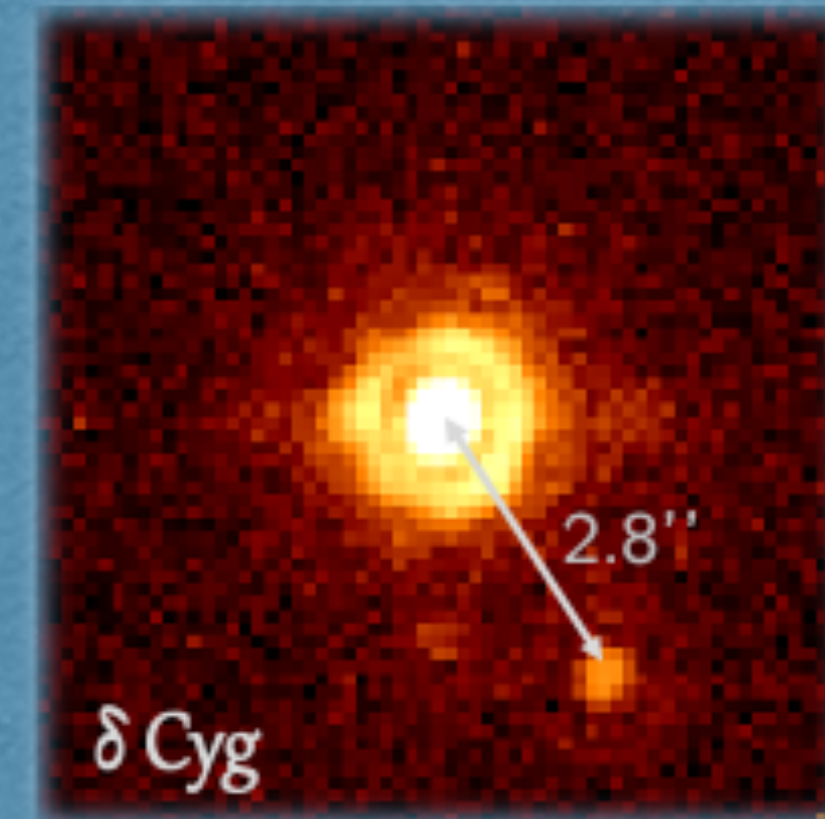


SALTO demonstrator: From concept to on-sky commissioning



Gilles Orban de Xivry

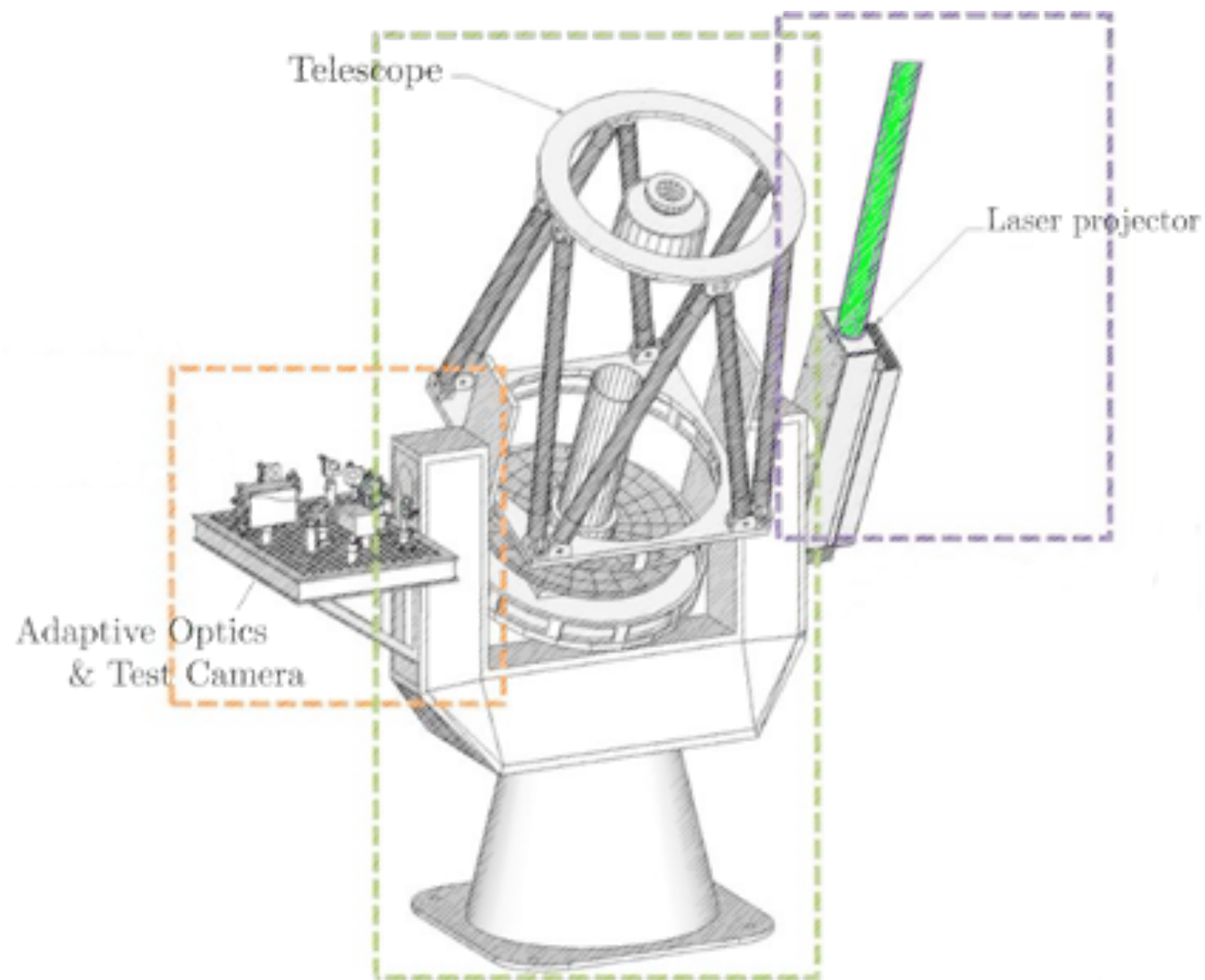
J. Paul, O. Absil

C. Adam, P. Albart, C. Bastin, A. Boulanger, J. de Ville,
E. Gabriel, L. Méant, V. Moreau, S. Orban, P. Remacle,
F. Languy, M. Georges, J-F Vandenrijt, G. Millou



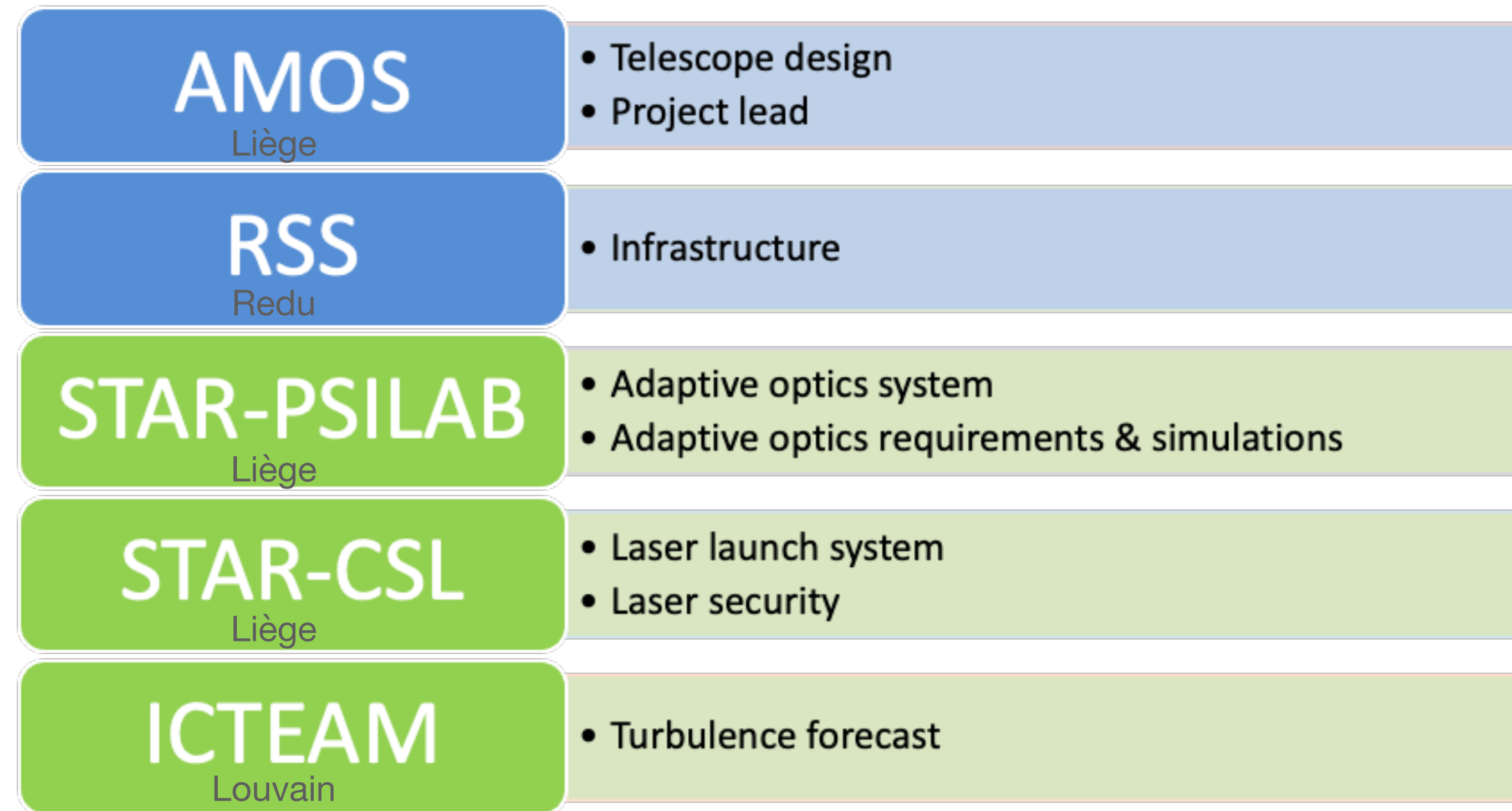
SALTO project

Smart **A**daptive-optics and **L**aser guide-star for medium **T**elescopes and **O**ptical communications



- ◆ Industry-oriented project led by AMOS
- ◆ 1-m class telescope with laser adaptive optics in the Belgian countryside
- ◆ Aim:
 - Develop expertise for AO on **2-4m class** telescope for **astronomy**
 - Demonstrate robust operation of **LGS-AO**
 - First step towards **optical communication**
- ◆ Current status: on-site installation and on-sky commissioning

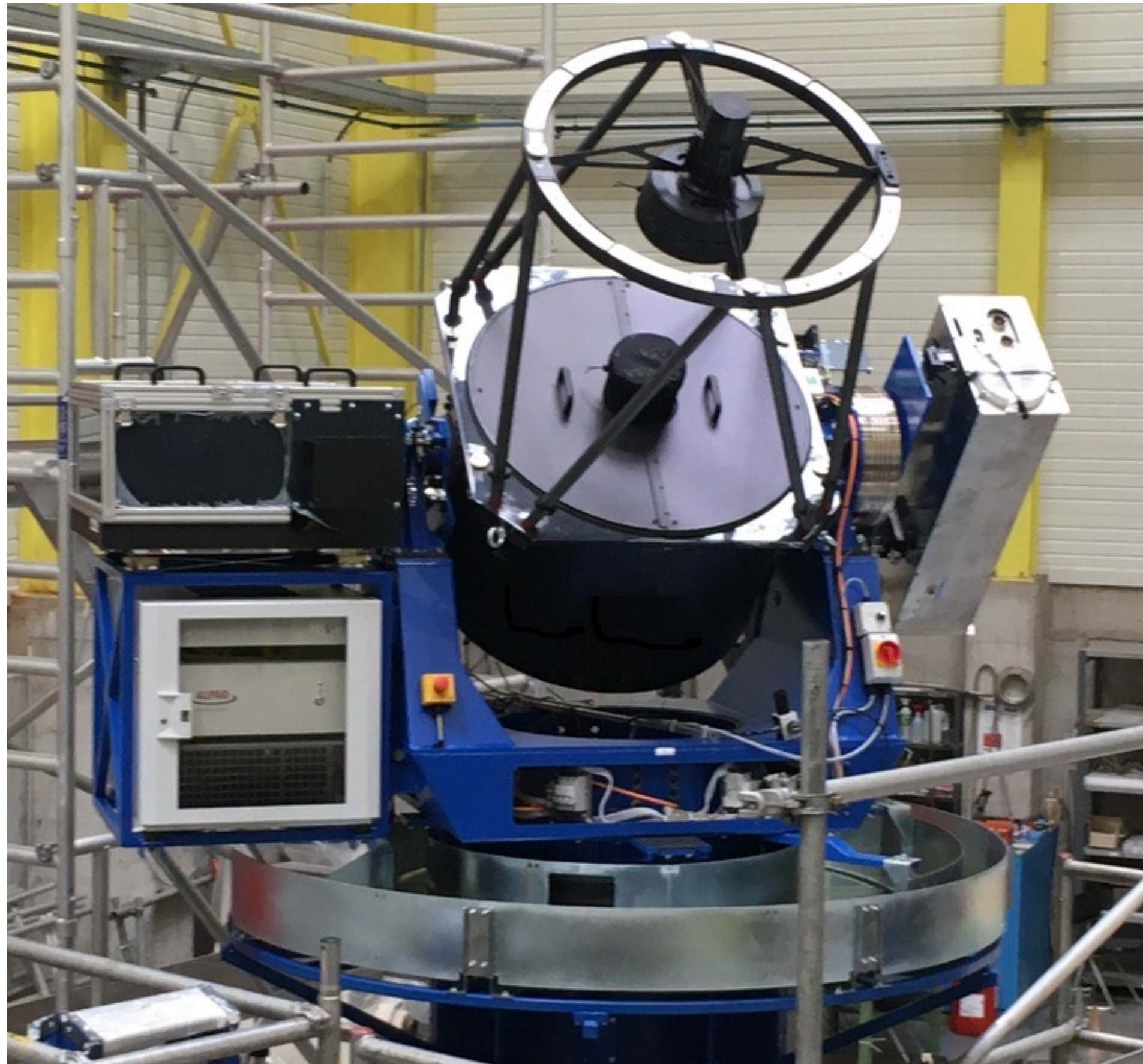
SALTO consortium



◆ Total budget: ~3.3M€

Demonstrator overview

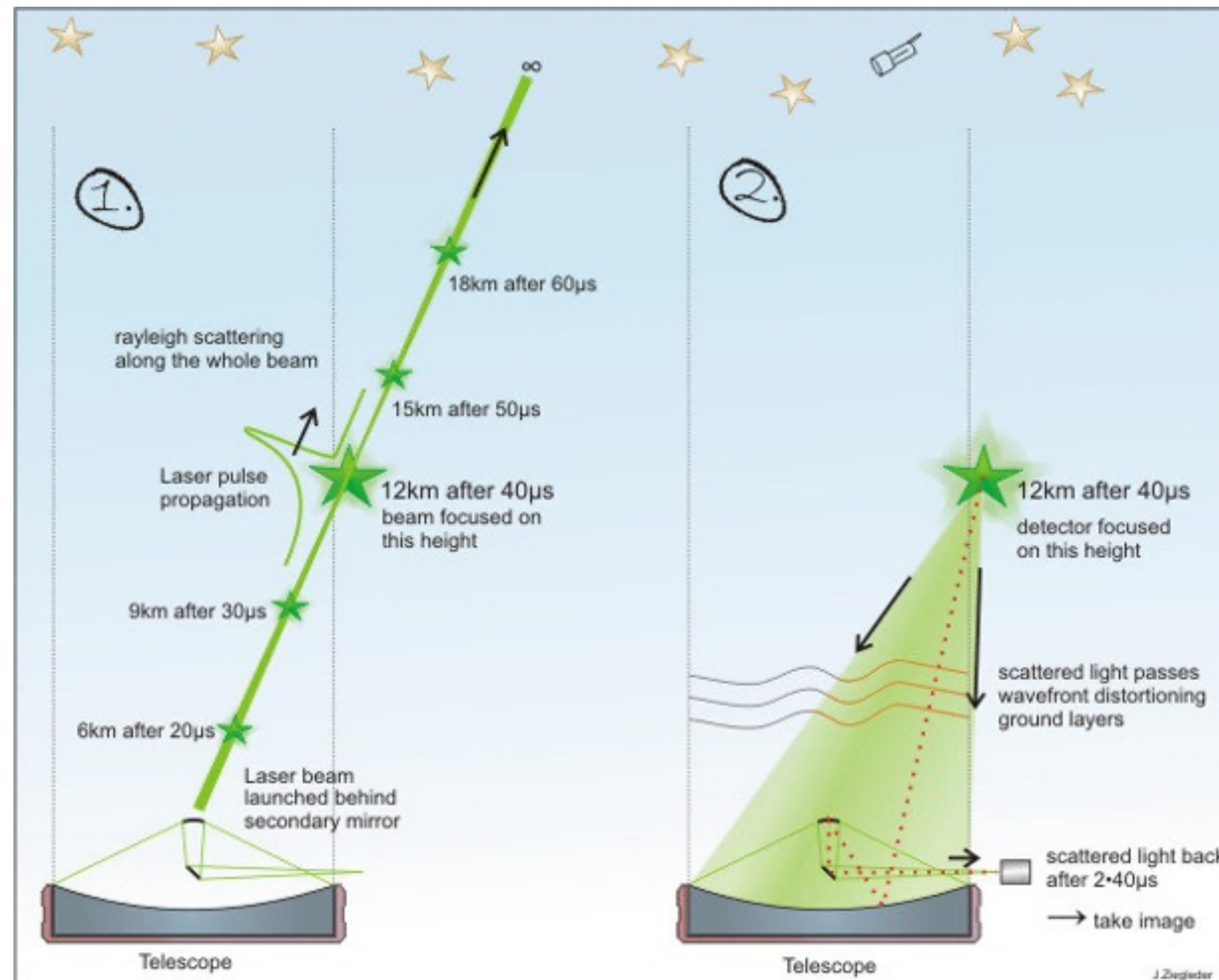
Integrated system at AMOS premises



- ◆ RC 800mm telescope
 - Robust custom mechanical mount
- ◆ Nasmyth AO instrument
- ◆ Laser system on the altitude axis

AO key concepts & parameters

- ◆ Two modes : NGS and LGS operation
- ◆ Rayleigh laser guide star system

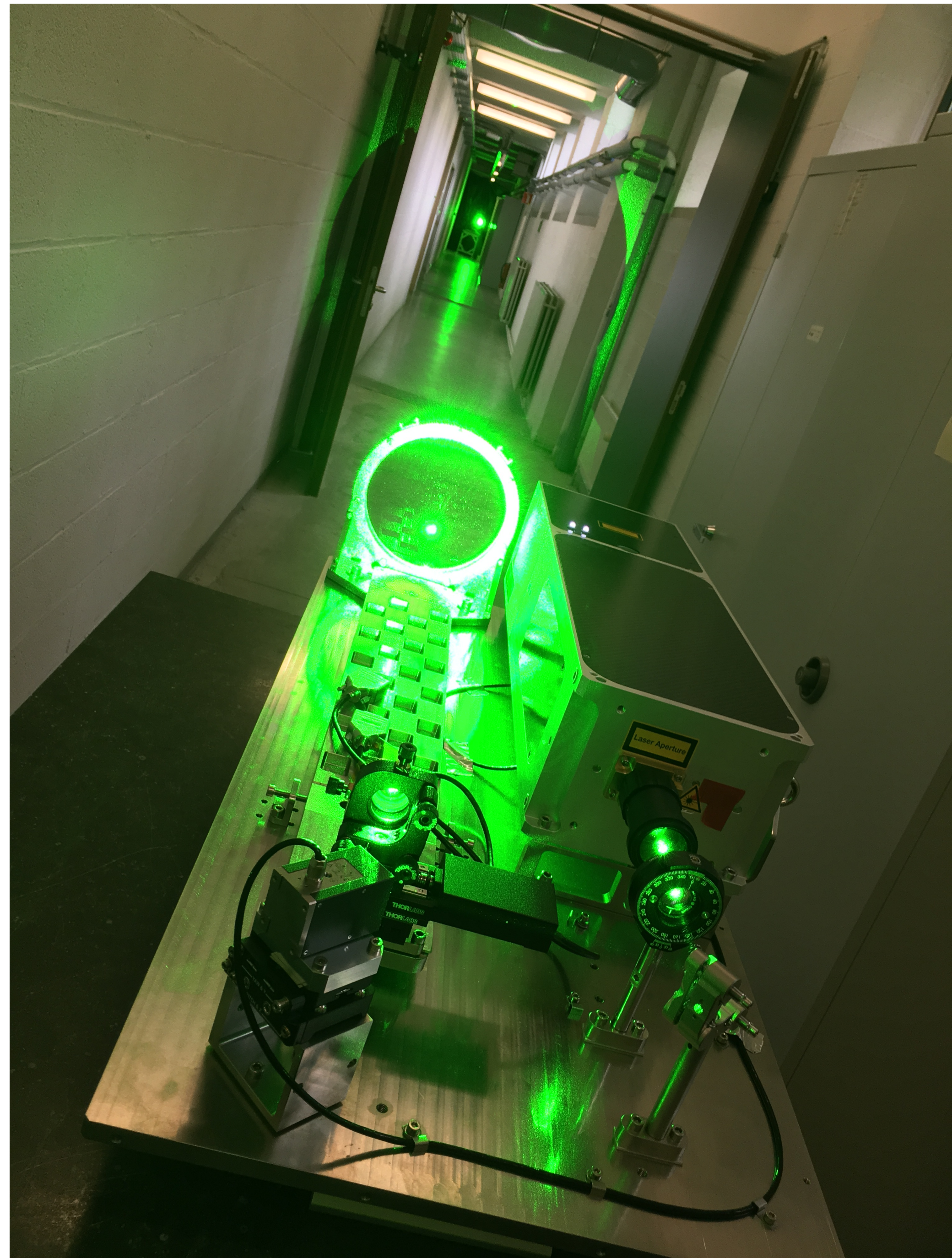


SALTO key parameters

- ◆ 10x10 SH WFS, 12.5"/subap (max)
- ◆ DM : 97 actuators
- ◆ WFS camera: <1e- RON at 1kHz
- ◆ 18W at 10kHz, 532nm laser @10km
- ◆ Gating with Pockels cell 2-10μs (300-1500m)
- ◆ Fast InGaAs camera for science & tip-tilt wavefront sensing
- ◆ In-house development of Real-Time Computer

Laser system

- Nd:YAG 532nm
- 10kHz pulsed, 18W
- Polarisation control
- Beam expander
- Fast steering mirror
- Focus control

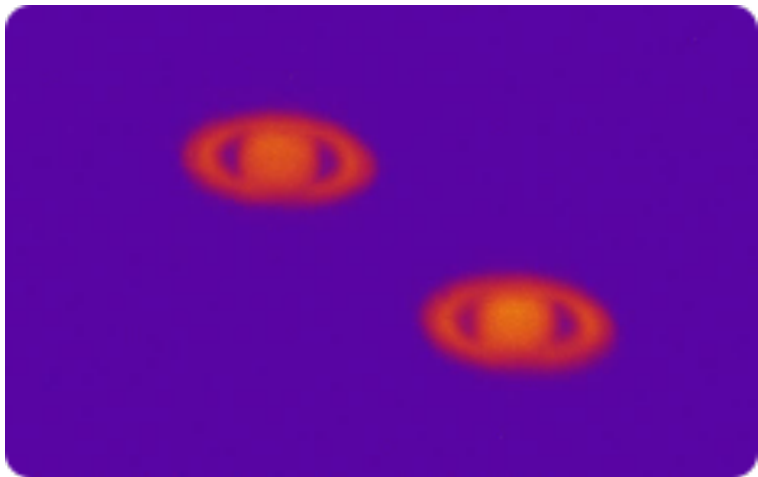


Early definition

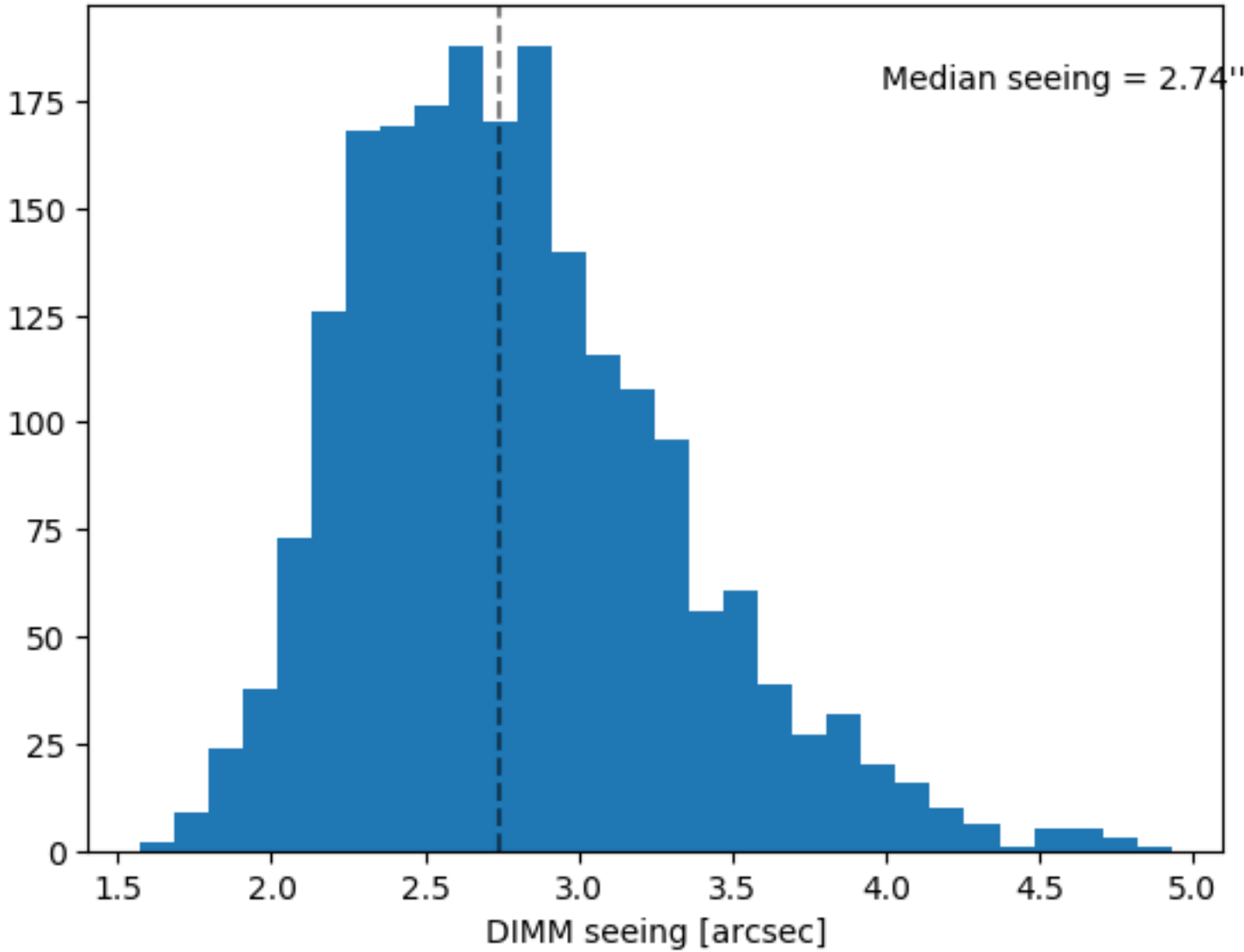
AO error budget & DIMM

Assuming 2" seeing, standard Cn2:

~145 nm WFE, or ~70% Strehl in the H-band



Error source	Values [nm rms]
Focus anisoplanatism	82
Fitting error	62
Aliasing error	36
Temporal error	91
Wavefront measurement error	33
Multispectral error (zenith)	0
Total	146



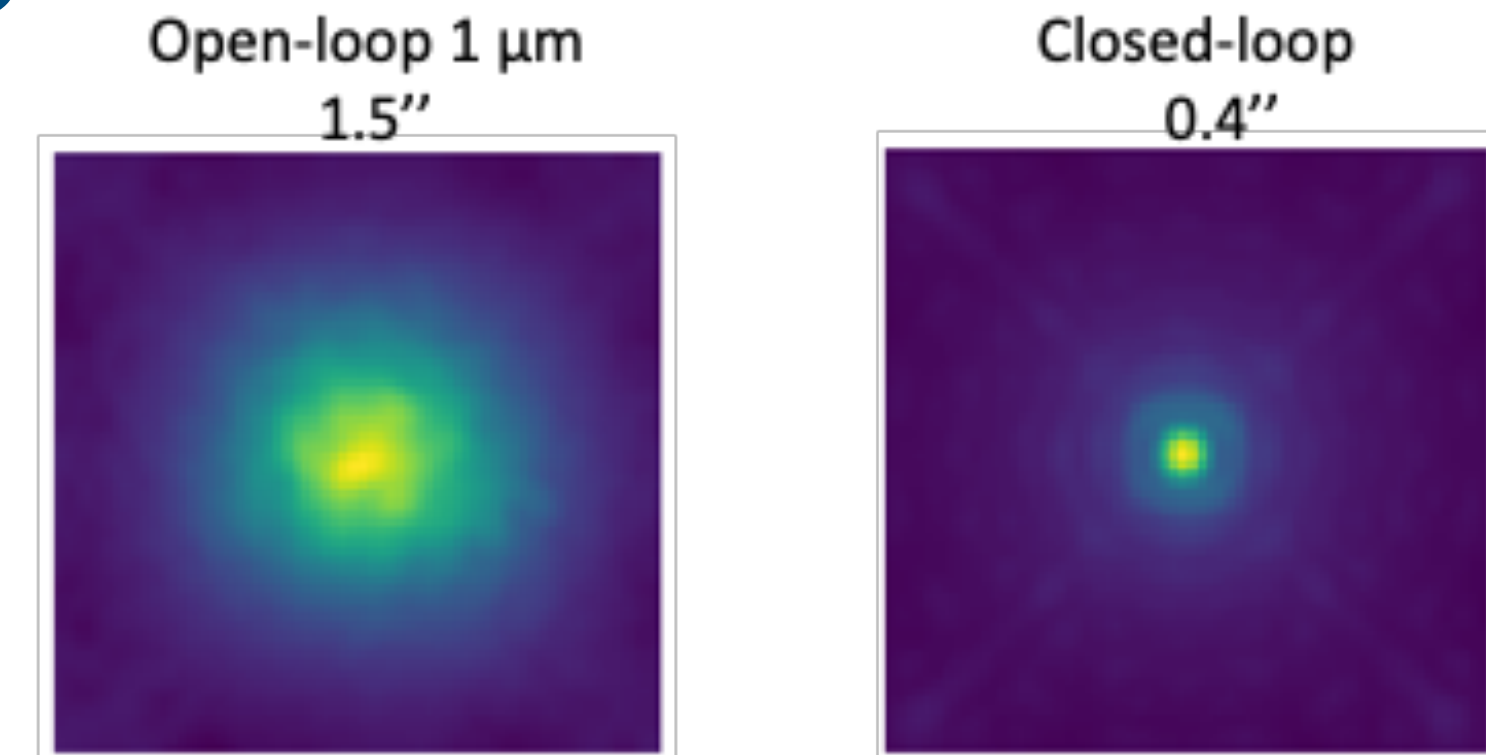
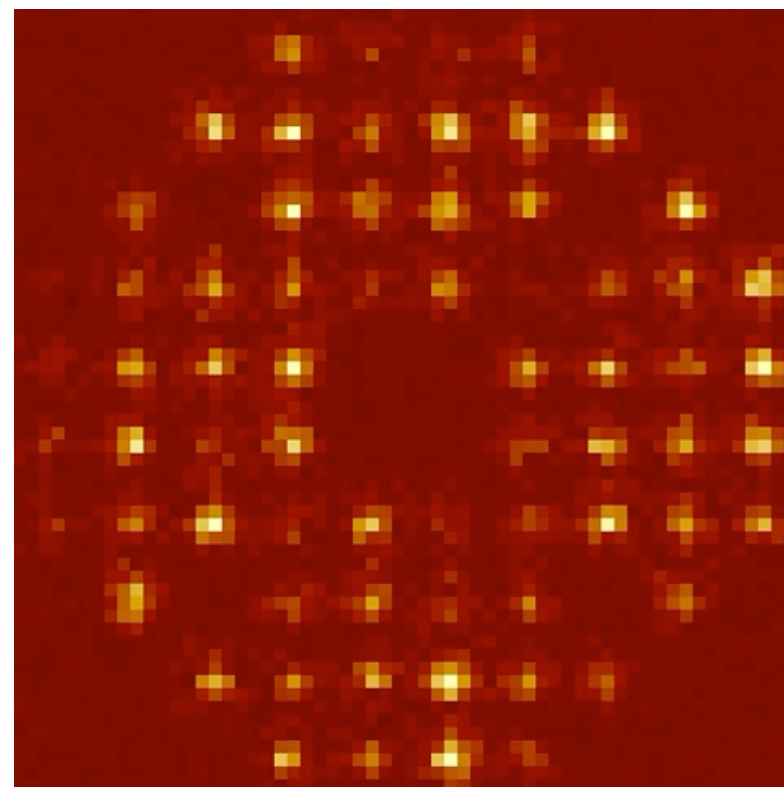
AO end-to-end simulations

◆ Tools : **SOAPY** and **AOtools**

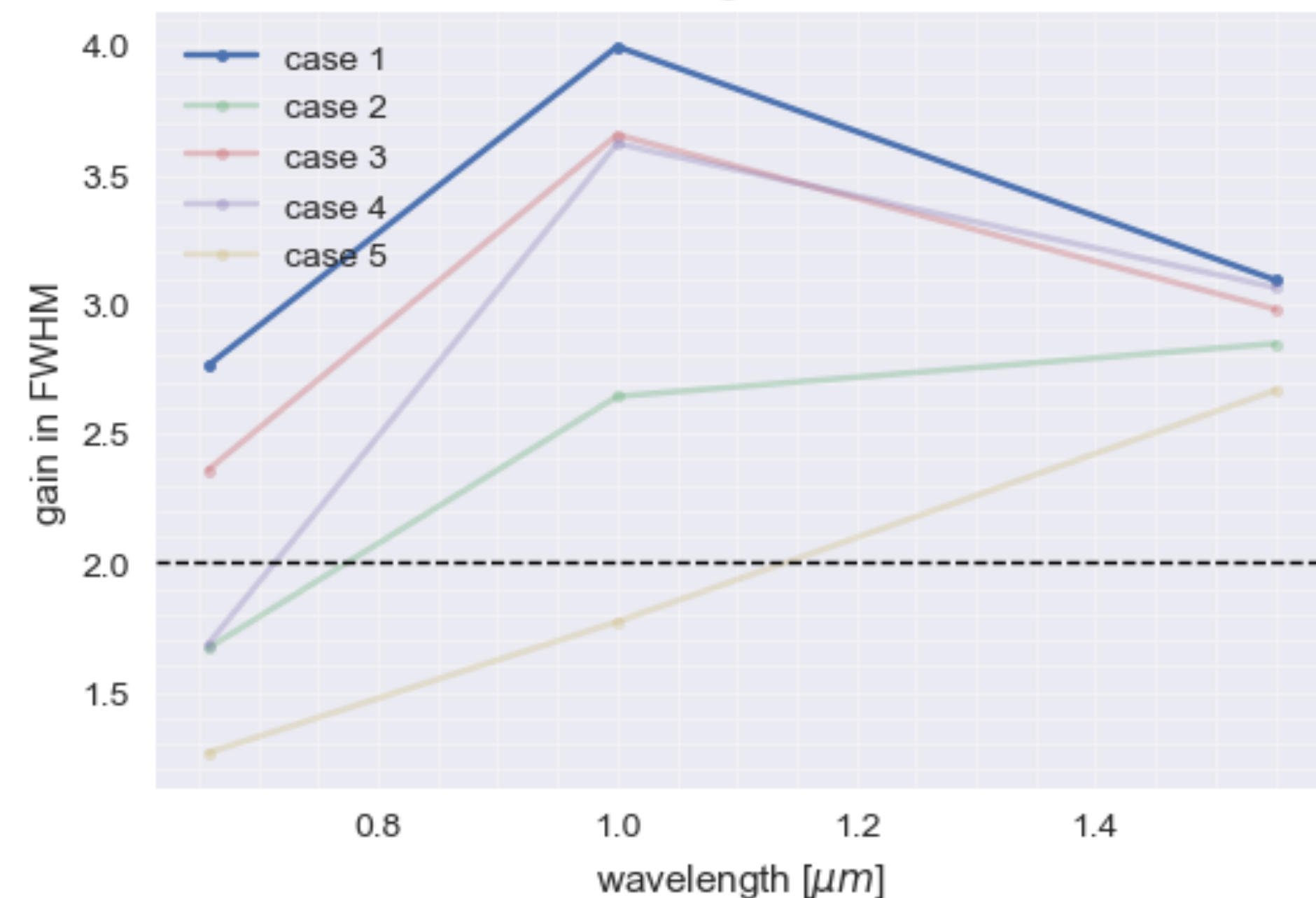
◆ Poor seeing as a major challenge:
study for 1.5'' - 5'' seeing

◆ Simulation features:

- Fresnel propagation to include *scintillation*
- Laser uplink
- AO system



For 3'': Gain of > 3x in FWHM expected at 1.55μm

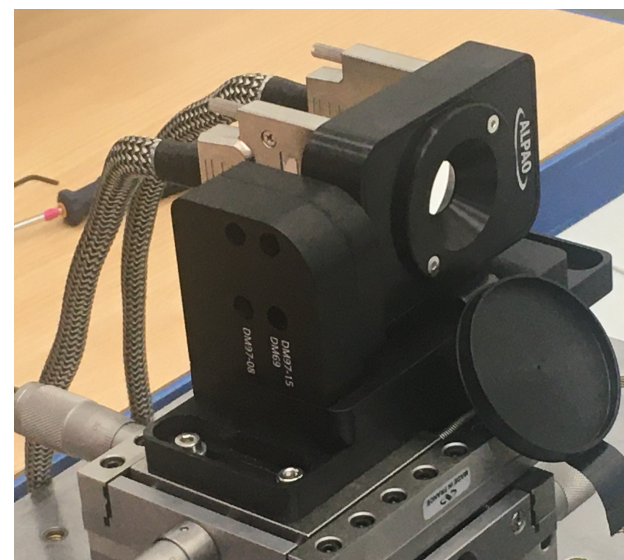


Adaptive Optics system of SALTO

From concept to opto-mechanical integration

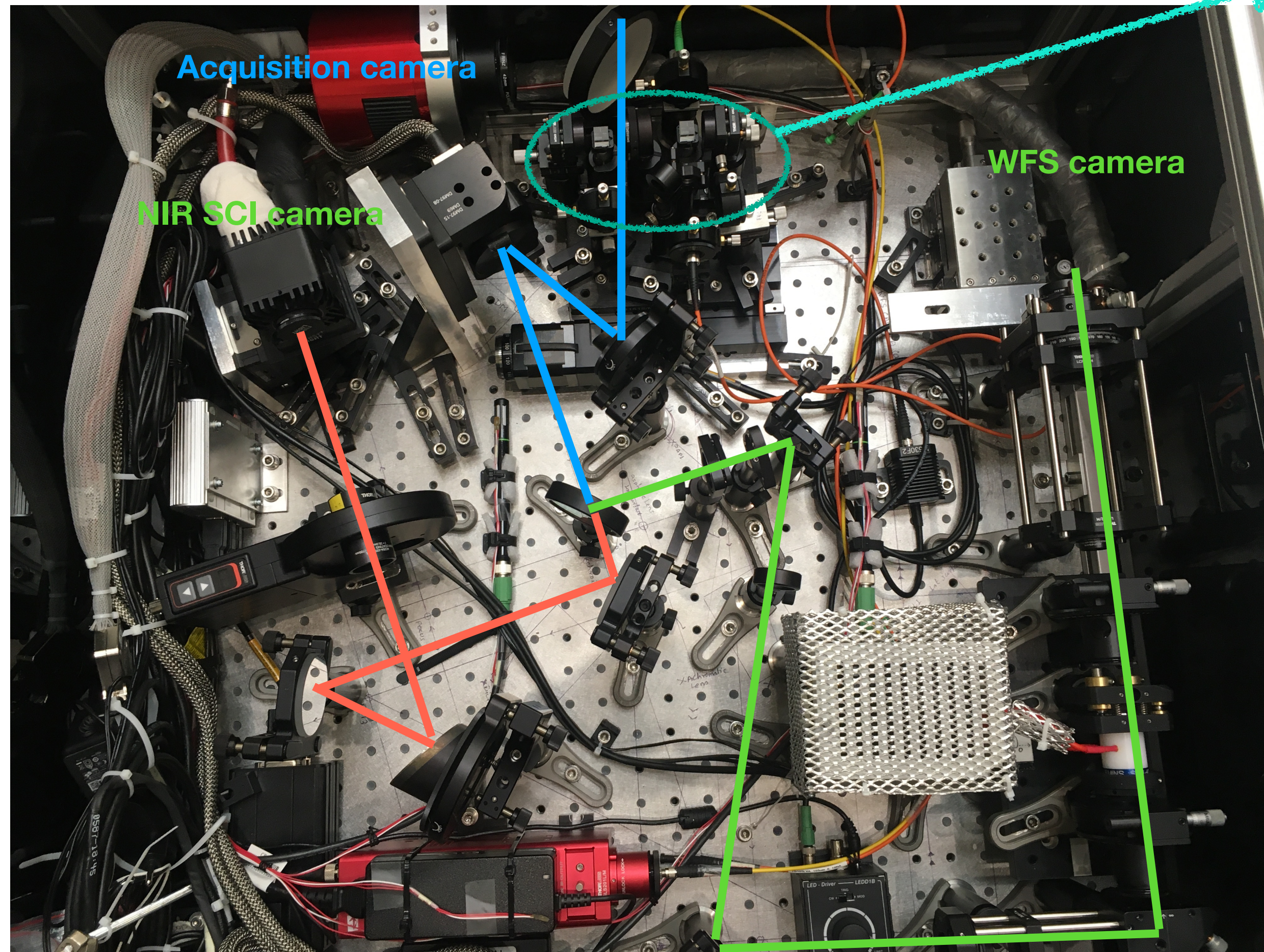


CRED-3
600Hz
640x512
InGaAs 900-1700nm



ALPAO 97-15 Hi-speed

700mm



Calibration unit



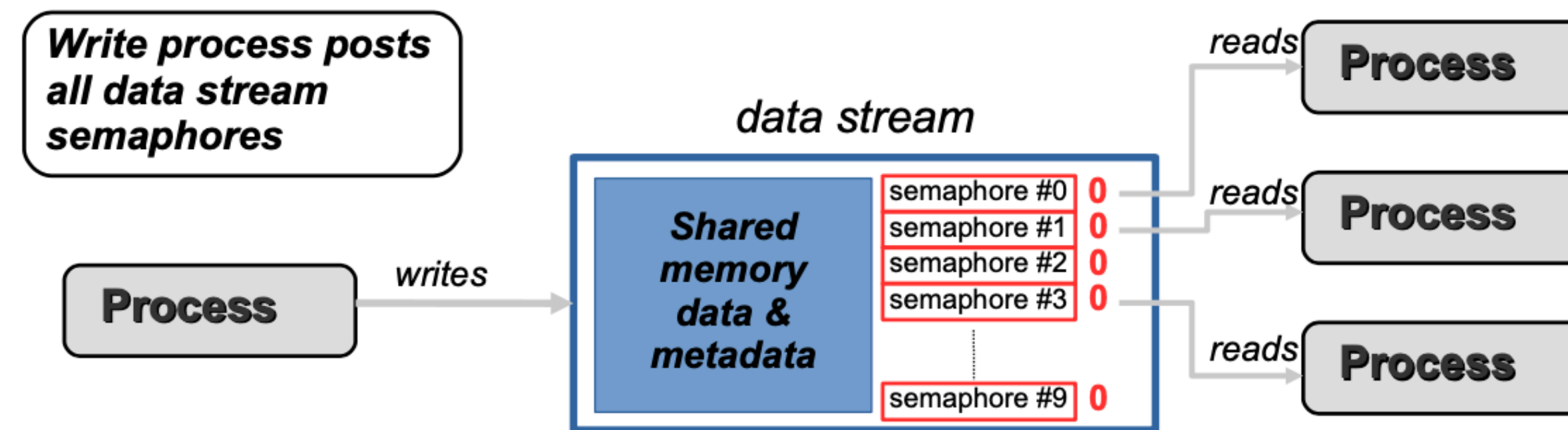
EMCCD 128x128
1kHz (1.8kHz in bin 2)
<1e- RON



KTP Pockels
>1:500
<4-10 μ s opening time, 10kHz
1/2 wave voltage ~1kV

RTC concept

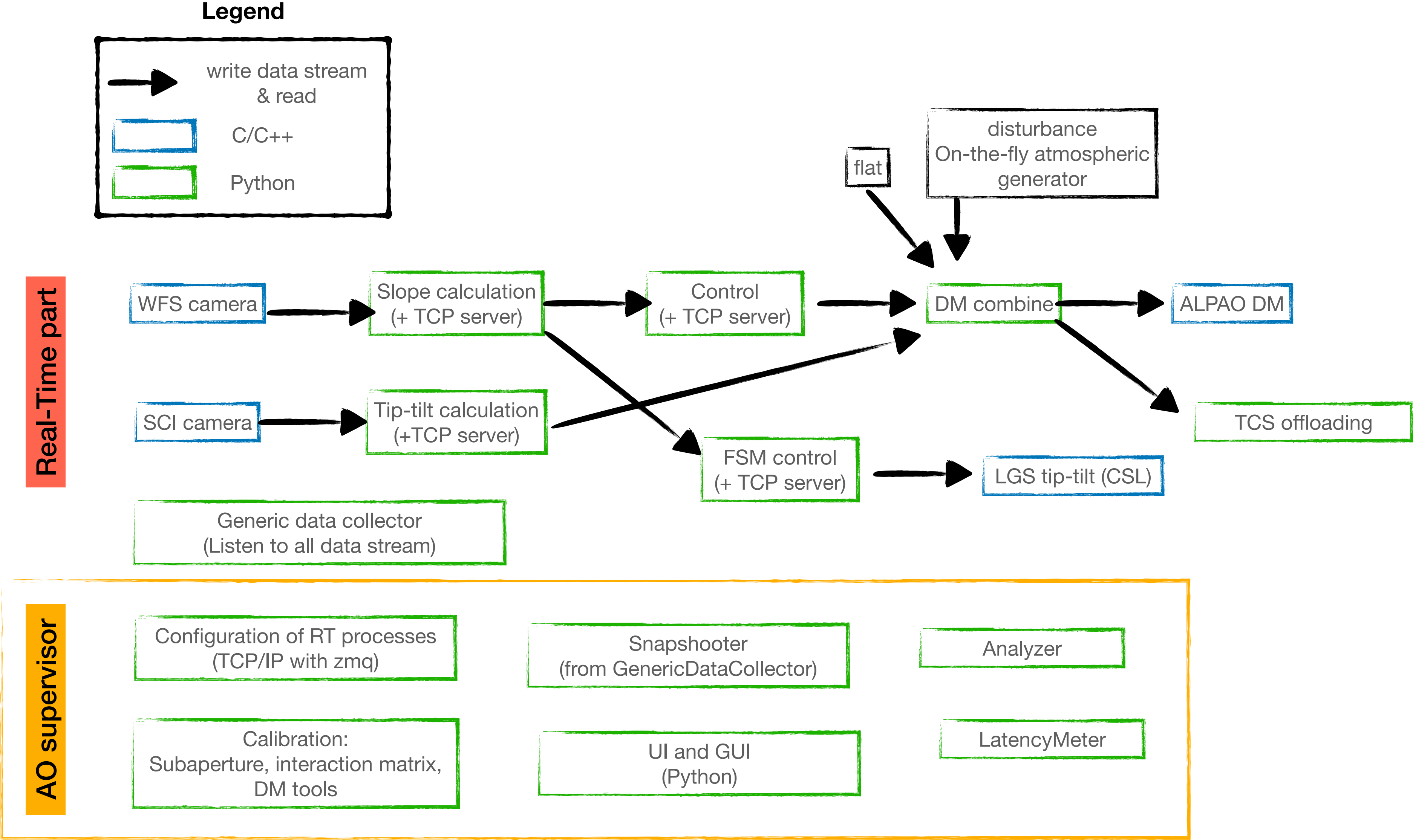
- Custom RTC software **but** using *data stream* concept of CACAO / MILK



Guyon et al. 2018

- IPC contained in the data, held in the shared memory and contain semaphores
- *ImageStreamIO* of MILK <https://github.com/milk-org/ImageStreamIO>
 - C and **Python** support

RTC architecture



Calibration & AO procedures

◆ AO control and procedures:

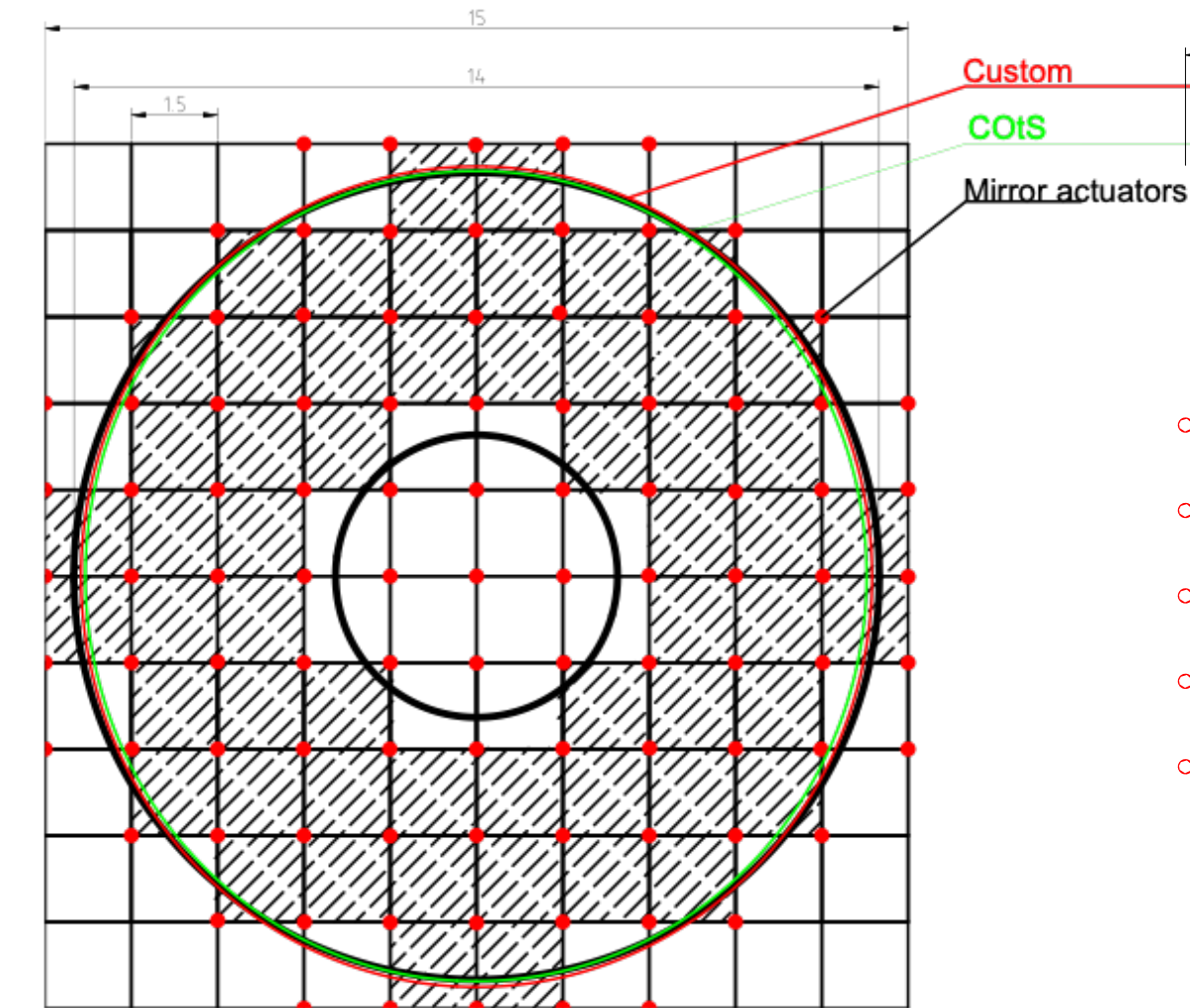
- tCoG (fixed or dynamic)
- K-L modes, leaky integrator — up to 66 modes
- Anti-windup
- LGS modes: async tip-tilt; focus, polarisation, etc. TBD
- DM to TCS offload

◆ Calibrations

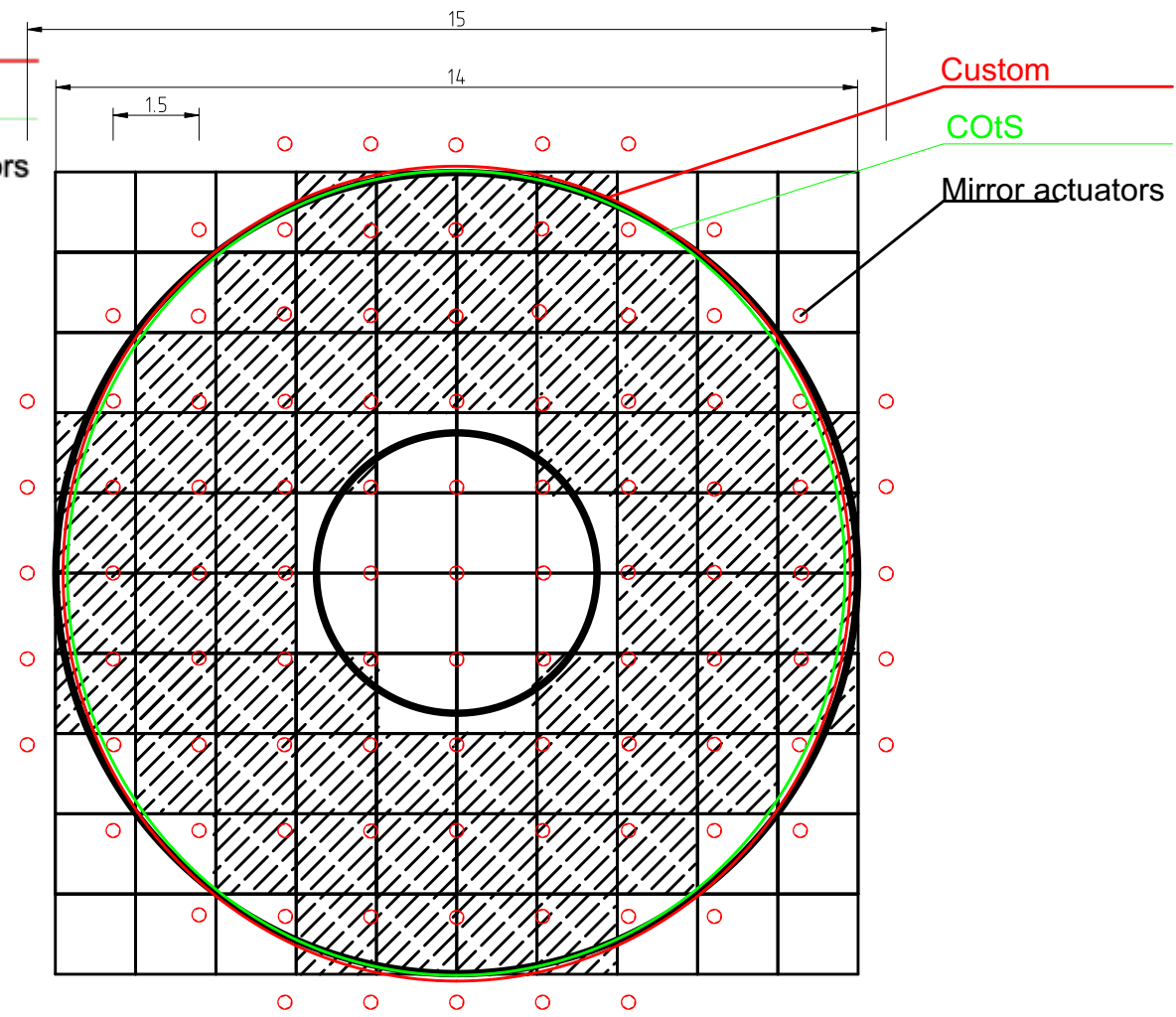
- Fried geometry
- Push-pull modal interaction matrix with modal amplitude

◆ Daytime test:

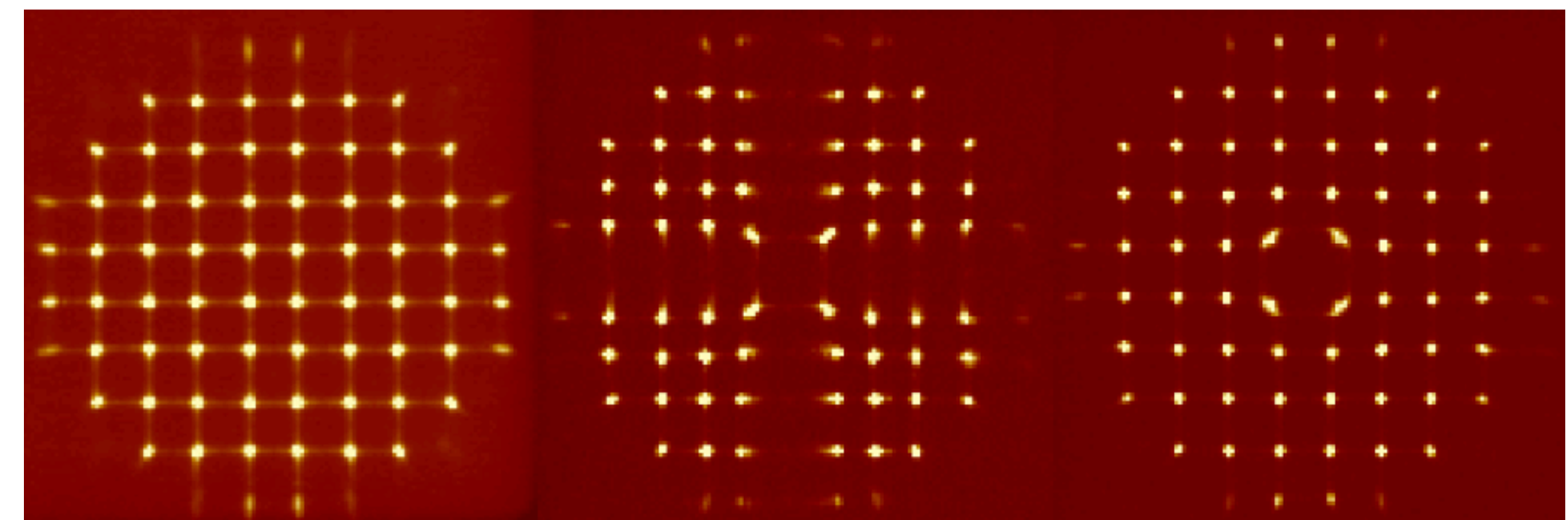
on-the-fly injection of turbulence using infinite (extruded)
phase screens



NGS: perfect Fried geometry



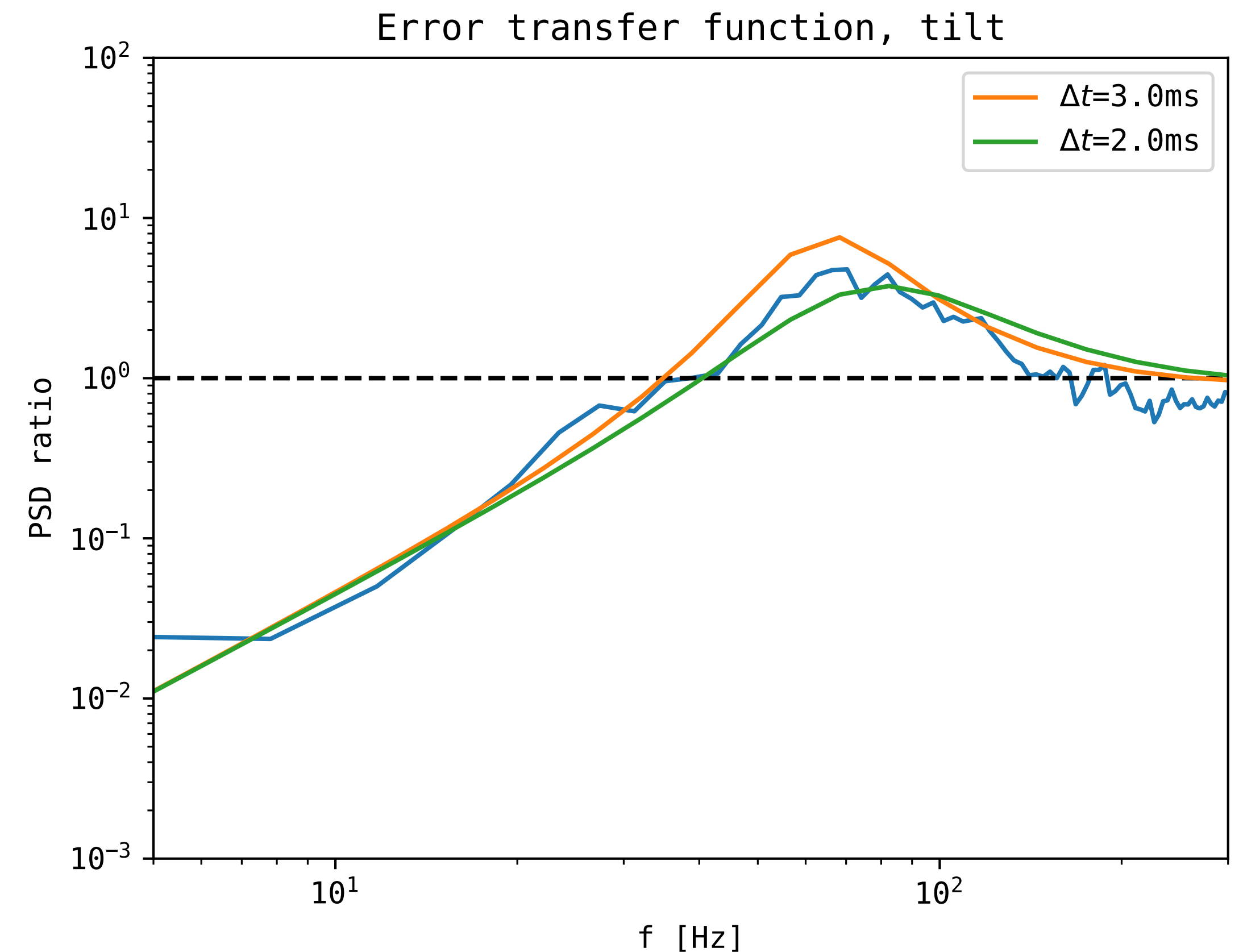
LGS: slight deviation from Fried geometry



Temporal performance

- ◆ Pure computation delay : $\sim 600\mu\text{s}$
- ◆ AO bandwidth characterisation
 - ETFs compared to standard control model
 - Pure delay of $\sim 2.5\text{ms}$ measured based on rejection

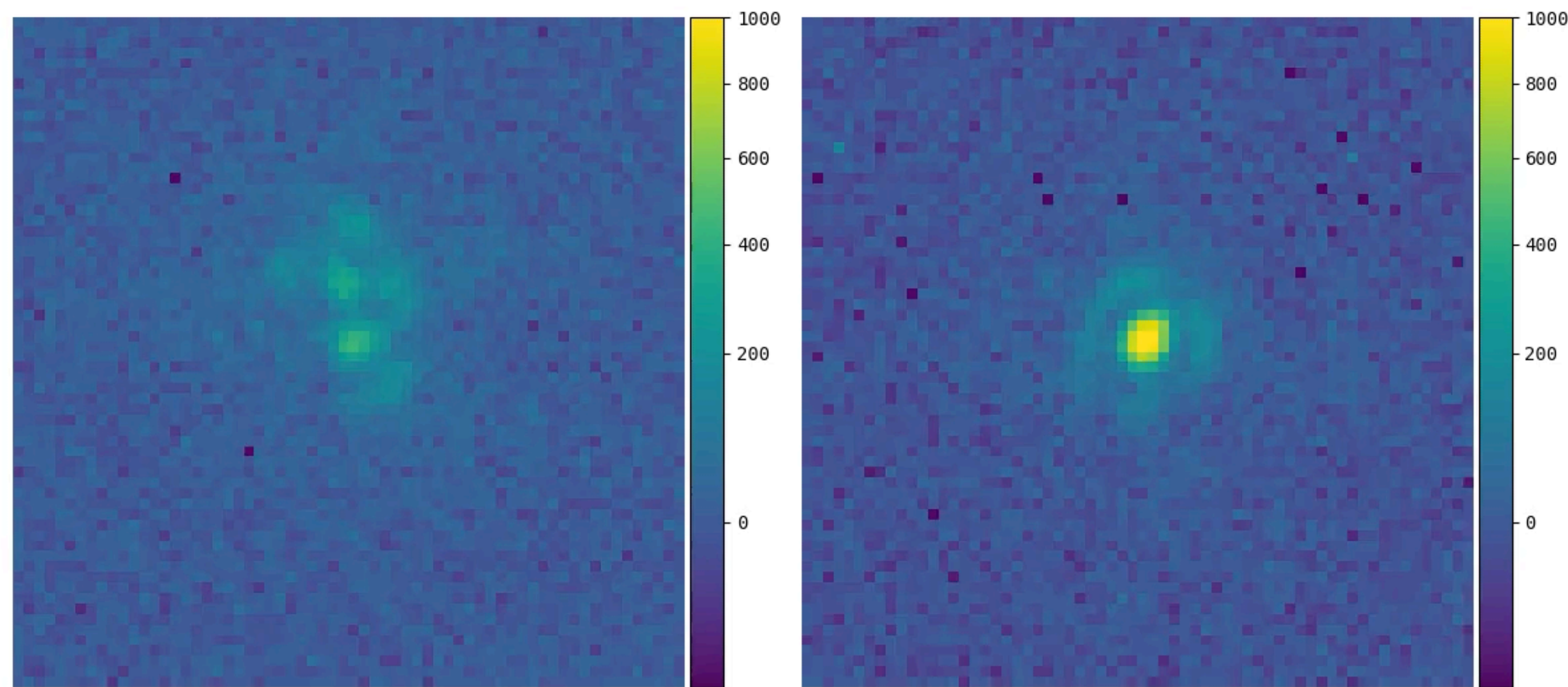
Readout	$\sim 1\text{ms}$
Computation	$\sim 600\mu\text{s}$
TBD (DM ?, Camera ?)	$\sim 1\text{ms}$



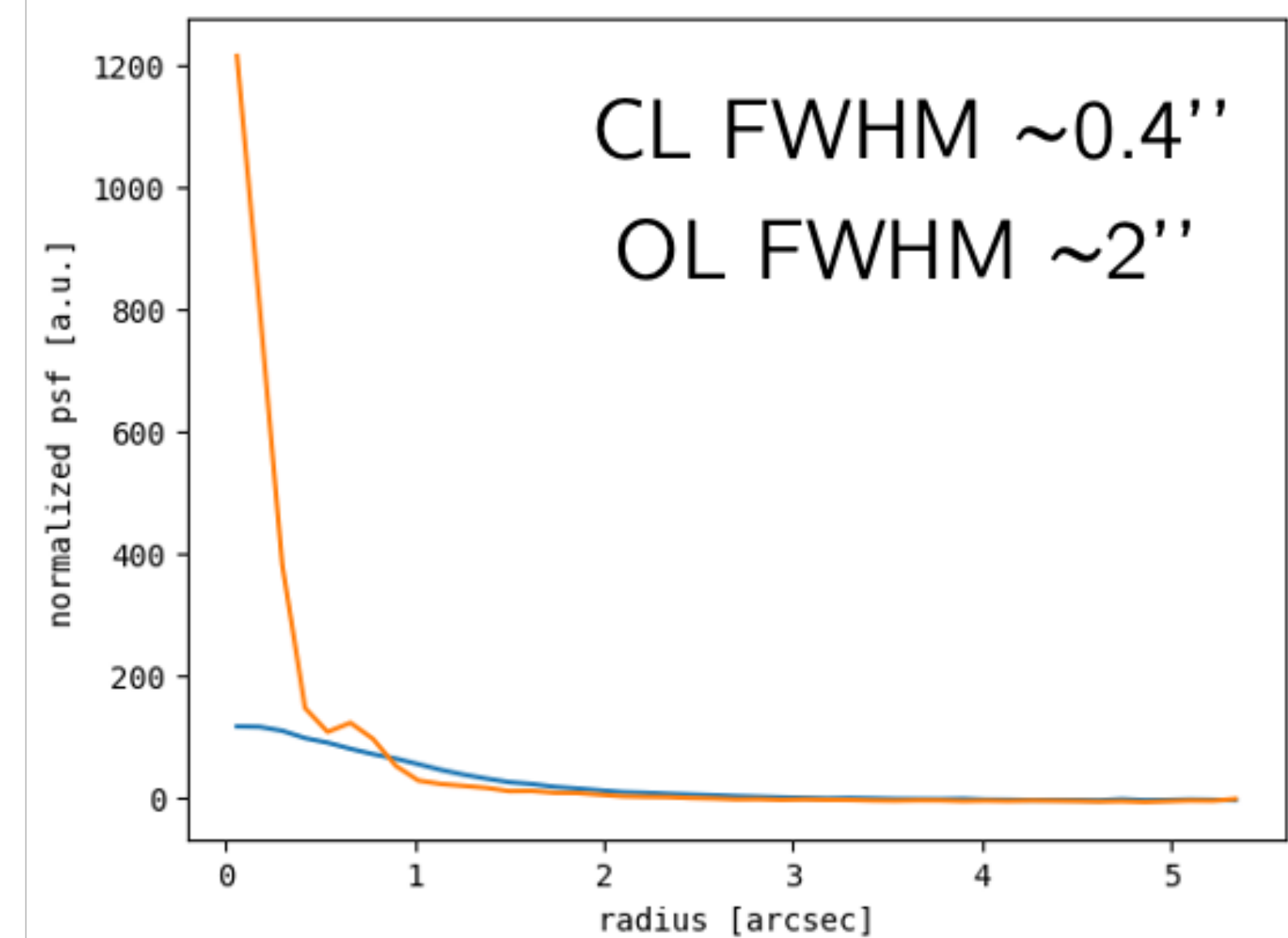
AO First light

NGS work 03/09/2021

- Closed-loop on NGS at 100Hz, 31 modes corrected
- Images taken at $1.55\mu\text{m}$ (0.1sec/frame)



10 seconds on-sky, $1.55\mu\text{m}$

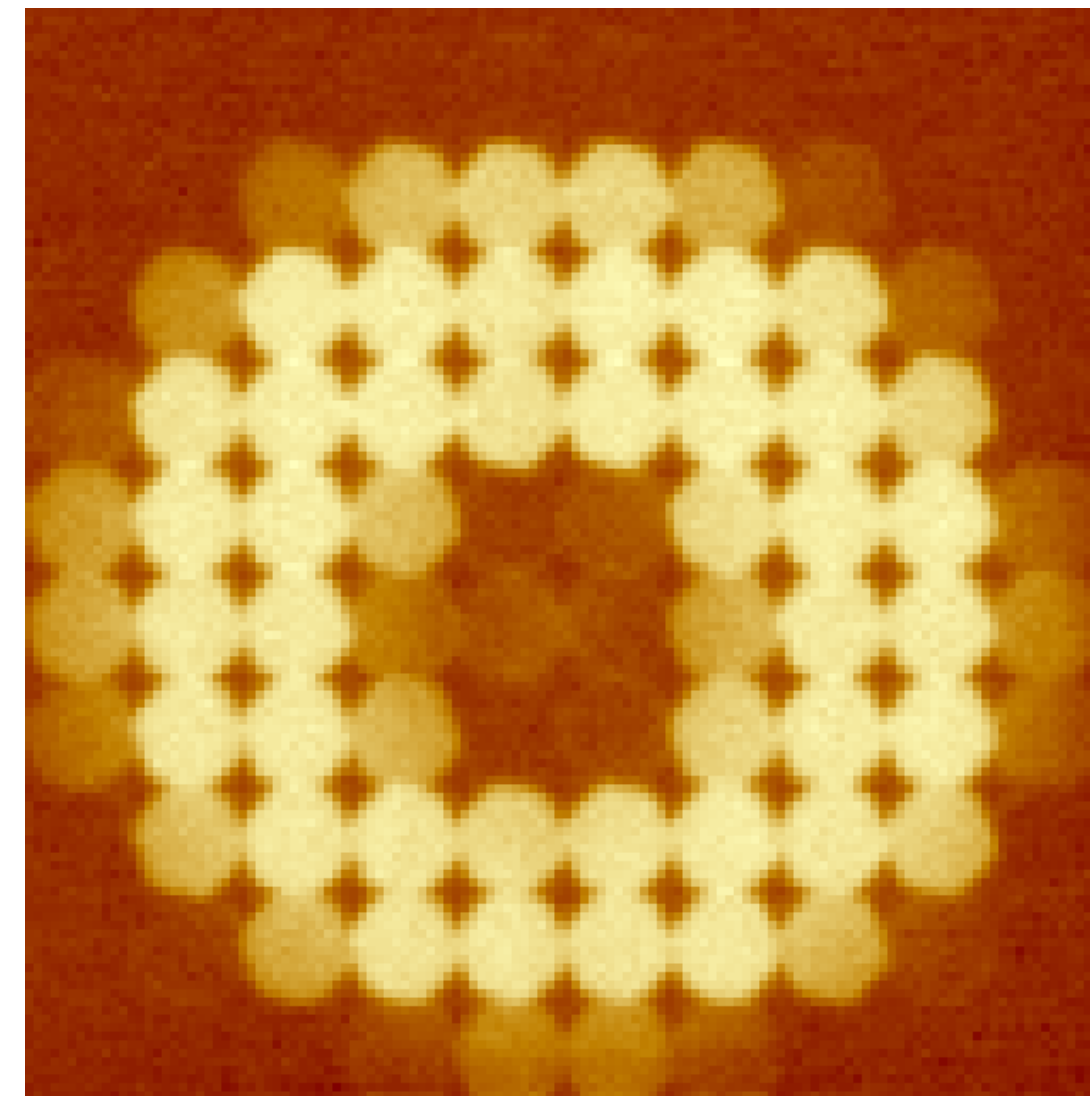


AO first light

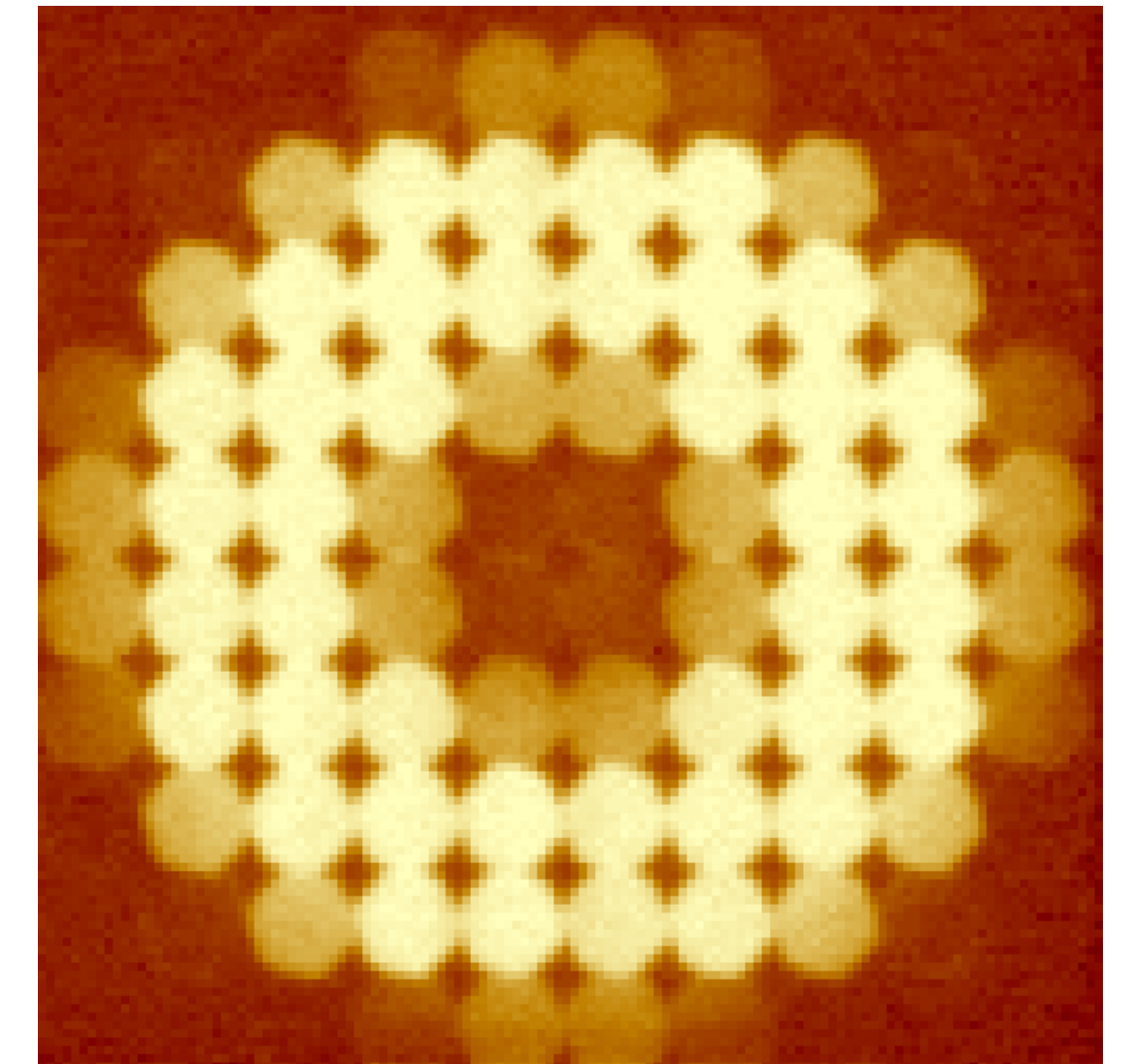
NGS work (con't) 09/09/2021 and 05/10/2021

- Re-alignment of pupil
- TCS offload
- Streamline AO operation
 - Test at 500Hz
 - 60 modes and better basis

Before



After



AO first light

LGS first light on the WFS 28/04/2021



- Lower power operations $\sim 200\text{mW}$
- Laser triggered operation
- Laser beam tuning
- Alignement & acquisition
- Centring on the WFS :
 - going from 30 arcmin to 12.5''

Current work & Prospects

- ◆ Finalise installation Redu Space Service
- ◆ NGS AO characterisation
- ◆ LGS AO commissioning
- ◆ Future
 - ◎ Use it as a platform for R&D (e.g. predictive control)

Any feedback & interest : gorban@uliege.be



