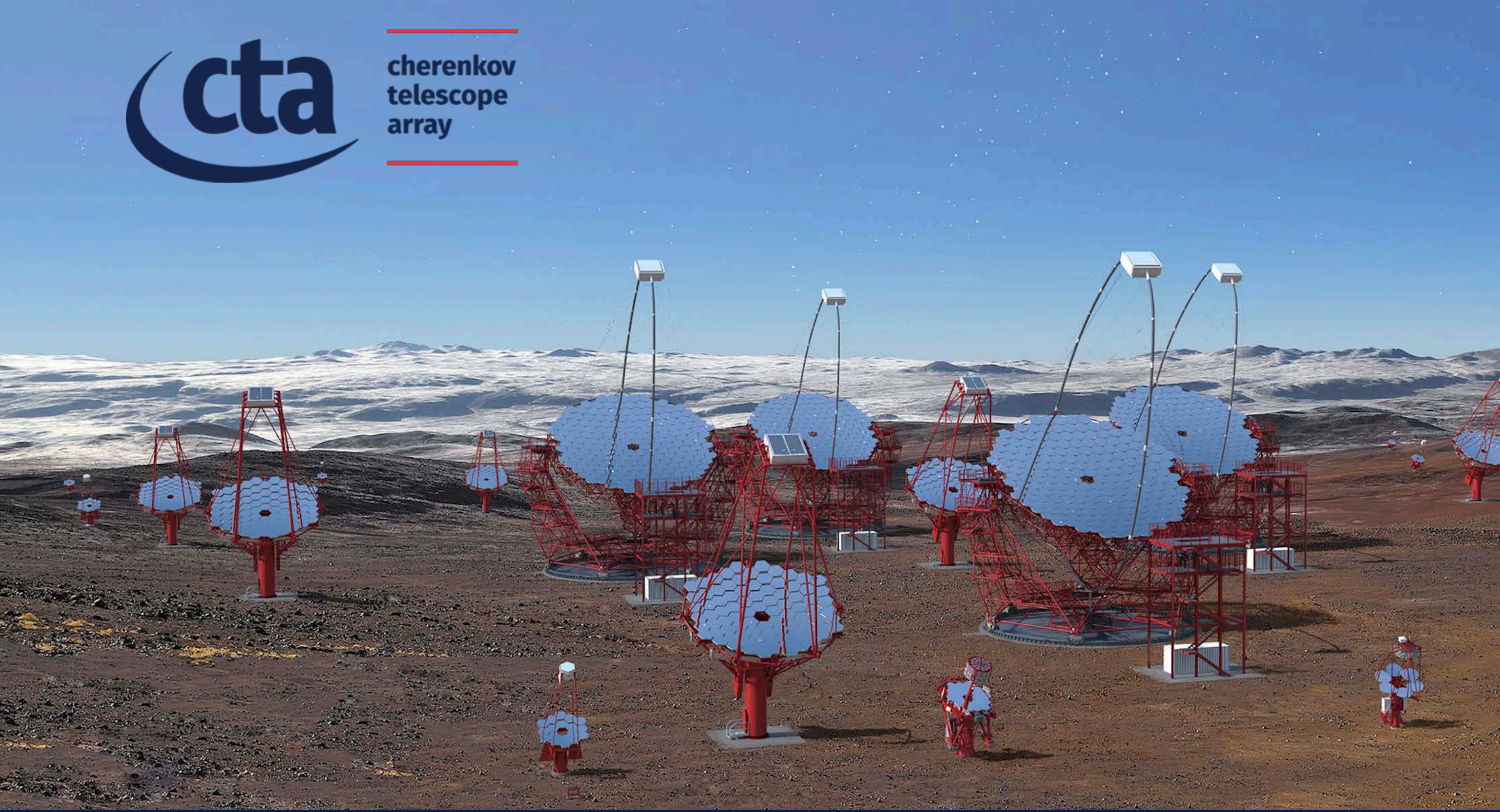
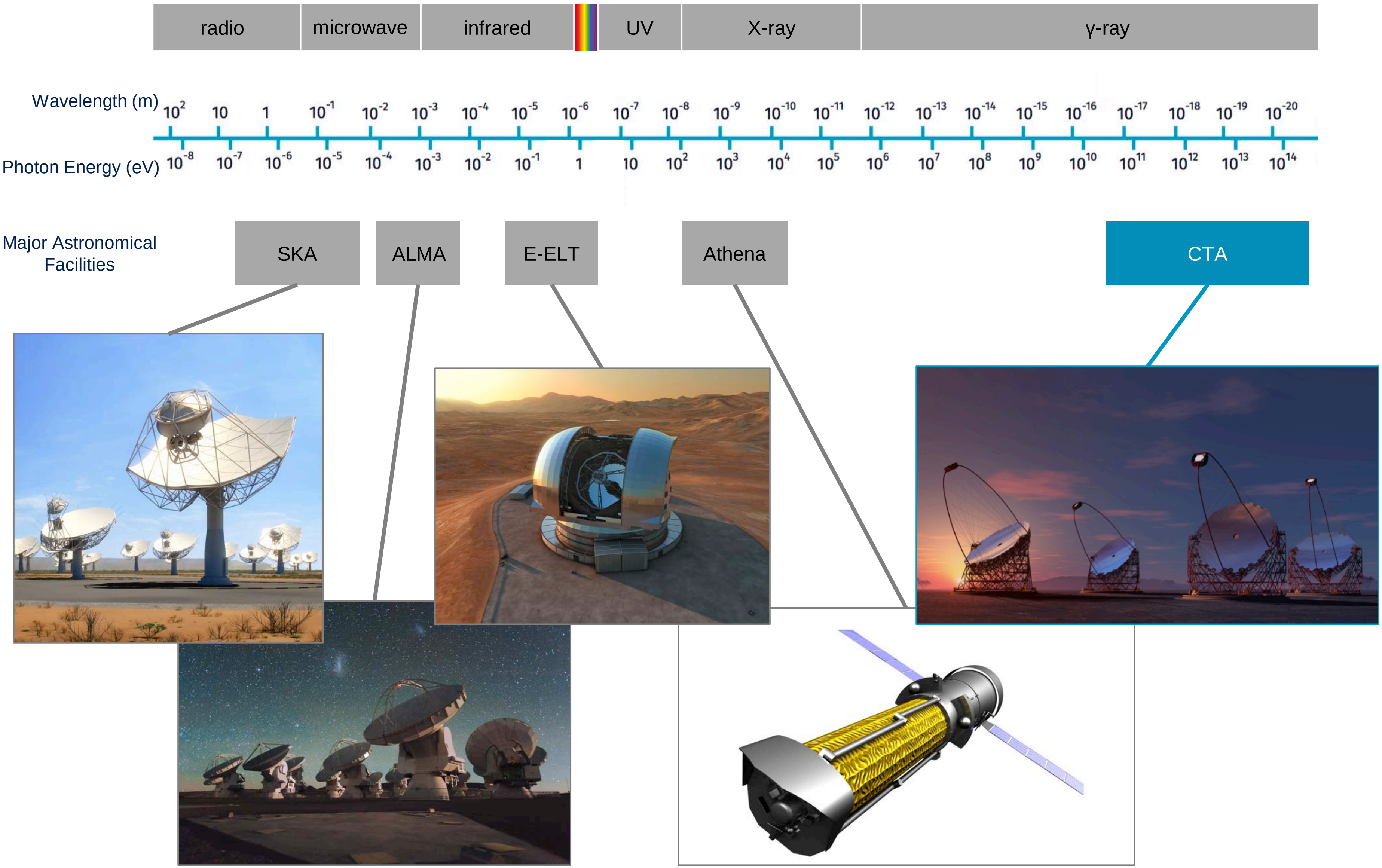


CTA Distributed Operations

Jim Hinton (CTA Project Scientist) 19/10/17

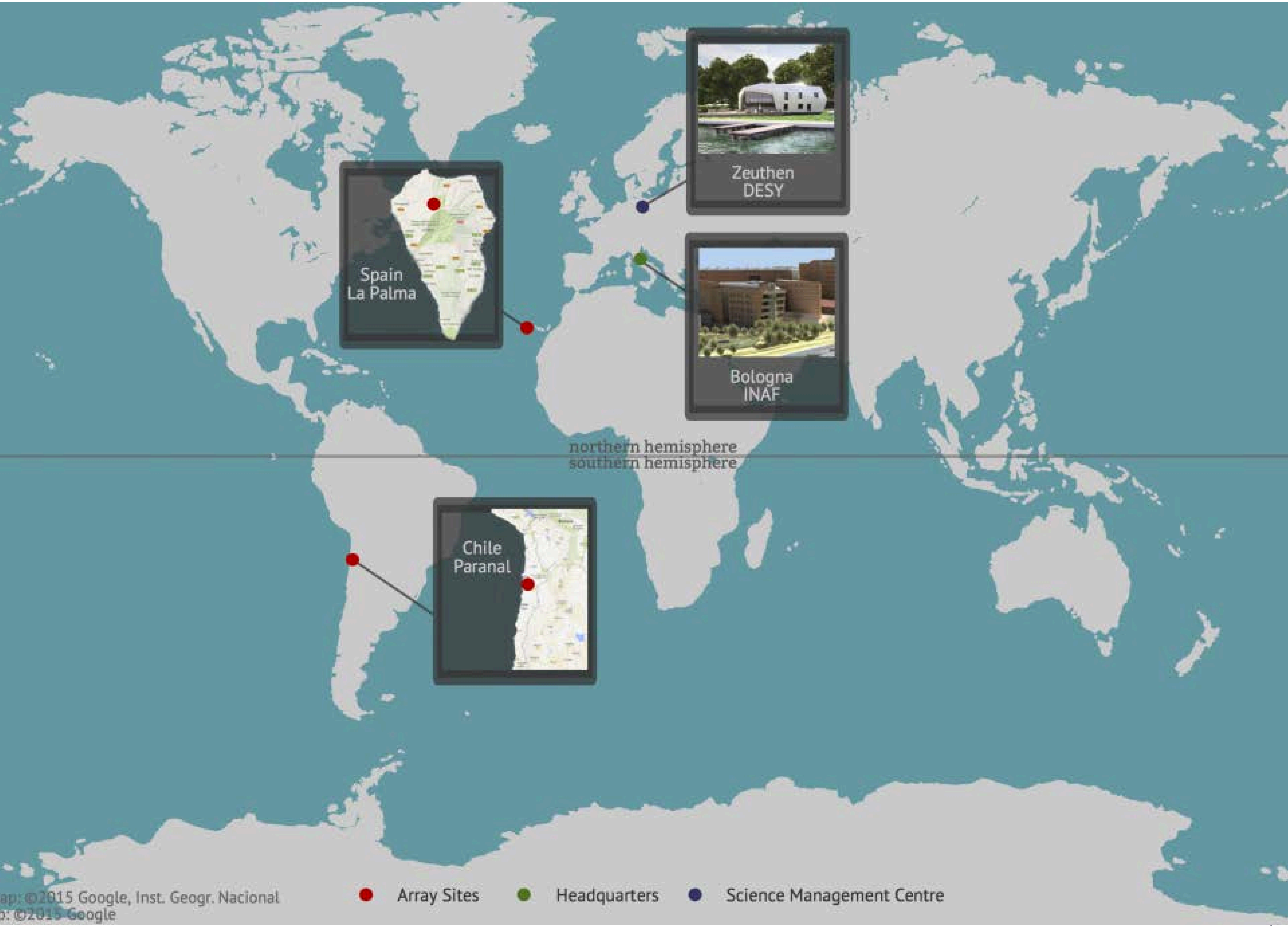
SciOps2017, ESAC Madrid


radio
microwave
infrared
UV
X-ray
γ-ray
Wavelength (m)
10^{2} 10 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13} 10^{-14} 10^{-15} 10^{-16} 10^{-17} 10^{-18} 10^{-19} 10^{-20}
Photon Energy (eV)
10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14}
Major Astronomical Facilities
SKA
ALMA
E-ELT
Athena
CTA

arXiv:1709.07997

Contents

Chapters and corresponding authors:



Zeuthen
DESY
Spain
La Palma
Bologna
INAF
northern hemisphere
southern hemisphere
Chile
Paranal
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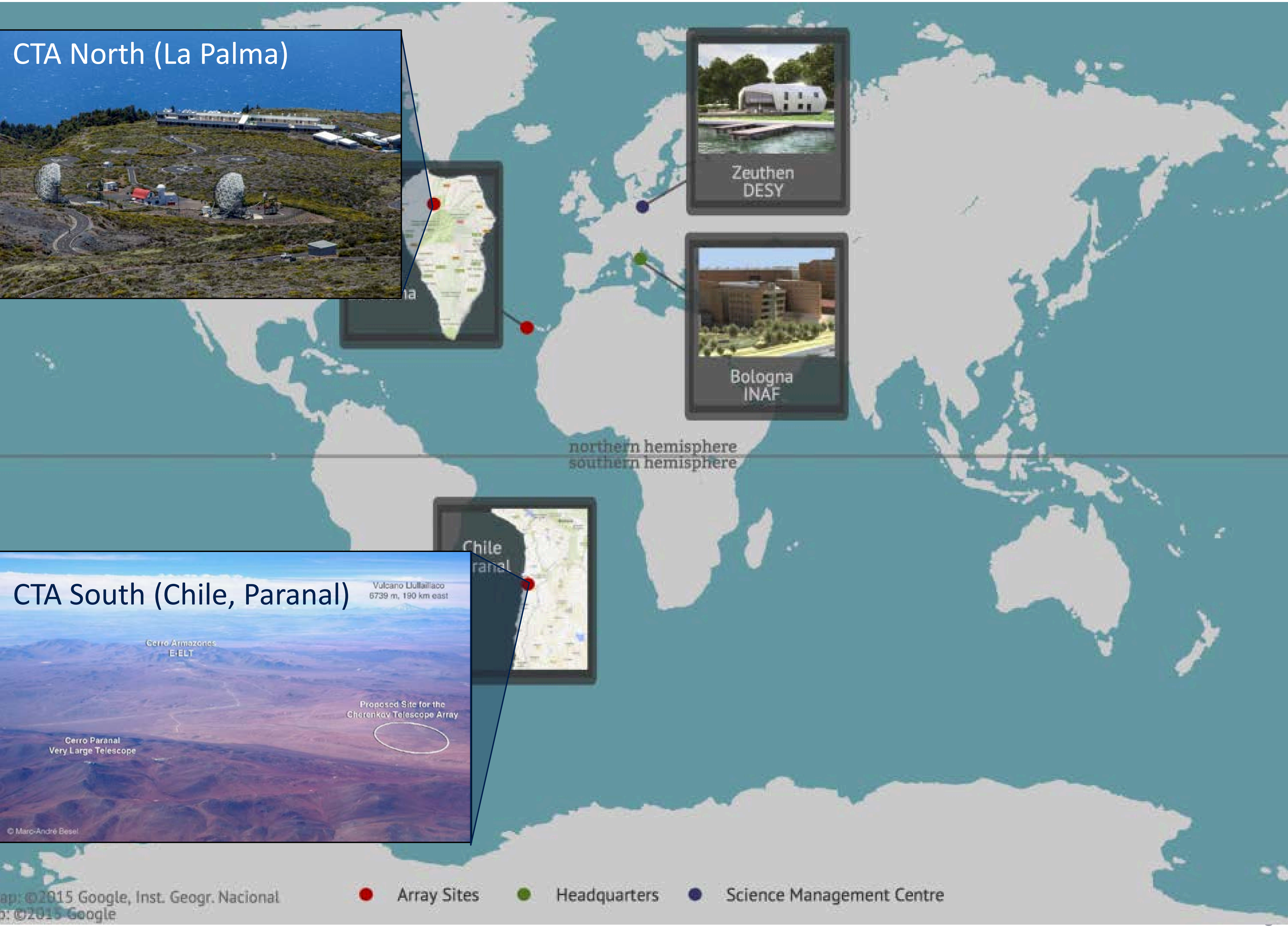
o: ©2015 Google
Array Sites
Headquarters
Science Management Centre



CTA North (La Palma)
Zeuthen
DESY
Bologna
INAF
northern hemisphere
southern hemisphere
Chile
CTA South (Chile, Paranal)
Vulcano Llullaillaco
6739 m, 190 km east
Cerro Armazones
E-ELT
Proposed Site for the
Cherenkov Telescope Array
Cerro Paranal
Very Large Telescope
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Array Sites
Headquarters
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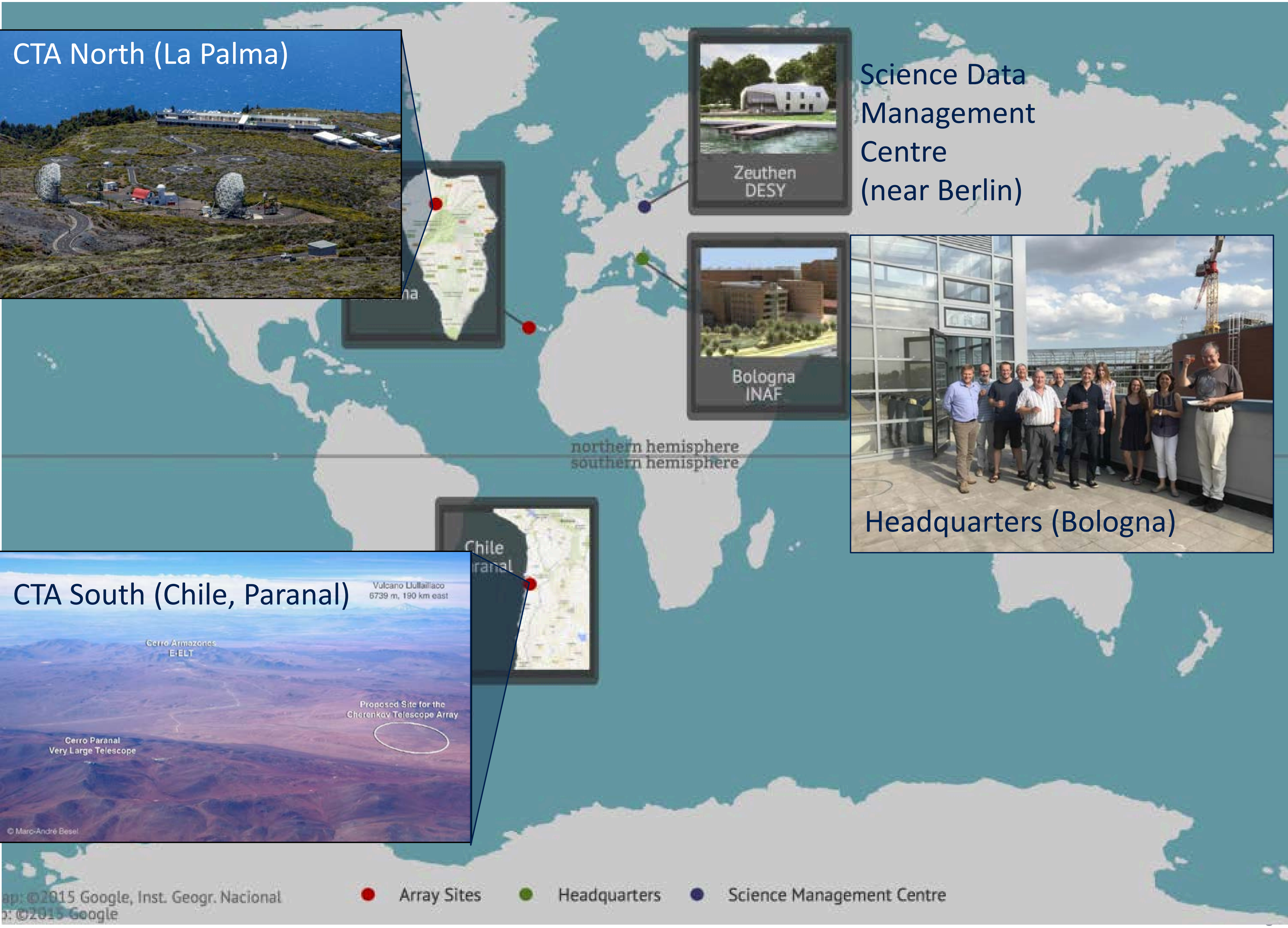
CTA North (La Palma)
Science Data Management Centre (near Berlin)
Zeuthen DESY
Bologna INAF
Headquarters (Bologna)
northern hemisphere
southern hemisphere
Chile
CTA South (Chile, Paranal)
Vulcano Llullaillaco
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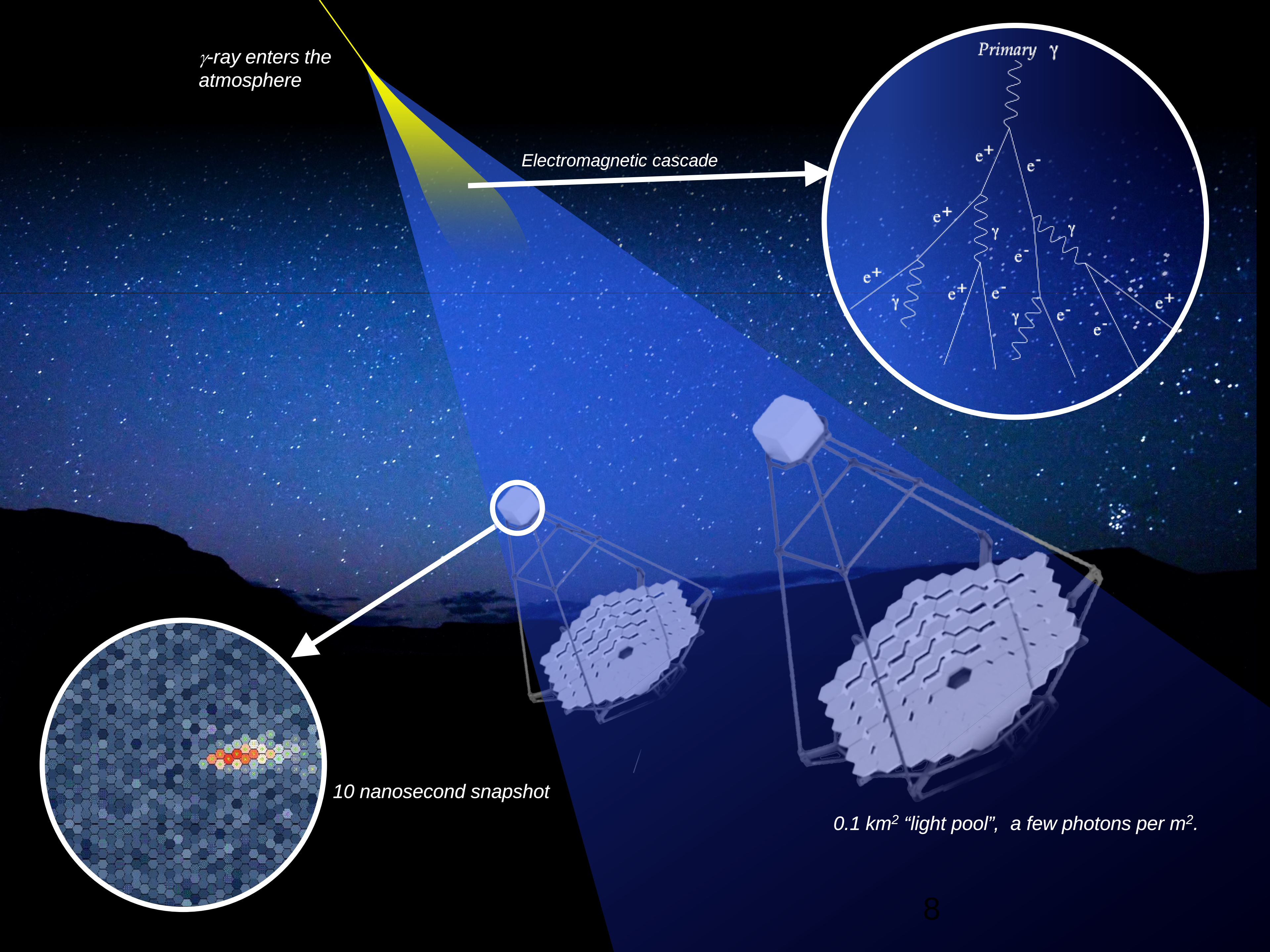
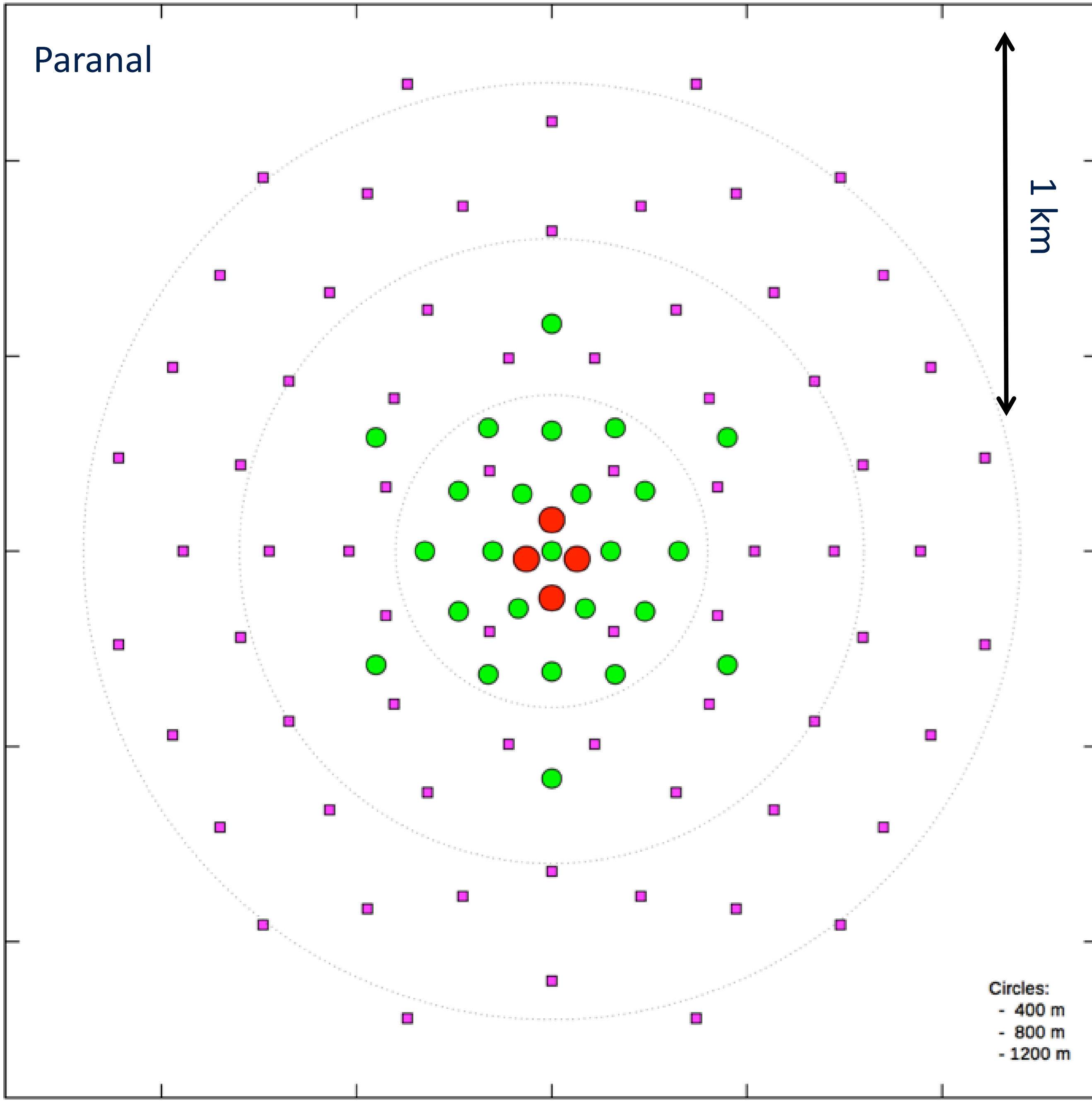
Array Sites
Headquarters
Science Management Centre

- CTA Consortium of >1000 scientists from 32 nations

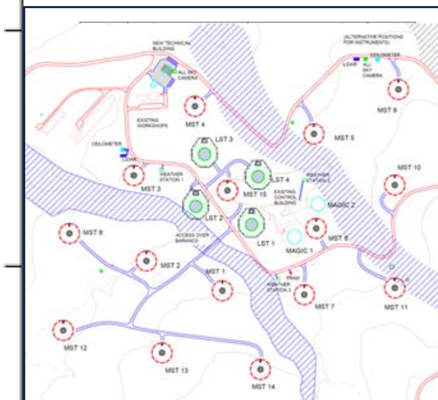


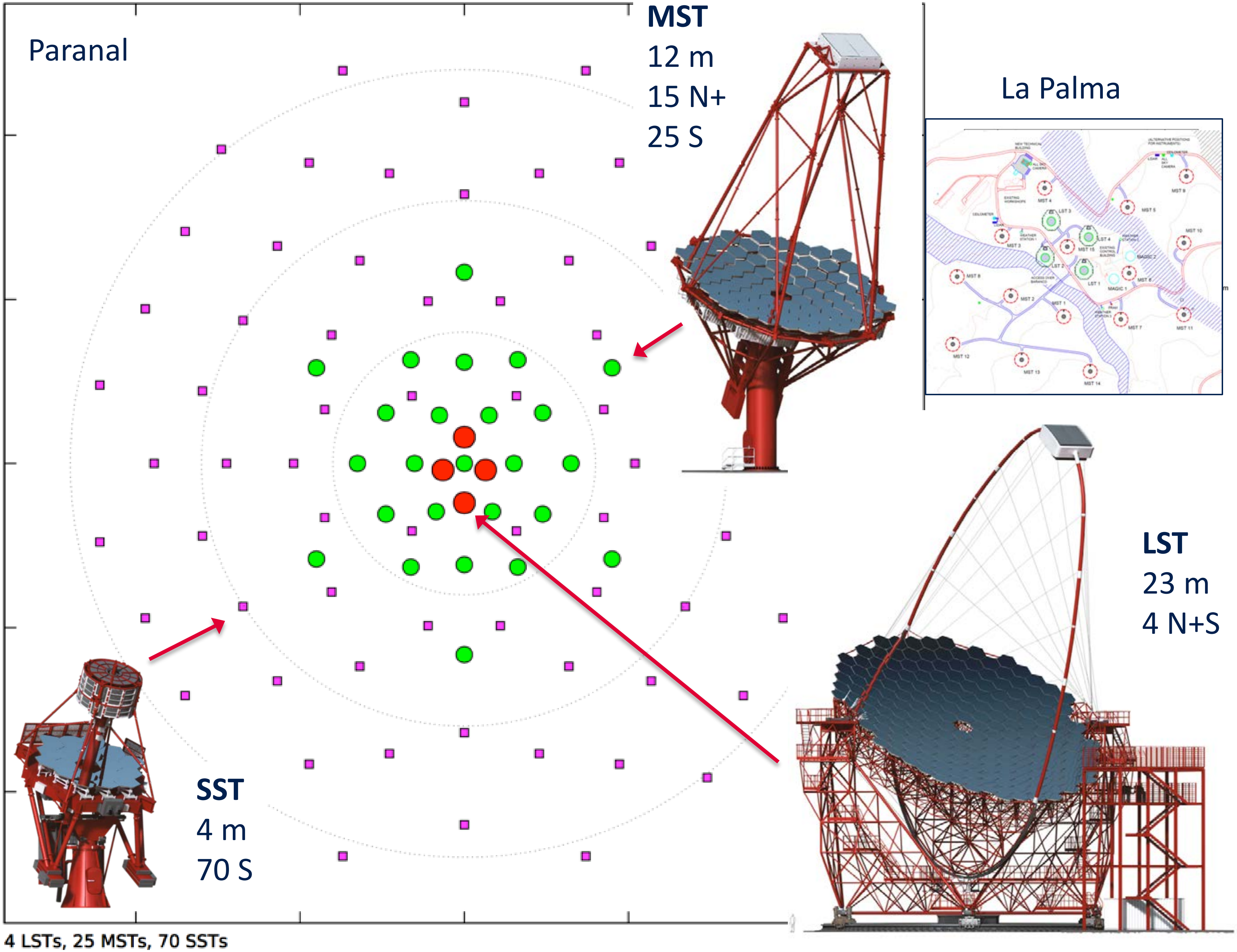
γ-ray enters the atmosphere
Electromagnetic cascade
Primary γ
e+
e-
γ
10 nanosecond snapshot
0.1 km² "light pool", a few photons per m².



4 LSTs, 25 MSTs, 70 SSTs

La Palma

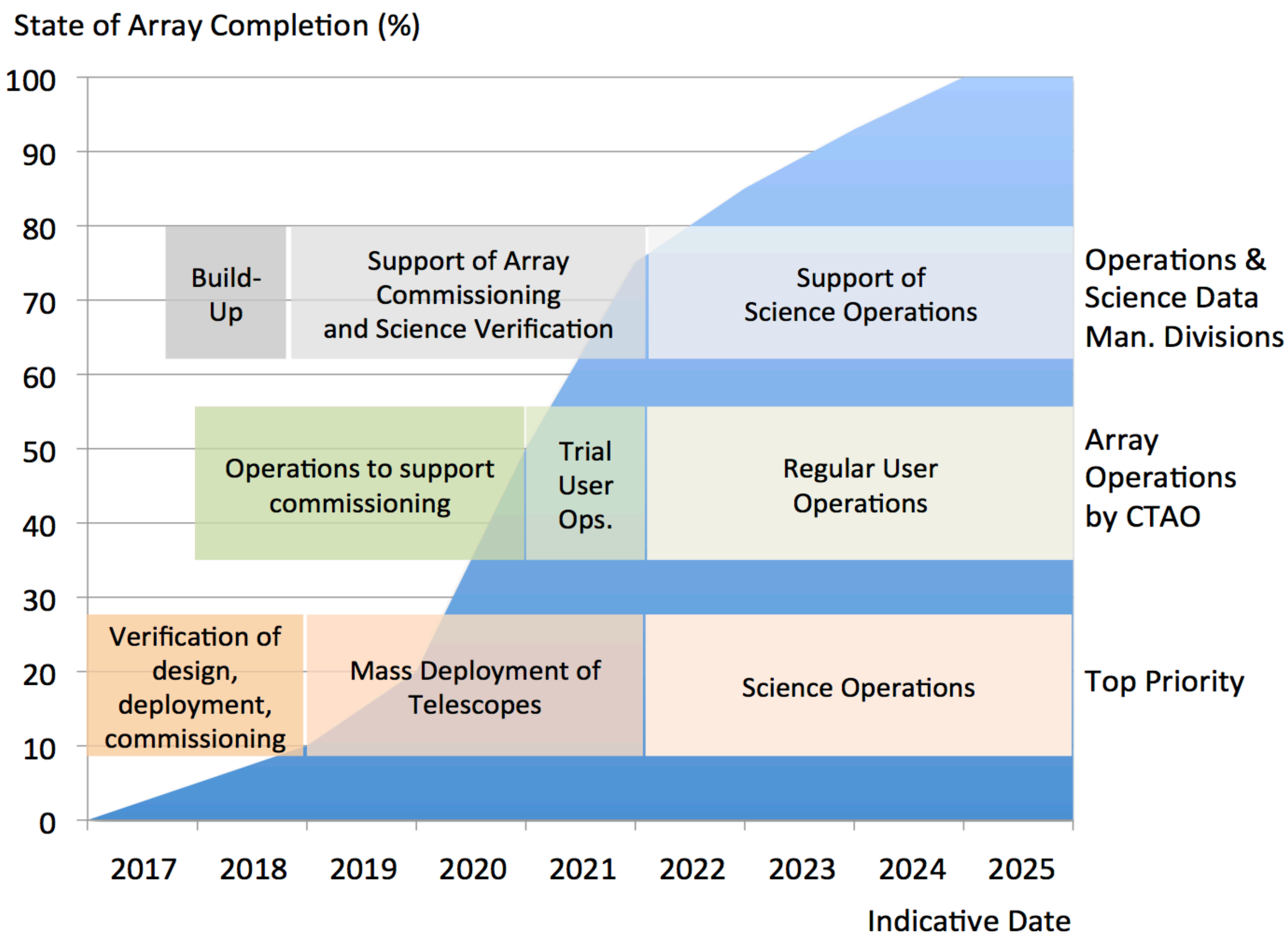



Paranal
MST
12 m
15 N+
25 S
La Palma
LST
23 m
4 N+S
SST
4 m
70 S
4 LSTs, 25 MSTs, 70 SSTs

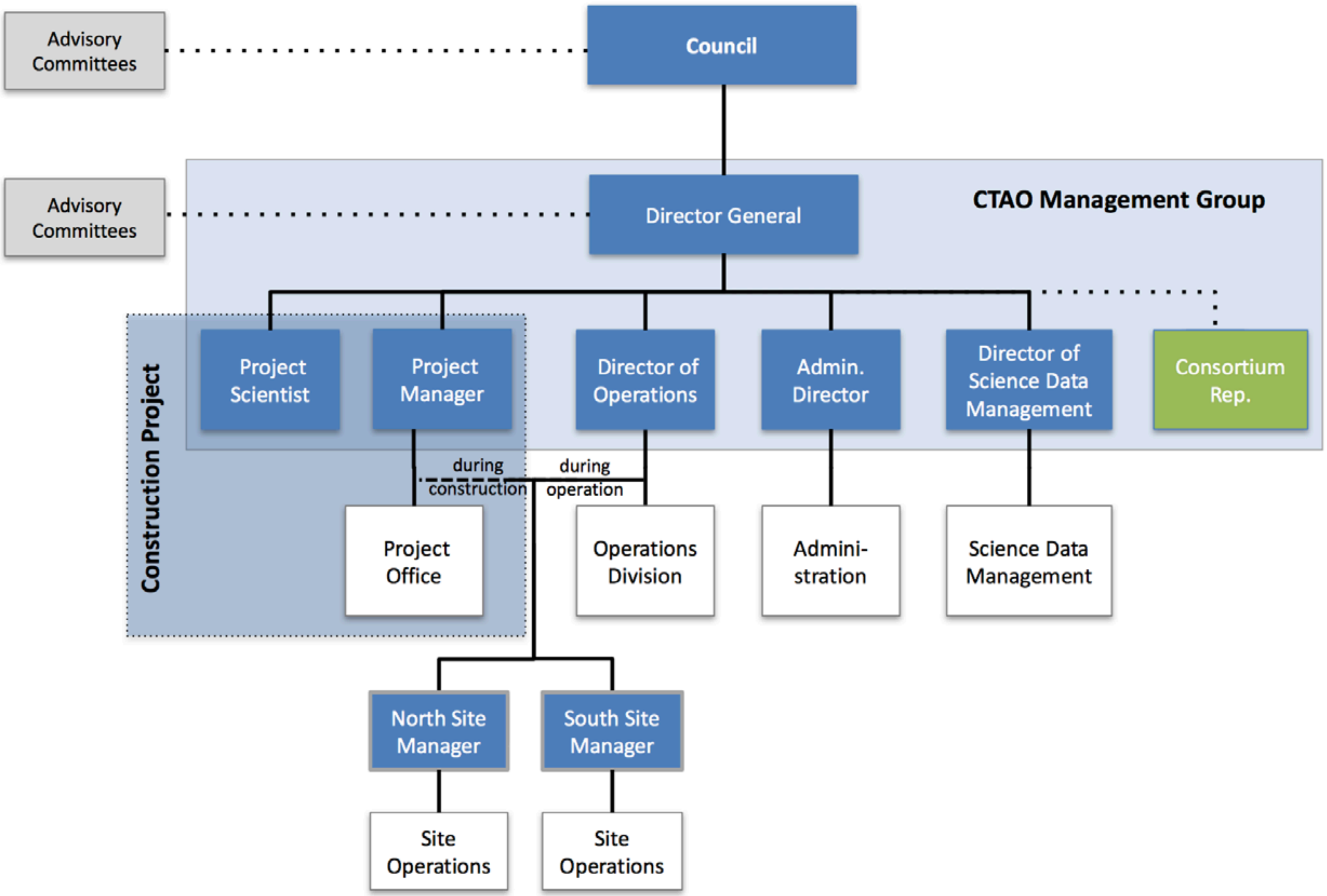
The Observatory

- An Open Observatory / User Facility
  - For the first time in this waveband
  - Annual AoO, TAC ranking, long-term schedule
  - Proposal preparation support, tracking, helpdesk +
  - Public science data archive
    - After proprietary period
- Two Telescope Arrays – one Observatory
  - Inter-site coordination
  - Uniform approach to science operations
- Main Challenges
  - Sub-array operation, wide field of view, instrument response generation, background modelling, rapid alert generation and response, data volume, science operations during construction

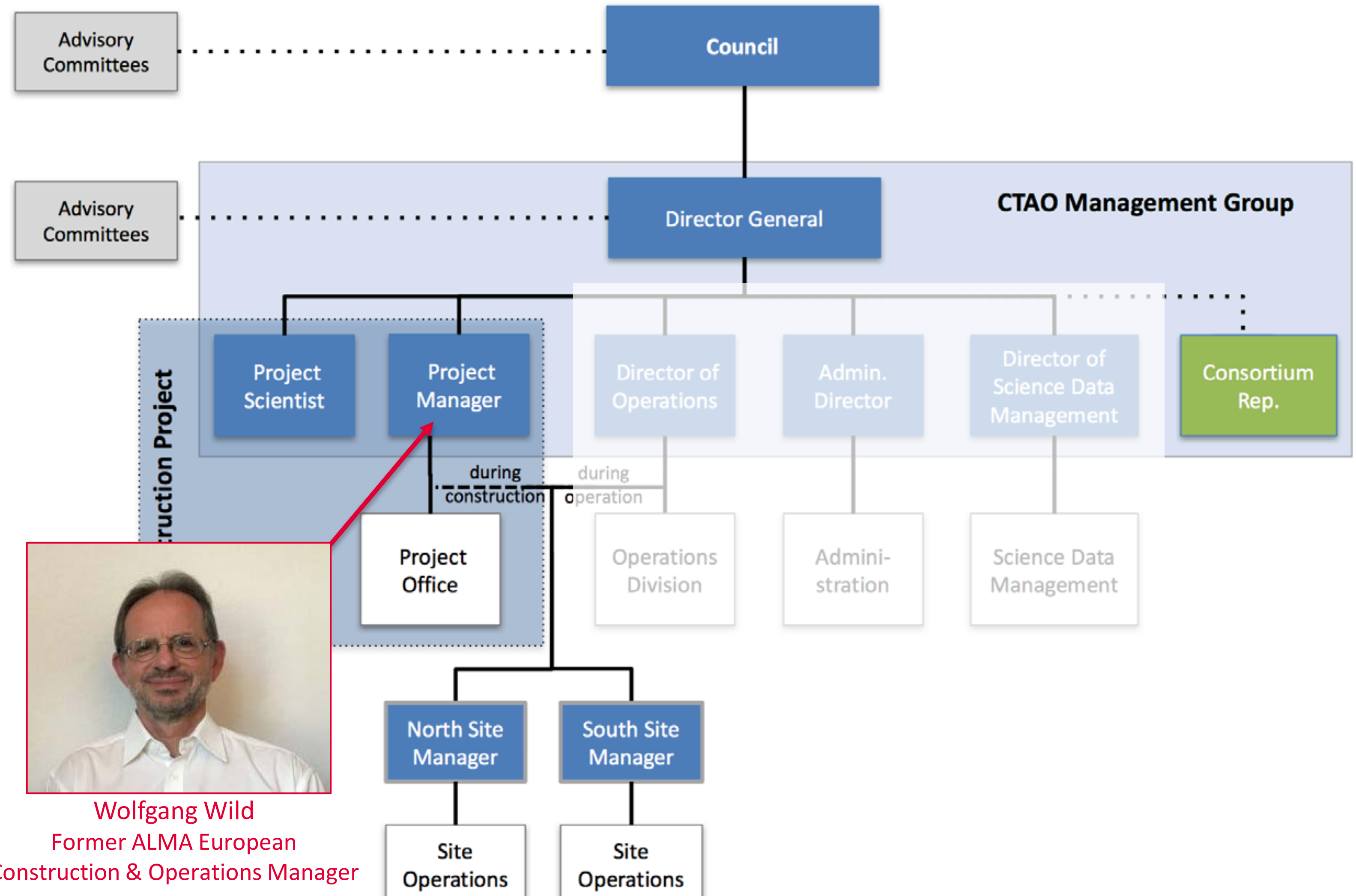
Phasing


State of Array Completion (%)
100
90
80
70
60
50
40
30
20
10
0
Build-Up
Support of Array Commissioning and Science Verification
Support of Science Operations
Operations & Science Data Man. Divisions
Operations to support commissioning
Trial User Ops.
Regular User Operations
Array Operations by CTAO
Verification of design, deployment, commissioning
Mass Deployment of Telescopes
Science Operations
Top Priority
2017
2018
2019
2020
2021
2022
2023
2024
2025
Indicative Date

Organisation



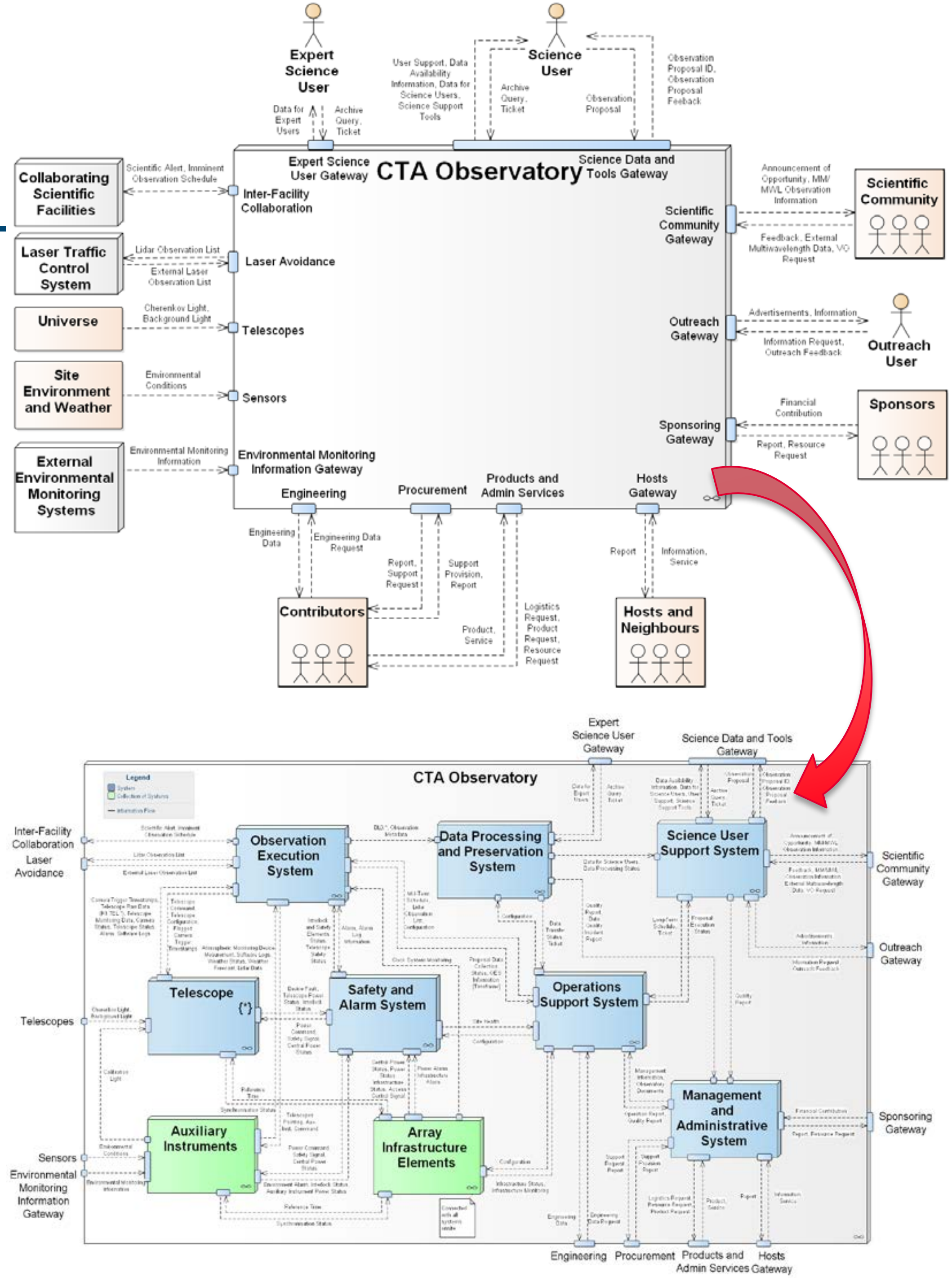
Organisation

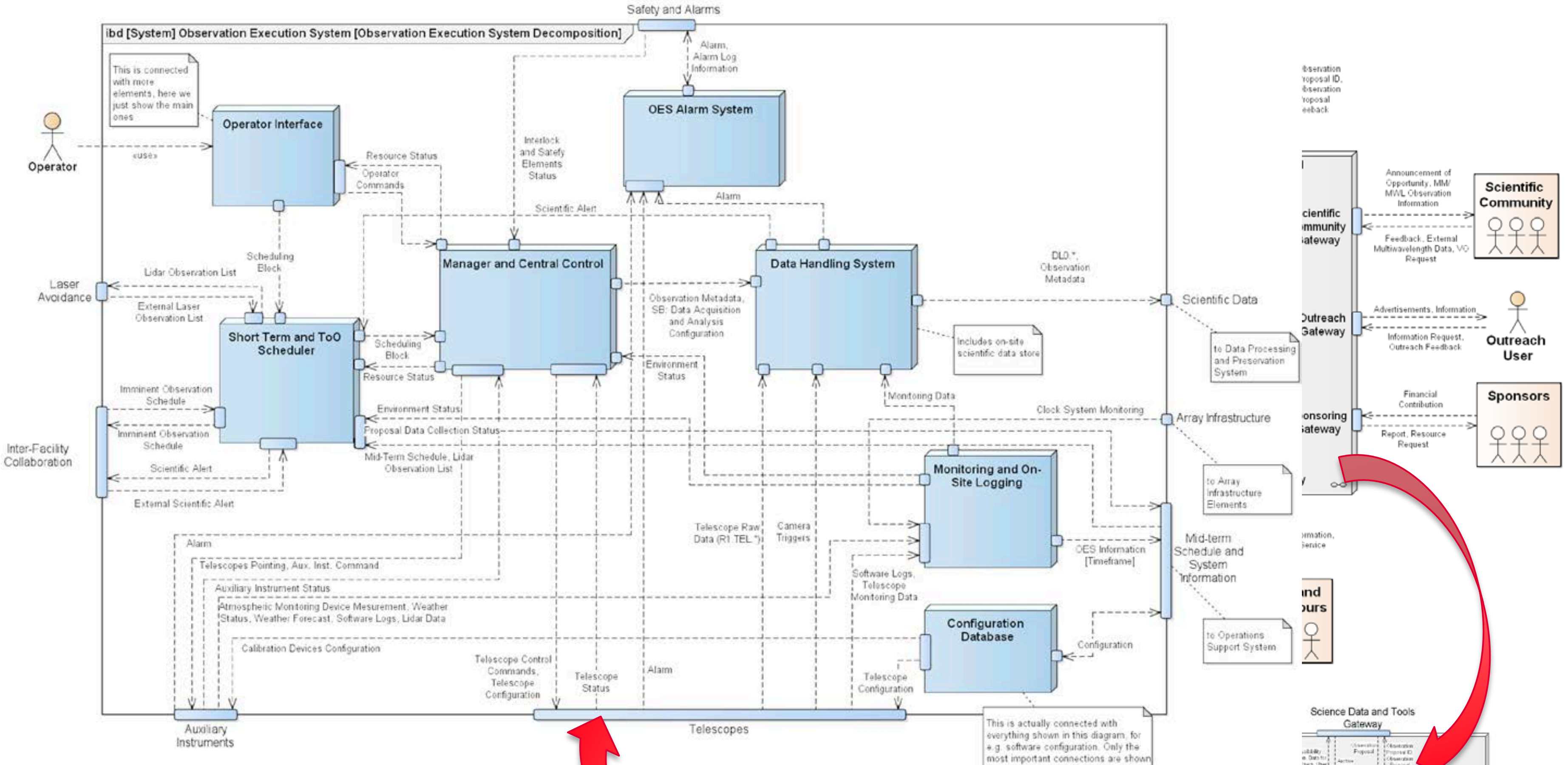


Wolfgang Wild
Former ALMA European
Construction & Operations Manager

CTAO As A System

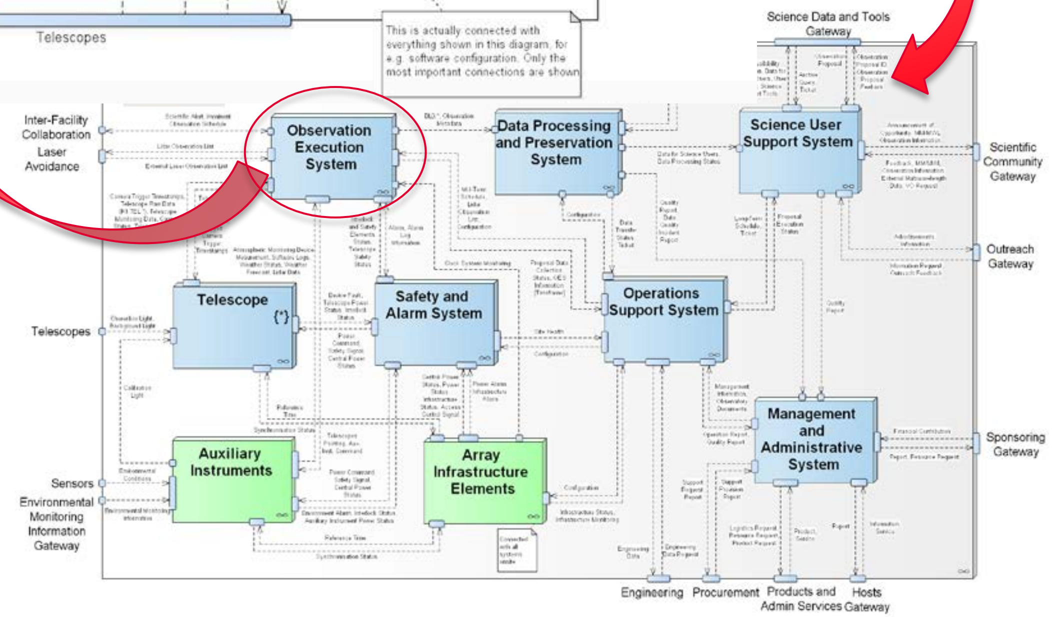
- System Architecture Definition
  - From observatory objectives and user needs → high-level operations processes → lower-level processes →actions
  - System decomposition, assignment of actions to systems / roles
- CTAO Team + Fraunhofer IESE (consultants)

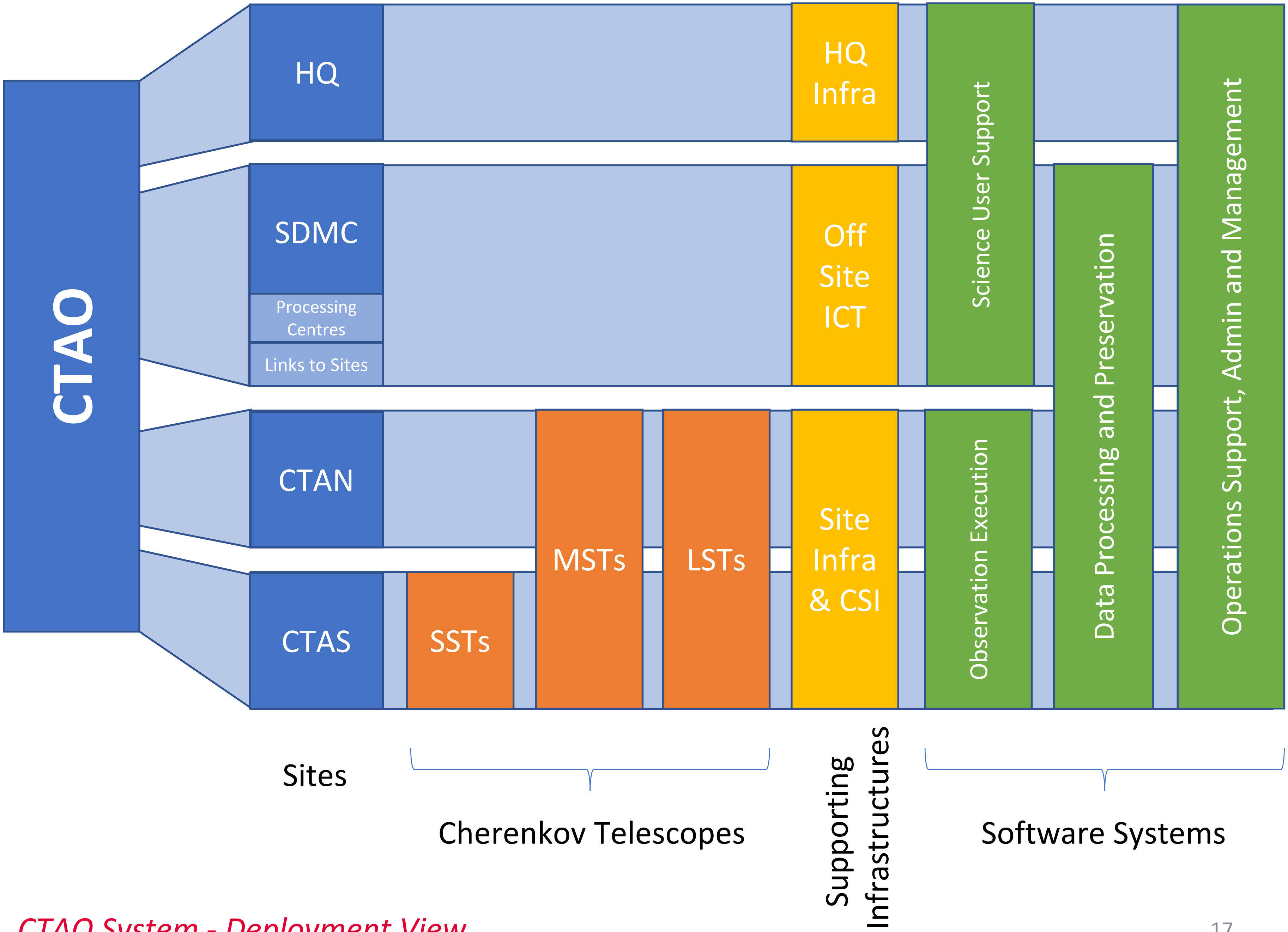




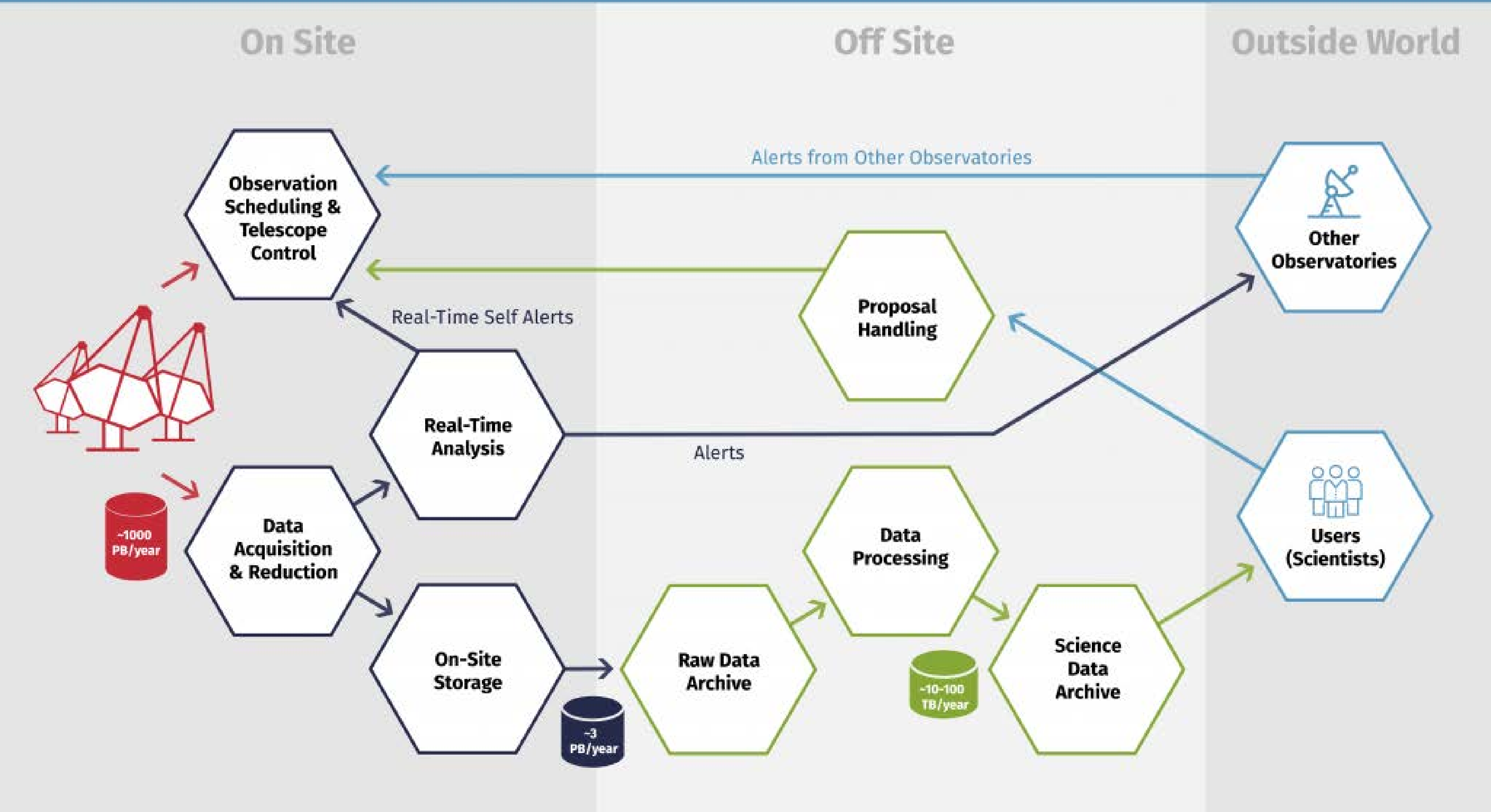
assignment of actions to systems / roles

- CTAO Team + Fraunhofer IESE (consultants)





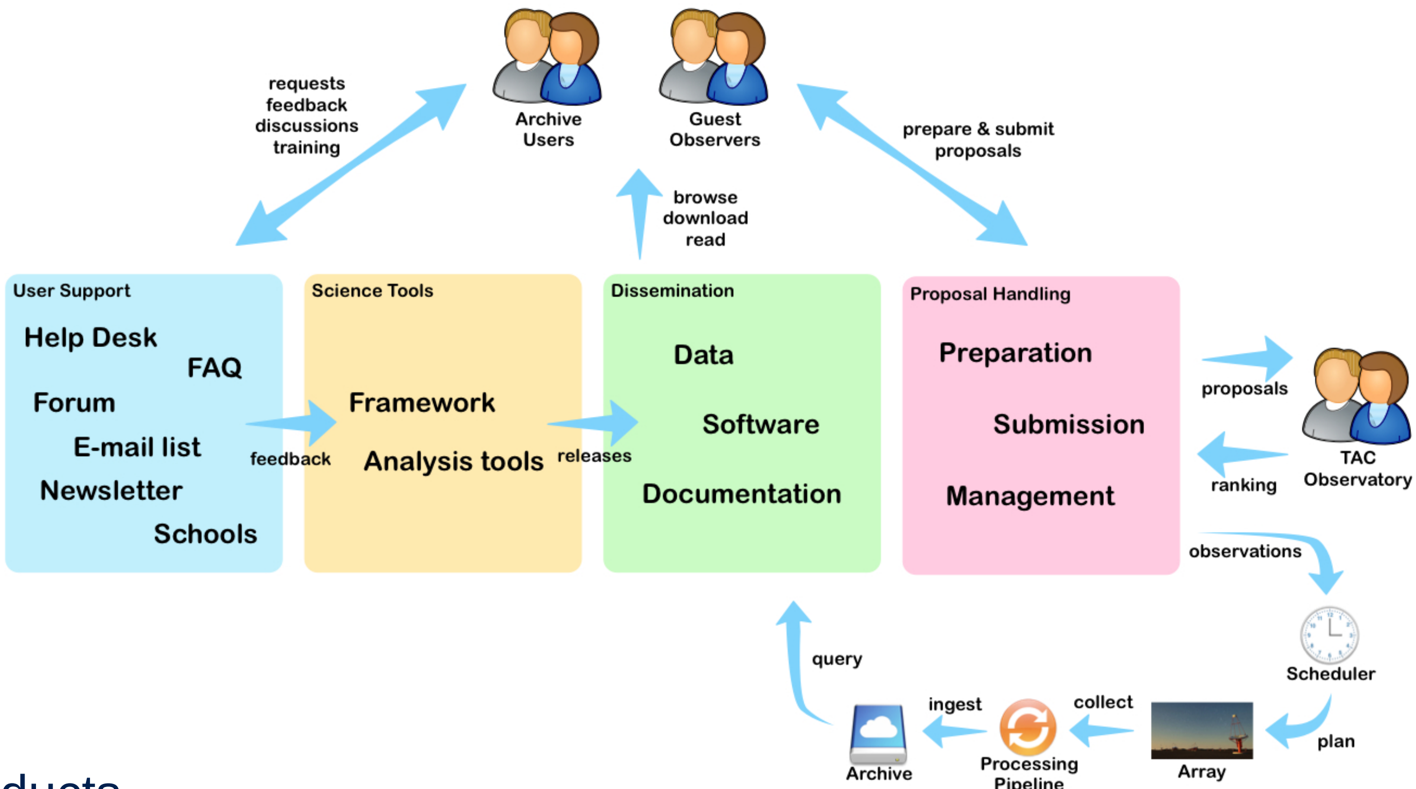
CTAO System - Deployment View



Observation Execution	Data Processing and Preservation	Science User Support

Initial calib./reduction →Transmission from site → Bulk data archive → Science data archive

Science User Perspective

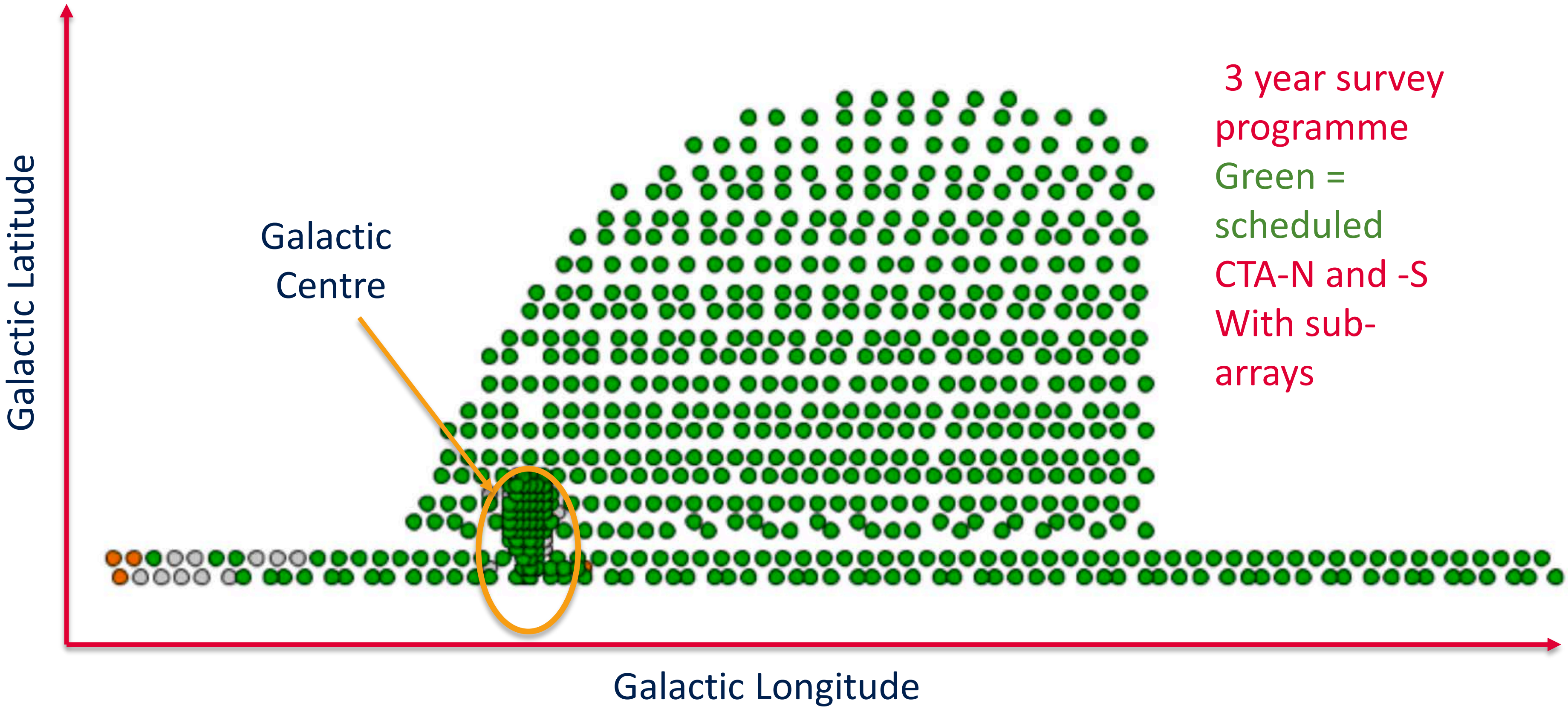


- Products
  - Photon (candidate) event list data (FITS)
  - Instrument response functions, background model
  - Science analysis tool suite, supporting documentation

Scheduling of Observations

- Many challenges
  - Coordination between sites, fast response to ToOs and internally generated science alerts, reoptimisation triggered by changing conditions, mixing technical and science ops, wide field of view → merging of proposals → pointings, sub-array operation (decision making on array splitting)
- Three step process:
  - Long-term – annual AO → TAC ranking – target grouping
  - Medium-Term – adaptation through season (weather++), technical and calibration actions, inter-site coordination
  - Short-term - automatically refined/adapted night time schedule, ToO reaction – preparing for complex inputs – e.g. gravitational wave error boxes, inter-observatory coordination
- Fairly advanced prototype – tested for first ‘Data Challenge’
  - Scheduling of surveys planned as Key Science Projects

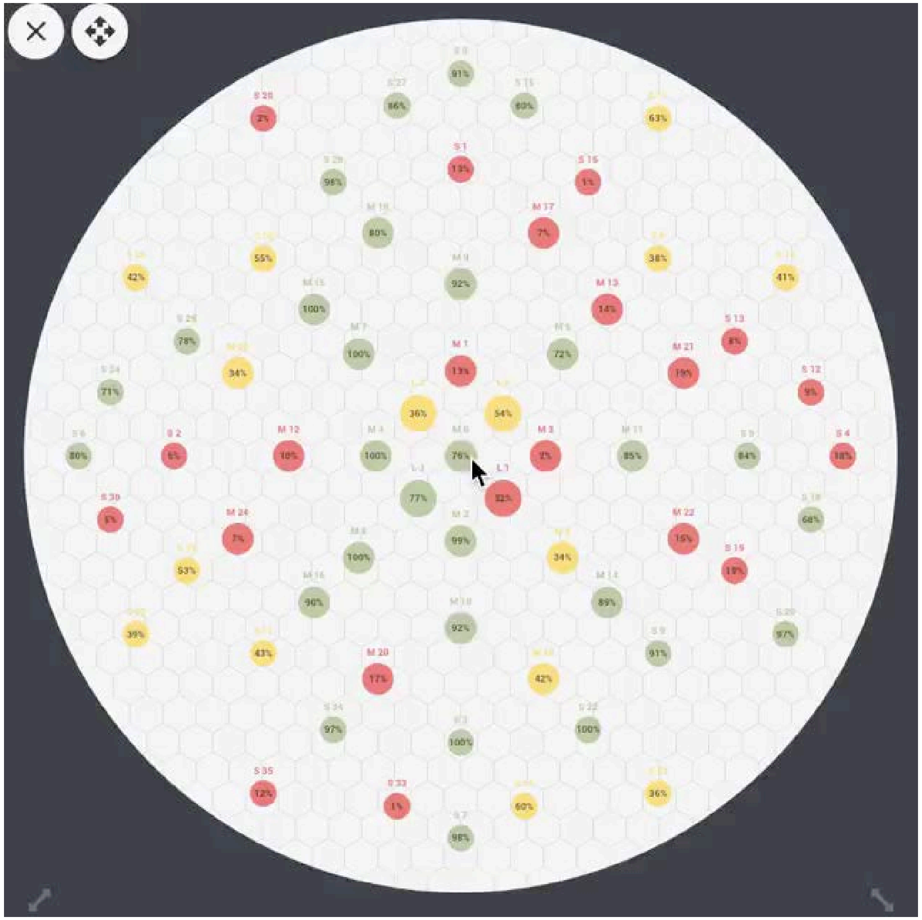
Scheduling



- Fairly advanced prototype – tested for first ‘Data Challenge’
  - Scheduling of surveys planned as Key Science Projects

Data Collection

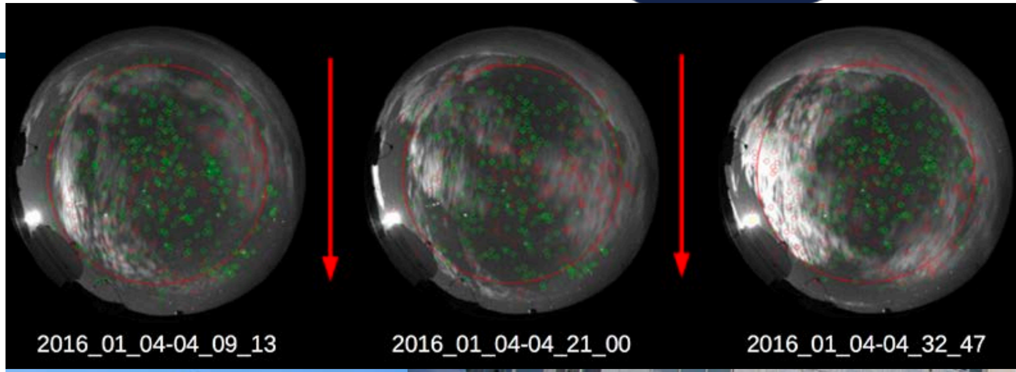
- Observation Execution System
  - Telescope control / sub-array operation
  - Data collection and first reduction/calibration steps
  - Science Alert Generation within 1 min.
  - ToO Handling
  - Dynamical adjustment of schedule based on atmo. monitoring input

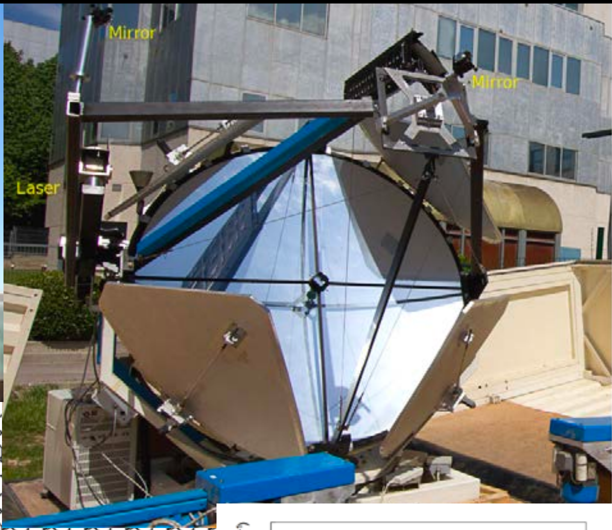


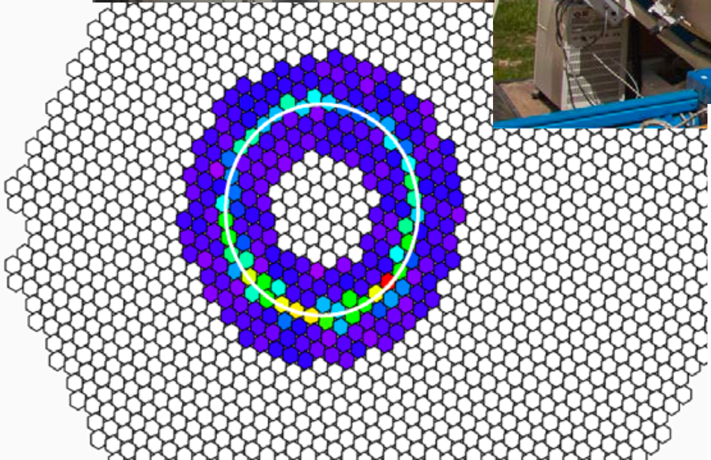
Prototype using ALMA Common Software (ACS) Framework fairly advanced

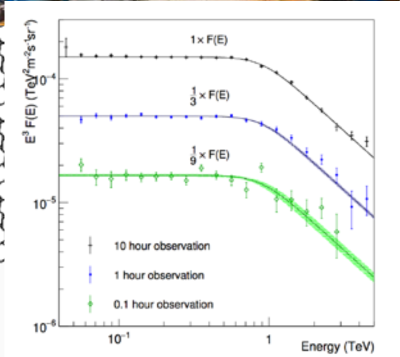
Atmospheric Monitoring + Calibration

- Atmospheric Monitoring
  - All sky camera for clouds
  - Ceilometer for height
- Atmospheric Calibration
  - Ramen LIDAR (scattering height profile), Small robotic telescope (transmission)
- Telescope Calibration
  - Multi-λ calibrated light flashers
  - Air showers and **muons**
    - Ring image of known intensity
  - +end-to-end cosmic ray **electrons**
    - Present in every field, look like γs, convenient spectral feature!

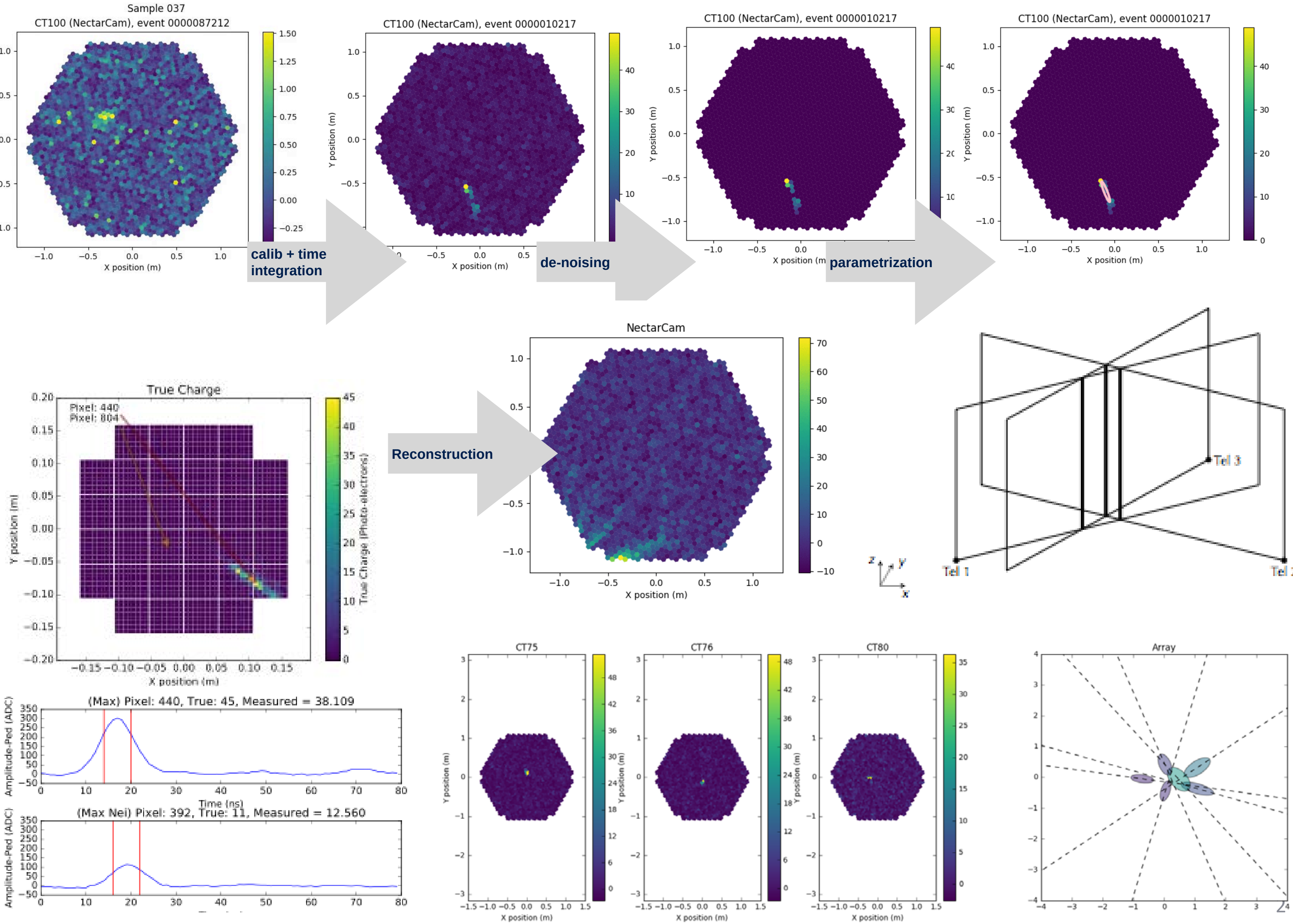


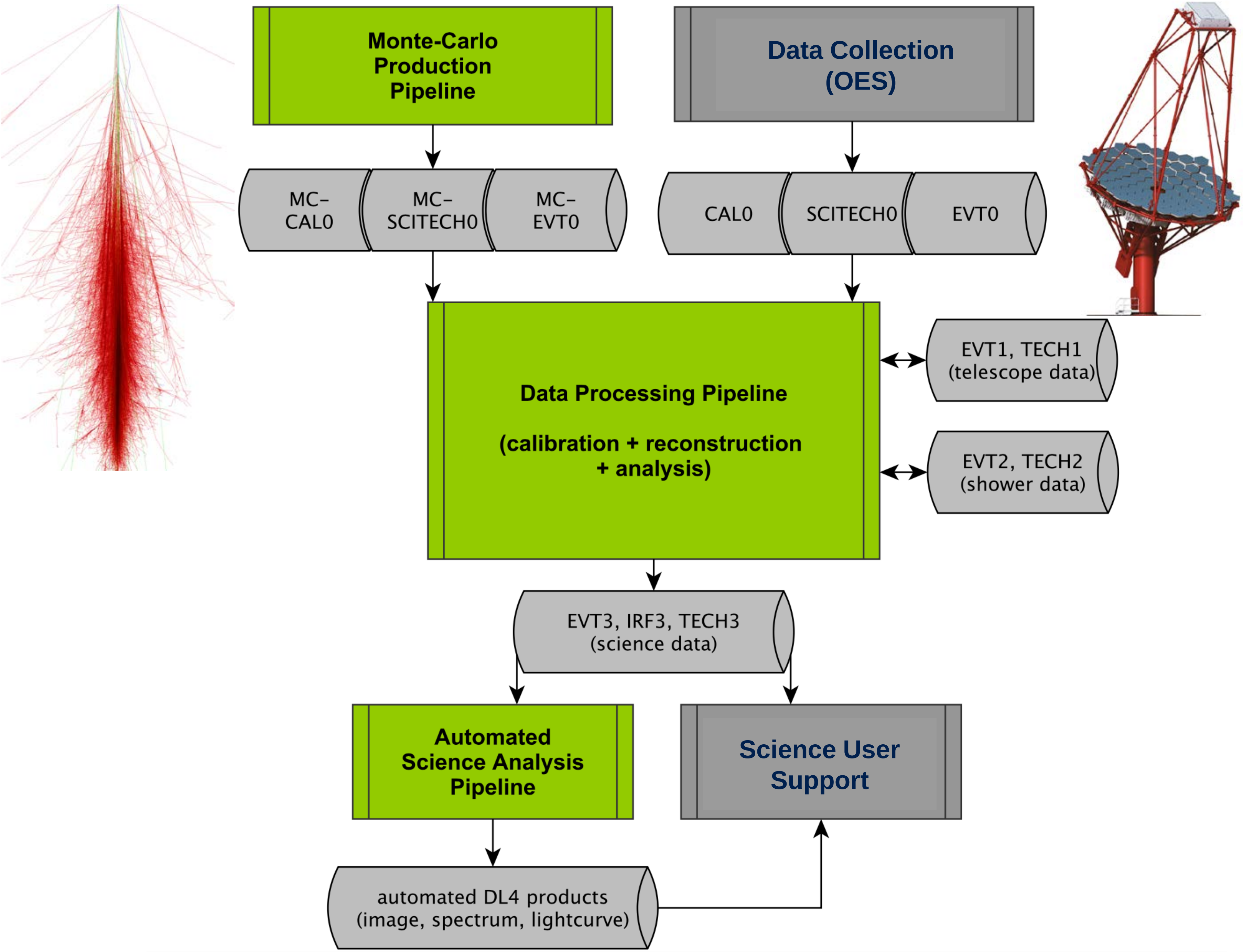






K. Kosack *ctapipe example*



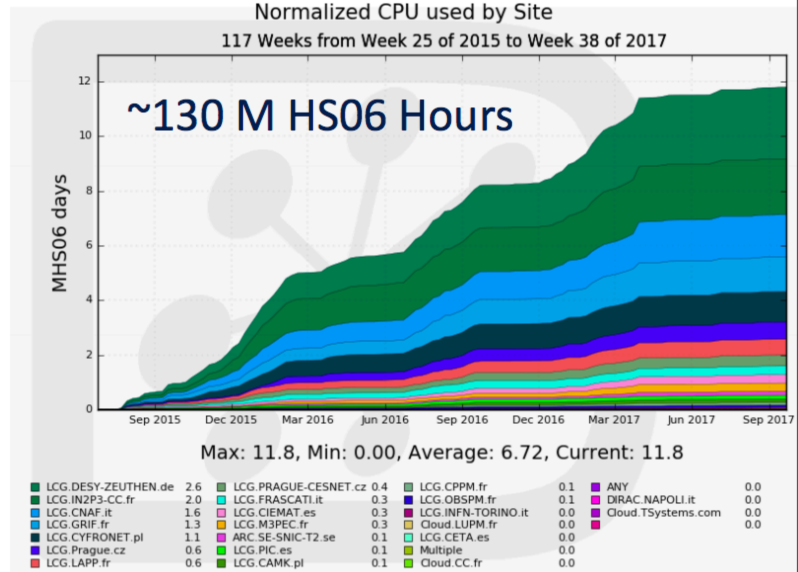

Monte-Carlo Production Pipeline
Data Collection (OES)
MC-CAL0
MC-SCITECH0
MC-EVT0
CAL0
SCITECH0
EVT0
Data Processing Pipeline
(calibration + reconstruction + analysis)
EVT1, TECH1 (telescope data)
EVT2, TECH2 (shower data)
EVT3, IRF3, TECH3 (science data)
Automated Science Analysis Pipeline
Science User Support
automated DL4 products (image, spectrum, lightcurve)

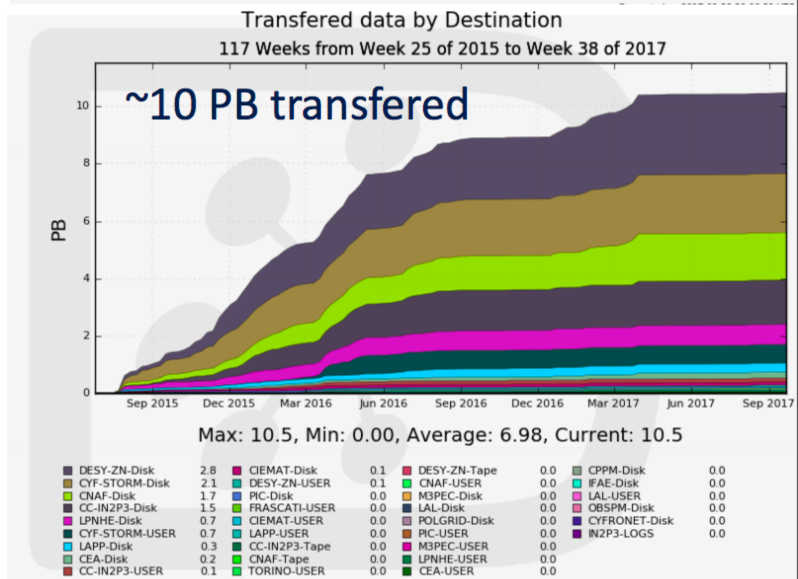
“Monte-Carlo” Simulations

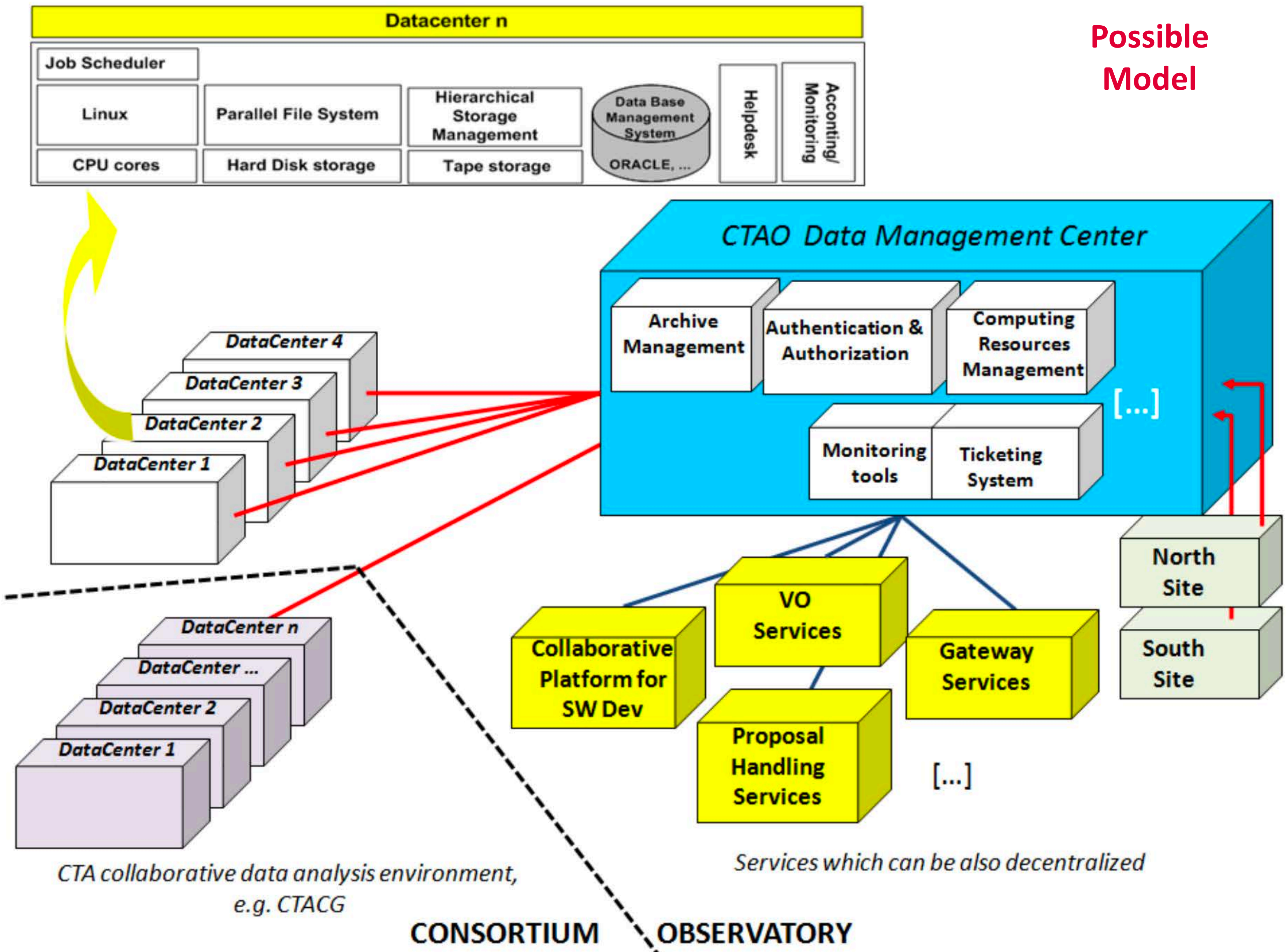
- Instrument response function generation for CTA is based on simulations (showers → atmosphere → telescope → electronics)
  - Energy dispersion matrix (E)
  - Point-spread function (E)
  - Effective Collection Area (E)
- All are functions of:
  - Site, Azimuthal Angle (geomagnetic effects), Atmospheric density profile (season), Aerosol optical depth height distribution
  - Sub-array configuration, Telescope configuration (mirror reflectivity, +++)
  - Zenith angle
- Huge phase space. Favoured solution:
  - Specific simulation tuned to the specific conditions / configuration used during a given observation
  - Challenging to generate and to deliver to end user in a simple way (time-dependence, FoV position-dependence, …)

Computing

- Approach used for design optimisation simulations
  - Site selection, array layout, telescope design …
- GRID-based approach using DIRAC
  - 130M HS06 CPU-Hours used
  - 10 PB transfered
  - CTA Grid Members: IN2P3-CC, DESY-ZN, CNAF, CYFRONET,GRIF,IN2P3-CPPM, IN2P3-LAPP, FASCATI, OBSPM, PIC, CESNET, CAMK, CIEMAR, INFN-Torino, M3PEC, …
- Model with distributed resources heavily explored for operations phase -

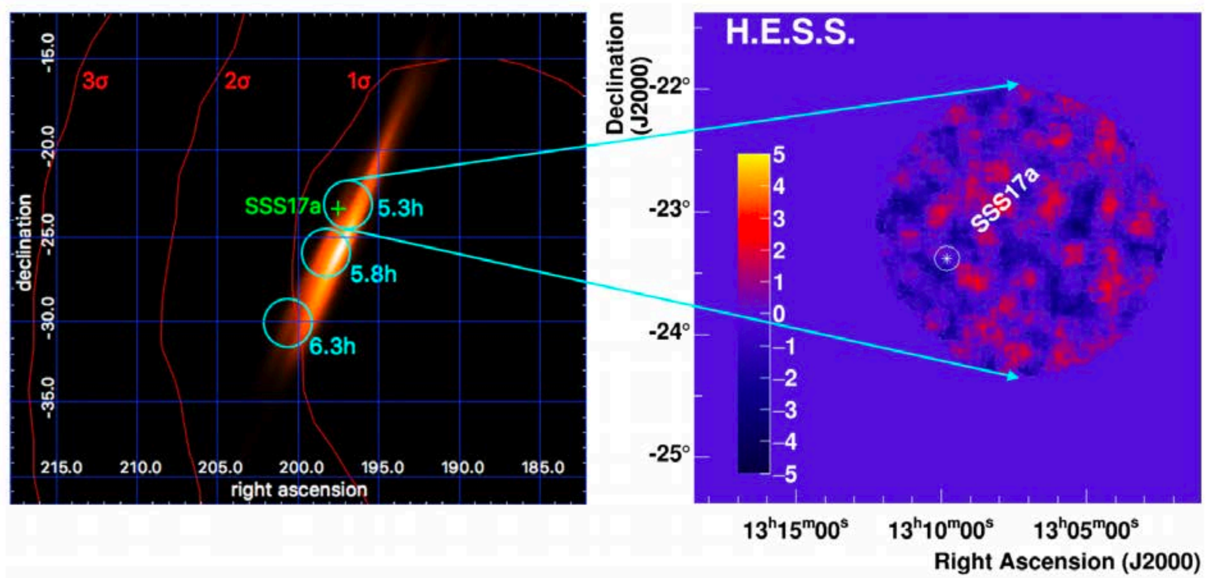


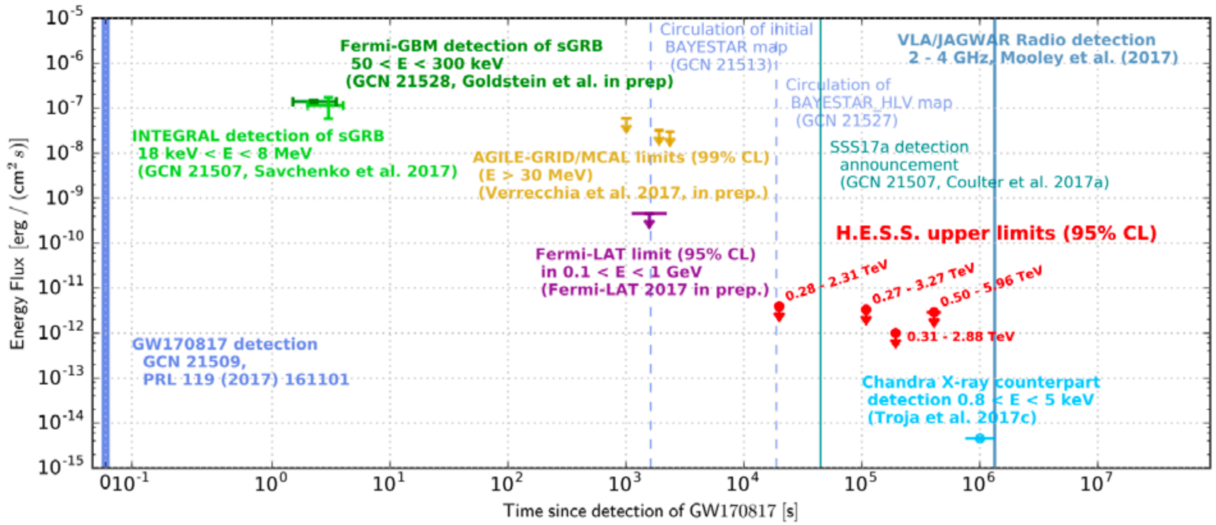



Possible
Model
Datacenter n
Job Scheduler
Linux
Parallel File System
Hierarchical Storage Management
Data Base Management System
ORACLE, ...
Helpdesk
Acconting/ Monitoring
CPU cores
Hard Disk storage
Tape storage
CTAO Data Management Center
Archive Management
Authentication & Authorization
Computing Resources Management
[...]
Monitoring tools
Ticketing System
DataCenter 4
DataCenter 3
DataCenter 2
DataCenter 1
DataCenter n
DataCenter ...
DataCenter 2
DataCenter 1
VO Services
Collaborative Platform for SW Dev
Gateway Services
Proposal Handling Services
[...]
North Site
South Site
CTA collaborative data analysis environment, e.g. CTACG
Services which can be also decentralized
CONSORTIUM
OBSERVATORY

GW170817

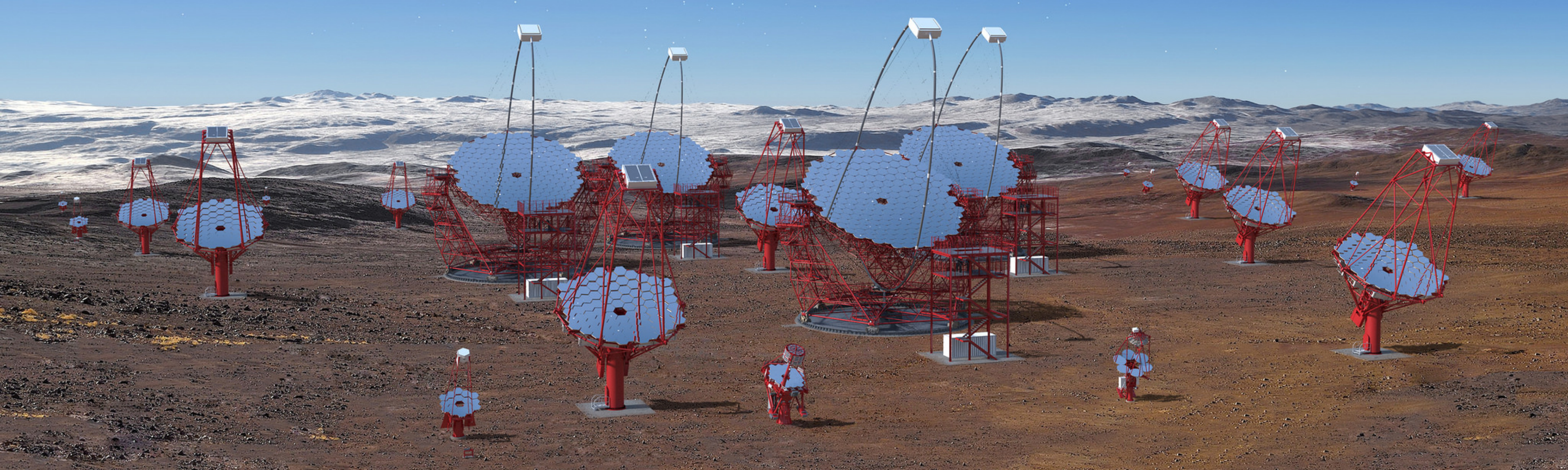
- Want to be prepared with CTA
  - ToO System
    - Automated
    - Fast
    - Intelligent
  - Rapid slewing
    - LST 30 s
    - Others ~1 min
    - To/from anywhere in observable sky



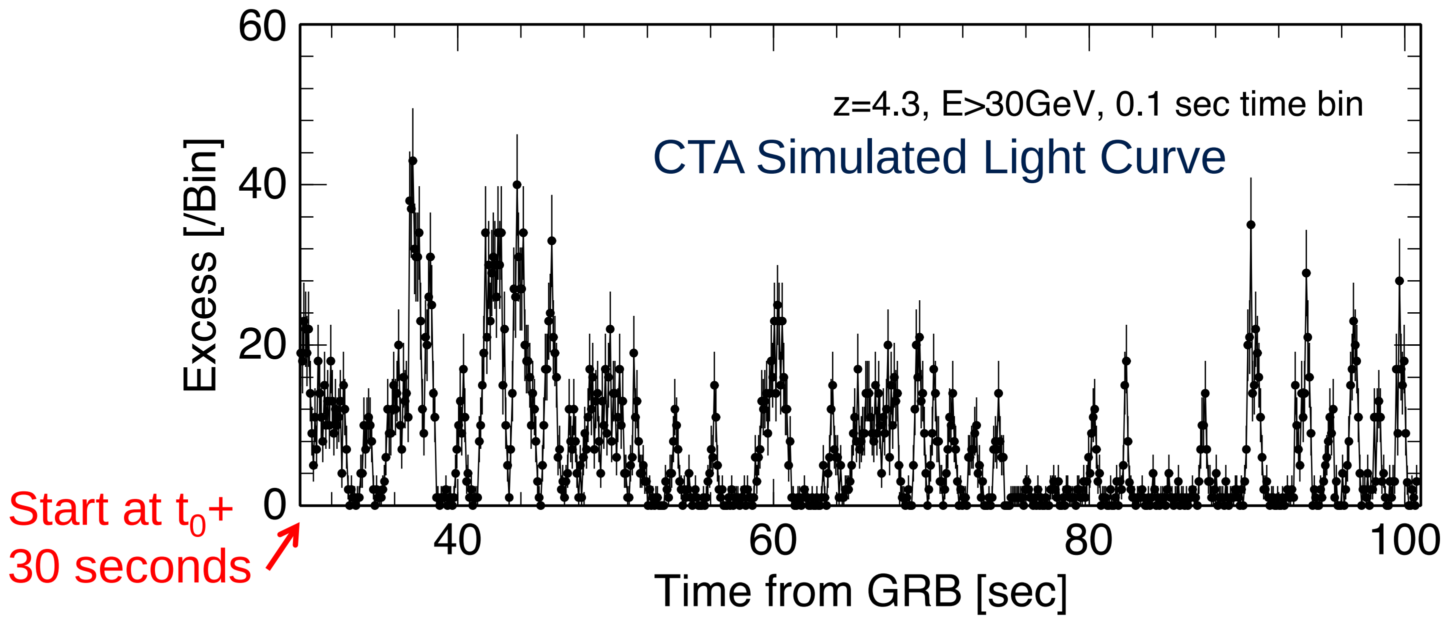


Conclusions

- CTA planned as a major new international user facility - many challenges in the area of science operations!
- Preparations more advanced in some areas than others – a lot of work ahead → goal is to be ready for guest observer access by 2021
- Clearly there is a lot we can learn from the many major observatories represented here



Alerts and Triggers



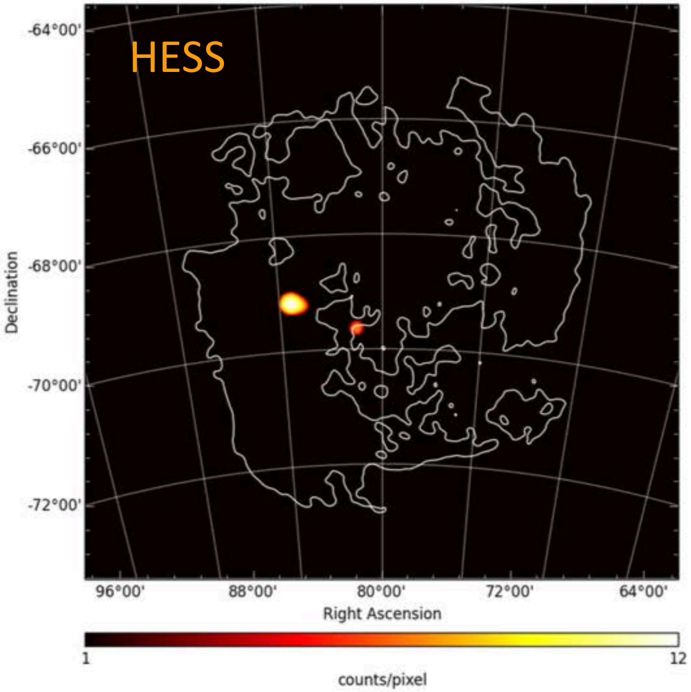
*Serendipitous detections possible, e.g. in divergent mode, huge potential for local, low-luminosity events

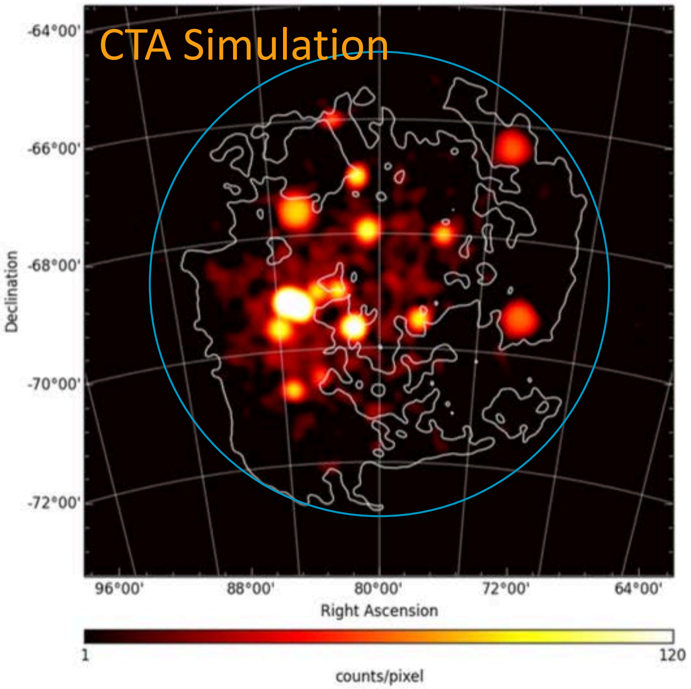
- Alerts and triggers to/from CTA for variable objects
  - Including gravitational waves and optical transient factories
- For GRBs - CTA requires (MeV) triggers*
  - Swift, Fermi GBM → SVOM, ? …
- Triggers from CTA** → broad astronomical community
  - Rate expected to be low – but identified events likely to be extremely important: GW sub-threshold, redshift measurement, …

**Alert generation in 1 minute

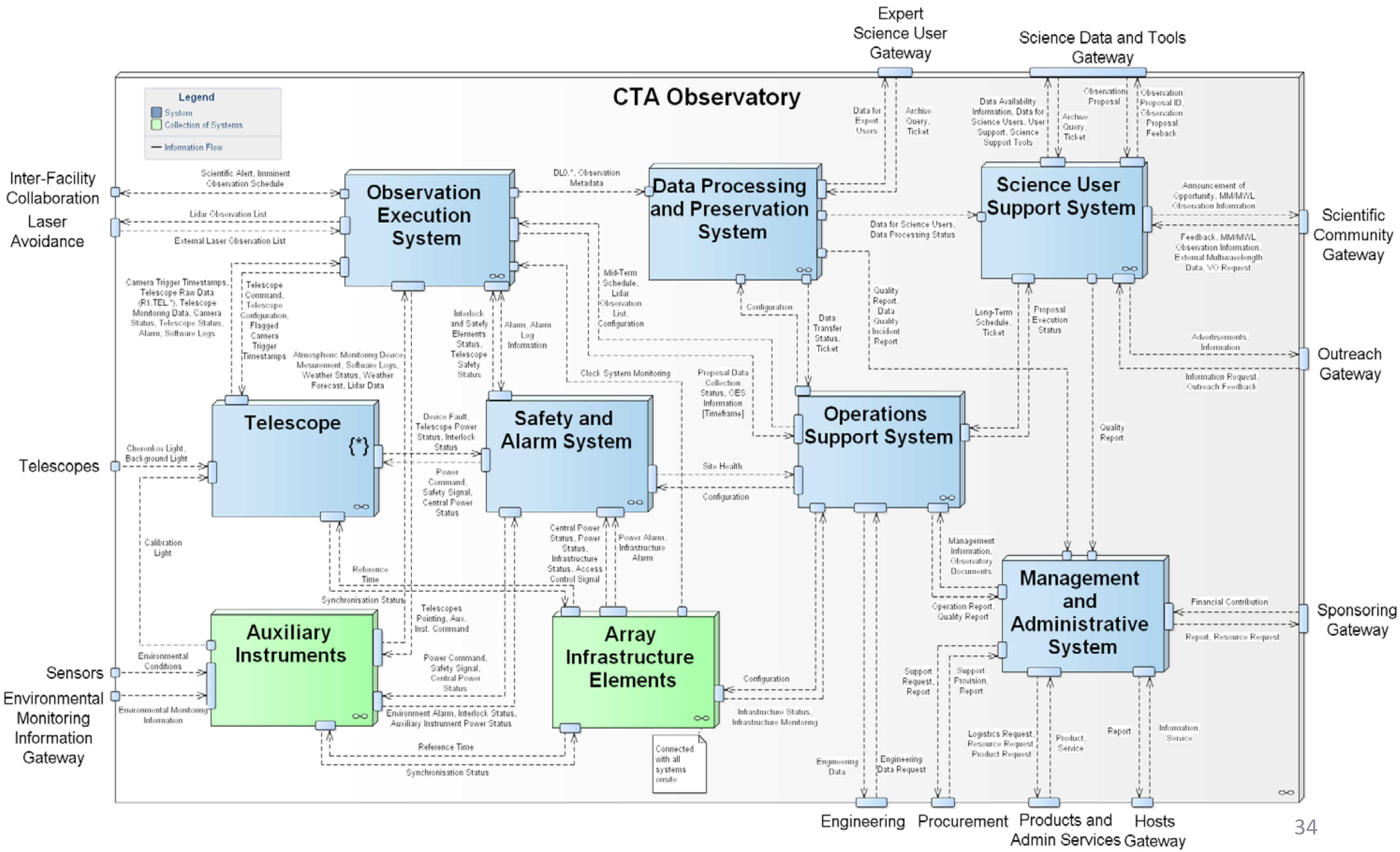
Field of View Example

The Large Magellanic Cloud

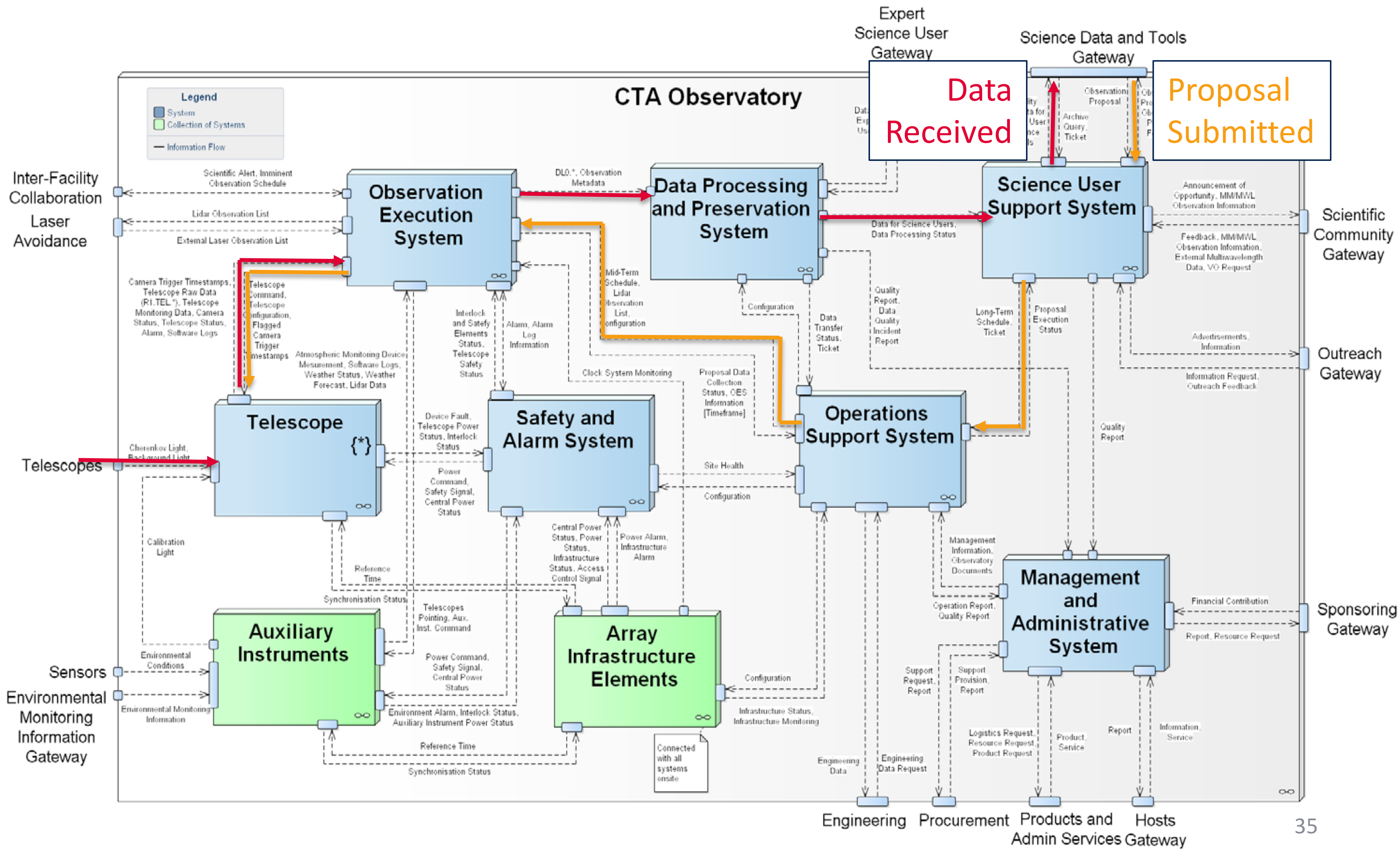




CTAO Systems



CTAO Systems



Calibration

		Time scale	Random triggered events	Air shower events	Muon events	On-telescope light source	Moveable precision light source	Light source on UAV	Central laser beam	Central timing distr. system	Camera tracker (LED+CCD)	Star currents (or noise) in pixels	Star images on special camera target	On-telescope star tracker	Remote sensing and global atmosph. models	LIDAR	Robotic telescopes for stellar photometry	Compartison with space instruments	Cosmic-ray electron flux and spectral break
	Requires manual intervention		no	no	no	no	**yes**	**yes**	no		no	no	no	no				no	no
Calibration for image reconstruction	Pixel baseline	sec	●	●	●														
	Pixel linearity	yr				(●)	●												
	Pixel spectral response	yr				(●)	●												
	Pixel integration window	day		●	●	●	●												
	Pixel signal per p.e.	day		●	●	●	●												
	Pixel flat fielding (amplitude)	h			●	●	●												
	Pixel flat fielding (timing)	h		●	●	●	●												
Trigger monitor ing	Pixel trigger thresholds	day		●			●												
	Image trigger threshold	day		●					(●)										
	Inter-telescope trigger timing	day		●						●									
Pointing calibration	Camera position rel. to optical axis	sec									●		●						
	Model for pointing corrections	mo										●	●						
	Real-time pointing monitoring	sec										●		●					
	Consistency of pointing calibration across telescopes	h		●															
Intensity calibration	Inter-calibration and cross-calibration of telescopes	mo		●	●		●	●	●										
	Absolute calibration: light yield to digital counts	yr			●		●	●	●										
Energy scale and effective area	Atmospheric profile	day													●				
	Atmospheric transmission	h		(●)											(●)		●		
	Aerosole profile	h		(●)											(●)	●			
	Absolute energy calibration	yr		(●)														●	●
	Effective area calibration	yr		(●)														●	●

On-Site Team

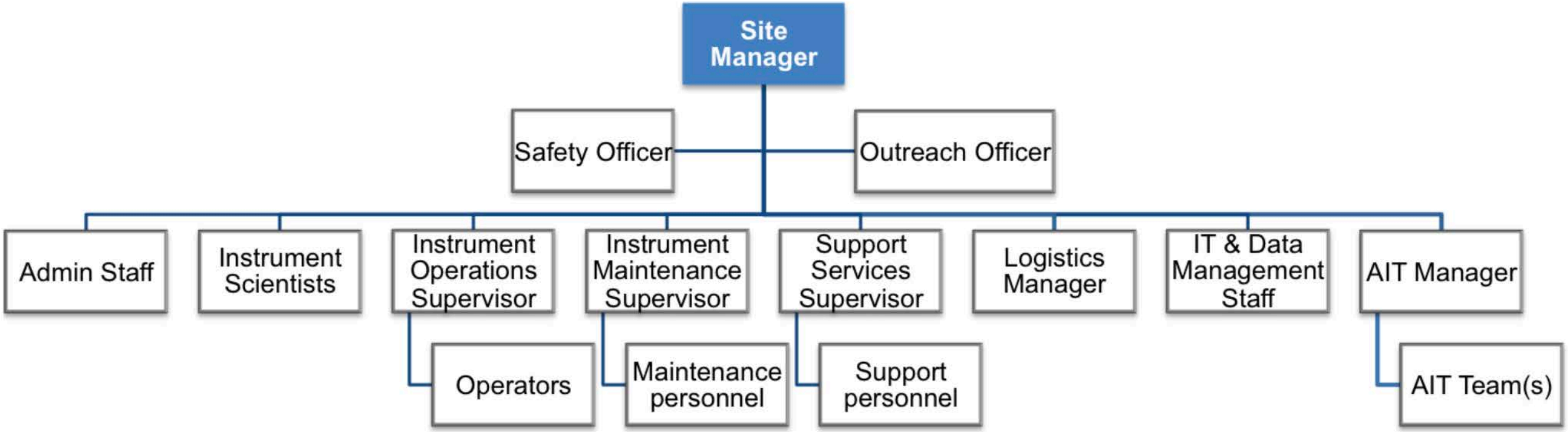


Figure 6.1 – Organigramme for on-site operations. See Figure 4.1 for embedding in the CTAO organisation. The Assembly, Integration and Test (AIT) branch exists only during construction; it is desirable to have part of the AIT personnel move to maintenance once construction is nearing completion.