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THE COROT TELESCOPE

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RESUME *- COROT a pour mission la mesure très fine des variations d'intensité d'étoiles. Cette mesure permettra d'obtenir des renseignements internes aux étoiles (sismologie) et externes (présence d'exoplanètes).*

Pour mener à bien ce programme, il sera capital de maîtriser l'environnement du télescope, en apportant une attention particulière à sa stabilité (thermique, mécanique et optique). Toute perturbation provoquant une variation du signal donné par l'étoile cible sera donc à minimiser. En particulier, la réjection de la lumière parasite générée par la Terre sera un paramètre déterminant dans le succès de la mission COROT.

Les études menées par Alcatel Space ont montré qu'un concept instrumental associant un télescope afocal - correctement bafflé - à un objectif dioptrique, permettait de satisfaire les exigences de réjection de lumière parasite. Ce concept a donc été sélectionné pour le projet COROT et sera prochainement développé pour le compte du Laboratoire d'Astrophysique de Marseille (LAM) par l'établissement de Cannes de la société Alcatel Space.

1-MISSION REQUIREMENTS

The COROT telescope, of which the customer is the French "INSU" / "CNES" *(Institut National des Sciences de l'Univers / Centre National des Etudes Spatiales)* is in fact a very precise and stable imaging instrument, which will be pointed towards fixed areas in the sky (each containing more than 3000 target stars) for periods of at least 5 months, in order to carry out its two missions:

- Stellar seismology : this will provide scientists with precious information related to the internal structure of stars other than our own sun.
- The search for exoplanets : this will be achieved through photometric detections of occultation events. COROT is likely to be the first instrument capable of detecting Earth like planets orbiting other stars !

The target stars will have visible magnitudes lower than 9 for the seismology mission, and lower than 13 for the detection of Earth-like exoplanets (a few tens of Earth-like planets and a few hundred Jupiter-like planets should be detected during the 2.5 years lifetime of the COROT mission) !

In order to comply with the above objectives, the instrument shall deliver a very stable signal ($\Delta S/S$ better than 10^{-6} over 150 days) from a stable source. This stringent stability requirement imposes a high level of performance from the following sub-systems :

- Earth straylight rejection (developed in the present article),
- Telescope PSF (Point Spread Function) stability (partly developed in the present article),
- Detector response stability,
- Read-out electronic stability.

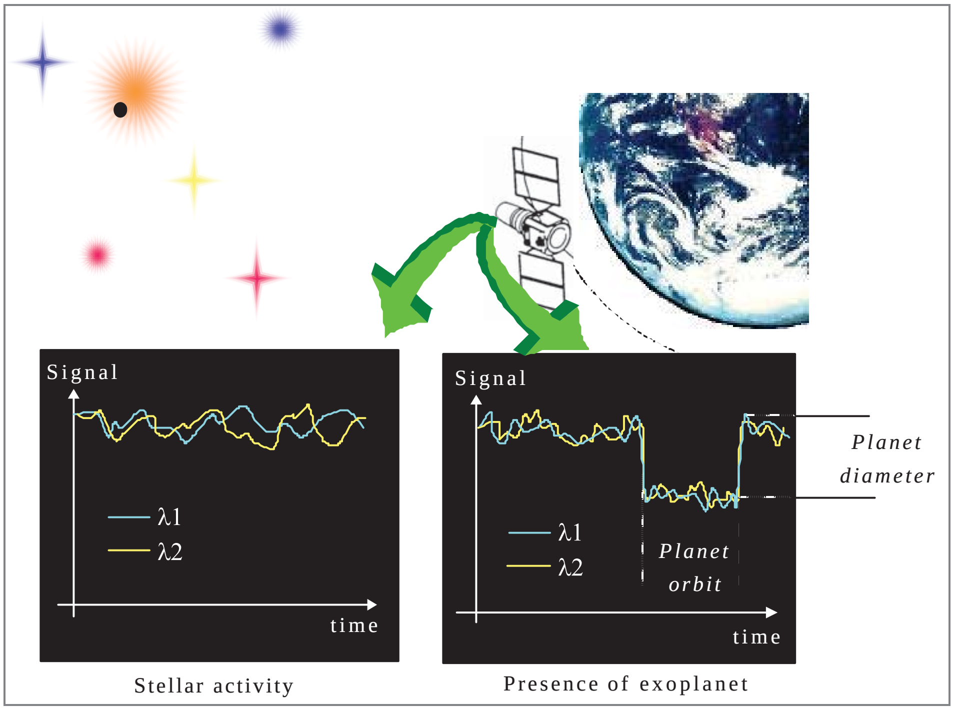

Figure 1 The COROT mission

The COROT payload will be mounted on a PROTEUS spacecraft (Plate-forme Reconfigurable pour l'Observation de la Terre, les Télécommunications et les Utilisations Scientifiques) under Alcatel Space prime contractorship. Its operational altitude will be around 850 km, with a polar orbit protecting the telescope from the solar flux (the sun will always be behind the entrance pupil of the telescope).

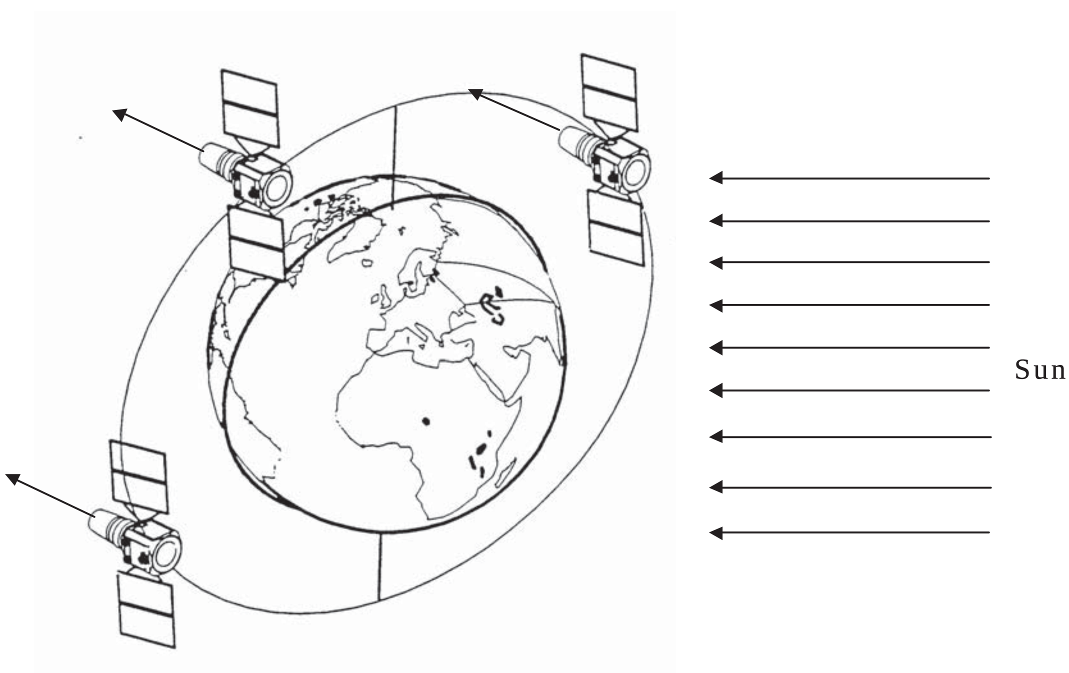

Figure 2 **COROT polar orbit**

2-TELESCOPE REQUIREMENTS

2.1 General requirements

The previous mission objectives lead to the following requirements at telescope level (optics and baffle):

Parameter	Specification
Pupil surface	> 570 cm²
Spectral range	370 – 950 nm
Field of view	2.7° x 3.05°
Pixel size	13.5 x 13.5 µm²
Number of pixels	4000 x 4000
Focal length	1.2 m
PSF	85% of energy < 40 µm
Allocated volume	0.86 x 0.86 x 2.9 m^3
Allocated mass	90 kg
Straylight	See § 2.2
PSF stability	See § 2.3

Table 1 Telescope requirements

Concerning the last two requirements (Earth straylight rejection and the PSF stability), both of these are considered to be challenging, and for this reason are described in greater detail in the following sections.

2.2-Straylight requirements

The system must be capable of measuring stellar signal variations with an accuracy better than 10^{-6}. This corresponds to a sensitivity of a few photons/pixel/second. Straylight flux shall therefore be typically less than **1 ph/pix/s**. The following table summarises the current specifications, derived from these requirements :

Parameter	Specification
Earth position (w.r.t. line of sight)	Between 20° and 90°
Baffle entrance diameter	≈ 800 mm
Cleanliness (in orbit)	2000 ppm
Mirror roughness	<1 nm
Lenses roughness	<3 nm
Ghost image	To be minimised
Straylight level	1 ph/pix/s

Table 2 Straylight specifications

With a baffle entrance diameter of around 800 mm, a line of sight (LOS) positioned around 20° from the Earth limb, and an altitude around 850 km, the collected photon rate (in the useful spectral range) originating from Earth is around 10^{20} photons/s.

This is equivalent, at focal plane level, to 6.10^{12} photons/pixel/s, such that the telescope baffle shall have a **straylight rejection capability of around 10^{12}**, which is the highest rejection ratio ever to have been required from a space telescope of this class.

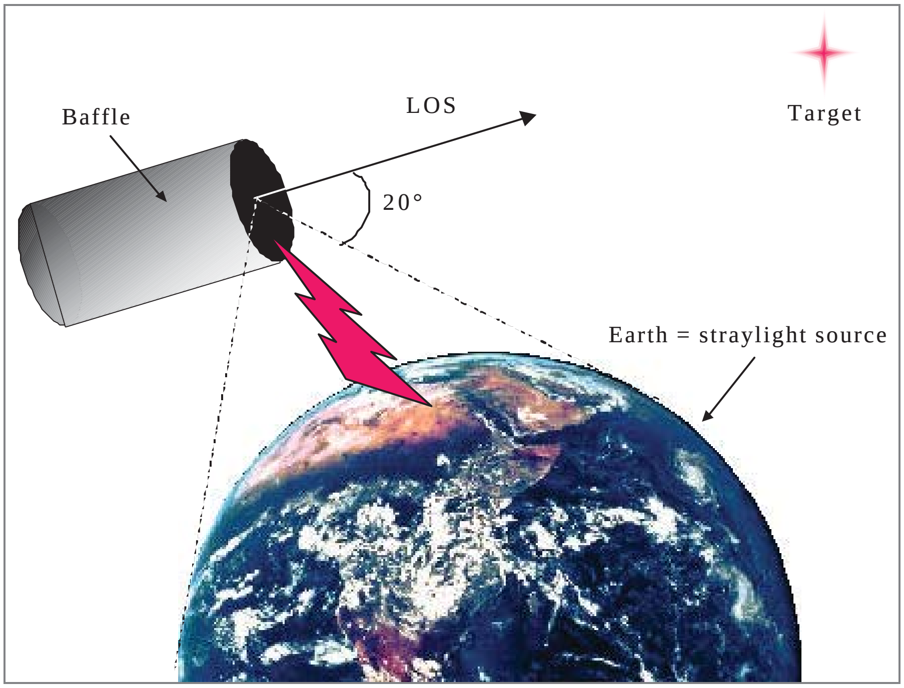

Figure 3 Straylight source

2.3-PSF stability requirements

At the focal plane level, the image is defocused in order to avoid detector saturation. The PSF will thus cover around 250 pixels, the summation of which will give the total energy received by the telescope from the target star.

Due to the non perfect uniformity of the detector's spatial response (which cannot be calibrated to an accuracy of 10^{-6}), signal errors can be induced by small displacements of the PSF relative to the detector. The following table gives the resulting PSF stability requirements, in terms of dimension and position.

Parameter	Specification
PSF diameter (defocus around 1 mm).	≈ 240 µm ± 10 µm
PSF diameter stability over 1 orbit.	± 2.7 µm
PSF diameter stability over 150 days.	± 27 µm

Table 3 PSF stability requirements

In terms of pointing accuracy, the system requirement is to stabilise the PSF on the detector to within ± 5.4 µm (equivalent to ± 4.5µrad, or ± 0.4 pixel). In order to reduce the severity of these requirements on the thermo-elastic stability of the optics, error signals generated by the telescope detector are used to drive the spacecraft pointing control loop. This approach allows the absolute LOS pointing stability of the telescope to be relaxed to around ±22.5 µrad over one orbital period. The fine pointing control is thus achieved by the PROTEUS platform, using its reaction wheels. The control loop has a discrete sample and correction rate of 1/32 Hz.

Parameter	Specification
PSF position stability over 32 s	± 5.4 µm (± 0.4 pixel)
Telescope LOS drift over 1 orbit	± 22.5 µrad

Table 4 PSF displacement requirements

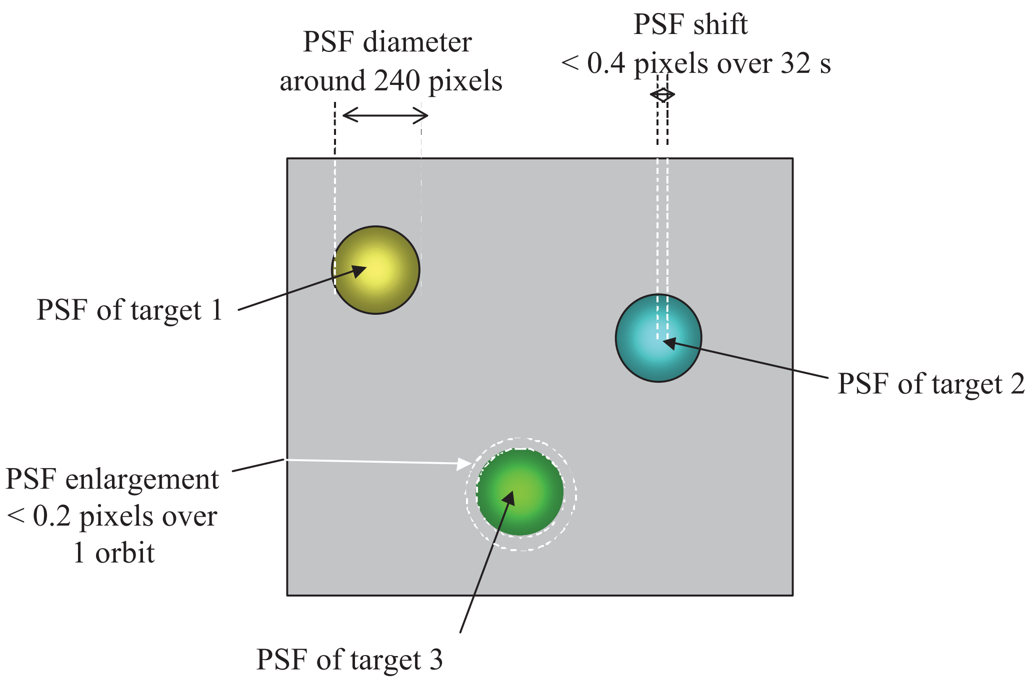

Figure 4 PSF requirements

3-STRAYLIGHT ANALYSIS & PERFORMANCE

3.1-Telescope concept

Firstly, the large diameter of the telescope entrance pupil (around ϕ 300 mm) favours a solution based on reflecting mirrors. Secondly, the large field of view requirement (around 3° x 3°) naturally leads to a TMA (Three-Mirror Anastigmatic) solution. Although such a telescope concept was initially proposed for the COROT mission, it was rapidly found to be unsuitable for reasons of its poor potential for straylight baffling: this would have led to a very long baffle (around 5m), as shown in the following figure.

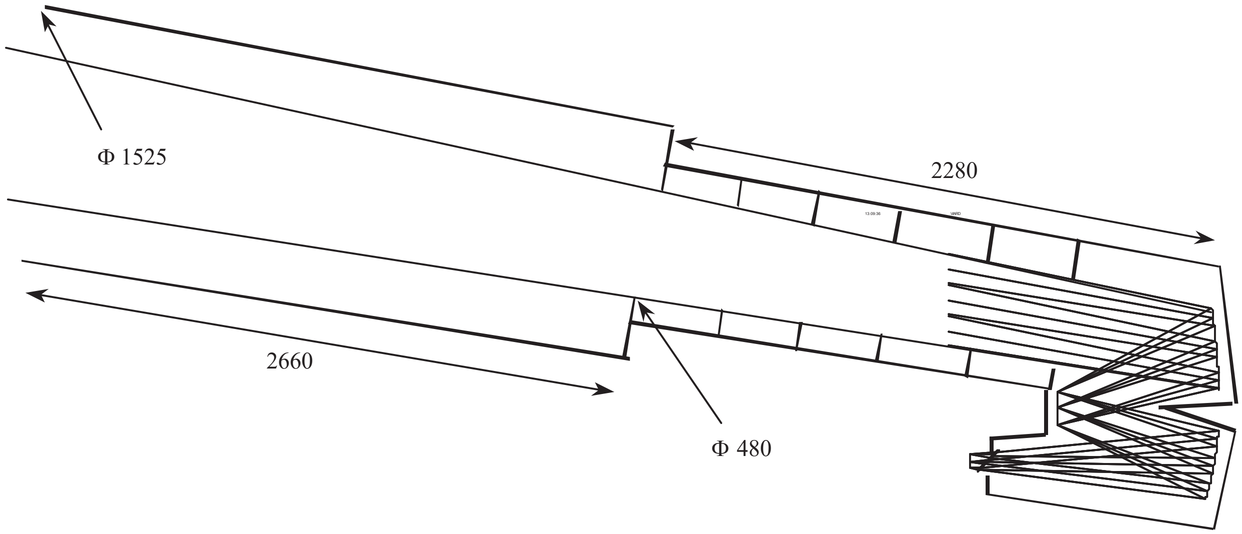

Figure 5 Baffling concept for a TMA telescope

As such a baffle would be highly incompatible with the weight, volume and cost allocations of the mission, a more compact solution was needed.

In this context, Alcatel Space has proposed an innovative concept, based on an afocal telescope feed and a dioptric imaging camera, in which two real pupils and a field stop are materialised. This design leads to a more compact entrance baffle and even better straylight rejection capacity than the TMA telescope.

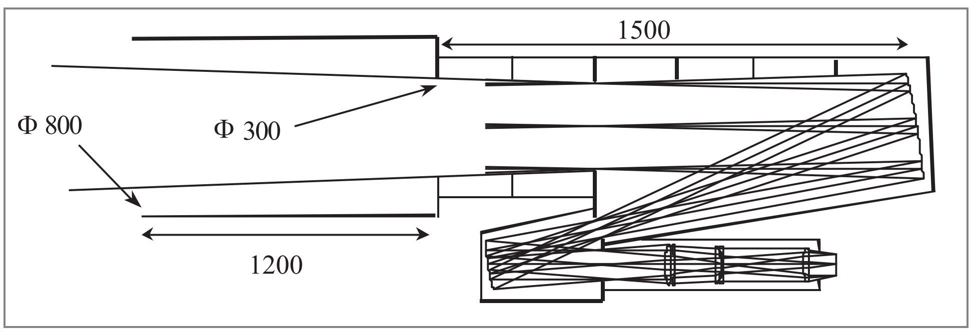

Figure 6 Baffling concept for the afocal telescope – imaging camera design

The telescope consists of two co-focal off-axis parabolic mirrors, which act together like a folded beam compressor. The common focal plane of the two mirrors is shared by the entrance and exit pupils of the telescope, and by a square field stop.

A dioptric camera is placed in the collimated exit beam, thereby producing an image of the sky on the detector.

3.1-Baffle concept

- Firstly, it should be noted that the background signal requirements are so severe that any straylight rays which succeed in reaching the detector must be diffused at least twice (preferably 3 times) by a black paint (Z306) surface, before entering the useful field of view !
- Secondly, the last straylight diffusion (reflection) occurrence takes place on the first optical element of the telescope (M_1), meaning that once a flux ray has entered the field of view it can no longer be blocked.

An entrance baffle in front of M_1 is thus an absolute necessity, and the required straylight rejection ratio must be achieved by the elements placed just *before* M_1. The design of this baffle must therefore adhere to the following rules :

- The first part of the baffle must be dedicated to the initial diffusion of straylight rays. As a consequence, this component (referred to as the "second stage") must not be directly visible from M_1 .
- The second part of the baffle must be dedicated to the second diffusion occurrence. Consequently, this component (referred to as the "first stage") must not see the straylight *source* (Earth).
- The third possible diffusion event occurs at the M_1 mirror, which means that its surface quality (roughness and particular cleanliness) must be very high in order to comply with the overall straylight requirement.

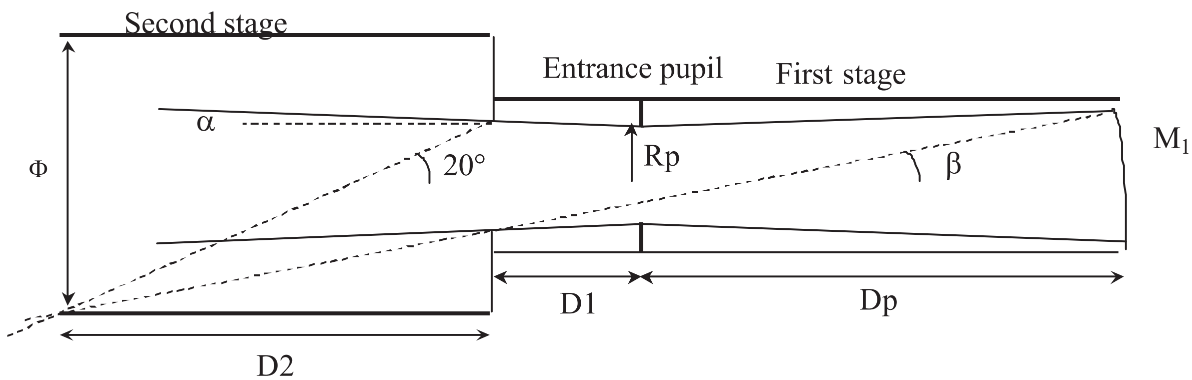

Figure 7 Baffling design rules

The positions of the baffle chicanes, whose principal purpose is to prevent or to limit grazing incidence specular reflections, have been optimised using APART software which takes into account all of the *diffraction* effects produced by the chicanes. The following figure provides the definition of the optimised baffle.

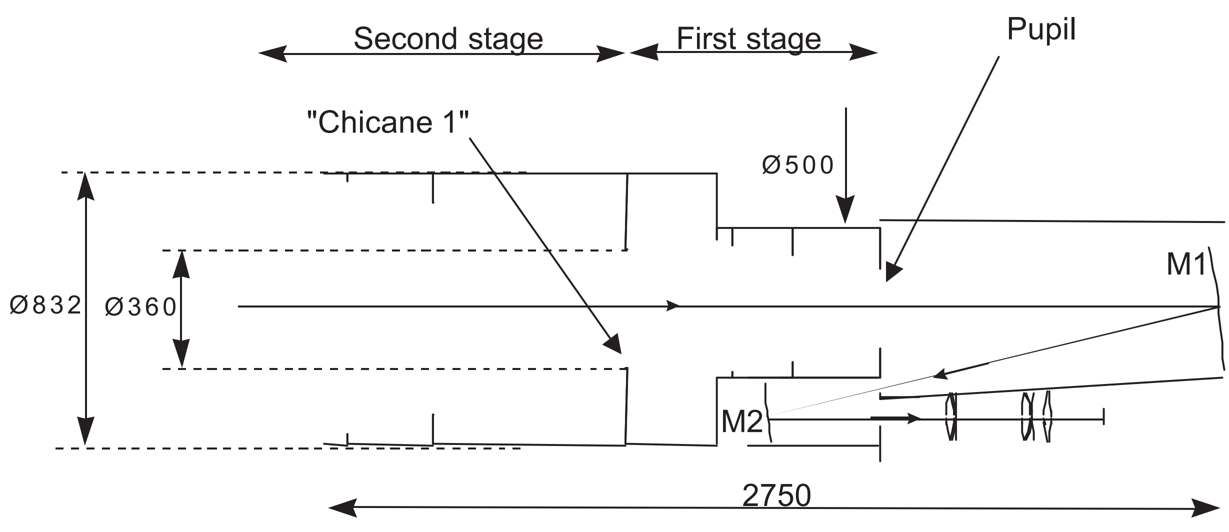

Figure 8 Optimal locations for baffle chicanes

3.1-Baffling performance

The performance of a baffle is generally given by its PST (Point Source Transmission) which, for a given incidence angle θ, is the ratio between the incidence irradiance of a point like source at instrument entrance pupil level, and the transmitted irradiance at focal plane level.

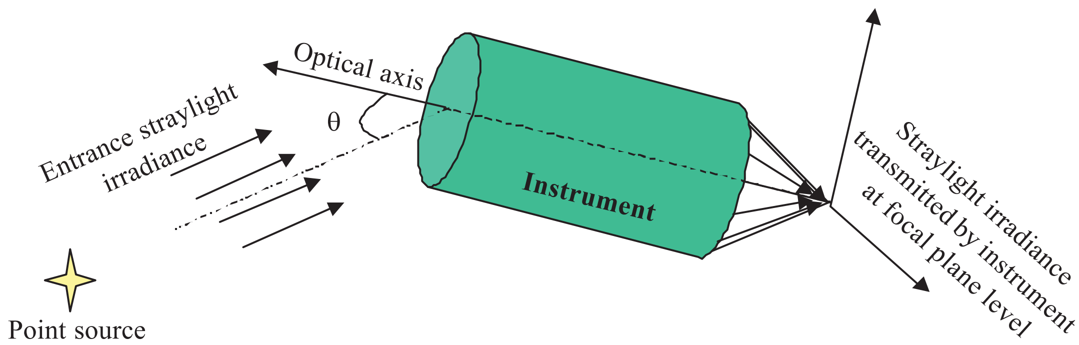

Figure 9 PST definition

The following curves give the PST of the previous baffle definition, for two different hypotheses of M_1 contamination level (400 ppm or 2000 ppm).

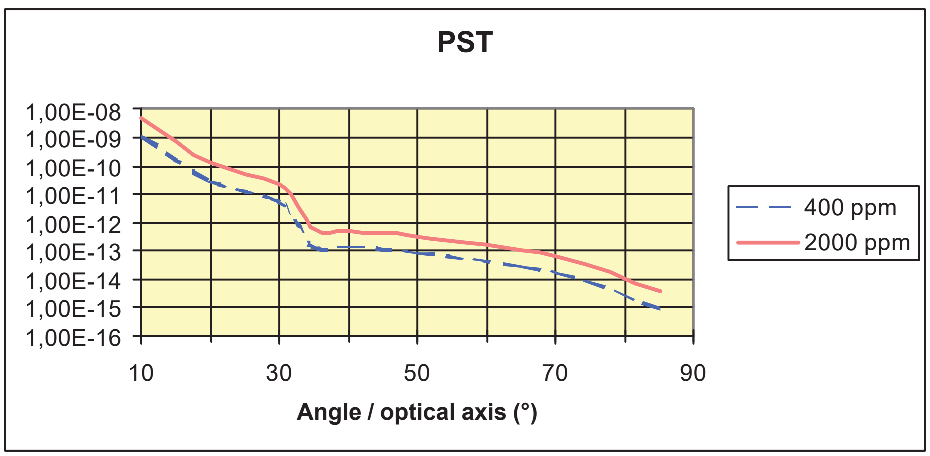

Figure 10 PST values

The PST function can be used to calculate the detector level irradiance for any given source, by integrating the Source x PST irradiance function over the solid angle represented by the source. It can be seen that between 20° and 90° (corresponding to the angular limits occupied by the Earth), the average PST is around 10^{-12}, which is the specified rejection ratio for the COROT mission. As a result, the Earth-generated straylight irradiance can be shown to produce a photon rate **lower than 1 ph/pixel/s**, in the case of a contamination level of around 2000 ppm. The baffle proposed by Alcatel Space is thus compliant with COROT's straylight requirements.

4-STABILITY ANALYSIS & PERFORMANCE

4.1-Derivation of requirements

The PSF requirements have been used to generate the optical parameters given in the following table :

Item	Allocation
In orbit mirror deformations	< λ/40
Distance stability between M_1 & M_2	± 6 µm over 1 orbit ± 50 µm over 150 days
Camera focal length stability (over 1 orbit)	± 10 µm
Mirror tilt stabilities (over 1 orbit)	± 17 µrad
Mirror misalignment stabilities (over 1 orbit)	± 24 µm
Camera tilt stability (over 1 orbit)	± 20 µrad

Table 5 Derivation of the PSF requirements

The proposed solution to satisfy the above requirements is to use a highly stable material, with a CTE of around 10^{-6} K^{-1} (CFRP type), associated with a thermal control stability of around ± 4°C. The dioptric camera has to be athermalised (by choosing an appropriate association of optics and barrel materials). Alcatel Space has proposed an opto-mechanical design for the complete telescope which is compliant with all of the above requirements.

4.2-Instrument mechanical concept

It is proposed to employ a mechanical structure comprising two CFRP honeycomb panels linked together with a 6-strut truss. The baffle is isostatically mounted directly onto the upper panel with thermal insulation. The baffle - telescope assembly (called "COROTEL") is isostatically mounted on the payload equipment module, which houses the payload electronics modules, and provides mechanical support and thermal decoupling of the payload from the spacecraft.

The current instrument design is illustrated in the following figure:

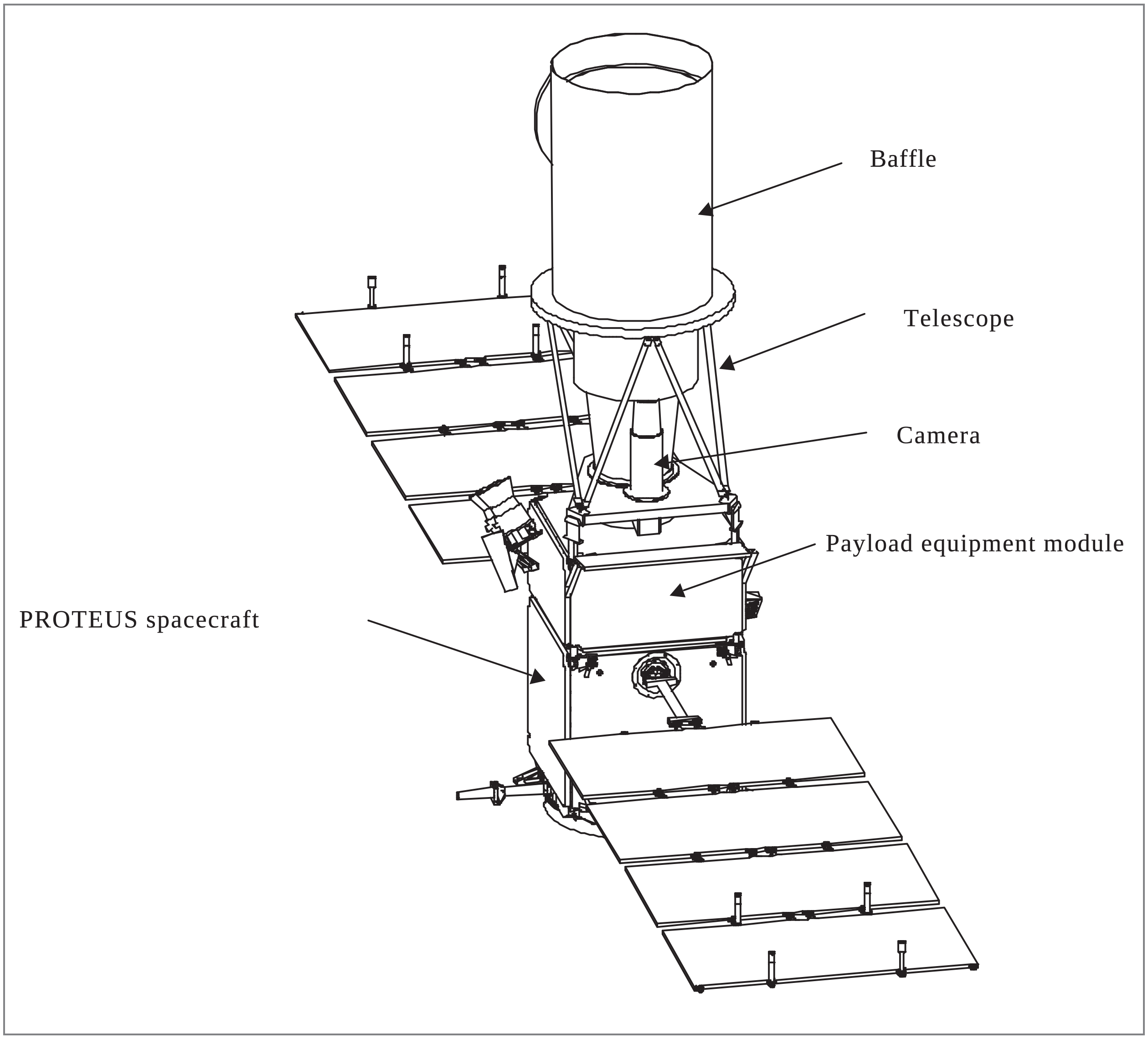

Figure 11 COROT instrument on the Proteus spacecraft

5-CONCLUSION

In the context of the very challenging COROT mission, Alcatel Space has proposed an original optical concept based on an afocal telescope, associated with a high-performance, compact two-stage baffle. When associated with a highly stable support structure, using Carbon based structural technologies familiar to the Cannes site of Alcatel Space, the proposed COROTEL telescope payload provides full compliance with all of the demanding requirements of the mission.

REFERENCE

"Cahier des Charges Techniques Particulières" COR-BC-31-GEST-324-LAS issu du CNRS - Laboratoire d'Astrophysique de Marseille (LAM).