Overview of the AO calibration strategies in the ELT context

Cedric, Taïssir HERITIER

LAM: **B. Neichel,** C. Correia, C. Bond, O. Fauvarque
ONERA: **T. Fusco,** J-F. Sauvage
INAF-Arcetri: **S. Esposito,** E. Pinna, G. Agapito, A. Puglisi
ESO**: S. Oberti**, P-Y. Madec, J.Kolb

Outlines

1. AO calibration in the ELT context
2. Numerical Simulations Tools
3. On-Sky Interaction Matrix: LBT Method
4. Pseudo-Synthetic Interaction Matrix: AOF Method
5. An ELT Calibration Strategy

AO Calibration in the ELT context

AO Calibration

- **Interaction Matrix:** Calibrate the link between the Wave Front Sensor (WFS) signals and the Deformable Mirror (DM) actuators.
- **NCPA:** Non Common Path Aberration.

AO Calibration in the ELT context

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ELT case:

- **No calibration source upward M4!**
- M4: Non-Fried Geometry
- Location of the DM => Mis-Regitrations (Shifts, Rotation, Magnification).
- ~5000 Actuators: Time to calibrate the system? Time to update the calibration?
- Complex model of WFS

AO Calibration in the ELT context

AO Calibration

- **Interaction Matrix:** Calibrate the link between the Wave Front Sensor (WFS) signals and the Deformable Mirror (DM) actuators.
- **NCPA:** Non Common Path Aberration.

ELT case:

Optimization of the calibration procedures is necessary!

On-Sky Interaction Matrix?

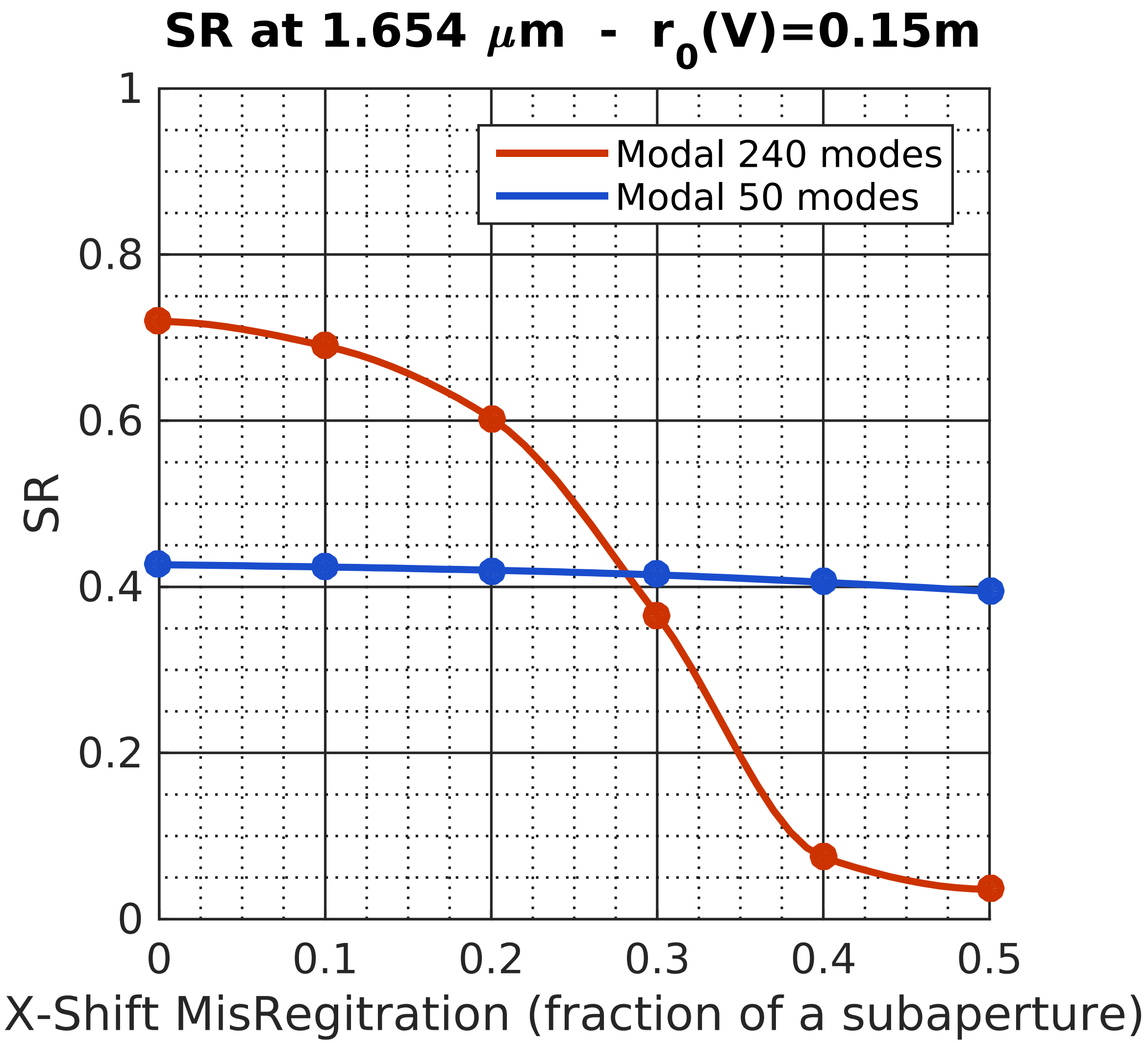
Pseudo-Synthetic Interaction Matrix?

Mis-Registration Effect

OOMAO[1]:

Object-Oriented Matlab Adaptive Optics

- **SCAO**
- **NGS**
- **Pyramid WFS**
- **r0=0.15m**
- **8m Telescope**
- **16x16 subapertures**
- **DM pitch: 50 cm**
- **KL Modal Basis**
- **500 Hz**



[1]R.Conan & C.Correia

On-Sky Interaction Matrix: LBT Method

Method developed at the LBT on FLAO.

Goal:

Modulate a mode on the DM with a sinusoid signal and retrieve the corresponding slopes maps through a demodulation process.

⇒We get rid of the turbulence!

1. S. Esposito ; R. Tubbs ; A. Puglisi ; S. Oberti ; A. Tozzi ; M. Xompero and D. Zanotti, ***"High SNR measurement of interaction matrix on-sky and in lab"***, Proc. SPIE, (2006).
2. S. Oberti ; F. Quirós-Pacheco ; S. Esposito ; R. Muradore ; R. Arsenault ; E. Fedrigo ; M. Kasper ; J. Kolb ; E. Marchetti ; A. Riccardi ; C. Soenke and S. Stroebele, ***"Large DM AO systems: synthetic IM or calibration on sky?"***, Proc. SPIE, (2006).
3. F. Pieralli; A. Puglisi; F. Quirós-Pacheco; S. Esposito, ***"Sinusoidal calibration technique for Large Binocular Telescope system"***, proc. SPIE (2008)
4. E. Pinna; F. Quirós-Pacheco; A. Riccardi; R. Briguglio; A. Puglisi; L. Busoni; C. Arcidiacono; J. Argomedo; M. Xompero; E. Marchetti; S.Esposito, ***"First on-sky calibration of a high order adaptive optics system"***, Proc. SPIE, (2012).

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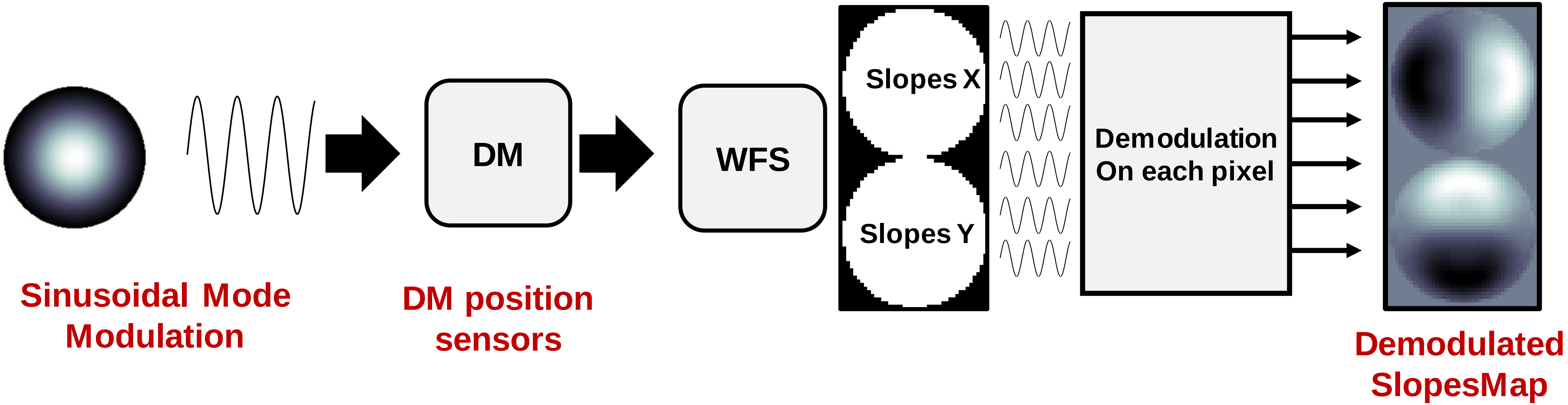


On-Sky Interaction Matrix: LBT Method

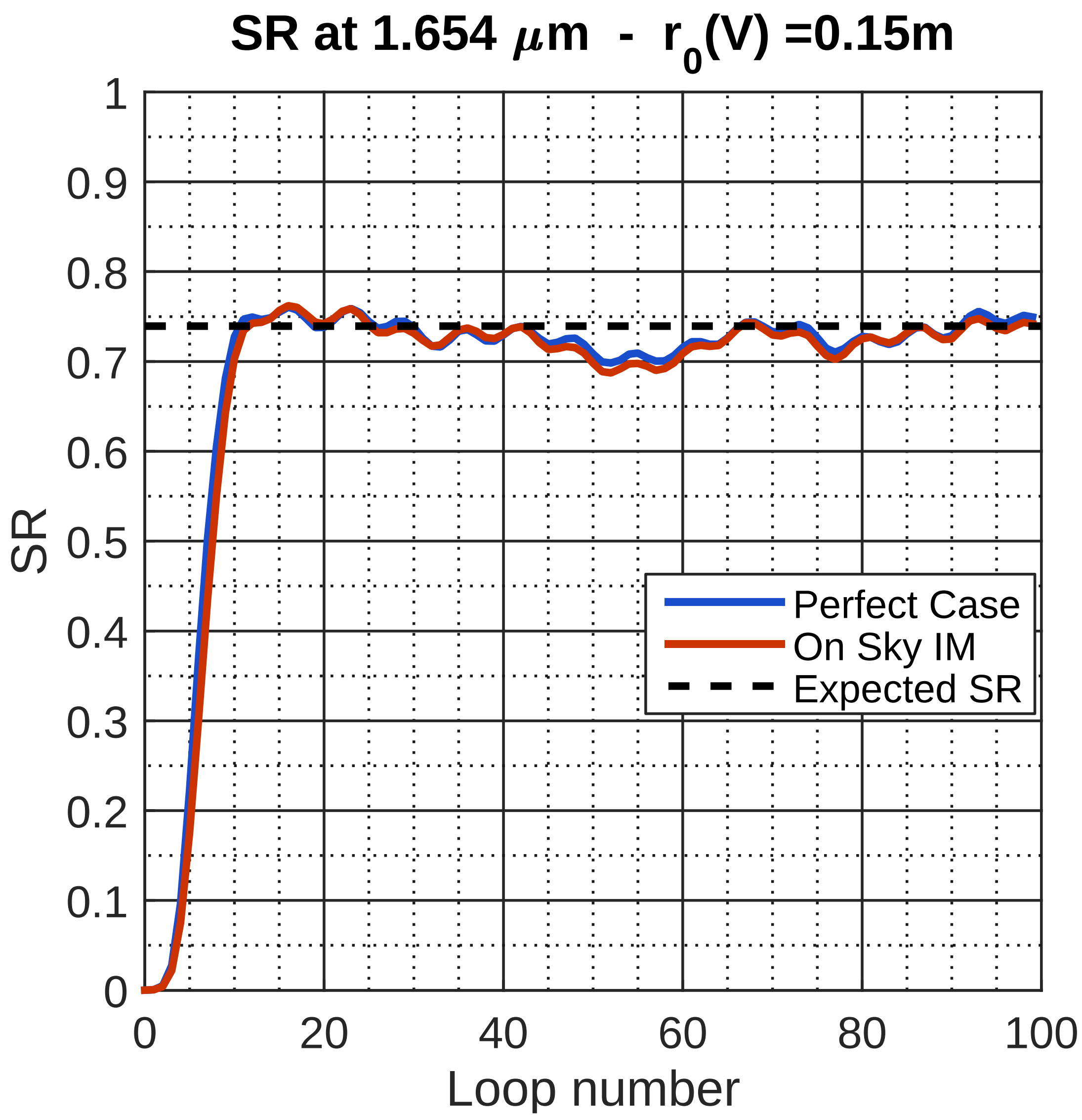
First Numerical Results: Validation

Perfect IM: No Noise, No Turbulence.

On Sky IM: Retrieved On Sky with Noise.

NO Mis-Registration!

- r_0: 0,15 m (V)
- f_{mod}: 200-208 Hz
- 150 Modes
- **Multiplexing:** 5 modes
- **WFS camera RON**: 0.1 e-
- **WFS camera Photon Noise**: On
- **NGS Magnitude:** 8



On-Sky Interaction Matrix: LBT Method

First Numerical Results:

IM Not Shifted: No Noise, No Turbulence, No shift.

IM Shifted: No Noise, No Turbulence, System shifted

On Sky IM: Retrieved On Sky

25% of a subaperture Shift!

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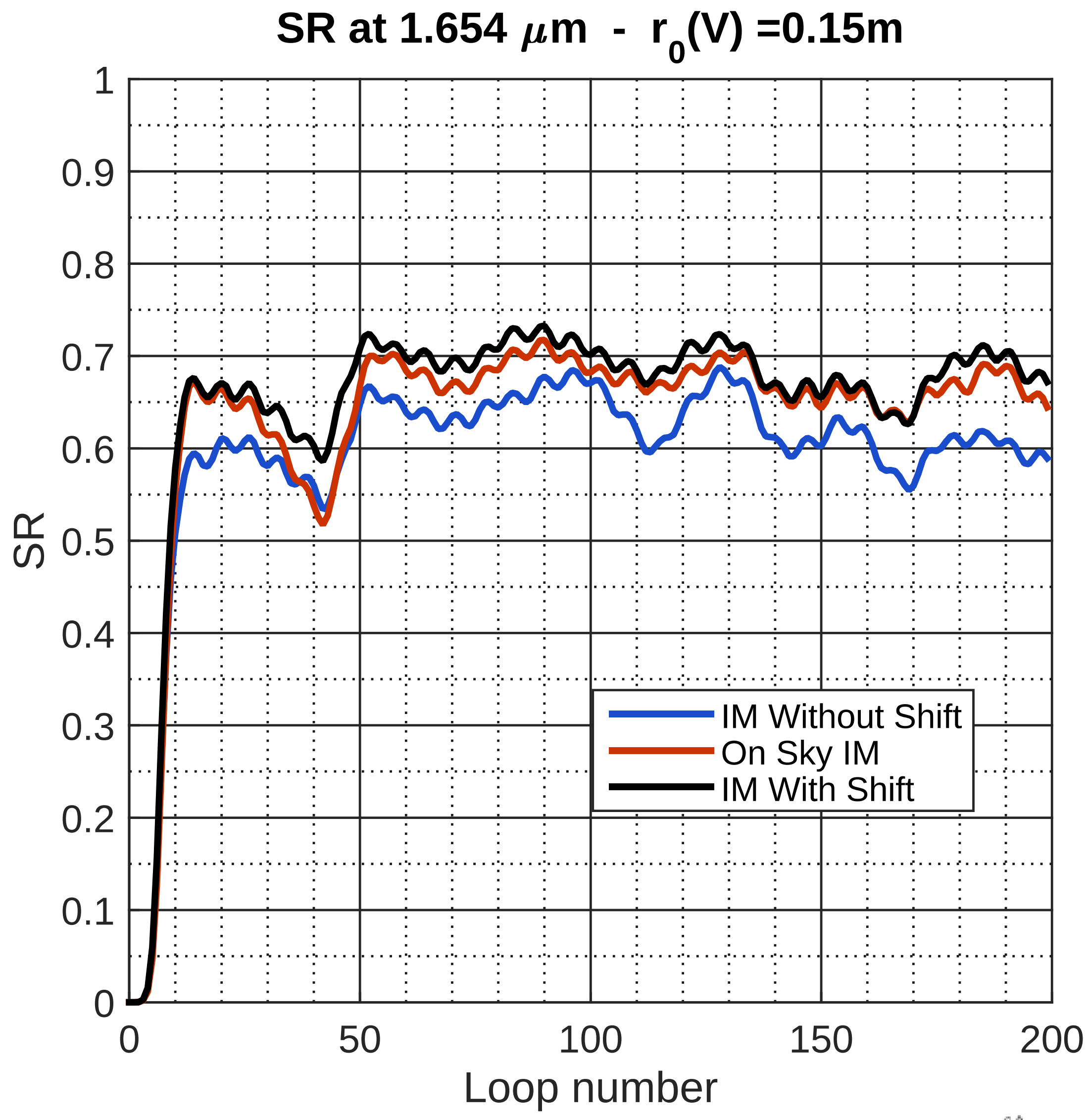


On-Sky Interaction Matrix: LBT Method

A trade-off has to be made!

ON GOING

- Multiplexing?
- Mode Amplitude?
- Frequency Optimization?
- Sampling vs SNR?

Pseudo-Synthetic Interaction Matrix: AOF Method

Method developed at the VLT on the AOF based on a PSIM:

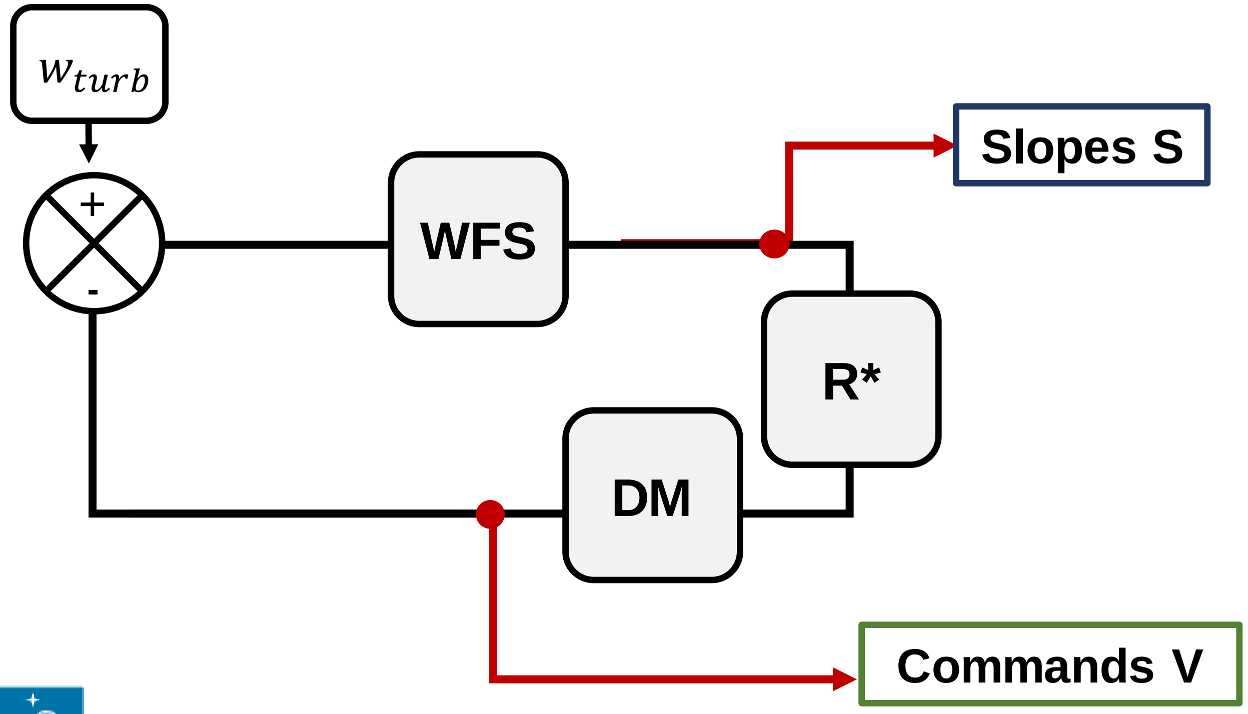
- DM model
- **Mis-Registration parameters**
- WFS model

1. Kasper, M., Fedrigo, E., Looze, D., and Bonnet, H., ***"Fast calibration of high-order adaptive optics systems"***, JOSA-A 21, 2004).
2. J.Kolb, P.-Y. Madec**,** M.Le Louarn, N.Muller, C. Béchet,***"Calibration strategy of the AOF"***, Proc. SPIE, (2006).
3. S. Oberti ; F. Quirós-Pacheco ; S. Esposito ; R. Muradore ; R. Arsenault ; E. Fedrigo ; M. Kasper ; J. Kolb ; E. Marchetti ; A. Riccardi ; C. Soenke and S. Stroebele, ***"Large DM AO systems: synthetic IM or calibration on sky?"***, Proc. SPIE, (2006).
4. C. Béchet, J. Kolb, P.-Y. Madec, M.Tallon, E. Thiébaut, ***"Identification of system misregistrations during AO-corrected observations"***, Proc. AO4ELT2 (2011)
5. C.Béchet, M. Tallon, E.Thiébaut, ***"Optimization of adaptive optics correction during observations: Algorithms and system parameters identification in closed loop"***, proc. SPIE (2012)
6. J. Kolb, P. Martinez, J.H.V. Girard, ***"What can be retrieved from adaptive optics real-time data"***
7. J. Kolb, ***"Review of AO calibrations, or how to best educate your AO system"***, Proc. SPIE, (2016).

Pseudo-Synthetic Interaction Matrix: AOF Method

Mis-Registration Identification:

Goal: Retrieve a noisy Interaction Matrix using closed-loop data that allows to retrieve Mis-Registrations parameters.



$$S_k = -IM(p).V_k + z_k$$

$$\delta S_k = S_{k+1} - S_k = -IM(p).\delta V_k + \delta z_k$$

If we get rid of δz_k: $IM(p) = \frac{\delta S_k}{\delta V_k}$

Pseudo-Synthetic Interaction Matrix: AOF Method

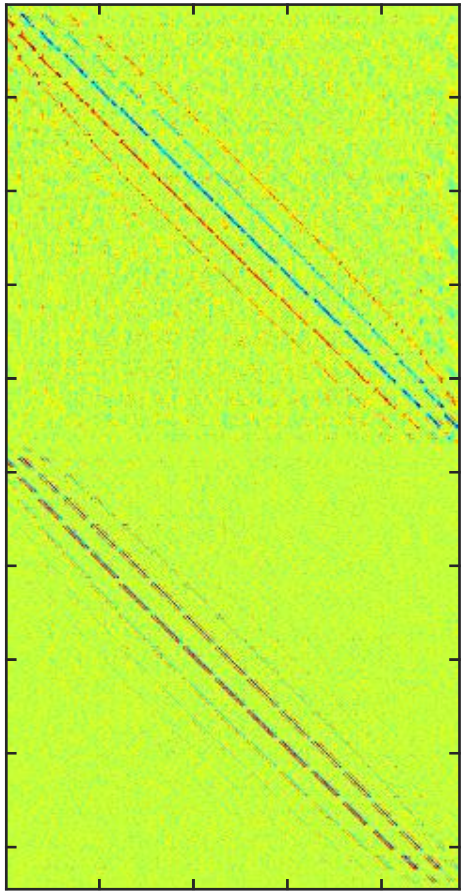
Mis-Registration Identification

ON GOING

1) Build a catalog of “Sensitivity IM”: $\delta IM_x, \delta IM_y, \delta IM_{rot}$ ...

2) Retrieve a noisy estimation of the IM and project it on the IM_0 and the δIM:

$$\alpha_0,\ \alpha_x,\ \alpha_y, \alpha_{rot}, \dots$$



3) Update the synthetic IM:

$$IM^* = \alpha_0 IM_0 + \alpha_x \delta IM_x + \alpha_y \delta IM_y + \alpha_{rot} \delta IM_{rot} + \cdots$$

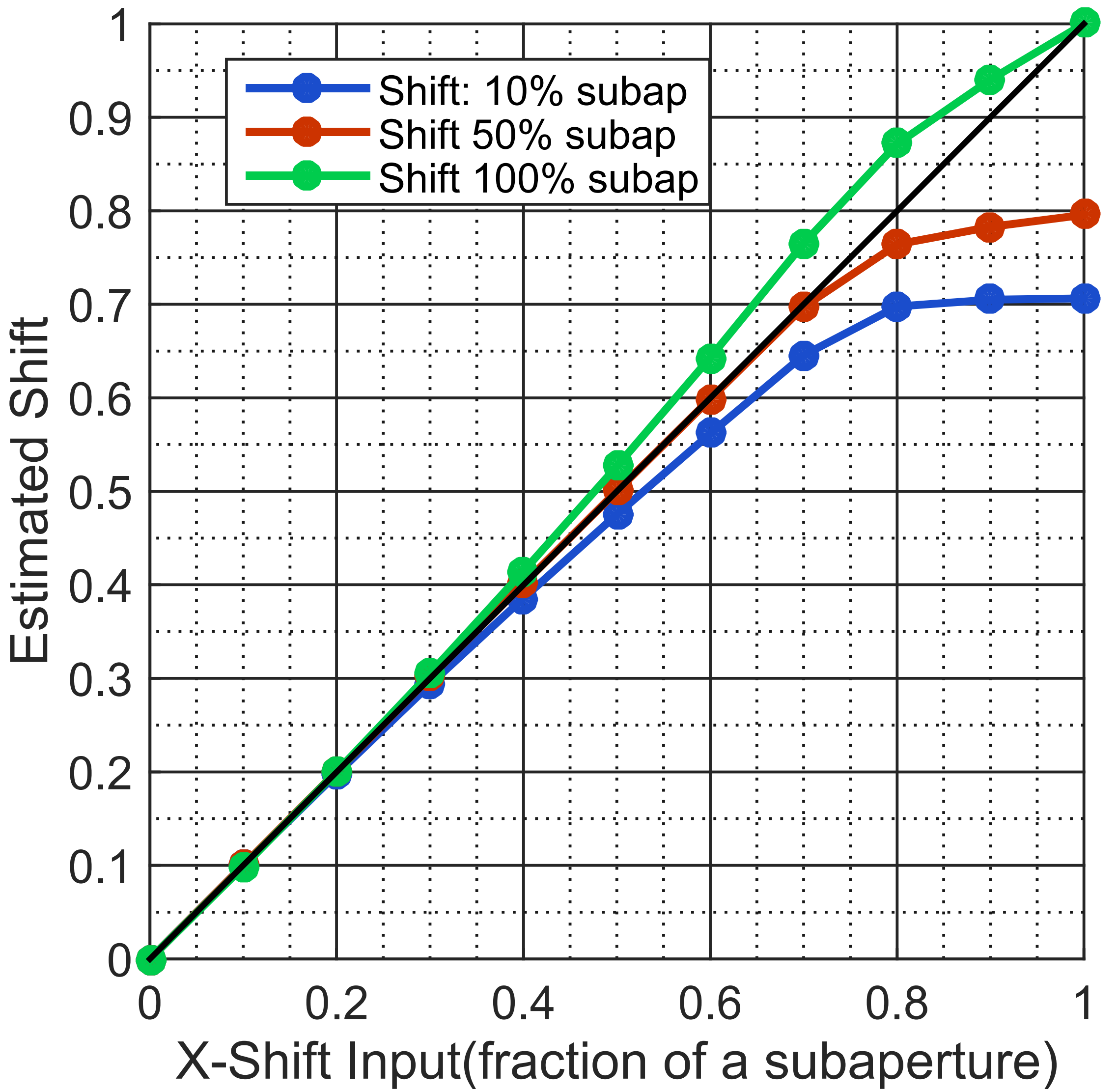
Pseudo-Synthetic Interaction Matrix: AOF Method

First Numerical Results: Sensitivity

1) We build 3 Sensibility matrix recorded for 10%, 50% and 100% shift of a subaperture.

2) We create several Interaction Matrix, shifting the DM in the X direction.

3) We estimate the shift by projecting on the sensibility matrix.



An ELT Calibration Strategy

An ELT Calibration Strategy

AIT

Synthetic IM

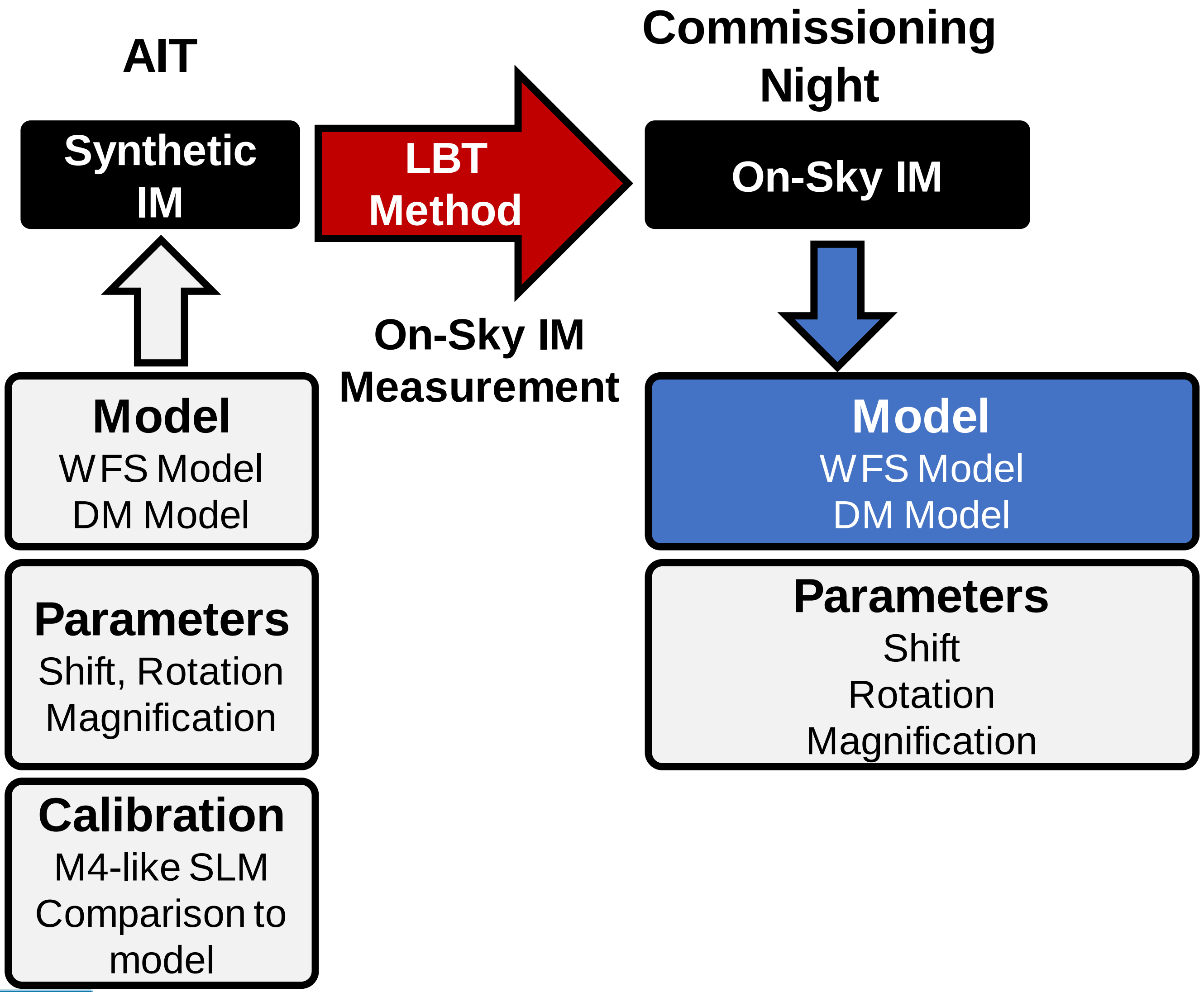
↑

Model
WFS Model
DM Model

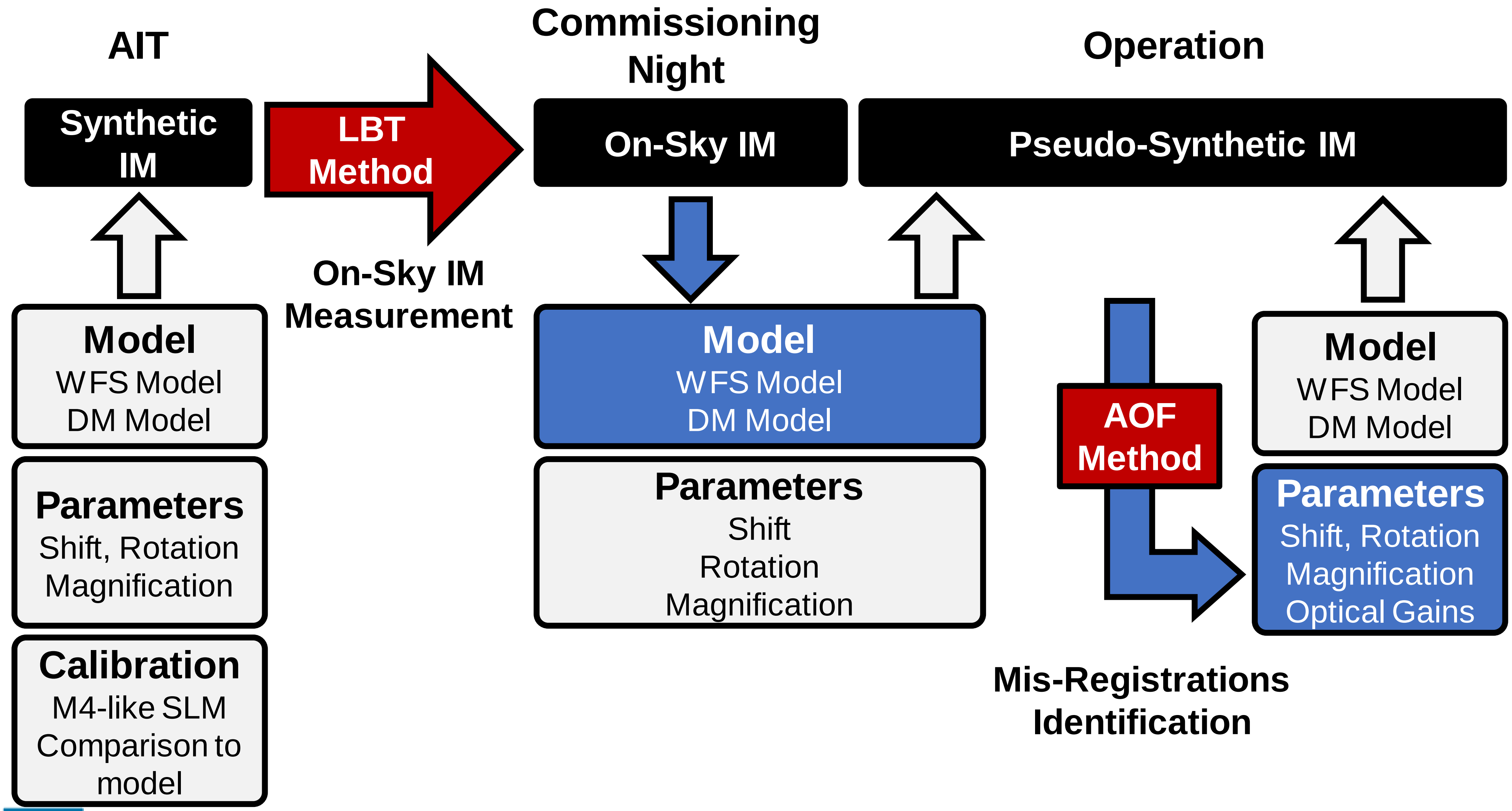
Parameters
Shift, Rotation
Magnification

Calibration
M4-like SLM
Comparison to model

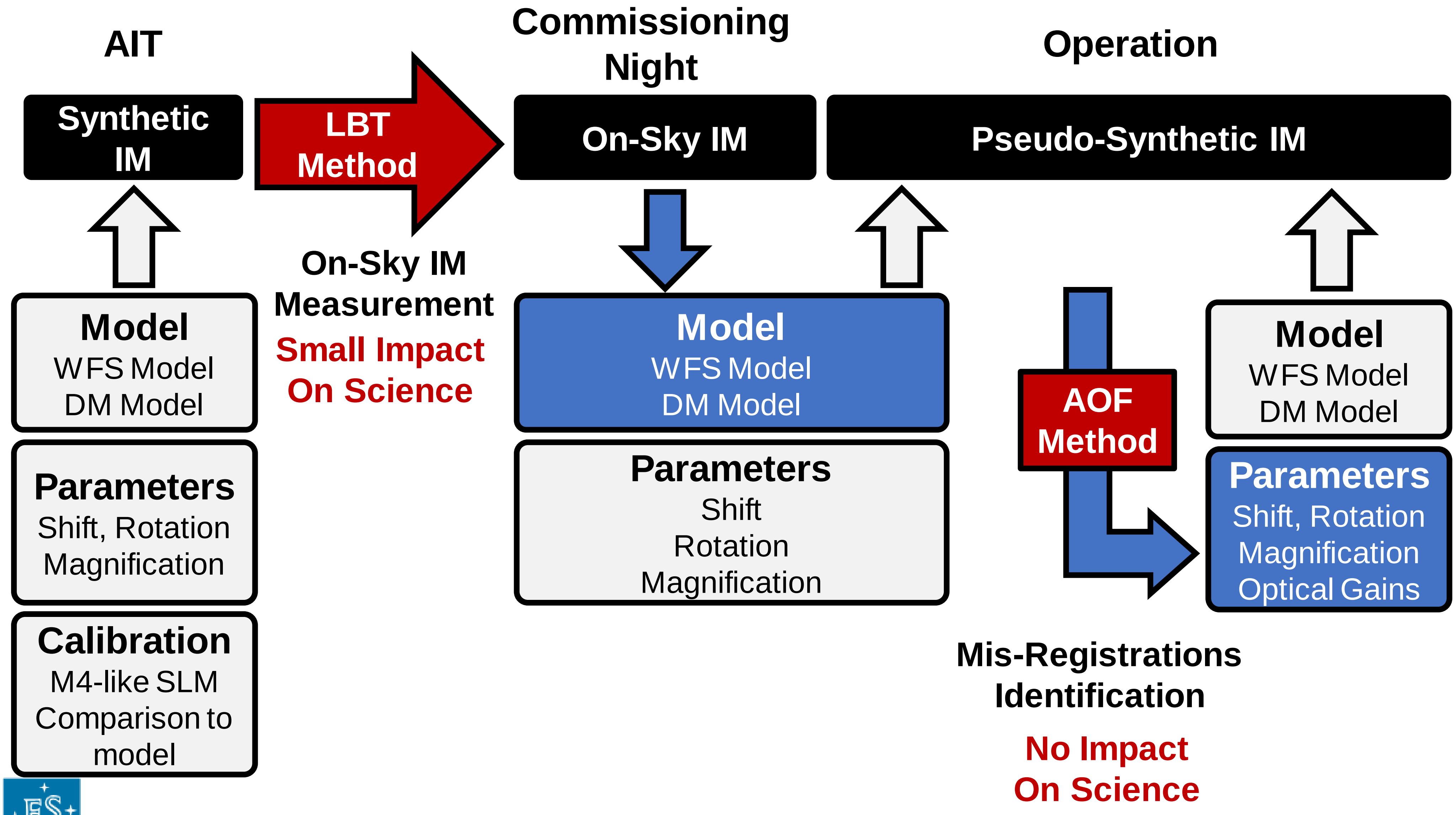
An ELT Calibration Strategy



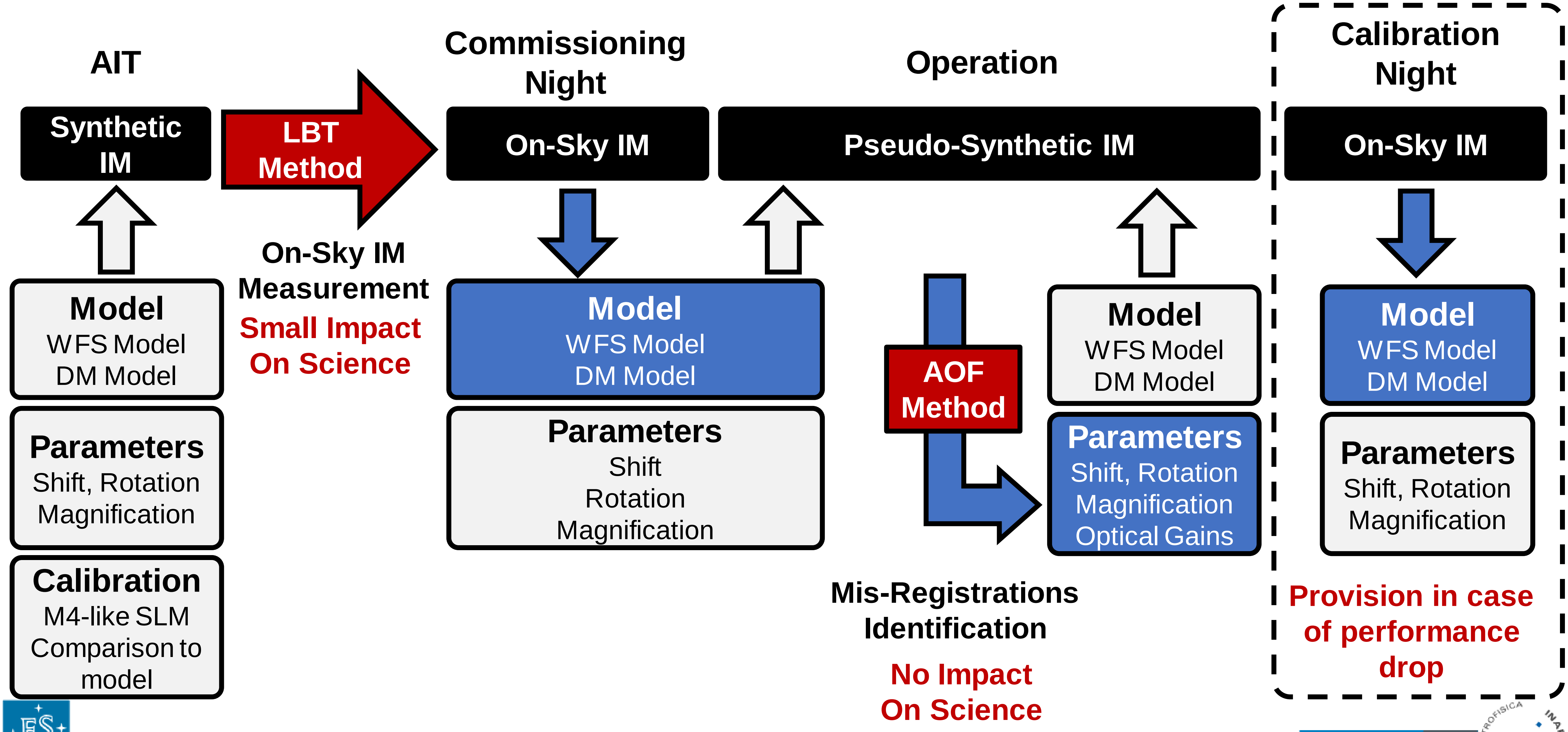
An ELT Calibration Strategy



An ELT Calibration Strategy



An ELT Calibration Strategy



Conclusion: On-Sky? PSIM?

On-Sky IM

- Measurement of the IM
- Small impact on the observations (~15 nm RMS)
- Multiplexing (So far 5 modes)
- Good results with small value of Mis-registration (<30% subap.)

Pseudo-Synthetic IM

- Update a Synthetic IM during the observations
- No impact on the observations
- Speed
- Infinite SNR

Accurate and fast identification of Mis-Registrations is necessary!

Thank you for your attention!

Appendix

Atmosphere	Wavelength	V (0,55 μm)
	r_0	0.15 m
	L_0	30 m
	3 Layers: [0 km,70%Cn^2],[4 km, 25% Cn^2],[10 km,5% Cn^2]	
Telescope	Diameter (m)	8.0
	Obstruction ratio	0%
	Resolution	64 pix
	Sampling Time (s)	1/500
NGS	NGS Wavelength	I (0,79 μm)
	NGS Magnitude	8
Science Object	OBJ Wavelength	H (1,65 μm)
	OBJ Magnitude	10
Pyramid WFS	# Subapertures	16x16
	Camera Noise	RON: 0,1 e-, Photon Noise
	Modulation	3 λ/D
Closed loop	Loop gain	0.5
	Loop delay	2 frames
DM	# Actuators	17x17
	Influence Function	Gaussian IF, 30% coupling

Pseudo Synthetic Interaction Matrix: AOF Method

AO Equation:

$$S_k = -IM(p).V_k + \underbrace{M_{WFS}.w_k^{turb} + e_k}_{= \ z_k}$$

$$\delta S_k = S_{k+1} - S_k = -IM(p).\delta V_k + \delta z_k$$

If we get rid of δz_k :

$$\boxed{IM(p) = -\frac{\delta S_k}{\delta V_k}}$$

Pseudo Synthetic Interaction Matrix: AOF Method