Dual Maxima Mira Variable Stars

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Amongst Mira variable stars with periods in excess of 400 days is found a small group which show two maxima in each cycle. Two of these have shown dramatic period changes. Other Miras with period changes may once have been members of this group. Light curves, colours and other behaviour are described as well as a curious distribution in the sky.

Introduction

The Auckland interest in these stars began in 1969, although the long variation periods had previously made them unattractive for observers. A young student, Ron Welch, was carrying out a photographic search for new variables and, with typical beginner's luck, found both Nova Sagittarii, 1969, and a strange new red variable star close to the Southern Cross, BH Crucis. There were some others including another very red star in Crux but these two were the most interesting

With our new UBV photometer and a half metre telescope we tried to follow through on anything found by our society observers so this star was added to the list. The RASNZ VSS rushed in with a period of ~220 days but it was clear from the colour variations alone that this was not correct. We later determined a period of 421 days and realised that this star was similar to R Centauri and R Normae. We began measures of R Centauri but lacking a chart of R Normae and with demands for flare star and CV monitoring this latter star was ignored.

Some time later Peter Williams asked for advice on an analysis of NSV 4721, now V415 Velorum, and it was immediately clear that this was a fourth one of these unusual objects. But his paper was never published by the VSS.

Mira Stars in General

Most variable star observers are familiar with these stars. They have large amplitudes, 3 to 10 magnitudes and periods of 100 to 600 days, ideal for visual observing with its rather low accuracy and undemanding in that a measure each week or two is adequate to produce a good light curve. There are well set up observers' groups to collect and publicise the observations and the pulsation mechanism is easy to understand. With the advent of computers and the Internet it's now easy to exchange information but one unfortunate aspect of the CCD age is that simple monitoring of CVs has attracted away many of the observers and inadequate attention is paid to some stars, such as these dual maxima objects.

Physically Mira stars are low mass objects usually between one and five solar masses but highly evolved and found in the upper right of the Hertzsprung-Russell diagram. Surface temperatures are in the 3000-4000K range, radii 300-1000 solar radii, and luminosities up to 10,000 times that of the Sun.

A light and colour curve of a typical Mira is shown in Figure 1.

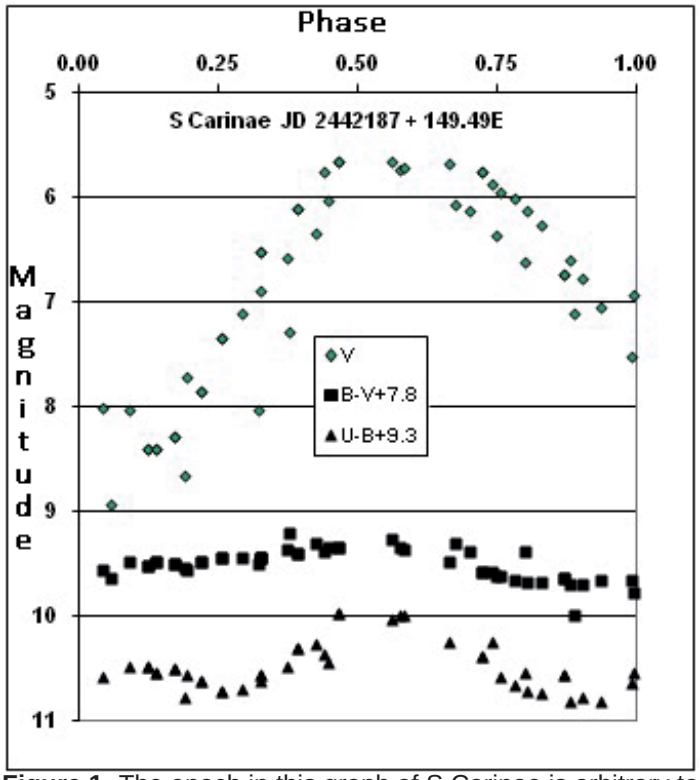

Figure 1: The epoch in this graph of S Carinae is arbitrary to present a clearer picture of the light curve shape. The B-V and U-B colours have been offset but the scale is identical to the V light curve.

This is S Carinae, marginally naked eye at maximum. Temperature is highest near maximum but the U-B curve shows an odd brightening near minimum, probably associated with radiation from the extensive gas shell around these objects which have low surface gravity.

The main amateur observer groups specialise in time series photometry - TSP - with the intention of recording changes in period or amplitude. On this basis Miras can be grouped: those with periods of 100-200 days often show evidence of two simultaneous pulsation periods although the second is quite weak; medium periods from 200-400 days seem very stable in their pulsations; the longer periods above 400 days often have period changes.

Apart from this, all Mira stars and many semi-regular stars alternate at intervals of a decade or two between two periods

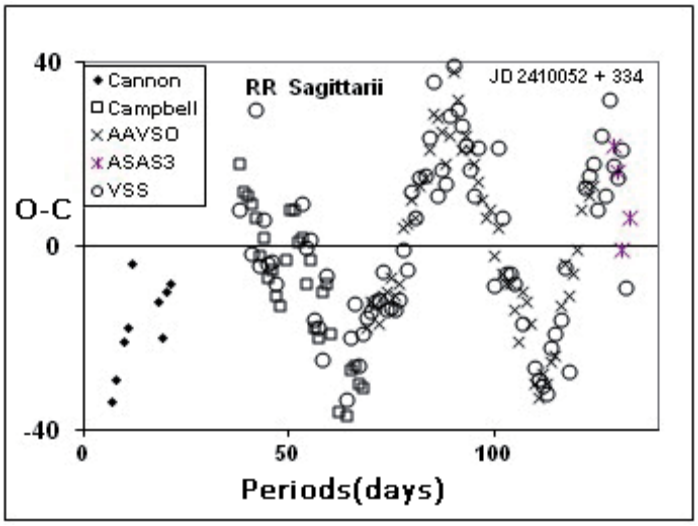

Figure 2: Period alternations in RR Sagittarii since 1886.

separated by a few percent of the period - see Figure 2. This is why almost all Mira stars in the General Catalogue of Variable Stars are shown as having variable periods. Many stars with periods in excess of 300 days show humps or bumps on their light curves. Finally, a few of the longer period objects show dual maxima. Period alternations of RR Sagittarii are shown in Figure 2.

The Dual Maxima Mira Objects

Table 1 lists all the known and suspected DMM objects. Not all are classified as Miras but the division between Miras and semi-regular stars at an amplitude of 2.5 magnitudes is artificial and confusing. The amplitude of these cool stars is very wavelength dependent.

In Figure 3 are shown V light curves for four stars from Table 1 using ASAS3 measures, Pojmanski, G, 1997. The shapes are reasonably similar with a sharp rise which is normal to many Mira stars but then a wide dual maximum and a much sharper decline to minimum than the majority of these stars show. The curve of TT Centauri does not quite follow this description and has some similarities to UZ Circini and BN Scorpii which can be thought of as stars with a strong hump on the rising branch. This also describes BH Crucis since 2000, in sharp contrast to its behaviour in the 1970s.

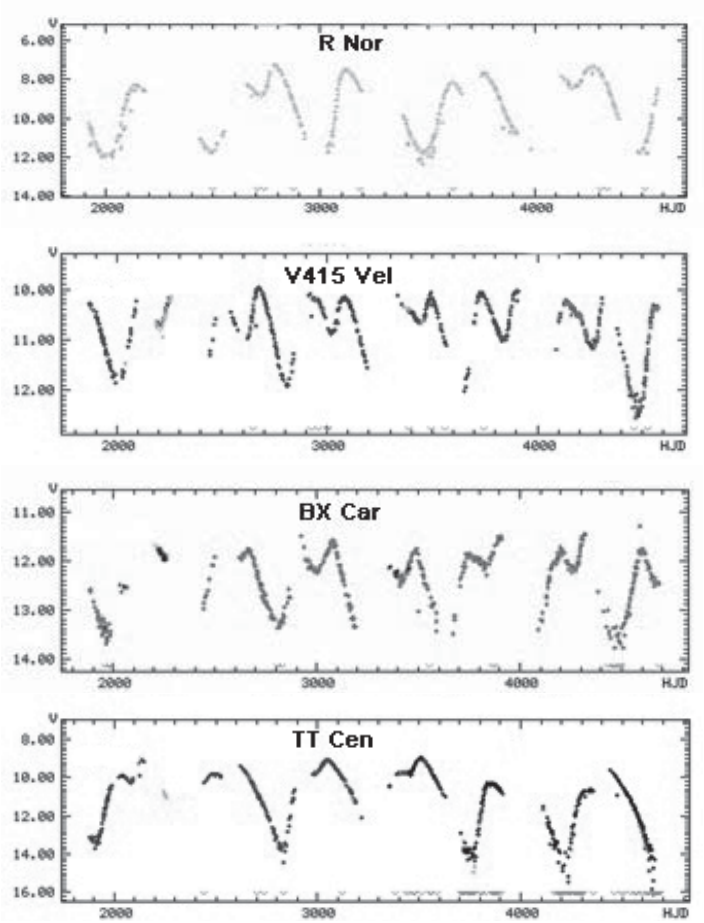

Figure 3: Some light curves from ASAS3. R Normae at the top, very similar to BH Crucis in 1970, V415 Velorum, classed as SRa due to its low amplitude, BX Carinae , another SRa star and TT Centauri, double peaked but a little different in shape overall.

Period Changes in Mira Stars

One of the main reasons for observing Miras is to keep track of evolutionary period changes. These seem to occur mainly in the longer period objects. Two pairs of examples are shown in Figure 4.

At the top are period graphs of two stars with slowly shortening periods - R Centauri with a period of ~560 days up to about the year 1940 but in 2013 about 497 days and R Aquilae where the first recorded cycle of ~350 days in 1856 has now reduced to ~260 days but shows signs of the onset of period alternations

Star	R.A. (h m s)	Dec.(° ')	Maximum	Minimum	Period (days)	Type	B°	Comments
R Centauri	14 16 34	-59 54.8	5.8	9.0	500: V	Mira	1.21	Prototype
R Normae	15 35 57	-49 30.5	6.4	12.0	507	Mira	5.08	Prototype
BH Crucis	12 16 17	-56 17.2	6.5	9.8	530: V	Mira	6.25	Evolved
V415 Velorum	10 03 30	-46 49.2	9.6	11.8	413	SRa	~5	Strong duality
BX Carinae	10 52 06	-62 29.0	11.7	13.8	427	SRa	-2.74	Very probable
TT Centauri	13 19 35	-60 46.7	9.0	13.4	462	Mira	1.90	Probable
UX Circini	14 20 52	-67 30.8	9.2	14.0	538	Mira	-6.12	Like R Cru now
BN Scorpii	17 54 10	-34 20.4	9.6	<15.0	616	Mira	-4.33	Probably not

Table 1: The first four stars have all shown strong double maxima behaviour.

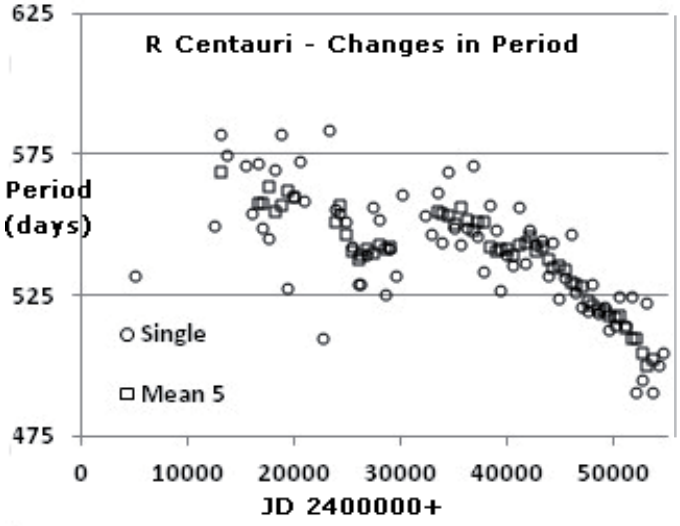

Figure 4a.

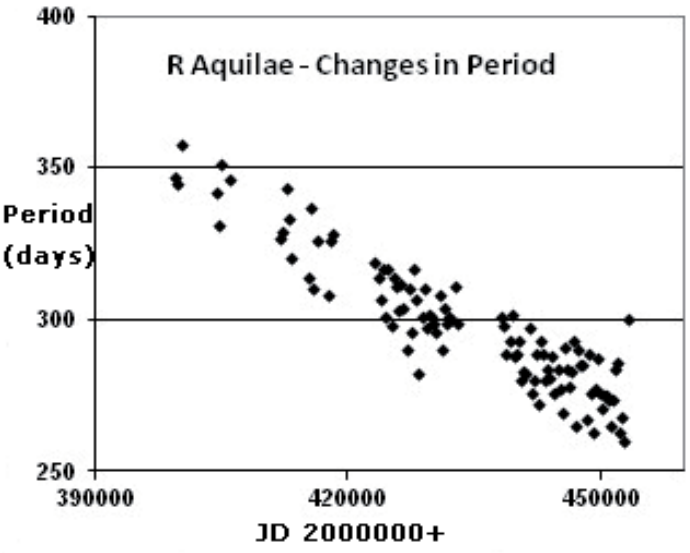

Figure 4b.

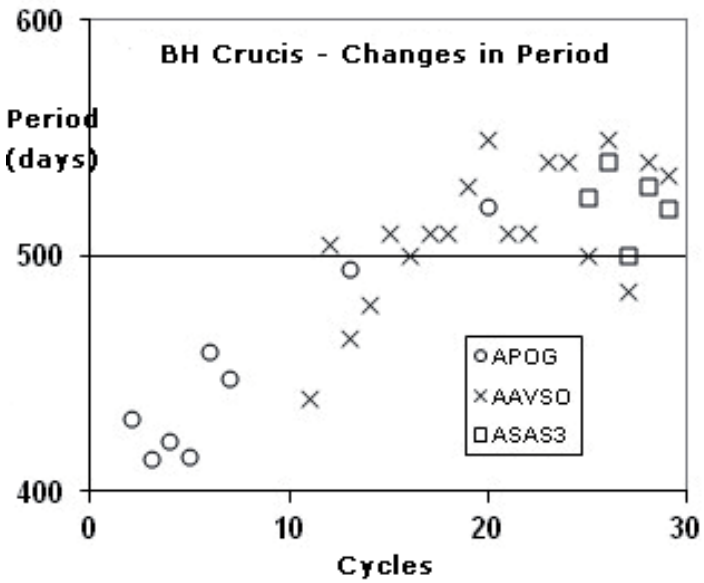

Figure 4c.

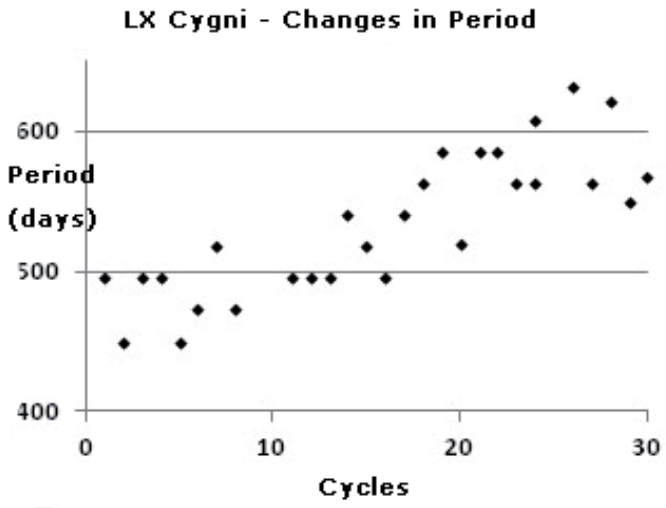

Figure 4d.

Figure 4: These four plots show contrasts in the speed of change. All have been attributed to a helium flash event causing a change in period. This may fit the first two as the change has lasted more than a century for R Aquilae and is still incomplete in both cases. But a different explanation seems necessary for the other two. See text for more details.

which indicates that this period change may be ending. This type of period change is attributed to a helium flash event in the outer region of the energy producing shell. The time scale is in julian days.

Lower down are shown BH Crucis with an increase in period from 421 days in the 1970s to ~525 days in little more than 20 years and LX Cygni, from ~480 days in the late 1960s to ~590 days, once again in about 20 years or 15 cycles. The time scale is in cycles. This type of change would appear to have another cause - perhaps a change of pulsation mode, possibly from the second to first overtone, which would differ from most Miras which pulsate in the fundamental mode or first overtone.

Not shown is R Hydrae, where a period of ~560 days in 1666 shortened to around 388 days by 1940. But two things emerge from this - stars with periods in excess of 400 days are more likely than others to undergo changes in period and of a small number of stars, six to eight, exhibiting dual maxima, two have shown period changes, although totally different in character. These two stars are examined in detail below.

BH Crucis

UBV measures of this star began in Auckland in 1970 and continued on until 1996. Light and colour curves obtained during the first four cycles are shown in Figure 5. The U-B data is very noisy as it's around U = 16 at minimum.

The V light curve is similar to most of these stars but with the first peak slightly lower than the second. The spacings in phase are very similar. The B-V light curve, showing temperature, is as one would expect with temperature greatest at the two maxima. But it's much redder than normal and the amplitude

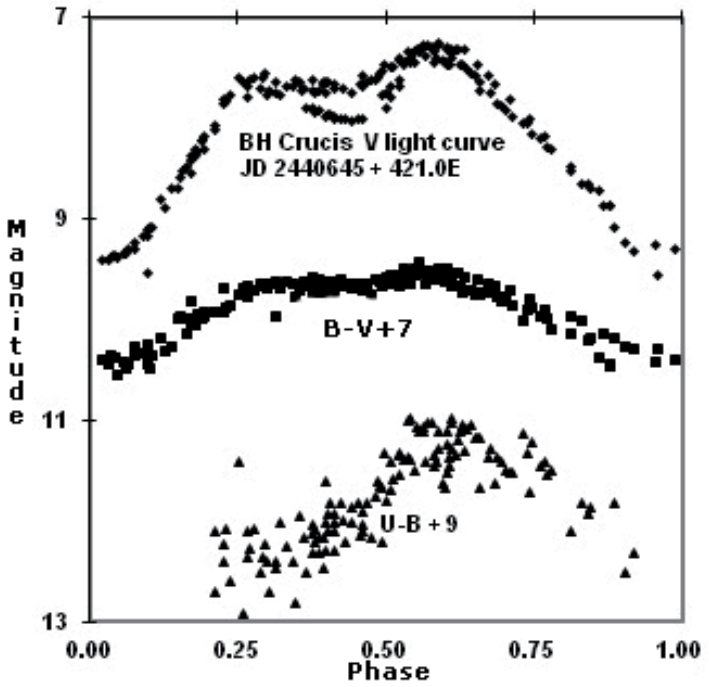

Figure 5: V, B-V and U-B curves of BH Crucis during the interval 1970-75.

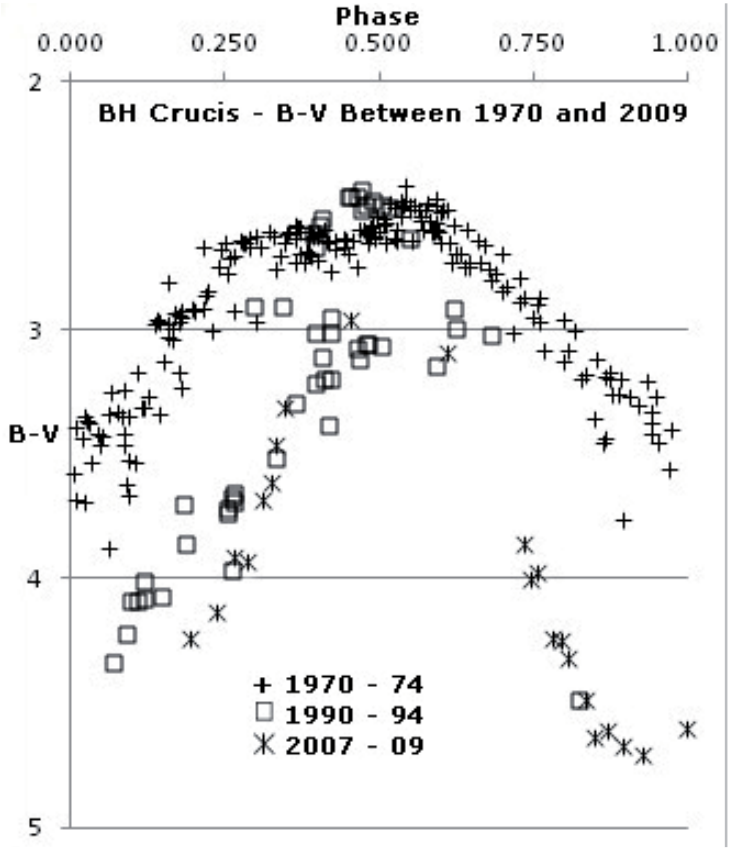

Figure 6: The upper curve, crosses, represent the B-V colours during 1970-74 over the first five measured cycles. The open squares are measures made during 1990-94 and show a marked reddening of the star as well as a larger amplitude. The complex crosses are CCD B-V measures during 2007-09 with the period as it was in 1990-94

quite large. The U-B curve, on the other hand, shows a completely different pattern. It is very weak at maximum I but quite bright at maximum II. This appears to completely preclude the idea held by some theoreticians that the period is half of 421 days but that the star shows very unequal maxima.

UBV measures were continued during most of the period shown in Figure 4c. The B-V measures and the temperature and radius implications were discussed in detail in Walker, 2009, but are summarised here. Over this long period the detector filter responses need to be carefully matched and transformed but this has been carried out well so we can trust the results.

These B-V colours of Figure 6 are in three groups. The upper colour curve is that of the first 5 cycles when the period was 421 days. Below that is the B-V curve when the period had increased to ~525 days in 1990. Finally there is a short segment from CCD measures in 2008-09 by Giorgio di Scala. Before discussing these, consider Figure 7 showing V measures of BH Crucis in 1970-76 as compared with those of 1990-94.

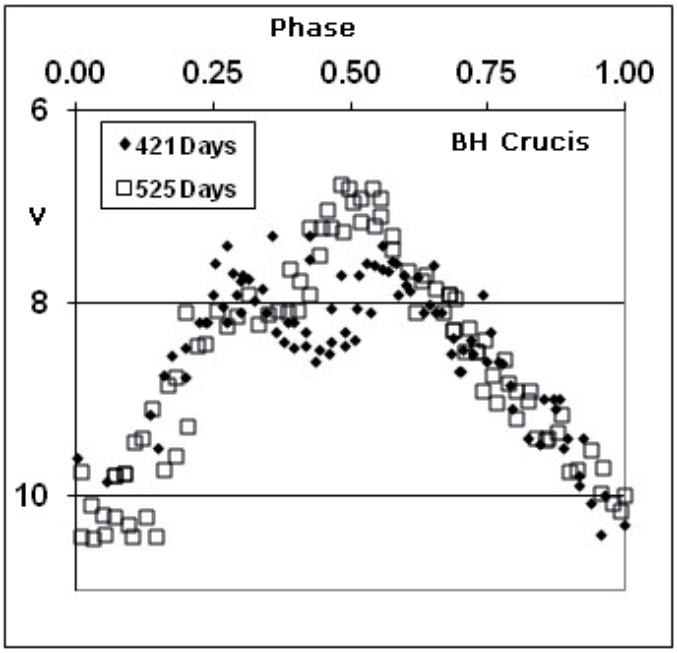

Figure 7: The V light curve of BH Crucis with a period of 421 days in the early 1970s is compared to the late 1990s and onward when it had increased to ~525 days. The increased brightness of the second maximum has almost completely hidden the original first maximum.

A variety of changes are evident but the main one is that the second maximum has increased strongly in strength. The first maximum is still present, but as a bump on the rise rather than a distinct maximum. As well the average brightness has increased.

When combined with the temperature changes of Figure 6 it appears clear that BH Crucis has cooled but its radius has expanded considerably if the increase in brightness is to be explained. Using the luminosity/radius relationship $L = T^4 \times R^2$ a radius increase of 20-25% is indicated.

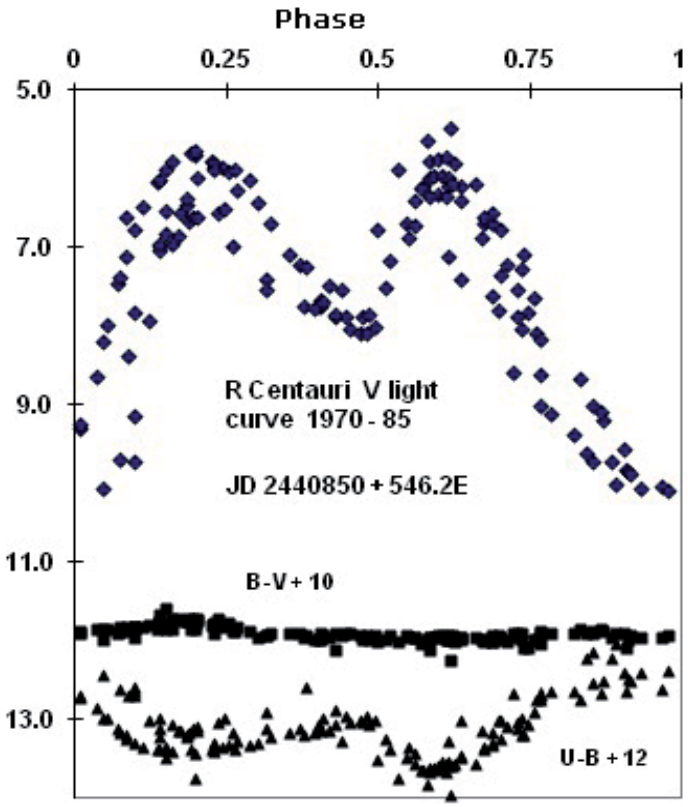

Figure 8: These measures are based upon the period in 1970 but by 1985 the changing period was clear in the V light curve. B-V measures show the temperature at maximum at the epoch of the first maximum, but the U-B curve is the reverse of what is expected. Either there is a second and hotter star in the system or a very close line-of-sight companion.

R Centauri

The prototype star of this group is R Centauri. UBV measures made at Auckland during the period 1970-85 are shown in Figure 8.

The V curve is beginning to be distorted by the changing period but the colour curves are unaffected. The B-V curve is flattish but is brightest just before the first maximum. There is also a slight ripple just before the main minimum. The U-B curve is puzzling, perhaps indicative of a hot blue companion, but this does not fit well with the theoretical Mira model of a low mass, highly evolved object. An alternative explanation might be similar to omicron Ceti's blue companion accreting material in a strong stellar wind but perhaps the simple explanation of an unresolved line of sight blue companion is better.

Whilst R Centauri's period is decreasing some dramatic changes in the shape of the light curve are taking place. Figure 9a shows visual measures in the 1970s, contemporaneous with much of Figure 8, but in Figure 9b which shows 5000 days up to late 2012 the light curve is very erratic. For a period the second maximum became very weak and the star at primary minimum was much brighter. As well, the shallow secondary minimum became very deep in some cycles. It has not yet stabilised and gives us an opportunity to follow the evolutionary changes as they occur.

Distribution in the Sky

John Greaves (2000) made the interesting comment that these stars were found in only a small part of the southern hemisphere.

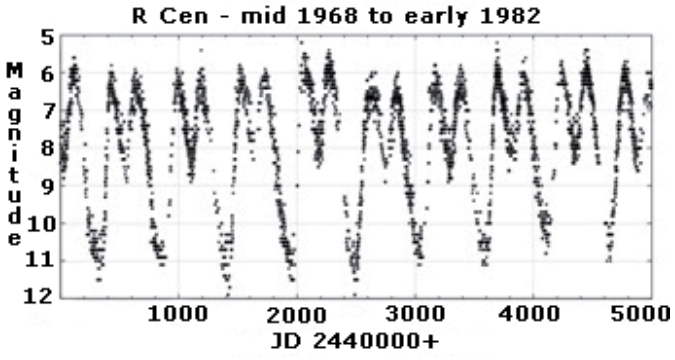

Figure 9a

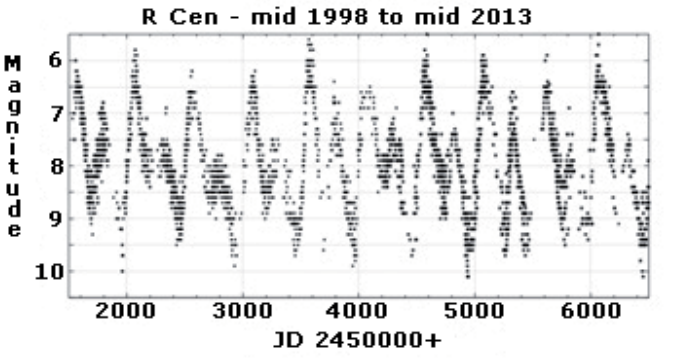

Figure 9b

Figure 9: This shows the contrasting behaviour of R Centauri in two 5000 day intervals - the first beginning in mid-1968, the second in late 1999. The data are from the International Database maintained by the AAVSO and are largely measures by the RASNZ VSS and Variable Stars South. Many are by Peter Williams who sends me monthly summaries of visual measures of some of these stars. But note the decline in numbers of the visual measures.

Reference to Table 1 supports this comment. But why? If BN Scorpii is excluded (and its light curve is not strongly of the DMM type) then the region they are found in comprises about 2% of the sky. There is one possible northern candidate, T Cassiopeia, but the visual data are inconclusive and the B and V measures are inconsistent. As northern observers become more active in colour photometry this situation may improve and this star can be classified with confidence.

The answer is probably simple. The dual maxima phenomenon could be a short-lived phase in Mira star evolution with only a few stars involved at any one time. To date most of the observations are of the bright objects, mostly identified more than a century ago. The fainter ones do not have completely observed cycles and are probably noted with periods in the 200-270 day range and, perhaps, misclassified as SR stars.

This suggests an interesting project for someone - to seach through ASAS3 and other patrol databases to locate others of this small group.

Conclusion

The colour photometry of BH Crucis and R Centauri by the Auckand group provides good physical information about two interesting Mira stars before, during, and in the case of BH Crucis after a major period change has occurred.

Originally most observers used UBV pep, (photoelectric photometers) but many observers are now making CCD BVRI measures and even simpler are BVR measures using DSLR cameras. For the objects with dual maxima measures every 10 days at the brighter levels will provide some good insights - why is the first maximum of R Centauri the dominant and bluer feature in contrast to BH Crucis where the second maxima takes that place? What is the situation with R Normae and V415 Velorum?

What is the mechanism which causes this duality and do the colour changes provide any information about this? Radial velocity measures would be useful to help determine whether something other than temperature is involved.

The two dramatically different types of period change and the high incidence of these changes amongst the longer period stars needs further study.

This is an area where DSLR observers could contribute useful measures in B and V. Even more interesting could be CCD BVRI measures.

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