Accurate pixel spatial response measurement of cooled infrared focal plane arrays

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Thanks to collaborators on this topic

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Introduction

➢ Why do we need an accurate pixel spatial response (*also called Intrapixel Sensitivy Variation or pixel **P**oint **S**pread **F**unction*) measurement of IRFPAs ?

- Enable precise image deconvolution and image interpretation for spatial and astronomy missions and end users
- Quantitative information for IRFPAs designers for improving the MTF (Modulation Transfer Function) performance of their IR sensors, especially when designing small pixel FPAs
- Reliable MTF values for infrared optical systems builders when comparing different IR sensors performance

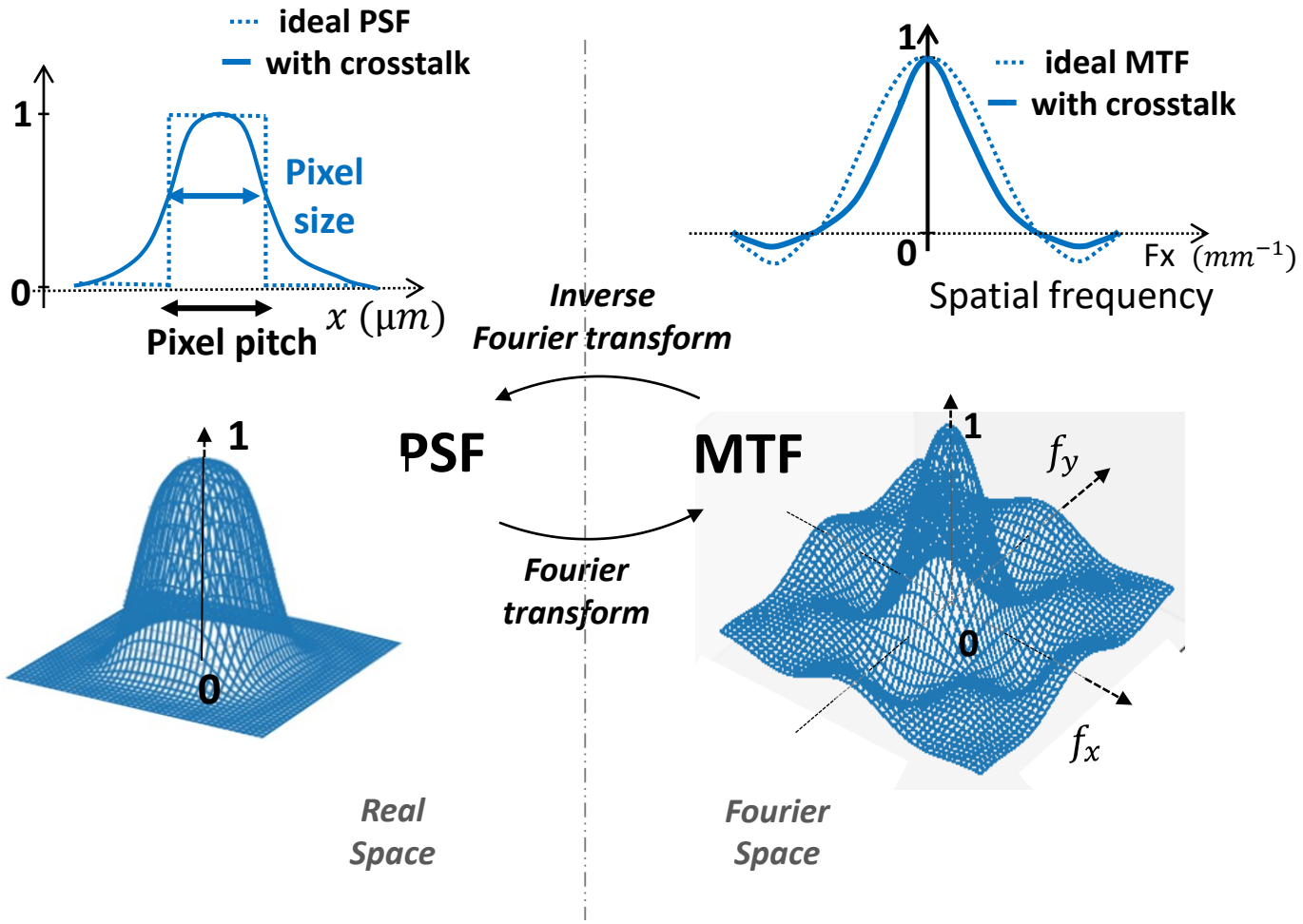
➢ How to achieve an accurate MTF/PSF measurement ?

Projection of an fine pattern
(optical objective, hole/slit metallization, interferometers, speckle diffuser, electron beams, …)

→ IRFPA pattern Image → Bench calibration / deconvolution → **accurate PSF / MTF**

Need an accurate measurement / simulation of the optical or electronical behaviour of the projection system

What does“accurate” mean in terms of PSF or MTF measurements ?



A few open questions to introduce this topic :

- Do you want accuracy at Nyquist frequency (error < 0,01 ?)
- How do you measure very low frequencies ?

(zero frequency MTF is not measurable and yet we need to normalize the function at Fx = 0…)

- PSF variations accuracy up to 1/10 size of pixel ?
- How do you finally measure the accuracy of your MTF / PSF measurement ?

Accuracy ≠ repeatability

Differents methods and differents deconvolution / interpretation issues…

Spot scan / slanted edge *Meas. of PSF/LSF* *(projection by classical optics* *- or metallization)* *Local / Global*			
Need to measure the optical PSF - seek for plasmonic effect for metallization holes /slits ?			

Differents methods and differents deconvolution / interpretation issues…

Spot scan / slanted edge *Meas. of PSF/LSF* *(projection by classical optics* *- or metallization)* *Local / Global*	**Interferometer / Gratings** *Meas. of MTF* *(Quantitative Interference)* *Global*		
Need to measure the optical PSF - seek for plasmonic effect for metallization holes /slits ?	Need to simulate quantitatively the fringe pattern and its Fourier content		

Differents methods and differents deconvolution / interpretation issues…

Spot scan / slanted edge	Interferometer / Gratings	Speckle diffuser	
Meas. of PSF/LSF (projection by classical optics - or metallization) Local / Global	*Meas. of MTF (Quantitative Interference) Global*	*Optical meas. of MTF (Statistical Interference) Global*	
Need to measure the optical PSF - seek for plasmonic effect for metallization holes /slits ?	Need to simulate quantitatively the fringe pattern and its Fourier content	Need to simulate statistically the fringe pattern and its Fourier Power Density Spectrum	

PLUMMER, Philip J., and al. "Generalized focal plane array modulation transfer function estimation approach for nonstationary laser speckle random processes. *Optical Engineering*, 2022, vol. 61, no 6, p. 064104-064104.

Differents methods and differents deconvolution / interpretation issues…

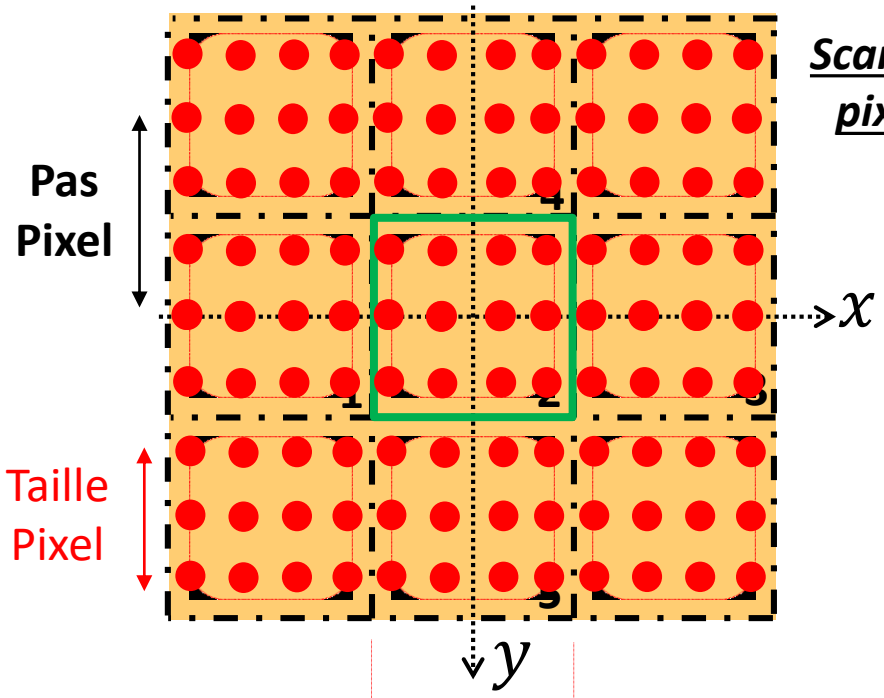
Spot scan / slanted edge	Interferometer / Gratings	Speckle diffuser	EBIC (Electron Beam Induced Current)
Meas. of PSF/LSF (projection by classical optics - or metallization) Local / Global	*Meas. of MTF (Quantitative Interference) Global*	*Optical meas. of MTF (Statistical Interference) Global*	*Electronic meas. of PSF Local*
Need to measure the optical PSF - seek for plasmonic effect for metallization holes /slits ?	Need to simulate quantitatively the fringe pattern and its Fourier content	Need to simulate statistically the fringe pattern and its Fourier Power Density Spectrum	Very thin injected spot, no deconvolution needed, but no optical contribution

Optical Methods implemented in MIRCOS cryogenic bench at ONERA

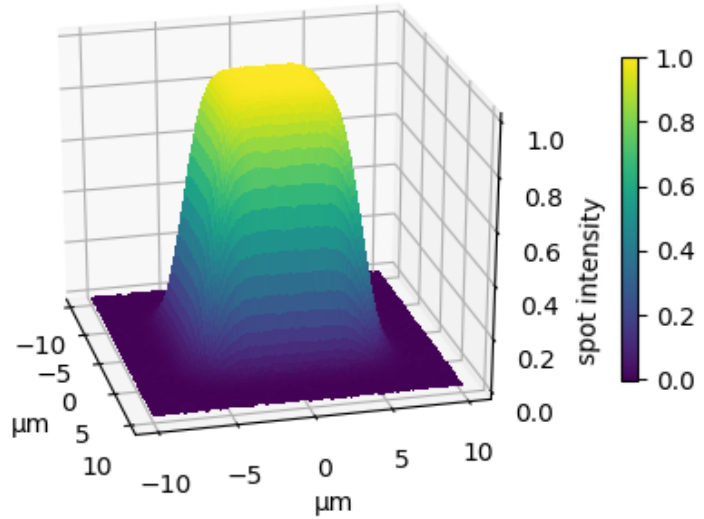
PLUMMER, Philip J., and al. "Generalized focal plane array modulation transfer function estimation approach for nonstationary laser speckle random processes. *Optical Engineering*, 2022, vol. 61, no 6, p. 064104-064104.

Yèche, A., et al. "MTF Characterization of Small Pixel Pitch IR Cooled Photodiodes Using EBIC." *Journal of Electronic Materials* 49 (2020): 6900-6907.

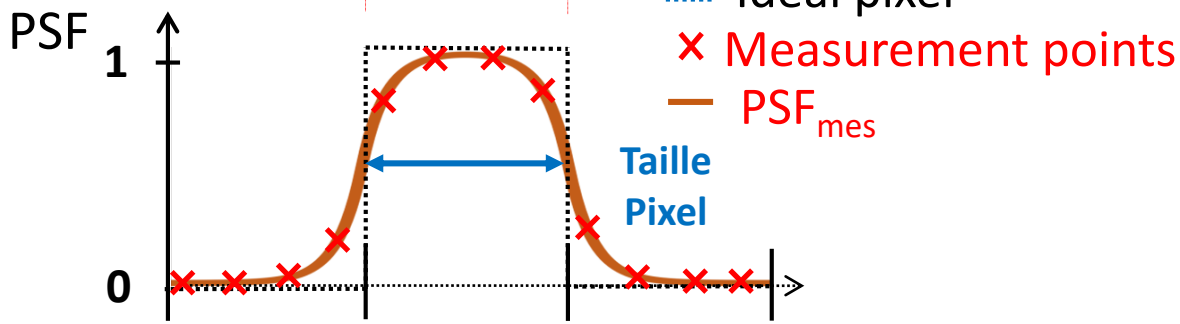
Optical spot scan : issue of the size of the projected spot VS the pixel pitch



Scan of a 3X3 pixels area



2D PSF Pixel
(Simulation)

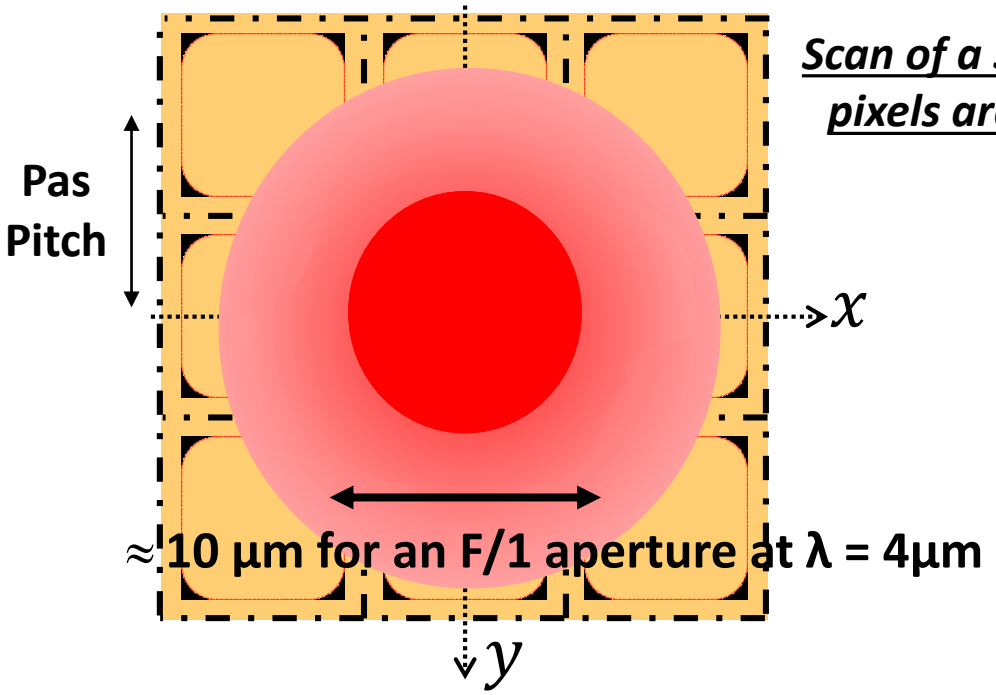


..... Ideal pixel

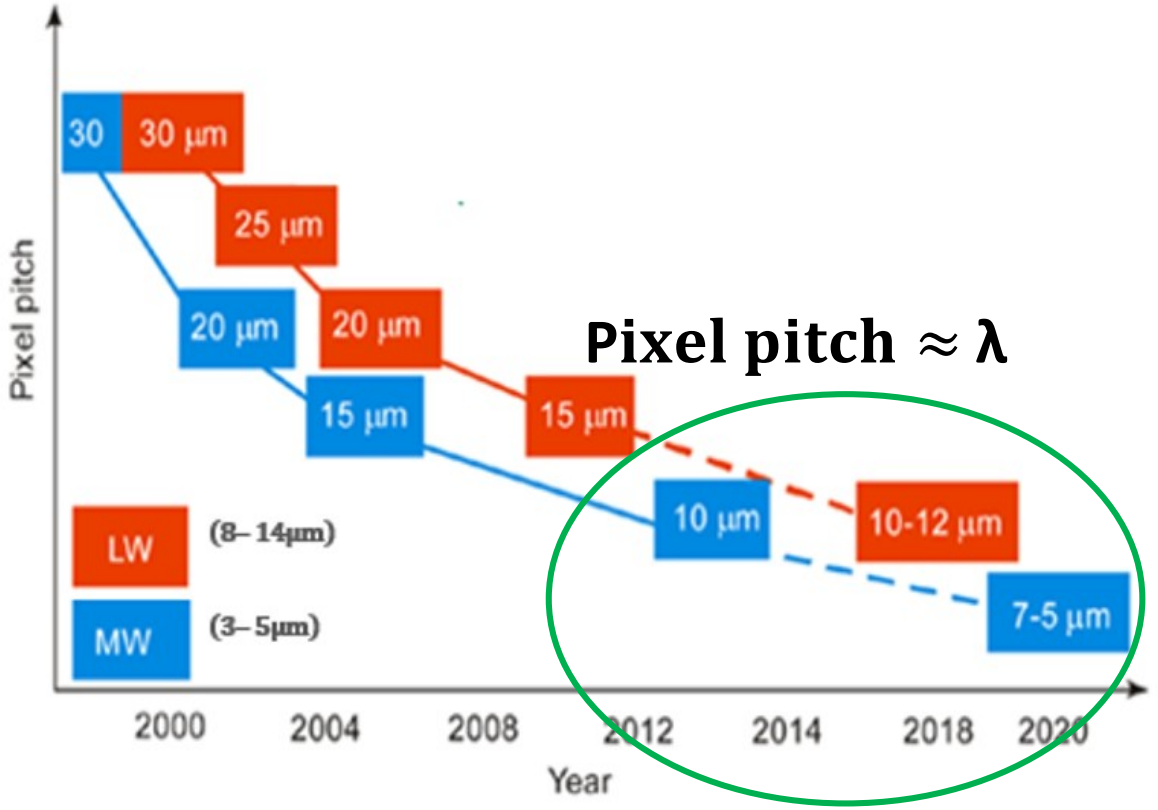
× Measurement points

— PSF_{mes}

Optical spot scan : issue of the size of the projected spot VS the pixel pitch



Scan of a 3X3 pixels area



Evolution de la taille pixel pour la technologie HgCdTe Durant la période 2000 – 2020 *Antoni Rogalski, RPP, 2016*

The method is sensible to

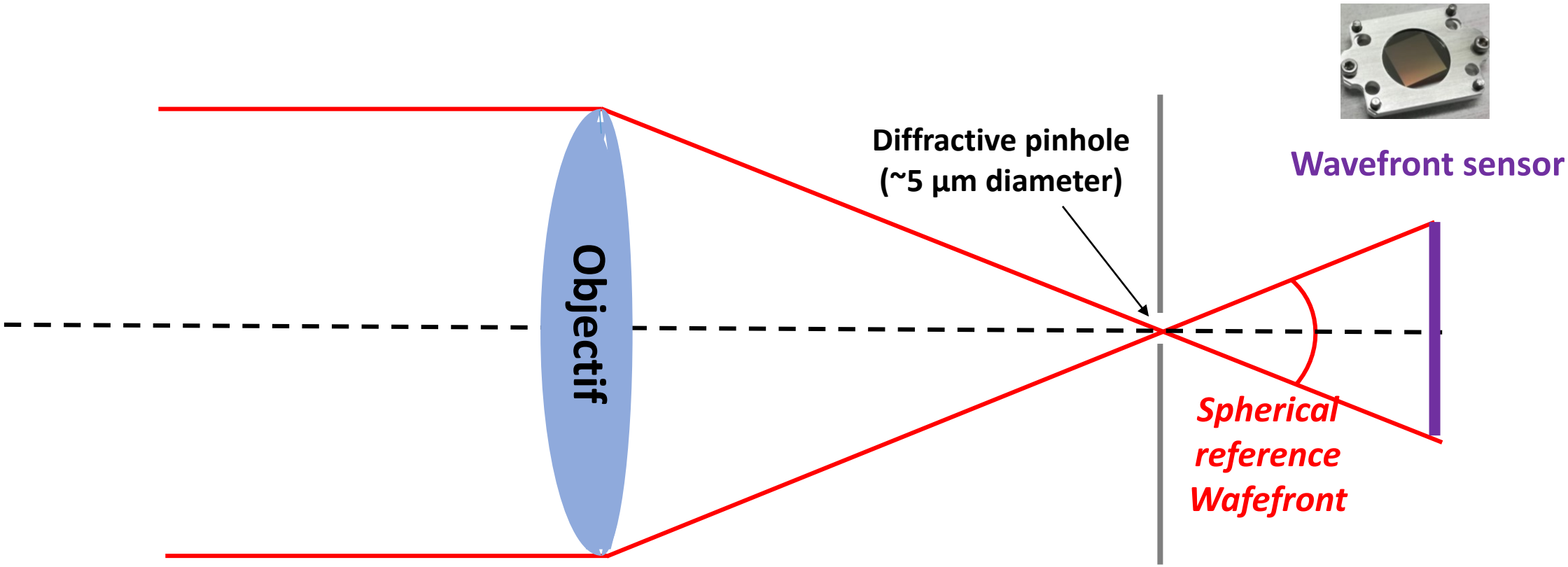
- **Focalization**
- **Optical abberations**

$$PSF_{mes} = PSF_{optics} * PSF_{pixel}$$

↳ ***Absolute wavefront measurement***

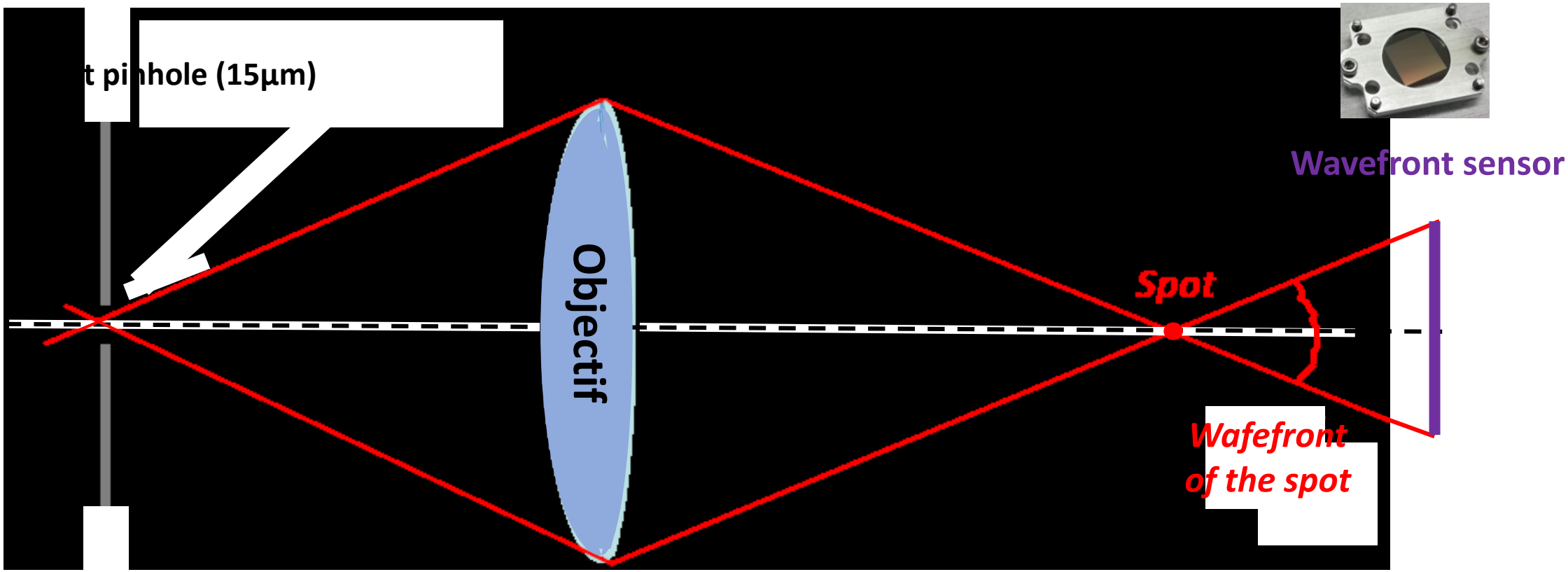
Absolute wavefront spot measurement by comparison to a perfect spherical wavefront

Step 1 **: Calibration of the wavefront sensor : a spherical wavefront is diffracted (Huygens –Fresnel Theory) by a very small diffractive hole**



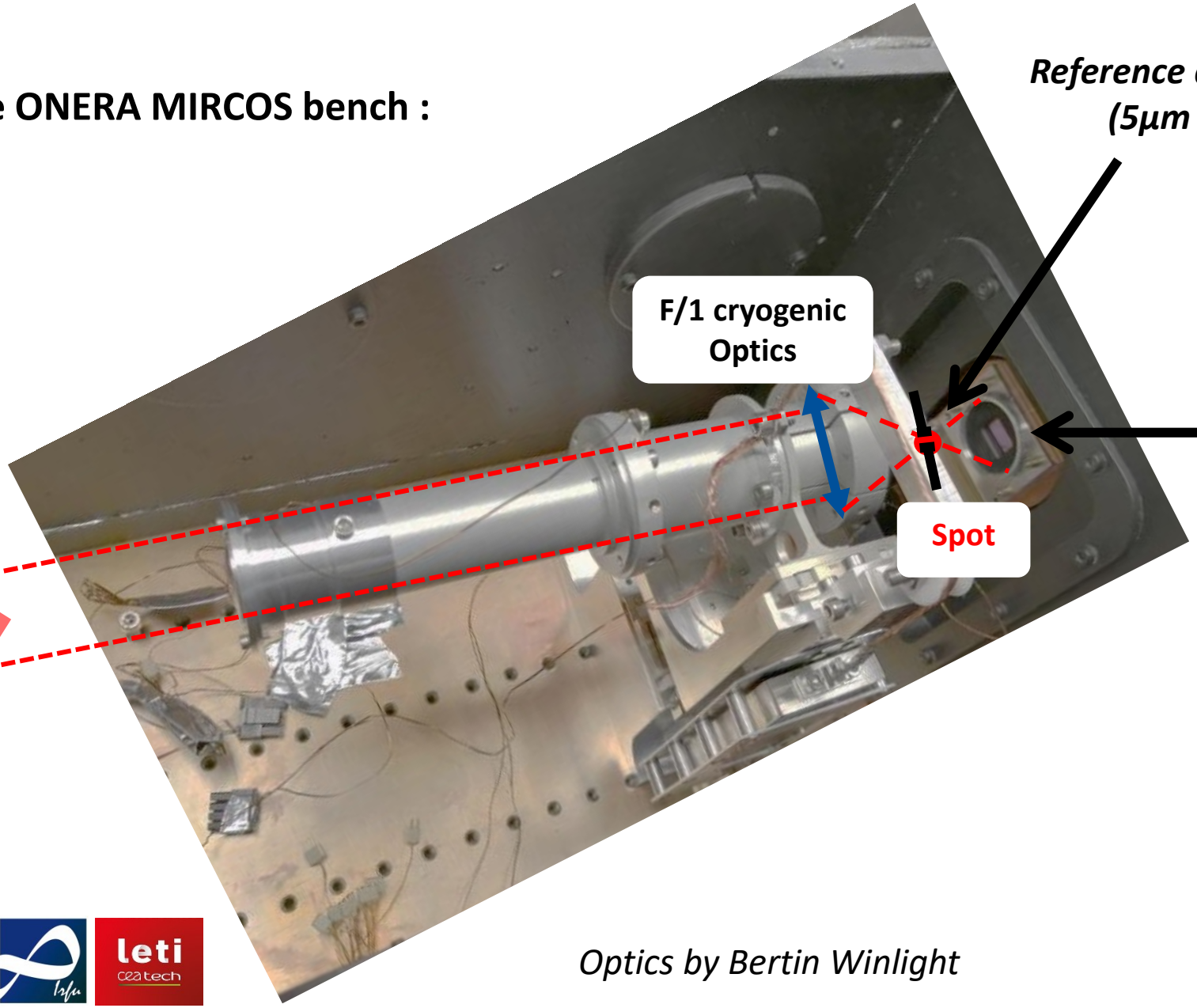
Absolute wavefront spot measurement by comparison to a perfect spherical wavefront

Step 2 **: measurement of the spot wavefront**



Absolute wavefront spot measurement by comparison to a perfect spherical wavefront

Picture inside ONERA MIRCOS bench :



Reference diffractive hole (5µm diameter)

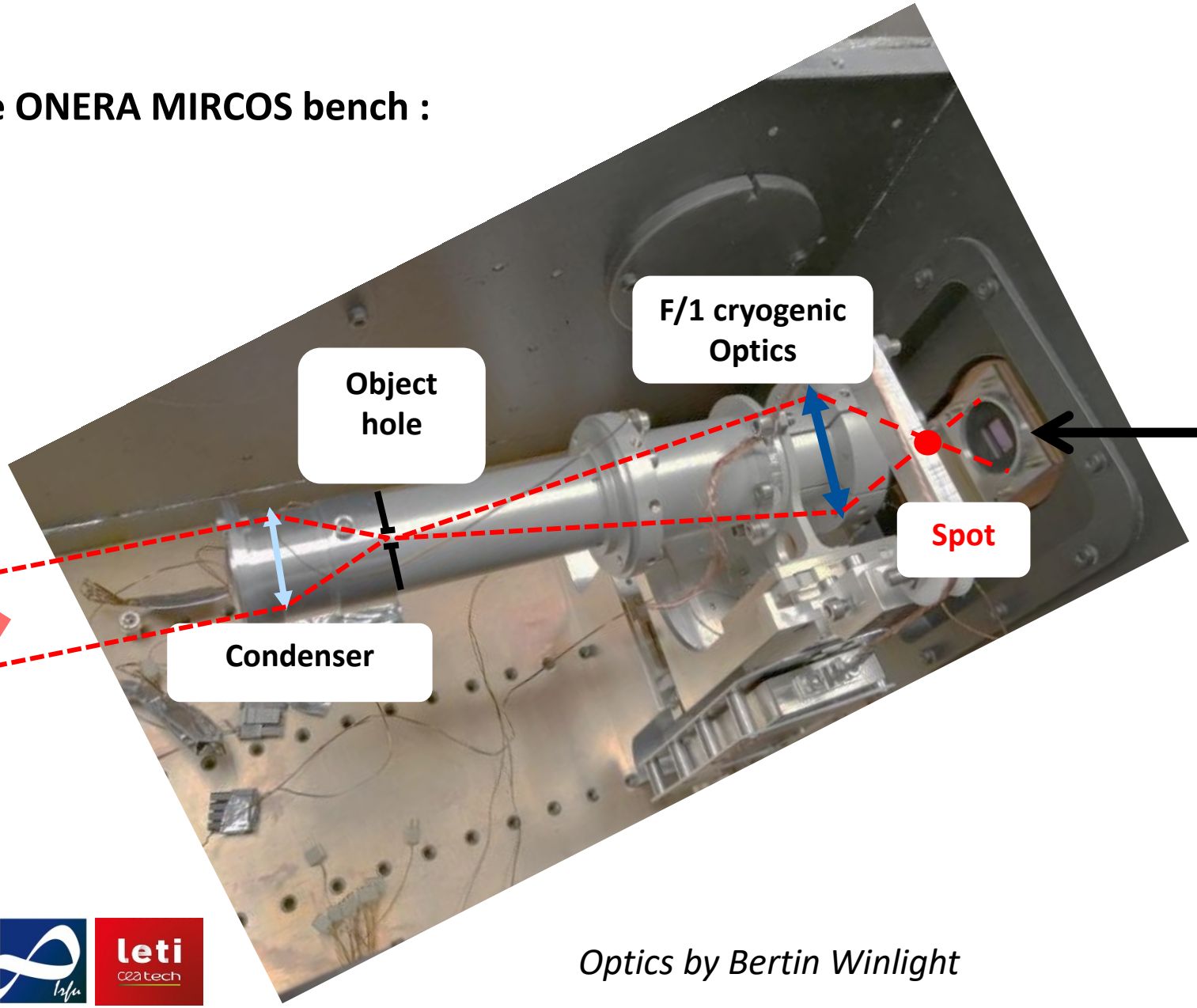
Wavefront sensor

IR collimated beam

Optics by Bertin Winlight

Absolute wavefront spot measurement by comparison to a perfect spherical wavefront

Picture inside ONERA MIRCOS bench :



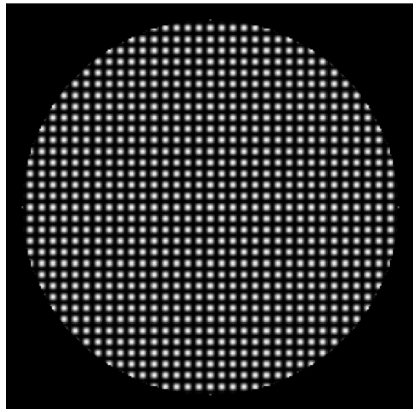
IR collimated beam

Wavefront sensor

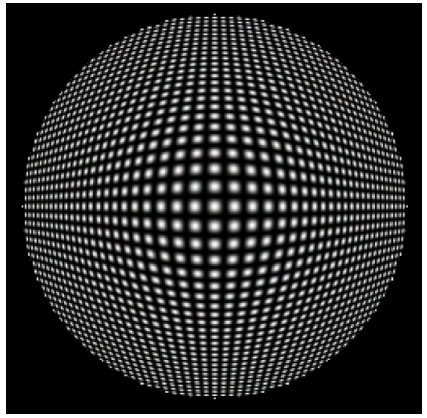
Optics by Bertin Winlight

Use of a specific wavefront analyser QWLSI (Quadriwave Lateral Shearing Interferometry)

No aberrations

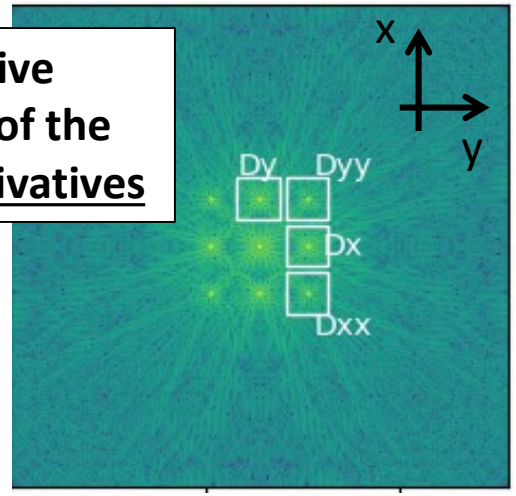


With spherical aberration



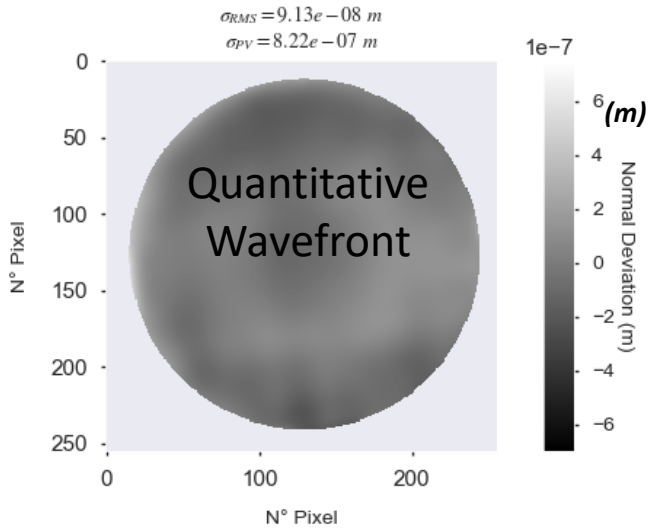
FFT

Analysis in Fourier Domain



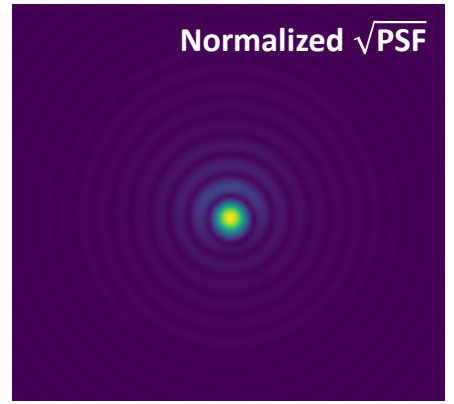
Quantitative information of the wavefront derivatives

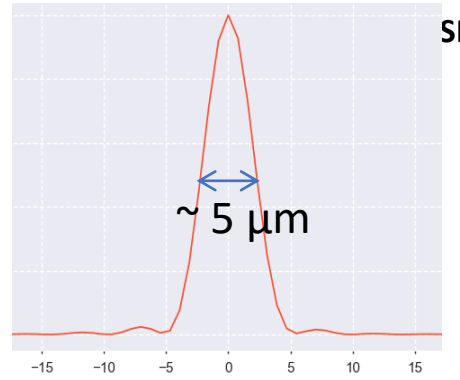
Integration over (x,y)



Propagation

(Wave optics physics)





SF

WORK in Progress (JORIS GOREE 3rd year PHD, end in next December)

Evaluation of error possible by the Schwarz Theorem

$$\frac{\partial}{\partial x}\left(\frac{\partial f(x,y)}{\partial y}\right) = \frac{\partial}{\partial y}\left(\frac{\partial f(x,y)}{\partial x}\right)$$

$$\frac{\partial Dx}{\partial y} - \frac{\partial Dy}{\partial x} = 0$$

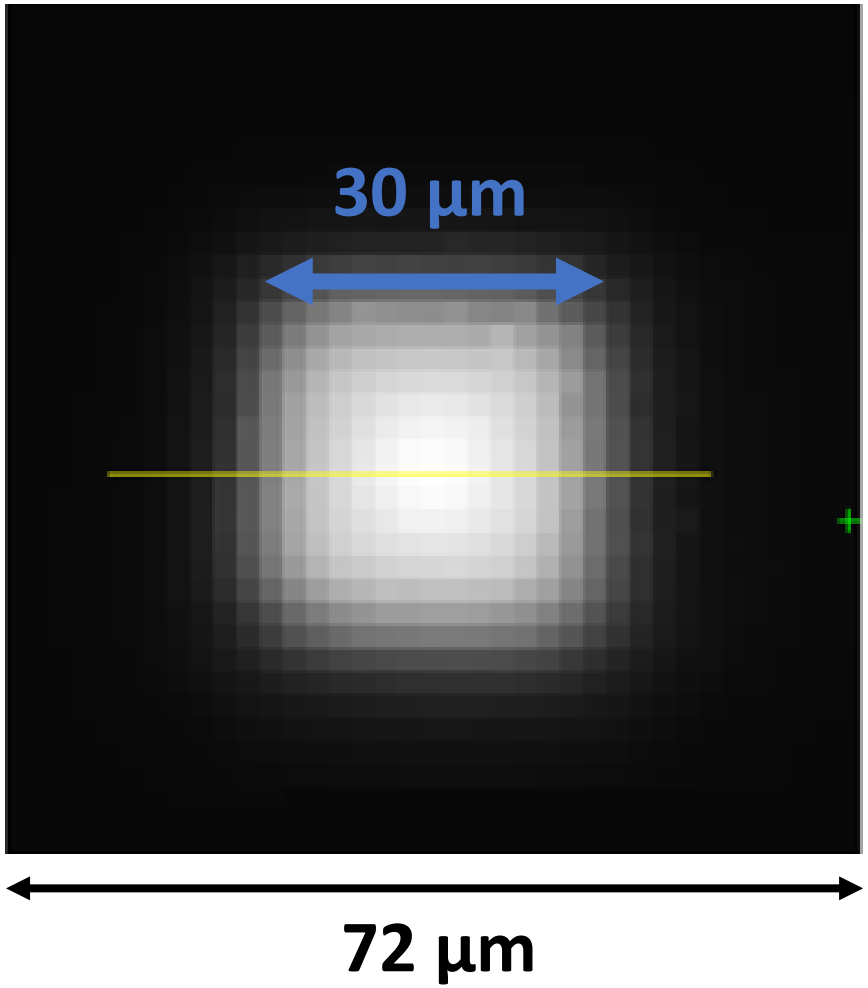
ONERA THE FRENCH AEROSPACE LAB

FOCUS 2 UNIVERSE SCIENCE

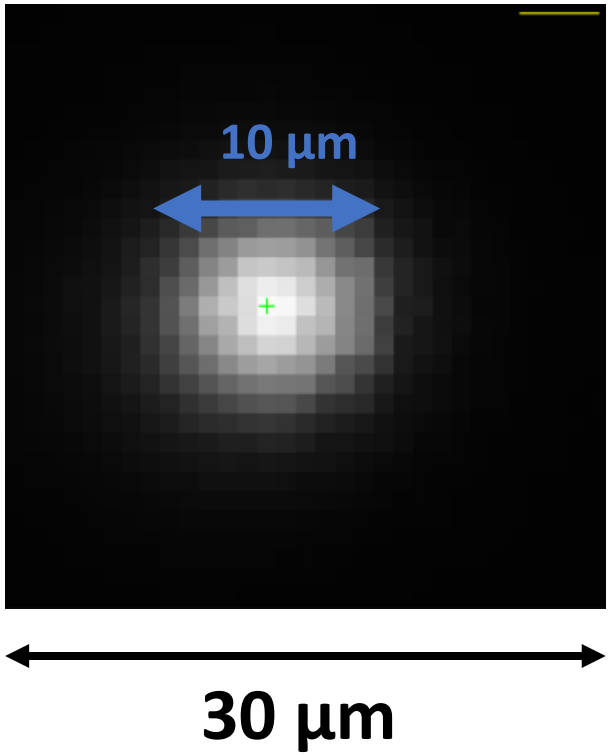
leti ceatech

Thank you for your attention !

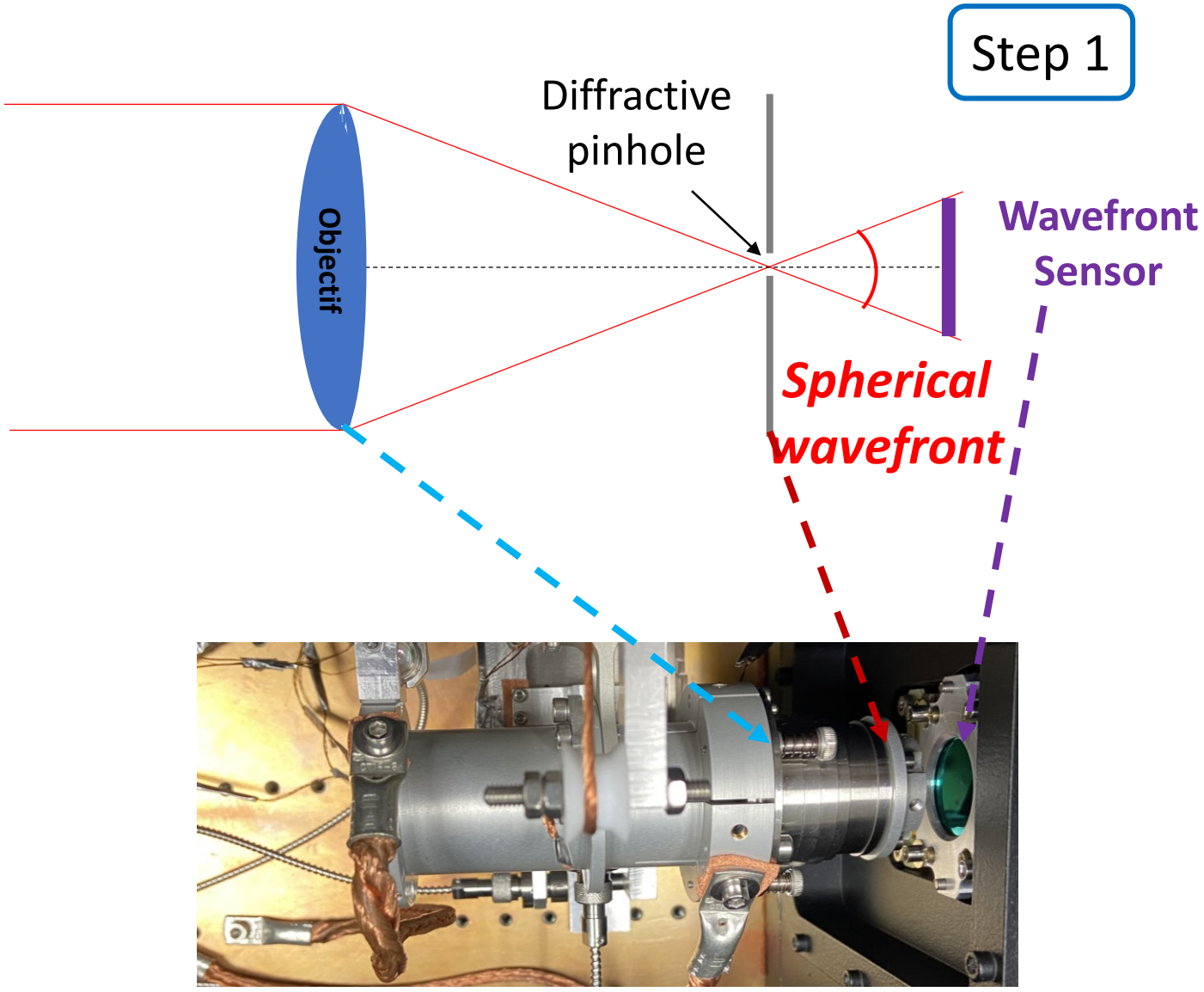
37x37 points, 2µm steps +/- 200nm
30µm pitch standard diode



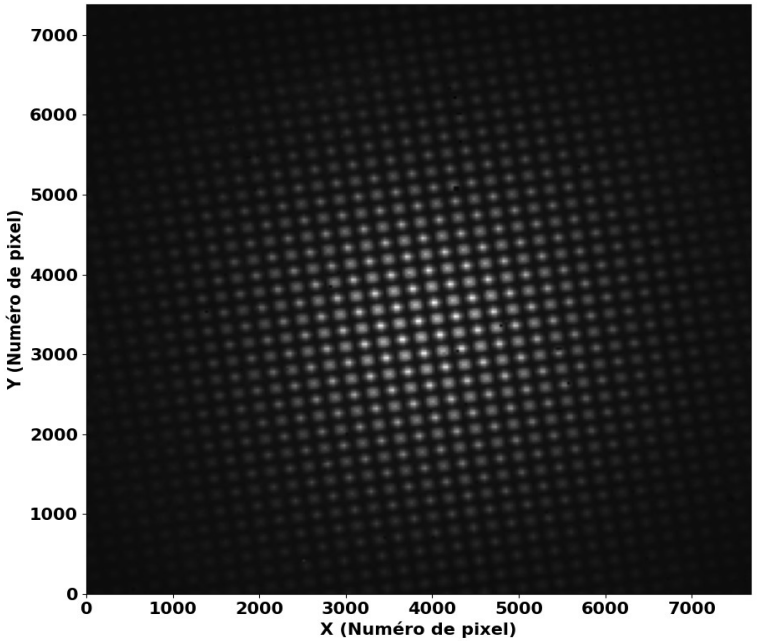
30x30 points, 1µm steps +/- 100nm
small diode in 30µm pitch



Back-up slides

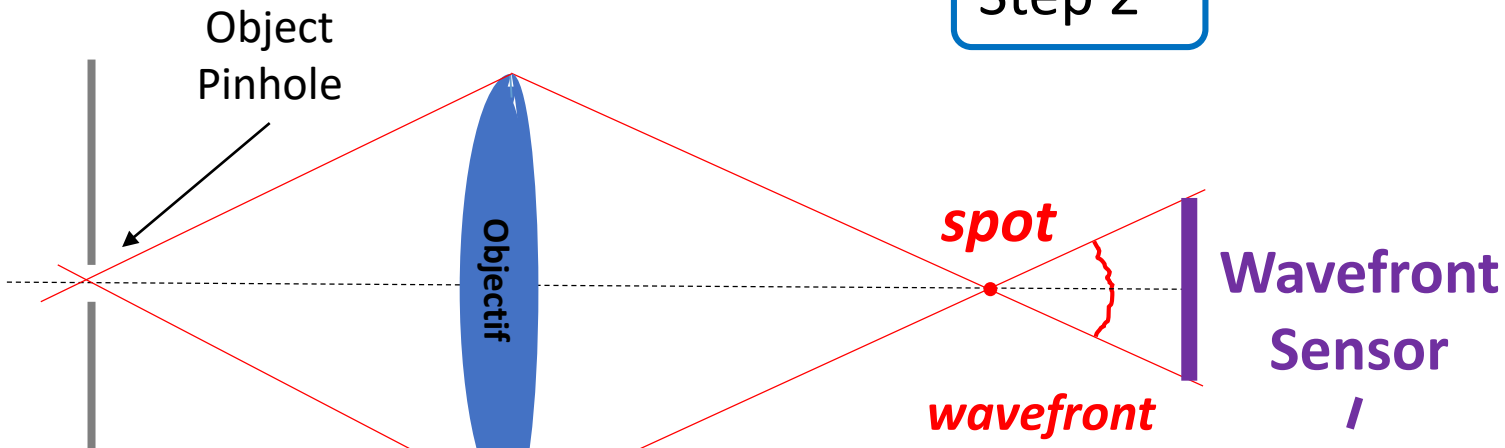


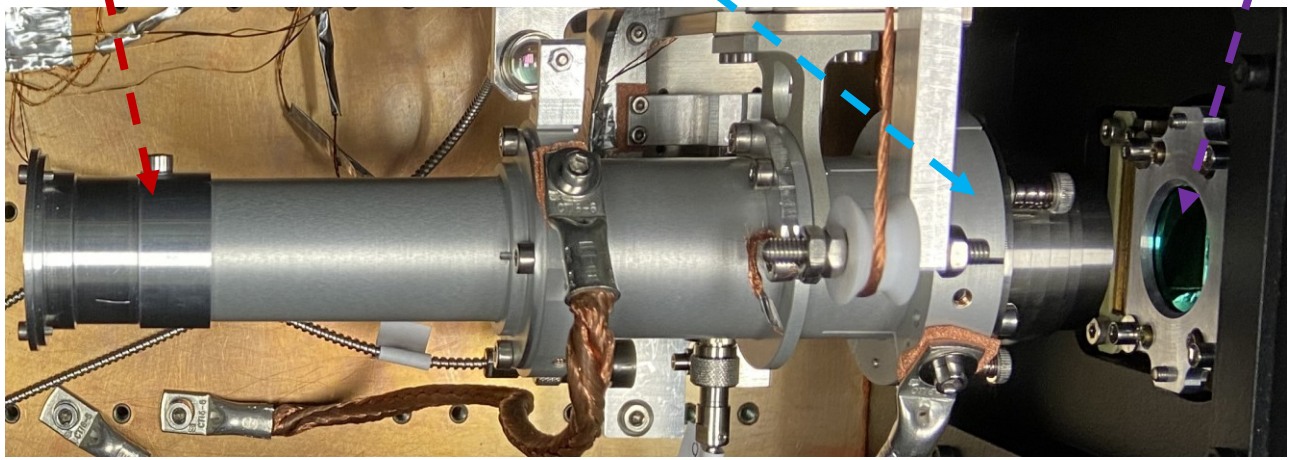
Reference



Back-up slides

Step 2





Measurement