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# Seismology and rotation of the Herbig Ae star HD 104237

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**Abstract.** HD 104237 is the first pulsating Herbig Ae star for which very recently a significant number of pulsation frequencies has been detected by means of high-resolution spectroscopy. The high quality radial velocity curve based on 1888 individual echelle spectra obtained in 42 nights in 1999 and 2000 revealed for the first time by spectroscopic means multiperiodic oscillations in a pre-main sequence star: a total of 8 frequencies have been detected so far, 5 amongst them were detected at a very high confidence level Böhm et al. (2004). This result encouraged us to develop asterosismological models for such young pre-main sequence pulsator (Dupret et al. (2005)), but the dramatic lack of a precise knowledge of the fundamental stellar parameters appear still to be critical. A summary of the main results of the pulsation study are presented and first indications for a stellar rotational modulation are exhibited.

**Key words.** Stars: pre-main-sequence – Stars: oscillations – Stars:individual: HD104237 – Binaries:spectroscopic

## 1. Introduction

The Herbig Ae/Be stars are pre-main sequence (PMS) objects of intermediate mass (2-8 $M_{\odot}$) (Herbig (1960)). They all show signs of intense stellar activity and strong stellar winds which are most likely linked to the presence of stellar magnetic fields and, in some cases, interacting circumstellar accretion disks. However, their position in the HR diagram indicates that they are in the radiative phase of their contraction towards the main sequence (Iben (1965)) and should in principle not possess any outer convective zone; therefore, if the young stellar evolutionary theory is correct, the classical solar-type magnetic dynamo mechanism could not be responsible for the observed phenomena. Finding the origin of this paradoxical activity is a major concern for young stellar evolution. Marconi & Palla (1998) predicted the existence of a pre-main-sequence instability strip, which is being crossed by most of the intermediate mass PMS objects for a significant fraction of their evolution to the main sequence. This strip covers approximately the same area in the HR diagram as the $\delta$ Scuti variables and until now about 20 PMS pulsators have been detected, HD 104237 being among the brightest PMS pulsators detected so far. Asteroseismological studies of these young pulsators will provide new insights about their internal structure and help understanding the origin of activity and winds in these objects.

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A recent review by Catala (2003) presents the status of observational studies of pulsations in these stars, but the field is actually in very quick evolution.

The aim of our study (Böhm et al. (2004)) was to provide a first set of asteroseismic constraints for forthcoming non-radial pulsation models by determining unambiguously a higher number of periodicities with their corresponding amplitude and phase values: to achieve this goal, we decided to perform high resolution spectroscopic observations on a large time basis and with optimized time coverage.

## 2. Detection of multiperiodic stellar oscillations

On the basis of two years of spectroscopic echelle observations providing a high precision radial velocity curve (the resolving power of the spectrographs employed in the bi-site campaign was higher than R = 35000), we clearly establish for the first time that HD 104237 A is a multiperiodic pre-main sequence pulsator. Five oscillation frequencies between 32.37 and 35.60 $d^{-1}$ have clearly been observed in 1999 and in 2000, but with different amplitudes and amplitude ratios. Their existence is therefore firmly established. An additional 3 frequencies are reported based on the 1999 observations, but have not been found in the year 2000 observations. The numerical results of the period analysis are given in Table 1.

## 3. Clues for rotational modulation

Detecting the largest possible amount of pulsation frequencies is obviously the essential factor concerning the development of reliable asteroseismological models. Of similar importance is however the precise determination of all fundamental stellar parameters which enter the oscillation code either directly (such as vsin i, sin i, $P_{rot}$) or indirectly via the stellar structure model (eg. $T_{eff}$, log g, metallicity). HD 104237 shows a fairly small vsini of 12±2 km $s^{-1}$ (Donati et al. (1997)), which could be due to i) an intrinsically large period of stellar rotation or ii) a star seen more or less pole on. Rotational splitting of oscillation modes being obviously sensitive only to (i), it was important to search for clues of rotational modulation of lines forming nearby the stellar photosphere providing us with an independent measure of the stellar rotation period. We produced therefore two-dimensional time series based on our extensive data set showing the evolution of highly resolved line profiles of the most active lines in the visible spectrum. Fig. 1 shows the variation of the H$\alpha$ profile during more than 350 hrs. It is clearly seen that around 50 hrs, 150 hrs and 250 hrs the blueshifted absorption component at approximately - 300 km $s^{-1}$ becomes significantly deeper and broader. If interpretated as corotating clouds close to the stellar surface, this would yield a $P_{rot}$ of 100±5 hrs. These results are still preliminary and need further confirmation. The 2D periodogram (right of Fig. 1) shows much more energy in the redshifted emission, which does not seem to be concentrated around a particular frequency. These results are difficult to interpret, but the residual profile 2D spectrum (obtained after subtracting an average profile from all individual profiles) represented in Fig. 2 shows interleaving emission and absorption features (relative to the average profile) transiting from the red to the blue part of the P Cygni emission profile. Typical transition timescales appear to be around 100 hrs. If confirmed, and by taking $T_{eff}$ = 8500 K, R = 2.5± 0.2 R$\odot$ (calculated from the stellar luminosities announced in the litterature) and vsini = 12±2 km $s^{-1}$, the inclination of the stellar rotation axis would be i = $23^{+9}_{-8}$ degrees, corresponding to an intermediate position, but closer to pole-on (i=$0^o$) than to edge-on (i=$90^o$).

## 4. First asteroseismological models

The numerous pulsation frequencies detected in HD 104237 give a unique opportunity to probe the internal structure of a young pre-main sequence star. Further work is required to understand the driving of the modes, which cannot be the classical $\kappa$-mechanism ( (2005)). HD 104237 is thus not a $\delta$ Sct-type pulsator. The equidistance found in the fre-

**Table 1.** Frequencies and amplitudes derived from the Fourier analysis of the 1999 (left) and 2000 (right) data. The uncertainty of the frequency is less than 0.04 c/d (Böhm et al. (2004)).

| 1999 | | | 2000 | | |
|---|---|---|---|---|---|
| Frequency (c/d) | Amplitude (km s$^{-1}$) | Conf. ¿% | Frequency (c/d) | Amplitude (km s$^{-1}$) | Conf. ¿% |
| $f_1$: 33.289 | 1.320 | 99.9 | 33.283 | 0.258 | 99.9 |
| $f_2$: 35.606 | 0.474 | 99.9 | 35.609 | 0.328 | 99.9 |
| $f_3$: 28.503 | 0.195 | 99.9 | 28.521 | 0.165 | 99.9 |
| $f_4$: 30.954 | 0.139 | 99.0 | 31.012 | 0.177 | 99.9 |
| $f_5$: 33.862 | 0.099 | 99.0 | | | |
| $f_6$: 32.616 | 0.105 | 99.0 | 32.375 | 0.113 | 99.9 |
| $f_7$: 34.88 | 0.1 | | | | |
| $f_8$: 35.28 | 0.05 | | | | |

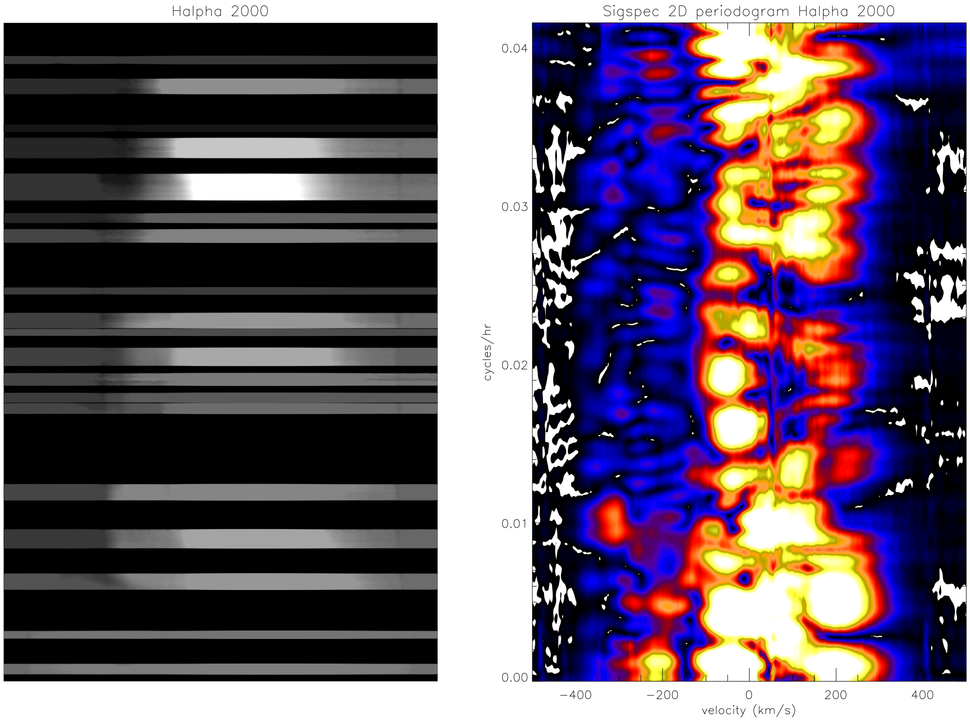


**Fig. 1.** Dynamical spectrum of the P Cygni H$\alpha$ profile during the bi-site campaign SAAO/Mt Stromlo in April 2000. The left figure shows the periodically varying blueshifted absorption component. The redshifted emission reaches up to more than 7 times the continuum and shows also strong variations, which are more difficult to interpretate. The right figure shows the corresponding 2D time serie analysis (frequencies being expressed in cycles/days). Each velocity bin was analyzed making use of the ”SigSpec” periodicity analysis software (P. Reegen, Vienna, private communication). The 2D periodogram reveals the presence of the periodically varying blueshifted absorption component at approximately - 300 km s$^{-1}$ and 0.01c/d.

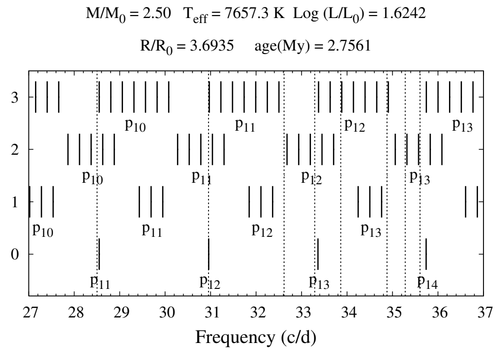


**Fig. 3.** Theoretical and observed frequencies for the actual "best fit" model of HD 104237. The observed frequencies correspond, if confirmed, to high radial order $p_{11}$ to $p_{15}$ modes.

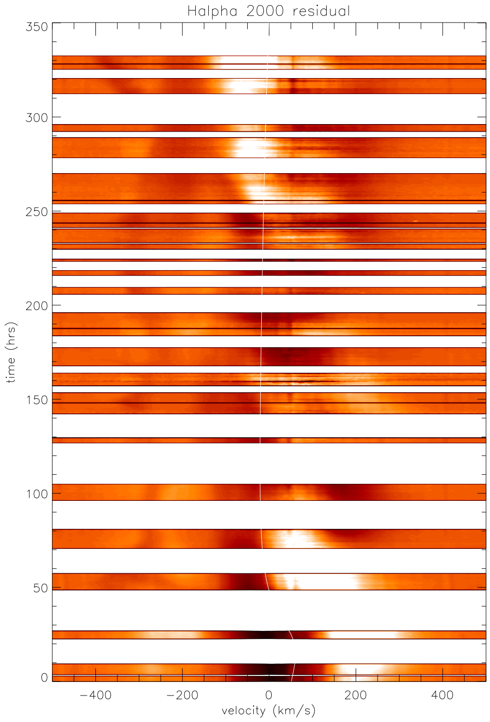


**Fig. 2.** Dynamical spectrum of the residual H$\alpha$ profile of HD 104237.

quency spectrum could be the large separation. Luminosities higher than the ones currently found in the literature (Van den Ancker et al. (1998)) are required to fit this large separation. Better spectroscopic determinations of $T_{eff}$ and log $g$ will be preformed soon by Böhm et al., which will allow us to go further in our seismic study and better constrain the internal physics of this star. The actual "best fit" model is represented in Fig. 3.

## 5. Conclusion

The work presented in this paper is still in a preliminary state. However, it can clearly be seen how promising is the interwork between high-resolution spectroscopic campaigns and their results and in-depth asteroseismological modeling. We intend to eliminate uncertainties on fundamental stellar parameters in the next step and to improve the precision of the model in the very near future.

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