Report on the Photometric Observations of the Variable Stars DH Pegasi, DY Pegasi, and RZ Cephei

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Abstract We report 872 observations on two RR Lyrae variable stars, DH Pegasi and RZ Cephei, and on one SX Phoenicis variable, DY Pegasi. This paper discusses the methodology of our measurements, the light curves, magnitudes, epochs, and epoch prediction of the above stars. We also derived the period of DY Pegasi. All measurements and analyses are compared with prior publications and known values from multiple databases.

1. Introduction

The Harvard Summer School is a program of Harvard University for secondary and college students to experience a Harvard education through two undergraduate courses at Harvard. The authors were enrolled in "Fundamentals of Contemporary Astronomy" taught by Prof. Rosanne Di Stefano. Part of this paper was meant to be a class project, but we found this topic interesting and decided to do more—thus, we observed the stars instead of just researching facts about them.

Throughout this study, we have focused on pulsating variable stars with exceptionally short periods. We have inspected the length of their periods, their change in apparent magnitude, time of epoch, and general shape of their light curves. Measurements of the following stars are presented, DH Pegasi, DY Pegasi, and RZ Cephei, all taken at the Clay Telescope (Harvard University, 0.4 m) with the Apogee Alta U47 Imaging CCD coupled with the Johnson V filter. DH Peg and RZ Cep are both RR Lyrae (RRC) type variable stars while DY Peg is a SX Phoenicis (SXPHE) type variable star. We compared our data to Hopp (1981) and Tifft (1964) while data for DY Peg are compared to Oja (2011) and Hardie and Geilker (1958).

2. The stars

The stars observed are presented in Table 1. The stars are identified by their variable star name as well as by their Hipparcos Catalogue numbers (HIP;

Perryman *et al.* 1997). The coordinates are from The International Variable Star Index (VSX; Watson *et al.* 2014) provided by the AAVSO.

Table 1. The stars used in this study.

Name	*Type*	*Identifier*	*R.A. (J2000)* h m s	*Dec. (J2000)* ° ′ ″
DH Peg	RRC	HIP 109890	22 15 25.64 (333.85683)	+06 49 21.4 (+6.82261)
DY Peg	SXPHE	HIP 114290	23 08 51.19 (347.21329)	+17 12 56.0 (+17.21556)
RZ Cep	RRC	HIP 111839	22 39 13.18 (339.80492)	+64 51 30.6 (+64.85850)

3. Observations

3.1. Methodology of measurements

Three variable stars—DH Peg, DY Peg, and RZ Cep—were selected based on their visibility from our location and their periods. We used CCD imaging at the Clay Telescope to take a total of 872 measurements of these three stars. We exposed the CCD for a specific amount of time (ranging from 20 to 60 seconds), beginning an exposure immediately after the previous had finished. Exposure time and the total number of images taken are presented in Table 2.

Table 2. Exposure time of each star in this study and the total number of observations.

Name	*Exposure Time (seconds)*	*Total Number of Observations*
DH Peg	60	170
DY Peg	20	432
RZ Cep	30	270

Note that during some exposures, clouds moved between the telescope and the star, obscuring the star in question from view. For this reason, approximately 50 images were removed before analysis and were not accounted for in the light curves. Photometric measurements were conducted only on the images without cloud cover.

3.2. Time frame

The time frame of the observations are presented in Table 3. The times are presented in Julian Date (JD) and the durations (ΔT) are presented in minutes.

Table 3. Time frame of the observations.

Name	T_i *(JD)*	T_f *(JD)*	*ΔT (minutes)*
DH Peg	2456861.69705717	2456861.84179564	208.423
DY Peg	2456869.69427083	2456869.81443287	173.033
RZ Cep	2456864.65042824	2456864.85385416	292.933

T_i represents the initial observation time. T_f represents the time of the last observation. ΔT represents the time difference between the first observation and the last.

3.3. Comparison stars

The magnitudes of the stars were measured through comparisons with other nearby standard (non-variable) stars. Each variable star has at least one comparison star with one check star. Aside from DH Peg, each star has two comparison stars and one check star. The comparison stars and check stars assigned to each variable star are shown in Table 4.

Table 4. Variable stars and their comparison stars.

Name	*Comparison Star 1*	*Comparison Star 2*	*Check Star*
DH Peg	TYC 565-1155-1	Not Used	BD+06 4987
DY Peg	BD+16 4876	GSC 01712-00542	GSC 01712-01246
RZ Cep	TYC 4273-435-1	TYC 4273-1351-1	TYC 4273-659-1

Note that there are special exceptions for check stars BD+06 4987 and TYC 4273-659-1. BD+06 4987 was not used during the first six observations of DH Peg because it was not in the image produced by the CCD. TYC 4273-659-1 was not used during the first 118 observations of RZ Cep for the same reason.

Details regarding the properties of the comparison stars, taken from the SIMBAD astronomical database, are shown in Table 5.

4. Results

4.1. Photometric measurements

Our photometric measurements for DH Peg, DY Peg, and RZ Cep are now available in the AAVSO International Database (AAVSO 2014). All uploaded measurements can be found under the observer codes MSAD, PDCA, AIBA, and FSHA.

Table 5. Properties of the comparison stars.

Name	*Type*	*R.A, (J2000) h m s*	*Dec. (J2000) o ' "*	*Apparent Mag. (Visual filter)*
TYC 565-1155-1	DH Peg Comparison Star 1	22 15 35.426	+06 53 28.32	10.08
BD+06 4987	DH Peg Check Star	22 15 00.980	+06 54 29.29	9.90
BD+16 4876	DY Peg Comparison Star 1	23 08 44.272	+17 18 18.86	11.0
GSC 01712-00542	DY Peg Comparison Star 2	23 08 51.53	+17 10 49.1	11.70
GSC 01712-01246	DY Peg Check Star	23 08 40.56	+17 08 14.4	11.10
TYC 4273-435-1	RZ Cep Comparison Star 1	22 39 19.125	+64 52 07.99	12.02
TYC 4273-1351-1	RZ Cep Comparison Star 2	22 39 46.798	+64 50 42.27	12.03
TYC 4273-659-1	RZ Cep Check Star	22 40 05.439	+64 57 18.97	10.84

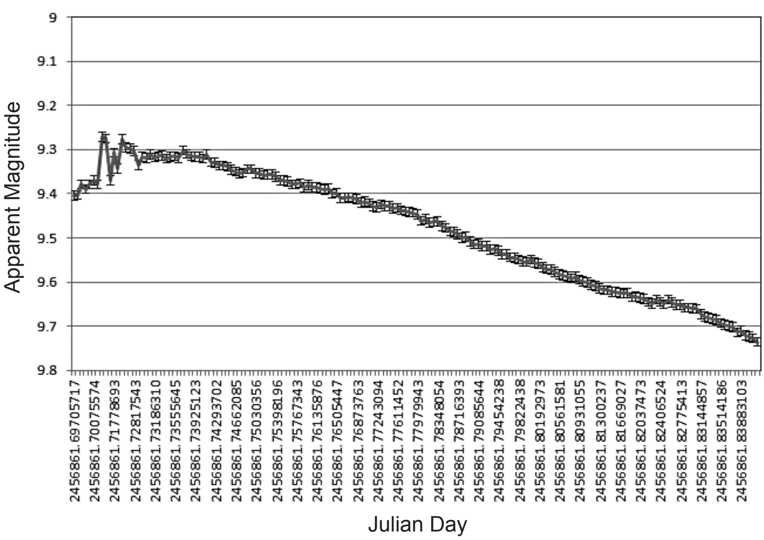

Figure 1. The authors' light curve for the RRC variable DH Peg.

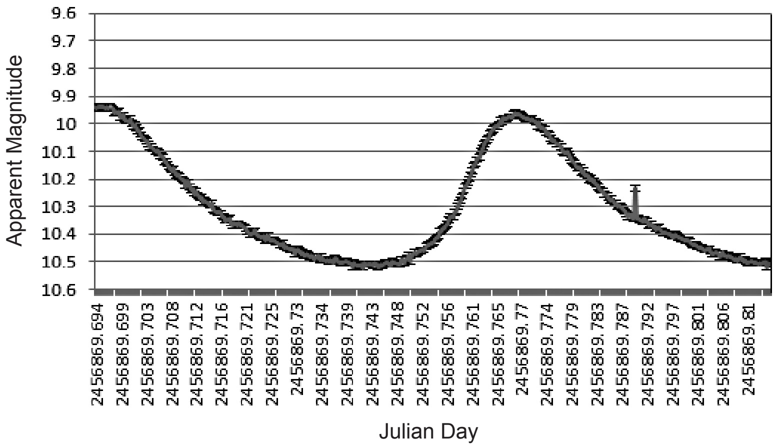

Figure 2.The authors' light curve for the SX Phe variable DY Peg.

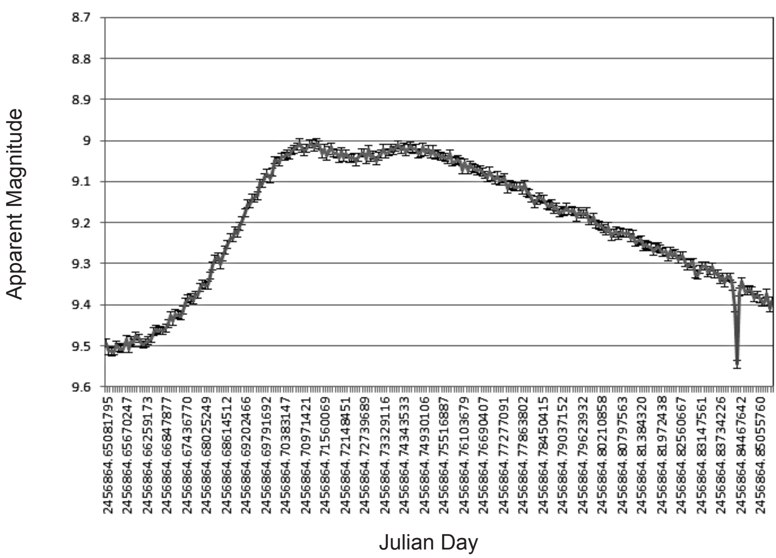

Figure 3. The authors' light curve for the RRC variable RZ Cep.

4.2. Light curves of the stars

The authors' light curves of the stars are shown in Figure 1 (DH Peg), Figure 2 (DY Peg), and Figure 3 (RZ Cep).

Note that in Figure 1, the first part of the light curve has a relatively erratic behavior. This is a result of a lack of valid data caused by cloud coverage at the time. In addition to this, there are also some inconsistencies seen in the other light curves. For example, the light curve for DY Peg has a sudden peak. After some thought, we concluded this to be a result of cosmic ray interference. Additionally, there is a dip towards the end of the light curve for RZ Cep. We are uncertain of the cause of this dip.

Aside from these few inconsistencies, our light curves follow a very nice trend. The light curve of RZ Cep has a clearly pronounced hump as described by Hopp (1981) and Tifft (1964) as characteristic of RR Lyrae variable stars. This hump is also expected with the light curve of DH Peg. Unfortunately, we experienced heavy cloud coverage during this period of time, leading to the erratic behavior described here and seen in the light curve.

4.3. Epoch comparison

Similar to the method Hopp (1981) used for RR Lyrae variable stars, we consider the epoch to be the maximum magnitude after the initial hump for DH Peg and RZ Cep. The epoch of DY Peg is simply the maximum magnitude. The observed epochs for each of the stars are presented in Table 6.

Table 6. Observed epochs.

Name	*Observed Epoch (JD)*
DH Peg	2456861.7200
DY Peg	2456869.7728
RZ Cep	2456864.7434

To validate the accuracy of our observed epochs we tested them against the predicted epoch of the stars. Note that with all the calculations in this section we assume that the periods of the stars stay constant.

We can use the modulo of the difference between our observed epochs and previously published epochs, with the period to calculate the difference between the predicted epoch and the observed ones. Since the function gives the difference, the output (ideally) should be very close to 0. This "modulo" function is described as:

$$\text{(Previously Published Epoch} - \text{Observed Epoch) mod (Published Period)} \quad (1)$$

Values returned by the modulo function are presented in Table 7.

Table 7. Modulo Function values.

Name	*Observed Epoch (JD)*	*Previously Published Epoch (JD)*	*Published Period*	*Modulo Function*
DH Peg	2456861.7200	2444463.571	0.25551040	0.01786673
DY Peg	2456869.7728	2444502.07044	0.072926297	0.014222824
RZ Cep	2456864.7434	2442635.374	0.3086853	0.09683877

Using the output of the modulo function, we found the number of cycles of fluctuation since the last observed epoch. This was found by using the cycle function described as:

$$(\text{Observed Epoch} \pm \text{Modulo Function Result}) - \text{Previously Published Epoch}) / \text{Published Period}) = \text{Cycle} \in \mathrm{N} \qquad (2)$$

This function must return a natural value because the number of times the function reaches the same point must be a positive whole number. Any result that does not satisfy this condition is considered erroneous. Therefore, the cycle function should return only one correct result despite the plus-minus operator.

To find the epoch predicted by previously published data, we used the following function:

$$\text{Predicted Epoch} = \text{Previously Published Epoch} + \text{Period} \times \text{Cycle} \qquad (3)$$

Values returned by the above function are presented in Table 8.

Table 8: Epoch Comparison. The predicted epoch was found by the Equation (3). The number of cycles was found by Equation (2).

Name	*Previously Publ. Epoch (JD)*	*Cycles Since Publ. Epoch*	*Predicted Epoch (JD)*	*Observed Epoch (JD)*
DH Peg	2444463.571	48523	2456861.7021	2456861.7200
DY Peg	2444502.07044	169592	2456869.7870	2456869.7728
RZ Cep	2442635.374	46097	2456864.8402	2456864.7434

4.4. Functions for epoch prediction

Using the above data, definitions, and functions, we can conclude that the general function for epoch prediction is described as:

$$\text{Predicted Epoch} = \text{Observed Epoch} + \text{Period} \times \text{Cycle} \qquad (4)$$

Where Predicted Epoch is returned in Julian Date and Cycle is the output of the cycle function described in section 4.3.

Assuming periods are constant, we present the following functions for DH Peg, DY Peg, and RZ Cep:

$$\text{DH Peg} = 2456861.72000593 + 0.2555104 \times \text{Cycle} \tag{5}$$

$$\text{DY Peg} = 2456869.77277800 + 0.072926297 \times \text{Cycle} \tag{6}$$

$$\text{RZ Cep} = 2456864.74343533 + 0.3086853 \times \text{Cycle} \tag{7}$$

4.5. Apparent magnitude range

From the photometric measurements collected during this research, we can find both the maximum and minimum magnitude of each star. A comparison of the values we found and previously published values is presented in Table 9.

Table 9. Apparent magnitude range.

Name	*Observed Min. Mag.*	*Observed Max. Mag.*	*Published Min. Mag.*	*Published Max. Mag.*
DH Peg	9.736	9.272	9.8	9.15
DY Peg	10.522	9.938	10.56	10.00
RZ Cep	9.545	9.006	9.72	9.15

4.6 Period of DY Peg

We did not determine the period of DH Peg and RZ Cep because we were not able to collect enough data to complete one whole period fluctuation in brightness of these stars. As a result, any period calculation is impossible. However for DY Peg, we collected sufficient data and were able to calculate its period as:

$$\text{period} = \text{Time at Epoch 2} - \text{Time at Epoch 1} \tag{8}$$

$$\text{period}_{\text{DY Peg}} = 2456869.77277800 - 2456869.69509259 = 0.07768541 \tag{9}$$

We calculated the period of DY Peg to be 0.07768541 day. When compared with previously published data from the *General Catalogue of Variable Stars* (GCVS; Samus *et al.* 2007–2012), 0.072926297 day, our value differs by only 0.00475912 day (6.8531328 minutes).

5. Conclusion

We were able to use the data collected from the photometric measurements described above to derive light curves, epochs, and magnitude ranges of DH Peg, DY Peg, and RZ Cep. We were also able to calculate the epoch-prediction function of all the stars and derive the period of DY Peg. Our observed measurements are in accordance with previously published data from Hopp (1981), Tifft (1964), Oja (2011), and Hardie and Geilker (1958). In order to glean more information, measurements of these stars would need to be conducted over a longer period of time and with minimal weather interference.

6. Acknowledgements

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This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France, and the International Variable Star Index (VSX), operated by the AAVSO.

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