COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 6145

Konkoly Observatory
Budapest
23 June 2015

HU ISSN 0374 – 0676

HIP10680/HIP10679: A VISUAL BINARY IN THE β PICTORIS ASSOCIATION WITH THE FASTEST ROTATING MEMBER

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Introduction

We are carrying out a photometric monitoring of confirmed and candidate members of the young β Pictoris association. Particular emphasis is given to multiple stellar systems to study the distribution of the rotation periods of their components. We want to investigate what causes significant differences among the rotation periods. Causes can be either different initial rotation periods or primordial disc lifetimes. Specifically, we find that components with very close either stellar or sub-stellar mass companions tend to exhibit a rotation period shorter than more distant components (see, e.g. Messina et al. 2014, 2015). In this paper, we present the case of the wide visual binary HIP 10680/HIP 10679 for which we have measured for the first time the rotation periods.

Literature information

HIP 10680 (RA = 02:17:25.3, DEC = +28:44:42.1, J2000, V = 6.95 mag) and HIP 10679 (RA = 02:17:24.73, DEC = +28:44:30.3, J2000, V = 7.75 mag) are components of a common proper motion visual binary (also named HD 14082AB, BD+28 382AB) consisting of F5V + G2V dwarfs. An angular separation $\rho = 13.8''$ between the two components is reported in The Washington Visual Double Star Catalog (Mason et al. 2001). The parallaxes measured by Hipparcos have an uncertainty of the order of 15%, and correspond to distances $d = 34.5$ pc for HIP 10680 and $d = 27.3$ pc for HIP 10679. The most reliable distance determination was recently provided by Pecaut & Mamajek (2013), who report for both components a kinematic distance $d = 37.62 \pm 2.73$ pc. This measurement is based on UCAC4 proper motions (Zacharias et al. 2013), the assumption of membership to the β Pictoris association, and the use the convergent point solution. In fact, this visual binary system is a well known member of β Pictoris association. Its membership was first proposed by Zuckerman & Song (2004), and subsequently confirmed by Torres et al. (2006), Lépine & Simon (2009), Kiss et al. (2011), and more recently by Malo et al. (2014).

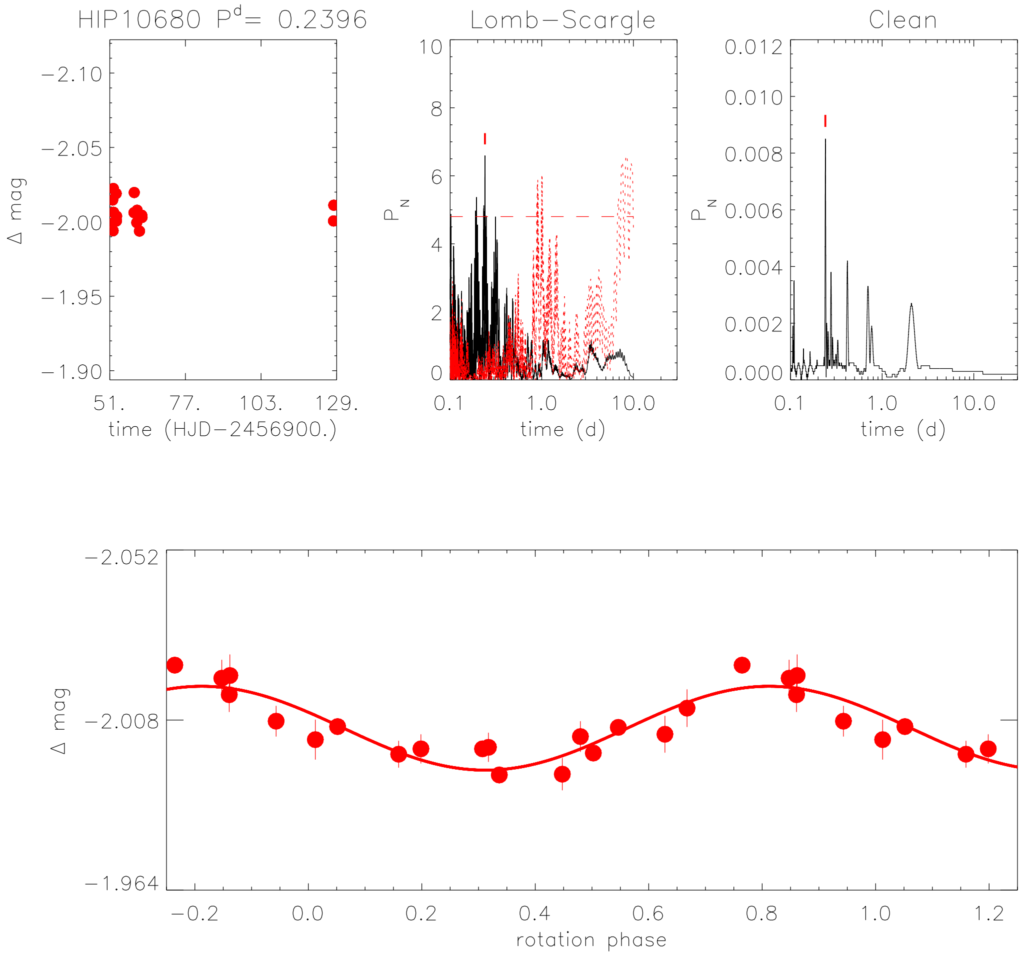

Figure 1. *top panels:* (left) Our new observations (combined B, V, and R magnitudes; see text) of HIP 10680 collected at the Taurus Hill Observatory; (middle) LS periodogram (dotted line is the window function and horizontal dashed line the power corresponding to a 99% confidence level); (right) CLEAN periodogram. *bottom panel:* light curve phased with the $P = 0.2396$ d rotation period and with overplotted (solid line) a sinusoidal fit with an amplitude of Δmag $= 0.026$ mag.

The cooler G2V component HIP 10679 hosts a debris disc first detected based on its infrared excess using the MIPS (Multiband Imaging Photometer for Spitzer) instrument onboard the Spitzer Space Telescope (Rebull et al., 2008). They derived a disc radius of 20 AU and a luminosity ratio $L_{\rm d}/L_\star = 80 \times 10^{-4}$. The disc was subsequently detected by Herschel Space Observatory, whose observations allowed Riviere-Marichalar et al. (2014) to infer an inner radius of 8.5 AU, mass $3.7 \times 10^{-3} M_\oplus$, and $T_{\rm dust} = 97$ K. In contrast, the same observations did not detect any evidence of disc around the hotter F5V component HIP10680. Both components were observed by Brandt et al. (2014) as part of the SEEDS high-contrast imaging survey of exoplanets and disks, but no companion was detected within a projected separation of 7.5″ (∼210 AU).

HIP 10680 and HIP 10679 have projected equatorial velocities $v \sin i = 37.6\,{\rm kms^{-1}}$ and $v \sin i = 7.8\,{\rm kms^{-1}}$, respectively (Valenti & Fischer 2005). Similar values, $v \sin i = 45\,{\rm kms^{-1}}$ and $v \sin i = 8\,{\rm kms^{-1}}$, respectively, are measured by Torres et al. (2006). Both components have well detected Li line. Mentuch et al. (2008) measured EW = 132 mÅ and EW = 172 mÅ for HIP 10680 and HIP 10679, respectively; da Silva et al. (2009) measured EW = 140 mÅ and EW = 160 mÅ for HIP 10680 and HIP 10679, respectively. Fast rotation and high lithium content are indicators of youth and are well consistent with the young age of 23 Myr inferred by Mamajek & Bell (2014) for the β Pictoris association.

HIP 10680 is reported in the Hipparcos catalogue as likely Algol-type eclipsing binary with period $P = 7.06$ d. However, a note to the catalogue reports the possibility that this photometry has been contaminated at some epochs by the presence of the close companion generating a spurious variability.

Consistently with the young age and their low-mass, we expect that both components exhibit photometric variability, possibly periodic, caused by the presence of surface temperature inhomogeneities. The photometric variability can in principle allow us to measure the rotation period. Multi-band photometric observations are suited to infer the rotation period and can add information on the nature of surface inhomogeneities, i.e. on their temperature, and on a lower limit on their covering fraction.

Observations

To measure the photometric rotation periods of both components we carried out a multi-filter photometric monitoring at the Taurus Hill Observatory (62°18′54″N and 28°23′21″E, 160 m a.s.l., Varkaus, Finland). Observations were collected with a 35-cm f/11 Celestron telescope on a Paramount ME German equatorial mount, and equipped with a SBIG ST-8XME CCD camera (1530×1020, 9 μm pixels size), and Johnson-Bessell BVR filters.

The visual binary HIP 10680/HIP 10679 was observed from October 21, 2014 until January 5, 2015 for a total of 7 nights. We observed in the B, V, and R filters and collected a total of 90 frames in each filter. On a few nights, we observed the binary up to four times at distance of about 2 hours from one pointing to the subsequent one. On each pointing, we collected five consecutive frames per filter. Exposure times were set to 15, 6, and 2 sec for the B, V, and R filters, respectively. Bias subtraction and flat fielding of science frames were performed with MaxIm DL 5.0 (Diffraction Limited, Canada) and the magnitude time series of each component and other nearby stars were extracted using aperture photometry. Each series of five consecutive magnitudes was averaged for the subsequent analysis. After averaging, we were left with 17 averaged magnitudes per filter whose photometric precisions turned out to be $\sigma_B = 0.006$, $\sigma_V = 0.006$, and

$\sigma_R = 0.007$ mag. The stars BD+28 381 (RA = 02:17:10.77, DEC = +28:40:55.60, J2000.0, $V = 9.09$, $B - V = 1.06$) and GSC 1777-01383 (RA = 02:17:24, DEC = 28:40:39, J2000, $V = 12.82$) turned out to be well suited to be used as comparison (C) and check (CK) stars to get differential magnitudes of our targets. The standard deviation of the CK−C magnitude time series turned out to be $\sigma_{\rm CK-C} = 0.009$ mag.

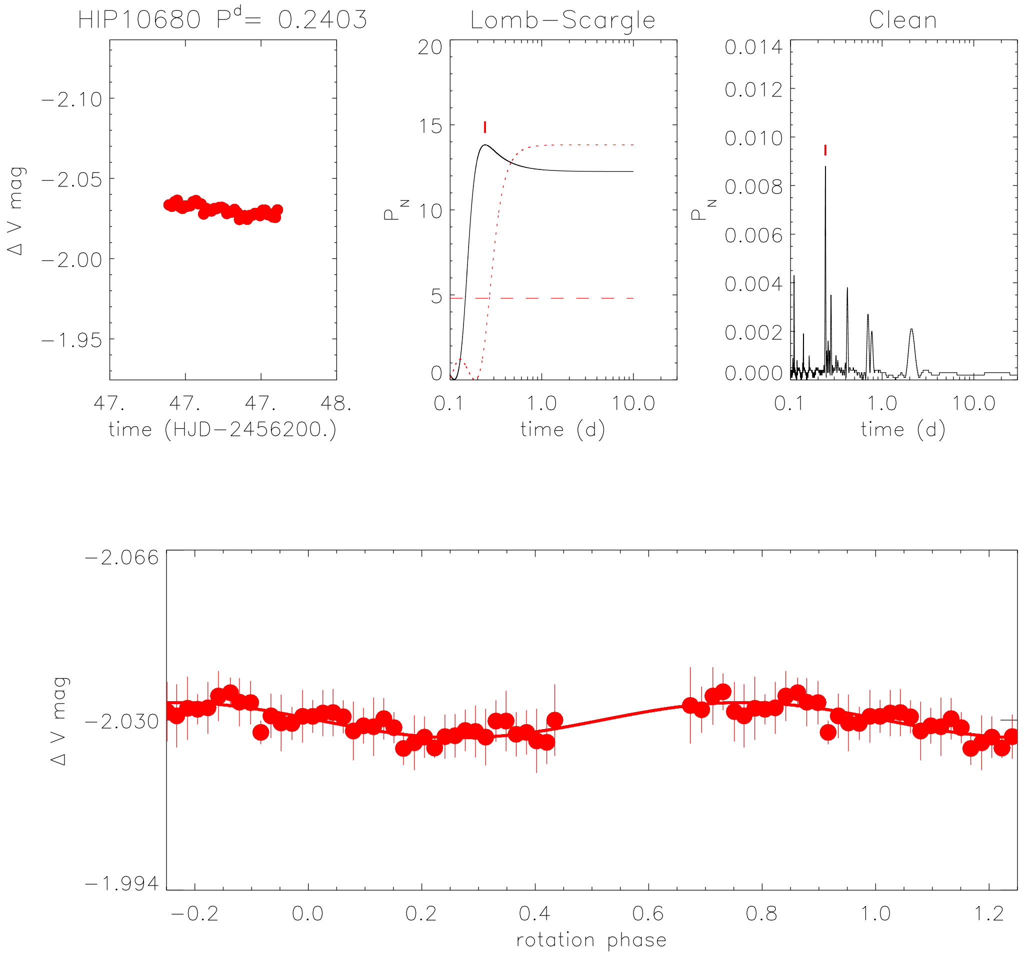

Figure 2. The same as in Fig. 1, but for data collected at Canis Mayor Observatory in the V band and phased with the rotation period $P = 0.2403$ d.

On one night, November 15, 2012, we could get a series of 390 frames in the V filter at the Canis Mayor Observatory (44°06′17″ N and 10°00′29″ E, 190 m a.s.l., La Spezia, Italy). Observations were collected by a 40-cm f/8 telescope equipped with a SBIG STL 6303 CCD camera (0.58″/pixel plate scale and 29.5′ × 19.7′ field of view) using 10-s exposure. Frame reduction was done as already described for the data collected at the Taurus Hill Observatory.

Search for rotation periods

HIP 10680

We carried out a Pearson linear correlation analysis among the magnitude variations in different filters and found that B, V, and R magnitude variations were well correlated (we measured the following linear correlation coefficients: $r_{BV} = 0.61$; $r_{BR} = 0.54$; $r_{VR} = 0.57$ with significance level $> 99.9\%$). To improve the S/N ratio of the magnitude time series for the periodogram analysis, we averaged the B, V, and R band light curves. The Lomb-Scargle (LS; Scargle 1982) and CLEAN (Roberts et al. 1987) periodogram analyses revealed a significant (FAP $< 1\%$) power peak at $P = 0.2396 \pm 0.0005$ d which we consider the stellar rotation period. For instance, this is to date the shortest rotation period ever measured in a member of the β Pictoris association. The light curve amplitudes inferred from the amplitude of the sinusoidal fit are $\Delta B = 0.035$, $\Delta V = 0.026$, $\Delta R = 0.021$ mag. An estimate of the False Alarm Probability (FAP), that is the probability that a peak of given power in the periodogram is caused by statistical variations, i.e., by Gaussian noise, was done using Monte Carlo simulations according to the approach outlined by Herbst et al. (2002). The uncertainty on the rotation period determination was estimated following Lamm et al. (2004; see also Messina et al. 2010). The results are summarized in Fig. 1.

The results of the periodogram analysis of the data collected at the Canis Mayor Observatory are summarized in Fig. 2. In this case, we note that the observations lasted about 0.19 d, and, therefore, were not long enough to measure the rotation period of HIP 10680 (the time span of observations should be at least longer than 1.5 times the searched rotation period). Nonetheless, thanks to the dense sampling we could retrieve the correct rotation period and, consistently with the other datasets, we presented the same analysis. In this case the results can be considered as a confirmation rather than an independent determination of the rotation period of HIP 10680.

We could retrieve observations of this binary system also from the SuperWASP (Butters et al. 2010) and Hipparcos (Turon et al. 1993) public archives. This binary system was observed by SWASP (1SWASP J021725.28 +284442.1) on three nights only, from 19 to 21 July, 2008. A total of 21 V-band frames were collected, where the two components are not spatially resolved. Owing to the stellar brightness, the photometric precision was very high ($\sigma_V = 0.003$ mag). The LS and Clean periodogram analyses revealed the most significant power peak at $P = 0.2405$ d, which is in very good agreement with our independent period determination. Although the components are unresolved in the SuperWASP photometry, the flux variability is likely dominated by the brighter F5V component (HIP 10680). The results are summarized in Fig. 3.

This binary system was also observed by Hipparcos from January 1990 to March 1992. After removing outliers, and averaging consecutive observations collected within 20 min, a total of 33 magnitudes were left for the subsequent analysis. Owing to the stellar brightness, the photometric precision was very high ($\sigma_V = 0.007$ mag). The LS and CLEAN periodogram analyses revealed the most significant power peak at P = 0.2805 d, and P = 0.2005 d. A note to the Hipparcos catalogue reports the possibility that this photometry has been contaminated at some epochs by the presence of the close companion generating a spurious variability. This may explain the about 10% discrepancy with respect to the period derived from our own and the SuperWASP photometry. The results are summarized in Fig. 4.

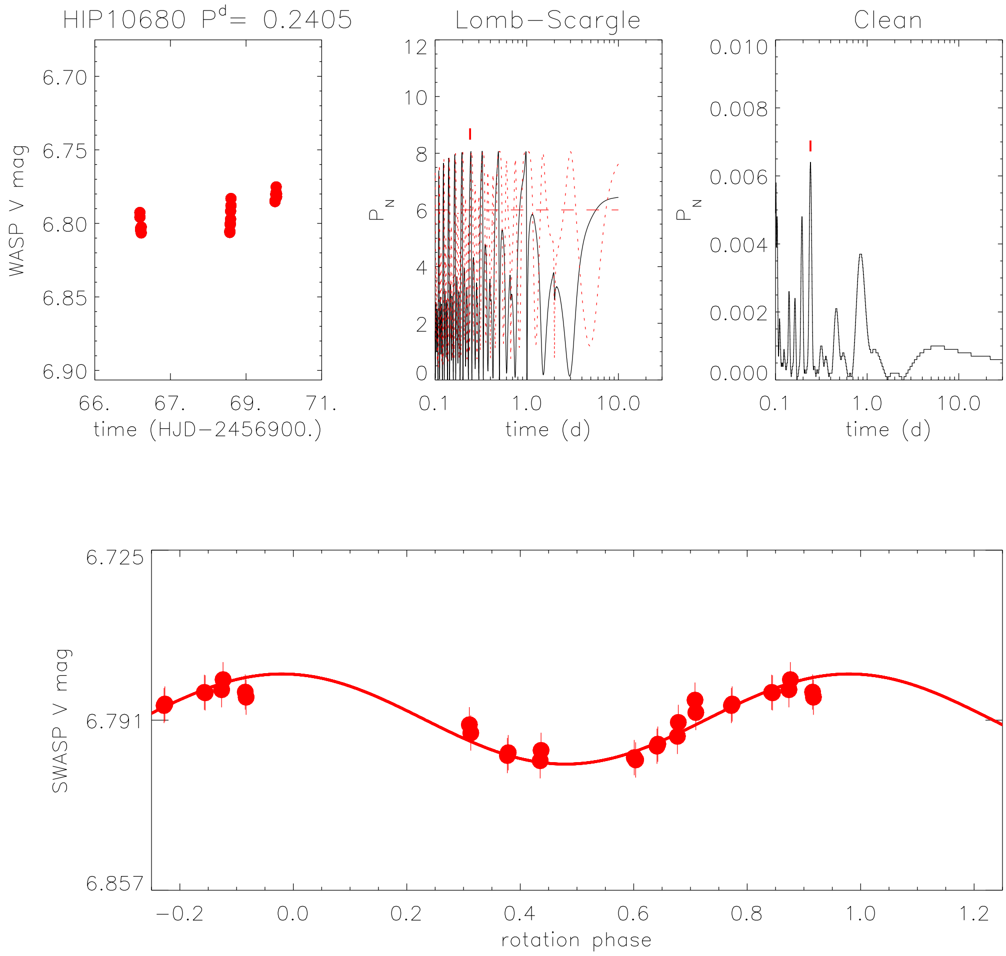

Figure 3. The same as in Fig. 1, but for data collected by SuperWASP for the unresolved system HIP10680+HIP10679. The light curve is phased with the P = 0.240 d rotation period and with overplotted (solid line) a sinusoidal fit with an amplitude of ΔV = 0.035 mag.

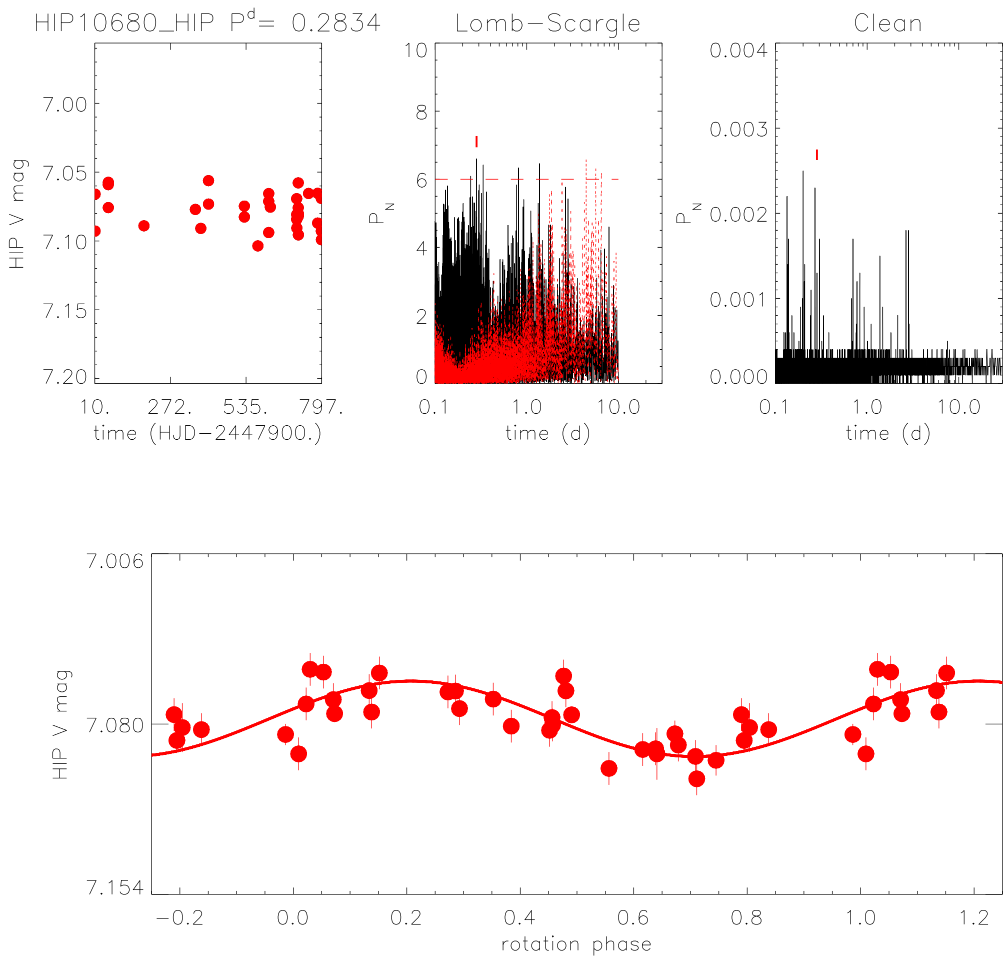

Figure 4. The same as in Fig. 1, but for data collected by Hipparcos. The light curve is phased with the $P = 0.240$ d rotation period and with overplotted (solid line) a sinusoidal fit with an amplitude of $\Delta V = 0.030$ mag.

HIP10679

We carried out a Pearson linear correlation analysis among the magnitude variations in different filters and found that the correlation coefficients are $r > 0.70$ with confidence level $> 99.8\%$. As done for HIP 10680, we averaged the multi-band light curves. The LS and CLEAN periodograms revealed the highest power peak to be at $P = 0.777 \pm 0.005$ d with FAP $< 1\%$. This is the stellar rotation period of HIP 10679. The light curves have peak-to-peak amplitudes $\Delta B = 0.06$, $\Delta V = 0.07$, and $\Delta R = 0.07$ mag. The results are summarized in Fig. 5.

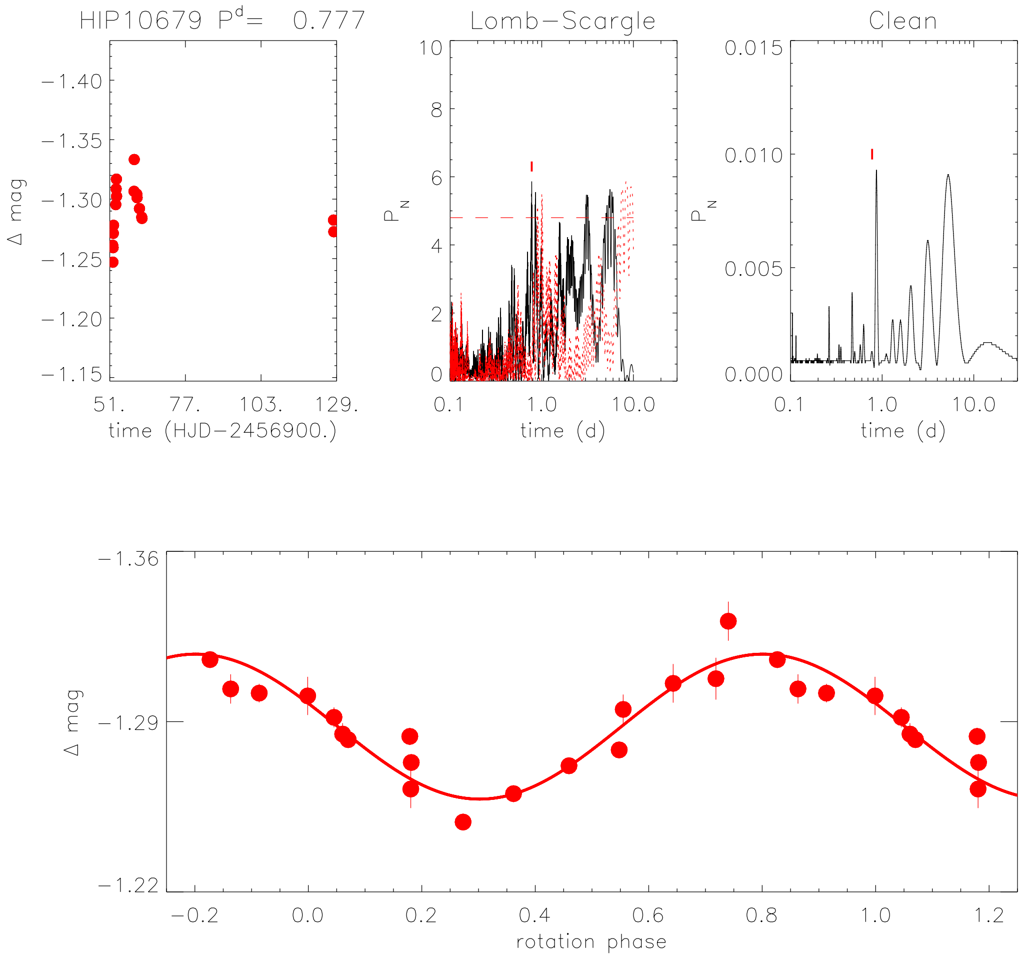

Figure 5. *top panels:* Our new observations (combined B, V, and R magnitudes; see text) of HIP 10679; LS periodogram (dotted line is the window function and horizontal dashed line the power corresponding to a 99% confidence level); and CLEAN periodograms. *bottom panel:* light curve phased with the $P = 0.777\,d$ rotation period and with overplotted (solid line) a sinusoidal fit with an amplitude of Δmag $= 0.07$ mag.

We could retrieve also the magnitude time series of HIP 10679 collected by Hipparcos.

Although the magnitudes are to some level contaminated by the flux from the nearby brighter star, we could retrieve from our periodogram analysis about the same rotation period $P = 0.78 \pm 0.02$ d. The results are summarized in Fig. 6. No similar rotation period was found in the short SuperWASP time series.

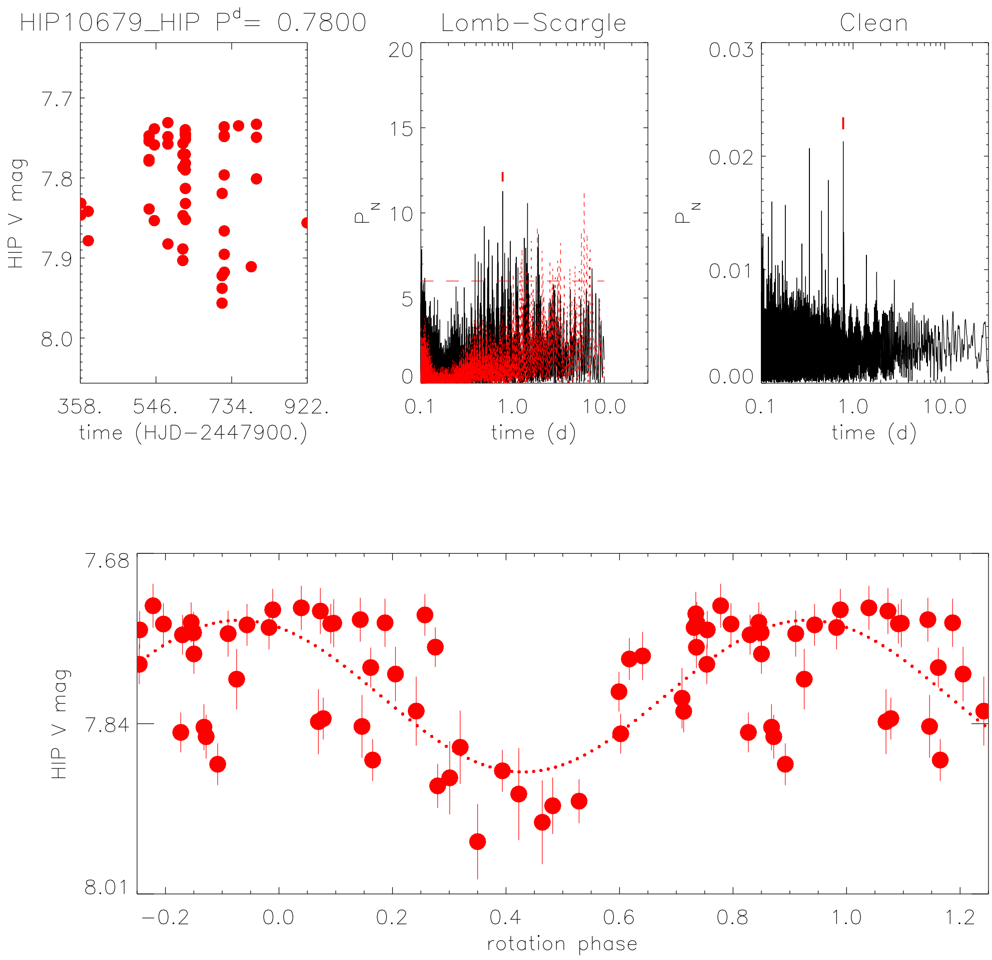

Figure 6. The same as in Fig. 5, but for data collected by Hipparcos. A mentioned in the text, this photometry may be contaminated by the flux from the brighter component.

Discussion

Using the observed V magnitude, the distance from Pecaut & Mamajek (2013), the bolometric correction and effective temperature proper for their spectral types from Pecaut & Mamajek (2013) we could estimate the luminosity and radius of both components. For HIP 10680, we derive a luminosity $L = 1.88 \pm 0.17\, L_{\odot}$, a radius $R = 1.11 \pm 0.10\, R_{\odot}$. Combining radius and average projected stellar velocity, we estimate an inclination of the stellar rotation axis $i \sim 10°$.

For HIP 10679, we derive a luminosity $L = 0.96 \pm 0.09\,L_{\odot}$, a radius $R = 0.95 \pm 0.09\,R_{\odot}$. Combining radius and average projected stellar velocity we estimate an inclination of the stellar rotation axis $i \sim 10°$. The same inclination likely arises from the common formation and early evolution processes of the two stars in the same binary system. An interesting aspect presented by this system is that the two components have a significant difference in their rotation periods. This difference may be due to the different masses. However, we find from a comparison with the evolutionary models of Siess et al. (2000) that this difference is not larger than about 15%. Different initial rotation periods may also have caused the presently observed difference. However, we note that the slower rotating G2V component hosts a debris disc. There is evidence of an anti-correlation between the presence of IR excess, revealing the presence of primordial discs, and the rotation period in very young stars (see, e.g. Bouvier et al. 1993, Rebull et al. 2004). In fact, the magnetic disc-locking should lock the rotation of the external star's envelope with the disc rotation and prevent the star to spin-up despite the stellar radius contraction. By the age of β Pictoris, such an anti-correlation is not as significant as in younger stars, and it appears as a weak tendency of fast rotators to have smaller IR excess (see Rebull et al. 2008). However, the available sample is not large and $v \sin i$ is used to measure the rotation rate, instead of the more robust rotation period. In our specific case, one possibility to explain the rotation period difference is that the component with IR excess HIP10679 may have had a disc-locking phase longer than the other component, for which no IR excess is detected. The shorter disc-locking phase of HIP10680 may have allowed this star to start the rotation spin-up, owing to radius contraction towards the ZAMS, earlier than HIP10679, and therefore reaching a shorter rotation period at the present age. However, we just propose it as one possibility.

What may have caused different disc-lifetimes for the two components and different rotation periods is currently unknown. In fact, neither binarity nor the presence of substellar companion have been reported for either star, that may have gravitationally perturbed the primordial disc of HIP 10680, enhancing its dispersal.

Conclusions

We have carried out a multi-filter photometric monitoring of the wide visual binary HIP10680/HIP10679. We found that HIP10680 has a rotation period $P = 0.2396 \pm 0.0005$ d, which is the shortest value ever measured in the β Pictoris association, whereas HIP10679 has a rotation period $P = 0.777 \pm 0.005$ d. Combining stellar radii and projected rotational velocities, we found that both components have same inclinations of their rotation axes, $i \sim 10°$ and, therefore, they are seen almost pole-on. Despite the low inclination, both components exhibit a significant photometric variability whose amplitudes in the V band are $\Delta V = 0.03$ mag and $\Delta V = 0.07$ mag, for HIP10680 and HIP10679, respectively. The G2V star, having a deeper convection zone, and consequently, a more efficient dynamo action, shows a larger amplitude variability. Although the two components have a mass difference not larger than 15%, they exhibit a significant difference between their rotation periods. Such difference may arise either from different initial rotation periods or to different disc life times. For instance, the slower component HIP 10679 hosts a well known debris disc.

Acknowledgements: The extensive use of the SIMBAD database operated by the CDS, Strasbourg, France, and the ADS database operated by the Smithsonian Astrophysical Observatory (SAO) under a NASA grant, are gratefully acknowledged. We thank the Super-WASP consortium for the use of their public archive in this research. We also thanks the anonymous Referee for useful comments and suggestions.

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