Nonradial modes in classical cepheids

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Abstract

Systematic search for multiperiodicity in the LMC Cepheids (Moskalik et al. 2004) has led to the discovery of low-amplitude nonradial modes in a substantial fraction of overtone pulsators. We present a detailed discussion of this new type of multimode behaviour. We also discuss first detections of nonradial modes in FU/FO double-mode Cepheids.

Individual Objects: LMC

LMC Cepheids: Data and Analysis

Our search for multiperiodic variations in Cepheids of the Large Magellanic Cloud (LMC) was performed with I-band DIA-reduced OGLE-II photometry (Żebruń et al. 2001). The data was analyzed with a standard consecutive prewhitening technique. First, we fitted the data with a Fourier sum representing variations with the dominant (radial) frequency. The residuals of the fit were then searched for secondary frequencies with a Fourier transform.

We analyzed all single mode and double mode Cepheids listed in the OGLE-II catalogs (Udalski et al. 1999; Soszyński et al. 2000), nearly 1300 stars in total. Full results of this survey are presented elsewhere (Moskalik & Kołaczkowski 2008). Here we discuss only our findings concerning the presence of nonradial modes in classical Cepheids.

First Overtone Cepheids

The OGLE-II catalog lists 462 first overtone (FO) Cepheids. We detected residual power in 64 of them. In 42 variables, which constitute 9% of the entire LMC sample, we were able to resolve this power into individual frequencies. (We consider two frequencies to be resolved if $1/\Delta f < 600 \text{ days}$). Following notation originally introduced for RR Lyrae variables (Alcock et al. 2000), we call these stars FO-$\nu$ Cepheids.

In most of the FO-$\nu$ Cepheids only one secondary peak was detected, but in several variables two peaks were found. In all cases they have extremely small amplitudes. With the exception of a single star, the secondary-to-primary amplitude ratio, $A_1/A_1$, is always below 0.1, with the average value of 0.048. We note, that secondary peaks detected in the LMC first overtone RR Lyrae stars are typically almost an order of magnitude stronger, with $A_1/A_1 = 0.31$ on average (Nagy & Kovács 2006).

It is easy to check, that period ratios measured in FO-$\nu$ Cepheids are not compatible with those of the radial modes. This implies, that the secondary frequencies detected in these pulsators must correspond to nonradial modes of oscillations.
The secondary frequencies in FO-ν Cepheids come in two different flavours. In 37 variables they are located close to the primary (radial) frequency, within |Δf| < 0.13 c/d. In 84% of cases, secondary frequencies are lower than the primary one (Δf < 0). When two secondary peaks are present, they always appear on the same side of the primary peak. In 7 FO Cepheids a secondary periodicity of a different type was found: a high frequency mode, with the period ratio of \( P_\nu / P_1 = 0.60 - 0.64 \). Such a period ratio places the nonradial mode just below the frequency of the (unobserved) fourth radial overtone. The two types of nonradial modes are not mutually exclusive. Indeed, in two Cepheids both a high frequency secondary peak and a secondary peak close to the primary frequency were found.

Although the population of FO Cepheids in the LMC extends down to periods as short as 0.4 day, we detected nonradial modes only in stars with \( P_1 > 1.2 \) day. In fact, the incidence rate of nonradial modes systematically increases with the primary pulsation period, reaching 19% for stars with \( P_1 > 3.0 \) day. We interpret this behaviour as a selection effect: the Cepheids with longer periods are brighter, consequently it is easier to detect very low amplitude secondary periodicities in their lightcurves. If so, then the true incidence rate of nonradial modes in LMC overtone Cepheids can be significantly higher that 9% derived in this survey.

**Fundamental Mode Cepheids**

OGLE-II catalog lists 719 fundamental mode (FU) Cepheids. We searched all of them for secondary periodicities. We found no nonradial modes in the FU Cepheids of the LMC.

**FU/FO Double-Mode Cepheids**

In the course of systematic frequency analysis of OGLE-II Cepheids, we discovered 4 new fundamental/first overtone (FU/FO) double mode pulsators. Together with stars listed in the OGLE-II catalog, this brings the total number of LMC Cepheids of this class to 23. We found nonradial modes in 3 of them. These are the first detections of nonradial modes in the FU/FO double-mode Cepheids. In the following, we call these stars FU/FO-ν Cepheids. In two cases the secondary mode appears very close to the first (radial) overtone. The values of the frequency differences \( \Delta f = f_\nu - f_{FO} \) are very similar to those observed in the FO-ν Cepheids. In the third star, the secondary mode was found at a high frequency, with a period ratio of \( P_\nu / P_{FO} = 0.623 \). This is the same mysterious period ratio, which is frequently observed in the FO-ν Cepheids. Clearly, nonradial modes detected in the FU/FO-ν Cepheids are somehow related to the first radial overtone and their frequencies are drawn from the same distribution as in the case of the FO-ν Cepheids.

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**References**