BRITE Observations of Classical Cepheids – an Update

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We briefly summarize the BRITE observations of classical Cepheids so far.

1 Introduction

BRITE is a constellation of five satellites, each equipped with a 3-cm telescope, observing the brightest stars in the sky (see e.g., Weiss et al., 2014; Pablo et al., 2016). Its primary targets are stars brighter than 4 mag in V-band, however fainter stars, with slow variability, such as classical Cepheids, can be observed at high enough precision for their normally large amplitudes. So far BRITE has observed eleven Cepheids. Initial results were reported in Smolec et al. (2017) and here we provide a short update.

Table 1 provides basic data on the observed Cepheids, of which six pulsate in the fundamental mode (top section of the Table) and five pulsate in the first overtone (bottom section). The consecutive columns provide the star's name and HD number, period as determined from the analysis of BRITE data, mean V-band brightness and a summary of observational data, i.e. satellite ID (UBr – UniBRITE, BTr – BRITE Toronto, BHr – BRITE Heweliusz) and field ID. A short series of test observations in the blue filter are not included.

The data reduction procedure was briefly described in Smolec et al. (2017). In a nutshell, the variability was first modelled with a Fourier series. The residuals were used to decorrelate the data with parameters like CCD temperature, star's position on the CCD or the satellite's orbital phase. The decorrelated data were then orbit-averaged. The remaining slow residual trends were modelled with polynomials. Outliers were removed during the procedure. Further details on BRITE photometry and its reduction can be found in Popowicz et al. (2017).

2 Results

Figs. 1 and 2 present a gallery of phased light curves for the fundamental mode and first overtone Cepheids, respectively. In each figure, stars are ordered with the

star	HD	P (d)	$\langle V \rangle$	summary of observational data
fundamental mode Cepheids:				
T Vul	198726	4.4355	5.75	UBr, BTr (Cyg-I), BTr (Cyg-II)
δ Cep	213306	5.3663	3.95	BHr, BTr (CasCep-I)
X Sgr	161592	7.0128	4.55	UBr (Sgr-I), BHr (Sgr-II)
W Sgr	164975	7.5949	4.67	UBr (Sgr-I), BHr (Sgr-II)
l Car	84810	35.601	3.72	UBr (Car-I)
U Car	95109	38.868	6.29	BHr (Car-I)
first overtone Cepheids:				
DT Cyg	201078	2.4991	5.77	UBr, BTr (Cyg-I), BTr (Cyg-II)
V1334 Cyg	203156	3.3328	5.87	UBr, BTr (Cyg-I), BTr (Cyg-II)
BG Cru	108968	3.3427	5.49	BTr (CruCar-I)
AH Vel	68808	4.2272	5.70	BHr, BTr (VelPic-II)
MY Pup	61715	5.6953	5.68	BHr (VelPic-I) BHr, BTr (VelPic-II)

Table 1: Basic data about Cepheids observed with BRITE (pulsation period, mean V-band brightness) and indication of satellites and observing campaigns in which data were gathered (red filter only; see http://brite.craq-astro.ca/ for more details). Stars are sorted by pulsation mode (fundamental mode stars in the top section of the table) and by increasing pulsation period.

increasing pulsation period. Data are plotted along with the Fourier fits; the data dispersion is given in each panel. Below we briefly summarize the most interesting results for each of the observed Cepheids, starting with the fundamental mode pulsators.

T Vul. No new data were gathered since our previous report. In the frequency spectrum, the radial fundamental mode is non-stationary. Time-dependent analysis indicates that a long-period modulation might be present in this star. Details in Smolec et al. (2017).

δ **Cep**. No new data were gathered since our previous report. Despite being one of the brightest Cepheids in our sample, the data are of the lowest quality and do not allow any detailed analysis. See the discussion in Smolec et al. (2017).

X Sgr and **W Sgr**. The initial data for these stars covered only four pulsation cycles and were gathered by UBr. Its performance for faint stars is much worse than that of BTr and BHr. The new data were gathered by BHr and extend for more than 16 pulsation cycles, which allows a proper analysis of the frequency content. In the frequency spectrum of W Sgr no additional signals are detected except the fundamental mode and its harmonics. X Sgr appears much more interesting. In addition to radial fundamental mode ($f_0 = 0.142593\,\mathrm{c/d}$) two other periodicities were detected (see Fig. 3): $f_{\mathrm{x1}} = 0.1190\,\mathrm{c/d}$ ($A_{\mathrm{x1}} = 3.6\,\mathrm{mmag}$) and $f_{\mathrm{x2}} = 0.2246\,\mathrm{c/d}$ ($A_{\mathrm{x2}} = 2.8\,\mathrm{mmag}$). The corresponding period ratios are $P_{\mathrm{x1}}/P_0 = 1.20$ and $P_{\mathrm{x2}}/P_0 = 0.635$. These additional periods cannot correspond to radial overtones; their origin remains unknown. Possible hypotheses include: non-radial pulsation, low-amplitude periodic modulation, which was recently reported in several tens of fundamental mode Cepheids by Smolec (2017) (interpretation for f_{x1}), or contamination. Interestingly, X Sgr and three first overtone Cepheids, V1334 Cyg, BG Cru and EV Sct (of which the first two were also observed by BRITE, see below) show unusual line profile structures, as investigated by Kovtyukh et al. (2003). They suggested that these features can

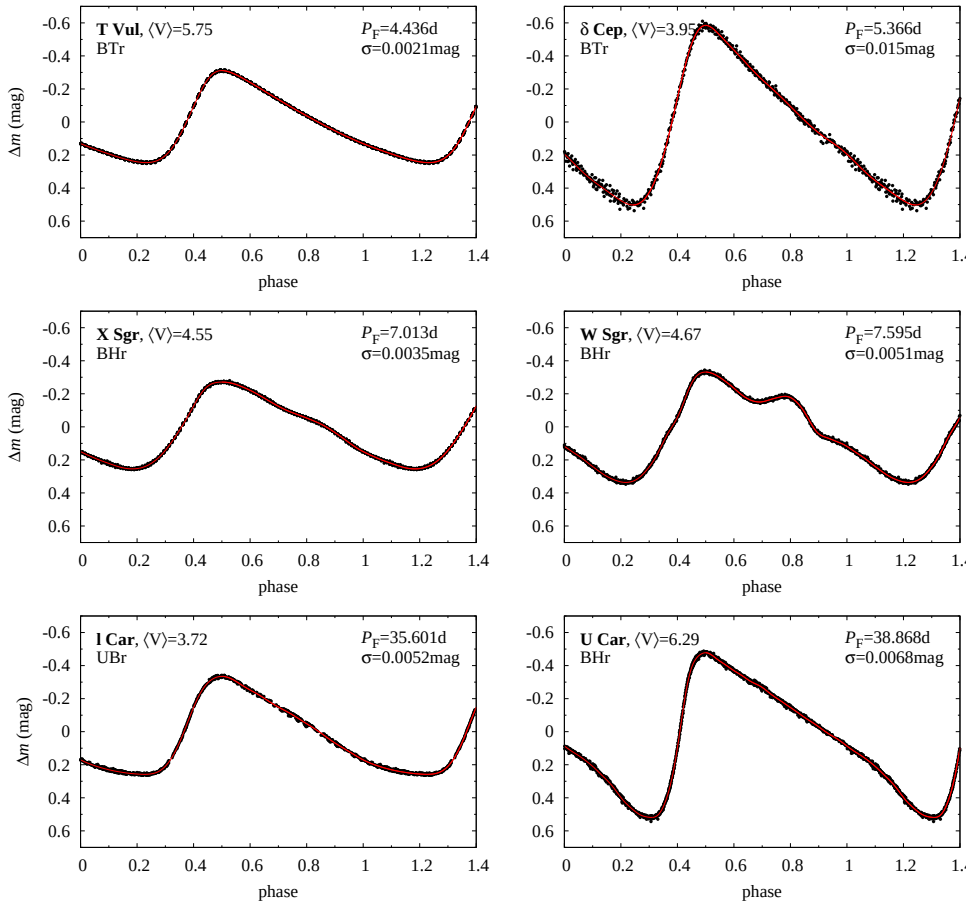

Fig. 1: Phased light curves with Fourier fits for the fundamental mode Cepheids observed with BRITE-Constellation. Basic data about the Cepheids is given in each panel.

be caused by the non-radial pulsations. The other interpretation are multiple shock waves propagating in the atmosphere (Mathias et al., 2006).

l Car and **U Car**. These are the longest-period Cepheids in our sample. Only three pulsation cycles were observed for each of them. Despite U Car being significantly fainter, data quality is similar to that for l Car. This is because U Car was observed by BHr, while l Car by UBr, performance of which is much worse than BHr. For these two stars pulsation periods were determined directly from the data, by minimizing the dispersion of the Fourier fit. Small cycle-to-cycle differences are apparent in the light curve of l Car. Interestingly, Anderson (2016) reported a cycle-to-cycle variability of spectral lines and atmospheric velocity gradients in this star. Without more observation and more detailed analysis however, we cannot rule out the possibility that the changes we observe in the BRITE data are of instrumental origin. The light curve of U Car appears more stable.

DT Cyg and **V1334 Cyg**. No new data were gathered for these first overtone pulsators since our previous report. Additional periodicities, that might be due to

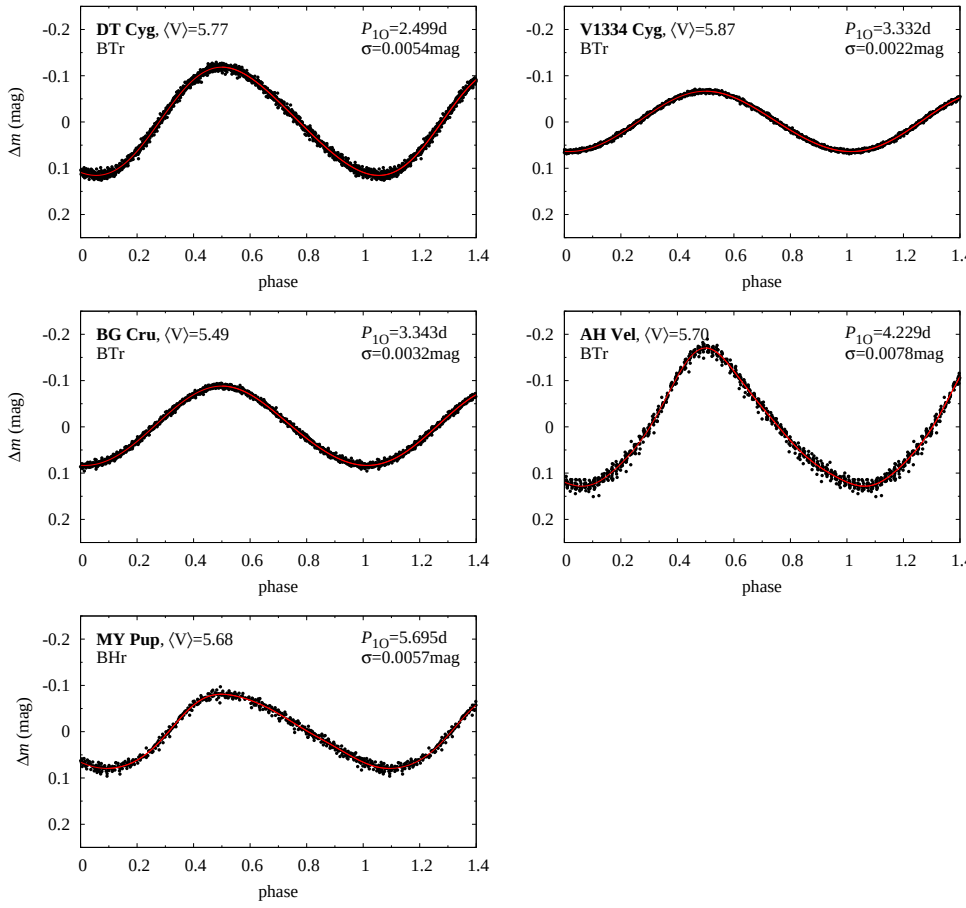

Fig. 2: Phased light curves with Fourier fits for the first overtone Cepheids observed with BRITE-Constellation. Basic data about the Cepheids is given in each panel.

modulation or due to non-radial modes, were detected in both stars. The reader is referred to Smolec et al. (2017) for more details.

BG Cru. Good quality data were gathered for BG Cru by BTr. Its frequency spectrum contains no significant periodicities in addition to radial first overtone and its harmonic.

AH Vel. The data for AH Vel consist of a few parts that significantly differ in quality. The mean flux level and pulsation amplitude (in flux) differ between the parts. The origin of these effects and the correct way of data processing needs to be investigated. Here we restrict the analysis to a single data chunk with the lowest dispersion of the light curve. Interestingly, after prewhitening with the first overtone and its harmonics, additional periodicity is clearly detected in the frequency spectrum (Fig. 4). The period ratio, $P_{1O}/P_x = 0.693$, may indicate that additional periodicity corresponds to the radial fundamental mode. We note however, that the period ratio is a bit too low, even at such relatively long pulsation periods. Also, at such long periods, it is the fundamental mode that typically dominates the double-

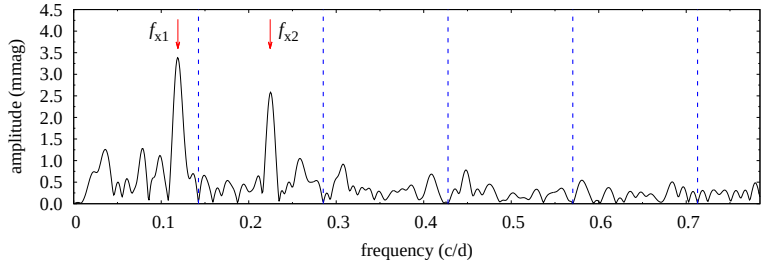

Fig. 3: Frequency spectrum for X Sgr after prewhitening with the fundamental mode and its harmonics (dashed lines). Two additional signals, marked with arrows, are clearly detected.

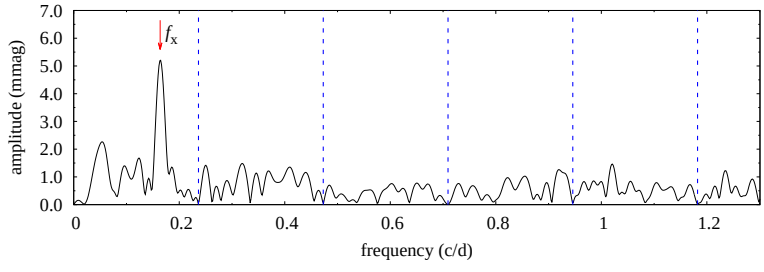

Fig. 4: Frequency spectrum for AH Vel after prewhitening with the first overtone and its harmonics (dashed lines). An additional signal is marked with an arrow.

mode pulsation. The periodicity needs to be confirmed in other data available for AH Vel, once these are correctly processed.

MY Pup. The new data gathered during the VelPic-II campaign show complex systematics, most likely of instrumental origin, that needs to be investigated in detail and corrected. Hence, in Fig. 2 we only show the light curve copied from our previous report (VelPic-I data).

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Conference dinner. Going clockwise around the table: Bert Pablo, Jason Rowe, Tahina Ramiaramanantsoa, Tony Moffat, Starla Talbot, Milena Ratajczak and Alexandre David-Uraz