Radiometric and spectral sizing of future CO_2 observing space missions

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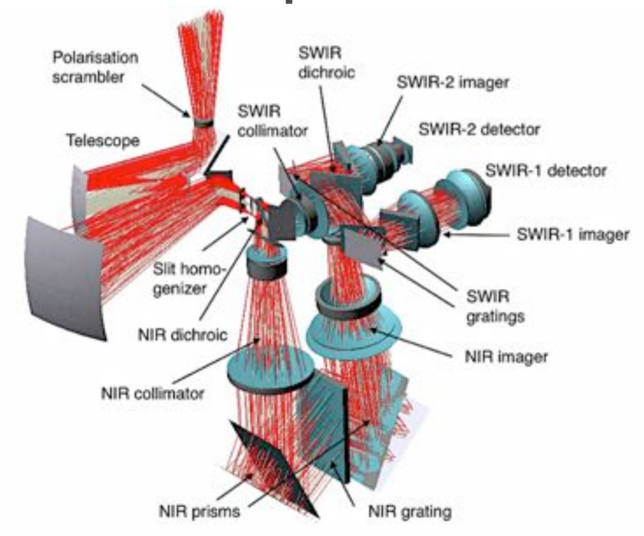
The CarbonSat mission

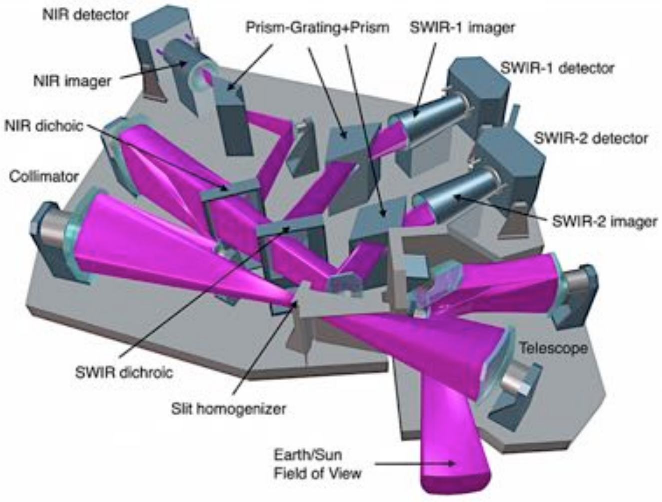
The CarbonSat mission

- Candidate mission for ESA's Earth Explorer program (EE8)
- Phase A/B1 (feasibility and design) with two industrial consortia
- Mission goals
  - biogenic sources and sinks
  - anthropogenic sources (cities and power plants)
- High spatial sampling, wide swath imaging of XCO_2 and XCH_4
  - 6 km^2 (3km ACT x 2 km ALT) spatial samples, 240 km swath width
  - High single sounding precision and accuracy (3 ppm rms / 0.5 ppm bias)

Concept A



Concept B

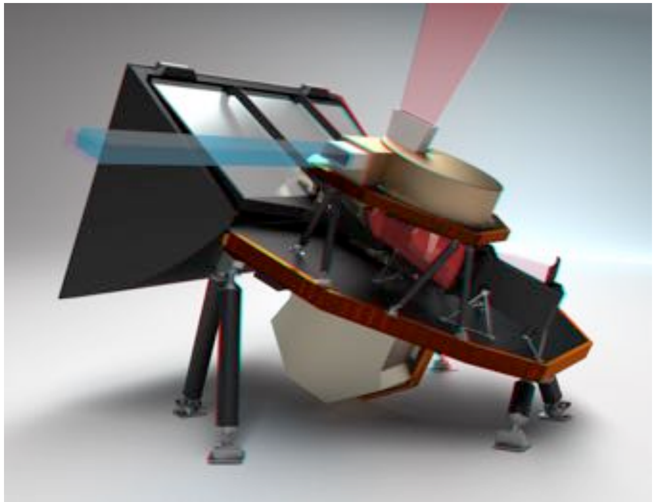


The CarbonSat mission

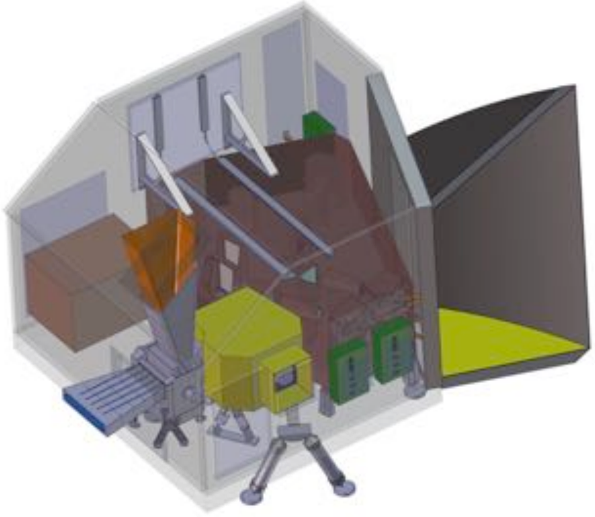
From CarbonSat to Copernicus mission

- The FLEX mission was selected as Earth Explorer 8
- CarbonSat instrument pre-development studies still on-going
- Serves as starting point for future European carbon monitoring system
  - Anthropogenic CO_2 emission as primary goal
  - High spatial resolution imaging of point sources (cities, power plants)
  - Global coverage at high temporal sampling
  - High single sounding precision and accuracy (1 ppm rms / 0.5 ppm bias)

Concept A



Concept B

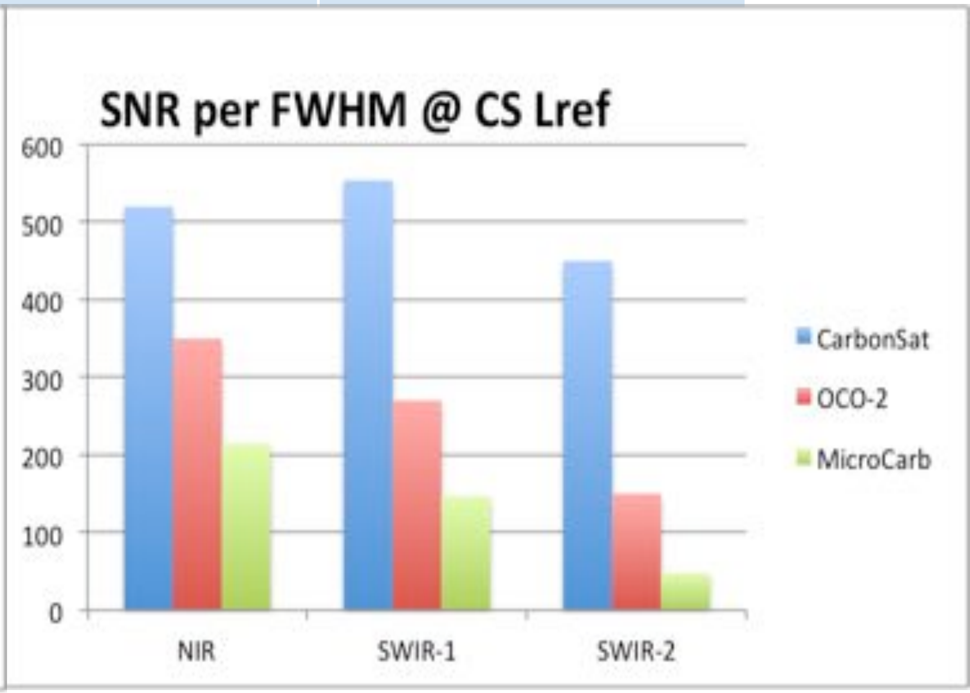


Spectral sizing of past and future missions

SNR and spectral resolution trade-off revisited

- CarbonSat was designed for low resolution / high SNR
- OCO-2 and MicroCarb (will) implement high resolution / low SNR

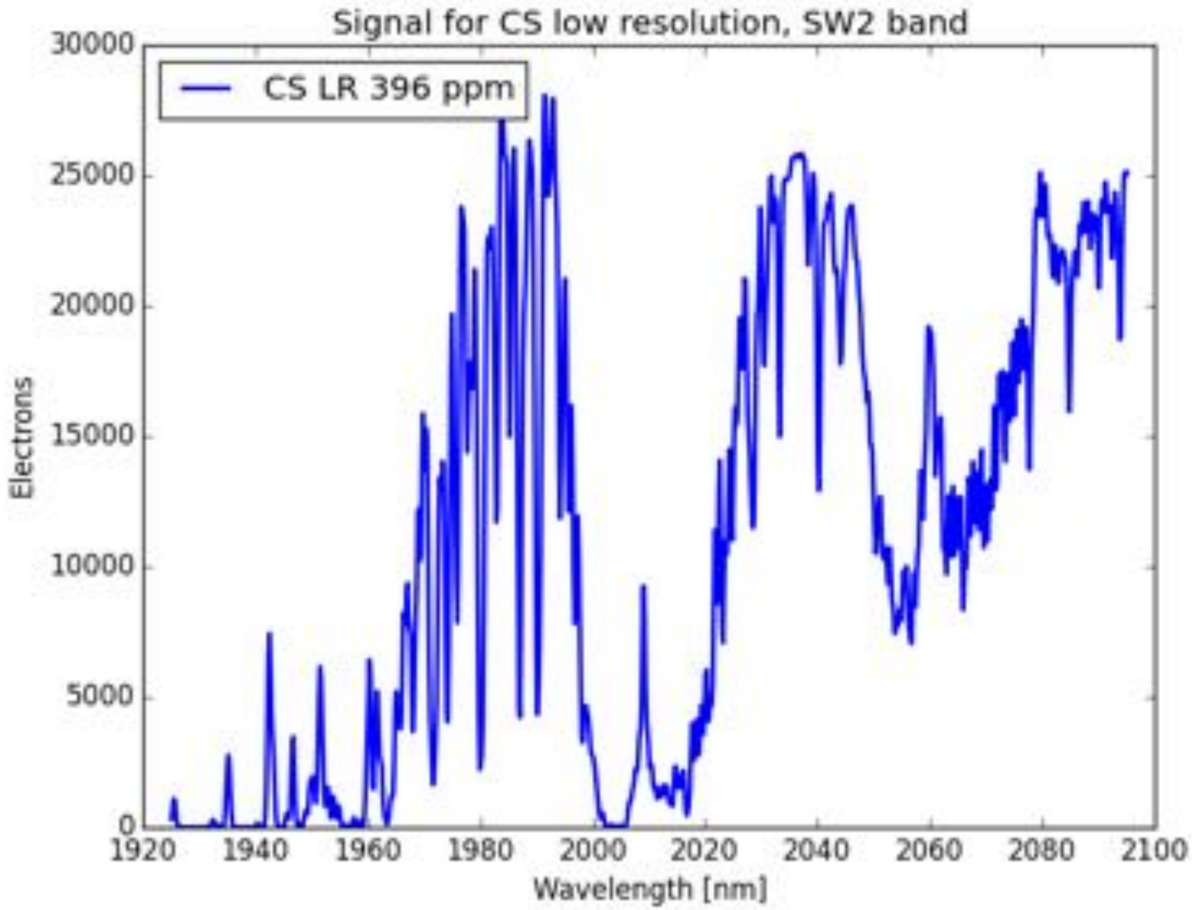
	CarbonSat	OCO-2	MicroCarb (ICSO 2014)
Spectral bands / band width [nm]	NIR: 747-773 SW1: 1590-1675 SW2: 1925-2095	NIR: 758-772 SW1: 1594-1619 SW2: 2045-2081	NIR: 751-772 SW1: 1582-1627 SW2: 2004-2061



High vs Low Resolution

Example: CarbonSat's SWIR-2 band (2.06 μm)

- Dark vegetation scenario (Albedo 0.05, SZA = 50°)
- XCO_2: 396 ppm



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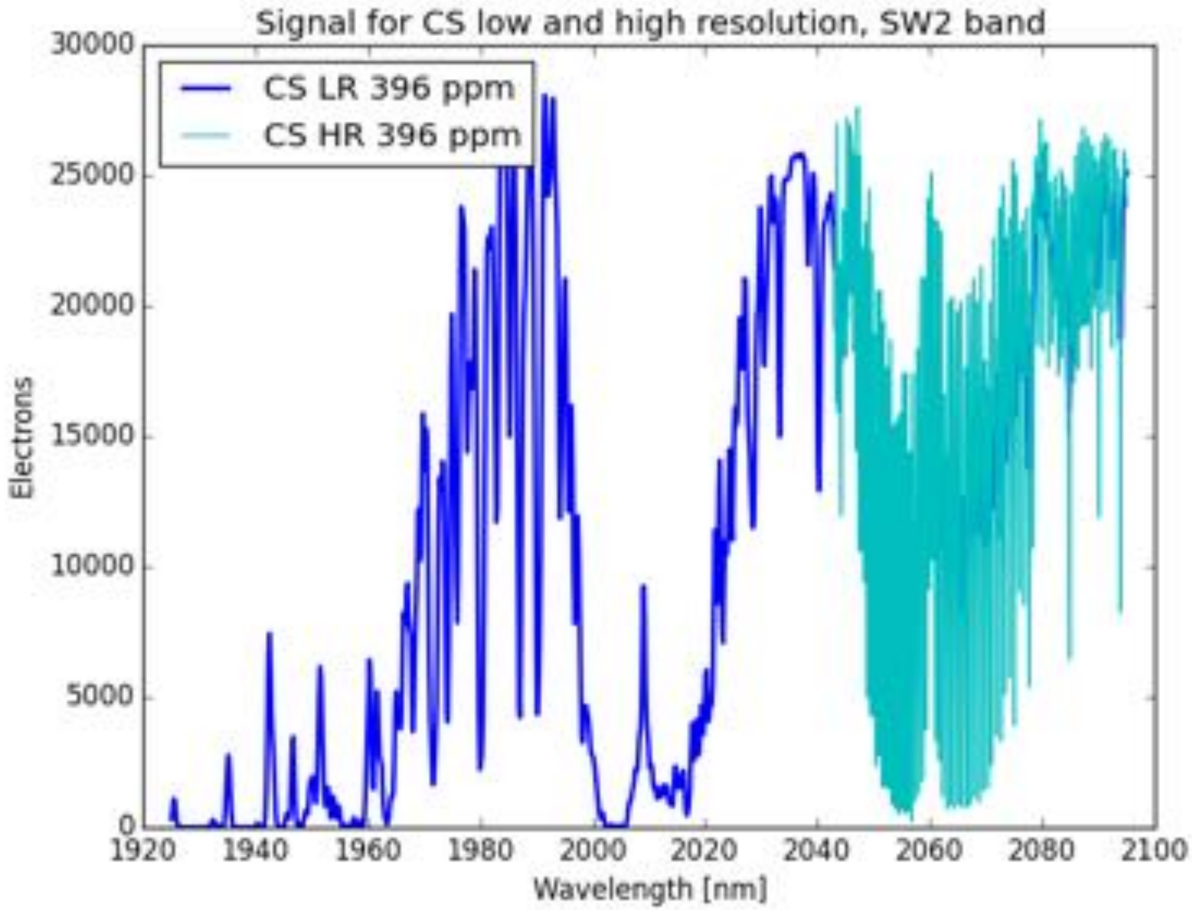

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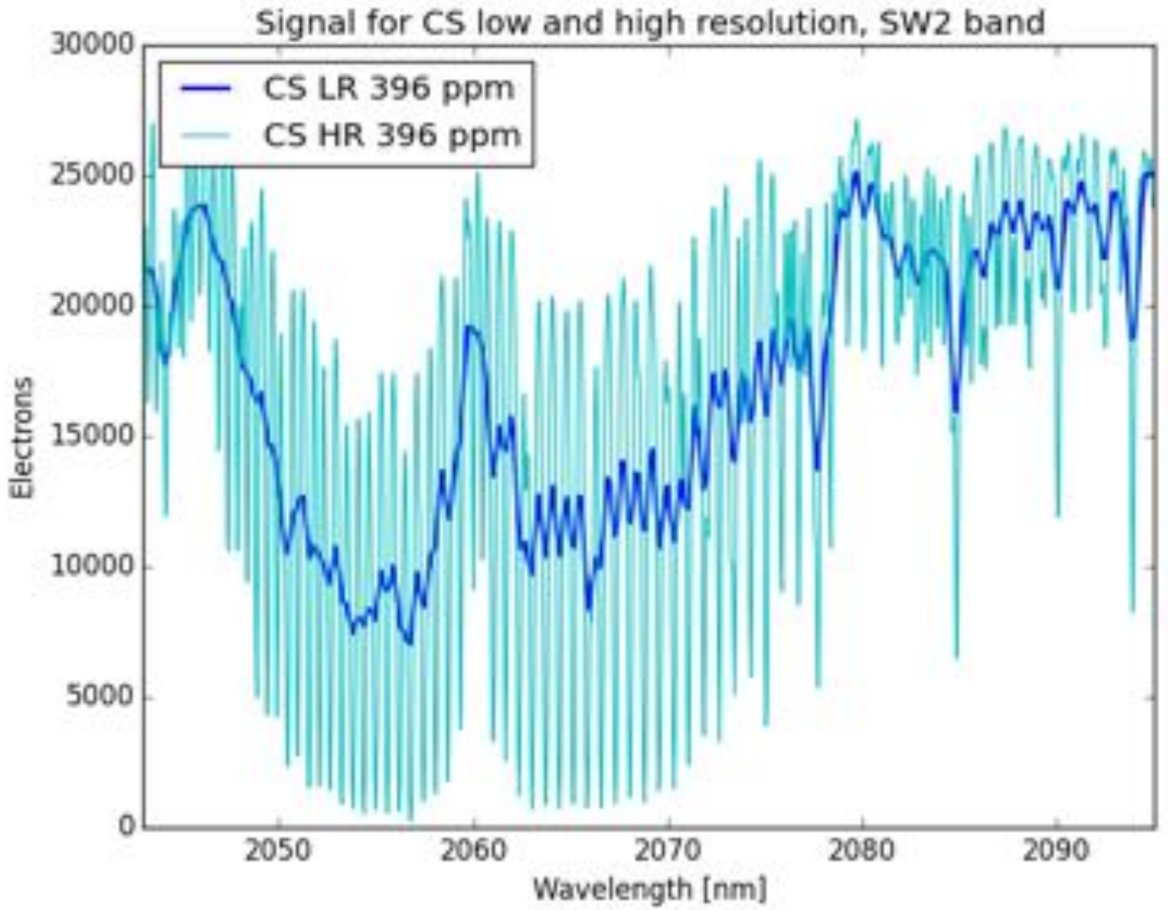
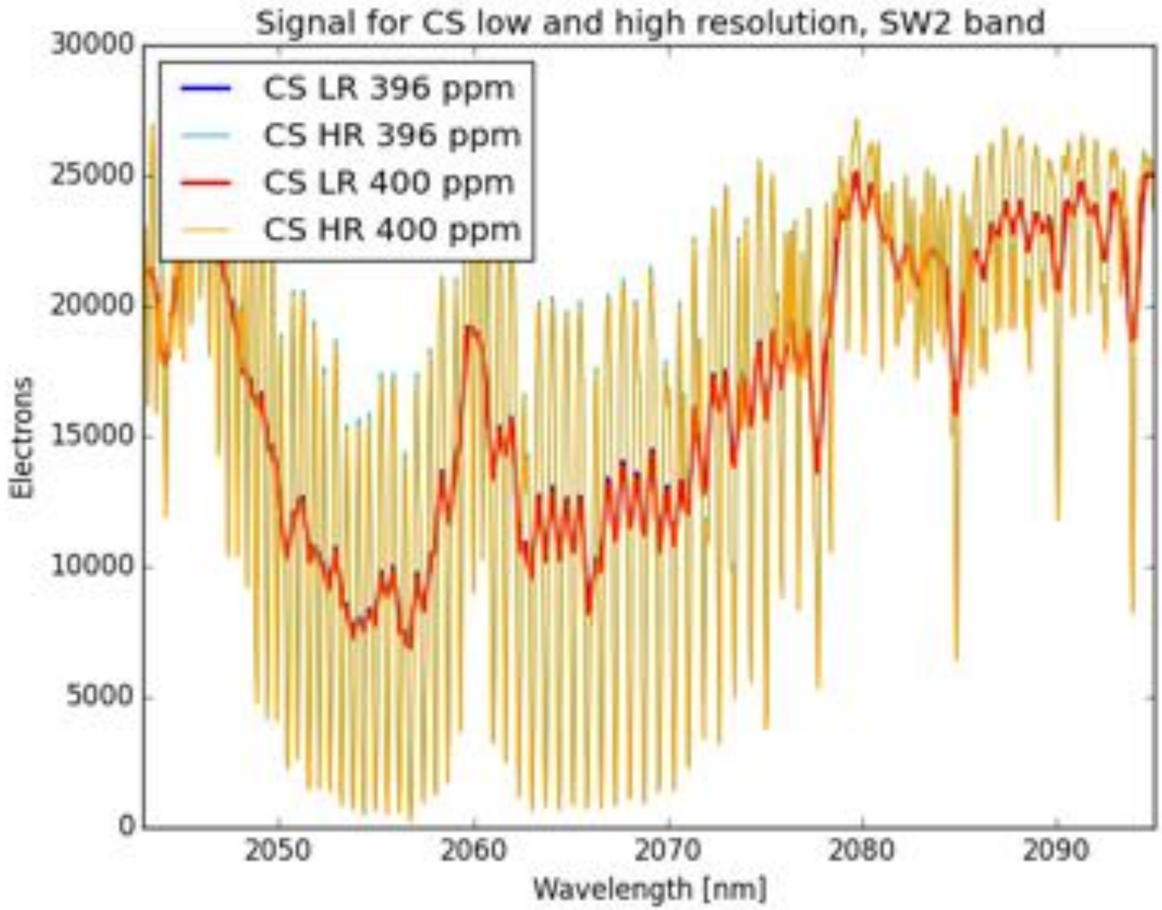
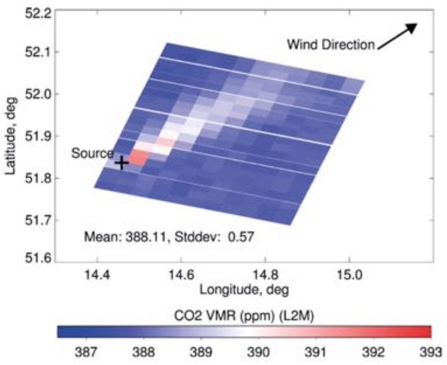


High vs Low Resolution

Example: CarbonSat's SWIR-2 band (2.06 µm)

- Dark vegetation scenario (Albedo 0.05, SZA = 50°)
- XCO_2: 396 ppm + 400 ppm (concentration gradient in power plant plume)

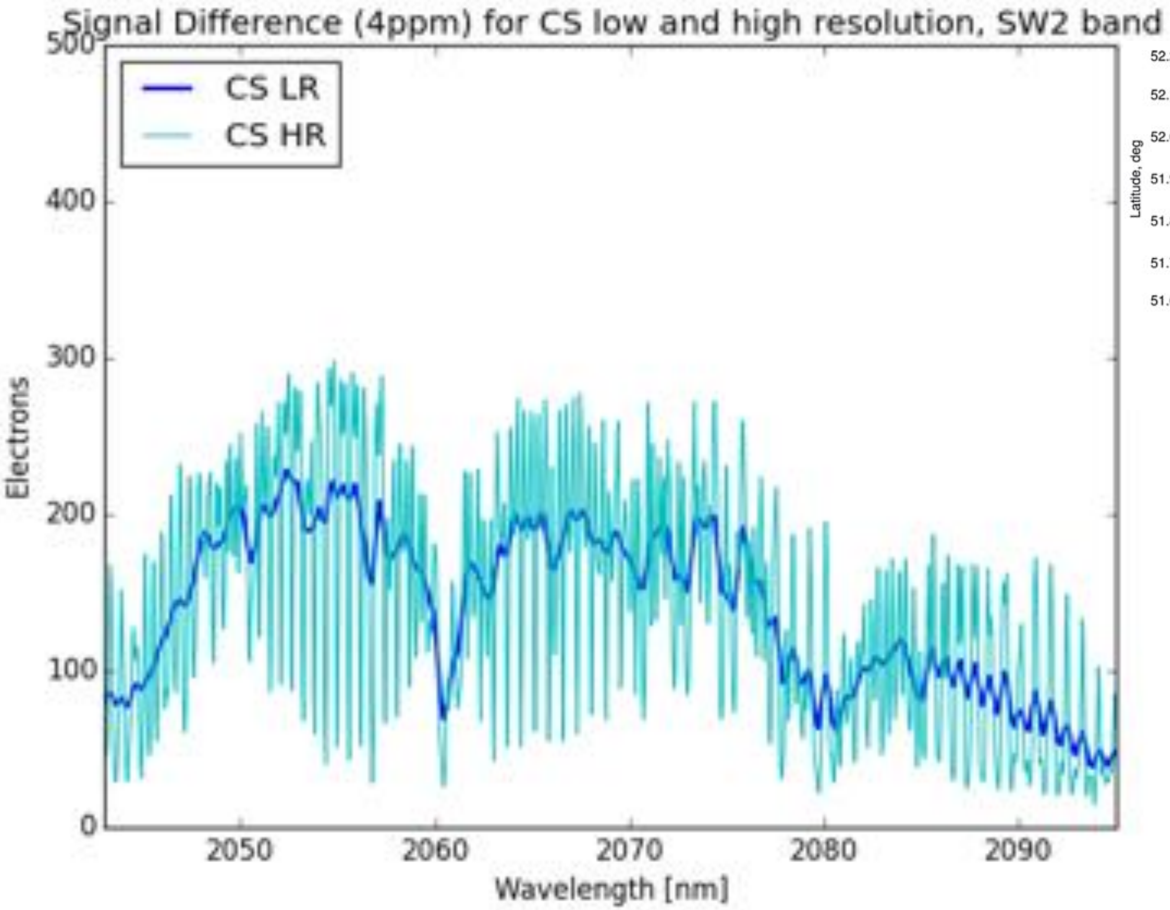


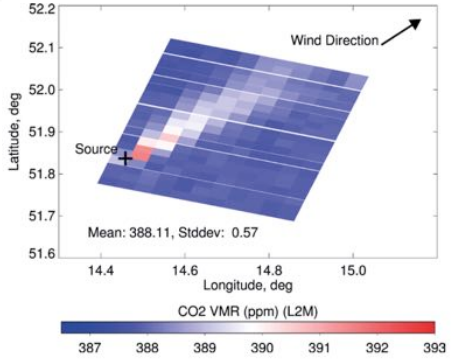


High vs Low Resolution

Example: CarbonSat's SWIR-2 band (2.06 µm)

- Dark vegetation scenario (Albedo 0.05, SZA = 50°)
- Delta XCO_2 (396 ppm - 400 ppm), **low res.** and **high res.**

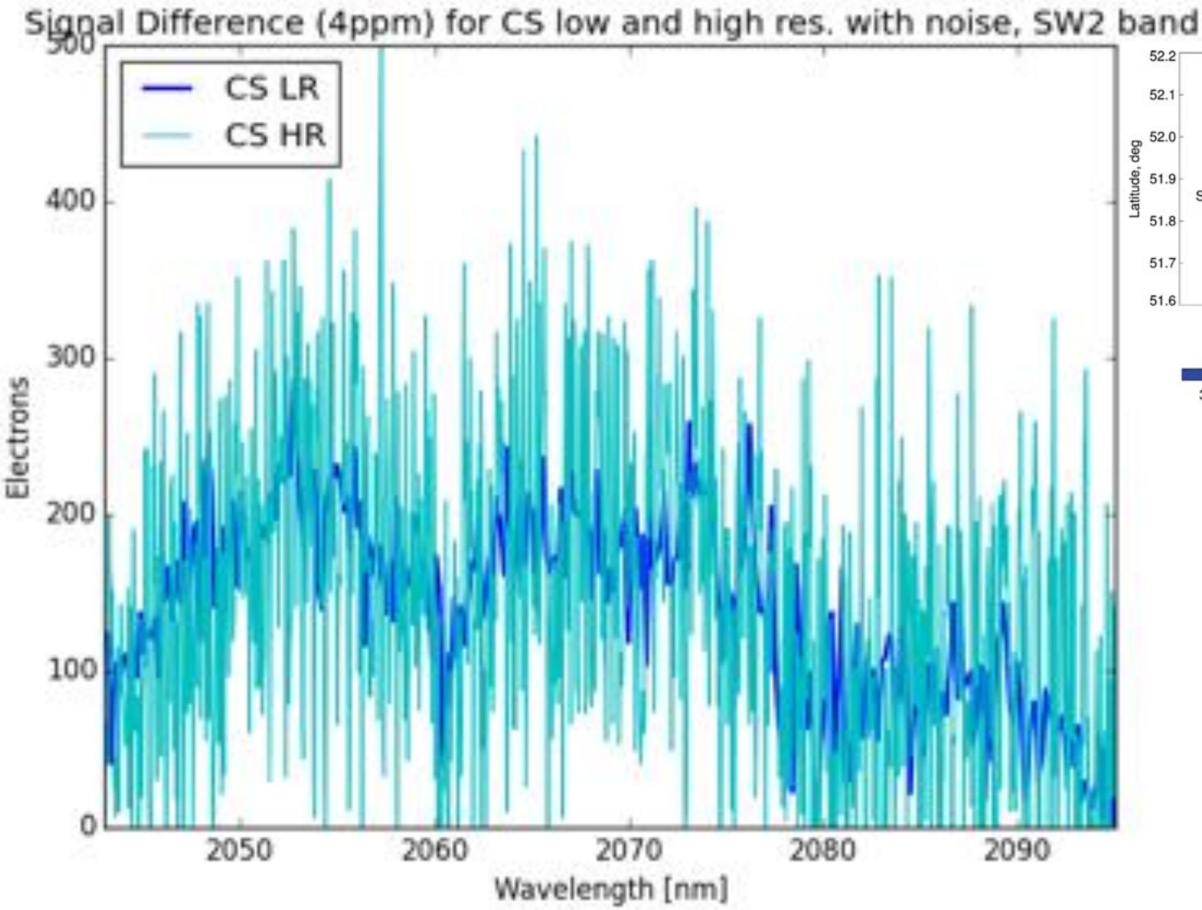


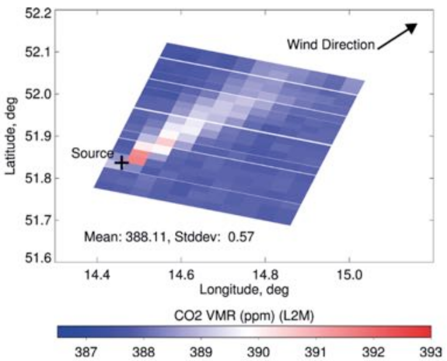


High vs Low Resolution

Example: CarbonSat's SWIR-2 band (2.06 µm)

- Dark vegetation scenario (Albedo 0.05, SZA = 50°)
- Delta XCO_2 (396 ppm - 400 ppm), **low res.** and **high res. with noise**



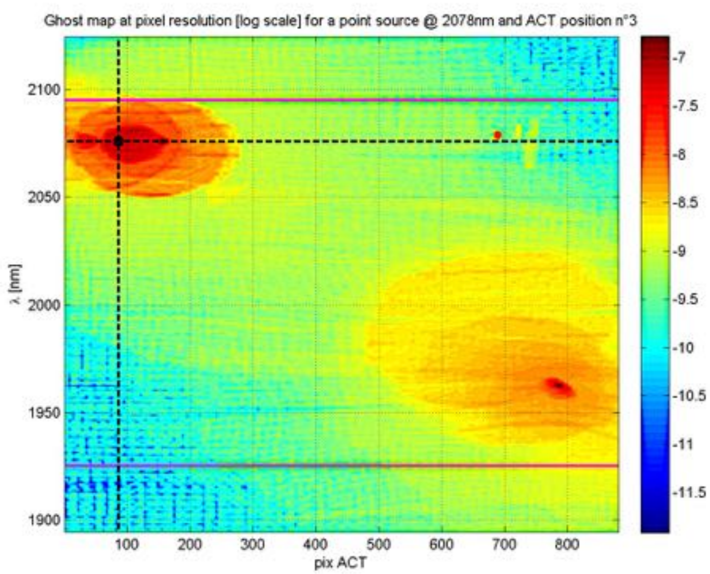


Spectral Sizing and systematic errors: Straylight

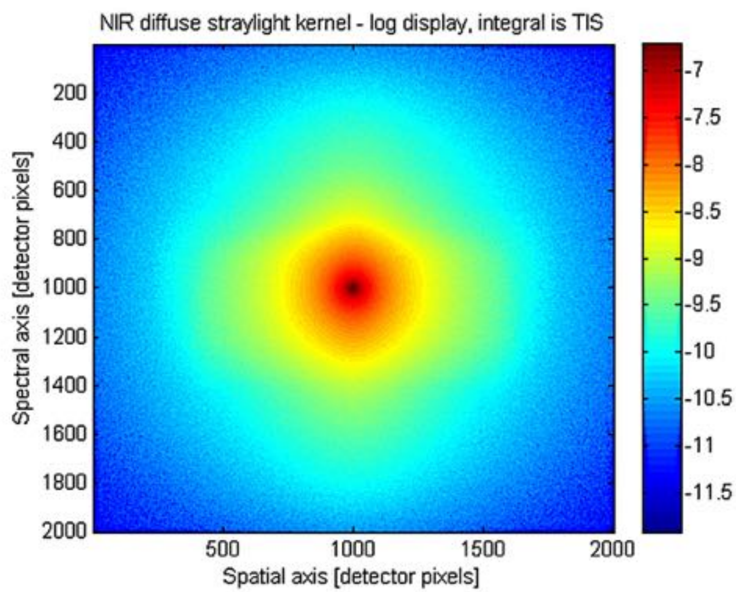
Impact of systematic errors

- Straylight is a major driver for instrument performance
- Found to be critical for CarbonSat
    - Imaging mode with large radiometric contrast
    - Interpreted as contributor to bias
    - Drives cleanliness, smoothness of optical components

SL ghosts (Concept A)



Diffuse SL kernel (Concept B)



Does the criticality depend on the spectral sizing ?

Optimizing spectral sizing

- **ESA initiated a scientific support study**
- **Objective: Investigate the relative impact of various error sources for different spectral sizing points**
  - Straylight
  - ISRF distortion
  - Polarisation sensitivity
  - Non-linearity
  - Diffuser features

Approach

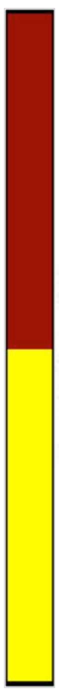
1. **Simulation of L1b measurements**
   - using results of CarbonSat instrument studies (SL kernels, Mueller matrices, non-linearity and speckle measurements)
   - simulating a large ensemble of geophysical scenarios
   - 3-4 spectral sizing configurations (high-low resolution/SNR)
2. **Perform Level-2 retrievals for various spectral sizing configurations**
3. **Compare performance in terms of accuracy and precision**

Straylight Simulation Approach

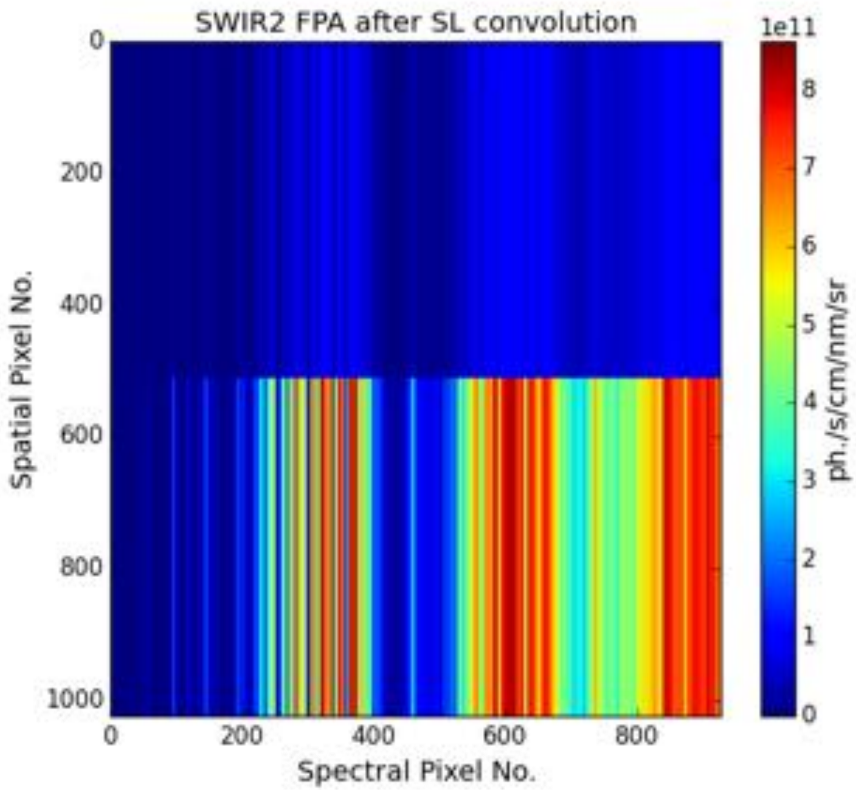
1.) Simulation of a measurement over a contrast scene

- Half of the entrance slit is illuminated with bright scene (Albedo 0.4)
- The other half with dark clear-sky vegetation scene (Albedo 0.05)
- The error-free signal on the focal plane is computed

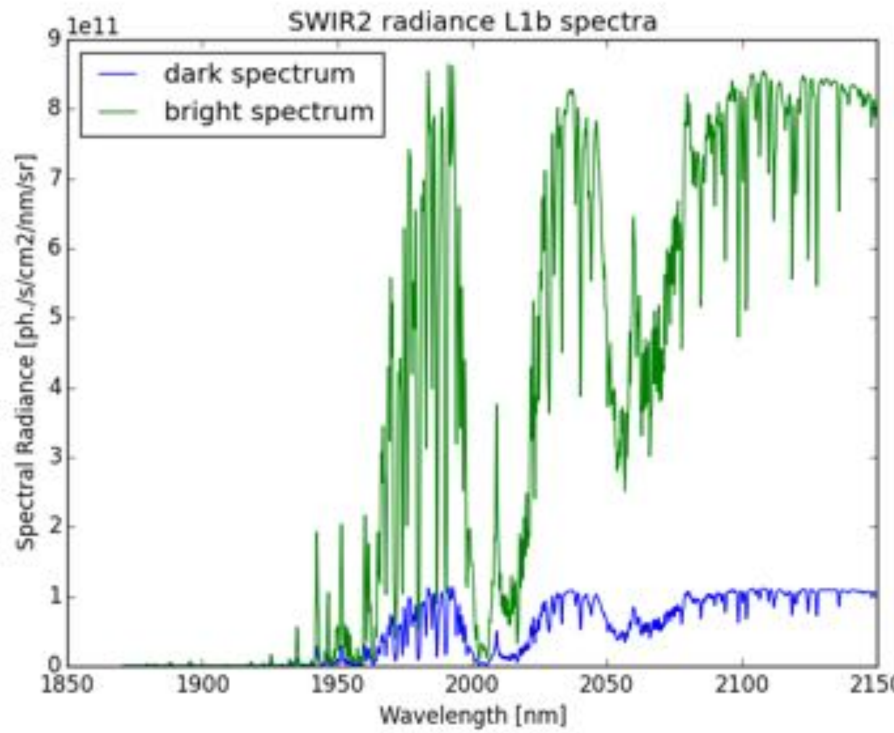
Entrance slit



Signal at detector



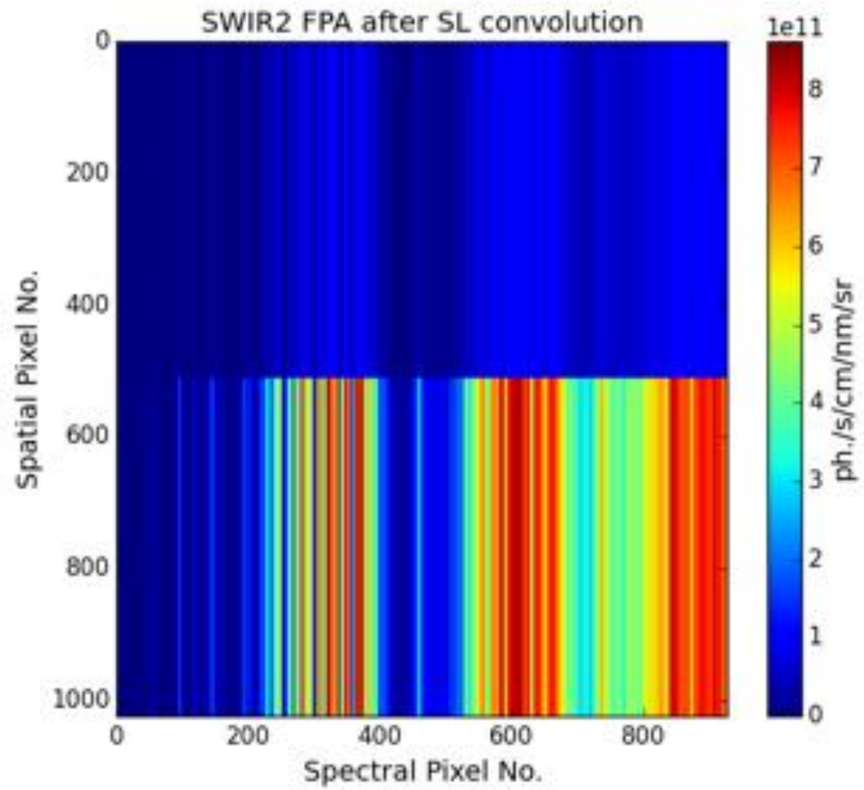
Reference spectra

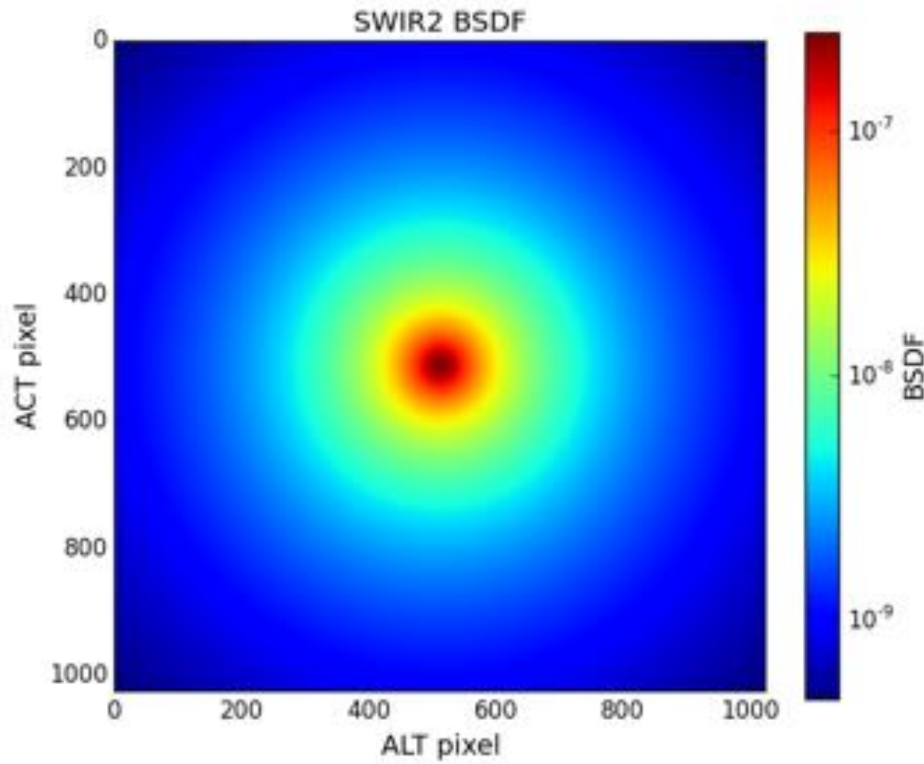


Straylight Simulation Approach

2.) Simulation of straylight

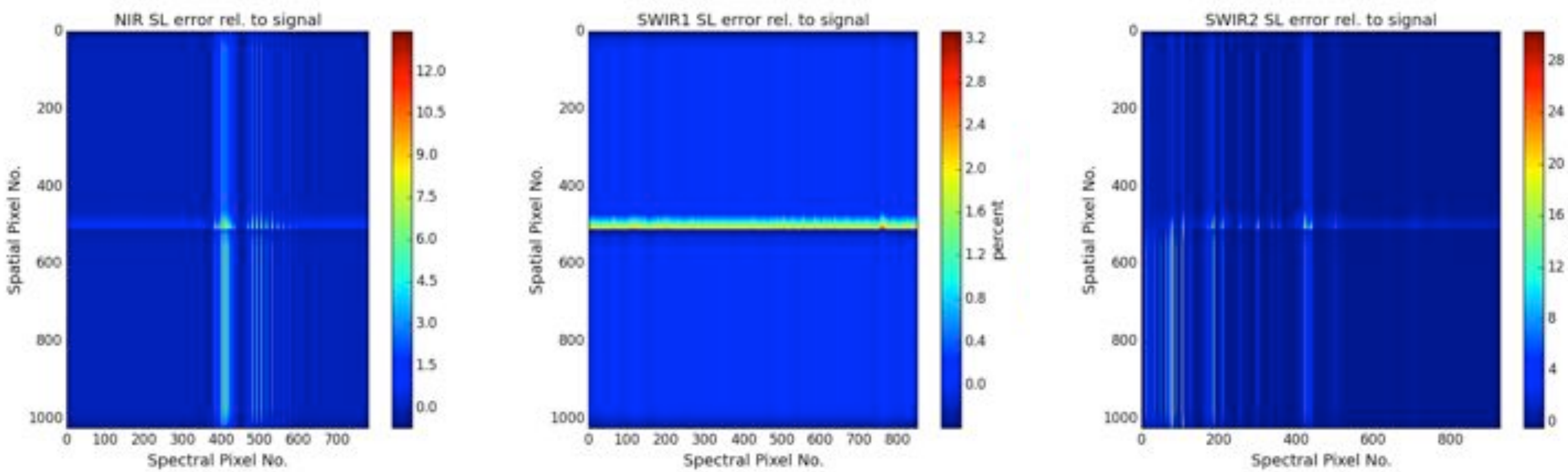
- The BSDF is derived from straylight simulations for CarbonSat studies
- A simplified straylight kernel is derived from the BSDF
- The straylight-affected signal is computed by 2-dimensional convolution with the kernel



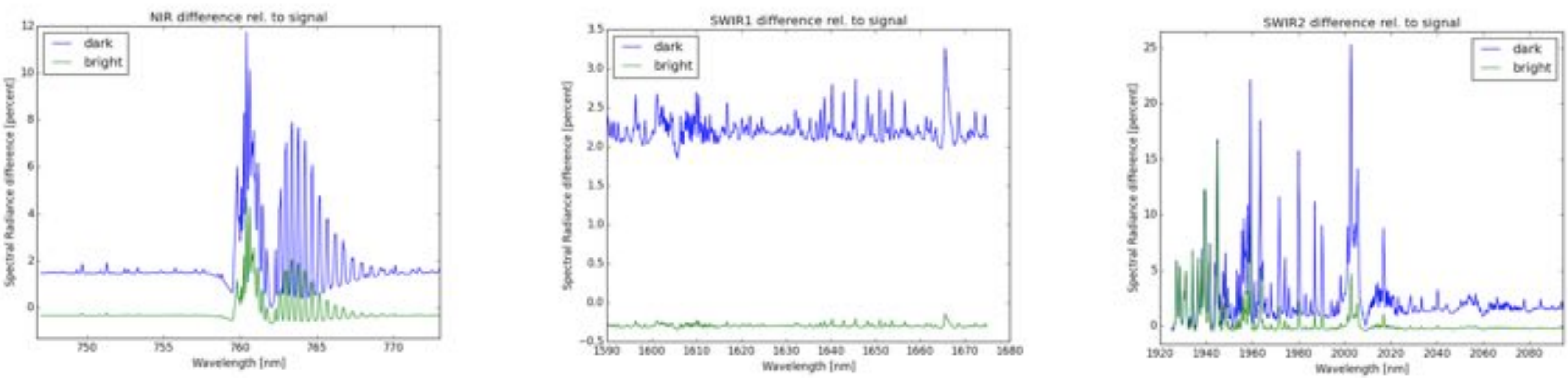


Straylight Simulation Results: Level-0

Relative straylight error across the focal plane (% of local radiance):



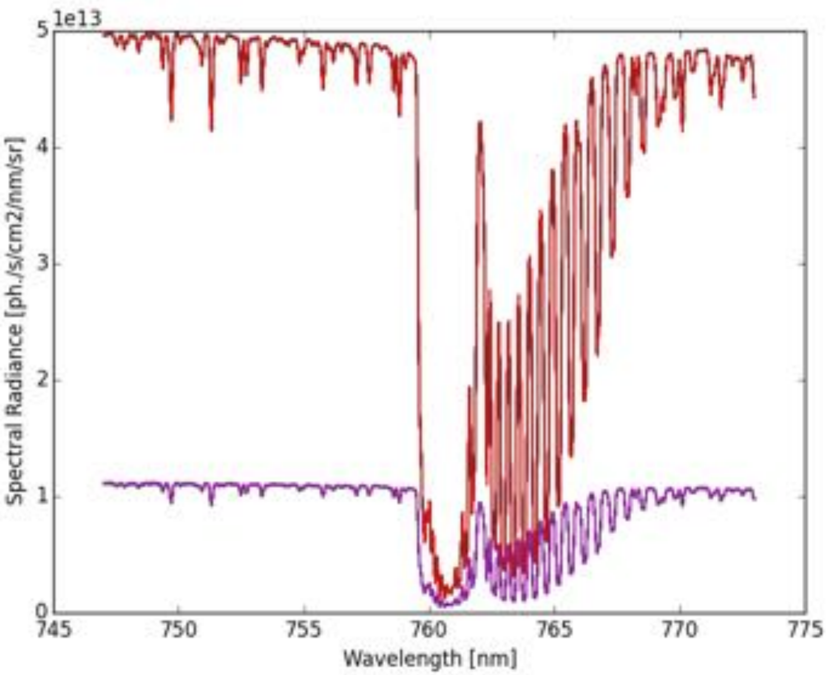
Relative straylight error for L1b spectra 5 SSD from the transition:

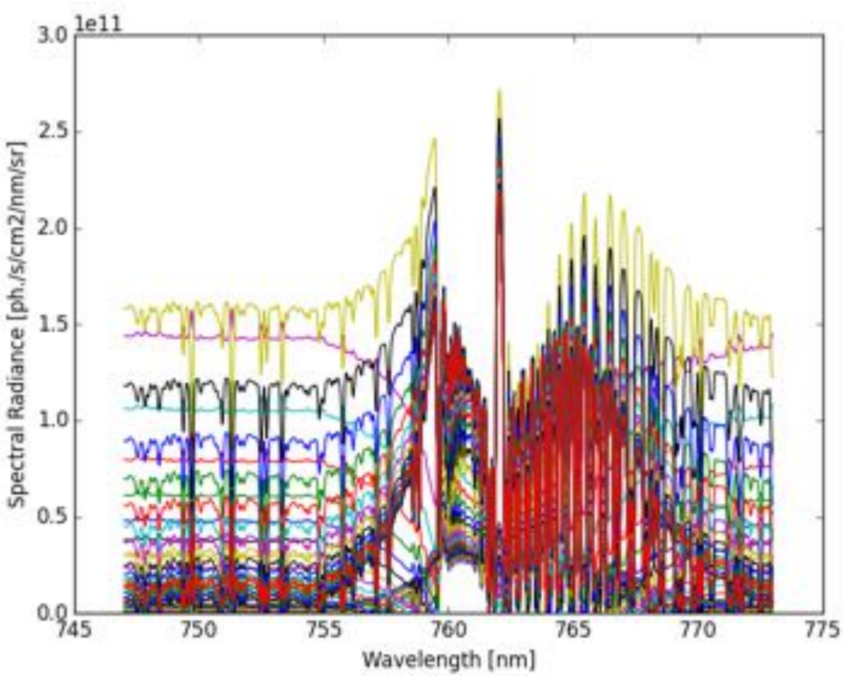


Straylight Simulation Results: Level-1b

3.) Generation of L1b data

- The Level-1b radiance spectra are computed by binning across the swath
- 10 spatial pixels form one ACT spatial sample of 3 km width
- 80 ACT spatial samples (Field-of-Views)
- Correspond to 240 km swath width
- Large radiometric errors near the transition dark/bright in the swath center

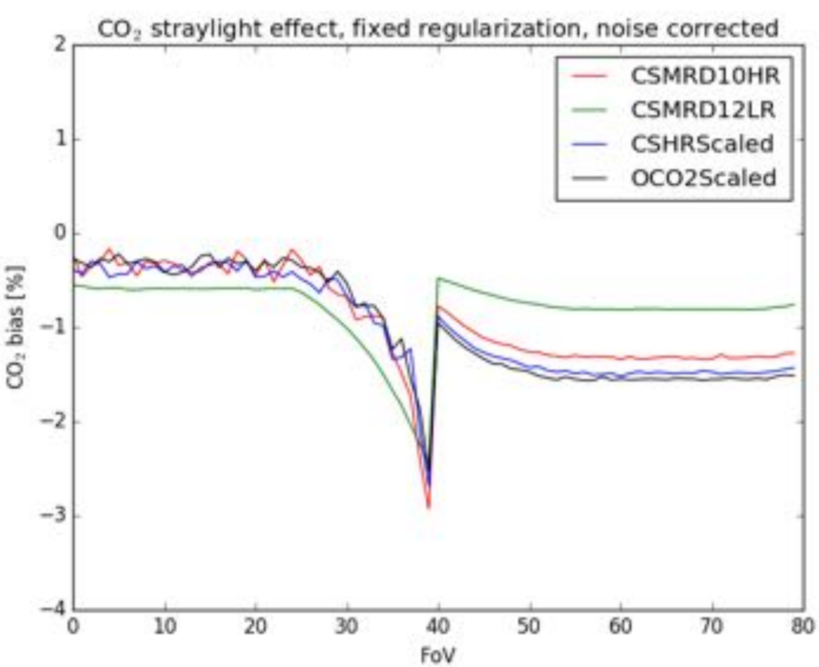


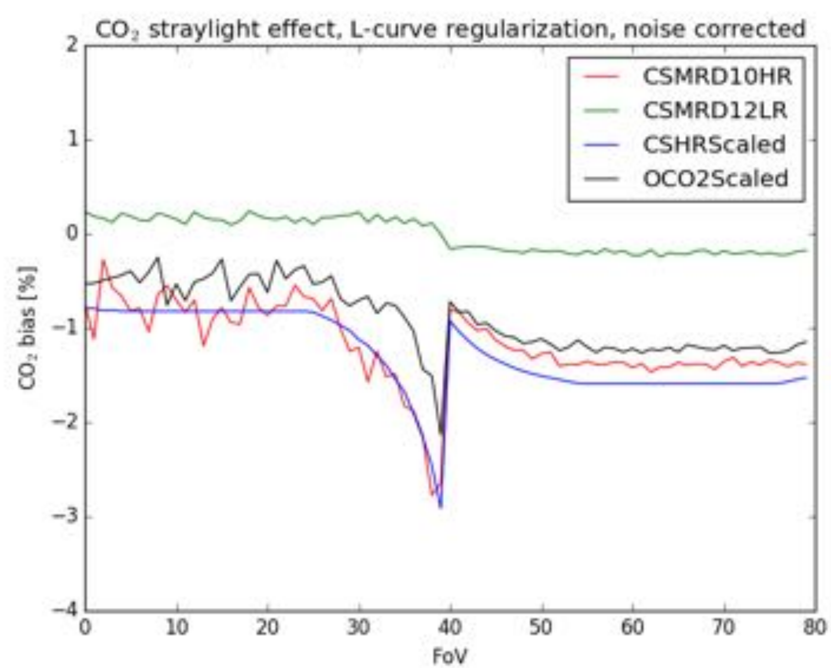


Straylight Simulation Results: Level-2

4.) Level-2 retrieval for all Level-1b spectra

- RemoTeC algorithm at SRON
- 80 Field-of-Views across the swath (ACT spatial samples)
- Four spectral sizing configurations (instruments)
    - 1 CarbonSat LR and 2 HR configurations
    - OCO-2
- Retrieval of XCO_2 and XCH_4 with and without regularization





Conclusions

- **ESA has initiated a study for verification of spectral sizing configurations**
  - In preparation for a future carbon monitoring system
  - High spatial sampling, wide swath imaging of emission point sources
- **Trade-off revisited in view of systematic instrumental errors**
  - wide vs. narrow spectral bandwidth
  - low vs. high spectral resolution
  - high vs. low SNR
- **First tests of straylight impact**
  - Simulation of L1b data for simple contrast scene
  - Level-2 retrieval (without correction for straylight)
  - Evaluation of bias performance
- **Preliminary indication:**
  - Low-resolution / high SNR CarbonSat configuration not more sensitive to straylight than high-resolution instruments

Outlook

- **Extensive study will be kicked off in June/July**
  - Space Research Organisation of the Netherlands (SRON)
  - Karlsruhe Institute of Technology (KIT), Germany
  - Institute of Environmental Physics (IUP), Bremen, Germany
  - University of Leicester, UK
- **Simulation of various instrumental error sources**
  - Straylight
  - Polarisation
  - Diffuser speckles
  - Detector non-linearity
- **Large number of geophysical scenarios**
  - Global clear-sky database (~ 10000)
  - Realistic aerosol/cloud scenes (Tropomi orbits, A-train data)
- **Wide range of spectral sizing points for limited subset**
- **Conclusions to be expected by end 2016**
- **Will determine operation point of a future European carbon mission**
- **Suggestions welcome !**