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Centre for Advanced Instrumentation

MKID-based pyramid wavefront sensor, wavelength sensitivity detector for tracking optical gain

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Energy sensitive detector for PWFS?

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Influence of λ?

- Optical Gain : change with r_0 which change with λ
- Corrected PSF diameter
- Pupil dispersion
- Atmospheric dispersion

Uses of using λ-signals?

- Optical gain monitoring
- Chromatic super resolution
- Pupil dispersion : widening the useable bandpass

Without energy sensitive detector?

- Multiple WFS/Camera
- Complicates optics
- Only for few wavelengths

What we have done?

- PWFS module simulate energy sensitive detector
- Impact of the pupil dispersion (SPIE 2022)
- Initial parametric model to track optical gain (now)

Microwave kinetic inductance detector (MKID) for XAO

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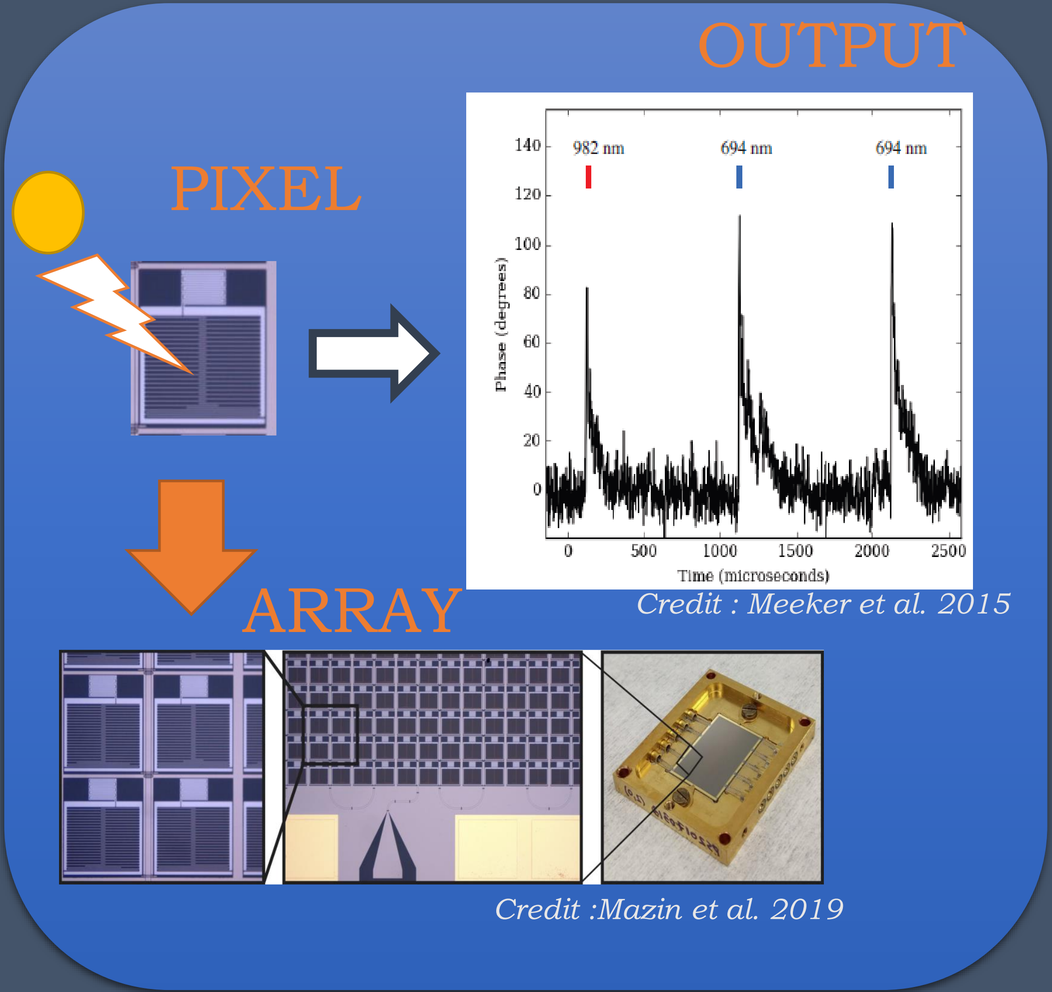
AO Requirements

- Every pixel is read out at **1MHz** independently in a continuous data stream
  - Match / exceed existing WFS detectors
- Number of pixels
  - MEC array : 20k
- Detection bandwidth demonstrated 400 nm to 1500[1] nm but no technical limits to go beyond

Additional features

- Energy sensitivity
  - Resolving power : R = 30
- Photon arrival time (to a microsecond)



Credit : Meeker et al. 2015

Credit :Mazin et al. 2019

[1] De Visser et al., 2021, DOI : 10.1103/PhysRevApplied.16.034051

How to simulate an MKID-based PWFS?

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Photon stream

- Sample / simulate the atmosphere at higher temporal resolution than the AO system update rate
- Modulation path can vary between frames
- Work in progress

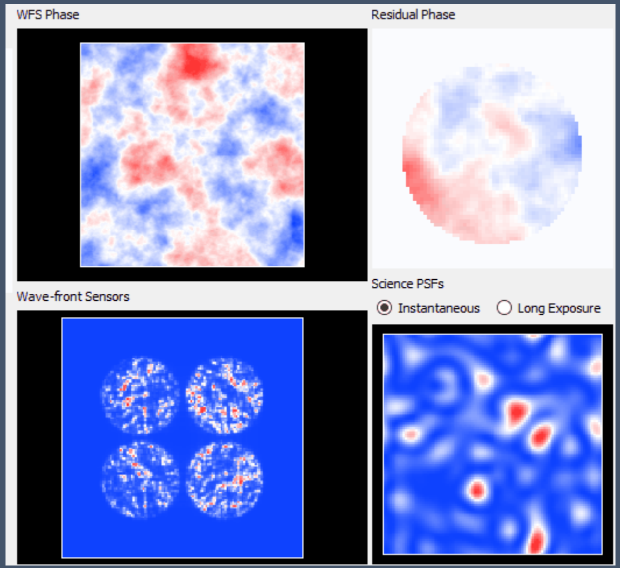
Wavelength sensitivity

- Run simultaneously at different wavelength
  - Fixed modulation radius
  - Same atmosphere
- Sampling according to the shortest wavelength

- Increase computation complexity

Soapy

- AO end-to-end simulation
- PWFS module update
- Available on Github : https://github.com/AOtools/soapy



Soapy's GUI

Motivation

Methods using energy sensitivity

- Chromatic super resolution
- Resolve pupil dispersion (SPIE)
- **Optical gain measurement**

Questions:

- What is the behaviour of the optical gain according to key parameters?
- Can we use the λ-measures to track this behaviour?

SPHERE like parameters

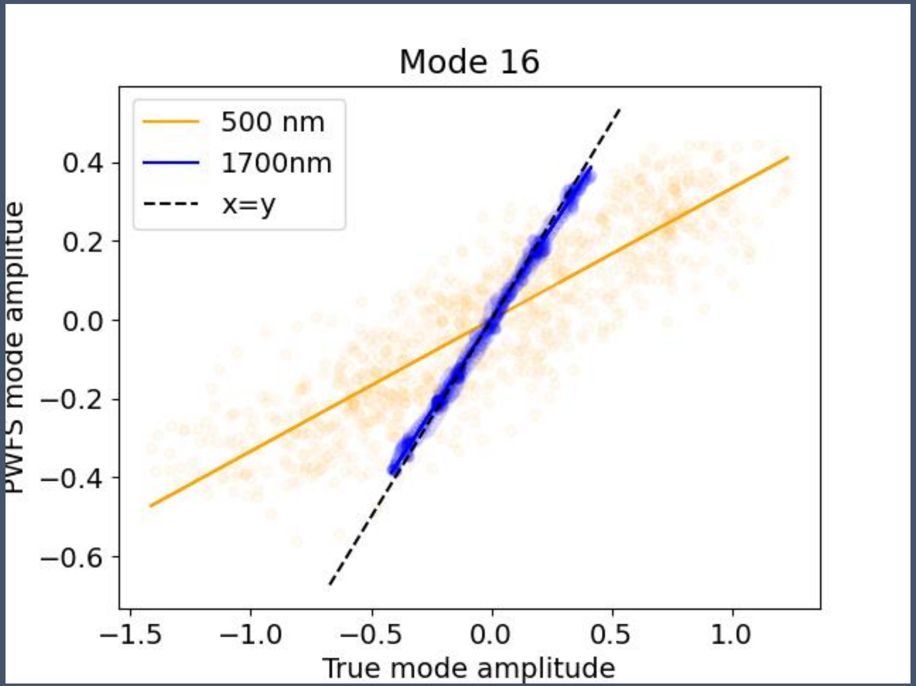
Name	Value
Pixels across pupil	40
Telescope Diameter	8 m
Frame latency	1
Frame rate	1kHz
Controlled modes	500

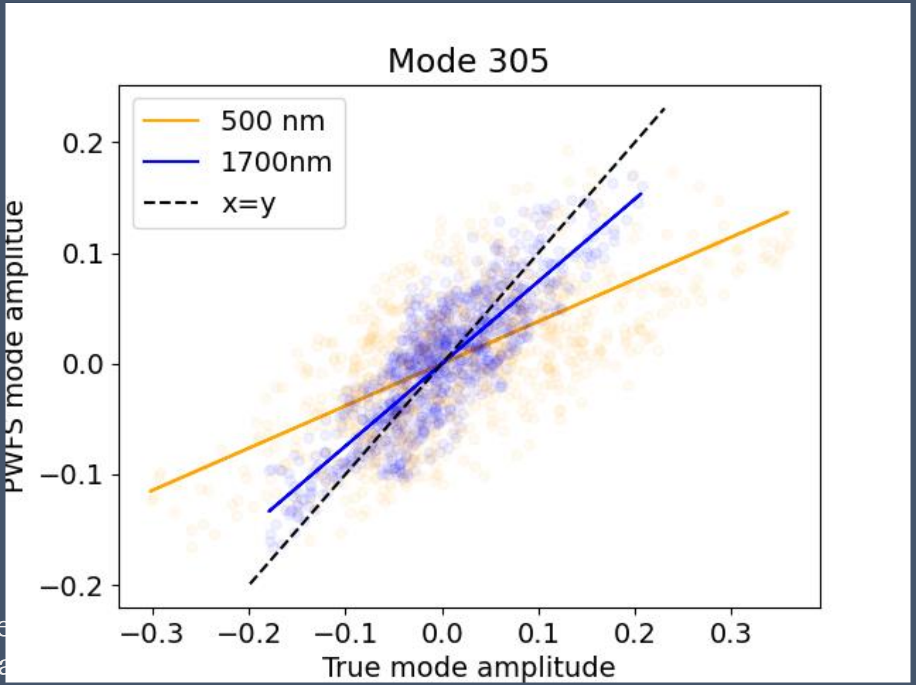
Measurement of optical gains (OG)

End-to-end simulation optical gain measure

1. Closed loop simulation
2. Decomposition of the PWFS input phase screen in KL modes
3. Plot amplitude measured vs true amplitude for each mode
4. Linear fitting : OG = slope coefficient

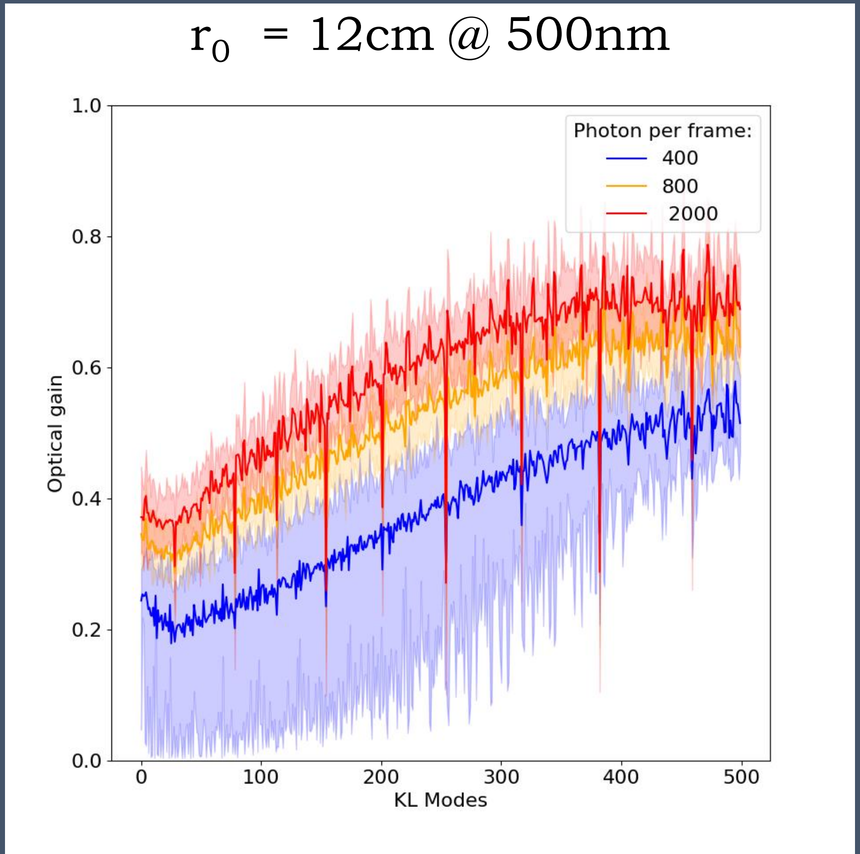
<u>Work in progress:</u> Compare with convolutional model

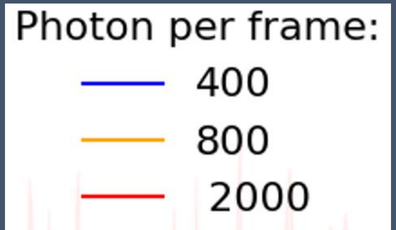


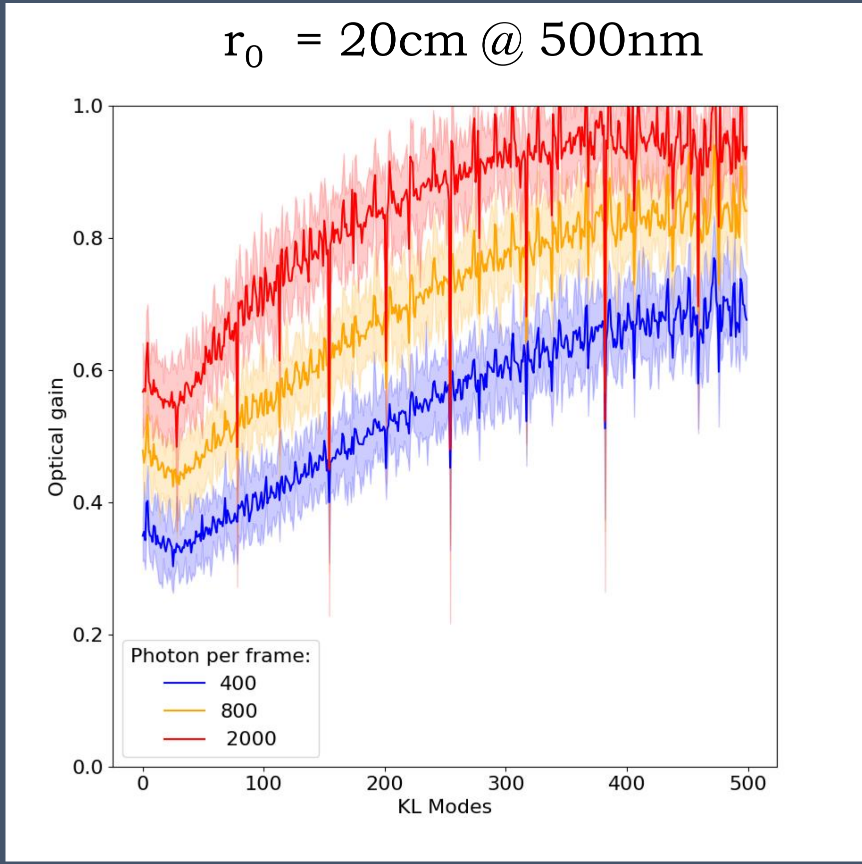


Optical gain behaviour : Photon noise and r_0

- Loop at 500 nm
- Optical gains increase with number of photons and r_0



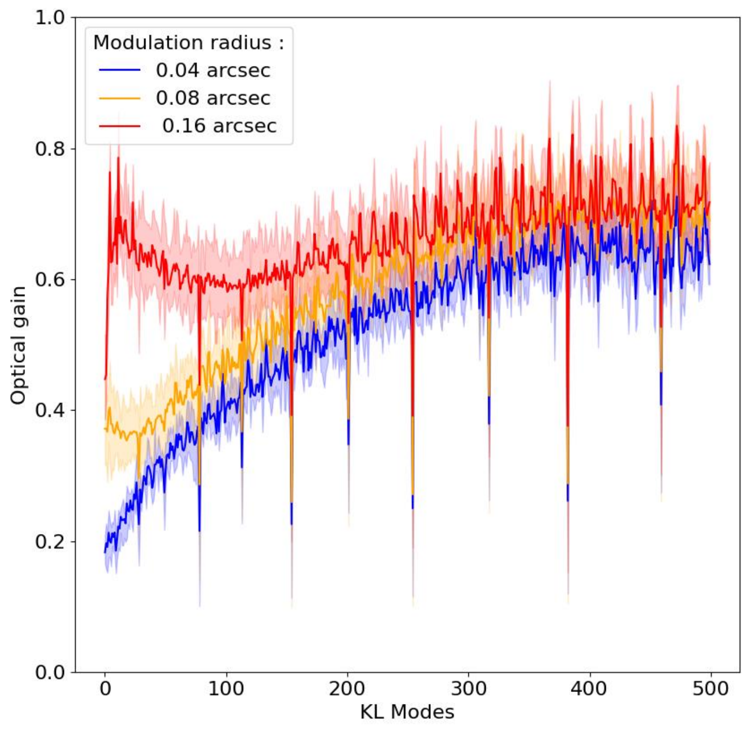


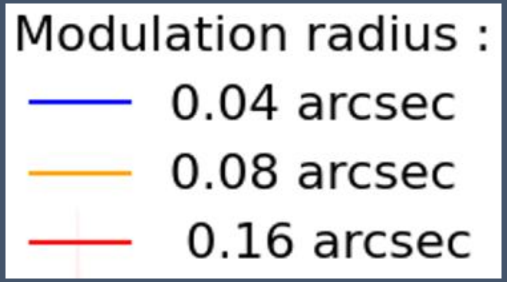


Optical gain behaviour : Modulation radius

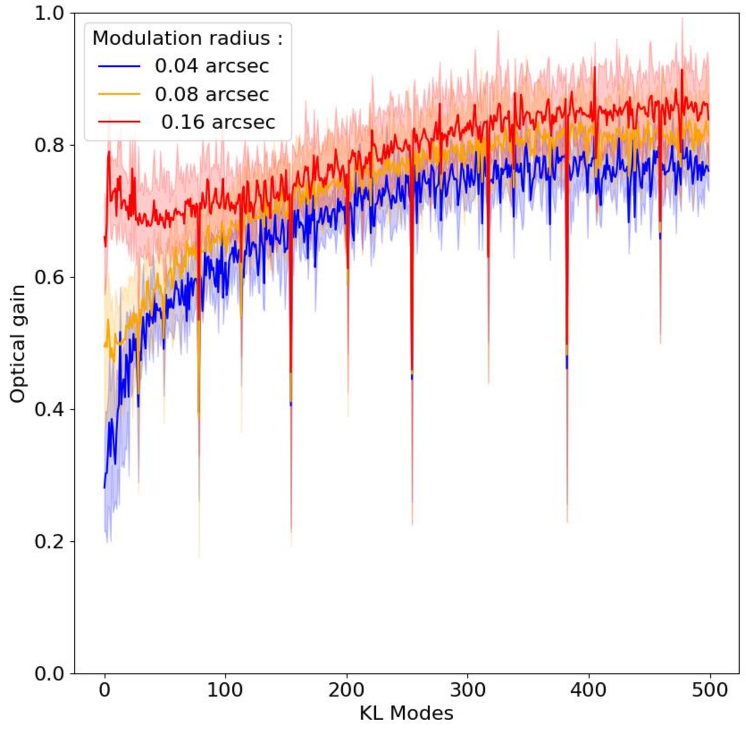
- Modulation radius change the dip in the mode space
- Dip changed at different wavelength : dip influenced by λ/modulation radius

Loop at 500nm



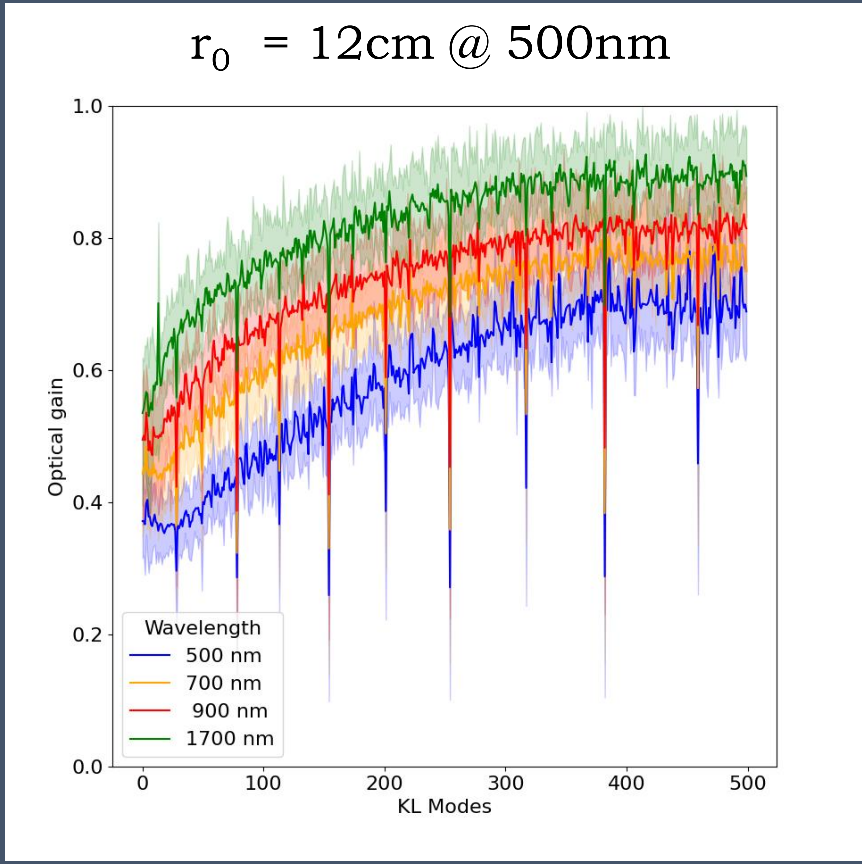


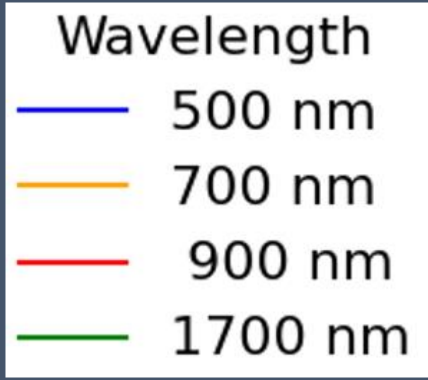
Loop at 900nm

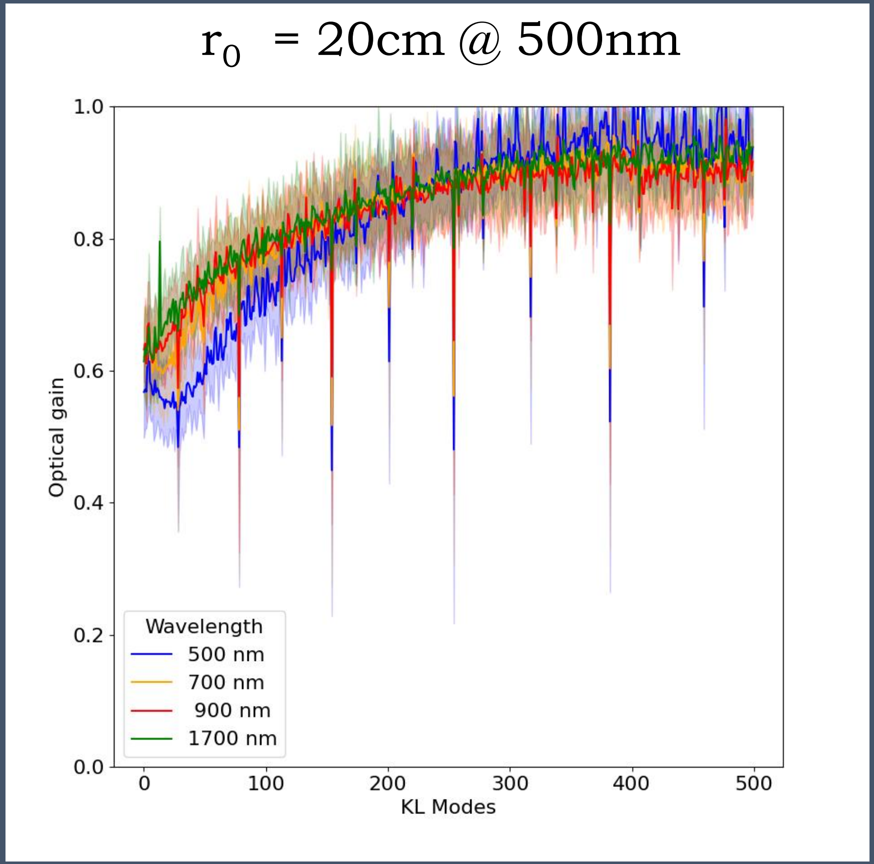


Optical gain behaviour : Wavelength

- Change in the dip : influenced by the ratio wavelength / modulation radius
- r_0 influences the ratio between OG at different







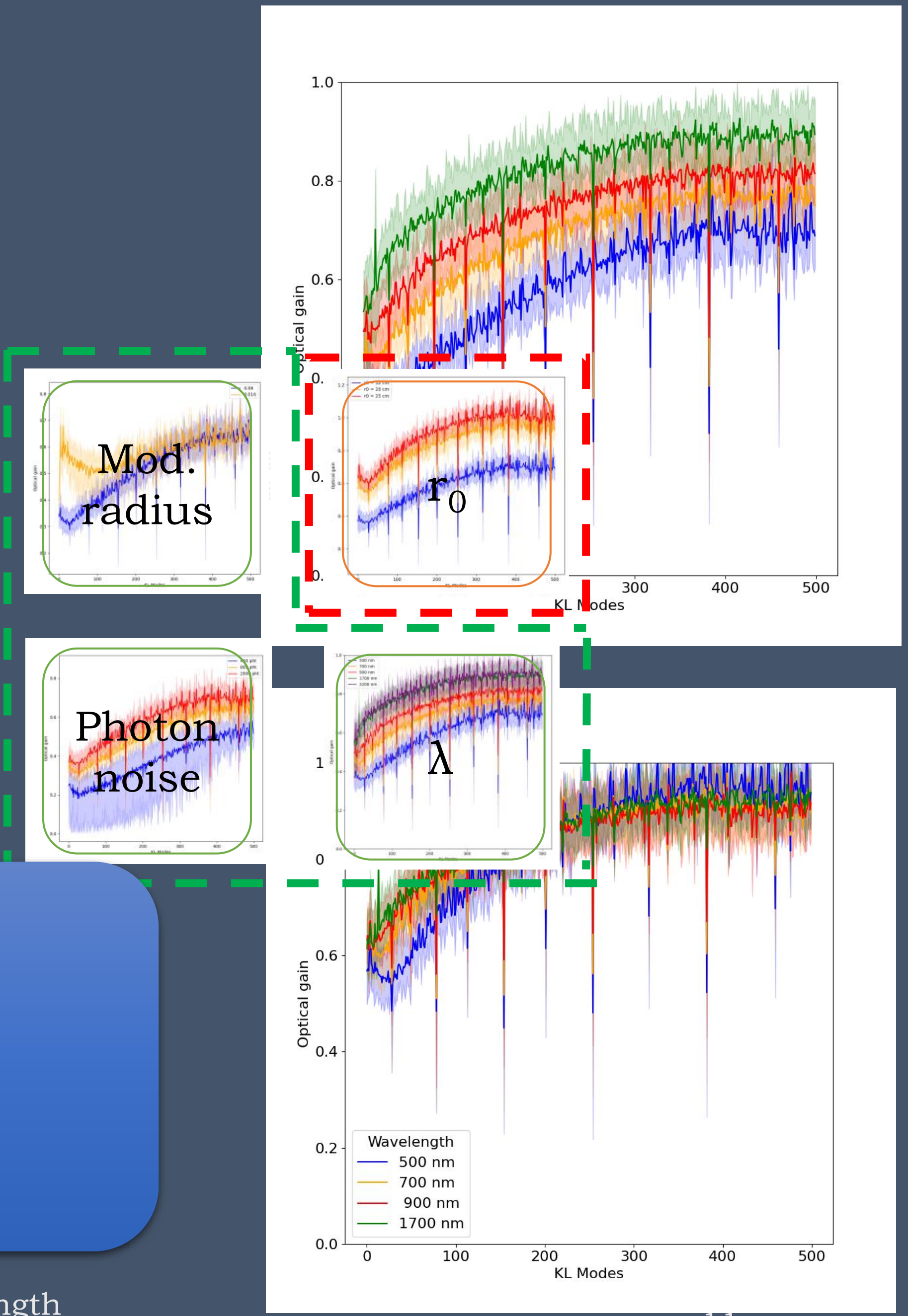
We don’t have the OG…

… we have the KL decomposition of the wavefront at different λ

OG modelisation?

➢ We need r_0 !

Ratio of the OG at different λ different for different r_0



1. Can the ratio of the PWFS measurements at different λ be linked to OG ratios?
2. Can we measure r_0 from these ratios to generate optical gain curves?

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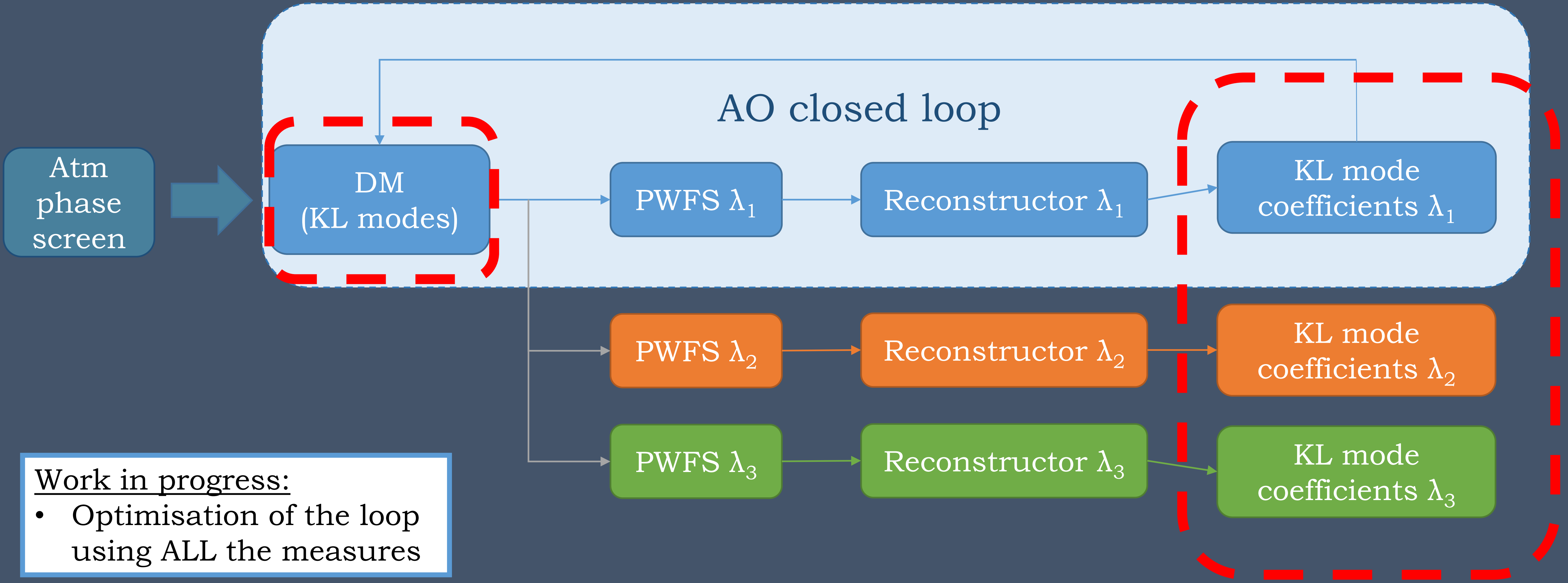
Simulation configuration

Data available on sky

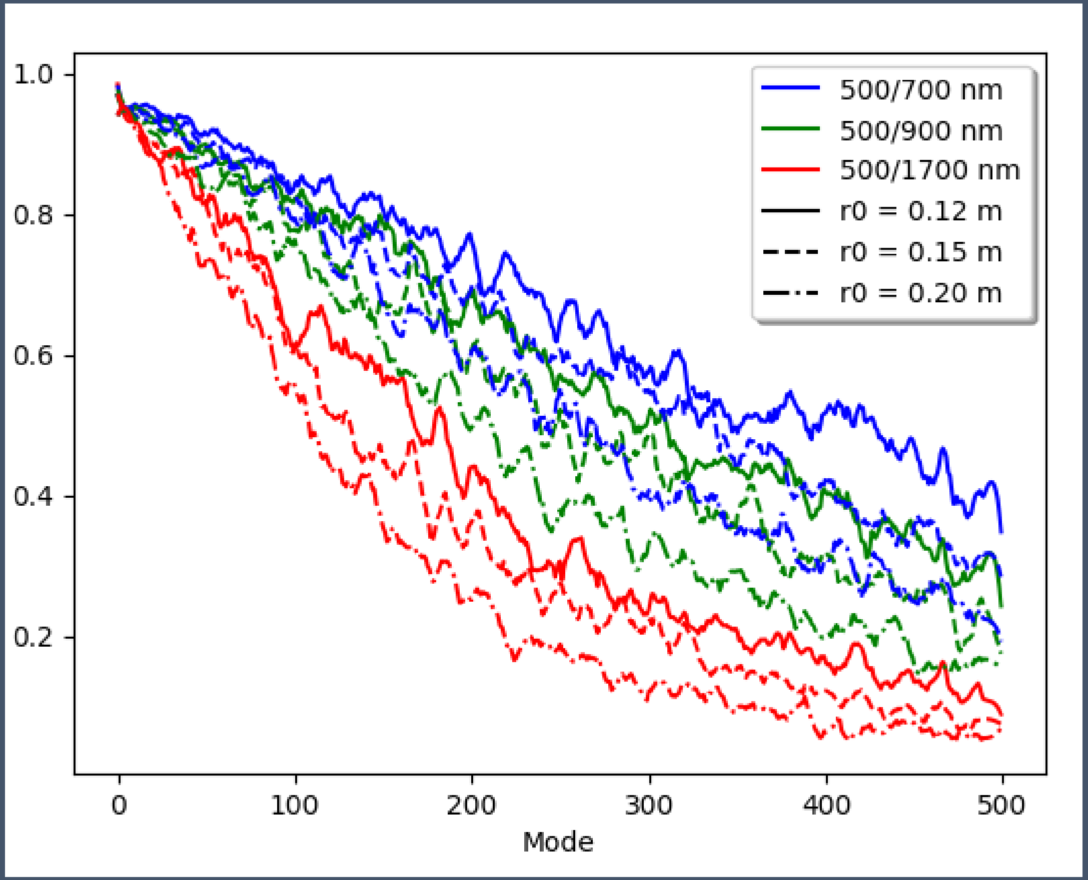


Work in progress:
- Optimisation of the loop using ALL the measures

MKID output : let's use it!

- Loop closed at 500 nm
- Pseudo open loop output (DM command + measure of the residuals by the PWFS) of the different PWFS
  - For different wavelength
  - At different r_0

Ratios



<u>Work in progress:</u>
- Close the loop at higher wavelength
- Understand more theoretically this behaviour.

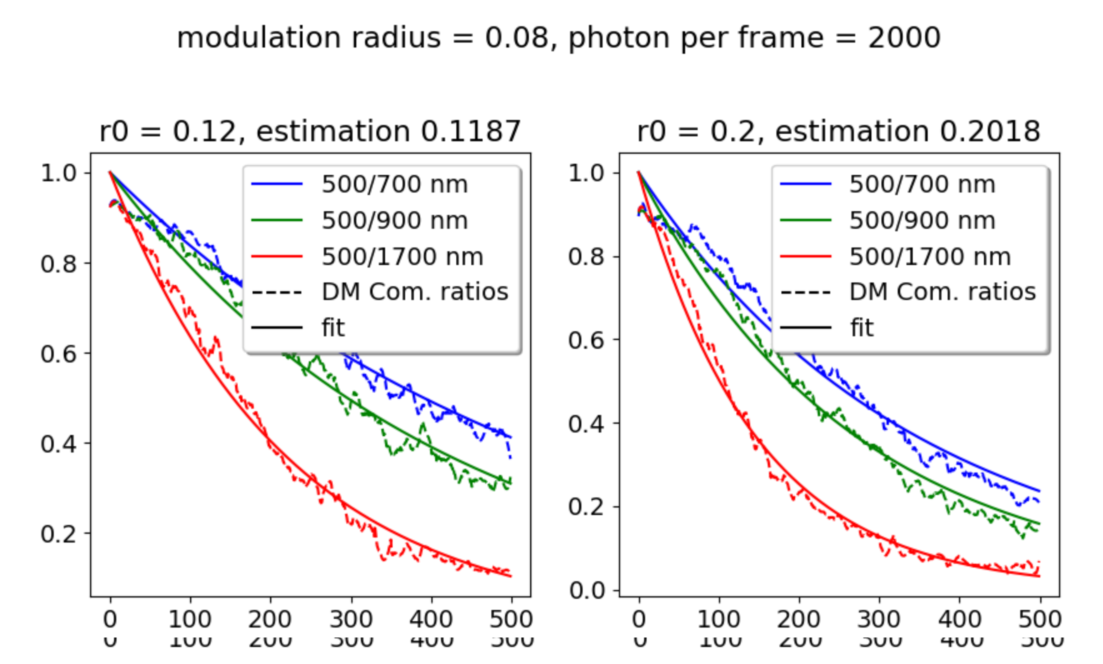
Parametric model : retrieve r_0

- Separation of the curves per r_0
- Fit of the curves

$$y = \frac{1}{exp^{ax}}$$

- Determination of a

$$a = \frac{\lambda_1}{\lambda_2} * C1 * r_0 + C2 * r_0 + C3 * \frac{\lambda_1}{\lambda_2} + \mathrm{C4}$$



r_0	Measured r_0
0.12	0.1187
0.15	0.1507
0.2	0.2018
0.25	0.2486

Parametric model : retrieve r_0

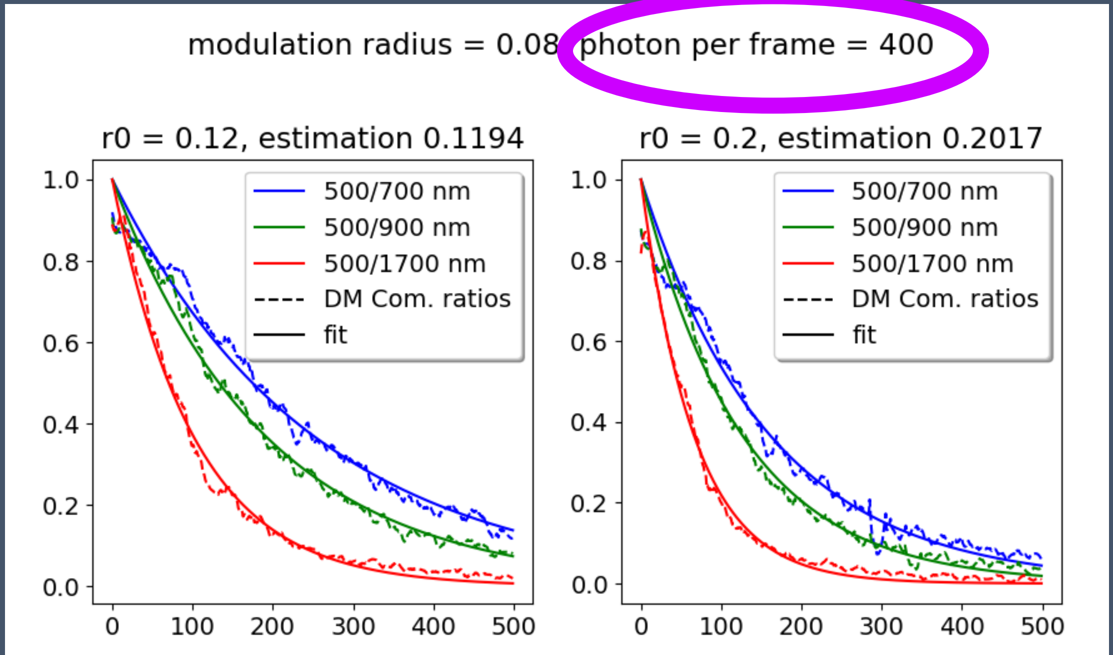
- Separation of the curves per r_0
- Fit of the curves

$$y = \frac{1}{exp^{ax}}$$

- Determination of a

$$a = \frac{\lambda_1}{\lambda_2} * C1 * r_0 + C2 * r_0 + C3 * \frac{\lambda_1}{\lambda_2} + C4$$

- Works with fewer photons

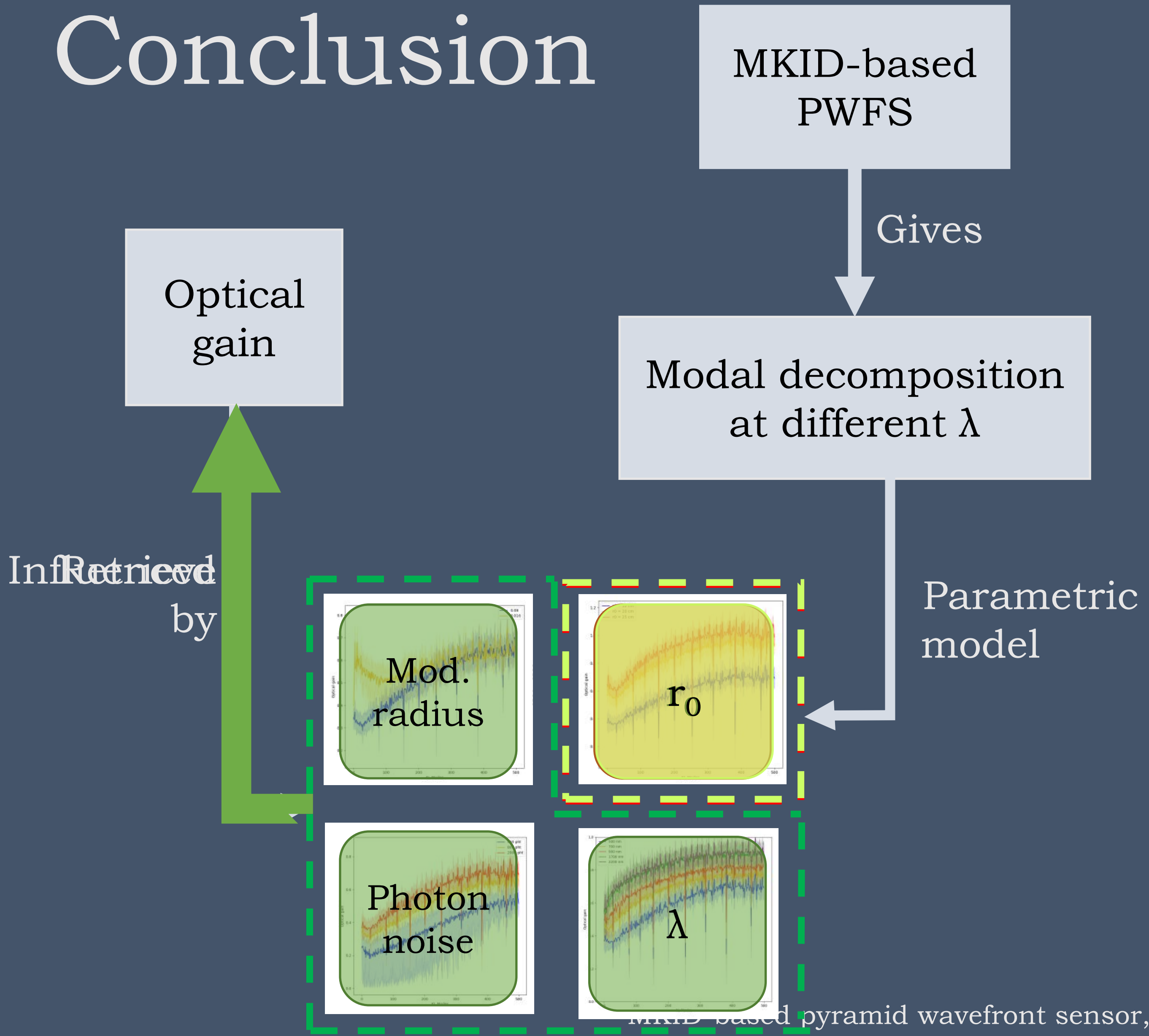


r_0	Measured r_0	Measured r_0 (less photons)
0.12	0.1187	0.1194
0.15	0.1507	0.1498
0.2	0.2018	0.2017
0.25	0.2486	0.2491

Work in progress:

- Change of the constants with the noise and other parameters: TBD
- Sensitivity of the model?

Conclusion



- End to end simulation shows parameters influence on OG
- Unknown in our system : r_0

- MKID : measure at different wavelength
- Parametric model : estimation of r_0

Next:

- Sensitivity of constants in the parametric model
- Optical gain model
- Optical gain compensation
- Go to the lab!!

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Thank you

Soapy :
https://github.com/AOtools/soapy