THE ORIGIN OF BRIGHTNESS VARIATIONS IN BC CYGNI

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ABSTRACT. The variability of the type C semi-regular (SRC) M3.5 Ia supergiant variable BC Cyg is examined with reference to measurements of its photographic B magnitude derived from 866 archival plates in the Harvard and Sternberg collections and eye estimates of its visual V magnitude made by members of the AAVSO. The star is the brightest member of the cluster Berkeley 87, so it has a well established reddening, distance, and age. BC Cyg exhibits interesting features in its century-long baseline of brightness variations that relate to pulsation and evolution: an $0^m.5$ increase in $\langle B \rangle$ over the past century in conjunction with a decrease in pulsation period from $\sim$ 700^d to 687^d. Associated colour changes imply that the star is hottest when brightest visually or photographically, coolest when faintest visually or photographically. Despite the increase in $\langle B \rangle$, the star's luminosity appears to have decreased over the past century, presumably as a result of stellar evolutionary effects.

Key words: stars: variable: other — stars: late-type — stars: individual (BC Cyg).

1. Background

Type C semi-regular variables (SRC) constitute a group of 55 stars in the *General Catalogue of Variable Stars* (Kholopov et al. 1985) that, in contrast to the SRA and SRB variables, include some of the most massive and exotic stars in the Milky Way, all having reached the red supergiant stage of evolution. A prime example is Betelgeuse (α Ori, spectral type M1-2 Ia-Ibe), its light variations having been followed since the early 1800s. The origin of the variability in such stars is not fully understood, although pulsation and rotation of bright or dark regions across the visible hemisphere are believed to play an important role.

The SRC variable BC Cygni is an M3.5 Ia supergiant displaying moderate amplitude variability that is located near the edge of the young cluster Berkeley 87 lying in a heavily-obscured region of Cygnus (Turner & Forbes 1982). Because of its likely cluster membership, the age (8×10^6 years), original mass ($\geq 20\ M_\odot$), space reddening (E_{B-V}(B0) $= 1.55\pm0.01$), and distance (1.1 kpc) of BC Cyg are known reasonably well.

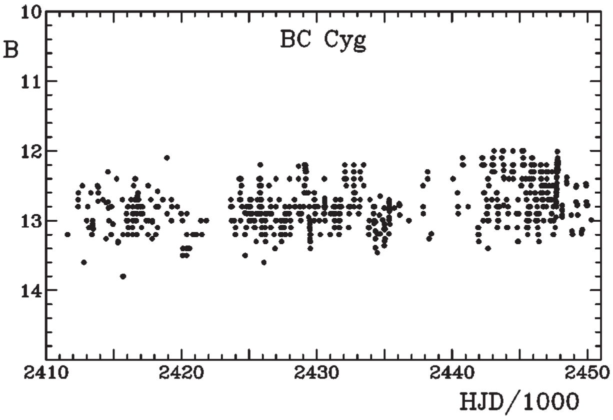

Figure 1: Combined eye estimates of photographic magnitude B for BC Cyg from plates in the Harvard and Sternberg collections.

A major obstacle to a full understanding of the physical mechanism(s) responsible for light variations in SRC variables is a lack of extensive temporal data on their brightness changes, which tend to be semi-repeatable with long-term excursions in average brightness over time scales of several hundreds of days or more. We have collected a large database of brightness estimates for BC Cyg that provides some clues on what may be responsible for its variability.

2. Observations

An extensive set of brightness data for BC Cyg was constructed using eye estimates of its photographic B magnitude relative to a reference sequence of stars in Berkeley 87, as obtained from 688 patrol series plates in the Harvard College Observatory Photographic Plate Collection as well as from 178 plates in the collection of the Sternberg Institute. Visual observations are also available (Waagen 2005) from recent estimates by ob-

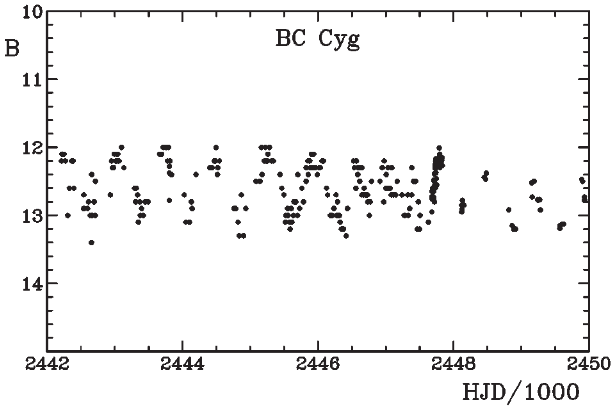

Figure 2: A smaller time segment of the data plotted in Fig. 1 illustrating the regular cyclical variations in BC Cyg.

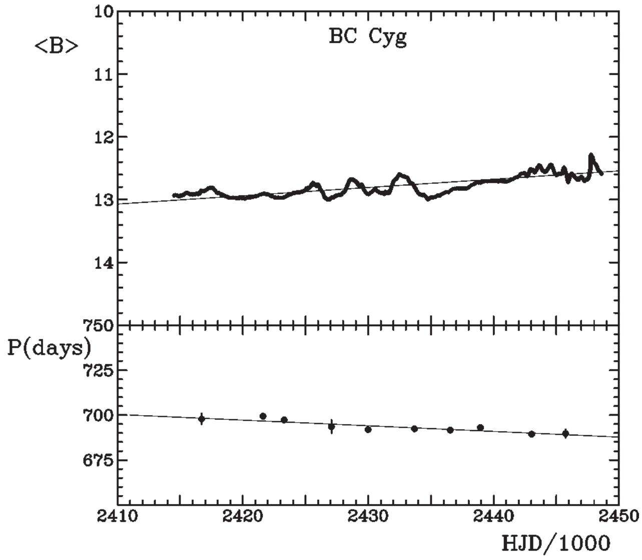

Figure 3: a) A plot of 50-point mean $\langle B\rangle$ magnitudes for BC Cyg from the data of Fig. 1 (top); b) estimates for the pulsation period of the star over restricted time intervals covering the same temporal interval (lower).

servers belonging to the American Association of Variable Star Observers (AAVSO).

The B data are illustrated in Fig. 1, all adjusted to the Harvard system. The regular cyclical nature of the star's brightness changes is more apparent when the data are restricted to less extensive time intervals, as in Fig. 2.

3. Analysis

An interesting feature of the light variations in BC Cyg, illustrated in Fig. 3, is their long-term behaviour. The mean $\langle B\rangle$ magnitude of BC Cyg has increased by $\sim 0^m.5$ over the past century (Fig. 3a), while the primary period of variability for the star has decreased monotonically over the same time interval (Fig. 3b), from $P = 700^d$ in 1900 to $P = 687^d$ at present, a rate of decrease of 3^h per year.

From AAVSO visual eye estimates, which appear to be reasonably close to Johnson system V magnitudes, it is possible to track changes in the colour of BC Cyg as it brightens and fades, as illustrated in Fig. 4. The analysis requires a combination of visual eye estimates with photographic magnitudes estimated from survey plates, both of which are subject to uncertainties of about $\pm 0^m.1$ to $\pm 0^m.2$. To the extent that the 66 data points selected to be nearly coincident in time represent the general trend when averaged, as in Fig. 4, it appears that the star gets redder as it gets fainter, bluer as it brightens. The implication is that BC Cyg is hottest when it is brightest photographically, coolest when it is faintest photographically.

We have used the above information in conjunction with the star's known space reddening and distance to track the periodic changes observed for the star in an H-R diagram. The conversion of B and V magnitudes and colours into $T_{\rm eff}$ and $\log L/L_\odot$ depends directly on the effective temperatures and bolometric corrections adopted for M supergiants. The present calculations rely upon the parameters tabulated by Lee (1970).

In the H-R diagram of Fig. 5, dotted lines lines indicate the location of the Cepheid instability strip, while solid relations represent theoretical stellar evolutionary tracks for stars with original masses of 5 $M_\odot$, 10 $M_\odot$, and 25 $M_\odot$ and $Z = 0.01$. The parameters for BC Cyg in 1900 at light maximum, light minimum, and mean light are shown by filled circles, those for 2000 by open circles. Over the past century it appears that BC Cygni has evolved downwards along the red supergiant branch towards lower luminosities, as confirmed by its gradually decreasing pulsation period (Fig. 3b), which is presumably tied to a diminishing mean radius.

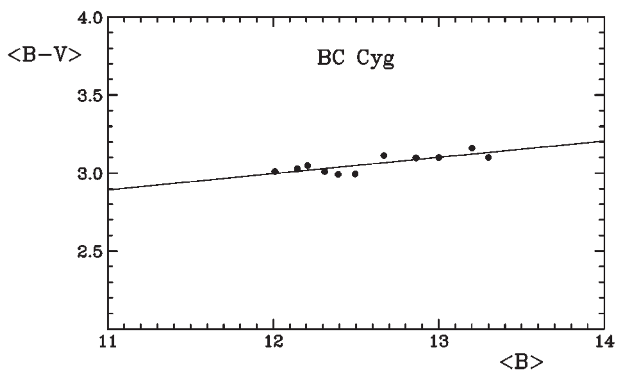

Figure 4: The observed colours of BC Cyg as a function of the star's photographic magnitude as derived from averages of AAVSO visual estimates with photographic estimates of the star made within roughly ten days of each other.

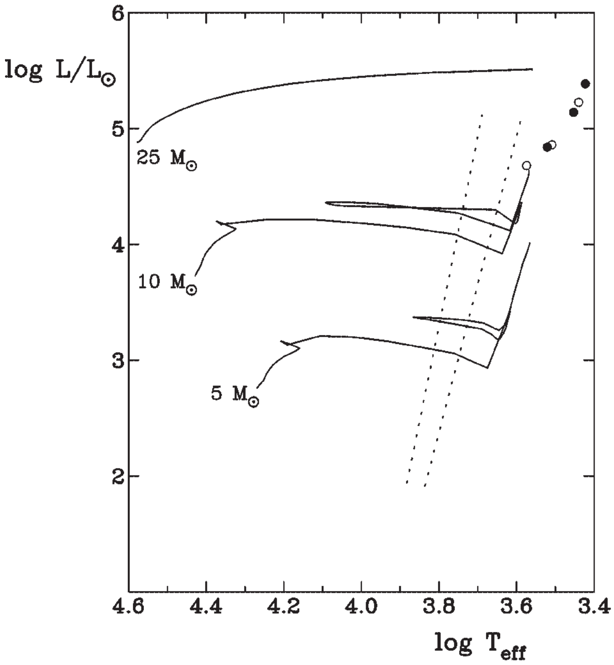

Figure 5: A theoretical H-R diagram showing evolutionary tracks for stars of 5 $M_\odot$, 10 $M_\odot$, and 25 $M_\odot$ and $Z = 0.01$, the region of the Cepheid instability strip (dotted lines), and the estimated parameters of BC Cyg over its pulsation cycle around 1900 (filled circles) and 2000 (open circles).

Although the mean B magnitude of BC Cyg increased over the past century, its bolometric luminosity actually decreased according to the adopted bolometric corrections and effective temperatures inferred from mean $B-V$ colours. Such features require independent confirmation. Existing stellar evolutionary models cannot replicate the observed changes in the star's parameters, according to the results of Fig. 5.

The regular periodic nature of the star's brightness variations is clearly tied to pulsation, as evident from the fact that BC Cyg, as well as SRC variables in Per OB1, follow a period-luminosity relation similar to that of Cepheids (Turner 2005).

4. Discussion

The photographic magnitude of BC Cyg increased by $\sim 0^m.5$ over the past century, but the star's bolometric luminosity apparently decreased by about the same amount over that interval, if the observed colour changes are accurate. The luminosity decline has been associated with an increase in the star's effective temperature and a decrease in mean radius, as evidenced by a period decrease for its 700^d pulsations. If the associated colour changes and assigned bolometric corrections are correct, the star is most luminous when it is faintest visually and photographically.

As recognized roughly fifty years ago by Struve (1959), "It appears that studies of period change are by far the most sensitive test available to the astronomer for detecting minute alterations in the physical characteristics of a star." That has been demonstrated previously to be true for Cepheid variables, which are yellow supergiants, but it also applies to the red supergiant variables belonging to the SRC class.

The primary brightness variations in BC Cyg display the regularity of pulsation, which was tested using simple models for the interior of the supergiant in conjunction with adiabatic pulsation calculations. The same technique was followed by Stothers (1969) in his modeling of M supergiants 36 years ago, under the assumption that the complex superadiabatic region near the surfaces of such stars is essentially insignificant relative to the adiabatic interior. The short-term cyclical variations in all SRC variables are similarly implicated to arise from pulsation. The longer-term brightness changes in BC Cyg, on the other hand, may be tied to evolutionary changes in the star.

BC Cygni is an important SRC variable since its cluster membership provides basic information about its reddening, luminosity, and evolutionary mass. The collection of a century-long baseline of data on its brightness variations provides a wealth of material for analyzing the nature of the star's variability. It is clearly useful to obtain similar information for other SRC variables if we are to understand in detail the mechanisms responsible for the full range of their light variations as well as to track their exact behaviour in the astrophysical H-R diagram.

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References

Kholopov, P.N., et al.: 1985, *General Catalogue of Variable Stars*, 4th Edition (Moscow: Nauka).
Lee, T.A.: 1970, *ApJ*, **162**, 217.
Stothers, R.: 1969, *ApJ*, **156**, 541.
Struve, O.: 1959, *Sky & Telescope*, **18**, 309.
Turner, D.G.: 2005, *Odessa Astron.Publ.*, **18**, this conference.
Turner, D.G., Forbes, D.: 1982, *PASP*,**94**, 789.
Waagen, E.O.: 2005, Observations from the AAVSO International Database, private communication.