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Seismological study of the solar-like star Procyon A

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Abstract. The F5 subgiant Procyon A was observed in January 2001 by the SARG spectrograph at TNG (Telescopio Nazionale Galileo) exploiting the iodine cell technique. The time series of about 950 spectra taken during 6 observation nights and a preliminary data analysis were presented in Claudi et al. (2005). These measurements showed a significant excess of power between 0.5 and 1.5 mHz, with 0.98 $\mathrm{ms^{-1}}$ peak amplitude. In this work we present a more detailed analysis of the time series than that presented in Claudi et al. (2005). An average large frequency spacing of 55.66 ± 0.14 μHz and a small spacing of 5.7 ± 0.3 μHz have been determined and twenty-one individual frequencies identified.

Key words. asteroseismology – solar-like oscillations – Procyon A – techniques: radial velocities, equivalent widths

1. Introduction

Procyon A (α Cmi, HR 2943, HD61421) is a F5 IV star with V = 0.363 at a distance of 3.53 pc in a 40-year period visual binary system; the companion is a white dwarf more than 10 mag fainter. Adopting the very accurate parallax measured by HIPPARCOS, $\Pi = 285.93 \pm 0.88$ mas, Prieto et al. (2002) derived a mass of $1.42 \pm 0.06\,M_\odot$, a radius of $2.071 \pm 0.02\,R_\odot$, and a gravity $\log g = 3.96 \pm 0.02$. The Procyon's spectra (950,$< t_{exp} >$=10s,$< S/N >$= 300 were collected in January 2001 by the SARG spectrograph at TNG (Telescopio Nazionale Galileo) exploiting the iodine cell technique (see also Claudi et al. this issue). With this technique a part of the spectra (from 460 to 620 nm) is characterized by the iodine absorption lines superimposed to the stellar spectra to obtain radial velocity measurements.

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2. Radial velocities analysis

Radial velocities have been obtained by means of the AUSTRAL code (Endl et al. 2000) which models instrumental profile, star and iodine cell spectra in order to measure Doppler shifts (see also Claudi et al. 2005). AUSTRAL also provides us with an estimate, σ_i, of the uncertainty in the velocity measurements. These values have been derived from the

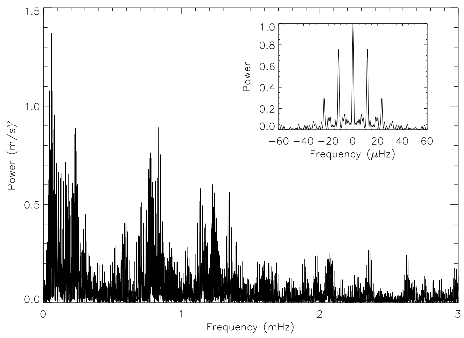

Fig. 1. The periodogram of the weighted data. An excess of power around 1 mHz is evident. The inset shows the power spectrum of the window function for a sine wave signal of amplitude 1 ms^{-1}, sampled as the observations. The power units are the same as the main figure.

Table 1. Prominent peaks (in μHz) in the periodogram of Procyon A, identified as oscillation frequencies in terms of n and l. In parenthesis are shown the values of the frequencies shifted for the daily alias of 11.57 μHz.

n	$l = 0$	$l = 1$	$l = 2$
8	556.057		
	(567.627-11.57)		
9			660.950
10		688.203	
		(699.773-11.57)	
11		746.731	
12	778.593		834.331
13	829.543	857.512	
14	889.467	914.091	
	(877.897+11.57)		
16		1027.797	
18	1114.223	1137.590	1162.783
19	1168.944		1218.158
20	1224.280	1249.396	1273.980
		(1260.966-11.57)	
22	1335.162		1385.934
$\Delta\nu$	55.2 ± 0.9	57.5 ± 0.7	55.59 ± 0.16

scatter of velocities measured from many ($\simeq$ 100), small ($\simeq$ 2 Å) segments of the echelle spectrum. As first step of our analysis we verified that these σ_i values reflect reflect the noise properties of the velocity measurements, following Butler et al. (2004) approach.

We obtain as result of this analysis the weighted power spectrum shown in Fig. 1.

We extracted, in the range between 0.5 to 1.5 mHz, the peaks of this power with an amplitude greater than 3σ (with σ the white noise evaluated in the power spectrum between 2.5-3 mHz). In order to identify the frequencies in terms of $l = 0, 1, 2$ modes, we produced several echelle diagrams shifting the frequencies for the daily alias. The best solution is presented in Fig. 2 and in Table 1. From this table we can obtain a measure of the large separation $\Delta\nu = 55.66 \pm 0.14\,\mu$Hz. This value results to be in good agreement with previous observations by Eggenberger et al. (2004).

We also derived the value of the small frequency separation, $\delta\nu_{02} = \nu_{n,0} - \nu_{n-1,2} = 5.7 \pm 0.3\,\mu$Hz, and the quantity $\delta\nu_{01} = (\nu_{n,0} + \nu_{n+1,0})/2 - \nu_{n,1} = 3.0 \pm 0.7\,\mu$Hz, which reflects the second order departures from the asymtotic theory.

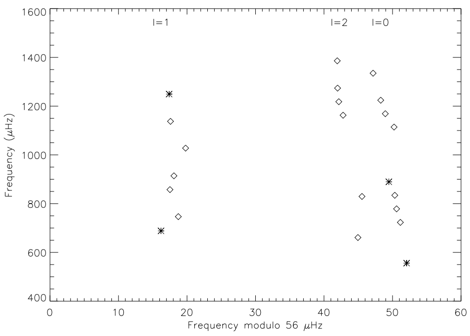

Fig. 2. The echelle diagram. The frequencies shifted for daily alias (11.57 μ Hz) are indicated by stars.

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