details about the program and the surveyed sample can be found in Perrier et al. (2003).

In this paper we present the detection of two bodies around the star HD 196885 A, one in the mass range of planets and the other believed to be a stellar companion. This star was previously described to harbor a planet with a period of about 386 days (although no published reference is known), but we could not confirm its presence in our observations (our analysis shows a planet with an orbital period of about 1349 days instead). The stellar companion was also recently observed using NACO adaptive optics by Chauvin et al. (2006, 2007). The stellar properties of HD 196885 A are briefly recalled in Sect. 2 and the radial velocities with the two detected companions are described in Sect. 3.

In Sect. 4 we discuss the possibility of existence of more companions, in particular around 368 days. Last section is devoted to our conclusions on this system.

2. HD 196885 A stellar characteristics

HD 196885 A was observed by the HIPPARCOS astrometric satellite (HIP 101966). A high-precision spectroscopic study of this star was also performed by Sousa et al. (2006) in order to examine the metallicity distribution of stars hosting planets. Moreover, this star was also studied by the near-infrared survey with adaptive optics of faint circumstellar environments, sensitive to companions within the stellar and the sub-stellar domains (Chauvin et al. 2006, 2007). Observed and inferred stellar parameters from these different sources are summarized in Table 1.

In the HIPPARCOS catalogue, HD 196885 A is given a spectral type F8 IV, a visual magnitude $V = 6.398$ and a color index $B - V = 0.559$. The measured parallax ($30.31 \pm 0.81$ mas) leads to a distance of $33.0 \pm 0.9$ pc and an absolute magnitude of $M_V = 3.8 \pm 0.1$. From CORALIE spectra, Sousa et al. (2006) derived an effective temperature $T_{\text{eff}} = 6340 \pm 39$ K, a gravity log $g = 4.46 \pm 0.02$ and a high metal content $[\text{Fe/H}] = 0.29 \pm 0.05$ (Table 1). The bolometric correction ($BC = -0.006$) is computed from Flower (1996) using the spectroscopic $T_{\text{eff}}$ determination. The bolometric magnitude is then $M_{\text{Bol}} = 3.791$, which allow us to derive a stellar luminosity of $L = 2.40 L_\odot$. Sousa et al. (2006) also compute the mass, $M = 1.33 M_\odot$, from evolutionary tracks using Geneva models (Schaller et al. 1992, Schaerer et al. 1993). From the $B - V$ value and ELODIE correlation functions we find $v \sin i = 7.3 \pm 1.5$ [km/s], meaning that the star is ro-
Table 1. Observed and inferred stellar parameters for HD 196885 A. Photometric and spectral type are from Chauvin et al. (2006). Astrometric parameters are from HIPPARCOS (ESA 1997). The mass $M$ and the atmospheric parameters $T_{\text{eff}}$, log $g$ and [Fe/H] are from Sousa et al. (2006). The bolometric correction is computed from Flower (1996) using the spectroscopic $T_{\text{eff}}$ determination. The activity level and the rotation period are from Pace & Pasquini (2004). The given age was obtained following the Bayesian approach of Pont & Eyer (2004).

| Parameter | HD 196885 A |
|-----------|-------------|
| Spectral Type | F8 V |
| $V$ | 6.398 |
| $B - V$ | $0.559 \pm 0.006$ |
| $\pi$ | $30.31 \pm 0.81$ |
| $d$ | $33.0 \pm 0.9$ |
| $M_V$ | $3.8 \pm 0.1$ |
| $BC$ | $-0.006$ |
| $M_{\text{bol}}$ | 3.79 |
| $L$ | $2.40$ |
| [Fe/H] | $0.29 \pm 0.05$ |
| log $R'_{\text{HK}}$ | $-5.01$ |
| $P_{\text{rot}}$ | 15 |
| $M$ | $1.33$ |
| $T_{\text{eff}}$ | $6340 \pm 39$ |
| log $g$ | $4.46 \pm 0.02$ |
| $v\sin i$ | $7.3 \pm 1.5$ |
| age | $2.0 \pm 0.5$ |

Fig. 1. ELODIE and CORALIE radial velocities for HD 196885 A, superimposed on a two-keplerian orbital solution (Tab.2).

3. Orbital solutions for the HD 196885 system

The ELODIE observations of HD 196885 A started in June 1997 and the last data acquired are from August 2006, since the ELODIE program was closed shortly after that date. The peculiar variations of the radial velocities (Fig1 and also non-confirmed announcements from other research teams (see section 4), prevented us from announcing this system earlier. However, the recent detection of a visual small stellar companion close to the main star (Chauvin et al. 2006, 2007), confirmed our suspicion of a long term drift of the radial velocities. Superimposed with the drift we can also observe a regular variation of a few years signalizing the presence of a sub-stellar companion.

Before the ELODIE program, the star HD 196885 A had already been followed between June 1982 and August 1997 by the CORAVEL spectrometers (Baranne et al. 1979) mounted on the 1-m Swiss telescope at Haute-Provence Observatory and on the 1.54-m Danish telescope at La Silla Observatory (ESO, Chile). The precision of CORAVEL is $\sim 0.3\text{ Kms}/s$, not enough to detect planetary objects, but very useful to help us to constrain the orbit of the stellar companion. From April 1999 to November 2002 a series of radial velocity measurements were also taken using the CORALIE echelle spectrograph (Queloz et al. 2000) mounted on the 1.2-m Swiss telescope at La Silla. This four year observational sequence is important to confirm the presence of the planetary companion, since the precision of CORALIE is slightly better than the precision of ELODIE.

With 111 radial-velocity measurements (69 from ELODIE, 9 from CORAVEL and 33 from CORALIE), spanning $\sim 14$ years of observations, we are able to describe the orbit of the sub-stellar body in the system, as well as slightly constrain the orbit of the stellar companion. Using the iterative Levenberg-Marquardt method (Press et al. 1992), we first attempt to fit the complete set of radial velocities with a single orbiting companion and a quadratic drift. This fit yields a planetary companion with $P = 1347\text{ days}$, $e = 0.44$, a minimum mass of $2.9 M_{\text{Jup}}$ and an adjustment of $\sqrt{\chi^2} = 1.811$ and $rms = 14.61\text{ m/s}$. We then fit the radial velocities using a model with two Keplerian orbits (Figs1 and 2). It yields for inner planet $P = 1349\text{ days}$, $e = 0.46$ and a minimum mass of $3.0 M_{\text{Jup}}$, while for the outer companion we have $P \approx 20000\text{ days}$, $e = 0.41$ and a minimum mass of $0.34 M_{\text{J}}$ (Tab.2). Despite all the uncertainties in the orbital parameters, the use of a Keplerian orbit for the massive outer body in the system proved to be a good approach, better than the quadratic drift, since the reduced $\sqrt{\chi^2}$ is now 1.494 and the velocity residuals drop to $rms = 11.87\text{ m/s}$ (Fig2). Of course one can always argue that increasing by four the number of free parameters in the model will improve the fit, but at least we are able to give constraints for the orbital parameters of the outer body. For instance, we find that it must present an orbital period $P > 40\text{ yr}$, a semi-major axis $a > 14\text{ AU}$ and a minimum mass $M \sin i > 0.28 M_{\text{J}}$, since all other fits coherent with the data found larger values for these parameters (Tab.3).

As expected, the orbital parameters of the outer body still present some uncertainties around the best fitted value. This is particularly true for the orbital period, meaning that this parameter may assume rather different values. The Levenberg-Marquardt method converges to a minimum $\chi^2$, but other close local minima may represent as well a good fit to our data. For
Table 2. Orbital parameters for two bodies orbiting HD 196885 A, obtained with a two-keplerian fit to observational data. Errors are given by the standard deviation $\sigma$. The orbital period of the outer body is much longer than the data acquired so far ($\sim 14$ yr) and thus we are unable to completely constrain its orbit. However, we noticed that it is actually better to fit a complete elliptical orbit to the present data, rather than use a quadratic drift, for which we obtained $\sqrt{\chi^2} = 1.811$ and $rms = 14.61$ m/s. Alternative solutions for the outer body with longer orbital periods exist, that match the data almost as good as the best fit (Tab.3).

| Param. | [unit] | HD 196885 Ab | HD 196885 B |
|--------|--------|--------------|--------------|
| $V$    | [km/s] | $-31.666 \pm 0.455$ | $3.69 \pm 0.03$ |
| $P$    | [year] | $55.43 \pm 19.48$ | $4041 \pm 270$ |
| $e$    | [deg] | $0.462 \pm 0.026$ | $227.6 \pm 23.4$ |
| $\omega$ | [deg] | $91.4 \pm 4.1$ | $2041 \pm 270$ |
| $K$    | [m/s] | $11.87 \pm 0.05$ | $11.88 \pm 0.05$ |
| $T$    | [JD-2400000] | $51236 \pm 18$ | $45928 \pm 2638$ |
| $a_1 \sin i$ | [$10^{-3}$ AU] | $4.45$ | $13.56$ |
| $f(M)$ | [$10^{-3}$ $M_\odot$] | $6.5 \times 10^{-6}$ | $13.56$ |
| $M \sin i$ | [$M_{\odot}$] | $2.96$ | $351.5$ |
| $M \sin i$ | [$M_{\odot}$] | $0.0028$ | $0.34$ |
| $a$    | [AU]  | $2.63$ | $17.23$ |
| $rms$  | [m/s] | $11.87$ | $11.88$ |
| $\sqrt{\chi^2}$ | | $1.494$ | $1.494$ |

Fig. 2. Phase-folded radial velocities measurements and best fit for the planetary companion of HD 196885 A (top) and the its stellar companion (bottom). For each body the contribution by the other companion has been subtracted from the observational data. The orbital period of the inner body is $P = 3.7$ yr, while for the outer body we have $P = 55$ yr (Tab.2). However, the fact that we are unable to completely cover in phase the orbit of the stellar companion, clearly indicates that its orbital period may be considerably longer (Tab.3).

Table 3. Alternative orbital parameters for the stellar companion HD 196885 B. With the present $\sim 14$ years of observational data it is still impossible to completely constrain the outer body orbit. Observations done by Chauvin et al. (2006, 2007) point to a small stellar companion with $0.5 \sim 0.6 M_\odot$ at about 23 AU. Fixing the orbital period at larger values, we are able to find orbital solutions compatible with those observations.

| $P$ | [yr] | $a$ | [AU] | $e$ | $\omega$ | [deg] | $T$ | [JD] | $M \sin i$ | $rms$ | [m/s] | $\sqrt{\chi^2}$ |
|-----|------|-----|------|-----|---------|-------|-----|------|---------|-------|-------|----------------|
| 40  | 13.7 | 0.50| 204  | 45983| 0.28    | 11.95| 1.504|
| 60  | 18.3 | 0.41| 233  | 45916| 0.36    | 11.87| 1.494|
| 80  | 22.4 | 0.42| 250  | 46136| 0.43    | 11.88| 1.495|
| 100 | 26.6 | 0.45| 258  | 45987| 0.55    | 11.88| 1.495|
| 120 | 30.4 | 0.49| 265  | 46110| 0.61    | 11.89| 1.496|

4. A second planet around one year?

In 2004 it was reported a $P = 386$ days companion to the HD 196885 A star, by the California & Carnegie Planet Search Team on their webpage\footnote{1} detected through radial-velocity measurements obtained with the Lick survey. This planet is also listed in the the exoplanets Encyclopediad\footnote{2} by Fischer & Valenti (2005), Chauvin et al. (2007) and Marchi (2007). Unfortunately it is not known any publication describing the system as noticed by many other authors (Chauvin et al. 2006; Sousa et al. 2006; Bonavita & Desidera 2007; Desidera & Barbieri 2007). Moreover, the system is not reported in the 2006 exoplanet catalog by Butler et al. (2006), so we assume there was no confirmation of this planet after the first announcement.

\footnote{1}{http://exoplanets.org/esp/hd196885/hd196885.shtml}
\footnote{2}{http://exoplanet.eu/planet.php?p1=HD+196885&p2=b}
Curiously, performing a frequency analysis of the ELODIE radial velocity residuals (Fig.1), we find an important peak signature at about $P = 368$ days (Fig.2), that could be interpreted as a second planet around HD 196885 A. However, this peak is not present when we analyze CORALIE data, casting some doubts on its origin. Computing the ELODIE window function, we also remark an important peak at exactly 368 days (Fig.3), clearly suggesting that the peak shown in the frequency analysis is nothing but an aliasing of the observational data. Performing a Keplerian fit to the ELODIE residuals, we find that the best fit corresponds to solutions with very high eccentricities ($e \sim 0.8$), that are not dynamical stable. Moreover, when we plot a phase-folded of the residual radial velocities (Fig.4), we can see that our observations only cover half of the orbit, preventing us from fully constrain it. Finally, we performed a Keplerian fit of the three bodies also including data from CORALIE and CORAVEL. We found $\chi^2 = 1.460$ and $rms = 11.30$ m/s, which does not represent a substantial improvement with respect to the system with only two companions (Tab.2). The presence of a companion around 368 days can thus be discarded.

Besides the false alarm companion at 368 days, we may ask if there are other companions at different orbital periods. For that purpose we used a genetic algorithm, since we cannot clearly isolate any other peak in the frequency analysis of Figure 3. The inclusion of a third companion in the system allow us to reduce the $\sqrt{\chi^2}$ up to 1.25 and the $rms = 10.5$ m/s. This represents only a slightly better adjustment of the model to the data that can be justified as a natural consequence of increasing the number of free parameters. Moreover, identical adjustments can be obtained with many orbital periods, as different as 1.3 days and 10 days, frequently with very high eccentricity values. Therefore, no other companion can be conclusively detected in the residuals from the orbital solution listed in Table 2.

5. Discussion and conclusion

In this paper we report the presence of a planet orbiting the HD 196885 A star, with an orbital period of 1349 days. We also detect the presence of the stellar companion HD 196885 B, that was recently observed by Chauvin et al. (2006, 2007). Its orbit is not completely determined, but we are able to provide some constraints: $P > 40$ yr, $a > 14$ AU and $M \sin i > 0.28$ $M_\odot$. It is possible to find a large set of orbits with much longer orbital periods, that fit the observational data as good as the minimum mass orbits (Tab.3). In particular, we find a solution at $P = 120$ yr with $M \sin i = 0.6$ $M_\odot$, the mass estimated by Chauvin et al. (2007).

The HD 196885 A system was previously described as a star orbited by a planet at 386 days by the California & Carnegie Planet Search Team, detected with data acquired with the Lick survey. Although the system is reported on their webpage and many other places, no publication describing the system is yet known. The data acquired with the ELODIE survey also present some signal around 368 days, but a more detailed analysis shows that this signal corresponds to an aliasing of the observational data, probably due to the similarities with the Earth orbital period. We thus do not confirm the existence of the planet obtained with measurements form the Lick survey.

The ELODIE radial velocity residuals after subtracting the signal from the two companions still presents a $O - C$ (Fig.1) slightly above the precision of the instrument. This suggests that the system may still hide additional planetary companions. However, we were unable to find them, even when using a genetic algorithm. The excess in the residuals can also be a contamination from the spectrum of the stellar companion HD 196885 B. We have searched for its presence in our ELODIE data using multi-order TODCOR, a two-dimensional cross-correlation algorithm (Zucker et al. 2004), but did not find anything convincing. We have also searched for correlations between line bisectors and radial velocity or residuals. No significant correlation could be detected. These negative results do not allow us to formally discard the blend scenario, but they render it an unlikely possibility.

The planet HD 196885 Ab is the fourth to be discovered in a close binary with a separation smaller than 25 AU. The other cases already known are Gliese 86 (Queloz et al.)
These systems are ideal for carrying out combined astrometric and radial-velocity observations to constrain the binary dynamic properties and the possible impact of a close binary companion on planet formation and evolution.

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