MIRAS FROM AN ASTROPHYSICAL VIEWPOINT

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ABSTRACT

One hundred and fifty years of intensive time series photometry (TSP) of long period variables such as Mira stars have found less than a dozen stars with true long term changes – thus interest seems to be falling. But amateurs now have access to equipment capable of measuring other aspects of these stars: filters and detectors which allow UBRVI colour photometry, with extensions to JH and K passbands; spectroscopic equipment capable of measuring radial velocities accurately; all of which can be combined with satellite measures of distance and other features.

This project is largely based upon the known attributes of two Mira stars which have shown two maxima per cycle. There are similar stars where detailed study of the astrophysical aspects would be valuable. When successful results are obtained these can be used as a template for observing the full range of long period cool pulsating stars – Miras, SR stars and similar objects. Colour photometry thus provides a raison d'ệtre for amateur measures of these stars for the next century, even though the increasing number of surveys may relegate TSP to a role comprising data-mining of these surveys.

THIS PRESENTATION

INTRODUCTION

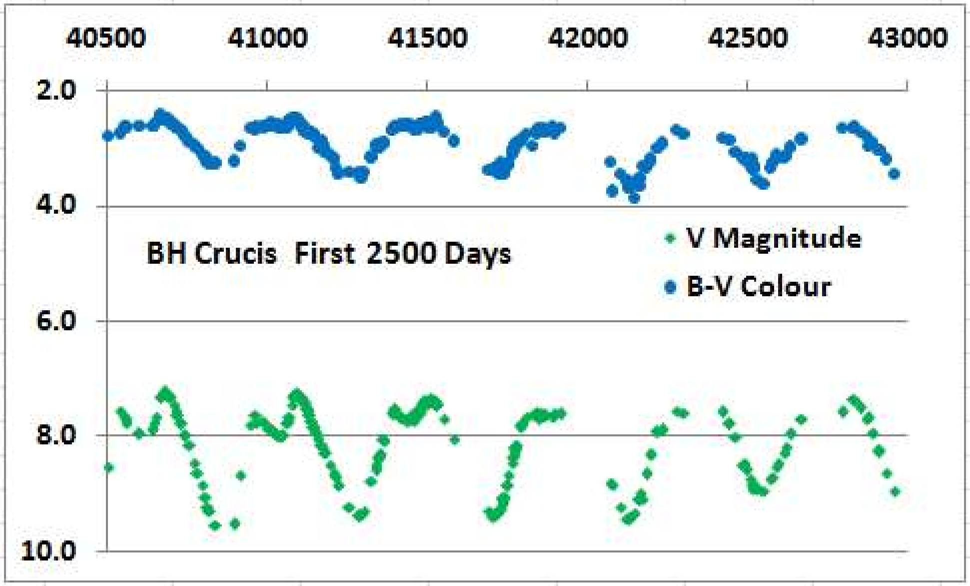
If we wish to study the evolutionary or other changes in stars which take thousands or millions of years to change we must seek targets among the stars which seem different.

The Dual Maxima Mira stars are one group of these. They comprise a small number of objects in the southern hemisphere centred on a region including and surrounding the Southern Cross.

In the 1960s only two, R Centauri and R Normae, were known and it was not clear whether the period was over 500 days or whether the stars had a period of half that with alternate deep and shallow minima.

Since then four others with the classic, almost symmetric light curves have been found. There are a dozen or more others which at times show two maxima but mostly of unequal brightness. These include two in the north, U Canis Minoris and T Cassiopeia. Light curves of six southern DM Miras are presented. Two of these stars have shown notable period and light curve shape changes, as well as changes in other features. I will present these in detail.

WELCH'S RED VARIABLE IN CRUX



This all began on 11 October, 1969, when we first measured Ron Welch's newly discovered variable star in UBV using the Auckland Observatory's new photometer. This shows parts of the first 6 cycles – the V light curve below, B-V above, both to the same scale. This was the third known double maximum Mira, notable for its very red colour and large B-V, or temperature, changes. The same year he discovered a fifth magnitude nova but few people remember that!

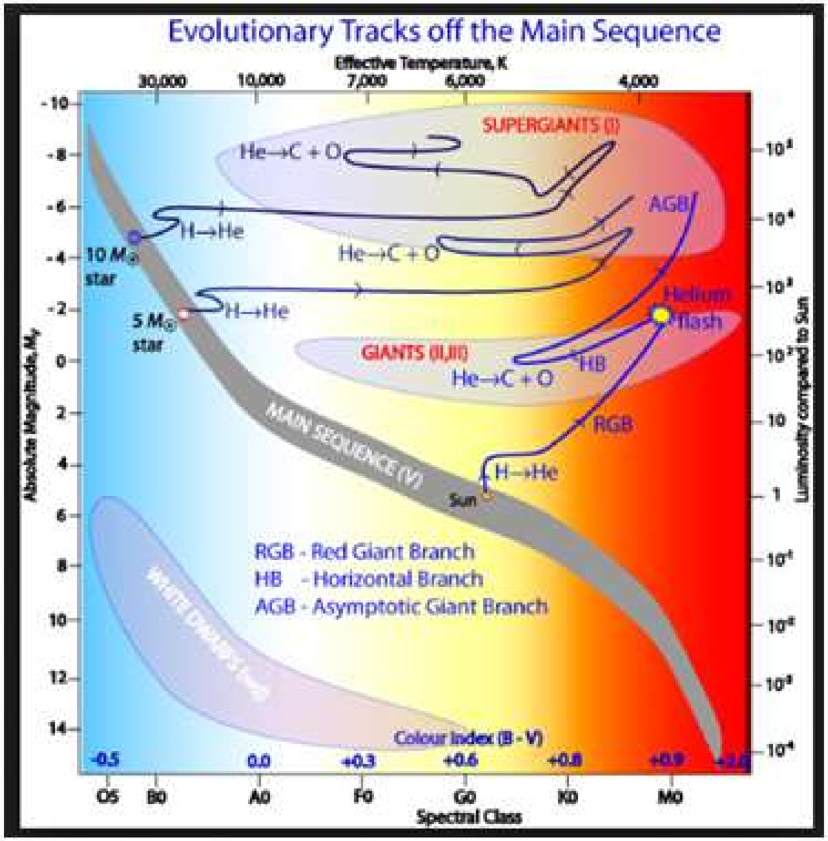
PULSATING STARS

Here we mean stars with radial pulsations which appear to be caused by shock waves resulting from the cyclic ionisation and recombination of one of two elements – helium in the case of the regular Cepheids and other variables in the well known instability strip and hydrogen in the much cooler stars of the AGB.

There is a critical difference. Although the ionisation/recombination takes place in a region of all stars where energy transfer is by radiative processes the shocks must travel through the star's envelope which is radiative for most Cepheids but becomes convective in the cooler stars such as Miras, semi-regular and other long period pulsating objects.

Thus the light curves of the cooler stars are less regular and show more forms of variation.. These additional types of variation provide information about the envelope through which they travel. One of these variations, Miras with dual peaks of brightness, is discussed at length below

WHAT IS A MIRA STAR?



These stars initially had main sequence masses of between 2 and 7 solar. Much of this has been lost during the red giant branch expansion – now they are evolving up the asymptotic giant branch, AGB, and still losing mass.

So they now occupy a less luminous , cooler and more spread out instability strip than Cepheids. Periods generally range from 100 to 600 days. They are now burning carbon and oxygen in the core, helium and hydrogen in shells around this.

EVOLUTIONARY TIME SCALES

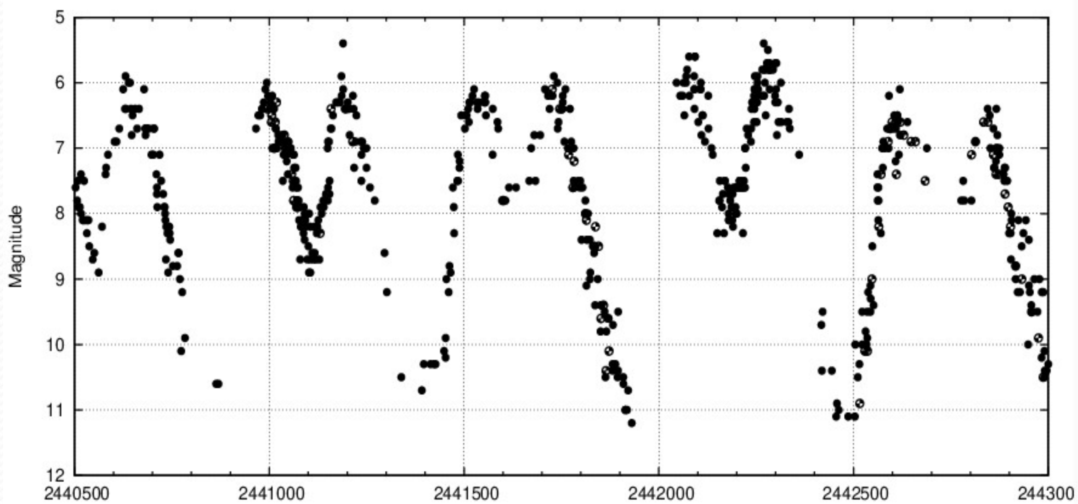
We cannot observe events which take place so slowly so must reconstruct event sequences as in the H-R diagram

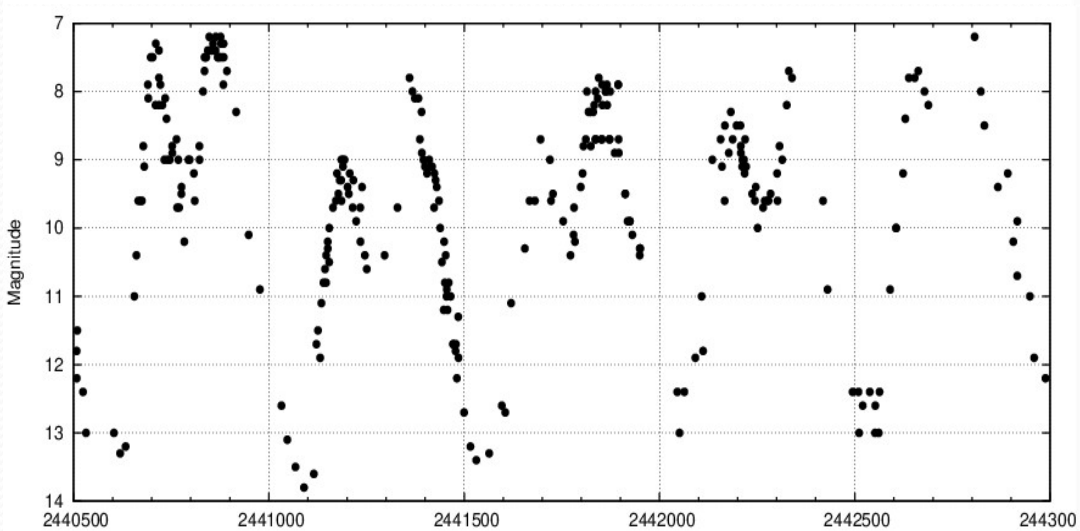
Blocker, 1995, studied mass loss and its effect on times of events;

- Initial masses from 1 to 7 solar masses – more massive objects evolve faster
- Evolutionary times on AGB from 1 x 10^6 to 5 x 10^7
- Thermal pulses occur during an interval of 4 x 10^4 years to 3 x 10^6
- Numbers of pulses range from 5 to 80
- Intervals between pulses range from 2,630 years to 95,000 years

These times may vary widely dependent upon a number of factors but illustrate one main point – nothing happens very quickly. But let's look at the effects of some of these events.

PROTOTYPE DOUBLE MAXIMA MIRAS



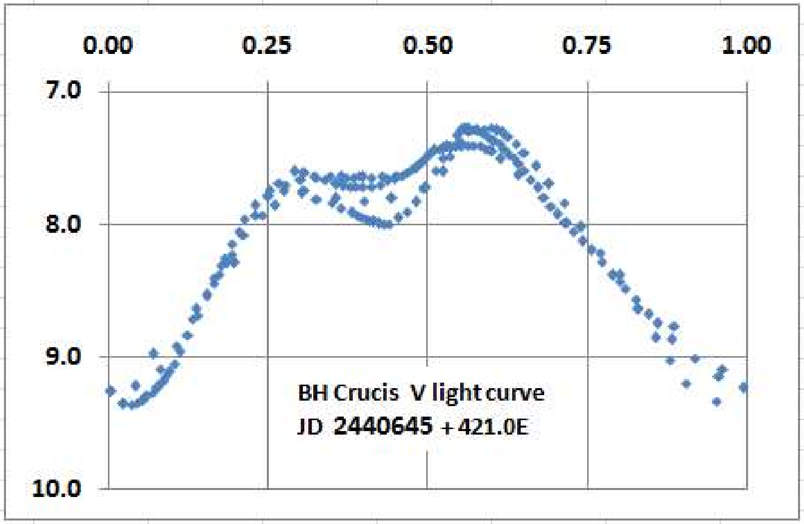


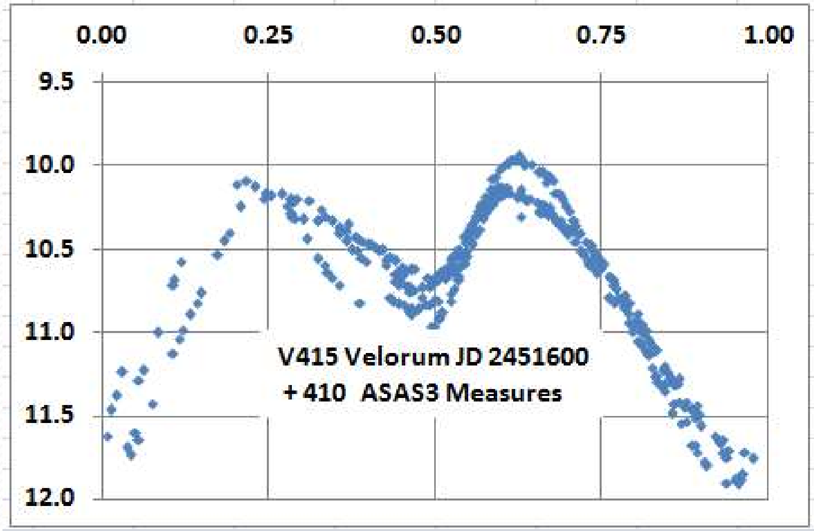
R Centauri in the upper graph is the brighter so is accepted as the prototype. R Normae, below, is much less well studied.

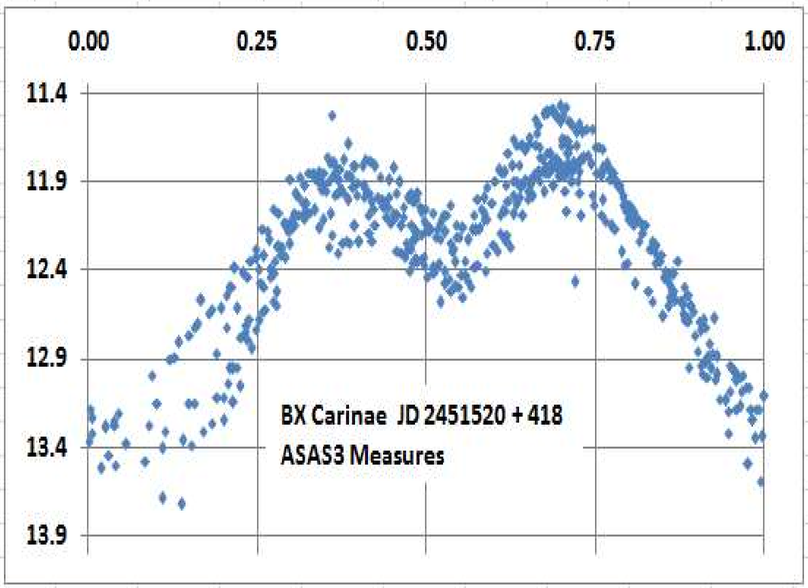
These visual measures graphs cover the same interval of 2500 days as the BH Crucis graph.

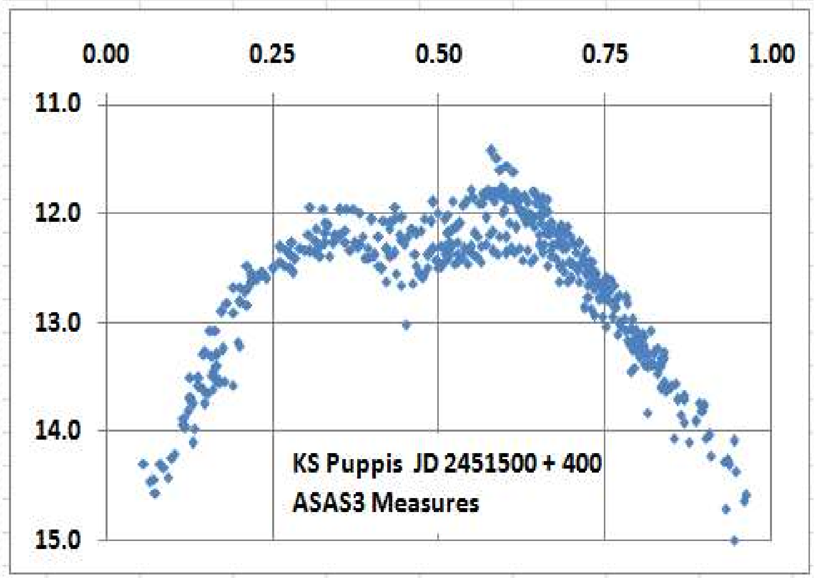
The two maxima are similar in brightness but it's often difficult to decide which is the more important. The light curves of these stars tend to be fairly symmetrical.

MORE DOUBLE MAXIMA MIRAS

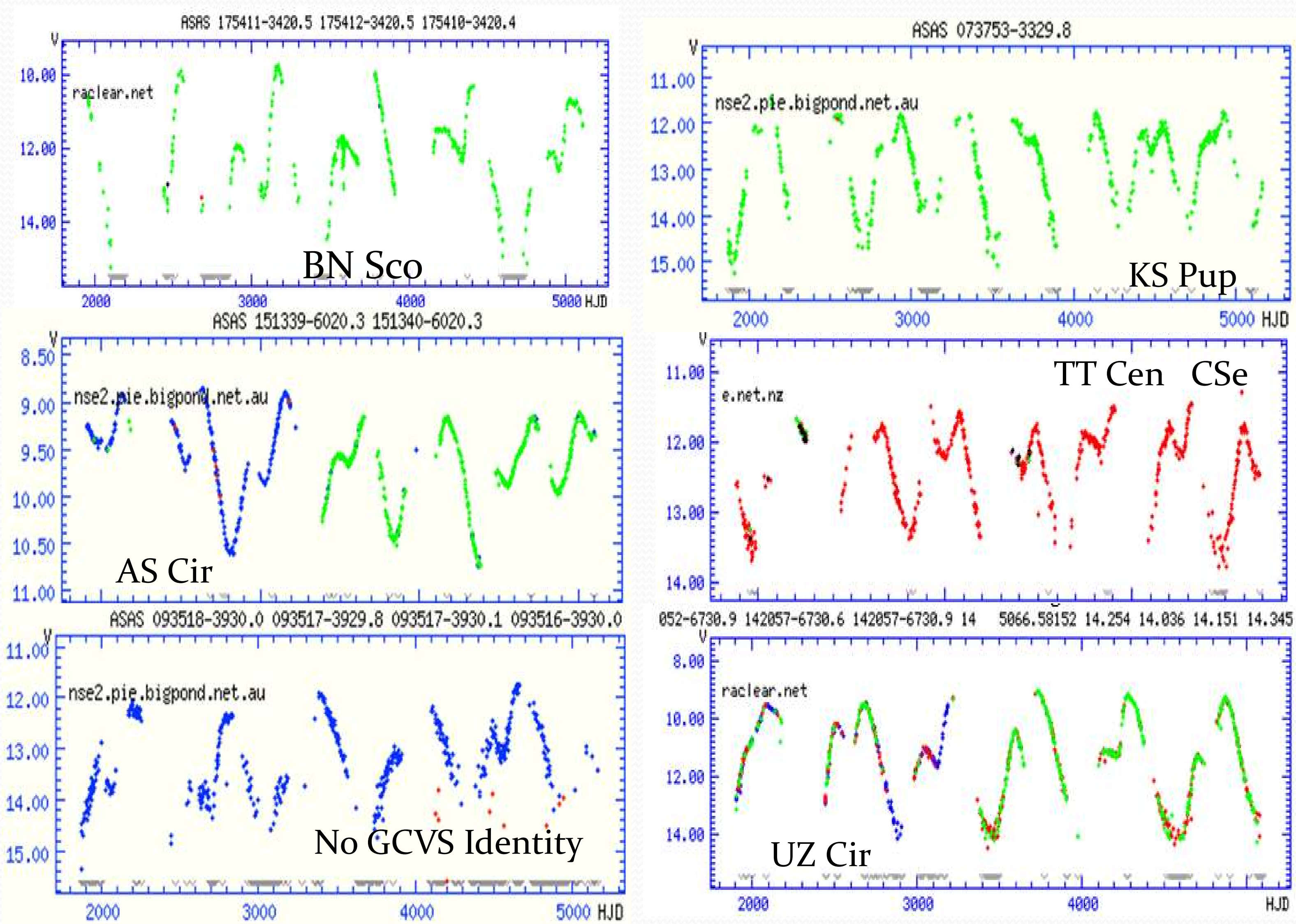






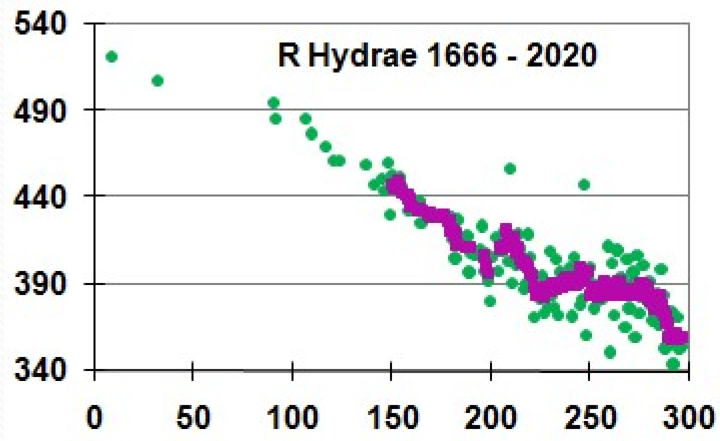


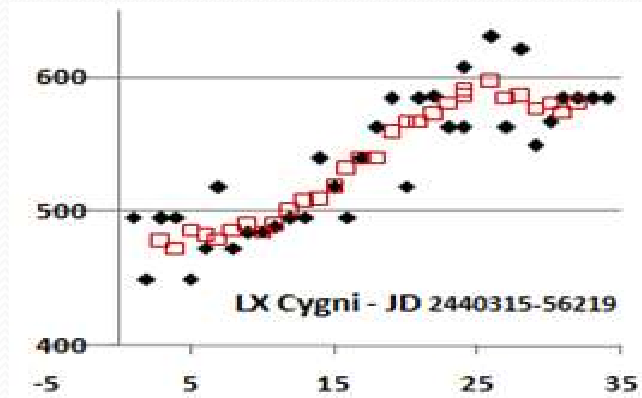
BUT WHAT ARE THESE OBJECTS?

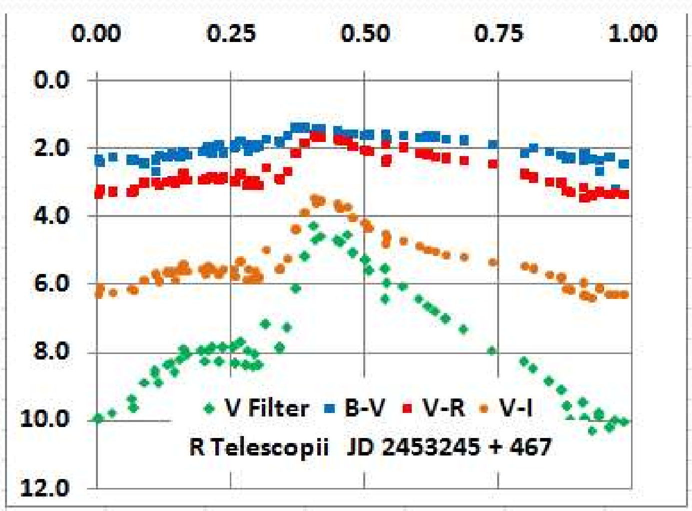


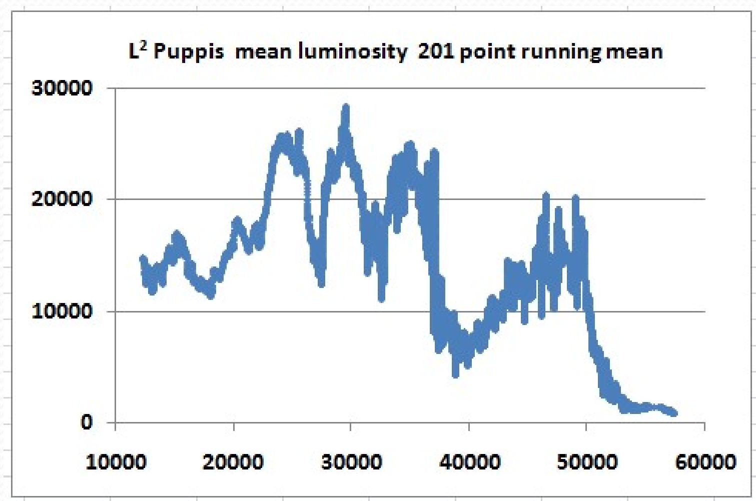
STARS WHICH ARE DIFFERENT

These are most interesting objects. Examples show two with changing periods, then R Telescopii with a hump on the rise to maximum (V is offset by -4 magnitudes), then one with major brightness changes L^2 Puppis SRa

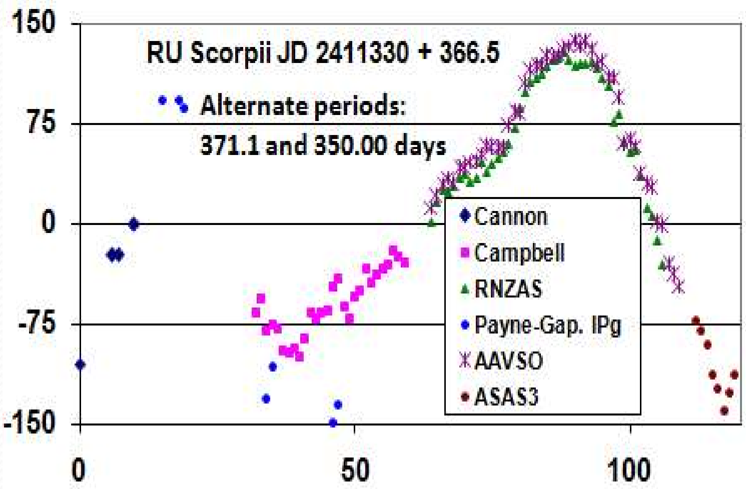


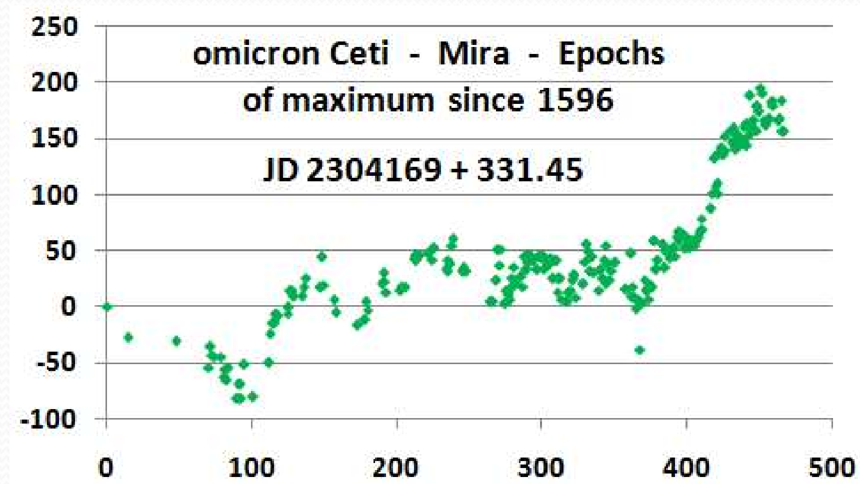






MORE DIFFERENT STARS





Why are some of these stars different?

- Periods of over 400 days seem to be less stable - stars are very large
- Spectral classes C and S or CS indicate highly evolved objects
- All these have low surface gravity – ejection of mass, often at high rates

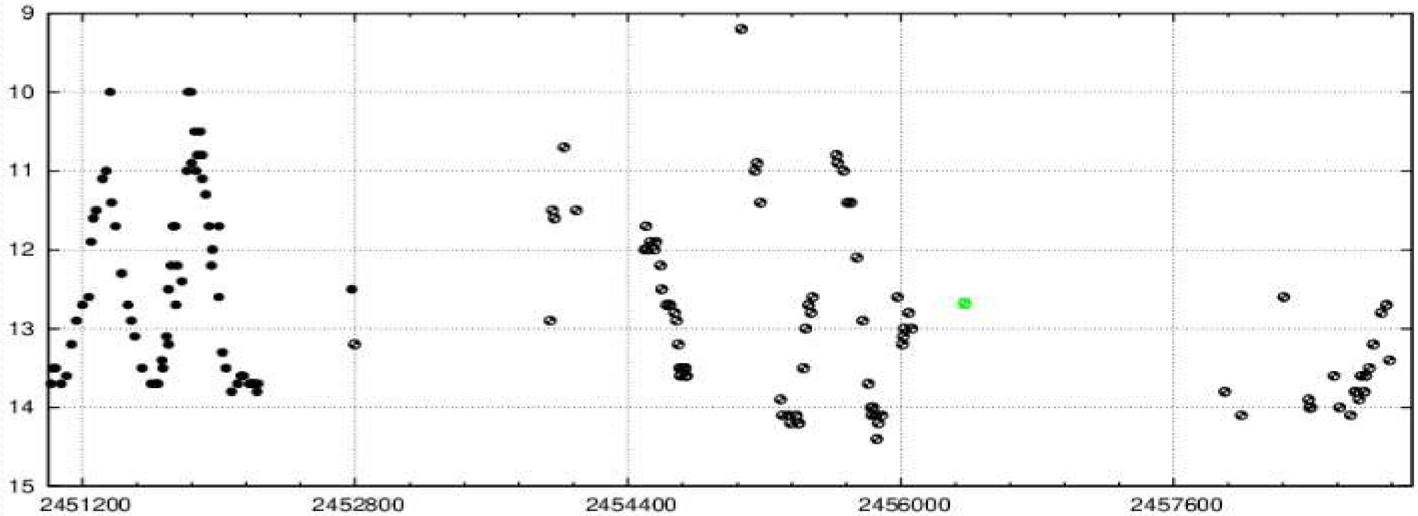
Slow reduction of period – helium flashes – neither start nor end seen

Fast increase in period – some aspect of helium flash – something else

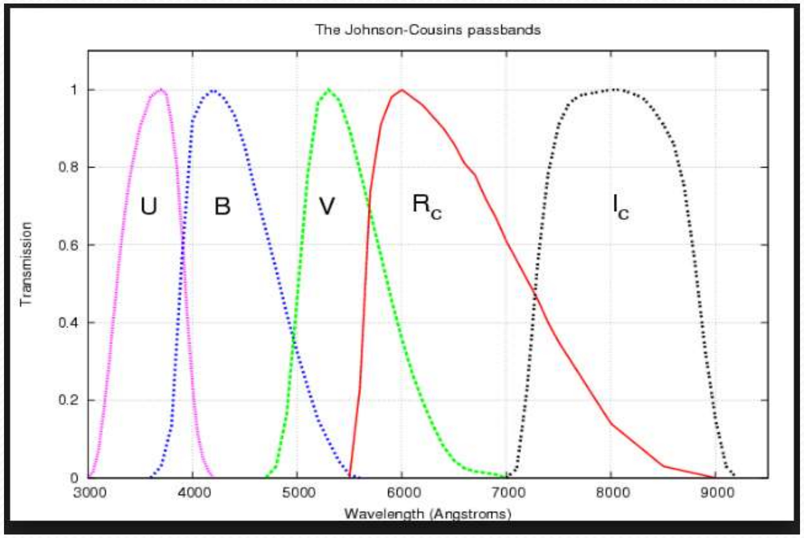
Abrupt changes like Mira– no ideas

THE VISUAL 'FINDS' - AN EXAMPLE?

KL Cygni satisfies some of the criteria for stars which may be making evolutionary changes. The GCVS quotes two periods – 536.8 days until 1962 and 526 days up to 1985 – but since 2001 it has hardly been observed. The GCVS gives a spectral class of Ce and Guide 9 a J-K of 2.58, so it's a red carbon star. There has been some discussion on the internet about a possible dramatic change in amplitude. Some BVRI measures might be rewarding as it reappears in the north morning sky. The only measures in the IDB are shown below. A target for northern observers. Only 3 !!



THE UBVRI SYSTEM



The UBRI system was devised by Johnson and colleagues in the 1950s. It comprised five coloured glass filters with specified wavelengths and band passes. It was designed to show certain features of a star's spectrum by the use of pairs of filters: V, B-V, U-B, V-R and V-I.

The most commonly used system then was V, B-V, U-B which showed:

V = Intensity or magnitude
B-V = Temperature
U-B = Strength of Balmer jump region

The detectors were usually 1P21, RCA 931A or EMI 6256 and 9502 all of which were most sensitive in the B filter region. R and I required cooling which was complex and costly

JOHNSON or SLOAN FILTERS?

This question is best asked in a century's time. But let's do our best.

- Neither system is all that suitable for cool red stars.
- Historical measures of these stars largely in V and B from 1950s
- B-V provides a good colour-temperature relationship
- Sloan has more precise boundaries but conversion is difficult

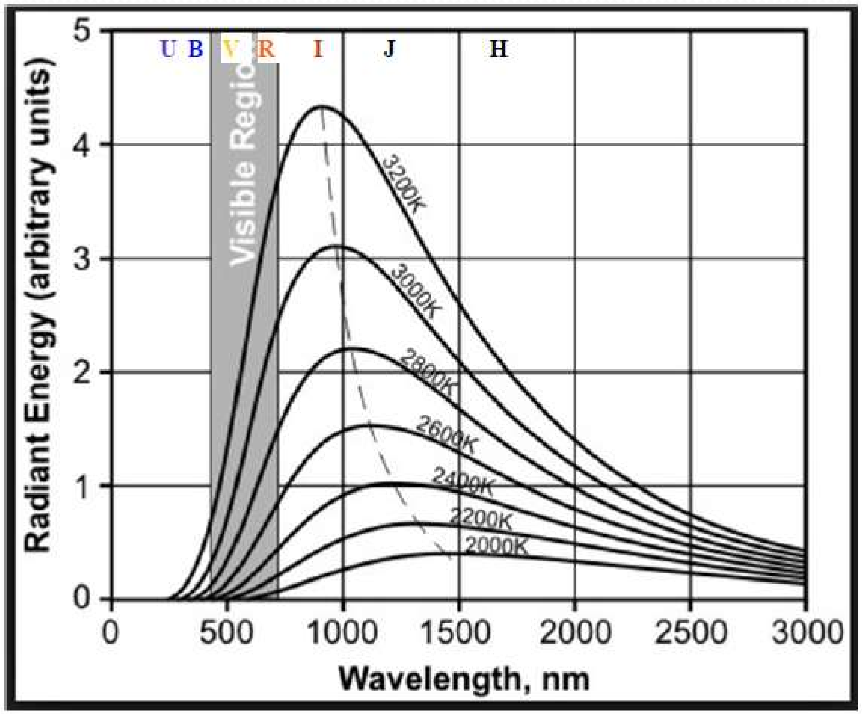
Probably most of the original work in the LPV field will continue to be done by amateurs with professionals following up with more detailed theoretical and physical explanations. So we should continue with the Johnson system at this stage.

Johnson	Eff Wl	Sloan	Eff Wl
U	365.6	u'	358
B	435.3		
		g'	475.4
V	547.7		
R	634.9	r'	620.4
		i'	769.8
I	879.7		
		z'	966.5

OTHER ASPECTS OF FILTERS

- Will UBVRI filters still be made?
- What are the markets for these filters?
- Visual observations are declining
- Colour photometry is an inefficient for tracking normal periodic behaviour - standard TSP is better
- Observers presently using only V filters should extend to B-V
- Increase of satellite and other surveys will produce masses of data
- How does one access these measures?

A REALITY CHECK



Why is there such a large range through different filters?

Miras are cool stars with temperature around 3000K. But amateurs are working in a narrow range of wavelengths. BVR filter s cover the visual range with the U filter picking up the UV radiation from gas around the star, the I filter radiation from hot dust shells.

Some amateurs are using JH filters with wavelengths of ~1220 nm and 1630 nm but the photometers are quite slow and crude as compared to CCD equipment.

RADIAL VELOCITY MEASURES

The development of low cost efficient spectrographic equipment sees amateurs becoming strongly involved in this area. Whilst spectral classes and maximum-minimum variations of almost all Miras are available from the GCVS and VSX little is known in most cases about RV changes during pulsation cycles. The exception is that it is clear that the star is smallest near maximum brightness and largest at minimum. The low surface gravity at minimum allows material to escape, hence the strong emission signatures.

- Hydrogen alpha and beta in emission most prominent – but these emanate from a gas shell – not the stellar surface
- Surface RVs need to be measured using other spectral lines
- What is available – see next slide?
- Let's look at some interesting possibilities
- BH Crucis as it is now – a brighter star than 50 years ago
- R Centauri – the prototype Dual Maxima Mira – period becoming shorter

SPECTROSCOPY

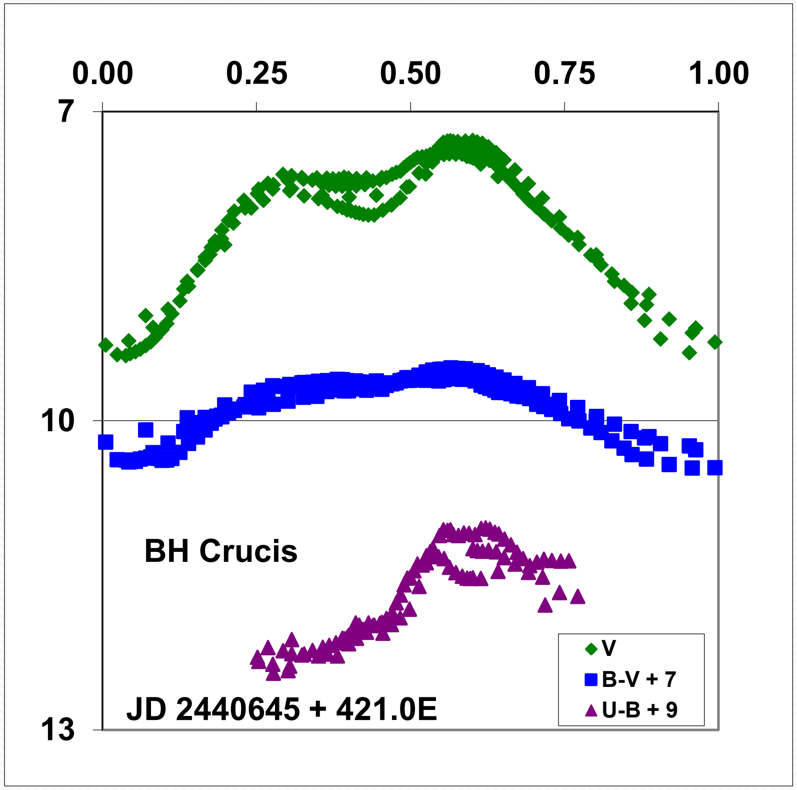
"I suggest measuring the ground level lines of Cr I, Mn I, Ca I, K I, Na I and Ca II. These have been used by earlier studies in the literature - they should be reasonably strong and thus detectable within the forest of lines usually visible in Mira spectra.

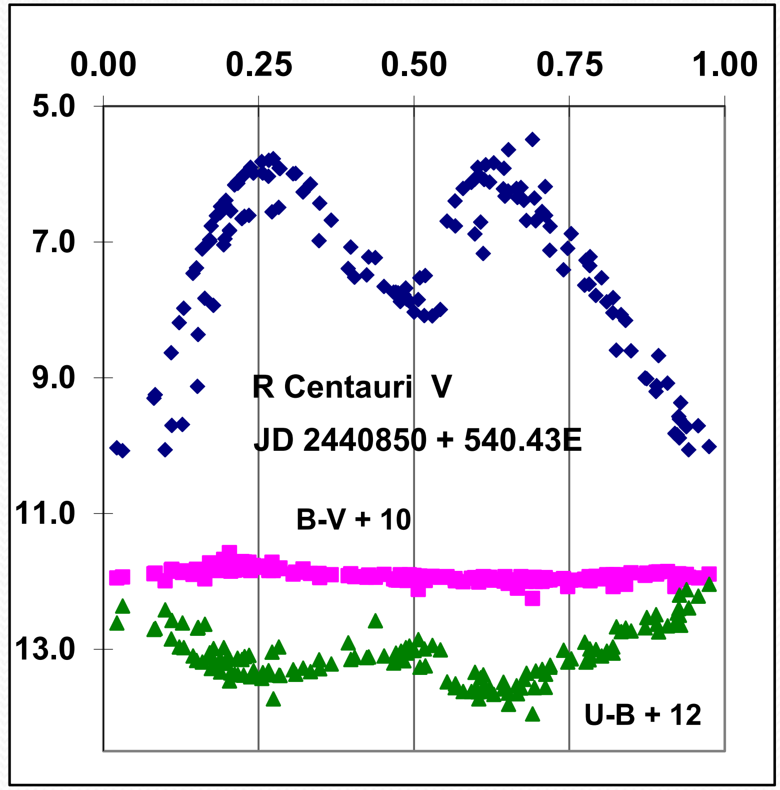
They should be present both in M- and C-type stars. As all ground level lines, they likely originate in the same part of the atmosphere. You can thus combine them to increase the accuracy (mean atomic line velocity).

This will likely need R around 10000 or better, I am not too optimistic for the R=4000 spectrographs. For the latter, however, one could try to use the TiO-band heads in the M-type stars. This are very clear spectral features, and you could probably achieve a reasonable accuracy by cross-correlation technique.

Also, for quite a number of LPVs there are no accurate spectral types determined yet. This would be a very valuable project that could be done at a comparably low spectral resolution of R=1000. It would also be interesting to monitor changes of the spectral type over the pulsation phase."

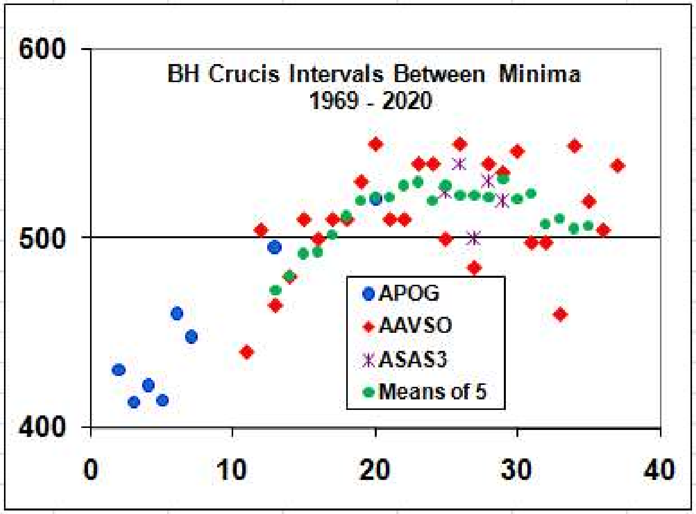
THE COLOURS OF MAXIMA

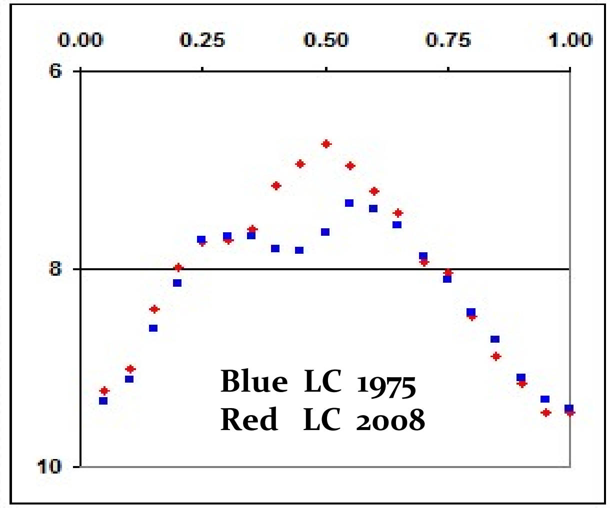


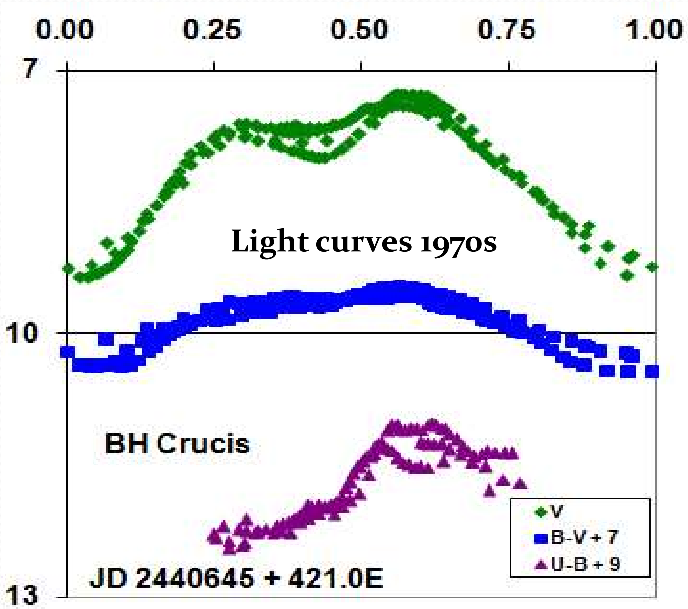


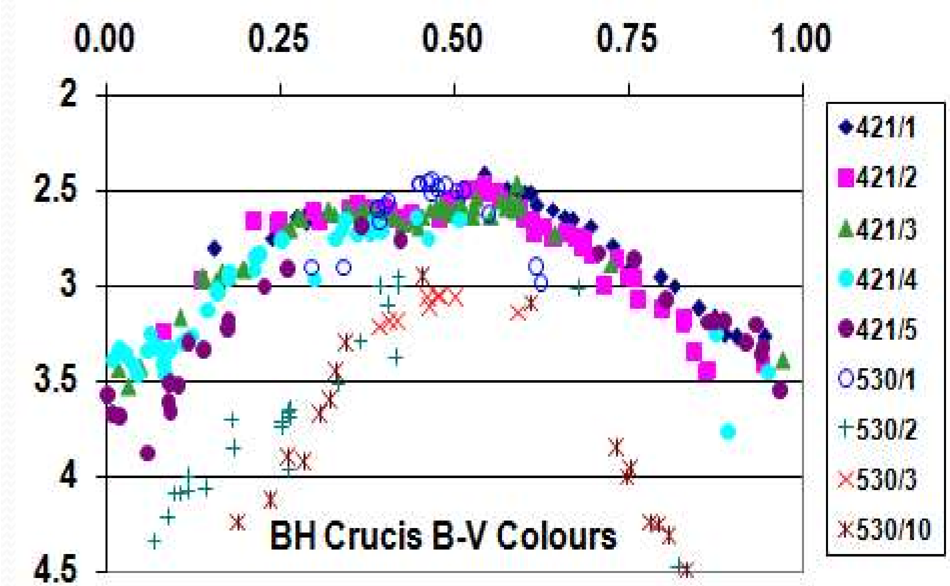
Our UBV measures in the 1970s are shown here. BH Crucis, as a carbon rich Mira, barely makes the 2.5 magnitude amplitude requirement. More important – the second maxima of BH Crucis is the brighter in B-V - thus the hotter in contrast to R Centauri where the reverse is found. ***Why*** - is an unanswered question.

CHANGES IN BH CRUCIS – 1975 to 2008

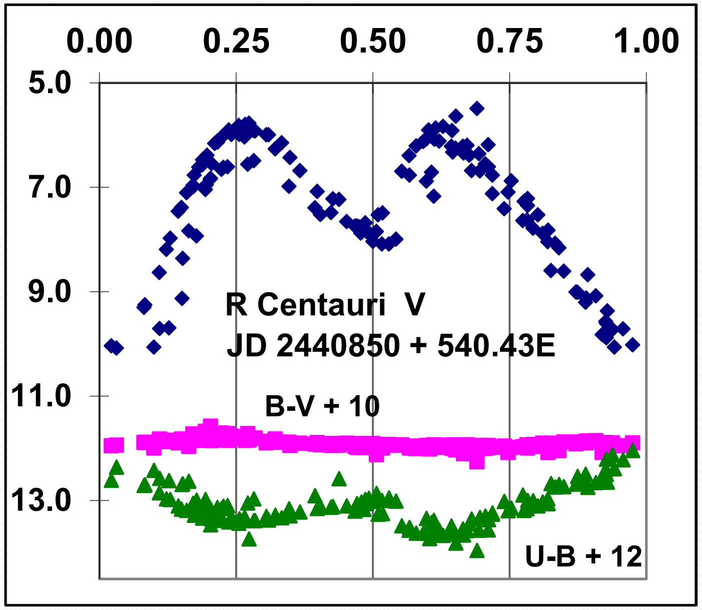


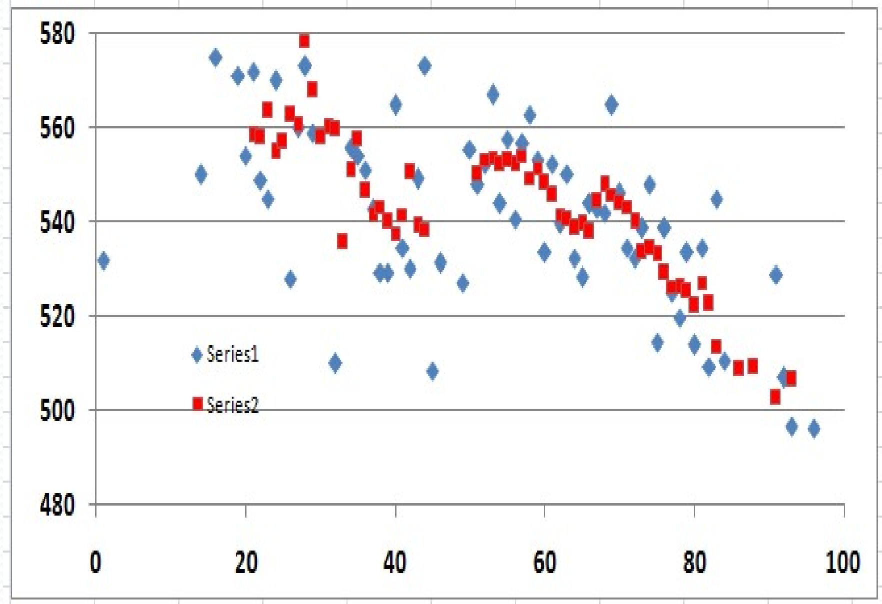






R CENTAURI - DUAL MAXIMA MIRA

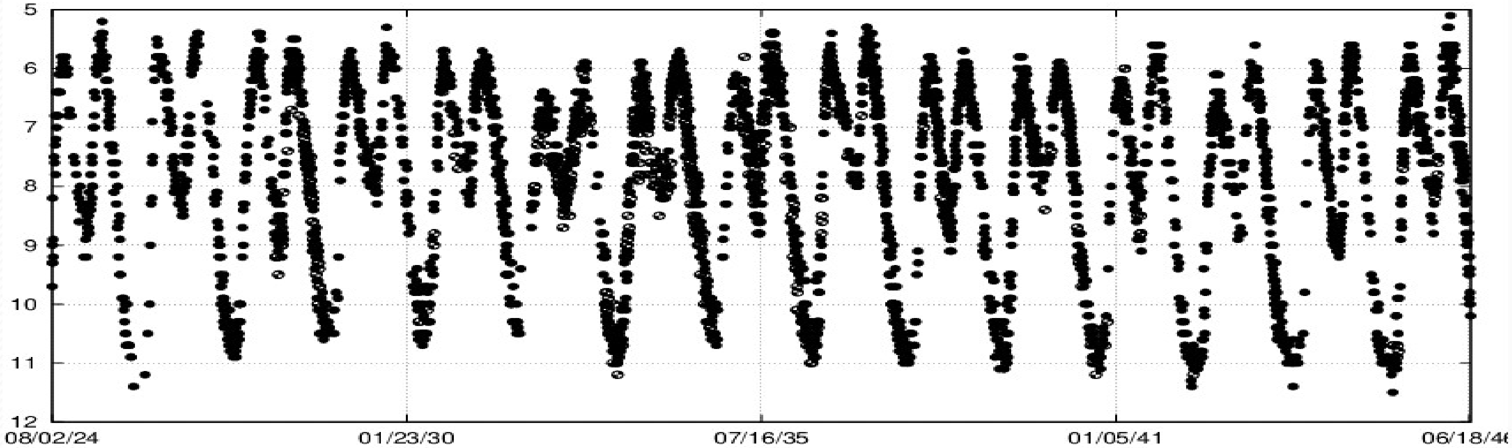


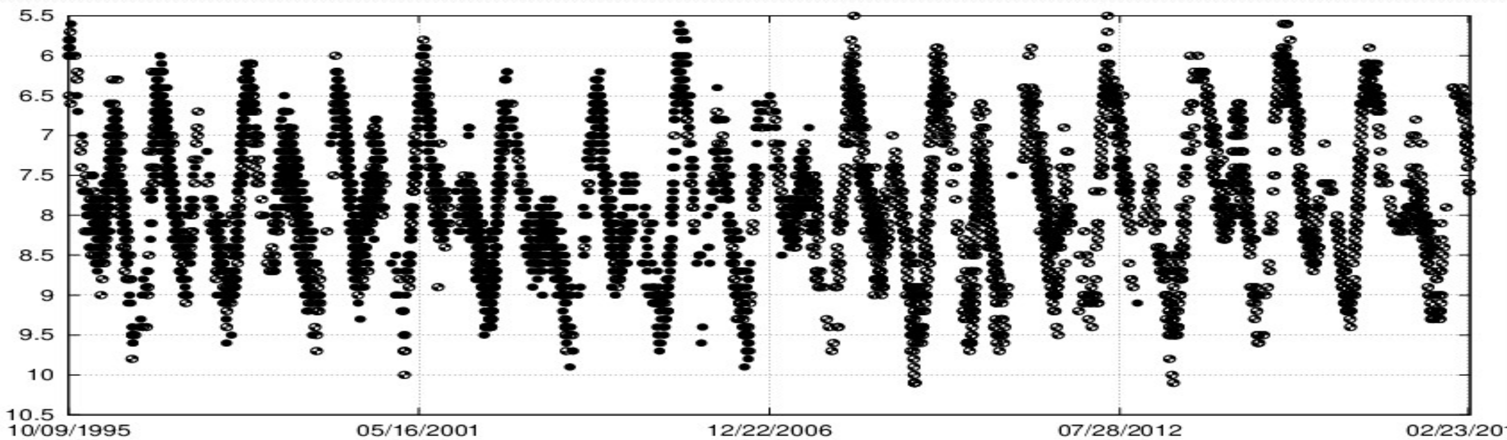


The left graph shows phased V, B-V and U-B measures during the 1970s. The star is at its hottest and brightest at phase 0.25 but reaches a similar brightness at phase 0.62, probably due to a larger radius. This graph centre is epoch 70.

The right hand graph presents a periodogram from 1872 to 2020. The presence of two maxima seems to make epochs of maxima a little more uncertain so it's hard to determine when the period change began. The blue points are single epochs, the red squares indicate means of 9 measures. The 560 day period of the 1890s is now 494 days. Primary minimum is a more reliable epoch marker!

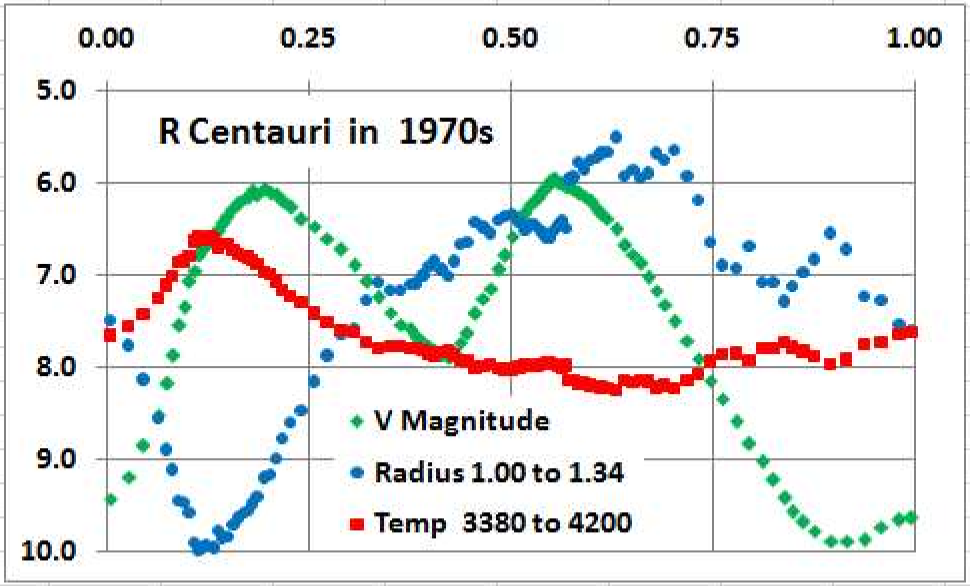
R CENTAURI - DUAL MAXIMA MIRA





Here we see overall changes in the light curve 1924-1946 compared to 1995-2018. The amplitude seems to have decreased slightly but this may be merely sequence changes. The lack of stability in the second maximum is clearly shown.

R CENTAURI - DUAL MAXIMA MIRA



This slide is a very crude adaption of the Stefan/Boltzsman relationship as it relates to luminosity, temperature and radius. At these temperatures the bolometric corrections are very high. Only radial velocity measures will allow accurate radius change values to be found.

A bolometric correction would see the second maximum much brighter than is shown here with a consequent increase in the radius It seems that the first maximum is associated with temperature, the second with maximum radius – but we need proof!

TARGET STARS FOR THE PROJECT

Star	R.A.	Dec.	Max	Min	Period	Spectrum	Type	L	B°
V415 Velorum	10 03 30	-46 49.2	9.6	11.8	410~		Mira	275.48	6.90
BH Crucis	12 16 17	-56 17.2	6.5	9.8	530:	SC4.5/8e 7/8e	Mira	298.04	6.25
R Centauri	14 16 34	-59 54.8	5.8	9.0	500:	M4e 8e II	Mira	313.42	1.21
R Normae	15 35 57	-49 30.5	6.4	12.0	507		Mira	328.32	5.08
BX Carinae	10 52 06	-62 29.0	11.7	13.8	427	--	SRa	289.63	-2.74
TT Centauri	13 19 35	-60 46.7	9.0	13.4	462	CSe	Mira	306.37	1.90
UZ Circini	14 20 52	-67 30.8	9.0	14.0	538	--	Mira	311.35	-6.12
KS Puppis	7 37 53	-33 29.7	11.4	15.0	427	J-K 1.58	Mira	247.73	-5.87

The goals initially will be:

- Obtain V and B-V of both maxima
- V, B-V of the light curve in the upper half of the range – V-R, V-I optional
- Radial velocity measures of the brighter objects across dual maxima region

Note that BH Crucis now is a ‘hump’ Mira but the area from phase 0.25 to 0.75 is interesting and worthy of attention.

OBSERVING THE TARGET STARS

Accuracy is essential. This is best obtained by using one reliable comparison star and two or three checks. The amplitude of most of these targets is relatively low so one set of Comp/Check stars is adequate. The lower part of the light curve is not as critical.

Details of the selected comp/checks are on the VSS website at -----link---- Do not use any other stars as their magnitudes are not as accurately known.

Since all of the periods are in excess of 400 days a measure each 10-15 days is adequate with, perhaps, every 5 days around the two maxima and the intervening minimum.

Predictions of the various phases are available at the same location.

With filters it's easier to use the IDB if a standard format is used. I'd suggest the order should always be UBVRI or whatever portion of these you observe.

WHAT AFFECTS MEASURES?

To convert your derived magnitudes to the standard system consider:

- The scale factor (transformation) to ensure your filters match the wavelengths of the standard UBVRI system. This needs pairs of filters
- Removing primary extinction if stars are measured at a significant air mass difference from each other. This should only happen at low altitudes – offsets from culmination due to azimuthal effects
- Adjusting for secondary extinction if stars are of different B-V and other colours

In the southern hemisphere the E and F Region standards should be used for deriving transformations. At fainter levels the Landolt standards may be used.

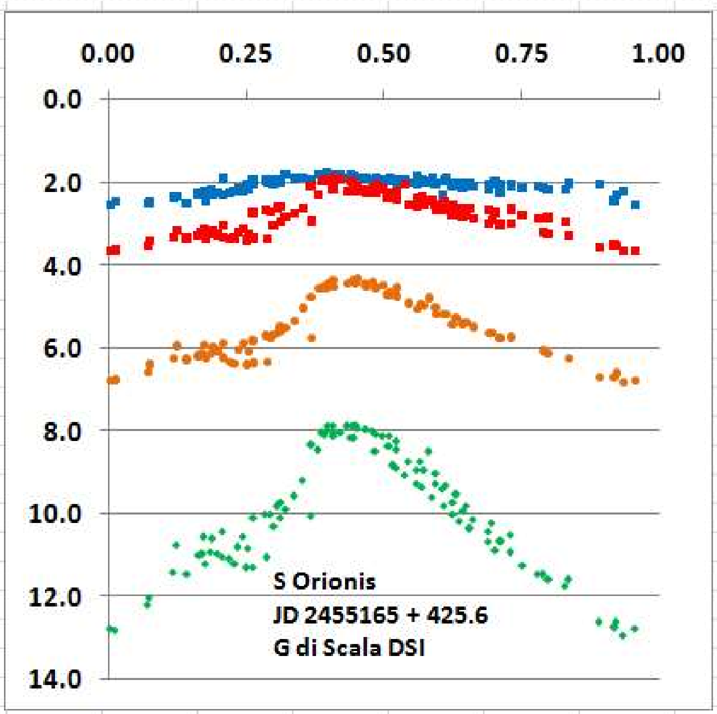
Primary extinction is highly variable but is largely negated by ensuring all stars are close together.

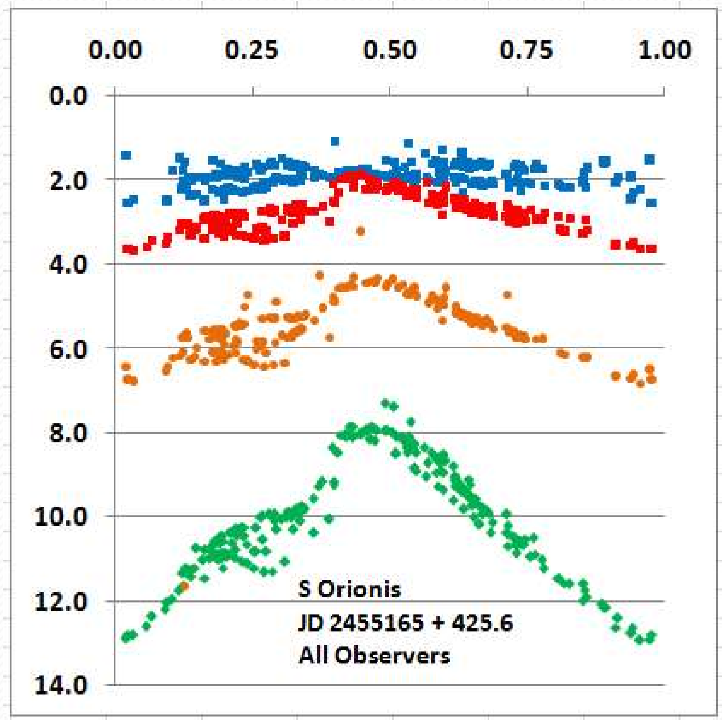
Secondary extinction is usually fairly constant and is always present when stars are of different colours.

The project takes these factors into account in selecting comparisons.

S ORIONIS - A PUZZLE

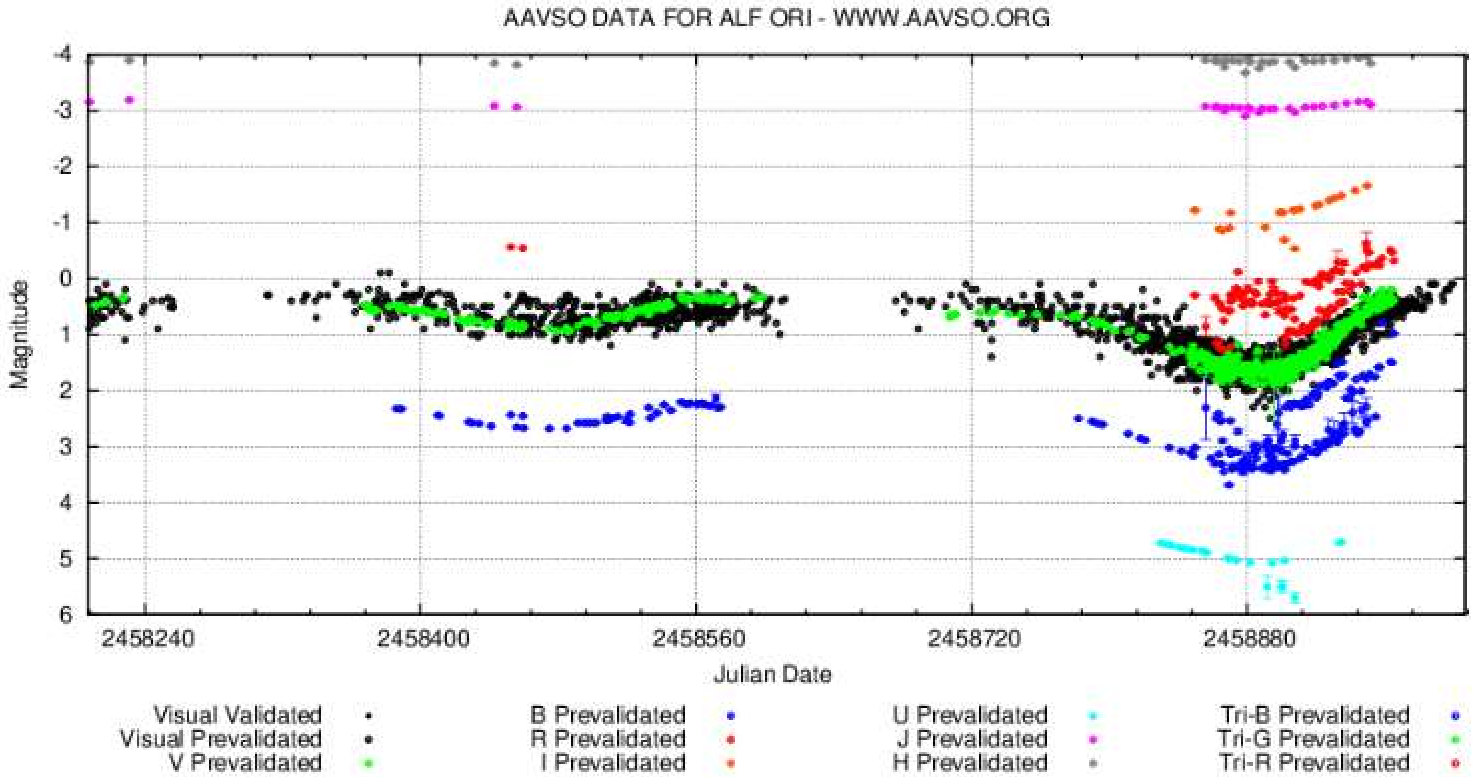
S Orionis is an interesting Mira in that it shows a pronounced hump on the rise to maximum. At -4° 40 declination it can be observed from almost anywhere . The left plot shows all sky measures by Giorgio di Scala, the right measures by all observers.





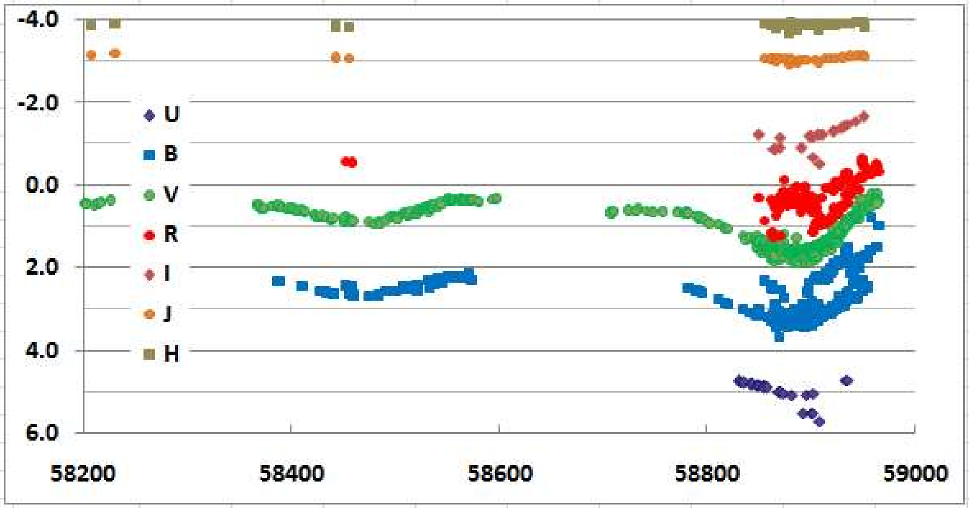
The curves from top to bottom are B-V, V-R, V-I, V

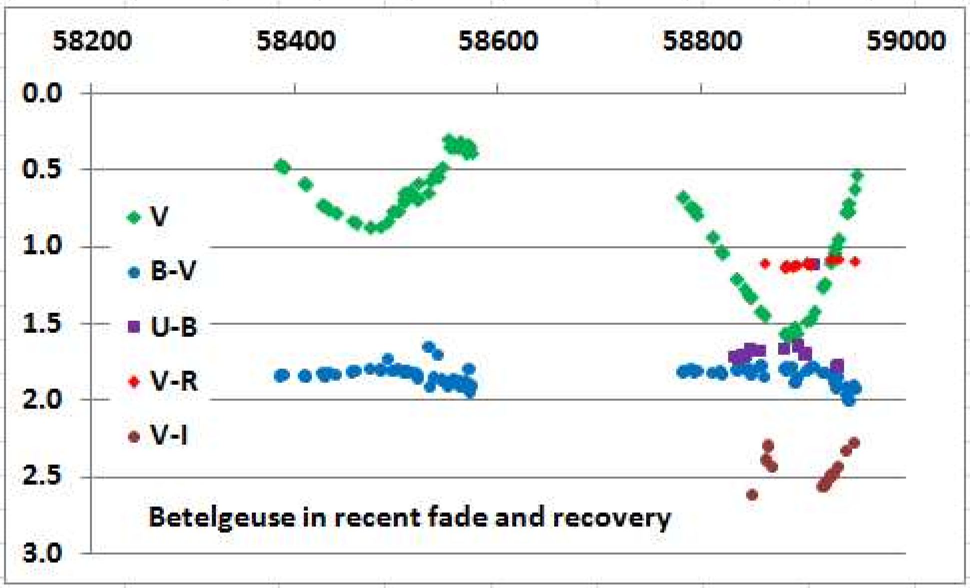
BETELGEUSE IN 2018-2020



This graph shows 800 days up to 6 June, 2020. There are some interesting aspects. There is little change in J and H and the V-R and V-I colours are closer to the expected ratios as compared to B-V. The different filter bandpasses are very confusing.

THE COLOURS OF BETELGEUSE





The upper graph shows measure through individual filters, the lower presents enough of these in V, B-V, U-B V-R and V-I to study colour changes and relationships.

V-R and V-I are close to expected values but B-V and U-B are inverted from normal. This would normally be associated with a hotter companion star but that seems very unlikely here. The U-B was only single filter but has been matched with similar time B measures.

THE SEARCH FOR ACCURACY

The last three slides I've shown have revealed that there is a considerable spread of magnitudes and colours. Why is this? Is it:

•Faulty sequences.
•Incorrect reduction techniques.
•Failure to correct for either primary or secondary extinction
•Something else

For the Dual Maxima project we require that measures be reduced to the format V, B-V, U-B, V-R and V-I.

This has the advantage that these two filter colours do not change dramatically during a cycle. Thus incorrect measures will stand out.

The traditional method of determining accuracy is to examine the difference between the observed and catalogue values of check stars.

Spread sheets to handle these measures are available.

Measures should also be submitted to the IDB in their own format

SOME SUGGESTED READING

Blocker, T 1995 A&A 297, 727 Stellar evolution of low and intermediate mass stars This discusses aspects of the frequency and number of '*helium flashes*' during the lives of Mira stars.

Hardie, R H 1962 Stars & Stellar Systems II Astronomical Techniques, P178 A very useful and practical description of converting UBV and other measures to the standard photometric system

Walker, Stan 2010 Variable Stars South Newsletter November 2010, High Precision UBVRI Transformations A simpler version of Hardie's method with some background by Tom Krajci

Tonry et al. ApJ, 2018, The ATLAS All-Sky Stellar Reference Catalog An interesting discussion of the work involved in setting up a reliable and highly accurate all sky system of stellar values.

SUMMARY

There are several important things about these stars which can be determined in a year or two of observing. These include:

- Whether there is a B-V colour difference between the two maxima.
- A full B-V light curve providing a more detailed view of temperature changes
- Radial velocity measures will provide a measures of radius variations during a cycle

On a longer time scale:

- V-R and V-I colours will be useful to future analysis
- In the wider Mira field do period alternations shown colour differences?
- Have the stars with period changes reverted to non-changing periods?
- Can we establish before and after colours for stars where periods change?

Other questions and answers will arise as more observational material is gathered

CONCLUSIONS

Conclusions:

This project conforms to the Variable Stars South goals of making observations which have lasting value but which also allow the discovery of important and publishable information about particular stars in a reasonable time.

One of the goals is to establish whether R Centauri is an unusual Mira apart from its dual maxima nature. In the determination of this the colours of the respective maxima are important as illustrated by the contrast between R Centauri and BH Crucis.

This presentation is, in effect attempting to rationalise what is now to some extent happening in the amateur LPV observing field. I have discussed some aspects of this with Mark Blackford, Richard Roberts and several professional astronomers. We had hoped for a discussion with Stella Kafka at Parkes - but the situation is now dramatically different.