Analytic modeling of AO correction of atmospheric turbulence and segmented telescope aberrations

Laurent Jolissaint, Observatory of Leiden

E-ELT Design Reference Mission Workshop, ESO, Garching, 20-21 May 2008

AO modeling tools, to do what ?

- Science case evaluation
- AO engineering - system’s design
- AO data reduction software design
- Demonstration / teaching

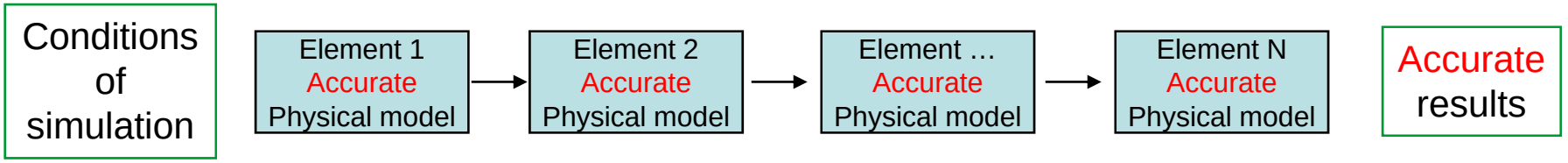
Two complementary modeling methods exist

1. End-to-end models

2. Analytical models

End-to-end models

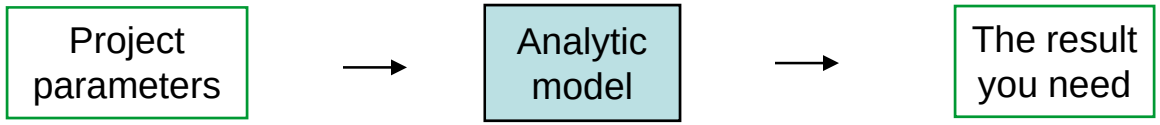
ex: OCTOPUS - Miska Le Louarn, ESO



- To reproduce nature's behavior with highest possible accuracy, **NO assumptions** on **general behaviour** are made, only for individual components
- If the simulation results looks strange, it's probably something real
- Output is an understanding of system's behavior
- **Consequence of high fidelity: heavy and slow** (PC clusters, hours/PSF)
  - Because to get long exposure PSF we need to average N >> 1000 instantaneous PSF

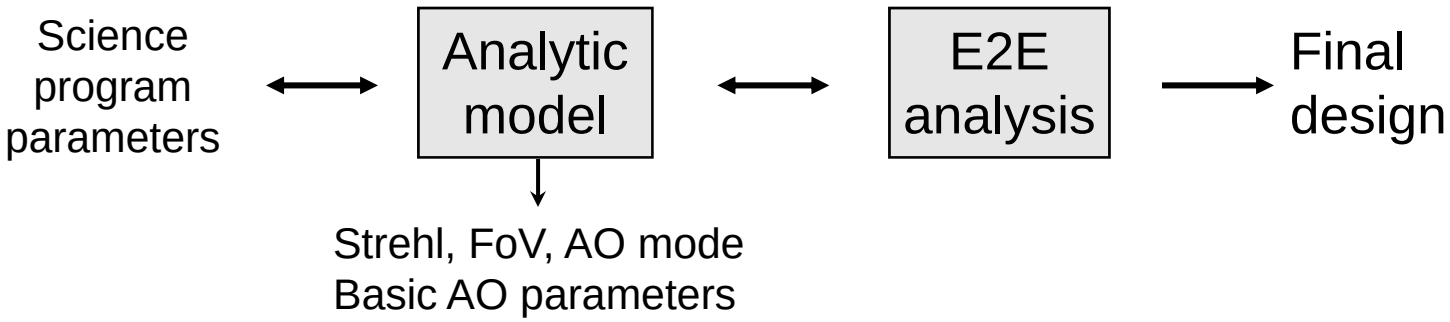
Analytic models

- ex: PAOLA - Laurent Jolissaint, Observatory of Leiden
- Once E2E models and real AO systems have produced understanding of systems behavior, AO analytic models can be built



- Accuracy depends on level of understanding of system's behavior
  - Completely knowledge-based: assumptions ARE needed.
  - If simulation results look strange, *check the model first…*
- Advantages: light and fast (1 PC, a few seconds for a PSF)
  - Long exposure PSF obtained in a single calculation (no loop)

- Today's tendency is to use E2E and analytic models in a complementary way
- Analytic models
  - rapid exploration of parameter space
  - ex: we need 441 PSF for MUSE data analysis software design 7 hours/analytic or 4 years/E2E
  - Accurate enough for science cases trade-offs
  - Astronomers can have their own, local AO models
- E2E
  - design of complex, non-linear issues, hard to get analytic model…
  - Overall check of final design



AO Analytic modeling: main paradigm

- *From AO knowledge*: AO correction can be seen as a spatial filtering of the turbulent phase (1st order)

$$\varphi_{res} = f_{AO} * \varphi_{atm}$$

- Assumption: stationarity of correction inside pupil
- Nice consequence $\tilde{\varphi}_{res} = F_{AO} \cdot \tilde{\varphi}_{atm}$
  - Modeling in the Fourier domain (pupil spatial frequency)
  - Models of the AO spatial transfer function F_{AO} are available

AO spatial filter F_{AO} is the central tool in analytic modeling

- Method can be applied everywhere - and works like a charm…
  - Telescope static aberrations AO correction
  - Telescope dynamic aberrations AO correction
  - Optical turbulence AO correction

My codes

- PAOLA started 2001
  - Telescope static aberrations
  - Atmospheric turbulence aberrations
  - 56 people in user group
  - Continuous development & maintenance

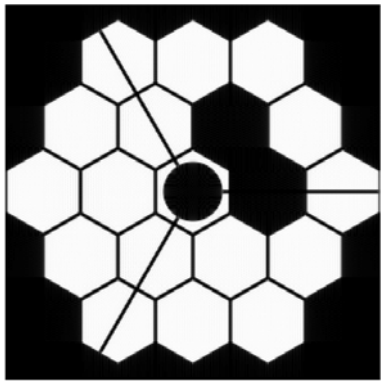
- OPTICA started 2006 for Thirty Meter Telescope Project
  - Telescope static aberrations
  - Telescope dynamic aberrations (wind jitter)

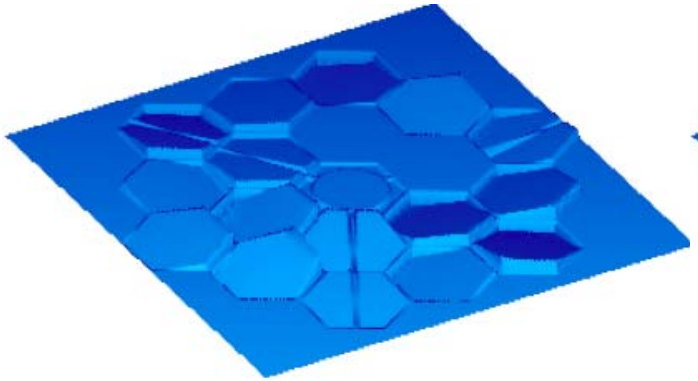
Download user manuals @ http://www.strw.leidenuniv.nl/~jolissaint/

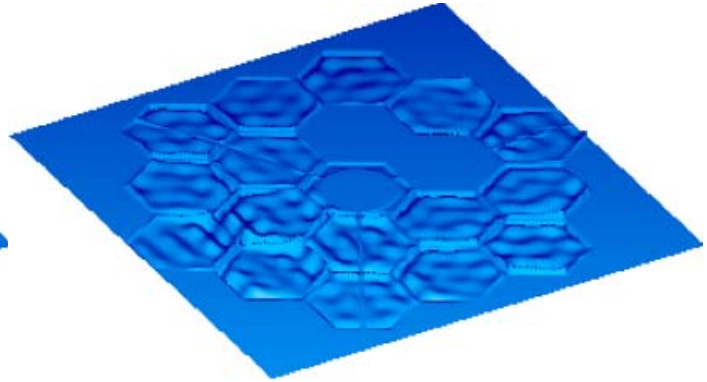
Some realisations with OPTICA & PAOLA

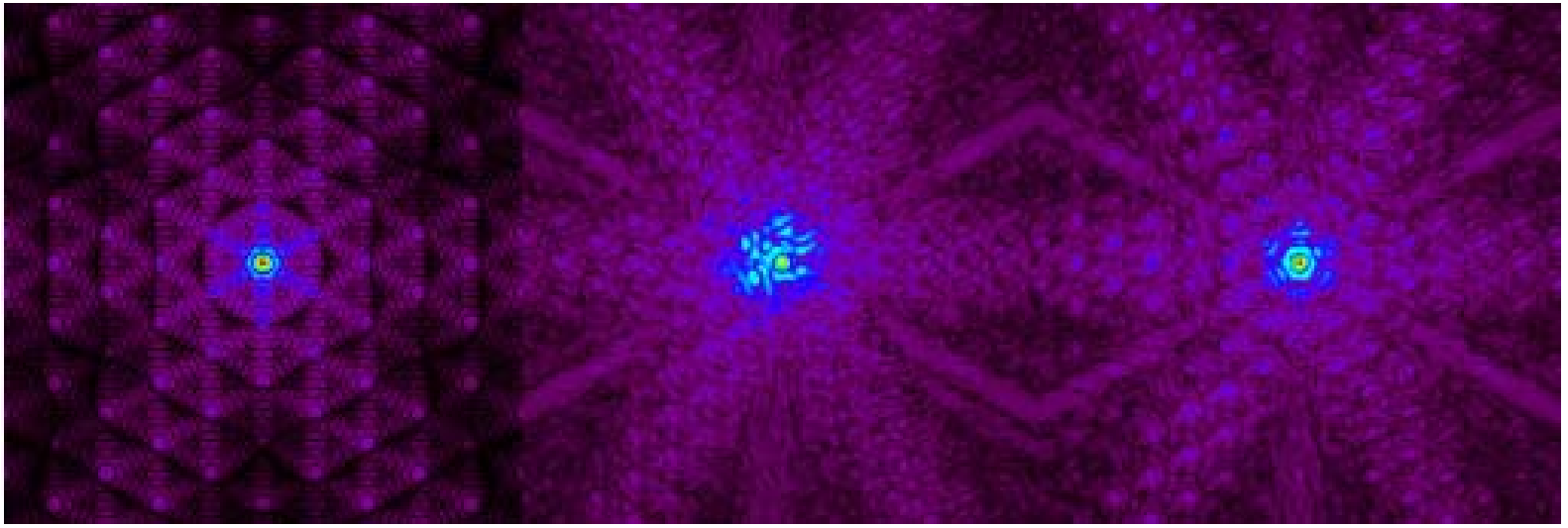
AO correction of telescope static aberrations

F_{AO} contains deformable mirror transfer function and wavefront sensor aliasing



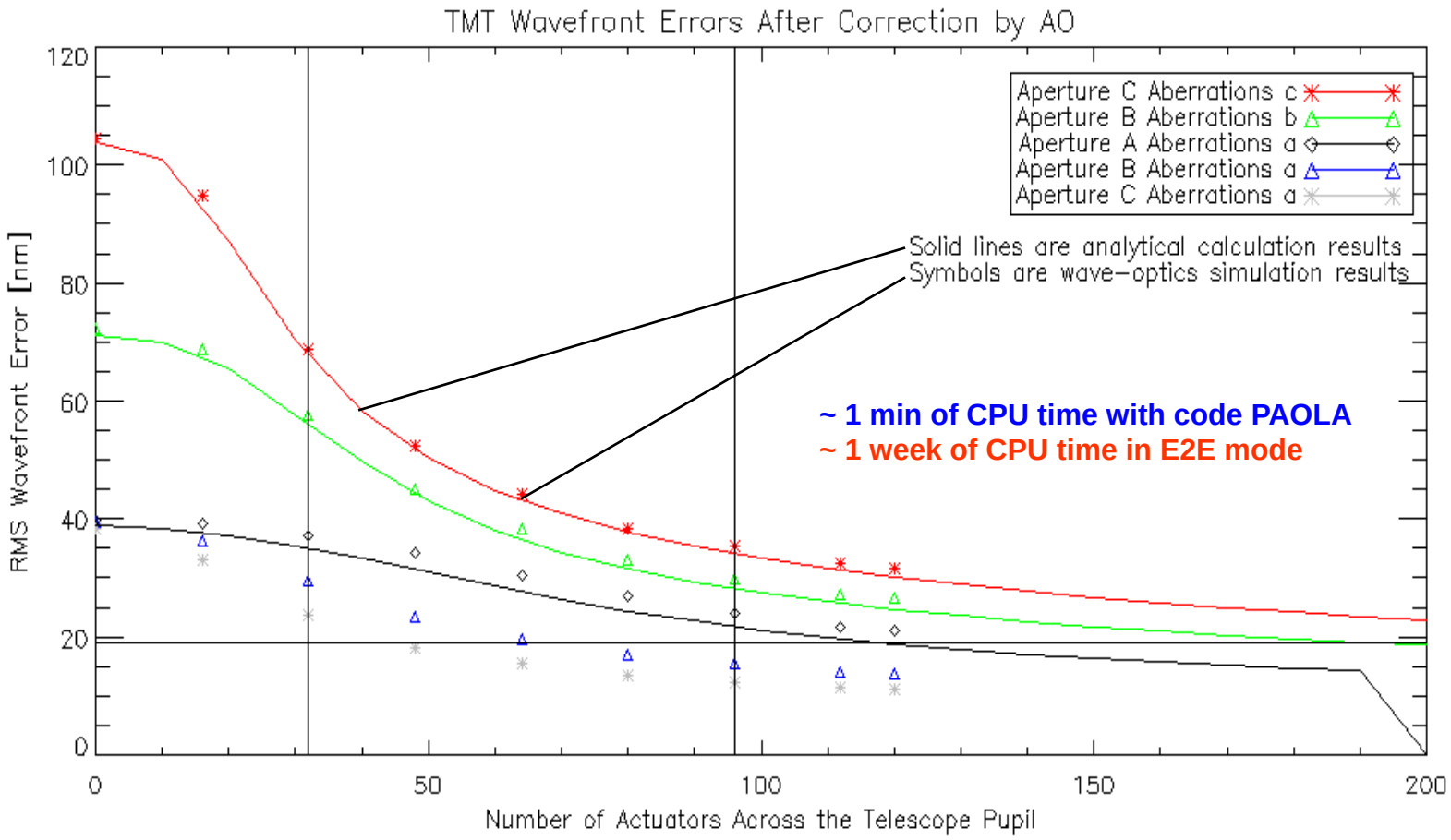






AO correction of telescope static aberrations

Thirty meter telescope project (TMT) ExAO studies - Mitch Troy, Laurent Jolissaint



AO correction of telescope dynamic aberrations

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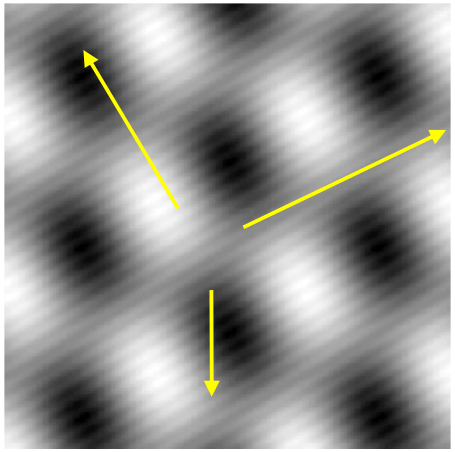
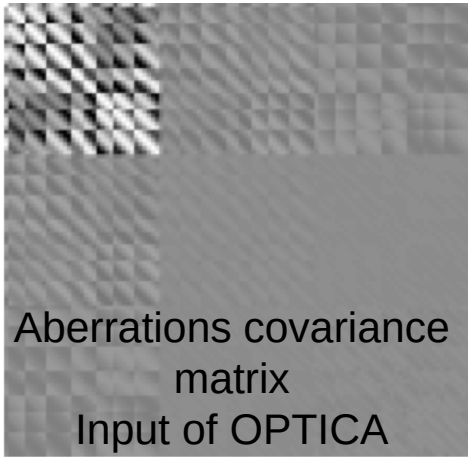
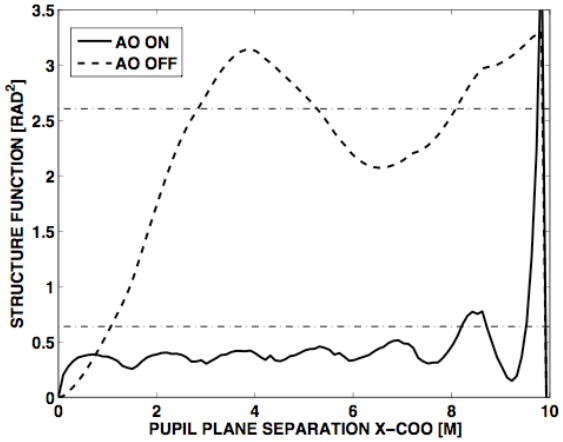
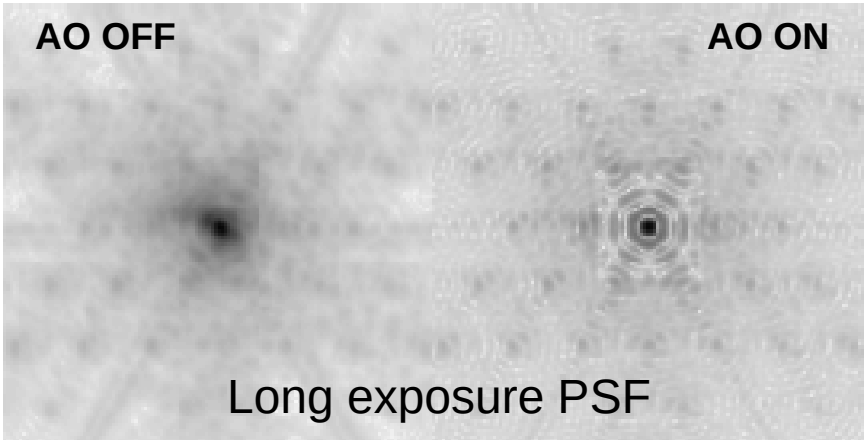


3 cosine waves travelling across segmented M1





Phase structure function



AO correction of turbulent phase aberrations analytical code PAOLA

Spatial filter F_{AO} more complex. Contains:

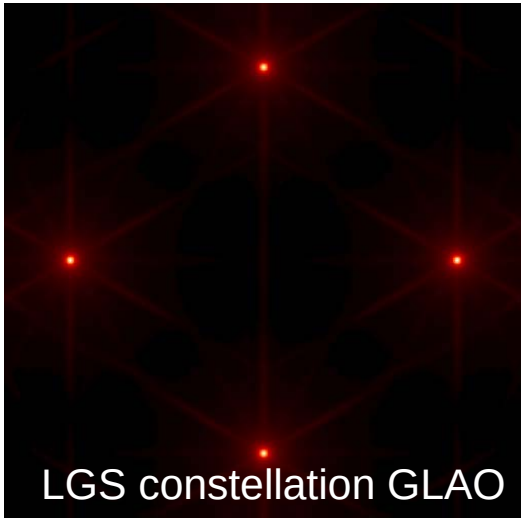
1. DM transfer function
2. Least square phase reconstructor
3. WFS spatial aliasing
4. AO loop servo-lag
5. Anisoplanatism - guide star no co-located with science object
6. WFS noise

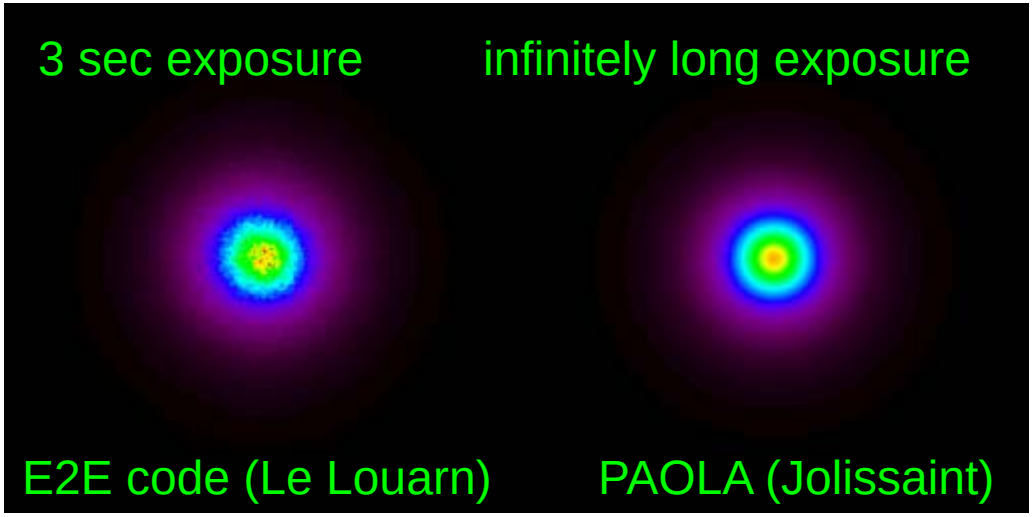
Analytical modeling of adaptive optics
L. Jolissaint, JP. Veran, and R. Conan
JOSA A 23, 2, 382-394, 2006/02

Other functionalities implemented in PAOLA

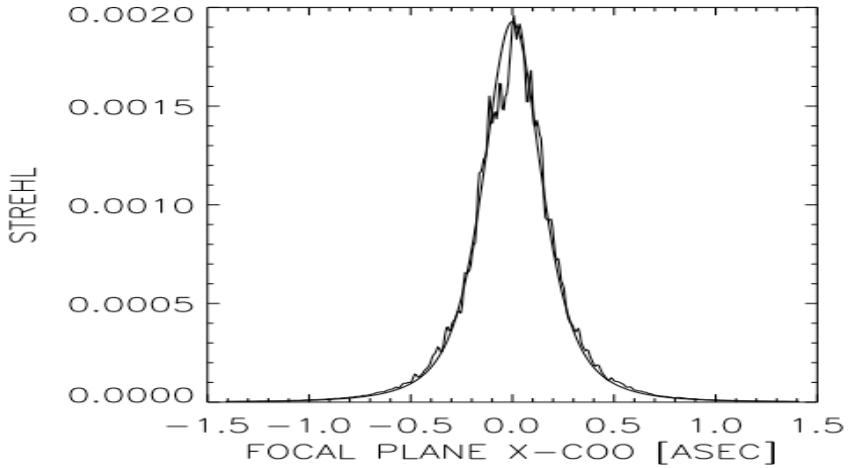
- DM spatial transfer function from influence functions
  - Boston MEMS, Xinetics, Gaussian, Pyramid
- WFS pitch <> DM pitch (limited either by DM or WFS)
- WFS integration time optimization
- Refractive index dispersion effects & water vapor on Cn2
  - Critical for METIS (medium IR AO for E-ELT)
- GLAO/NGS
- Tip-tilt jitter
- Scintillation
- On-going developments
  - LGS
  - LTAO, MCAO, MOAO (NGS based) collaboration with Benoit Neichel, ONERA
  - LTAO, MCAO, MOAO - LGS based

GLAO system for VLT (AO Facility, GALACSI - MUSE)

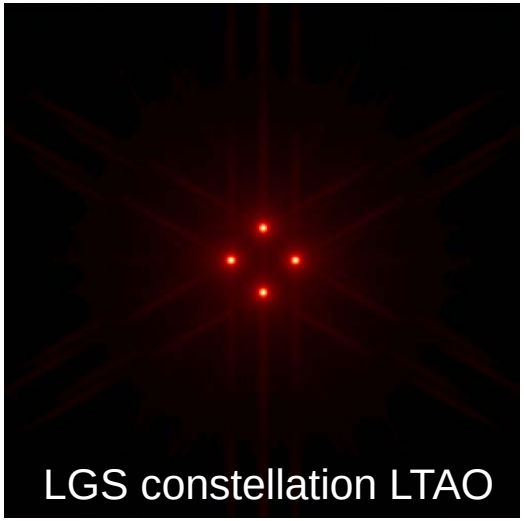




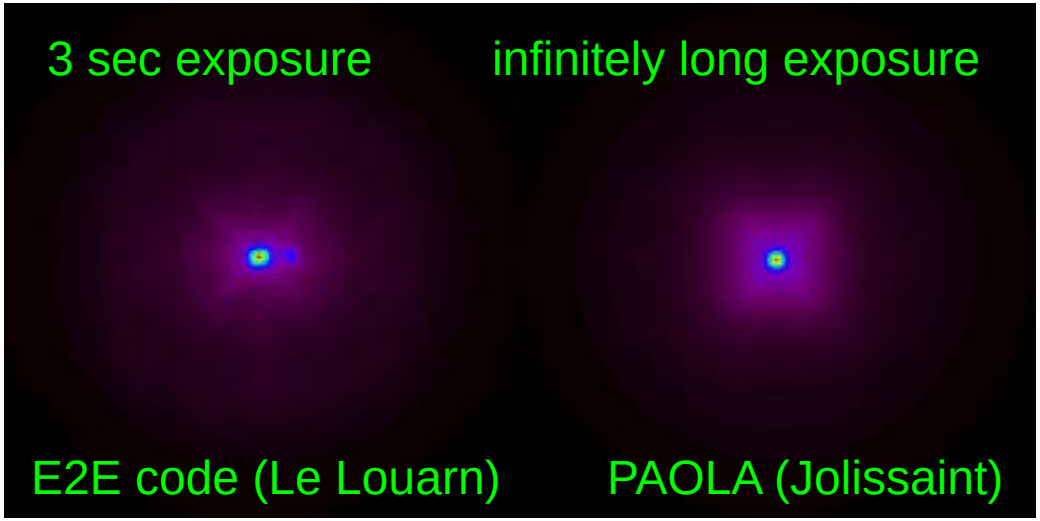
120”



LTAO system for VLT (AO Facility, GALACSI - MUSE)

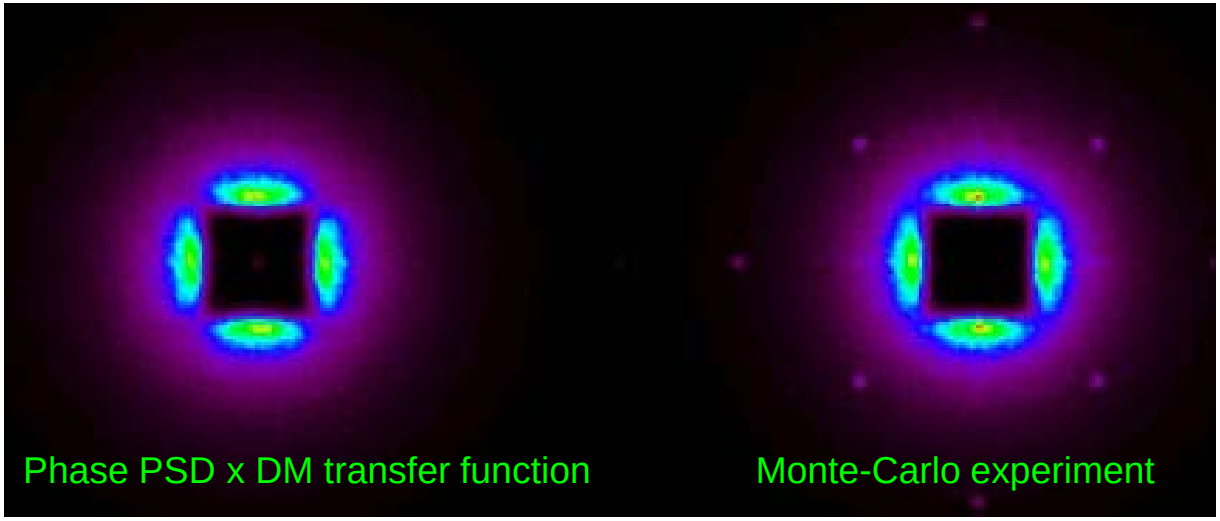


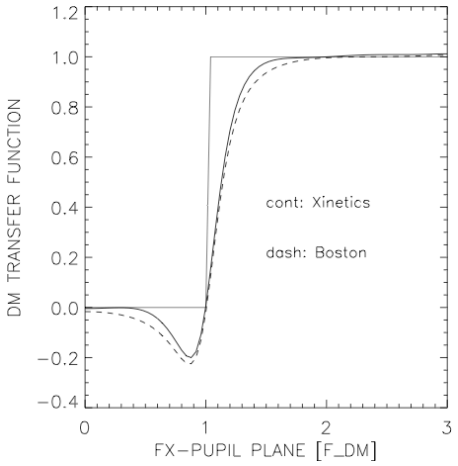
20”



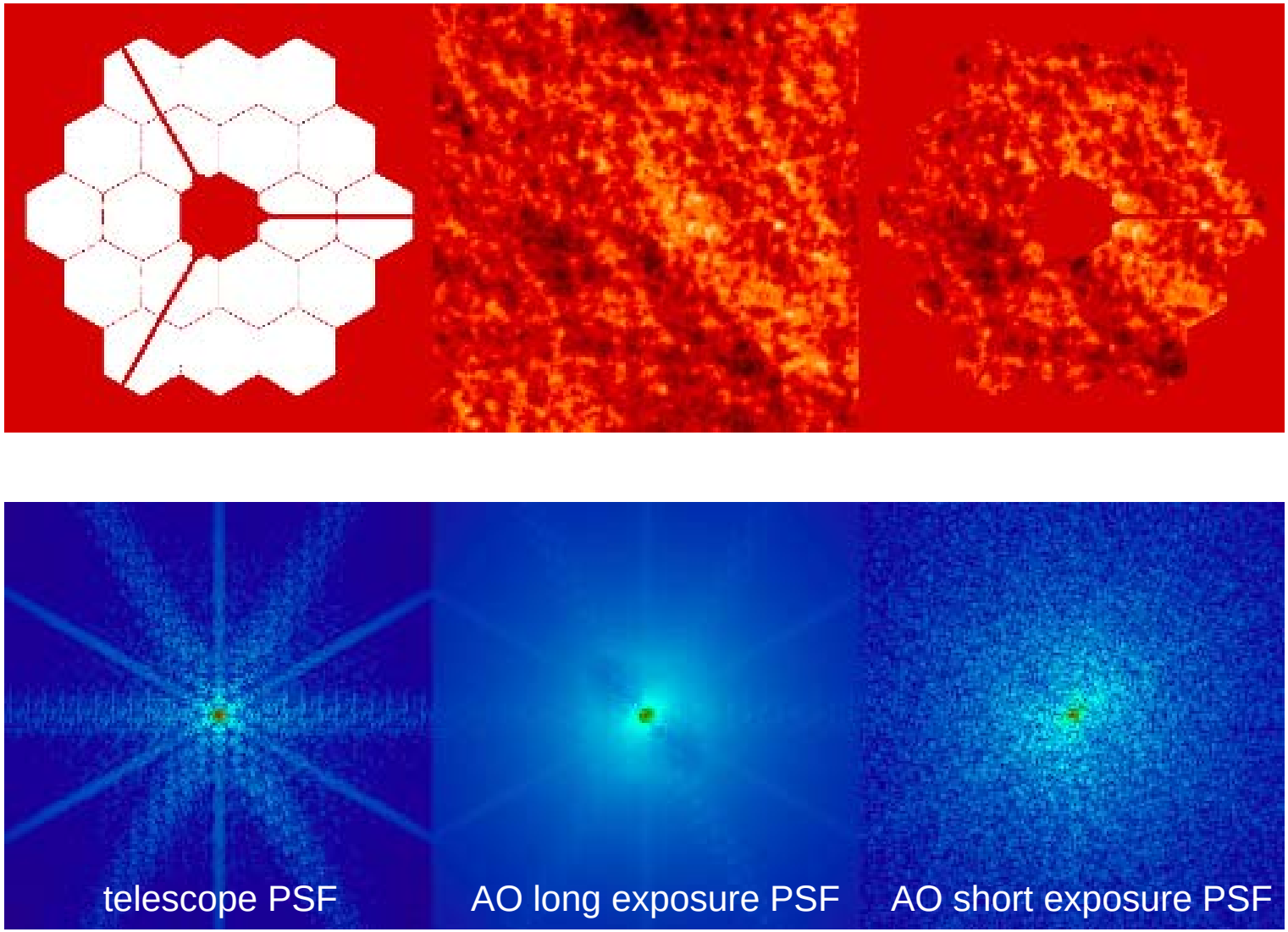
3”

Testing Xinetics Influence Function model





Generating instantaneous PSF for coronagraphic studies



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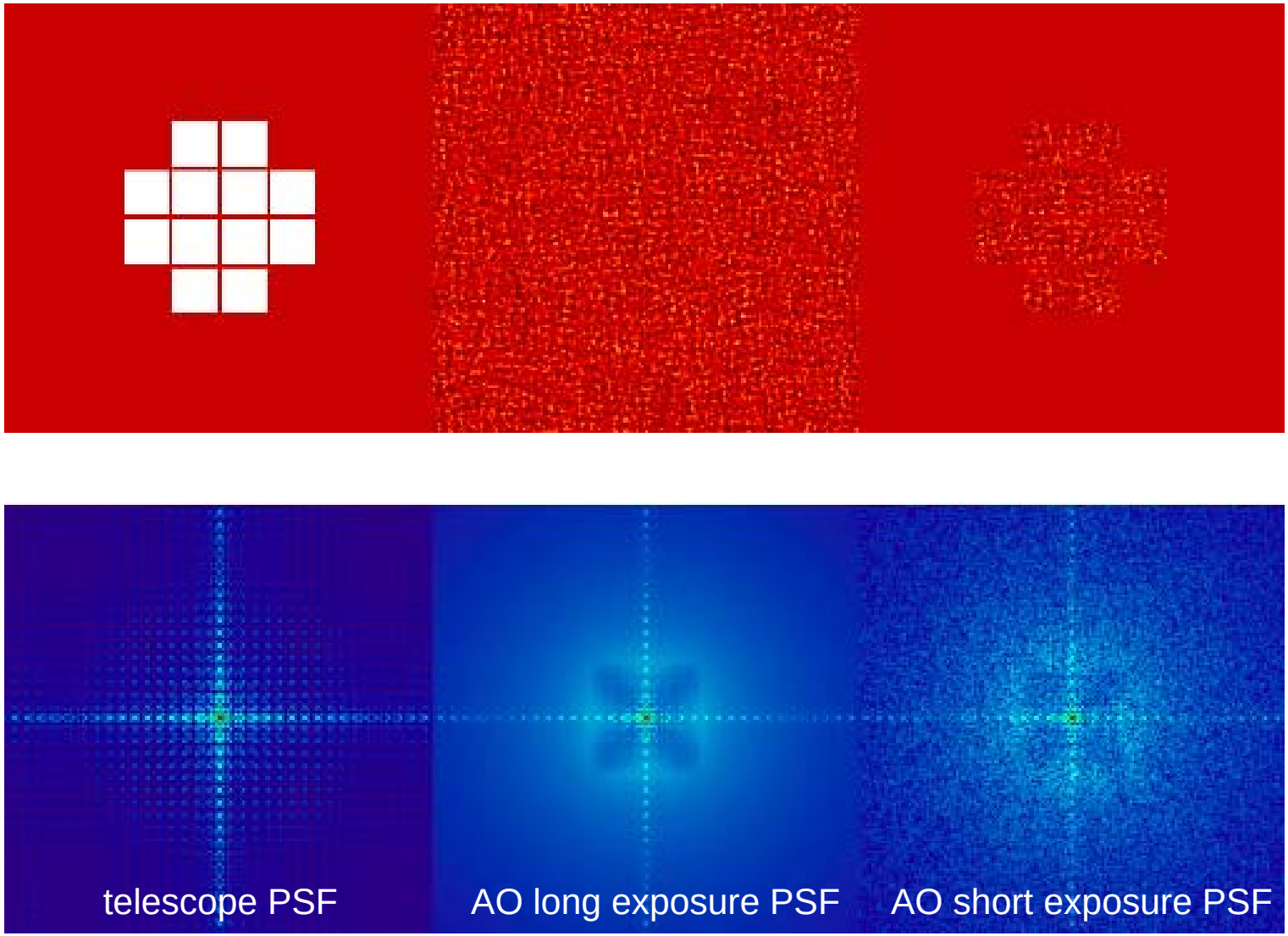
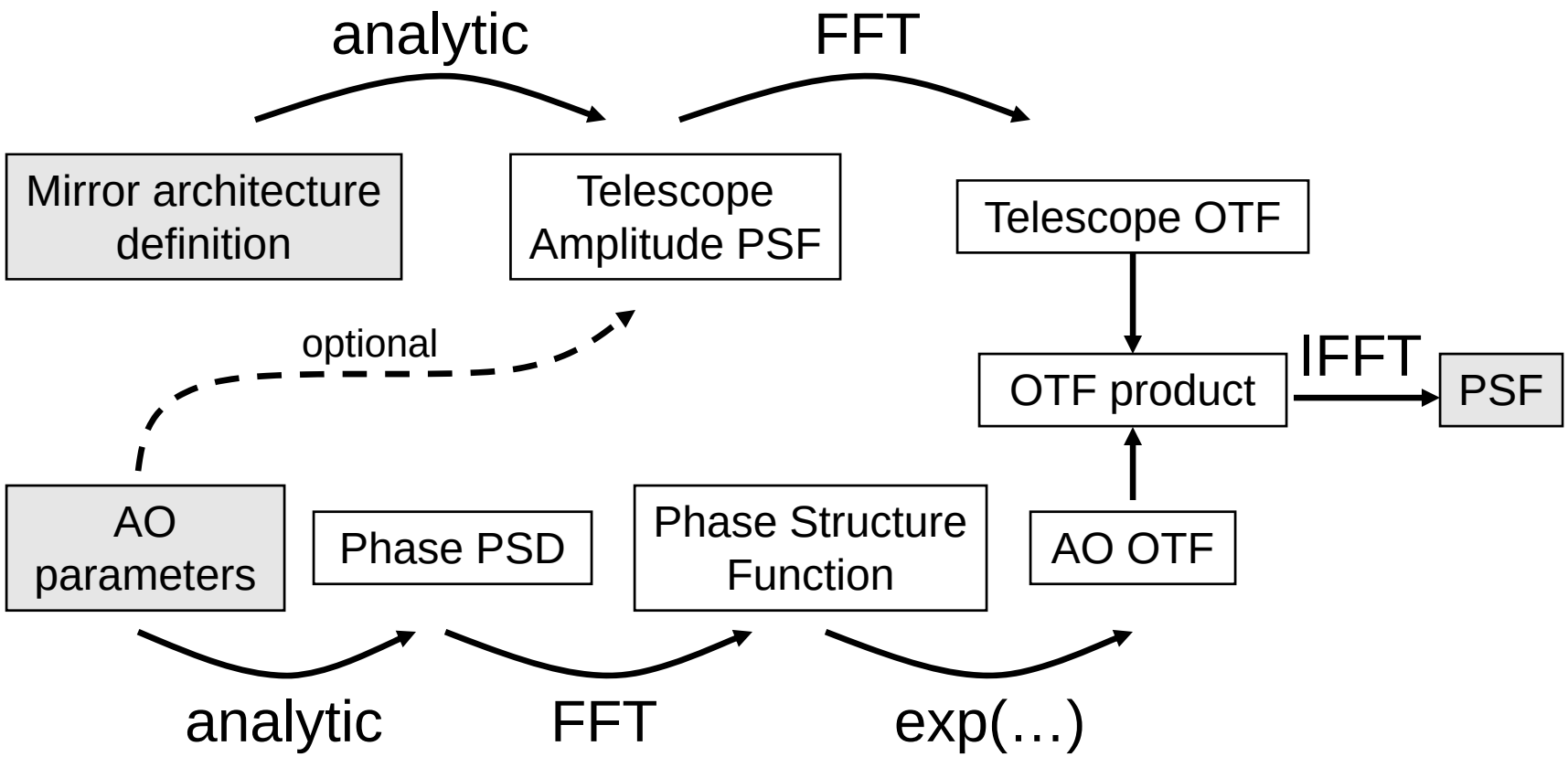


Summary

- Analytical codes for modeling AO correction of
  - Telescope static aberrations
  - Telescope dynamic aberrations
  - Optical turbulence aberrations
  - Including hexagonal segments
- Fast
- Tested
- Maintained
- We have what we need to help with the DRM
  - Open to fruitful collaboration…

for details, check
http://www.strw.leidenuniv.nl/~jolissaint/


analytic
FFT
Mirror architecture definition
Telescope Amplitude PSF
Telescope OTF
optional
IFFT
OTF product
PSF
AO parameters
Phase PSD
Phase Structure Function
AO OTF
analytic
FFT
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