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BALLOON 090100001: A LINK BETWEEN THE TWO CLASSES OF PULSATING HOT SUBDWARFS

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Abstract. We present results of photometric observations of the high-amplitude EC 14026-type star, Balloon 090100001. The data were obtained in broad-band B filter and span over five weeks, consisting of about 150 hours of observations. Fourier analysis of these data led us to the detection of at least 50 modes of pulsation, out of which 37 are independent. The frequencies of 22 detected modes are in the region of pulsations of EC14026-type stars, theoretically attributed to p-modes, and cluster into four narrow ranges, around 2.8, 3.8, 4.7 and 5.5 mHz, where the radial fundamental mode, the first, second and third overtones are likely to occur. Surprisingly, we also detect 15 independent modes in the low-frequency domain, between 0.1 and 0.8 mHz. These modes are typically found in PG 1716+426-type stars, recently discovered among cool B-type subdwarfs, and theoretically attributed to high-order g-modes. As both kinds of oscillations are observed in Balloon 090100001, it represents a link between the two classes of pulsating hot subdwarfs. At present, it is probably the most suitable target for testing evolutionary scenarios and internal constitution models of these objects by means of asteroseismology. Three of the modes we detect form an equidistant frequency triplet which can be explained by invoking rotational splitting of an $\ell = 1$ mode.

Key words: stars: oscillations – stars: individual: Balloon 090100001

1. INTRODUCTION

Balloon 090100001 (BA09) was found to be an sdB star by Bixler et al. (1991). Although it is one of the brightest sdB stars its pulsational nature was discovered only recently by Oreiro et al. (2004). Owing to a very short run, the authors were able to extract only two independent modes and the first harmonic of the main mode. Beside these three peaks, they noted a small signal around 0.3 mHz, whose appearance was surprising for an EC14026 star. With a B magnitude of 11.8, periods around 300 s and amplitude up to 50 mmi for the main mode, this

EC14026 object turned out to be an excellent candidate for follow-up photometry.

2. OBSERVATIONS

BA09 was re-observed independently by two of us (A.B. and R.O.) in 2004 August and September. A.B. used a SBIG ST-10XME CCD camera attached to a 60 cm telescope at Mt. Suhora Observatory. Johnson-Cousins *UBVR* filters were used. R.O. employed the TCP instrument on the 80 cm IAC80 telescope. Only a *B* filter was used in this case, allowing a cycle time of 10 s. Results of the analysis of these data are published separately (Baran et al. 2005; Oreiro et al. 2005). Some time later, we combined our *B* filter data and made a common FT analysis. The light curve of our combined data is presented in Figure 1. In this way we improved the spectral window (Figure 2), but the difference is not significant since our sites are located at similar longitude, and the observations were not simultaneous.

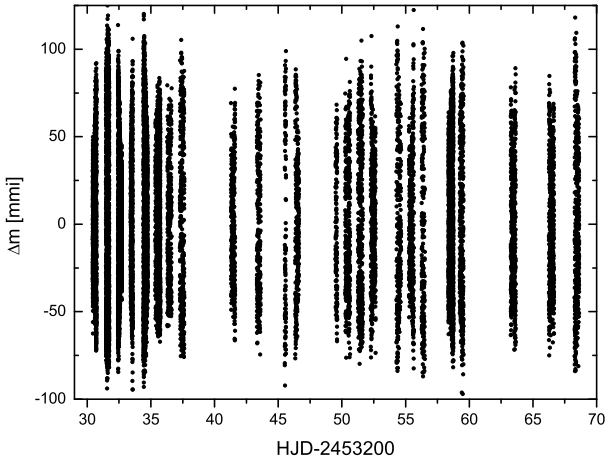

Fig. 1. Light curve from Tenerife and Poland.

3. PERIODOGRAM ANALYSIS

Figure 3 shows the Fourier spectrum for non prewhitened data. Note that the highest peak (with an amplitude of 53 mma) is truncated in order to better view the signal with lower amplitudes. At first look, seven groups of peaks can be distinguished (not all of them turned out to be real). Down to *S/N* about 7 we revealed 50 frequencies, which are listed in Table 1. Frequencies f_2, f_3, f_4 form an equally spaced triplet. If we assume they are due to rotational splitting of an $\ell = 1$ mode, with $C_{nl} = 1$ then a rotation period of 7.1 days is derived. Despite the large data set we still have an aliasing problem, and in a few cases we were not able to distinguish correctly between a real mode and its aliases. In

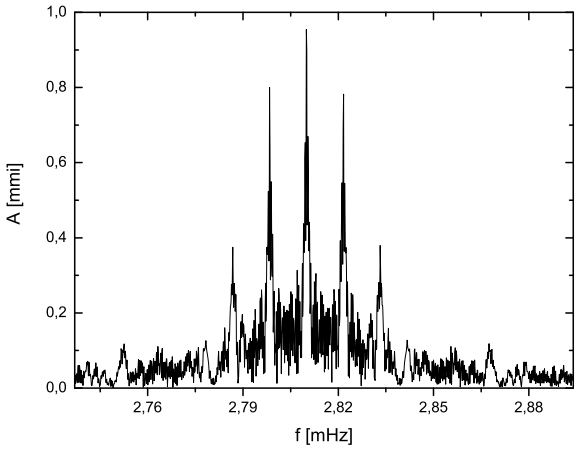

Fig. 2. Spectral window resulting from the Poland-Tenerife combined data.

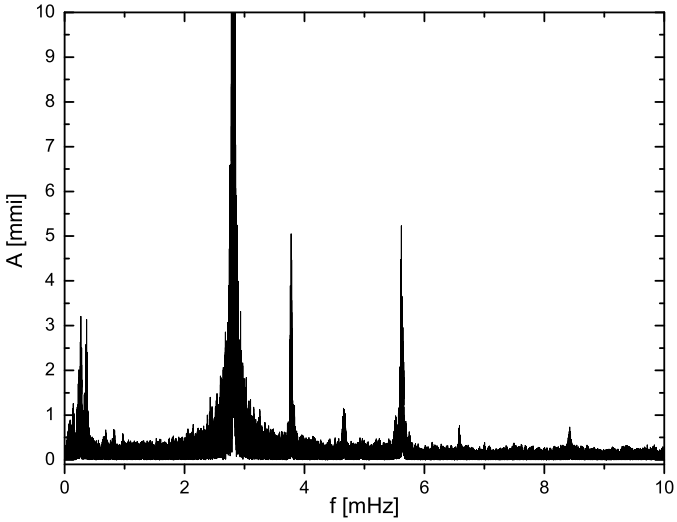

Fig. 3. Amplitude spectrum calculated on joined data.

Figure 4 residuals out of 50 frequencies subtracted are shown. As can be seen there are still many peaks that could be real, but this can be verified only with data of better quality.

4. 2005 CAMPAIGN

In order to get such a higher quality set of data, we are arranging for the summer of 2005 a simultaneous photometric and spectroscopic campaign on BA09. The official web page can be found at `http://webpages.ull.es/users/raquelor`, where the relevant information on the campaign is posted. Some photometric and spectroscopic sites have already agreed to participate although for some of them the observing time has not yet been awarded. All observatories but one will use CCD cameras with a B filter. Two sites will use multicolor photometry, so we will be able to compare amplitudes from two seasons. With these new data we will also make an attempt to identify the pulsational modes in BA09. In particular, the method which uses spectroscopy and multicolor information, described in detail in Daszynska-Daszkiewicz (2003), will be used for that purpose.

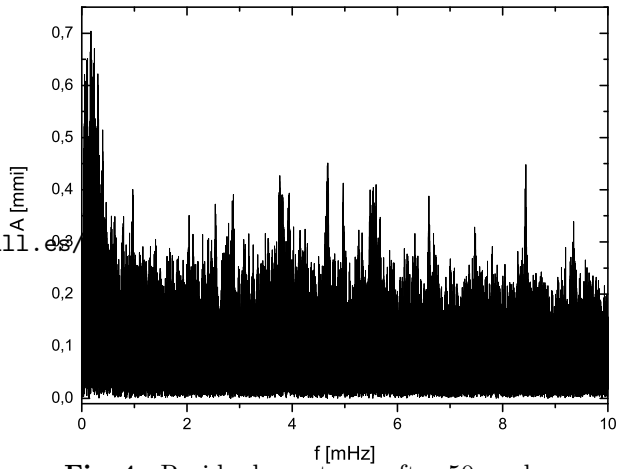

Fig. 4. Residual spectrum after 50 peaks subtracted.

Table 1. Frequencies, amplitudes and phases of the prewhitened peaks from the Poland–Tenerife combined data. Letter (number) subscripts refer to g-mode (p-mode) frequencies

	Freq. (mHz)	Ampl. (mma)	Phase		Freq. (mHz)	Ampl. (mma)	Phase
f_A	0.2724	2.886	2.646	f_{11}	3.7918	1.143	2.906
f_B	0.3658	2.708	2.843	f_{12}	3.7867	1.223	3.091
f_C	0.2400	1.848	1.228	f_{13}	3.8229	0.827	2.353
f_D	0.3257	1.092	4.600	f_{14}	4.6511	0.768	5.712
f_E	0.2463	0.970	3.013	f_{15}	4.6761	0.967	6.135
f_F	0.1451	0.874	5.569	f_{16}	4.6591	0.882	2.447
f_G	0.2110	0.987	4.646	f_{17}	4.6686	0.760	3.257
f_H	0.3312	1.067	5.106	f_{18}	4.6421	0.621	5.684
f_I	0.0904	0.888	5.794	f_{19}	4.6614	0.648	6.005
f_J	0.2989	0.822	6.040	f_{20}	5.5329	0.770	4.097
f_K	0.1356	0.828	0.479	f_{21}	5.4944	0.623	5.903
f_L	0.2480	0.815	4.578	f_{22}	5.5551	0.626	5.759
f_M	0.6844	0.702	5.466	$f_1 - f_B$	2.4417	0.739	0.429
f_N	0.8331	0.623	4.416	$f_1 - f_D$	2.4818	0.404	4.933
f_O	0.6311	0.492	0.568	$f_1 + f_1$	5.6149	5.930	4.560
f_1	2.8075	53.101	3.030	$f_1 + f_2$	5.6307	4.496	4.609
f_2	2.8232	20.539	3.061	$f_1 + f_3$	5.6323	2.785	2.150
f_3	2.8248	12.075	0.603	$f_1 + f_4$	5.6338	0.970	3.695
f_4	2.8264	4.800	2.069	$f_2 + f_3$	5.6480	0.709	1.882
f_5	2.8539	1.665	1.208	$f_2 + f_2$	5.6465	0.719	4.458
f_6	2.8557	1.212	4.244	$f_2 + f_4$	5.6496	0.441	4.462
f_7	2.8585	1.140	5.084	$f_1 + f_9$	6.5835	0.684	4.891
f_8	2.8250	0.901	2.605	$2f_1 + f_1$	8.4224	0.846	0.031
f_9	3.7761	4.572	3.694	$2f_1 + f_2$	8.4381	0.523	6.051
f_{10}	3.7956	1.111	1.421	$2f_1 + f_3$	8.4397	0.458	3.847

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