



The Carina nebula is the subject of two articles in this newsletter. Stan Walker writes about eta Carinae, the brightest star (a binary) in this nebula; while Mark Blackford outlines a programme to study QZ Carinae, a quadruple system which was first shown to be a variable by Stan Walker and Brian Marino in 1972.

Image courtesy of ESO - The Carina Nebula by ESO/IDA/Danish 1.5 m/R. Gendler, J-E. Ovaldsen, C. Thöne, and C. Feron. Licensed under CC BY 4.0 via Wikimedia Commons

Contents

From the director - <i>Stan Walker</i>	2
NSV 7590: Resolution of a mystery - <i>Mati Morel</i>	4
UU Vul recovered - <i>Mati Morel</i>	6
Dual maxima Mira stars in colour - <i>Stan Walker</i>	8
V1369 Centauri after 500 days - <i>Stan Walker</i>	9
eta Carinae - <i>Stan Walker</i>	10
QZ Carinae project - <i>Mark Blackford, Ed Budding, Roger Butland and Stan Walker</i>	12
Observing Betelgeuse in the near IR - <i>Carl Knight</i>	16
About	28

From the Director – *Stan Walker*

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I often wondered what the director did and why such a simple task interfered with Tom's observing. Well, now I have found out. Apart from coping with our annual summer drought in New Zealand's Far North (our local region's official title) there's been preparations for two conferences at Tekapo - the fiftieth anniversary of the opening of Mt John Observatory and the RASNZ's own annual conference 6-8 May, 2015 and 8-10 May, respectively. Then Bob and I have been involved in organising aspects of Stella Kafka's - the new director of the AAVSO - visit to these conferences and talks at two other centres, Auckland and Wellington. And Variable Stars South needs to be seen at the Tekapo conferences so there are a variety of papers and other things being done by members.

In his final comment Tom mentioned help from other people and this has been formalised by including these in a '**management committee**' to spread the responsibilities and load a little - Phil Evans as editor, David O'Donnell, webmaster, Bob Evans, membership and treasurer are joined by David Moriarty and Mark Blackford, with Tom Richards, as the retired director, providing the benefit of his experience.

The Mt John Symposium is attracting an interesting variety of professional astronomers. I look forward to meeting many friends but also others whose papers I've read with interest. Combined with the RASNZ conference it will be quite a week. Details are on the RASNZ and Canterbury University websites. We have just completed a poster presentation covering many of our projects, binaries of various types, semi-regular stars and LPVs, DSLR and JH photometry, visual, bright Cepheids. Phil Evans handled the editing of a wide range of articles from project leaders - David Moriarty, Tom Richards, Mark Blackford, Alan Baldwin, Aline Homes, Carl Knight, Pauline Loader, Margaret Streamer and Stan Walker. The final version turned into a two board spread - equivalent to about 32 A4 pages.

There will be other papers presented at the RASNZ conference by David Moriarty with *V626 Sco* and *V775 Cen*, together with a paper on *Photometry and Astrophysical modelling of the Southern Eclipsing Binary BC Gru*, Neil Butterworth, Andrew Pearce and Stan Walker about *ST Puppis*, and Malcolm Locke on the *Periastron Passage of eta Carinae*. Another presentation is *The VSS Southern Semi-regulars Project* by Aline Homes, Pauline Loader, Stan Walker, Peter Williams, Neil Butterworth and Andrew Pearce.

At this stage five of our committee will be in Tekapo (David O'Driscoll and Phil Evans are unable to be present) and this will provide an opportunity to discuss matters of mutual interest with Stella. Amateur variable star astronomy is making another of its periodic leaps forward in techniques with the development of colour photometry with CCD and DSLR cameras and I think that we all need to become familiar with the advantages and pitfalls in doing this. AAVSO is heavily involved with encouraging spectroscopy but this is very much in the learning stages at present.

All of this attention given to electronic aspects of astronomy seems to be at the expense of the visual observers who were the backbone of these groups in earlier times. Perhaps we are creating the impression that unless you have a CCD camera, or can use DSLR in a similar manner, that we are not interested. Are we becoming too involved in our own personal projects. Many years ago a prominent professional visiting Auckland Observatory made the comment '**amateurs are much more familiar with the general astronomical scene - professionals are too specialised**'. So think a little about some of the projects other than your own and how we can persuade some of the armchair astronomers or deep sky photographers to look at variable stars.

This comment seems now to apply to local societies as well. Members can tell you about the research on Mars, the latest models of the universe and the monster telescope the Europeans are hoping to set up in Chile. But most of them are completely at sea when it comes to using a telescope unless it has goto features and a catalogue of deep sky pretty objects.

Bearing this in mind we need to extend our web site to become more helpful to the absolute beginners who have neither experience nor any real idea of what aspects of astronomy will interest them. A few

samples of various types of variable stars suited to different observing abilities and methods is proposed. It's also in our best interests to help local societies attract new members at all levels even though only a small percentage will become variable star observers.

Alan Baldwin and I have discussed a number of ideas to encourage more observers. This needs to involve more than one or two of our members. From an interest viewpoint it doesn't really matter which part of astronomy we promote - as long as more people get out there in the open under the sky. Some of these will become variable star observers, preferably visual observers initially. We should look seriously at a 'beginner's section' on our website, with a variety of possible types of star for these people to choose from. Perhaps some video material showing stars in action - on several occasions I showed groups a sequence of the dwarf nova, Z Chamaeleontis, going through an eclipse - very spectacular.

Many years ago Ron Welch persuaded me to look at an eclipse of XZ Sagittarii - up and down two magnitudes in an evening. There are other eclipsing stars with even greater ranges - you need a telescope for most but most people have them, or access to one - *so it's real* - like the first time I saw Saturn's rings.

Another thought is satellites in the windows after sunset and before sunrise. I have no idea what is around at the moment or if there are even any - given that most orbits are synchronous. But they used to fascinate my daughters. So some practical ideas would help our group and help Alan.

UNESCO has decided that will be the International Year of Light. This has been endorsed by the IAU and other groups have taken it up, although it's hard to find out much detail.



Anyone interested in following this up or suggesting a useful project? Whilst light at various wavelengths is critical to astronomy how do you promote this theme without becoming too complex. And since we do most of our observing at night the idea seems incongruous.

AAVSO is also promoting this so we might have some ideas after meeting with Stella.

We also have a project running on QZ Carinae. We would greatly appreciate a good longitude coverage - Mark Blackford reports on progress to date elsewhere in this issue and the challenge that this massive multiple system presents.

Summary

NSV 7590 is a lost variable, according to VSX. I have previously examined the circumstances of its discovery in a previous issue of the **VSS Newsletter** (2013-2, July/Aug. 2013, p11). Recent examination of Harvard patrol plates for August and September 1922, and visual observations of the field, reported after 1900, indicate that most probably NSV 7590 = CoD-22°11462.

Nakamura's 'new variable'

In Bulletin 31 (1922) of Kyoto University Observatory, Kaname Nakamura, observer at Kwasan Observatory, reported the discovery of a new variable star near M80. He was only 18 years of age. The position of the new star was given as (1900) $16^{\text{h}}11^{\text{m}}10^{\text{s}}$ $-22^{\circ}38'$. His estimates were reported thus:

1922 August	13	11.6v
	19	11.9v
	22	11.1v
September	13	10.4v

Note the long period of visibility. Modern spectral catalogues do not point to any star with a spectral signature consistent with a long plateau of visibility. There is no very red star in 2MASS, for instance, within 4' or 5' of the published position. Nakamura states that his star could not be found on Hagen's chart for R and S Sco, near M80 (Ser. I, 1899). He mentions no other published charts or sequences, published in the early 1900s. Hagen's chart was apparently his only reference.

Patrol plates from *DASCH*

A project is under way to scan the Harvard plate collection, and make it accessible online. The project is called *DASCH* (*Digital Access to a Sky Century @Harvard*). The latest Data Release can be searched and downloaded to one's PC. There may be problems with the quality of the plates, however. No attempt is made to remove plate flaws; it's a case of what-you-see is what-you-get. The particular patrol camera plates which interested me were the "am" series, numbers 1-16457, taken at Arequipa, Peru, between 1899 and 1923. The camera was fitted with a 1-inch Cooke portrait lens. The plates exposed in August and September 1922 often had star images which were trailed or distorted, reaching 11th magnitude only. Four or five plates covered the time period of interest. None of them showed any definite image at the stated position of NSV 7590. Two plates appear to bracket Nakamura's observation of August 22. These are detailed as follows:

am 16043 1922-08-20 00:12:29 UT <11.5p Not found
am 16044 1922-08-22 01:55:19 UT <11.5p Not found

The relevant portion of 'am 16044' is reproduced here as Fig. 1. This plate contains multiple images for bright stars, such as HD 146367 and HD 146457. The observer's log book describes the sky, at start of 45m exposure, as "very hazy", which probably accounts for the multiple images. The camera was apparently stopped, then restarted several times. The first three exposures were approximately 5-7mins long, the fourth of about 10min, and the final one of about 18min, reaching 11th mag.

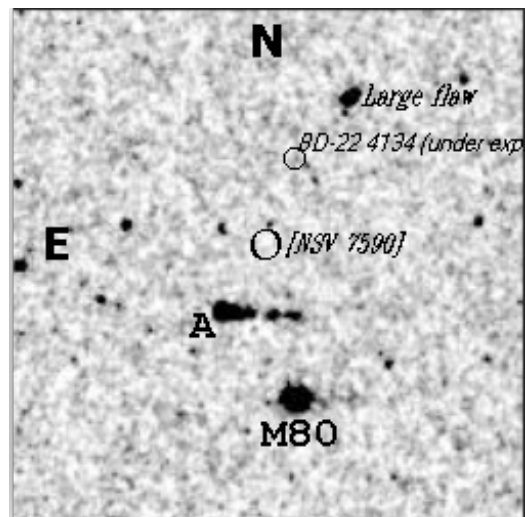


Figure 1. Extract from Harvard patrol plate **am 16044**, 1922 Aug. 21 (45m). Field size: 10' x 10'. M80 is the globular cluster. A = HD 146457, with multiple exposures (see text). The nominal position of NSV 7590 is shown as an open circle, while Star C = BD-22 4134 (red, 11.5p) barely registers on the plate; the random black dots are artifacts. They are not stars. North is at top, East is to left. Extracted image courtesy of DASCH system.

Discussion

Nakamura noted that his new variable was missing on Hagen's chart (for R & S Sco). However, I can point to other missing stars, CoD-22°11461 and 11462, both 11th mag, lying 44s RA due west and about 117" apart. These two stars, labelled **J** and **K** respectively on Fig. 2, have declinations which are both consistent with NSV 7590. Star K, the northern one, is brighter than its southern companion. Both had already been measured, in terms of position and magnitude, by Pogson and Wendell (at Harvard). Both of these authors published visual sequences for R & S Sco which included my stars J and K, while noting that neither had numbers in Hagen, i.e. missing from the Hagen chart. Apparently Nakamura failed to note these omissions, from the literature of his day. The following table summarizes the assigned magnitudes for J and K, from 1852 onwards.

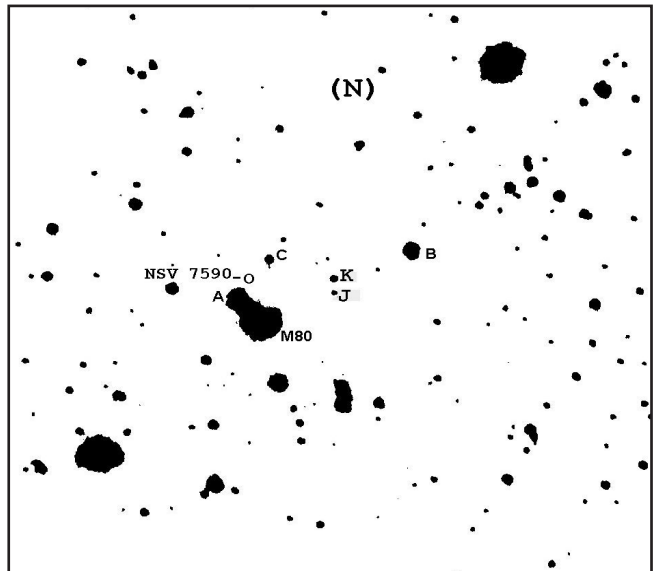


Figure 2. *Wide field view of the region of M80 & NSV 7590. It is not hard to see how a mistake in the new object's position could have arisen. Stars A-K-B lie on a straight line as seen through the telescope. J & K are missing on Hagen's chart. When plotting the position of his "new" star (K?), Nakamura may have placed it on the line joining A and C by mistake, leading to his RA being too far east by 44sec. A = HD 146457; B = HD 146175; C = BD-22°4134.*

Table 1. Magnitude Data for Missing Stars J and K

K = CoD-22°11462. (J2000) 16^h16^m23^s.67 -22°52'22.9"

J = CoD-22°11461. (J2000) 16^h16^m23^s.71 -22°54'20.2"

Mag	Band	Source	
Star K			
11.0	v	Chacornac (1852.5)/ Knott	1899MmRAS..52....1K
11.51	v	Schönfeld (Harvard reduction)	1912AnHar..64...55P
11.54	v	Wendell (Harvard photometry)	1902AnHar..37..145W
12.0	v	Pogson. N.	1908MmRAS..58....1P
11.239	V	ASAS-3. V_err 0.032.	
0.635	B-V	Tycho-2	
Star J			
12.09	v	Schönfeld (Harvard reduction)	1912AnHar..64...55P
11.87	v	Wendell (Harvard photometry)	1902AnHar..37..145W
12.0	v	Pogson, N.	1908MmRAS..58....1P
11.502	V	ASAS-3. V_err 0.032	
11.51	V	Harris & Racine	1974AJ.....79..472H
1.14	B-V	Harris & Racine	1974AJ.....79..472H
1.208	B-V	Tycho-2	
Neither J or K is variable according to ASAS-3 light curves.			
NSV 7590 (J2000) 16 ^h 17 ^m 08 ^s .0 -22°53'21"			

Conclusion

In proposing an identification for NSV 7590, I note the following:

- Nakamura was quite young, only 18 years of age, and just beginning to submit observations of variable stars to the AAVSO. One would think that his experience at this point was very limited.
- The Harvard patrol plate record is far from optimal. Figure 1, an extract from plate *am 16044*, shows how many flaws and artifacts one may encounter on one of the better plates, such as this one. Even so, a transient object of “normal” colour would surely have been recorded; there is no sign of a bright object near the published position, >11.5p.
- No very red objects lie in the field, according to the 2MASS catalogue, ruling out an unrecognized Mira variable.

Taking all the above into consideration, I propose that NSV 7590 is most likely a case of an erroneous position. The scatter in Nakamura’s observations may not be remarkable, given his lack of experience and the poor visual sequence used. It is not certain which field star Nakamura may have been watching, whether J or K. The brighter star (K) is more likely, in my opinion.

I propose that NSV 7590 = Star K = CoD-22°11462.

References

DASCH	2015	http://dasch.rc.fas.harvard.edu/	Digital Access to a Sky Century@Harvard
Hagen J.G.	1899	Atlas Stellarum Variabilium, Ser. I	
Harris W.E. & Racine R	1974	Astron. J. 79,472	
Morel M.	2013	VSS Newsletter 2013-2 (July 2013), p11	http://www.variablestarsouth.org/
Morel M.	2013	VSS Newsletter 2013-3 (Oct. 2013), p4	
Nakamura K.	1922	Kyoto University Observatory Bulletin No. 31	

UU Vul recovered - *Mati Morel*

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Summary

I report the recovery of the obscure variable UU Vul (hitherto lost), and it proves to be identical with EN Vul. The positional error which caused the problem can probably be explained.

Introduction

Wolf (1924) announced the discovery of nine new variables in Vulpecula, based on photographic observations. One entry in his list, 39.1923, has proved difficult to identify, probably due to an incorrect position as noted in the GCVS. Nothing exists at Wolf’s position, and it is certainly not HD 352712 (F0, 10.16V) as claimed at one time. 39.1923 has subsequently been named UU Vul.

Identification material

Wolf published no finder charts for his variables. However, at the foot of his table of observations he listed up to six neighbouring field stars for 39.1923, giving rough photographic magnitudes, as well as approximate positions and distances from the variable. These are as follows:

*16 *sp* 0.9' = 54"

*15 *sf* 0.7' = 42"

*12.5 *ssp* 1.4' = 84"

**14,13,12 *f* 4.3' - 4.7' = 258"-282"

This information permits a field map to be drawn (Figure 2). Stars 14,13 and 12 form a little group.

Wolf provides a semi-precise position for 39.1923, for ep. 1875. By searching Vulpecula I found that 39.1923 and nearby stars are a good match for another variable, EN Vul. See Figures 1 and 2.

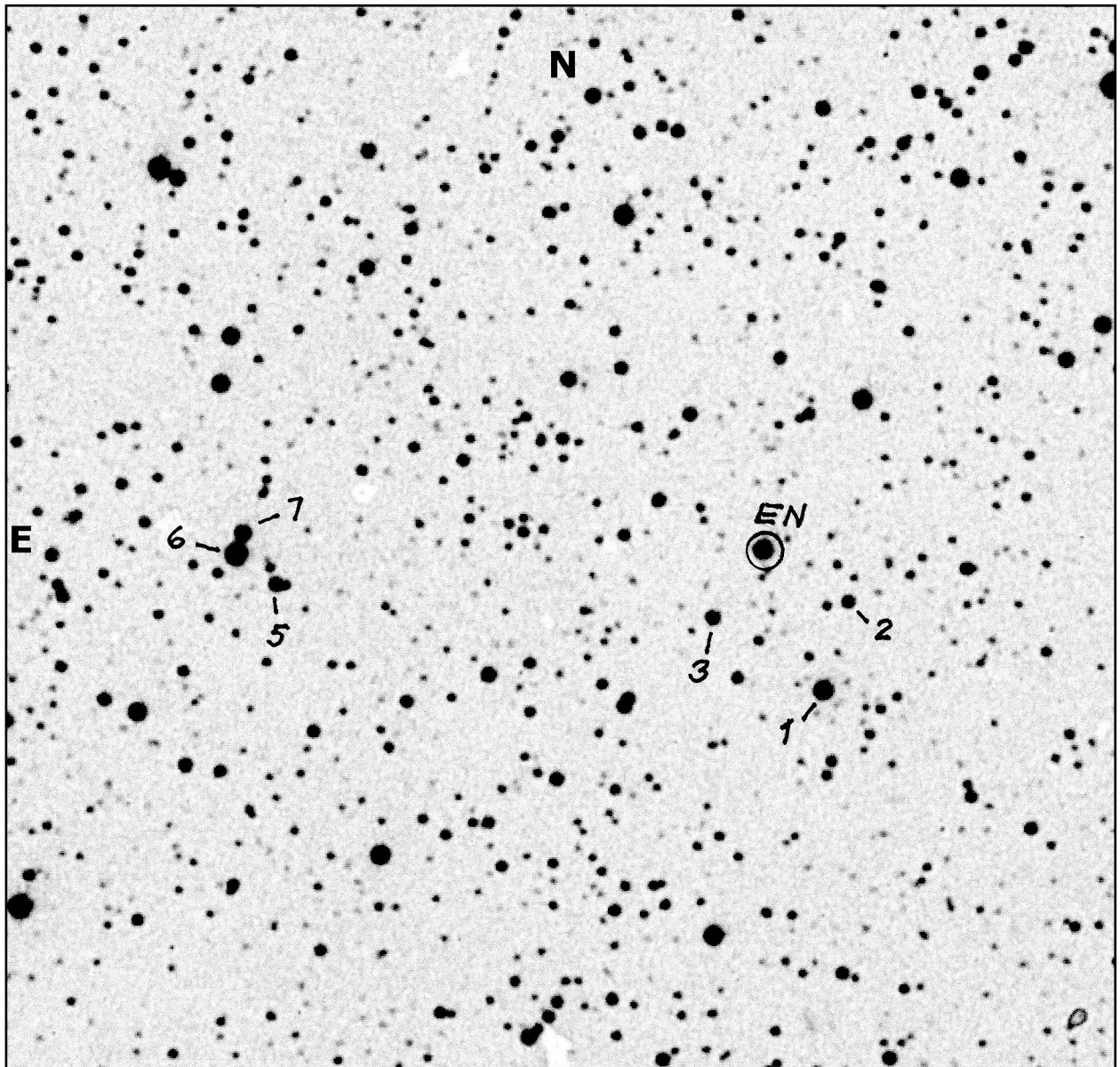


Figure 1. POSS1 blue plate, showing EN Vul and neighbouring stars 1-7 as listed in the text.

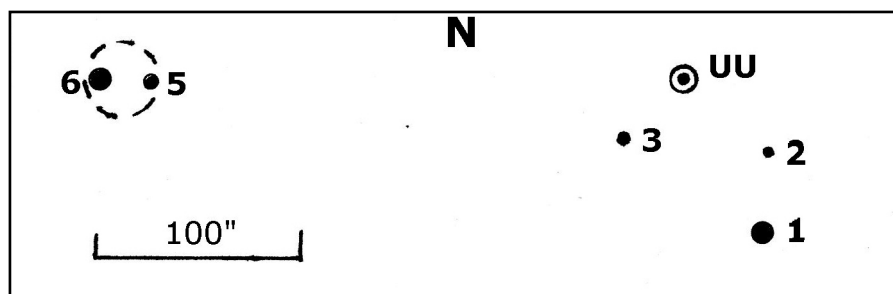


Figure 2. Plot of UU Vul and neighbouring stars according to Wolf (1924). The location of star 7 is not shown as its position is obscure. It is in the vicinity of 5 and 6 (Wolf 1924). Figures 1 and 2 are to the same scale

Wolf's position for UU Vul

There appears to have been an error in entering its position for 1875. The declination degree given by Wolf is $+20^\circ$, but this appears to be a typo. “ $+20$ ” may have been the southern limit of the zone in which he was working, or it may be the hour of RA (20^h), entered in the wrong column by mistake. Compare the 1875 positions of these two variables.

UU Vul	20 37 04.3	$+20^\circ 27' 01''$	Wolf (1924)
EN Vul	20 37 03.6	$+27^\circ 01' 59''$	Tycho-2 as converted.

Data for field stars around EN Vul = UU Vul

Star #	(J2000)	APASS		A2.0		Wolf (AN 221)		
		V	B-V	B	r	mp	r	
1	20 42 19.46 +27 27 32.6	13.12		13.8	80.8"	12.5	84"	
2	20 42 18.42 +27 28 20.0	15.25		15.7	51.9	16	54	
3	20 42 23.91 +27 28 12.6	14.51		15.1	44.3	15	42	
4	20 42 21.79 +27 28 47.5	12.27		13.2	--	13	--	EN Vul
5	20 42 41.27 +27 28 32.7	14.37		14.4	260	14	258	
6	20 42 42.91 +27 28 48.3	12.13	0.40	12.4	282	12	282	
7	20 42 42.56 +27 28 59.2	-----		14.0		13		

Notes

1. *V* rounded to two decimals, is taken from the APASS database of the AAVSO.
2. *B* is from USNO-A2.0, for comparison. Distance (*r*), in arcsec from the variable, from precise positions.
3. Wolf's rough data (*mp* and *r*) is shown for comparison.

Reference

Wolf, M. Astron. Nachrichten. 221,267,1924

Dual maxima Mira stars in colour - Stan Walker

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We are now getting a number of useful colour measures of these stars in BVRI with the odd JH measure as well. These are from the International Database of the AAVSO but the majority of those measures come from southern observers like Neil Butterworth, Giorgio di Scala and Mike Heald.

The first figure shows 2000 days of BH Crucis to 4 April 2015. This is a little under four cycles.

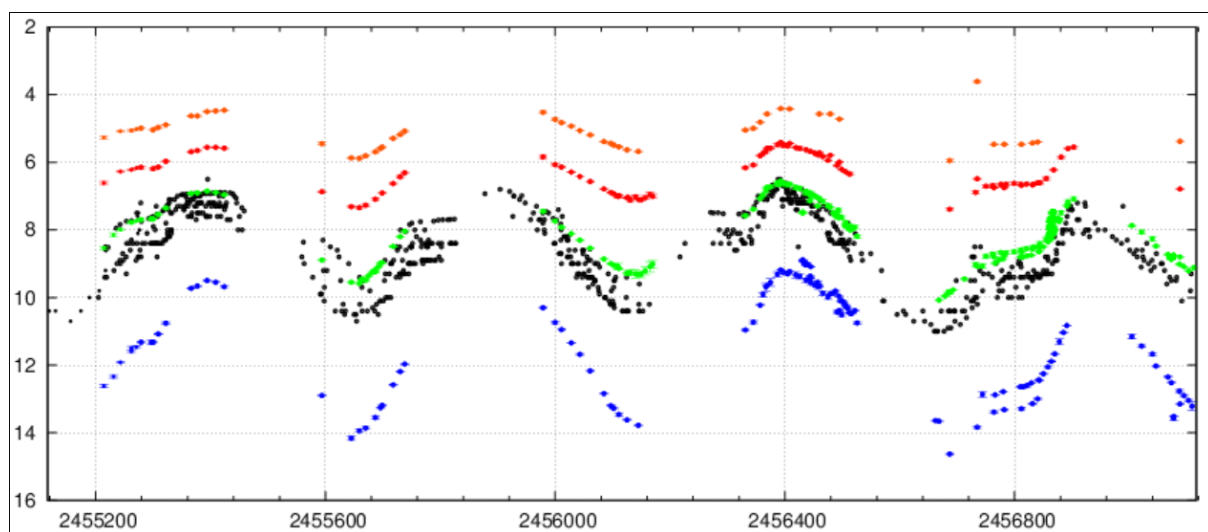


Figure 1. BH Crucis in BVRI with visual measures in black. It's noticeable how the amplitude lessens as the filter wavelength shortens - but the star is brighter in that filter.

It's now possible to produce good B-V values from these light curves and these show the same pattern as has been evident since the period decreased to 525 days. But this period is very erratic, the last four intervals of minima being 505, 504, 472 and 532 days between minima. The hump on the rise which is

the last vestige of the old first maximum is very pronounced at times.

This star would be very worthy of spectroscopy at 30 day intervals, perhaps more frequently on the rise around the time of the hump - but this is likely to occur when the star is close to the Sun later this year. The B-V colour varies from ~ 2.8 to ~ 4.6 . In the past both BH Crucis and R Centauri showed different colours in each of the maxima and spectroscopy may go some way to explaining why.

R Centauri's period continues to shorten but quite slowly - only a day or so per cycle with, once again, an erratic minimum. Minimum is the best period marker but has been missed in recent cycles.

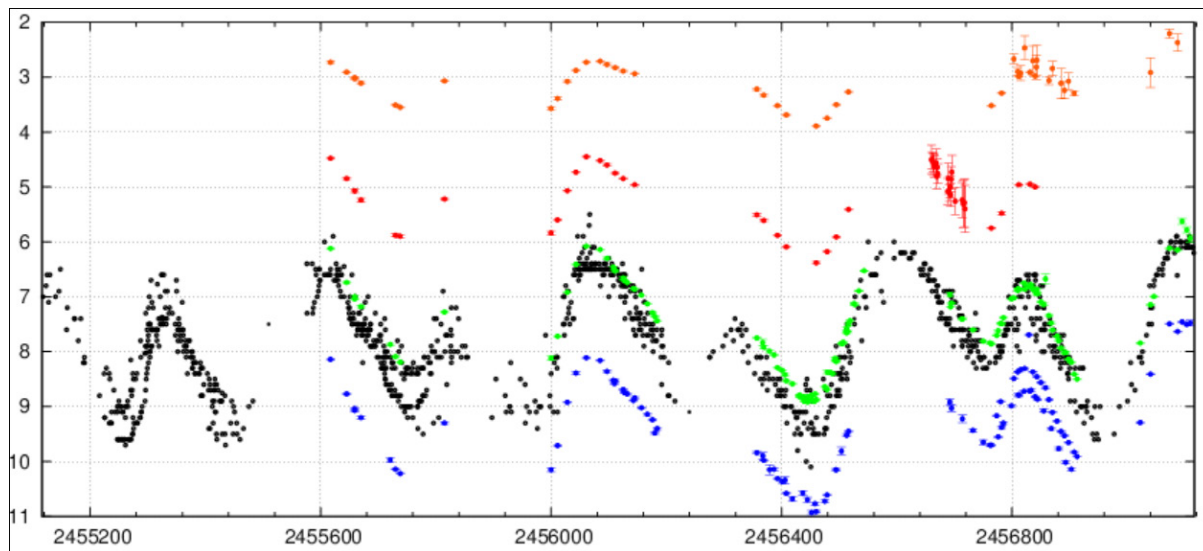


Figure 2. The last 2000 days of R Centauri similar to BH Crucis. The second maximum is very erratic both in amplitude and phase at present.

There are two other stars of this type which would also reward colour measures - R Normae and V415 Velorum. The latter, being quite faint, is a good target for CCD photometry but DSLR measures would be useful on the former.

The parallel curves in V are a result of different filter sensitivity and can easily be removed in subsequent analysis and modelling.

This is a long term project - it took almost 40 years to determine the colour and radius changes in BH Crucis - and this was one of the fastest period changes known in these stars. So it's an investment for the future - someone will look at these measures with gratitude in time!

V1369 Centauri after 500 days - Stan Walker

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Let's introduce this by showing measures from the International Database maintained by the AAVSO in Figure 1. Quite clearly this is a very slow nova. It was discovered by John Seach on 2 December, 2013, and after 488 days since maximum has only declined in V by 6.6 magnitudes.

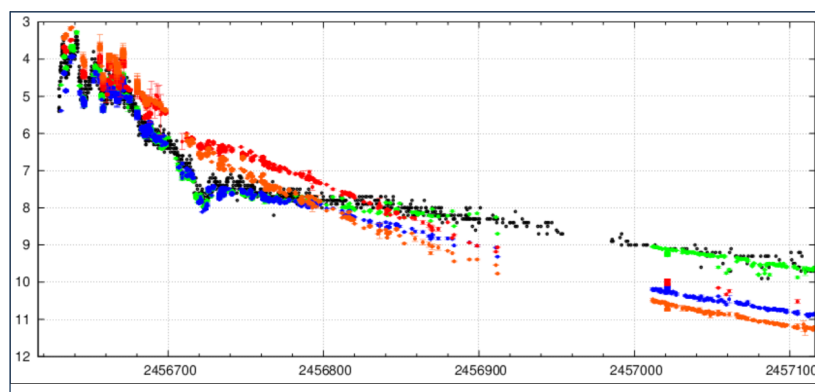


Figure 1. This shows the overall light curve to 4 April, 2015. Filter colours in the figure are as they look, except that I is orange and visual black. In the visual and V bands the decline has been almost linear since the recovery from the event of March, 2014, which seemed to have little effect on the R and I filters.

With a normal nova by now the orbital period would have been determined but I haven't seen this anywhere as yet. The ejected shell is still probably too bright and opaque but a run of 6-9 hours before the Sun gets too close might be interesting. Periods are mostly around 4-5 hours but can be a couple of hours to most of a day. It's probably best to use a B or V filter as this will exclude the longer wavelengths which in this type of monitoring merely add to the noise. Transformations for this are pointless

eta Carinae - Stan Walker

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Almost every visual variable star observer in the southern hemisphere has looked at eta Carinae at some stage. In Auckland we began doing this 50 years ago, in 1965. We're not looking at the surface of a star in visible wavelengths, but rather an expanding shell of gas, the Homunculus Nebula, ejected around 1840, when it became the second brightest star in our sky, even at a distance of probably 7500 light years, or 870 times that of Sirius. Using the inverse square law this suggests it was then about 10 million times brighter than the Sun. It's fainter now, but still the most luminous star system in our galaxy.

In the early days of the Auckland Observatory, from 1967 onward, flare stars were an exciting area for observations. We began visually but, with help from various people, had a UBV photometer up and running by 1969. Then our visual observers (who had been collaborating with Bruce Slee of CSIRO in a flare star project) began seeing flares everywhere, not just on the strange red dwarf stars like UV Ceti where they are most prominent - brightening by up to 5 magnitudes in seconds and fading away in a few tens of minutes. One of the flares, on EX Hydrae, turned out to be the 67 minute brightening of the system caused by the rotation of the white dwarf component of this dwarf nova system - allowing us to see accretion heating as its pole turned towards us.

The report of a flare on eta Carinae must surely have been wishful thinking. What we see visually, at a very large distance, subtends an angle of a few arcseconds. So the nebula is big. If the star suddenly brightened for some reason the visible brightening of the nebula would take hours, perhaps days, depending on the distance of various parts from the central pair. It takes over 5 hours for light from our Sun to reach the outer planets and this distance is trivial by comparison.

This suggested that it might be worth measuring eta. The illustration below shows measures from 1971 to 2002.

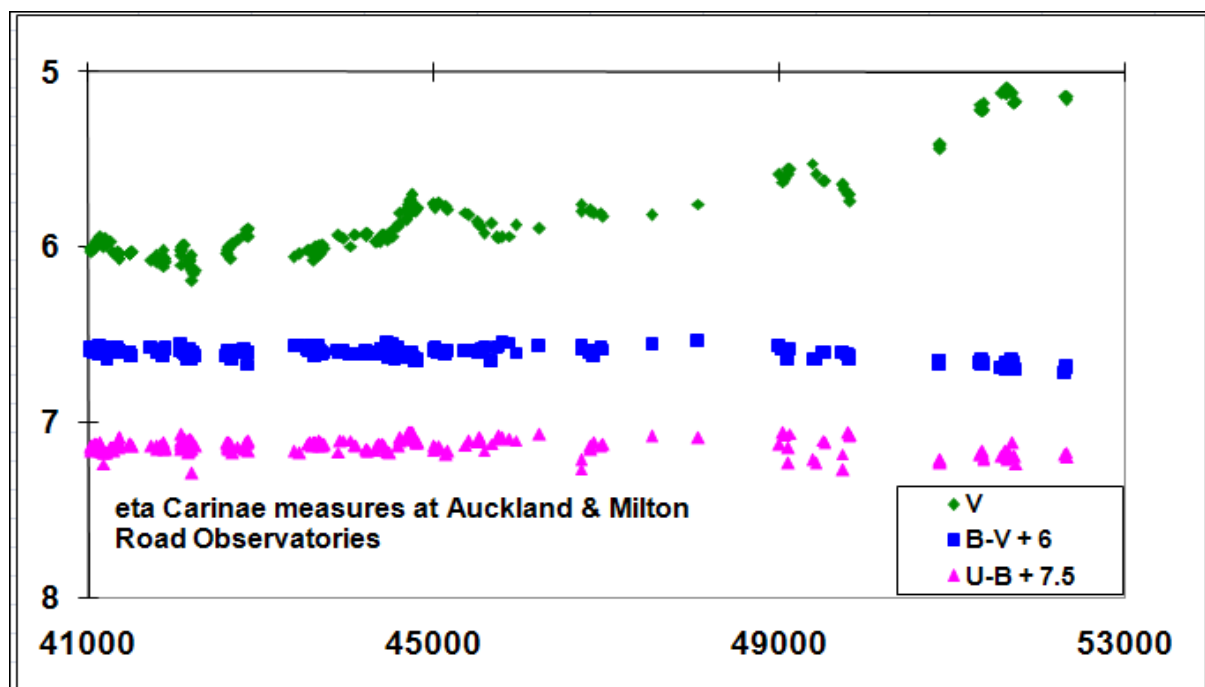


Figure 1. V magnitudes are shown in green, B-V in blue, but offset by 6 magnitudes, U-B in purple and offset by 7.5 magnitudes.

The central star is now known to be a massive binary pair with masses of about 90 and 30 solar masses and a period of ~ 5.5 years or ~ 2009 days. The orbit is eccentric with a periastron of ~ 2 AU at which time the system brightens. Despite the gaps some of these measures fit well to this period and epoch determined with the latest event - see Figure 2 - at $\sim$ JD (24)56868. Both B-V and U-B show the gradual cooling as the nebula expands.

The measures of Figure 2 show the improving techniques available to amateurs. Harry Williams' last measure was in February 2002, identifiable by the pale blue U points between the green of V and the blue of the B filter. This graph also shows measures by Bill Allen with Giorgio di Scala's few points in J and H. The brightest measure was at JD 2456868, 2014 July 29.

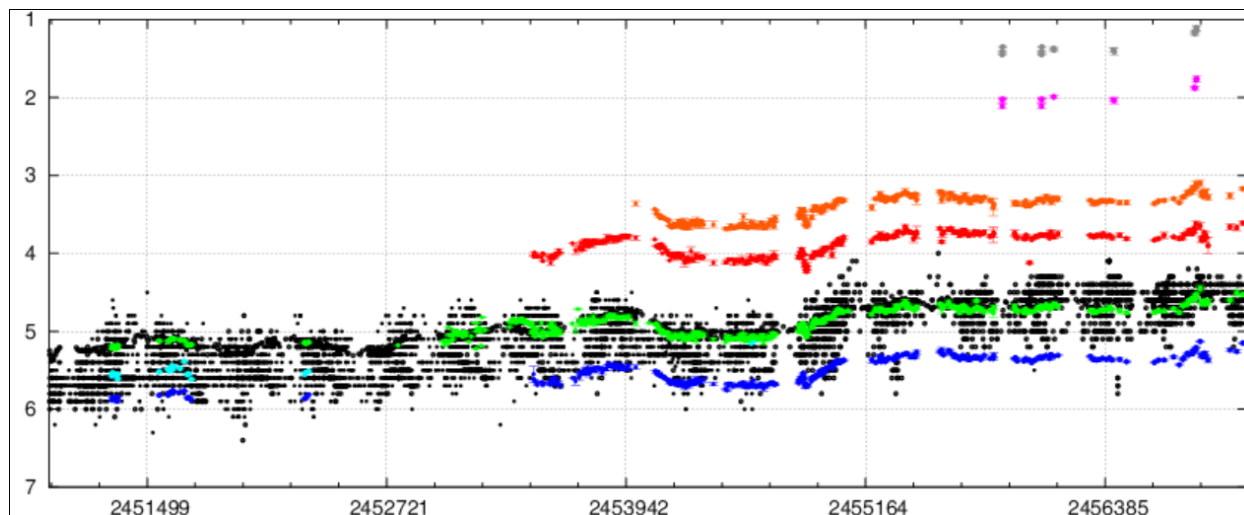


Figure 2. Measures from the International Database since JD 2451000 (August 1998). Note that this graph shows magnitudes through various filters but not colours. From top, H, J, I, R, V and B. The black points are visual.

Using the ephemeris $\text{JD (24)56868} + 2009$ days we might see similar brightenings in the V of Figure 1. Points around 42855 and 44734 look probable and 49094 is close. But the overall light curve suggests that irregular brightenings from other causes are also present - and with such massive stars anything is possible.

Since we were observing in the area we also measured the SR stars BO and RT Carinae. We began by using HD 93737 as a check star but this was obviously a low-amplitude variable - it's now V522 Carinae, an alpha Cygni star. HD 93131 is a WR7 Oc star and now is known to have an A type companion. This system is listed as NSV 18488 but this classification may be incorrect - many hot stars are so listed due to poor photometric transformations. About the only ordinary star in this area is our main comparison star, HD 93695, B5V, but even this foreground and unreddened star has made it to the NSV as 4978. The Hipparcos scatter of 0.007 rather belies that.



This is an image of the region around eta, the Homunculus Nebula. It illustrates the problems involved in measuring the brightness, particularly with CCD or DSLR cameras. These rely on a sky background as an annulus around the central object. Even this provides problems as the magnitude varies according to the focal plane aperture used. So conventional PEP is the best way of measuring the overall brightness changes. If you have access to an old pm type photometer or something like an SSP3 or 5 your measures on a monthly basis would be valuable.

Let's conclude with an interesting side effect. Brian Marino and I had been certain that one of the comparison stars for eta was variable. The new photometer proved this contention and led to our discovery of QZ Carinae, another massive binary system containing four stars with a combined mass of ~90 solar masses. Not quite in eta's class but still up there amongst the supersystems of our galaxy. Mark Blackford describes below the current project to understand this object.

QZ Carinae Project – Mark Blackford, Ed Budding, Roger Butland, and Stan Walker

Despite (or perhaps because of) its brightness and location within the eta Carinae nebula (Figure 1) the eclipsing binary QZ Carinae has received surprisingly scant attention.



Figure 1. Location of eta and QZ Carinae within the keyhole nebula complex.

Background

QZ Carinae lies within HD 93206, a quadruple system of massive stars arranged in two pairs: an eclipsing secondary pair with a period very close to 6 days (QZ Car) and a non-eclipsing primary pair with a period of about 21 days. These pairs orbit a common centre of gravity in ~25 to ~50 years, the actual period has yet to be conclusively determined (Figure 2).

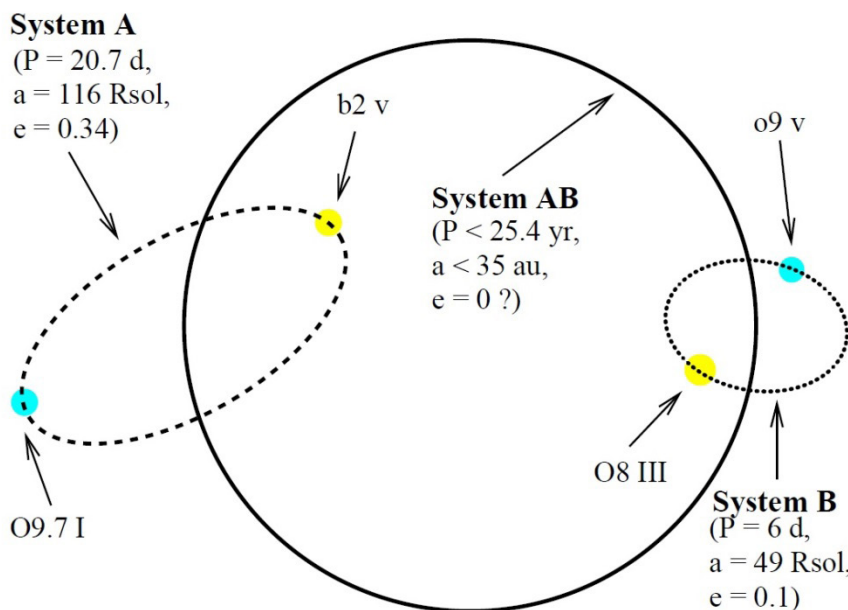


Figure 2. Schematic (not-to-scale) of multiple star HD 93206 containing the eclipsing binary QZ Car (System B). From Parkin et al. (2011).

The period of system A was determined by Mayer, et al (2001) to be 20.73596 days from spectroscopic radial velocity analysis. They used photometric Times of Minimum to determine the period of the eclipsing pair, system B, to be 5.9991 days.

The dimmer, less massive component of the non-eclipsing pair has so far not been detected in high resolution spectra. Lines of the brighter component of the eclipsing binary were detected in near-quadrature (ie near phase 0.25 and 0.75) spectra, while signatures of the fainter, but more massive component could be identified in only a few spectra. Lines of the primary component of the non-eclipsing pair and of both components of the eclipsing pair were found to be variable in position and strength. Thus interpretation of spectra is very complicated.

The long orbital period of system A and system B about their common center of gravity (system AB) has not been well determined. Mayer et al (2001) concluded the period might be of the order of several decades, possibly longer than the previous estimate by Leung et al (1979) of ~25 years. They suggest speckle interferometry may separate systems A and B, thereby helping to define the orbital elements and distance more precisely.

Eclipse times have been used to construct an O-C diagram (not shown) in which the light travel time effect induced by the orbit of system AB is clearly visible showing amplitude of ~0.6 days, or 14.4 hours. Further eclipse timings over coming years will help define the long orbit period.

There have been few published photometric measurements of this system. Walker and Marino (1972) published the first light curve with subsequent observations by Moffat (1977) and Mayer et al (2001). The best quality light curves to date are those of HIPPARCOS (ESA 1997) and ASAS3 (Pojmanski 2002) shown in Figure 3.

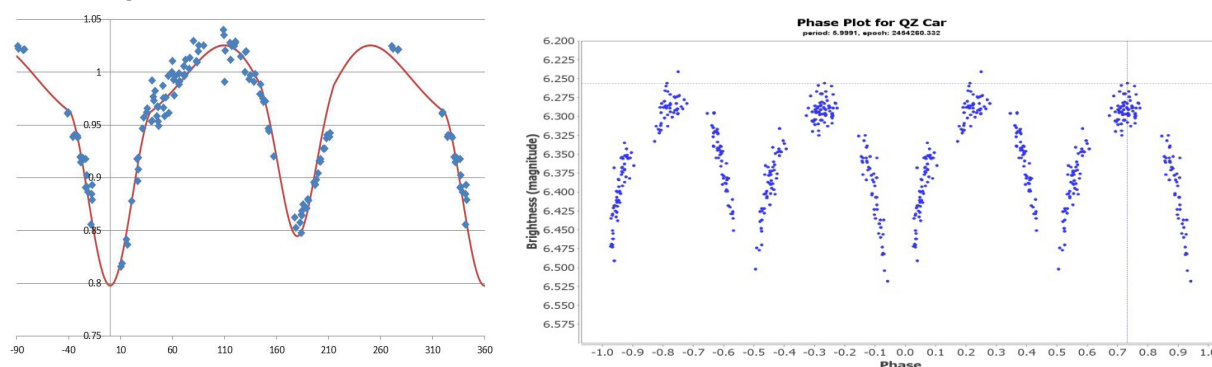


Figure 3. HIPPARCOS light curve (left) with model fitting (Ed Budding) and ASAS3 light curve from a subset of data collected between Dec 2004 and Nov 2009.

The AAVSO International Database contains 324 observations between 1985 and 2015, all before 2009 are visual estimates by 14 different individuals. Terry Bohlsen contributed CCD observations in 2009 and 2013, and Rolf Carstens reported CCD observations in late March 2015.

Ground based photometry is complicated by the location of QZ Carinae within the open cluster Collinder 228 in the Carina Nebula region, and by the near integer day period of the eclipsing pair. The duration of totality and the awkward orbital period make determination of mid-eclipse difficult. Eclipses are observable from only a relatively small band of longitudes each season. This band takes ~11.5 years to make one circuit of the Earth in longitude. It would, of course, be an ideal project for an Antarctic telescope. Alternatively, a collaboration of observers distributed longitudinally around the southern hemisphere could potentially collect a complete light curve in a single season.

In all published light curves there is a significant amount of scatter which suggests some source of photometric variability over and above mutual eclipses of stars in system B. Analysis of X-ray emissions from QZ Car (Parkin et al, 2011) suggests a complex interaction of stellar winds from each of the massive stars in the quadruple system, together with significant mass loss from the O8 III primary star of system B. It seems plausible that at least some of the photometric scatter is due to these interacting wind and mass loss processes.

Current QZ Carinae Project

A new campaign is underway to try to better understand this complex quadruple system. In December 2014 Ed Budding and Roger Butland used the HERCULES spectrograph on the 1m McLellan telescope at Mt John University Observatory to record high resolution spectra of QZ Car (Figure 4). Full analysis of these spectra is yet to be completed.

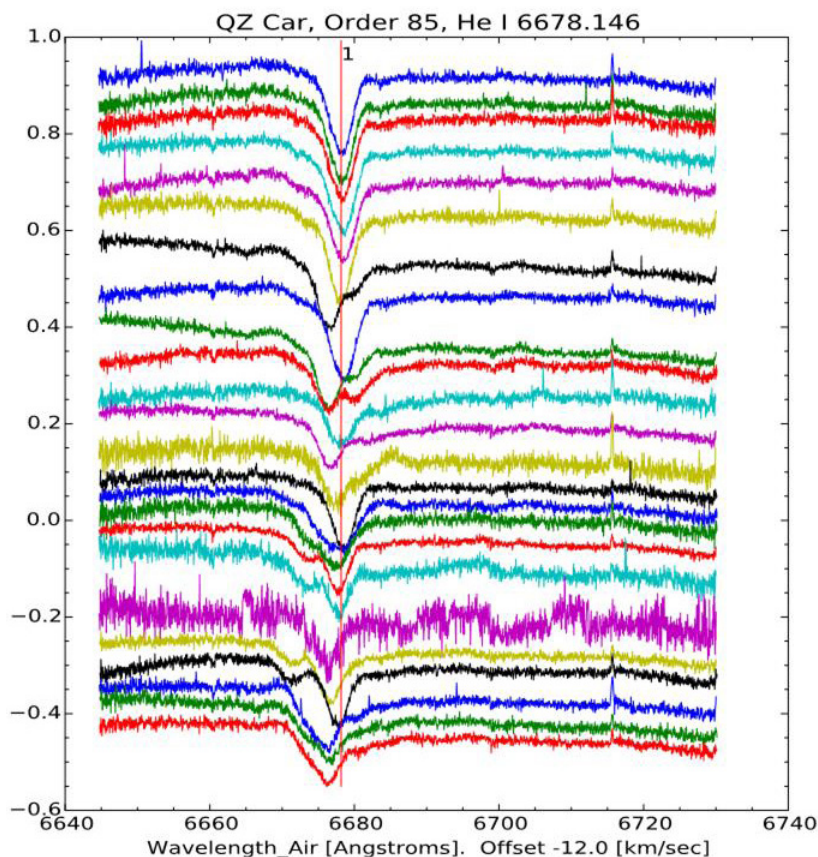


Figure 4. High resolution spectra showing variations in He I 6678.146 Å line due to orbital motion of both the non-eclipsing system A and eclipsing system B.

DSLR time series BVR photometry is being collected from Sydney, NSW (Mark Blackford) and CCD snapshot BVRI photometry is being collected by AAVSO Bright Star Monitor telescopes in Ellinbank, Vic (Peter Nelson) and Perth, WA (Greg Bolt). Figure 5 shows the combined V light curve from these observers from November 2014 through to early April 2015.

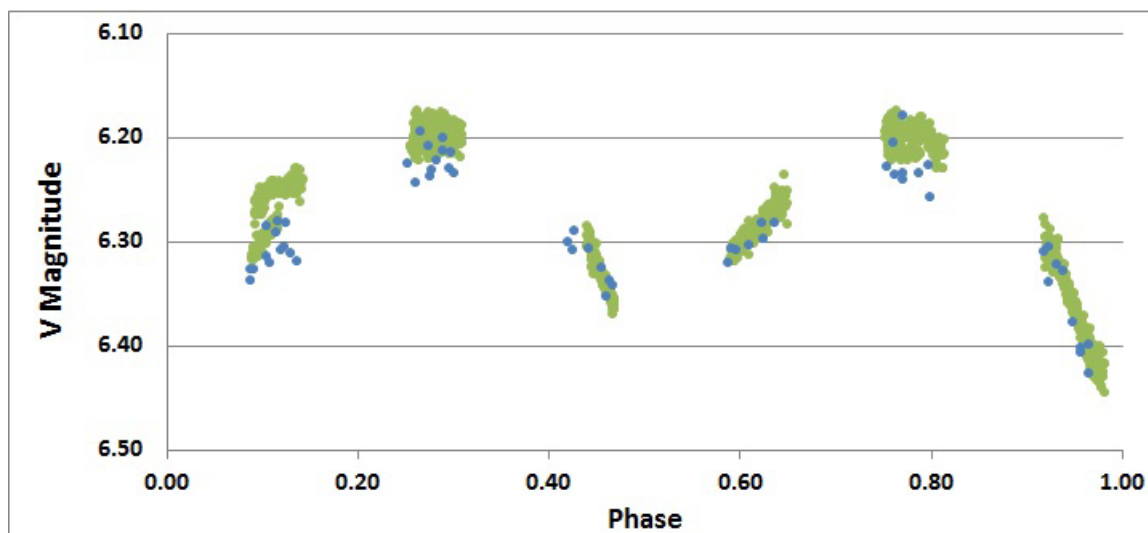


Figure 5. DSLR time series (green circles) and CCD snapshot (blue circles) photometry from the 2014/2015 observing season.

Almost exactly the same phase range is covered every sixth night; however magnitude does vary on a different timescale due to some intrinsic variability in the quadruple system. This can be clearly seen at phase 0.1 where two time series recorded 36 days apart are offset by about 0.04 magnitude.

A third AAVSO Bright Star Monitor telescope in Argentina, soon to be brought on line, will help fill in some of the phase gaps. Stan Walker has been corresponding with Brian Fraser in South Africa and we are hopeful he can provide some photometry in the near future. We would welcome additional observers in the mid Pacific and mid Indian oceans.

Photometry will continue for the remainder of the current season and potentially for several years to come.

John Eldridge (The University of Auckland) is interested in applying his Binary Population and Spectral Synthesis code (BPASS) to the QZ Car quadruple system. Below is his preliminary assessment of the system from published data (private communication):

“So the models I refer to here are my binary stellar evolution calculations (bpass.auckland.ac.nz). They predict how the stars appear over time and they evolve. What is useful here is that there are 4 stars which I can constrain or assume they must have similar ages. In fact when you do the comparison it turns out that their ages are around 4 to 5 Myrs. Most of the stars are on the main-sequence except for B1 (the more luminous star in system B) which is a very interesting object. There is also evidence that rotational mixing is required to explain the stars in binary A although I’d need better masses to know for certain.

So the B1 component that really interests me as this star is evolved off the main sequence and in a key evolutionary phase that we know very little about. My evolution models indicate that it’s mostly a helium star with a thin shell of hydrogen on the surface. Looking at some of the papers that do have spectra the HeII 4686Å line looks very interesting and its breadth/shape is very Wolf-Rayet like however there also appears to be an overlapping absorption component so it’s difficult to tell.

..... this really is quite a special binary of binaries! It really does provide quite unique constraints on stellar physics.”

Our recent high resolution spectra and photometry may help answer some of the outstanding questions concerning this complex quadruple system.

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Observing Betelgeuse in the near IR - *Carl Knight*

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Abstract

Betelgeuse is highly evolved red supergiant with multiple modes of pulsation and variability in V. With a surface temperature around 3000 K its peak emission lies in the near infra-red (IR). Some features, such as its large convective cells, are only visible in near IR. It is a candidate for the next type II supernova in our neighbourhood. It has attracted considerable professional interest, but with a V magnitude brighter than 0.5, J magnitude brighter than -2.99 and H brighter than -3.99, it is much too bright for professional observatories. In this paper the case is made for amateur photometric observations, particularly in the J and H near IR bands.

Introduction

The material presented here was originally a presentation made for the Phoenix Astronomical Society's Stardate 2015 event. The figures are taken from the slides used in that presentation. As such they are only suitable for electronic formats or colour printing.

Spectral class

Betelgeuse is a spectral class M2 Iab¹ supergiant with a spectrum dominated by molecular bands, particularly titanium oxide (TiO) (Inglis 2003). It is a cool, bright, and highly evolved star hence its position on the H-R diagram in Figure 1.

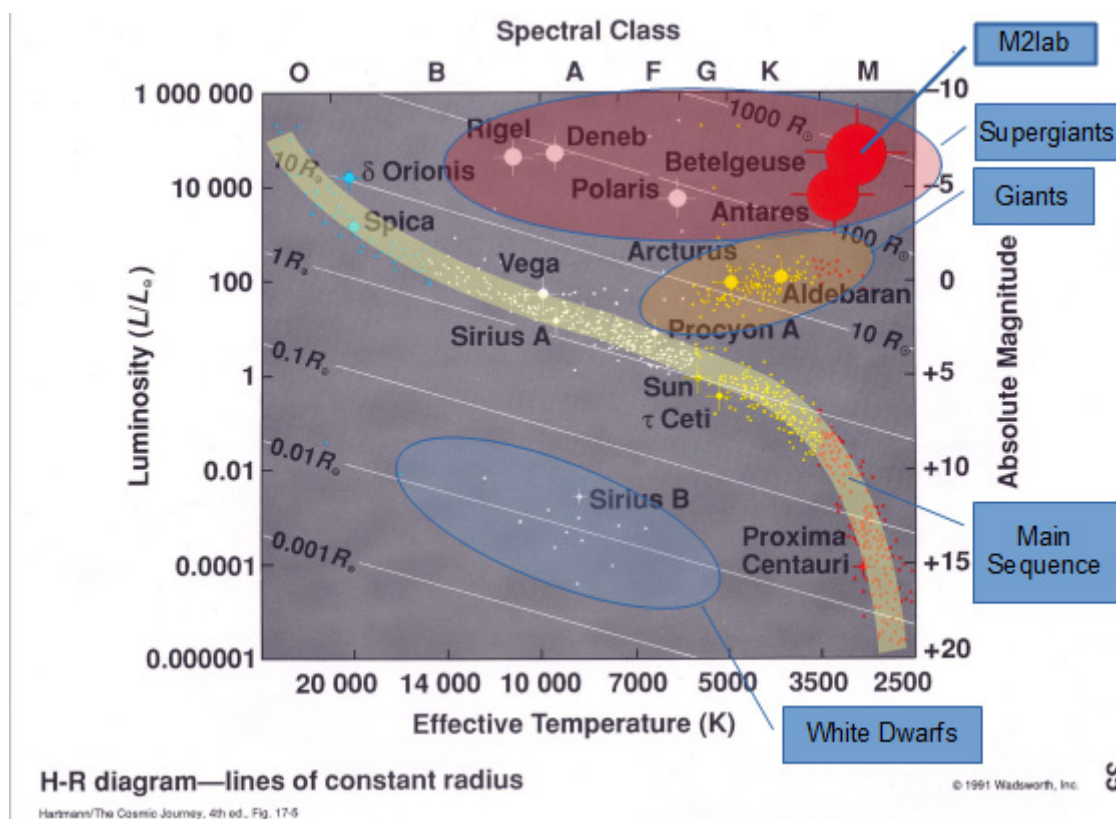


Figure 1: Betelgeuse in the HR diagram

¹ M stars are cool (in stellar terms). M2 is cooler than M1. The Roman numeral I indicates its luminosity class, in Betelgeuse's case, supergiant. The ab is an extension from Yerkes Morgan-Keenan (MK) spectral classification giving Iab for intermediate luminous supergiants (cf Inglis 2003; Morgan & Keenan 1973).

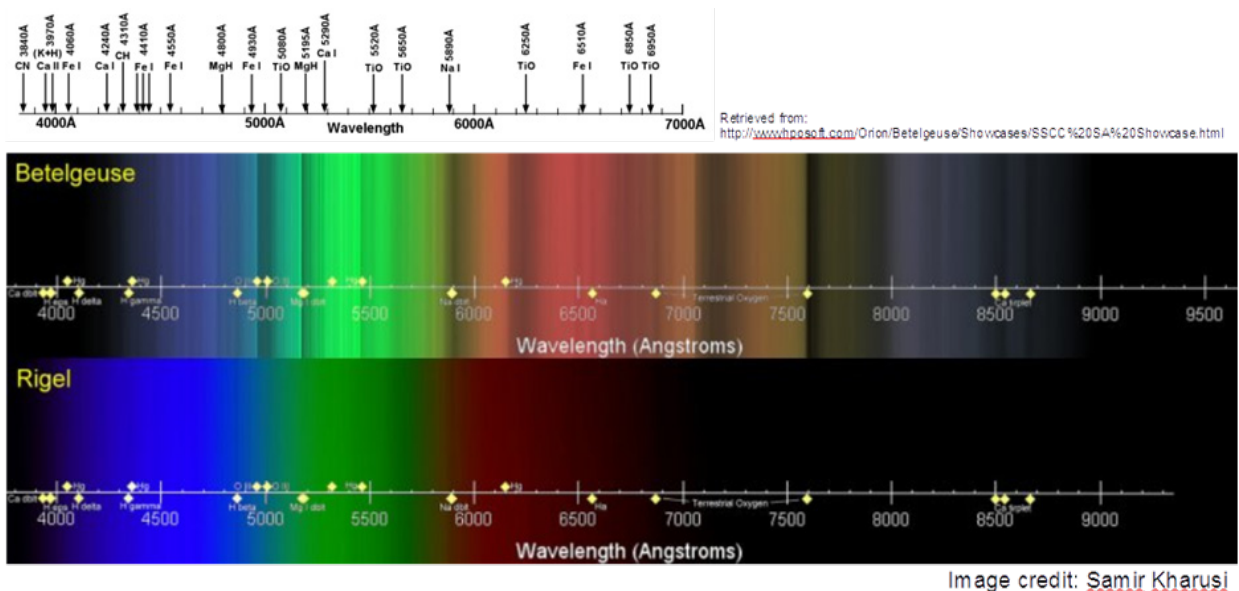


Figure 2. Comparison of Betelgeuse and Rigel Spectra

In Figure 2 the grid above the spectrum of Betelgeuse is roughly aligned with wavelength, and clearly indicates the atoms and molecules contributing the absorption features between 4000 Å and 7000 Å. Compare the busy spectrum of Betelgeuse with the largely uncluttered spectrum of Rigel. Rigel is far hotter with a spectral classification of B8 Ia), corresponding to a hot blue-white supergiant with a surface temperature of ~20,000 K, far too hot for the existence of molecules such as those found in the atmosphere of Betelgeuse. The only absorption lines in the spectrum of Rigel are those of neutral He and H (Inglis 2003).

Peak emission

As a black body with a peak temperature of close to 3000 K Betelgeuse's peak emission is in the near IR.

It is not the brightest star in Orion in V. But it is easily the brightest in peak magnitude. Currently (early 2015) it is ~3.0 in J and ~4.1 in H (AAVSO International Database Alf Ori). Lobel and Dupree (2000) refer to it as "...the brightest star in Orion" presumably for this reason.

By way of comparison, from the author's location in 12 months from January 2015, Venus' peak apparent magnitude will be ~-4.69 (NASA JPL HORIZONS Web-Interface 2015a). Jupiter's peak apparent magnitude will be ~-2.57 (NASA JPL HORIZONS Web-Interface 2015b). Given those magnitudes, Jupiter at its brightest is less bright visually than Betelgeuse is in J and Venus visually is around a half magnitude brighter than Betelgeuse is in H.

Issues with scale and distance.

Size and distance scales for Betelgeuse are not well understood with a variety of estimates in the literature. There are issues with the calculated distance and hence of size. Harper et al. (2008) discusses the various parallax angles determined for it:

"Prior to the Hipparcos Catalogue the most up-to-date published parallax for Betelgeuse was $\pi = 9.8 \pm 4.7$ mas ($d \sim 102$ pc [parsec] [~332ly]) from the Fourth Edition of the Yale Trigonometric Parallaxes [Yale Catalogue of Trigonometric Stellar Parallaxes] (van Altena et al., 1995), while the Hipparcos Input Catalogue, Version 2 (ESA 1993) gives a trigonometric parallax of $\pi = 5 \pm 4$ mas ($d \sim 200$ pc [~652ly])."

Gray (2000) surmises that: "... [a]lthough this [Hipparcos] is a considerable improvement over previous measurements, this star [Betelgeuse] has significant surface features that vary with time, possibly altering the photometric centroid of the Hipparcos images and compromising the parallax study."

The Hipparcos Catalogue value yielded a distance of $103 \pm 30 \text{ pc}$ ($\sim 335.78 \text{ ly}$). Using the VLA radio telescopes, Harper et al (2008) obtained a radio position for Betelgeuse that called the accuracy of the Hipparcos parallax into question. Re-examining the Hipparcos data, they arrived at a revised distance of 131 pc (427 ly) and combining it with the VLA estimate of closer to 250 pc ($\sim 815 \text{ ly}$), they derived a new distance of 200 pc ($\sim 652 \text{ ly}$), see Table 1.

Who	When	Distance
ESA (Hipparcos Input Catalogue version 2)	1993	$\sim 652 \text{ ly}$
Yale Catalogue of Trigonometric Stellar Parallaxes	1995	$\sim 332 \text{ ly}$
ESA Hipparcos Catalogue	1997	$\sim 336 \text{ ly}$
Harper et al. (2008) revised Hipparcos	2008	$\sim 427 \text{ ly}$
Harper et al. (2008) VLA	2008	$\sim 815 \text{ ly}$
Harper et al. (2008) conclusion	2008	$\sim 652 \text{ ly}$

Table 1. Distances derived for Betelgeuse from Harper et al. (2008)

Evolution

While Betelgeuse is a red supergiant and nearing the end of its days, it is only 6-10 million years old (cf Kaler 2014; Dolan et al 2014).

How fast is this evolution? Chinese astronomers have access to two millennia of naked eye observations. A first century record of standard star colours describes Sirius as white, Antares as red, Betelgeuse as yellow, and Bellatrix as blue (as reported in New Scientist 1981 October). Any modern observer would agree with the colours assigned to Sirius, Antares and Bellatrix, but not Betelgeuse. This may suggest that it has evolved from a yellow supergiant to the red supergiant we see today in the last 2000 years.

Over its lifetime the core of Betelgeuse has changed from burning H to He to burning He to carbon (C) and oxygen (O) with H burning in a shell further out. The increased temperature and output of the core caused the outer layers to expand into the red supergiant we see today (cf Arnett 1996 §8; Inglis 2003 §3.9).

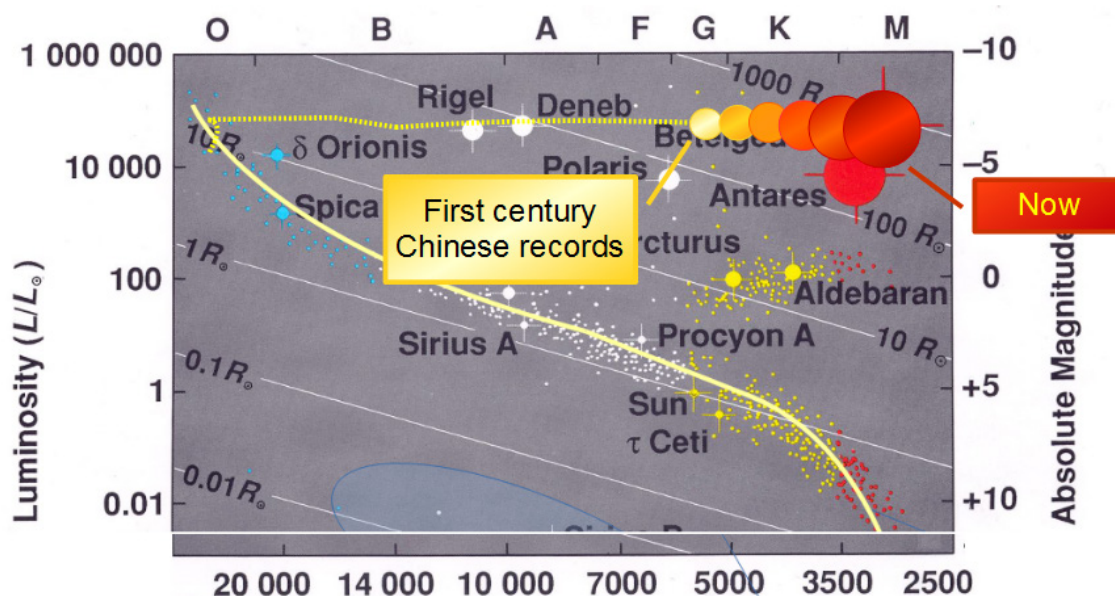


Figure 3. Possible Evolutionary Track for Betelgeuse

Dolan et al (2014) have modelled the evolution of Betelgeuse, using existing observable features (visible historic mass loss, current mass loss, temperature, estimates of current mass, etc), working both backwards in time to derive a progenitor mass and forward to make predictions about the path it is most likely to take. They suggest a progenitor mass of $19\text{-}20 M_{\odot}$. The evolutionary track they derive looks something like the dashed yellow trace² in Figure 3. They suggest Betelgeuse was on the main sequence as a spec-

² The author's artistic license should not be taken to represent the accuracy of the work of Dolan et al. (2014).

tral class O³ star. On the main sequence, it burned H to He via the carbon-nitrogen-oxygen (CNO) cycle. It rapidly evolved off the main sequence maintaining almost constant luminosity – as it has evolved, the output of its core has increased. Betelgeuse expanded and its surface temperature cooled as its diameter grew. Correspondingly the surface area from which it emits light increased enabling it to change to cooler colours and yet maintain a relatively static luminosity.

Variability

Pulsation

The diameter of Betelgeuse is changing enormously. As a variable star, it is classified as SRc (cf AAVSO VSX 2015a) – a semi-regular pulsating red supergiant star. If it were to be put at the centre of the solar system its diameter would vary between the orbits of Mars and Jupiter. It exhibits a main period of 2335 days with additional periods of 300 and 150 days (cf Kaler 2014; Townes et al 2009). The 2335 day period is likely not due to pulsation but may be a sunspot cycle much like that of the Sun (Turner 2015). The mechanism of pulsation is thermal instability (Kaler 2014). When Betelgeuse contracts, its atmosphere becomes more dense and traps more radiation. This trapped radiation causes the temperature to rise and the star to expand. As it expands, its atmosphere becomes less dense, heat can escape more easily and so it cools, and as a result of cooling it contracts.

Spectral classification

Betelgeuse changes colour and temperature as it pulsates. As a result it cycles through hotter and colder spectral classifications. It goes from an M1 to M2 Iab to a cooler M2 Ibe/M3 Ib (AAVSO VSX 2015a / Moncrieff et al 2011 Table 2 “Sp Type”) – in the case of M2 Ibe, this indicates a supergiant less luminous than Ia with emission lines present (cf Morgan & Keenan 1973)⁴. Betelgeuse changing in this manner is indicative of the change in density and temperature of its outer photosphere between minimum and maximum radius.

Radial velocity

Moncrieff et al. (2011) showed using observations from the AAVSO International Database that “...*α Ori reaches its latest spectral type [M3 Ib as discussed above] and lowest luminosity near light minimum*”. Interestingly, and in line with Goldberg (1984), Moncrieff et al also found “...*[r]adial velocity maximum (greatest photospheric recession) is reached near light maximum and the star reaches mean radial velocity (indicative of smallest dimensions) near light phase 0.27.*” This indicates that the radial velocity is anti-phased to the light curve with a relatively small offset in phase.

The star’s erratic period and outburst events have been discussed by Goldberg (1984) who studied 60 years of data for Betelgeuse, systematically examining the relationship between light curve periodicity and radial velocities. While the generalisation of Moncrieff et al. (2011) and Sanford (1933) (as cited in Goldberg 1984) is that “...*the radial velocity and brightness may [be] anti-correlated...*” (Goldberg 1984; cf Turner et al 2013 §3), the relationship is punctuated by events where both may increase or decrease together briefly. Such an event occurred in December 1925. The radial velocity was in decline and the brightness had increased by 0.2 magnitudes in the same time frame. The northern spring and summer interrupted for nearly 200 days and when observations resumed both the radial velocity and brightness were found to be in steep decline. Goldberg postulated that:

“...it seems equally plausible that the sharp drop in radial velocity was accompanied by an initial brightening followed by rapid fading. It is as though gaseous matter were ejected from the star, then diffused outward and condensed into grains, which became optically thick at visible wavelengths.”

Goldberg suggested that there have been other points (eg 1941/42 and others) around the minimum of the mean radial velocity where a steep decline in radial velocity followed by brightening has then been

³ This is the author’s deduction based upon Dolan et al (2014) estimates of temperature and luminosity.

⁴ Absorption lines dominate where the medium is more dense (relatively speaking) and therefore more filtering of line of sight light takes place. The electrons in atoms absorb photons of the characteristic energy required to move them from one lower energy orbital to one of higher energy. Emission lines dominate where the medium is rare and sufficient light escapes to weaken the absorption lines (see Robinson 2007 pp 69-83;93-105).

accompanied by a sudden fall in brightness. Goldberg suggested, “... *that major disturbances in the atmosphere are likely to occur during the year or two following the minimum in the six-year radial-velocity curve.*”

Spectral line depth and blending

Gray (2000) examined variation in the spectra of Betelgeuse over time. He compared spectral lines of Betelgeuse and M0 IIIa (AAVSO VSX 2015b) β Andromedae finding that while β Andromedae displayed sharp spectral lines (see Gray 2000 Fig 1), those of Betelgeuse were not as distinct and appeared blended. Rotation causes broadening of the spectral lines due to Doppler shift, but Gray argues that by itself rotation is insufficient to explain the blending found. He suggests that macro-turbulence, which introduces many more random velocity components, is responsible for the blending. This effectively causes a broadening of Doppler profiles such that the spectral lines blend.

Additionally Gray found that the spectral line depths alter over time (Gray 2000 Figs 3a-d are particularly illustrative) but otherwise the same lines are present. He found the lines shallowest near minimum brightness and deeper when the star is brighter, “... ie, variations in line depths are in phase with variations in brightness.” Effects similar to this might be seen where there is an early spectral type companion present. The comparatively bland spectra of the early spectral type companion weakens those of the cooler star outside of eclipse – i.e. maximum light. However, the lines of Betelgeuse are weakest at minimum light so the phenomena observed is not due to the presence of a companion (Gray 2000 §4) so another explanation is required

Gray’s hypothesis is:

“A disturbance rises through the outer envelope triggering an increase in continuous opacity. The opacity increase extends from below the lower photosphere upward through the line-forming region. The increase in opacity restricts the amount of light getting out, so the star dims. The increase in opacity weakens the spectral lines without distorting their profiles, as demanded by the spectroscopic observations presented above [Gray 2000 Figs. 3,5,6 and spectral line depths discussed above]. Further, an increase in continuous opacity weakens weaker lines more; stronger lines have to be brought down the saturation part of the curve of growth⁵, which means they change less.”

Gray’s discussion of the observations explained by this hypothesis is beyond the scope of this work. For the purposes of this discussion the spectral line profiles are found to vary in a non-linear manner in phase with the star’s brightness – adding to the many ways in which Betelgeuse is variable.

Phenomena visible in different wavelengths of light

Beginning at the photosphere, Kervella et al (2011) found that Betelgeuse has enormous convective cells exceeding its radius in size. These structures are visible in the infra-red and exist on time-scales of years. Superimposed on these enormous convective cells are smaller structures, discernible in visible wavelengths, which evolve on time scales of months. In visible wavelengths the larger convective structures are hidden – we will discuss the significance of this for observations and the light curve in due course.

Moving on to the chromosphere, UV observations (Lobel & Dupree 2000; Lobel et al 2003) show the asymmetric deformation of Betelgeuse’s chromosphere directly (Figure 4⁶).

Lobel et al (2003) took spectra at different offsets (yellow crosses in Figure 4) from Betelgeuse looking for emission lines that indicate the presence of the chromosphere, specifically lines indicating chromospheric temperatures. The temperature is ~3000 K at the top of Betelgeuse’s chromosphere. By way of comparison the top of the Sun’s chromosphere is ~20,000 K (Hathaway 2014). What they found in the case of Betelgeuse was the presence of “...*chromospheric plasma out to $40R_{\star}$...*” where it “...*must coexist with cool gas of the circumstellar dust envelope.*” Proportionally this is significantly different from the

⁵ The weakening of the lines in the spectra Gray presents is non-linear and instead is best scaled by a curve. The “saturation part of the curve of growth” is where the growth slows significantly (saturates).

⁶ Regarding Figure 4, the white arrows in the panels indicate north – so these must be aligned when comparing the individual images. The yellow curves to the right of each panel in Figure 4 are spectra from the HST Space Telescope Imaging Spectrograph (STIS). Specifically singly ionised iron (Fe II) at a wavelength of 2869Å (UV) (Lobel et al 2003 §2). The yellow rectangles indicate the STIS field of view and the yellow crosses in each panel indicate the offsets from Betelgeuse at which measurements were made (Lobel et al. 2003 §1).

Sun where the top of the chromosphere is a mere 2000 km above the photosphere (Hathaway 2014).

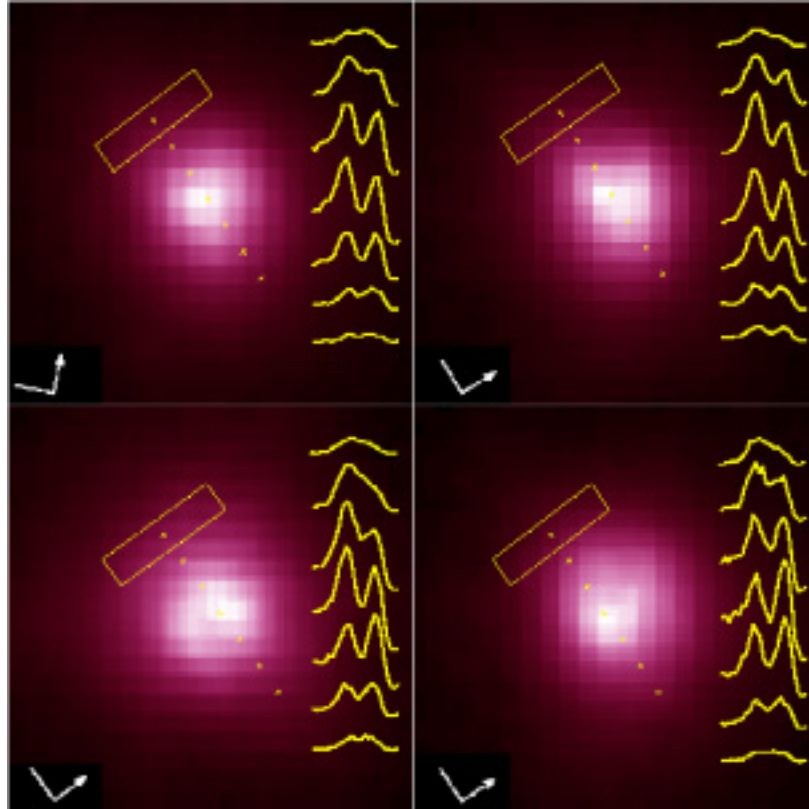


Figure 4. Hubble STIS UV observations (Lobel et al. 2003)

Kervella et al (2011) have examined the close circumstellar environment beyond the chromosphere, in particular the mass loss that makes the stellar boundary and its environment fuzzily defined at best. They describe it as having a “...relatively high degree of clumpiness...” indicating “...an inhomogeneous spatial distribution of the material lost by the star.”

To summarise, the star itself is deformed by massive convection cells; its chromosphere interacts with material lost by the star at significant distances, and that mass loss material is clumpy and inhomogeneous and found at vast distances from the star itself.

End game

As discussed, Hipparcos data have been called into question. ESA’s Gaia is not likely to improve matters because Betelgeuse is too bright for its instruments whose upper limit is magnitude 6 (see Michalik et al 2012). These distance derivation issues impact estimates of size and therefore mass.

Betelgeuse’s progenitor mass may have been as little as $11M_{\odot}$ or as great as $17M_{\odot}$ according to Kaler (2014). However, Dolan et al (2014) suggest the progenitor mass is $19\text{--}20M_{\odot}$. They also conclude that the onset of core He burning is relatively recent and that in approximately 100,000 years, Betelgeuse will commence C burning and go supernova shortly after that:

“ α Orionis will continue burning He, eventually core C burning will begin followed by core O burning and then core Si burning as it continues to increase in luminosity. We estimate that in a little less than 10^5 y, α Orionis will supernova, releasing 2.0×10^{53} erg in neutrinos along with 2.0×10^{51} erg in explosion kinetic energy (Smartt 2009) and leaving behind a neutron star of mass $\sim 1.5 M_{\odot}$.”

It is worth noting that the entire output from the expected 10Gy lifetime of the Sun is about 1.3×10^{51} erg (cf Cornell 2015). So the expected output of a Betelgeuse supernova exceeds this. Dolan et al (2014) conclude that:

“When this supernova explodes it will be closer than any known supernova observed to date,

and about 19 times closer than Kepler's supernova. Assuming it explodes as an average Type II supernova, the optical luminosity will be approximately -12.4, becoming brighter than the full moon. The X-ray and γ -ray luminosities may be considerable, though not enough to penetrate the Earth's atmosphere."

Why observe Betelgeuse?

Firstly, the author hopes to have established that Betelgeuse is a very interesting star with plenty of phenomena worthy of study.

Additionally, Hopkins (2014) notes strong interest among professional astronomers for regular observations of Betelgeuse due to the lack of coverage it receives – ironically it is too bright for much professional equipment. Dr Matthew Templeton, science director for the AAVSO further notes there have been “...209 papers about or mentioning Betelgeuse since 2009...” (Templeton, 2015) and that, “...professionals don't commonly have access to (or don't try to build) small aperture telescopes, which good photometry of Betelgeuse requires.”

Not only is the peak emission of a star like Betelgeuse in the near IR, but some key phenomena are only visible in the near IR and will likely modulate the light curve in those bands differently than in V. As we shall see shortly, these near IR data are largely absent from the likes of the AAVSO International Database.

Betelgeuse also seems to be undergoing rapid change. This is possibly the most important reason for observations, particularly in the near IR. Townes et al (2009) note that:

“ISI [Infrared Spatial Interferometer] measurements over the last 15 years clearly show a systematic change in the diameter of α Ori. This change may or may not be periodic; if it is, the period is likely rather long, perhaps a few decades.”

They showed that the angle subtended has changed from 56mas in 1993 to a minimum of 47mas in 2007/8 and, at the close of the period they examined, the angle subtended was 48mas. Interestingly enough, they note “...the modest known variations in luminosity are probably not simply related to size and the visible band photometric record of the AAVSO does not resemble the size variation.” In other words, the changes in size are not recognizably impacting the visual luminosity. Again making the gathering of near IR observations imperative, we do not know definitively how the near IR light curve might be affected by this behaviour.

Importantly, Turner et al (2013) suggest that due to the abundance of M supergiants like Betelgeuse, possibly “... ~100 times more common than Cepheids in galaxies...” and “... their high luminosities ($10^{4.5-5.5}L_{\odot}$)...”, M supergiants may be more useful as standard candles than Cepheids:

“The observations indicate that BC Cyg [M3.5 Ia SRc AAVSO VSX (2015c)] pulsates much like Cepheids, being hottest when it is smallest, 0.2 cycle before light maximum, and coolest when it is largest, half a cycle later, the radial velocity variations being a mirror image of the light variations with a small phase offset of +0.05 cycle. The photometric results for α Ori and TV Gem [10] show similar variations, suggesting that the dominant light variations in SRcs arise from pulsation.”

Such use of the IR period-luminosity (PL) relation for SRc variables has been made to determine distances to the Large Magellanic Cloud and M33 (Turner et al 2013). These efforts are hampered by the fact that “... the scatter in SRc PL relations is large [7, 8, 3], affecting their potential usage.” (Turner et al 2013)

Near IR results so far in context

In 2008, Arne Henden, then director of the AAVSO, brought an Optec SSP-4 J and H near IR photometer to New Zealand. This equipment was initially used by Stan Walker, current VSS director, who then passed it on elsewhere where it languished unused until the author received it via Ian Cooper, past Palmerston North Astronomical Society president, in early 2014. After cleaning and some 780 individual counts taken to determine extinction and transformation coefficients, it is doing useful work again.

The vast majority of work to date has been calibrating the instrument. Typical standard deviation (sd) measuring Betelgeuse is ± 0.02 magnitudes; if conditions allow the sd can be ± 0.005 or lower.

In Figure 5 the majority of the J and H observations are the author's. The absence of data from the author after the return of Orion from behind the Sun (onset of visual observations August 2014) but prior to November 2014 reflect the appalling spring weather in the rural Rangitikei. Getting up at 2am and even resorting to sleeping in the observatory did not avail suitable PEP observing opportunities.

J and H photometry was done on other nights and not submitted where the results proved to be too poor or where due to key indicators (below) observing was abandoned.

The author has now learned not to judge any particular night – beyond the obvious such as cloud obscuring the target, wind, etc – until seeing the numbers, as they have proven to be the only true indicators of what the conditions are for near IR observations. Early indicators are the sky counts and then J-H, if these hold steady during an observing run the results will inevitably be good despite what naked eye intuition might suggest.

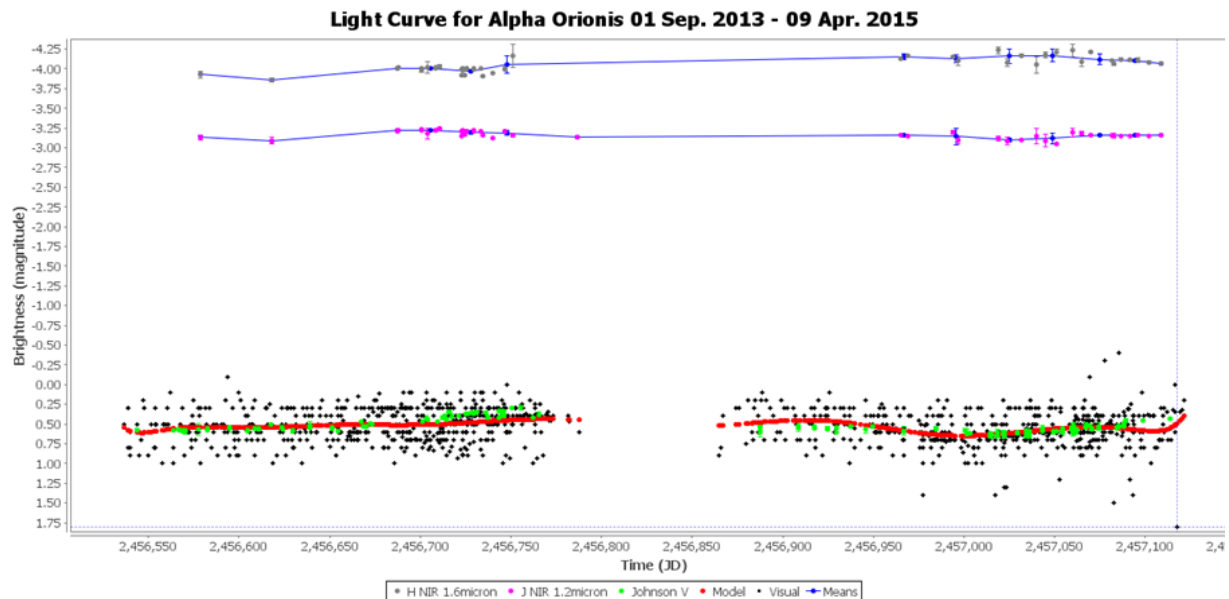


Figure 5. AAVSO International Database J light curve with 20 day average September 2013 - April 2015 (VStar).

Figure 5 shows what J and H band photometry there is in the AAVSO International Database with 20 day averages (blue traces) compared to the visual and Johnson V record.

To put the author's and others' near IR results in context, I examine the data available for visual and Johnson V in the AAVSO International Database over a longer arbitrary period.

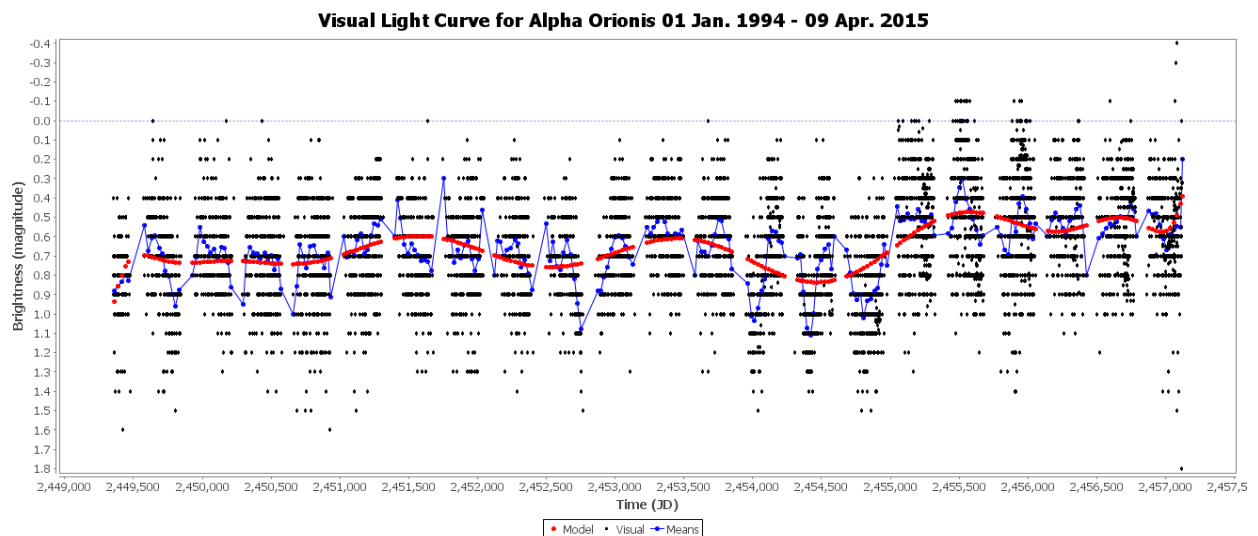


Figure 6. Visual, 25 day average and polynomial fit to average January 1994 - April 2015 (VStar).

The AAVSO visual data (Figure 6) clearly show shorter period variability superimposed upon a longer period variability. A 25 day average (blue trace) has been applied to the visual estimates and a 15th degree polynomial fit has been applied to the 25 day average (red) for illustrative purposes, as this clearly indicates the longer period in the data.

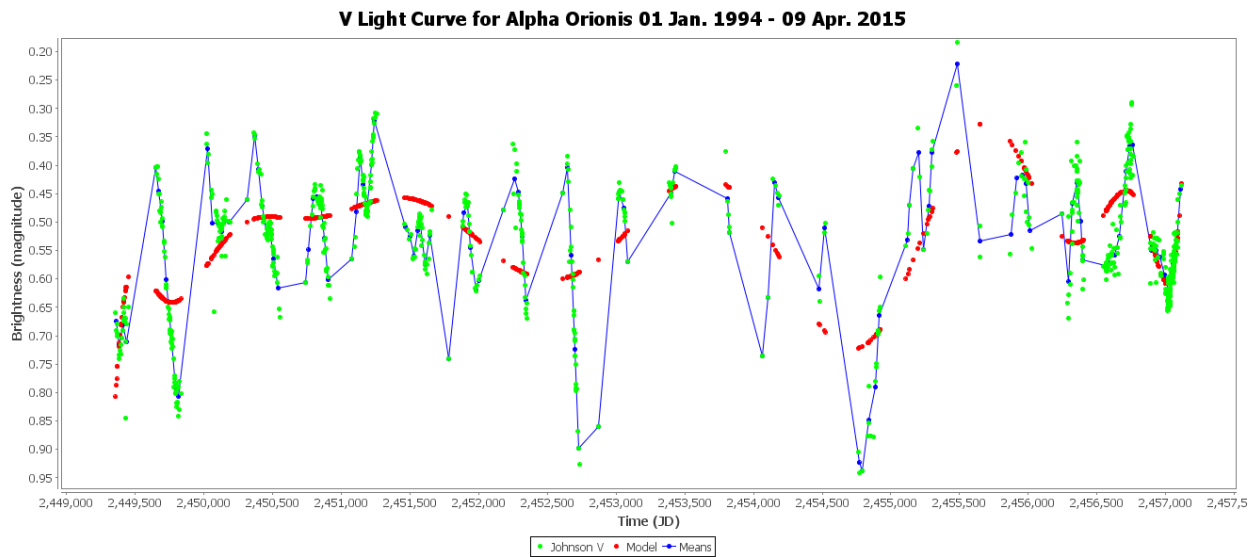


Figure 7. Johnson V 25 day average and polynomial fit to average January 1994 - April 2015 (VStar).

Comparison between Figure 6 and Figure 7 shows a marked spread in visual estimates for the same JD and relatively little in V. There are obviously many more data points available for visual estimates than for V. That said, the V filter is narrow band and the human eye is anything but (cf Bessel 1990; Warner 2006). Importantly Goldberg (1984) notes:

“The AAVSO [visual] data must be viewed with great caution. The standard deviation of a single estimate may be as high as 0.2-0.4 mag, but the number of estimates entering into each 25-day mean may be as high as 50. Some observers tend to be systematically high in their estimates and others systematically low; differences as large as 0.5 mag. have been noted for the same night. Nevertheless, the sheer volume of the data and their extensive temporal coverage make them worthy of attention. Moreover, the data show several systematic trends, some over long time periods, which are difficult to attribute to observational error.”

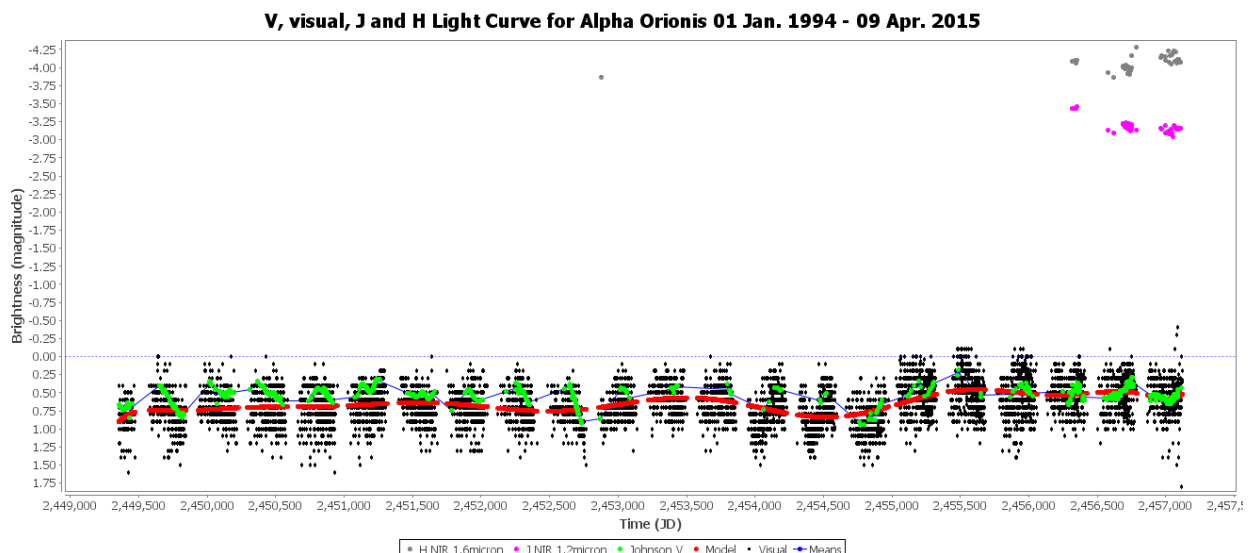


Figure 8. Visual, Johnson V, J and H light curve January 1994 to April 2015 (VStar).

Figure 8 shows the AAVSO data for Visual, Johnson V, J and H near IR. The Johnson V (blue trace) has a 25 day average applied. A 15th degree polynomial fit has again been applied to the visual data for illustrative purposes to show the longer period variability that the shorter periods can be seen on top of.

It can be seen in Figure 8 that it is very early days getting J and H near IR photometry for Betelgeuse.

The J and H near IR data are a long way from being able to see any periodicity or modulation by the physical phenomena only visible in the near IR discussed earlier.

Conclusion

Conspicuous by their absence are R and I band photometry in addition to J and H. These are probably less commonly owned photometric filters in the amateur community, but given the nature of Betelgeuse, they are more important than V.

We can conclude that because R, I, J and H are absent and important, and the professional community is using the AAVSO International Database (eg Townes et al 2009; Goldberg 1984; Moncrieff et al 2011) it is imperative the amateur variable star observer community plug the R, I, J and H holes in the data.

Presuming that V is a good enough analogue of what is happening in the other redder bands is forgetting that the colours of those filters mean they are tracking the stellar atmosphere and environs at lower temperatures and therefore potentially track different phenomena. As discussed earlier, the large scale convective cells Kervella et al (2011) present are visible in the near IR and not V. Only smaller scale structures are visible in V. Any modulation of the light curve by these convective structures in the near IR is missing from the AAVSO International Database. These effects may be found as a second order effect in the V light curve, but they will be directly measurable in the near IR light curve.

Period-colour, amplitude-colour and phase relationships have been found elsewhere for Cepheids (Ngeow & Kanbur 2008) using B, V and I data. These studies have found important differences between populations of Cepheids and have led to discussion of hydrodynamic/physical causes of the observed relationships (eg Ngeow & Kanbur 2008). These studies are also crucial to the use of Cepheids as distance markers.

Similarly SRc variables like Betelgeuse are candidates for an even more useful standard candle than Cepheids⁷ (cf Turner et al 2013). There is the IR PL relation work such as that discussed by Turner et al (2013) that requires decades long IR light curves – further argument for closing the gap on the longer wavelength filter bands in the AAVSO data.

It seems intuitive to conclude that as red supergiants in particular are far cooler than Cepheids that we ought to be interested in period-colour, amplitude-colour and phase relationships in the redder/IR bands ie the missing filter bands from the AAVSO International Database.

Appeal for photometry and spectroscopy

Perhaps you might consider observing Betelgeuse in R and I, or investing in something like the Optec SSP-4 and providing the missing bands from the AAVSO data on Betelgeuse?

Spectra of sufficient resolution would also allow pulsation radial velocities to be determined and related to the light curve – in addition to providing a record of the star's spectral changes.

The commitment needed is long term but need not be onerous as the periods in question are in the order of years and months so measurements need not be of high frequency.

The author hopes to be able to get a near unbroken 15 year run of J and H photometry of Betelgeuse.

The changes in the near IR light curve that might be seen based on the work of Kervella et al. (2011) identifying the large scale convective cells or any relationship to the large scale diameter changes found by Townes et al. (2009) will take years to acquire, but it can be done.

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⁷ Unlike Cepheids, the cooler M supergiants have evolved from spectral class O progenitors and are therefore all population I stars, so we need not concern ourselves with different populations (David Turner (see §12) personal correspondence with the author 22 February 2015).

Dr Matthew Templeton, AAVSO science director and Dr Arne Henden, past director of the AAVSO, also provided useful early input when this was just a simple presentation.

Use and reference has been made throughout of the AAVSO International Database. Indeed this paper is largely about increasing the filter bands covered, accuracy and therefore usefulness of the same.

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