New Observations of the Am Star BP Octantis

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Abstract New observations are presented and analyzed for the Am star BP Oct. While a previously reported period of ~3 days cannot be unequivocally confirmed or dismissed, evidence is mounting that BP Oct is a binary and thus typical of Am stars. As light variations reported for BP Oct are no more than 0.03 magnitude, attempts to confirm or dismiss such variations remain challenging.

1. Introduction

Controversy has surrounded the variability of the Am star BP Oct (HR 5491) since Bessell and Eggen (1972) first reported a visual light range of around 0.03 magnitude with a period of about 0.08 day. Breger *et al.* (1972) observed BP Oct soon after but found no evidence of short-period variability in their one night of data. From the spectrum they confirmed that it was a classical Am star near the main sequence; additionally, they noted that there was no indication of spectral variation. When Eggen (1973) re-observed BP Oct he found it constant in light and so suggested its oscillations were multi-periodic, being at a low-amplitude phase at the time he re-observed it.

Coates *et al.* (1982) observed BP Oct on 15 nights during a period spanning more than 100 days, accumulating 95 measurements in total. There was no sign of short-period variability (<0.3 day) in the data, indicating it is unlikely that BP Oct undergoes short-period oscillations greater than 0.01 magnitude in amplitude. There was, however, an indication of a possible 3-day variation of a little under 0.03 magnitude amplitude in V-band suggesting BP Oct is a binary. This would be consistent with observations that most, if not all, Am stars are members of binary systems (Eggen 1995; Smith 1996; Debernardi 2000). As the observations were made at two different sites with different equipment (Moon 1984), the two sets of observations were analyzed both as individual and combined datasets with appropriate corrections made for atmospheric extinction. Small differences that might arise from applying color corrections to the data (taken by the two different systems) were considered, noting that, while the comparison stars varied significantly in their colors, they did not show a similar variation to that observed for BP Oct. Color corrections alone would not account for the magnitude of the variations observed. A combined uncertainty of at least 0.01 magnitude, however, remains. Importantly, such an uncertainty significantly affects the estimated period for the small amplitude suggested.

Soon after, radial velocity measurements were attempted for different estimated phases (Moon 1984). Unfortunately poor weather and equipment failure resulted in only three usable measurements with a mean of $-7.2 \pm 3.6\,\mathrm{kms}^{-1}$. Gontcharov (2006) lists a mean value of $-14.5 \pm 2.9\,\mathrm{kms}^{-1}$ for BP Oct and Eggen (1998) a value of $-9\,\mathrm{kms}^{-1}$ with a note that it is variable. While listed as a bright star (Hoffleit and Warren 1991), BP Oct is within 2 degrees of the South celestial pole and has not been a popular candidate for long-term monitoring. It is thus not surprising that observations over the intervening years are sparse. New observations, along with an assessment of any other data taken in the intervening years, were thus in order. As an intensive observing program of BP Oct by Coates *et al.* (1982) provided no evidence that its light output varied on the timescale of hours, collection of new observations focused on investigating the reported 3-day variation.

2. Astrophysical significance of checking variability in Am stars

Kurtz (1989) discussed the observed properties of Am stars in the context of the underlying astrophysics at work. From his discussion the following are noted:

- A high proportion of normal A stars in the δ Scuti region (i.e. A stars later than about A2) exhibit oscillations with amplitudes above 0.01 magnitude.

- Most slowly-rotating A-type stars are Am stars.

- For classical Am stars the spectral classification based on the Ca II K-line and that based on metal lines differ by five or more sub-types.

- Most, if not all, classical Am stars are constant in their light output (to within 0.01 magnitude).

- There is strong evidence that the line strength anomalies observed in Am stars are due to atmospheric abundance peculiarities.

- The "diffusion" hypothesis is the prevailing explanation for the differences in the observed properties of Am and normal A-type stars. This hypothesis suggests that in the envelopes of Am stars, where a metal ion with many absorption lines is near its flux maximum, the radiation pressure drives the ion towards the star's surface. Where the absorption lines are not near their flux maximum (or are mostly saturated), those ions sink under their own weight in the layer of surrounding hydrogen. Slow rotation is seen as a

> necessary precursor to such diffusion, the result of which is the observed relative over- and under-abundances of various elements.

The measurement of the light of Am stars, particularly those reported as varying, remains important for understanding the astrophysical mechanisms at play, namely the hypothesized causal links among stellar rotation, diffusion, and pulsation.

3. New observations

3.1. V-band photoelectric photometry

Photometric observations of Am stars present some challenges which largely revolve around seeking to measure their light to an accuracy of 0.01 magnitude or better. These include:

- Precisely measuring and applying color corrections when stars are observed through air masses approaching 2. This is particularly problematic for BP Oct when observing it from latitudes typical of the populated land masses in the southern hemisphere where it will be observed at air masses around 2 all year round.

- Choice of non-variable comparison stars of similar spectral type. A high proportion of normal A-type stars vary by more than 0.01 magnitude, necessitating the choice of later or earlier spectral types for the comparison stars. Color corrections must then be applied but can give rise to greater uncertainties when data from different systems are combined.

- Changes in atmospheric extinction while observing.

- Searching for periodicities in low signal-to-noise data.

As indicated above, the choice of comparison stars for accurately measuring the constancy of the light output of Am stars poses a significant challenge. As a high proportion of normal A stars are variable at a greater than the 0.01 magnitude level, we chose comparison stars that were of a V magnitude similar to BP Oct with one being an earlier spectral type and the other a later type. Table 1 lists the adopted values of V and B–V, spectral type, and the source of those data for the comparison stars we chose. Neither was listed as being variable.

Table 2 presents 89 new V-band photometric measurements taken between 15 January 2004 and 17 November 2010 using the photoelectric photometer, equipment, and techniques described in Otero and Moon (2006). These data were corrected for atmospheric extinction and color corrections applied using coefficients that have been derived separately but shown to be stable for this equipment over the timescale of the observations made.

Table 1. Listed data for comparison stars used for new measurements of BP Oct.

Star	*V*[1]	*B–V*[1]	*Spectral Type*[2]	*Parallax*[2]
HR 6133	6.564	0.900	G4III	5.4 ± 0.38 mas
HIP 60041	6.630	–0.068	B9V	5.33 ± 0.39 mas

Notes: 1. Johnson V and B–V for HR 6133 from the General Catalogue of Photometric Data *(GCPD; Mermilliod* et al. *1997). As HIP 60041 is not listed in the GCPD, the values shown are from the Hipparcos catalogue (ESA 1997). 2. Spectral types and parallaxes from the Hipparcos catalogue (ESA 1997); values of parallax as reprocessed by van Leeuwin (2007).*

Table 2. New Johnson V-band photometry measurements of BP Oct.

Julian Date	*V*	*s. d.*	*Julian Date*	*V*	*s. d.*
2453020.040	6.496	0.005	2454609.915	6.481	0.009
2453022.993	6.490	0.007	2454618.986	6.454	0.002
2453025.008	6.461	0.012	2454632.976	6.465	0.011
2453026.991	6.496	0.010	2454641.940	6.475	0.004
2453028.988	6.493	0.003	2454659.974	6.484	0.006
2453031.008	6.488	0.008	2454674.911	6.484	0.009
2453031.989	6.480	0.009	2454713.981	6.437	0.009
2453034.983	6.495	0.007	2454728.010	6.484	0.005
2453046.994	6.519	0.01	2454741.992	6.539	0.006
2453047.973	6.486	0.011	2454747.997	6.499	0.011
2453053.983	6.490	0.016	2454755.001	6.506	0.006
2454462.017	6.486	0.006	2454769.966	6.451	0.012
2454467.010	6.477	0.009	2454816.006	6.464	0.007
2454478.995	6.490	0.014	2454818.002	6.472	0.011
2454482.988	6.477	0.008	2454834.010	6.468	0.012
2454489.993	6.476	0.005	2454845.004	6.469	0.011
2454493.995	6.522	0.006	2455112.943	6.504	0.008
2454496.998	6.486	0.009	2455122.978	6.482	0.007
2454503.996	6.484	0.008	2455125.953	6.472	0.004
2454507.989	6.504	0.014	2455131.980	6.448	0.014
2454520.983	6.438	0.011	2455245.986	6.497	0.005
2454521.992	6.476	0.006	2455249.990	6.460	0.007
2454541.965	6.476	0.012	2455250.997	6.481	0.009
2454549.944	6.489	0.006	2455256.992	6.472	0.006
2454571.000	6.477	0.007	2455257.979	6.481	0.010
2454571.990	6.494	0.007	2455258.961	6.464	0.005
2454573.969	6.484	0.004	2455265.955	6.467	0.006
2454574.932	6.479	0.009	2455270.942	6.468	0.006
2454595.977	6.465	0.011	2455274.962	6.479	0.008

Table continued on next page

Table 2. New Johnson V-band photometry measurements of BP Oct, cont.

Julian Date	*V*	*s. d.*	*Julian Date*	*V*	*s. d.*
2455276.933	6.496	0.008	2455379.912	6.471	0.005
2455277.980	6.464	0.007	2455382.902	6.450	0.004
2455278.929	6.465	0.004	2455401.989	6.484	0.006
2455285.942	6.475	0.011	2455402.918	6.480	0.007
2455297.931	6.466	0.011	2455437.957	6.485	0.005
2455298.967	6.494	0.005	2455447.969	6.492	0.007
2455300.914	6.470	0.005	2455464.988	6.460	0.007
2455308.006	6.495	0.004	2455474.922	6.485	0.006
2455324.992	6.470	0.007	2455477.940	6.501	0.003
2455325.961	6.473	0.007	2455489.991	6.494	0.005
2455329.967	6.502	0.002	2455493.952	6.479	0.008
2455337.910	6.482	0.005	2455494.972	6.454	0.004
2455349.930	6.463	0.007	2455504.990	6.478	0.009
2455350.966	6.522	0.015	2455505.957	6.484	0.008
2455361.921	6.474	0.005	2455517.981	6.467	0.007
2455374.006	6.477	0.006			

3.2. Radial velocity measurements

As only three useable Radial Velocity (RV) measurements were obtained in 1983 an attempt was made by one of us (JI) to obtain further measurements. Table 3 presents these unpublished RV data measurements including the three taken in 1983.

The RV observations from the mid-1980s (i.e. all but the last two entries in the table) were obtained with the Cassegrain echelle spectrograph on the 1.0-m Siding Spring reflector. Typically, exposures were made in the 5000- to 7000-Ångstrom region, and were usually around 2,000 seconds in duration. The resolution (two detector elements) was near 0.2 Ångstrom. Counts in the continuum pixels were around 200 to 1,000 depending on seeing and weather conditions. Velocity data were derived via digital cross-correlation of spectra of radial velocity standard stars, using the Mt. Stromlo PANDORA data-reduction package. Estimated total errors (statistical and systematic) are likely of the order ± 5 $\mathrm{kms^{-1}}$ for a given measurement.

The two most recent measurements were obtained through the UCLES (University College London Echelle Spectrograph) service observing program of the Anglo-Australian Telescope. Data reduction was carried out with the NOAO IRAF package, again via cross-correlation with spectra of radial velocity standard stars. Each measurement of these two recent data points represents the mean of three successive high signal-to-noise ratio exposures. Ten echelle orders in each spectrum were used. Internal errors are on the order of 0.4 $\mathrm{kms^{-1}}$. External errors are likely to be on the order 2 $\mathrm{kms^{-1}}$ or less.

Table 3. Previously unpublished radial velocity measurements of BP Oct.

HJD	$RV_\odot$ *(km/s)*	*HJD*	$RV_\odot$ *(km/s)*
2445509.973	–7.2	2445986.229	–16.3
2445566.939	–8.8	2446103.259	–7.8
2445568.072	–5.5	2446105.259	–10.3
2445928.018	–30.3	2446106.249	–21.1
2445981.187	–14.0	2446107.236	–26.0
2445982.145	–16.2	2446108.269	–24.9
2445984.229	–21.6	2452625.068	–26.0
2445985.229	–17.6	2452838.862	–26.9

While the data are consistent with previous published values (Gontcharov 2006; Eggen 1998), and clearly show some variation, we feel they are insufficient to determine periodicity.

4. Analyses

In addition to the new observations discussed above, we are aware of the following photometric datasets for BP Oct that have become available since the observations by Coates *et al.* (1982):

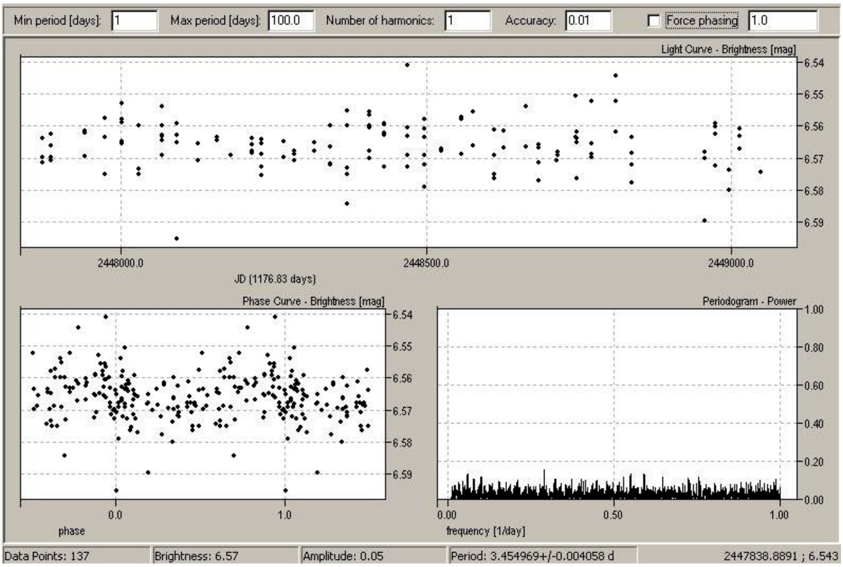
1. Hipparcos, HJD 2447871 to 2449048 (ESA 1997)

2. Tycho, HJD 2447871 to 2449014 (ESA 1997)

3. ASAS-3, HJD 2452439 to 2455111 (Pojmański and Maciejewski 2004)

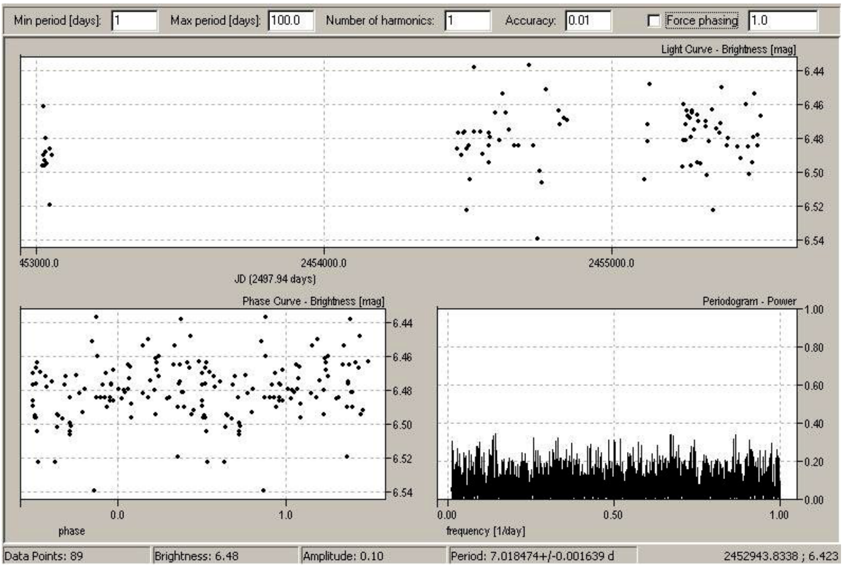
The Tycho and ASAS-3 datasets have typical standard errors greater than the variation reported for this star so they were not considered for detailed period-search analysis. Standard errors were, however, generally less than 0.01 magnitude for Hipparcos data thus a period-search analysis was undertaken using the software PERSEA (Maciejewski 2005). The data downloaded were Hp magnitudes. As our focus was on looking for periodicities in the data, these were not corrected to V magnitudes. In the screen capture of the analysis of the Hipparcos data shown in Figure 1 there are no predominant peaks in the power spectrum over an interval of 1 to 100 days. PERSEA applies weightings relative to the standard error of each photometric measurement and also searches for the most significant periodicity in the data. Interestingly, PERSEA returned a "most significant" periodicity of around 3.5 days for these data. While the associated peak in the periodogram of Figure 1 is sharp and clearly visible, its power level is barely above a S/N of 2. Consequently we could not claim it to be significant with a degree of confidence.

Figure 2 gives a screen capture of the analysis and all the new observations given in Table 2 using PERSEA. As there was a significant gap in the observations


Min period [days]: 1
Max period [days]: 100.0
Number of harmonics: 1
Accuracy: 0.01
☐ Force phasing 1.0

Data Points: 137
Brightness: 6.57
Amplitude: 0.05
Period: 3.454969+/-0.004058 d
2447838.8891 ; 6.543

Figure 1. Screen capture of the analysis, using PERSEA, of the Hipparcos data for BP Oct. The periodogram is at bottom left.


Min period [days]: 1
Max period [days]: 100.0
Number of harmonics: 1
Accuracy: 0.01
☐ Force phasing 1.0

Data Points: 89
Brightness: 6.48
Amplitude: 0.10
Period: 7.018474+/-0.001639 d
2452943.8338 ; 6.423

Figure 2. Screen capture of the analysis, using PERSEA, of BP Oct data taken at Blakeview.

between HJD 2453054 and 2454462 we also ran the software using only the data points collected after this gap. For both analyses we searched for periods from 1 to 100 days. Again there were no predominant peaks in the periodogram but interestingly PERSEA identified a "most significant" periodicity of 7 days; twice that for the Hipparcos data. For the periodogram of Figure 2 there is strong aliasing from the uneven distribution in the times the data were collected. The associated peak is thus less clearly defined than for the Hipparcos data and, with a S/N of barely 2, again we could not claim the period to be significant with any degree of confidence.

Period-search analyses were also undertaken on:

- Observations of the comparison star, HIP 60041, taken concurrently with the new observations of BP Oct
- Hipparcos data for HIP 60041

Neither analysis indicated any significant periodicities from 1 to 100 days.

Using the V magnitude for the first comparison star, HR 6133, as listed in the *General Catalogue of Photometric Data* (GCPD; Mermilliod *et al.* 1997; see Table 1), the mean magnitude for the second comparison star, HIP 60041, was calculated to be 6.624 ± 0.014. This value provides a precise reference for further measurements of BP Oct. The mean magnitude for the 89 measurements of BP Oct was calculated to be 6.480 ± 0.018, consistent with the value given in the GCPD.

5. Discussion

The entry for BP Oct in the *General Catalogue of Ap and Am Stars* (Renson and Manfroid 2009) lists its K line as indicating spectral class A3 and its metallic lines F2. This is consistent with a spectral type of A2mA7-F2 listed by Skiff (2009). It has been well established (Smith 1996; Koen *et al.* 1999; Debernardi 2000) that Am stars have low rotational velocities (vsini ≤ 100 kms^{-1}). Also, there is very little overlap in the vsini distributions of normal A and Am stars, which supports the hypothesis of slow rotation being a pre-condition for diffusion (Smith 1996), the result of which is the observed over- and under- abundance of metals that are characteristic of the spectra of Am stars. Głębocki and Gnaciński (2005) list a rotational velocity for BP Oct of 85.6 ± 1.0 kms^{-1}, which is within the range of vsini measured for Am stars. The classical Am status of this star is thus not at issue.

Both Eggen (1995) and Smith (1996) note the high incidence of spectroscopic binaries among Am stars. Debernardi (2000) confirms this noting a range of periods from 0.77 to more than 1,000 days and the link to slow rotational velocities. Furthermore, in a study of 19 Am stars in the Praesepe and Hyades clusters, Debernardi *et al.* (2000) found that only two have no evidence of radial-velocity variations. This predominance of binarity in Am stars continues to be seen as explaining the reason for slow rotation of many Am stars, a binary companion providing a rotational "braking mechanism." Slow rotation then permits the onset of diffusion in the stellar envelope, resulting in observed over- and under-abundances of the specific elements that give rise to a star being categorized as Am.

Since the Hipparcos mission, a new method of detecting binaries has been developed (Wielen *et al.* 1999; Quist and Lindegren 2001). The method compares quasi-instantaneous measurements of proper motion from Hipparcos data (averaged over three years) with long-term averaged proper motions from ground-based data. Where the difference between these two measures is statistically significant with respect to the measurement errors, the star is designated as a "$\Delta\mu$ binary." The criterion for statistical significance was chosen by Wielen *et al.* (1999) to give a strong indication of binarity such that among 10,000 truly single stars only 27 would be wrongly classified as being $\Delta\mu$ binaries. A catalogue of $\Delta\mu$ binaries (Makarov and Kaplan 2005) was compiled and can be accessed at http://dc.zah.uni-heidelberg.de/dmubin/q/cone/info.

BP Oct is listed in this $\Delta\mu$ binary catalogue but is at the lower end of the threshold chosen for statistical significance. It should also be noted that its detection as a $\Delta\mu$ binary would not explain a 3-day variation in light as the $\Delta\mu$ binary technique only detects binaries with periods in the order of years.

6. Conclusions

We conclude that, through an analysis of the new observations presented here and Hipparcos data, the proposition of a faint companion to BP Oct giving rise to small variations in the measured light over a timescale of several days cannot be discounted. Furthermore, both datasets show no evidence of short-period variations (≤ 0.3 day) and little evidence of any other periodicity from 1 to 100 days. Coupled with the listing of BP Oct as a $\Delta\mu$ binary and the known high rate of binarity amongst Am stars, the hint of a 3.5-day period in the measured light of BP Oct supports the proposition of there being a binary companion. Variations of ≤ 0.03 magnitude, however, remain difficult to confirm, with any estimate of a period being highly uncertain. From the parallax of BP Oct (van Leeuwen 2007) we calculate an $M_V = 2.41 \pm 0.04$. A K-type dwarf with an M_V in the range 6.4 to 7.4 could then add ≤ 0.03 magnitude to the observed V magnitude of BP Oct.

Further observations to test a binary-star hypothesis for BP Oct would be challenging as they would require sustained, accurate observations over a long timescale. Both authors now live in Tasmania and would be able to regularly observe BP Oct (subject to the vagaries of weather) through air masses around 1.5, possibly increasing the accuracy of observations over those reported here and previously. A thorough observing program would, however, demand measurement on most available fine nights. For a variation of several hundredths of a magnitude any periodicity detected would continue to have a large uncertainty associated with it. Noting Debernardi's (2000) question "Are there any single Am stars," the question of the possible binary nature of BP Oct remains interesting and further studies important. BP Oct would then be most suited to observations by space-borne telescopes or from small telescopes located in Antarctica.

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