

DETECTION OF SOLAR-LIKE OSCILLATIONS IN TWO RED GIANT STARS

C. Barban¹, J. De Ridder¹, A. Mazumdar¹, F. Carrier², P. Eggenberger², S. De Ruyter³, J. Vanautgaerden¹,
F. Bouchy⁴, and C. Aerts¹

¹*Katholieke Universiteit Leuven, Instituut voor Sterrenkunde, Celestijnenlaan 200 B, 3000 Leuven, Belgium*

²*Observatoire de Genève, 51 chemin des Maillettes, 1290 Sauverny, Switzerland*

³*Universiteit Gent, Sterrenkundig Observatorium, Krijgslaan 281 S9, 9000 Gent, Belgium*

⁴*Laboratoire d'Astrophysique de Marseille, Traverse du Siphon-Les trois Lucs BP 8, 13376 Marseille Cedex 12, France*

ABSTRACT

We report here a preliminary analysis of red giants data obtained on two stars, ϵ Oph and η Ser, in which we are looking for solar-like oscillations. An excess power is clearly detected in the power spectrum obtained for these two stars. This excess power occurs around 60 μ Hz with a maximum amplitude of about 3 m/s for ϵ Oph and around 130 μ Hz with a maximum amplitude of about 2 m/s for η Ser. A preliminary search for equidistant peaks suggests a possible large separation, $\Delta\nu$, of ~ 7 μ Hz for ϵ Oph and ~ 8 μ Hz for η Ser. The frequency range where these two excess powers are observed and the possible large separations are in agreement with the results we obtained from theoretical frequency sets.

Key words: Asteroseismology; Observations; Solar-like oscillations; Giant stars: ϵ Oph, η Ser.

1. INTRODUCTION

The study of solar oscillations or helioseismology has demonstrated the power of this tool to test the physical conditions in stellar interiors. Solar oscillations, i.e. p -modes, are excited by turbulent convection near the surface (e.g., Balmforth, 1992a,b). Similar oscillations might then be expected in stars with an external convective envelope.

The detection of such oscillations in distant stars requires very precise and stable instruments due to the very weak signal, typically from few cm/s to few m/s, in radial velocity measurements, with periods ranging from a few minutes up to a couple of hours. Thanks to recent great progress in instrumentation, such oscillations have now been detected clearly in several stars on the main sequence or close to it (for recent reviews see Bouchy & Carrier, 2003; Bedding & Kjeldsen, 2003; Kjeldsen & Bedding, 2004).

Detection of such oscillations in red giant stars α UMa (Buzasi et al., 2000), Arcturus (Retter et al., 2003) and ξ Hya (Frandsen et al., 2002; Stello et al., 2004) have been also reported.

New results obtained for two red giant stars, ϵ Oph (G9.5III, $m_v=3.24$) and η Ser (K0III, $m_v=3.26$), during a two-month bi-site campaign using the CORALIE and ELODIE spectrographs, are presented here.

2. TARGET SELECTION

ϵ Oph (HD 146791) and η Ser (HD 168723) have been chosen for the following reasons:

- their spectral type (G9.5III for ϵ Oph and K0III for η Ser) for which we expect solar-like oscillations;
- their magnitude ($m_v = 3.24$ for ϵ Oph and $m_v = 3.26$ for η Ser) to have a S/N high enough to detect the signal associated to the solar-like oscillations;
- their low $v \sin i$ ($v \sin i = 2.8$ km/s for ϵ Oph and $v \sin i = 0.4$ km/s for η Ser, determined using CORALIE spectra) to obtain precise radial velocity measurements;
- their low and comparable declination ($\delta = -04\ 41\ 33.0$ for ϵ Oph and $\delta = -02\ 53\ 55.8$ for η Ser) to be able to observe these two stars from both La Silla, Chile and OHP, France during the same observing campaign.
- the absence of a close companion which can cause variations in the radial velocity and interfere with the seismic signal.

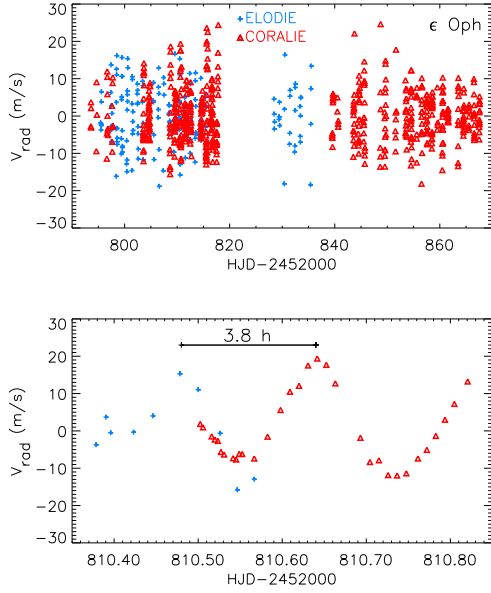


Figure 1. Radial velocity measurements of ϵ Oph as a function of time. Top: the whole time series. Bottom: a closeup of the whole time series. The blue sign symbols are for ELODIE data and the red triangles for CORALIE data.

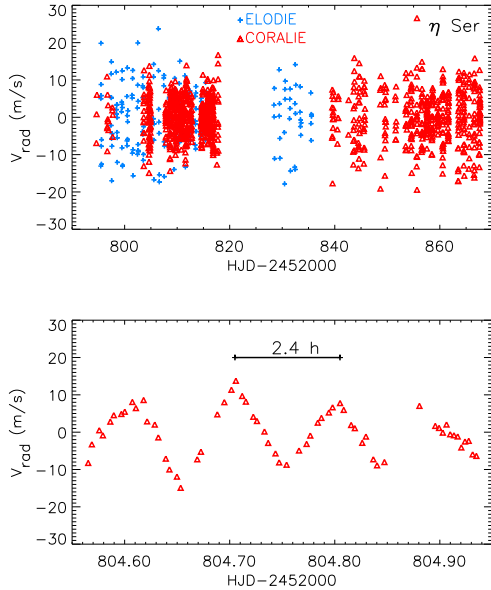


Figure 2. Same as Fig. 1 but for η Ser.

3. OBSERVATIONS AND DATA REDUCTION

ϵ Oph and η Ser have been observed during a bi-site campaign held in the summer of 2003 covering ~ 74 days. Two high-resolution fibre-fed echelle spectrographs have been used: CORALIE (Queloz et al., 2001) mounted on the 1.2-m Swiss Euler telescope at La Silla (Chile) and ELODIE (Baranne et al., 1996) mounted on the 1.93-m OHP telescope (France).

The data reduction process is presented by Bouchy & Carrier (2001) and Bouchy et al. (2001). The exposure times, for both stars, were 180 s except at the beginning and at the end of each nightly run, when the airmass was high, the exposure time was then 200 s. The two stars have been observed one after each other during the observing campaign; η Ser has been sampled twice as often as ϵ Oph because of its expected shorter pulsation period.

For each night, radial velocities were computed relative to the spectrum with the highest signal-to-noise ratio by the use of the optimum-weight procedure described by Bouchy et al. (2001). The radial velocity measurements are shown in Fig. 1 and Fig. 2. For ϵ Oph, 635 radial velocity measurements have been obtained with CORALIE and 176 with ELODIE; for η Ser, 1062 with CORALIE and 189 with ELODIE. The uncertainties due to photon and detector noise vary between 0.57 m/s and 2.19 m/s for ϵ Oph and between 0.6 m/s and 2.35 m/s for η Ser.

A clear periodic signal is seen in the time series (see bottom panels of Fig. 1 and Fig. 2) at a period of a few hours which would be expected for solar-like oscillations in such stars.

4. PRELIMINARY DATA ANALYSIS

4.1. Power spectrum analysis

The power spectrum of each of the time series shown in Fig. 1 and Fig. 2 (top panels) are presented in Fig. 3 (bottom panel) for ϵ Oph and in Fig. 4 (bottom panel) for η Ser. In these two figures, an excess power is clearly visible around $60 \mu\text{Hz}$ with a maximum amplitude of about 3 m/s for ϵ Oph and around $130 \mu\text{Hz}$ with a maximum amplitude of about 2 m/s for η Ser. In order to show that these excess powers are not due to elimination of power at low frequencies by the reduction procedure, a power spectrum for both stars for which no correction of drift has been applied is shown in the top panel of Fig. 3 and Fig. 4. The excess power in the mentioned ranges is clearly present even in these diagrams.

The power spectra of the observational windows (see inset plots in Fig. 3 and Fig. 4, bottom panels) still show, despite the bi-site observations, strong peaks at $11.6 \mu\text{Hz}$ (the first daily alias) and multiples of this value. These spectral window functions complicate the analysis of

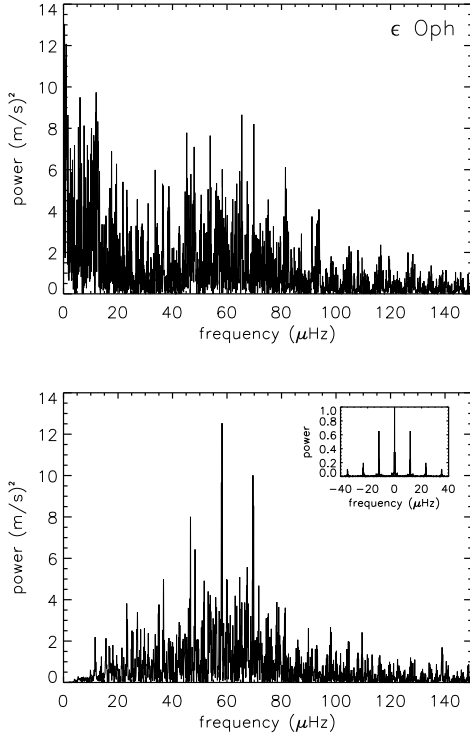


Figure 3. Top panel is the power spectrum of ϵ Oph when no shift correction has been made. Bottom panel is the power spectrum of the time series shown in Fig. 1. The inset of the bottom panel corresponds to the window function.

the power spectra by introducing peaks due to the daily aliases.

Peaks seen at low frequencies (below 50 μHz) in the power spectrum of η Ser (Fig. 4) are spaced by about 11.6 μHz ; they are the daily aliases of a much lower frequency peak due to a long term variation. The period of this long term signal is not resolved; so any explanation for it would require a longer observing run.

4.2. Search for frequency equidistances

Dziembowski et al. (2001) have shown that in red giants the non radial modes are expected to have much lower amplitudes than the radial oscillation modes. Therefore a regular pattern of peaks in the power spectrum corresponding to the dominant radial modes is expected. This is according to the asymptotic theory of solar-like oscillations (see e.g., Tassoul, 1980), which predicts evenly spaced eigenfrequencies at the higher frequency range. Therefore, it is reasonable to search for the so-called large separation, $\Delta\nu$, i.e. the separation between modes of the same degree and adjacent radial order, in the power spectrum of such giant stars.

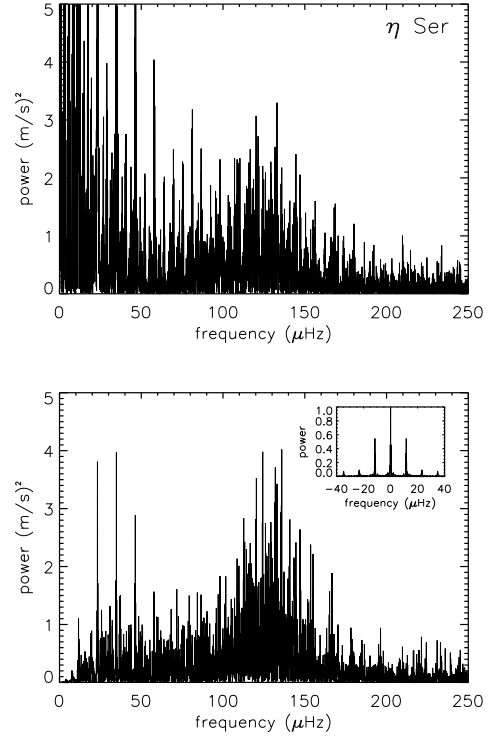


Figure 4. Same as Fig. 3 but for η Ser.

In order to search for such regular patterns in the observed excess power, a method based on a histogram of frequency equidistances (Barban et al., 1999) has been used. The histogram of ϵ Oph's excess power is shown in Fig. 5b and the one of η Ser in Fig. 6.

In Fig. 5b, the strongest peak at 11.6 μHz is due to the first daily alias. A series of different features around 2, 5, 7 and 9 μHz is also clearly visible. In order to understand these features, data have been simulated.

Following Anderson et al. (1990), the data are simulated assuming that each oscillation mode can be described as a damped harmonic oscillator excited by a random force identified with the granulation. Then, each oscillation mode is modeled by a Lorentzian profile:

$$P(\nu) = \frac{A(\Gamma/2)^2}{(\nu - \nu_0)^2 + (\Gamma/2)^2} \quad (1)$$

where A is the maximum signal power in $(\text{m/s})^2/\text{Hz}$; Γ , the full width at half maximum; ν , the Fourier frequency and ν_0 , the mode oscillation frequency. $A = v^2/\text{II}\Gamma$ where v is the mode oscillation amplitude in m/s and $\Gamma = 1/(\tau\text{II})$ where τ is the mode life time. Then, the stochastic excitation is introduced. The forcing function of the damped harmonic oscillator is provided by the turbulent convection which occurs at the surface of the star.

Because of the large number of granules, this forcing function is normally distributed which implies that the power spectrum is distributed as χ^2 with two degrees of freedom. To reproduce this statistics, the Lorentzian profile is multiplied by $-\ln(y)$, where y is a random number drawn from a uniform distribution $0 \leq y \leq 1$ (Anderson et al., 1990). The resulting power spectrum is then convolved with the window function. Finally, noise corresponding to the level of the observed power spectrum estimated in the frequency range where no excess power is seen is added assuming white noise. Only radial modes are assumed to be present following Dziembowski et al. (2001). Different realisations of the power spectrum have been computed using different values of A , τ , $\Delta\nu$, in which peaks are assumed to be strictly equidistant. Again different realisations of the random numbers are used for the mode excitation and the noise.

A simulated power spectrum corresponding to a given realisation is presented in Fig. 5c. A comparison between the observed power spectrum and the simulated one (Fig. 5a and Fig. 5c) shows that they are quite similar. However, the simulated power spectrum is less dense than the observed one. This could be explained by the presence of a non-white noise of an instrumental and/or stellar origin in this frequency range that was not taken into account in the simulations. Another explanation could come from the presence of non-radial modes (see Frandsen et al., 2002). In the simulated power spectrum, the strongest peak is an oscillation mode surrounded by its first daily aliases.

The histogram of the frequency spacings computed from the simulated power spectrum of ϵ Oph with a large separation of $7 \mu\text{Hz}$ shows features similar to the observed one at about the same frequencies. The features around 2, 5 and $9 \mu\text{Hz}$ can be explained as combination of the first daily alias, which is seen at $11.6 \mu\text{Hz}$, with the large separation, $\Delta\nu$, of $7 \mu\text{Hz}$.

Equidistant peaks were also searched in the observed excess power of η Ser (Fig. 6). Three features around 4, 8 and $11.6 \mu\text{Hz}$ are observed. As for ϵ Oph, the peak at $11.6 \mu\text{Hz}$ is due to the first daily alias. The peak at $4 \mu\text{Hz}$ can be explained as the frequency spacing $\Delta\nu$ or as a combination of $\Delta\nu$ and the first daily alias, and the second peak at about $8 \mu\text{Hz}$ as twice the frequency spacing $\Delta\nu$ or as the frequency spacing $\Delta\nu$ itself.

5. DISCUSSION AND CONCLUSION

An excess power is clearly seen in the power spectrum of the radial velocity variations of the giants ϵ Oph and η Ser with a power distribution very similar to what is observed for the Sun. This excess power occurs between 30 and $90 \mu\text{Hz}$ with a maximum power of $\sim 9 (\text{m/s})^2$ for ϵ Oph and between 80 and $170 \mu\text{Hz}$ with a maximum power of $\sim 4 (\text{m/s})^2$ for η Ser. The frequency range where these two excess powers are observed are in agreement with the results we obtained for stars of such spectral type using

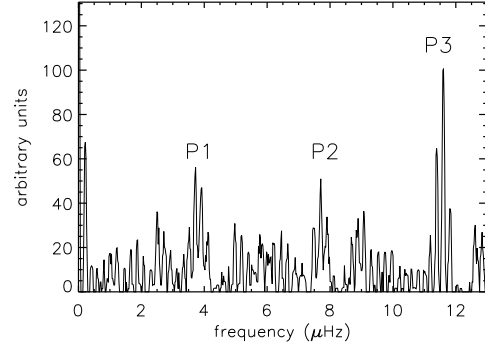


Figure 6. Histogram of frequency spacings of the observed excess power of η Ser. P1 could be $\Delta\nu$ or $\Delta\nu - P3$ and P2, $2\Delta\nu$ or $\Delta\nu$. P3 is due to the first daily alias at $11.6 \mu\text{Hz}$.

theoretical models (details of these models will be given in a subsequent paper).

Assuming only radial modes, the signature of equidistant peaks, a characteristic of the oscillation spectrum of solar-like oscillations, has been searched. A possible value for the large separation of around $7 \mu\text{Hz}$ is suggested for ϵ Oph. This value is in agreement with theoretical frequency sets which have been computed. For η Ser, theoretical models exclude a large separation around $4 \mu\text{Hz}$. The other signature detected in the histogram of the frequency spacings, i.e. $8 \mu\text{Hz}$, might then be associated with the large separation.

The analysis of these data is still in progress. A more detailed work will be presented in two forthcoming papers (De Ridder et al., in preparation; Carrier et al., in preparation). The result on the large separation of ϵ Oph needs to be confirmed; simulations need to be done over a larger parameter space to check if a unique combination of parameters for which the simulated data reproduce the observational data can be found (Barban et al., in preparation).

This work confirms that solar-like oscillations are present in giant stars. The detection and the study of such oscillations in this type of stars opens this part of the HR diagram to asteroseismology.

ACKNOWLEDGMENTS

The Leuven contribution to the data was made possible thanks to financial support from the Fund for Scientific Research - Flanders (FWO), under project G.0178.02. CB, AM and CA are supported by the Research Fund K.U.Leuven under grant GOA/2003/04. JDR acknowledges support from the Fund for Scientific Research - Flanders. This work has made use of the Simbad data base, operated at CDS, Strasbourg, France.

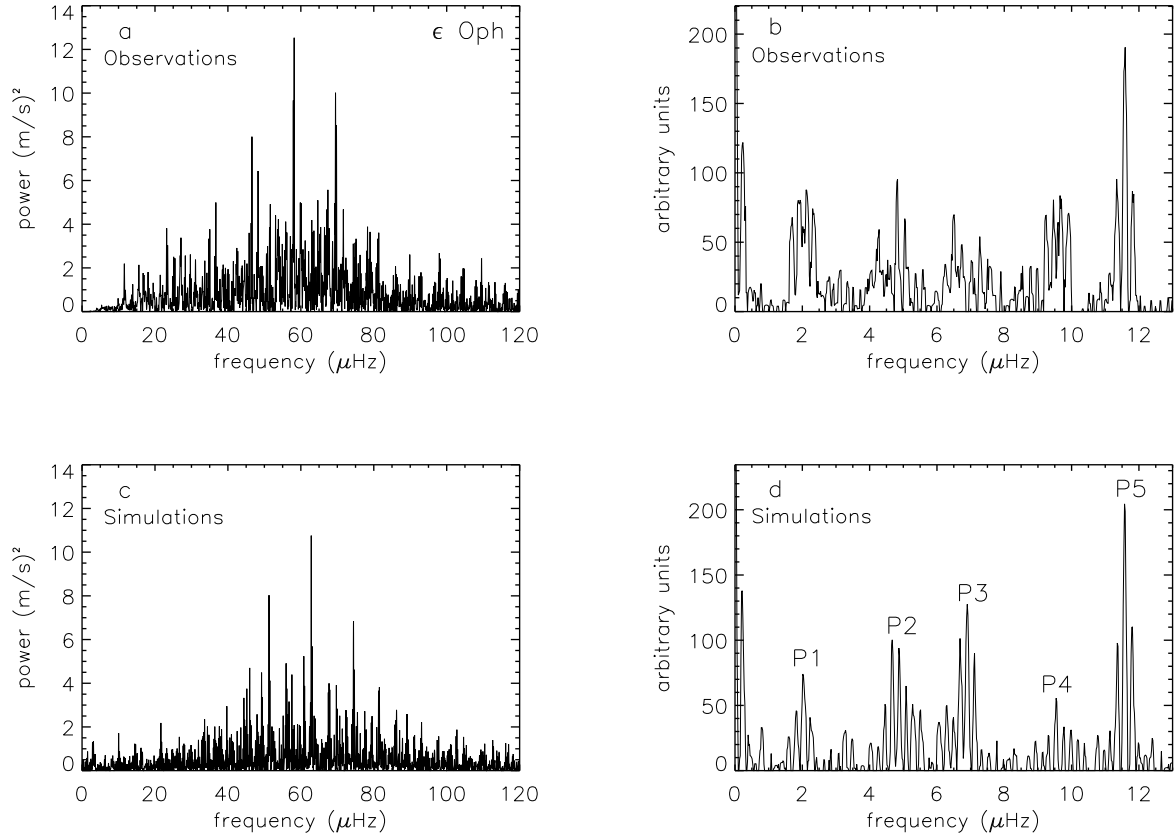


Figure 5. *a: Observed power spectrum of ϵ Oph. b: Histogram of frequency spacings of the observed excess power of ϵ Oph. c: Simulated power spectrum of ϵ Oph ($A=3$ m/s, $\tau=7$ days, $\Delta\nu=7$ μHz). d: Histogram of frequency spacings of the simulated excess power of ϵ Oph. P1 corresponds to $2\Delta\nu - P5$, P2 to $P5 - \Delta\nu$, P3 to $\Delta\nu$, P4 to $3\Delta\nu - P5$ and P5 to the first daily alias at 11.6 μHz .*

REFERENCES

- Anderson E.R., Duvall T.L., Jefferies S.M., 1990, *ApJ*, 364, 705
- Balmforth N.J., 1992a, *MNRAS*, 255, 603
- Balmforth N.J., 1992b, *MNRAS*, 255, 639
- Baranne A., Queloz D., Mayor M., et al., 1996, *A&AS*, 119, 1
- Barban C., Michel E., Martic. M., et al., 1999, *A&A*, 350, 617
- Barban C., et al., in preparation
- Bedding T.R., Kjeldsen H., 2003, *PASA*, 20, 203
- Bouchy F., Carrier F., 2003, *Ap&SS*, 284, 21
- Bouchy F., Carrier F., 2001, *A&A*, 374, L5
- Bouchy F., Pepe F., Queloz D., 2001, *A&A*, 374, 733
- Buzasi D., Catanzarite J., Laher R., et al., 2000, *ApJ*, 532, L133
- Carrier F., et al., in preparation
- De Ridder J., et al., in preparation
- Dziembowski W.A., Gough D.O., Houdek G., et al., 2001, *MNRAS*, 328, 601
- Frandsen S., Carrier F., Aerts C., et al., 2002, *A&A* 394, L5
- Kjeldsen H., & Bedding T.R., 2004, these proceedings
- Queloz D., Mayor M., Udry S., et al., 2001, *The Messenger*, 105, 1
- Retter A., Bedding T.R., Buzasi D.L., et al., 2003, *ApJ*, 591, L151
- Stello D., Kjeldsen H., Bedding T. R., et al., 2004, *SoPh*, 220, 207
- Tassoul M., 1980, *ApJS*, 43, 469