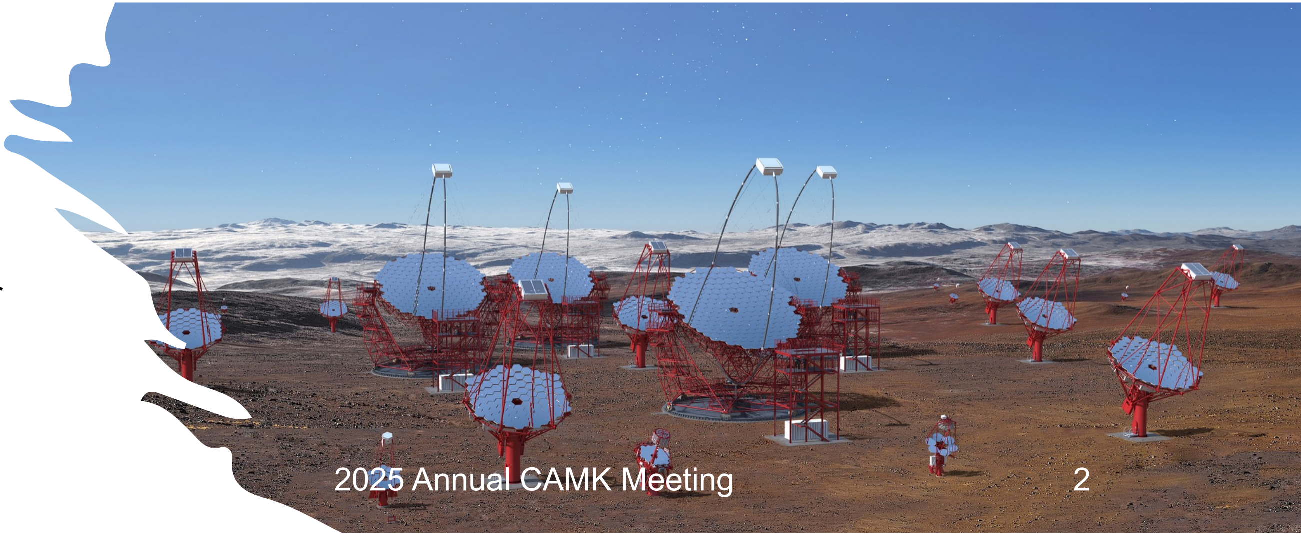
VHE gamma-ray astronomy CTA, HESS, SST-1M

CAMK Annual Meeting 2025

Rafał Moderski

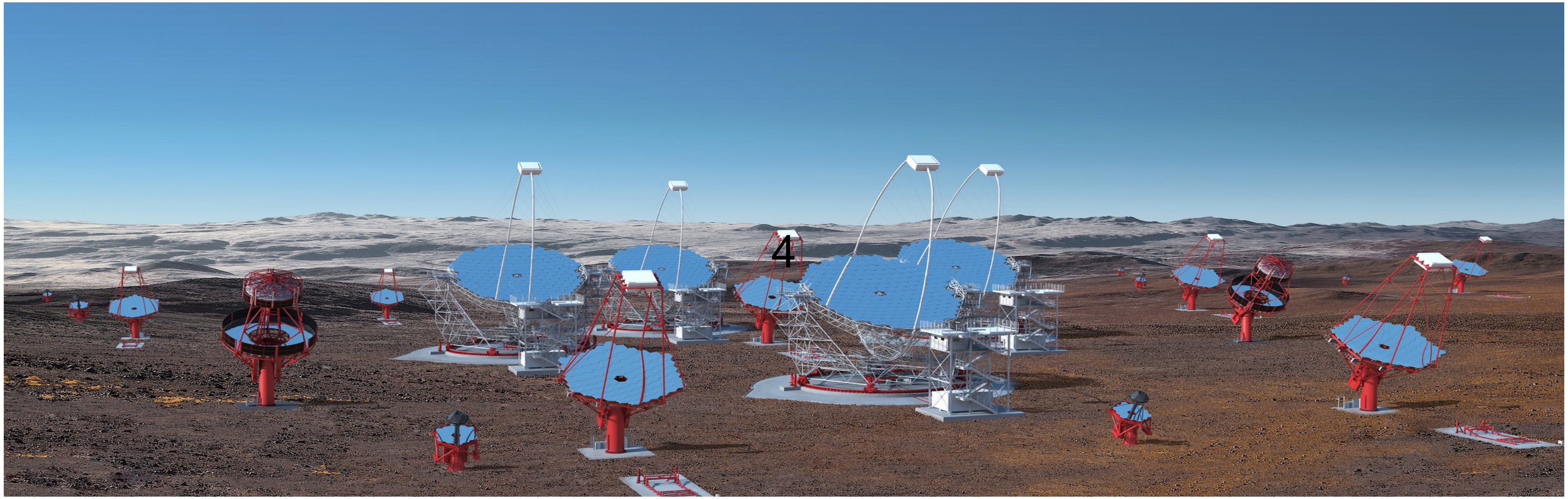
Cherenkov Telescope Array OVERVIEW

- next generation **astronomical observatory** of the very high energy **gamma-rays** (20 GeV – 300 TeV)
- **two sites**: Southern site in Chile, Northern site on La Palma Island – **118 telescopes**
  1st stage (α) reduced to 51 + 13
- **THE LARGEST OBSERVATORY ON THE EARTH** (include ALMA has only 66 antennas)
- science topics include: understanding of the origin of cosmic particles; probing extreme environments: cosmic explosions, black holes, etc.; exploring frontiers of physics: searching for dark matter and deviations from the theory of relativity



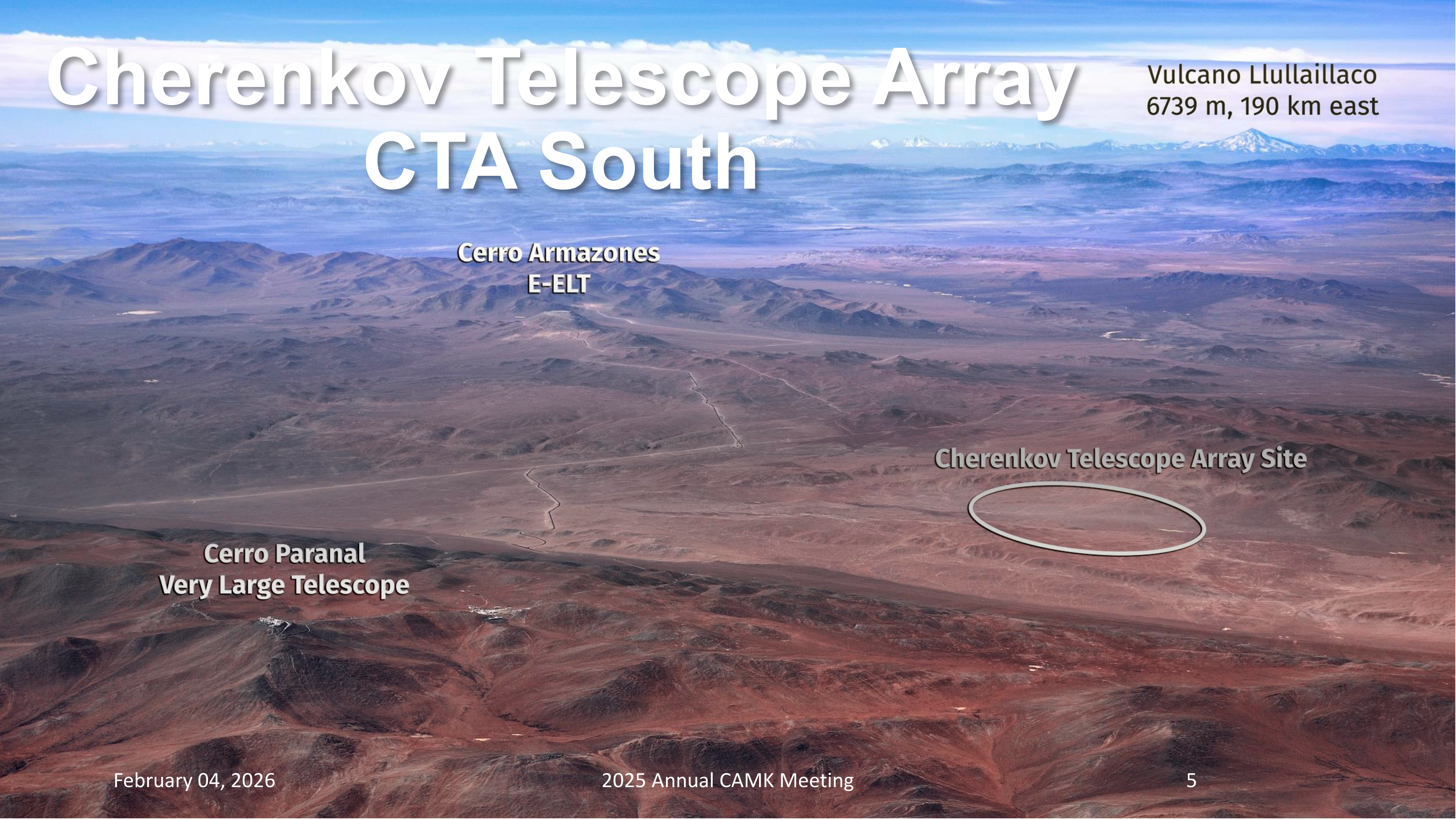
Cherenkov Telescope Array
ORGANIZATION

- **CTAO Consortium established in 2008 – about 1500 members from 25 countries**
- **On the ESFRI Roadmap since 2008 (promoted to "landmark" in 2018; ASTRONET Roadmap 2022-2035; Polish Roadmap since 2020**
- **CTAO (Cherenkov Telescope Array Observatory) ERIC (European Research Infrastructure Consortium)**
  established by EC on January 7, 2025 – MNiSW grant received 2026-2029
  - **9 founding members** (including **Poland**)



Cherenkov Telescope Array CTA North

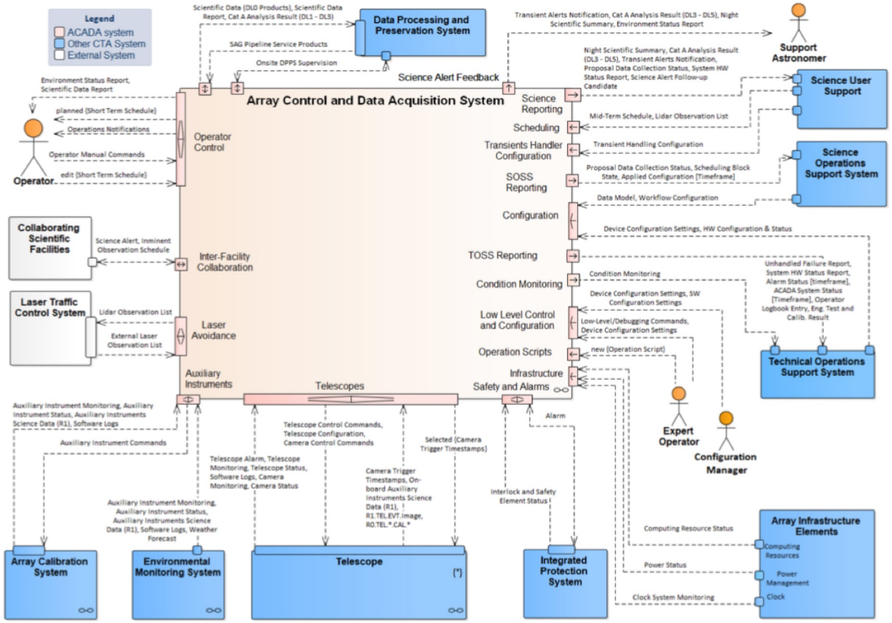
Cherenkov Telescope Array
CTA South

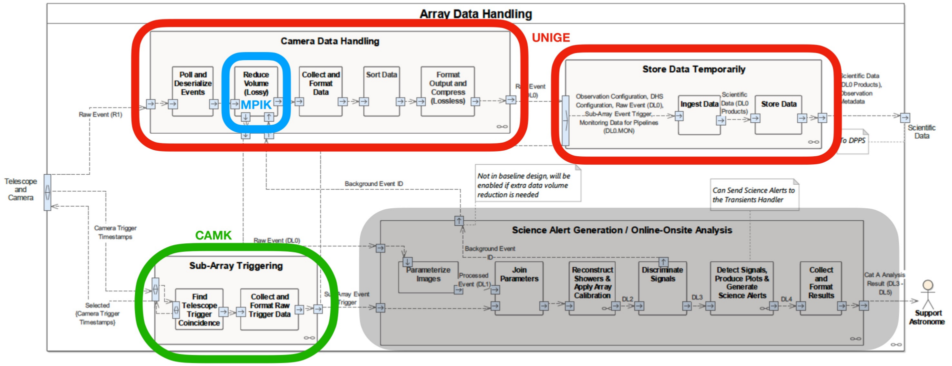


Cherenkov Telescope Array
α SOUTH

Cherenkov Telescope Array ACADA

- ACADA (Array Control and Data Acquisition) is the central software responsible for controlling the operation of CTA telescopes. CAMK team is responsible for **SWAT (SoftWare Array Trigger)** – central array trigger originally developed by Jurek Borkowski
- **Current CAMK Team consists of Bronek Rudak (coordinator), Jurek Borkowski, Adam Muraczewski, and Rafał Moderski**

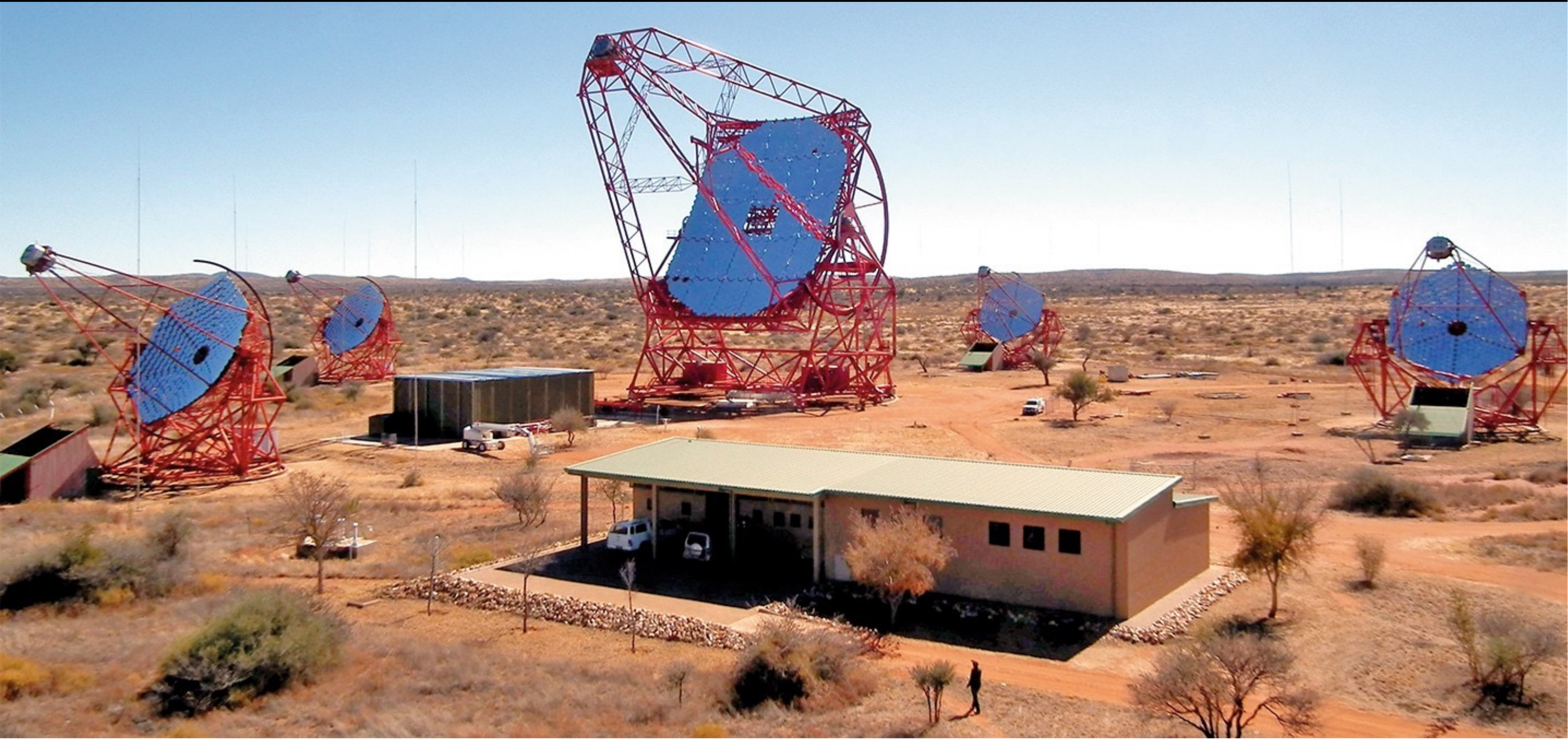




Cherenkov Telescope Array ACADA

- CTAO ACADA Collaboration is now part of CTAO ERIC

H.E.S.S.



HESS results 2025

The H.E.S.S. extragalactic sky survey with the first decade of observations
H.E.S.S. Collaboration
A&A, 695, A261 (2025)

H.E.S.S. collaboration: HEGS : The H.E.S.S. extragalactic survey

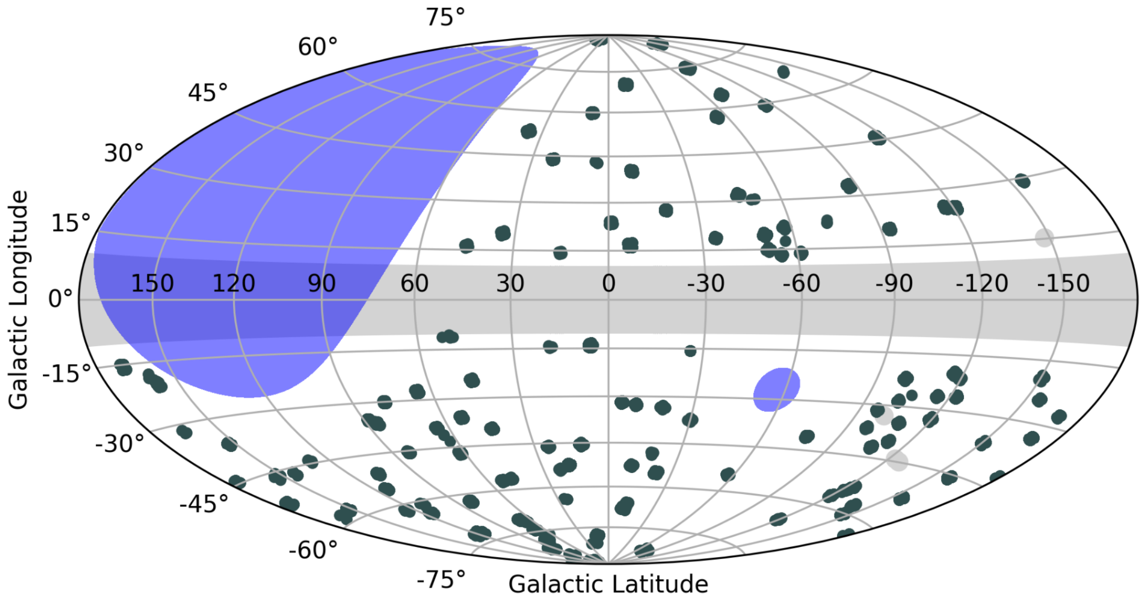
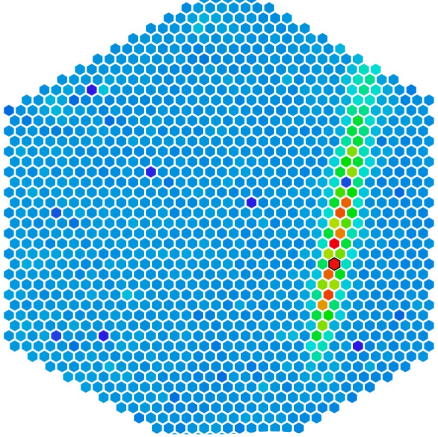


Fig. 1. Hammer-Aitoff sky map showing the HEGS clusters (dark green areas). The central grey band shows the regions with $|b| < 10°$ that are discarded in this work. The other grey areas show the rest of discarded regions (see text). The blue areas denote the part of the sky not observable by H.E.S.S. , due to the zenith angles for observing these regions being above 60°.

- •**Dataset:** 2720 h of H.E.S.S.-I observations (2004–2012), **5.7% sky coverage**, uniformly re-analysed modern calibration and analysis
- •**Detections: 23 VHE sources**, dominated by **BL Lac objects (18/23)**; plus radio galaxies, one FSRQ, and the starburst galaxy **NGC 253**
- •**Spectra:** BL Lacs show **soft VHE spectra (Γ ≈ 3.25)**; **EBL-corrected Γ ≈ 2.16**, consistent with intrinsic blazar emission
- •**Variability & HE–VHE link: 7 variable sources**; combined Fermi-LAT + H.E.S.S. spectra reveal a **systematic HE–VHE spectral break**
- •**Population & impact:** Strong bias toward **nearby hard-spectrum HBLs**, which **dominate the extragalactic γ-ray background above ~100 GeV**

Small-Size Single-Mirror Telescope SST-1M

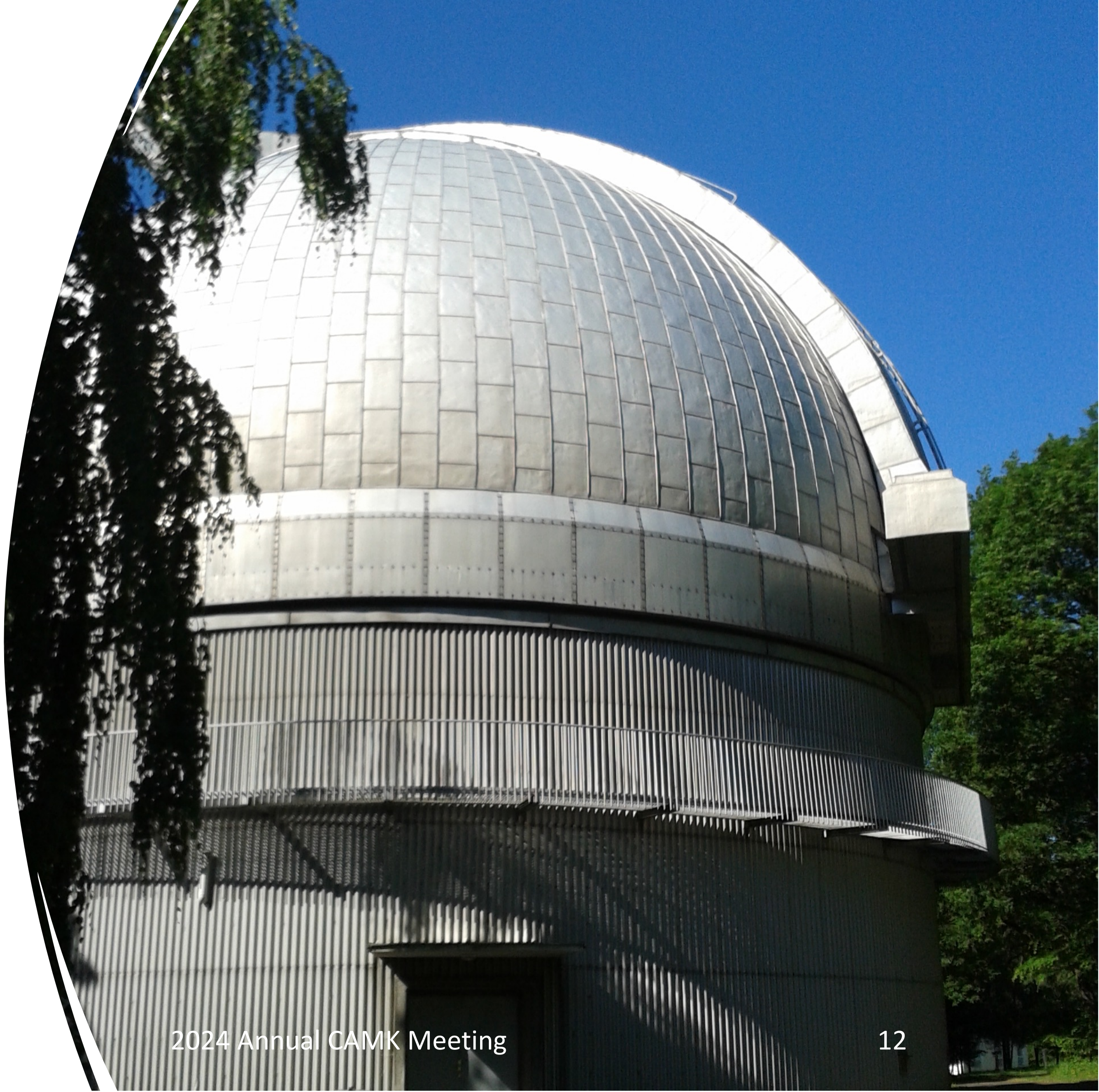
- – supposed to be the main contribution of Poland to CTA – SST-1M but in 2019 the CTA Council decided that **“the CTA-SST design should be based on the ASTRI/CHEC design”**
- – fully working prototype constructed at IFJ PAN, Kraków, funds received to complete the **array of 2 telescopes**



SST-1M at Ondrejov Observatory

- Located 40 km south-east of Prague is the principal astronomical observatory of the Astronomical Institute (Astronomický ústav) of the Academy of Sciences of the Czech Republic. A 2-meter telescope, which is the largest in the Czech Republic is located there.

- Two SST-1M mini array has been constructed at the Ondrejov Observatory

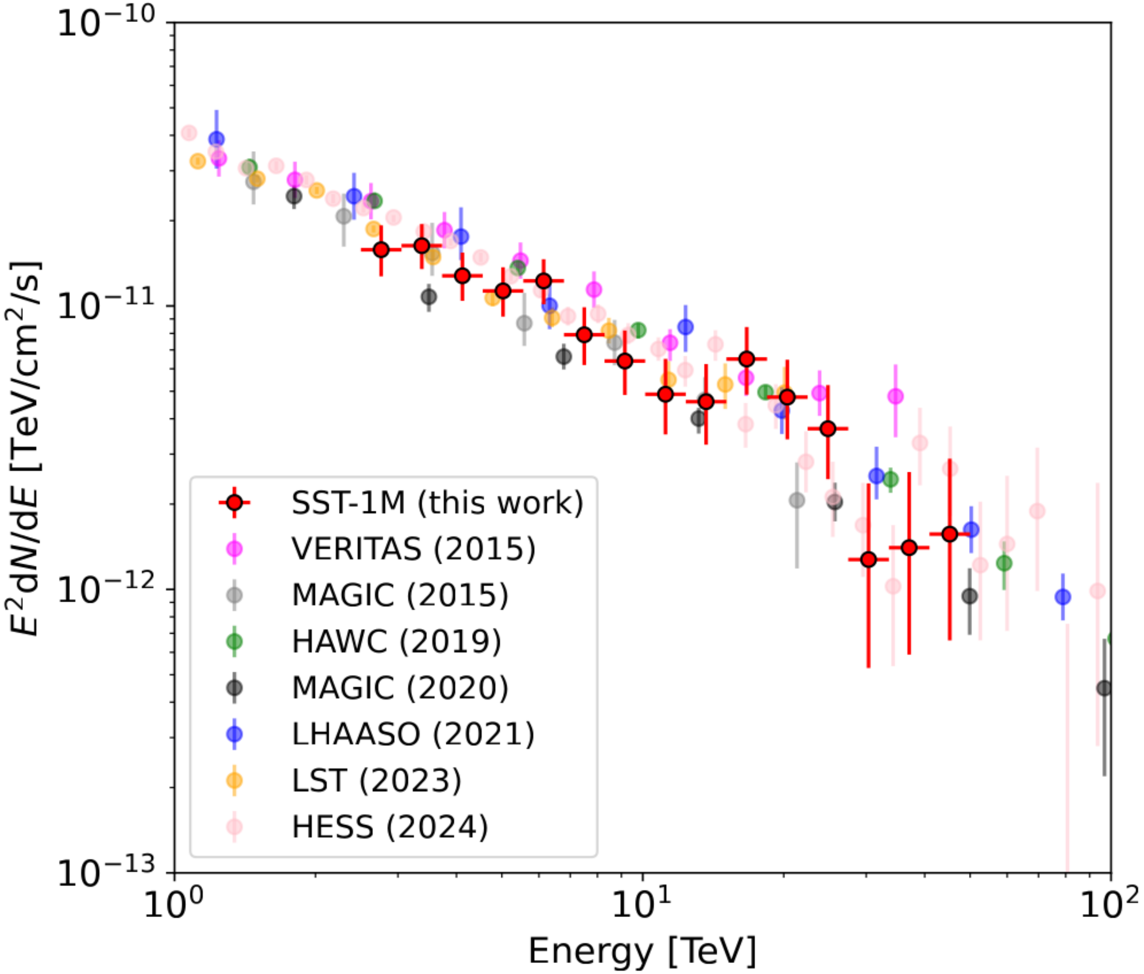


SST-1M at Ondrejov Observatory

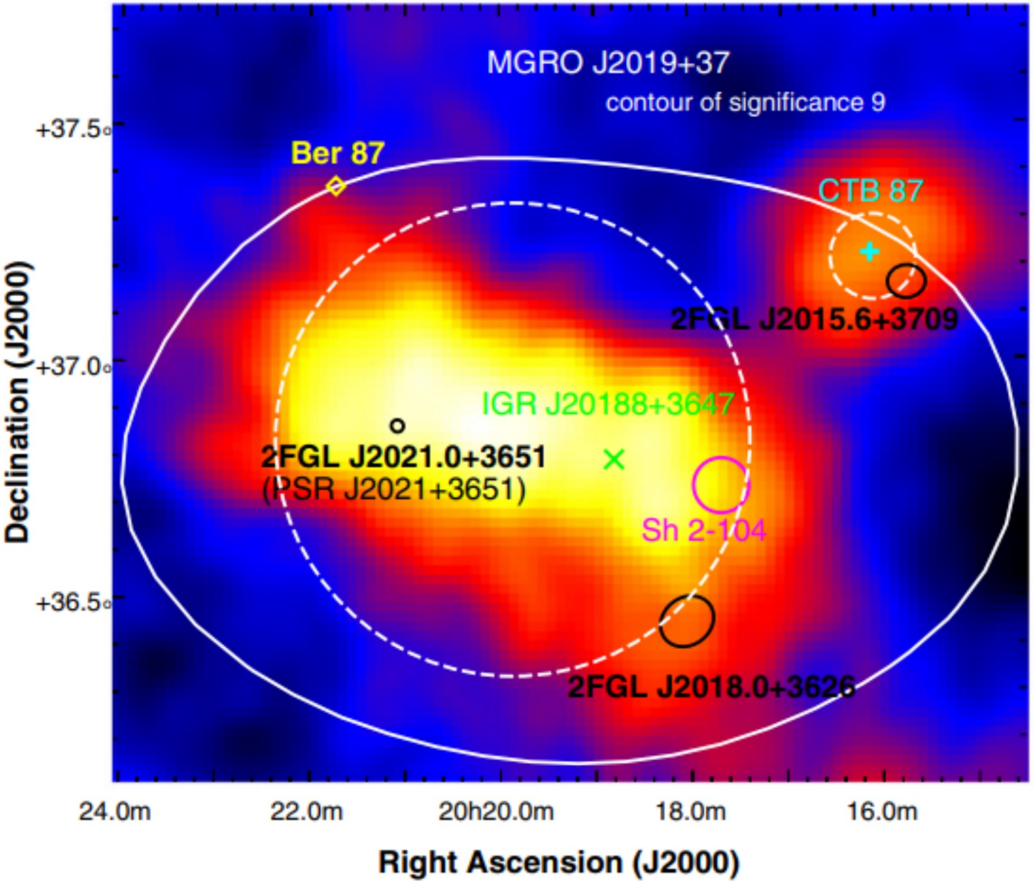
Observation of the Crab Nebula with the Single-Mirror Small-Size Telescope stereoscopic system at low altitude
SST-1M Collaboration
A&A, 699, A255 (2025)
https://doi.org/10.1051/0004-6361/202555292

SST-1M

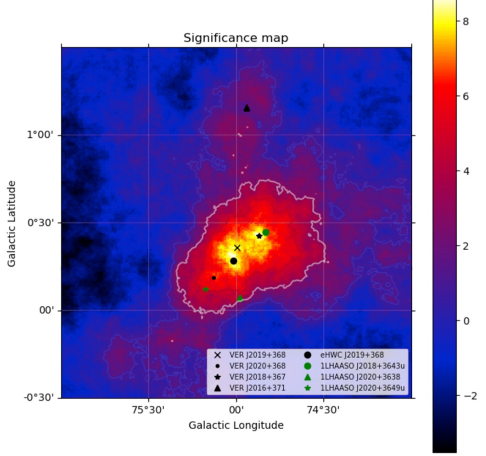
- **Full end-to-end validation of the SST-1M system**, using Crab Nebula observations in **both mono and stereo modes**, with a **fully tuned MC model** (optics, camera, atmosphere) reproducing data at all analysis levels.
- **High-significance Crab detection** (tens of σ) with **~50 h mono** and **~30 h stereo** exposure, demonstrating stable performance and robust γ/hadron separation.
- **Measured performance consistent with MC:** energy threshold ~1–1.3 TeV, angular resolution down to ~0.10° (stereo), confirming reliable reconstruction.
- **Sensitivity to the highest energies**, with reconstructed events extending to **>100 TeV**, validating SST-1M capability for **multi-TeV and ultra-high-energy γ-ray astronomy**.



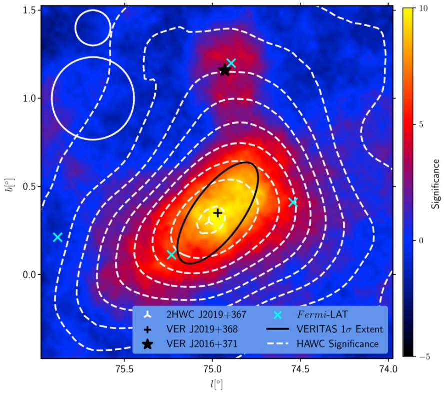
SST-1M



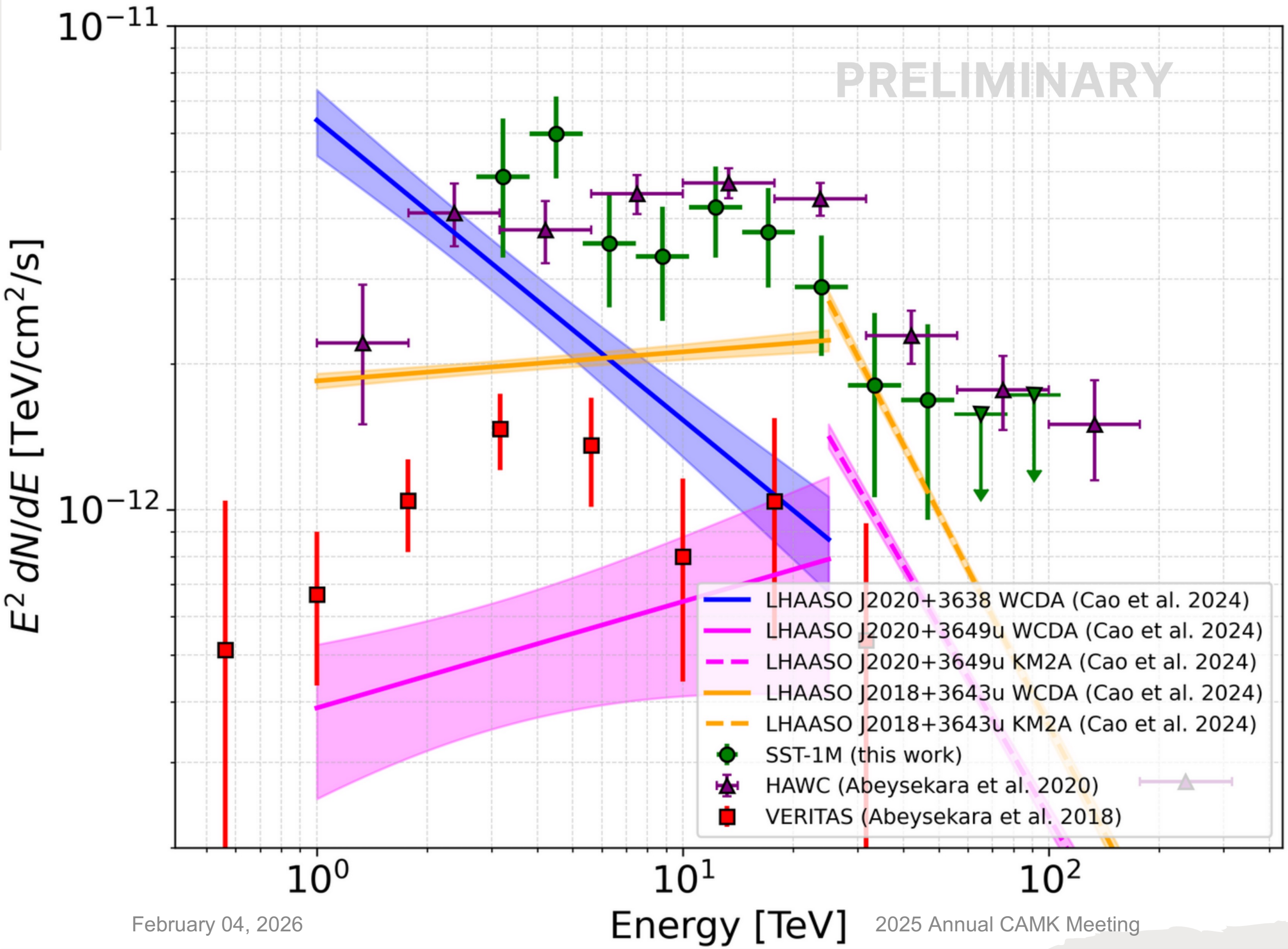
SST-1M

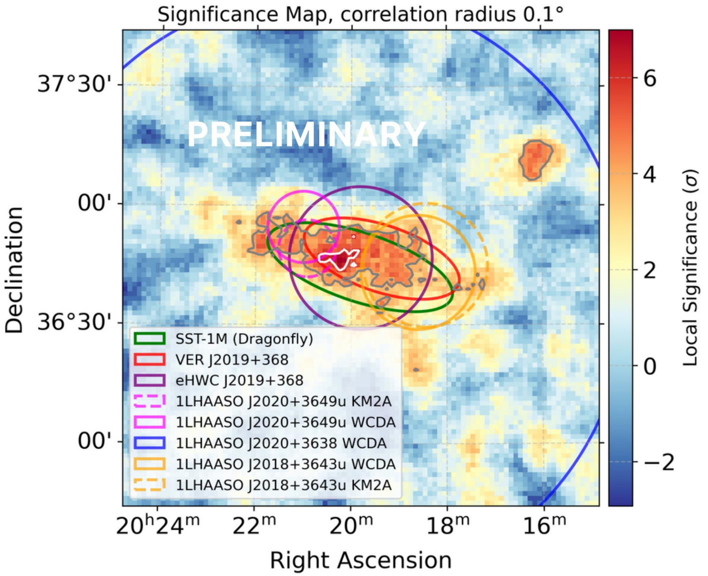


VERITAS



SST-1M


PRELIMINARY
10^{-11}
10^{-12}
$E^2\, dN/dE$ [TeV/cm^2/s]
10^0
10^1
10^2
Energy [TeV]
LHAASO J2020+3638 WCDA (Cao et al. 2024)
LHAASO J2020+3649u WCDA (Cao et al. 2024)
LHAASO J2020+3649u KM2A (Cao et al. 2024)
LHAASO J2018+3643u WCDA (Cao et al. 2024)
LHAASO J2018+3643u KM2A (Cao et al. 2024)
SST-1M (this work)
HAWC (Abeysekara et al. 2020)
VERITAS (Abeysekara et al. 2018)


Significance Map, correlation radius 0.1°
PRELIMINARY
Declination
37°30'
00'
36°30'
00'
Right Ascension
20^h24^m
22^m
20^m
18^m
16^m
Local Significance (σ)
6
4
2
0
−2
SST-1M (Dragonfly)
VER J2019+368
eHWC J2019+368
1LHAASO J2020+3649u KM2A
1LHAASO J2020+3649u WCDA
1LHAASO J2020+3638 WCDA
1LHAASO J2018+3643u WCDA
1LHAASO J2018+3643u KM2A