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CHEOPS: towards exoplanet characterisation

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Abstract

The CHaracterising ExOPlanet Satellite (CHEOPS) is a joint ESA-Switzerland space mission dedicated to search for exoplanet transits by means of ultra-high precision photometry. It is expected to be launch ready at the end of 2017. CHEOPS will be the first space telescope dedicated to search for transits on bright stars already known to host planets. It will have access to more than 70% of the sky, allowing almost any interesting target to be observed. This will provide the unique capability of determining accurate radii for planets for which the mass has already been estimated from ground-based spectroscopic surveys and for new planets discovered by the next generation ground-based transits surveys (Neptune-size and smaller).

1. Introduction

The two most successful detection methods of exoplanets rely on detecting dynamical (radial velocity) or photometric (transit) perturbations on the host star induced by the presence of one or several planets [1]. While the first detection method provides a lower limit on the mass of the planet, the second one provides an estimate of the radius of the planet. Planets that are detected by both methods are particularly interesting; as for these objects both mass and radius are known. From these values, a mean density can be derived and a first information on the physical nature of the planet can be obtained.

Nowadays, the number of known exoplanets exceeds 1000 (http://exoplanet.eu/). In order to understand the great diversity of the planetary zoo, characterisation programmes are in order. The knowledge of the mass and radius for a significant sample of planets in the range 1-30 M_{Earth} will provide a measure of the diversity of structures and compositions (e.g. [2]). These kinds of planets will be the main targets of CHEOPS.

2. Science objectives

With an accurate knowledge of masses and radii for an unprecedented sample of planets, CHEOPS will set new constraints on the structure and hence on the formation and evolution of planets with masses lower than the Saturn mass.

The measurement of the radius of a planet from its transit combined with the determination of its mass through radial velocity techniques gives the bulk density of the planet. Scientifically, this quantity provides direct insights into the structure (e.g. presence of a gaseous envelope) and/or composition of the body. This, in turn, helps to constrain the formation and evolution of planetary systems.

In addition, by detecting and modelling small changes in the orbital period of an already known transiting planet other bodies in a planetary system can be discovered. This technique is called Transit Time Variation (TTV). From the measured TTV signal it is possible to infer the parameters of the third body by assuming that it is gravitationally perturbing the known planet. We expect that these additional planets will be quite common especially among the Neptunes and super-Earths in the CHEOPS sample, as about 20% of stars hosting planets with masses < 30 M_{Earth} are expected to host at least another transiting planet [3].

3. Science Requirements

In order to meet the scientific objectives, a number of requirements have been derived that drive the design of CHEOPS.
For the detection of Earth and super-Earth planets orbiting G5 dwarf stars (stellar radius of 0.9 R_{sun}) with *V*-band magnitudes in the range $6 \leq V \leq 9$ mag, a photometric precision of 20 ppm (goal: 10 ppm) in 6 hours of integration time must be reached. This time corresponds to the transit duration of a planet with a revolution period of 50 days.
In the case of Neptune-size planets orbiting K-type dwarf stars (stellar radius of 0.7 R_{sun}) with *V*-band magnitudes as faint as V=12 mag (goal: V=13 mag), a photometric precision of 85 ppm in 3 hours of integration time must be reached.
Besides the noise associated with the detector itself, stray light is the main source of noise. This stray light is minimized through the design of the telescope itself, the orbit chosen (Low Earth Orbit, ~700 km), and by limiting the directions in which the telescope points in order to avoid solar light reflected by the Earth and/or the Moon to reach the detector.
The total required duration of the CHEOPS mission is estimated to be 3.5 years (goal: 5 years).

4. Payload

The CHEOPS mission payload consists of only one instrument, a space telescope of 30 cm clear aperture, which has a single CCD focal plane detector.
The CHEOPS optical design is based on a Ritchey-Chretien style telescope, which provides a defocussed image of the target star while minimizing straylight using a dedicated field stop and baffle system. The Back-End Optics (BEO) re-images the telescope focal plane on the detector and provides an intermediate pupil, at which location a mask is placed for the stray light rejection. The BEO has been optimised on a field of view having a diameter 0.32°. The detector area of interest is 200×200 pixels and its location will set inside the optimised Field of View. No filter will be used, but all wavelengths in the range 400-1100 nm are cumulated according to the quantum efficiency of the CCD. The photometric precision will be achieved by using a single frame-transfer backside illuminated CCD detector cooled down to 233K and stabilized within ~10 mK.
The nominal CHEOPS operational orbit is a circular Sun-synchronous orbit (SSO) with an altitude of ~700 km and a local time of the ascending node (LTAN) of 6 am; the orbital period is ~100 min. As CHEOPS will be in a LEO orbit, straylight suppression is a key point to allow the observation of faint stars. The telescope will be the only payload on a spacecraft platform providing a pointing stability of < 8 arcsec rms, a maximum power of 60W for instrument operations and a downlink transmission rate of at least 1Gbit/day. Both CHEOPS paylaod and platform will rely mainly on components with flight heritage.

5. Challenges

CHEOPS is the first small mission in the ESA Science Programme to be implemented in partnership with a nationally funded consortium led by Switzerland. As a result, an unconventional management structure had to be set-up that reflects the responsibilities of the partners and allows for an appropriate flow of information, flexibility, and rapid decisions.
The design of the CHEOPS spacecraft is driven by the need to use existing small platforms based on a flight-qualified design, with minimum mission specific changes and compatible with shared launch configurations inside existing fairings. These key constraints are actually set by the ESA S-Mission programmatic constraints (ESA cost at completion < 50 M€ at 2012 economic conditions and launch by 2017).
As the first small mission (S-mission) in ESA's Science Programme, CHEOPS is truly a pathfinder. The constraints set by ESA and the SPC on the cost to ESA and development time (4 years or less than half the development time of an M-mission) had never been applied before. Whether they can actually be met remains to be seen. The continuation of an S-mission line in ESA's Science programme hinges on the success of CHEOPS.

References

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