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Time-resolved CCD photometry and time-series analysis of the RR Lyrae type star RR Gem

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Abstract We present the results of a time-resolved photometric and time-series analysis of an RR Lyrae type star RR Gem. The main results are as follows: we found RR Gem's pulsation period, 0.39689 d, and its V and I mean magnitudes, 11.277 (V) and 11.063 (I) mag respectively. We confirm its variability type as RRab/BL because it manifests the Blazhko effect, and it also exhibits asymmetric light curves (steep ascending branches), periods from 0.3 to 1.0 d and amplitudes from 0.3 to 2 mag in V. They are fundamental mode pulsators.

Key words: stars: individual: RR Gem — stars: variables: RR Lyr — stars: oscillations — stars: variables: RRAB/BL — stars: variables: Blazhko effect — techniques: photometric

1 INTRODUCTION

RR Lyrae variables are older pulsating white giants with low metallicity. They are common in globular clusters – dense groups of old stars in the halos of galaxies. Like Cepheids, their pulsations are periodic. RR Lyraes have ~ 0.5 solar mass, and display a short pulsation period of 0.2 to 0.85 d and amplitude variations of 0.3 to 2 mag. RR Lyrae stars are usually spectral class A. The main sequence and horizontal branch (HB) do not intersect. RR Lyrae stars are on the HB, indeed where the instability strip intersects the HB. The HB stars have left the red giant branch and are characterized by helium fusion in their cores surrounded by a shell of hydrogen fusion. All of the RR Lyrae stars in a cluster have the same average apparent magnitude. In different clusters, the average apparent magnitude is different. This is because all RR Lyraes have about the same average absolute magnitude of +0.75.

RR[1] means that this is the RR variable in the constellation Lyra. These are radially-pulsating giant A-F stars having amplitudes from 0.2 to 2 mag in the V band. Cases of variable light-curve shapes as well as variable periods are known. If their amplitudes and periods are modified, then this is called the "Blazhko effect" (Blažko 1907) (denoted by the subtype BL). The majority of these stars belongs to the spherical component of the Galaxy; they are present, sometimes in large numbers, in some globular clusters, where they are known as pulsating HB stars. Like Cepheids, the maximum expansion velocities of surface layers for these stars practically coincide with maximum light.

RRAB/BL[2] type variable stars are RR Lyrae variables with asymmetric light curves (steep ascending branches), periods from 0.3 to 1.0 d and amplitudes from 0.5 to 2 mag in the V band. They are fundamental mode pulsators. BL indicates RR Lyrae stars exhibit the Blazhko effect.

J. Jurcsik and her team (Jurcsik & Kovacs 1996; Jurcsik 1998; Jurcsik et al. 2005, 2006b,a,c, 2008b,a; Jurcsik 2009; Jurcsik et al. 2009a,b) have done remarkable work on the Blazhko behavior of the star RR Gem, and in particular on RR Lyrae type stars manifesting the Blazhko effect. Most RR Lyrae stars repeat their light curves with remarkable regularity. About 30% of the known Galactic RR Lyrae stars, however, display cyclic modulation in the shape and amplitude of their light curve over tens of pulsation cycles.

2 METHODOLOGY

2.1 Instrumentation

M.K. Bhavnagar University's Kumari Aanya Binoy Gardi Observatory[3] was used for this study. The fully auto-

[1] `https://www.aavso.org/vsx/index.php?view=help.vartype&nolayout=1&abbrev=RR`

[2] `https://www.aavso.org/vsx/index.php?view=help.vartype&nolayout=1&abbrev=RRAB\%2FBL`

[3] `https://www.google.com/maps/place/Bhavnagar+Observatory/@21.7537555,72.1302003,`

mated observatory contains a 14 inch Celestron Schmidt-Cassegrain reflector type telescope mounted on a German equatorial mount. The telescope has an SBIG STF-7 CCD camera along with an SBIG CFW-8 filter wheel with Johnson-Cousins $UBVRI$[4] photometric filters incorporated into the CCD, attached to the telescope. The telescope can be operated manually as well as fully computer controlled and the telescope has two stepper motors for the RA and DEC axes which were developed locally in collaboration with the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune. Open source software SCOPE was used to adjust the stepper motor controller and Cartes du Ciel (Sky Chart) was employed for the CCD control as well as to give position commands to the SCOPE software which sends commands to the stepper motor controller. The stepper motor controller performs the Pulse Width Modulation (PWM) and sends electrical signals to the RA and DEC stepper motors. There is a USB connection between the CCD and PC for data as well as commands. Astronomy data are locally stored in a Windows XP based PC. A GPS receiver is also connected with the Windows PC which periodically updates the time of the PC which in turn updates the DOS based PC clock and thus the whole system's time gets updated periodically. A manual sliding rooftop is connected with a motor through a pulley to open and close the observatory's roof.

2.2 Observations and Data Reduction

2.2.1 Differential photometry

MaxIm DL[5] photometric image analysis software was employed for our data reduction work. Each and every time-series astronomical image was first calibrated for basic noise removal and then every continuous sequence was aligned and photometry was performed on them.

For differential photometry (Rodríguez-Gil & Torres 2005) we needed our object star (RR Gem)[6], one or more check stars and one reference star (standard star). Standard observatory procedures were applied with minimum air-mass considerations.

For data reduction (calibration), flat field frames, dark frames and bias frames as well as light frames (see Fig. 1) were required, so we programmed this into our MaxIm DL software and then it was done automatically according to our exposure time and other Johnson-Cousins *UBVRI* filter value settings. For flat fielding, we utilized daily twilight images and after all these we made master files for each of these and used them in our final calibration part.

In MaxIm DL, we combined all the flat, dark and bias files and combined them into single standard master files according to different photometry filters. For calibration, we employed these master files. We first opened all the object star's light images, loaded the master calibration files and performed calibration using the calibrate all menu. From this we retrieved all the calibrated files, then we again opened the calibrated light images and aligned them using the align tool.

To perform the photometry, we again opened all the light images and, using the photometry menu's differential photometry tool, we did the photometry analysis on the light images by selecting each individual object star, reference star and check stars. Finally it gave us results in a magnitude vs. Julian Day (JD) graph in a CSV or AAVSO text format file.

2.2.2 Time-series analysis

The VStar (AAVSO)[7] program was used for performing time-series analysis (Rodríguez-Gil & Torres 2005). We used DC DFT with the Period Range tool and fed the proper values into it with low period of 0.1 d, high period of 0.5 d and resolution of 0.0001, and we got the periodogram with period 0.39689 d.

We downloaded the standard published data for our star from the AAVSO data tool[8] for a period of 10 months to get a bigger view of our star and performed the same process as mentioned above, and retrieved the results (see Figs. 2 and 3). Then we also downloaded about 1 month of data near our observing period, analyzed them in the same way and procured the results (see Figs. 4 and 5). By comparing this one month's data with our data (see Figs. 6 and 7 for (V) and Figs. 8 and 9 for (I)) we found them to be nearly perfectly matched with the magnitude as well as with the period. This confirms that our observations and data reduction process are standardized.

According to AAVSO (VSX)[9] its spectral type is A9-F6. It was discovered by L. Ceraski (Ceraski 1903) and all this information is based on 1972 Feb 9 (HJD 2441357.205). Its AAVSO UID: 000-BBM-940. Its other names are AAVSO 0715+31, AN 13.1903 and HIP 35667. Our data are from JD: 2456764.16483 (2014 Apr 16) to JD: 2456801.11748 (2014 May 23), totaling 15

18z/data=!4m5!3m4!1s0x395f509a719b3a2b:0x30504b9860ad6057!8m2!3d21.7542085!4d72.1303511?hl=en

4 http://www.aip.de/en/research/facilities/stella/instruments/data/johnson-ubvri-filter-curves

5 http://diffractionlimited.com/product/maxim-dl/

6 https://www.aavso.org/vsx/index.php?view=detail.top&oid=14304

7 https://www.aavso.org/vstar

8 https://www.aavso.org/data-download

9 https://www.aavso.org/vsx/index.php?view=search.top

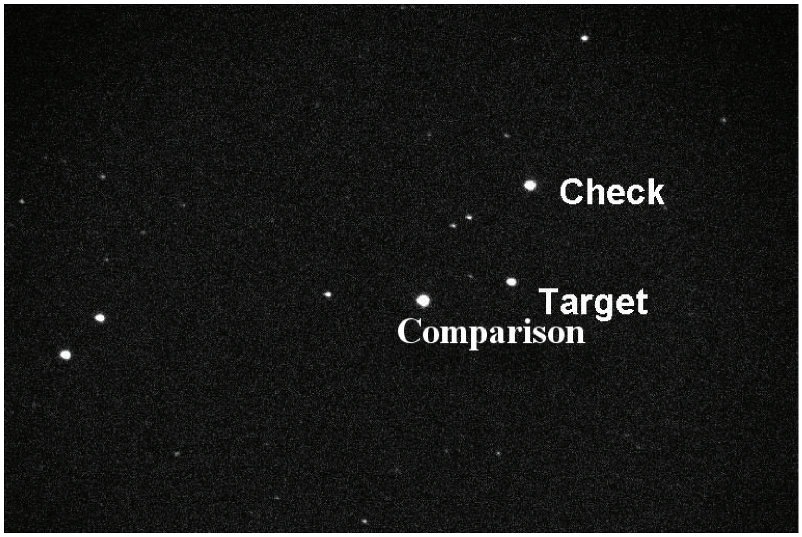

Fig. 1 Clear filter object, comparison and check star field-CLEAR Filter: 16–04–2014.

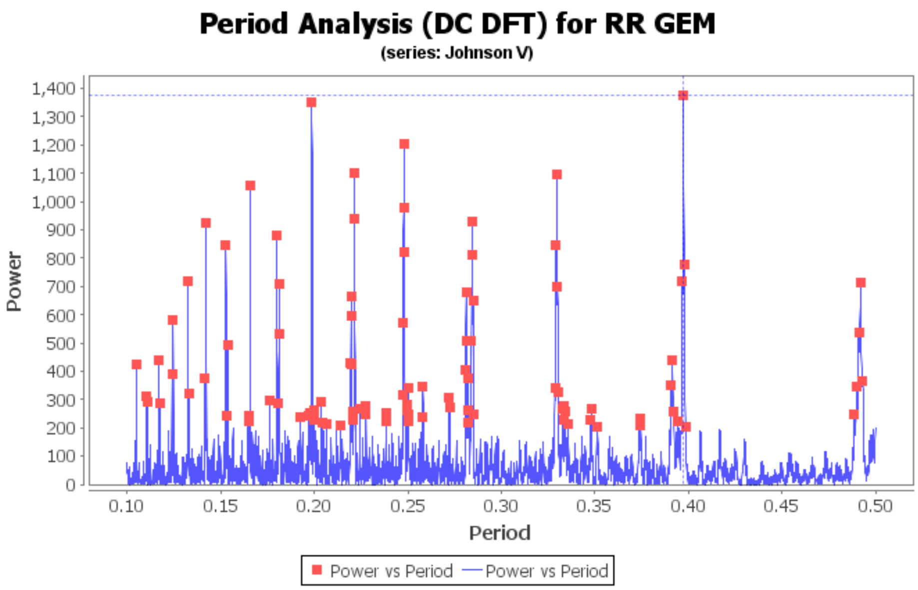

Fig. 2 Ten months of data for RR Gem from 2014, Johnson V Periodogram.

nights. During this time, the mean magnitudes in visual and infrared filters were 11.277 (V) and 11.063 (I).

We also compared our results with other astronomical databases. The details are as displayed in Table 1.

As shown in Table 1, we compared our results with many astronomical databases such as VSX, ASAS-SN[10], CDS[11], GCVS[12] and General Variable Star Search Gateway[13].

We found our mean magnitude in the V band to be 11.277 mag and that in the I band to be 11.063 mag, which is quite close to the published database values like 11.185 mag in the V band with the difference between our results and that in VSX (AAVSO) being minor, 0.092.

We also compared our period with the astronomical databases and found that our period of 0.39689 d is very close to the published value of 0.3973106 d with VSX (AAVSO) with a minor difference of 0.0004206 d.

[10] https://asas-sn.osu.edu/database/light_curves/195828

[11] http://cdsportal.u-strasbg.fr/?target=rr\%20gem

[12] http://www.sai.msu.su/gcvs/cgi-bin/search.cgi?search=RR+Gem

[13] http://var2.astro.cz/gsg/index.php?star=rr+gem&all=yes&alldata=yes&oejv=yes&gcvs=yes&nsv=yes&brka=yes&meka=yes&czev=yes&bcvs=yes&dssplate=yes&usecoords=GCVS&rezim=search_now

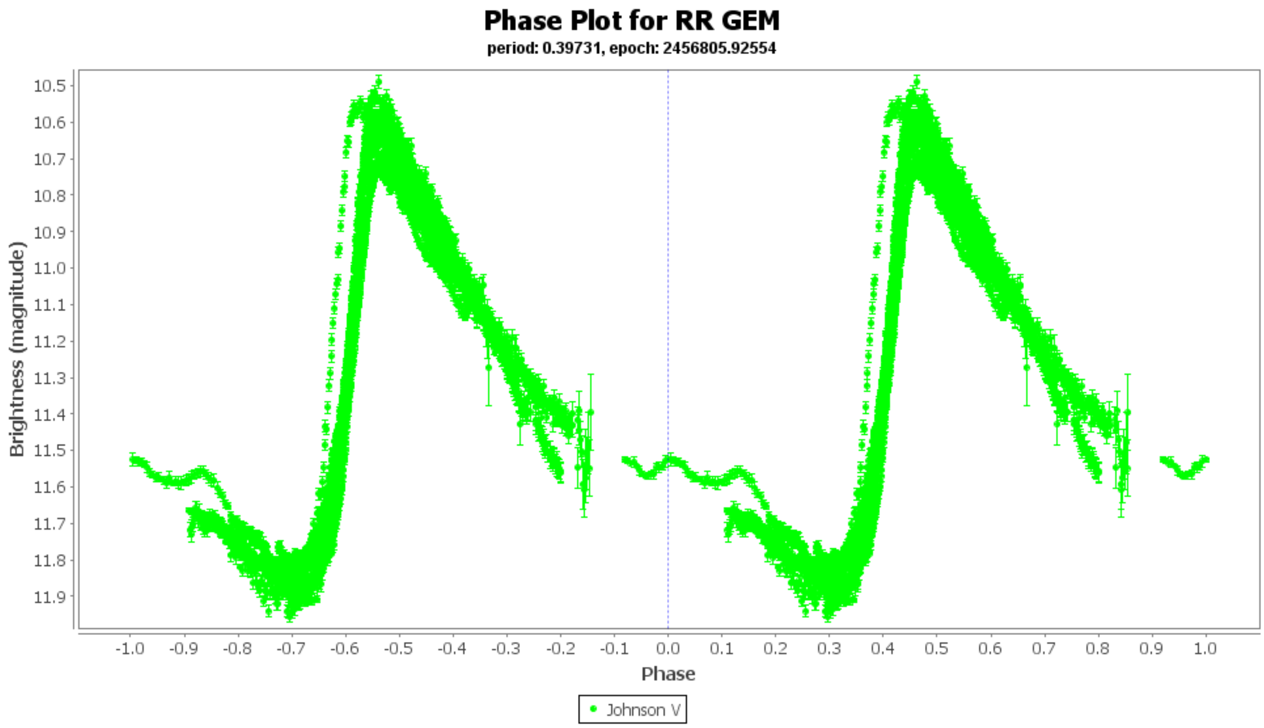

Fig. 3 Ten months of data for RR Gem from 2014, Johnson V Phase Graph.

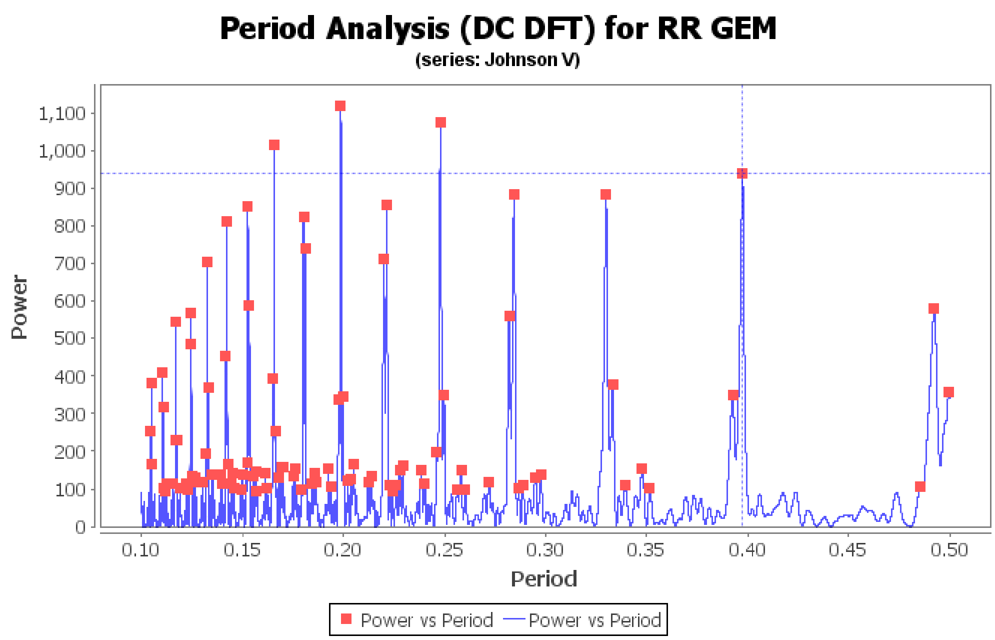

Fig. 4 One month of data for RR Gem from 2014, Johnson V Periodogram.

2.2.3 Comparison and check stars

We used check and comparison stars[14] from field photometry[15] for RR Gem from the AAVSO Variable Star Database:

The comparison/standard star and check stars were selected from the AAVSO's field photometry section. They were selected because they are very near, in the same CCD field. They were chosen because they were about the same magnitude as well as being within the CCD field. All the

[14] *https://www.aavso.org/apps/vsp/photometry/?fov=18.5&scale=F&star=rr+gem&orientation=ccd&maglimit=18.5&resolution=150&north=up&east=left&type=chart*

[15] *https://www.aavso.org/apps/vsp/photometry/?fov=18.5&scale=F&star=rr+gem&orientation=ccd&maglimit=18.5&resolution=150&north=up&east=left&type=photometry*

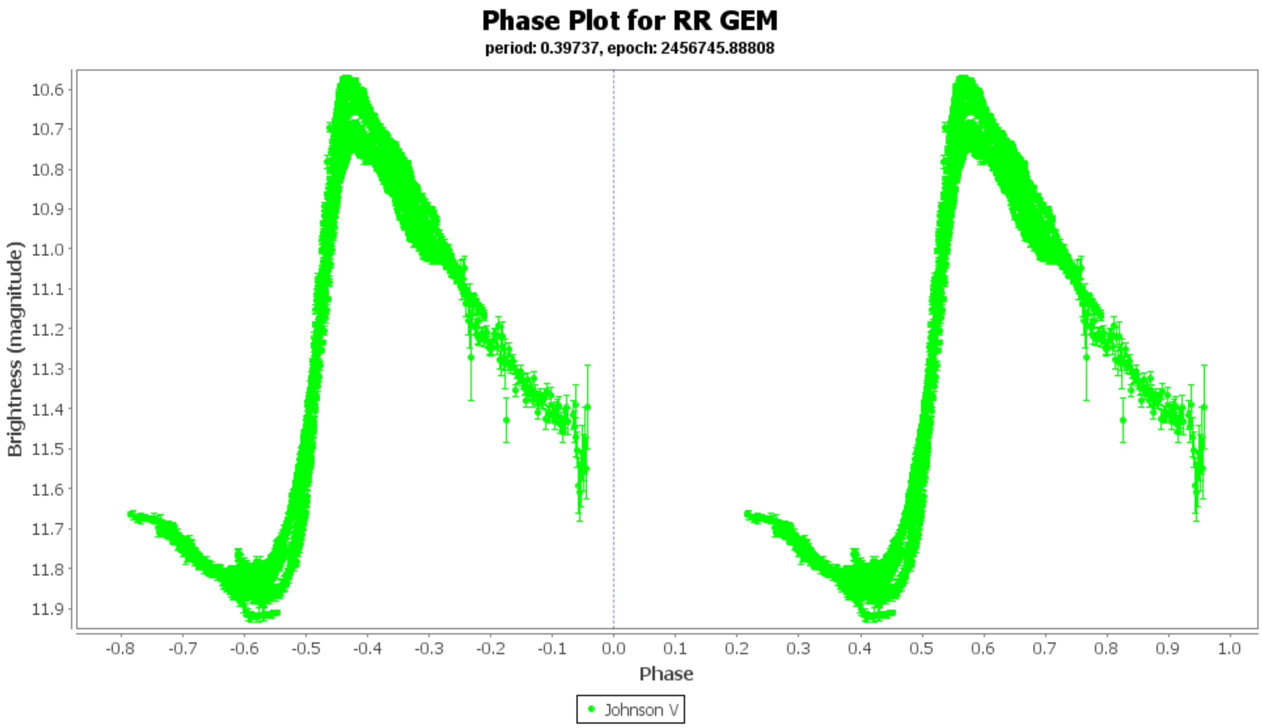

Fig. 5 One month of phase data for RR Gem from 2014, Johnson V Phase Graph.

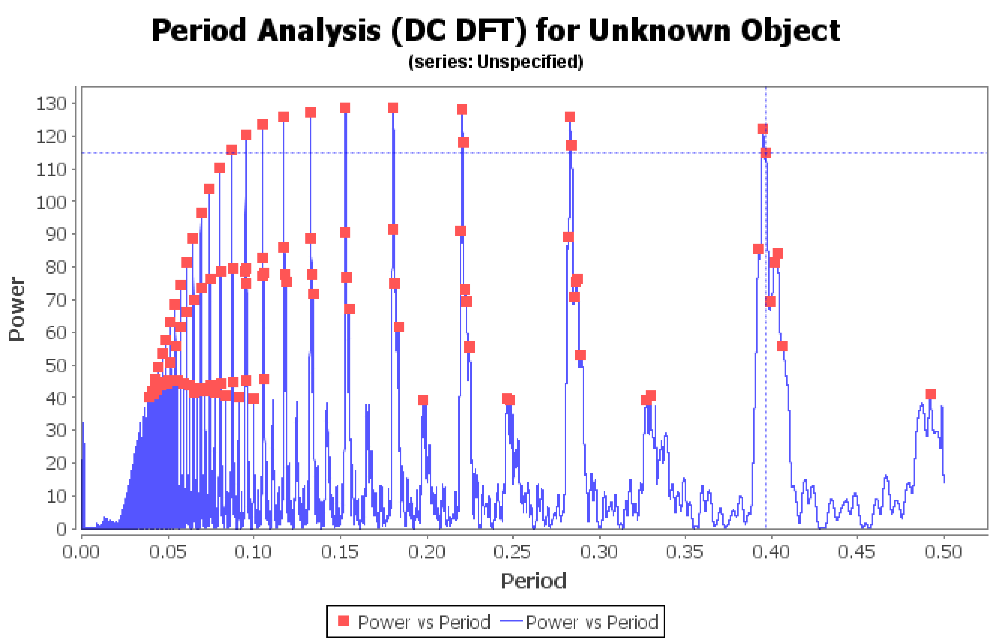

Fig. 6 Fifteen days of RR Gem data from 2014, Johnson V Periodogram.

details are provided in Table 2. Practically, they should be near the object star and their magnitude as well as spectral class should also match. The comparison star should be a standard non-variable star and the check star could be non-variable or variable for the aperture (differential) photometry. So, they were chosen accordingly and we found them to be satisfactory as per our requirements.

3 RESULTS

RR Gem's mean magnitude for V was 11.277 (V) mag and for I was 11.063 (I) mag. We also compared the star's data from the AAVSO Variable Star Database for nearly the same time period and found its visible filter's mean magnitude to be 11.185 V, which gives a difference of 0.092 V which is also quite negligible.

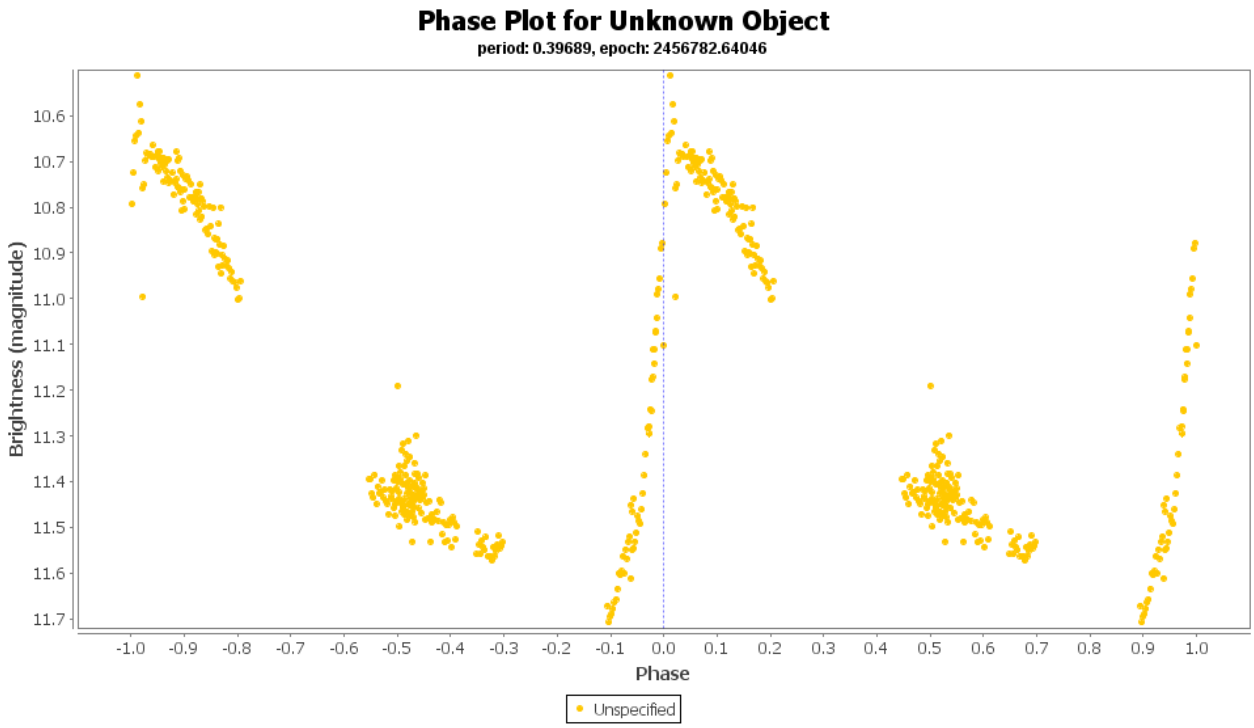

Fig. 7 Fifteen days of RR Gem phase data from 2014, Johnson V Phase Graph.

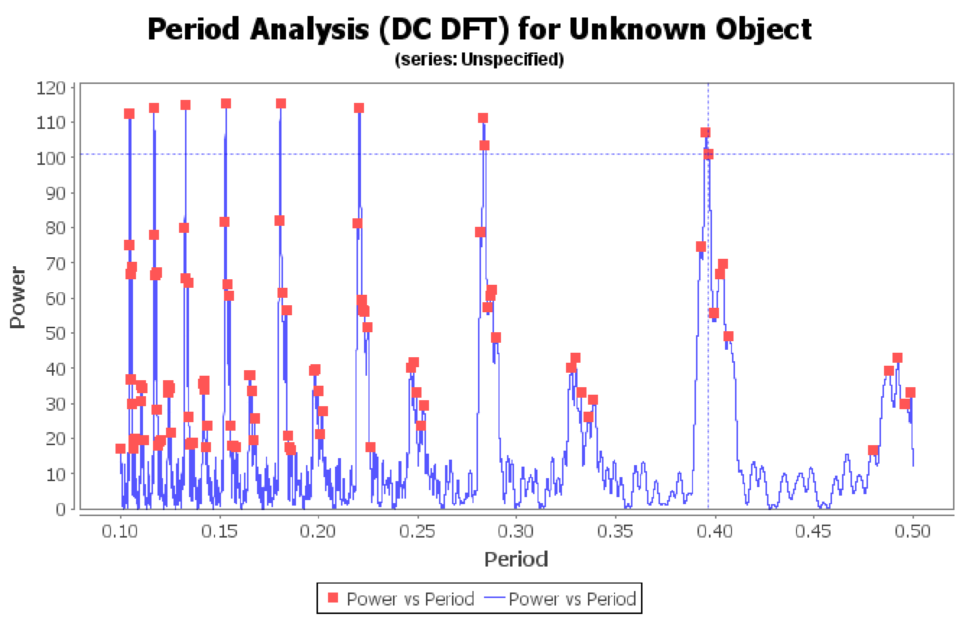

Fig. 8 Fifteen days of our RR Gem data from 2014, Johnson I Periodogram.

After performing time-series analysis, it was found that the period of RR Gem published in the VSX (AAVSO) database was 0.3973106 d and after our analysis we found it to be 0.39689 d. The difference between the two is 0.0004206 d which is quite low. Thus this establishes that our analysis matches the published literature values.

4 CONCLUSIONS

We have established that our observations reported in this paper are in very good agreement with the published data for the star RR Gem and that it is an RR Lyrae type star, its variability type is RRab/BL and it clearly manifests the Blazhko effect. We also conclude that our observatory can now be used for future studies of variable stars and in particular will be useful for performing optical light curve

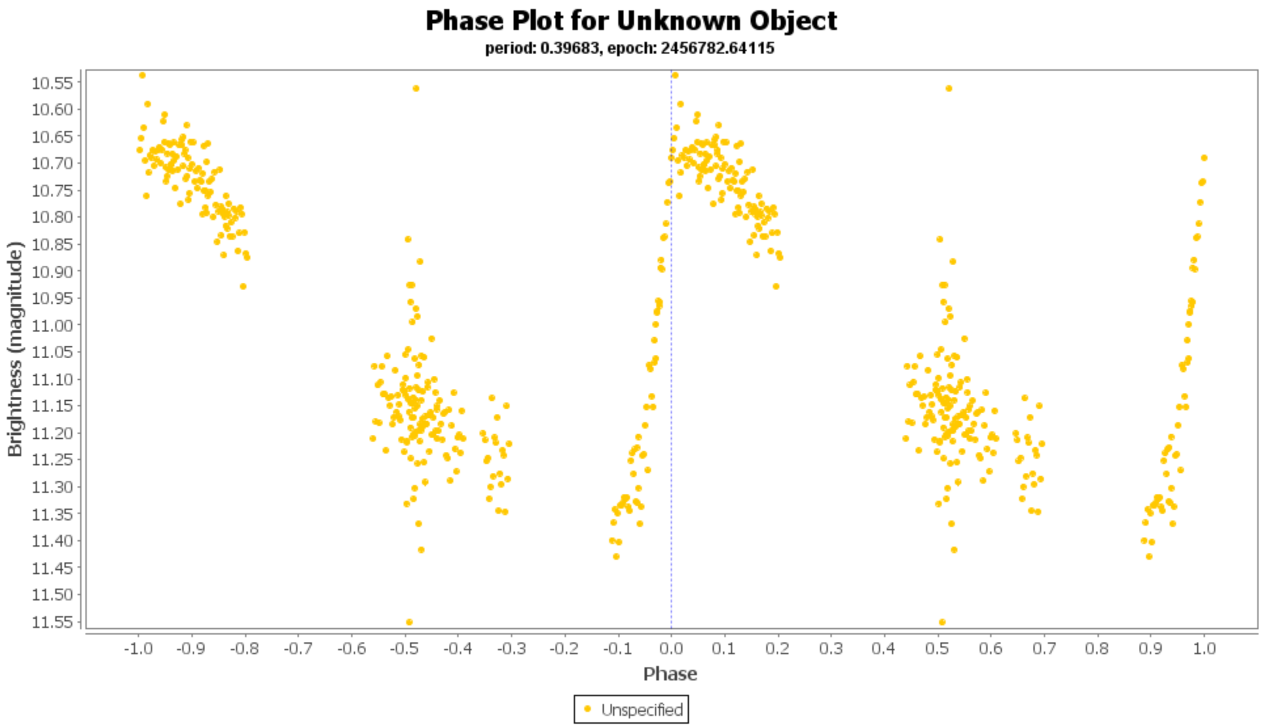

Fig. 9 Fifteen days of RR Gem phase data from 2014, Johnson I Phase Graph.

Table 1 RR Gem in Different Astronomical Databases

Database	ID / Name	J2000.0 RA	J2000.0 DEC	Type	V mag (Max)	V mag (Min)	Period (d)	Epoch	Spectral[a] Class
VSX[b]	000-BBM-940	07:21:33.53	30:52:59.50	RRab/BL	10.62	11.99	0.3973106	2441357.205(HJD)	A9-F6
ASAS-SN[c]	ASASSN-VJ072133.66+305259.7	07:21:33.66	30:52:59.70	RRab	-	11.34	0.3992869	2457690.06(HJD)	-
CDS[e]	V* RR Gem	07:21:33.53	30:52:59.46	Variable Star of RR Lyr type	-	11.92	-	-	A8
GCVS[f]	RR Gem	07:21:33.53	30:52:59.50	RRab	10.62	11.99	0.3973106	41357.21	A9-F6
GVSSG[g]	RR Gem / 380010	07:21:33.50	30:52:59.50	RRab	10.62	11.99	0.3973106	41357.21(JD)	A9-F6

[a]: `https://www.handprint.com/ASTRO/specclass.html`;
[b]: Variable Star Index (AAVSO);
[c]: The All Sky Automated Survey for SuperNovae;
[e]: Strasbourg Astronomical Data Center (CDS-Strasbourg);
[f]: General Catalog of Variable Stars;
[g]: General Variable Star Search Gateway.

Table 2 Comparison and Check Star Table for RR Gem

Star Type	AUID	J2000.0		Magnitudes				
		RA	DEC	B	V	$(B-V)$	Rc	Ic
Standard / Comparison Star	000-BJR-395	07:21:40.41	30:52:23.80	9.560(0.020)*	9.412(0.016)*	0.148(0.026)	9.322(0.020)*	9.219(0.021)*
Check Star	000-BBM-938	07:21:33.34	30:54:43	10.652(0.016)*	10.271(0.014)*	0.381(0.021)	10.043(0.017)*	9.826(0.019)*

data and related analysis for upcoming transient alerts such as gravitational waves and gamma-ray bursts which require optical followups from ground based telescopes during their bright phases (at various geographic longitudes).

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