Blue Large-Amplitude Pulsators in Zwicky Transient Facility Photometry

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We present the preliminary results of our analysis of the Zwicky Transient Facility photometry of blue large-amplitude pulsators (BLAPs). We find that high-gravity BLAPs may not be a distinct class of variables and that some BLAPs exhibit complex variations in pulsation periods that may result from their binarity.

1 Introduction

Based on the analysis of a large sample of data from the Optical Gravitational Lensing Experiment, Pietrukowicz et al. (2017) announced the discovery of a new class of evolved compact pulsating stars. Members of this class were found to be hot (their effective temperatures were of the order of 30 000 K) and showing large amplitudes of variability. They were therefore named blue large-amplitude pulsators (BLAPs). In the Hertzsprung-Russell (H-R) diagram, these stars occupy region between hot subdwarfs and hot massive main-sequence stars. Kupfer et al. (2019) found four stars with effective temperatures similar to BLAPs, but much higher surface gravities, pulsating with periods ranging from 3 to 8 minutes. The stars were therefore dubbed high-gravity BLAPs (hgBLAPs). Several searches for BLAPs and hgBLAPs conducted since 2017 resulted in about 80 members (or candidates) of these two groups presently known.

BLAPs pose a challenge to the theory of evolution. Several scenarios of their formation have been proposed (Pietrukowicz et al., 2017; Byrne & Jeffery, 2018, 2020; Romero et al., 2018; Wu & Li, 2018; Byrne et al., 2021; Meng et al., 2020; Xiong et al., 2022; Zhang et al., 2023). All they assume that the progenitors of BLAPs were or still are the members of binary systems. They also predict different masses of BLAPs, between 0.25 and 1.1 $M_\odot$. Masses of BLAPs could be derived if some will be found in binary systems. This would help to verify the theories of their origin. Unfortunately, to date, only two BLAPs, HD 133729 (Pigulski et al., 2022) and ZGP-BLAP-01 (McWhirter & Lam, 2022; Lin et al., 2023), have been convincingly shown to be the members of binary systems. In order to understand the evolution of BLAPs, it is therefore necessary to better characterize this group of pulsating stars and search for more BLAPs residing in binaries.

2 ZTF and the first results

Zwicky Transient Facility (ZTF) is an ongoing ground-based photometric survey (Bellm et al., 2019; Masci et al., 2019) carried out with the Samuel Oschin 48-inch telescope located in Palomar Observatory (CA, USA). The survey was commissioned

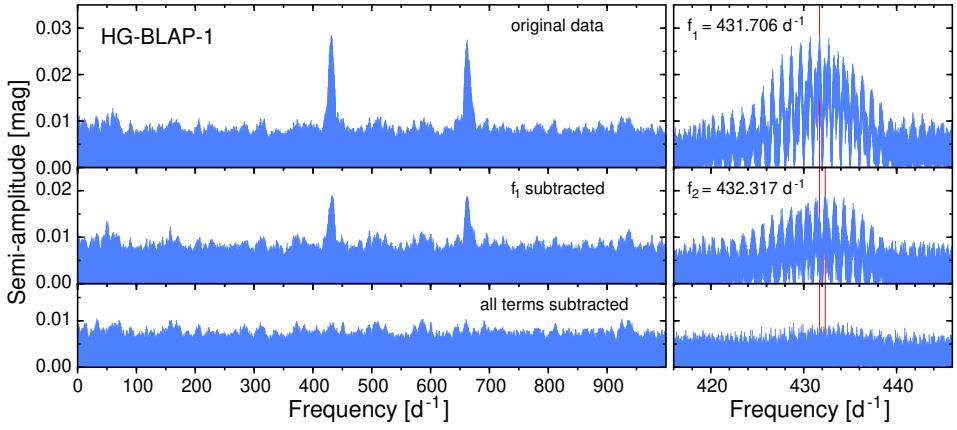

Fig. 1: Fourier frequency spectra of the ZTF DR19 combined r- and g-filter data of HG-BLAP-1. Left panels show Fourier spectra for three steps of prewhitening: for original data, after subtracting $f_1 = 431.706\,\mathrm{d}^{-1}$, and after subtracting f_1, $f_2 = 432.317\,\mathrm{d}^{-1}$ and three other, weaker terms. Right panels zoom on a narrow range of Fourier spectra in the vicinity of f_1 and f_2. Vertical red lines mark the frequencies of the two strongest modes.

in 2018 and superseded the (Intermediate) Palomar Transient Factory survey carried out in the years 2009 – 2017. The ZTF photometric data are made public to the astronomical community every two months. At the time of writing (November 2023), the 19th Data Release (DR19) of the ZTF data is available. The survey is carried out in three Sloan passbands, g, r and i.

As a part of the ongoing project aimed at a characterisation of BLAPs and hgBLAPs and the detection of their binarity, we analyzed ZTF photometry of all known members of both groups. We show here two examples of the results obtained from this analysis. A full analysis of the ZTF data will be published elsewhere (Pigulski et al., in preparation). The two examples are the following:

- HG-BLAP-1 (Kupfer et al., 2019), one of the first four members of the group of hgBLAPs, shows at least two modes of pulsation (Fig. 1). We found that other hgBLAPs and candidates for hgBLAPs also exhibit multimode behaviour. We therefore conclude that hgBLAPs may not constitute a distinct group of pulsating stars. Since they are in the same region of the H-R diagram as hot subdwarfs, they may simply be stars of this type with relatively large pulsation amplitudes.

- Some BLAPs show the changes of pulsation periods that cannot be explained with a constant rate of period change. An example is shown in Fig. 2. The $O-C$ diagram for the ZTF DR19 data of ZGP-BLAP-08, discovered by McWhirter & Lam (2022), shows phase changes with a range of about 12 minutes, that is, ∼35% of the pulsation period. The ZTF data are too short to conclude that the changes are periodic and thus could be caused by the light travel-time effect in a binary system, but this is a possible explanation.

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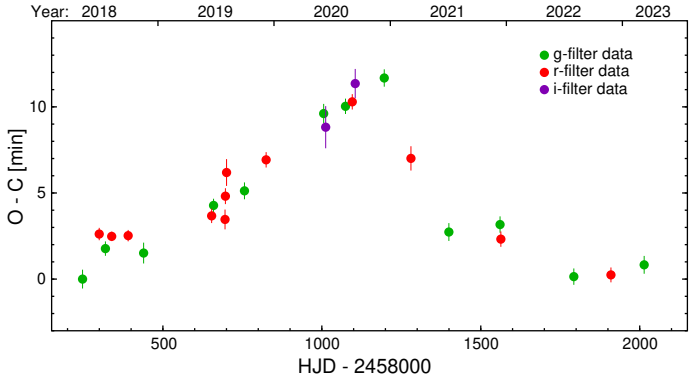

Fig. 2: O − C diagram obtained from the times of maximum light derived using the ZFT DR19 data of ZGP-BLAP-08 split into subsets. The O − C values derived from data made in different filters are shown with different colours. The initial epoch and pulsation period used in obtaining O − C values are HJD 2458247.25764 and 0.0244008485, respectively.

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