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VARIABLE STAR DESIGNATIONS FOR EXTREME HELIUM STARS

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Variability in hydrogen-deficient Bp supergiants was first established in BD+13°3224 = V652 Her and HD 160641 = V2076 Oph by Landolt (1975). Reports of variability in other hydrogen-deficient Bp supergiants followed. Amongst these was the detection of small-amplitude variations in HD 168476 = PV Tel by Walker & Hill (1985). After establishing that several such stars were variable, the GCVS identified a new class with PV Tel as the prototype and a definition: "a helium supergiant Bp star with weak hydrogen lines and enhanced lines of He and C. They pulsate with periods of approximately 0.1 to 1 days, or vary in brightness with an amplitude of 0.1 mag in V during a time interval of about a year." (Kholopov et al., 1985–88). The GCVS contains twelve confirmed PV Tel variables, three unconfirmed PV Tel variables and V652 Her, which "resembles PV Tel type stars but is a helium rich subdwarf."

The PV Tel designation is useful because it identifies A- and B-type hydrogen-deficient stars which are also variable. It presents problems because it misrepresents the types of variability observed. We propose a revision of the PV Tel designation.

Why should the designation be changed? First, observations of the helium-rich Bp supergiant PV Tel (Walker & Hill, 1985) showed evidence for light and radial velocity changes over intervals of the order of a year. There is no doubt that the star is variable. However the Walker & Hill data are also consistent with variability on shorter timescales. Subsequent observations have shown PV Tel to vary quasi-periodically with an amplitude of about 0.1 mag on a timescale of 8 – 10 days (Jones et al., 1989; Lawson et al., 1993). Hence PV Tel is not a PV Tel variable – according to the definition.

Second, the inclusion of periods of approximately 0.1 to 1 d followed the detection of variability in V652 Her (P=0.108d, Landolt, 1975), V2076 Oph 0.7 - 1.1 d (Landolt, 1975; Lynas-Gray et al., 1987) and BD+10°2179 = 0.16 d (Bartolini et al., 1982). The light curves of V652 Her and V2076 Oph are easily distinguished from one another, the former is strictly regular, the latter is either multiperiodic, quasiperiodic or irregular. Which one is not yet clear. BD+10°2179 was shown to be non-variable (Hill et al., 1984; Grauer et al., 1984). Hence, simply changing the definition of the PV Tel class (*e.g.* by extending the period range) fails to use available information. A corollary would be the need for two classes of pulsating subdwarf B star, namely EC14026=V361 Hya and PG1716=V1093 Her variables, with periods of ~ 100 s and ~ 3000 s, respectively.

Table 1: Types of light variation in hydrogen-deficient supergiants.

V*	Other	$P[d]$		Light curve
PV TEL I				
FQ Aqr	BD+1°4381	19–22		Jeffery & Malaney, 1985
NO Ser	BD−1°3438	5–8		Jeffery et al., 1985
PV Tel	HD 168476	8–10		Walker & Hill, 1985; Jones et al., 1989
V354 Nor	CPD−48°7730, =LSS 3378	10-15		Lawson et al., 1993
V2244 Oph	LS IV−1°2	10–11		Morrison, 1987; Jones et al., 1989
V4732 Sgr	LS IV−14°109	∼ 25		Lawson et al., 1993
V1920 Cyg	HD 225642, =LS II+33°5	3–4		Morrison & Willingale, 1987
	LSS 4357	?		Lawson & Kilkenny, 1998
	CoD−46°11775, =LSE 78	?		Lawson & Kilkenny, 1998
Ups Sgr	HD 181616	∼ 21	SB	Malcom & Bell, 1986
KS Per	HD 30353	∼ 30	SB	Osawa et al., 1963; Morrison & Willingale, 1987
V426 Car	CPD−58°2721, =LSS 1922	∼ 20	SB	Morrison et al., 1987
V1037 Sco	HD 320156, =LSS 4300	15–20	SB	Jones et al., 1989; Frame et al., 1995
PV TEL II				
V2076 Oph	HD 160641	0.7–1.1		Landolt, 1975; Lynas-Gray et al., 1987; Wright et al., 2005
V2205 Oph	BD−9°4395	3–9		Jeffery et al., 1985, Jeffery & Heber, 1992
V5541 Sgr	LSS 5121	?		Lawson & Kilkenny, 1998; Woolf et al., 2001
BX CIR				
V652 Her	BD+13°3224	0.1		Landolt, 1975
BX Cir	LSS 3184	0.1		Kilkenny & Koen, 1995
not pulsating				
(V821 Cen)	HD 124448	–		Jeffery & Lynas-Gray, 1990
(DN Leo)	BD+10°2179	–		Hill et al., 1984; Grauer et al., 1984
	HD 144941	–		Jeffery & Hill, 1996
MV Sgr		–	RCB	De Marco et al., 2002
DY Cen		–	RCB	De Marco et al., 2002
not known				
	LS IV+6°2			Lawson & Kilkenny, 1998
	LSS 99			
	BD+37°442			
	BD+37°1977			
	LSE 153			
	LSE 259			
	LSE 263			

Proposed variability classes. The variability types exhibited by helium-rich Bp supergiants (referring to luminosity class, since these are all low-mass stars) can be quite clearly divided into sub-types. For continuity, we propose to preserve the PV TEL moniker for two of these, simply adding the principal spectral type for each group:

PV TEL I: Hydrogen-deficient A or late-B supergiants showing low-amplitude quasi-periodic light variations on a timescale of 5 – 30 days; radial velocity variations are also seen.

Theoretically, these variations are interpreted as due to radial pulsations driven by strange-mode instability (Saio & Jeffery, 1988). The prototype FQ Aqr = BD+1°4381 (Jeffery & Malaney 1985) is the coolest EHe, other recognised members of the class include NO Ser, V354 Nor, V2244 Oph, V4732 Sgr, V1920 Cyg, up to the hottest PV Tel = HD 168476 itself. LSE 78 and LSS 4357 were reported variable by (Lawson & Kilkenny, 1998).

This proposed class definition also includes the hydrogen-deficient binaries υ Sgr, KS Per, V426 Car and V1037 Sco (Table 1). These single-lined spectroscopic binaries are easily distinguished from EHes by other means. However, all show low-amplitude light variations in the 15 – 30 days range.

PV TEL II: Hydrogen-deficient O or early-B supergiants showing low-amplitude quasi-periodic light variations on a timescale of 0.5 – 5 days; radial velocity and line-profile variations are also seen.

Theoretically, these variations are interpreted as non-radial g-mode pulsations driven by strange-mode instability (Saio & Jeffery, 1988), since "periods" are much longer than the dynamical timescales in these stars. The prototype V2076 Oph = HD 160641 (Lynas-Gray et al., 1987) is the hottest EHe, other members of the class are V5541 Sgr (Lawson & Kilkenny, 1998; Woolf et al., 2001) and V2205 Oph = BD−9°4395 (Jeffery et al., 1985).

The third sub-type is quite distinct, and its designation should reflect this:

BX CIR: Hydrogen-deficient B stars showing low-amplitude variations in light (0.1 mag in V) and radial velocity with a unique and regular period of a few hours.

Theoretically, we ascribe the variation to radial pulsations driven by the κ mechanism through Z-bump instability (Saio, 1993). The class comprises V652 Her and BX Cir. Unlike the PV TEL variables described above, the pulsations are so regular that both stars can be used as clocks (Kilkenny et al., 2005).

V652 Her was originally classified as a helium-rich subdwarf; in fact its gravity is lower than that of the main-sequence (Jeffery et al., 2001), so it is a helium-rich Bp giant, with a well-defined period (as well as $\dot{P}$ and $\ddot{P}$, Kilkenny et al., 1982, 1984, 1996) and an amplitude of 0.1 mag.

A minority of EHes are established as *not* varying on short timescales, including BD+10°2179 (=DN Leo), HD 124448 (=V821 Cen) and the metal-poor HD144941 (Grauer et al., 1984; Hill et al., 1984; Jeffery & Lynas-Gray, 1990; Jeffery & Hill, 1996). These stars lie below the instability boundary for the appropriate metallicity (Fig. 1) (Jeffery & Saio, 1999). Variability in LS IV+6°2 and LSS 99 has not been confirmed. The hot R Coronae Borealis (RCB) stars DY Cen and MV Sgr strongly resemble EHe stars LSE 78 and HD 124448 respectively (Jeffery & Heber, 1993; Jeffery et al., 1988). They showed strong RCB-like variability in the past, but are not currently known to vary on short timescales (De Marco et al., 2002).

Table 1 summarises the principal variability characteristics for all known EHe stars. Approximate timescales P are given for PV TEL variables, but the term is used loosely. Major references are given for the definition of the light curve types and the estimate of periods. The proposed classes are sensible for several reasons. They can be simply established from the timescale, light curve and amplitude of the variation and from the spectral class of the variable (which was already required for the PV TEL classification). Figure 1 shows the $log\ g - log\ T_{\rm eff}$ diagram for extreme helium stars, including the position of the Eddington limit (assuming Thomson scattering: dashed) and the loci of stars with given luminosity-to-mass ratios (solar units: dotted). Stars above the boundaries shown for metallicities $Z = 0.004, 0.01, 0.03$ (dot-dash) are predicted to be unstable to pulsations (Jeffery & Saio, 1999). Ellipses (coloured in electronic version) identify three groups of pulsating helium stars. In the electronic version, PV TEL I variables are shown in purple and red (H-def binaries), PV TEL II variables in blue, and BX CIR variables in green. Non-variables are black. The values and sources for $T_{\rm eff}$ and $log\ g$ are given in Table 2. There has to be some question about the high value of log g for NO Ser.

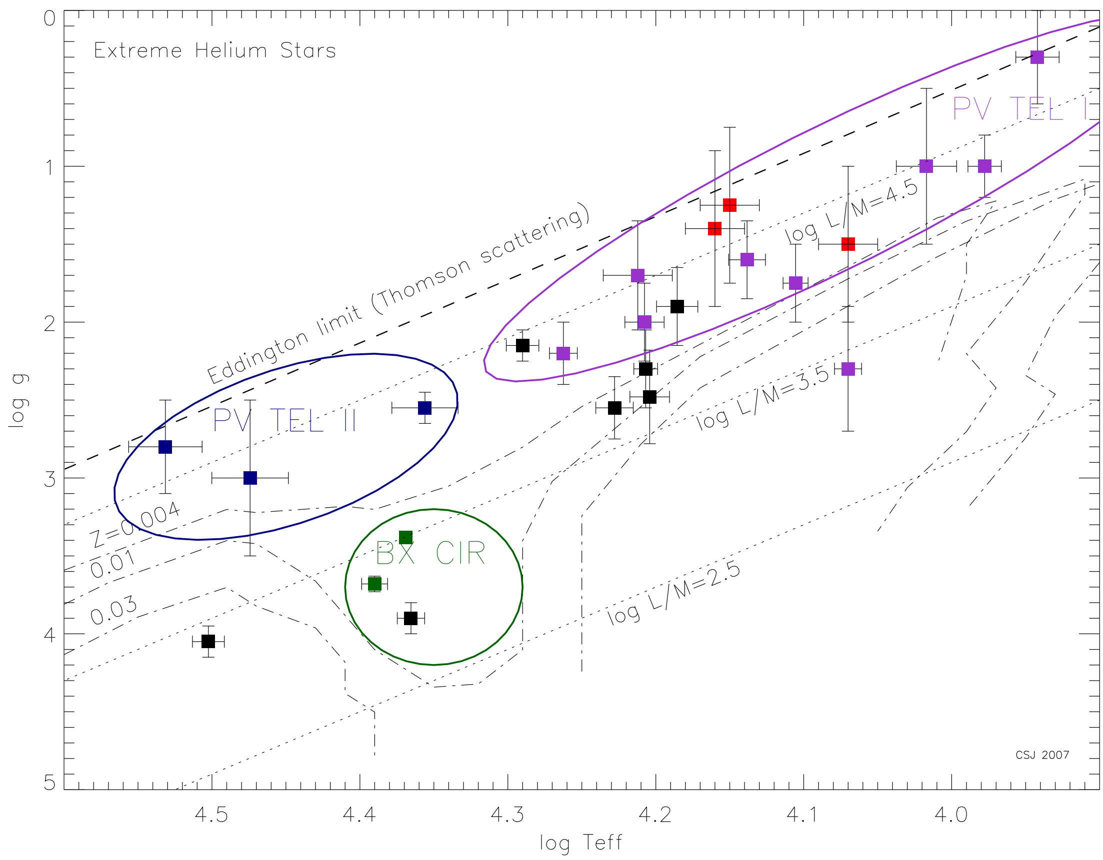

Figure 1. $log\ g - log\ T_{\rm eff}$ diagram for H-deficient variable stars

Each type of variable has a different physical mechanism, and occupies a separate region of the Hertzsprung-Russell or $log\ g - log\ T_{\rm eff}$ diagram. Since these classes have been well established for over a decade (Saio & Jeffery, 1988; Saio, 1993), a revision to the single PV TEL designation is overdue. The suggested division into classes PV TEL types I and II and BX CIR reflects current knowledge.

Table 2: Surface properties for O, B and A type extreme-helium stars

V*	Other	$T_{\rm eff}$	log g	Reference
PV TEL I				
FQ Aqr	BD+1°4381	8750±300	0.30±0.30	Pandey et al., 2006
V4732 Sgr	LS IV−14°109	9500±250	1.00±0.20	Pandey et al., 2006
V354 Nor	CPD−48°7730, =LSS 3378	10400±500	*1.00±0.50	Pandey & Reddy, 2006
NO Ser	BD−1°3438	11750±250	2.30±0.40	Pandey et al., 2001
V2244 Oph	LS IV−1°2	12750±250	1.75±0.25	Pandey et al., 2001
PV Tel	HD 168476	13750±400	1.60±0.25	Pandey et al., 2006
	LSS 4357	16130±500	2.00±0.25	Jeffery et al., 1998
V1920 Cyg	HD 225642, =LS II+33°5	16300±900	1.70±0.35	Pandey et al., 2006
	CoD−46°11775, =LSE 78	18300±400	2.20±0.20	Pandey et al., 2006
Ups Sgr	HD 181616	11750±750	1.5 ±0.5	Dudley, 1992
KS Per	HD 30353			
V426 Car	CPD−58°2721, =LSS 1922	14000±800	1.25±0.5	Morrison, 1987
V1037 Sco	HD 320156, =LSS 4300	14500±800	1.4 ±0.5	Schönberner & Drilling, 1984
PV TEL II				
V2205 Oph	BD−9°4395	22700±1200	2.55±0.10	Jeffery and Heber, 1992
V5541 Sgr	LSS 5121	29800±1830	*3.00±0.50	Jeffery et al., 2001
V2076 Oph	HD 160641	34000	2.80	Rauch, 1996
BX CIR				
BX Cir	LSS 3184	23390±90	3.38±0.02	Woolf and Jeffery, 2002
V652 Her	BD+13°3224	24550±500	3.68±0.05	Jeffery et al., 1999
not pulsating				
MV Sgr		16000±500	2.48±0.30	Jeffery et al., 1988
(V821 Cen)	HD 124448	16100±300	2.30±0.25	Pandey et al., 2006
(DN Leo)	BD+10°2179	16900±500	2.55±0.20	Pandey et al., 2006
DY Cen		19500±500	2.15±0.10	Jeffery & Heber, 1993
	HD 144941	23200±500	3.9 ±0.1	Harrison & Jeffery, 1997
not known				
	LSS 99	15330±500	1.90±0.25	Jeffery et al., 1998
	LS IV+6°2	31800±800	4.05±0.10	Jeffery, 1997
	BD+37°442	53000	4.0	Heber et al., 1987
	BD+37°1977	56000	4.1	Darius et al., 1979
	LSE 153	70000±2000	4.75±0.15	Husfeld et al., 1989
	LSE 259	70000±3000	4.9 ±0.25	Husfeld et al., 1989
	LSE 263	70000±7000	4.4 ±0.3	Husfeld et al., 1989

*: estimated

Cool H-deficient variables. We conclude with a remark on designations for some related variables. Theoretically speaking (Saio & Jeffery, 1988), there is a probable physical connection between PV TEL-type variations described above and the $\sim$ 40 d pulsations observed in cool RCB variables such as RY Sgr (Alexander et al., 1980) and the late-type carbon-rich hydrogen-deficient giants such as HM Lib = HD 137613 (Kilkenny et al., 1988; Jones et al., 1989). RCB-type minima are definitive and, coupled with an appropriate spectral type, the designation needs little modification. Indeed, the RCB definition includes "cyclic pulsations with amplitudes up to several tenths of a magnitude and periods in the range 30-100 days". Of those hydrogen-deficient giants which do not show RCB-type minima, the GCVS tentatively describes HM Lib as a semi-regular variable ("SR:"). Three other variables are LV Tra = HD 148839, V4152 Sgr = HD 175893, and HD 173409 (Kilkenny et al., 1988; Jones et al., 1989). Only HD 182040 has *not* been proven to vary on these timescales (ibid.). Radial velocity variations have been observed on the same timescales (Lawson & Cottrell, 1997). While LV TrA is classified "RCB:", it is not clear that it has ever shown a deep RCB-type minimum. Meanwhile, there is increasing evidence for an evolutionary connection between all of these groups of stars (Saio & Jeffery, 2002; Pandey et al., 2006; Clayton, 2008). Perhaps the PV TEL designation should be further extended to include these cool giants:

PV TEL III: Hydrogen-deficient and carbon-rich F or G supergiants showing low-amplitude quasi-periodic light variations on a timescale of 30 – 100 days; radial velocity variations are also seen.

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