
# MicroCarb, first European program for CO2 monitoring: nearing development conclusion before launch

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MICROCARB

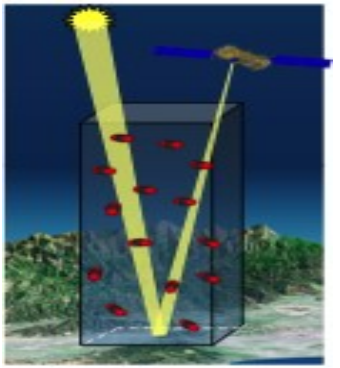
**Denis JOUGLET, Philippe LANDIECH, François-Marie BREON**

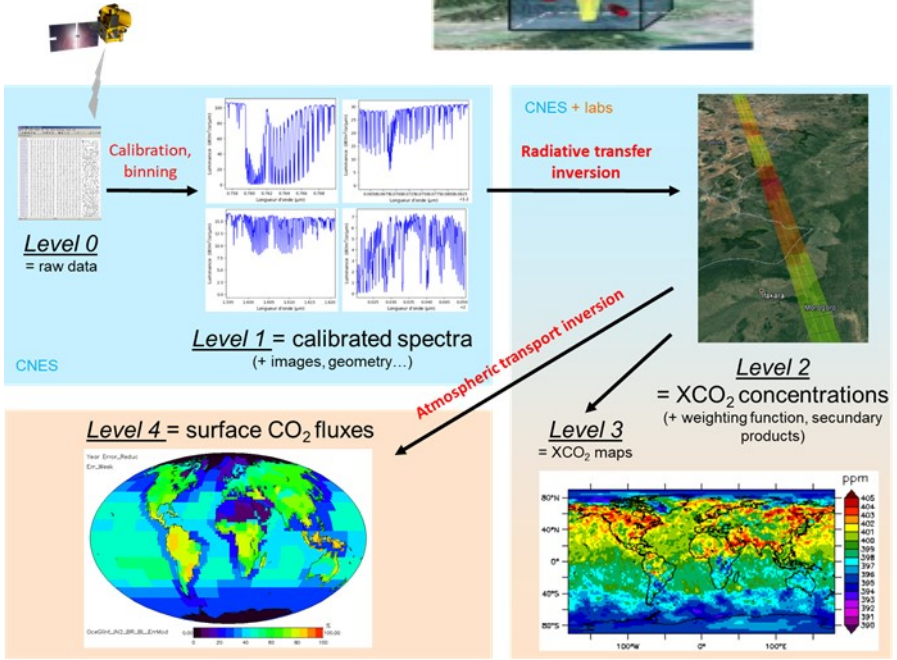
**And the MicroCarb team**

cea cnrs cnes INVESTIR L'AVENIR UK SPACE AGENCY EUMETSAT esa European Space Agency

# MicroCarb Mission reminder

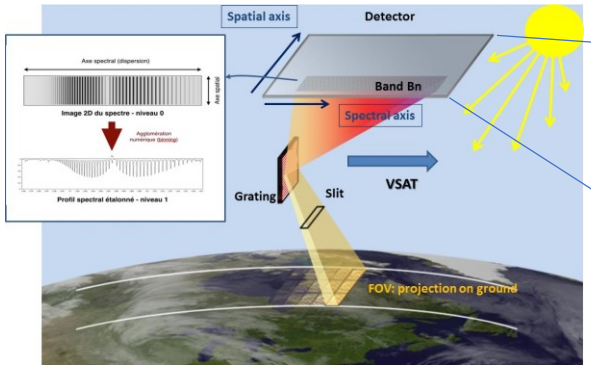
- Science mission
  - Primary objective : CO2 natural fluxes
  - Demonstration for CO2 local emission with the city mode
- Measurement of the column integrated CO2 atmospheric concentration
- Passive VNIR & SWIR spectrometer
  - CO2 : 1.6 µm & 2.04 µm
  - O2 : 0.76 µm & 1.27 µm
- Carried on microsatellite < 200kg
- Orbit SSO – 649 km – 22h30 LTAN - 25 day cycle
- Life time: 5 years

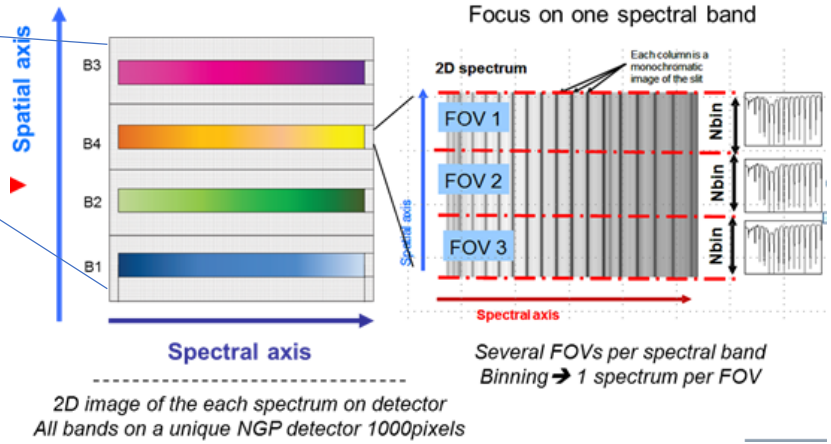


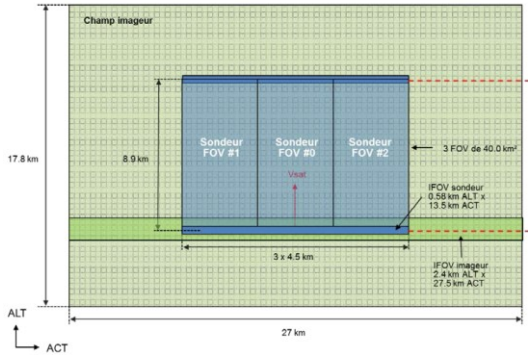


# Instrument basics

- Compact: 1 telescope, 1 spectrometer, 1 NGP detector for 4 spectral bands
- Instrument <60kg, <55W
- 3 FOV (swath 13.5km), each FOV ~4.5x9 km$^2$, every 1.3s
- Grating spectrometer
- High spectral resolution and high SNR
- ACT scanning mirror
- Embedded imager (one red band, 120mx150m) for cloud detection and geolocation refinement
- All ACT pixels data + intermediate readings sent to ground ➔ intra FOV information



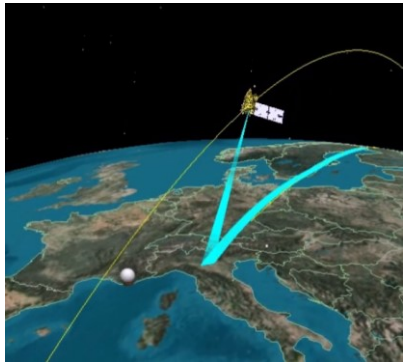
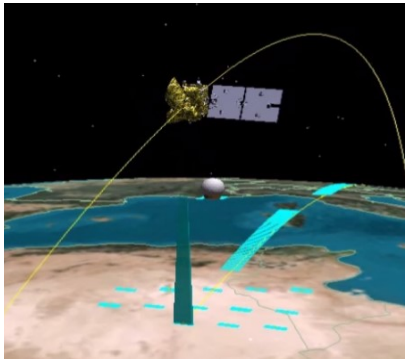
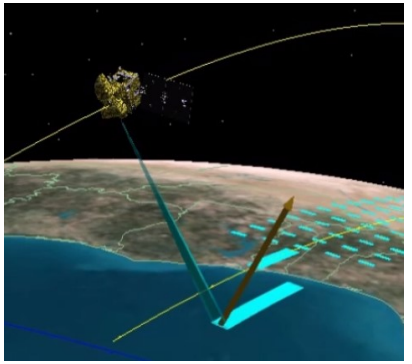



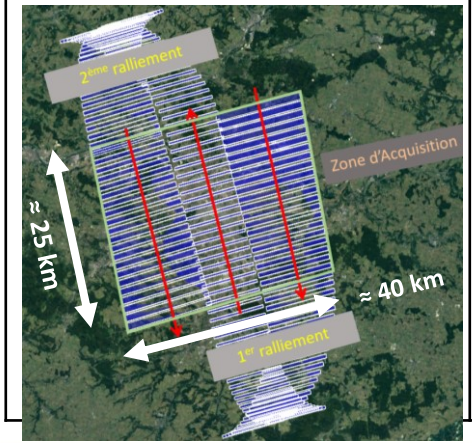
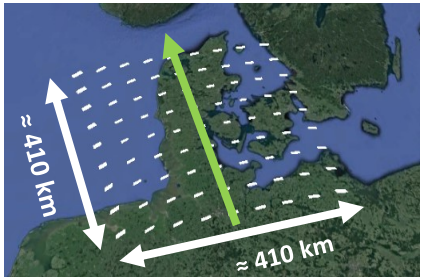
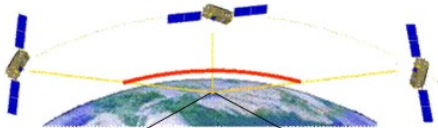




| | B1 | B2 | B3 | B4 |
|---|---|---|---|---|
| λmin (nm) | 758.281 | 1596.772 | 2023.018 | 1264.630 |
| λcenter (nm) | 763.500 | 1607.900 | 2037.100 | 1273.400 |
| λmax (nm) | 768.817 | 1618.946 | 2051.116 | 1282.191 |
| Sampling @ λcenter | 2.85 | 2.84 | 2.81 | 2.91 |
| Resolution @ λcenter | 26040 | 26146 | 26420 | 25520 |
| SNR@Lmin per channel | 61 à 106 | 121 à 163 | 54 à 66 | 81 à 118 |
| SNR@Lmean per channel | 194 à 320 | 394 à 497 | 174 à 211 | 288 à 400 |
| SNR@Lmax per channel | 494 à 753 | 1086 à 1309 | 886 à 1016 | 843 à 1092 |

# Observation modes

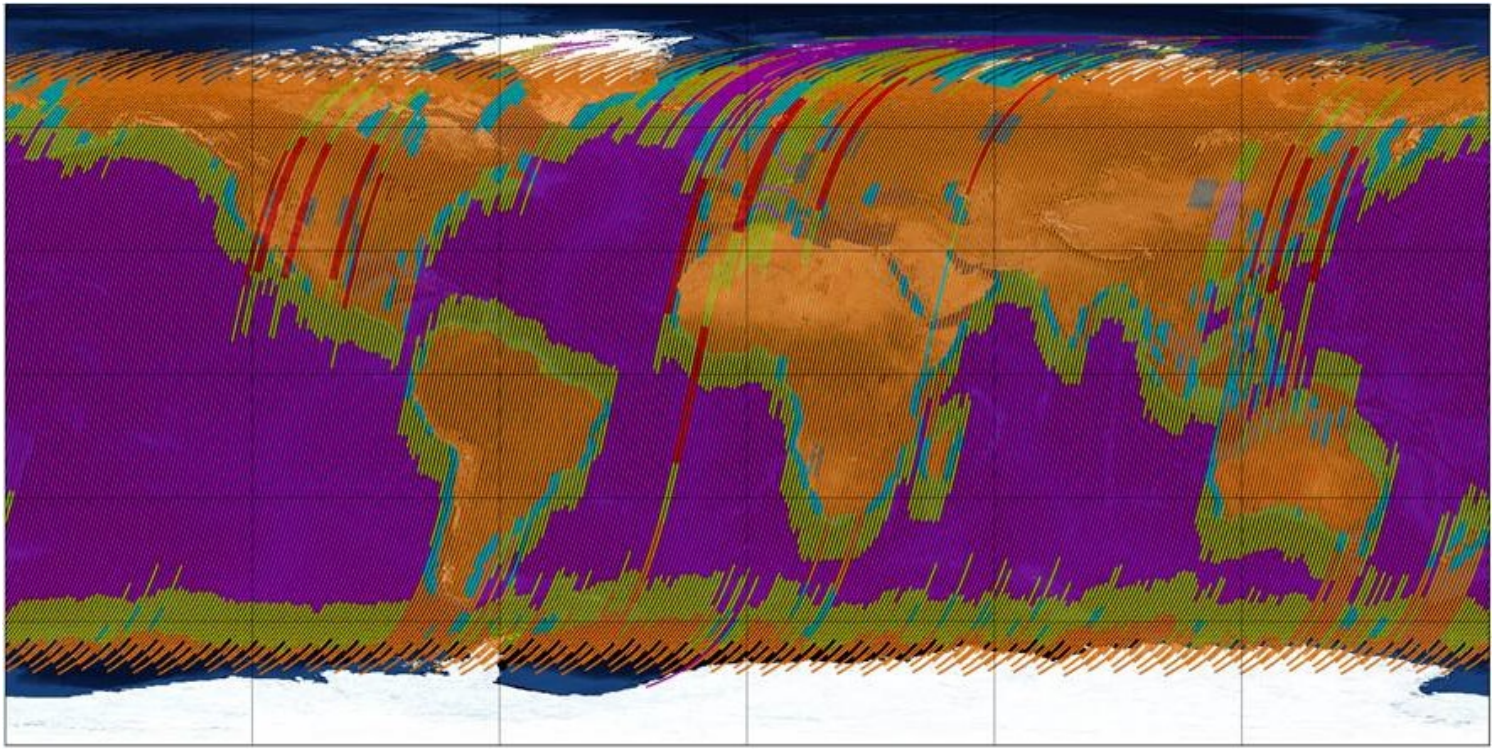
- **Science nominal modes**
  - Nadir (lands)
  - Scan (lands to decorrelate footprints)
  - Glint (ocean)
  - Offnadir target
- **Probatory modes**
  - City
  - Region
- **Calibration modes**
  - Target (L2 validation)
  - Calibration : sun, lamp, shutter, cold space, moon…
  - Limb for 1.27µm airglow

| Nadir | Scan | Glint |
|---|---|---|
|  |  |  |

| City | Region | Target |
|---|---|---|
|   |   | Target Mode observes surface zenith angles between ±75°  |

# Mission planning

- Example of mission plan during one cycle (25 days)
- Large flexibility thanks to scanning mirror and platform agility



# Organization

Mission Advisory Group

- System design and development
- Satellite design an development
- Instrument specification
- L1&L2 Processing definition
- Mission performances
- Calibration and validation
- Operations

Instrument development qualification and calibration

Satellite Assembly integration and Test

Data production, archiving and dissemination

Launch service

# Last year progress

## A very busy year since last IWGGMS-16 !!!

- **COVID 19 particularly impacted the distant platform AIT in UK, …**

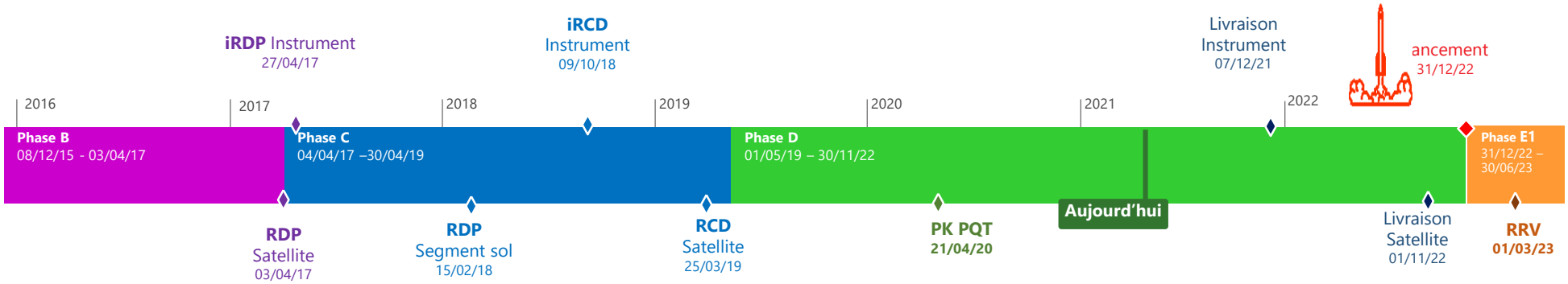
- **Detector performances characterization on prototypes then on Flight Models 1 & 2 (spare), several defects evidenced**
  - Remanence effect
    - Several seconds for recovery after a strong light transition, non-linear effect ➔ strong impact at L2
    - Choice a detector low sensitive to this effect (FM2)
    - Implementation of a diffuse optical background light added to mitigate any ageing effect
  - History effect : long-term remanence, to be modelled and corrected
  - Recombination: low flux loss of linearity, to be characterized then compensated by model
  - ROIC effects

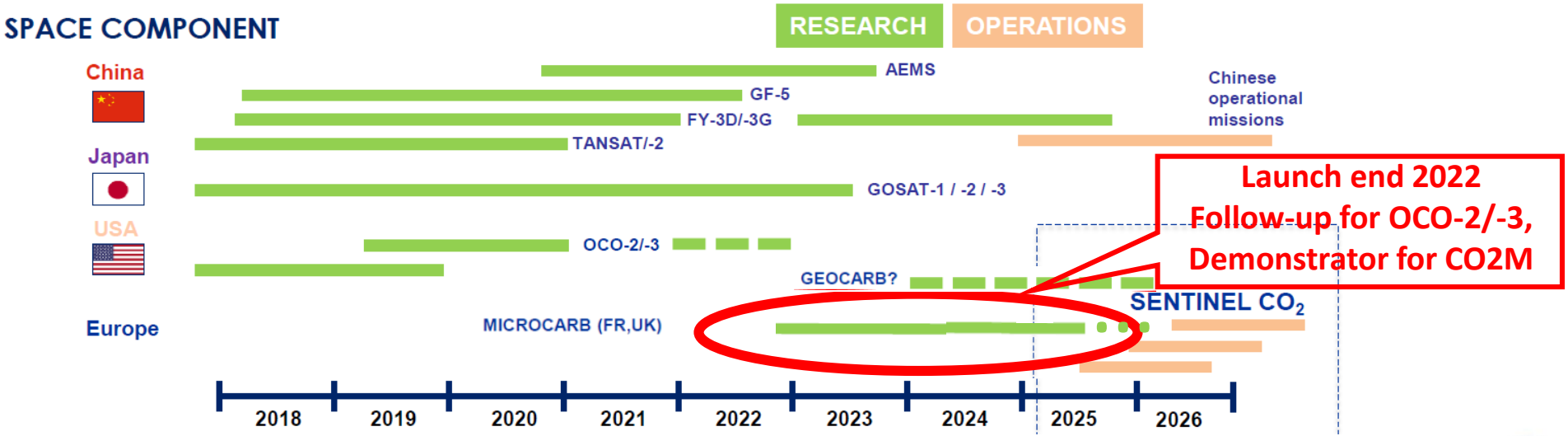
- **Delay in instrument delivery schedule, but now back on track !**

- **Launch scheduled end 2022 on a VEGA-C charter flight**

- **Then a 12 month Cal/Val phase split in 2: 6 months for L1 Calibration then 6 months for L2 Validation prior to open access to MicroCarb data**

# MicroCarb will enforce the CO2 global monitoring continuity

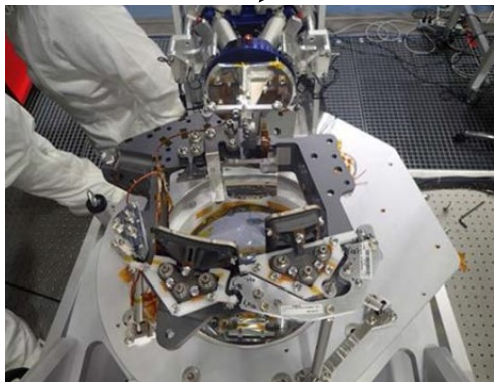


# Instrument AIT Activities

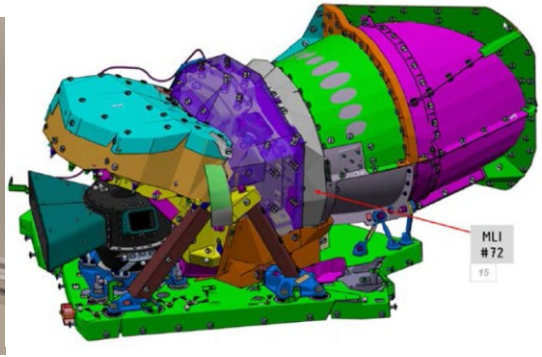
- All equipment received
- Separate Telescope and Spectrometer integrations underway with alignments and individual performances checks
- Before Instrument complete integration, need to finalize NGP detector characterization plan at 150 K in all Bands
  **=> critical path**
- Then, main step will be Instrument Thermal Vaccum test in with a thorough qualification / calibration test plan applied: 40 days identified, including sunlight test

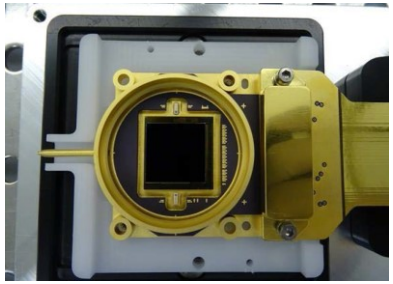
Spectro



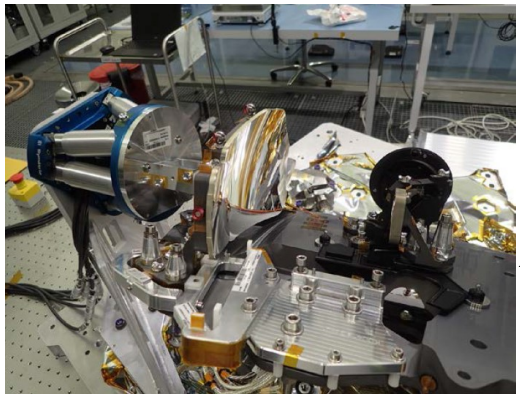
Baffle Therm.

Archi MLI



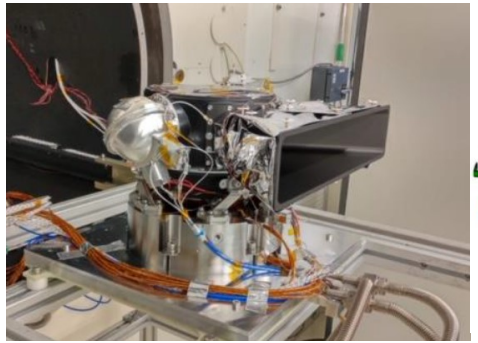



NGP detector FM



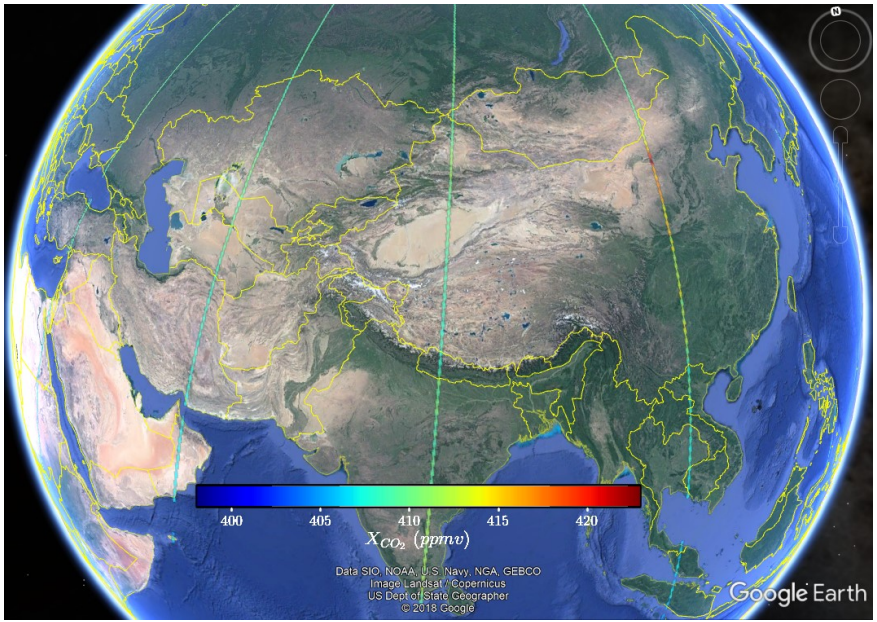
PCS

Teles-cope

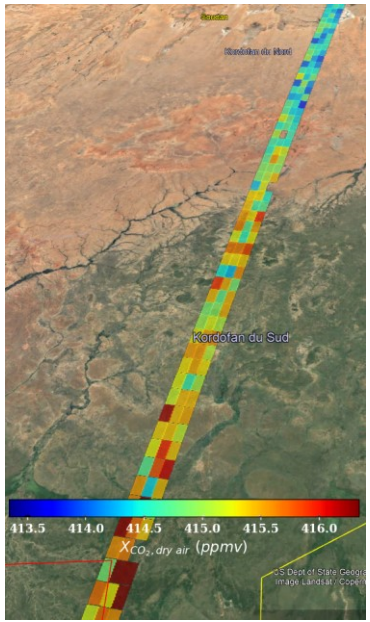


# Performance orbital simulator

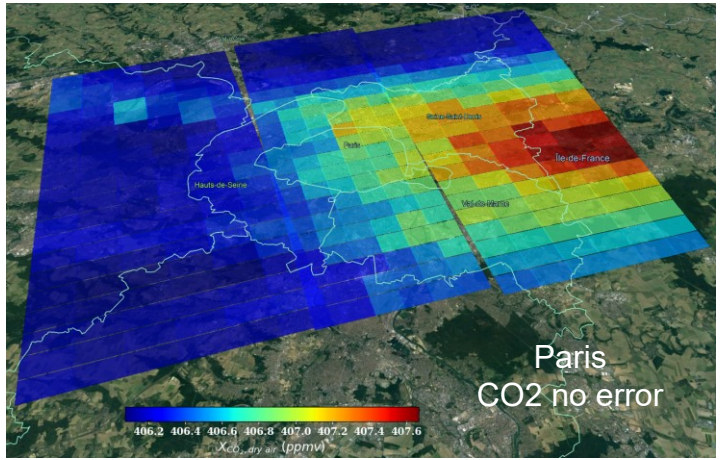
- Our orbital performance simulator is now ready for the performance budget
- Simulates L1 and L2
- This gives access to spatial scales of errors (to discrimintate random error and regional bias)
- Gain matrix mode & retrieval mode
- Is used also for demo products, ground segment tests and Cal/Val preparation

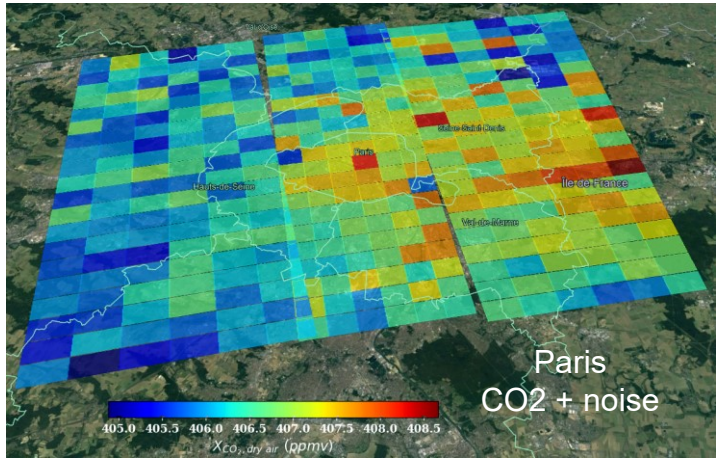



Orbital mode (nadir)




Zoom




City mode

# 2021 L2 performance budget

## Methodology

- Mostly based on orbital simulator, > half of the defects coded inside
- 1 sigma budget, quadratic summation
- Raw budget without calval improvement nor bias characterization
- No EOF here

## Main results

- Random error is largely compliant with spec < 1.5 ppm
- Raw regional biais is not compliant with spec < 0.2 ppm
  - L1 algorithms still under improvement
  - Aerosols and spectroscopy are dominant but will be improved
  - The 1.27µm O2 band (B4) is still to be fully exploited

➔In-depth ground calibration

➔In-depth L1 & L2 calval

- For L2 : massive statistics with TCCON, EM27 and models

| Performance Item | CO2 random error (ppm) | | | CO2 regional bias | CO2 global bias |
|---|---|---|---|---|---|
| | Max | Med | Min | 1sig | |
| **L1 radiometry** | | | | | |
| Radiometric noise (SNR) | 0.94 | 0.35 | 0.15 | | |
| Absolute gain residual | | | | 0.32 | 0.24 |
| Band to band gain residual | | | | 0.25 | 0.02 |
| Channel to channel gain residual | | | | 0.04 | 0.01 |
| Dark signal residual | | | | 0.14 | 0.11 |
| Dark signal channel to channel residual | | | | 0.03 | 0.05 |
| Non-linearity residual | | | | 0.09 | 0.05 |
| Instrumental polarization residual | | | | 0.15 | 0.25 |
| Straylight | 0.25 | 0.25 | 0.25 | | |
| Detector persistence | 0.30 | 0.30 | 0.30 | 0.10 | |
| **L1 spectrometry** | | | | | |
| Spectral shift | | | | 0.35 | 2.00 |
| Limited knowledge of the ISRF (uniform scenes) | 0.07 | 0.07 | 0.07 | 0.32 | 0.15 |
| Limited knowledge of the ISRF (heterogenous scenes | 0.10 | 0.10 | 0.10 | | |
| **L1 geometry** | | | | | |
| Limited knowledge of geolocation | | | | | |
| Intra-band misregistration | 0.14 | 0.14 | 0.14 | | |
| Inter-band misregistration | 0.25 | 0.25 | 0.25 | | |
| Limited knowledge of VZA | 0.20 | 0.20 | 0.20 | 0.20 | |
| Inter band differential VZA | 0.15 | 0.15 | 0.15 | 0.15 | |
| FOV spread function shape | | | | | |
| Limited knowledge of the FOV spread function | | | | | |
| **L2 processing** | | | | | |
| Limited a priori knowledge of CO2 | | | | 0.01 | 0.02 |
| Limited knowledge of weather analysis and DEM | 0.5 | 0.25 | 0.07 | | |
| Spectroscopy misknowledge | | | | 0.30 | 2.50 |
| Impact of aerosols (incl. apriori) | | | | 0.70 | |
| Limited knowledge of the solar spectrum | | | | | |
| Unscreened clouds | 0.20 | 0.20 | 0.20 | 0.10 | |
| Impact of 1.27 µm airglow | 0.22 | 0.22 | 0.22 | | |
| Impact of 0.76 µm vegetation fluorescence | | | | 0.03 | 0.05 |
| Impact of 4AOP calculation accuracy | | | | 0.20 | 0.67 |
| **Approximation of gain matrix formalism (added)** | | | | 0.30 | |
| **Mission Requirement (ppm)** | **0.5 - 1.5** | | | **0.1 - 0.2** | |
| **Random error budget (ppm)** | **1.24** | **0.76** | **0.66** | | |
| **Regional bias budget (ppm)** | | | | **1.37** | |
| **Global bias budget (ppm)** | | | | | **3.29** |

Budget before calval and bias correction

# The 1.27µm O2 band is very promising!

**Simulations in orbital simulator**

- **No noise**
- **Airglow perfectly retrieved**

- **4ARTIC baseline is to invert the 4 spectral bands**
  - **But B4 is much closer to the CO2 bands**
  - **Some experiments performed here**

- **Reminder of 4ARTIC scheme for aerosols:**
  - 3 retrieved parameters [ln(AOD($\sigma_0$)), k, $z_{aero}$]
  - Prior from CAMS
  - AOD($\sigma$) = AOD($\sigma_0$)($\sigma/\sigma_0$)$^k$
  - Gaussian vertical distribution with mean altitude $z_{aero}$
  - SSA=0.98, g=0.8 (soon taken from CAMS)

| O2 | Direct | Inverse | A priori for aerosols | Moy (ppm) | Std (ppm) | Conclusions |
|---|---|---|---|---|---|---|
| 0.76 & 1.27 | Realistic profiles | No aerosol | | 0.114 | 1.732 | Without aerosol in inverse<br>- B1+B4 : bad results<br>- B1 alone is worse<br>- B4 alone improves a lot, but not enough<br>➔ Need for an aerosol parametrization |
| 0.76 | Realistic profiles | No aerosol | | 0.116 | 1.917 | |
| 1.27 | Realistic profiles | No aerosol | | 0.083 | 0.831 | |
| 0.76 & 1.27 | Realistic profiles | 4ARTIC scheme | Truth-like | -0.243 | 0.562 | The 4ARTIC aerosols parametrization implies a regional biais of 0.6 ppm<br>➔ Need for parametrization imrpovement |
| 0.76 & 1.27 | Realistic profiles | 4ARTIC scheme | Truth-like + large random perturbation | -0.214 | 1.059 | A priori aerosol uncertainty degrades the results<br>➔ Need for a good aerosol prior |
| 0.76 | Realistic profiles | 4ARTIC scheme | Truth-like + large random perturbation | -0.475 | 1.611 | With aerosol parametrization and large aerosol prior uncertainty:<br>- removing B1 improves the results<br>- Removing B4 dergades the results<br>➔ **High interest of B4!** |
| 1.27 | Realistic profiles | 4ARTIC scheme | Truth-like + large random perturbation | -0.213 | 0.414 | |

# Conclusion

- Additional partnership are put in place at European level to place MicroCarb in an European frame and contribute to prepare future operational systems (Copernicus)
- Instrument and satellite AIT started despite COVID 19 situation
- Processors still under improvement, payload ground segment close to end of development
- Complete and consolidated performance budget with promising results (simulated data and OCO-2 real data)
- Launcher main passenger looked for
- MicroCarb heading for a launch end 2022-beginning 2023

**Thank you for your attention !**