Stellar Oscillations Network Group - SONG

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Abstract. The Stellar Oscillations Network Group (SONG) is an initiative which aims at designing and building a ground-based network of 1 m telescopes dedicated to the study of phenomena occurring in the time domain. In particular the study of stellar oscillations and the search for and characterisation of extra-solar planets. There will be eight identical nodes in the network, located at existing sites. Each node will have two instruments: 1) a high-resolution spectrograph for obtaining high precision radial velocities using an iodine cell as velocity reference – this will be the main instrument for asteroseismology because solar-like oscillations are much easier to detect in velocity than intensity; and 2) an optical imager which will be used for photometry and guiding. Detailed design of the network prototype node will begin in 2008, and a fully functioning and tested prototype will be ready by the end of 2011, with the goal of achieving a fully operational network around 2014.

1. Introduction

After the first detections of oscillations in the Sun it was quickly realized that in order to exploit their scientific potential long, continuous observations were needed. This led to the development of several ground-based networks such as BiSON [1] and GONG [2] dedicated to the observation of the global solar oscillations.

Today, \(\sim 6\) years after the first definite detections [3, 4] of solar-like oscillations in stars other than the Sun the field of asteroseismology is in a rapid phase of development, similar to helioseismology \(\sim 25\) years ago. The impressive development in measuring precise radial velocities [5, 6] has made the detection of solar-like oscillations “routine” and resulted in the detection of these in several stars. Solar-like oscillations can also be observed in intensity although, owing to noise induced by the Earth’s atmosphere, such observations are essentially only possible from space. Indeed, extensive data on solar-like oscillations are expected from the CoRoT and Kepler missions [7, 8]. Even so, the most detailed investigation of these oscillations can be made through Doppler-velocity observations, since the ratio between oscillation signal and stellar background ‘noise’ (e.g., from granulation) is far higher for velocity than for intensity observations [9]. Such velocity observations are most conveniently carried out from the ground.

It is, however, well known that asteroseismology (and the study of stellar oscillations in general) suffers from the lack of facilities to provide long, un-interrupted time-series observations. This is essential in order to provide adequate accuracy for the measured frequencies and to separate closely spaced frequencies. To date the largest observing campaign for a single star is that described by Arentoft \textit{et al} [10] and Hekker \textit{et al} [11] where 10 instruments observed Procyon A.
Figure 1. A possible distribution of nodes for SONG. The plot shows the observability for a target on Aug. 24, with $\alpha = 22^h$ and $\delta = 0^\circ$, observed at zenith distances less than 20 degrees.

for about 500 hours, obtaining 90% duty cycle during a 9-day period. However, asteroseismology and other fields of astrophysics depending on observations in the “time domain”, such as the search for extra-solar planets, need dedicated facilities to achieve the required extensive and nearly continuous observations.

Stellar Oscillations Network Group (SONG) is an initiative dedicated to overcome the problems of short observing runs and non-continuous data, by building a telescope network which will study solar-like oscillations in nearby, bright stars and search for planets around other stars. In this contribution we will focus on the aspects related to stellar oscillation work, but we note that the instrumental setup for both applications is similar and that for radial velocity observations the data collected will serve both purposes. By obtaining oscillation spectra based on data of high quality and extending over several months SONG will allow proper tests of stellar evolution theory and the determination of, for example, stellar ages and helium abundance [12].

2. SONG – network description
SONG will consist of 8 identical telescope nodes, with 1 m class telescopes, distributed globally to provide maximum temporal coverage, with the aim to achieve full sky coverage. The best observing duty cycle will be for the region around the celestial equator, where a duty cycle in excess of 80% will be possible. Towards the celestial poles the expected duty cycle will be less,
but also dependent on observing season. In Fig. 1 a possible allocation of nodes for SONG is shown. The nodes shall be located at existing observatories in order that no significant new infrastructure needs to be built and such that staff will be available for emergency situations and scheduled maintenance.

The instrumentation package will consist of a high-resolution spectrograph and an imaging camera which will be used for guiding during spectroscopic observations, but can also be used as science imager. The high-resolution spectrograph will be optimized for measuring high-precision radial velocities and hence will be able to achieve very high precision despite the relatively modest size of the telescopes.

For the scientific operations it is the aim to observe targets for extended periods, up to \( \sim 4 \) months to allow exquisite frequency separation and precision to be obtained. Given an aperture of 1 m the asteroseismology targets for SONG will primarily be stars brighter than \( V = 6 \). This provides several stars in nearly all of the known classes of variables. We note here that since the targets are so bright it will be possible to measure precise radii for the SONG targets with existing interferometers. This will provide an important extra constraint on the stars under study which is not available from satellite missions such as CoRoT \([13]\) or Kepler \([14]\). Furthermore, most stars will be quite close to the Sun, such that their parallaxes are well determined, and with spectroscopic data oscillation modes with \( l = 3 \) can also be observed.

In Fig. 2 simulated power spectra for five important target stars are shown – these simulations assume 100\% duty cycle and include realistic measurement errors for the stars, corresponding to their brightness. The length of the time series is 4 months. It is clear from the figure that such a network will allow data of very high quality to be obtained. We have carried out detailed simulations of time-series data and it is possible to determine the large and small frequency separations in 1 week of observing time for solar-like stars. In this respect, SONG can carry out a programme to determine the ages of all planet hosting stars brighter than \( V \sim 6 \) through asteroseismology.

3. Technical outline
One of the key aspects in the design of the network will be to keep operation costs to a low level. This implies robotic observations and a design which is robust and can be remotely controlled. At the same time measures that can be taken to reduce the major maintenance tasks should be implemented.

In order to reduce the impact on the sites selected for SONG we also aim to reduce the “footprint” of each node. This will be achieved by using a standard 20 foot shipping container as enclosure. On top of the container a dome will be placed in an arrangement similar to that shown in Fig. 3\(^1\). The dome diameter will be approximately 4 m, and will only contain the telescope which will be on an alt-az mounting.

The instruments will be placed inside the container at the telescope Coudé focus. We have chosen this option since this removes the instruments from the dome environment and thus they can be kept under “laboratory” conditions.

For determining the radial velocities the iodine method \([15]\) will be employed. This technique employs a glass cell filled with an iodine gas for providing a very stable velocity reference. We have chosen this method because it has proven to work very well at different telescopes and is capable of producing velocities with a precision matching that of HARPS \([16]\). The primary advantage of using an iodine cell is that the requirements on instrumental stability are somewhat less severe than when using a ThAr based reference – thus reducing construction costs.

The spectrograph is designed to work at a resolution of 100 000 (2.4 pixel sampling) in order to provide the highest possible velocity precision. For the iodine method only the wavelength region

\(^1\) The Bradford Robotic Telescope, http://www.telescope.org, employs a similar approach
Figure 2. Simulated power spectra for five likely SONG targets. In the simulations realistic noise has been included. A 100% duty cycle is assumed. Similar simulations have shown that for these types of stars it is possible to determine the large and small frequency separations to high precision with observations lasting 5–10 nights.
between 500 – 600 nm is needed. This allows us to use highly optimized coatings and results in a spectrograph of very high efficiency. A collimated beam of 70 mm diameter is foreseen, and we wish to use an R4 echelle grating. The slit will be 1.12 arcseconds wide. The spectrograph camera which focuses the light onto a 2K×2K pixel detector has been optimized to have a very well behaved PSF, which is essentially constant over the whole detector and diffraction limited. The spectral coverage will range from 4800 Å to 6690 Å. The spectrograph will be housed in a thermally controlled enclosure.

Figure 4 shows the calculated velocity precision for a one minute observation with SONG based on efficiency estimates of the optical components. We have assumed 5 s readout time and 55 s integration time.

As guide camera we will employ a fast readout CCD camera which can be used for “lucky-imaging” [17]. This camera will be used for guiding during spectroscopic observations and to control a tip/tilt correction mirror that will correct and stabilize the image sent to the spectrograph entrance slit. In the focal plane an image de-rotator and atmospheric dispersion corrector will also be available.
Figure 4. The predicted velocity precision for SONG as a function of stellar magnitude, assuming a spectral type similar to the Sun and low rotational velocity. The calculation has been carried out for a relatively high airmass and poor seeing, since it cannot be expected that all sites will be capable of producing sub-arcsecond seeing for a large fraction of the total time. Thus these conditions should be realistic for the overall network. We included a realistic (not gaussian) stellar profile in the efficiency calculation to account for slit losses.

During daytime SONG will observe the solar oscillations by pointing the telescope to the blue sky through a window in the dome. This will allow us to monitor the behaviour of the spectrograph during daytime and provide independent checks against the other SONG nodes and e.g. the BiSON network velocities.

4. Schedule and current status
The schedule for SONG includes ample time for the development of a prototype. In mid 2007 the conceptual design phase for SONG was completed and we have applied for funding through Danish sources to develop a prototype unit – at the time of writing we are awaiting an answer to the application. The major part of the detailed design work will take place during 2008 followed by construction, assembly, integration and tests. Currently we anticipate that a fully tested and functioning prototype SONG node will be ready by the end of 2011; this should include the data reduction software. In parallel with the prototype development work will be initiated to formalize an international collaboration, involving network sites and/or contribution of network nodes, such that the complete network can be established and ready for operation by 2014.

Acknowledgments
The authors gratefully acknowledge financial support from Danish AsteroSeismology Centre (DASC), Carlsbergfondet and Villum Kann-Rasmussen Fonden.
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