Periodic mass-loss episodes due to an oscillation mode with variable amplitude in the hot supergiant HD 50064*

C. Aerts1,2, K. Lefever1,3, A. Baglin4, P. Degroote1, R. Orio1, M. Vučković1, K. Smolders1, B. Acke1,*, T. Verhoelst1,*, M. Desmet1, M. Godart1, A. Noels1, M.-A. Dupret1, M. Auvergne5, F. Baudin6, C. Catala1, E. Michel1, and R. Samadi3

1 Institut voor Sterrenkunde, K.U.Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium
2 Department of Astrophysics, IMAPP, University of Nijmegen, PO Box 9010, 6500 GL Nijmegen, The Netherlands
3 Belgisch Instituut voor Ruimte Aeronomie (BIRA), Rijkslaan 3, B-1180 Brussels, Belgium
4 LESIA, CNRS UMR8109, Université Pierre et Marie Curie, Université Denis Diderot, Observatoire de Paris, 92195 Meudon cedex, France
5 Institut d’Astrophysique et de Géophysique, Université de Liège, Allée du 6 Août 17, B-4000 Liège, Belgium
6 Institut d’Astrophysique Spatiale, CNRS/Université Paris XI UMR 8617, F-91405 Orsay, France

Received ; accepted

ABSTRACT

Aims. We aim to interpret the photometric and spectroscopic variability of the luminous blue variable supergiant HD 50064 (V = 8.21) and its spectroscopic variability, with an average value of log(M) = -5 (in M☉ yr^-1). We tentatively interpret the 37 d period as the result of a strange mode oscillation.


1. Introduction

One of the goals of the asteroseismology programme (Michel et al. 2006) of the CoRoT satellite (Baglin et al. 2006) is to explore the Hertzsprung-Russell diagram (HRD) through uninterrupted time series of white-light photometry of unprecedented precision. In this context, numerous non-radial pulsators of various kind have been observed and analyzed, among which massive stars on the main sequence (e.g., Degroote et al. 2009; Neiner et al. 2009). With the goals of mapping the uppermost part of the HRD and understanding the role of oscillations in the mass loss of evolved massive stars, a hot supergiant was observed in the seismic programme of the satellite.

The B-type supergiant HD 50064 (V mag of 8.21) has not been studied in detail. Its spectral type assignments range from B1Ia (Jacoby & Hunter 1984) to B6Ia (Blanco et al. 1970). It was monitored by CoRoT, whose performance not only delivers two orders of magnitude better precision than any ground-based photometry, but even more importantly for supergiant stars, also guarantees uninterrupted data during several months. This is essential for progress in understanding massive evolved stars, because ground-based data for supergiants have so far suffered severely from very low duty cycles.

The oscillations of evolved massive stars known so far essentially come in two flavours. Classical gravity mode oscillations with periods of a few days excited by the k mechanism, have recently been found from space photometry (Saio et al. 2006; Lefever et al. 2007a). On the other hand, theory predicts so-called strange modes with periods between roughly 10 and 100 d in stars with masses above 40 M☉. These strange modes, which can be both radial and non-radial in nature, are modes trapped in a cavity caused by a density inversion in the very outer, highly non-adiabatic envelope of stars with a high L/M ratio whose radiation pressure dominates over the gas pressure (Glatzel & Kiriakidis 1993; Saio et al. 1998; Glatzel et al. 1999; Dorfi & Gautschy 2000). This type of oscillation has been claimed to be responsible for the mass-loss episodes of luminous stars, such as luminous blue variables (LBVs), e.g. Glatzel & Kiriakidis (1993), but observational proof of the occurrence of strange modes has not been established so far. Our data of HD 50064 suggests that the star undergoes a strange mode oscillation.
2. Data description

2.1. The CoRoT data

HD 50064 was observed by CoRoT during a long run in the anticentre direction (LRaO1) for 136.9 days. It is the only hot supergiant among the seismology targets so far. The CoRoT light curve contains 319,913 datapoints, with a time sampling of 32 s, after deleting the measurements suffering from hot pixels during the passage through the South Atlantic Anomaly. In order to compare the space photometry behaviour of HD 50064 with the one reported in the literature (Halbedel 1990), we transferred the CoRoT fluxes to white-light magnitudes.

All seismology targets of LRaO1 are subject to a small downward trend of instrumental origin. In the case of HD 50064, the trend is clearly stronger and probably intrinsic to the star. It was corrected for by a linear approximation. This detrended light curve is shown as the thick line in the upper panel of Fig. 1. Large variations occur, with peak-to-peak values of ~ 0.2 mag and with a time scale of about one month. This is compatible with the scarce data in Halbedel (1990). The light curve also reveals a sudden rise in amplitude near day 62.

2.2. Follow-up spectroscopy

Halbedel (1990) took one spectrum of HD 50064 and found a PCyg Hα profile with a V/R ratio of 0.23 and a maximum red emission peak value of 4.2 continuum units. A few low-resolution low signal-to-noise UV spectra taken in 1979 with the IUE satellite are also available, but they do not allow quantitative estimates of the stellar parameters to be derived. We assembled 14 high-resolution échelle spectra of the star with the CORALIE spectrograph attached to the 1.2m Euler telescope in La Silla, Chile, at three epochs (5, 5, 4 spread over 6, 8, 6 nights in Oct. 08, Jan. 09, Mar. 09, respectively), after the CoRoT data revealed the star’s variability. The integration time was 30 min, leading to an S/N level of about 50. The usable parts of the spectrum have wavelengths between 4000 Å and 7000 Å.

The average profile of some selected lines for the three epochs are shown in Fig. 2. The Balmer lines point towards mass loss that is variable on the same time scale as the CoRoT photometry. The He and Mg lines are also variable on this time scale. We cannot exclude additional spectroscopic variability with periods below a day.

2.3. Interferometry

Given that the star is surrounded by circumstellar matter, as the Balmer lines reveal, we observed HD 50064 with the near-IR interferometric instrument VLTI/AMBER (Petrov et al. 2007) during Belgian GTO time in March 20091. The measurement was performed on the closed triangle A0-K0-G1, providing baselines of 90, 80, and 125 m, respectively. Our analyses show that the target was not resolved. Based on the spread on the data, we find that the target’s half-light radius must be less than 1 milli-arcsec. For the distance estimate of ≥ 2900 pc (Halbedel 1990), this upper limit of 1 milli-arcsec translates to 650 Rₖ, for the disk or a disk-to-star flux ratio below 7% in the covered wavelength range (1.2 – 2.5 μm) when assuming a simple model of a circumstellar disk around an unresolved star.

1 program ID 083.D-0028
3. Analyses of the data

3.1. Modelling of the CoRoT light curve

![Amplitude spectrum of the CoRoT data of HD 50064](image)

Fig. 3. Amplitude spectrum of the CoRoT data of HD 50064, up to 5 d⁻¹ (57.87 μHz). At higher frequencies, only harmonics of the satellite orbit of 6184 s occur, with an amplitude below 1 mmag. The insets show an enlarged section at low frequencies (left) and the amplitude spectrum of the residuals after prewhitening with the dominant frequency and six of its (sub)harmonics (right).

A first look at the detrended light curve immediately revealed large non-sinusoidal variations in amplitudes in several hundreds of a magnitude, with periodicity of tens of days (Fig. 1). The data is thus highly oversampled. We binned the light curve by averaging 101 consecutive data points. All the results we list but with an amplitude and/or phase change near day 62. A separate harmonic fit with 0.027 d⁻¹ fixed for sets A and B and including the (sub)harmonics \( n f \), for \( n = 1/2, 1, 3/2, 2, 5/2, 3 \) is shown as a dashed line in Fig. 1. This leads to an amplitude and phase which we allow the frequency to be optimised for sets A and B (dotted line in Fig. 1). The residuals in the bottom panel of Fig. 1 show variability at the 1 mmag level (inset in Fig. 3) caused by the higher harmonics of 0.027 d⁻¹, while no additional independent frequencies were found.

We conclude that the CoRoT light curve of HD 50064 can be characterised by a single period of 37 d with a sudden amplitude increase of a factor 1.6, which occurs once on a time scale of 137 d.

3.2. Spectroscopic behaviour

![Phase diagrams of the radial velocity and equivalent width](image)

Fig. 4. Phase diagrams of the radial velocity and equivalent width of the three spectral lines He I 4471 Å (squares), He I 6678 Å (triangles), and Mg II 4481 Å (filled dots). Each measurement occurs twice for visibility purposes.

Our spectroscopic data of HD 50064 is limited to 14 spectra of moderate S/N, but it spans 169 d (Rayleigh limit of 0.006 d⁻¹). We computed the centroid velocities (see Aerts et al. 1992) for the least blended spectral lines, as well as their Fourier transform. This led to clear confirmation of the photometric period. Phase diagrams for the He I 4471 Å, He I 6678 Å, and Mg II 4481 Å lines are shown in Fig. 4. We find a consistent radial-velocity (RV) amplitude of 12.52 km s⁻¹ from these three lines. This amplitude is similar to the one of B-type radial pulsators along the main sequence (e.g., Aerts & De Cat 2003). Large equivalent width (EW) variations occur for the three considered lines, with relative peak-to-peak values near 50% (see bottom panel of Fig. 4). These also reveal the 37 d period for the two He lines. The phase difference between the EW and RV variations amounts to 277° ± 14° for He I 4471 Å and 246° ± 10° for He I 6678 Å. Adiabatic pulsation modes would give rise to values of 90° or 270°, depending on the spectral line. Deviations thereof are usually interpreted as non-adiabatic effects (De Ridder et al. 2002).

We computed an average spectrum for the three epochs after shifting each spectrum to the centroid velocity of the Mg II 4481 Å line (Fig. 2). This reveals a range in centroid velocities of up to 50 km s⁻¹ for lines formed at different optical depths. The V/R ratio of Hα is about 0.44 in Oct. 08, 0.56 in Jan. 09, and 0.73 in Mar. 09. Both Hα and Hβ evolve from a double-peaked emission profile to a P Cygni profile in that period, while Hγ transforms from an inverse P Cygni profile in Oct. 08 to a modest P Cygni profile in Jan. 09 and an absorption profile in Mar. 09, and Hδ is always in absorption. We interpret this behaviour in terms of radial motion of the atmosphere in the line.
forming region of Hα and Hβ in Oct. 08 while at the same time material recedes towards the stellar centre deeper in the atmosphere where Hγ and the He and metal lines are formed. This situation evolves to an expanding upper atmosphere in Jan. and Mar. 09, which are separated by two pulsation cycles.

We determined $T_{\text{eff}}$ and log $g$ from the EW of Si ii and Si iii lines, as well as He i lines, by comparing with the predictions for the extended grid of FASTWIND model atmospheres BSTAR06 in Lefever et al. (2007b). The absence of H en and Si iv lines places a clear upper limit to $T_{\text{eff}}$. Restricting the models to the solar Si abundance (Asplund et al. 2009) led to $T_{\text{eff}} = 13500$ K, log $g = 1.5$, where the differences for the three epochs were less than the typical uncertainties of 1000 K and 0.2 dex. The EW of the Balmer lines led to log $Q = \log (M_{\text{Sun}} R_{\odot})^{-1} = -11.5$. On the other hand, the peak heights of H α range from 1.5 in this study to 4 in Halbedel (1990) and this leads to the rough estimate $M \approx 10^{-5} M_{\odot}$ yr$^{-1}$ as an average mass-loss rate. This, combined with the value of $v_{\lambda 600} = 100$ km s$^{-1}$ derived from the blue wings of the Hα profiles, gives a radius estimate of $\approx 200 R_{\odot}$ and a luminosity log $(L/L_{\odot}) = 6.1$.

4. Interpretation

The 37 d period found in the CoRoT photometry and in the spectroscopy is compatible with the radial fundamental mode for the parameters of HD 50064, assuming $M \approx 45 M_{\odot}$ (e.g., Lovy et al. 1984). The behaviour of the Balmer lines is hard to explain in terms of non-radial gravity modes as found in other B supergiants (Lefever et al. 2007a). While the overall morphology of the light curve with the sudden amplitude changes resembles the theoretically predicted modes by Dorfi & Gautschy (2000), their predicted periods are an order of magnitude too short, and they did not give rise to mass-loss episodes. We thus suggest that HD 50064 is subject to a radial strange mode oscillation.

The spectrum of HD 50064 shows a strong resemblance to that of LBVs with moderate mass loss, e.g. HD 160529 (Stahl et al. 2003). We thus suggest that HD 50064 is on its way to that stage, by building up a circumstellar envelope while pulsating. The main conclusion of our work is that its pulsation mode is clearly connected with its variable mass loss. With only three epochs of spectroscopy, we cannot make a detailed comparison of the spectroscopic and pulsational behaviour, but we suggest a coordinated action for long-term photometric and high S/N spectroscopic follow-up observations in order to understand the detailed behaviour of the (strange) mode(s) and the relation with the mass loss of this supergiant.

Acknowledgements. CA and KL acknowledge discussions with Joachim Puls on stellar winds. The research leading to these results received funding from the ERC under the European Community’s 7th Framework Programme (FP7/2007- 2013)/ERC grant agreement n°227224 (PROSPERITY), as well as from the Research Council of K.U.Leuven and from the Belgian Federal Science Policy Office.

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