Light variations and angular momentum loss from the He-strong magnetic chemically peculiar star HD 37776

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Abstract. We present a principal component analysis of multicolour light variations of the He-strong magnetic chemically peculiar star HD 37776 and its (O-C) diagram. The period increase rate found, \( \dot{P}/P = 5.5 \cdot 10^{-6}/\text{year} \), is consistent with the conception of angular momentum loss through magnetically confined stellar wind.

1. Introduction

HD 37776 = HIP 26742 = V901 Ori, B1 IV, is a member of the well studied Orion OB 1 association. The star was recognized as a helium-strong CP star by Nissen (1976). Pedersen & Thomsen (1977) and Pedersen (1979) published 54 excellent u bypass and 53 photometric measurements of the He I \( \lambda 4026 \) line of the star revealing it as both a low amplitude spectrum and light variable with a rotational period of 1.5385 ± 0.003 days.

Walborn (1982) and Shore & Brown (1990) reported on the periodic variability of its H, He, C, Si and perhaps Mg spectral lines. Thompson & Landstreet (1985) found an extraordinary double-wave magnetic curve with a period of 1.53869 days and argued that this star has a dominantly quadrupolar field geometry. Adelman & Pyper (1985) and Adelman (1997) obtained spectrophotometry and two sets of u bypass photometry (18 and 42 observations respectively). Adelman defined the period more precisely and gave the ephemeris:

\[
\text{JD}(B^+_1) = 2445724.669(20) + 1.538675(5) \cdot k, \quad (1)
\]

where \( k \) is an integer. The zero phase corresponds to the first magnetic maximum after Thompson & Landstreet (1985). The star was photometrically observed in a near infrared region (Catalano & Leone 1998, 40 observations in JHK colours) and by HIPPARCOS (103 \( H_p \) measurements, ESA 1997).

2. O-C diagram. New ephemeris

One of unsolved problems of the physics of the He strong/He weak mCP stars is the nature of photometric spots on their surfaces which are the cause of the observed photometric variations of these stars. We have chosen HD 37776 as
a prototype of the He-strong mCP group of stars as it seems to us to be a relatively simple and at the same time very well monitored object. A partial step of our research was to improve the rotational ephemeris of the star, so that it was applicable to the whole interval of 35 years covered by measurements of all kind.

For this purpose we used all the satisfactorily accurate photometric data available, namely the 3 sets of \textit{uvby} observations (Pedersen & Thomsen 1977, Adelman & Pyper 1985 and Adelman 1997) and \textit{H}_\text{p} measurements (ESA 1997). This material comprises 559 individual measurements in 5 photometric colours and spans over 20 years. The data were processed by our own code \texttt{PERSYL} based on the principal component analysis using the robust regression approaches (Mikulášek et al. 2005 and 2003).

![Fig. 1: O-C diagram for HD 37776 versus linear ephemeris.](image)

The departures we found in the (O-C) vs. linear light elements dependence lead us to introducing a quadratic term in to the ephemeris. Then the moments of the maxima of the light curves, JD$_\text{max}$, are given by the relation:

$$
\text{JD}_\text{max} = M_0 + P_0 \cdot k + \frac{1}{2} \dot{P} P_0 \left( k^2 - \frac{E^3}{E^2} \cdot k - E^2 \right),
$$

where $M_0$ is the moment of the basic maximum for the $k = 0$. $E$ is the epoch, overlines denote the mean weighted values of a quantity, $P_0$ is the mean period corresponding to linear approximation, $\dot{P}$ is the derivative of the instantaneous period, $\overline{E^2} = 4254.000$, $\overline{E^3/E^2} = 1409$, $M_0 = 2445224.197(19)$, $P_0 = 1.5386762(17)$ days, $\dot{P} = (23.2 \pm 3.3) \cdot 10^{-9}$, $\dot{P}/P_0 = 5.5 \cdot 10^{-6}$/year. It is very likely the period is truly increasing as the value of $\dot{P}$ is 7-times larger than its uncertainty. The mean period $P_0$ is exactly equal to the Adelman’s value but with the error significantly reduced.

Reiners et al. (2000), as well as Oksala & Townsend (2006) noticed increase of a period of another magnetic He-strong star: $\sigma$ Ori E. Using the period given in the latter paper and the value given in Hesser et al. (1977) we inferred the rate of spindown of the star: $\dot{P}/P_0 = 3.2 \cdot 10^{-6}$/year, in a good agreement with the one given by Reiners et al. (2000), i. e. $2.7 \cdot 10^{-6}$/year.
3. Discussion. Conclusion

The helium-strong stars represent a relatively small group of early B stars (B1 V to B3 V) that show unusually strong He lines for their effective temperature. They are believed to represent a high-temperature extension of the classical magnetic Ap/Bp stars. The observed chemical peculiarity is probably a consequence of elemental separation under influence of stellar wind.

Provided that the period change (3) is due to a momentum loss through a magnetically confined stellar wind, then the period change is (assuming a rigid-body rotation):

$$\frac{P}{P_0} = \frac{\xi \dot{M} r^2}{I}$$

where $r_{\text{cor}}$ is the radius of the effective corotation, $\xi$ is a geometric factor, $I = \eta M_* R^2_*$ is the stellar moment of inertia given by a dimensionless constant $\eta$ and the stellar mass $M_*$ and radius $R_*$. Let us assume that $r_{\text{cor}}$ is given by the Alfvén radius (Weber & Davis (1967)) and that the mass-loss rate corresponds to the value required by the diffusion theory $\dot{M} \sim 10^{-13} M_\odot$/year (Michaud et al. (1987)). For HD 37776 with $\xi = 0.1, \eta = 0.06$ we obtain $r_{\text{cor}} = 10000 R_*$ and the spin-down rate $\dot{P}/P \sim 10^{-6}$/year consistent with our finding. For the mass-loss rates anticipated by the decoupling theory (Hunger & Groote (1999)), $\dot{M} \sim 10^{-10} M_\odot$/year we obtain the same spin-down rate since $r_{\text{cor}}$ is now lower.

The nonzero $\dot{P}$ (if real) however, could also be explained by e.g. the light time effect due to an unresolved secondary. New photometric and spectroscopic observations of the star that are expected to help resolving the problem are in progress.

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References

Adelman, S. J. 1997, A&AS, 125, 65
Adelman, S. J., & Pyper, D. M. 1985, A&AS, 65, 279
Catalano, F. A., & Leone, F. 1998, Contr. Astron. Obs. Skalnaté Pleso, 27, 243
ESA 1997, in The Hipparcos and Tycho Catalogues, ESA SP-1200, Noordwijk
Hesser, J. E., Moreno, H. & Ugarte, P. P. 1977, ApJ, 216, L31
Hunger, K., & Groote, D. 1999, A&A, 351, 554
Oksala, M., & Townsend, R. 2006, These Proceedings, xxx
Mikulášek, Z., Žižňovský, J., Zverko, J., & Polosukhina, N. S. 2003, Contr. Astron. Obs. Skalnaté Pleso, 33, 29
Michaud, G., Dupuis, J., Fontaine, G., & Montmerle, T. 1987, ApJ, 322, 302
Mikulášek, Z., Zverko, J., Žižňovský, J. & Janík, J. 2005, in The A-Star Puzzle, IAU Symposium No. 224 Proceedings, Cambridge University Press, 657
Nissen, P. E. 1976, A&A, 50, 343
Pedersen, H., & Thomsen, B. 1977, A&A, 30, 11
Reiners, A., Stahl, O., Wolf, B., Kaufer, A. & Rivinius, T. 2000, A&A, 363, 585
Thompson, I. B., & Landstreet, J. D. 1985, ApJ, 289, L9
Walborn, N. R. 1982, PASP, 94, 322
Weber, E. J., & Davis, L. 1967, ApJ, 148, 217