SOLAR-LIKE OSCILLATIONS ON α CENTAURI A

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ABSTRACT   Detection of individual modes of oscillation near 5 minutes period is proposed, based on the comb-like signature which is similar to that found in the sun. The mean peak amplitudes (a_p) of the strongest individual modes are $75 \leq a_p \leq 120$ cm/s, and the mean separation between alternate modes is 55.3 ± 3.6 µHz. Apparent modal lifetimes are on the order of 2 days, but we suggest this may be caused by interference of adjacent modes.

1. INTRODUCTION

For the past decade serious attempts (e.g. Brown and Gilliland 1990, Brown et al. 1991, Gelly et al. 1986, Noyes et al. 1984) have been made to detect solar-like p-modes on bright solar-like stars. It is expected that p-modes measured on solar-like stars will result in the determination of two parameters, $\Delta\nu_0$ and D_0, which are closely related to the sound speed integral across the solar radius and the sound speed gradient inside the nuclear burning core respectively (cf. Christensen-Dalsgaard 1984, 1988).

2. OBSERVATIONS

Our observations of αCenA were made during 6 consecutive nights, 2 - 7 April 1990, using a single channel, Fabry-Perot (F-P) based, velocity monitor with the 3.6-m telescope of the European Southern Observatory at La Silla, Chili. The instrument makes use of a specially stabilized version of the ET-50 tunable etalon marketed by Queensgate Instruments, Ltd. (Butcher and Hicks 1986).

For the present observations, the F-P interferometer was combined with an order isolation interference filter to yield a narrow band filter, of 0.12 Å FWHM tunable over ± 50 km/s about the FeI absorption line at λ=5576 Å. When the filter is tuned to the line flank to provide maximum sensitivity to radial velocity, the system response was determined to be $\Delta I/I = 4.44 \times 10^{-5}$ per m/s, where I is the intensity signal measured by the Si photodiode detector, and was found to be linear with velocity over the range required.

The design goal for stability of the bandpass of the interferometer of less than 1 m/s for time scales between a few seconds and many minutes has been achieved on the one hand by incorporation of low noise etalon servo electronics, and on the other by characterizing the system response to temperature, pressure, and optical illumination variations, then stabilizing these environmental factors to the required degree. No separate, stabilized

reference has been employed (except during test measurements to verify performance).

The velocity data time series discussed here consist of 0.2 seconds integrations taken in repeated I_1 - I_2 - I_3 - I_4 sequences, where I_1 and I_4 are intensity signals with the etalon band tuned to the blue flank of the absorption line, and I_2 and I_3 are the signals on the red flank. These raw measures have been combined ('dechop') to generate a velocity sensitivity parameter $R(t)=((I_1+I_4)-(I_2+I_3))/(I_1+I_2+I_3+I_4)$.

3. ANALYSIS

The 'dechop' procedure transforms the intensity measurements into relative velocities. The resulting velocity curve shows the diurnal motion of the earth's rotation, which during a typical observation period of nine hours on αCenA from La Silla, shows a velocity difference of about 500 m/s. For comparison we note that typical solar modes of oscillation have amplitudes in the order of 20-40 cm/s, and periods in the order of 5 minutes. The earth's rotational trend has been removed from the data by subtracting a 6th order polynomial fit. Individual bad points (clouds, shutter closure) are replaced with linearly predicted points. Finally the data are smoothed by subtracting the convolution product with a Gaussian function from the data (full width at half height ≈ 45 minutes). This filtering process should therefore leave any solar like oscillation signal from αCenA intact.

The power spectrum of the complete data set does not show a statistically significant excess power in the 3 mHz region. Since it is expected that the power spectrum is almost periodic in frequency we calculated the power spectrum of a certain range within the power spectrum, as described by Gelly et al. (1986).

4. RESULTS

4.1. Power spectra

N random fluctuations, each with an rms amplitude of A, produce a signal of $A/\sqrt{N}$. Our stellar data show a rms (σ_m) of 8.4 m/s per 51.2 seconds integration time. The amplitude (a_s) for a continuous sine function to reach this power level in a 'white' spectrum therefore is: $\sigma_s = \sigma_m/\sqrt{N} \approx 15$ cm/s. Power spectra of two-nights sequences show slight (but not significant) enhanced power in the 3 mHz region. The relative error of a peak $P(v)$ in the power spectrum at low frequencies (3 mHz region) for peaks with a power less than 0.375 $(m/s)^2/\Delta v$ (complete data series) or 1.0 $(m/s)^2/\Delta v$ (two-nights) is ≥ 49%. Assignment of possible p-modes is discussed by Pottasch et al. (1992).

4.2. Power spectra of power spectra

The p-mode structure in the power spectrum consists of first order spacings [$v(n,l)$ - $v(n-1,l)$], and second order spacings [$v(n,l)$ - $v(n-1,l+2)$]. Each peak in the Fourier domain is furthermore convolved with the Fourier transform of the window function (1/24 hours spacing). The resulting sidelobe structure can to some extent be removed by the CLEAN procedure. If the power spectrum shows a solar-like periodicity in frequency then the power spectrum of the power spectrum will reveal: 1) the distance $0.5\Delta v_0$ and its higher harmonics (where $0.5\Delta v_0 \approx <v(n,l) - v(n-1,l)>/2$) and 2) the frequency separation Δv_0 will be visible as a minor peak accompanied by its higher harmonics. We find that $0.5\Delta v_0 = 55.3 \pm 3.6$ µHz.

5. DISCUSSION AND CONCLUSION

The power spectrum of the complete data set does not improve the signal to noise ratio as would be expected for modes with lifetimes in the order of 3 to 6 days, as on the sun (Libbrecht 1988). The best signal-to-noise ratio appears in two-nights data segments. When we have a closer look at the power spectra of these segments it becomes apparent that only a few major peaks occur in more than one two-nights power spectra. On the Sun (Ehgamberdiev et al. 1991) and possibly on Procyon (Brown et al. 1991) it has become evident that the occurrence of p-modes in the power spectrum, shows a large scatter from day to day. This daily scatter in amplitude is believed mainly to be caused by interference between unresolved modes contributing to each observed peak in the power spectra. The intermittent occurrence of peaks in the successive two-nights power spectra is therefore probably caused by the combination of a short measurement interval and the particular separations of adjacent modes. Indeed the power spectrum of the complete data set shows linewidths that correspond to longer lifetimes. If interference is the cause of amplitude variations on timescales of two nights, then on days of largest amplitude the interference is likely to be constructive. Therefore we estimate the amplitudes of the individual modes consequently to be in the range: 75 cm/s ≤ amplitude ≤ 120 cm/s.

When adopting a value for $0.5\Delta v_0 = 55.3 \pm 3.6$ µHz (αCenA) and a solar value for Δv_0 = 135 µHz, the corresponding radius $R_{\alpha CenA} = 1.17 R_\odot \pm 0.05 R_\odot$, since Δv_0 is roughly proportional to $(M/R^3)^{0.5}$ (where $M_{\alpha CenA} = 1.085 M_\odot$ [7]). Furthermore $L_{\alpha CenA}/L_\odot = 1.33 \pm 0.11$, for $T_{eff}(\alpha CenA) = 5710$ K and $T_{eff}(Sun) = 5770$ K.

Christensen-Dalsgaard (1984) showed that first and second order frequency spacings can be used to infer the age or mass of a star ($\Delta v_0 - D_0$ diagram). We find that $[v(n,0) - v(n-1,2)]/6 \approx D_0 \approx 1.18 \pm 0.27$. The $\Delta v_0 - D_0$ diagram yields an age for αCenA of 7.2 ± 2.6 Gy.
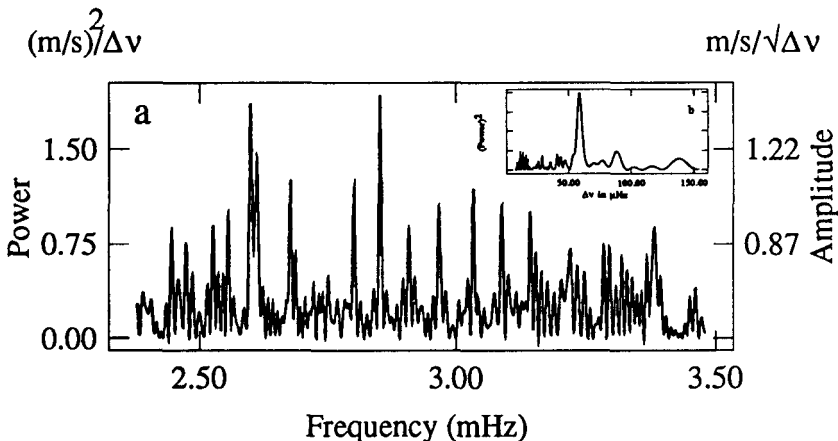

Fig.1. (a) CLEANed power spectra of two consecutive nights of observation. It is suggested that individual peaks are likely constructed by interference with neighbouring peaks. Therefore it is likely that the mode amplitudes (a_p) are in the order of 75 ≤ a_p ≤ 120 cm/s. (b) The power spectrum of the power spectrum indicates that the p-modes are periodic in frequency space, where the spacings between the individual modes $0.5\Delta v_0 = 55.3 \pm 3.6$ µHz.

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