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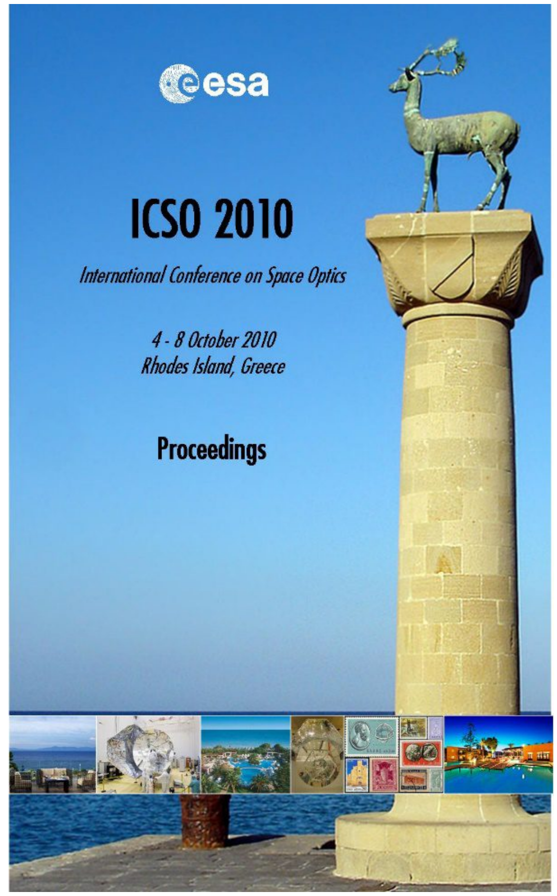

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PILOT, A BALLOON BORNE EXPERIMENT UNDER GROUND TESTS

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I. INTRODUCTION

PILOT is a balloon borne experiment, which will measure the polarized emission of dust grains, in the interstellar medium, in the sub millimeter range (with two photometric channels centered at 240 and 550 µm).

The primary and secondary mirror must be positioned with accuracies better than 0.6 mm and 0.06°. These tolerances include environmental conditions (mainly gravity and thermo-elastic effects), uncertainties on alignments, and uncertainties on the dilatation coefficient. In order to respect these tolerances, we need precise characterization of each optical component. The characterization of the primary mirror and the integrated instrument is performed using a dedicated submillimeter test bench.

A brief description of the scientific objectives and instrumental concept is given in the first part. We present, in the second and in the third part, the status of these ground tests, first results and planned tests.

II. GENERAL DESCRIPTION

A. Scientific objectives

The first main objective of the PILOT experiment is to constrain the magnetic field of our Galaxy at large scale: it will give information in particular about the magnetic field's role in star formation. The second objective is the characterization of polarized emission from dust grains: it will be helpful for foreground subtraction (in the frame of CMB future analysis), but also for the study of the interstellar grains physical properties ([1], [2]).

Simulations including realistic instrument performances show that after three flights (of about 24hrs each) it will be possible to cover the full galactic plane map (± 30degrees in latitude). In addition, several deep surveys will be performed at high galactic latitude.

Scientific by-products of the PILOT experiment will include a large point-source catalog (several hundred sources should be detected per hour).

B. Instrumental design

In order to reach high sensitivity, we will use a stratospheric platform and bolometer arrays (Fig.1.). For sky survey, the azimuth and elevation range will be respectively ±30° and from 20° to 60°. The reconstruction of the fine attitude and effective pointing direction will be done using a stellar sensor co-aligned with the submillimeter axis (amplitude error of 10" on the three axis).

The optical design is based on a Gregorian type telescope coupled to a photometer/polarimeter ([3]). The telescope respects the Mizuguchi Dragone condition, in order to limit instrumental polarization and parasitic lights ([4]). The principle of the polarization measurement uses a design based on a rotated wave plate and a fixed grid polarizer. The rotation of the wave plate is done by discrete steps to avoid a modulation of the background. Several scans are done for the same region using different wave plate angles, allowing to determine successively I and U, I and Q Stokes parameters.

All optical elements are cooled at cryogenic temperature (about 3K), except the primary mirror in order to reduce the instrumental background (the main optical characteristics are given in Table 1.). The mirrors and mechanical structure are made of aluminium. The two focal planes are composed of four bolometer arrays, 2 per wavelength channel, cooled at 300 mK. Each array is composed of 16×16 pixels of 750 µm², so there is a total of 2048 bolometers. An internal source of calibration is used to perform in flight inter calibration.

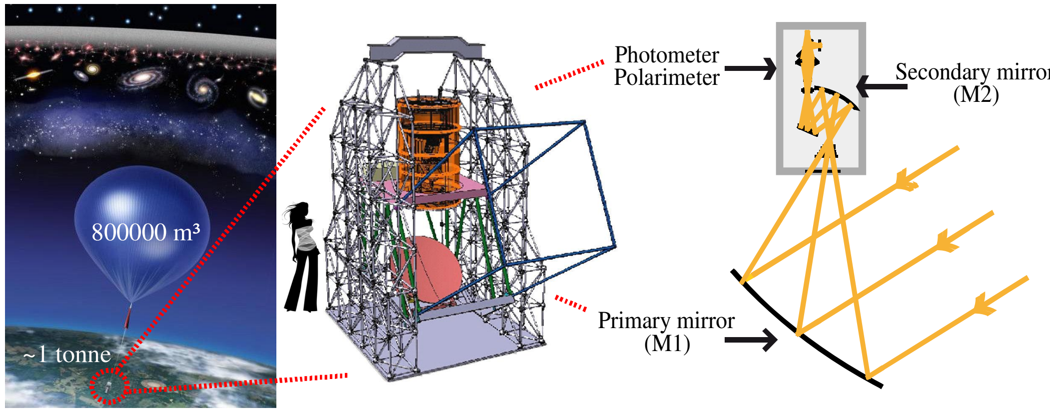

Fig.1. From left to right, a representation of the stratospheric balloon and onboard experiment, the instrument in the pointed payload, the optical concept

Tab.1. Optical parameters

Optical characteristic	Value
Field of view	1° x 0.8°
Beam FWHM	1.4' at 240 μm
Strehl Ratio	0.95 (diffraction limited)
Equivalent focal distance	1800 mm
Numerical aperture	F/2.5
Magnification	1 mm on focal plane ≅ 1.9' on sky
Distortion	Maximum 5% in the corner
Polarization	Maximum 5% in the corner

Optical tolerance calculations show that we need to align the primary mirror with an accuracy of 0.6 mm and 0.06° (in offset and tilt around the nominal position), with respect to the rest of optical elements: precise alignment and characterization have to be done in our case. All optical parameters will be measured during end to end ground tests.

II. PRIMARY MIRROR CHARACTERIZATION

The primary mirror is the master optical piece of the PILOT instrument. It is also the most sensitive element and the only one to be at ambient temperature during in flight measurement. So it is necessary to evaluate precisely the optical parameters according to the environmental conditions (mainly thermal and gravity effects). Moreover, it is necessary, to obtain optimal image quality, to perform measurements on the mechanical structure. With optical and mechanical measurements, we will validate the model including deformations due to environmental conditions.

A. Image quality in the submillimeter range at 21°C

3D measurements have been done, by the manufacturer, on the primary mirror (2072 points equivalent to one point every 2 cm) and on three reflective reference balls, located on the edges of the mirror (Fig.2.). From these measurements, accurate calculations have been performed, in order to evaluate the optical parameters and associated uncertainties. A model with Zemax software was developed, using 3D measurements results as input. One of the objectives of the characterization of the primary mirror, now in progress at CESR, is to validate these calculations.

For these tests, we use a submillimeter experimental set-up, developed at CESR, for the integrated tests of the Odin satellite ([5]). This bench is including the following equipments (Fig.3.):

- 1m diameter collimator (Newton-type),
- submillimeter source mounted on a motorized three axis system (high pressure mercury vapour arc lamp),
- silicon bolometer cooled to liquid Helium temperature (T=4K).

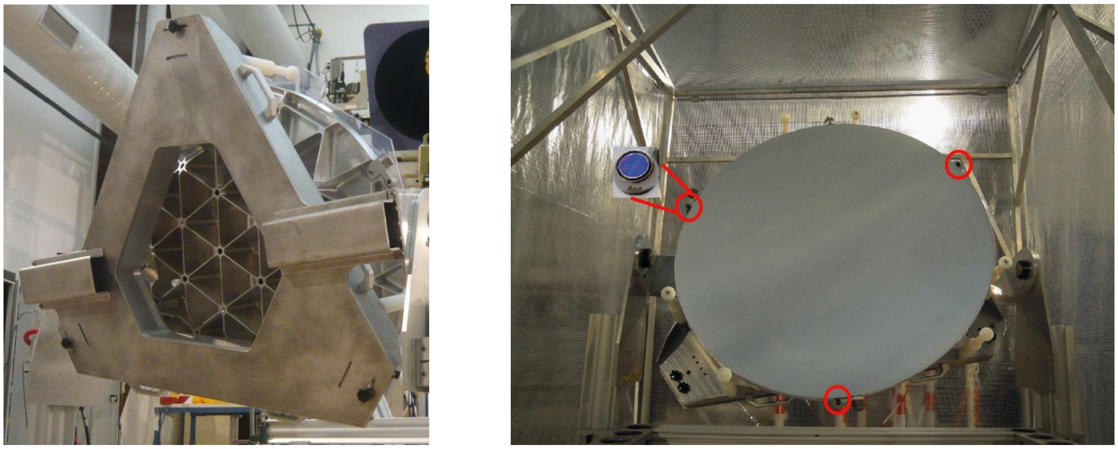

Fig.2. Primary mirror on his test support: on the left, view on the lightened part; on the right, view on the optical part, red circle indicates the position of the three reflectors balls

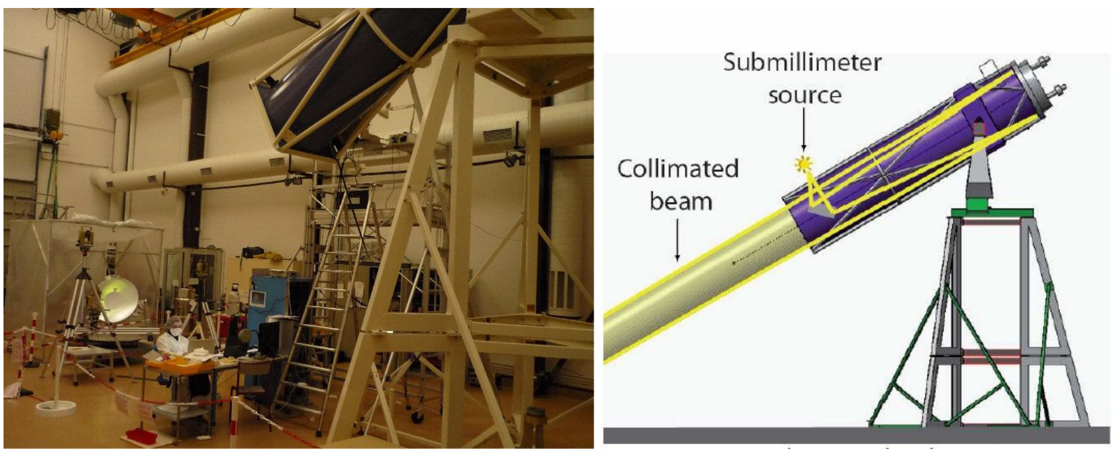

Fig.3. On the left, primary mirror under characterization; on the right, representation of the 1m diameter collimator and the incident submillimeter collimated beam (at an elevation angle of 30°)

The collimation of the incident beam is done using theodolites, with a precision of ±2". The alignment of the primary mirror axis and collimated beam is done using a 3D coordinate measuring machine. The 3D measurement is done without contact, with a precision of ±10µm + 5µm/m. The 3D coordinates of three reflective balls, placed on the contour of the mirror, are used to locate the optical axis and focus.

The image quality is analyzed for different incident angles of the collimated beam (range of ±0.06°). For each alignment, several measurements are done along the associated optical axis (range of ±0.6 mm). This will allow us to verify the accuracy of the model for different positions of the mirror toward the incident collimated beam, and to characterize the best focal image.

Fig.4. gives the PSF obtained at the predicted best position. On the cross section, the squares are the measured points and the line is a Gaussian fit. This image is the best we have measured after exploring a wide range of space parameters and this result gives good confidence on the model predictions. Additional measurements will be done in order to evaluate precisely the uncertainties of the test bench and on the image intensity distribution (radius, contours...) compared to the model.

B. Planned tests

For the moment, the measurements have been performed at 21°C, temperature of the clean room during the 3D measurements done by the manufacturer. This allows us to verify the optical parameter without thermo elastic effects. If we want to keep the optical performances near the diffraction limit, it will be necessary to evaluate precisely the deformations induced by environmental conditions. So measurements at different homogeneous temperatures are planned in order to validate the thermo elastic effects model.

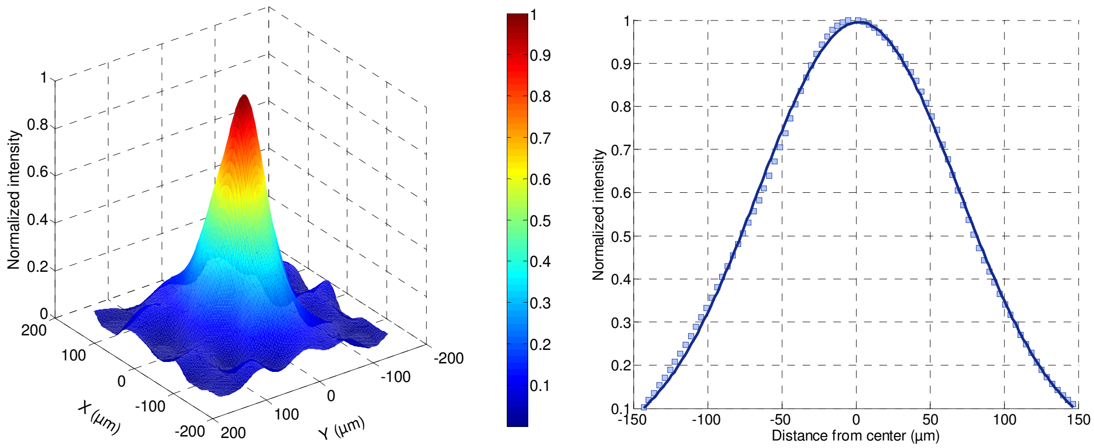

Fig.4. At the predicted best position: on the left, PSF; on the right, cross section (square are measured points, line is a Gaussian fit)

The optimization of the image quality requires further tests on the primary mirror and on mechanical structure too. The tests on mechanical structure will include measurement of deformation at different homogeneous temperatures and different elevations (impact of gravity). The tests on the mechanical structure will be done, in a first time, using mechanical model of primary mirror, photometer and electronic. These models are representative in terms of mass and size. The center of gravity of the mechanical model of the photometer can be adjusted.

Results on the primary mirror, coupled to the results obtained on the mechanical structure, will allow the validation of the mirror alignment support (support which allows six degrees of freedom). This knowledge will allow adjustments of the primary mirror before launch, in order to have optimal performances in flight.

III. INTEGRATION AND TEST OF THE INSTRUMENT

We describe in this parts, the main steps of the integration, alignments and tests of the instrument, which comprise image quality with polarized, unpolarized light and gravity effects.

A. Integration of the cold optics inside the photometer

All the optical elements contained in the photometer (lenses, wave plate, secondary and third mirror) will be characterized with 3D measurements, as it was done for the primary mirror (Fig.5.). Knowledge of their precise characteristics at ambient temperature, will allow us to predict the optimized alignment at 3K. These predicted positioning will be used to align mechanically all the elements, using 3D measurements.

Several reflectors balls will be placed on the external envelop of the photometer. The principle is the same as the one described for the primary mirror: these reflectors will allow us to determine the position of the optical axis of the photometer (which corresponds to the optical axis of the secondary mirror).

A measurement, done in the visible range, will verify the orthogonality between the optical axis and the focal plane.

B. Alignment of the primary mirror with the photometer, image quality

The photometer axis has to be aligned with the primary mirror optical axis with a tolerance of ±0.6 mm and ±0.06° (including environmental conditions: temperature, gravity). So in this step, we align the secondary and primary mirror axis in order to have the two focus coinciding. To do this we will do 3D measurements on the reflective balls located on the primary mirror and on the photometer. We will then perform the adequate actuations on the hexapod until obtaining the best predicted alignment.

In order to verify the alignment of the primary mirror and photometer, we will characterize the image quality in the focal plane (1°×0.8°) of the integrated instrument, with the same test bench used for the primary mirror characterization. The nominal image pattern to be achieved is diffraction limited and corresponds to 1.4’ at 240 µm and 3’ at 550 µm.

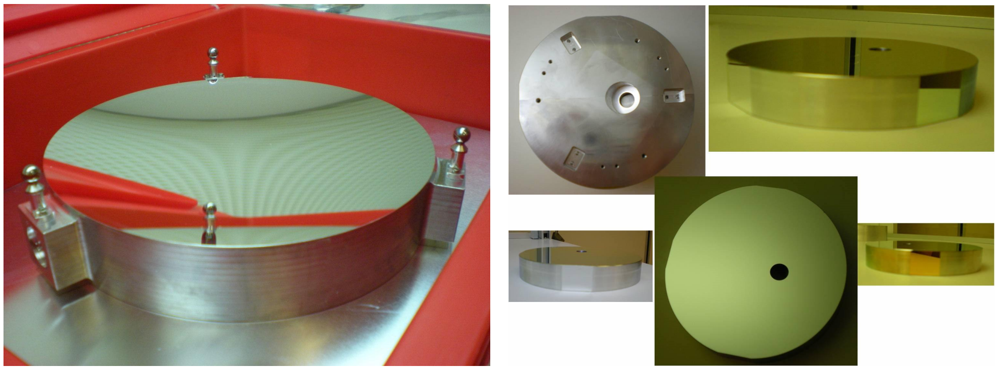

Fig.5. On the left, the secondary mirror with reference balls, on the right, the third mirror (the hole will be used for the internal calibration source)

C. Effects of gravity

It is necessary to verify the image quality for different elevations. The elevation will induce gravity effects on the primary mirror, the photometer and the mechanical structure (these effects varying with the instrument elevations). Preliminary model have shown that gravity will not affect the characteristics of the primary mirror. However, it is necessary to verify this impact on the integrated instrument (in particular the relative alignment between the primary mirror and the photometer). The collimator is mounted on a 6 meter high tower. This will allow the characterization of the image quality toward gravity: the measurements will be done for different elevations of the instrument between 20° and 60°. During these tests, we will locate the submillimeter axis and the stellar sensor axis. This measure will be useful for scientific data processing.

D. Instrumental polarization

The degree of polarization, during scientific observations, is expected to be less than 5%. Consequently, although the optical design is optimized in order to reduce instrumental polarization, it is necessary to measure the instrumental polarization, during ground tests.

For that purpose we will introduce a wire grid polarizer in the collimated beam. A dedicated test support is currently under development, in order to keep the polarizer orthogonal to the incident beam and to know precisely the direction of the polarized light for each rotation of the polarizer.

The polarizer is composed of 6 square polarizers of dimension 250mm×250mm which are assembled into a single 1m×1m large polarizer. Each individual square is composed of 50 µm diameter Cu-Be wires with a period of 100 µm. For every position of the polarizer, the rotation of the wave plate will be similar to those planned during flight measurements.

IV. CONCLUSION

We have presented the status of the ground tests for the PILOT balloon borne experiment. The first result on primary mirror gives good confidence in the modelling, based on 3D measurements. Additional tests will be performed in order to evaluate precisely the uncertainties on results. Moreover, measurements will be done at different homogeneous temperatures, in order to optimize the in-flight image quality.

Next steps will be the integration and characterization of the photometer, done by IAS. The photometer will be delivered at CESR with reference reflective balls, which will be used to locate the photometer axis. We will then integrate the instrument and characterize the payload image quality with polarized and unpolarized light and gravity effects.

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