SST-1M

FACULTY OF PHYSICS
UNIVERSITY OF BIALYSTOK

SST-1M stereoscopic system: Overview and preliminary results

Laetitia Gibaud
University of Białystok, Poland

on behalf of the SST-1M collaboration

PAiP-2025, 20-22 February 2025

Outline

- SST-1M overview
  - ➢ Project & status
  - ➢ The SST-1M telescopes
  - ➢ Stereoscopic system
- Preliminary results
  - ➢ Crab Nebula
  - ➢ Blazar MRK 421
  - ➢ Complex region VER 2019+368
- Summary & perspectives

SST-1M overview

The SST-1M project & status

Consortium of research institutions from Czech Republic (6 institutes), Poland (7), and Switzerland (3)

Originally developed for the Cherenkov Telescope Array as prototypes of small size telescopes (SST)

- Frame built in Krakow
- Camera built in Switzerland
- Mirrors made in Czech Republic
- 2 fully operated telescopes re-installed in Ondřejov Observatory, operating in mono and stereo regimes:
  - 1 prototype
  - 1 pre-production

Designed to detect very high energy γ rays, induced atmospheric showers in the energy range of 3-300 TeV (Heller et al. 2019).

The SST-1M project & status

2017
- First camera installed (IFJ Krakow)
- First light (September)

2021
- Installation of Tel 1 & 2 in Ondřejov

2022
- First showers with Tel 1 & 2
- First light in stereo regime

2023
- Time stamps in both telescopes synchronized using White Rabbit
- First real-time stereo observations

2024
- Pipeline repository public

2025
- Relocation project to more favorable observation site

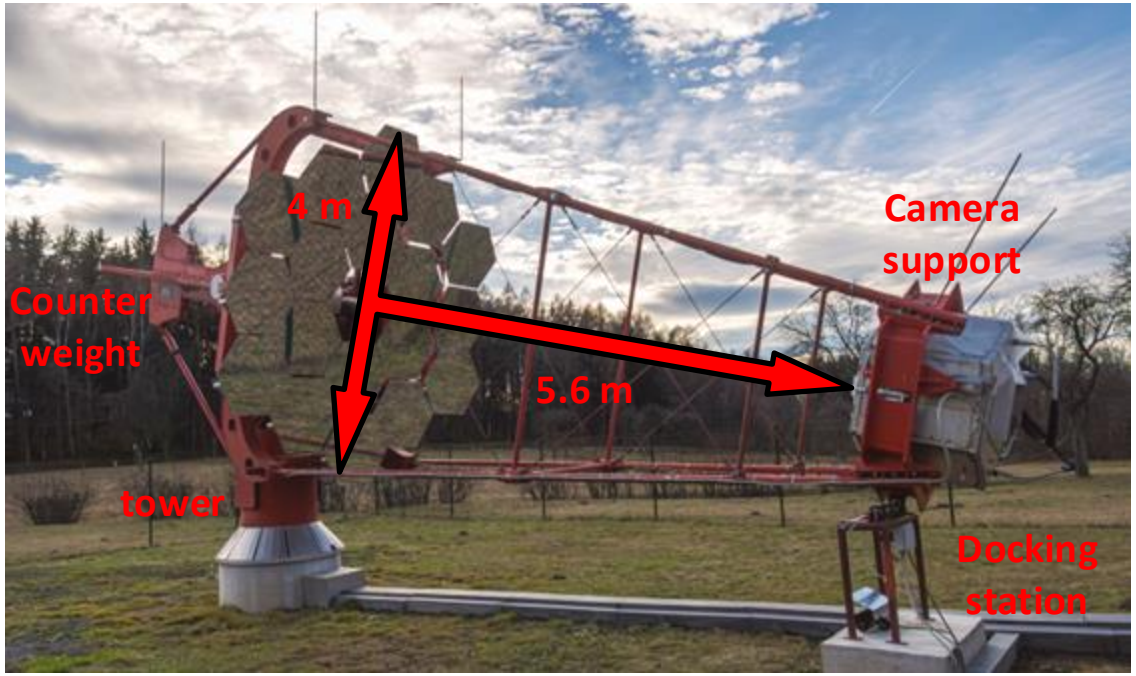
From 2022: SST-1M pipeline development

From 2023: obs. campaigns (e.g., Crab Nebula, MRK 421)

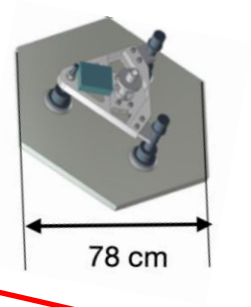
The SST-1M telescopes

Structure & optics

- lightweight & compact structure of 8.6 tons
- optical layout: Davies-Cotton design
- 4 m diameter, primary multi-segment mirror dish
- f/D 1.4



18 hexagonal facets



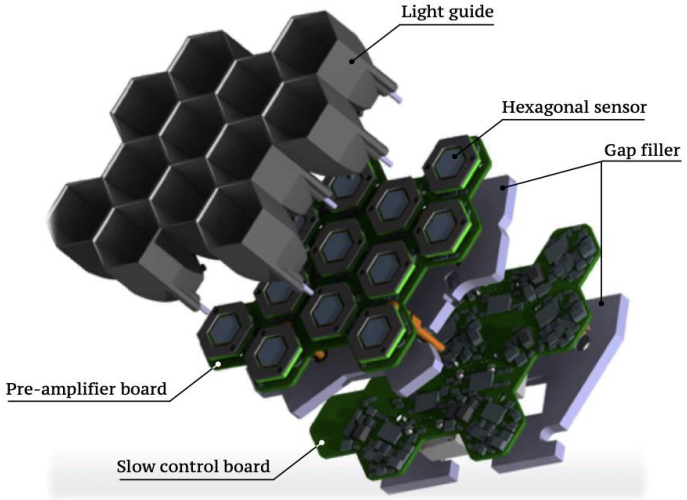
Mirror facet with alignment system

CCD & PSF cameras (used for telescope pointing)

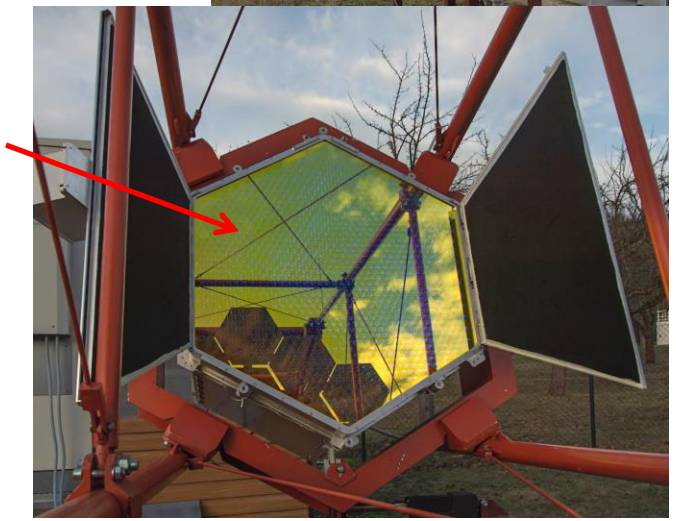
The SST-1M telescopes

Innovative camera

- Silicon Photo-Multipliers (SiPMs) based camera
- 1296 pixels (linear size: 2.34 cm) ; each one using Bèzier curves cones
- FOV of all Cherenkov light camera: 9°
- Equiped with fully digital trigger and readout architecture (Digicam)
- Entirely remotely controlled through GUI

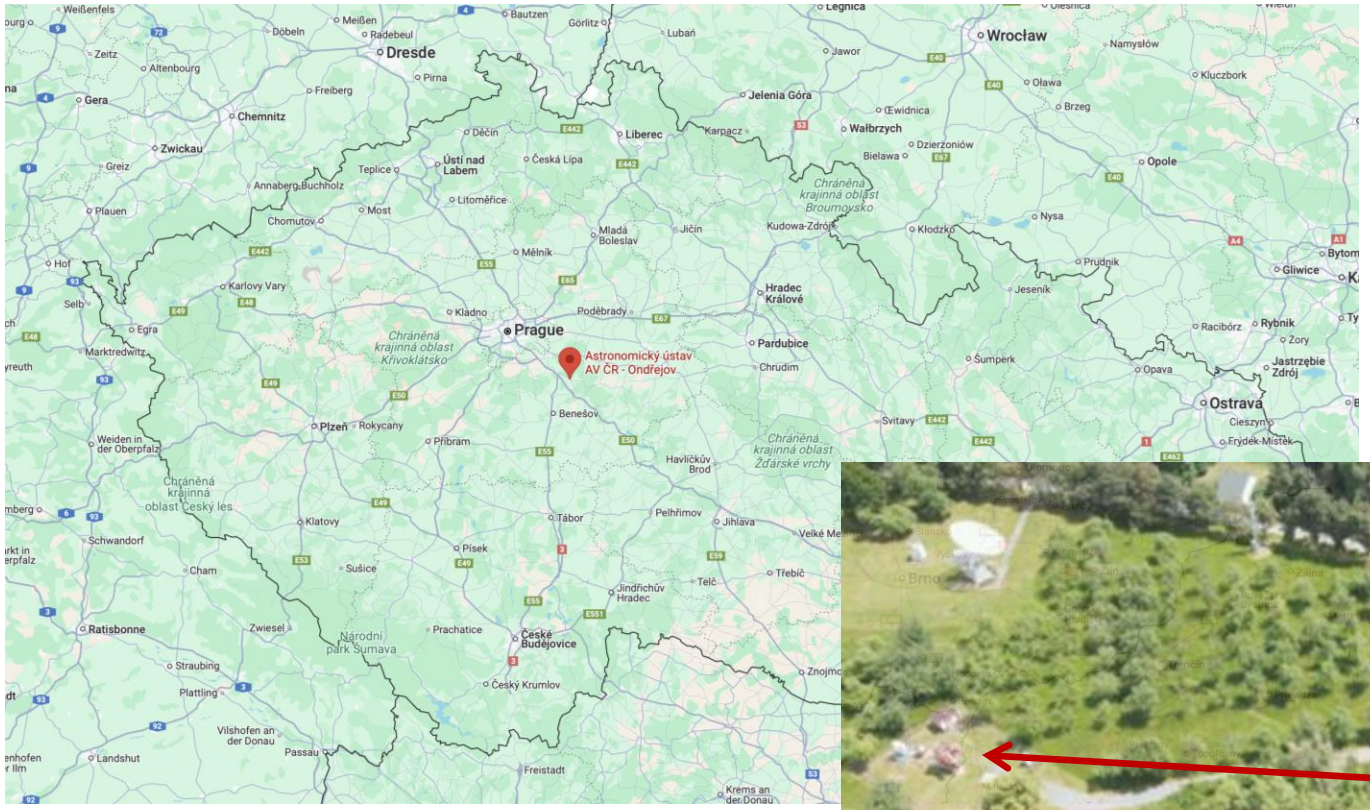


Entrance window 3 mm Borofloat coating (filter optimized for light below 540 nm)



Alispach et al. JCAP02(2025)047

The SST-1M stereoscopic system



Ondřejov Observatory, Czech Republic

- 510 m a.s.l
- 35 km SE of Prague

The SST-1M stereoscopic system

Tel 1

Tel 2

The SST-1M stereoscopic system

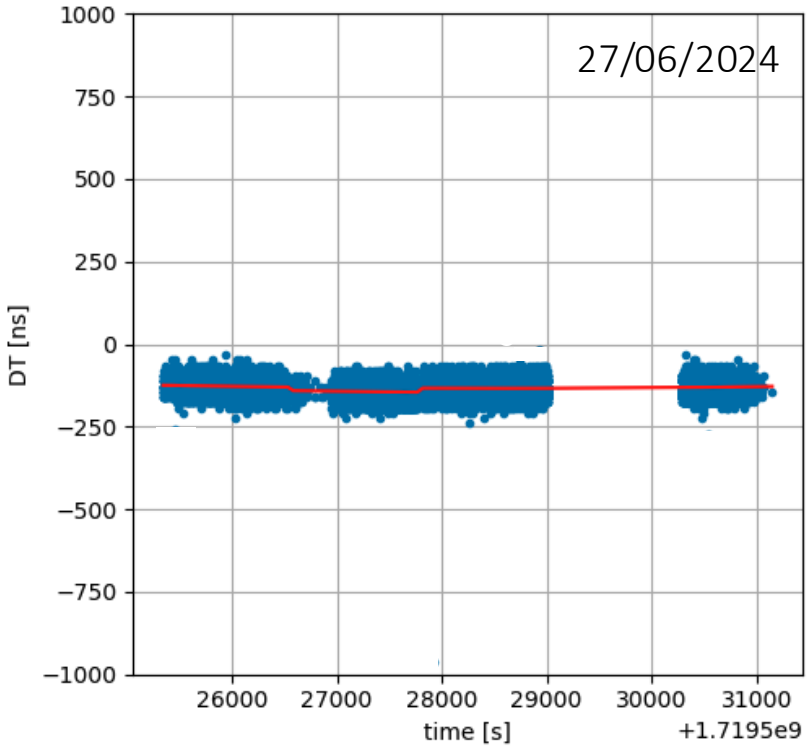
Readout chain implementation

Both cameras connected to White Rabbit for synchronization

Reception of a trigger

Event data packets sent to the Camera Server

DT: time diff. of same obs. with both telescopes



Observation time

The SST-1M stereoscopic system

Stereo trigger management

Trigger packets from both telescopes

↓

Camera servers send timestamps

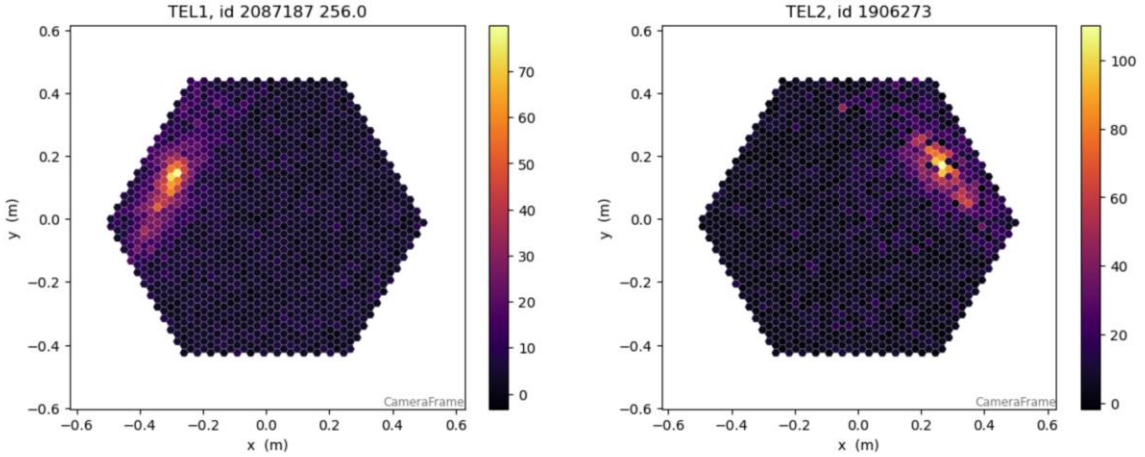
↓

SWAT (Software Array Trigger) searches for coincidence

↓

Possible stereo

1rst stereo obs. of a single shower – 04/2023

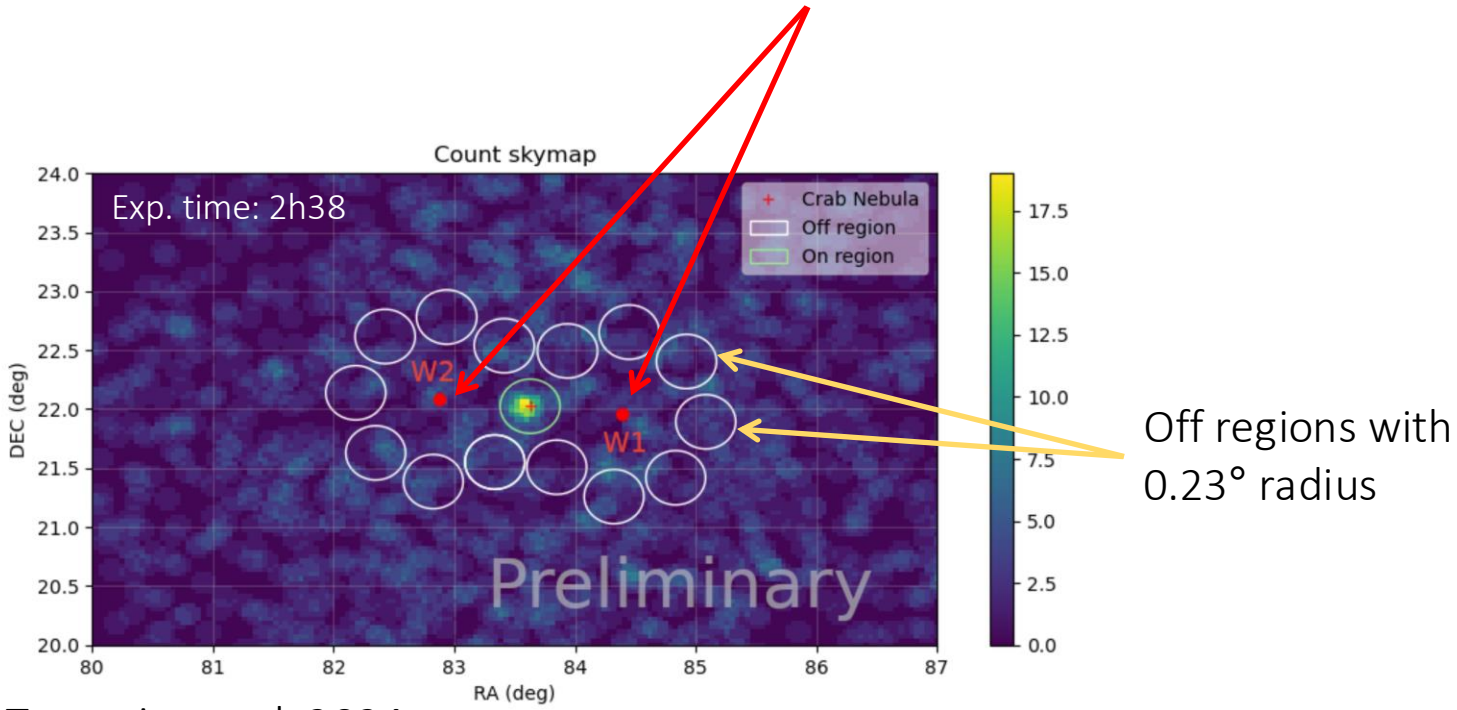


Preliminary results

Crab Nebula

Obs. campaign 2023/2024
=> **23.6 hours** of **stereo** data after quality cuts

Crab stereo data set acquired with two wobbles configurations

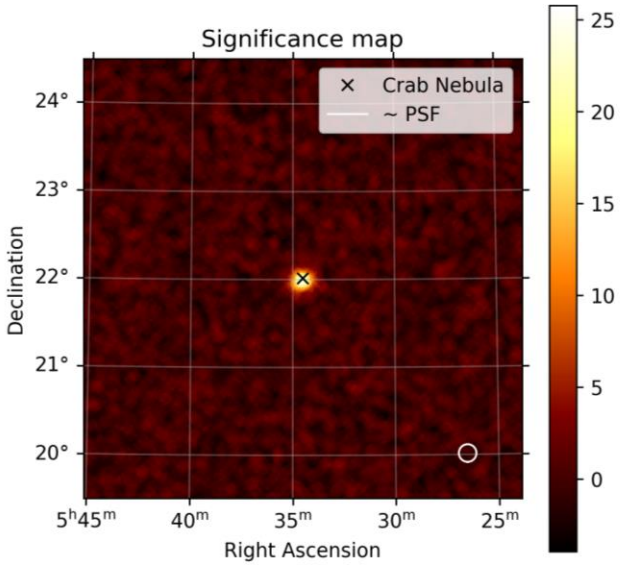


Off regions with
0.23° radius

Tavernier et al. 2024

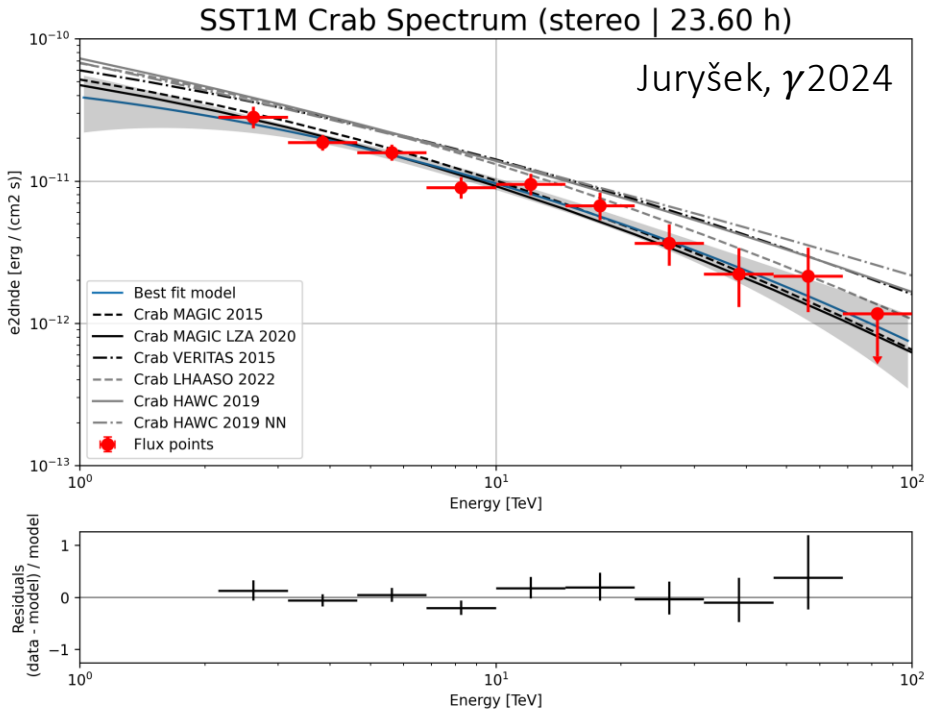
Credit: NASA, ESA, CSA, STScI, T. Temim (Princeton Univ.)

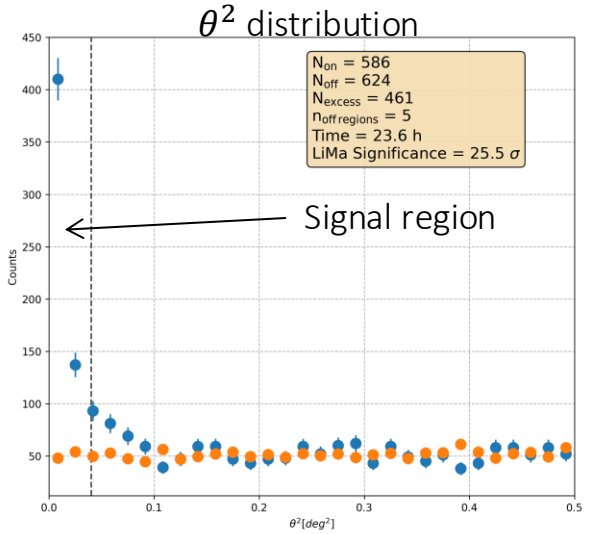
Crab Nebula



Outstanding **background homogeneity** on a scale of a few degrees

Promising capabilities for obs. of **extended sources**





- ON-source events
- OFF-source events

Best fit with log-parabola: $\phi(E) = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha+\beta \log(E/E_0)}$

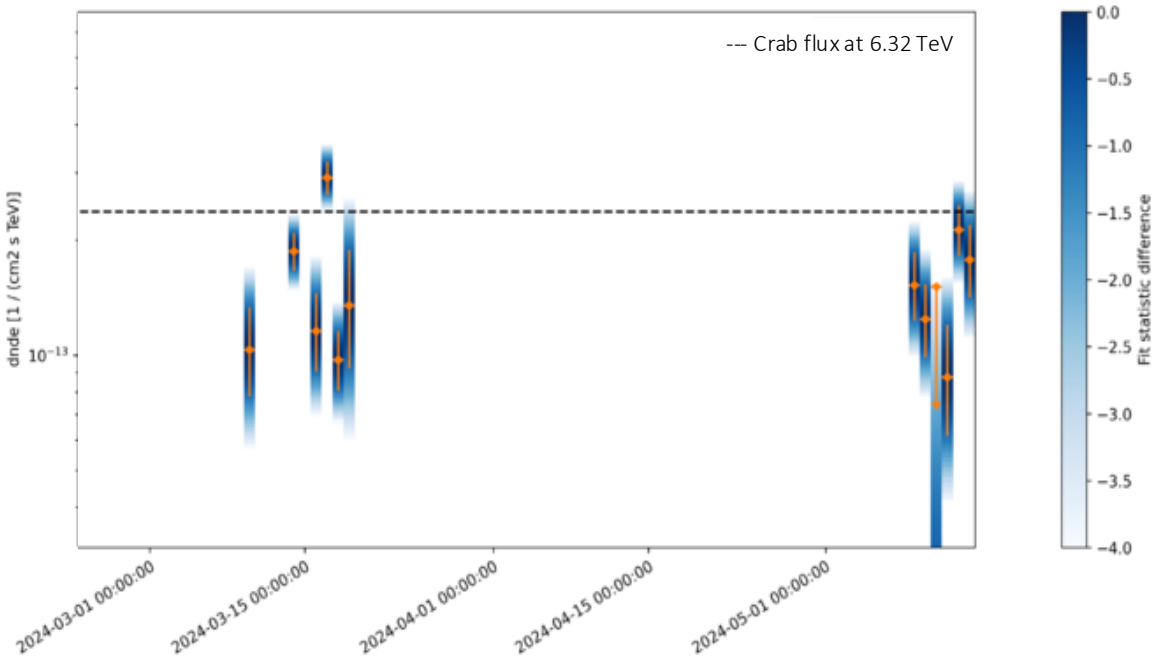
- $\alpha = 2.76 \pm 0.11$
- $\beta = 0.11 \pm 0.09$

Blazar MRK 421

Obs. campaign spring 2024 – nearby AGN monitoring
=> **23.5 hours** of **stereo** data after quality cuts

First extragalactic source in real SST-1M stereo regime

High state detected on 13/03/2024 -> **ATel #16533**



Source: http://skyserver.sdss.org/

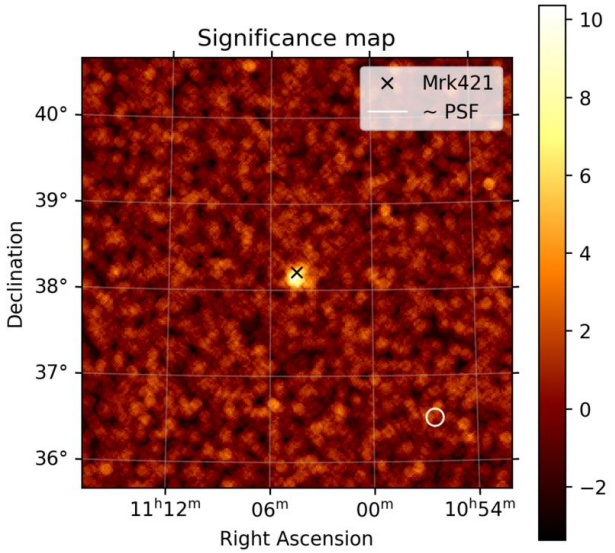
Detection of enhanced very-high-energy gamma-ray emission from Markarian 421

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)

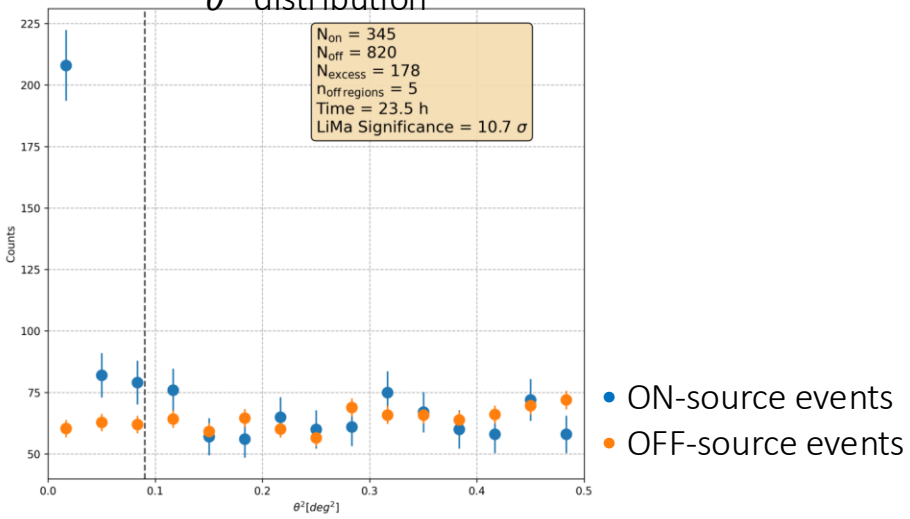
Subjects: Gamma Ray, TeV, VHE, AGN, Blazar

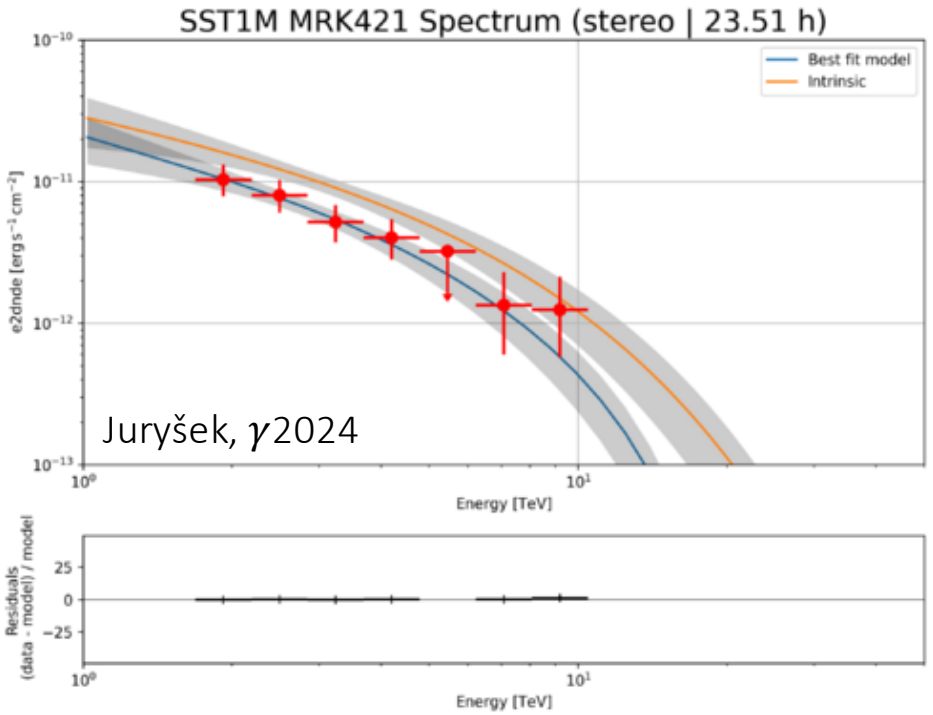
Referred to by ATel #: 16537

Blazar MRK 421



θ^2 distribution



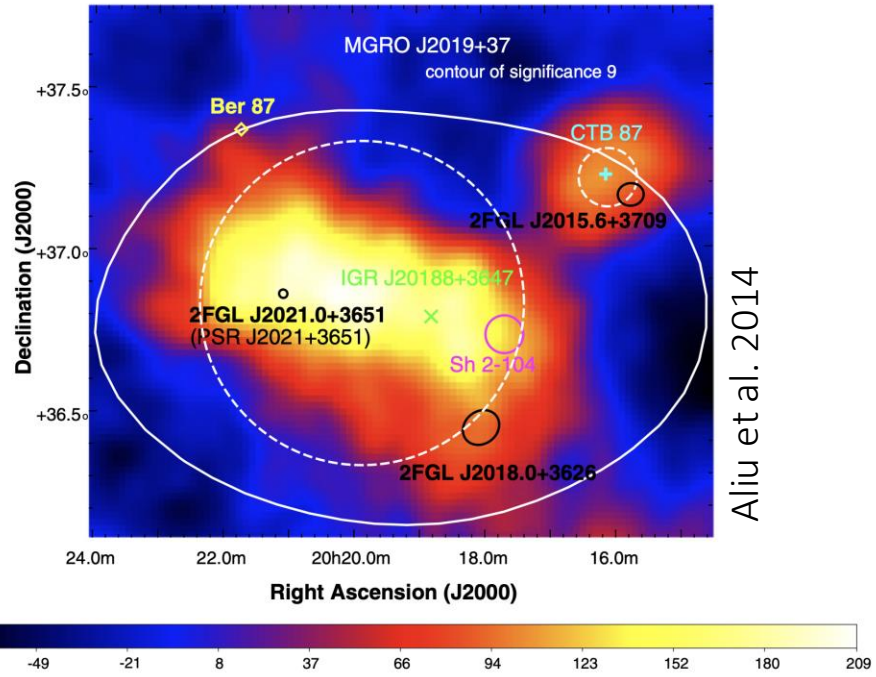


Exponential cutoff power law: $\phi(E) = \phi_0 \left(\frac{E}{E_0}\right)^{-\Gamma} \exp(-(\lambda E)^{\alpha})$

- $\Gamma = 2.61 \pm 0.33$ (HAWC result: 2.26 ± 0.12)
- E_{cut} fixed to E = 5.1 TeV (Albert et al. 2022)

Complex region VER 2019+368 (Dragonfly)

- Discovered by MILAGRO (Abdo et al. 2009)
- Slightly extended (approx. 0.5°) and asymmetric region
- Complex region showing multi sources in radio, X rays, γ rays:
  - SNR CTB 87
  - 2 pulsars
  - PWN G75.2+0.1
  - Fast X-ray transient IGR J20188
  - Star forming HII region Sh 2-104
  - Wolf-Rayet star WR 141

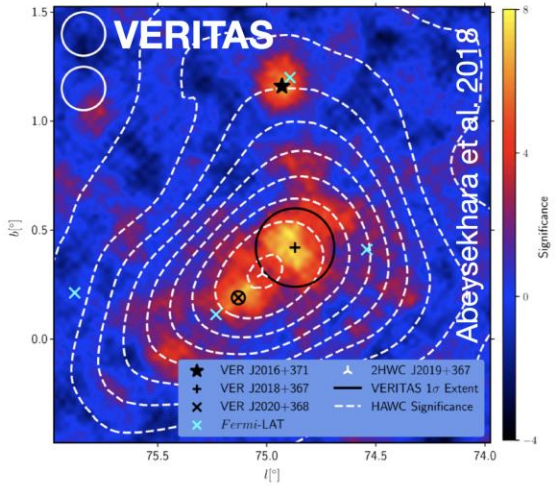


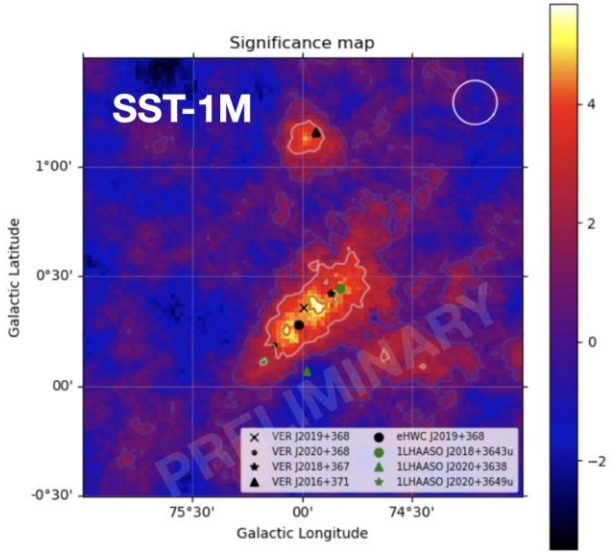
Aliu et al. 2014

Complex region VER 2019+368 (Dragonfly)

SST-1M obs. campaign in 2024
~44 hours of **stereo** data after quality cuts

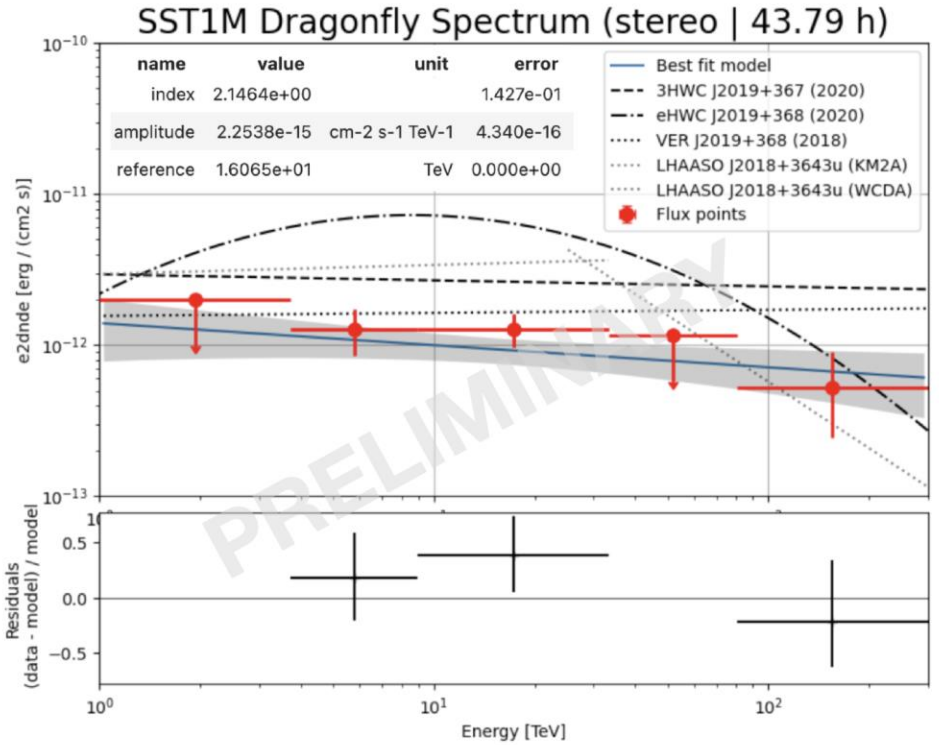
- Obs. with significance: 6 sigma
- CTB 87 and VER J2019 regions **clearly resolved**





Juryšek, γ2024

Spectral analysis with a fixed signal region on the VERITAS reported position and size (Abeysekara et al. 2018), testing for the presence of a source:



Summary & perspectives

Key takeaways & future directions

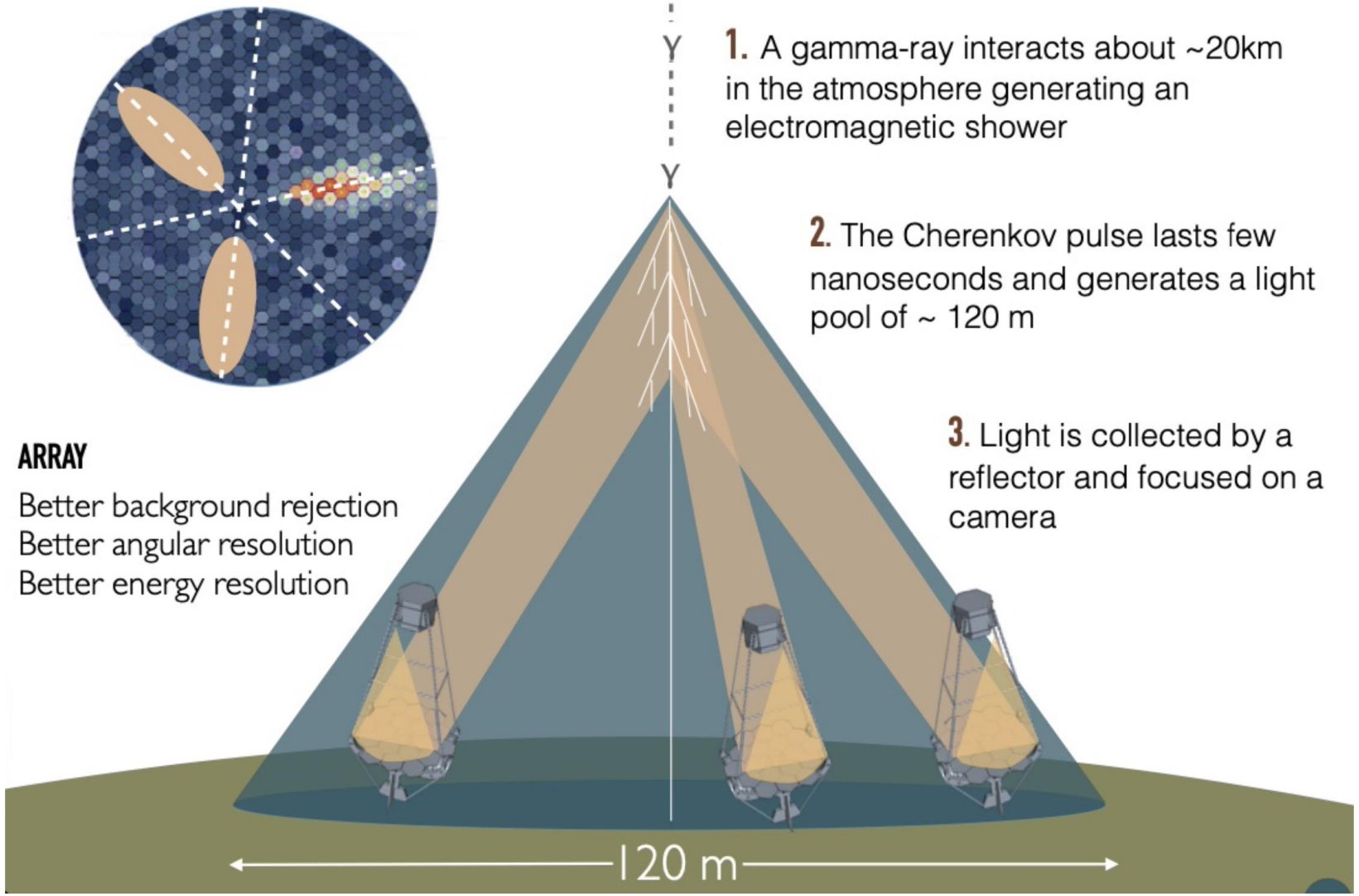
- 2 telescopes successfully built and operational, collecting data since 2022
- Innovative detector technology, featuring a fully digital readout (DigiCam)
- Observations in both **mono** & **stereo** modes confirm SST-1M's capabilities for γ ray astronomy
- Successful detections of both **galactic** and **extragalactic** sources
- Capabilities for observation of **extended sources**
- Ongoing 2nd observation campaign
- Relocation project underway to move the telescopes to a higher altitude observation site

SST-1M

Thank you!

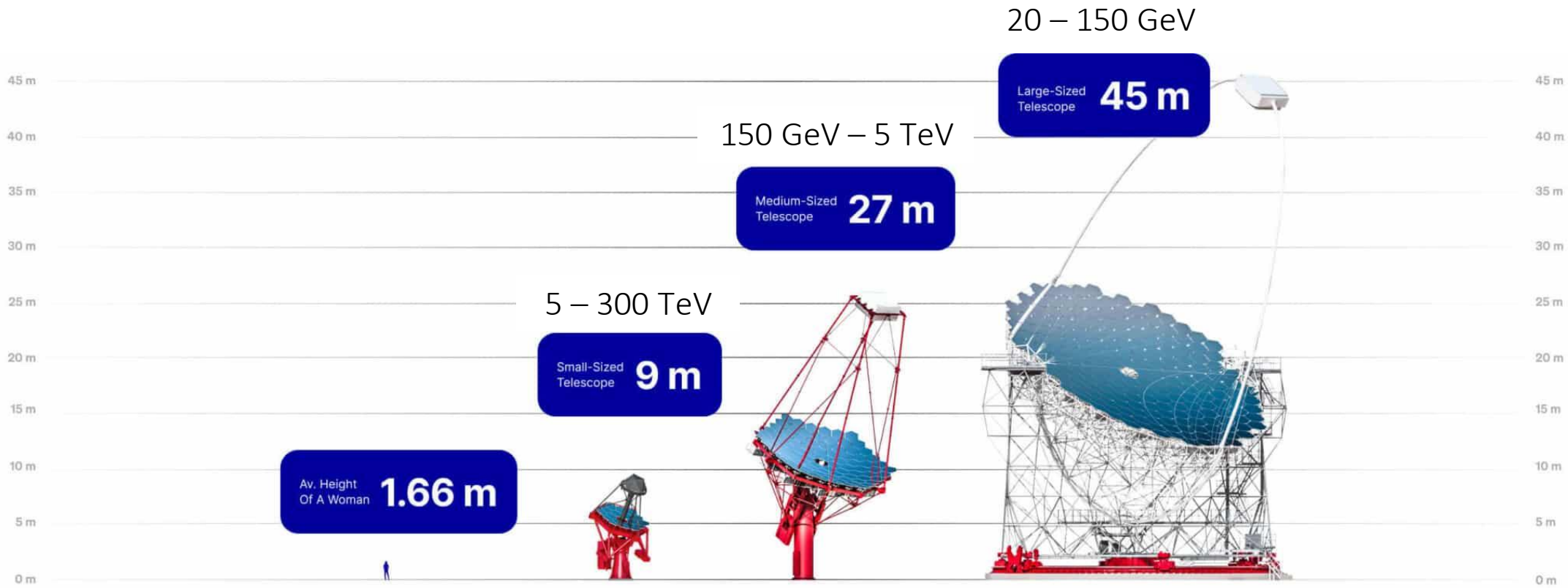
Extra materials

Why array?



Credit: J.A. Aguilar (UniGe)

Comparisons



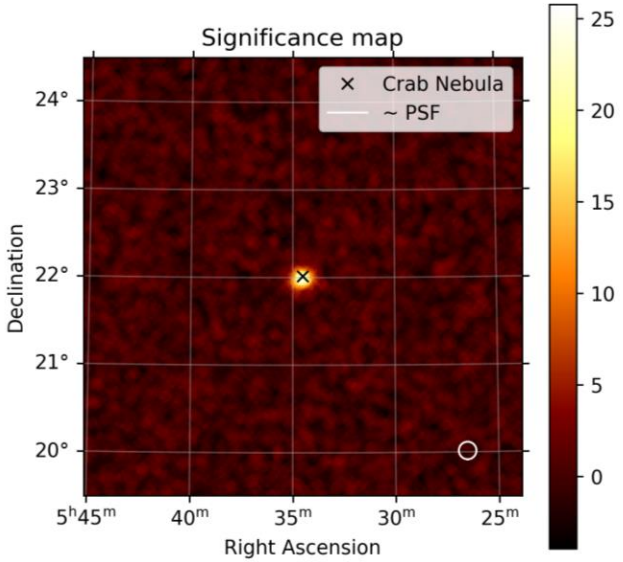
Diameter: 4 m
FOV: 9°

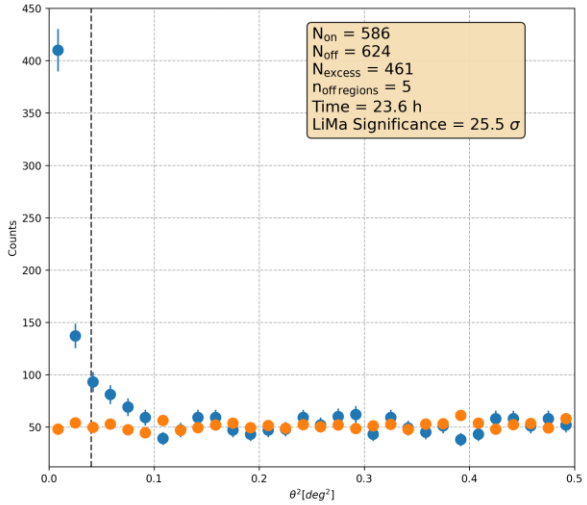
Diameter: 12 m
FOV: 8°

Diameter: 23 m
FOV: 4.5°

Adapted from ctao.org

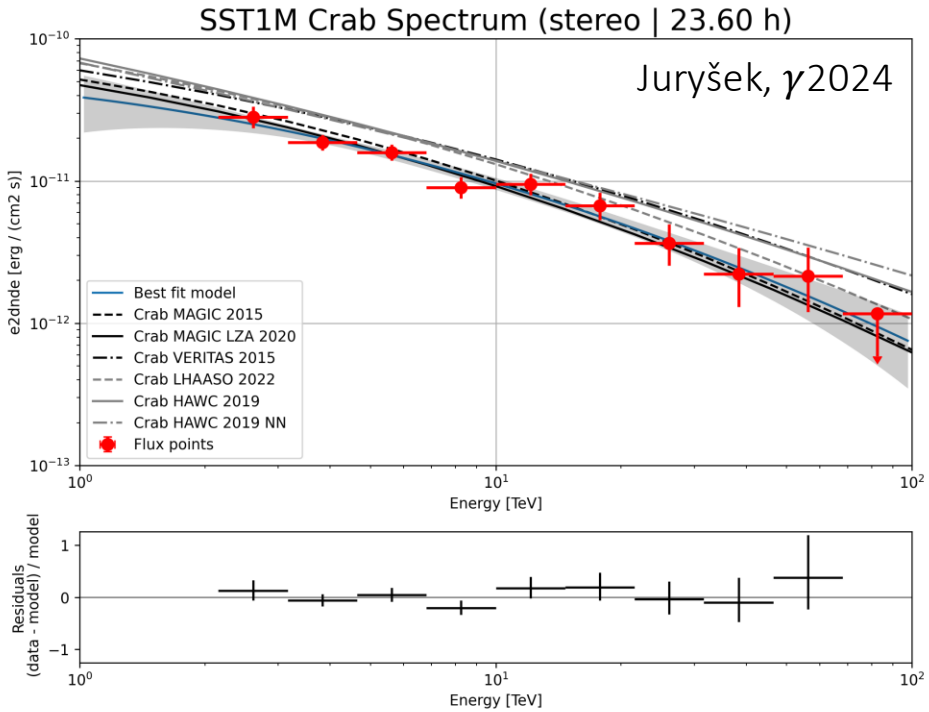
Crab Nebula





Outstanding **background homogeneity** on a scale of a few degrees

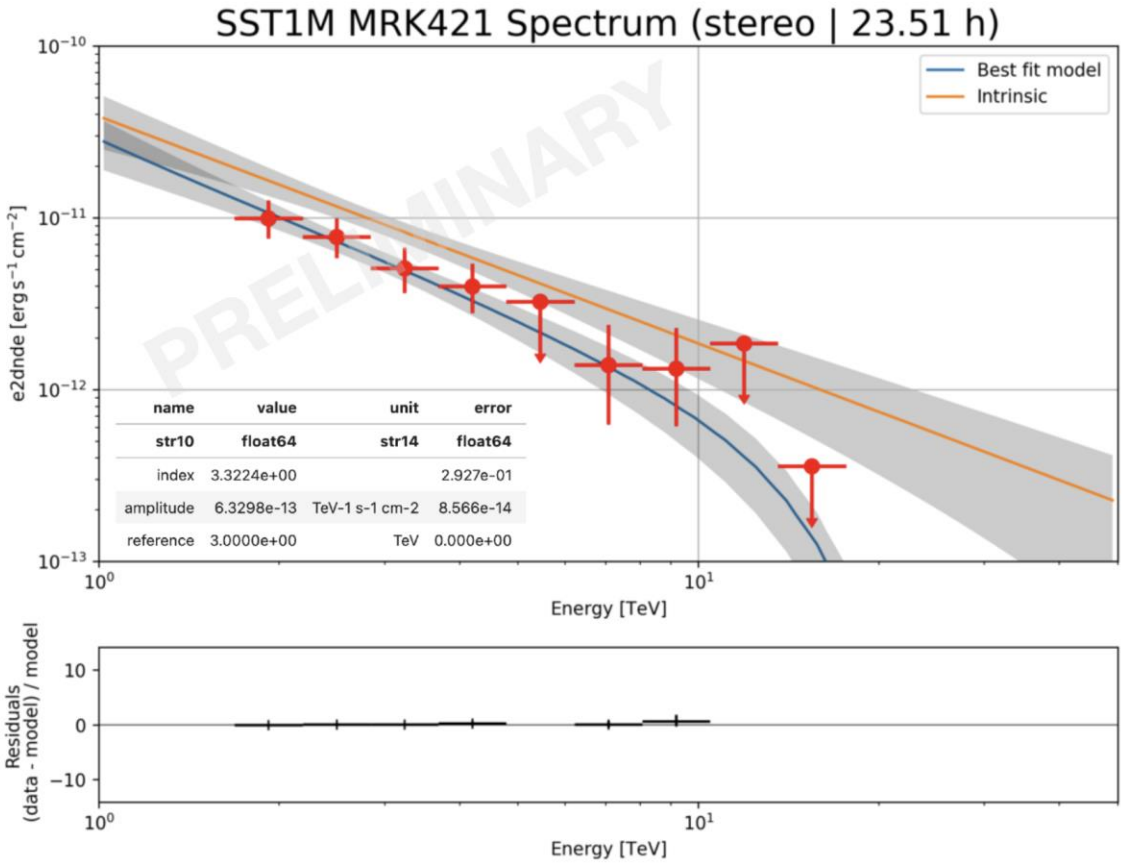
Promising capabilities for obs. of **extended sources**



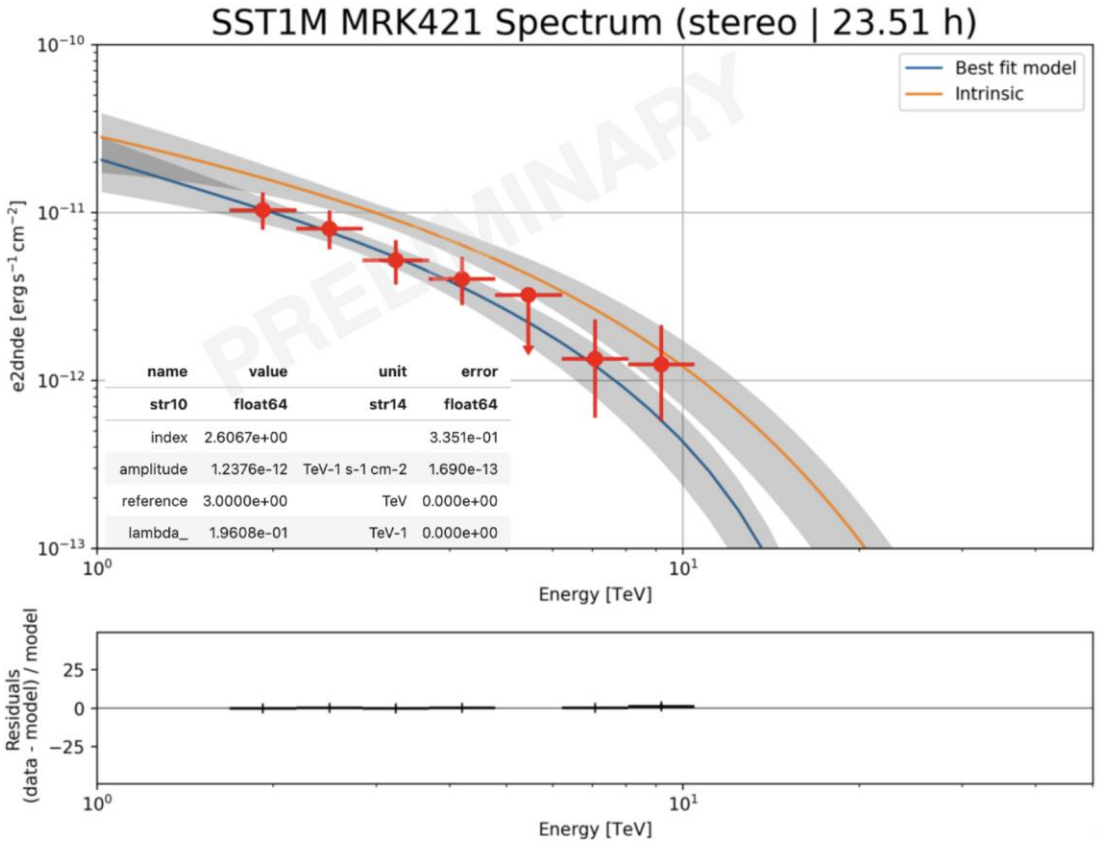
Best fit with log-parabola: $\phi(E) = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha+\beta \log(E/E_0)}$

- ϕ_0 = (2.19 ± 0.17) 10^{-13} TeV^{-1} cm^{-2} s^{-1}
- E_0 = 6.31 TeV
- α = 2.76 ± 0.11
- β = 0.11 ± 0.09

Blazar MRK 421 – PL & ECPL fits



name	value	unit	error
str10	float64	str14	float64
index	3.3224e+00		2.927e-01
amplitude	6.3298e-13	TeV-1 s-1 cm-2	8.566e-14
reference	3.0000e+00	TeV	0.000e+00



name	value	unit	error
str10	float64	str14	float64
index	2.6067e+00		3.351e-01
amplitude	1.2376e-12	TeV-1 s-1 cm-2	1.690e-13
reference	3.0000e+00	TeV	0.000e+00
lambda_	1.9608e-01	TeV-1	0.000e+00

Juryšek, γ2024