Photometric Study of RR Lyrae Star TV Lyn

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Abstract. In this research, we are reporting the light curve of RR Lyrae type variable star TV Lyn. This star is observed in the northern hemisphere and its coordinates are 07:33:31.7 +47:48:09.8. We have used data from Las Cumbres Observatory (LCO) which consists of a worldwide network of robotic telescopes. Photometric measurements were conducted using the SBIG 6303 0.4-meter telescope with a field of view of 29'x19'. Depending on what the color of a star is when different filters are applied to it, the luminosity will change accordingly. Our data consists of four filters, Bessell B (Blue), Bessell V (visual), SDSS-I (Infrared), and PAN-STARRS-Z (Near Infrared). Results show that this star has a variability period of 0.2407±0.002 days, metallicity -1.49, and located at a distance of 1362±118 pc. We have used an estimate of the reddening E(B-V) as 0.08. This research is a part of an Our Solar Sibling Project by an undergraduate student with the help of a faculty advisor and an Our Solar Sibling Project Investigator.

INTRODUCTION

RR Lyrae type stars are one of the brightest representative variable stars in the galaxy. They are variable stars since they pulsate. These stars are older than 10 Giga-years. They are typically low mass and found within an instability strip with a temperature ranging from 6000 K to 7250 K [1]. They change internal temperature due to being compressed by gravity which causes photons to be trapped inside the star, making the temperature rise. This increases pressure within the star, which then makes the gas expand allowing the photons to escape and the pressure to release. The study of these stars can provide us information on the distance and properties of star clusters. Their brightness can range from a thousandth of a magnitude to as much as twenty magnitudes over periods of a fraction of a second to years, depending on the size. There are over 150,000 RR Lyrae stars known and catalogued, and many more are suspected to be RR Lyrae stars. The study of variable stars allows us to study the universe because stars are the primary engines of cosmic evolution. Variable stars teach us about stellar properties such as mass, radius, luminosity, temperature, composition, and evolution. There are many types of variable stars such as Cepheid variables, Mira variables, and cataclysmic variables. Cepheid type variable stars play a major part in determining distances to far away galaxies and determining the age of the universe. Mira variables allow us to analyze the evolution of stars and Accretion disks help us to understand disk behavior [2,3].

Study of RR Lyrae stars can provide important information on chemical compositions and dynamical properties of old stellar populations. RR Lyrae stars in Galactic globular cluster (GC) systems are of particular importance to address the question of the early history and structure of our Galaxy [2]. Drake et al. [4,5] and Pietrukowicz et al. [6] have used RR Lyrae stars to understand the substructures in the Galactic halo expected from the theory of the hierarchical structure formation and to delineate the bar structure in the central part of our Galaxy. Lee et al (2014) have presented a high-precision BV CCD photometry of RR Lyrae stars in NGC 6723 galaxy [7]. They studied the

RR Lyrae star population in NGC 6723 and estimated the distance scale. Fitzgerald et al [8] have used photometric methods to study open cluster NGC 2215.

This research focuses on RR Lyrae type variable star TV Lyn located in Lynx constellation and in NGC 2770 galaxy in the northern celestial hemisphere. The coordinates of TV Lyn are: 07:33:31.7 +47:48:09.8. The light-curve of a stellar object is important for astronomical research and studying this star can provide concepts of distance scale, formation process of the galaxy, age, stellar content, and metallicity [8].

Observations

We have used photometric analysis to obtain the light-curve of the variable star TV Lyn. Photometry is the measurement of brightness. Time series photometer monitors the light variation from an astronomical object over the time. The data contains a series of images of a stellar object over the time, typically over different color filters to extract different brightnesses [10]. Inner and outer sky annulus and the size of the photometry aperture are three main parameters for photometric analysis. The inner radius needs to be large enough to include all light from the star but not too much of the sky. The outer radius determines the size of the sky annulus, this is important because the sky is a variable and changes over short time intervals. Aperture size of the star can be calculated by counting the pixels that form the center of the star.

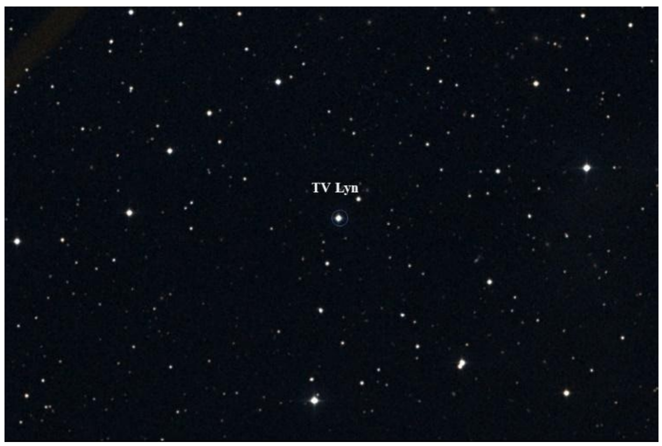

FIGURE 1. TV Lyn on a night sky! (Courtesy: Las Cumbres Observatory; FOV: 29’x19’)

For better representation of the images of celestial bodies from telescopes, astronomers usually place a unique piece of colored glass into the path of light called a filter. Astronomical filters allow light of different wavelengths to pass through while also blocking unwanted wavelengths. Any set of color filters with known light transmission properties is called a photometric system. At present, there are over 200 photometric systems. There are two types of color filters: wide band and narrow band filters. Visible light photometry most commonly uses wide band filters by the names of U, B, V, R, and I [10]. The U filter stands for ultraviolet and allows light of wavelengths about 320 nm and 400 nm to pass through. The B filter stands for blue and allows light of wavelengths about 400nm and 500 nm. The V, R, and I filters stand for visible, red, and infrared and their respective wavelength ranges are 500-700 nm, 550-800 nm, 700-900 nm.

For this research, we initially have used images of the star TV Lyn from Las Cumbres Observatory (LCO) over the course of 5 days in U, B, I, and V filters. Figure 1 shows an image of TV Lyn in the night sky with a field of view of 29’x19’, courtesy of our LCO telescope data. Each filter needs a specific exposure time in order to give the best quality, therefore, the 4 test images had base exposure times of 12 to 30 seconds. We were able to calculate the desired exposure times of TV Lyn and requested 2 weeks of data during the period of January 2020 with new exposure times B: 40s, V: 5s, I: 20s, and Z: 70s. LCO’s SBIG 6303 telescope recorded the light from TV Lyn with a CCD camera with a pixel scale of 0.571 (bin 1x1). This telescope has an aperture of 0.4 m. Around 50 images were received and placed in a google drive folder by the Our Solar Sibling Project Investigator. As a part of the Solar Sibling project, a series of automated python scripts were provided by Michael Fitzgerald to calculate time period from the light curve by observing how bright the standard stars comparable in size to TV Lyn are and plotting it as phase vs magnitude. The python scripts also allowed us to observe apparent magnitude and metallicity of the variable star in different filters. Some of the standard stars used to observe TV Lyn's brightness were: LP 162-33, TYC 3409-2065-1, TYC 3409-2187-1, and BD+48 1546 with Bessell B magnitudes of 11.7, 18.7, 12.8, 12.1, and 11.1 respectively.

We obtained four light curves for the star TV Lyn for the filters B, V, I, and Z. The details of these light curves are discussed in the results section of this paper.

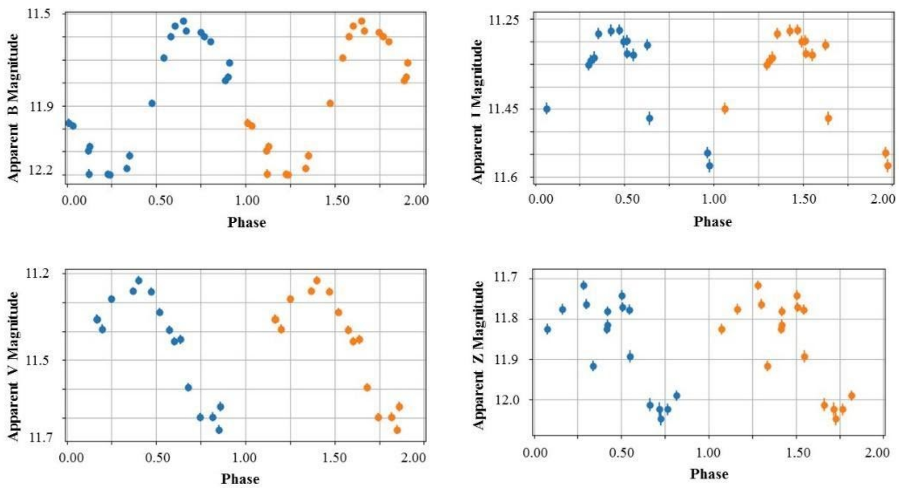

FIGURE 2. Light curves of RR Lyrae star TV Lyn over two cycles in B, V, I, and Z filters

RESULTS

Figure 2 shows the light curves of the star TV Lyn for two cycles of most likely period with error bars in B, V, I, and Z filters. The error bars should be based on the variations of the differences between the comparison and check star magnitudes. Actual error could be more than that though, due to external factors. Based on the shape of the sinusoidal graph, we classify TV Lyn as an RRc variable star [11]. The time period of the star in different filters, with standard deviations, are shown in Table 1. Theoretical period-luminosity of the RR Lyrae stars were used from Catelan et al [1] and Caceres and Catelan [12].

$$M_v = 2.288 + 0.882logZ + 0.108(logZ)^2 \quad (1)$$

$$M_i = 0.908 - 1.035logP + 0.220logZ \quad (2)$$

$$M_z = 0.839 - 1.295logP + 0.211logZ \quad (3)$$

$$logZ = \left[\frac{M}{H}\right] - 1.765 \quad (4)$$

$$\left[\frac{M}{H}\right] = \left[\frac{Fe}{H}\right] + log(0.638f + 0.362) \quad (5)$$

Where f = $10^{0.3}$(as provided by Our Solar Sibling project), M_v, M_i, and M_z are the absolute magnitude in V, I, Z filters. P is the pulsation period, Z is metallicity. We have used metallicity Fe/H value as -1.490 (as provided by Our Solar Sibling project). Absolute magnitudes are calculated using metallicity (Z) and time periods using equations 1, 2, and 3. We received excel files from the python scripts containing calibrated TV Lyn magnitudes as well as differential magnitudes. Calibrated magnitudes are exact measurements of a celestial object, whereas differential magnitudes are more variable because their brightness is being compared with nearby stars of similar magnitude.

The average time period of all the filters is around 0.24 days with an error estimate of 0.003 days. The luminosity is calculated with the average of maximum and minimum values of magnitudes. For B it is 11.87±0.057, for V it is 11.43±0.025, for I it is 11.34±0.018, and for Z it is 11.88±0.011. Table 1 shows all the time period data with standard deviation. In our data we have used an estimate of reddening E(B-V) as 0.08 based on minimum variance in distance among V, I, and Z filters. The distance (d) of the star TV Lyn in parsec is calculated using the theoretical relation between absolute magnitude (M) and apparent magnitude (m) are shown in Table 2.

$$m - M = 5logd - 5 \tag{6}$$

$$d = 10^{((m-M+5)/5)} \tag{7}$$

TABLE 1. Time periods in B, V, I, Z filters with standard deviation

Filter	Wavelength	Period	Standard Deviation
B (Blue)	400-500 nm	0.2407 days	0.002 days
V (Visible)	500-700 nm	0.2407 days	0.002 days
I (Infrared)	700-900 nm	0.2407 days	0.002 days
Z (Near Infrared)	~900 nm	0.2406 days	0.002 days

TABLE 2. Comparison of distances in V, I, and Z filters with GAIA.

	Distance (parsecs)	Error (parsecs)
GAIA	1219	73.5
V	1362	118
I	1252	73
Z	1564	64
Average (V, I, Z)	1393	49

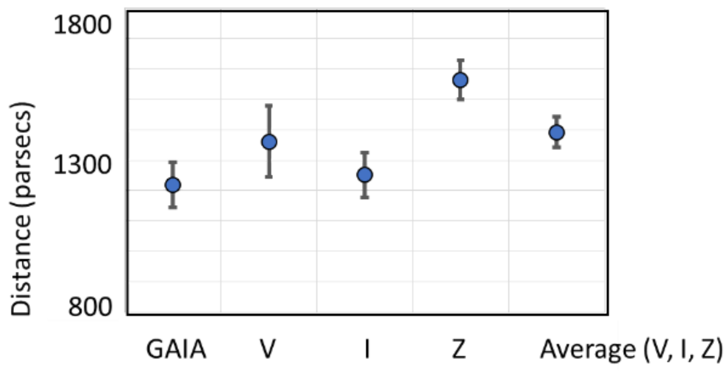

FIGURE 3. Comparison of TV Lyn distance from LCO data with GAIA telescope.

Table 2 and Fig. 3 show the comparison of the star TV Lyn distance in V, Z, I with GAIA distance. GAIA is a space observatory that measures the distance, position, and motion of the stars. V and I distance measurements agree with GAIA distance within the error limit, whereas Z and Average do not [13,14].

Conclusion

In this paper, we have studied the light curve of the variable star TV Lyn. We have measured the time period of variation, distance, luminosity, and metallicity using the robotic telescope data from LCO. Our data shows that TV Lyn is an RRc type variable star with a periodicity of 0.2407 days. The distance of the star is 1362 parsecs. The luminosity of the star is 11.87 Watts and metallicity is -1.49. These results are consistent with results presented in Cohen et al [15] and Fitzgerald [10] for other RR Lyrae stars. One of the sources of error is estimation of reddening E(B-V). A change of E(B-V) by 0.03 leads to 8% to 13% of distance error in V filter [9].

Acknowledgments

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