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UVCI for HERSCHEL: instrument description and activity status report

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Abstract. The Ultraviolet and Visible light Coronagraphic Imager (UVCI) is an imaging coronagraph that will take pictures of the solar corona from 1.4 up to 3.5 solar radii at three different wavelengths, HI Ly-α 121.6 nm, HeII Ly-α 30.4 nm, and broadband visible polarized light. It is part of the HERSCHEL experiment (HElium Resonant Scattering in the Corona and HELiosphere) and it will fly on a sounding rocket. The instrument optical design consists of two twin off-axis Gregorian externally occulted telescopes, with multilayer-coated optics optimised respectively for the HI and HeII lines.
We describe the instrument structure design and the associated optical tolerances analysis. The structure is conceived to attain high stiffness with the lowest possible weight. Tolerances on the positioning of the optical elements, for alignment purpose, have been evaluated through a geometrical approach and ray-tracing method.

Key words. Coronagraphs – Solar Corona – Instrumentation

1. Scientific background

The HERSCHEL experiment is an international collaboration between seven italian institutions led by Osservatorio Astronomico di Torino and the Solar Physics branch of the Naval Research Laboratory. The aim of the scientific investigation is:

1) Provide the first global images of the HeII corona;
2) Provide the first global EUV images of the corona for the two most abundant elements, H and He;

3) Provide the first maps of He abundance in the corona;
4) Provide the first global maps of the solar wind outflow (neutral hydrogen atoms and singly-ionized helium outflows);
5) Directly test models of solar wind acceleration based on helium abundance and H, He outflow velocities;
6) Establish proof-of-principle for the UVC, which is in the ESA Solar Orbiter Mission baseline.

The instrument package is composed of the Ultraviolet and Visible-light Coronagraphic Imager (UVCI) and the Extreme-ultraviolet Imaging Telescope (EIT), and will fly on a sounding rocket. The monochromatic H I and He II images obtained will provide simultaneous abundance, densities and velocities diagnostics from 1 to 3 Solar Radii. The coronal electron density required for the analysis will be derived from the visible light images. The EIT will obtain the intensity of the 304 Å resonantly scattered He II line below the field of view of the coronagraph, as well as the He II disk images necessary for the analysis of the coronal emission.

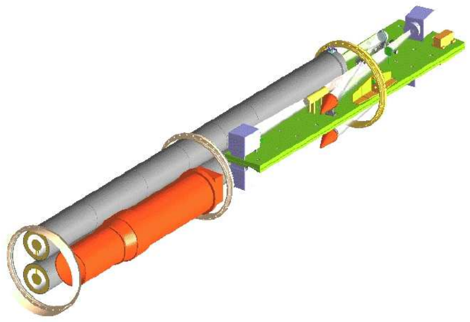

Fig. 1. HERSCHEL instrument

2. Optical design

A detailed description of the UVCI optical design can be found in Antonucci et al. (2000) and Fineschi et al. (2002), here we only recall some relevant aspects. Due to the short duration of the rocket flight, UVCI hosts two twin telescopes, optimised respectively for the H I (channel A) and He II (channel B) lines. The optical configuration of each telescope is an externally occulted off-axis gregorian, with a third mirror placed at the level of the entrance pupil of the sistem and used for rejection of the light coming from the Sun disk.

Design drivers are characterised by a high number of constraints: two mirrors with multilayer coatings, to minimise the number of reflections and enhance the reflectivity in the Ultra-Violet region; external occultation and coupling with internal optical elements, to obtain efficient stray-light suppression; gregorian design, to have a real image between M1 and M2; many parameters of the optical elements (i.e. focal lengths, sizes, distances) are given by geometrical constraints (i.e. rocket) and design requirements.

In this framework, analysis of tolerances is crucial to ensure that the requirements on instrument performances, given not only by image quality but also by occultation and stray-light rejection efficiency, are satisfied.

3. Tolerances

We present here a preliminary analysis of the tolerances on positioning of the optical elements performed on the basis of the optical design described. The aim of the analysis is to obtain reasonable values for the most relevant Tolerance Parameters (TPs) related to the optical elements, matching the requirements on system performances, both in terms of image quality at the focal plane and occultation efficiency of the sistem.

We will see in the following that the latter imposes the most stringent values on TPs in many cases. In general, the problem of tolerancing can be described in two ways:
1) calculate the effect on the system performances, given a realistic value to the TPs (referred hereafter as direct mode);

2) derive the values for a set of TPs satisfing the requirements, given the expected system performances (inverse mode).
In other terms, TPs and system performances can be evaluated one from the other by means of a *merit function*.
The number of TPs is usually very high so that the use of ray tracing software is a better choice with respect to analytical calculation. In this way, one can more easily handle the large number of degrees-of-freedom. To evaluate the occultation efficiency, we wrote custom merit functions, which unfortunately cannot be used in the inverse mode. Our approach has therefore been twofold:

a) an analytical (geometrical) single degree-of-freedom calculation: the contribution to the system performance degradation has been evaluated separately for each degree-of-freedom, to find out the critical tolerance value associated to a given parameter. This means to assign a maximum acceptable worsening of the system performances, and consequently derive the value of each TP as if it was the only responsible of the entire amount of degradation;

b) the results, appropriately rescaled, have then been used in a Monte-Carlo simulation by ray tracing method to evaluate the system performance degradation due to the effect of all the TPs considered together, and parameter values have been further adjusted as a consequence of the result in order to obtain the required performances.

In principle, every TP is a function of the whole set of TPs. In practice, it is possible and useful to simplify the problem approximating the system with the sum of a given number of simpler subsystems, neglecting the weaker couplings between TPs. In our case, we describe the system with a sum of five simpler subsystems, identified by the task they must perform from the point of view of the optical properties:

(1) External Occulter (EO) - Rejection Mirror (M0); task: rejection of Sun disk light
(2) External Occulter (EO) - Rejection Mirror (M0); task: occultation of Sun disk light
(3) External Occulter (EO) - Primary Mirror (M1)- Internal Occulter (IO); task: first order stray-light suppression
(4) Rejection Mirror (M0) - Primary Mirror (M1) - Secondary Mirror (M2); task: second order stray-light suppression
(5) Primary Mirror (M1) - Secondary Mirror (M2) - Focal Plane (FP); task: Image position and quality

Table 1. Subsystem imposing the most stringent value on roto-translational Tolerance Parameters (see text).

	Tolerance Parameter					
	Δx	Δy	Δz	$\Delta\alpha$	$\Delta\beta$	$\Delta\gamma$
EO	(2)	(2)				(3)
M0	(2)	(2)		(1)	(1)	
M1	(3)	(3)	(5)	(3)	(3)	(3)
IO	(3)	(3)				(3)
M2	(5)	(5)	(5)	(5)	(5)	(5)
FP	(5)	(5)				

The first four subsystems are related to what we called *occultation and stray-light rejection efficiency*, while the last one refers to the *image quality* of the optical system. Table 1 shows the results. For each optical element, and for each TP, the subsystem which requirements impose the most stringent value to the TP is labelled (only roto-translational parameters are shown).

4. Structure and mounts

Results of the tolerance calculation have been useful to identify a baseline solution for the instrument mechanical structure

and for the optical elements' mounts.
The structural concept hereafter described aims to optimise the calibration activity while respecting all the functional and environmental requirements. The interface to the rocket is a bulkhead in intermediate position, which improves the dynamic behaviour with respect to a fully cantilever accommodation of the payload. The structure is based on an optical bench assembly made by two independent sandwich plates (hosting the two optical channels A and B) so that each one can be separately calibrated, tested and then joined together by means of screws. Bench 1 provides the accommodation of the two launcher interface fittings. Due to this, its thickness is higher with respect to Bench 2.
To obtain the required positioning, all the components placed on each bench allow a tuning positioning capability with respect to a global reference system. Moreover each single component may be individually adjusted, by means of micrometrics mechanism, with respect to its own local reference system. The two benches are of aluminum honeycomb material with CFRC skins.
The boom carrying the External Occulter, the Sun disk rejection mirror and the baffling system is made of Filament-Winding CFRC. The boom is aligned with respect to its own optical bench. The material used for the boom employs an high modulus of elasticity in longitudinal direction. The alignment between the two coronographs is made by means of a single precision pin (leaving one degree of freedom free for angular positioning) and torque tightened screws to freeze the position itself after the alignment. The foremost end of the optical bench is provided with a damper which reduces booms and bench displacements as long as its stiffness is augmented. A Finite Element Model (FEM) has been prepared to check the main structural requirements: the first eigen-frequency is around 20 Hz which seems compatible with launcher requirements. From the random spectra, the related design loads have been then derived: this leads to a deflection of 23.8 mm at the foremost edge of the occulter boom, which is acceptable. Since the structure most critical parameter is the stiffness, the related stresses are well within the limits, even considering the lower material allowables against non linearities (to prevent hysteresis effect and then alignment shift).

5. Conclusions

We presented the status of the UVCI coronagraph project. Non conventional tolerance analysis based on the present optical design was used to produce a preliminary design of the instrument structure and mounts, and a preliminary FEM has shown compatibility with launcher requirements. Work is also in progress to define the design requirements for multilayer coatings of the mirrors (Pelizzo et al. 2002) and characterisation of the Liquid Crystal Variable Retarder which will be used in the polarimetric system (Zangrilli et al. 2003).

References

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