OBSERVATIONS OF RAPID VARIABILITY IN Be STARS
(Review Paper)

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Abstract. Photometric and/or spectroscopic variability on time scales of approximately 0.2 to 2 days has been observed in over 40 Be stars, and is suspected in many more. This paper reviews the observational aspects of this phenomenon: both surveys and studies of individual objects. This phenomenon is not easy to study and interpret: (i) the time scale is inconvenient (ii) there have been very few simultaneous photometric and spectroscopic studies of individual objects (iii) the photometric variability is small, often irregular and superimposed on longer-term variability and (iv) the spectroscopic variability is usually observed as absorption line profile variability, which requires special instrumentation. For these and other reasons, there is not yet a universal agreement about the nature of this phenomenon. Nevertheless, it deserves further intensive study, not only because it is common, but also because in one or two stars, there is evidence that the rapid variability may be related (causally perhaps?) to the longer-term variability in these stars - variability whose ultimate cause is still not known.

Introduction.

This paper deals with the observational aspects of the rapid variability in Be stars - here defined as variability on time scales of approximately 0.2 to 2 days. This range includes the expected time scales of pulsation and rotation in these stars; one or both of these processes is believed to cause or control the rapid variability. Long-term variability is of course well known in Be stars. A few Be stars show regular variability on a time scale of a few days or weeks (CX Dra for instance), and have been shown to be binary systems. Perhaps surprisingly, there are no reports of Be stars with dominant periods of a few hours, and there is no convincing evidence for variability on a time scale of minutes (Lacy 1977).

Rapid variability was observed in one Be star (o And) as early as during World War I Guthnick(1941). Walker (1953) discovered the photometric variability of EW Lac, and Lynds (1959ab, 1960) V923 Aql and EM Cep. The variability was ascribed to duplicity (o And and EM Cep) or to rotation (V923 Aql and EW Lac) but for various reasons - including the many observational difficulties listed below - detailed observation and interpretation of these stars was not carried out.

The present interest in the rapid variability of Be stars began about 1980, for several reasons. The development and use of modern spectro-

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scopic detectors by Baade, Penrod, Smith, Vogt and Walker enabled line profile variability to be studied in detail. Meetings such as the Workshop on Pulsating B Stars, in Nice in 1981, brought together those studying Be stars and those studying other types of pulsating B stars. The identification of stable short periods in 28 CMa and λ Eri by Baade and Bolton, respectively, promoted an interest in searching for more periodic variables. Finally, the organization of the IAU Working Group on Be stars, of its Newsletter, and of photometric and spectroscopic "campaigns" on Be stars has encouraged and focussed the research on these stars.

Related Variables.

The Be stars share their location in the H-R diagram with several other types of "rapid" variables. These provide clues about the nature of rapid variability in Be stars. They must also be distinguished observationally from the rapid variable Be stars. Auvergne et al. (1981), Harmanec & Pavlovski (1983), Lesh (1982) and Percy (1980) give useful reviews of rapid variability in B stars.

(i) Ellipsoidal and shallow eclipsing variables are common among the early type stars, and many may go unrecognized (Beech 1986ab). They have stable light curves and usually large radial velocity variations.

(ii) Helium-strong, -variable and -weak stars are found among the early, middle and late B stars, respectively. The variability is due to the rotation of a star with a strong magnetic field and an inhomogeneous photosphere and/or magnetosphere. Bolton et al. (this volume) provide an excellent description of the nature and variability of σ Ori E, a bright member of this class.

(iii) Beta Cephei stars are pulsating stars with periods of a few hours, moderate to large variations in radial velocity, and early B spectral types. They are believed to be pulsating in radial modes (and in some cases in one or more non-radial modes as well). The cause of the pulsation is still a mystery.

(iv) 53 Persei stars are O9 to B5 stars of various luminosity classes which have large absorption line profile variations. They are believed to be low-order non-radial pulsators, though Balona (preprint) has recently suggested that the small light variability could be modelled by rotation. The 53 Persei stars have small v sin i. The bright B0.7III star ε Per, with a moderate v sin i, shows very large absorption line profile variations which have been successfully modelled by Smith (1985) as -m = l = 4 and -m = l = 6 non-radial pulsations. Bolton, Fullerton & Geis (private communication) have discovered absorption line profile variations in many O stars. These may also be similar to the 53 Persei stars. See Baade (1986b) for a good recent review.

(v) Numerous B supergiants show light, radial velocity and/or absorption line profile variability on a time scale of days to weeks, most likely due to non-radial pulsation (Maeder 1986). The irregularity

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of the variability, and other observational problems, makes it difficult to confirm this hypothesis. Harmanec (preprint) has suggested that the variability may be due in some cases to rotation or duplicity.

Models for the Rapid Variability.

Various models for Be stars and their variability are discussed in detail elsewhere in this volume, but are listed here for reference. It is entirely possible that different models may explain rapid variability in different stars, or even different aspects of the rapid variability in a given star.

(i) Pulsation. The periods and the absorption line profile variations require that the pulsation be non-radial. The dominant mode is usually a low-order ($l = 2$) g mode. The light variability seems to rule out r modes.

(ii) Rotation. An oblique dipole magnetic field may produce photospheric temperature differences between the magnetic poles and equator, or may "lock" circumstellar material above the magnetic poles. Alternatively, there may be discrete spots like sunspots, which produce variability by their cooler temperature, or by clouds of circumstellar material which are locked to them by magnetic loops.

(iii) Duplicity. Although some rapid variable Be stars were initially thought to be ellipsoidal or shallow eclipsing variables, this hypothesis seems to be ruled out by the lack of radial velocity variations, and by the rapid changes in the light curves of some stars.

(iv) Circumstellar material. Although some aspects of the rapid variability can be successfully modelled by inhomogeneities in an equatorial disc (see Vogt and Penrod (1983) for instance), these must be locked to the star somehow in order to produce the stable periods which are observed in some stars.

Problems of Studying Rapid Variability in Be Stars.

Primarily for the following reasons, our progress in understanding the rapid variability in Be stars has been slow. Also for these reasons, reports of rapid variability, and determinations of periods should be regarded as tentative until confirmed by independent observations.

(i) The time scales are inconveniently close to one day. Photometric and spectroscopic analyses are plagued by aliasing - uncertainty in the number of cycles from one night to another.

(ii) The photometric amplitudes are small, often variable and superimposed on longer-term variability. This greatly complicates the process of period determination. In some stars, night-to-night variability has made period determination impossible. Similarly, there are often irregularities in the absorption line profile variations which make analysis and interpretation difficult.

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(iii) The light curves are usually non-sinusoidal. This complicates the process of period determination using Fourier methods which assume that the light curve is sinusoidal. For this reason, Stellingwerf's phase dispersion minimization method of period determination is preferred by some observers. In stars with double-wave light curves, there is an ambiguity in period when the waves are nearly identical.

(iv) The absorption line profile variability can only be observed in detail with spectrograph-detector systems which give high resolution (>30 000) and signal-to-noise (>200). These are few in number, seldom available for long observing runs, and limited in their wavelength coverage.

(v) The spectra of Be stars are often unsuitable for the study of absorption line profile variations, because of the presence of emission. Even in normal B stars, the number of suitable lines is limited.

(vi) There are difficulties in modelling, and therefore interpreting the variability, either in terms of pulsation or rotation. Aside from the problems of understanding a normal B star atmosphere, there are the problems of knowing the effects of the rapid rotation, mass loss and possibly magnetic field.

The solution to many of these problems lies in coordinated multi-site multi-technique observations. A rather successful mini-campaign on five rapid variable Be stars was held in 1983 (Stagg, this volume; Stagg et al., in preparation). In this case, there were additional problems of combining photometric observations from several observers at the Hvar (Yugoslavia), Dunlap (Canada), McDonald and Kitt Peak (USA) and Peking (China) Observatories. Nevertheless, the mini-campaign was successful in demonstrating the varied behaviour in these stars. Follow-up observations of these stars in 1984 by Percy, Harmanec et al. and others were useful for investigating the long-term changes in the light curves. Both Baade and Balona have attempted to organize some coordinated observations of southern Be stars. At this IAU Colloquium, a group was formed to organize further coordinated observations of a small number of suitable stars. The difficulties of organizing such observations cannot be overestimated!

The Incidence of Rapid Variability in Be Stars.

About two dozen Be stars are known to be rapid variables, and a similar number are suspected to be such. Many of these are listed in the Appendix. This random sample is probably not suitable for estimating the incidence, or its dependence on spectral type or v sin i. Percy (unpublished) searched the archive of UBV photometry of Be stars at the Ondrejov Observatory in Czechoslovakia, and studied Be stars for which there were many observations on adjacent nights. About 25 per cent of such stars showed night-to-night scatter corresponding to an amplitude greater than $0\overset{m}{.}03$. There was a marked tendency for the definite and probable rapid variables to be B5 or earlier (16 of 18 stars) and for

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the nonvariables to be B6 or later (9 of 10 stars). The sample of stars studied, however, could not be considered complete and unbiased.

Balona and Engelbrecht (1986) surveyed seven Be stars in the open cluster NGC 3766. Four were strictly periodic (see Appendix) and two others were definitely variable. From this and their other southern surveys (this volume), they feel that there is no dependence of the incidence of rapid variability on spectral type.

The largest and most unbiased survey of rapid variability is by Stagg (this volume), who surveyed 85 bright southern Be stars and found that about 50 per cent seem to vary from night to night with an amplitude of $0^{m}.01$ or greater. The degree of variability (especially in U) was greater in the B0-B5 stars. There was no apparent dependence of the incidence on v sin i. If all Be stars have similar v, then this implies no dependence on sin i.

With regard to spectroscopic variability: Penrod (this volume) has surveyed about two dozen Be and Bn stars, and has found absorption line profile variability in nearly all of them. The Be stars have a distinctive type of variability characterized by varying line asymmetry. Baade (this volume) states that "....my experience with more southern Be stars is the same, except for the late B types".

The Nature of the Rapid Photometric Variability.

A large number of light curves of rapid variable Be stars are shown in the contributions of Balona and Engelbrecht, Harmanec *et al.*, Stagg and others to this volume. The following is a summary of their properties.

(i) The well-determined periods are in the range 0.3 to 2 days. A period of 0.21 day is suspected in 25 Cyg; it is important that this be confirmed, because this period (or even twice this period) would be too short to be explained by rotation. Likewise, the well-determined period of 0.3 day in LQ And has been interpreted as half of the true period (Harmanec 1984a).

(ii) The period is reasonably stable in many of the stars, in the sense that similar periods are obtained from different runs of observations, and light curves with little scatter can be formed from observations obtained over several weeks. In a few stars (such as o And, LQ And, EM Cep, and possibly EW Lac and λ Eri), there is evidence that the period is stable over many years.

(iii) There is no firm evidence for a substantial period change (such as might be expected for pulsational mode-switching) in any of these stars. In the stars whose behaviour is complex, however, (EW Lac, KX and KY And, for instance) this possibility cannot be ruled out.

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(iv) There is no firm evidence for the sort of photometric multiperiodicity that is found in the β Cephei and 53 Persei stars. Baade (1982a), however, has suggested that the photometric period of 28 CMa is much shorter than the spectroscopic period, and Balona and Engelbrecht (this volume) have identified periods of 1.075 and 0.193 day in ζ Oph. Spectroscopic multiperiodicity has been found in a few of these stars.

(v) The light curves are occasionally sinusoidal (as in LQ And) but are more usually non-sinusoidal. Double-wave light curves, or light curves with two unequal minima are common.

(vi) The photometric amplitudes are typically $0\overset{m}{.}01$ to $0\overset{m}{.}10$, but occasionally reach as much as $0\overset{m}{.}2$ (in U) in one or two stars.

(vii) Colour amplitudes are seldom measured in these stars, but when they are, they tend to be small - more so in (B-V) than in (U-B).

(viii) The photometric amplitudes can occasionally change on a time scale as short as a few days (Percy 1981) and commonly change on a time scale of months. LQ And, however, has remained stable over almost a decade.

(ix) The shape of the light curve can change on a time scale as short as a few days. This occurred in EW Lac during the 1983 minicampaign (Stagg, this volume; Stagg et al., in preparation).

The Nature of the Rapid Spectroscopic Variability.

Seen at high dispersion and high signal-to-noise, the rapid absorption line profile variability in Be stars consists of a changing asymmetry, on which are sometimes superimposed moving narrow components colloquially known as "bumps and wiggles". These are clearly seen in Figure 1. Other examples are shown in the contribution by Baade in this volume. If the spectra are observed at lower resolution or signal-to-noise, the variability may take the form of radial velocity changes (depending on how the radial velocity is measured). If there is overlying emission, the absorption line profile variability may cause an apparent V/R (violet component/red component) variability. The following is a summary of the nature of the spectroscopic variability, based mainly on the work of Baade and of Penrod (this volume).

(i) The spectroscopic period is the same as the photometric period, where both are known.

(ii) These periods range from about 0.2 to 2 days.

(iii) Rapid spectroscopic variability is seen in virtually all Be and Bn stars, but the Be stars show changing asymmetries and sometimes bumps and wiggles; the Bn stars show only the latter.

(iv) The amplitude of the rapid spectroscopic variability, expressed as a non-radial pulsation velocity, ranges up to about 20 km s^{-1}, the approximate sound speed. It can change on a time scale of a few days.

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(v) Transient events may appear in the line profile. Features may appear or disappear suddenly. There may be irregularities in the asymmetry changes. Bumps and wiggles may vary in amplitude from one cycle to the next. These irregularities may be found to be common when more stars are studied in more detail.

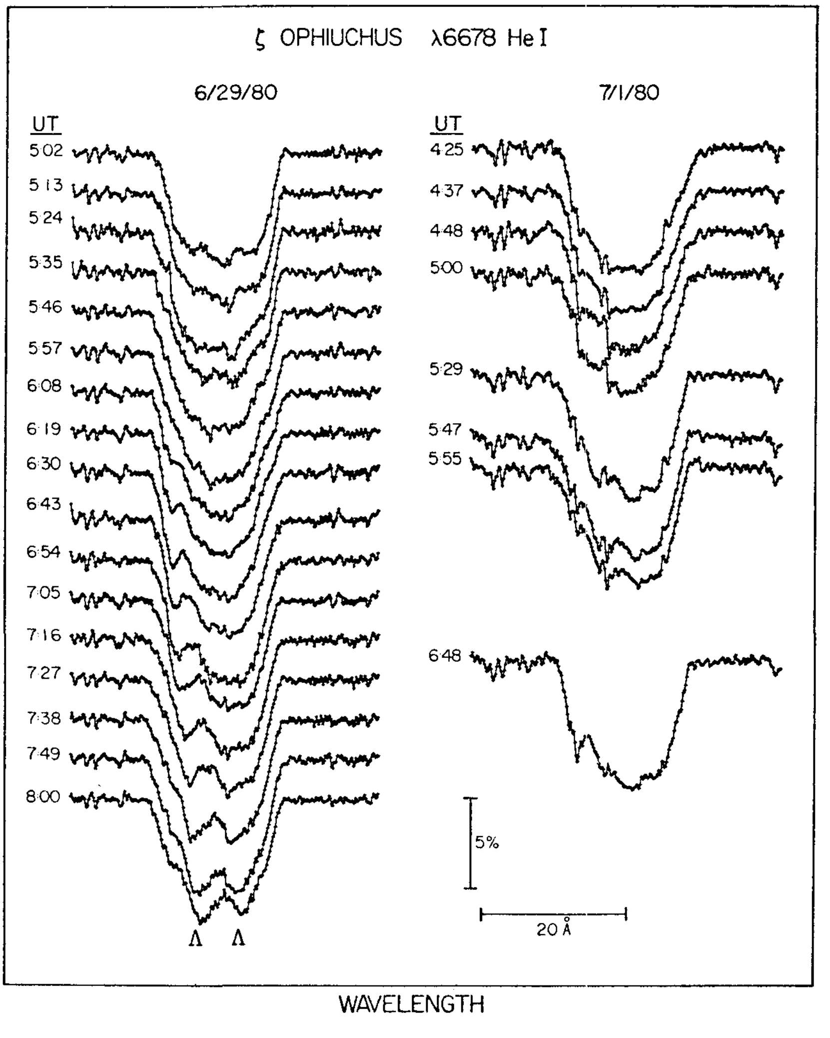

Figure 1. Rapid absorption line profile variability in the O9.5Ve star ζ Oph (Vogt and Penrod 1983). Note the changing asymmetry and the bumps and wiggles marked with an inverted V. These can be seen best by looking at the figure at a shallow angle.

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Correlation between Rapid and Long-term Variability.

The nature and cause of the long-term photometric and spectroscopic variability in Be stars is still not clear. Both seem to be related to changes in the amount of material in the circumstellar disc, and therefore to changes in the rate of mass transfer into and out of the disc. There is some evidence that changes in the amplitude of the rapid variability may be correlated with changes in emission - the so-called "emission episodes". This possibility was proposed by Bolton (1982) in the case of λ Eri and by Baade (1983) in the case of η Cen, but the necessary simultaneous monitoring of the rapid and the long-term variability were lacking. Vogt and Penrod (1983) presented somewhat stronger evidence for such a correlation in ζ Oph. The amplitude decreased as an emission episode began, then slowly increased as the emission episode died out.

In late 1983, Penrod (1986) was fortunate to observe the absorption line profile variability in λ Eri at a time when a major emission episode began. He found that the amplitude of the asymmetry changes was largest (about 20 km s^{-1} when expressed as a pulsation velocity) before the emission episode, declined slowly during the emission phases to a fraction of its previous value, then slowly recovered over the course of a few months to its original value.

Harmanec (1984b) investigated the long-term behaviour of o And, one of the best-studied of all Be stars. He found that the amplitude of the rapid photometric variability was largest when a shell episode was in progress. At these times, the shell spectrum was at maximum strength, and the mean brightness of the star was at minimum. Confirmation of the correlation between rapid and long-term variability in this and other stars will require continuous monitoring with a variety of techniques - a requirement that is easier stated than accomplished!

Future Directions.

At present, there are two competing hypotheses about the cause of the rapid variability: non-radial pulsation and rotation. The former is supported especially by the large body of spectroscopic data accumulated by Penrod (this volume), data which is unfortunately not yet published. The latter is supported especially by certain qualitative features of the light curves, though Harmanec et al. (this volume) have constructed some quantitative models. Though the modelling procedures have deficiencies in both cases, it is most important that both models are confronted with the totality of the spectroscopic, photometric and other data. It is also important to identify the crucial observations which distinguish between the two models.

As always, we need more and better data - both accurate photometry and high resolution and high signal-to-noise spectroscopy. Ultraviolet observations would also be useful. Where possible, multi-site observations must be obtained because of the time scales involved. In order to achieve the necessary coordination, a small working group has been established. It will also be necessary to choose a small

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number of stars for detailed study. These should be bright, well-distributed in right ascension and declination, with spectra which are interesting but not so complex that absorption line profile variability cannot be observed.

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APPENDIX: LISTS OF DEFINITE, PROBABLE AND POSSIBLE RAPID VARIABLES

Table 1: Definite Rapid Variables

This list includes variables which have been confirmed by two or more observers and/or in which a "period" has been determined. Some of the periods are in need of confirmation, but it is highly likely that the stars are rapid variables. In the remarks column, BE indicates that the star is discussed by Balona and Engelbrecht (this volume), and DW refers to a light curve with a double-wave shape. Most of the stars are further discussed in the notes.

HD	HR	Name	Sp.T.	vsini	Δm	P(d)	Remarks
10144	472	α Eri	B3Vpe	251	0.04	1.26	BE,DW
33328	1679	λ Eri	B2IVe	336	0.03var	0.70	BE,DW(?)
37490	1934	ω Ori	B3IIIe	194	0.05	1.910	BE,DW
56014	2745	27 CMa	B3IIIe	139	0.02	1.274:	BE, = EW CMa
56139	2749	28 CMa	B2.5IVe	120	0.02var	1.37	BE, = ω CMa
120324	5193	μ Cen	B2IV-Ve	175		0.51	
127972	5440	η Cen	B1.5Vne	333		hours	
148184	6118	χ Oph	B1.5Ve		0.05	0.935	BE
149757	6175	ζ Oph	O9.5Vne	379	0.02	1.075	BE, also P=0.193
157042	6451	ι Ara	B2IIIne	369	0.05	0.515	BE,DW
158427	6510	α Ara	B2.5Ve	298	0.04	0.658	BE,DW(?)
172256			B5e		0.12	0.5::	
180968	7318	2 Vul	B0.5IVe	332	0.06	0.61	DW, = ES Vul
183656	7415	V923 Aql	B5Ve	180	0.10	0.85:	
189687	7647	25 Cyg	B3Ve	229	0.03	0.21:	
191610	7708	28 Cyg	B3Ve	310	0.06var	0.7	= V1624 Cyg
200310	8053	60 Cyg	B1Ve	320	0.05:	1:	
205637	8260	ε Cap	B3Ve	293	0.03	0.769	BE,DW
208392		EM Cep	B1IIIe		0.15	0.4	DW? (P=0.8)
209014	8386	12 PsA	B8Ve		0.02	0.774	BE,DW?, = η PsA
209409	8402	o Aqr	B8Vpe	227	0.03	1.449	BE,DW
217050	8731	EW Lac	B4IIIe	350	0.06var	0.72	DW
217675	8762	o And	B6IIIe	330	0.05var	1.57	DW
218393		KX And	Bpe		0.10	0.47:	39^d binary
218674		KY And	B3IVe		0.10	1.51:	DW?
224559	9070	LQ And	B3IVe		0.03	0.31	DW? (P=0.6)
		NGC3766-01	B2IVp(e)		0.03	1.739	BE(1986),DW?
		NGC3766-15	B2IIIe		0.05	0.946	BE(1986),DW?
		NGC3766-63	B1.5Vn		0.03	0.844	BE(1986),DW
		NGC3766-88	B3npe		0.05	0.955	BE(1986),DW

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Table 2: Probable Rapid Variables

The division of stars between Tables 2 and 3 is to some extent a matter of judgement. Those in Table 2 are more likely to be rapid variables, those in Table 3 less so. In the remarks column, H and PR refer to unpublished observations made by the Czechoslovak and Yugoslav observers at Hvar Observatory, and by Percy & Richer at Toronto.

HD	HR	Name	Sp.T.	vsini	Remarks
4180	193	o Cas	B5IIIe	260	Horn et al. (1985), P=1^{d}.1679?
13890			B1IIIpe	50	Hill (1967), Stagg (1983)
37202	1910	ζ Tau	B4IIIpe	310	Harmanec (1983a)
41335	2142		B2Ve	419	Percy (1981)
48917	2492	10 CMa	B2IIIe		Baade (1984a), = FT CMa
50013	2538	13 CMa	B1.5IVne	199	Baade (1984a), = κ CMa
89890	4074		B3IIIe	81	Baade (1984a)
118246			Be		Turner et al. (1978)
156325	6422		B5Vne		Stagg (1986)
161756	6621	V3894 Sgr	B4IVe		Stagg (1986)
168797	6873	MWC 601	Be		H, PR(1986)
184279		V1294 Aql	B0e		H, PR(1986)
192685	7739		B3V	249	H, PR(1985,1986)
200120	8047	59 Cyg	B1IVe	374	Tarasov & Shcherbakov (1983)
		NGC3766-26	B2IVne		Balona & Engelbrecht (1986)
		NGC3766-36	B4Vne		Balona & Engelbrecht (1986)

Table 3: Possible Rapid Variables

HD	HR	Name	Sp.T.	vsini	Remarks
5394	264	γ Cas	B0IVe	300	Harmanec (1983b)
14422			B2Vpe	> 280	Hill (1967)
22192	1087	ψ Per	B5Ve	369	Percy et al. (1981)
25940	1273	48 Per	B3Ve	217	Percy et al. (1981), = MX Per
32343	1622	11 Cam	B2.5Ve	131	Percy et al. (1981)
36576	1858	120 Tau	B2IV-Ve	271	H
39340			B3V	>330	Hill (1967)
105435	4621	δ Cen	B2IVne	181	Percy et al. (1981)
109387	4787	κ Dra	B6IIIpe	249	Harmanec (1983b)
112091	4899	μ^2 Cru	B5Vne	201	Percy et al. (1981)
138749	5778	θ CrB	B6Vnne	393	Roark (1971)
174237	7084	CX Dra	B2.5Ve	170	H
212571	8539	π Aqr	B1Ve	278	Harmanec (1983b)
217543	8758	MWC 395	B3Vpe	370	H

Table 2 and particularly Table 3 are by no means complete. All stars in these tables, however, are in need of monitoring for rapid variability.

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Notes on Table 1.

These notes, and those on Tables 2 and 3 are not exhaustive. Further notes and references are contained in the reviews by Harmanec (1983b,c), as well as in other bibliographic sources.

HD 10144. This bright Be star shows significant flux variability in the UV. In the Yale Catalogue of Bright Stars, it is referred to as an eclipsing or ellipsoidal variable.

HD 33328. Bolton (1982) found a stable period of $0\overset{d}{.}701538$ in the radial velocity and brightness of this star. Percy (1986) discusses the brightness variability. Balona and Engelbrecht (this volume) observed this star in 1985-86; they prefer a period of $0\overset{d}{.}408$, or possibly a period of $0\overset{d}{.}816$ with a double-wave light curve. Penrod (1986) has observed both low-order and high-order line profile variations, and finds a correlation between the amplitude of the rapid spectroscopic variability and the occurrence of an emission episode. Smith et al. (this volume) describe transients in the rapid spectroscopic variability.

HD 37490. This star shows significant short-term flux variability in the UV. Baade (1986a) discusses the possible relation between the rapid spectroscopic variability and the major emission episodes (Hayes & Guinan 1984; Guinan & Hayes 1984).

HD 56014. The Yale Catalogue of Bright Stars refers to this star as a $0\overset{d}{.}261975$ spectroscopic binary. There is a close visual companion.

HD 56139. The discovery of an unusually short stable period in this star (Baade 1982b) was a great impetus to the further study of rapid variability in Be stars. Baade (1982a) proposed a photometric period of $0\overset{d}{.}435$. Stagg's (1986) observations are consistent with the spectroscopic period. The analysis of the photometry is complicated by aliasing problems and significant night-to-night variability.

HD 120324. Baade (1984b) discovered absorption line profile variability which he interpreted in terms of two retrograde modes (l = 2 and 10) of non-radial pulsation. Peters (1986) reported on the onset of an emission episode which developed in only two days, and was accompanied by rapid (10 to 20 minutes) variability in HeI λ6678. The star is photometrically variable according to Percy et al. (1981)

HD 127972. Baade (1983a) reported rapid spectroscopic variability on a time scale of hours, and suggested that these might precede an emission episode. Stagg (1986) discovered photometric variability in this star in the course of his southern photometric survey.

HD 149757. Detailed observations and modelling of this star are reported by Vogt and Penrod (1983). Note that Balona and Engelbrecht (this volume) find periods of both $1\overset{d}{.}075$ and $0\overset{d}{.}193$ in their photometric observations.

HD 172256. This faint Be star shows variability of up to $0\overset{m}{.}13$ within a few hours, on several occasions, but a precise period has not yet been derived (Heck et al. 1984).

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HD 180968. The photometric variability was discovered by Lynds (1959a), who obtained a period of $0^d.6096$. Stagg (1983) confirmed the variability but not the period. Percy & Richer (1985 and 1986 unpublished observations) also confirmed the rapid variability but have not yet investigated the periodicity.

HD 183656. The rapid photometric variability discovered by Lynds (1960) has been confirmed by the Hvar observers (Harmanec 1983a) and by Percy & Richer (1986 unpublished observations), but the period is in need of confirmation.

HD 189687. The photometric variability of this star is discussed by Percy & Lane (1977) and by Percy et al. (1981). No rapid variability was observed in 1985 (Percy & Richer, unpublished). The short period of $0^d.21$ is in need of confirmation, but its reality is supported by the discovery by Penrod (private communication) of line profile variability on the same time scale.

HD 191610. The rapid photometric variability of this star has been discussed by Percy & Lane (1977), Percy et al. (1981), Spear et al. (1981) and Catalano & Umana (this volume). The rapid variability is large (up to $0^m.10$) and seems to be quite complex; Percy & Richer (unpublished) have analyzed multi-site August 1985 observations, and were unable to find a period. The Yale Catalogue of Bright Stars lists spectroscopic periods of $226^d.0$, $45^d.33$ and $1^d.51775$ for this star. The photometric period appears to be about $0^d.7$, and absorption line profile variability on the same time scale has been observed (Penrod, private communication).

HD 200310. Harmanec et al. (1986) discovered rapid photometric variability with a most probable period of $2^d.4$, but the aliasing problems in the power spectrum were severe. Percy & Richer (1986 unpublished observations) confirm the variability but not the period; the strongest period in their power spectrum is at about $0^d.75$.

HD 208392. The rapid variability of this star has been reviewed by Harmanec (1983b). It has a stable period of $0^d.806187$, a slightly variable light curve with double-wave structure, absorption line profile variability but no radial velocity variability.

HD 217050. The rapid variability of this star has been reviewed by Harmanec (1983b). In the 1983 mini-campaign, it showed a complex light curve which changed significantly within a few days (Stagg, this volume; Stagg et al., in preparation). Pavlovski (1986 preprint) maintains that this star may be strictly periodic. In 1984, the photometric amplitude had dropped to nearly zero (Percy, unpublished).

HD 217675. The rapid variability of this bright, well-studied Be star has been described in detail by Harmanec (1983b). Harmanec (1984b) subsequently determined that this star had a stable short period of $1^d.571272$ whose amplitude was correlated with the presence of a shell spectrum and with the mean brightness of the star. Observations made during the 1983 mini-campaign are consistent with this short period (Stagg, this volume; Stagg et al., in preparation). The photometric behaviour since 1983 is described by Harmanec et al. (this volume).

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HD 218393. This $38^{d}.919$ spectroscopic binary shows complex photometric and spectroscopic variability (Harmanec et al. 1977). The presence of photometric variability on a time scale of about $0^{d}.47$ was discovered by Koubský & Pavlovsky (1982) and confirmed during the 1983 mini-campaign (Stagg, this volume; Stagg et al., in preparation).

HD 218674. Rapid photometric variability has been found by several observers, who report different periods, however: $0^{d}.40$ (Percy, 1981 unpublished observations), $0^{d}.714$ (Pavlovski 1983) and $0^{d}.753$ or $1^{d}.506$, depending on whether a single-wave or double-wave light curve is assumed (Stagg, this volume; Stagg et al., in preparation).

HD 224559. Earlier observations of this star are reviewed by Percy (1983). Harmanec (1984a) suggested that the period might be $0^{d}.62$ rather than $0^{d}.31$, and that the light curve might have two slightly unequal minima. Most other observers do not believe that this is the case (see Sareyan et al., this volume, for instance). Penrod (private communication) finds little or no rapid spectroscopic variability in this star. More and better observations are necessary to determine whether the light curve of this star is completely stable.

Notes on Table 2.

HD 4180. Photometric as well as spectroscopic variability occurs on a time scale of a day or two (Horn et al. 1985; unpublished Hvar observations).

HD 37202. This star has a long history of suspected rapid variability. See Gies & McDavid (this volume), for instance.

HD 41335. The suspected rapid photometric variability (Lynds 1959a; Percy 1981) is in need of confirmation.

HD 200120. Percy (1981) and Percy & Richer (1986 unpublished observations) find no significant rapid photometric variability.

Notes on Table 3.

HD 5394, HD 109387, HD 212571. Harmanec (1983b) has reviewed and commented upon the extensive and contradictory reports of rapid variability or non-variability in these stars.

HD 138749. Roark's (1971) report of large, rapid photometric variability is not confirmed by the many subsequent observations.

HD 174237. This well-studied $6^{d}.7$ binary shows photometric variability on many time scales. It is not clear whether rapid variability (as defined in this paper) is found in this star.

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DISCUSSION FOLLOWING PERCY

Bolton:

I think it is worth pointing out that *all* of the "models" that have been suggested to explain short term variability in Be stars are *ad hoc* in the sense that they have no firm theoretical basis which will allow the effects that are modeled to be predicted ahead of time. They are merely mechanical or mathematical methods for predicting future behavior of the observed quantity, and the only test that we have of these models is their ability to reproduce the behavior of a second observable quantity without adding additional fitting factors. Some models appear to have so little physical content that they cannot predict the fit of other observables from the "fit" to one, but the nonradial pulsation, spot, and spoke models all can be used to predict the behavior of other observables from the observed behavior of one. This work has not been done in detail for any of these models, but I think that it is easy to see that the spot and spoke models fit to helium line profile variations lead to predictions of large scale variations in Hα which have never been seen.

Doazan:

Last week, at the workshop on pulsating stars at Los Alamos, there were several discussions on nonradial pulsations in Be stars. It is particularly regrettable that those who advocated that nonradial pulsations might be the cause of the Be-phenomenon were not there. Several persons have emphasized (1) the difficulty of determining a reliable value for the modes from the available observations, and (2) the large number of *ad hoc* assumptions made for deriving the values.

Sareyan:

I should like to know if we have any observational evidence of a pulsating Be star (i.e. a star for which period(s) and mode(s) are not only an interpretation, but are the parameters of a proven pulsation).

Percy:

The question is a difficult one, in part because some of the strongest evidence for nonradial pulsation (Penrod's line- profile studies) is still unpublished. The pulsation of Be stars is not *proven*, but the pulsation hypothesis seems to be the most consistent and successful in explaining the spectroscopic and photometric observations.

Balona:

I think it is very important to get away from the point of view that nonradial pulsation has been *proved* in these stars. You have shown that the observations are subject to a considerable number of interpretations. We require more data before adopting a specific model.

Percy:

I agree. The greatest necessity is for the spectroscopic work to be published and thereby examined, since this seems to provide the strongest evidence for nonradial pulsation. I cannot object to more, better and more selective observations!

Underhill:

Any star in the mass range greater than 12 solar masses appears to pulsate in a nonradial manner. Detailed spectroscopic observations of line profiles show bumps, wiggles on and changing asymmetry of photospheric lines. Most of the stars do not show any of the phenomena which lead to the classification Be. One may question whether nonradial pulsation has a direct causal relationship to the occurrence of a Be spectrum. Consideration of nonradial pulsation may be a red herring. One wishes to isolate the physical causes of the

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Be phenomena and separate them from general properties of stars in a restricted mass range. Can we answer the question why Be stars have these (hopefully few) special properties?

Percy:

According to the observations by Penrod, and some very qualitative theoretical discussions by L.A. Willson and others, it would be the *combined* effect of radiation pressure (i.e. hot star), rotation (i.e. reduced equatorial gravity) and low-order nonradial pulsation (i.e. sustained vertical motions) which produces the mass ejection.

Balona:

I have no objection against nonradial pulsation as such, but only in the way the models have been made. Often variable periods, variable amplitudes etc. are invoked. In this way one can explain everything, but no predictions or physics can be obtained. This is a bad theory.

Percy:

I understand your concern, but the complex changes in the amplitudes in some stars are apparently a property of the star's pulsation, and are not invoked simply to "patch up" the model.

Henrichs:

I would like to stress the importance of including UV spectroscopy in your proposed simultaneous observations. The discrete absorption components in the UV wind lines are known to be variable and are in a few cases demonstrated to be correlated with Hα and optical line profile variations. In particular λ Eri is one of them.

Percy:

I agree that UV spectroscopy would be scientifically very valuable. My only hesitation was with the logistics of arranging simultaneous optical and UV observations.

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