The following full text is a publisher’s version.

For additional information about this publication click this link.
http://hdl.handle.net/2066/71967

Please be advised that this information was generated on 2020-05-12 and may be subject to change.
PLATO: PLAnetary Transits and Oscillations of stars

This article has been downloaded from IOPscience. Please scroll down to see the full text article.
(http://iopscience.iop.org/1742-6596/118/1/012040)

View the table of contents for this issue, or go to the journal homepage for more

Download details:
IP Address: 131.174.17.26
The article was downloaded on 24/06/2011 at 09:14

Please note that terms and conditions apply.
PLATO: PLAnetary Transits and Oscillations of stars

Claude Catala and the PLATO consortium

LESIA, Observatoire de Paris, CNRS, UPMC, Université Paris Diderot ; Place Jules Janssen 92190 Meudon, France

E-mail: Claude.Catala@obspm.fr - http://www.lesia.obspm.fr/~catala/plato_web.html

Abstract.

The PLAnetary Transits and Oscillations of stars Mission (PLATO), presented to ESA in the framework of its "Cosmic Vision" programme, will detect and characterize exoplanets by means of their transit signature in front of a very large sample of bright stars, and measure the seismic oscillations of the parent stars orbited by these planets in order to understand the properties of the exoplanetary systems. PLATO is the next-generation planet finder, building on the accomplishments of CoRoT and Kepler: i) it will observe significantly more stars, ii) its targets will be 2 to 3 magnitudes brighter (hence the precision of the measurements will be correspondingly greater as will be those of post-detection investigations, e.g. spectroscopy, asteroseismology, and eventually imaging), iii) it will be capable of observing significantly smaller exoplanets. The space-based observations will be complemented by ground- and space-based follow-up observations.

These goals will be achieved by a long-term (5 years), high-precision, high-time-resolution, high-duty-cycle monitoring in visible photometry of a sample of more than 100,000 relatively bright (m_V ≤ 12) stars and another 400,000 down to m_V = 14.

Two different mission concepts are proposed for PLATO: i) a "staring" concept with 100 small, very wide-field telescopes, assembled on a single platform and all looking at the same 26° diameter field, and ii) a "spinning" concept with three moderate-size telescopes covering more than 1400 degree².

1. Introduction

The question of the existence of life beyond Earth has been of concern to humanity for several thousand years. In this context, the search for and study of planetary systems around other stars, and in particular the search for life signatures in exoplanetary systems, is a prerequisite towards generalising our understanding about the distribution of life in the Universe and how it may have arisen on Earth.

Today, one decade after the discovery of the first giant exoplanet, we are entering a new era with the recent launch of CoRoT in December 2006 [2], and with the prospect of the Kepler launch in 2009 [3]. These missions will certainly discover terrestrial exoplanets, and will allow us to start studying the distribution of planet sizes and orbits down to Earth-sized bodies, but they both have their limitations in terms of minimum planet size, maximum orbital period, number of detected exoplanets and capability of further characterization of exoplanet and their host stars. Clearly, we need to overcome these limitations and take the next step in exoplanet detection and characterization.

1 see http://www.lesia.obspm.fr/~catala/plato_web_files/cois_plato.jpg
Most importantly, in addition to the detection of a large number of exoplanets, we need to determine the characteristics of their host stars, such as radius, mass, age, and element abundances. The radii and masses of the host stars must be measured accurately in order to provide a precise measurement of sizes and masses of the detected planets, while the ages of the central stars will provide us with an estimate of the ages of their planetary systems. One of the most powerful tools for this characterization is asteroseismology.

Asteroseismology of a large sample of stars all across the HR diagramme can also bring us a full and deep understanding of stellar evolution, which is central to astrophysics. In this area, a first important step will be taken by CoRoT, while Kepler will also include an asteroseismology programme, but they will both provide seismic data for only a handful of targets, and a next generation mission is clearly needed.

The basic goals of the PLATO mission are therefore:
- to open a new way in exoplanetary science, by providing a full statistical analysis of exoplanetary systems around stars that are bright and nearby enough to allow for simultaneous and/or later detailed studies of their host stars;
- to extend by a factor $\approx 4$ the statistical analysis of exoplanetary systems initiated with Kepler, by surveying many more stars down to a magnitude allowing for the detection of Earth-sized planets;
- to perform seismic analysis for a very large sample of stars all across the HR diagramme, including those with detected exoplanetary systems.

Understanding the processes of star and planet evolution, by the study of stellar interiors and the distribution of planetary systems will constitute a major step for future progress in most areas of astrophysics and in the scientific and philosophical approaches towards the origin of life in the Universe. It is the cornerstone that will bring us from the first, still fairly unsystematic planet discoveries towards a systematic survey, providing a global understanding of the richness and diversity of the “Other Worlds” that populate the Universe.

2. Science objectives: evolution of stars and their planetary systems

2.1. Studying stars and their planets

In our conception of planetary systems, the formation and evolution of both components, stars and planets, are intricately related. Stars and planets are born together from the same parental material, and therefore share a common initial history. In particular the initial protoplanetary disc and its central stellar core have the same chemical composition and their respective angular momentum reflects the angular momentum distribution in the protostellar/protoplanetary nebula. Also, in the early phases of evolution, young stars exchange angular momentum with their accretion protoplanetary discs, which eventually evolve into planets and transfer their angular momentum to planet orbits.

Even later in the evolution, various processes occur that result in mutual interactions between the stars and their planets. The stellar radiation flux obviously impacts the planet atmospheres, while particle bombardment of the planet by the stellar winds can also affect the chemical and biological evolution of the planets. Planets can also influence their parent stars, e.g. by colliding with them, and enriching them in various chemical elements [6]. Giant planets in close-in orbits can also influence their star’s rotation via tidal effects.

The study of planetary system evolution thus must be considered as a whole and it cannot be separated from that of stellar evolution. We cannot understand how planets are formed and how they evolve without a proper knowledge of stellar formation and evolution. We cannot characterize planetary systems without characterizing precisely their host star. The basic philosophy behind the PLATO mission is precisely to study complete planetary systems composed of planets and their host stars, these two components being observed together with the same technique.
2.2. Evolution of planetary systems

Our understanding of planetary system formation and evolution is insufficient. Detections of giant exoplanets have revealed a large variety and complexity of configurations in exoplanetary systems, which was totally unexpected. Major questions and uncertainties remain, which hamper our progress in this area.

The true distribution of characteristics of exoplanets and of their orbits is unknown, with current knowledge strongly biased from the detectable sub-sample. In particular, we do not know the distribution of planets with sizes and masses significantly smaller than those of gaseous giant planets. The extension of our investigation of exoplanets toward lower masses, down to terrestrial planets, may reveal further surprises.

The basic goal of PLATO is to provide a large sample of exoplanets around bright stars, spanning a wide range of orbits, sizes and masses, and to measure precisely and reliably their orbital parameters, sizes, masses and ages. This requires a detailed characterization of their central stars, involving both seismic observations with PLATO and ground-based support observations, allowing us to measure all their fundamental parameters, including mass, radius, age, temperature, chemical composition, rotation. Exoplanetary transit techniques indeed give access to the ratio of planet to star radii, so that the planet sizes cannot be determined if the star radii are not perfectly known. Similarly, radial velocity techniques, even when the inclination angle is known, provide the ratio of planet to star masses, and a good measurement of the star’s mass is needed. Star radii and masses are usually estimated by locating the star in the HR diagramme, which is imprecise and often unreliable. Finally, the understanding of exoplanetary system evolution requires an estimate of their ages, which can only be obtained by a measurement of the age of their central stars.

Such an approach is beyond our capabilities for most of the planets that will be discovered by CoRoT and Kepler, which are orbiting stars that are too distant and too faint for such a detailed characterization, but is within reach of PLATO, which focuses on stars that are bright and nearby.

Moreover, a full statistical description of exoplanetary systems, down to masses and sizes of a fraction of those of the Earth, is a prerequisite for any decisive advance in the field of planetary formation and evolution. It is therefore necessary to extend significantly the sample of detected exoplanets beyond CoRoT and Kepler, which is also an objective of PLATO.

2.3. Stellar evolution

Theory of stellar evolution has undergone major progress in the last decades. However, in spite of the progress in our understanding of microscopic physics in stellar interiors, our description of some physical processes controlling stellar structure and evolution is subject to major uncertainties. Convection and various other mixing and transport processes are poorly understood and yet play a major role in stellar evolution, determining evolution timescales, and must be taken into account for measuring stellar ages. Our current poor knowledge of most of these processes is usually compensated in our modeling by some poorly constrained parameterisation, and therefore the resulting stellar ages are strongly model dependent and unreliable.

One of the consequences of this unsatisfactory modeling is that the ages of the oldest globular clusters are still very uncertain, and for some values of the model free parameters can still be higher than the estimated age of the Universe [12] [5] [7]. Additionally, the relatively large adopted value of the core overshooting parameter needed to fit young open cluster data [8] is in contradiction with recent asteroseismic estimates for this parameter for field β Cephei stars [1] [9]. This clearly points out that our current knowledge of convective and rotational mixing processes inside massive stars is very incomplete, resulting in huge uncertainties in stellar masses and ages of supernova progenitors. Uncertainties in convective overshooting can lead to uncertainties in
the ages of open clusters up to a factor of two [10]. Considering these difficulties, it is clear that the age ladder of the Universe, which rests on stellar age estimates, is still highly unreliable.

Our modeling of stellar interiors and stellar evolution therefore needs to be seriously improved. The situation for the Sun has evolved considerably with the advent of helioseismology, which has provided precise insight into the properties of the solar interior [4]. Based on this very positive experience, it is clear that asteroseismic investigations, i.e. measurements of oscillation frequencies, amplitudes and lifetimes of a large number of stars of various masses and ages constitute the only and necessary tool to constrain efficiently our modeling of stellar interiors, and improve our understanding of stellar evolution [11].

The pioneering CoRoT space mission is bringing us essential information to progress in this area, by providing high precision asteroseismic measurements for a few dozen stars distributed in several regions of the HR diagramme. The *Kepler* mission will also include a limited asteroseismology programme. However, these first measurements will remain limited to small and strongly constrained samples, which do not contain for example members of open clusters, or old population II stars, which would constitute major targets for such investigations. A better and more complete exploration of seismic properties of various classes of stars, sampling all stellar parameters (mass, age, rotation, chemical composition) is necessary. Such is the goal of PLATO.

2.4. Required observations

2.4.1. Stellar sample The PLATO science objectives require long uninterrupted high precision photometric monitoring of a large sample of stars. The primary stellar sample for PLATO will be a set of at least 100,000 stars brighter than $m_V = 11 - 12$, observed at ultra-high precision. In addition to this main sample, for which both transit search and asteroseismology will be performed, an extended sample of 400,000 fainter stars, down to $m_V = 14$, will be observed to a sufficient precision to detect the transits of Earth-sized planets.

Moreover, as mentioned earlier, asteroseismic observations of stars that are members of open clusters, chosen to offer a complete sequence of ages, as well as old population II stars, will be of major interest, and such targets will be included in the programme.

2.4.2. Photometric noise level In order to detect transits of earth-size planets in front of cool stars, at more than $4\sigma$, we need to obtain a photometric noise level lower than about $2.5 \times 10^{-5}$ in 12 hours, i.e. about $8 \times 10^{-5}$ in one hour. However, this requirement must be considered as the minimum one, since the detection of planets with sizes smaller than the Earth’s, the detection of Earth-sized planets in front of stars hotter than the Sun, and the measurement of several points across the transits would be of major interest. We will set as a goal specification a photometric noise level of $2.5 \times 10^{-5}$ in one hour, allowing us for instance to measure about ten points across the transits, and therefore to characterize them with high reliability and precision. Such a low noise level would also allow us to detect Earth-sized planets in front of $2 R_\odot$ stars, which are in principle less active and therefore less intrinsically variable than solar twins, so that the detection of such exoplanets may in fact be easier than for solar-Earth twin systems; we would therefore extend to hotter stars the statistics of terrestrial exoplanets.

Figure 1 shows simulated light curves with various levels of noise, all including a 12 hour transit with a depth of $10^{-4}$, illustrating the absolute need for a noise level better than $8 \times 10^{-5}$ in one hour for detecting such a transit and the potential for precise transit characterization at a noise level of $2.5 \times 10^{-5}$ in one hour.

Seismic investigations of planet host stars require that we should be able to detect individual $p$-mode oscillations in cool dwarf stars as faint as $m_V = 11$. This means that the total photometric noise in the observations must remain below $\pm 1$ ppm after approximately 30 days of observation, down to $m_V = 11 - 12$, in the whole frequency range of interest, i.e. from 0.1
Figure 1. Simulated light curves assuming various noise levels, and including one single transit with a depth of $10^{-4}$ and a duration of 12 hours.

to 10 mHz. Figure 2 shows a portion of the simulated power spectrum for a 1.2 $M_\odot$ star observed for 50 days with such a photometric noise, as well as that expected for brighter stars leading to lower noise levels. The spectrum was generated with a simulator built in preparation for CoRoT, including photon noise and stellar granulation noise, and its results have been successfully compared to the early results of CoRoT.

The noise levels requirements of $2.5 \times 10^{-5}$ in one hour and one ppm in 30 days are very similar. These photometric noise requirements impose that i) the photon flux of the target stars is sufficiently high to ensure that photon noise complies with the final noise specifications, implying the use of a large collecting area, and ii) that all other sources of noise remain well below photon noise in the frequency range of interest.

2.4.3. Duration of observations and duty cycle The duration of the observations needs to be longer than three years, so that at least three consecutive transits for Sun-Earth analogs can be detected during the mission lifetime. A goal specification for the duration should be four years, allowing us to detect planets in more distant orbits than the Earth’s and also increasing the transit detection probability.

A monitoring time of at least a few months (minimum 1 month) is required for the seismic analysis of the programme stars, yielding a precision of about 0.3 mHz for oscillation frequencies of solar-type stars.

The duty cycle of the monitoring needs to be maximized, in order to make sure that no transit is missed due to gaps in the data, and also to avoid side lobes in the oscillation spectra.

3. Instrumental concepts Two different instrumental concepts have been studied for the PLATO mission, involving different observational strategies. Note that alternative concepts have also been envisaged,
Figure 2. Expected power spectrum for a 1.2 $M_\odot$ star, observed for 50 days, with a noise level of one ppm in 30 days (lower curve). Such a noise level will typically be obtained at $m_V=11.5$ or 12 with PLATO, depending on the details of the instrumental design. The next two curves correspond to better noise levels of 0.5 and 0.25 ppm in 30 days, achievable with PLATO at $m_V=10$ and 8.5, respectively. The upper curve shows a preliminary result obtained with CoRoT in 50 days on a solar-type star with $m_V=5.7$, which translates to $m_V=8.5$ for PLATO when the ratio of collecting areas is taken into account. This CoRoT result demonstrates that the noise levels introduced in the simulation are realistic and that solar-like oscillations can indeed be easily observed in photometry from space.

and could be investigated in further studies.

3.1. The “staring” concept

3.1.1. Observation strategy In the staring concept, a first phase of the mission, with a duration of typically three or four years, is spent observing continuously the same field. This field is chosen to provide a sufficient number of stars, as well as to contain stars presenting a specific interest for the seismology objectives of the mission, e.g. open clusters.

During this first staring phase, the field is observed continuously with a duty cycle close to 100%. This staring phase will be followed by a “step and stare” phase of typically one additional year, where the payload will be pointed successively to several additional fields, each one monitored continuously for one to several months. The goal of this second phase will be: i) to extend to other regions of the galaxy the exoplanet statistics for planets on orbits shorter than a couple of months; and ii) to optimize the sample of stars of the seismology programme.

3.1.2. Payload The science objectives of PLATO require both a very wide field of view ($\geq 300$ deg$^2$) and a large collecting area ($\geq 0.7$ m$^2$). The very wide field of view requires a short focal length yielding a large plate factor, which implies the use of a small pupil, since the optics
cannot easily be made faster than f/1.5 – f/1.3. In order to comply with the collecting area requirement, we propose to use a large number of identical small size optics, each one coupled to its own focal plane, all of them observing the same stellar field. Figure 3 shows the proposed payload on the recurrent Herschel platform, which is foreseen for this mission.

Figure 4. Optical design of the individual cameras. The prime mirror has a diameter of 240mm.

The majority of these small pupil optics will be devoted to the study of faint (mV ≥ 9) stars in the field, using an elementary exposure time minimizing the losses during camera readout. For the observation of brighter stars that saturate the detectors with this exposure time, the plan is to use a small number of telescopes, with shorter elementary exposure times.

Optical design

The concept (Figure 4) consists of 100 identical axi-symmetric compact cameras, each one covering the same annular field of view between 13° and 6° radius. The optical design is based on a One Mirror Anastigmat (OMA) already proposed for the Eddington mission. Its advantage is its capability to work with fast aperture and wide field of view. A second advantage is that the 100mm pupil is placed on the first lens of the corrector so that the total mass is minimised by decreasing the lens dimension. On the other hand, the mirror diameter (240 mm) is larger than the pupil size, due to the pupil scan generated by the field of view (26°). With a focal length of 227 mm, the plate scale is 1.1 μm per arcsec. The optical performance is optimised to get a homogeneous spot inside this field, when a defocus of -50μm is applied. The spot size in this case varies between 25 and 35μm, i.e. about two to three pixels, across the field.

The coloured information required by some of the science objectives can be obtained by introducing a dispersive system in the optical design, for instance a small angle prism. The introduction of a prism in the optical beam, completed by the construction of appropriate numerical masks for the aperture photometry algorithm, will result in the production of light curves in three colours, in a similar way as in CoRoT.
Focal plane concept

Each one of the 100 focal planes is made of several identical detectors, with 13 μm pixels. Many possibilities can be proposed for the actual size of the chips and their accommodation. One of them is given in Figure 5, based on 800 × 1800 pixel CCDs.

The CCDs are defocused to produce a PSF varying across the field between 2 and 2.5 pixels, i.e. between 20 and 25 arcsec. This defocusing is needed both to avoid saturation while collecting large photon fluxes, and to limit the impact of satellite jitter on the photometric performance.

3.1.3. Expected performance The performance of the design presented above can be estimated in terms of number of accessible targets and achievable level of noise.

Because the field obstruction varies significantly across the field, targets with the same magnitude are not observed with the same level of noise across the field. In other words, a given level of noise will correspond to stars with different magnitudes at different locations in the field. The expected performance can therefore be expressed in terms of number of targets observable with various levels of noise. These predictions, which are summarized in Table 1, are compliant with the basic requirements of this mission, since we can observe more than 100,000 stars at a noise level better than $2.6 \times 10^{-5}$ per hour, and up to 360,000 stars with a noise better than about $8 \times 10^{-5}$ per hour.

The proposed design can also achieve a very high photometric and astrometric precision for the observation of very bright stars in the field. Table 2 summarizes the performance, assuming that stars brighter than $m_V=9$ are monitored with ten telescope units only. The performance summarized in this table show that giant exoplanets on close-in orbits can be detected around bright stars, using the photometric modulation due to scattered stellar light on the planet atmospheres, while the astrometric wobble of the stars produced by exoplanets with Jupiter mass orbiting their stars at typically one AU are detectable at least down to $m_V=8$.

3.2. The “spinning” concept

3.2.1. Measurement principle The spinning concept is based on the re-use of Gaia Service Module, and on the use of three telescopes of aperture 0.72 m$^2$ and FOV 23 degree$^2$ each. The concept enables terrestrial planet detection in solar-type systems for a sample of 144,000 stars by exploring a field of view larger than 1400 degree$^2$, and the detection of planets with radii ≤ 4 earth radii in solar-type systems for more than 2,500,000 stars. Colour measurements can be included for enhancing transit discrimination. The instrument is operated in two modes: the search mode for planet finding and asteroseismology, and the fine observing mode for improving the planet transit measurements and for asteroseismology.

The payload consists in three identical telescopes observing in directions regularly distributed on a great circle. When the entire system is rotated about an axis perpendicular to the great circle with a period $T$, each telescope will scan a band centred on the great circle of width equal
Table 1. Number of stars observable with various levels of photometric noise.

<table>
<thead>
<tr>
<th>noise ppm/hr</th>
<th>noise ppm/30 d</th>
<th># stars</th>
<th>dwarfs</th>
<th>astrom. range</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.4</td>
<td>10,000</td>
<td>5,200</td>
<td>9.3-9.9</td>
</tr>
<tr>
<td>15</td>
<td>0.5</td>
<td>21,000</td>
<td>11,000</td>
<td>10.1-10.7</td>
</tr>
<tr>
<td>20</td>
<td>0.7</td>
<td>49,000</td>
<td>25,000</td>
<td>10.7-11.3</td>
</tr>
<tr>
<td>25</td>
<td>1.0</td>
<td>101,000</td>
<td>52,000</td>
<td>11.3-11.9</td>
</tr>
<tr>
<td>53</td>
<td>2.0</td>
<td>263,000</td>
<td>137,000</td>
<td>12.8-13.4</td>
</tr>
<tr>
<td>81</td>
<td>3.0</td>
<td>360,000</td>
<td>187,000</td>
<td>13.7-14.3</td>
</tr>
<tr>
<td>100</td>
<td>3.7</td>
<td>410,000</td>
<td>213,000</td>
<td>14.2-14.7</td>
</tr>
</tbody>
</table>

Table 2. Bright stars observable with PLATO.

<table>
<thead>
<tr>
<th>mv</th>
<th># stars</th>
<th>noise ppm/hr</th>
<th>noise ppm/30 d</th>
<th>astrom. noise/30 d (µas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>85</td>
<td>6.4</td>
<td>0.3</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>270</td>
<td>11</td>
<td>0.5</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>810</td>
<td>17</td>
<td>0.8</td>
<td>15</td>
</tr>
</tbody>
</table>

to the telescope field of view (FOV) across scan. Any object located in the scanned band will be regularly observed with a sampling time $T/3$.

The telescopes have a rectangular collecting aperture $0.9 \times 0.8 \text{ m}^2$, and the rotation period is $T = 20 \text{ min}$. The use of Three Mirror Anastigmat optics provides a large FOV $5.9°$ (along scan) $\times 3.9°$ (across scan) = $23 \text{ degree}^2$ per telescope. The design assumes a re-use of Gaia detectors, with a binning of 21 (along scan) $\times$ 7 (across scan) pixels, providing a macro-pixel sky resolution of 12.4 arcsec with 3.5-m focal length, and a charge collection capacity of about $3 \times 10^7 \text{ e-}$ per macro pixel.

There are two operating modes, the search observing mode and the fine observing mode, which are detailed below, assuming equal time sharing between the two modes.

For the search observing mode, the satellite is rotated so as to scan the galactic disk. This mode explores a FOV of about $1400 \text{ deg}^2$ for planet detection and enables potential terrestrial planet detection for more than 144,000 stars. It can also achieve asteroseismology of classical pulsators in the upper main sequence, such as $e.g.$ 5 Scu, $\gamma$ Dor, $\beta$ Cep, Be stars, whose pulsation frequencies are sufficiently low to be well sampled by the spinning procedure.

For the fine observing mode, the instruments are operated in staring mode for maximizing the observing time on selected areas that have been determined in the search mode. One of the telescopes is pointed to the galactic disk while the two others are exploring new areas of galactic latitudes below 60°. One can observe in fine mode up to one third of the stars that have been measured in search mode (plus extra stars due to the FOV extension and position).

The observation strategy relies on the separation of the year in two parts: one when the spacecraft is rotated to scan the galactic plane permanently and one when the spacecraft has a fixed three-axis control to point one of its telescope towards a selected target field.

3.2.2. Payload definition. The three telescopes are mounted on a common tore structure and use separate focal planes. The mirrors and the tore are made of silicon carbide, providing low mass and high stability. The telescope mirrors and the instrument structure are within current manufacturing capabilities. Figure 6 shows the proposed payload.
The telescope optics is constituted of three aspheric mirrors (Figure 7). The pupil (0.9 × 0.8 m²) has been located on the primary mirror and the inter-mirror distance was set about 2.2 m for accommodation purpose. The largest mirror is the tertiary M3 (≈ 1.6 × 1.2 m²).

Colour information can be obtained by locating a disperser close the focal plane. The focal plane assemblies can be based on a strict re-use of the existing Gaia CCD. In fine observing mode, the transfer time is small in comparison to the integration time (≤10%) and the observation can be achieved without implementing a shutter, as already demonstrated in Eddington studies. The Gaia CCD TDI gates can be used for reducing the integration time and managing the star magnitude dynamical range from mV = 4 to 14, without detector saturation. TDI gates are also useful in fine mode for star position measurements at a high rate (≈ 1 Hz) for attitude control purpose.

### 3.2.3. Expected performance

The overall performances of the “spinning” concept can be estimated in a straightforward way and are given in Table 3, in terms of the expected number of stars observed at different noise levels both in search and fine modes.

As for the “staring” concept, we can achieve a very high photometric and astrometric precision for the observation of very bright stars. This approach will be particularly attractive in “search” mode when the whole galactic plane will be surveyed, and the use of programmable gates in the CCD TDI process will allow us to very bright stars without saturating the detectors. Table 4 summarizes the expected performance.

### 4. Comparison with existing & planned missions

Table 5 compares the characteristics of CoRoT and Kepler with those planned for PLATO.

These previous space missions will leave a strong need for a further mission aiming at establishing a complete and unbiased statistical knowledge of exoplanetary systems. PLATO, by largely extending the results of CoRoT and Kepler in the area of exoplanet search and characterization, and in that of stellar structure and evolution, represents a natural step in our investigation of stellar and planetary system evolution. Filling and extending the important place in the European strategy that was left vacant by the cancellation of Eddington, PLATO will complete our knowledge of the statistics of extrasolar systems and stellar evolution. Hence, flying a mission like PLATO after CoRoT, Kepler and Gaia is a requirement for our understanding of...
Table 3. Number of stars observable with various levels of photometric noise.

<table>
<thead>
<tr>
<th>noise (ppm/hr)</th>
<th>ppm/30 d</th>
<th>stars</th>
<th>dwarfs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>search mode</strong>, duration 1825 days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>55,600</td>
<td>28,900</td>
<td>10</td>
</tr>
<tr>
<td>81</td>
<td>144,000</td>
<td>75,000</td>
<td>11</td>
</tr>
<tr>
<td>130</td>
<td>240,000</td>
<td>125,000</td>
<td>11.5</td>
</tr>
<tr>
<td><strong>fine mode</strong>, duration 30 days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.7</td>
<td>85,000</td>
<td>44,000</td>
</tr>
</tbody>
</table>

Table 4. Bright stars observable with PLATO in the spinning concept.

<table>
<thead>
<tr>
<th>mission</th>
<th>coll. area (m²)</th>
<th>f.o.v. (deg²)</th>
<th>monitoring (days)</th>
<th># stars exo</th>
<th>mag range exo</th>
<th># stars seismo</th>
<th>mag range seismo</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoRoT</td>
<td>0.057</td>
<td>4</td>
<td>150</td>
<td>60,000</td>
<td>11.5 - 15.5</td>
<td>100</td>
<td>5.5 - 9.5</td>
</tr>
<tr>
<td><strong>Kepler</strong></td>
<td>0.7</td>
<td>111</td>
<td>1460</td>
<td>100,000</td>
<td>9 - 14</td>
<td>1400</td>
<td>9 - 11</td>
</tr>
<tr>
<td>PLATO 1 'staring'</td>
<td>0.75</td>
<td>400</td>
<td>1825</td>
<td>100,000</td>
<td>4 - 12</td>
<td>100,000</td>
<td>4 - 12</td>
</tr>
<tr>
<td>PLATO 2 'spinning'</td>
<td>0.72</td>
<td>1240</td>
<td>1825</td>
<td>144,000</td>
<td>4 - 11</td>
<td>144,000</td>
<td>4 - 11</td>
</tr>
</tbody>
</table>

Table 5. Comparison of performance of CoRoT, Kepler, and the two instrumental concepts envisaged for PLATO.

...stellar and planetary formation and evolution...

References