Changing Periods of ST Puppis

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Abstract ST Puppis is a reasonably bright W Virginis variable star, a Type 2 Cepheid with a record of substantial and erratic period changes—21 during the interval 1900 to 1985 with a range of magnitude from 17.4 to 19.2 days. It was observed as part of Variable Stars South's Cepheid project by Butterworth in 2014 and 2015 using DSLR photometry in BGR passbands and visually by Pearce in 2015. The known period changes are shown graphically and doubtful ones examined and discarded if necessary. With its period and amplitude with a frequently changing period it is a suitable and worthwhile object for visual observing.

1. Introduction

Variable Stars South has a project involving measures of bright southern Cepheids. Details of this may be found at http://www.variablestarssouth.org/BrightCepheidsVisual and http://www.variablestarssouth.org/BrightCepheidsDSLR. It involves fitting of seasonal measures of selected Cepheids to mean light curves to determine annual epochs. At intervals of 5 or 10 years more comprehensive measures will continue to be made to look for shape or color changes in the light curve.

Mean light curves are prepared from high quality data, in the case of ST Pup from Kilkenny *et al.* (1993), and good epochs can be obtained by fitting 15 to 20 DSLR measures in V, or 25 to 35 visual measures made using a very precise comparison sequence.

Our project has mainly been restricted to classical Cepheids but Butterworth decided to measure ST Pup in 2014 as a test of the limits of his system—a Canon 550D DSLR camera using a 135mm f2.0 lens on a Sky-Watcher altazimuth mount producing fully transformed BVR measures.

2. Historical background

Most of these bright Cepheids have a lengthy baseline of measures which is largely part of the reason for observing current behavior. ST Pup, which is a W Virginis star, is no exception and the GCVS (Kholopov *et al.* 1985) lists 21 different periods in the interval ranging back to 1900. The original fit of the DSLR measures was disappointing, but not unexpected given the erratic period and perhaps light curve variations of this Cepheid subtype. Summer of 2015 in Queensland was particularly cloudy and a visual observer, Pearce, was called in to gather enough data to determine a current epoch and period.

We began by collecting as many published measures as we could. UBV measures date from about the year 1954 but many observers made only a few, perhaps 5 to 20 measures in a season, and epochs of maxima are difficult to determine. The main sources were Irwin (1961), Mitchell *et al.* (1964), Eggen (1986), ASAS3 (Pojmański 2002), and Berdnikov (2008). From all of these we produced the O–C diagram of Figure 1.

The cycle numbers are rather uncertain and in many cases were determined from visual measures in the AAVSO

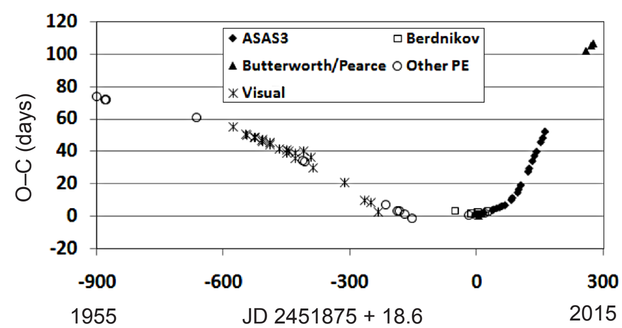

Figure 1. The O–C diagram of ST Puppis since 1955. The vertical scale shows days late (+) or early (–) as compared to the given ephemeris. This clearly shows major changes in period but the uncertainty of the cycle count makes it probably inaccurate for the first 300 cycles. The value of the visual measures from the AAVSO International Database is quite clear, although the accuracy of those epochs is probably ± 2 days at best.

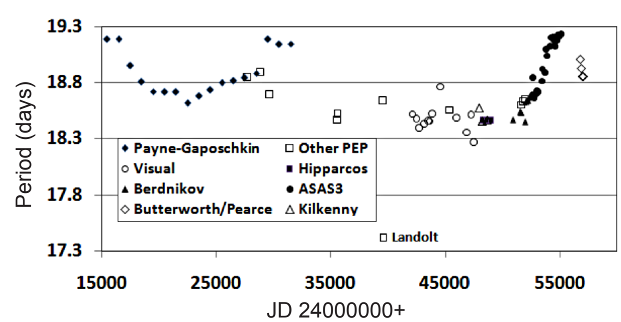

Figure 2. ST Pup periodogram showing the period variations in a more informative manner. The uncertainty of cycle counts is overcome but many photoelectric measures could not be used as they were too few to determine reliable periods. Landolt's measure is separately identified.

International Database (AID; Kafka 2015) using a process of inspection for maxima. Prior to 1955 there are not enough available data. Because of these factors we then produced the periodogram of Figure 2, a better way of tracing and displaying the large period variations of this star.

Periods have been determined by taking two successive epochs of maximum and dividing by the apparent number of cycles between the two. In the case of the periods determined by Payne-Gaposchkin (1950), her values have been accepted and the JD located at the center of each interval. In all cases MJD has been used based on JD –2400000.

This shows some interesting aspects. Three times the period appears to have peaked at ~19.2 days, although that of JD 2430000–2432000 conflicts with other measures. As well, there is a single period derived by Landolt (1971) which does not fit well. We examined these points in detail.

Landolt (1971) discussed the derivation of this period and epoch. It is based upon 21 measures covering 1.3 cycles. Marino (1971), in a discussion of RS Col, compared all-sky measures by Bond and Landolt (1969) to the light curve obtained at Auckland Observatory and estimated their errors at ±0.02 to 0.04 in V. If these uncertainties are similar for ST Pup, the data are far too inaccurate to use the method adopted by Landolt in arriving at his period. In Figure 3 we show that a period of 18.5 days produces a more likely looking light curve for this star. Whilst some data points of the two different cycles coincide better with the shorter period the initial decline is pinched in and abnormal. This period has not been included in Figure 4 as we believe that there are insufficient measures to determine an accurate value.

The other ill-fitting data points were determined by Payne-Gaposhkin (1950) by fitting cycles to 1,000-day intervals. Her data were not published, but presumably they were sparse and photographic in nature. By adding one cycle in each of the last three of the intervals a better fit is obtained. We have no proof that this correction is valid and since this is merely an assumption both sets are included in Figure 4.

This amended periodogram shows an abrupt decline from the originally observed period of ~19.2 days with a slow and erratic decline to ~18.46 days. The visual determinations in this context are low weight. Beginning about 1999 the period began to lengthen quite sharply, reaching a probable peak around 2011 before the present reversal to a shorter period began (Figure 5).

3. Other physical aspects

Gonzalez and Wallerstein (1996) examined ST Pup in detail spectroscopically and concluded that it was a binary system with a period of 410.4±2.9 days. It has some spectral peculiarities. The orbital eccentricity is low, which appears to rule out any possibility of interaction causing the dramatic period changes. But Kiss *et al.* (2007), looking for possible reasons for the very erratic period, suggested a period of 18.4298 days was likely during the period of the Gonzalez and Wallerstein (1996) measures. Kiss *et al.* proposed an orbital period of 25.67 days and some probable interaction. The suggested pulsation period seems strongly based on the Landolt period but periods shown

Table 1. Table of orbital periods of ST Pup during the interval JD 2447362–2449741 obtained by dividing intervals by number of epochs.

Epoch (start-end) JD 2400000+	*Source*	*Orbital Period (d)*
47846–48363	Perryman *et al.* (1997)	18.46107
48456–48696	Perryman *et al.* (1997)	18.46098
48696–49028	Perryman *et al.* (1997)	18.46102
47939–48252	Kilkenny *et al.* (1993)	18.45724
48252–48640	Kilkenny *et al.* (1993)	18.46704
48640–50911	Kilkenny *et al.* (1993) / Berdnikov (2008)	18.46497

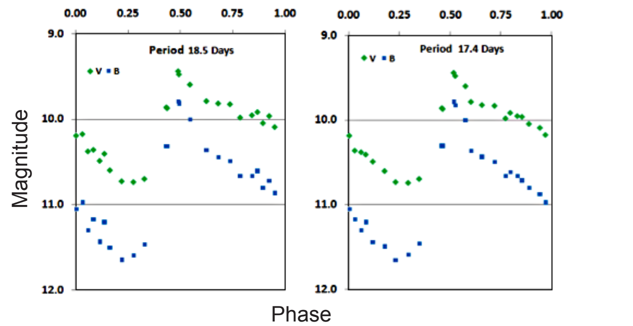

Figure 3. Two treatments of the measures of ST Pup by Landolt (1971). On the right the data are phased using his period of 17.4 days, on the left the same data with a period of 18.5 days, which seems more likely in view of other measures near that time. The left curve looks similar to other measures of this star; that on the right shows a very pinched maximum and a strange step in the early stages of the decline. The decline in other observers' data does have a shoulder but it does not appear like the right-hand graph.

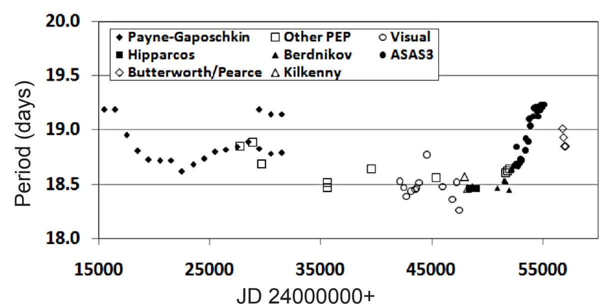

Figure 4. Same data as Figure 2 but with the Landolt epoch omitted and two alternative positions for Payne-Gaposchkin's (1950) last three intervals.

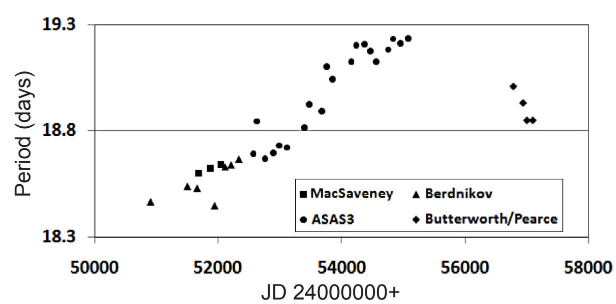

Figure 5. ST Pup period changes since 1999. We hope to add further points over the next year or two.

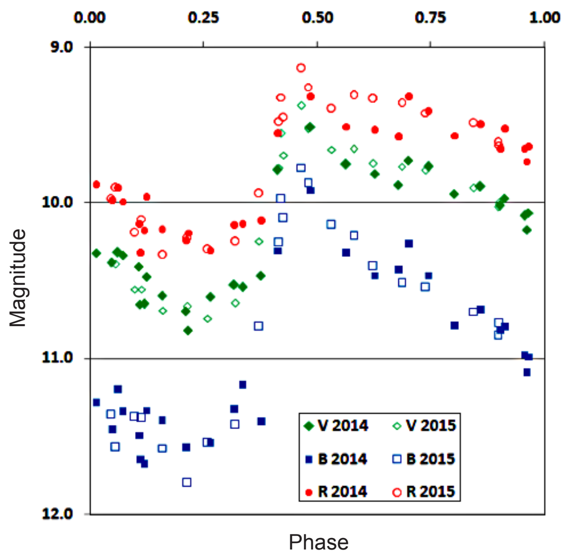

Figure 6. Butterworth DSLR measures of ST Pup for the 2014 and 2015 seasons. Solid points are 2014, open points 2015. This star is rather too faint for the camera set-up described and cycle 7 further complicated by the period change between the two seasons. The phases shown are from two arbitrary epochs offset by ~0.5 cycle.

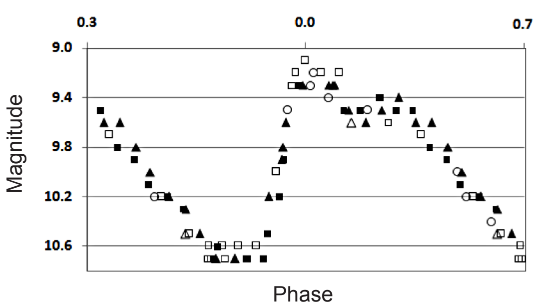

Figure 7. Pearce visual measures of ST Pup over 6 cycles during the 2015 season. The data illustrate that with a large amplitude Cepheid visual measures are quite capable of determining a seasonal epoch. We are now providing visual comparison stars with two decimal accuracy and average sequence steps of 0.2 magnitude.

in Table 1 appear to preclude such an interpolation.

ST Pup is noted by Welch (2012) as one of five known Type 2 Cepheid binaries in the Milky Way Galaxy. It has by far the longest pulsation period of these binary stars and the Gonzalez and Wallerstein orbital period (1996) is also much greater than the others. Eggen (1986) had earlier drawn attention to this star as an important "anomalous" Cepheid. There are, of course, longer period Type 2 Cepheids not in binary systems and our range of targets will be extended to include these.

4. Ongoing measures

In Figures 6 and 7 we present measures made in 2014 and 2015. During this interval the period was changing quite quickly. The two seasons of measures by Butterworth are fitted by a period of 18.905, while the measures in 2015 by Pearce show a best fit of 18.85 days. The measures are listed in Tables 2 and 3.

Table 2. DSLR measures of ST Pup made by Neil Butterworth transformed into V, B–V, V–R, with error values.

HJD 2400000+	*V*	*B–V*	*V–R*	*V Error*	*B–V Error*	*V–R Error*
56663.93741	9.752	0.568	0.242	0.052	0.049	0.031
56702.91874	9.815	0.652	0.285	0.055	0.045	0.035
56703.91879	9.888	0.538	0.315	0.052	0.032	0.048
56710.90736	10.380	1.073	0.400	0.048	0.045	0.041
56730.92974	10.412	1.080	0.280	0.064	0.073	0.067
56731.89251	10.594	0.800	0.425	0.055	0.050	0.046
56732.89412	10.695	0.874	0.456	0.058	0.066	0.041
56733.89003	10.604	0.937	0.302	0.052	0.038	0.047
56734.90317	10.528	0.796	0.388	0.060	0.047	0.043
56749.89053	10.656	0.993	0.339	0.048	0.052	0.057
56751.88007	10.821	1.226	0.627	0.056	0.055	0.049
56754.90878	10.467	0.935	0.355	0.053	0.041	0.048
56761.87745	9.767	0.700	0.359	0.047	0.041	0.044
56764.87466	10.019	0.794	0.368	0.051	0.043	0.038
56765.87718	10.083	0.892	0.431	0.054	0.044	0.037
56767.87732	10.321	0.872	0.419	0.046	0.038	0.032
56775.88248	9.514	0.406	0.202	0.046	0.040	0.059
56781.86953	9.943	0.843	0.374	0.051	0.059	0.030
56784.86954	10.171	0.915	0.438	0.054	0.058	0.038
56785.86669	10.322	0.959	0.443	0.052	0.049	0.055
56787.86479	10.650	1.027	0.477	0.057	0.083	0.049
56798.86831	9.728	0.531	0.412	0.053	0.049	0.059
56801.85731	9.896	0.787	0.401	0.055	0.053	0.031
56802.86197	9.971	0.822	0.450	0.049	0.049	0.037
56803.86318	10.063	0.928	0.424	0.050	0.043	0.023
56805.88077	10.336	1.001	0.343	0.057	0.049	0.048
56806.86364	10.472	0.863	0.513	0.053	0.056	0.035
56810.86080	10.543	0.624	0.410	0.051	0.050	0.052
57095.89551	9.789	0.518	0.239	0.034	0.049	0.014
57096.89665	9.374	0.398	0.234	0.037	0.037	0.015
57099.89717	9.747	0.660	0.414	0.038	0.035	0.015
57107.89168	10.385	0.980	0.409	0.037	0.034	0.017
57108.89140	10.555	0.824	0.360	0.039	0.043	0.024
57111.89848	10.743	0.802	0.441	0.036	0.028	0.022
57114.88384	9.774	0.482	0.290	0.039	0.038	0.024
57133.86952	9.555	0.421	0.233	0.037	0.027	0.017
57136.87180	9.654	0.559	0.346	0.036	0.033	0.020
57138.87561	9.767	0.747	0.405	0.037	0.035	0.022
57139.86880	9.790	0.757	0.369	0.035	0.024	0.025
57141.86835	9.906	0.794	0.417	0.035	0.026	0.030
57142.87511	10.028	0.824	0.418	0.036	0.038	0.028
57145.88177	10.395	1.176	0.491	0.038	0.030	0.025
57147.86441	10.692	0.884	0.356	0.037	0.028	0.020
57148.86540	10.669	1.133	0.439	0.039	0.038	0.020
57150.86718	10.646	0.781	0.397	0.038	0.027	0.024
57151.86392	10.247	0.547	0.304	0.038	0.017	0.017
57152.87494	9.694	0.405	0.238	0.037	0.024	0.017
57153.87241	9.524	0.352	0.267	0.036	0.028	0.024
57154.87649	9.659	0.484	0.264	0.042	0.034	0.019
57161.86713	9.997	0.778	0.367	0.044	0.020	0.016
57165.85940	10.556	0.831	0.452	0.038	0.033	0.019

5. Conclusions

While ST Pup is an interesting star, the period changes show no predictability, and our future observing will be along the lines discussed in the introduction. It is probably too faint for DSLR photometry except through a telescope, but would reward a season's observing at intervals by CCD BVRI photometry. Quite clearly, competent visual observers in the bright Cepheid project are capable of producing good seasonal light curves and epochs of maximum.

Table 3. Visual measures of ST Pup made by Andrew Pearce.

JD	Magnitude	JD	Magnitude
2456976.2694	10.4	2457030.23889	9.8
2456985.2778	9.4	2457031.0938	10.0
2456993.1097	10.0	2457032.2271	10.2
2456999.0986	10.7	2457033.2201	10.3
2457000.0903	10.6	2457034.0924	10.5
2457001.0896	10.2	2457035.0840	10.7
2457002.05000	9.4	2457036.2319	10.7
2457003.0549	9.3	2457038.2500	10.2
2457003.2389	9.2	2457039.0319	9.9
2457005.0632	9.5	2457039.1201	9.8
2457006.0569	9.5	2457039.2917	9.6
2457007.2278	9.4	2457040.2896	9.3
2457007.2611	9.4	2457042.2271	9.3
2457008.2271	9.5	2457043.2424	9.6
2457009.2319	9.5	2457052.0535	10.5
2457010.2563	9.8	2457063.0674	9.5
2457011.2833	9.9	2457069.0632	10.2
2457012.1146	10.1	2457077.0611	9.5
2457013.2458	10.2	2457090.0222	10.5
2457014.2396	10.3	2457091.0792	10.7
2457016.0389	10.7	2457092.0194	10.6
2457016.2660	10.6	2457092.98333	10.6
2457018.0229	10.7	2457094.07639	10.6
2457018.0819	10.7	2457097.02569	9.1
2457019.0507	10.7	2457097.99236	9.2
2457019.2896	10.5	2457099.03264	9.2
2457020.0285	10.2	2457101.9986	9.6
2457020.2986	9.9	2457104.0278	9.7
2457021.2465	9.3	2457109.9806	10.6
2457023.0403	9.3	2457111.0264	10.7
2457023.2660	9.3	2457126.0264	10.2
2457024.2257	9.5	2457128.9667	10.7
2457025.2444	9.6	2457132.9861	10.0
2457026.2243	9.5	2457133.9542	9.3
2457027.26250	9.4	2457134.0819	9.2
2457028.27639	9.6	2457134.9444	9.2
2457029.24931	9.6	2457135.0813	9.2

A strong reason for measuring Cepheids and following period changes is the frequency with which they occur. The classical pulsating targets for visual observers are the large amplitude Mira stars but a perusal of the results suggests that true period changes—such as with R Hya, R Aql, and the dual maxima stars BH Cru and R Cen—occur at a rate of approximately 1% of the target stars per century. Period changes in the longer period Cepheids, >10 days, occur perhaps 10 times more frequently and have amplitudes suited to capable visual observers.

6. Acknowledgements

Several members of the AAVSO contributed visual measures for the old AAVSO Cepheid section, including, Tom Cragg, C. Patrick Mahnkey, Robert B. Ariail, and Paul Goodwin. Their measures filled in a large time gap effectively. The International Database operated by the AAVSO was invaluable there. Our thanks also to Orlon Petterson who searched out MacSaveney's doctoral thesis (2003) and measures. One of us, Walker, also wishes to remember the late Tom Cragg who, in 1984, persuaded a group at Auckland to make UBV measures of these stars but not, unfortunately, ST Pup.

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