CTA-CZ: Cherenkov Telescope Array - participation of the Czech Republic

Czech activities

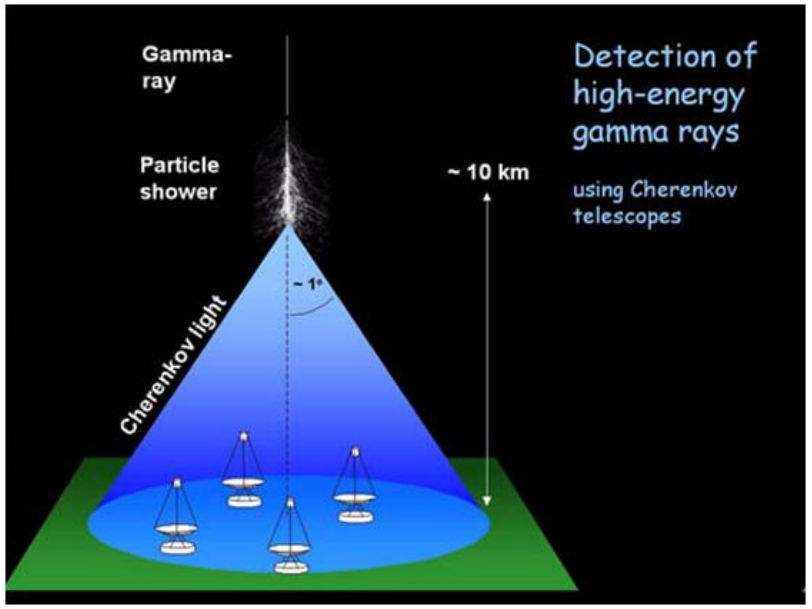
Institute of Physics of the Czech Academy of Sciences (FZU – Fyzikální ústav)
– hosting institution
Charles University (CU)
Palacy University (PU)
Astronomical Institute of the Czech Academy of Sciences (ASU)

Michael Prouza, Petr Travnicek (FZU)

Cherenkov Telescope Array

CTAO | Czech Republic

- Largest and most sensitive gamma ray observatory ever
- broad energy range – 3 telescope types
- Full sky coverage (south – Chile, north – La Palma)

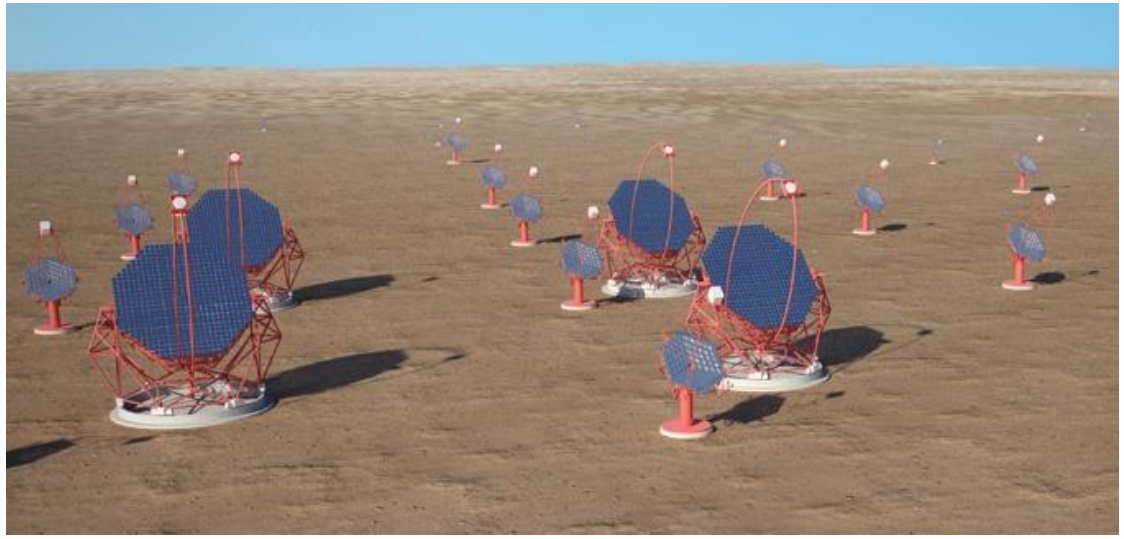


Physics potential

Extragalactic Gamma-Ray Sources
Active Galactic Nuclei
Extragalactic Background Light
Gamma-Ray Bursts
Galaxy Clusters

Galactic Gamma-Ray Sources
Supernova Remnants
Pulsar Wind Nebulae
Pulsar Physics
Star-Formation Regions
The Galactic Centre
X-Ray Binaries & Microquasars

Fundamental Physics
Dark Matter
Quantum Gravity
Charged Cosmic Rays …



Czech node involved in:

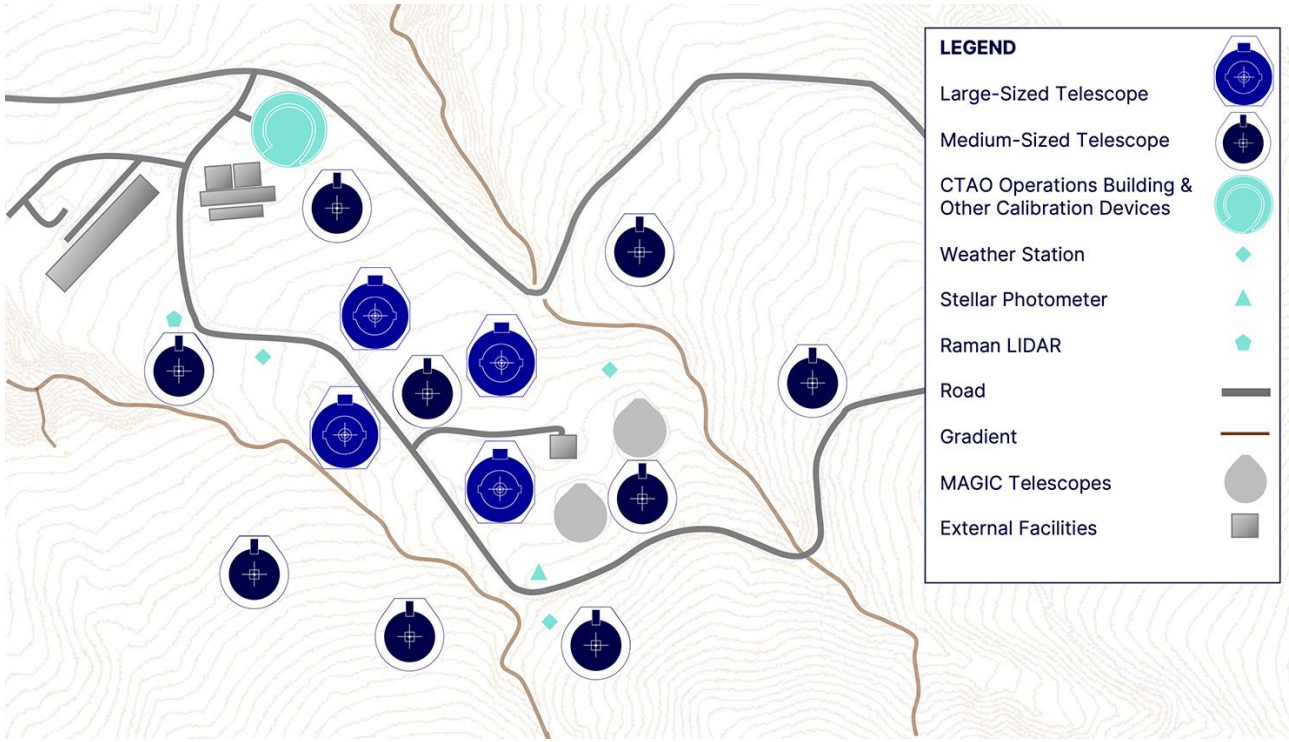
Central calibration
- FRAM
- Ceilometers
- Sun/moon phtometers
- All sky cameras
- CTC method

Previous activity in SST-1M
- Mirror production
- Optical tests
- Alignment

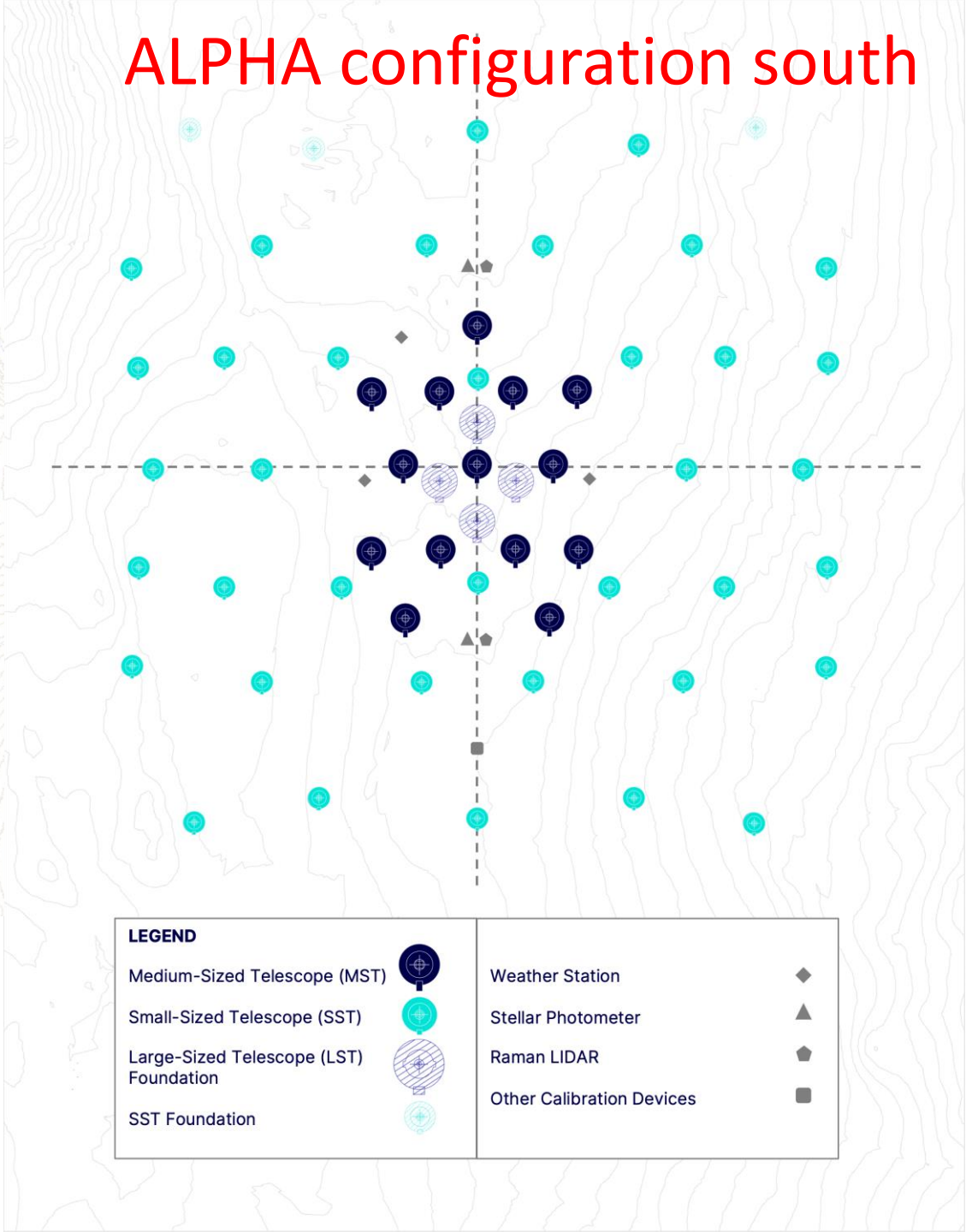
Refocused activity in LST (and MST)
- Optical maintenance
- Alignment
- Optical calculations
- Physics analysis

Computing

ALPHA configuration north



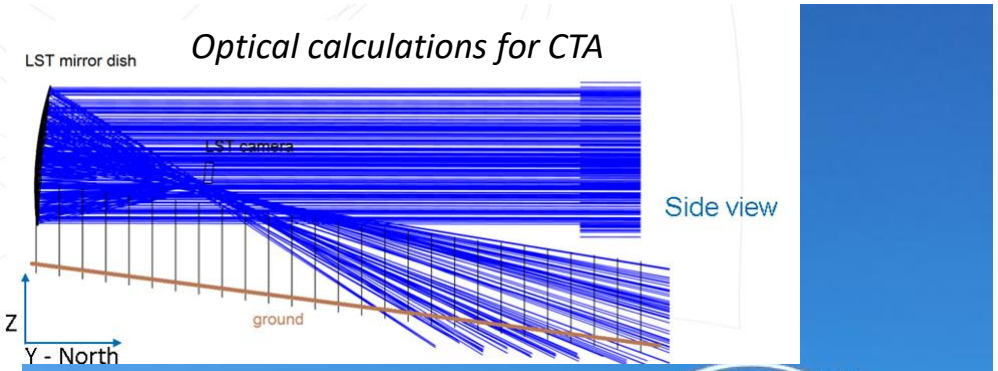
ALPHA configuration south



Activities of CTA-CZ

CTAO Czech Republic

Optical calculations for CTA



➢ **Optical lab in Olomouc**

(one of the best equipped in central Europe)

- Mirror production up to 1 m diameter and strong recent involvement in LST
- Extensive tests of optical samples for the entire CTA
- Professional optical calculations for the entire CTA consortium

➢ **Central calibration**

CTA-CZ provides several types of devices

- FRAM devices
- all sky cameras
- sun moon photometers, ceilometers

➢ **Involvement in LST**

- Optical maintenance
- Optical calculations
- LST2-4 construction
- Data analysis

➢ **SST-1M prototypes**

- used in Ondrejov

Development of CTAO Observatory & CTA-CZ

2000–2008 first conceptual ideas of CTA; 2008 - CTA listed on EU ESFRI roadmap; 2010–2014 Preparatory phase from EU; 2013 - Preliminary design review; 2014 - Site pre-selection; 2014 - creation of CTAO gGmbh (legal entity responsible for the preparation of CTA construction); 2015 - La Palma and ESO Chile selected as final sites of CTA and negotiations started; 2016 - agreement between CTAO and IAC (La Palma) regarding installation of CTA on the northern hemisphere signed; 2016 - Memorandum of Understanding form CTA construction signed by first partners; 2017 - Agreement between CTAO and ESO regarding installation of CTA on the southern hemisphere ready for signature; 2017 - First prototypes of telescope structures exist in Krakow, Berlin, Paris; 2018 – ERIC chosen as the solution for final legal entity; 2018 – CTA reached the status of ESFRI landmark; 2019 – first LST telescope commissioned at La Palma; 2019 – phase 1 submission of ERIC statutes to EU commission; 2021 – phase 2 submission of ERIC statutes expected at the end of the year, 2022 – step 2, submitted in May 2023 - first Science paper published from LST data, 2024 – LST2-4 construction

- CU part of CTA effort since beginning, **2008**
  - **2011** FZU joined CTA consortium
  - **2012–2014** Czech team part of Site selection group and took responsibility for evaluation of cloudiness above candidate places, 9 Czech cameras installed at 9 candidate sites all over the World
  - **2013** initial activities funded within the MEYS project LE13012
  - **2014** Czech team became part of the SST-1M telescope group, extensive participation in designing the optical system
  - **Dec 2014** - based on the negotiations with MEYS the Institute of Physics became the 4th shareholder of CTAO, gGmbh, finance via project MEYS LG14019 (nowadays via LM2015046 and LM20180105)
  - **2014** - successful application to Large Research Infrastructure Program of MEYS
  - **2015** – responsibility taken over the SST-1M optical system
  - **2015** - first mirrors coated in Olomouc and delivered to the prototype site
  - **2015** - design of FRAM telescope finished, first prototype constructed
  - **2015** – Czech scientist selected as a part of CCF CTA management
  - **2015** – analysis from ASC extensively used for site selection process
  - **2015** – negotiations with MEYS about CTA-CZ concluded and project LM2015046 started in 2016
  - **2016** – SST-1M prototype aligned
- **2016** – second FRAM housing delivered and constructed
  - **2016** – exact location of site at La Palma for FRAM telescope chosen and negotiated with IAC and the MAGIC project, agreement between IAC and FZU regarding FRAM installation signed
  - **2016** – mirror test facility in Olomouc developed to provide the absolute reflectivity measurements for SST-1M segments
  - **2017** - The first FRAM for the southern site in Chile has been shipped to the site, assembled and commissioned
  - **2018** - The FRAM system for the northern site has been delivered, assembled and commissioned in La Palma
  - **2018** - A study describing the unique Cherenkov Transparency Coefficient method for the monitoring of both atmospheric conditions and telescope efficiencies has been finalized.
  - **2019** - the second FRAM was installed at the southern site of the CTA Observatory
  - **2019** - SST-1M decision the group shifted activities towards LST (and MST), possible installation of the SST-1M prototypes at another international observatory.
  - **2019** we have finalized a new mount for the Ceilometer device
  - **2019** – FRAM became official pathfinder of CTA, based on the decision of CTAO council
  - **2020** – installation ceilometer on the roof of FZU in Prague for testing, second ceilometer purchased and new custom made mount finished
  - **2021** LST optical maintenance on site

2022 – LST activities including physics analysis

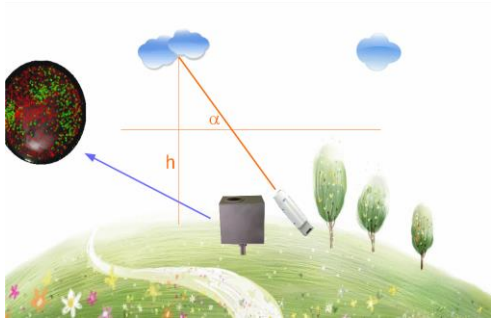
2023 - leadership in Galactic science LST, optics for LST

2024 – CZ participates in LST2-4 construction, LST meeting in Prague, SST-1M to present first science data

Activities in atmospheric monitoring

Ceilometers

- Measures cloud height / profile up to 13 km (Lufft CHM15k)
- Primary use: meteorology, air traffic control
- Small infrared LIDAR: pulse laser (1M class), wavelength 1064 nm, detects elastic backscattering
- *in CTA*: map the clouds detected by the All-Sky Camera – input for the Smart Scheduler of observations



Aug 2018: First ceilometer delivered to FZÚ
custom Alt-Az mount design ordered

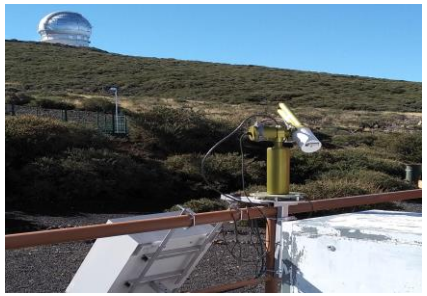
Jan 2020: Installed on Alt-Az mount on FZÚ roof
start testing, software development

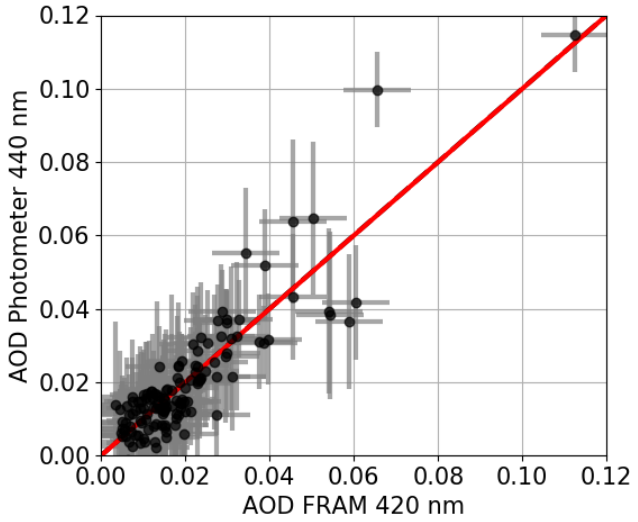
Aug 2020: Second ceilometer delivered to FZÚ
Alt-Az mount modifications for CE compliance

Apr 2024: One ceilometer installed in Ondrejov

Sun/Moon photometer

- The flux above the Earth's atmosphere is stable (Sun), or can be determined from a model (Moon)
- From difference of the ground-level flux measured by the photometer and the calculated above-atmospheric flux, the **integral aerosol optical depth (AOD)** of the atmosphere can be determined (non-invasive technique)
- One photometer at CTA-S since 2016, second at CTA-N since 2018
- 9 photometric pass-bands, standalone (solar panel and batteries)
- High cadence of measurements – all pass-bands every three minutes
- Site characterization, intercalibration of the other instruments (FRAM, LIDARs)





Activities in atmospheric monitoring

All-Sky camera

The All Sky Camera analyzed the night sky images and uses astrometry and basic photometry to produce the cloud maps, atmosphere transparency condition and report an output for the CTA observatory scheduler to secure a safe and good quality observation. Based on the result additional instrument (like FRAM) continue the more detailed investigation of the scheduled observation sources of the CTA telescopes.

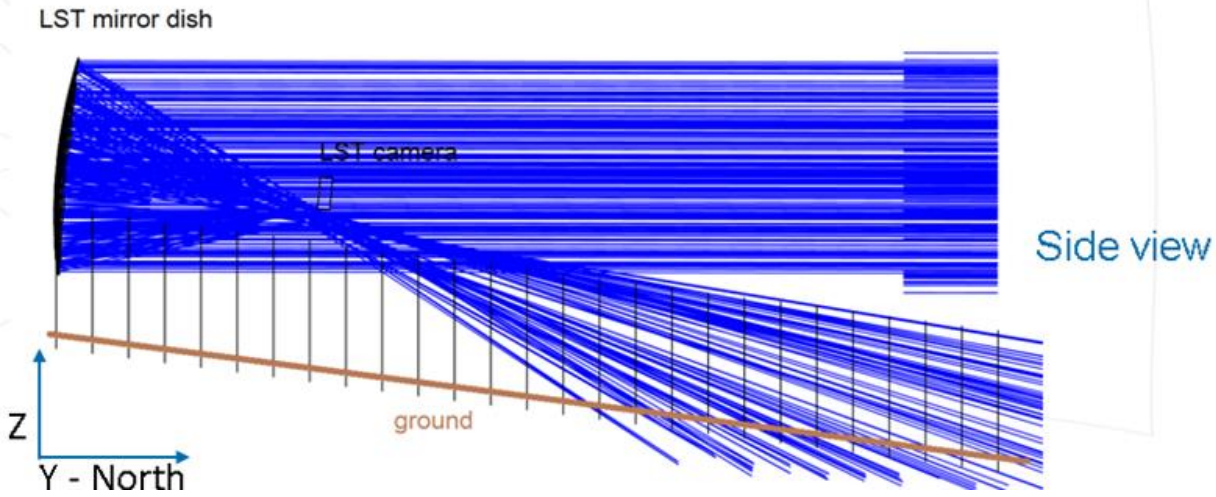
All Sky Camera at the MAGIC control room La Palma – future CTA North site

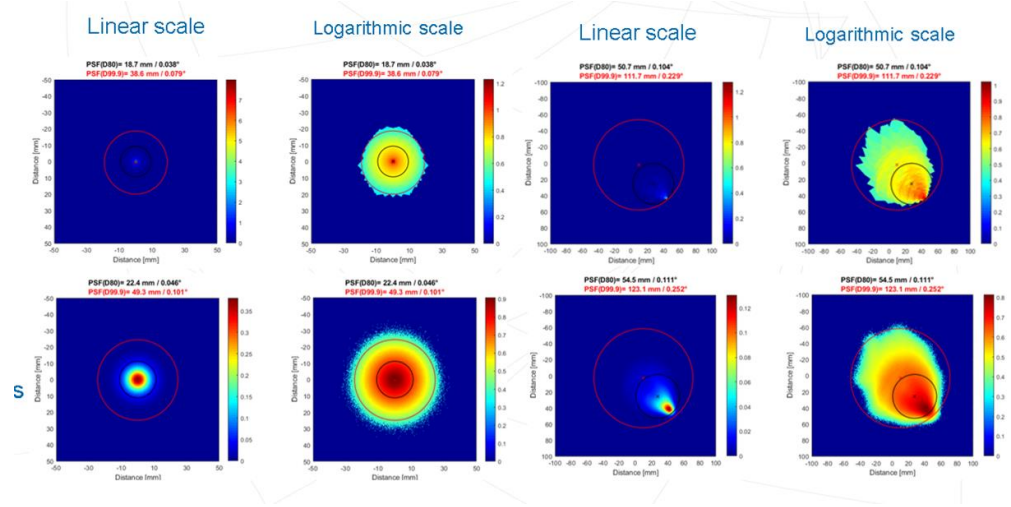
FRAM telescopes

- using stars as reference light sources presents a unique way to measure transparency of the atmosphere without producing any extra light
- non-invasiveness key for use at large astroparticle observatories, where observational time is extremely valuable
- laser-based methods very precise, but induce observation down-time
- the FRAM approach: wide-field imaging of many stars with a CCD camera
- the world first practical application of a large number of stars as light sources for this purpose
- possible only because of state-of-the-art calibration and analysis
- non-linearity and spectral sensitivity calibrated in laboratory
- telescope parameters calibrated in a data-driven approach
- data processing optimized for maximal precision over a large parameter space
- 2021 paper - A New Method for Aerosol Measurement using Wide-field Photometry

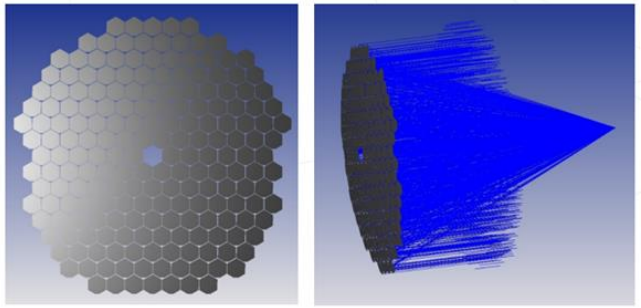
Contribution to optical solutions

Ray tracing simulation of the CTA LST telescope using Zemax OpticsStudio for the optical performance study, design validation and improvement.

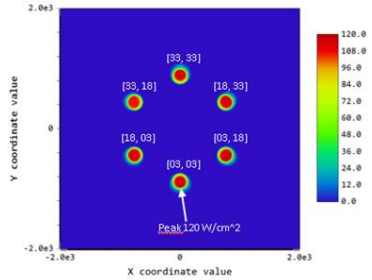




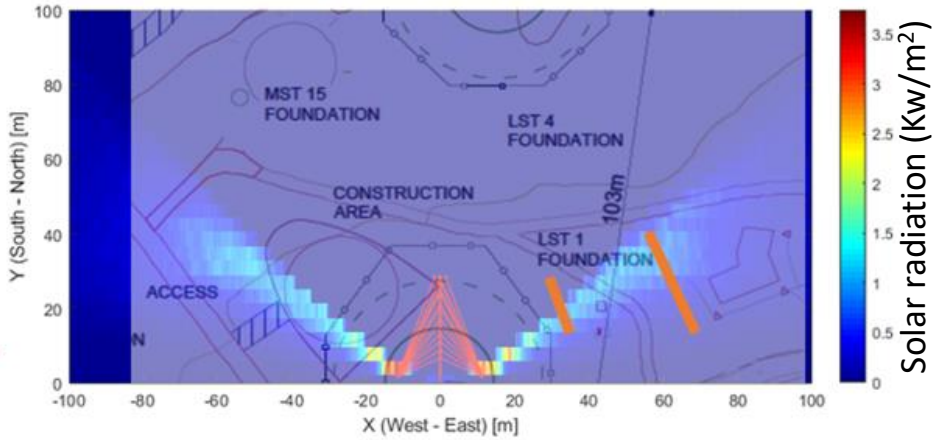
Point Spread Function (PSF) simulation of an ideal (top) and mirror with real parameters, ON (left) and OFF(right) axis position shows a good comparison with real PSF measurement and validity of the Zemax optical model.

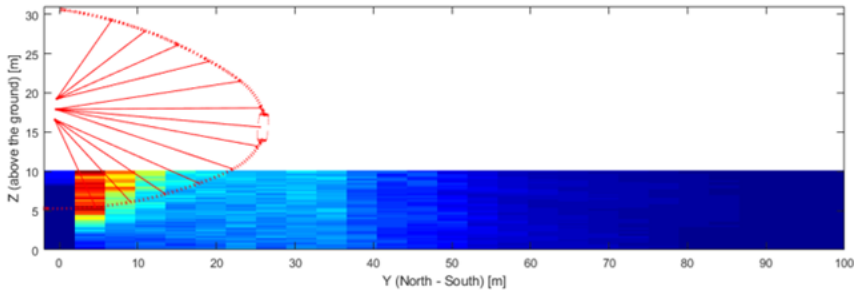


CTA LST ray tracing Zemax model



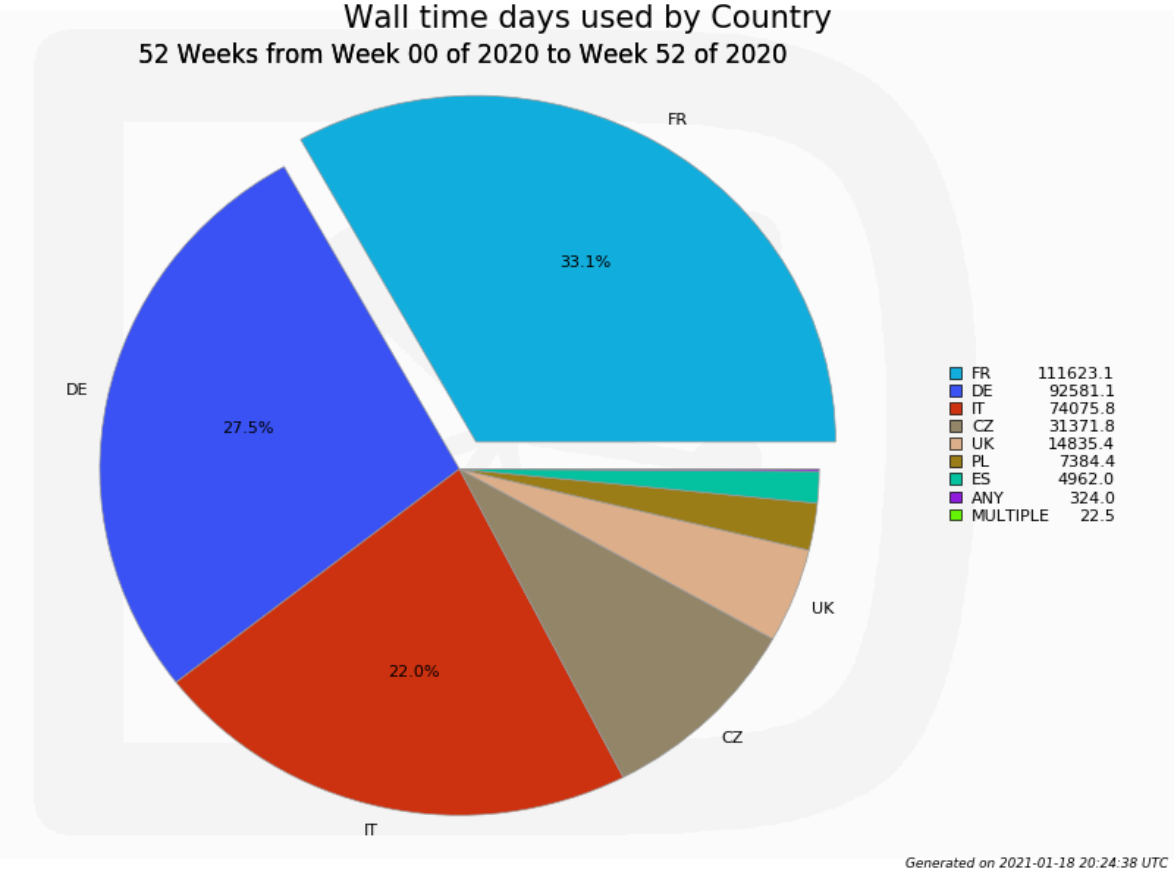
Simulation of safety-defocusing of the mirrors in case of power failure





The same model is used for the calculation of the Sunlight focusing of the LST telescope in the parking position and validating of a defocusing procedure of the mirrors for the reduction of the phenomena and potential damage of the surrounding.

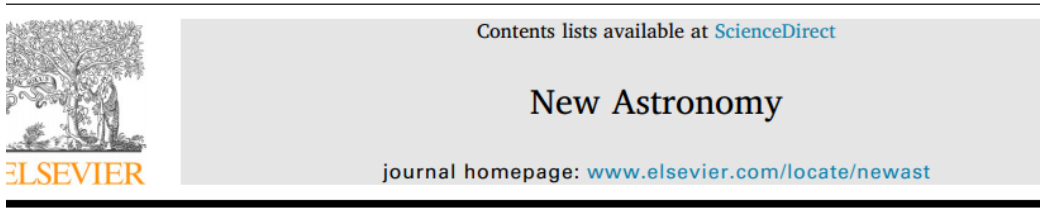
Computing



- CTA-CZ provides computing and storage resources for the whole project via Computing and Storage elements connected to the EGI grid

Services for CTA and astroparticle physics community – CTA-CZ

CTAO Czech Republic



)X Cygni: A triple system with mass transfer

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Variable Star and Exoplanet Section, Czech Astronomical Society, Czech Republic

- The Joint Laboratory of Optics in Olomouc as a reference optical laboratory for the study of optical and mechanical properties of various components. Tests of samples of mirrors and optical surfaces for several CTA mirror technologies
- Our technologies developed for CTA have potential application elsewhere e.g. SPB2@POEMA
- Responsibility for maintenance of various telescope components (active mirror control system for LST)
- Atmospheric data and technologies for its collection and analysis (all sky cameras) shared with community in order to help in identifying locations for other future observatories such as e.g. SWGO; impact also to atmospheric physics and climatology

- Data from FRAM telescopes are being made available to astronomers, including amateur astronomers
- Atmospheric monitoring data (FRAM and all sky cameras) is shared with the institutes in CTA
- FRAM and all sky camera data from La Palma are being shared with MAGIC collaboration
- All sky camera data already used by VLT at ESO Paranal

- CTA-CZ computing resources contributes to Monte Carlo calculation of detector responses for full CTA

SST-1M prototypes - story continues in CZ

Site preparation and telecope installations 2020, 2021, 2022; Data >2022; Scientific results 2024

Large Size Telescope (LST)

CTAO | Czech Republic

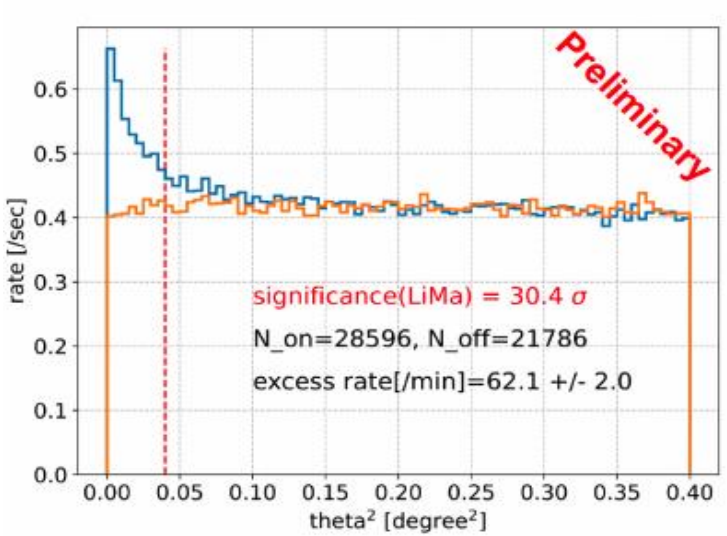
- Prototype construction completed in October 2018, La Palma
- Dec 2018 first light, commissioning phase since then (camera calibration, bending model of the structure, mirror alignment and PSF stability tests, ...)
- Regular observations of many galactic and extra-galactic sources: Crab Nebula, Mrk 421, Mrk 501, etc.
- Joint observations with MAGIC, observation proposals from the members of LST col.
- LST 2-4 under production, starting installation in La Palma

	Large-Sized Telescope (LST)
Required energy range	20 GeV – 3 TeV
Energy range (in which subsystem provides full system sensitivity)	20 GeV – 150 GeV
Number of telescopes	4 (South) 4 (North)
Optical design	Parabolic
Primary reflector diameter	23.0 m
Secondary reflector diameter	--
Effective mirror area (including shadowing)	370 m^2
Focal length	28 m
Total weight	103 t
Field of view	4.3 deg
Number of pixels in Cherenkov camera	1855
Pixel size (imaging)	0.1 deg
Photodetector type	PMT
Telescope readout event rate	>7.0 kHz (after LST array trigger)
Telescope data rates (readout of all pixels; before array trigger)	24 Gb/s
Positioning time to any point in the sky (>30° elevation)	30 s
Pointing precision	<14 arcseconds
Observable sky	Any astrophysical object with elevation > 24 degrees

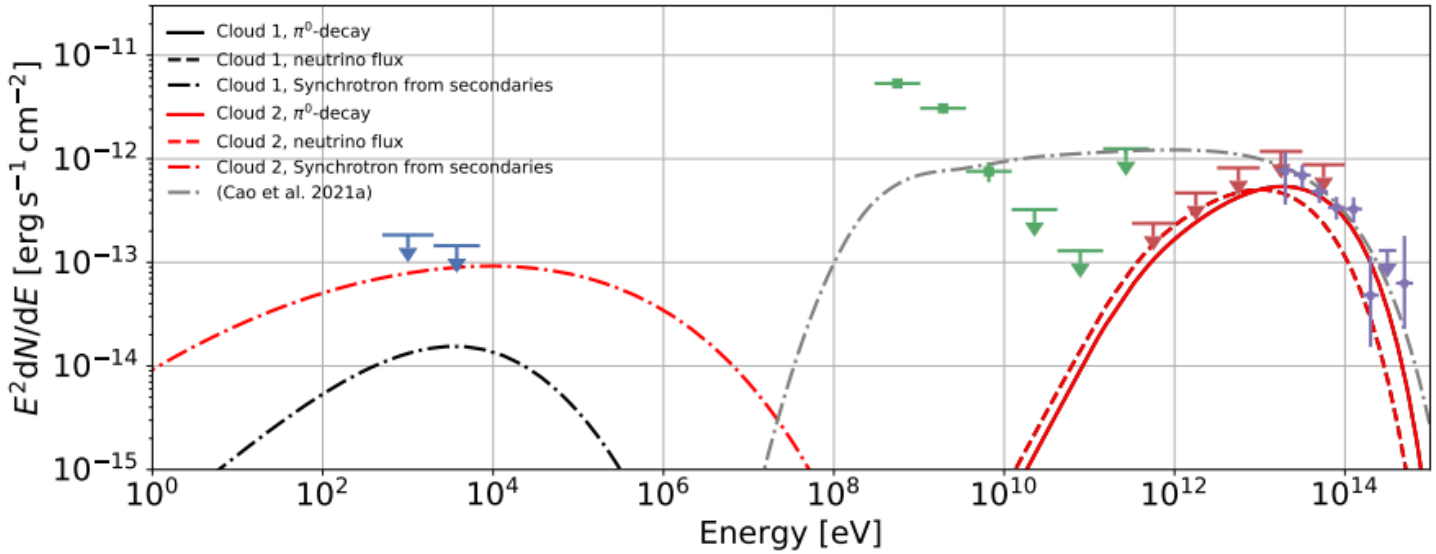
LST-1: first science

- BL Lac flare, first ATEL published by CTA
- A paper demonstrating LST-1 mono performance on Crab data in preparation
- Galactic PeVatron candidate LHAASO J2108+5157: no significant detection in TeV range (3.7sigma), but important upper limits supporting TeV halo + gamma-ray pulsar scenario of emission - [2210.00775.pdf (arxiv.org)]

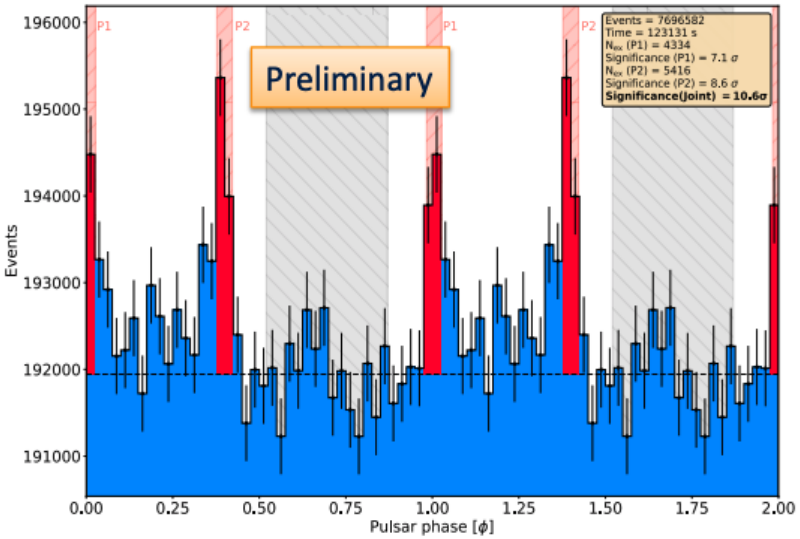
Detection of BL Lac flare



LHAASO J2108+5157



Crab pulsar (to be published in the performance paper)



Path To The Alpha Configuration

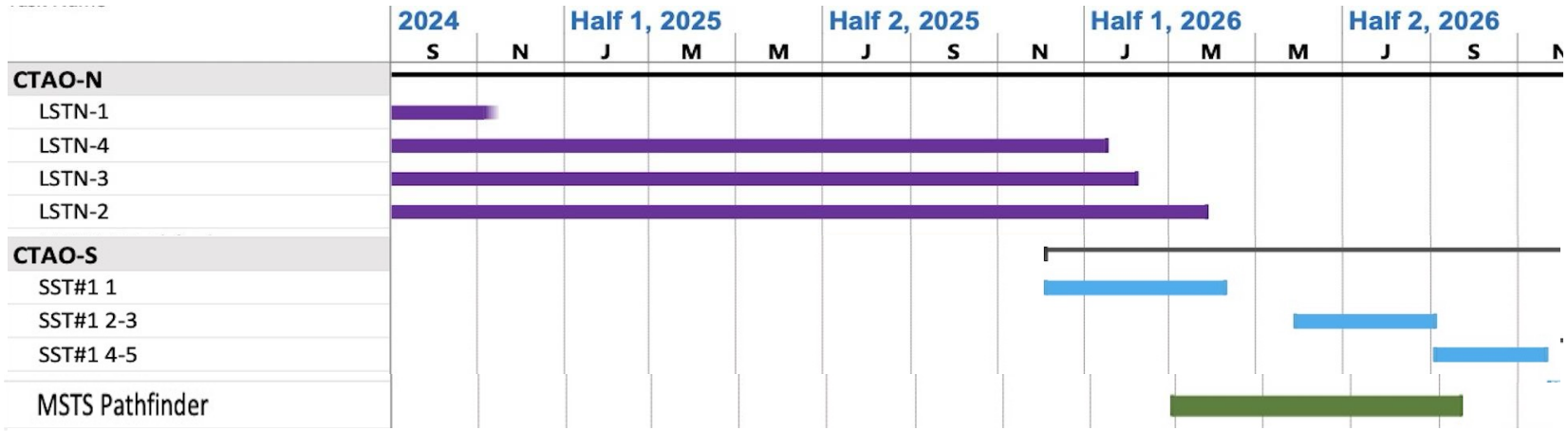
Build sub-arrays to reduce risk and produce early science

- The CTAO is a modular observatory and can be considered as a set of smaller arrays and telescopes
- Various telescopes will be available in a few years
  - North Site: 4 LSTs and 1 MST (being updated) 2026
  - South Site: 5 SSTs, 1 MST, (2 LSTs) 2026
  - Potential additional telescopes from additional COVID relief funds

- Rephasing infrastructure and software development supports operation of **intermediate** (sub) **arrays**

- **Why build these intermediate arrays?:**
  - **Integrating early identifies problems and reduces risk (reduces total project cost)**
  - **Mid-term 3 year goal keeps groups together while FLE is finalized**
  - **Produces some early science data**
  - **Shows potential of Alpha Configuration and engages broader group of scientists**

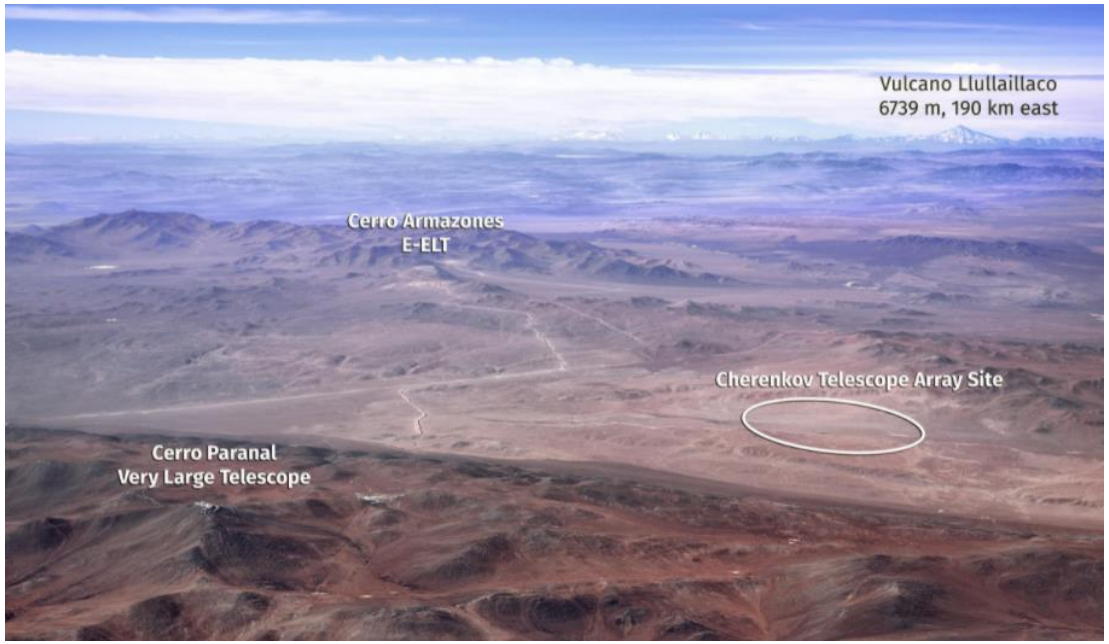
Towards an Integrated Project Schedule



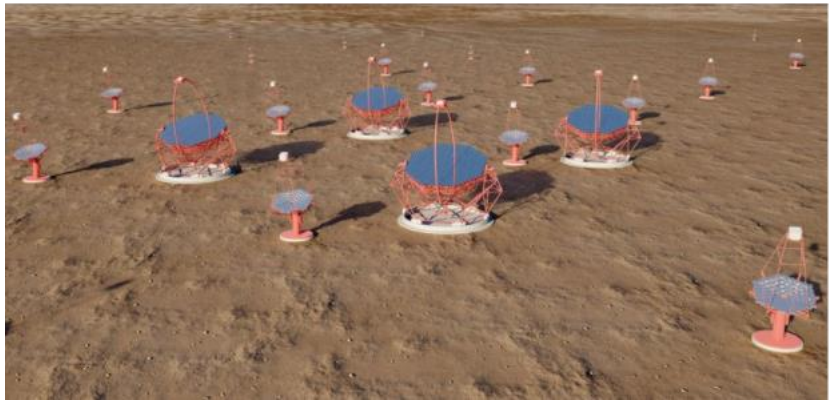
- Schedule updated: meeting September 18 – link to milestones
- CTAO-S
  - Access road - Infrastructure tenders prepared – see previous slide
  - SST design finalized - CDMR late January – followed by construction
  - MST-STR CDMR passed – structure production progressing, cameras prepared
  - LST CDMR under discussion – contract for design and manufacturing of two mounts soon
- CTAO-N
  - LST1 prototype commissioning and operating – towards acceptance
  - LST2-4 under construction
  - MSTs plan under discussion
  - New Observatory Building – building prepared

Key milestones >2024, activities

Day 0



Day X



Observatory level

- **CTA main construction (day 0 hopefully in 2025)**
  - Infrastructure (much more demanding at south)
  - Telescopes and auxiliary devices
- Commissioning phase (different at different sites)
  - Engineering data (but with scientific potential)
  - Subarrays
- Operation phase (can start ca 5 years after day 0)

CTA-CZ level

- Several of Czech devices are already on sites, but
  - Relocation and final adjustments of CTA-CZ FRAMs to exact locations (2025 La Palma, probably later in Chile)
  - Relocation of all sky cameras
  - Relocation of sun/moon photometers
- Transport and installation of ceilometers (>2025)
- Participation on construction of LST2-4 telescopes (>2024)
- Continuing support for LST1 maintenance
- Operation of Czech instruments
- Analysis of engineering and scientific data

Today-Tomorrow, October 14-15th, 2024 Desy, Zeuten

SDMC headquarters inauguration

CTAO council –

to negotiate 2025 gmbh budget and ERIC transition

CTAO BGR (Board of Govermental Representatives) –

to refine ERIC policy documents