SONG

The Stellar Observations Network Group
http://song.au.dk

The SONG of stars and planets

SONG stands for **S**tellar **O**bservations **N**etwork **G**roup and was launched in 2006 by astronomers at Aarhus University and the University of Copenhagen. SONG is a Danish-led international, collaborative project set to design and build a global network of small telescopes that should specifically target the study of stars and planetary systems around stars. The idea was to develop a prototype of a new ultra-modern robotic telescope that would be inexpensive and efficient to run.

The **Hertzsprung Telescope**, i.e. the prototype of the SONG network, is financed by the *Carlsberg Foundation*, the *Villum Kann Rasmussen Foundation*, the *Danish Council for Independent Research Natural Sciences (FNU)*, the *University of Copenhagen, Aarhus University and the Instituto de Astrofísica de Canarias (IAC)*.

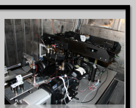
Who can apply for time?
Each **SONG partner*** has invited a number of associates to participate in the SONG collaboration. Only SONG associates and partners are entitled to apply as PI for observing time. Additionally, SONG associates have the opportunity to invite scientists to become collaborators to be part of a specific application. Collaborators will have access only to the observations made for the proposal they are part of.

***SONG partners (contacts):**
Aarhus University (Jørgen Christensen-Dalsgaard)
Copenhagen University (Uffe Gråe Jørgensen)
Instituto de Astrofísica de Canarias (Pere L. Pallé)
National Astronomical Observatories, China (Licai Deng)

SONG scientific goals using single and time series observations:
#study the internal structure of stars using asteroseismology
#detection and characterization of exoplanets
#related studies of binary and multiple stellar systems, stellar atmospheres and the Sun

In addition to the Hertzsprung Telescope on Tenerife, the SONG network is building a telescope in China, which is based on the Danish prototype and is currently in the testing phase.

Instruments



Spectrograph:

Resolutions: 60000-112000 (5 slits)
Wavelength range: 4400Å – 6900Å, 51 spectral orders
Readout time(s): 2.5s & 5s
Wavelength calibration: Iodine cell & ThAr

As a general rule we obtain ~2m/s precision for slowly-rotating solar-like stars in 4min. integrations at V~4. Most targets observed so far have had oscillation amplitudes higher than 3 times solar. For 'fast' rotators (vsini ~10-15km/s) the obtained precision is generally lower, but not yet well characterized.

Photometry:

A lucky-imaging facility with simultaneous two-colour photometric capability (currently undergoing commissioning)
Two cameras (Andor iXON 897)
512 x 512 pixels, up to 33 fps
0."08 / pix → 40" x 40"
Visual and red channel, split @ 6500Å - V and I filters or 'open' available

To see the lucky-imager rotating please follow https://www.youtube.com/watch?v=_ZHQZDYwEsQ&feature=youtu.be

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Observations of Red Giant stars with SONG

ABSTRACT:
The two-year continuous operation of the "Hertzsprung SONG Telescope" at Observatorio del Teide has demonstrated not only the robustness and efficiency of the remote and robotic concept of this installation but also the capability to execute highly valuable scientific programs – thanks to the superb performance of its high-resolution spectrograph – in different domains of the stellar astrophysics. Although most of the observing time was devoted to programs in the area of asteroseismology of bright solar-like stars, others, like follow-up of binary systems and planetary systems, high-resolution spectroscopy, high frequency pulsations in O and B stars and even solar observations have been considered and – sometimes – with unforeseen and exciting results. In this work we present a global programme, developed inside the SONG collaboration, to perform specific observing campaigns aiming to provide a seismic characterization of a sample of Red Giants (RGs) bright stars located at different evolution stages. Although new insights and understanding of red giants has been provided by the outstanding results of CoROT and *Kepler*, bright stars (mv <6) could not be observed with these space missions while they are well suited for SONG ground-based radial-velocity measurements. In addition, complementary of target brightness between SONG and the future TESS mission will, for the first time, provide contemporary asteroseismic photometric and spectroscopic measurements of the same targets.
The characteristics of this on-going program, gathered data, their analysis and preliminary results are presented in this poster.

The SONG RGs Targets

Parameter	γ Cep	46 LMi	α Boo
Spec. Type	K 1 III-IV	K 0 III	K 0-2 III
m_V	2.52	3.83	-0.05
Teff (K)	4794 ± 35	4690 ± 50	4286±30
L/Lo	10.6	27 /34	170
M/Mo	1.18 ± 0.11	2.73	1.08 ± 0.06
R/Ro	5.01 ± 0.05 (i)	7.9 ± 0.2(i)	25.4 ± 0.2 (i)
log g	3.18 ± 0.06	2.61 ± 0.2	1.66 ± 0.05
[Fe/H]	+0.01 ± 0.05	-0.1 ± 0.1	-0.52 ± 0.04
Vrot (Km/s)	1.6	2.1	2.4
		RGs scaling law	
Δν (μHz)	13.4	10.3	1.1
ν_{max} (μHz)	188.5	51.2	6.0

Table 1.- Basic parameters of the three Red Giants observed with SONG, extracted from literature. The values of the radius were obtained from interferometry observations (i). The corresponding global seismic parameters Δν and ν_{max} were derived from the observational parameters and using the corrected scaling law for RGs (Mosser et al. 2013)

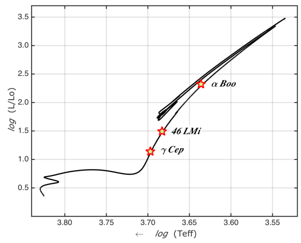

Figure 1. - The HR evolution track of a 1.08 Mo star (α Boo) together with the locations on it of the three selected RGs targets. As seen in the plot, they sample the Red Giant first ascending branch and, given uncertainties in α Boo model, also maybe a more evolved stage (post-Helium flash).

α Boo

The evolved RG Arcturus, despite being the brightest star in the Northern hemisphere and a reference calibration star with very well determined physical parameters, lacks a proper seismic characterization although some relevant attempts took place more than 15 years ago (Belmonte et al. 1990 & Retter et al. 2003). The main reason for that is the frequency location of the excess of power around 2 days, so many months of continuous observations are required to try to unveil the normal modes characteristics and their structure. SONG capabilities (automatic and robotic) are well suited to undertake this task by means of a dedicated campaign, as has been on-going since March 2016. In this campaign, see **Figure 8**, observations were taken a few times every night (4 to 10 shots each one of a few minutes length) with integration times of 20 s. Because of the high value of the flux, the precision of the velocity determination is limited only by intrinsic noise, the mean uncertainty per point being about 0.8 m/s.

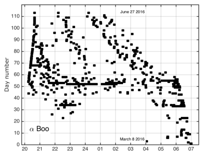

Figure 8.- Time coverage of the α Boo campaign. As the normal modes of this star will be of the order of few days period, a high cadence is not required.

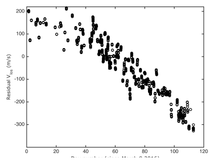

Figure 9.- Residual velocity of the on-going α Boo observations. The slow decreasing trend is of particular interest and deserves further analysis.

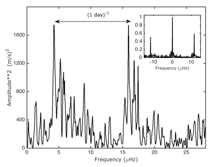

Figure 10.- Power spectrum of the α Boo time series . Inset is the normalized window function. The excess of power around 4 μHz with amplitudes of about 30-40 m/s is seen and its first side lobe indicated. This is consistent with the findings of Belmonte et al, 1990.

γ Cep

Our target star γ Cep (Errai) – located in its first ascent in the RG branch **(see Figure 1)** – is in fact the primary component of a binary system with a red dwarf (M4) companion almost six magnitudes fainter. It will succeed Polaris as the Earth's northern pole star, and it is believed to have an extrasolar planet orbiting it. It has been observed with SONG spectrograph (Iodine mode) during autumn 2014 for a total of 76 consecutive nights at a high cadence rate (120 s. integration time) as a priority asteroseismology program so providing a total of 12 ,667 spectra (433 hours of data) which represents a 24 % duty cycle over this time span **(see Figure 2)**
The processing and reduction of the échelle spectra to obtain the radial velocity of the star and its associated uncertainty (below 1.3 m/s per point) have been carried out using the SONG pipeline (based on Piskunov & Valenti, 2002). In **Figure 3** the whole residual time series of the radial velocity is shown together with a zoom on a single night's data (in which the oscillatory pattern is clearly seen). The periodogram of this time series has been computed using different techniques, and in **Figure 4** is shown the spectrum obtained using a weighted least-squares fit of sinusoids (Corsaro et al, 2012 and references therein), in which the high frequency (800 – 1000 μHz) noise level is ~ 3 cm/s. The window function **(inset in Figure 4)** has a major contribution to the resulting the high density of peaks in the spectrum (spurious side lobes at ± 11.57 μHz – 1day period), and this will be a major limiting factor to unambiguously extract and identify the normal modes of oscillation. Different techniques have been used to derive the global seismic parameters (Δν and ν_{max}) from this spectrum, and they provide consistent results **(see Table 2)**. Furthermore, using advanced cleaning techniques, a series of tentative peaks have been selected, and those with amplitudes between 1.8 m/s and 0.55 cm/s will be considered for further analysis. In **Figure 5**, an échelle diagram with the selected peaks and model-computed frequencies is shown.

ν_{max} (μHz)	Δν (μHz)	Technique/Reference
186 ± 8	12.5 ± 0.1	A2Z pipeline (Mathur et al. 2010)
-	12.5	"Comb" function (Corsaro et al.. 2012)
-	12.2	From echelle diagram
188.5	13.4	RGs scaling law (Mosser et al. 20 13)

Table 2.- Derived global seismic parameters from the power spectrum and those from the modified RGs scaling law using the best determinations of the physical parameters (R, M, Teff and log g).

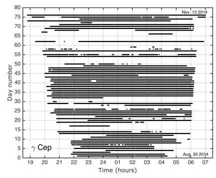

Figure 2.- Time coverage of the γ Cep campaign. The last observing day of the campaign (Nov. 30th) consists of 12.3 hours of continuous and uninterrupted data.

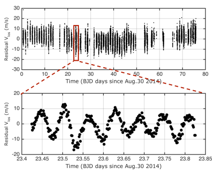

Figure 3.- Residual radial velocity as a function of time of the entire run (top) and a zoom on a given night (bottom). The signature of the oscillatory behaviour is clearly seen.

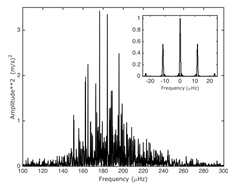

Figure 4.- Power spectrum of the Υ Ceph time series . Inset is the normalized window function showing strong signals at the two first side lobes.

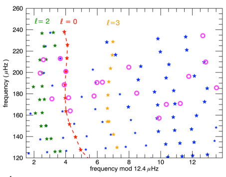

Figure 5.- Échelle diagram showing the frequencies of the 20 highest-amplitude observed peaks (open circle) and the surface corrected frequencies (star) of a model with M=1.1Mo , R=5.01Ro computed with MESA code. No overshooting was considered and the Initial values of Y and Z and the mixing length parameter were chosen such as to minimize the differences with the observed parameters T_{eff}, [Fe/H], R and the frequencies of the radial modes.

46 LMi

This was the first RG target observed with SONG (even during commissioning phase) and corresponds to a more evolved stage than γ Ceph **(see Figure 1)**. Observations were carried out during winter-spring 2014 for a total of 55 consecutive nights at a high cadence rate (240 s. integration time) so providing a total of 3.211 spectra (216 hours of data) which represents a 16 % duty cycle over this time span **(see Figure 6)**. The low duty cycle was mainly due to interruptions for technical work at the telescope. Data reduction to obtain the radial velocity was carried our following the same procedures as in the case of γ Cep. The extensive seismic analysis carried out (see Frandsen et al., 2016 in preparation) concluded with a much better determination of mass and age of 46 LMi (uncertainties ~ 4 and 23 % respectively) thanks to tentative identification of individual modes **(see Figure 7)**.

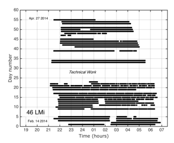

Figure 6.- Time coverage of the 46LMi campaign. Interrupted observations in the middle of the run were due to technical work at the telescope.

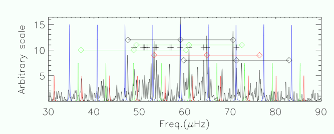

Figure 7.- Modelling the observed spectrum of 46 LMi with the asymptotic relation as described by Mosser et al. (2011): the Universal Red Giant Oscillation Pattern. Blue vertical peaks indicate the position of the dipole modes; green are the quadrupole modes and red the radial modes. The black curve is the observed power spectrum. The crosses are the frequencies from the cleaning process. The vertical lines connect identified modes with their daily alias peaks. There are four peaks that match very well with the asymptotic prediction. The black lines correspond to two dipole modes and the green lines to quadrupole modes. The red line shows the presence of a mixed mode. The solution is the one with the best match obtained by varying the two parameters in the asymptotic relation: ε and Δν. The present best fit corresponds to Δν = 6.11 μHz and ε = 1.12.

• The SONG concept (efficient-flexible-robotic operation and quality of the radial velocity data) has demonstrated to be perfectly suited to detect solar-like oscillations in bright Red Giant stars at different evolutionary stages.

•A complete and detailed characterization of the oscillations spectrum requires necessarily to minimize the spurious contribution of diurnal side lobes, i.e. MORE OPERATIVE NODES!!!

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References: | # Corsaro E. et al,. A&A 537, A9 (2012) | # Mathur, S. et al., A&A 511, A46 (2010) | # Frandsen S. et al. In preparation (2016) | # Piskunov, N. E.; Valenti, J. A., 385, 1095 (2002) | # Mosser B. et al., A&A 550, A126 (2013) | # Mosser B. et al., A&A 525, L9 (2011) | # Belmonte et al., ApJ 358, 595 (1990) | # Reder A. Et al., ApJ 591, L151 (2003)

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