The readout and control system of the mid-size telescope prototype of the Cherenkov Telescope Array

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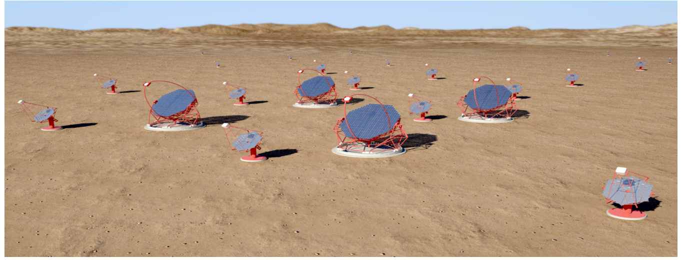
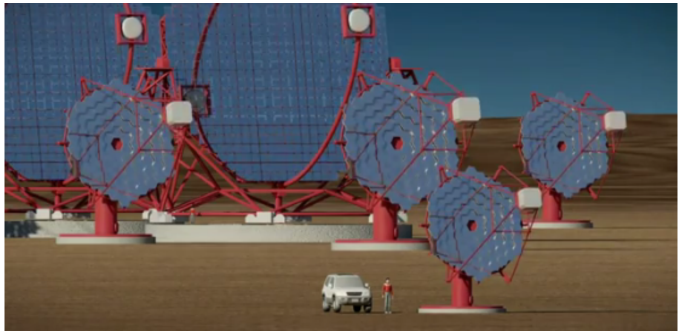
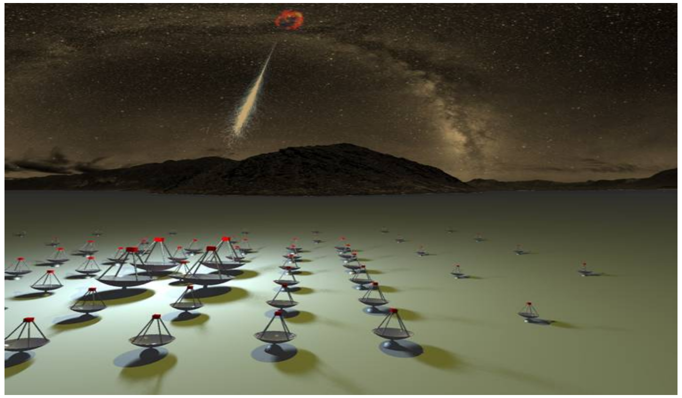
On behalf of the CTA consortium

Cherenkov Telescope Array (CTA)

- Next generation VHE gamma-ray observatory
- Northern and Southern arrays for full-sky coverage
- Energy range → 10's of GeV to above 100 TeV
- Several types of Cherenkov Telescopes will provide:
  - Better Sensitivity
  - Better Energy Range
  - Better Angular Resolution
- The main science goals of the CTA project:
  - Understanding the origin of cosmic rays and their role in the Universe
  - Understanding the nature and variety of particle acceleration around black holes
  - Searching for the ultimate nature of matter and physics beyond the Standard Model

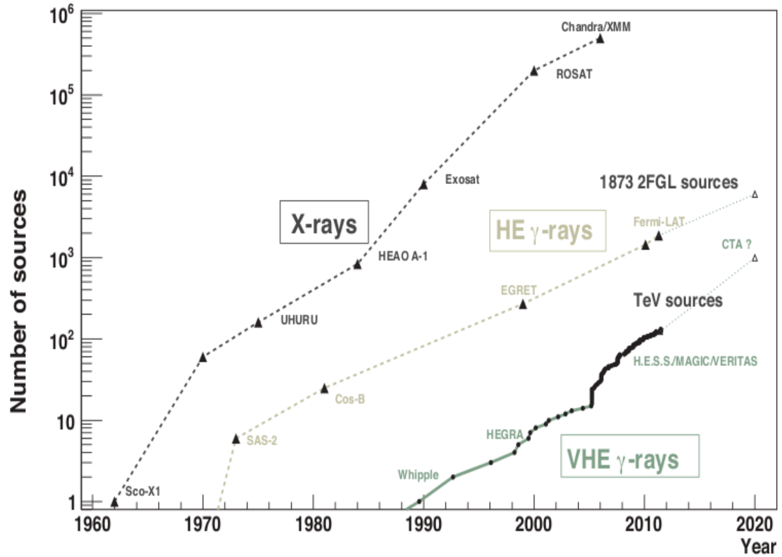


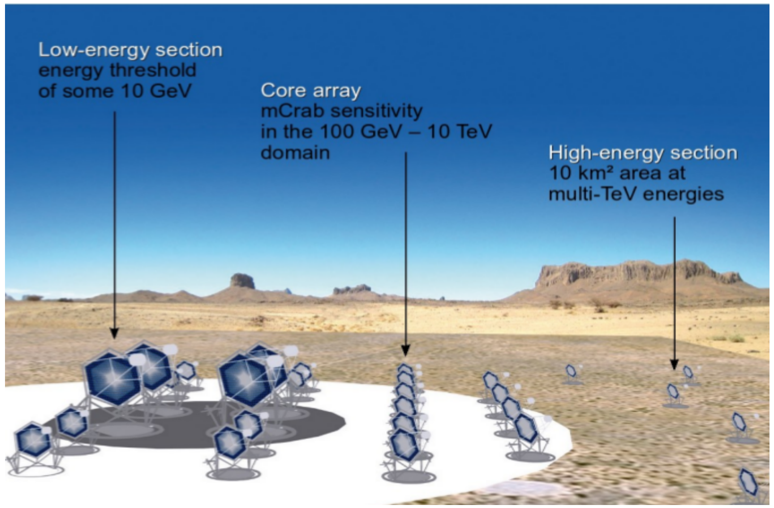




Cherenkov Telescope Array (CTA)

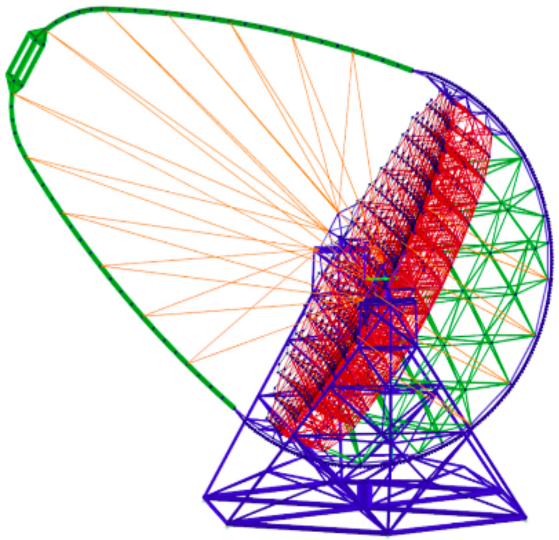
- CTA will be the most sensitive array operating in VHE (E > 10 GeV) domain
- Number of detected VHE source will be greatly increased
- Enhanced angular resolution will allow detailed morphology studies
- CTA will detect weak sources within minutes, rather than hours.
- (Northern and Southern Array) - Total cost ~200M€

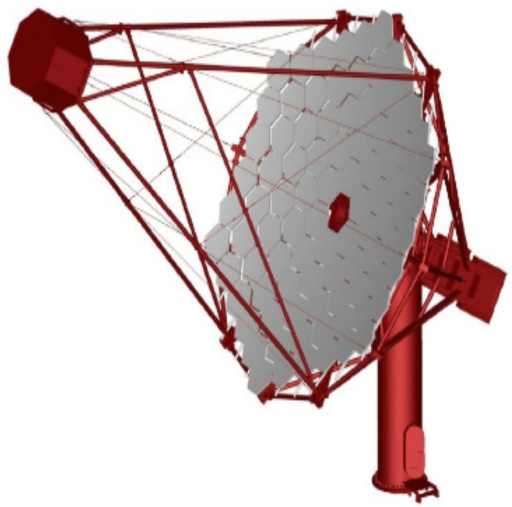


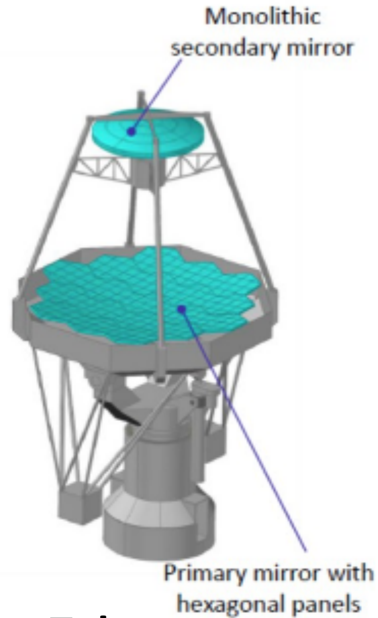


CTA telescope types

- Highly sensitive within a wide energy range (10's of GeV to >100 TeV)







Large Size Telescope (LST)

- 23 m diameter
- E < 100 GeV
- Parabolic Mirror
- ~4 Telescopes
- 5° Field of View (FoV)
- Improved photon collection

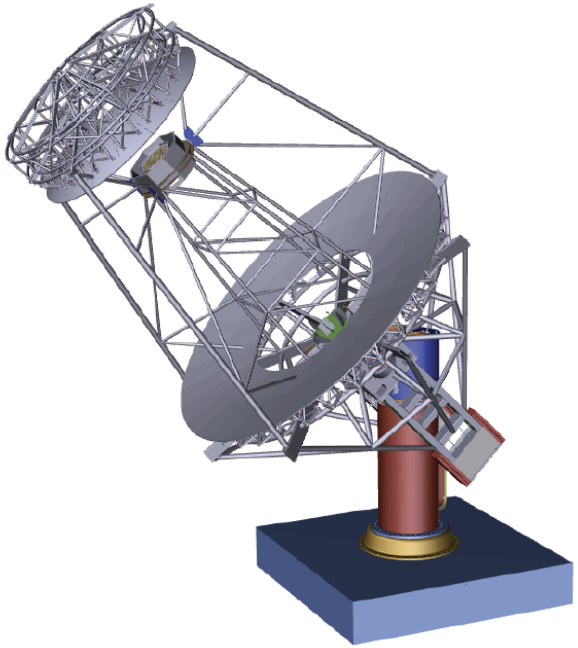
Mid Size Telescope (MST)

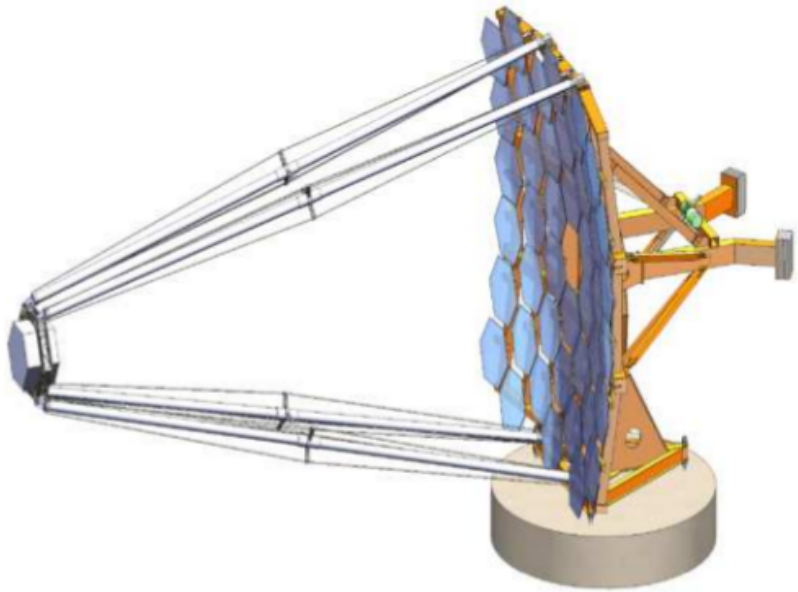
- 12 m diameter
- 100 GeV < E < 10 TeV (The Core Energy Range)
- Davies-Cotton design
- ~25 Telescopes
- 7 - 8° FoV
- Improved Gamma / hadron separation

Small Size Telescope (SST)

- 4-7 m diameter
- >10 TeV
- Schwarzschild-Couder
- ~30 Telescopes
- 10° FoV
- Improved effective area
- Southern site only

CTA telescopes, further Designs





MST

- CTA-USA Design (AGIS*)
- Schwarzschild-Couder
- 9.7 m diameter (primary mirror)
- 8° FoV
- 20-30 telescopes

*Advanced Gamma-ray Imaging System

SST

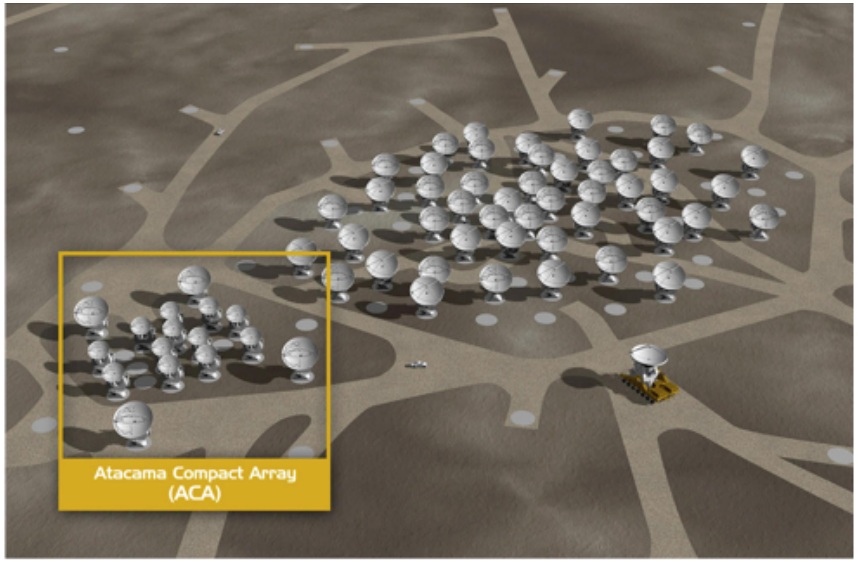
- Davies-Cotton Design
- Large FoV needs relatively larger camera
- Costs more
- Less complex design

The Array control challenge

- CTA will be an open astronomical observatory:
  - Announcements of opportunities
  - Proposal-driven operation
  - Professional operators
- Diverse operation modes:
  - Pointed observations
  - Scans
  - Sub-Arrays
  - Targets of opportunity
  - Multi-wavelength campaigns
  - Alerts from/to other observatories
- Pseudo real-time analysis

- Select and time-tag stereoscopic showers at high efficiency while suppressing background.
- Read-out and store all the information needed for offline reconstruction.
- Support diverse operation modes
- Ensure optimal use of available observation time
- Handle hardware and software failures in a flexible and smart way

CTA array control approach



- Attempt to re-use the experience from current-generation experiments
- Use commodity hardware for processing, networking, and triggering whenever possible
- Promote software standard for the communication of subsystems
- Use a well-defined software framework for all processes in the distributed ACTL system
- Re-use developments made for observatories with similar requirements – in particular for ALMA
- Ensure seamless integration of offline reconstruction code

Software technologies for CTA

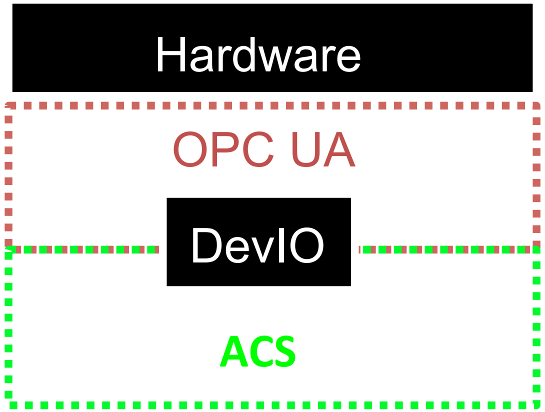
ACS: ALMA Common Software

- Framework for distributed applications used for the control of the ALMA array, one of the largest astronomical projects, similar in many aspects to CTA
- C++, Java and Python implementations
- Framework for a distributed system
- Environment for implementing CORBA applications
- Uses Container/Component Model

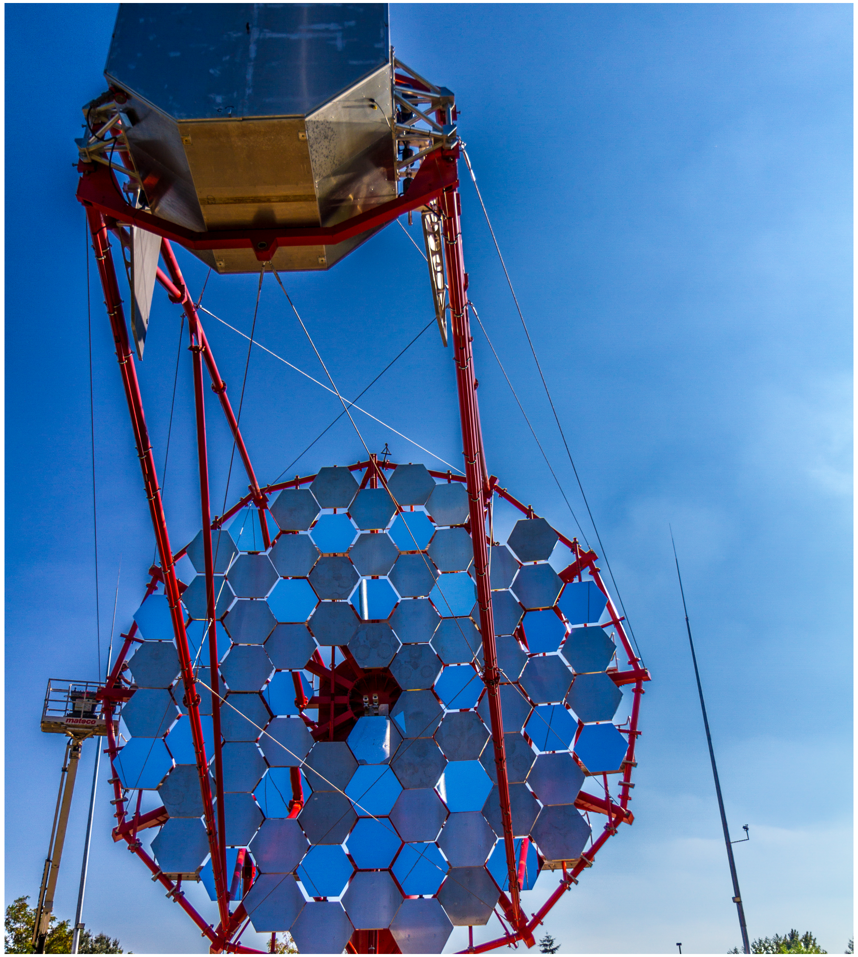
OPC UA: OPC Unified Architecture

- Open Platform Communications specification from the OPC Foundation
- A cross-platform service-oriented architecture for process control
- Multi-platform implementation, including portable ANSI C, C++, C#, Java and .NET implementations
- High scalability: from smart sensors and actuators to mainframes and servers on embedded systems

DevIO: *is an ACS simple and generic abstraction of hardware monitor and control point, based on the Bridge design pattern.*



The MST prototype: characteristics



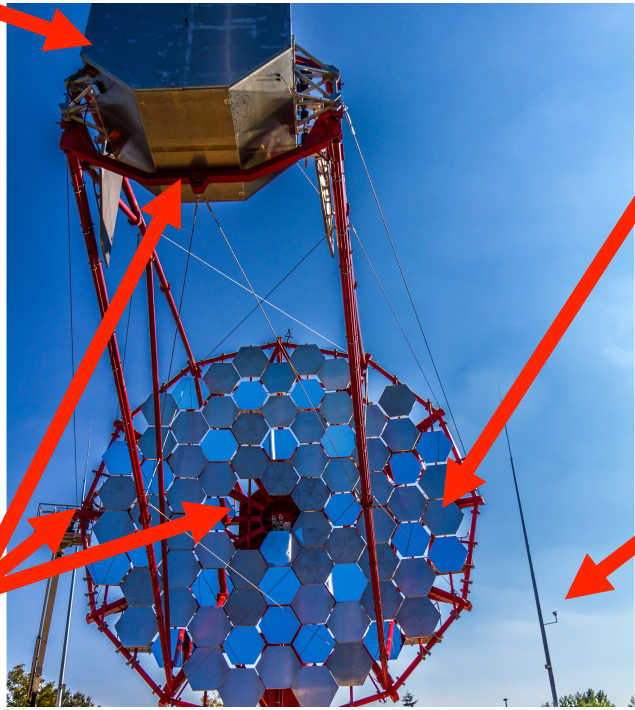
- Located at Berlin-Adlershof
- *Davies-Cotton* design
- Effective mirror area: ~ 100 m2
- Dish diameter D=12m
- Focal length F=16m (>1.3xD)
- Dish curvature radius=19.2m (=1.2×F)
- Camera FoV 8°
- Hexagonal mirrors, 1.2m, 35 kg/m2
- Slewing speed: Rotate to any point in the sky above 30° in elevation≤90 s
- Optical PSF (80% containment diameter) ≤ 1 pixel diameter out to 80% of the camera radius
- Post-calibration pointing precision ≤ 7 arcsec rms in space (5" in elevation and 5"/ sin(elevation) in azimuth)
- Lifetime expectancy (bearings and structure) ~ 30 years
- Control software based on ACS and OPC UA

The MST prototype instrumentation

Camera dummy
OPC UA server
Java ACS component

<u>Drive System</u>
PLC with **OPC UA** server
Java ACS component

<u>5 CCD units</u>
OPC UA server
Java ACS component
Video display application
Document oriented database



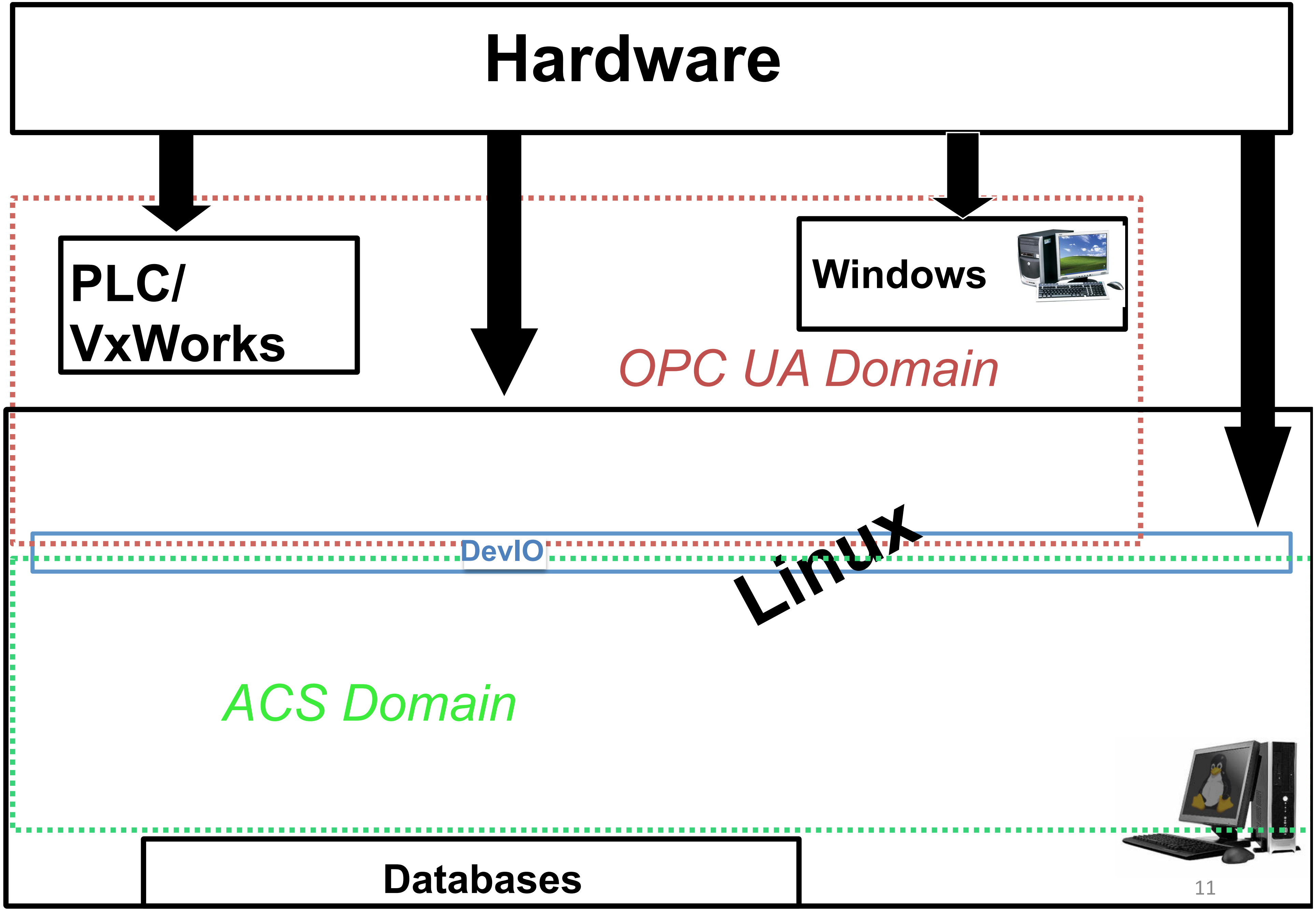
<u>Active mirror control</u>
Different designs:
- Xbee wireless
- CAN-bus

ACS components, common interface

<u>Weather station</u>
OPC UA server
Java ACS component

<u>Telescope Control server</u>
Dell PowerEdgeR720xd
2 CPUs (12 CPU cores)
128GB main memory
6TB local disk space.
Scientific Linux 6.4

MST array control, general view



The CCD Cameras (I)

Devices

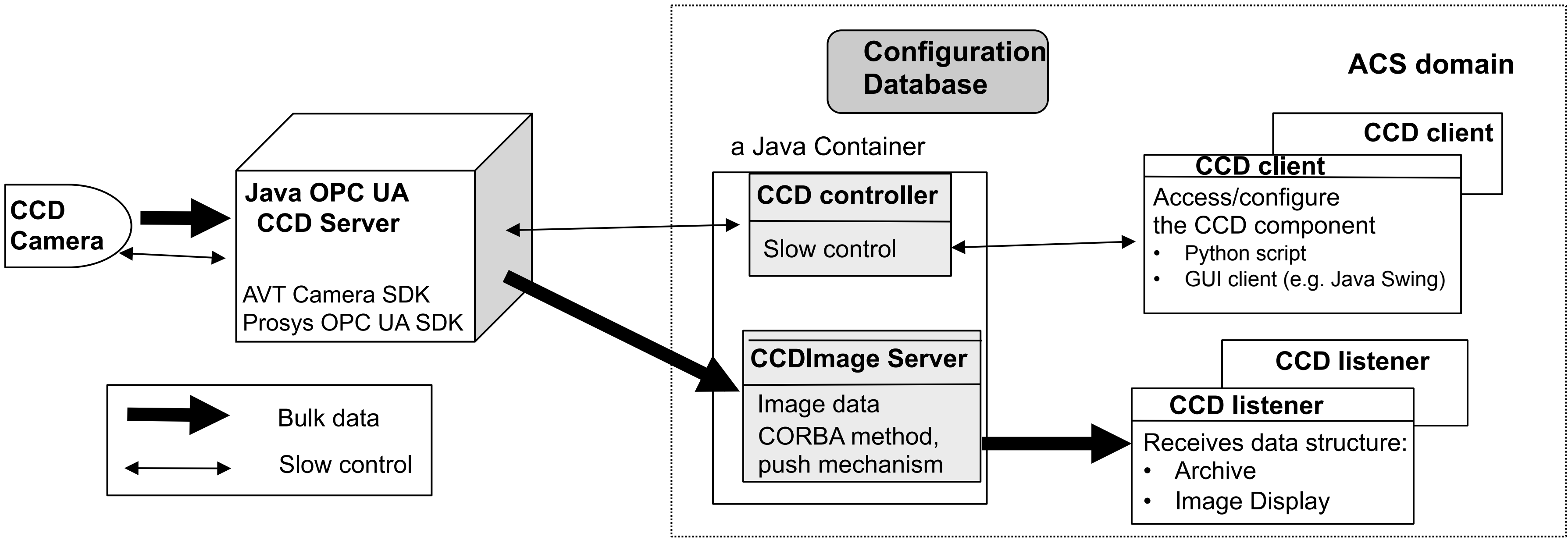
- AVT Prosilica GC1350
- Sony ICX205 ½" Progressive scan CCD
- Maximum 1360 x 1024 Pixels
- Pixel size =4.65 µm
- 8/12 bit depth
- Maximum rate 20 Hz
- Interface: GigE Vision (IEEE 802.3, up to 1000 Mbit/s on 1000BASE-T)

CCD Control software requirements

- 5 CCDs, several or all must operate concurrently. (3 already installed)
- Some of them acquire data at a rate of 10 Hz
- Images need to be correlated with other device measurements (weather station, drive, non optical sensors)

The CCD Cameras (II)

- OPC UA server provides the camera information model (Data&State Model + Basic functions), uses the SDKs from the CCD camera manufacturer for hardware accessing
- Using the Java DevIO and Prosys Java SDKs for OPC UA and ACS communication.
- Image data transferred (push) by a CORBA method call on one or more "listeners" (ACS components or CORBA objects): Idea to test several other data transfer technologies
- Images inserted in the GridFS and linked into the MongoDB together with meta-data

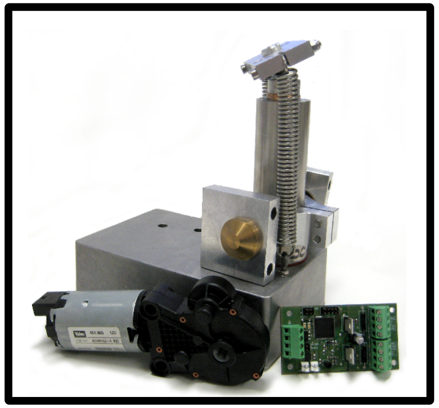


The drive system

- From Bosch-Rexroth
- Composed, at a lower level, of the control of 6 drives (2 for azimuth and 4 for elevation)
- Communicating via a Bosch-Rexrot programmable logic controller (PLC) → Native OPC UA server inside the firmware can be directly accessed via the OPC UA DevIO mechanism
- Pointing to any position and to track any astronomical object.
- Control component implemented as a Java ACS component

The AMC system (I)

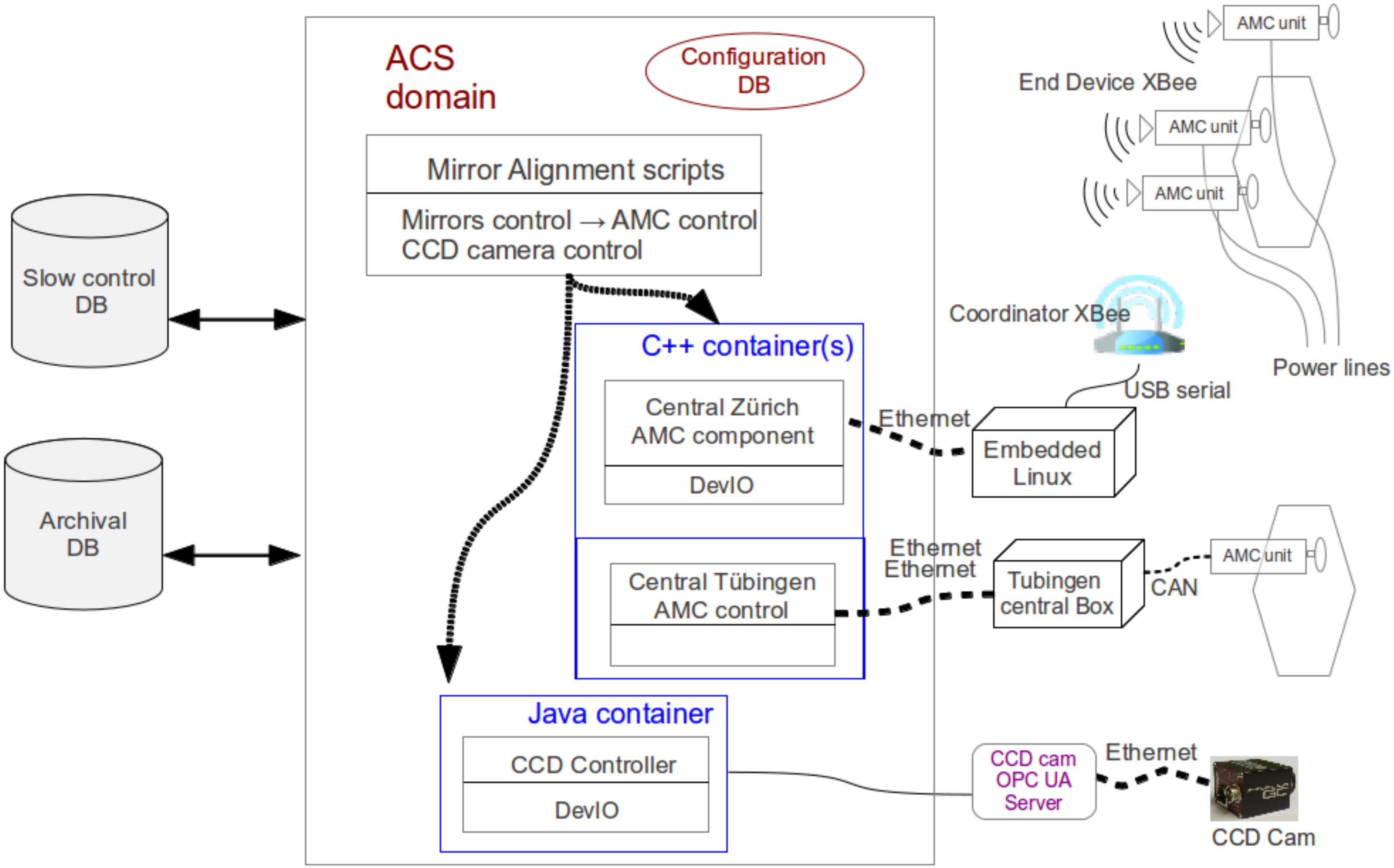
- Use of a tessellated reflector composed of individual mirrors
- Each individual mirror facet is moved by an AMC unit which allows perfect mirror alignment.
- This allows online and off-line re-alignments .
- The dish of the MST prototype is covered by a combination of real and dummy mirrors.
- AMC units of two different designs installed.
  - Zurich: XBee WPAN
  - Tübingen: Can-BUS + Ethernet gateway



Tübingen Actuators

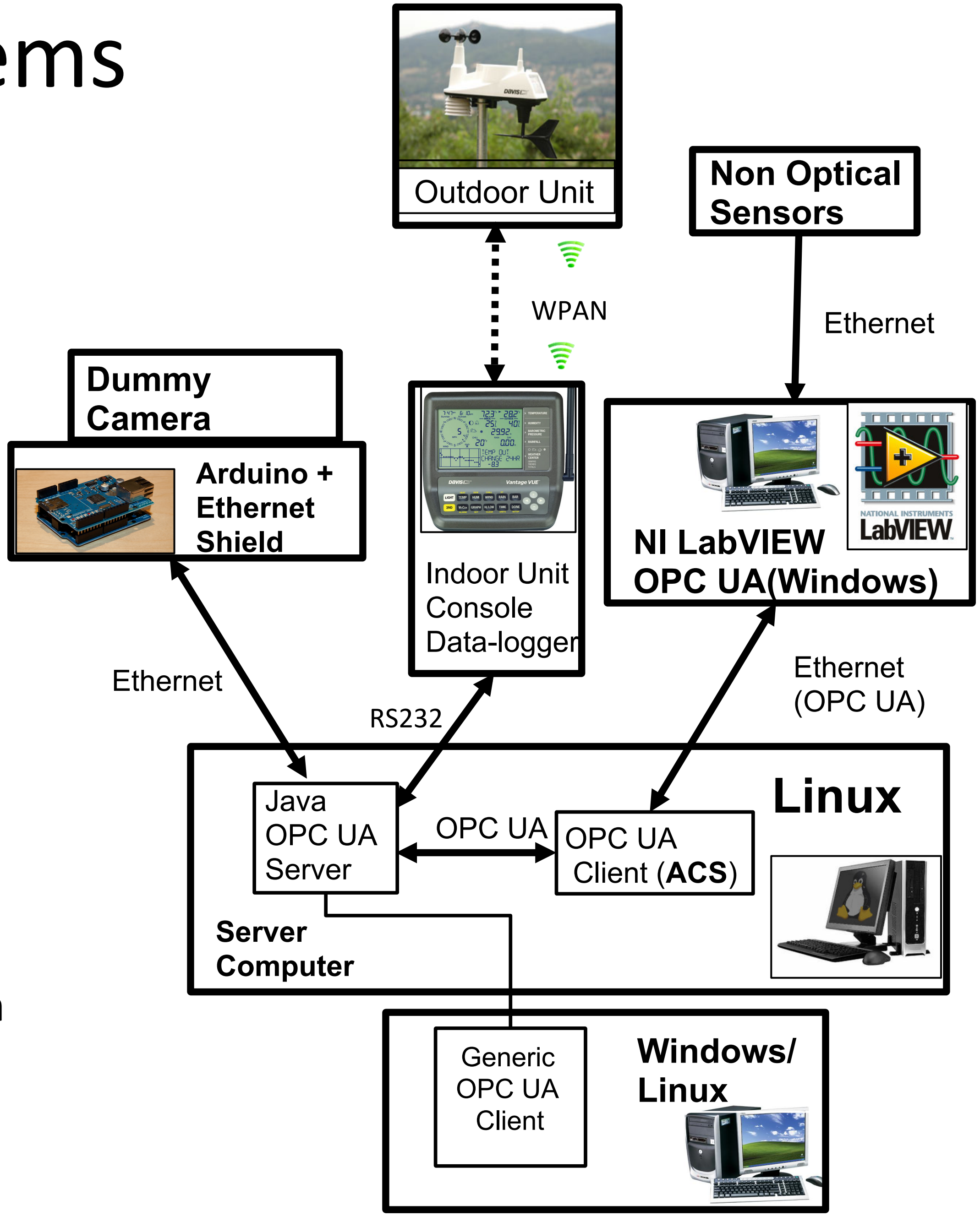
Zurich Actuators

The AMC system (II)



Other systems

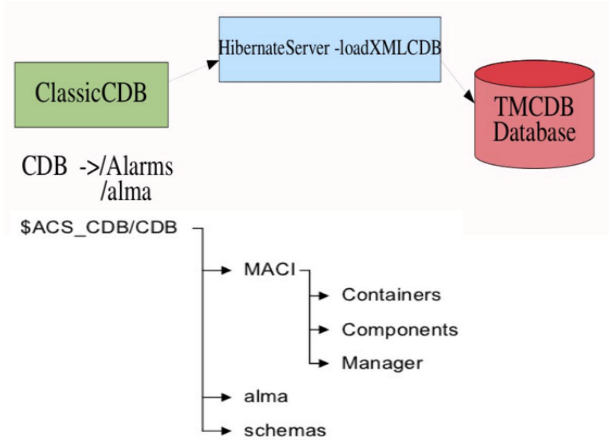
- Weather station
  - Java OPC UA server
  - Java ACS component
  - Running at 24/7 since 3 months
- 'Dummy Camera'
  - Contains sensors, LEDs, and Camera Lids
  - Uses an Arduino controller, Java OPC UA Server and ACS component
- Extra sensors
  - NI Labview on Windows with emdedded OPC UA server



Data persistence and archives

Configuration database (CDB)

- Device configuration and default values
- Front End: ACS TMCDB
- Backend: MySQL

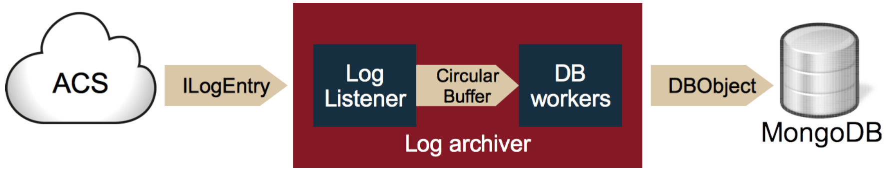


CCD Data storage

- Store the CCD images and headers in the same database
- Front-End: CCD camera readout
- Back-End: MongoDB, images in GridFS

Logging/alarms storage

- Front-End: ACD logging and alarm providers
- Backend: MongoBD



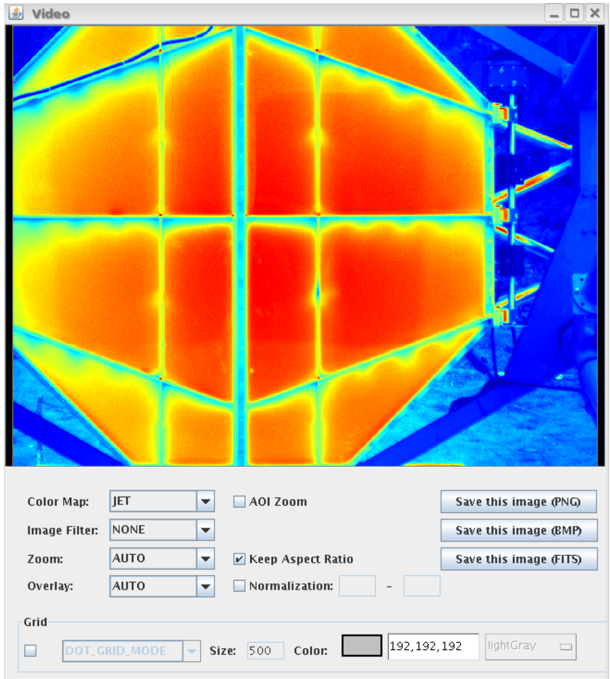
Monitoring storage:

"Property Recorder"

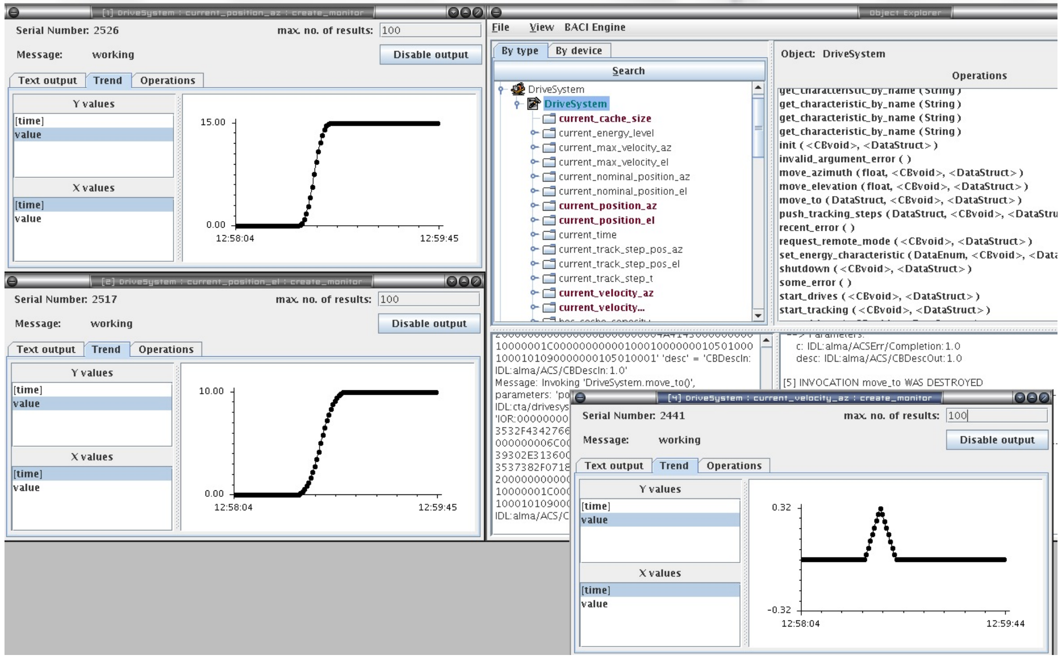
- Monitoring points in device properties
- Periodic and/or value change monitors
- Front-End: Python ACS applications
- Back-End: MongoDB and MySQL

First integrated operations

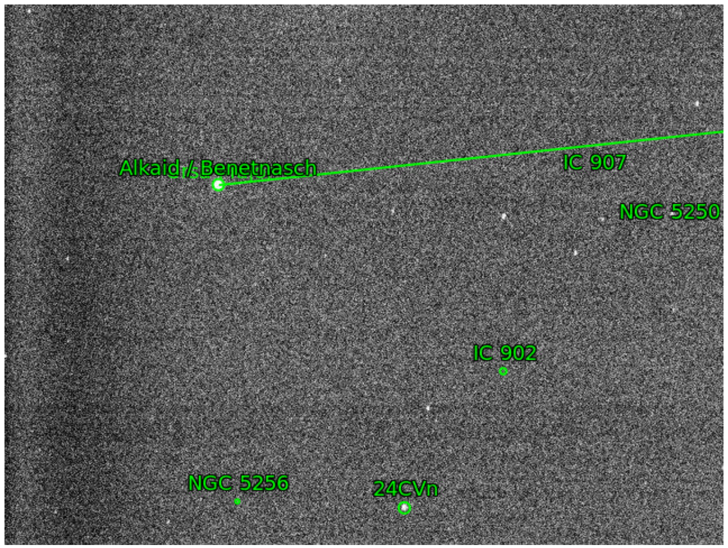
- Move system and display and record CCD images
- Track stars and acquire images with a CCD camera
- Store the images in the MongoDB/GridFS
- Read offline images from the DB and analyze



Lid CCD image display



Drive system control and monitoring GUIs



Identified stars from a CCD image

Conclusions and outlook

- A control and readout software for a telescope is being implemented using the ACS and OPC UA technologies → The CTA ACTL concept is being validated
- First operations have been successfully performed
- Higher level functionality under design and development:
  - Operator GUI
  - Interface to automatic scheduling tools. → Automatic execution of an observing program
  - Web browser based displays for system monitoring plots. *Django* and *Grails* under consideration
- CTA central array control under design → MST test bed