The ASTRI-Horn Telescope Control System

Federico Russo – INAF OAS Bologna

for the ASTRI Project

TEchnologies for Telescopes and Instruments control Software

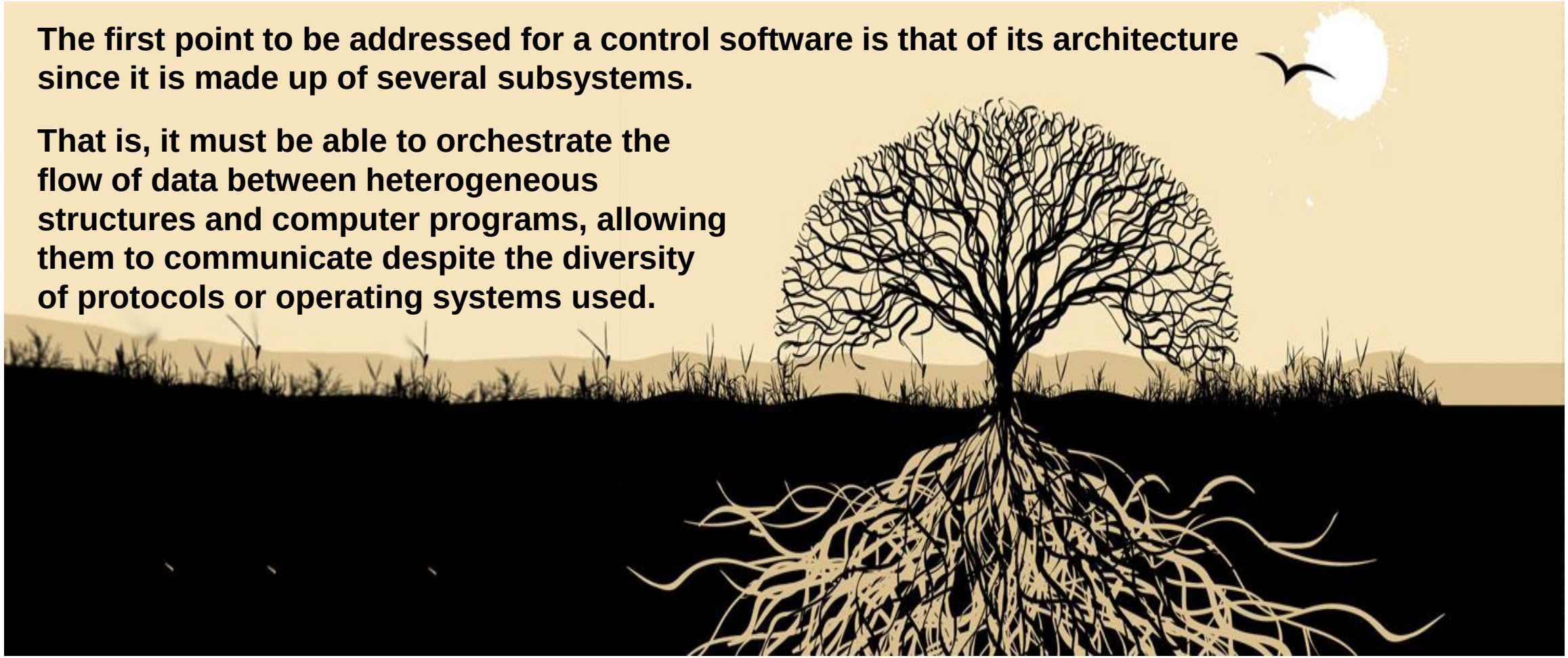
ASTRI-Horn

- The ASTRI-Horn Cherenkov telescope, installed at Serra La Nave on the Mount Etna (Italy), has been developed by INAF in the context of the ”Astrofisica con Specchi a Tecnologia Replicante Italiana” (ASTRI) Project.
- INAF proposed a prototype for the Small Size class of Telescopes of the future Cherenkov Telescope Array (CTA), and for the INAF Mini-Array which will be installed at the Observatory of Teide in Tenerife (Spain).
- Astri-Horn uses a dual-mirror configuration and a Cherenkov camera having a detector composed of an array of monolithic silicon photomultiplier sensors (SiPM), coupled with a specifically designed front-end and back-end electronics.
- The Astri-Horn telescope represents a successful innovative solution for the detection of very high energy gamma-rays with ground-based atmospheric Cherenkov telescopes, as was demonstrated by the detection of the Crab Nebula during the Science Verification phases.

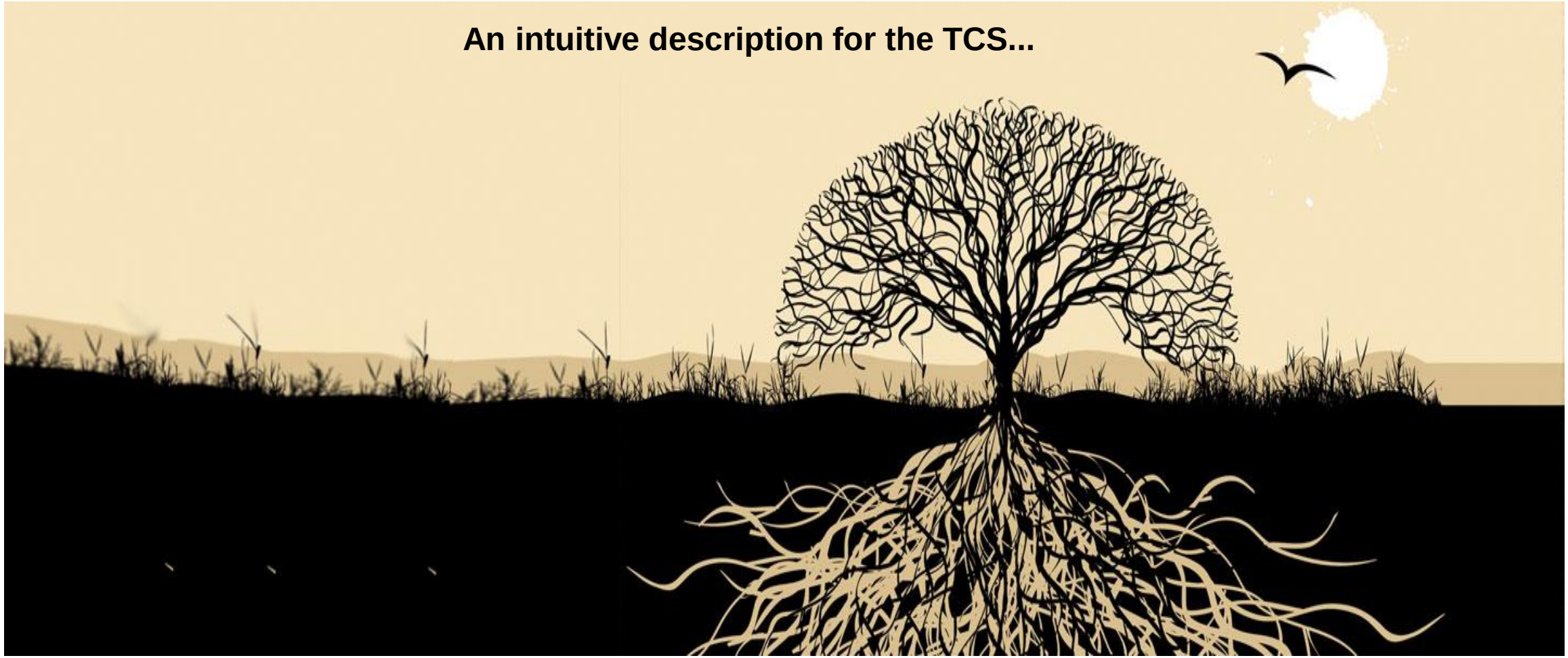
ASTRI-Horn Telescope Control System

The first point to be addressed for a control software is that of its architecture since it is made up of several subsystems.

That is, it must be able to orchestrate the flow of data between heterogeneous structures and computer programs, allowing them to communicate despite the diversity of protocols or operating systems used.



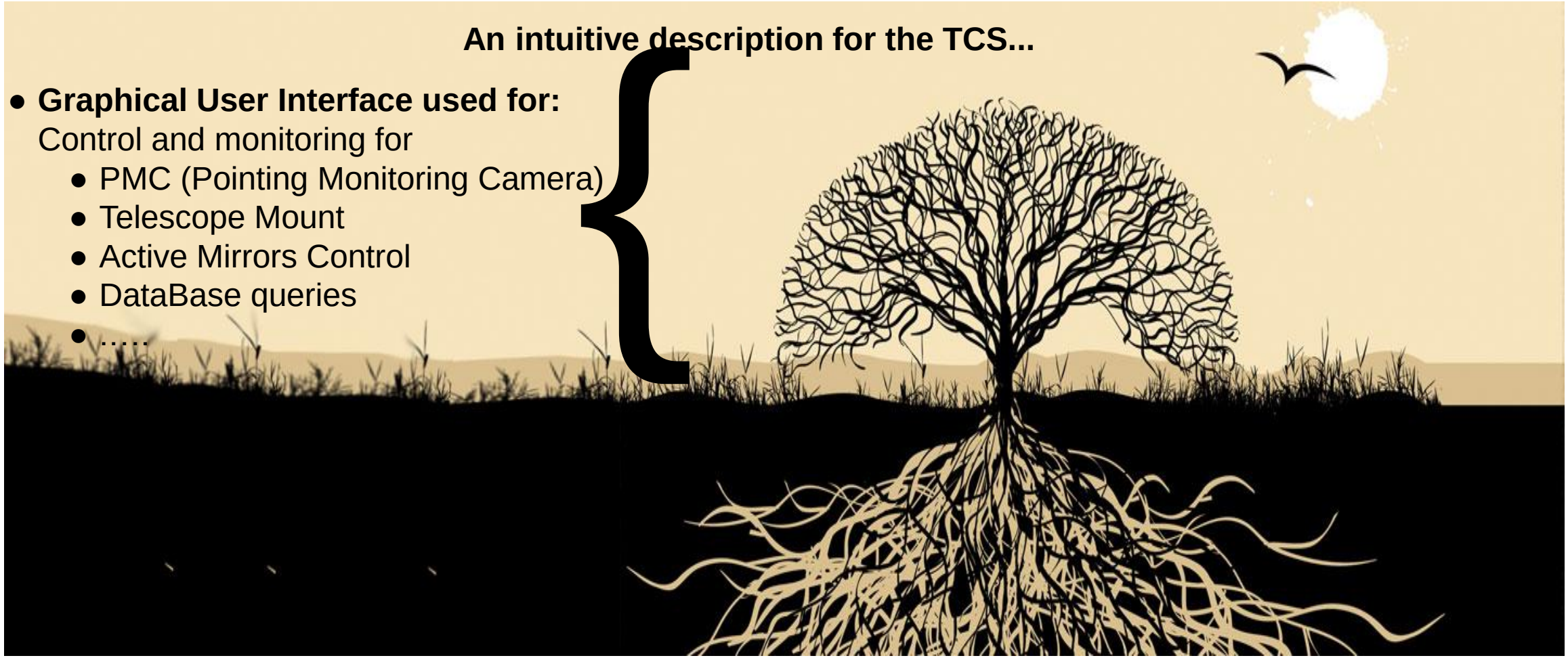
ASTRI-Horn Telescope Control System



ASTRI-Horn Telescope Control System

An intuitive description for the TCS...

- **Graphical User Interface used for:**
  Control and monitoring for
  - PMC (Pointing Monitoring Camera)
  - Telescope Mount
  - Active Mirrors Control
  - DataBase queries
  - .....



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  Control and monitoring for
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  - Telescope Mount
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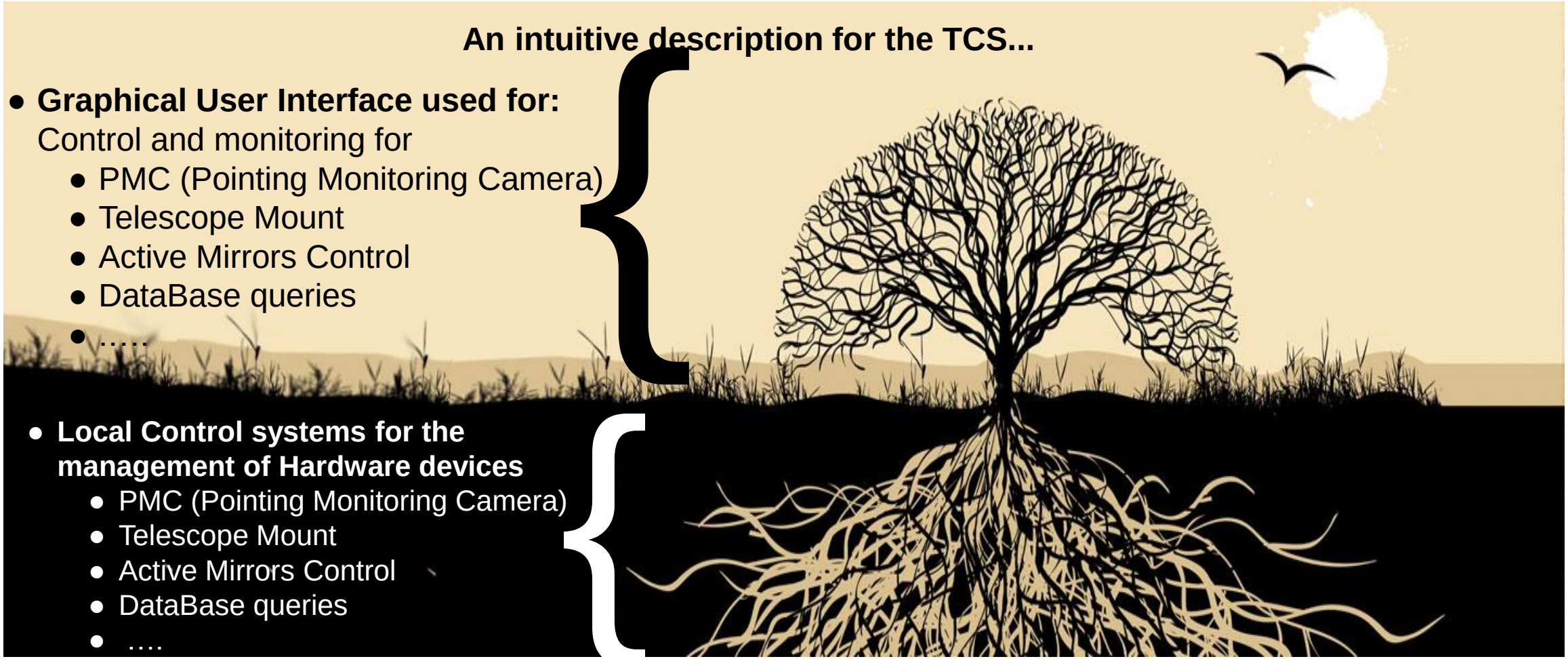
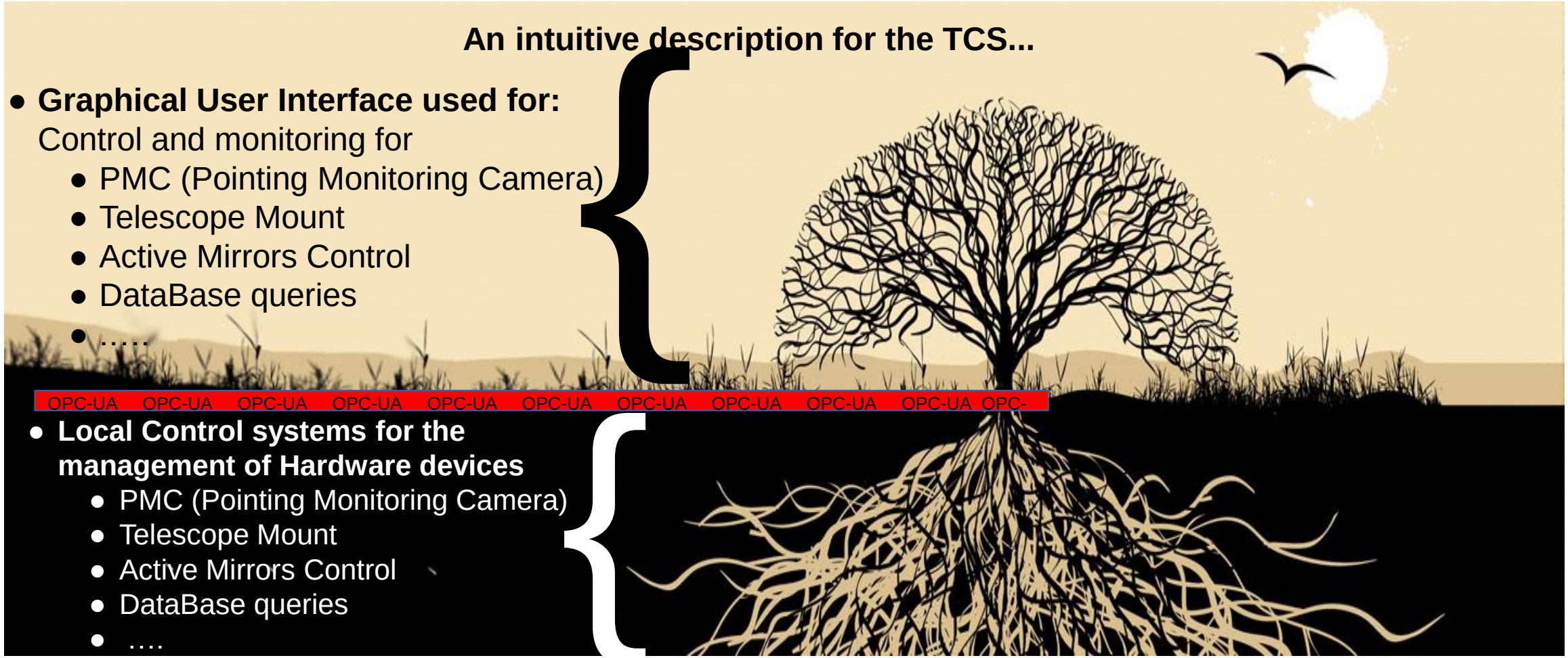
- **Local Control systems for the management of Hardware devices**
  - PMC (Pointing Monitoring Camera)
  - Telescope Mount
  - Active Mirrors Control
  - DataBase queries
  - ….



ASTRI-Horn Telescope Control System



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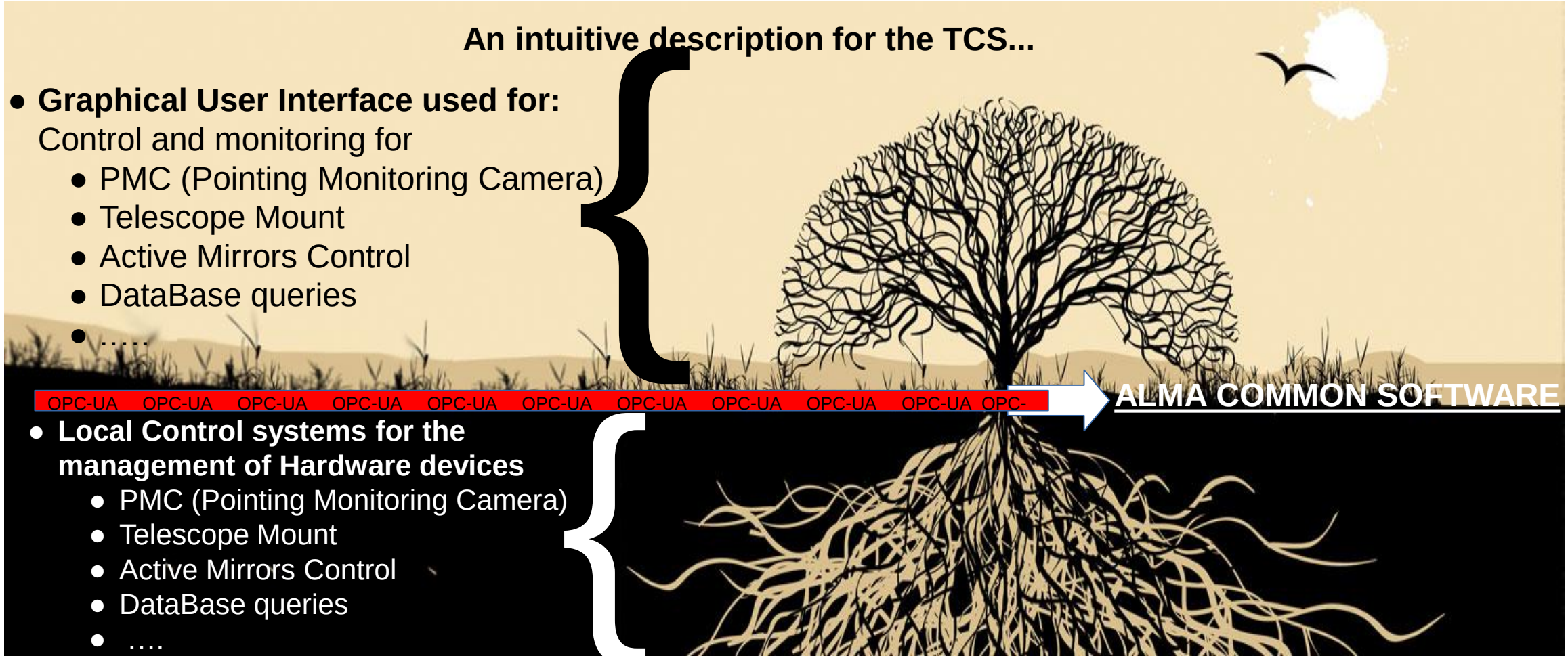
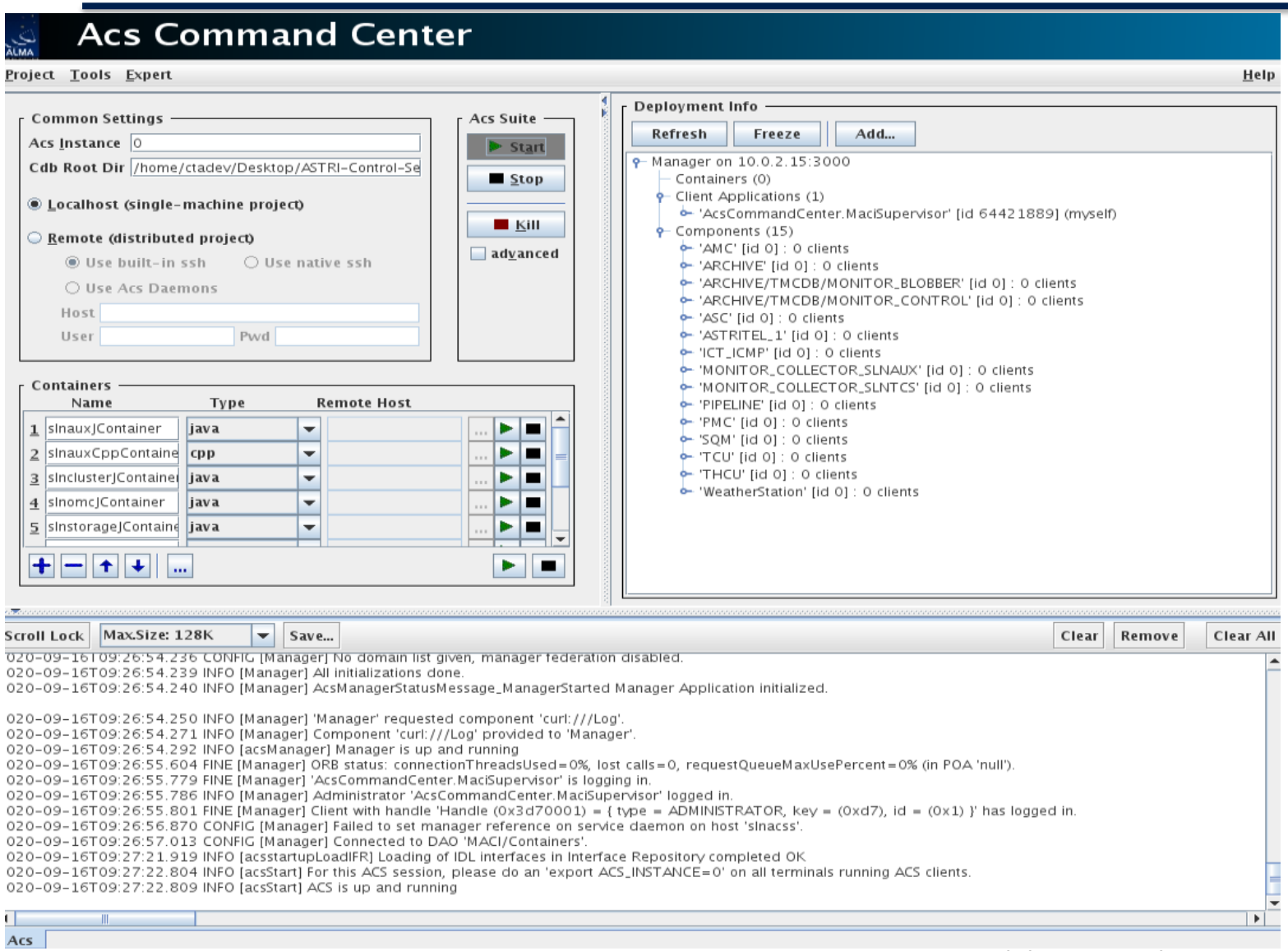


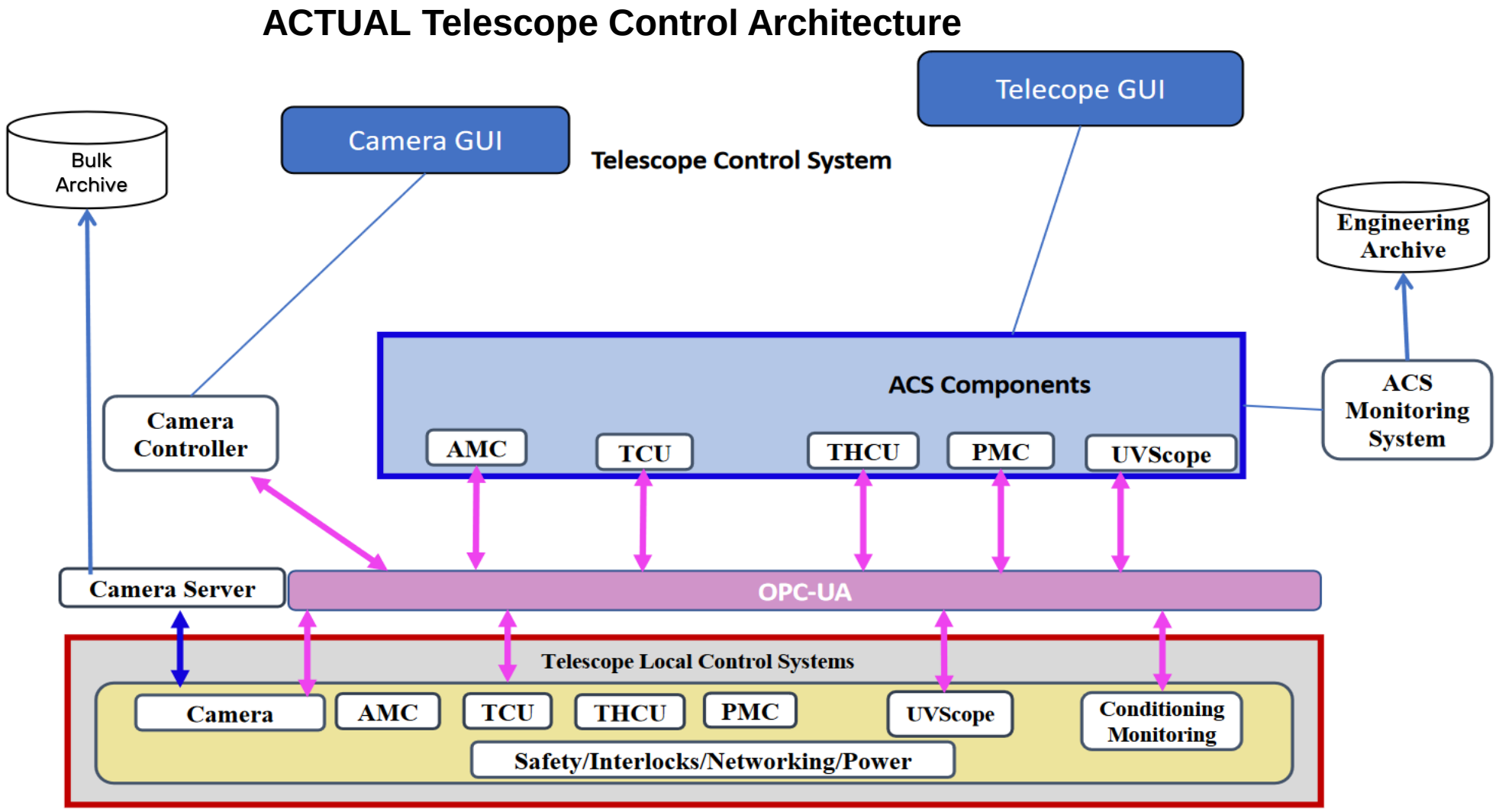
Alma Common Software (ACS)



ACS

- A middleware software infrastructure
- Based on distributed **Components**
- C++, Java, Python **Containers**
- Logging services
- Errors and alarms management
- Configuration database
- Lifecycle management
- OPC-UA libraries

ASTRI-Horn Telescope Control System



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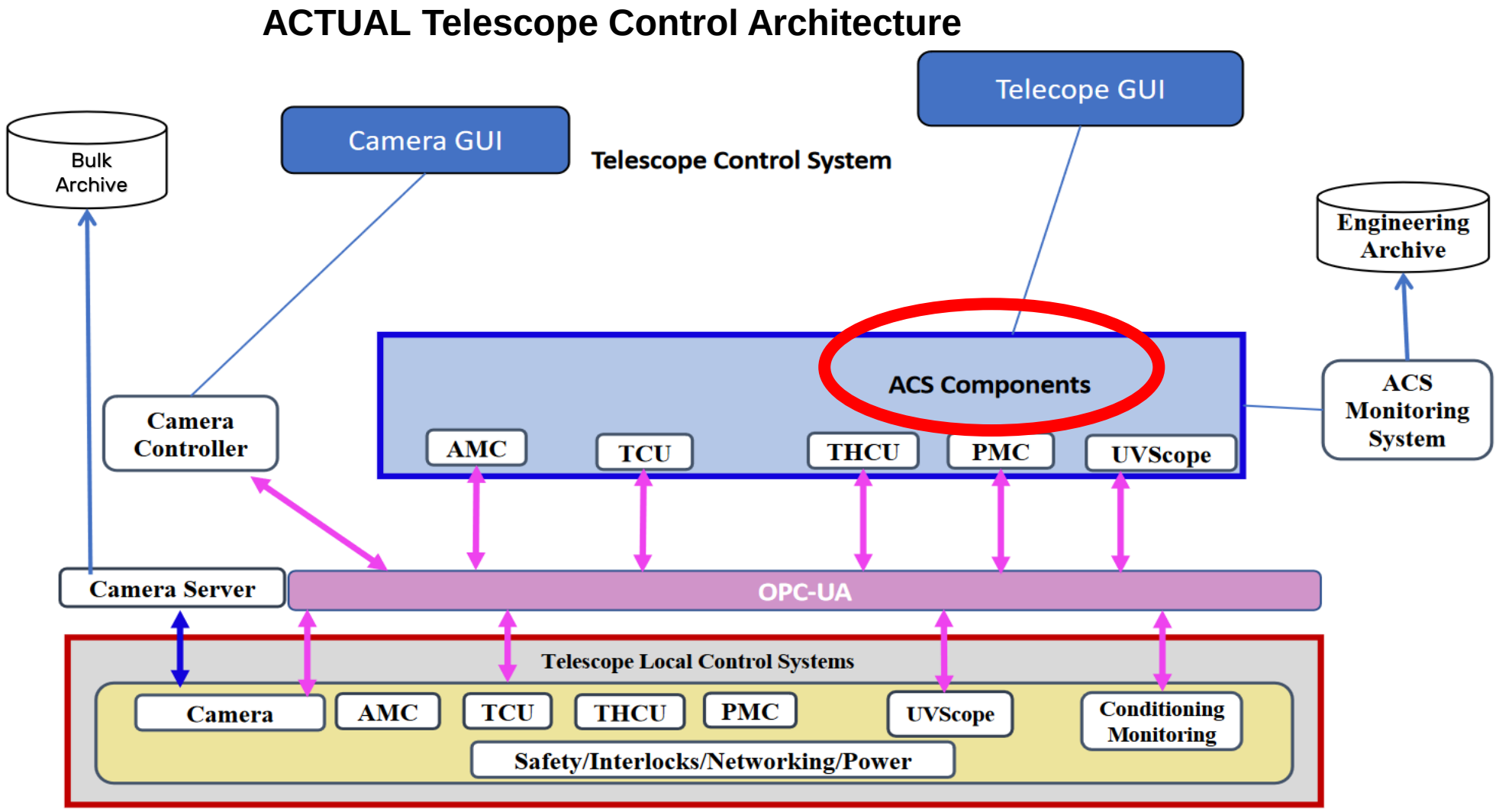

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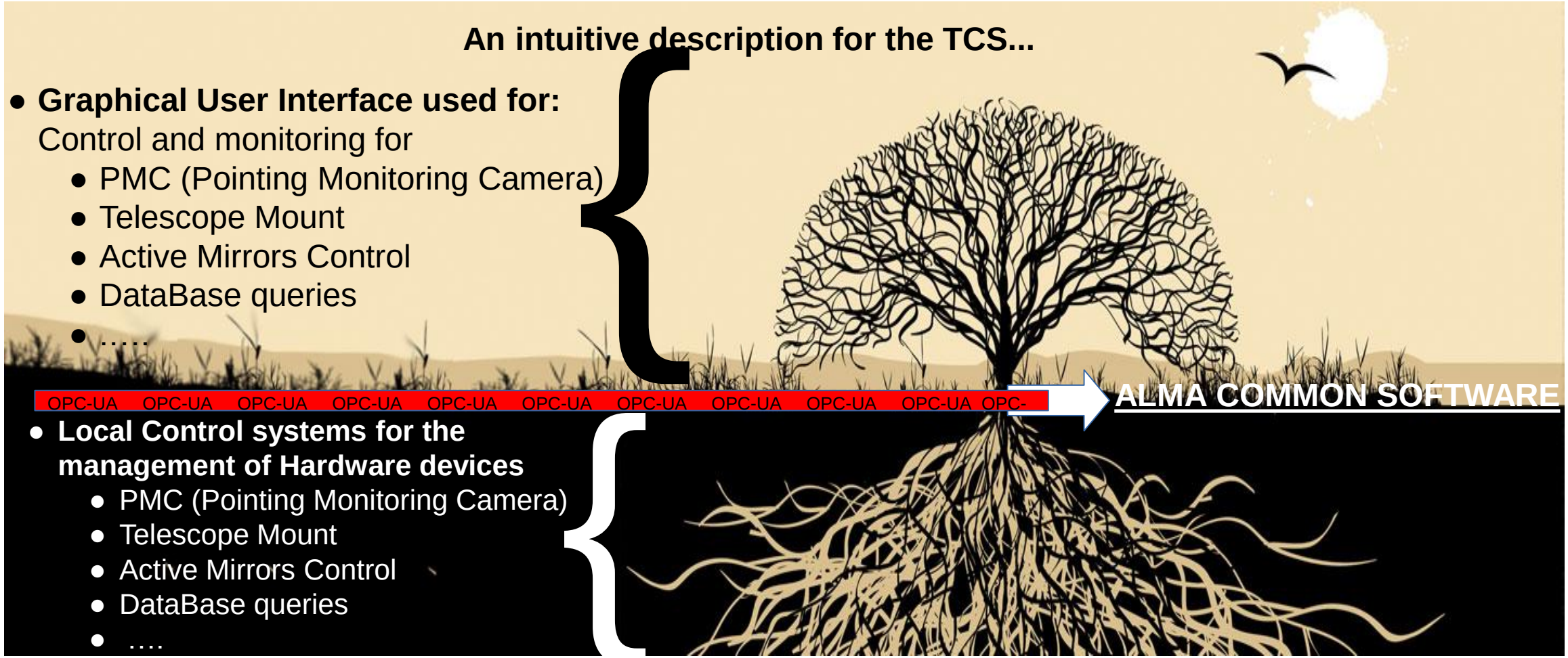

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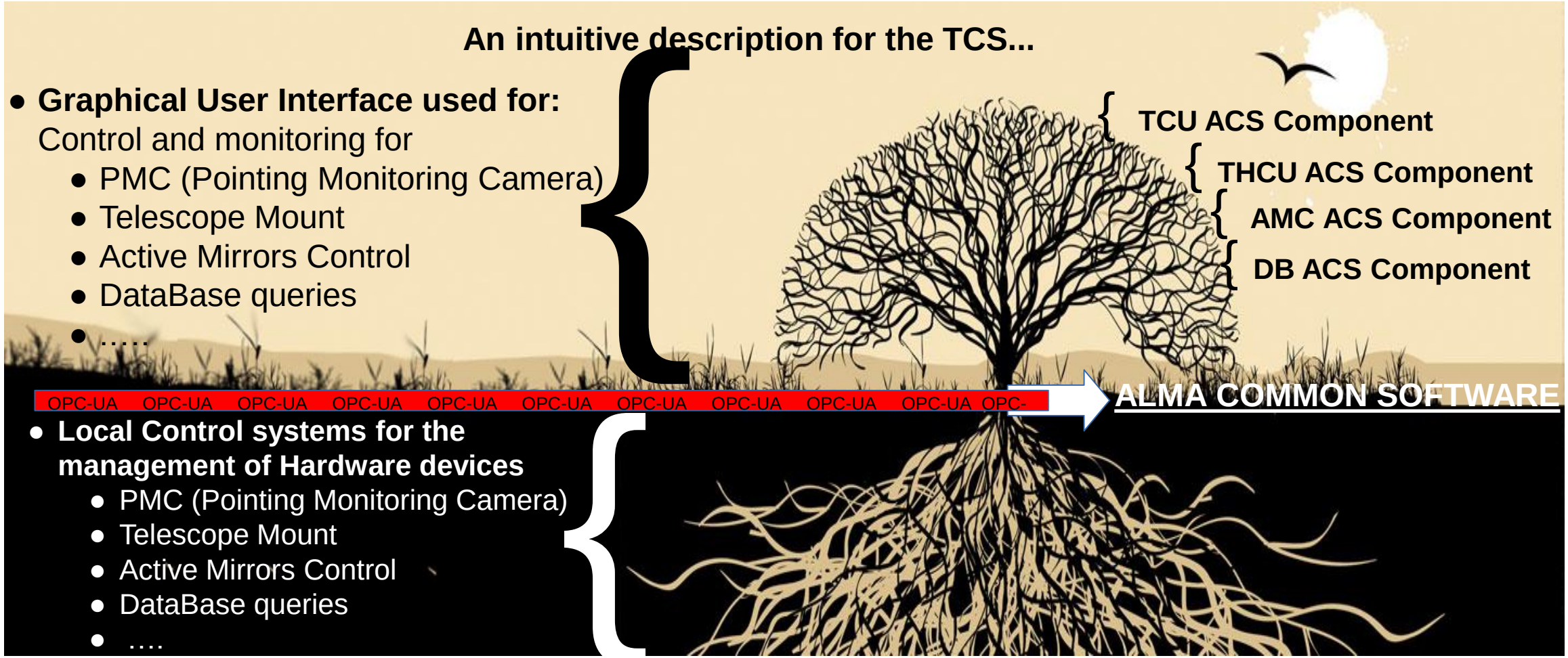

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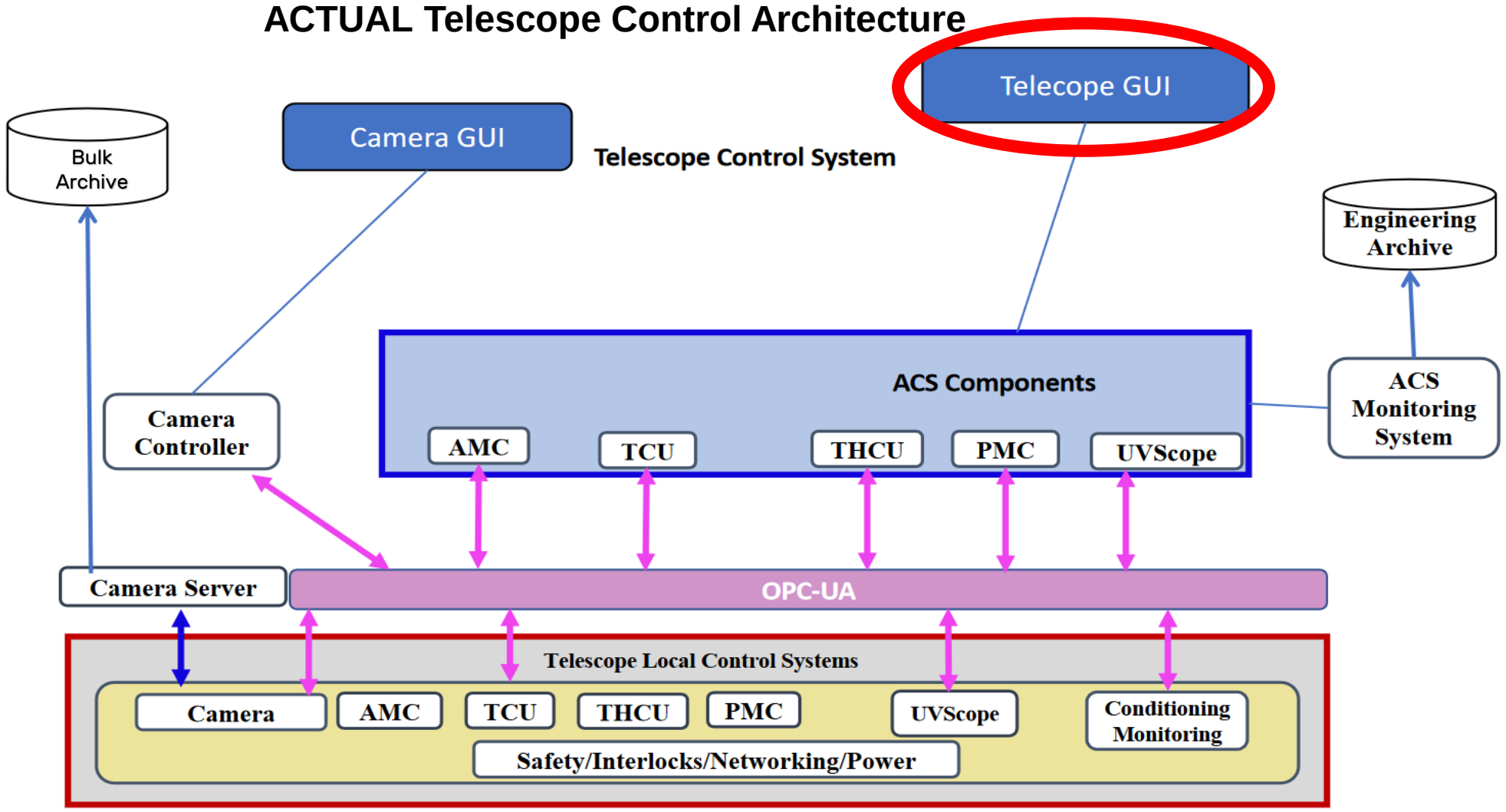
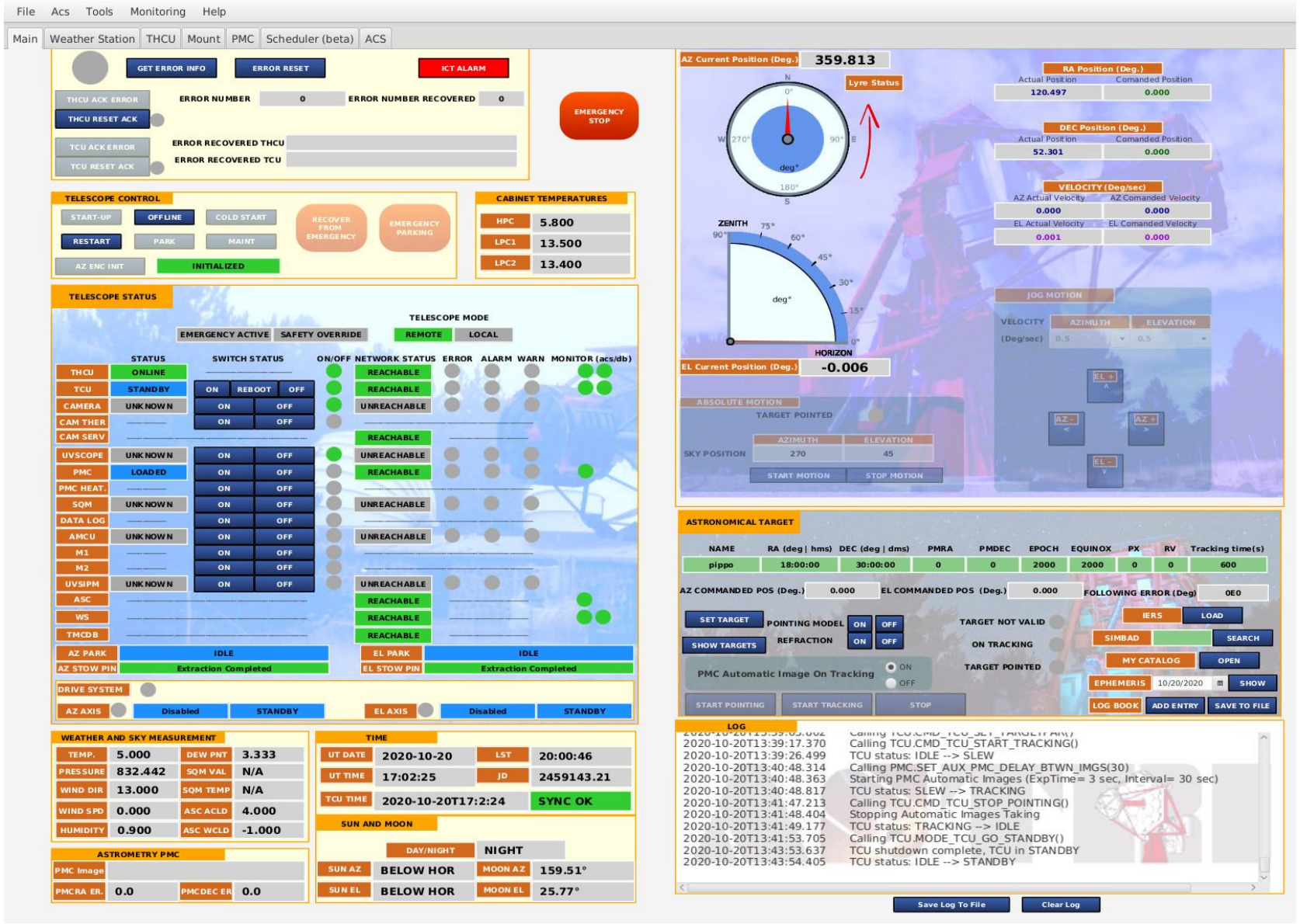


The ASTRI-Horn GUI



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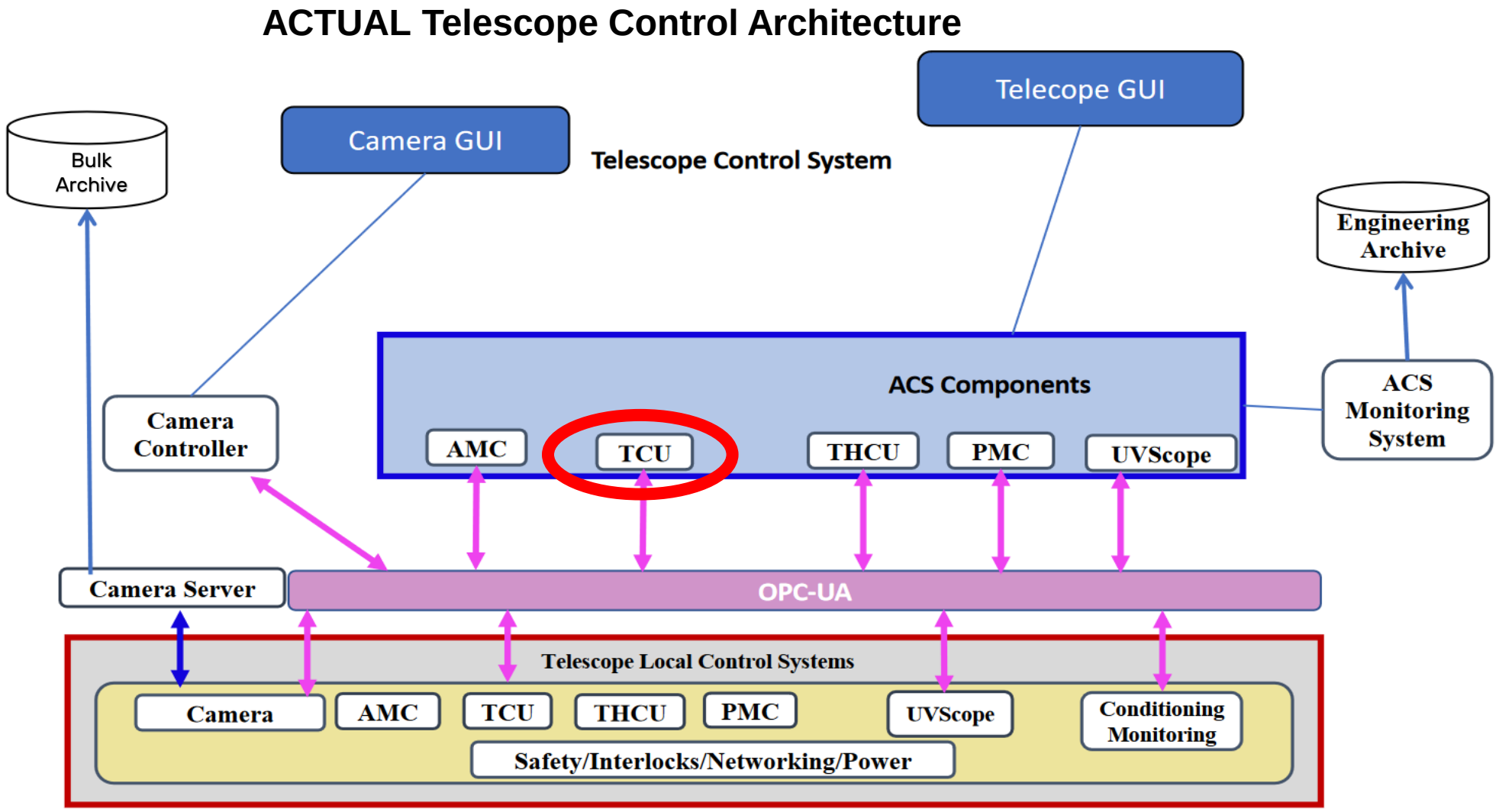
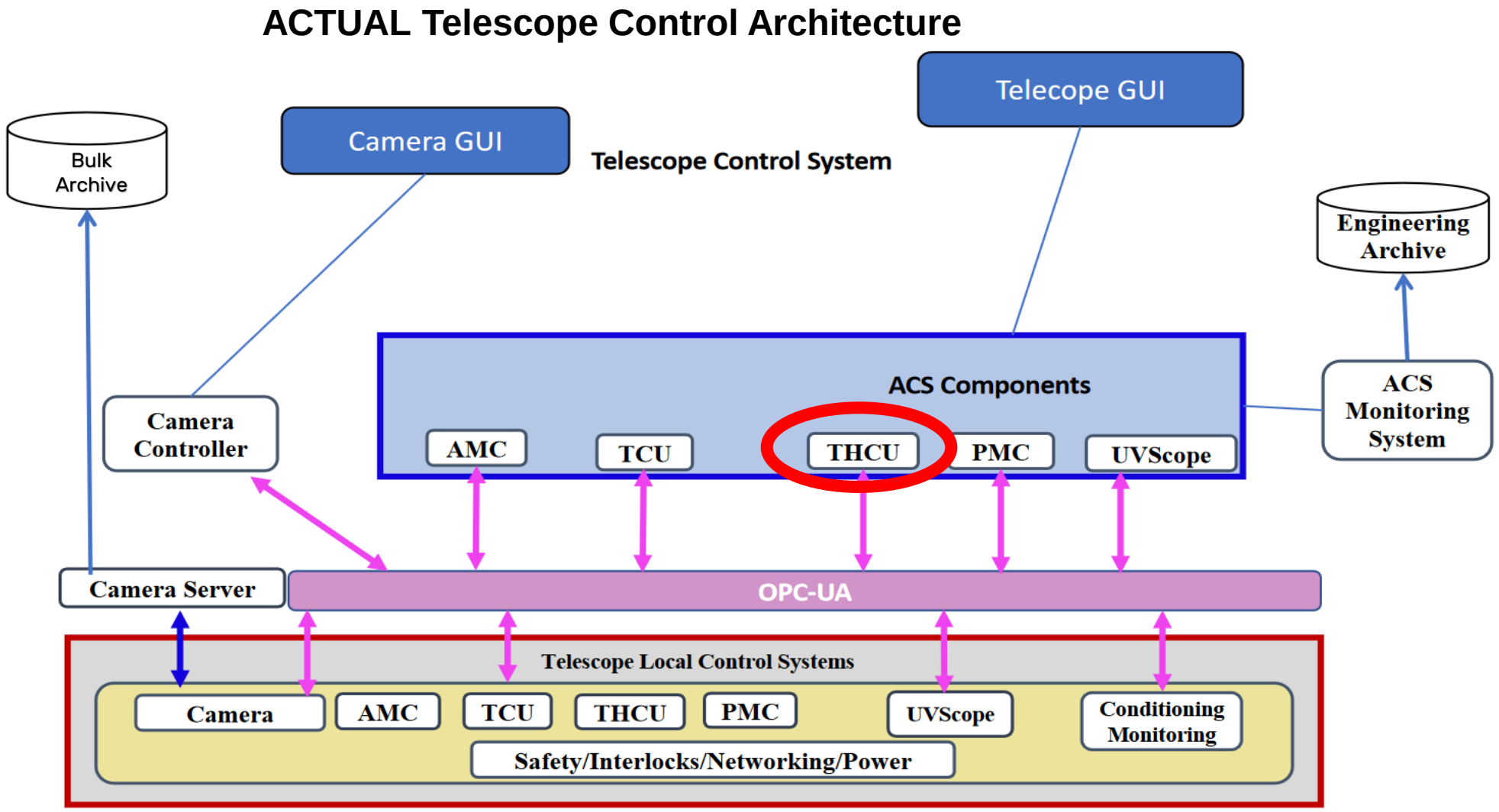


The ASTRI-Horn GUI

ASTRI-Horn Telescope Control System



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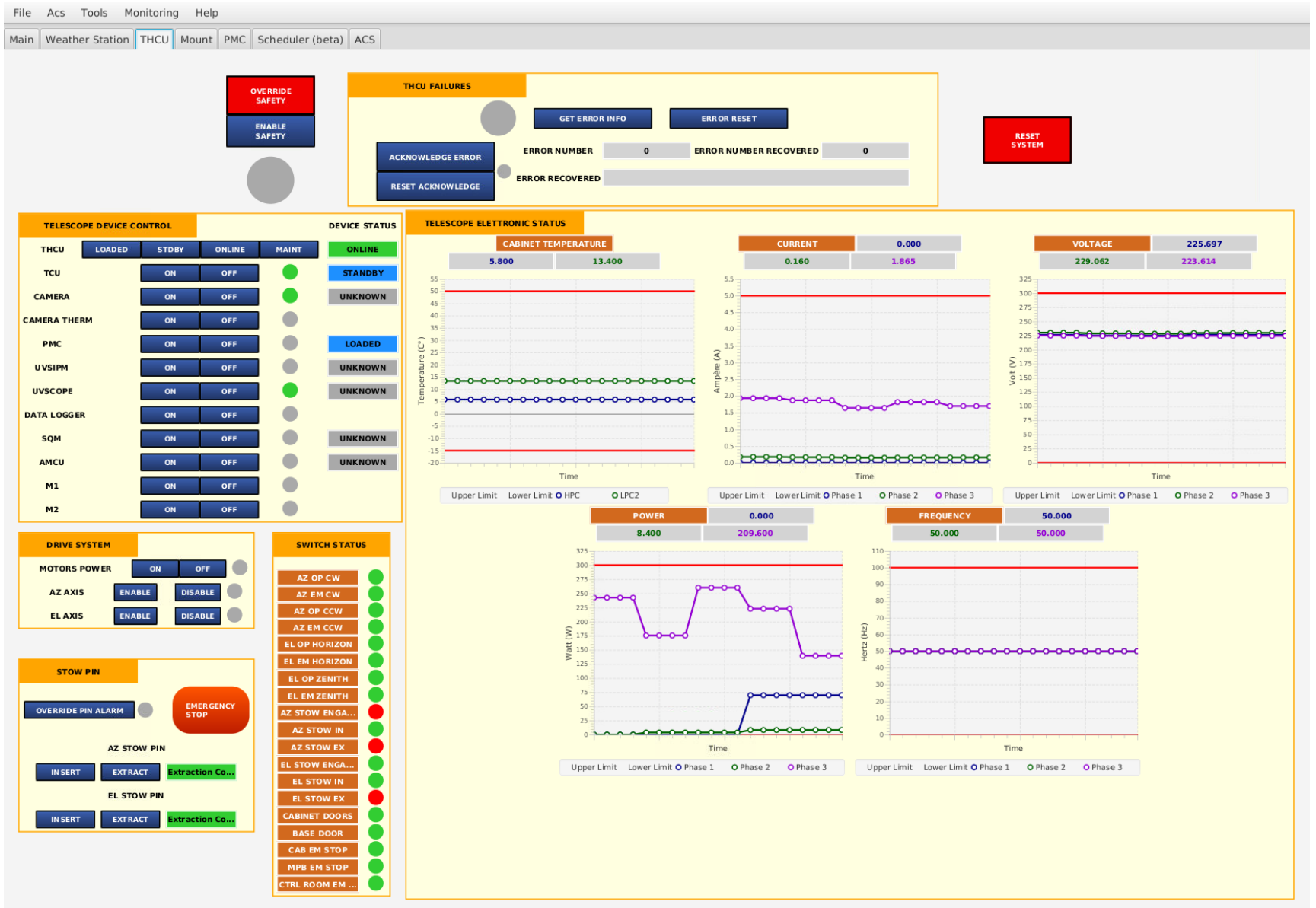

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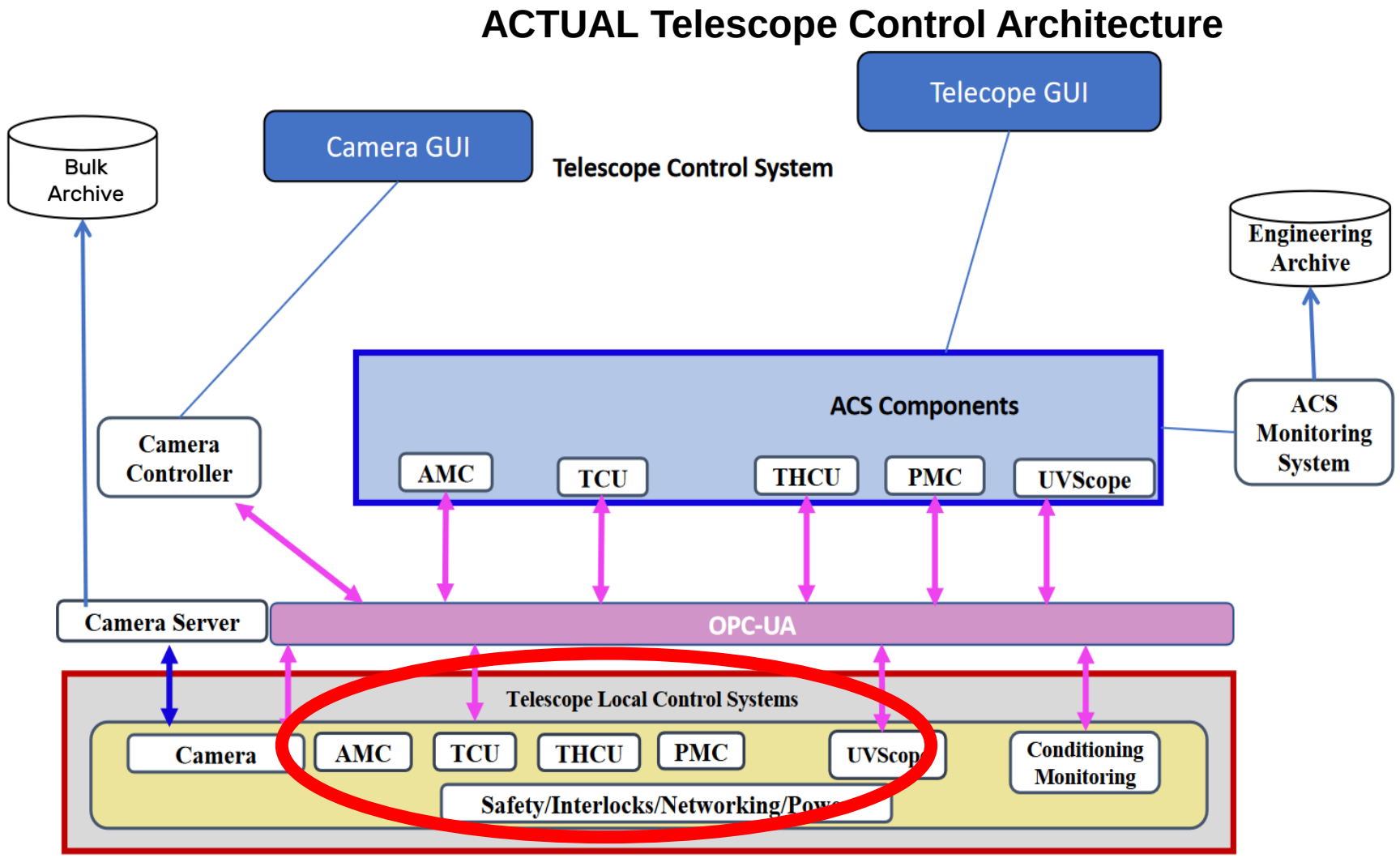
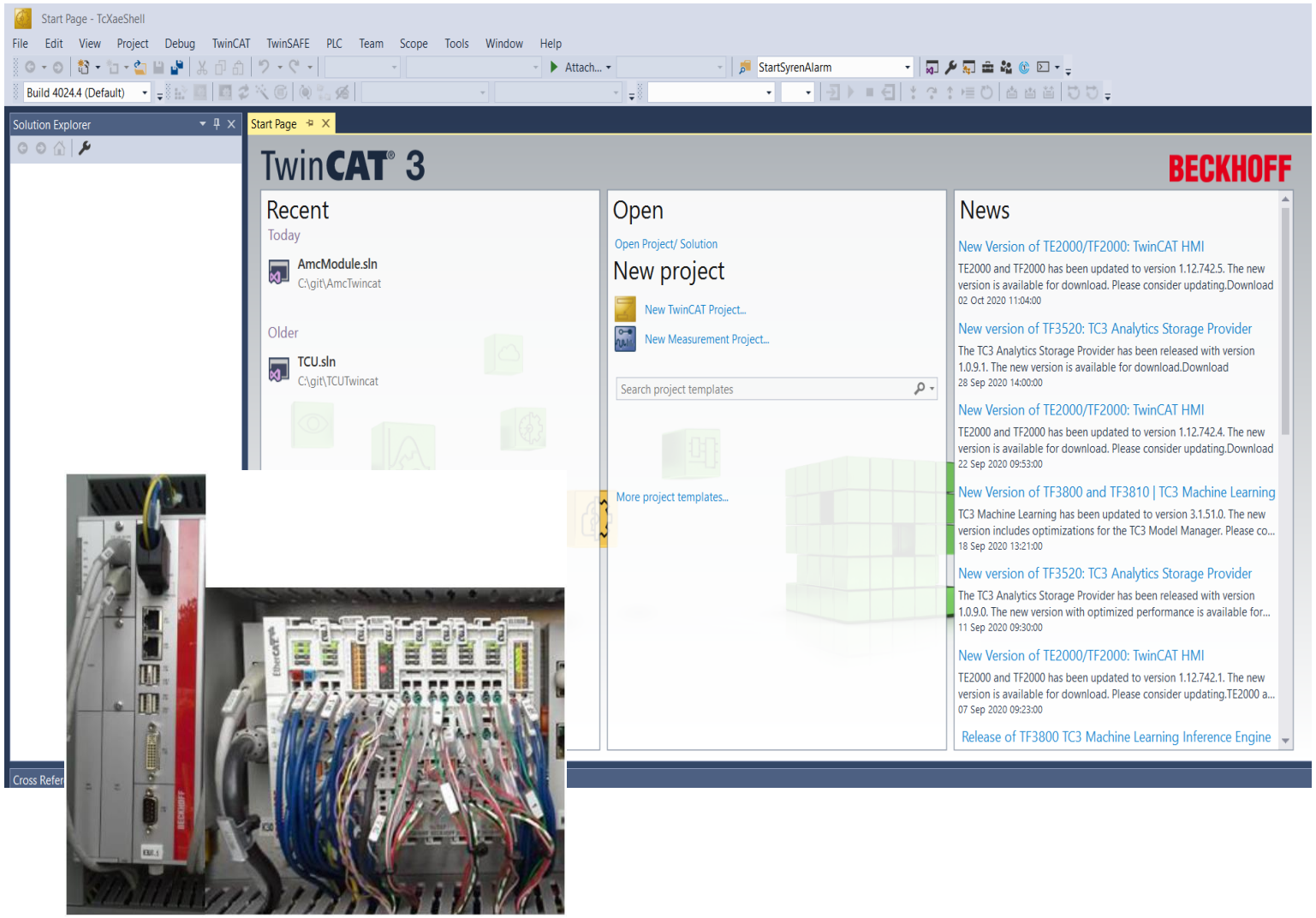


- The software that implements the local control systems has more stringent requirements regarding performance, reliability and safety.
- This software level is where the real handling logic, for the hardware management, resides.
- The software have to provide a reliable industry standard for programming numerically controlled systems.

TwinCAT

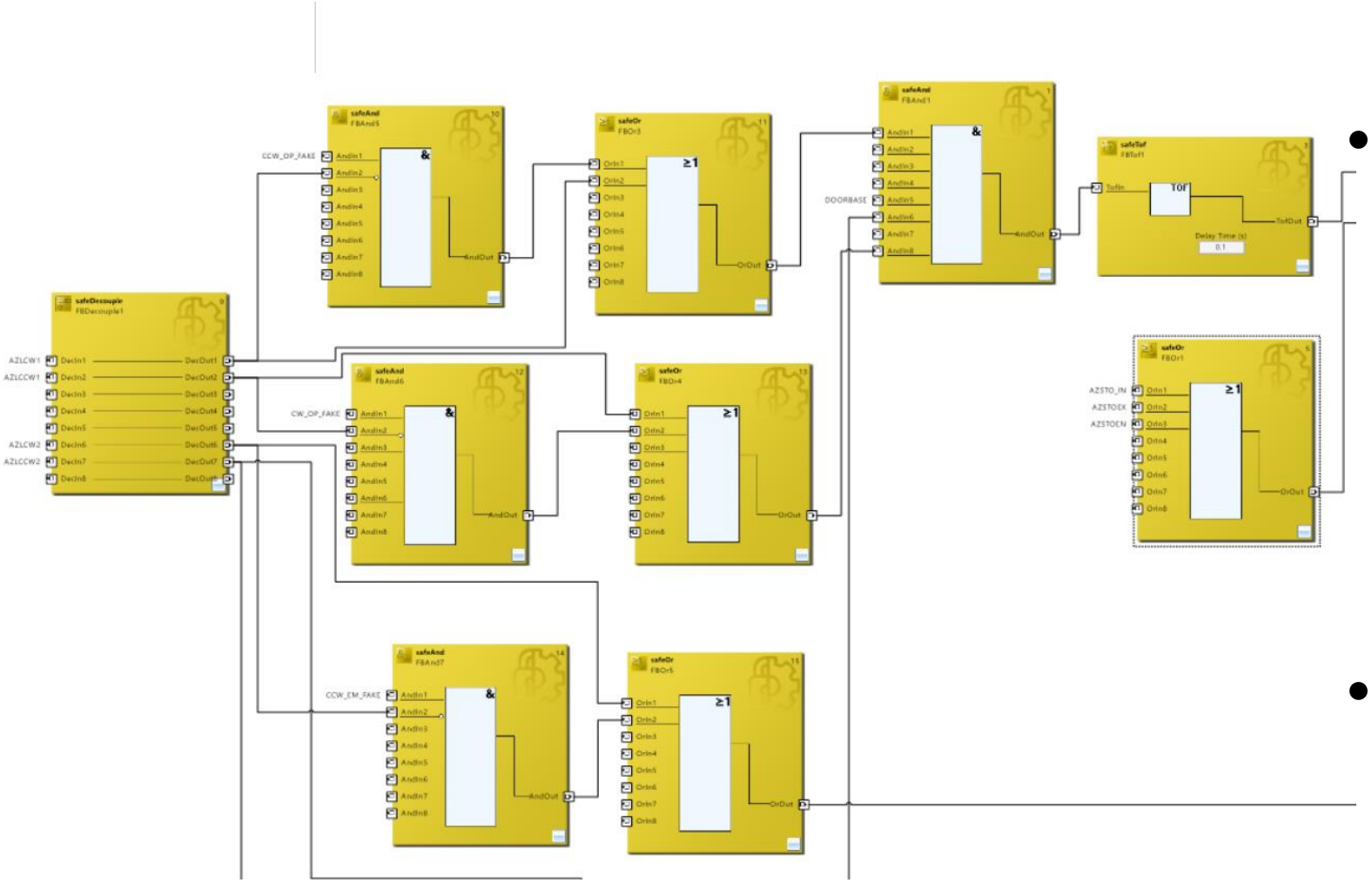


BECKHOFF TWINCAT

- **TwinCAT** (The Windows Control and Automation Technology) is a platform that meets all the above requirements by transforming a Windows PC into a real-time controller with a **multi-PLC** system, **NC axis control** PID (Proportional-Integral-Derivative) controls, **programming environment**, operating station and integration of the **Safety system**.

- Performance similar to a real-time controller: to ensure that pointing and tracking meet accuracy requirements. In particular, the interaction between the encoders and the actuators can reach a frequency of the order of milliseconds.

TwinCAT Safety integration



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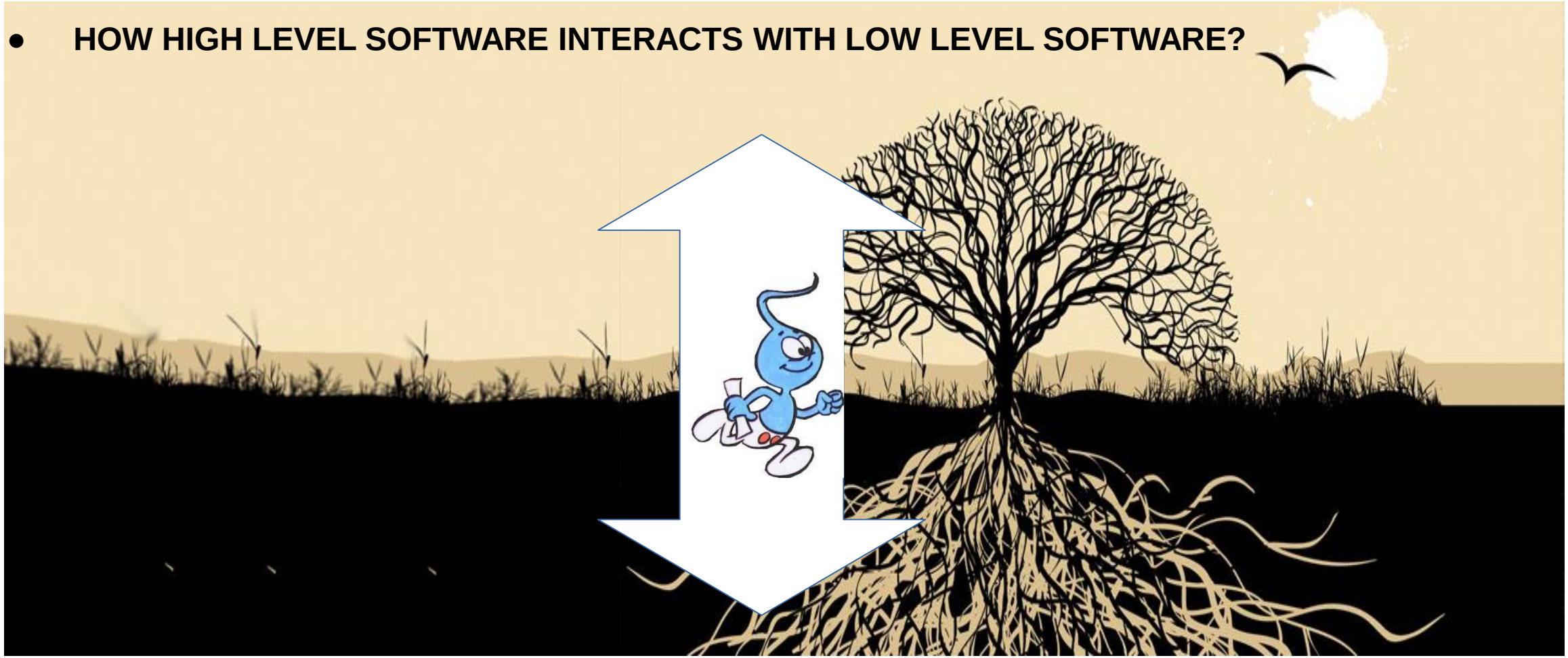
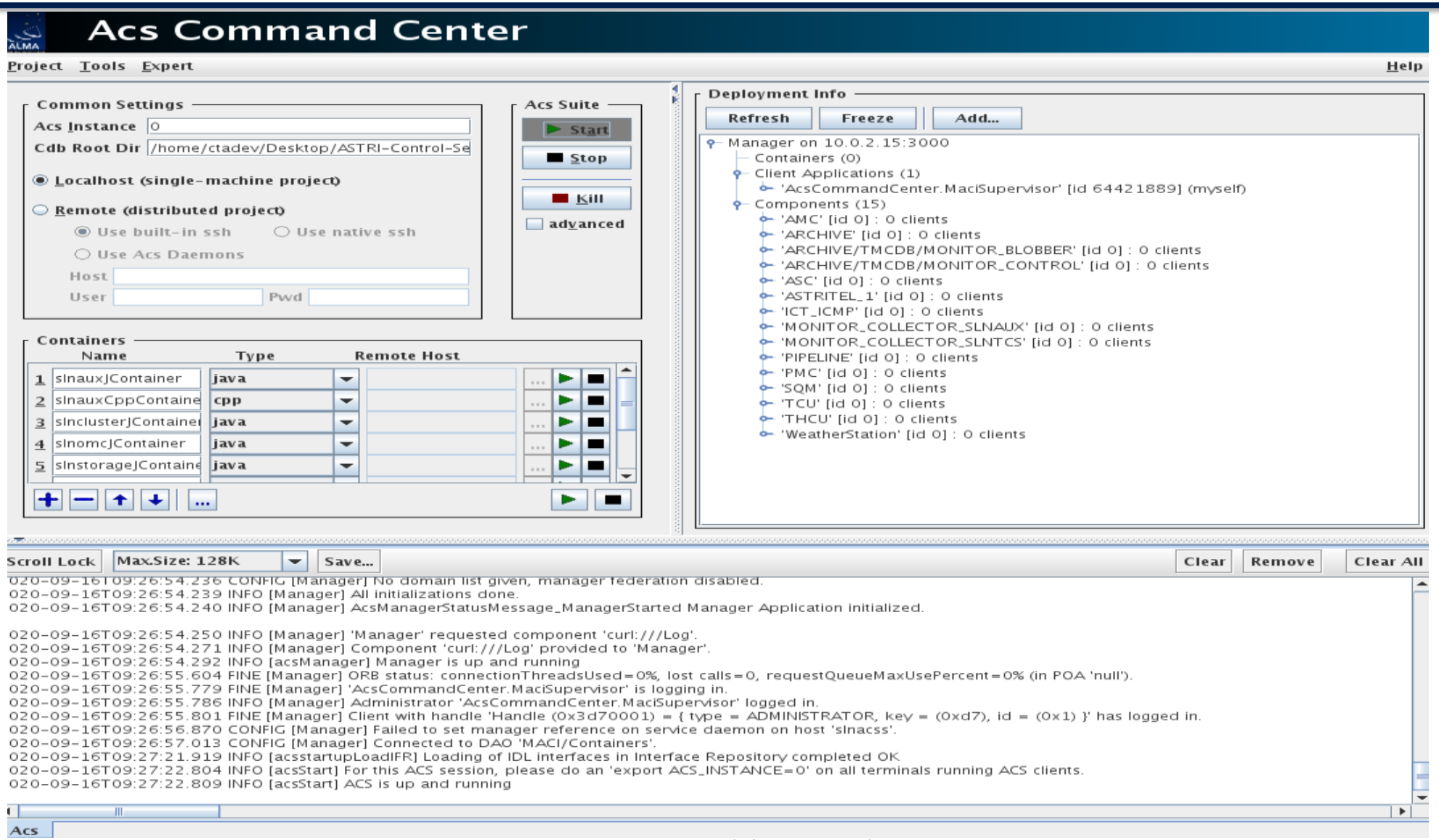
ASTRI-Horn Telescope Control System

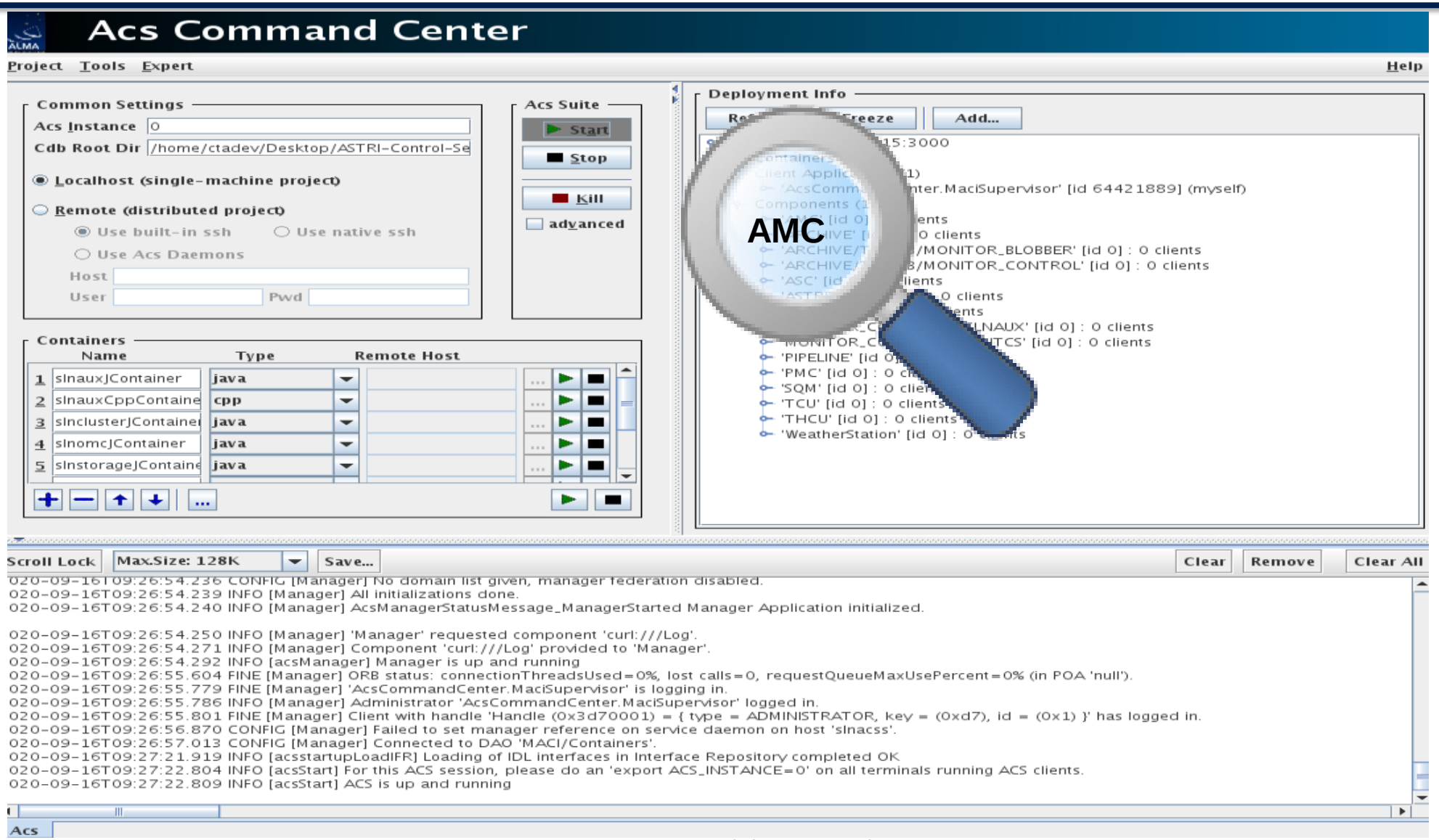
- **HOW HIGH LEVEL SOFTWARE INTERACTS WITH LOW LEVEL SOFTWARE?**



A trip among the TCS software levels



A trip among the TCS software levels



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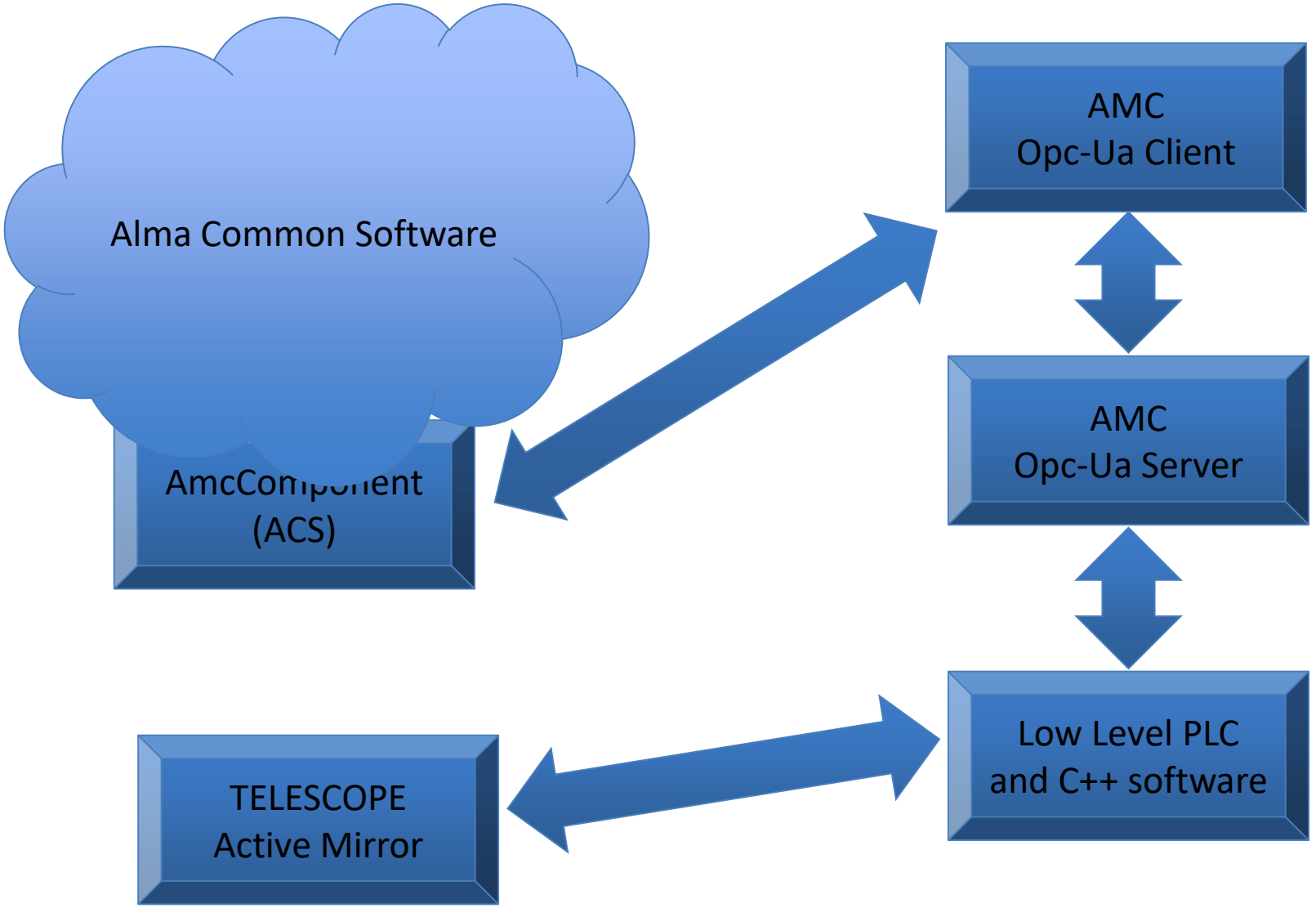


A trip among the TCS software levels

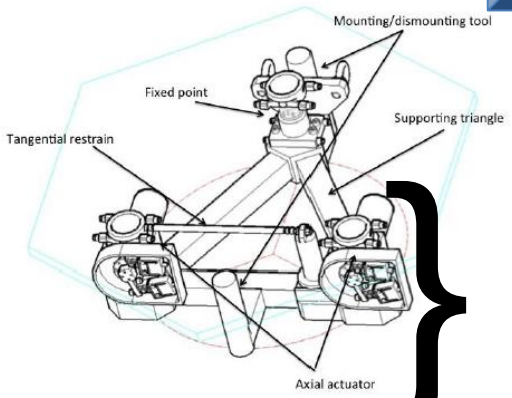
AMC
Opc-Ua Client

OPC-UA OPC-UA OPC-UA OPC-UA

OPC UA

AMC
Opc-Ua Server

AmcComponent
(ACS)

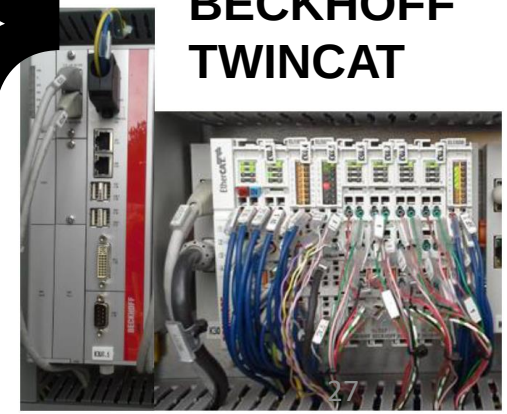


HARDWARE

TELESCOPE
Active Mirror

Low Level PLC
and C++ software

BECKHOFF
TWINCAT



A trip among the TCS software levels

Alma Common Software

AMC Opc-Ua Client

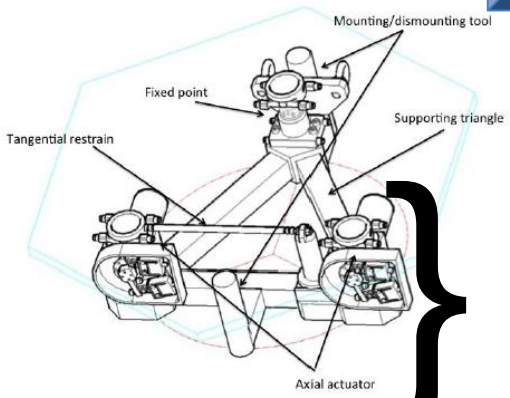
ICD

OPC-UA

OPC-UA

AMC Opc-Ua Server

AmcComponent (ACS)



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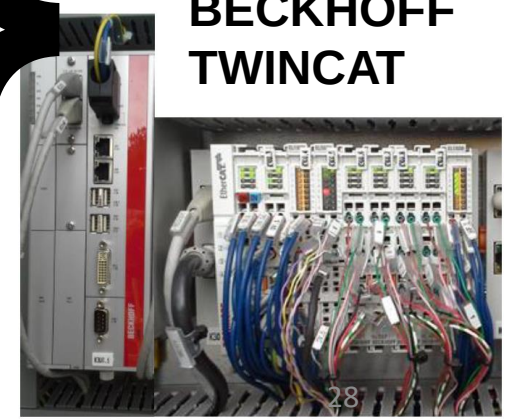


ASTRI-Code Generator

	GET_AMC_MAXTEMPWARNING			
Node ID: TBD	ns=4;s=MAIN.AMC_MAXTEMPWARNING			
Description:	Read the set temperature limit for the Nanotec boards			
Data size/type:	INT64			
Sampling Interval:	On request			
Units:	°C			
Range:	ALARM LOW		ALARM HIGH	
Operation States:	MAINTENANCE			

ICD Document

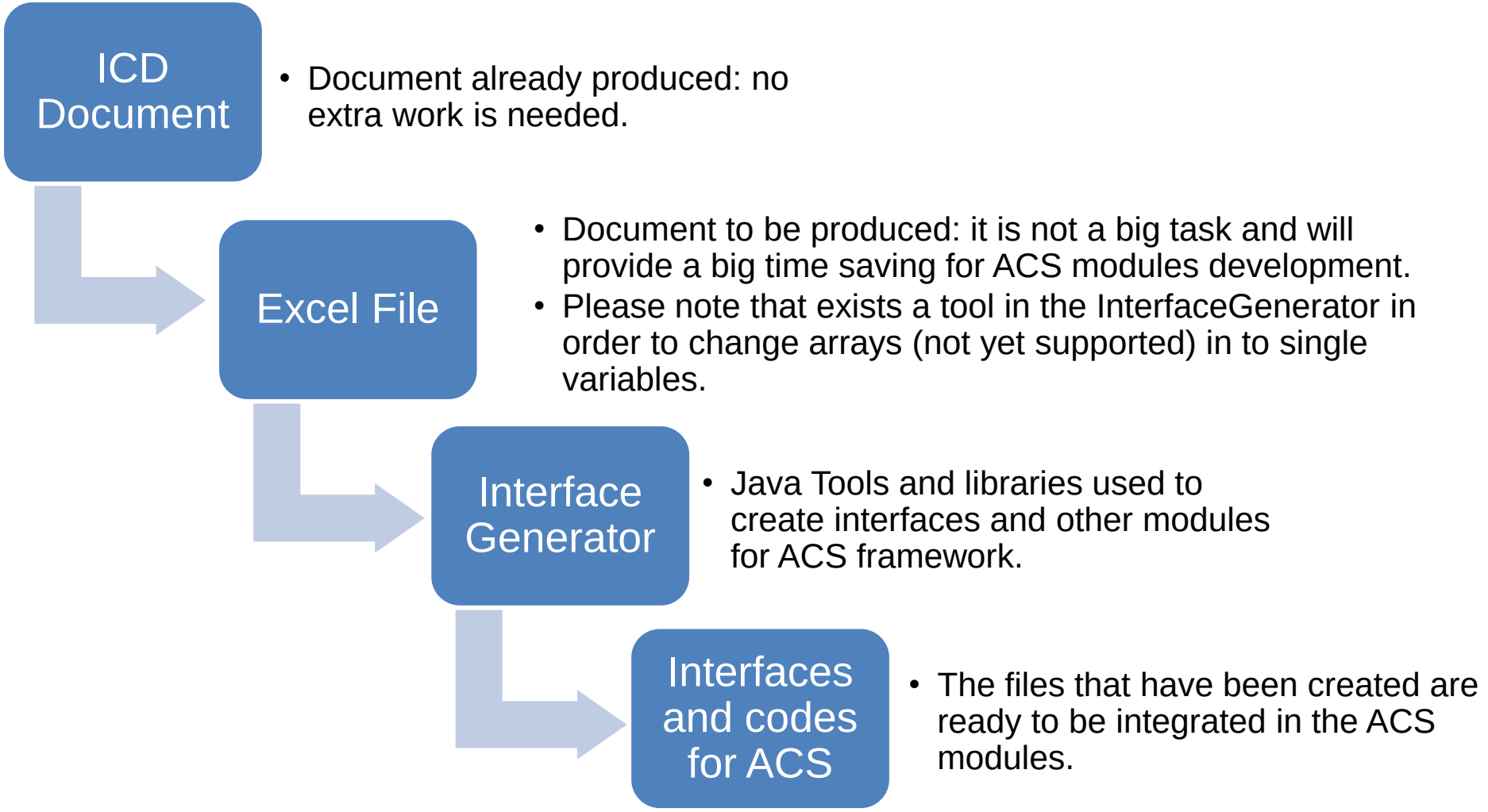
	GET_AMC_M1TEMPWARNING			
Node ID: TBD	ns=4;s=MAIN.AMC_M1TEMPWARNING			
Description:	Read the actual temperature of the Nanotech boards for M1			
Data size/type:	ARRAY<INT64> [36]			
Sampling Interval:	10			
Units:	°C			
Range:	ALARM LOW		ALARM HIGH	MAXTEMPWARNING
Operation States:	ONLINE			

Excel File

	GET_AMC_M2TEMPWARN
Node ID: TBD	ns=4;s=MAIN.AMC_M2TEM
Description:	Read the actual temperature
Data size/type:	ARRAY<INT64>[3]
Sampling Interval:	10

	A	B	C	D	E	F	G	H	I
1	Name of command	Actione	Short name	ADS variable	OPC_UA node	OPC UA Data type	CMD/MODE value	Sampling Interval (s) / ON CHANGE	Default val
2	GET_AMC_MAXTEMPWARNING	AMC	MAXTEMPWARNING		ns=4;s=MAIN.AMC_MAXTEMPWARNING	INT64		On request	
3	GET_AMC_M1TEMPWARNING	AMC	M1TEMPWARNING		ns=4;s=MAIN.AMC_M1TEMPWARNING	ARRAY<INT64> [36]			
4	GET_AMC_M2TEMPWARNING	AMC	M2TEMPWARNING		ns=4;s=MAIN.AMC_M2TEMPWARNING	ARRAY<INT64>[3]			
5	GET_AMC_MAXPOWRCONSUMP	AMC	MAXPOWRCONSUMP		ns=4;s=MAIN.AMC_MAXPOWRCONSUMP	INT64		On request	
6	GET_AMC_M1POS	AMC	M1POS		ns=4;s=MAIN.AMC_M1POS	ARRAY<DOUBLE> [36]			
7	GET_AMC_M2POS	AMC	M2POS		ns=4;s=MAIN.AMC_M2POS	ARRAY<DOUBLE> [3]			
8	GET_AMC_M1POSABS	AMC	M1POSABS		ns=4;s=MAIN.AMC_M1POSABS	ARRAY<DOUBLE> [36]		On request	
9	GET_AMC_M2POSABS	AMC	M2POSABS		ns=4;s=MAIN.AMC_M2POSABS	ARRAY<DOUBLE>[3]		On request	
10	GET_AMC_M1ABSLIMITS	AMC	M1ABSLIMITS		ns=4;s=MAIN.AMC_M1ABSLIMITS	ARRAY<DOUBLE>[72]		On request	
11	GET_AMC_M2ABSLIMITS	AMC	M2ABSLIMITS		ns=4;s=MAIN.AMC_M2ABSLIMITS	ARRAY<DOUBLE>[6]		On request	
12	GET_AMC_M1ACTSTATUS	AMC	M1ACTSTATUS		ns=4;s=MAIN.AMC_M1ACTSTATUS	ARRAY<INT64> [36]			

ASTRI-Code Generator



- Document already produced: no extra work is needed.

- Document to be produced: it is not a big task and will provide a big time saving for ACS modules development.
- Please note that exists a tool in the InterfaceGenerator in order to change arrays (not yet supported) in to single variables.

- Java Tools and libraries used to create interfaces and other modules for ACS framework.

- The files that have been created are ready to be integrated in the ACS modules.

A trip among the TCS software levels

Mini-Array

Alma Common Software

AmcComponent (ACS)

AMC Opc-Ua Client

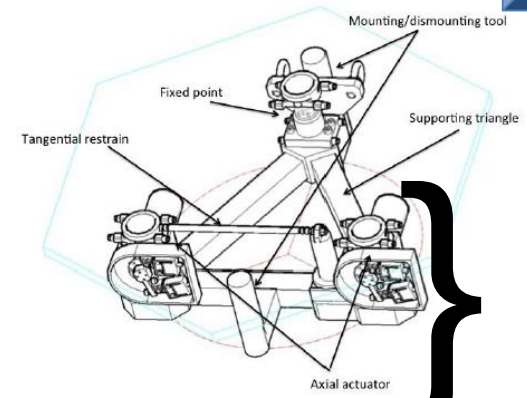
OPC-UA OPC-UA OPC-UA OPC-UA

OPC UA

AMC Opc-Ua Server

Low Level PLC and C++ software

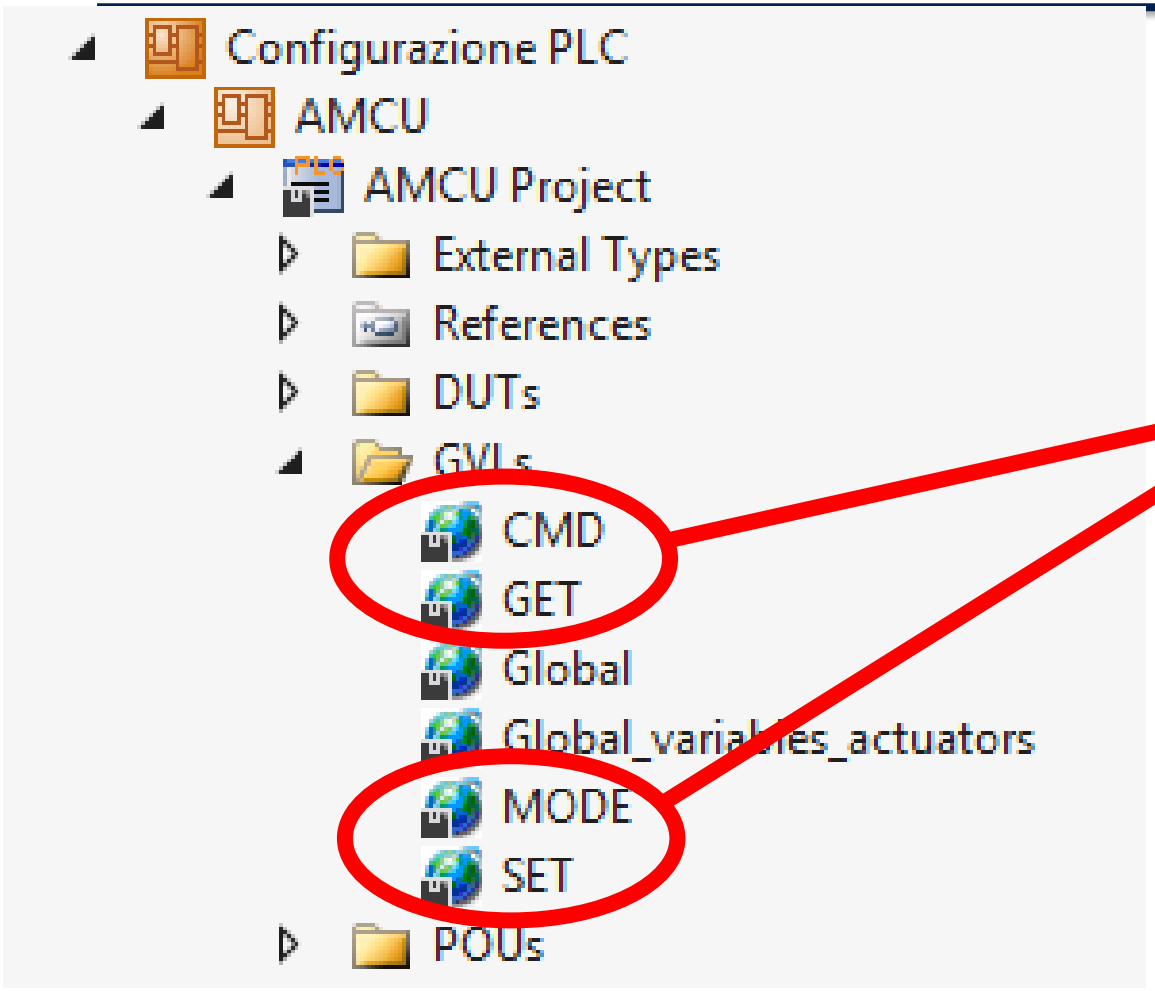
BECKHOFF TWINCAT



HARDWARE

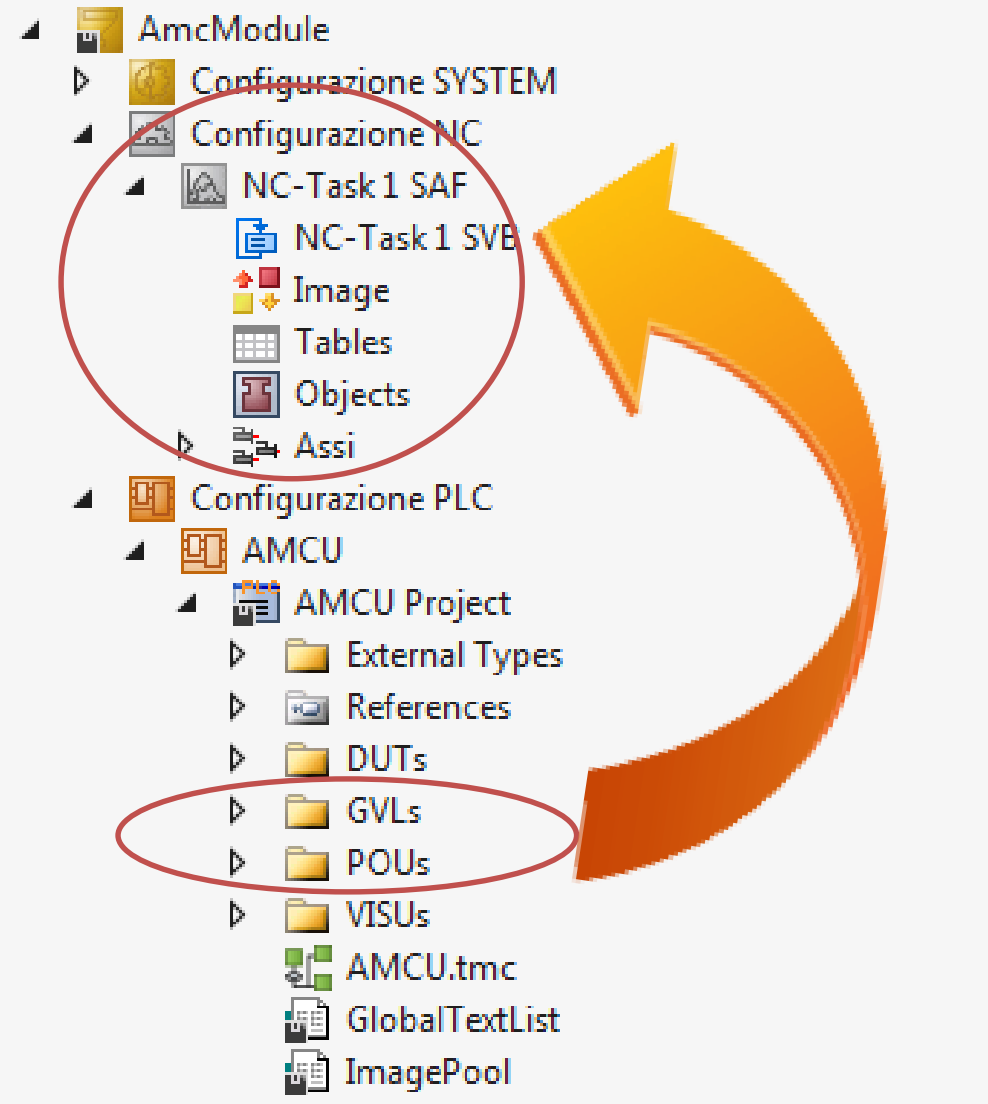
TELESCOPE Active Mirror

A trip among the TCS levels… (Twincat)



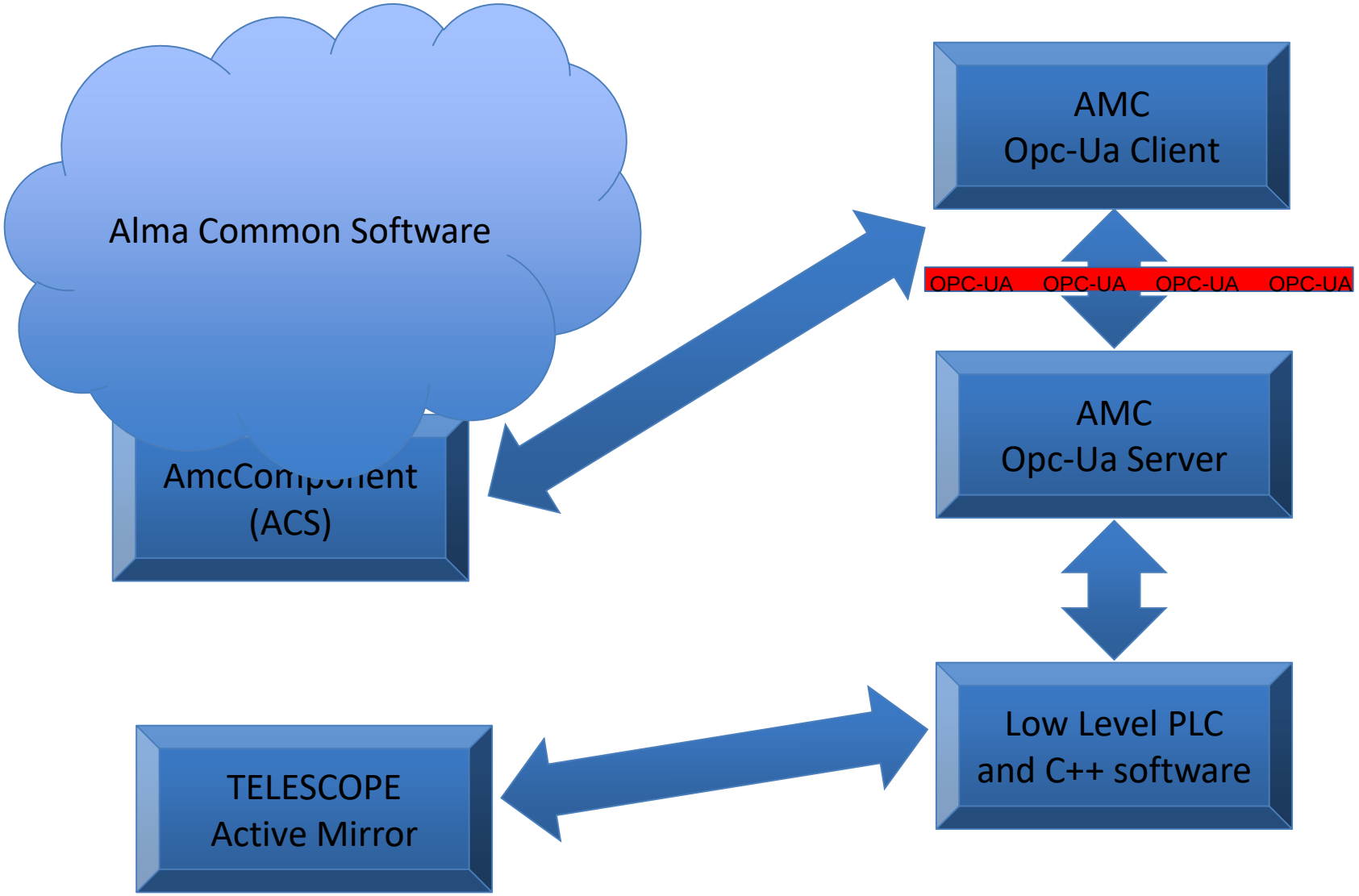
- **OPC-UA Global Variables!**
  that match the ICD variables names

A trip among the TCS levels... (Twincat)



- The commands received trigger the twincat project internal logic that calculates the parameters for required movement.
- The PLC routines apply the calculated positions to the axis module (Numeric Control) and manage their executions by an interpolated mode.
- Error management, running always in background, takes care of all the unexpected behaviour of both hardware and software
- All the monitored data received from the hardware device update the corresponding opc-ua variables in every cycle.

A trip among the TCS levels… (Twincat)



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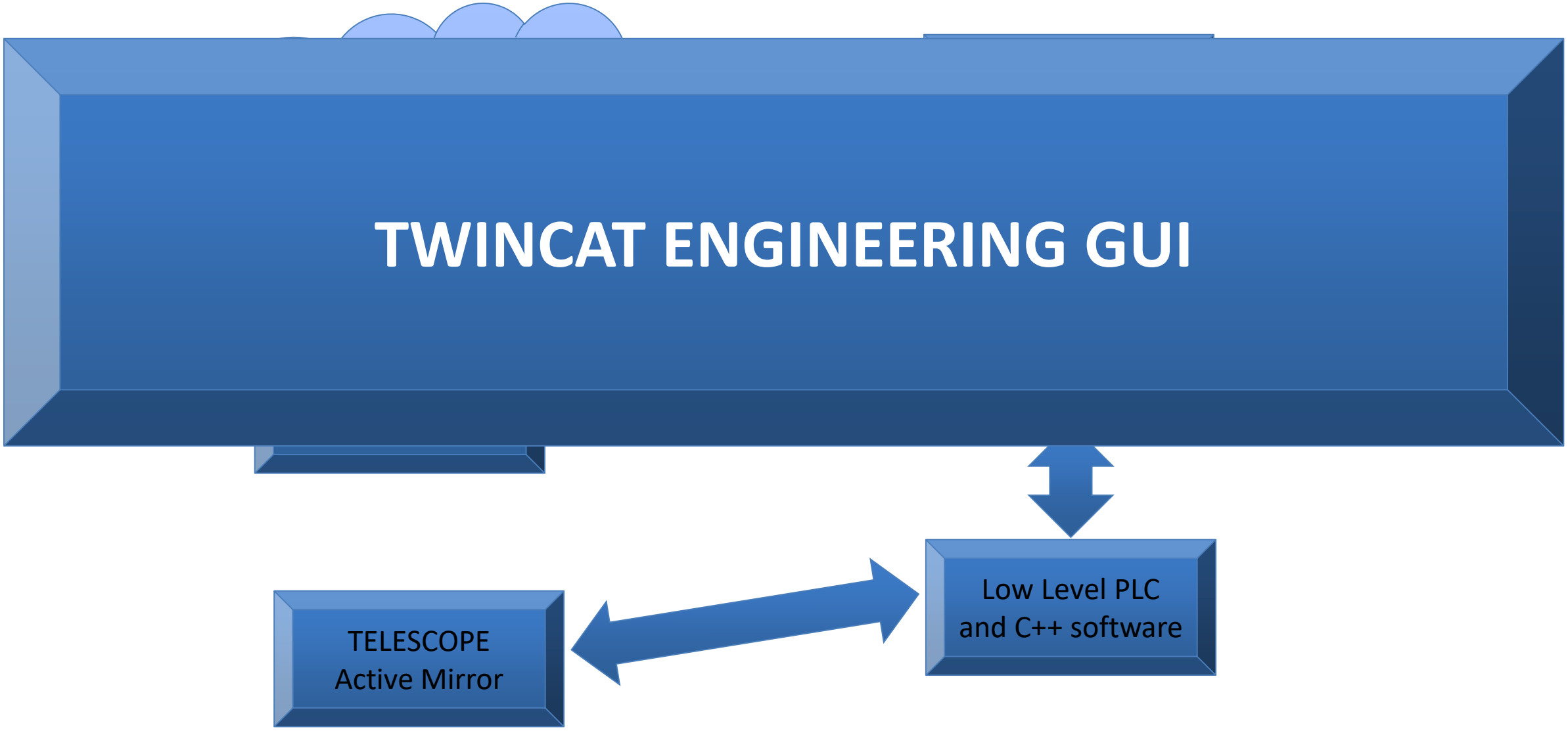

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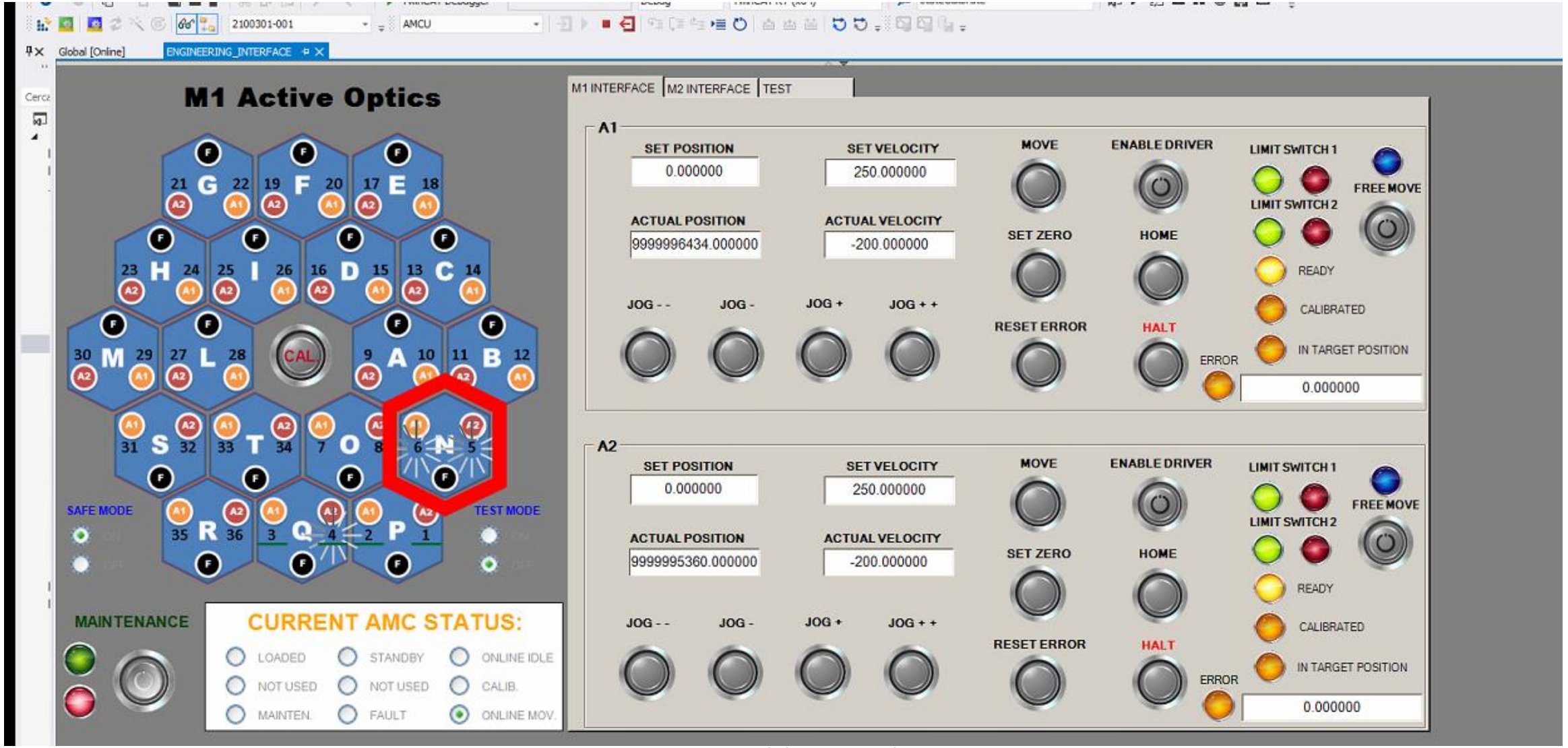

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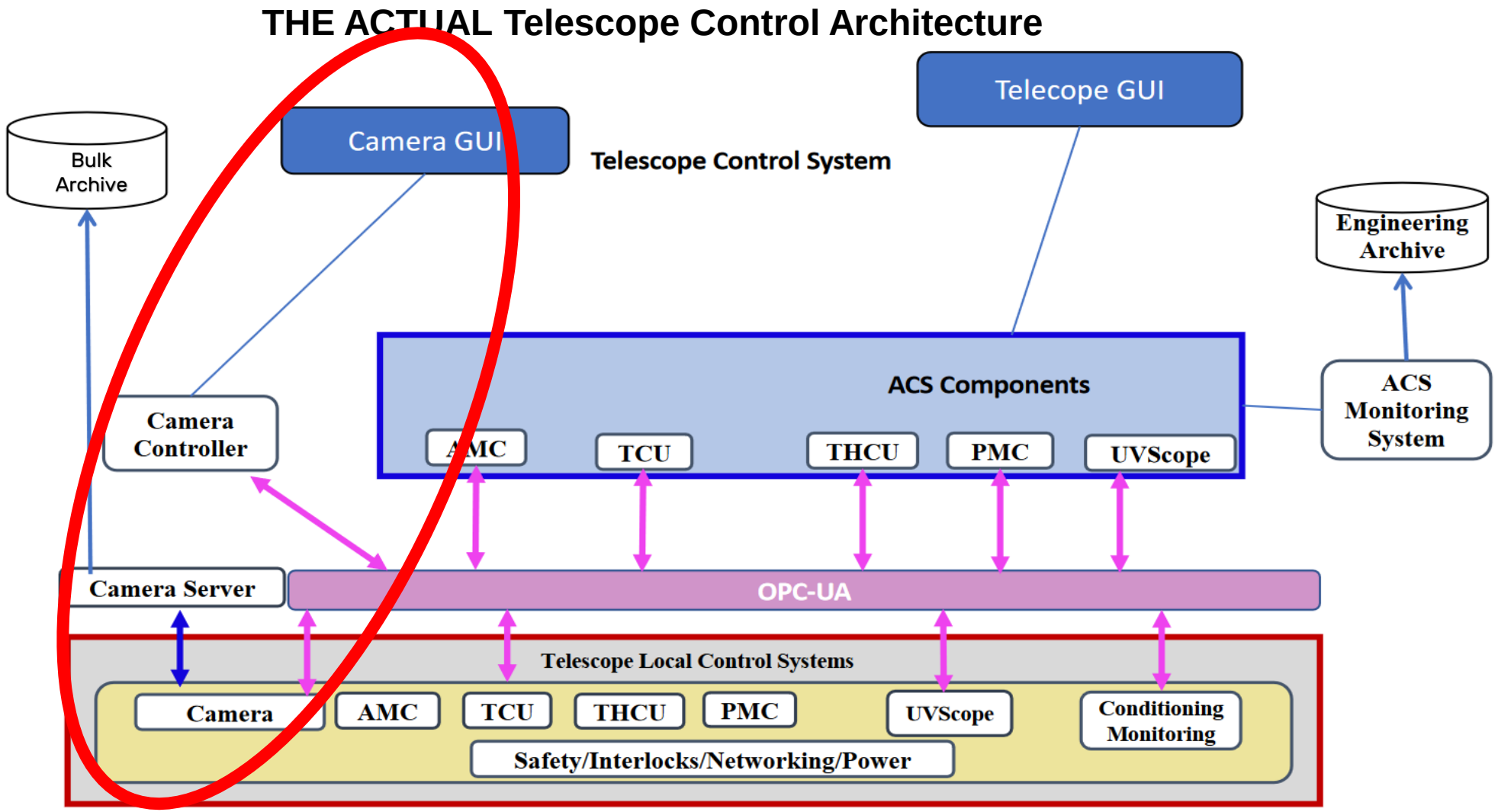
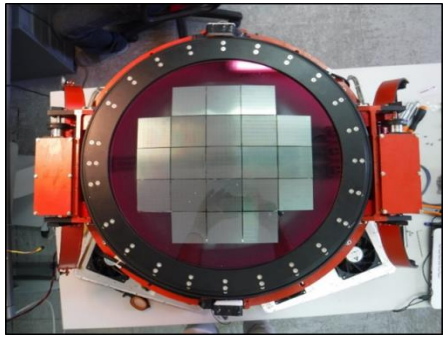
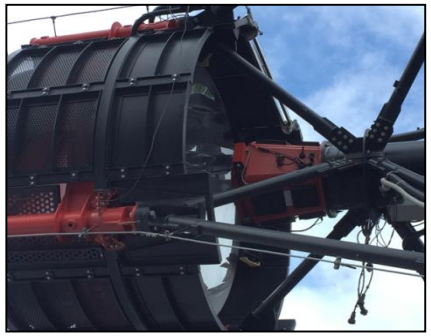
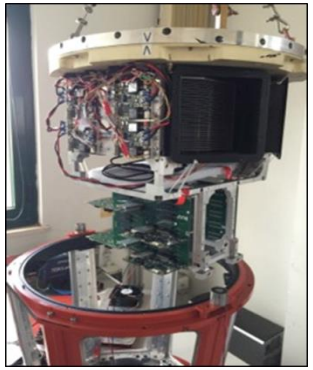


Camera Specifications







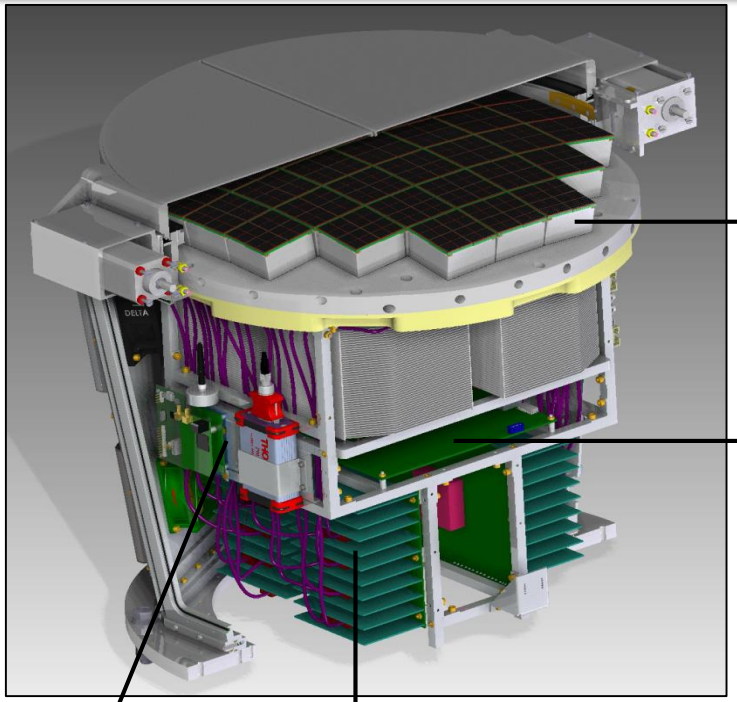
Cherenkov Camera:

- Innovative design based on SiPM (Silicon Photo Multiplier) sensors and specifically designed front-end electronics for signal capture
- Fully compliant with the CTA requirements

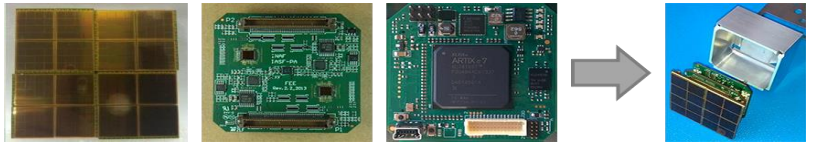
Cherenkov Camera	
Camera opening Angle	70°
Sensors	SiPM
Number of Pixels	2368 (1344 protoype)
Pixel size	7x7 mm
Pixel rate	600 Hz
Dynamical range	1 – 2000 pe-/pixel
Photon Detection Efficiency	> 35% @ 400nm
FoV	10.5° (7.8° prototype)
Weight	73 kg
Dimensions	0.52m x 0.66m x 0.56m
Power consumption	0.65 kW

Camera Electronics

Mini-Array



- **37 (21) Photo Detection Module (PDM) units containing**
  - ✓ SiPM board with 9 embedded temperature sensors
  - ✓ Front End Electronics (FEE) board with 2 CITIROC ASIC
  - ✓ PDM FPGA Board (*Xilinx Artix 7*)



- **Back End Electronics (BEE) unit**

XILINX ALL PROGRAMMABLE™

- Custom built solution based on the **Xilinx Zynq-7000** All Programmable SoCs.
- Dual ARM® Cortex™-A9 Processing System and FPGA Programming Logic.
- Custom built Linux distribution Debian Wheezy

- **PDM Voltage Distribution Box (PDM VDB)**

Custom built boards (2 mainboards with 19 daughterboards for each) to provide power (Low and Hi Voltages) to the PDMs with real-time control and monitor functionalities

Novasis

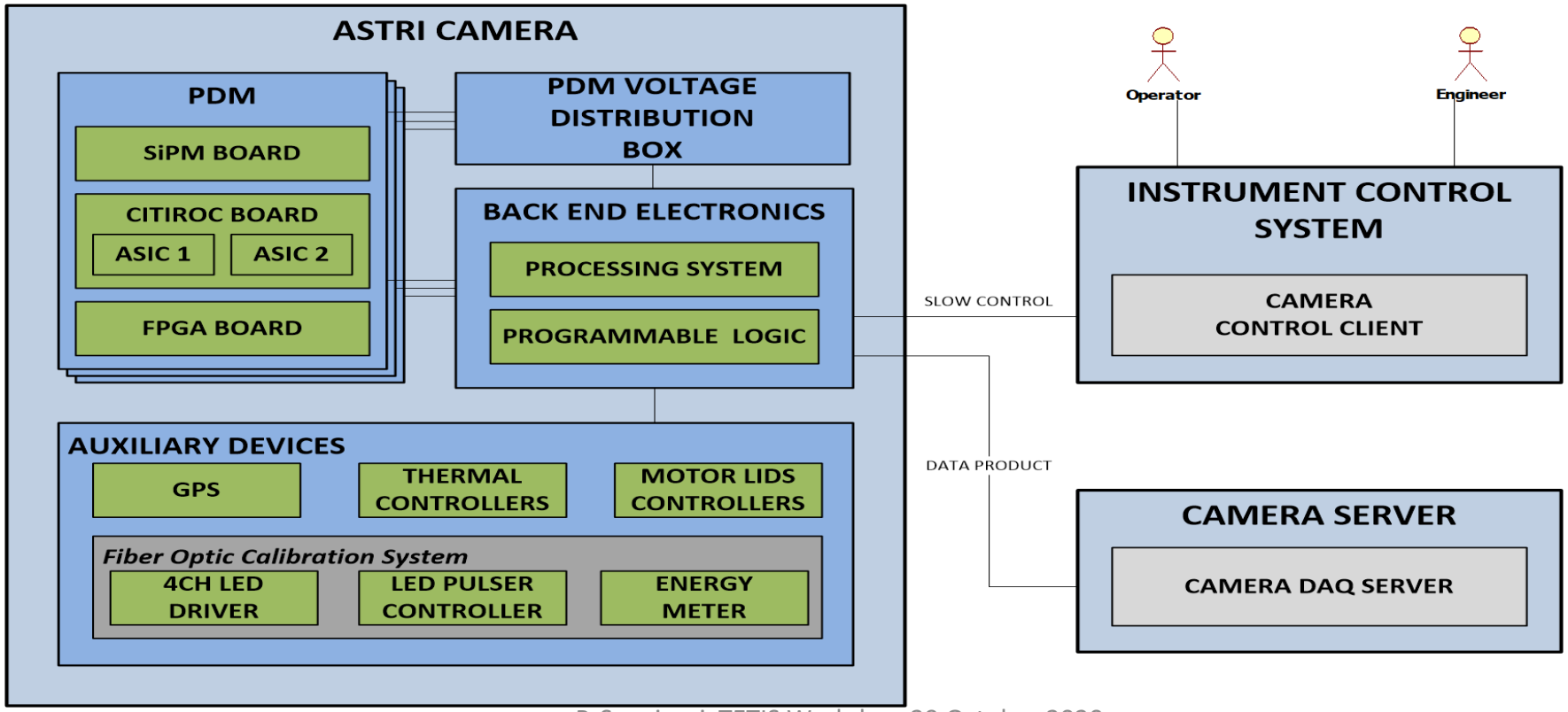
- **Set of auxiliary devices like GPS for synchronization, Fiber Pulser and Energy Meter for calibration, Motor Lid and Thermal controllers** (provided by several vendors)

i-LOTUS Nanotec PLUG & DRIVE THORLABS PicoLAS meerstetter engineering

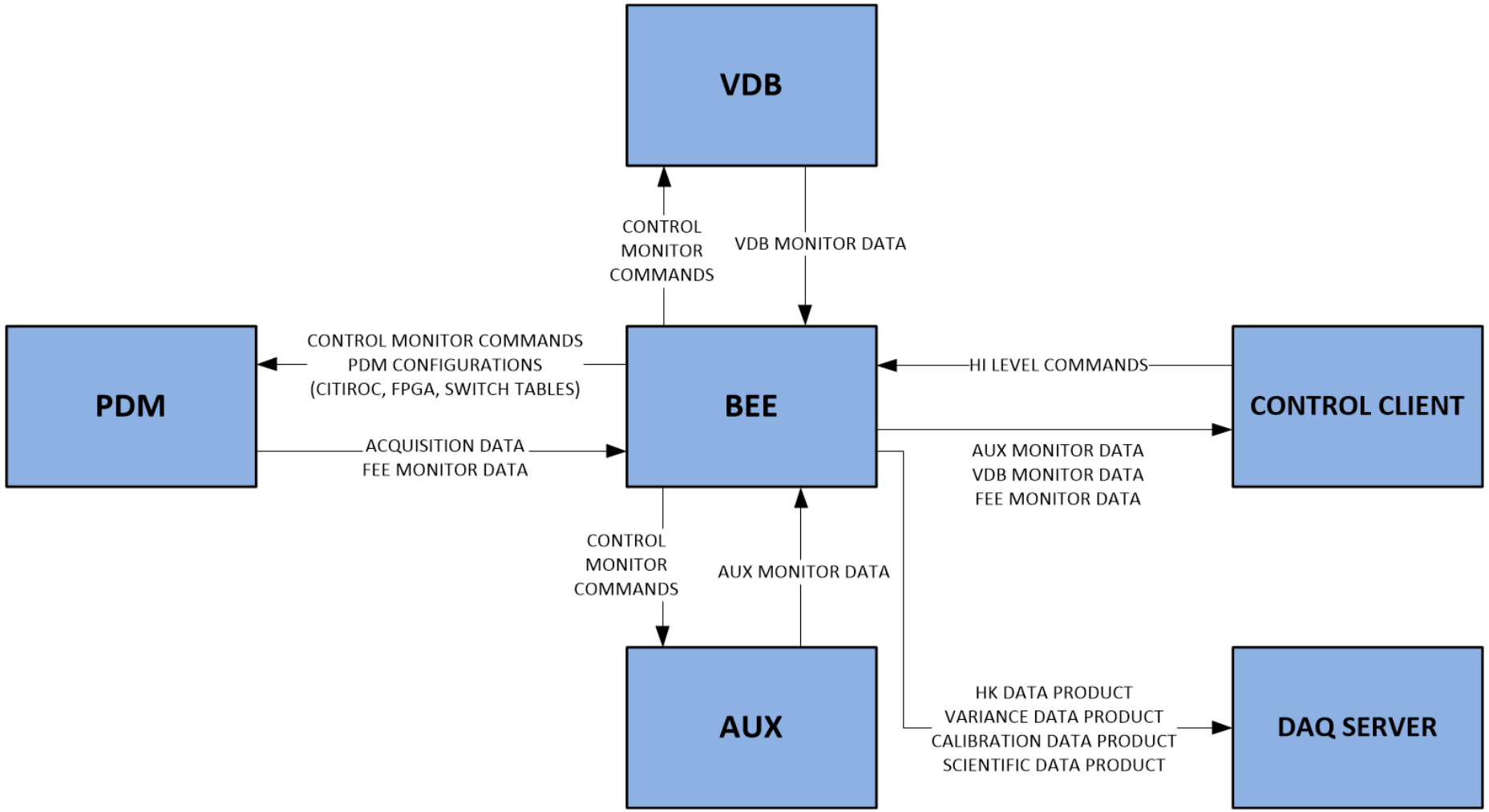
Camera Logical View

All the devices and systems are interconnected by the BEE, which is the main elaboration unit of the camera, managing all its functions:

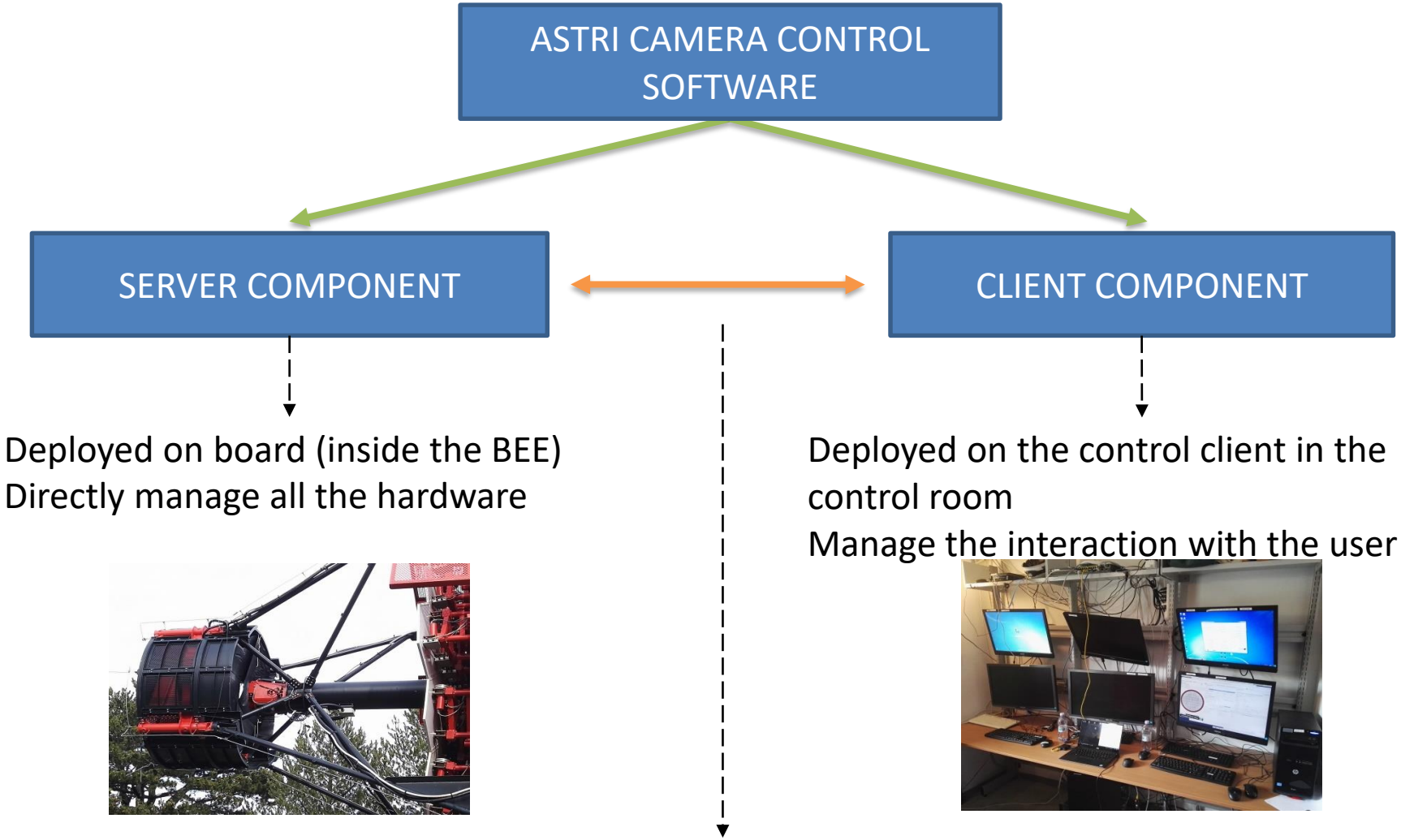
- Receive commands from the camera control client
- Control and monitor the auxiliary devices
- Manage and acquire data from the PDMs
- Prepare and send packets to the Camera Data Acquisition Server



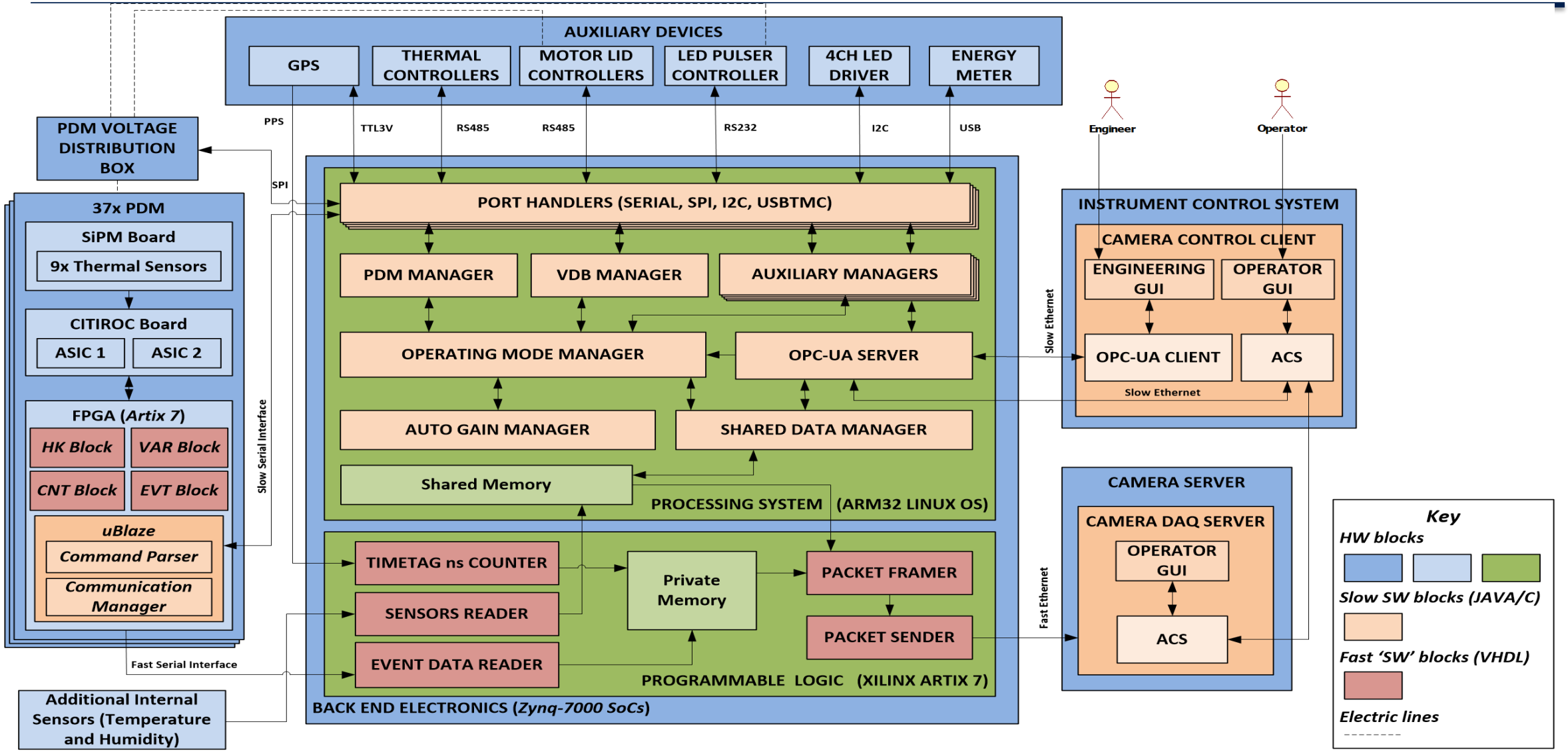
Camera Logical View



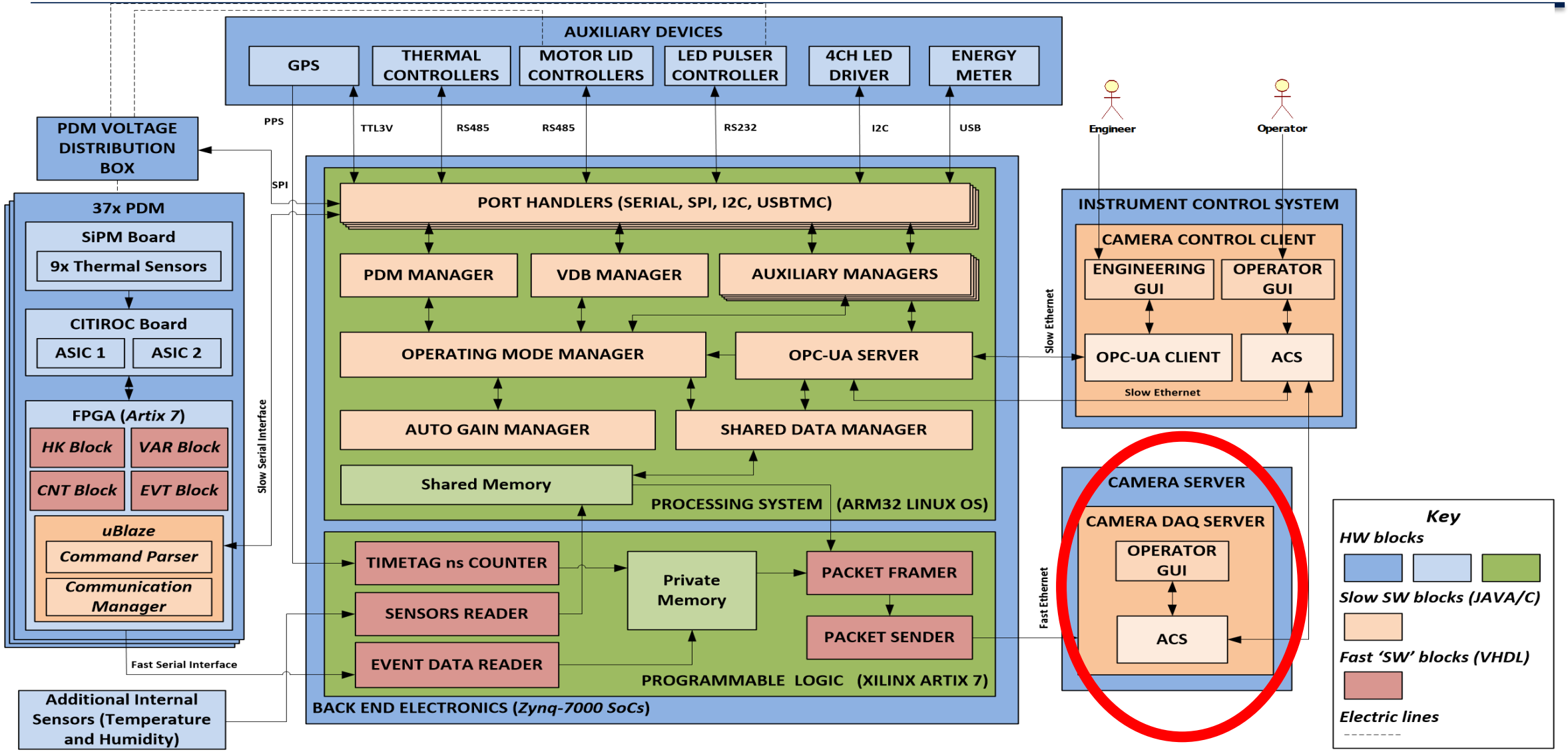
Camera Logical View



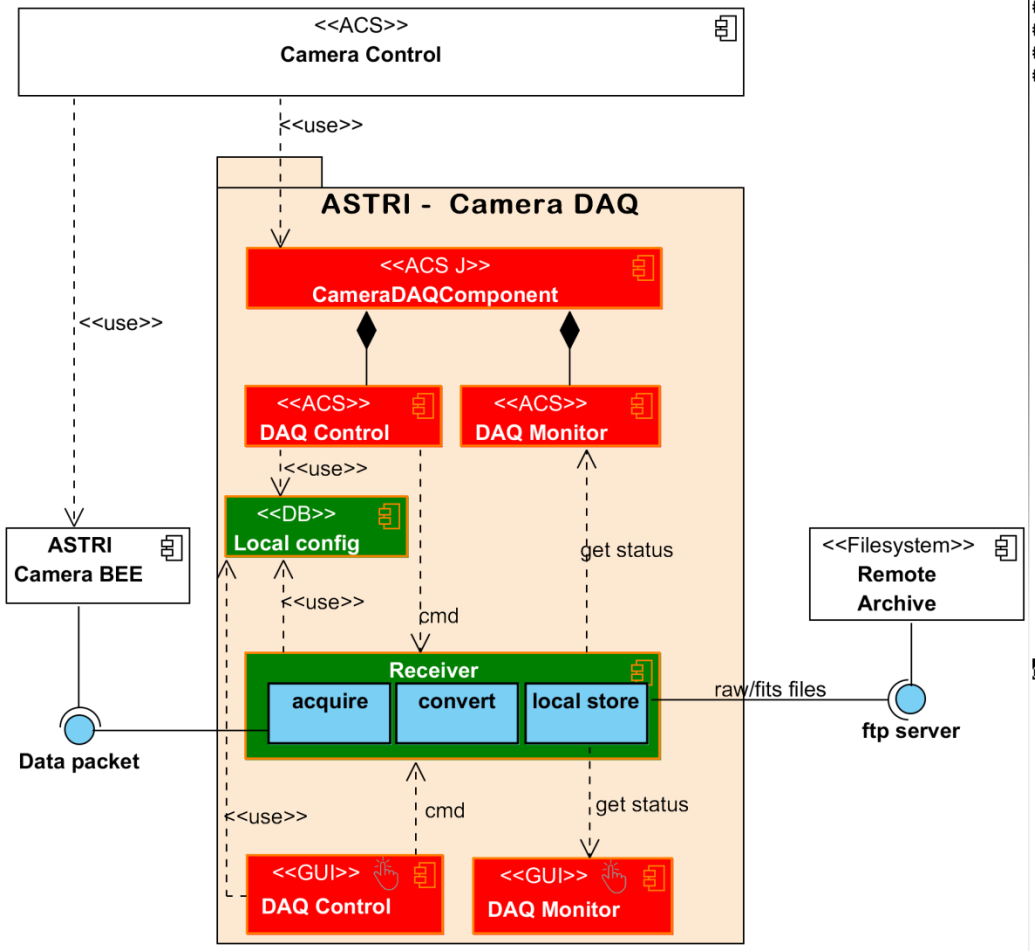
Camera Architecture

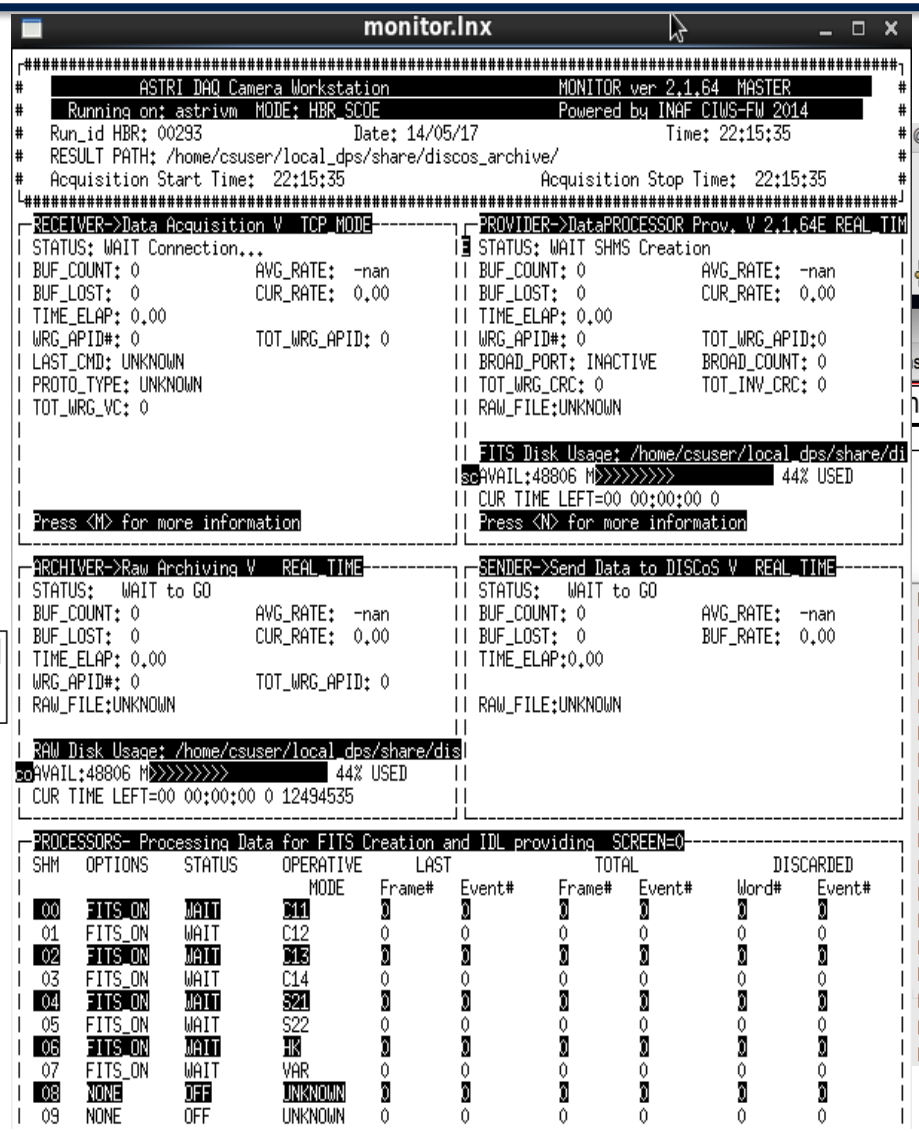


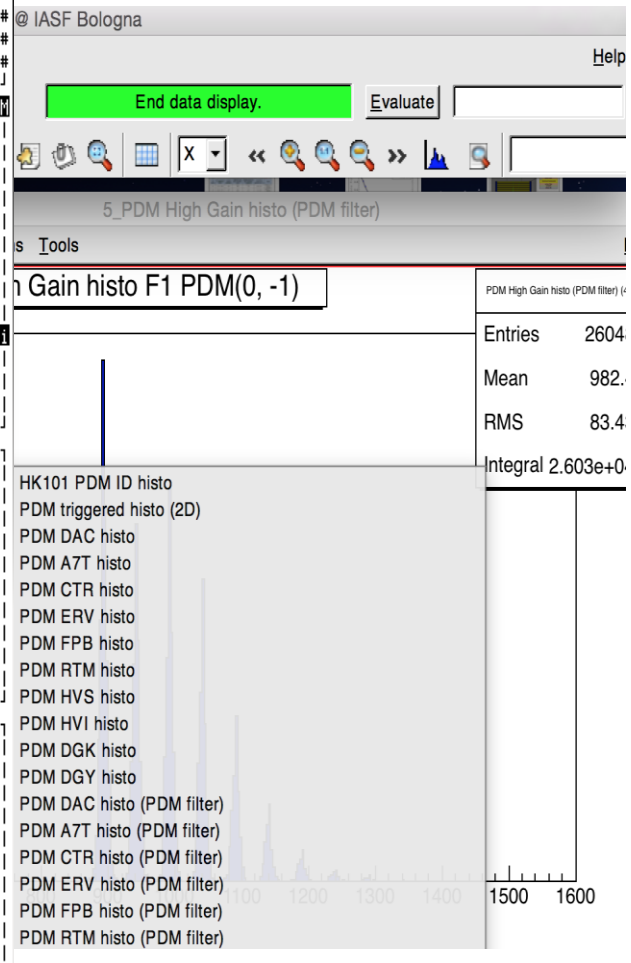
Camera Architecture



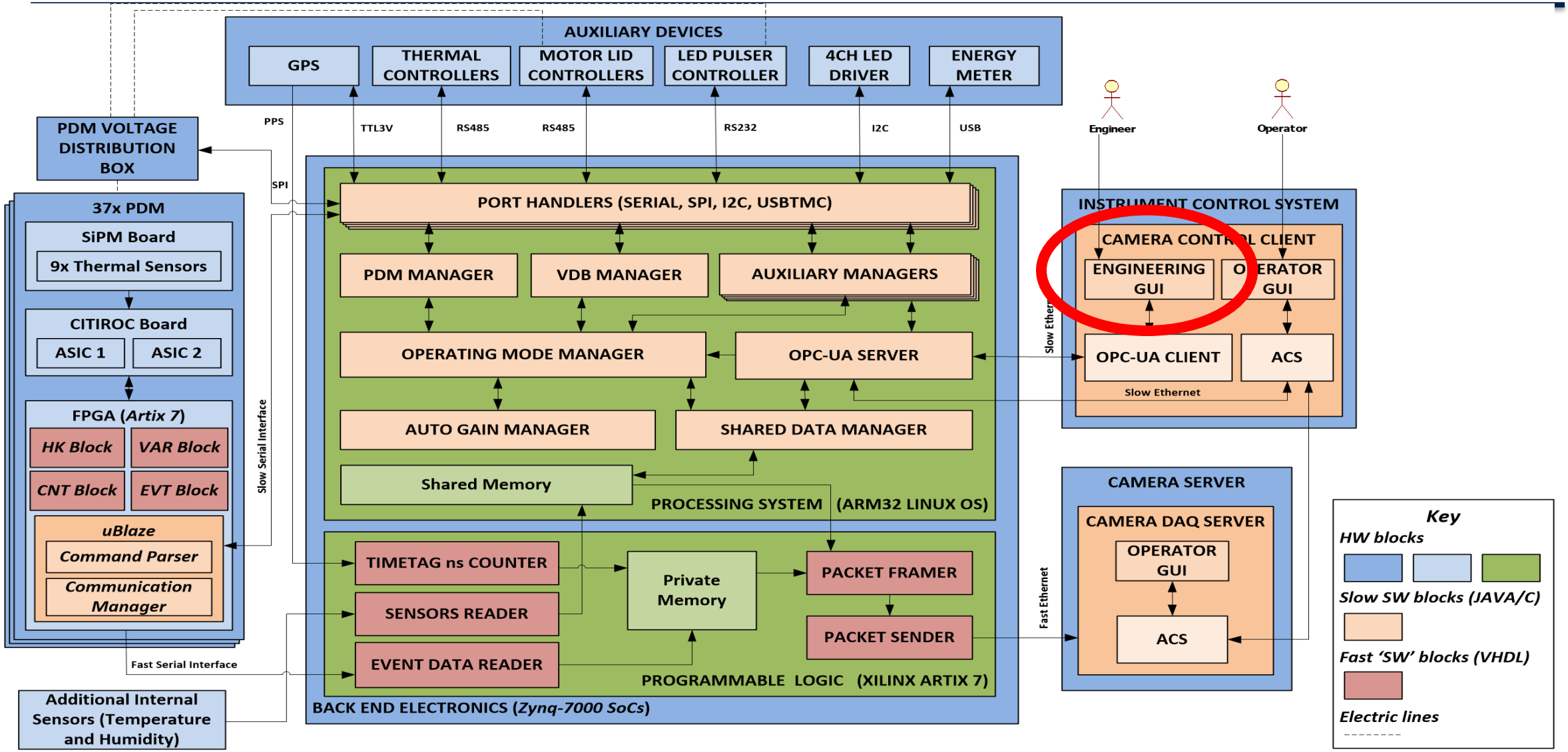
Camera Data Acquisition System



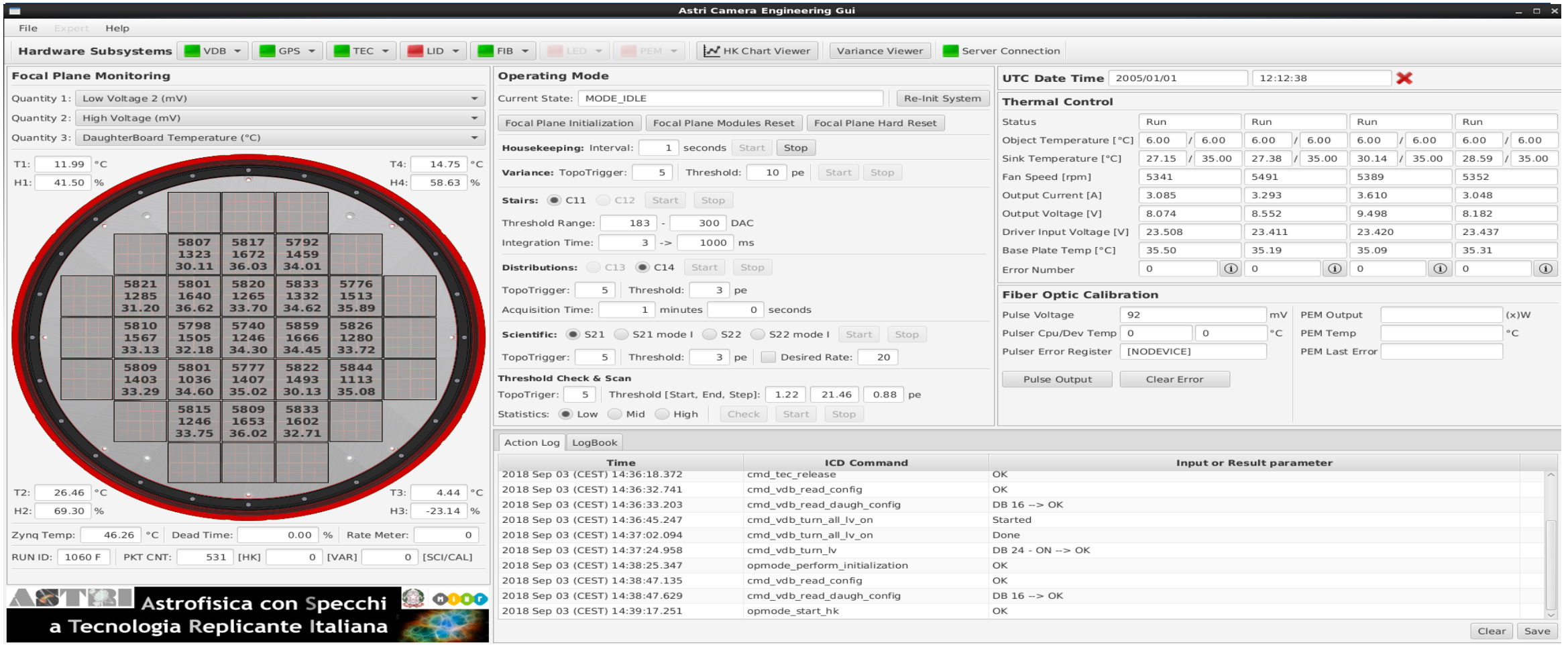




Camera Architecture

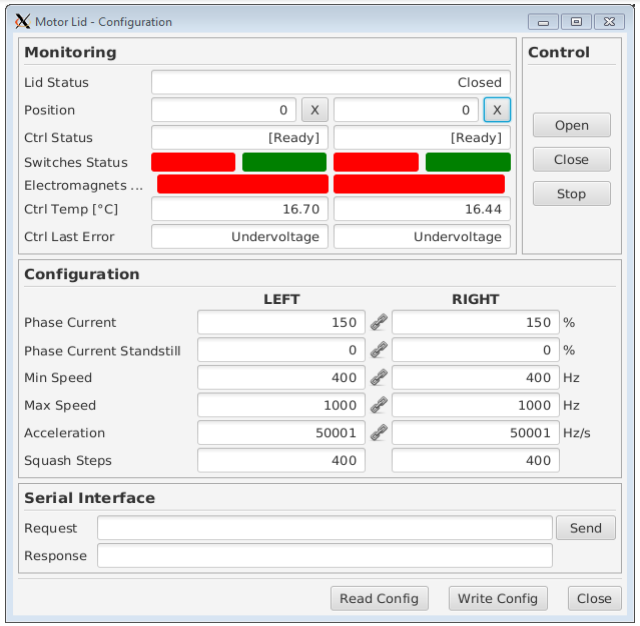


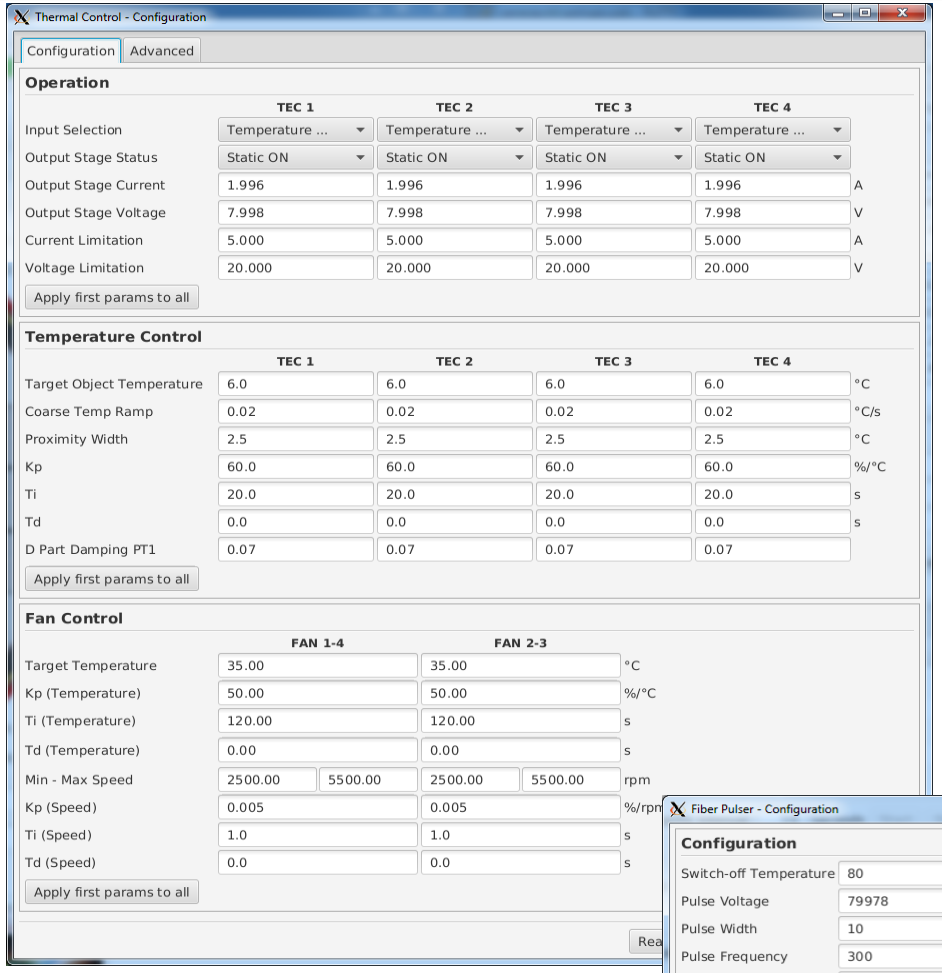
Camera Engineering GUI (Main)

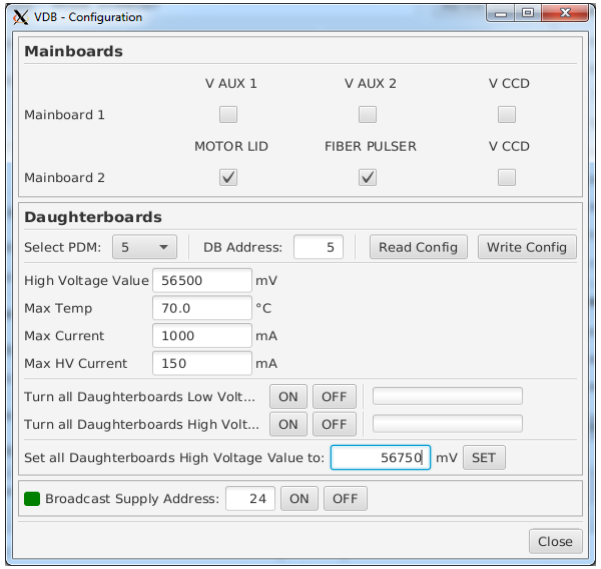


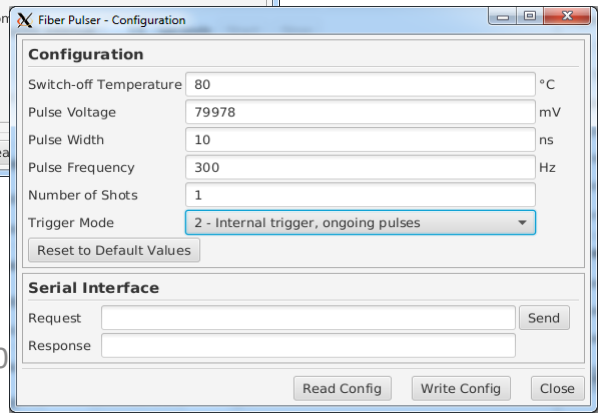
- Every high level commands (GET, SET, CMD) must be accessible from the Engineering GUI
- Lots of controls and information for expert users, but must be user friendly
- One single Main GUI with information and commands frequently useful

Camera Eng. GUI (Devices Configuration)



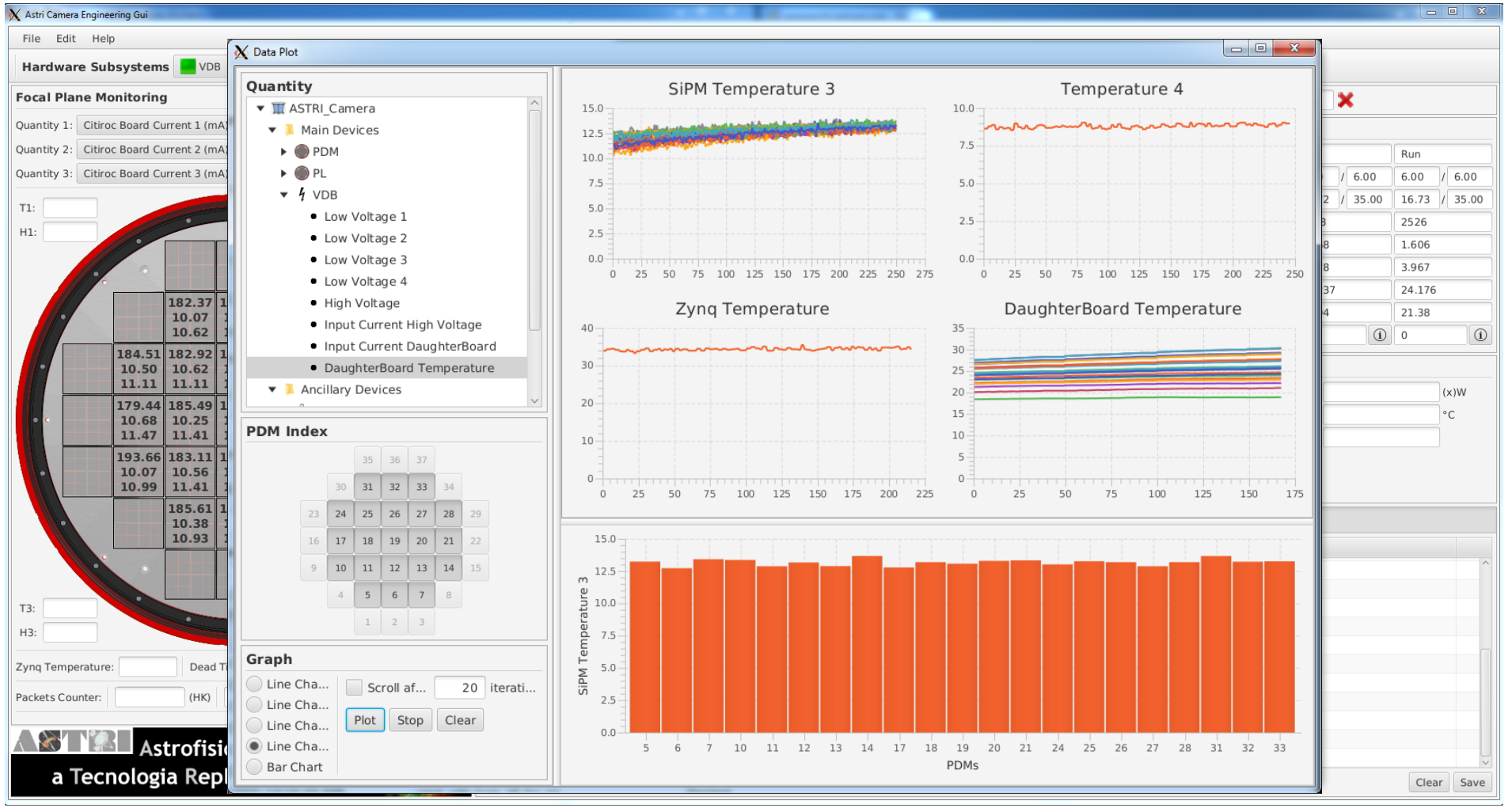






Camera Engineering GUI (HK Viewer)

A dedicated window shows in real-time all the HK information in different graph types



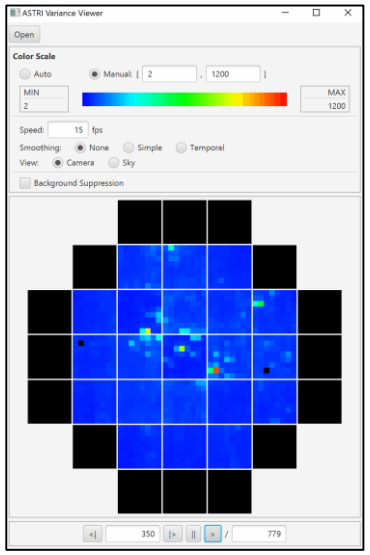
Camera Eng. GUI (Variance Viewer)

Integrated real-time viewer of Variance data (that measures the fluctuation of the signal acquired by the SiPM)

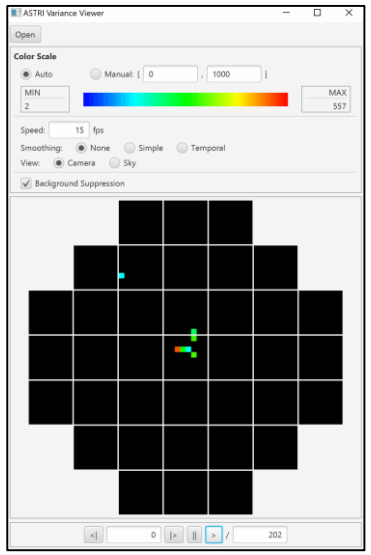
Allow us to evaluate:

- Effective Pointing of the telescope
- Presence of clouds
- Mirror alignment
- Electronics Health Status

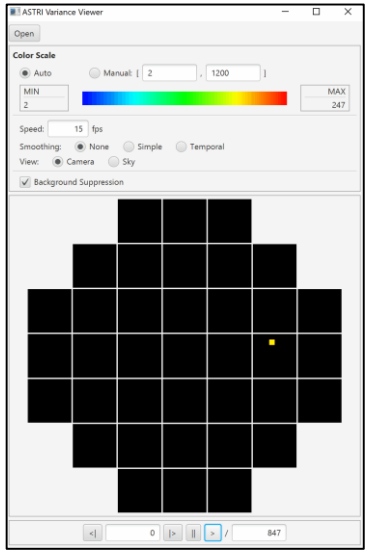
Example animations (15 fps) created using three different pointing:



a) Orion's Belt



b) Capella *(bg suppression)*

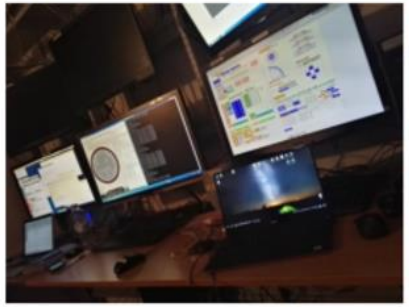


c) Fixed point at Az, El *(bg suppression)*

Detection of the Crab Nebula!

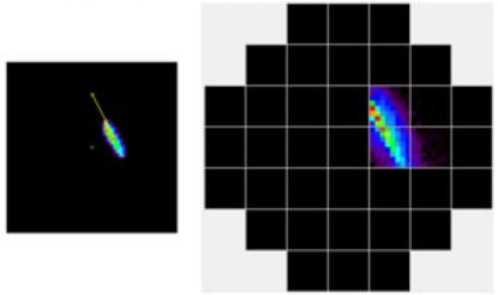
We started the engineering test at the astronomical site of Serra La Nave (Mount Etna) in Sicily…






…spending cold nights around bugs and lots of hard work, pizza and beer

25 and 26 May 2017: the ASTRI camera recorded its first ever Cherenkov light…



So… it works!

ASTRI-Horn

...Questions?