SIAMOIS : asteroseismology in Antarctic

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SIAMOIS is an instrumental project devoted to ground-based asteroseismology, to be installed at the Dome C station in Antarctic. SIAMOIS is currently the only asteroseismic programme that can succeed the space project COROT : it will carry unique informations on G and K type stars in the main sequence, that will not be observed by COROT. Spectrometric analysis with SIAMOIS will be complementary to the space photometric observations. And SIAMOIS will be able to make the follow up of similar seismic targets as the one discovered by the secondary programme of COROT. The SIAMOIS concept is based on Fourier Transform interferometry (Mosser, Maillard & Bouchy 2003). Such a principle leads to an instrument much smaller than a grating spectrometer, but with similar performances. The design of SIAMOIS is developped for the harsh conditions in Antarctic : the instrument will be fully automatic, with no moving parts, and a very simple simple set up in Antarctic. The single dedicated scientific programme avoids the complication due to a versatile instrument.

Dome C appears to be the ideal place for ground-based asteroseismic observations. The unprecedented good weather gives a duty cycle as high as 95%, as was observed during the 2005 wintering. This duty cycle, a crucial point for asteroseismology, is similar to the best space observations. SIAMOIS is an instrument designed for a 2-m class telescope, but a significant part of the scientific programme can already be achieved with a smaller collector. The construction and installation of the instrument can be achieved within 2.5 years. The SIAMOIS project is intended to participate to the very first observational projects in astronomy at Dome C, and will constitute a first step preparing programmes requiring a more sophisticated instrumentation and a greater collector.

1 Ground-based asteroseismology

The asteroseismic signal can be observed through different ways. The photometric monitoring of the relative flux change of stellar oscillations, as low as a 1 ppm, is only feasible in space, eg the Canadian micro-satellite MOST (Matthews 2004), or the French-European mission COROT (Baglin 2002).

The Doppler signature of solar-like oscillations, about a few cm/s, requires a very high instrumental stability.

1.1 Spectroscopy

Spectroscopy with an échelle spectrometer allows the measurement of small Doppler shifts, with repeated recording of a high-resolution visible spectrum of the star.

Ultra-high stability and sensitivity are required, expressed by the following specifications :

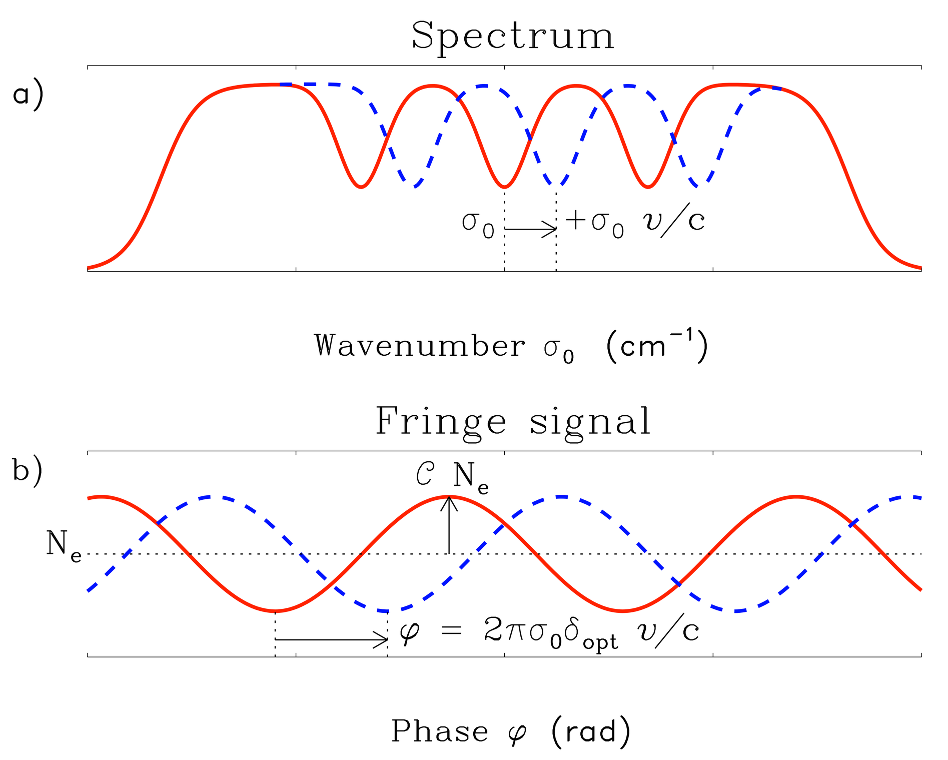
- High spectral resolution — $\sim$ 100 000
- Broad spectral coverage — visible
- High optical efficiency
- Very stable — temperature controlled $\sim$ 0.01 K
- High-stability spectral reference — 10^{-9}

The instruments HARPS at ESO 3.6-m telescope (Pepe et al. 2000) or SOPHIE at OHP 2-m telescope, dedicated for radial velocity measurement, fulfil these specification. However, asteroseismology needs continuous measurements, therefore a worldwide network of several instruments of comparable capabilities. Such a network does not exist.

Another approach : Fourier Transform seismometry

2 FT seismometry : principle

The Doppler signal can be searched in the interferogram of a stellar spectrum limited by a filter (bandwidth $\Delta\sigma$).



The repeated recording of the same fringe allows us to construct the Doppler signal, related to the phase shift φ :

$$\varphi = 2\pi\ \sigma_0\delta_{\rm opt}\ \frac{v}{c}$$

σ_0 being the wavenumber, $\delta_{\rm opt}$ the optical path difference.

Compared to a grating spectrometer (GS), a Fourier Transform seismometer (FTS) is a much simplest and smallest instrument. Furthermore, the signal is a simple sinewave !

Simple data reduction ; low output flow

3 Photon noise limited performances

3.1 Performances

The photon noise limited performances express as (Mosser et al 2003) :

$$v_{\rm rms} = \frac{c}{Q\sqrt{N_{\rm e}}}$$

This 1-σ noise level depends on :

- The quality factor :

$$Q = \sqrt{2}\pi\ \sigma_0\delta_{\rm opt}\ \mathcal{C}$$

the wavenumber σ_0 and optical path difference (opd) $\delta_{\rm opt}$ are related to the stellar line width Δv : $\sigma_0\ \delta_{\rm opt}\ \propto\ 1/\Delta v$; $\mathcal{C}$ is the fringe contrast at opd $\delta_{\rm opt}$

- The number of detected photoelectrons $N_{\rm e}$. $N_{\rm e}$ is related to the luminosity of the instrument, and increases with the filter bandwidth $\Delta\sigma$.

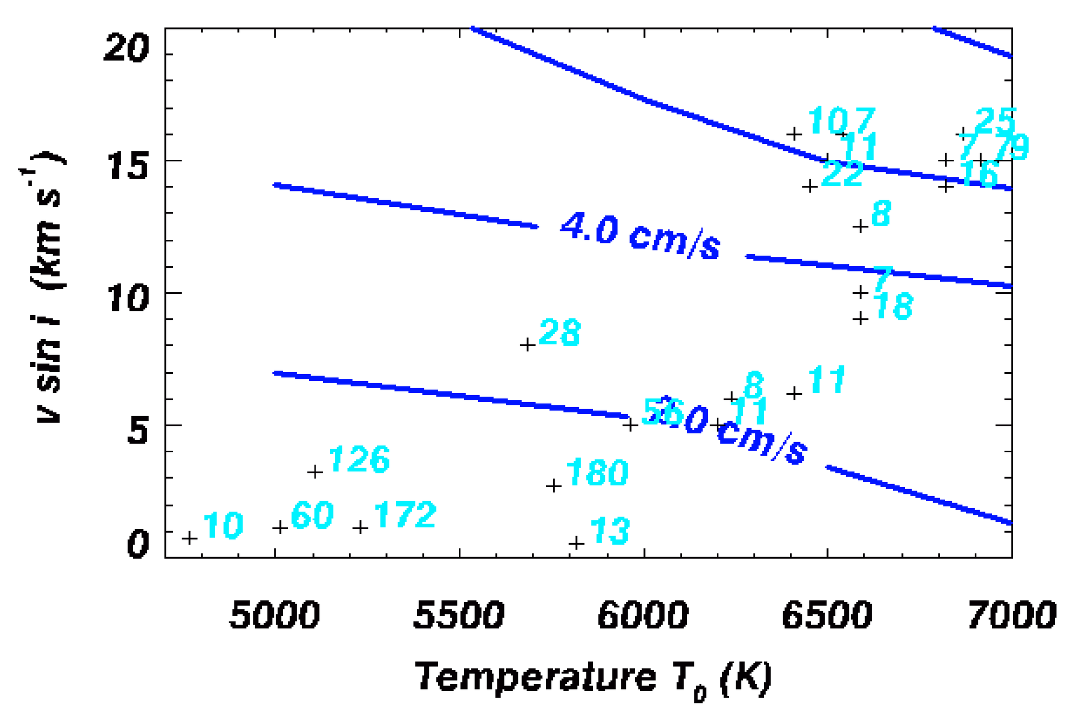
High performances require to optimize simultaneously the photometric signal $N_{\rm e}$ and the quality factor Q. However, an increase of $N_{\rm e}$, obtained with an enlargement of $\Delta\sigma$, gives a reduced $\mathcal{C}$, hence a reduced Q.

Therefore, a low resolution post-dispersion is required in order to optimize the signal.

Fourier Interferometer + low resolution post-dispersion

3.2 Simulations

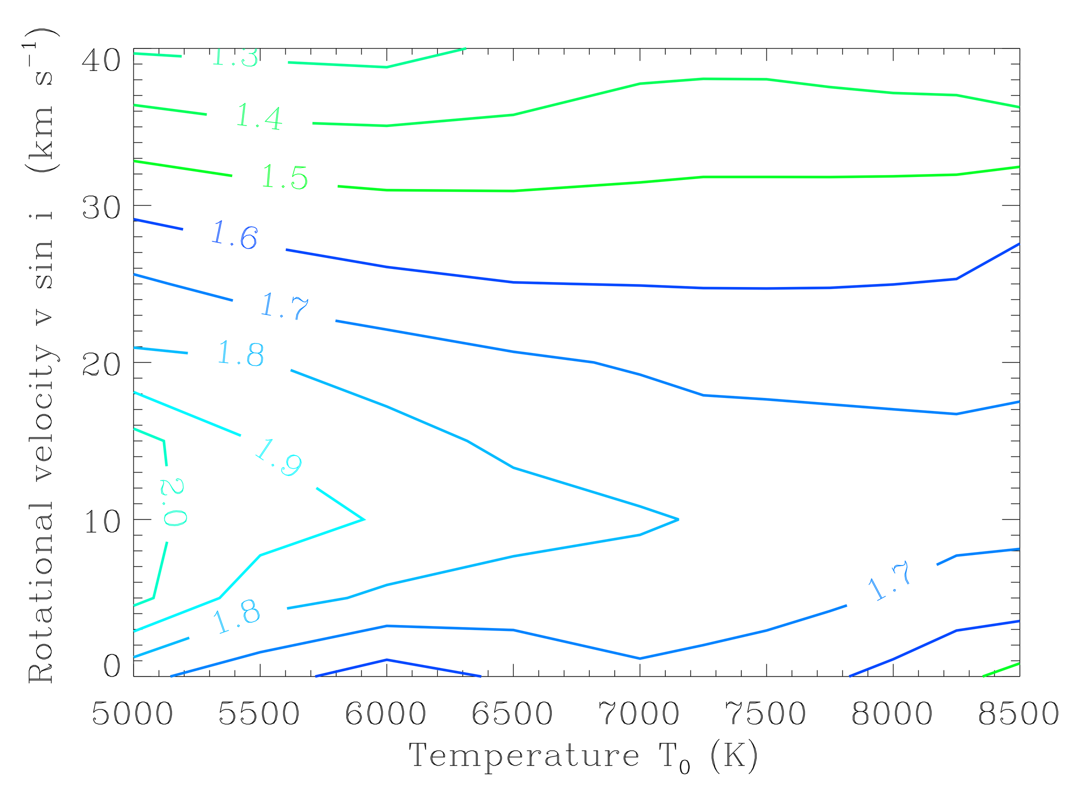
Simulations were made with synthetic spectra of dwarf stars ($T_{\rm eff}$ = 5000 to 7000 K), in the spectral range 380 - 680 nm (14700 - 26300 cm^{-1}).



Isovelocity levels give the performance $v_{\rm rms}$ 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 $A/v_{\rm rms}$, where A is the maximum oscillation amplitude predicted by Samadi et al [2005], 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.

3.3 FTS versus GS (grating spectrometer)



Ratio $\delta v_{\rm FTS}/\delta v_{\rm GS}$ of the performances obtained with the FTS (with post-dispersion of (R=1200)) and a grating spectrometer (R=100 000) as Harps (Bouchy et al. 2001)

Similar photon noise limited performances : $\delta v_{\rm FTS}/\delta v_{\rm GS} < 2$

4 SIAMOIS

SIAMOIS is a FTS dedicated to asteroseismology. It stands in French for :

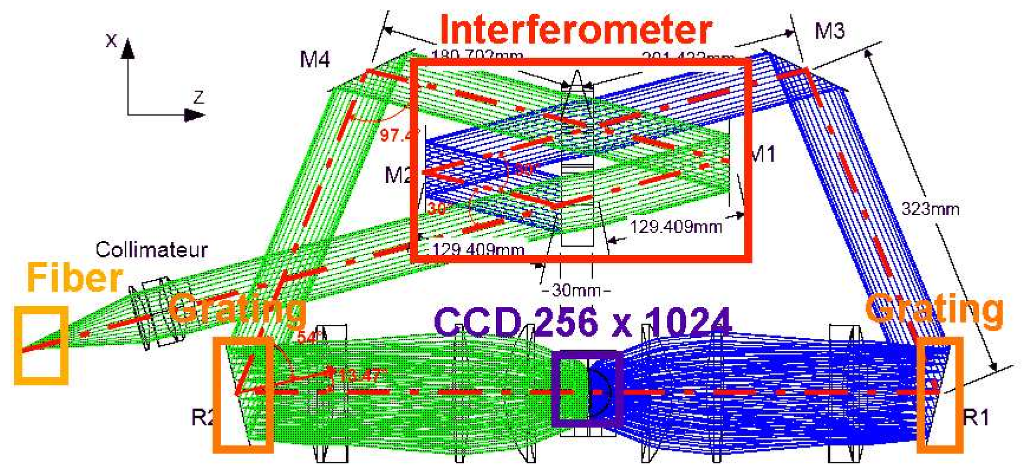
Sismomètre Interférentiel A Mesurer les Oscillations des Intérieurs Stellaires

4.1 Instrumental concept

- Feeding of the instrument by optical fiber — single 50μm fiber, 2" on the sky
- Optical fiber adapter $f/2.5$ — stabilization of star image
- Fixed o.p.d — by a parallel plate in one arm
- Sampling of a fringe — by 5 points
- One mirror of the interferometer with steps — 5 steps of depth = $\lambda_0/10$
- Post-dispersion by two low-resolution gratings — R=1200

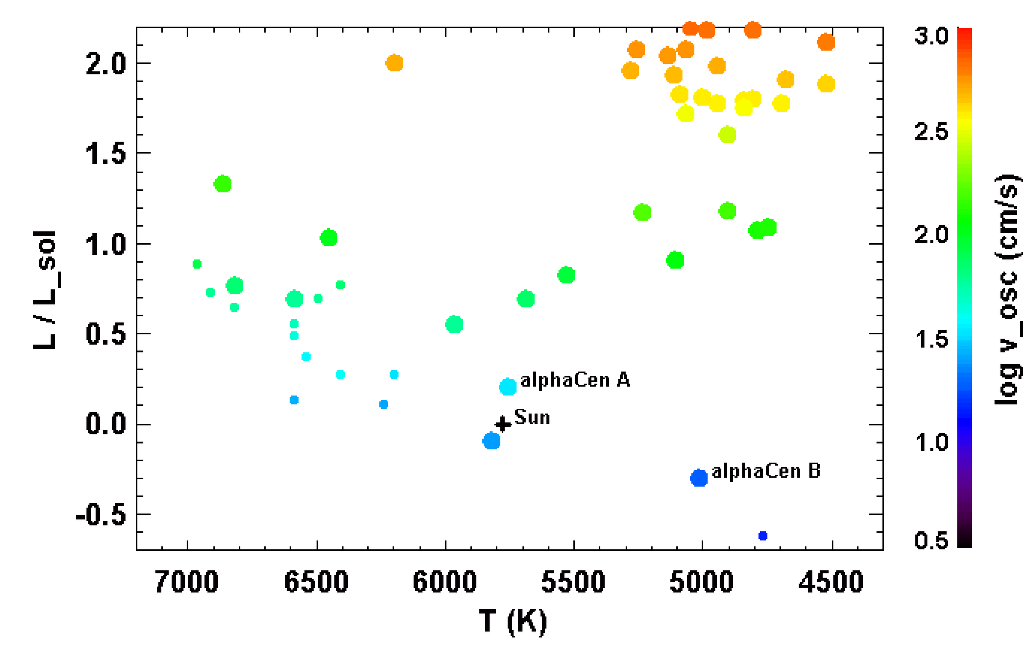
4.2 Optical layout of SIAMOIS

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.



High stability, simplicity, small size, reduced cost

5 Seismic targets at Dome C



Estimations of the stellar oscillation amplitude of possible seismic targets observable at Dome C were made by Barban (private communication). Large circle are observable targets with a 80-cm telescope (as the IRAIT project, Tosti et al 2004) ; the observation of stars indicated with a small symbol requires a 2-m class telescope.

$v\sin i$	0 – 10	10 – 20	20 – 40 (km/s)
V class target	11	20	8
IV class target	2	6	2

SIAMOIS, with a small collector, is already efficient for stellar magnitudes up to 5 with $v\sin i$ up to 40 km s^{-1}.

More than 40 solar-like targets observable at dome C

6 Outstanding science for Dome C

6.1 Performances

Dome C is an exceptional site for astronomy :

- Latitude 75° S — single instrument for continuous observation of circumpolar targets
- Transparence stability — continuous several weeks data acquisition, as in space

Duty cycle up to 100% during weeks

- High altitude — optimum transparency even at large HA
- Image quality — important for a fiber-fed instrument

Performance 3 times better than a dedicated network

However, Dome C offers severe conditions : isolated site, with temperature down to −80°C. An instrument at Dome C must be simple, robust, remotely controlled. A dedicated FT seismometer as SIAMOIS, with efficient performances, remains small, simple, monolithic, robust.

SIAMOIS fulfills all the criteria for Dome C instrumentation

6.2 Dome C versus space observations

Spectrometric ground-based observations are complementary to space photometric observations. SIAMOIS will provide a possible follow-up of COROT secondary targets, as well as the observation of low-mass stars not observable with COROT.

6.3 Schedule and programme

- The SIAMOIS instrument can be realized within 24 months.
- The SIAMOIS project fits exactly to the conditions for a first ambitious observation programme at Dome C.
- The SIAMOIS asteroseismic programme makes ful benefit of the exceptional astronomical site at Dome C.

Références

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