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SIAMOIS : A DOPPLER ASTEROSEISMOMETER FOR DOME C

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Abstract. The photometric instruments in space (MOST, COROT) are going to open new insights on the knowledge of stellar interiors. However, ground-based asteroseismic observations remain justified as they can bring complementary velocity measurements, and allow the study of much more targets. A competitive instrument must make it possible the observation of a representative set of solar-like stars with magnitude down to 5, and a velocity precision as low as a few $\mathrm{cm\,s^{-1}}$ after 5 nights behind a 2-m class telescope. The SIAMOIS project based on a Fourier interferometer has emerged as a suitable solution to fulfil the specifications for a ground-based asteroseismic network. The photon noise limited performances have been examined and compared to those of a grating spectrometer (Mosser *et al.* 2003) showing that this type of instrument can reach the required specifications. With a design based on a monolithic interferometer, with a compact instrument easy to set up, to operate remotely with a limited data-flow, it can fit well the harsh conditions of Dome C. Main advantage, a single unit is needed due to the circumpolar position of the targets for the Doppler detection of stellar oscillations on solar-type stars. As a test bed, SIAMOIS could be put on 0.8-m class telescope like IRAIT (Busso *et al.*, these proceedings).

1 Introduction

Observational asteroseismology has benefited from the stable échelle spectrometers developed for the search of exoplanets with precise radial velocity measurement. Unique results have been obtained on bright stars (Bedding & Kjeldsen 2003 and references therein). After these single site observations on very bright stars, network observations or continuous observations on various targets are necessary to

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fully develop the potential diagnosis of asteroseismology for studying the structure of stellar interiors. Two-sites operations, as made by Bedding *et al.* (2004) on α Cen A with the spectrometers UVES at ESO/VLT and UCLES at AAT, are limited in times and only applicable for the brightest stars.

We expose in this paper the concept of SIAMOIS[1], a spectrometer for asteroseismic measurements, to be installed for mono-site but continuous observations at Dome C. Observational asteroseismology is presented in Sect. 2. The principle and the performances of Fourier transform seismometry, already developed in previous works, are briefly exposed in Sect. 3; the optical design of the instrument is proposed. What should be an asteroseismic programme at Dome C is presented in Sect. 4, and the numerous advantages of Dome C for this programme are discussed. Section 5 is devoted to conclusions.

2 Observational asteroseismology

Continuous observations are mandatory for making the best from seismic observations, and the requirement of uninterrupted continuous time series is the first argument for space project (up to 5 months for the prime targets of COROT, with a duty cycle better than 95%). Space missions dedicated to asteroseismology (MOST, COROT) are sensitive to the photometric signature of the stellar oscillations, due to the temperature changes associated to the seismic wave. The required photometric precision has to be better than 10^{-6}.

Ground-based observations cannot offer continuous data acquisition on a given star without the completion of a worldwide network of instruments. However, such observations are more versatile, and can give access to a larger number of stellar targets, representative of the portion of the HR diagram where solar-like oscillations are expected. Moreover, complementary observations are then possible, since space projects are searching for the photometric signature of the oscillation, whereas ground-based observations provide the Doppler signature. Helioseismology has shown the potential of comparing both signatures (Toutain 1997). Their comparison gives access to different parameters related to the oscillation excitation mechanism and damping.

In order to obtain an efficient duty cycle, any seismic network needs at least 3 instruments, and an optimum number of 6 instruments. This has been achieved for the Sun, with very small collectors and a dedicated instrumentation working in a very narrow bandpass (GONG network, see `site http://gong.nso.edu/`). For a star, due to the lack of photons, much larger collectors are necessary, with instruments working in the full visible spectrum. Due to the numbers of instruments in the network and to the duration of the project (more than 1 month per target, and tens of possible targets), both collectors and instruments have to be fully autonomous, as should be an instrument for Dome C. Therefore, single site

[1]SIAMOIS stands in French for Sismomètre Interférentiel à Mesurer les Oscillations des Intérieurs Stellaires

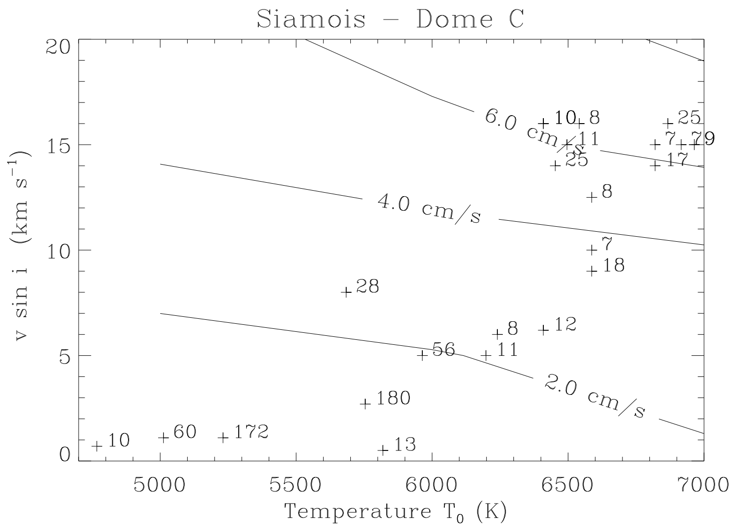

Fig. 1. Performance $\delta v_{\rm rms}$ as a function of effective temperature and $v \sin i$, obtained in the following conditions: 2-m class telescope, 5 nights with a global duty cycle 95%, and 4th magnitude star. The ratio $A/\delta v_{\rm rms}$, where A is the maximum oscillation amplitude predicted by Samadi *et al.* (2004), has been superimposed for all F, G and K type targets of class IV or V observable from Dome C. This ratio takes into account the magnitude and the real duty cycle of each target.

observation at Dome C appears as an attractive alternative: of course environmental conditions at Dome C are much harder, but for the same result one instrument at Dome C will give similar (in fact better, as seen below) results than 6.

A possible ground-based spectrometric solution should be a replicate of an échelle spectrometer (Bouchy *et al.* 2004, these proceedings). In the continuation of seismic observations conducted with a Fourier transform spectrometer (FTS) (Mosser *et al.* 1998; Mosser *et al.* 2003 and references therein), we have examined the fundamental capabilities of such a device for asteroseismology. We showed that a dedicated instrument based on an interferometer can be an attractive alternative to a high-resolution échelle spectrograph designed for the same purpose (as HARPS, Pepe *et al.* 2002), being simpler and smaller but achieving similar performances.

3 Fourier Transform seismometry

The Doppler observable of a FT seismometer is the phase shift measured in the interferogram of the stellar spectrum. The determination of this phase shift requires the recording of fringes with a high contrast, what limits the bandpass. On the other hand, a broad bandpass is necessary in order to reach high photon-noise limited performances. Both conditions imply the addition to the interferometer of a low-resolution post-disperser.

Simulations have been presented by Mosser *et al.* (2003). They allow to esti-

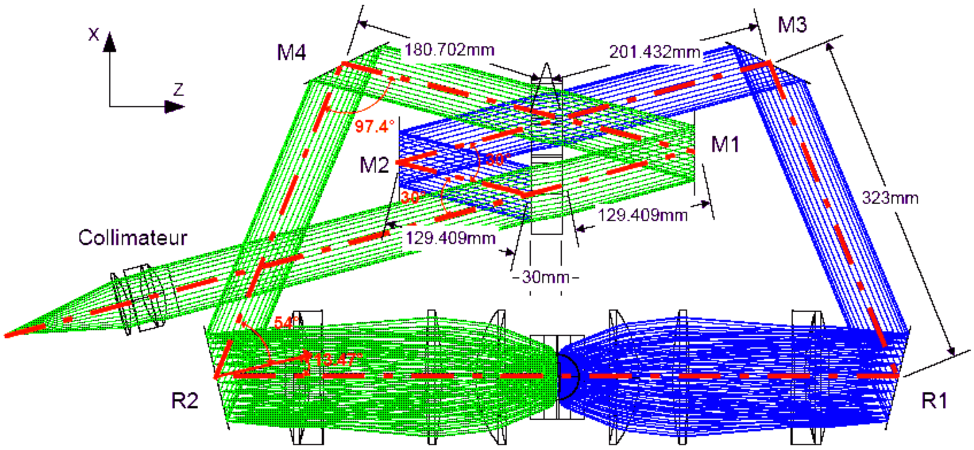

Fig. 2. Optical design of SIAMOIS. The instrument is fed via a single 50 μm fiber, selecting 2" on the sky. The optical fiber adapter $f/2.5$ insures the stabilization of the star image. The optical path difference is fixed by a parallel plate in one arm (not shown on this Figure). M1 is a flat mirror, but M2 presents 5 steps of depth 40 nm, in order to get the sampling of a blue fringe by 5 points. Two folding mirrors M3 and M4 insure the cross-separation of the 5×2 channels. The post-dispersion is due to the low-resolution ($\mathcal{R}$=1200) gratings R1 and R2. The 256×1024 pixels CCD camera registers 5×2 spectra, from 400 to 560 nm, allowing the determination of about 350 different fringes. The phase of each fringe gives an independent radial velocity measurement.

mate the photon noise limited performance of an instrument as SIAMOIS (Fig. 1). The stellar rotation is a key parameter, since the efficiency of the detection is highly sensitive to the stellar line widths: performances decreases with $v \sin i$ as $1/v \sin i$, so that an efficient instrument at Dome C is practically limited to $v \sin i \simeq 20$ km s^{-1} targets.

The performances of SIAMOIS are comparable to the ones obtained with a grating spectrometer: they remain a factor about 1.5 lower than an instrument similar to CORALIE (Queloz *et al.* 2000). The SIAMOIS concept is just more simple and can be implemented rapidly at Dome C, for a lower cost. This is justified by the fact that the high spectral resolution necessary to measure very precise radial velocities needs a $\mathcal{R} = 60\,000$ grating spectrometer, but is achieved in the case of a FT seismometer with a single scan of one fringe at the working path difference (around 1 cm) and with a $\mathcal{R} = 1200$ postdisperser. All the results of the simulations used to define the characteristics of a FTS dedicated to asteroseismology. In order to guarantee a simple, stable and luminous instrument, the design of the interferometer is monolithic and excludes moving parts (Fig. 2). Contrary to a basic Fourier Transform Spectrometer scanning the fringes with a moving mirror, a simultaneous sample is permitted by a mirror with different steps (M2, Fig. 2). As a result, the instrument is able to operate without any adjustment, servo-system or electronics control.

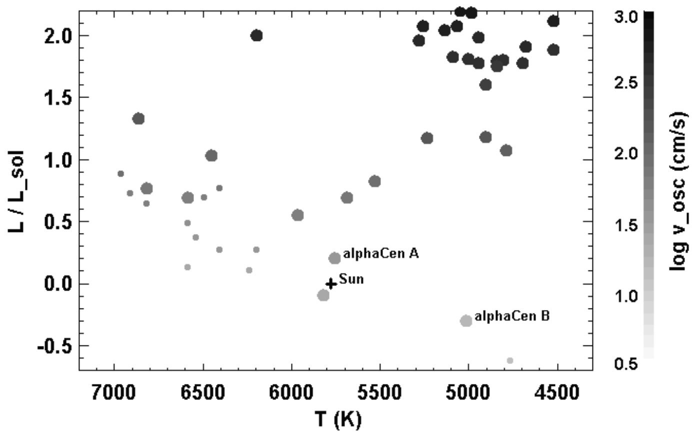

Fig. 3. Estimation of the stellar oscillation amplitude of possible seismic targets observable at Dome C with a 2-m (small symbol) or a 80-cm (large symbol) telescope (Barban, private communication).

4 An asteroseismic programme at Dome C

We have examined the possible solar-like targets observable at Dome C with accurate performances. A systematic exploration of all possible targets has been performed with the criteria : F, G or K type, class V or IV, $m_{\rm V} < 5$, low $v \sin i$ (< 20 km s^{-1}), and $\delta < -20°$ for long time series at Dome C. In agreement with the expected developments at Dome C, we consider two cases: first a 0.8-m telescope (as the IRAIT project, Busso *et al.*, these proceedings), then a 2-m class project. Ten targets are then observable with a SNR better than 5 with a 0.8-m class telescope, and up to 24 with a 2-m (and in both cases twice more when including red giants, that show also p-mode oscillations). This demonstrates the feasibility to operate efficiently at Dome C, even with a small collector. Due to their magnitudes and the expected performances, the targets α Cen A and B are of course major candidates, especially since the results with 2 telescopes (Bedding *et al.* 2004) remain limited by the window function. In the HR diagram of Fig. 3 we present the maximum velocity expected for solar-like oscillations, varying with the stellar mass and luminosity as $(L/M)^{0.65}$ (Samadi *et al.* 2004). The set of possible targets will permit to examine lower mass stars in the HR diagram than with space missions.

Astronomic observations at Dome C are characterized by different outstanding observational conditions. Asteroseismology will benefit particularly from a very clean duty cycle, allowing continuous observation with a duty cycle better than 80% over several weeks, and near 100% over several days. The excellent seeing at Dome C will provide a very high efficiency. Observations with an échelle spectrograph as HARPS are highly limited by the poor efficiency of the entrance fiber, that accepts only 1" on the sky. Most of the time, at least 50% of the stellar flux is simply lost outside the fiber, and more than 85% is lost at high airmass in median seeing conditions (Mosser *et al.* 2004), what reduces drastically the photon noise limited performance. Operating an instrument at Dome C will therefore be much more efficient than observing in any other site. Furthermore, due to the high altitude, the atmospheric transmission will be much better, especially in the blue part of the spectrum, that gives the best contribution to oscillation quality factor of the detection (Mosser *et al.* 2003).

5 Conclusion

An extensive asteroseismic observational programme at Dome C is feasible in the near future and will fully exploit the outstanding quality of the site. For continuous observations, observing at Dome C is equivalent to a full network, but will give much better results than in any other sites. An instrument as SIAMOIS coupled with a small (0.80 m) telescope is already efficient for 10 targets (F, G and K type, V and IV class), with stellar magnitudes up to 5 and $v \sin i$ up to 20 km s^{-1} (24 targets with a 2-m class telescope).

It will be possible to examine solar-like oscillation in the whole HR diagram, including low mass stars which cannot be observed with current space mission. At the same time, spectrometric ground-based observations will be complementary to the photometric observations of COROT: the comparison of two different seismic observables will open new insights in asteroseismology. Ground-based follow-up of detections made by COROT will be possible with a similar efficient duty cycle.

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