SIAMOIS: Asteroseismology in Antarctica

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SIAMOIS is a ground-based asteroseismology project, to pursue velocity measurements from the Dome C Concordia station in Antarctica. Dome C appears to be the ideal place for ground-based asteroseismic observations as it is capable of delivering a duty cycle as high as 90% during the three-month long polar night, as observed in 2005. This high duty cycle, a crucial point for asteroseismology, is comparable to the best space-based observations.
SIAMOIS is the only asteroseismic programme that can follow the way opened by the space project CoRoT: it will provide unique measurements of the eigenfrequencies of bright ($m \leq 5.5$) main sequence G and K type stars; velocity measurements will be complementary to CoRoT's intensity measurements, and will be able to detect $\ell = 3$ oscillation modes that cannot be analysed by photometry.
The SIAMOIS concept is based on Fourier Transform interferometry, which leads to a small instrument designed and developed for the harsh conditions in Antarctica. The instrument will be fully automatic, with no moving parts, and it will require only a very simple initial set up in Antarctica. The single dedicated scientific programme will avoid the complications related to a more general purpose instrument. Data reduction will be performed in real time, and the transfer of the asteroseismic data to Europe will require only a modest bandwidth. SIAMOIS will observe with a dedicated small 40-cm telescope.

1 Ground-based asteroseismology

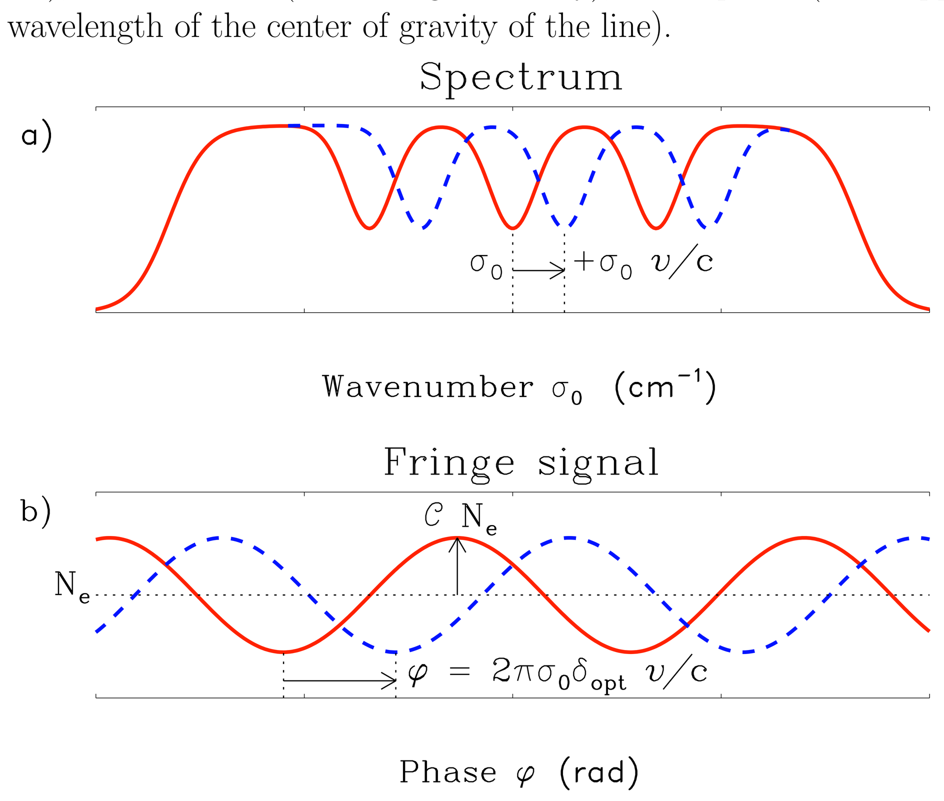
The analysis of stellar oscillation modes constitutes a powerful tool to probe their internal structure. Already applied to the Sun with remarkable success, this technique is now opening up to stars, but asteroseismic observations have very stringent requirements in order to give precise constraints 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.

Scientific specifications: high duty cycle, long duration

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 world-wide network of half a dozen or more matched instruments in superb sites, which however does not exist. To date, only two-site observation have been realized, on α Cen A and B (Bedding et al. 2004), with a useful time series of 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.

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 spectrograph [e.g. ELODIE]. Fourier Tachometry instead measures the phase of a fringe in the stellar interferogram.
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 (`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 phase of the fringe signal gives directly the Doppler signal.

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

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

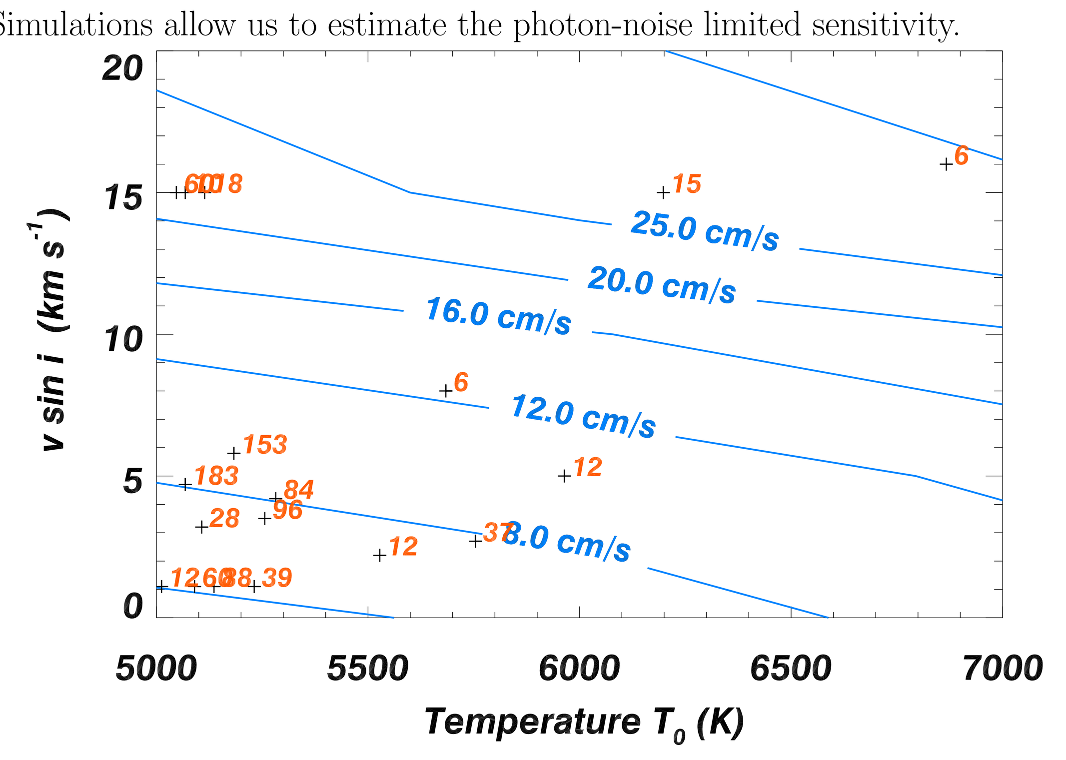
Simple data reduction; low output flow

3 Performance

The photon noise limited performance can be expressed as (Mosser et al 2003): $v_{\rm rms} = c / Q\sqrt{N_{\rm e}}$. The quality factor $Q = \sqrt{2}\pi\ \sigma_0\delta_{\rm opt}\ \mathcal{C}$ measures the fringe contrast $\mathcal{C}$. The number of photoelectrons $N_{\rm e}$ is related to the brightness of the signal. High performance requires that we optimize *simultaneously* $N_{\rm e}$ 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.

Fourier Tachometer + low-resolution post-dispersion

Simulations allow us to estimate the photon-noise limited sensitivity.



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 95%, 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.

4 Seismology in Antarctica

4.1 Performance; duty cycle

Dome C is an exceptional site for astronomy:

- Latitude 75° S — continuous observation of circumpolar targets
- Transparency stability — continuous for several weeks
- High altitude — optimum transparency even at large HA
- Long polar night — 100 nights, from May 7 to August 11

Duty cycle up to ≃100 % during weeks

Dome C has challenging conditions: isolated site, with temperatures down to −80°C. An instrument at Dome C must be simple, remotely controlled. A dedicated FT such as SIAMOIS with a monolithic interferometer provides efficient performance, but remains robust, with a simple setup.

4.2 Dome C versus space observations

Spectrometric ground-based observations are complementary to space photometric observations. They give access to spherical harmonic $\ell \leq 3$ modes. SIAMOIS offers a unique scientific programme starting in 2011, after the results of the CoRoT mission.

Spectometric observable: $\ell = 3$ modes more visible; less noise

4.3 Dome C versus network observations

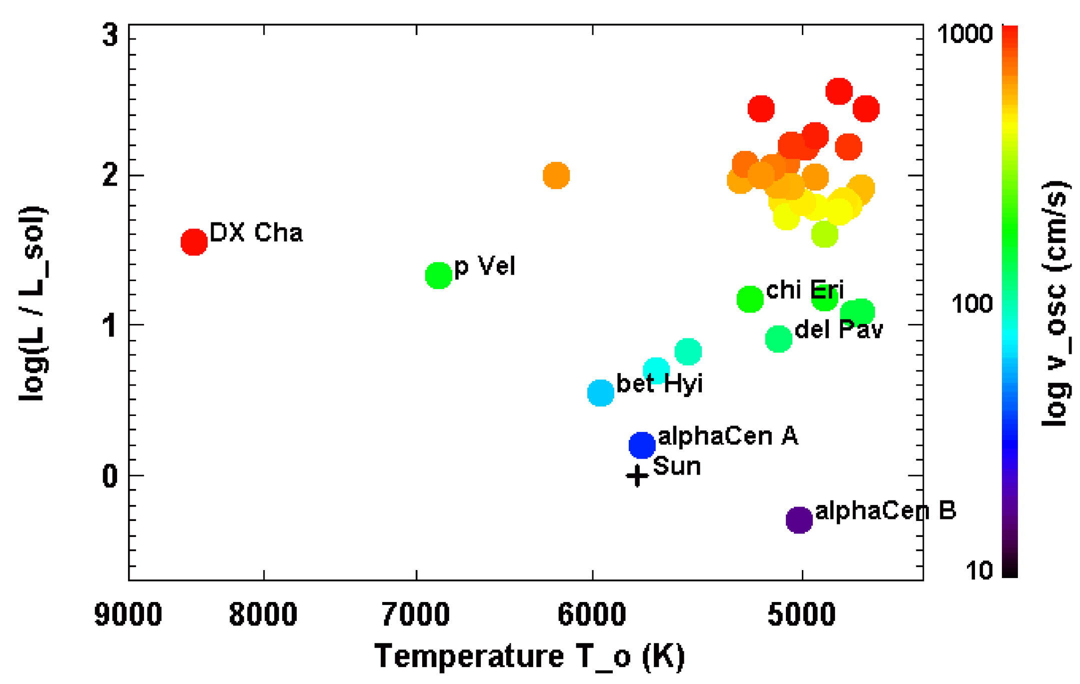
A network, such as the proposed SONG project (`astro.phys.au.dk/SONG/`) cannot provide such a high duty cycle, and continuous observations of a given target are limited to about 1 month. A network requires at least 6 sites.

Antarctica: higher duty cycle, longer observations.

In fact, Dome C is the best ground-based site addressing the specifications: continuous long-duration observations.

Program for 1 winter: continuous monitoring of 1 target

5 Seismic targets at Dome C



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.

SIAMOIS is efficient for stellar magnitudes less than 5 with $v \sin i$ up to 40 km s^{-1}. According to the scientific specifications, each target showing solar-like oscillations is observed continuously during at least 3 months. Possible targets are: dwarfs or giant with solar-like oscillations, pulsators such as PMS, δ-Scuti...

A scientific programme for more than 6 winters

6 SIAMOIS

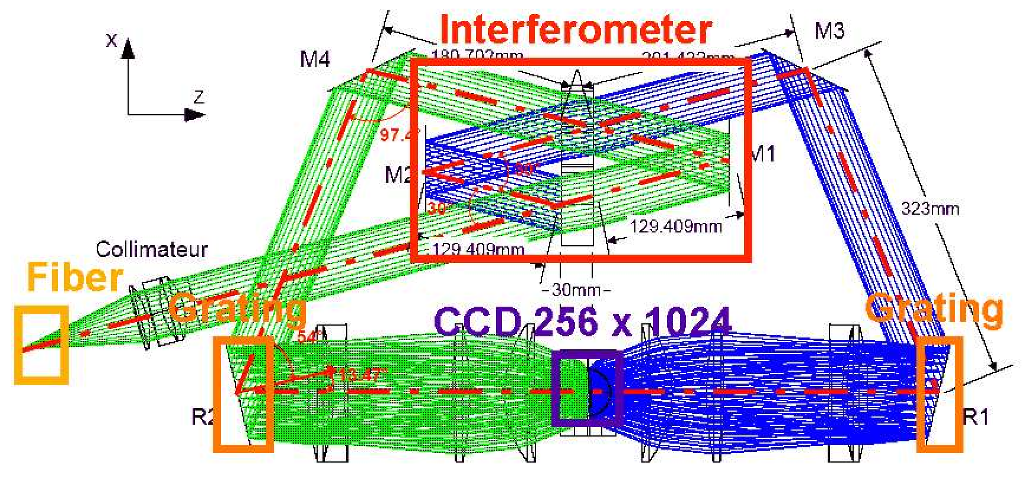
In French it stands for: *Sismomètre Interférentiel A Mesurer les Oscillations des Intérieurs Stellaires*; and in English: *Seismic Interferometer Aiming to Measure Oscillations in the Interior of Stars*.

6.1 Instrumental concept

- The instrument is fed by a single optical fiber — 50μm, 5" on the sky
- Fixed optical path difference — by a parallel plate in one arm
- Sampling of a fringe — by 5 points
- Post-dispersion by two low-resolution gratings — $\mathcal{R}$=1000

6.2 Optical layout of SIAMOIS

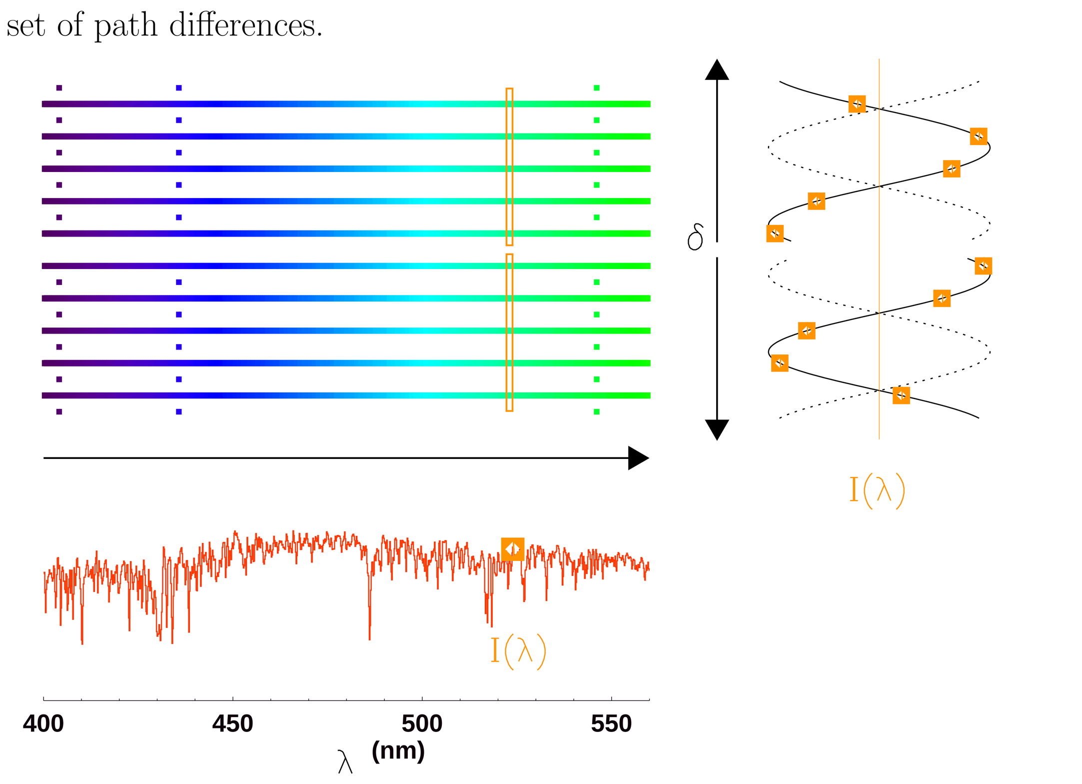
The optical path difference is fixed by a parallel plate in one arm (not shown on this Figure). M1 is a flat mirror, but M2 presents 5 steps in order to sample the fringe at 5 points. Two folding mirrors M3 and M4 insure the cross-separation of the 5×2 channels. The post-dispersion is due to the low-resolution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



High stability, fully automatic, simple setup

6.3 Data reduction

The Doppler information is coded between the different spectra, obtained for a set of path differences.



Synthetic image 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.

6.4 Schedule

2007: PDR, FDR
2009: integration
2010: tests, summer campaign at Dome C
2011: first wintering at Dome C

7 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.

References

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