Astronomy
&
Astrophysics

Letter to the Editor

P-mode observations on α Cen A[⋆]

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Abstract. We have made a clear detection of p-mode oscillations in the nearest solar-like G2V star α Cen A with the CORALIE spectrograph on the 1.2-m Swiss telescope at the ESO La Silla Observatory. We report the 5 nights of observation on this star in May 2001 during which 1260 high precision radial velocity measurements were obtained. The power spectrum clearly shows several identifiable peaks between 1.7 and 3 mHz. The average large splitting of 105.7 μHz and the amplitude of about 35 cm s^{-1} of these modes are in agreement with theoretical expectations.

Key words. stars: individual: α Cen A – stars: oscillations – techniques: radial velocities

1. Introduction

One of the major objectives of the stellar physic is the understanding of stellar interiors and the modelisation of star evolution. Asteroseismology, which consists to measure amplitudes and frequencies of oscillation modes is an ideal tool to constrain stellar models and evolutionary theory.

Recent results of ground-based observations using Doppler techniques have permitted to detect solar-like oscillations in the F5IV-V star Procyon (Martic et al. 1999) and the G2IV star β Hydri (Bedding et al. 2001; Carrier et al. 2001). These two stars exhibit good evidence for excess power centered at 1 mHz with peak amplitude of about 50 cm s^{-1}.

A primary and challenging target for the search for p-mode oscillations is the G2V star Rigil Centaurus (α Cen A, HR 5459). Thanks to its proximity and its belonging to a binary system, its characteristics are well-determined which simplifies the interpretation of asteroseimological results. Scaling from the solar case, the frequency of its greatest mode is expected to be $\nu_{\max}$ = 2.3 mHz, the primary frequency splitting $\Delta\nu_0$ = 105.8 μHz and the oscillation amplitude $A_{\rm osc}$ = 31.1 cm s^{-1} (Kjeldsen & Bedding 1995a). Detailed Models with seismological analysis have been recently proposed for α Cen A (see, e.g., Pourbaix et al. 1999; Guenther & Demarque 2000; Morel et al. 2000).

Several groups have already conducted thorough attempts to detect signature of the p-mode oscillations on this star. Two groups claimed mode detections with amplitudes 3.2–6.4 greater than solar (Gelly et al. 1986; Pottasch et al. 1992). It was however infirmed by three others groups which obtained upper limits of mode amplitudes of 1.4–3 times solar (Brown & Gilliland 1990; Edmonds & Cram 1995; Kjeldsen et al. 1999). More recently Schou & Buzasi (2001) have made photometric observations of α Cen A with the WIRE spacecraft and reported a possible detection of p-modes.

We obtained high precision radial velocity (RV) measurements on α Cen A and report in this paper our observations and the power spectrum analysis of this star.

2. Observations and data reduction

The observations of α Cen A were carried out with the CORALIE fiber-fed echelle spectrograph (Queloz et al. 2000) mounted on the 1.2-m Swiss telescope at the ESO La Silla Observatory. CORALIE is the southern hemisphere twin of the ELODIE spectrograph (Baranne et al. 1996), both of them well known for their discoveries of extrasolar planets. The wavelength domain ranges from 3875 to 6820 Å recorded on 68 orders. Thanks to a slightly different optical combination at the entrance of the spectrograph and the use of a 2k by 2k CCD with 15-μm pixels, CORALIE reaches a spectral resolution of 50 000 with a 3 pixels sampling. The total efficiency including atmosphere, telescope, spectrograph and detector was measured and reaches about 1.5% at 5500 Å in the best seeing case. During stellar exposures, the spectrum of a thorium lamp carried by a second fiber is simultaneously recorded in order to monitor the spectrograph instability and thus

⋆ Based on observations collected with the CORALIE echelle spectrograph on the 1.2-m Euler Swiss telescope at La Silla Observatory, ESO Chile.

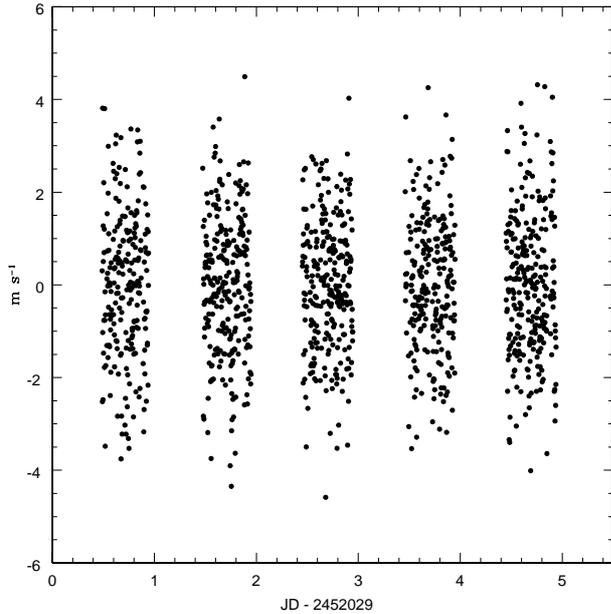**Fig. 1.** Radial velocity measurements of α Cen A. A 3 order polynomial fit subtraction was applied on each night. The dispersion reaches 1.47 m s^{-1}.

to obtain high precision velocity measurements. Spectra are extracted and reduced in real time using the INTER-TACOS software package developed by D. Queloz and L. Weber at the Geneva Observatory (see Baranne et al. 1996).

The standard RV computation by a cross-correlation algorithm was replaced by an algorithm based on the optimum weight procedure first proposed by Connes (1985). We developed this method and showed that the optimum procedure is a factor 1.6 more efficient in term of photon noise than the cross-correlation procedure (Bouchy et al. 2001). The method uses the full spectral information available and compares two spectra of the same source to compute their velocity difference. Its present limitation is that the Doppler shift must remain small compared to the line-width. This is the case in the time scale of few hours when the velocity change, dominated by Earth motion, is less than 100 m s^{-1} ($\sim$1/50 of a typical stellar line-width). During a whole night, Earth motion can introduce a Doppler shift greater than 500 m s^{-1}. An error of about 3 to 5% is then introduced if an unique "reference" spectrum is used during the whole night. However, this effect can be entirely eliminated by a low order polynomial fit subtraction without consequences for the characterization of high frequency oscillation modes.

α Cen A was observed over 5 nights in May 2001. A journal of these observations is given in Table 1. We took sequences of 40-s exposures with a dead time of 110-s in-between. In total, 1260 spectra were collected with typical signal-to-noise ratio in the range 300–420 at 550 nm.

Radial velocities are computed for each night relatively to the highest signal-to-noise ratio spectrum obtained in the middle of the night. The resulting velocities are presented in Fig. 1. The dispersion of these measurements

Table 1. Distribution and dispersion of RV measurements.

Date	Nb spectra	σ (m s^{-1})
2001/04/29	220	1.58
2001/04/30	259	1.49
2001/05/01	268	1.39
2001/05/02	246	1.40
2001/05/03	267	1.53

reaches 1.47 m s^{-1} and the individual value of each night is listed in Table 1. The precision of our RV measurements is compared with the fundamental uncertainty due to photon noise using the method described by Bouchy et al. (2001). The uncertainties coming from the stellar spectrum and from the simultaneous thorium spectrum used in the instrumental tracking are typically the same and equal to 0.50 m s^{-1}. The quadratic sum of these two photon noise contributions is 0.70 m s^{-1}.

3. Power spectrum analysis

In order to compute the power spectrum of the velocity time series of Fig. 1, we used the Lomb-Scargle modified algorithm (Lomb 1976; Scargle 1982) for unevenly spaced data. The resulting LS periodogram, shown in Fig. 2, exhibits a series of peaks between 1.7 and 3 mHz modulated by a broad envelope, which is the typical signature of solar-like oscillations. This signature also appears in the power spectrum of every individual night. Toward the lowest frequencies ($\nu < 0.5$ mHz), the power rises and scales inversely with frequency squared as expected for instrumental instabilities. The mean white noise level $\sigma_{\rm ps}$, computed in the range 0.5–1.5 mHz, reaches 3.06×10^{-3} m^2 s^{-2}. With 1260 measurements, the velocity accuracy corresponds thus to 0.98 m s^{-1}.

Observed mode frequencies expected for solar-like stars correspond to low angular degree l and high radial order n and are well approximated by the asymptotic relation:

$$\nu(n,l) \approx \Delta\nu\left(n + \frac{l}{2} + \epsilon\right) \tag{1}$$

with $\Delta\nu = \nu_{n,l} - \nu_{n-1,l}$.

The large splitting $\Delta\nu$ reflects the average stellar density and ϵ is a constant near unity (1.46 for the Sun) sensitive to the surface layers. In order to determine the average large splitting $\langle\Delta\nu\rangle$, we calculate the comb response of the power spectrum as proposed by Kjeldsen et al. (1995b). An average comb response is computed using all peaks greater than 0.03 m^2 s^{-2} (i.e. with S/N greater than 3 in the amplitude spectrum) in the frequency range 1.7–3 mHz. The resulting comb response shown in Fig. 3 gives $\langle\Delta\nu\rangle = 105.7$ μHz.

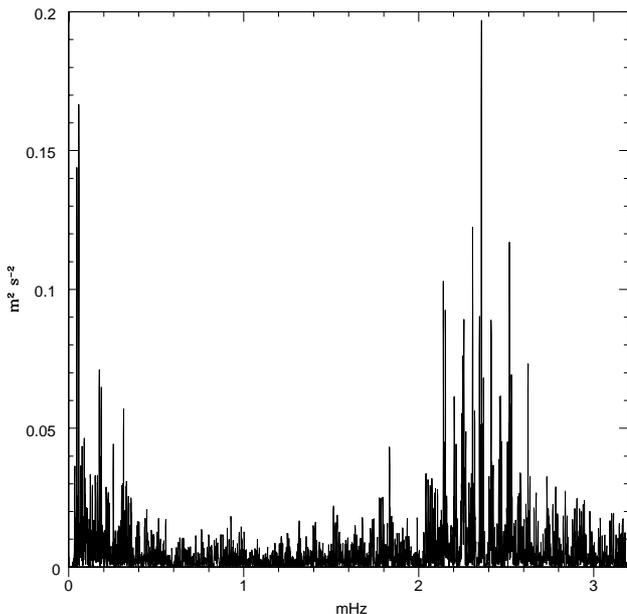In order to estimate the average amplitude of modes, we followed the method described and used by

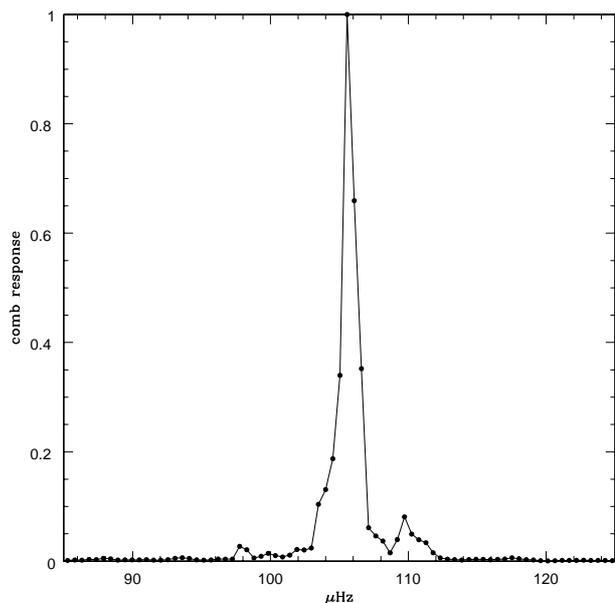**Fig. 2.** Power spectrum of the radial velocity measurements of α Cen A.

Fig. 3. Average comb response of the power spectrum of α Cen A computed with 0.5 μHz resolution.

Table 2. Mode frequencies (in μHz) of α Cen A estimated with the CLEAN procedure. The frequency resolution of our time series is 2.6 μHz.

	$l = 0$	$l = 1$
$n = 16$	1833.1	-
$n = 17$	-	-
$n = 18$	2041.1	2095.6
$n = 19$	2146.4	2203.1
$n = 20$	2251.0	2308.4
$n = 21$	2358.9	2414.1
$n = 22$	2463.3	2519.1
$n = 23$	2566.5	2625.1
$n = 24$	2671.6	2732.7
$n = 25$	-	2838.0
$\Delta\nu$	105.5 ± 0.6	106.1 ± 0.4

asymptotic relation (see Eq. (1)) assuming that the main peak corresponds to $n = 21$ and $l = 0$. With this configuration, the parameter ϵ is estimated to 1.35. This value is located in-between the Sun value (1.46) and the value deduced from theoretical models (Guenther & Demarque 2000; Morel et al. 2000) which give ϵ in the range 1.07–1.27. The last row in Table 2 gives the average large splitting for $l = 0$ and $l = 1$. Both values are in agreement with this deduced from the comb response.

4. Concluding remarks and prospects

Our observations of α Cen A conduct to an obvious detection of p-mode oscillations. Several identifiable modes appear in the power spectrum between 1.7 and 3 mHz with an average large splitting of 105.7 μHz and an amplitude of about 35 cm s^{-1}. These characteristics are in full agreement with the expected values scaling from the Sun presented in Sect. 1 and will bring constraints on theoretical models.

This result demonstrates the power of the simultaneous thorium RV method which reaches here the precision of 1 m s^{-1} at frequency higher than 0.5 mHz. We hope to obtain similar convincing seismological results on some bright solar-like stars with CORALIE.

Observations of α Cen A were conducted by T. Bedding and his collaborators during the same period with the UCLES spectrograph on the 3.9-m Anglo Australian Telescope and the UVES spectrograph on the 8.2-m Very Large Telescope. We hope that these observations will conduct to multi-site data combination in order to improve the spectral window and explore further the p-mode spectrum of α Cen A.

We are aware that ground based observation is far from the expected accuracy of the future space missions like MOST, MONS and COROT. However the future spectrograph HARPS (Pepe et al. 2000), which will be installed on the 3.6-m ESO telescope at La Silla Observatory at the end of 2002, is expected to observe stars with
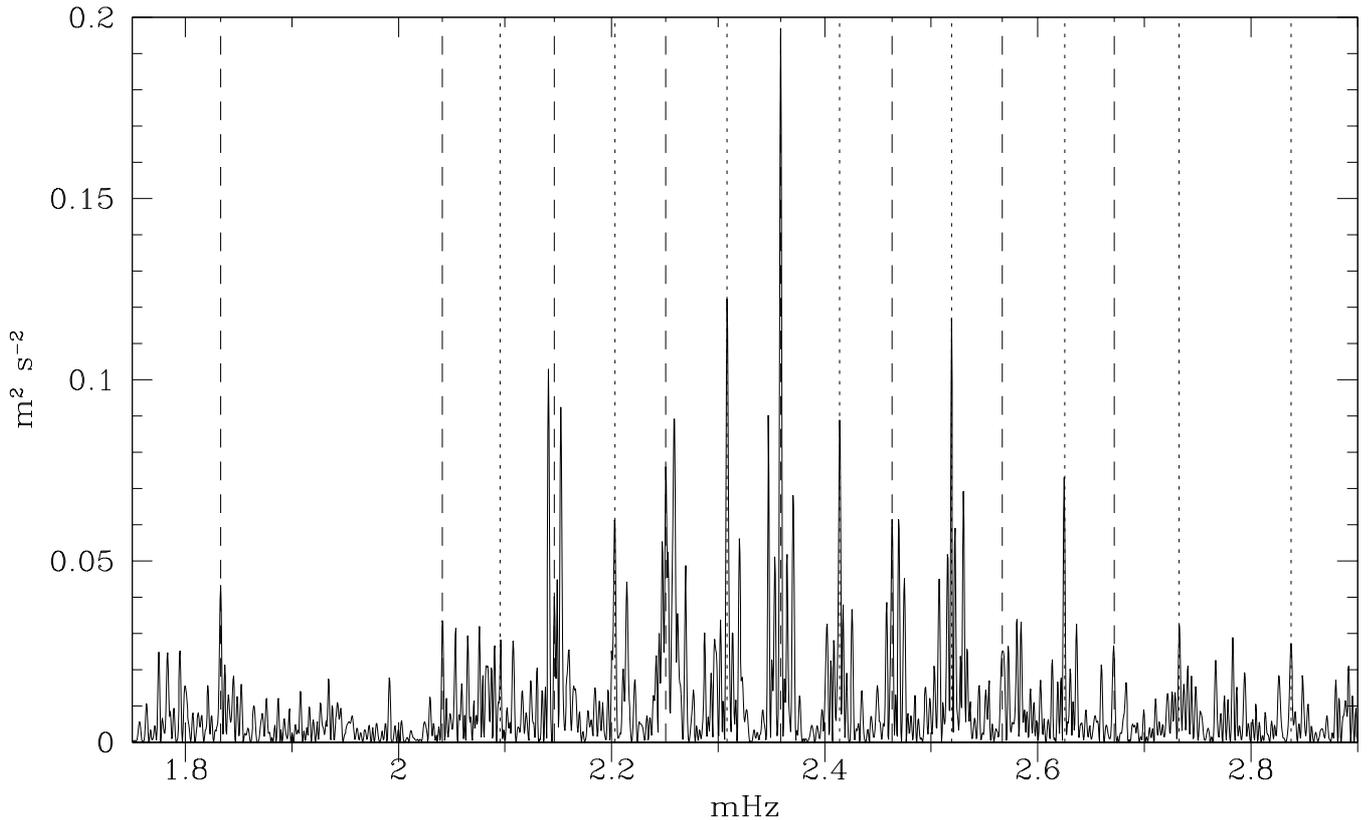
Kjeldsen & Bedding (1995a). A simulated time series was generated with artificial signal plus noise using our window function. The generated signal corresponds to 20 modes centered at 2.36 mHz, separated by $\Delta\nu/2$ and convolved by a Gaussian envelope. The generated noise is Gaussian with a standard deviation of 1 m s^{-1}. Several simulations show that the average amplitude of peaks is in the range 33–37 cm s^{-1}.

An attempted identification of the strongest modes was processed with the CLEAN algorithm (Roberts et al. 1987) in order to remove the effect of the window function. The identified modes are listed in Table 2 and shown in Fig. 4. The values of n and l are deduced from the

Fig. 4. Identified p-mode oscillations of α Cen A in the power spectrum. Dashed lines and dotted lines correspond respectively to the modes $l = 0$ and $l = 1$ listed in Table 2.

magnitude 5 dimmer than CORALIE (Bouchy et al. 2001). It will thus be able to conduct complementary ground based asteroseismological study on a large sample of stars.

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