Greenhouse gases measurement from portable infrared spectrometer

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Introduction:

CHRIS (**C**ompact **H**igh-spectral **R**esolution **I**nfrared **S**pectrometer; Fig. 1) is a prototype based on the EM27/SUN (Bruker) instrument. It allows recording infrared spectra between 15 and 1.8 µm. This transportable instrument is designed to perform ground-based measurements of greenhouse gases (CO_2, CH_4, H_2O), trace gases (SO_2, CO, HCl, NO_x…) in the low atmospheric layers, but also aerosols and clouds which have very typical spectral features in the infrared region. One of the main reason of its acquisition is its ability to operate in field campaigns and therefore to validate the satellite measurements.

Figure 1: The instrument CHRIS on the roof of the LOA (Villeneuve d'Ascq)

I- Instrument:

This system combined a Michelson interferometer which is permanently aligned and a CCD camera that controls the solar tracker which observes an image of the sun inside the instrument. The spectral resolution can be modified and can reach 0.135 cm^{-1} (non-apodized) with a spectral sampling every 0.065 cm^{-1} which satisfies the Nyquist criterion. The acquisition time depends of the spectral resolution and the spectral range covered. The detector is cooled by Peltier effect so it overcomes the liquid nitrogen cooling, and it also weighs approximately 42 Kgs which makes it transportable and adequate for field campaigns.

	CHRIS	IASI
Observation type	Direct solar absorption	Thermal infrared emission
Spectral range (cm^{-1})	700-1250, 1800-2300, 2400-3600, 3900-5200	645-2760
Spectral resolution (cm^{-1})	0.135	0.5
Observation frequency	Meteorological conditions	2 times/day for the same region
Scan time	0.83 s	8s (30x4 pixels)

Table 1: Characteristics of CHRIS and IASI.

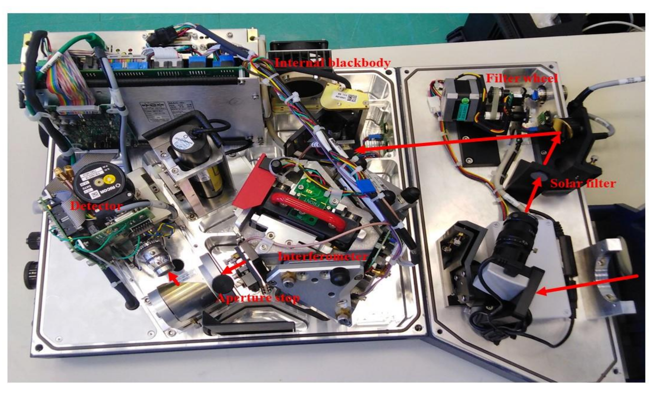


Figure 2: Interior view of CHRIS, the red arrows indicate the path of the light rays in the instrument.

II- Instrumental characterization:

The radiometric calibration has to be performed before and after the measurements campaigns with a high temperature (>1200 K) cavity blackbody (Fig. 3). This calibration is used to analyze the data properly and introduce it into a radiative transfer model.

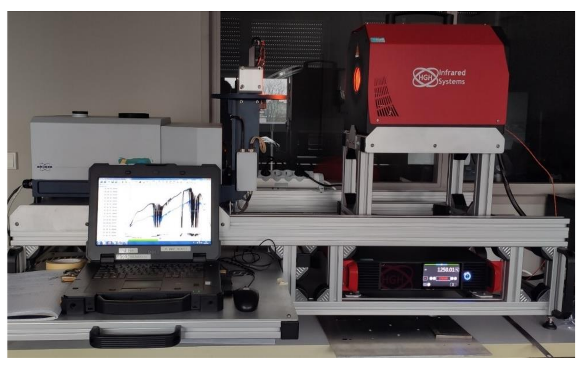


Fig. 3: Installation of the radiometric calibration experiment.

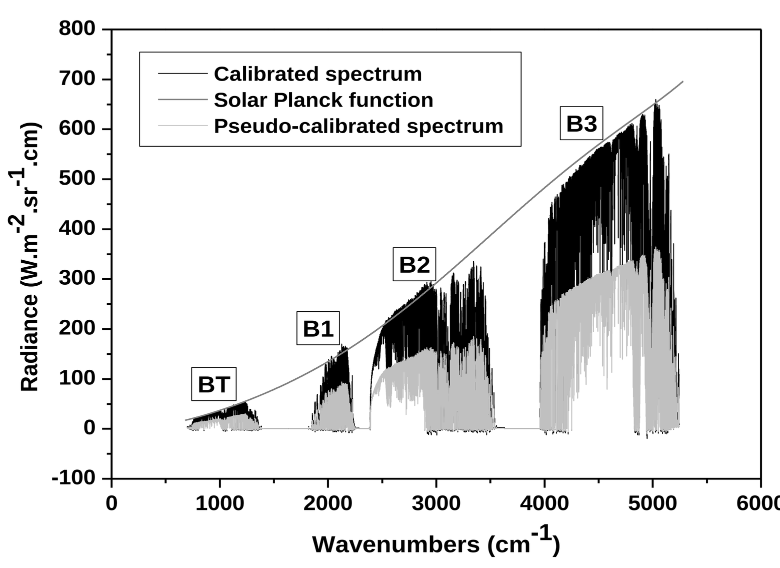
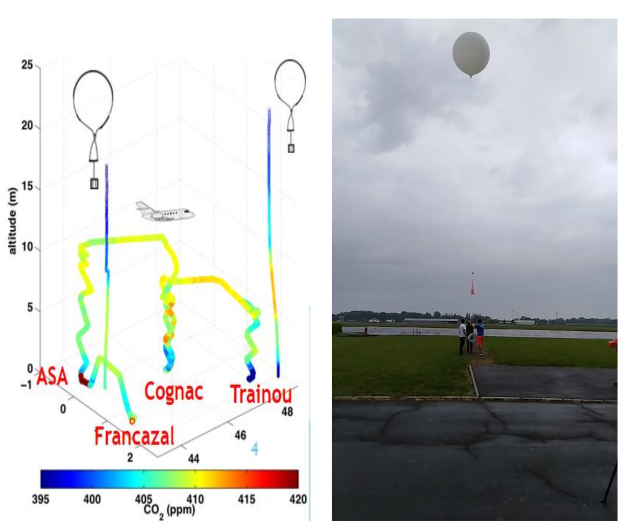


Fig. 4: The calibration process (spectral and radiometric) transforms the uncalibrated spectrum (light gray) into a luminance spectrum (black) that corresponds to the solar Planck function (solid gray line).

III- Campaigns:



The **MAGIC** (**M**onitoring of **A**tmospheric composition and **G**reenhouse gases through multi-**I**nstruments **C**ampaigns; Fig. 5) is a multi-mission and multi-instrument campaign to validate the future satellites MicroCarb, Merlin and IASI-NG, in order to improve our knowledge of the vertical distribution of CO_2 and CH_4.

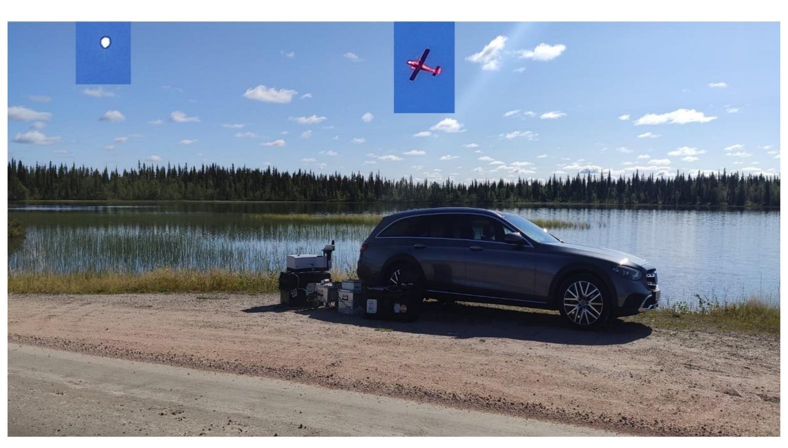


Figure 5: a) Vertical distribution of the CO_2 using different measurement techniques at different places during the campaign, **b)** An AirCore balloon before its launch, **c)** Measurements near the fall of the BSO and the passing of the plane (TwinOtter) during the MAGIC2021 campaign.

Amongst other several measurement campaigns, ImagEtna (Fig. 6) is specifically dedicated to measure rare gases in Etna and Stromboli.

Figure 6: CHRIS was also part of the ImagEtna campaign to measure SO_2 and volcanic ashes.

IV- Line by Line simulation:

A line-by-line simulation, using the LOA radiative transfer code ARAHMIS, of the first 6 molecules found in the atmosphere is shown in the following figure. These simulations are superimposed with a transmittance obtained in a clear and unpolluted atmosphere at Izaña (Fig. 7).

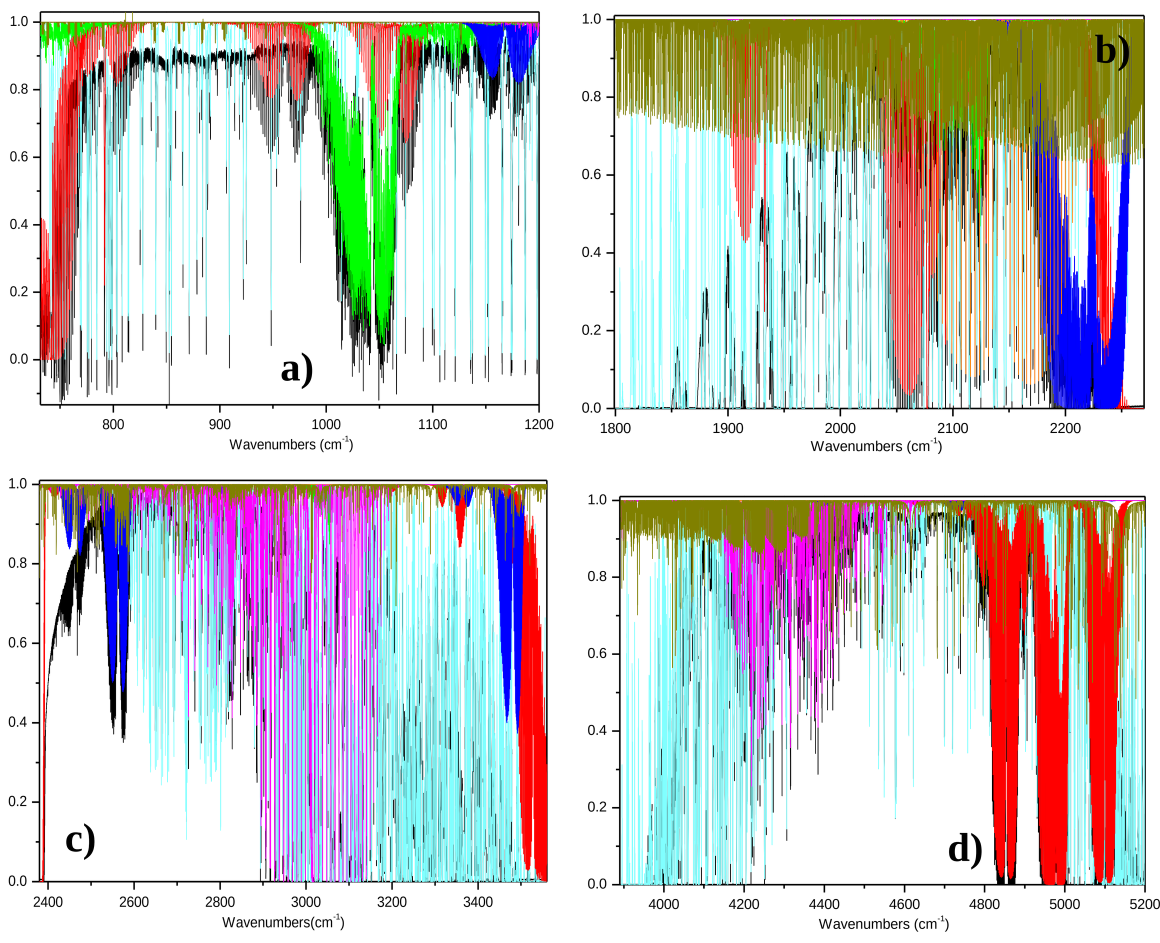


Figure 7: Representation of the first 6 molecules found in a clear atmosphere in a CHRIS spectrum: **a)** Thermal band (750-1250 cm^{-1}), **b)** Band 1 (1800-2300 cm^{-1}), **c)** Band 2 (2400-3600 cm^{-1}), **d)** Band 3 (3900-5200 cm^{-1}).

The following figure illustrates the analogy between the spectral ranges covered by IASI and CHRIS respectively.

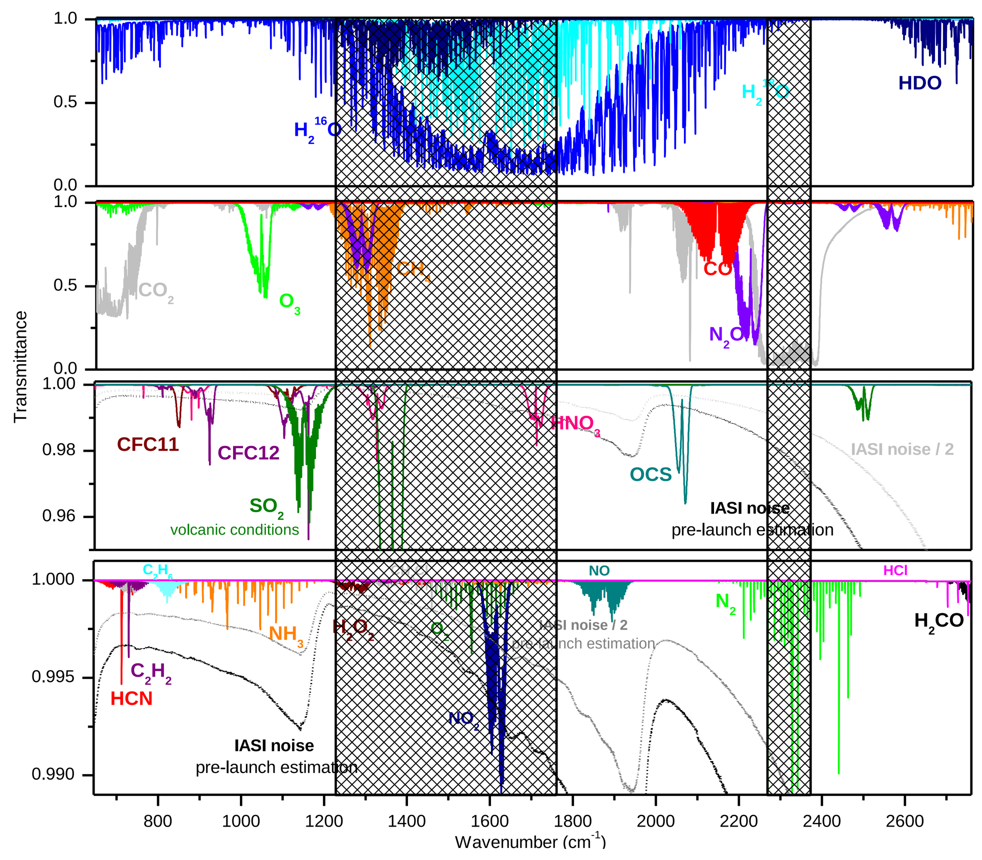


Figure 8: Simulation of gaseous species in a IASI spectrum, the hatched area is the area where CHRIS has no signal due to water vapor saturation

V- Data exploitation:

In the context of the MAGIC campaign, an inter-comparison exercise with the EM27/SUN was done, since the 2 instruments have a common spectral region (band 3: 4700-5200 cm^{-1}). The data are used later for the comparison between the 2 instruments using a complete Information Content (IC) study.

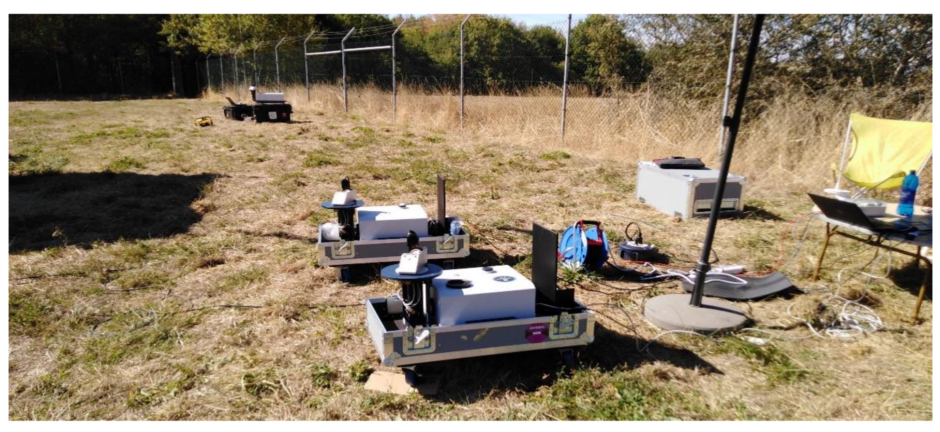
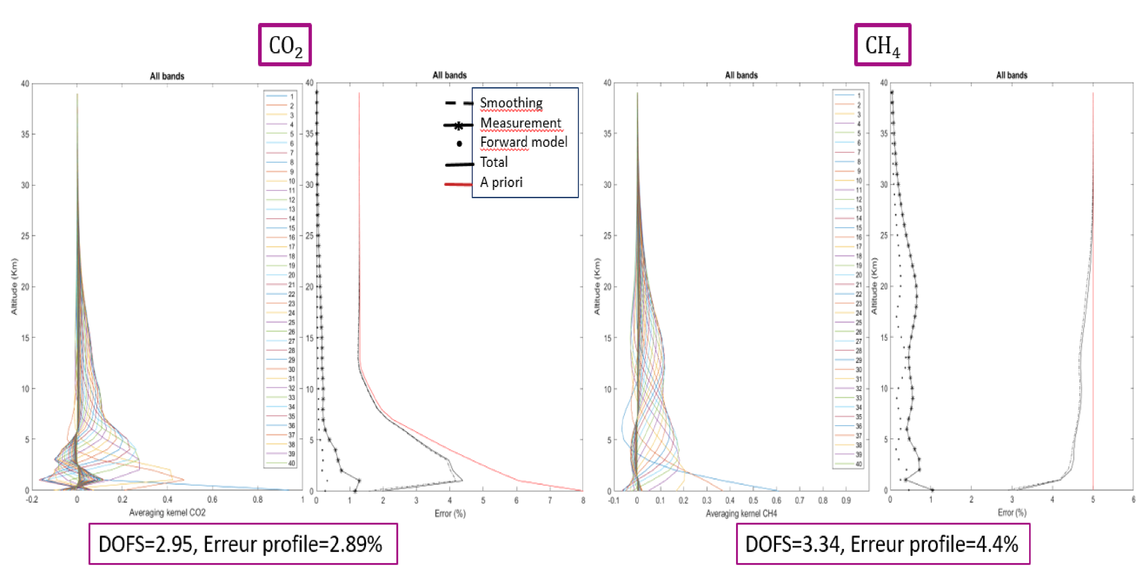


Figure 9: The inter-comparison exercise in Trainou, France.

Information content study quantify the impact of spectral synergy on the retrieval accuracy. For this purpose, an extensive IC is done for CHRIS as well as the EM27/SUN (using the data from Figure 7) for the 2 greenhouse gases CO_2 and CH_4. The averaging kernel, the error budget and the DOFS are presented as follow:



The IC shows that CHRIS is an efficient instrument to measure and quantify the greenhouse gases CO_2 and CH_4 in the tropospheric layer. CHRIS and EM27 have the same degree of information for CO_2, but for CH_4, CHRIS allows us to retrieve more information than EM27/SUN. Furthermore, when combining the data from the 2 instruments (CHRIS and EM27/SUN) we can see that there are minimal differences in the information that can be retrieved.

CO_2		Toutes les bandes DOFS	Erreur
CHRIS	Angle 10	2.95	2.89%
	Angle 80	3.71	2.6%
CHRIS avec covariance	Angle 10	2.38	1.01%
	Angle 80	3.08	0.94%

CH_4		Toutes les bandes DOFS	Erreur
CHRIS	Angle 10	3.34	4.4%
	Angle 80	4.26	4.19%
CHRIS avec covariance	Angle 10	2.57	1.5%
	Angle 80	3.21	1.46%

DOFS => Improvement with SZA
Erreur => Improvement with SZA

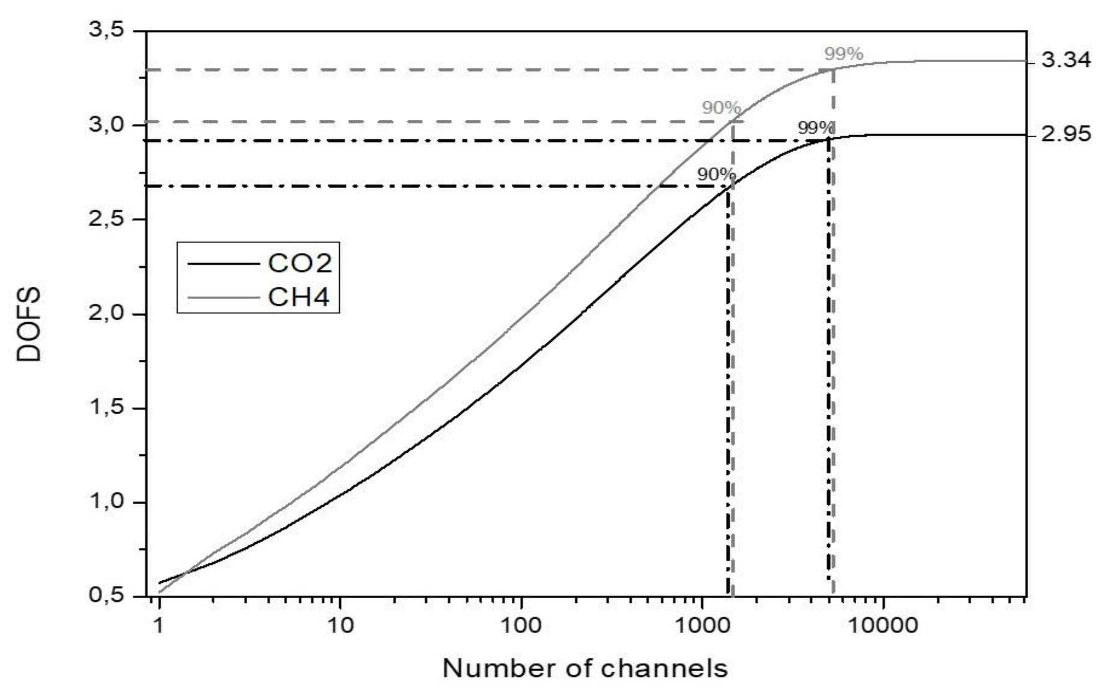
Covariance matrix => decrease in DOFS => Improvement of the error %

Comparaison

CO_2		Toutes les bandes DOFS	Erreur
CHRIS avec covariance	Angle 80	3.08	0.94%
EM27/SUN avec covariance	Angle 80	2.68	0.97%
IFS125HR avec covariance	Angle 80	3.53	0.95%

CH_4		Toutes les bandes DOFS	Erreur
CHRIS avec covariance	Angle 80	3.21	1.46%
EM27/SUN avec covariance	Angle 80	1.81	1.55%
IFS125HR avec covariance	Angle 80	3.81	1.46%

Complementarity of CHRIS + EM27/SUN: For CH_4, the DOFS increases to 4.43 (angle 80) which shows a significant improvement. However, for CO_2, the DOFS improves slightly to 3.93 (angle 80).



- For CO_2, 90% of the information is reached after 1329 channels (2.15% of the channels).
- For CH_4, 90% of the information is reached after 1387 channels (2.25% of the channels).

		BT	B1	B3	Toutes bandes
		DOFS			DOFS
CHRIS	Angle 10	2.01	2.32	2.62	2.95
	Angle 80	2.56	2.67	3.34	3.71
CHRIS avec covariance	Angle 10	1.45	1.7	2.15	2.38
	Angle 80	1.89	1.92	2.68	3.08

CO_2 = 1/3 TIR + 2/3 SWIR et CH_4 : ¼ TIR + ¾ SWIR => Synergy TIR/SWIR

Inversion of CO_2

BT	B1	B3	All bands
402.12 ppm	405.25 ppm	406.10 ppm	404.56 ppm

True value → AirCore: 403.73 ppm

- The concentration of BT is less than the other bands with a deviation <1% which is explained by the overcompensation of the surface temperature
- The "all-bands" value of XCO_2 is the closest which allows us to exploit the TIR/SWIR synergy by using the BT, B1 and B3 bands together.
- The value of XCO_2 obtained by the EM27/SUN at the same time is 410.4 ppm (difference of 5 ppm) => the EM27/SUN was located at the CNES station at ASA (52 km from the drop point).
- Uncertainty for the CO_2 column from CHRIS = 404.56 ppm ± 0.1.
- The difference is 0.83 ppm, or 0.2% which is very small: the two measurements are not perfectly simultaneous and the vertical profile is not strictly identical.

Conclusion and perspectives:

- Radiometric and spectral calibrations were fully performed on the prototype CHRIS.
- An extensive information content study was carried out for CHRIS and EM27/SUN.
- The degrees of freedom (DOFS) are ~4 for CO2 and CH4, which is higher than those obtained by IASI (~1) which makes CHRIS an efficient tool for measurement campaigns and validation of satellite missions.
- Some perspectives will include:
  - An information content study is done for CHRIS where some aspects are compared to IASI.
  - Inversion of the measurements in the MAGIC context.
  - Participate in field campaigns to measure trace gases and aerosols.
  - Perform radiance comparaison with Microcarb and IASI-NG missions.

Acknowledgments

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