The A-Star Puzzle
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Multisite observations of the pre–Main-Sequence δ Scuti star IP Per

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Abstract. We present preliminary results of a photometric multisite campaign on the δ Scuti-type Pre–Main-Sequence star IP Per. Nine telescopes have been involved in the observations, with a total of about 173 hour of observations over around 40 nights. Our current data permitted us to confirm the multiperiodic nature of this star and to determine at least 9 pulsational frequencies. A preliminary nonradial theoretical analysis seems to show that the star pulsates in a mixture of l=0, 1, 2 modes.

Keywords. Stars: Pre-Main-Sequence, stars: oscillations (including pulsations), stars: variables: δ Scuti, stars: interiors, stars: individual: (IP Per)

1. Introduction

Stellar pulsation is a very useful tool to investigate the internal structure and evolution of stars. This kind of analysis has been adopted for many MS and post-MS stars. In the last few years, new evidence showed that the intermediate mass Pre–Main-Sequence (PMS) Herbig Ae stars pulsate while crossing the Instability Strip for δ Scuti stars (see the review by Ripepi & Marconi 2004). For more details on pulsation in PMS stars, see Bernabei *et al.* (2005), Marconi & Palla (2005), and Zwintz *et al.* (2005). Now we will concentrate on the detailed photometric study of IP Per.

IP Per is a Herbig Ae star with: V = 10.34, sp. type A7V, $\log L/L_{\odot} \sim 1.00 \pm 0.05$, and $T_{\rm eff} \sim 8000 \pm 200\,$K (Miroshnichenko *et al.* 2001). With these values of the stellar

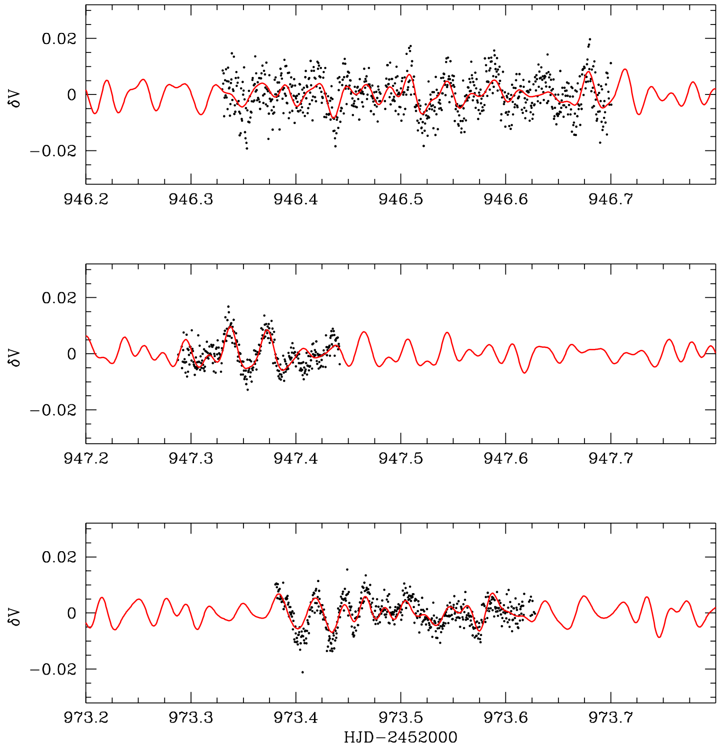

Figure 1. Data collected in Loiano with the TTCP during Nov./Dec. 2003 (dots). The solid line shows the fit to the data with 9 frequencies obtained from the frequency analysis.

parameters, IP Per falls very close to the blue edge of the theoretical instability strip for δ Scuti pulsation studied by Marconi & Palla (1998). An exploratory observing run during 2002/2003 revealed that IP Per indeed pulsates as expected, showing a multiperiodic behaviour with 6 significant frequencies (Ripepi & Marconi 2004). To overcome the well known one day alias problem, we decided to organize a multisite photometric campaign for fall-winter 2003. Preliminary results of this campaign are presented.

Table 1. List of telescopes and instruments involved in the multisite campaign.

Observatory	Telescope	Instrument
Loiano (Italy)	1.5m	CCD - 2002/2003 data
Loiano (Italy)	1.5m	Three Channel Photometer
Beijing Astronomical Observatory (China)	0.85m	Three Channel Photometer
San Pedro Martir - SPM (Mexico)	1.5m	Danish (*uvby*) Photometer
Kitt Peak National Observatory (USA)	0.9m SARA	512 × 512 CCD
Teide (Spain)	1.0m OGS	1024 × 1024 CCD
Fairborn (USA)	0.75m APT	PMT
Sierra Nevada (Spain)	0.9m	(*uvby*) Photometer
Serra la Nave (Italy)	0.9m	PMT
SOAO (Korea)	0.6m	CCD

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2. Observations and data reduction.

The campaign on IP Per can be divided in two parts, 1) single site observations during winter 2002/2003 (Loiano telescope) and 2) multisite campaign during winter 2003/2004, involving 9 different telescopes as listed in Table 1. A total of about 173 hour of observations were obtained over about 40 nights. Each dataset has been reduced using the proper procedures for the three types of instruments available: CCD, single channel PMT, and three channel PMT. The dataset from each telescope was carefully inspected. Values due to bad weather (very frequent for PMT data) or system faults have been removed.

Due to differences among the various instruments (CCD, PMT) and filters used, and to prevent problems with consequent zero point variations between different datasets, we decided to detrend the data to a common average zero value. Of course, this procedure does not allow us to investigate low frequencies (roughly $\sim 3\ \mathrm{d}^{-1}$).

Thus we have obtained three different time series, 1) B-filter data from Loiano 2002/2003 observations, 2) B-filter data from the multisite campaign 2003/2004, and 3) V-filter data from the multisite campaign 2003/2004.

To show the quality of the data obtained in 2003 from the multisite campaign, we present in Figure 1 the observations collected in Loiano with the three channel photometer.

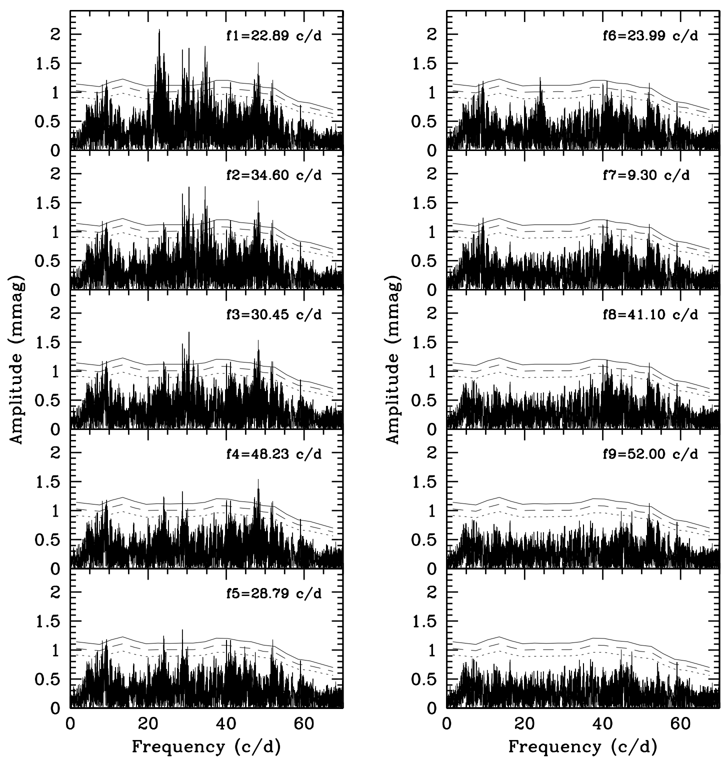

Figure 2. Fourier analysis of the V data of the 2003/2004 campaign. Each panel reports the periodogram after prewithening for the labeled frequency. The solid, dashed and dotted lines show the 99.9%, 99% and 90% confidence levels respectively.

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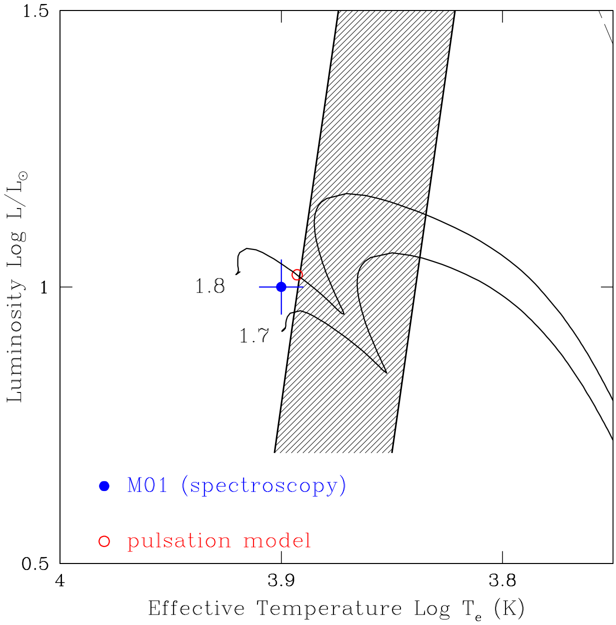

Figure 3. Position of the variable IP Per in the HR diagram according to the spectroscopic measurements of Miroshnichenko *et al.* (2001) (filled dot). The dashed region is the predicted Instability Strip for the first three radial modes by Marconi & Palla (1998), whereas the black lines are the PMS evolutionary tracks computed with the FRANEC code (see Chieffi & Straniero 1989) for the labeled masses. The open symbol is the selected PMS evolutionary model which was perturbed for nonradial pulsation.

2.1. *Frequency analysis*

The frequency analysis has been carried out using Period98 (Sperl 1998). Each data set described in the previous section has been analysed separately and the results cross-checked. On the basis of this analysis, we have found 9 significant frequencies which are shown in Figure 2 (campaign 2003/2004, V-filter). Here, each panel shows the periodogram after prewithening for the labeled frequency. The solid, dashed and dotted lines show the 99.9%, 99% and 90% confidence levels (see e.g., Breger *et al.* (1993) and Kuschnig *et al.* (1997)).

3. Comparison with theory: preliminary results

We tried an asteroseismological interpretation of the data using the Aarhus adiabatic nonradial pulsation code (`http://astro.phys.au.dk/~jcd/adipack.n/`). In particular, we run the FRANEC stellar evolution code (Chieffi & Straniero 1989) to construct PMS evolutionary tracks in the range 1.6–2.0 $M_\odot$ and compared the resulting positions in the HR diagram with the position of IP Per based on the spectroscopic measurements of Miroshnichenko *et al.* (2001). As shown in Figure 3, this determination is intermediate between the evolutionary track for 1.7 $M_\odot$ and 1.8 $M_\odot$, but slightly in better agreement with the latter. We then applied the Aarhus adiabatic pulsation code to evolutionary models located along the 1.8 $M_\odot$ PMS track and within the empirical uncertainty box of the spectroscopic determination. The output frequencies were compared with the observed periodicities leading to the best fit solution shown in Figure 3, which corresponds to a model likely pulsating in a mixture of $l=$ 0, 1, 2 modes. This preliminary analysis

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needs to be refined and a systematic detailed investigation of the dependence of theoretical results on the model properties is in progress. Finally, the position of IP Per in the HR diagram indicates a mass around 1.8 $M_\odot$. Therefore this object could represent an ideal target to test the theoretical study by Suran *et al.* (2001) who investigated possible discriminating properties between preMS and postMS structures with 1.8 $M_\odot$ on the basis of nonradial pulsational analysis.

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