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ON THE POSSIBLE 9-DAY PERIODIC VARIABILITY OF DI Cep

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Despite numerous currently existing observations of individual T Tauri stars (TTSs), the principal causes of variability are not completely understood for this group of stars. Different variability mechanisms were suggested for classical TTSs (CTTSs) and weak-line TTSs (WTTSs) (Herbst *et al.*, 1994). There exists an opinion that while, most likely, CTTSs vary in brightness and spectrum because of changing parameters of their accretion zones, brightness variations of WTTSs arise from rotational modulation because of spotted photospheres. It can be possible to reveal common properties, needed to understand the nature of young stars, only from long-time observations. In this study, we report on periodic variability of the spectra and brightness of the classical T Tauri star DI Cep on the basis of its long-time photoelectric and spectroscopic observations.

For our analysis, we use the published results of spectroscopic observations by Grinin *et al.*, (1980) (the same data on these spectroscopic observations are repeated in Krasnobabtsev, 1982) and by the author (Ismailov, 1987a, 1987b, 1988, and four observations so far unpublished; for convenience, we repeat all our observations in the electronic table, its four last lines corresponding to the unpublished observations). All the spectra, obtained at the Crimean and Shemakha observatories, had approximately the same mean linear dispersion (93–100 Å/mm). The observations by Grinin *et al.* (1980) were obtained during the single season of 1975, and our observations, in 1975–1987.

Our search for possible periodicity in the light variations (see below) and the spectrum of the star made use of the Scargle (1982) periodogram method, in its later modification by Horne and Baliunas (1986) (the code we applied had been written by I. Antokhin). To preserve uniformity, the data from each season were processed separately. The search for the period was carried out within the 0–1 d^{-1} range of frequencies. Krasnobabtsev (1982) and Ismailov (1987a) suspected periodic variations in the spectrum of DI Cep, with a time scale about 16–18 days. Spectral variability with an 11-day period was suspected by Fernández and Eiroa (1996), Gómez de Castro and Fernández (1996). For this reason, we were mainly interested in the significant power spectrum peaks in the 0.025–1 d^{-1} range. The power spectra calculated using the spectroscopic data from Grinin *et al.* (1980) and from Ismailov (1987a) have shown significant peaks, exceeding the 3σ level, in the 0.1–0.2 d^{-1} frequency interval.

The results of our frequency analysis based upon the equivalent widths (W_λ) of the Hα and Hβ emission lines reveal that different data sets confidently show the frequency corresponding to the period $P = 9\overset{d}{.}24 \pm 0\overset{d}{.}07$. This spectral variability period is found in individual one-year data sets with high reliability.

The basic observational material for our frequency analysis of V magnitudes of DI Cep was the Herbst *et al.* (1994) data base, available in Internet. We used up to 450 measurements from this data base (mainly observations from Kardopolov and Filip'ev, 1985 and unpublished data by V.S. Shevchenko), including 58 measurements by the author (Ismailov, 1988, 1997) as well as 97 measurements from Grinin et al. (1980) averaged over individual nights of observations.

The power spectrum computed from all available photometric V-brightness data does not show any significant periods in the studied interval of frequencies. The reason can be that the complete data set consisted of measurements from different authors. The periodicity can be masked because of phase jumps, systematic and random mistakes of individual observers. To have the observing data uniform, we subdivided the set into 6 subsets, each consisting of data acquired during one year, and processed each subset separately.

This analysis has shown that the power spectrum for the V-brightness data often contains the frequency 0.053 ± 0.003 d^{-1}, corresponding to the period $18^{\rm d}_{.}28 \pm 1^{\rm d}_{.}75$. The power spectrum for the third subset contains a very significant peak at the frequency 0.028 d^{-1} that corresponds to the period $35^{\rm d}_{.}71$. A part of the photometric data from Grinin et al. (1980) reveals a significant peak near the 9-day ($8^{\rm d}_{.}91 \pm 0^{\rm d}_{.}82$) period. The frequency of the latter period was also confidently observed in our photometric data.

It should be noted that the 9-day period in the photometric data can be revealed only from carefully chosen homogeneous material, acquired during a short time interval. The period $18^{\rm d}_{.}28$, as well as the period $35^{\rm d}_{.}71$, are, within errors, multiples of the 9-day period. In the following, we accept the value $P = 9^{\rm d}_{.}24 \pm 0^{\rm d}_{.}07$ as the period of spectral and photometric variability of DI Cep.

The Figure shows a comparison of the behavior of equivalent widths and of photometry with the phase of the 9-day period. Upper panels correspond to spectroscopy, and lower panels, to photometry. Left panels are the data from Grinin et al. (1980), and right panels, those by the author. For all the plots, we adopted JD2442616.472 as the initial epoch. The amplitude of changes of equivalent widths with phase exceeds 100% of their minimal values. It appears from the Figure that there exists a phase shift between these data and the data set from Grinin *et al.* (1980).

The spectral type of DI Cep was estimated as G5 (Brodskaya, 1951), G8V (Herbig, 1977; Krasnobabtsev, 1982). Variation of the star's spectral type within F4–K5 (with the most probable spectral type G5–G7.5 $\pm$ 1.5 V) were found by Ismailov (2001). Using the adapted temperature scale from Cohen and Kuhi (1979), we find, for the effective temperature of a young G8V star, $T_{eff} = 5400$ K, and for its color index, $(B-V)_0 = 0^{\rm m}_{.}75$. Then, with the average observed color $\langle B-V \rangle = 0^{\rm m}_{.}88$, we obtain the color excess $E(B-V) = 0^{\rm m}_{.}13 \pm 0^{\rm m}_{.}25$. For the star's distance of 200 pc (Grinin *et al.*, 1980), the absolute magnitude is found to be $M_V = 4^{\rm m}_{.}0 \pm 0^{\rm m}_{.}3$, and, taking into account the bolometric correction, we find for the star's radius the value of $R_* = 1.8 \pm 0.2\ R_\odot$.

The projected rotation rate of DI Cep was estimated as $v \sin i = 28$ km/s (Bouvier *et al.*, 1986) and as 23 km/s (Gameiro and Lago, 1993). If the period we found is the period of the star's axial rotation, we can estimate the inclination of the rotation axis to the line of sight, $i = 27^\circ \pm 2^\circ_{.}5$.

The analysis of rotational modulation for WTTSs shows that usually the initial epoch in such a cycle remains rather stable (Petrov *et al.*, 1994; Grankin, 1998). However, already Herbst *et al.* (1994) noted phase instability of the periodic light variability for CTTSs. In our opinion, the phase shift can be due to two reasons. First, the value of the

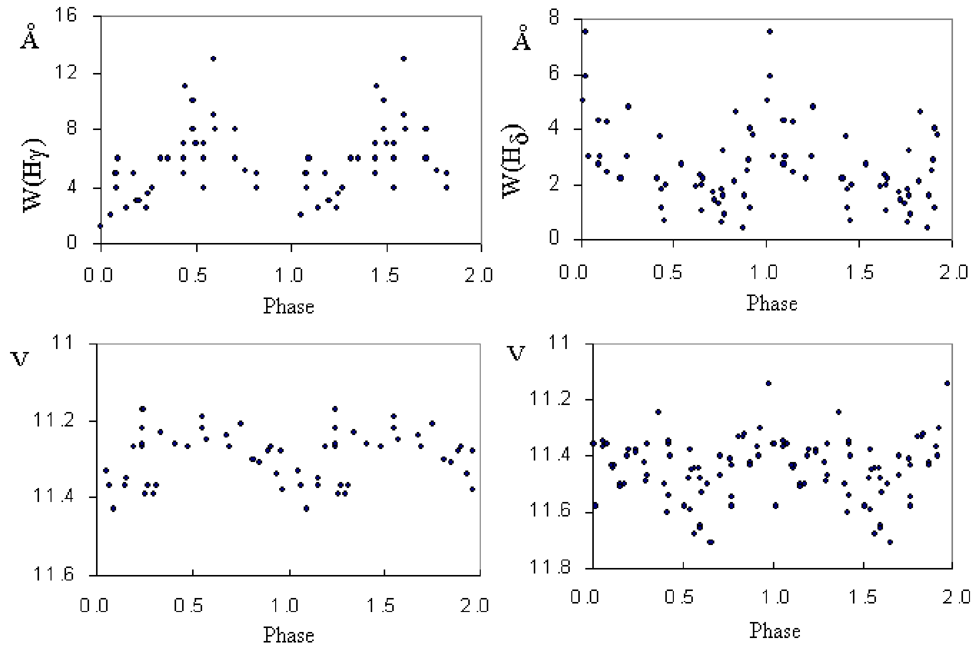

Figure 1. Top: the equivalent widths of emissions in the spectrum of DI Cep versus the phase of the 9-day period; the left panel corresponds to the data from Grinin *et al.* (1980), and the right panel, the author's data. Bottom left: photometry from Grinin *et al.* (1980). Bottom right: the author's photometry.

modulation period can be insufficiently accurate. In such a case, it can be corrected using the two different initial epochs, assuming that the active emission area (hot spot) in the atmosphere of the star does not move. The latter assumption seems rather improbable. Second, if the value of the 9-day period is precise enough, the displacement of the phase of the 9-day period is quite possible if the accretion process creating the hot spot is unstable.

The color variations of DI Cep are easily explained by the presence of the hot spot (Ismailov, 1988; Fernández and Eiroa, 1996), thus the observed 9-day modulation of the emission spectrum and brightness in absence of a correlation between the absorption and emission spectrum (Ismailov, 1987a) shows that the hot spot can be located in the excitation region of the hydrogen emission spectrum, *i.e.* in the circumstellar environment or in the disk of the star. To confidently follow possible displacements of the hot spot, long runs of continuous observations are needed.

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