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M. Heydari-Malayeri, C. Reylé and R. Samadi (eds)

GAIA AND ULTRA HIGH PRECISION SPACE PHOTOMETRY

Baglin, A.[1] and Catala, C.[1]

Abstract. The era of ultra high precision stellar photometry from space on long and continuous duration has started with the launch of CoRoT. It is followed by Kepler (NASA) and will continue hopefully in the next decade by PLATO (ESA). All these missions need precise determinations of the fundamental parameters of their targets through other means. GAIA will be the mission to provide these data and then to increase significantly their scientific return.

1 Introduction

With the launch of CoRoT, starts a very rich period for high precision relative stellar photometry.

The major scientific objectives to be accessed by this technique are of essentially two kinds:

- detection of candidate exoplanets through their transit in front of their parent star

- stellar flux variability as an indicator of the physics of the stellar body, through asteroseismology but also through direct time indicators like modulation due to rotation.

Both fields need a good knowledge of the stellar fundamental parameters (temperature, mass, luminosity, chemical composition......) as illustrated with some CoRoT results. GAIA, with the determination of distance, temperature, chemical composition and in some cases mass, will be the best complementary mission to fulfill this need.

Table 1. The 3 major ultra high stellar photometry missions

Mission	**CoRoT**	**Kepler**	**PLATO(n)**
Period of operation	2007-2012	2009-2014+	2017- 2023
Duration: 1 obs	150 d	5 y	3y + 2y +nx(3-5 months)
Sampling	32s	15 to 1min	50s
Continuity	97%	?	$\geq$ 95%
Diameter (cm)	27	90	76
Targets Nb	150 000	100 000	250 000 (500000)
Magnitude range	10-16	9-14	4-13
Distance range	500-1000	400-800	10-500

2 Preparation and Interpretation

The need for stellar fundamental parameters is important for both the preparatory phase, and the interpretation of the data, but is treated in a different way.

During the preparatory phase, one has to optimise the selection of the targets among the different candidates in a given field. The interpretation needs the best knowledge of the properties of the observed stars, obtained by all possible means.

[1] LESIA, Observatoire de Paris.

As CoRoT and Kepler have been launched before GAIA, the complementarity will concern only the intepretation phase. Their preparations have used specific ground based observations to determine luminosity class and spectral types. For PLATO, the situation is more favorable, as GAIA will be able to contribute to both phases.

3 Stellar variability as seen from CoRoT

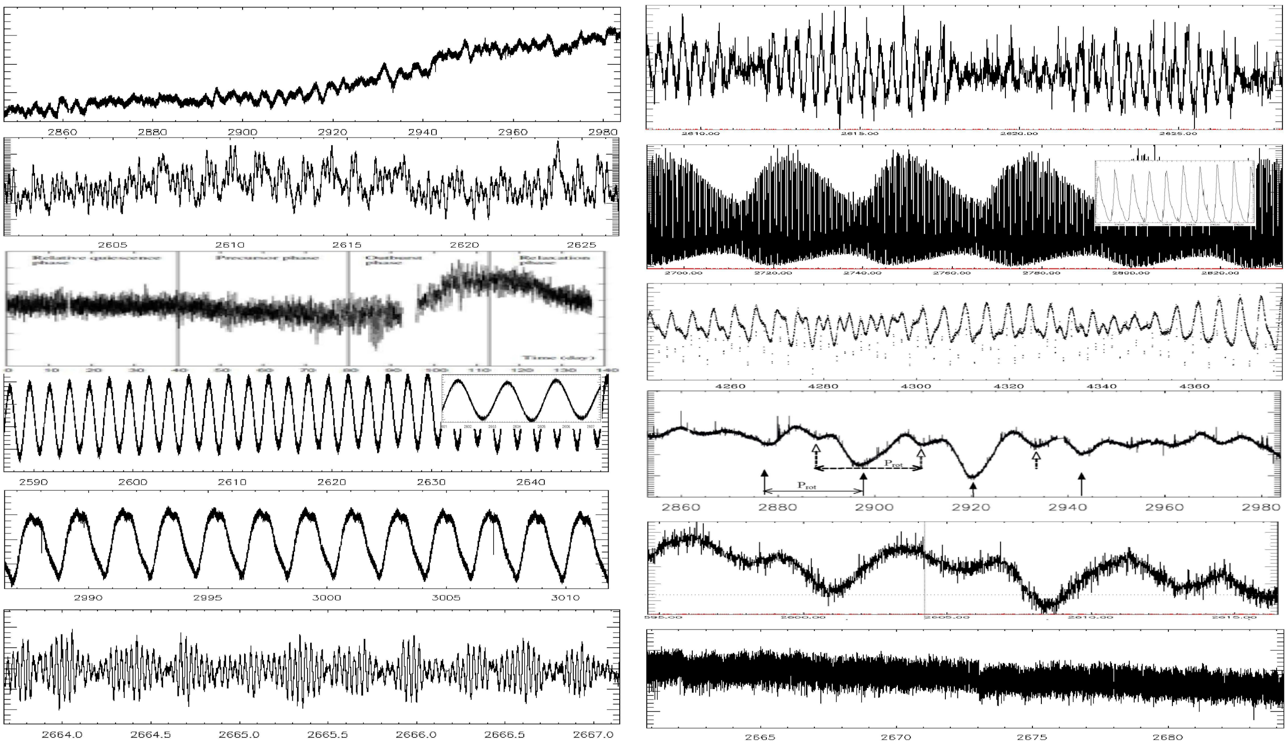

Fig. 1. Lights curves of several CoRoT targets on different durations. The left part correponds to the seismology channel, and the right one to the exoplanet channel. The accuracy on each measurement is approximately 10^{-4}

At the level of CoRoT photometric accuracy, more than 45 % of stars have detectable periodic variations. Many more vary but with no detected periodicity, and more work is needed to interpret all these data. What does this infomation tell us about stellar physics? Let's cite just a few early examples.

3.1 Rotation

The generally spotted nature of the surface of stars is seen in very accurate photometry as modulations at the rotation frequency. So true surface rotation is a direct product of CoRoT. Combined to other fundamental parameters it becomes possible to trace its variations during the evolution of stars using a large sample of targets if their parameters (T_{eff}, M, L) are well known (Fig. 2,a).

3.2 Seismology

Results are numerous in seismology as already 100 stars have been observed with a sufficient quality for such studies. Interpretation take more time than expected because Nature is always more complex than we foresee! The discovery of solar like oscillations in solar like stars, which was the major goal fo CoRoT has been achieved (fig 2b). But, in the already observed targets, which are slightly hotter than the Sun, the data analysis and mode identification is difficult due to small life times of the modes, the larger rotation, and a quite strong surface activity. The first interpretation leads to a determination of the convective core larger than expected. In B stars, the low frequency modes discovered by CoRoT can be interpreted only with an analogous structure.

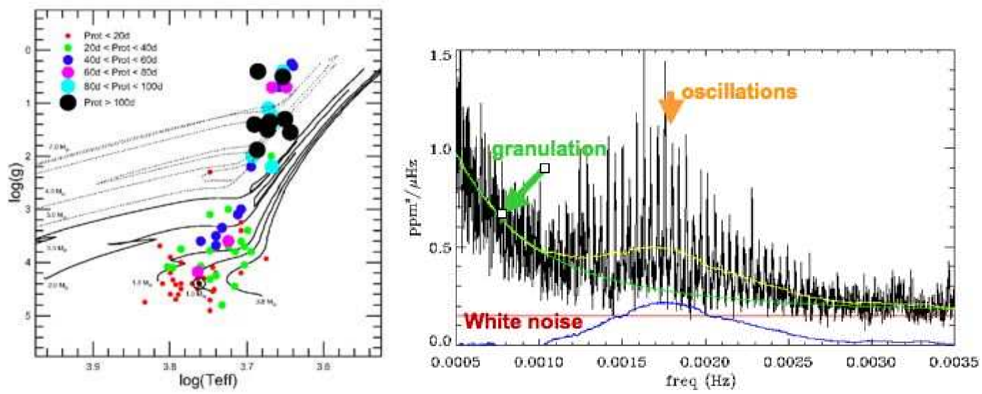

Fig. 2. *a, left*: Evolution of the rotation along the evolutionnary track of the Sun derived from CoRoT observations. *b, right* : Power spectrum of a 6th magnitude solar-like star, observed during 60 days, showing the different components : white instrumental noise, granulation and oscillations, in the frequency domain (0.5, 3.5) mHz.

3.3 Seismology and galactic structure

CoRoT has discovered solar like oscillations in a large sample of red giants, as a additional programme of the exoplanet field. They are identified as red-clump stars. The distribution of the maximum amplitude and of an average large separation give access to the distribution of the stellar radius and mass, and thus represent a most promising probe of the age and star formation rate of the disk, and of the mass-loss rate during the red-giant branch.

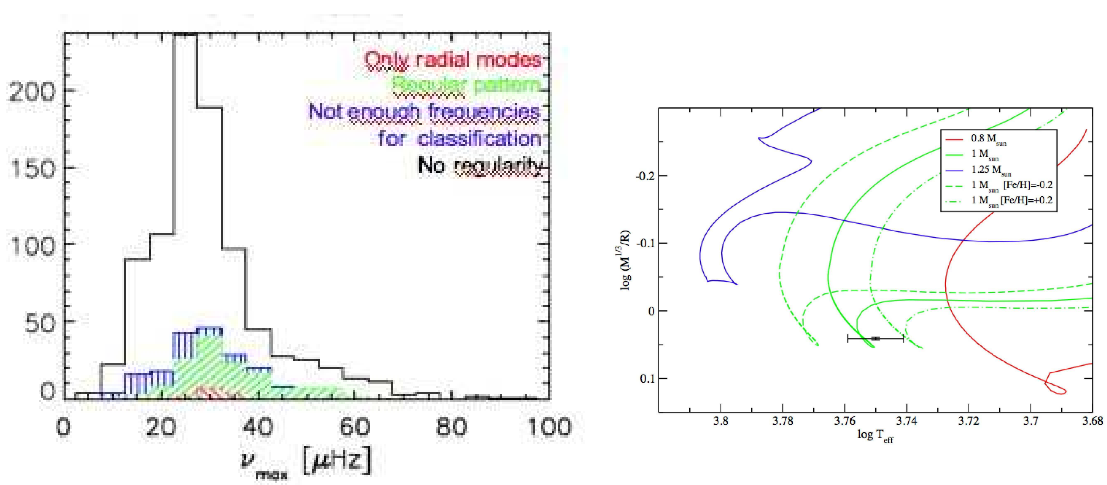

Fig. 3. *a, left:* Histogram of the frequency of the maximum amplitude of the solar like oscllations in red giants. *b, right*: Evolutionnary tracks in the $logT_{eff}$, $\frac{M_{star}^{1/3}}{R_{star}}$ plane illustrating the uncertainties in the mass determination.

3.4 Granulation

Superimposed on the oscillations in the domain of frequencies around one mHz, a continuum component, already known in the Sun is easily measured in most solar type stars with CoRoT (Fig. 2,b). These stars (slightly hotter than the Sun) have higher energy in the granulation. More targets will confirm this result (or not!).

4 Planets ans stellar parameters

Transits give access to $\frac{R_{pl}}{R_{star}}$ and $\frac{M_{star}^{1/3}}{R_{star}}$ with a very high precision (10^{-3}). Radial velocities measure the amplitude of the orbital variations and determine $\frac{M}{M_{star}}$ $\sin i$. If the planet transits, i is known from the light curve, so the mass ratio is determined with a high precision. But, as illustrated by Figure 3b, uncertainties on the stellar parameters remain quite large. For instance, an uncertainty of 50K on the effective temperature (which is preently not reachable) leads to an uncertainty on the mass of 0.06 solar mass. Even more important is the determination of the chemical composition. An uncertainty of 20% translates into an uncertainty on the mass of 10% (assuming that the surface composition is the initial composition of all the material).

The very poor knowledge of the mixing proceses in the stellar interiors lead to estimate the corresponding uncertainties to at least 13% in Mass, 5% in Radius. But the situation will certainly be improved by the seismology results. Only the knowledge of the size of the convective cores of intermediate stars will help improving the ages determintations close to the main sequence.

5 The PLATO(n) mission

Selecting targets for the PLATO input catalogue:
The observation strategy is to have two long (2 to 3 year) sequences of monitoring of two distinct fields, followed by a one-year step-and-stare phase during which several additional fields will be observed for a few months each.

A first major task in preparation of the mission will be to identify the cool dwarfs/subgiants in the very wide field of view of the instrument. A most efficient way of achieving this target selection will be to rely on stellar radii determined from early GAIA results. With stellar luminosities known to better than 30-40% and effective temperatures determined to within about 10% (500 K accuracy), which is well achievable using astrometry and multiband photometry in the first two years of GAIA exploitation, stellar radii will be known to within 15-20%, which is amply sufficient to distinguish dwarfs and subgiants from giants and supergiants.

This information is needed at least 18 months before launch, i.e. in mid-2016 for a launch at the end of 2017, in order to allow enough time to set up completely the PLATO input catalogue, and prepare all parameters of the data treatment software. This is more than four years after GAIA launch, and more than two years after the expected first partial release of GAIA results. Access to the needed data should therefore present no difficulty, even in the hypothesis of a GAIA delay, either of the launch, or of the first data release.

Characterizing the neighbourhood of PLATO selected targets:
PLATO photometry will be sensitive to the presence of nearby polluting sources, which can either be intrinsically variable, or simply create spurious signal in the photometric algorithm due to satellite jitter. Methods have been developed to correct for these perturbations, but a precise knowledge of the vicinity of each PLATO target is needed for these corrections to be applied.

What is needed is a full catalogue of faint neighbouring sources, including their positions, magnitudes and colours, down to approximately 19th magnitude, in sub-fields of at least 1 arcmin around each PLATO target. This information will be used to optimize the photometric algorithm for each target, and therefore will impact on the fine tuning of the onboard data treatment software. It is therefore also needed by mid-2016. The information that could be contained in GAIA first release (positions, G band magnitudes, and colours from the red and blue spectrophotometry) will be sufficient for this purpose.

Interpretation of the PLATO(n) data:
A more precise measurement of the radii of all stars observed by PLATO, and more particularly of the host stars of the detected exoplanets, will be necessary at the time the first results from PLATO will become available. This will happen about 2 to 3 years after the launch, i.e. not earlier than 2019. The final release of GAIA may be available by then (in the case that the observational phase is five years and the final catalogue is produced two years after that). In that case the access to the needed data should be straightforward. However, if GAIA is extended to six years, it is probable that the intermediate GAIA data releases will suffice.

More precisely, stellar radii to within 2-3% will be necessary, both to measure the planet radii to the same kind of accuracy, and second to place tight constraints of stellar interior structure models of the exoplanet host stars, coming in addition to the seismic observations of PLATO. This implies a knowledge of the stellar luminosities to within 5%, which will be easily achieved by GAIA for cool dwarfs as bright as 11th or 13th magnitude, and therefore closer than 200 (resp 500) pc. Effective temperatures will also need to be determined to within 1% (50 K). This will be achieved with the help of dedicated high resolution, high signal-to-noise spectroscopic observations obtained as part of the groundbased follow-up programme.

Hopefully, new generations of ultra high recision velocimeters as EXPRESSO will be available at that time beng able to measure the masses of planets as small as 1 earth mass and even smaller.

6 Conclusions

The ESA cosmic vision programme, if it selects PLATO will provide a unique combination of stellar parameters measurements which will improve considerably our physical knowledge of the stars, of their role in the galactic evolution, and of their planetary systems.