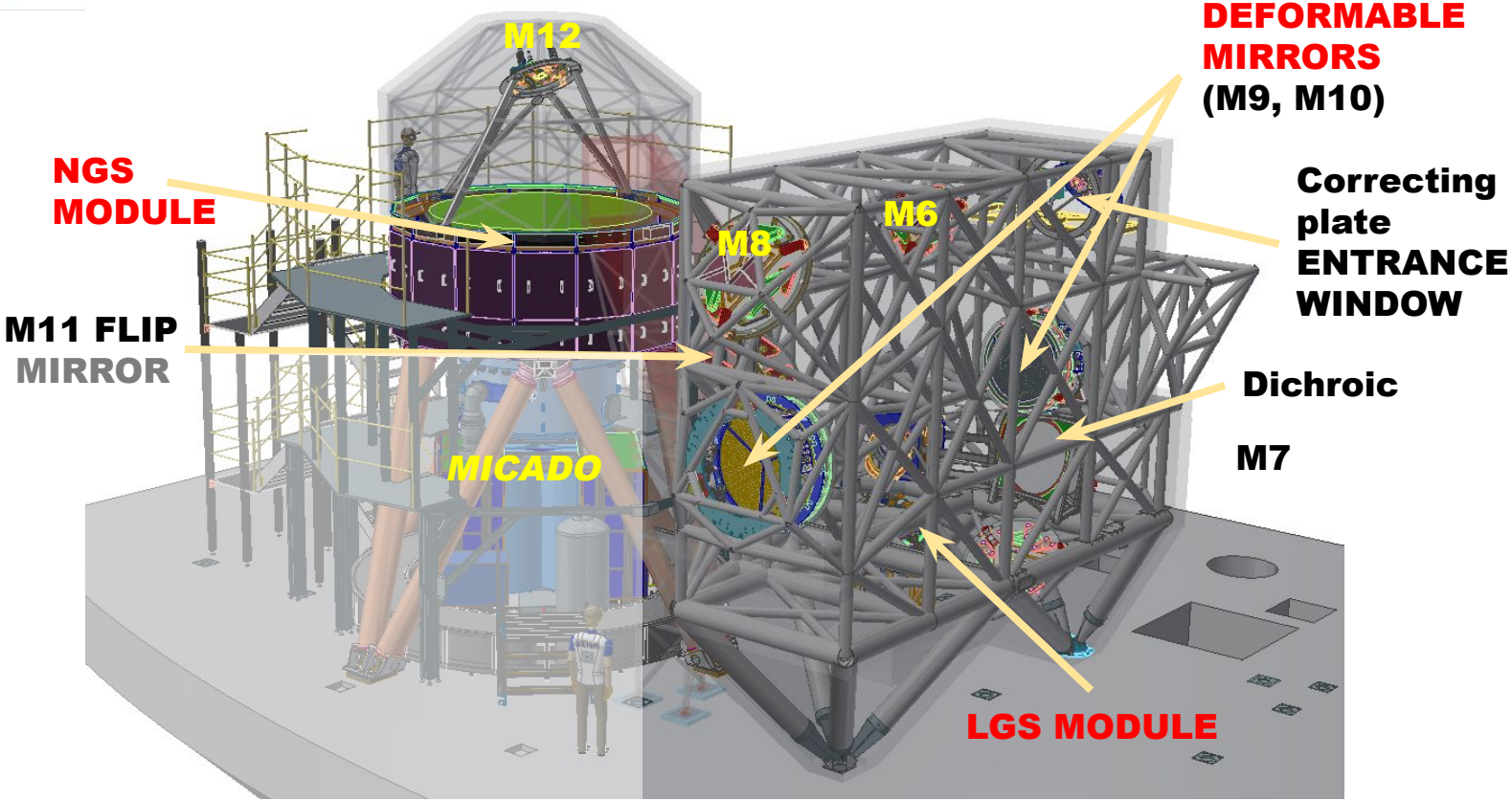
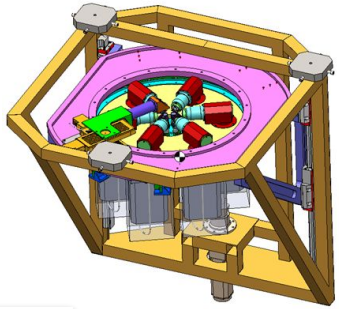
MORFEO
Real Time Computer

Italo Foppiani on behalf of the **whole** team

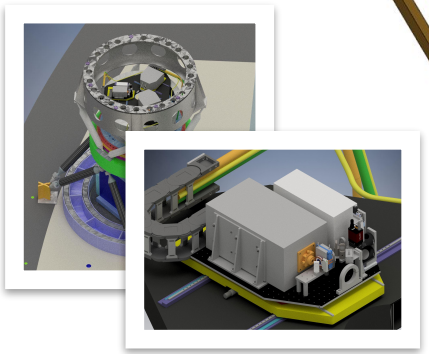
MORFEO


M12
DEFORMABLE MIRRORS (M9, M10)
NGS MODULE
M8
M6
Correcting plate ENTRANCE WINDOW
M11 FLIP MIRROR
Dichroic
M7
MICADO
LGS MODULE

Control Requirements

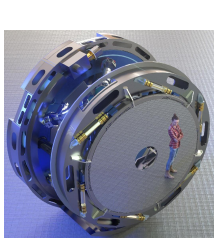


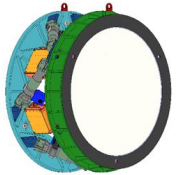
- 6 LGS probes
- 1100×1100 px images
- 68×68 sub-apertures
- 500 fps



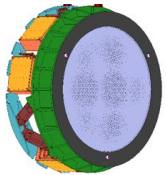
- 3 NGS probes with 2 cameras each
- Low Order WFS:
  - 256×256 px images
  - 2x2 sub-apertures
  - up to 1000 fps

- Reference WFS:
  - 240×240 px images
  - 10x10 sub-apertures
  - 0.1 -100 fps





- Telescope M4 DM:
  - 2.4m flat
  - 5300 actuators



- Post focal DMs:
  - 0.9m diameter convex spherical
  - 1000 actuators
- Post focal DMs:
  - 1.2m diameter concave spherical
  - 1150 actuators

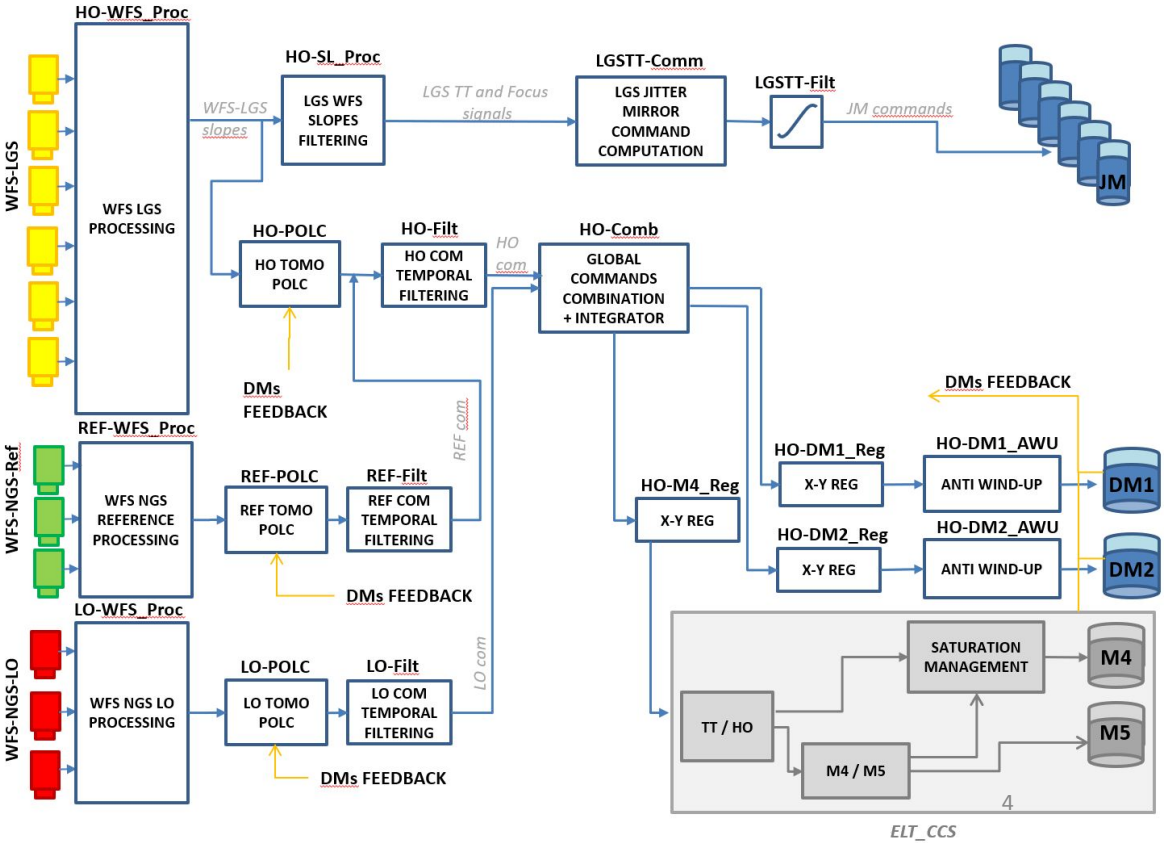
High level control scheme: HRTC

$$e^j = PR\ s^j + \left(PR\ ID \sum_{i=0}^{m} p^i c^{j-i} - \sum_{i=0}^{m} p^i c^{j-i} \right)$$

s	measured slope
e	error term DM space
$PR=P\#R$	Projector # Reconstructor (8k × 42k coeff.)
ID	DM interaction matrix
c	DM shape
p	weighting coefficients

Computational complexities:

- 672 MFLOP for $PR\ s^j$
- 128 MFLOP for $PR\ ID \sum_{i=0}^{l-1} \alpha^i c^{j-(d+i)}$



High level control scheme: SRTC

- *PR* update

$$R = C\ A^{T}\left[\left(A\ C\ A^{T} + CN\right)\right]^{-1}$$

$$A = IP\ ML^{GS}$$

$$P = \left[\frac{\sum_{i=1}^{N\_Opt_x}\left[\left(MD^{Opt_i}\right)^{T} MD^{Opt_i}\right]}{N\_Opt}\right]^{+}\left[\frac{\sum_{i=1}^{N\_Opt_x}\left(MD^{Opt_i}\right)^{T} ML^{Opt_i}}{N\_Opt}\right]$$

IP	pupil interaction matrix
$C,$	Atm Turbulence covariance
CN	WFS noise covariance
ML^{GS}	Atm layers projections along GS
MD^{Opt}	DM projections along optimization

  - Computational complexity: ~700 TFLOP
  - Minimum updating period: 6 min

- 40 data tasks at least
- telemetry storage

Telemetry Requirements

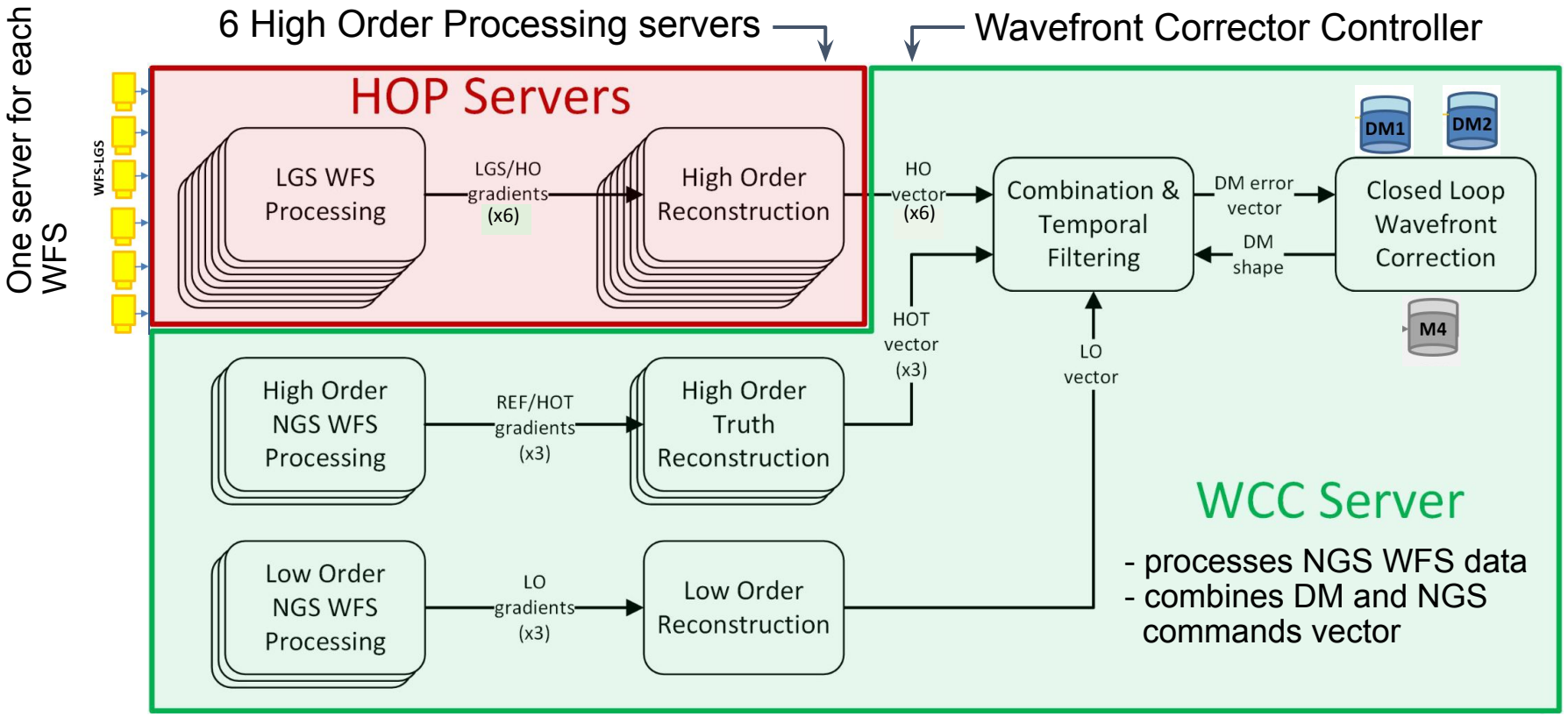
	Number of elements	Number of channels	Data Type [bit]	Frame rate [Hz]	Bandwidth per channel[Gbit/s]	Total Bandwidth [Gbit/s]
LgsPixel	1210000	6	16	500	9,680	58,080
NgsLoPixel	62500	3	16	1000	1,000	3,000
NgsRefPixel	57600	3	16	100	0,092	0,276
LgsSlopes	7000	6	32	500	0,112	0,672
NgsLoSlopes	8	3	32	1000	0,000	0,001
NgsRefSlopes	200	3	32	100	0,001	0,002
LgsIntensities	3500	6	32	500	0,056	0,336
NgsLoIntensities	4	3	32	1000	0,000	0,000
NgsRefIntensities	100	3	32	100	0,000	0,001
PFDM1 sent/applied Commands	1000	2	32	1000	0,032	0,064
PFDM2 sent/applied Commands	1150	2	32	1000	0,037	0,074
M4 Commands	5300	2	32	1000	0,170	0,339
JM Commands	2	6	32	500	0,000	0,000
LgsSlopes Disturbance	7000	6	32	500	0,112	0,672
PFDM1 Commands Disturbance	1000	1	32	1000	0,032	0,032
PFDM2 Commands Disturbance	1150	1	32	1000	0,037	0,037
M4 Commands Disturbance	5300	1	32	1000	0,170	0,170
JM Commands Disturbance	2	6	32	500	0,000	0,000

MORFEO HRTC based on HEART

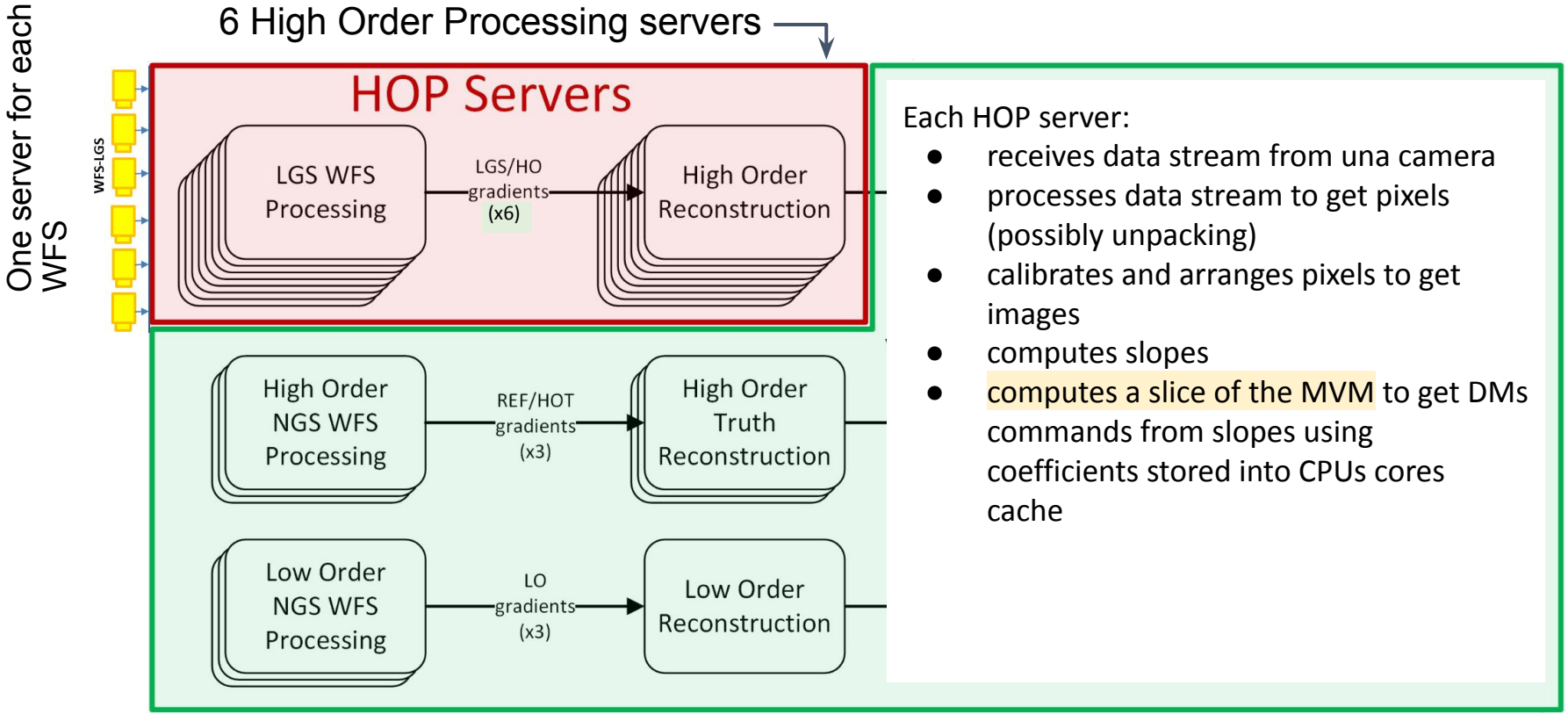
- **Herzberg Extensible Adaptive optics Real-time Toolkit** (HEART) has been shown in the previous presentations (by Malcom, Jennifer ,Ed) about CPU based systems:
  - Key features:
    - modular structure of generalized control code and utilities easily configurable
    - distributed architecture (internal UPD/IP real-time communication)
    - CPU-based architecture for off-the-shelf hardware
    - Implemented in C for Linux with real-time patch

- MORFEO RTC feasibility/preliminary study based on HEART was carried out during phase B.
- **NRC Herzberg Astronomy and Astrophysics institute is joining the MORFEO consortium** as responsible of final design and build of the HRTC

MORFEO HRTC based on HEART



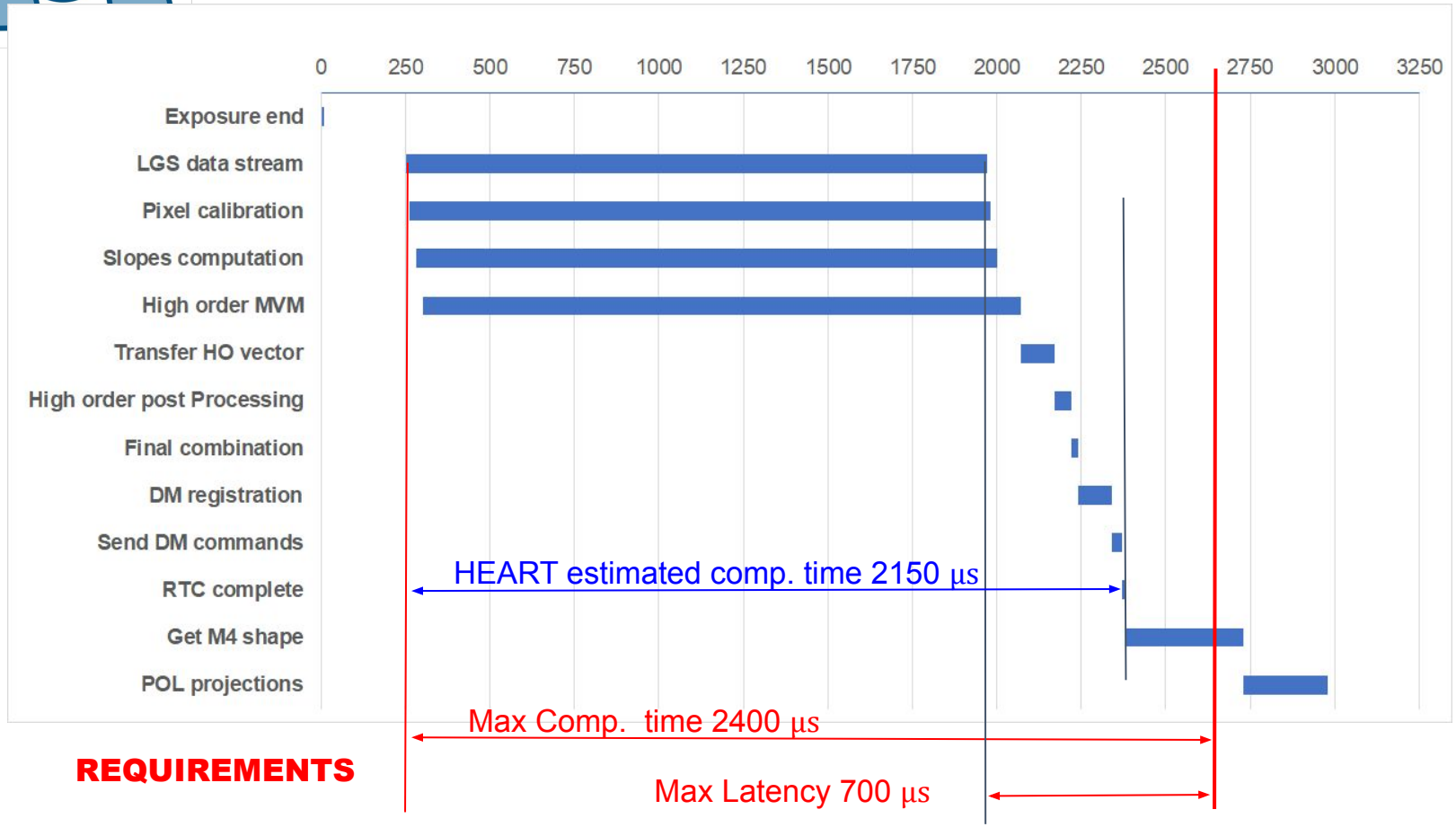
MORFEO HRTC based on HEART



Each HOP server:

- receives data stream from una camera
- processes data stream to get pixels (possibly unpacking)
- calibrates and arranges pixels to get images
- computes slopes
- computes a slice of the MVM to get DMs commands from slopes using coefficients stored into CPUs cores cache

HRTC Timing



REQUIREMENTS

MORFEO SRTC

Soft-RTC subsystem main functionalities

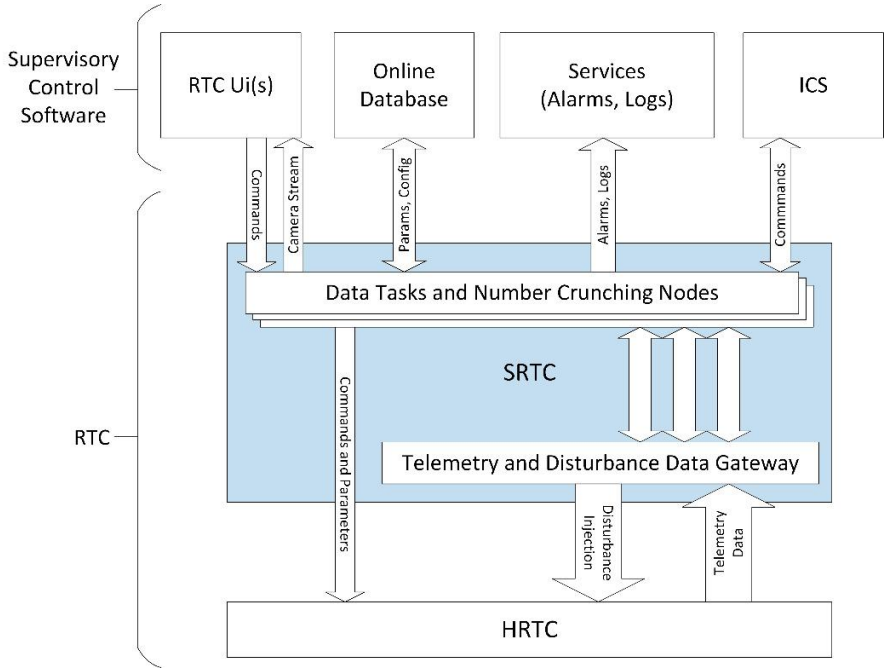
- interface towards the Instrument Control System for supervisory and monitoring purposes
- coordinates the RTC in response to commands
  (setup AO modes, open/close loops, ...)
- carries out AO related co-processing
  (such as loops optimisations, calibrations, measurements, data recording, ...)

MORFEO SRTC

The Morfeo SRTC follows the ELT RTC reference architecture and is based on the ESO RTC Toolkit.

Its main components are:

- Supervisor node
- Telemetry Gateway
- Computing nodes: to perform the required co-processing requirements
  - Number cruncher
  - Pixel processor
  - Storage node
  - Atmospheric parameters estimation



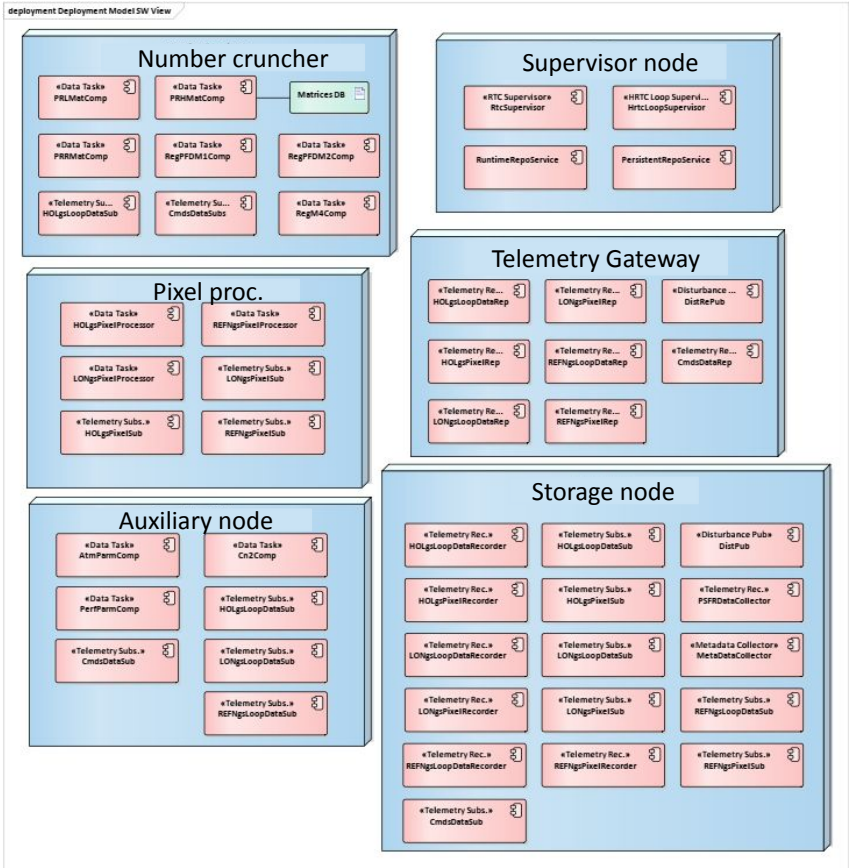
MORFEO SRTC Co-processing

Main computational functionalities	SRTC Nodes
• Control matrices updates (*PR*) • Mis-registration	→ • Number cruncher
• Pixel maps (sub-ap. weights, dark, background, …)	→ • Pixel processor
• Atmospheric parameters estimation	→ • Auxiliar node
• Telemetry and metadata recording	→ • Storage node

MORFEO SRTC Co-processing

Total of about 40 datatasks distributed among 4 computing nodes optimized for computing power or connectivity or storage

The telemetry gateway will be deployed in a ESO standard IT server in accordance with architecture requirements and preliminary benchmarks

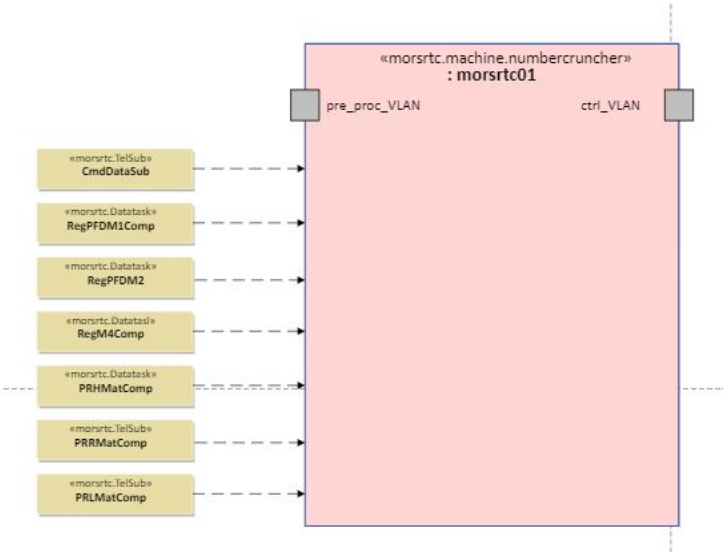


Number cruncher node

- High performance node w/GPU
- Computes:
  - PR updates
  - DMs mis-registrations

Computation requirements

- PR update for LGS (the most demanding one) requires ~700TFLOP.
- Benchmarks show that a CPU system needs several minutes for this computation.
- A GPU offload foreseen for these (mostly algebraic) computations to increase timing margins.



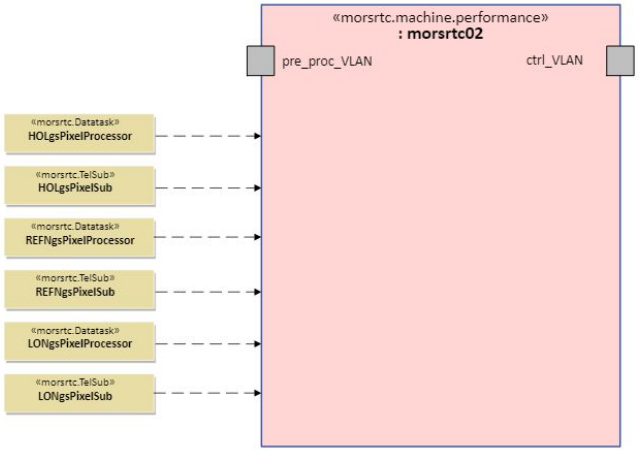
Pixel processor node

- High performance CPU node
- Computes Pixel based computations
  (e.g. background map optimization, dark map optimization, threshold map optimization, slope offset optimization, …)
- Computations I/O bound

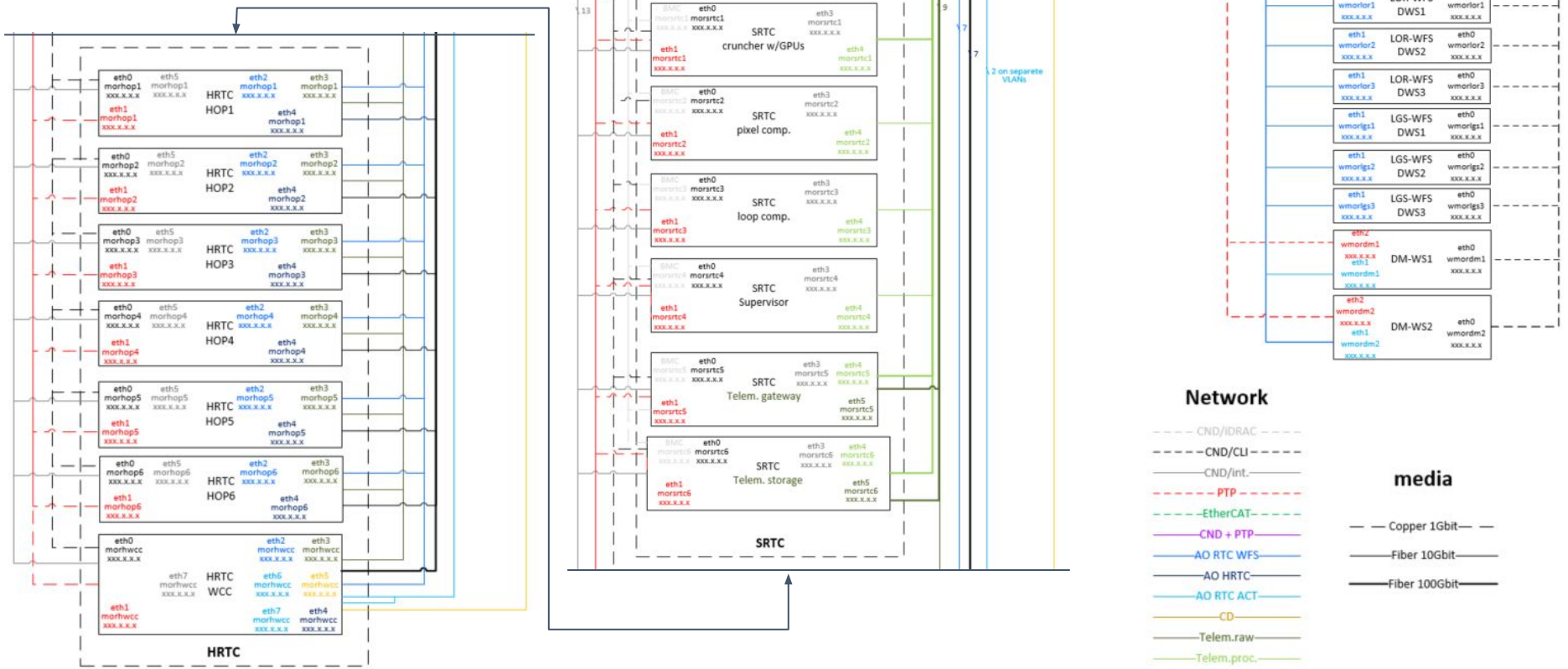
Computation requirements

	#streams	*#pixels*	*(max.) framerate [Hz]*	*(min.) sub-sampling*	*operations per pixel (estimate)*	*total number of operations per second [GFLOP]*
LGS	6	1210000	500	10	10	3.63
LO	3	62500	1000	10	10	0.19
Ref	3	57600	100	10	10	0.02

Resulting total computational power is ~3.8 GFlops



NETWORK


Computer room SCP
12 (to WFS)
2 (to DMs)
CISCO RTC-ND
Cisco 9300-Fx2/3 or Cisco 9300-Fx2/3 + IE4010 w/L3 lic.
CISCO RTC-D
Cisco 9300-Fx2/3
2 on separete VLANs
SRTC
cruncher w/GPUs
pixel comp.
loop comp.
Supervisor
Telem. gateway
Telem. storage
HRTC
HOP1
HOP2
HOP3
HOP4
HOP5
HOP6
WCC
IWS
SCAO-WFS DWS
LOR-WFS DWS1
LOR-WFS DWS2
LOR-WFS DWS3
LGS-WFS DWS1
LGS-WFS DWS2
LGS-WFS DWS3
DM-WS1
DM-WS2
Network
CND/iDRAC
CND/CLI
CND/int.
PTP
EtherCAT
CND + PTP
AO RTC WFS
AO HRTC
AO RTC ACT
CD
Telem.raw
Telem.proc.
media
Copper 1Gbit
Fiber 10Gbit
Fiber 100Gbit