The Stellar Observations Network Group – the Prototype

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Abstract. The Stellar Observations Network Group (SONG) has obtained full funding for the design, construction and implementation of a prototype telescope and instrumentation package for the first network node. We describe the layout of such a node and its instrumentation and expected performance for radial-velocity measurements. The instrumentation consists of a 1m telescope, equipped with two cameras for photometry of microlensing events with the lucky-imaging technique and a high-resolution spectrograph equipped with an iodine cell for obtaining high-precision radial velocities of solar-like stars, in order to do asteroseismology. The telescope will be located in a dome of $\sim 4.5\text{m}$ diameter, with two lucky-imaging cameras at one of the Nasmyth foci and the spectrograph and instrument control computers at a Coudé focus, located in an adjacent container. Currently the prototype telescope and instrumentation are undergoing detailed design. Installation at the first site (Tenerife) is expected during mid–late 2010, followed by extensive testing during 2011.

1. Introduction

Stellar Observations Network Group (SONG) is an initiative started in Denmark to create a global network of highly specialized 1m telescopes aimed at doing time-domain astronomy. In particular the goals are to: produce exquisite data for asteroseismic studies of stars across most of the HR diagram (with focus on solar-like stars), and to search for, and characterize, the population of low-mass planets in orbit around other stars via the microlensing and radial–velocity methods.

A ground-based network with a sufficient number of nodes will ensure observations with a high duty-cycle, needed to obtain stellar oscillation spectra with high frequency precision and without aliasing problems. Furthermore, the light-curve anomalies in microlensing events occur at unpredictable times and thus, to find and characterize these, near-continuous observations are needed.

The group behind SONG has obtained funding for the design and construction of a full prototype network node which shall be completed in late 2011. In the following we describe some of the aspects of the ongoing work and the expected performance of the prototype.
2. Observational goals

Below we shall briefly account for the main goals and requirements that the SONG instruments must fulfil in order to meet the requirements to do asteroseismology and measure microlensing light curves.

2.1. Asteroseismology

To study efficiently the oscillations of solar-like stars, the best strategy for ground-based observations is to measure the change in radial velocity of their surface. This requires a high radial velocity precision in the few m/s range.

For the best ground-based instruments this level of precision is now routine, and some are at the sub-meter per second precision level (Mayor et al. 2003; Butler et al. 1996) over short timescales. For the SONG project the aim is to achieve a velocity precision better than 1 m/s for a $V = 0$ star per minute of observation. This requires an efficient, high-resolution spectrograph and a CCD camera with a fast readout in order to allow a high observing duty cycle.

Our aim is to obtain a network duty cycle near 80%. This will be achieved by having 8 nodes distributed at existing northern and southern hemisphere sites, and well distributed in longitude. Experience from BiSON (Chaplin et al. 1996) show that it is realistic to reach this level with 6–8 stations, consistent with the results of Mosser & Aristidi (2007). It is clear that targets in the equatorial zone will have the highest degree of coverage since these can be observed from both northern and southern nodes. With both northern and southern sites in the network, full-sky coverage will be possible.

2.2. Gravitational microlensing

For the study of microlensing events towards the bulge of the Milky Way, SONG will employ the lucky-imaging method (Baldwin et al. 2001). By observing the target field with a CCD camera which can read out at high speeds ($\approx 30$Hz), and then only selecting the images of best quality for subsequent co-addition, it is possible to obtain images with high spatial resolution. Since the bulge fields are in general quite crowded, this offers a big advantage in the achievable photometric precision and depth. Observations for this purpose only require a small field of view, and the current design foresees a field of $46'' \times 46''$. The microlensing observations have similar requirements as the asteroseismic observations with respect to the observing duty-cycle. Jørgensen (2008) discusses the prospects for microlensing studies with SONG in more detail.

2.3. Other possibilities

One of the possibilities we are considering for SONG is to use the spectrograph to observe the oscillations of the Sun during daytime. This is done by pointing the telescope to the blue sky and measuring the velocities in exactly the same way (through the iodine cell) as the stars are observed at night. In this way we will observe the sun-as-a-star and complement the existing facilities (ground and space) for solar observations. See Kjeldsen et al. (2008) for an example of this with the HARPS and UCLES spectrographs.
3. Layout of the instrumentation

The instrumentation at each site consists of a 1m telescope equipped with a high-resolution spectrograph at a Coudé focus and two lucky-imaging cameras at one of the two Nasmyth foci. This allows simultaneous two-colour imaging.

3.1. Dome and enclosure

The telescope will be housed in a dome of approximately 4.5m diameter, and the Coudé room will be located in a 20 foot shipping container with a significant level of insulation. Computers and hard drives for observatory control and data reduction will be located in this container as well. The use of a container for housing instrumentation and computers allows cost savings and provides for a rather small footprint, since the only permanent buildings needed will be the telescope concrete pier and the footings on which the container is attached to the ground. A separate concrete foundation will carry the support for the spectrograph such that it is mechanically de-coupled from the container. Figure 1 shows the general layout.

Since any potential SONG node should be at an existing observatory, access to electrical power and internet will already be available. A weather station with a cloud monitor is also part of the instrumentation. The expected date for arrival of the telescope to the first site is mid-2010.

Figure 1. The basic structures of a SONG node, comprising a concrete pier for supporting the telescope, a 20 foot container and a dome support structure. In the final version the structure carrying the dome will be approximately 1m higher with the dome floor at the level of the container roof. Side-ports will be installed in the extra 1m height to improve nighttime ventilation of the dome. The inside of the container will be split in two compartments, one for the instruments nearest to the telescope pier, and one at the other end for control computers and other electronics.

3.2. Telescope optics and imaging

Lucky-imaging for the microlensing science will be carried out with two cameras located at one of the two Nasmyth stations. We decided to not place these at
the Coudé focus since this would lead to less than optimal image quality (many optical surfaces), lower overall efficiency and higher costs. At the Nasmyth station a mirror slide with several positions will send the light to the two imaging cameras, or allow the light to pass on to the Coudé train.

For lucky-imaging it is important to have correction for atmospheric dispersion (ADC), as well as field de-rotation (the telescope is alt-az mounted). The field de-rotation will be done with an optical de-rotator of the Abbe-König type for both imaging and spectroscopy. The imaging at Nasmyth will be in two wavelength regions, with a split at 6700 Å. In the “short” wavelength channel a beam splitter will be placed, which sends a small fraction of the light to a (cheap) CCD camera for continuous focus monitoring. In this way the telescope will always be at its optimal focus. Both of the two imaging channels will be equipped with filter wheels.

The pixel scale for the lucky-imaging cameras is \(\sim 0'09\) in order to provide adequate sampling (in the red channel) for nearly diffraction-limited imaging. At a seeing of 1" FWHM, the 1m SONG telescope has \(D/r_0\) of 5–6 at a wavelength of 8000 Å. In this regime the lucky-imaging method works extremely well, which implies that a very significant improvement in image quality can be expected via the use of this method. At the best observing sites, imaging with a FWHM close to 0'3 can be expected.

We should note that the CCD cameras will of course also offer the possibility to do photometry of other objects, such as variable stars and gamma-ray bursts.

### 3.3. The Coudé train and spectrograph focal plane

The second main instrument for SONG is the spectrograph which is located at a Coudé focus. By removing the mirror that directs the light to the Nasmyth station the light from M3 will instead go to other mirrors (M4, M5, M6, M7 and M8, see Fig. 2) and ultimately end in the instrument container where the spectrograph is located. Radial velocities are measured using the iodine technique (Butler et al. 1996). This implies that only a limited wavelength range, 5000–6200 Å is needed (discussed in more detail below). With such a short wavelength interval to be “transported” to the Coudé focus, highly optimized anti-reflective and reflective coatings can be used. This results in the total efficiency of the Coudé train being nearly 95%.

At the pre-slit assembly several functions will be available; these include calibration light (ThAr and halogen lamps), slit viewing, focus monitoring, tip-tilt correction and telescope pupil monitoring and correction. In addition to this, a temperature stabilized iodine cell is also available for providing an accurate velocity reference. The spectrograph will be located in a temperature-stabilized box for improved stability.

The light path from M4 to the Coudé room will be in vacuum tubes – this will ensure a minimal level of maintenance of the optics as well as a low impact of thermal differences along the light path from the instrument room to the dome. The instrument room is expected to be kept at a temperature of 15–20°C.

### 3.4. Auxiliary instrumentation

The telescope has two Nasmyth ports of which only one will be used initially. In order to allow for future instrument upgrades, the telescope will, however, be
designed such that installation of a rotating tertiary mirror will be relatively sim-
ple. This allows auxiliary instrumentation to be placed at the second platform. The secondary mirror is designed to allow a field of view of $10' \times 10'$.

4. Spectrograph

For the asteroseismic observations, the Coudé spectrograph is the principal instrument. In order to determine the required high-precision velocities an iodine cell will be used for wavelength reference. The spectrograph will have a (2 pixel) resolution of 120,000 for a 1" slit and employ an R4 echelle and a collimated, F/6, beam diameter of 75mm. The slit is 10" long, and via the instrument rotator it can be rotated in any desired direction allowing the possibility of doing asteroseismology for close binary stars such as α Cen A and B.

The spectrograph is designed to cover a wavelength range of 4800–6800 Å. The orders are fully covered at wavelengths shorter than 5200Å; in the future a larger detector will allow full coverage of the spectral orders.

The spectrograph has been designed by P. Spanò, with inspiration from the design of UVES, HARPS and other modern high-resolution spectrographs. It is very compact, roughly $50 \times 90 \times 15$cm (without mounts), which is expected to be an advantage with respect to temperature control.

In order to provide a well behaved instrumental profile, emphasis was put on the design of the spectroscopic camera. This resulted in a design with an instrumental profile which is nearly diffraction limited over the entire area of the detector. The detector system will be a 2K×2K system from Andor of Belfast. This camera has an advanced peltier cooling system that does not need liquid nitrogen or closed cycle cooling, and furthermore the vacuum is “permanent” – so the camera is essentially maintenance free. The electronics allow full-frame readout in 5s with a readout noise less than 10 electrons, thus giving only very small overheads for the spectroscopic time-series observations. The CCD camera is capable of reading out frames at a speed of 5Mpix.

4.1. Spectrograph efficiency and performance

Due to the small wavelength range covered by the spectrograph it is possible to employ coatings with very high efficiency for both reflective and transmissive optics. Many optical companies can deliver optics with a reflectivity higher than 99.5% and anti-reflection coatings with transmissions better than 99.5% over the spectrograph design wavelength interval. Our calculations of the spectrograph efficiency (no slit or detector included), show that a throughput in excess of 50% can be expected. With a relatively small telescope and a 75mm beam the slit product is a generous 120,000, much higher than for larger telescopes, implying smaller slit losses under typical seeing conditions.

We have carried out calculations of the total efficiency of the spectroscopic system, including all sources of light loss (from atmosphere to detector) and these indicate that in 1" seeing the total system throughput is in excess of 8%.

For the design of the prototype we have included provisions for continuous control of the location of the telescope pupil on the grating as well as allowing tip-tilt correction to provide a very stable illumination of the slit.

On the assumption that our data reduction code reaches a level of performance as that of Butler et al. (2004) for α Cen A (their Fig. 5) we arrive at a
predicted velocity precision of better than 1m/s per minute of observation for stars brighter than $V \approx 1$. Stars with lower metallicity, shallower lines and higher rotational velocities will not allow such a high precision to be obtained. In Fig. 3 the calculated velocity precision vs. stellar magnitude is shown. For stars where a sample time of 1 minute (5s read + 55s exposure) is sufficient it will be feasible to carry out asteroseismic campaigns to $V \approx 6$.

It should be noted that the iodine cell is not located permanently in the light path; therefore “conventional” spectroscopy with ThAr calibration exposures prior to, and after, science exposure will be possible. Thus programmes which do not demand the highest velocity precision are possible in the same way as for other telescopes.

4.2. Iodine-based velocities with iSONG
We have developed an IDL-based data reduction code, called iSONG, for the extraction of velocities based on iodine-cell observations. At this point, the code has been tested on the Butler et al. (2004) UVES observations of $\alpha$ Cen A (the
raw data were retrieved from the ESO archive) and the SARG observations of \( \mu \) Herculis (Bonanno et al. 2008). For the analysis of the \( \alpha \) Cen A data we achieve a velocity precision of 77 cm/s per data point; only slightly poorer than the 70 cm/s achieved by Butler et al. on the same 688 frames. The current (incomplete) analysis of the data for \( \mu \) Her indicates that we reach a similar precision as that of Bonanno et al. (2008). For an example of velocity time-series with this code we refer the reader to Grundahl et al. (2009).

5. Summary and status of SONG

As of late 2008 the SONG project has obtained full funding for the development of a prototype node. Our design revolves around a high-performance 1m telescope equipped with a dual-colour lucky-imaging camera system and a highly efficient high-resolution spectrograph which will allow 1 m/s precision velocities to be obtained for the brightest stars in the sky. Better than 10 m/s precision is expected for stars brighter than \( V = 6 \) per minute of observation.

SONG is now in its detailed design phase. The optical design is completed thus allowing final design of the remaining elements. Mechanical design of the spectrograph, Nasmyth focal plane and pre-slit systems is on-going. These systems, with control software, will be tested and integrated in Aarhus during 2010, with expected delivery to the telescope on the first site (Tenerife) in late 2010. The telescope is expected to be delivered to the site in mid 2010.

The ongoing prototype work aside, the main challenge for the coming years will be to develop the international consortium that will enable the setup of the full network. Work towards this purpose will be kick-started with a workshop in Aarhus in March 2009 (see http://astro.phys.au.dk/SONG).

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