The Cherenkov Telescope Array Data Management Model

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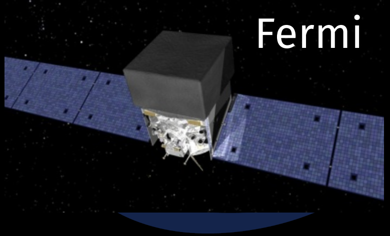
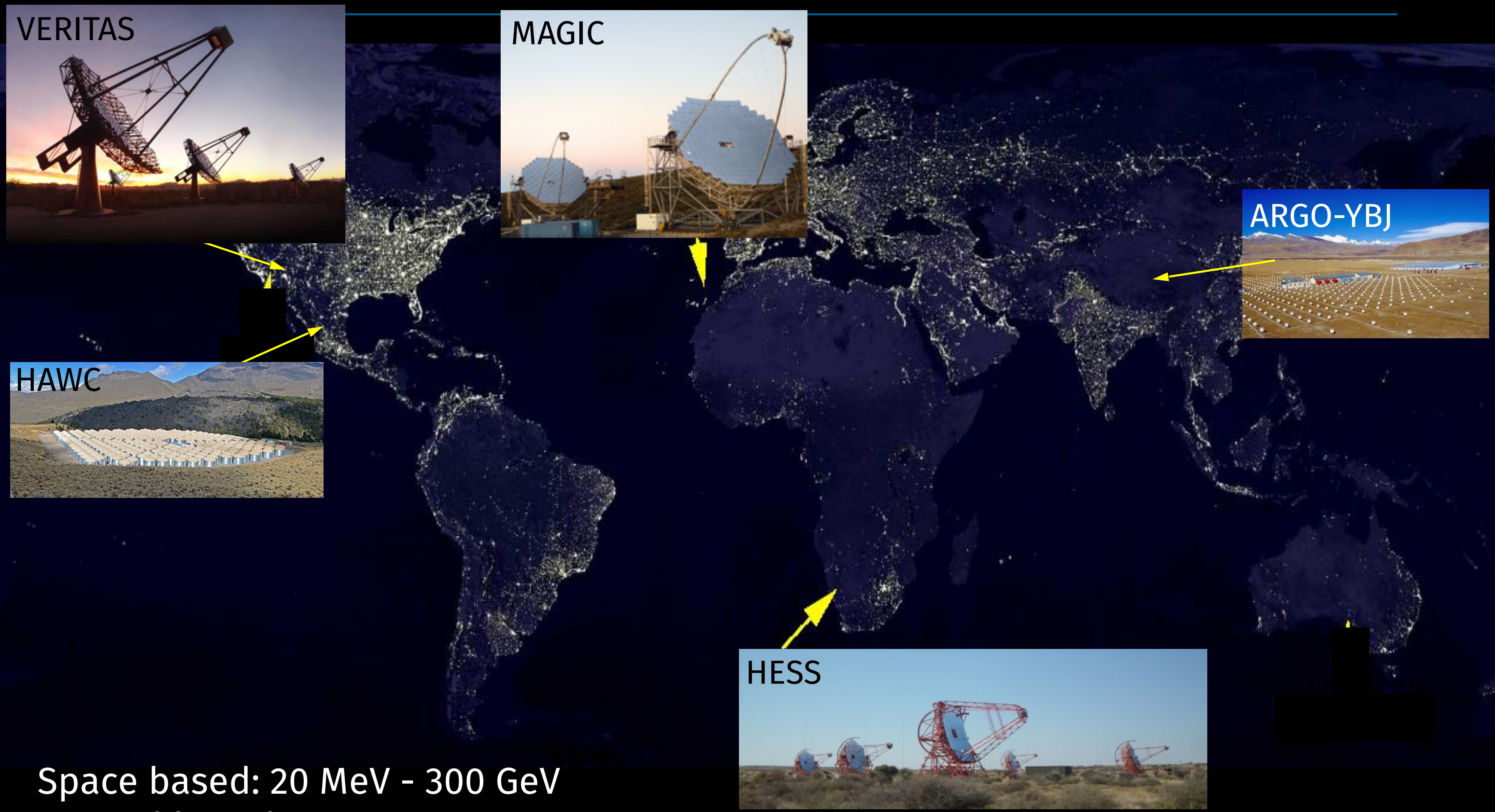
Computing Coordinator

Gamma-Ray Instruments

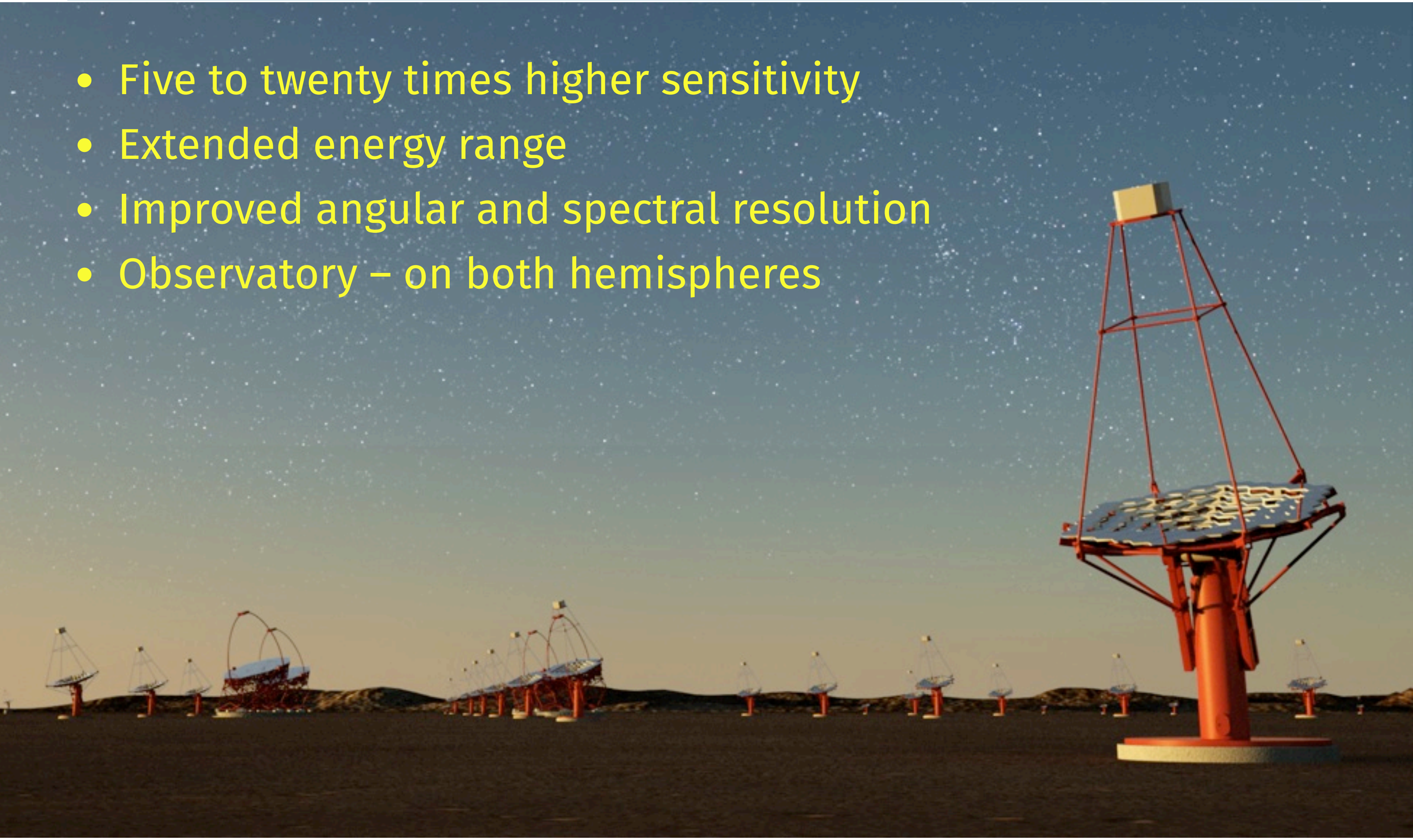




Space based: 20 MeV - 300 GeV
Ground based: 25 GeV - 1 PeV

Cherenkov Telescope Array
CTA Observatory

- Five to twenty times higher sensitivity
- Extended energy range
- Improved angular and spectral resolution
- Observatory – on both hemispheres



Top-Level Construction Time Line

- Hosting agreements HQ, North, South, SDMC signed
- European Research Infrastructure Consortium (ERIC) in formation
- Major reviews on hardware and software projects - and costs
- Phase 1 definition
- System definition
- CTA-North
  - Initial infrastructure work
  - First telescope prototype in commissioning
  - Prepare acceptance of telescopes
- CTA-South
  - Infrastructure planning
- Prepare system integration & commissioning
- Prepare science verification

The CTA Observatory

- Legal entity that will operate the instrument over 30 years
- Observation proposal collection
  - Guest observers, consortium, observatory users
- Responsible for science user support
  - Science tools (images, spectra, light curves, …)
  - High-level science data (events & technical data plus instrument response functions)
- Data will be public after predefined proprietary period
  - Archive will ensure data access
  - Open data formats
- Virtual Observatory compatibility
- Operates outreach gateway

Science Themes

Theme 1: Cosmic Particle Acceleration

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

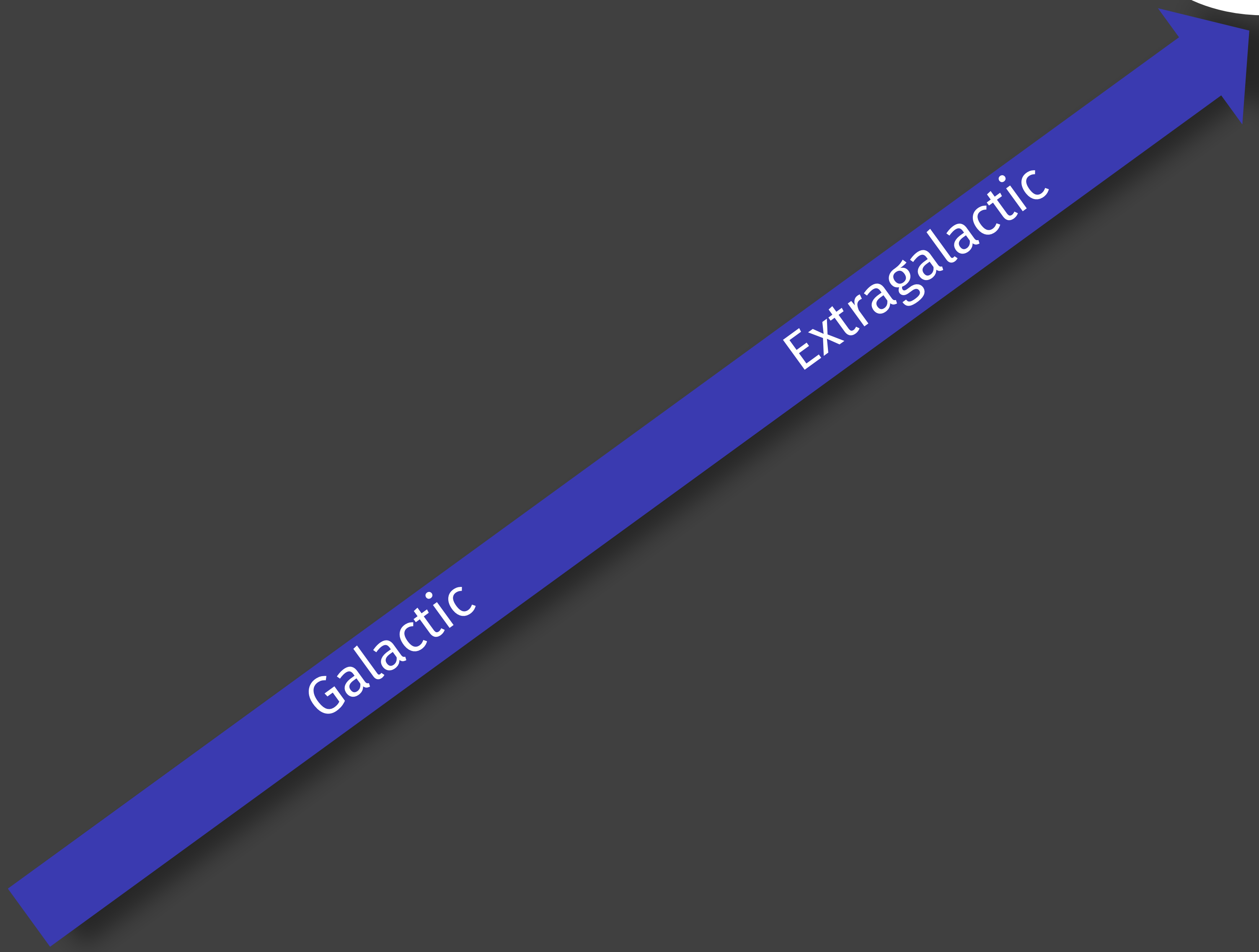
Theme 2: Probing Extreme Environments

- Processes close to neutron stars and black holes?
- Processes in relativistic jets, winds and explosions?
- Exploring cosmic voids

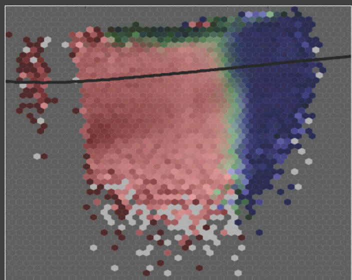
Theme 3: Physics Frontiers – beyond the SM

- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high energy photons?
- Do axion-like particles exist?

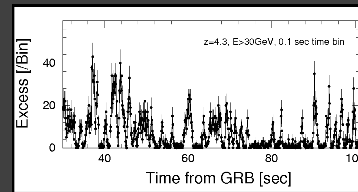
Key Science



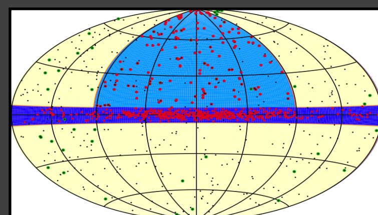
Key Science



Dark Matter Programme

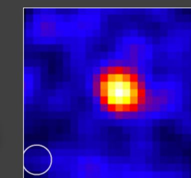


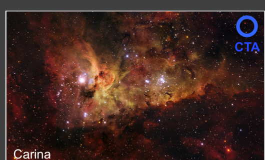
Transients



ExGal Survey

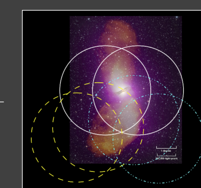
Galaxy Clusters



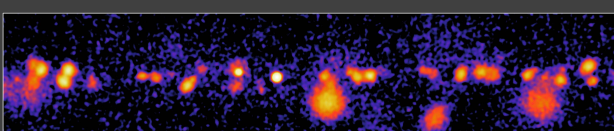


Star Forming Systems

AGN



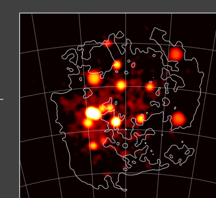
Extragalactic



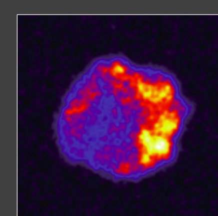
Galactic Plane Survey

Galactic

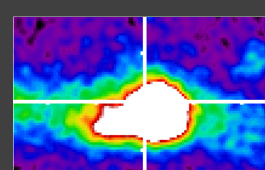
LMC Survey



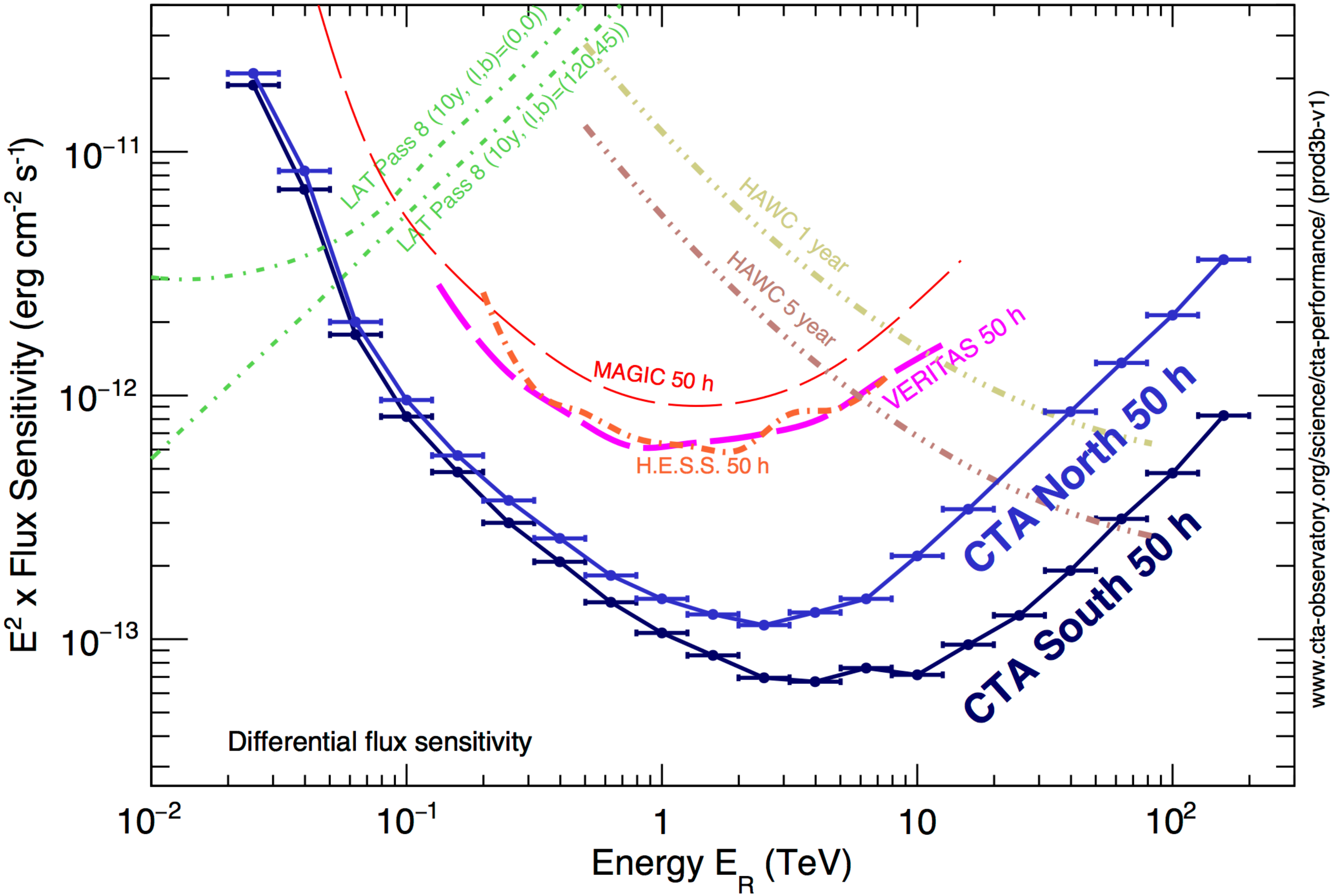
PeVatrons



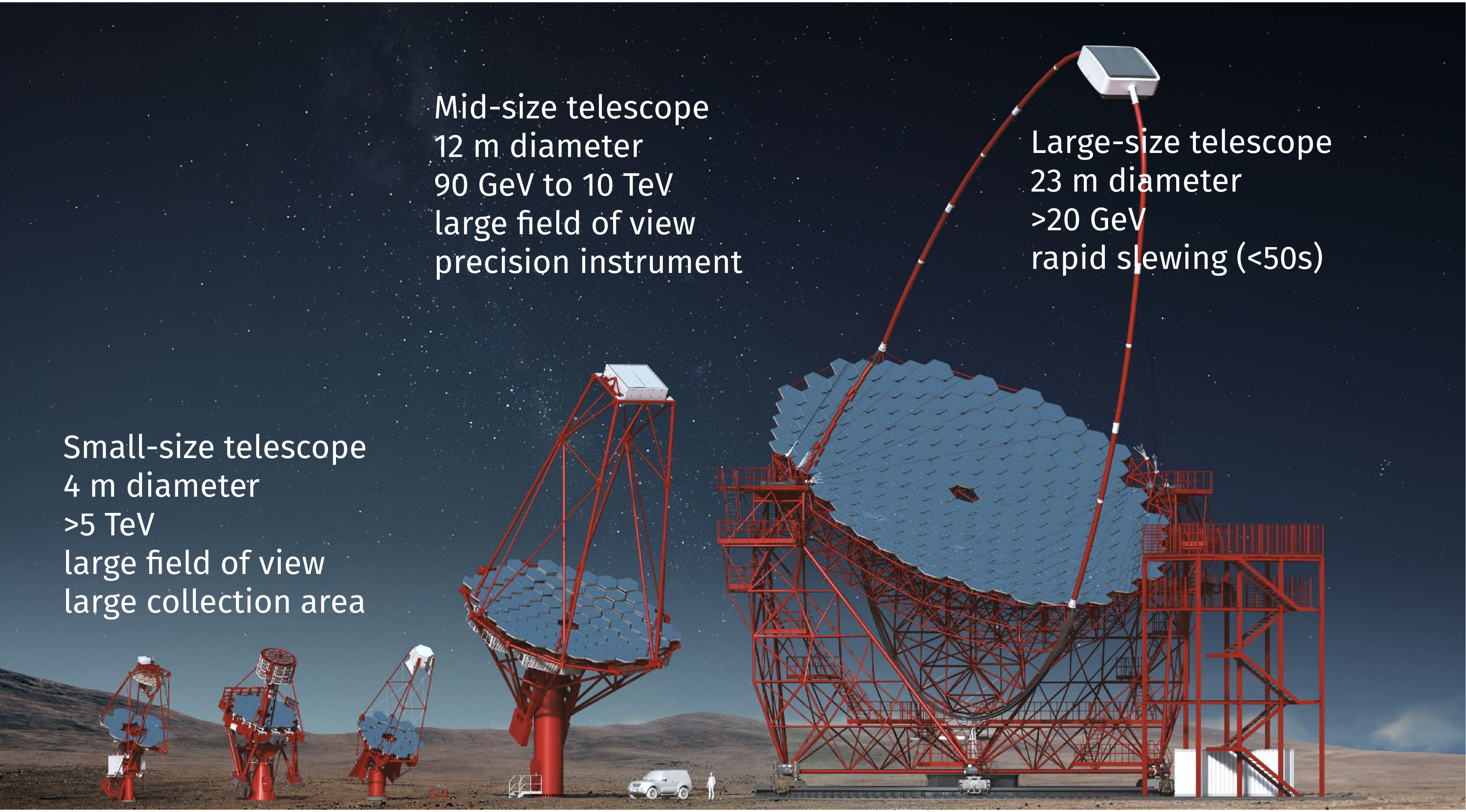
Galactic Centre Survey



Sensitivity

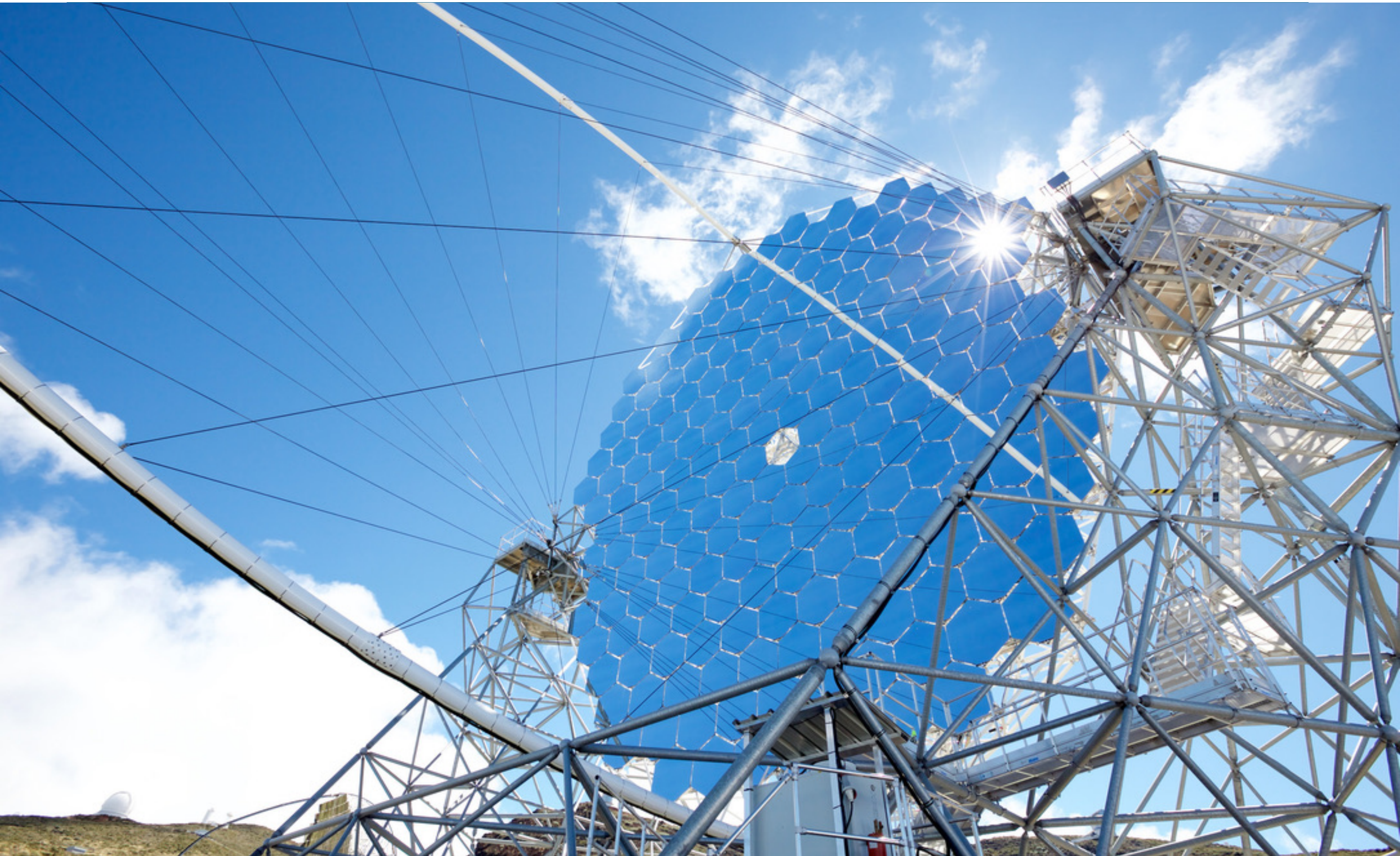


Two Array of Telescopes
In Chile and Spain



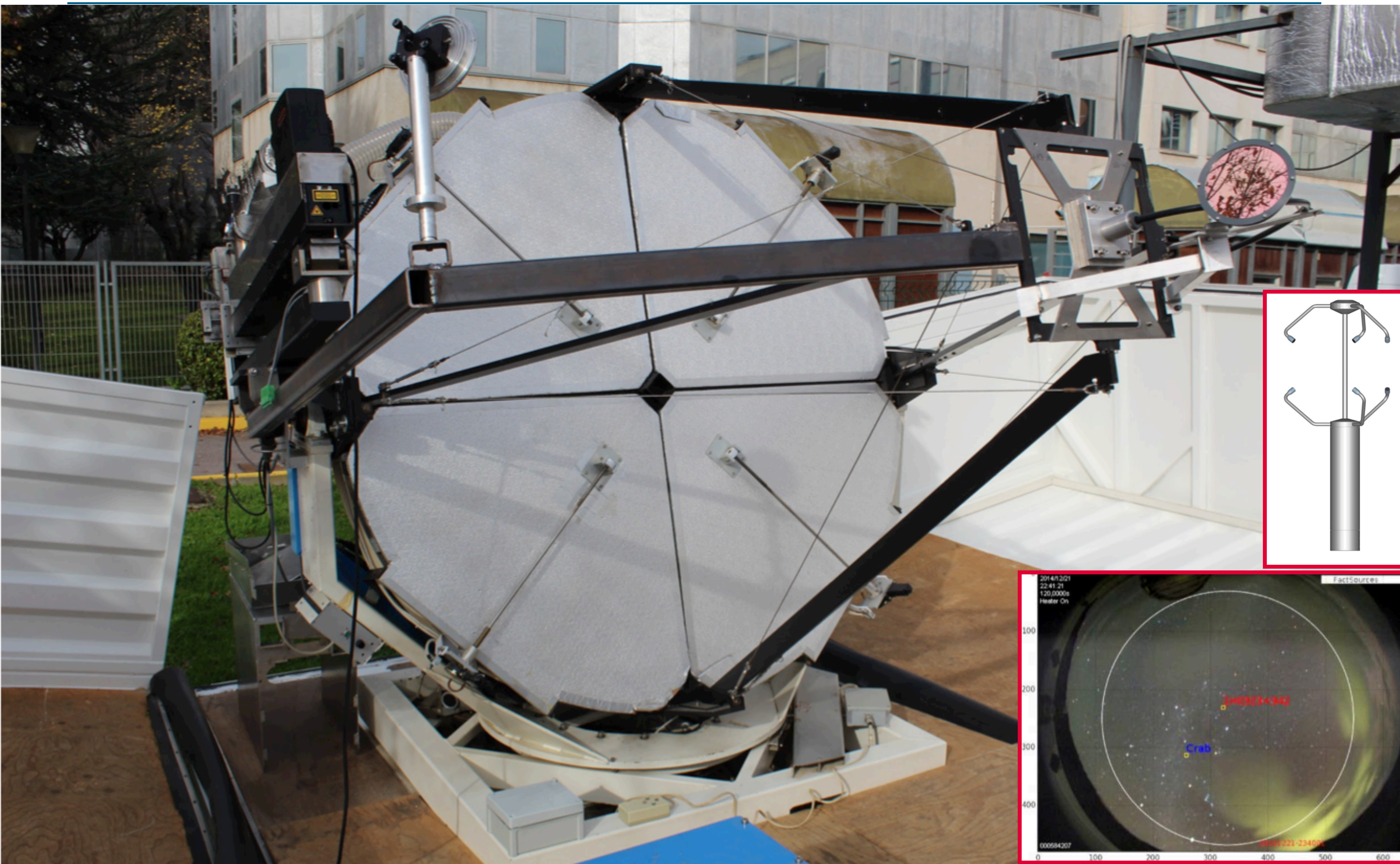
Typically ~2000 pixel cameras with trigger rates: LST 15, MST 9, SST 0.6 kHz
Readout of roughly 60-100 ns with 0.25-1 GHz sampling

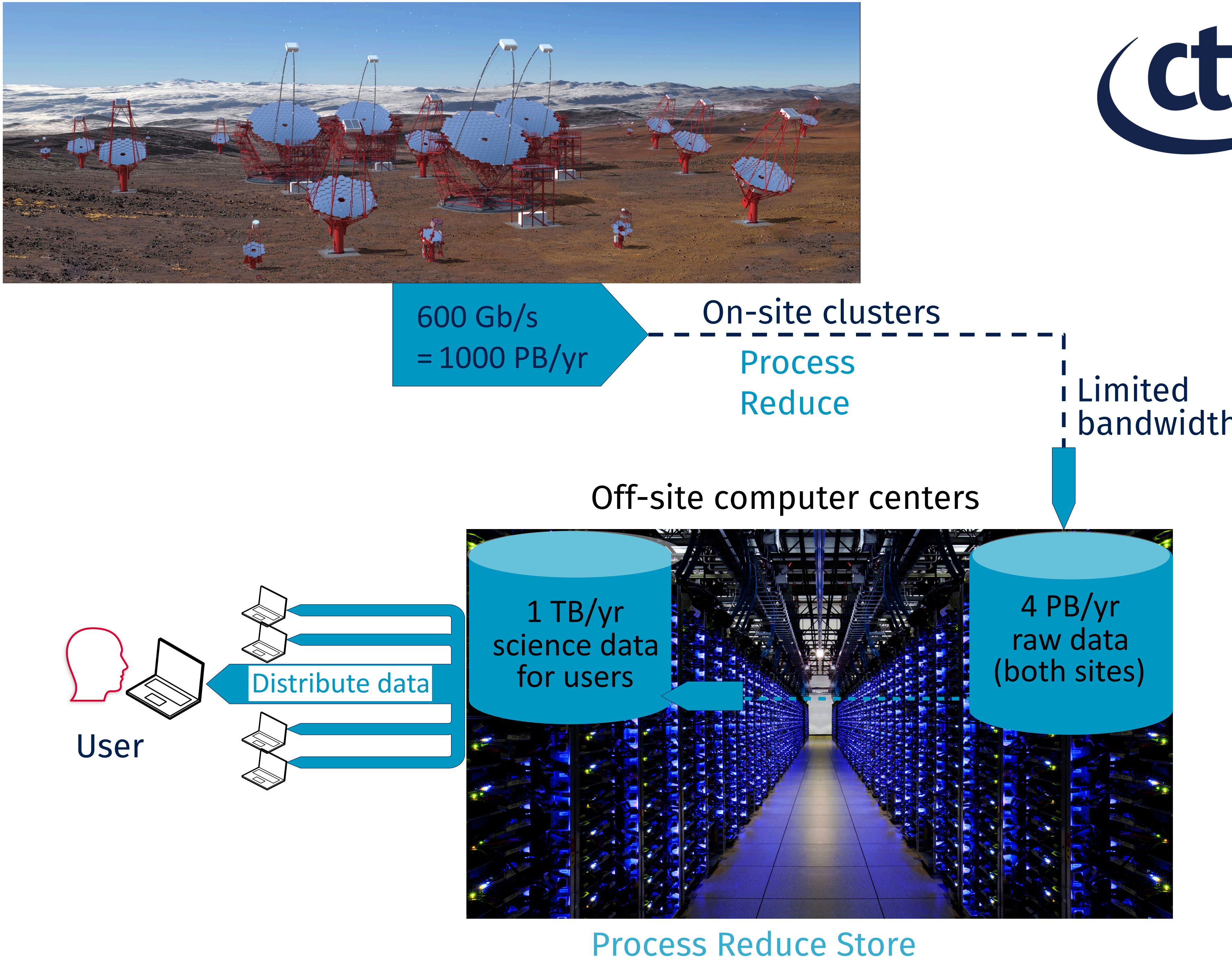
Large Size Telescope



Medium Size Telescope

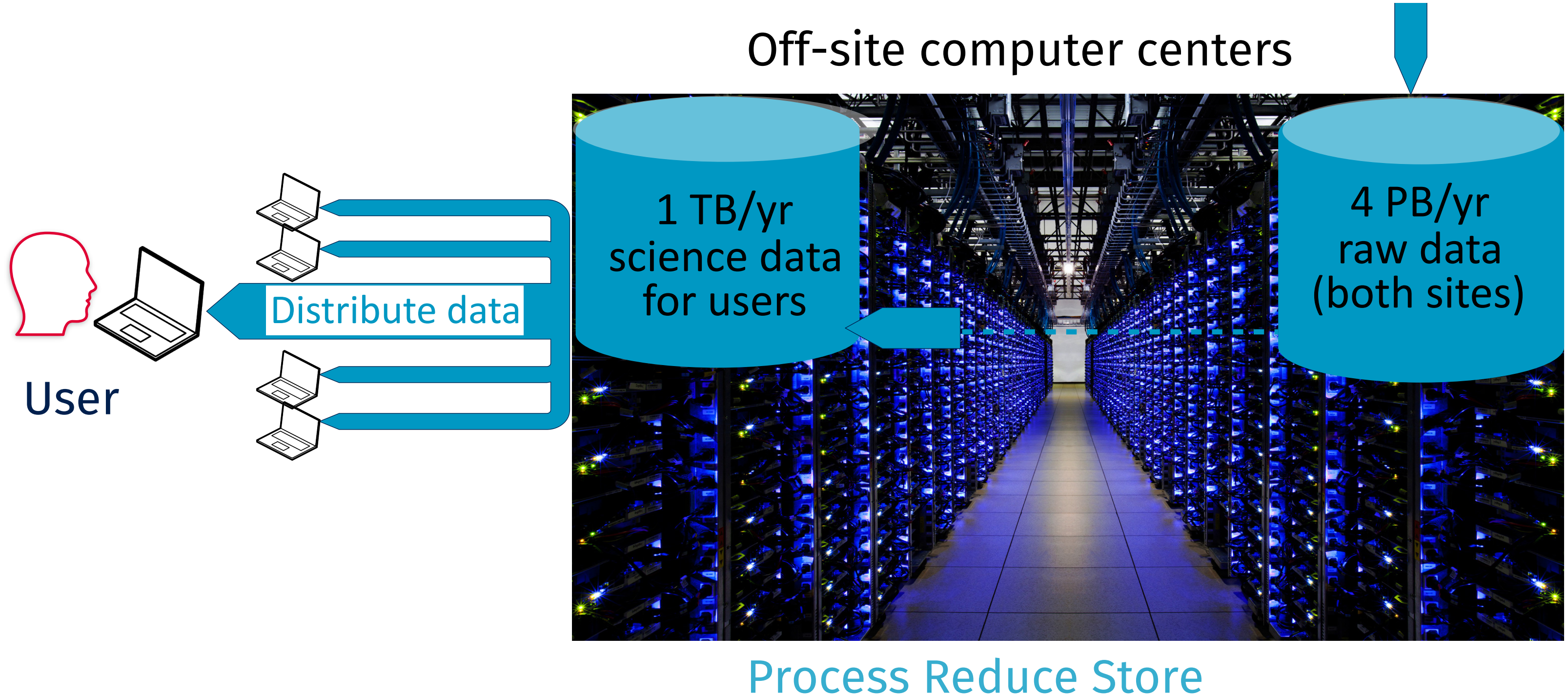
Calibration Devices




600 Gb/s
= 1000 PB/yr
On-site clusters
Process
Reduce
Limited
bandwidth
Off-site computer centers
1 TB/yr
science data
for users
4 PB/yr
raw data
(both sites)
Distribute data
User
Process Reduce Store

Large quantity of simulated data will be produced and archived during the construction phase to characterize the site - and the performance and response of the instruments

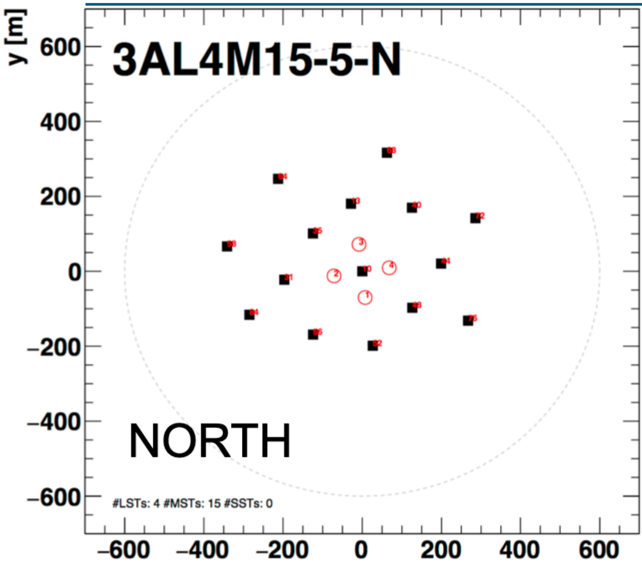
Monte-Carlo data processing is needed during the operation phase to produce up-to-date Instrument Response Functions, and for validation of new algorithms and software versions

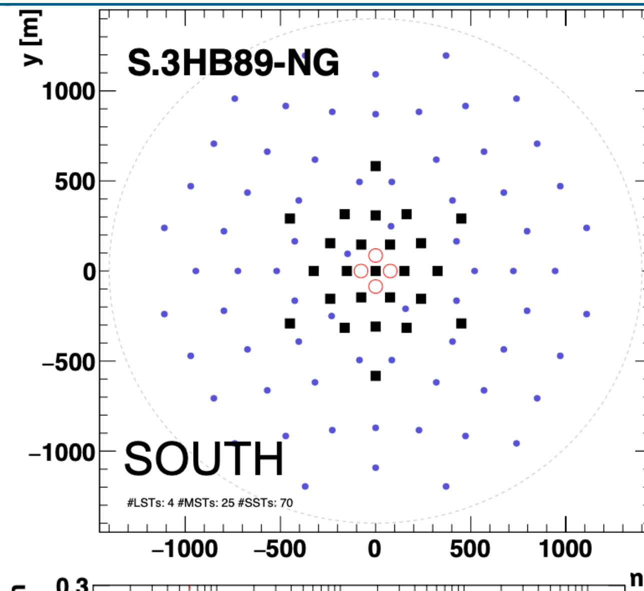


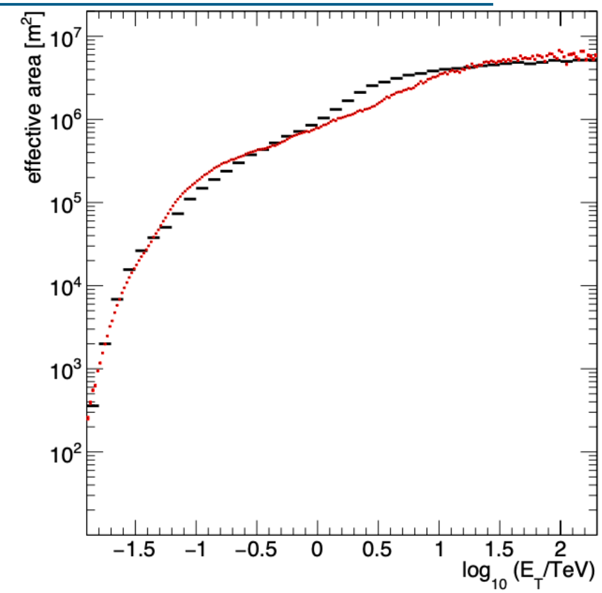
Production of Monte-Carlo Data

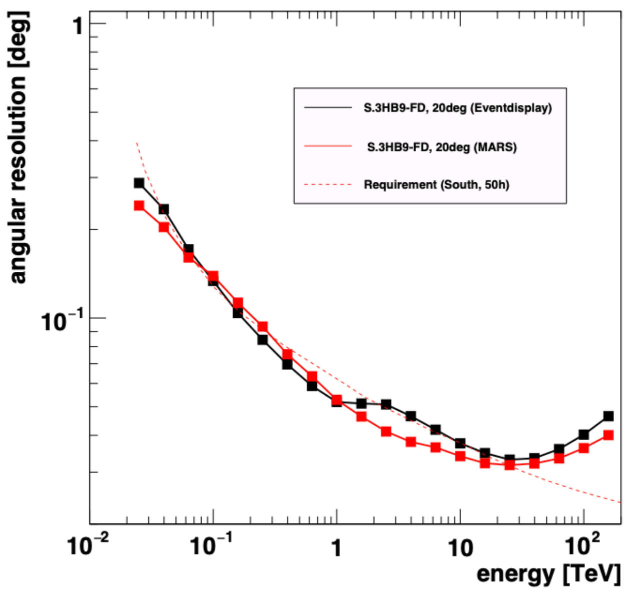
- CTAC wide grid and non-grid resources – using DIRAC interware
- CTAO Project Scientist and
  CTAC Analysis and Simulation Working Group
- Currently Service Level Agreement between CTAC and computer centres 'For the provision of CTA-DIRAC services' -
  and yearly agreements on "pledges"
- Will be CTAO Service Level Agreement
- DIRAC instances requires engineering and hardware support delivering a high performance, reliable and high availability service
  - Workload Management System expert
  - Production Manager
  - Simulation Scientist

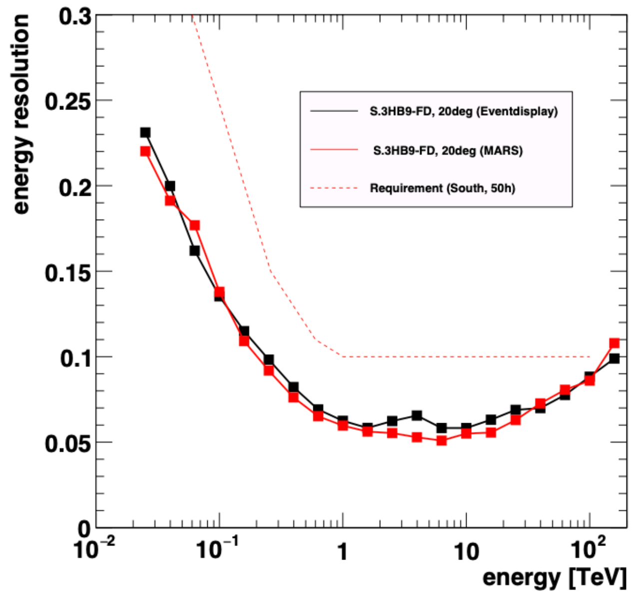
Use of Monte Carlo Data





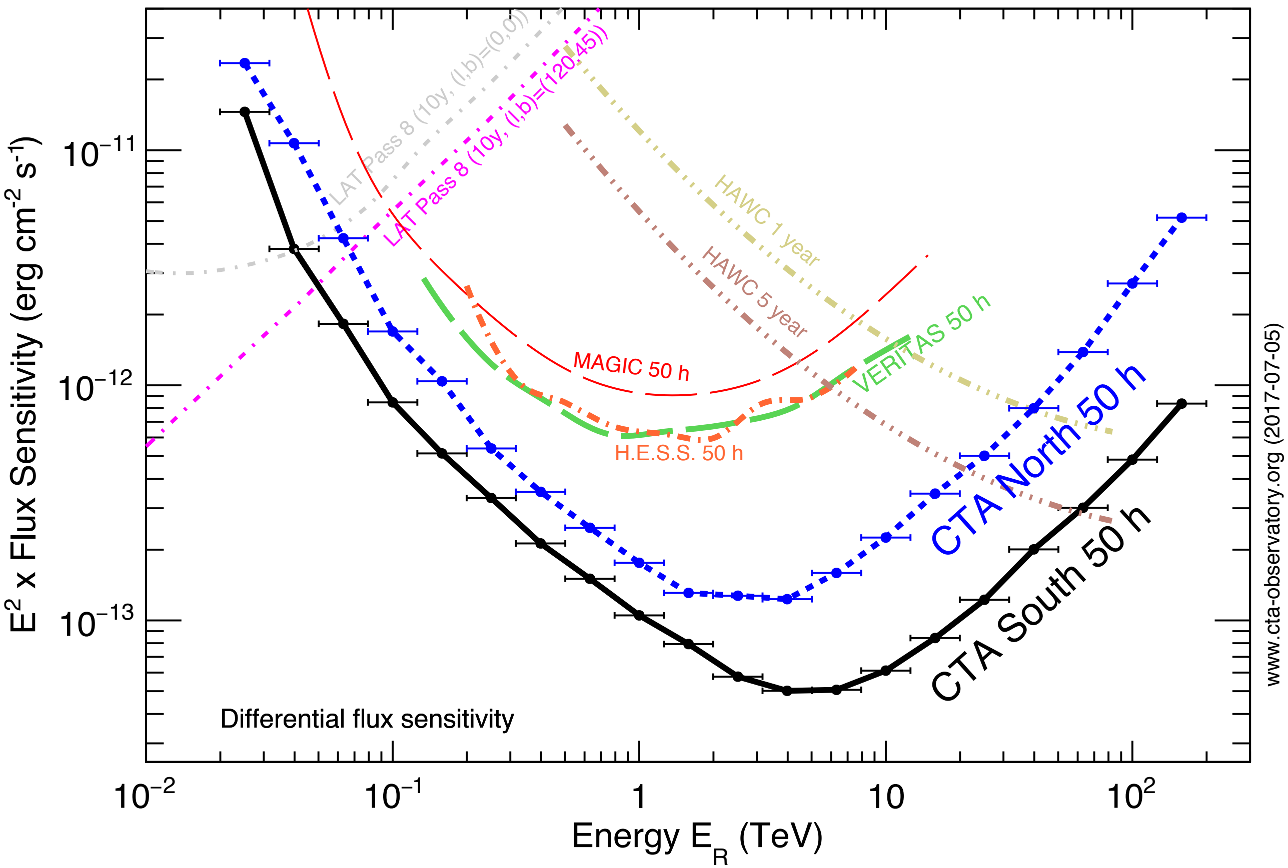


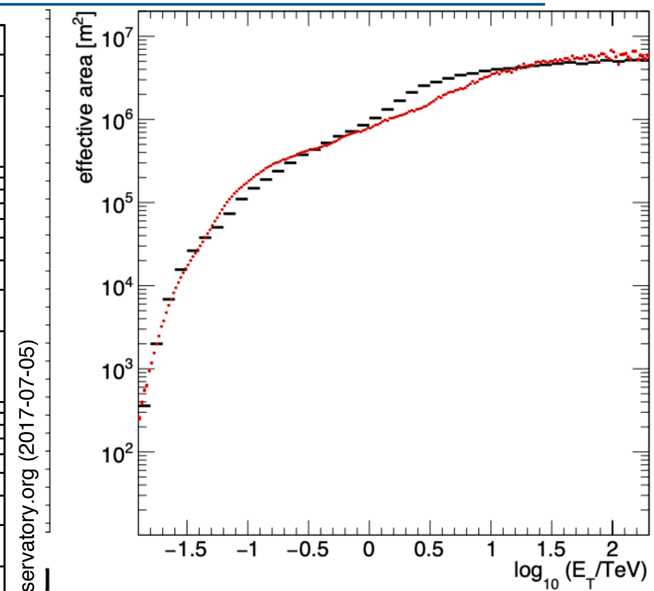


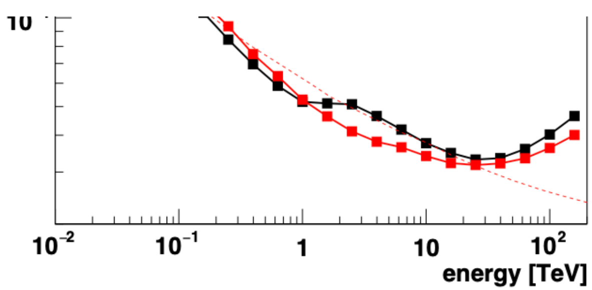


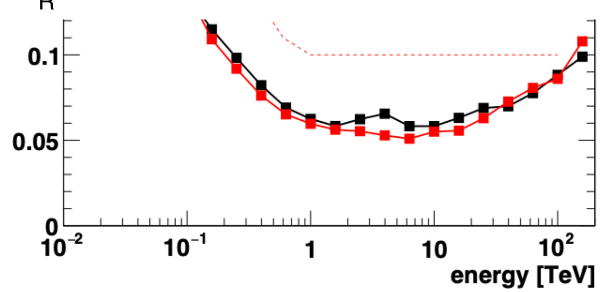
Calculate the Instrument Response Functions

Use of Monte Carlo Data



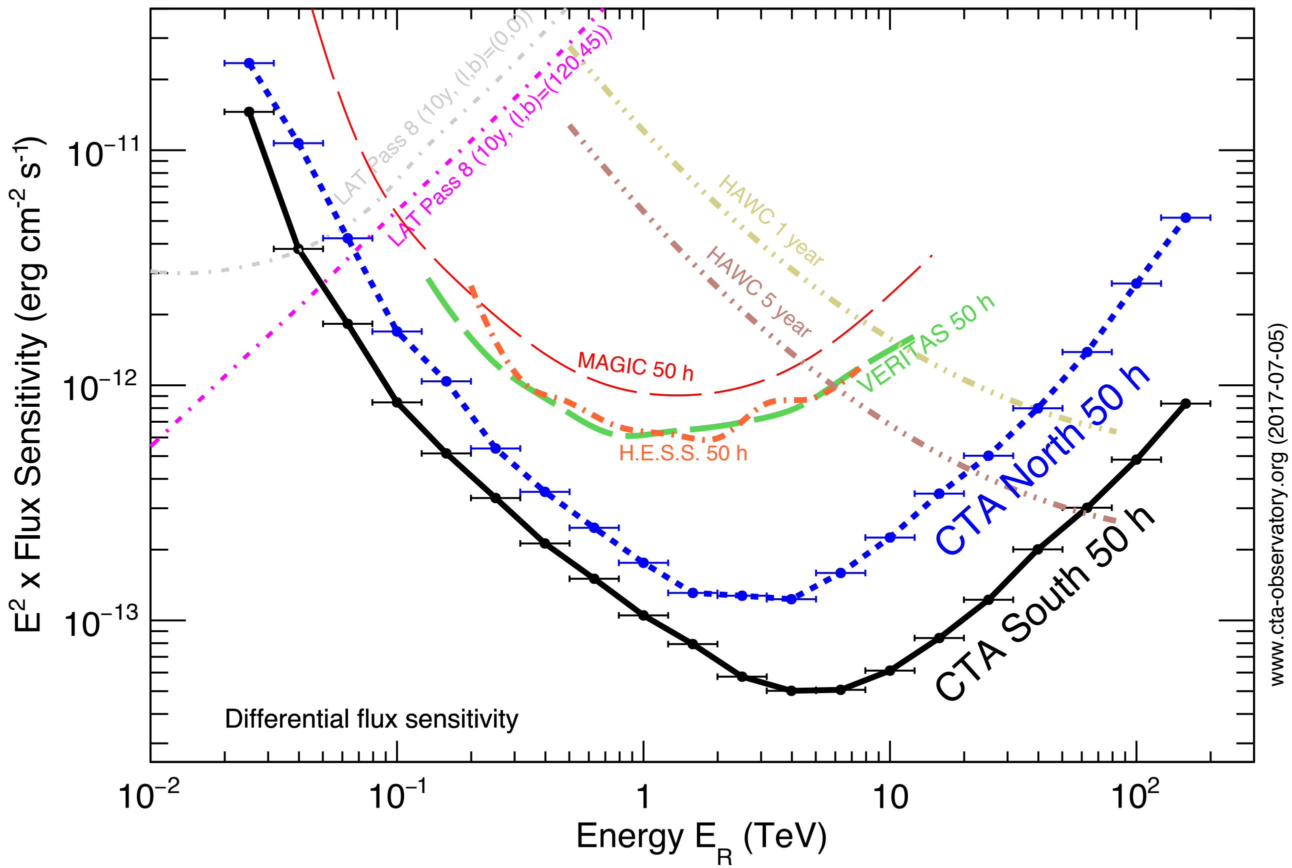


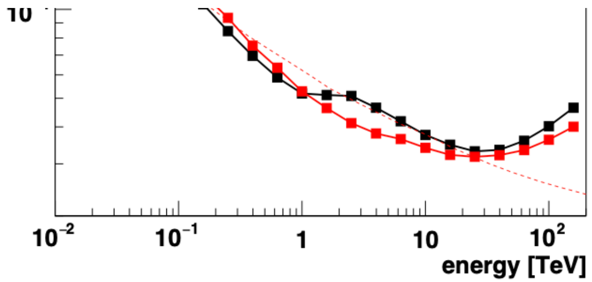


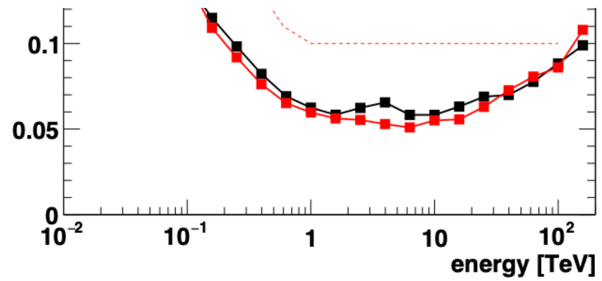


Calculate the Instrument Response Functions

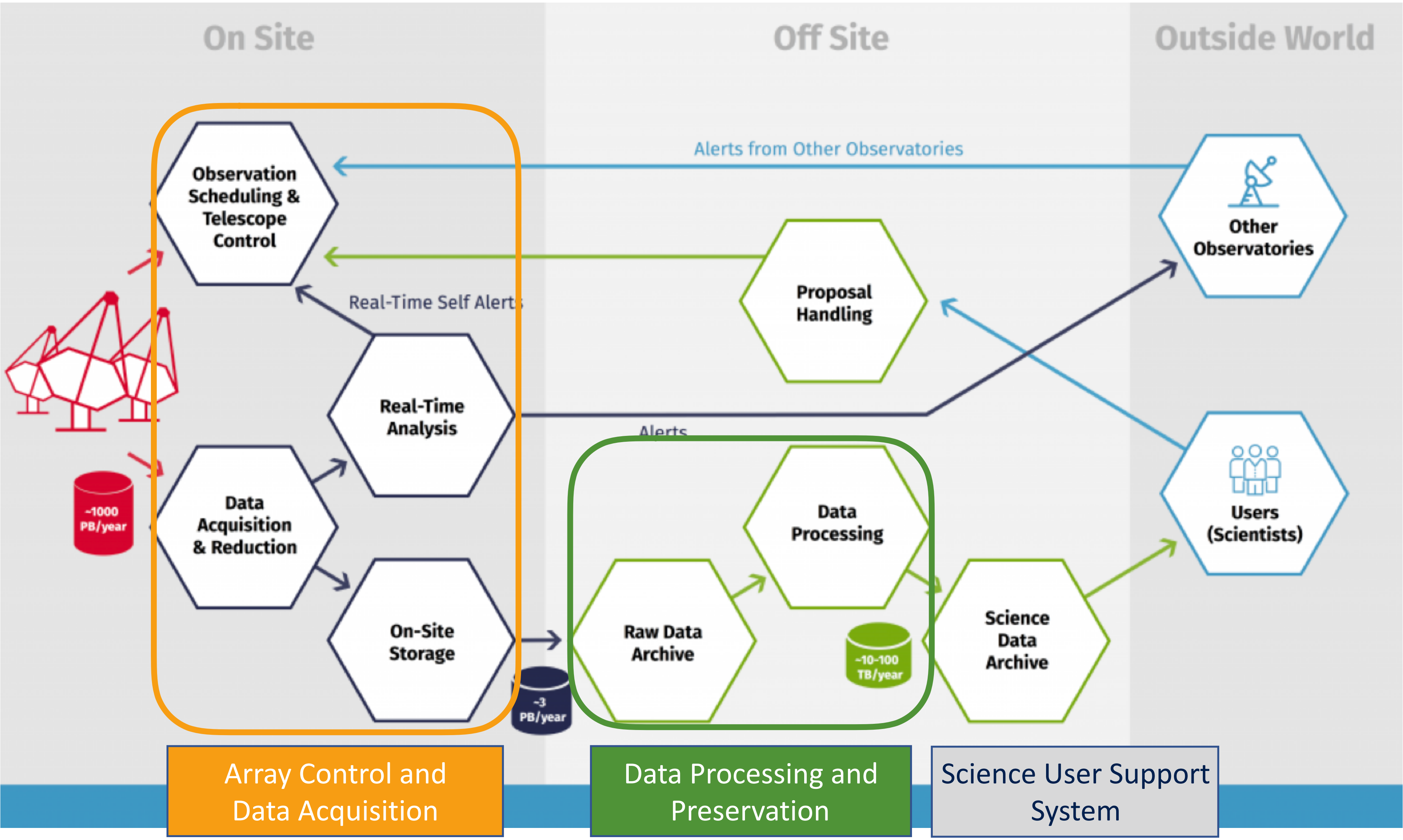
Use of Monte Carlo Data

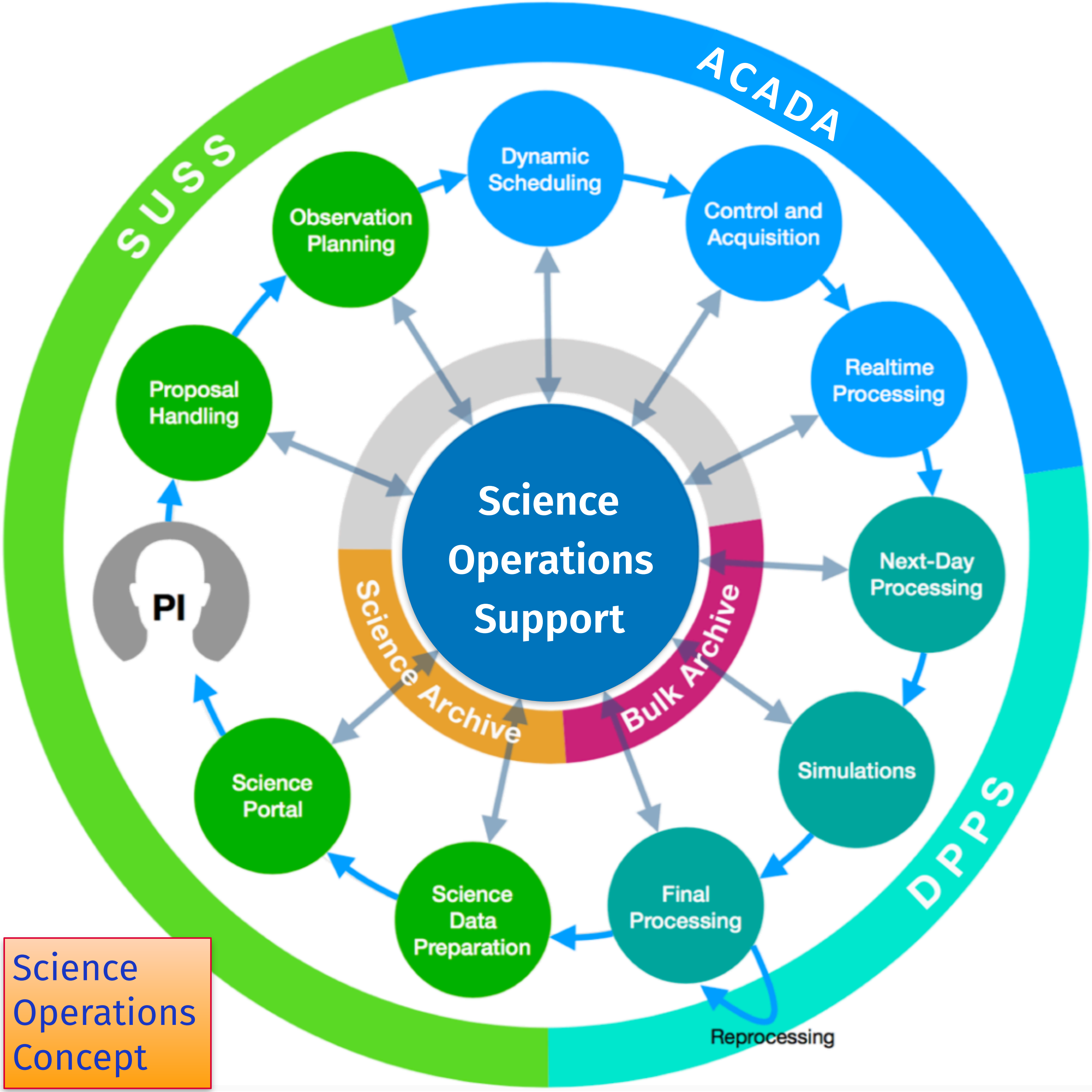






Calculate the Instrument Response Functions


On Site
Off Site
Outside World
Alerts from Other Observatories
Observation Scheduling & Telescope Control
Proposal Handling
Other Observatories
Real-Time Self Alerts
Real-Time Analysis
Alerts
Data Acquisition & Reduction
~1000 PB/year
Data Processing
Users (Scientists)
On-Site Storage
Raw Data Archive
~10-100 TB/year
Science Data Archive
~3 PB/year
Array Control and Data Acquisition
Data Processing and Preservation
Science User Support System

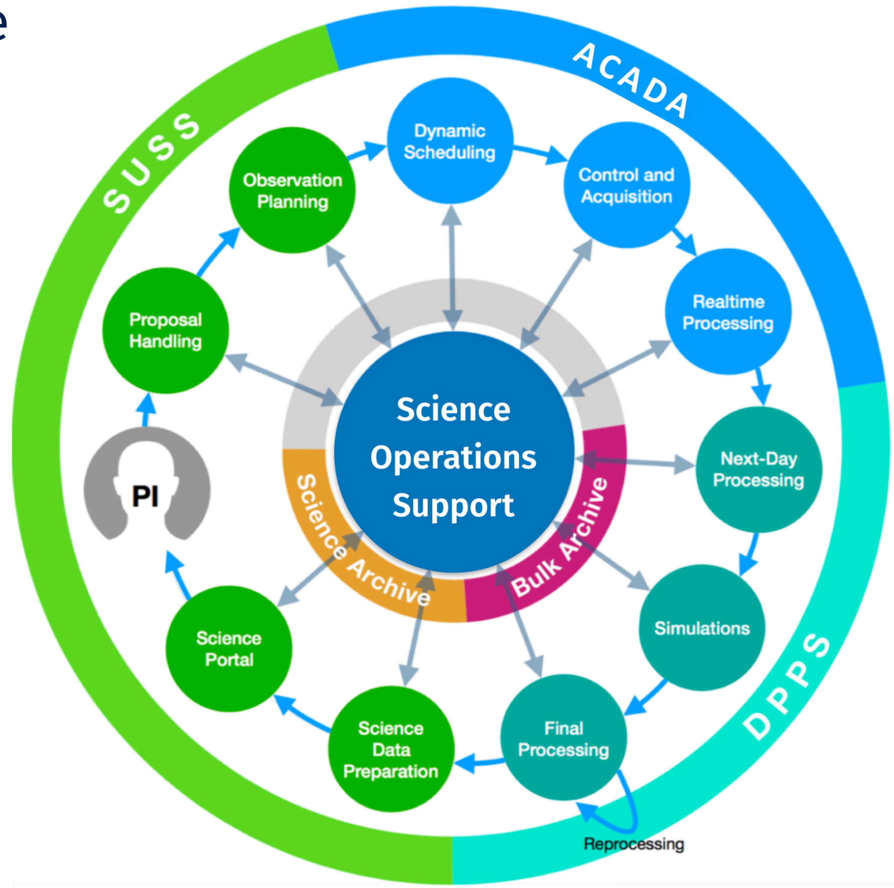


CTA Observatory science operations – primary processes

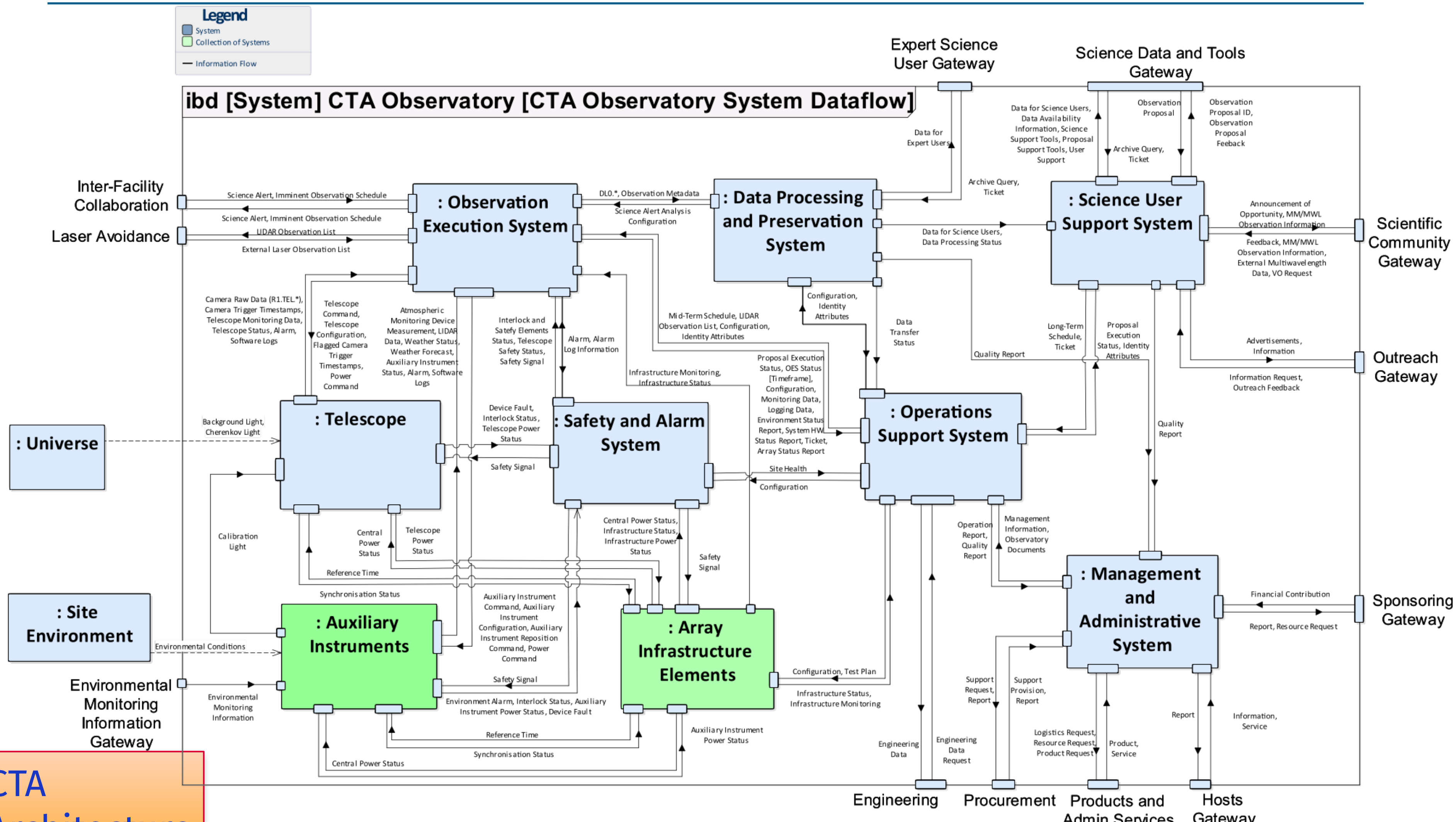
Science Operations Concept

Science Operations

- Archives are in the centre of science operations from begin to end
- Archiving of data at different levels (DL0-DL3, DL5, DL6)
- Archiving of metadata linked to the different levels, including provenance information
- Additional information:
  - Proposals and Schedules
  - Status information
  - Monitoring and engineering data

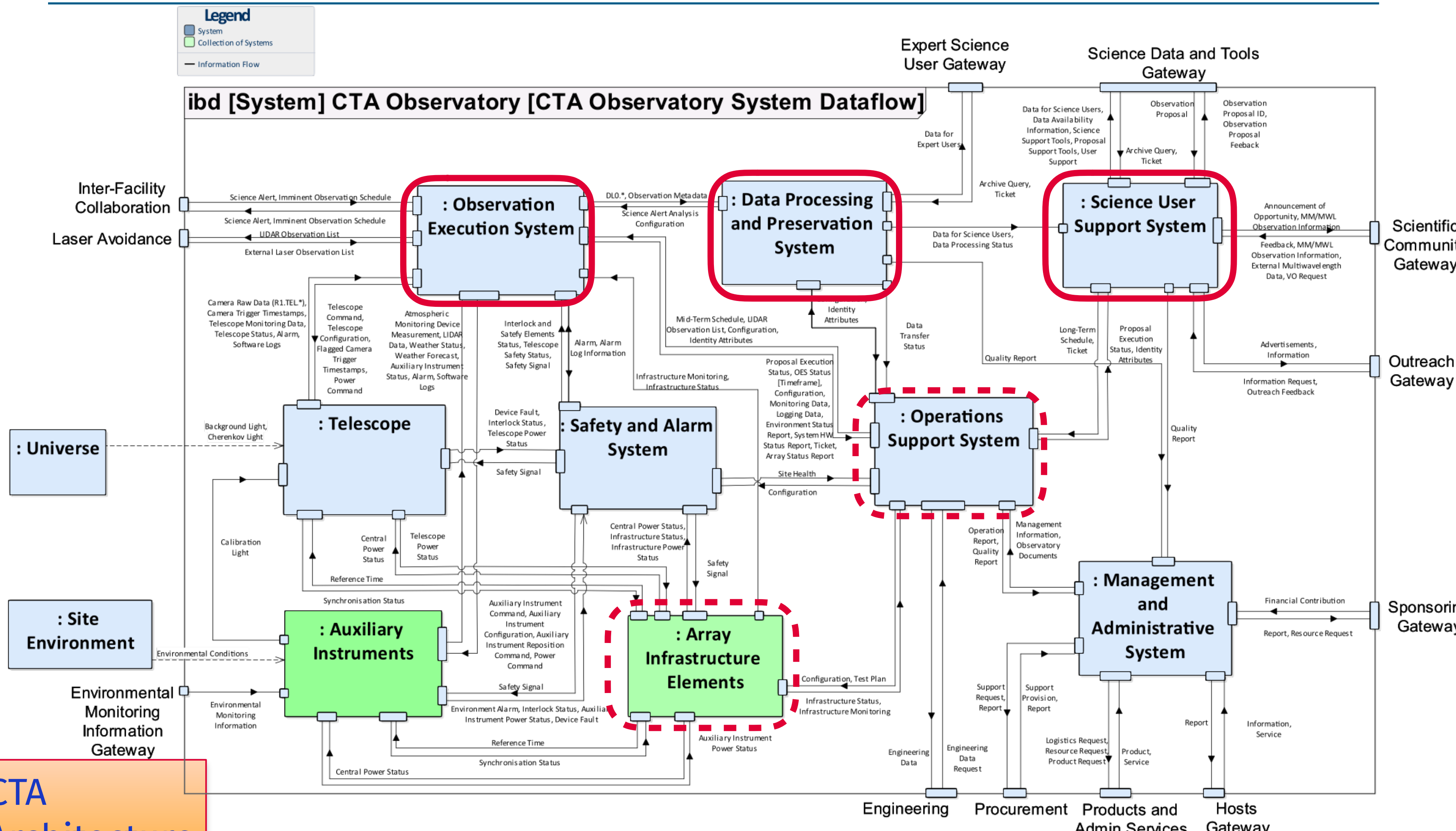


The CTA Systems Structure



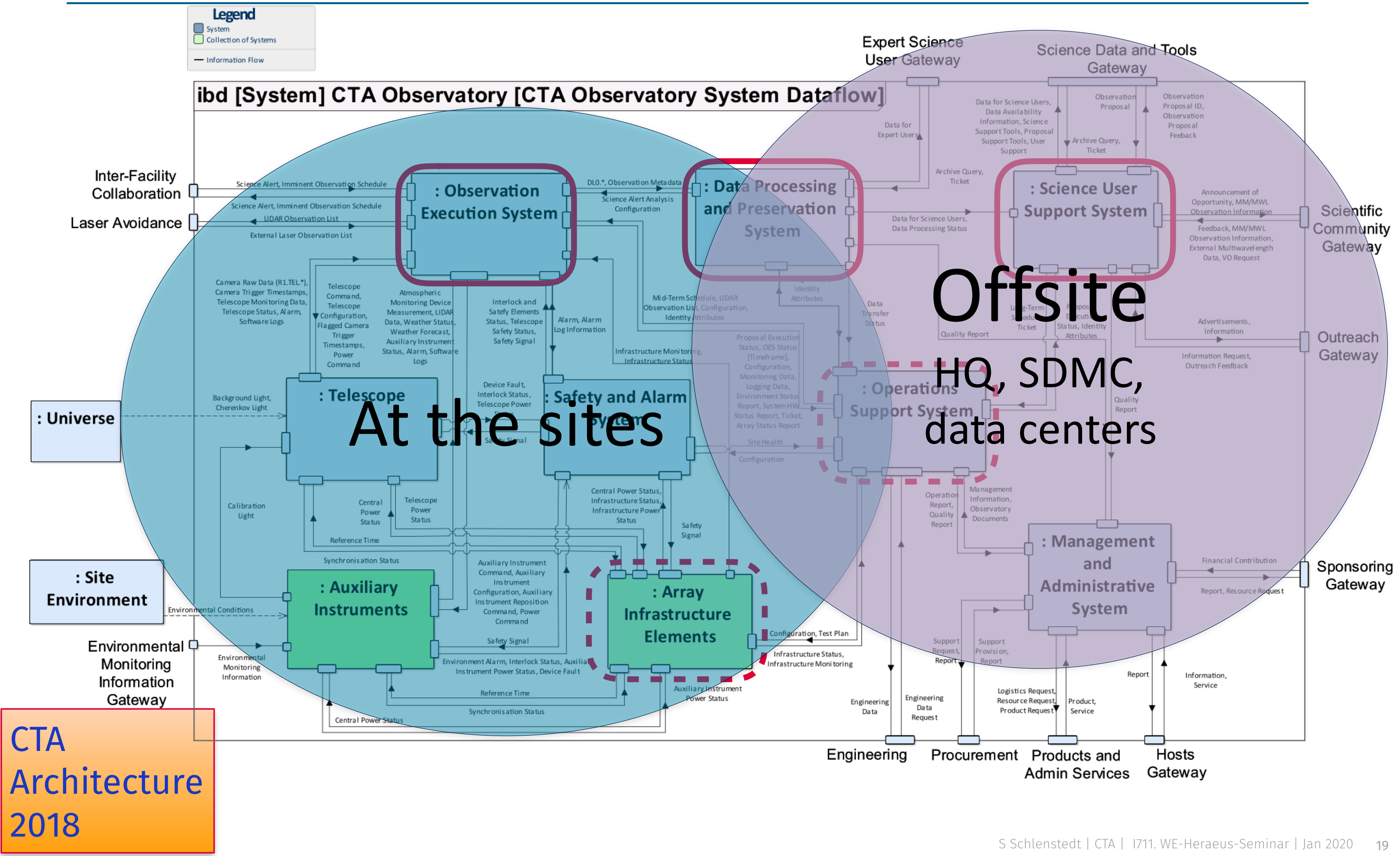
CTA Architecture 2018

The CTA Systems Structure

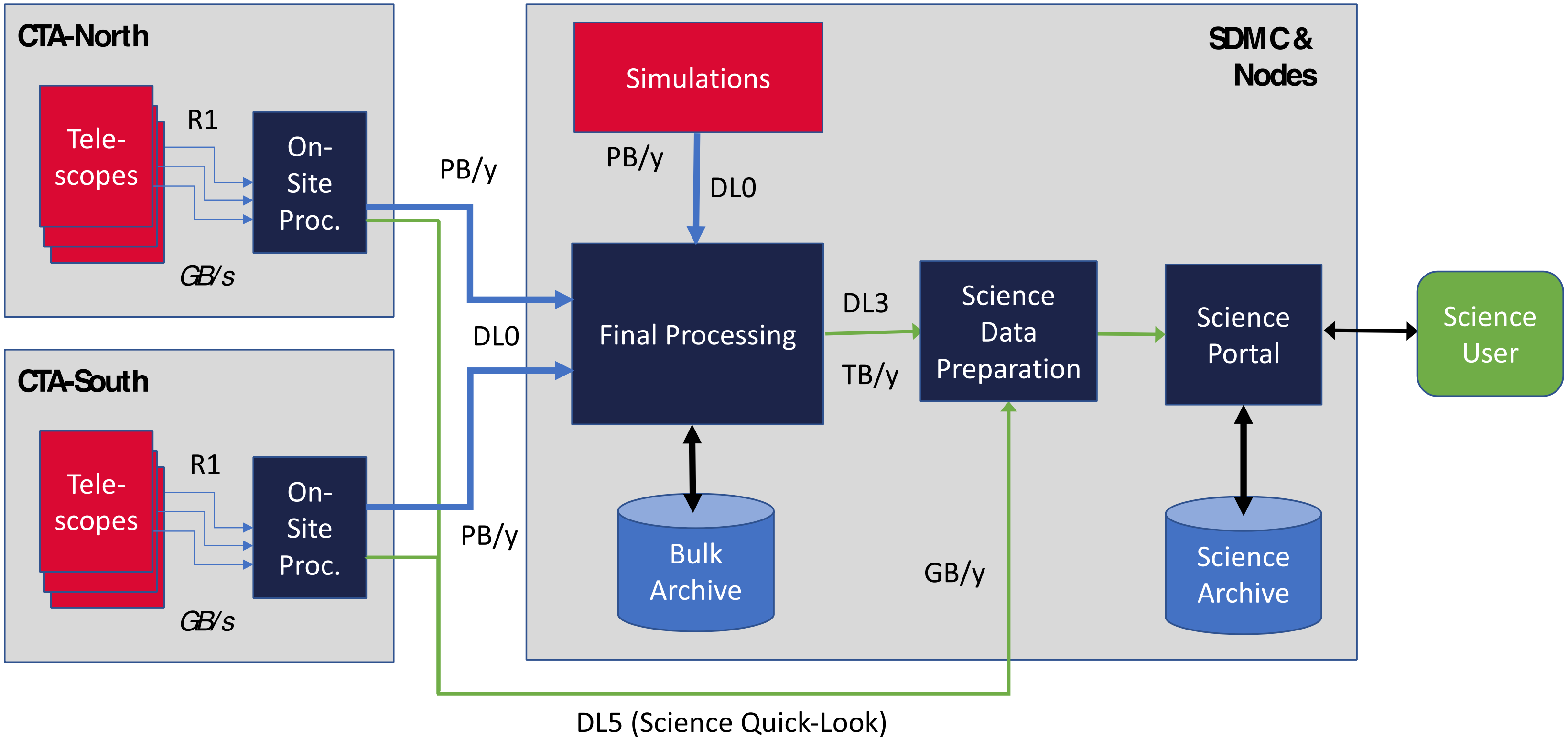


CTA Architecture 2018

The CTA Systems Structure



Data Flow and Categories



- Strong data reduction along the processing steps
  - From PB/y (at raw data level) to GB/y (high-level science data)
- Open access through Science Portal
  - access to science archive, to science analysis tools
  - Exploration of quick-look data products

Data Categories

- **A** (real-time) Data products produced and distributed rapidly for science alert generation and rapid data quality evaluation. These generally have the lowest precision and highest systematic uncertainties arising from basic calibration and simplified analysis techniques.
- **B** (next-day) Data products produced and distributed after some off-line processing on-site, by the next observation day. These have somewhat better precision and lower systematics than category-A products, but still may use simplified analysis or calibration techniques appropriate for relatively fast science alerts and proposal monitoring.
- **C** (final) Data products produced by the full high-quality data processing chain, off-site in CTA data centres, with a delay of ~weeks from data taking. These use the best calibration and algorithms, providing precision and systematics meeting or exceeding CTA requirements, and thus are the products intended for final analysis and publication of results.

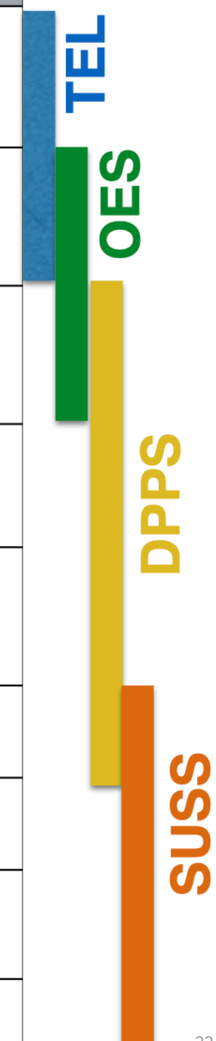
minute

day

month

Data Levels

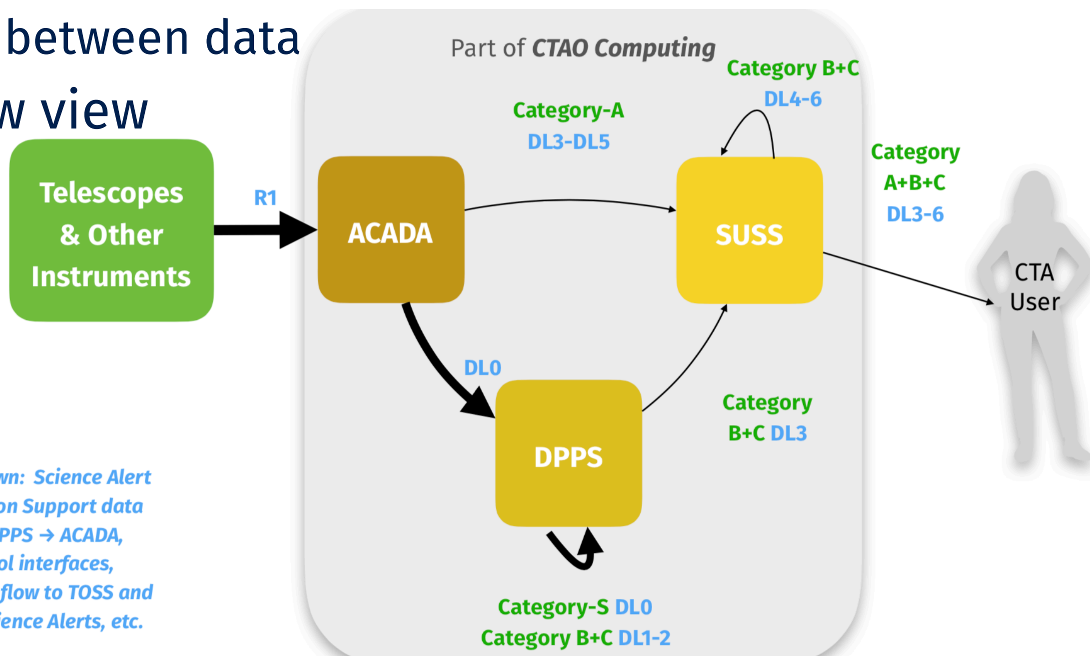
Data Level	Short Name	Definition
R0	Raw Internal	On-site streamed raw data, not normally preserved long-term in this form. R0 content and format is internal to each device / controllable system, such as raw data transmitted from the physical device / system to its respective server in the on-site Data Centre.
R1	Raw Common	On-site stream raw data meeting common standards, transmitted on-site from a Camera or other on-site system to the OES. This is the first level of data seen by the OES, that will typically need some pre-processing from the R0 data format. Exceptionally, some R1 data may be stored for engineering purposes.
DL0	Raw Archived	All archival data from the data acquisition hardware/software, transmitted from the OES to the DPPS. This is the lowest level of data that are intended for long-term storage in the bulk archive. This includes both camera event data and technical data from other sub-systems, such as non-camera devices or software.
DL1	Processed	Processed DL0 data that may include telescope-level (TEL) data and parameters derived from them. Typical contents include calibrated image charge, Hillas parameters, and a usable telescope pattern. DL1 data is not normally stored long-term.
DL2	Recon-structed	Reconstructed shower parameters such as energy, direction, particle ID, and related signal discrimination parameters. Does not include telescope-level (TEL) information. For each event this information may be repeated for multiple reconstruction and discrimination methods. DL2 data is not normally stored long-term.
DL3	Reduced	Sets of selected events with a single final set of reconstruction and discrimination parameters, along with associated instrumental response characterizations and any technical data needed for science analysis.
DL4	Binned	Data product produced by binning of DL3 data, including data cubes and maps which are suitable for combination/summation to produce DL5 products.
DL5	Science	Data product produced by combination of DL4 products an extraction target specific region(s) of interest. Includes for example light-curves and spectra, along with associated data such as source models and fit results.
DL6	High-Level	High-level or legacy observatory data, such as survey maps and source catalogues.



Top-Level Data Model

- **Formal description** of any **data exchanged** between systems or distributed to users
  - Common dictionary of terms
  - Definition of data types
  - Definition of data structures
  - File content descriptions
  - Relationships between data
- Primary data flow view

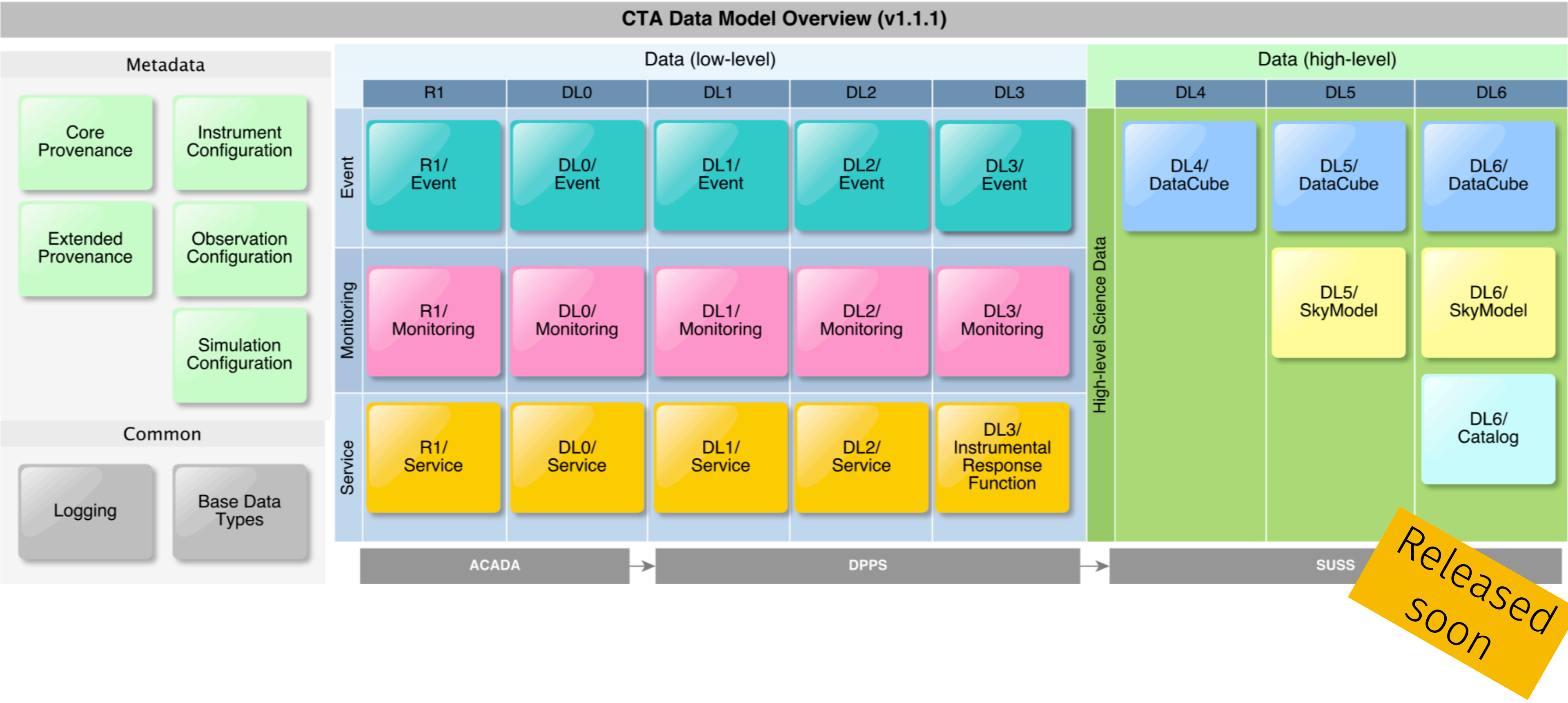
A core part of the Computing Architecture of an Observatory



** Not Shown: Science Alert Generation Support data from DPPS → ACADA, Control interfaces, metadata flow to TOSS and SOSS, Science Alerts, etc.*

Top-Level Data Model

- **Formal description** of any **data exchanged** between systems or distributed to users

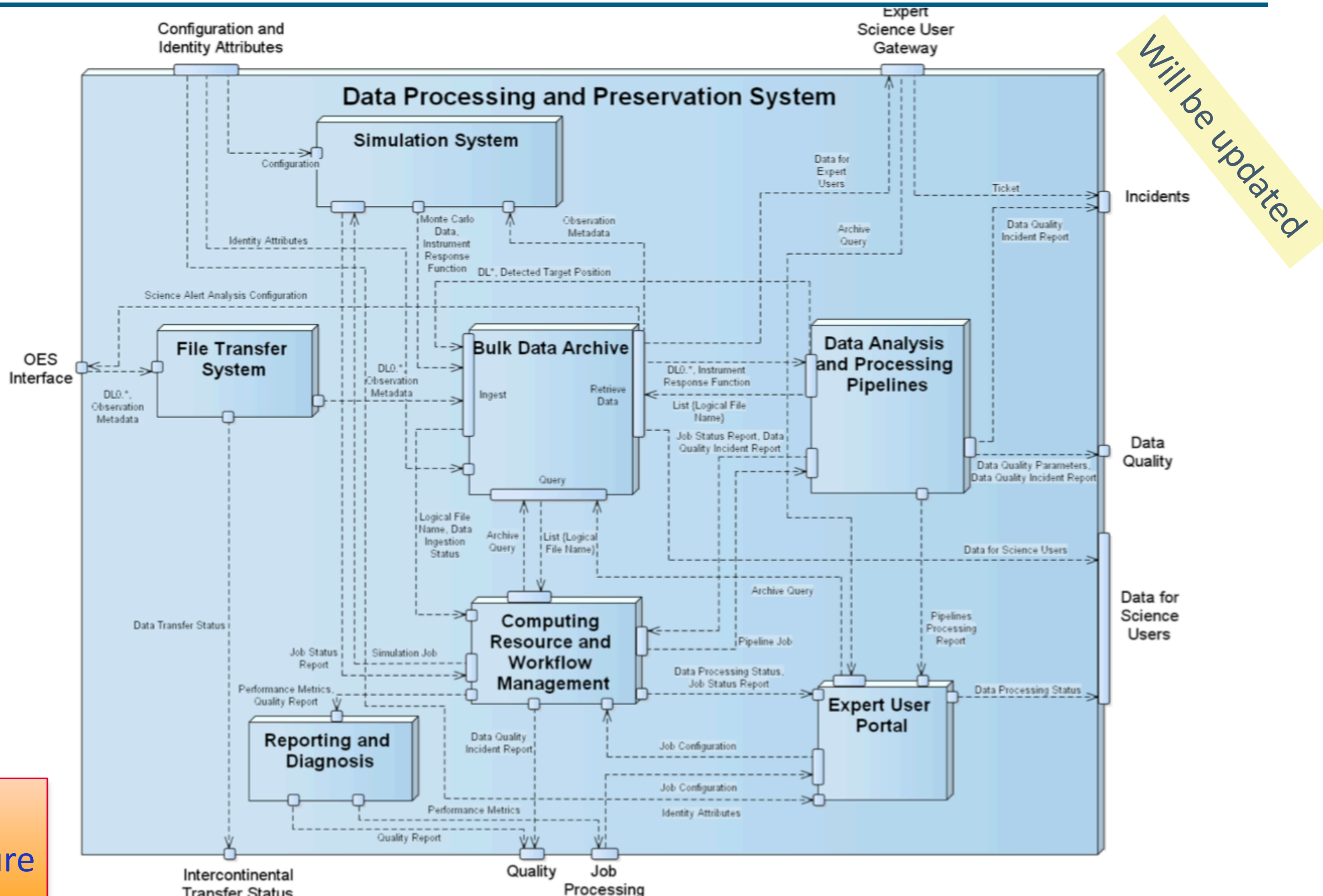


Distributed Data Processing and Storage
DPPS

- Manages the data
- Responsible for processing it down to a form usable by scientists
- Responsible for simulating the data needed to characterize the instrument
- Reprocessing

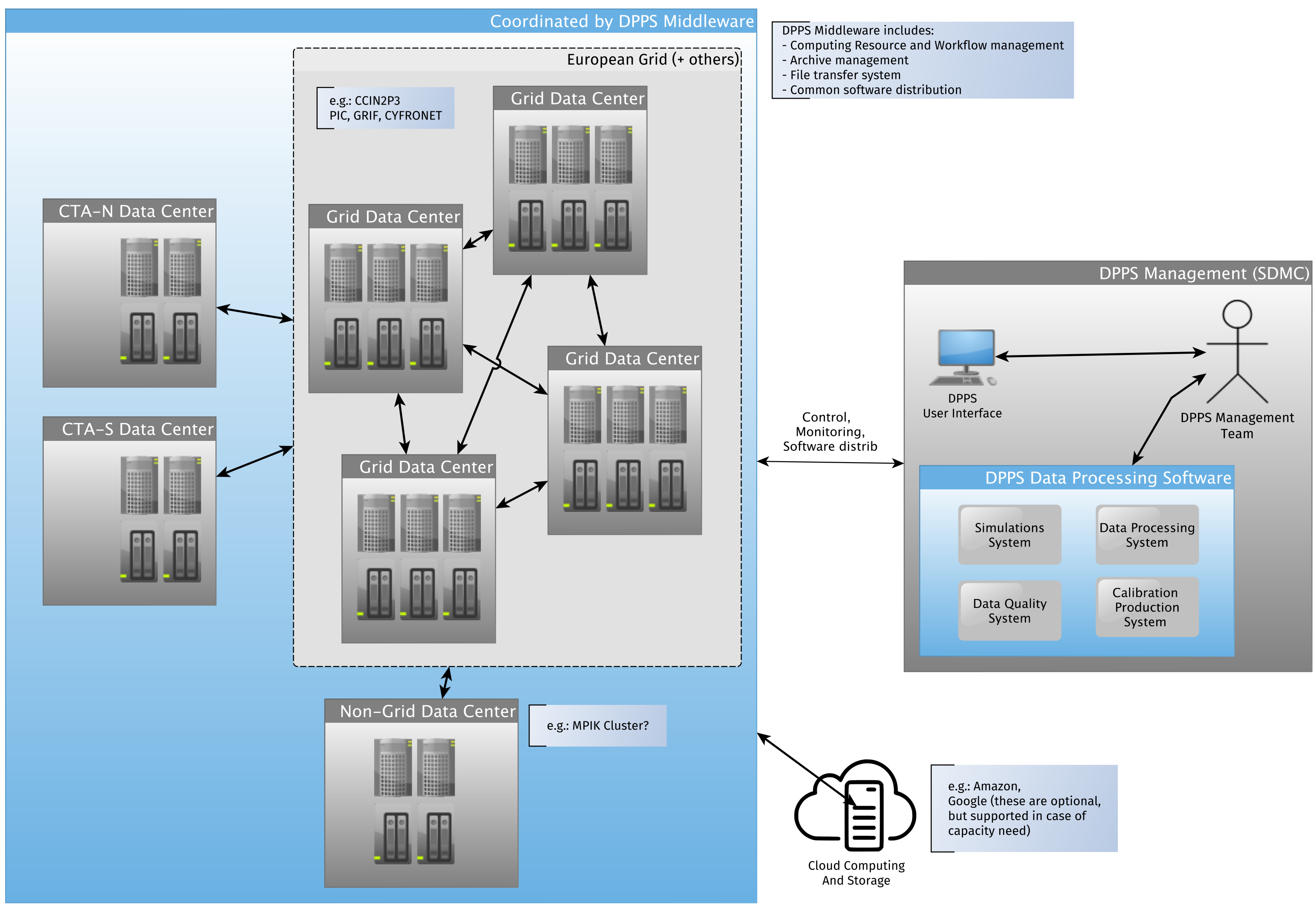
Requires a complex chain of algorithms running in parallel at multiple data centers

Distributed Data Processing and Storage DPPS



CTA Architecture 2018

DPPS Concept



DPPS Concept

- Distributed Data Processing and Storage is a “cloud”
  - Centrally managed at Science Data Management Centre (SDMC)
- Software is running at all Data Centers, including the sites
- The software running on a single data center is a Data processing and preservation node (DPPN)
  - What we deliver to the site is the software and data packages necessary to make the site’s Data Center a DPPN
  - ‘Just’ a sub-set of the packages needed to run the full DPPS, e.g.
    - No simulation pipelines
    - Data processing pipelines only need subset of functionality

DPPS Products

Full system managed by SDMC

- Documentation

Middleware

Common Libraries and Frameworks
Computing Resource and Workflow Management Middleware
Bulk Archive Management Middleware
File Transfer Middleware

Pipelines

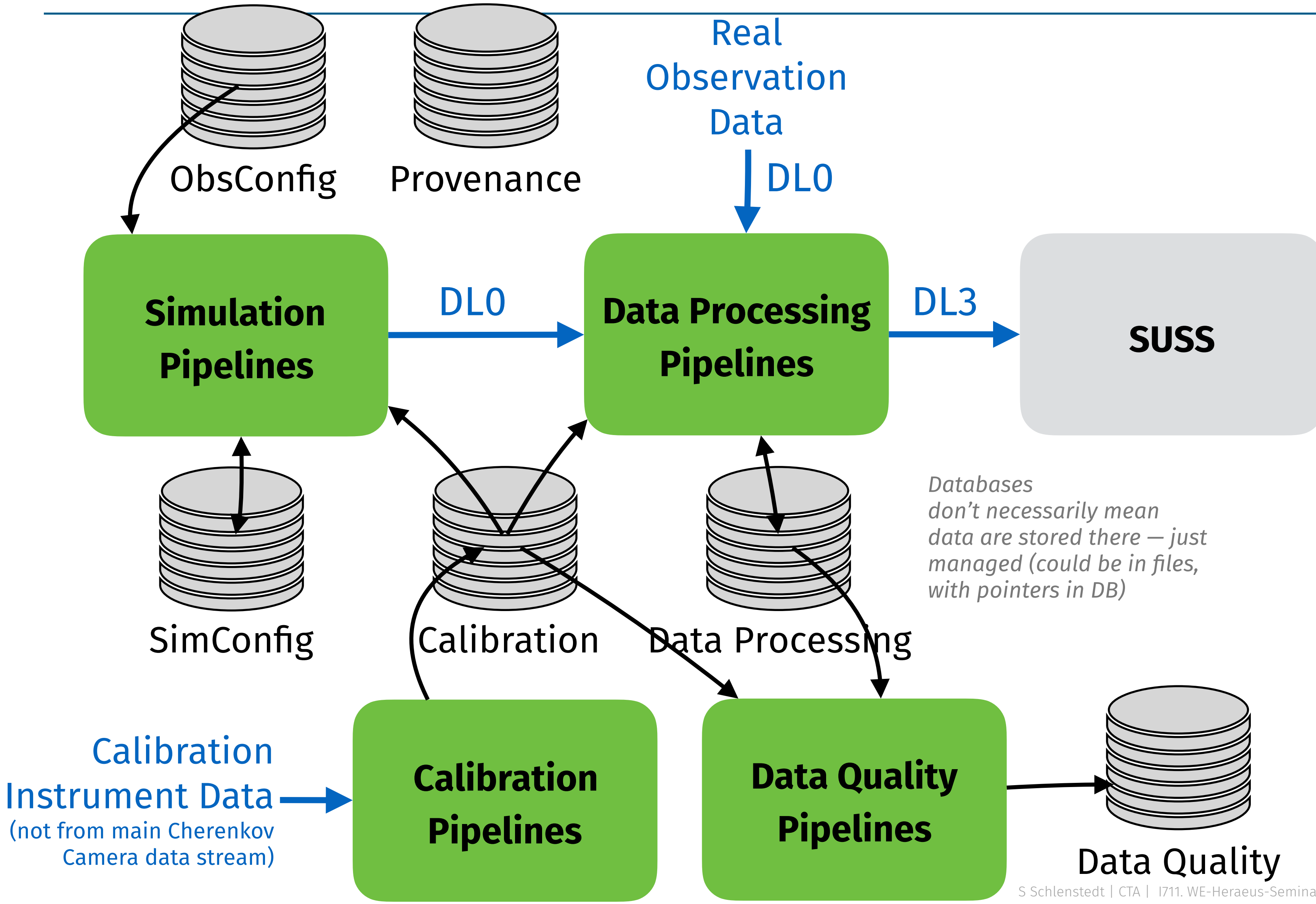
Simulation Pipelines System →
Data Processing Pipelines System →
Calibration Pipelines System →
Data Quality Pipelines System →

Pipeline systems each have similar substructure:

- Framework
- Tools
- Workflows
- Database

- Operations UI
- Data Quality UI and Reporting

DPPS Pipelines Concept



Archives

- Archives are in the centre of science operations from begin to end
- Archiving of data products and software at different levels
  - Bulk Archive for DL0-DL3
  - Science Archive for DL3, DL5, DL6
- Archiving of metadata linked to the different levels, including provenance information
- Archiving of additional information (the Central Hub / Science Operations Support System):
  - Proposals and Schedules
  - Status information
- Archiving of monitoring and engineering data

Approach to Archives in CTA

A lot of definition and prototyping work done in the past and documented in the DATA Technical Design Report, e.g.

- Detailed data volume calculations
- Design studies for archive systems
- Use cases for archive access

Prototyping work in framework of European Projects

- European H2020 Projects where CTA participates as a major use case study (e.g. ASTERICS, XDC, ESCAPE)

Some key aspects:

- Established Open Archival Information System (OAIS) model as basis for the archive
- Based on assumptions on operational model of CTA data handling and access

Data Usage Scenarios

- CTA Data at DL0 and above (except intermediate data) needs to be preserved long-term
- CTAO internal users need access to DL0 and DL2 data for reprocessing and diagnostics / quality monitoring → bulk data archive (DPPS)
- End/science users need flexible query-based access to DL3-6 products → science archive (SUSS)
- End/science users and CTAO internal users need fast, flexible, query-based access to CTA meta-data in bulk archive and science archive depending on the planned data access
  - Access to lower-level data for small number of end/science users
  - Large number of workflows associated with operations
  - Concept in need of elaboration

CTA Data Archives

- Long-term Preservation of Bulk Data (in DPPS)
  - **Large** amounts of **data** [10s of PB/yr]
  - **Small** number of **users**
  - Need for coordinated computing and storage (likely distributed)
  - No need to be maintained after end of CTA operational phase
- Long-term Preservation of Science Data (in SUSS)
  - **Small** amount of **data** [10+ years of archive fits on an SDCard]
  - **Large** number of **users**
  - Outlives operational life of CTA by 10+ years
  - Can be centralized
- Clear difference in access needs
- Functional split – can use the same technology / be implemented as a single archive or as two separate (implementation detail)

Standards

The *Bulk* and *Science Archives* will be built using existing, open, standards

OAIS

Archive Architecture Model (definitions, Best-Practices, Guidelines, and Concepts)

IVOA

Virtual Observatory Interoperability Standards

As well as Findable Accessible Interoperable Reusable **principles**

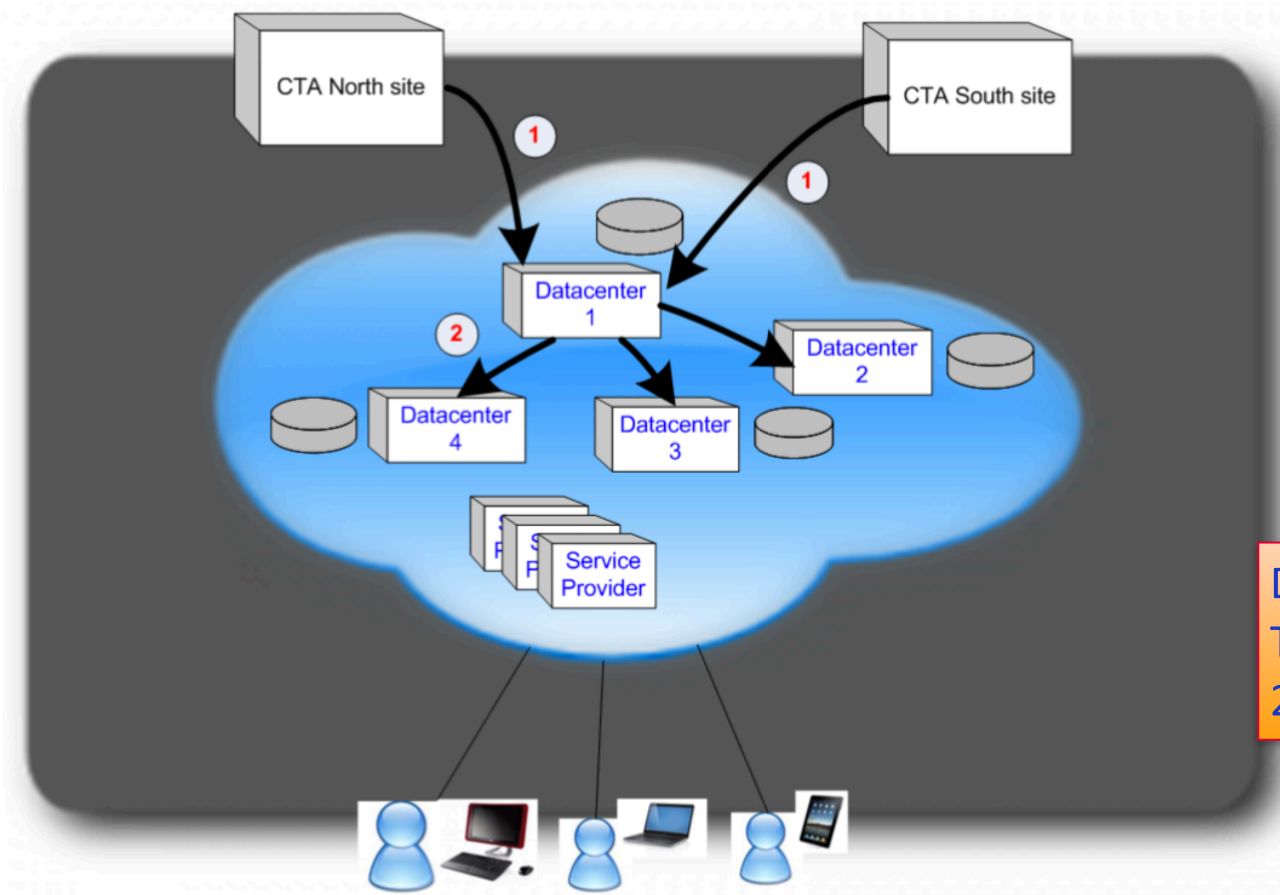
The Bulk Archive

- DPPS provides *Archive Management Middleware* (software)
  - The software that manages the preservation of CTA data, and ensures its availability for access for (re)processing.
  - Ensures “RAID-like” replication between *N* Data Centers (subject to computing model decision):
    - each file must be at at least two Data Centers
    - but not necessary that there are *only* two Data Centers
  - Provide interface like Open Archival Information System (ingest, retrieve, query)
    - implies also a file catalogue with search on file meta-data
- This software and the service agreements with *N* data centers, integrated and centrally managed by the SDMC is The Bulk Archive
  - Therefore an IKC to produce the DPPS Archive Management Software is not creating the full archive, rather

The Distributed Computing Model

Under investigation

- Under responsibility of SDMC

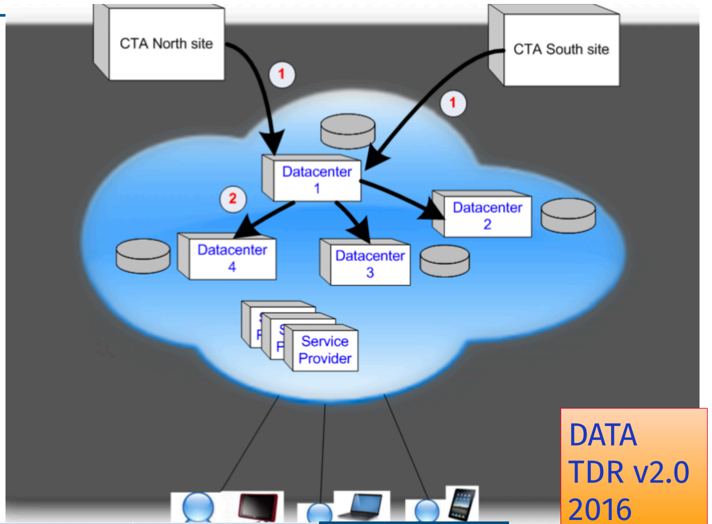


DATA
TDR v2.0
2016

- #data centres and data flow – updated in the Computing Model

Computing Model

- Requirements from SUSS/DPPS/SOSS and specific for off-site ICT
  - Include simulation data
- Data Management Plan
- Service agreements with data centers, network and other providers



DATA TDR v2.0 2016

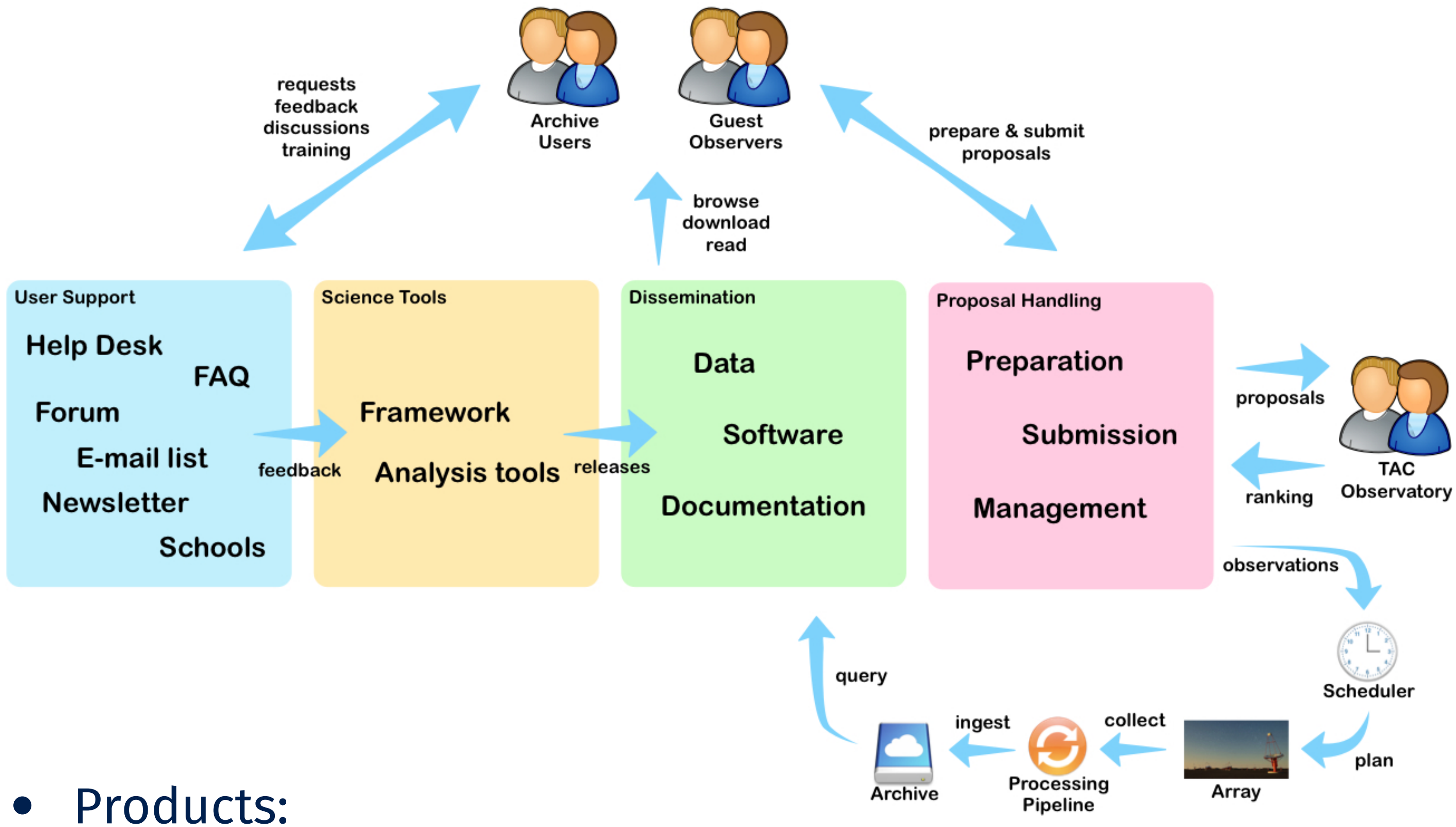
Computing model design	Perfor-mance	Availabi-lity	Costs	Reliability	Scalability	Managea-bility	TOTAL
Centralized with primary/ backup data center	1	3	1	3	3	1	12
Centralized with two primary data centers	1	2	2	3	3	2	15
Distributed (from 3 data centers)	1	1	3	2	1	3	10

Work in progress

1 best →
3 worst
solution

- Proposal by CTAO – Decision by Council

Science User Perspective



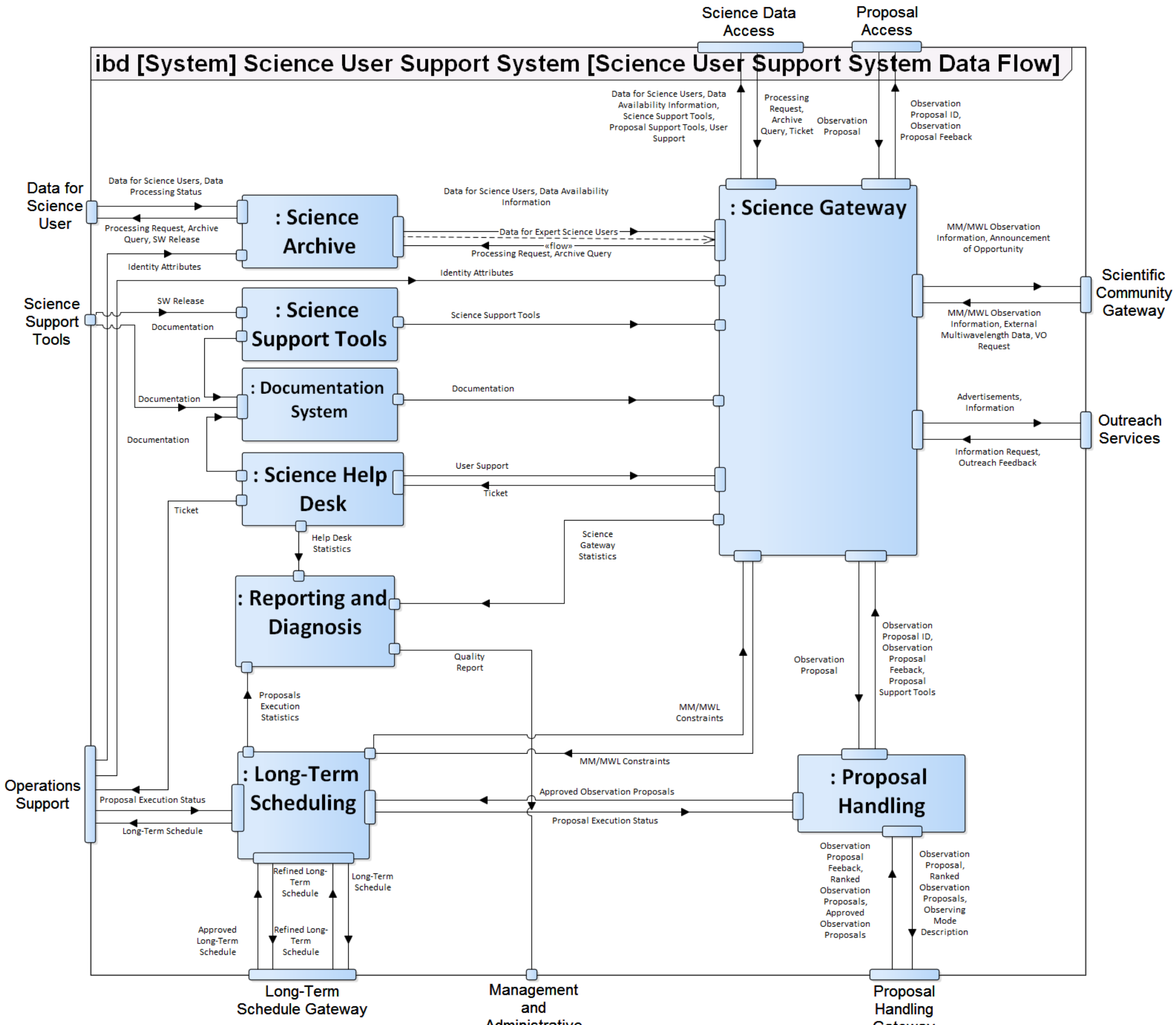
- Products:
  - Photon (candidate) event list data (FITS)
  - Instrument response functions, background model
  - Science analysis tool suite, supporting docs

Science User Support System
SUSS

The software systems responsible for science operations – gateway to the world - includes software for :

- Proposal handling and observation planning
- Long-Term and Mid-Term Scheduling
- Automatic high-level data processing (DL3→DL5) and data quality monitoring (at science verification level)
- Science Analysis Tools
- Science Archive
- Science Portal
- Support multi-messenger/multi-wavelength observation coordination, exchange of information via a common external astronomical standard (e.g. the Virtual Observatory standard)
- Help Desk and User Support
- Reporting/Diagnosis

Science User Support System

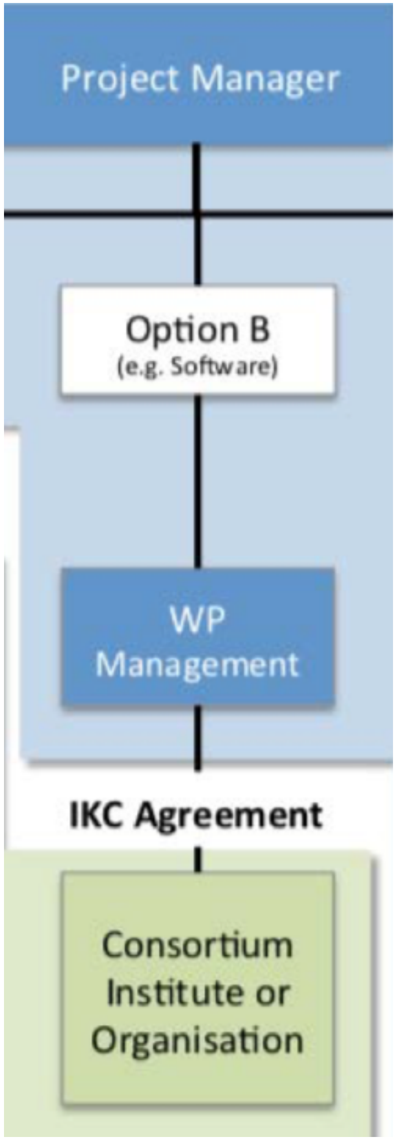


Will be updated

CTA Architecture 2018

CTA Software

- Responsibility for the **construction** of all software is with CTAO:
  - Management and Coordination
  - Architecture, Design, Specification
  - Definition of software Standards
  - Quality Assurance, Release, Testing, Integration, Acceptance
  - Coordination of implementation
    - via IKC, contracts with company, in-house implementation
- Strong involvement from contributors needed for implementation of software products
  - Including detailed design, quality assurance, testing, integration



Archives

- Long-term Preservation of **Bulk Data** in DPPS
  - Large amounts of data [10s of PB/yr]
  - Small number of users
  - No need to be maintained after end of CTA operation
- Long-term Preservation of **Science Data** in SUSS
  - Small amount of data [10+ years of archive fits on an SDCard]
  - Large number of users
  - Outlives operational life of CTA by 10+ years

Clear difference in access needs

➡ Workshop on Jan 27-29 2020 at the SDMC
  - The CTA Computing Model
  - Use-cases and requirements for bulk data and science data archive
  - Prototypes and Lessons Learned for the archives, plans how to proceed with its realization
  - From implementation(s) to benchmarking to integration test

Bulk Archive Requirements 1

- Preserve bulk raw data and higher-level data products (DL0-DL3) over the lifetime of CTA
- Preserve associated metadata and provenance information
- Preserve DL0 simulation data for at least 3 years after production
- Located at least at two sites with 300 km distance
- Handle increasing data volume of at least 6 PB/yr
- Allow fast (re-)processing of data (annual reprocessing of all data within one month)
- No data loss over the full lifetime of CTA
- Bulk Archive will follow OAIS standard (or reference model or reference architecture)
  - The “O” in OAIS represents the “open way the standard was developed,” and does not represent “open access”
  - Note: Bulk Archive is not planned to be publicly open

Bulk Archive Requirements 2

- Storage-related requirements
  - Access rights management supporting specific roles for CTAO staff (Archive Manager, Data Processing Manager)
  - Unique identifiers for all data products that are independent of the storage location or number of copies
  - Versioning of data products
  - Placement, replacement, duplication, migration of data products and metadata
  - Bulk Archive validation and preservation of archive organization
- Ingest/Access-related requirements
  - Metadata extraction and browsing (separate DB for faster queries?)
  - Update and regeneration of metadata from data products
  - Confirmation of the availability of requested data products and estimation of the retrieval time < 1s (on average)

Science Archive Requirements

- Public access with data rights management (proprietary period)
- Preserve science data products > 10 yr beyond the lifetime of CTA
- Preserve associated metadata and provenance information
- Versioning of data products (unique identifiers) and software
- Flexible queries for users
- Fast access (product searches within 1 min)
- Support automatic data processing (DL3→DL5) – verification
- Support data browsing and interactive exploration
- Support standard interfaces (VO compliance)
- Highly available, high quality of service and products

Further considered:

- User-contributed part of the science archive for end-users
- Link of data products identifiers with publications and usage

Management Systems

- **Transfer:** efficiently move large files over long distances (between on → off-site data centers) with variable-quality link characteristics
- **Bulk Archive:** ensure (mainly DL0) data are preserved long-term and accessible for (re)processing, provide query/ingest/retrieve interface
- **Workload:** Manage efficient execution of workflows onto distributed computing system (data centers, clouds, etc), coupled closely with Bulk archive.
- **Operations:** Provide coordination and control of all DPPS as a whole (incl. web portal, scripting entry point, ACADA interface), and generates reports

Example technology

FTS GridFTP

RUCIO GAMAS eXtreme DataCloud
DIRAC -DMS THE INTERWARE

DIRAC -WMS THE INTERWARE

DIRAC -web THE INTERWARE
(but no full prototype)

Designated Community

- **Designated Community**: Set of consumers who are able to understand the preserved information, via their **Knowledge Base**

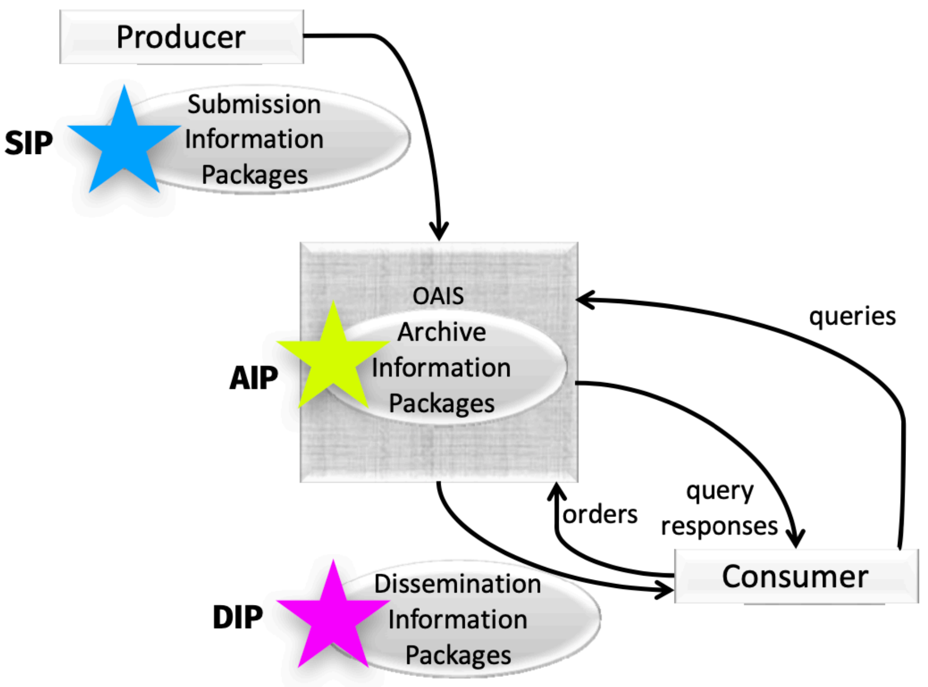
- **Bulk Archive ➔** Internal CTAO Staff
- **Science Archive ➔** CTAO User Community

- The Designated Community may *change over time*, for example:
  - open Bulk Archive more widely in the future, if cost allows
  - provide Science Archive access to machine learning consumers (rather than astrophysicists)

Information, Not Files

- An OAIS focuses on information content
- Basic unit is the Information Package:
  – Content Information (data)
  – Preservation Description Information (metadata)
    - **Provenance**: data source
    - **Context**: relationship to others
    - **Reference:** unique identifiers
    - **Fixity:** e.g. checksum
    - **Access Rights:** terms of access, permissions
    - … (e.g. domain-specific metadata)

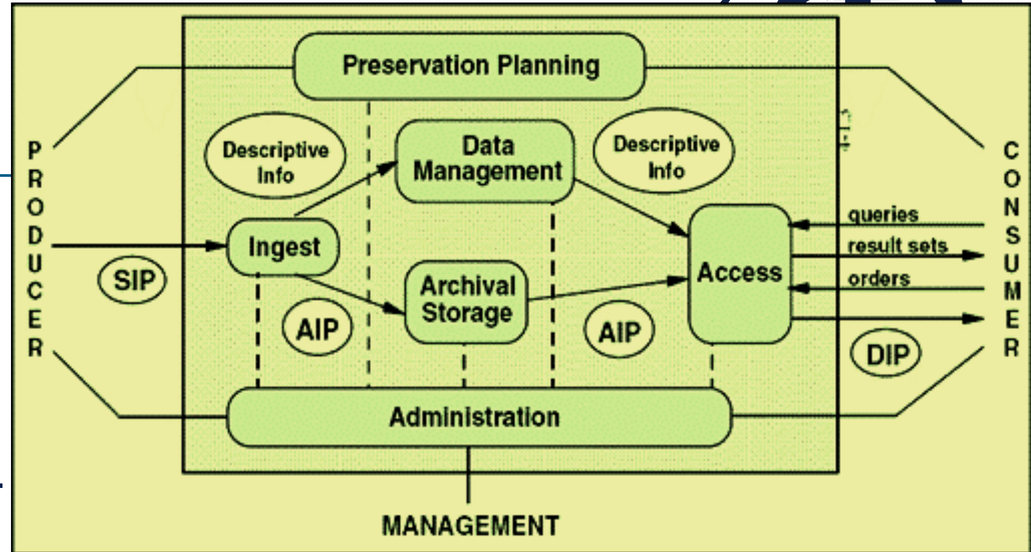
Distinguishes between *3 Information Packages:*



Content may be the same, but the PDI can vary between these.

Archives – Status

- Requirements and use-cases and operating model
- Compliance with OAIS (Open Archival Information System) – organization of people and systems



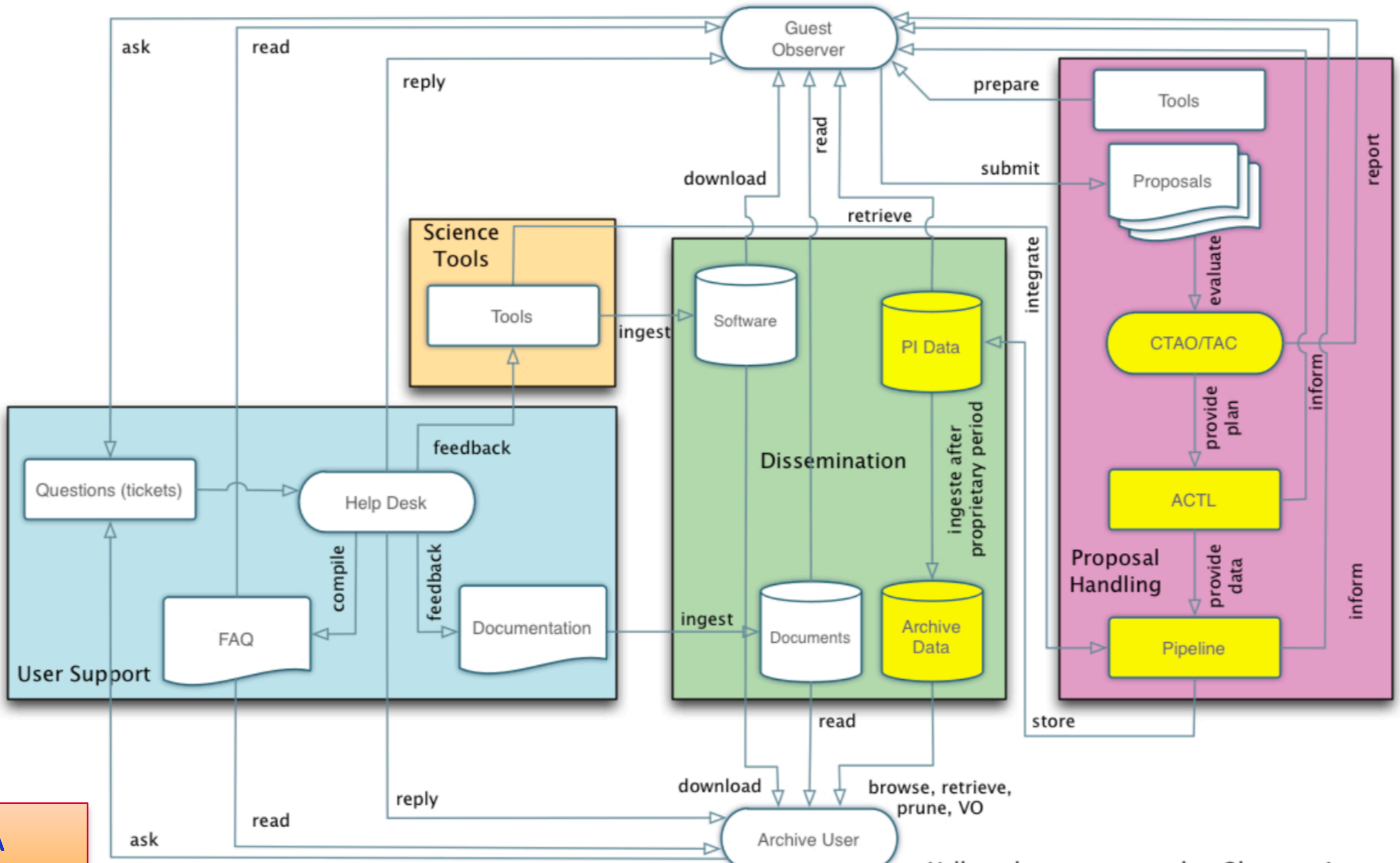
Reference Model *for* an OAIS (ISO 14721:2012)

- CTA archive prototypes exist for both Bulk and Science Archive
  - INAF/ SSDC: INDIGO-DataCloud (H2020) based on OneData
  - LAPP: eXtreme DataCloud (H2020) based on OneData+dcache
  - UniGe/ETH: GAMAS - python-based development
  - LUPM: Data management using DIRAC
- Prototypes – verification and validation – selection

Science User Access

- Major interface between CTAO and the scientific user community
  - Services and tools that are needed by Guest Observers and Archive Users to perform a successful scientific analysis
- User Support
- Dissemination of software to access high-level data (Science Data Access), documentation, and software
- Science Tools – the software to derive images, spectra and light curves (DL4) from processed CTA high-level event data (DL3)
- Proposal Handling

Science User Access



Yellow elements external to Observer Access

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DATA TDR v2.0 2016

Interoperability and Archives

In the time of CTA, SKA, LSST...

- Interoperability of the observatories is key to enable the astronomers to generate the best science
  - Interactions with science community, data products, observatory operations (e.g. scheduling, transients handling/science alerts)
  - Our archives will support interoperability wrt access to archives (and archived data of many observatories)
- CTA contributes to standards definition and develop prototype projects to improve interoperability
  - Member institutes actively involved in IVOA working groups
  - CTA fully supports VO standards and tools – data model and metadata for the data products
  - In the ASTERICS H2020 program: operations, data products, ...
  - In the ESCAPE H2020 program: build a prototype for the European Open Science Cloud

Archives and Interoperability

- CTA Science Archive will support the VO standards and tools
  - CTA data will follow FAIR principles (for metadata and data)
    - Findable, Accessible, Interoperable, Reusable
  - Configuration and Provenance data model in International Virtual Observatory Alliance (IVOA)
  - Data findable via VO registry and VO tools
  - Expose data via (machine-readable) interfaces
- One step further:
  - Integration of Science Archive + Science Gateway + Interactive Data Exploration and Processing to a Science Platform
- Interests/ explorations beyond archives with community/ in H2020:
  - Sharing of observation schedules for coordinated campaigns
  - Common proposal handling tools
  - Setup of multi-observatory federation for A&A
  - Best practices for data processing and science workflows

The Cherenkov Telescope Array

- Will be a unique and versatile instrument for astronomy and astro-particle physics
- Uses experience of H.E.S.S., MAGIC and VERITAS
- Will be the first VHE observatory open to the world-wide community
- Will be the first observatory in TeV band on both hemispheres
- Is in a phase of preparing the production and deployment
  - Design, prototypes, cost-model, quality control
  - Site selection and development
  - Establish project structure and observatory
- Is preparing science operation

The CTA Computing Task

Major challenges ahead to get ready on CTA-sites, the SDMC and the HQ

- CTA – an open Observatory
  - User services and support in the core
- CTA requires well designed software systems in order to manage its almost 120 telescopes as a single efficient system
- Data challenges
  - Several PB/y raw data to be handled
  - High-quality science data products and software tools
- Transparent planning between the Computing Department of CTAO, in-kind contributors from the CTA consortium and industry
- From software prototypes to roll-out of quality software
- Milestones: first telescope acceptance in 2021 and Early Science in 2022