Mem. S.A.It. Suppl. Vol. 2, 162

Memorie della
Supplementi

Asteroseismology of α Centauri from Concordia

G. Grec , C. Renaud , G. Berthomieu and J. Provost

Département Cassini, UMR 6529 du CNRS, Observatoire de la Côte d'Azur, 06304 Nice cedex, France.

Abstract. Following the significative progress in the knowledge of the solar interior due to the analysis of the acoustical eigen modes, the observationnal chalenge is presently to obtain similar data for several other solar-like dwarf stars, leading to a new determination of their fundamental data as mass and age. On a southern site, the bright binary star α Centauri is the higher priority. Our group works on the concept and realisation of an automated photometer usable for long observations covering the antarctic night. An evolution to the measurement of the variations of radial velocity of bright stars is also considered.

1. Introduction: sounding a star

The seismology of a star relies on the analysis of the temporal spectrum of their vibrating modes, a series of spherical harmonics (Fig. 1). For any random source of excitation (the convective zone is presently believed to be the source of the solar oscillations), the star is a mechanical filter for a discrete spectrum of eigen frequencies. This spectrum is related to the physical conditions inside the star, from the outer layers to the core. The internal structure of the star can be deduced from the calculation of the eigen frequencies for a given numerical model for the physics of the star. The first observations of the Sun as a star in 1979-1980 (Fig.2 and Fig.5) did allow the detection of low-degree oscillations and their identification as acoustical modes. Significant progress in the knowledge of the deep solar interior come from 20 years of observations, mainly the GONG network (Leibacher, (1999)) and the instruments devoted to helioseismology aboard the SoHO spatial observatory, in operation since 1996 (Domingo *et al.* (1995)):

- The frequency series of acoustical modes (Fig. 3 obtained with the GOLF instrument, Gabriel *et al.*, (1995)) gives strong constraints for the modeling of the solar evolution (Basu et al. (2000).)
- The core rotation is measured thanks to the splitting of the low-degree modes.
- The relations to the solar activity are under study and may allow forecast of solar eruptions.

The knowledge of several other stars is now a need for the understanding of the stellar evolution. The stellar acoustical modes result in a variable velocity field and in local-temperature variations of the stellar atmosphere. The changes in radial velocity produce a Doppler effect observable using spectroscopic technics. The temperature variations are detected monitoring the

Send offprint requests to: G. Grec
Correspondence to: grec@obs-nice.fr

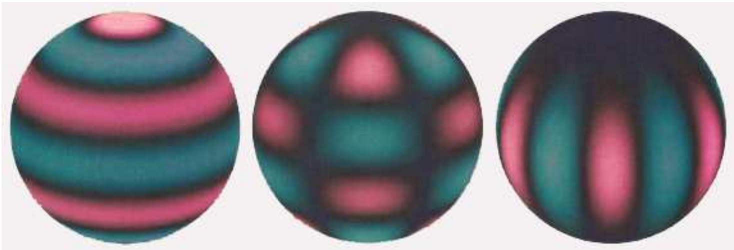

Fig. 1. Examples of low-degree $l = 6$ modes for tesseral order $m = 0$ (left, polar modes), $m = 3$ (center) and $m = 6$ (rigth, equatorial modes). The geometric averaging limits the stellar observations to the modes $0 \leq l \leq 3$. The pattern related to m allows the measurement of stellar rotation. The null-velocity zones are black, inward or outward velocity is displayed in red or blue.

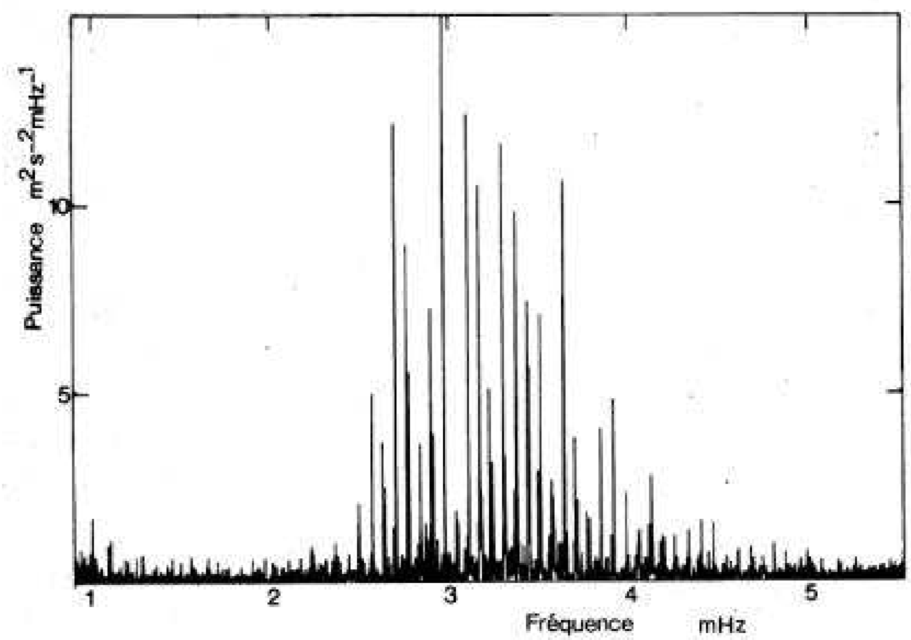

Fig. 2. Power spectrum vs. time frequency of the 5 min solar oscillation observed in the Doppler shift during 7 days from the South Pole station (from Grec *et al.*, (1980).)

changes of the global luminosity. For the Sun, the acoustical modes are in the 5 min range, the rms amplitude range is a few m s^{-1} for the velocity and 10^{-6} for the luminosity changes. All those signals are small in amplitude, the global luminosity variations are only observed from space.

2. The α Cen project for Concordiastro

The instrument now in preparation is dedicated to the photometry of bright stars similar to the Sun, in order to extend the domain of validity of the solar evolution-

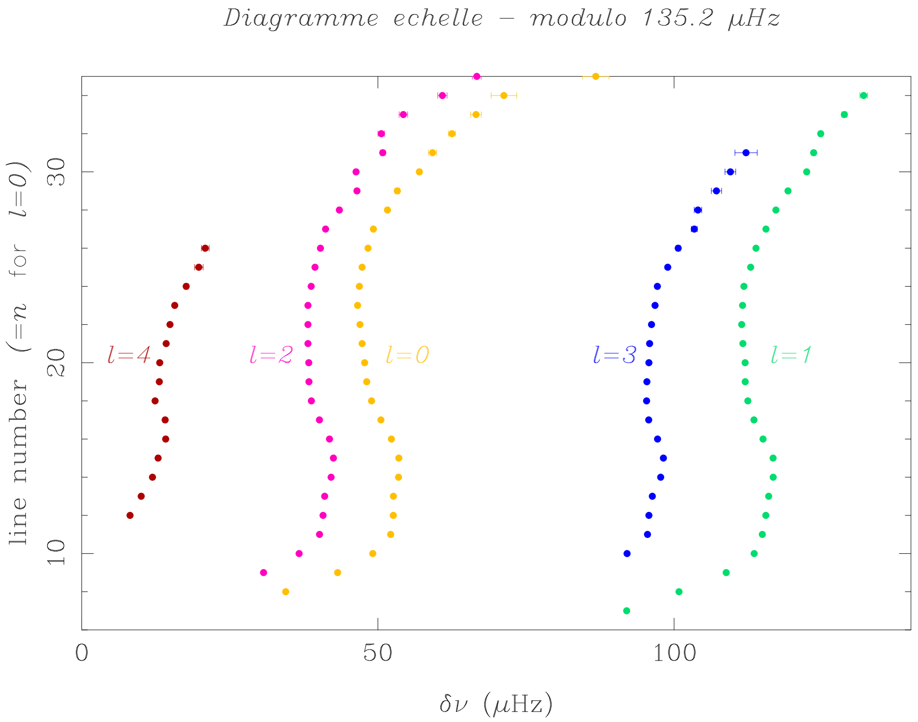

Fig. 3. Diagramme echelle of the solar eigen frequencies for the successive values of the spherical degree l (deduced from the frequency table in Gelly *et al.*, (2002).) The spacing of the mode frequency is characteristic to the Sun and related to the internal structure.

nary model. The lower magnitude star in the southern sky eligible for this study is α Centauri, a double star with 2 main components A and B, 2 dwarf stars close to the Sun in the Hersprung-Russel diagram. The mass determination of the components of the α Centauri system is classically derived from the orbit's determination. Additional constraints came newly from asteroseismology of α Cen A (Fig. 4, Bouchy & Carrier, (2002)). It resulted a new determination of the evolutionnary models, implying a discussion on the mass of the B component (Thevenin *et al.*, (2002)). The diametres deduced from these new internal structure models for α Cen A and B are in good agreement with the large-base interferometric measurements (Kervella *et al.*, (2003)). This result is not in close agreement with the former value of the mass of α Cen B deduced from the orbit determination (Pourbaix *et al.*, (1999)), this discrepancy being dependant on the determination of the spectroscopic parameters of the binary system and on the physics included in the stellar modelling. An extended and more accurate series of eigen frequencies of α Cen A and the seismology of α Cen B would contribute to clarify this open question. Up to now, the acoustic spectrum of α Cen A comes from spectroscopic measurements of Doppler shift. The need for a large telescope (or a network of those) allows only limited and not continuous time window. It is then difficult to achieve the very hight resolution in the frequency domain required for the numerical analysis of the internal structure. In addition, as it is known for the Sun, most of the lower frequency stellar modes are likely not detected

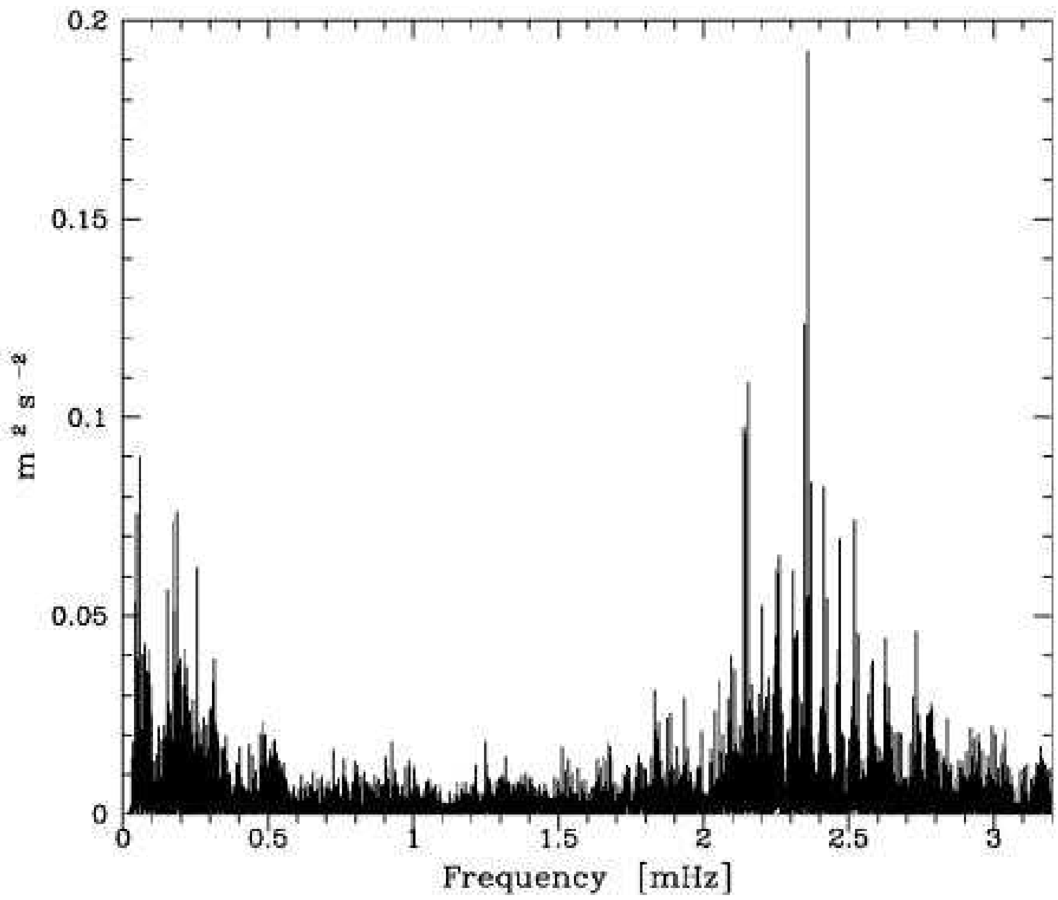

Fig. 4. Power spectrum of the variations of the Doppler shift of α Centauri after the deconvolution of a set of observations obtained over 13 nights, 120 cm swiss telescope at La Silla. (from Bouchy & Carrier, (2002).)

in a relatively short set of data, like a week. Our objective is to be free of those limitations: a telescope operated on antarctic plateau is usable 24 hours per day for the monitoring of α Cen. The temperature variations related to the acoustical modes are detected thanks to the measurement of the global luminosity. The low level of modulation implies that the luminosity variations of a typical dwarf star are not detected in the noise due to the atmospheric perturbations. That is the case in the best sites already studied for astronomy. Several spatial telescopes, still in preparation, are devoted to those observations but likely will be limited to higher-magnitude stars (Corot, Kepler, Eddington.) From the first results of the day-time measurements of the atmosphere at Dôme C we can estimate for the night time a very low level of atmospheric turbulence. This results in a low signal coming from the scintillation and allows the measurement of the faint stellar luminosity variations.

Fig. 5. The instrument and the team during the first solar observations at the South Pole, thanks to the support of the Deep Freeze project of the National Science Foundation and to The Bartol Institute and the collaboration of Martin Pomerantz, who worked tenaciouslyl to promote Astronomy in Antarctica.

3. Main specifications for the device

- Photometry in the whole visible spectrum. Integration time is 30 s.
- Power spectrum resolution $\ll 1$ μHz, corresponding to 11 d of continuous data. Long lasting continuous data are foreseen: $>$ 100 days to achieve a 100 nHz resolution.
- Short daily technical gaps ($<$ 1 min telescope rotation).
- Temperature range from -80 C to -20 C.
- 35 cm telescope aperture, Smith Cassegrain.
- Photon count $> 10^9$ s^{-1} for a 0-magnitude star.
- Imaging CCD camera for complex image measurement. The 2 stars are defocused on the photosensitive surface and measured simultaneously.
- Exposure time relative error $< 10^{-8}$ (hardware synchro).
- Shutterless camera, back illuminated and trame transfert CCD, temperature stabilised.
- A secondary camera is used for field acquisition and guiding, short time exposure. Image recording for sky monitoring.
- Local control panel for settings, remote log on from the station for routine operations. The data will be displayed on terminal on field and in station. A local operator is required for the initial settings. No operator constraint in normal observing time.
- Accurate datation of each measurement (integrated GPS).
- Remote low rate HSK data via Internet, Near real time data reduction for low-rate telemetry via Internet. The purpose is to help the local operators and to monitor the real quality of data from our lab.

– Project runs now under RT Linux.
– Depending on the capacity and availability of an internet link, the system allows remote login and makes possible a full remote control from our lab.
– Local data storage needed < 100 Gbytes per winter season, copy on removable hard disk for data transportation.

4. Conclusion: looking forward

1. The monitoring of the temporal spectrum of the acoustical modes of α Cen A and B is the primary objective of this experiment. The extended observation time will allow an improved temporal resolution compared to the presently available results, opening new fields of research.
2. The data analysis will take in account to 2 other topics:
   The scintillation is a key parameter of the site testing for astronomy. The present project will allow a precise measurement of this parameter and of the related temporal power spectrum.
   In the very low frequency domain, an hypothetical transit of exoplanet will be monitored.
3. The addition of a second telescope is foreseen for the following year, after the qualification of the first instrument. The analysis of the correlation function of the 2 measurements of the same star will increase the accuracy of the stellar oscillations measurements and reduce the uncorrelated noise. It will refine the measurements of the scintillation parameters.
4. The highest signal to noise ratio for astroseismology can be achieved measuring the variations of the Doppler shift of the star instead of the luminosity. Using the same concept than presented for the SYMPA experiment on Jupiter (Schmider, these proceedings), a 1,5 m class telescope complies with the counting rate requirements for a solar-like magnitude 0 star. The jovian project can then be replicated for Astroseismology of bright stars.

Acknowledgements. The astroseismology of α Cen is a part of Concordiastro, the astronomy program at Concordia. This program is founded by IPEV, Institut Paul-Emile Victor. The instrument for the α Cen photometry is build thanks to the financial support of IPEV.

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