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Short-lived and Long-lived Outbursts in B and Be Stars from Hipparcos Photometry and Modelling

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Abstract. The number of Be stars which showed short- and long-lived outbursts during the Hipparcos photometric survey, previously reported in Hubert and Floquet (1998), have been increased by examination of light curves of fainter objects. Long-lived outbursts have been modelled as being due to an ejected layer/slab which becomes gradually diluted.

1. Introduction

Ground-based intensive photometric campaigns on several targets and long-time photometric surveys have allowed to detect outbursts in Be stars. Using Hipparcos photometry Hubert & Floquet (1998) have extended the outburst detection to a very large number of Be stars, some of them having been poorly observed in photometry and/or in spectroscopy up to now; outbursts have been preferentially detected with a higher level (ΔHp ≤ 0.3 mag) in early Be stars with a low to moderate $v\sin i$. Pavlovski et al. (1998) derived the same conclusion from their investigation of Hvar survey data (Pavlovski et al. 1997).

2. Investigation of Hipparcos Variability Annex

In Hubert & Floquet (1998) the search for the presence of outbursts was first made for bright Be stars (V $\leq$ 7) selected from the list established by Jaschek & Egret (1982). In a second step unsolved light curves reported in Hipparcos Variability Annex (part C) for stars with V<10 were investigated to enlarge the number of detections of Be stars which showed during the Hipparcos mission (from mid-1989 to mid-1993) short-lived (days, tens of days), sometimes recurrent, outbursts or/and long-lived outbursts. These later are characterized by a strong increase of brightness (ΔHp ≤ 0.3 mag) over a hundred or several hundred days followed by a slow gradual decrease.
Using the list of Be stars given by Jaschek & Egret (1982), a recent study on newly discovered Be stars and $v\sin i$ measurements by Halbedel (1996), Slettebak (1982) and the SIMBAD database, we have found that in fact the B stars whose unsolved light curves are reported in the Hipparcos catalog are mainly Be stars.

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Table 1. Short-lived outbursts from Hipparcos photometry

HD	Name	Sp. Type	Time span d	ΔHp mag	vsini km/s	Remarks
6226		B2 IV-V	230	0.08		(1)
11606	V777 Cas	B1 Ve	50-100	0.15		(2)
13051	V351 Per	B1 IV	400?	0.14	168	
15450	V555 Per	B1 IIIe		0.17		
25348	DE Cam	B1 Ve		0.12		(3)
25734		B9		0.12		
33152	V413 Aur	B1 Ve	500/200	0.23		(4)
33328	λ Eri	B1 Ve	50-100	0.08	220	(2)
37490	ω Ori	B3 IIIe	250-300	0.06	160	(2)
37657	V434 Aur	B3 Ve	200-300	0.15		(2)
40978	V447 Aur	B1 Ve		0.14	200	
46547		B2 V		0.06	120	(5)
50868	V744 Mon	B2 Ve		0.2		
56139	ω CMa	B2 IV-Ve	200/330	0.30	80	(2)
62753	V387 Pup	B3 Ve		0.11		(4)
67888	PQ Pup	B3 Ve	100-200	0.20		(2)
68570	V426 Pup	B2 IIIe	200/250	0.14		
	DO Cru	B2 Ve		0.21		(3)
102776		B3 Ve		0.08	210	
105521	V817 Cen	B3 IVe	50-100	0.17	130	(2)
120324	μ Cen	B2 IV-Ve	20-30	0.06	155	(2)
120991	V767 Cen	B2 IIIe	250-330?	0.25	70	(2)
127449	V1008 Cen	B2/3 Ve		0.08		
128293	CK Cir	B3 Ve		0.08		
164284	66 Oph	B2 Ve	400-500	0.15	240	(2)
174513	V457 Sct	B1 Ve		0.25	200	
180126	V1448 Aql	B3e		0.17		
186272	V341 Sge	B2.5 Ve		0.17		
187811	V395 Vul	B2.5 Ve	100-200	0.11	230	(2)
193009	V2113 Cyg	B1 Ve	100-300	0.18-0.20		(2)
194335	V2119 Cyg	B2 Ve	150?	0.10	350	(2)
194883	V2120 Cyg	B2 Ve	100-200	0.20		(2)
195907	V2123 Cyg	B1.5 Ve	200/300	0.14		
197419	V568 Cyg	B2 IV-Ve		0.15		
204722	V2162 Cyg	B2 Ve		0.10		(6)
211835	V404 Lac	B3 Ve	200/300	0.2		(7)
212076	31 Peg	B1 Ve		0.30	100	
223036	V817 Cas	Be	100/700	0.305		

(1) suspected to be a Be star by Božić & Harmanec (1998, A&A330, 222)
(2) already reported in Hubert & Floquet (1998)
(3) with long-term variations
(4) few data, several outbursts or quasi-periodic oscillations (QPO)
(5) star in a triple system
(6) with a slow decrease
(7) with long-term variations or long-lived outbursts ?

- 38 B and Be stars which showed short-lived outbursts are listed in Table 1; all of them except two stars have a spectral type earlier than B4. In some cases time span between short-lived outbursts could be estimated and maximum intensity associated with them. In spite of the lack of *vsini* determination for fainter ones, stars with short-lived outbursts are seen with a low to moderate inclination except in one case.

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- 32 B and Be stars which showed long-lived outbursts are listed in Table 2. Spectral types are mainly earlier than B3. Stars having a *v*sin*i* determination are found with a moderate inclination angle. An estimation of the duration of brightness increase and of the subsequent decay is also given in Table 2.

Table 2. Long-lived outbursts from Hipparcos photometry.

HD	Name	Sp. Type	Increase d	Decrease d	Δ Hp mag	*v*sin*i* km/s	Remarks
	V399 Cep	B2	150	200/300	0.192		
	V548 Per	B2 IVe		$\sim$ 600	0.336		
20809	V 575 Per	B5 V	$\leq$ 200	$\sim$ 200	0.049	250	(1)
	CT Cam	B2 Ve		$\geq$ 600?	0.132		
29441	V1150 Tau	B2 Ve	< 150	> 400	0.097		(2)
34921	V420 Aur	B0 IVe	300	> 500	0.111	240	
34986	V423 Aur	B8	180	400	0.158		(3)
36012	V1372 Ori	B5 Ve	< 200	> 800	$\geq$ 0.18		(4)
49131	HP CMa	B2 Ve	100	400	0.35		(4, 5)
	LL CMa	B3 Ve	$\leq$ 150	$\geq$ 300	0.276	150	
53085	V749 Mon	B8e	$\sim$ 250	550	0.167		
53367	V750 Mon	B0 IVe	$\sim$ 400		0.25		(4)
54309	FV CMa	B2 Ve	100	> 400	0.20	200	(4)
55538	HI CMa	B2 Ve	200	250	0.214	130	
57539	V757 Mon	B5 III	$\geq$ 300?		0.091		
92938	V518 Car	B3 Ve	200	500	0.15		(4)
306798	V911 Cen	Be	$\sim$ 100	$\sim$ 300	0.447		(6)
	V959 Cen	Be	200	350	0.335		
106881	KV Mus	B3 Ve	130	300	0.151		
127489	V1010 Cen	B2 Ve	$\sim$ 200	$\sim$ 400	0.300		
130287	CP Cir	B5 IVe	$\sim$ 170	$\sim$ 350	0.228		
148259	OZ Nor	B2 Ve	$\sim$ 100?	200	0.290		
171406	V532 Lyr	B4 Ve		$\geq$ 350	0.094		
178175	V4024 Sgr	B2 Ve	$\geq$ 300		$\geq$ 0.12	120	(4)
198895	V417 Cep	B1 Ve	100	200	0.194	190	
200269	V2144 Cyg	B5 Ve	250?	400	0.150		
202904	υ Cyg	B2 Ve	100	> 400	0.20	180	(4)
203467	6 Cep	B3 IVe	< 200		$\geq$ 0.20	150	(4)
206135	V433 Cep	B3 Ve	150?	300	0.170		
211835	V404 Lac	B3 Ve	300?	500 ?	0.195		(6)
213129	V409 Lac	B2e	$\sim$ 250	500	0.208	190	
239618	V420 Cep	B2 Ve	50/100	100/200	0.29		(7)

(1) dimple activity in He I, Smith et al.(1996, ApJ469, 336)
(2) long-lived outburst or quasi-cyclical variation
(3) recurrent long-lived outbursts?
(4) already reported in Hubert & Floquet (1998)
(5) recurrent long-lived outbursts
(6) several short-lived outbursts prior to a long-lived one
(7) several long-lived outbursts with different intensities

3. A model for light curves of long-lived outbursts

We assume that the star ejects a massive layer whose mass is roughly given by: $\Delta M/M_{\odot} \sim 8\,10^{-11}(R_{\star}/R_{\odot})^2\,E\,\tau_e$ where τ_e is the initial radial electron scattering opacity of the ejected layer and E is its ellipticity. Two scenarios were

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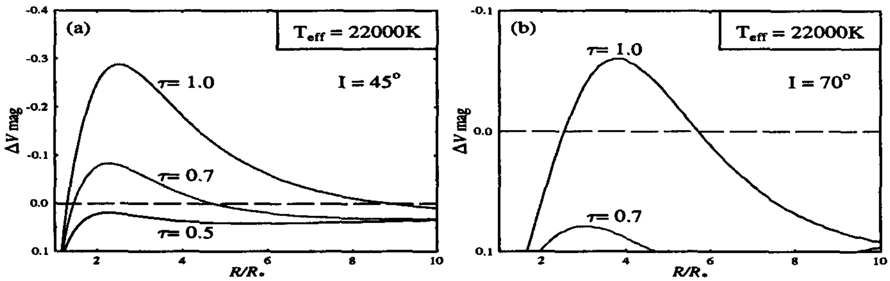

Figure 1. Variation of the magnitude V as a function of the external radius R/R_* and of the aspect angle i of an ejected layer whose ellipticity is variable $E = R_\star/R$. The ejected mass is roughly: $\Delta M/M_\odot \sim 8\,10^{-11}(R_\star/R_\odot)^2\,E\,\tau_e$

calculated: (a) once the layer is ejected, it goes on expanding preserving its total mass and its ellipticity E; (b) the expansion of the layer pursues preserving its mass but its ellipticity changes as $E = R_\star/R$, where R is the equatorial radius of the expanding ellipsoidal layer.

The light change produced by the expanding layer is understood in terms of the well known optical depth variation of the layer (Sobolev 1990). Hence, two phases are distinguished. In the first phase, the opacity is high and the photometric evolution of the star-layer system is determined by the increase of the layer radius R. In the second phase, the layer becomes progressively transparent as its opacity decreases. The reduction of its optical depth is due to the lowering of its mean opacity during the expansion. In Fig. 1 are presented the light curves for ejected layers which follow scenario (a). These scenarios may easily explain light curves observed during the Hipparcos mission. The final shapes of these curves still depend on the velocity law assumed for the expansion. On the other hand, we can also see that these massive ejections might supply enough matter to build up circumstellar envelopes in Be stars, as in each ejection there is about as much matter as ejected by an annual continuous mass ejection process. It is expected, however, that the discrete mass ejections will produce clumpy circumstellar envelopes or with quite irregular mass distributions.

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