

# SOME PRACTICAL EXPERIENCES

## ON PHOTOMETRY

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**Abstract.** The authors review the results obtained by them during the Visnjan School of Astronomy 2003. Measures of the  $\delta$  Scuti pulsating variable V1644 Cygni has been obtained on two consecutive nights by means of a SSP-5A photoelectric photometer attached to a 0.1m f/10.5 Maksutov telescope. Data has also been remotely collected on V4743 Sgr (Nova Sgr 2003 nr.3) by means of the 0.3m f/9 (plus unfiltered SiTe 1024 back-illuminated CCD) reflector of the Osservatorio Astronomico de Mallorca.

**Key words:** stars: delta Scuti, novae, photoelectric photometry, education in astronomy

### PHOTOMETRY: AN INTRODUCTION

Mankind has always been showing great interest in the night sky, trying to describe the behaviour of sky objects using any means available. Through time, more and more sensitive and accurate instruments and methods were available. After the discovery of the photoelectric effect (Hertz, 1887) and its explanation using quantum physics (A. Einstein, 1905), astronomers were given the finest detection instrument so far especially well for differential measurements. The basics of this instrument are shown in Figure 1.

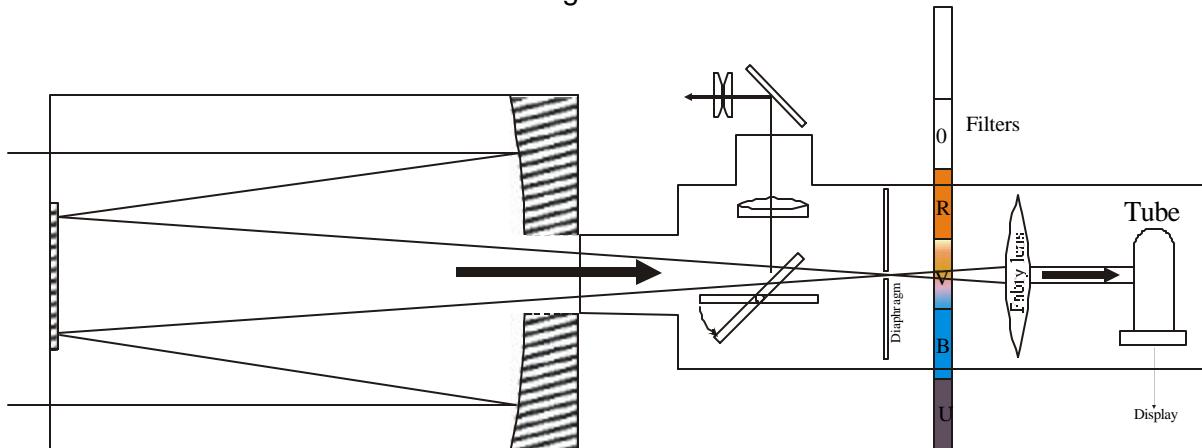


Figure 1 Schematics of the telescope and photoelectric photometer optics head

The light from the star has to be focused through the pinhole in a diaphragm so that additional light from surrounding background would be greatly reduced. Therefore light can be redirected into the eyepiece for accurate placement of the star. After the diaphragm are filters used to transmit a certain interval of wavelengths. Before hitting the photomultiplier tube, photons pass through a Fabry lens, which directs them into a parallel beam on the photomultiplier window. The photomultiplier tube consists of three main parts: the photocathode, which emits electrons when hit by photons, dynodes that amplify the signal, and anode that receives and measures that signal. This small current is then amplified by additional electronics, and read out, either by a PC or a simple counter.

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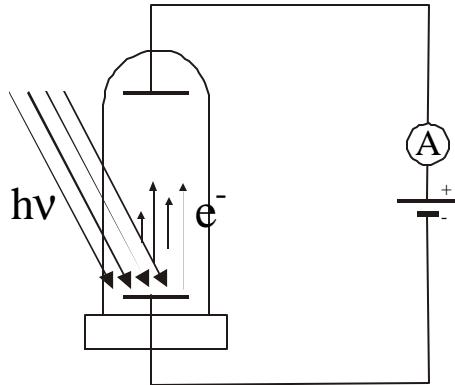


Figure 2 Photomultiplier tube schematics

An [Optec SSP-5](#) photometer with a photomultiplier tube was used in our observations. The filters mounted in the optical path are Johnson standard UBVR. Figure 3 shows the transmission curve of these filters:

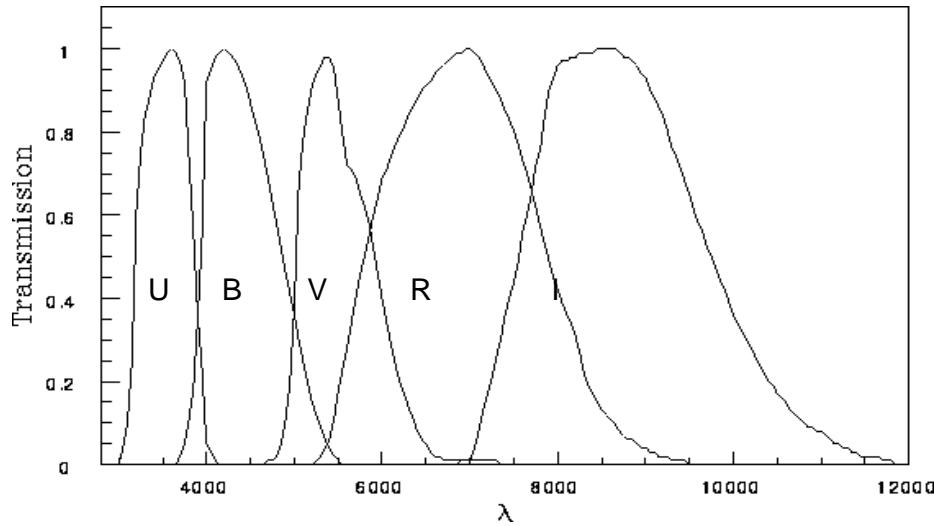


Figure 3 Transmission curves for UVB (RI) Johnson photometric bands

The Johnson UVB photometric standard system is most commonly used because of its two most important components: V magnitude (usually a close match to the visual magnitude) and the B-V and U-B colour indices (that provides important clues on astrophysics). These colour indices show the difference in magnitude measured in different filters, and therefore the difference in emission in long and short wavelengths. A white star has a colour index equal to 0, for red stars it is higher, and negative for blue stars. There are also other filter standards, like the Strömgren - uvby system.

Normally the measurements are collected in the following order: DC-SB-A-B-V-V-B-A-SB-DC, where DC is the dark current (actually it's the amount of electrons emitted by the electronics mainly for thermal effects), SB is the natural emission of sky background due to scattered light in the atmosphere, V is the variable, B is the reference and A is the check star. These measurements are converted into instrumental magnitudes using the classical Pogson formula:

$$v_i = -2.5 \cdot \log(c_v - c_s)$$

where  $v$  is the instrumental magnitude,  $c_v$  and  $c_s$  are the instrumental variable star and sky background counts.  $C_s$  is a mean value of the sky background counts before and after the measurement set.

For each series of measurements of the variable star a mean value and standard deviation were calculated. The formula for the standard deviation is: ( $n$  is the number of measurements in a set)

$$s_{\bar{v}} = \sqrt{\frac{\sum_{i=1}^n (\bar{v} - v_i)^2}{(n-1) \cdot n}}$$

$$\bar{v} = \frac{\sum_{i=1}^n v_i}{n}$$

This set is represented by a single point on the graph, with the value of  $\bar{v} \pm \sigma_{\bar{v}}$ .

For sure the reference and check star should be non-variable stars. If one is interested in differential photometry only, then it's even not needed to know their actual magnitudes, as the results will be shown as relative deflections toward the two reference stars, and not actual magnitudes.

Light coming from the star has to pass a certain amount of air in the atmosphere, which changes through the observation due to the Earth's rotation. This air mass  $X$  is approximated with  $X = \sec(z)$ , where  $z$  is the star's angle from the zenith. This approximation is correct until about  $40^\circ$  from the zenith. In order to reduce the error from this approximation stars should be observed close to the zenith. The instrumental magnitude of reference stars is then plotted vs. their air mass. The linear dependence coefficient obtained by the least squares method is called  $K_v^1$  or the first order extinction coefficient.  $K_v^1$  is used for the air mass correction of the variable star instrumental magnitudes using the next formula:

$$v_0 = v - K_v^1 \cdot X$$

The second order extinction coefficient ( $K_v^2$ ) is normally used if one takes into account also the colour change vs. the air mass. However, normally it is negligible if the variable and reference stars are of the same spectral class and if they are less than 1 degree apart.

$$v_0 = v - K_v^1 \cdot X - K_v^2 \cdot (b-v) \cdot X$$

The least squares method is used to calculate an ideal fit of a line or curve from scattered data. For each value on the x axis there is a value of the function  $y=y(x)$ . In order to calculate the coefficients the next formula is used:

$$y = a + b \cdot x$$

$$b = \frac{n \sum_{i=1}^n x_i y_i - \sum_{i=1}^n x_i \sum_{i=1}^n y_i}{n \sum_{i=1}^n x_i^2 - \left( \sum_{i=1}^n x_i \right)^2}$$

$$a = \frac{n \sum_{i=1}^n x_i^2 \sum_{i=1}^n y_i - \sum_{i=1}^n x_i y_i \sum_{i=1}^n x_i}{n \sum_{i=1}^n x_i^2 - \left( \sum_{i=1}^n x_i \right)^2}$$

## POSSIBLE ERROR SOURCES

Photoelectric photometry is, in principle, a powerful mean for the accurate determination of star brightness. However, in order to achieve precise results one should minimize every possible error source. In our opinion, the following causes of inaccuracies could be listed:

- Moonlight disturbance
- Light pollution
- Wildfire smoke
- Passing clouds
- Star not centred in the diaphragm
- Reference stars inaccurate magnitudes

## CALIBRATION

The calibration of a photometer is necessary for converting instrumental magnitudes into those of a given standard photometric system. For this we measured the star sequence belonging to the well-calibrated open star cluster IC 4665 in Ophiucus. These stars are particularly suitable for this purpose because of several reasons: there are reference stars belonging to a wide range of magnitudes and colours indices (i.e. spectral classes), they are very close to each other (so the measurements can be very quick and the difference in air masses and sky background among each single star is negligible). The stars that were observed for our calibration are shown in Table 1.

Table 1 Stars used for calibration with their characteristics

Star	Spectral class	Magnitude	B - V
A, 3483	B4	6,85	0,01
C, 3484	B9	7,34	0,02
D, 3514	A2	7,43	0,33
E, 3504	B9	7,49	0,02
H, 3469	K2	7,83	1,28
I, 3524	K0	7,89	1,03
J, 3488	F0	7,94	0,45
K, 3466	A0	8,05	0,07
L, 3491	B9	8,22	0,11
M, 3471	B9	8,31	0,06
N, 3498	K5	8,33	1,73
O, 3500	K2	8,40	1,23
Q, 3503	-	8,96	1,25

For our measurements blue and visible filters were used. First we measured the dark current contribution (that is the instrumental electronic “noise”, mainly due to the high temperature of these nights); then we measured the sky background luminosity near every star we were interested in. After this we centred the target star in the photometer diaphragm taking 6 consecutive readings. Dark current, sky background and star luminosity were always obtained through the same amplification scale on the instrument, and with the same integration time (10 seconds). This procedure was repeated for B and V filters, respectively on every star in Table 1.

The data was reduced in the classic fashion. At first we determined the deviation between standard and instrumental magnitudes for the V filter, vs. colour indices. Then we calculated the slope coefficient of the plot that defines the instrumental deviation. The final formula for the instrumental calibration is:

$$V - v_0 = \epsilon(B - V) + Z_{v^0}$$

$V - v_0$  – difference between standard and instrumental magnitude

$\epsilon$  - correction coefficient

$B - V$  – colour index

$Z_{v^0}$  – zero point

where the coefficients were obtained from the plot by means of least square method.

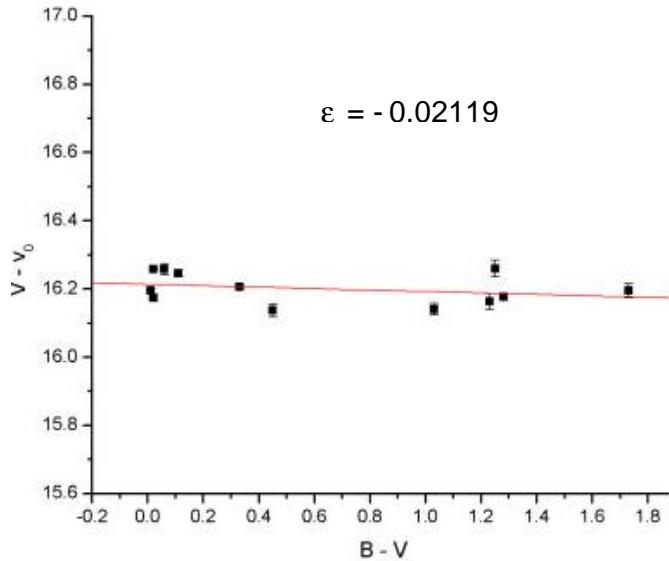


Figure 4 Calibration curve - visible filter

In Figure 4 the difference between standard magnitudes and instrumental magnitudes according the colour index is shown. The coefficient  $\varepsilon$  is a slope of the plot  $(V - v_0)$  versus  $(B - V)$  and has been determined to be equal to - 0.02119. This means that in our instrumental set-up red stars (that are on the right part of graph) are measured slightly fainter than in reality.

Second correction is colour correction that has been calculated using the next formula. Formula has been obtained using measurements of stars in IC 4665.

$$(B - V) = m(b - v)_0 + V_{bv}$$

$B - V$  – colour index

$\mu$  - correction coefficient

$(b - v)_0$  – standard colour index

$\zeta_{bv}$  – zero point

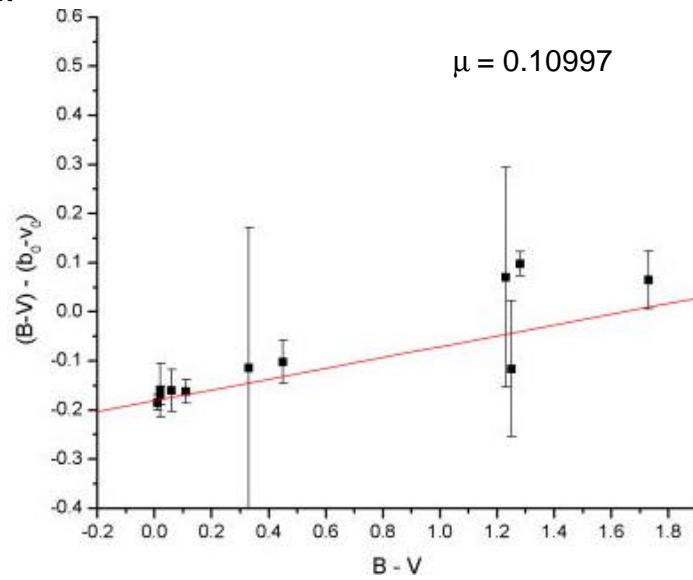


Figure 5 Calibration curve - colour terms

In graph 5 the difference between colour index and standard colour index according to standard colour index is shown. The error bars are pretty high because the fainter stars were observed during the full moon period. In this graph it's possible to see that in our instrumental system, for greater  $B - V$  (redder stars) our calibration curve departs from the theoretical "zero"

reference line by a factor  $\mu=0.10997$ . In other words, our photometer plus B and V filters are showing the redder stars a little bluer than what is reported in the literature.

Our photometer (photo multiplier plus filters) seems to be pretty close to the international standard of Johnson and Morgan (Johnson, H.L. and Morgan, W.W. 1953. *Ap.J.* **117**, 313 and Johnson, H.L. and Harris, D.L., III 1954. *Ap. J.* **120**, 196) and only minor corrections are needed to precisely match it.

During the VSA 2003 the general environmental conditions were pretty bad so our measurements were not very precise. It was full moon period, so we had to choose brighter stars. We also had some problems because thin cirrus was passing by what our instrument registered before we did. During the calibration near Višnjan local fires severely effected our measurement. Because of all these problems we decided to use it like an exercise.

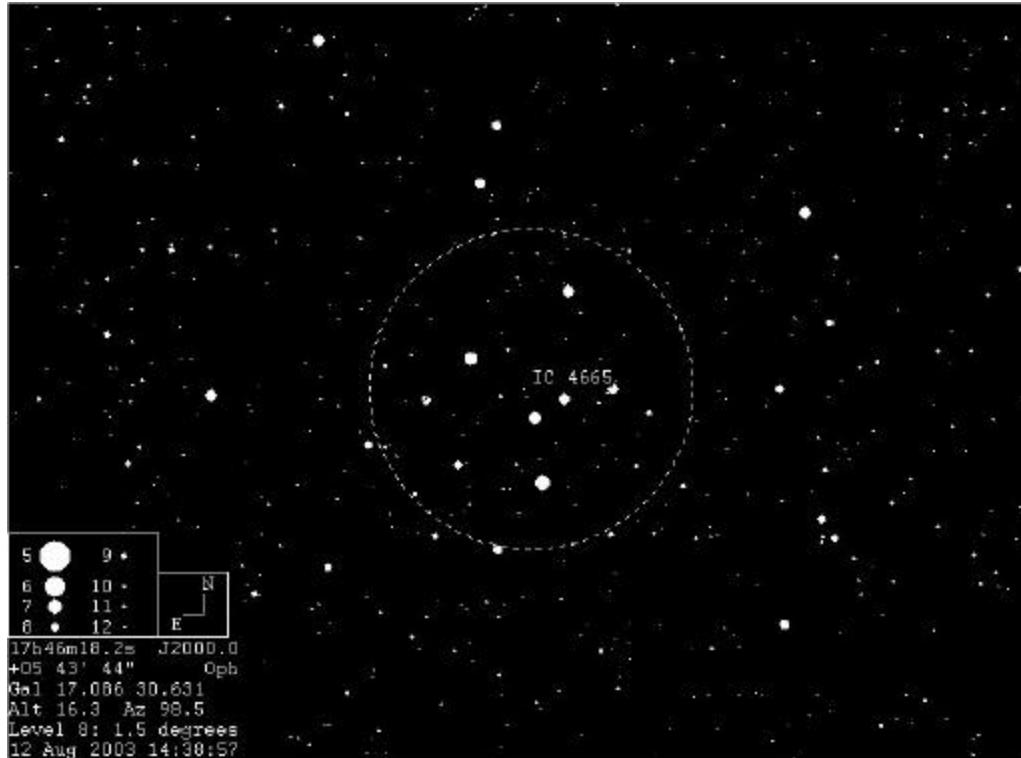


Figure 6 Sky map of open cluster IC 4665

## V1644 CYGNI

### Introduction

During the VSA2003 workshop we decided to apply the methods of photoelectric photometry on fast pulsating variables of the delta Scuti class. These stars have short periods of variation (0.02 – 0.25d) and low amplitude (below 1<sup>m</sup>) with spectral types A0 – F5 and luminosity class III - V. They are part of the delta Cephei instability strip in HRD and it is likely to find more delta Scuti stars with very low amplitudes in that region. Most of them are non-radial pulsating stars and objects of astroseismology research.

V1644 Cyg is a lambda Boötis star, which is a subclass of delta Scuti stars that have peculiar chemical composition. The main cause of the instability is helium burning within the stellar interior. V1644 Cyg has low space and large rotational velocity, absolute magnitude M=2.53, amplitude varies from 0.015<sup>m</sup> to 0.030<sup>m</sup> and the period is P=0.031d. Its spectral type is A2 (hydrogen and weak metallic lines). It was chosen for observations at VSA2003 because of its brightness (~5<sup>m</sup>), short period and current position close to the zenith; these facts have reduced the environmental disturbances (moonlight, unstable sky conditions).

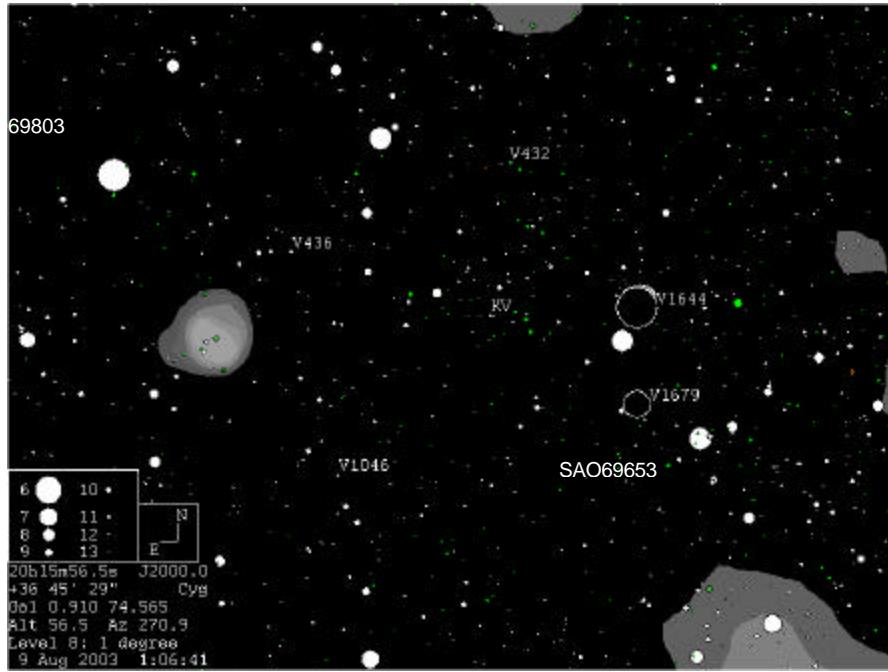


Figure 7 Sky map with V1644 Cyg and used reference stars

Table 2 Stars used in V1644 Cygni photometry with their characteristics

Star	Spectral type	B-V	Magnitude
V1644 Cyg	A2	+0.16	4.94-4.97
SAO69803	A0	+0.04	5.58
SAO69653	A2	-0.02	6.48

### Measurements

The star was observed for 2 consecutive nights (8 and 9 Aug) using 105 mm Maksutov telescope on equatorial mount with Optec SSP – 5A photometer in visual band (Johnson's UBVR filter system). Two comparison stars were used; a reference (SAO 69653) and a check star (SAO69803). Both observations lasted about 1<sup>h</sup>. Integration time for each measurement was 10<sup>s</sup>. To get a single value of star brightness, 6 measurements were taken and averaged; the sky background contribution was determined averaging 3 consecutive readings (10 sec each integration time) taken in an area close to the target, free from background stars. Photometric measurements of check star were taken at the beginning and the end of the observing period. During first night, measurements of sky background were taken after 6 star measurements (every 1 minute). Since the sky was stable, the next night its measurements were taken after 30 star measurements (every 5 minutes). In this second night the reference star was measured every 15 minutes.

The obtained data was reduced to get the light curve of the object. Magnitudes (with standard deviation error bars) were calculated using Pogson formula.  $K_V^{-1}$  correction for atmospheric extinction (Figure 8) was applied. The period was obtained with PDM, the program for calculating periods and all the measurements were converted into phase.

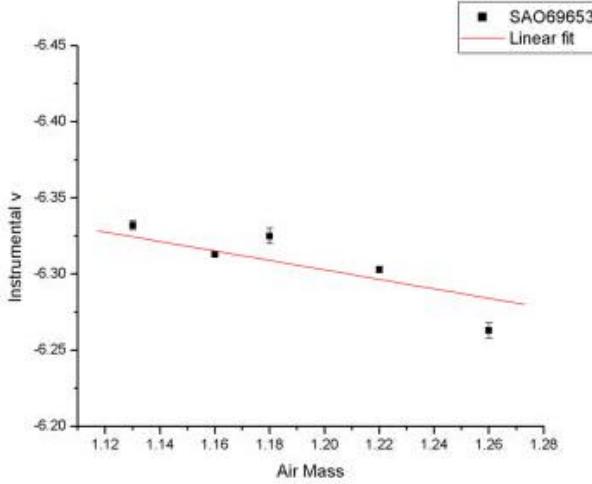


Figure 8 Atmospheric extinction correction graph (8/9 Aug), Kv=0.486

## Results

After the instrumental magnitude was calculated and a period of 0.0313d was determined, the light curves for each observing night were plotted.

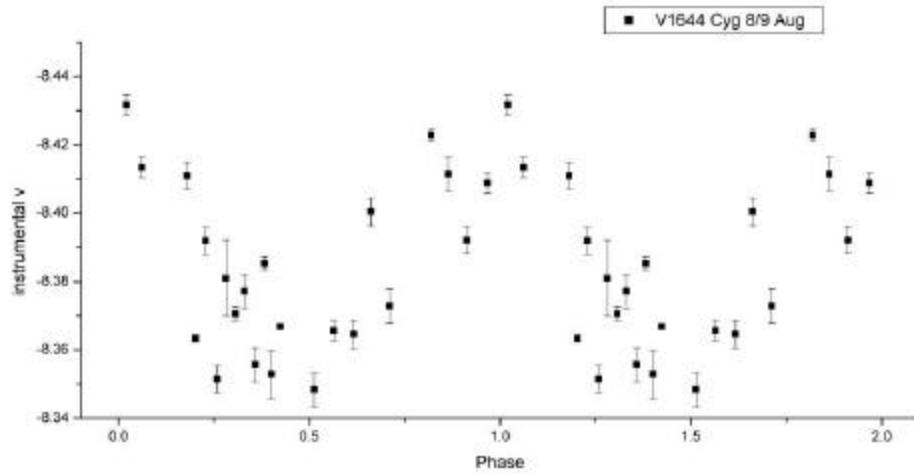
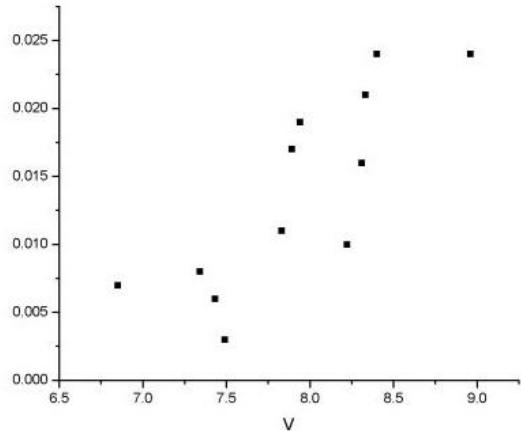


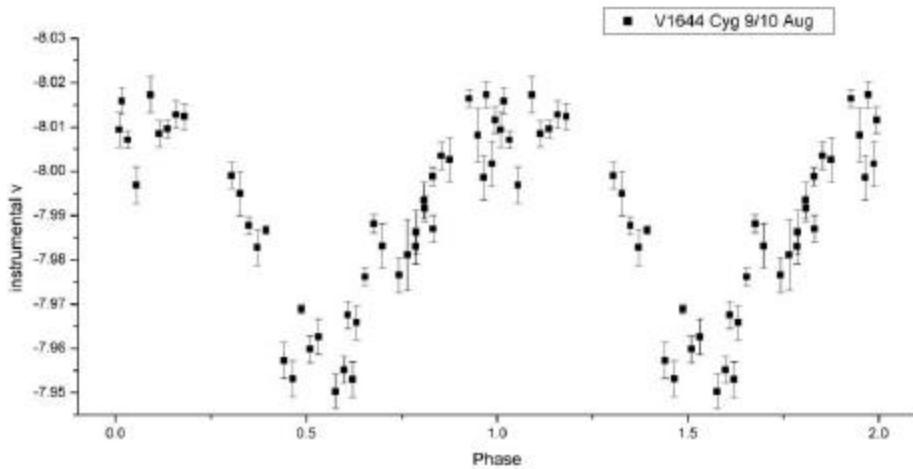
Figure 9 The phase light curve of V1644 Cyg (8/9 Aug) with a coupled phase for better view and instrumental magnitude

Figure 9 shows the light curve for the first night of observation. Peak to valley amplitude in brightness variation is close to  $0.04^m$ . Average internal error of the measurements is  $0.004^m$ , and external is  $0.02^m$ .

Internal errors represent the repeatability of 6 integrations and compensate for the dark current fluctuations and photometer sensitivity. They are shown by error bars, which are standard deviation of one data point and linearly increases with magnitude (Figure 10). External errors encompass clouds and smoke in the field of view, moonlight, light pollution effects and false star positioning in the diaphragm. These errors are estimated by the scattering at the minimum of the light curve. The data points are much more scattered than the internal errors, which is likely due to unstable sky transparency conditions along the observing run.



**Figure 10 Internal errors linearly increase with magnitude**



**Figure 11 The phase light curve of V1644 Cyg (9/10 Aug) with a coupled phase for better view and instrumental magnitude**

The second night light curve (Figure 11) has less scattered data points (external error is  $0.01^m$ ) and they better fit the overall light curve pattern. Average internal error is  $0.004^m$ .

V1644 shows a light variation of almost  $0.04^m$  in period of 0.031 days, which corresponds to the reference information about the star. The light variation was noticeable using a 105 mm telescope and a photoelectric photometer.

## CCD PHOTOMETRY

### Measurements

Except the photoelectric photometry, during VSA2003 CCD photometry was also done to study objects fainter than  $10^m$ . The LX 200 (0.3m aperture, f/9) robotic telescope at Osservatorio Astronomico de Mallorca was used with SiTe 1024 CCD camera and controlled by web interface. Processed \*.fits images (dark frame subtracted and divided by flat field) of  $10^s$  exposures were taken and then downloaded.

## Aperture photometry

Astroart software was used for the photometric measurements of imaged objects. Two comparison stars were used. Counts above the nearby background (that was subtracted from the total counts) were measured for each star. The difference in magnitude between the object and a reference star (differential photometry) was calculated using Pogson formula.

### V4743 Sgr (Nova Sgr 2002 No. 3)

Nova Sagittarii 2002 No. 3 was discovered on September 2002 at magnitude 5. During 18, 19 and 21 July this year unfiltered and B-band photometric measurements from Cerro Tololo showed sinusoidal light variations of amplitude  $0.2^m$  and period  $P=0.281 \pm 0.003$  d. This is believed to be the modulation induced by the orbital motion of the double system of stars.

84 unfiltered images of this star, spanning almost 1<sup>h</sup> were taken on the night of 14/15 Aug. Reference stars (SAO187576 and SAO187580) were on the same field of view and differential photometric data reduction was applied. Exposure time and centre of the exposure were extracted from the image header and the resulting light curve is visible in Fig. 10. The difference between the reference and check stars is also plotted, to see whether the brightness variations are caused by external causes (like passing cirrus clouds).

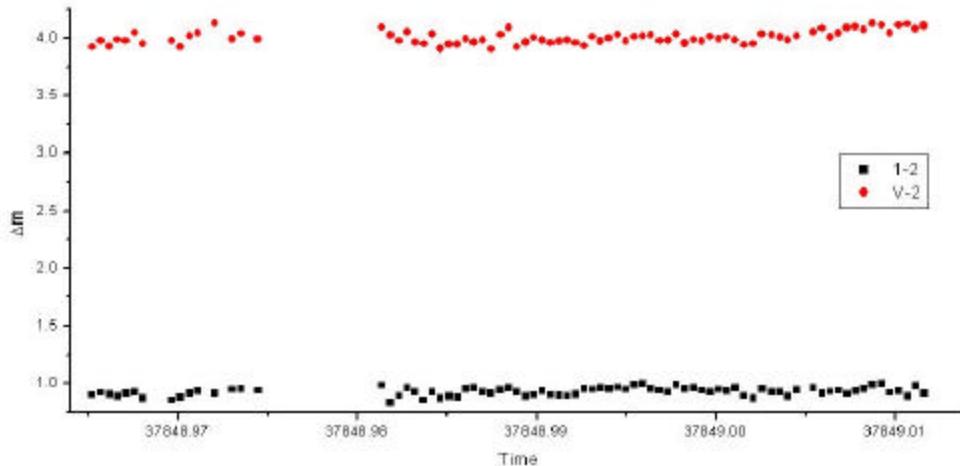


Figure 12 Light curves of V4743 and SAO187576 compared with SAO187580.

The light curve (Figure 12) shows very small fluctuations (amplitude around  $0.1^m$ ) for the variable star, as well as for the reference star. This implies that we are dealing with the noise of the data, and that the real light variation wasn't actually detected. Though, the period of variation is  $6.7^h$  and the observational period lasted about 1<sup>h</sup>, it is entirely possible that the brightness hasn't changed in that period for an appreciable amount. However at the end of the observing run, a slight brightness increase is visible in the variable light curve, but further measurements are needed to confirm if it is due to the physical change or not.

According our brief experience, CCD and photoelectric photometry have some important differences: normally photoelectric photometer allows higher accuracy and time resolution, while its data acquisition and reduction are faster. However, CCD can collect data on fainter objects, also in non-perfect nights, but with lesser accuracy.

The light curve we obtained on V4743 Sgr shows no apparent brightness change; this can be due to the short observing period of our run, or just because the measured light fluctuations were smaller than our instrumental sensitivity.

## CONCLUSIONS

During VSA we got familiar with the methods of photoelectric and CCD photometry. Our results show high accuracy and confirm previously published data on the topics of our research. The photoelectric photometry is highly accurate, as the period and amplitude of V1644 Cygni obtained through software exactly match the ones from literature. The CCD is less sensitive when observing such small variations, but allows the observation of fainter objects.

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