ASTEROSEISMOLOGY OF PROCYON A WITH SARG AT TNG

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ABSTRACT

We present the high precision radial velocity measurements on the F5 IV Star αCMi obtained from the SARG spectrograph at TNG (Telescopio Nazionale Galileo) exploiting the iodine cell technique. The time series of 950 analyzed spectra taken during 6 nights of Procyon observation, shows individual measurement error of 1.3 m/s (very close to the theoretical photon noise limit Brown et al. (1994)). An excess of power between 0.5 and 1.5 mHz, detected also by Martic et al. (2004) is found, but additional structure in the periodogram show up around 2.0 mHz.

Key words: Asterosismology; Solar-like oscillations; Procyon A.

1. INTRODUCTION

Procyon A (αCmi, HR 2943, HD61421) for its proximity and brightness has already attracted attention of stellar seismologists (Barban et al. (1999), Chaboyer et al. (1999), Guenther et al. (1993), Martic et al. (1999)). It is a F5 IV star with $m_v = 0.363$ at a distance of $3.53pc$ in a 40-year period visual binary system, sharing the systemic velocity with a white dwarf more than 10 mag fainter. Adopting the very precisely measured parallax by *Hipparcos*, $P = 285.93 \pm 0.88$ mas, Prieto et al. (2002) derived a mass of $1.42 \pm 0.06\ M_\odot$, a radius $R/R_\odot = 2.071 \pm 0.02$ and a gravity $log\ g = 3.96 \pm 0.02$ (in cgs units).
These parameters are not enough to clearly establish the evolutionary status of the star, which could be either in the core hydrogen-burning phase or in the more advanced hydrogen shell-burning phase, after the core has been exhausted and is composed almost purely of helium. Seismology would help to establish the evolutionary status of Procyon A as discussed by Di Mauro et al. (2001).
Martic et al. (2004), in their observations of Procyon found in the power spectrum several frequencies that resemble a comb-like pattern with roughly equal spacing of 54 μHz in the region of excess power around 1 mHz. On the other hand Matthews et al. (2004), instead, with photometric data from space (MOST satellite), did not find p-mode oscillations in their Procyon data.

2. OBSERVATIONS

The observations were carried out with SARG spectrograph mounted on the 3.5 m TNG (Telescopio Nazionale Galileo). SARG is a high resolution optical spectrograph (Gratton et al. (2001)). This cross dispersed echelle spectrograph offers both single object and long slit (up to 26 arcesec) observing modes covering a spectral range from $\lambda = 370$ nm up to about 1000 nm, with a resolution ranging from $R = 29,000$ up to $R = 164,000$. Cross dispersion is provided by means of a selection of four grisms; interference filters may be used for the long slit mode. A dioptric camera images the cross dispersed spectra onto a mosaic of two 2048×4096 EEV CCDs (pixel size: 13.5 μm). What makes SARG an interesting instrument for asteroseismology is the possibility to insert in the path of light an iodine-absorbing cell in order to obtain high precision radial velocities.
Our spectra were obtained at $R = 144,000$ in the wavelength range between 462 and 792 nm using the iodine absorbing cell. During the observations (the very first SARG scientific approved run composed by 6 nights) were collected around 950 high signal to noise ratio spectra with a mean t_{exp} of about 10s. Due to weather and technical condition (see Table 1 for more details) a few gaps are present in the time series.
The whole echelle spectrum is divided in two parts: blue and red. The blue one (from 462 to 620 nm), where iodine absorption lines are superimposed to the stellar spectra (see Fig.1), has been exploited in measuring star Doppler shift. The red one (from 622 to 792 nm) has been exploited to measure equivalent width of sensitive to temperature absorption lines. The two parts of the spectrum

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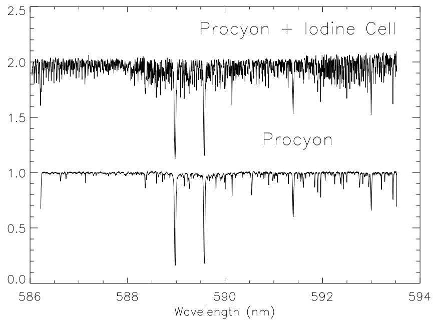

Figure 1. The iodine cell technique. AUSTRAL models the Procyon spectrum plus iodine cell and uses this stuff as a reference to Doppler shifts measurements.

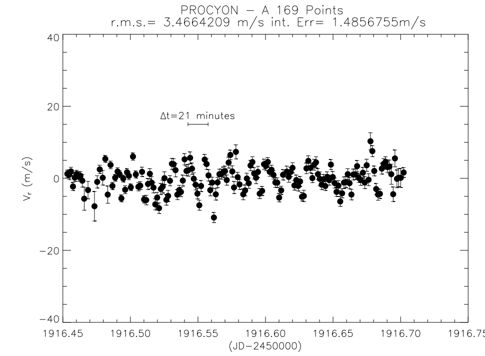

Figure 2. Radial velocities measurements of fourth night data. The measure has an internal error of 1.48 m/s and a r.m.s. of 3.5 m/s. The 21 minutes pulsation is pointed out.

Table 1. Run observations details

Date	N^o spectra	$< SNR >$	$< Seeing >$ (arcsec)
2001/01/02	160	325 ± 4	1.04 ± 0.02
2001/01/03	149	248 ± 4	0.81 ± 0.01
2001/01/04	181	292 ± 3	0.82 ± 0.01
2001/01/06	181	295 ± 5	0.93 ± 0.01
2001/01/08	125	291 ± 5	0.89 ± 0.02
2001/01/09	153	328 ± 4	0.87 ± 0.01

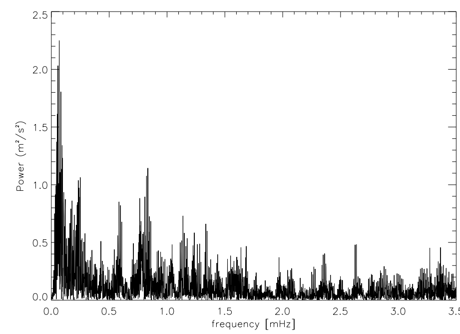

Figure 3. The Scargle-Lomb periodogram of data. An excess of power around 1 mHz is evident. Moreover some structures can be seen also around 2 mHz.

(red and blue) were reduced separately using IRAF tasks devoted to echelle spectra.
Radial velocities have been obtained using AUSTRAL code (Endl et al. (2000)). This code models instrumental profile, star and iodine cell spectra in order to measure Doppler shift.

3. DATA ANALYSIS

A sample (the fourth night) of the six night long time series is shown in Fig.2. For this night we have a radial velocity internal error of 1.48 m/s and a r.m.s. of data of 3.5 m/s. In this time serie the 21 minute pulsation is also visible where there is not negative interference with other pulsation mode. In the modified Scargle-Lomb periodogram (Fig.3) of the whole observing run an excess of power can be seen around 1 mHz.
We found several frequencies in our analysis of the power spectrum. The frequencies that have a confidence level larger than 90% are listed in Table 2, where in bold face are shown the frequencies that are compatible (in our time resolution: 2Hz) with those found by Martic et al. (2004). In order to estimate the large separation $\Delta\nu_0$ in the region of the excess power found in the periodogram we CLEAN-ed the spectrum by the window function. Successively we used the comb response method onto the CLEAN-ed power spectrum using the comb response function modified by Martic et al. (2004) as:

$$C(\nu_0, \Delta\nu_0) = \prod_{i=0}^{4}[S(\nu_0 + i\frac{\Delta\nu_0}{2} + \delta)S(\nu_0 - i\frac{\Delta\nu_0}{2} + \delta)]^{\alpha_i} \quad (1)$$

Where $\delta = \pm(i \bmod 2)D_0$ according to mode degree $l = 0$ or $l = 1$ at the central frequency ν_0 and $\alpha_i = 1$ for $i = 1$ or 2, $\alpha_i = 0.5$ for $i = 3$ or 4.
For each central frequency ν_{0c}, alternatively considered as l=0 and l=1, we have searched for the maximum comb response for $20 \leq \Delta\nu_0 \leq 80\mu Hz$ and $0.3 \leq D_0 \leq 2$ finding a $\Delta\nu_0 = (56 \pm 2)\ \mu Hz$. This value of the large separation is in agreement with those given by models of Chaboyer et al. (1999) and Matric et al. (2004) measurements.
The analysis of the red part of spectra is in progress. Our preliminary tests on 4 Fe I lines do not show an excess of power in the periodogram.

Table 2. Frequencies (in mHz) with a confidence level larger than 90%: bold characters indicates the same (according to our resolution (2mHz)) frequencies found by Martic et al. (2004).

167.0	257.0	778.5
178.9	291.0	790.2
210.5	**302.0**	**808.8**
230.2	**428.0**	820.5
233.7	440.2	**822.8**
238.4	**596.5**	1138.0
241.9	766.8	1224.0
245.4	**776.7**	1236.0

4. CONCLUSIONS

We have shown that the SARG spectrograph can be extremaly useful in performing asteroseismic observations program aimed to detect solar like pulsations in stars. In the case of Procyon A, the analysis of the periodogram shows a p mode spectrum charactarized by a large frequency separation $\Delta\nu_0 = (56 \pm 2)\ \mu$Hz in agreement with Chaboyer et al. (1999) and Martic et al. (2004).
At variance with what has been found by Matthews et al. (2004) our results strongly support the idea that the excess of power found by Chaboyer et al. (1999) and Martic et al. (2004) in the range from 0.5 up to 1.5 mHz is determined by *p* mode oscillations.
With an extended ground-based multi-site campaign on Procyon we would be able to measure oscillation frequencies with an accuracy better than 2 mHz. In this way we hope to constrain the theoretical model of Procyon in order to extabilish the evolutionary status of this star.

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