SEVEN NEW VARIABLE STARS IN CYGNUS

STAN WATERMAN AND RICHARD STRATFORD

Introduction

This is the first of a series of articles about variable stars in Cygnus, found by what is now called 'The Cygnus Project'. I, (SW) have been collecting data in a 2.8° square, densely populated patch of sky in Cygnus, since August the 9th 2003. These articles will describe some of the more interesting of the five hundred or so variable stars in that area. Some of them are challenging, and we shall be soliciting help in explaining them, or in making more measurements. At this point I'd like to thank my friend and colleague, Richard Stratford, for all the work he has done and, and continues to do, on these stars. All the astrophysical information and deductions in these articles are due to him.

We are starting with six stars belonging to five of the major classes of variable stars; an eclipsing binary, a possible Cepheid, a Mira type, a Red Semi-regular, a fast pulsator and two other pulsating stars, not identified with certainty.

Background

First I'd like to mention the numbering system for the stars. In work of this kind it is essential to have one's own starlist, which is cross-correlated to other catalogues. In my case the numbering system is TE*nnnnn where the * stands for the particular sky area which is denoted by the letters 'a' to 'i' in Cygnus and 'p' for my one area in Auriga. Area 'a' is the prime one, and the one I'm dealing with now, centred at (J2000) 21h 08m 30s, +46° 30'. The nnnnn stand for five digits so the catalogue can run to 99999 and the TE is for Temple End, where I live, a settlement of just two houses! So, for example, star TEa01732 is in area 'a' and is in fact an eclipsing binary in the GCVS (V530 Cygni). The numbers run roughly in magnitude order, from around magnitude 9 at a00001 and magnitude 14 at a21394 (the last one in the 'a' catalogue currently).

The eight equal areas 'b' to 'i' surround area 'a'. The vast majority (60,000 of 90,000) of the images collected so far have been in area 'a', so we have dense data to study, and that data can be averaged over a night or a season to probe deeper.

The dates in the figures below are all JD or HJD from Jan 1, 2000. The earliest measurements are from 2003, Sept. 6th, date 1344 and currently processed ones run to 13th Dec. 2007, date 2903. The magnitudes quoted in the light curves are for guidance only. They are derived from the R2 magnitudes in the USNO B1.0 catalogue. The magnitude differences will, however, be much more reliable, in some cases good to better than 1 mmag.

Below, in decreasing order of brightness, are the stars to be discussed in this article. The column 'other ID1' is the USNO B1.0 id if it exists, 'other ID2' is a useful id, for example the IRAS reference for a11459. The value MAGM is the maximum magnitude in a red filter, MAGR the variability, and period1 the dominant period in days.

cat. name	other ID 1	other ID 2	MAGM	MAGR	Period1
TEa00121	3588 1106601	GSC 3588-11066	9.25	0.977	294+2940
TEa00169	3588 623801	BD+45?3394	9.36	0.03	0.03333
TEa00255	3593 106701	TYC 3593 1067 1	9.618	0.057	1.57344
TEa00596	3592 425301	TYC 3592 4253 1	10.597	0.047	1.7698

cat . name	other ID 1	other ID 2	MAGM	MAGR	Period1
TEa02726	1367 417232	V356 Cyg. Cepheid	11.51	0.61	5.0572
TEa03238	3588 7601	TYC 3588 76 1	12.12	0.68	2.77384
TEa07269	1358 404638	GSC 3588-2414	12.53	0.12	0.363727•}3E^{-6}
TEa11459	0 0	IRAS 21032+4642	13.3	6.03	472

The stars in the table range 88,000 -1 in period and 2000-1 in amplitude.

Below is basic data from Vizier/ Nomad on the stars.

Star	J	H	K	B	V	R
121	4.668	3.562	2.924	--------- data not reliable ---------		
169	9.367	9.391	9.301	9.669	9.553	9.48
255	9.432	9.378	9.372	10.275	10.061	9.93
596	10.294	10.335	10.33	10.694	10.57	10.5
2726	9.669	9.157	8.935	12.89	12.26	11.26
3238	11.57	11.406	11.336	12.198	12.262	12.3
7269	11.574	11.275	11.112	13.41	12.96	11.89
11459	7.538	6.182	5.349	--------- data not reliable ---------		

For some of the stars we show its setting in a small image sample from Sept 2004, either 121 pixels square (5 arc-min), or 251 pixels square (10.3 arc-min).

——————————TEa00121——————————

Figure 1: Five year light curve of star a00121.

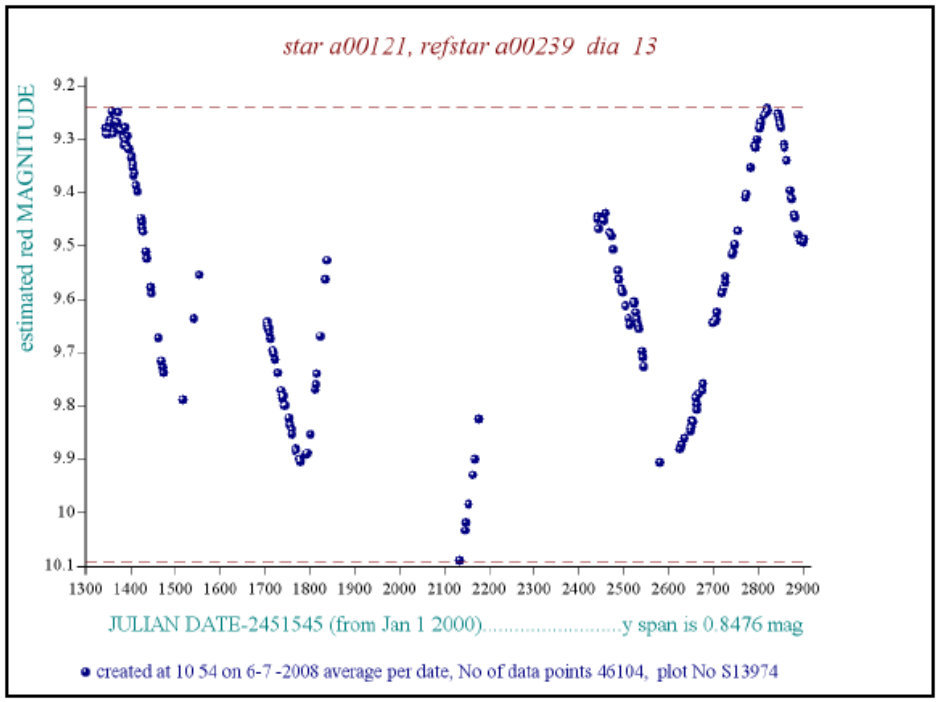
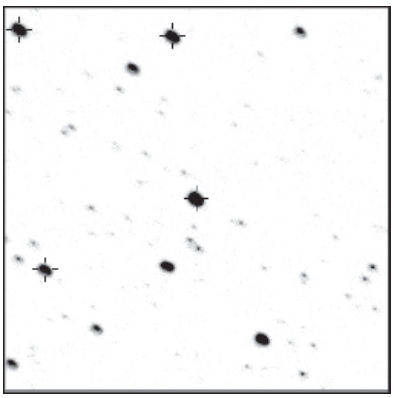


Figure 2: Star a00121



The star images are slightly elliptical because this star is in the corner of the field. There happens to be three other variables in this sample (251 pixels square). The five year light curve is shown above. There are clearly at least two frequencies. The slow one can be only guessed at, and I make it 2940 days. The next most obvious is 5 cycles at about 294 days. Colour temperature estimate: 4105ºK. Norman Walker* has done a power spectrum analysis of this star and gets an additional period of 523 days.

RS. In the *J-H,H-K* diagram, a00121 is redder than most of Stan's variable stars. It lies in the same part of the diagram as the SRb semi-regular carbon star V Aquilae (C5,4-C6,4, or N6), the Lc-type irregular N-type carbon star SU Andromedae (C6,4), the SRb semi-regular carbon star RT Capricorni (C6,4 or N3) and the Mira variable R Lionis Minoris (M6.5e-M9.0e (Tc:)). V Aql, RT Cap and R LMi all have periods between 300 and 400 d.

LMC red variable stars with log $P \sim 2.5$-2.6 are extremely luminous, with $K \sim 10$ and $M_K \sim -9$. If star 121 has the same absolute magnitude, then $K = 2.924 \Rightarrow d \sim 2.3$ kpc.

This is one of the most westerly of Stan's stars. It is involved in the emission nebulosity north-east of the North America Nebula (NGC 7000). Although a00121 itself is near to the centre of a small fairly dense star cloud, it is in an area of patchy obscuration, and the Vizier data suggest that it is somewhat reddened in the infrared.

This is probably a double-mode semi-regular variable, and possibly a carbon star. The proper motion is $\mu \sim 0.0060$" a^{-1}, although there is a large error. If $d \sim 2.3$ kpc, $v_{tr} \sim 65$ km s^{-1}; in spite of the large uncertainty, this seems a reasonable transverse velocity for an asymptotic giant branch star. **RS**

TEa00169

Star a00169 is one of the highest frequency variables in the list, from area 'a', and has the interesting period of 0.03333 days, or 30.003 cycles a day. A small amount of averaging makes the oscillations more clearly visible, and the plot (Fig.4, page 16) shows a 10 point, or 9 minute average during one night in 2004. The p-p amplitude of the oscillations varies and although the low amplitude makes it hard to be certain of the range, a value between 25 and 29 mmag is most common, but it is often smaller, or a little larger than that. The variability of this star was found by a Fourier search program. It's not sufficiently deviant to show up on a noise scan.

Using simple methods, we can see no change of frequency between 2004 and 2007. The periodogram (2004+2007), (Fig. 3, page 15), shows peaks that are both close to 0.0333318.

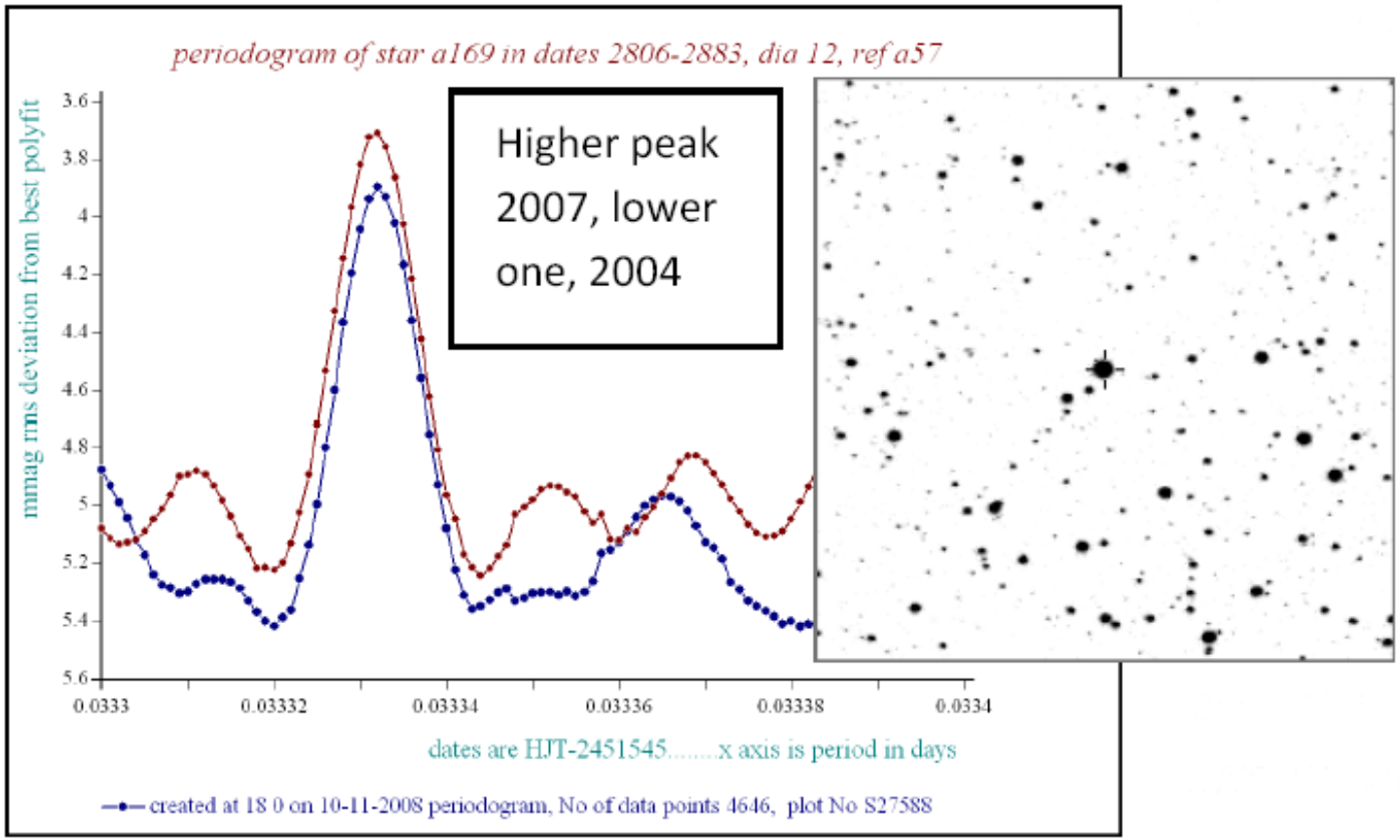
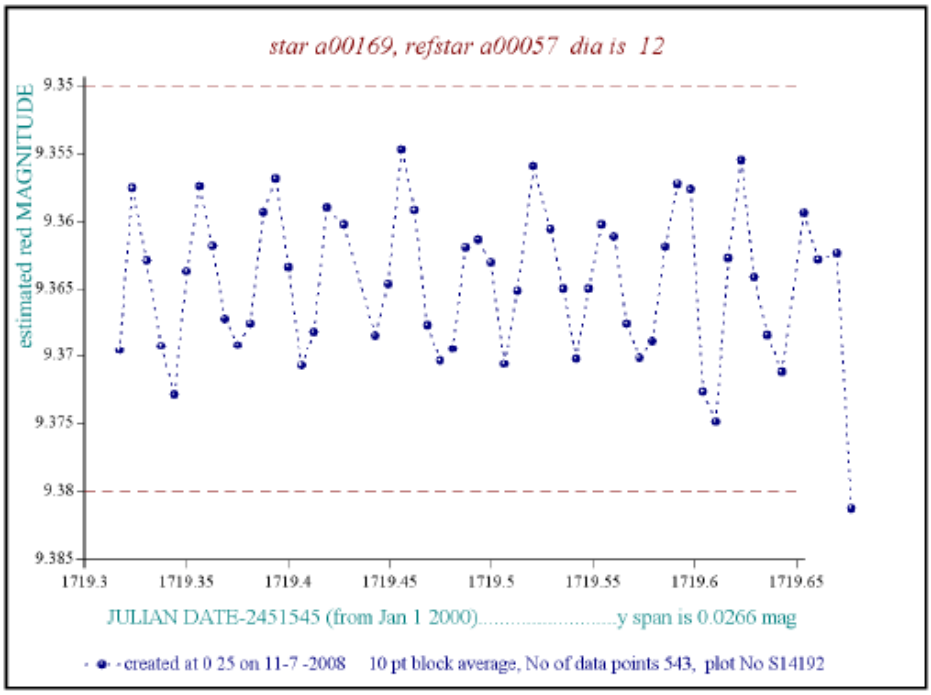


Figure 3: Periodogram, star a00169

Figure 4: Star a00169



RS. According to Vizier, this is an A2 Ib star, with an implied $M_V \sim -5$. Given that $V = 9.553$, $d \sim 8$ kpc. The BVR photometry suggests an early or middle A-type star, around A3-5 V or an earlier-type giant or supergiant. The JHK photometry suggests an early A-type star, and the *B-R/J-K* and *R-J/J-K* diagrams suggest a middle A-type star. The fact that the photometric spectral type agrees with the spectroscopic spectral type shows that the star is at most only slightly reddened ($E_{B-V} \leq 0.07$) and therefore that it is not at the great distance required by its being a supergiant.

A study of the photometric, pulsational and kinematic properties of the different types of pulsating A and F-type stars suggests that this is a short-period early-type λ Bootis star, similar to HD 210111 (NSV25839, in PsA), V1644 Cygni, V1790 Orionis, V346 Pavonis, and ρ Virginis. It is interesting that the λ Bootis stars seem to fall into two subclasses, one with $B\text{-}V \sim 0.09\text{-}0.18$ and $P \sim 0.031\text{-}0.043$ d (log $P \sim -1.37$ to -1.51) and the other with $B\text{-}V > 0.20$ and $P \sim 0.11\text{-}0.13$ d. However, I cannot say whether this apparent subdivision is real. **RS**

——————————TEa00255——————————

We are still not certain what kind of star this is. At first it looked like a Cepheid but it is too hot at a B-V of only 0.214 or a colour temperature of 8,430K. Our measurements make it 8,800K in reasonable agreement. The period has been checked by a correlation method which seems foolproof and at 1.57344 days it is too long for an RR Lyrae star.

RS. On the *B-V, V-R* diagram, a255 appears to be a late A-type star; in fact, it has essentially the same colours as SX Phoenicis. In the JHK two-colour diagrams, it appears

to be an early A-type star, which may make it too early for a Cepheid. Stan's 'steps' function gives it T = 8822 K (log T = 3.946), corresponding to a middle A-type supergiant. The *P-L* relation yields M_V = -1.94 for this star, implying d ~ 2520 pc and v_{tr} ~ 30 km s^{-1}. This is all very well, but I am not quite sure about it. Could this be a magnetic Ap star? That would be more consistent with the colour indices and the amplitude. Alternatively, it might be a reddened slowly pulsating B-type star (an LPB in the GCVS), although the colours imply too late a spectral type. **RS**

Figure 5.

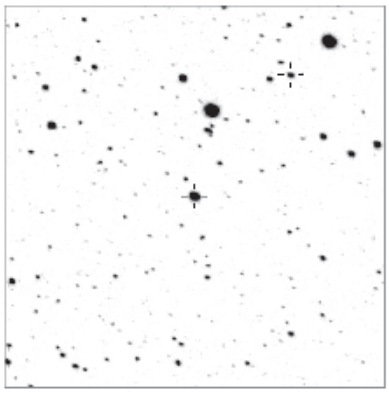
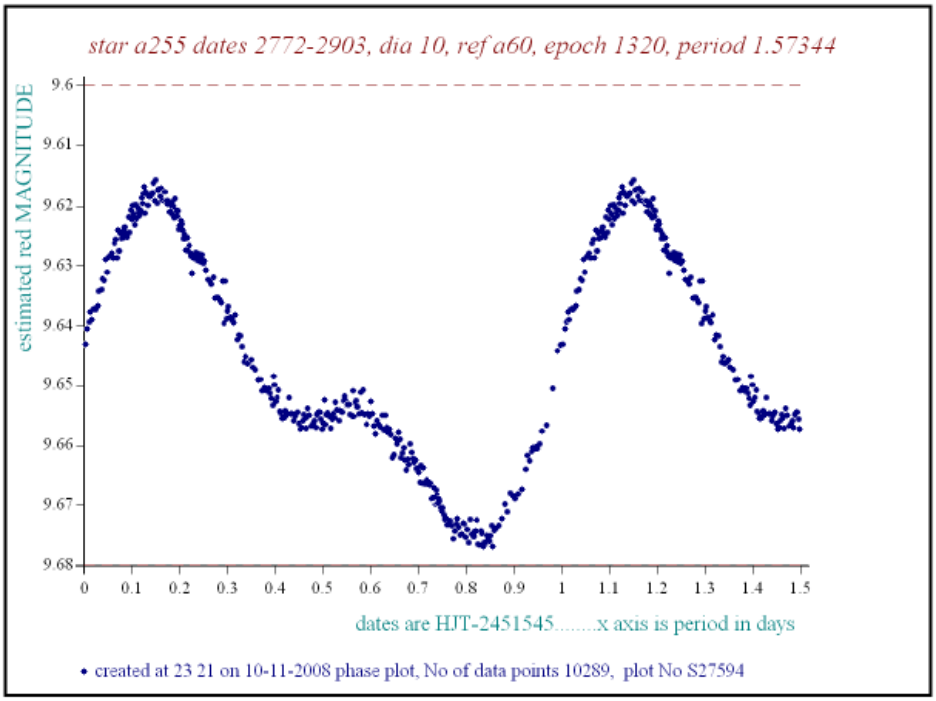


Figure 6: A phase plot of star a00255 from 2007 data.



TEa00596

This star is similar in some ways to the above in that it is hot, the catalogue B-V leads to Tc=9,400K and our approximate measurements to 10,100K. Again the period is too long for an RR Lyrae star, and it's too hot for a classical Cepheid or W Virginis. So what is it?

RS. At first glance, this is an obvious Cepheid variable, with P = 1.7698 d. However, in

the *BVR* and *JHK* two-colour diagrams, it appears to be an A-type star. In the *H-K,J-K* two-colour diagram, the star has almost the same colours as the hot Siλ4200 star HD 124224 (CU Virginis) and similar colours to those of the B8 IIIp (HgMn) star κ Cancri. In the *B-V,V-R* diagram, the star has *B-V* = 0.124, *V-R* = 0.07 and is located near to the A4 V star δ Leonis, but the colours are still quite inconsistent with those of a Cepheid variable. Stan's 'steps' function yields T_{eff} = 10128 K (log *T* = 4.0055), consistent with a spectral type of B9-9.5 V, M_V ~ 0.0, and *d* ~ 1300 pc. The *B-V* colour implies T_{eff} ~ 8400 K, rather too hot for an RR Lyrae star (T_{eff} ~ 6.3-7.6 kK) and definitely too hot for a Cepheid. The *P-C* relation derived from Allen (1973) yields $(B\text{-}V)_0$ ~ 0.361, so the star is too blue for its period by Δ(*B-V*) ~ -0.24.

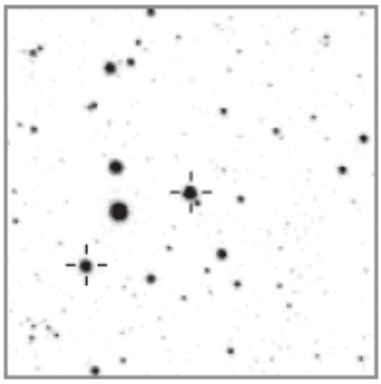


Figure 7.

For what it is worth, BL Bootis, the prototype of the BL Boo stars, has *J-H* ~ 0.209, *H-K* = -0.036, *J-K* = 0.173, and falls among the F-type stars. It also has a much shorter period (*P* = 0.821295 d) and Δ*m* = 0.61 mag. BL Herculis is no better; its spectral type is F3 II-III, and it falls among the F-type stars in all the two colour diagrams. The thing begins to look like a Slowly Pulsating B star (or LPB in the GCVS). These have $(\log T)_{min}$ ~ 4.05, or T_{min} ~ 11220 K, implying a spectral type of about B8. **RS**

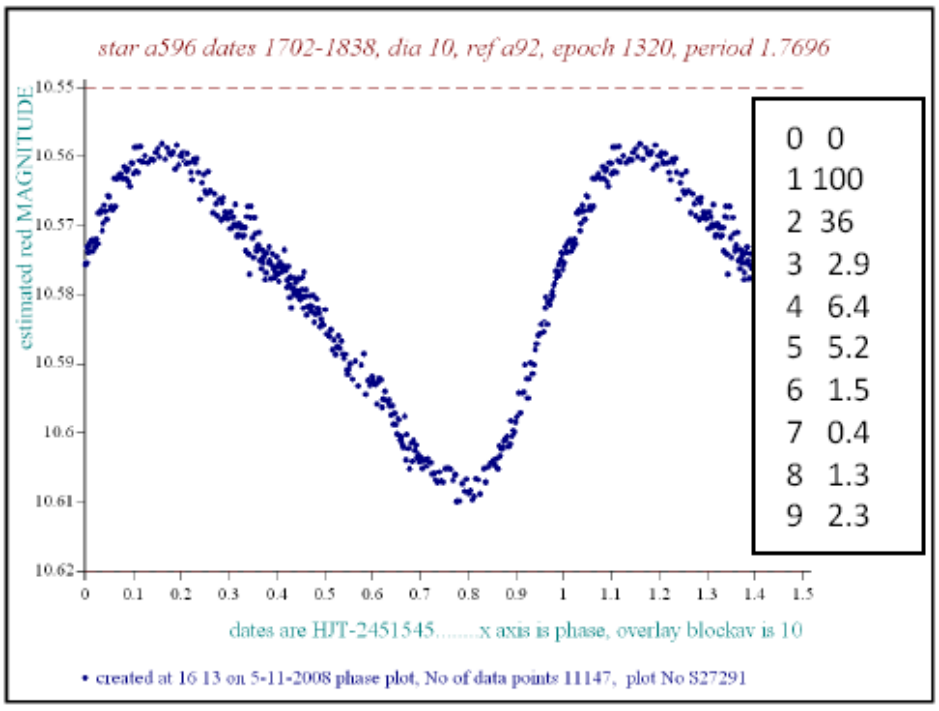


Figure 8: A phaseplot of star a00596 from 2004 data. The table lists the Fourier coefficients for this star in 2004.

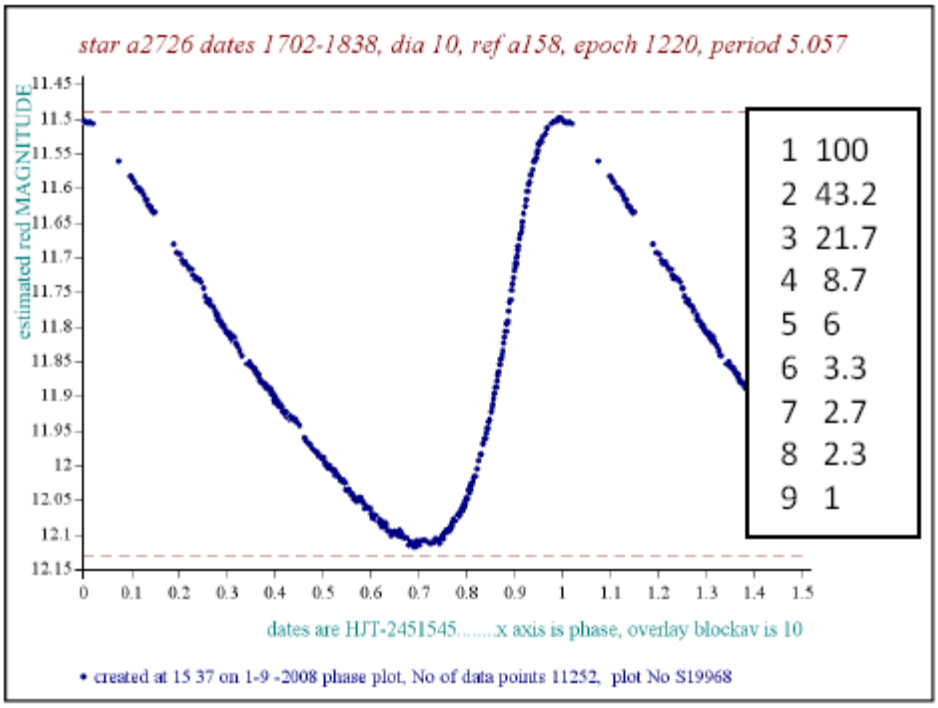


Figure 9: Phase plot of V356 Cygni made from 2004 data.

For comparison, here is a phase plot of V356 Cygni made from 2004 data. The gaps are caused by the period being so near to an integral number of days. The plot has much less scatter than star 00596 (Fig.8,p.18) because, although it is nearly a magnitude fainter, its amplitude is 613 mmags compared to only 49 mmags for 00596. The data for both these plots was captured between 29th August 2004 and 12th January 2005.

The Fourier plot of this phase data (right) shows a smooth, almost exponential decline,the normalised coefficients are on the phase plot above (Fig.9).

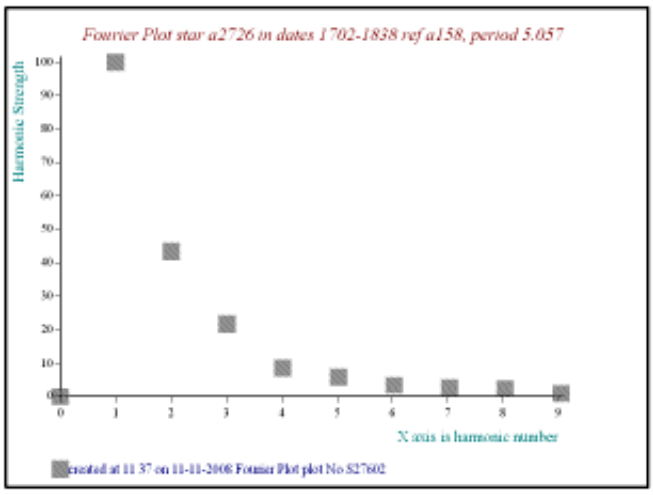


Figure 10: Fourier plot of phase data of V356 Cygni.

Next, an eclipsing binary. With over 100 in the area there is plenty of choice so this one was chosen almost at random. Shown are phase plots from 2007 data. There is no discernable eccentricity.

M1 and M2 have depths of 0.64 and 0.12 magnitudes and half-widths of 8.2% and10.2% respectively. Our measurements suggest a Tc of 7600°K or a B-V of 0.306 which is quite at variance with the numbers above (-0.022).

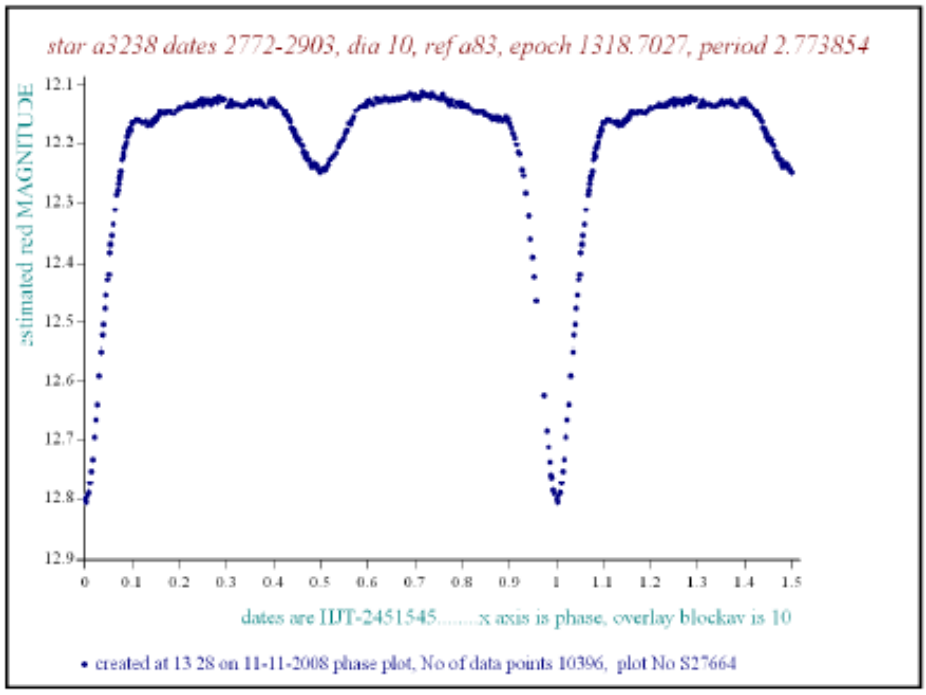


Figure 11: Phase plot of star a03238 from 2007 data.

RS. The observations yield a very good typical semidetached Algol-type light curve. There is a modest reflection effect, with $\Delta m \sim 0.05$ mag.

The BVR colours suggest a late B-type star (about B9), whereas the JHK colours suggest an early F type star; these spectral types are probably consistent with the light curve. The proper motion suggests $d > 1$ kpc and $M_V \sim -0.1$; this absolute magnitude is consistent with a spectral type of about B9, so the star does not appear to be as much reddened as I should have expected from the inferred distance. **RS**

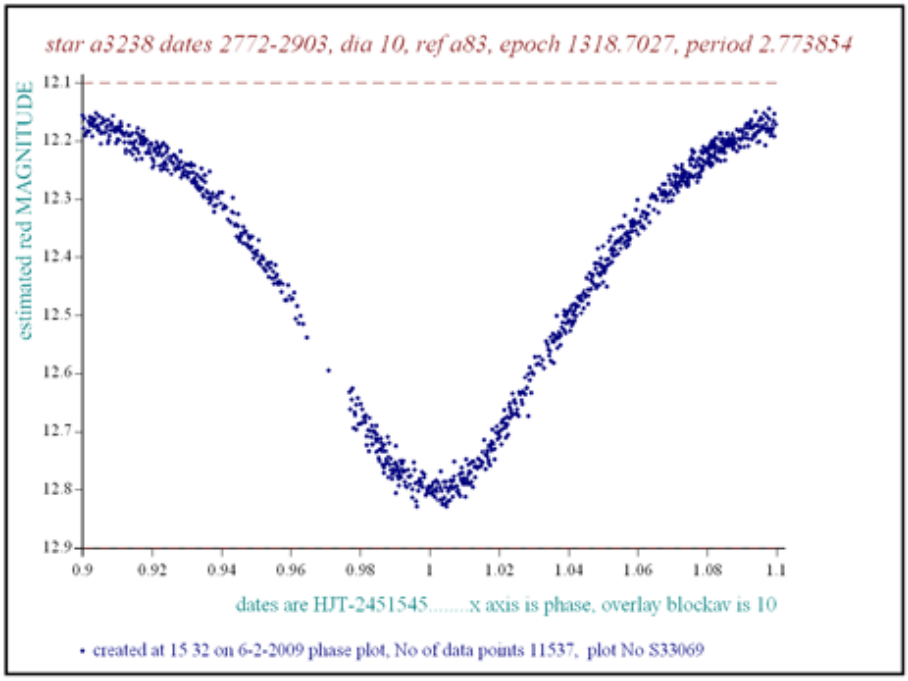
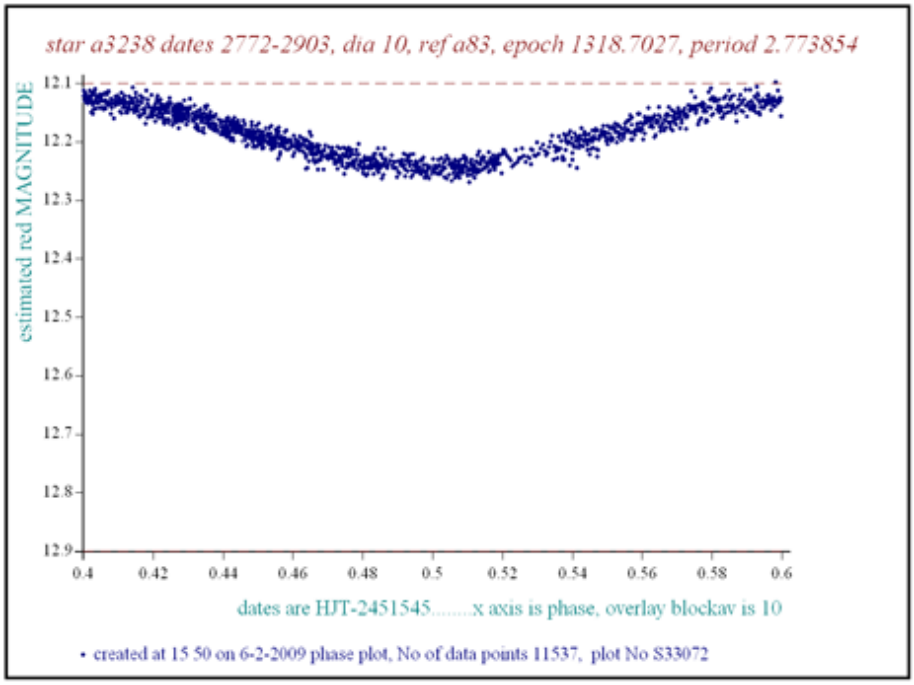


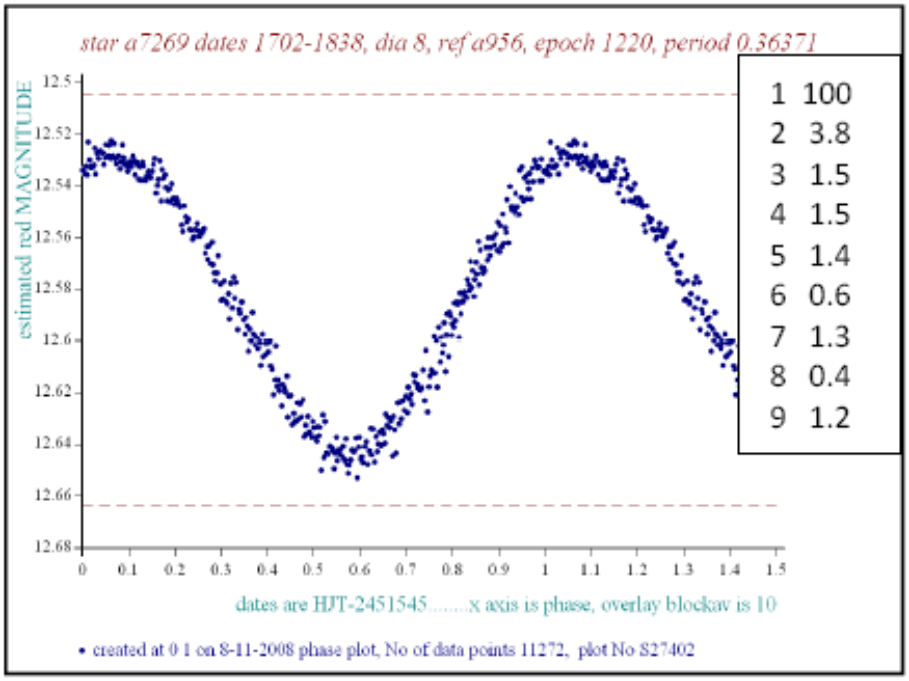
Figure 12: Phase plot of Primary Eclipse.

Figure 13: Phase plot of Secondary Eclipse.



This star is included for the interest that its phase plot is so near to a pure sinewave, only 3.8 second harmonic distortion! The phase plot below is from 2004/5 but a very similar result is obtained for other years.

Figure 14.



RS. An RRc-type pulsating variable. The light curve is almost symmetrical, with $\phi_{min} = 0.50$.
For the period 2003 to 2007 I conclude that $P = 0.363727 \pm 3 \times 10^{-6}$ d, and there is no evidence for any variation in the period.

The photometric data suggest that this is a late F or G-type star. The JHK colours (J-H = 0.299, H-K = 0.163) are very similar to those of the G2 Ib star ζ Mon. The star is in a dense field, with no obvious evidence of extinction; there are many fainter

Figure 15: Fourier Plot star a07269 in dates 1702-1838 ref a956. period 0.36371

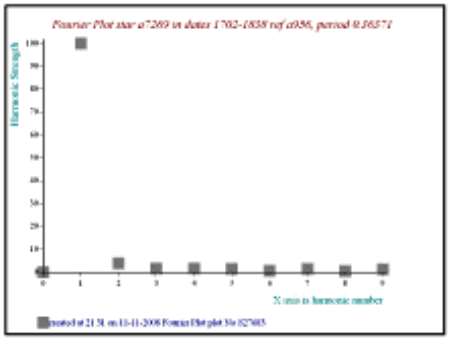
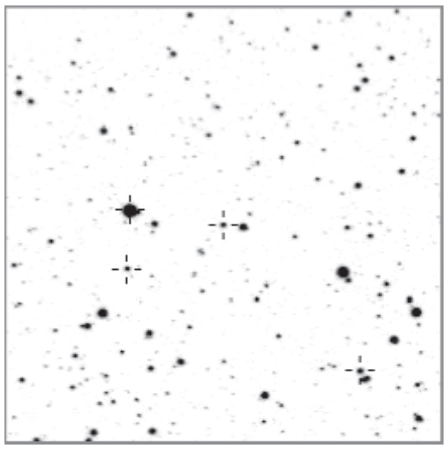


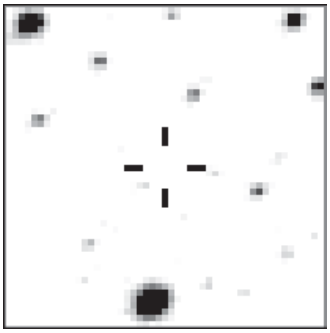
Figure 16.



stars in the field. *B-V* for the star is 0.45 mag., but Allen (1973) gives a mean value of *B-V* = +0.2 mag. for RR Lyrae stars. If $E_{B-V} \sim +0.25$ mag, $A_V \sim 0.78$, so $V_0 \sim 12.96\text{-}0.78 \sim 12.18$. With $M_V \sim +0.6$, $d \sim 2.1$ kpc. **RS**

TEa11459

Figure 17.



So far this is the most variable star in area 'a' and a special effort was needed. For a star of this brightness, using a 5" refractor, 30 second exposure and processing single images we run out of S/N at about magnitude 15.5. The quantum noise and back-ground noise and errors are about equal to the signal. By adding 100 images that can be improved to about magnitude 18. I don't actually add the images in fact, but small samples centred on the correct RA and DEC, and previously cut out for every star and every picture. In this particular case it is further complicated by the existence of three very faint companions not many arc-sec away. A few pixels are pared away from the edge of the target star nearest to the brightest interferer to reduce errors when the target star is at its faintest.

Figure 18.

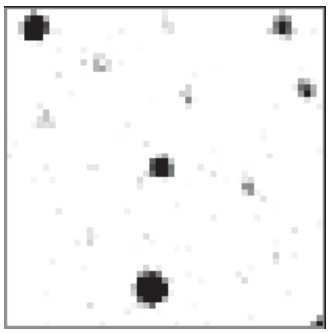


Figure 19.

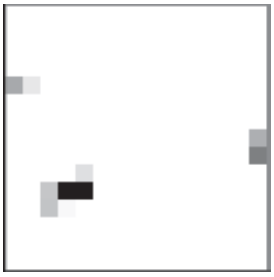


Figure 17, is the star on September 1st 2004 (date 1705) and figure 18 is the star at it's recent brightest, September 14th 2007 (date 2813). The 1st two clips above are 2.1arc-min square. The three very faint companions can be seen on Figure 19, the third clip, which is 10 times more stretched, and

37 arc-sec square; the target is in the middle and invisible on this clip. The nearest and strongest interferer is 10 arc-sec away from the centre of a11459.

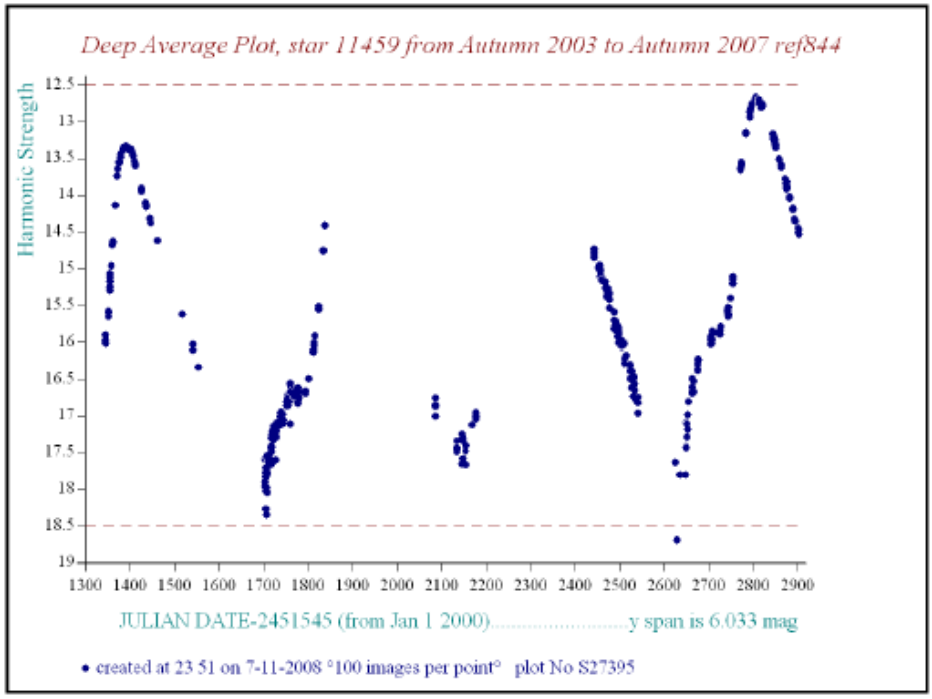


Figure 20: The 5 year plot shows a change of six magnitudes. The downslopes are almost perfectly linear. The upslope has a well defined kink in the two we can see.

RS. A Mira variable, with $P \sim 440$-470 d.

This is one of the reddest of Stan's stars, and is probably a carbon star.
The pulsation period $P \sim 468$ d, combined with the formula $M_K = 3.47(\pm 0.19) \log P + 1.00(\pm 0.08) \Rightarrow M_K = -8.3 \pm 0.6$. If $A_K = 0$, the apparent magnitude $K = 5.349 \Rightarrow$ d ~ 5.5±1.5 kpc.

If B.C. ~ -4.1 mag., $M_{bol} \sim -4.2 \pm 0.6$ and $L \sim 3700 \pm 2000$ and $L_{\odot}$ ($\log L \sim 3.57 \pm 0.23$), consistent with a location of the star on the upper AGB. This appears to be one of the most distant stars on Stan's list. **RS**

* Much more detail on all these stars including Norman's analysis of TEa00121 (and many others) can be found on the website:
www.the-planet-project.com