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GSC 7672:2238: a binary system near the Delta Scuti star AI Vel

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We report the results of a photometric and spectroscopic study of an eclipsing binary star in the field of the Delta Scuti variable AI Vel. Time-series CCD photometry was performed allowing almost complete phase coverage. Our period search gave an orbital period of $0\overset{d}{.}9719$. The light curve is typical of short-period Algol stars and suggests the presence of phase-related increase of brightness ($\phi = 0.1 - 0.2$) which can be due to mass transfer phenomena. Another possibility is the presence of a spotted region. Spectroscopic observation shows the Balmer Hα absorption line, typical of Algol systems with a transient or absent disc.

1 Introduction

Since 2001, we are conducting systematic monitoring of High Amplitude Delta Scuti (HADS) stars aiming to confirm/improve period determinations and looking for pulsational period variations and microvariability. In the course of a photometric campaign on AI Vel, we detected a short-period binary system. Initially used as a check star during the photometric monitoring of AI Vel, GSC 7672:2238 ($\alpha_{2000} = 08^{\rm h}14^{\rm m}18\overset{s}{.}6$, $\delta_{2000} = -44°36'32\overset{''}{.}7$, $V \sim 12.0$) turned out to be variable as soon as we started the project. Although no previous variability detection could be found in the SIMBAD (operated at CDS, Strasbourg, France) and GCVS (Kholopov et al. 1998) databases, this star is present in the ASAS-3 catalog (Pojmanski 2003) as an eclipsing variable with a period of about 12 hours. We collected more data trying to confirm and classify the observed variability using one of the telescopes (10″) located at the Rio de Janeiro Planetarium. In addition, we acquired a single spectrum to help clarifying the situation. The light curve has a morphology typical of Algol-type variables.

The Algols are close interacting binary stars. They consist of a B–A main sequence primary star and an F–K giant or subgiant secondary. In general, the star eclipsed at the primary minimum is the more massive component, very similar to Main Sequence stars. This picture gave rise to the well-known Algol paradox (an unevolved more massive primary accompanied by an evolved low-mass secondary).

Mass transfer (due to the secondary star's evolution, which expands to its Roche lobe limit) is likely to occur in a permanent way in the long-period Algol systems ($P > 6$ days) giving rise to a stationary disk, while in the short-period Algols ($P < 6$ days), accretion is less stable. The primary star is very large in comparison with the binary's separation, and the transferred gas stream impacts its surface straight off. As a result, very complex structures can arise, such as a transient accretion disk or even a less homogeneous structure (for $P < 4$ days), called an *accretion annulus*. The accreted material can be observed at UV and visible light, and the Hα line is frequently used as diagnostic of mass transfer (Albright & Richards 1996; Richards, Jones, & Swain 1996, and references therein.)

In the present paper, we report on photometric and spectroscopic characteristics of GSC 7672:2238.

2 Observations and data reduction

We carried out our time-series unfiltered differential CCD photometry during two seasons, in 2002 and 2003. We observed GSC 7672:2238 with a SBIG ST7E or ST8E thermoelectrically cooled CCD camera (510×765, 1020×1530 pixels) attached to the Meade LX200 $10''$ Schmidt–Cassegrain (F/6.3) telescope of the Rio de Janeiro Planetarium Foundation in south-east Brazil. For the useful field of view, these sets gave $10' \times 15'$ and $16' \times 24'$, respectively.

Our data reductions made use of the Image Reduction and Analysis Facility (IRAF) software. All images were dark-subtracted and flat-field-corrected. The photometric uncertainty was estimated from the standard deviation of the magnitude difference between the comparison (C1) and check (C2) stars.

GSC 7672:1538 ($\alpha_{2000} = 08^{\mathrm{h}}14^{\mathrm{m}}21\overset{\mathrm{s}}{.}2$, $\delta_{2000} = -44^{\circ}39'01\overset{''}{.}4$, $11\overset{\mathrm{m}}{.}6$ V) was used as the comparison star and GSC 7672:1586 ($\alpha_{2000} = 08^{\mathrm{h}}14^{\mathrm{m}}19\overset{\mathrm{s}}{.}4$, $\delta_{2000} = -44^{\circ}38'28\overset{''}{.}06$, $11\overset{\mathrm{m}}{.}8$ V), as the check star. Since the angular distances of all the stars in the field were small, we did not introduce any correction for differential extinction. The estimated differential-photometry accuracy ranged from $0\overset{\mathrm{m}}{.}005$ to $0\overset{\mathrm{m}}{.}012$. The finding chart is presented in Fig. 1.

The log of observations is given in Table 1. Δt is the integration time, N the number of frames in each run, <C1–C2> the mean values of C1–C2, to check long-term constancy, and the last column lists the uncertainty in the photometry.

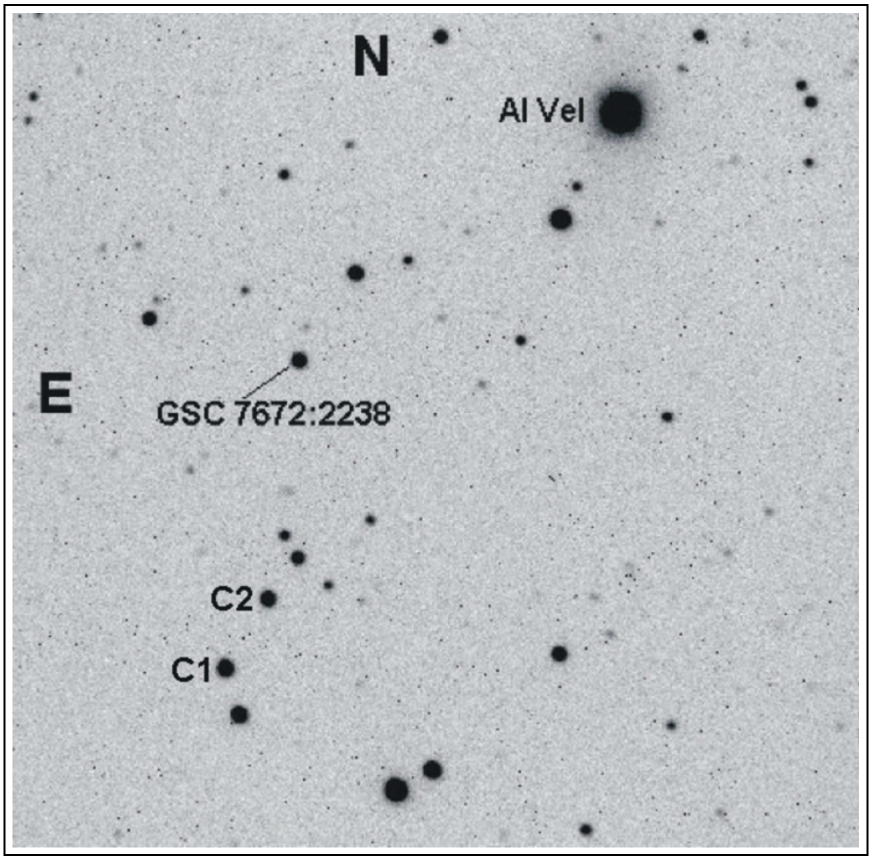

Figure 1: The finding chart for GSC 7672:2238 ($\alpha_{2000} = 08^{\mathrm{h}}14^{\mathrm{m}}18^{\mathrm{s}}.6$, $\delta_{2000} = -44°36'32''.7$). The scale is $7' \times 7'$.

Table 1. Log of the observations of GSC 7672:2238.

Date	Δt (s)	N	length (hours)	<C1–C2>	σ
Apr. 01, 2002	20	156	4.1	0.428	0.010
Apr. 02, 2002	20	217	5.5	0.430	0.010
Apr. 17, 2002	20	191	4.3	0.425	0.009
Apr. 18, 2002	20	202	4.8	0.429	0.012
Jan. 08, 2003	60	153	4.5	0.430	0.005
Jan. 09, 2003	60	169	5.7	0.430	0.007
Feb. 03, 2003	60	210	6.0	0.425	0.009
Feb. 05, 2003	60	98	3.8	0.433	0.007
Feb. 06, 2003	60	82	3.4	0.427	0.008
Feb. 10, 2003	60	176	4.3	0.424	0.005
Feb. 12, 2003	60	98	2.2	0.424	0.006
Feb. 13, 2003	60	94	2.4	0.429	0.012
Feb. 19, 2003	60	90	4.1	0.424	0.005
Feb. 25, 2003	60	216	5.8	0.435	0.007
Mar. 01, 2003	60	107	2.4	0.424	0.006
Mar. 07, 2003	40	120	2.3	0.429	0.008

In addition, we made a single spectroscopic observation of GSC 7672:2823 with the 1.6 m Perkin–Elmer telescope located at the Pico dos Dias Observatory, operated by the CNPQ/National Laboratory of Astrophysics, Minas Gerais, Brazil, on April 17, 2002. A medium-resolution spectrum in the 5700–6750Å range was obtained in the Cassegrain focus with a 900 lines/mm grating. The spectrum was subjected to wavelength and flux calibration using IRAF tasks. LIT 3218 was used as the spectrophotometric standard to perform flux calibration (Hamuy et al. 1992, Hamuy et al. 1994). We used a He–Ar lamp to calibrate in λ, the integration time was 20 minutes.

3 Results and analysis

3.1 Photometry

We determined CCD times of the primary minimum using the Kwee & van Woerden method (Kwee & van Woerden 1956), which is suitable for symmetrical light curves. Table 2 gives the heliocentric times of primary minima. Epochs and O–C values were computed with respect to the linear ephemeris given in eq. (1).

Table 2. Times of primary minimum for GSC 7672:2238.

HJD (error)	Epoch	O–C
2452382.5037(1)	0	–0.00039
2452383.4764(2)	1	0.0004
2452696.4188(2)	323	–0.000002

After the least-square fit to the data given in Table 2, we found the following preliminary ephemeris for the primary minima:

$$\mathrm{HJD}_{\mathrm{min}} = 2450514.4794 + 0.9719 \times E. \qquad (1)$$

We made a further analysis of the light curve of GSC 7672:2238 using two different methods to search for periods.

First, we applied the classical phase-dispersion-minimization (PDM) technique (Stellingwerf 1978), which is very useful when the light curve is highly non-sinusoidal. This method folds the data on groups of trial frequencies and constructs phase-folded data for each of them. After defining the number and width of bins over the generated diagram, the variance for each bin is calculated. Figure 2 shows the PDM periodogram. The strongest (deepest) signal is $P = 23.1027$ hours ($0\overset{\mathrm{d}}{.}9626$), it has the smallest variance.

Another period search was performed with the ANOVA method, which uses periodic orthogonal polynomials to fit data. Evaluation of the fit is made by analysis of variance (ANOVA) statistic (Schwarzenberg-Czerny 1996). This method improves strongly the signal detection and is very effective damping alias signals. The ANOVA periodogram is displayed in Fig. 3 and shows the main peak at $P = 23\overset{\mathrm{h}}{.}3263$ ($0\overset{\mathrm{d}}{.}9719$), which is in nice agreement with the value found from the O–C analysis.

Additional analysis was done with the ASAS-3 data using the PDM and ANOVA methods. We found strong signals for both methods at $P = 23\overset{\mathrm{h}}{.}3281$ ($0\overset{\mathrm{d}}{.}9720$). Figure 4 shows the phase-folded diagram with respect to $P = 0\overset{\mathrm{d}}{.}9720$ for the ASAS-3 data, indicating that the 12-hour period is probably wrong.

Figure 5 shows the phase-folded diagram (for the data obtained by us) with respect to eq. (1). We note a strong modulation with two minima per cicle, probably related to the orbital motion of a binary system consisting of deformed components. Both primary and secondary eclipses are V-shaped and centered at phases 0.0 and 0.5 respectively, indicating a circular orbital motion.

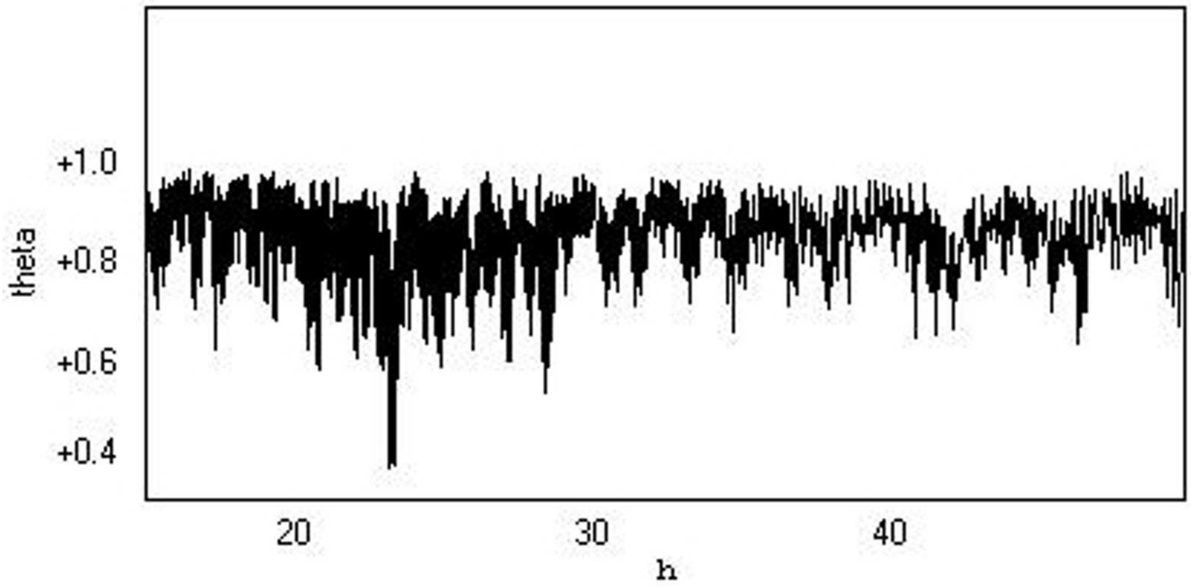

Figure 2: The PDM periodogram for GSC 7672:2238. The main signal corresponds to $P = 23^{\mathrm{h}}.1027$ ($0^{\mathrm{d}}.9626$).

The primary eclipse is fainter by about $0^{\mathrm{m}}.35$ than the secondary one. The light curve shows a morphology typical of Algol systems. An interesting characteristic of the light curve is a larger scatter during maxima (centered at ϕ=0.7). The same picture is seen during secondary eclipses.

From the same figure, we note obvious changes around phases 0.1 to 0.2, when the brightness had increased slowly by about $0^{\mathrm{m}}.06$ in 10 days. The gray, brown, and red colors are associated to dates Feb. 25, 2003, Mar. 1, 2003, and Mar. 7, 2003, respectively. Such behavior can be explained in terms of mass transfer from the lobe-filling secondary star. An impact zone (over the primary, facing the secondary) would produce the brightening just after the primary eclipse. Due to the close orbit, the impact zone would be strongly asymmetric and plump. Eventually, an extended region can be formed which could be a potential source of continuum. Besides the observed variability at $\phi = 0.1 - 0.2$, this process can explain the larger scatter (around ϕ=0.7) mentioned above.

Another possibility is the presence of photospheric spots over the secondary. It is well known that enhanced magnetic fields in the convective envelopes of such stars are common. They are responsible for strong microwave, X-ray, and visible activity in short-period Algols.

3.2 Spectroscopy

Figure 6 shows the optical spectrum obtained on April 17, 2002. The time of observation was 22:00 UT corresponding to ϕ=0.9, just before the primary eclipse. At this phase, if a disk exists, we expect to find an emission Hα line. In our spectrum, we see a strong absorption Hα Balmer line. Another strong feature is the absorption sodium line, probably associated to the cooler secondary star. The first feature (the Hα absorption line) is common in other short-period systems such as V505 Sgr, δ Lib, AI Dra, TW Cas, and TV Cas, all with periods shorter than $2^{\mathrm{d}}.4$. Only a weak single-peaked emission is found in the difference spectra (modelling and subtracting the spectrum of the photospheres of

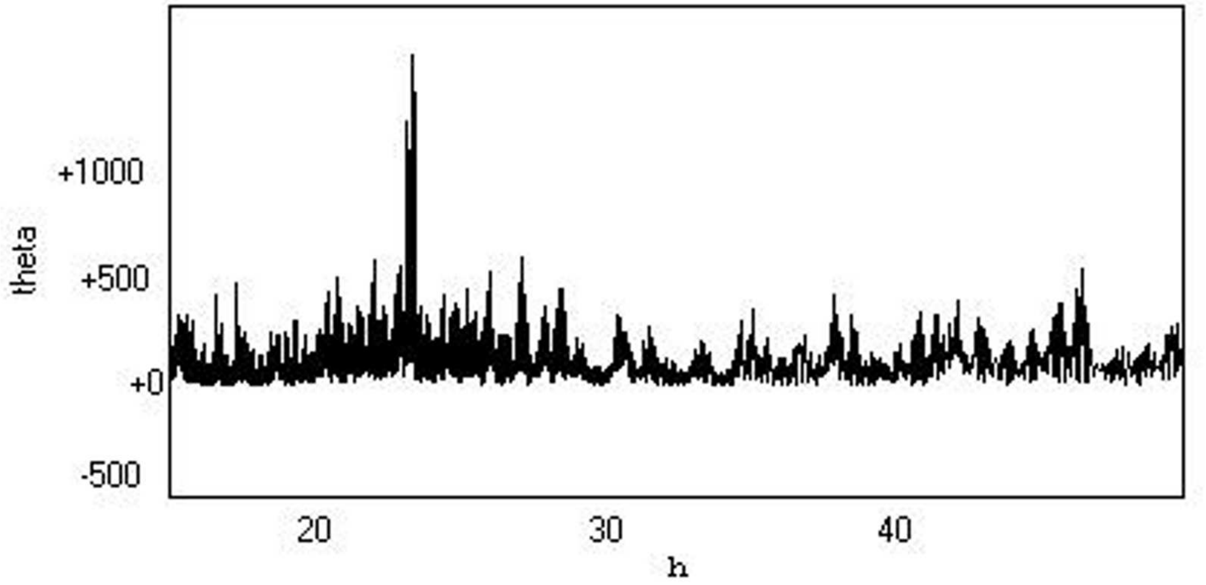

Figure 3: The ANOVA periodogram for GSC 7672:2238. The main signal corresponds to $P = 23^{\rm h}\!.3263$ ($0^{\rm d}\!.9719$).

the components) of V505 Sgr and δ Lib (Richards & Albright 1999). The same authors show that this feature (weak or absent Hα in emission) is permanent at all orbital phases for systems with $P < 2^{\rm d}\!.4$.

In this sense, GSC 7672:2238 shows a spectrum which is typical of short-period Algols with transient or absent disks. The primary star should be very large in comparison to the binary's separation, and the mass eventually transferred has no space to form classical accretion structures. We remember that the spectrum had been acquired about one year earlier than the variability at $\phi = 0.1 - 0.2$ was detected.

4 Conclusions

We have observed the poorly studied eclipsing binary system GSC 7672:2238. Despite the small number of times of minimum, we found $P_{\rm orb} = 0^{\rm d}\!.9718$ using independent methods, which gave consistent values. The amount of data and the behavior of the light curve led us to interpret this modulation as related to the orbital motion of a short-period Algol.

We found strong photometric evidence for phase-related phenomena (at $\phi = 0.1 - 0.2$) probably associated with a long-term mass transfer (about 10 days) from a lobe-filling secondary star. Another possible source are photospheric spots.

The single spectrum acquired (at $\phi = 0.9$) showed a strong Hα absorption line, which is indicative of transient or even absent disk structure. This characteristic is frequently found in the short-period systems($P < 4^{\rm d}\!.5$), which have small binary separations and large primary stars. As a result, the mass transfer impacts the primary star avoiding formation of a stable accretion disk. In fact, the gas transferred may graze the surface of the primary star and spread matter into a transient structure. The resulting "plump" structure could be the source of continuum excess after primary eclipses, observed at Feb. 25, 2003, Mar. 1, 2003, and Mar. 7, 2003 and of the increased scatter at $\phi = 0.7$.

In order to characterize GSC 7672:2238 with better certainty, multicolor photometry

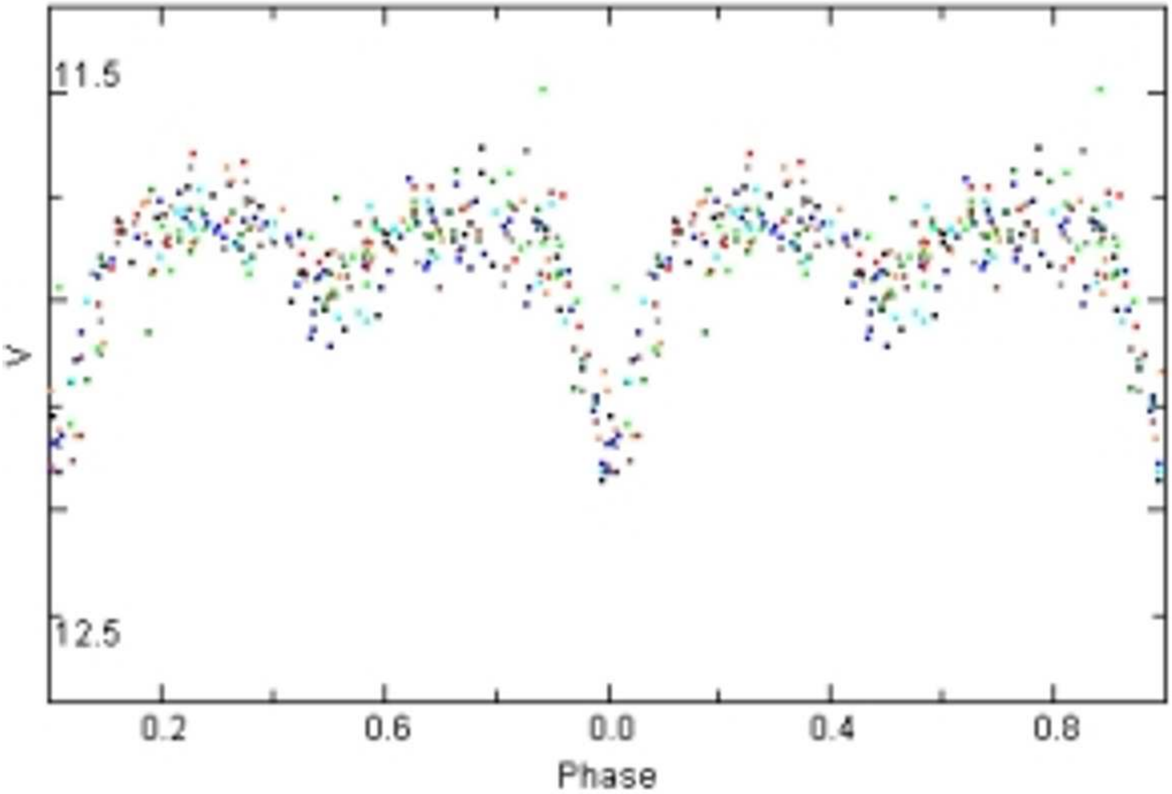

Figure 4: The phase-folded diagram for GSC 7672:2238 using the ASAS-3 data for $P = 23^{\mathrm{h}}.3281$ ($0^{\mathrm{d}}.9720$). Colors correspond to different nights.

would be of great importance. In particular, a good coverage could help to identify the source of variability near the primary eclipse.

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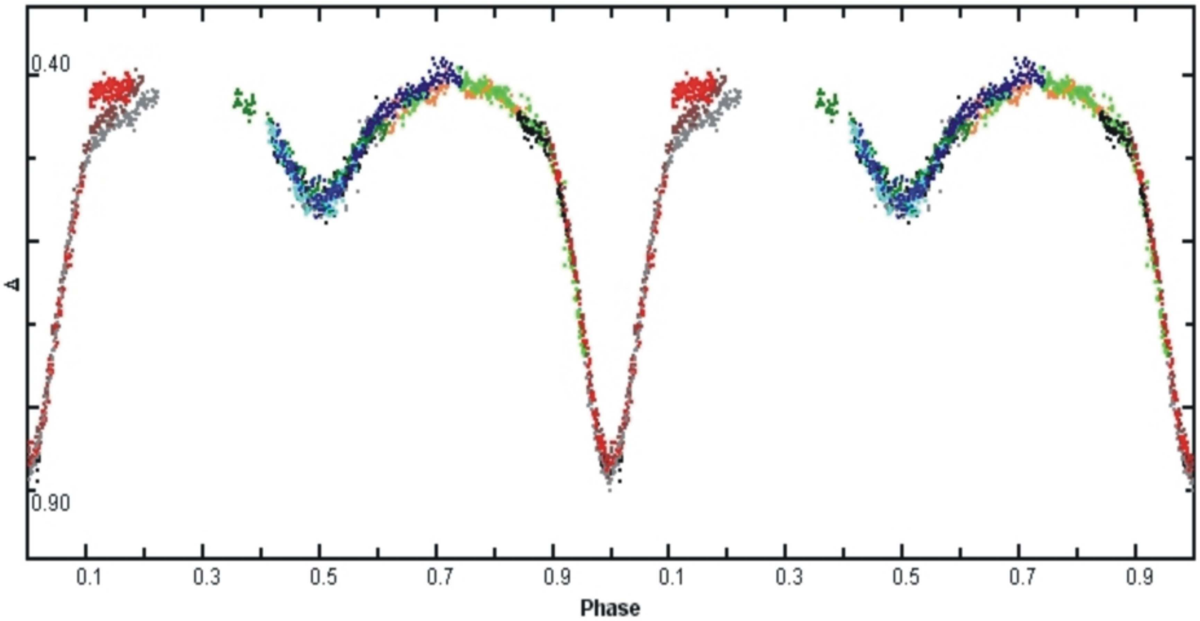

Figure 5: The unfiltered phase plot for GSC 7672:2238 with $P = 0\overset{d}{.}9719$. The magnitudes are differential. Colors correspond to different nights.

Schwarzenberg-Czerny, A., 1996, *ApJ*, 460, L107
Stellingwerf, R. F., 1978, *ApJ*, 224, 953

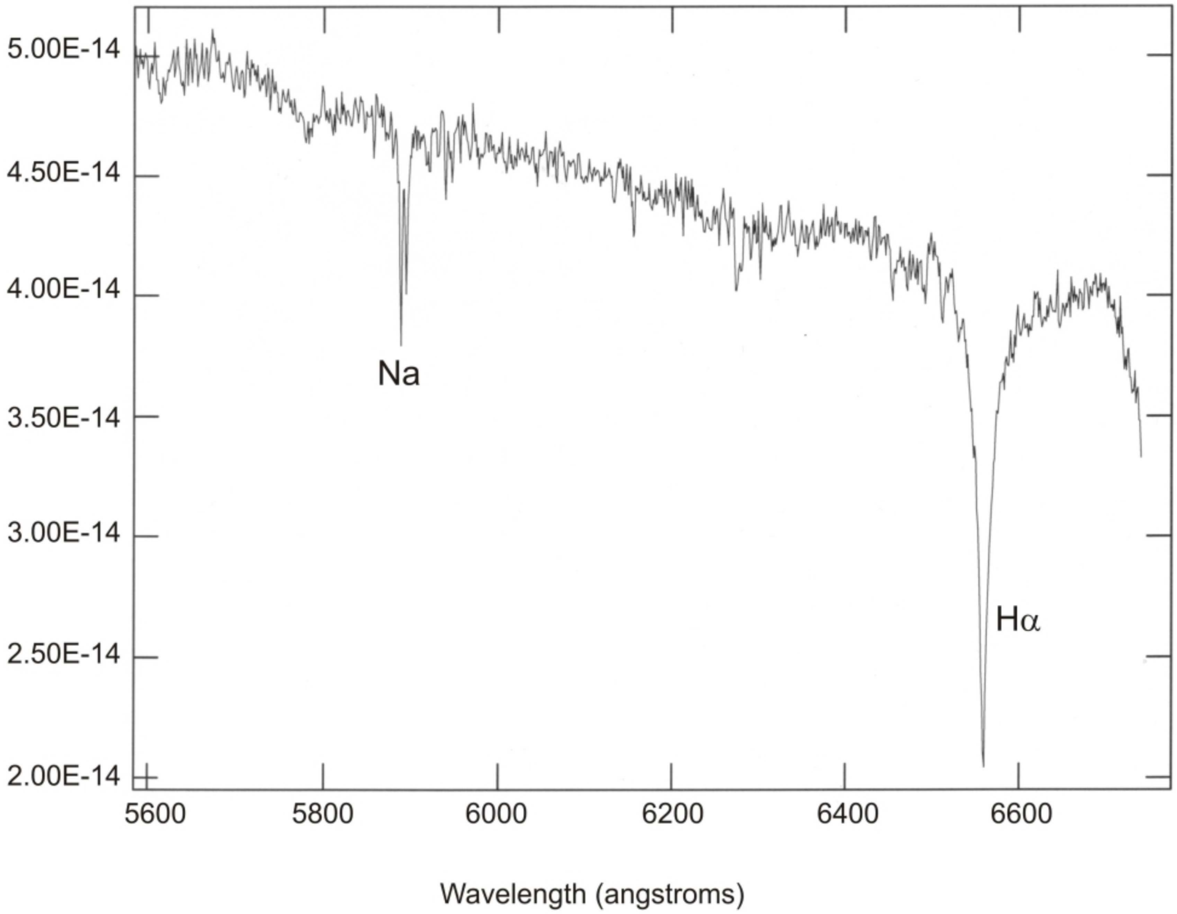

Figure 6: The spectrum of GSC 7672:2238.