Mode Identification and Seismic Modelling of the β Cep Star EN (16) Lac *

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Abstract. We perform for the first time spectroscopic mode identification in EN (16) Lac. Although we do not come up with a unique solution, the combination with existing photometric identifications allows us to make an unambiguous decision on the wavenumbers of the two main modes. Using these wavenumbers, we computed numerous stellar models for the stellar parameters of EN (16) Lac. This allows us to conclude that the metallicity of the star amounts to Z=0.015 and its age is 1.5×10^7 years. The models without overshooting agree best with the data.

Keywords: β Cep stars, pressure modes, high-resolution spectroscopy

1. History of EN (16) Lac

EN (16) Lac (B2IV) is a non-radial p-mode oscillator of the class of β Cep stars. Chapellier et al. (1995) summarized all photometric and radial-velocity (RV) studies of the oscillation modes of the star. They conclude with a definite identification as $\ell = 0, 2, 1$ for the degrees of the modes with the three well-known frequencies. For the latter, we here adopt the latest values derived by Lehmann et al. (2001): $f_1 = 5.91128\,\mathrm{c\,d^{-1}}$, $f_2 = 5.85290\,\mathrm{c\,d^{-1}}$, $f_3 = 5.50259\,\mathrm{c\,d^{-1}}$.

Lehmann et al. (2001) have made a very detailed spectroscopic study from the point of view of the orbital variations of EN (16) Lac, which is also an eclipsing and spectroscopic binary. They disentangled the orbital and pulsational RV variations and derived more accurate orbital elements, among which $P_{\mathrm{orb}} = 12.096864\,\mathrm{d}$ and $e = 0.0539$.

The investigation of EN (16) Lac is important, as it is a prime testcase to perform a ground-based seismic study of a massive star, i.e. a star with a large convective core. An additional reason for choosing this star is of course its well-known binary and pulsational nature.

Dziembowski & Jerzykiewicz (1996) were the first to attempt a seismic analysis. The latter was hampered, however, by the multitude of possibilities among theoretically predicted modes and they urged for spectroscopic mode

* Based on observations gathered with the coudè spectrograph attached to the 2.0 m reflector telescope at Tautenburg Observatory

identification. They firmly concluded, independently of the exact mode identification for f_2 and f_3, that the interior of EN (16) Lac rotates significantly faster than the outer layers.

2. Goal of the Study

It is clear that EN (16) Lac is one of the few β Cep stars of which we have sufficient information to try a detailed seismic analysis. Our current goal is threefold :

1. to perform mode identification from line-profile variations;
2. to re-evaluate the photometric mode identification by means of a non-adiabatic formalism (see Dupret et al., this conference);
3. to calculate seismic models of the star and derive information about the internal stellar physics.

In particular, we want to confront our results with those by Dziembowski & Jerzykiewicz (1996).

The data we use for this study is a set of 940 high-resolution high S/N spectra of the star gathered with the coudé spectrograph attached to the 2.0 m reflector telescope at Tautenburg Observatory, with a total time base of 474 days.

In this poster paper we give a summary of our findings. We refer to the two papers by Aerts et al. (2003a,b) for a complete description of the analyses we performed.

3. Spectroscopic Mode Identification

We have used 2 methods to derive the spherical wavenumbers (ℓ, m) of the 3 modes: a new version of the moment method (Briquet & Aerts, this conference) and the method of the phase variations across the profile (Telting, this conference).

The moment variations of EN (16) Lac lead to the following most likely identification, among several candidate combinations :

$$\begin{cases} \ell_1 = 0,\ m_1 = 0,\ \text{ampl} = 13.1\,\text{km s}^{-1}, \\ \ell_2 = 2,\ m_2 = 0,\ \text{ampl} = 13.5\,\text{km s}^{-1}, \\ \ell_3 = 1,\ m_3 = 0,\ \text{ampl} = 4.1\,\text{km s}^{-1}, \\ v\sin i = 35\,\text{km s}^{-1},\ \sigma = 8\,\text{km s}^{-1},\ i = 35^\circ. \end{cases}$$

(see Briquet & Aerts, this conference, for further explanation and the meaning of the symbols). This solution is compatible with the amplitude and phase

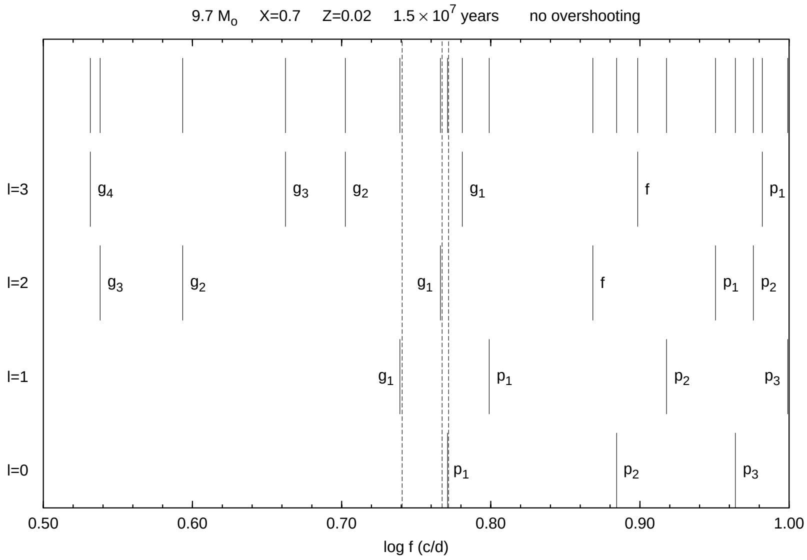

Figure 1. One of the three theoretical models with solar metallicity for which the frequencies (full vertical lines) and mode identification agree with the observed ones (dashed vertical lines); this model is fully compatible with the spectroscopic mode identification with the moment method given above.

variability across the profile. However, several other (ℓ,m) combinations also explain well the amplitude and phase behaviour. All the good candidate combinations have **axisymmetric** $\ell \leq 2$ modes for f_1 and f_2, which is a very important constraint for the modelling. We finally point out that the new photometric mode identification by Dupret et al. (this conference) also leads to the identification $\ell = 0,2,1$ for respectively f_1, f_2, f_3.

4. Seismic Modelling

Given that we have obtained the severe restriction $m_1 = m_2 = 0$, $\ell \leq 2$, it is worthwhile to perform modelling as the stellar parameters of EN (16) Lac are relatively well constrained thanks to its binary nature. We have computed numerous stellar models and compared their frequencies with the observed values of f_1 and f_2, as these are axisymmetric modes. We subsequently investigated for which of the models the three modes are compatible with the mode identification. We find in this way three acceptable models among those with solar metallicity. In all three cases, f_1 corresponds to the radial fundamental, f_2 to the $\ell = 2$ g_1-mode and f_3 to the $\ell = 1$ g_1-mode.

A confrontation between observed photometric amplitude ratios and non-adiabatic eigenfunctions according to the formalism of Dupret (this conference) allows subsequent further constraining of the models. Indeed, the computed amplitude ratios are very dependent on Z (Dupret, this conference). Values below Z= 0.015 do not lead to excitation of the modes. We obtain a better agreement between observed and theoretical photometric amplitude ratios for a model with Z=0.015 instead of Z=0.02 and which has also an age of 1.5×10^7 years and no overshooting, while the corresponding frequencies agree equally well as for the model shown in Fig. 1.

5. Conclusions and Future Work

We have derived for the first time overall consistency between photometric and spectroscopic mode identification and theoretical modelling in the β Cep star EN (16) Lac by means of a stellar model without overshooting and an age of some 15 million years.

We do not see any reason to have to assume that EN (16) Lac rotates significantly faster in its interior.

We will further explore additional models of slightly more massive stars in the near future in order to see if our solution is unique in explaining all aspects of the observational variations of the star. The results will be presented in Aerts et al. (2003a,b).

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