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THE FRENCH AEROSPACE LAB

FOCUS
Focal Plane Array for Universe Sensing

Development of a cryogenic spot scan bench for the study of mid-infrared detectors

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AG LABEX FOCUS 2022

cea irfu

leti cea tech

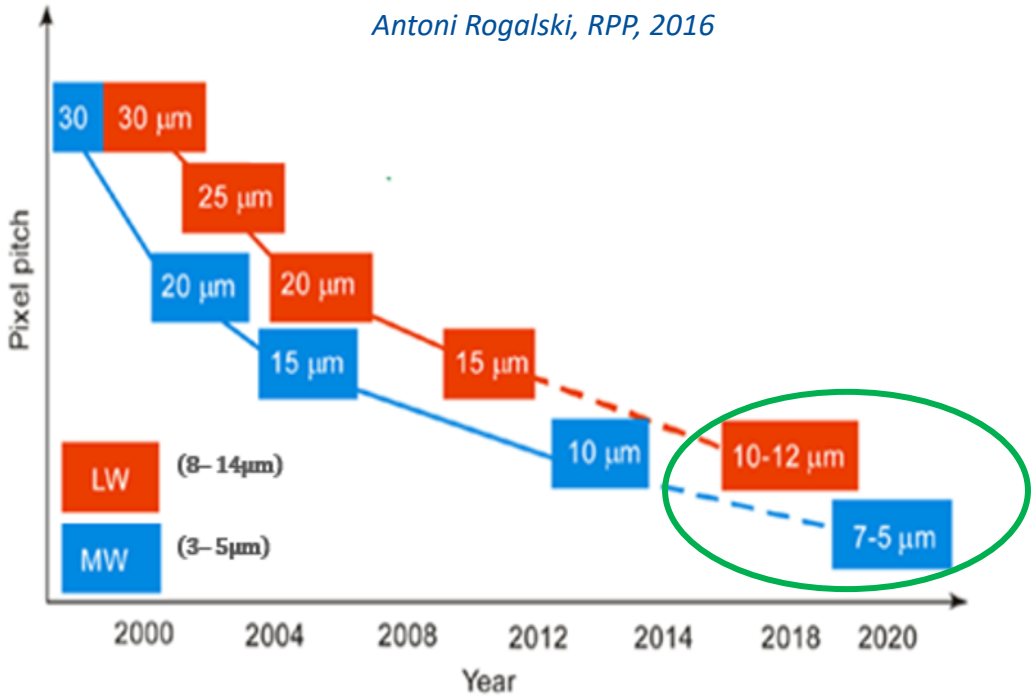
Presentation plan

- ❑ Background on high performance infrared detection
- ❑ Principle of spot scan measurement in the MIRCOS cryogenic bench
- ❑ Validation of the bench performance on a HgCdTe Focal Plane Array at 30µm pitch
- ❑ Conclusion and outlook

Current technological developments

Pixel size evolution for HgCdTe technology over the period 2000 - 2020

Antoni Rogalski, RPP, 2016

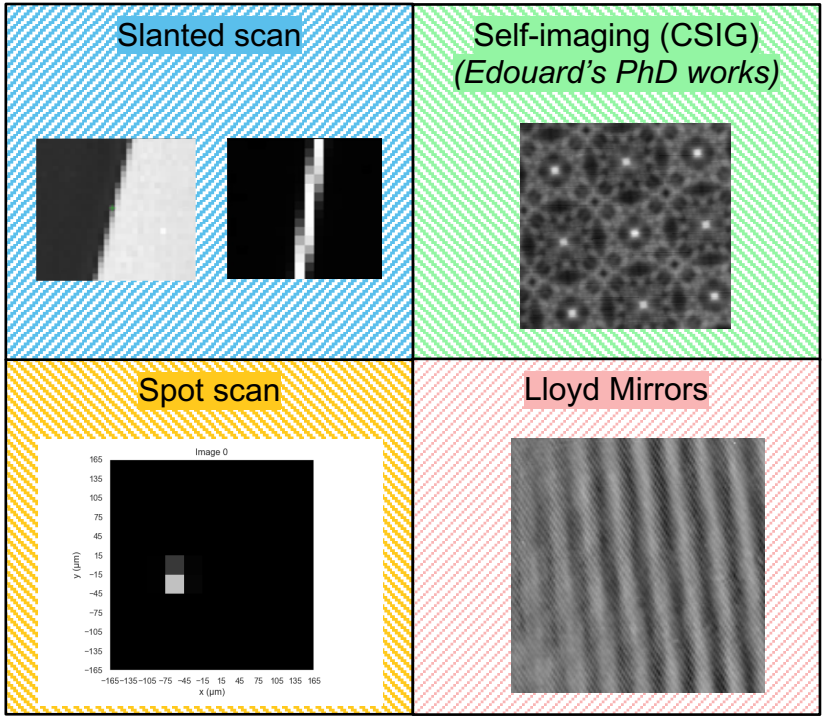


High spatial resolution characterization

↓

Development of a test bench to measure the spatial response of IR detectors at different wavelengths

PSF/FTM measurement approaches



Variables :

- Mono/poly-chromatic sources
- Incidence geometry of rays
- Spatial distribution of illuminance on the FPA
- Necessity or not of a scan

Intercomparing different characterization approaches

- EBIC at CEA/LETI,
- CSIG *(Edouard's PhD works)* at ONERA…

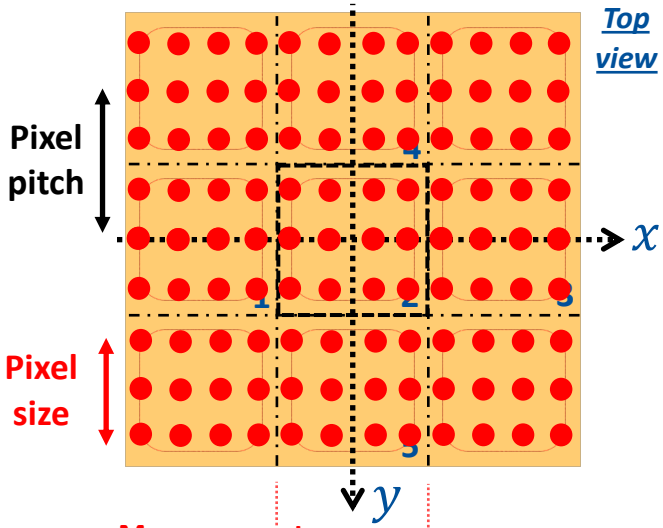
On **various infrared detectors** of interest for the LabEx FOCUS

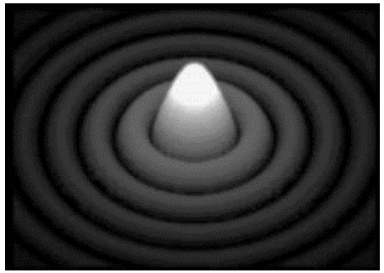
- Superlattices,
- HgCdTe…

Integration of the characterization needs of detectors dedicated to astrophysical missions in the measurement protocol, with CEA-IRFU.

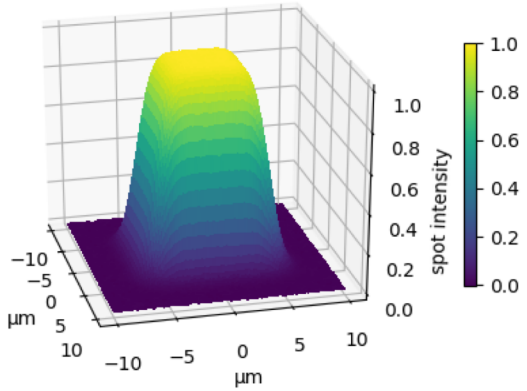
Principle of spot scan measurement in the MIRCOS cryogenic bench

Spot Scan measurement: How does it work?





Airy spot



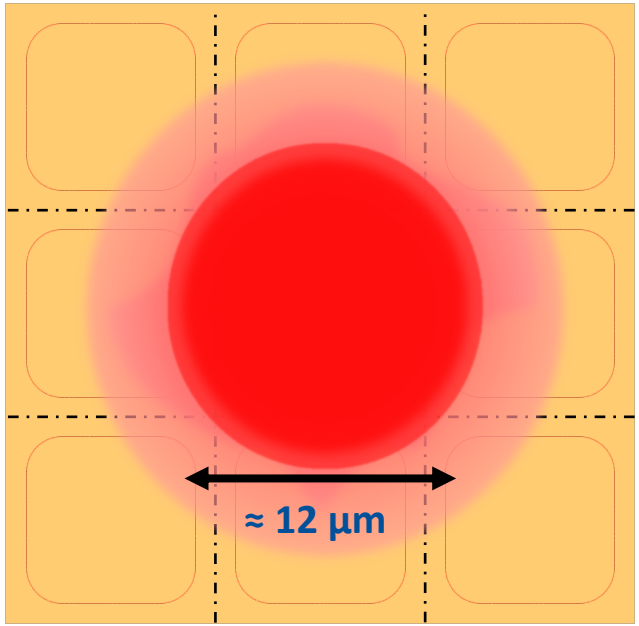
Two-dimensional Pixel PSF (Simulation)

$$PSF_{meas} = PSF_{optic} * PSF_{pixel}$$

PSF = Point Spread Function

Spot Scan Measurement: Small Pixels (~10µm)

« Spot scan »



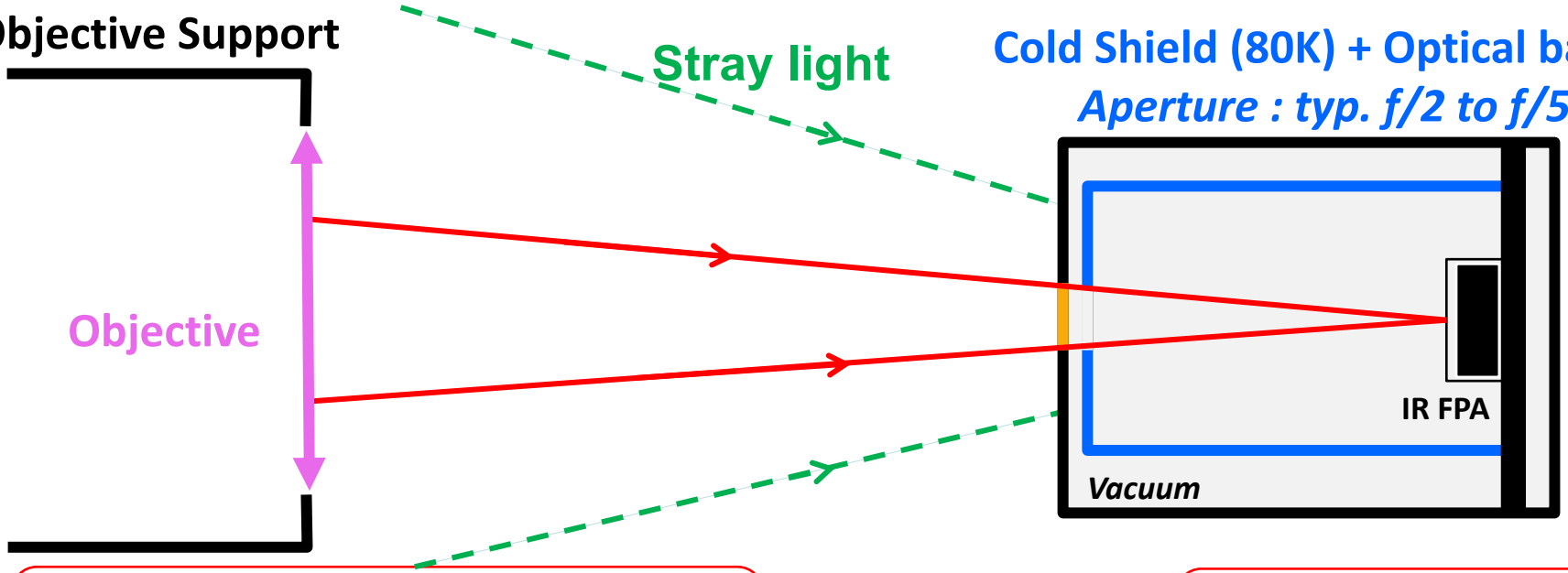
Diffraction pattern of an IR objective
(Aperture : F/1.2, λ ≈ 4 µm ($D = 2.44\lambda N$))

Challenging measurement for small pixels

Need to use optics with a low aperture number

- **Focus sensitive**
- **Sensitive to optical aberrations**

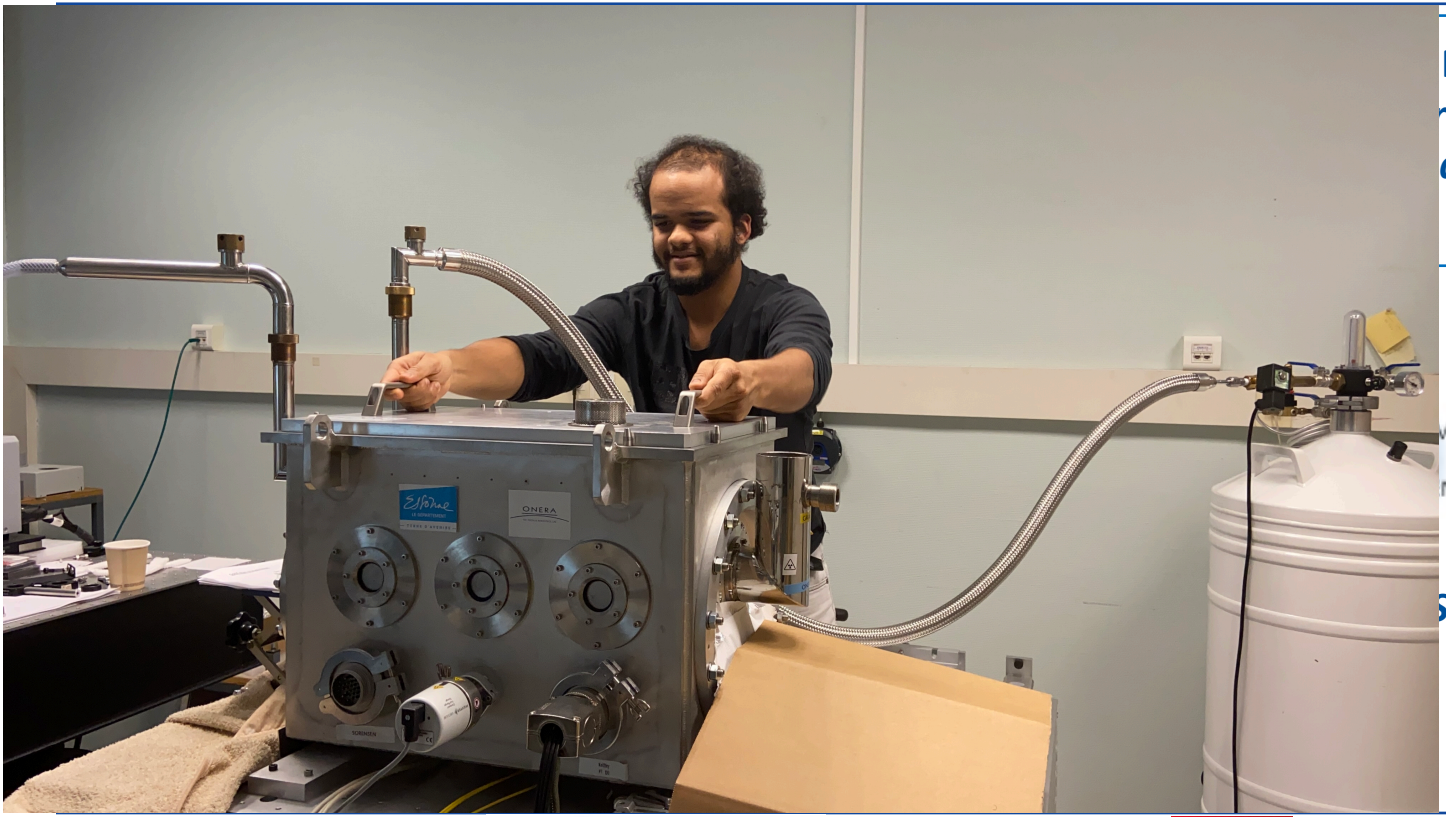
Thermal background issues in the mid-infrared (3 - 5.5 µm)



Surrounding thermal background (Stray light)

Optics with high aperture number

Integration into the cryogenic bench



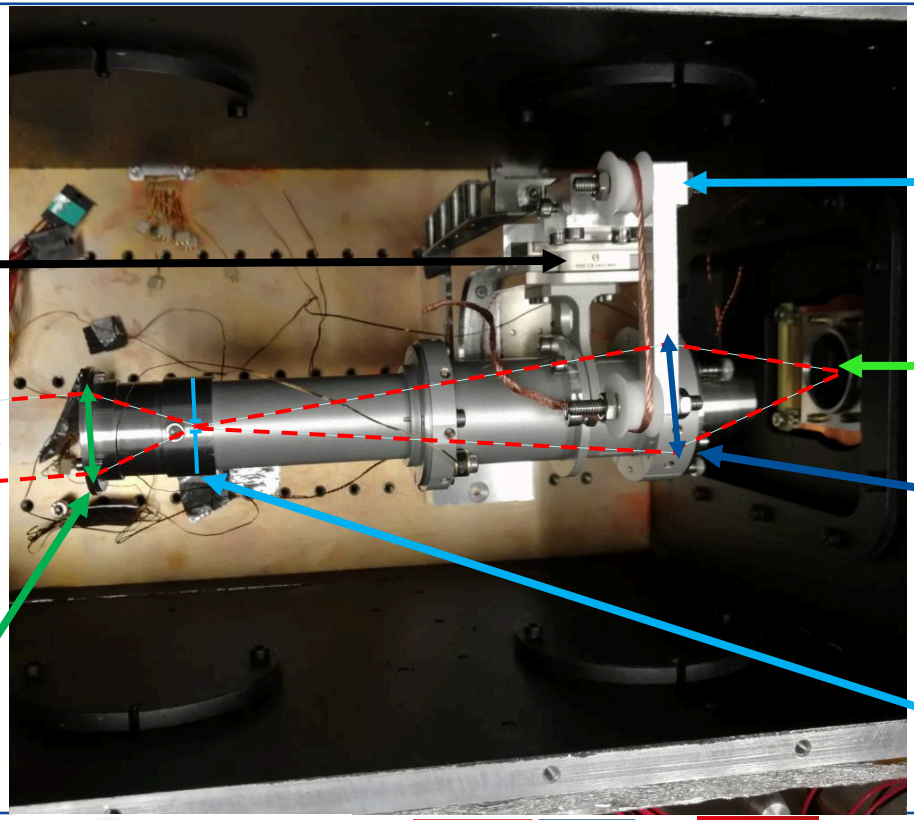
RCOS platform
rarouge Refroidi pour la
ation d'Optiques et de
Systèmes)

VERSE
NCE

Essonne LE CONSEIL GÉNÉRAL

S.T.R.E. Funding

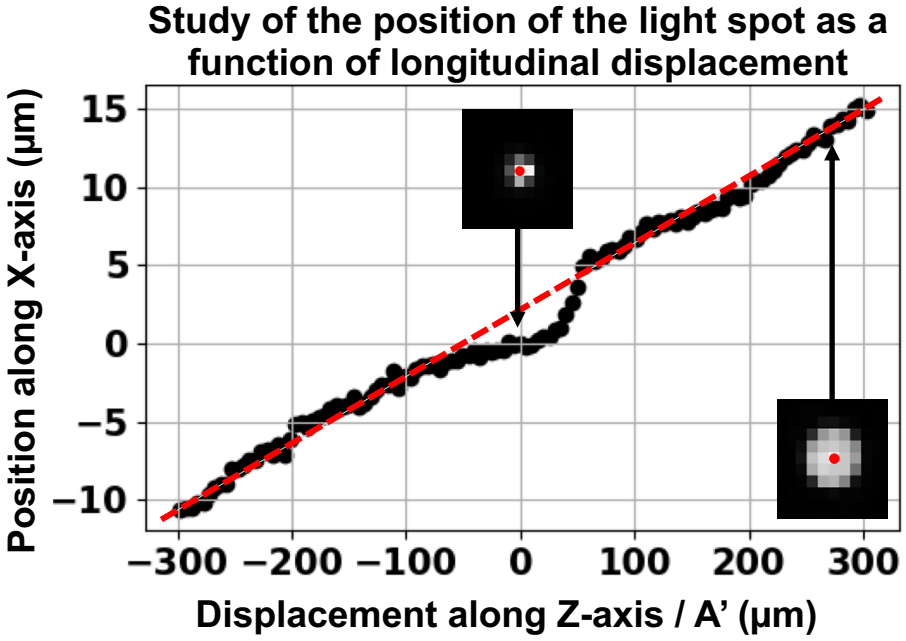
Current technological developments

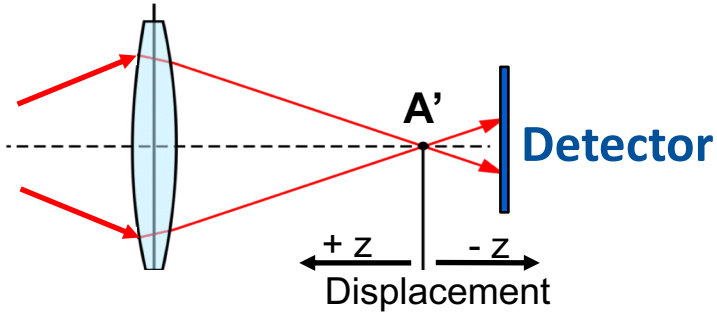


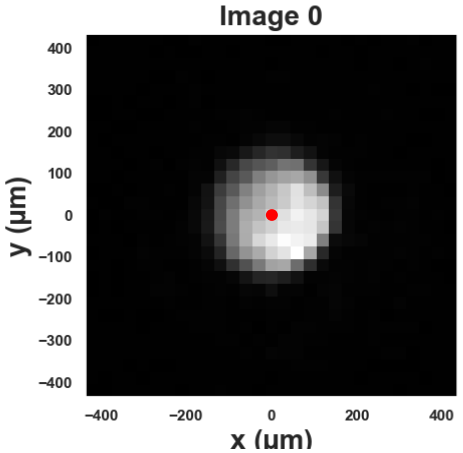
Validation of the bench performance on a HgCdTe Focal Plane Array at 30µm pitch

1. Characterization of the optical alignment of the bench

- From images acquired for different positions along Z-axis



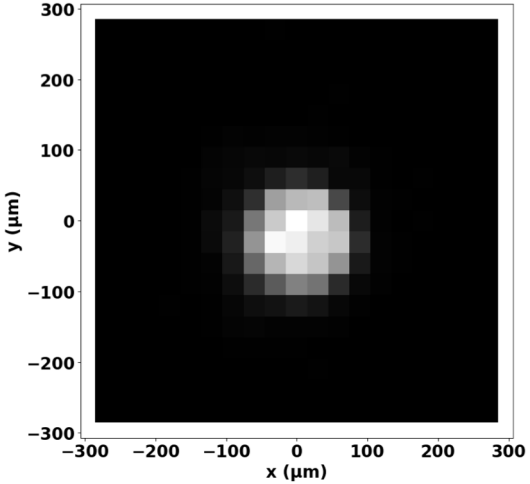




2. Validation of positioning for a fixed position

Determining the position :

- **From a defocused image**
- **Using the barycentre method**

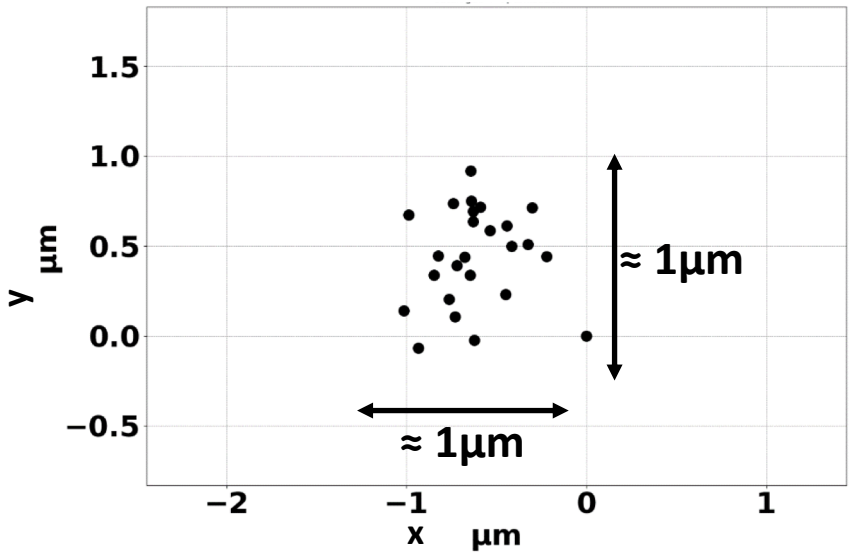


150 µm defocused image

$T_i = 0,05\ ms$

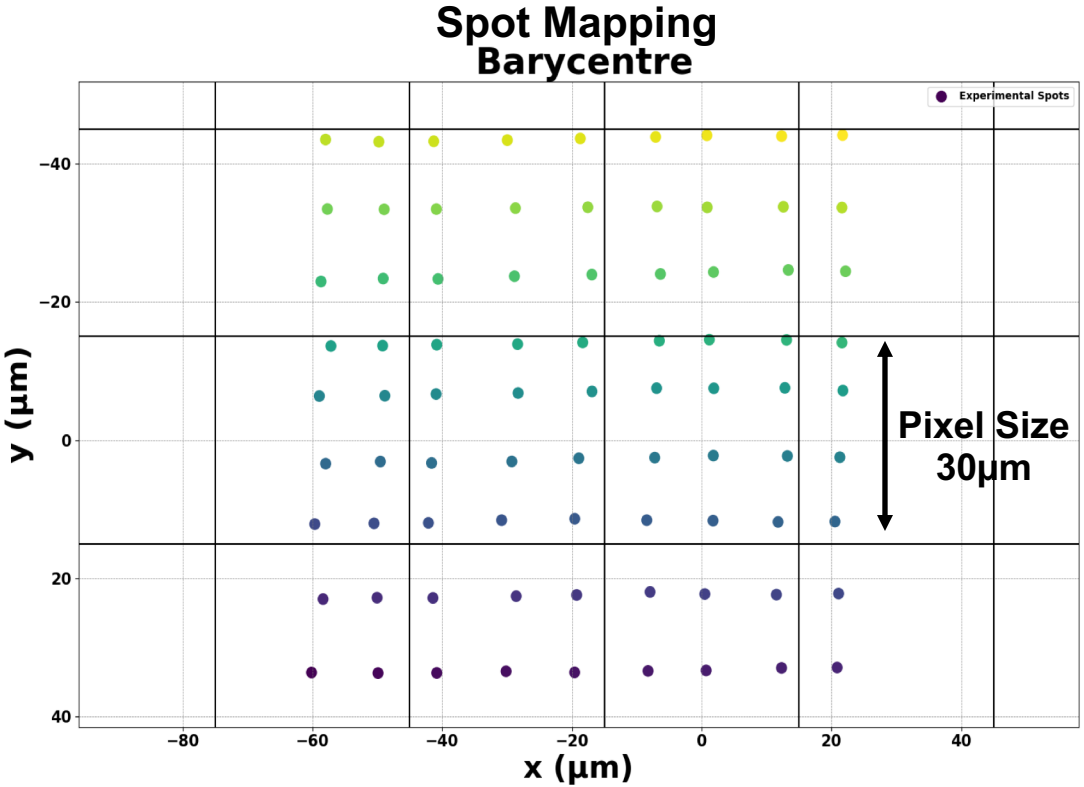
Restitution of the light spot position

Measurement time ≈ 1 sec



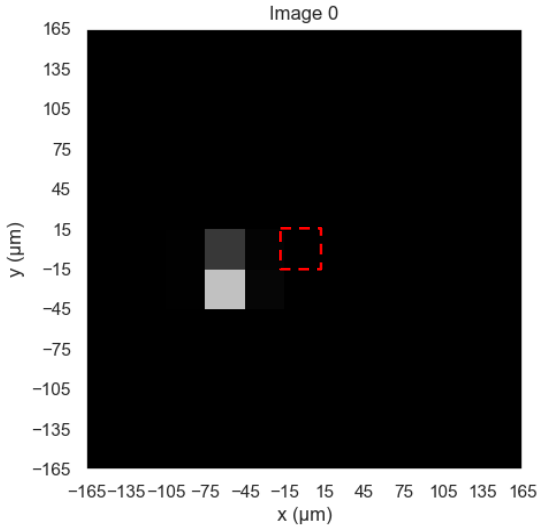
3. 2D Scanning accuracy

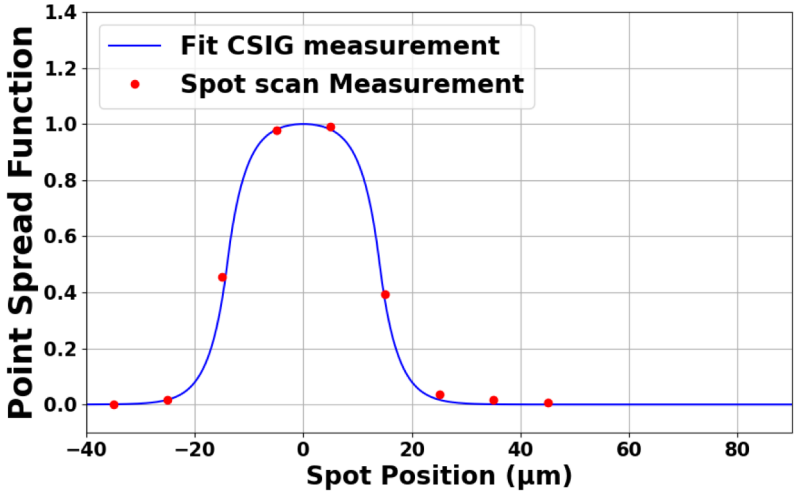
- 3x3 Pixels serpentine scan from defocused images (10 µm scan pitch)
- *Measurement duration : 10 min*



4. Spot Scan Measurement

Serpentine scan on 3x3 pixels of 30 µm
(10 µm scan pitch)
Measurement duration : 10 min





Coherent with measurements made with an interferometric technique (Huard et al. JEM 2020)

Conclusion and Outlook

Work done

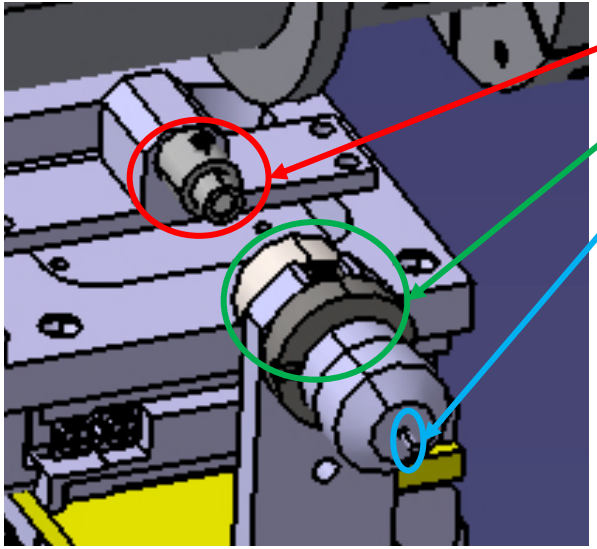
MIRCOS platform integration

Bench validation on a known FPA with a 30µm pixel pitch

Current work

Improvement of the positioning accuracy

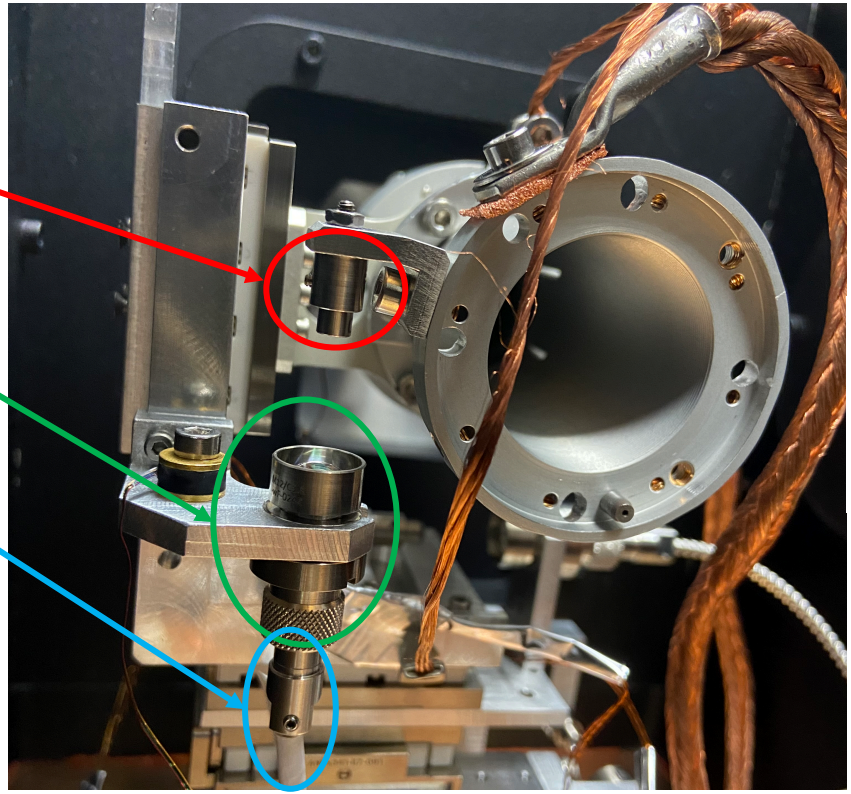
Adding interferometric sensors



Spot scan measurement on an FPA with a 10µm pixel pitch or less

Purpose

Conclusion and Outlook



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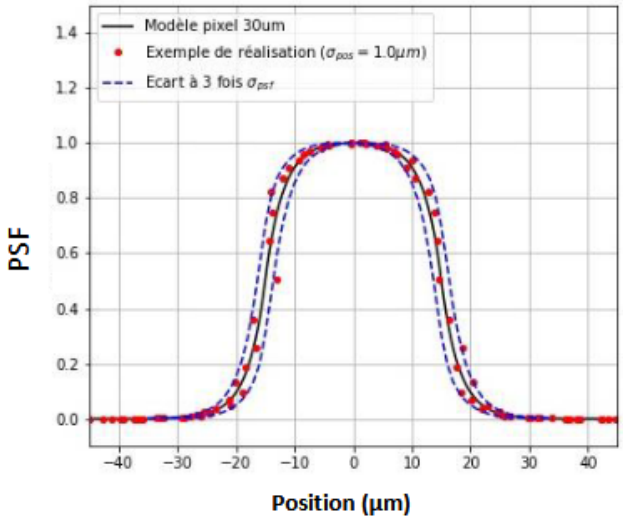
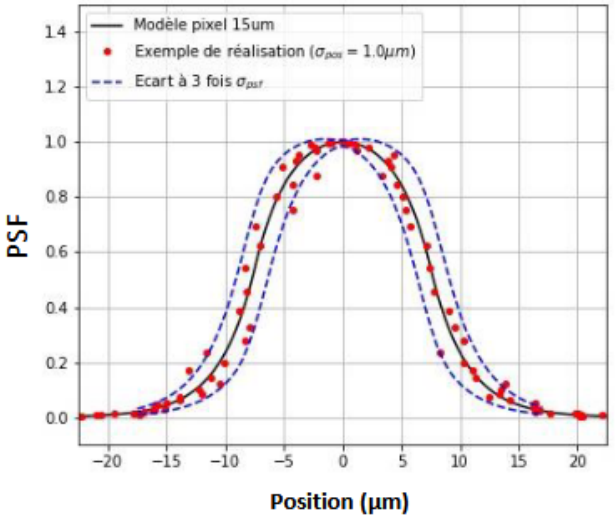
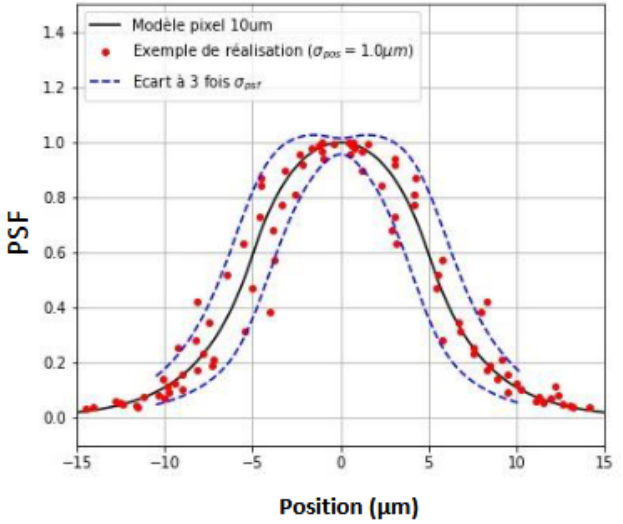
Spot Scan Measurement: Simulation



a). Pixel size : 30 µm



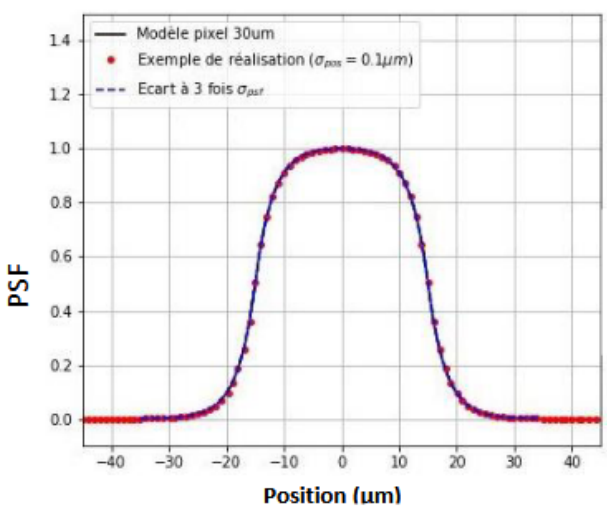
b). Pixel size : 15 µm



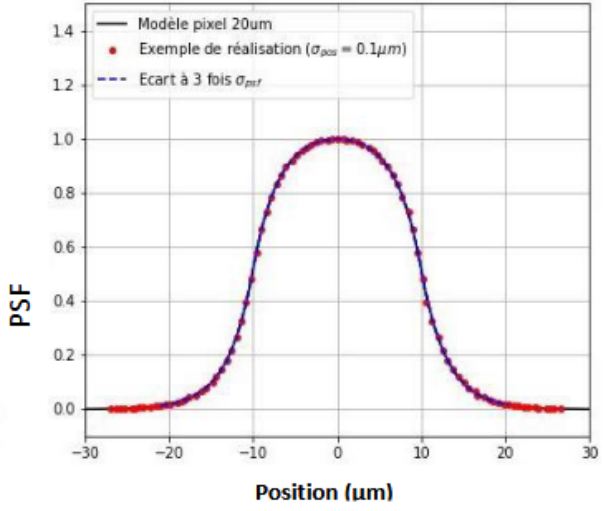
c). Pixel size : 10 µm

Figure 5 – Restitution of the error bars of the PSF of the detector for a standard deviation of 1µm

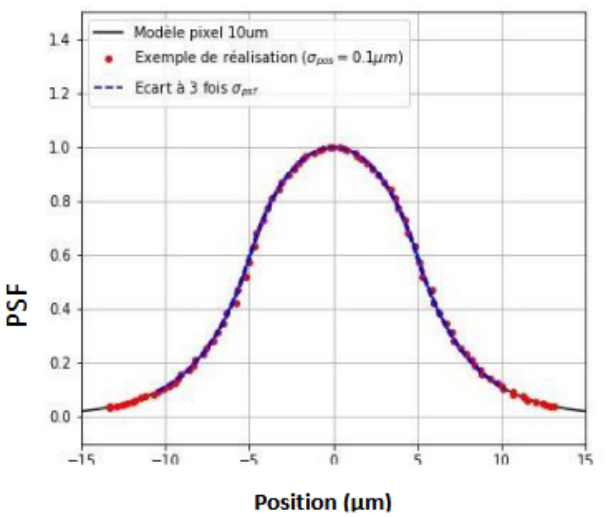
Spot Scan Measurement: Simulation



a). Pixel size : 30 µm



b). Pixel size : 20 µm



c). Pixel size : 10 µm

Figure 6 - Restitution of the error bars of the PSF of the detector for a standard deviation of 0.1µm

Conclusion and Outlook

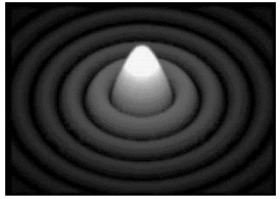
Work done

MIRCOS platform integration

Bench validation on a known FPA with a 30µm pixel pitch

Improvement of the positioning accuracy

Characterisation of the optical spatial response of the objective



Current work

Adding interferometric sensors

Embedding the FPA into the cold shield (Removing the dewar)

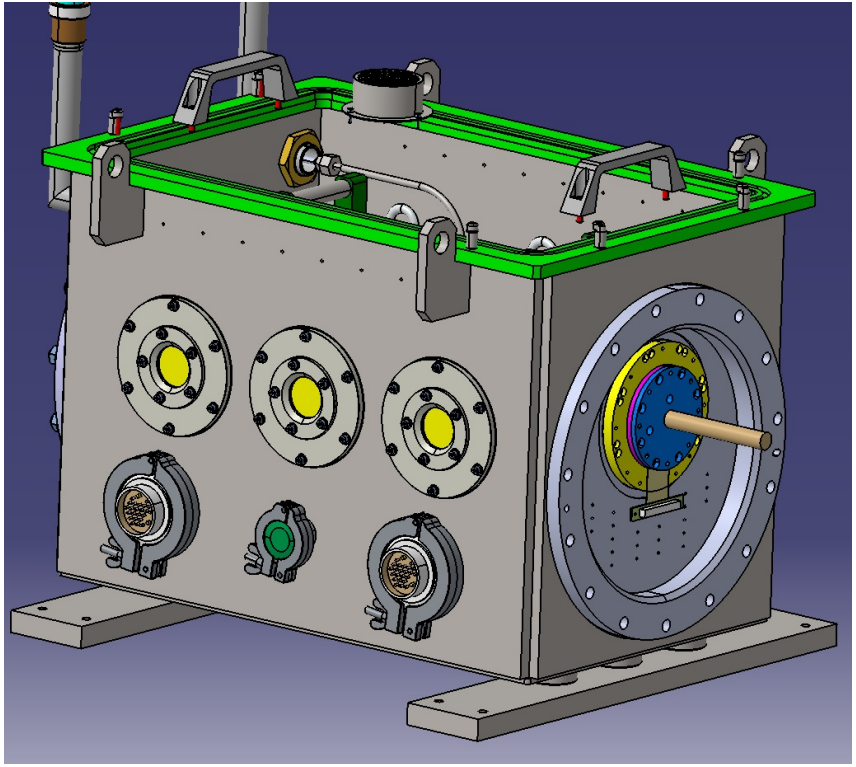
Spot scan measurement on an FPA with a 10µm pixel pitch or less

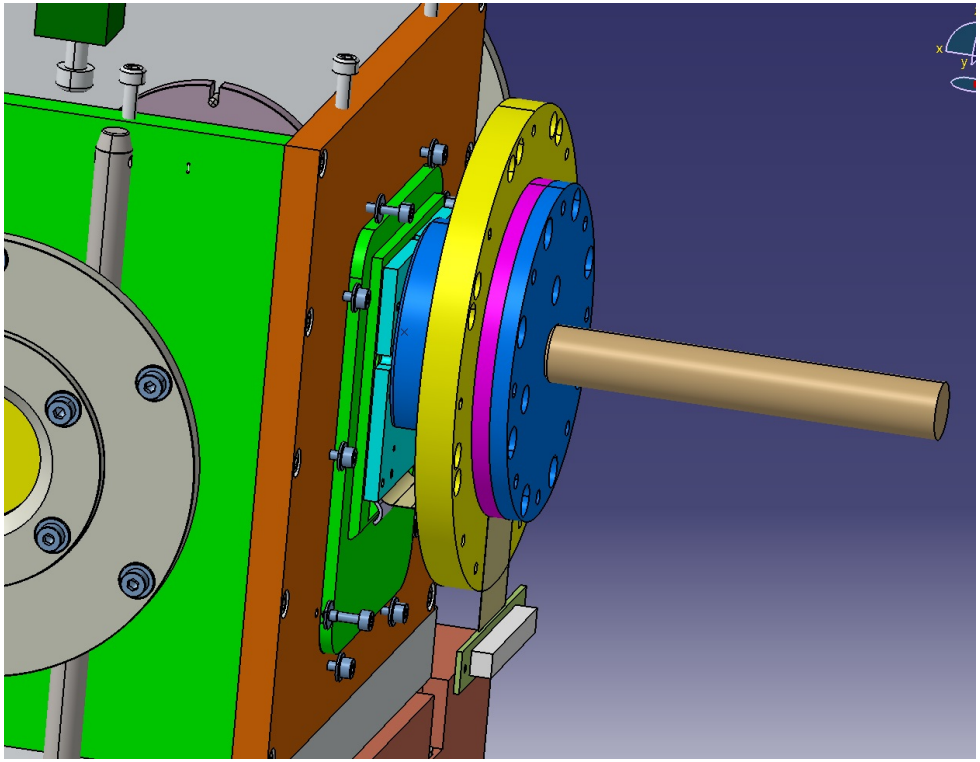
Purpose

Thank you for your attention!

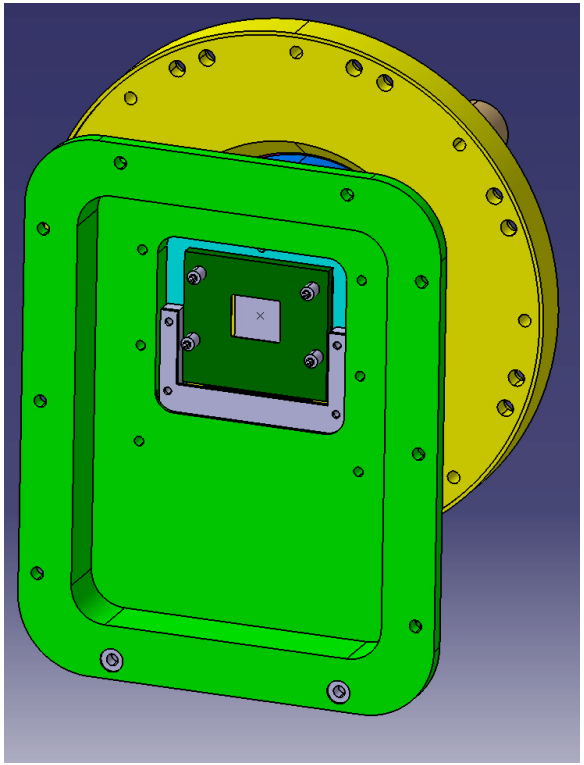
Appendix

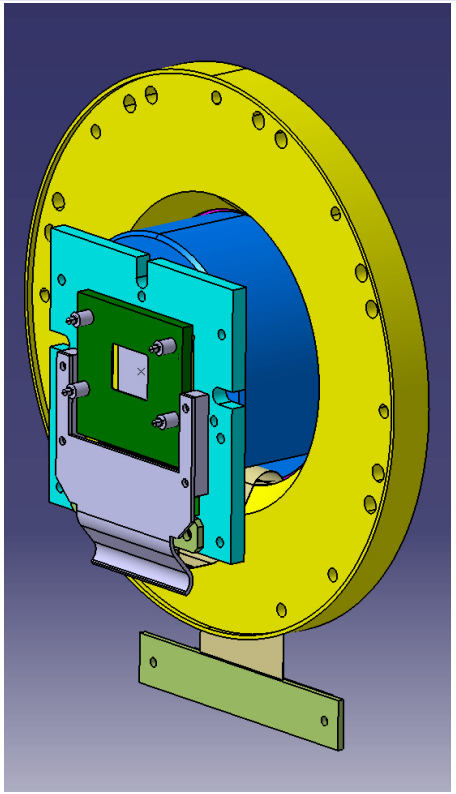
Detector embedding

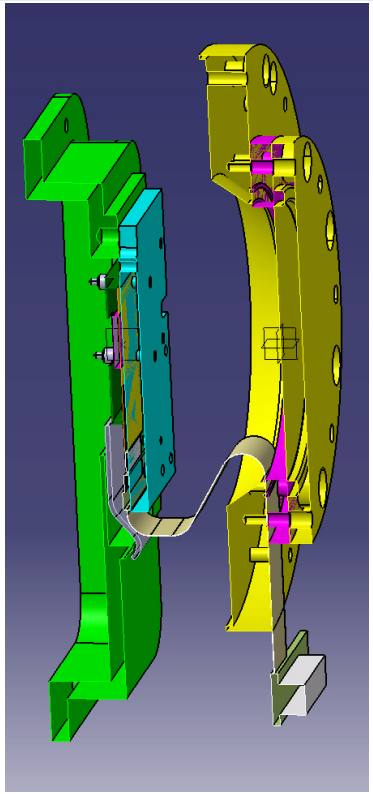




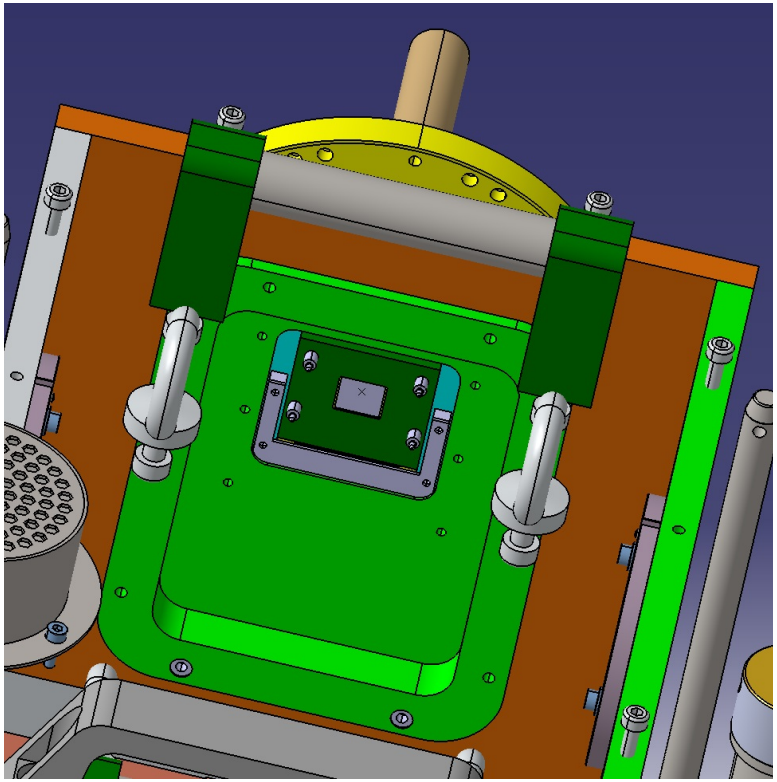
Detector embedding





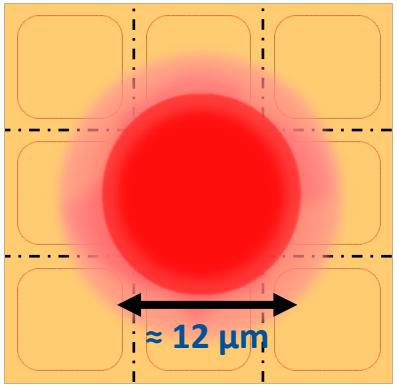


Detector embedding



Spot Scan Measurement: Small Pixels (~10µm)

« Spot scan »



Diffraction pattern of an IR objective
(Aperture : F/1.2, λ ≈ 4 µm ($D = 2.44\lambda N$))

- Focus sensitive
- Sensitive to optical aberrations

⇨ ***Challenging measurement for small pixels***

2 necessary steps :

Identify the lightspot position during a scan

Nanometric stages : Control over the objective displacements

Image processing : Identify the precise spot position on the pixel array

⇨ **Validation of mechanical accuracy**

Identify the spot shape

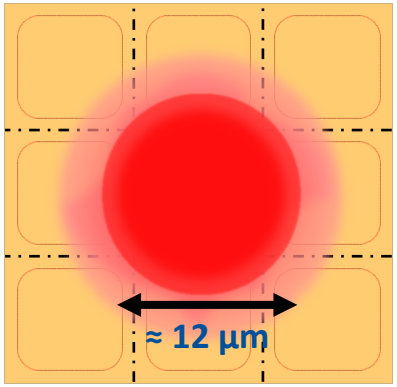
Quadri-lateral Shearing interferometer : Measurement of the wavefront

⇨ **Characterisation of the performance of the optical system**

Image modelling on the pixel array

Spot Scan Measurement: Small Pixels (~10µm)

« Spot scan »



Diffraction pattern of an IR objective
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- Focus sensitive
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Identify the spot shape

Quadri-lateral Shearing interferometer : Measurement of the wavefront

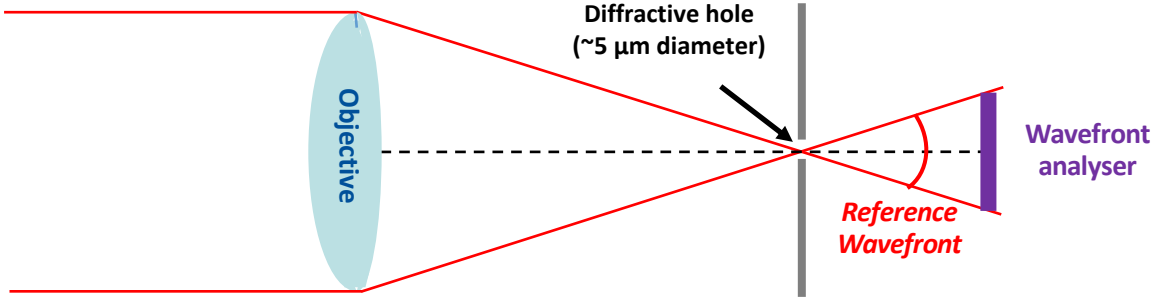
⇨ **Characterisation of the performance of the optical system**

Image modelling on the pixel array

Characterisation of the spot scan objective

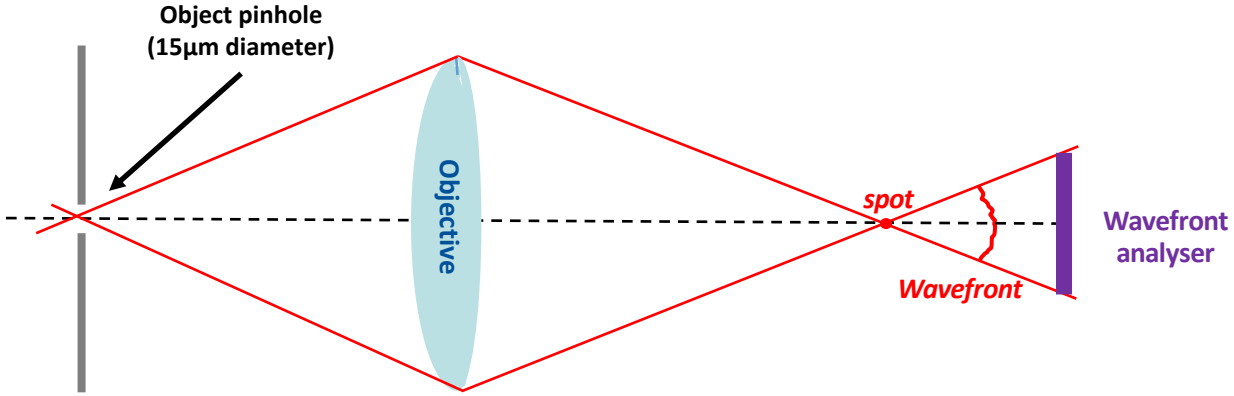
Stage 1 : Reference wavefront

Calibration of the wavefront analyser with a diffractive hole

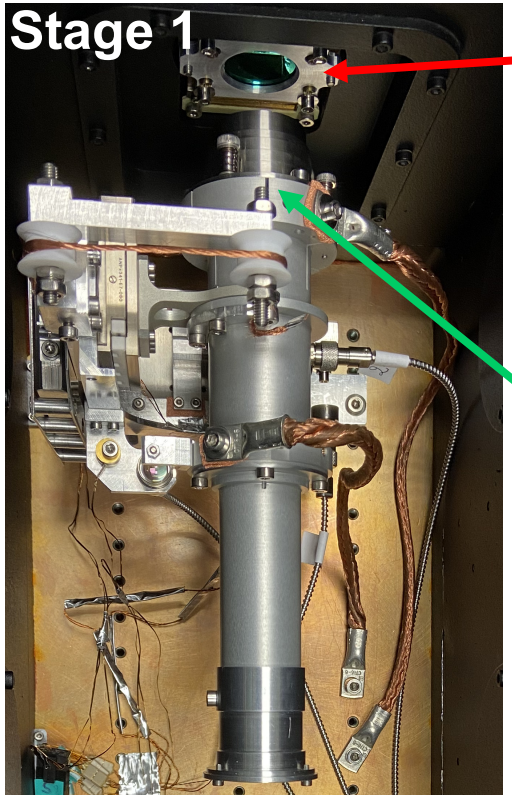


Stage 2 : Wavefront Measurement

Measurement of the objective wavefront



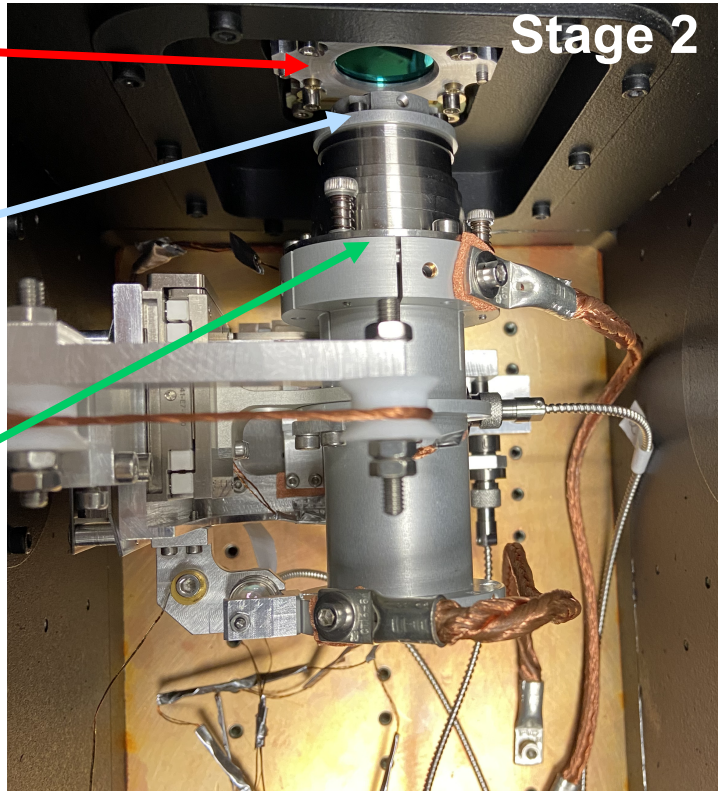
Characterisation of the spot scan objective



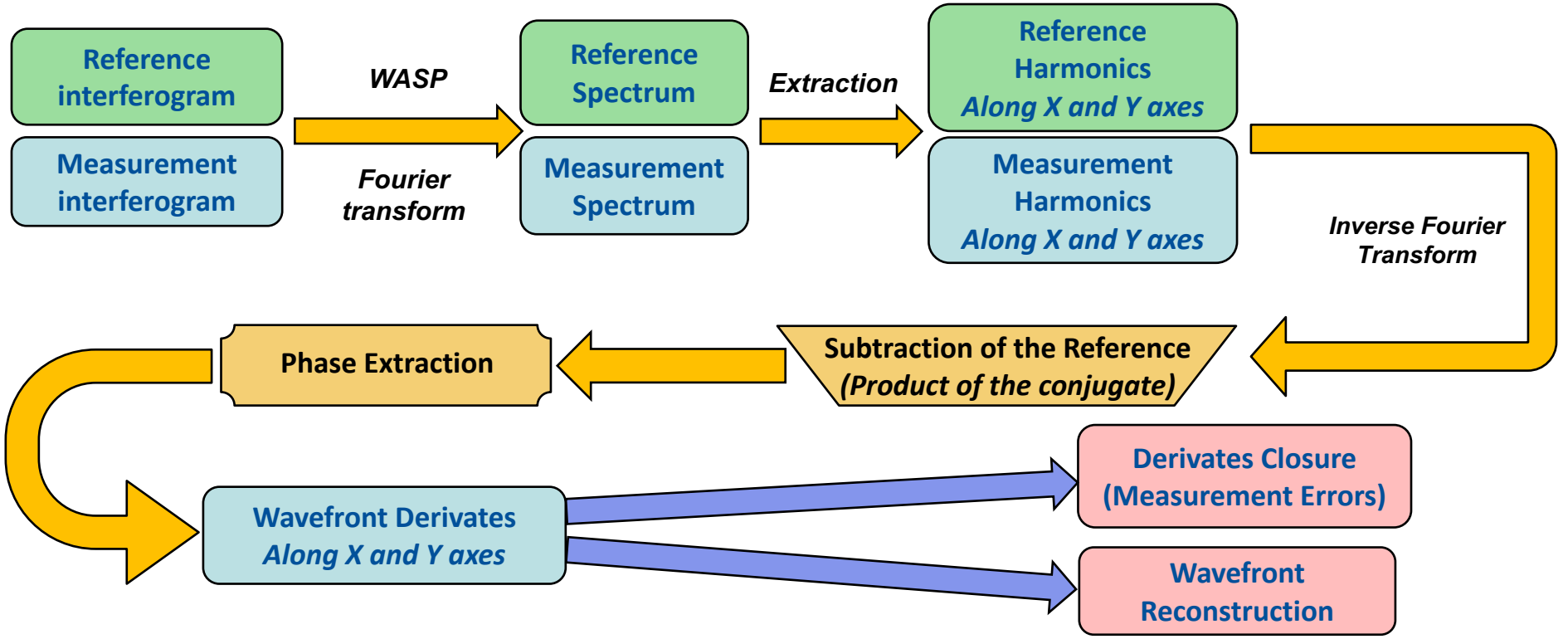
QLSI

Diffractive hole
(5 µm)

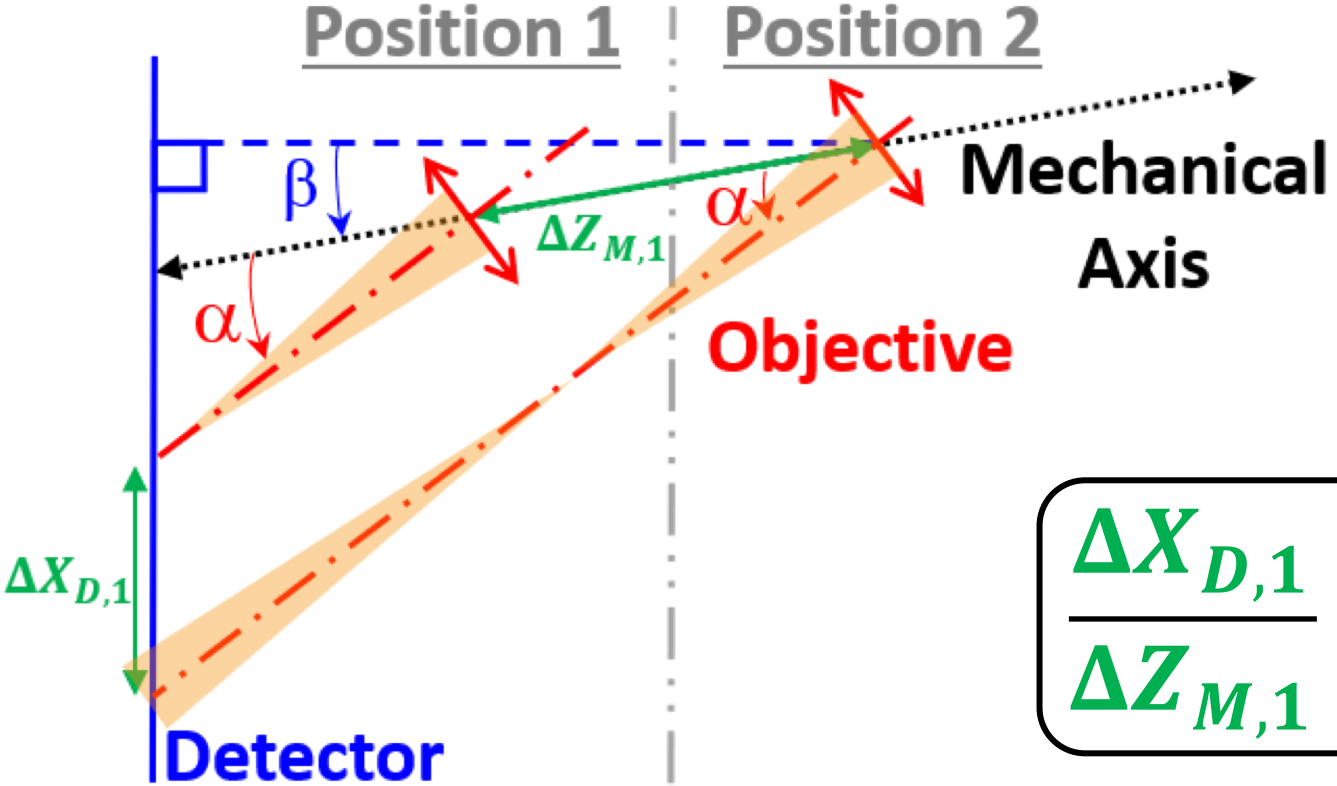
Objective



Characterisation : Algorithm

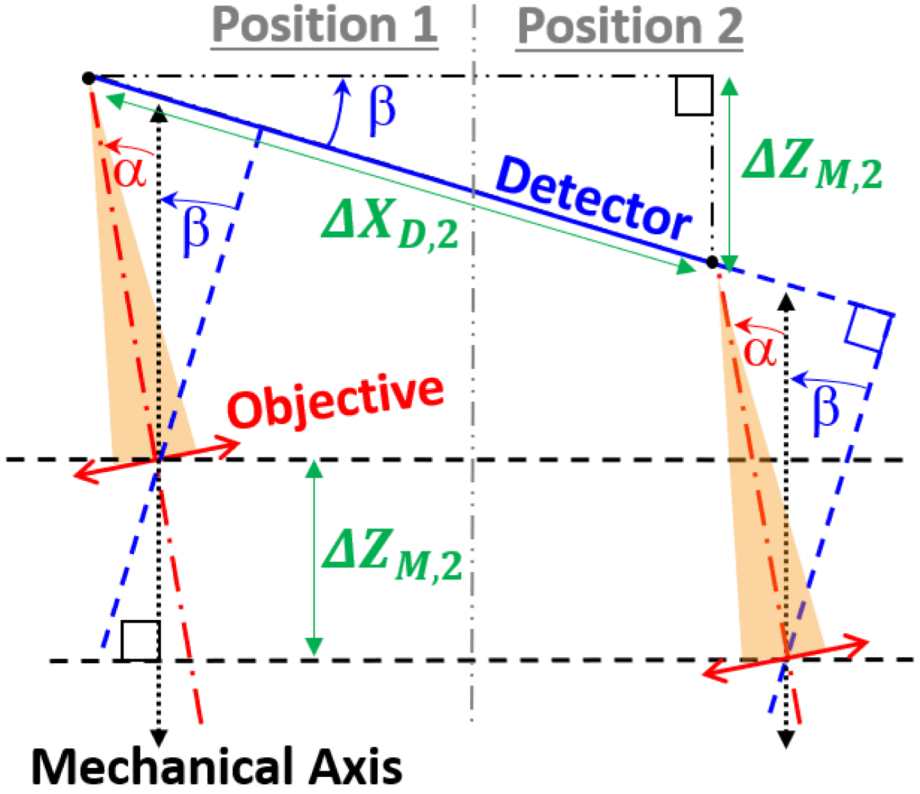


Determination of tilts (1)



$$\frac{\Delta X_{D,1}}{\Delta Z_{M,1}} = \frac{\sin \alpha}{\cos \alpha + \beta}$$

Determination of tilts (2)

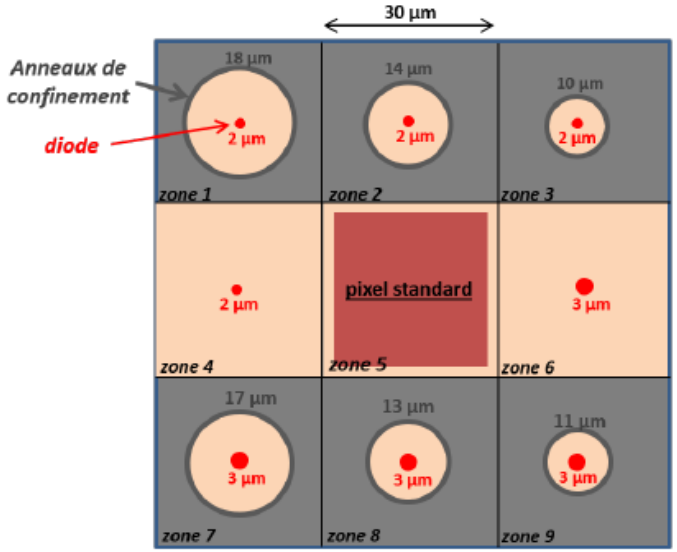


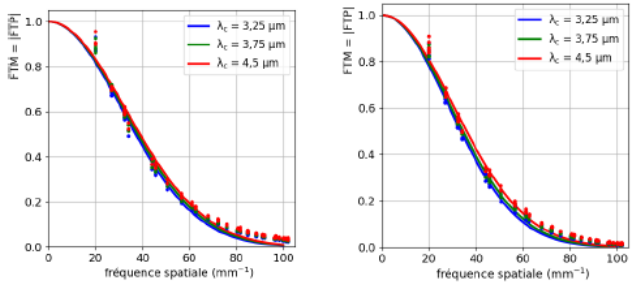
$$\frac{\Delta Z_{M,2}}{\Delta X_{D,2}} = \sin \beta$$

First measurements : Choice of the detector

- HgCdTe MWIR 9 areas FPA
  - 320x256 pixels of 30 µm in size
  - 9 areas with different fill factors

  Reference : Edouard's Thesis





(a) zone 4 (b) zone 6

Figure 4.15 – FTM des zones 4 et 6 en fonction des filtres.

Zone 4	$\lambda_c = 3.25$ µm	$\lambda_c = 3.75$ µm	$\lambda_c = 4.5$ µm
$L_{diff,\ x}$ (µm)	10.0	9.8	9.6
$L_{diff,\ y}$ (µm)	9.8	9.6	9.4

Zone 6	$\lambda_c = 3.25$ µm	$\lambda_c = 3.75$ µm	$\lambda_c = 4.5$ µm
$L_{diff,\ x}$ (µm)	11.3	10.7	10.3
$L_{diff,\ y}$ (µm)	10.4	10.2	10.1

Table 5.1 Longueurs de diffusion effectives en fonction du filtre pour les zones 4 et 6. La longueur de diffusion effective diminue avec la longueur d'onde.

ZEMAX Spectral Simulation