In search of RR Lyrae type stars in eclipsing binary systems
(Research Note)

OGLE052218.07-692827.4: an optical blend

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ABSTRACT

During the OGLE-2 operation, Soszynski et al. (2003) found 3 LMC candidates for an RR Lyr-type component in an eclipsing binary system. Two of those have orbital periods that are too short to be physically plausible and hence have to be optical blends. For the third, OGLE052218.07-692827.4, we developed a model of the binary that could host the observed RR Lyr star. After being granted HST/WFPC2 time, however, we were able to resolve 5 distinct sources within a 1.3'' region that is typical of OGLE resolution, proving that OGLE052218.07-692827.4 is also an optical blend. Moreover, the putative eclipsing binary signature found in the OGLE data does not seem to correspond to a physically plausible system; the source is likely another background RR Lyr star. There are still no RR Lyr stars discovered so far in an eclipsing binary system.

Key words. Methods: data analysis, observational – binaries: close, eclipsing – variables: RR Lyr – stars: individual: OGLE052218.07-692827.4 – techniques: astrometric, photometric

1. Introduction

Eclipsing binary systems (EBs) have long been recognized as one of the most astrophysically rewarding targets for the reliable determination of masses, radii, luminosities and other physical stellar properties. The precision of the derived parameters is typically better than a few percent; it enables the studies of stellar structure and evolution, and yields reliable distances that are independent of any calibrations or empirical relations. EBs thus serve as astrophysical laboratories suitable for the study of individual component properties. The importance of finding intrinsic variables in EBs is thus obvious: being able to obtain the fundamental properties of such stars provides improved theoretical understanding, better calibrations, and in some cases leads to improving the cosmological distance ladder (Guinan et al. 1998; Fitzpatrick et al. 2003). Cepheids, for example, have been found in galactic EBs (Freyhammer et al. 2005; Antipin et al. 2007) as well as in the LMC (Alcock et al. 2002; Lepischak & Welch 2004; Guinan et al. 2005); there are more than 30 known δ-Scuti type components in EBs (see e.g. Dallaporta et al. 2002; Rodriguez et al. 2004; Christiansen et al. 2007), and several other types such as slowly pulsating B stars (Pigulski & Michalska 2007; Pilecki & Szczygieł 2007). To date, though, no RR Lyr type star has been found in an EB. Recently, however, an accurate parallax and relative proper motion of RR Lyr itself was obtained with the HST Fine Guidance Sensor (Benedict et al. 2002) that estimated its absolute magnitude of $M = 0.61 \pm 0.1$.

The Optical Gravitational Lensing Experiment (OGLE) carried out a 4.5 square degree survey of the LMC during the second phase of operations (Jan 1997 – Nov 2000; Soszynski et al. 2003). They discovered 7612 RR Lyr-type objects: 5455 fundamental mode pulsators, 1655 first-overtone, 272 second-overtone, and 230 double-mode pulsators, along with several dozen other short-period pulsating variables. Three objects in their sample exhibited a superimposed RR Lyrae type variability on an eclipsing binary light curve: OGLE052218.07-692827.4, OGLE051822.60-691817.3, and OGLE050731.10-693010.3. These could be either the results of blending, or genuine RR Lyr stars in eclipsing binaries. In the latter case it would be possible, with additional spectroscopic data, to determine a reliable mass and radius estimate of an RR Lyr star for the first time. Given their (nearly) constant mean luminosities ($\langle L \rangle \sim 45 L_\odot$ for RR Lyr type ab) and easily recognizable light curves, RR Lyr stars are important for the studies of the formation and evolution of population II stars, and for determining the galactic distance scale (globular clusters, LMC, and the local group; see Brown et al. 2004; Sarajedini et al. 2006). Although considerable effort went into calibrating the luminosity function for RR Lyr stars, it is compromised by dependences on metallicity, reddening, and possibly on period and/or pulsational modes (Sollima et al. 2006).

Of the three candidates, Soszynski et al. (2003) concluded that, based on the period of the binary, the latter two are likely to be blends, leaving OGLE052218.07-692827.4 as the remaining candidate for an EB system hosting an RR Lyr component. We conducted a thorough feasibility study for all three candidates confirming their preliminary results: only the OGLE052218.07-
Table 1. Preliminary parameters of OGLE052218.07-692827.4 HB–RR Lyr EB obtained by fitting the residual light curve depicted in Fig. 1 (right). Values denoted with an asterisk (*) are assumed. The errors in the table are formal, derived from the covariance matrix.

| Parameter: ID | Filter: | HJD–2450000 | Exp: | $\Phi_{\text{RR Lyr}}$ | $\Phi_{\text{EB}}$ |
|---------------|---------|-------------|------|----------------|----------------|
|               |         |             | [s]  |               |               |
| 1             | F255W   | 4298.94141  | 1000 | −0.1997       | 0.0399        |
| 2             | F255W   | 4298.95460  | 1000 | −0.1764       | 0.0414        |
| 3             | F555W   | 4298.96988  | 230  | −0.1493       | 0.0431        |
| 4             | F300W   | 4299.00738  | 350  | −0.0829       | 0.0473        |
| 5             | F300W   | 4299.01363  | 350  | −0.0719       | 0.0480        |
| 6             | F336W   | 4299.02196  | 500  | −0.0571       | 0.0490        |
| 7             | F555W   | 4299.03029  | 160  | −0.0424       | 0.0499        |
| 8             | F380W   | 4299.03516  | 300  | −0.0337       | 0.0504        |
| 9             | F439W   | 4299.07404  | 350  | 0.0351        | 0.0548        |
| a             | 156.66  | 0.06 156.66 | 500  | 0.0609        | 0.0564        |
| b             | 184.67  | 0.07 184.67 | 500  | 0.0671        | 0.0568        |
| c             | 195.63  | 0.08 195.63 | 500  | 0.0806        | 0.0577        |

Table 2. HST/WFPC2 observation log. ID denotes HST archival identification. HJD values pertain to exposure starts. $\Phi_{\text{RR Lyr}} = (\text{HJD} – 2450452.24866)/0.564876$ and $\Phi_{\text{EB}} = (\text{HJD} – 2450452.466)/8.92371$ are the phases of observations for RR Lyr and EB, respectively, where phase 0 for RR Lyr corresponds to maximum light, and phase 0 for EB corresponds to the primary eclipse (cf. Fig. 1).

2. Observations

To further investigate this system, we applied for multi-wavelength HST Wide Field Planetary Camera 2 (WFPC2) observations in Cycle 16 (PI Guinan, proposal ID #11223). Table 2 summarizes the acquired observations and provides heliocentric Julian dates (HJD) and the orbital phases computed according to the following RR Lyr and EB ephemerides:

$$\Phi_{\text{RR Lyr}} = \frac{2450452.24866 + E 0.564876}{T_{\text{eff}}},$$

$$\Phi_{\text{EB}} = \frac{2450452.466 + E 8.92371}{T_{\text{eff}}},$$

where Eq. 1 refers to the phase of maximum light and Eq. 2 refers to the EB primary minimum.

All exposures were corrected for geometric distortion, rotation, offsets, and scale differences between WFPC2 chips. For the purpose of analyzing the target (centered in the PC field), we extracted and trimmed the PC portion of the calibrated image. For the purpose of field astrometry and photometry we used all 4 fields corrected with IRAF’s task metric. Cosmic rays were cleaned using IRAF’s crcrej task. In cases where a single exposure in a given filter was acquired (F336W, F380W, F439W, F675W, and F814W), the images were combined w.r.t. the highest degree of similarity and with a 1% scale noise to account for sub-pixel offsets. Photometry was done independently with IRAF’s daophot task (Stetson 1987) and a stand-alone June 2008 version of the hstphot program (Dolphin 2010) that uses a PSF library to overcome the PSF undersampling issue. Due to the WFPC2 instrumental sensitivity drop in UV and IR there were insufficient counts in the F255W, F300W, F336W and F953W passbands to perform accurate photometry. For the remaining passbands the results from both methods are within their standard errors.

3. Results

The median seeing of OGLE photometry is estimated to ~1.34″ (Soszynski et al. 2003), which corresponds to ~30 pixels in the PC field. Using high resolution HST/WFPC2 photometry, we

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*Because of the HST/ACS failure in 2007 for which the initial proposal was made, the observations fell back on the less sensitive WFPC2 instrument. Moreover, the requested exposure times were computed for a single source of $I_C$ ~ 18 that turned out to consist of 5 distinctly fainter sources.*
were able to resolve as many as 5 distinct sources within the 30 pixel diameter centered on the target (cf. Fig 3) with their astrometric and photometric properties listed in Table 5. Two consecutive F555W exposures acquired during the minimum and maximum RR Lyr light (cf. Table 2) greatly facilitated its identification in the field. At ~18.2” from the optical center of the LMC, the estimated color excess of $E(B - V) = 0.075$ yields the maximum unreddened $(B - V)_0 = 0.112 \pm 0.05$, which corresponds to the maximum surface temperature of $T_{\text{max}} = 8360 \, \text{K} \pm 400 \, \text{K}$. The mean apparent magnitude $(V) = 19.309 \pm 0.02$ is corrected for reddening $(AV = 0.249)$ and bolometric correction $(\Delta V = 0.06)$; adopting the distance modulus of 18.43 to the LMC (Fitzpatrick et al. 2003), this yields the absolute magnitude of the RR Lyr to be $(M) = 0.57 \pm 0.02$, rendering OGLE052218.07-692827.4 a typical single RR Lyr type ab.

The residual OGLE $I_C$ light curve depth of ~0.15 magnitudes implies that, with an average 3rd light contribution of $76.3\% \pm 0.5\%$ (64.8\% at RR Lyr minimum, 87.9\% at RR Lyr maximum), only the second brightest source (S1) could possibly be an EB, since the remaining sources could not cause the observed ~15% change in the composite light. The unreddened value of $(B - V)_0 = 0.355 \pm 0.05$ yields the effective temperature of the putative EB of $T_{\text{eff}} = 6940 \, \text{K} \pm 245 \, \text{K}$, making it an early-to-mid F type system. Given the fractional radius $\rho = R/a = 0.3$ that is determined by the eclipse width, such a binary would have an absolute magnitude of at least $-0.5$, almost 2 magnitudes brighter than the distance to the LMC would allow. If, on the other hand, we imposed that the binary is in the LMC, the derived orbital semi-major axis of ~12 $R_\odot$ implies masses smaller than 0.2 $M_\odot$. In other words, there is no physically plausible model that would attribute the observed signature in the $I_C$ residuals to an EB.

The source is thus most likely a single star of mid-F spectral type and an unreddened absolute bolometric magnitude of $M = 1.12 \pm 0.02$. Plotting these values in a H-R diagram ($T_{\text{eff}} = 6940 \, \text{K}$, $L/L_\odot = 27$) places this star in the very center of the RR Lyr type region (see, i.e., Fig. 1 of Gaitschky & Said 1995). To assess the possibility that the source is a shorter period pulsating star, we analyzed all weaker PDM minima and found the possible periods of ~4.5-d (half-EB period) and ~0.82-d. The cadence of OGLE observations did not allow for a reliable search of even shorter periods. The shape of the residual light curve (i.e. the absence of a saw-tooth-shaped signature), the 3rd light contaminated variability amplitude $\Delta I \sim 0.15$, and a larger absolute magnitude of $M \sim 1.12$ indicates an RR Lyr type c star. These stars have periods between 0.25-d and 0.4-d (Szewczyk et al. 2008), a period range unreachable with PDM using the OGLE data alone.

A field including OGLE052218.07-692827.4 had been observed previously in a broad V band (F606W) by HST/ACS in April and July 2006 (HST proposal ID 10753, PI Diaz-Miller), taking us a step closer to understanding the nature of this object. We reduced the ACS data by a similar approach as outlined in Section 2 and obtained an additional 18 photometric points listed in Table 4. The data clearly show the star’s variability with the amplitude of ~0.18 and a period of several hours (cf. Fig. 4). There is insufficient information to attempt to determine the period (due to a very non-uniform time coverage), but the observations qualitatively support the RR Lyr type c hypothesis. Additional observations are needed to resolve the ambiguity. The remaining three sources (S2, S3, S4) are constant within their respective errors.

4. Conclusions

This paper establishes the nature of OGLE052218.07-692827.4 as a single RR Lyr type star. Moreover, it shows the two-fold danger of third light contamination: 1) the binary model based

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**Fig. 1.** Left: light curve of OGLE052218.07-692827.4 phased with the RR Lyr pulsation period ($P_{\text{RRLyr}} = 0.564876$-d). The solid line represents a 2nd order polynomial chain fit obtained by polyfit (Prša et al. 2008). The apparent scatter under the curve is due to the putative EB signature. Right: residual light curve after subtracting the theoretical RR Lyr pulsation fit, phased at the EB period ($P_{\text{EB}} = 8.92371$-d). The solid line depicts a model solution derived by PHOEBE.

**Fig. 3.** Surface plot of the 1.34” field (30 × 30 px) in the vicinity of the target (ID3 exposure close to the RR Lyr minimum). The inset depicts the field with a circle of diameter 29.43 px corresponding to the median OGLE resolution. The astrometric center of the image is a weighted photometric average. PC observations thus resolve 5 distinct sources that contribute to OGLE photometry, indicating that OGLE052218.07-692827.4 is an optical blend rather than an RR Lyr star in an EB.
on OGLE data alone provided a perfectly plausible physical description with virtually no means of resolving it without additional observations, and 2) although the residuals appeared to clearly point to the binary star signature, it seems that, somewhat ironically, the source of this secular variation is a distinct short period RR Lyr type c star. Being aware of these traps is all the more important in the era of fully automatic surveys and missions, where human supervision and a detailed object-by-object study is no longer possible. False positives present a serious challenge not only for ground-based observations, but for the upcoming space missions like Kepler and Gaia as well, emphasizing the importance of follow-up observations.

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References
Alcock, C., Allsman, R. A., Alves, D. R., et al. 2002, ApJ, 573, 338
Antipin, S. V., Sokolovsky, K. V., & Ignatieva, T. I. 2007, MNRAS, 379, L60
Benedict, G. F., McArthur, B. E., Fredrick, L. W., et al. 2002, AJ, 123, 473
Brown, T. M., Ferguson, H. C., Smith, E., et al. 2004, AJ, 127, 2738
Christiansen, J. L., Derekas, A., Ashley, M. C. B., et al. 2007, MNRAS, 382, 239
Dallaporta, S., Tomov, T., Zwitter, T., & Munari, U. 2002, Informational Bulletin on Variable Stars, 5312, 1
Dolphin, A. E. 2000, PASP, 112, 1383
Fitzpatrick, E. L., Ribas, I., Guinan, E. F., Maloney, F. P., & Claret, A. 2003, ApJ, 587, 685
Freyhammer, L. M., Hensberge, H., Sterken, C., et al. 2005, A&A, 429, 631
Gautschy, A. & Saio, H. 1995, ARA&A, 33, 75
Guinan, E., Fitzpatrick, E., Ribas, I., et al. 2005, in Bulletin of the American Astronomical Society, Vol. 37, Bulletin of the American Astronomical Society, 1479–
Guinan, E. F., Fitzpatrick, E. L., Diefarw, L. E., et al. 1998, ApJ, 509, L21
Lepischak, D. & Welch, D. L. 2004, in Astronomical Society, Vol. 37, Bulletin of the American Astronomical Society, 1479–
Munari, U. 2002, Informational Bulletin on Variable Stars, 5312, 1
Pigulska, A. & Michalska, G. 2007, Acta Astronomica, 57, 61

Table 3. Astrometric and photometric results for the sources in the vicinity of OGLE052218.07–692827.4. Right ascension α and declination δ are computed by flux-weighted averaging of the WCS data in all exposures where the sources were detected. The absolute astrometric accuracy of ~ 0.1″ is imposed by the Guide Star Catalog (GSC) accuracy, whereas the relative astrometric accuracy given in the table below does not exceed several mas. Photometry was performed using the June 2008 version of hstphot for the aperture radius of 0.5″ (11 px) and gain 7. The values are given in the STMAG system and are corrected for Charge Transfer Efficiency (CTE) and zero-point (ZP) offsets.

Table 4. HST/ACS photometric results for the RR Lyr and S1 sources. ID denotes HST archival identification. HJDs pertain to exposure starts.

fig. 4. Top: HST/ACS photometric curve of the RR Lyr folded according to the ephemeris given by Eq. (1). Bottom: HST/ACS photometric curve of the source S1, folded to $P = 0.3579$-d. Although this period has the lowest PDM θ value, it should not be considered significant due to a limited number of data points. Solid lines are computed by polyfit and bear no physical significance – they are included to help guide the eye.
Pilecki, B. & Szczygiel, D. M. 2007, Informational Bulletin on Variable Stars, 5768, 1
Prša, A., Guinan, E. F., Devinney, E. J., et al. 2008, ApJ, xxxx
Prša, A. & Zwitter, T. 2005, ApJ, 628, 426
Rodríguez, E., García, J. M., Mkrtichian, D. E., et al. 2004, MNRAS, 347, 1317
Sandage, A. 2004, ArXiv Astrophysics e-prints
Sarajedini, A., Barker, M. K., Geisler, D., Harding, P., & Schommer, R. 2006, AJ, 132, 1361
Sollima, A., Cacciari, C., & Valenti, E. 2006, MNRAS, 372, 1675
Soszynski, I., Udalski, A., Szymanski, M., et al. 2003, Acta Astronomica, 53, 93
Soszynski, I., Zebrun, K., Udalski, A., et al. 2002, Acta Astronomica, 52, 143
Stellingwerf, R. F. 1978, ApJ, 224, 953
Stetson, P. B. 1987, PASP, 99, 191
Szewczyk, O., Pietrzyński, G., Gieren, W., et al. 2008, AJ, 136, 272
Wilson, R. E. & Devinney, E. J. 1971, ApJ, 166, 605