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Low flux NGP characterisation for microcarb application

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ABSTRACT

CNES (French Space Agency) is developing a microsatellite to monitor and characterize CO_2 surface fluxes, that is, the exchanges between sources (natural or anthropogenic) and sinks (atmosphere, ocean, land and vegetation). A better assessment of carbon fluxes is necessary to improve our understanding of the mechanisms governing the exchanges between sources and sinks, their seasonal variability, and their evolution in response to climate change. Values of CO_2 concentrations need to be measured with high precision, of the order of 1 ppm (to be compared with the CO_2 concentration of 400 ppm) to be able to estimate gradients which amounts to a few ppm.

The instrument on board MicroCarb is an infrared passive spectrometer operating in four wavelengths using an echelle grating (dispersive element) to achieve spectral dispersion. The spectral bands cover vissible end Short Wave infrared domain, from 764 µm to 2,075 µm.

The selected detector is the NGP (new Generation Panchromatic) manufactured by Sofradir, supplied with a specific AntiReflection coating in order to optimize both sensitivity and stray light.

The high accuracy level of the mission requires a high performance detector, operating at low incident flux, and whose imperfections will be very well known, in order to be corrected. The detector non-linearity is the main performance that has to be calibrated in order to allow the overall scientific objectives. CNES has developed a specific test bench in order to assess this performance.

This paper describes in detail

- The test bench constitution
- The test bench calibration
- The first detector measurements

Keywords: Microcarb**,** infrared spectrometry, low flux, detector non linearity, test bench.

1. INTRODUCTION

CNES (French Space Agency) is developing a microsatellite named Microbcarb, to monitor and characterize CO_2 surface fluxes, that is, the exchanges between sources (natural or anthropogenic) and sinks (atmosphere, ocean, land and vegetation).

. Anthropogenic emissions bring an quantity of 10 gigatons of carbon, with the effect of disrupting the natural climate balance. This surplus is half absorbed by vegetation, land and the oceans, the other half being of the reason for the increase in the atmospheric concentration of greenhouse gases (mainly CO2), driving climate change.
MicroCarb will also imeasure atmospheric methane, the second most important anthropogenic greenhouse gas whose emissions are poorly known.
A better assessment of carbon fluxes is necessary to:

- Improve our understanding of the mechanisms governing the exchanges between sources and sinks, their seasonal variability, and their evolution in response to climate change,
- Identify the parameters that control carbon exchanges
- Validate and improve (by reducing their uncertainty) the models simulating the carbon cycle

In addition, MicroCarb aims to be a precursor of a future operational system able to accurately monitor global fossil emissions.

Fluxes cannot be directly measured but must be calculated from measurements of atmospheric concentration made by satellites and from the inversion of these data by mean of an atmospheric transport model. The surface fluxes thus obtained are global fluxes taking into account natural and anthropogenic fluxes.

Concentration values of gases are themselves computed from measurements of the atmospheric spectrum in some wavelengths specific to these gases. CO_2 (and methane) is a gas with absorption lines in the infrared (at 1.6 and 2.0 µm); solar radiation reflected by Earth then goes through the atmosphere twice before reaching the satellite and carries the signature of these molecules. The concentration is deduced from the depth of these absorptions in the measured spectra.
MicroCarb will then measure the spectral radiance of the solar radiation reflected by Earth, at nadir on land surfaces and at glint on the oceans. These spectral radiance measurements will be converted into column integrated concentrations of CO_2 by applying a mathematical inversion of the spectrum.

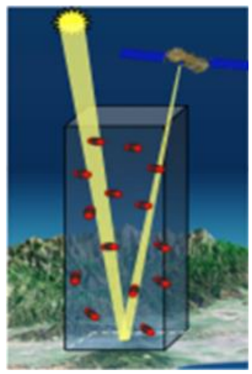

Figure 1. MicroCarb measurement principle

The instrument on board MicroCarb is an infrared passive spectrometer operating in four wavelengths using an echelle grating (dispersive element) to achieve spectral dispersion.

The instrument measure atmospheric spectra for the following species:

- Oxygen (O_2 at 0.8 µm) to retrive the surface pressure and then normalize the computed CO_2 column concentration
- Carbon dioxide (CO_2) in two bands: a first band around 1.6 µm, a second band around 2 µm,
- Methane (CH_4) about 1.67 µm.

The entrance of the spectrometer is a narrow slit perpendicular to the track of the satellite that scans the ground during the detector integration time.
The echelle grating performs spectral dispersion and optical narrow band filters select the useful bands. The light beams are then directed towards a detector which is then used for both dimensions:

- a spectral dimension, used to collect the spectrum of each band
- a spatial dimension, which is the image of the ground as seen by the slit for each of the bands

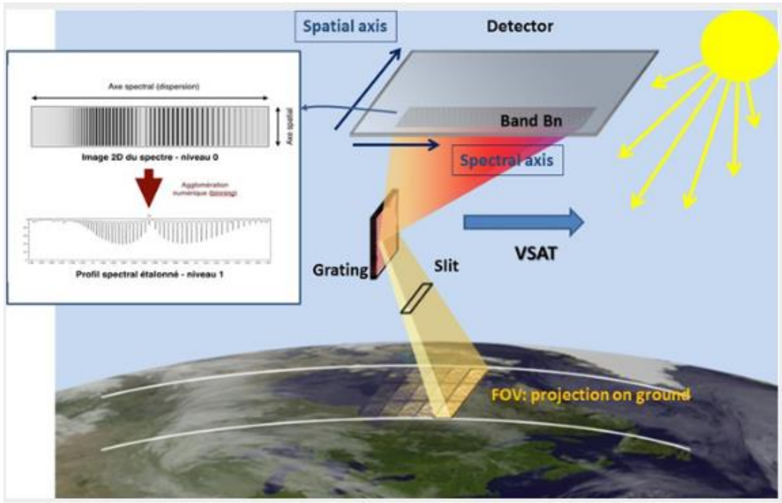

Figure 2:. MicroCarb instrument principle

The instrument includes an imager designed to detect clouds whose presence would cause erroneous measurements by the spectrometer.

Type	Passive infrared spectrometer			
Principle	Echelle grating			
Wavelengths	764-768 nm	1,602-1,619 nm	2,037-2,065 nm	1,660-1,672 nm
Spectral resolution	> 25,000	> 25,000	> 25,000	> 25,000
Signal to noise ratio	600	600	280	600
Detector	HgCdTe 1k x 1k matrix			

Table 1: MicroCarb spectrometer mail performances

Values of CO2 concentrations need to be measured with high precision, of the order of 1 ppm (to be compared with the CO2 concentration of 400 ppm) to be able to estimate gradients which amounts to a few ppm. This requires the knowledge of detector non linearity with an accuracy better than 0,1%

The detector non-linearity characterization must be representative of on flight conditions, and so must fulfill the following condition

- Fixed Integration Time : 1 s
- Varying illumination
- input signal range : between 4500e-/s/pixel and 60000 e-/s/pixel, including background flux and dark current

Non linearity definition
The non-linearity is Ratio between the measured signal and an reference curve (straigth line or polynomial)
We compare the measured signal and its linear regresssion.

$$NL_{\%}(\textit{Received signal}) = 100 * \frac{\textit{Mesured Signal} - \textit{linear regression value}}{\textit{linear regression}}$$

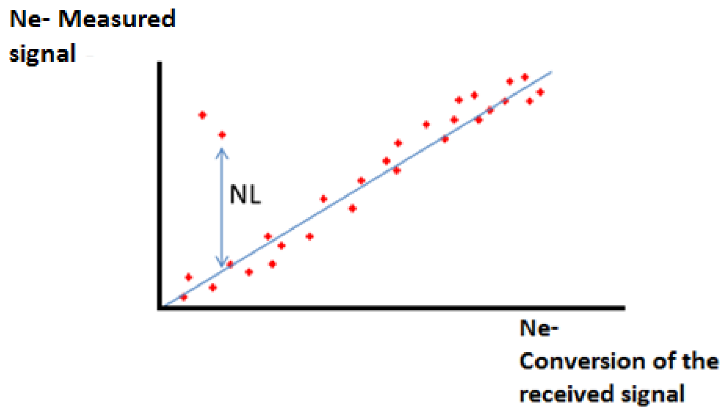

Figure 3 : non linearity definition

For MicroCarb a requirement is to know the residual non-linearity (after correction) with an uncertainty of 0.3% after correction (goal 0.1%).

The detector selected for MicroCarb is the SOFRADIR NGP (New Generation Panchromatic) with a CTIA (Capacitor Transimpedance Amplifier) ROIC. The linearity of the CTIA stage is unknown for low signals

The NGP Detector MCT used for the characterization has

- The same ROIC than Microcarb one
- MCT cut off : 5,3 µm (2,5µm for MicroCarb)
- Detector temperature : 60K
- Dark current 2500 e-/s
- Colbalt 60 irradiated component

2. TEST BENCH DESCRIPTION, CAPABILITIES AND PERFORMANCES

The optical bench is included in a vacuum dewar with the following parts :

- Detector NGP with cooling stage
- Custom analog board to manage video chain and power supply
- A black body to generate the flux (From IASI project)
- Stray light shield with narrow filter @ 70K
- The NGP detector and its proximity electronics

Outside the dewar

- A space qualified Analog to Digital Converter
- The Pulse generator to manage the acquisition
- The Computer
- The compressor

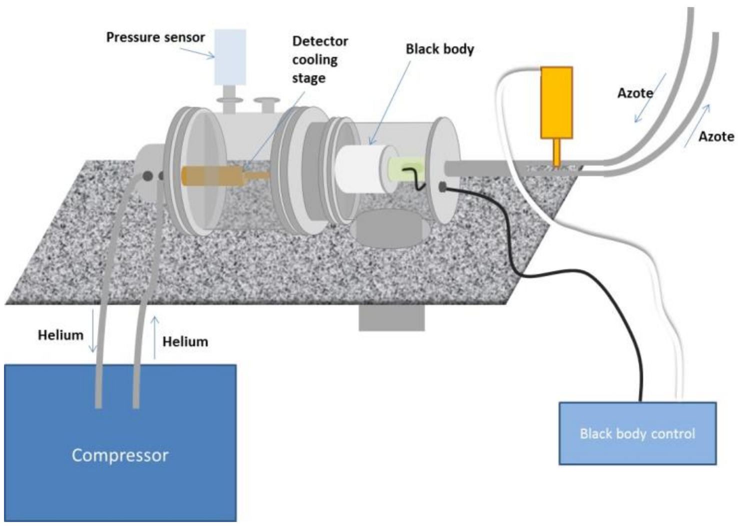

Figure 4 : Bench description

Stray light mtigation

In order to reduce the stray light, several elements have been implemented

- A Radiation shield @ 70K to remove background effect
- Pass-band filter at 2.9µm +/- 100nm measured @70K to reduce the spectral band
- The optical Aperture N=12
- The Black body used in range 160K to 285K with 3 thermal sensors to measure its temperature.

The parasitic current is as low as20e-/s/pixel

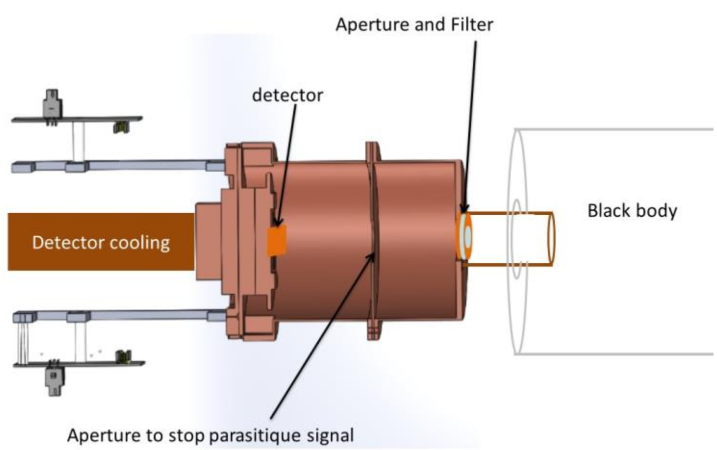

Figure 5: detector Housing

Electronics

The electronics consists in 4 analog chains, with gains between 0.8 and 10, and using 14 bits ADC RHF1401
Each cahin has been calibrated in terms of

- NLI : Integral no linearity : 3LSB
- NLD Differential no linearity 0.3 LSB

Electronics NLI and NLD will be corrected in the detector acquired data

3. ACQUISITION PRINCIPLE

For each Blackbody temperature, we perform acquisitions using the "up ramp mode": 16 acquisition points between 110µs (the lowest available integration time) and 1,3s (the MicroCarb mission acquisition time) : We will see that this will allow to compensate bench drifts

We can use different areas for calculation
- Pixel
- Macro pixel : Median of 10x10 pixel
- Frame : Median of 256x1024 pixel

Linearity definition
2 type of non linearities are measured :
- 1 - linearity with constant flux and **Integration time variation**

→ allow to reduce uncertainty of input signal
- 2 – linearity with constant integration time (MicroCarb nominal one) and **illumination variation**.

→ Mission representative

Received signal from black body
To have a linearity “measured/received electrons” we need to estimate the number of converted electrons for each black body temperature.

Signal per pixel
The formula given the received signal is given below:

$$Signal_{e^-}(T) = K * T_{int} * \Omega_{i,j} \int \varepsilon\,(\lambda) * Q_{e_{i,j}}(\lambda) * Tr(\lambda) * L(\lambda, T) d\lambda$$

So it depends on
- Integration time (known)
- Filter band (measured at operating temperature
- Solid angle (independent of BB temperature, constant factor
- Detector properties (CVF measured, QE estimated from another component of the same production)
- Black body temperature (measured)

Processing before linearity calculation
Before linearity calculation the following operations are processed:
- Estimation of the received flux per pixel
- Subtraction of the dark current (measured @160K)
- Correction of the PRNU (Photo Response Non Uniformity) by normalization

4. VALIDATION AND CALIBRATION

Due to the required accuracy level, it's particularly important to perform an accurate bench calibration
Accurate NL measurement requires the following calibrations and corrections :
- Electronic noise and linearity
- Detector measurement (CVF, QE, ROIC noise)
- Flux level at the detector (filter, solid angle, black body flux)

- Drift short time and long time (electronic and black body)
- Dark current measurement
- Sensitivity test
- Repeatability (form is constant, offset error <0,2% flux variation, 0,05% Tint variation)
- Area selection for the linear regression calculation. In order to compare the measurement together.
- Accuracy estimation

Drift compensation

- Blackbody temperature drift : The Temperature of the black body during is measured before each acquisition and a possible drift is corrected
- Electronic offset : Electronic offset during is measured at each acquisition of the detector, by Up the ramp mode reading at 110µs, and subtracted from the acquired value : so we are insensible to

Random accuracy estimation

Random accuracy depends on several factors :

- Electronic Noise (191^{e-} for BB at 160K), 1.3s including background, analog chain, ROIC, signal, dark current
- Low frequency variation in 100s < 12^{e-}
- Back body variation 100s <0,01K
  - 31^{e-} for Tcn 285K
  - 0,3^{e-} for Tcn 240K
    - → For low flux, reduction of the noise with macro pixel (10x10) or frame
    - → Low frequency variations have a strong impact to the NL (0,1% for 10ke-)

The Signal to Noise Ration is measured as below

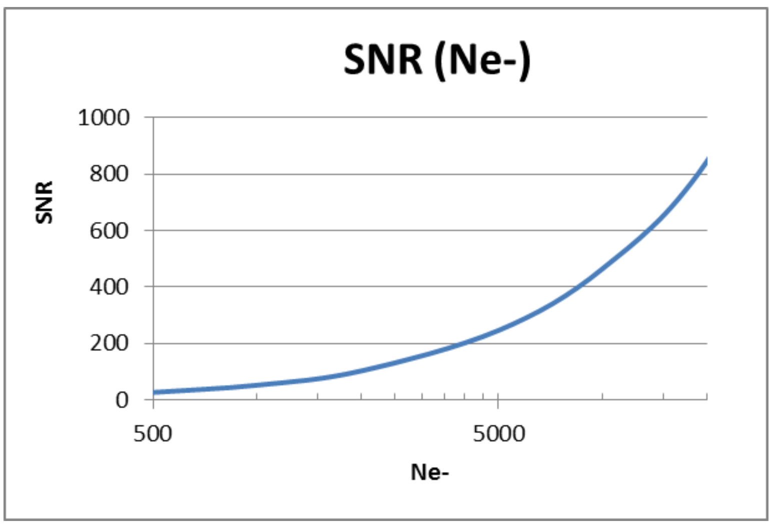

Figure 6: Signal to Noise Ration measurement

Worst case random error including:

- Noise 3σ
- Black body variation@280K in 100s
- Low frequency variation in 100s

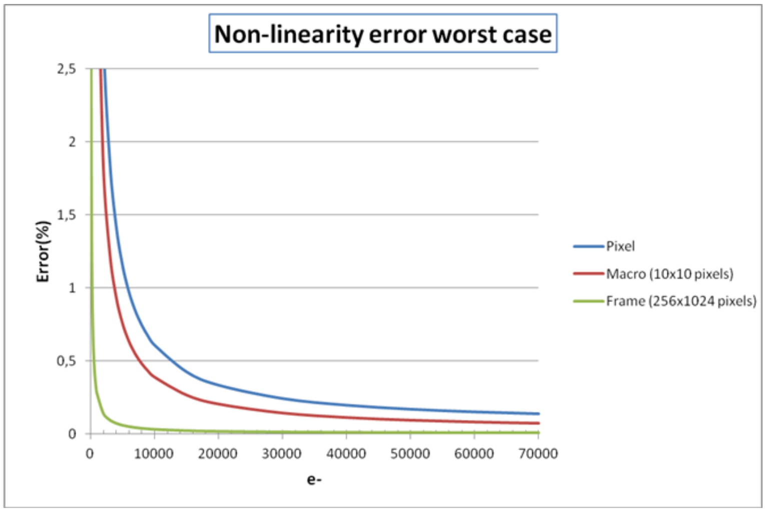

Figure 7 : total random accuracy level

5. RESULTS

<u>Preliminary results (with flux variation) are given below</u>

Median of 1024x256 pixels

- Temperature from 160K to 330K
  - No back body temperature stabilization
- 10 samples to have a high number of measurements

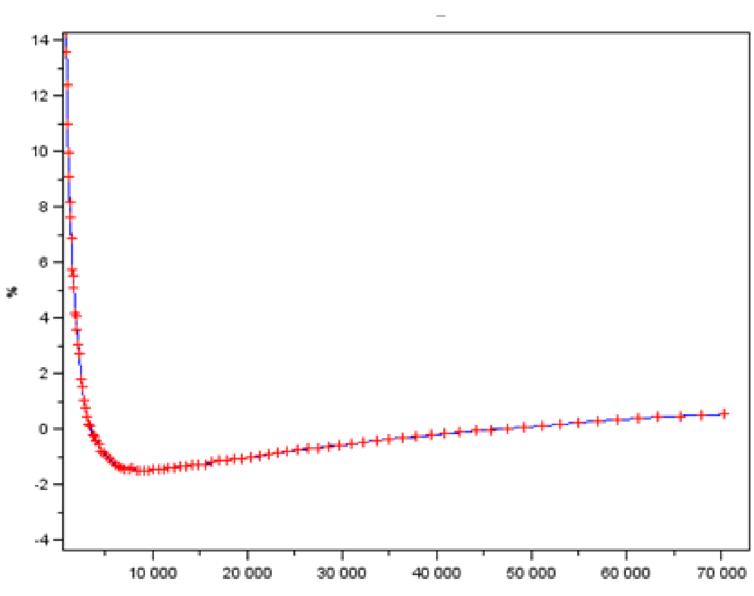

Figure 8 : matrix level non linerity (illumination variation)

Macropixel level

Macro pixels (10x10 pixels) had been compared to verify if the areas of the detector have the same linearity.
For one video channel: no disparity has been detected.
The disparities are at the noise level.

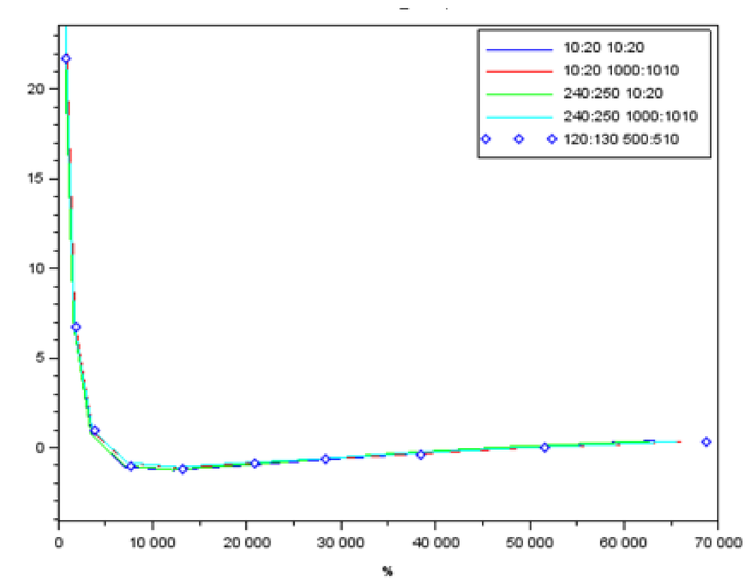

Figure 9: NL Measurement for 5 Macro pixels 10x10 in different locations ((illumination variation)

Pixel level

In a macro pixel for 100 samples, the difference between the pixels is included in the noise

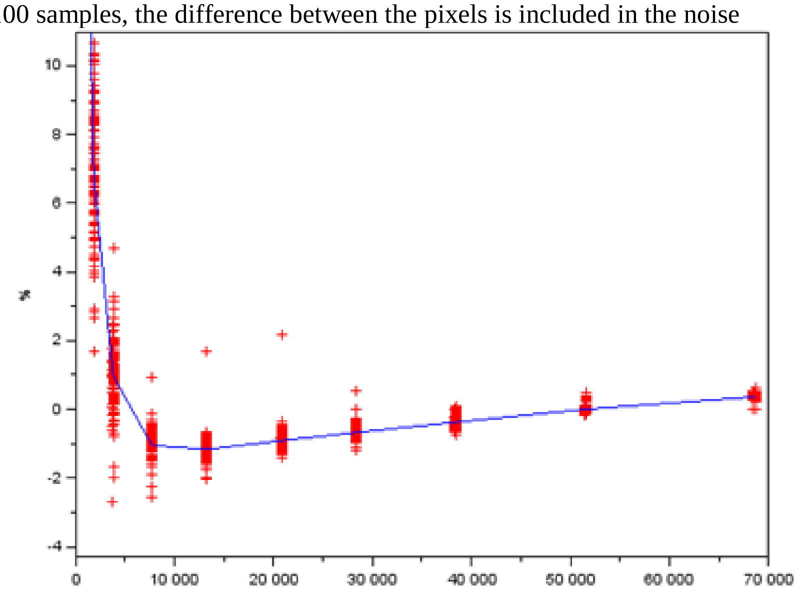

Figure 10 : NL at pixel level (illumination variation)

Preliminary result – Integration time variation

The curve corresponds to an assembly of linearity result for integration time variation at several flux levels in order to cover the dynamin with a good resolution
Median of 256x1024 pixels and 100 reading
Different measurments matched in the overlap to reduce effect of QE uncertainty (assuming low non linearity)

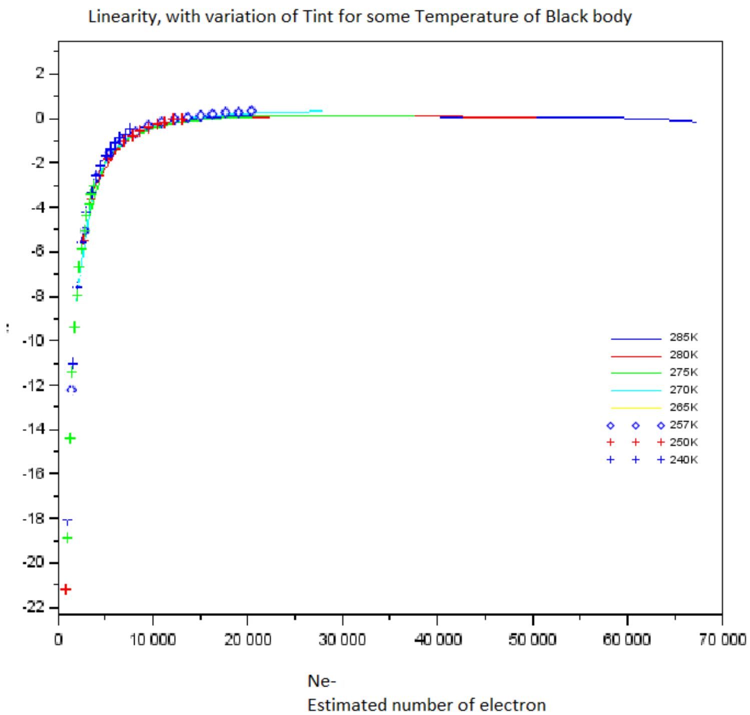

Figure 11 : NL at matrix level (Integration time variation)

6. NEXT STEPS

Several improvement are planned in the next future

- New Analog Board and wires to optimize noise and CEM protection
- New Analog to digital converter of 16 bits with characterization
- Reduce the error due to uncertainty on Quantum efficiency to confirm the NL with flux variation
- Verify the impact of the detector temperature to the linearity

7. CONCLUSION

Detector non-linearity is a key element for the realization of the mission scientfic objective, that is CO2 fluxes measurement. But non linearity measurement is particularly difficult to perform, due to low signal level, and high accuracy. We achieve to make this measurement. During bench calibration, we have stated that noise is more important than the NL linearity at low level
So we confirm that the NGP detector non linearity is suited to MicroCarb mission.