A new snapshot interferometric imaging spectrometer: a first comparison with a classical grating spectrometer

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Summary

1. Introduction
2. ImSPOC instrument
   - Concept
   - Signal and image processing for ImSPOC
3. Experiments
   - Acquisitions
   - Calibration
   - Spectra reconstruction
4. Preliminary results
5. Conclusion

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Introduction

- Atmospheric gas monitoring is of major importance for CC and air quality
- Nowadays, **conventional dispersive hyperspectral imaging systems** are used

Advantages

- Good performances for current monitoring but better performances are always required to increase the measurement precision

Disadvantages

- Compromises in terms of price, spectral and spatial resolutions and temporal acquisition frequency

Introduction

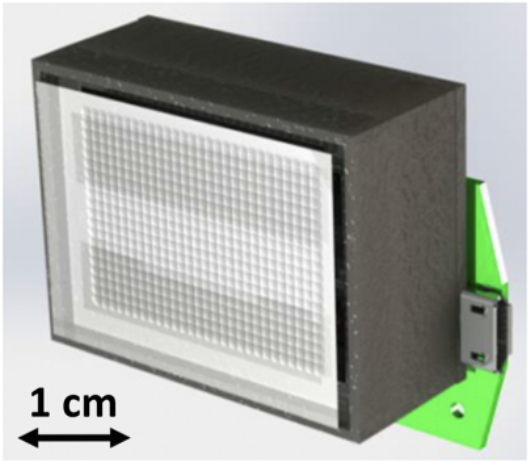
- Presentation of a new ground-breaking device currently developed under the name **Imaging Spectrometer on Chip (ImSPOC)**

Advantages

- Snapshot with significant spectral and spatial resolutions

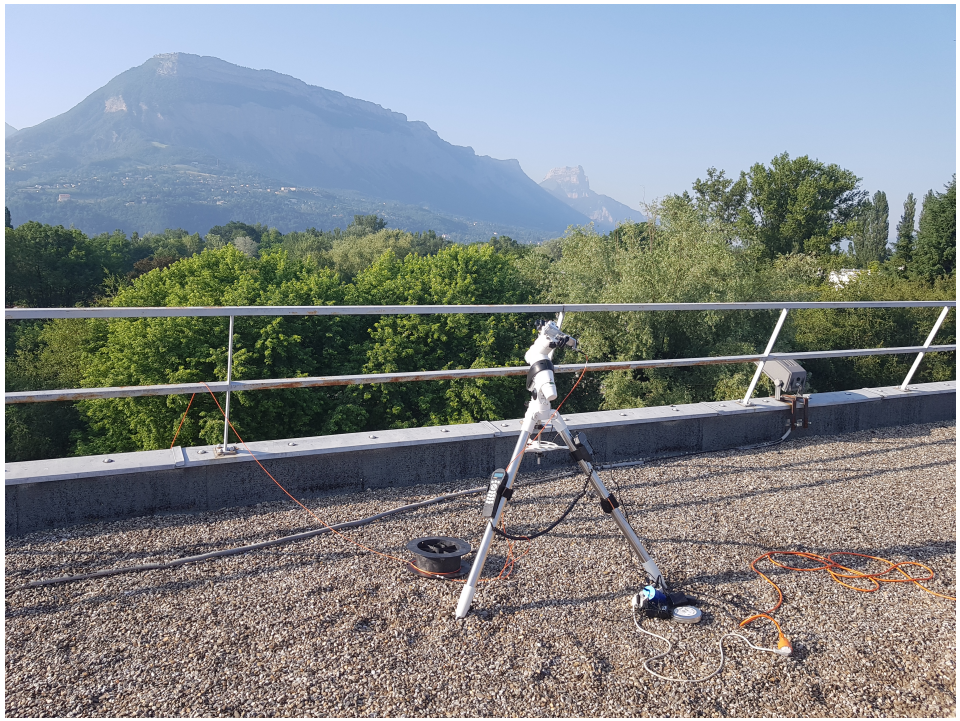
Disadvantages

- Challenges in term of signal and image processing



Introduction

- This study presents the first experiments done with the ImSPOC sensor
- **Sun tracking acquisitions** were done in Grenoble, France with both:
  - ImSPOC sensor
  - Conventional dispersive hyperspectral imaging system (USB2000+, Ocean Optics)



- Preliminary results of comparison between both instruments measurements are highlighted

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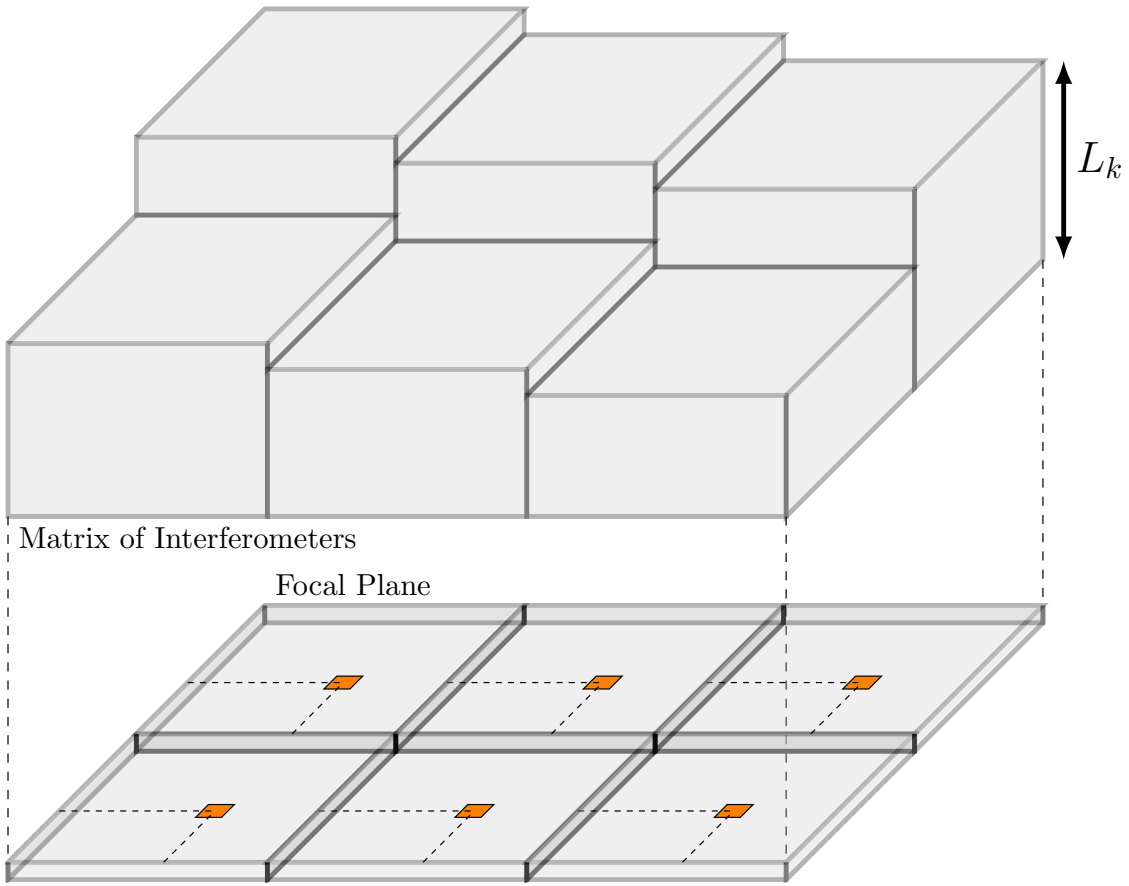
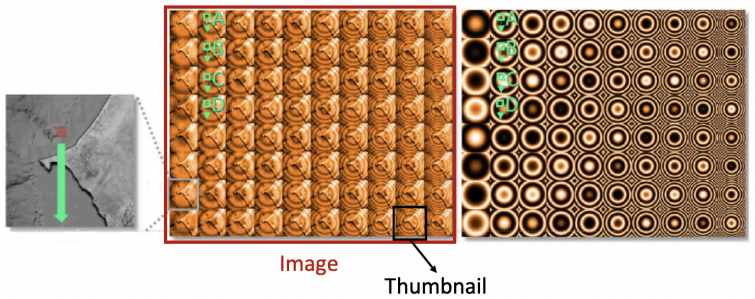
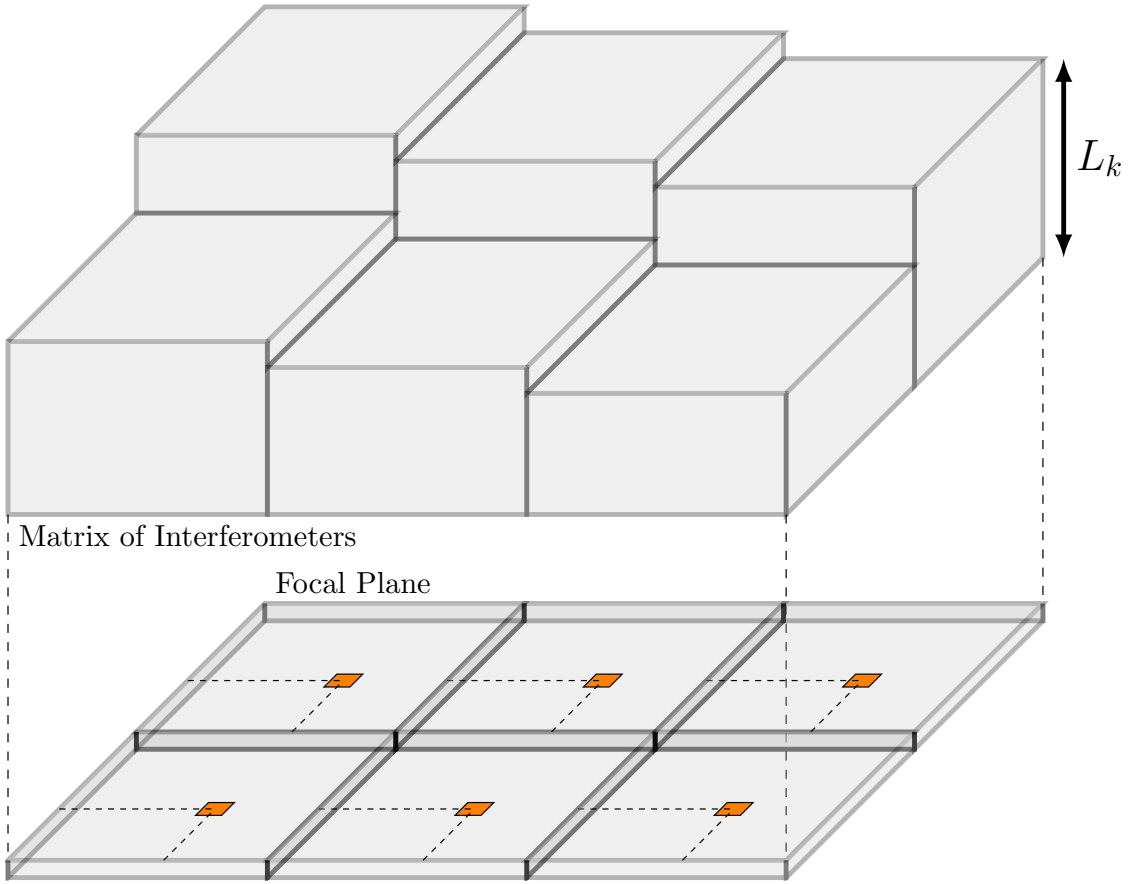
ImSPOC concept



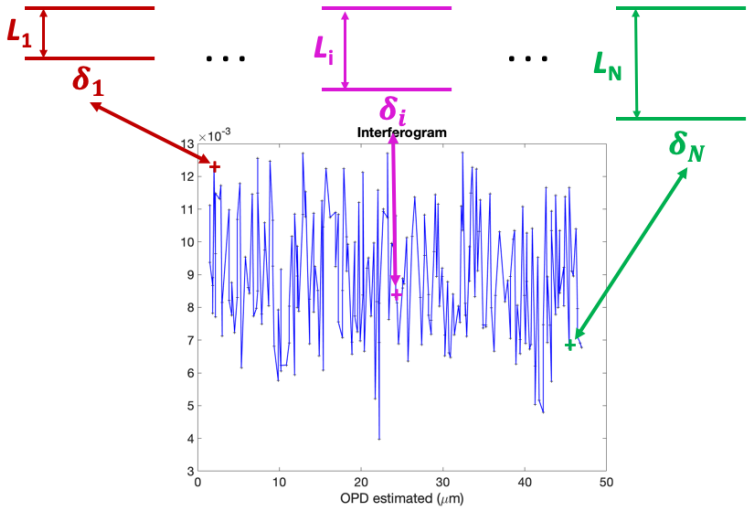
- An array of Fabry-Perot interferometers allows snapshot acquisitions of multiple thumbnails on the same focal plane



ImSPOC concept

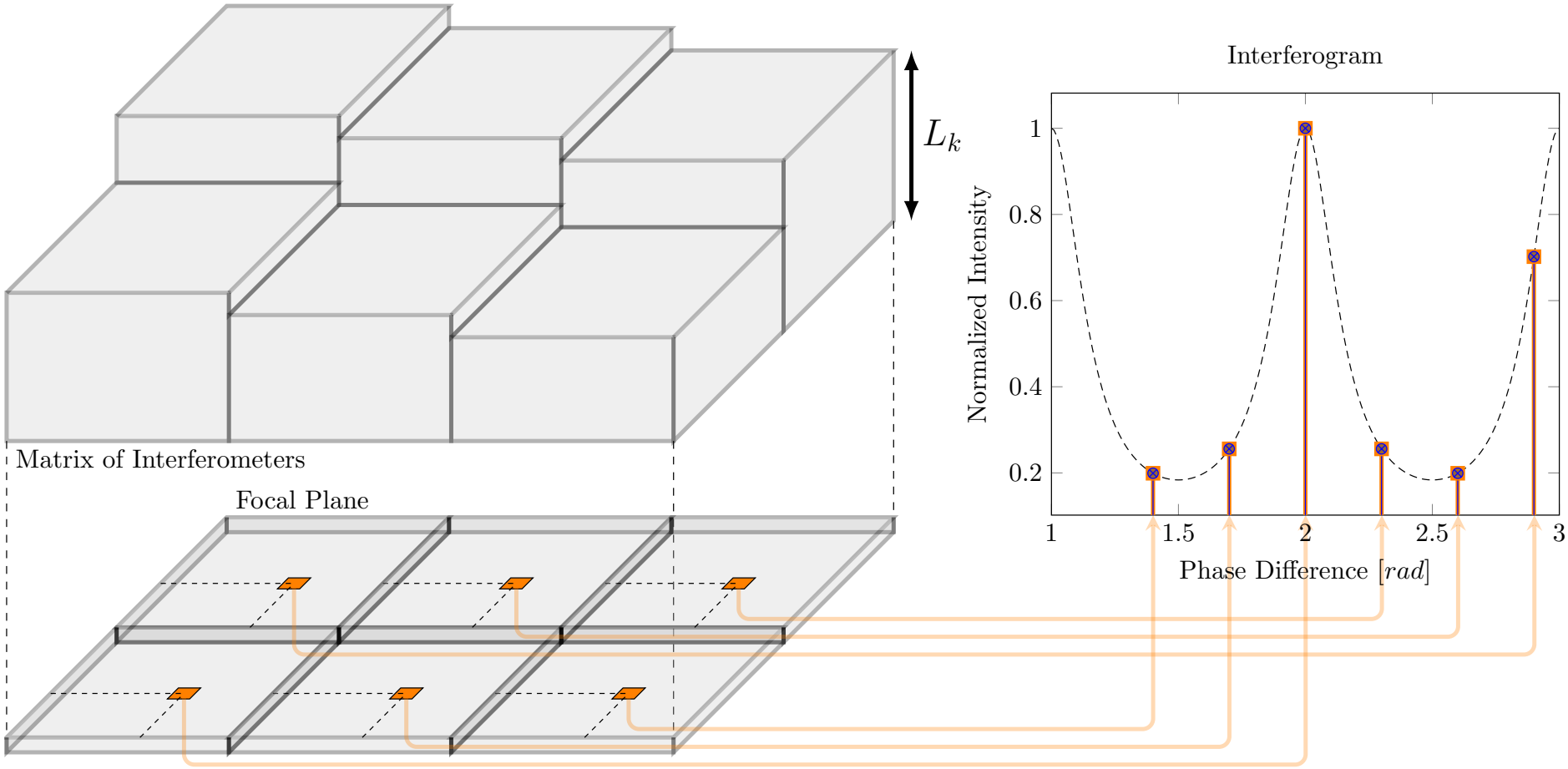


- The acquisition over different thumbnails generates a sampling of the interferogram



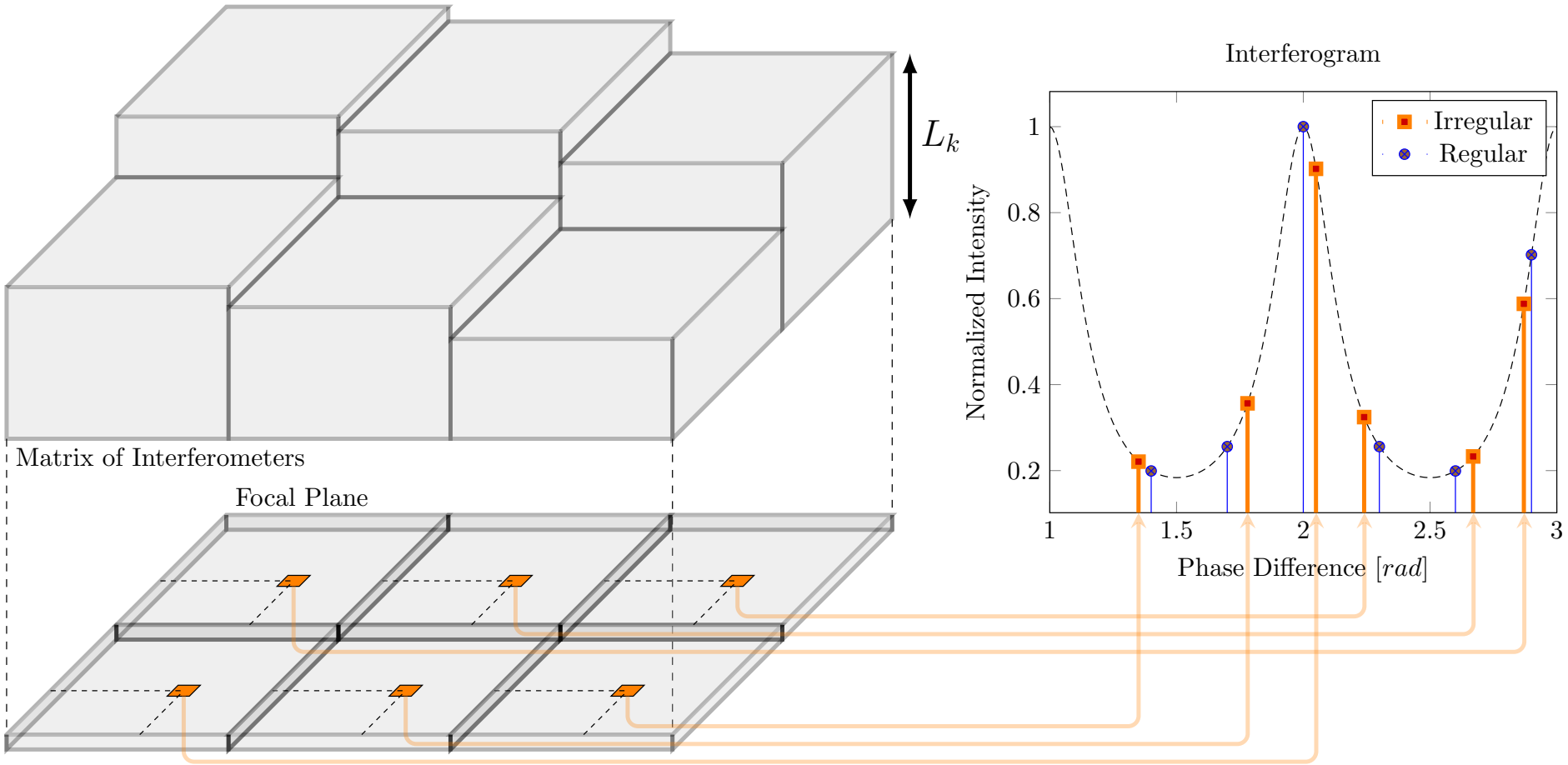
ImSPOC concept

- Theoretically, the interferograms should be regularly sampled



ImSPOC concept

- However, after fabrication of the instrument, the interferograms are actually **irregularly sampled**



Signal and image processing for ImSPOC

- Objectives
  - Calibration :
    - ★ Optimal interferogram reconstruction
  - Spectrum reconstruction : interferogram inversion
  - Concentration estimation :
    - ★ Gas detection
    - ★ Concentration quantification

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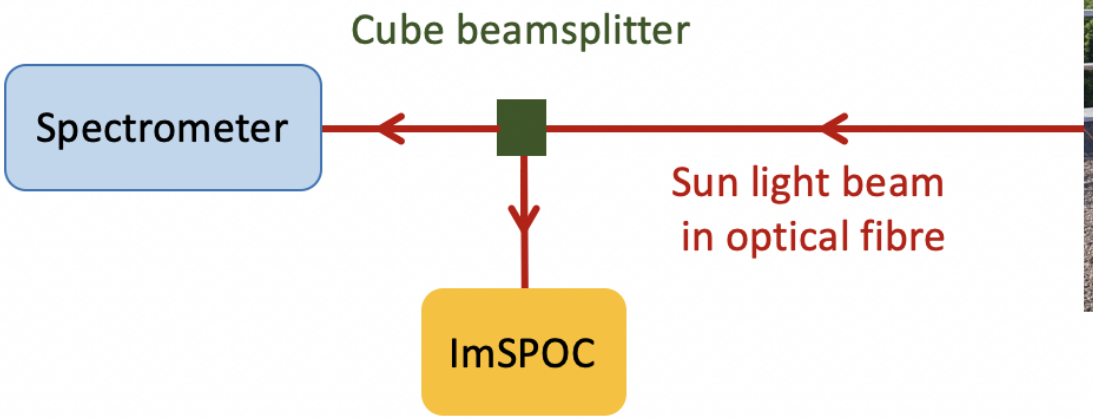
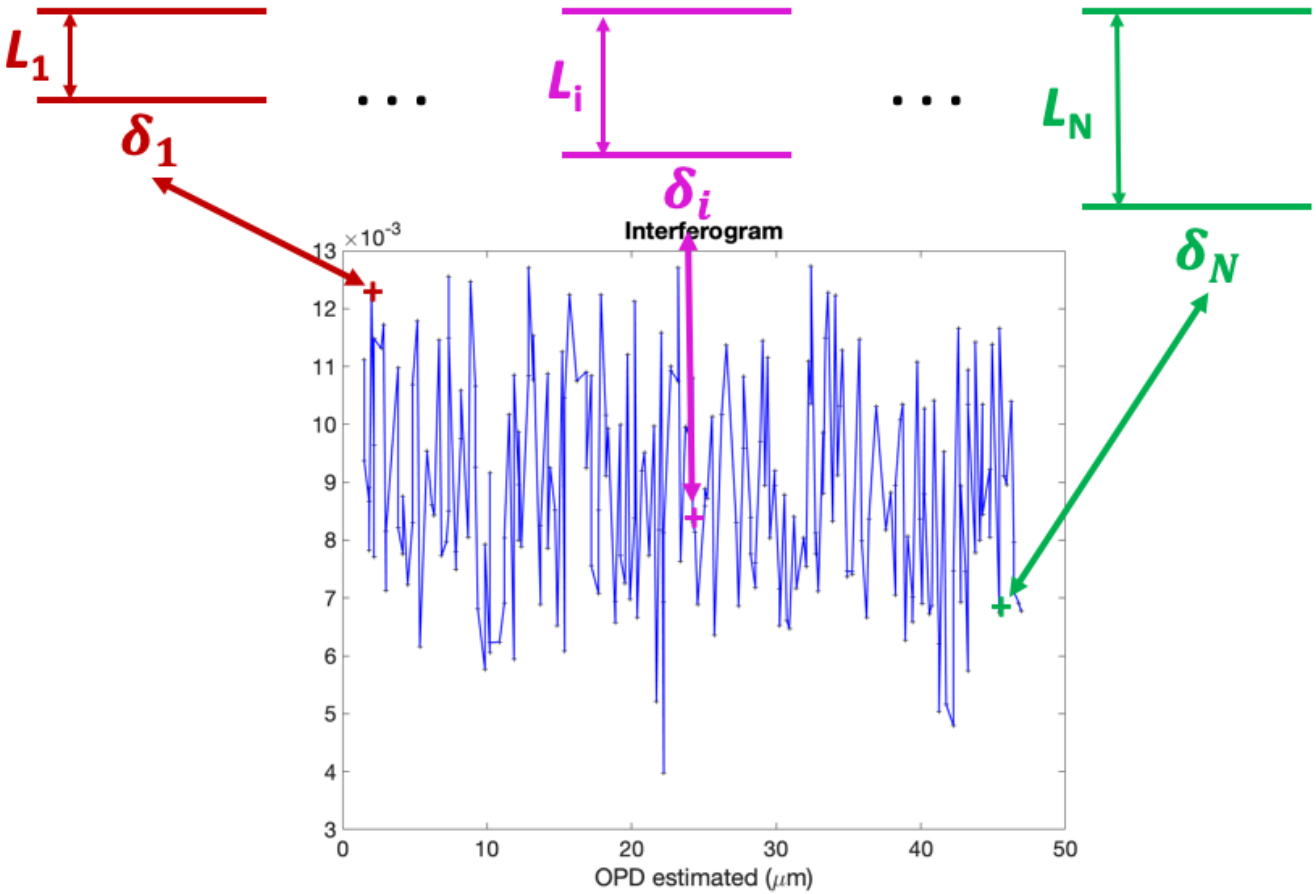
Sun tracking acquisitions

- Acquisitions were done on June 19, 2019
- Every ≈ 50 seconds from 1pm to 6pm
- Synchronized acquisitions from the Ocean spectrometer and Imspoc instrument



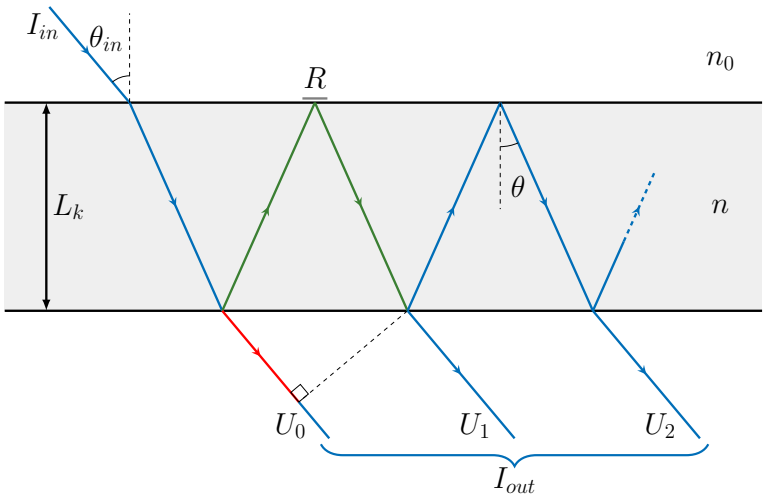
ImSPOC calibration

- The thickness of each interferometer was previously estimated to correctly reconstruct the acquired interferograms [Dolet et al., 2019, Picone et al., 2020]



Spectra reconstruction

- To reconstruct spectra, different models of the ImSPOC intrument can be taken into account [Picone et al., 2020]:
  - For each interferometer, the Fabry-Perot interferometry principle can be applied



- R: Reflectivity of the surface
- $\phi = 2\pi\sigma\delta_k$: Round-trip Phase Difference
- $\delta_k = 2nL_k \cos\theta$: Optical Path Difference
- θ: Inner Reflection Angle

$$U_k = \left(Re^{-j\phi}\right) U_0$$

$$I_{out} = \sum_{k=0}^{\infty} |U_k|^2$$

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$$T_k(\phi) = \frac{I_{out}}{I_{in}} = \begin{cases} 1 + R^2 + 2R\cos\phi & \text{2 Waves Model} \\ \dfrac{1 + R^{2N} - 2R^N \cos(N\phi)}{1 + R^2 - 2R\cos\phi} & \text{N Waves Model} \\ \dfrac{(1-R)^2}{1-R^2}\left(1 + \dfrac{4R}{(1-R)^2}\sin\left(\dfrac{\phi}{2}\right)\right)^{-1} & \text{Infinite Waves Model} \end{cases}$$

- The 2 Waves Model can be approximated by a cosine Fourier Transform
- In this study, a **cosine Fourier Transform** is apply to the interferograms to reconstruct spectra

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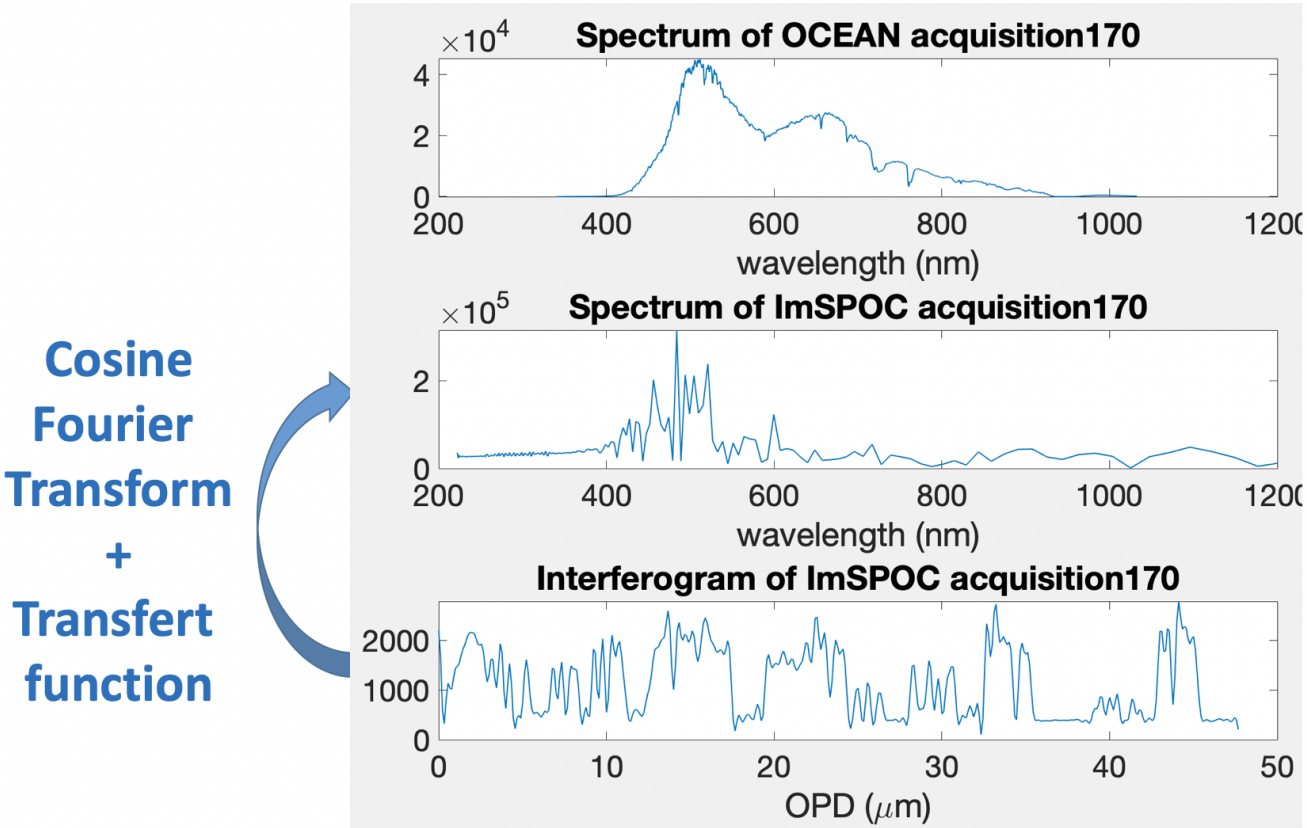
Preliminary results

- To reconstruct the ImSPOC spectrum, we use the **Cosine Fourier transform** and we apply the **transfer function** between both instruments, calculated from the calibration

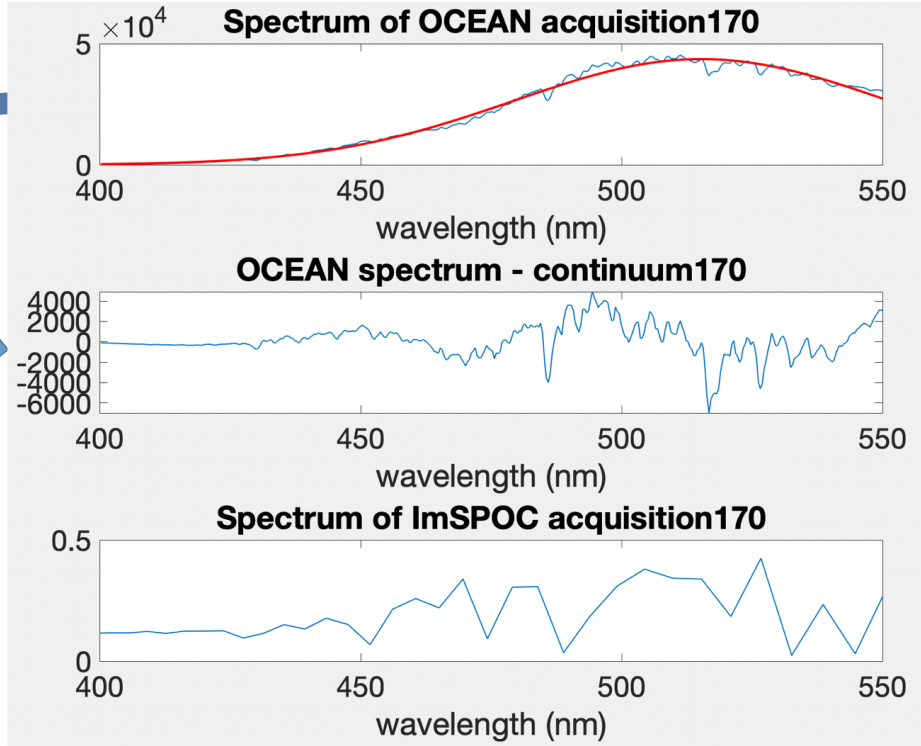


- The ImSPOC spectrum has more fluctuations between 400 nm and 550 nm. We will then focus the study to this range.

Preliminary results

- We know that, with the ImSPOC sensor, we miss the continuum as it is impossible to have an interferometer of zero thickness
  - We approximate the continuum (red curve), using a gaussian approximation, and subtract it to the dispersive spectrometer spectrum to compare the result to the ImSPOC spectrum

Substraction of the continuum to the spectrum (first step of DOAS analysis)



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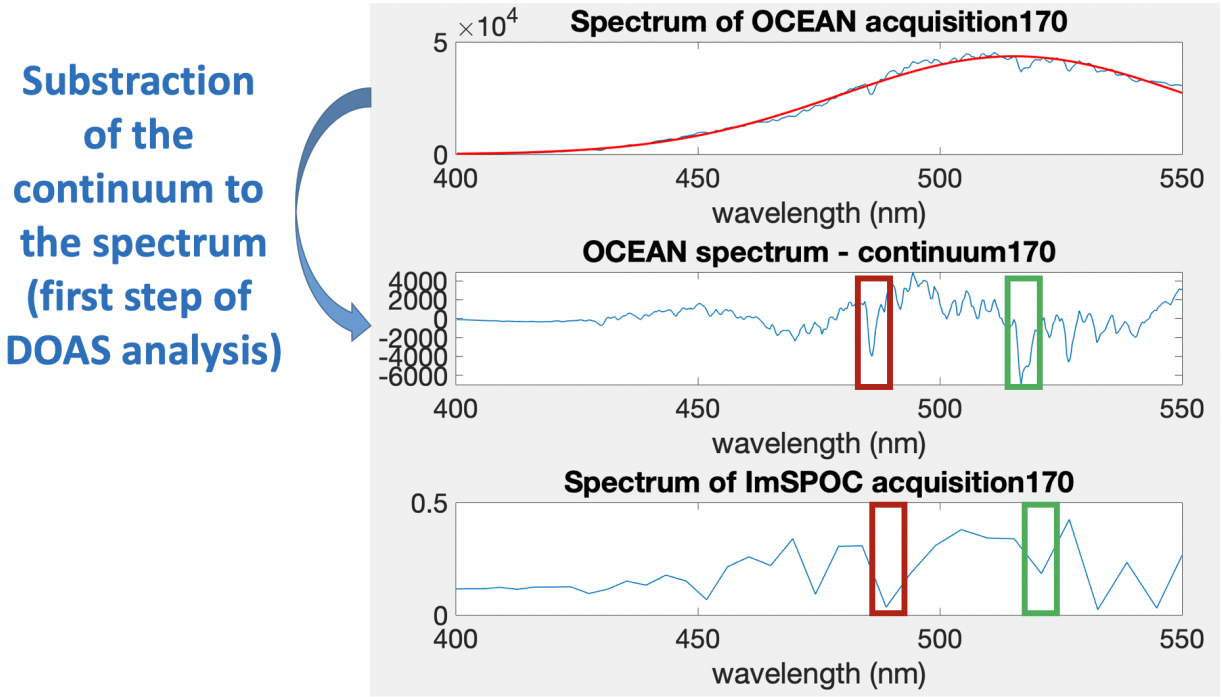

- The spectral resolution of ImSPOC is too low to precisely detect gas
- However, ImSPOC allows to see absorption peaks that can be seen with the OCEAN spectrometer

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Conclusion

- This study shown that **the ImSPOC spectrometer can be sensitive to some absorption peaks**.
- However, the low spectral sampling rate of ImSPOC does not allow a precise localization of absorption peaks.
- In further study:
  - The sample rate of the ImSPOC reconstructed spectra should be improve.
  - We used for this first study the 2 Waves Model for the spectrum reconstruction. **Other models (N Waves or Infinite Waves Models)** will now be tested solving an inverse problem.
  - A quantitative comparison of the two acquisitions will be done.
  - Gas quantification method, as DOAS, should be tested on ImSPOC spectra to access concentration quantities
  - A DOAS method could probably also be **directly applied to the interferogram**.
  - Finally, new prototype with larger sensitivity range should allow a study on a larger wavelength range.

The end!

Thank you!

Bibliography

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