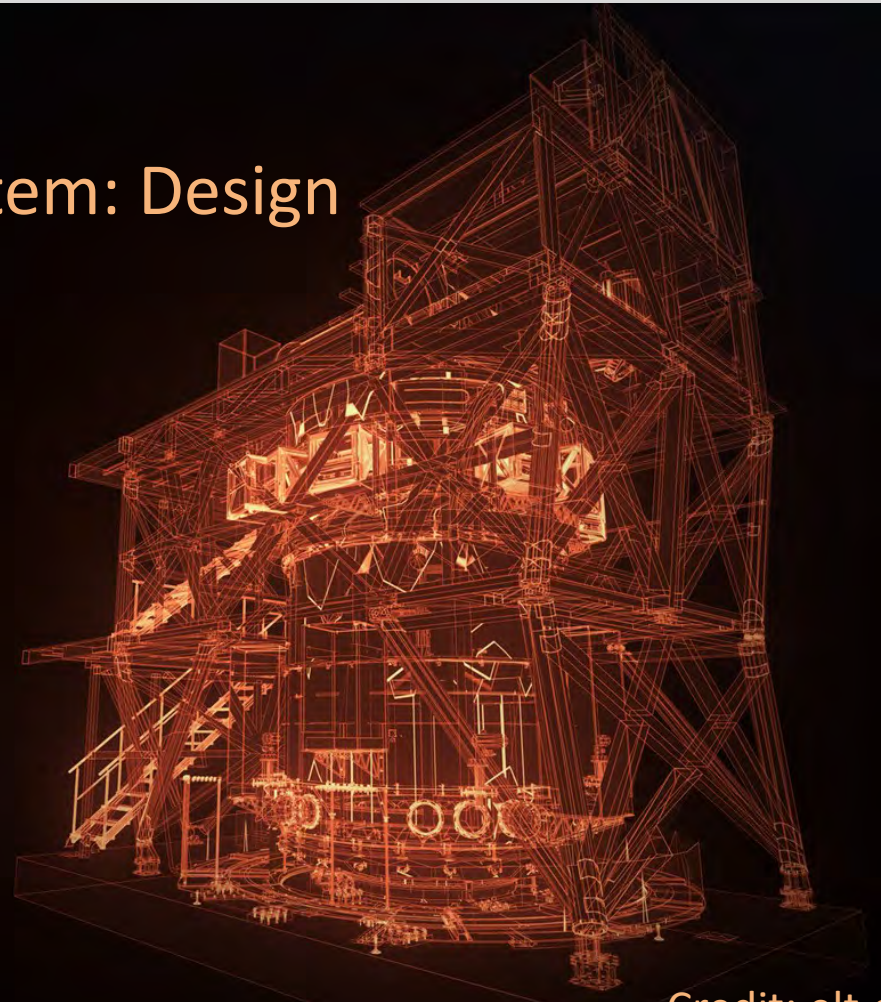
HARMONI's Adaptive Optics Control System: Design and performance Update

Prepared By: David Barr, Sylvain Cetre, Sofia Dimoudi, Andrew Dunn and Tim Morris.

Date: 2023-11-08



Credit: elt.eso.org

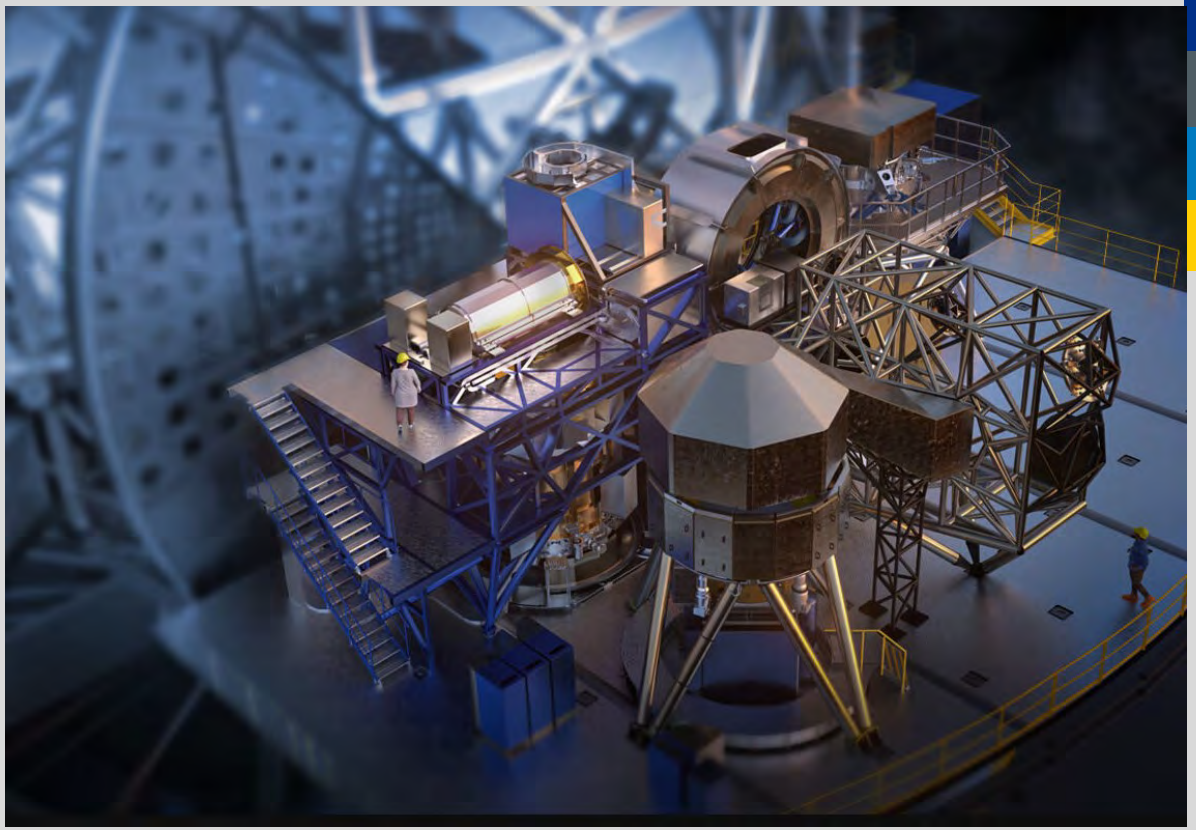
Contents

- HARMONI Overview
- What is the AOCS
- Current design and Prototyping results
  - HRTC (DAO)
  - SRTC
  - Camera integration
  - Going on-sky

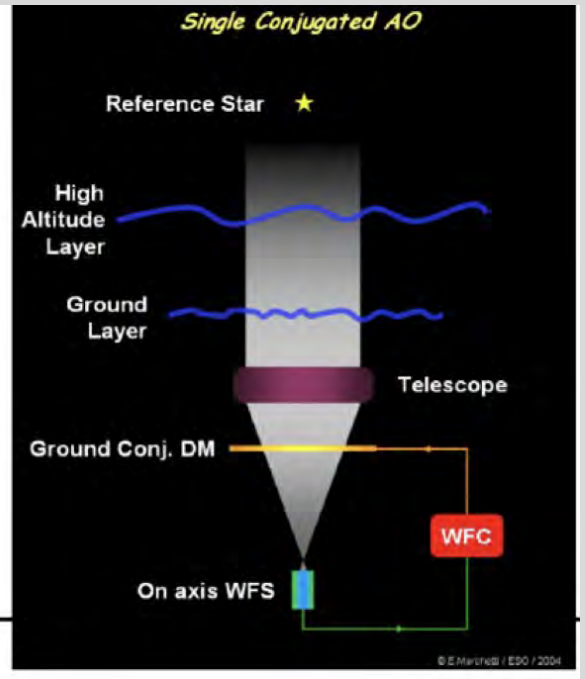
High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph

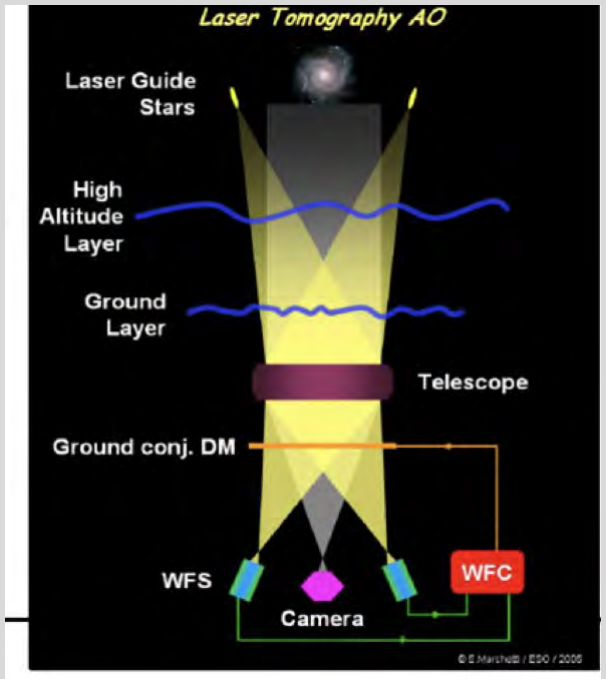
HARMONI — the High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph — will be the ELT's workhorse instrument for visible-light and near-infrared spectroscopy. It is an integral field spectrograph, and will simultaneously acquire spectra at 30 000 adjacent points on the sky to map an astronomical object over a wide range of wavelengths.

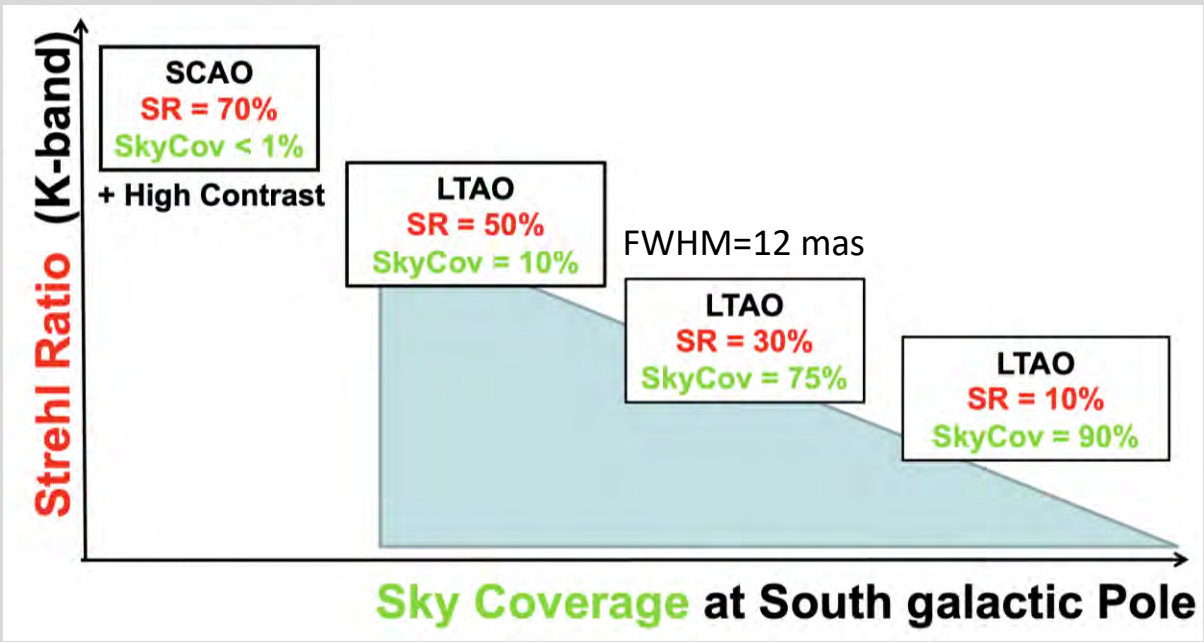
From: ESO website



Wavelength	(0.47) 0.8– 2.45 um
Spectral resolution	R ~ 3500, 7500, and 18000 (R~3500 in VIS)
Simultaneous spectral range	One full band (i, z, J, H, K) at R~7500, two at R~3500
Field(s)-of-view	Four, corresponding to different spatial scales
AO	LTAO, SCAO – also , HCAO and NoAO modes



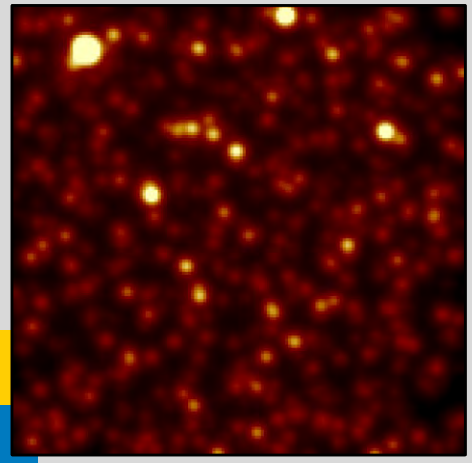
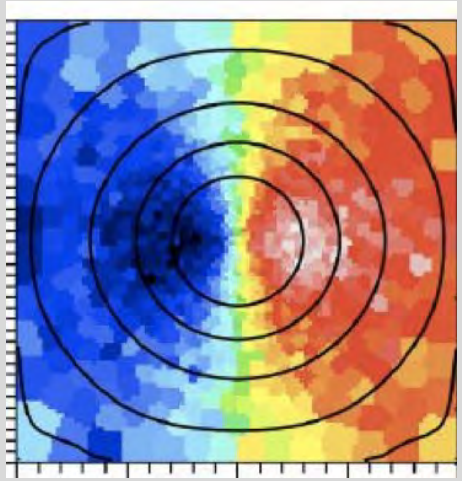
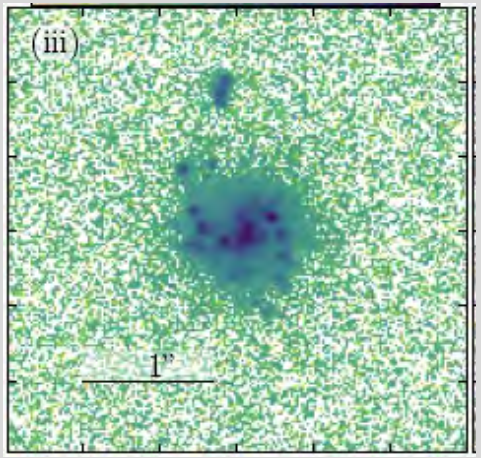
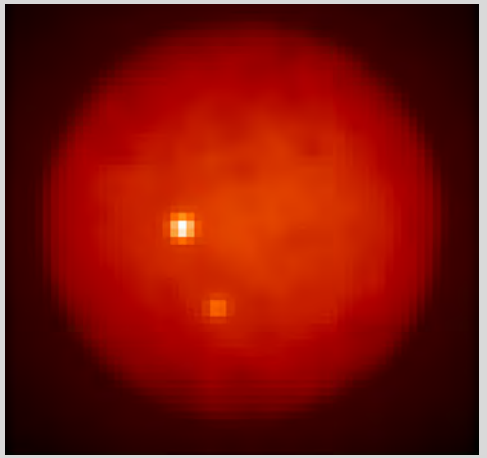
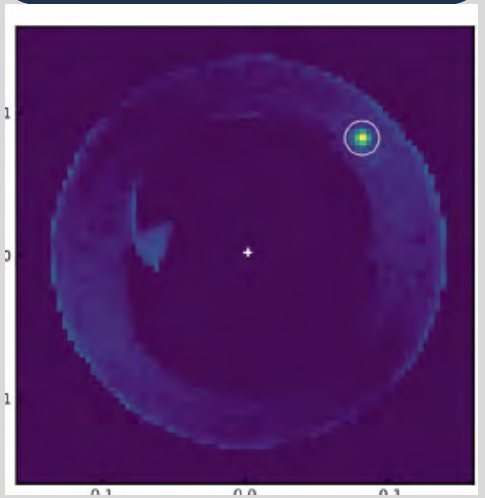




The science objectives of HARMONI

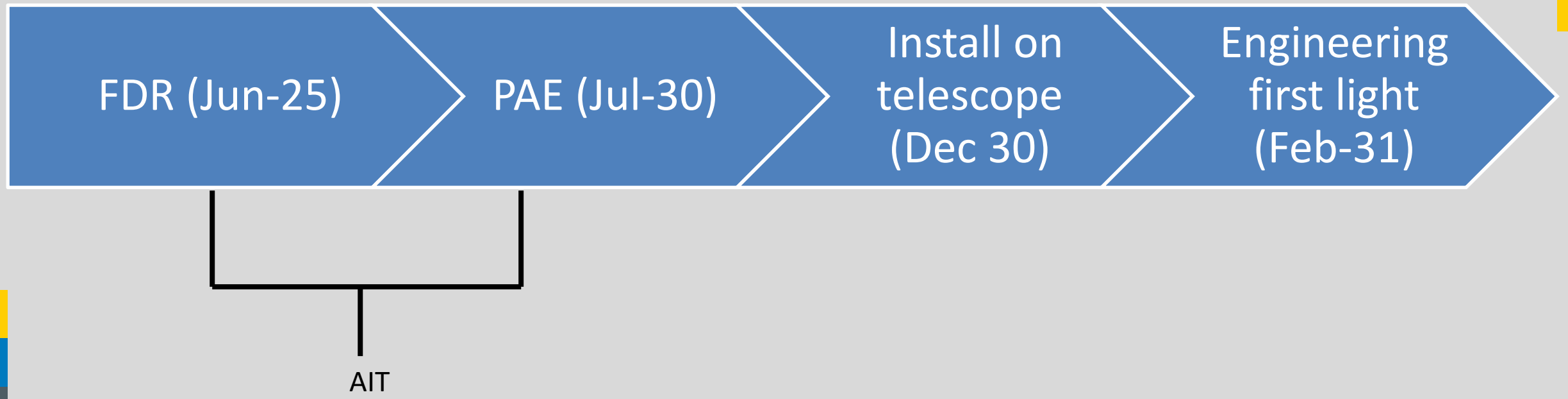
HARMONI will be the ELT's work-horse. Will have a wide range of users in all branches of astrophysics. The discovery space opened by its capabilities is a fundamental driver

Science Team – Science Working Groups

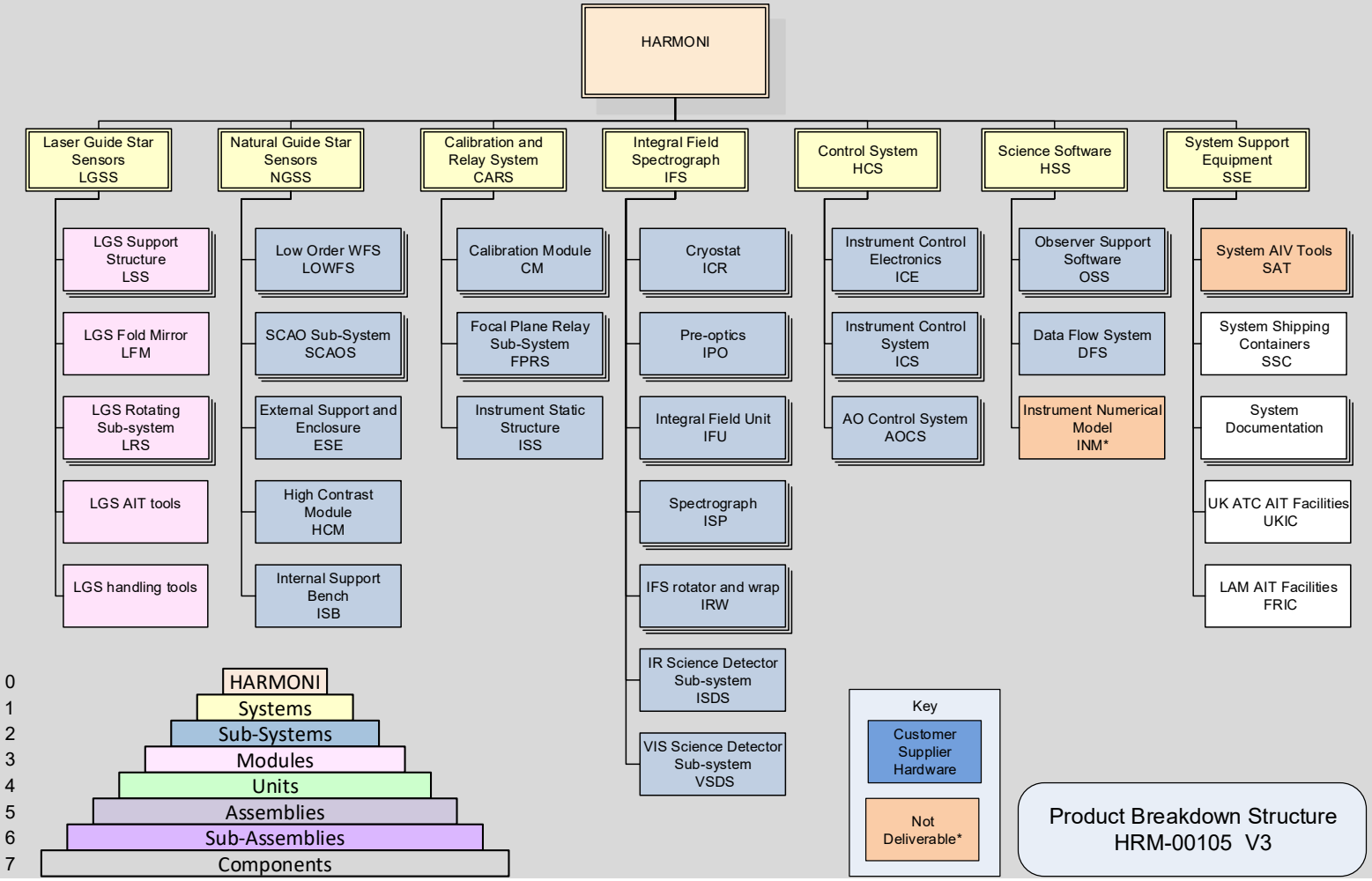
Resolved Stellar Populations	Nearby Universe	High Redshift	Solar System	Exoplanets
				

HARMONI Reference Science Cases – Dedicated Simulations with HSIM

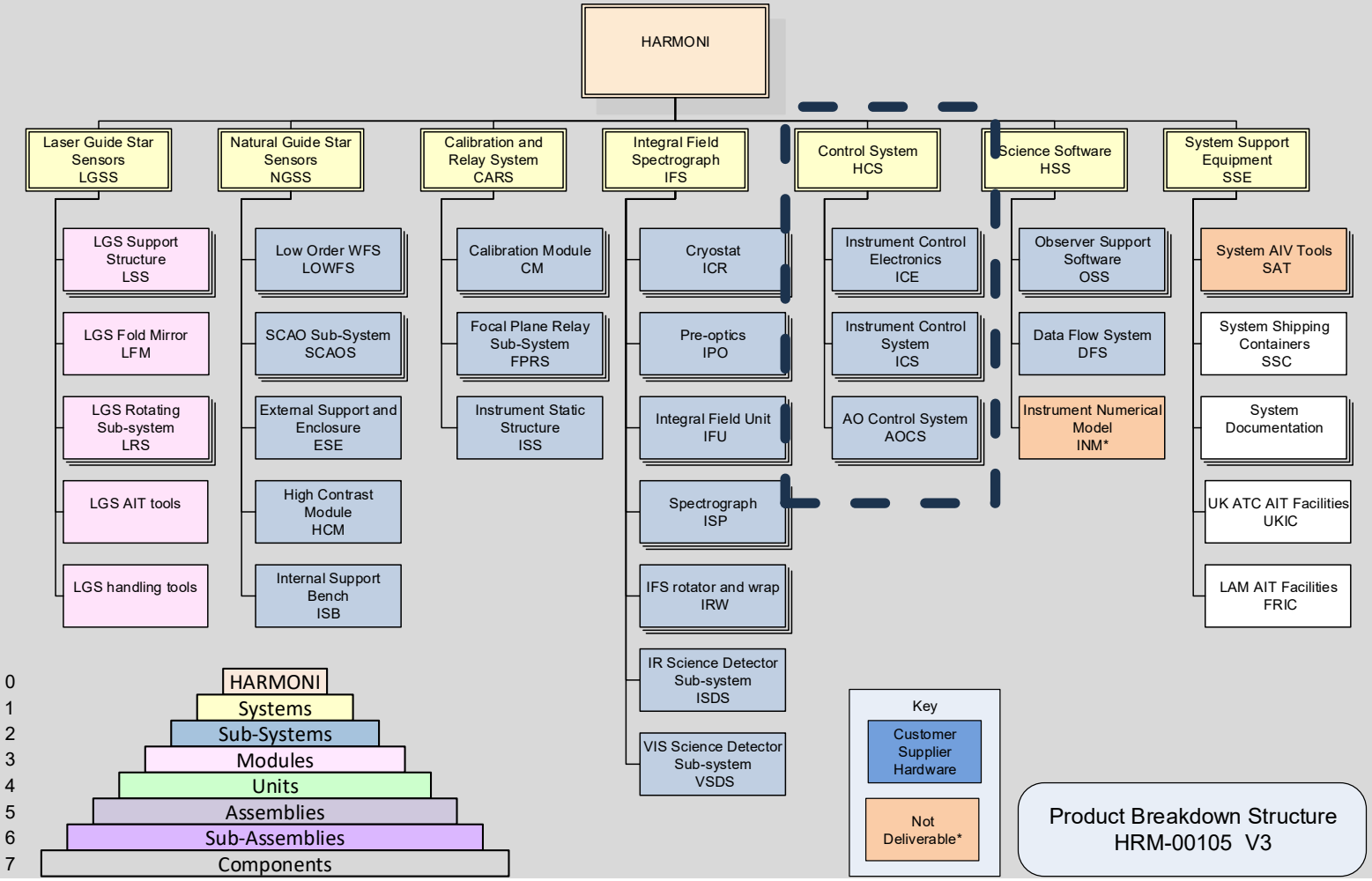
Timescales


FDR (Jun-25)
PAE (Jul-30)
Install on telescope (Dec 30)
Engineering first light (Feb-31)
AIT

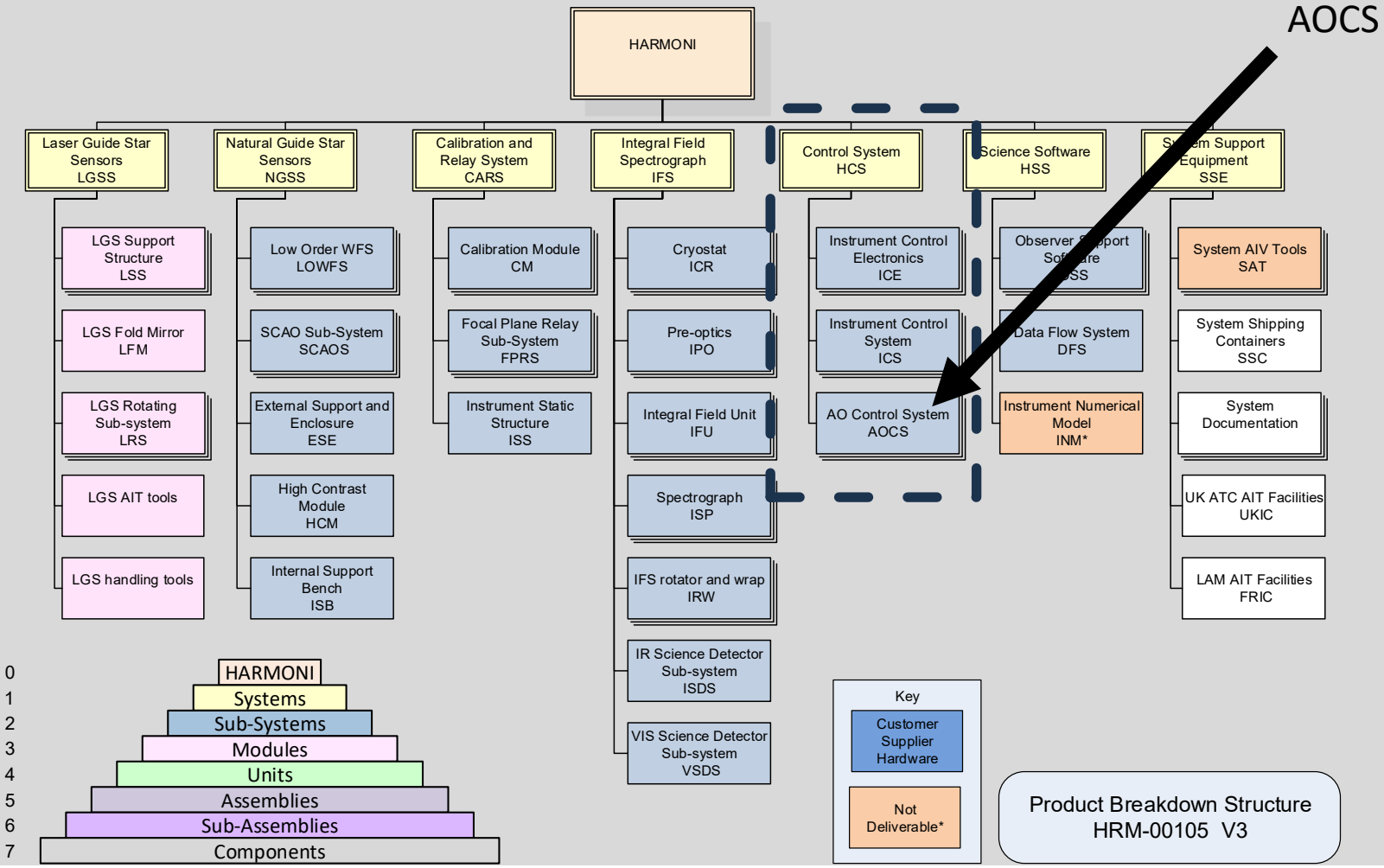
System Overview



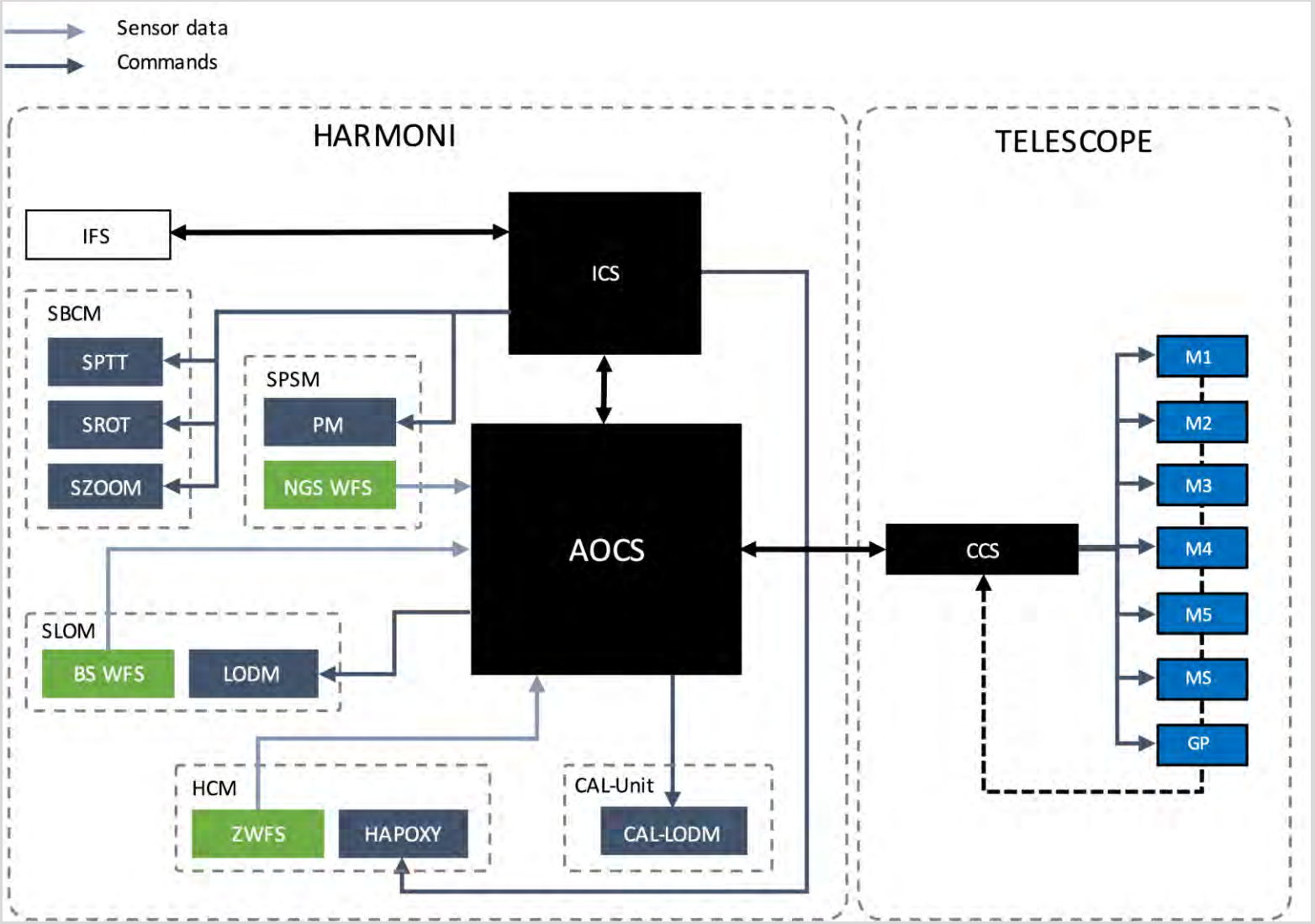
System Overview



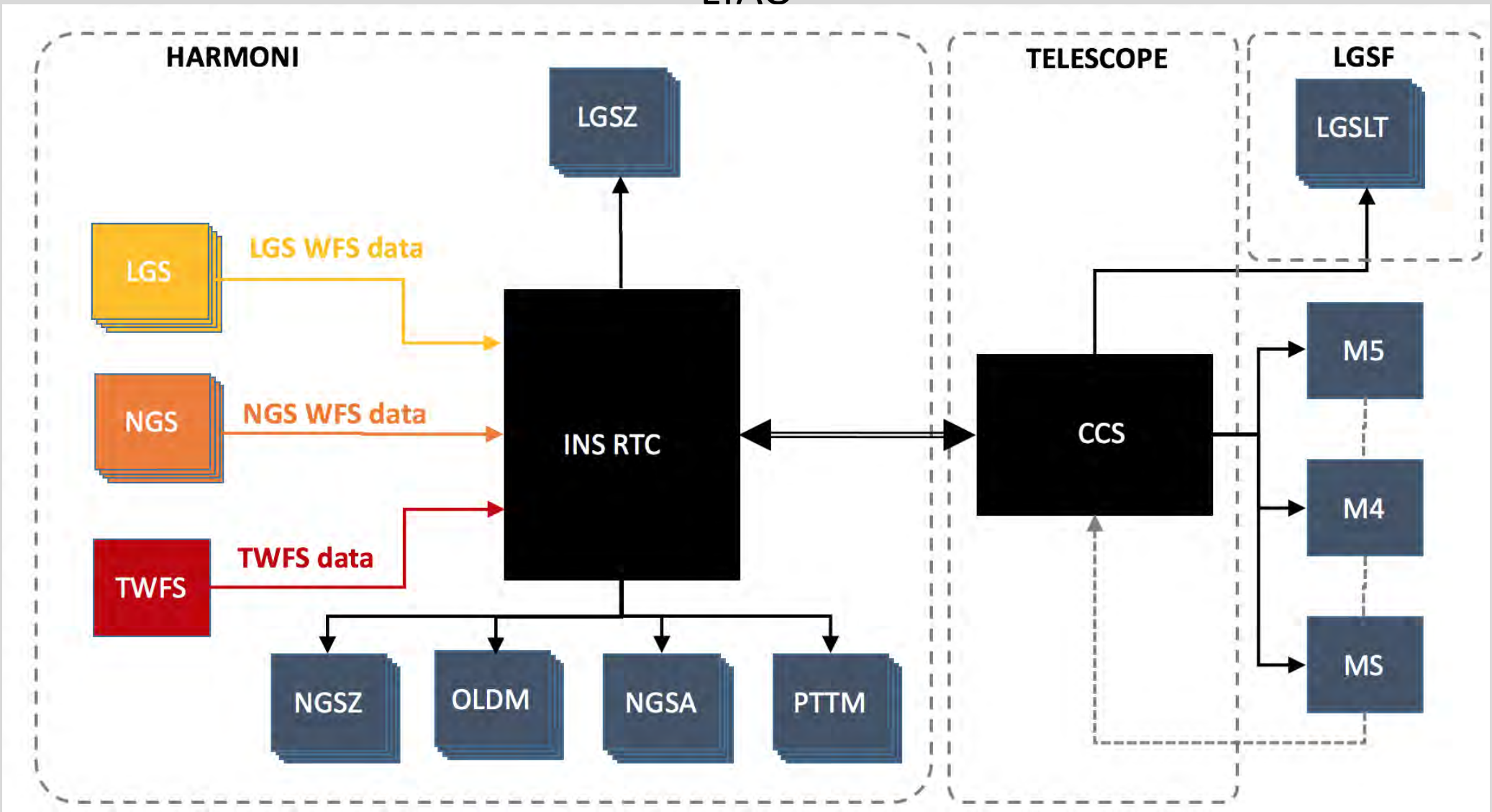
System Overview



SCAO and HCAO

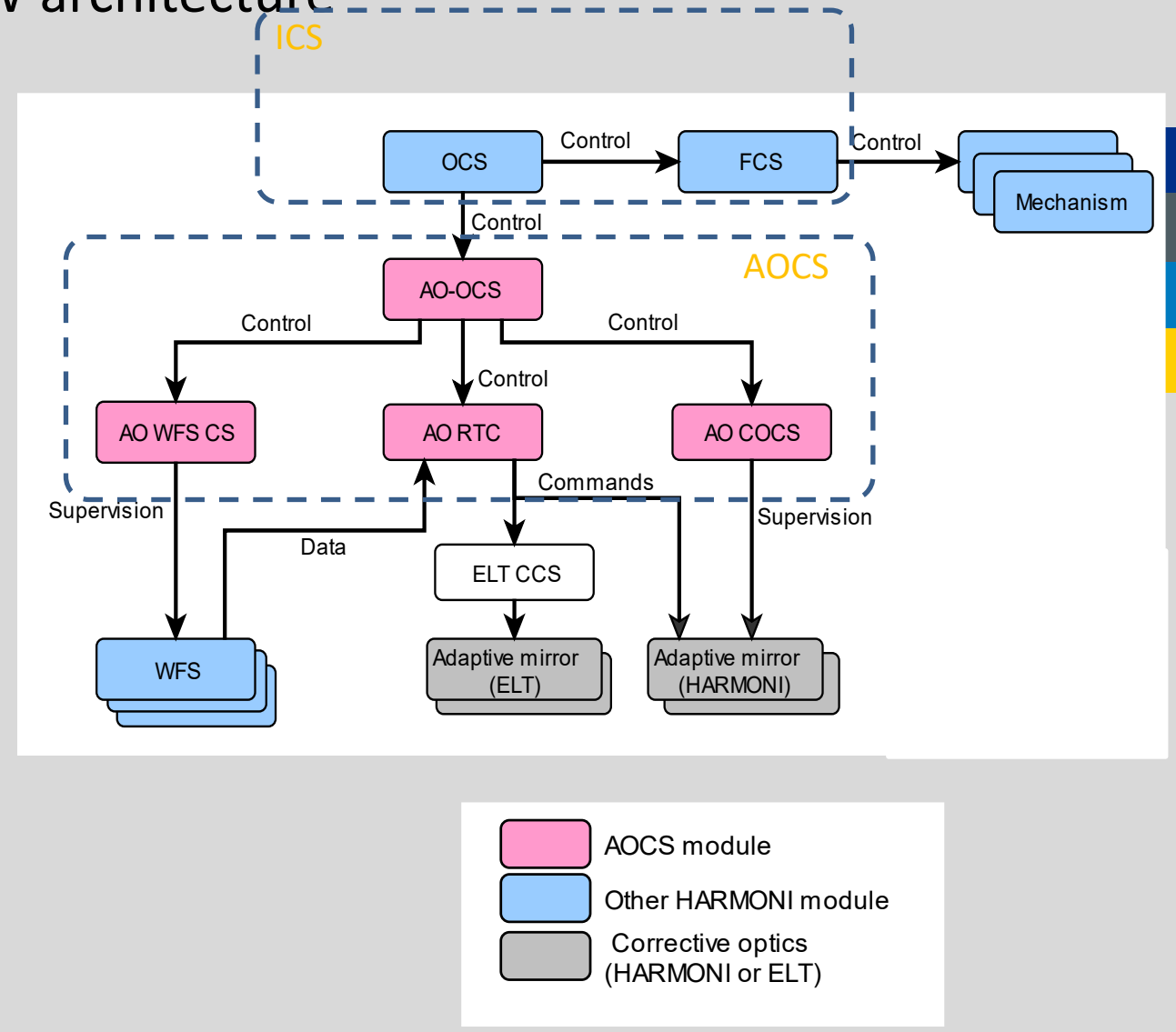


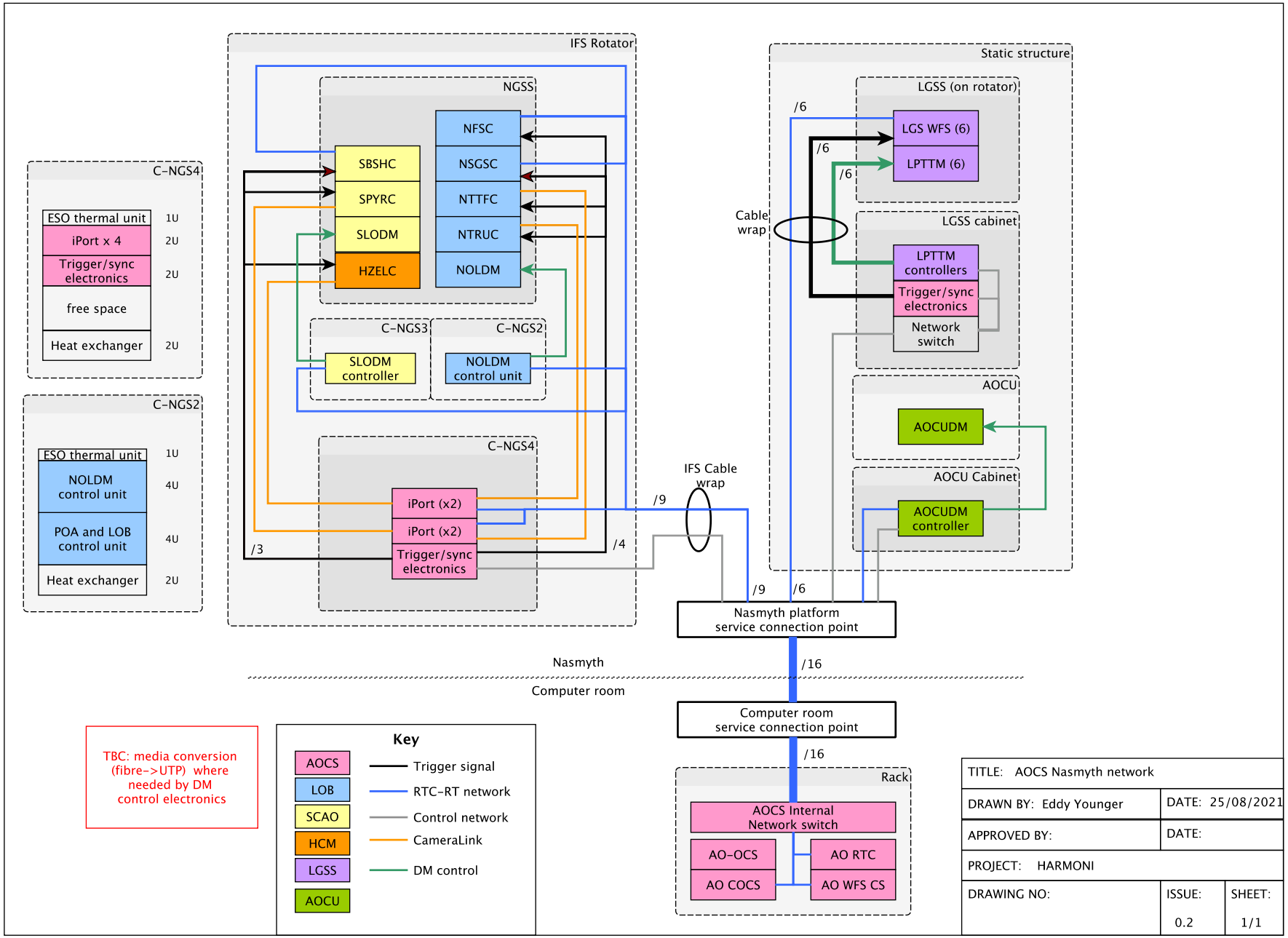
LTAO


HARMONI
TELESCOPE
LGSF
LGSZ
LGSLT
LGS
LGS WFS data
NGS
NGS WFS data
TWFS
TWFS data
INS RTC
CCS
M5
M4
MS
NGSZ
OLDM
NGSA
PTTM

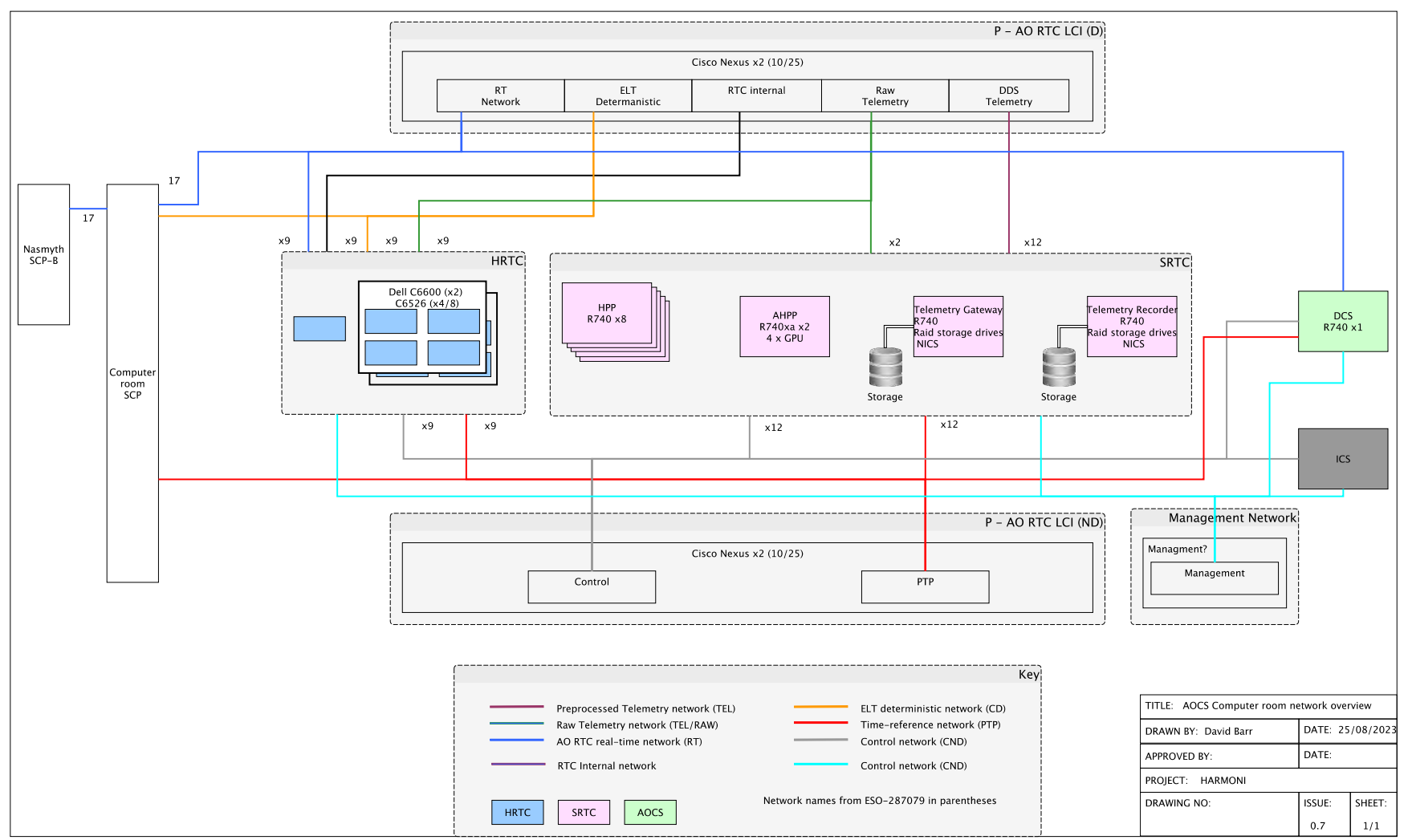
AOCS SW architecture

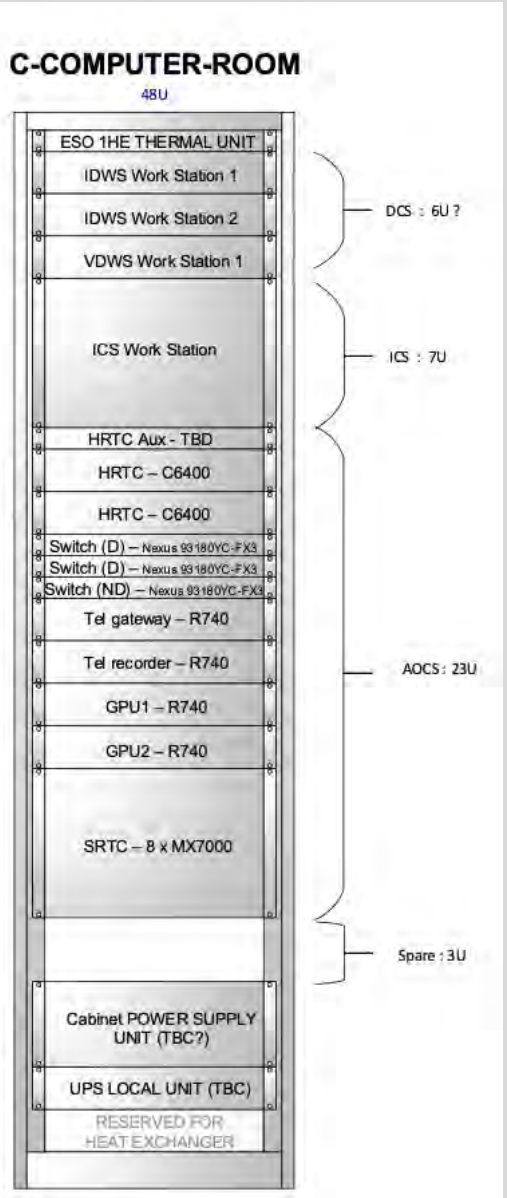
- Part of the HCS
- AO RTC
  - HRTC running DAO
  - SRTC running ESO RTC Tk
- AO WFS workstation running ESO DevEnv
- GUI & DISPLAY



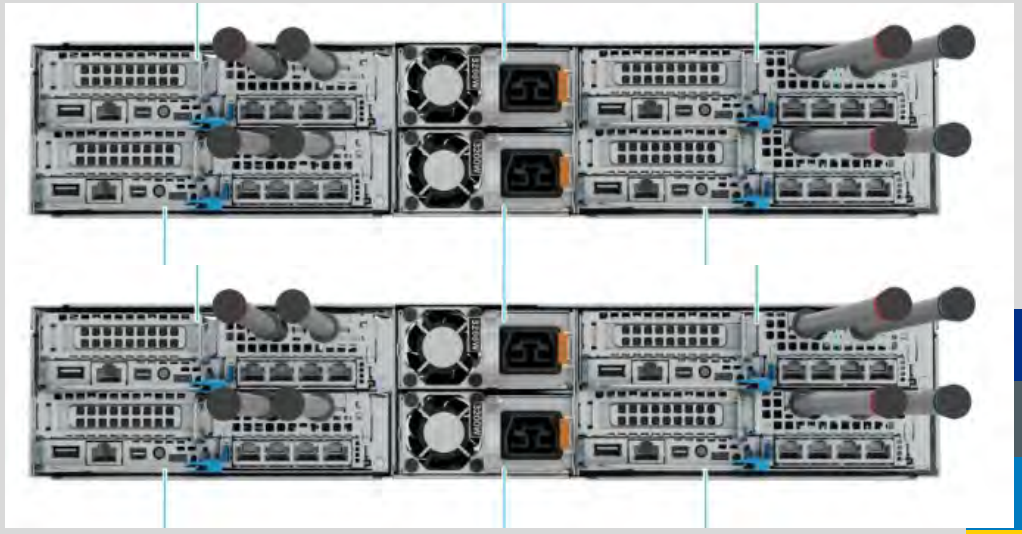

IFS Rotator
NGSS
NFSC
NSGSC
NTTFC
NTRUC
NOLDM
SBSHC
SPYRC
SLODM
HZELC
C-NGS3
C-NGS2
SLODM controller
NOLDM control unit
C-NGS4
iPort (x2)
iPort (x2)
Trigger/sync electronics
/3
/4
/9
IFS Cable wrap
Static structure
LGSS (on rotator)
/6
/6
/6
LGS WFS (6)
LPTTM (6)
Cable wrap
LGSS cabinet
LPTTM controllers
Trigger/sync electronics
Network switch
AOCU
AOCUDM
AOCU Cabinet
AOCUDM controller
/9
/6
Nasmyth platform service connection point
Nasmyth
Computer room
/16
Computer room service connection point
/16
Rack
AOCS Internal Network switch
AO-OCS
AO COCS
AO RTC
AO WFS CS
C-NGS4
ESO thermal unit
1U
iPort x 4
2U
Trigger/sync electronics
2U
free space
Heat exchanger
2U
C-NGS2
ESO thermal unit
1U
NOLDM control unit
4U
POA and LOB control unit
4U
Heat exchanger
2U
TBC: media conversion (fibre->UTP) where needed by DM control electronics
Key
AOCS
LOB
SCAO
HCM
LGSS
AOCU
Trigger signal
RTC-RT network
Control network
CameraLink
DM control
TITLE: AOCS Nasmyth network
DRAWN BY: Eddy Younger
DATE: 25/08/2021
APPROVED BY:
DATE:
PROJECT: HARMONI
DRAWING NO:
ISSUE: 0.2
SHEET: 1/1

AOCS


P – AO RTC LCI (D)
Cisco Nexus x2 (10/25)
RT Network
ELT Determanistic
RTC internal
Raw Telemetry
DDS Telemetry
17
17
Nasmyth SCP-B
Computer room SCP
x9
x9
x9
x9
x2
x12
HRTC
Dell C6600 (x2) C6526 (x4/8)
SRTC
HPP R740 x8
AHPP R740xa x2 4 x GPU
Telemetry Gateway R740 Raid storage drives NICS
Telemetry Recorder R740 Raid storage drives NICS
Storage
Storage
DCS R740 x1
ICS
x9
x9
x12
x12
P – AO RTC LCI (ND)
Cisco Nexus x2 (10/25)
Control
PTP
Management Network
Managment?
Management
Key
Preprocessed Telemetry network (TEL)
Raw Telemetry network (TEL/RAW)
AO RTC real-time network (RT)
RTC Internal network
ELT deterministic network (CD)
Time-reference network (PTP)
Control network (CND)
Control network (CND)
Network names from ESO-287079 in parentheses
HRTC
SRTC
AOCS
TITLE: AOCS Computer room network overview
DRAWN BY: David Barr
DATE: 25/08/2023
APPROVED BY:
DATE:
PROJECT: HARMONI
DRAWING NO:
ISSUE: 0.7
SHEET: 1/1


C-COMPUTER-ROOM
48U
ESO 1HE THERMAL UNIT
IDWS Work Station 1
IDWS Work Station 2
VDWS Work Station 1
DCS : 6U ?
ICS Work Station
ICS : 7U
HRTC Aux - TBD
HRTC – C6400
HRTC – C6400
Switch (D) – Nexus 93180YC-FX3
Switch (D) – Nexus 93180YC-FX3
Switch (ND) – Nexus 93180YC-FX3
Tel gateway – R740
Tel recorder – R740
GPU1 – R740
GPU2 – R740
SRTC – 8 x MX7000
AOCS: 23U
Spare : 3U
Cabinet POWER SUPPLY UNIT (TBC?)
UPS LOCAL UNIT (TBC)
RESERVED FOR HEAT EXCHANGER

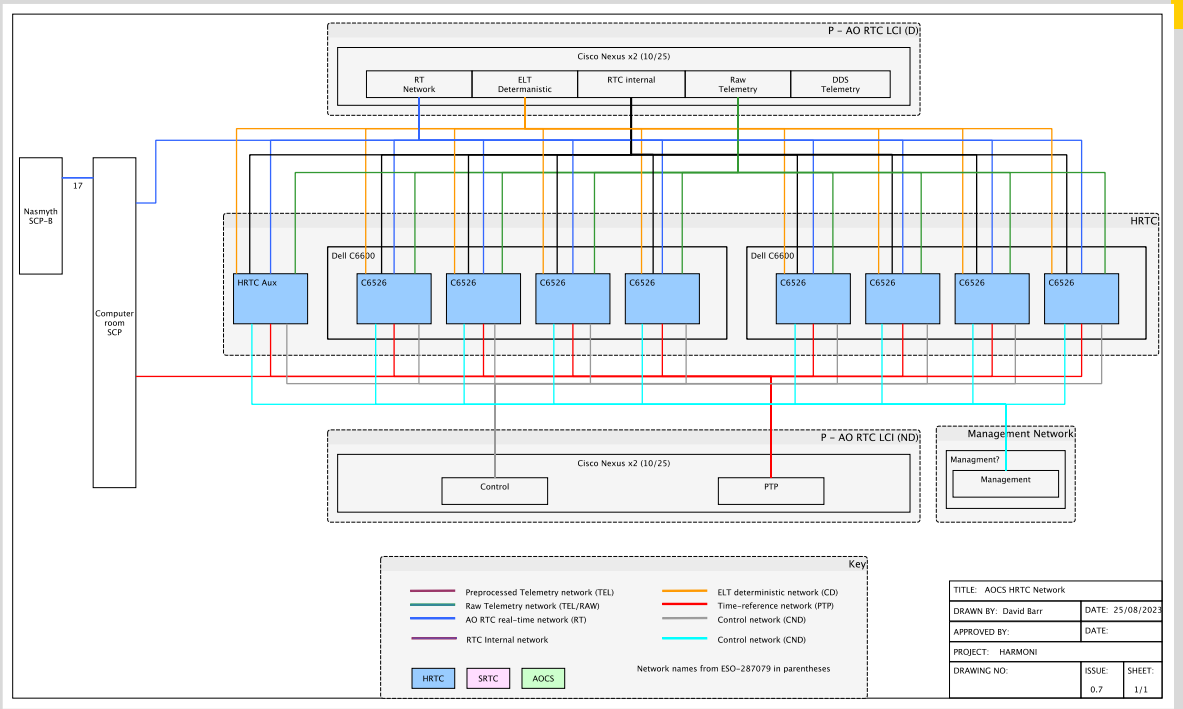
HRTC



- Dell 6400:
  - Each has 4 sleds.
  - Each sled Dual AMD EPYC 7702
  - 48 cores
  - L3 cache 256 MB.
  - High memory bandwidth.

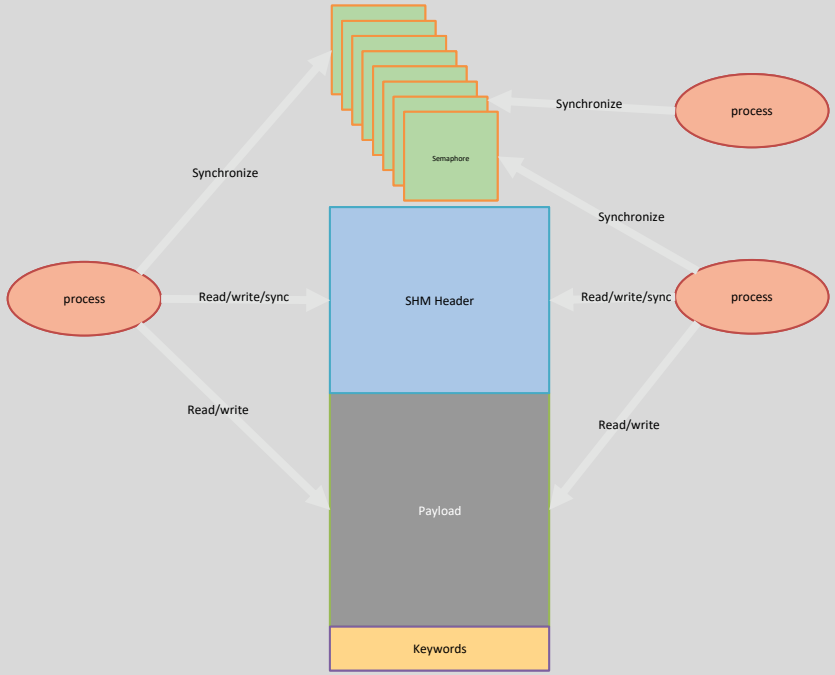
- Interconnected:
  - 10 GbE prototype
  - 25 GbE Design

- Likely: 1U machine for slow HRTC Auxiliary loops (TBD)



HRTC: DAO

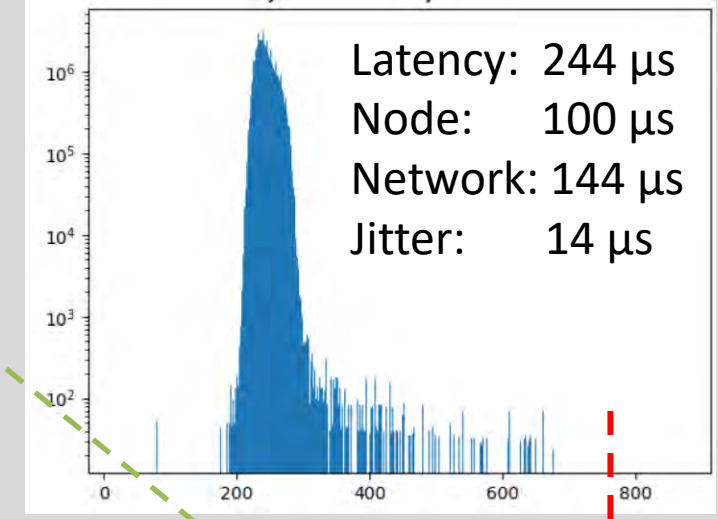
- Shared memory-based data exchange
  - Semaphore for process synchronization.
  - Polling counters for performance.
- MUDPI-RTMS/GigE Vision compatible
- Redis db for parameter control and updates.
- Open source, maintain by Durham*
- C/C++ and python based
  - Network logging
  - Low latency and low jitter
- Internal tools to control and monitor the system (included GUIs in QT)
- Local telemetry and network logging
- Local timing monitoring.



*public release coming soon now dual use export license is under control.

SCAO pipeline

Image: 240x240 u16@1kHz
CM: 29472x4358
Node: 29472x1453



telemetry

HRTC1

turb sim

Dm Cmd

combiner

Dm TT Cmd

Sender*

Receiver*

Raw IM

combiner

res WF

filter

Dm TT Cmd

Pixels multicast
GIGE or MUDP

HRTC2

receiver

Raw IM

cal

CAL IM

comp

Intensities

MVM

Residual WF

Camera simulator

sender

HRTC3

receiver

Raw IM

cal

CAL IM

comp

Intensities

MVM

Residual WF

receiver

M4/5 simulator

HRTC4

receiver

Raw IM

cal

CAL IM

comp

intensities

MVM

Residual WF

ELT RT network (10Gb)

HARMONI RT network (10Gb)

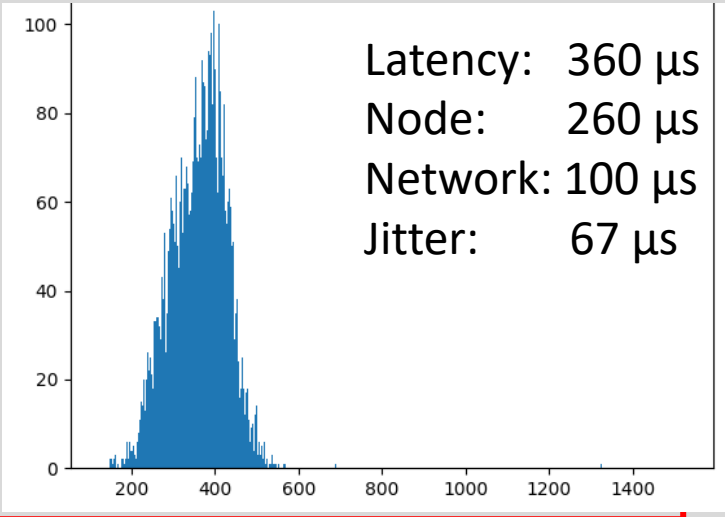
Telemetry network (40Gb)

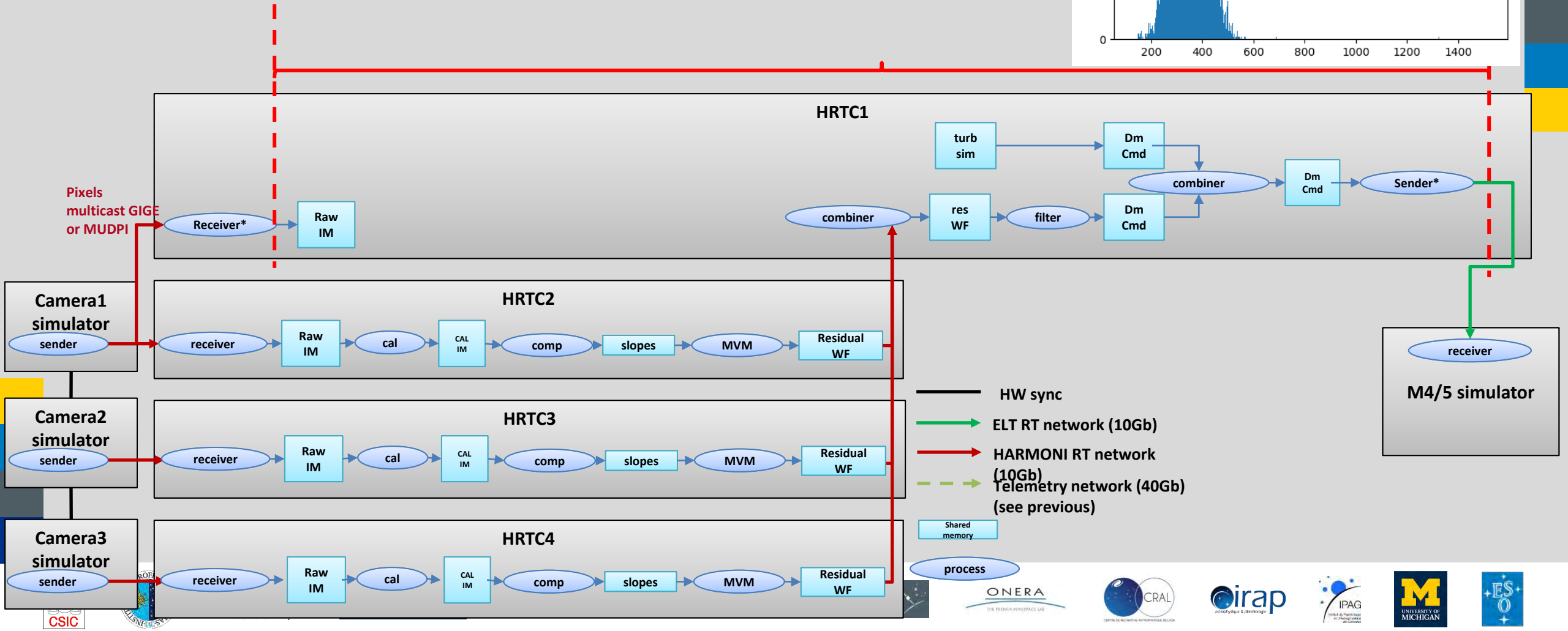
Shared memory

DAO process

LTAO pipeline

LGS: 6x1092x1092 u16 @ 500Hz
Node: 1x1092x1092
6x reconstructor 9200x4358 (size if we use 6 nodes)

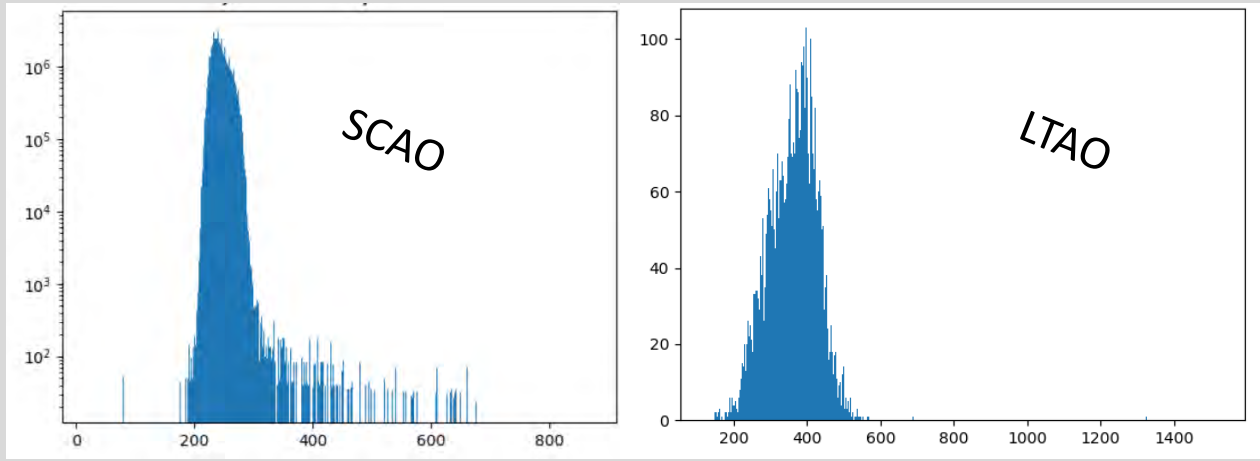




HRTC Summary

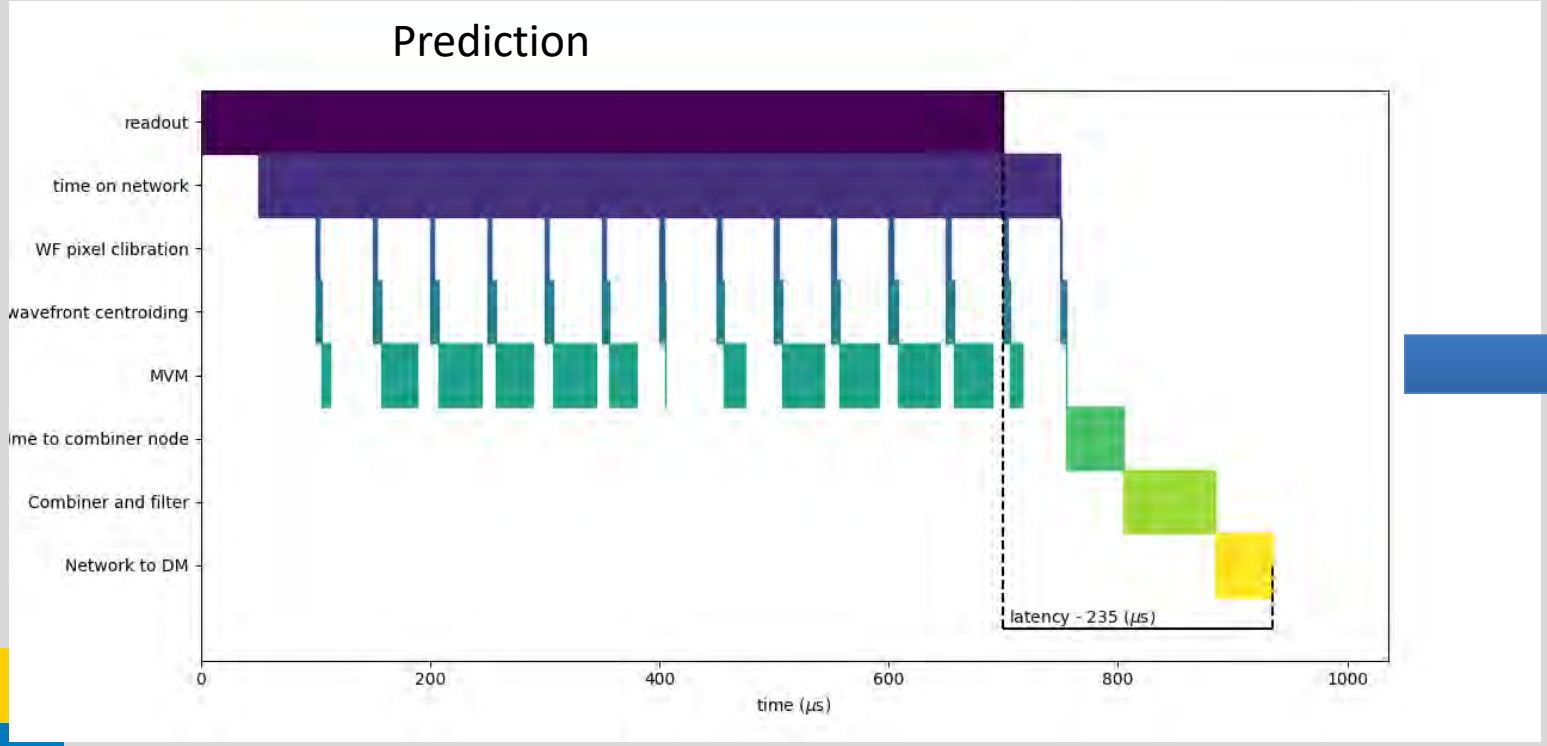
- Using DAO RTC
  - Shared-memory process independent.
  - Utilizing cache, NUMA and resource shielding in com
- Main SCAO pipeline running.
  - Meeting requirements.
- Main LTAO pipeline running.
  - Needs some tuning for jitter but meets latency requirements
- Meeting requirements 2 years ahead of FDR why go further?

	SCAO (us)	LTAO (us)
Overall Latency	244	360
Communication latency	144	100
Node latency	100	260
Overall jitter	14	67

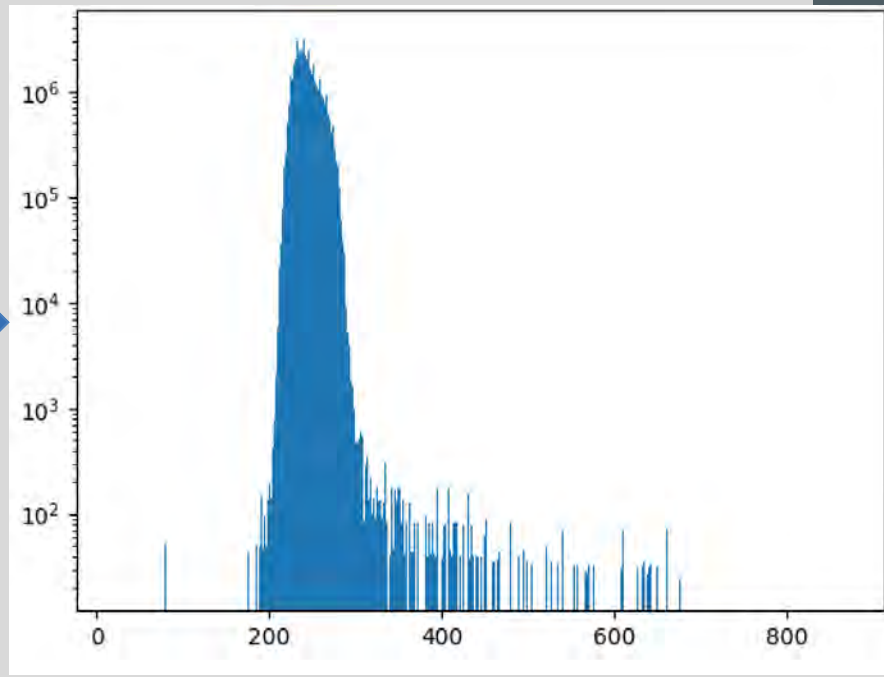


HARMONI

Prediction



Results



WFS camera integration

- DAO is currently compatible
  - ESO MUDPI
  - GigE Vision cameras.
- Tested:
  - Multiple C-BLUE's on bench.
  - IPORT + Cred2 On bench
  - MUDPI cameras software emulated.
- 11 camera interfaces fully or partially integrated.
- 11/15 interfaced and tested.
- Cameras will take a hardware trigger which will use PTP.

Type	HARMONI location	HRTC status	Issues
CBLUE	6 x LGS WFS 1 x DM figure sensor	Integrated on bench with HRTC + streaming via 10G ethernet	C-BLUE does not support multicast – vendor willing to implement.
OCAM2K	1 x Pyramid WFS	All use iPort Camera Link to GigE Vision Convertor • Latency tested (<20 us jitter) • Camera stream emulated using FPGA	Do not have access to cameras yet.
CRED1	1 x Tip-tilt focus WFS		
CRED2	1 x Zelda WFS 1 x Truth Sensor 1 x Second arm sensor	Currently being integrated on the bench. Iport CameraLink to GigEVision Convertor	On-going testing
AVT ProSilica	1 x Blue SH WFS 1 x NoAO guiding	No tests, but cameras are native GigEVision	Camera not tested
ESO (MUDPI)	(1 x Tip-tilt focus WFS)	Software emulation only in RTC toolkit	Cameras don't exist

Camera integration

Test C-BLUE WFS on bench
(configured as a WFS for another experiment)

Config for multi-node tests

Switch

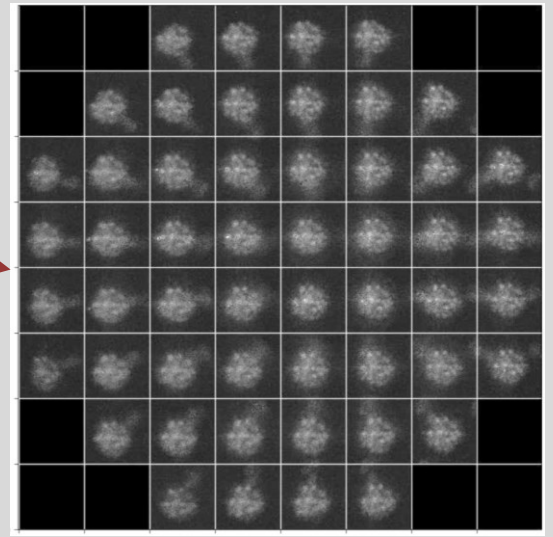
DAO

WFS controller

Camera development required

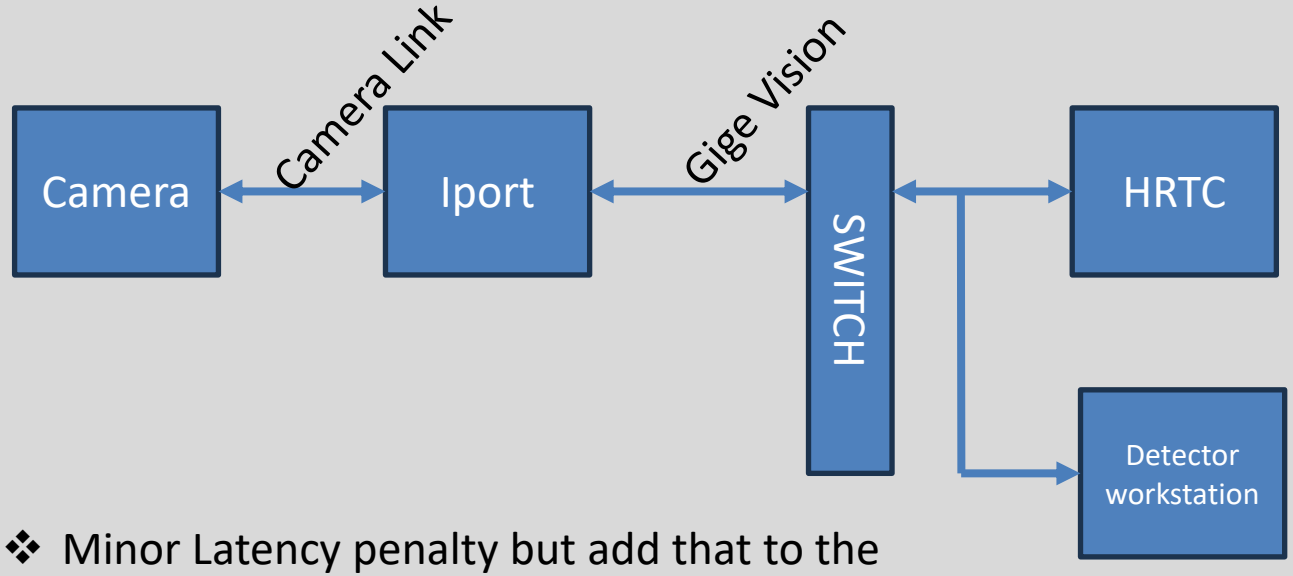
ESO development in toolkit

Wide-field corelating WFS
(similar to Solar AO)



Engineering real-time display
Python QT based

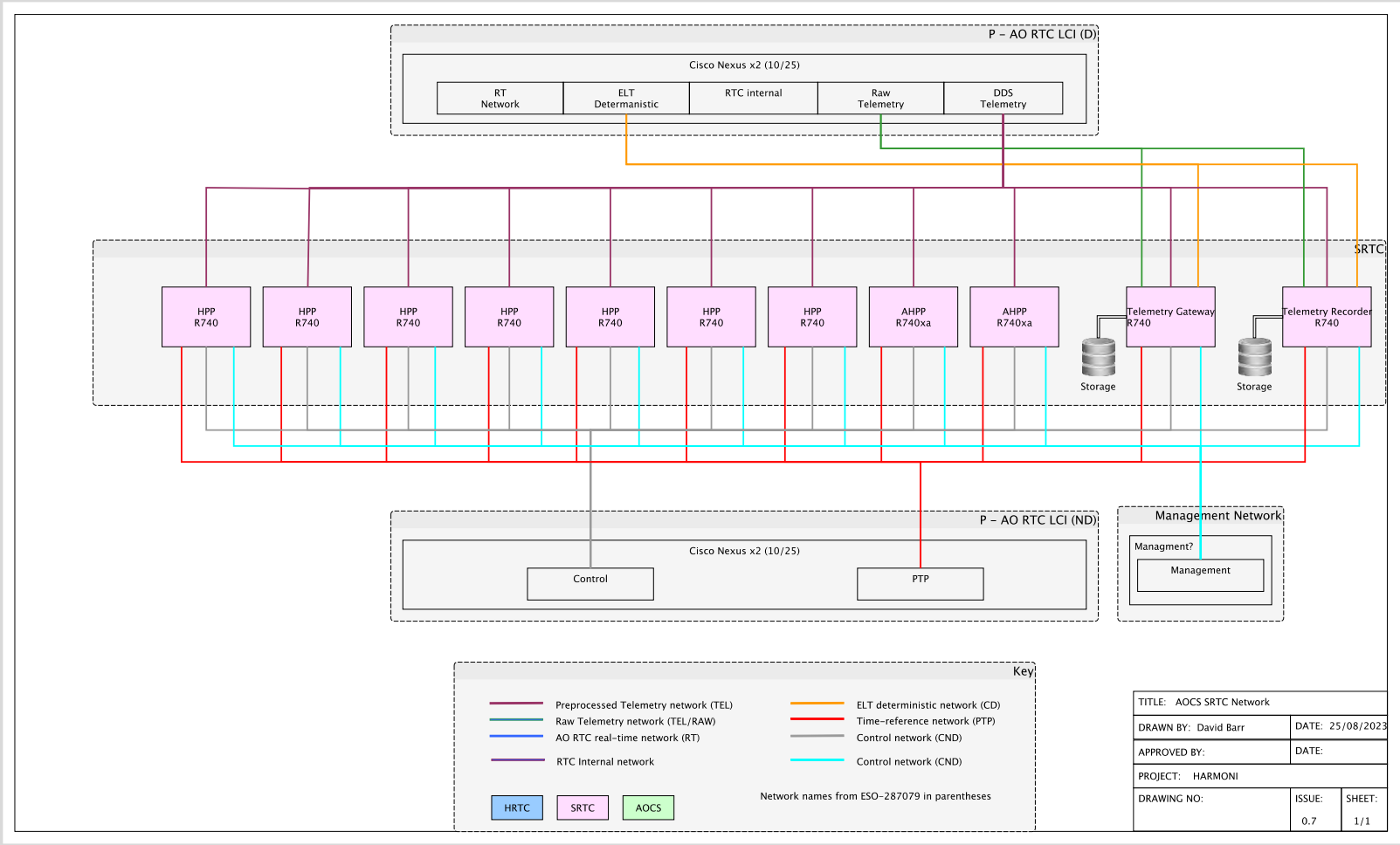
IPORT and Camera link



- Minor Latency penalty but add that to the readout latency.
  - FLI Cred1 x 1
  - FLI Cred2 x3
  - Ocam2k x 1

- ESO CCF already provides control via Aravis for Gige vision Cameras control

SRTC Network Layout



SRTC

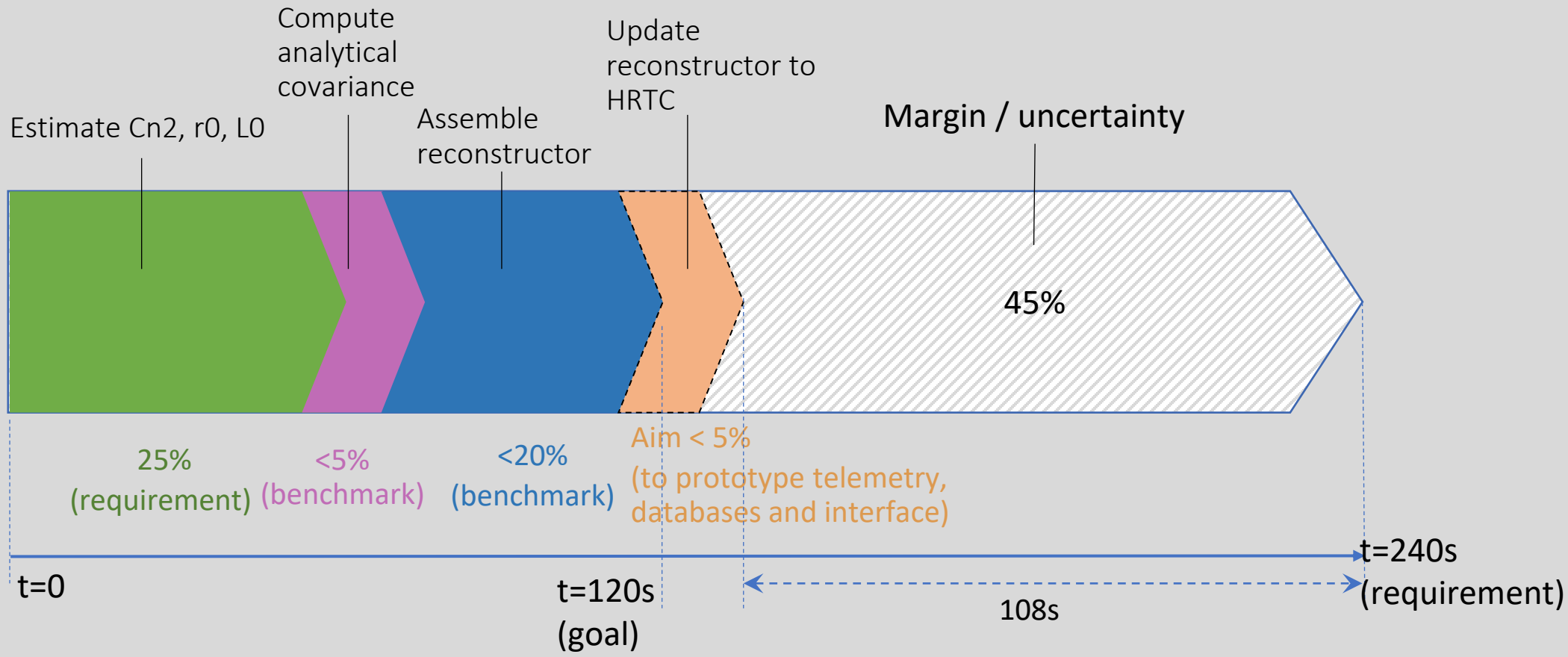
- Mx7000
  - 8 x MX750C sleds
  - Each sled with dual intel CPUs
  - Large memory
  - 25 Gbe Networking
- PowerEdge R750
  - Telemetry Gateway with large storage banks
  - Multiple 25 Gbe Links
- PowerEdge R750Xa with 4 Nvidia A100s
  - Algorithms tested: Titan V

SRTC prototyping

- Complete SRTC RTC-tk installation
  - Distributed OLDB
  - Runtime repo
- Telemetry being distributed
  - Definition of shared memory topics
- Show distribution of telemetry to compute nodes.
  - Data task templates outlined.
  - Skeletons of components being developed.
- LTAO atmospheric parameter estimation under development
  - Compute optimization and benchmarking against unmet requirement.
  - To be integrated into an RTC-Tk when stable.

```
namespace harmoni::srtcTopic {

//////////////
// SENSORS //
//////////////

// Pyramid
constexpr unsigned PYR_NUM_PIXELS = 200u * 200u;
constexpr unsigned PYR_N_SLOPES   = 20000u;
constexpr unsigned PYR_N_SUBAPS   = 10000u;
// Blue SH
constexpr unsigned BSH_NUM_PIXELS = 4400u * 4400u;
constexpr unsigned BSH_N_SLOPES   = 104u;
constexpr unsigned BSH_N_SUBAPS   = 52u;
// LGS SH
constexpr unsigned LGSSH_NUM_PIXELS = 1100u * 1100u;
constexpr unsigned LGSSH_N_SLOPES   = 12168u;
constexpr unsigned LGSSH_N_SUBAPS   = 6084u;
// TTFS
constexpr unsigned TTFS_NUM_PIXELS = 320u * 256u;
constexpr unsigned TTFS_N_SLOPES    = 8u;
constexpr unsigned TTFS_N_SUBAPS    = 4u;
// TRUTH WFS
constexpr unsigned TWFS_NUM_PIXELS = 512u * 640u;
constexpr unsigned TWFS_N_SLOPES    = 200u;
constexpr unsigned TWFS_N_SUBAPS    = 100u;
// FIGURE SENSOR
constexpr unsigned FIGS_N_SLOPES   = 1922u;
constexpr unsigned FIGS_N_SUBAS    = 961u;

//////////////
// MIRRORS //
//////////////

// M4/5
constexpr unsigned M4_5_N_COMMANDS = 4868u;
constexpr unsigned M4_5_N_FEEDBACKS = 9736u;
// SLODM
constexpr unsigned SLODM_N_COMMANDS = 81u;
// CALLODM
constexpr unsigned CALLODM_N_COMMANDS = 81u;
// NOLDM
constexpr unsigned NOLDM_N_COMMANDS = 820u;

// Basic pixels topics
template <unsigned int NPIX>
struct PixelBaseTopic {
```

Tomography Timeline vs Requirements



- Timing close to goal, preliminary results for Cn2 profile within requirement (1x GPU)
- Results need to be evaluated against AO performance metrics

SRTC Data tasks (in-progress): SCAO subset

Category	Codename	Title	telemetry Input	input frequency (Hz)	Input duration (s)	vector size	data type	Parameter input (OLDB, Runtime repo)	Parameter vector size	Outputs	Min update Period	dataTask type
System Parameter Estimation	TurbEst	Turbulence Parameter Estimation	Pseudo open loop KL coefficients	500	10	4868	fp32			r0 L0 wind speed	10 s	Runnable
	VibEst	Vibration Estimation	LO pseudo open loop KL coefficients	500	10	2	fp32			Vibration coefficients – amplitude, frequency and bandwidth	10 s	Runnable
	M4RegEst	M4 Registration Estimation	NGS WFS slopes	500	60	40000	fp32				5 min	Runnable
			M4 commands	500	60	4868	fp32			2x translation magnification rotation		
Loop Parameter Optimisation - Main loop	[NGSWFS]-[BackOpt]	NGS WFS Background Optimisation	NGS WFS processed pixels	500	TBC	57600	fp32	NGS WFS background map		NGS WFS background map	1 hz	Runnable
	[NGSWFS]-[ThresOpt]	NGS WFS Threshold Optimisation	NGS WFS processed pixels	500	TBC	57600	fp32	Threshold percentage		NGS WFS Threshold	1 hz	Runnable
	[MAOL]-[PupilTrack]	Main AO Loop Pupil Tracking	NGS WFS processed pixels	500	TBC	57600	fp32	NGS WFS Threshold		Valid sub-aperture map valid actuator map	1 hz	Runnable
	[MAOL]-[UpCM]	Main AO Loop Update Command Matrix	N/A	N/A	N/A	N/A	N/A	Interaction Matrix valid actuator map conditioning threshold number of controlled modes		command Matrix	1 min (TBC)	Optimisable
	[MAOL]-[PyrOG]	Main AO Loop Pyramid Optical Gain Estimation and Compensation	TBC	TBC	TBC	TBC	TBC	Modulation function # controlled modes High order NCPA correction r0 estimate		Optical gain estimate Optical gain compensation NGS WFS reference slopes		TBC
	[MAOL]-[HOTempFOpt]	Main AO Loop Higher Order Temporal Filter Optimisation	Pseudo open loop KL coefficients	500	TBC	4868	fp32	Rejection transfer function parameters		[MAOL] IIR parameters	10s (TBC)	Runnable
	[MAOL]-[LOTempFOpt]	Main AO Loop Lower Order Temporal Filter Optimisation	N/A	N/A	N/A	N/A	N/A	r0, L0, wind speed, vibration parameters		Kalman matrices	10s (TBC)	Optimisable
Loop Parameter Optimisation - LODM loop	[BSWFS]-[BackOpt] BSWFSBackOpt	BS WFS Background Optimisation	TBC	TBC	TBC	TBC	TBC			BS WFS Background map		TBC
	[BSWFS]-[ThresOpt] BSWFSThreshOpt	BS WFS Threshold Optimisation	BS WFS processed pixels	1	TBC	2E+07	fp32	Threshold percentage		BS WFS thresholds	10s (TBC)	Runnable

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	[BSWFS]-[ThresOpt] BSWFSThreshOpt	BS WFS Threshold Optimisation	BS WFS processed pixels	1	TBC	2E+07	fp32	Threshold percentage		BS WFS thresholds	10s (TBC)	Runnable

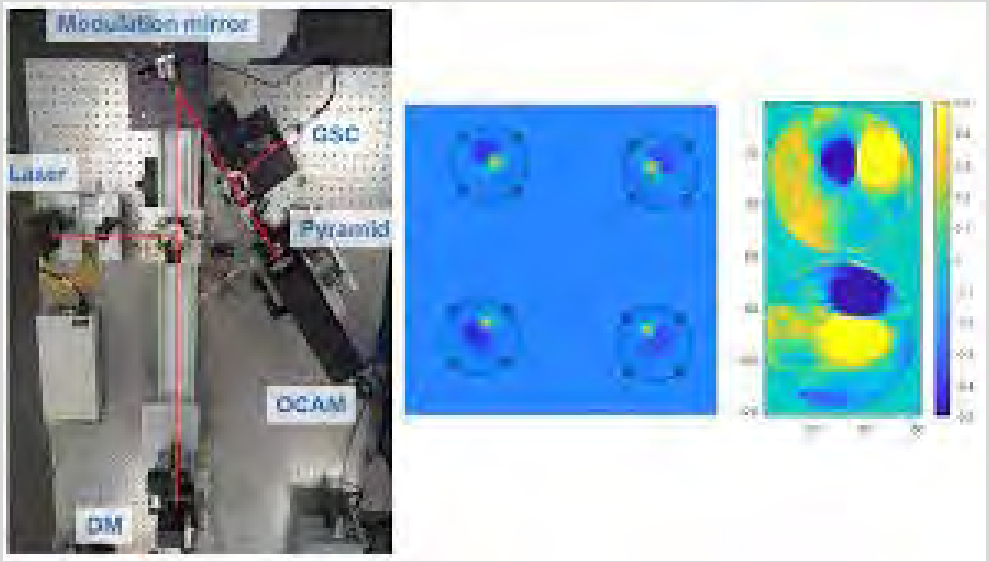
50 + data tasks across SCAO and LTAO

OHP and going on-sky

- Papyrus
  - SCAO with a Pyramid
  - OHP 1.52 m
- Currently running CHAI RTC.
  - Installed DAO
- Delivered a New RTC based on AMD EPYC
  - Developing OCAM2k interface
  - Deployed ALPAO interface
- Planning a run later in November

Highlights

- Same Camera OCam2k
- Similar Pyramid.
- Same CPU
  - Same optimizations
- HARMONI Pathfinder and Risk reduction.



Credit: Muslimov et al 2019

Thanks for listening

CFAI Recruitment

Current/closed

- Postdoc MKID + AO (deadline 5th)
- Assistant Optical Engineer (deadline 10th)

Upcoming

- post docs in AO focuses on RTC
- graduate software engineer roles.

Website, talk or email me for more information

https://www.durham.ac.uk/job-vacancies/
david.barr@durham.ac.uk

Credit :Durham University