May 21-22

Nick Kornweibel

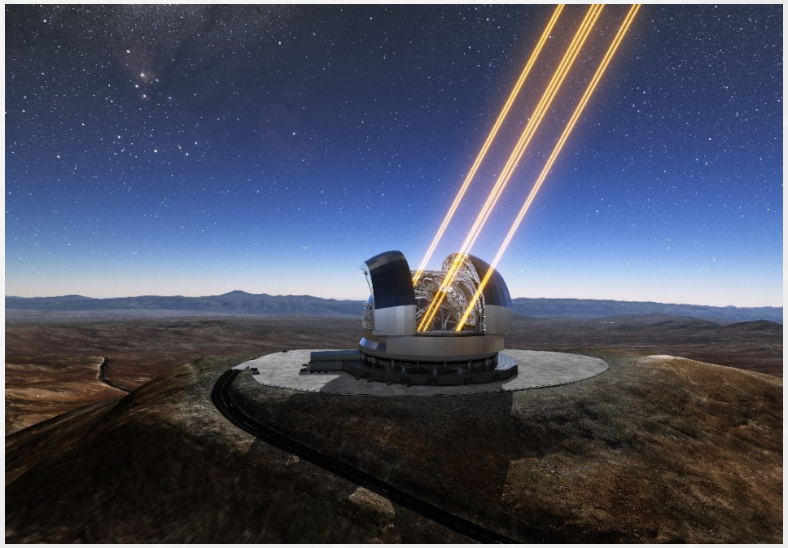
ESO

The ELT Control System
Overview and Update

- Nick Kornweibel
  ELT Control System Project Manager

ESO's Extremely Large Telescope (ELT)

- Largest optical telescope in the world
- 39m diameter primary mirror
- Focal length: 740m
- Angular resolution: 0.005 arcsecond
- Science: earth-like planets, deep universe, origins of the universe, star formation, and ?

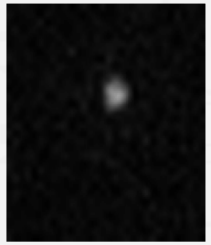


- System Design complete – Construction on going on Cerro Armazones

- Timeline 2014-2025
- Capital cost: ~1175 MEur
- Operation cost: ~50 MEUR / year

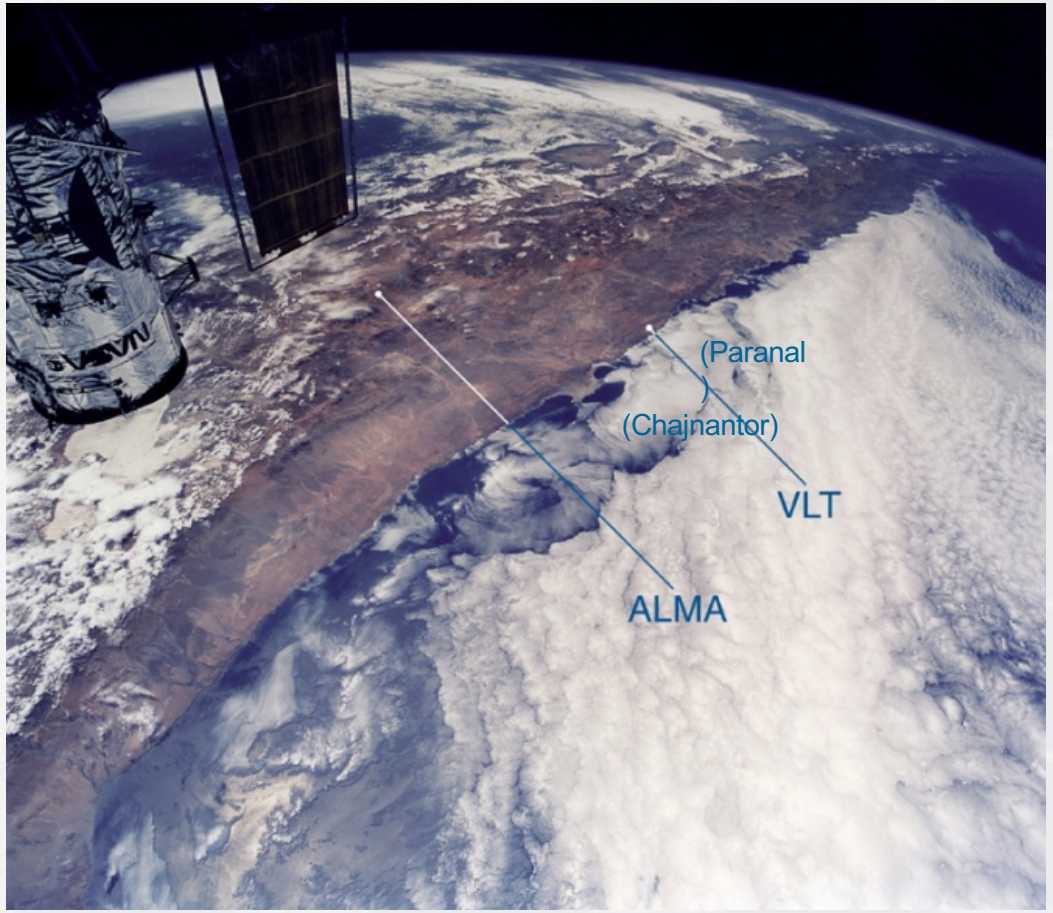
Why Chile?

- Excellent weather in the Atacama Desert:
  - No clouds
  - Extremely dry
  - Clean air
  - Low turbulence
  - Very low light pollution

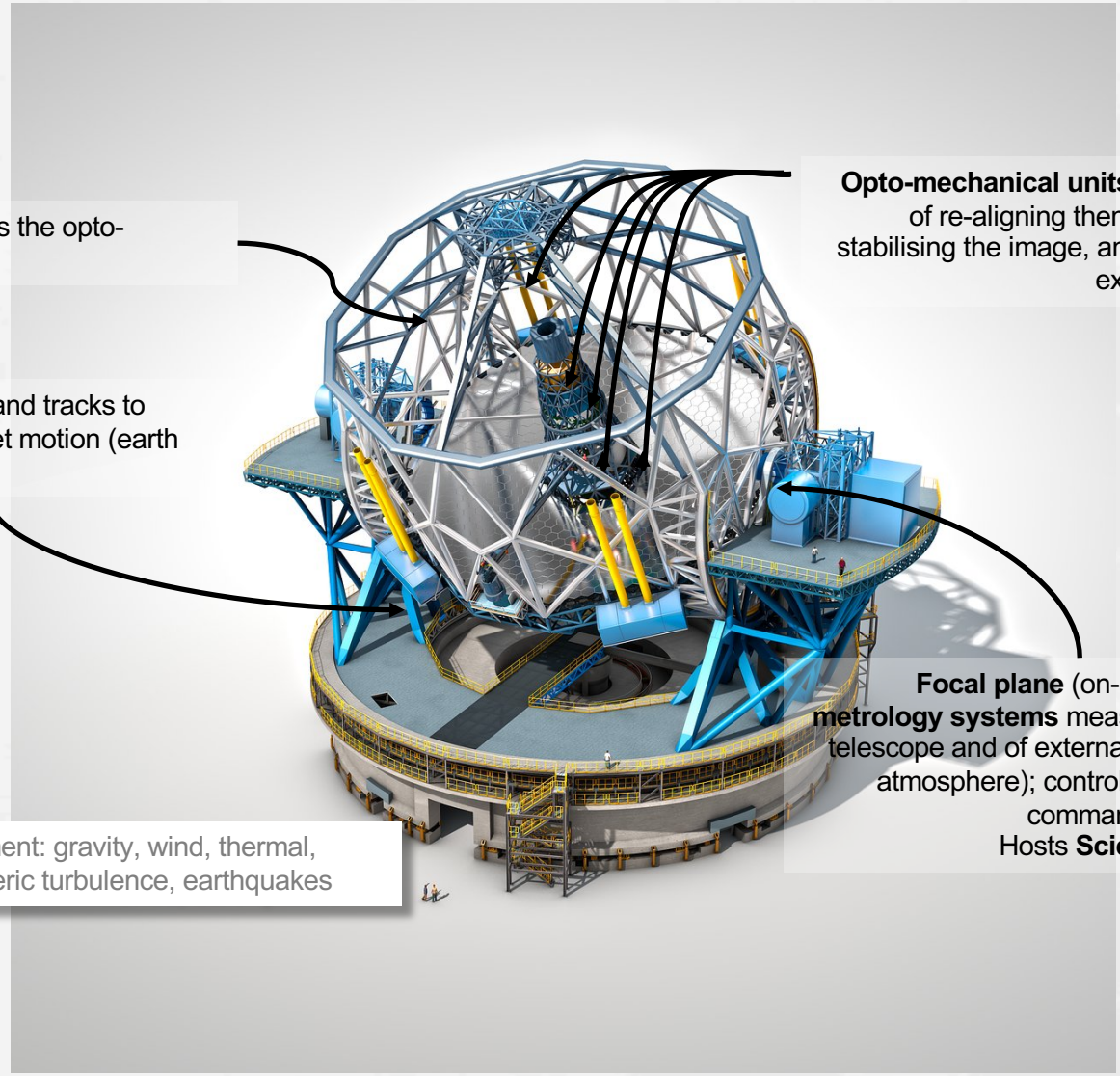


Somewhere else

Chile



The Telescope



Main Structure holds the opto-mechanical units

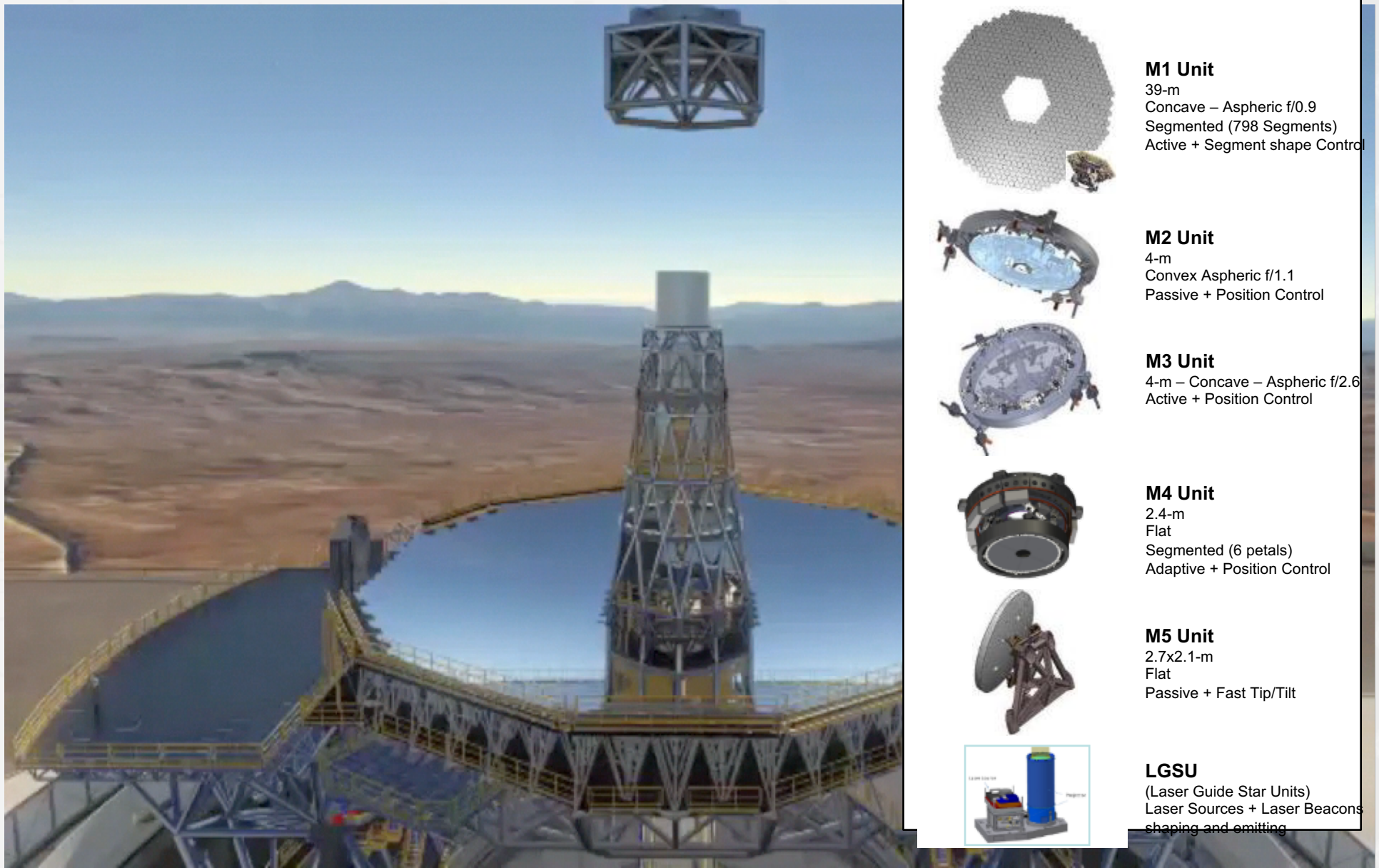
Alt-Az mount points and tracks to compensate for target motion (earth rotation)

Environment: gravity, wind, thermal, atmospheric turbulence, earthquakes

Opto-mechanical units are jointly capable of re-aligning themselves, refocusing, stabilising the image, and compensating for external perturbations

Focal plane (on-sky) and embedded **metrology systems** measure the state of the telescope and of external perturbations (e.g. atmosphere); control system derives the commands sent to the units
Hosts **Scientific Instruments**

Optomechanics



M1 Unit
39-m
Concave – Aspheric f/0.9
Segmented (798 Segments)
Active + Segment shape Control

M2 Unit
4-m
Convex Aspheric f/1.1
Passive + Position Control

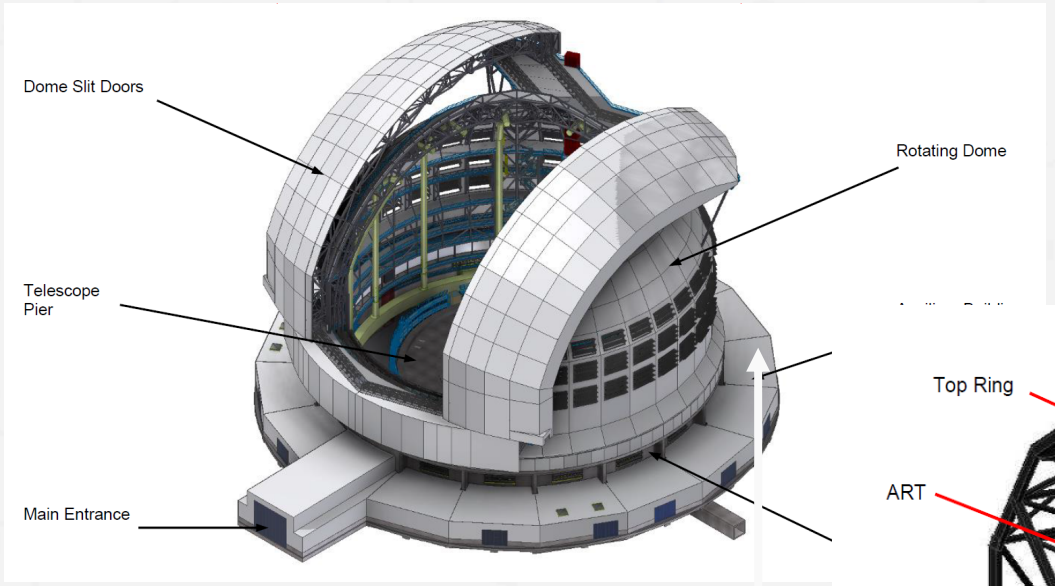
M3 Unit
4-m – Concave – Aspheric f/2.6
Active + Position Control

M4 Unit
2.4-m
Flat
Segmented (6 petals)
Adaptive + Position Control

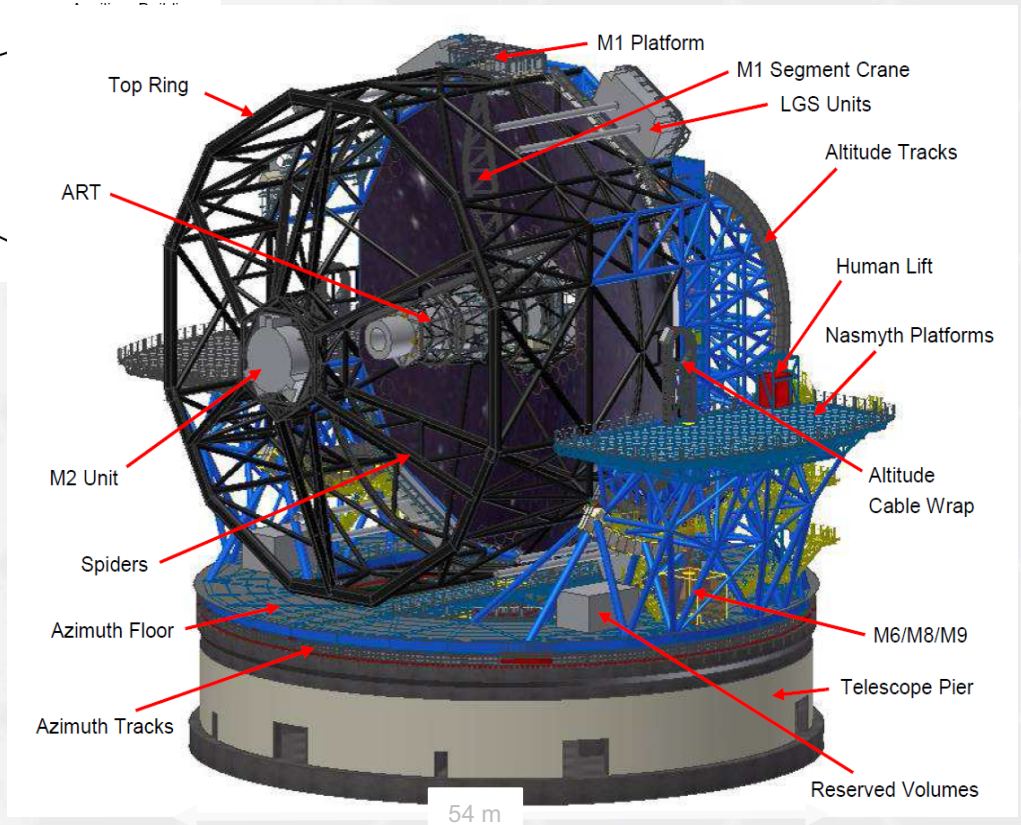
M5 Unit
2.7x2.1-m
Flat
Passive + Fast Tip/Tilt

LGSU
(Laser Guide Star Units)
Laser Sources + Laser Beacons
shaping and emitting

ELT Dome & Main Structure (DMS)



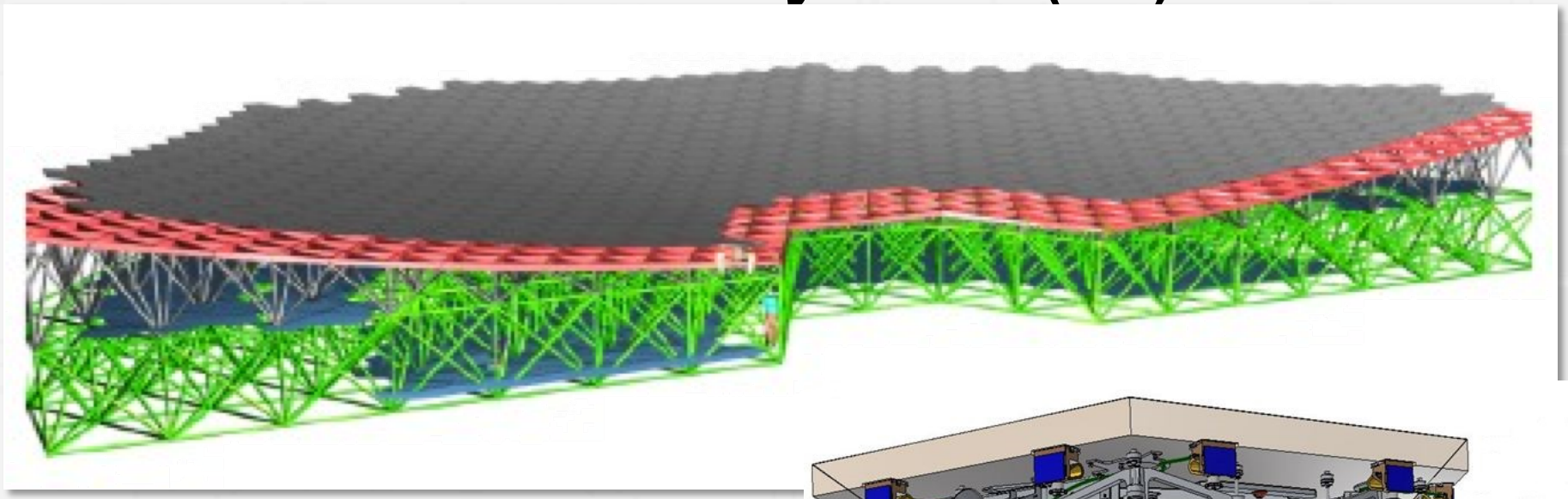
- Alt/Az telescope
- MS+optics: 2800 tonnes



Control System:

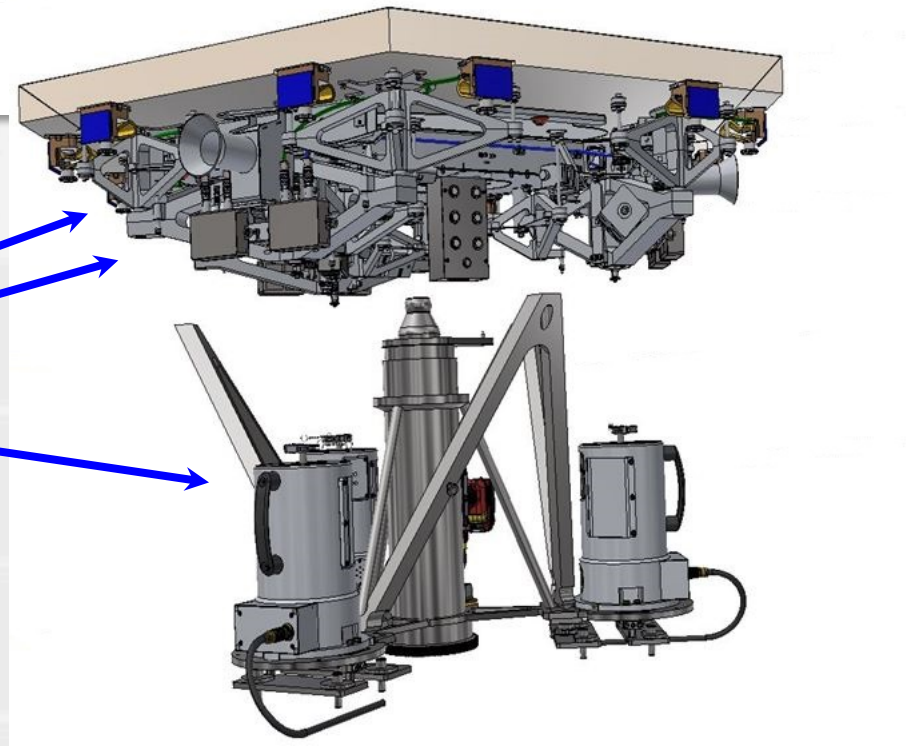
- Industrial Automation (PLCs)
- Large safety component
- Finely tuned Alt/Az tracking
- OPC/UA interface (PLC)
- External (RT) interface:
  - Tracking (20Hz)
  - Alt/Az encoders (200Hz)

The Primary Mirror (M1)

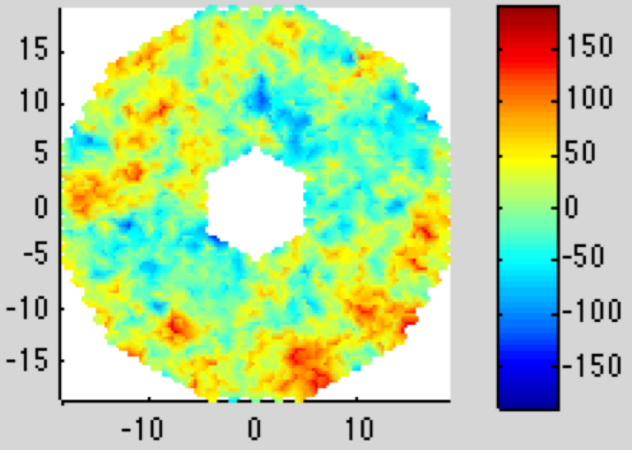


Segment Control:

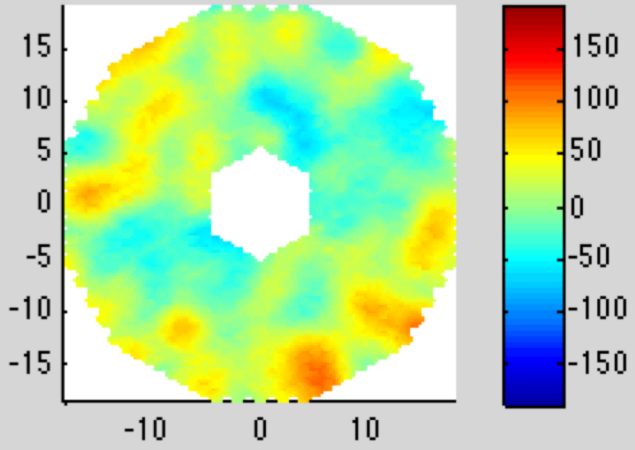
- 6 Edge Sensors (Piston/Shear/Gap)
- 1 Surface Deformation harness
- 3 Actuators (Piston/Tip/Tilt)



M1 Mirror Control

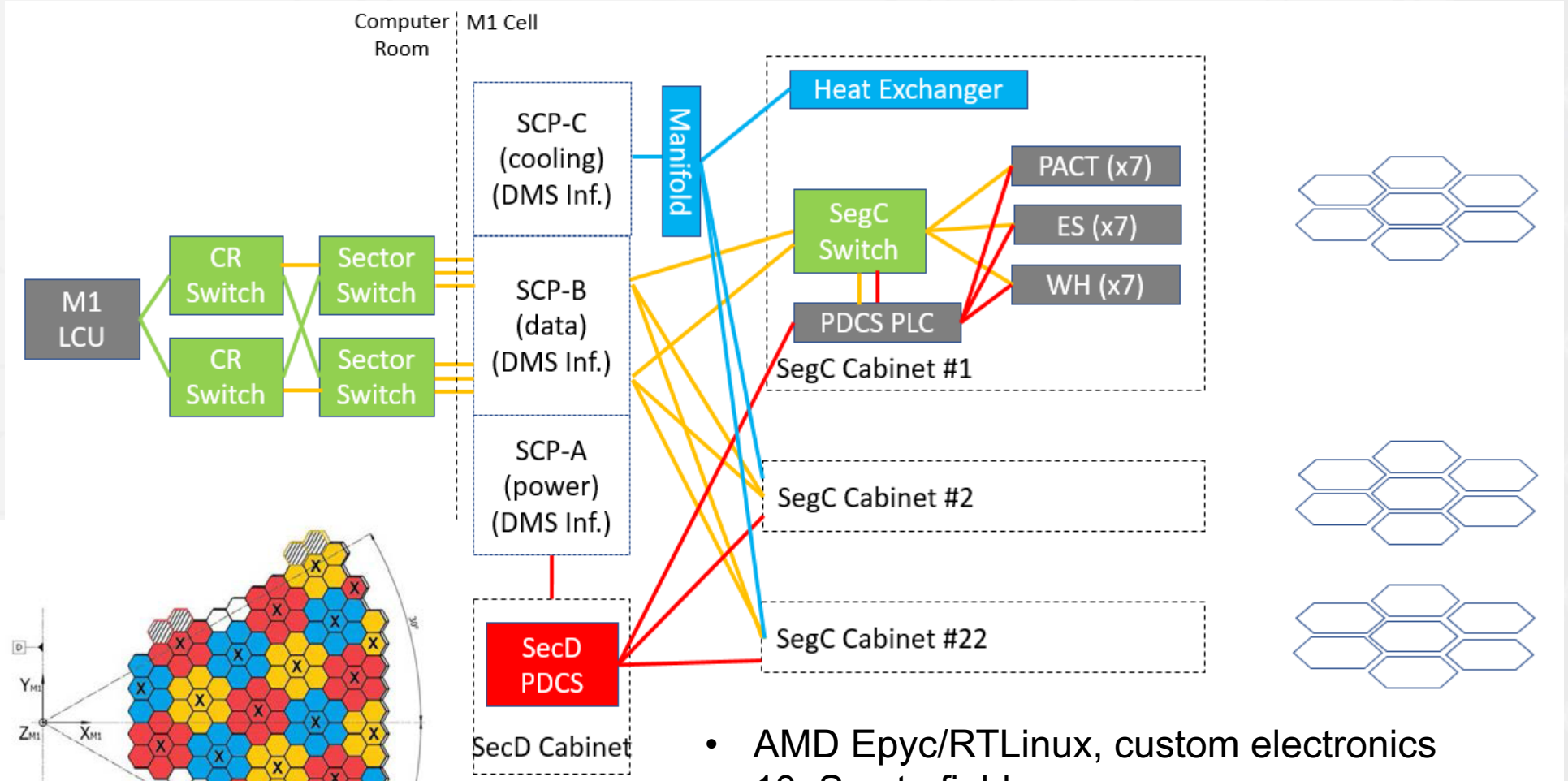


Open Loop Segmented Mirror

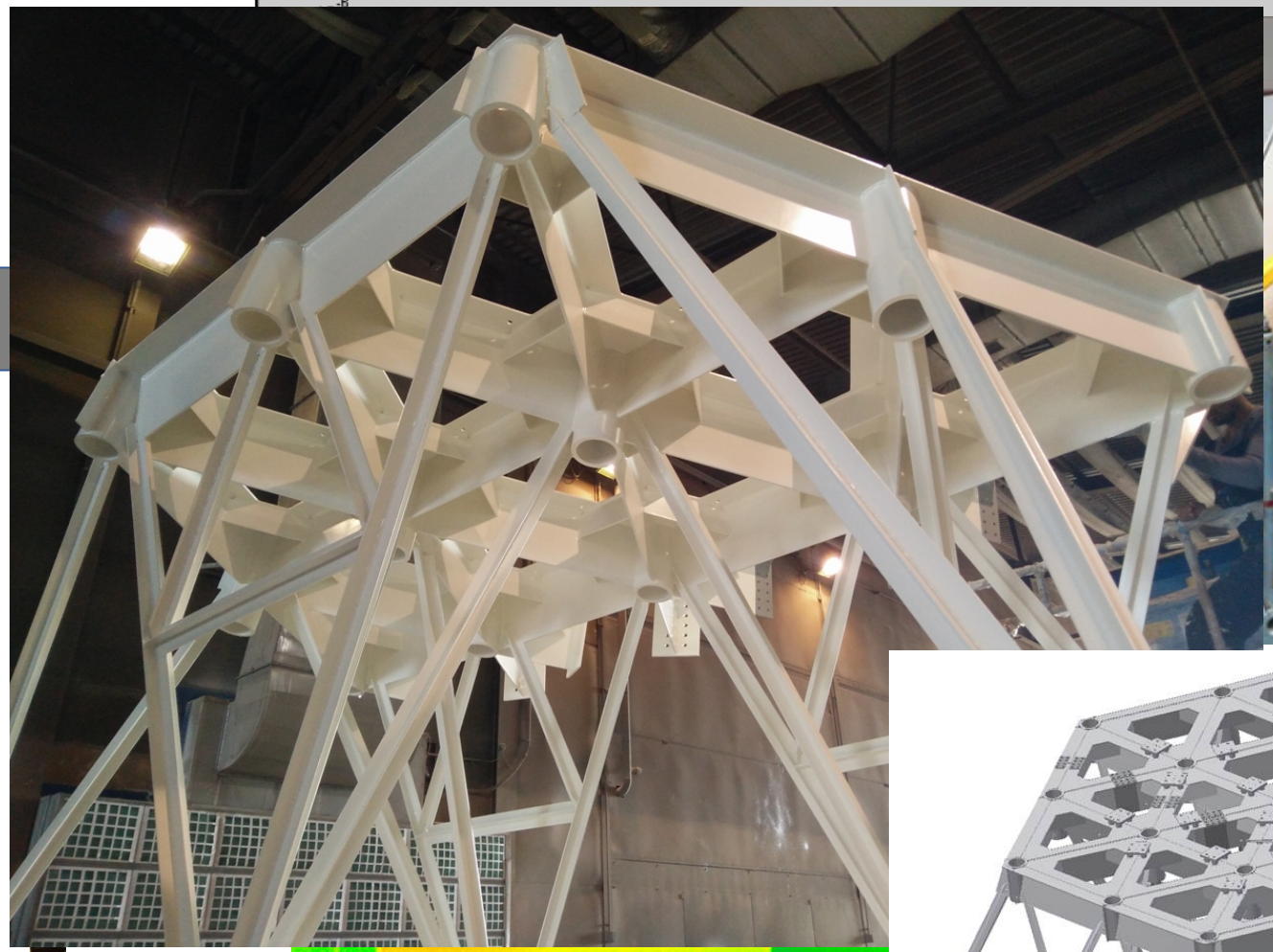


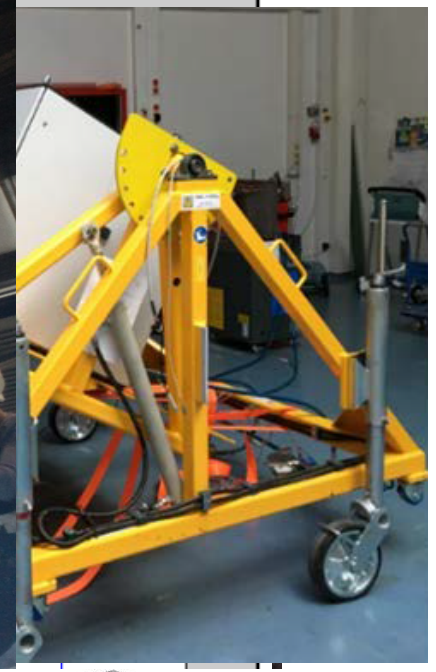
Closed Loop Segmented Mirror

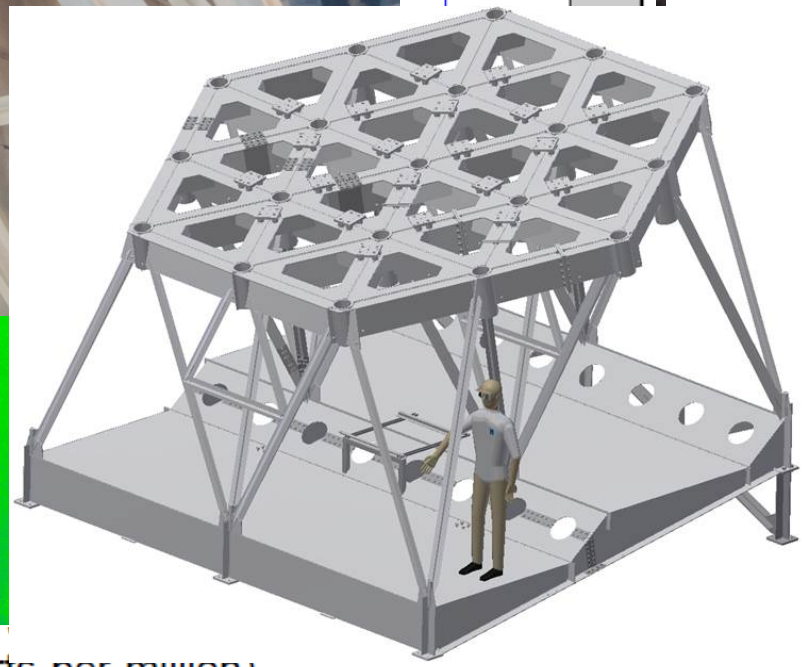
M1 Local Control System Progress

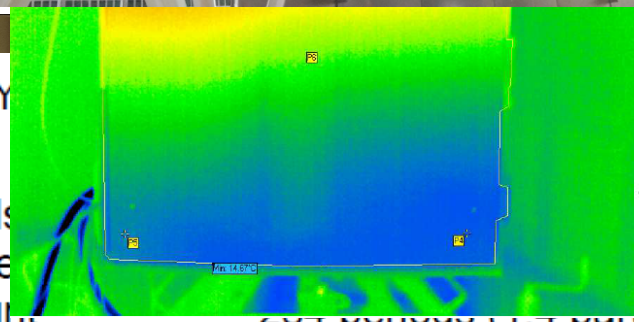


- AMD Epyc/RTLinux, custom electronics
- 10uSec to field
- 10uSec jitter
- 500Hz control loop
- ~1GB/s UDP traffic









Recording the SY

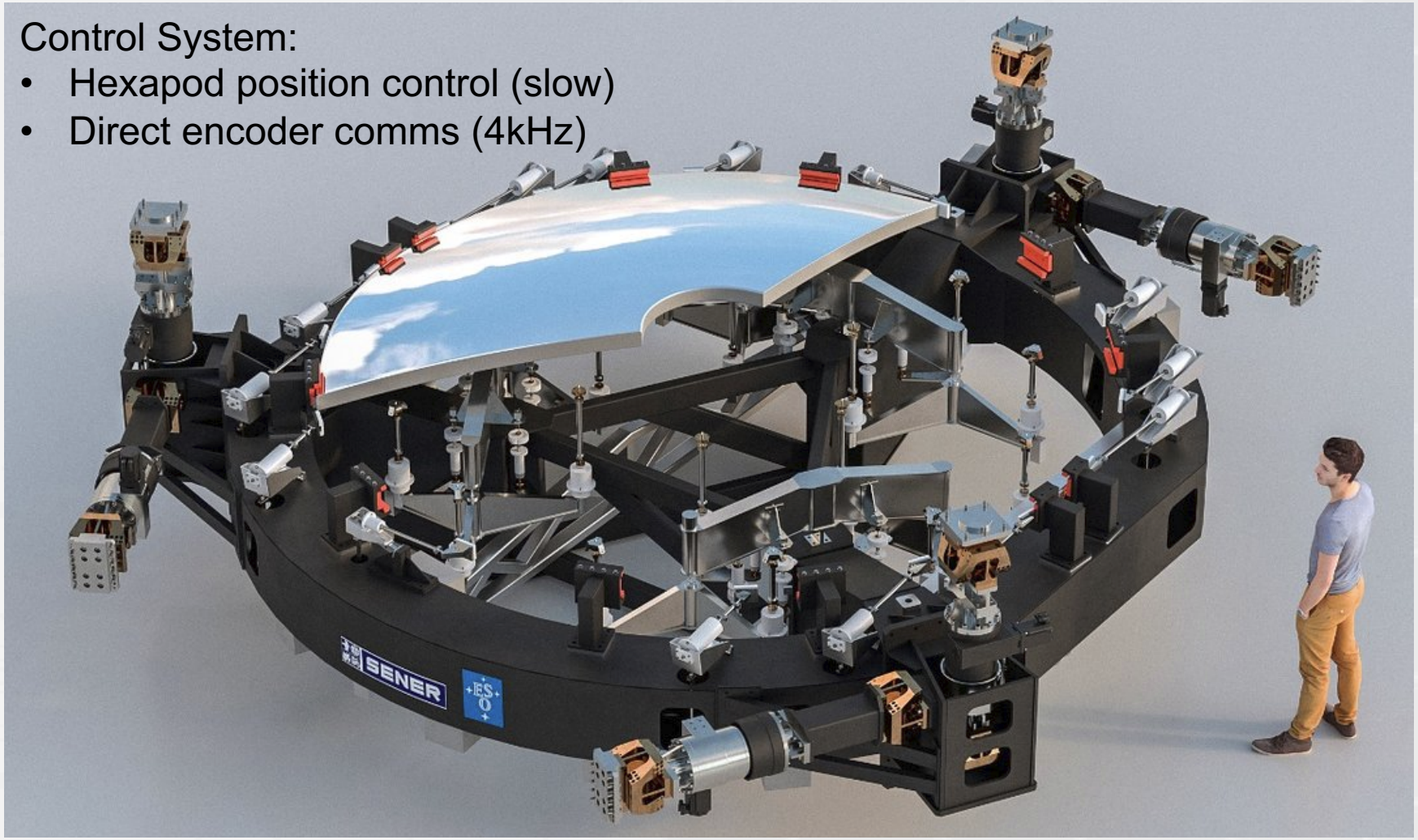
Total time
Total loop periods
Max absolute jitte
Above 10 us coun
Above 15 us count

79 periods (0.39 parts-per-million)

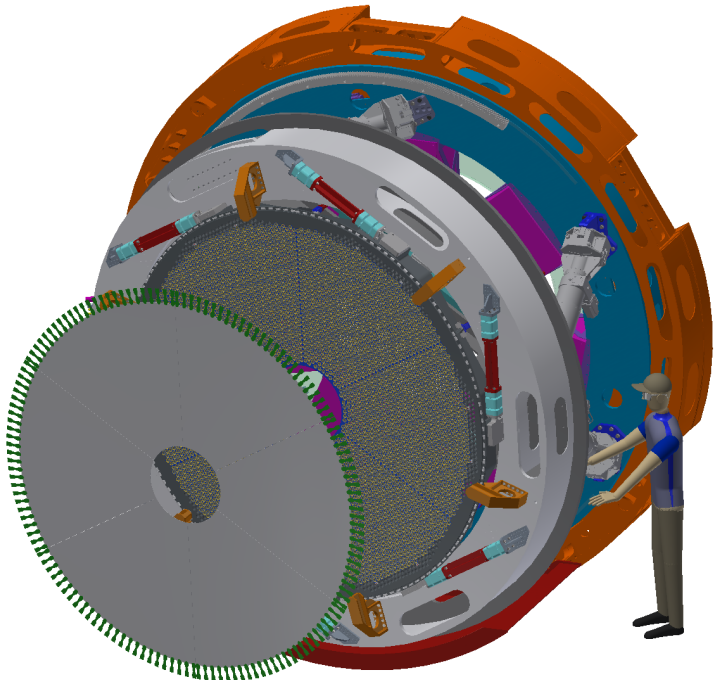
M2 and M3 Mirrors

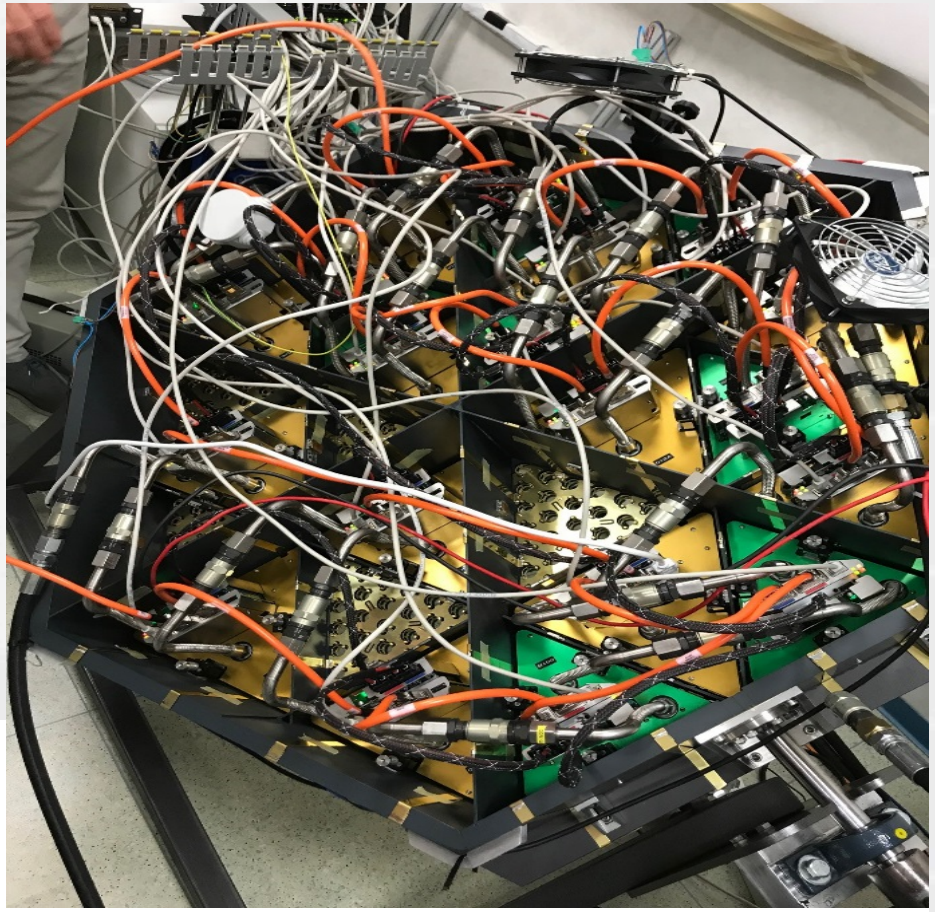
Control System:

- Hexapod position control (slow)
- Direct encoder comms (4kHz)



M4 Mirror (adaptive mirror)





- 2.4-m flat, fast, adaptive mirror
- 6 pie-shaped petals of 1.95 mm

Control System

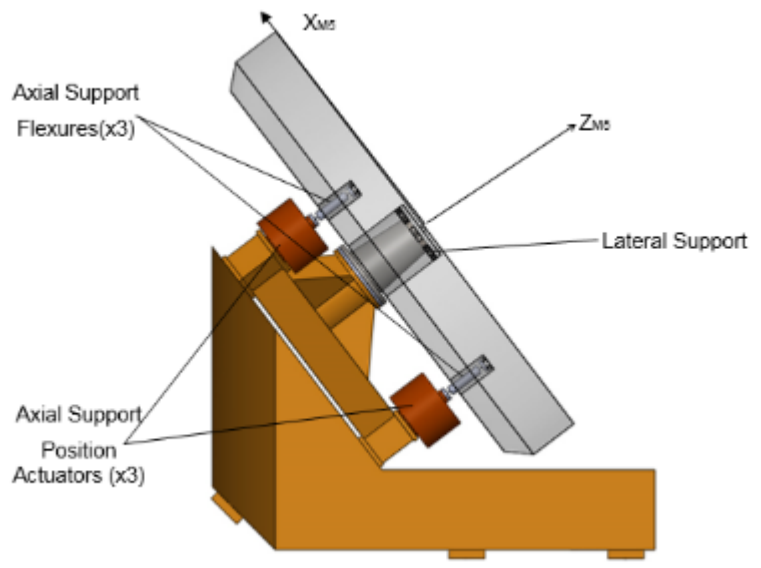
- FPGA and custom electronics
- ~5300 VC actuators position shell (80kHz), 40Hz bandwidth
- Externally driven at 1kHz (+/-10uSec jitter)

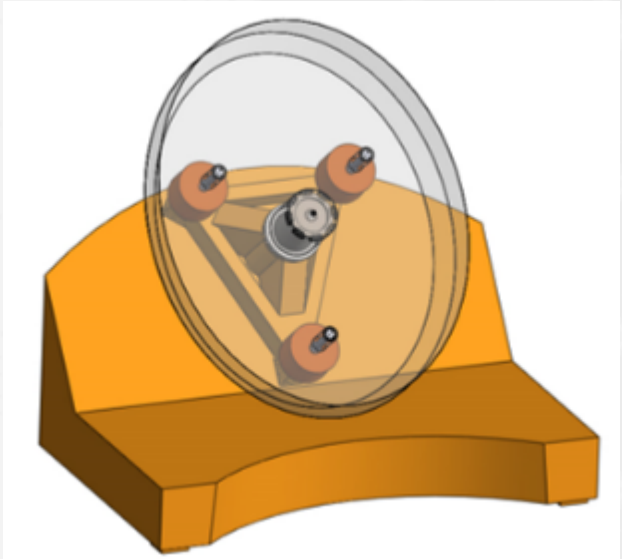
M5 Mirror (Fast Tip-Tilt Mirror)

- Stabilizes the image movements induced by MS and wind shaking
- 2.7 x 2.2 m flat M5 Mirror

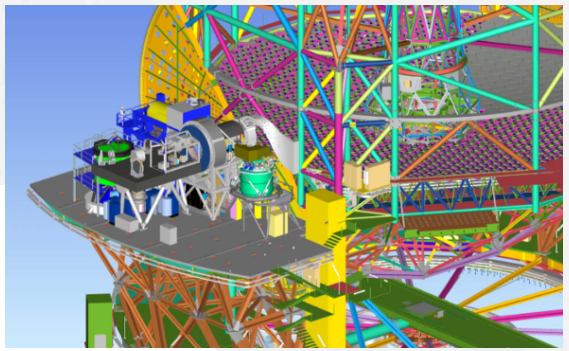
Control System

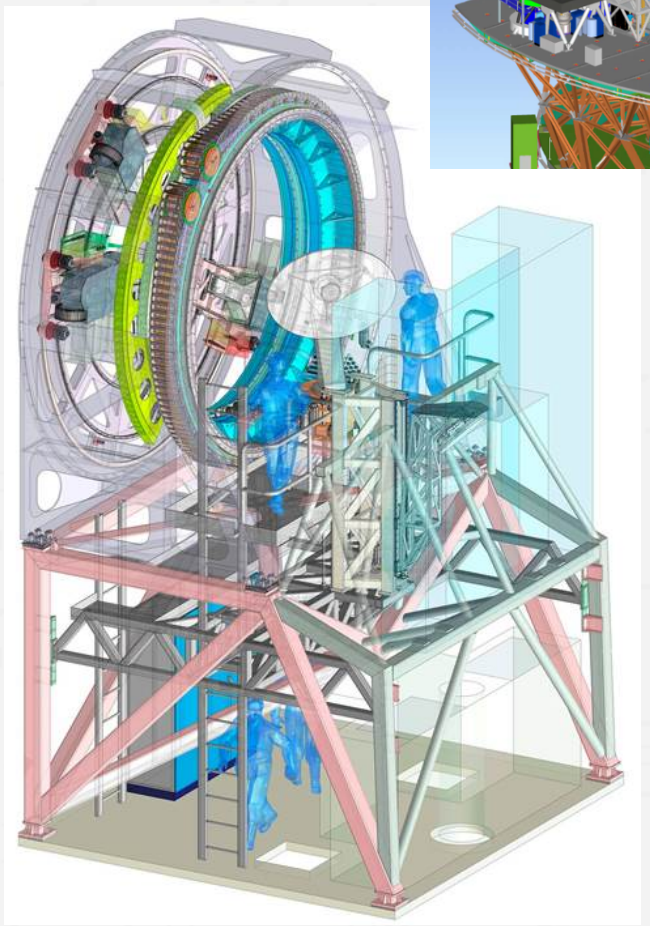
- TBD hardware/solution.
- Tip and tilt control with 10 Hz bandwidth
- Externally driven at 1kHz (+/-10uSec jitter)

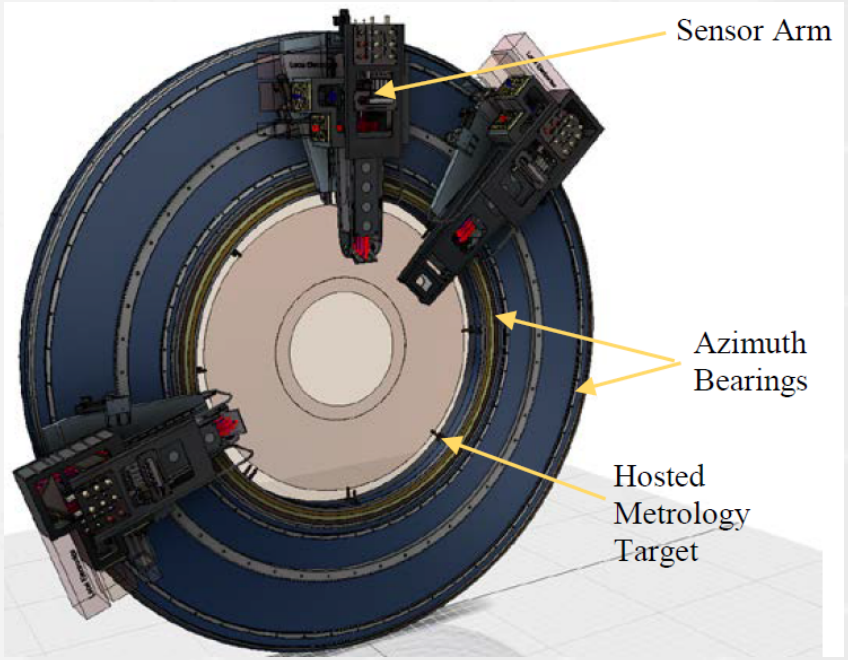




Pre-focal Station







- Measure the state of the telescope and sky
- Highly rigid structure with three pick-off arms
- Three guide star imaging cameras
- Calibration optics.

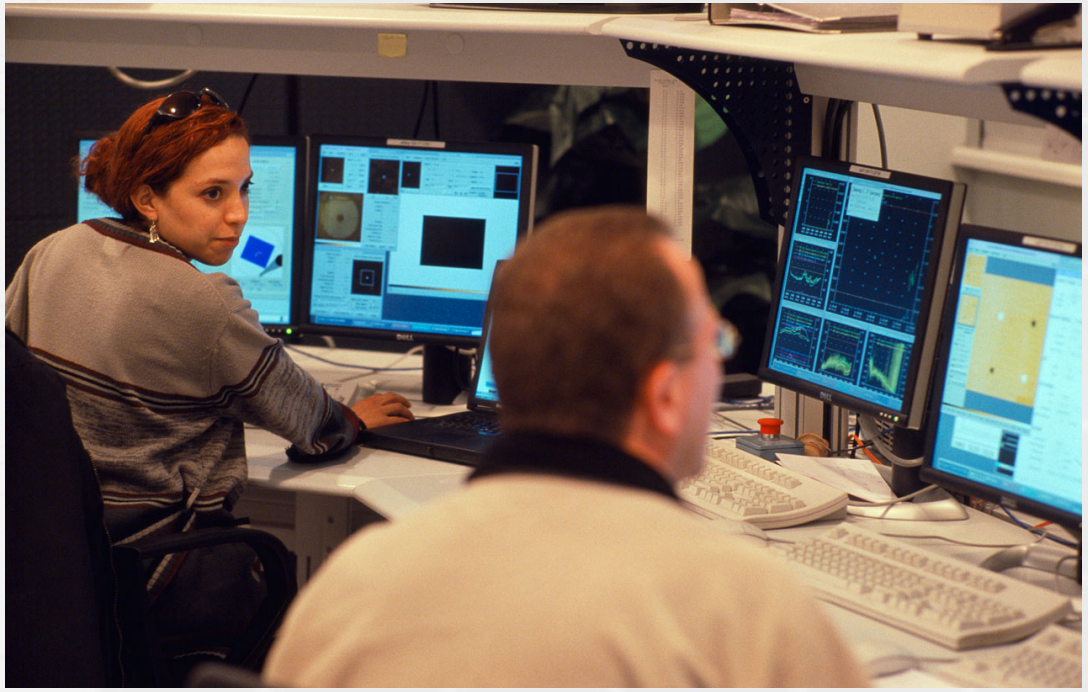
Control System

- PLC-based industrial automation (OPC/UA)
- Fine motion control requirement
- External (RT) tracking commands at 20Hz

What does Central Control System do?

- Do science (in combination with instruments)
  - Tracking, guiding, blind optical corrections, wave front control
- Support day-time activities:
  - Calibrations, Mirror Exchange, Diagnostics and monitoring
- Keep people and equipment safe:
  - Turning/tilting structures, cranes, doors, lasers, earthquakes.

- Provide a User Interface:
- 15000 actuators
- 25000 sensors
- 5-6 display terminals
- 2-4 operators,
  - eventually 27km away.



Control System Architecture

- System of Systems:
  - *Local Control System(s)* fully responsible for subsytem function and safety.
  - *Central Control System:* integrated control and telescope level safety.

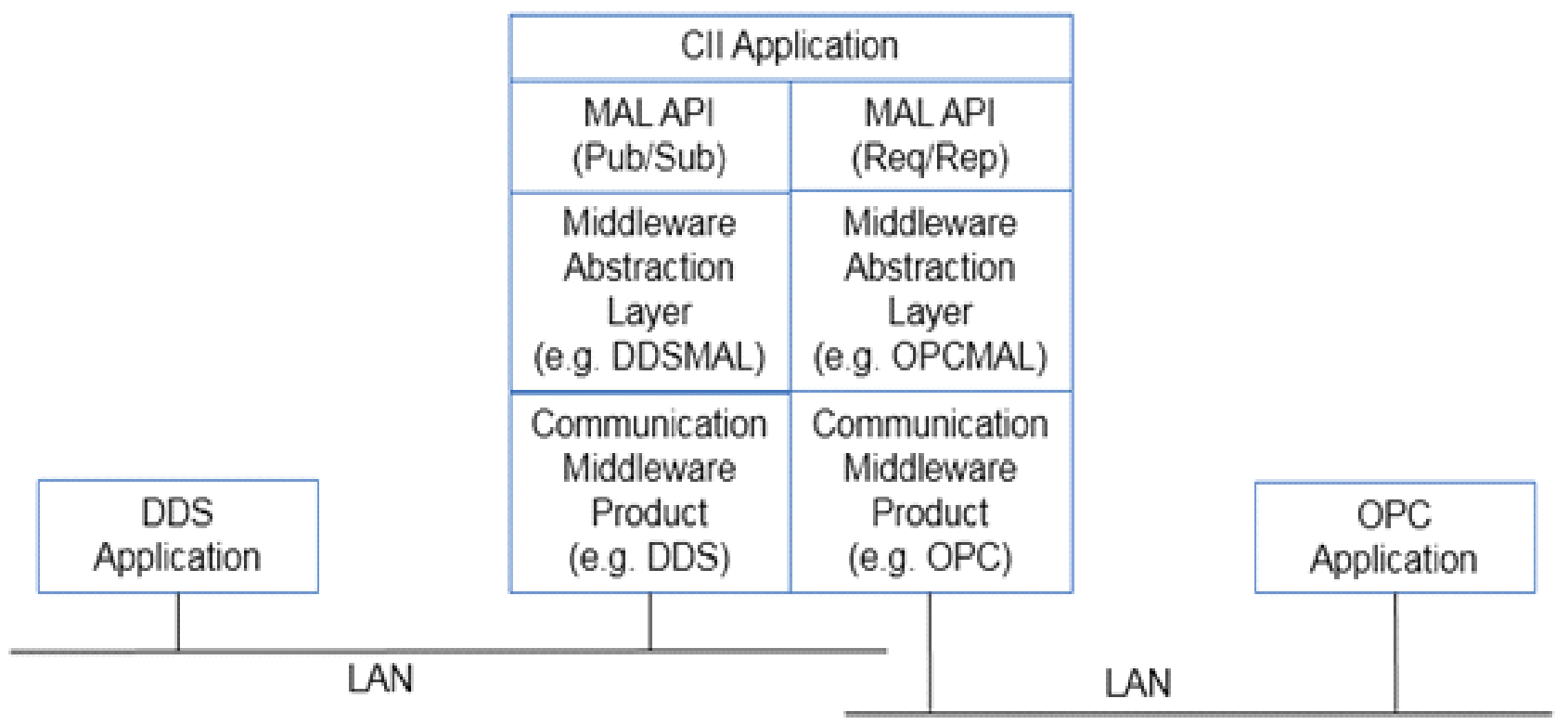
- Principals:
  - Separation of control and safety functions
  - Physical separation between computing units and field devices.
  - Usage of mainstream industrial standards.
  - Usage of mainstream COTS components.

Ethernet Interfacing Standards

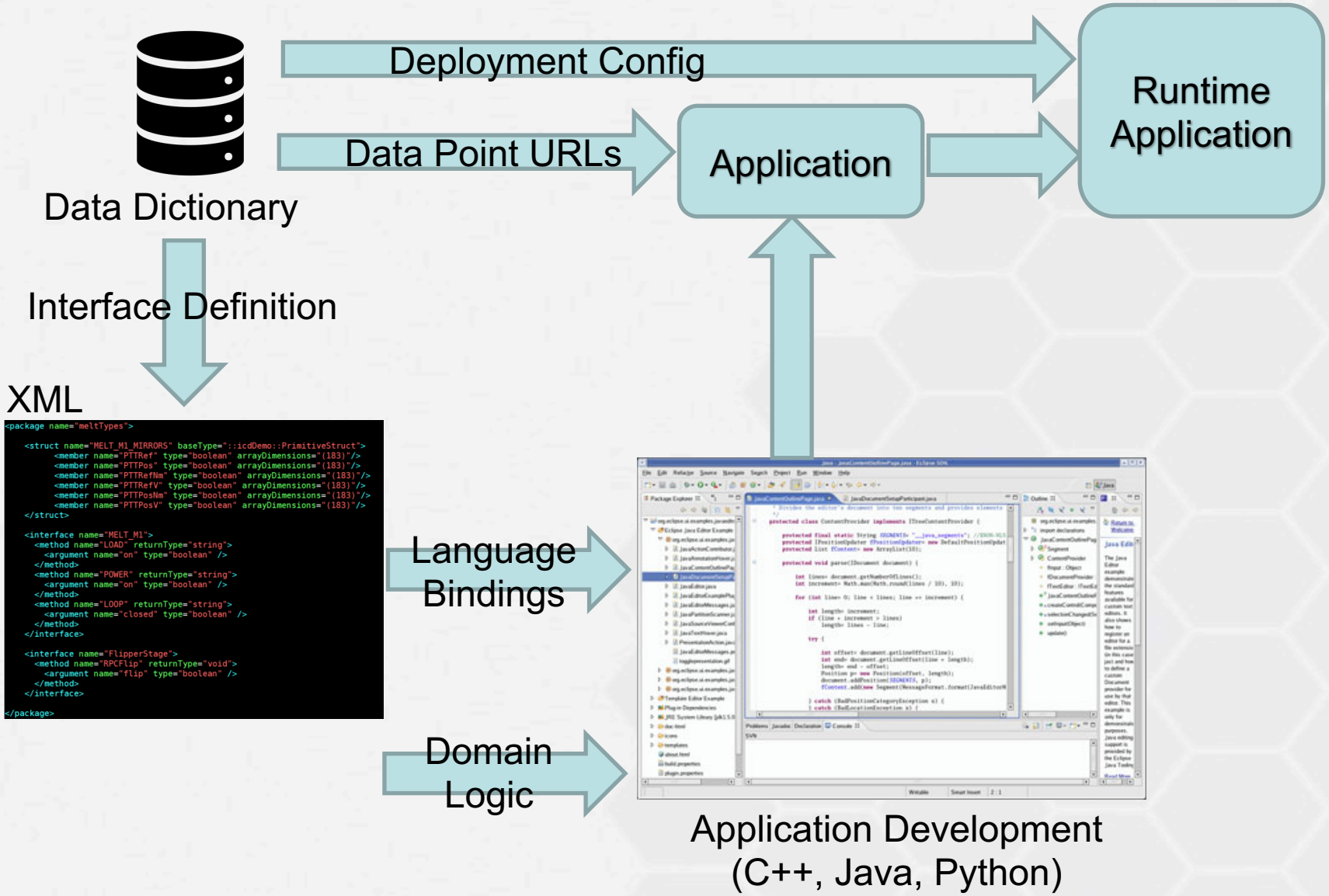
- CCS – LCS interfaces are Ethernet based
  - 10GB/s Switched Ethernet core, 100MB/s and 1GB/s in the field
  - 2km SM fibre between field and computer room.
  - Time (PTP), safety, deterministic separate from control networks

	Determinism	Bandwidth	Pub/ Sub	Req/ Rep	Comments
OPC/UA			X		PLC Std.
DDS					OMG Std. Discovery
ZMQ/PB					No discovery
MUDPI (multicast UDP)				X	Very simple, no discovery FPGA/custom electronics

Middleware Abstraction Layer



Application Development using MALs



Data Addressing

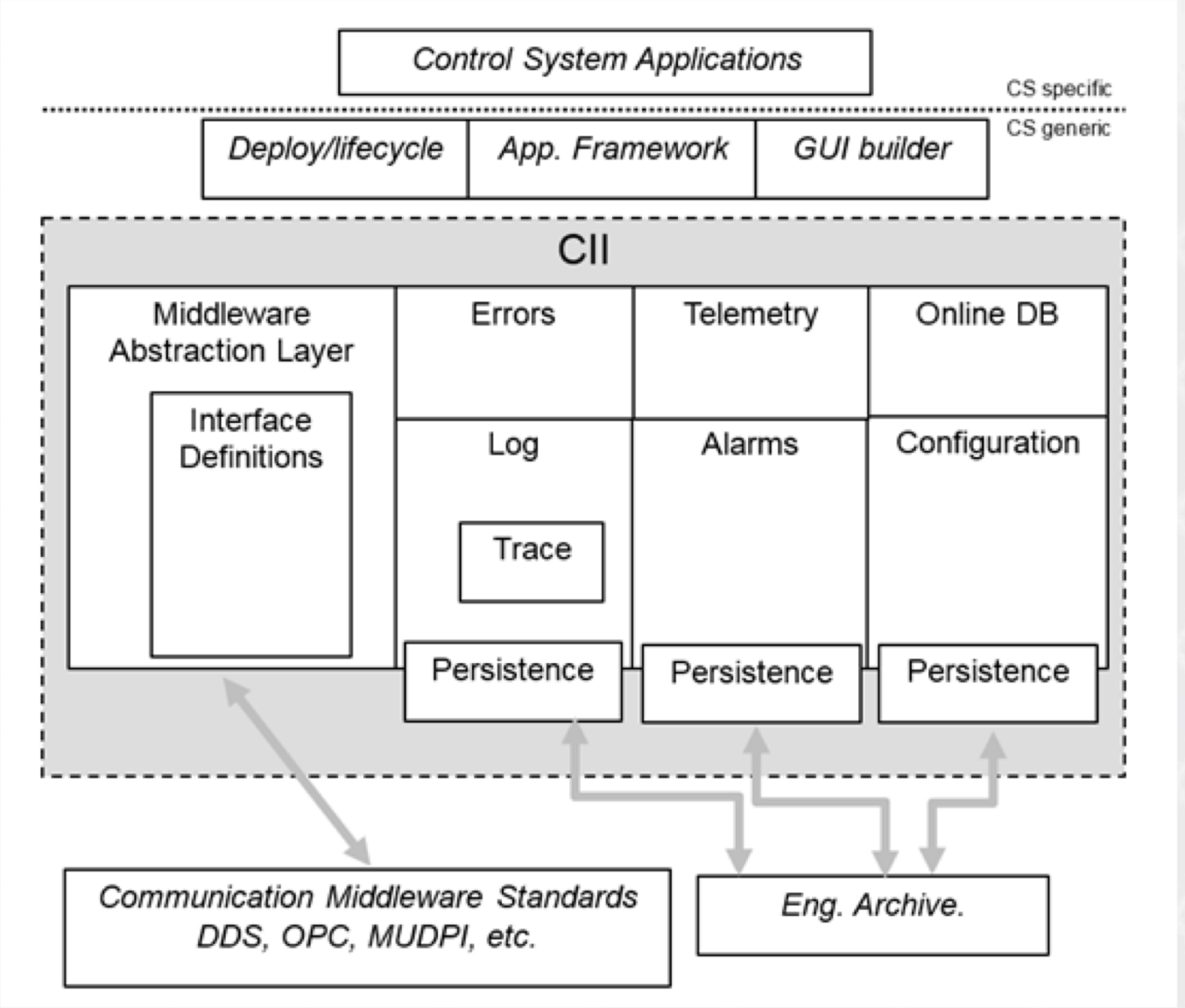
```
<scheme>:[//<authority>]</path>[?<query>][#fragmen
t]
(cf. IETF RFC 2396)

e.g., for DDS:
dds.ps:///m1/Cabinet/Telemetry/BoardTemperature
dds.ps:///m1/Cabinet/Telemetry/Cables?Key=M1-011
dds.rr:///m1/Cabinet/Control/LifecycleIF

Others:
cii.cfg://cfgsrv.elt/m1/SegConc?Id=12#numSegments
zpb.ps://m4lsv.elt:1741/Cabinet/Telemetry/PwrConsu
mp
```

MAL to load (runtime)

MAL-specific topic/address

CS Service

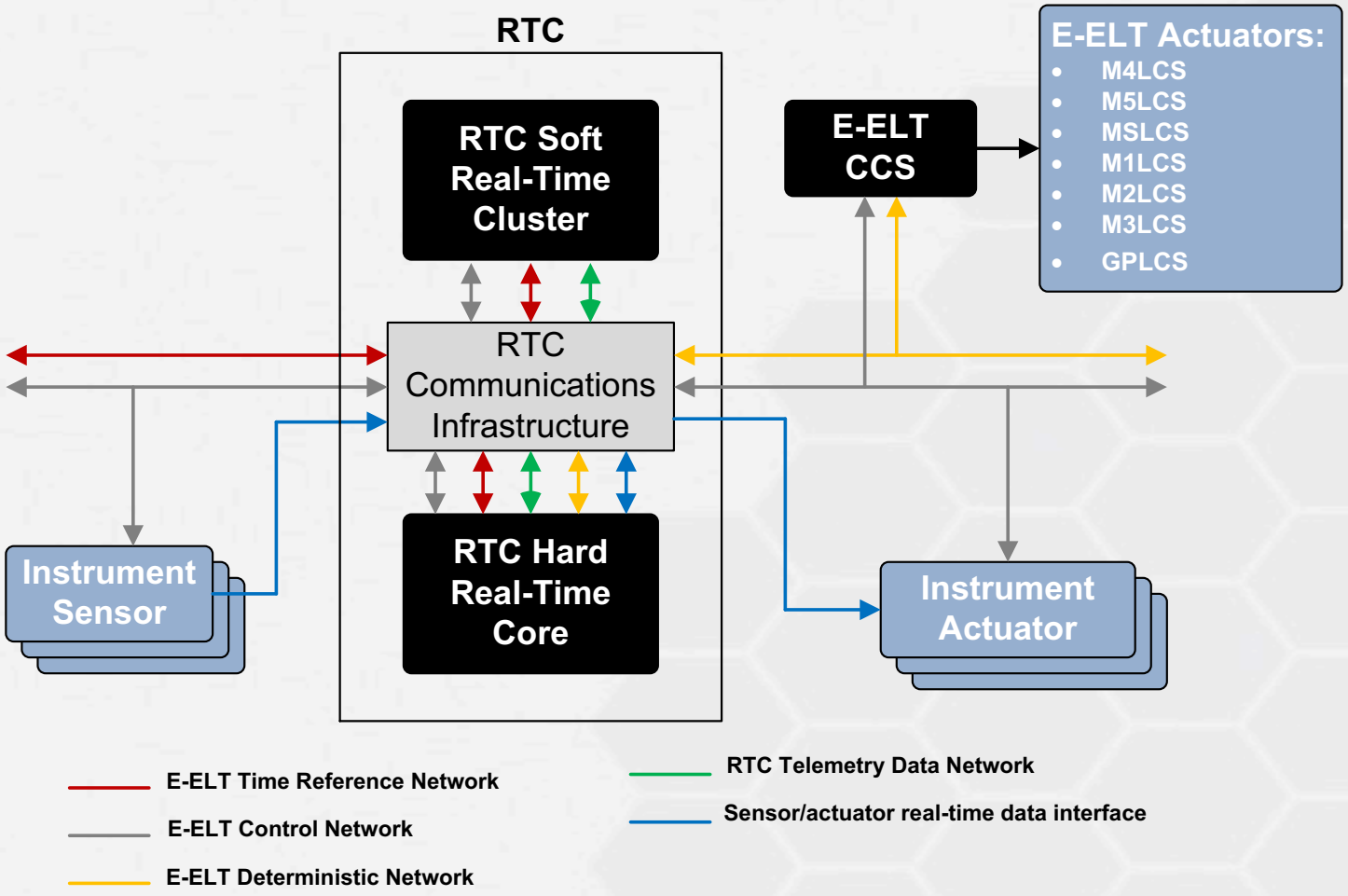
Core Integration Infrastructure



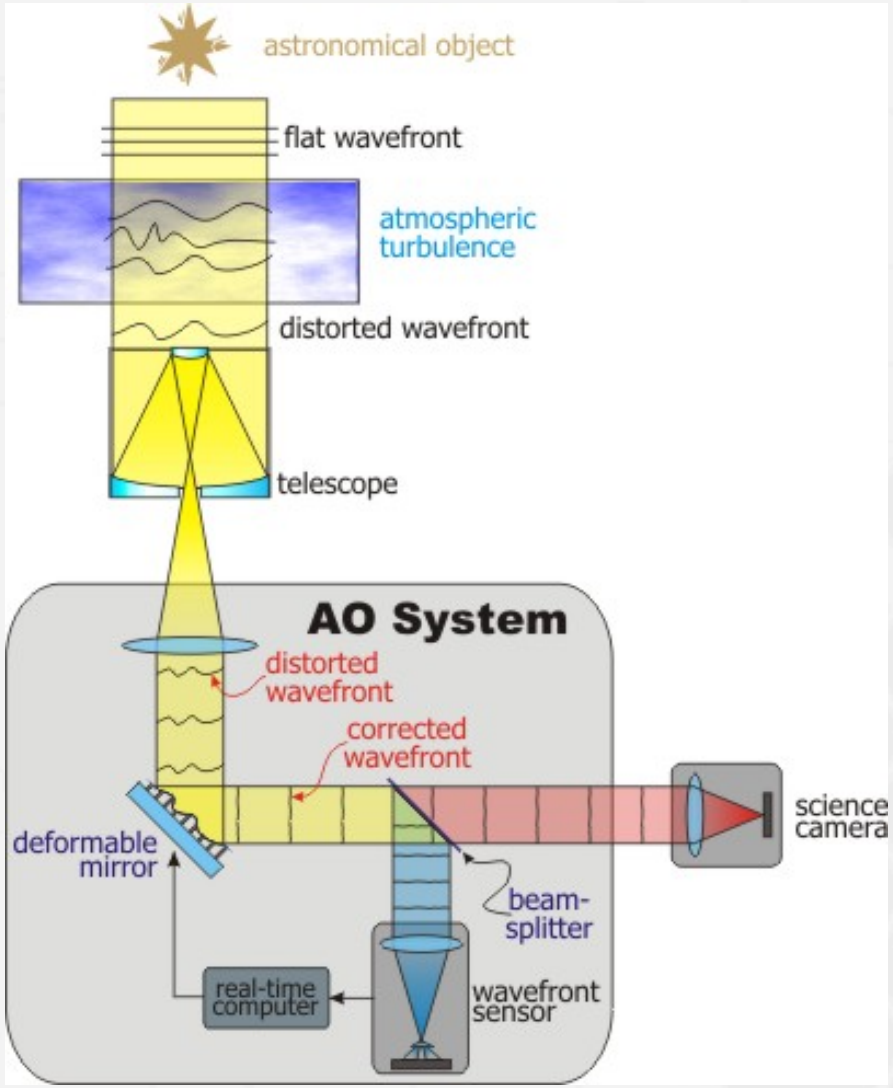
CII & MAL Progress

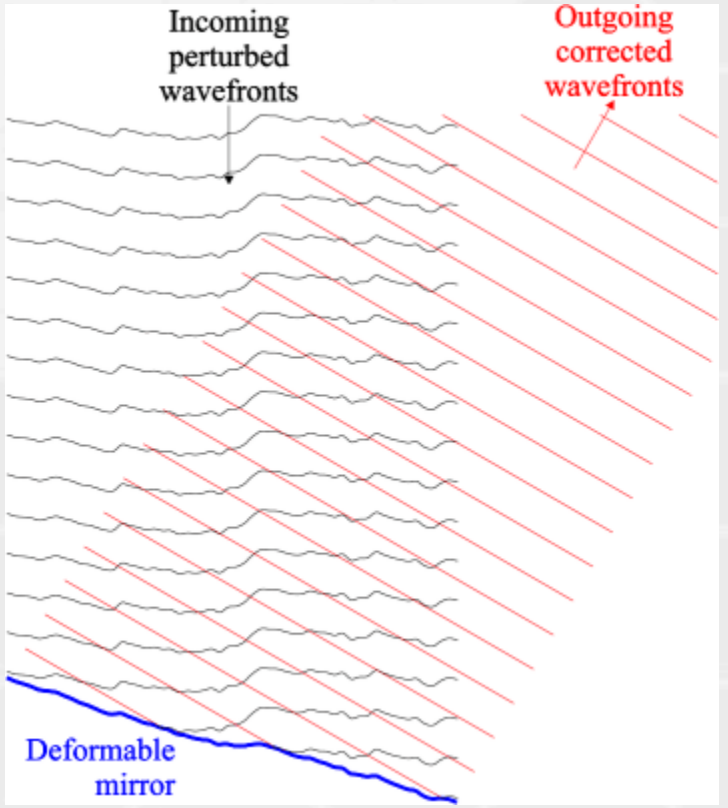
- MAL v1 released
  - DDS, OPC, ZMQ/PB supported
  - MUDPI MAL in progress
  - Integrating into existing systems
- OLDB: federated with scalar values only.
  - GUIs, scripts, reports.
  - E.g. Redis.
- Logging, Error, Config on-going

ELT MIMO Controllers (RTCs)

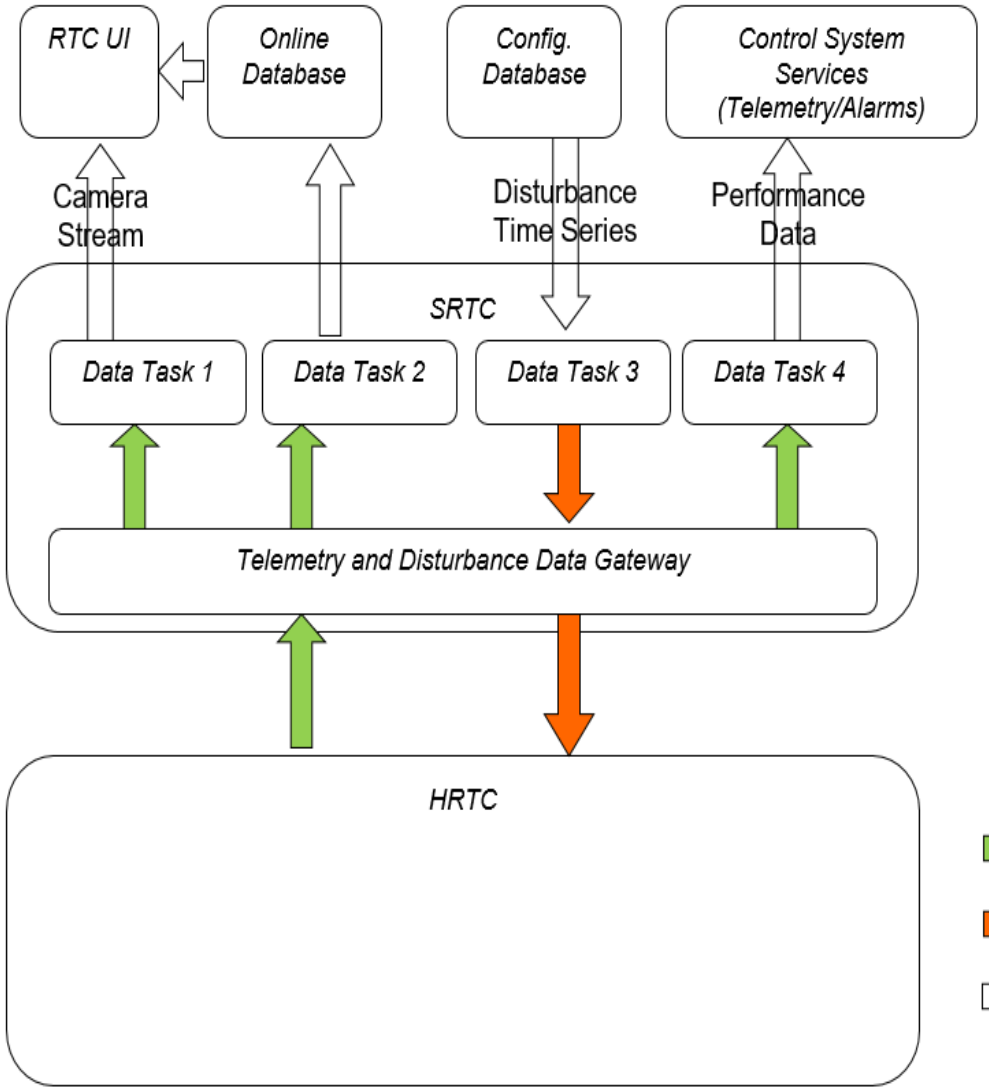


Adaptive Optics





MIMO Controllers (RTCs)



Typical SRTC:

- 10 AMD Epyc servers
- 56 tasks receiving data at 1kHz

Typical HRTC:

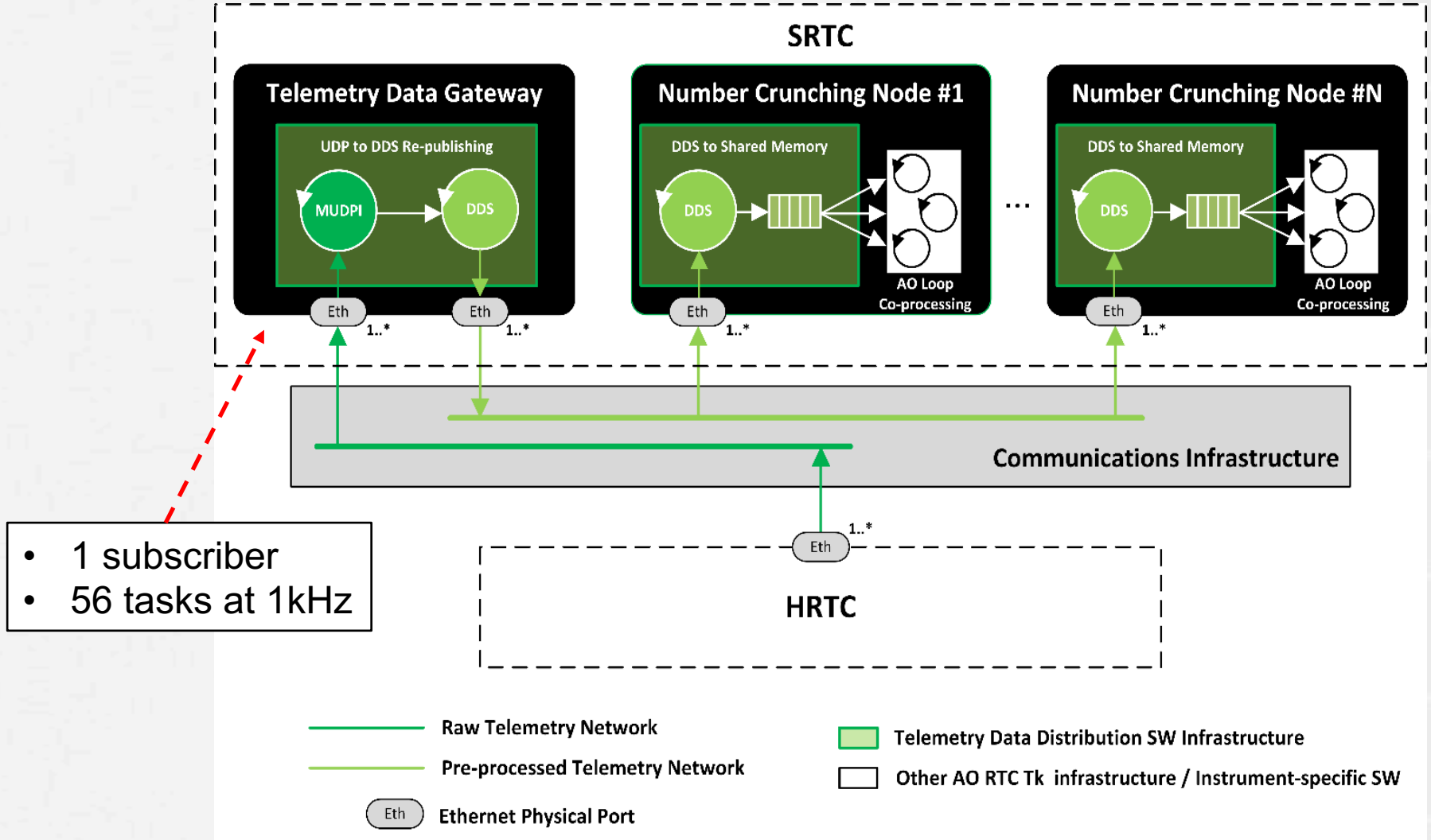
- Sensors up to1kHz
- Actuators up to 1kHz
- 1.4 TFLOPS
- <1ms Compute Time
- Low Jitter

Telem Data (SRTC input)

Disturbance Injection (SRTC output)

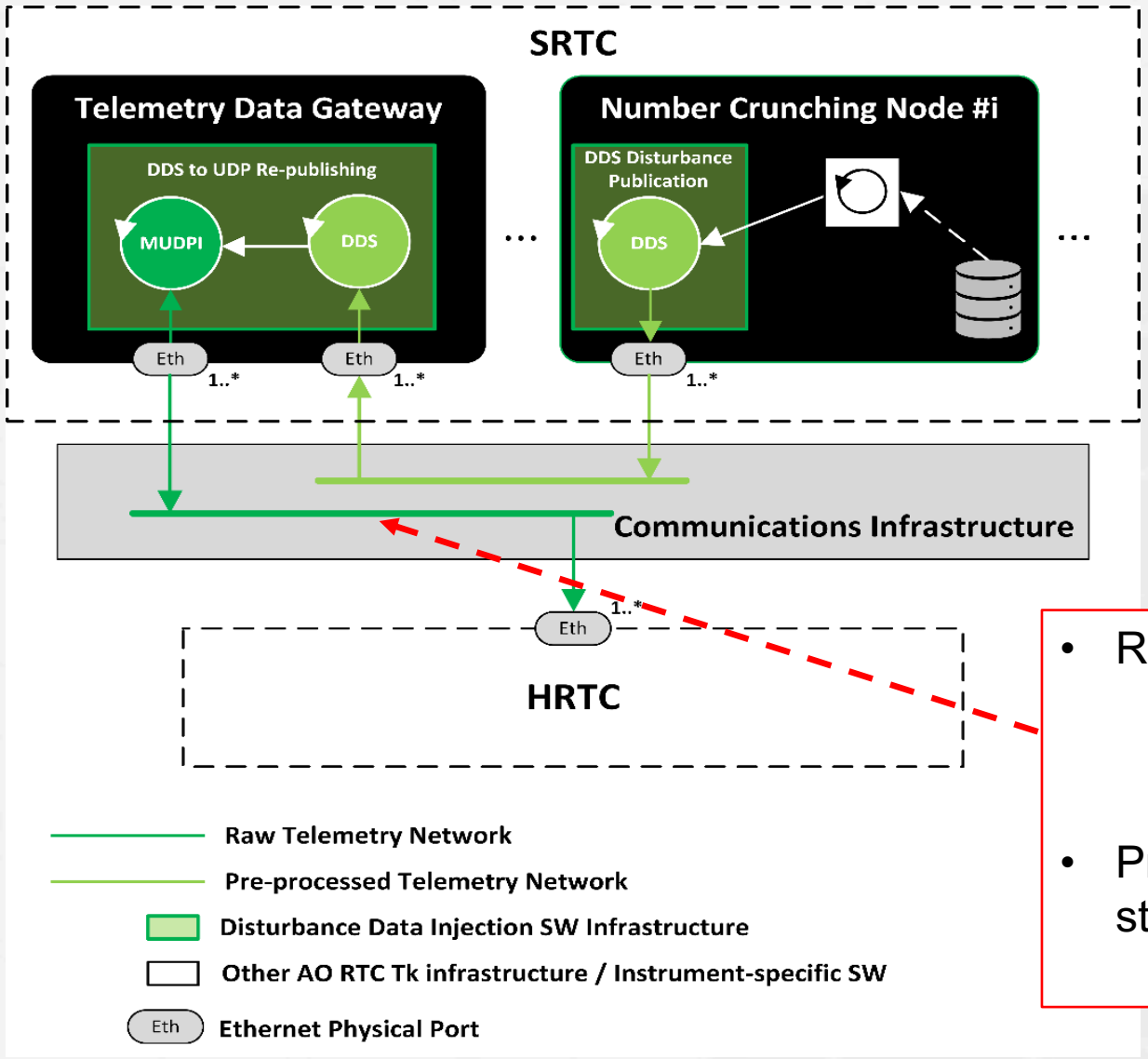
Other Data (as labeled)

SRTC Telemetry Distribution



Needed Linux cgroups to set NIC a DDS publisher used for multicast publishing.

SRTC Disturbance Injection



- Regular status msg
  - HRTC → SRTC
  - FIFO/Queue limit
- Proportional controller on status message
  - Data rate control

Why RTI Connext DDS?

- Rich and complete DCPS
  - Open Standard at API and wire protocol levels
  - Proven interoperability
  - Discovery
- Reliable multicast publishing
  - Multicast UDP, unicast UDP retransmit.
  - Performant
  - Tunable
  - Dependable
- Powerful Tools for tuning and diagnostics