BH Crucis: Period, Magnitude, and Color Changes

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Abstract The period changes of the dual maxima Mira star BH Cru and the associated color changes are discussed. *UBV* measures before the change in period began are compared with those after the star had stabilized at the new, longer, period and those made during the twelve cycles of lengthening period are summarized. A 30% increase in mean *V* brightness is noted, as is a distinctly redder color in *B–V*. The apparent single maximum that has now appeared can be explained by a relative brightening of the second maximum with the first maximum now somewhat hidden by it.

1. Introduction

BH Crucis was discovered in October 1969 by Ronald G. Welch of Auckland, New Zealand, during a photographic search for new variables. His request to the Auckland Observatory for confirmation resulted in its being added to the *UBV* observing program. Since then 417 *UBV* measures have been made: 366 at Auckland Observatory, 38 at the Milton Road Observatory in Auckland, and 13 at the Wharemaru Observatory near Awanui. These ceased in 1996. The first 181 measures, during which the period was stable at 421 days, are shown in Figure 1.

The *B–V* and *U–B* color measures provide information about the temperature changes in the star and have not previously been discussed. Over this long time scale the stability of the measuring system comes into question so this is described. During the period 1970–1990 all measures were made at the Auckland Observatory using either of two EMI 9502 photomultiplier tubes. Both were calibrated using the E Region standards (Cousins and Stoy 1962). Two adjacent stars were selected as comparison and check and values determined:

HD 106475	*V* = 7.29	*B–V* = 1.33	*U–B* = 1.33	Comparison
HD 106202	*V* = 8.17	*B–V* = 0.32	*U–B* = 0.15	Check

No indication of variability has been found in either star. All photomultiplier tubes used have S11 photocathodes with a similar wavelength response, but the Aukland Observatory measures used the 14-stage, EMI 9502 photomultiplier tube, while the Milton Road and Wharemaru observatories used the less sensitive, but less costly, 11-stage version.These were calibrated in the same manner. Transformations were checked several times each year.

Error values for these observations are not available, but for both *V* and *B–V* are <0.02, probably <0.005 at the brighter levels. The *U–B* for such a red star is not as good due to faintness in the *U* filter but would usually be within 0.05 to 0.10. In all the figures the zero phase is that of the deeper minimum, which is not normal for Mira stars, but adds clarity and is similar to the policy with RV Tauri stars, which objects BH Cru resembles in some ways with dual maxima and strong color changes during each cycle (Kholopov 1985). It is redder, however, with a much longer period than an RV Tau star. As noted in the text the period has changed noticeably over the forty years since discovery.

At the time of discovery only R Cen and R Nor were considered to be members of the unusual group of Mira stars with double maxima. Some time later NSV 4721, now V415 Vel, was noted as another such object by Williams (1980). These stars are characterized by a wide double-peaked maximum, with a steep rise to the first maximum and a sharp drop to minimum from the second. As a consequence, the minima are quite sharp.

How these stars differ from a number of other variables which show bumps on the light curves, or which sometimes appear almost double peaked, is not clear. Many of these are amongst the semiregular stars and the amplitude of BH Cru is, at times, close to the minimum for a Mira star. Even more confusing is that both R Cen and BH Cru have recently evolved in such a manner that they now show strongly single maxima. In the case of R Cen there is now a well-defined hump on the falling light curve. In contrast, BH Cru shows only a small hump on the rise to maximum.

A number of other stars have been ascribed to this group at times but the closest to the symmetrical light curve characteristics appear to be BX Car and perhaps TT Cen. Others such as DH Cyg (Templeton *et al.* 2005) and several mentioned by Campbell (1955) appear to be Miras of half the quoted periods, but with frequently irregular erratic maxima and minima. Some unambiguous method of identifying objects of this group is needed.

2. Period changes

This small group of variables is unusual in that two of the stars have shown dramatic changes of period. The period of R Cen is slowly becoming shorter, with the second peak becoming much smaller and now lacking the dramatic fall in brightness. The period of BH Cru, on the other hand, increased by 104 days, or 25%, in a mere twelve cycles. This is shown in Figure 2.

There is a suggestion of earlier period changes in Ziljstra *et al.* (2004) but as the observations come from random sky surveys this is uncertain. When classifying this star, Walker *et al.* (1972) drew attention to some of these early measures and the difficulty of determining any useful periods due to the variety of film types and the paucity of the data. If BH Cru did have a longer period prior to 1970 the star becomes even more puzzling.

The exact length of the present period is uncertain. Ziljstra *et al.* determined 540 days using a wavelets analysis, the epochs of minimum show 525 days, and the later PEP and CCD measures are best fitted by a 530-day period, as are some of the visual measures.

3. Color photometry

Figure 3 shows *B–V* colors of BH Cru during the first five cycles observed, then the first three cycles of the 530-day period. All of these were made by the Auckland Photoelectric Observers' Group (APOG) using PEP. One final color cycle was made by G. di Scala using CCD photometry.

This figure appears to confirm a cooling of BH Cru, expected if its radius has increased as deduced from the change in period.

Figure 4 presents *V*, *B–V*, and *U–B* measures since JD 2448997. There are inadequate measures during the intervals where the period was changing (155 measures over thirteen cycles) to allow determination of any periods suitable for data plotting. But the salient features are presented in Table 1. For cycles 19–21, by which time the period had stabilized, there are fifty-one measures; and di Scala made twenty-one in cycle 29, and two in cycle 30, as shown in the AAVSO International Database. He did not measure in U so there are no *U–B* values for the last two cycles. Cycles are shown as filled diamonds, 530/1; open squares, 530/2; square crosses, 530/3; and complex crosses, 530/10 and 530/11. It should be remembered that the period derived from the photoelectric measures differs slightly from that of the visual period. One noticeable feature is that there is a pronounced difference between the *B–V* colors in cycle 530/1 and the subsequent cycles.

4. Mean brightness of BH Cru

Has BH Cru changed in average brightness as a result of these changes in period and color? Figures 5a and 5b show mean *V* light curves in 1970–1975 and 1993–2009. The mean magnitudes at intervals of 0.05 cycle have been determined by phasing and averaging the *V*-measures—221 in the first interval, 74 in the second. From these, intensities were derived and a mean intensity during each cycle, which was then reconverted to mean magnitudes.

Visual measures were made from 1969 onward, but those up to 1985 have not been published in detail. Those used in Figure 7 were provided by Bedding (2009). ASAS3 untransformed V measures (Pojmański 2002), in view of the large *B–V* changes, were considered incompatible in this context. The latter, however, have been used in determining the minima of Figure 2.

While the star was pulsating with a period of 421 days, the mean magnitude was 8.047, but now the period is 530 days with a mean magnitude of 7.762. This represents an increase in *V*-brightness of exactly 30%, in spite of the decreased temperature.

5. Evolution and changes in the light curves

In Figure 6 the separate *V* light curves are superimposed. The result shows that the changes are almost all associated with the region between phases 0.35 to 0.65. The original first maximum has now become the hump on the rise, and the dip prior to the second, brighter maximum has been replaced by a feature which turns the light curve into a relatively normal Mira light curve.

Various ideas have been put forward for the double maxima phenomenon. The more generally accepted one involves double mode pulsation, with the ratio being almost exactly 2:1. Other possibilities include atmospheric filtering (Templeton *et al.* 2005), perhaps even other mechanisms.

The question which is posed by Figures 6 and 7 is why the change in period and shape of the light curve should result in increased brightness in BH Cru. This argues for some other discrete cause rather than the normally quoted helium ignition events. In stars such as R Aql and R Hya the consequences of the helium event are relatively long lasting with a much slower rate of period change. Little information is available about possible brightness changes for those two stars.

There are twelve cycles between the two graphs in Figures 5a and 5b and fourteen between the two curves of Figure 6. These are summarized in Table 1. During this interval BH Cru was unstable in period, the nature of the maxima changed and the maximum became brighter toward the end of the interval.

It can be seen that the double maxima continued until JD 2446132, although the previous rather bright maximum perhaps indicated a change was imminent.

The change in period was relatively smooth but there were some partial reversions to a shorter period. In summary, the light curve shape changed significantly at JD 2445500 with a single reversion to the previous double maxima. This was much in line with the changing brightness.

The single maximum appears to have replaced the second maximum but occurs about 5% earlier in each cycle. The first maximum is still present, but shows only as a hump on the light curve at the same phase as previously. This has not affected the deeper minimum, but the shallow secondary minimum has been hidden by the greater brightness and width of the second, and now clearly, primary maximum.

6. Conclusion

Since its discovery in 1969 BH Cru has evolved in a unique manner. Its period has changed by 25% over a mere twelve cycles, its color has reddened by 0.5 magnitudes in *B–V*, and the amplitude of the color change in *B–V* during each cycle has increased by a similar amount of 0.5 magnitudes. Its mean brightness has increased by 30%, at the same time as it changed from a double maxima Mira star to a more normal looking Mira with a noticeable hump on the rise. As shown by the photoelectric measures, this hump is at exactly the same magnitude and phase as the initial first maximum of the 1970s and 1980s.

The *B–V* colors indicate a cooler temperature as expected from the longer period. But the increase in brightness is unexpected and implies a rather larger radius change than that calculated by Zijlstra *et al.* (2004). All indications are that some other event occurred around 1983 to 1986. In R CrB stars, abrupt changes in brightness can be caused by obscuring dust clouds, but Whitelock *et al.* (2000) argue that the mass loss rate from BH Cru is unusually low, which precludes any suggestion that an obscuring cloud around the star is now less opaque.

7. Acknowledgements

The *UBV* measures used were made by a variety of Auckland Astronomical Society members using the Edith Winstone Blackwell telescope and equipment at the Auckland Observatory. Later measures came from the Milton Road Observatory of Harry Williams and the author's observatory at Wharemaru. *BVRI* measures by Giorgio di Scala were obtained from the AAVSO International Database (AAVSO 2009).

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Table 1. BH Cru: sparsely observed cycles in interval of period change.

Cycle No.	*No. of Obs.*	*Epoch of Max (JD)*	*Max V mag.*	*Comments*
6	22	2442831	7.354	Double maximum
7	11	2443304	7.404	Double maximum
8	11	2443725	7.580?	Double maximum
9	10			First maximum only observed
10	20	2444683	7.525	Double maximum
11	16	2445152	7.234	First maximum only observed
12	15	2445574	7.141	Brighter than normal, hump at first maximum position
13	26	2446132	7.512	Double maximum
14	8	2446562	7.154	Single maximum only
15	8	2447023	7.190	Probable single maximum
17	18	2448045	7.069	Probable single maximum

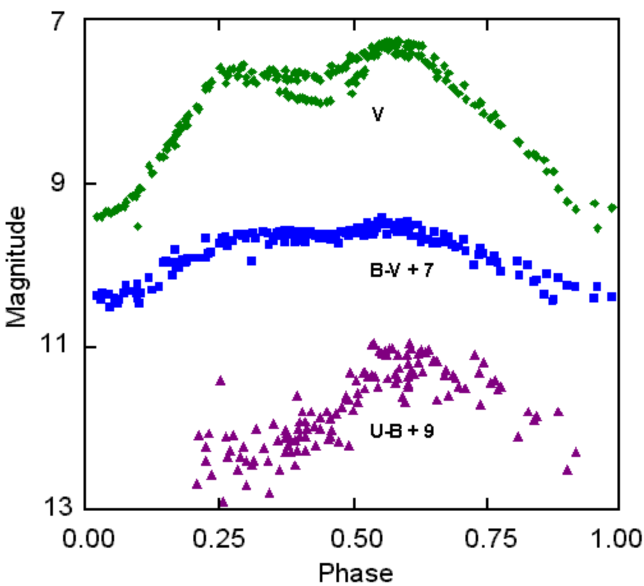

Figure 1. Phase diagram for BH Cru showing *V, B–V*, and *U–B* colors during the interval JD 2440862–2442544 phased to the light elements of the deep minimum, JD 2440645+421E. The *B–V* has been offset by adding 7, *U–B* by adding 9. The scales are identical otherwise. *U–B* colors up to phase 0.20 were very poor due to the faintness of BH Crucis in *U*—magnitude 15–16 at those phases. However, these still show the remarkable difference between the *U–B* color of the two maxima.

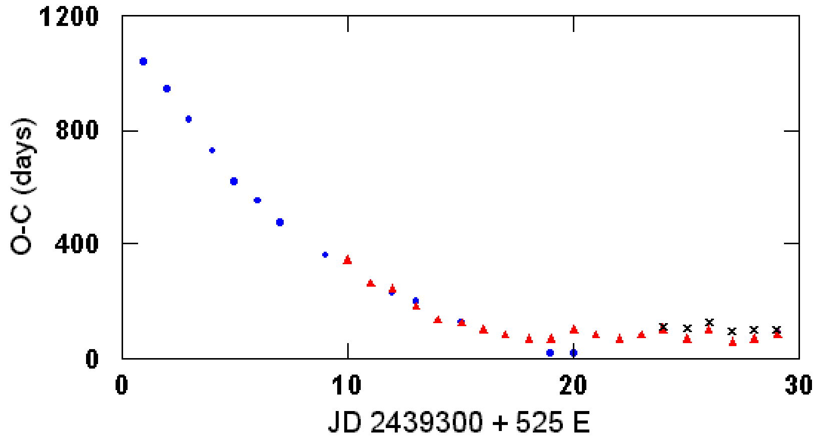

Figure 2. Due to the changing shape of the light curve it is preferable with BH Cru to determine epochs using minima. This O–C plot shows the first five minima with a stable period of 421 days; the next twelve show a gradual increase in period—with some deviations—then the present visually-based period of 525 days. Circles represent Auckland Photoelectric Observers' Group (APOG) data; triangles, AAVSO data; crosses, ASAS3 data.

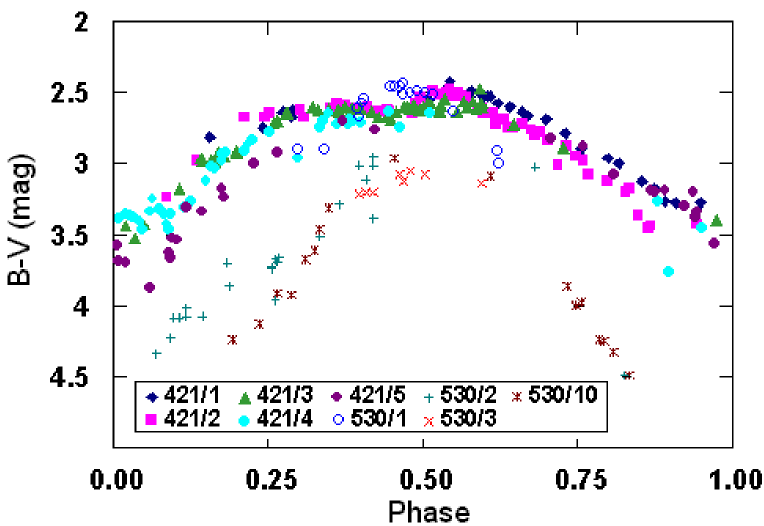

Figure 3. Phase diagram for BH Cru showing *B–V* colors during the two stable periods shown in Figure 2. The earlier cycles are denoted by solid colors, more recent ones by unfilled circles or crosses of various kinds. There is a noticeable change in the *B–V* amplitude, from 1.0 magnitude in the 1970s to 1.5 magnitudes in the 1990s and 2000s.

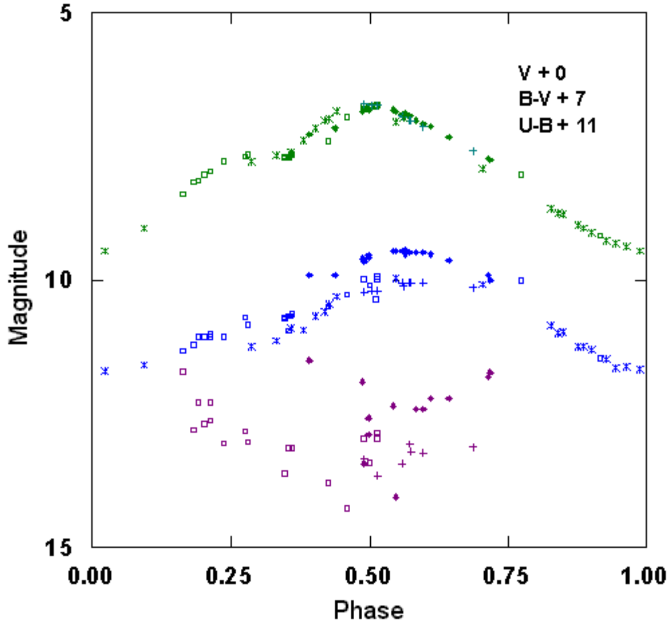

Figure 4. Recent phase diagrams for BH Cru in *V*, *B–V*, and *U–B*. The *V*-curve shows a marked hump on the rising branch, but is certainly not double peaked as it was on discovery. Peak brightness seems to occur slightly earlier than previously, although there are not enough measures and too few cycles to be certain. Cycle 530/1 is rather brighter in *B–V* than the remainder, although this does not show in the *V* brightness. The *U–B* measures appear quite different from those of Figure 1, but the detectors used were less sensitive and the data are noisy.

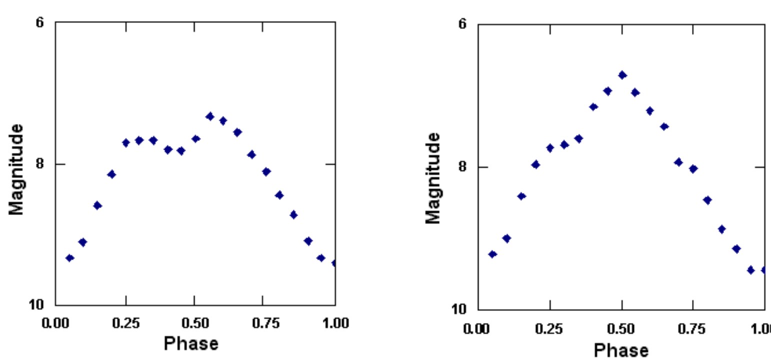

Figure 5a, 5b. Mean phase diagrams for BH Cru, determined in the manner described in the text. These appear to show an increase in mean brightness in *V* of 30% over the ~20-year interval.

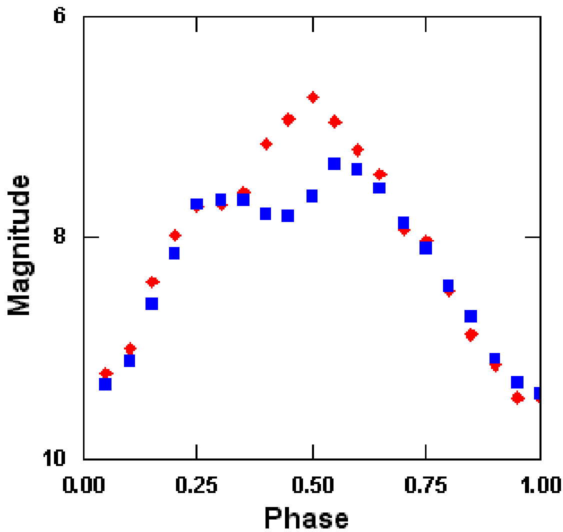

Figure 6. BH Cru: the *V* phase diagrams of Figure 5 superimposed to show the continued presence of the first maximum, as well as the increase in brightness from phase 0.35 to 0.65.

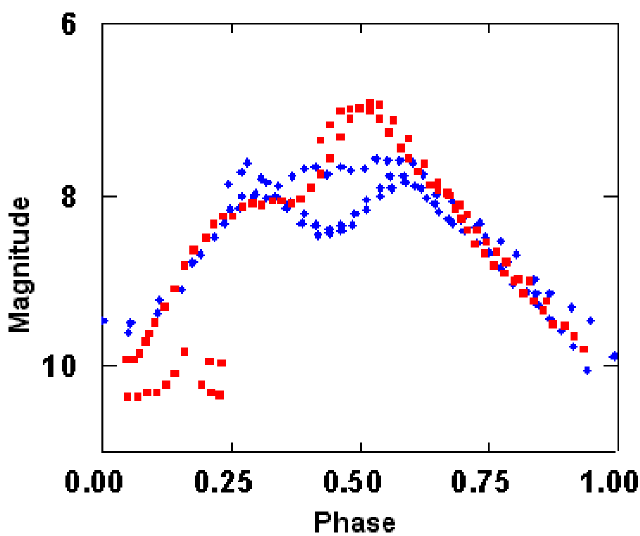

Figure 7. Visual observations of BH Cru made by members of the RASNZ. Cycles 1–4 are shown as diamonds, with cycles 18–22 shown as squares. A five-point running mean has been applied to the data.The visual observations seem more divergent as to amplitude than the photoelectric measures but, in general, are similar to Figure 6.