Where is the energy or where does it come from?

On the amplitude of harmonics of the CoRoT RR Lyrae star 101370131

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Abstract

Corot 101370131 has been discovered to be a monoperiodic RR Lyrae by the CoRoT satellite during its first long run (LRc01). It pulsates highly non-linearly with a 0.619332719 day period: 33 harmonics of the main frequency are identified in the Fourier spectrum. Our fit based on this Fourier decomposition is the most accurate one which has been ever done for a monoperiodic RR Lyrae star. The amplitude behaviour of the harmonics does not follow a simple exponential decrease. By investigating the energy balance of the pulsation we tested two alternative explanations of this strange behaviour.

Data & analysis

Observations

Data of CoRoT 101370131 ($\alpha = 19^{\mathrm{h}}\,28^{\mathrm{m}}\,14.4^{s}$, $\delta = +00^\circ\,06'\,3.27''$, $V = 15.28$ mag) have been measured by the CoRoT exoplanet CCDs during the first long run (from 16 May 2007 to 15 October 2007) in the centre direction (LRc01) of the Galaxy. The total time span is 152 days, the time sampling of the light curves is 512 seconds. We used here the resulting "white" flux.

Analysis

A standard Fourier analysis was made by use of the MuFrAn (Multi-Frequency Analyzer) package (Kolláth 1990). **The spectrum is dominated by the main pulsation frequency $f_0 = 1.614641$ d^{-1} and its harmonics up to the 33th order**. This is the highest number of harmonics ever detected in a monoperiodic RR Lyrae star. The good sampling and high accuracy allowed us to detect significant peaks up to the Nyquist frequency ($f_N = 84.375$ d^{-1}). CoRoT data surpass all ground-based observations in accuracy and even *Kepler* long cadence data as well in respect of time resolution.

Amplitude decrease

By investigating the amplitude of harmonics we see that **there is a local minimum of the harmonics' amplitude at the 11th harmonic**, as it has been mentioned by Paparó et al. (2009). The exact behaviour is shown in **Fig 1**. Similar feature was also found in other CoRoT RR Lyrae star V1127 Aql (Chadid et al. 2010), although the amplitudes of V1127 Aql show only a standstill instead of the turning back presented in **Fig 1**.

Current models are not able to reproduce the finest details of RR Lyrae light curves. Nevertheless, we can address the question based on the observation: is there any **energy blocking mechanism** acting, producing lower amplitude around 10-15th harmonics or **some extra energy** is included in the highest order (12-33th) harmonics? The energy requirements of both options are tested.

References

[1] Chadid, M. et al. (2010) *A&A*, **510**, A39
[2] Kolláth, Z. (1990) Occ. Tech. Notes. Konkoly Obs. No 1.
[3] Paparó, M. et al. (2009) AIP Conf. Proc. 1170, p. 240.

Amplitude of the harmonics

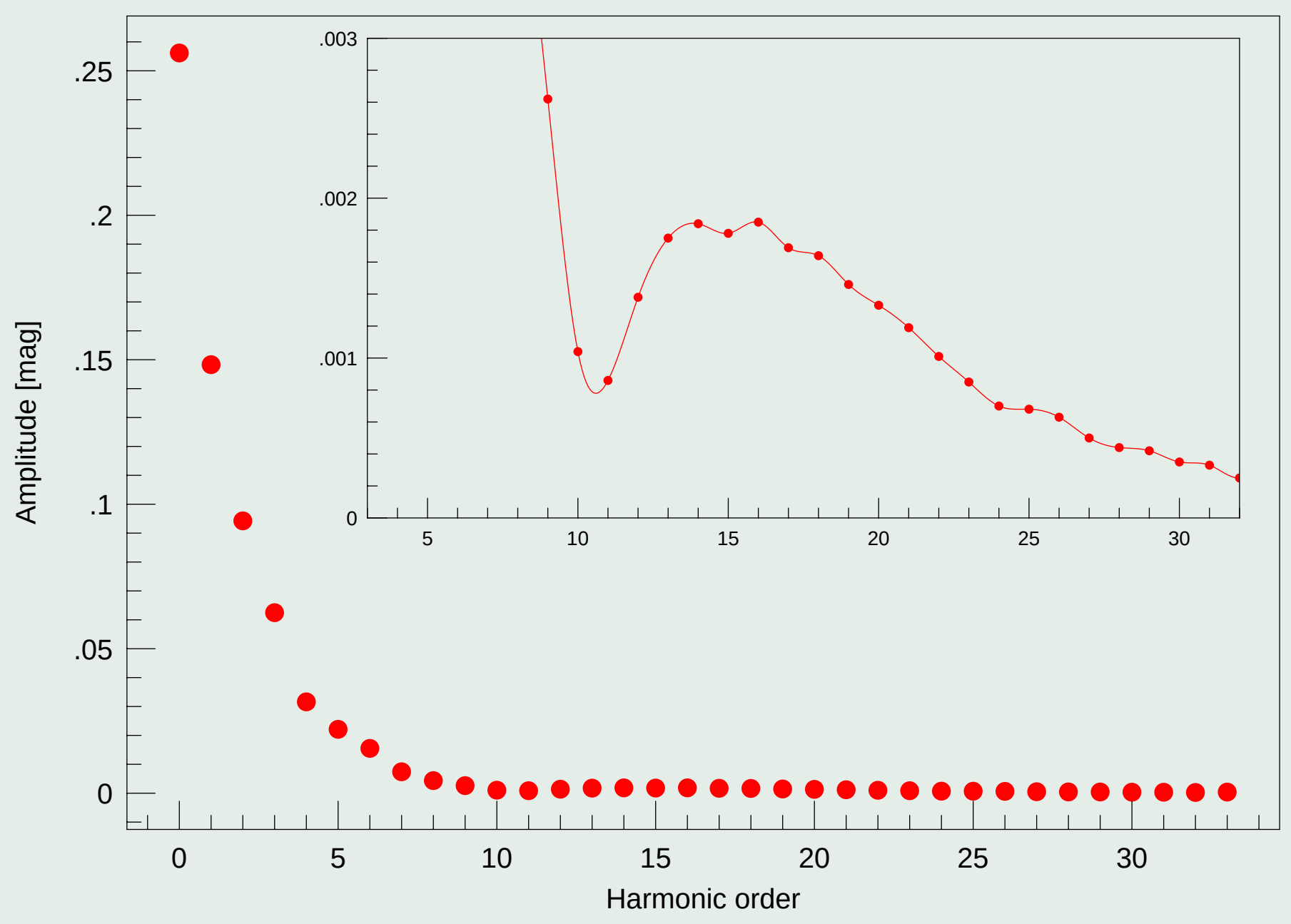

Fig. 1. Fourier amplitude behaviour of Corot 101370131. The main panel shows the decrease of the amplitudes on an overall scale. **The amplitude behaviour seems to follow an exponential decrease** as it was noticed in previous ground-based investigations. Since with our high quality data set we can follow the harmonics up to 33th order, we could investigate the amplitude behaviour of the higher order harmonics with much lower amplitude. As the insert shows **the higher order harmonics do not follow the exponential amplitude decrease** of the lower order harmonics.

Fits for the amplitudes

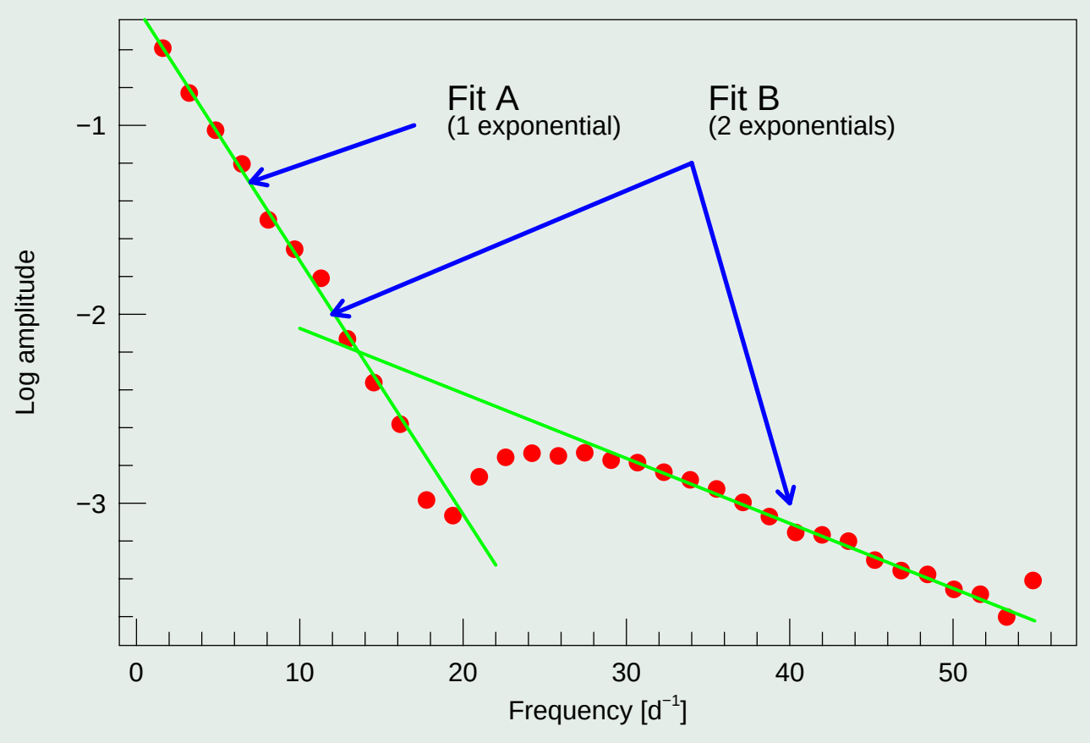

Fig. 2. Amplitude behaviour represented on the logarithmic scale. The (green) lines show the fitted exponential functions. **Fit A** represents the case where amplitudes decrease according to the rate of lower (0-11th) harmonics. **Fit B** uses two exponentials with a breaking point at the local minimum in amplitude at the 11th harmonic.

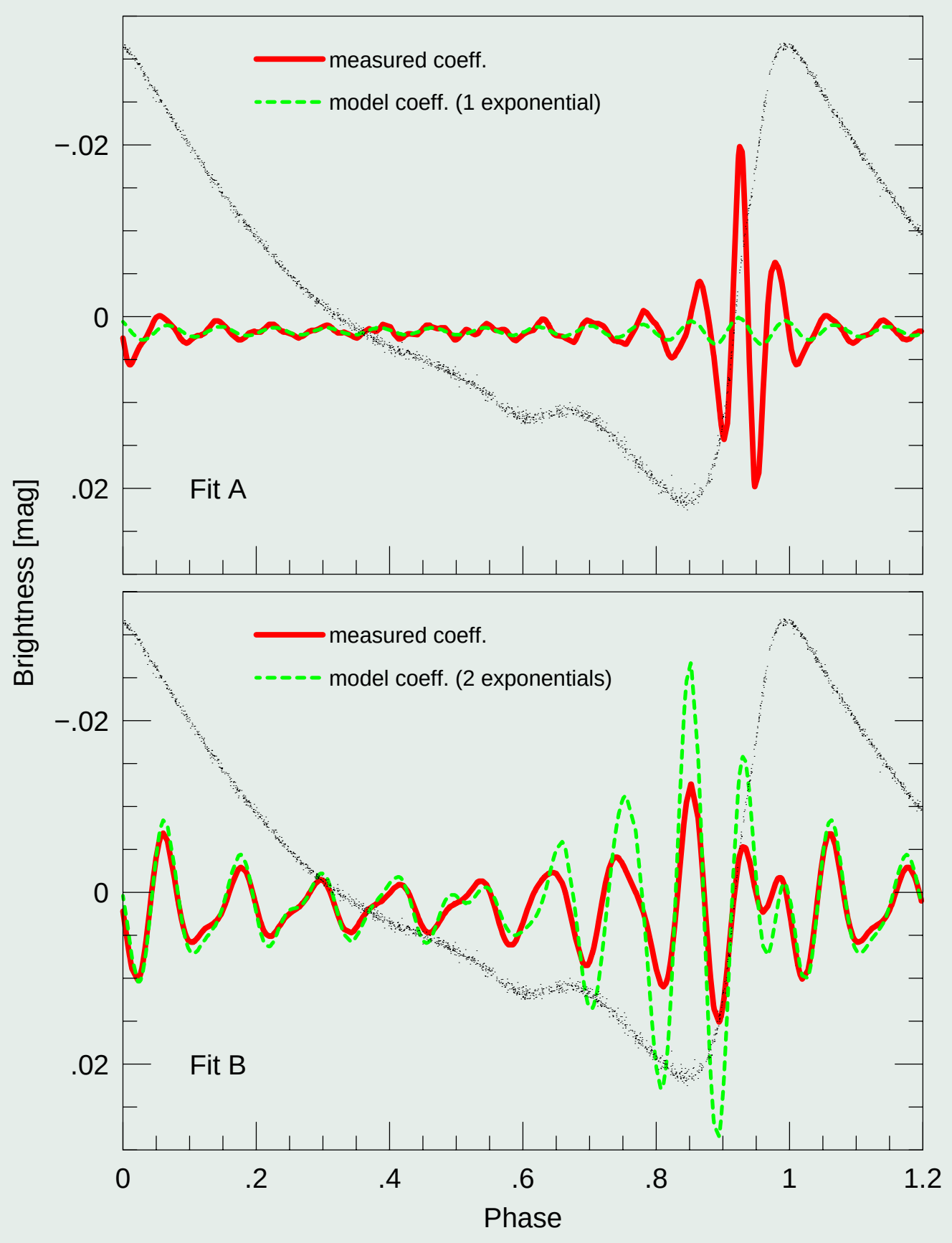

Fig. 3. Location of the brightness differences between the model light curves and observed data. Red continuous lines show the folded sythetic light curves calculated with the appropriate observed parameters (see text for the details). Green dashed lines show the same functions prepared for the model parameters. For comparison the observed data points are rescaled and plotted (small dots).

Fit A

We **suppose that the amplitude behaviour of the harmonics follow the same exponential decrease as determined by the lower order harmonics (first green line in Fig. 2.)** The higher order harmonics have much higher amplitude that we can expect by the single exponential behaviour. In that case we have to explain some energy gain over the pulsation.

We separated the contribution of the higher order harmonics using the observed Fourier parameters and supposing Fourier amplitudes according to a single exponential decrease. Synthetic light curves were calculated in both cases and compared them in the **top panel of Fig. 3**. **Red continuous line** shows the light curve contribution of 12-33th harmonics of the observed Fourier parameters, while **green dashed curve** were generated by the same harmonics having amplitude determined by the single exponential decrease.

Comparing the red continuous and the green dashed curves we found a narrow phase region ($\sim 0.8 - 0.9$) where the model and the real light curves differ. As we see this region locates in the ascending branch of the pulsation, where the shock wave is the strongest.

Fit B

An other option is a fit using two exponentials (green lines in Fig. 2.) with a breaking point at around the 10th harmonics. Here we suppose that the medium order harmonics (10-15th) behave in amplitude according the second exponetial determined by the highest order harmonics.

Synthetic light curves were calculated again using the median order (10-15th) harmonics in two ways: using the observed Fourier parameters (**red line in bottom panel of Fig. 3.**) or calculating the amplitudes according to the exponential function of the higher order harmonics (**green dashed line**).

The measured amplitudes present smaller contribution than the model light curve. The difference between two curves localized in a wider range than in Fit A around the minimum of the light curve. This is around the phase of the early shock ends and where the main shock starts.

Energy balance

A monoperiodic RR Lyrae star pulsates with extremely high regularity. The kinetic energy included in the pulsation is the same from cyle to cyle. Compared to the observations our first hypothesis (singe exponential fit: Fit A) revealed 0.03% extra energy. The second hypothesis (two exponentials in the fit: Fit B) showed 0.05% missing (blocked) energy.

In both hypotheses the differences concentrate in the phases where the shock waves appear in the atmosphere of RR Lyrae stars. In the first case, extra energy is superposed to the pulsation by shock weaves, while in the second case some part of the pulsation energy is blocked by shock waves.

Acknowledgments

JMB, MP and RSz acknowledge the support of the ESA PECS projects No. 98022 & 98114.