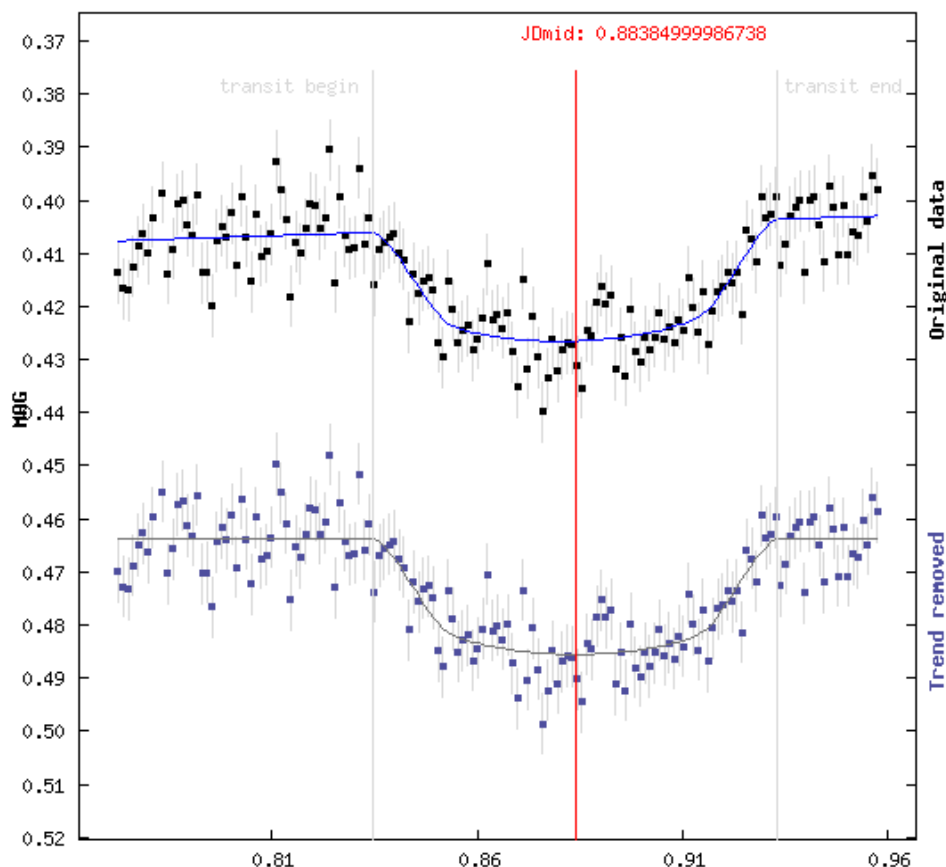




The light curve of the transit of exoplanet HATS-28 - upper curve is original data, lower curve has been de-trended for airmass. See "Exoplanets for amateurs" on page 28

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From the director – *Stan Walker*

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In the 1970s most of the serious optical astronomy in New Zealand was carried out by amateurs - there was a very strong presence in the visual observation of variable stars but also a very active UBV photometry group in Auckland and others were being established in Dunedin and Christchurch.

At a recent meeting in Auckland involving many of New Zealand's leading astronomers it was clear that if measured by observing hours a similar situation has probably already developed again. If we define optical as the range of the human eye, with a little ultraviolet and some near infrared thrown in to match the commonly used detectors, we are then looking at a narrow band of wavelengths which we call visual. But to understand our solar system, the structure and evolution of stars, our galaxy and the universe in general much larger telescopes need to be employed, looking at a much wider range of frequencies. So astronomy is moving away from many ground based visual astronomy sites and developing massive cooperations such as the square kilometre array (SKA) of radio telescopes in Australia and South Africa, with links to other countries, and the data is being analysed by theoreticians spread around the world. Then, if the atmospheric effects can be removed by the use of satellite telescopes, the quality and accuracy improves dramatically - resulting in much optical astronomy moving into space.

But there are some bright spots, mainly in amateur areas. Phil Evans has been monitoring exoplanet transits for many years and has recently become involved in a project in collaboration with a Czech professional astronomer and our members are invited to participate - see the project page on our VSS website. In New Zealand some groups have been involved in the detection of these by using microlensing techniques but that's a bit of a lottery - you cannot select the type of stars you think are most likely to have detectable planets. And the number found in this manner is quite a small percentage of the total. Here, also, satellite observations are now dominating the field.

Phil has also received the a request for collaboration from Sergio Messina of the Italian Institute for Astrophysics which is reproduced here - *"I write to kindly ask whether you may be interested to collaborate with me in the observational study of some young low-mass stars. Specifically, I am interested to derive their rotation period by collecting series of photometric observations.*

The stars I am talking about are too bright to be observed with large telescopes, whereas they are best suited for smaller telescopes like yours.

What I propose you is to observe one or more of such targets with your telescope in order to get a sequence of frames. Generally, it is necessary to get observations for a number of days (not necessarily consecutive) in order to derive the rotational period of the star.

In the case we get sufficient data and we can measure the rotation period we can communicate our results to some astronomical journal and you would certainly be co-author."

Sergio has previously collaborated with amateur astronomers and has several publications with amateur astronomers as co-authors.

<http://arxiv.org/abs/1603.07189>

<http://arxiv.org/abs/1607.06634>

<http://arxiv.org/abs/1506.04520>

<http://arxiv.org/abs/1510.08994>

<http://arxiv.org/abs/1506.07278>

If any VSS member is interested please contact Sergio direct at sergio.messina@oact.inaf.it.

One of our members - Andrew Pearce of Perth, as co-ordinator - has transformed the AAVSO LPV area into quite an informative part of their website with references to interesting papers and a star of the month

feature. But I notice little colour photometry of any of the highlighted stars other than those in our own dual maxima mira project. UBVRI photometry of these and some of the ‘hump’ stars might produce some interesting results.

Many observational research and analysis papers have been published in the RASNZ Journal, Southern Stars, over the years and it is good to see that these are now available through NASA ADS. This provides another useful outlet for papers at an appropriate level for some of our work. Since Variable Stars South is a section of RASNZ we should support that organisation when we can. The editor is a member, Bob Evans, bevans@es.co.nz and they publish in March, June, September and December. It is available on-line to their members with a hard copy version as well.

This looks a useful area in which to publish a review of the visual, photoelectric and CCD measures of L² Puppis which is under preparation at his time. We have now obtained a spectrum of V777 Sagittarii which is awaiting analysis and this project can then be successfully concluded.

On the personal front I’ve recently had a strong lesson in how much we now depend upon the internet. At 6:05 am in mid-August I was wandering around rather lazily when there was a brilliant flash and a tremendous bang which plunged everything into darkness. We’d had a very close lightning strike which affected everything electronic. The inverter - the house is more than a kilometre from the road so we use solar panels, wind generator and batteries - switched itself off and other equipment was fried by the electronic pulse. Even a couple of hundred metres of buried phone line has had to be replaced. So no internet for several weeks. A lash-up system restored some items - at least I could operate my bank accounts in a couple of days - but for some time I was on receive only in a very isolated area where service is erratic. So it’s been difficult to look up NASA ADS and other sources of background information - and observations - to complete articles.

In the sky the southern Milky Way is now coming into view in the early hours of the morning - so maybe a few measures of L² Puppis and some of the longer period Cepheids might be possible. My own observatory is now back in action so maybe you’ll even see a few measures from Waiharara.

The story of S Telescopii = CPD-55°9313 – *Mati Morel*

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Summary

The exact location of S Telescopii has been contentious for some considerable time. A study of the paper trail, from the moment of discovery in 1896, permits the conclusion that this variable is best reconciled with CPD-55°9313 (a lost or transient object), not GSC 8780-1530, a nearby 13^m star.

Background

The *Cape Photographic Durchmusterung* (CPD) was initiated at the Royal Observatory, Cape of Good Hope, in the 1880s at a time when two technical advances had converged.

- dry plate photography now made celestial photography feasible (by exposures of up to 60 minutes).
- the ‘Rapid Rectilinear Lens’, invented by Dallmeyer in 1866, made distortion-free images possible over the whole field of view.

Lenses by Dallmeyer were much employed by Gill at the Royal Obs., Cape, and 613 definitive plates for the CPD were secured between April 1885 and December 1890. In fact, all fields were taken at least twice, and often 3, 4 or even 5 times. The very best were reserved for the CPD and the rest, though often still quite good, set aside as “rejected”. The plan of publication, as it came to fruition, was

Part 1	Declination	-18° to -37°	(published 1895)
Part 2	Declination	-38° to -52°	(published 1897)
Part 3	Declination	-53° to -90°	(published 1900)

Several lenses were employed, with apertures from 4-inches up to 9-inches. The positions of 454877

stars were measured and published, for the equinox of 1875.0, but mean epoch of ~1888.2. The entire field which could be photographed was 6° x 6°, but it was arranged that only a clear central region of 5° x 5° would be used for measurements. No grid was printed on the plates, rather a measuring device known as a “parallactic apparatus” was used. Two plates were placed, one in front of the other, and examined through an eyepiece with a magnifying power of 3.3 diameters. Kapteyn says:

“In the common focus of the objective and eyepiece is inserted an excellent glass scale for measurement of the declinations. The scale is a photographic one; the surface of the film is protected by another glass plate, and covers the whole field. A single line, on which the pointings for right ascension are made, stretches along the diameter of the field at right angles to the declination axis. There are 66 division lines, one for every minute of declination, and 3 above and 3 below the whole degree of declination, to give a bit of overlap.”

Routine measurements were made directly from the eyepiece scale. No intermediate readings or reduction was needed. Pointings to bright reference stars (from Gould Zone catalogue) were made as necessary to tie the measurements to the 1875.0 frame of reference. However, the distribution of Gould’s zone stars was often uneven, and accurate pointing often depended on only 2 or 3 stars.

CPD - 55°9313 (9.0) = S Telescopii

This star was found bright (on the CPD magnitude scale) on two CPD plates.

Plate no. 776	1887 Sept. 17	9.0	Plate centre	20 ^h 0 ^m .0 -55°.5
Plate no. 780	1887 Sept. 20	9.0	Plate centre	20 ^h 0 ^m .0 -55°.5
Plate no. 2749	1890 July 9	<10.4		
Plate no. 2894	1890 Oct. 22	<10.4		
Plate no. 2919	1890 Nov. 4	<10.1		

The discovery was made in 1896, some years after the event, and reported by Kapteyn in *Astron. Nachrichten* (#3389, 1896 Nov. 30). The details of the discovery plates were repeated by Innes (Cape Ann.9, 1902), under *Observations of Variable Stars*. The CPD position of -55°9313 is quoted. S Tel is also listed by Müller and Hartwig (1920), with CPD number and position.

On modern DSS plates nothing can be seen at this spot down to $m = 20.7$. The old CPD scale is too bright compared to modern B magnitudes. I have compared a dozen CPD stars around S Tel with modern APASS magnitudes, with these results.

CPD	B (mean)	N	
9.0	10.01	5	Range 9.75-10.17
9.8	11.75	2	
10.4	12.4	5	Range 12.24-12.62

Visual observations

From 1897 Aug 8 to 1901 Oct 2, Innes (1902) observed the position of the star on 54 nights. Apart from one positive observation on 1897 Sept 13 (self-acknowledged as erroneous), there were no positive sightings. Using a 7" Merz refractor he could on occasion reach ~14.0v, on the modern scale. There was no deep photometric scale at that time, only the observer’s personal judgement. No sequence or chart was published for S Tel, but Innes provided charts and sequences for many long-period variables in Cape Ann 9. It is clear from inspection that his visual scale is too bright. So, when Innes claimed to reach a particular magnitude, he was by modern standards actually going much deeper. An example is his sequence for S Tucanae (abbreviated here), compared to APASS photometry.

Innes	V
10.5	12.0
11.5	12.7
12.0	13.2
12.5	13.7 (extrapolated)

On at least ten occasions Innes found S Tel invisible at <13.2v. On 4 nights it was recorded as invisible, <13.7v on the modern scale. I surmise that since S Tel was discovered on CPD plates, and he would have been acquainted with its **exact** position, while observing at the Cape, his 54 observations must be accorded the highest weight.

Harvard scrutiny of S Tel

It is clear from notes in Cape Ann,9 that by the late 1890s equivocation had already crept in as to which field star may be identified with CPD-55°9313. Pickering, at Harvard Obs., was asked to look on their plates for a star showing variability. In a reply dated 24th Sept. 1901, Pickering noted that a star in the vicinity showed variation from 11.5 - 13.0p on nine plates. But, which star? My study of small scale photos of the region, down to 13th mag, shows that the position given in the CPD, and the star found by Pickering are quite close. The workers at Cape around 1890, using very slow plates, would hardly have recorded other faint background stars for the CPD, nor did they need to. If Pickering had only an approximate position to work with, it would not be surprising if a misidentification arose. The CPD plates from 1890 show that the star had faded by the time attention could be given to it.

Innes and Pickering appear to have studied two different positions. A clear indication of the position adopted at Harvard for Pickering's star is given by Campbell (1913), a visual sequence for S Tel. His coordinates for S Tel (still called by its CPD no.) are given as:

(1900) 19 58 20 -55 51.5, equivalent to (J2000) 20 06 16.2 -55 34 30.2.

This is a close match for GSC 8780-1530, lying 86" Sw of CPD-55°9313. As of 1951, a field photograph and an AAVSO standard chart for S and RR Tel, endorsed by Harvard Observatory, adopted the same position and visual sequence as that given by Campbell (1913). Modern APASS and ASAS-3 observations give us the following :

	B	V	
GSC 8780-1530	13.589	13.02	APASS (29)
	13.05 (0.09)		ASAS-3. No significant variation.

The same Harvard photo was used to create RASNZ chart 210.

It appears that the GSC star was not observed by Innes. It would have been within his reach, yet he always found S Tel invisible through a 7" refractor on more than 50 nights.

Validation of CPD positions near S Tel

At this point in time it is not possible to confirm the accuracy of the CPD position of -55°9313 as the original plate is not available. It is however possible to validate the quality of the CPD positions, generally, in the vicinity of the variable, to determine any systematic errors. I have done this by examining all CPD stars in a 30' x 30' box, centred on CPD-55°9313. Eleven stars are listed, none variable, and all can be identified in modern astrometric catalogues, such as UCAC4. By taking their positions for epoch/equinox J2000 and known proper motions I have calculated their **true** positions for epoch 1887.9 and equinox 1875.0. This yielded their true positions on the CPD plates of September 1887, and can be compared with the published CPD positions. See Table 1. The original CPD positions are given in full, but I give only the end figures of my calculated positions, to save space. Differences are given, in the sense $RA_{CPD} - RA_{UCAC4}$ (in RAs^{ec}); $DEC_{CPD} - DEC_{UCAC4}$ (in arcsec).

Table 1: Comparison of CPD and Epoch 1887.9 positions of nearby CPD stars

CPD	mag	B	V	(1875, CPD)	Endfigs	1887.9	ΔRAs	Δarcsec
-55 9303	10.4	12.44	12.18	19h54m18.8s -55°50'24"	18.24	26.7	+0.56	- 2.7
-55 9308	9.4	10.69	9.47	55 35.3 -55 42 30	35.34	26.9	-0.04	+ 3.1
-55 9309	9.8	11.67	11.25	55 40.3 -55 28 54	40.14	53.3	+0.16	+ 0.7
-55 9312	10.4	12.38	11.75	55 59.8 -55 29 48	59.92	45.7	-0.12	+ 2.3
-55 9314	10.4	12.62	11.90	56 52.8 -55 37 54	52.81	52.0	-0.01	+ 2.0
-55 9315	10.4	12.43	12.01	57 5.3 -55 28 06	4.31	12.8	+0.99	- 6.8
-55 9316	10.4	12.39	11.78	57 26.8 -55 57 00	25.91	43.7	+0.89	+16.3
-55 9320	10.4	12.73	10.83	58 11.3 -55 43 00	10.93	50.0	+0.37	+10.0
-55 9322	10.0	12.24	10.63	58 14.8 -55 55 54	14.27	37.8	+0.53	+16.2
-55 9323	10.4			58 18.3 -55 11 00	17.68	47.2	+0.62	+12.8
-55 9324	8.6	9.92	8.51	58 24.9 -55 02 30	24.37	21.2	+0.53	+ 8.8
-55 9325	9.6	1.43	10.16	58 57.6 -55 53 00	56.88	53.2	+0.72	+ 6.8
CPD 9303-9314						Means	+0.11	+ 1.1
CPD 9315-9325						Means	+0.66	+ 9.2

These rigorous calculations fully confirm a trend which I had previously observed by casual plotting of CPD positions using Guide9®.

From these results one can see that from -55°9303 to 9314 the pointing of this plate is quite accurate, with commendably small errors. At about 19^h57^m.0 there is an abrupt change, with errors being much larger. I interpret this as being due to a change in the pointing, probably to a new reference star. CPD-55°9313 = S Tel falls within the domain of low errors, and therefore one would not have any good reason to doubt its accuracy. The positional accuracy should be good to within ±3", or better.

[A very detailed description of the methods used to take plates for the CPD, and measure star positions is given by Gill (1895), in the introduction to Part 1 of the CPD.]

Conclusion

On modern UK Schmidt plates the positions of CPD-55°9313 and GSC 8780-1530 are very well resolved. From my analysis of CPD positions there is nothing to suggest errors in both coordinates of the order of +5°.0 in RA and 75" in Dec, which has been inferred. Rather it is more likely that the Harvard workers misidentified the CPD star, as shown by their own records. If S Tel is real (not yet recovered), an apparent transient, a nova or other eruptive type, then its range is from 10.0B - <20.7. It is probably best to retain the original CPD position to avoid continued confusion. By applying correction for precession from 1875, we have

$$\text{CPD-55°9313} = \text{S Tel (J2000)} \ 20^{\text{h}}06^{\text{m}}21^{\text{s}}.10 \ -55^{\circ}33'05.9''$$

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NSV 4964 recovered – *Mati Morel*

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Summary

The obscure object **NSV 4964** = **Innes b** is now identified. Precise astrometry and photometry is now reported, though its variability cannot be confirmed. Provisionally, it is non-variable.

Introduction

Innes (1914) announced three new variables, provisionally labelled **a**, **b** and **c**. The identities of **a** (=AP Car) and **c** (=BX Car) are secure. The remaining star, **b** = NSV 4964, is poorly known, with only an approximate position. Innes gives (1875) 10^h40^m.4 -59°9'. Apart from the initial announcement in UOC 18 (1914), further observations (7) were reported in UOC 26 (Innes 1915). The star was estimated with certainty on two Union Observatory plates - 1911 April 18 (16p, exp. 65min) and 1914 April 27 (15.8p, exp. 75min). An approximate or uncertain estimate of 16p was made on 1897 Jan. 30. On four other plates it was invisible. From this one can surmise that NSV 4964 is a rather faint star, barely within the grasp of early 20th century equipment.

Identification material

Innes (1914) provides a half-tone reproduction of the field, centred on Eta Carinae. Star **b** is labelled, but the scale is compressed and the poor quality of the reproduction makes identification impossible. In the text Innes states that **b** is 0.8' north of a 15th magnitude star, which can be identified by reference to

Harvard Ann. 26, Plate V, 2, with offsets of 39.5mm in from the bottom LH corner, and 45.0mm up. This star is found at (J2000) 10 45 14.817 -59 49 29.8 UCAC4 and has APASS data : $V = 12.934$, $B - V = 0.668$.

NSV 4964

Astrometric position. I find a star which best fits the stated offset (0.8' N), at this position:

ICRS (J2000) **10 45 13.331 -59 48 42.13** according to SIMBAD.

BV Photometry. Magnitude data is available from VizieR/SIMBAD from multiple sources. Two recent sources, for instance, are given below, with their uncertainties.

Name	V	B-V	B	Source
[HSB2012]3630	15.750 (0.005)	0.749 (0.008)	16.50	Hur et al 2012
"	15.683 (0.106)	1.030 (0.26)		APASS

Optically the star is rather faint, and would probably have been glimpsed by early observers only under very favourable seeing conditions This would explain the failure to see the star on most of their plates. NSV 4964 is not in the GDS (Hackstein et al 2015). Variability cannot be confirmed, though one must have severe doubts. See **Figure 1**.

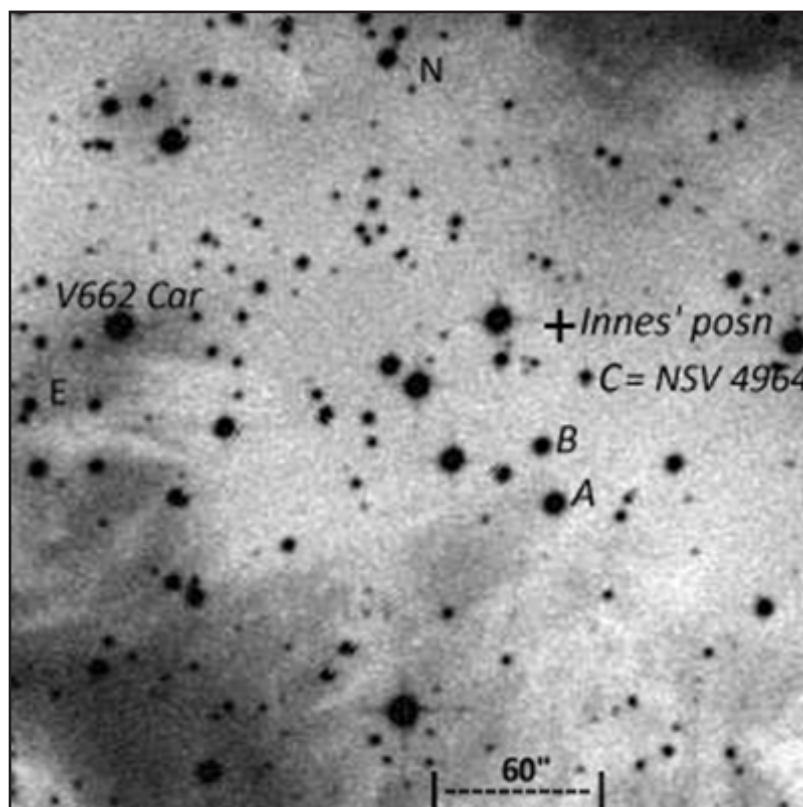


Figure 1. Field chart. Star A is Innes' 15mag star (refer to text); is actually $V = 12.934$, $B = 13.60$. Star B (14.19, 15.00) is not Innes' variable, as it appears on many archival images from 1895 onwards, from observatories at Sydney, Cape and Harvard. Innes' approx. position marked by cross. Star C is the best fit to NSV 4964, consistent with stated offset from A. [Red light image from Digitized Sky Survey].

Conclusion

It should be noted that lack of visibility is not, in itself, proof of variability. Negative results can result from other causes - atmospheric or instrumental. This seems to be the case with NSV 4964, which was always close to the threshold of the instruments in use in the early 1900s. While the exact position of NSV 4964 now seems secure, there is no convincing evidence of variation.

Acknowledgements

This research made use of VizieR and catalogues in SIMBAD.

This research was made possible through the use of the *AAVSO Photometric All-Sky Survey (APASS)*, funded by the Robert Martin Ayers Sciences Fund.

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CE Puppis and other long-period Cepheids – Stan Walker

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Introduction

The short term period changes in Cepheids with periods of over 35 days such as RS Puppis and U Carinae are now well documented with epochs derived from observations by ASAS3, Pojmanski, 2002, and a compilation by Berdnikov, 2008.

To extend this concept a little further I analysed available data on the even longer period object, CE Puppis. It was first described by Hertzsprung, 1941, who assigned an epoch of JD 2426222.2 and a period of 49.53 days from 45 measures of photographic observations on the rising branch over 16 cycles. There is no reason to suspect this value. He also commented that by JD 2428000 the maxima were occurring about 0.25 phase early. Pel, 1976, included it in his analysis of Cepheids and other supergiants but had problems with the period - the best fit to his data was 49.123 days based on matching two rising branches.

The conventional method of determining a period by taking two widely separated epochs and dividing by the number of cycles strikes problems when there are short term period variations superimposed on a constant period, or even one with changes over a longer time scale. This is clearly shown in figure 1 where a period of 49.380 fits the interval 50000 to 55000 as a whole but is in reality made up of two periods of 49.43 and 49.28 days.

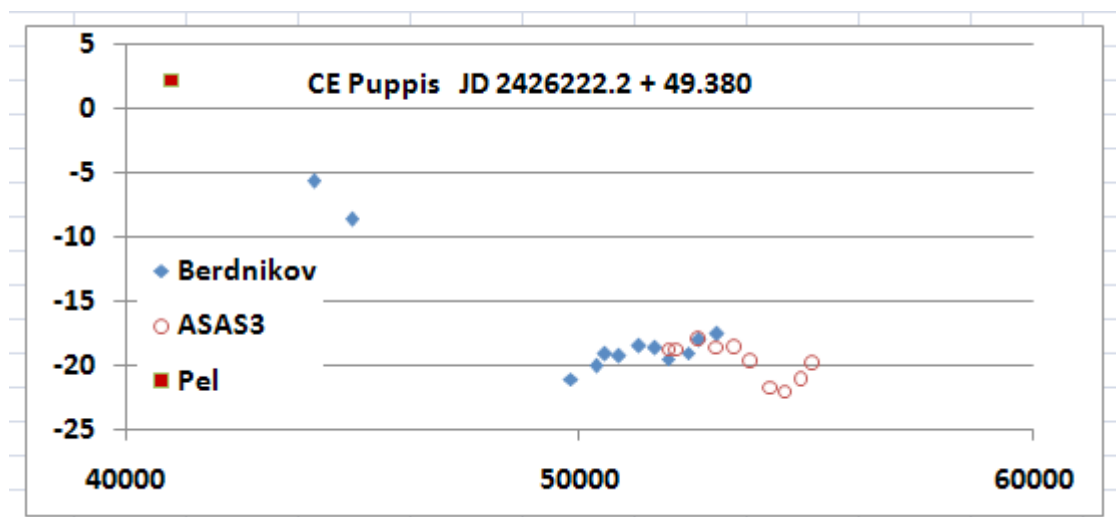


Figure 1. Photoelectric maxima of CE Puppis as determined by fits to the published measures. There are two periods clearly shown in this graph: a period of 49.2489 covering the first four points and a longer period of 49.380 from 1995 to 2009.

To help resolve this problem as it relates to CE Puppis let's consider the interval 26222 to 41137 during which there is no available data. It is possible to determine four possible periods based on the assumed number of cycles:

300 cycles	49.7167 days	301 cycles	49.5515 days
302 cycles	49.3874 days	303 cycles	49.2244 days

The last measure used by Hertzsprung in his analysis was JD 2426514 leaving an interval to the confusing measure at JD ~2428000 of 1500 days, or ~30 cycles,. Adopting the 303 cycle period as the

closest fit from the much longer interval as above a difference in period of 0.3056 days is derived. Over 30 cycles this amounts to 9.2 days. But there are enough uncertainties to accept this as a reasonable fit to the data. The mean uncertainty of the fit of the original 45 epochs was 0.94 days, the probable change in period could have occurred slightly earlier than the end of the dataset and the current behaviour as shown by the ASAS3 and Berdnikov data shows a spread of 5 days, probably cyclical - finally a 'quarter phase' could in itself be uncertain by several days. So it all fits together.

U Carinae and RS Puppis

How does the performance of CE Puppis match two stars we have been measuring and analysing? Parts of the light curves of U Carinae and RS Puppis are shown in Figure 2 and 3. These are from a poster paper presented by the Cepheid group at VSSS4 earlier this year. Less certain is another long period star, l Carinae. Most measures of this are visual and the amplitude is low.

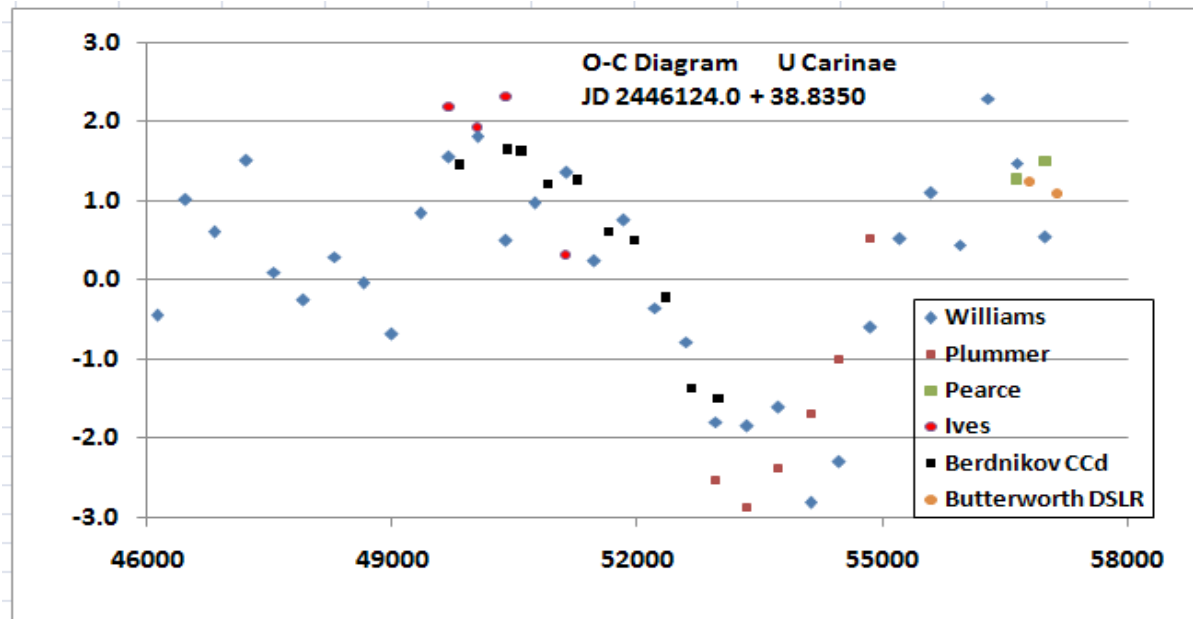


Figure 2. This shows a mix of visual and photoelectric measures of U Carinae since 1985. Each point represents an epoch of maximum derived from a season's (one year) measures from the named observers. The first four observers are visual. Similar behaviour was observed by Roberts, a well-known South African visual observer in the interval 1891-1920.

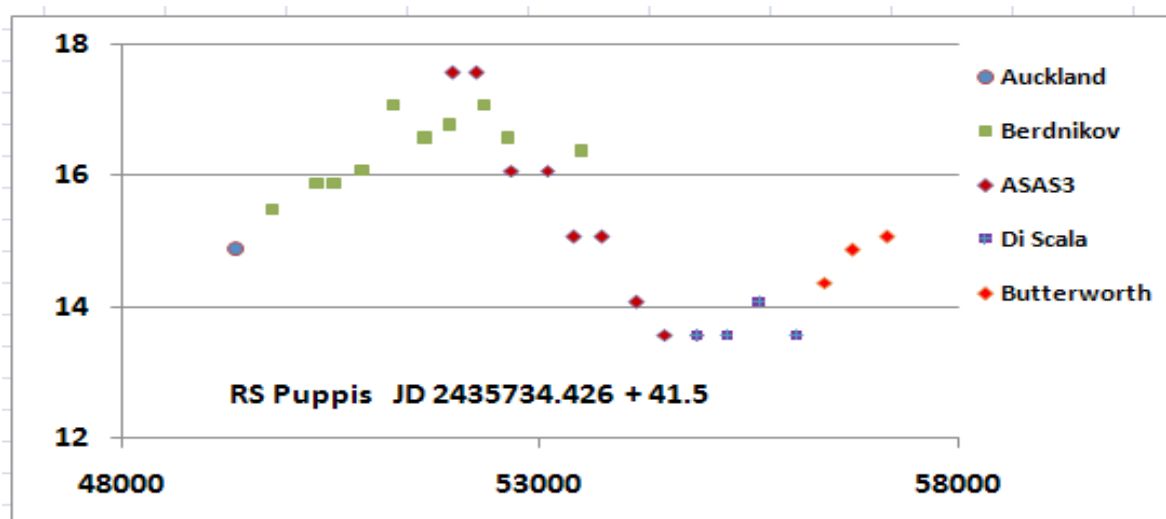


Figure 3. This graph shows PEP, CCD and DSLR epochs of RS Puppis since 1990. The original epoch is based upon the GCVS value but the period is that of the current interval. The period has changed from 41.3876 about year 2000 which accounts for the apparent lateness of the epochs. There are not enough visual measures of this star at present to add these to the plot.

What of even longer period Cepheids?

The GCVS, Samus et al, 2007, lists 27 Cepheids with periods longer than 30 days of which 20 are in the southern hemisphere. But these are not as well studied as their northern counterparts, two of which are close together in Vulpecula. Figure 4 shows an O-C diagram of S Vulpecula from Mahmoud & Szabados, 1980. This covers the period 1862 to 1979 and there are clear indications of a cyclic period - which they estimate as 25 years - superimposed on the mean period of ~ 68.0 days. The GCVS quotes the amplitude of this Cepheid as 0.72 magnitudes which is marginal for visual observers so this should be borne in mind when considering the analysis.

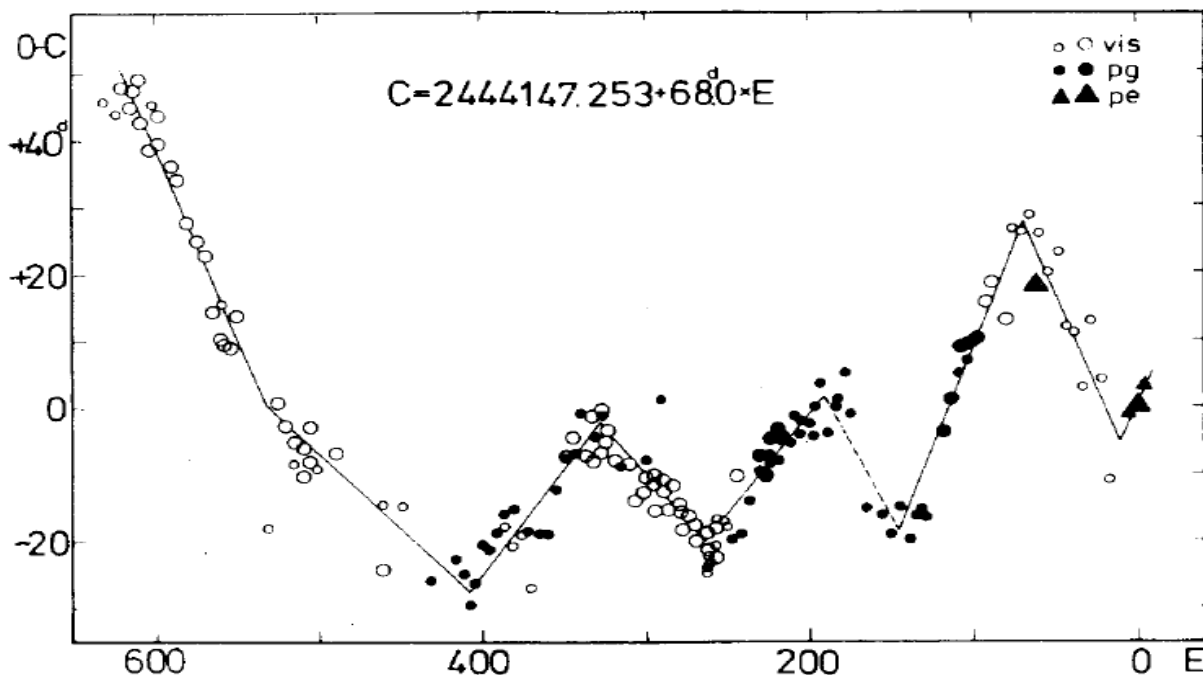


Figure 4. Epochs of maxima of S Vulpecula from 1862 to 1979. Note that these were based entirely on visual measures until 1899 and then photography and visual until 1968. Epochs are negative, -600 is 1866, -400 is 1905, -200 is 1942. This figure is from Mahmoud & Szabados, 1980.

The amplitude of the cyclic period is variable and as it is in large part based upon visual measures is uncertain, but it is in the order of 20 days with a period of 22 to 26 years. The later photoelectric measures show similar values which account for the slight waviness in the last 16 measures of figure 5 below. This may well apply to the very early measures as well but there are too many gaps in the data to conclude anything.

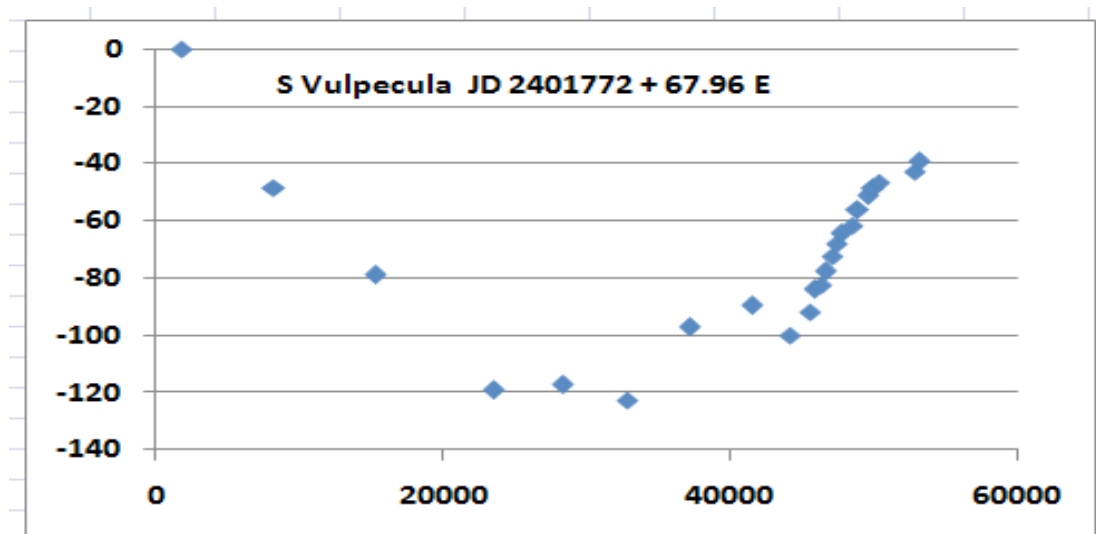


Figure 5. An updated version of figure 4 incorporating additional epochs from Berdnikov and a few from

ASAS3. Earlier epochs are from the GCVS. The period alternations are not shown in this graph but it displays the behaviour of S Vulpecula over 150 years much more clearly.

From figure 5 it is clear that the period from 1862 to 1905 was ~67.59 days, then ~67.96 days until ~1973 and is now ~68.40 days.

There are reliable colour measures in Berdnikov's compilation and from these the star appears normal for a Cepheid of such a long period. There may be some U excess but there is little to compare it with. Mahmoud and Szabados' colours are too blue but they have mentioned trouble with a close companion to the comparison star and certainly their V magnitudes are 0.15 too faint. This is puzzling. The separations of ~18" should not have been a problem - we measured individual components of KZ Pavonis at Auckland in the 1980s. This has a separation of only 5" to 7" and on good nights the individual components could be measured separately. S Vulpecula lies within one degree of the galactic plane and clearly there is heavy reddening - about 1.0 in B-V and the colours appear Miralike.

Whilst visible for our northern members the presence of this close companion at 18" makes DSLR photometry uncertain. Close by is an even brighter Cepheid, SV Vulpecula, V = 6.72-7.79 with a 45 day period which might be interesting as a target.

Observational methods

Many of the available observational datasets comprise 25-40 measures during a single cycle and not all of these include maximum or significant portions of both the rising and falling branches. Thus accurate transformations become critical - although for these long period objects epochs of +/- a day are adequate. Our observers use a less concentrated approach, making random measures during a season which is six months for most of these stars, located as they are close to the galactic equator.

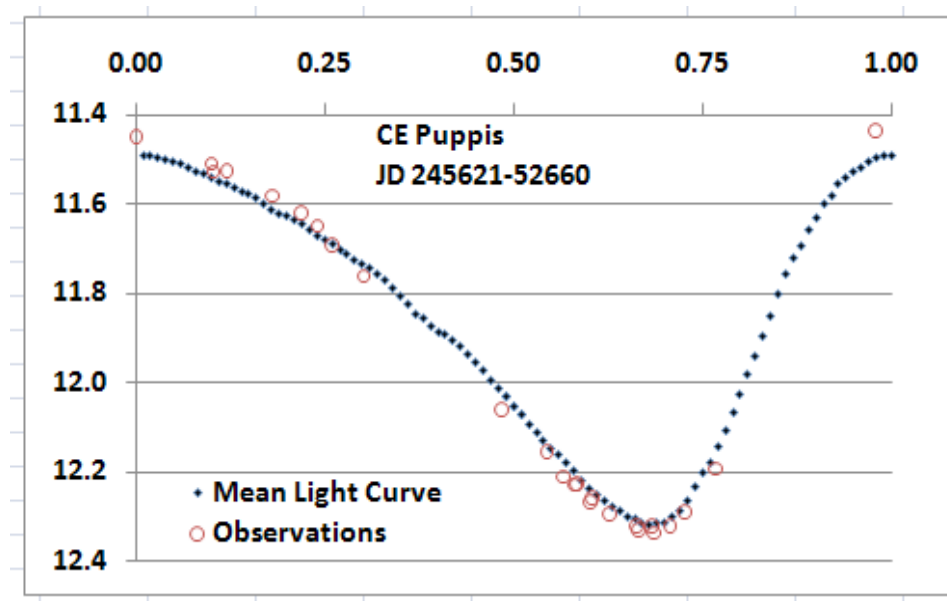


Figure 6. This illustrates two of the reservations discussed - a 40 day observing season covers only 80% of the light curve and most of the rising branch which provides the highest weight to the measures is missed. The slight disparities in the fit of maxima and minima may be related to the radial velocity variations considered in the text. The fluctuations in period as shown in figure 1 make mean light curves a little inaccurate as well.

A recent paper by Anderson, 2014, involved the study of radial velocities of four stars, QZ Normae and V335 Puppis, as well as the two long period objects, I Carinae and RS Puppis. In all of these stars he found radial velocity modulations which may have been periodic - but it is a small sample. If there are RV modulations then there should be accompanying magnitude variations. This suggests that seasonal measures are probably more accurate.

Another aspect of the published measures of CE Puppis was that later measures did not include the B filter. The declining branch of the light curve differed slightly in shape, presumably as a result of using

V-I to determine V instead of B-V. These later measures had a slightly curved decline with a very slight shoulder reminiscent of W Virginis stars. But this does not affect the epochs.

It is unlikely that CCD or DSLR epochs of these longer period Cepheids can be determined to much better than 0.5 days but an accuracy of one day is probably sufficient given the amplitude of the epoch variations. Thus 10-15 measures away from maximum or minimum should be adequate. I was amused by a determination to three decimal places of one epoch of S Vulpecula based on four measures, two of which didn't match the rest very well.

Conclusion and project extension?

It's interesting that some of these longer period Cepheids seem to show similar cyclic fluctuations in periods to those of Mira and SR stars. Most of them are in the south so it would be useful to obtain DSLR and CCD measures of these stars.

It is generally accepted that energy transport by convection becomes important at around spectral class F5 with stars cooler than this having convective envelopes. The longer period Cepheids have spectral classes which lie partly in this cooler region during a pulsation cycle. This allows mechanisms which can distort the pure radial pulsations generally associated with Cepheids and which may be associated with these cyclic period variations

A list of southern Cepheids with periods of more than 30 days is appended. One interesting feature is that the amplitude begins to decrease at around 40 days making them less suitable for visual measures. But then the comparisons are probably closer in many cases which makes for greater accuracy. Presumably APASS can provide comparison values for stars of $V = 11$ or fainter - at brighter levels use the Hipparcos/Tycho V values. Or maybe one of our members with a wide field CCD could produce a useful comparison sequence for the fainter objects.

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Appendix 1. Southern long period Cepheids

NAME	R A	Dec	MAX	MIN	RANGE		EPOCH	PERIOD
BZ Tuc	4143.4	-734324	11.53	12.44	0.91	V	44141.64	127.61
V4061 Sgr	185617.5	-273126	12.9	14	1.1	B	41842.	92.2
V2719 Sgr	181355.7	-324238	15.6	18.8	3.2	p	35687.9	70.8
V0686 Cen	113137.5	-610321	12.4	14	1.6	p	28720.	69.3
S Vul	194823.8	271711	8.69	9.42	0.73	V	44147.2	68.464
II Car	104849.1	-600347	14	14.9	0.9	p	24884.80	64.24
CG Sgr	190016.5	-354607	14	14.5	0.5	p	14127.	64.1
GY Sge	193513.6	191209	9.84	10.6	0.76	V	44700.50	51.0625
SS Tuc	10149.5	-720545	12.87	13.57	0.7	V	27750.478	49.684
CE Pup	81408	-423405	12.5	13.6	1.1	p	26222.20	49.53
SV Vul	195130.9	272737	6.72	7.79	1.07	V	43086.89	45.0121
RS Pup	81304.2	-343443	6.52	7.67	1.15	V	35734.426	41.3876
U Car	105748.2	-594356	5.72	7.02	1.3	V	37320.055	38.7681
EV Aql	190646.2	145546	12.4	13.9	1.5	p	36762.2	38.767
V2641 Oph	173357.2	-203024	12.9	13.8	0.9	V	52934.50	38.518
EN TrA	145700.7	-685023	8.7	9.1	0.4	p	41785.0	36.54
I Car	94514.8	-623028	3.28	4.18	0.9	V	40736.9	35.53584
V0641 Cen	143907.9	-595009	9.96	10.86	0.9	V	41771.771	35.216
EZ Vel	92507.4	-531236	13.4	14.96	1.56	B	34532.64	34.5346
V0567 Sco	164950.7	-405506	12.21	13.31	1.1	V	29820.0	34.0483
KN Cen	133636.9	-643330	9.28	10.36	1.08	V	36238.172	34.0457
ST Hyi	14032.2	-743026	12.58	13.7	1.12	V	30561.604	33.326668
RV Nor	160410.2	-560448	12.2	13.8	1.6	V	44119.43	32.333
AQ Pup	75822.1	-290748	8.08	9.39	1.31	V	44676.57	30.104

It's about time – part 2 – *Phil Evans*

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In a previous article (NL15-3) I wrote (following advice from Blair Lade from the Australian Defence Science and Technology Organisation) that simple GPS devices without pulse-per-second (pps) output will keep your computer accurate to only the last second. Alas my \$25 GPS unit from Amazon did not have pps output and the only ones I could find online at the time were hundreds to thousands of dollars.

I have now found a relatively inexpensive one that does – the Garmin 18x LVC available for US\$64 from Amazon.



Garmin 18x LVC GPS Navigator Unit

by Garmin

★★★★★ 27 customer reviews | 7 answered questions

Price: **\$63.85** & **FREE Shipping**. [Details](#)

In Stock.

Want it Thursday, Oct. 20? Order within **16 hrs 53 mins** and choose **One-Day Shipping** at checkout.

[Details](#)

Ships from and sold by Amazon.com. Gift-wrap available.

Package Type: **Standard Packaging**

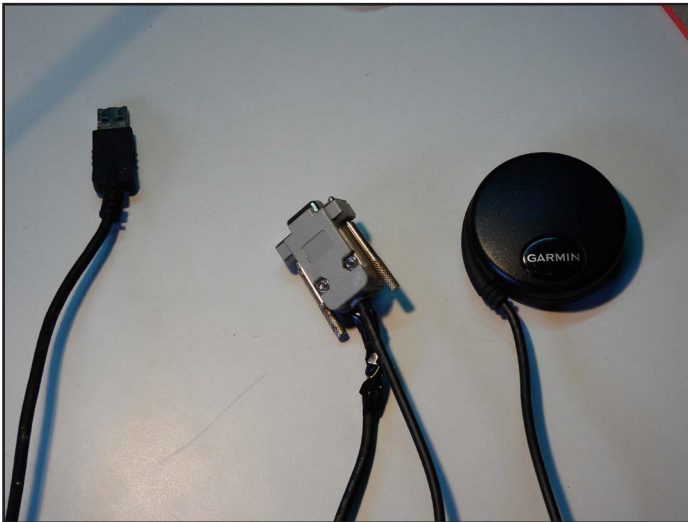
- High Sensitivity LVC Sensor with Bare Wire Connection
- WAAS Enabled High Sensitivity GPS Receiver
- Comes w/A Connector End that Can Attach to a CMOS for OEM Applications
- Non Volatile Memory for Storage of Configuration Information
- Raw Measurement Output Data for Sophisticated Customer Applications

51 new from **\$45.00**

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It is small, less than 7cm in diameter, and comes with a very long (5 metres) cable but you will notice from the photo above that the end of the cable is bare and that means some assembly is required.

The unit expects to find a serial port on your computer (get a serial card) but it also needs to have around 5V to power it and that's not available from a serial port but is from a USB port. So I cut the plug off the end of a spare USB cable and soldered the power lines to that and the signal lines to a DB9 serial plug. From memory there's six wires in the cable, four go to the DB9 – Rx Tx and ground - and the other two, which are red and black, I joined to the ground (black) and power (red) lines in the USB plug.



For the DB9 connector the yellow wire is soldered to pin 1, white to pin 2, green to pin 3 and one black to pin 5. The remaining black and the red are joined to the black and red wires from a USB connector.

Next I needed software to drive it and online I found NMEATime at www.visualgps.net. It wasn't quite what I wanted which was a program that I could script to cause it to update my computer clock between CCD images. So I wrote to the author and he told me he was developing a new program NMEATime2 which would maintain the computer's clock to within a few milliseconds by a feedback process and he asked me to test it. It turned out to be perfect and I didn't even need to write a script.

I don't pretend to know how it works so I'll quote from the web site:

NMEATime2 is very different from the original. It's set up as a system service where the PC clock is disciplined to the NMEA string from the GPS. The control loop uses the same techniques in disciplining OCXO oscillators and atomic Rubidium clocks. By characterizing the arrival of NMEA messages, NMEATime2 uses advanced digital filters to minimize communication jitter and achieve the best reference to train the PC clock.

Because of this, there are some requirements that need to be met. Specifically, the rate output of NMEA message GPGGA and GPRMC.

It's getting more difficult to find a PC with a native RS-232 serial communication port, most GPS receivers that interface to a PC use a USB. The majority of the USB GPS receivers will look to the PC as if it is a serial port. However, the modern USB GPS looks to the PC as a USB to Serial driver that emulates the serial port. In the USB world, it's referred as a CDC (communication device class) device.

NMEATime2 will use the NMEA string (GPGGA) transmitted from the GPS, time tag the first character of the that command and use this as a timing reference. As you would expect, there are delays between the 1PPS epoch and the RS-232 causing software jitter. The delay can be calibrated out. NMEATime2 will use digital filtering ... and discipline the PC clock to this reference.

So now you know and it only costs \$20.48.

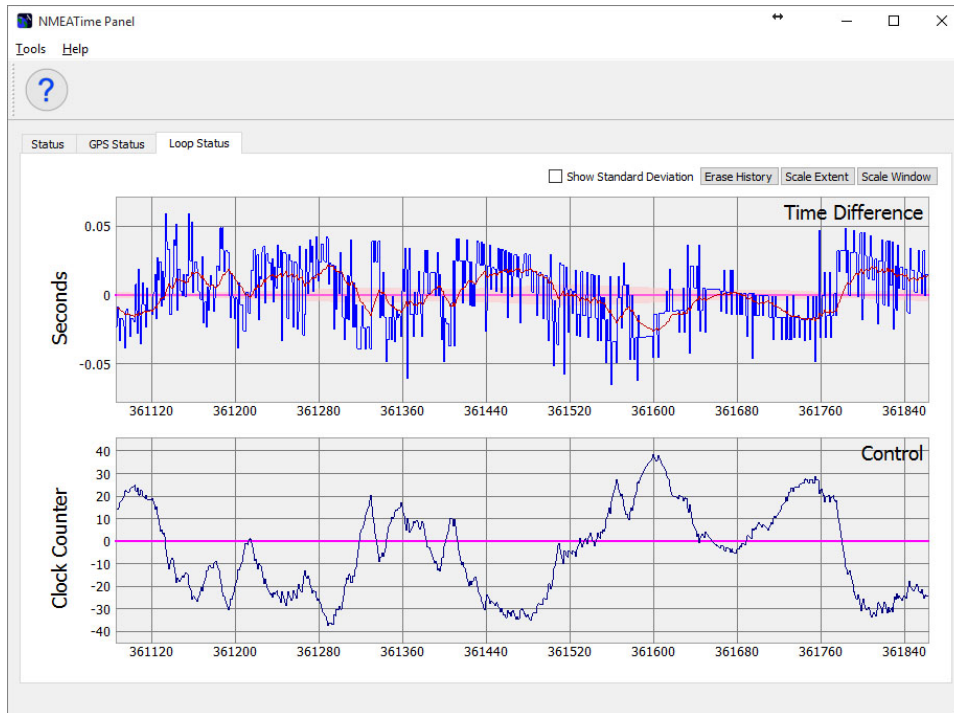
However before you can use NMEATime2 the Garmin needs to be configured to output the required NMEA sentences, which are:

- GPGGA - must be at least once/second
- GPRMC - must be at least once/second

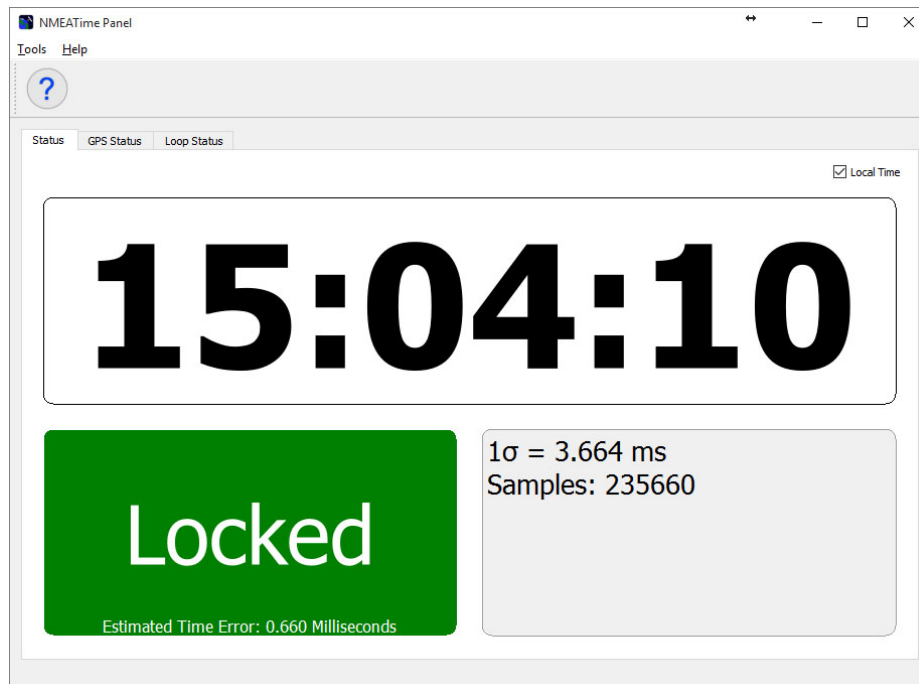
- GPGSA - every two seconds
- GPGSV - every two seconds

This you do with a small utility available on the Garmin web site - SNSRXCFG_330.exe.

Once that is done NMEATime2 will keep your computer's clock to within 50 ms of GPS time. There's no other configuration to do. It takes several minutes to get the clock's accuracy down to less than 50ms but once there it will keep it there all night long.



At any time you can check the clock from the Status tab and you'll see this display:



So for less than US\$100 I now have a computer clock that's accurate to better than 50ms.

Semi-regulars project update – *Aline Homes*

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The analysis of all L2 Puppis data is now complete and part 2 of the article will appear in the next newsletter, once we have checked for any further publications relating to this star. This is a very interesting and complex system and we would like to receive as many observations as possible, including DSLR and/or CCD photometry. The possible presence of a previously unsuspected companion has introduced a further level of complexity which makes this a very rewarding target. If this companion is real and not simply light from the primary reflecting off a particularly dense clot of dust, the geometry of the system as inferred from recent images (Kervella et al. 2015), would imply L2 Puppis not only pulsates but is also some kind of eclipsing binary.

We will now be moving on to analysis of some other targets for which we have data, and this will appear in due course. If you have been observing one or more semi-regulars as a part of your programme, please send us the results. I realise that if the weather in Australia for the last year or so has been anything like it has been this side of the ditch this might be rather sparse, but every little helps. Our new analyst, John Homes, is now up to speed and rearing to go.

A note on AAVSO data analysis – *Alan Baldwin*

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Variable star data analysis

The AAVSO has a section on data analysis – this was featured in the AAVSO September Monthly Newsletter. The topics listed would be worth perusing by anyone new to VS analysis or with an interest in extending their knowledge of variable stars.

To find this AAVSO resource, go to the white on black Menu Table at the bottom of the Home page on the AAVSO website, find the Data column and select Data Analysis. This folder contains, amongst others, the following sections:

- 5-star Analysis Tutorial.
- Time Series Tutorial.
- VPhot (Photometry).
- VStar – VS data analysis tool (Java based).
- Variable star Astronomy Chp 5 & 6, pdf documents that describe some of the basics of VS data analysis.
- A link to the Data Analysis Forum, for people to discuss issues within the AAVSO community

The 5-star analysis tutorial section

Here is the web address <https://www.aavso.org/5-star-analysis-tutorial>

In the 5-Star Analysis Tutorial page there is a link to download the tutorial. Listed under the link is a list of other links that may be useful. Amongst these are links to

blog posts by Grant Foster (look for the item “blog posts by Grant Foster”) former AAVSO staff member and pioneer of many of the AAVSO data methods & software used for data analysis. Some of the work reported here, which I found interesting as a visual observer, was a comparison of the utility of numerous visual observations compared with more limited instrumental observations, and investigations into changes in periods (secular changes) of Mira variables

The blog post headings are:

- *Through a Picket Fence* - About the problem of aliasing in variable star analysis
- *Seeing the Light* - About the precision of large data sets of visual observations

- *Skin a cat* – Investigating with BH Crucis three different methods of analysis:- WWZ = weighted wavelet Z-formation, a method used by Templeton & Willson, 2005; Windowed Fourier analysis; CLEAnest analysis method.

The Nov 2016 superoutburst of VW Hydri – *Stan Walker*

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Introduction

VW Hydri is probably the most studied dwarf nova in the sky although its history does not go back as far as some of the northern objects. Much of our understanding of CVs comes from studies of this star. At 71S it's circumpolar for most of our members so it's disappointing that with the fall in the numbers of visual observers some of its outbursts have been missed in recent times. Figure 1 from the International Database presents the 1000 day period up to 17 September 2016 and the gaps are clearly visible.. Even the superoutburst of November, 2015, is a little hard to identify.

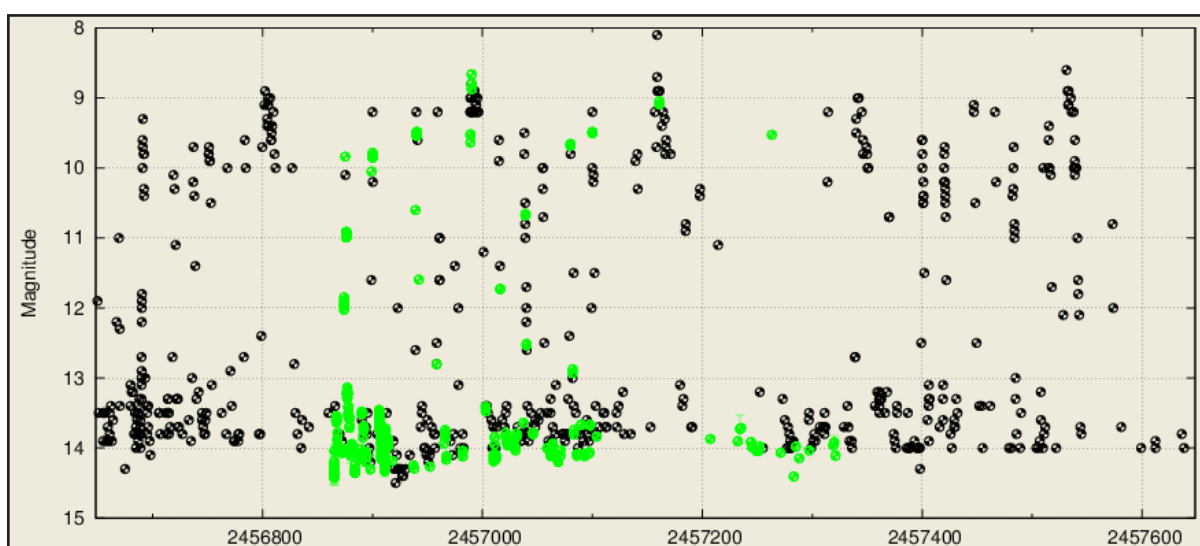


Figure 1. Positive measures over the 1000 day interval to September 2016, from the International Database. Negative measures have been deleted to make the behaviour clearer. The green symbols represent measures by Peter Starr and Rolf Carstens, although Terry Bohlson made a few colour measures a little before this graph.

I'd like to suggest that some of our members might find it interesting to observe the expected November outburst, largely for entertainment, but who knows what might come to light?

The orbital period and superoutbursts

Brian Marino and I began looking at this star in 1967 in an attempt to find eclipses and determine its orbital period, then unknown. First visually, then from 1969 photoelectrically. But there were no eclipses, only orbital humps resulting from the impact of a gas stream on a disc around the white dwarf component. Were these periodic? Back in those days without personal computers observations were difficult to analyse.

With its minimum at ~13.5 the star was not bright in our photometer but even so we collected many hours of unfiltered measures, also colour measures during the outbursts. As expected from the models based on the few other photoelectric observers' data, the humps we could measure at minimum disappeared during the normal outbursts but to make things confusing seemed to reappear during the superoutbursts.

By 1972 we had collected timings of many of these humps but were confused as they were not regular.

We later separated them into those observed at minimum and those during the superoutbursts. The ones at minimum were periodic but could not be fitted to those when the star was bright, nor did these latter show much periodicity. So how could we be measuring an orbital period - the variations in orbital times were not physically possible? Finally we decided that the humps at minimum defined the orbital period of 0.0742711 days - even if the star was non-eclipsing - and published these findings in IBVS 864 in early 1974. Using the time and phase of the hot spot humps to determine a period was a new technique which no one had tried up until then.

The same paper also presented a list of the ‘orbital’ humps during superoutbursts. It was left to Brian Warner of the SAAO to propose that these were caused by an eccentric disc which also changed in size during the outburst - thus explaining the slightly different period which in itself changed during the evolution of the outburst.

One other explanation to explain the differences was required and at IAU Colloquium 46 in 1978 we presented our ideas on how the superoutburst was triggered by an ordinary outburst which - instead of being a brief collapse of the disc around the white dwarf star - at intervals could trigger a mass flow for 10 or more days which drove the superoutburst. Figure 2 shows details - similar to that originally published in the proceedings of that colloquium - but in colour to make it easier to follow.

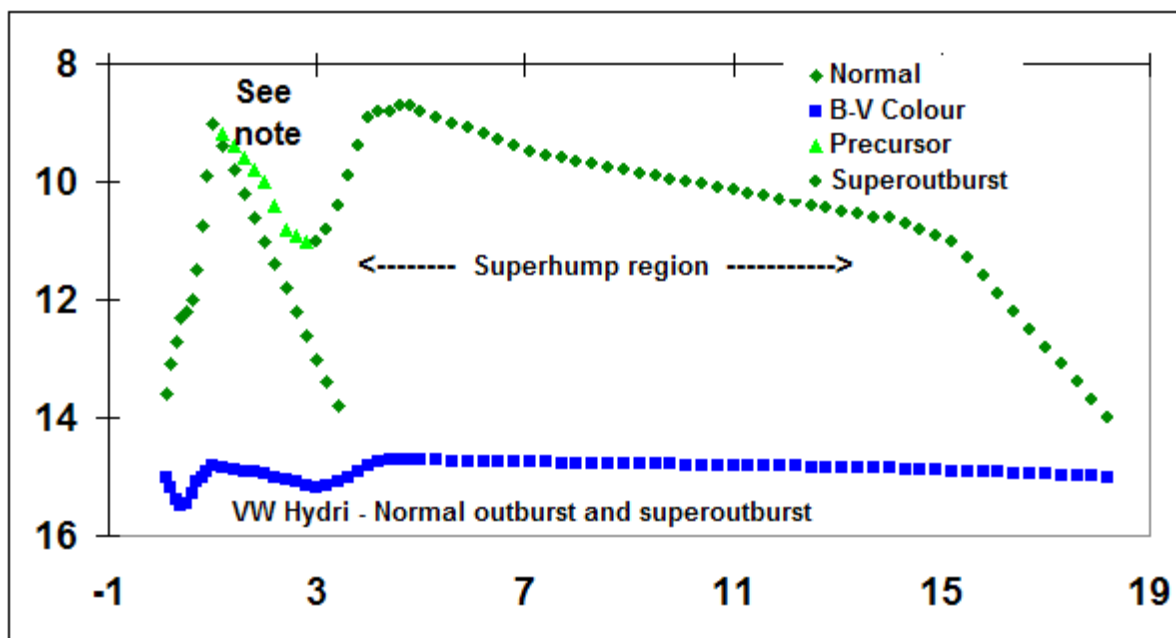


Figure 2. A composite of the VW Hydris outbursts over a period of 20 days. The vertical axis is magnitudes, although B-V needs 15 magnitudes subtracted. The horizontal scale shows days elapsed. The normal outburst is a single shot event which lasts 3-4 days. When conditions are suitable, usually at intervals of about 180 days, the normal outburst which occurs at ~30 day intervals will trigger a superoutburst. At this time, enhanced orbital humps—a signature of increased mass transfer—can be seen in measures on the declining branch of the precursor. The rate of decline slows in these cases, until the superoutburst, with its sharp peaks, indicative of an eccentric disc, begins. The overall shape is from visual measures—the details photoelectric photometer from Auckland Observatory. The colours show that the system gets quite red initially, the dip in the B-V, reaching a maximum equivalent to late F spectral class at the twelfth magnitude pause on the rise, before returning to show a temperature of about 20,000°. This pause was initially detected from an analysis of visual measures.

What might be observed

The normal outburst begins with a substantial reddening of the B-V colour, probably caused by obscuration of the very hot white dwarf as the disc collapses but there is a swift recovery as the system brightens and the hot spot on the disc is drowned out by the increased light from accretion onto the white dwarf.

But since most time series photometry is unfiltered the colour changes will not be seen. U-B/B-V plots show interesting colour/colour loops.

Sometimes the onset of the superoutburst is too quick for the enhanced orbital humps to be seen but normally there will be a period of 12 to 48 hours when these humps can be seen with an amplitude of 30-40 millimag. Once the superhumps start they quickly become very pronounced with a distinctive peak. During the superoutburst the amplitude of these becomes smaller but the period usually gets longer.

At the brighter levels the V of DSLR photometry can be used. But unfiltered detectors like video cameras are also adequate. Timing need not be too precise - so much is happening in these systems that they are only approximately repetitive and can vary by a very slight percentage of the orbital period in short observing sessions.

So let's take some real examples from May, 1977. The first of these appears in figure 3 and represents measures in the decline of the precursor - the light green area in Figure 2.

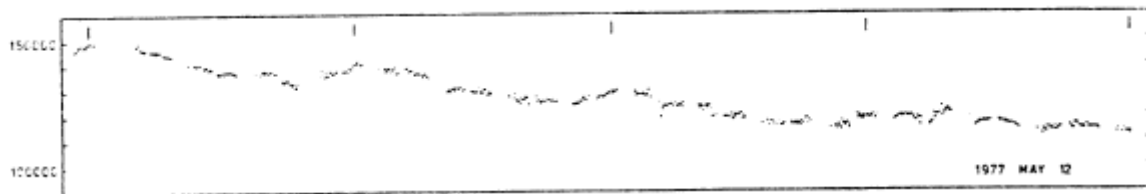


Figure 3. *The vertical scale is in intensity units, the horizontal scale was omitted by the publisher but the ticks marks above show the predicted maxim of the normal period orbital humps. Four cycles cover ~ 0.297 days during which interval the star passed through its nadir of 16 degrees above our local horizon. Magnitudes are $V = 9.65-9.84$.*

During the seven hours of observations VW Hydri faded but toward the end this fading slowed somewhat. The increased mass flow is visible as humps or peaks with an amplitude of $\sim 3-4\%$. Incidentally, all of the points in these illustrations are hand plotted - no Excel in those days and quite obviously the printing standards were also less good. The numbers are in photons detected per second.

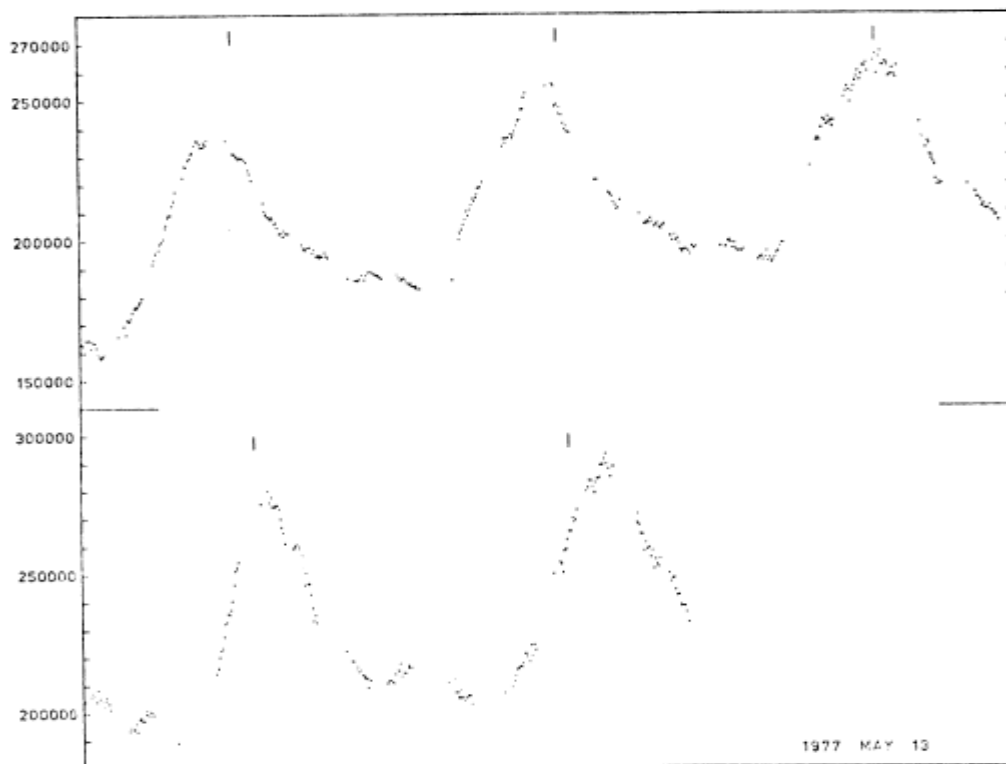


Figure 4. *The main superoutburst is now beginning. The magnitude is higher than the previous night, $V = 9.3 - 9.0$, showing an increase of several tenths during the 8 hour run. The longer period is clearly apparent, as is the phase displacement.*

Measures were also made on 16 and 19 May where the brightness and amplitude were both decreasing. Earlier on 11 May, a cloud-interrupted observing run showed very small indications of enhanced humps at appropriate phases - the beginnings of increased mass transfer.

Some elementary astrophysics

What does all of this tell us? On the night of 12 May (UT) the enhanced orbital humps indicate that the flow from the secondary star through the L1 point has increased to ~30 times the normal level but has not yet affecting things greatly. The white dwarf's brightening as a result of the partial disc collapse has ceased and its fading causes the overall decline in brightness.

By the following night the impact of 30 times the normal flow has begun to displace the disc as well as introducing some ellipticity. The period as shown by the humps has also increased to 0.07836 days, an increase of 5.5%. The system is brightening as seen by the minima and the need to change the scale on the lower part of figure 4.

The longer period suggests that the disc is larger, as would be expected from more mass being put into it. Also, the bright spot associated with the stream's impact on the disc has initially shifted but is then outshone by the increased luminosity of the disc as a whole. What we then end up seeing (but later in the outburst than shown here) are ellipticity effects where the increased area with the disc side on produces more luminosity from the observer's viewpoint.

Vogt and others reanalysed much of their historical data in 1978 after the symposium and noted that there were indications of enhanced humps on other normal outbursts of VW Hydri which had not been thought of as significant. Their strength increased as the time for the superoutburst approached, suggesting some other factor which governed the timing of these events. This may well have been slow mass-loss induced pulsations of the cool star.

Conclusion

The study of dwarf novae in the 1960s and 1970s was new and exciting. It was only a few years since Joy had realised that these were all binary stars and astronomers such as Kraft, Mumford, Merle Walker, Warner and others were using the recently developed techniques of high speed photoelectric photometry to try to understand the nature of these objects. This article describes one area where amateurs played a significant role but there are others.

To some extent the theoretical requirements have passed beyond the scope of amateurs but there are still surprises, particularly amongst the stars with very infrequent outbursts. The novalike stars are another area which produces occasional unusual behaviour with a star suddenly becoming active. Then there are the polars and intermediate polars - where strong magnetic fields on the white dwarf star result in disc-less accretion and we see the spin rate of the WD component. EX Hydrae is one example with a slowly changing spin rate.

This is an area where perhaps one of our members might like to assume a leadership role and encourage others to join in an area which requires more attention than it receives at present.

References

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Reading the clues in light curves of eclipsing binaries

Part II – Interpreting eclipse depths

In Part I (this *Newsletter*, July 2016) I discussed how to recognise total eclipses by the flat bottom of an eclipse curve, and how to use the time of ascent from (or equally descent to) a flat bottom, and the length of totality, to determine the sizes of both stars relative to their orbit. I explained why those times had to be the same for both the primary and secondary eclipse. That was under the assumption of the orbit being edge-on to the observer; and I discussed what happened if it wasn't while still having totality.

Continuing in the same vein of just arguing logically from basic geometrical intuition and avoiding all but simple arithmetic; I will in this article look at what we can learn from the depths of eclipses, whether total or not. But first, a corollary of sorts to last month's article – how to recognise if the two stars are close together or not.

Close and distant pairs

Whether or not an eclipse is total, whether or not the orbit is edge-on to us ($i = 90^\circ$), we know that the total time of an eclipse, from first to fourth contact, is given by the width of the eclipse curve. Figure 1 illustrates this, showing the four contacts of a total transit (or equally occultation) with $i = 90^\circ$. (This and other figures, and associated astrophysical models, are from CALEB, the Catalog and Atlas of Eclipsing Binaries (Bradstreet 2004).) Relative to the period P , the diameter of the smaller star is $t_2 - t_1$, of the larger $t_4 - t_2$.

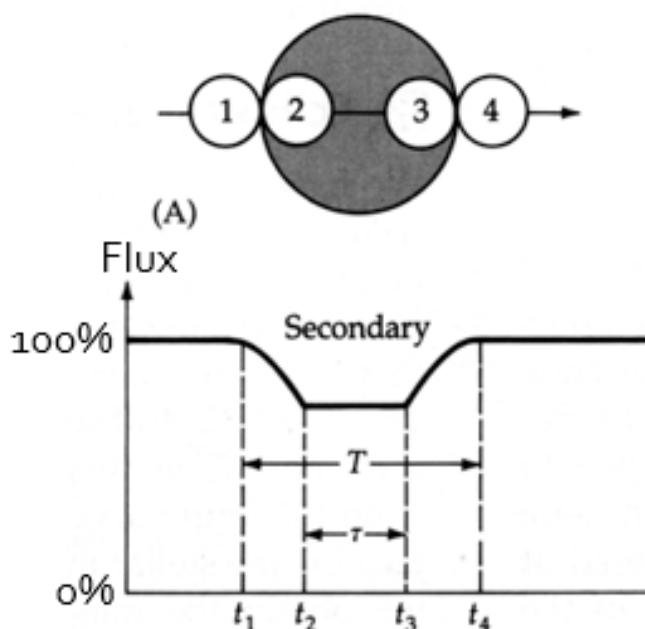


Figure 1. Geometry of a total transit with $i = 90^\circ$.

Apply that to GZ CMa in Figure 2, where the eclipses are narrow.

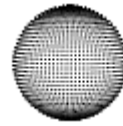
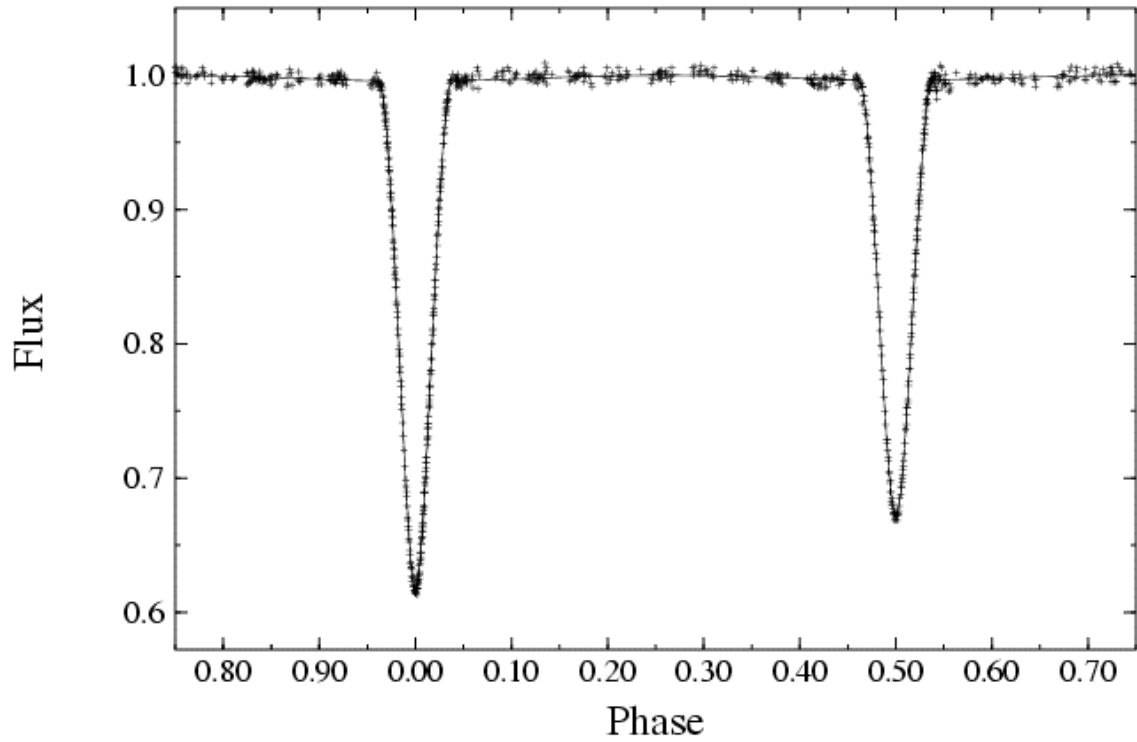


Figure 2. *GZ CMa. Two well separated stars. (From CALEB).*

Measure one eclipse width (which is $t_4 - t_1$ as in figure 1) relative to the total period P in the diagram (left edge to right edge). I got 6%. Assuming $i = 90^\circ$, that must be the sum of their diameters relative to the length of the orbit, as in figure 1. Astrophysical modelling, as seen at the bottom of figure 2, shows their actual separation.

Figure 3 shows a very different situation, where eclipses in AZ Cam take up about 25% of P (measured across the kinks at about 92% flux). Modelling (bottom of the diagram) confirms their closeness.

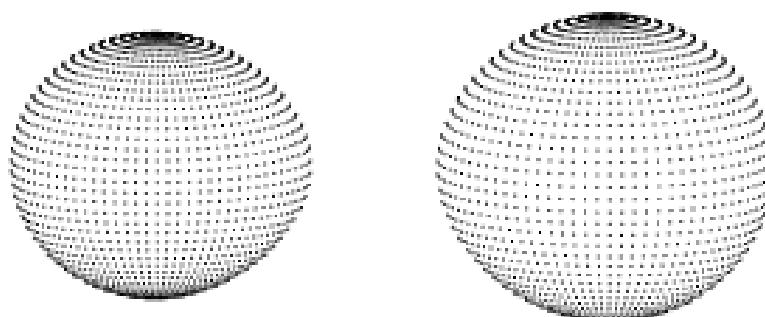
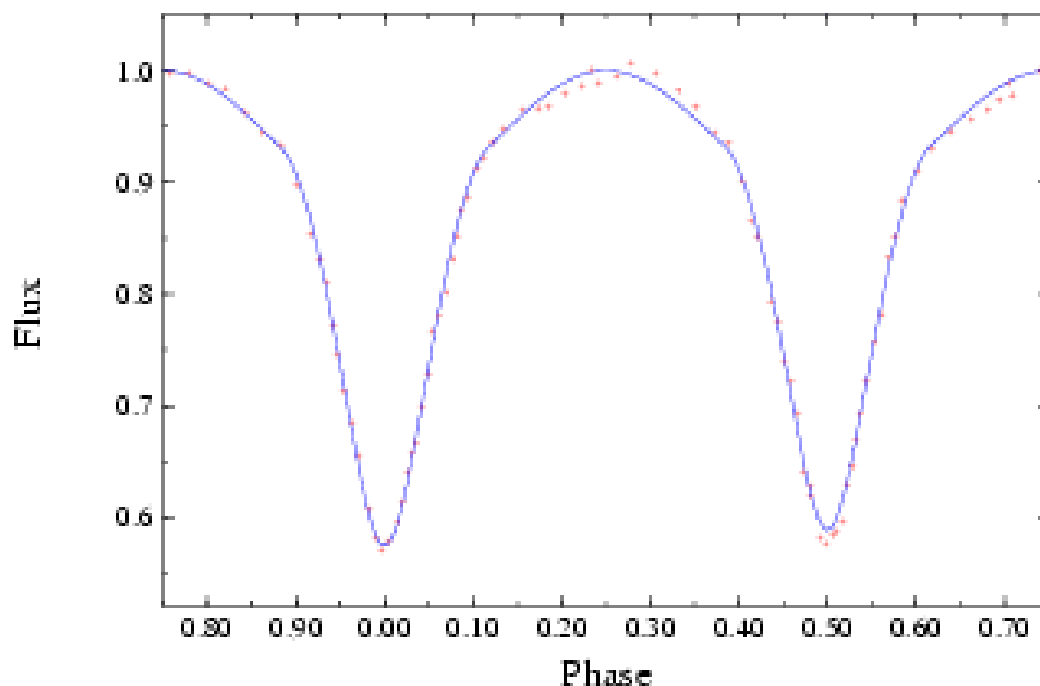


Figure 3. *AZ Cam, a close pair (from CALEB).*

But now, why the hump in the uneclipsed parts of the light curve? Notice it peaks exactly halfway between the two eclipses, when the stars are side on to us. It's hard to imagine it could be because the sides of the stars are brighter, so it must be because their profiles are largest then – which could only be due to tides. That close, stars raise tides in each other with high tide where the other star is “overhead” and closest. You have discovered tidal distortion! – again just from geometrical reasoning plus one very plausible assumption.

Eclipse depths

You may have thought of a very good objection to the reasoning in the previous section. What if, in figure 2, the eclipses were just grazing? Then they wouldn't take much time eclipsing, and the stars could be very big compared to the orbit, as in the lower half of figure 3.

Relative depths

To answer that, you have to look at the depths of the eclipses. In figure 2's primary (deeper) eclipse, the total flux as we see it drops to 61%, and the secondary to 66%. (The vertical scale is flux – the amount of light reaching us. A linear scale is much easier to work with than magnitudes.) So, at primary minimum,

the occulted part of the back star deprived us of 39% ($100 - 61$) of the system's total flux, and at secondary minimum the occulted part of the other star removed 34%. As we saw in the previous instalment, those two occulted areas must be equal as we see them, so immediately we know that the *brightness* ratio of the two stars is as 39 to 34. (By *brightness* I mean flux per unit area – equal areas are occulted.)

So we conclude, figure 4 gives us another example. Here, the relative depths are 3.5:1, so one star is 3.5 times brighter. The modelling shows two stars of very unequal size, so which is more *luminous* (brightness $\times$ total surface area)?

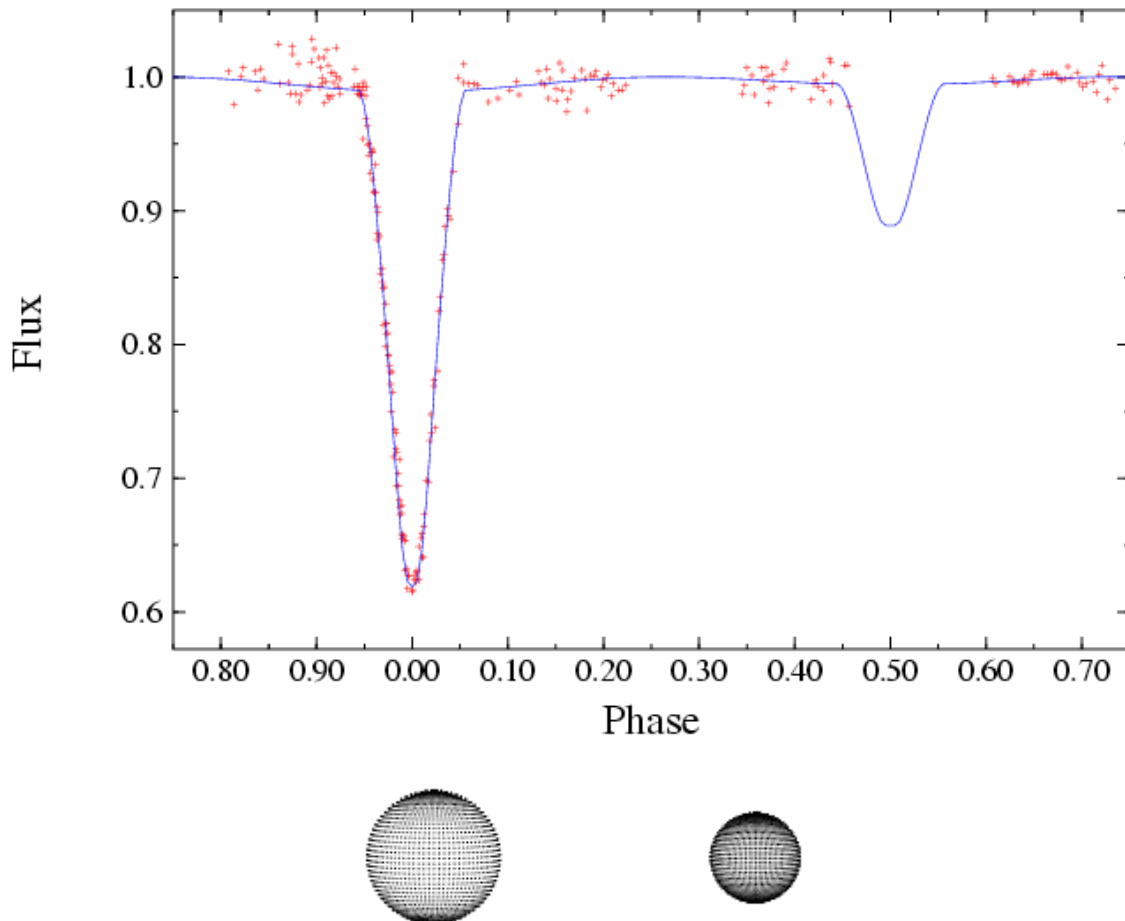


Figure 4, *BH Dra (from CALEB).*

The problem is illustrated in figure 5. It's drawn for a total eclipse, but the same problem applies to partial eclipses.



Figure 5. *Which is more luminous?*

Suppose the bigger star is much more luminous (total flux), so much so that its *brightness* (flux per unit area) is greater than for the smaller star. Then more light is lost when the smaller star transits it, than half

an orbit later when the smaller is occulted. So, as labelled in the diagram, the primary (deeper) eclipse is when the smaller star is in front.

Suppose alternatively the surface brightness of bigger star is *less* than for the smaller one. Then the situation is reversed: when the smaller star is in front we have a secondary eclipse. Maybe the bigger star is the less luminous (brightness $\times$ area), or maybe its bigger size still makes it the more luminous, despite its lower surface brightness. We can't tell.

Absolute depths

But we can learn more than that from eclipse depths, which takes us back to that earlier question – if the eclipses are just grazing, then the stars could be very big compared to their orbit (as in figure 3) but still create narrow eclipses, as with GZ CMa in figure 2. So maybe GZ CMa's stars are not far apart at all.

Well, if the eclipses are grazing, very little light will be lost at either eclipse, so the eclipse curves will be shallow – unlike the case of GZ CMa which are quite deep. We can infer that the eclipses, while not total, must cover a lot of the back star.

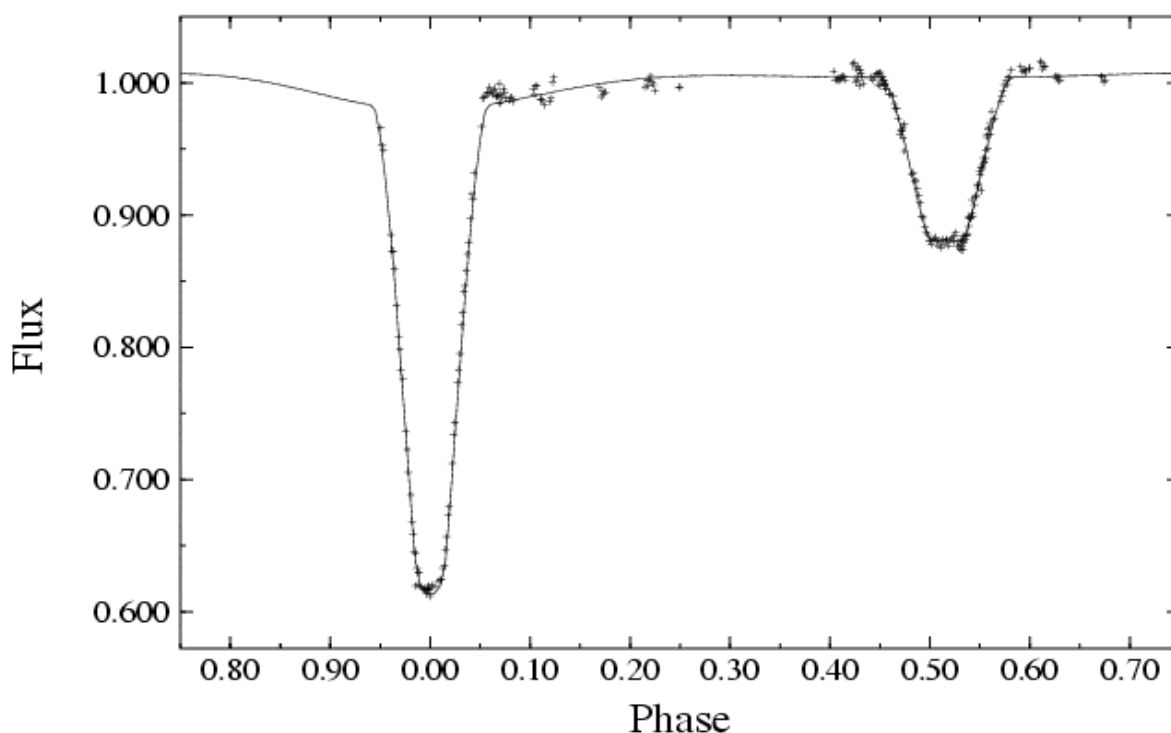


Figure 6. *IQ Per (from CALEB).*

It's beyond the scope of our essentially qualitative approach to handle the relationships between inclination i and eclipse widths and depths – that's for sophisticated modelling software such as BinaryMaker 3 (Bradstreet 2005) and PHOEBE (Prša & Zwitter, 2005). But there's some interesting special cases where eclipse depths can give some firm results just using geometrical intuition.

Totality is always helpful. In figure 6, the secondary eclipse of IQ Per is total, so the eclipsed star must be the smaller. Moreover if you measure its depth on the flux scale with a ruler, it's about 13%, so it contributes 13% of the total light of the system. Luminosity ratio is 13/87. By measuring the relative depths, the brightness ratio is 15/40. Bearing in mind that luminosity = brightness $\times$ area, I'll leave it to you to calculate the relative radii of the two stars.

Note that the primary eclipse is not total. Yet by symmetry we must have a transit of the smaller star lasting as long as totality in the secondary eclipse. So why isn't it flat? You have discovered limb darkening.

Finally, let's look at DM Vir in figure 7.

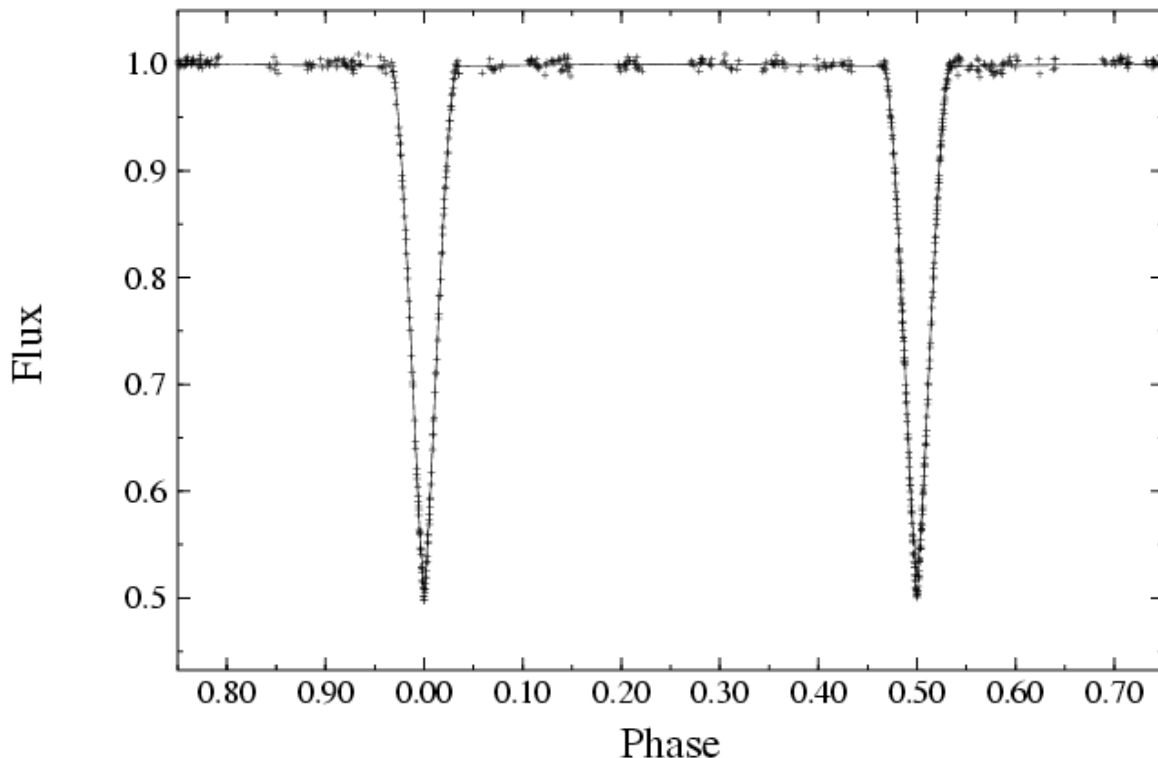


Figure 7. *The very symmetrical DM Vir: (from CALEB).*

The two eclipse depths are not only equal but at 50% depth: each removes half the total luminosity. That must mean both eclipses are total occultations. Why? Suppose one is not, Then at that minimum all of one star and some of the other must be visible. But if the other is total, it contains half the luminosity of the system, so the first eclipse, showing it and some of the other, must be shallower. Or, suppose both aren't total. Then at each eclipse all of one star and some of the other are showing, So the flux (brightness) of the front star must be less than half the total, and the same for the other eclipse. Impossible — their brightness must total 100%.

So both eclipses are total, and since the depths are 50%, they are equally bright. And being both total, the stars must be the same size and $i = 90^\circ$ and totality lasts for an instant. This is in fact the case for DM Vir. Astrophysical modelling confirms all those results closely.

Summary

We have seen how eclipse widths in light curves can tell us if the stars are close or well separated. We saw that relative depths tell us relative brightnesses, and absolute depths give us strong clues about how complete the partial eclipses are. In the case of total eclipses, we saw further that we can derive the relative luminosities from the relative depths, and hence by combining luminosity and brightness, get the relative radii.

We derived all those features of the eclipsing system by thinking qualitatively about the geometry. OK we measured eclipses with a ruler and did some trivial arithmetic, but so could a ten-year-old. Our main tool was logical reasoning from trivially available facts about light curves.

Aside from the satisfaction of getting all that way just by careful reasoning, getting such results are an invaluable check on any astrophysical modelling you might go on to perform. Modelling is notoriously an “inverse problem” – working from solution back to data. You propose a solution — some parameters such as relative size, relative brightness, and others, and see whether the modelling software produces a

light curve to match your data. It won't, so you weak the parameters and try again, and again, and again. Even if it outputs a light curve that matches your own closely, the solution behind that light curve might be quite wrong. Your reasoning can provide some of the input parameters, helping to narrow your search space as well as avoiding silly solutions which superficially seem good.

In the next article I'll finish with light curves and get on the the question of colour.

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Introduction

A new field of astronomy began in 1995 when the first exoplanet was detected around the star 51 Peg. Since then the field has blossomed in observatories all over this world and in space with thousands of exoplanets now known and thousands more candidates awaiting confirmation.

The first was discovered by observing the motion of the parent star and measuring variations in the star's radial velocity using a spectrograph capable of a precision of better than 10m/s. New advances in spectroscopy have substantially lowered that to better than 1 m/s.

Such instruments are out of reach for the amateur so we must use an alternative method of detection called the transit method which just requires a telescope and a camera, preferably a CCD camera.

If the plane of a planet's orbit lies along the line of sight from the telescope to the star then when the planet crosses in front of the star it will block some of its light and with careful photometry that dip can readily be detected with amateur equipment.

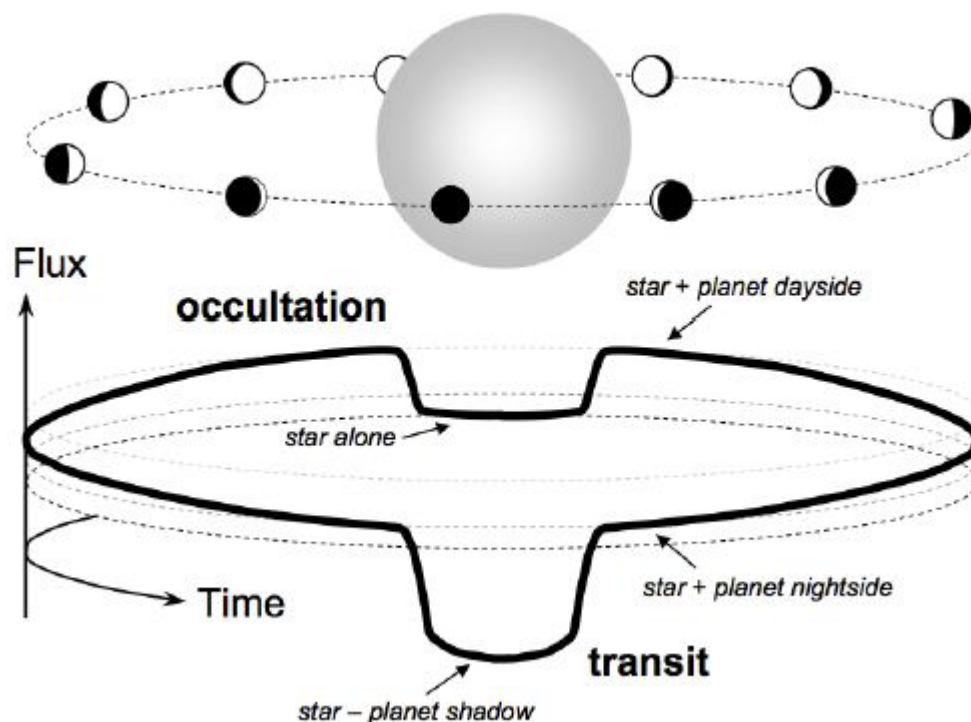


Figure 1. *The geometry of a planetary transit (from Winn, J., 2010)*

A second dip in the light will occur when the planet passes behind the star but that is usually very small and pretty well beyond the reach of amateur telescopes.

The first planet detected by the transit method was HD209458b (Charbonneau et al, 2000) and was achieved using a homemade telescope with a 10cm aperture sitting on a Meade fork mount.

Even with such a small aperture Charbonneau was able to get a decent light curve showing the dip as the planet transited across the face of the star

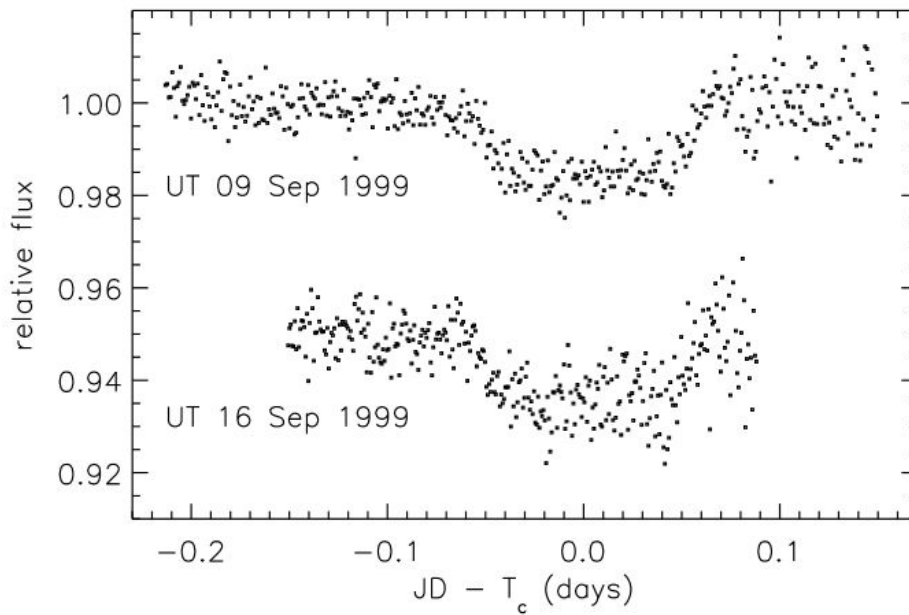


Figure 2. The first two transit light curves ever detected {Charbonneau et al, 2000}.

Equipment

Charbonneau's observation shows that you don't need a big telescope but you will need a decent camera, either a cooled CCD or a good quality DSLR.

Here's a record of a transit made with a Canon t3i camera and a Nikon 300mm lens.

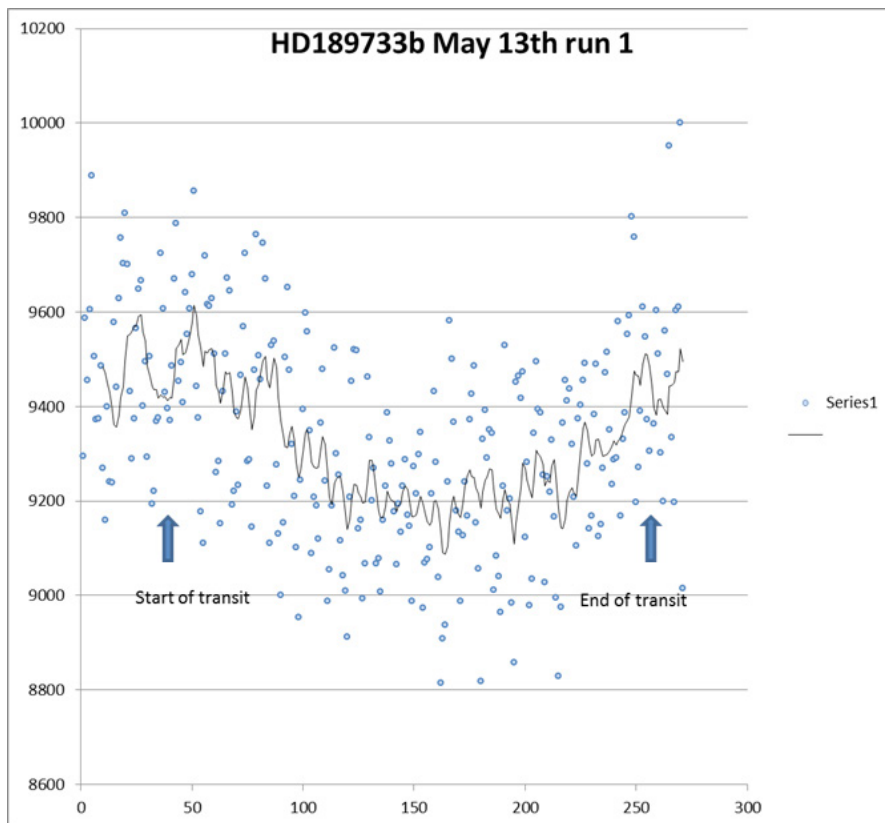


Figure 3. Transit of HD189733b taken in May 2014. (http://webpages.marshall.edu/~maynard169/exoplanets/hd189733b_transit_051314.htm)

There's a good deal of scatter in that plot but the transit is unequivocal. It's quite a deep dip at around

30mmag so is a good one to get started on. With better equipment it's possible to detect transits with much lower depths. With a 25cm SCT and a cooled CCD camera transits with depths down to around 10mmag are routinely possible.

There are now many web sites that have data on the timing of transits at a given location but the best one I have found is the Exoplanet Transit Database (ETD) run by the Czech astronomical society (<http://var2.astro.cz/ETD/predictions.php>).

All you need to do is enter your approximate location - latitude and east longitude (degrees east from north) - and you will get a list of all the transits available where the star is above 20° altitude at mid-transit.

Having got your target coordinates let's now look at technique.

Technique

With good technique you can get a result with lower quality equipment but bad technique can negate the use of the best gear.

Check how bright the parent star is – its V magnitude will be given on the ETD site so decide if you can use a filter and still use integrations of less than 120 seconds to give reasonable time resolution to your light curve. Too short a time can result in excess read-out errors and, in the case of some modern CCD cameras, excessive residual bulk image (RBI) errors. Try to achieve high ADU values without saturating the target pixels - the higher the counts the less the Poisson noise and the better your photometric precision.

Why use a filter? Because your results will be more interesting to professional astronomers if they know the passband of your photometry. For example, the radius of the planet can be found from knowing the depth of the transit in a particular passband and the radius of the parent star. That can be found from its temperature and classification.

If the star isn't bright enough to use a filter with your equipment don't worry, your work will still be valuable if you can catch even half of the transit – perhaps just the ingress or just the egress. At least that will tell the professionals that their ephemerides are either right or wrong.

Figure 4 shows the O – C plot for Wasp-17 and it is clear from that the published period is out by a few seconds. Four of those data points are from my unfiltered transit observations and were in part taken during collaboration with a professional astronomer from the Pulkova Observatory in St Petersburg.

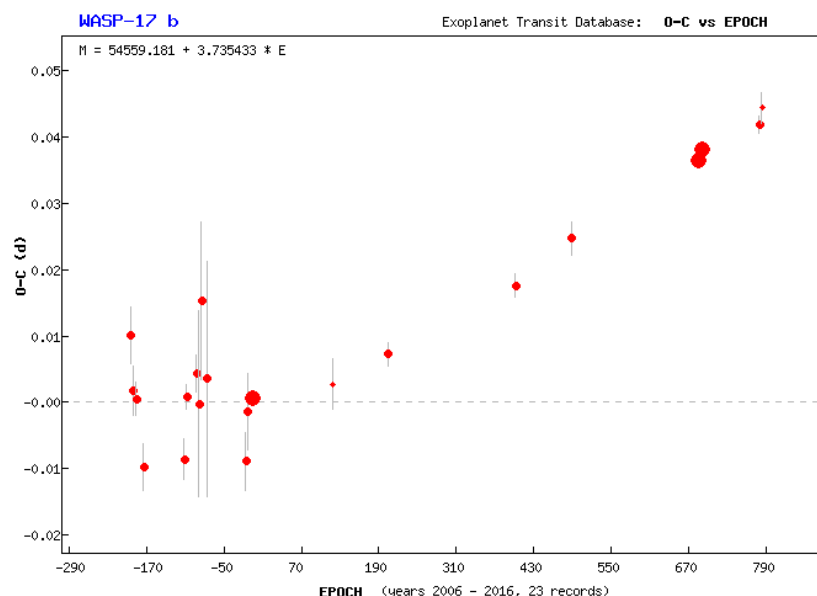


Figure 4. O-C diagram for transits of Wasp-17 showing that the published period is wrong (from ETD website <http://var2.astro.cz/ETD/etd.php?STARNAME=WASP-17&PLANET=b>).

If you use a filter what should it be? If you are a serious amateur astronomer you will already have some

of the Johnson-Cousins set of B V Rc & Ic. Which to use? In general the redder the better as this minimises the effect of reddening effect on comp stars which are a different colour to the parent star. Because your observation period is likely to cover several hours and large swathes of the sky reddening effects can reduce your photometric precision.

If you can manage simultaneous observations in two filters then you can look for differences in the depths of the transit.

As an extreme example the Hubble telescope was used to observe the transit of HD209458b in ten band-passes and the differences in the shape and depths of the light curves are clearly illustrated in figure 5.

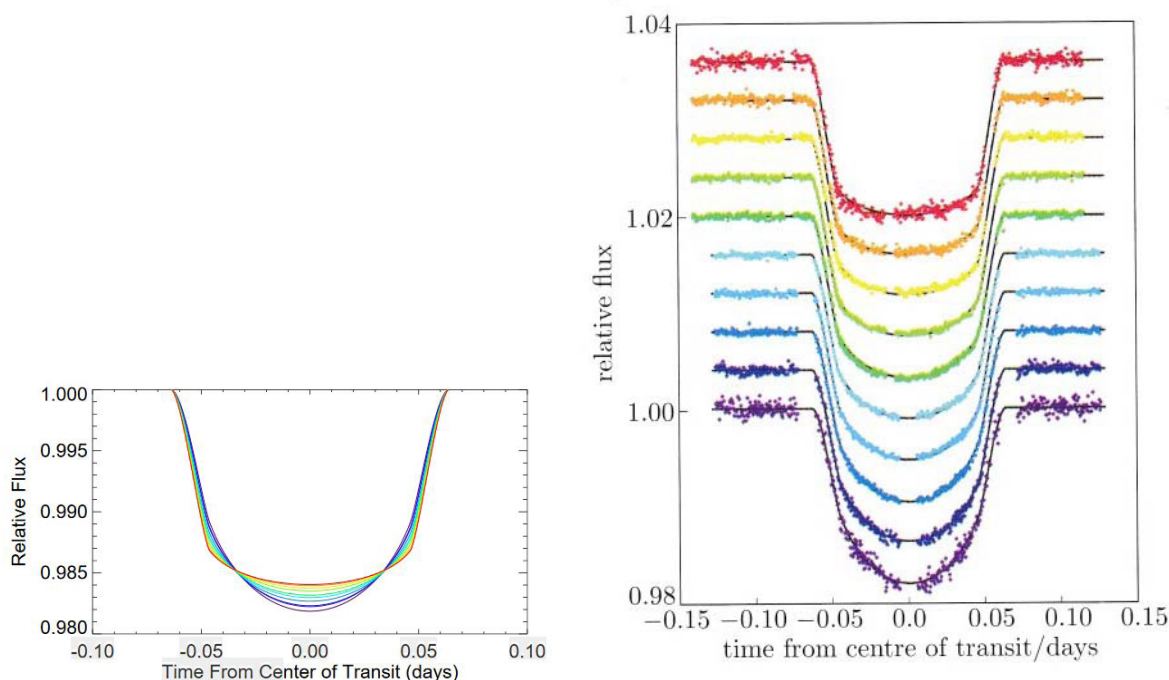
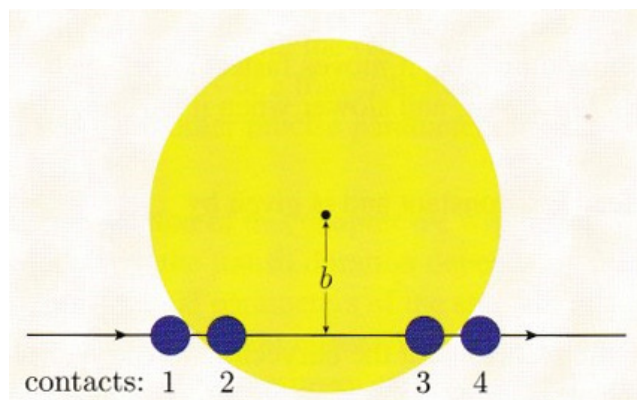


Figure 5. (left) Theoretical transit curves modelled from (right) data taken with the Hubble telescope. (from Knutson et al 2007)

The reason for different shape of the curves is that longer (redder) wavelengths are less affected by limb darkening on the parent star, giving us another reason for using a redder filter as it is much easier to discern the time of the second and third contact points (see figure 6) and also to measure the depth of the transit, quantities that are required to calculate the radius of the planet.

Now, you've decided on a filter or no filter it's time to focus. Or should you? If the field is not crowded and defocusing will not make blends with adjacent stars then it is much better practice to defocus your telescope. Not only does this reduce the risk of a large portion of a tightly focused star's energy falling on the spaces between the pixels of your detector but in spreading the energy you significantly reduce the risk of saturating the CCD pixels of your target and comp stars. When you defocus you smear the light



over many pixels allowing you to obtain higher total counts for a given target, thus increasing your photometric precision. And in spreading your target over many pixels you reduce errors due to inadequate flat-fielding.

Should you bin? Yes. And it is better to do it in camera than afterwards in software. If your CCD has a well depth of, say 60,000 electrons per pixel then binning 2x2 will give your new combined pixel a well depth of 240,000 electrons – the higher the counts the better the precision of your photometry.

Figure 6. The four contact points of a transit light curve (from Haswell, 2010)

When should you begin observing? ETD will tell you the times of ingress and egress but you need to be able to measure a baseline flux in order to be able to determine the depth, so you should begin about an hour before ingress and continue for an hour after egress. When you model the transit curve on the ETD website your light curve will also be de-trended for changing airmass. So you should have flat sections before and after the transit.

If you have already been doing variable star work then you will be familiar with the need to properly calibrate your light frames with darks and flats before doing the photometry of your target. Taking care with these will always improve your photometric precision.

Photometry

There are no specific requirements for photometry of exoplanet transits that differ from your normal variable star work but I will just mention that if you want to achieve a professional result then you must ensure that your uncertainties are accurately reported. I use Maxim for control of the scope and camera but because they do not release their method of calculating uncertainties I prefer to use Muniwin which comes with a full manual and theoretical explanations. It is free of charge. For programmers all its methods are available. Other free programs that do a good job of reporting uncertainties are AIP4WIN and AstroImageJ. I'm sure there are many others of which I am unaware.

Muniwin, AIP4WIN and AstroImageJ will all allow you to use ensemble photometry which will improve the precision of your photometry over the use of a single comp star. AstroImageJ has far greater options in this respect than Muniwin.

Modelling the transit

Once you have a good light curve save the data as a text file and you can then use ETD's modelling feature. Select "Model-fit your data", fill in the filename of your data file, select the JD format and brightness method as below and continue.

Leave the three radio buttons set on and leave the impact factor as this will be accurate for that particular planet. You can change the limb darkening as ETD sets this at 0.5 for all stars. To get a more accurate value try firstly at the EXOFAST web site <http://astroutils.astronomy.ohio-state.edu/exofast/limbdark.shtml>. If the planet is pre-loaded on that site then selecting it from the drop-down menu and submitting will give you the first two terms of the quadratic limb-darkening. You need only the first number. If your planet is not listed then you'll have to resort to looking up in the discovery paper where you will usually find the appropriate value. If you click on the name of the planet from the leftmost column you will usually see the discovery paper listed as the first reported transit and it will usually be available from a public site such as the arXiv

If the limb darkening factor is not listed look for the following data in the paper: star temperature T_{eff} , metallicity [Fe/H] and surface gravity $\log(g)$ then go back to the EXOFAST web site and fill in the boxes. In the case of HATS-28 it was not pre-loaded on EXOFAST and the discovery paper did not list it explicitly but the values for temperature, metallicity and surface gravity were listed. Plugging these into EXOFAST yields a value of 0.522.

Back at ETD submitting your data will result in a de-trended graph with a best-fit theoretical light curve (figure 7).

If, for example, you only managed to get half of the transit (see figure 8) then it's probably best to turn off both the Mid-Transit and Duration radio buttons since it would not be possible to make a good model fit without the full transit data. You can still use your data to get a measure of the transit depth.

It's a good idea now to copy the table of de-trended data and save it on your computer. If you are part of a professional collaboration looking at improving knowledge of the properties of exoplanets they will want this table. See VSS web site for more information on a professional collaboration <http://www.variablestarssouth.org/projects/projects/exoplanet-transits>

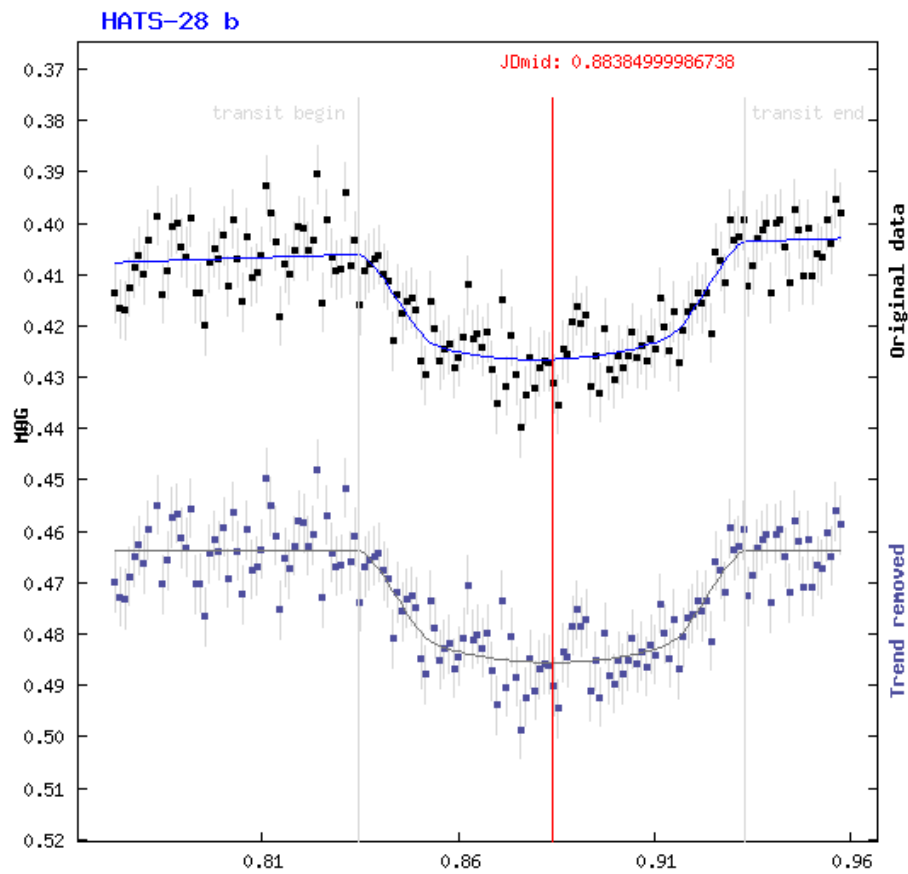
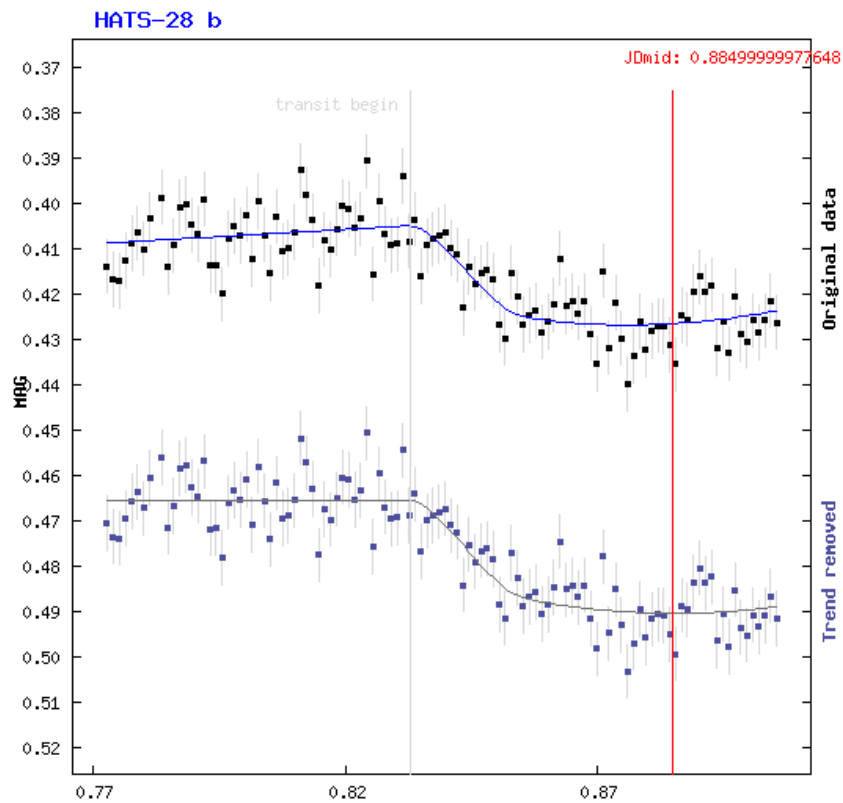


Figure 7. The resultant de-trended light curve fitted with a best-fit theoretical light curve (solid line). (From ETD, data by the author).



I

Figure 8. Even half a transit is useful as it will show both the ingress time and the depth.

Conclusion

I've shown that it is easily possible to observe the transit of an exoplanet across the face of its parent star with the same sort of equipment that you ordinarily use for your variable star work. Your best photometric precision will be achieved with careful planning, choice of filter, de-focusing and binning, thus making your contributions more interesting to professional astronomers.

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About

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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.

To find out more, please visit our website, where, incidentally, you will find PDF copies of all our newsletters. Our website has a great deal of information for VSS members, and for anyone interested in southern hemisphere variable star research. All VSS project information and data is kept here too.

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