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An improved MicroCarb dispersive instrumental concept for the measurement of greenhouse gases concentration in the atmosphere

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OUTLINE

- MicroCarb status
- Initial dispersive spectrometer description and adaptation
- Focus on optical design
- Focus on detection
- Preliminary assessment

MicroCarb Status

- MicroCarb mission objective is to better understand the carbon cycle and predict its evolution.

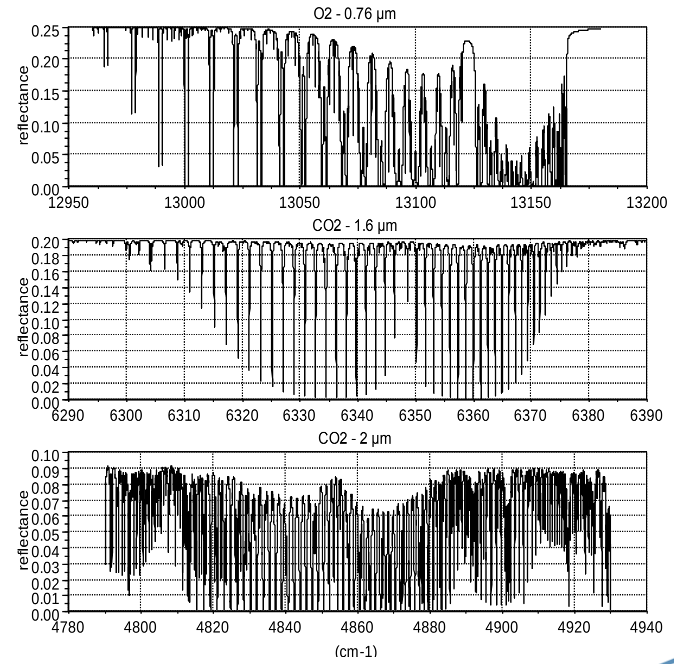
- MicroCarb will measure vertically integrated CO_2 concentration
  - to quantify CO_2 surface fluxes at regional scales
  - to identify and monitor global carbon sources and sinks

- The CO_2 concentration will be retrieved by measurements of the absorption of reflected sunlight by CO_2 in the near and short wave infrared. The payload consists in a passive instrument.

- In order to better quantify the CO_2 fluxes at the surface, very high quality of CO_2 concentration measurements are necessary
  - Priority is given to precision of measurements (in ppm) rather than high spatial resolution or sampling

MicroCarb Status

- Myriade Evolution platform with Myriade Flight Operation Center design shall be used.
- Mission design shall be based on technology with moderate development schedule and risks: a compact and low cost concept mission.
- MicroCarb requirement are defined as:
  - ✦The goal gives the same level 2 performance as OCO
  - ✦The threshold is such that the level 2 performance is relaxed by 35%
- Spectral bands: measurement in SWIR CO_2 and O_2 Band to correct from aerosol/cloud effect
  - ✦0.76µm O_2 A-Band : Surface pressure, clouds/aerosols
  - ✦1.61 µm CO_2 band : Column CO_2
  - ✦2.06 µm CO_2 band : Column CO_2 , clouds/aerosols



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MicroCarb status

- Design activities were performed in parallel by two manufacturers Thales Alinea Space and Airbus Defence Space with technological pre-development and characterization of critical devices.

- The MicroCarb phase A was concluded end 2013 with a Preliminary Requirements Review (PRR).
- Both manufacturers proposed each an instrumental concept compatible of Myriade Platform resources and compliant with the MicroCarb requirements.

- **Based on this feasibility, a second CNES internal study was initiated with the objectives :**
  - **to improve the instrumental concept compacity**
  - **to add some new capability in particular access to other greenhouse gases as CH4, H20, CO**

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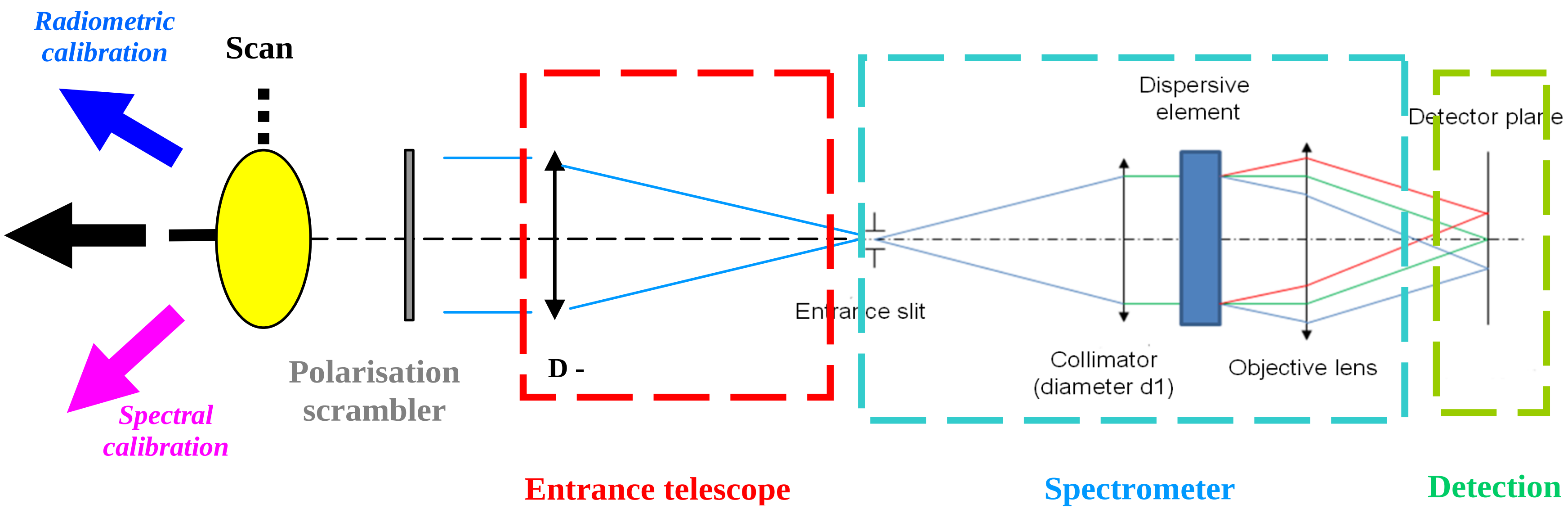
Initial dispersive spectrometer principle



- MicroCarb Operating point chosen:
  - Choice of the high power resolution (λ/dλ up to 25 000) is justified by the nature of the observed signal: If the line depth assimilated to its surface or Equivalent Width (EW) varies of 0.25%, the integrated CO2 column concentration varies of 1 ppm
  - Relax significantly the radiometric constraints like residual non uniformity of response, ghost images, slit effect…
- An option studied by CNES: Use of the echelle grating with high interference orders k_n

Initial dispersive spectrometer principle

- Benefits of the echelle grating:
  - the grating diffracts a wide spectral domain in the same direction: the grating is used in quasi-littrow configuration:

$$\lambda_B = \frac{2\sin\theta_B}{k_n\ m}$$

With :
Θ_B = blaze angle
m = groove density
λ_B = blaze wavelength

  - Possible to find couples (Θ_B, m) for which the blaze wavelength corresponds to the center of each MicroCarb spectral band
  - High spectral resolution power R is optimised by increasing the blaze angle for a given instrument volume

$$R = \frac{2\ d\ \tan\theta_B}{\phi\ D}$$

With :
ϕ = angular width of slit (radians)
D = entrance telescope diameter
d = internal spectrometer pupil (linked to spectrometer size)

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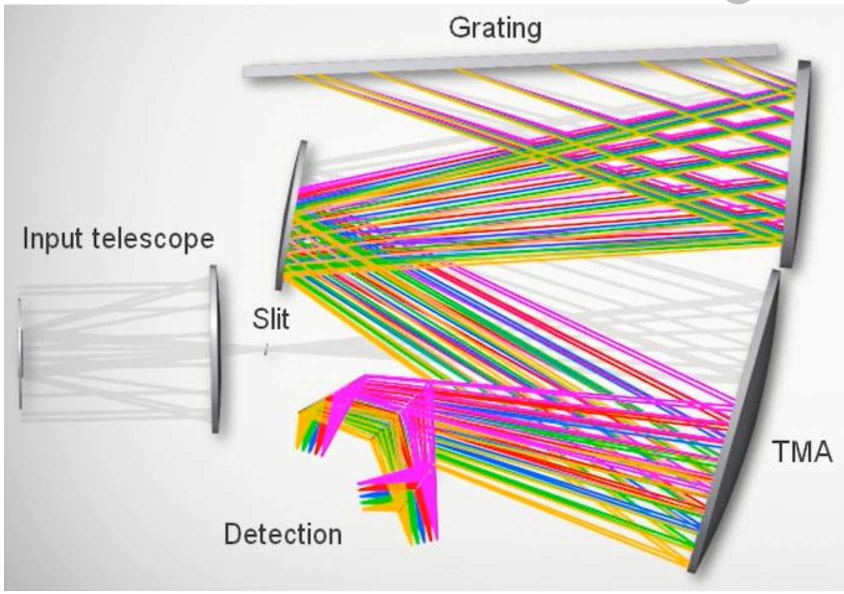
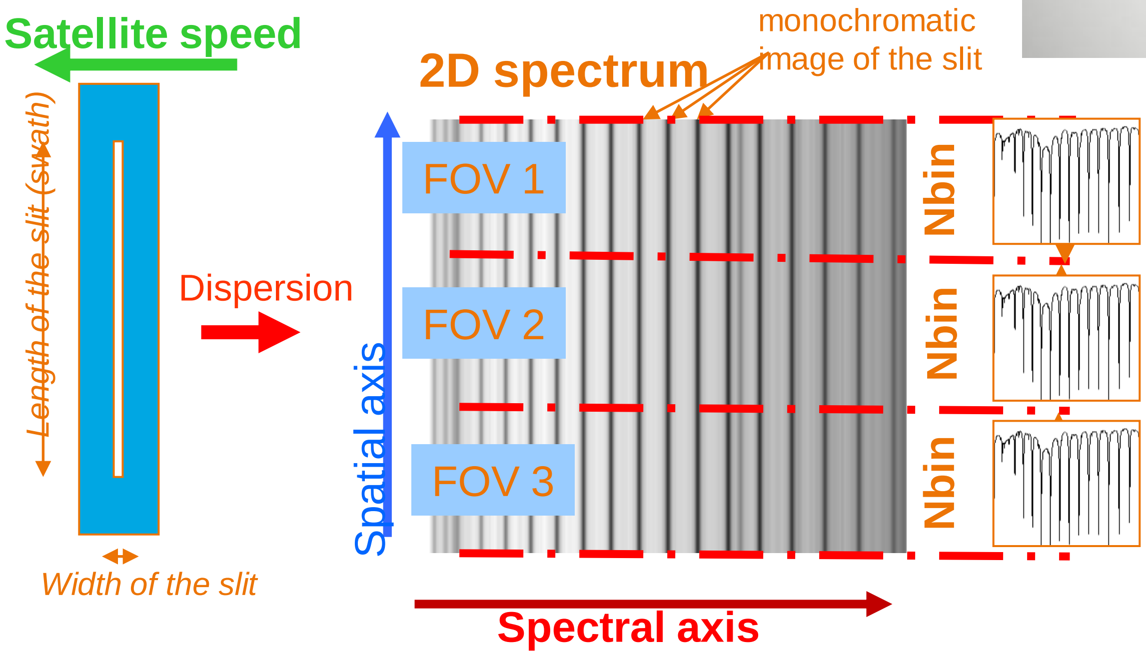
Initial dispersive spectrometer principle

- Compactness is a fundamental characteristic of the MicroCarb instrument: Same optical components are used for collimation function and camera lens function

  ➔ **double pass TMA**



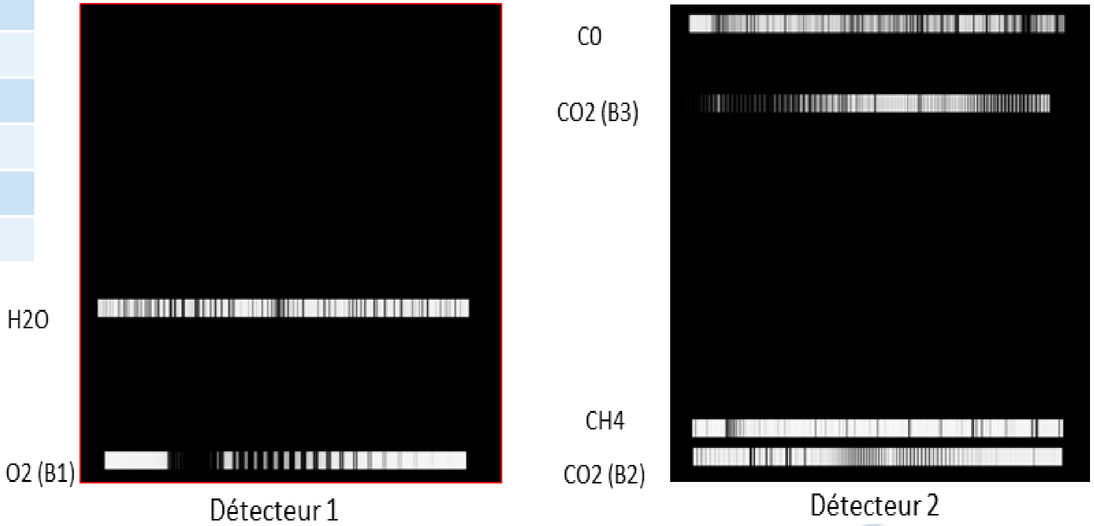


- Spectrum segments matched to the orders are separated by spectral filters
- 3 detectors associated with 3 bands

Adaptation of initial design

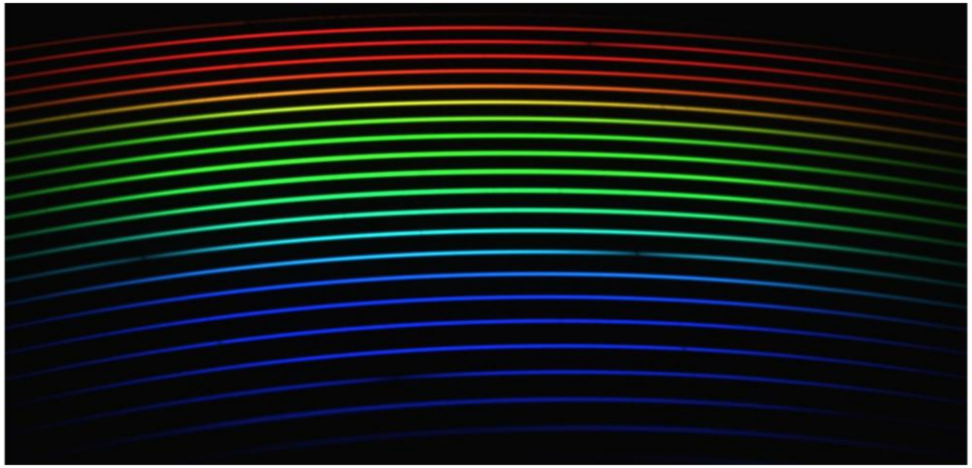
- The idea is to reduce the numbers of detectors needed for the mission:
  - first gain is the volume but also the design is simplified
- In parallel, study of the possibility to extend the spectral domain to other chemical species with the echelle concept
- Illustration of the implementation of all the spectral bands in the surface of two detectors :

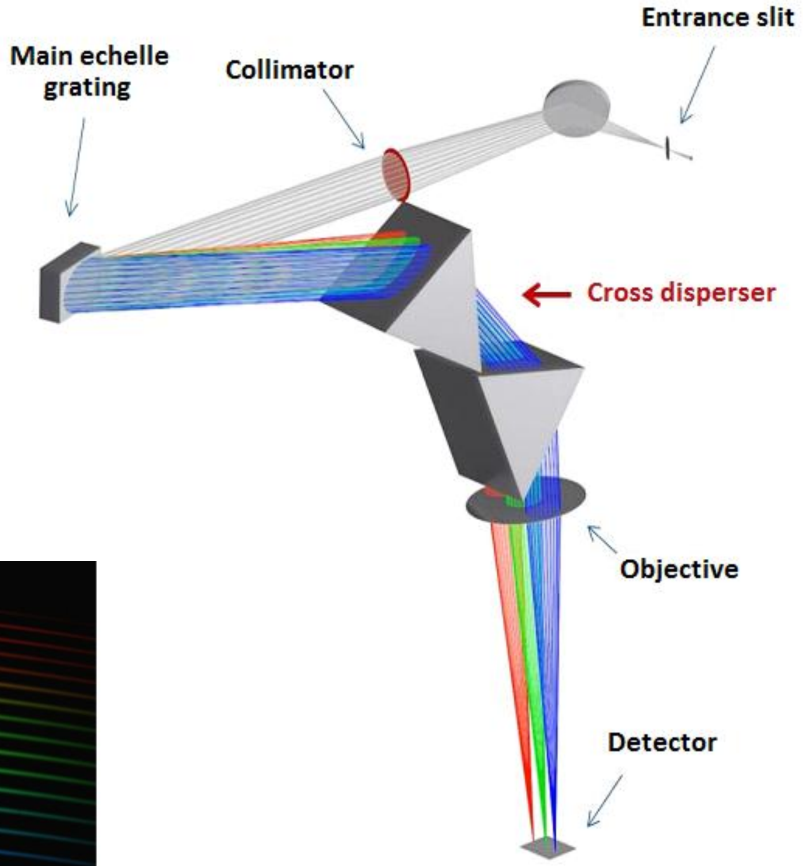
Spectral Band	Observed gazes	Central wavelength
B1	O_2	763 nm
B1’	H_2O	824 nm
B2	CO_2	1605 nm
B2’	CH_4	1695 nm
B3	CO_2	2034 nm
B4	CO	2346 nm



Adaptation of initial design

- A concentrated dispersive system is added in the optical design:
  - dispersion axis perpendicular to the echelle grating: cross-disperser
  - Various orders are separated over the detector surface
  - Each segment is a portion of the spectrum. All segments constitute a very large domain of wavelength

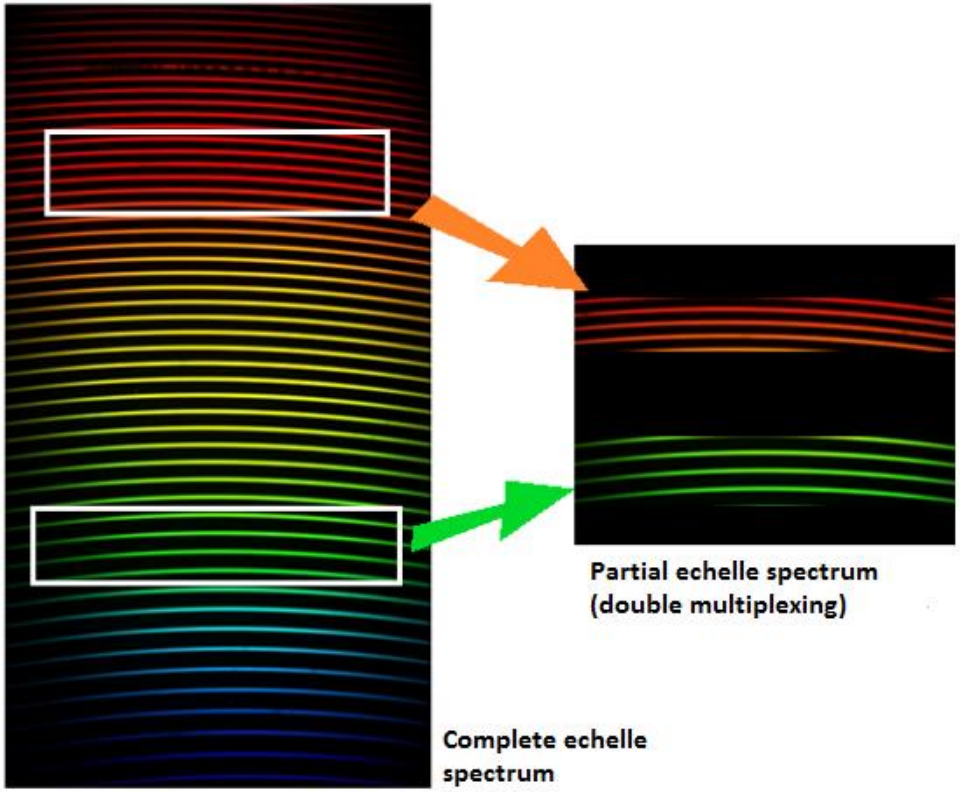




Adaptation of initial design

- Only the orders which contain the spectral signature of the chemical elements of interest are useful.
- Use the cross-disperser grating with the diffraction orders k=1 and K=2 and add a second multiplexing level with cross-disperser grating

➔ **double multiplexing:**
The two spectral bands B1 (0.77µm) and B2(1.55µm) can exist on one detector only



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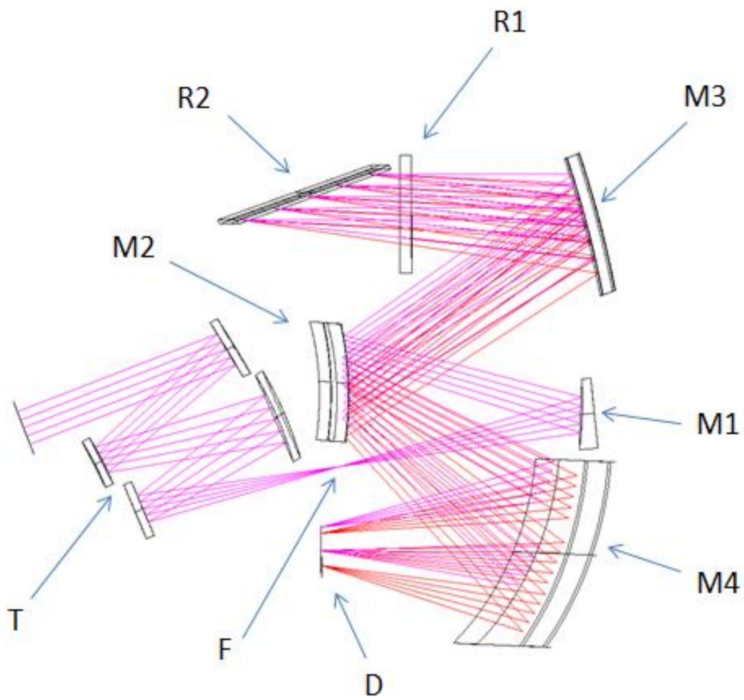
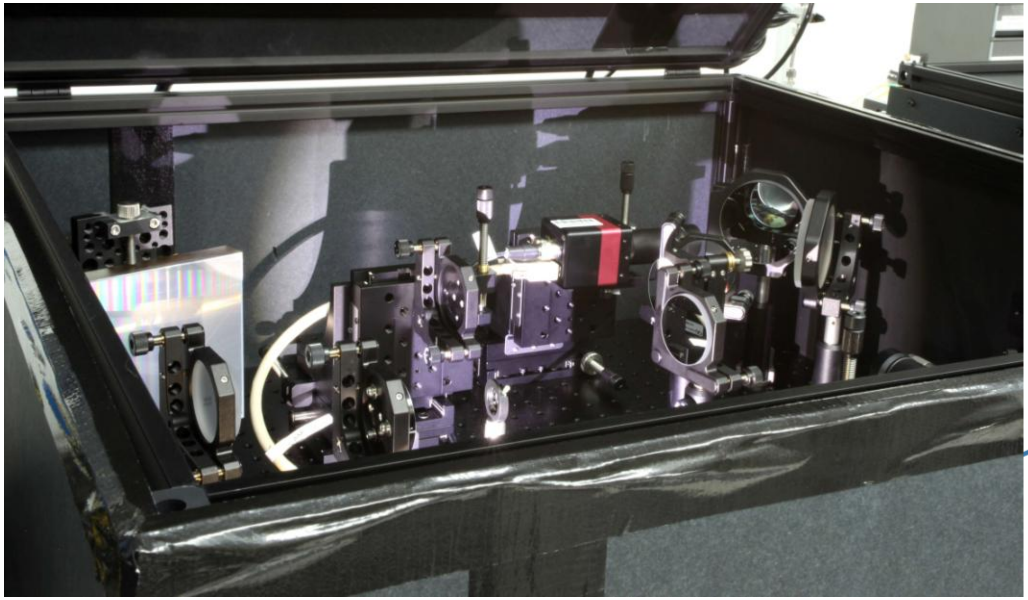
Focus on optical design



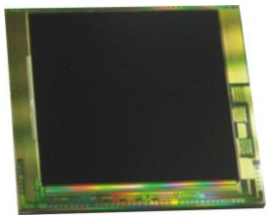
- Entrance telescope (T) focuses light on slit 'F)
- M1,M2,M3 form the collimator
- Light goes through the transmission grating R1called cross disperser grating
- Echelle grating R2 diffracts the light
- Light scattered by R2 goes back through R1
- M3, M2, M4 form the objective that focus the spectrum on single detector



- A new optical breadboard is in progress

Focus on detection

- Large detector in both directions is necessary for the double multiplexing concept
- Use only one detector for all spectral bands ➔ good efficiency from visible to 2.5µm is nedded



- Choice of new SOFRADIR VISIR 1k x 1k detector : Next Generation Panchromatic detector (NGP)

Array size, pitch	1024x1024, 15µm
ROIC noise	140 electrons
Charge Handling capacity	0,7 Me-
QE [0.35µm-2.5µm]	> 70%

Non linearity performance under 10% of the maximum well capacity must be evaluated due to low signal level in the spectrometer (usually this performance is evaluated between 10% and 90%)

Preliminary assessment

Signal to Noise Ratio (SNR), spectral resolution (R), bandwidth (BW), number of accross-track and along-track FOV (N, M)

- They are the instrument driving parameters for the CO_2 retrieval accuracy
- As very different combinations of these parameters might give similar good level 2 performances, we want to give such a freedom to the industry

⇒ great flexibility for the choice of the instrumental operating point

⇒ k is fixed so that p=required performance in ppm

$$p = \frac{k}{BW^{\alpha} SNR^{\beta} R^{\gamma} N^{\delta} M^{\delta}}$$

Another driver requirement is the limitation of the « pseudo noise » = term used for the instrumental defects that degrade radiometric noise more precisely :

- Spectral defects as ILS knowledge and stability, keystone, smile…
- Polarization defects due to optic components (grating, mirrors): need of grating polarization model, specific grating and polarisation scrambler as J.loesel describes in ICSO session 4B
- Non linearity and non uniformity defects…
- Geometric defects like inter-band and intra-band co-registration…

Preliminary assessment

- Level 1 performance of the new design using the cross disperser grating are compliant with the requirements

BANDE	ESPECE CHIMIQUE	DOMAINE SPECTRAL (nm)	LUMINANCE (W/cm2/sr/µm)	ORDRE RESEAU	DECTECTEUR	RESOLUTION	SNR (par FWHM)	SNR L / 10
B1	O_2	751 - 772	8,64 x 10-3	40	#1	23000	1300	280
B1'	H_2O	812 – 835	7,20 x 10-3	37	#1	23000	1290	270
B2	CO_2	1582 – 1627	1,20 x 10-3	19	#2	23000	780	92
B2'	CH_4	1670 – 1717	0,98 x 10-3	18	#2	23000	720	84
B3	CO_2	2004 – 2061	2,79 x 10-4	15	#2	23000	324	35
B4	CO	2312 – 2378	0,93 x 10-4	13	#2	23000	150	16

- Level 2 performance estimation of CO2 concentration (0.2ppm) with the new design is close to the level 2 performance estimation of the baseline design (0.23 ppm) (estimation made with the same retrieval tools and the same scene)
- Able to retrieve the CH4 volume mixing ratio with a random error of 6.21ppb which is compliant with Merlin requirement (<8ppb) and Carbonsat requirement (<10ppb)

Conclusion

- Use of a cross-disperser grating in Microcarb concept studied by CNES gives the ability to reach high-quality CO2 measurements with a very compact design

- This compact design offers a low cost solution with mature technologies (TRL > 5) compliant with the CO2 mission purposes

- This concept is also adapted for other missions like the measurement of CH4, H20 and CO concentration

More information can be found on the CNES website http://microcarb-mission.cnes.fr

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