SIAMOIS : AN ASTEROSEISMIC NETWORK WITH 1 SITE... IN ANTARCTICA

Mosser Benoît[1] and the SIAMOIS team[2]

[1]*LESIA, Observatoire de Paris/CNRS UMR 8109, F-92195 Meudon, France*
[2]*Observatoire de Paris/LESIA, IAP, IAS, UNSA/LUAN, OMP/LATT, OCA*

ABSTRACT

SIAMOIS is a project devoted to ground-based asteroseismology, involving an instrument to be installed at the Dome C Concordia station in Antarctica. Dome C appears to be the ideal place for ground-based asteroseismic observations. The unequalled weather conditions yield a duty cycle as high as 90% over 3 months, as was observed during the 2005 wintering. This high duty cycle, a crucial point for asteroseismology, is comparable to the best space-based observations. Long time series (up to 3 months) will be possible, thanks to the long duration of the polar night. As a consequence, SIAMOIS proposes a unique asteroseismic programme that can follow the way opened by the space project CoRoT: it will provide unique information on G and K type bright stars on the main sequence. In addition, spectrometric observations with SIAMOIS will be able to detect oscillation modes that cannot be analysed in photometry, and will be less affected by stellar activity noise, increasing the complementarity with space-based photometric observations. The SIAMOIS concept is based on Fourier Transform interferometry. Such a principle leads to a small instrument designed and developped for the harsh conditions in Antarctic. The instrument will be fully automatic, with no moving parts, and a very simple initial set up in Antarctic. The single dedicated scientific programme will avoid the complications related to a versatile instrument. Data reduction will be performed in real time, and the transfer of the asteroseismic data to Europe will require a modest bandpass. SIAMOIS will observe with a dedicated small 40-cm telescope.

Key words: Instrumentation, Antarctica, Stars: oscillations.

1. INTRODUCTION

The analysis of stellar oscillation modes constitutes a powerful tool to probe their internal structure. Already applied to the Sun with remarkable success, this technique is now opening up to stars, but asteroseismic observations have very stringent requirements in order to give precise constraints on stellar modelling: duty cycle greater than 80%, over long intervals of time (typically several months). Space-based observations (such as the European-French CNES mission CoRoT, Baglin et al. 2002) meet these specifications, with very precise photometric observations. However, spectrometric observations are able to detect $\ell = 3$ oscillation modes that cannot be analysed in photometry, and they are less affected by stellar activity noise.

Spectroscopy with an échelle spectrometer allows the measurement of small Doppler shifts due to solar-like oscillations (HARPS at the ESO 3.6-m telescope (Pepe et al. 2000) or SOPHIE at the OHP 2-m telescope). However, asteroseismology needs continuous measurements, for example from a worldwide network of half a dozen or more matched instruments in superb sites, which however does not exist. To date, two-site observation have been realized on a very limited number of very bright targets, such as α Cen A and B (Bedding et al. 2004), and with a time series limited to only a few days. Alternative solutions must be explored: the SIAMOIS Fourier Tachometer at the Concordia station in Antarctica meets all of the scientific and technical objectives.

Section 2 reports some properties of Fourier transform seismometry. Simulations and performance are analyzed in Section 3, then specific properties of asteroseismology in Antarctica are given in Section 4. The Fourier tachometer SIAMOIS dedicated to asteroseismology is presented in Section 5. In French, SIAMOIS stands for: Sismomètre Interférentiel A Mesurer les Oscillations des Intérieurs Stellaires; and in English for: Seismic Interferometer Aiming to Measure Oscillations in the Interior of Stars.

2. FOURIER TRANSFORM SEISMOMETRY: PRINCIPLE

Typically the Doppler velocity of a star is obtained from the spectrum of an absorption line, either from several narrow-band filter measurements in the steep part of the line profile [e.g. GOLF on SOHO], or by measuring the line profile with a very stable spectrogrameter [e.g. HARPS]. Fourier Tachometry instead measures the phase of a fringe in the stellar interferogram (Fig. 1).

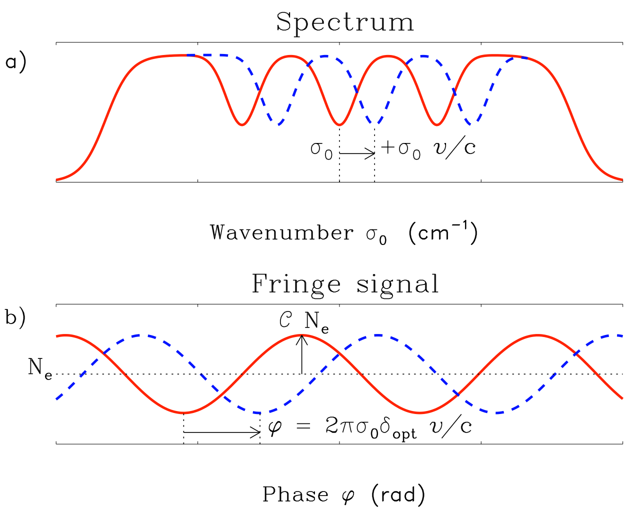

Figure 1. Principle of a Fourier tachometer: the phase of the fringe signal gives a measuremen of the radial velocity.

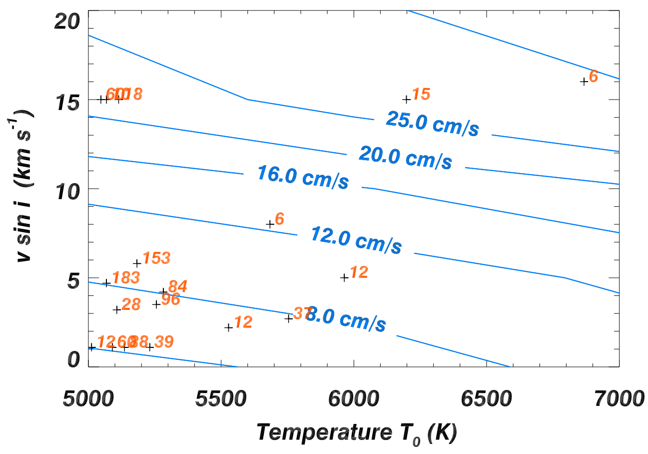

Figure 2. Isovelocity levels give the performance $v_{\rm rms}$ as a function of effective temperature and $v \sin i$, obtained in the following conditions: 40-cm telescope, 5 nights with a global duty cycle 90%, and 4th magnitude star. The ratio $A/v_{\rm rms}$, with A the maximum oscillation amplitude (Samadi et al 2005), has been superimposed for targets observable from Dome C.

Applied to the Sun in the 1980's, Fourier Tachometry was chosen for the GONG helioseismic network after a long study of competing measurement strategies (`http://gong.nso.edu`), and it forms the basis of the Michelson Doppler Imager instrument on the SOHO spacecraft as well as the Velocity and Magnetic Imager on the forthcoming SDO spacecraft. The data analysis is extremely simple: the sine-wave fit yields an amplitude (essentially the strength of the line), a mean value (the average intensity), and a phase (the Doppler shifted wavelength of the center of gravity of the line).

The repeated recording of the same fringe allows us to construct the Doppler signal, related to the phase shift φ (Fig. 1). The phase of the fringe signal gives directly the Doppler signal.

$$\frac{\varphi}{2\pi} = \sigma_0 \delta_{\rm opt} \, \frac{v}{c} \qquad (1)$$

σ_0 being the wavenumber, $\delta_{\rm opt}$ the optical path difference. Compared to a grating spectrometer, a Fourier Tachometer is a much simplest and smallest instrument, with a simple data reduction and low output flow.

3. SIMULATIONS

3.1. Performance

The photon noise limited performance of a Fourier tachometer can be expressed as (Mosser et al 2003):

$$v_{\rm rms} = \frac{c}{Q\sqrt{N_{\rm e}}} \qquad (2)$$

and depends mainly on 2 parameters. The quality factor $Q = \sqrt{2}\pi \, \sigma_0 \delta_{\rm opt} \, \mathcal{C}$ measures the fringe contrast $\mathcal{C}$ multiplied by the efficiency factor $\sigma_0 \delta_{\rm opt}$. This factor is related to the stellar line width Δv through $\sigma_0 \, \delta_{\rm opt} \propto 1/\Delta v$. The number of photoelectrons $N_{\rm e}$ is related to the brightness of the signal.

The filter bandwidth plays an important role, since $N_{\rm e}$ increases with $\Delta\sigma$ when Q decreases with it. High performance requires the *simultaneous* optimization of $N_{\rm e}$ and Q. An increase of $N_{\rm e}$, obtained with a broader bandpass, gives a reduced $\mathcal{C}$, hence a reduced Q. Therefore, a low-resolution post-dispersion is required in order to optimize the signal.

3.2. Velocity performance

Simulations have been realized with synthetic spectra of dwarf stars ($T_{\rm eff} = 5000$ to 7000 K), in the spectral range 380 - 680 nm (14700 - 26300 cm^{-1}). They allow us to estimate the photon-noise limited sensitivity (Fig. 2). Key parameters are the stellar V magnitude (magnitudes 0 to 5 were considereed) and the rotational velocity $v \sin i$ (0 to 40 km s^{-1}). Photometric conditions concern a 0.4-m class telescope, as is currently available at Dome C, and an observing duty-cycle of 90% (Aristidi, private communication).

4. ASTEROSEISMOLOGY IN ANTARCTICA

4.1. Performance; duty cycle

Dome C is an exceptional site for astronomy (Aristidi et al 2005). At latitude 75°, a single instrument may track continuously circumpolar targets. The high altitude (3200 m, equivalent to a barometric altitude of 3700

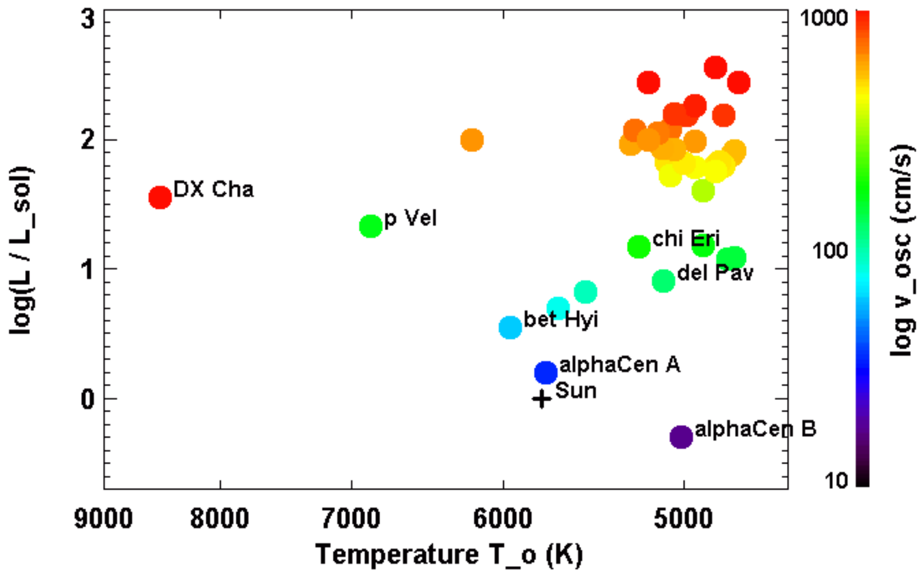

Figure 3. Estimations of the stellar oscillation amplitude of circumpolar targets observable at Dome C, with a 40-cm telescope. The Sun is indicated as a reference. This list is non exhaustive: many more targets, such as δ Scuti, have to be identified.

m) provides an optimum transparency. The polar night at Dome C extends from May 7 to August 11, providing about 100 nights. Meteorological conditions are optimum. In fact, observations conducted at the Concordia station in 2006 show that the clear sky fraction is higher than 0.9 84% of the time. The average number of consecutive clear days (with a sky fraction > 0.9) was about 6.8 (E. Aristidi, private communication).

But Dome C has challenging conditions: the site is completely isolated, with a mean winter temperature about $-60°$C and minimum temperatures down to $-80°$C. Therefore, any instrument at Dome C must be simple, remotely controlled. A dedicated FT such as SIAMOIS was conceived to obey such specifications. With a monolithic interferometer and a small antarctized telescope, it provides efficient performance, but remains robust, with a simple setup.

4.2. Dome C versus space or network observations

Spectrometric ground-based observations are complementary to space photometric observations. They give access to spherical harmonic $\ell \leq 3$ modes, contrary to photometry, hence to the small frequency separation between $\ell = 1$ and $\ell = 3$ modes. This small separation gives precise clue on the stellar core structure.

A network, such as the proposed SONG project (`http://astro.phys.au.dk/SONG/`) cannot provide a duty cycle as high as 90% (Mosser and Aristidi, submitted to PASP). To be efficient, it requires at least 6 sites, as it was demonstrated for solar networks (Hill & Newkirk 1985). Therefore, the quality and reliability of each instrument of the network must be nearly perfect, since any failure in one site reduces drastically the property of the whole network. An instrument at Dome C must be as efficient and reliable, but in that case constraints and costs are not multiplied by 6 or more. Dome C appears to be the best ground-based site addressing the specifications: continuous *and* long-duration observations.

4.3. Seismic targets at Dome C

With a collector limited to 40 cm, SIAMOIS is efficient for stellar magnitudes brighter than 5. Furthermore, efficiency requires low values of $v \sin i$. Possible targets are: dwarf or giant stars with solar-like oscillations, pulsators such as PMS, δ Scuti, γ Doradus... as soon as the rotational velocity does not exceed 15 km s^{-1} (solar-like oscillors) or 40 km s^{-1} (pulsators).

The number and the diversity of the targets (Fig. 3) provide a scientific programme for more than 6 winters, that reap the benefit of the investment. According to the scientific specifications, each target showing solar-like oscillations will be observed continuously during at least 3 months.

5. SIAMOIS

5.1. Instrumental concept

The instrument is fed via a single 50 μm fiber, selecting 5" on the sky. The optical fiber adapter $f/4$ insures the

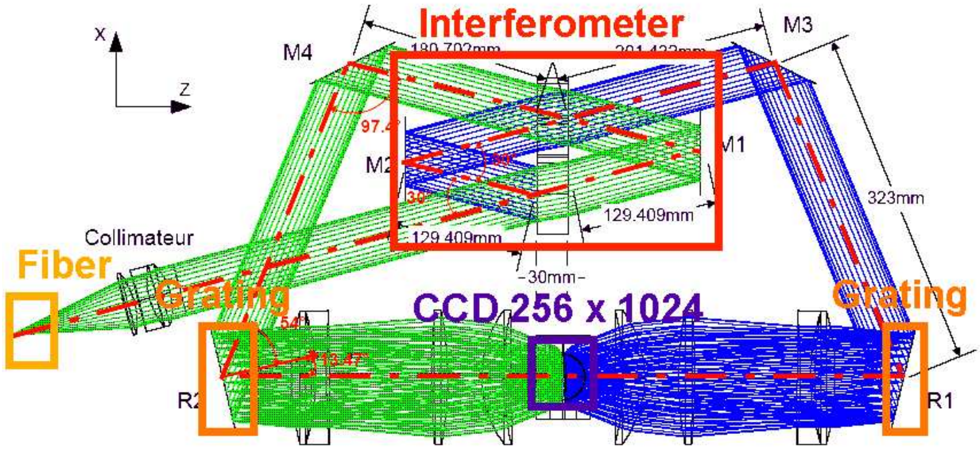

Figure 4. Optical layout of SIAMOIS, obeying the specifications: high stability, fully automatic, simple setup.

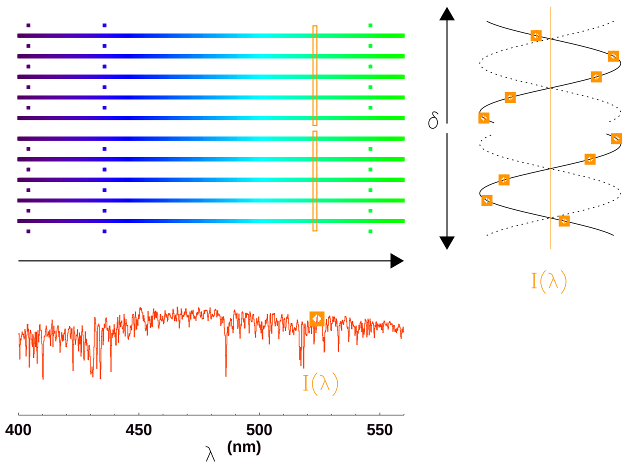

Figure 5. Synthetic image on a CCD of SIAMOIS: wavelength on abscissa, optical path difference on ordinate. At fixed color, the signal gives 2 complementary fringes (1 for each arm of the interferometer), whose phase gives the Doppler velocity.

stabilization of the star image. The optical path difference is fixed by a parallel plate in one arm (not shown on (Fig. 4). M1 is a flat mirror, but M2 presents 5 steps in order to sample the fringe at 5 points. Two folding mirrors M3 and M4 insure the cross-separation of the 5×2 channels for 1 target. The post-dispersion is due to the low-resolution gratings R1 and R2, for a post-dispersion resolution $\mathcal{R} \simeq 1000$. The 256×1024 pixels CCD camera registers 5×2 spectra of the star, from 400 to 560 nm, allowing the measurement of about 350 different fringes. The phase of each fringe gives an independent radial velocity measurement (Fig. 5).

5.2. Operations

The multiplex advantage of a Fourier Tachometer makes possible to obtain the radial velocity coded on a limited number of pixels on the CCD camera. So, SIAMOIS will observe simultaneously at least 2 stars, each one observed with a given collector. SIAMOIS, currently in phase A (2006-2007), offers a unique scientific programme starting in 2011, after the results of the CoRoT mission.

6. OUTSTANDING SCIENCE FOR DOME C

The SIAMOIS project is an excellent match of a high payoff pioneering observational programme at Dome C. A Fourier tachometer is a very suitable concept for installation and setup at Dome C. Dome C, a unique site for asterosismology, provides 3-month continuous observation with duty cycle better than 90%. This will give unprecedented precise spectrometric Doppler measurements, for unprecedented precise stellar modelling. SIAMOIS offers a specific scientific program after CoRoT, for more than 6 winters. High performance is obtained with a 40-cm collector. The SIAMOIS instrumental concept opens new insights for multi-targets radial velocity measurements.

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