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Astronomical & Astrophysical Transactions

The Journal of the Eurasian Astronomical Society

Publication details, including instructions for authors and subscription information:
<http://www.informaworld.com/smpp/title~content=t713453505>

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Online Publication Date: 01 April 2006

To cite this Article: Alekseev, I. Yu. and Bondar, N. I. (2006) 'Spots on the surface of the active late-type star PZ Mon', *Astronomical & Astrophysical Transactions*, 25:2, 247 - 250

To link to this article: DOI: 10.1080/10556790600918554

URL: <http://dx.doi.org/10.1080/10556790600918554>

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Spots on the surface of the active late-type star PZ Mon

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(Accepted 29 June 2006)

The photometric properties of the late-type star PZ Mon are analysed assuming the presence of spots on its surface. The long-term variability in brightness is considered using photographic data together with photoelectric data in the *B* band. The combined light curve covers the time span from 1898 to 2004 and shows two deep minima which might be interpreted as an activity cycle with a period of 50 years. The investigation of seasonal variations is based on *UBVRI* observations carried out with the 1.25 m telescope at the Crimean Astrophysical Observatory in 1992–2004. The derived colours of PZ Mon indicate that the spectral type of the star is K5 and therefore the parameters of spots were calculated adopting a value for the temperature of the photosphere of 4800 K. Applying the simple model of star spots we found that a seasonal variability can be produced by spots which cover 17–30% of the hemisphere. The spot temperatures are constant and close to 2700 K. If the deep minima on the long-term curve are also produced by the spots, the spotted area should be extended in these epochs to 50%.

Keywords: Stellar photometry; Red dwarf stars; Stellar activity; Stellar spots

1. Introduction and results of observations

PZ Mon is a late-type star (dK2e) with a low flare activity [1]. Its long-term photographic light curve showed minima in 1899 and 1944–1950 and maxima in 1917–1935 and 1975–1988. At the minimum brightness the star becomes fainter (with a brightness magnitude of about 0.8–1.0) than at the maximum brightness. Seasonal changes demonstrate a small amplitude magnitude of about 0.1–0.3. This variability may be caused by the different levels of spot activity in different epochs and, if the activity is cyclic, the length of the cycle is 50 years [2]. In order to confirm this assumption and to study the parameters and evolution of star spots we began in 1992 simultaneous *UBVRI* observations of PZ Mon with the photometer–polarimeter described by Pirola [3] mounted on the 1.25 m telescope at the Crimean Astrophysical Observatory. According to observations of the check star HD 289116 the accuracy of measurements is 2% for the *B* and *V* bands and about 3% for other bands. Comparison stars did not show variations exceeding the 3σ level. The mean photographic magnitude of the check star corresponds to its mean *B* magnitude ($m_{pg} = 10.35$; $B = 10.33$). This good agreement allows us to construct the combined blue light curve of PZ Mon. The full circles in figure 1 demonstrate

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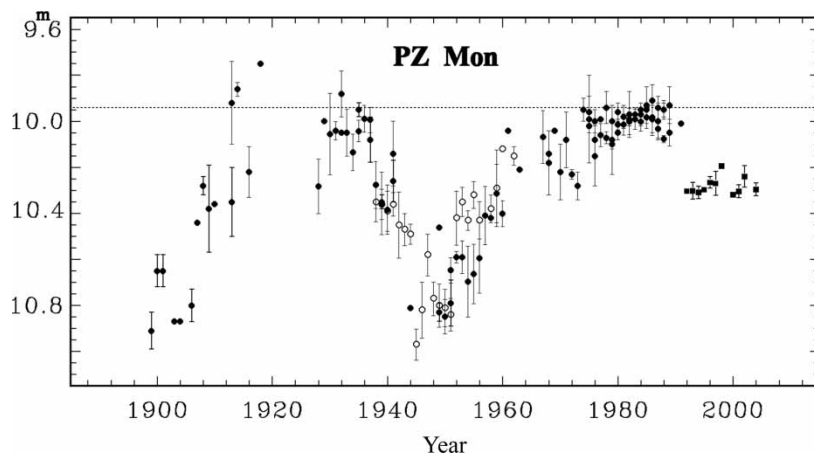


Figure 1. The long-term variability of PZ Mon. The light curve is based on the photographic and B -band data.

results from [2], the open circles are results from [4], the full squares show photoelectric data obtained in 1992–2004, and the dashed line indicates the maximum level of brightness. It is clear that only long-term observations allow us to find the brightest magnitude, which is the input parameter required to calculate the parameters of the spots. Figure 2 displays the $UBVRI$ light curves of PZ Mon and the check star HD 289116. Each point gives the mean magnitude for a given date.

The amplitude of the seasonal variations in brightness indicate the degree of spottedness of the stellar surface. Figure 3 shows the variations around the mean brightness in the V band during November 1993–April 1994.

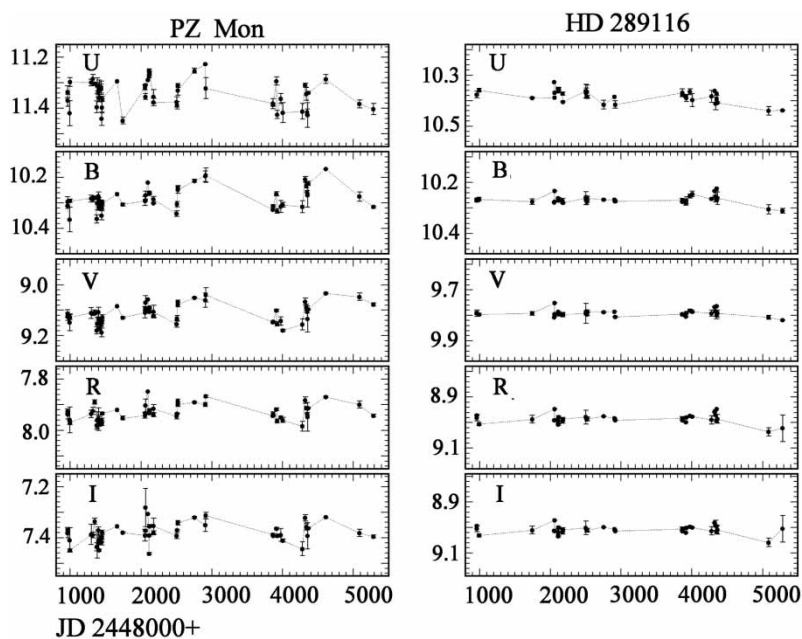
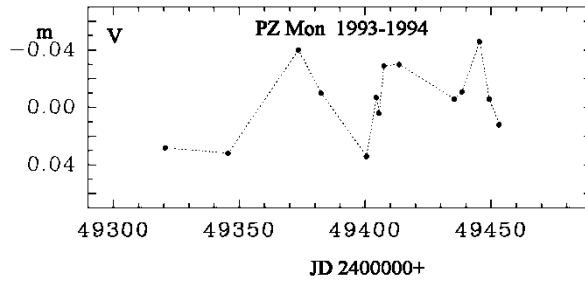


Figure 2. $UBVRI$ photometry of PZ Mon in 1992–2004.

Figure 3. Seasonal changes in the V light of PZ Mon.

2. Calculation parameters of spots

The obtained $UBVRI$ light curves are a source used to detect star spots and to study their features. The inclination of the rotation axis of PZ Mon and the precise parameters of its photosphere, T_{eff} and $\log g$, are unknown. Therefore the features of spots were calculated in a simple iteration by Vogt [5]: $\Delta m_{\lambda} = -2.5 \log[1 - (1 - \beta_{\lambda})S]$, where β_{λ} is the ratio of the surface brightness of the spot to that of the photosphere and S is the spot area in a fraction of the visual surface. The fact that the contribution of the chromospheric flux and darkening effects are decreased in the V and I bands are taken into account [6]. The input parameters for calculation are the difference ΔV_{max} between the brightest magnitude and the maximum value at a given epoch, the amplitude ΔV of the rotation modulation in each season and the ratio $\Delta I/\Delta V$. The values $\Delta B/\Delta V$ and $\Delta R/\Delta V$ are used to control the results. The output parameters include the spot areas S_1 and S_2 corresponding to the seasonal maximum and seasonal minimum brightness of the star and the spot temperature computed for a given temperature of the photosphere. Figure 1 shows that the highest brightness B_{max} corresponds to a magnitude of 9.94. From the obtained colour characteristics $\Delta B/\Delta V = 1.17$, $\Delta U/\Delta V = 0.68$, $\Delta R/\Delta V = 0.68$ and $\Delta I/\Delta V = 0.82$, the following values result: $V_{\text{max}} = 8.83$, $U - B = 1.19$, $B - V = 1.11$, $V - R = 1.09$ and $V - I = 1.68$. These colours correspond to the K5 spectral type and then the temperature of the unspotted photosphere is 4800 K. Table 1 contains the results of our calculation and shows that changes in the V light can be produced by spots covering 17–30% of the hemisphere. The spot temperatures are almost constant and less than the temperature of the unspotted photosphere about 2100 K. A similar result was obtained from data in the B band, but in the R band the discrepancy between temperatures is smaller because of the

Table 1. Areas of spots on the surface of PZ Mon.

Season (year)	ΔV_{max}	ΔV	ΔB_{max}	ΔB	S_1	S_2
1992–1993	0.28	0.04	0.35	0.07	23.1	25.9
1994.3	0.28	0.08	0.33	0.09	23.1	28.6
1994–1995	0.25	0.05	0.30	0.05	20.9	24.5
1996.1	0.23	0.06	0.28	0.08	19.4	23.8
1997.2	0.24	0.08	0.30	0.10	20.2	25.9
1997–1998	0.22	–	0.27	–	18.6	–
1998.3	0.21	0.02	0.25	0.01	17.9	19.4
2000.1	0.27	0.08	0.32	0.07	22.4	27.9
2001	0.24	0.08	0.27	0.10	20.2	25.9
2002	0.20	–	0.23	–	17.1	–
2003	0.22	–	0.33	–	18.6	–
2004	0.25	–	0.38	–	20.9	–

contribution of chromospheric lines. Photoelectric data show that large spotted areas were detected in 1992–1994 and 2000. If considerable minima in the long-term light are produced as a result of spot activity, the fraction of spotted surface should be increased to 50%.

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