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Research Note

A photometric survey of stars with circumstellar material⋆

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Abstract. We present the result of a follow-up Strömgren photometric survey of sixteen southern bright stars with circumstellar material, in order to detect possible weak photometric variations. We found new variations of the β Pictoris brightness from 1999 to 2002 with a weak long-term variation of $\sim-0.8 \times 10^{-3}$ mag per year, over about 3 years. These variations look similar to those seen from 1975 to 1981 and from 1995 to 1998 (Nitschelm et al. 2000, A&AS, 145, 275). They can be due to differential occultation by dust inhomogeneities transiting the star through the years. We detected new periodic variations for HD 256 (HR 10) with periods ranging from 0.35 day to 6.69 days during several months. These variations may also be interpreted in terms of variable obscuration due to structures in the circumstellar disk suspected to be surrounding this star.

Key words. stars: individual: β Pic, HR 10, HD 38392, V1026 Sco – circumstellar matter – planetary systems

1. Introduction

The so-called "debris-disks" must be the by-product of (young?) planetary system activity. Among stars with circumstellar material in the form of a "debris-disk", β Pictoris has a very peculiar status with the closest and brightest circumstellar disk. Because this disk is observed nearly edge-on, a photometric survey can be used to search for signature of material passing in front of the star.

β Pictoris presents δ Scuti type stellar variations over periods of about 30 min (Koen et al. 2003) which are likely to be unrelated to the circumstellar material. But long-term photometric measurements have revealed that β Pictoris presented slow brightness variations from 1975 to 1981 and rapid and "large" amplitude ($\gtrsim$0.04 mag) variations in November 1981. This last event lasted about 10 days and showed a sharp transit-like signature during the central night of this puzzling, but extremely significant observation. It has been interpreted in terms of an occultation of the star by either a planet or a giant comet (Lecavelier des Etangs et al. 1995, 1997a; Lamers et al. 1997).

Photometric surveys thus appear as a powerful tool to probe circumstellar material. We undertook a new survey with the Strömgren *uvby* photometric system using the SAT automatic 50 cm Danish telescope atop La Silla observatory. We have performed six observational campaigns of 4 to 5 months each year from 1995 to 2002. The analysis of the three first years of observation from 1995 to 1998 has been reported by Nitschelm et al. (2000, Paper I). Here we report the new results obtained by addition of the last three years of observation. The program carried out from 1999 to 2002 consists of a relatively small number of targets up to 16 stars (Table 1). The target stars were selected because they present either signatures of variability similar to the β Pictoris ones (e.g., HR 10), "debris-disks" (e.g., ε Eridani), or because they present some infrared excess with known high $v \sin i$ value to enhance the probability of extinction by dust within the disk. These three additional years of photometric observations obtained with the same instrumentation provide a comprehensive large set of homogeneous data. Here we report on the analysis of these data (Sect. 2), while the results are given and discussed in Sects. 3 and 4.

2. Data analysis

Using standard programs, the *uvby* observations were reduced by the SAT group of Copenhagen University Observatory (see Crawford & Barnes 1970; Olsen 1994). For each period of observation, the final data contain the Strömgren V magnitude, the $b - y$ color index, the $m_1 = (v - b) - (b - y)$, and the $c_1 = (u - v) - (v - b)$ parameters. The accuracy of the

⋆ Based on observations obtained at the Danish 50 cm telescope (SAT) at ESO, La Silla, Chile.

Table 1. List of targets in our Strömgren photometric survey. Target selection is as follow: harboring a planet (Pl), photometric variable (PV), spectroscopic variable (SV), infrared excess (IR), circumstellar gas (CG), and imaged circumstellar dust (IM). N is the number of measurements for each target between 1999 and 2002.

Object		Spectral type	$v \sin i$ (km s^{-1})	N
HR 10	PV, SV, CG	A2IV/V	241	361
τ Ceti	IR, IM	G8V	8	51
ε Eridani	IR, IM	K2V	8	290
HR 1307	IR, IM	B8Vn	175	254
γ Leporis B	PV	K2V		292
γ Leporis A	IR	F7V	15	294
δ Dorado	IR	A7V	172	289
β Pictoris	all	A5V	130	1146
HR 2174 A	CG	A2V	242	276
HR 3497	IR, Pl	G0Ia-0		295
HD 130322	Pl	K0III		156
HD 141569 A	IR, CG, IM	A0V	258	153
V1026 Sco	IR, PV	A8V		135
51 Ophiuchi	IR, SV, CG	A0V	205	140
HD 192263	Pl	K0		54
HD 209458	Pl	G0V		22

different parameters was evaluated to be $\sigma_V \lesssim 0.006$ mag for the V magnitude and $\sigma_{b-y} \lesssim 0.005$ mag for the $b-y$ color index.

We searched for short-term and long-term, as well as periodic, variations. For each target star, the data analysis was performed by using differences between measurements of the target star and the corresponding measurements made on the comparison stars (see Paper I, for details). A suspected variation was considered as real when detected for two different comparison stars.

2.1. Short-term variations

Short-term variations were detected if two subsequent measurements differed by more than 3 sigma from the average value of the data set. Over our three campaigns and within the accuracy of the measurements, no short-term fluctuations were observed in any of our program stars, except V1026 Sco which is already known as a variable Herbig star (see Sect. 3.2.1).

In the case of β Pictoris, a rapid photometric variation was observed on November 10th, 1981. As this event can be explained by the transit of an extrasolar planet or giant comet (Lecavelier des Etangs et al. 1995; Lamers et al. 1997), periodic repetition of this event can be expected. By assuming it to be periodic, the absence of observation of similar photometric variations in our data set allowed us to eliminate a large range of periods (Paper I). We conclude that 96% of the periods between 0 and 1000 days can be eliminated. 63% of periods between 1000 and 2000 days, 45% of periods between 2000 and 3000 days, and more than 40% of periods between 5000 and 6000 days and between 6500 and 7500 days are also eliminated.

2.2. Long-term variations

To detect possible weak long-term variations, we used the same method as described in Lecavelier des Etangs et al. (1995). We fitted the data from each star (s) by a linear function of the time (t): (a_s+$b_s t$). For all the stars except β Pictoris, we did not find b_s values significantly different from. This shows that our program stars had no significant brightness variations during the survey, and underlines the quality of the survey and the robustness of the detected variations in the case of β Pictoris (Sect. 3.2.4).

2.3. Periodic variations

To search for periodic variations, we calculated the periodogram for each star and the corresponding probability that an apparent period is due to noise (Scargle 1982; Grison 1994). We considered as significant those periods detected with both comparison stars and for which the probability P that the period is due to noise is less than 10^{-2}, or $(-\log_{10} P) > 2$.

The test that both comparison stars give the same signal is crucial. For instance, the magnitude difference between β Pictoris and its comparison star HD 40200 showed a significant period of about 3.2 days. However a test with the other comparison star (HD 35580) demonstrated that these were due to brightness variations of HD 40200.

3. Results and discussion

3.1. Stars without evidence of photometric variations

Most of the stars did not show evidence of photometric variations with a low dispersion in the measured brightness of about $\sigma_V \sim 0.006$ mag. These stars are τ Ceti (HD 10700), ε Eridani (HD 22049), HR 1307 (HD 26676), γ Leporis A (HD 38393), δ Dorado (HD 39014), HR 2174 A (HD 42111), HR 3497 (HD 75289), HD 130322, HD 141569 A, 51 Ophiuchi (HD 158643), HD 192263, and HD 209458 (observed outside the planetary transits).

3.2. Stars with evidence of photometric variations

3.2.1. V1026 Sco (HD 142666)

The Herbig star V1026 Sco was added to the target list because it is known to be an infrared excess source (Walker & Wolstencroft 1988) and a photometric variable. The brightness variations are clearly detected with a maximum amplitude of more than 0.3 mag (Fig. 1). In addition, we note a clear correlation between the brightness and color variations. This behavior significantly differs from most β Pic variations, which do not show color signature. Typically for Herbig stars, V1026 Sco appears to be redder when fainter. If these photometric variations are due to dust, the dust must be typically smaller than $\sim 1\,\mu$m. This small size raises the question of the survival of such small grains that should have been rapidly blown out by the radiation pressure, except if they are dragged by circumstellar gas. We also searched for, but failed to detect, any periodicity in the data of V1026 Sco.

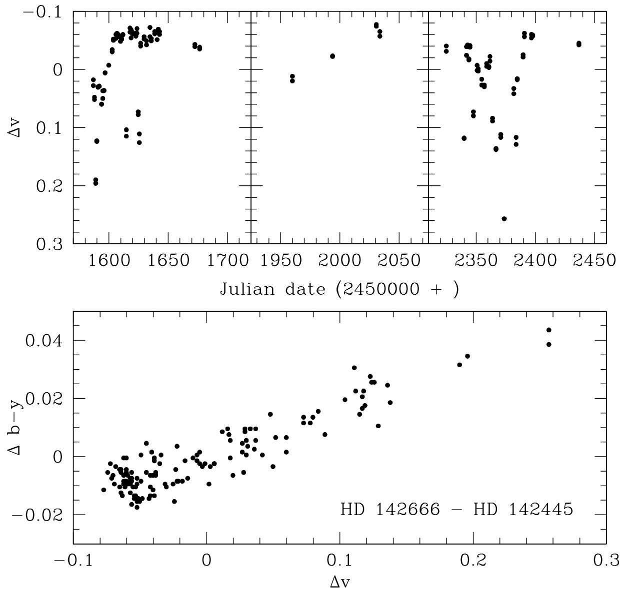

Fig. 1. V1026 Sco (HD 142666) brightness and color variations.

3.2.2. HR 10 (HD 256) periodic variations

HR 10 exhibits clear similarities to β Pictoris, such as similar redshifted variable absorption features (Lagrange-Henri et al. 1990). HR 10 spectra also show signatures of circumstellar gas through the presence of Fe II ions at excited levels requiring large densities, and evidence that clumpy gas is continuously falling onto this star (Lecavelier des Etangs et al. 1997b).

For HR 10, we already detected a short-term photometric variation in January 1990 (Lecavelier des Etangs et al. 1995). Photometric measurements obtained later also show a possible brightness variation around December 25th, 1996 (Nitschelm et al. 2000). New data collected since 1999 do not show this type of variability.

In the new data and for the first time, we found significant periods in the HR 10 brightness from 1999 to 2002. A plot of the periodogram clearly shows signals mainly at 0.54, 1.17, and 6.70 days (see Figs. 2 and 3). In the subset of data collected from October 1999 to February 2000, these periods are also proeminent with probabilities of false detection (P) well below 10^{-2} no matter what the comparison star is used. But in addition, a new period appeared in these four months of observation. We found a significant period of 0.35 days in 1999–2000 with $-\log_{10} P(0.35\,\mathrm{days}) \sim 12$. The other periodic signals are still present but fainter in the data collected from September 2000 to January 2001. No significant periodic variations are detected in data collected from October 2001 to January 2002.

We checked for the presence of periodic signals in the $b-y$ colour index, and no obvious period arised. This is consistent with the low amplitude of the variations and lower signal-to-noise ratio of the colour index. The reason for these newly detected variations remains unknown. We can speculate that these variations could be linked to variable obscuration due to structures in the circumstellar disk suspected to surround this star. New observations are needed to confirm or infirm this hypothesis.

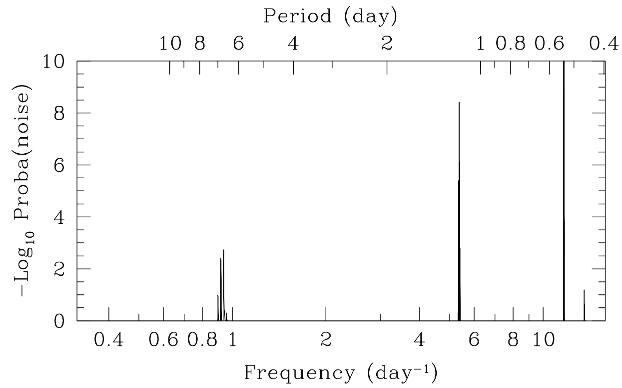

Fig. 2. HR 10 periodogram. This periodogram was obtained by using the data gathered from 1999 to 2002 and using HD 203 as the comparison star. The periodic signals at 0.54, 1.17, and 6.70 days clearly appear with probability of being due to the noise of less than 10^{-2}. The other comparison star HD 693 gives the same results.

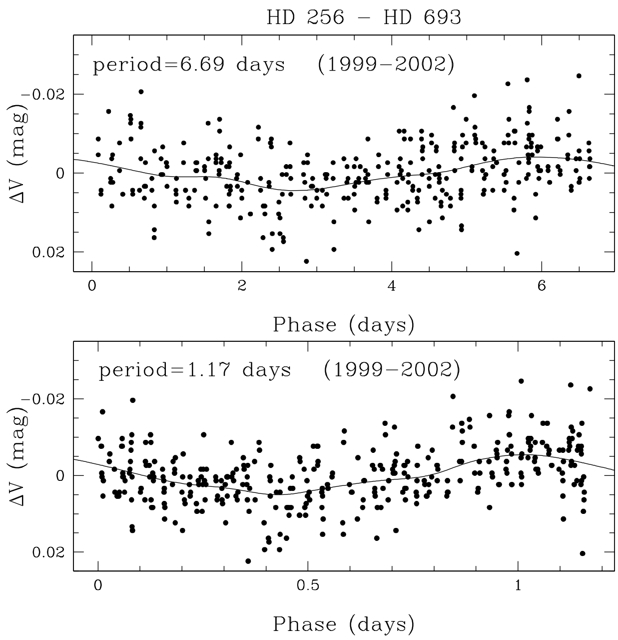

Fig. 3. HR 10 variations with 6.69 and 1.17 days periods in data gathered in the 3 years of observations from 1999 to 2002.

3.2.3. HD 38392 (γ Lep B) pseudo-periodic variations

In the three first campaigns we detected periodic variations in HD 38392 brightness with a period of 21.4 days (Nitschelm et al. 2000). These variations are compatible with the stellar activity of this K2V type star with a rotation period inferred to be of about 20 days from emission in the H and K lines of Mg II (Stepién & Geyer 1995). The new data confirm this interpretation. In the data collected from 1999 to 2002, we found similar periodic brightness variations. However, the periodogram shows various periods for different epochs of observations. In the 1999–2000 data, the brightness variations have a period of about 18.9 days, while in the 2000–2001 data the period is about 21.4 days, linked with another period of 10.5 days. We interpret this as confirmation that the photometric variations are due to stellar activity like stellar spots with various periods

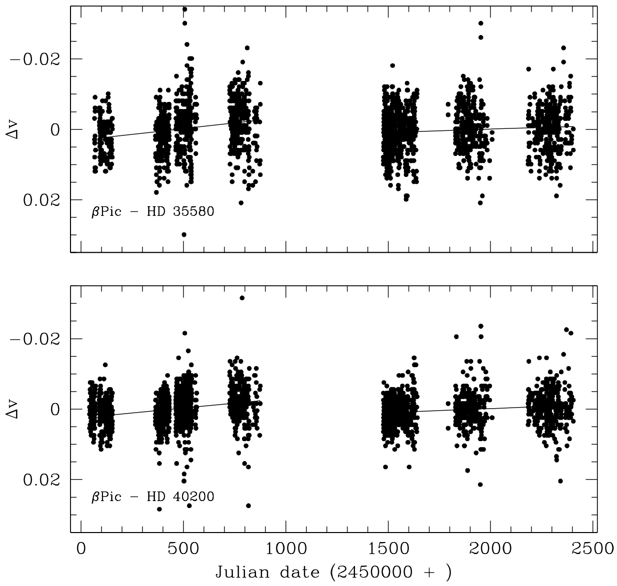

Fig. 4. Plot of the magnitude variations of β Pictoris, using HD 40200 and HD 35580 as comparison stars. β Pictoris shows long-term variations with a significant slope that does not depend upon the comparison star used for the subtraction.

depending upon the latitude of the activity responsible for the observed variations.

3.2.4. β Pictoris (HD 39060) long-term variations

As from our previous surveys, β Pictoris is the only case for which long-term photometric variations are detected. The calculated slopes $b_{\beta\,\mathrm{Pic}}$ are significantly different from 0 (Fig. 4). The probability that the slope is due to statistical noise is $P(b > b_{\beta\,\mathrm{Pic}\ 1995-1998}) \ll 10^{-7}$ in the data obtained from 1995 to 1998 and $P(b > b_{\beta\,\mathrm{Pic}\ 1999-2002}) \ll 10^{-3}$ in the data from 1999 to 2002. The fit of the new data obtained from 1999 to 2002 gives a slope of $(-2.08 \pm 0.36(1\sigma)) \times 10^{-6}$ mag per day. This corresponds to a variation of -0.76×10^{-3} mag per year. As a conclusion, the brightness of β Pictoris obviously increased from JD 2 451 476 (October 24th, 1999) to JD 2 452 404 (May 9th, 2002) by about 1.9×10^{-3} mag.

4. Conclusion

Our Strömgren photometric survey of sixteen southern bright stars with circumstellar material made from 1999 to 2002 gives the following result: twelve targets appear to be constant at the detection limit, whereas four stars show clear variability features.

In particular, the star γ Lep B (HD 38392) turns out to be a pseudo-periodic low amplitude variable, likely due to the presence of stellar spots at different latitudes and to the differential rotation of the star. The Herbig star V1026 Sco shows large amplitude brightness and color variations, but no periodicity was found in our data. The star HR 10 appears to be a low amplitude periodic variable with periods of 0.54, 1.17, and 6.70 days between 1999 and 2001. We also find new long-term variability for β Pictoris, and we note the absence of new rapid photometric variations similar to the November 10th, 1981, event. The origin of these newly detected variations remains unknown but they may be related to differential occultation by structures in the disks surrounding these stars.

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