Photometric monitoring of the young star Par 1724 in Orion

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We report new photometric observations of the ~200 000 year old naked weak-line run-away T Tauri star Par 1724, located north of the Trapezium cluster in Orion. We observed in the broad band filters B, V, R, and I using the 90 cm Dutch telescope on La Silla, the 80 cm Wendelstein telescope, and a 25 cm telescope of the University Observatory Jena in Großschwabhausen near Jena. The photometric data in V and R are consistent with a ~5.7 day rotation period due to spots, as observed before between 1960ies and 2000. Also, for the first time, we present evidence for a long-term 9 or 17.5 year cycle in photometric data (V band) of such a young star, a cycle similar to that to of the Sun and other active stars.

1 Introduction: Par 1724

About 400 years ago, Galileo could observe the rotation of a star due to spots and wrote: I am at last convinced that the spots are objects close to the surface of the solar globe ... also that they are carried around the Sun by its rotation (Galileo 1613). Later on, Schwabe (1843) published in this journal the 2 x 11 year Sun spot cycle. In the last few decades, the rotational periods of many stars have been determined from periodic photometric variability due to surface spots. Also, several old stars (≥4.6 Gyr) were shown to display cycles with similar length, observed often as variability in the Ca H & K emission (e.g. Baliunas et al. 1995), sometimes also in broad photometric bands (e.g. Alekseev 2005); only rarely, stars younger than 1 Gyr were shown to display cycles (Baliunas et al. 1995; Alekseev 2005).

The K0 pre-main sequence star Par 1724 (or P1724) in Orion is listed as star number 1724 in Parenago (1954), it is located at $\alpha = 5^h35^m4.21^s$ and $\delta = -5^\circ 8'3'3.2''$ (J2000.0), i.e. just 15' north of the Trapezium cluster; this star is also called V1321 Ori (Kazarovets & Samus 1997), JW 238 (Jones & Walker 1988), or HBC 452 (Herbig & Bell 1988).

Par 1724 is one of the most active and variable young stars known; see e.g. Neuhäuser et al. (1998) for an extensive observational study: It shows a photometric rotation period of ~5.7 days (seen so far in all data sets from 1968 to 1997); this period is also evident in the radial velocity data; the photometric variability is mostly due to a large solar spot detected indirectly by Doppler imaging; the star also shows strong and variable Hα and X-ray emission as well as other youth indicators (Li 6708 A absorption); according to its luminosity (~49 L⊙) and temperature (5250 K for K0 spectral type) and comparison with evolutionary models, it is ~200 000 years old with a mass of ~3 M⊙; there is no evidence for multiplicity nor for infrared excess emission or circumstellar material; while its mean radial velocity is fully consistent with membership to the Orion Trapezium cluster, its proper motion is somewhat different, but consistent with having been ejected from the Trapezium towards the north some 100 000 years ago; hence, Par 1724 is a run-away weak-line naked T Tauri star; see Neuhäuser et al. (1998) for details. The rotational period of ~5.7 days has also been found by Cutispoto et al. (1996).

The previous photometry resulted in the following average magnitudes (with ranges given in parentheses), data are from Neuhäuser et al. (1998) and literature given therein: $B = 11.87 \pm 0.25$ mag (from 11.41 to 12.33 mag), $V = 10.72 \pm 0.13$ mag (from 10.44 to 10.99 mag), $R = 9.81 \pm 0.17$ mag (from 9.44 to 10.18 mag), and $I = 9.08 \pm 0.16$ mag (from 8.71 to 9.44 mag).

The star may also show a long-term change of its optical...
magnitude, namely getting fainter by $\sim 0.2$ mag in $V$ over 40 years, see Fig. 5 in Neuhäuser et al. (1998), but with long data gaps.

In this work, we observed Par 1724 again in the Bessel $B$, $V$, $R$, and $I$ filters as well as in the Gunn $i$ filter: We took new images in March 1998 with the 90 cm Dutch Telescope on La Silla; then more new images in late 2004 and early 2005 with the 90 cm telescope on Mount Wendelstein observatory of Ludwig-Maximilians University of Munich (USM), located in the southern German Alps; and finally many new images in 2007 and 2008 with the 25 cm (11 inch) Cassegrain-Teleskop-Kamera (CTK) installed piggy back on the tube of the 90 cm telescope at the University Observatory Jena near Großschwabhausen (GSH), see Muguera (2009) for details on CTK.

We present the observations and data reduction in Sect. 2, and the results of absolute and relative photometry in Sects. 3 and 4, respectively. In Sect. 5, we also study again the long-term photometric behaviour of Par 1724 using all data available so far as listed in Neuhäuser et al. (1998), Cutispoto (1998), Cutispoto et al. (1998, 2001, 2003), this work, plus also $V$-band data from the All Sky Automated Survey (ASAS) project available online. We summarize the results in Sect. 6.

## 2 Observation and data reduction

For the observations at the Dutch Telescope, we used the Tektronix TK512CB grade 1 thinned back-illuminated CCD chip, $512 \times 512$ pixels, each 27 $\mu$m in size, to give a field of view of $3.77' \times 3.77'$; see the ESO 90 cm Dutch Telescope Users Manual for more information (www.eso.org).

For the observations at the USM Wendelstein 80 cm telescope, we used the CCD camera MONICA, equipped with a 1k Tektronix chip and Johnson-Bessel $B$, $V$, $R$, and $I$ filters, mounted at the Cassegrain focus.

For the GSH/CTK observations, we use an optical CCD camera IMG 1024S from Finger Lake Instrumentation with a 2.2065 $\pm 0.0008''$ per pixel as pixel scale and a $37.7' \times 37.7'$ field of view, 1024 pixels with 24 $\mu$m each; see Muguera (2009) for details on telescope and CCD.

We present the observations log in Table 1.

For all science frames obtained, we also took several darks with the same exposure time; and for all filters used, we also obtained several sky flat fields (and again several darks with the same exposure time). We then took the median of the darks for each exposure time and subtracted the corresponding medium dark from the flat field frame for each filter. The bias level is included in the dark frames. Then, we normalized the flat fields and took the mean for each filter. Finally, we could subtract the darks from the science frames and divide them by the respective normalized mean flat field. All this was done with IRAF and MIDAS.

We show a typical image of Par 1724 in Fig. 1 (three color image with Orion nebula) and Fig. 2 ($R$-band image of central part with comparison stars indicated).

### Table 1 Observations log for Par 1724.

| Date of Night | Filter | No. of Images | Exposure [s] | Abs./Rel. Photom. |
|--------------|--------|---------------|--------------|-------------------|
|              | Dutch telescope observations |              |              |                   |
| 28 Feb 1998  | $V$    | 8             | 15 to 40     | abs. & rel.       |
|              | $R$    | 8             | 10 to 20     | abs. & rel.       |
| 1 Mar 1998   | $i$    | 11            | 15 to 30     | abs. & rel.       |
|              | Wendelstein telescope observations |              |              |                   |
| 24/25 Nov 2004 | $B$ | 6            | 60 to 120    | abs. & rel.       |
|              | $V$    | 5             | 15 to 25     | abs. & rel.       |
|              | $R$    | 4             | 5 to 20      | abs. & rel.       |
|              | $I$    | 4             | 1 to 20      | abs. & rel.       |
| 25/26 Nov 2004 | $B$ | 7            | 40 to 75     | abs. & rel.       |
|              | $V$    | 10            | 1 to 60      | abs. & rel.       |
|              | $R$    | 5             | 10 to 15     | abs. & rel.       |
|              | $I$    | 10            | 1 to 60      | abs. & rel.       |
| 7/8 Dec 2004 | $B$    | 5             | 15 to 50     | abs. & rel.       |
|              | $V$    | 5             | 10 to 25     | abs. & rel.       |
|              | $R$    | 4             | 20           | abs. & rel.       |
| 10/11 Dec 2004 | $B$ | 4            | 75 to 200    | abs. & rel.       |
|              | $V$    | 6             | 12 to 25     | abs. & rel.       |
|              | $R$    | 3             | 7 to 12      | abs. & rel.       |
|              | $I$    | 10            | 12 to 30     | abs. & rel.       |
| 29/30 Jan 2005 | $B$ | 5            | 100          | abs. & rel.       |
|              | $V$    | 3             | 40 to 100    | abs. & rel.       |
|              | $R$    | 8             | 1 to 20      | abs. & rel.       |
|              | $I$    | 6             | 10 to 20     | abs. & rel.       |
|              | University Observatory Jena (GSH) |               |              |                   |
| 15/16 Mar 2007 | $V$ | 1            | 60           | relative          |
|              | $R$    | 3             | 60           | relative          |
|              | $I$    | 3             | 60           | relative          |
| 27/28 Mar 2007 | $V$ | 3            | 60           | relative          |
|              | $R$    | 3             | 60           | relative          |
| 4/5 Apr 2007 | $B$    | 3             | 120          | relative          |
|              | $V$    | 3             | 60           | relative          |
|              | $R$    | 3             | 60           | relative          |
|              | $I$    | 3             | 60           | relative          |
| 5/6 Apr 2007 | $B$    | 12            | 120          | relative          |
|              | $V$    | 12            | 60           | relative          |
|              | $R$    | 9             | 60           | relative          |
|              | $I$    | 9             | 60           | relative          |
| 11/12 Apr 2007 | $B$ | 4            | 120          | relative          |
|              | $V$    | 3             | 60           | relative          |
|              | $R$    | 4             | 60           | relative          |
|              | $I$    | 4             | 60           | relative          |
| 12/13 Apr 2007 | $B$ | 3            | 120          | relative          |
|              | $V$    | 3             | 60           | relative          |
|              | $R$    | 3             | 60           | relative          |
|              | $I$    | 3             | 60           | relative          |
| 13/14 Apr 2007 | $B$ | 4            | 120          | relative          |
|              | $R$    | 6             | 60           | relative          |
|              | $I$    | 6             | 60           | relative          |
| 14/15 Apr 2007 | $B$ | 4            | 120          | rel. & abs.       |
|              | $V$    | 8             | 60           | rel. & abs.       |
|              | $R$    | 8             | 60           | rel. & abs.       |
|              | $I$    | 8             | 60           | rel. & abs.       |
| 23/24 Oct 2008 | $V$ | 5            | 60           | rel. & abs.       |
|              | $R$    | 5             | 60           | rel. & abs.       |
|              | $I$    | 5             | 50           | rel. & abs.       |
3 Absolute photometry

During the night 28 Feb to 1 March 1998 on La Silla, we also observed several photometric standard stars from Landolt (1992).

Also, in the nights 14/15 April 2007 and 23/24 Oct 2008 at GSH, we observed photometric standard stars from Landolt (1992) and Galadi-Enriquez et al. (2000) at two or more different airmasses, see Figs. 3 to 5 for those fields and Table 2 for the known magnitudes of the standard stars.

During the observing nights at Wendelstein, we did not observe official photometric standard stars in addition to Par 1724, because we were originally only interested in relative photometry of Par 1724 and other stars. However, several nights were good enough for absolute photometry, so that we can try to use constant bright stars in the Par 1724 fields for absolute photometric calibration. We use the most constant and brightest four comparison stars determined as constant comparison stars for the relative photometry in the next section (see Fig. 2). The mean of the BVRI magnitudes found with VizieR (mostly from Morel & Magnenat 1978) are listed in Table 2.

We obtained aperture photometry with IRAF (for Dutch and Wendelstein telescope data) and MIDAS (for GSH data) for all images obtained. In the Par 1724 field, we obtained photometry for Par 1724 itself and several comparison stars around Par 1724. For the standard stars, we used the same aperture size as for Par 1724, but different sizes in different nights depending on the FWHM.

For nights with absolute photometric conditions (clear and cloudless), we then used photometric standard stars to determine the atmospheric extinction and zero points for each filter using the well-known equation

\[ m = c + m_{\text{instr}} - k \cdot Y \]  

for apparent magnitude \( m \) (known for standard stars or to be obtained for science targets), instrumental magnitude, detector zero point \( c \), atmospheric extinction \( k \), and airmass \( Y \). Using the aperture photometry of the standard stars, we can then obtain the apparent magnitudes for \( B, V, R, \) and \( I \) for Par 1724, see Table 3, for all three telescopes used. The Gunn \( i \) filter data can be transformed to standard \( I \) using Jordi et al. (2006). We will use the new absolute photometric data in Sect. 5 below to investigate possible long-term brightness changes.

4 Relative photometry: rotation period

For the data obtained in 2007, all within one month (nine nights from 15 March to 14 April), we tried to find a periodicity in the photometry. We first searched for constant,
Table 2 Photometric standard stars observed.

| Date of Night | Standard Stars | $B$        | $V$      | $R$      | $I$      | Ref. (*) |
|---------------|----------------|------------|----------|----------|----------|----------|
| 28 Feb to     | PG 1047+003 A  | 13.512 ± 0.0046 | 13.0900 ± 0.0053 | 12.6720 ± 0.0058 | L 1992   |
| 1 March       | PG 1047+003 B  | 14.751 ± 0.0050 | 14.3600 ± 0.0055 | 13.9870 ± 0.0099 | L 1992   |
| 1998          | PG 1047+003 C  | 12.453 ± 0.0093 | 12.075 ± 0.01 | 11.716 ± 0.010 | L 1992   |
| 24 Nov 2004   | BD−05°1310     | 10.997 ± 0.025 | 10.458 ± 0.031 | 10.029 ± 0.045 | 9.859 ± 0.403 | VizieR   |
| to            | BD−05°1309     | 11.340 ± 0.020 | 10.991 ± 0.009 | 10.680 ± 0.049 | 10.439 ± 0.105 | VizieR   |
| 29 Jan 2005   | BD−05°1316     | 9.383 ± 0.025 | 9.348 ± 0.038 | 9.425 ± 0.063 | 9.418 ± 0.051 | VizieR   |
|               | Par 2020       | 12.843 ± 0.127 | 11.930 ± 0.066 | 11.127 ± 0.133 | 10.864 ± 0.162 | VizieR   |
| 14/15 Apr     | SA 107 970     | 12.535 ± 0.0076 | 10.939 ± 0.0074 | 9.797 ± 0.0077 | 8.365 ± 0.0084 | L 1992   |
| 2007          | SA 107 1006    | 12.478 ± 0.0014 | 11.712 ± 0.0010 | 11.270 ± 0.0013 | 10.849 ± 0.0014 | L 1992   |
| 23/24 Oct 2008| A              | 11.329 ± 0.002 | 10.935 ± 0.0022 | 10.565 ± 0.0028 | G-E 2000 |
|               | B              | 11.713 ± 0.006 | 11.046 ± 0.0067 | 10.484 ± 0.0078 | G-E 2000 |
|               | 5              | 13.844 ± 0.003 | 13.489 ± 0.0042 | 13.155 ± 0.0058 | G-E 2000 |
|               | 9              | 13.099 ± 0.007 | 12.744 ± 0.0092 | 12.387 ± 0.0081 | G-E 2000 |
|               | 22             | 10.187 ± 0.003 | 9.6040 ± 0.0095 | 9.085 ± 0.0058 | G-E 2000 |
|               | 23             | 13.569 ± 0.005 | 13.268 ± 0.0058 | 12.978 ± 0.0078 | G-E 2000 |
|               | 29             | 13.563 ± 0.008 | 13.215 ± 0.010 | 12.897 ± 0.0094 | G-E 2000 |
|               | 30             | 12.747 ± 0.008 | 12.368 ± 0.0094 | 12.747 ± 0.0089 | G-E 2000 |

Remarks: $B$ and $V$ in the Johnson system, $R$ and $I$ in the Cousin system; (*) L 1992 is Landolt (1992), and G-E 2000 is Galadi-Enriques et al. (2000); VizieR: median from data collected from VizieR (mostly from Morel & Magnenat 1978).

Fig. 2 Central part of one of our GSH/CTK $R$-band images of the star Par 1724 (60 s exposure) in the center with the comparison stars used for relative photometry also marked; those stars indicated with four tick marks each are the four comparison stars used for absolute photometry for the Wendelstein data (Table 2); field size shown is 18.3′ × 18.3′.

Fig. 3 Part of one of our GSH/CTK $R$-band images of the Landolt standard star field PG 1047+003 (40 s exposure) with the three standard stars A, B, and C marked; field size shown is 3.8′ × 3.8′; North up, East left.

Similarly bright, nearby comparison stars for Par 1724; after the first iteration, we omitted variable stars; the remaining bright, constant comparison stars are shown in Fig. 2. The brightness variations of those comparison stars have standard deviations of ±0.01 mag or less; two of them are listed as variable stars in Simbad, but their variability amplitude was very small or negligible during our observations; the light curve of one of them is shown in Fig. 6. The variability
Table 3  New absolute photometry for Par 1724.

| Date          | UT [hh:mm] | Zero Point² [mag] | Extinction [mag] | Result³ [mag] |
|---------------|------------|-------------------|------------------|--------------|
| 1 Mar 1998    | 00:44:03:15 | 22.155 ± 0.028    | 0.158 ± 0.008    | V = 10.833 ± 0.014 |
| and MJD = 50873.1 |          | 22.073 ± 0.016    | 0.073 ± 0.004    | R = 10.076 ± 0.008 |
| 24/25 Nov 2004 | 22:09:03:06 | 20.77 ± 0.13      | 0.265 ± 0.064    | B = 11.872 ± 0.06 |
| and MJD = 53334.5 |          | 22.01 ± 0.12      | 0.221 ± 0.059    | V = 10.453 ± 0.044 |
| 25/26 Nov 2004 | 21:54:03:04 | 21.82 ± 0.30      | 0.09 ± 0.15      | R = 9.656 ± 0.013 |
| 7/8 Dec 2004  | 21:37:03:09 | 20.53 ± 0.35      | 0.09 ± 0.18      | I = 9.14 ± 0.058 |
| and MJD = 53347.0 |      | 21.93 ± 0.21      | 0.127 ± 0.098    | I = 9.100 ± 0.017 |
| 10/11 Dec 2004 | 21:58:02:36 | 21.05 ± 0.11      | 0.422 ± 0.045    | B = 12.16 ± 0.20 |
| and MJD = 53350.0 |      | 22.077 ± 0.095    | 0.285 ± 0.044    | V = 10.667 ± 0.062 |
| 29 Jan 2005   | 18:00:23:31 | 18.21 ± 0.21      | 1.092 ± 0.093    | B = 12.07 ± 0.14 |
| and MJD = 53399.9 |      | 23.43 ± 0.17      | 1.021 ± 0.070    | V = 10.609 ± 0.092 |
| 14 Apr 2007   | 19:05:19:14 | 18.379 ± 0.073    | 0.35 ± 0.15      | B = 11.3 ± 0.3  |
| and MJD = 54204.6 |      | 19.356 ± 0.051    | 0.2556 ± 0.0034  | V = 10.462 ± 0.020 |
| 24 Oct 2008   | 01:07:01:37 | 18.939 ± 0.067    | 0.267 ± 0.080    | V = 10.50 ± 0.11 |
| and MJD = 54763.1 |      | 18.906 ± 0.055    | 0.158 ± 0.073    | R = 9.745 ± 0.091 |

¹: from absolute photometric nights only; ²: given for that band and normalized to 1 s exposure; ³: in most cases, error-weighted mean values are given for several exposures, so that the final magnitude error can be slightly smaller than the error in the zero point.

amplitude of Par 1724 is relatively large with several tenth of a mag (Neuhäuser et al. 1998, and this work).

We determined the photometric magnitude of Par 1724 relative to those eight constant comparison stars, done for the bands BVRI. Then, we calculated the mean of the relative magnitude changes between Par 1724 and each comparison star between the first night and any other night. We then searched for periodicity signals in the data using the standard methods string length (Lafier & Kinman 1965; Burke et al. 1983; Dworetsky 1983; Broeg et al. 2005), Lomb-Scargle (Scargle 1982; Horne & Baliunas 1986; Broeg et al. 2007), and a Fourier analysis (Lenz & Breger 2005). Signals with low false-alarm probability are found only in the V and R bands (Figs. 7 and 8 for the V band, Figs. 9 and 10 for the R band); the data in the B and I bands are too noisy, amplitudes are too small, or not enough data are available.

In both the R and V band, the string length, Lomb-Scargle, and Fourier analysis give best periods of ~5.6 to 5.7 days. The false-alarm probabilities are below 0.001. Phase-folded light curves in V and R pass a visual inspection test best for 5.7 days as period (and slightly less well for both 5.6 and 5.8 day periods). Taking all these tests into consideration, we obtain a rotational period of 5.7 days. The final phase-folded light curves for the V and R bands with 5.7 day period are displayed in Figs. 11 and 12, respectively.

We can confirm a period of ~5.7 days already found by Cutispoto et al. (1996) and Neuhäuser et al. (1998) in earlier data, the apparent period has not changed, a spot is still or again present, we see no indication for differential rotation.

5 Long-term variability: a cycle?

Using the data from the 1960ies until 1998 in Neuhäuser et al. (1998), those in Cutispoto (1998) and Cutispoto et al. (2001, 2003), and the new data listed in this work (Tables
Fig. 4 Part of one of our 0.9 m-Dutch telescope $I$-band images of the Landolt standard star field SA 107 (15 s exposure) with the two standard stars 970 and 1006 marked; field size shown is $18.3' \times 18.3'$; North up, East left.

3 and 4), we can also study possible long-term photometric variability. From the data of the night we did absolute photometry, we can also derive $BVRI$ data points for Par 1724 for those nearby nights (within a few rotation periods), when we did only relative photometry (Table 4); those data points are included in Figs. 13 and 14 ($BVRI$).

In addition, we use the $V$-band data available online\(^1\) from the All Sky Automated Survey (ASAS), where the whole observable sky (down to 14 mag) is monitored with one observation per night using telescopes on Las Campanas, Chile, and Haleakala, Hawaii. Almost 700 fully reduced $V$-band data points for Par 1724 are available (by mid Jan 2009) for five different aperture sizes; we use the average of those five values per night (but see the same trend with any of the five aperture sizes).

We used the $V$-band data of $\sim 40$ years to search for an additional long-term period or cycle. The three periodogram analysis tools used (see Sect. 4 for details) gave five different possible long-term periods (see Fig. 15):

- $10 193.4 \text{ d} = 27.9 \text{ yr}$ with relatively high false alarm probability of 0.058 (Fourier);

\(^1\) www.astrouw.edu.pl/asas

Fig. 5 Part of one of our GSH/CTK $I$-band images of the Galadi-Enriques standard star field number 1 around Landolt standard stars SA 4428 (labelled A) and SA 44 113 (labelled B) with stars used for relative photometry as marked by letters and numbers (60 s exposure); field size shown is $9.2' \times 9.2'$; North up, East left.

Fig. 6 We see no significant variations in the comparison stars, one of which is plotted here (BD $-5^{\circ} 1316$, relative magnitude versus observing day). Standard deviations of our comparison stars are $\pm 0.01$ mag or less, which is roughly the amplitude of the error bars achieved in the Par 1724 data shown below. These data were obtained with GSH/CTK in March and April 2007. Relative magnitudes are plotted versus observing time (in days since 1 February 2007).
Fig. 13 Absolute photometry for Par 1724 from the 1960ies until January 2009 for $B$ (top), $V$ (second from top), $R$ (second from bottom), and $I$ (bottom) according to data in Neuhäuser et al. (1998), Cutispoto (1998), Cutispoto et al. (2001, 2003), and this work (Table 4). We plot absolute magnitudes versus Modified Julian Date (MJD = JD – 2400000.5). In the plot for $V$-band data, we also show data from the ASAS project as small dots, see text. A possible 17.5 year cycle is shown as upper envelope with dashed lines. We see an increase in amplitude and a decrease in the faintest magnitudes in $B$, $V$, $R$, and $I$ at around MJD = 50 000.

- 6392 d = 17.5 yr with string length 42.7 (string length), and
- 13 477.5 d = 36.9 yr or 3273.9 d = 8.96 yr or 2210.93 d = 6.05 yr with powers 104.33, 34.04, and 12.98, respectively (Lomb-Scargle test).

Visual inspection of the phase-folded light curves of those five possible periods confirm that either the 9 or 17.5 year period are possible (Fig. 16). One of them can be an alias of the other. These two periods are also consistent with the light curves plotted in Fig. 14 (magnitude versus observing data instead of phase).

The magnitudes in the other bands ($BRI$) as plotted in Fig. 13 would also be consistent with a long-term periodic or cyclic behaviour, a 9 or 17.5 year cycle.

Such a long-term period would be similar to the 11 year solar cycle. Long-term brightness changes could be due to spots getting larger or smaller in size and/or getting hotter or cooler in temperature and/or increasing or decreasing in number (total area). However, we cannot draw a firm conclusion in this regard, mainly because of the time gaps.

The $V$ band peak-to-peak amplitude was $\Delta V = 0.2$ to 0.3 mag from 1968 to 1995 (data in Neuhäuser et al. 1998), then suddenly increased to 0.4 mag in the season 1995/1996, as already noticed by Cutispoto et al. (2003), then was again 0.25 mag from 2001 to 2006, to fall down to 0.2 in the last season 2008/2009 (Fig. 17).

In Fig. 17, we show the ASAS data of the different seasons always folded with the 5.7 day period. We can now
investigate whether the amplitude of the variability in V due to spots changes periodically with the cycle length. For the first five ASAS seasons (2001 to 2007), the maximum was at the same phase (near 1) and the amplitude was also nearly constant around 0.25 mag (peak-to-peak in V). Both values, however, were different in the very last (current, incomplete) season 2008/2009, when the amplitude is smaller (∼0.2 mag). This would indicate a decrease in spot size and/or temperature difference, and a recent change in spot location (i.e. a change in phase). This should be confirmed by a new Doppler image.

We can consider whether the changes in V-band variability amplitude is consistent with any of the long-term cycles suggested above. In the solar maximum, there are more dark spots, so that the variability amplitude would be larger. For Par 1724, the 9 year cycle (plotted in Fig. 14) would predict extremes in 1993 and 2001/02 (faintest magnitudes) and in 1997/98 and 2006 (brightest magnitudes); this is not consistent with the observations (but data gap around 1998). The 17.5 year cycle (also plotted in Fig. 14), however, would predict the extreme with faintest magnitudes and largest amplitude for 1996–1999 and the extreme with brightest magnitudes and smallest amplitude for very recently (2005–2008). Indeed, we saw a sudden increase in amplitude from 1995 to 1996, where the star became as faint as $V = 11$ mag (MJD = 50 000), i.e. an increase in spottedness; also in our 1998 observations at the Dutch telescope, the star was still relatively faint (but only one night), see Table 3. Also, we just saw a decrease in amplitude in the last season 2008. This could be seen as supporting evidence for the 17.5 year cycle, but has to be confirmed with further observations and Doppler images. The data for the previous Doppler image (Neuhäuser et al. 1998) were taken in December 1995 and January 1996, i.e. during the time, when we would expect a maximum in spottedness, according to the arguments above for a 17.5 year cycle; that Doppler image has shown a large polar spot (or group of spots) covering 12% of the visible stellar disk with a temperature difference of ∼800 K compared to the surrounding photosphere (Neuhäuser et al. 1998).

We will continue to monitor the star more frequently from GSH in the next few years and decades – in particular also in the B and I bands (not covered by ASAS) – to confirm or reject the hypothesis of a long-term cycle and to constrain the cycle length.
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Fig. 16  Absolute photometry for Par 1724 from the 1960ies until January 2009 for the V band only, for the same data as in Fig. 13. We plot absolute magnitude in mag versus phase for the two best long-term periods (or cycles), namely for ∼ 17.5 years (6392 days) in the top panel and for ∼ 9 years (3274 days) in the bottom panel. A long-term cycle would be seen not only in sinusoidal variations, but the star should also show a smaller amplitude when being brightest and a larger amplitude (going towards fainter magnitudes) when being faintest; this is the case for both cycle length shown here: For 17.5 yr (top) the amplitude is smallest around phase 0.85 (faintest) and largest around phase 0.85 (faintest), but with sparse data here; for the 9 yr cycle (bottom), this trend is even more pronounced, small amplitude at phase 0.5 (brightest) and large amplitude around phase 0.8–1.0 (faintest). The B-band data are also consistent with the both 17.5 yr and 9 yr cycles, while the R- and I-band data are not inconsistent with such a cycle (but too many data gaps). Given the results shown in Figs. 13–15, however, it is difficult to distinguish between the two best possible cycles, so that further observations are needed.

6 Summary

Rotational periods and long-term cycles are important to understand the angular momentum evolution and the dynamo in young and active stars.

With ∼ 800 new photometric observations of the young naked weak-line run-away T Tauri star Par 1724 near the Orion Træpezium cluster, we could confirm again the ∼ 5.7 rotation period (in the V and R bands), now observed in all data since the 1960ies.

In addition, with the new data from 1998 to 2009, we cannot confirm a steady decrease in brightness, as was suggested in Neuhäuser et al. (1998) with data until 1997.

However, we find for the first time indications for a 9 or 17.5 year cyclic behaviour similar to the 2 × 11 year cycle in the Sun, found for Par 1724 in the V-band data, maybe also in BRI. This observation needs to be confirmed with additional data over the next few decades, if possible also with new Doppler imaging observations almost every year to check for possible changes in the spot(s) size(s), temperature distribution(s), and/or location(s). Such a 9 or 17.5 year cycle would be similar to the cycle length found in other relatively young active stars (Baliunas et al. 1995; Alekseev 2005), but our star Par 1724 may be the youngest (200 000 years) ever found to show a long-term brightness variability cycle.

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Fig. 17  Phase-folded light curves with ASAS $V$-band data for the different seasons with ASAS observations (given with MJD range), always plotted in phase for the 5.7 day rotation period. The maximum is always near phase 1, but different in the last season (lower right, most recent season 2008/2009), which would indicate a recent change in spot location. The peak-to-peak amplitude is always $\sim 0.25$ mag, but only about 0.2 mag in the last season (2008/2009), which would indicate a recent change in spot size and/or temperature difference.
Table 4 All new photometric data for Par 1724*.

| MJD    | B [mag] | V [mag] | R [mag] | I [mag] |
|--------|---------|---------|---------|---------|
| 50873.031 | 10.856  | 9.280   |
| 50873.032 | 10.851  | 9.277   |
| 50873.033 | 10.847  | 9.279   |
| 50873.036 | 10.078  |         |
| 50873.037 | 10.081  |         |
| 50873.038 | 10.080  |         |
| 50873.039 | 9.280   |         |
| 50873.040 | 9.277   |         |
| 50873.041 | 9.277   |         |
| 50873.041 | 9.277   |         |
| 50873.068 | 10.840  |         |
| 50873.069 | 10.836  |         |
| 50873.071 | 10.074  | 9.260   |
| 50873.072 | 10.074  | 9.257   |
| 50873.073 | 9.262   |         |
| 50873.131 | 10.069  |         |
| 50873.132 | 10.075  |         |
| 50873.133 | 10.077  |         |
| 50873.134 | 10.812  |         |
| 50873.135 | 10.813  |         |
| 50873.136 | 10.811  |         |
| 50873.137 | 9.254   |         |
| 50873.138 | 9.247   |         |
| 50873.139 | 9.257   |         |
| 50873.140 | 9.258   |         |
| 50873.071 | 10.074  | 9.260   |
| 50873.072 | 10.074  | 9.257   |
| 50873.073 | 9.262   |         |
| 50873.131 | 10.069  |         |
| 50873.132 | 10.075  |         |
| 50873.133 | 10.077  |         |
| 50873.134 | 10.812  |         |
| 50873.135 | 10.813  |         |
| 50873.136 | 10.811  |         |
| 50873.137 | 9.254   |         |
| 50873.138 | 9.247   |         |
| 50873.139 | 9.257   |         |
| 50873.140 | 9.258   |         |

La Silla Dutch 90 cm telescope:

| MJD    | B [mag] | V [mag] | R [mag] | I [mag] |
|--------|---------|---------|---------|---------|
| 50873.031 | 10.856  | 9.280   |
| 50873.032 | 10.851  | 9.277   |
| 50873.033 | 10.847  | 9.279   |
| 50873.036 | 10.078  |         |
| 50873.037 | 10.081  |         |
| 50873.038 | 10.080  |         |
| 50873.039 | 9.280   |         |
| 50873.040 | 9.277   |         |
| 50873.041 | 9.277   |         |
| 50873.041 | 9.277   |         |
| 50873.068 | 10.840  |         |
| 50873.069 | 10.836  |         |
| 50873.071 | 10.074  | 9.260   |
| 50873.072 | 10.074  | 9.257   |
| 50873.073 | 9.262   |         |
| 50873.131 | 10.069  |         |
| 50873.132 | 10.075  |         |
| 50873.133 | 10.077  |         |
| 50873.134 | 10.812  |         |
| 50873.135 | 10.813  |         |
| 50873.136 | 10.811  |         |
| 50873.137 | 9.254   |         |
| 50873.138 | 9.247   |         |
| 50873.139 | 9.257   |         |
| 50873.140 | 9.258   |         |

Wendelstein 80 cm telescope

| MJD    | B [mag] | V [mag] | R [mag] | I [mag] |
|--------|---------|---------|---------|---------|
| 53334.5 | 11.87   | 10.453  | 9.656   | 9.14    |
| 53335.0 | 11.82   | 10.389  | 9.638   | 9.100   |
| 53347.0 | 11.87   | 10.43   | 9.67    | 9.15    |
| 53350.0 | 12.16   | 10.667  | 9.73    | 9.243   |
| 53399.9 | 12.07   | 10.609  | 9.74    | 9.23    |

University Observatory Jena (GSH)

| MJD    | B [mag] | V [mag] | R [mag] | I [mag] |
|--------|---------|---------|---------|---------|
| 54175.0 | 10.330  | 9.778   | 9.274   |
| 54186.7 | 10.356  | 9.821   |
| 54194.7 | 11.46   | 10.481  | 9.816   | 9.151   |
| 54195.7 | 11.43   | 10.455  | 9.907   | 8.985   |
| 54201.7 | 11.54   | 10.399  | 9.942   | 9.116   |
| 54202.7 | 11.45   | 10.369  | 9.893   | 9.177   |
| 54203.7 | 11.4    | 9.841   | 9.157   |
| 54204.7 | 11.3    | 10.462  | 9.809   | 9.235   |
| 54763.1 | 10.50   | 9.745   | 9.06    |

* Data from both absolute photometric nights (as in Table 3) and also other nights close to the absolute photometric nights, for which we can deduce the photometry from the values in the absolute photometric nights and stable standard stars.

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Fig. 9  Results of period search by the string length (top) and Lomb-Scargle (bottom) methods for the $R$-band data from March and April 2007 from GSH. The minimum in the string length (2.7) indicated the best period: 5.65 days (top). The maximum power in the Lomb-Scargle test (13.7) is for a period of 5.6 days.

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Fig. 10  Results of period search by Fourier transformation analysis for the $R$-band data from March and April 2007 from GSH. The 1st maximum in the left corresponds to 14 days and is spurious due to sampling effects. The 2nd maximum (amplitude $A = 0.0639$) from the left is for a period of 5.615 days, which we regard as true rotational period. The other lower maxima between frequency 0.8 and 1.0 per day are alias signals expected (for 5.615 and 14 day periods) according to Tanner (1948).

Fig. 11  Phased-folded plot for $V$-band photometry for Par 1724 obtained in March and April 2007 with GSH/CTK – folded with a 5.7 day period and showing a $\sim 0.2$ mag peak-to-peak amplitude.
**Fig. 12** Phased-folded plot for $R$-band photometry for Par 1724 obtained in March and April 2007 with GSH/CTK – folded with a 5.7 day period and showing a $\sim 0.15$ mag peak-to-peak amplitude.

**Fig. 15** We show here the periodograms for the long-term variability of Par 1724 using the ASAS $V$-band data for string length method (top) and Lomb-Scargle (bottom) with the possible periods (or cycle length) of 6392 days (17.5 yr) in the top panel as well as 3274 days (9 yr) and 13478 days (37 yr) in the bottom panel. The most likely cycle length are 17.5 or 9 years. Phase-folded light curves can be found in Fig. 16.