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CoRoT - a so near future

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Abstract. CoRoT will be launched in about one year from now. We take advantage of this proximity to sum up, as precisely as possible, various aspects of the mission profile and instrument foreseen performances. We also present simulations of what can be expected in terms of final precision on the frequencies determination for representative targets to be observed during the first long runs.

Key words. Stars: oscillations – Stars: variables: general – Space vehicles: instrument – Techniques: photometric

1. Introduction

With a launch in 2006, it is hopefully one of the last times that CoRoT is presented in the "Future and Prospects" session of a colloquium. As time progresses, instrumental tests are performed and preparation works are completed in the scientific working groups. The different aspects of the mission profile and instrument performances become more and more precisely known, hopefully confirming expectations. This is the reason why we found it worth to present here with as much precision as possible what our present knowledge allows to extrapolate in terms of mission profile, observational programme, instrumental performances, etc... focussing on aspects relevant for the seismology programme (see Baglin et al. (2002) for a more general review, and http://corot.oamp.fr/).

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2. By the end of 2006 - First results

2.1. The orbit and the ground segment

By summer 2006, CoRoT is launched from Baikonour, Kazakhstan, by a Soyuz-2 rocket. It is placed on its low earth polar orbit (896km altitude), with a 6174s ($\sim$ 1h43mn, $(162\mu\mathrm{Hz})^{-1}$ orbital period. This orbit is inertial in order to allow the long runs (150 days) on a given field, which are specific of the CoRoT programme.

The altitude choice is a trade-off between keeping CoRoT below the South Atlantic magnetic anomaly and have it as far as possible from the Earth to avoid light scattered by the earth. Even so, the Earth limb always comes at 28 degrees from the optical axis or closer, at least once per orbit. This made the scattered light one of the key points to be handled by the instrument design and the mission profile.

The Proteus platform is operated by CNES from the Corot Mission Center (at Centre Spatial de Toulouse), via the Icones antena network (CNES).

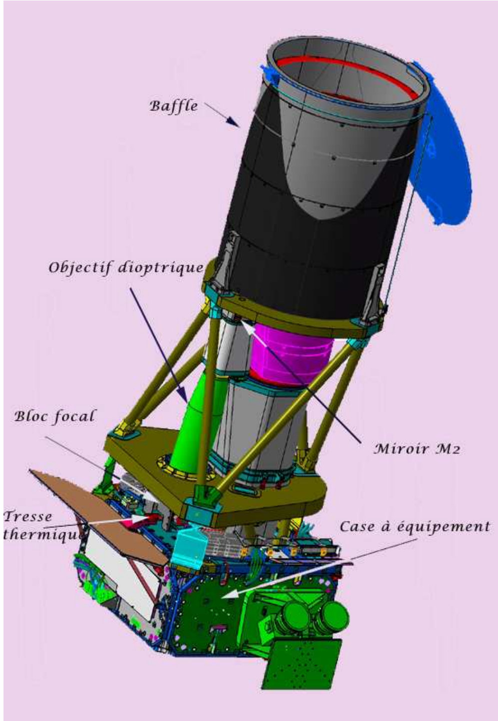

Fig. 1. Schematic representation of CoRoT.

The 1.5Gb/d of scientific data are downloaded via the Icones network + the Alcantara antena (Brazil), completed for security by the Antena of the MOST project in Vienna (Vienna Univ.). Data are preprocessed at CMC and then conveyed the Data Centre (Paris-Meudon Observatory) for a final processing, then archived at Institut d'Atrophysique Spatial, Orsay.

2.2. *The instrument*

Figure 1 represents the instrument as integrated in August 2005 and delivered in december 2005. The instrument (300kg, 1x1x3 meters) is mainly composed of an off-axis telescope plus a dioptric objective giving access to a 3x2.7 degres field of view for a 588 cm^2 collecting area, equivalent to a 27 cm aperture.

The telescope is equiped with a 3-stages baffle, which has been specified to reach a 10^{-13} atenuation for angles larger than 20 degres from the optical axis.

The focal plane hosts 4 CCDs (2k by 4k pixels) used in the frame-transfer mode, cooled at −40 Celsius and stabilized to $\pm 10^{-2}$ degree.

These different parts plus the equipment bay containing the electronics have been integrated together during the summer 2005, the whole instrument being delivered in december 2005.

Half of the field (2 CCDs) is mainly devoted to the seismology programme of CoRoT. It is defocussed (diameter of the star spot ~ 18 px, i.e. ~ 41 arsec) and 10 target stars with $5.4 < m_V < 9$, can be observed simultaneously with a 1 second sampling time.

By default, 10 windows are read for targets and 10 for background estimates. An onboard real-time photometry is achieved. Some of these images can be downloaded for further refined analysis (6 among 10 for a 32 seconds sampling).

The "exoplanet field" is in focuss and it is possible to observe 12000 targets with $11 < m_V < 16$ and a sampling time of 512 s. Thanks to a prism put on the exo-field, each target image is slightly dispersed and for the brightest objects ($m_V < 14.5$), a 3-colors information (white-blue-red) can be obtained.

For a limited number of targets (~ 500), an over sampling rate can be used (32s).

2.3. *In-flight tests and photometric performances*

Soon after the plateform and instrumental checkup (~1 month), the phototmetric perfomances of CoRoT can be checked during a short run (typically a few weeks).

As specified, the instrument is essentially photon noise limited for targets with $5.4 < m_V < 9$ in the frequency range [0.1 − 10 mHz]. The perturbations induced by the environment at the orbital period appear as narrow peaks at $\omega_0 = 162\mu$Hz, $2\omega_0$, $4\omega_0$, $5\omega_0$, essentially, as expected from the simulation of the depointing induced by the gravitational and magnetic perturbations (see Fig. 2).

In this context, the photometric performances obtained with CoRoT are $\sigma = 0.6$ppm

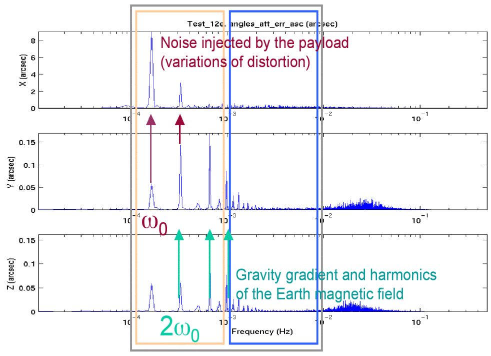

Fig. 2. Spectrum of the image excursion in the focal plane due to gravitational and magnetic perturbation along the orbit. Upper panel: rotation around the optical axis; middle and lower panels: X and Y directions in the focal plane.

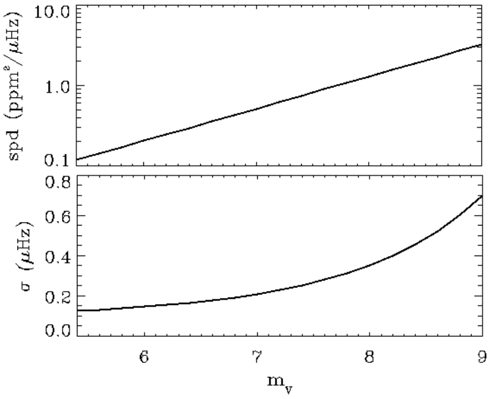

Fig. 3. Upper pannel: Photometric performance expected for CoRoT (spectral power density) for the range of m_V considered. Lower pannel: 1-σ precision estimate for mode amplitudes and lifetimes taken from the Sun.

in 5 days for a $m_V = 5.7$ target ($\sigma_{1s} \sim 4\ 10^{-4}$ and 0.156 ppm$^2/\mu$Hz). In Fig. 3, the evolution of this performances are shown, in the m_V range of interest here. For a $m_V = 9$ target, these numbers become $\sigma = 2.75$ppm in 5 days ($\sigma_{1s} \sim 1.8\ 10^{-3}$ and 3.26 ppm$^2/\mu$Hz).

At this stage, it might be worth to remind that one of the main objective and constraints for CoRoT definition has been to aim at a precision of the order of 0.1μHz in the determination of eigenfrequencies for solar-like pulsators, preliminary work having shown that most of the characteristics we want to address in fine stellar structure understanding had signatures at this level in the eigenfrequencies.

Considering mode amplitudes of the order of 2 ppm and linewidths of 1μHz (representative of the Sun), following Libbrecht (1992), we see in Fig. 3 that for CoRoT 150 days runs, the 1-σ precision on frequency determination is reaching this range of values for the lower part of the m_V range considered for CoRoT, passing below 0.2μHz for $m_V < 7$, approximately.

3. The first long runs - targets and performances

As already mentioned, CoRoT mission profile is characterized by the possibility to dedicate long runs (up to 150 days) on a specific field. The price for this is that CoRoT observations are restricted to 2 observing zones defined as cônes of 10 degrees on the sky, around one position A, roughly in the Galactic anticenter direction ($\alpha = 18h50$, $\delta = 0$) and its opposite position: C , roughly in the Galactic center direction ($\alpha = 6h50$, $\delta = 0$).

The mission profile is thus built around successive 150d long runs, alternatively in the center and anticenter directions, separated by short runs (3-4 weeks) also in one of these accessible cônes.

3.1. *The content of the first long run seismo field*

The field of the first long run has been decided at the CoRoT-Week-8 workshop in Toulouse (June 2005). This field contains different types of targets including known solar-like and "classical" pulsators (Be stars here).

Because of their so low intrinsic amplitudes, solar-like pulsators have been a dimensioning case for the CoRoT instrument and mission profile definition. HD49933, to be observed during the first long run, is illustrative of this kind of targets.

HD49933 is a 1.15 – 1.20$M_\odot$ Main sequence star. Its low metallicity (Fe/H=-0.4) makes it a relatively hot object (log Teff ~ 3.82) for such a mass. Its variability has been confirmed by HARPS observations (Mosser et al. (2005)). It has been identified as a ”Primary candidate” for solar-like oscillation in the process of the CoRoT field evaluation. This means that its brightness ($m_V = 5.7$), in the framework of performances commented in Sect.2.3, makes it a candidates for which the optimal precision ($\sim 0.1\mu$Hz) can be expected.

This precision however is depending on linewidth values which are expected to vary with temperature and gravity. In addition to this, photon noise is not the only contribution to consider when estimating this precision: granulation noise might constitute a significant, sometimes dominant contribution.

A simulation tool has been developed in the framework of the CoRoT Seismology Working Group (http://www.lesia.obspm.fr/~corotswg). This tool takes into account theoretical mode excitation rates following (Samadi & Goupil (2001)), theoretical mode damping rates (Houdek et al. (1999)), granulation noise estimates following (Harvey (1985)) and photon noise in the CoRoT framework.

Figure 4 shows what is obtained for HD49933, after a 150 days of observation with CoRoT.

The seismic signal comes out clearly, between 1 and 2 mHz mostly. It is thus free of the orbital perturbations introduced in Sect.2.3

Another information illustrated by Fig. 4 is that, in the case of HD49933, the spectral ”noise” in the domain of the pulsation signal, is expected to be dominated by the granulation noise.

In order to explore what the final precision on frequencies determination could be for such a target, we considered the following cases:

-a) The reference case: precision on frequencies determination is established considering only photon noise and taking 1μHz as a fixed value for linewidths. The excitation rates are computed following Samadi & Goupil (2001).

-b) as case a, but linewidth are from Houdek et al. (1999).

-c) As case b, but photon noise and granulation noise contributions are considered.

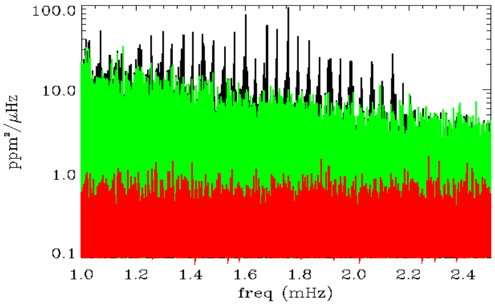

Fig. 4. Simulation of the power spectrum expected for HD49933, including photon noise (dark grey) and granulation noise (light grey) estimates as described in the text.

In each of these cases, the 1-σ precision on frequency determination is estimated following Libbrecht (1992). For case b and c, in order to illustrate the uncertainty on the input of the simulations, results have been computed for values of linewidths estimated by Houdek et al. (1999), as well as for twice and half these values.

These results (Fig.5) confirm that for case a, a 1-σ precision better than 0.1μHz should be expected for oscillation frequencies of HD49933. In case b, we notice that, when theoretical linewidth estimates are taken into account, expected precision is below 0.2μHz, and that it remains below 0.3μHz, when taking a factor two of uncertainty in the linewidth estimates. Case c confirms that the granulation noise, as estimated here, is expected to be a dominant factor compared with photon noise. The precision expected is of the order of 0.3μHz or below, but it can reach $\sim 0.5 - 0.7\mu$Hz, for less favorable estimates of linewidths.

Beside principal targets like HD49933, the set of 10 targets per field has been completed with ”secondary candidates”. This denomination might be a bit misleading since it mostly reflects the procedure adopted to evaluate candidate fields. We first considered candidates which were the most demanding in terms of photometric performances and thus in terms of brightness. Then, the associated field were searched for less demanding or less rare candidates. These secondary candidates feature

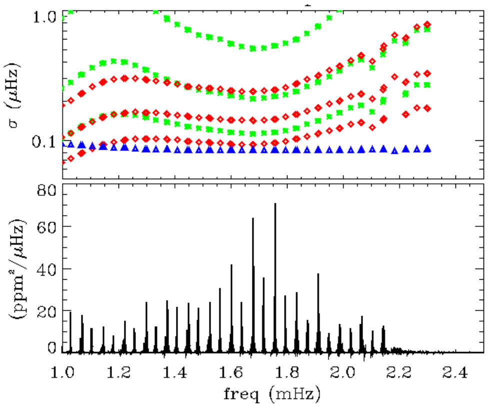

Fig. 5. Lower panel: simulation of the pure seismic signal expected for HD49933. Upper pannel: Estimates of the 1-σ precision on the determination of eigenfrequencies, for case a,b and c (resp. triangles, rhombs, stars) as described in the text.

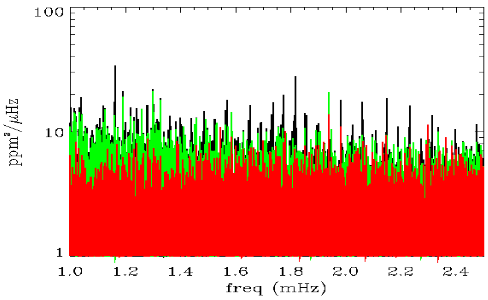

Fig. 6. Same as Fig.4 for HD49385.

known classical pulsators which have been characterized by preparatory ground-based observations (see e.g. Neiner et al. (2005), Poretti et al. (2005),...). It also features objects expected to oscillate on theoretical grounds (located in a known instability strip) which failed to reveal pulsation from the ground, as well as eventually objects outside any known instability strips.

This set of targets also features some solar-like pulsators candidates for which, according to current theoretical amplitude estimates, one can expect detection of a significant number of peaks, but no guarantee of a high precision of the frequency measurment. This is the case of HD49385 (m_V = 7.9), a $1.20 M_{\odot}$ star by the

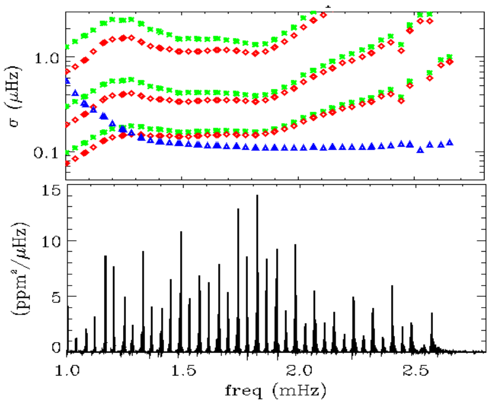

Fig. 7. same as Fig.5, for HD49385.

end of main sequence evolution stage, also to be observed during the first long run.

The result of the simulation for HD49385 can be seen on Fig. 6.

Here again, the oscillation signal is clearly seen, between 1 and 2.5 mHz approximately, but this time, we see that the photon noise is higher and the granulation noise only slightly contributing to the noise level in this domain.

This is confirmed in the precisions estimates shown in Fig. 7. We see that the precisions obtained for case b and case c (respectively without and with granulation contribution) are approximately the same. They indicate an expected 1-σ precision around 0.4-0.5μHz, possibly reaching 2μHz, for less favorable linewidths values.

3.2. next long runs - scanning the HR diagramme

A few days after the first long run, the platform will be turned to the center direction and CoRot will point the field selected for the second long run. This run, as decided at CW8 in Toulouse in June 2005, features among others, a known Main Sequence δ Scuti star, a known β Cephei, and a good candidate for solar-like oscillations.

For classical pulsators with eigenfrequencies in the $0.1 - 1$ mHz, the perturbations associated with the orbital period (see Sect. 2.3) will have to be taken into account, however, in the hypothesis of steady coherent oscillations, a simple scaling can give us a flavor of what can be expected from such runs. Even for a $m_V = 9$ object, $\sigma = 0.5$ppm in 150 days grants a detection level better by two or three orders than what is commonly achieved from the ground. This, plus the high duty cycle (specified higher than 90%) over time scales unreachable from the ground (5 months), bring the promiss of a unique and exciting insight into pulsational behavior of these objects at very low amplitude.

Then, run after run, CoRot will observe more and more objects, with the idea to complete a significant sample of objects representative of MS and slightly more advanced stages as illustrated on Fig.8.

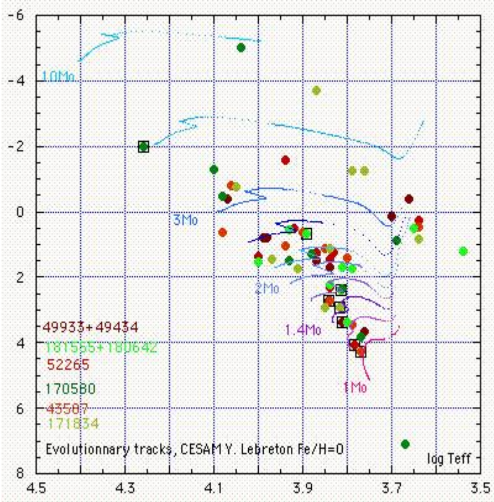

Fig. 8. The CoRot HR diagramme. Illustration of what could be the set of objects observed during 150d runs after 3 years.

4. Conclusions

The results of our simulations show how granulation noise might be a significant source of "noise" for the seismic analysis of some objects. They also confirm that effective lifetimes of the modes will be a determinant factor in the final performances in terms of of precision on the eigenfrequencies determination. The same results suggest that even in less favorable values foreseen for modes lifetimes, these perfomances remain of the order of a few 10^{-1}ppm for the brightest solar-like targets.

These data will be soon available to the whole community, since according to the Data rights policy, of CoRot, they will be released after the one year privacy given to the CoRot community.

Beyond this, with about 12000 objects observed per field, the exoplanet-field, will constitute a rich source of data for seismology. The precision of course is lower than in the seismo-field, but for intrinsically large amplitude enough pulsators, this constitutes a unique source, allowing statistical studies out of the reach of the seismo restricted set of targets. These data are accessible via CoRot Additional programs, which are subjects to AOs open to all members of the contributing countries. The AO are opened each year, the first one has been issued in spring 2005.

References

Baglin, A., Auvergne, M., Barge, P., Buey, J.-T., Catala, C., Michel, E., & CoRot Team 2002, in First Eddigton Workshop, Eds. Favata, F., Roxburgh, I. W., Galadi, D., ESA-SP 485, 17

Mosser, B., Bouchy, F., Catala, C., Michel, E., Samadi, R., Thevenin, F., Eggenberger, P., Sosnowska, D., Moutou, C., & Baglin, A. 2005, A&A, 431, 13

Samadi, R. & Goupil, M.J. 2001, A&A, 370, 136

Houdek, G., Balmforth, N.J., Christensen-Dalsgaard, J., & Gough, D.O. 1999, A&A, 351, 582

Harvey, J. 1999, ESA SP-235,199

Libbrecht, K. G. 1992, ApJ, 387, 712

Poretti, E., Alonso, R., Amado, P. J., Belmonte, J. A., Garrido, R., Martín-Ruiz, S., Uytterhoeven, K., Catala, C., Lebreton, Y., Michel, E., Suárez J. C., Aerts, C., Creevey, O., Goupil, M. J., Mantegazza, L., Mathias, P., Rainer, M., Weiss, W. W. 2005, AJ, 129, 2461

Neiner, C., Hubert, A.-M.,& Catala, C. 2005,ApJS, 156, 237