

## Amplitude modulation in the ZZ Ceti star GD 244

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**Abstract.** Previous studies of GD 244 revealed seven pulsation frequencies (two doublets and three single periods) in the light variations of the star. The data obtained at McDonald Observatory between 2003 and 2006, and our additional measurements in 2006 and 2007 at Konkoly Observatory, allow the investigation of the long-term pulsational behaviour of GD 244. We found that the 307.1 s period component of one of the doublets show long-term, periodic amplitude modulation with a time scale of  $\sim 740$  days. Possible explanations are that nonlinear resonant mode coupling is operating among the rotationally split frequency components, or two modes, unresolved in the yearly data are excited at  $\sim 307.1$  s. This is the first time that such long-term periodic amplitude modulation is published on a ZZ Ceti star.

### 1. Introduction

GD 244 (V394 Peg, WD 2254+126,  $V = 15.6$ ) was discovered to be a luminosity-variable DA white dwarf by Fontaine et al. (2001). Based on their 3-hour-long photometric observation with the Canada-France-Hawaii Telescope (CFHT), Fontaine et al. (2001) determined four independent pulsation frequencies between  $\sim 200 - 300$  s and a few combination terms. According to its atmospheric parameters ( $T_{\text{eff}} = 11\,680$  K,  $\log g = 8.08$ ), GD 244 is situated in the middle of the empirical DAV instability strip. Photometric data were collected again on GD 244, between 2003 and 2006 (41 nights), with the 2.1-m Otto Struve Telescope at McDonald Observatory (Yeates et al. 2005; Mullally et al. 2008). The star was one of the targets of a survey, in which isolated and stable-amplitude modes were utilized to search for possible low-mass companions of pulsating white dwarf stars applying the  $O - C$  technique. The survey did not reveal any sign of a stellar- or planetary-mass companion of GD 244.

We collected data on GD 244 on 19 nights in 2006 and 2007 with the 1-m Ritchey-Chrétien-Coudé telescope at Piszkestető mountain station of Konkoly Observatory. Fergal Mullally kindly provided the survey measurements on GD 244 for our analysis. These data and our additional measurements at Konkoly Observatory allow the detailed investigation of the long-term pulsational behaviour of GD 244. We present our first findings here.

## 2. Pulsation periods

Table 1 lists all the independent pulsation frequencies and the corresponding periods and amplitudes of GD 244 published so far. Previous light-variation studies revealed seven pulsation frequencies, two doublets and three single periods. One of them (at 203 s) proved to be considerably stable, and this was utilized to search for a possible planetary-mass companion in the survey of Mullally et al. (2008). Not all the periods were detected in both data sets: e.g. the 294.6 s mode found by Fontaine et al. (2001) was not reported in the 2003 McDonald data (Yeates et al. 2005). There is a well-known general trend observed in the DAV stars that towards the red edge of the instability strip the light variations are more complex, non-sinusoidal, with longer periods and higher amplitudes. Short-term amplitude variations are also more common among the cooler ZZ Ceti stars (see e.g. Handler 2003), which may be responsible for the different set of periods observed in different epochs.

Table 1. Pulsation frequencies of GD 244.

	McDonald Obs. data 2003 <sup>a</sup>			CFHT data 1999 <sup>b</sup>
	Freq. ( $\mu$ Hz)	Period (s)	Ampl. (mma)	Period (s)
$f_1$	4926.7	203.0	4.0	203.3
$f_2$	3903.3	256.2	6.7	256.3
$f_3$	3897.7	256.6	12.3	
$f_4$				294.6
$f_5$	3261.9	306.6	5.0	
$f_6$	3255.9	307.1	20.2	307.0
$f_7$	1103.7	906.1	1.7	

<sup>a</sup> Yeates et al. (2005), <sup>b</sup> Fontaine et al. (2001)

## 3. Amplitude modulation

We checked the amplitudes and frequencies on daily, monthly and yearly time bases. We used PERIOD04 (Lenz & Breger 2005), and for comparison, custom developed software tools, including the light curve fitting program LCFIT (Sódor 2012). LCFIT has linear (amplitudes and phases) and nonlinear (amplitudes, phases and frequencies) least-squares fitting options, and can handle base frequencies and linear combination terms as input.

Periods around 203, 256 and 307 s can be detected practically in all daily data sets. The daily data suggested long-term periodic variation in the case of the 307 s peak (see panel A of Fig. 1), with  $\sim 740$  day period. From one year to the next, the increase or decrease in the average of the daily amplitudes found to be 2-6 times larger than the corresponding standard deviations. However, we know that there are actually at least two peaks at 307 s, which cannot be resolved by the daily measurements, as their separation is  $\sim 0.5 \text{ d}^{-1}$ . Thus, we checked the amplitudes of the doublet components separately on longer time bases. We found that the 307.1 s period component of the 307 s doublet show clear long-term amplitude modulation. Neither the other component

of this doublet (at 306.6 s) nor any of the other known doublet's components (at 256 s, see panel B of Fig. 1) show similar variations. The 203 s mode also remains stable both in amplitude (panel C of Fig. 1) and in frequency. The frequencies of the doublet at 307 s do not seem to vary (see Fig. 2).

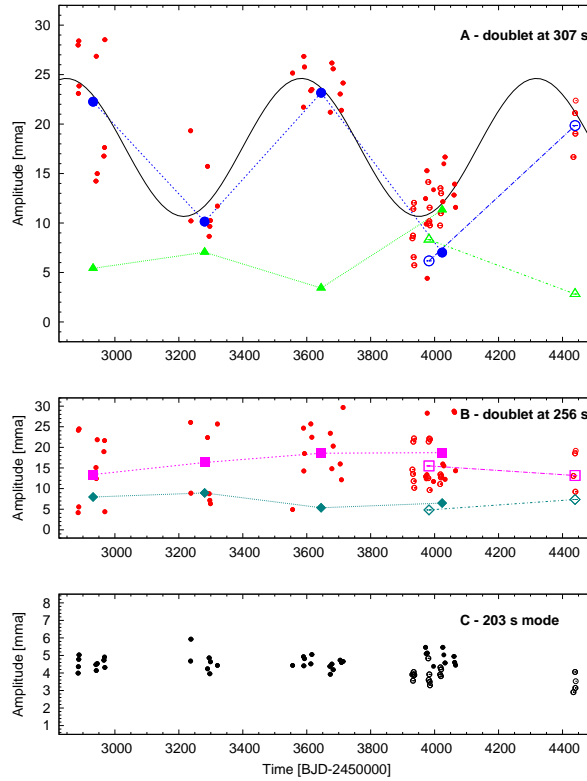


Figure 1. Amplitudes of different frequency components. *Filled and open circles*: McDonald and Konkoly Observatory data, respectively. *Small red* (panels A and B) and *black* (panel C) *dots*: daily values. *Large blue dots and green triangles* (panel A), *magenta squares and teal diamonds* (panel B): yearly amplitudes of the 307.1, 306.6, 256.6 and 256.2 s peaks, respectively. The standard errors of the fits are smaller than the sizes of the symbols used. *Black solid line* (panel A): sine wave fit to the daily data. The frequency used for the fit was fixed according to the frequency separation of the two closely spaced peaks found at  $f_6$  by the combined 2003–2006 McDonald Observatory data ( $\delta f = 0.00136 \text{ d}^{-1}$ ,  $P \approx 735 \text{ d}$ , see Sect. 4).

#### 4. Discussion and conclusion

One possible explanation for the observed amplitude modulation is that two modes of fairly close frequencies are excited at  $\approx 307.1 \text{ s}$ . We analysed together all the 2003–2006 McDonald Observatory data for this purpose. For this preliminary analysis, we did not include the Konkoly data, to eliminate the possible instrumental effects caused by the different detectors and filters used for the observations. The analysis revealed that we can detect indeed two significant peaks in this region of the Fourier spectrum of the

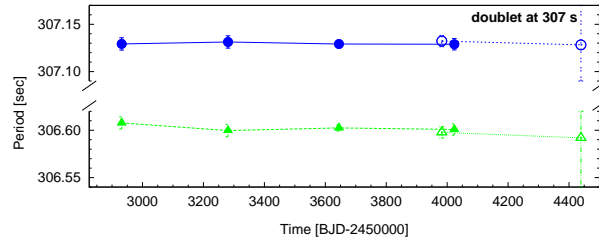


Figure 2. Yearly periods of the doublet components at 307 s. The errors are calculated as  $\pm 0.5(1/\Delta T)$ , that is, half of the Rayleigh frequency resolution.

combined yearly data, with the frequency separation of  $\delta f = 0.00136 \text{ d}^{-1}$  ( $0.016 \mu\text{Hz}$ ). This is about three orders of magnitude smaller than the separation of the known  $f_5-f_6$  doublet components. If these two peaks represent independent pulsation frequencies, they cannot be resolved by one-season-long observations, which can cause the observed apparent amplitude variation of the 307.1 s peak showed in Fig. 1. This explanation also implies that both of these close-frequency modes have stable frequencies and amplitudes. Panel A of Fig. 1 shows a sine wave fit to the daily amplitude solutions with the frequency fixed to the  $0.00136 \text{ d}^{-1}$  ( $P \approx 735 \text{ d}$ ) value.

Frequency and amplitude modulation in a similar time scale were reported in the case of the DBV-type *Kepler* target KIC 08626021 (Zong et al. 2014), which were explained as the results of nonlinear resonant coupling operating among rotational triplet components. Our case seems to be different: only one frequency component of the doublets shows clear sign of amplitude modulation, and we cannot find evidence of frequency modulation either. However, this cannot rule out that this same physical reason is responsible for the observed variation, as nonlinear resonant coupling can cause the amplitude modulation of only one frequency component. In this case, the closely spaced peak with  $\delta f$  separation is only a mathematical representation of the amplitude modulation in the Fourier spectrum.

This is the first time that such long-term periodic amplitude modulation was published on a ZZ Ceti star.

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