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USE OF « COTS » UNCOOLED MICROBOLOMETERS FOR THE OBSERVATION OF SOLAR ERUPTIONS IN FAR INFRARED

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ABSTRACT

The Small Explorer for Solar Eruptions (SMESE) mission is a French-Chinese satellite dedicated to the combined study of coronal mass ejections and flares. It should operate by the beginning of 2013. The spacecraft is based on a generic MYRIADE platform developed by CNES. Its payload consists of a Lyman α imager and a Lyman α chronograph (LYOT), a far infrared telescope (DESIR) and a hard X and γ ray spectrometer (HEBS). Its Sun-synchronous orbit will allow for continuous observations.

LESIA (Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique, in Paris-Meudon Observatory) is in charge of DESIR instrument. DESIR (Detection of Eruptive Solar InfraRed emission) is an imaging photometer observing the sun in two bandwidths: [25; 45 μ m] and [80; 130 μ m].

The detector is a commercially available, uncooled microbolometer focal plane array (UL 02 05 1, from ULIS) designed for thermographic imaging in the 8-14 μ m wavelength range. The 160x120 pixels are based on amorphous silicon, with dimensions 35x35 μ m².

The performances in terms of noise and dynamics given by the manufacturer associated with simulations of a perfect quarter-wave cavity to predict the microbolometer absorption, make possible the use of such a detector to fulfil the DESIR detection specifications in the two FIR bandwidths.

During the A Phase, tests have been carried out in our laboratory to validate the feasibility of the project. In this work, we present the first results obtained on the microbolometer performances in the FIR domain.

1. INTRODUCTION

1.1 Scientific Specifications

DESIR is a low spatial resolution imaging photometer which measures the time evolution of the flux densities of flares in two spectral bandwidths with central wavelengths in the ranges 35-80 μ m and 100-250 μ m respectively. The bandwidths are about $\Delta\lambda = \pm 0.3 \lambda$ and $\lambda_2/\lambda_1 \approx 3-4$. Such bandwidths and wavelength ratio have been adopted in order to both collect the largest possible flux and evaluate the spectral slope of the far infrared spectrum. The instrument essentially consists of a three mirrors telescope which images the Sun on two arrays of uncooled microbolometers. A set of filters is used to reject the thermal flux, to separate and select the two bandwidths.

1.2 Technical Requirements

These requirements are the result of a trade-off between the scientific goals, the allocated resources on the platform, and available detectors.

Table 1: PARAMETERS VALUES

Central wavelength λ_1	35 μ m
Central wavelength λ_2	105 μ m
λ_2 / λ_1	3
Spectral bandwidth λ_1	25 , 45 μ m
Spectral bandwidth λ_2	80 , 130 μ m
Detection threshold @ λ_1	$10^{-18} \text{ W m}^{-2} \text{ Hz}^{-1}$
Detection threshold @ λ_2	$10^{-18} \text{ W m}^{-2} \text{ Hz}^{-1}$
Flux measure accuracy @ λ_1	30%
Flux measure accuracy @ λ_2	30%
Expected max flux @ λ_1	$3 \cdot 10^{-16} \text{ W m}^{-2} \text{ Hz}^{-1}$
Expected max flux @ λ_2	$10^{-16} \text{ W m}^{-2} \text{ Hz}^{-1}$
Spatial resolution	50 arcsec at 35 μ m

Cadence	Goal : 0.1s (Acceptable : 1s)
Field of view	Full disk

1.3 Instrument design

The main drivers for the design are listed below:

- Use of an uncooled thermal detector (high solar flux level);
- Need of good thermal filtering at the entrance of the instrument (rejection of short wavelengths);
- Need of specific filters for both channels;
- Need of high aperture to limit the diffraction effect at long wavelengths;

The optical design is showed hereafter :

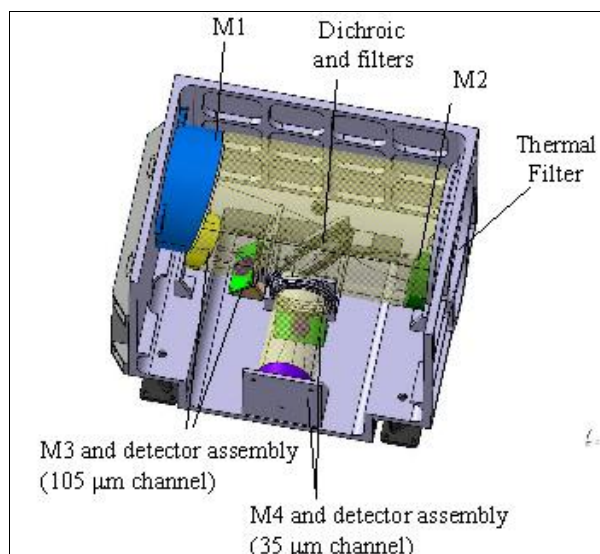


Fig. 1: the design of DESIR instrument

The two bandwidths have a dedicated detector. Light is collected by a common telescope (two off-axis parabola), and focused on each detector by a third off-axis parabola. A thermal filter is placed at the entrance of the instrument in order to reject wavelengths lower than 20 μm . A beamsplitter separates both channels, and bandwidths are selected by a set of filters placed between the beamsplitter and the focusing parabola.

2. IMPLEMENTATION OF THE DETECTOR

2.1 Description of the detector

From the earliest proposal, DESIR, which is an exploratory instrument, was based on a simple design avoiding cooled detectors and cooled instruments. Only thermal detectors were conceivable. The three

candidates were pyroelectric detectors, thermopiles and microbolometers. Pyroelectric detectors and thermopiles were excluded because of their too weak sensitivity.

We selected the ULIS “UL 02 05 1” for both channels

- Amorphous silicon microbolometer
- Uncooled operation
- Adjustable integration time
- 160 x 120 pixel focal plane array (5.6 x 4.2mm²)
- MIL STD 883-810 qualified
- Frame rate up to 60 Hz
- Pixel-pitch: 35 μm
- Fill factor: 80%
- NEDT= 55 mK @ f/1, 300K, 60 Hz

From these data, the NEP calculated in the standard band [8; 14 μm] is about 30pW.

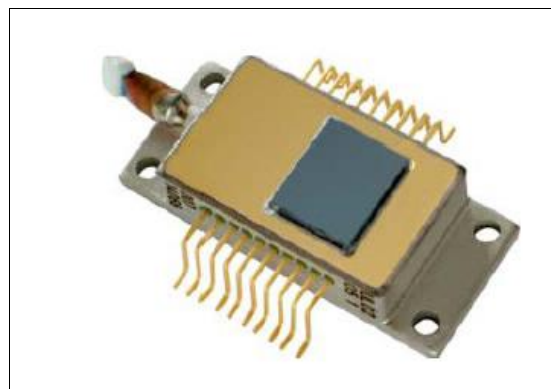


Fig. 2: the “UL 02 05 1” with Ge window

2.2 Adaptation to FIR wavelengths

Absorption efficiency in the FIR domain is limited by three parameters :

- The Ge window is opaque around 30 μm
- The pixel surface is smaller than the PSF (Point Spread Function) size
- The quarter wave cavity is optimized at 10 μm , and thus shows a poor absorption in FIR (theoretically, 60% at 35 μm and 15% at 100 μm)

- The first point was resolved by removing the Ge window by courtesy of ULIS. The microbolometer is then set up in a vacuum chamber with a diamond window. Another solution would be a Si or Picarin window.
- To solve the second point, we have to sum four neighbouring pixels [1].
- For the third point, CEA-LETI, who designed this microbolometer, studied the adding of adapted multilayers above the cavity. Theoretical simulations gave good results in our two channels, but the technological development of such a solution was too expensive for our small mission.

2.3 Photometry in the FIR

Considering the optical layout of the instrument and absorption efficiency of the detector, we can evaluate the incident flux on one pixel :

Table 2: EXPECTED VALUES ON ONE PIXEL

Band	[25; 45 μm]	[80; 130 μm]
Flare min	2,5 nW	0,073 nW
Flare max	1600 nW	14 nW
Quiet Sun	54 nW	1,8 nW
Temperature variation of 5°C	29 nW	29 nW

In the lower bandwidth, the SNR (Signal to Noise Ratio) of 80 is high enough to detect the minimum flare. But in the upper bandwidth, the SNR corresponding to the minimum flare is only 2.5, which is too low for detection. Thus, on-board detection will be realized only by the 35 μm channel, and measurement will be recorded by both channels.

The detector integrity is based on the maximal flare. In [25; 45 μm], the flux can raise the pixel temperature about 50°C : in power-on mode, this can destroy the detector. Two solutions are under consideration : close a shutter or turn off the detector (if we have time!).

The quiet sun flux is much lower than the maximum flare. It can therefore be included in our measurement range without loss of resolution. It's a good news because this allows measuring the sky too (like a reference).

The variation of the instrument temperature giving the same level as the flare is a few 10⁻³ K. It is not conceivable to regulate the instrument with this accuracy. We will use the fact that the phenomena have different time constants and geometries to separate them. But a rough regulation is always necessary in order not to leave the dynamic of measure.

2.4 Electrical management of the detector

Fig. 3 shows the readout circuit of the detector. It allows many degrees of freedom to adapt the pixel reading with our constraints.

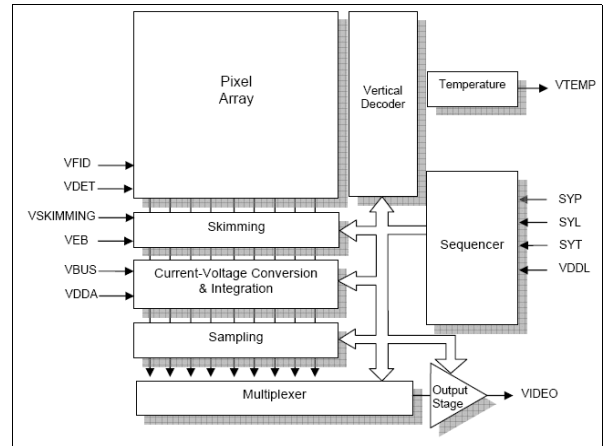


Fig. 3: the "UL 02 05 1" ROIC

Our test bench includes a low noise electronics with which we were able to vary multiple parameters:

- « standard » variable polarizations VFID (for gain) and VSKIM (for offset),
- « exotic » polarizations VEB and VBUS,
- Sampling frequency through SYP,
- Integration time through SYL,
- Frame rate through SYT,
- Detector temperature with the TEC.

Two configurations have been tested: first one is the « standard » (with a CEDIP electronics) and second one is more specific (with our electronics).

Table 3: DETECTOR READOUT SETTINGS

Use	Standard	Specific
VFID	around 3,3V	around 2,8V
VSKIM	around 5,5V	around 4,9V
VEB / VBUS	2,2V / 3,2V	2,2V / 3,2V
Sampling	5,3MHz	1MHz
Integration time	60 μs	180 μs
Frame rate	50Hz	40Hz
Detector temp	around 30°C	Around 20°C
Resolution	14 bits	16 bits
Windowing	no	yes

2.5 Radiation tolerancy

SMESE mission is on heliosynchronous, low earth orbit. No specific test was made but we can notice that (cf [2], the UBBA project, in the framework of the MERTIS instrument for BepiColombo mission) :

« ... although these devices were not specifically hardened for the space radiation environment, they will be suitable for demanding space applications - although latch-up protection will be needed.. »

3. FIRST RESULTS IN THE [8; 14μm] BANDWIDTH

This first step was to check that the detector is properly driven by our electronics and reaches manufacturer performances. This work was conducted in the standard bandwidth [8; 14μm]. The Germanium window was still mounted on the chip. A blackbody was focused on the detector with a ZnSe lens (f/#3) with optimized coating.

Below, for example, the fig. 4 shows the response for two set of polarizations, with our electronics. From temporal noise on each pixel, it was deducing a mean NEP of about 30pW, according to preliminary data.

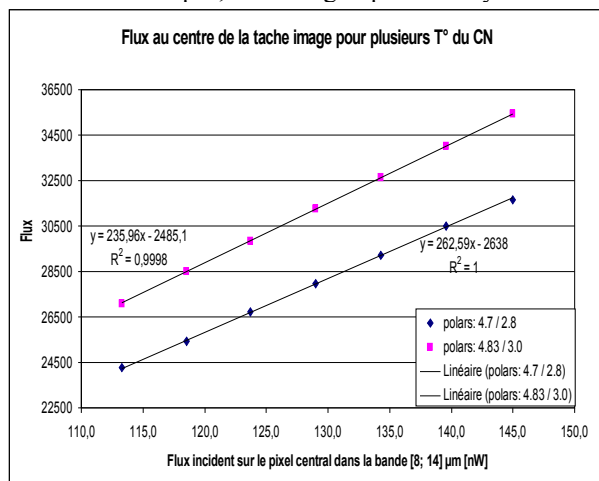


Fig. 4: Flux response of detection chain

The electronic parameters of the chain of detection were validated and quantified (limits, drift, noise), then we could characterize the response of bolometer in our specific bandwidths.

Table 4: SOME RESULTS FOR Tint = 60 / 180 μs

VSKIM domain	from 3,2V to 5,2 / 5,5V
dVout / dVSKIM	10 / 30
VFID domain	from 0V to 3,2 / 3,5V
dRESP / dVFID	3 / 6% ΔVFID=100mV
NEP abs. at VFID= 3,5 / 3V	0,05 / 0,03nW
Dynamic at VFID=3,5 / 3V	300 / 170nW

4. LASER ILLUMINATION

During this project, one of the hardest issues to solve was to find a powerful source in the [20; 150μm] bandwidth. GES (Groupe d'Etude des Semiconducteurs, Montpellier University, France) has a gas laser which provides a line at 118.8μm (2.5THz).

Fig.5 shows an image recorded with the microbolometer

(Ge window removed) illuminated by the laser:

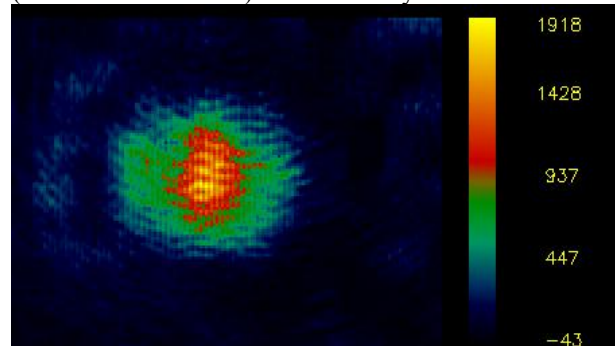


Fig. 5: Laser 2,5THz with 2,5mm metal diaphragm

Too many uncertainties on the laser beam forbade us to estimate the absorption efficiency. As against, it was a good encouragement to view this « color » with a good S/N (above 10).

5. FOURIER TRANSFORM SPECTROMETRY

5.1 Integration

In order to measure the spectral response of the microbolometer, we used a FIR FTS (Fourier Transform Spectrometer) kindly lent by IAS (Institut d'Astrophysique Spatiale, Orsay, France). The FTS is a SPS-200 model from Sciencetech. It uses a Mercury medium pressure lamp and a 4K cooled bolometer in synchronous detection (presence of a chopper and lock-in amplifier), placed in the condensing beam.

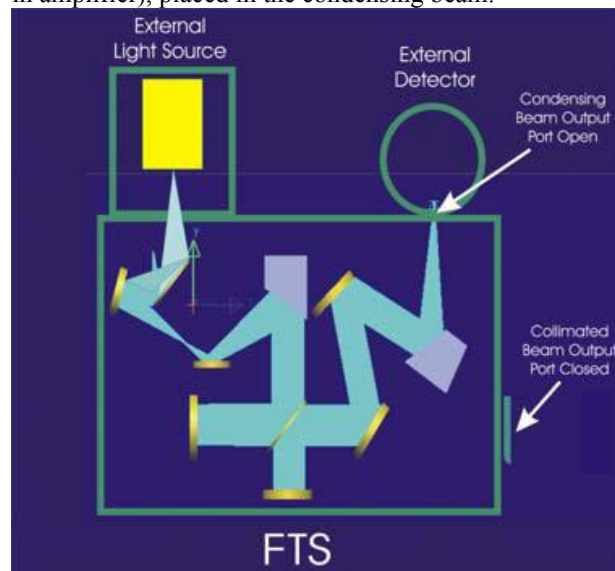


Fig. 6: Spectral analyzer layout

Our microbolometer is mounted on the second external port (see “Collimated Beam Output” on Fig.6). An off-axis parabolic focuses the beam on the detector. The FTS runs in “step and integrate” mode to synchronise

movement of the scanning mirror and data acquisition with the microbolometer. Synchronisation is achieved by homemade software. The scanning mirror travels through the distance needed to obtain a spectrum resolution of 5 or 10 cm⁻¹. One interferogram requires several minutes of acquisition.

5.2 Signal cleaning

An example of image is shown below, with the scanning mirror close to ZPD (Zero Path Difference). The three rectangles on the right show the areas where pixels containing signal are averaged. The rectangles on the left lie exactly on the same rows: they are subtracted from the first ones to correct drifts, if any.

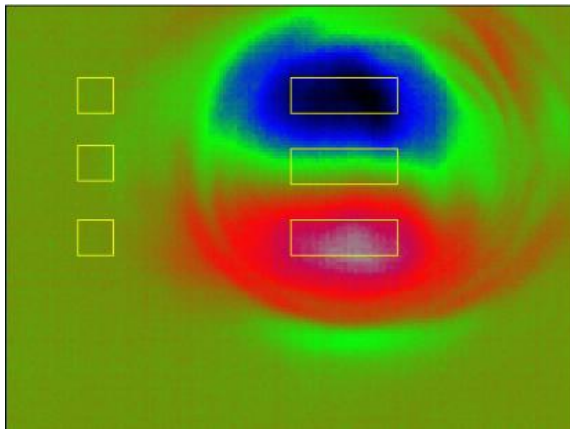


Fig. 7: Image near the ZPD

The figure below shows the interferograms obtained after corrections by reference areas. Drifts have been eliminated and a zoom would show the shift between the three ZPD positions.

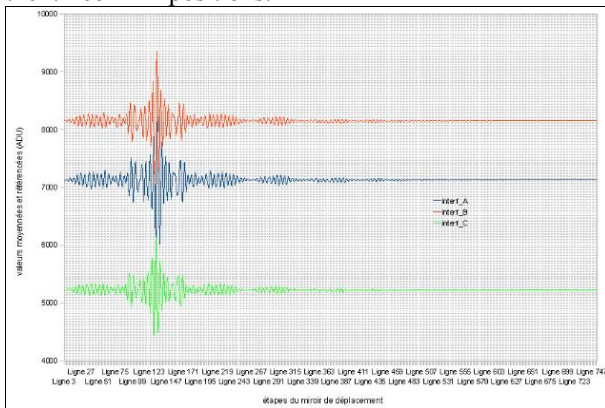


Fig. 8: Interferograms of three zones

Such measurements were made with both microbolometers: one with the Ge window and the other one with the diamond window. Fourier Transform of the interferogram results in a spectrum of detected flux.

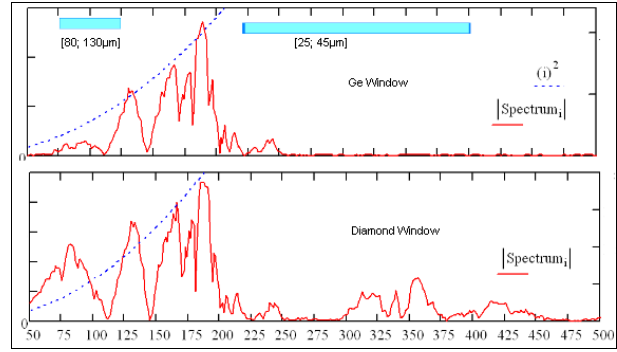


Fig. 9: Spectra vs wavenumber (cm⁻¹)

Spectra show that the replacement of the Ge window by a diamond window is effective in our two bands of interest. The absence of flux (from 250 to 300cm⁻¹) seems to be a beamsplitter effect.

A measure of absolute absorption requires a reference to the same spectrum by the Golay detector (supposed with flat response). Given that the detector is not on the same optical path, we must also correct the spectra of the various transmissions (filters, windows). This analysis is still ongoing.

5.3 Thermal evolution

We took advantage of good stability of this test bed for conducting tests in temperature. For several levels of flux, we vary the temperature of the microbolometer around the ambient (21 ° C), thanks to the TEC (Thermo-Electric Cooler) integrated into. We must be careful because it's the temperature of the die, not the package.

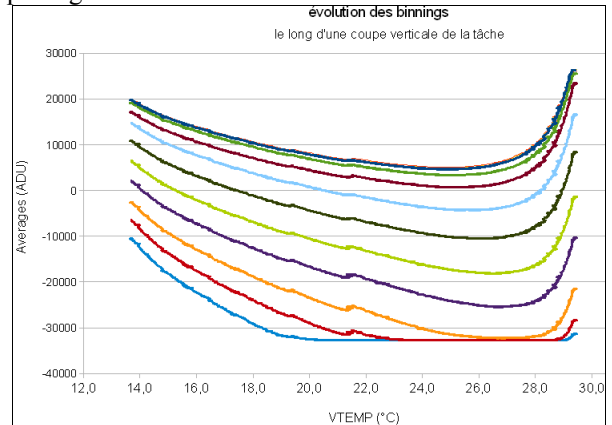


Fig. 10: Interferograms of three zones

This result is interesting in that it shows a relatively flat area: the detector must operate at a few degrees above its surroundings to minimize temperature fluctuations effects. A similar effect was obtained in an electro-thermal modelling of a pixel. This makes us confident in understanding its behaviour.

6. SIMULATION OF THE INSTRUMENT

6.1 Experimental setup

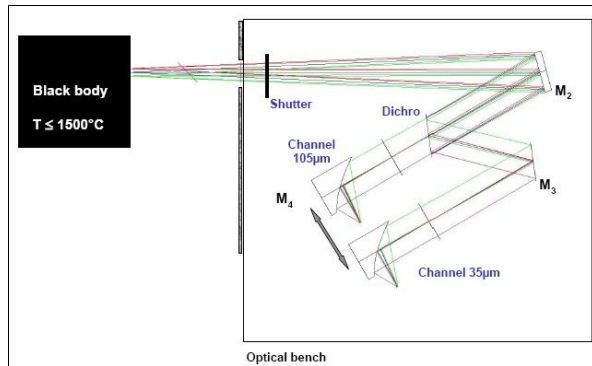


Fig. 11: LESIA test bench

The test bed developed in LESIA facilities aims at simulating DESIR instrument. It consists in imaging an optical source providing flux in FIR onto a microbolometer, using metal mesh filters to select the useful bandwidths.

The optical source is a black body lent by ONERA/DOTA (Département d'Optique Théorique et Appliquée, Palaiseau, France), which temperature can reach 1500°C. Even at that temperature, the flux given by the black body at 105µm is weak. Mirror M2, spherical, with gold coating (as the other ones) collimates the incident beam before the filters. The metal mesh filters have been designed and manufactured by QMC Instrument Ltd. (Cardiff) according to DESIR specifications. They have been delivered with their performance measurements. The set of filters includes:

- Two thermal filters
- One dichroic filter which separates the two channels and achieves the low pass filter for the 35µm channel in reflection;
- One high pass filter for the 35µm channel;
- One blocking filter for the 35 µm channel;
- One low pass filter for the 105 µm channel;
- One high pass filter for the 105 µm channel;
- One blocking filter for the 105 µm channel.

The blocking filters ensure an out of band rejection better than 10^8 . Mirror M4, an off-axis parabolic mirror, focuses the beam on the detector. M4 and the vacuum chamber containing the detector can translate in order to select the 35µm or 105µm channel.

6.2 [25 ; 45µm] bandwidth

With a black body at 1500°C and a good atmospheric transmission in the band [25; 45µm], the flux is high enough to easily adjust the focus (real-time viewing on raw images of bolometer, see Fig.12).

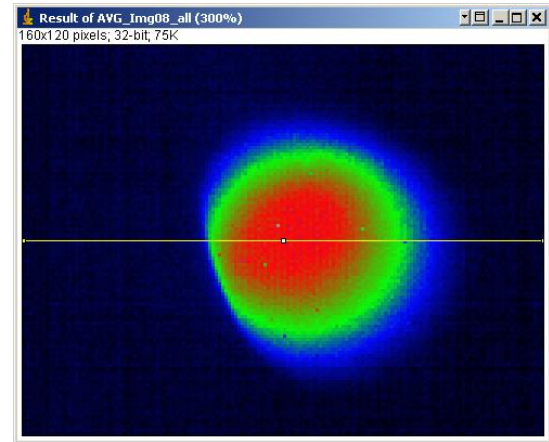


Fig. 12: 1050°C black body @ 35µm

Considering transmission data given by QMC, perfect black body (emissivity of 1) and theoretical absorption of a 10µm quarter-wave cavity, numerical value of response can be expected. A cut of the previous image is shown below:

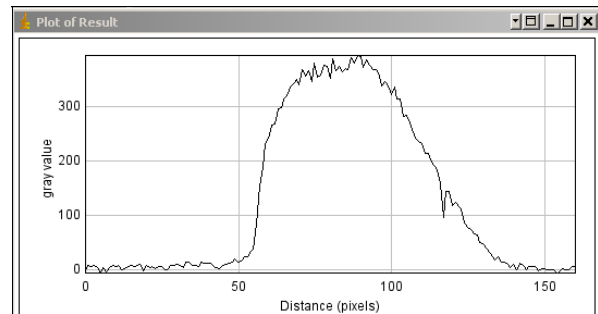


Fig. 13: Shape of image @35µm

The SNR is approximatively three times smaller than estimated by calculation. It remains compatible with the instrument specifications.

6.3 [80 ; 130µm] bandwidth

In these bandwidth, it is necessary to work under dry nitrogen (optical path 2m). Focusing the beam on the detector has been more difficult to achieve and the image appears distorted (presence of filters?).

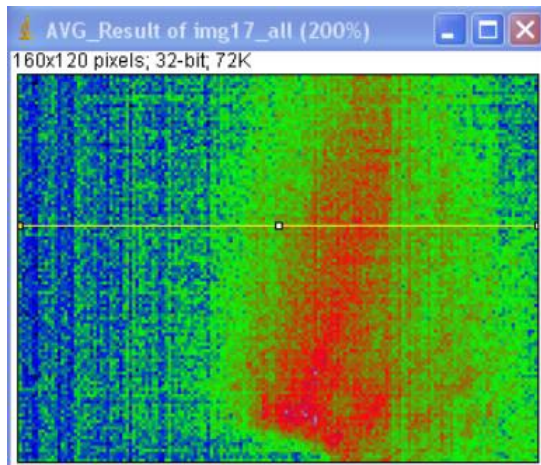


Fig. 14: 1500°C black body @ 105µm

Here, the SNR is about two times smaller than estimated and again compatible with the specifications.

Another long-term test was conducted: periodically, the output of the black body was obstructed. A recording of about six minutes is shown here:

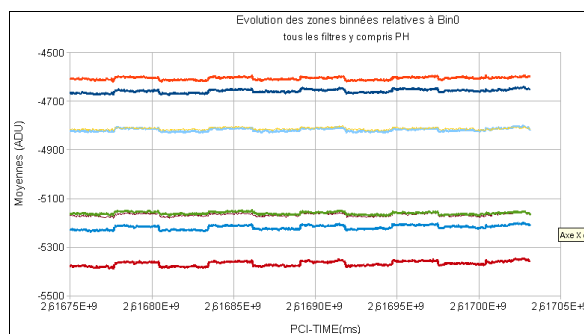


Fig. 15: Temporal evolution of different binned zones

Though weak, moments of enlightenment are obvious. It should be noted that during this test, there was no thermal regulation. Again, the drifts were eliminated by subtracting to dark areas of the image.

7. CONCLUSION

Start with the good results:

We managed to detect light in FIR in several configurations: with laser illumination at 118.8µm, with a large spectrum on the FTS, and in the two DESIR bandwidths on the LESIA test bed. During these experiments, we mastered the use of this detector and quantified the influence of some thermal and electrical parameters.

But ... we still do not know precisely the absolute value of absorption in our two bandwidths. To obtain this important information, several works have to be carried out:

- THz laser: GES should measure the beam shape and its absolute intensity; moreover, we could use a second line at 100µm.
- FTS: a better understanding of the different elements would get this absorption. If the beam was more intense (Global hotter) or if the efficiency of beamsplitter increased (Si beamsplitter thick).
- LESIA test bed: nevertheless as we took in our calculations the maximum values of device (blackbody, filters, mirrors...) performances, the estimation is obviously conservative. The mastery of the use of filters should be increased (multiple reflections?). We need more than that automating the test bench under nitrogen to work more effectively.

The microbolometer behaviour under strong illumination remains to be precisely checked. For an absorbed power of 1000nW, the pixel temperature rises to about 40°C. Some studies have already shown an effect of remanence. This phenomenon must be quantified in terms of level of flux and duration.

Another very important point, that requests a budget we don't have for the moment, is the influence of polarization on the absorption of such a grid of pixels...

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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