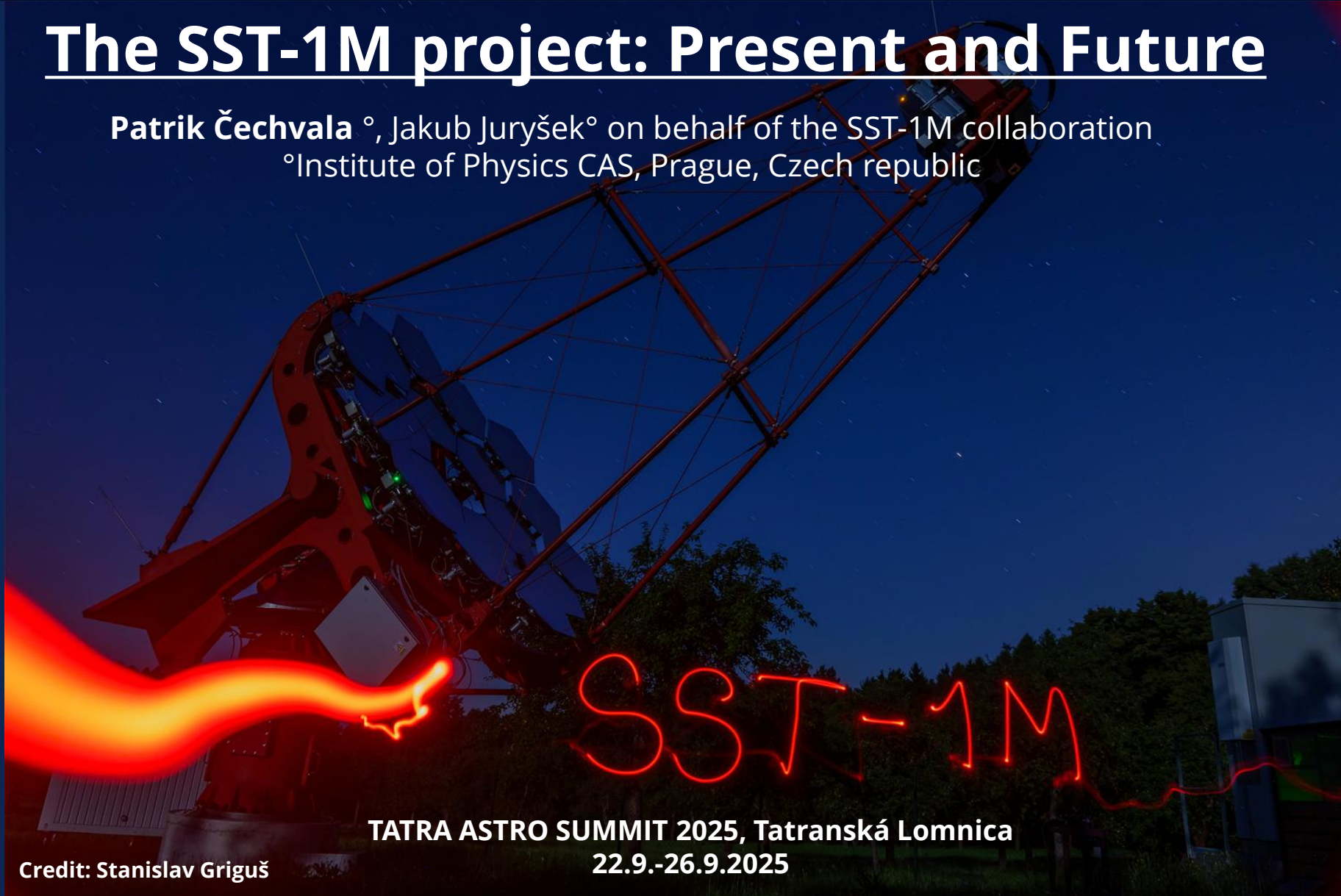


The SST-1M project: Present and Future

Patrik Čechvala °, Jakub Juryšek° on behalf of the SST-1M collaboration
°Institute of Physics CAS, Prague, Czech republic



TATRA ASTRO SUMMIT 2025, Tatranská Lomnica
22.9.-26.9.2025

Credit: Stanislav Griguš



SST-1M

Single-Mirror
Small Size Telescope



FZU

Institute of Physics
of the Czech
Academy of Sciences

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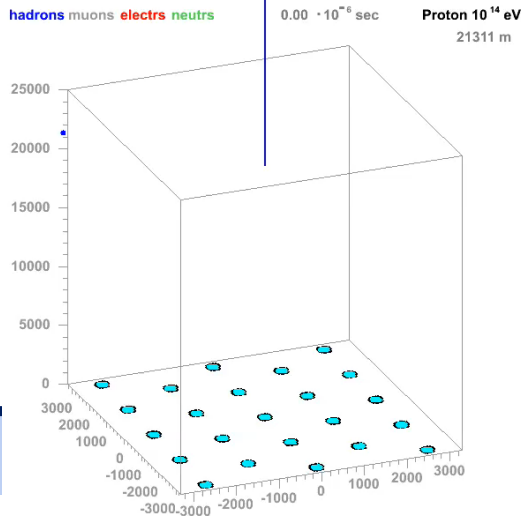
Co-funded
by the European Union

Outline

- **Imaging Atmospheric Cherenkov Telescopes**
- **Single Mirror Small Size Telescopes – SST-1M project**
- **Performance and scientific results of SST-1M**
- **Future prospects**

Detection techniques in gamma-ray astronomy

(Longair, 1992)



Credit: The University of Sheffield

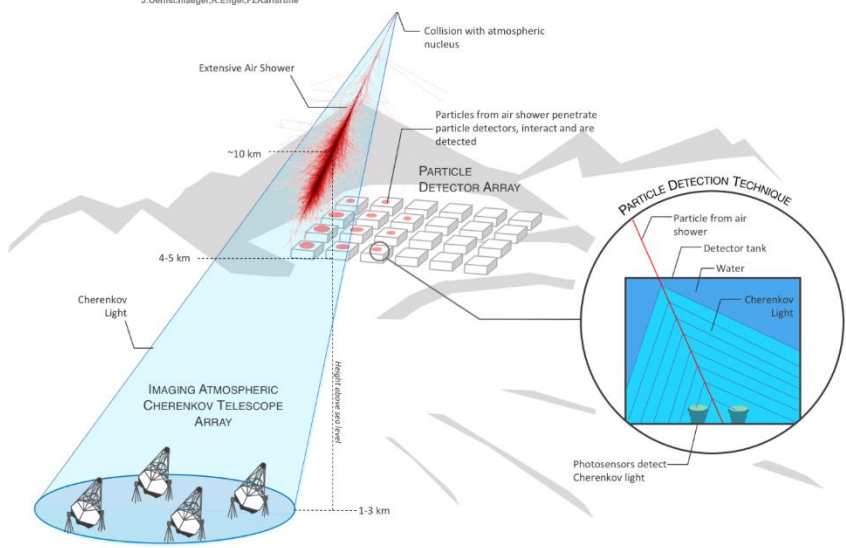
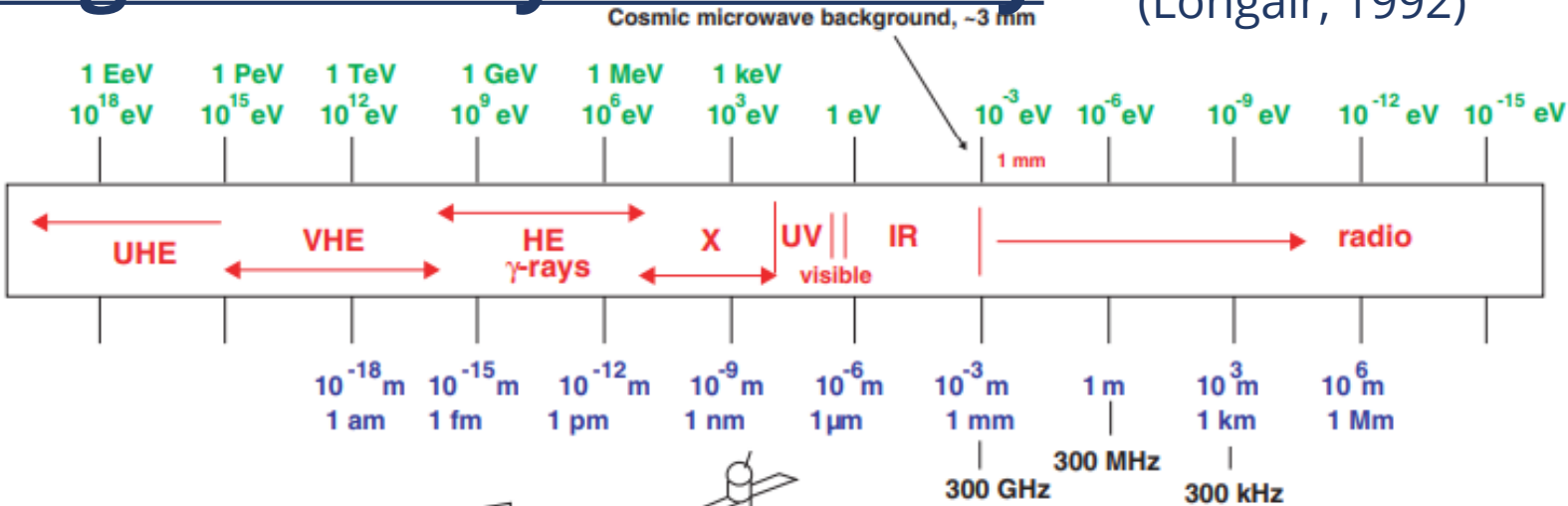
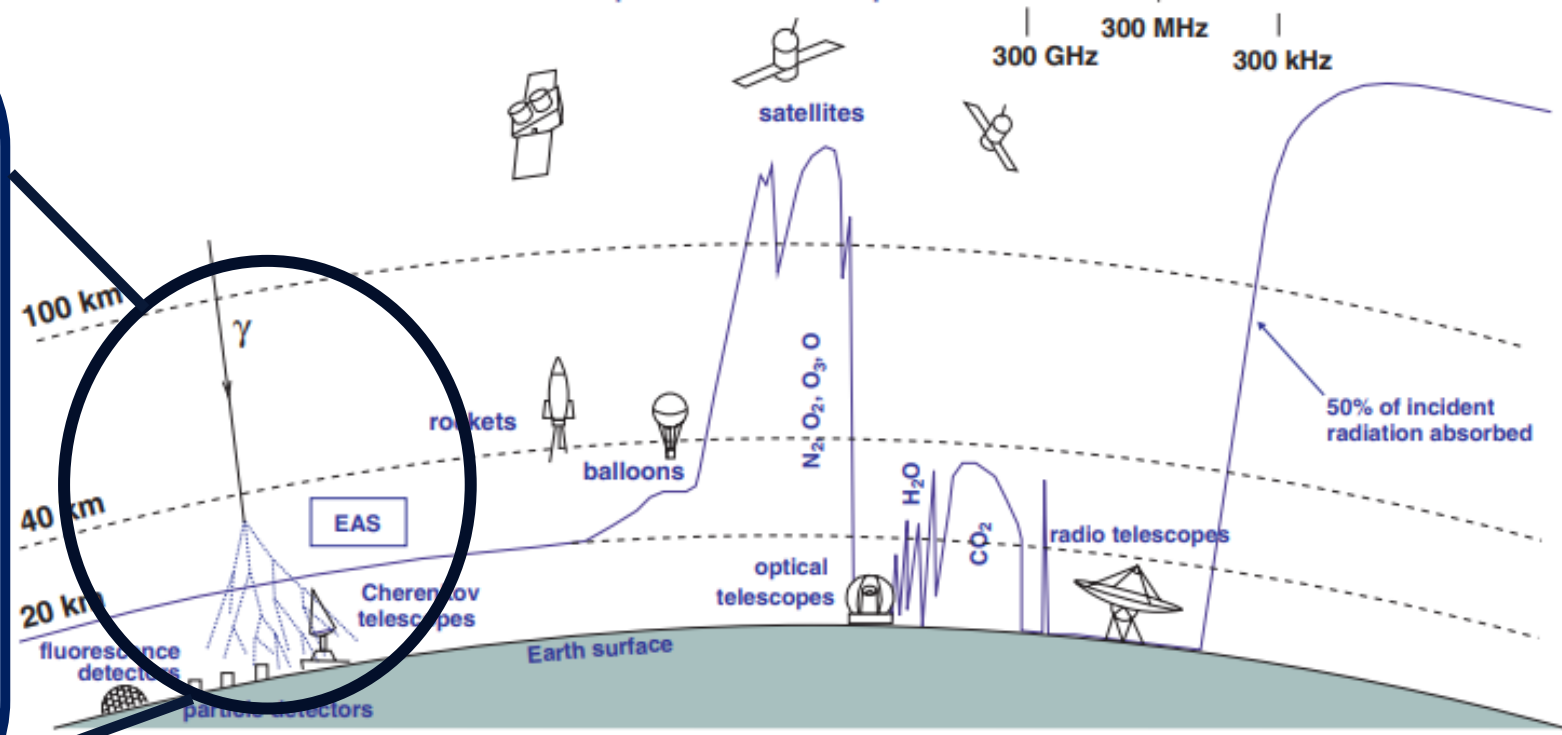
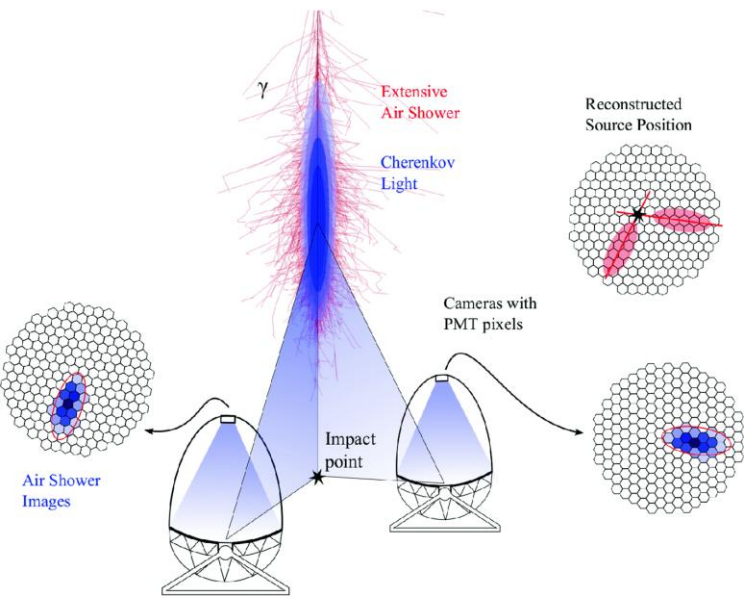


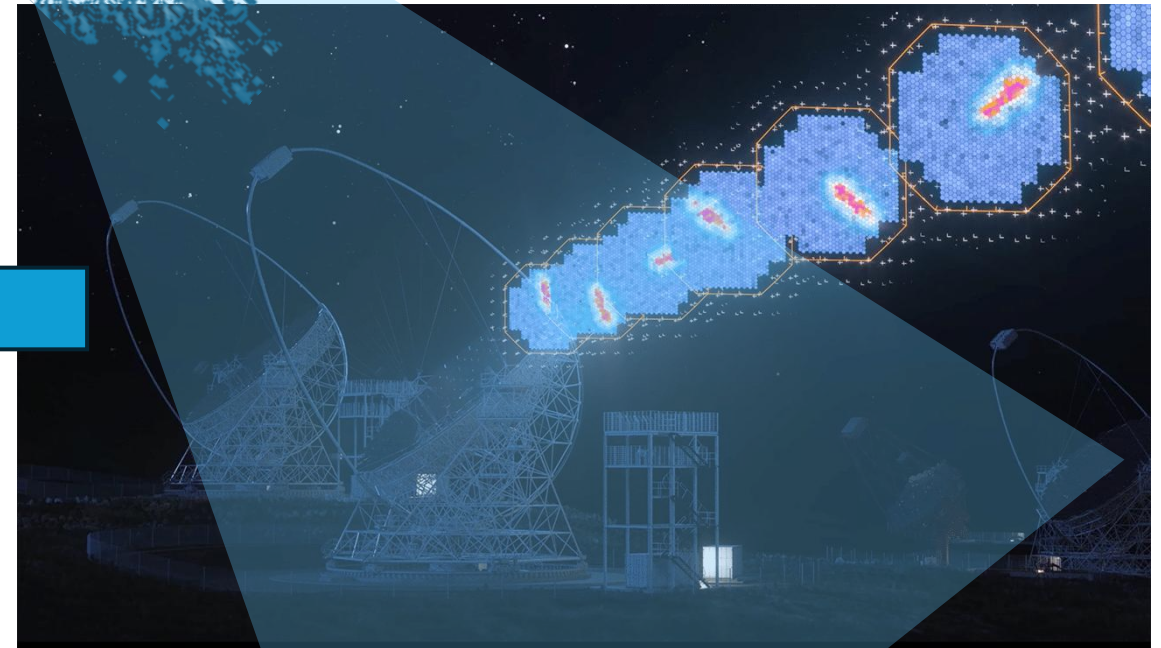
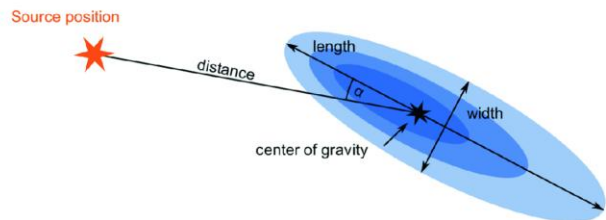
Illustration of the complementary detection techniques of high-energy gamma rays on ground. (Credit: Richard White, MPIK)



Imaging Atmospheric Cherenkov Telescopes



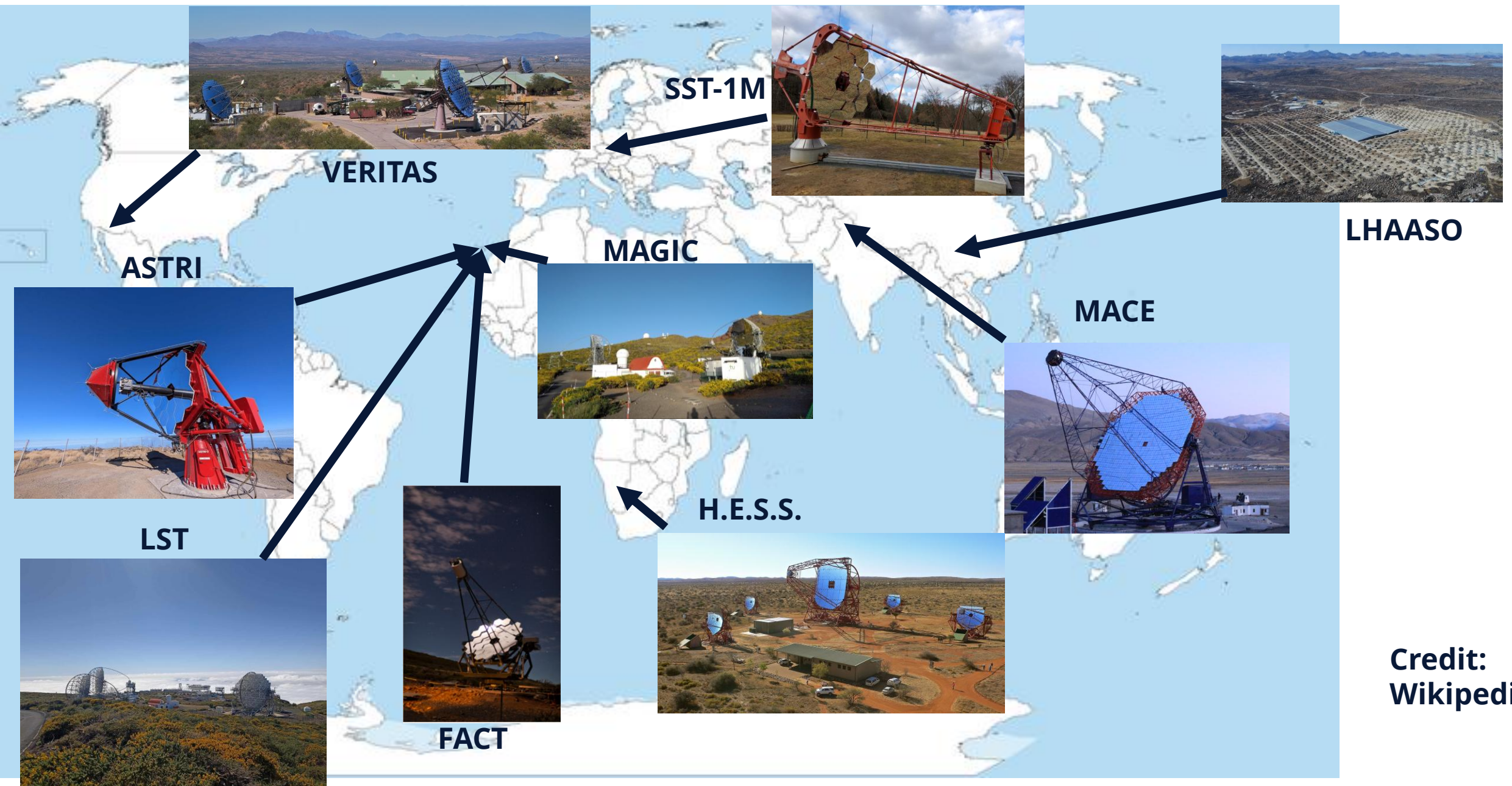
- **Reflective telescopes** on Alt-Az mounts – first in 1980s Whipple telescope
- Sensitive camera photo-detection plane composed of an array of silicon photomultipliers
- Parametrisation of the shower image – **Hillas parameters** (Hillas, 1985)
- For multiple telescopes, possibility to operate in **stereo regime** – improvement of **γ /hadron separation, direction reconstruction** and **energy reconstruction**





Credit: CTAO

Imaging Atmospheric Cherenkov Telescopes (IACTs) across the world



Credit:
Wikipedia

SST-1M project



SST-1M

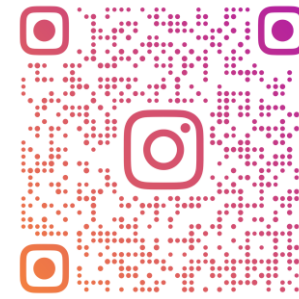
Single-Mirror
Small Size Telescope

- Collaboration of 17 institutes from **3 countries** – **Czechia, Poland and Switzerland**
- Developed as a design of Small Sized Telescopes for CTAO – **other design was selected**
- Constructed **2 SST-1M prototypes** – relocated in 2022 from Poland to **Ondřejov Observatory** of Czech Academy of Sciences near Prague

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<https://sst-1m.science/>



SST1M_SPACE



Nicolaus Copernicus
Astronomical Center



Centrum Badań Kosmicznych
Space Research Centre



THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES



University of Science and
Technology



JAGIELLONIAN
UNIVERSITY
IN KRAKOW



UNIVERSITÉ
DE GENÈVE
FACULTÉ DES SCIENCES



UNIWERSYTET
WARSZAWSKI



FZU
Fyzikální ústav
Akademie věd
České republiky



Astronomický
ústav
AV ČR



Palacký University
Olomouc



The SST-1M collaboration

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Y. Favre
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A. Nagal
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L. Gibaud
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M. Miroń
M. Nikolajuk



J. Borkowski
R. Moderski
A. Muraczewski



M. Ostrowski
K. Ziętara



T. Bulik



The SST-1M collaboration

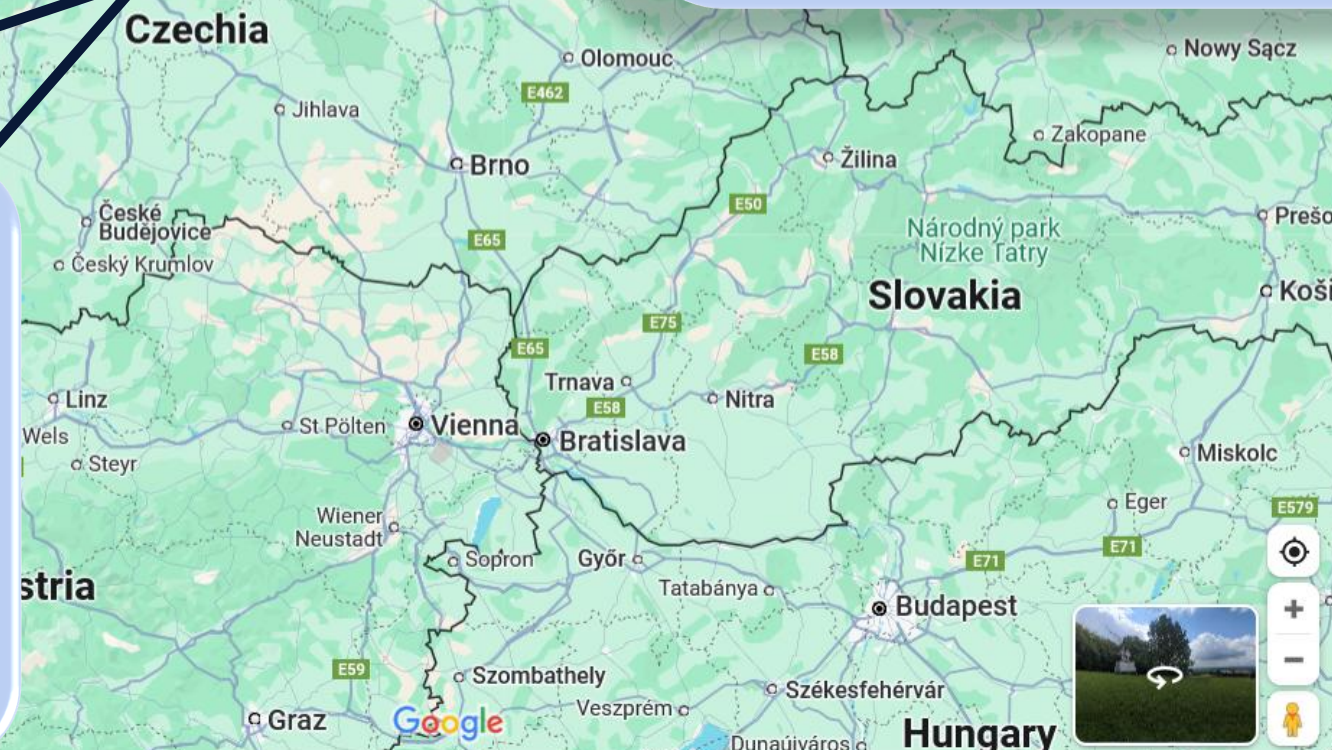
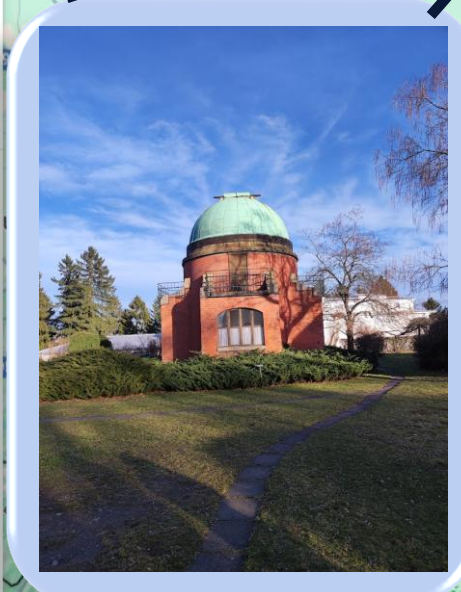
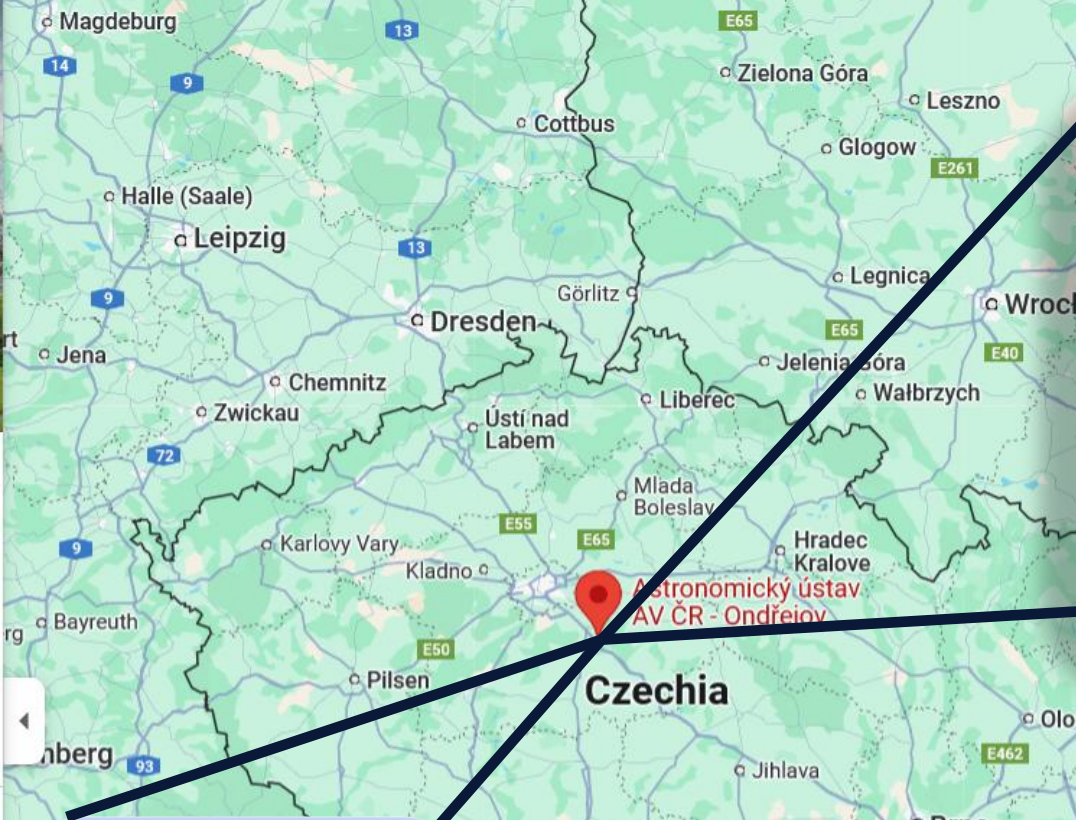


Photo taken during the International Cosmic Ray Conference in July 2025, Geneva

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Photo taken during the last collaboration meeting December 2024, Geneva



Ondřejov Observatory

<https://asu.cas.cz/>

Source: Google maps

SST-1M major milestones

Analysis/science related

- February/November 2022 – Telescope 2/1 installation in Ondřejov
- March 2023 – first sst1mpipe prototype
- April 2023 – Crab nebula **detection** in mono mode
- June 2023 – Crab nebula **detection** in stereo mode (without White Rabbit)
- July 2023 – first extragalactic source **detected** 1ES 1959+650 detection
- October 2023 – Crab nebula **detected** in true stereo mode (using White Rabbit)
- November 2023 – first release of sst1mpipe
- March 2024 – **detection** of increased activity of Markarian 421, **first ATel #16533**
- August 2024 – first extended source **detected** in stereo mode
- February 2025 – hardware paper **published**, C. Alispach *et al* JCAP02(2025)047
- July 2025 – performance paper **published**, A&A

Detection of enhanced very-high-energy gamma-ray emission from Markarian 421

ATel #16533; **Thomas Tavernier, in the behalf of SST-1M Consortium**
on 15 Mar 2024; 16:55 UT

Credential Certification: Thomas Tavernier (tavernier@fzu.cz)

Subjects: Gamma Ray, TeV, VHE, AGN, Blazar

Referred to by ATel #: 16537

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

RECEIVED: September 18, 2024
REVISED: November 27, 2024
ACCEPTED: January 5, 2025
PUBLISHED: February 19, 2025

The SST-1M imaging atmospheric Cherenkov telescope
for gamma-ray astrophysics

**Astronomy
Astrophysics**

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

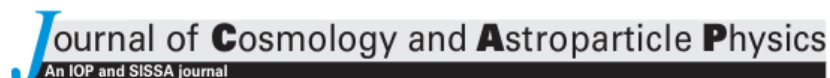
C. Alispach¹, A. Araudo², M. Balbo¹, V. Beshley³, J. Blažek², J. Borkowski⁴, S. Boula⁵, T. Bulik⁶, F. Cadoux¹, S. Casanova³, A. Christov², J. Chudoba², L. Chytka⁷, P. Čechvala², P. Dédic², D. della Volpe¹, Y. Favre¹, M. Garczarczyk⁸, L. Gibaud⁹, T. Gieras⁵, E. Głowacki⁹, P. Hamal⁷, M. Heller¹, M. Hrabovský⁷, P. Janeček², M. Jelínek¹⁰, V. Jilek⁷, J. Juryšek², V. Karas¹¹, B. Lacave¹, E. Lyard¹², E. Mach⁵, D. Mandát², W. Marek⁵, S. Michal⁷, J. Michałowski⁵, M. Miron⁹, R. Moderski¹⁴, T. Montaruli¹, A. Muraczewski⁴, S. R. Muthyala², A. L. Müller², A. Nagai¹, K. Nalewajski², D. Neise¹³, J. Niemiec², M. Nikolajuk⁹, V. Novotný^{2,14,*}, M. Ostrowski¹⁵, M. Palatka², M. Pech², M. Prouza², P. Schovanek², V. Sliusar¹², L. Stawarz¹⁵, R. Sternberger⁸, M. Stodulska¹, J. Świerblewski⁵, P. Świerk⁵, J. Štrobl¹⁰, T. Tavernier^{2,1*}, P. Trávníček², I. Troyano Pujadas¹, J. Vicha², R. Walter¹², and K. Zięta¹⁵

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Publication status

Published papers

- C. Alispach et al JCAP02(2025)047 - *The SST-1M imaging atmospheric Cherenkov telescope for gamma-ray astrophysics*, 10.1088/1475-7516/2025/02/047



RECEIVED: September 18, 2024
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The SST-1M imaging atmospheric Cherenkov telescope for gamma-ray astrophysics

C. Alispach et al. (2025). Observation of the Crab Nebula with the Single-Mirror Small-Size Telescope stereoscopic system at low altitude. *Astronomy and Astrophysics*. <https://doi.org/10.1051/0004-6361/202555292>

A&A, 699, A255 (2025)
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**Astronomy
&
Astrophysics**

Observation of the Crab Nebula with the Single-Mirror Small-Size Telescope stereoscopic system at low altitude

C. Alispach¹, A. Araudo², M. Balbo¹, V. Beshley³, J. Blažek², J. Borkowski⁴, S. Boula⁵, T. Bulik⁶, F. Cadoux¹, S. Casanova³, A. Christov², J. Chudoba², L. Chytka⁷, P. Čechvala², P. Dedic², D. della Volpe¹, Y. Favre¹, M. Garczarczyk⁸, L. Gibaud⁹, T. Gieras⁵, E. Glowacki⁹, P. Hamal⁷, M. Heller¹, M. Hrabovský⁷, P. Janeček², M. Jelínek¹⁰, V. Jilek⁷, J. Juryšek^{2,*}, V. Karas¹¹, B. Lacave¹, E. Lyard¹², E. Mach⁵, D. Mandát², W. Marek⁵, S. Michal⁷, J. Michałowski⁵, M. Mironi⁹, R. Moderski⁴, T. Montaruli¹, A. Muraczewski⁴, S. R. Muthyala², A. L. Müller², A. Nagai¹, K. Nalewajski⁵, D. Neise¹³, J. Niemiec⁵, M. Nikolajuk⁹, V. Novotný^{2,14,*}, M. Ostrowski¹⁵, M. Palatka², M. Pech², M. Prouza², P. Schovanek², V. Sliusar¹², Ł. Stawarz¹⁵, R. Sternberger⁸, M. Stodulska¹, J. Świerblewski⁵, P. Świerk⁵, J. Štrobl¹⁰, T. Tavernier^{2,*}, P. Trávníček², I. Troyano Pujadas¹, J. Vicha², R. Walter¹², and K. Ziętara¹⁵

Conference contributions

• 2023

International Cosmic Ray Conference

- Juryšek et al., **PoS(ICRC2023)592** - Mono and stereo performance of the two SST-1M telescope prototypes, <https://doi.org/10.22323/1.444.0592>
- Tavernier et al., **PoS(ICRC2023)741** - Analysis of commissioning data from SST-1M: A Prototype of Single-Mirror Small Size Telescope, <https://doi.org/10.22323/1.444.0741>

• 2024

IAU General Assembly 2024

- M. Nikolajuk – **poster**, SST-1M mini-array progress at the Ondřejov observatory

Gamma 2024

- J. Juryšek – **talk**, Observation of Astrophysical Sources with SST-1M Telescopes
- M. Heller – **poster**, Commissioning and Operation of the SST-1M Stereoscopic Imaging Atmospheric Cherenkov Telescopes

TDiHEP III 2024

- P. Čechvala – **talk**, Overview of the SST-1M project – triggering and recent scientific results

WDS

- S. Muthyala – **talk**, Gamma-ray emission from Markarian 421

Moriond

- T. Tavernier – **talk**, SST-1M IACTs : Commissioning and Preliminary Observation Results

TeVPA

- T. Tavernier – **talk**, SST-1M IACTs : Commissioning and Preliminary Observation Results

Publication status

Conference contributions

- **2025**

Bezovec, Conference of Young Astronomers 2025

- P. Čechvala – **talk**, *Gamma-ray astronomy with SST-1M Imaging Atmospheric Cherenkov Telescopes*

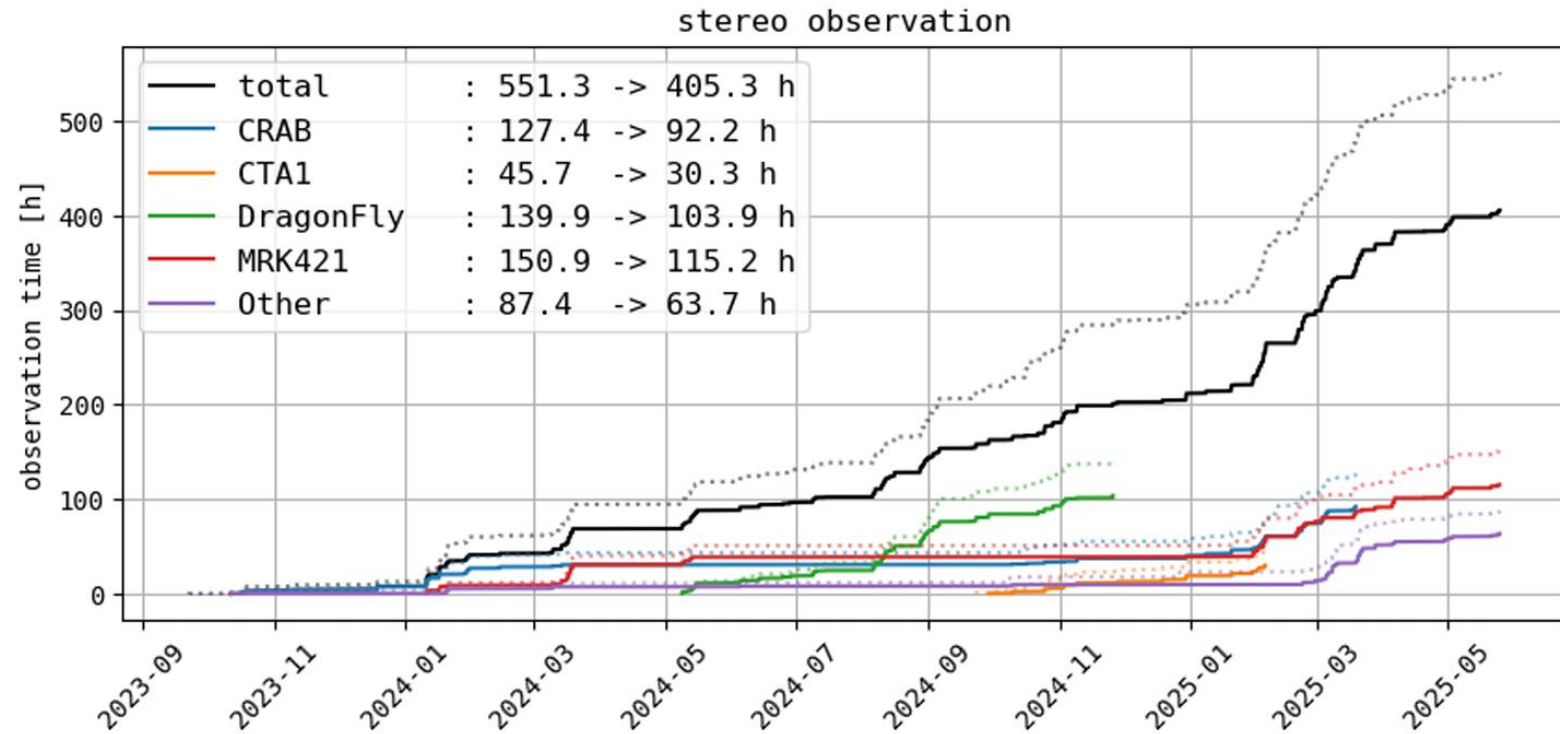
International Cosmic Ray Conference

- Alispach et al., **PoS(ICRC2025)771** - *The SST-1M stereoscopic systems*, <https://doi.org/10.22323/1.501.0771>
- Tavernier et al., **PoS(ICRC2025)861** - *Calibration and Performance Validation of the SST-1M Telescopes Using Crab Nebula Observations*, <https://doi.org/10.22323/1.501.0861>
- Muthyala et al., **PoS(ICRC2025)776** - *SST-1M Observations of Markarian 421*, <https://doi.org/10.22323/1.501.0776>
- Lacave et al., **PoS(ICRC2025)719** - *Stereo observations of CTA 1 with SST-1M*, <https://doi.org/10.22323/1.501.0719>
- Juryšek et al., **PoS(ICRC2025)703** - *Observation of VER J2019+368 with the SST-1M stereoscopic system*, <https://doi.org/10.22323/1.501.0703>
- Mandát et al., **PoS(ICRC2025)746** - *Operation of the SST-1M Cherenkov telescope gammaray stereoscopic system*, <https://doi.org/10.22323/1.501.0746>
- Čechvala et al., **PoS(ICRC2025)908** - *Stereo performance of SST-1M at different altitudes*, <https://doi.org/10.22323/1.501.0908>
- Bakalová et al., **PoS(ICRC2025)558** - *Hybrid concept of detection for a wide-field gamma-ray observatory using Cherenkov telescopes*, <https://doi.org/10.22323/1.501.0558>



SST-1M telescopes

- Davies-Cotton optics
- Segmented mirror – 18 hexagonal mirror facests
- Fully remote observations



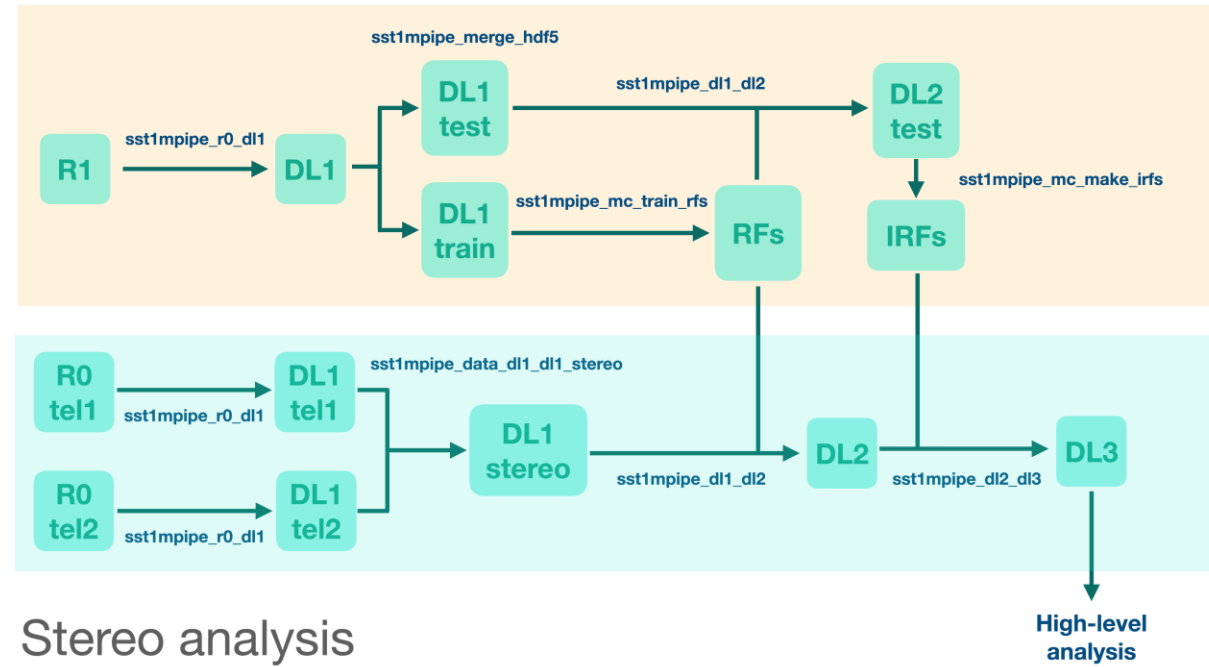
Alispach et al., JCAP02(2025)047

Mandát et al., PoS(ICRC2025)746

sst1mpipe

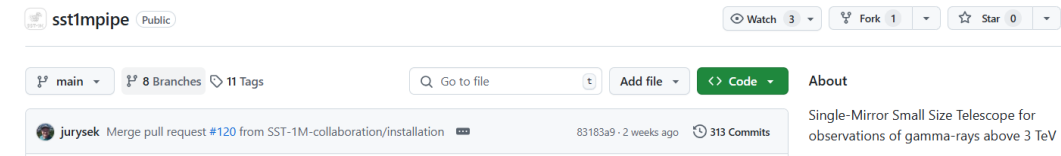
- Data and Monte Carlo analysis **software for low-level analysis** – waveform calibration and integration, shower-image parametrisation, stereo reconstruction, random forest training, instrument response function (IRF) calculation
- Pipeline is divided into several steps (r0 -> dl1 -> dl2 -> dl3) – based on **functions adopted from ctapipe** <https://github.com/cta-observatory/ctapipe> and **follows lstchain** [cta-observatory.github.io/cta-lstchain/](https://github.com/cta-observatory/gammapy)
- Results are **compatible with gamma-astro-data-format** (GADF) -> can be forwarded for high-level analysis (dl4/dl5/dl6) performed by gammapy

Monte Carlo

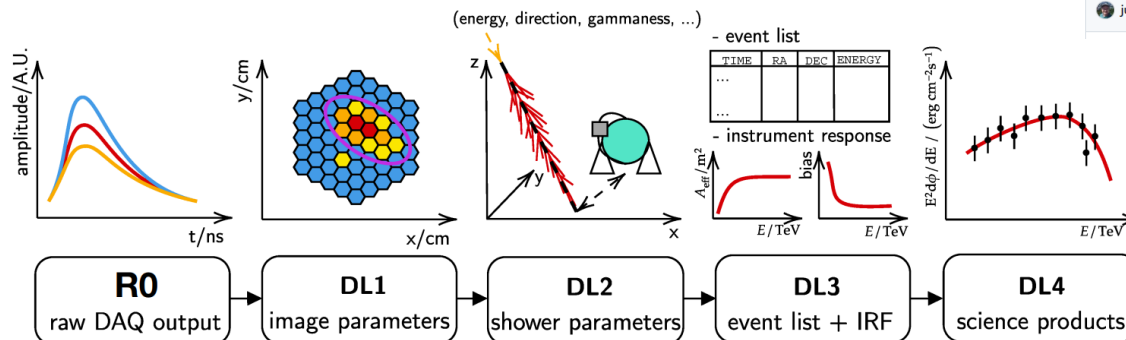


Stereo analysis

- Juryšek et al., PoS(ICRC2023)592
- Juryšek et al., 2024, sst1mpipe v.0.4.1, Zenodo
- <https://github.com/SST-1M-collaboration/sst1mpipe>



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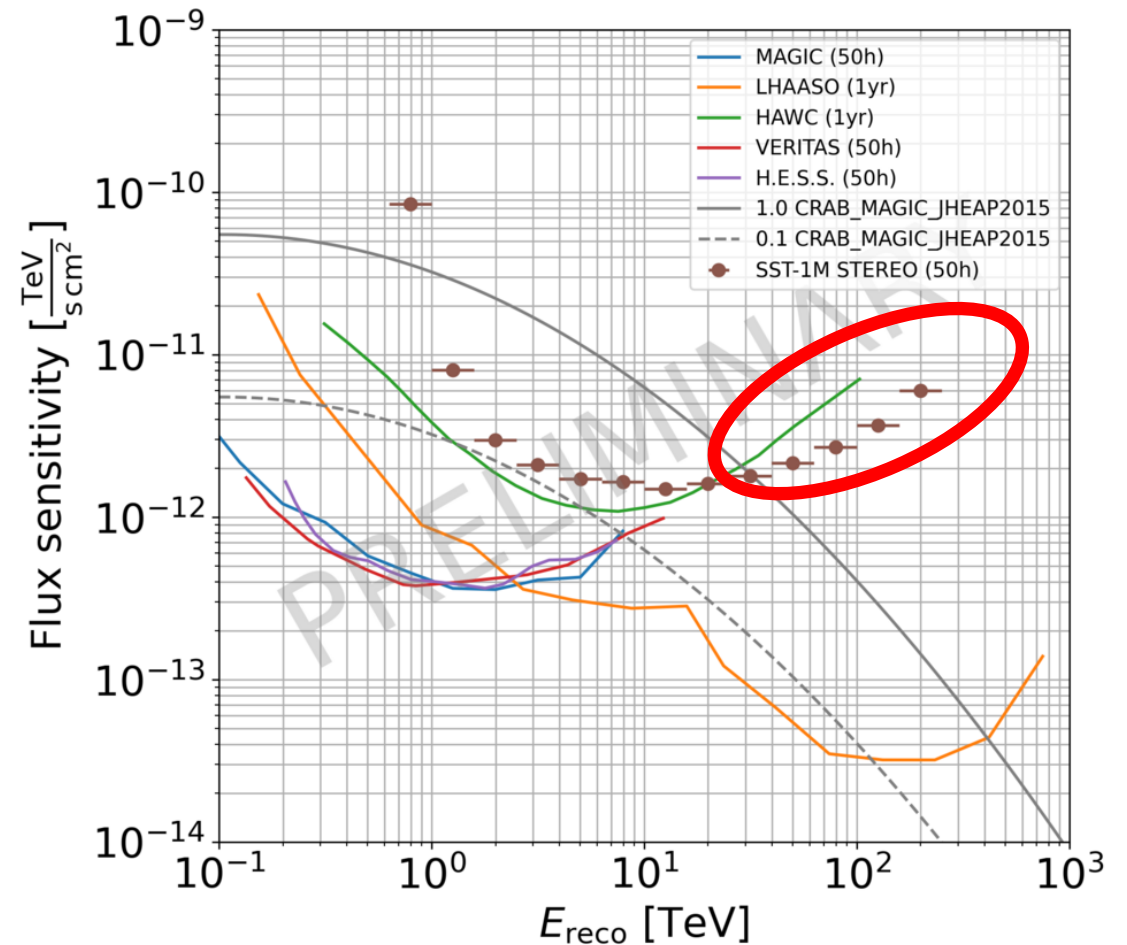
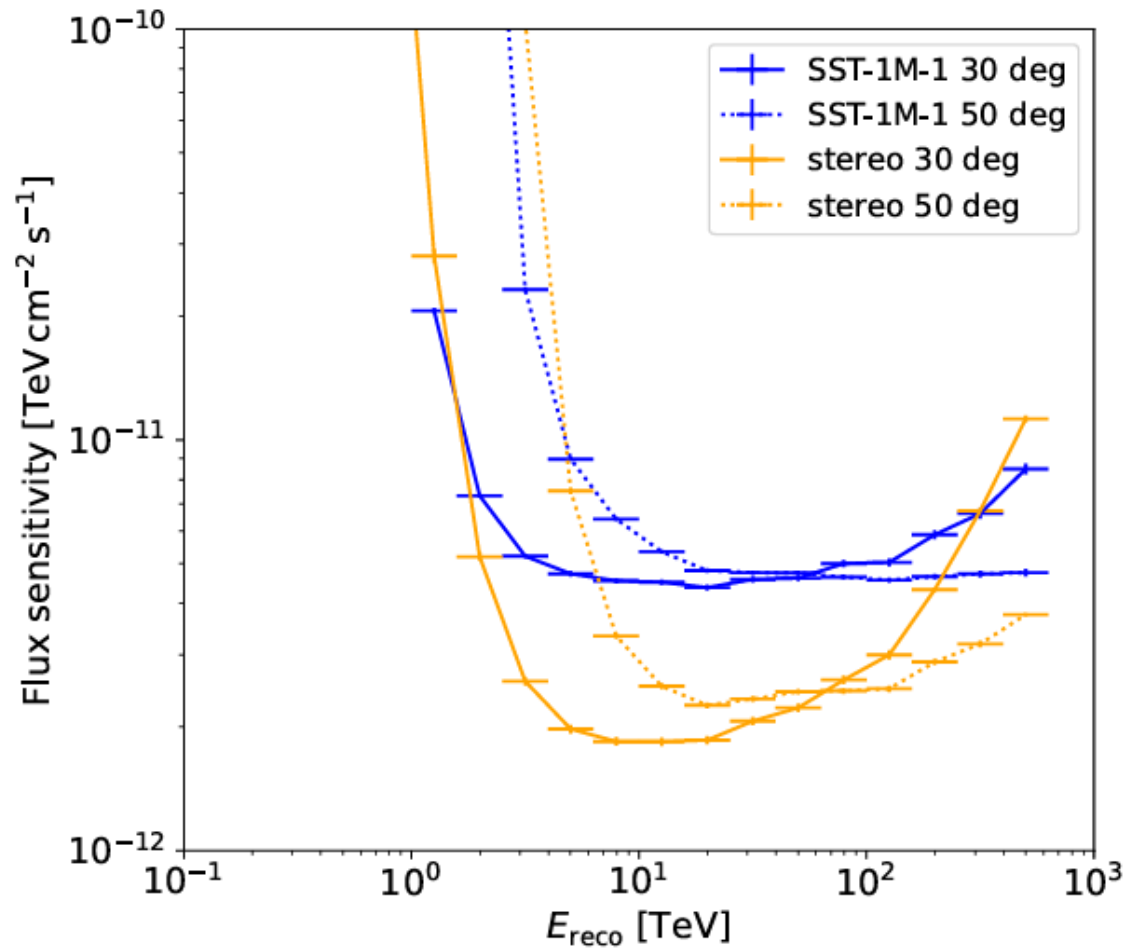
Nigro, C., Hassan, T., & Olivera-Nieto, L. (2021). Evolution of Data Formats in Very-High-Energy Gamma-Ray Astronomy. *Universe*, 7(10), 374.
<https://doi.org/10.3390/universe7100374>

Performance of SST-1M (Ondřejov)

Juryšek et al., (2023), PoS(ICRC2023)592

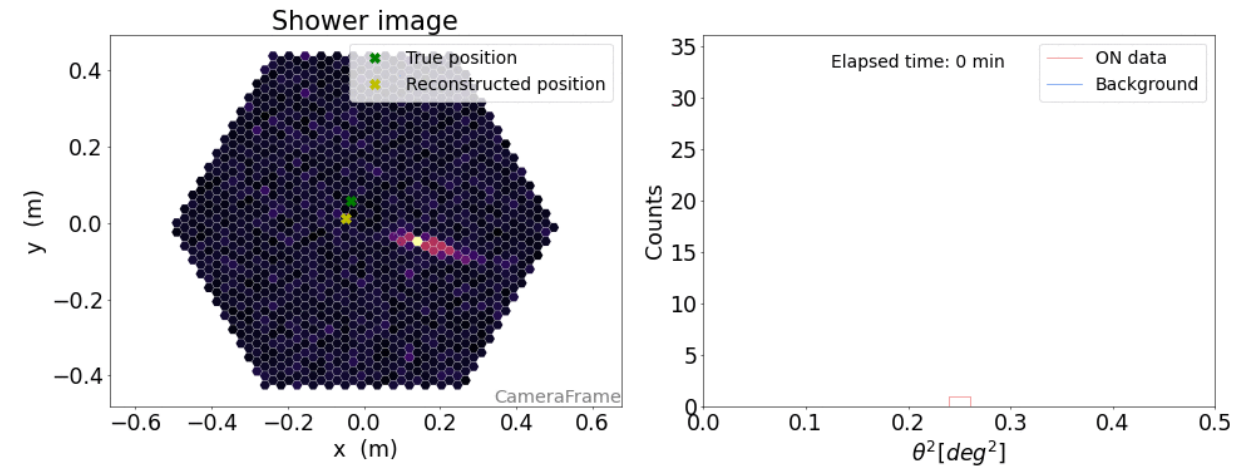
Alispach et al., (2025), A&A

- Sensitivity in energy domain approx. 1 TeV – 100 TeV
- Significant improvement of performance in stereo mode comparing to mono mode
- Results in stereo mode
- Angular resolution in stereo $\approx 0.1^\circ$
- Energy resolution in stereo $\approx 10\%-15\%$

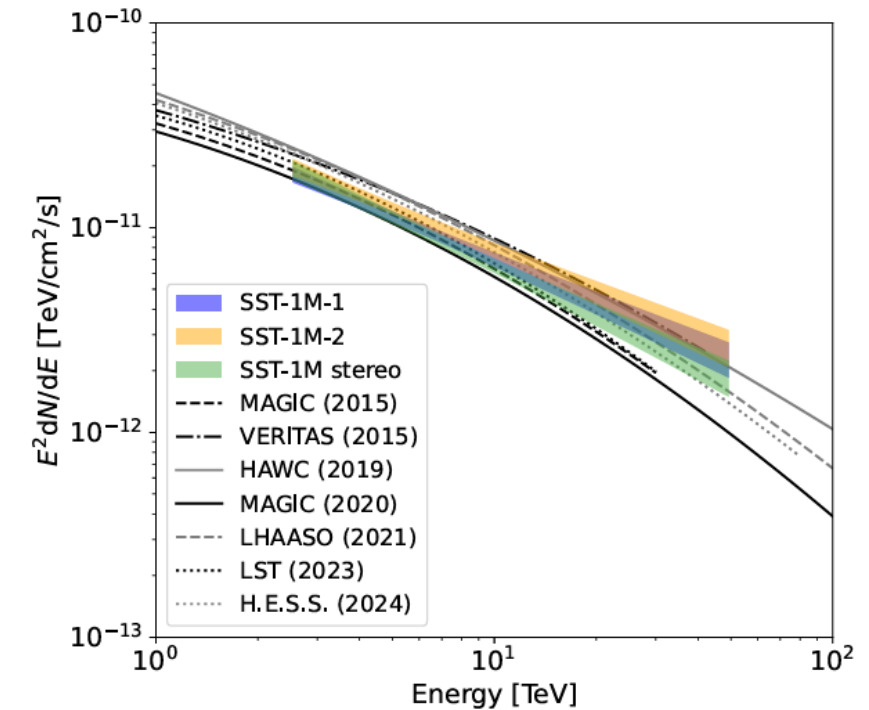
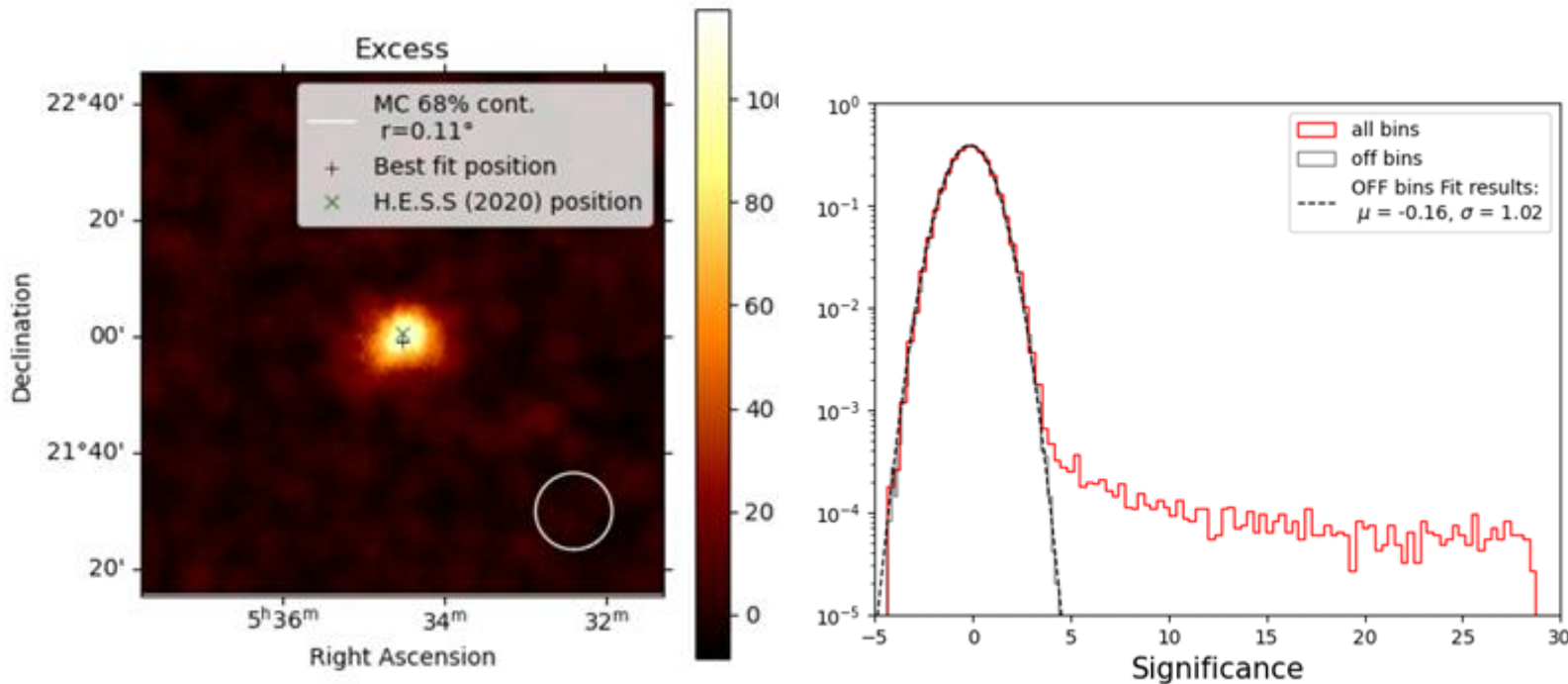


Crab Nebula (M1) observation

- Standard candle in gamma-ray astronomy
- Obs. campaign 2023/2024 - approx. 25 hours of stereo data after quality cuts
- Data zenith angle $< 53^\circ$ and energy threshold 1.0 TeV (mono), 1.3 TeV (stereo)
- 5σ detection in less than 2 hours in stereo (in less than 3 hours for mono)



Tavernier et al., (2023,) PoS(ICRC2023)741
Alispach et al., (2025), A&A



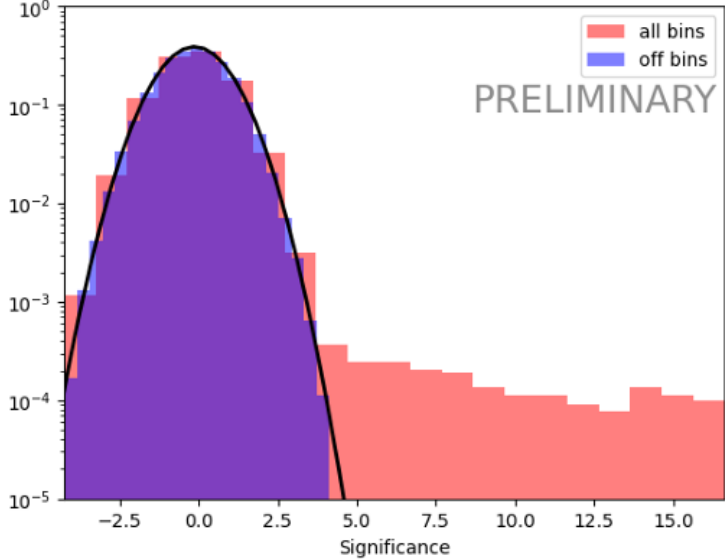
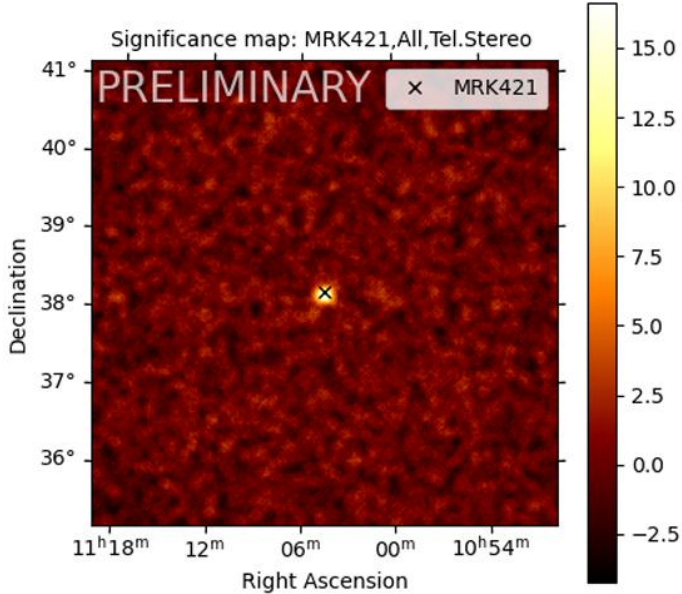
AGN activity monitoring – Mrk 421

- First extragalactic source in true stereo detected by SST-1M
- Higher activity detected on 15 of March 2024

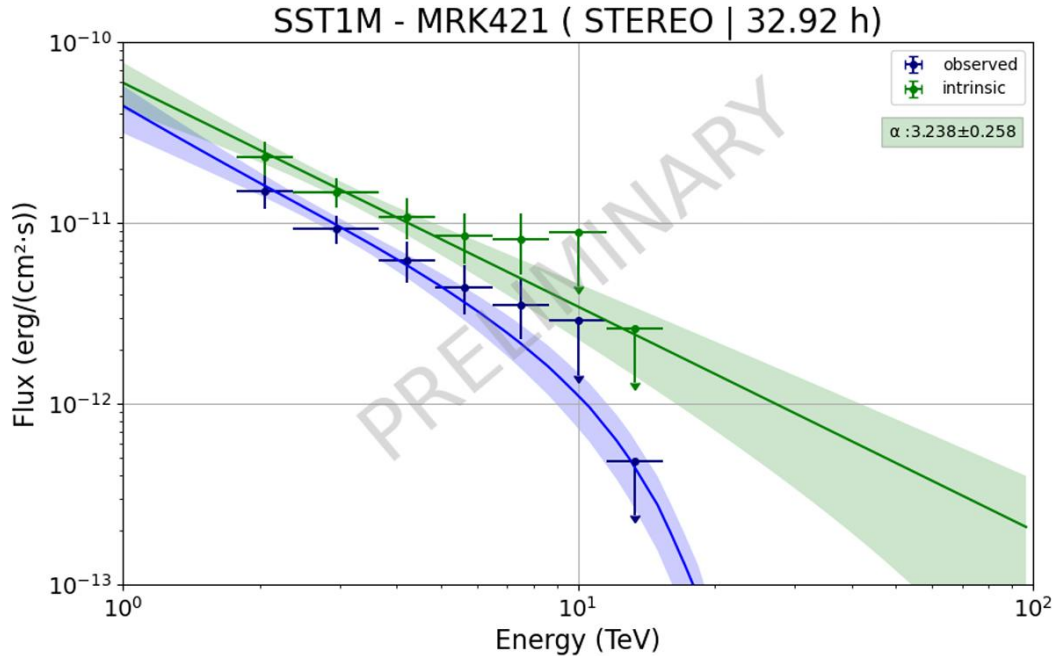
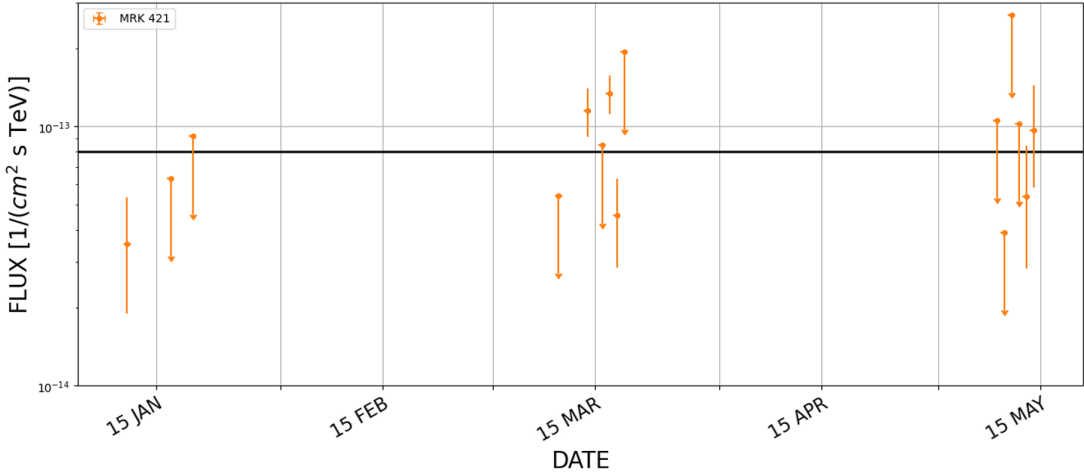
Detection of enhanced very-high-energy gamma-ray emission from Markarian 421

ATel #16533; *Thomas Tavernier, in the behalf of SST-1M Consortium*
on 15 Mar 2024; 16:55 UT
Credential Certification: Thomas Tavernier (tavernier@fzu.cz)

Best fit parameters	Power law index	Amplitude ($\text{TeV}^{-1}\text{cm}^{-2}\text{s}^{-1}$)
Intrinsic Spectrum	3.24 ± 0.26	$(1.06 \pm 0.12) \times 10^{-12}$



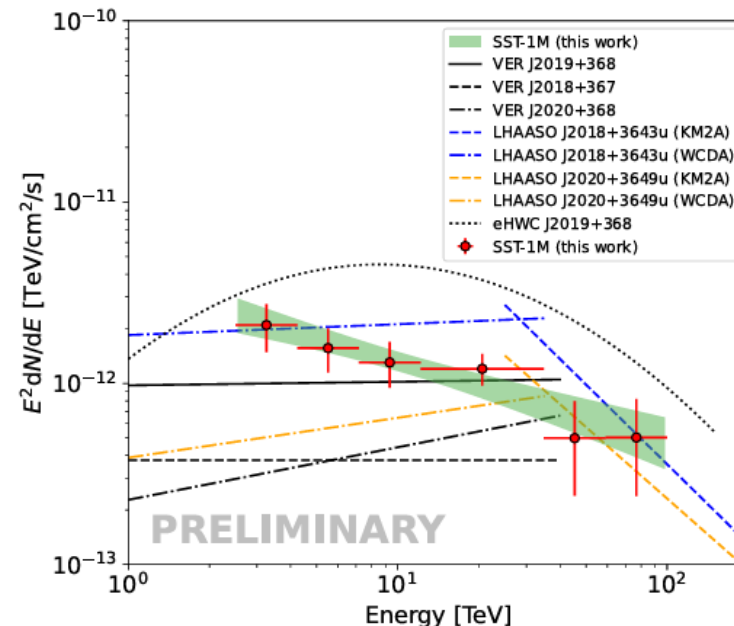
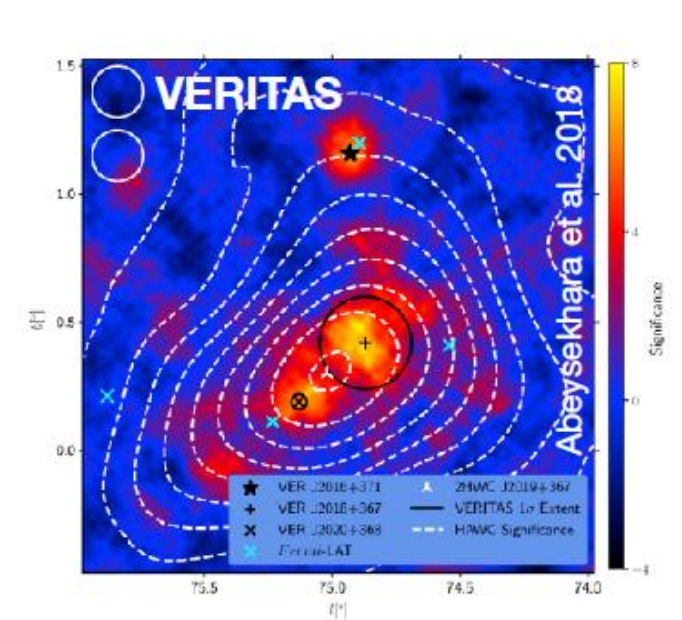
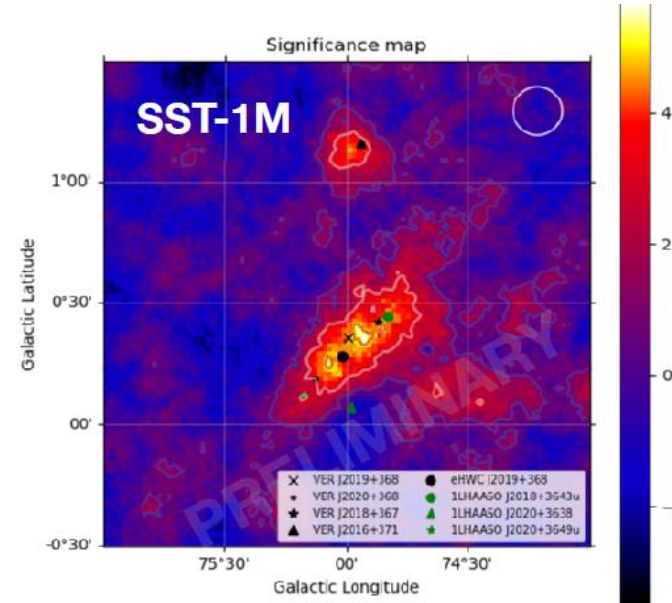
Muthyala et al., PoS(ICRC2025)776



VER J2019+368 (Dragonfly)

Juryšek et al., PoS(ICRC2025)703

- Complex region with multiple sources – in radio, in X-rays and in gamma rays
- Slightly extended source (approx. 0.5°)
- Observational campaign in 2024 – zenith angle ranging 5° - 60°
- Region discovered by MILAGRO (A. A. Abdo *et al* 2007 *ApJ* 658 L33)
- Resolved into different sources by VERITAS (A. U. Abeysekara *et al* 2018 *ApJ* 861 134)
- Source(s) resolved – VER 2019+368 together with CTB 87
- Ongoing analysis

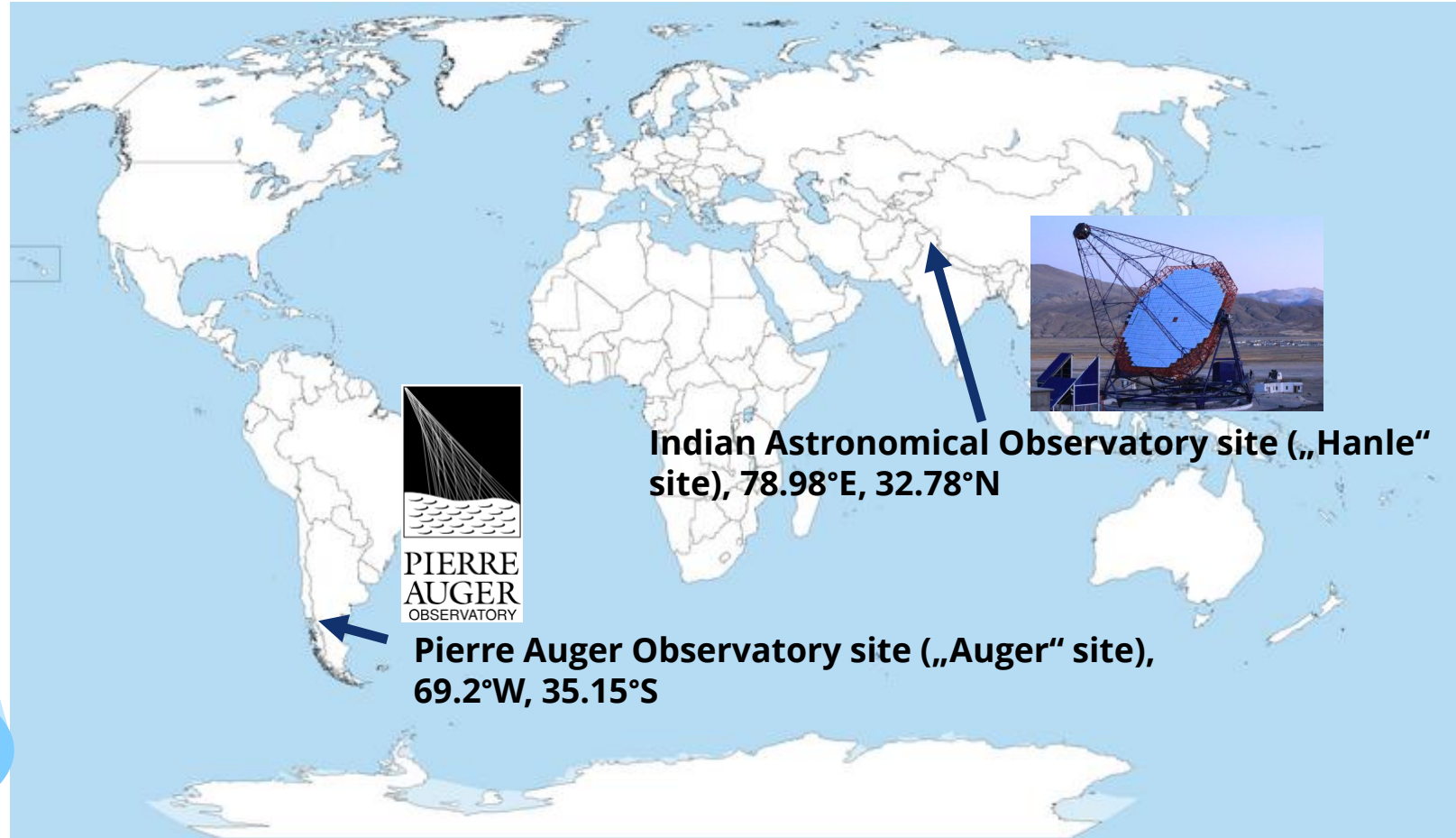
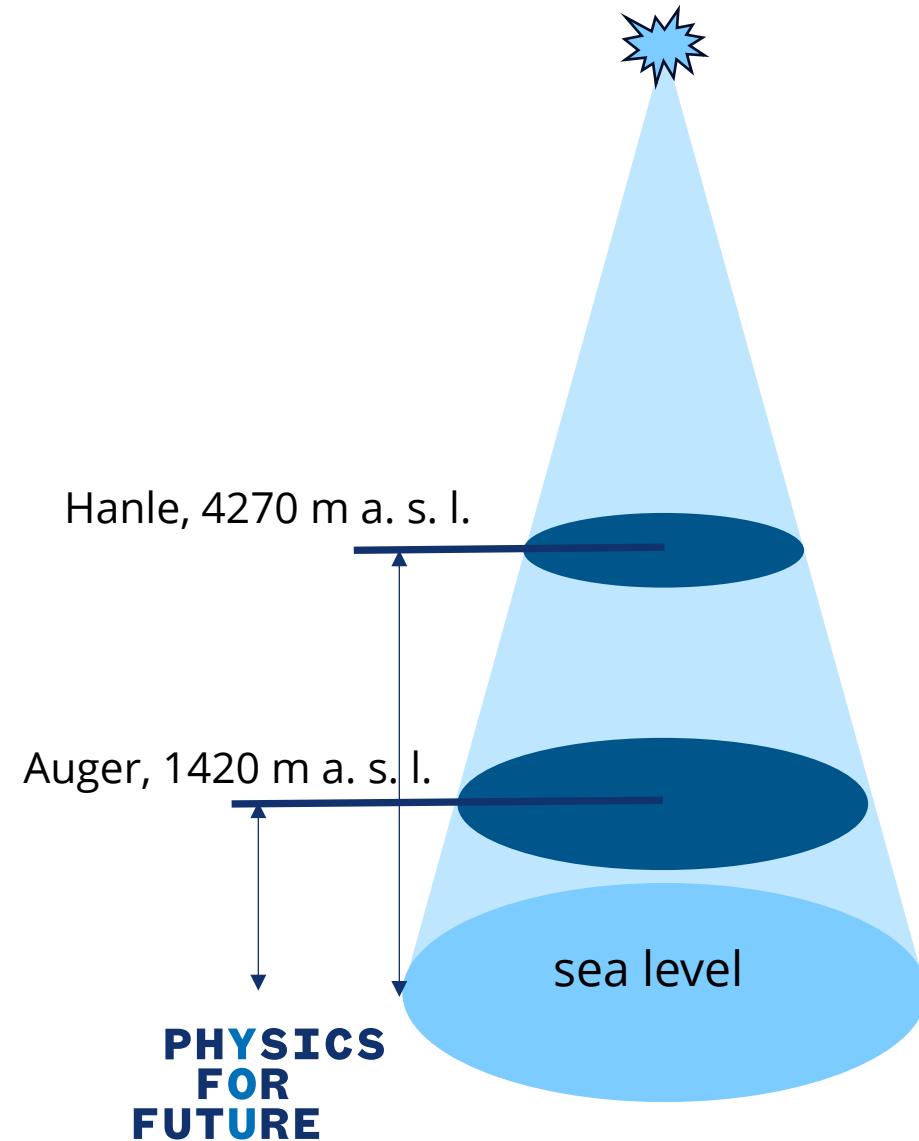


Searching for a new home for SST-1M telescopes

Čechvala et al., PoS(ICRC2025)908

- Atmospheric conditions in Ondřejov are not satisfactory – number of clear-sky nights

Credit:
Wikipedia

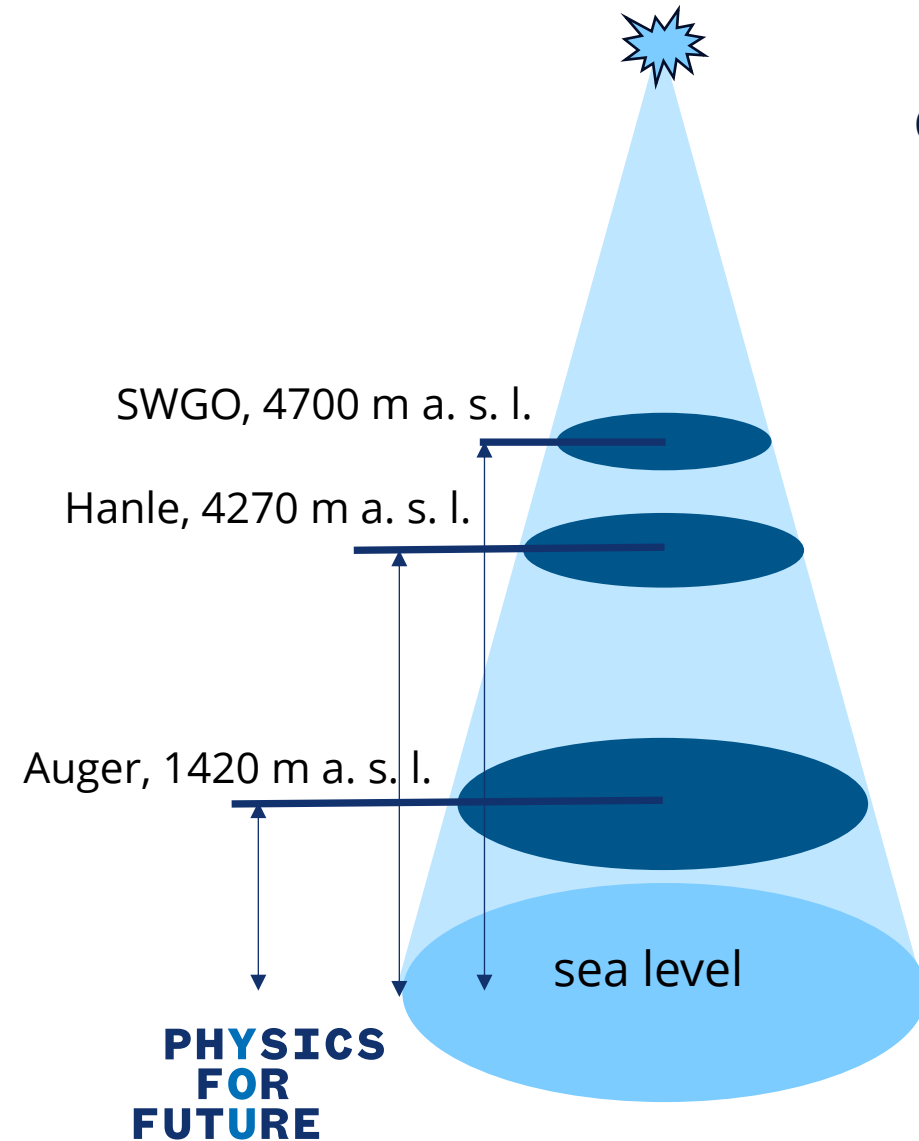


IACTs and surface array joining forces



Bakalová et al., PoS(ICRC2025)558

Credit: Wikipedia



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SST-1M
Single-Mirror
Small Size Telescope



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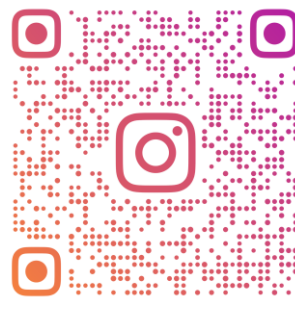
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