A LGSWFS prototype for the ELT

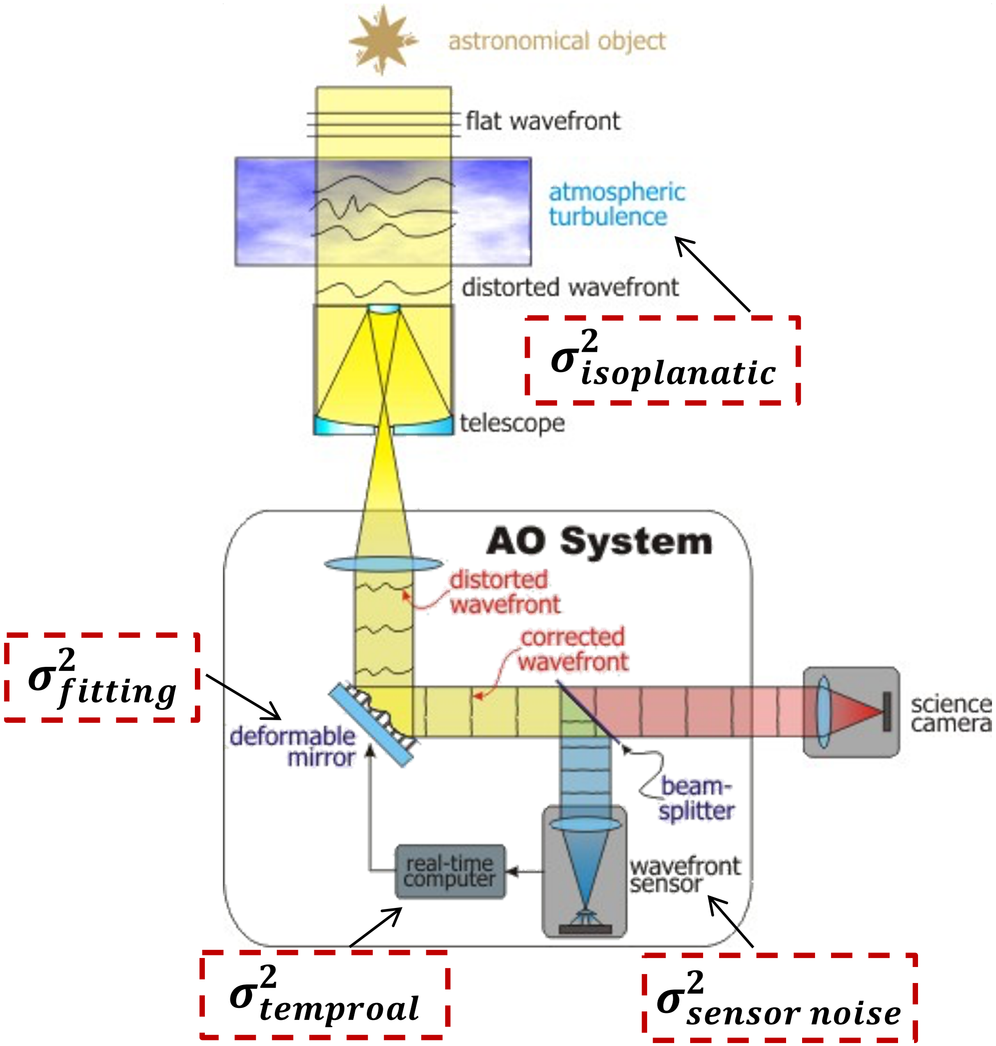
Zibo KE

14/01/2021

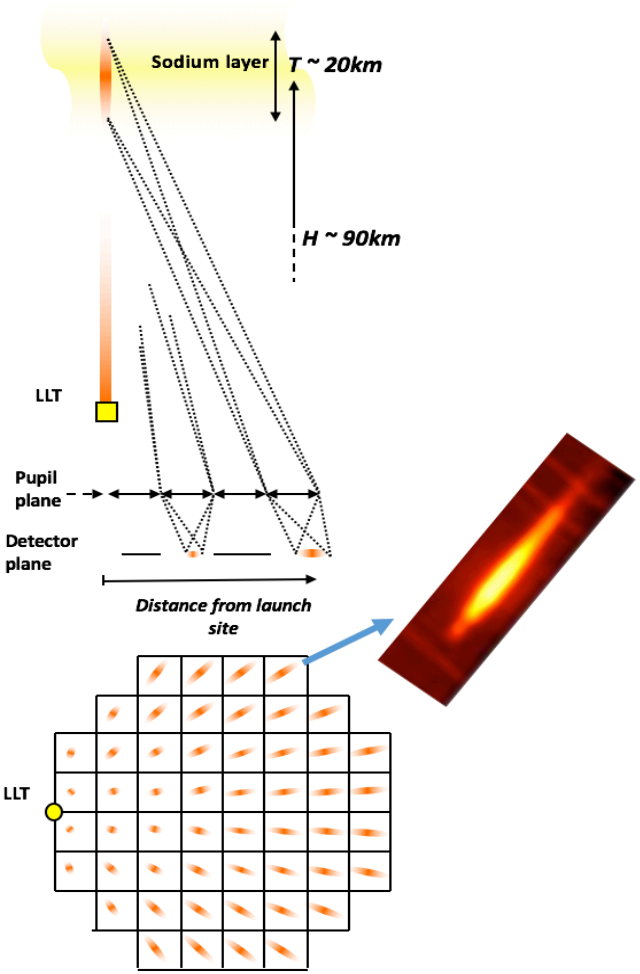
Supervisors: NEICHEL Benoit
FUSCO Thierry

PhD time: 30/09/2018 - 30/09/2021

Research background

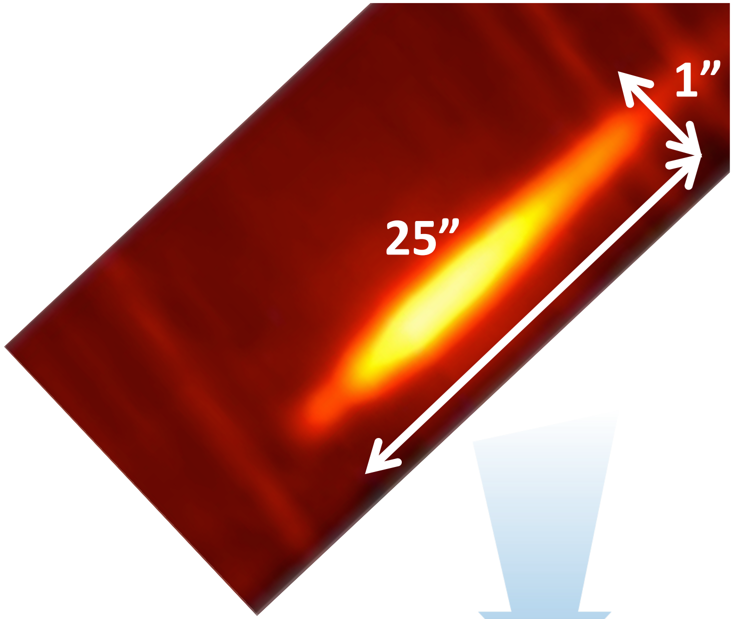


Principle of Adaptive Optics



Elongation on the detector

Research background



2000x2000 pixels detector, running at 500Hz, with RON<3e- does not exist…

We study the possibility to use SONY-CMOS detectors with: 1100x1100pixels
RON<3e-
Fps = 480Hz
Global shutter

Ideally, we need subapertures with 25x25 pixels of ~1” /pixel

For 80x80 subapertures, we need 2000 x 2000 pixels

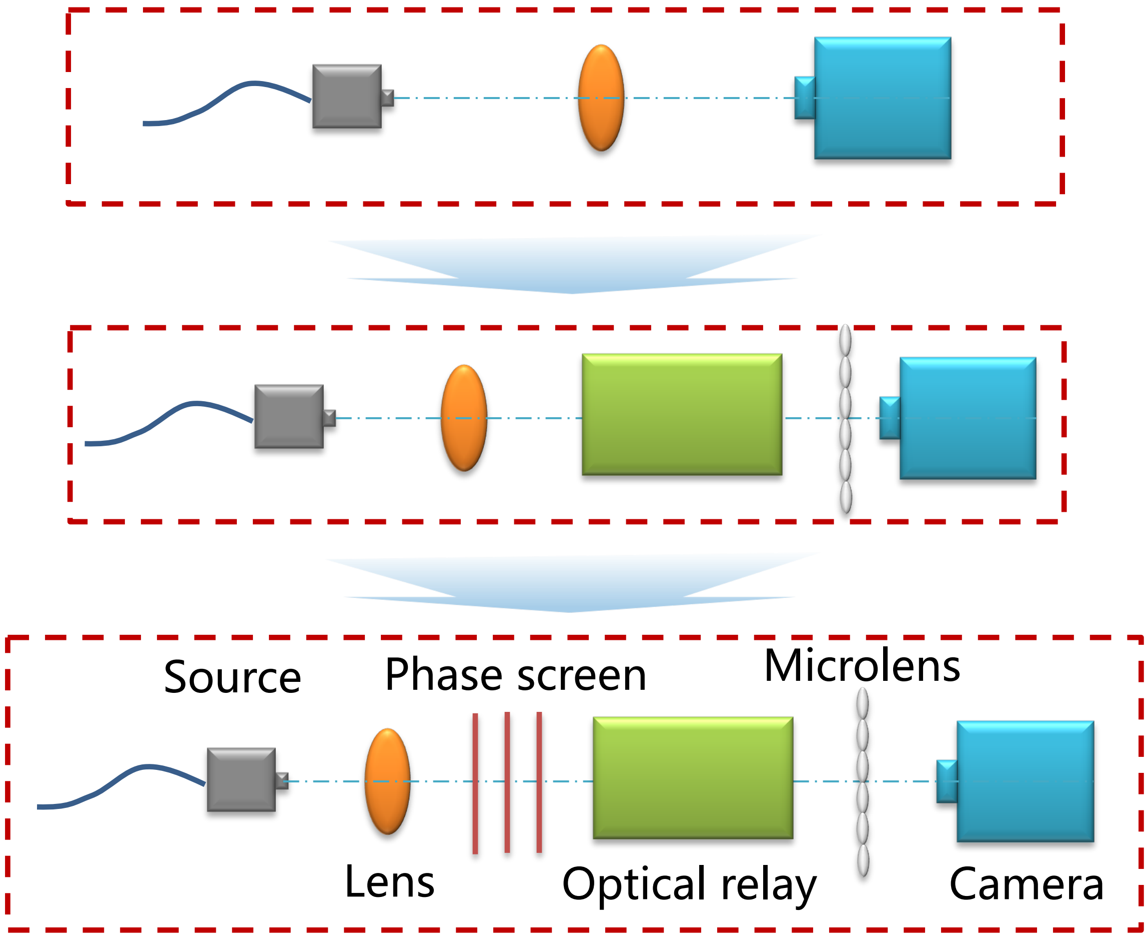
Research objective

Real system + Simulation

Step 1

Step 2

Step 3



Detector characterization

Optical relay + Lenslet tests => Start WFSensing

Elongation + Phase screens => Full scale test

The work is to develop a prototype to experimentally validate a full-scale version of a LGSWFS for the ELT

Current work

Detector characterization

Noise analysis

Angle of acceptance

Centroids variation

$\sigma^2_{sensor\ noise}$

AO Simulation for shutter impact

Open loop

Close loop

$\sigma^2_{temproal}$

Noise analysis

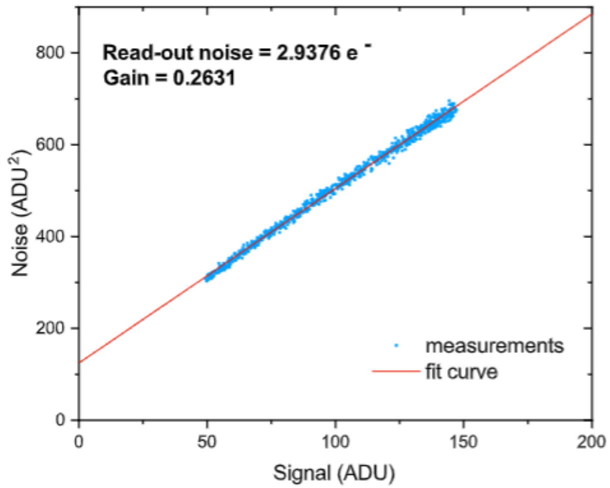
Photon transfer curve

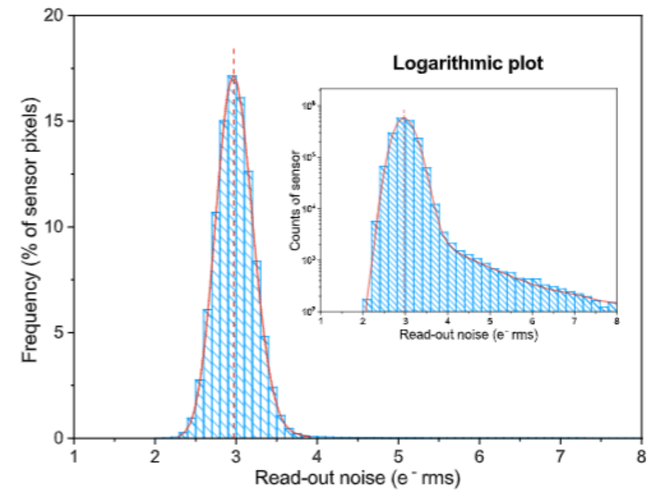
$$\sigma^2_{I_{\mathrm{ADU}}} = \frac{1}{g} \cdot S_{\mathrm{ADU}} + \sigma^2_{R_{\mathrm{ADU}}},$$

Uniform source

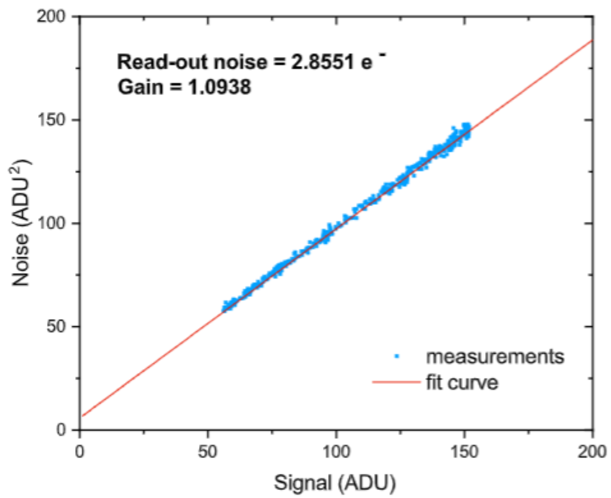
Dark frames without source

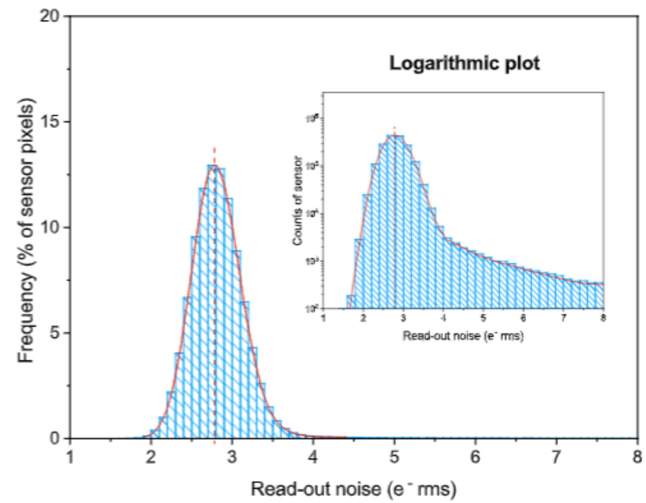
12 bits





8 bits

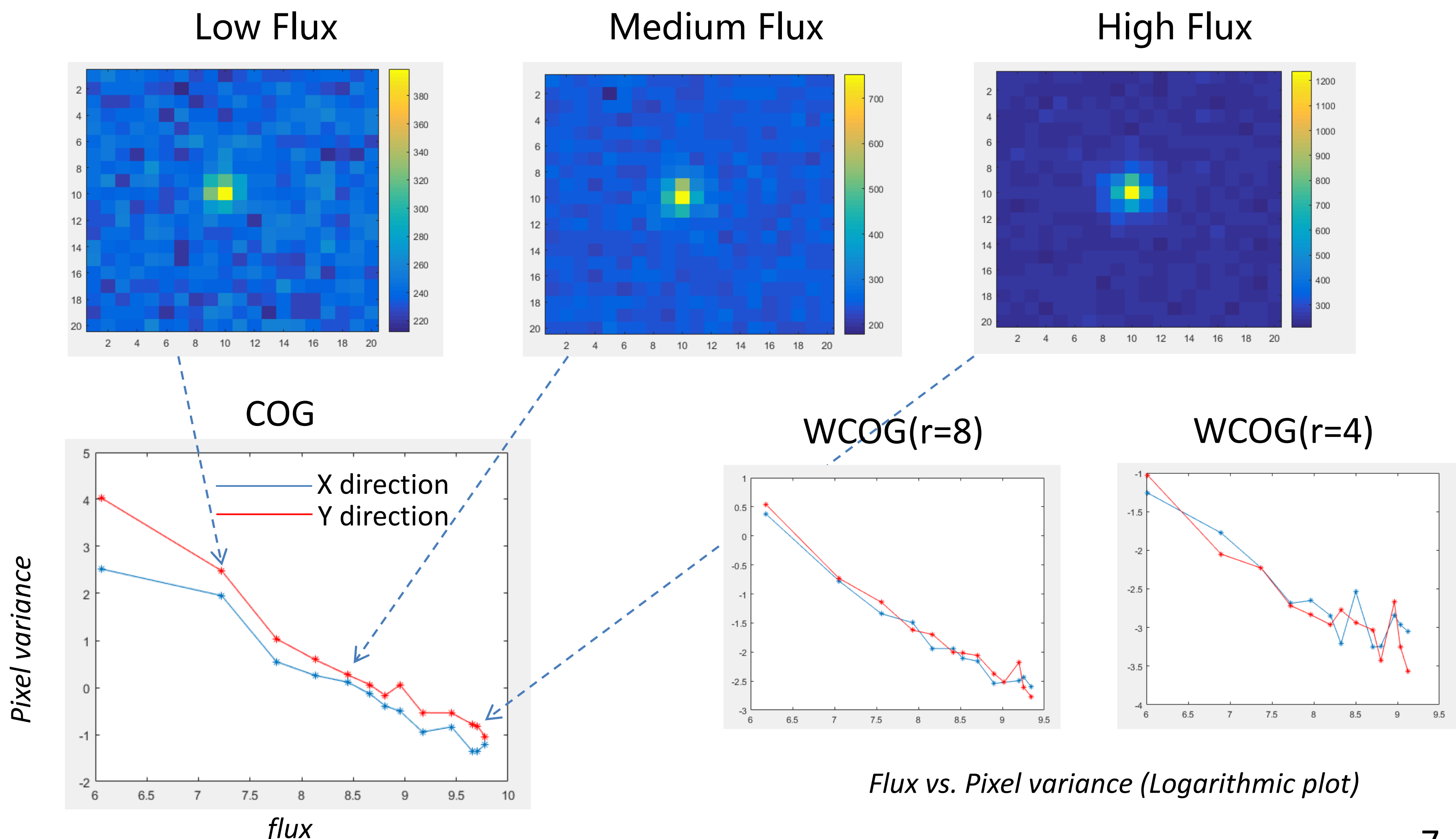




Noise analysis

Photon noise (PN)

Testing Centroiding accuracy vs. different level of flux



Flux vs. Pixel variance (Logarithmic plot)

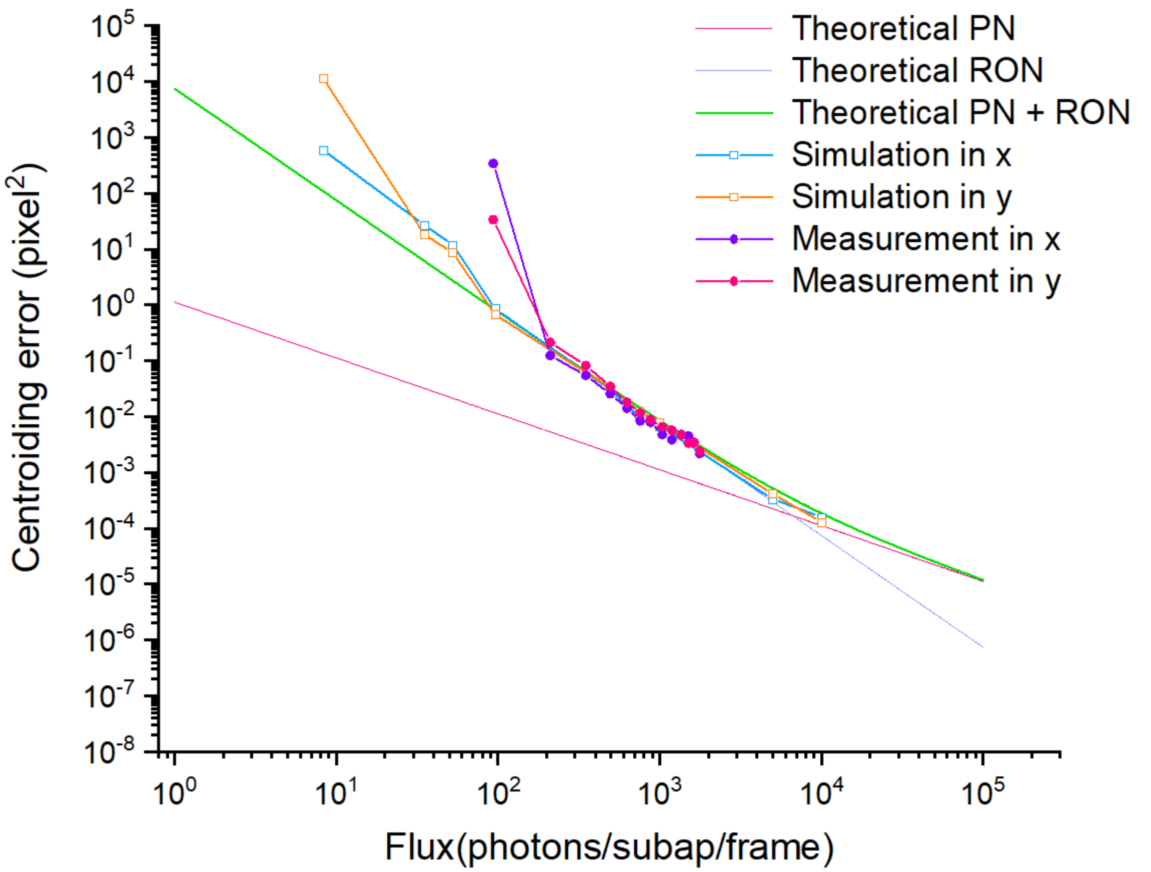
Noise analysis

Photon + Read-out noise (PN + RON)

COG Theory

$$(\sigma^2_{\Delta Cx})^{COG}_{th} = \underbrace{\frac{N_T^2}{8\, ln(2)\, \mathcal{N}_{ph}}}_{Photon} + \underbrace{\left(\frac{\sigma_{det}}{\mathcal{N}_{ph}}\right)^2 \cdot \left(\frac{N_S^4}{12}\right)}_{Detecteur}$$

N_T=2.5， N_S=10

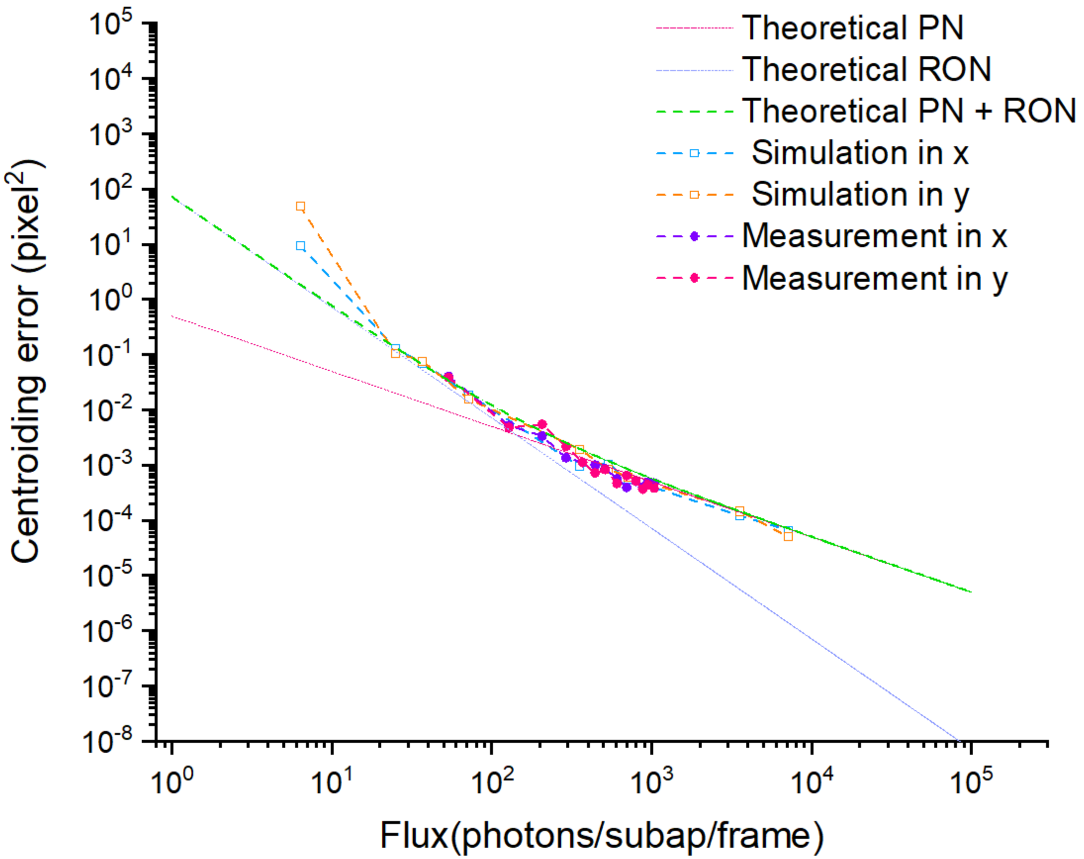


Noise analysis

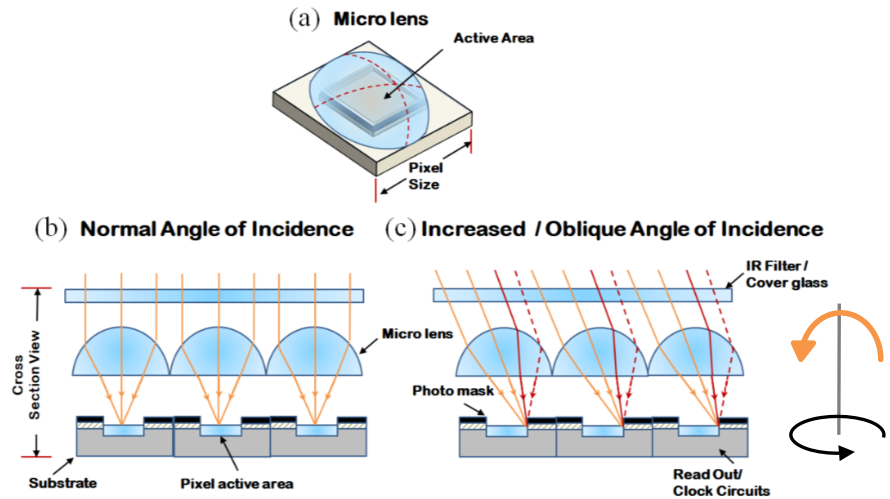
Photon + Read-out noise (PN + RON)

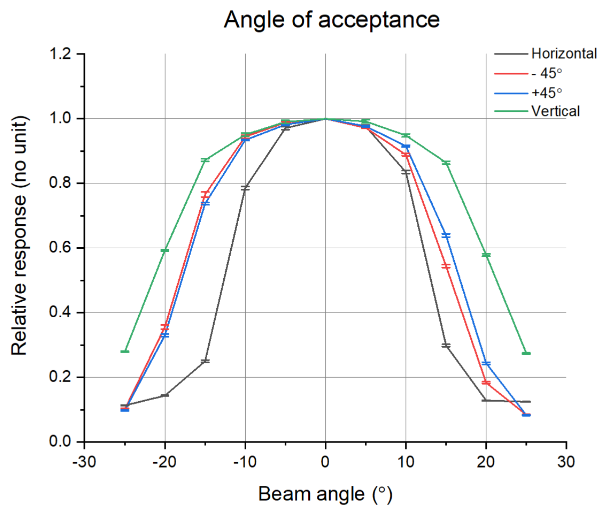
WCOG Theory $$(\sigma^2_{\Delta Cx})^{WCOG}_{th} = \underbrace{\frac{N_T^2}{8\ ln(2) N_{ph}} \cdot \left(\frac{N_T^2 + N_W^2}{2N_T^2 + N_W^2}\right)^2}_{Photon} + \underbrace{\frac{\pi}{128} \frac{\left(N_T^2 + N_W^2\right)^2}{(ln(2))^2} \cdot \left(\frac{\sigma_{det}}{N_{ph}}\right)^2}_{Detecteur}$$

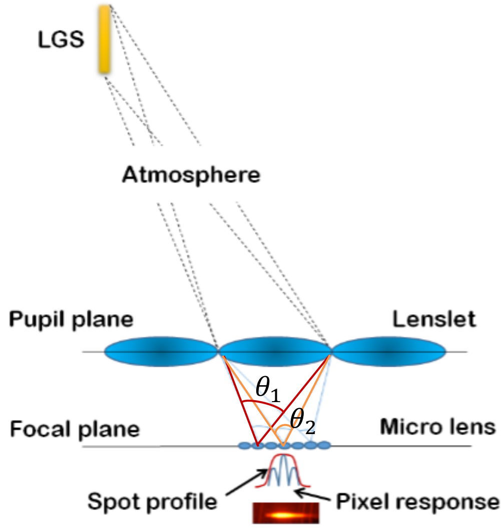
N_T=2.5， N_W=2.5

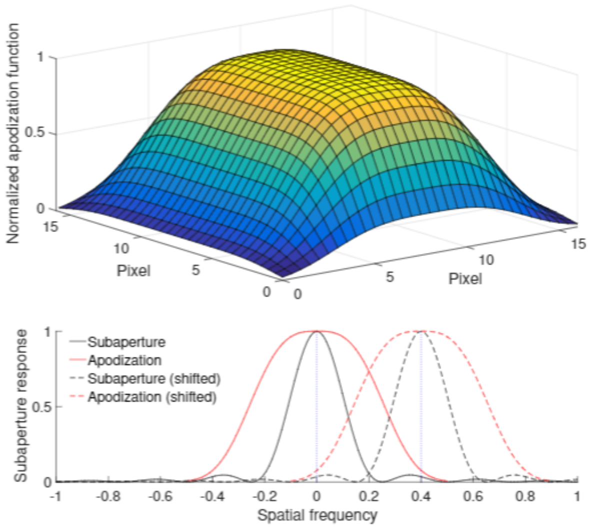


Angle of acceptance



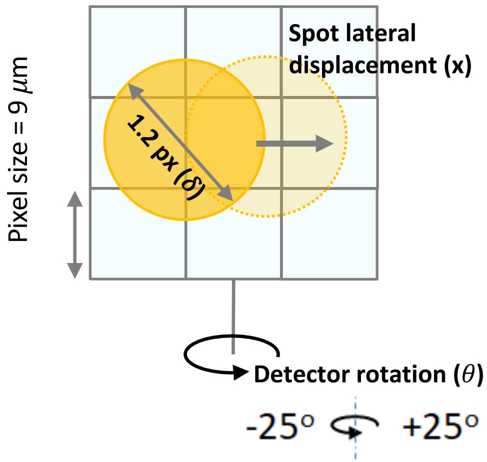


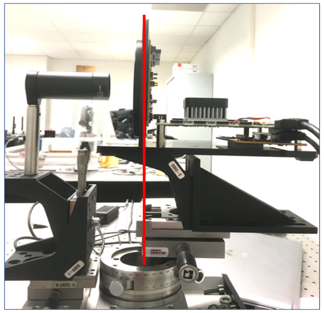




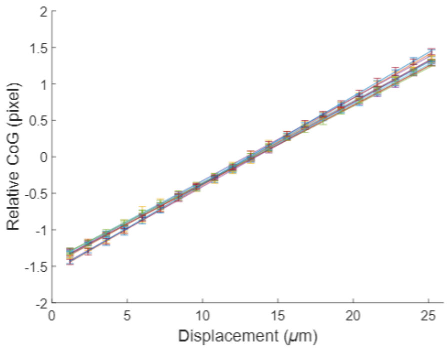
Centroids variation

0µm → 25µm (3 pixels)

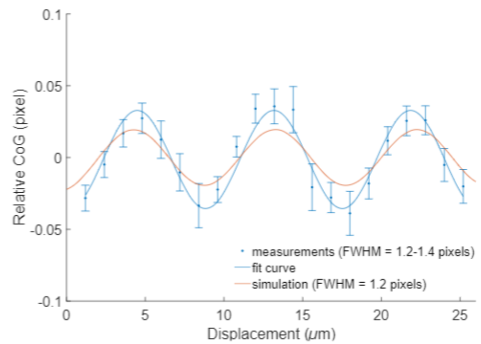




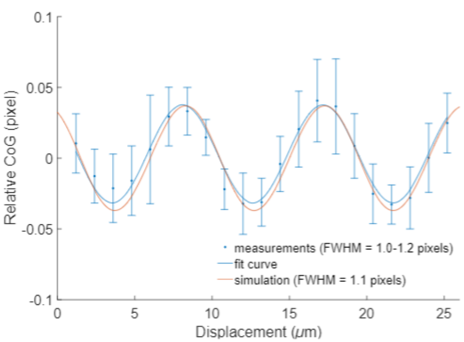
Linear fit (δ =1.2 pixels)



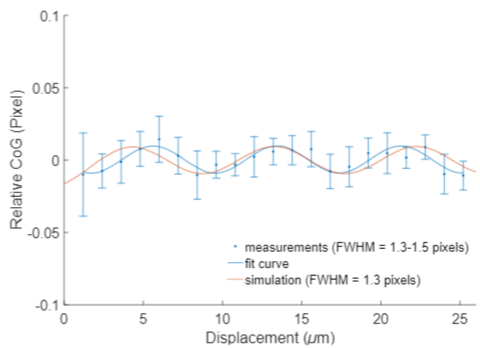
Residuals (δ =1.2 pixels)



Residuals (δ =1.1 pixels)



Residuals (δ =1.3 pixels)

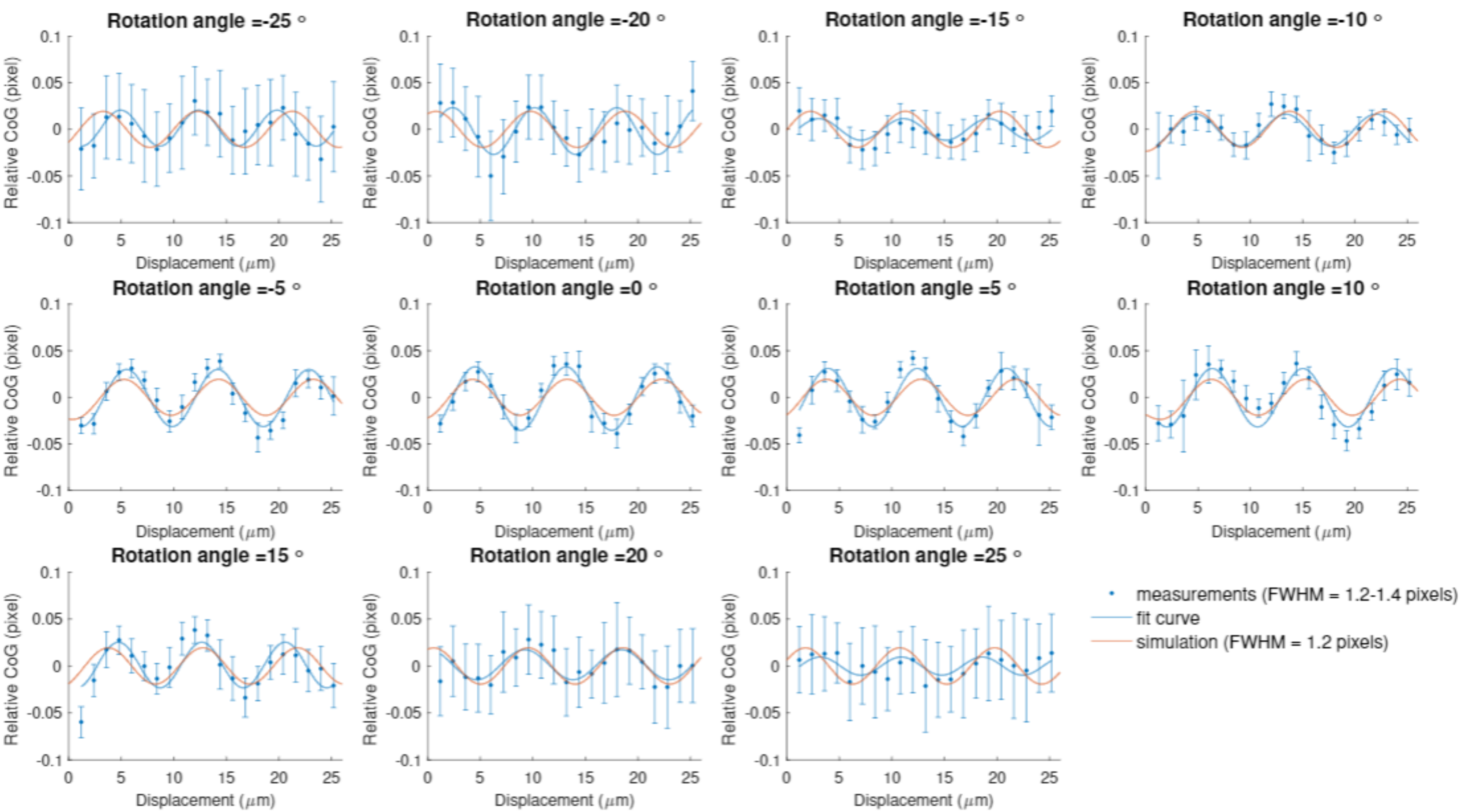


- Measurement of Center of Gravity (**CoG**) as a function of spot lateral **displacement** (x), **incident angle**(θ)**, and spot size** (δ).

$$\mathrm{CoG}(x;\theta,\delta) = \underbrace{A(\theta)\,x + B(\theta)}_{\textbf{Linear fit}} + \underbrace{\alpha(\delta)\sin(\beta x + \gamma)}_{\textbf{Residuals}}$$

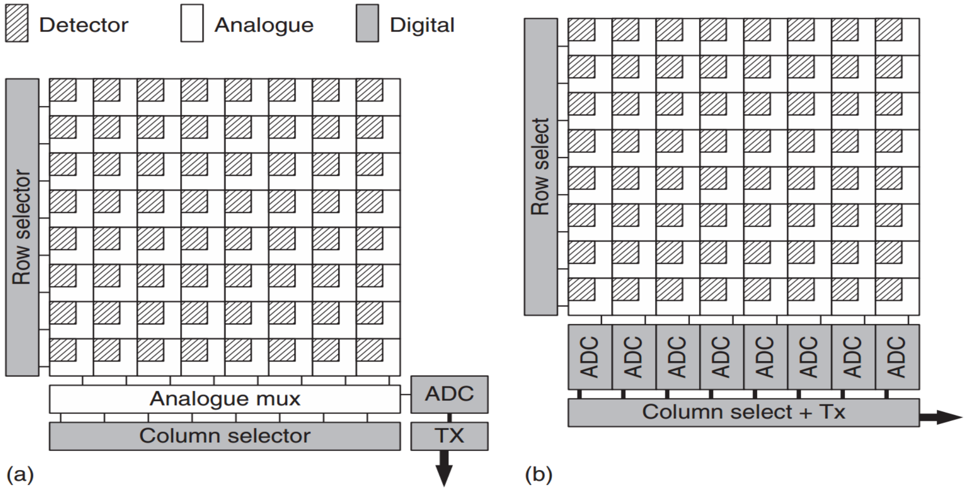
Centroids variation

Residuals (δ =1.2 pixels)



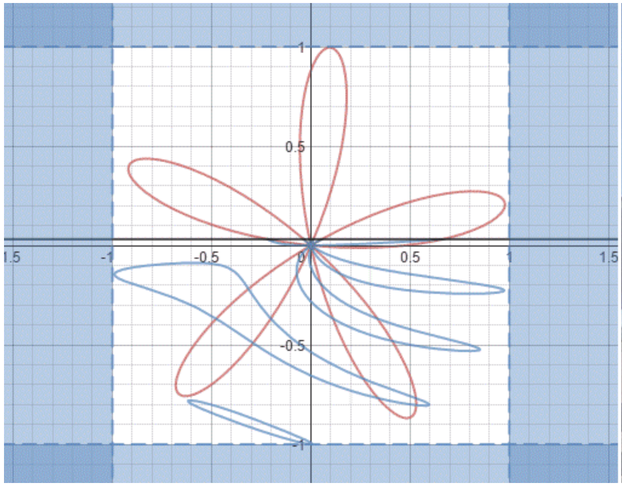
Global shutter vs. Rolling shutter

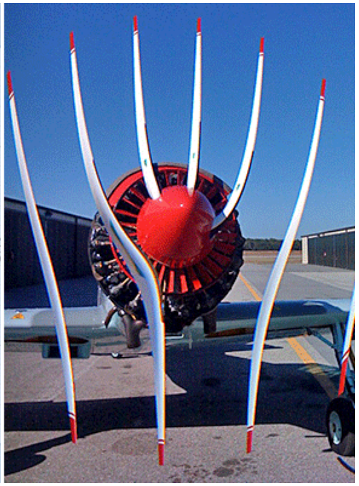
Principle

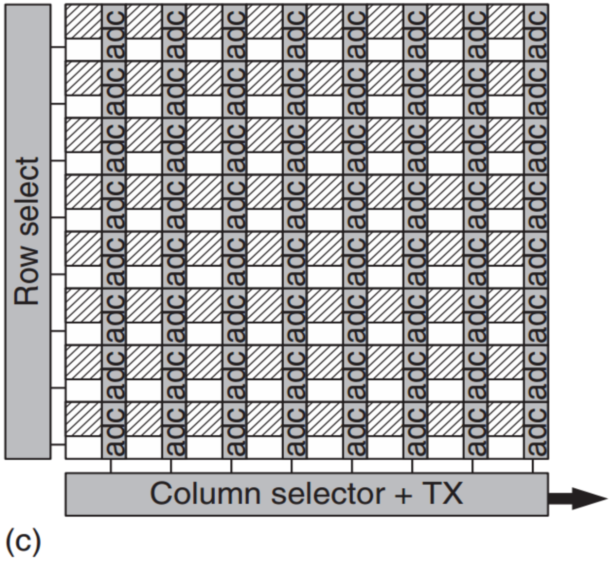


CCD (global shutter)

CMOS (rolling shutter)



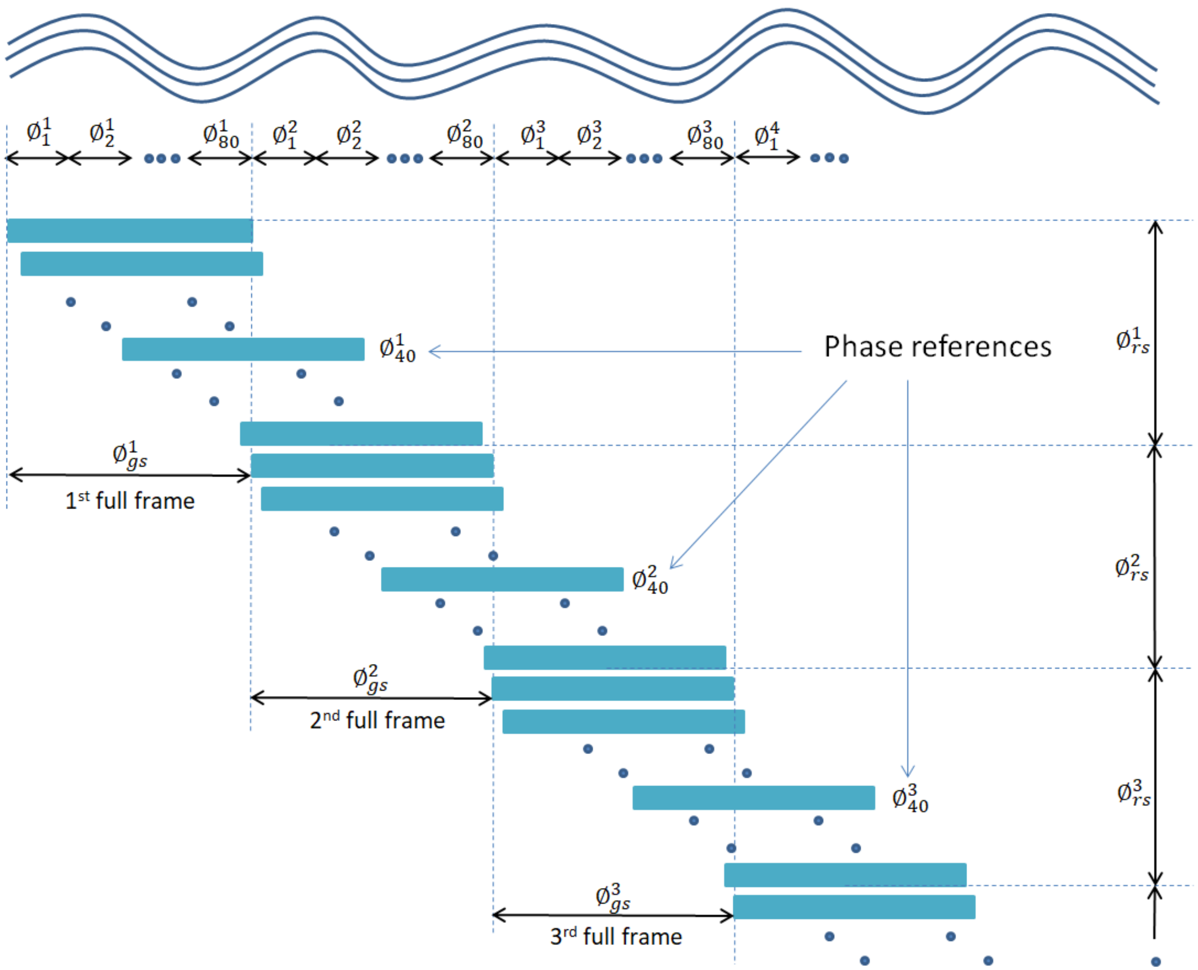


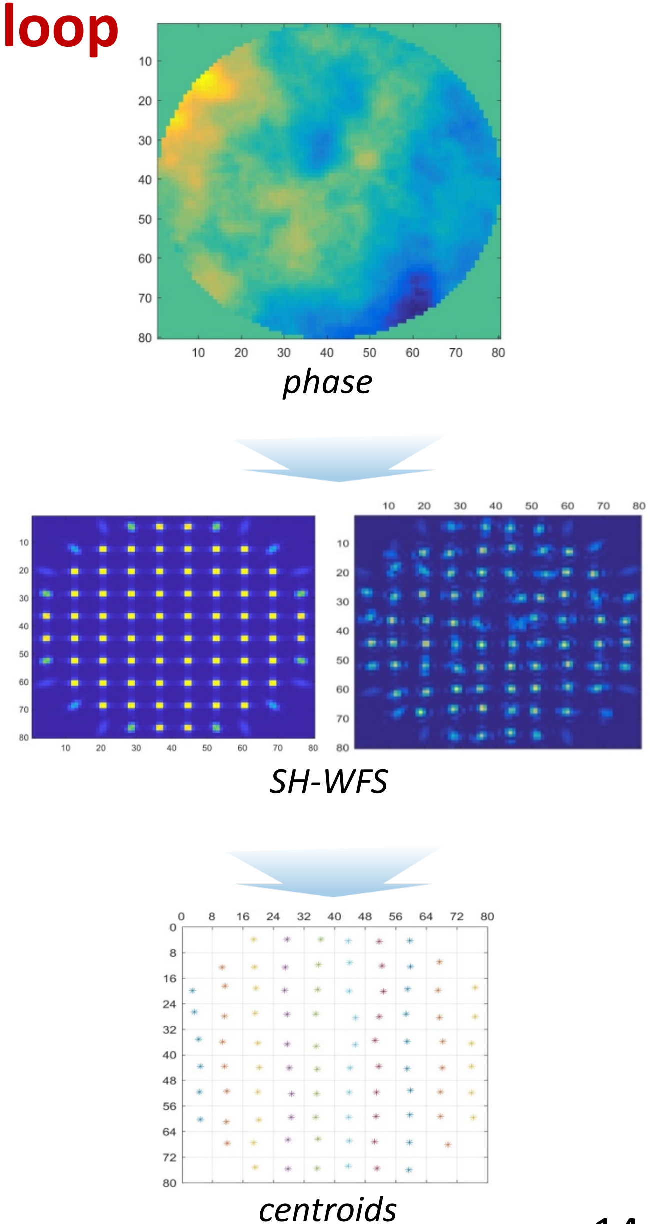


CMOS (global shutter)

Global shutter vs. Rolling shutter

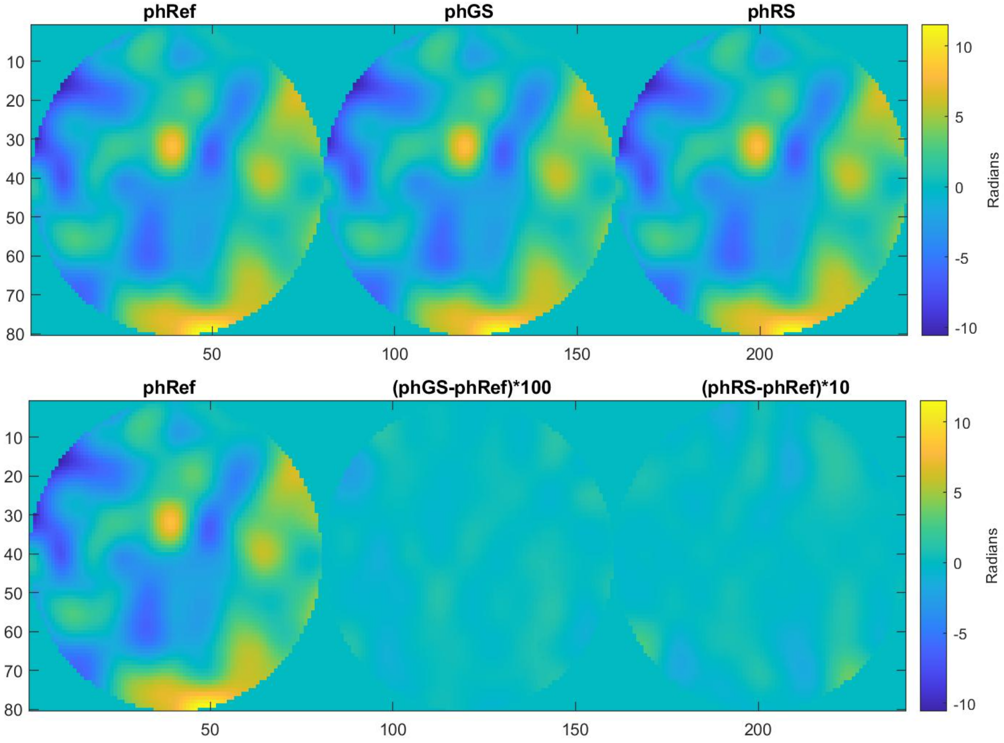
Open loop





λ= 550nm, r0 = 50.00cm, samplingTime=1/(80*500),D=8m;
subapertures=10x10, resolutions=80x80;

Global shutter vs. Rolling shutter



Comparison between reconstructed phase for GS and RS acquisition process

$$rms(\varphi) = \sqrt{\frac{1}{\sum_x \sum_y Pup(x,y)} \sum_x \sum_y (\varphi(x,y))^2}$$

Open loop

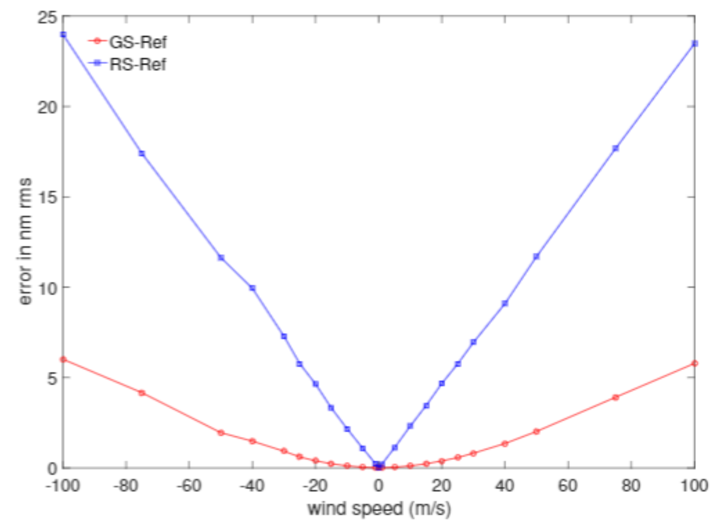
Rms(phRef)=299 nm (3.4 rad)

Rms(phGS-phRef)=0.4 nm (0.005 rad)

→ **0.15 %**

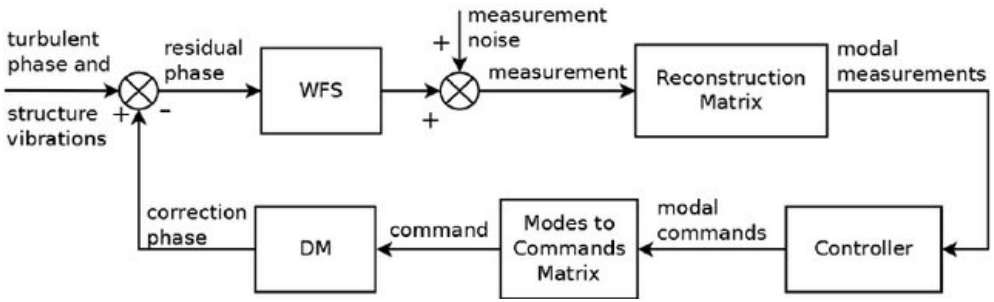
Rms(phRS-phRef)=5.6 nm (0.064 rad)

→ **2 %**

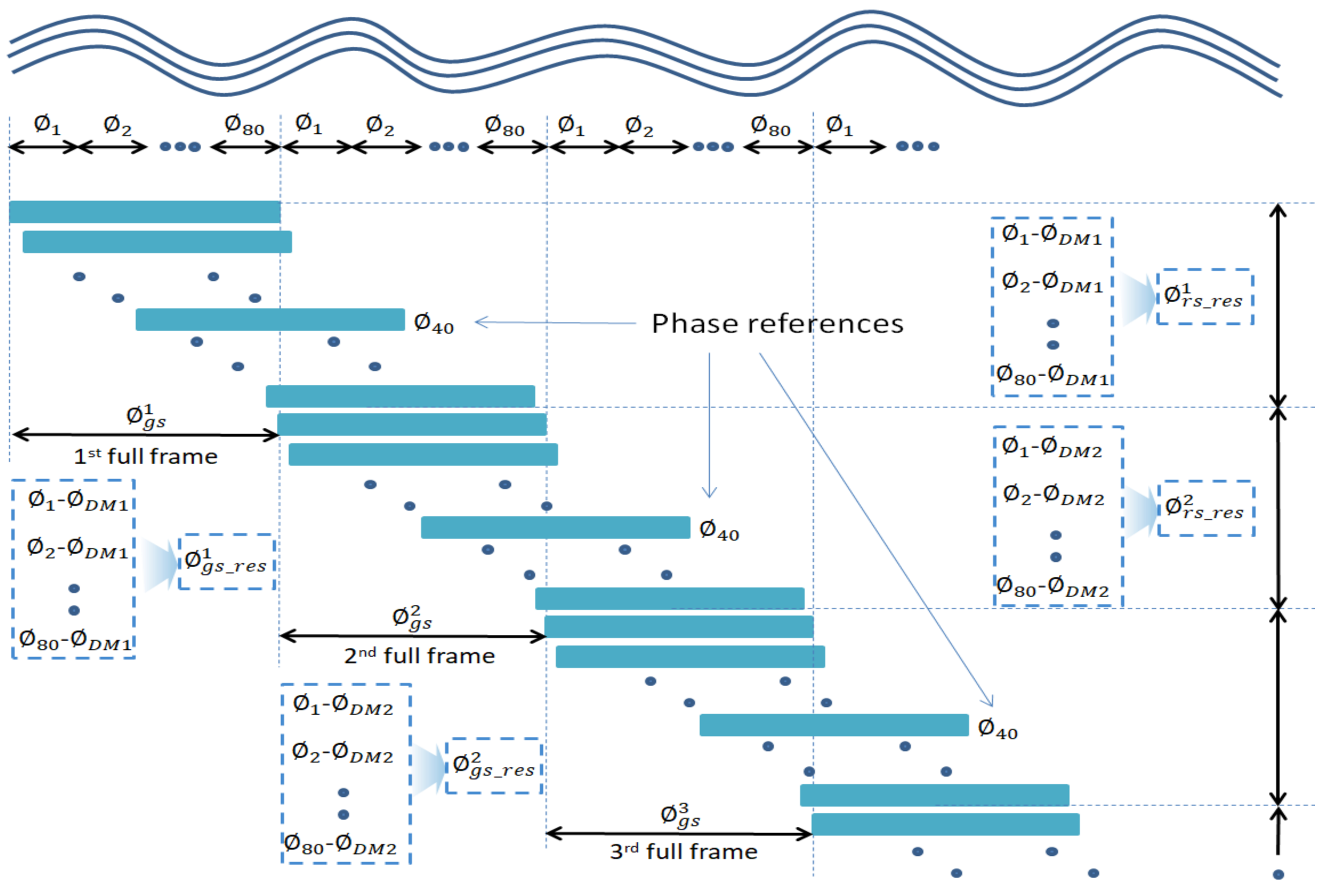


OL error for GS and RS scheme as a function of wind Speed

Global shutter vs. Rolling shutter



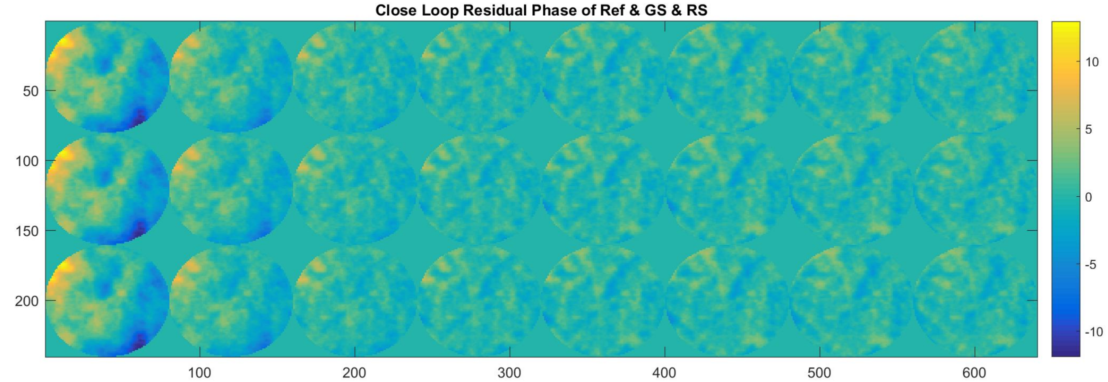
Close loop

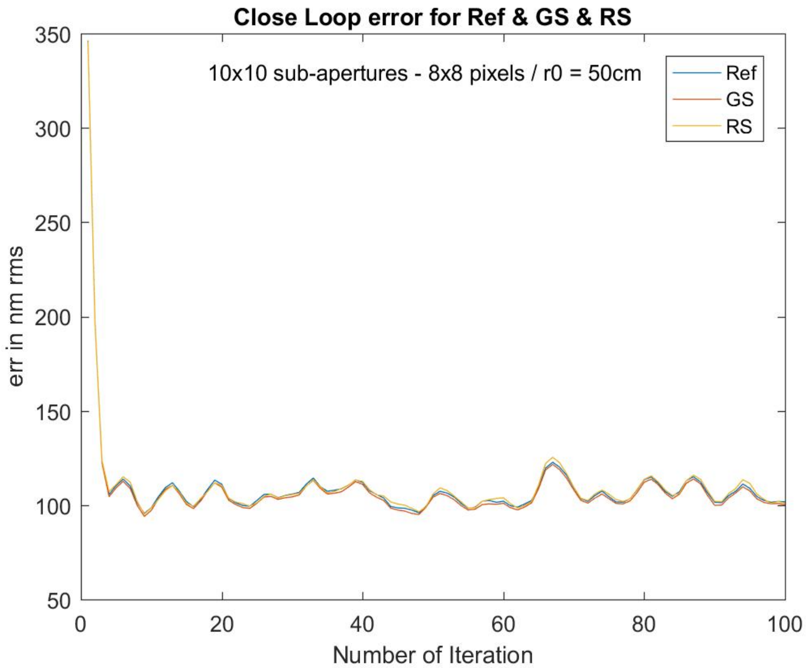


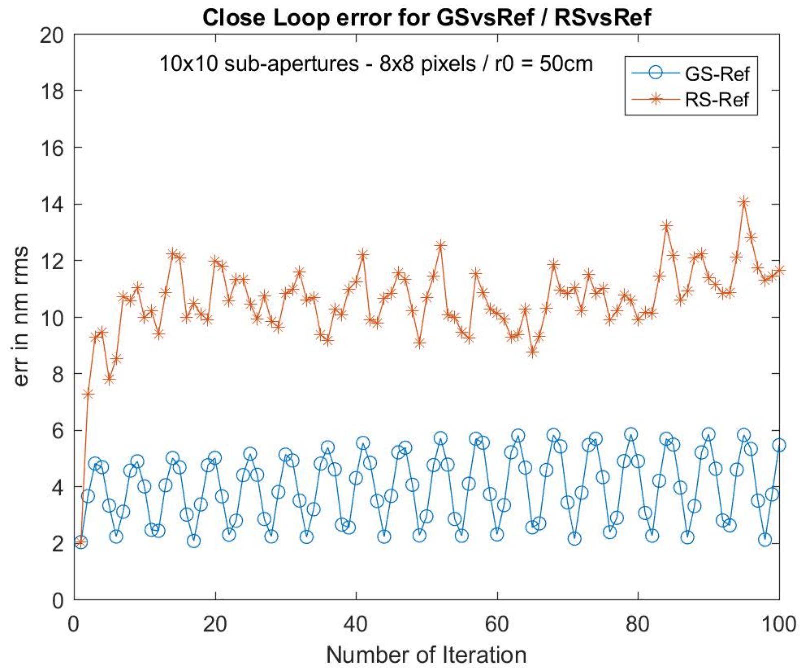
The schematic diagram of creating GS & RS phase

Global shutter vs. Rolling shutter

Close loop

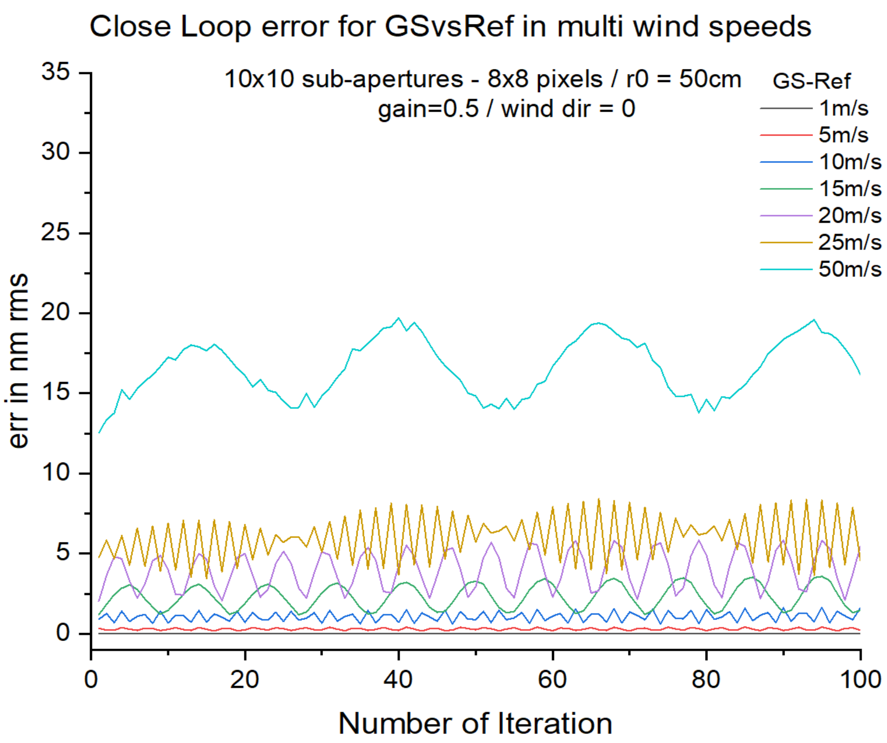


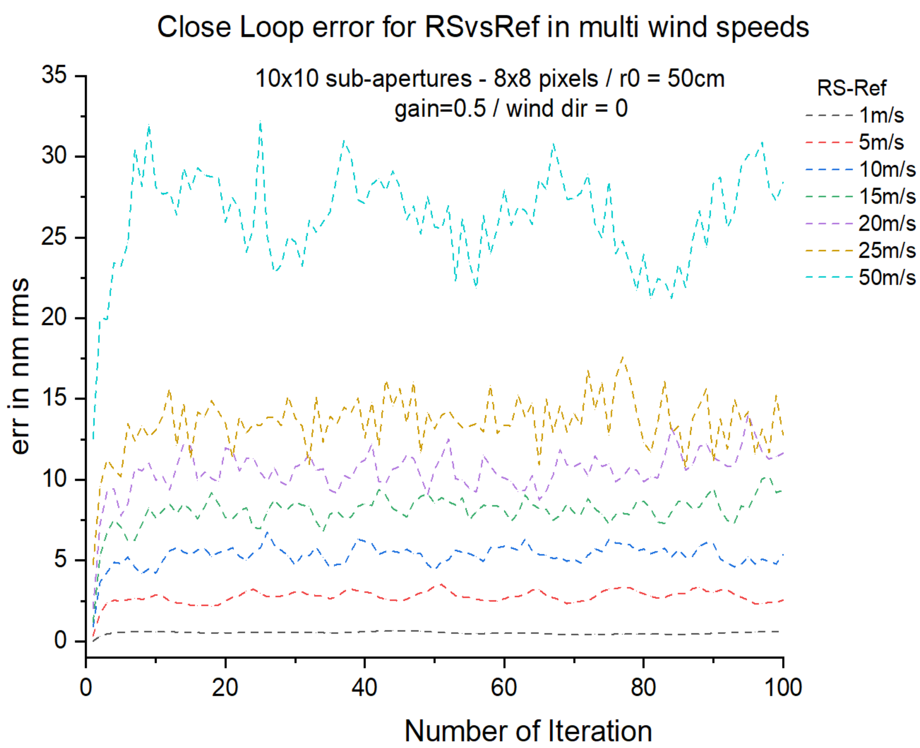




Global shutter vs. Rolling shutter

Close loop

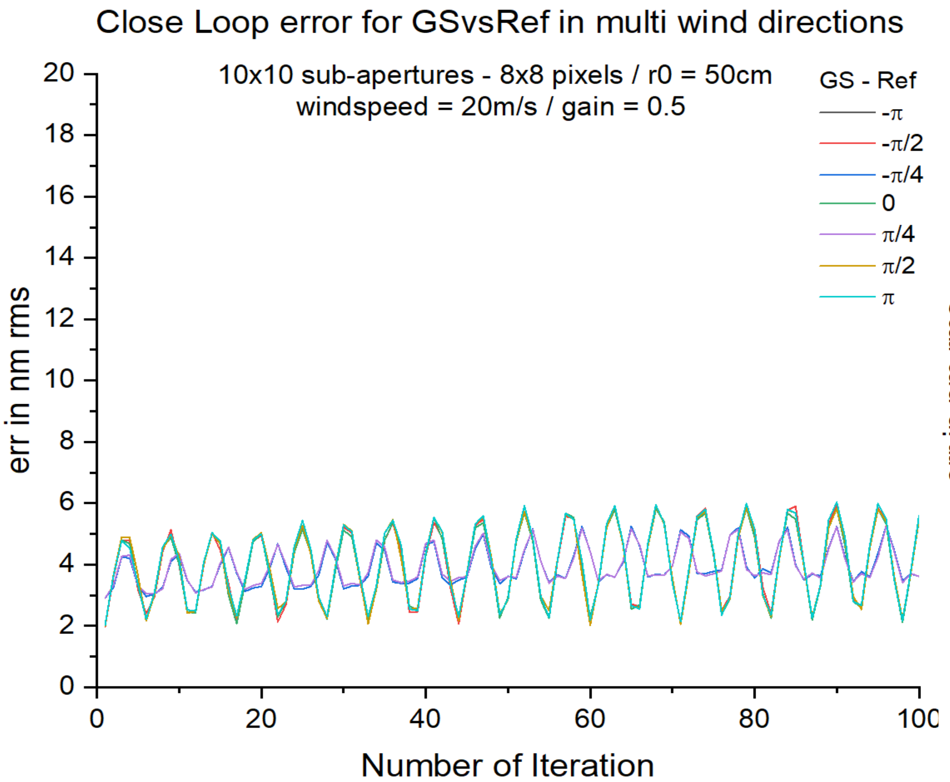


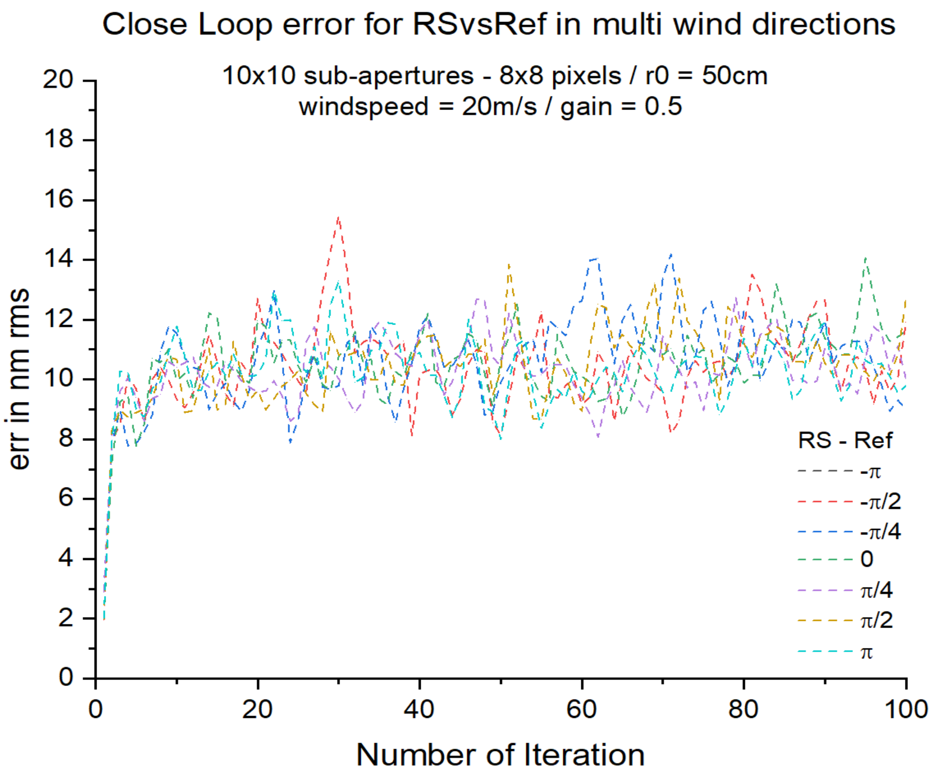


Single gain, single wind direction, multi wind speed

Global shutter vs. Rolling shutter

Close loop

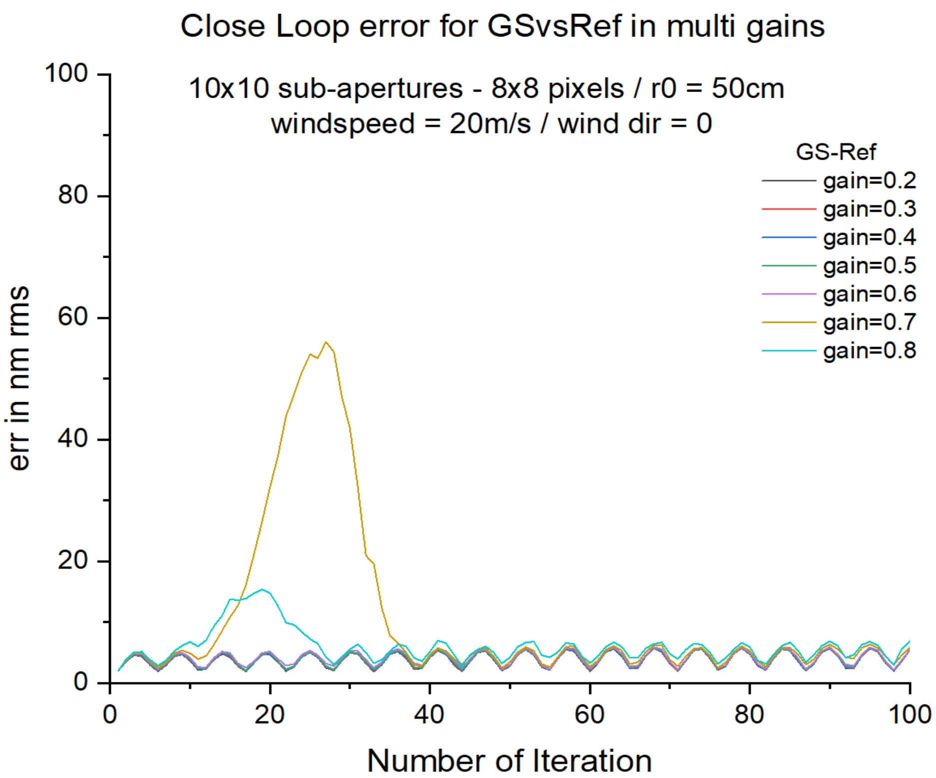


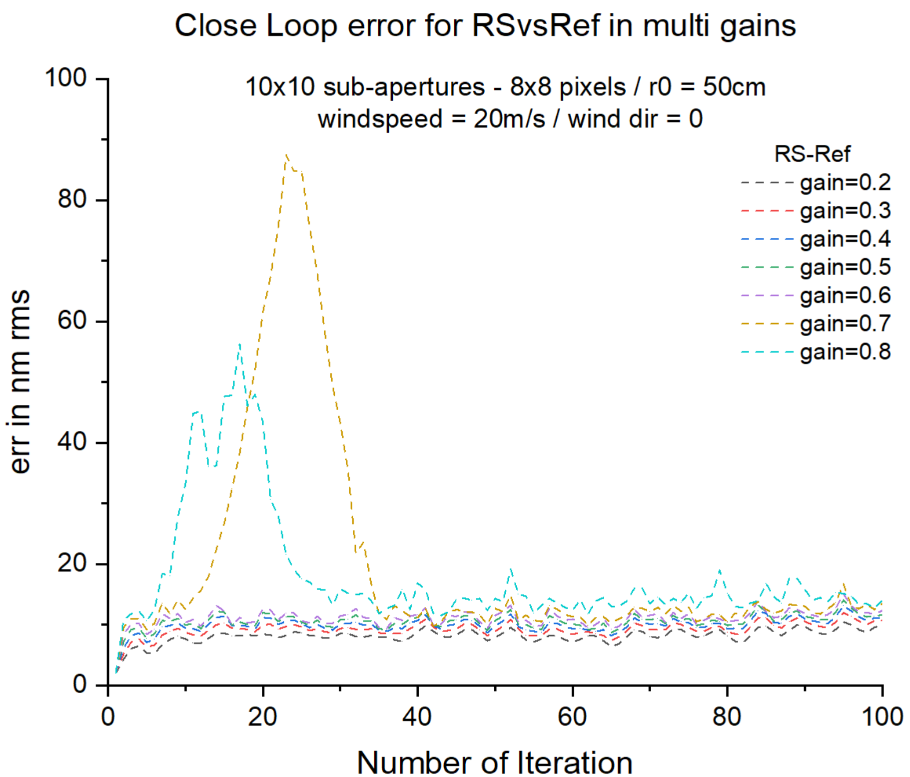


Single gain, multi wind direction, single wind speed

Global shutter vs. Rolling shutter

Close loop





Multi gain, single wind direction, single wind speed

Conclusions

Sensor characterization

Noise analysis

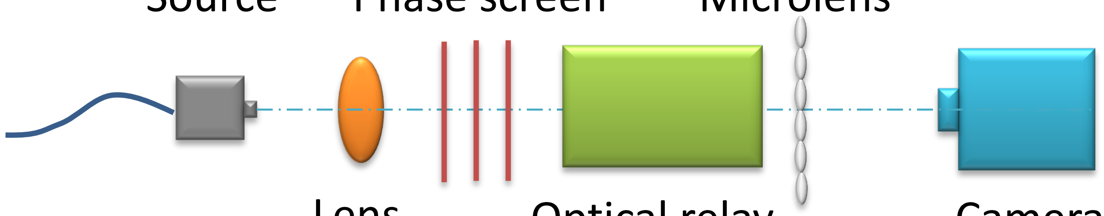
Angle of acceptance

Centroids variations

AO Simulation for shutter impact

Open loop

Close loop



2021.10

Bench work

Tomographic aspects

Thank you for your attention