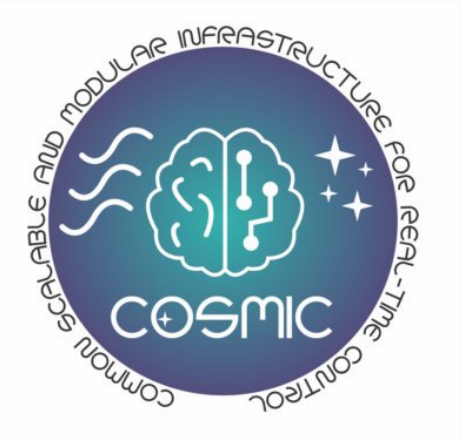


Entering the final design phase for the MAVIS RTC & Control

(not a RTC h/w or s/w technical talk :-)

Francois Rigaut

With inputs (explicit or not) from Damien Gratadour, Jesse Cranney, Guido Agapito, Julien Bernard, Nicolas Doucet, and the ObsPM COSMIC crowd.

COSMIC, CONTEXT, POLITICS AND FTEs

- Leveraging 8 years of R&D and implementations (Green Flash from 2015, COSMIC) at Observatoire de Paris and ANU
  - **Observatoire de Paris - Université PSL**
    - D.Gratadour, F. Ferreira, A. Sevin, J. Plante and C. Cetre
  - **Research School of Astronomy & Astrophysics, ANU**
    - D.Gratadour, N. Doucet, J. Cranney, J. Bernard, J. Smith, C. Gretton and F. Rigaut
- **Number of FTEs** for the COSMIC development:
  - ~ 30 (over last 8 years @ ObsPM);
  - ~ 10 (over last 3 years @ ANU).
- **Typical for a MAVIS like RTC project ~ 25 to 30 FTEs**, leveraging COSMIC development (similar for MICADO?)
- **COSMIC development is partly done within projects, and project use instance of COSMIC development. A circular process, win-win process.**
- **MoU between ObsPM and ANU in the works** to define COSMIC co-ownership and the free sharing of COSMIC IP

COSMIC

General concept:

- General **Damien Gratadour**'s talk this morning
- HRTC, dev and COSMIC future (**Julien Bernard's talk**)

Facility instruments

- **Keck**: already online, delivering science (**see R. Biasi's talk**)
- **Micado**: being integrated (**see F. Ferreira's talk**)
- **MAVIS**: final design phase, passed preliminary design
  - SRTC architecture & benchmarking: **see N. Doucet's talk**
  - Application to MAVIS: this talk
- **SPHERE+**: preliminary design phase
- (**NenuFAR**): important building blocks (e.g. data ingestion) tested and integrated on radio-telescope for transients detection (**see J. Plante's talk**)

Lab experiments

- GHOST @ ESO: used to drive the AO bench and interface with ML (see **Jalo's talk**)
- LabRTC @ INAF: used for prototyping (incl. on-sky) new WFS concepts
- Micado demo @ LESIA (up and running at scale, see **Florian's talk**)

ASTRALIS - THE AUSTRALIAN INSTRUMENTATION POLE

- Created 2018
- From “Astra” (*star* in latin) and “Australia/Australis”
- Instrumentation consortium gathering:
  - AAO (Macquarie Uni)
  - AITC (Australian National Uni)
  - Uni of Sydney (Dep of physics, SAIL group)
- https://astralis.org.au
- About 150 people
- Expertise in
  - Spectrographs and imagers
  - Fibers and photonics
  - Adaptive Optics
  - Astronomy software
  - Detectors

Astralis

MACQUARIE University

THE UNIVERSITY OF SYDNEY

Australian National University

Astronomy Australia Ltd.

MAVIS

Sharper than JWST, Deeper than HST

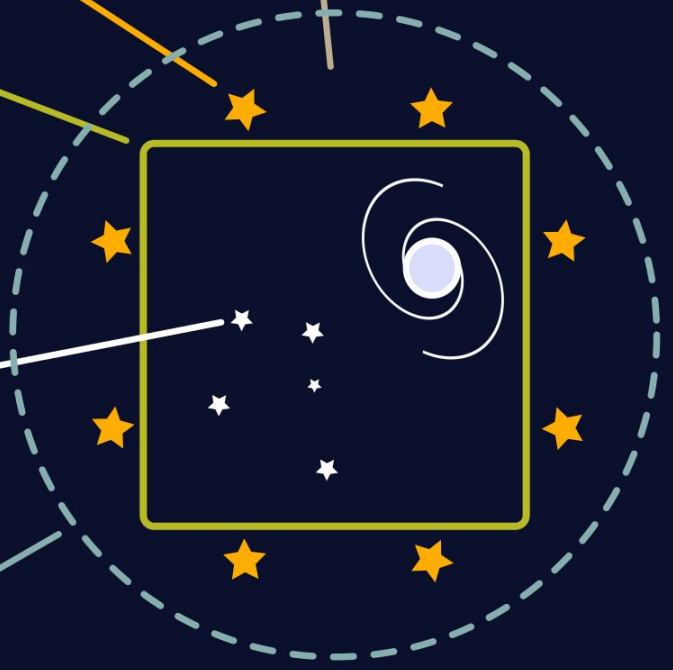
VLT 8-m ⌀ Adaptive Optics Facility optical feed

8 Laser Guide Stars

30"×30" Field of View

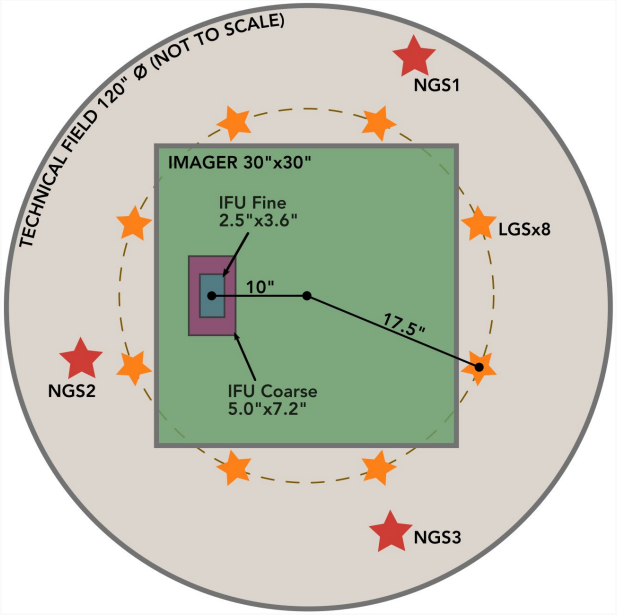
Resolution 3× sharper than HST (18mas @ V band)

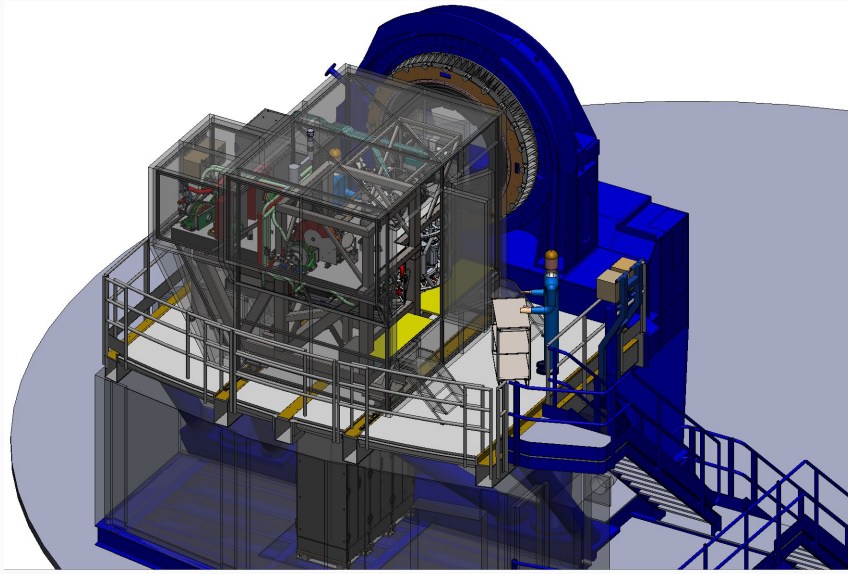
4k×4k imager and 4k-15k λ resolution IFU



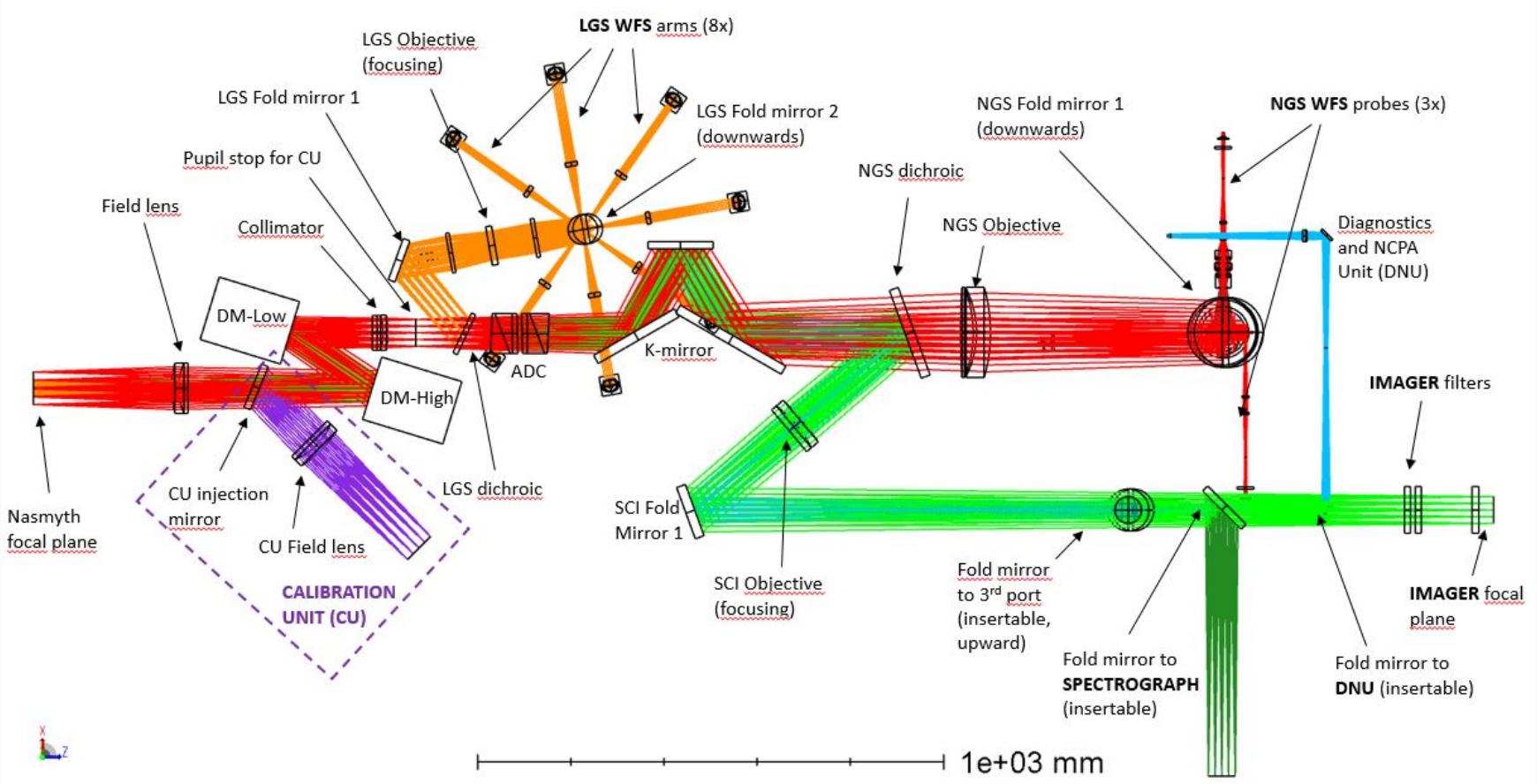
MAVIS: DEEPER THAN HST, SHARPER THAN JWST

- **Multi-conjugate Adaptive Optics** system for correction in the **visible**
  - complete with an **4k × 4k imager** @ 7.3mas pixels
  - and an **IFU w/ 4 spectral resolution modes** (4-12k), ¼ number of MUSE spaxels
- Expecting > **10% Strehl** (goal 15%) **at V band** over **30”x30”**
- **50% sky coverage** @ South GP for 15% encircled energy in 50 mas spaxel
- Imager 5 sigma limiting mag in 1 hour **V = 29.5** (SNR = HST x 2 on . source)
- Tight Consortium: **ASTRALIS** (lead) / **INAF / LAM / ESO**
- Passed phase A 06/2020, **first light expected 2030**
- For the ESO VLT AOF (UT4)
  - 4x2 Laser Guide Stars;
  - 3 Near-IR NGS Wavefront Sensors (using SAPHIRA);
  - 3 Deformable mirrors (DSM + 2 post focal DMs);
- A **brilliant science case** (publicly available on arXiv)





MAVIS Optical Design



MAVIS ORDER OF MAGNITUDE, SIMILAR TO MICADO

Input data:

- LGS (CCD220): 8WFS x 240x240Pixels x 2Bytes x 1000FPS = 1GB/s = 16Gb/s
- NGS (Saphira): 3WFS x 256x320Pixels x 2Bytes x 1000FPS = 0.5GB/s = 8Gb/s
- Nslo ~ 22800 slopes
- Nact ~ 5420 active actuators
- POLC: Nact x Nact MVM, followed by Nslo x Nact MVM

Typically similar to ELT-size systems like MICADO SCAO, HARMONI SCAO or METIS.

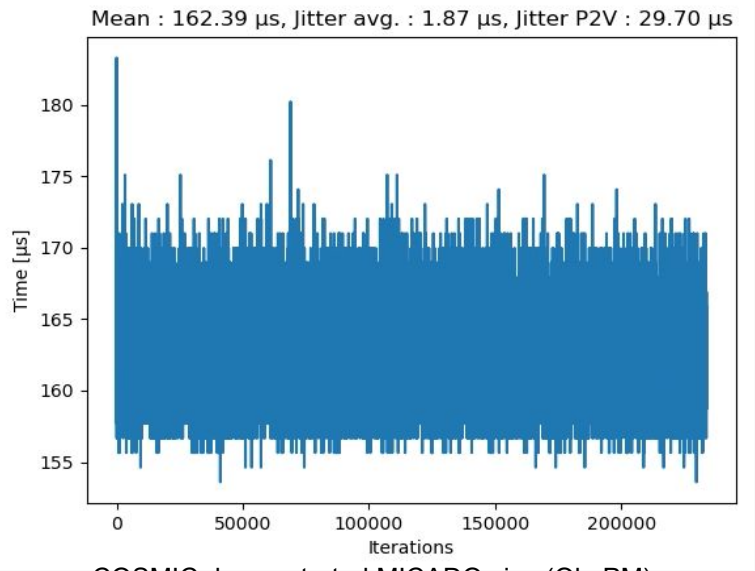
MAVIS is following ELT-SW standards.

REAL-TIME CONTROLLER (RTC) & CONTROL

- Top expertise in **tomographic wavefront control**
  - MMSE / Learn & Apply / Pseudo-Open Loop Control
  - Using experience from GeMS, ERIS, LBT, GALACSI
  - New results in predictive controls provide performance margin
- Agreed with ESO on a **RTC architecture that satisfies ESO ELT standards** while retaining all the developments done within the Green Flash project.

Two components RTC (COSMIC platform, **synergy with MICADO**):

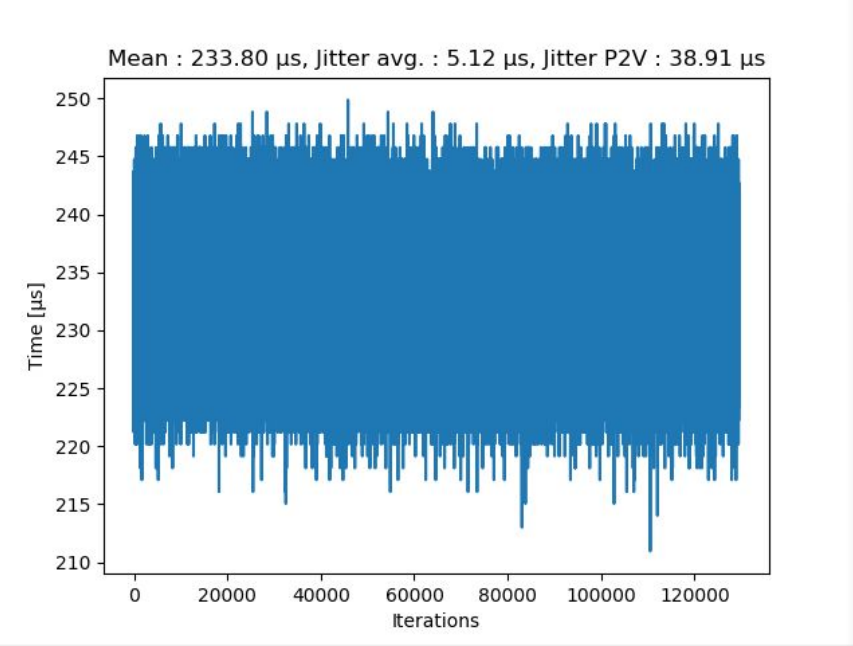
- **Hard RTC** (HRTC):
  - Extremely fast: **160us latency, 2us jitter**
  - Interfaces to h/w (WFS, DMs)
  - Multi-GPU server, **prototype exist**, COTS
- **Soft RTC** (SRTC):
  - Telemetry
  - CPU server w/ GPU accelerators
- **COSMIC** now **demonstrated on sky** (Keck, 04/2021) with ~110 µs latency.

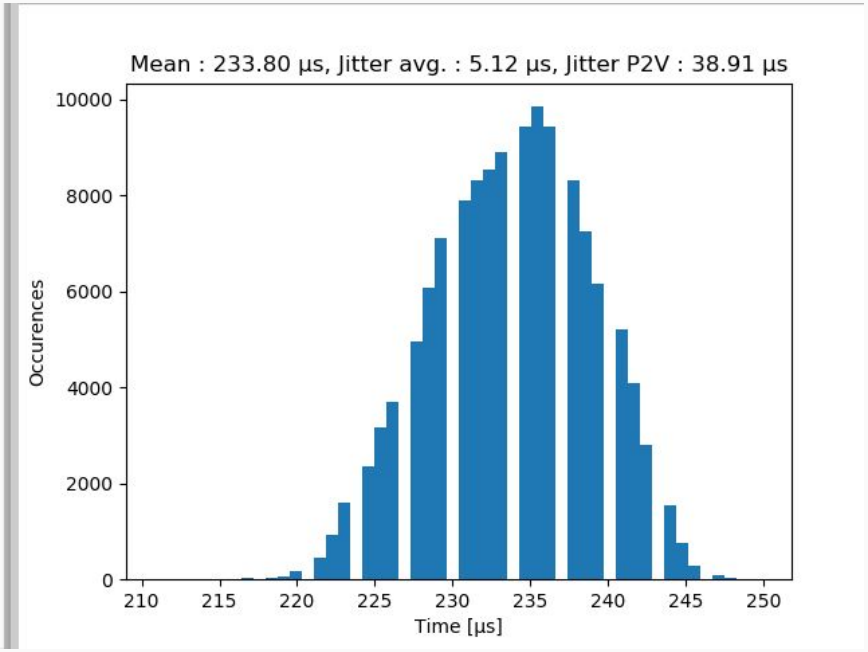


COSMIC demonstrated MICADO size (ObsPM)

MAVIS-SIZE DEMONSTRATOR

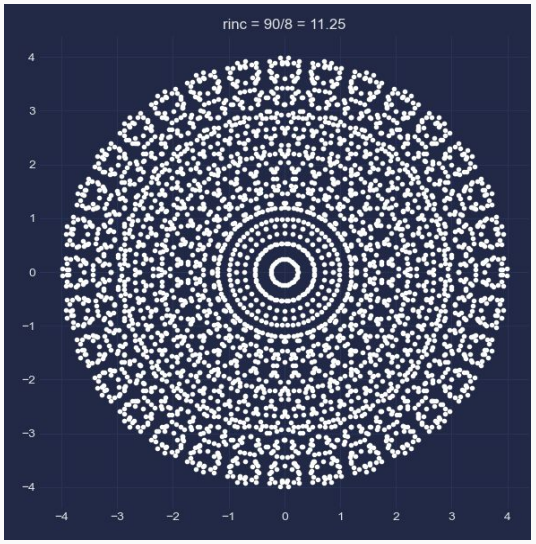
- COSMIC MAVIS Demonstrator, real size
- 4 x V100
- Latency defined as last pixel received to first command out



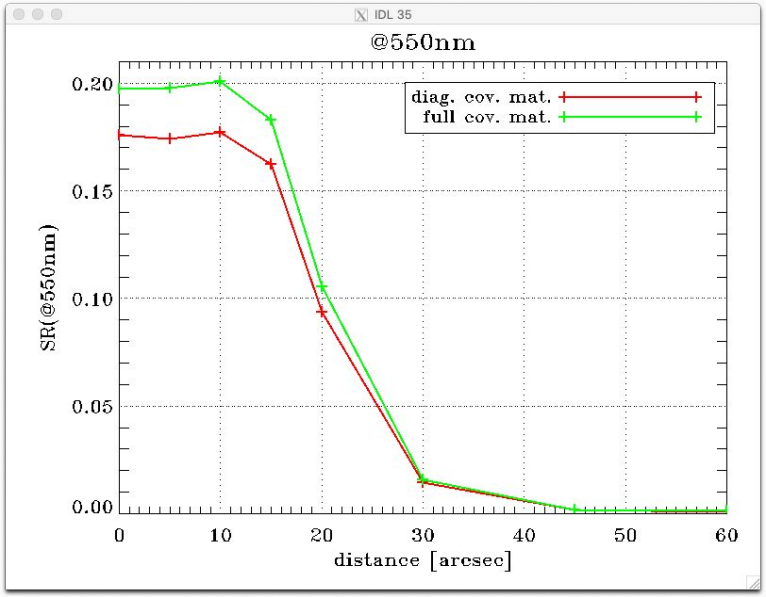


AO PERFORMANCE

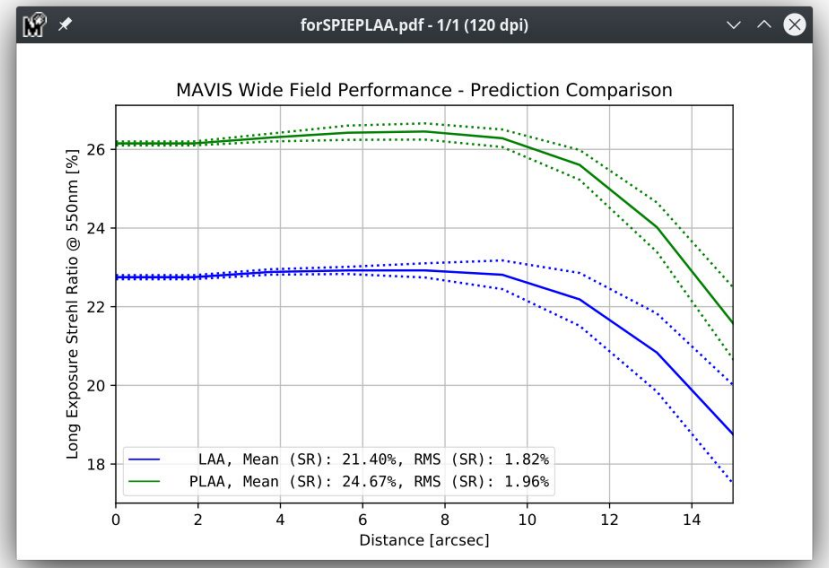
- Simulation team: **Arcetri** (Synergy w/ **MAORY**), seconded by **AAO-Stromlo**
- **4+ simulations tools** from Arcetri (**PASSATA, Fourier code**), LAM (**Fourier code**) and AAO-Stromlo (**yao, COMPASS**). Good redundancy. Now also using **TIPTOP**.
- Comprehensive AO simulation driving the design



New super-resolutions methods (Jesse Cranney & Guido Agapito)



Example of performance under median conditions (Guido Agapito)



Performance with predictive methods (Jesse Cranney)

AO CONTROL TIPS AND TRICKS

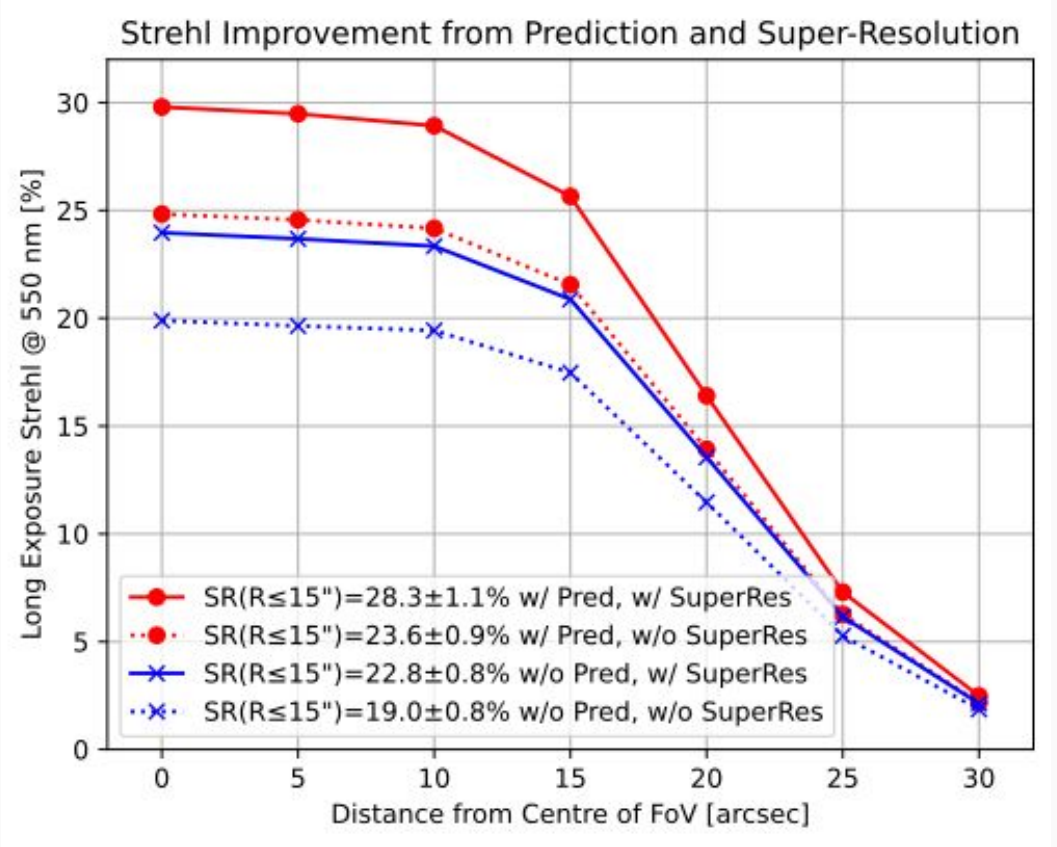
Control law based improvements:

- 39 nm RMS gain: Learn & Apply ➜ predictive L&A
- 35 nm RMS gain: Super Resolution
- Total 52nm RMS WFE,
  - S(550nm)=20%
    ➜ 111nm rms
    ➜ $(-52\text{nm})^2$
    ➜ 98 nm rms ➜ S=28.5%

Being progressed:

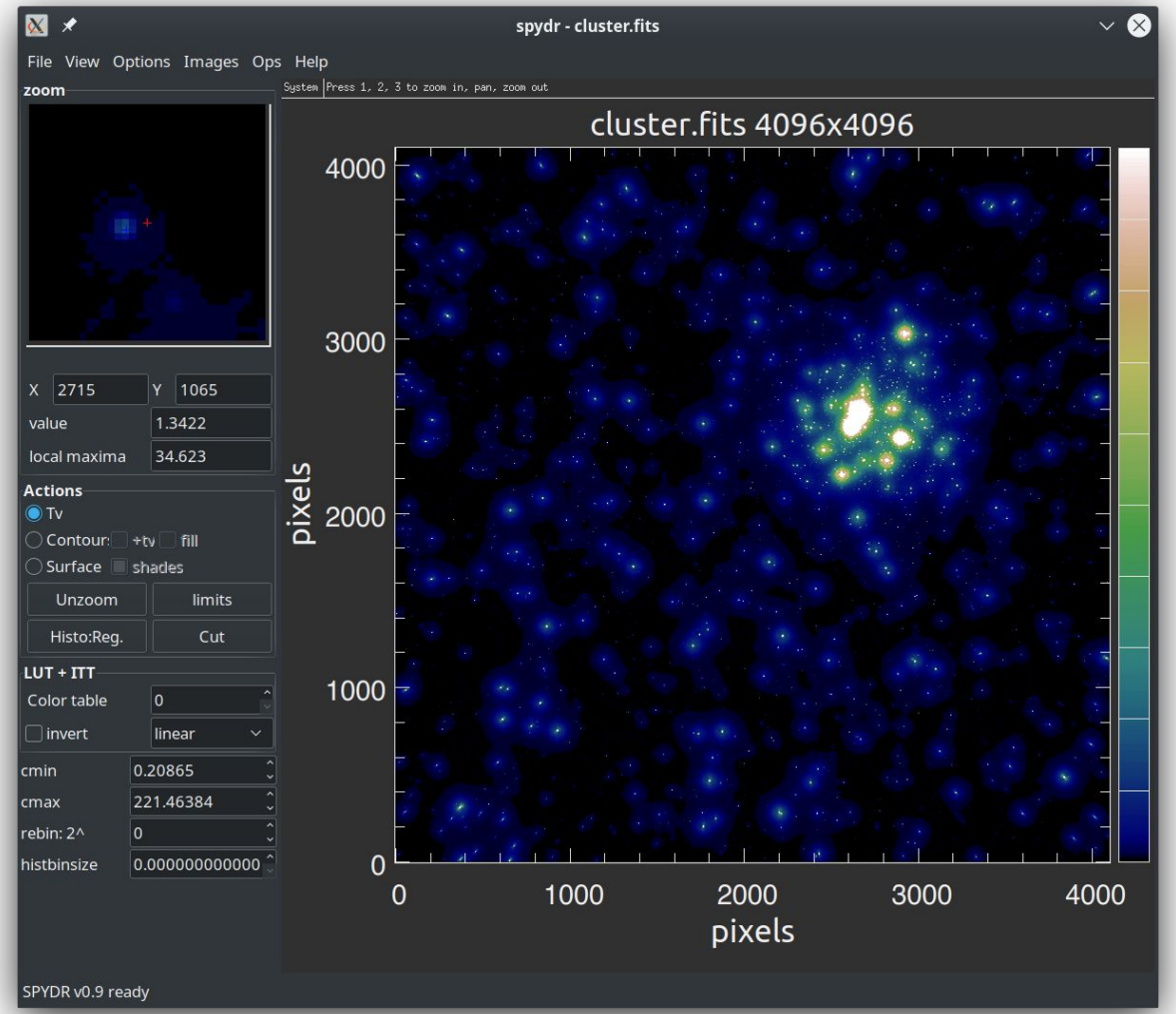
- Vibration mitigation
- DSM simulator
- GPU-ify all control calculations
- Supervisor loop,
- NCPA correction,
- Multirate (NGS + LGS) control,

Non-predictive / predictive



Science image Simulator & PSF reconstruction

- S.Monty. Use both simple Fourier and end-to-end PSFs.
- **Object** models, combined w/ **AO** and **instrument** performance models to generate image
- Used to investigate **astrometric** performance
- **PSF reconstruction** WP also in the work, led by LAM. Folded in from the start.



SOME MAVIS DOCUMENTS DELIVERED TO ESO

Real Time Computer User Requirements Document

Document Number	MAVIS-SENG-REQ-0016
Version	632
Status	Released
Release Date	2023-02-03
DRD Type	DRD230

Document Approval

	Name	Date	Signature
Prepared by:	J. Cranney Additional authors: V.Viotto	06/12/2022	
Checked by:	D. Brodrick, D. Gratadour	2023-02-03	
Approved by:	F. Rigaut	2023-02-03	

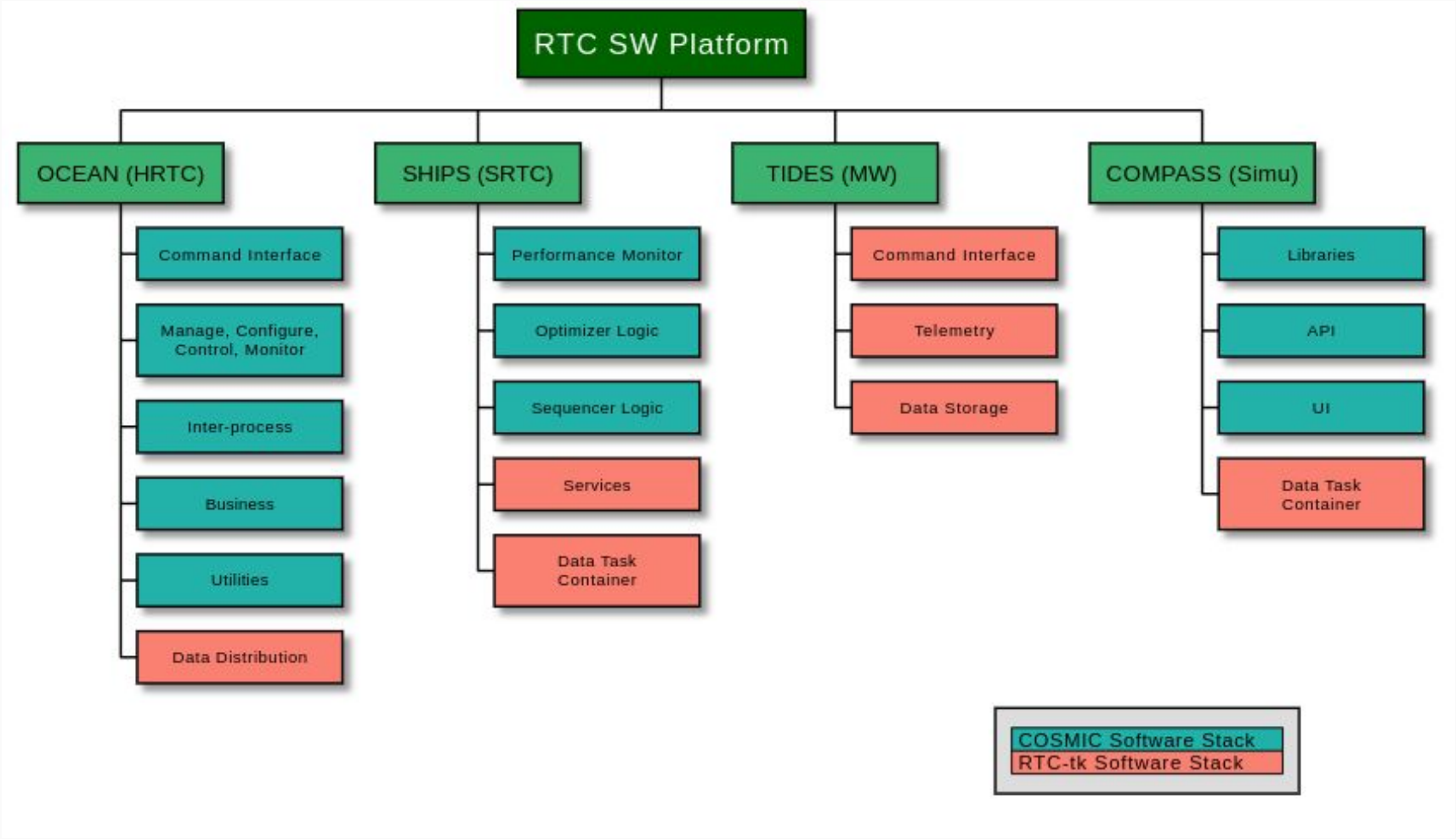
Real Time Computer Design Description

Document Number	MAVIS-AOM-RTC-REP-0001
Version	1
Status	Released
Release Date	2023-02-02
DRD Type	DRD210/DRD220

Document Approval

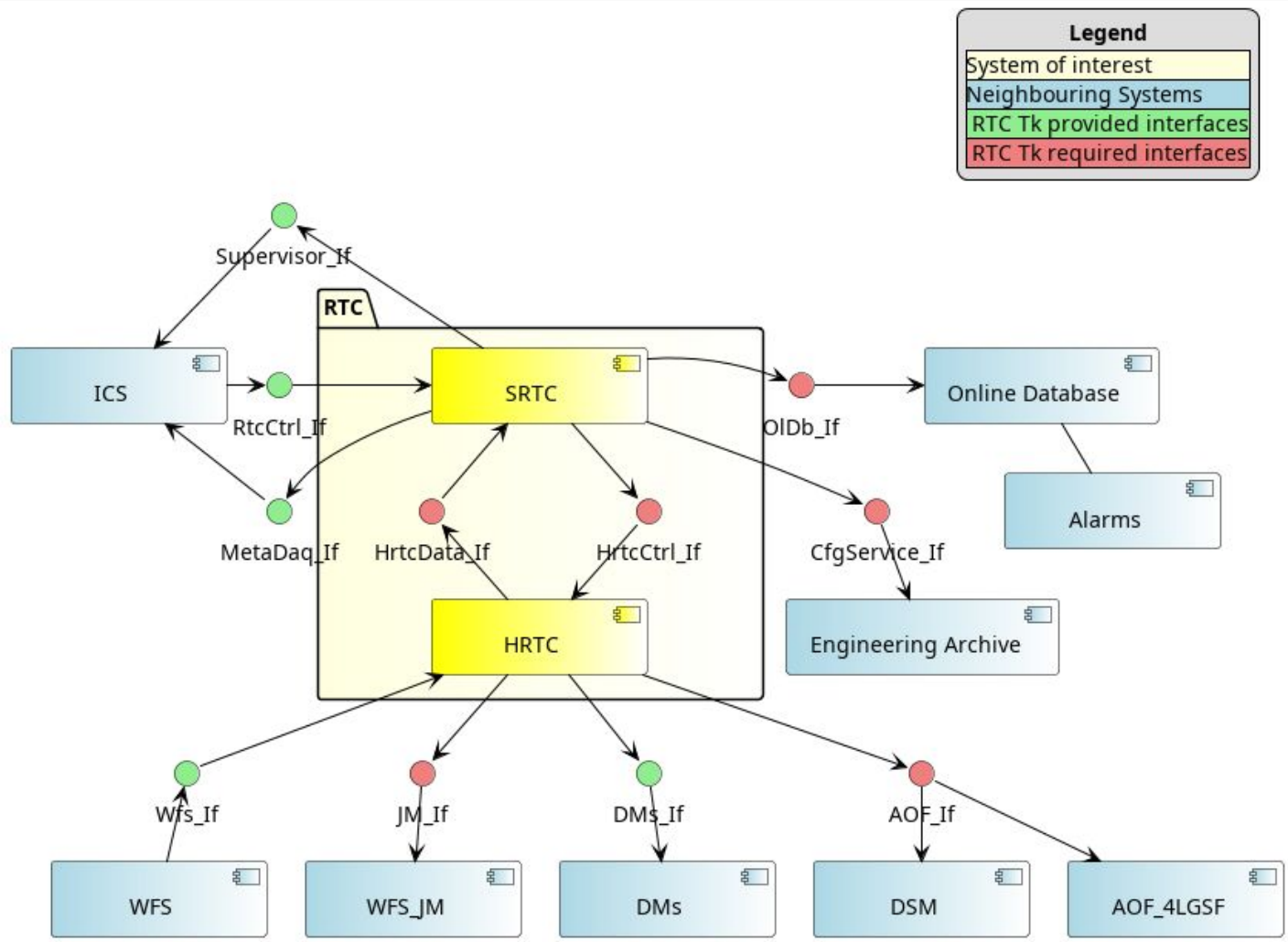
	Name	Date	Signature
Prepared by:	Damien Gratadour	2022-12-20	
Checked by:	Francois Rigaut, David Brodrick	2023-01-23	
Approved by:	Francois Rigaut	2023-02-02	

Cosmic Software Stack



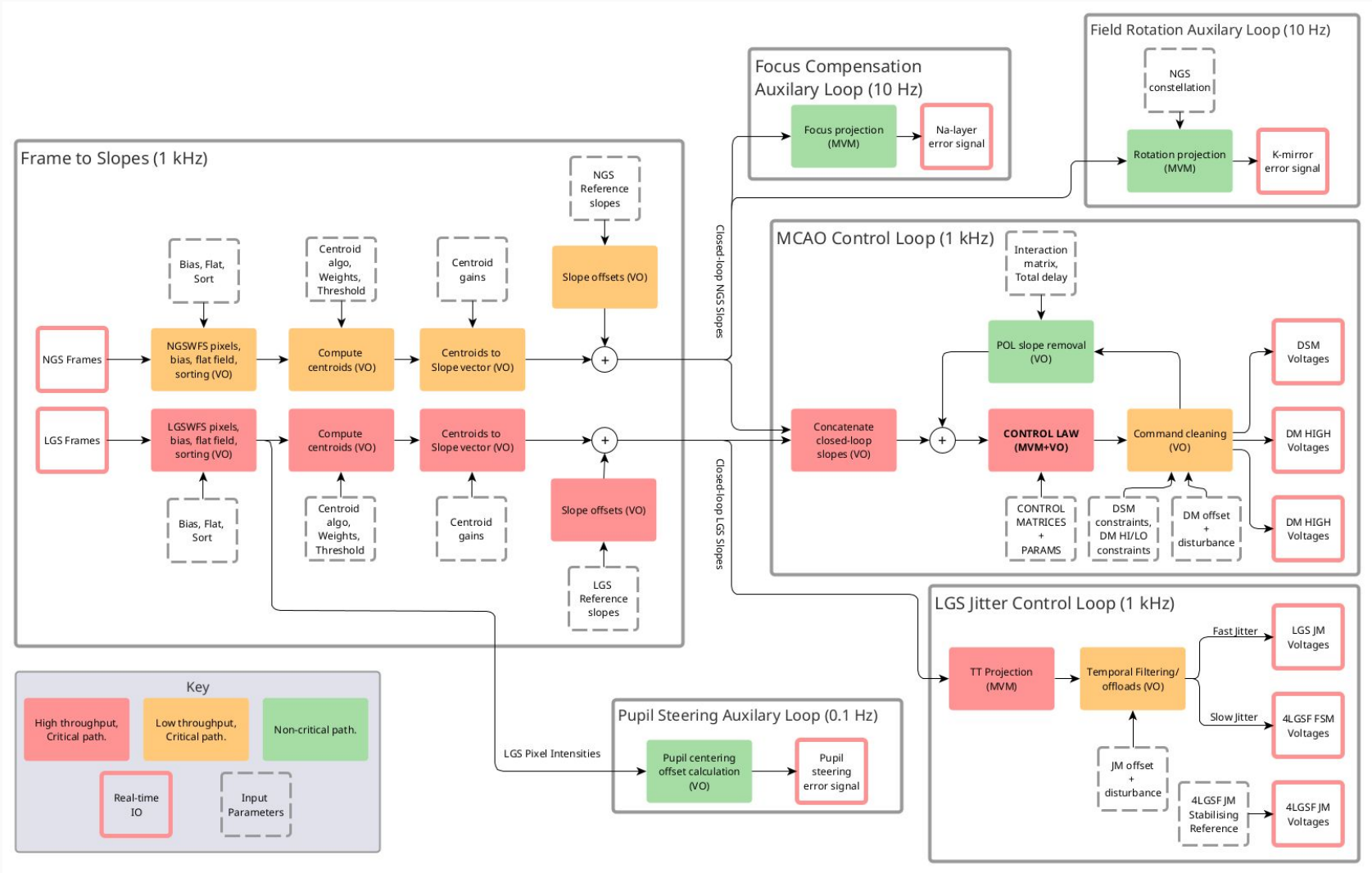
From the MAVIS phase B RTC design description

MAVIS RTC Software Context



From the MAVIS phase B RTC design description

MAVIS Processing Pipeline



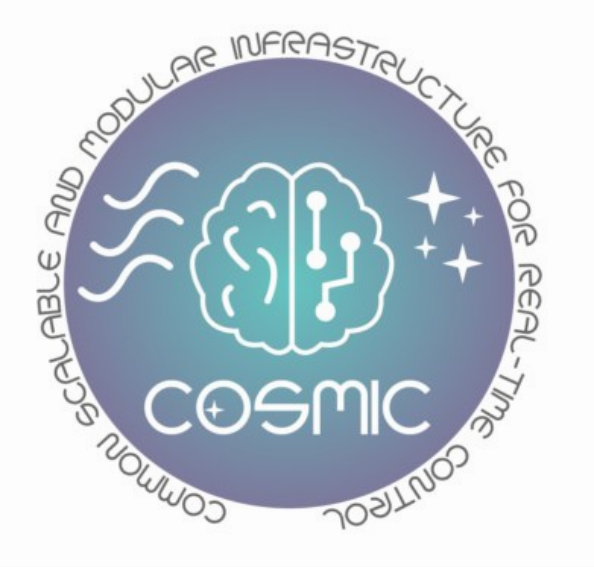
From the MAVIS phase B RTC design description

Management challenges for RTC developments

- Balancing latest and more efficient technologies with ESO required stability requirements
- Insuring long lifetime for chosen s/w and h/w solutions
- Retaining gifted s/w developers
- **Keeping teams alive**!
  - How to do it in systems w/o recurrent funding/permanent staff?
- Spare equipment stocking vs compatible replacements

THE END


MAVIS


COMMON SCALABLE AND MODULAR INFRASTRUCTURE FOR REAL-TIME CONTROL
COSMIC