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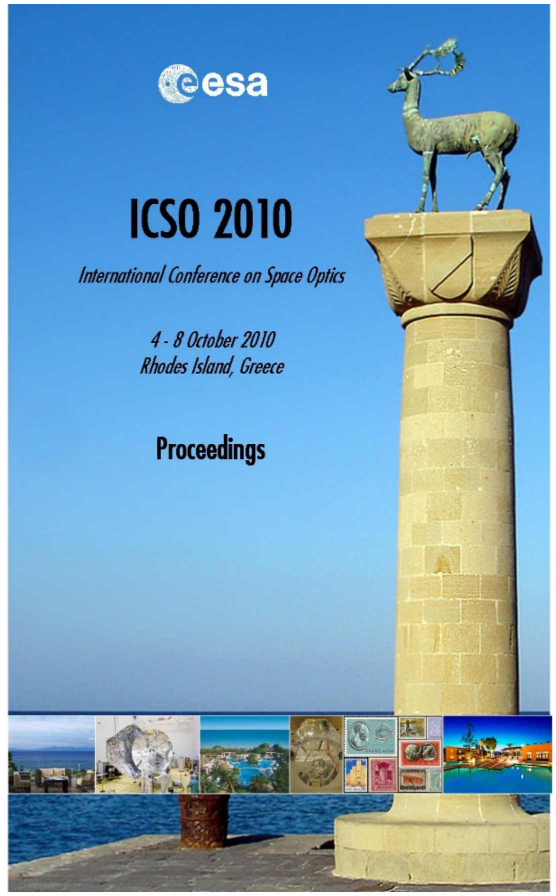

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FEASIBILITY STUDY OF A THERMAL SPECTRO-IMAGER FOR SPACE MISSIONS TO SMALL BODIES

E. Brageot[1], O. Groussin[1], P. Lamy[1], J-L. Reynaud[1], and G. Fargant[2]
[1] *Laboratoire d'Astrophysique de Marseille, Université de Provence, CNRS, 38 rue Frédéric Joliot-Curie, 13388 Marseille cedex 13, France.*
(Emily.Brageot@oamp.fr, Olivier.Groussin@oamp.fr, Philippe.Lamy@oamp.fr, Jean-Louis.Reynaud@oamp.fr)
[2] *Thalès Alenia Space, 100 Boulevard du Midi, 06156 Cannes La Bocca, France.*
(Guy.Fargant@ThalesAleniaSpace.com)

ABSTRACT

In this paper, we report on an on-going feasibility study of a thermal spectro-imager for future space missions to small bodies in the Solar System. Thanks to the recent development of uncooled micro-bolometer technology, we decided to use such a detector as a baseline for our study. For this feasibility study, we have defined four objectives using this detector to perform : (i) uncalibrated images, (ii) calibrated radiometric images, (iii) spectroscopic measurements, and (iv) a definition of the instrumental concept including the optical and mechanical design. Here we present our progress on the first two objectives of this work.

I. INTRODUCTION

The thermal properties of small bodies in the Solar System extensively contribute to the knowledge of their global physical properties and dynamical evolution. Their determination allows us to constrain the surface properties (roughness, presence of regolith), the internal structure through the thermal inertia, and to quantify the Yarkovsky effect that controls the non-gravitational evolution of the orbit. The latter is particularly important for the prediction of the orbit of NEAs (Near Earth Asteroids), such as Apophis that could impact the Earth, hence for the design and development of future space missions to change the trajectory of those bodies. The thermal properties are best determined by the space-resolved mapping and spectroscopy of the surface of the body. This requires a specific and dedicated instrument, implemented on a spacecraft for a flyby, or better a rendezvous mission.

We are realizing the feasibility study of a thermal spectro-imager for future space missions to small bodies in the Solar System. With the recent progress of uncooled micro-bolometers (silicon detectors) technology and its space qualification under progress at the Centre National d'Études Spatiales (CNES, France), we aim to use such an infrared (9-14 µm) detector as a baseline for our thermal spectro-imager. We have defined four objectives to be achieved in order to reach our goal :

1. Understand the behaviour of the detector and obtain uncalibrated images.

2. Define a calibration method and operational modes to obtain calibrated radiometric images (thermal imaging follows very different constraints than visible imaging).

3. Perform spectroscopic measurements to check their feasibility with such a detector and define the best suited spectroscopic technique.

4. Define the instrumental concept including the optical and mechanical design and build a demonstrator.

In this paper, we show our progress on the first two objectives of this work.

II. EXPERIMENT

Our experiment to perform uncalibrated and calibrated radiometric images is composed of :

i) an IRXCORE640 module from the INO company (Québec), based on a 640x480 micro-bolometer array from the ULIS company (France) [1], and its associated electronics (Fig.1),

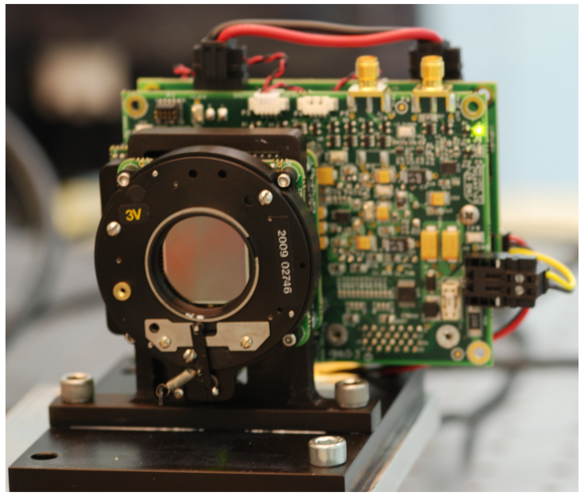

Fig. 1. The IRXCORE640 module: a 640x480 micro-bolometer array (front) and its associated electronics (back).

ii) a Surnia Series germanium objective (f = 50 mm @ f# = 0.86) from the JANOS TECHNOLOGY company (USA) (Fig.2),

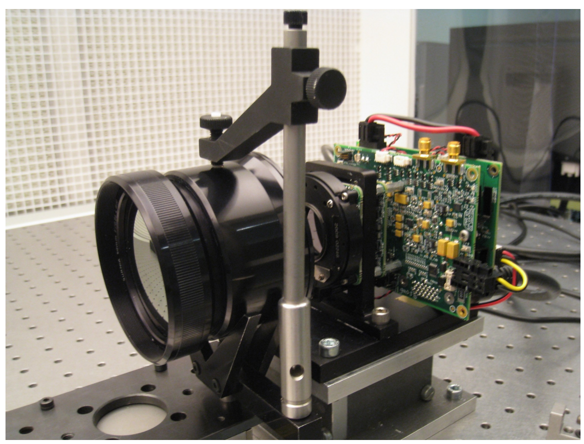

Fig. 2. The Surnia Series germanium objective (left) next to our detector, the IRXCORE640 module (right).

iii) and an OMEGA Engineering, Inc. black body with a temperature range from -18°C to +150°C with a maximum calibration uncertainty of +/- 0,2°C (Fig.3).

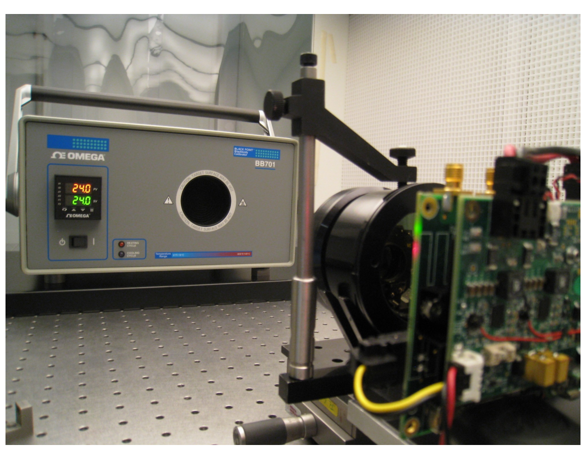

Fig. 3. The OMEGA Engineering, Inc. black body (grey box on the back).

III. RESULTS

A. Uncalibrated images

To complete our first objective, we took a series of uncalibrated images (Fig.4) while heating the black body. Thus, we were able to characterize the response of the detector for different integration times, gains, and detector operating temperatures.

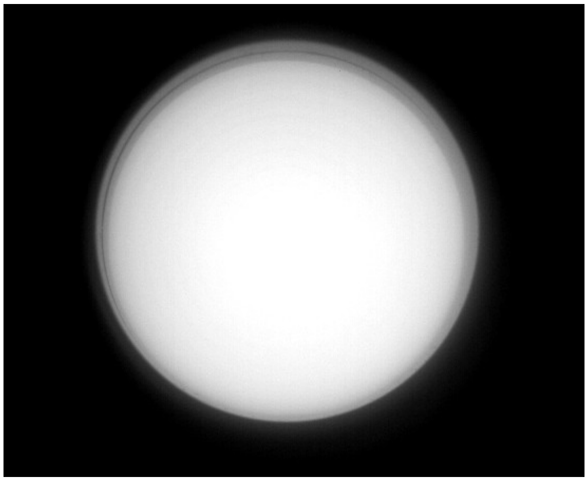

Fig. 4. An uncalibrated image showing the surface of the black body (in white).

We first established that for an integration time between 9 µs and 36 µs, and an operating temperature of the detector between 20°C and 30°C, the variations of the response of the detector are negligible (<0.3 %). We also tested the response of the detector for gain values ranging from 1.0 to 4.5. As expected, larger gain values lead to a larger dynamic but a smaller measurable temperature range.

Finally, we tested the stability of the signal of the detector over time (Fig.5). It takes approximately three hours for the detector to reach a temperature equilibrium with its surroundings (the room temperature is 20°C) after it is switched on. After those three hours, the signal remains stable, with for example variations lower than 0.2 % over a 16 minutes period. The long stabilization time is likely due to the initial heating of the read out electronics placed close to the detector.

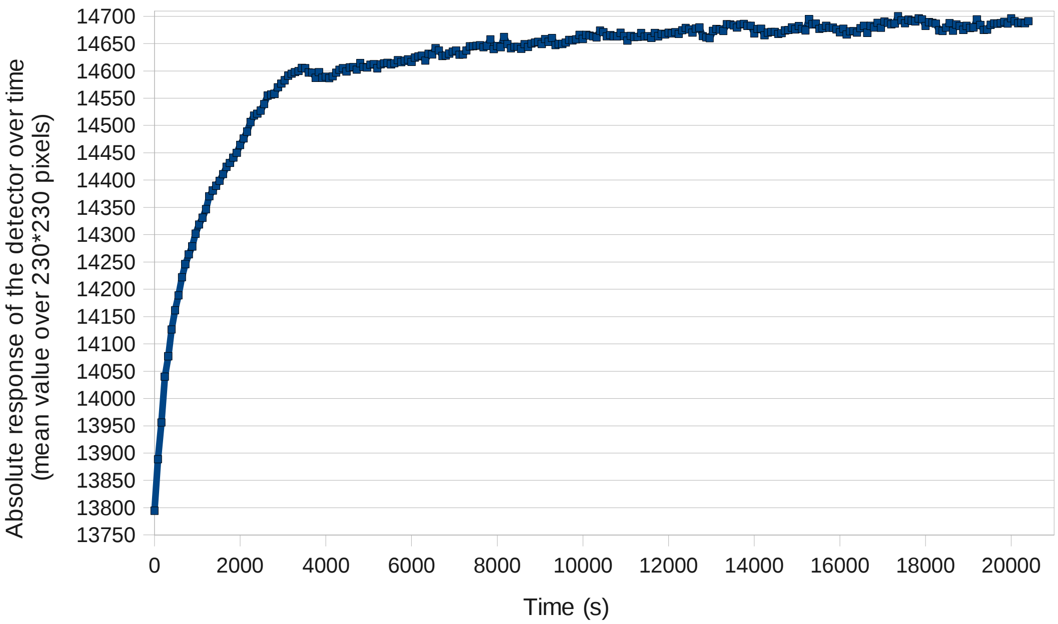

Fig. 5. Measurement of the signal of the detector over a period of six hours.

B. Calibrated radiometric images

To complete this objective, we took a series of calibrated images (Fig.4) while heating the black body and monitoring its temperature from 10°C to 70°C. We measured ten responses curves which can be seen in Fig. 6. These curves were all plotted using measurements done in the same conditions, though not on the same date, and they all show good repeatability.

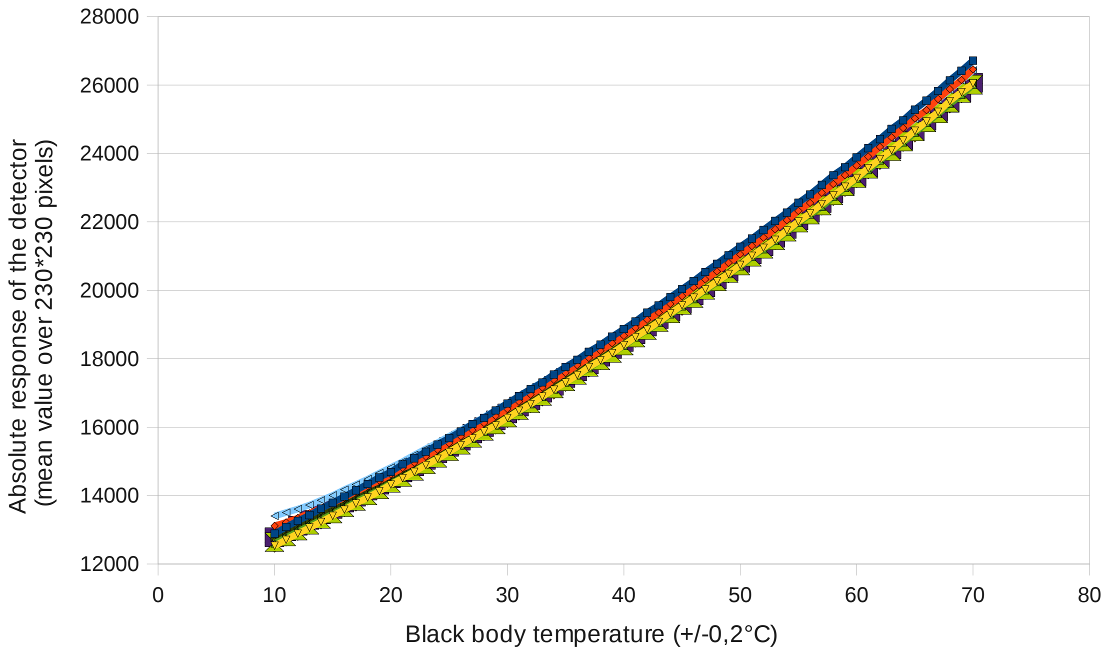

Fig. 6. Absolute response of the detector measured using a black body as our temperature controlled scene, with a temperature ranging from 10°C to 70°C.

According to the theory of microbolometers, we expect the response curves to be proportional to T^4, where T is the temperature of the scene. So, we fitted the ten responses with a fourth degree polynomial equation, and computed the mean deviations and maximum deviations (Tab.1). Assuming the temperature indicated by the black body to be exact as a first approximation, we converted the counts into Celsius degrees. Residuals are lower than 0,4% over the temperature range 10-70°C, for a mean value of 0,1%, corresponding to 0,1°C. Since we aim for absolute measurements of the temperature with an accuracy of about 1K, this looks a promising result.

Tab. 1. Mean deviations and maximum deviations of the residuals between fitted and measured response curves of the detector.

Mean deviation :										
Units	**Curve 1**	**Curve 2**	**Curve 3**	**Curve 4**	**Curve 5**	**Curve 6**	**Curve 7**	**Curve 8**	**Curve 9**	**Curve 10**
counts	9,31	12,97	15,32	9,96	14,16	9,24	10,5	12,84	8,65	9,64
°C	0,07	0,09	0,11	0,07	0,1	0,07	0,08	0,09	0,06	0,07
%	0,08	0,11	0,13	0,08	0,12	0,08	0,09	0,11	0,07	0,08
Maximum deviation :										
Units	**Curve 1**	**Curve 2**	**Curve 3**	**Curve 4**	**Curve 5**	**Curve 6**	**Curve 7**	**Curve 8**	**Curve 9**	**Curve 10**
counts	25,27	34,14	36,34	34,84	45,73	34,35	24,38	27,5	23,6	22,17
°C	0,18	0,24	0,26	0,25	0,33	0,25	0,17	0,2	0,17	0,16
%	0,21	0,28	0,30	0,29	0,37	0,28	0,20	0,23	0,19	0,18

IV. CONCLUSION AND PERSPECTIVES

Our first results to demonstrate the possibility to use an uncooled microbolometer for a thermal imager for space missions to small bodies look promising. However several points need to be addressed before we can design the instrument. In particular, during the next months, we will extend the temperature range of the scene to lower temperatures (up to -10°C), we will optimize the calibration (absolute accuracy and number of sources), and we will investigate the feasibility of spectroscopic measurements.

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