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The *Observatorio del Teide* welcomes SONG: the Stellar Observations Network Group

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Abstract

The Stellar Observations Network Group (SONG) is an international network project aiming to place eight 1 m robotic telescopes around the globe, with the primary objectives of studying stellar oscillations and planets using ultra-precision radial velocity measurements. The prototype of SONG will be installed and running at the *Observatorio del Teide* by Summer 2011. In these proceedings we present the project, primary scientific objectives, and instrument, and discuss the observing possibilities for the Spanish community.

1 Introduction

The Stellar Observations Network Group (SONG) is an initiative to design and build a global network of small telescopes. The goal of SONG is to become a key facility in both asteroseismology and planet search research programmes, a facility that provides state-of-the-art data of a quality that could not be achieved by use of any other space-based or ground-based facility [8, 15, 17, 16, 18].

SONG is proposed to have a total of eight nodes, four located in the northern hemisphere and four in the south. By placing the telescopes at roughly equally-spaced longitudes, long-term nearly continuous observations can be obtained. Each telescope has an aperture of 1m and will be equipped with a high resolution spectrograph for measuring very precise doppler velocities and dual–color lucky-imaging cameras for photometry of faint stars in crowded fields.

The prototype of SONG has been fully financed and a site on the Observatorio del Teide is being prepared for its installation.

2 Scientific goals

The primary scientific goals of SONG are to conduct asteroseismology for bright solar-type stars and to characterise extra-solar planetary systems. SONG will be open to collaboration and proposals for any other scientific topic are welcome, including long-term continuous observations.

2.1 Asteroseismology

Asteroseismology is the study of the interiors of stars using observations of stellar pulsations (e.g., [5, 7, 1]). The stellar oscillations can be determined with extremely high precision ($< 0.1\%$) so if they can be measured, they provide strict constraints for stellar modelling [24, 20, 9, 23, 21, 11, 12, 25, 10]. The frequencies are determined by the sound-speed profile across the star, and so they are sensitive to the mass and size of the star, internal structure and rotation. The amplitudes and lifetimes of the modes are sensitive to near-surface physics, including convective dynamics.

The goals of asteroseismology depend on the observations that are available for a star. One of the primary aims is the characterise global stellar properties, for example, determine the mass, radius, mean density, age, luminosity, and chemical composition. If we have a stellar laboratory that is well-characterised, then we can go a step further and investigate detailed internal structure and dynamics of stars. Asteroseismology aims to improve our understanding of the physics of stellar interiors, and thus aims to improve stellar models.

The first power spectrum showing the Sun's five-minute oscillations appeared in the literature roughly thirty years ago [14]. Today, the power spectra for other stars far exceeds the quality of those first spectra. We have been able to measure oscillations using ground-based spectrographs for over 20 such stars (e.g., [3, 6]). In Figure 10 of [3], they show how the acoustic power varies with stellar properties. Detected power is found at increasing frequencies as the acoustic cavities (the sizes of the stars) shrink, while the amplitude of oscillations increases as the acoustic cavity grows [13]. The size of the acoustic cavity depends mainly on the radius (mass) and the age (chemical profile) of the star.

So, why do we need a ground-based network measuring radial velocities? To date, we have vast quantities of data for solar-like stars on fainter stars from the CoRoT and Kepler missions (e.g., [2, 22, 4, 19]). Because the stars are fainter, this implies that the oscillation amplitudes are even more difficult to detect. The most recent observations of such stars have been restricted to oscillations in red giants, where the amplitudes are much more detectable.

These satellite missions measure in photometry and although we can observe many stars simultaneously, photometry is sensitive only to the modes of degree 0, 1, and 2.

Radial velocity measurements can reach precisions typically below 1 m s^{-1}. The tiny amplitudes of oscillations in main sequence stars can thus be observed, and mode degrees $\ell < 4$ will be detected. SONG will observe only bright targets ($V < 6$) and these can be well-characterised with complementary observations, such as interferometry and spectroscopy. The additional observations constrain the model parameters, so that the frequencies can be used uniquely to learn about the stellar interior.

2.2 Extra-solar planets

The characterisation of extra-solar planetary systems will be done using radial velocity observations and gravitational micro-lensing. The radial velocity observations will allow us to identify and characterise masses of planets much smaller than those from traditional radial velocity searches. Simulations of SONG radial velocity data based on convolving available SOHO solar data, indicates that we will be able to identify Earth-mass planets orbiting solar type stars with periods shorter than 8 days, Mars-mass planets in orbits shorter than 1 day, and Earth-mass planets in orbits shorter than 20 days. The major SONG exoplanetary effort will, however, be through microlensing observations, and the design of the lucky imaging camera is optimized to make such observations most efficient. The microlensing time series at SONG will be sensitive to analogues of all of the planets in our own solar system (except Mercury), including planets as small as Mars in terrestrial-like orbits around solar type stars.

When two stars pass very close to one another on the sky, the gravitational field from the foreground star (the lensing star) will magnify the light from the background star (the source star). SONG will follow the magnified light curve of many hundreds of such stellar lensing events per year. If the lensing star is orbited by a planet, the gravitational field from the planet can cause an asymmetry in the magnified light curve. Analyses of the form and magnitude of such asymmetries give us information about the planetary mass and orbit. If standard theories of planet formation are right, we will expect the SONG network to discover of the order of 100 new terrestrial-like extrasolar planets per year. Also the seemingly rare Saturn-Uranus-Neptune analogues in Saturn-Uranus-Neptune like orbits are within the reach of the SONG microlensing programme.

3 Design and characteristics

3.1 Telescope

The telescope for SONG has an aperture of 1m and is equipped with a coude path which feeds the light to the high resolution spectrograph, and two nasmyth foci used for the lucky imagers (see Fig. 1). It is housed in a modified Ash dome of ≈ 5 m diameter. To ensure a good image quality the thin (5 cm) primary mirror is equipped with active optics. This will ensure optimal performance for the lucky-imaging observations of microlensing fields. Two nasmyth foci are available (initally only one will have instruments) via a computer

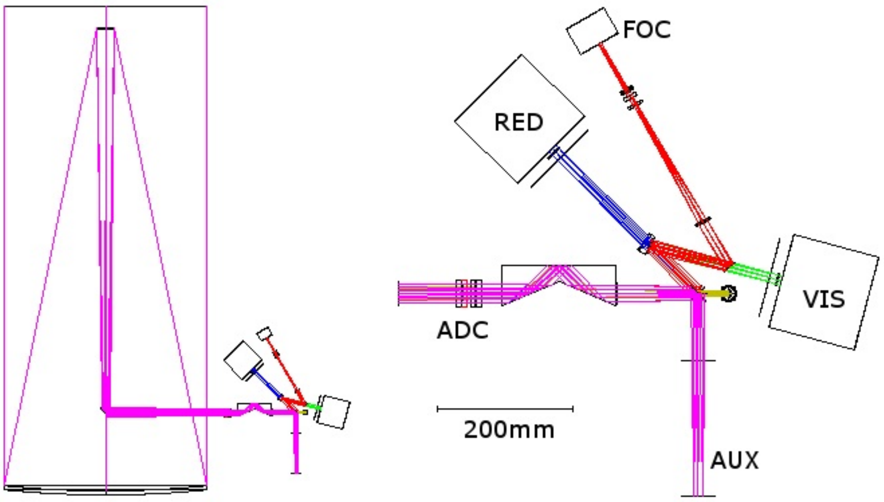

Figure 1: Light path. Once the light reaches one of Nasmyth focii, the light goes through the ADCs, the de-rotator and then to the three-position wheel: either to the Coude path (yellow path), to the two lucky-imaging cameras (red path), or to an auxiliary position.

controlled tertiary mirror. The primary nasmyth focus is equipped with an optical image derotator of the Abbe-König type and an atmospheric dispersion corrector (ADC). Since the telescope must be able to acquire objects automatically the blind pointing will be better than 5 arcseconds. Slew speeds can be up to 20 degrees per second.

3.2 Nasmyth instrumentation

For microlensing observations one of the nasmyth foci will be equipped with two lucky-imaging cameras to allow dual-color, simultaneous, imaging in a visible and red channel, with a wavelength split at 650 nm (see Fig. 2). Since the field of view required for the photometric observations is small we have designed the instrument with a sampling of 0.09 arcsecond per pixel, which allows to sample the diffraction limit at 800 nm with two pixels. We have adopted the lucky-imaging method in order to obtain high-resolution images for the photometry. The microlensing fields towards the Galactic Bulge are typically very crowded and for such fields a high spatial resolution is clearly advantageous. Lucky imaging is already well developed at OT (see spie.org/x648.html?product_id=788834) and has demonstrated that near diffraction limited performance for a 1.5 m telescope at OT is possible. Due to the smaller aperture of the SONG telescope we can expect that a large fraction of the images can be used to ensure images of 0.5 arcsecond for a substantial part of the available time.

3.3 Spectrograph

The asteroseismic observations require very precise doppler velocities of the stars under study. To enable such measurements the spectrograph is designed (by Paolo Spanò) for high reso-

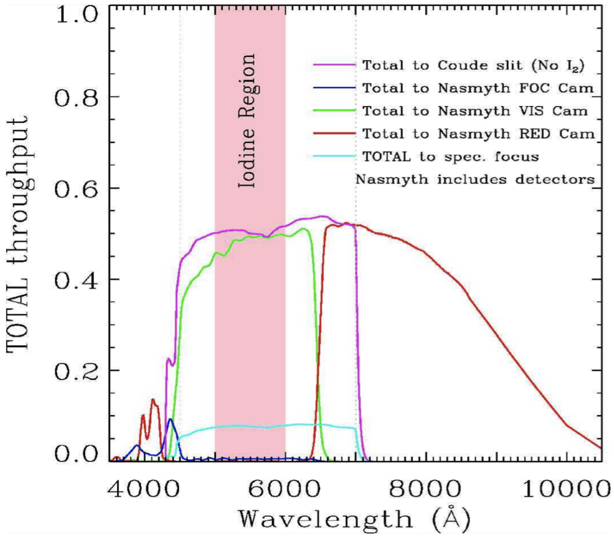

Figure 2: The observable spectral range with SONG.

lution and efficiency. The aim is to be able to measure velocities with a precision of 1 m s^{-1} for the brightest ($V < 2$) stars (see Fig. 3).

Spectral resolutions between 60 000 and 180 000 are available, although the two pixel sampling limit is at 120 000. The spectrograph in located in a temperature controlled box at a coude focus in the container next to the telescope pier. For wavelength reference we employ an iodine cell. All optics in the system (coude path + spectrograph) have been optimized for the 480–680 nm region to provide a high throughput.

The spectrograph beam diameter is 75 mm, and an R4 echelle is used, and the resolution of 120 000 is achieved with a 1 arcsecond slit. In order to provide a stable illumination of the slit the light is fed to the spectrograph via a fast tip/tilt mirror, allowing corrections up to 100 Hz. Furthermore, we have a camera for monitoring the location of the telescope pupil (to make sure the illumination of the grating is not changing), and one of the coude mirrors can be used to control the pupil location if it changes in time.

The iodine cell, flat field lamp, ThAr lamp and guiding system is mounted in a separate pre-slit unit before the light enters the temperature stabilized spectrograph box. Note, that the iodine cell can be removed from the light path, allowing the spectrograph to be used in a "normal" fashion, as requested by the user.

4 Operations and current status

There are currently (December 2010) many activities ongoing at Aarhus and Copenhagen Universities, and at the *Observatorio del Teide*. The mechanical parts for the instruments are nearly completed, with only minor components missing, and the assembly and integration of the spectrograph is starting. A test container is installed in Aarhus, where all items will

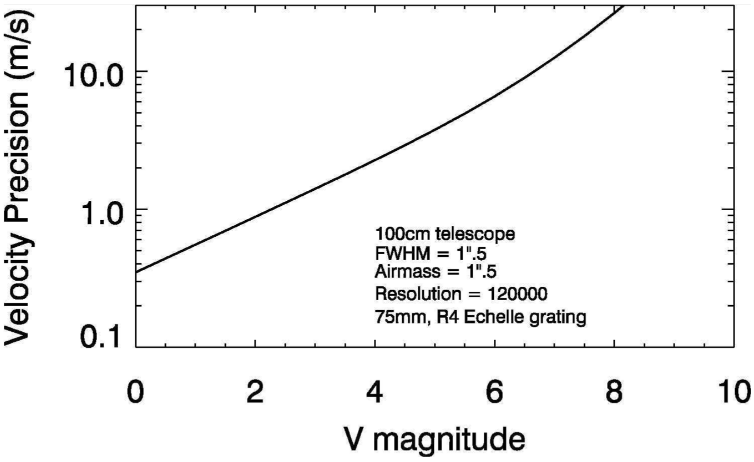

Figure 3: Radial velocity precision as a function of stellar V magnitude, for a spectral resolution of 120 000.

be mounted and system integration and testing will be performed, before the instruments are shipped to Tenerife. The software for controlling the prototype, and ultimately the network is being developed, and the setup for automatic execution of observations and copying of data to archives and databases is ready. The site at *Observatorio del Teide* is being prepared, and installation of the dome support structure and container is scheduled for early 2011, followed by an extensive testing period lasting until the end of 2011.

Arrangements have already been made to construct a second SONG node in China, and this should be operating by Summer 2012. The much improved spectral window will allow us to obtain data with much better precision on the individual frequencies.

In Spain, the SONG activities are being led by the research group at the *Instituto de Astrofísica de Canarias*. Interest in using the SONG telescope should be directed towards any of these authors. The scheduling of the observations has not been finalised, and input is requested from the full scientific community. Ideally each telescope node (or nodes) will dedicate a block of time to observing one target for asteroseismology, then a few months will be exclusively used for planet-searching. A third block of observations can be granted to exciting proposals that require these telescopes characteristics, and in this sense, the telescope is open to all areas of scientific interest. It is also possible to propose single observations, or periodic observations, such as, a single spectrum at the beginning of each night during a certain period of time. All proposals are welcome and will be considered. More information can be found at http://astro.phys.au.dk/SONG/, the SONG web page.

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