



ASA's Michael Brown (Monash University) presents the Page Medal to David Moriarty See report page 4.

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From the director – *Mark Blackford*

Greetings fellow variable star observers, welcome to the second VSS Newsletter for 2018. I hope you all enjoyed the Easter break.

I was unable to attend the 28th NACAA in Ballarat over the Easter weekend myself, but for those who were there I hope the meeting was a great success. In this newsletter Tom Richards gives a rundown of the variable star aspects of the NACAA meeting. I'm sure our editor would welcome reports from others as well, especially articles from people who gave talks on any aspect of variable star astronomy.



Congratulations to David Moriarty on his award, see Tom's article on page 4 for details.

As mentioned in previous VSS Newsletters, the 5th Variable Stars South Symposium will be held immediately after the May 4th – 6th RASNZ Conference in Christchurch. By the time this newsletter is published the meeting will be just a couple of weeks away. We have a full programme of exciting presentations, including two from professional astronomers Ed Budding and Yael Hillman. The full list of talks is on page 3 in this newsletter. It promises to be an exciting symposium and a great opportunity to meet fellow VSS members and other people interested in variable stars. Christchurch is easily accessible so I encourage you to register if you haven't already done so. See the RASNZ home page (<http://rasnz.org.nz/>) for registration details.

Our long running QZ Carinae project received a very welcome boost recently after a successful request to the BRIT-Constellation consortium for QZ Car to be included in the list of targets for satellite observations in 2018. These are now underway and results should be available in a few months. Furthermore, Andrzej Pigulski was able to extract observations from the 2017 observing programme which we are currently analysing. Stan Walker presents a brief update on the project on page 6 of this newsletter and will give further details in Christchurch.

Meanwhile, back on earth the weather at Congarinni Observatory has been relatively conducive to astronomy since January. Fog after midnight continues to be an issue most clear nights, never-the-less I've managed to record multiple time series of a dozen or so targets for the VSS Southern Eclipsing Binaries project. My observing over the next couple of months, however, will be fairly lean as I'll be travelling

Variable Stars South Symposium 5 – Christchurch May 6 - 7, 2018

Preliminary Programme (subject to change)

SUNDAY		
7:00 pm	Welcome	Mark Blackford
7:15 pm	Exoplanets and Solar System & Pro-Am collaborations	Phil Evans "Confessions of an exoplanet junkie" Yael Hillman "Novae – where simulations meet observations" Carl Knight "Exoplanet transits: the challenge" Carl Knight "Detected precession of asteroid 4963 Kanroku"
9:15 pm	Supper	
MONDAY		
9:00 am	Eclipsing Binaries I	Mark Blackford "V883 Sco Period determination" Tom Richards "When Homer nods - reconciling our period analysis of V883 Sco with history" David Moriarty "Determining radial velocities with the broadening function & spectral types of eclipsing binaries in the V magnitude range 9 – 14" David Moriarty "Photometry, spectroscopy & radial velocities of ST Cen, V775 Cen & TW Cru"
10:30 am	Morning tea	
11:00 am	Eclipsing Binaries II	Stan Walker "QZ Carinae – 2018 update" Ed Budding "The multiple star systems V454 Car and HX Vel"
12 noon	Lunch	
1:30 pm	Equipment and Techniques	John Drummond "Applying astrophotography skills to astronomical science" Roy Axelsen "DSLR photometry in white light: a novel concept"
3:00 pm	Afternoon tea	
3:30 pm	Pulsating and Other Variables	Stan Walker "R Centauri - an interesting and perhaps unique Mira star" Roy Axelsen "Updated O-C diagrams for the delta Scuti stars RS Gru and V393 Car"
4:30 pm	Concluding review	

The National Australian Convention of Amateur Astronomers is the premier – indeed only – conference venue for amateurs to present and discuss their research, study and significant happenings. This year it was Ballarat's turn to host and the very active Ballarat Astronomical Society did a great job. It was a pleasure also to visit their historic observatory, founded in the goldfields days 132 years ago, and to listen to an excellent talk by Judith Bailey on its significant past – including the survey baseline determination needed to settle definitively the plots allocated to the diggers. The observatory and the BAS have inspired many young people to follow astronomy and the sciences, not the least being our keynote speaker, Professor Virginia Kilborn of Swinburne University. She discussed the present “golden age” of Australian astronomy and the ambitious decadal plan covering frontier multi-wavelength research on formation and evolution of planets, stars and galaxies, and dark matter and dark energy. The decadal plan includes major equipment investments here in Australia and overseas, notably with the ESO, and supercomputing facilities.

The first variable-star paper was by **Roy Axelsen and Tim Napier-Munn** on *AD CMi, a Delta Scuti Star in a Binary System*. Data up to 1992 revealed an O-C diagram best fitted by a quadratic indicating increasing pulsation period, but more recent data added a light-time effect fitted by a trigonometric function, which may take years before it is pinned down.

David Moriarty followed with *Photometry, Spectroscopy and Radial Velocities of the Near Contact Binary V0775 Cen and the Contact Binary TW Cru*. His work, including spectroscopy using the ANU 2.3m at Siding Spring, established the astrophysical parameters and evolutionary status of both systems, showed that TW Cru is chromospherically active, and that both are triple systems.

Steve Fleming and Tex Moon discussed the introduction of (relatively) cheap CMOS astronomical cameras and their promise for amateur and citizen astronomy, in *CMOS Cameras for Astronomy Education and Research*. Their cheapness, complete linearity, much faster cadence than CCDs and higher quantum efficiency make them a strong competitor to CCD astro-cameras. The presenters demonstrated their superiority in a study of the fast flickering in a symbiotic binary, with time-resolution beyond what a CCD can achieve.

Col Bembrick and myself presented on the pipeline of observation and analysis steps for research on eclipsing binaries and similar fast-changing stars, in *From Point of Light to Astrophysical Model – the Research Reach of the Modern Amateur*. This attempted to show, especially to astro-imaging enthusiasts, that doing research in this field was fairly straightforward, exciting, and with many publishable types of results. We also presented a poster paper *Neglected Southern Binaries – Astrophysical Modelling* illustrating the outcomes of this process for three eclipsing binaries.

Alan Plummer was the last presenter on variables, with *The Magellanic Cloud Luminous Blue Variables*, a most challenging visual study he has worked on rather heroically for years. He discussed their evolutionary status, light curves, and their tricky telescopic fields.

A great highlight of the conference was the presentation of the Astronomical Society of Australia's **Berence and Arthur Page Medal** to David Moriarty for his outstanding research on eclipsing binaries – an award that everyone agreed was most highly deserved. The ASA awards the Page Medal “for excellence in amateur astronomy in Australia and its territories. It is normally awarded every two years for scientific contributions by an amateur astronomer who has served to advance astronomy.”

David is the third variable-star researcher in a row to receive the award, following Tim Napier-Munn and Roy Axelsen, all from the Astronomical Association of Queensland. The award carries with it the right to join the ASA, a professional association not normally open to amateurs.

Following the award David gave a fascinating presentation on the likely origins and early evolution of life here and in the universe – a professional interest of his as a marine biochemist.

Progress with the mean light curve (MLC)

The measures made at Auckland Observatory in 1971 and 1972 are shown in Figure 1 as unfilled red squares fitted to the mean light curve as derived by Leung et al. This used a classical Algol shape with clearly shown first and fourth contact points but curved maxima similar to a beta Lyrae star which latter was how it was described in our original paper.

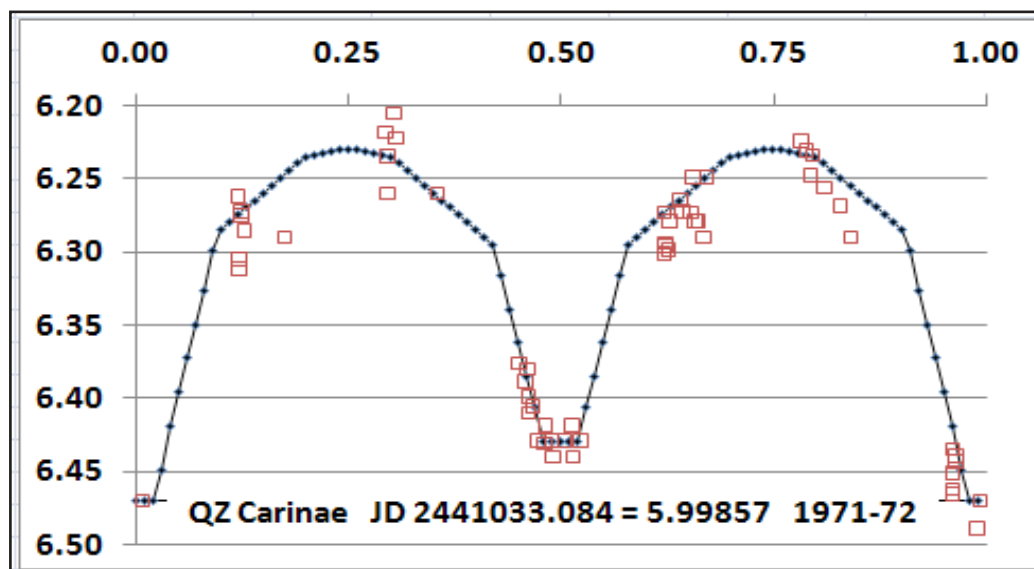


Figure 1. Leung et al's derived light curve is shown as blue points. The Auckland measures are shown as unfilled red squares. The fit is not ideal as discussed in the text.

Random measures do little to illustrate the light curve shape and many have been made of the eclipses themselves to determine epochs of minima - with limited success due to the long duration and the low amplitude of the light variations.

Measures by Hipparcos from 1990-93 tended to favour a more beta Lyrae light curve with poorly defined first and fourth contact points as well as a wider beginning and ending of eclipse. The accuracy was not all that good and the points too sparse and scattered in time to use to define a better mean light curve.

The BRITE measures

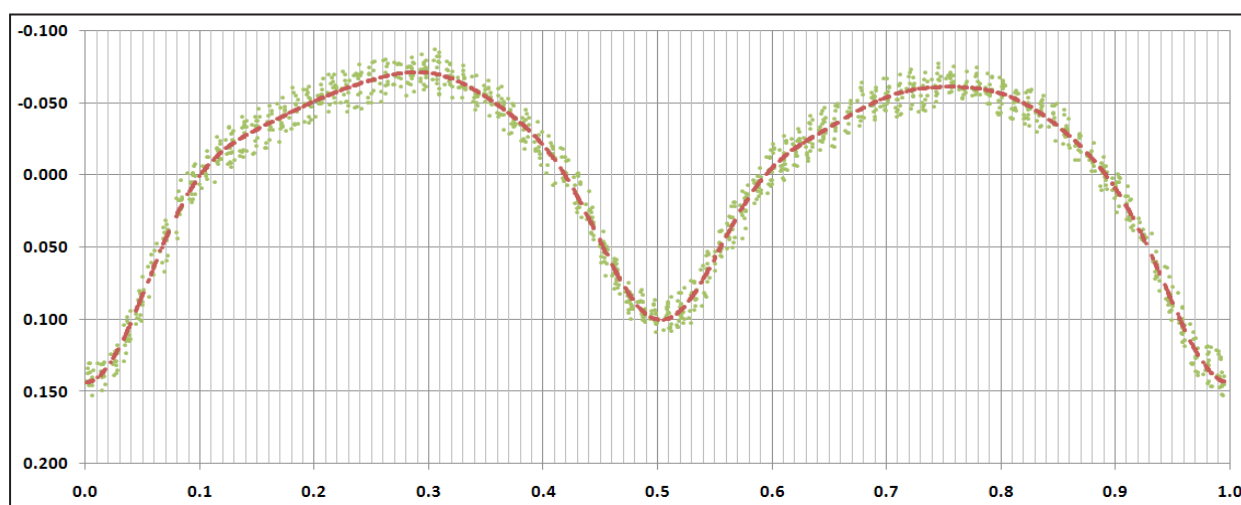


Figure 2. The light curve of QZ Carinae from the BRITE satellite as described in the text. The vertical scale is in BRITE's units, the horizontal scale one cycle of 5.99857 days

Late in 2017 Mark Blackford contacted Bert Pablo, staff astronomer at the AAVSO, who had previously worked with the BRITE satellite team in measuring a variety of very bright objects. As a result measures made by the BRITE-Heweliusz (BHR) satellite in 2017 were supplied to us by Andrzej Pigulski and the BRITE-Constellation Executive Science Team. They were made using a non-standard broadband red filter and each of the green points is the mean of all observations in one satellite orbit. An 8 harmonic Fourier fit to the measures is shown in Figure 2.

The new mean light curve - MLC

These measures were then translated into 100 points to make a MLC of a full orbit of the eclipsing pair. The harmonic Fourier fit obscures the totality of eclipses and this was adjusted using the known width from photoelectric and CCD measures. Some thought was given to transformation but as QZ Car is a collection of very hot and luminous blue stars with no perceptible colour changes the BRITE light curve was merely stretched to match the believed V amplitude range of QZ Car. This is shown in Figure 3.

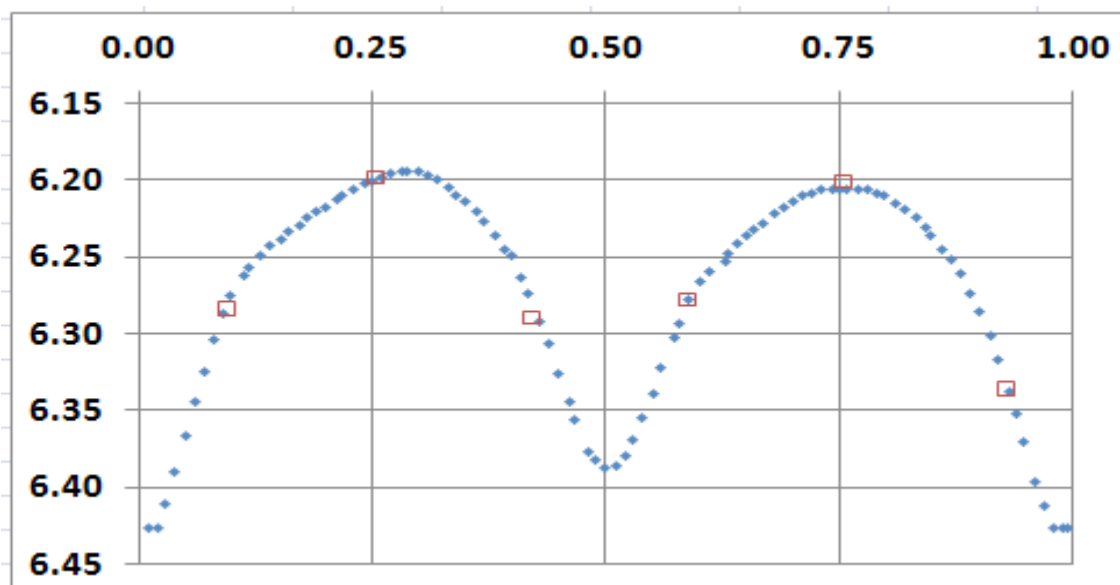


Figure 3. The composite mean light curve derived in the manner described in the text is shown as blue points. The primary eclipse now shows a flat bottom but the secondary has not been changed as we have no high quality measures of that. In all our calculations the central primary eclipse has been used as the epoch marker. The red unfilled squares are from ASAS3 in 2008.

We have now reanalysed all the available measures using this mean light curve and the results will be presented at Variable Stars South Symposium 5 on 6-7 May. The observed points in Figure 3 are from ASAS3 with a revised treatment as follows. These were first sorted into phases using the light elements $JD\ 2441033.08 + 5.99857$. They were then divided into the six nightly blocks based on the mean phase and magnitude. A magnitude correction of -0.045 was then applied. This is needed due to slight saturation at this level - brighter than $V = 7.0$ where saturation is expected to begin. The fit is by eye but reasonably accurate. For reasons discussed in the next section a final analysis has not yet been attempted.

The primary minimum and its duration

There is still a problem - what is the duration of the flat bottom of primary eclipse. Figure 4 shows Greg Bolt's measures of primary eclipse from Perth fitted to the composite mean curve. In this figure point A fits the old derivation well but point B might well be the true onset of totality.

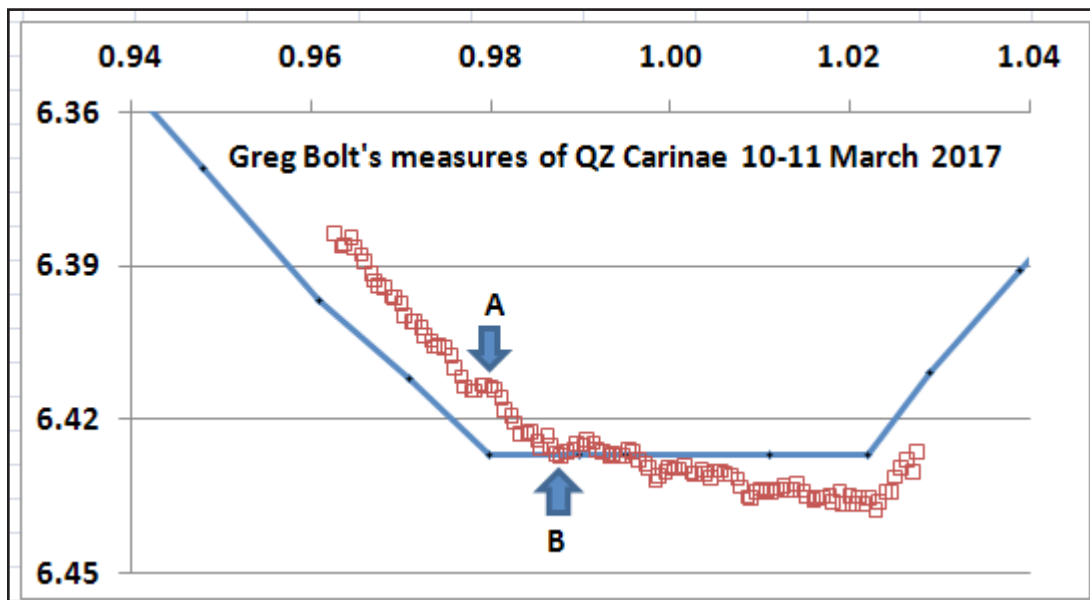


Figure 4. A primary eclipse measured by Greg Bolt on 10-11 March, 2017. The blue points and line are from the new mean light curve, the red unfilled squares are means of 9 measures. The end of totality is quite clear but not the beginning. Is it at point A or point B? The slope of ~15 millimags in the diagram may well be real as this is a very active system.

So this is where we stand in 2018. We have asked some of our members who have shown the ability to obtain good BV measures at this rather bright level to attempt to finally define the times of the start and finish of totality and thus its duration. The target points are quite clear from Figure 4. So if you can help contact either Stan Walker or Mark Blackford for information about times and comparison stars. We'd be grateful.

Introduction

CCD cameras have been widely and routinely used in the citizen astronomy community for more than a decade. For photometry a system comprises: CCD camera, filter wheel (FW) and filters. There is a wide range of commercially-available CCD cameras and electronic filter wheels but many camera/FW combinations cost several thousand dollars or more. Recently, low-cost astro-cameras with CMOS sensors have become available; some of these retail for as little as several hundred dollars. Coupled to the cheaper electronic filter wheels now available, a combined camera and filter wheel assembly can be bought for less than AU\$1000 (£600). Commercial photometric filters, however, remain expensive with a set of BVRI filters typically costing as much as a low-cost CMOS camera and filter wheel!

Reducing the cost of equipment is important if we wish to encourage more citizen astronomers to take up photoelectric photometry. The cost of photometric filters currently represents a significant barrier to the realisation of a low-cost photometric system. Consequently I decided to explore the construction of photometric filters using readily available planetary filters.

Planetary filters are dye-in-glass coloured filters loosely based on Wratten filter prescriptions. These include the #47, #38A and #56 bandpass filters, and the #12, #15, #21, #23A and #25 longpass filters. They are optically flat and come mounted in 1.25-inch cells that screw into most filter wheels. Transmission curves are, however, not readily available.

Background: BVRI passbands

In UBVR photometry portions of a star's spectrum are selected using optical filters. For such broad-band photometry the resulting passbands have a full-width half maximum (FWHM) ~ 100 nm (Majewski 2008). The sampling of a star's spectrum by the passband is, however, a combination of the transmission of the filter and telescope optics, the response of the detector, and the transmission of the atmosphere as a function of wavelength.

The spectral transmission of the telescope optics and spectral response of the detector may change over the long-term but can be considered constant over the course of the night and from night to night. Temperature changes can cause small changes in the transmission of the filters. The change is ~ 0.1 nm per degree Celsius which can give rise to a change of several thousandths of a magnitude per degree Celsius (Young 1967). The transmission of the atmosphere is particularly important in the U-band where the atmospheric cut-off at around 300 nm can define the short-wavelength edge of the passband.

In the 1940s and leading into the 1950s astronomical photometry was the domain of a handful of specialists. There was much discussion at the time on what type of system to introduce as a 'standard' with no consensus on the type and number of bands to adopt (Hearnshaw 1996). The UBVR broad-band photometric system was introduced by Johnson & Morgan (1953) and quickly became the *de facto* standard. The response of the 1P21 photomultiplier (PM) tube defined the spectral region that could be measured and, along with considerations of the existing photographic photometry system, determined the choice of filters to realise the defined UBVR bands (Hearnshaw 1996; Johnson 1955).

Kron et al. (1953), Johnson (1966), Eggen (1975) and Cousins (1976) all extended the original UBVR system to R and I but they used different R and I filters resulting in different passbands (Bessell 1979; Bessell 2005). The UBVR system in widespread use today came about by combining the Johnson UBVR and Cousins VRI systems. Passbands and filter prescriptions for this contemporary UBVR system are given by Bessell (1990, 2005), Bessell & Murphy (2012) and Munari *et al.* (2002). Standard stars are provided by Menzies et al. (1989), Landolt (2017) and the AAVSO (standard stars in selected open clusters).

Since about 1980 the Johnson RI system has fallen into disuse, the contemporary system being based on Cousins R_c and I_c bands. Johnson (1966), Bessell (1979) and Taylor (1986) have all noted that transformation between the two systems is non-linear.

Filters used in the standard BVRI system

Johnson's original filters were made of Corning glass. For the V filter he had a Corning 3384 (yellow) filter ground and polished. This defined the 'blue' edge of his V-band and the drop off in response of his uncooled 1P21 defined the 'red' edge. The filter was thus a bespoke filter, not a commercially-off-the-shelf (COTS) one. The U filter was made from Corning 9863 glass and the B filter from a combination of Corning 5030 and Schott GG13 glasses. Filter prescriptions and passbands for the original UBV system are given by Johnson (1955). Subsequently there were some concerns raised about 'replicating' these bands and Johnson noted that the published response curves may be slightly in error as a result of his having switched to a cooled photomultiplier (PM) tube later on (Johnson 1962).

Because of their availability and quality, photometrists that followed Johnson turned to Schott glasses for their systems. Schott has a range of similar (but not identical) filters to Corning so it was possible to match the blue edge of the V band (e.g. with a Schott GG495) and similarly the blue and red edges of the B band. With questions over the red edge of Johnson's original 1P21, and later PM tubes with extended red responses, a Schott blue-green (BG39 or BG38) passband filter was added to define the red edge of the V filter and cut out any infrared leak in the blue glasses used for the B filter. This approximated rather than replicated the original B and V bands. (A similar situation ensued for the U filter.)

For an instrumental photometric band that is sufficiently matched to a standard band there is a linear transformation of the observer's instrumental measurements to published values of standard stars. Typically this applies over a wide range of spectral types and luminosity classes but may not apply to very red or chemically unusual stars (e.g. Carbon and S-type stars). Perhaps the process of matching filters and detectors to the spectral response of a photometric band is better viewed as mimicking rather than replicating the standard photometric bands, the aim being to match them sufficiently well for a linear transformation to be used over a wide range of spectral type and luminosity class.

A number of manufacturers make dye-in-glass coloured filters. These include Schott, Hoya and Kopp (Corning prescriptions). Wratten gelatin filters sandwiched between glass covers have also been used by photometrists. Types and transmissions of these filters can be found at:

Schott: http://www.schott.com/advanced_optics/english/syn/advanced_optics/products/optical-components/optical-filters/optical-filter-glass/index.html

Hoya: http://www.hoyaoptics.com/color_filter/ir_transmitting.htm

Kopp: <http://www.koppglass.com/solutions/colored-filter-glass.php>

Wratten: <http://www.karmalimbo.com/aro/pics/filters/transmission%20of%20wratten%20filters.pdf>

Standard Stars for BVRI photometry

Johnson's original primary standard stars (Johnson and Harris 1954) only defined the UBV system from about B8 to K4 for luminosity classes V to III. The 108 secondary standards extended this somewhat. Later, Johnson (1955) published a catalogue of 382 stars encompassing a wider range of spectral types and luminosity classes. He noted that a list of standard stars must include all kinds of stars and it is for this reason that his list contains nearly 400 stars.

While Cousins (1976) carefully and precisely extended the UBV system to the southern hemisphere, there is a paucity of very cool, very hot or chemically peculiar stars in his list of Harvard E and F-region standard stars. Although in excellent accord with Johnson's original UBV system, the issue of possible limitation on types of stars to which a linear transformation can be applied remains for today's photometrists. For example, measured B-V indices for M giants can vary from one observer's system to another by as much as 0.05 magnitudes (Moon, Otero & Kiss 2008). This arises through a slight shift in an instrumental system's 'sampling' of molecular bands over the broad portion of a star's spectrum measured through a broad-band filter. The B-V index is a useful temperature surrogate for earlier type stars but for M giants becomes more of an indicator of their chemistry. (Astronomers thus turn to other bands for determining the temperature of M giants.)

For the contemporary UBVRI system, standard stars are given by Menzies et al. (1989), Landolt (2017) and AAVSO standard clusters (AAVSO 2017).

Filters: Published prescriptions

Many different filter prescriptions have been used since the introduction of the UBV system in 1953. Changes have been driven by availability, cost and introduction of new detectors. In particular, some filter types have been discontinued or become difficult to source necessitating changes to the original filter prescriptions. The extension of PM tubes into the red and infrared, introduction of photodiode detectors, advent of CCD/CMOS sensors have all had an impact on the practical realisation of the standard UBVRI bands.

The original prescriptions for UBV filters were given by Johnson (1955) along with the spectral response and effective wavelengths of the resulting bands. For the RI bands of the contemporary UBVRI system the original filter prescriptions and responses of the bands were given by Cousins (1974; 1976). Summarised details for the UBVRI and other photometric systems have been usefully assembled into the *Asiago Database on Photometric Systems, ADPS*, (Munari et al. 2002). For convenience published filter prescriptions for the UBVRI system are summarised here in Table 1 below.

Bessell (1990) and Sung & Bessell (2000) have provided filter prescriptions for the contemporary UBVRI system with a view to other photometrists adopting them thus making the UBVRI system more universally consistent and readily realised. The use of photodiodes, advent of CCD/CMOS sensors and discontinuance of some filter types have, however, necessitated changes to such UBVRI filter prescriptions over time.

Table 1. Published UBVRI filter prescriptions.

Passband	Detector	Published filter prescriptions	Reference
U	S4/S11 PM tubes	Coming 9863	Johnson (1955)
		Schott: UG1 (1mm) + WG320 (2 mm)*	Bessell (1990)
	GaAs/S25 PM tubes	Schott: UG1 (1 mm) + BG39 (1 mm)	Bessell (1990)
	CCDs	Schott: UG1 (1 mm) + S8612 (2 mm) + WG295 (2 mm)†	Sung & Bessell (2000)
B	S4/S11 PM tubes	Coming 5030 + Schott GG13	Johnson (1955)
		Schott: BG12 (1mm) + GG395 (2 mm)	Bessell (1990)
	GaAs/S25 PM tubes	Schott: BG12 (1mm) + BG18 (2 mm) + GG385 (2 mm)	Bessell (1990)
	CCDs	Schott: BG37 (3 mm) + BG39 (1 mm) + GG395 (1 mm)	Sung & Bessell (2000)
V	S4/S11 PM tubes	Coming 3384	Johnson (1955)
		Schott GG515	Bessell (1990)
	GaAs/S25 PM tubes	Schott: GG495 (3 mm) + BG38 (1 mm)	Cousins (1976)
		Schott: GG495 (2 mm) + BG18 (1 mm) [+ BG38 (1 mm)]‡	Bessell (1990)
	CCDs	Schott: GG495 (2 mm) + BG40 (3 mm)	Sung & Bessell (2000)
R	S25 PM tubes	Grubb & Parsons interference filter or Schott OG570 (2 mm)	Cousins (1976)
	GaAs PM tubes	Schott: OG570 (2 mm) + KG3 (2 mm)	Bessell (1990)
	CCDs	Schott: OG570 (3 mm) + KG3 (2 mm)	Sung & Bessell (2000)
I	S20/GaAs	Wratten 88A or Schott RG9	Cousins (1976)
		Schott RG9 (3 mm)	Bessell (1990)
	CCDs	Schott: RG9 (2 mm) + WG295 (3 mm)†	Sung & Bessell (2000)

Notes: * To be used with UV glass PM tubes. † Used as a fill glass. ‡ for GaAs PM tubes. S25 is also called extended S20 or Extended Red Multi-Alkali (ERMA).

It is worth noting that the response of the detectors available at the time Cousins introduced his RI system defined the long wavelength cut-off of the I-band (Cousins 1976). This is a similar situation to the UBV system when originally introduced by Johnson (1955) where he used the response of the S4 cathode of an uncooled 1P21 PM tube to define the red edge of the V-band. In both instances the use of a detector to define the red edge of the bands was to later cause problems when new detectors were introduced.

Commercial filters

Currently (i.e. January 2018) UBVRI filters can be bought from the following companies:

- Andover Corporation: <https://www.andovercorp.com/products/astronomy-filters/ubvri/>
- Astrodon: http://astrodon.com/store/p10/Astrodon_Photometrics_UVBRI_Filters.html
- Baader Planetarium: <http://www.baader-planetarium.com/en/filters/planetary.html>
- Chroma: <https://www.chroma.com/products/single-bandpass-and-single-edge-filters/application/>

[astronomy](#)

- Custom Scientific: <http://www.customscientific.com/astronomy.html>
- Optec Inc.: https://optecinc.com/astronomy/catalog/ifw/ifw_wheels.htm

Response or transmission curves are provided but the filter prescriptions used are not included. Generally, filter transmissions have been tailored so that resulting bands match Bessell's prescription for the UBVRI system, a notable exception being the Optec R and I filters used in their SSP3 photometers (Persha 1999).

Ongoing development of UBVRI filters has been necessitated by the introduction of CCD cameras and the discontinuance of some glasses previously used in construction of the filters (Goldman, Henden & Schuler 2005; Henden 2009). In particular, the higher infrared response of CCD (and now CMOS) sensors leads to the original prescription for the I filter producing a 'tail' extending past the I-band's specified cut-off at 920 nm. To better match the original I-band (Cousins 1974, 1976; Munari *et al.* 2002), and Bessell's later version of it, a dielectric coating has been added to the recommended coloured glass filter by Astrodon (Goldman, Henden & Schuler 2005). This increases the price of the I-filter so two I-bands have emerged:

- An Ic band matching the published response for the Cousins/Bessell I-band (dielectric coating added).
- An Is band using the original coloured glass filter recommended by Bessell (1990).

The addition of a dielectric coating is, however, only important for measurements of the reddest stars (Goldman, Henden & Schuler 2005). For example, Moon (2013) obtained a linear transformation over a wide range of spectral types using a coloured glass filter only for the I-band and showed that it could also be reliably applied to measurements of red giant branch (RGB) stars.

Dielectric coatings are used by some manufacturers to better match the UBVRI prescriptions. However Bessell (2005) and Majewski (2008) note that, depending on the f /ratio of the telescope, the bandwidth of an interference filter can change across the field of view introducing systematic differences in the photometry. Any 'tilting' of an interference filter will also introduce changes to its transmission characteristics. Baader (2016) outline some other problems that may occur when using interference filters.

Commercial filter sets are designed to be 'parfocal' (i.e., all the same thickness) and to have a high throughput. Even with parfocal filters some minor refocusing may be needed as a result of temperature changes (Baader 2016). Problems have also been encountered with respect to the chemical stability of Schott BG39 and KG3 glasses. In particular the Schott BG39 can develop a haze on its surface. It has been reported that hydrogen peroxide will remove this. Another option is to cover these glasses with a clear window.

Low-cost DIY filters

Astronomical CMOS cameras using sensors like the Sony IMX174 can be used for photometry with an uncooled version retailing for ~AU\$800 (£450). As 5-position electronic filter wheels now cost as little as AU\$260 (£150), BVRI filter selling for ~\$AU1000 (£600) thus cost as much as the camera and filter wheel. I thus decided to explore a do-it-yourself (DIY) approach to BVRI filters.

Challenges for standardising measurements in the U passband are well documented (Bessell 1990; Moon 2017). This is exacerbated by the typically poor sensitivity of CCD/CMOS sensors in U band. An assessment of return on investment by citizen scientists undertaking photometry with small telescopes, and with limited time and resources, is likely to lead to a decision not to bother making U band measurements. I have thus not explored making a low-cost U filter.

B filter

In contrast to the U and V bands Johnson's original B-band was a combination of 2 filters. The introduction of PM tubes with responses extending to longer wavelengths required the addition of a Schott BG38 or BG39 filter to mimic the original B-band (by cutting out the B-filter's transmission in the infrared). The prescription for B filters then involved cementing together 3 different types of glasses. Modern B filters

such as those supplied by Baader Planetarium instead use an interference film on a 'blue' glass to realise the standard B band.

Noting this, I thus decided to explore using a planetary 'blue' filter with a standard UV/IR cut interference filter. The most promising of the available planetary filters was the dark blue #38A. (Planetary filters are dye-in-glass filters based on Kodak Wratten specifications.) The response of the combination of a planetary #38A with a UV/IR cut filter used with a Sony IMX174 (CMOS) sensor is shown by the solid blue line in Figure 1. Also included is the response of Johnson's original B band as listed in the ADPS (Munari *et al.* 2002), shown as a dashed blue line. For comparison the response of a Baader Johnson B filter is shown as a dash-dot cyan line. Measurements of 24 AAVSO standard stars in NGC 3532 gave a linear transformation (see Figure 2) with a smaller transformation coefficient (~ 0.07) than that measured for the Baader Planetarium B-filter (~ 0.12).

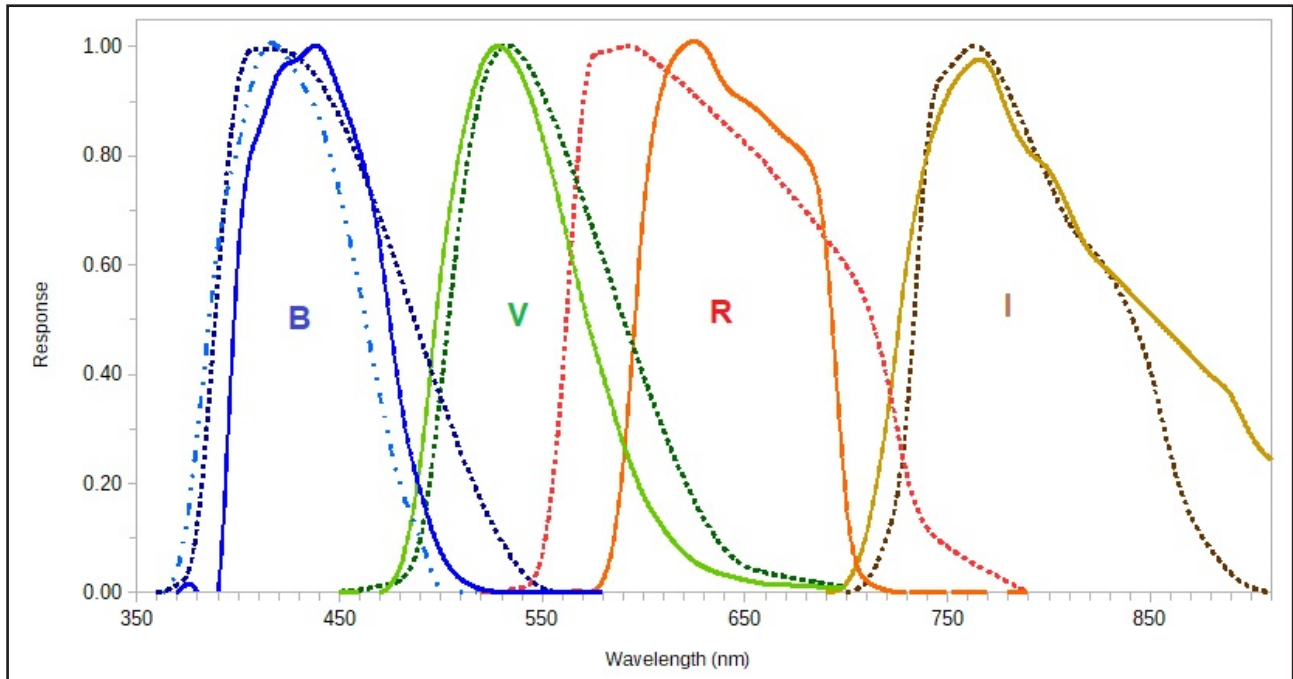


Figure 1. Response of DIY filters used with a CMOS IMX174 sensor (solid lines). Standard passbands as listed in the ADPS are shown as dashed lines. For comparison the response of a Baader B-filter is shown as a dash-dot cyan line.

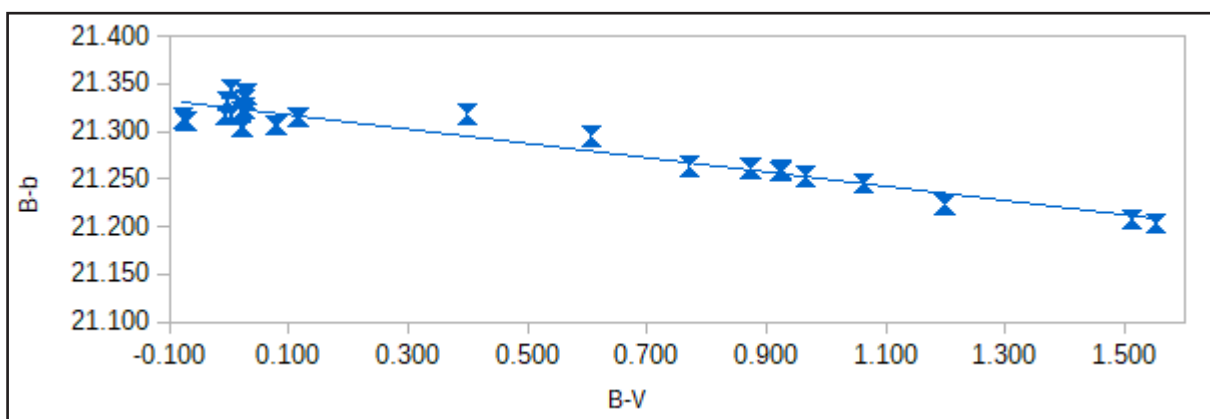


Figure 2. Difference between published and measured B magnitudes as a function of B-V for 24 AAVSO standard stars in NGC 3532.

Combining a planetary #38A with a UV/IR cut filter thus provides a satisfactory B filter for less than AU\$50 ($\sim$ £30).

V filter

To define the blue edge of the V-band I have used a yellow planetary filter (#12) which cost $\sim$ AU\$20

(~£10). To define the red edge I originally used a Schott BG39. Thor Labs in the US supply BG39 filters which are 25.4 mm in diameter and 2 mm thick. In cementing the 25.4 mm BG39 to the yellow planetary filter it was necessary to keep the filters concentric. This left a 1.3 mm ‘ring’ of exposed yellow filter which needed to be covered or blacked out with paint.

Combining a #56 planetary filter with the #12 resulted in the response shown in Figure 1. Also included is the response of Johnson V-band from ADPS (Munari *et al.* 2002). Measurements of 24 AAVSO standard stars in NGC 3532 gave a linear transformation (see Figure 3) with a small transformation coefficient (~ -0.02).

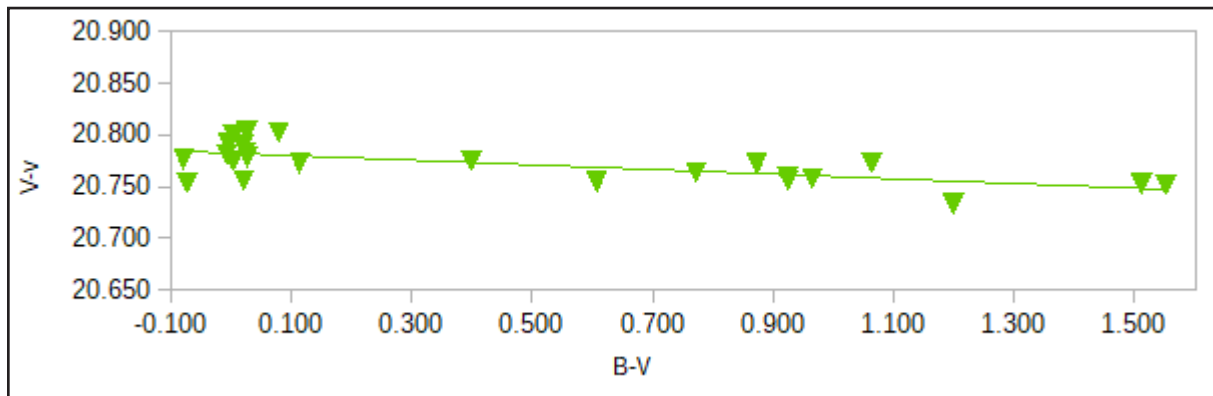


Figure 3. Difference between published and measured V magnitudes as a function of $B-V$ for 24 AAVSO standard stars in NGC 3532.

R filter

For R-band a Schott OG570 is specified for the short wavelength cut-on and a Schott KG3 filter for the long wavelength fall-off. Schott OG570 and KG3 glasses that are 25.4 mm in diameter and 2 mm thick can be sourced from Thor Labs. For DIYers prepared to cement the two glasses together and mount the resulting filter in a suitable cell, there can be a significant saving from buying commercial ones.

The light-red planetary filter (#23A) appears to be a similar longpass filter to the Schott OG570 so I decided to explore its use in making an R filter. For the long wavelength cut-off I used a UV/IR cut filter. These can be purchased on ebay or from telescope retailers for about AU\$25 (~£15). The resulting passband is somewhat narrower than the prescribed R-band but has a similar central wavelength (see Figure 1). Measurements of 24 AAVSO standard stars in NGC 3532 gave a linear transformation (see Figure 4) with a small transformation coefficient (~ -0.05).

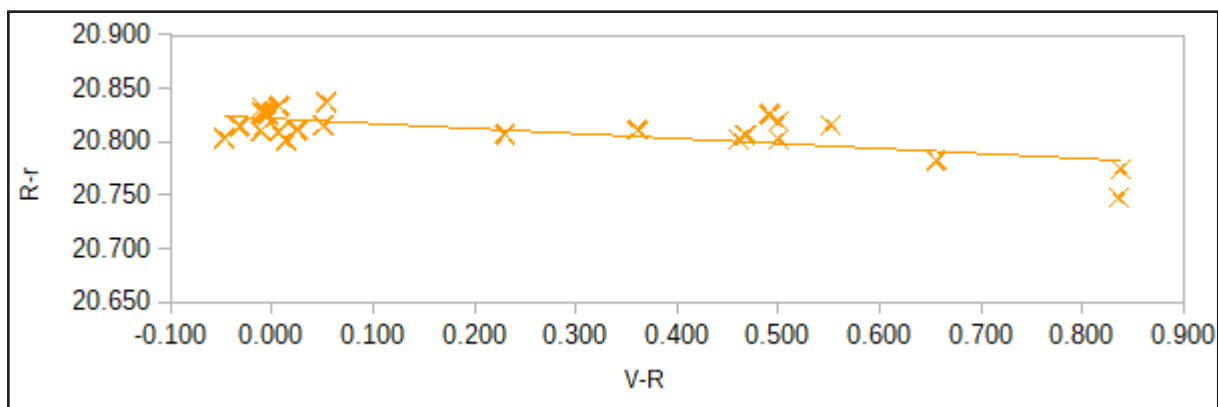


Figure 4. Difference between published and measured R magnitudes as a function of $V-R$ for 24 AAVSO standard stars in NGC 3532.

I filter

For I-band, a Schott RG9 filter is specified (Cousins 1976; Bessell 1990; Sung & Bessell 2000). The RG9 alone is used for the Astrodon I_s band and is also the coloured glass component of Astodons I_c filter.

An I_s filter is thus easy to make with 25.4 mm diameter, 3 mm thick RG9 filters available from suppliers such as Edmund Optics for about AU\$65 (~£35). The 25.4 mm diameter, 2.5 mm thick Hoya RT-830 is a similarly priced equivalent with essentially the same spectral response as the RG9 (Moon 2013). The main challenge is mounting a 25.4 mm glass in a cell made for 28 mm glass. (Some of the cheap planetary filter sets sold on ebay use a standard threaded 32 mm cell but have 25 mm diameter glass rather than 28 mm glass and are thus excellent for mounting the 25 mm Schott or Hoya glasses from suppliers such as Edmund Optics.)

An alternative is to combine an orange or red (#15, #21, #23A or #25) planetary filter with a violet filter (#47). As shown in Figure 5 the violet filter has high transmittance in the infrared as well as the violet. The longpass orange or red filter then blocks the violet transmission; cost of the two filters is ~AU\$40 (~£25). For comparison the measured transmittance of a Schott RG9 is also shown.

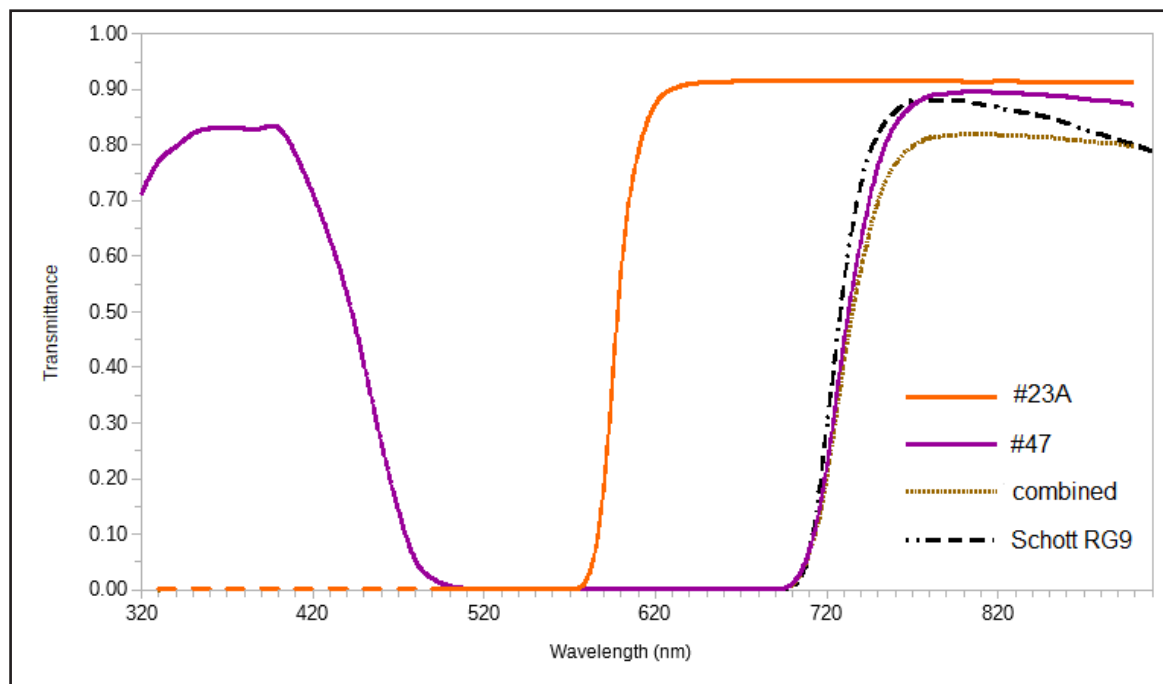


Figure 5. Transmittance of DIY I-filter and its individual components. For comparison the transmittance of a Schott RG9 is also shown.

Figure 1 shows the response of a DIY I-filter when used with a Sony IMX174 sensor and the response of the Cousins I-band as listed in the ADPS. Measurements of 24 AAVSO standard stars in NGC 3532 gave a linear transformation (see Figure 6) with a small transformation coefficient (~ 0.02).

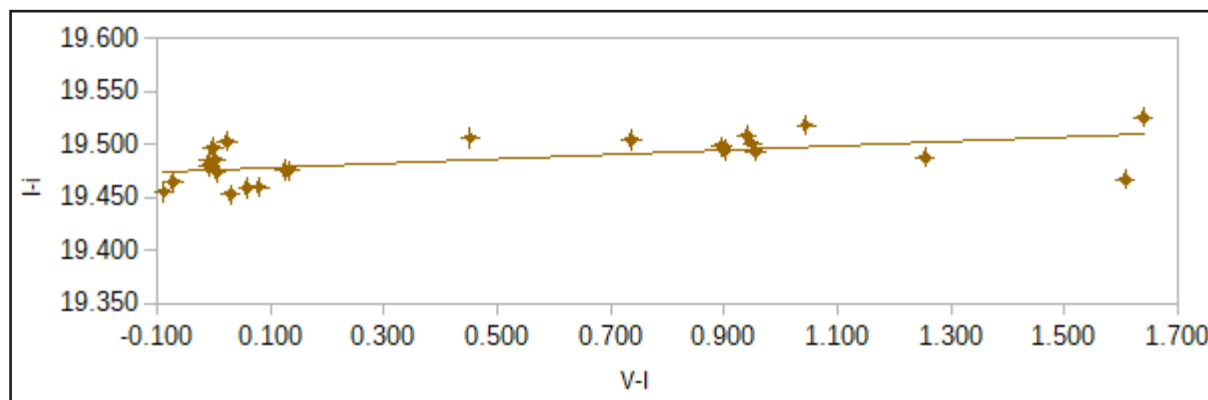


Figure 6. Difference between published and measured I magnitudes as a function of V-I for 24 AAVSO standard stars in NGC 3532.

For DIY filters the individual components can be assembled without cementing them provided they are separated by a thin spacer to eliminate interference fringes (Newton's rings). Cementing the components will increase the overall transmission by about 10% for 2-component filters (Miles 1998). Optical adhe-

sives are available from specialist suppliers but cementing components together can be challenging and is best done by an optical technician.

Discussion and summary

Current BVRI filter sets retail for around AU\$1000 (~£550). A low-cost set of BVRI filters can, however, be constructed from readily available planetary and UV/IR cut filters for around AU\$130 (£70). Measurements of AAVSO standard stars in the southern cluster NGC 3532 show that these filters, used with CMOS sensors, give linear transformations from $-0.1 < V-I < 1.70$ covering a range of spectral types and luminosity classes.

The central wavelengths and FWHM for the DIY filters used with a CMOS sensor are given in Table 2. For comparison the values for the BVRI bands from responses listed in the ADPS are included.

Table 2. Central wavelengths and FWHM for DIY filters used with CMOS sensor and for the BVRI bands as specified in ADPS.

Band	λ_c (nm)		FWHM (nm)	
	ADPS	DIY	ADPS	DIY
B	438	438	98	75
V	547	535	87	76
R	647	644	152	98
I	787	788	110	123

The thicknesses of the DIY filters can vary depending on the brands used. They may thus not be parafocal. My experience is that a minor refocusing when changing filters is not onerous but note this can be an advantage of commercially-available filters over DIY ones.

Filter components can be cemented together using cheap ‘super’ glue but ensuring there are no bubbles trapped between the components is challenging. The components do not have to be cemented provided a thin spacer is used to eliminate interference fringes (Newton’s rings). This results, however, in a throughput loss of around 10% for a 2-component filter. Again, throughput has not been an issue for me as I’ve successfully used DIY filters for measuring stars down to 12th magnitude with a 150 mm f/5 Newtonian and CMOS camera using exposure times no longer than 60 seconds.

Transmission of planetary filters may vary somewhat from one manufacturer to another. In particular I found the Prostar brand of filters to be a lighter tint than other brands and unsuitable for constructing BVRI photometric DIY filters. GSO filters (often re-branded under the retailer’s name) seem to provide cheap, good quality planetary filters that are suitable for making BVRI filters.

Finally, for any filter set, it should be remembered that a linear transformation derived from measuring standard stars strictly only applies to the range of colour indices, spectral types and luminosity classes measured. There is no guarantee that such linear transformation can be applied to stars with unusual spectra or very red stars with many molecular bands in their spectra.

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Analysis of the evolution of ASASSN-17gk colour indices and spectra over time – *Carl Knight and Terry Bohlson*

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Abstract. 2017 May 17.28 UT a classical nova (CNe) was discovered in Centaurus and designated ASASSN-17gk (J2000 coordinates: R.A. 13 20 55.32 Dec. -63 42 18.5). AAVSO and VSS observers commenced BVRI photometry of the nova. As this progressed it occurred to one of the authors (Knight) that the B-V colour index of the nova ejecta might yield a black body temperature for the ejecta at some point. This led to a larger body of work analysing the change in colour indices (CI) of the nova over time for this purpose and to see if the basic premise of Powles & Knight (2014) – that B-V and V-R in particular are indicators of the strength of H α at 6563 Å (pink red) and H β at 4861 Å (cyan) emission and B and R increase and decrease with the H emission relative to V and I – holds true.

Introduction

A CNe is a runaway CNO thermonuclear reaction on a white dwarf (WD) in an accreting binary system. The conditions necessary and nuclear reaction networks are covered elsewhere at length (see José 2012 & Schwartzman et al. 1994).

Previously we (Powles & Knight 2014) examined spectra and CI from Nova Centauri 2013. We found that spectra showing enhanced H β correlated well with increasingly -ve trending B-V and similarly spectra showing enhanced H α correlated well with increasing +ve trending V-R whilst the ejecta dominate the light curve and there is no contribution from the progenitor WD system.

If this phenomena is present in ASASSN-17gk then the CI will change similarly and we can use the CI to predict where we should find that H emission correlated with the CI trend.

Furthermore, the idea that photospheric emission might dominate the very early ejecta and beyond is explored. It was hoped to obtain something of a temperature profile as the colour indices evolve over time. The limits of this are discussed in the body of this work.

Light curve

The light curve (bottom panel of Figure 1) covers from Day 0 at JD=2457892.95139 (18 May 2017 UT) to last observed at JD=2458024.81390 (28 September 2017 UT). The V-magnitude at Day 0 was $V_0 = 10.075$. The V-magnitude when last observed was $V_L = 15.073$. An absolute difference $V_0 - V_L = 4.998$ magnitudes.

CNe speed class

The time to diminish in V by three magnitudes (t_3) for the nova is approximately 113 days making the speed class of ASASSN-17gk a slow nova (NB) (see Shara 1980).

Oscillations

The light curve shows some pronounced oscillations. These are poorly resolved as the cadence of observations has dropped off at the major oscillations so the drop off in cadence may exaggerate the size and shape of the oscillations.

That said, Hillman models (Hillman, 2014) of low mass ($0.65M_{\odot}$), slow accreting ($<10^{-11}M_{\odot}\text{yr}^{-1}$) CNe progenitors show oscillations believed to be caused by the progenitor WD envelope repeatedly rebalancing as it first expands and then the gravitationally bound portion contracts and zeros in on hydrostatic equilibrium.

Such progenitors have less violent eruptions (see Shara et al. 1980) and tend to be of slow CNe speed class as is ASASSN-17gk.

Colour indices

BVRI measures have been obtained from the AAVSO International Database for the nova using the AAVSO VStar (Benn 2012) tool to provide daily averages (see Table 1 below). Not all days have all four bands. All have at least B and V.

The colour indices have been graphed (top panel in Figure 1) for the same period as the light curve.

Relative and calibrated spectra

Spectra have been obtained from two sources with permission. The British Astronomical Association (BAA) Spectroscopy Database and the Astronomical Ring for Access to Spectroscopy (ARAS) Database.

Relative spectra simply show the strength of flux at any arbitrary wavelength compared to any other wavelength across a spectrum. Calibrated spectra are all in the units of $\text{erg/cm}^2/\text{s}/\text{\AA}$ and direct comparison across spectra is possible. The units are energy per unit area over time across light wavelength.

JD	B	V	R	I	B-V	V-R	V-I	R-I
2457892.01582	11.781	10.705			1.076			
2457895.48132	12.072	11.083	9.912	9.111	0.989	1.171	1.972	0.802
2457897.98881	12.321	11.280	10.440	9.339	1.041	0.840	1.941	1.101
2457900.23319	11.952	10.885	9.804		1.067	1.081		
2457901.47046	11.925	10.884		8.994	1.041			
2457902.97874	12.114	11.061	9.860	9.066	1.053	1.201	1.995	0.794
2457903.23892	12.154	11.185	9.897	9.160	0.969	1.288	2.025	0.737
2457905.02306	12.527	11.543	10.174	9.465	0.984	1.369	2.078	0.709
2457906.78767	12.382	11.404	10.166	9.450	0.977	1.239	1.955	0.716
2457908.96374	12.617	11.564			1.052			
2457910.78632	12.240	11.103	10.099	9.208	1.136	1.004	1.896	0.891
2457911.86213	12.176	11.158	10.184	9.231	1.018	0.974	1.927	0.953
2457916.99324	12.222	11.146		9.240	1.077		1.906	
2457918.98764	11.928	10.863		9.035	1.066		1.828	
2457920.66848	12.174	11.165	10.133	9.164	1.009	1.032	2.002	0.970
2457921.79181	12.333	11.128	9.943	8.991	1.205	1.185	2.137	0.952
2457924.77133	12.369	11.258	9.989	9.107	1.111	1.269	2.151	0.882
2457925.89293	12.303	11.174	9.986	9.108	1.129	1.189	2.066	0.878
2457926.94134	12.359	11.217	10.021	9.222	1.142	1.196	1.995	0.799
2457930.8787	12.399	11.224		9.185	1.176		2.039	
2457932.02684	12.680	11.611			1.070			
2457934.85626	12.596	11.351	10.186	9.368	1.245	1.165	1.983	0.818
2457935.99519	12.343	11.230	10.093	9.309	1.113	1.137	1.921	0.784
2457937.88108	12.116	10.919	9.772	8.909	1.197	1.147	2.010	0.863
2457939.86418	12.949	11.537	10.341	9.559	1.412	1.196	1.978	0.782
2457941.36861	12.533	11.415	10.246	9.407	1.118	1.169	2.008	0.839
2457942.27923	12.822	11.726		9.306	1.096		2.420	
2457947.8059	13.771	12.784	11.307	10.578	0.987	1.477	2.206	0.729
2457952.83814	13.566	12.497	11.267	10.584	1.069	1.230	1.913	0.683
2457955.84242	12.650	11.447	10.304	9.362	1.203	1.143	2.085	0.942
2457956.9686	12.940	11.863	10.618	9.769	1.077	1.245	2.094	0.849
2457959.78773	12.876	11.811	10.575	9.711	1.065	1.236	2.100	0.864
2457962.95227	12.625	11.608	10.384	9.649	1.017	1.224	1.959	0.735
2457966.90832	13.250	12.320			0.930			
2457969.33005	13.361	12.360	11.032	10.277	1.001	1.328	2.083	0.755
2457972.78014	13.778	12.843	11.500	10.829	0.935	1.343	2.014	0.671
2457974.90573	14.126	13.348	11.886	11.433	0.778	1.462	1.915	0.453
2457975.92176	13.893	12.955	11.746	11.141	0.938	1.209	1.814	0.605
2457977.86769	13.480	12.463	11.325	10.628	1.017	1.138	1.835	0.697
2457983.79734	13.522	12.564	11.249	10.457	0.958	1.315	2.107	0.792
2457985.78722	13.016	11.846	10.500	9.414	1.170	1.346	2.432	1.086
2457986.85104	12.926	11.829	10.544	9.600	1.097	1.285	2.229	0.944

JD	B	V	R	I	B-V	V-R	V-I	R-I
2457989.96633	13.251	12.250			1.002			
2458000.79223	13.656	12.732	11.273	10.478	0.924	1.459	2.254	0.795
2458006.33352	14.396	13.591	11.797	11.607	0.805	1.794	1.984	0.190
2458007.79806	14.784	13.810	12.080	11.964	0.974	1.730	1.846	0.116
2458016.31756	15.153	14.190	12.756	12.867	0.964	1.434	1.323	-0.111
2458024.81390	15.731	15.073	13.289	13.047	0.658	1.784	2.026	0.242

Table 1. AAVSO BVRI average magnitudes and colour indices

The spectra obtained generally only show two prominent emission lines and these are H α at 6563Å (pink red) and H β at 4861Å (cyan).

CI and spectra evolution over time

Figure 1 serves to identify the common points in the CI chart and light curve for discussion. Each is identified by lower case Roman Numerals *i* through *xv* in an attempt to avoid confusion with any magnitudes (digits) or filter bands (upper case letters BVRI).

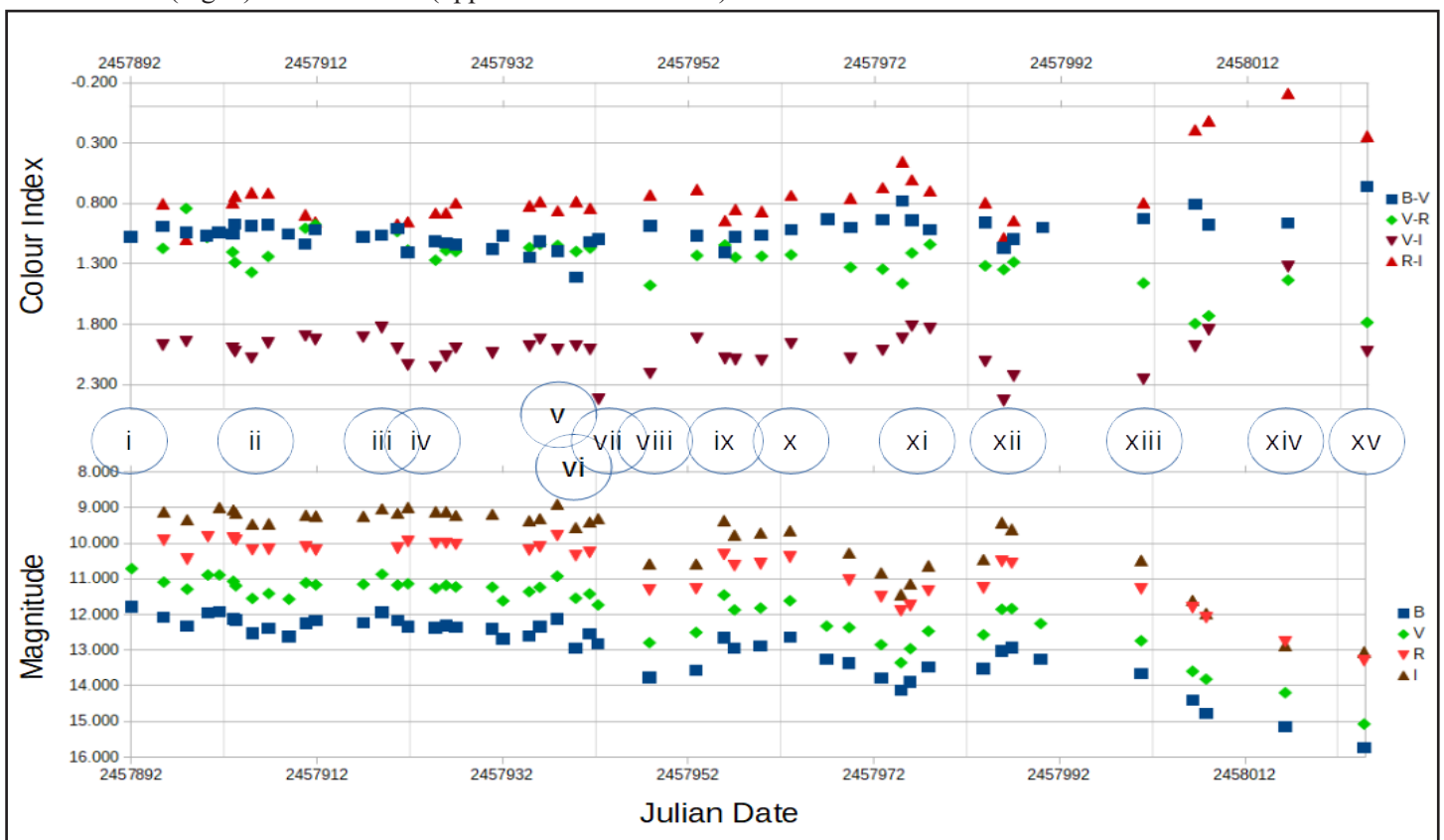


Figure 1. Identifying CI chart and light curve discussion points.

Each point discussed from and identified on Figure 1 appears below as a subheading.

i. Ejecta as a pseudo-photosphere – Day 0

This is our Day 0. Maximum light is achieved as V=10.705.

The basic premise one of the authors (Knight) wished to explore is that when the ejecta are thick enough and opaque enough can the ejecta be treated as a pseudo-photosphere (Arai et al. 2010) and as such can a black body temperature be obtained?

Arai et al. (2010) have determined that this phase only lasts up to maximum light (*Day 0* in the literature). The photospheric emission ceases to dominate as the light curve decline begins and features like H emission (see H emission peaks in Figure 2 below) begin to muddy the photospheric emission.

The data for ASASSN-17gk in the AAVSO International Database include data at or about maximum

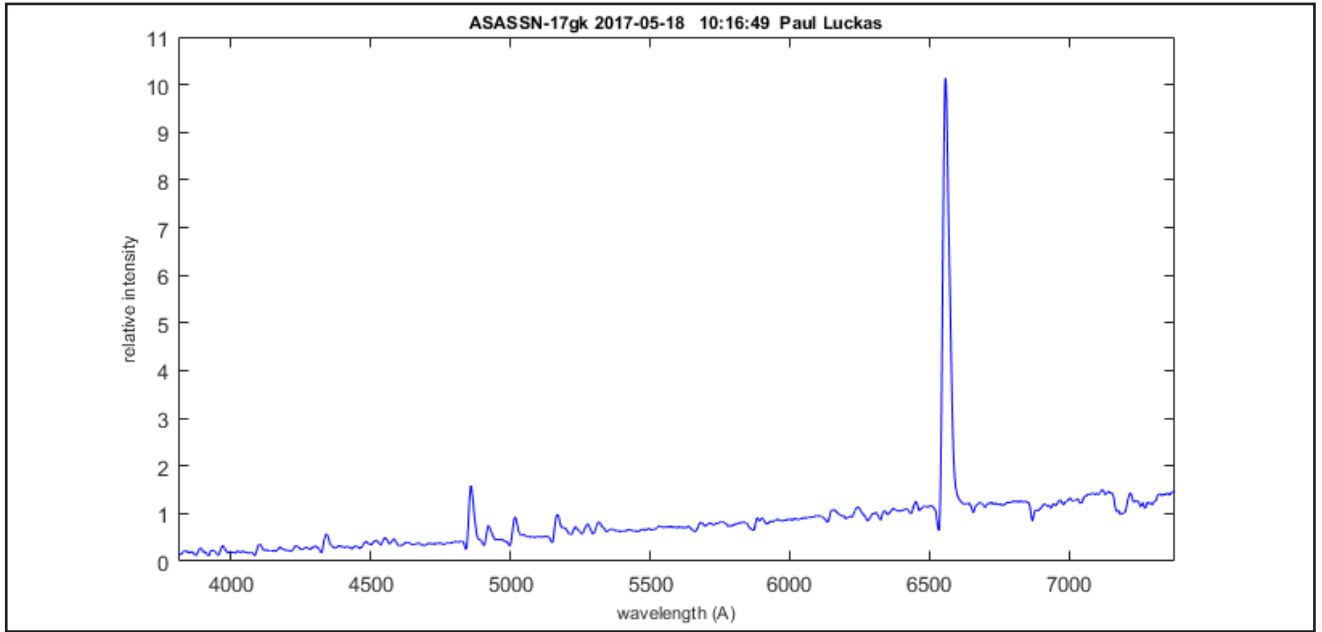


Figure 2. ASASSN-17gk earliest relative spectra - Day 1. Paul Luckas. ARAS.

light – Day 0 = JD=2457892.95139 (see Table 1 above).

To relate the CI that might be obtained to the temperature of the pseudo-photosphere we need formulae to relate the two. Ballesteros (Ballesteros 2012) has done significant work on empirical formulae to relate CI to black body temperature. He derives the following formula to derive a black body temperature from the B-V CI:

$$T = 4600 \times \left(\frac{1}{0.92 \times (B - V) + 1.7} + \frac{1}{0.92 \times (B - V) + 0.62} \right)$$

Using Ballesteros (2012) Eq. 14 and ASASSN-17gk B and V at Day 0 from the AAVSO International Database (Table 1 above) we have the following B, V and B-V:

- B=11.781
- V=10.705
- B-V=1.076

$$T = 4600 \times \left(\frac{1}{0.92 \times 1.076 + 1.7} + \frac{1}{0.92 \times 1.076 + 0.62} \right) = 4567 \text{ K}$$

We determine a black body temperature for ASASSN-17gk at Day 0 of 4567 K. This temperature correlates to between MKK stellar spectral classes K and M (see Morgan, Keenan & Kellman 1943) ie very red if it were a stellar photosphere.

That said, Figure 2 above suggests the H emission is already well established at our Day 0 so this is an exercise of a technique and something for others to attempt if spectra can conclusively show the H emission is not yet dominating, or better yet establish a black body temperature V-I relationship (instead of B-V) such that the H emission effects are minimised. Might this then not allow the temperature profile of the ejecta to be determined over a longer period?

ii. Day 12

We are now passed the point where the photosphere like emission dominates the ejecta, ie it is no longer like a simple black-body.

In a previous article, spectra (Powles & Knight 2014) show that H emission can dominate and as the different H emission bands (particularly H α and H β) increase and decrease, so do the standard photometric filter bands to varying degrees.

ii then is a peak in R-I and B-V but a dip in V-R and V-I. This is all driven by a more significant dip in V in the light curve relative to the other bands. That is, V becoming weaker makes V-R and V-I more +ve and B-V less +ve. R-I peaking toward less +ve means R is brighter relative to I. This is suggestive of H α emission dominating. V weakening but B not weakening suggests B is supported by H β emission relative to the declining V.

Then the significant rise of R-I declines as does the less significant rise in B-V. V-I and V-R both recover. This is the inverse of the V decline described above.

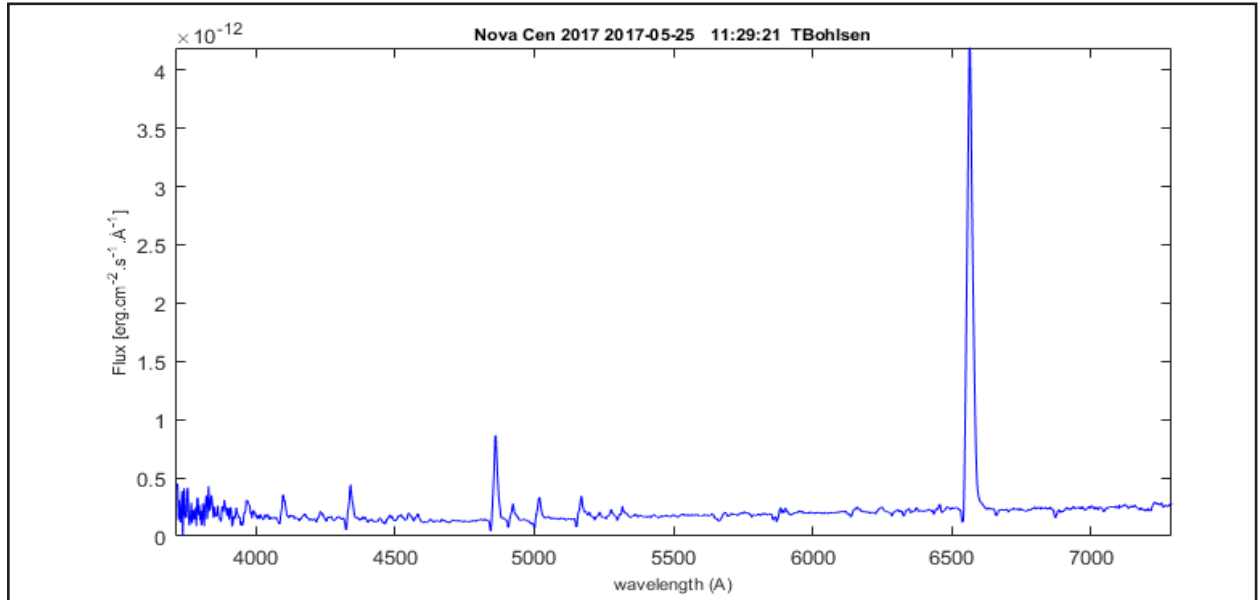


Figure 3. ASASSN-17gk calibrated spectra – Day 6. Terry Bohlsen. ARAS.

Bohlsen's spectra in Figure 3 above for ASASSN-17gk show the expected prominent H α at 6563Å and H β at 4861Å. During the period under discussion here Bohlsen has obtained the spectra shown in Figure 4 below. Noticeable is the decreasing of both H α (greatest) and H β (least) compared to the earlier spectra by Lukas.

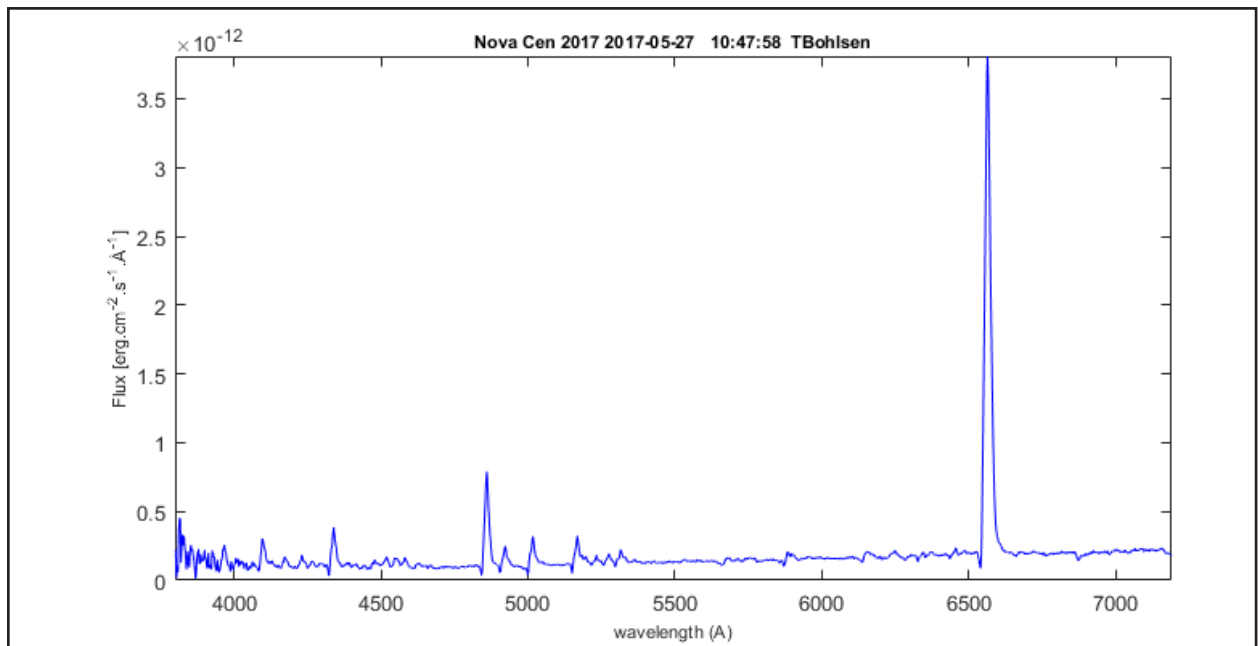


Figure 4. ASASSN-17gk calibrated spectra – Day 8. Terry Bohlsen. ARAS.

These spectra support the argument above that the CI move from B and R excess to their decline.

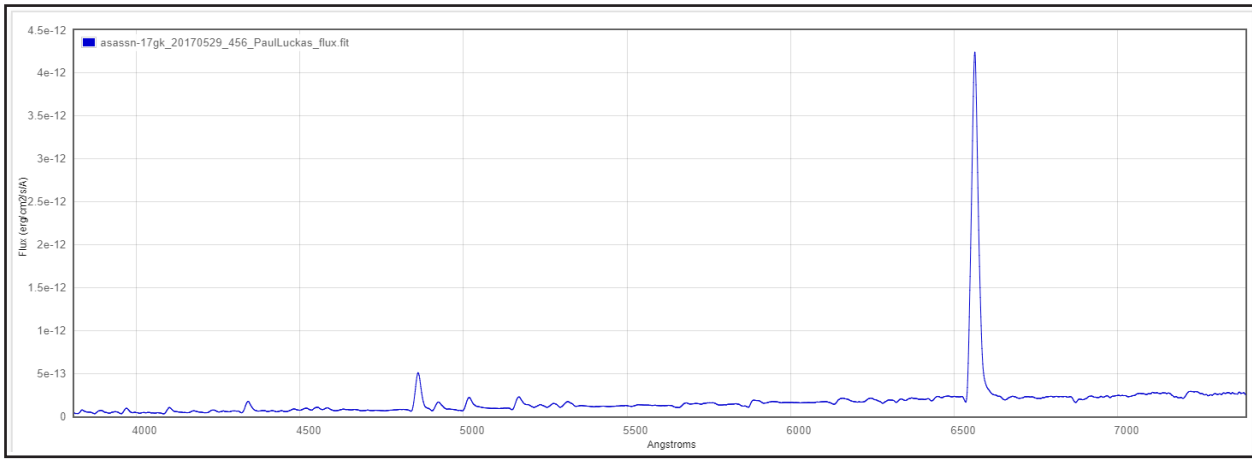


Figure 5. ASASSN-17gk calibrated spectra – day 10. Paul Lucas. BAA.

iii. Day 24

iii is a peak in V-I and essentially flat in B-V, V-R and R-I. *iii* immediately precedes a dip in V-I, B-V and V-R. Shortly after this time a rise in R-I commences while V-R, V-I and B-V all decline. The B-V decline indicates that this is not a simple decline in V as described in *ii* above. V-R and V-I declining indicate the R and I bands dominating. B-V declining indicates the V band dominating relative to the B band. R-I rising indicates R dominating relative to I. In effect everything indicates moving to longer wavelengths (temperature decreasing) with most likely H α emission causing the spike in R-I. V dominating B may also indicate a decline in H β emission. This supports the notion of an overall temperature decline given the higher excitation energy required for H β emission.

iv. Day 28

The dip in V-I indicated by *iv* is at the end of the decline of B-V and V-R also. R-I continues to climb. The basic explanation for *iii* holds. Note that B-V and V-R cross at this point. V-R trending +ve and B-V is also but less rapidly.

iv-v. Day 29 – Day 43

iv to *v* is largely a plateau even though the light curve rises to a peak in all photometric bands. This is likely an increase in ejecta temperature despite expansion and thinning. That said the plateau is also exaggerated due to the missing V and I bands.

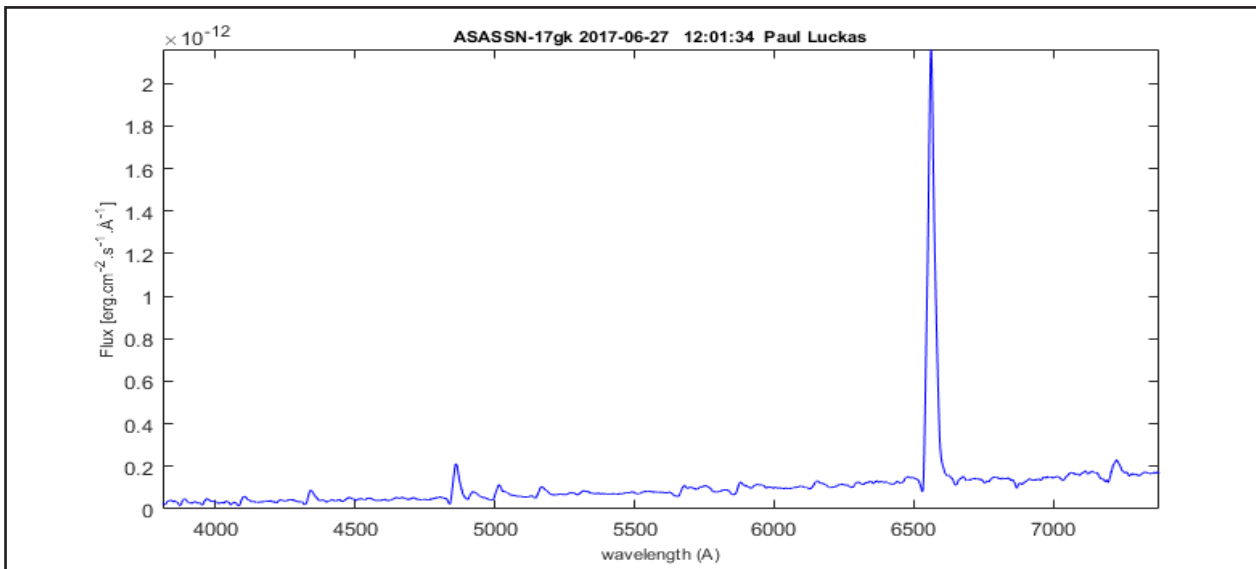


Figure 6. ASASSN-17gk calibrated spectra. Day 39. Paul Lucas. ARAS

We expect to see the rebalancing WD (see Hillman et al. 2014 discussion of oscillations; Hillman 2017) imprinting on the expanding ejecta as the WD supersonic wind is inhomogeneous as is its velocity profile. Thus we expect interaction and collision to cause additional heating and emission and subsequent brightening of the expanding thinning ejecta.

Comparing Luckas' spectra from Day 39 (Figure 6), Bohlson's Day 43 (Figure 7) and Luckas' spectra from Day 49 (Figure 8) during the time covered by discussion points *iii-vi*. It can be seen that the H β emission decreased, increased and decreased once more respectively.

H α tells a subtly different story over the same interval. The H α flux has simply decreased throughout. Unfortunately the V-R and R-I is largely absent. B-V is present and shows B-V moving +ve (less B) toward -ve (blue excess) and back toward V again and then once more toward B. Given the corresponding spectra for the same period.

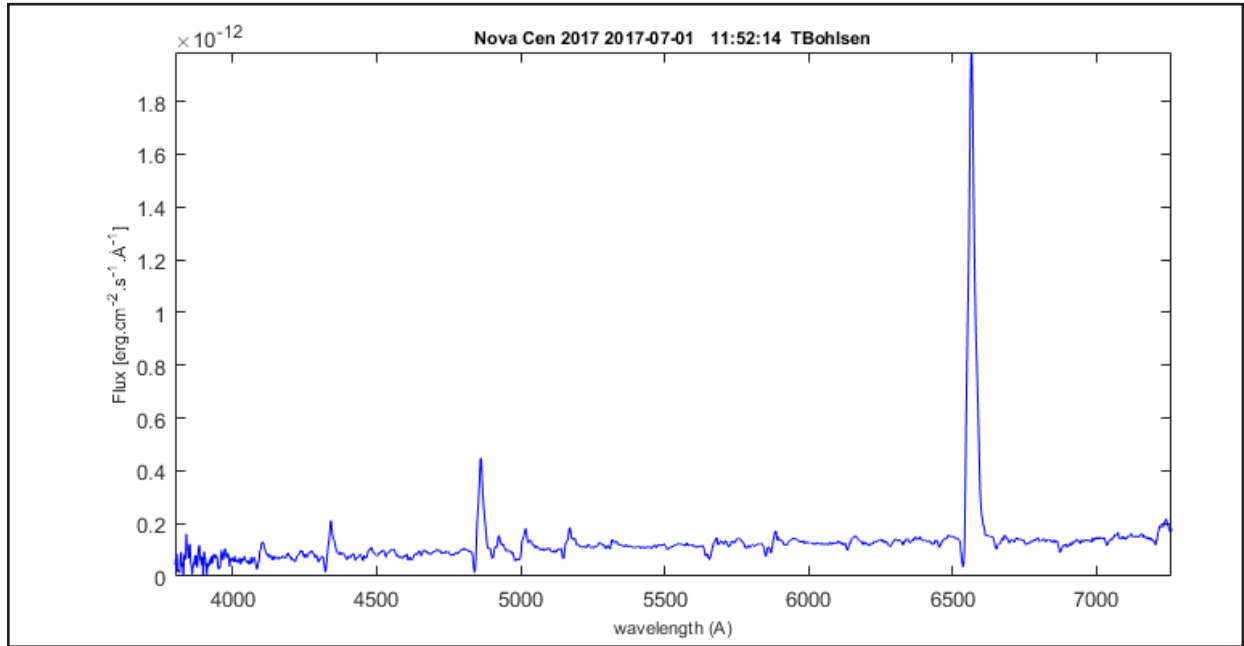


Figure 7. ASASSN-17gk calibrated spectra. Day 43. Terry Bohlson. ARAS.

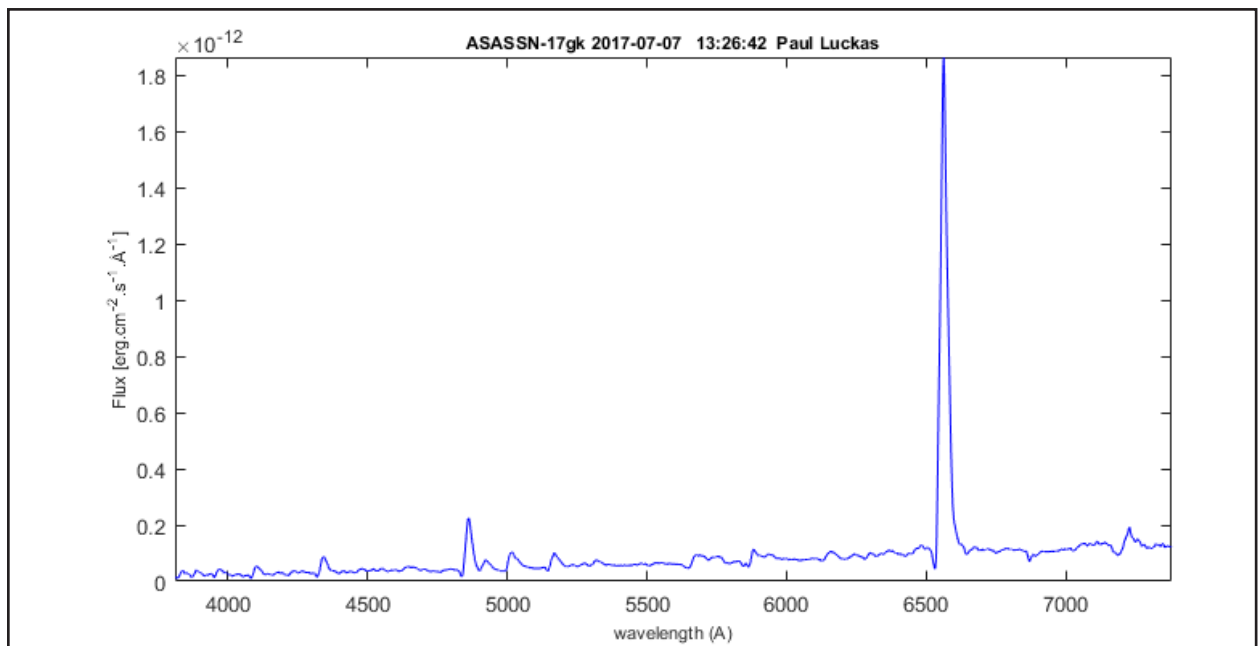


Figure 8. ASASSN-17gk calibrated spectra – day 49. Paul Luckas. ARAS.

vi. Day 46

There is a prominent dip in B-V but none of the other bands at vi. The lack of a similar feature in the other bands rules out a decline in V as cause and instead suggests a decline in B. It is worth noting that we don't expect to see anything of the progenitor WD at this stage. If we did, then we would see a blue excess as the B-V of the WD is -ve. This feature then is indicative of a decline in H β emission more likely.

vii-viii-ix. Day 49 – Day 64

The dominating feature in the light curve here is the prominent dip commencing about Day 49, reaching minimum about Day 59 and being fully recovered by Day 64. This decline affects all four photometric bands examined.

The colour indices indicate a rise in R-I, B-V and a dip in V-R and V-I. Overall this indicates a decline in V relative to all the other bands. R-I tending toward R is indicative of H α emission dominating relative to the other bands. B as argued above is supported by H β emission relative to V.

Summarising the prominent dip, there has been an overall decline in brightness and this has made H α emission more prominent relatively speaking leading to the red excess in R-I and H β emission providing a blue excess in B-V despite the overall decline.

x-xi-xii. Day 70 – Day 94

These three points indicate a short plateau in V-I followed by a significant dip again in the light curve. This dip is bounded by Day 70 and Day 94. Around the minimum of the dip at Day 81 V-R has declined with the other colour indices all at peak or climbing. This as elsewhere is a general decline in V.

xii-xiii. Day 94 – Day 108

The light curve in all bands declines. I has declined more rapidly than R. Both B and R have also declined less than V between those points—though not by much. V-I is almost constant which can only hold true given I has declined more rapidly than R, and V more rapidly than B.

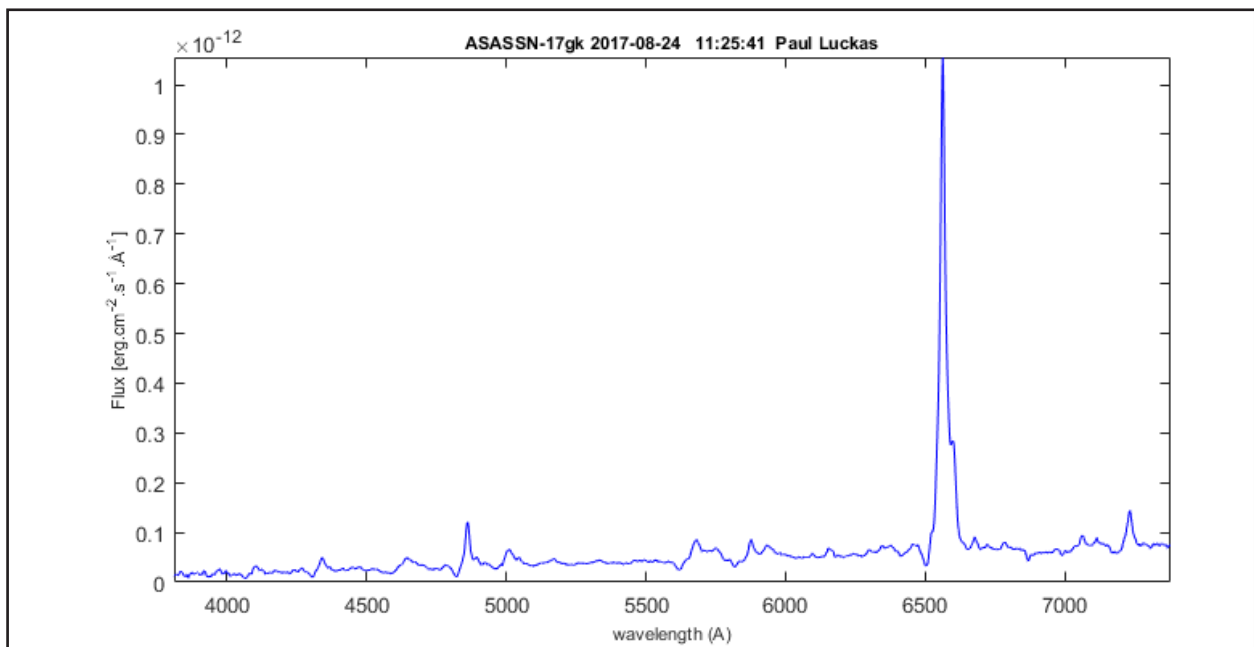


Figure 9. ASASSN-17gk Calibrated Spectra. Day 99. Paul Luckas. ARAS.

We have argued that B is more greatly supported by H β emission relative to the declining V. Similarly that V-R trending to R more than V can be suggestive of H α emission dominating.

So here we have likely H emission keeping the B and R bright relative to the declining V and I and all bands decline generally.

It also must be remarked that resolution of the light curve and subsequently the CI suffer at this point. The authors attempted photometry and spectroscopy whenever the weather allowed but that was infrequent and the low altitude of ASASSN-17gk from the respective observatory locations at twilight made the effects of cloud and trees that much worse.

Between Day 94 and Day 108 the spectra is limited but does show the H emission roughly halving in absolute flux terms. That said it remains prominent.

xiii-xiv. Day 108 – Day 123

In the colour indices, V-I rises sharply. R-I likewise. Indeed R-I is now -ve at $R-I = -0.111$ in the second to final datum for the R-I series.

Both the V-I and R-I tending toward smaller (even -ve) numbers is indicative of the sharp weakening of I. This is a sharp transition and likely indicative of the heat from the thinning ejecta no longer dominating the light from the nova.

B has also weakened relative to V as indicated by the colour indices found for Day 113 and Day 123 ($B-V = 0.805$ to $B-V = 0.964$).

R has also weakened relative to V over the same date range ($V-R = 1.794$ to $V-R = 1.434$).

A decline in B and R relative to V suggests H emission has declined.

We have noted a prior apparent halving of the $H\alpha$ and $H\beta$ flux in absolute terms above, so this is indicative of the same weakening of H emission.

What is unclear is whether any sign of the WD progenitor has occurred at this time. X-ray flux is expected (see Williams et al. 2008) once the nova ejecta have thinned enough for shorter wavelengths to penetrate. This would help confirm or reject the hypothesis that the thinning ejecta is now only partially opaque to the light from the progenitor system. i.e. We are catching our first glimpse of the progenitor post nova.

Regardless, this is not unusual and expected as the ejecta thin to irrelevance.

xv. Day 133

This is the final BVRI sequence obtained by one of the authors.

B-V has trended -ve. This indicates blue excess relative to V. V-R has trended +ve indicating a red excess relative to V. V-I has trended +ve indicating strengthening of I relative to V. This weakening of V can also be seen in the light curve. R-I has trended +ve also indicating strengthening of I relative to R. In the light curve we see that I has again become more bright than R. This is also borne out by the V-I and R-I trends.

The most marked drops in brightness are respectively V (0.884), B (0.578), R (0.533) with the least being I (0.18).

Summary

It remains plausible that we have expanding cooling ejecta generally moving towards longer wavelengths with increasing and decreasing $H\alpha$ and $H\beta$ emission superimposed and that $H\beta$ yields blue excess and $H\alpha$ yields R excess in the CIs ($B-V$, $V-R$ and $R-I$).

V can decline independently being less related to the overall temperature of the expanding cooling ejecta (peak black-body emission in I) nor being supported by $H\alpha$ or $H\beta$ emission.

At maximum light, colour indices can be used to derive a black-body temperature for the ejecta. This is the “pseudo-photosphere” of Arai et al. (2010). Beyond this point, H emission dominates $B-V$, $V-R$ and $R-I$. $V-I$ is unaffected.

It is conjectured that a black body temperature to $V-I$ relationship might avoid prominent emission in the ejecta and allow a longer period of the ejecta temperature profile to be determined than using a $B-V$ relationship where $H\beta$ emission creates a blue excess. It is anticipated that when the WD and companion

dominate ($U > B > V$) any such relationship would cease to hold. By this stage the ejecta are a very rare gas at best.

Given the temperature profile of the expanding and cooling ejecta commencing at the black-body temperature derived for the “pseudo-photosphere” phase, peak black-body emission for the ejecta is located initially in R and moves towards I.

Specifically ASASSN-17gk is a slow nova (NB) of probable low mass as it resembles Hillman models.

Acknowledgements

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Spectra were obtained from the British Astronomical Association (BAA) Spectroscopy Database.

Spectra were also obtained from the Astronomical Ring for Access to Spectroscopy (ARAS) Spectroscopy Database with permission.

Figures showing spectra contain acknowledgement for individual observers from the BAA and ARAS.

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Introduction

The first measures of this star were made in 1666 when the period was ~ 521 days. Consistent measures, however, did not begin until 1795 by which time the period had shortened to ~ 490 days. When I last analysed the period in 2002 it appeared that the period had stabilised at ~ 385 days by 1947 and was now alternating between ~ 380 and ~ 390 days with reversals every two or three decades as is normal with many Miras. But a study of the epochs since JD 2450000 shows that this is not the case.

Observed behaviour

Figure 1 is a periodogram showing the observed periods over the interval of 351 years. In the seventeenth century period variations were not expected and determination of epochs of maximum were only approximate so it is not clear whether the period was decreasing at that stage. But more consistent measures from 1795 onward showed that the period, 490 days by then, was clearly decreasing. But why the large scatter in the twentieth century?

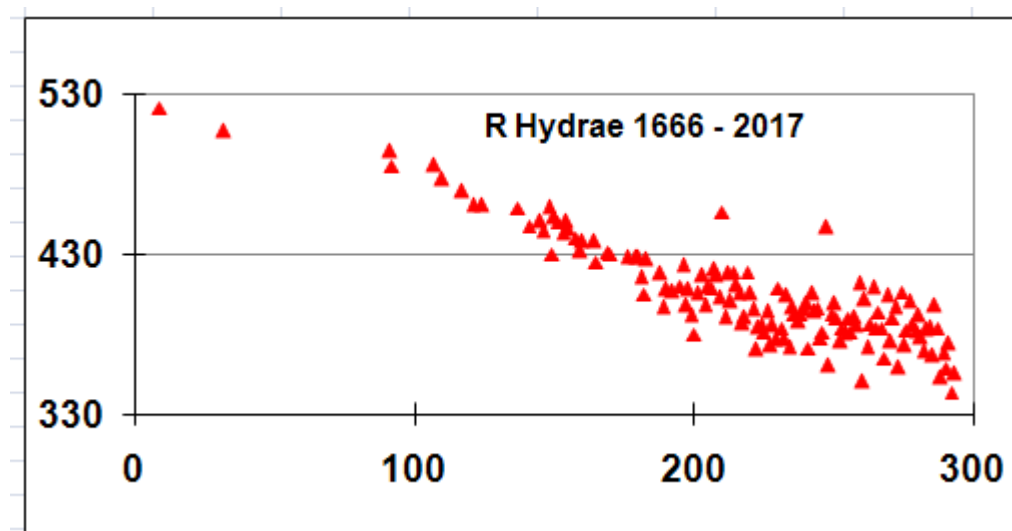


Figure 1. In this periodogram the period scale is shown vertically, epochs on the horizontal scale. The first two epochs are rather uncertain as to the period and a shift of the second epoch from 507 to 521 days would fit the slope better and indicate that the decrease in period began close to that year, 1708.

R Hydrae at RA 13 29 43 Dec -23 16 53 is only ~ 11 degrees from the plane of the ecliptic. There is thus a substantial period when it is unobservable. This is the situation at present and I have used epochs of minimum - after a correction for the offset - to determine epochs. This method is often used for Miras with dual or extremely wide maxima.

But there is another factor involved. If R Hydrae is nearing the end of the helium flash period change then it will begin to show alternations of a few percent around a mean period. These two factors would explain the messy latter part of Figure 1.

Are alternating periods the answer?

In the 2002 analysis this looked to be the case. But in 2017 that is not as certain. Whilst the mean curve shows some indications of alternate periods there was still a slope from 1947 to 2003 when the period was ~ 381 days. But the last 11 cycles have shown a dramatic decrease in period to ~ 360 days.

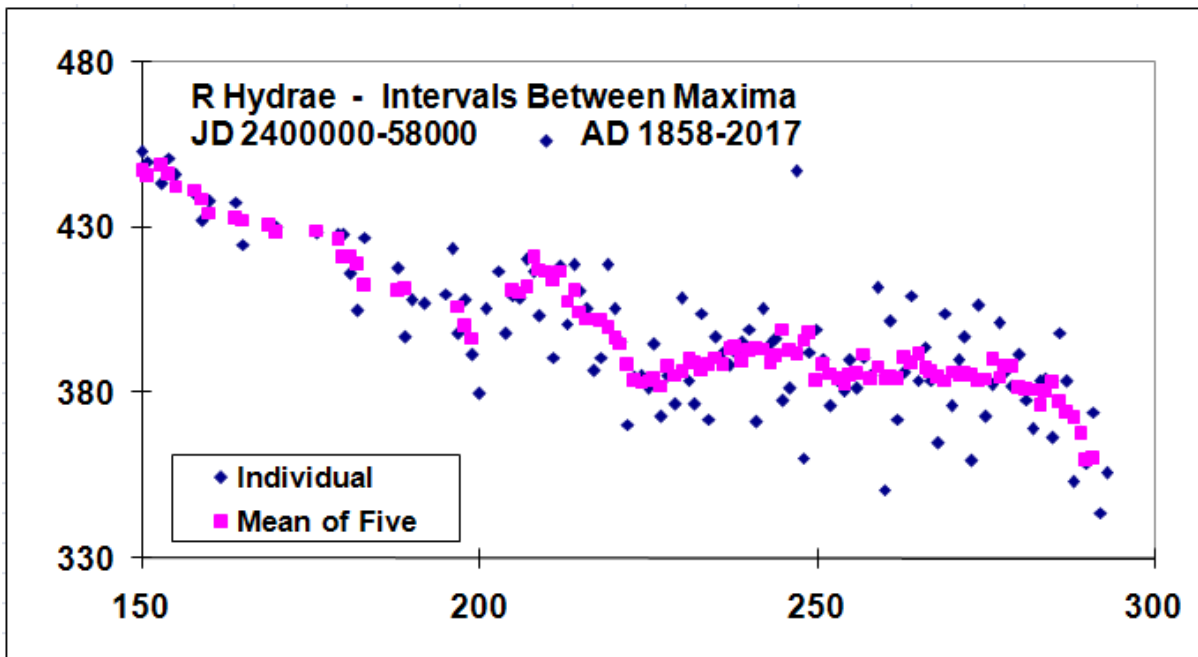


Figure 2. This periodogram covers the interval from 1858 to 2017. Until cycle 200 in 1917 the decline continued with the period reducing to the 1947 value of ~385 days at cycle 227. This slowly reduced to 382 days by cycle 285 when the present quick decline began.

General comments

The present period makes R Hydrae a real observational challenge. This is shown in Figure 3 where maximum has not been observed over the 2000 day period. The last maximum observed was in 2003 and if the period of 360 days persists it may be more than a decade from now before another maximum can be measured with certainty. It is just past minimum at present and after another month or two on the rise another epoch can be added.

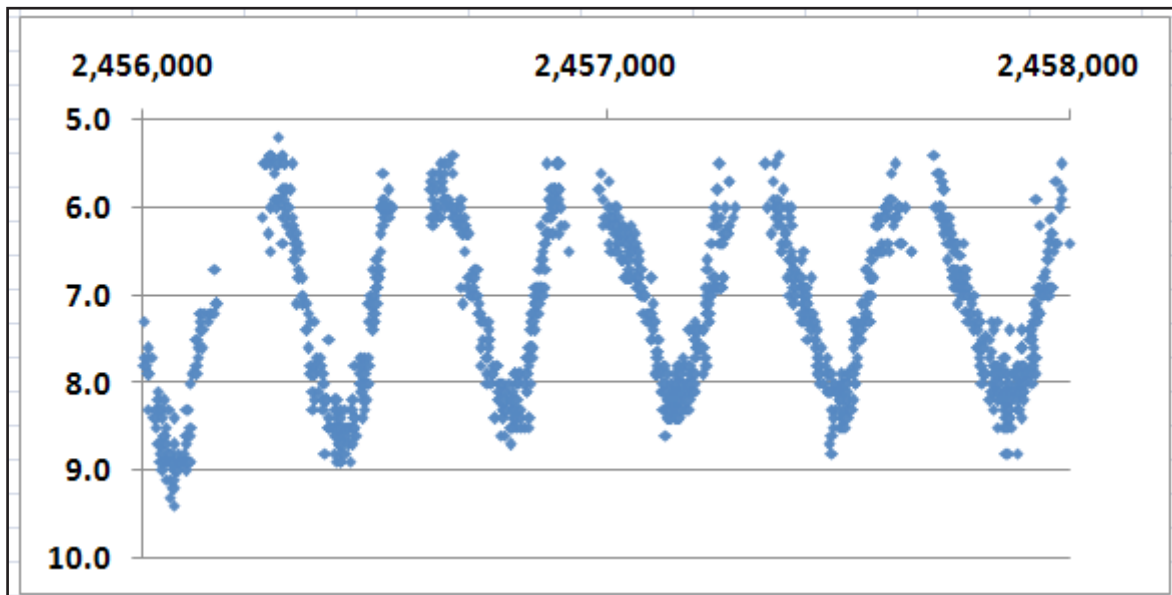


Figure 3. Measures of R Hydrae over 2000 days show the present difficulties in monitoring period change.

VSY shows a period of 380 days with a parabolic term - which latter might be expected with an eclipsing binary where the epochs can be determined accurately but seems rather imaginative for a Mira.

For those interested in Miras with humps R Hydrae shows the occasional well-defined hump at about 60-70% on the rising branch. This is where the hump on the rising branch of BH Crucis appears and I've often wondered whether R Hydrae once had a dual maxima. But the types of period change for these two stars are completely dissimilar so that is probably wishful thinking. Considering the brightness there is a surprisingly large scatter of the visual measures of this star - perhaps the lack of close comparisons is one factor here.

This star seems a good target for UBVRI measures but the brightness is something of a challenge. Even some DSLR BVR measures would be of interest. A snapshot measure every two weeks should provide an interesting light curve although there's the problem with the unfortunate period.

So this star was first observed about the time of the great fire of London and three and a half centuries later it's still not clear what it's doing. Observing Miras requires patience!

About

Variable Stars South is an international association of astronomers, mainly amateur, interested in researching the rich and under-explored myriad of southern variable stars.

Renamed from the Variable Star Section of the Royal Astronomical Society of New Zealand, it was founded in 1927 by the late Dr Frank Bateson, OBE, and became the recognised centre for Southern Hemisphere variable star research.

VSS covers many areas and techniques of variable star research, organised into projects such as Beginners' Visual Observations and Dual-Maxima Miras. The goal of each project is to obtain scientifically useful data and results. These may be published in recognised journals, or supplied to international specialist data collection organisations.

VSS is entirely an internet based organisation, working through our website <http://www.VariableStars-South.org> and its e-group <http://groups.google.com/group/vss-members>. It also encourages members to work in with major international organisations such as the British Astronomical Association, the Center for Backyard Astrophysics and the American Association for Variable Star Observers.

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