SIAMOIS: Seismic Interferometer Aiming to Measure Oscillations in the Interior of Stars

May 2007, SIAMOIS scientific council

Scientific case

The targets of the main program will be selected by the scientific committee, among cool stars of G and K-type, on the main sequence or giant branch. Each one will be tracked continuously for 3 months. In addition, less demanding targets will be observed, during periods when twilight and dawn may hamper the continuous observations (1 month each). These additional targets can be chosen among slowly-rotating high-amplitude classical pulsators, such as delta Scuti stars (main sequence, or PMS).
The expected very high precision on the measurements of eigenfrequencies will allow us to tightly constrain the models of the interiors of these stars, extending to cooler stars the observational constraints brought by the CoRoT space mission. The much better S/N in the velocity data leads to more accurate frequency determination and the ability to detect modes of lower frequencies that buried in the noise in intensity observations. Both points are very important for structure inversion and asteroseismic investigation of stellar interiors.

Frequency analysis
The detection of solar *p* modes gained enormously from longer observation. The main improvement was for resolved modes (mode with a lifetime shorter than the observation time) for which precision on the mode frequency increases like the square root of the observation time, i.e. an observation 4 times longer provides a frequency precision twice better (Libbrecht, 1992; Toutain and Appourchaux, 1994). Translated into structure inversions it directly provides a two-fold improvement in the precision. The signal-to-noise ratio for non-resolved modes (mode with a lifetime longer than the observation time) increases as the observation time to the power 3/2 (Koen 1999). In addition the number of detected modes will be higher with stellar radial velocities compared to those detected in intensity. As an example of the impact, structure inversion for the Sun obtained with GOLF (solar radial velocities looking at the Sun as a star) compared to that of VIRGO (intensity looking at the Sun as a star), is 4 time more precise for the inner regions of the Sun, thanks to low-frequency modes that cannot be observed in intensity.

With SIAMOIS, 3-month long time series and the absence of day-night interruption (Mosser & Aristidi 2007) will give access to unprecedented precision in stellar structure compared to any other ground-based observations. Overall, the structure inversion will be significantly better with uninterrupted and longer time series, as demonstrated by the helioseismic community.

Amplitudes
For the Sun, it is possible for several years to measure independently the amplitudes and lifetimes of the detected *p* modes. These measurements enable us to compute the rates at which energy is supplied into the modes by turbulent convection, and hence to derive strong constraints on turbulent convection. They also provide constraints on the damping processes, mainly attributed to coupling between the modes and turbulent convection. Both mechanisms (excitation and damping) are still poorly modelled and need additional constraints to those obtained from helioseismology.

Current ground-based observations are not yet able to provide such constraints for asteroseismology. CoRoT will provide them for a large set of solar-like oscillating stars, but amplitudes determined from a photometric signal depend on the radiative losses of the oscillations in the outer layers of the star. The SIAMOIS Doppler signal, not sensitive to that effect, will yield a more precise determination of the amplitudes.

Interior models: composition

The observation of the exoplanet host star mu Ara (Bazot et al. 2005) gives an example of current limitations of ground-based oscillations. Stars with exoplanets present an average overmetallicity of ~ 0.2 dex compared to stars without planets (Gonzalez 1998; Santos et al. 2003), which may be due either to high initial metal content in the proto-stellar gas or to accretion of hydrogen-poor matter during the planetary formation process, or both. In the first case the stars should be completely overmetallic while in the second case the overmetallicity should be confined to the outer layers. For stars with masses around 1.1 M_{sun}, there is a substantial difference between the two kinds of models: the completely overmetallic ones have a convective core while the accretion models do not. This difference could be detected from asteroseismology, through the small separations (Bazot and Vauclair 2004). Unfortunately, in spite of the very good SNR obtained with HARPS the precision on the eigenfrequencies available in single-site observation is limited and not sufficient to reach a clear conclusion.

A longer coverage with no diurnal interruption in the time series, such as only instruments like CoRoT and SIAMOIS can offer, is thus necessary to fully exploit the asteroseismic potential of stars with solar-like oscillations.

Red giants

Asteroseismology gives also a unique opportunity to probe the interior of evolved stars. Red giants differ from main sequence stars because of their large radii, their extremely dense cores and the fact that they are in the hydrogen-shell burning phase. Detection of solar-like oscillation has been reported in few red giants (e.g. Frandsen et al. 2002, de Ridder et al. 2006). These stars have in fact an external convective envelope, where the excitation is located. They show oscillation amplitude of the order of few m/s (~20 cm/s for the Sun) and oscillation period of the order of few hours (around 5 min for the Sun). Despite the successful detections of solar-like oscillations mentioned above, the physical interpretation remains limited. Higher duty cycle and a longer time coverage are needed to fully exploit the seismic data. The recent results obtained by the MOST satellite on these kind of stars demonstrate the promise of extended time coverage and high duty cycle for red giant targets.

The gain in time coverage and in duty cycle obtained with SIAMOIS will allow us to make a big step forward for the seismic study of this kind of stars.

Delta Scuti

Delta Scuti pulsators are variable stars representative of intermediate mass stars (1.5-2.5 M_{sun}) in the Pre-Main Sequence, Main Sequence, and slightly Post-Main Sequence phases (Hydrogen shell-burning phase). They thus constitute ideal targets to study physical key-processes driving the main sequence phase (90% of the stellar life time), the 'initial conditions' inherited from the PMS phase, and the dramatic phase ending the main sequence phase, when core hydrogen exhaustion induces rapid and important changes in the structure of the stars on their way to the red giant branch. Among these key-processes, one can cite transport of angular momentum, of chemical species via large scale circulation vs gravitational settling balance, inertial extension of the chemical mixing beyond the classical limit of the convective core (overshooting process) with dramatic influence on the evolution time and age determination. Although these objects are traditionally fast rotators, several objects exist, showing low enough Vsini to constitute good targets for spectrometric measurements.

For most of these objects, the expected noise level with SIAMOIS is much less than 10 m/s, which is ten times better than what is currently achieved in spectroscopy for these objects (see e.g. Rho Pup, Mathias et al (1997). In addition to this, the continuity and the duration will be a great advantage to help resolving beating modes, when the theoretical spectrum is too dense to be resolved by classical observations spanning only 2 or 3 weeks.

Gamma Doradus

Gamma Doradus stars are *g* mode pulsators, located on the main sequence between A7 and F5, and having periods of typically 1 day. Compared to the other groups of *g* mode stars, they are much more numerous and bright, rendering their study easier. Moreover, being close to the Sun on the Main Sequence, and although their envelope structure differ from solar, the studies of gamma Doradus stars can bring new insights into the structure of the deeper layers.

Spectroscopic studies show that rotation does not inhibit pulsation, since Vsini values for these stars vary between a few km/s and more than 100 km/s. Therefore, many low Vsini pulsators can be easily proposed as targets. The typical amplitudes are a few 100 m/s, which correspond to the actual detection threshold. No doubt that lower amplitude modes will be detected with SIAMOIS.

RESULTS WITH SIAMOIS

SIAMOIS is the first ground-based project ensuring the essential property of asteroseismic observations: long and uninterrupted time series.

Six winterings with SIAMOIS will provide 6 long runs (3 months) with a duty cycle about 90 % on 6 bright targets, plus 12 runs (1 month) on secondary targets (red giant, delta Scuti, gamma Dor, beta Cep, PMS …) with a duty cycle better than 60 %.

With a second telescope, the number of targets will be doubled. The instrument is in fact initially designed to be fed with 2 scientific fibers, each fiber being coupled to a given telescope, for the simultaneous observation of 2 stars.

Compared to current ground-based observations, the gain is duty cycle and frequency resolution will provide very precise eigenfrequencies measurements, with a precision increased by a factor better than 5 compared to the rare available measurements. This translates to the same gain in precision for structure inversion. Modes amplitudes and lifetimes will be measured with an unprecedented precision.

Spectrometric measurements with SIAMOIS will yield complementary observables and measures to the CoRoT photometric observations. The better S/N in the velocity data obviously leads to more accurate frequency determination, especially at low frequency, for accurate stellar inversion.

Fig 1: *HR diagram with observable targets at Dome C with SIAMOIS, with a SNR better than 6 after 5 days and 90% duty cycle. The maximum expected oscillation amplitudes are* *derived from Samadi et al. 2003. For clarity, large amplitudes have been truncated at 10 m/s. Numerous giant targets are available, as well as low rotation δ Scuti, γ Dor or PMS (only a few examples are shown). The position of the Sun is only given as a reference.*

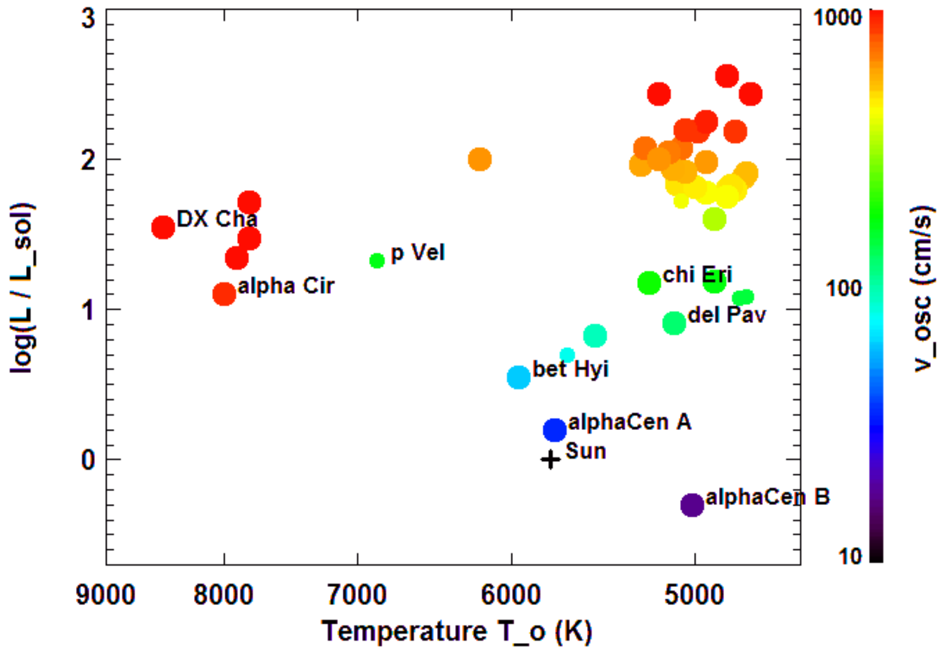

Fig 2: *Inversion of solar sound speed as a function of depth for 6 months of VIRGO data and contemporaneous GOLF data (from Gabriel et al 1997 and Appourchaux et al 1997). The precision in the structure inversion in the velocity data is 4 times better.*