Possible application of FPGA to the MAORY Real Time Computer

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Abstract

MAORY is the Multi-Conjugate Adaptive Optics module for the European Extremely Large Telescope first light.

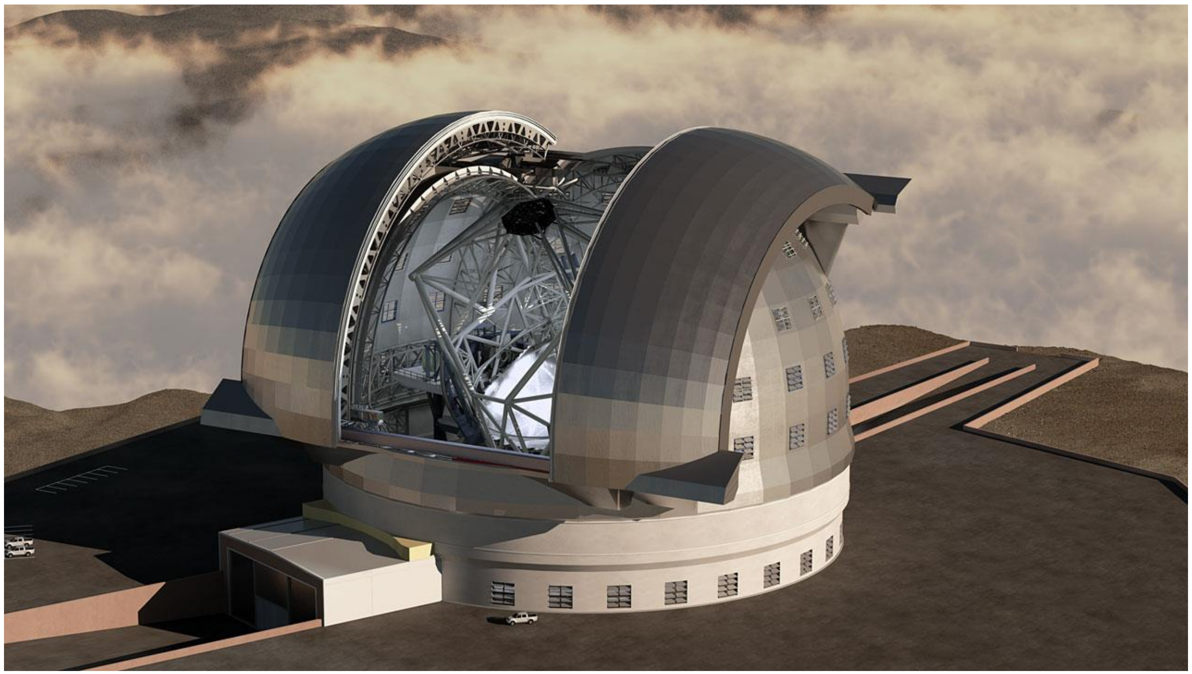
The baseline of MAORY is to rely upon the use of multiple Laser Guide Stars (6), multiple Natural Guide Stars (3) for wavefront sensing and multiple Deformable Mirrors (DM) for correction (M4/M5, that are part of the telescope, and 2 post focal DMs).

The Real-Time Computer is a key sub-system of MAORY. It must collect the measurements from various sensing devices and drive several thousands actuators within high demanding latency requirements dictated by the system performance needs.

The FPGA technology has been widely diffused in Real Time Systems due to its low latency and high determinism.

Performance evaluation of this technology for the wavefront sensors images calibration and processing is in progress.

E-ELT



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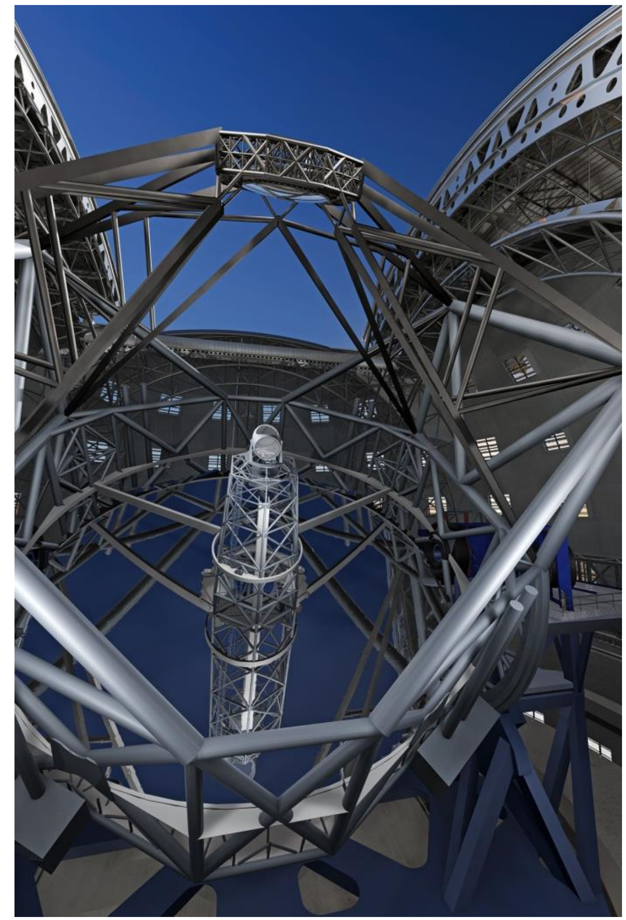

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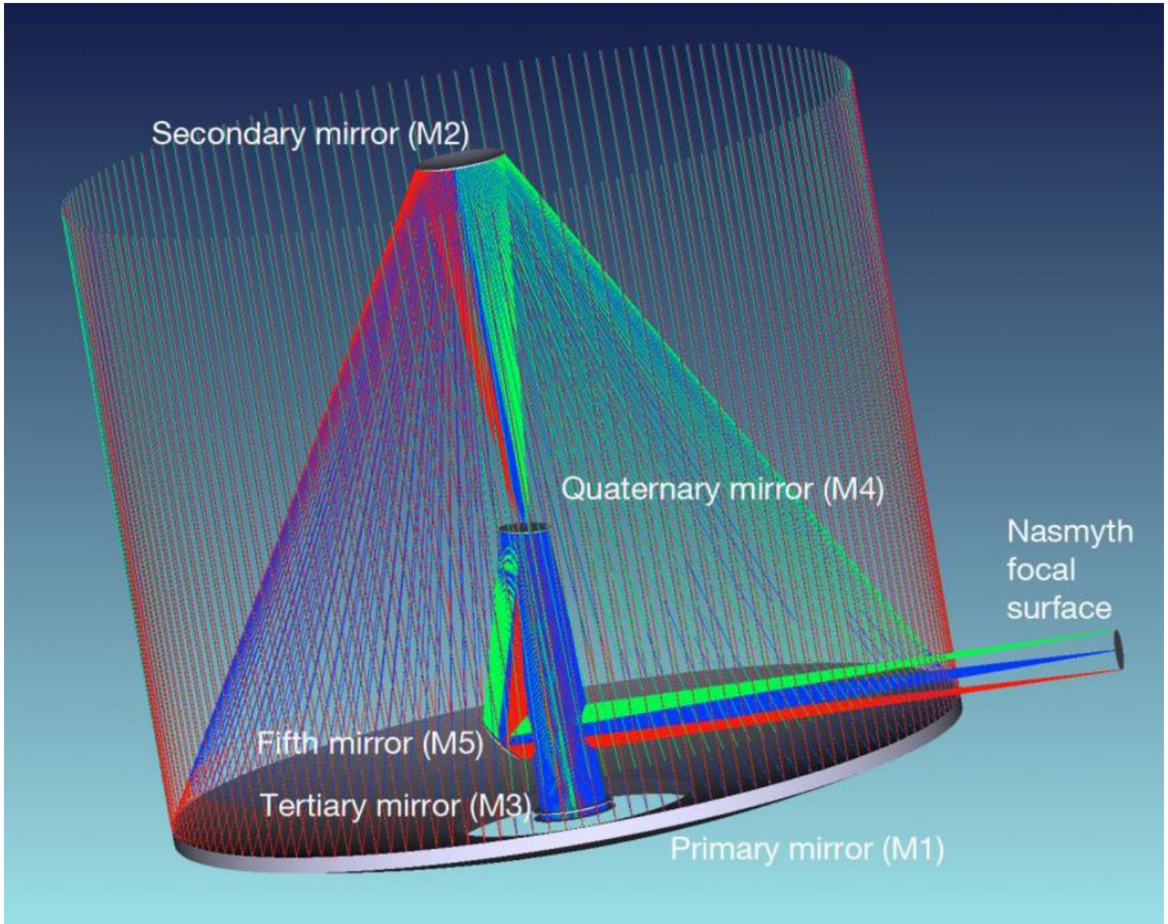
- ESO: European Southern Observatory
- ESO E-ELT programme fully approved
- Largest optical/near-infrared telescope in the world
- Cerro Armazones: 3060 m (Atacama Desert)
- First light: 2024

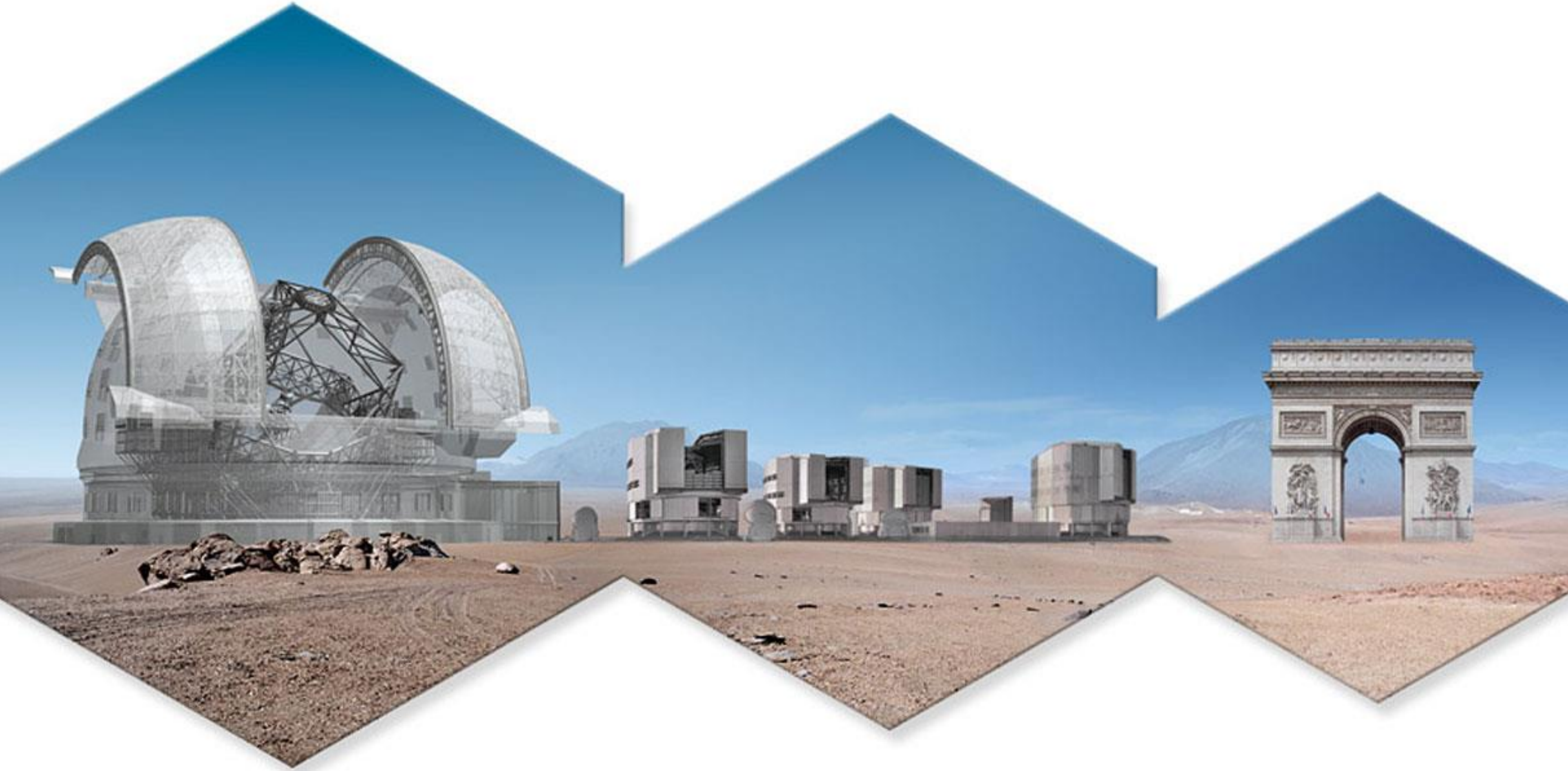
E-ELT: An adaptive telescope



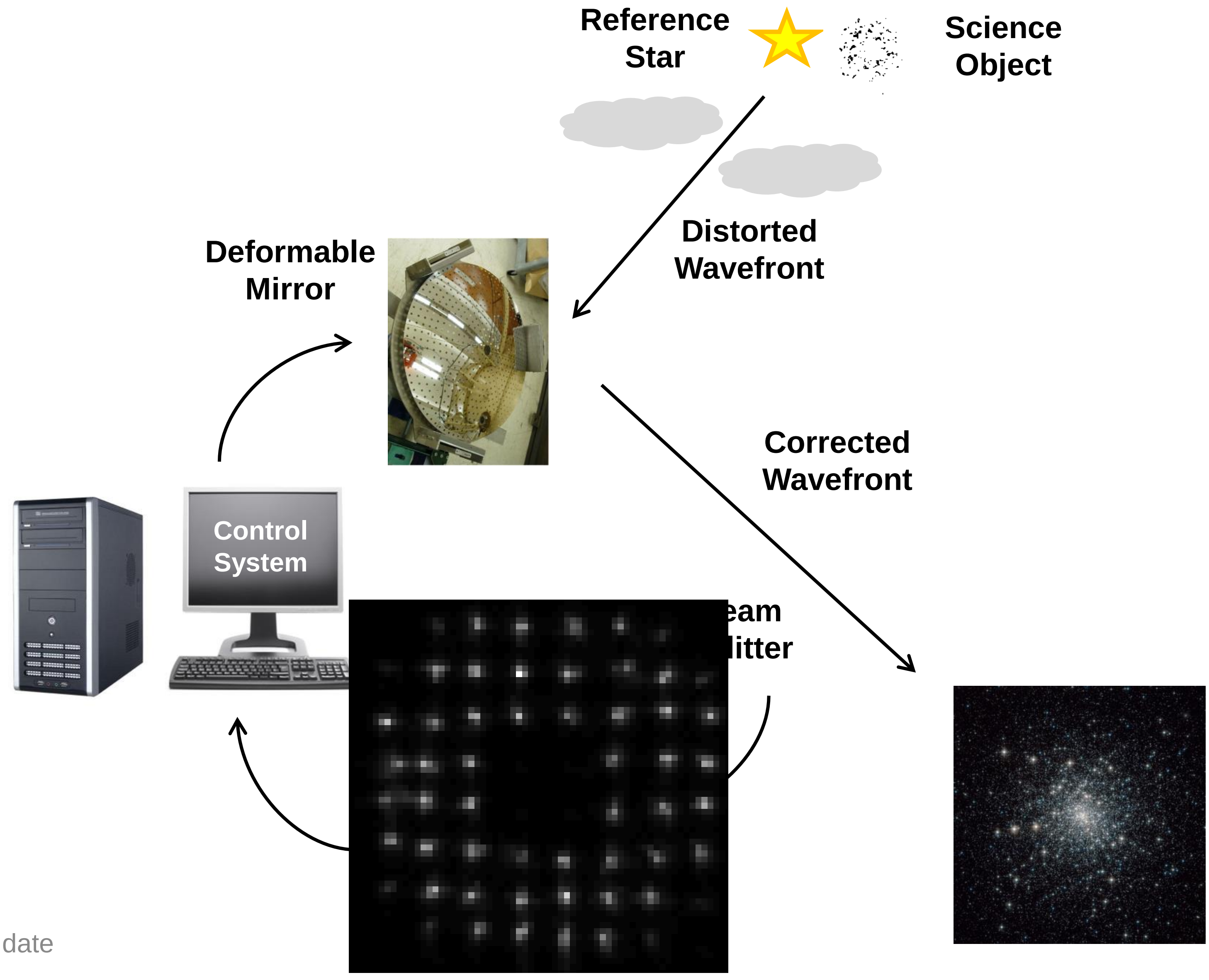
Da “E-ELT Construction Proposal”, © ESO

Mirror	Diameter	Notes
1	39 m	Segmented 798 segments
2	4.1 m	Active
3	3.7 m	Active
4	2.4 m	Adaptive >5000 DoF
5	2.6 m	Tip-tilt

FoV: 10 arcmin

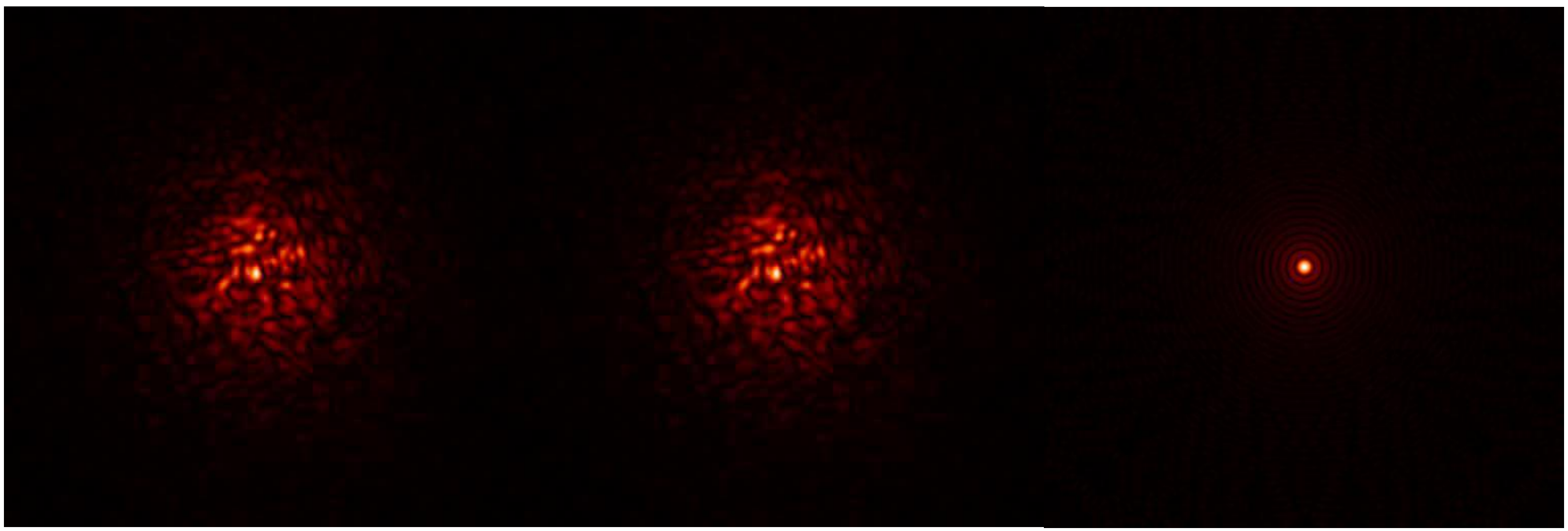


Adaptive Optics



Adaptive Optics

The aim is to measure the wavefront and to correct it in order to recover the diffraction limit PSF, and so to reach the maximum definition allowed by the aperture size.



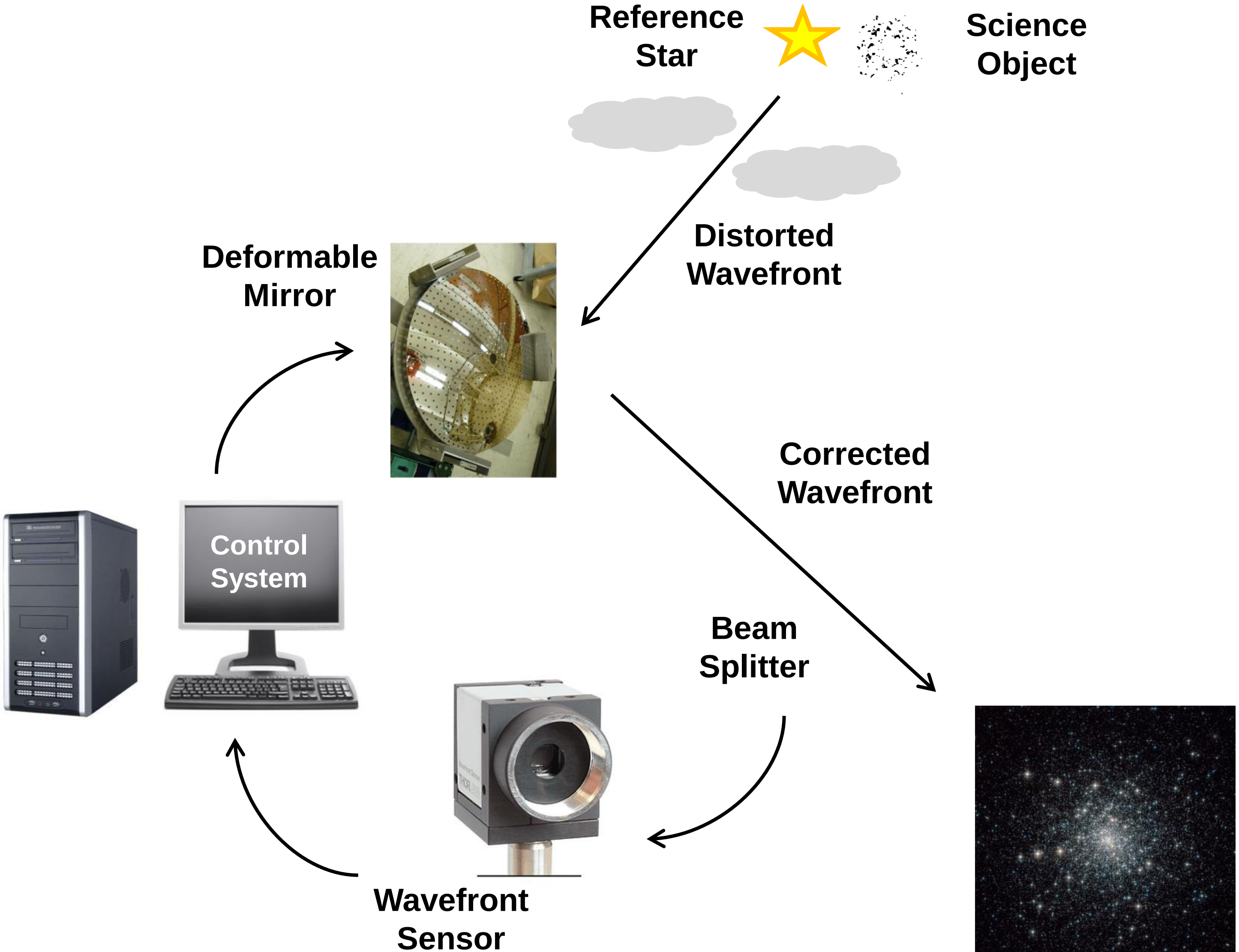
Short exposure PSF | Long exposure PSF | Diffraction limited PSF

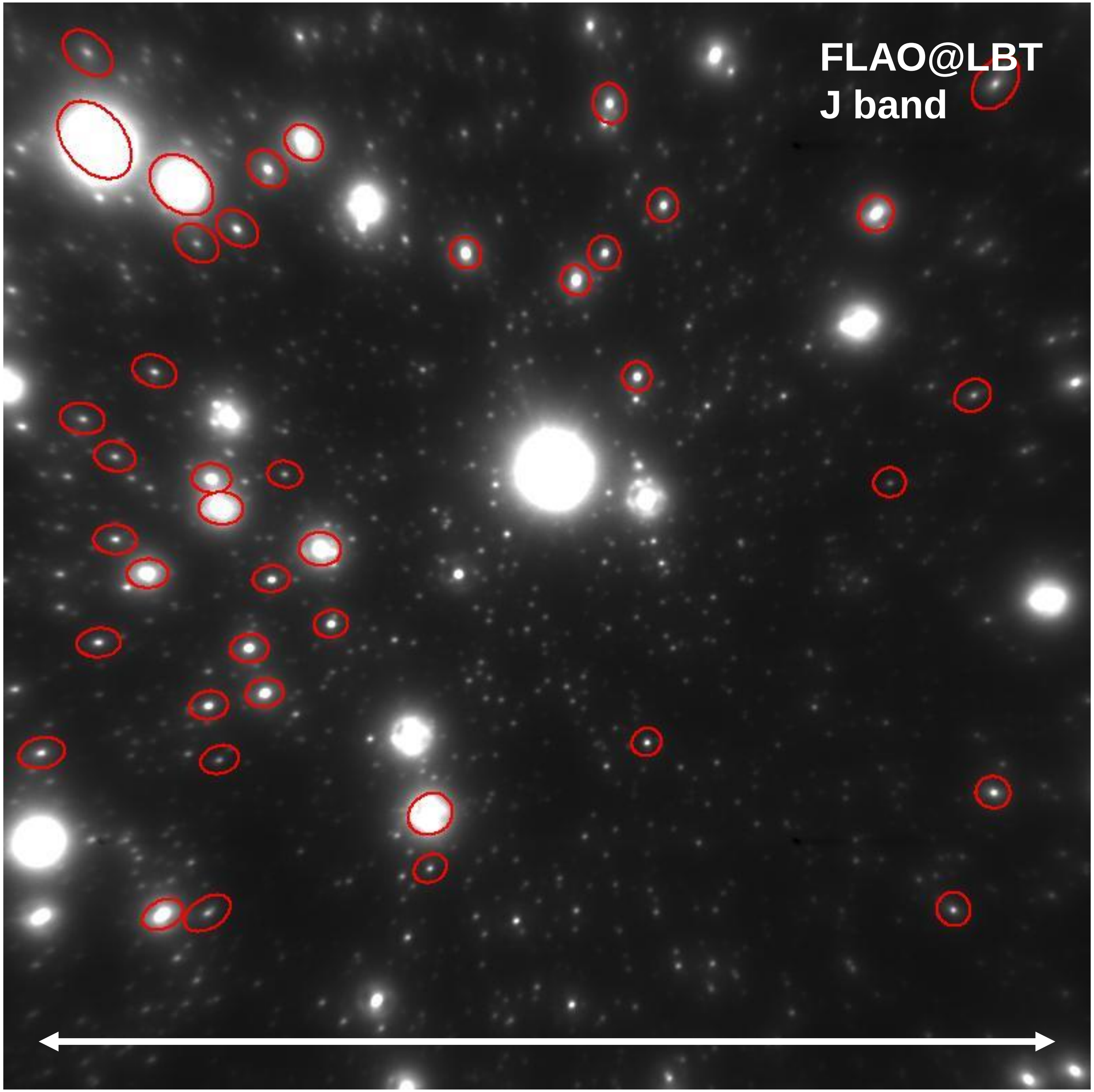
E-ELT image FWHM k band: 0.5’’ (seeing) → 11 mas (DL)

MAORY

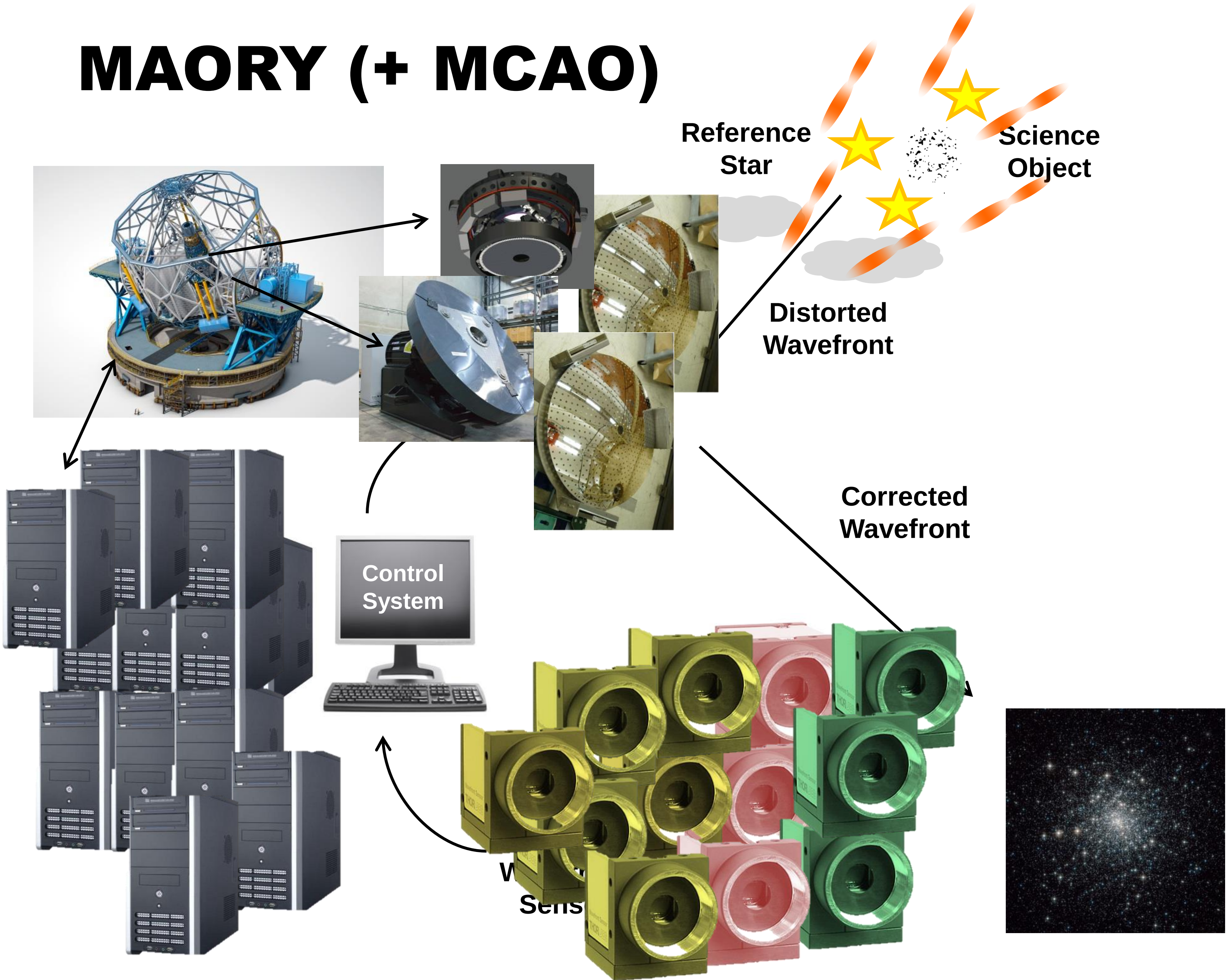
- E-ELT Multi Adaptive Optics Relay for MICADO and another ins.
- Wavefront sensing based on 6 Sodium LGS and 3 NGS
- Wavefront Correction operated by M4/M5 (Telescope) and 2 Post focal deformable mirrors conjugated at 5 km and 12.7 km
- MCAO and SCAO modes

Classical Adaptive Optics (SCAO)

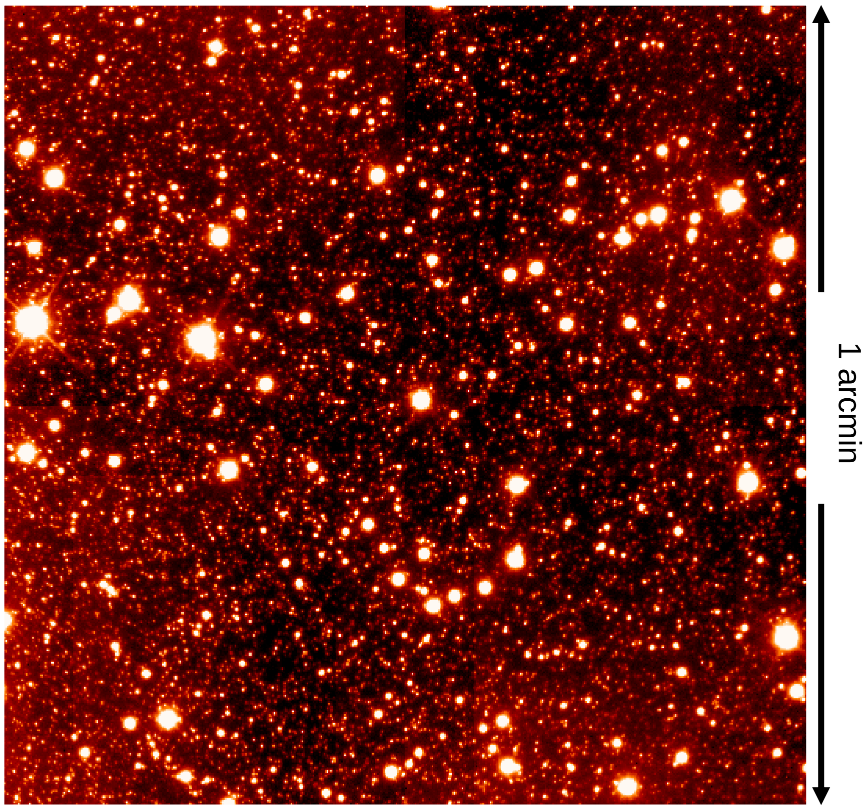



FLAO@LBT
J band

MAORY (+ MCAO)


Reference Star
Science Object
Distorted Wavefront
Corrected Wavefront
Control System

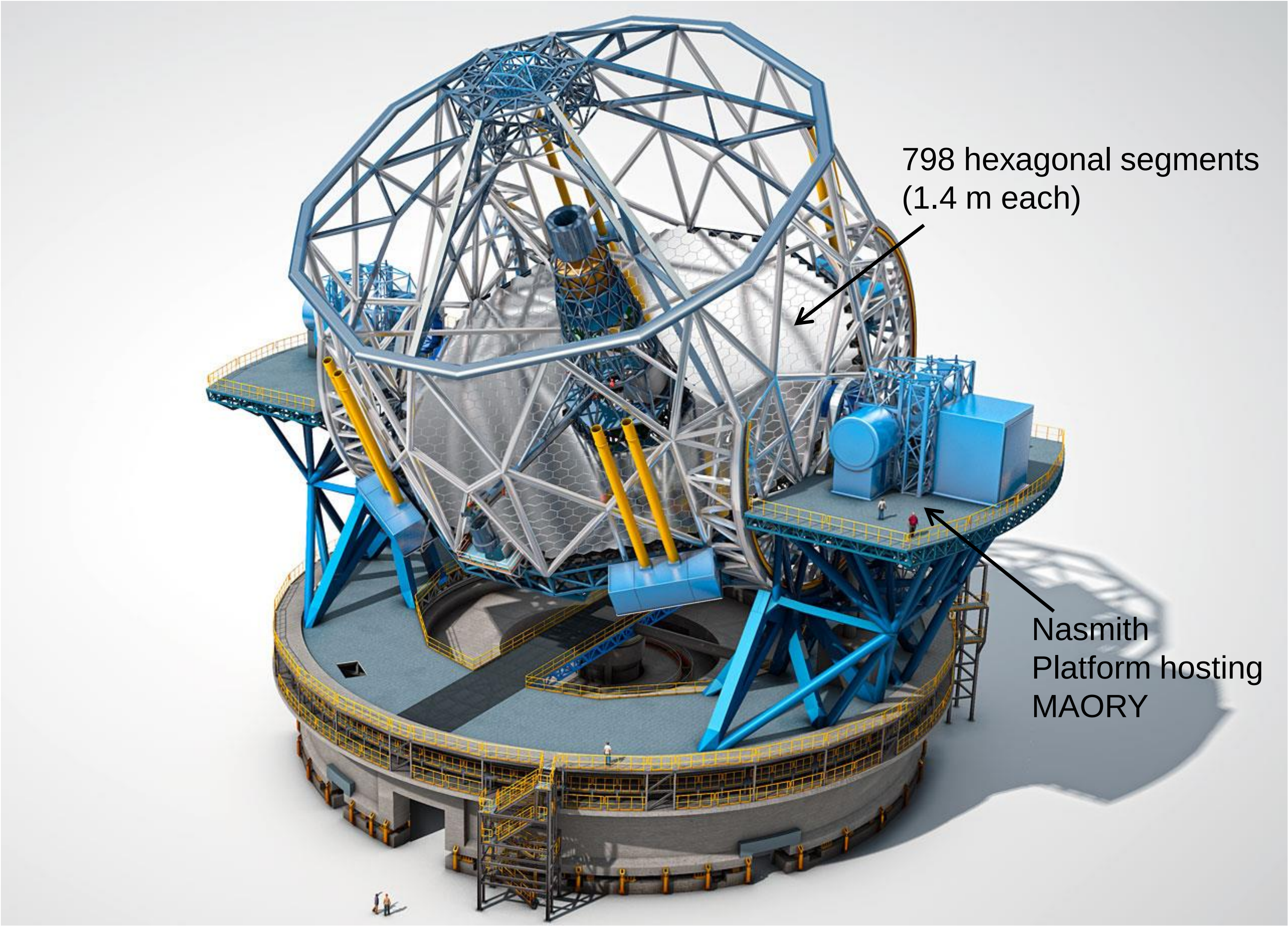
MAD @ VLT: MCAO demonstrator



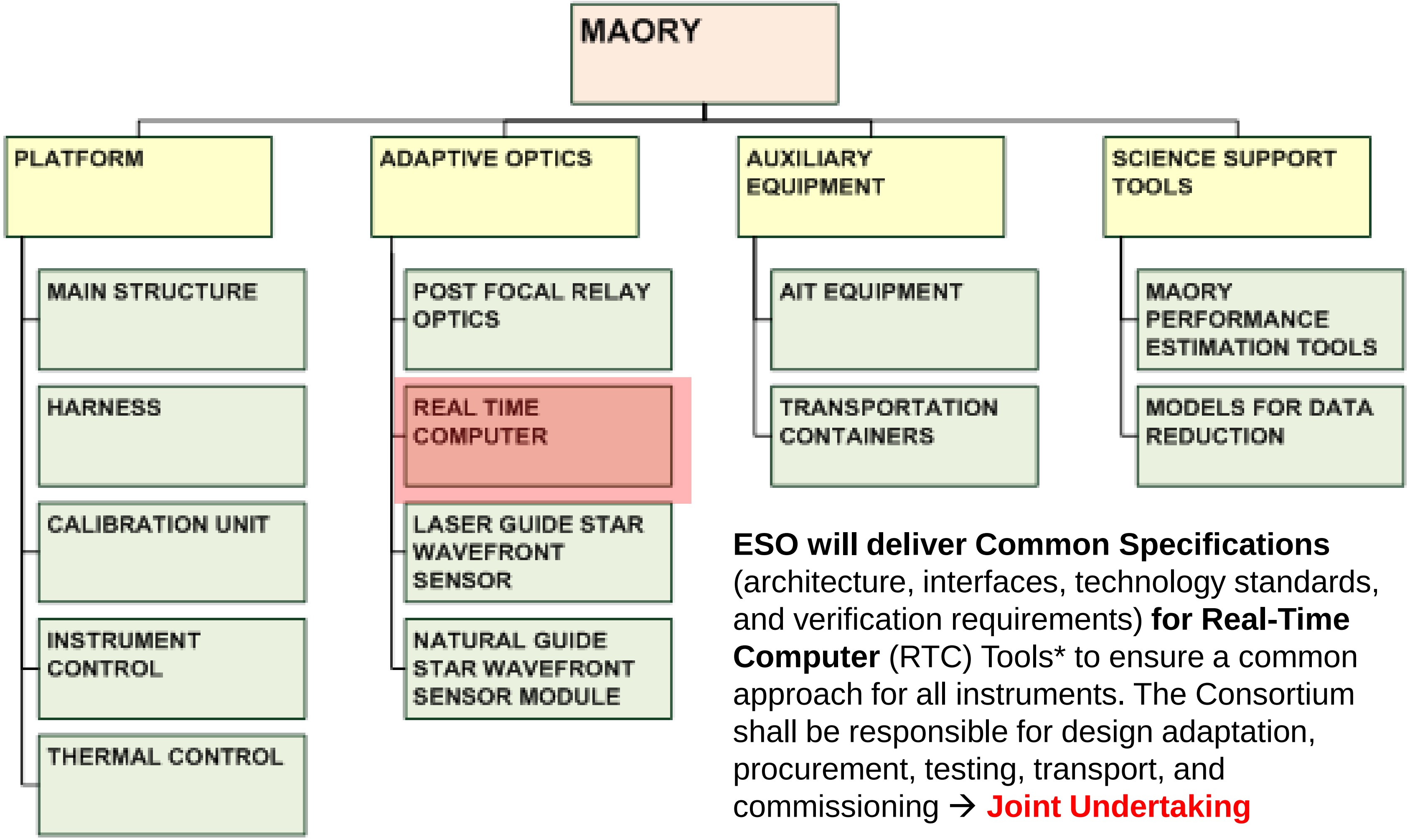
T_{exp}[Ks]: 600s
FWHM: 100mas
K~20.5
DIMM: 0.69"
3 NGS on 2 arcmin

- Uniform PSF across a ‘large’ FoV

E-ELT


798 hexagonal segments
(1.4 m each)
Nasmith
Platform hosting
MAORY

MAORY Product Tree



ESO will deliver Common Specifications (architecture, interfaces, technology standards, and verification requirements) **for Real-Time Computer** (RTC) Tools* to ensure a common approach for all instruments. The Consortium shall be responsible for design adaptation, procurement, testing, transport, and commissioning → **Joint Undertaking**

*Tools shall be bespoke components (software and/or hardware) re-usable implementations (either partial or complete) of key RTC processing stages or infrastructure for which standardization across instruments is deemed critical.

MAORY Control System

Sensors:

- 6 Laser Guide Star WFS (589 nm) → 80x80 sub-apertures, 10x10 pixels each, 500-1000 Fps, 10 bit pixels (TBC)
- 3 Fast NGS WFS (IR) → 2x2 sub-apertures, 125x125 pixels each (goal 250x250), 500-1000 Fps, 32 bit pixels (TBC)
- 3 Slow NGS WFS (Visible) → 5x5 – 20x20 sub-apertures, 0.1-10 Fps, 32 bit pixels (TBC)

(Fast) Actuators:

- Telescope M4, deformable, 5316 DoF, 500-1000 Hz
- Telescope M5, tip tilt, 2 DoF, 500-1000 Hz
- Maory DM1 and DM2, deformable, 500-2000 DoF, 500-1000 Hz (TBC)
- Maory LGS WFS Jitter mirrors (x6), 2 DoF, 500-1000 Hz (TBC)

MAORY Real Time Control

In Adaptive Optics the control has to be done in Real Time

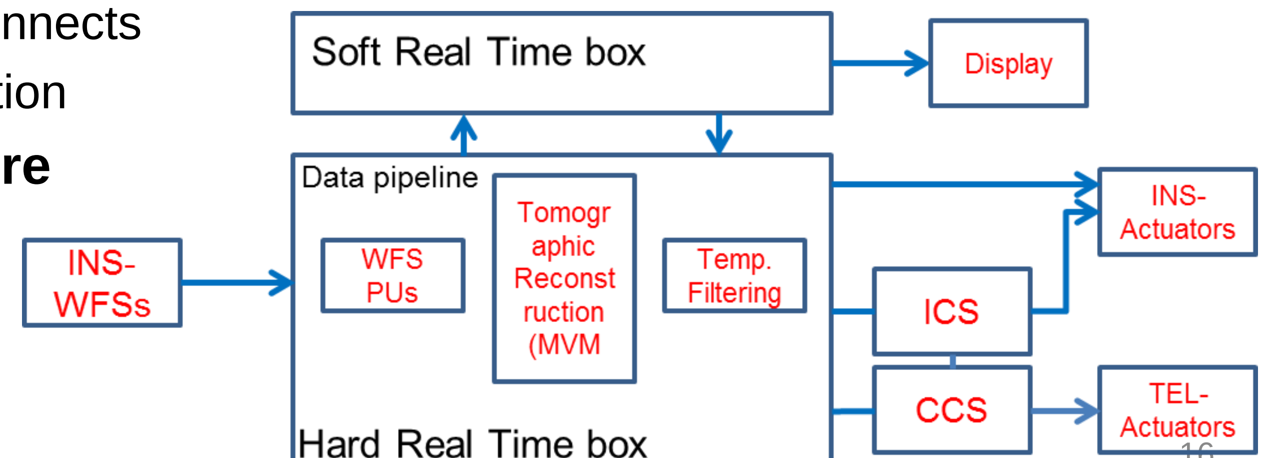
- Real time means deterministic
- Deterministic means that tasks has to be executed within their deadline
- Scheduling management

… moreover it has to be fast

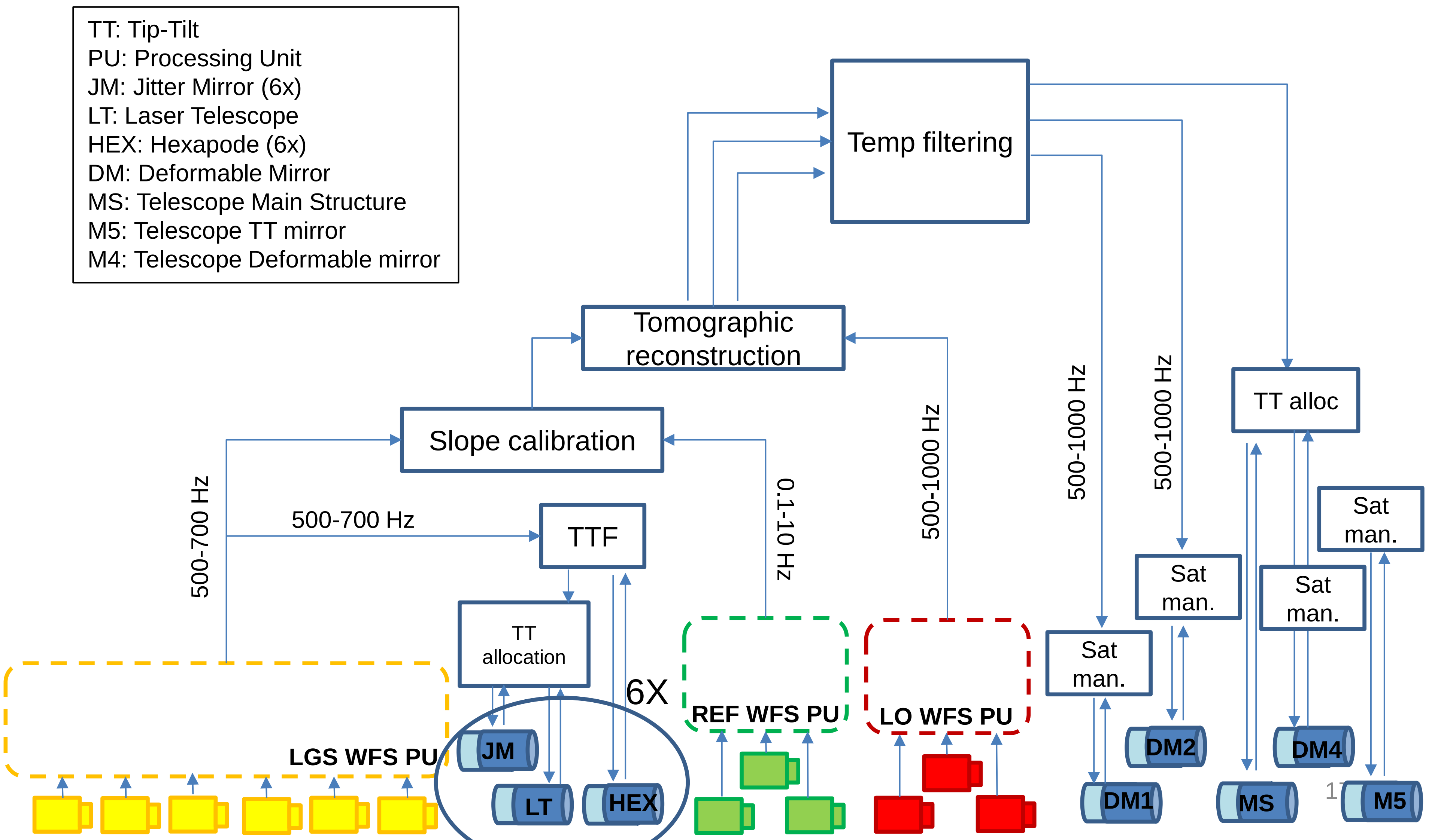
- Low latency → Hardware choice
- GPU, **FPGA**, Multi Integrated Core tecnology (Xeon Phy)
- Smart/Fast interfaces
- Smart/Fast interconnects
- Software optimization

General Architecture

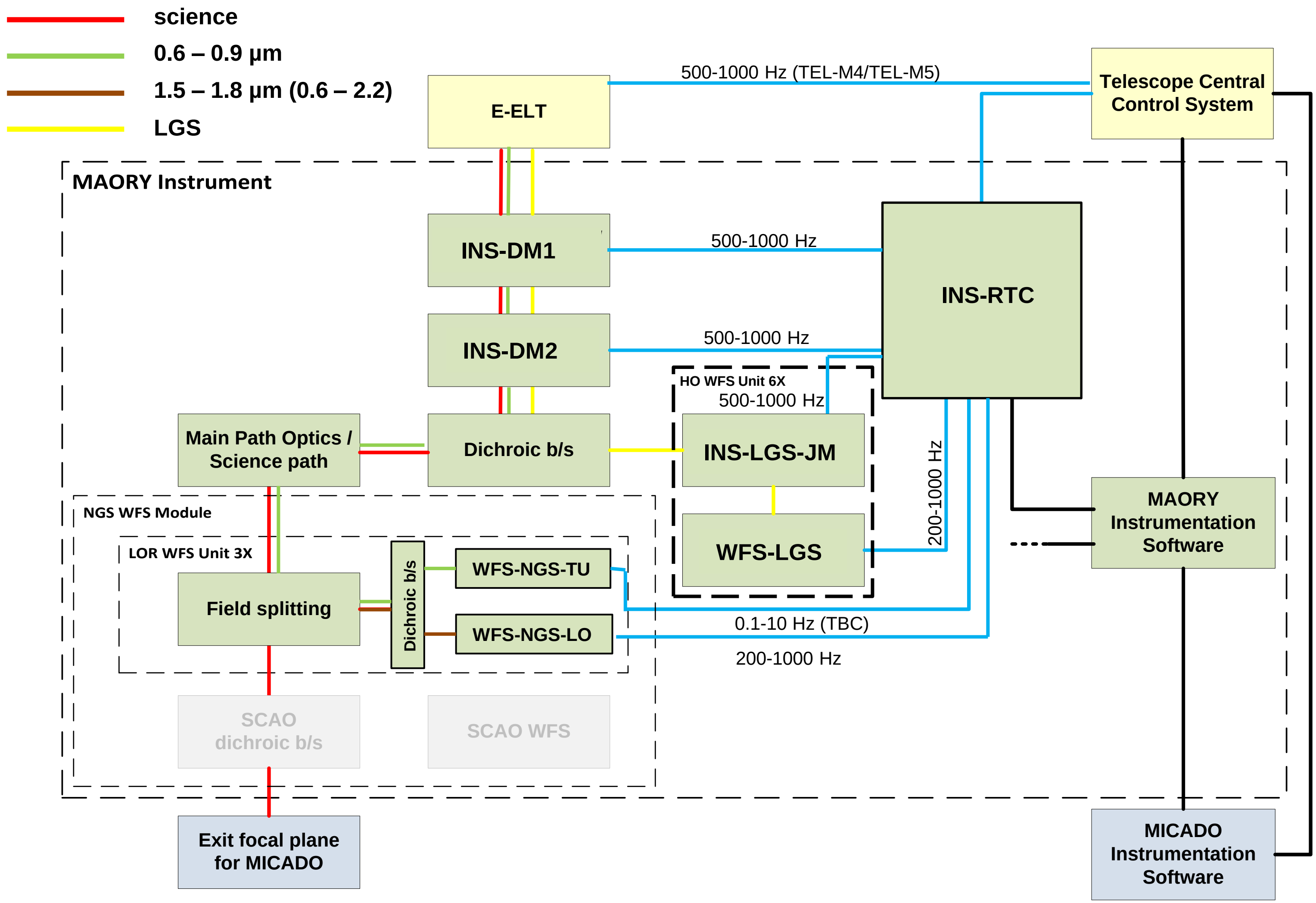
- Hard Real Time
- Soft Real Time



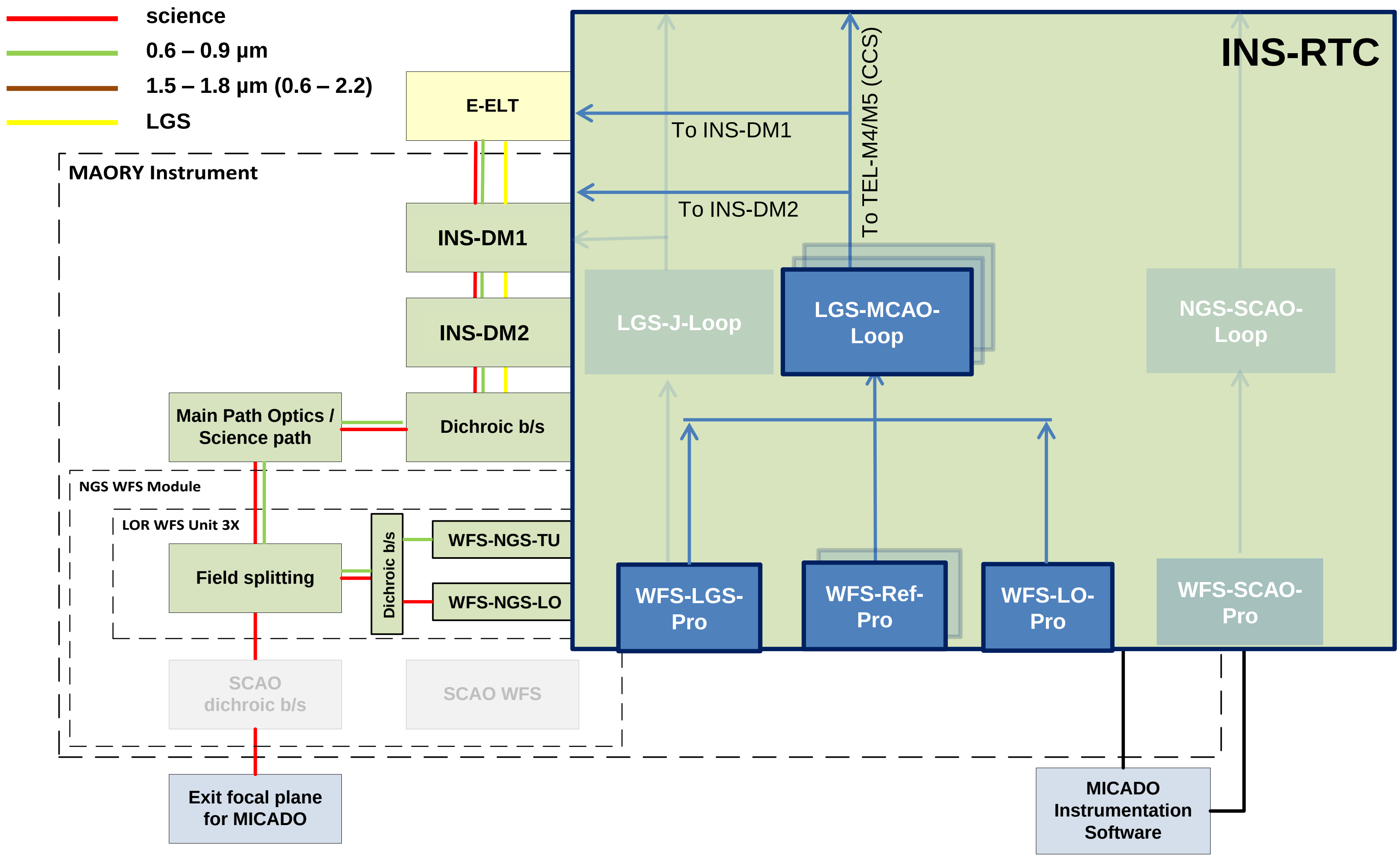
MAORY Real Time Control View



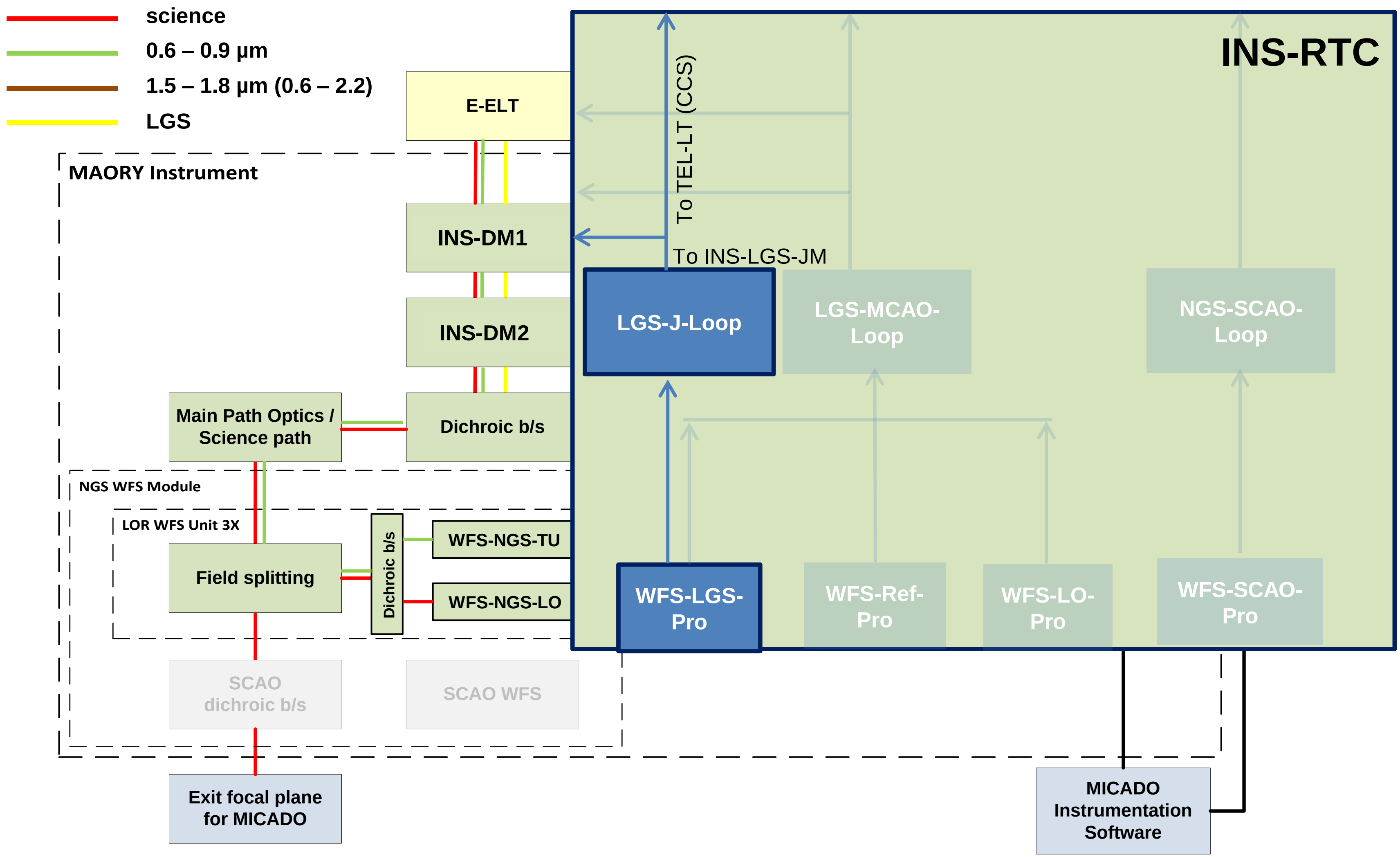
MAORY LGS-MCAO mode



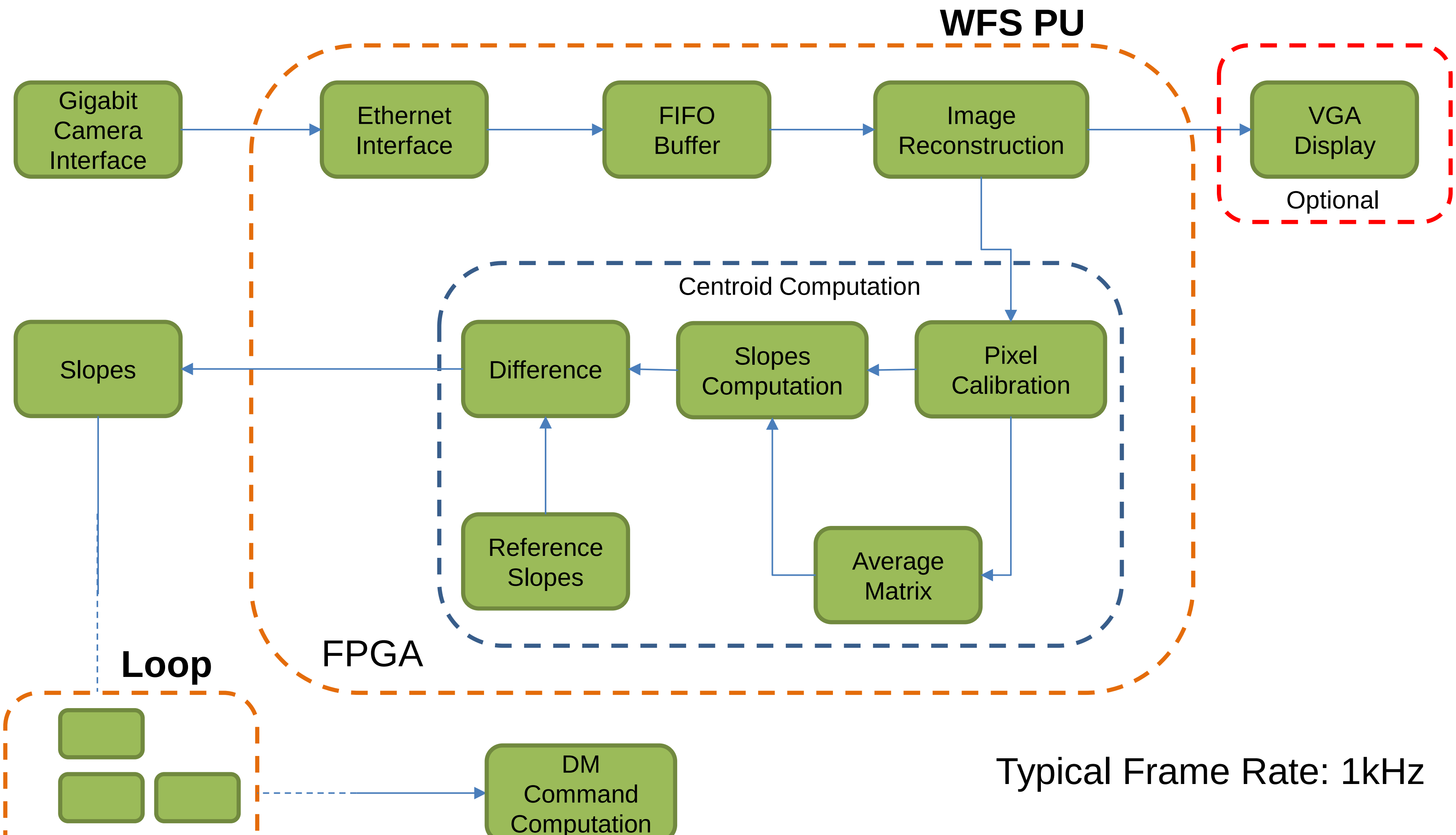
MAORY LGS-MCAO mode



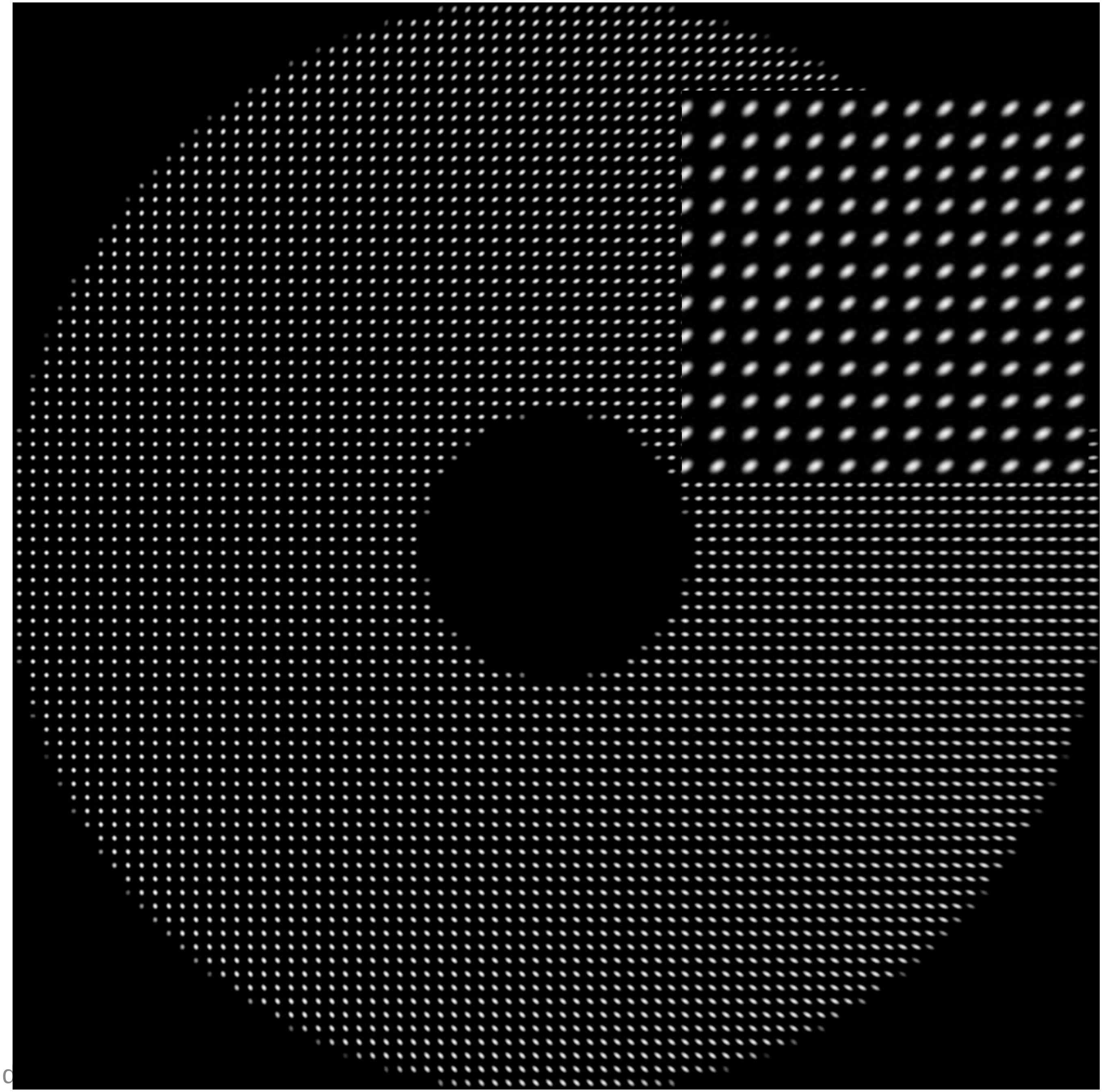
MAORY LGS-MCAO mode



RTC embedded in FPGA



Typical Frame Rate: 1kHz



Centroid Computation

$$C_x = \gamma . \frac{\sum_{i,j} x_{i,j} W_{i,j} I_{i,j}}{\sum_{i,j} W_{i,j} I_{i,j}} \qquad C_y = \gamma . \frac{\sum_{i,j} y_{i,j} W_{i,j} I_{i,j}}{\sum_{i,j} W_{i,j} I_{i,j}}$$

Weighted Center of Gravity (baseline)

$x_{i,j}$, $y_{i,j}$ are the pixel coordinates

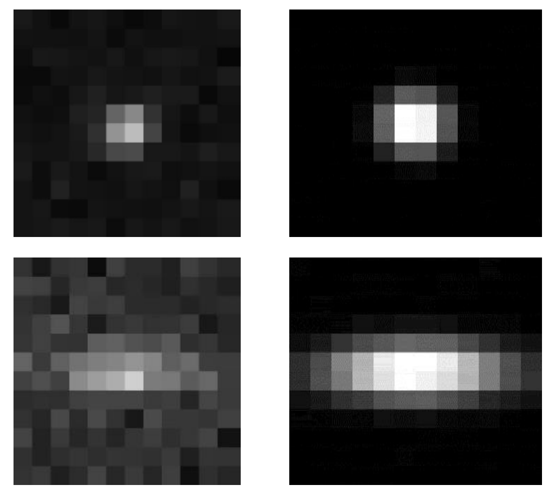
$W_{i,j}$ is Weighting function

$I_{i,j}$ is Pixel Intensity

The weighting function can be the average spot of the previous N Loops, according to SNR

Instantaneous (2ms) spots and average spot over 500 realizations (nph=500 and RON=3)

Inst. spots **Average spot**



Centroid Computation

WFS data rate (per WFS):

WFS	Matrix	Frame Rate(fps)
LGS (baseline)	(880*840) 10bits	700-1000 (goal)
LGS (goal)	(1760*1680) 10bits	700-1000 (goal)
NGS LO (baseline)	(320*256) 32bits	1000-2000 (goal)
NGS LO (goal)	(500*500) 32bits	1000-2000 (goal)

Dimension memory: 29.6 Mbits

Total System Operation: 27.9 MFlop

The computing requirements with a frame rate of 1000fps are:

29.6 Gbps (LGS goal) and 27.9 GFlop/s memory bandwidth

Once degree of optimization can be achieved parallelizing CC using FPGA

Latency Estimation

Latency is defined as the time elapsed between the reception of the first WFS readout data by the RTC and the moment at which the last actuator command is sent to DM

RTC Latency is calculated as: $T_{RTC} = T_{read} + \tau_{WFSPU} + \tau_{Rec} + \cdots$

T_{read} is the WFS readout time
$\sum \tau$ is the maximum RTC computation delay

Module	Latency(clock cycle)	Latency(ns)
Pixel Calibration	4	20
Slope Computation	10	50
Other	4	20
TOTAL(τ)	18	90

$f_{clock} = 200MHz$

Total Maximum Latency: 2ms (Goal: 1ms)