Mem. S.A.It. Vol. 75, 69

Memorie della

Ground–based characterisation of the asteroseismic targets for the COROT space mission

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Abstract. We illustrate the approach to the use of asteroseismology to sound stellar interiors. We also present the spectroscopic and photometric observations carried out to give the complete characterisation of the potential targets of the space mission COROT. The Italian contribution plays an important rôle in the preparation of the observational basis of this space mission.

Key words. Asteroseismology – space missions – δ Sct stars – stellar parameters

1. Introduction

The COROT (*COnvection, ROtation and planetary Transits*) mission has been scheduled by the French space agency, CNES, to be launched in late 2005. The final decision confirming the mission has been recently taken (April 2003). Besides a major French participation (80%), the COROT mission also involves other european countries: Spain, Austria, Belgium, Germany as well as a participation of ESA. In a short–sighted way, the Italian Space Agency ASI withdrew the official participation to the project. Despite this, a group of researchers still remains active on various aspects of the project.

The COROT mission is intended to provide high-precision (micro-magnitude level) photometric monitoring of stellar targets to achieve three main objectives:

1. stellar seismology of dwarf stars to give direct information on the structure and dynamics of their interiors; among those, a dozen bright stars ($m_V \leq 6.5$) will be studied continuously for 150 days (central program, noise level in the frequency spectrum 0.7 ppm over a 5 d time baseline), while about 100 fainter ($m_V \leq 8$) stars will be monitored for up to 30 days in an exploratory phase of the mission (exploratory program; noise level in frequency spectrum 2.5 ppm over a 5 d time baseline) once they are selected on the basis of the ground-based preparatory survey;
2. the detection of Earth-like planets from eclipses of their parent stars;
3. the accurate high precision, continuous, photometric monitoring of many thousands of fainter stars that lie in the target fields.

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The orbital plane of the satellite will be not subjected to precession so that all observations should be made in the same area, defined by a cone with 11° half-angle, except for a 180° rotation. More precisely, the targets of the seismology central program are bright F–G dwarfs and δ Scuti stars, while those of the exploratory program are fainter stars, and will be chosen so as to cover the HR diagram near the Main Sequence, as completely as possible.

2. The asteroseismic aspect

The COROT mission should detect a large number of excited modes for each target. In stars hotter than the Sun, the oscillations are driven by opacity. They are found in the instability strip and amongst more massive and hotter stars on the main sequence. Each frequency is associate with a nonradial mode pattern (ℓ, m) on the surface. We remind the reader that ℓ determines the horizontal wavelength (the number of patches on the surface), while m measures the number of nodes around the equator. For each spherical harmonic, the star supports a series of modes of different structure in the radial direction, characterized by the radial order n, which, approximately, measures the number of radial nodes. For a spherically symmetric star, the oscillation frequencies do not depend on m. This degeneracy is lifted by any departure from spherical symmetry; in particular, rotation induces a splitting with respect to m.

Observations of stellar oscillations provide information on many aspects of the stellar interior. The frequencies of the oscillations depend on the structure of the star, particularly the distribution of sound speed and density, and on gas motion and other properties of the stellar interior. The amplitudes of the oscillations are determined by the excitation and damping processes, which may involve turbulence from convection, opacity variation and magnetic fields. The best targets are stars which oscillate in several modes simultaneously. Each mode has a slightly different frequency, reflecting spatial variations of the structure within the star, and the combination places strong constraints on the internal properties.

Although this means we cannot extract the same level of detail on sound speed as we did for the Sun, observations of stellar oscillations provide information on many aspects of the eigenspectrum according to the asymptotic pulsation theory. In such an eigenspectrum, the frequency ν of a mode of degree ℓ and overtone n is

$$\nu_{nl} \sim \Delta\nu_0(n + \ell/2) + \delta(\ell(\ell + 1)\Delta\nu_0^2)/\nu + ... \quad (1)$$

The second term in this equation is small: at a first approximation, the p-mode eigenspectrum will be a combination of frequencies with nearly equal spacing $\Delta\nu_0$ since the modes with (ℓ, n) and $(\ell \pm 2, n \pm 1)$ are almost degenerate in frequency. The fundamental frequency spacing $\Delta\nu_0$ is equal to the time for a sound wave to traverse the diameter of the star. This depends on the square root of the star's mean density, so is sensitive to the stellar mass and radius. Actually, the second term in the equation is not zero, so the mode degeneracy is broken. The magnitude of the second–order splittings, δ, depends heavily on the sound speed gradient in the star's core. In the nearly isothermal core of a star, that gradient depends most strongly on the composition gradient created by fusion reactions. This gradient changes with stellar age, as the star gradually converts its central supply of hydrogen into helium. Therefore, the second-order splittings of the eigenspectrum act as a main–sequence lifetime clock.

Rotation may have important effects on stellar structure and evolution and it affects the oscillations, leading to a splitting of the frequencies according to m:

$$\nu_{nlm} = \nu_{nl0} + m\Omega_{nl}/2\pi \quad (2)$$

where Ω_{nl} is an average of the angular velocity weighted by the structure of the given mode. When only low–degree modes are observed these averages all extend over most of the star. However, even such limited information will give some indication of the variation of rotation with depth in the star, particularly if it is combined with measurement of the surface rotation (via spectroscopic observations, for example).

Table 1. Summary of the spectroscopic observations.

COROT potential primary and secondary targets	
Total number	957
In the Galactic Center direction	366
In the Galactic AntiCenter direction	591
In the Northern Hemisphere	548
In the Southern Hemisphere	409
Observed at ESO/FEROS	423
Observed at OHP/ELODIE	419
Observed at Brasil/FEROS	87
Observed at TNG/SARG	73
Observed at Euler/Coralie	17
Observed at Tautenburg	11

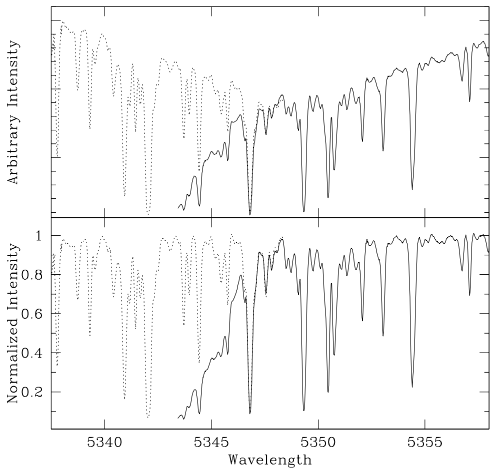

Fig. 1. Example of the automatic normalization procedure applied to the SARG spectrum of HD 44019. Top panel: original data for two adjacent orders, indicated with different line types. Bottom panel: normalized data for the same orders. The procedure works well, except for the extreme blue border of the order more to the red, where the intensity drops too fast.

2.1. The spectroscopic observations

It is essential to have an accurate and reliable knowledge of T_{eff}, log g, abundances, v sini parameters for the potential targets in order to quickly exploit the photometric data which will be supplied by COROT. One of the goals of the mission is to provide seismological analysis of stars well distributed in this parameter space. Therefore, one have been selected 957 stars located in the COROT field–of–view which can be potential primary or secondary targets, i.e., we excluded stars fainter than V=8.0 and known giant stars. The observational effort to secure at least one high–resolution ($R \sim 50\,000$) spectrum involved several telescopes and intruments (Tab. 1); the task has been achieved in due time (February 2003) and SARG provided an important contribution, allowing to complete the survey of northern targets. Moreover, ESO/FEROS observations have an Italian P.I. and the FEROS automatic pipeline has been improved by the Merate team. A further, original Italian contribution to COROT is based on the monitoring of some targets to establish the level of the stellar activity (Catania team, observations from Serra La Nave). A team chaired by Werner W. Weiss (Vienna University) is trying to build–up a semi–automatic procedure to reduce SARG spectra. Figure 1 illustrates the application of the current version of the automatic normalization procedure to HD 44019 (spectral type K2), one of the COROT candidate targets. It is a zoom of a region with two overlapping orders. As can be seen, the normalization (bottom panel) is satisfactory compared with the original data (top panel) despite the presence of a lot of spectral lines. It is, however, still unsatisfactory at the extreme blue border of the order more to the red, where the intensity drops too fast. Improvements are expected in the near future.

To determine automatically the effective temperature, gravity, and metallicity of the observed stars from the high–resolution spectra, the current approach uses primarily the ETOILE programme (Katz 2000), which is an extension of the TGMET programme developed by Katz et al. (1999). A new, semi–authomatic method has been developed to analyze the high–resolution spectra (VWA; Bruntt et al. 2002). The procedure selects the least blended lines from the atomic database VALD and consequently adjusts the abundance in order to find the best match between the calculated and observed spectra. The whole atlas of the high-resolution spectra and all the derived fundamental parameters will be made accessible to the community, constituting by their own a powerful tool to investigate properties of stars along the main sequence. Teams working on atmosphere models are invited to join this aspect of the project.

2.2. The photometric observations

The δ Sct class covers both the early main-sequence evolutionary stage, when the star is burning hydrogen in the core, and the following one, when it leaves the Terminal–Age Main Sequence burning hydrogen in a shell. These two different stages correspond to different types of structures and their study offers different insights into the physics of the stellar interiors. Therefore, both types of variables deserve interest. However, the primary objectives of COROT are highly focused on core overshooting processes and on transport of angular momentum and chemical species. These processes are crucial in the main–sequence stage for intermediate– and high–mass stars. None of the well–known δ Sct stars studied in the past years is included in the COROT field–of–view. Therefore, we put a strong priority in searching for new δ Sct stars close to the Main Sequence. The observational effort has been primarily addressed in the Center direction, as there are no good primary targets in such a direction. We photometrically surveyed 68 potential δ Sct variables and we found that 23% of the sample actually display multiperiodic light variability up to few mmag of amplitude (Poretti et al. 2003). We note that by observing a zone of 450 deg^2 on or just above the galactic plane in the solar neighbourhood we discovered variables well mapping the lower part of the instability strip. Accurate $v \sin i$ values (± 5 km s^{-1}) have also been obtained on the basis of the spectroscopic observations collected for the purposes described in the previous subsection.

3. Conclusions

The Italian contribution to the COROT space mission will allow the full spectroscopic characterisation of the targets (by means of the high–resolution spectra taken with SARG, FEROS and the stellar activity monitoring from Serra La Nave) and to a precise photometric evaluation of the δ Sct variability in the COROT field–of–view and, more in general, in the lower part of the instability strip. If we also consider that observations with adaptive optic (to detect close companions of primary targets) have also been undertaken, the Italian contribution continues to be both original and useful, despite the ASI withdrawal from the project.

Acknowledgements. The author wishes to thank Werner W. Weiss for the data reduction (within project P14984 of the FWF Austria) which inspired Fig. 1.

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