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## Light curve and period of the Blazhko RRc star GSC 03529-02286 and GSC 2.3 N0ZY002187, a new variable in the field

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**Abstract:** *By analysis of SWASP and CRTS data, Bernhard et al. (2013) have recently shown that GSC 03529-02286 (18 14 48.187 +47 10 03.12, J2000) is an RRc type variable showing indications of Blazhko effect. A night by night reanalysis of SWASP data yielded 70 maxima and 73 minima times which revealed a Blazhko period* $P_B$ *= 20.26 d. CCD observations on 13 nights in August 2013 yielded another 11 maxima and 4 minima times, covering a little more than one Blazhko cycle. It could be shown that the secondary period prevails until now. The ephemeris for the maxima could be improved to*

*HJD (Max.) = 2456495.4317(37) + 0.27719643(46) d x E.*

*The CCD observations also revealed a short period eclipsing variable in the vicinity (GSC2.3 N0ZY002187; 18 14 26.76 +47 19 09.38, J2000) showing shallow 0.15 mag. deep eclipses with the ephemeris HJD (Min.) = 2456493.3980(6) + 0.340055(12) x E.*

### 1. GSC 03529-02286 (18 14 48.187 + 47 10 03.12), 2MASS 18144819+4710031

In BAV Rundbrief 3/2013, Bernhard, Sdroc and Hümmerich [1] presented three new RR Lyrae stars, which had been discovered by analysis of data from the SuperWASP Public Archive [2] and Data Release 2 (CSDR2) of the Catalina Sky Survey [3]. One of them, GSC 03529-02286, stands out for its light curve (LC), which shows indications of Blazhko effect. Being favourably situated at the common boundary of the constellations Lyra, Hercules and Draco, the star was included in the observation program. Prior to the beginning of the observing season, SWASP data were reanalysed with the method outlined in [4].

### 1.1. SWASP data analysis

SWASP data consists mainly of two densely sampled time series won through the cameras labelled 1.03 and 1.44 with 4,109 and 8,049 measurements, respectively. The earliest series taken through camera 1.03 lasts from 2004-05-13 to 2004-09-29. The 1.44 camera series splits in two parts, first from 2007-07-15 to 2007-09-29 and from 2008-04-23 to 2008-08-09 with 1751 and 6298 points, respectively. The times of 70 maxima (max.) and 73 minima (min.) and their instrumental magnitudes could be derived.

Fig. 1 illustrates the measurements of camera 1.44 reduced with the ephemeris (1) shown in section 1.2. The LC apparently exhibits a broad, double-humped max. However, the double hump is only caused by the phase shifting of the max. during the Blazhko cycle. The arrows mark the slightly different heights of the max., indicating the limits of the phase shifting. The timings of the max. and min. were analysed with a period search program. In both cases, a neat frequency peak was present at a secondary period of 20.26 d.

Fig. 2 illustrates that the times of the extrema vary regularly against the timings given by the ephemeris, occurring between half an hour before and half an hour after the calculated times.

From the SWASP observations of 2004 until now, the Blazhko period seems to have remained essentially constant. The min. timings also follow the cycle in phase with the max., indicating that the steepness of the rising branch in the LCs remains constant.

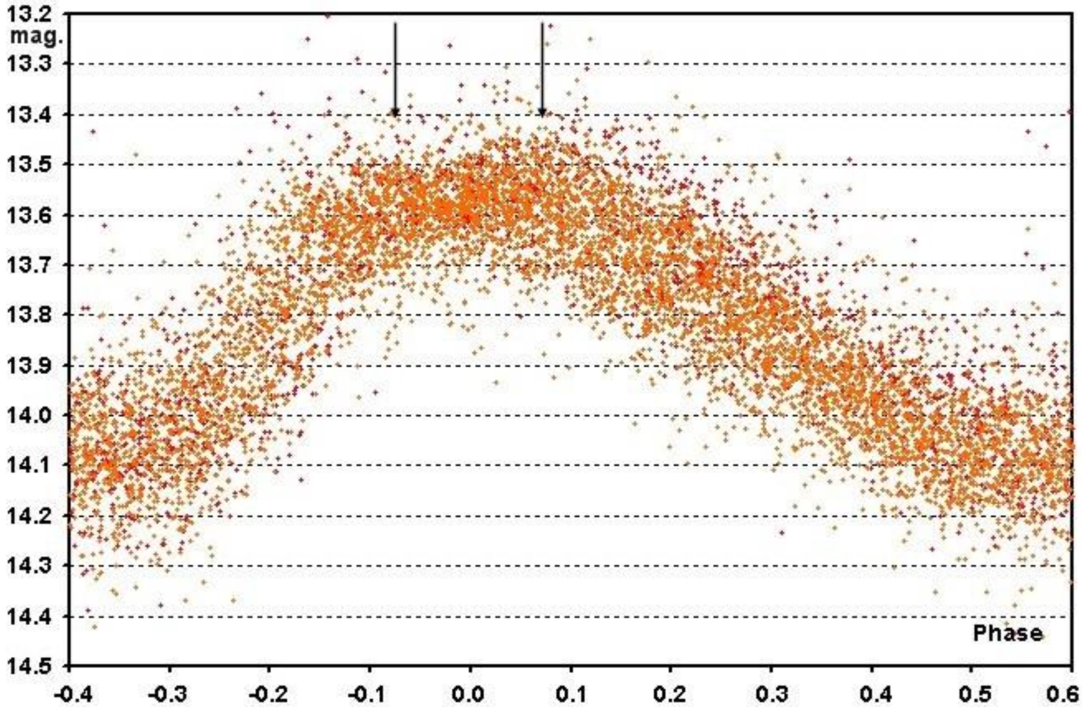


Fig. 1: The measurements of camera 1.44 reduced with ephemeris (1).
The peaks of the apparent double max. are marked with arrows.

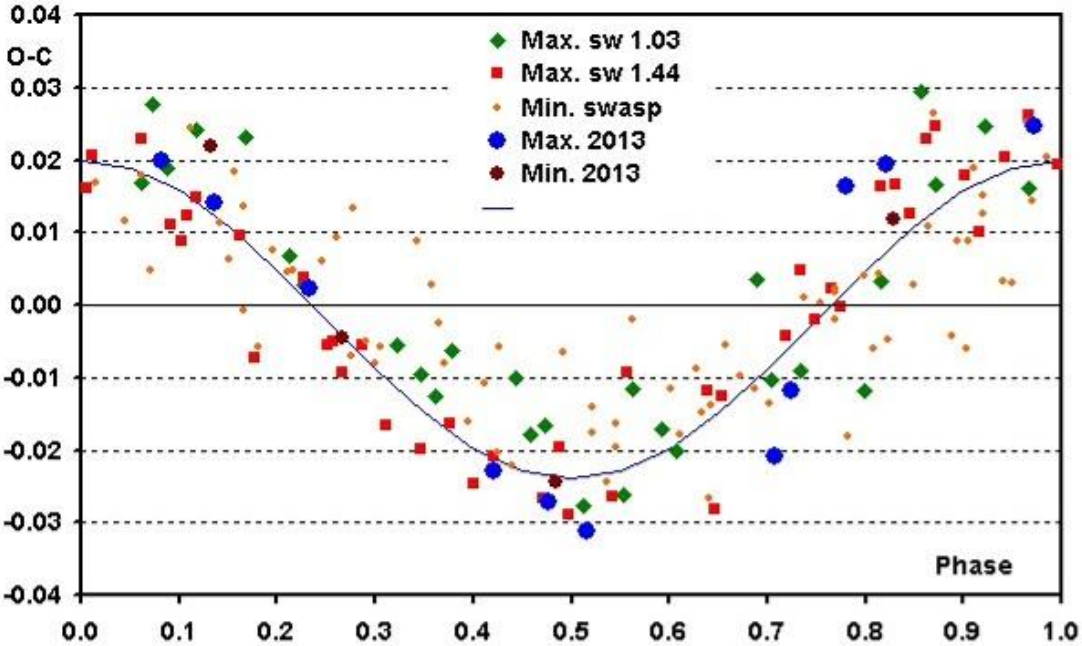


Fig. 2: The derived times of extrema, reduced with the Blazhko period $P_B$ = 20.26 d.

Fig. 3 shows a particularly densely covered series from SWASP camera 1.44. From 2008-06-23 to 2008-07-13, the phase shifting of the max. over one Blazhko cycle can be closely followed. The shape of the second last LC (JD 4659) illustrates a peculiarity in the cycle, which will be described in more detail below.

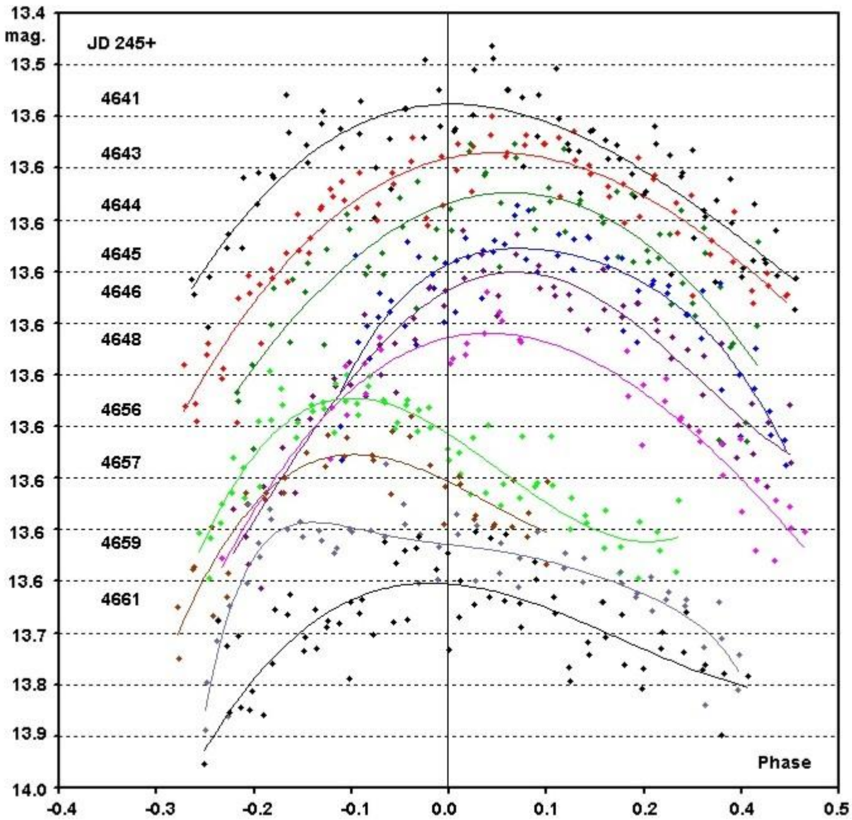


Fig. 3: A sample of SWASP LCs covering one Blazhko cycle. For clarity, the LCs are limited on both sides of the max. and shifted by 0.1 mag.

Another way to illustrate the behaviour of the star during the Blazhko cycle is shown in Fig. 4. The (O-C) values of the max. timings have been taken as abscissa and their corresponding magnitudes as ordinate, so that the Blazhko cycle is shown as a closed loop. In Le Borgne et al. [5], a great diversity of cycle shapes is shown. The shape of the cycle seems to be characteristic for a given Blazhko RR Lyrae star.

The slight differences in the heights of the max. shown in Fig. 1 suggest that the Blazhko effect affects not only the phase but – to some extent – also the amplitude of the pulsations. Because of this, one would expect an ellipse instead of a horizontal line in the diagram in Fig. 4. However, the amplitude modulations get lost in the observational scatter and, consequently, are not apparent in this diagram.

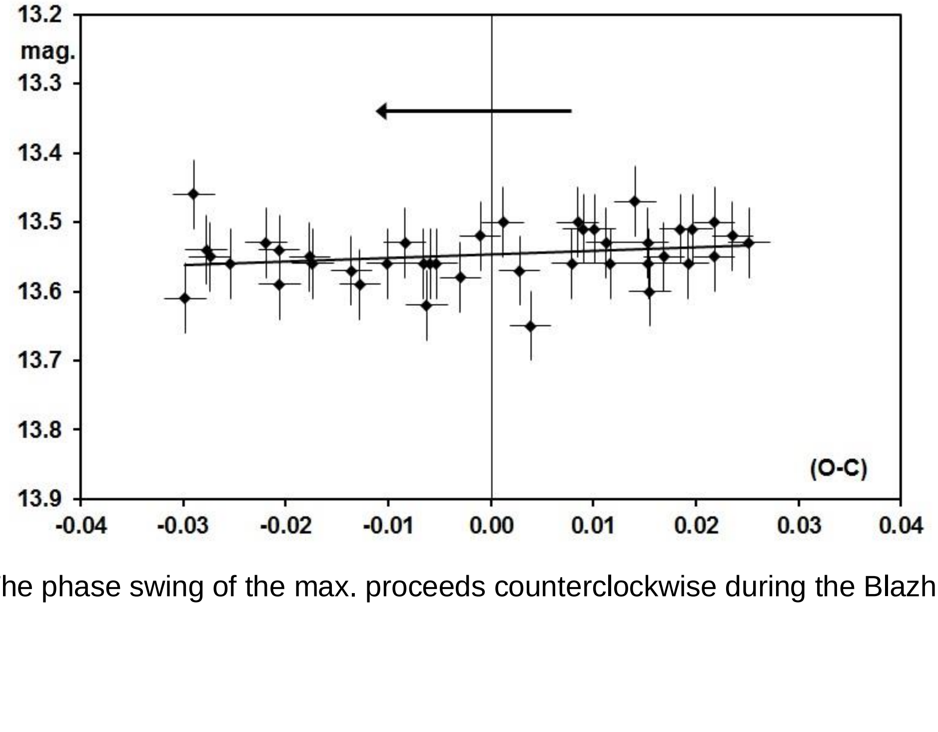


Fig. 4: The phase swing of the max. proceeds counterclockwise during the Blazhko cycle.

## 1.2. The 2013 measurements

In 13 nights from 2013-07-18 to 2013-08-20, extended image series could be won under mostly good sky conditions with a 10” SCT in a semi-automated mode and a SBIG ST8XME camera. With an exposition time of 120 s in the 2x2 binning mode, a total of 1,710 measurements could be won; the corresponding light curves are shown in Fig. 5. To increase the S/N ratio, no filter was used. Twilight sky-flat images were used for flatfield corrections. The reductions were performed with the Muniwin reduction program [6].

It is always recommended to choose reference stars with spectral classes matching the variable as closely as possible, but this information is usually not available for relatively faint stars. In their discovery publications, Bernhard et al. make use of the (J-K) index as an approximate indicator of the spectral class. The index employs the infrared J (1120 nm) and K (2190 nm) magnitudes derived from the 2MASS or CMC14 catalogues. A correlation between spectral classes and (J-K) index has been established in [7]. Similar tables can be found in [8] and [9]. A comparison shows that – in a spectral range from B8 to M0 –, the agreement is quite good. At least for main sequence stars, the (J-K) index seems to be a valuable spectral class indicator.

| Star | CMC14 | r mag. | J mag. | K mag | (J-K) Index | ~Sp. Kl. |
|---|---|---|---|---|---|---|
| Var. | 181448.1+471003 | 14.102 | 13.508 | 13.328 | 0.18 | F0 |
| C | 181505.2+471309 | 14.075 | 12.927 | 12.491 | 0.44 | G6 |
| C1 | 181442.6+471329 | 13.998 | 12.920 | 12.467 | 0.45 | G6 |
| C2 | 181448.0+471238 | 13.788 | 12.571 | 12.049 | 0.52 | K0 |
| C3 | 181439.0+470900 | 14.190 | 12.963 | 12.446 | 0.52 | K0 |

Table 1: The variable, the reference stars and their estimated spectral class.

Furthermore, J-K indices are often available via Guide 9.0 [10], so that an appropriate selection of reference stars could be made. In the present case, an exact match to the spectral class of the variable was not available in the field of the camera. Nevertheless, a comparison of the reference stars to one another showed no influence of differential extinction through variable airmass.

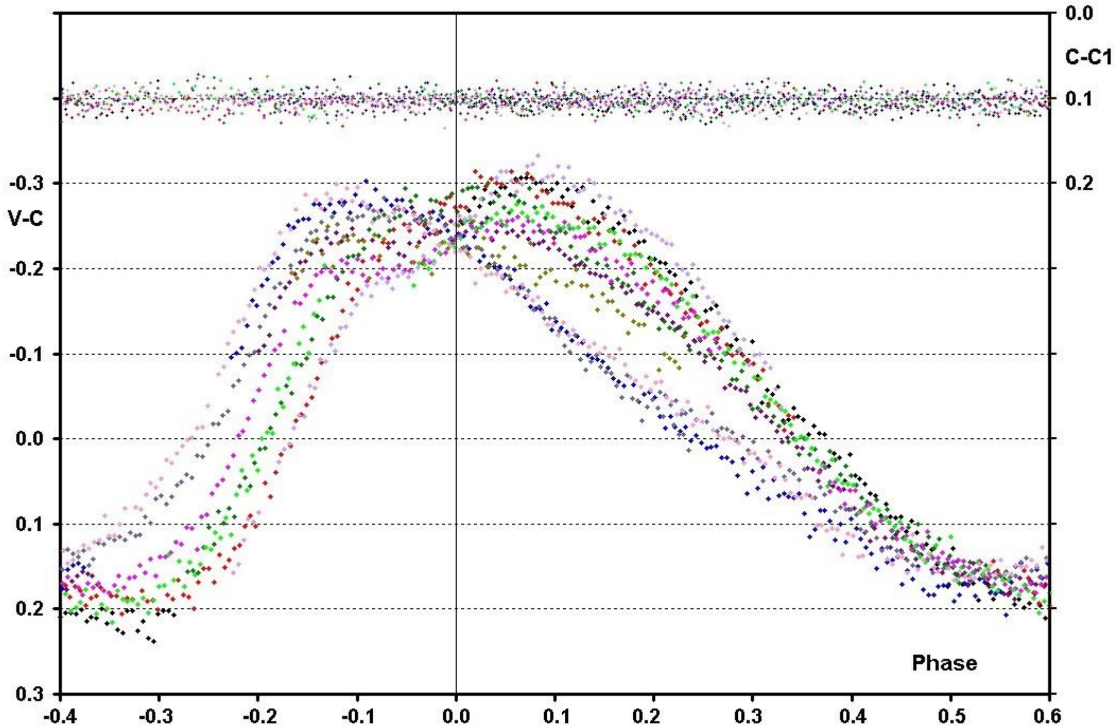


Fig. 5: An overview of the LCs won in the 2013 observation season.

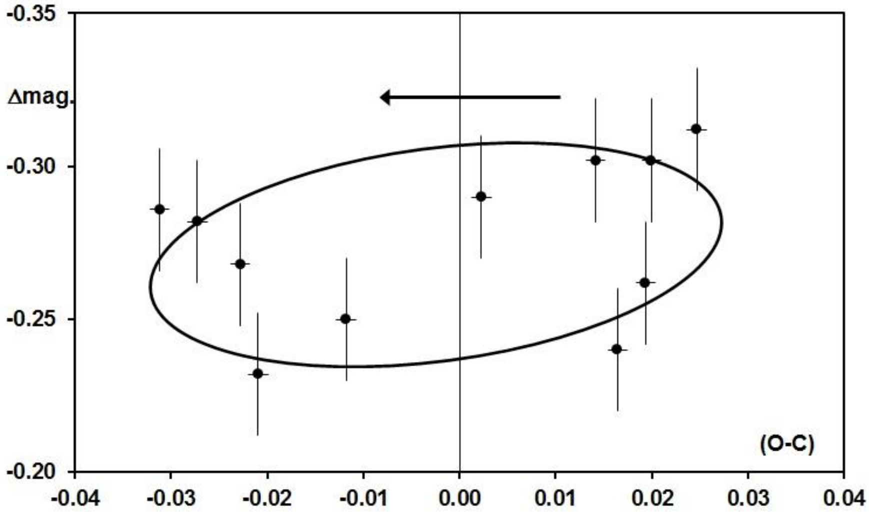


Fig. 6: The corresponding Blazhko cycle.

A little more than one Blazhko cycle was covered (cf. the LCs in Fig. 5). The observed behaviour is very similar to what has been observed in the SWASP data. Therefore, it seems that – at least from 2004 until now – the Blazhko period remained essentially constant. Additionally, the small magnitude differences in the heights of the max. suggested in Fig. 1 could be recorded in more detail, which leads to the cycle diagram shown in Fig. 6. A double max. is observed during parts of the cycle (at JD 6505 and JD 6506; cf. Fig 7). As the max. are coming in later, the left peak of this double max. seems to get progressively fainter while the right peak gains in brightness. Only continued observations could show if this phenomenon occurs each cycle.

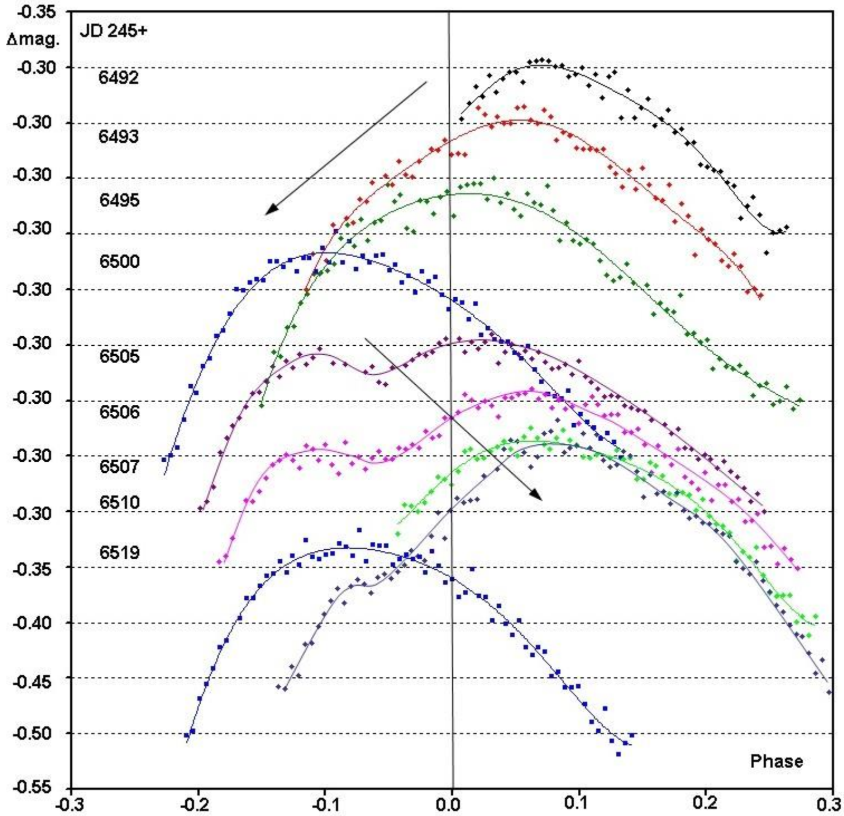


Fig. 7: The Blazhko cycle as shown by the 2013 observations. For clarity, the LCs are limited on both sides of the max. and shifted by 0.05 mag.

From the 2013 observations, the times of 11 max. and 4 min. could be determined and, in combination with the SWASP extrema, the ephemeris

$$\text{HJD (Max.)} = 2456495.4317(37) + 0.27719643(46)\ \text{d} \times \text{E}. \qquad (1)$$

was derived. The deviations of the min. times were calculated with the ephemeris

$$\text{HJD (Min.)} = 2456516.3877(38) + 0.27719676(42)\ \text{d} \times \text{E}. \qquad (2)$$

The times of all observed extrema yield the (O-C) diagram presented in Fig. 8 and are tabulated in the appendix.

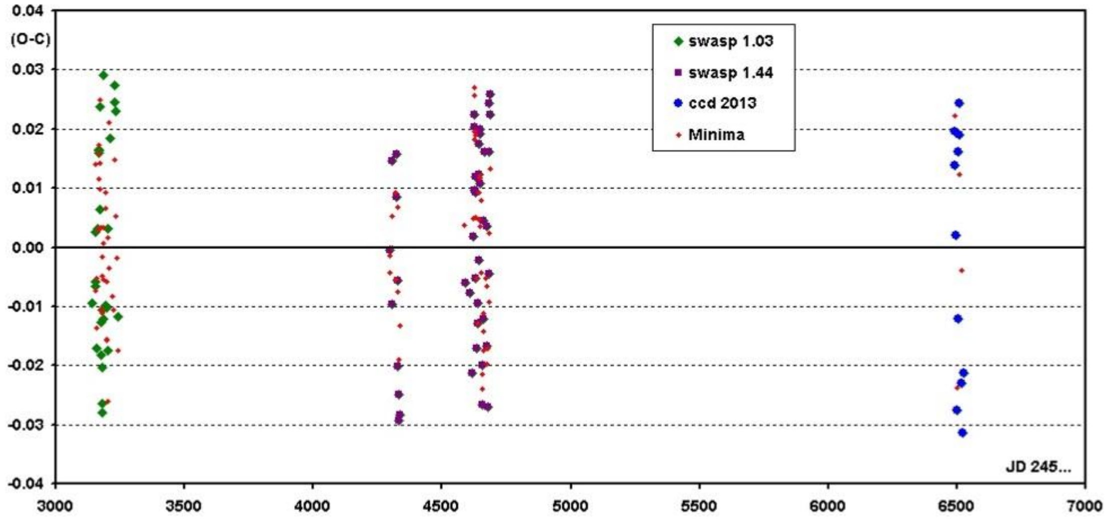


Fig. 8: (O-C) diagram with the SWASP and the 2013 extrema reduced with ephemeris (1).

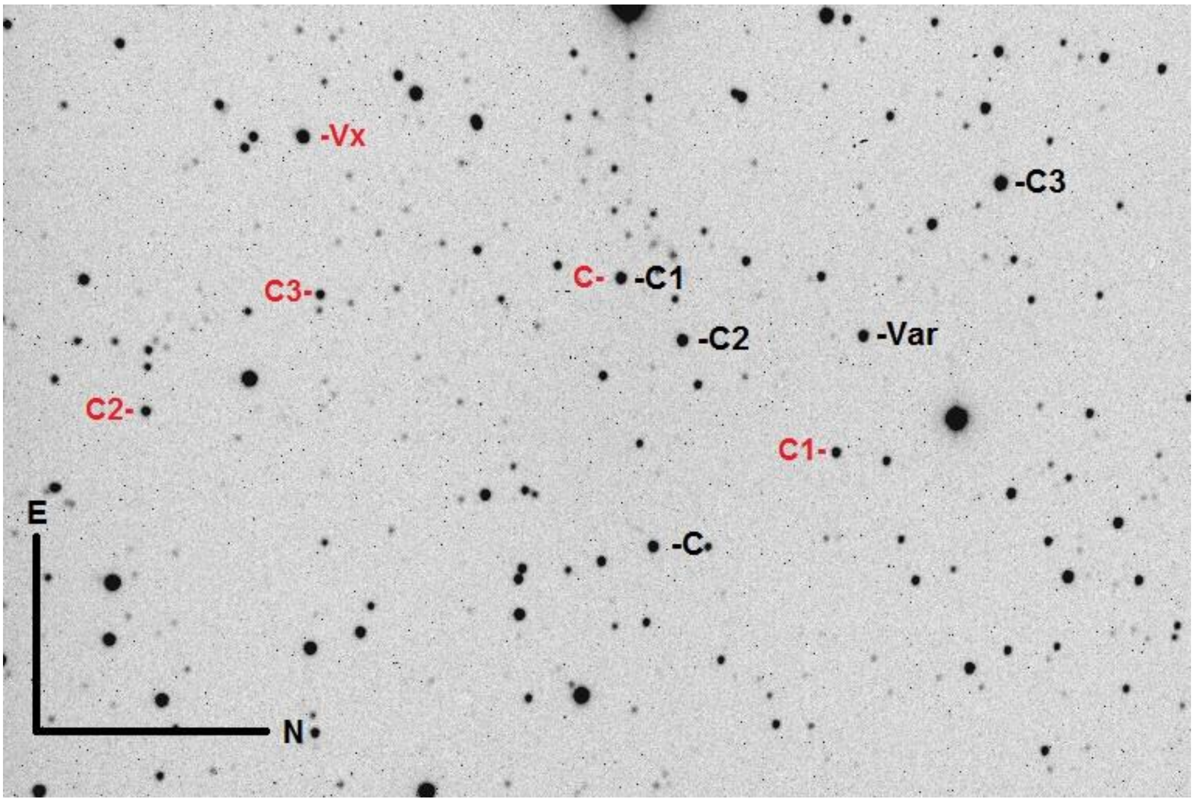


Fig. 9: The 20´ x 13´ field of the camera with the RR Lyrae star (Var),
the new variable (Vx) and their reference stars.

**2.Vx: GSC 2.3 N0ZY002187 (18 14 26.76 +47 19 09.38), 2MASS J18142676+479096**

The CMC14 catalogue lists an R magnitude of 15.19 mag. for this star. The faintness of the object leads to increased scatter, so that the mean of five consecutive measurements was taken. In the LC (Fig. 10), the standard deviation of each point has been indicated. The star is probably a short period eclipsing variable (of W UMa type?) with shallow, 0.15 mag. deep eclipses. There does not seem to be a difference in depth between both minima, so that min. I was taken arbitrary. Six times of min. I and min. II (Table 2) were derived and lead to the ephemeris

$$\text{HJD (Min.)} = 2456493.3980(6) + 0.340055(12)\ \text{d} \times \text{E}. \quad (3)$$

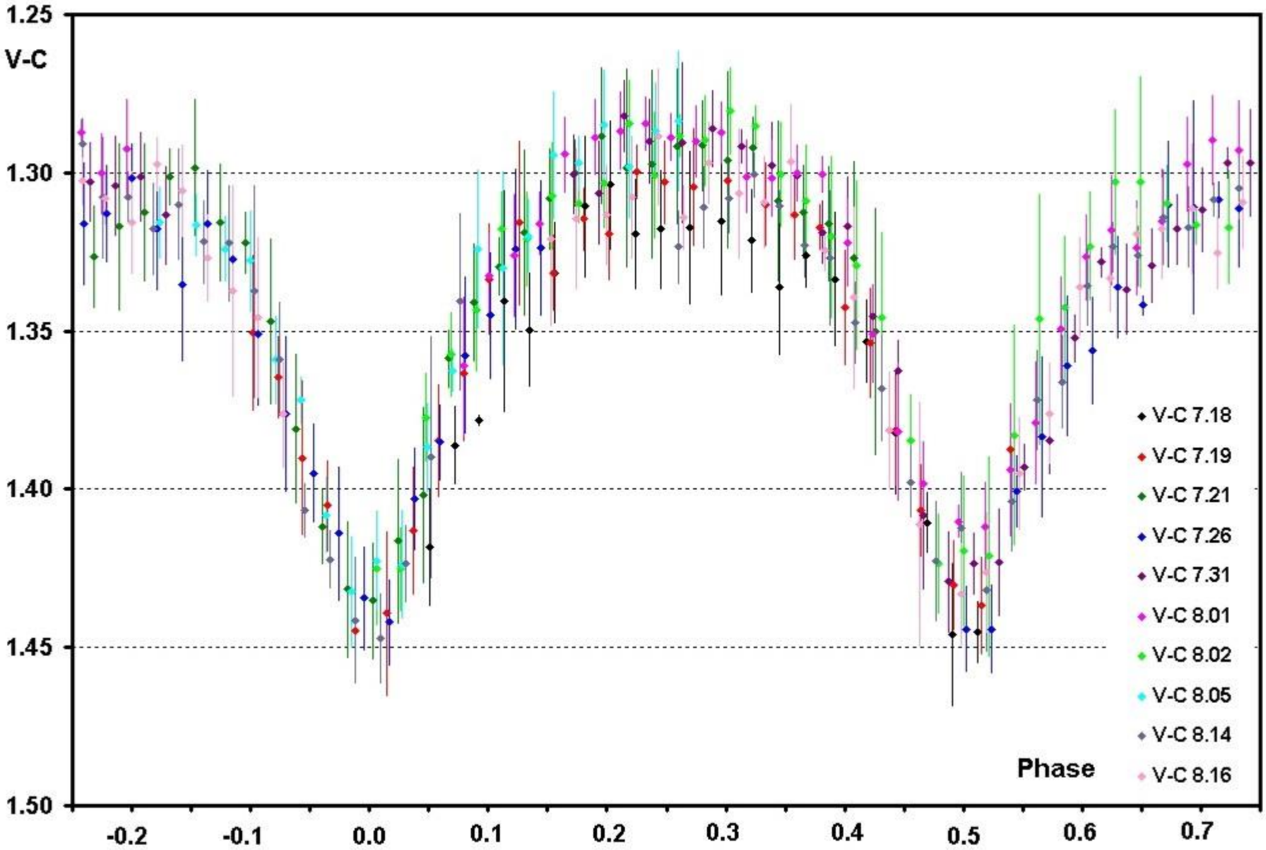


Fig. 10: The LC of GSC2.3 N0ZY002187 shows shallow eclipses with a period of 8 ¼ h.

| J.D. Hel. | | Epoch | (O-C) | J.D. Hel. | | Epoch | (O-C) |
|---|---|---|---|---|---|---|---|
| 2456493.400 | Min I | 0.0 | 0.002 | 2456507.509 | Min II | 41.5 | -0.001 |
| 2456493.567 | Min II | 0.5 | -0.001 | 2456510.401 | Min I | 50.0 | 0.000 |
| 2456495.437 | Min I | 6.0 | -0.001 | 2456519.412 | Min II | 76.5 | 0.000 |
| 2456500.539 | Min I | 21.0 | 0.000 | 2456519.581 | Min I | 77.0 | -0.001 |
| 2456505.472 | Min II | 35.5 | 0.002 | 2456521.454 | Min II | 82.5 | 0.001 |
| 2456506.490 | Min II | 38.5 | 0.000 | 2456525.363 | Min I | 94.0 | 0.000 |

Table 2: Minima of GSC2.3 N0ZY002187.

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Translation of the german version in BAV Rundbrief 32,228 (2013)

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**Appendix:** Maxima and minima of the RR Lyrae star GSC 03529-02286.

| HJD Max. | W | (O-C) | HJD Max. | W | (O-C) | | HJD Min. | W | (O-C) | HJD Min. | W | (O-C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2453141.623 | 5 | -0.009 | 2454621.586 | 5 | 0.002 | | 2453152.619 | 5 | 0.014 | 2454328.466 | 5 | -0.008 |
| 2453151.614 | 5 | 0.003 | 2454623.547 | 5 | 0.023 | | 2453154.538 | 5 | -0.007 | 2454333.444 | 5 | -0.019 |
| 2453153.546 | 5 | -0.006 | 2454624.643 | 5 | 0.010 | | 2453155.649 | 5 | -0.005 | 2454335.390 | 5 | -0.014 |
| 2453154.654 | 5 | -0.006 | 2454626.594 | 5 | 0.021 | | 2453157.581 | 5 | -0.014 | 2454584.607 | 5 | 0.004 |
| 2453156.584 | 5 | -0.017 | 2454628.526 | 5 | 0.012 | | 2453162.587 | 5 | 0.003 | 2454622.584 | 5 | 0.005 |
| 2453163.534 | 5 | 0.003 | 2454629.632 | 5 | 0.009 | | 2453164.536 | 5 | 0.012 | 2454623.715 | 5 | 0.027 |
| 2453164.656 | 5 | 0.017 | 2454631.558 | 5 | -0.005 | | 2453165.649 | 5 | 0.016 | 2454624.539 | 5 | 0.019 |
| 2453166.596 | 5 | 0.016 | 2454632.655 | 5 | -0.017 | | 2453167.591 | 5 | 0.017 | 2454625.654 | 5 | 0.025 |
| 2453168.537 | 5 | 0.017 | 2454637.652 | 5 | -0.009 | | 2453169.539 | 5 | 0.025 | 2454627.587 | 5 | 0.018 |
| 2453169.653 | 5 | 0.024 | 2454639.589 | 5 | -0.013 | | 2453170.637 | 5 | 0.014 | 2454629.528 | 5 | 0.019 |
| 2453171.576 | 5 | 0.007 | 2454641.540 | 5 | -0.002 | | 2453172.573 | 5 | 0.010 | 2454630.623 | 5 | 0.005 |
| 2453174.606 | 5 | -0.012 | 2454643.495 | 5 | 0.013 | | 2453174.507 | 5 | 0.003 | 2454632.553 | 5 | -0.006 |
| 2453176.541 | 5 | -0.018 | 2454644.609 | 5 | 0.018 | | 2453175.602 | 5 | -0.010 | 2454640.584 | 5 | -0.013 |
| 2453177.640 | 5 | -0.028 | 2454645.443 | 5 | 0.020 | | 2453178.660 | 5 | -0.002 | 2454642.542 | 5 | 0.004 |
| 2453178.473 | 5 | -0.026 | 2454646.551 | 5 | 0.019 | | 2453179.482 | 5 | -0.011 | 2454644.487 | 5 | 0.009 |
| 2453179.588 | 5 | -0.020 | 2454648.483 | 5 | 0.011 | | 2453180.597 | 5 | -0.005 | 2454645.590 | 5 | 0.003 |
| 2453181.538 | 5 | -0.010 | 2454656.491 | 5 | -0.020 | | 2453182.543 | 5 | 0.001 | 2454647.539 | 5 | 0.012 |
| 2453183.477 | 5 | -0.012 | 2454657.593 | 5 | -0.026 | | 2453184.486 | 5 | 0.003 | 2454649.479 | 5 | 0.011 |
| 2453184.627 | 5 | 0.029 | 2454659.548 | 5 | -0.012 | | 2453185.586 | 5 | -0.005 | 2454650.584 | 5 | 0.008 |
| 2453194.567 | 5 | -0.010 | 2454661.505 | 5 | 0.005 | | 2453192.528 | 5 | 0.007 | 2454652.512 | 5 | -0.005 |
| 2453196.507 | 5 | -0.010 | 2454663.457 | 5 | 0.016 | | 2453194.471 | 5 | 0.009 | 2454655.544 | 5 | -0.022 |
| 2453199.549 | 5 | -0.017 | 2454671.483 | 5 | 0.004 | | 2453195.555 | 5 | -0.016 | 2454657.482 | 5 | -0.024 |
| 2453201.510 | 5 | 0.003 | 2454674.512 | 5 | -0.016 | | 2453197.505 | 5 | -0.006 | 2454659.432 | 5 | -0.015 |
| 2453209.564 | 5 | 0.019 | 2454676.442 | 5 | -0.027 | | 2453198.604 | 5 | -0.016 | 2454660.544 | 5 | -0.011 |
| 2453226.479 | 5 | 0.025 | 2454681.454 | 5 | -0.004 | | 2453200.534 | 5 | -0.026 | 2454662.478 | 5 | -0.018 |
| 2453229.531 | 5 | 0.028 | 2454683.415 | 5 | 0.016 | | 2453202.502 | 5 | 0.002 | 2454670.529 | 5 | -0.005 |
| 2453231.467 | 5 | 0.023 | 2454684.532 | 5 | 0.025 | | 2453205.546 | 5 | -0.004 | 2454672.468 | 5 | -0.007 |
| 2453239.471 | 5 | -0.011 | 2454686.474 | 5 | 0.026 | | 2453207.511 | 5 | 0.021 | 2454675.504 | 5 | -0.020 |
| 2454297.541 | 5 | 0.000 | 2454688.411 | 5 | 0.023 | | 2453220.510 | 5 | -0.008 | 2454677.447 | 5 | -0.017 |
| 2454304.486 | 5 | 0.015 | 2456492.403 | 10 | 0.020 | | 2453222.448 | 5 | -0.011 | 2454680.504 | 5 | -0.010 |
| 2454307.511 | 5 | -0.009 | 2456493.506 | 10 | 0.014 | | 2453227.463 | 5 | 0.015 | 2454682.456 | 5 | 0.002 |
| 2454322.505 | 5 | 0.016 | 2456495.434 | 10 | 0.002 | | 2453232.443 | 5 | 0.005 | 2454685.516 | 5 | 0.013 |
| 2454324.438 | 5 | 0.009 | 2456500.394 | 10 | -0.027 | | 2453235.485 | 5 | -0.002 | 2456493.402 | 10 | 0.022 |
| 2454327.473 | 5 | -0.005 | 2456505.399 | 10 | -0.012 | | 2453240.459 | 5 | -0.017 | 2456500.563 | 10 | -0.024 |
| 2454329.399 | 5 | -0.020 | 2456506.536 | 10 | 0.016 | | 2454297.426 | 5 | -0.002 | 2456507.529 | 10 | 0.012 |
| 2454330.503 | 5 | -0.025 | 2456507.371 | 10 | 0.019 | | 2454298.532 | 5 | -0.004 | 2456516.383 | 10 | -0.005 |
| 2454332.439 | 5 | -0.029 | 2456510.425 | 10 | 0.025 | | 2454303.531 | 5 | 0.005 | | | |
| 2454335.489 | 5 | -0.028 | 2456519.525 | 10 | -0.023 | | 2454305.466 | 5 | 0.000 | | | |
| 2454591.641 | 5 | -0.006 | 2456521.457 | 10 | -0.031 | | 2454318.489 | 5 | -0.006 | | | |
| 2454609.657 | 5 | -0.007 | 2456525.348 | 5 | -0.021 | | 2454320.444 | 5 | 0.009 | | | |
| 2454614.633 | 5 | -0.021 | | | | | 2454325.431 | 5 | 0.006 | | | |