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THREE NEW GALACTIC DOUBLE-MODE PULSATING STARS

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We report the discovery of the double-mode nature of three pulsating variable stars; V2157 Sgr, V767 Sgr and V363 Cas, observed with the Optical Monitoring Camera (Mas-Hesse et al., 2003) on board the Integral satellite (Winkler et al., 2003). The observations are available via the OMC Data Server (Gutierrez et al., 2004). We have used this database to analyse light curves of RR Lyrae variables observed by OMC for any sign of light curve variability (eg. Blazhko-effect or double-mode nature). The light curves are available as FITS tables which were converted into ASCII tables using the OMC2ASCII program as described by Sokolovsky (2007). We have analysed the light curves of all the variables down to $V \sim 17$ which were classified as RR Lyrae by the OMC Input Catalogue and which have more than 200 data points using the 630 second sampling of OMC observations. The result of our analysis is the identification of double-mode nature in three of the variables. Based on their period ratios, periods, and light curves' shape, two of the stars are pulsating simultaneously in the first and second overtones (FO/SO) and are in fact short period Cepheid stars, not RR Lyrae variables. The OMC observes through a Johnson V filter, allowing us to combine the observations of OMC with ASAS (Pojmansky, 2002) V lightcurves, when they are available. When combining the lightcurves, offsets of the zero-points were taken into account. During the analysis, some outlier points were removed manually. The log of observations of the three new double mode variables is shown in Table 1.

Table 1. Log of observations

Star	Dataset	JD 2400000 +	No. of datapoints*	mean V mag
V2157 Sgr	OMC	53110 – 54051	541	14.483
V2157 Sgr	ASAS	51875 – 53894	271	14.121
V767 Sgr	OMC	52729 – 54763	640	12.532
V767 Sgr	ASAS	51940 – 53294	540	12.463
V363 Cas	OMC	52654 – 53956	1120	10.569

* After the rejection of outlying points.

V2157 Sgr ($\alpha_{2000.0} = 19^{\rm h}40^{\rm m}15^{\rm s}, \delta_{2000.0} = -39°21'42''$): The combined OMC and ASAS data revealed that this variable is a double-mode RR Lyrae. As it is common in RRd stars, the dominant mode is the first overtone, however, the fundamental mode has commensurable amplitude to that of the first overtone mode. In the Fourier spectrum of the light-curve, apart from the fundamental mode and the first overtone and their harmonics, linear combination terms of f_1 and f_0 also appear. The folded light curves, the Fourier-spectra and the spectral window of the observations are plotted in Fig. 1.

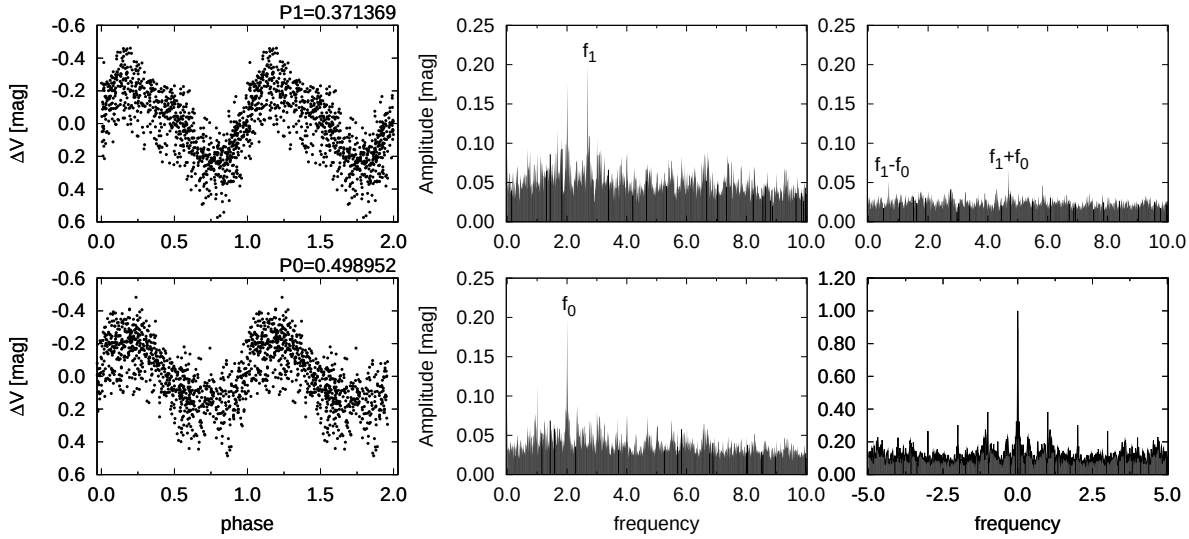

Figure 1. Light curves, Fourier spectra and the spectral window of V2157 Sgr. The light curves folded with the primary (top-left panel) and secondary (bottom-left panel) periods are prewhitened for the signals belonging to the other detected frequencies. The top and bottom panels in the middle show the Fourier spectrum of the original data and the data prewhitened for the primary period and its harmonics, respectively. In the top-right panel the spectrum after prewhitening for both the primary and the secondary frequencies and their harmonics are shown. In this residual spectrum the linear combinations of the two main pulsation components appear. The spectral window is shown in the bottom-right panel.

Table 2. Fourier parameters of the frequencies detected in the spectrum of V2157 Sgr.

V2157 Sgr	P_1=0.371369	P_0=0.498952		P_1/P_0=0.7443	
	frequency	amplitude / error		phase*/error	
	cycle/day	magnitude		radian	
f_1	2.692739	0.2248	0.0063	2.15	0.06
$2f_1$	5.385478	0.0646	0.0061	1.54	0.13
$3f_1$	8.078217	0.0135	0.0062	4.83	0.45
f_0	2.004201	0.1942	0.0062	2.85	0.08
$2f_0$	4.008403	0.0376	0.0062	1.69	0.25
$3f_0$	6.012604	0.0287	0.0061	2.20	0.33
$4f_0$	8.016805	0.0204	0.0062	1.81	0.42
$f_1 + f_0$	4.696940	0.0659	0.0061	1.24	0.13
$f_1 - f_0$	0.688538	0.0527	0.0065	5.07	0.13
	r.m.s	0.117 mag			

* According to sine term decomposition. Initial epoch is 2 452 027.

V767 Sgr ($\alpha_{2000.0} = 19^{\rm h}52^{\rm m}28^{\rm s}, \delta_{2000.0} = -26°42'12''$): The main period of this star is 0.67 d ($f_1 = 1.49$ c/d), that would correspond to the period of a fundamental mode RR Lyr variable. However, its secondary frequency is at $f_2 = 1.86$ c/d with a period ratio

of 0.8, indicating that the star is pulsating simultaneously in the first and second radial mode overtones. Based on the period values of these modes the star is more probably a short period Cepheid than an RR Lyrae.

After prewhitening the light curve with the frequencies of the two radial modes and their linear combination term, a signal appears in the residual spectrum near the primary period, indicating period change during the observations (the observations are spanning almost eight years). The folded light curves, the Fourier-spectra and the spectral window of the observations are plotted in Fig. 2. Table 3 lists the Fourier parameters of the detected frequencies.

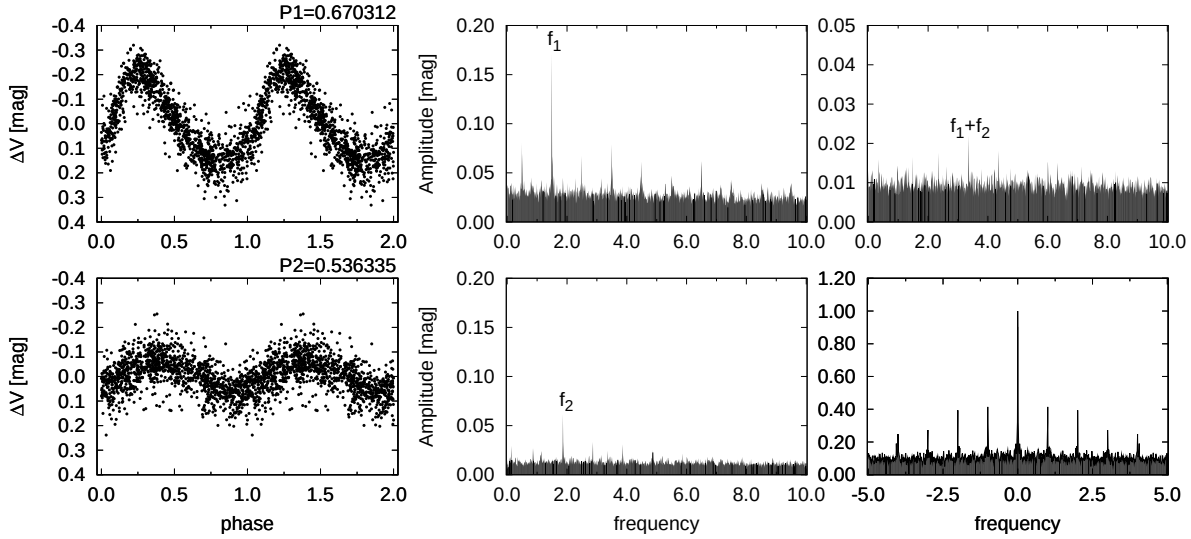

Figure 2. Same as Fig. 1, but for V767 Sgr. Note the different scales on the Y axes of the residual spectra.

Table 3. Fourier parameters of the frequencies detected in the spectrum of V767 Sgr.

V767 Sgr	P_1=0.670312	P_2=0.536335		P_2/P_1=0.8001	
	frequency cycle/day	amplitude / error magnitude		phase* /error radian	
f_1	1.491842	0.1760	0.0024	3.97	0.02
$2f_1$	2.983684	0.0338	0.0023	3.87	0.08
$3f_1$	4.475526	0.0129	0.0024	3.93	0.50
f_2	1.864508	0.0624	0.0024	4.05	0.08
$f_1 + f_2$	3.356350	0.0233	0.0024	4.05	0.12
	r.m.s	0.057 mag			

* According to sine term decomposition. Initial epoch is 2 451 940.

V363 Cas ($m_V \approx 10\overset{\text{m}}{.}61, \alpha_{2000.0} = 00^{\text{h}}15^{\text{m}}14\overset{\text{s}}{.}333, \delta_{2000.0} = +60°20'11\overset{''}{.}99$): This star is classified by the GCVS as type of RRab. Schmidt & Seth (1996) suggested to revise the type to RRc:, while Fernley et al. (1998) noted that this star is probably an Anomalous Cepheid. Despite being a moderately bright star, the double-mode nature of V363 Cas was not discovered by earlier studies due to the very small, 0.02 mag amplitude of its secondary mode. The analysis of the OMC data revealed that V363 pulsates in two radial modes with 0.802 period ratio corresponding to the first and second overtone periods. The periods of the identified modes support that instead of being an RR Lyrae, V363 Cas is also a short period Cepheid.

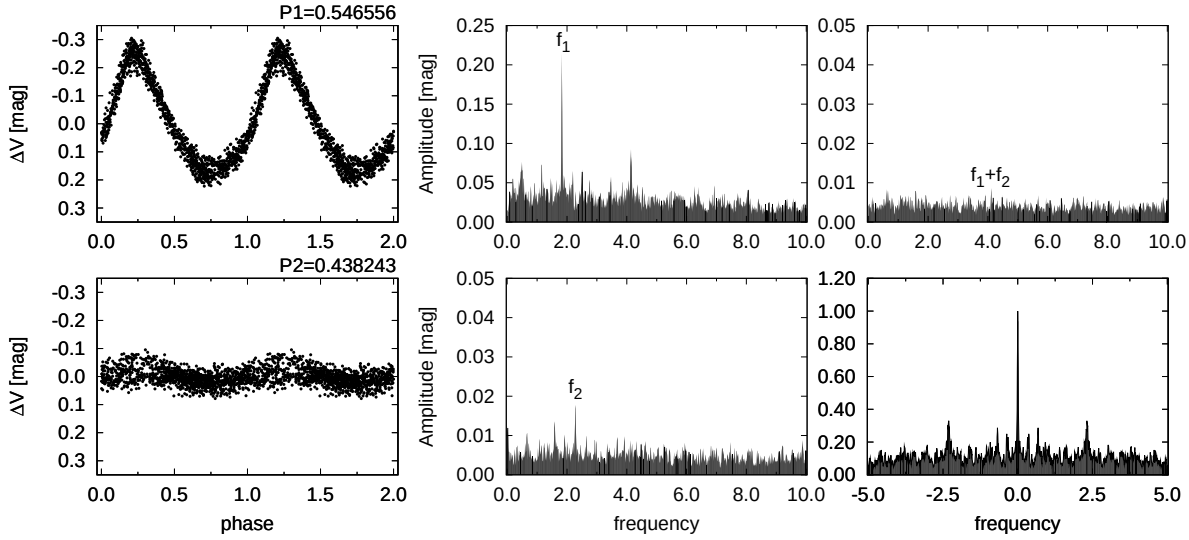

Figure 3. Same as Figs. 1 & 2, but for V363 Cas. Note the different scales on the y axes of the residual spectra.

Table 4. Fourier parameters of the frequencies detected in the spectrum of V363 Cas.

V363 Cas	P_1=0.546556	P_2=0.438243		P_2/P_1=0.8018	
	frequency	amplitude / error		phase* /error	
	cycle/day	magnitude		radian	
f_1	1.829638	0.1980	0.0011	5.77	0.02
$2f_1$	3.659276	0.0392	0.0011	0.85	0.04
$3f_1$	5.488915	0.0165	0.0011	2.60	0.08
f_2	2.281842	0.0196	0.0012	4.08	0.16
$f_1 + f_2$	4.111480	0.0080	0.0012	5.55	0.19
	r.m.s	0.026 mag			

* According to sine term decomposition. Initial epoch is 2 452 654.

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The correct coordinates of two variables discussed in this issue of the IBVS are as follows:

V767 Sgr: $\alpha_{2000.0} = 17^{\rm h}52^{\rm m}28\overset{\rm s}{.}4, \delta_{2000.0} = -26^\circ42'12\overset{''}{.}5$

V363 Cas: $\alpha_{2000.0} = 00^{\rm h}15^{\rm m}14\overset{\rm s}{.}3, \delta_{2000.0} = +60^\circ20'25\overset{''}{.}7$

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