Hare & Hound exercise with simulated COROT data

G. Berthomieu [1], T. Appourchaux[2] on behalf of the COROT Seismology Working Group[†]
[1] *Département Cassini, UMR CNRS 6529, Observatoire de la Côte d'Azur, BP 4229, 06304 Nice Cedex4, France.*
[2] *Research and Science Support Department of ESA, ESTEC, P.O.Box 299, NL-2200AG Noordwijk, The Netherlands.*

Abstract. With the aim of preparing the interpretation of future COROT observations, a hare-and-hound exercise has been performed on a solar-like oscillating star. The methods used to construct simulated time series and to recover the properties of the star using the frequencies extracted from these time series are described and the comparison between the results and the theoretical inputs are presented.

1. Construction of simulated time series

Two hare-and-hound exercises (H&H) have been performed, by the teams of the COROT sismogroup. The different steps of the H&H exercise are the following:

• Construct a stellar model M (mass), Y (helium), Z/X (metallicity), ζ_{ov} (overshoot) with constraints[1] on luminosity ($L/L_\odot$), effective temperature (T_{eff}) and metallicity (Fe/H). Compute the frequencies of the models $\nu_{n,\ell}$. Construct a simulated time series which represents what the observation of the pulsating model by COROT would give.

• Extract the frequencies: hereafter referenced as 'observed frequencies' $\tilde{\nu}_{n,\ell}$ and rotational splittings (not yet exploited).

• Interpret them in terms of internal structure and rotation of the star. Hereafter results concern the direct approach that is the search for the closest model to the 'observations'. No inversions are presented.

Two input models (respectively Ex1 and Ex2), satisfying the constraints, have been constructed by the Nice and Meudon groups using the CESAM code; their frequencies computed and provided to the teams in charge of constructing the time series (referenced hereafter by Appourchaux, Toutain). Simulated time series are constructed assuming amplitudes and damping rates according to Houdek et al. (1999 *A&A*, 351, 582), stellar noise according to solar noise (or even flat) + COROT noise and a given inclination of the stellar rotation axis.

[†] *T. Appourchaux, C. Barban, F. Baudin, G. Berthomieu, M. Bossi, P. Boumier, M.J. Goupil, Y. Lebreton, P. Morel, B.L. Popielski, J. Provost, T. Toutain, I. Roxburgh*

[1] The constraints on the models are: $0.86 < log(L/L_\odot) < 0.89$; $3.8062 < log(T_{eff}) < 3.8195$; $0.019 < Z/X < 0.03$

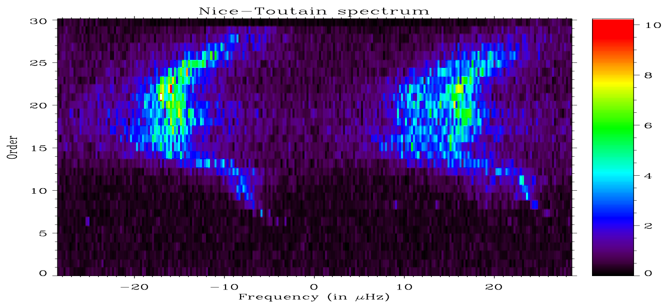

Figure 1. The echelle diagram for Ex1

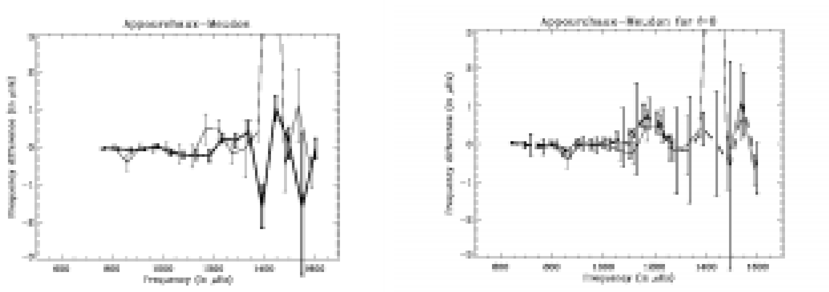

Figure 2. a) Difference between extracted frequencies and theoretical input frequencies for Ex2 ($\ell = 0$ in thin line,$\ell = 2$ in heavy line) relatively to the frequency; b) Difference between extracted frequencies by three independent groups and theoretical input frequencies for Ex2, $\ell = 0$ as a function of frequency.

The identification of the modes (degree l and azimuthal order m) is made with the help of the echelle diagramne. The degrees are identified according to the splitting structure of the $(l = 0, l = 2)$ pair versus that of the $(l = 1, l = 3)$ pair.

The determination of the mode parameters (here principally frequencies) is made using Maximum Likelihood Estimators. The model used for fitting assumes a Lorentzian profile of the mode, a degree-dependent visibility, a rotational splitting, a star inclination and a flat background noise. The statistics of the power spectra is a χ^2 with 2 degree of freedom. The modes are fitted by pairs over a 40-μ Hz (or so) window. Figure 2 gives the differences between the extracted frequencies and theoretical input frequencies.

2. Interpretation of the ‘Observed frequencies’

In Ex2, according to Berthomieu et al 2002, Provost et al. 2001, the aim is to select the models which fit the ‘observed’ large spacing $\Delta_{n,l} =$

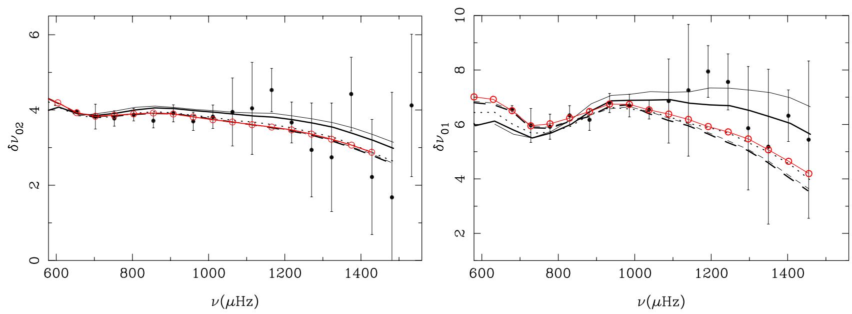

Figure 3. Small frequency spacings $\delta\nu_{02}$ and $\delta\nu_{01}$ for different models satisfying 'observed' large spacing, 'observations' (full dots) and input model (open circle) with M_1 (heavy line), M_2 (dashed line).

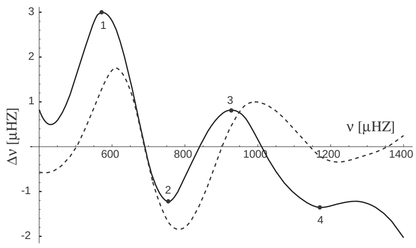

Figure 4. Reduced echelle diagramme for degree $l = 0$ for a model (solid curve) and observations (dashed).

$\nu_{n,l} - \nu_{n-1,l}$ and the small 'observed' spacings defined by: $\delta\nu_{02} = \nu_{n,l=0} - \nu_{n-1,l=2}$; $\delta\nu_{01} = 2\nu_{n,l=0} - (\nu_{n,l=1} + \nu_{n-1,l=1})$ Small spacings are sensitive to the core overshoot parameters, with a highest sensitivity at high frequency.

Among all the models which fit the large spacing, the fit with 'observed small frequency spacings' in large frequency range favours models with low core overshoot M1 (considered as first choice: output1 in table 1), while the fit in the low frequency range where the error bars are smaller favour models M2 (output2 in Table 1).

In Ex1, the frequencies for $l = 0$ are developped according to: $\nu_{n,0} = \nu^0_{cut} + k < D_0 > + \nu^0_{offset}$, where $< D_0 >$ is a mean large spacing, $\tilde{\nu}^0_{offset}$ is a third order polynomial fit of 'observed' ν^0_{offset} The reduced echelle diagramme (Figure 4) is defined by the difference $\nu^0_{offset} - \tilde{\nu}^0_{offset}$. Four extreme points are chosen to characterize the spectrum. These points and the mean large spacing are used to constrain the five parameters involved in the model computations (see Popielski et al 2001). Several models can fit well the constraints. The 'best-fit' model is chosen as that which provides most of the 'observed' frequencies.

Table I. Comparison between 'input' and 'output' models for the two exercises.

Ex1	Input Nice	Output Meudon	Ex2	Input Meudon	Output1 Nice M1	Output2 Nice M2
$M/M_\odot$	1.54	1.52		1.48	1.50	1.50
X	0.712	0.722		0.715	0.70	0.715
Z/X	0.025	0.024		0.0210	0.0214	0.0210
ζ_{ov}	0.0	0.04		0.15	0.05	0.15
$log(L/L_\odot)$	0.840	0.828		0.86	0.88	0.870
$log(T_{eff})$	3.817	3.814		3.809	3.81	3.811
Age (My)	1699	1908		2200	1810	2050
X_c	0.159	0.190		0.17	0.09	0.19
$r_{core}/R_\star$	$5.82\ 10^{-2}$	$6.12\ 10^{-2}$		$5.9\ 10^{-2}$	$5.2\ 10^{-2}$	$6.2\ 10^{-2}$
$r_{ZC}/R_\star$	0.915			0.922	0.917	0.926

3. Conclusion

The data analysis of the simulated time series has produced 'observed frequencies' in good agreement with that of the theoretical frequencies except in low and moderate frequency range. The errors are of the order of 0.1 to 0.5μHz except in the large frequency domain. Using these 'observed' frequencies we are able to find models close to the input models but the solution is not unique. In Ex2, the results stress the importance of the small spacing $\delta\nu_{01}$, that is very sensitive to the core overshooting, for discriminating the models. However the 'observed $\delta\nu_{01}$' have large errors in the high frequency domain. This may alter the choice of the best fit. In Ex1, despite the use of different stellar evolution codes and oscillation codes the input and output models are close. For future works, we need to improve the criteria of model selection and to study the sensitivity of the models to stellar parameters, to numerical codes and to the physics. The next step will be to perform the inverse problem with the best models as reference model.

References

Berthomieu G., Toutain T., Gonczi G., Corbard T., Provost J., Morel P.: 2001, Proceedings of SOHO10/GONG2000, ESA SP-464, 411

Popielski B., Goupil M.J.: 2001, Proceedings of the COROT Week 1 Vienna http://www.astrsp-mrs.fr/projets/corot/meeting/CW1.html

Provost J., Berthomieu G., Morel P.: 2001, COROT H&H2 results and conclusions, http://www.astrsp-mrs.fr/projets/corot/meeting/CW1.html