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GSC 00143-00813, a New Triple-mode Classical Cepheid

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I present my detection of a new triple-mode Classical Cepheid, pulsating in the fundamental mode, first- and second-overtone modes. I analyzed all observations available for the star in the ASAS-SN and ZTF online public archives using the period-search software developed by Dr. V.P. Goranskij for Windows environment. Light elements and parameters of the light curves for the three oscillations were obtained.

1 Introduction

Triple-mode Classical Cepheids, pulsating in the fundamental mode, first- and second-overtone modes (C012), are a very rare stellar variability subtype. For a long time, this group included only two stars. One of them, AC And, was discovered by Florya (1937) as a double-mode variable; later, Fitch & Szeidl (1976) detected an additional third radial mode (the second overtone). Variability and multiperiodicity of the second of such stars, V823 Cas, were detected by Antipin (1997). Both stars have short periods (P_0 0.71 and 0.67 respectively) and are classified not as Cepheids in the AAVSO VSX[1] database (AC And as an RRd star, V823 Cas as a HADS(B) variable). In the GCVS catalog (Samus et al., 2017), both variables were classified as unique stars (marked with an asterisk in the "Type" column).

The OGLE Collection of Variable Stars[2] (Udalski et al., 2018) contains two C012 stars in the Galactic disk (OGLE-GD-CEP-1011 and OGLE-GD-CEP-1704) and one C012 star in the Large Magellanic Cloud (OGLE-LMC-CEP-1378). In addition, one star is classified as a Galactic anomalous Cepheid pulsating in the fundamental mode, first- and second-overtone modes (OGLE-GAL-ACEP-091, Soszyński et al. 2020) and one triple-mode variable is classified as a Galactic bulge anomalous RRd star pulsating in the same three main modes with $P_0 = 0.48$ days (OGLE-BLG-RRLYR-38791; Soszyński et al., 2017). According to the cited authors, the classification of the last of these objects is unclear.

Jurcsik et al. (2018) detected multi-periodicity of ASASSN-V J065759.86+053444.9, a C012 classical Cepheid.

An interesting case is a V0979 Mon. The double periodicity of this star was detected by the author (Khruslov, 2009), the variable was classified as a first- and second-overtone Cepheid using ASAS-3 data (Pojmanski, 2002). Poretti et al. (2014) detected the third

[1] https://www.aavso.org/vsx/index.php?view=search.top

[2] https://ogledb.astrouw.edu.pl/õgle/OCVS/index.php

oscillation (fundamental mode) using CoRoT data (therefore, the type is C012). In the OGLE Collection of Variable Stars, this star, OGLE-GD-CEP-0057, is a classical Cepheid pulsating in the first- and second-overtone modes. I analyzed all available observations from the All-Sky Automated Survey for Supernovae (ASAS-SN; Shappe et al., 2014, Kochanek et al., 2017) and the Zwicky Transient Facility (ZTF; Bellm et al., 2019; Masci et al., 2019) archives, re-analyzed OGLE data, and did not detect the fundamental-mode oscillation in any of these photometric series. Mode switching or amplitude modulation of the fundamental mode are not excluded; my result can also be explained with insufficient accuracy or completeness of the analyzed data.

In this paper, I present my detection of a new triple-mode Cepheid of the C012 subtype. Variability of GSC 00143-00813 = USNO-B1.0 0970-0096856, RA(J2000) = $06^{\rm h}13^{\rm m}37\overset{\rm s}{.}33$, Dec(J2000) = $+07^\circ02'35\overset{''}{.}0$, was announced in the First Catalog of Variable Stars Measured by the Asteroid Terrestrial-impact Last Alert System (ATLAS, Heinze et al., 2018). The variable was designated as ATO J093.4055+07.0430, type IRR (irregular variables). The star is contained in the ASAS-SN Catalog of Variable Stars, part IX (ASASSN-V J061337.33+070234.7, Jayasinghe et al., 2021), where the variable was classified as a DCEP star, period $P = 0\overset{\rm d}{.}7885696$. However, the variable was classified as an RR Lyrae star in the Zwicky Transient Facility Catalog of Periodic Variable Stars (ZTFJ061337.32+070235.0, Chen et al., 2020), where the period is given in two versions: $P_g = 0\overset{\rm d}{.}7886820$ from g-band data or $P_r = 0\overset{\rm d}{.}7885387$ from r-band data. In the AAVSO VSX database, the variable is listed as an RRAB star.

I analyzed all observations available for this star in the ASAS-SN[3] and ZTF (the SNAD ZTF viewer[4], Malanchev et al., 2021) online public archive using Deeming's method (Deeming, 1975) implemented in the WinEfk[5] code written by V.P. Goranskij. My study detected oscillations in the fundamental mode, first- and second-overtone modes.

The radial pulsation modes were identified by the period ratio ($P_{\rm short}/P_{\rm long}$), see the study on this problem in Petersen (1973), Smolec & Moskalik (2010).

The star was identified in the GSC (Morrison et al., 2001) and USNO-B1.0 (Monet et al., 2003) catalogs. The tabulated coordinates of the variable were drawn from the Gaia EDR3 catalogue (Gaia Collaboration, 2021).

The data from the ASAS-SN and ZTF surveys are available online in the html version of this paper as a zip-archive. The finding chart is displayed in Fig. 1.

[3] https://asas-sn.osu.edu/
[4] https://ztf.snad.space/
[5] http://www.vgoranskij.net/software/

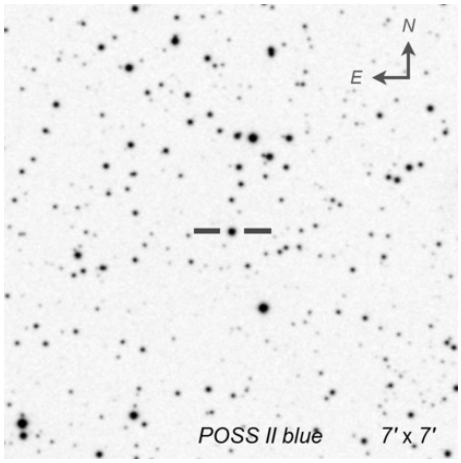

Figure 1. The finding chart of GSC 00143-00813.

Table 1. Pulsations of GSC 00143-00813

		P_0	P_1	P_2
Period, d		1.070450	0.788585	0.635820
Epoch, HJD 2457777+		0.780	0.470	0.047
Semi-amplitude,	V, ASAS-SN	0.056	0.165	0.050
	g, ASAS-SN	0.064	0.202	0.062
	r, ZTF	0.035	0.140	0.039
	g, ZTF	0.068	0.206	0.062

2 Results

The light elements of GSC 00143-00813 were derived using the ASAS-SN and ZTF data. Information on the light elements of three radial pulsation modes is presented in the Table: period in days, epoch of maximum (HJD – 2457777.0), semi-amplitudes in the V and g bands from ASAS-SN data, in the r and g bands from ZTF data.

The period ratios, $P_1/P_0 = 0.7367$ and $P_2/P_1 = 0.8063$, are typical of pulsations in the fundamental mode, first- and second-overtone modes. The first-overtone period is dominating.

GSC 00143-00813 is located at a small distance from the Galactic plane, its galactic latitude is $b = -5\overset{\circ}{.}1$, which suggests its classification as a classical Cepheid.

The range of variability, according to ASAS-SN data, is $13\overset{m}{.}62 - 14\overset{m}{.}35$ in the V band and $14\overset{m}{.}03 - 14\overset{m}{.}94$ in the g band. The range of variability. according to ZTF data, is $13\overset{m}{.}31 - 13\overset{m}{.}85$ in the r band and $14\overset{m}{.}01 - 14\overset{m}{.}81$ in the g band.

The color indices are: $J - K = 0.59$ (2MASS; Skrutskie et al., 2006); $B - V = 0.96$ (APASS[6]).

In addition to the three main modes, I detected the following interaction frequencies: in the ZTF data (r and g bands), $f_1 + f_0$ and $f_2 + f_1$; in the ASAS-SN data (g band), $f_1 + f_0$, $f_2 + f_1$, $f_1 - f_0$, $f_2 - f_1$, and $2f_1 + f_0$.

Power spectra of the variable from all analyzed data, for the raw data and after consecutive subtraction of the fundamental-mode oscillation, are shown in Fig. 2 (ASAS-SN, V and g bands) and Fig. 3 (ZTF, r and g bands). In all the panels, the structure of the

[6]https://www.aavso.org/download-apass-data

power spectra shows that the fundamental and second-overtone modes are real.

The phased light curves of GSC 00143-00813 from ASAS-SN and ZTF data are displayed in Figs. 4 and 5.

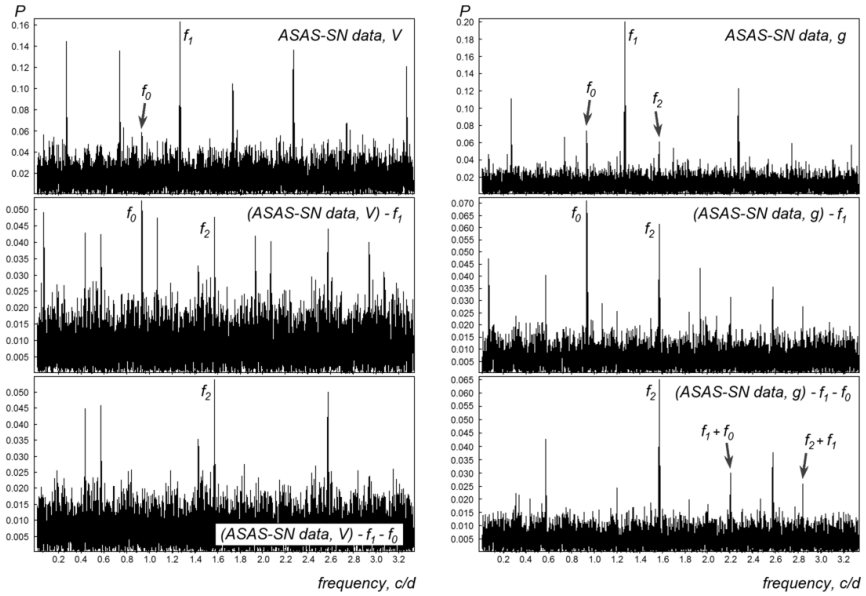

Figure 2. The power spectra of GSC 00143-00813 from ASAS-SN data.

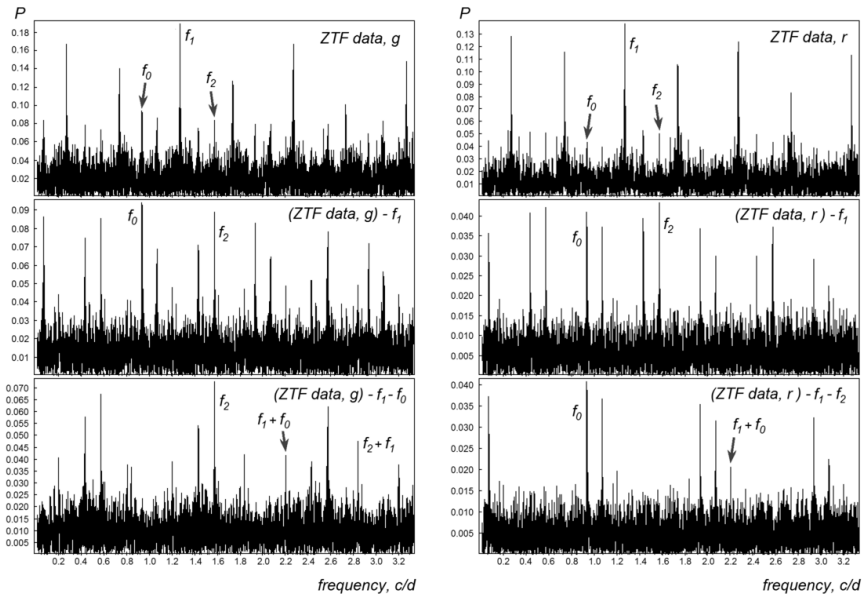

Figure 3. The power spectra of GSC 00143-00813 from ZTF data.

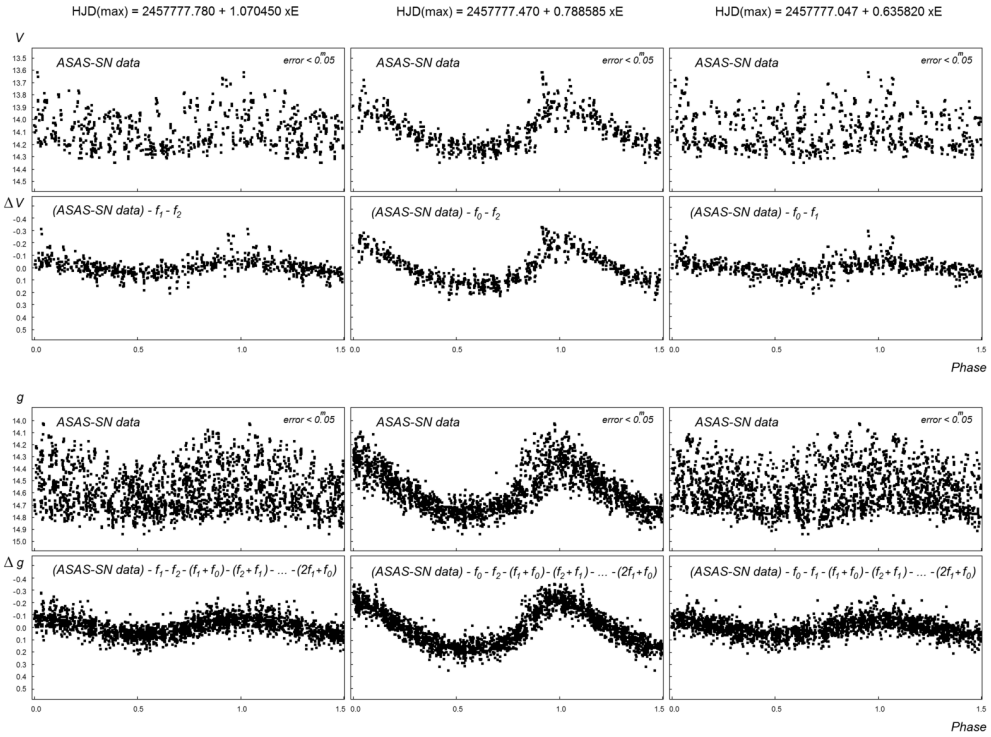

Figure 4. The light curves of GSC 00143-00813 from ASAS-SN data.

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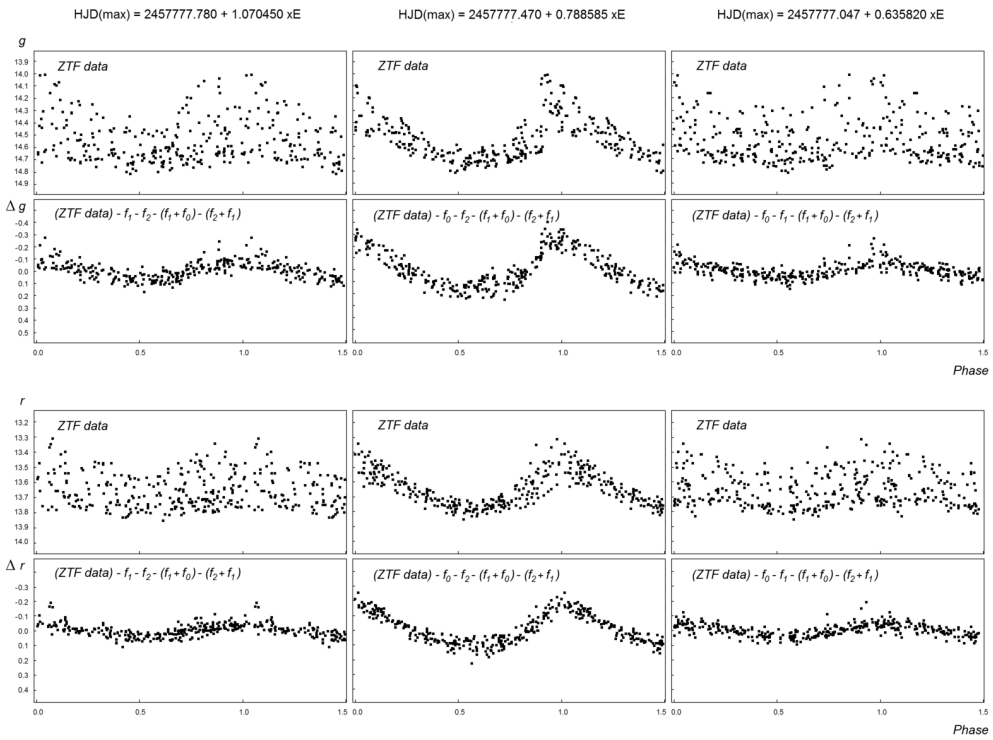

Figure 5. The light curves of GSC 00143-00813 from ZTF data.

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