Report of the hare-and-hound exercise of the Data Reduction Team

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ABSTRACT

Here we report on the results of a hare-and-hound exercise performed by the Data Reduction Group. Spectra of 6 different stars have been simulated and fitted for extracting the small and large separation of the stars. Rotational splittings were also fitted. The ability of the group for detecting low-degree stellar p modes is at least proven on high signal-to-noise ratio spectra. Further work will be needed for making the simulation more real and less easy. A new hare-and-hound exercise is already planned.

1. Introduction

Hare-and-hounds (H-H) exercises are commonly performed in helioseismology. These kinds of blind tests are heavily linked towards testing inversions. In the recent years, the emphasis has slowly shifted to testing any alleged technique thought to detect g modes. A similar approach for detecting stellar p modes is now envisaged since the strongest modes might be at the limit of detection.

Hereafter, we describe first how the stellar time series are simulated, second how the synthetic spectra are fitted and/or the stellar p-mode parameter extracted. Then, we discuss the different techniques of detecting stellar p modes. We close the report by looking how the simulation can be improved, and set the scene for the next round of H-H.

2. Spectrum simulation

In helioseismology, the solar p modes are stochastically excited by convection. It results that the statistics of the spectra is well known: it is a χ^2 with 2 degrees of freedom (Woodard, 1984; Anderson et al., 1990; Appourchaux et al., 1998). For stellar p modes, we have taken the same assumption. As soon as the Fourier spectra can be calculated, the inverse Fourier transform provides the time series. It is not necessary to excite the p modes in the time domain as performed by Barban et al. (1999). The former is more efficient than the latter.

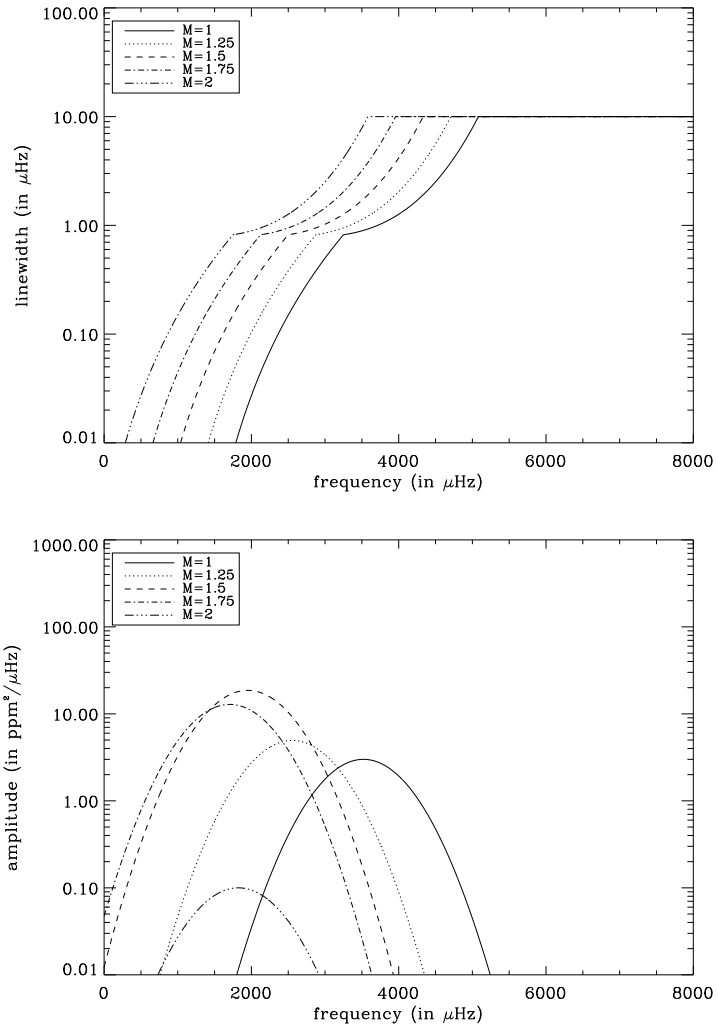

Fig. 1.— Linewidth and amplitude of the modeled stellar p modes as a function of frequency for different stars. They are here independent of age.

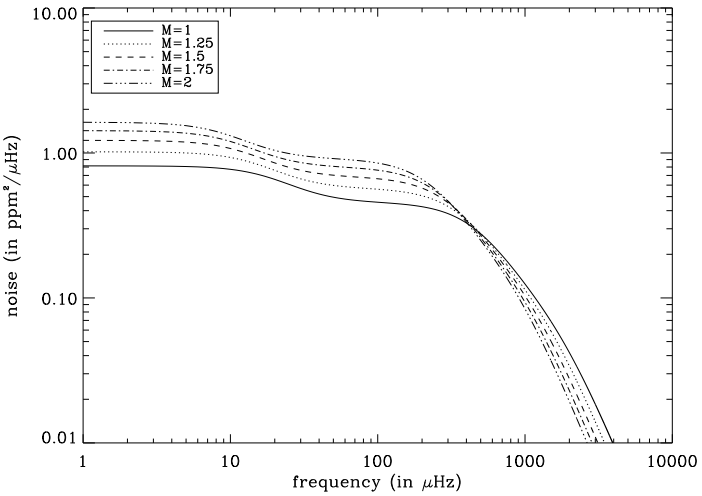

Fig. 2.— Modeled background stellar noise as a function of frequency for different stars. The time scales are a linear function of mass. The amplitude of the 3 different noise are independent of age and mass.

In both cases, we need to know how one can simulate properly the characteristics of the stellar spectrum, namely: Mass, Age, Temperature, Fine internal structure, Internal dynamics, Mode excitation and damping, Stellar and Instrumental noise.

The first three items determine the central frequency (ν_0), the large ($\Delta\nu_0$), the small separation (D_0) and the smaller separation (d_0) (Christensen-Dalsgaard, 1984). The essential data were taken from Audard & Provost (1994) and were interpolated from 1 $M_\odot$ to 2 $M_\odot$, and from a grid of hydrogen content X ranging roughly from 0. to 0.7. For mass lower than 1 $M_\odot$ we extrapolated the interpolation down to 0.8 $M_\odot$. The formula was used for getting the frequencies of modes $l = 0$ to 3; modes of higher degree were not included in the simulation.

The mode excitation and damping was derived from the work of Houdek (1996) and of Houdek et al. (1999). The amplitudes and linewidths were often extremely simplified. Figure 1 gives an example of the variation of the linewidth with frequency for various stellar masses. Since the model was done very quickly, it is quite likely that these figures do not exemplify fine details as reported by Houdek (1996); it should be taken only as a starting point for a finer modeling.

For simulating the internal dynamics of the stars, we assumed that the stars rotate rigidly with their rotation axis perpendicular to the line of sight. As for the distribution of amplitude with the degrees, we assume that the relative amplitudes follow the geometrical visibilities usually used for the VIRGO data and IPHIR data (Toutain & Fröhlich, 1992).

The noise was derived from that of the solar noise. For the stellar noise, we arbitrary decided that the time scales defining the various super-, meso- and granulation noise be scaled like the stellar mass (i.e. the

heavier the star the longer the time scales) like shown on Fig. 2. Of course, a better work needs to be done for the noise if we want to make the simulations more real.

The simulated time series are 1 month long with a 30-s sampling time. Six time series were simulated for six different stars which main characteristics are given in Table 1. The data were blindly generated so that even the hare could play the role of the hounds.

Star	Mass (in $M_\odot$)	X_c	$\Delta\nu_0$	Ω_r (in μ Hz)
1	1.33	0.23	84.90	1.00
2	1.23	0.39	106.80	0.56
3	1.86	0.69	81.20	1.50
4	1.26	0.13	87.50	1.50
5	1.21	0.58	120.10	0.25
6	0.85	0.17	151.40	0.69

Table 1: Main characteristics of the simulated stars. X_c is the hydogen content, and Ω_r is the rotation rate of the star as a rigid body.

3. Data analysis

3.1. Echelle diagram

One of the simplest, quickest and dirtiest method to detect the large separation and other details of the stellar p-mode spectra is to produce an Echelle diagramme. The original idea was from Grec (1981) who used the asymptotic property of the solar p modes for showing how each degree would line up in such a diagramme. The Echelle diagramme consists in cutting in pieces of $\Delta\nu_0$ the spectra of the star, and then to pile up these pieces on top of each other. If modes are indeed detected vertical lines should appear clearly in the diagramme. The trick is really to find the $\Delta\nu_0$ that would produce such 'vertical' lines. With some experience, and with simulated data with high signal-to-noise ratio, it takes just a few tens of minutes to get the proper separation. Trial and error will do especially on a Friday afternoon before the week-end.

Figure 4 shows the results of this procedure, and Table 2 gives the large separation obtained accordingly.

3.2. Histogram

This technique was developed by Barban et al. (1999). Figure 5 shows the result of this procedure. Table 2 gives the large separation obtained with this technique.

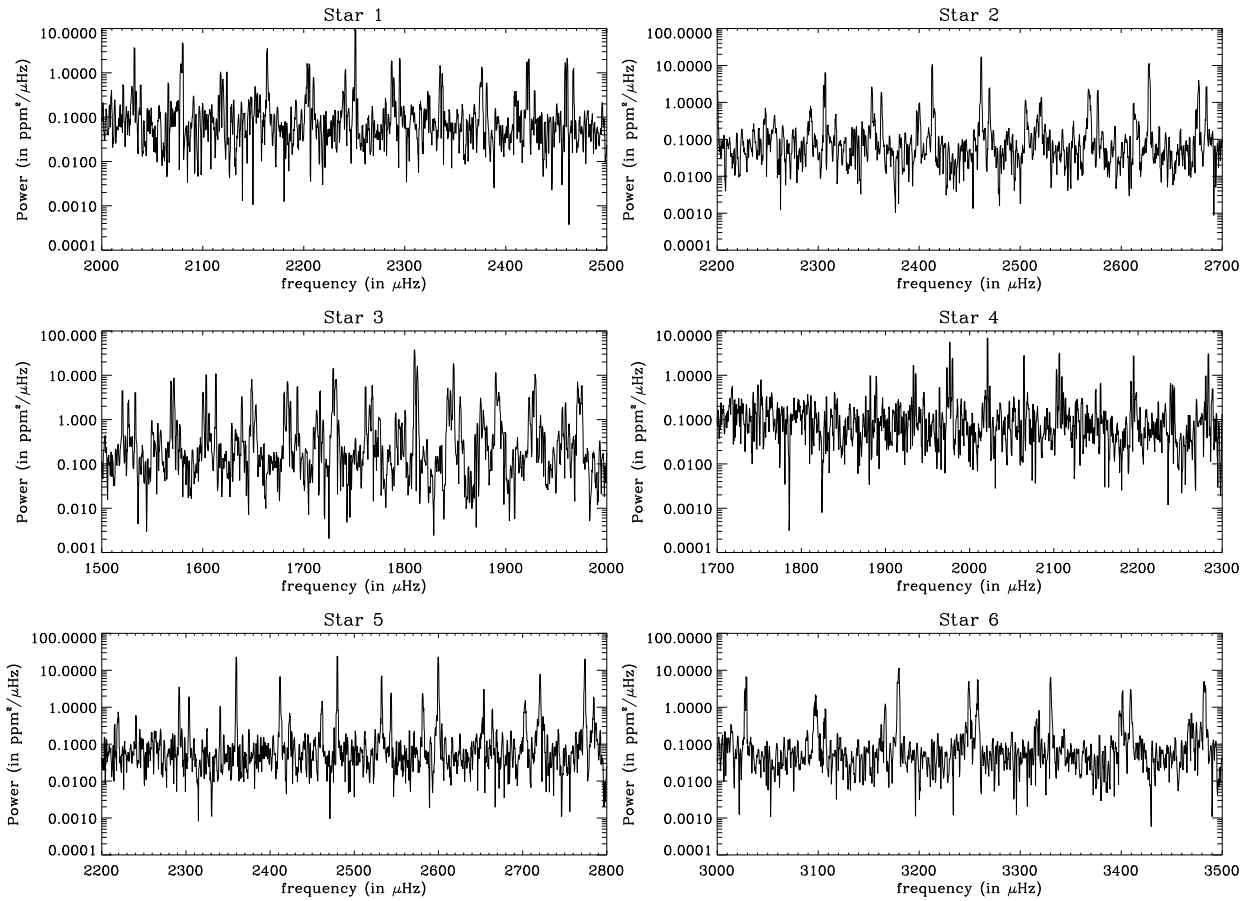

Fig. 3.— Power spectra (smoothed to 1 μHz) for the 6 synthetic time series. The signal-to-noise ratio is at best about 100.

3.3. Maximum likelihood fitting

The technique used for fitting stellar spectra is the same as for full-disk solar spectra Toutain & Fröhlich (1992). We use Maximum Likelihood Estimators known as MLE, for a review see Appourchaux et al. (1998). Table 2 shows the result obtained; all the mode frequencies are available upon request (ask ThierryA or Toutain for details).

4. Discussion

It is quite clear that the helioseismologists were at an advantage mainly because they were at the end of the processes: synthetic data production (ThierryA) and MLE (Toutain). As a matter of fact, the analysis and simulation performed are too closely related to solar-type stars. Nevertheless, this bias created an interesting

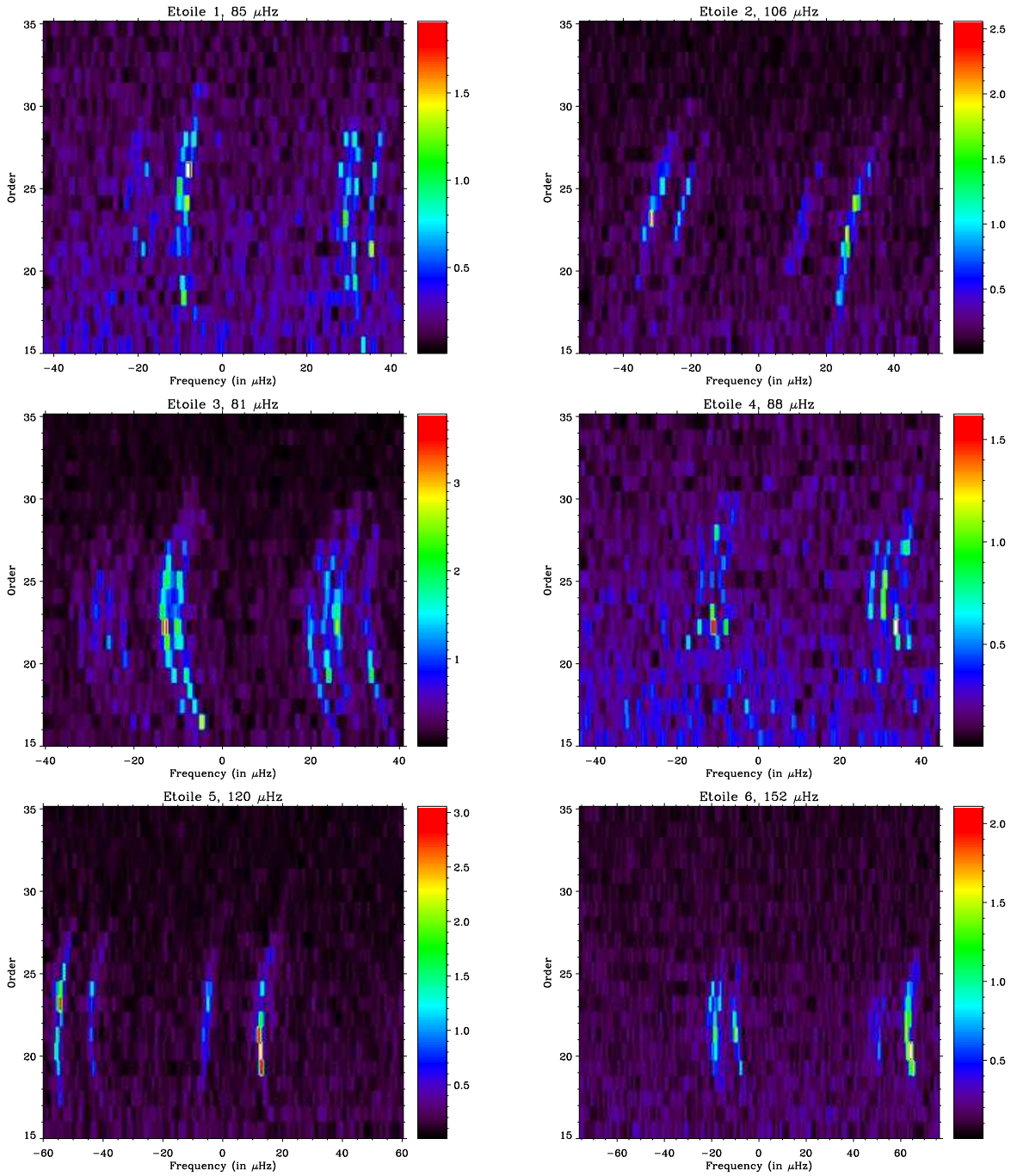

Fig. 4.— Echelle diagrammes for the 6 synthetic stellar spectra. The modes can be identified according to the way the ridges are split. For instance, the top left diagramme shows clearly from left to right, the l=3, 1, 2, 0 ridges. The parabolic curvature of the ridges is due to the asymptotic formula used.

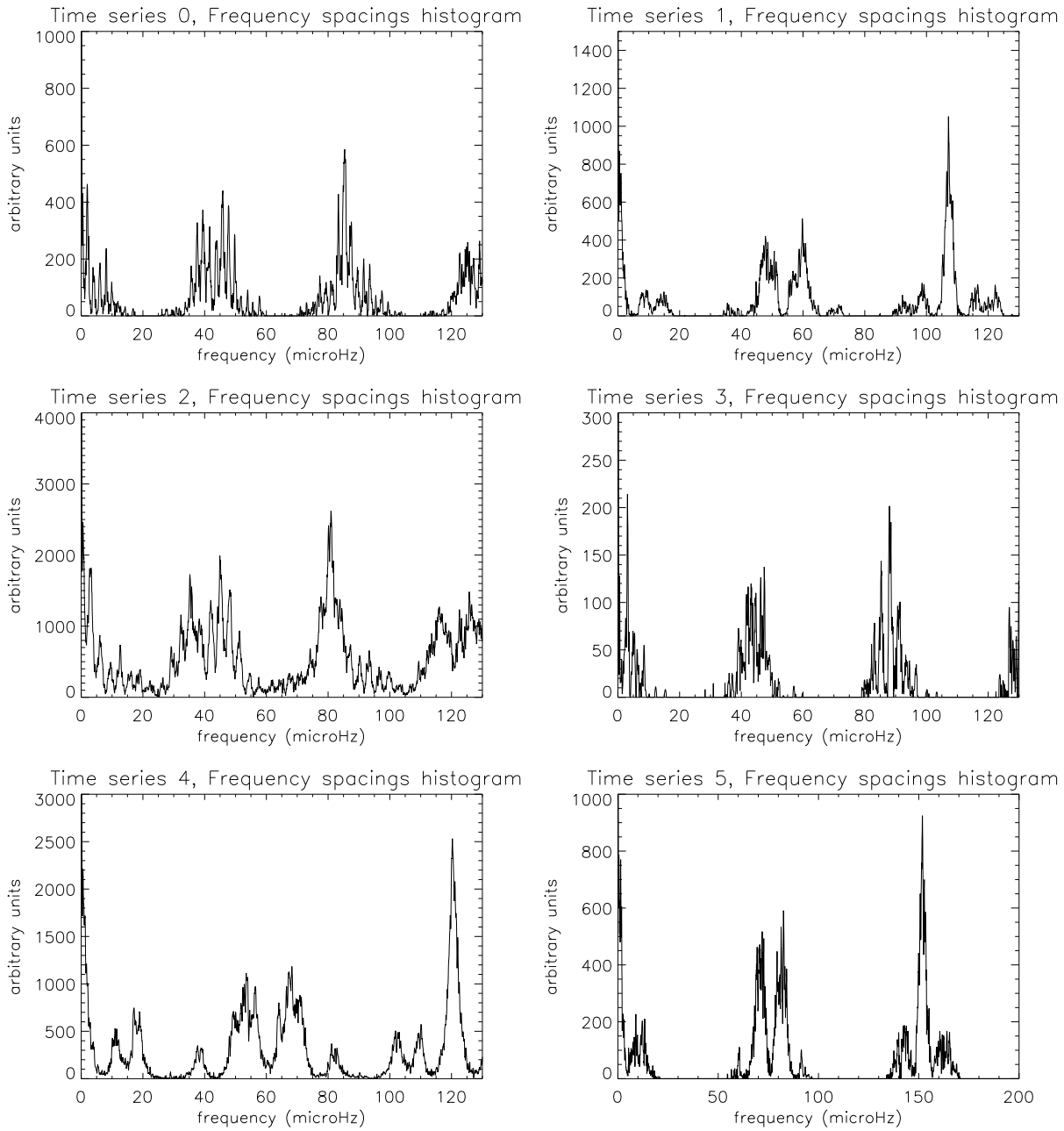

Fig. 5.— Histogrammes of the stellar spectra as computed by Barban et al. (1999). The largest peak indicates the location of the large separation. The second two largest peaks display the mean structure of the mode located at $|\Delta l| = 1$. The sub-structure of within the largest peak is a manifestation of the splitting (See time series 0 and 3, i.e. stars 1 and 4)

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Star	Mass (in $M_\odot$)	$\Delta\nu_0$ (in μ Hz)			Ω_r (in μ Hz)		
		Echelle	MLE	Histo.	Echelle	MLE	Histo.
1	1.33	85.0	85.4	90.0	-	0.963 ± 0.034	-
2	1.23	106.0	107.0	108.0	-	0.507 ± 0.016	-
3	1.86	81.0	81.5	80.0	-	1.502 ± 0.013	-
4	1.26	88.0	88.5	87.0	-	1.520 ± 0.012	-
5	1.21	120.0	120.0	120.0	-	0.196 ± 0.022	-
6	0.85	152.0	152.0	151.0	-	0.659 ± 0.019	-

Table 2: Main characteristics of parameters derived from the 3 main analysis techniques.

'bug': the psychological approach used by one of the fitter made him thought that the data producer may have forgotten to produce synthetic data for a star with an inclined rotation axis. The simulated data were a bit too easy to play with: a more realistic and a more noisy spectrum should be simulated in the future.

As far as the simulation is concerned, several improvements should be included such as:

- Inclined rotation axis
- Differential rotation
- Better linewidths and amplitudes
- More realistic stellar noise
- Lower signal-to-noise ratio

As far as the H-H exercise is concerned, we will likely make a full H-H involving 2 complete teams of Modelers-Observers doing a double blind H-H using simulated data from the other team. This activity has been started and will be reported during the next team meeting.

Acknowledgments

Many thanks to our beloved PI, Annie Baglin, for keeping alive the flame of the COROT project, and for keeping on fighting: 'You'll never walk alone'. For anyone reading who is that quote from? Send your answer to thierrya@so.estec.esa.nl.

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