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ON A CYCLIC ACTIVITY AND DIFFERENTIAL ROTATION OF Par 1724 = V1321 Ori

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Abstract. We applied the Gregory-Loredo method (for periodic signal detection of unknown shape in time-series with Gaussian errors) to the 200000 year old naked, weak-line, run-away T Tau type star Par 1724, located north to of the Trapezium cluster in Orion, for which measurements of the stellar magnitudes in V-band and corresponding errors spanning more than 50 years are available. Preliminary results indicating on a cyclic activity of Par 1724 with a period of $\sim$ 18 years. It also revealed a second significant periodic signal, in the range of 5.85-5.95 days (together with 5.67 days period, known as rotational one), which might be a mimic on a differential rotation.

1. INTRODUCTION

The K0 pre-main sequence star Par 1724 in Orion is listed as star number 1724 in Parenago (1954), it is located at $\alpha = 5^{\mathrm{h}}35^{\mathrm{m}}4.21^{\mathrm{s}}$ and $\delta = -5°8'13.2''$ (J2000.0), $15'$ north of the Trapezium cluster in Orion. Par 1724 is one of the most active and variable young stars known. It is known to show photometric variability since 1996 (Cutispoto et al. 1996). An extensive photometric study was made by Neuhäuser et al. in 1998 (Neuhaeuser et al. 1998). The origin of the photometric variation is a rotational modulation due to a large polar spot, detected indirectly by Doppler imaging (Fig. 1). Par 1724 rotates with a period of $P \approx 5.7$d, the amplitude of variation is about 0.2 mag in V-band. This period is seen so far in all data sets from 1968 to 1997. Beside this rotational period, the star may also show a long-term change of its optical brightness, namely getting fainter in V over 40 years, see Fig. 5 in Neuhaeuser et al. (1998).

2. DATA ANALYSIS AND RESULTS

For our analysis of the rotation period we used data obtained in 2007 (nine nights between March 15 and April 14) at the University Observatory in Jena. Eight nearby bright comparison stars were used to determine the photometric amplitude of Par 1724 relative to these eight stars. We then calculated the mean of relative magnitude

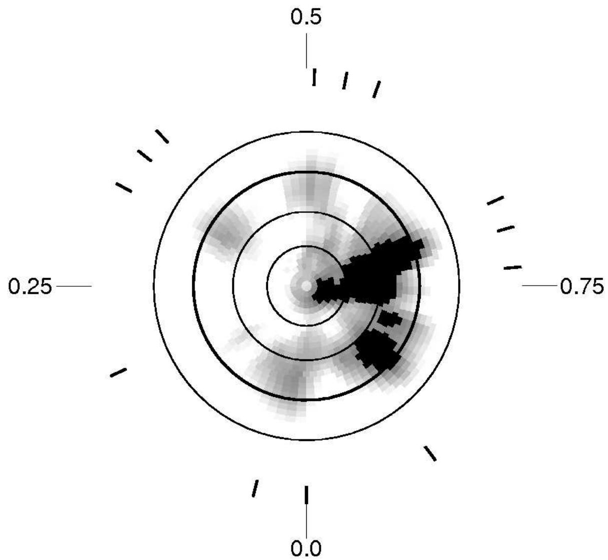

Figure 1: Doppler Image of Par 1724 obtained in 1997 showing the location of the spot. The ticks mark the rotational phase spectra were taken.

changes between Par 1724 and each comparison star between the first and any other night, see Neuhäuser et al. (2009) for further information.

Beside these data points obtained in Jena, we used V-band data available online[1] from the All Sky Automated Survey (ASAS), where the whole observable sky (down to 14 mag) is monitored using telescopes on Las Campanas, Chile and Haleakala, Hawaii. Almost 700 fully reduced V-band data points for Par 1724 are available.

To analyse the long-term brightness change we used all available data from the 1960ies on and in addition to this own data from La Silla, Chile (1998) and Wendelstein Observatory, Germany (2004).

2. 1. PREVIOUS STUDY

We searched for periodicity signals in all data using the standard methods stringlength (Broeg et al. 2005 and references therein), Lomb-Scargle (Scargle 1982, Horne 1986) and a Fourier analysis (Lenz and Breger 2005).

For both data sets (Jena and ASAS), we obtain the already known 5.7d period. Fig. 2 shows the phase-folded lightcurves for the ASAS data.

To obtain information about the long-term change we used all available data from the 1960ies to 2009, covering about 40 years of observation. Using the same tools for analysis, we found five different possible periods: $P_1 = 6.05$ yr (Power 12.98), $P_2 = 8.96$ yr (Power 34.04), $P_3 = 36.9$ yr (Power 104.33), $P_4 = 17.5$ yr with a stringlength of 42.7 and $P_5 = 27.9$ yr with high false alarm propability of 0.059. Figure 3 shows the periodograms of the stringlength algorithm (top) and Lomb-Scargle (bottom).

[1] www.astrouw.edu.pl/asas

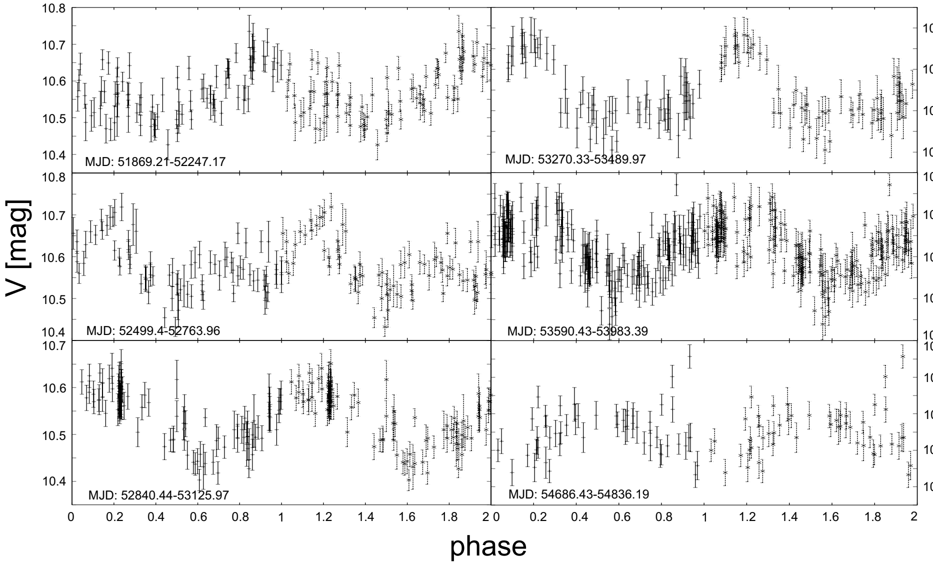

Figure 2: The phase-folded lightcurves for the ASAS data. The data are always plotted in phase with the 5.7d period.

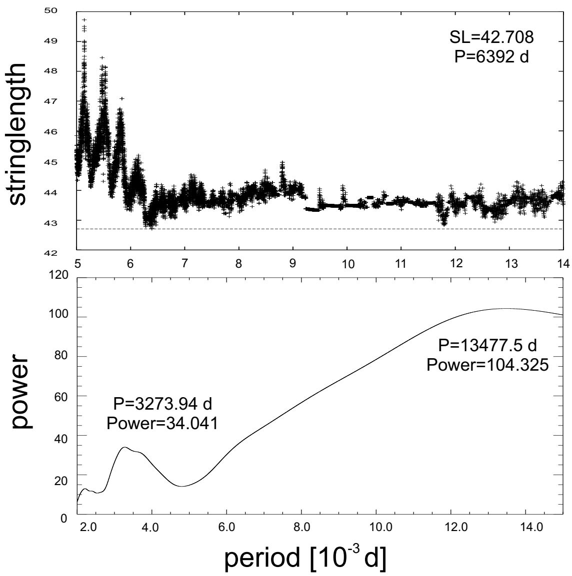

Figure 3: Periodograms of stringlength and Lomb-Scargle with the most propable periods (or cycle lengths) of 9 and 17.5 years.

The two periods that describe the long-term variation best, are $P_2 = 9\,\mathrm{yr}$ and $P_4 = 17.5\,\mathrm{yr}$. This would indicate a cycle similar to the 11 year solar cycle.

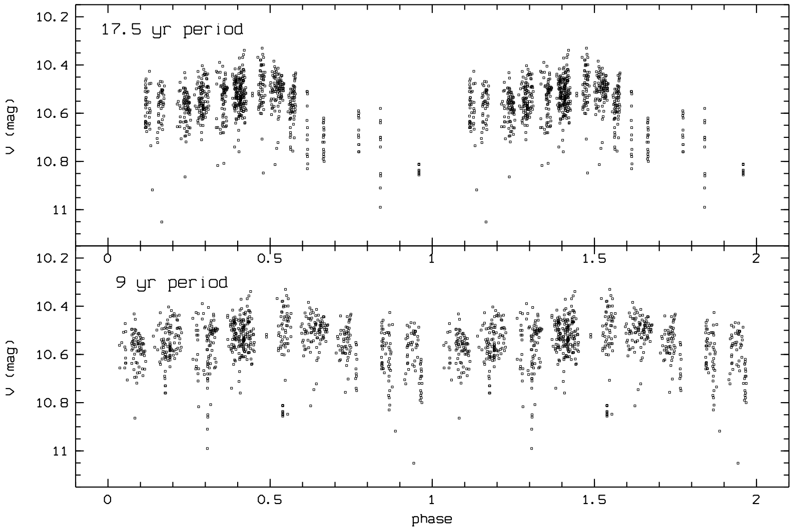

Figure 4: Absolute photometry data for Par 1724. We plot absolute magnitude in mag versus phase for the two best periods, namely 17.5 years and 9 years.

2. 2. BAYESIAN APPROACH

In order to detect cyclic activity of Par 1724 we applied a a method developed by Gregory & Loredo (1992) in the case of Gaussian errors (Gregory 1999, 2005).

The method is using a Bayesian approach to the problem of detection and characterization of a periodic signal in a time series when we have no specific prior knowledge of the existence of such a signal or of its characteristics, including shape.

Originally, the method was developed to deal with photon arrival time data sets in X-ray and gamma-ray astronomy, where the appropriate sampling distribution is the Poisson distribution.

In the current approach, we are dealing with stellar magnitude measurements (or timing residuals after folding into the rotational period), i.e. analyzing a sampled time series with Gaussian noise (Gregory 1999). This analysis does not assume uniform sampling; the approach allows us to draw optimal inferences about the nature of the signal for whatever data is available.

Thus, the Par 1724 data sets, for which long term observations are available (Neuhäuser 2009), we can represent the measurements of the stellar magnitudes in V-band and corresponding errors spanning more than 50 years, by the equation

$$V_i^O = V_i^M + \epsilon_i + \epsilon_0$$

where V_i^O is the measured data at time t_i, V_i^M the periodic model or constant model prediction at time t_i, ϵ_i the component of V_i^O, which arises from measurement errors, and ϵ_0 is any additional unknown measurement errors plus any real signal in the data that cannot be explained by the model prediction V_i^M.

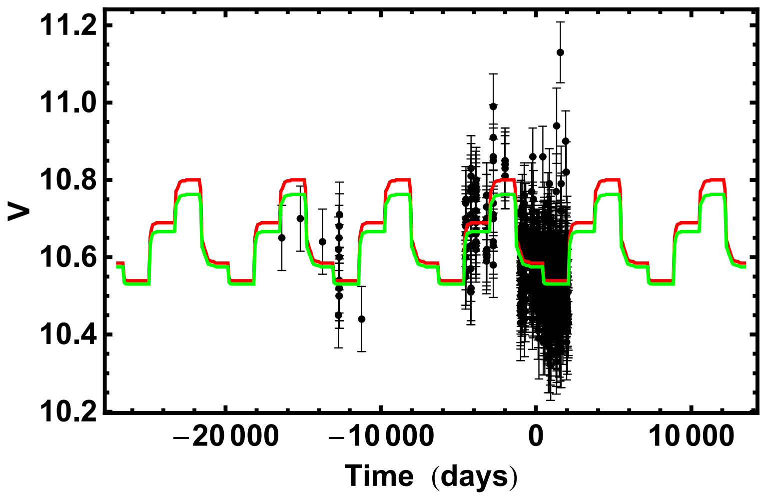

Figure 5: Long-term light curve of Par 1724 for cyclic activity period of ∼ 18 years is shown. The shape of the phase folded light curve shape determined by application of the GL method, a Bayesian approach for periodic signal detection of unknown shape with Gaussian noise (for details, see text).

Under the proposition that the quantity $V^O - V^M$ obeys to the Gaussian distribution, we computed the ratio of the probabilities (odds ratio) of two models, ie. periodic and constant. Periodic model is a family of models capable of describing a background plus a periodic signal of arbitrary shape.

A priori, we assumed that constant and periodic models have equal probability. Each member of the family of periodic models is a histogram with m bins, with m ranging from 2 to some upper limit, typically 12. The unknown parameters are P (period), ϕ (phase offset of start of data and beginning of first bin), m (number of bins), and ϵ_0 (extra Gaussian noise parameter, for details, see Gregory (1999, 2005), Hambaryan (2010), Hambaryan et al. (2010), Borisova et al. (2010).

The long-term period search was performed in the range of 2.5 to 22.0 years. As a result, we obtained a most likely periodicity of 6665 days (e.g. 2 × 9 years) with a 1 σ credibility range of 6635 to 6676 days cycle length. This confirms the preliminary result in Neuhäuser et al. (2009), being 17.5 years, and it also supersedes it by the fact that this new value of cycle length is shown to be more significant than the other candidate cycle length (9 years, Neuhäuser et al. (2009)) and it can now be given with a significant error range (see Fig. 5).

We also performed periodicity search analysis by applying the GL method in the range of 4-6 days. It also revealed a second significant periodic signal, in the range of 5.85-5.95 days (together with 5.67 days period, known as rotational one), which might be a mimic on a differential rotation (see Fig. 6).

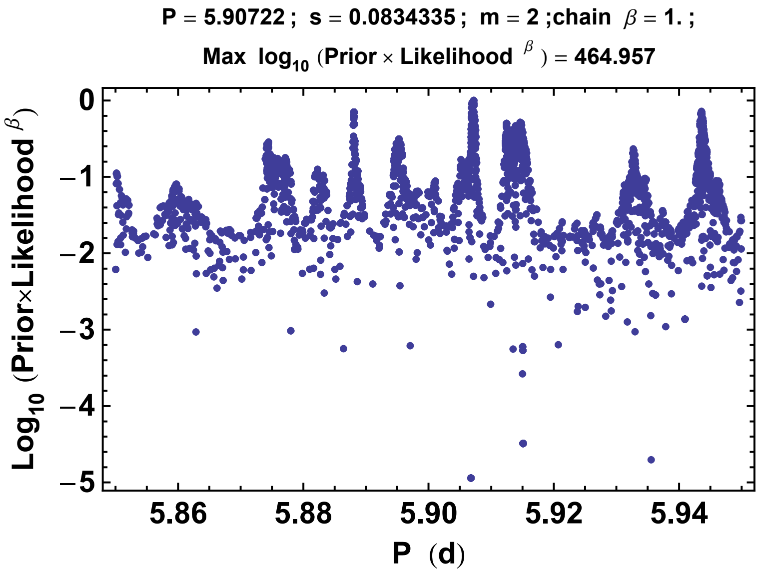

Figure 6: Markov-Chain Monte-Carlo approach for periodicity search by the GL method with Gaussian noise, in the range of 5.80-5.95 days of Par 1724. A significant peek at P=5.90 days together with well known 5.67 days rotational period may mimic on a differential rotation of Par 1724 (3-5% longer than rotational one).

References

Borisova, A., Laskov, L. and Hambaryan, V.: 2010, *Bayesian probability theory in astronomy: Looking for stellar activity cycles in photometric data-series*. In *VIIth Bulgarian-Serbian Astronomical Conference*, volume this issue.

Broeg, C., Fernández, M. and Neuhäuser, R.: 2005, *A new algorithm for differential photometry: computing an optimum artificial comparison star*. *Astronomische Nachrichten*, **326**, 134.

Cutispoto, G., Tagliaferri, G., Pallavicini, R. Pasquini, L. and Rodono, M.: 1996, *Photometric and spectroscopic studies of cool stars discovered in EXOSAT X-ray images. III. Photometric properties*. *Astronomy and Astrophysics Supplement*, **115**, 41.

Gregory, P. C. and Loredo, T. J.: 1992, *A new method for the detection of a periodic signal of unknown shape and period*. *ApJ*, **398**, 146.

Gregory, P. C.: 1999, *Bayesian Periodic Signal Detection. I. Analysis of 20 Years of Radio Flux Measurements of the X-Ray Binary LS I +61 deg303*. *ApJ*, **520**, 361.

Gregory, P. C.: 2005, *Bayesian Logical Data Analysis for the Physical Sciences: A Comparative Approach with 'Mathematica' Support* (Cambridge University Press).

Hambaryan, V. V.: 2010, *Bayesian probability theory in astronomy: Timing analysis of neutron stars*. In *VIIth Bulgarian-Serbian Astronomical Conference*, volume this issue.

Hambaryan, V., Tsvetkov, M., Tsvetkova, K. and Poghosyan, A.: 2010, *On a possible cyclic activity of Pleiades flare star HCG 377=II Tau*. In *VIIth Bulgarian-Serbian Astronomical Conference*, volume this issue.

Horne, J. H. and Baliunas, S. L.: 1986, *A prescription for period analysis of unevenly sampled time series*. *ApJ*, **302**, 757.

Lenz, P. and Breger, M.: 2005, *Period04 User Guide*. *Communications in Asteroseismology*, **146**, 53.

Neuhaeuser, R., Wolk, S. J., Torres, G., Preibisch, T., Stout-Batalha, N.-M., Hatzes, A. P., Frink, S., Wichmann, R., Covino, E., Alcala, J. M., Brandner, W., Walter, F. M., Sterzik, M. F. and Koehler, R.: 1998, *Optical and X-ray monitoring, Doppler imaging, and space motion of the young star Par 1724 in Orion. Astronomy and Astrophysics*, **334**, 873.

Neuhäuser, R., Koeltzsch, A., Raetz, S., Schmidt, T. O. B., Mugrauer, M., Young, N., Bertoldi, F., Roell, T., Eisenbeiss, T., Hohle, M. M., Vaňko, M., Ginski, C., Rammo, W., Moualla, M. and Broeg, V.: 2009, *Photometric monitoring of the young star Par 1724 in Orion. Astronomische Nachrichten*, **330**, 493. 0905.1807.

Parenago, P. P.: 1954, *Catalogue of stars in the area of the Orion Nebula. Trudy Gosudarstvennogo Astronomicheskogo Instituta*, **25**, 1.

Scargle, J. D.: 1982, *Studies in astronomical time series analysis. II - Statistical aspects of spectral analysis of unevenly spaced data. ApJ*, **263**, 835.