Part 10

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Asteroseismology with COROT

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Abstract. The COROT project has been developed in the framework of the CNES small satellite programme, with European and Brazilian cooperation. It will be launched in 2006. It is dedicated to seismology and detection of telluric planets. It will perform relative broad-band photometry in visible light during very long (150 d) observing runs in the same direction, plus a number of short (10–20 d) observing runs. Both programmes will work simultaneously on the same region of the sky. The seismology programme aims to map the HR diagram and study in detail approximately 50 targets brighter than magnitude 9. The exoplanet programme will search for telluric planets slightly larger than the Earth orbiting around stars of magnitude 12 to 16, located in the habitable zone and closer. The data collected will also allow valuable seismic studies. A number of additional scientific programmes will also be conducted. The mission characteristics derived from the scientific objectives, the instrument and its performances for seismology, as well as preliminary observing plans, are presented.

1. COROT: summary

The goal of the COROT space mission is twofold: 1) the study of the stellar interiors, and 2) the search for exoplanets. The data will also be used to perform additional science. To achieve these goals, COROT will perform very high precision, very long duration photometry to 1) study the asteroseismological properties of a hundred of selected stars, and 2) to detect and characterize planetary transits in front of their parent stars.

The mission has a unique instrument: a 27-cm aperture telescope equipped with a wide field (6.8 square degrees) photometer composed of 4 CCD detectors. It will be placed on a PROTEUS platform and launched on a polar inertial orbit at an altitude of 896 km. The mission is financed by the French Space Agency (CNES) for 62%, by CNRS/INSU (17%) and by European countries (ESA, Germany, Spain, Austria and Belgium) and Brazil for 21%. Fig. 1 shows the updated design of the satellite.

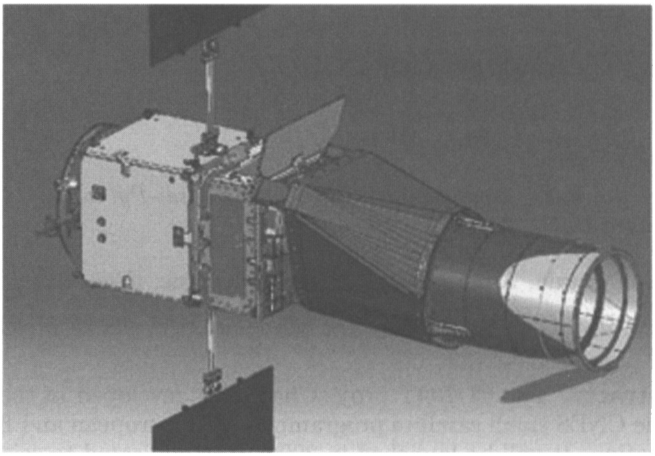

Figure 1. The design of the COROT satellite: the left part is the PROTEUS platform. The telescope is in the middle part, while the baffle, with its cover, is seen on the right side.

The mission will last at least 3 years. The launch is scheduled in the first semester of 2006, either by a ROCKOT rocket, managed by the Russo-German society EUROCKOT, from Plesetsk, or by Arianespace with a new Soyuz vehicle from the Kourou Space Center (French Guyana).

In this presentation, we concentrate on the asteroseismology programme, to stay in the framework of this colloquium devoted to variable stars. The aspects of the mission related to the exoplanet search will not be further discussed, except for those specifications useful for the seismology additional programmes which will use the exoplanet field.

2. Specifications for seismology

It is clear that many aspects of the stellar structure modelling and of the basic underlying physics need improvements. Among those aspects, we can quote the description of the convection, generally parameterized by the so-called mixing length "theory", the estimate of the overshoot extension, the inclusion of the effects of the rotation and their role in producing turbulent mixing and in transporting angular momentum, the effects of the chemical species diffusion on the chemical stratification and its feed-back on the rotation, etc. This list is far from being exhaustive.

The theory of stellar evolution cannot be adequately tested without information coming directly from inside the stars. This is the goal of asteroseismology. The frequency spectrum of the stellar oscillations contains information on the internal structure and physical conditions which asteroseismology can reveal.

The COROT seismology core programme consists of two parts:

- *the central programme* composed of at least five observations of 150 d each to focus on a detailed study of variable stars on the main sequence, mostly of spectral types A, F and G.

- *the exploratory programme* consisting of several shorter runs (approximately 20 d) to extend that study to other types of variable stars in the HR diagram.

The specifications for the seismology programme have been defined on the basis of the performances expected for the central programme. In the A–F range the aim is to study variable stars of δ Scuti type, whose amplitudes of pulsation as observed from the ground are generally about 10 mmag. In those stars modes of low order and low degree are excited by the κ-mechanism induced by the helium opacity. In the solar-type stars, the excitation mechanism is different. The pulsations are triggered by stochastic excitation due to the turbulent motions in the surface convection zone. As a consequence, the amplitudes are smaller, of the order of 2.5 ppm, as observed in the Sun. As the coherence life-times of the solar oscillations are a few days, depending on the frequency, the specifications for the seismology programme have been defined to allow the detection of modes with amplitudes $\geq 4\sigma$, where σ is the noise level, on a timescale of 5 d. This leads to a noise level of $\sigma \leq 2.5$ ppm for A and F stars and $\sigma \leq 0.6$ ppm for G stars, which translates into $3.7 \times 10^5\,\mathrm{s}^{-1}$ and $6.4 \times 10^6\,\mathrm{s}^{-1}$, respectively. The size of the telescope (27-cm aperture) was optimized to fulfil these requirements.

The 150-day-long-run observations will provide a 0.1 μHz frequency resolution in Fourier space, which means that the frequency accuracy of the observed modes will be better than 0.1 μHz. With such a frequency accuracy, the frequency spectra will be well-resolved. Amplitudes and profiles of the modes in the Fourier spectra will be known precisely. In addition, owing to the required high duty cycle ($\geq 90\%$) there will be no significant secondary lobes. The rotational splitting of the modes will be measured accurately, giving information on the differential rotation.

Finally, the large field (6.8 square degrees) of the instrument will allow observations at the same time of a bright star ($m_V \approx 6$) and 9 fainter stars called secondary targets.

3. The COROT Fields

The choice of the region of the sky that will be observed with COROT results from a compromise between the instrumental constraints and the specifications of the scientific programme.

The CNES "small mission" cheap line of products based on the PROTEUS platform implies the use of a low earth orbit. Continuous observations on such a trajectory is possible only in the direction perpendicular to the plane of the orbit, to avoid the earth. So a polar orbit with an inertial plane has been chosen. Then the observable regions of the sky are around the celestial equator. On the other hand, the statistical estimate of the expected number of planetary transits requires a sufficiently large number of stars to be observed simultaneously for the exoplanet search programme, which obviously means that rather crowded fields are required, close to the galactic plane. The selected directions, best satisfying those constraints are at RA = 18h50 towards the galactic center, for the summer observations, and at RA = 6h50, in the opposite direction for the winter observations. The continuous viewing zones are circles of $\sim 10^\circ$ angular radius centered on these RA values and on 0° declination. The exact value of the angular radius depends on the performances of the baffle protecting the telescope from the solar light diffused by the Earth's atmosphere.

The focal plane is composed of 4 CCDs with frame transfer, 2 for the seismology programme and 2 for the exoplanets programme. The field of view for each programme will be $2.6^\circ \times 1.3^\circ$. For each long run a primary target of $m_V = 6 - 7$ will be positioned on the seismology CCDs so as to optimize the signal/noise ratio expected on that target. The chosen position should also allow 9 secondary targets, of $m_V \leq 9$, to be observed. To achieve the best photometric accuracy, the image will be defocused (on $\approx$400 pixels). On the adjacent CCDs devoted to the exoplanets programme, a total of 12 000 stars will be observed simultaneously, (6 000 per CCD), of $12.0 \leq m_V \leq 15.5$. The image will be in focus, but a prism is added to produce a low dispersion spectrum of each star. The chromatic information provided will help distinguishing true planetary transits, which have no chromatic signature, from stellar activity, which does have a chromatic signature. To perform photometry of these images to the expected level of accuracy, a mask will be associated with each selected target, chosen from a collection of 256 different patterns, taking into account both the spectral energy distribution corresponding to the star's spectral type and the presence of polluting stars in the crowded nearby environment. Fig. 2 shows the image characteristics for each programme.

4. Ground-based preparatory observations

The best scientific choice for the primary targets of the seismology programme, as well as for the secondary ones, required a large observational effort to improve our knowledge on the COROT potential targets. Strömgren photometry of all the potential targets has been obtained from which T_{eff}, $\log g$ and $[F_e/H]$ may be derived. High resolution spectroscopy has been performed for the brightest targets on various 2-m class telescopes. From these data a homogeneous set of basic parameters are derived: T_{eff}, $\log g$, the detailed abundances and there potential anomalies, $v \sin i$. They are also useful to identify spectroscopic binaries and detect any variability. To detect any nearby faint stars which would preclude performing the expected high accuracy photometry on the primary targets, the imaging of the targets' environments has been undertaken by close examination of Schmidt plates and/or by performing high spatial resolution imaging with adaptive optics on 4-m class telescopes (at CFHT and TNG).

For the millions of stars of the exoplanets search programme, it is necessary to know their spectral type in order to distinguish the dwarf stars from the giants, and to reject those stars not suitable for a good detection of planetary transits. This is, of course, not available for the stars up to magnitude 16 in the regions of the sky selected for COROT. A large field broad-band photometric survey is being undertaken in the exoplanet fields associated with the primary seismology targets. The survey is being performed with 2-m telescopes or larger, at ESO, INT and with Megacam at the CFHT. It is complemented by the IR

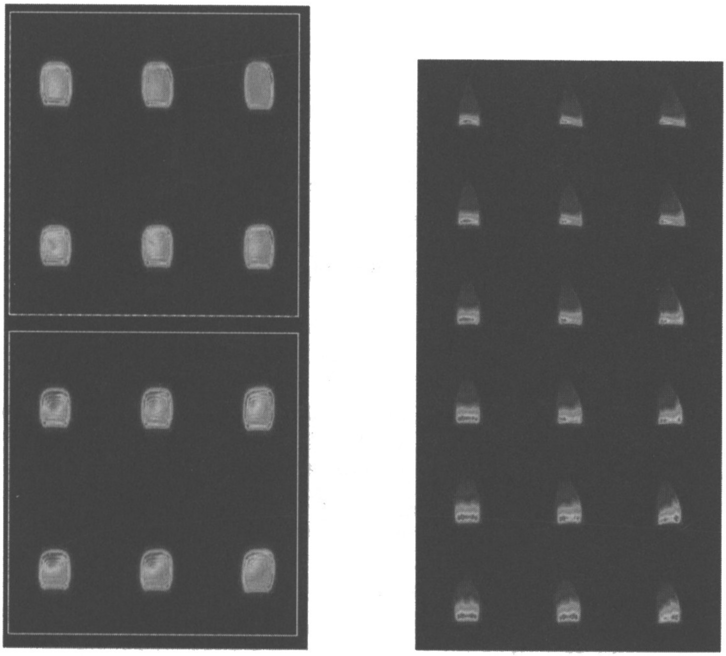

Figure 2. In the left figure are shown the images of the PSF at different locations in the seismology focal plane, demonstrating the optical properties of the instrument. The right figure shows the same thing in the exoplanet focal plane. As there is a bi-prism added in the exoplanet channel, each image of a star is a small spectrum. The dispersion of the bi-prism is along the vertical axis, with the blue part above and the red part below each of the individual spectra.

data from the DENIS and 2MASS surveys. Those data, specifically obtained to define the exoplanets search programme, will be useful for the preparation of the additional programmes using data obtained in those fields.

All the data obtained during the preparatory phase of the project (photometric data, spectra, and the derived stellar parameters) will be made available, first to the participants to the project and later to the whole community, in a data base accessible through the internet.

5. The additional programmes

In parallel with the core programme there will be the opportunity to propose additional programmes. The major goal of these additional programmes is to get the best possible scientific return from the unique database on stellar variability, on time scales from 1 s to 5 months, produced by COROT.

There will be three means to propose additional programmes:

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- ask for a few specific targets (approximately a few hundred) in the exoplanet fields,
- ask for a short run of 20 d on a specific region (approximately 5 possibilities),
- or use the data of the core programme for a purpose other than the core programme objectives.

At the end of the mission, a huge number of light curves will be available with a photometric accuracy $\sigma \leq 7 \times 10^{-4}$ in 1 h on a $m_V = 15.5$ star. 60 000 objects in the range $12 < m_V < 16$ will have been observed during 150 d and also at least 60 000 during 20 d. Seismic studies of stars in the exoplanet fields are evidently one major issue of this programme.

The data acquired for the transit search will have a nominal sampling rate of 8 min, but a few hundred stars will be read at a 32-s sampling rate, mostly to follow accurately the identified planetary transits. However, some of them could be used to do asteroseismology of rapidly oscillating stars, such as the roAp stars, the sdBV and the pulsating white dwarfs.

A number of additional programmes have already been identified and discussed during the various COROT meetings. They concern the study of: pre-main sequence pulsators of Herbig Ae/Be types, central stars of planetary systems, pulsators in eclipsing binaries, β Cep stars, Be stars, Cepheids, γ Dor stars, HgMn stars, λ Bootis stars, and the above-mentioned roAp stars, sdBV and white dwarf stars. Most of these additional programmes will use the data archived with the nominal sampling rate, except the rapidly pulsating ones already mentioned which need the shorter sampling rate.

The targets will be selected by the scientific Committee through an Announcement of Opportunity.

6. Conclusion

COROT, which is planned to be launched in 2006 June, will be the first space mission devoted to asteroseismology and search for exoplanets that will provide both very high photometric precision and very high frequency accuracy, due to the long observing runs. It will provide a unique database on stellar variability, on time scale from 1 s to 5 months, with unprecedented accuracy. It will give precise measurements of the stellar oscillation frequencies for a number of main sequence stars, especially for solar-type stars, allowing detailed asteroseismic analysis. It will also probably detect the first telluric exoplanet. Finally, a number of additional programmes, covering many different aspects of stellar astrophysics will make use of the COROT data.

For more information, see http://COROT.astrsp-mrs.fr

Gérard Vauclair, Michael Snowden, Hiromoto Shibahashi and Don Kurtz meet a Christchurch "lady".

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