Friedrich-Alexander-Universität
Erlangen-Nürnberg

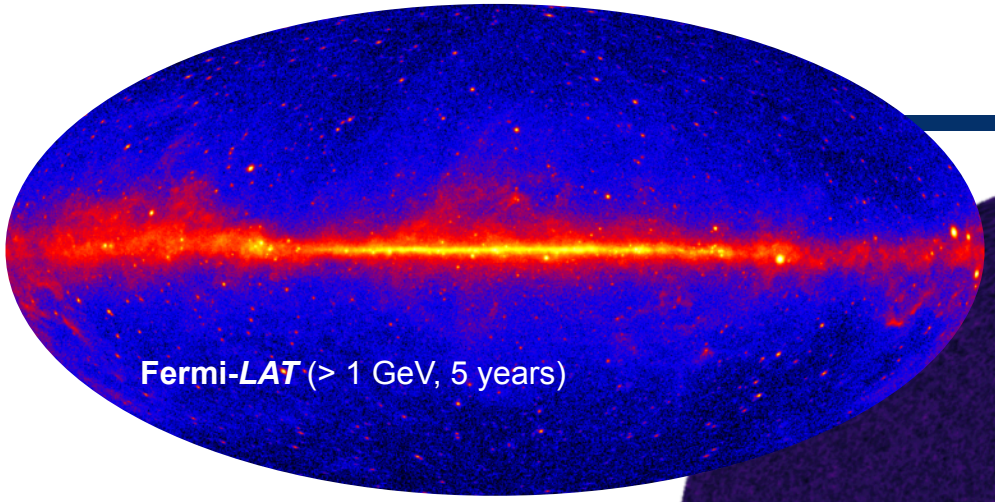
FAU

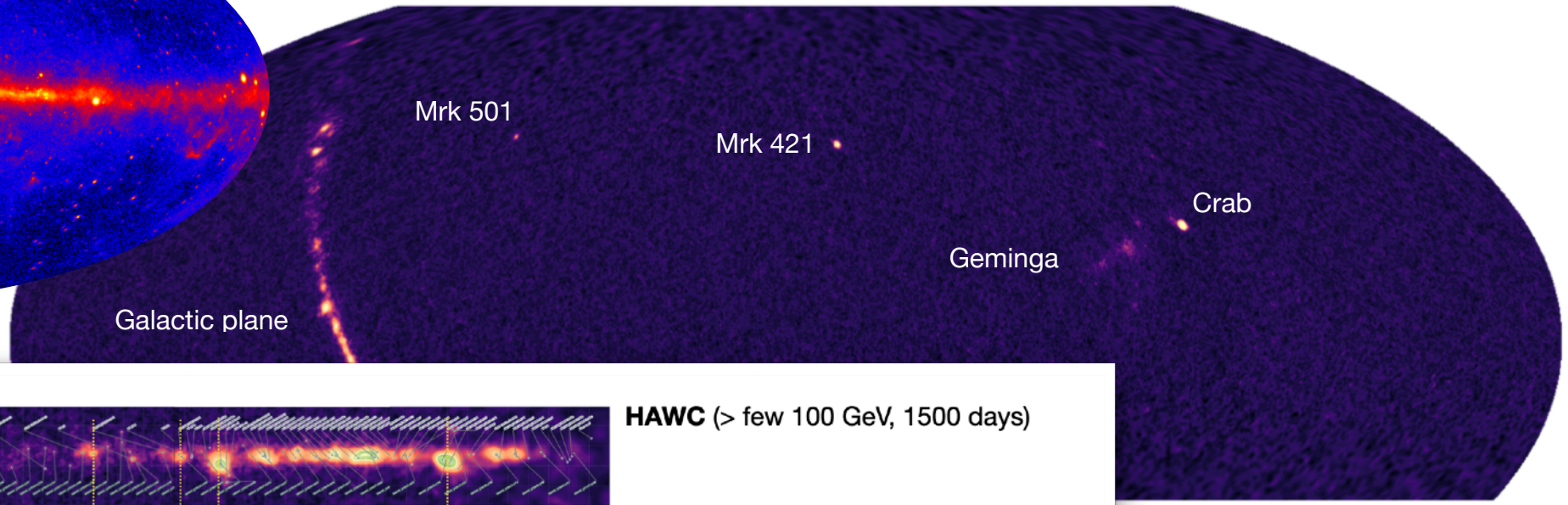
Gamma-ray Astronomy @ FAU

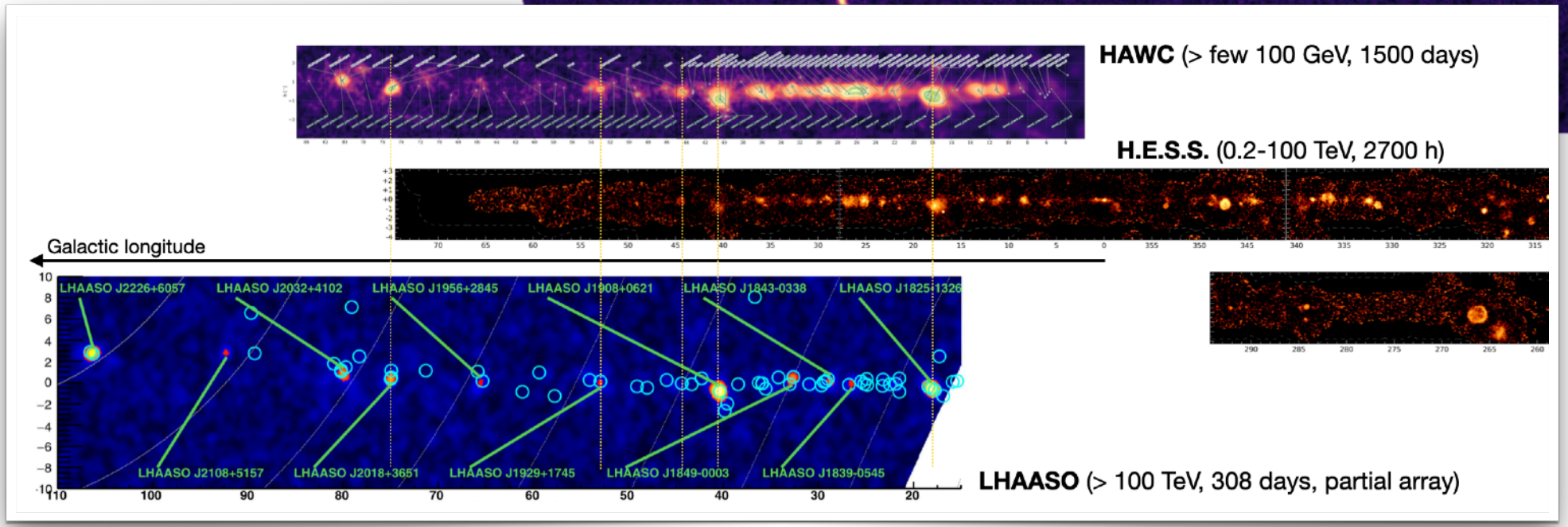
Christopher van Eldik • Stefan Funk • Alison Mitchell • ECAP

April 4, 2022

Science Case







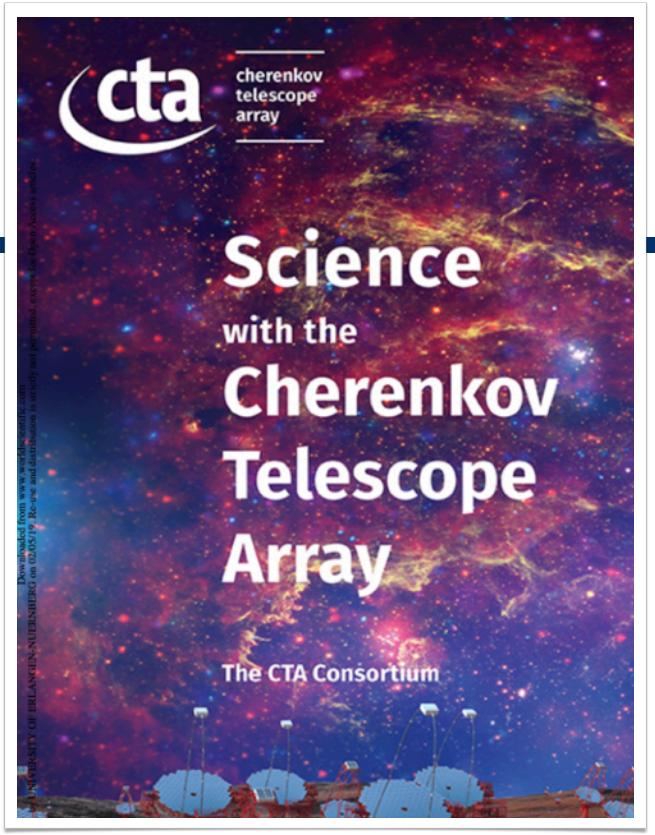
2022 census of non-thermal gamma-ray sky:

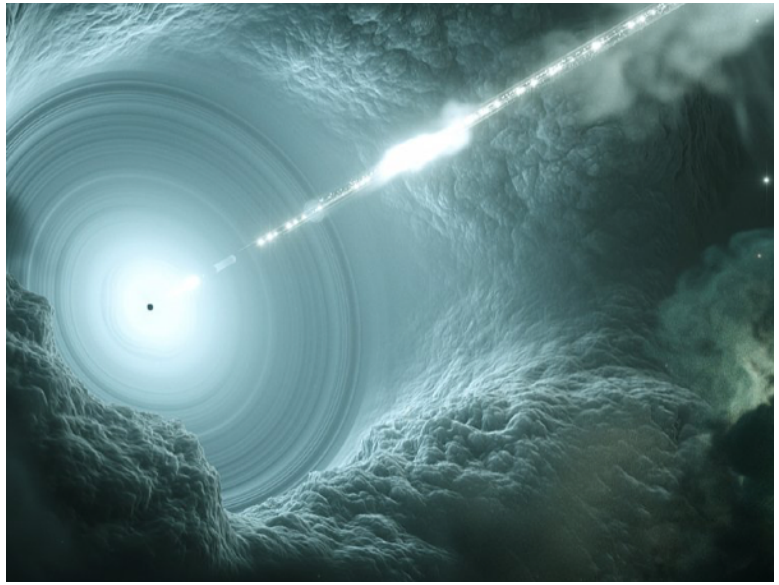
- 2700 sources > 50 MeV
- 250 sources > 1 TeV
- 10 sources > 100 TeV

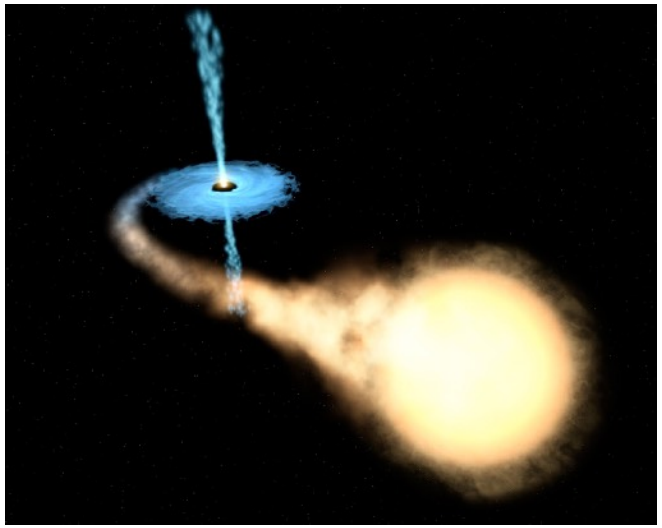
Science Case

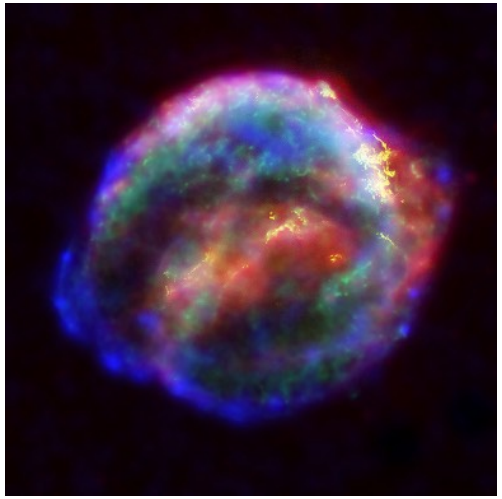
(Astrophysical) **key science questions:**

- **Where** are charged particles accelerated to ultrarelativistic energies?
- **How** do these sources function?
- **What** are the acceleration processes at play?
- **How** does particle transport into their environments work?
- **How** do particles feed back on their environment?
- **What** is their contribution to the cosmic ray population?
- **What** is the nature of dark matter?









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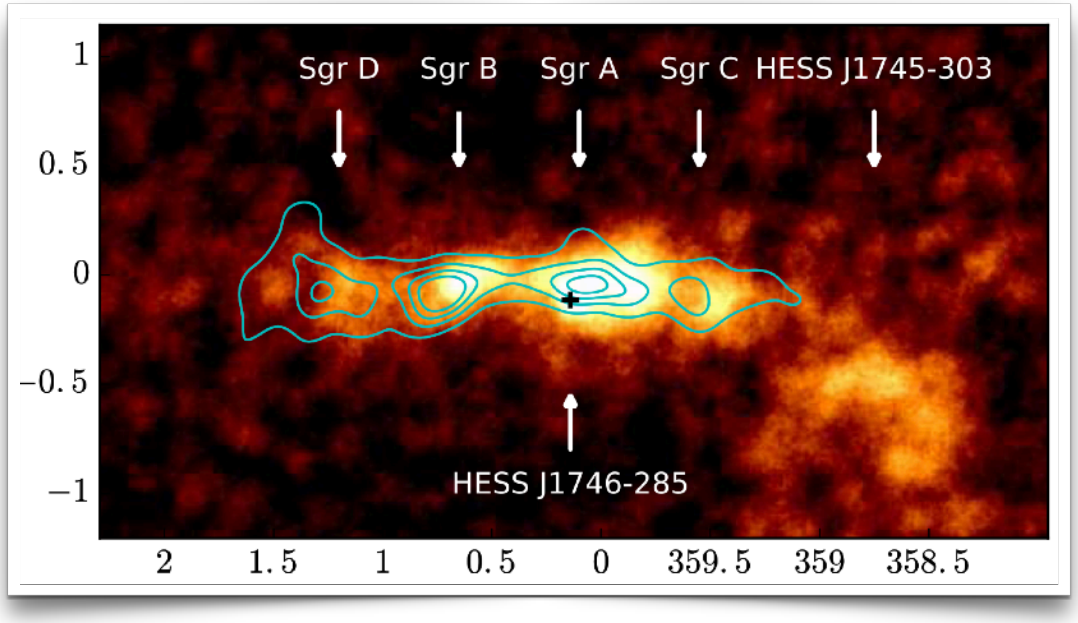
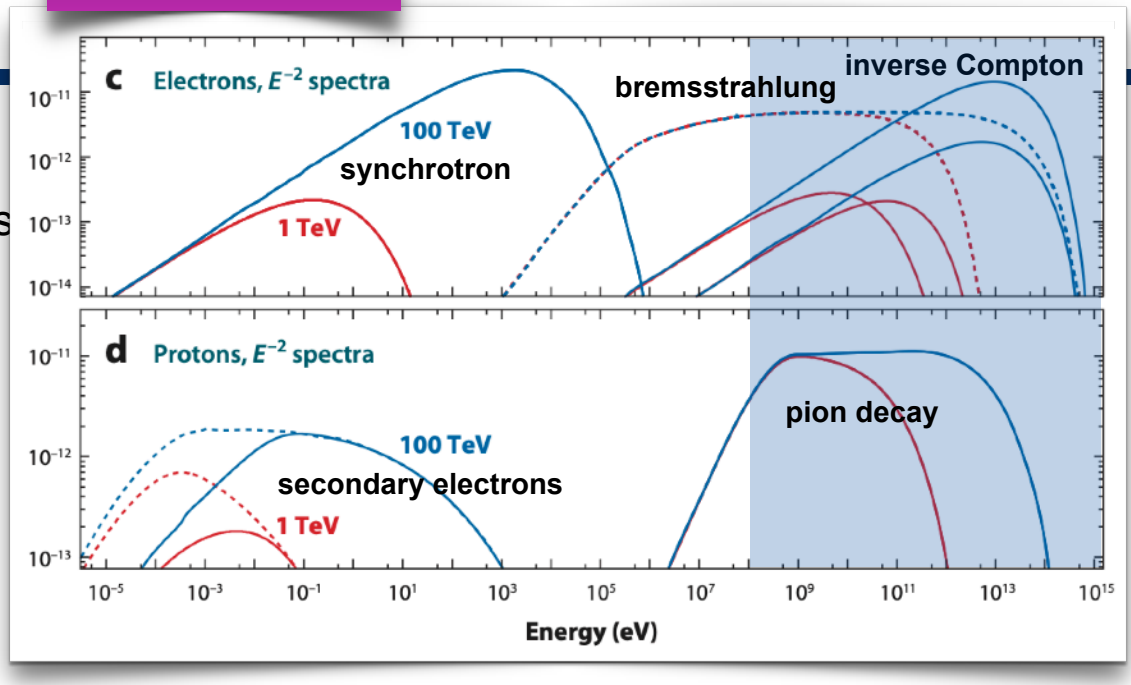


Hinton & Hofmann (2009)



gamma rays enable

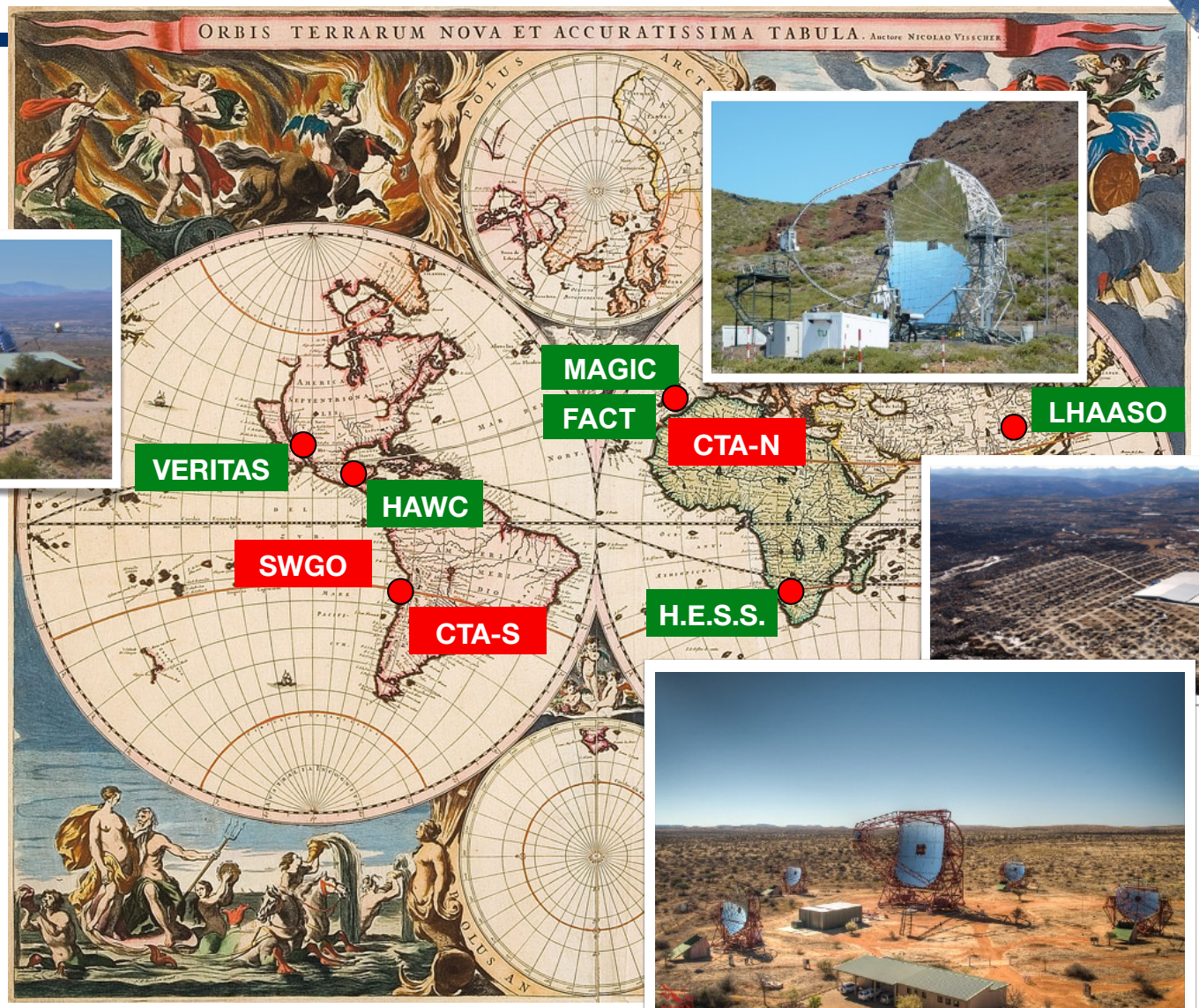
- access to non-thermal electrons (complementary to e.g. X-rays)
- unique access to non-thermal **proton/ion** populations

MWL/multi-messenger coverage often key:

- identification of dominant particle population
- understanding source physics through broad-band coverage

→ contemporaneous multi-instrument campaigns
→ ToO follow-ups

Instruments for Gamma-ray Astronomy



Fermi-*LAT*

operating

design/construction

Instruments for Gamma-ray Astronomy

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

operating

design/construction

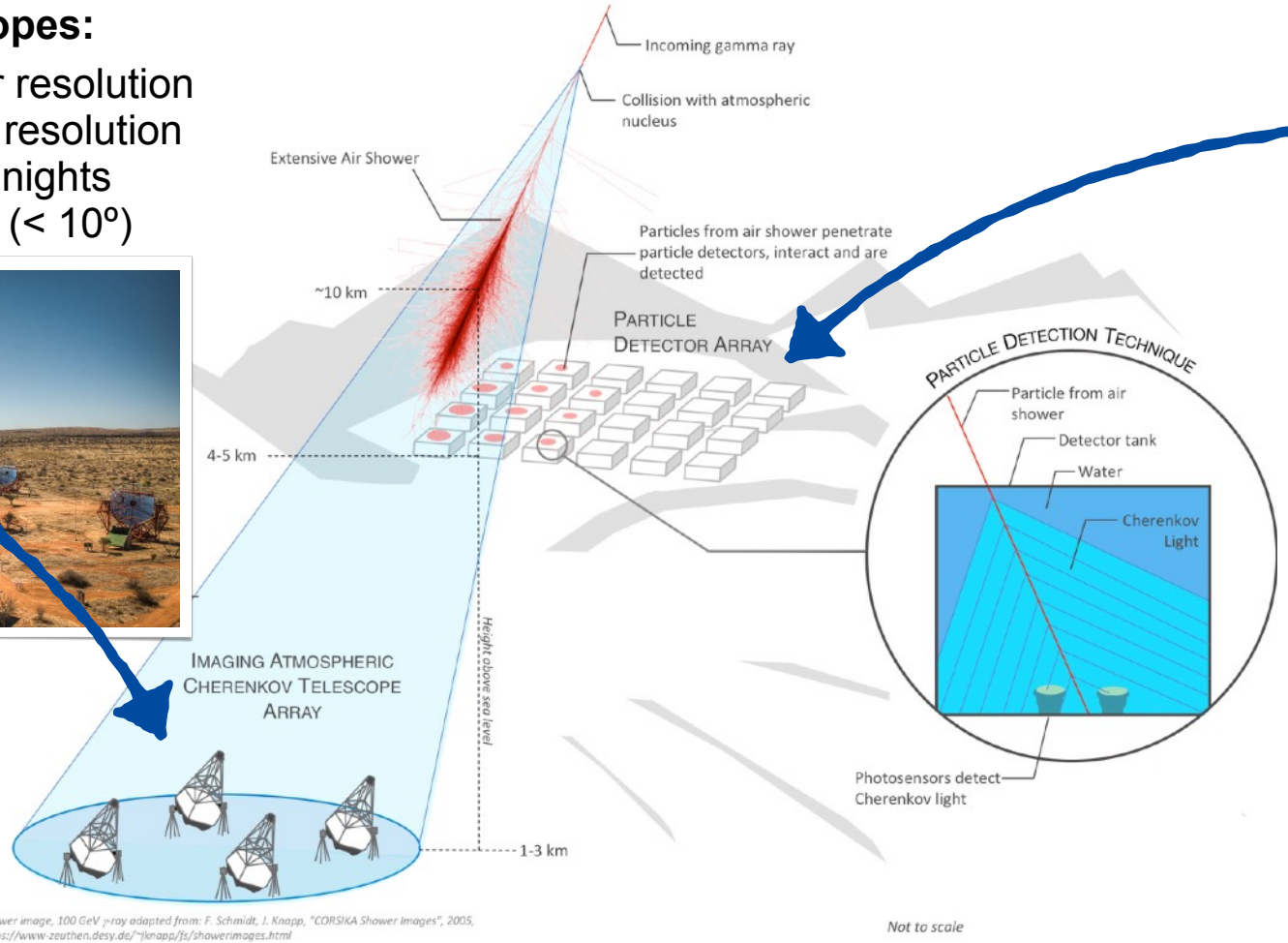
Instrument Complementarity

Detection technique

Imaging Atmospheric Cherenkov Telescopes:

- very good angular resolution
- very good energy resolution
- operation in clear nights
- small field of view (< 10º)

H.E.S.S. VERITAS MAGIC FACT CTA (North) CTA (South)

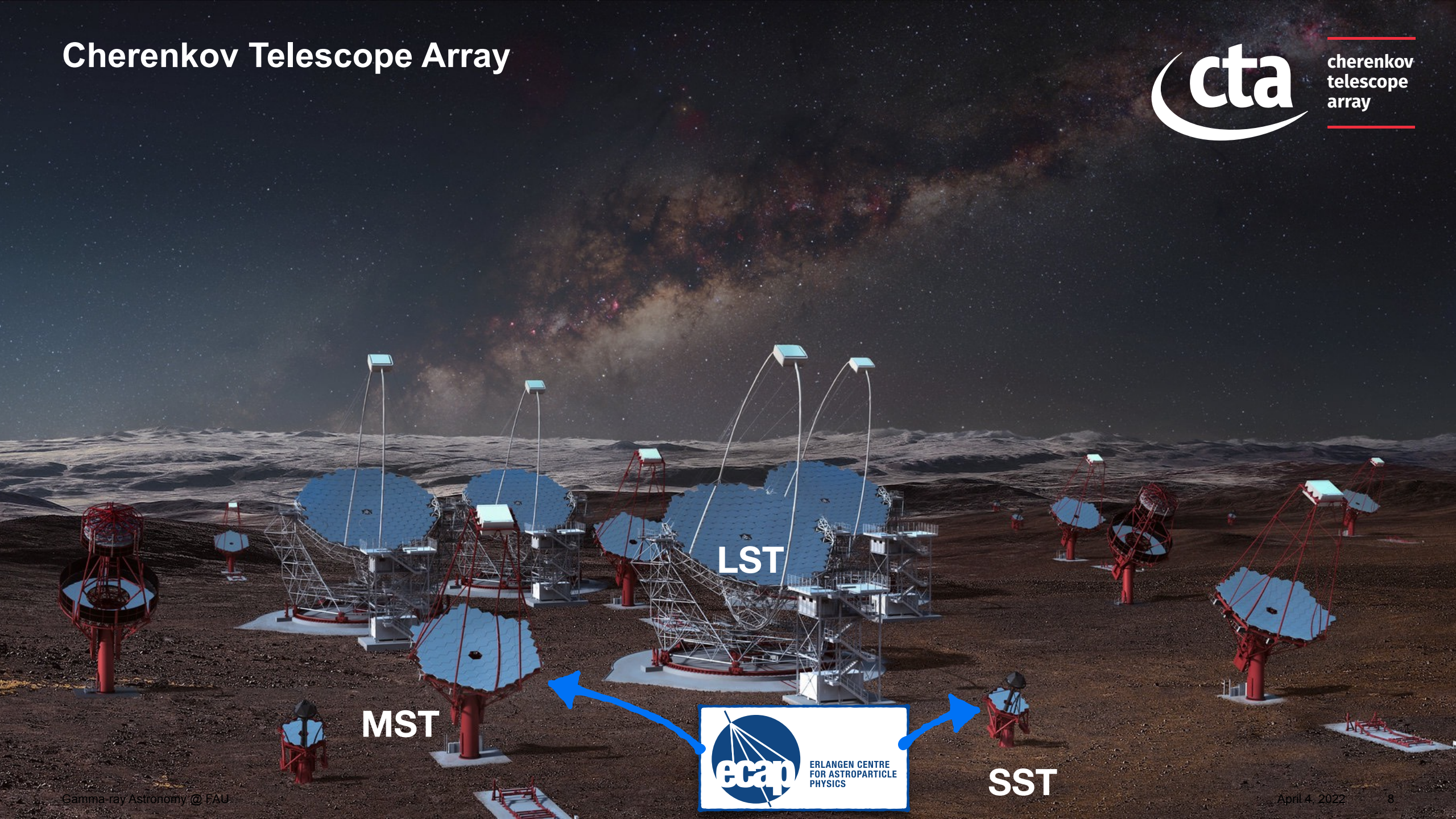


HAWC LHAASO SWGO

Particle Detector Arrays:

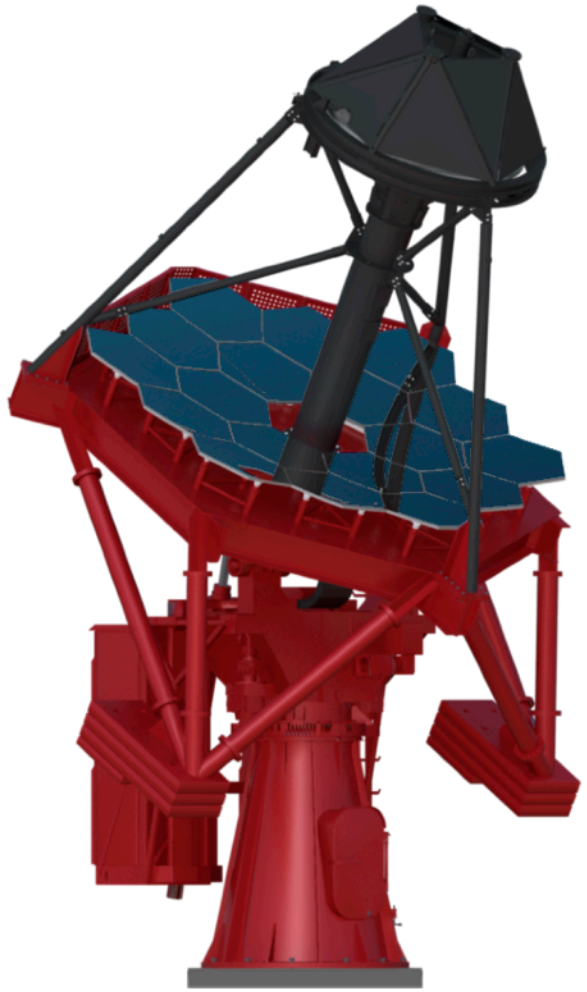
- 100% duty cycle
- very large field of view (~15% sky)
- moderate angular resolution
- moderate energy resolution

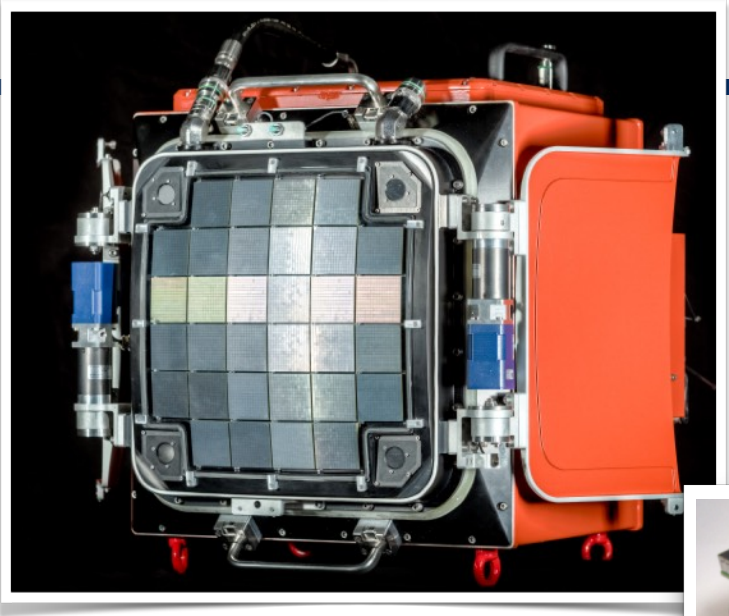
Cherenkov Telescope Array



Cherenkov cameras - SSTCam

ECAP contributions to CTA



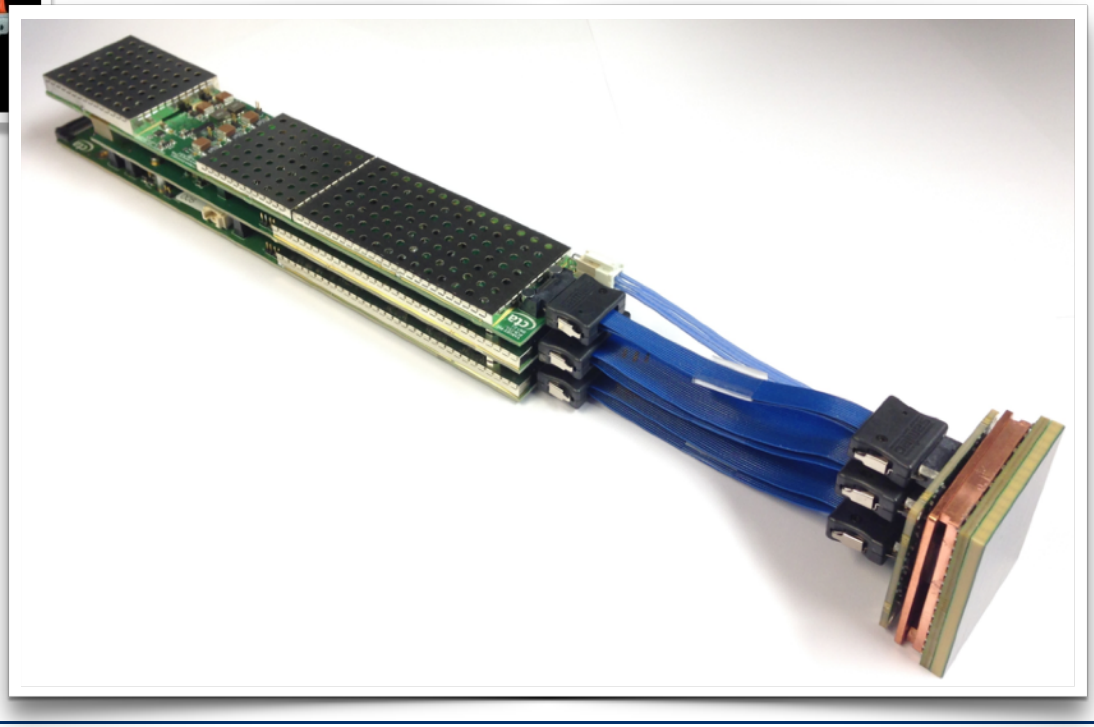


SSTCam: Compact camera using SiPMs

- 9° field of view, 2048 pixels, 1 GHz sampling rate
- 37-46 cameras for CTA-S array

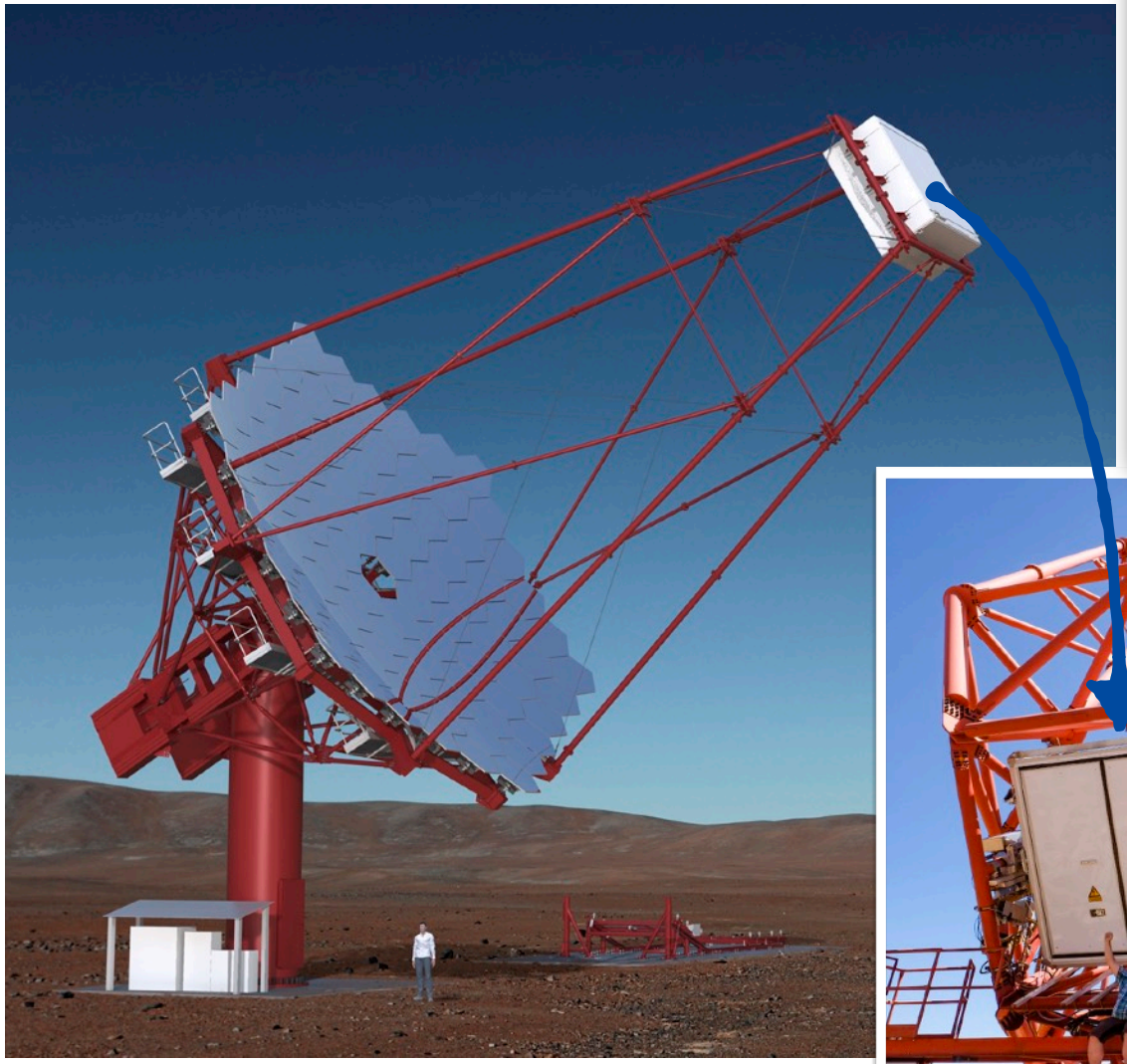
ECAP:

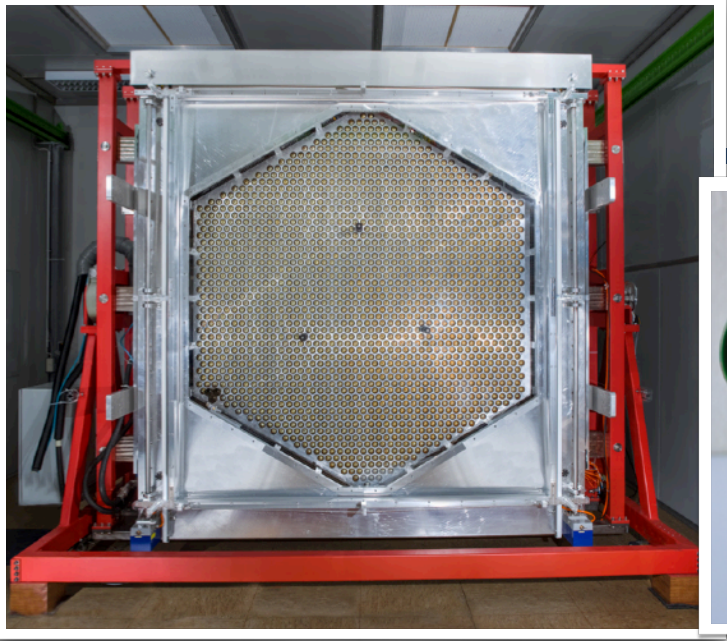
- development of read-out electronics
- signal characterisation and calibration



Cherenkov cameras - FlashCam

ECAP contributions to CTA





MST camera for CTA-S

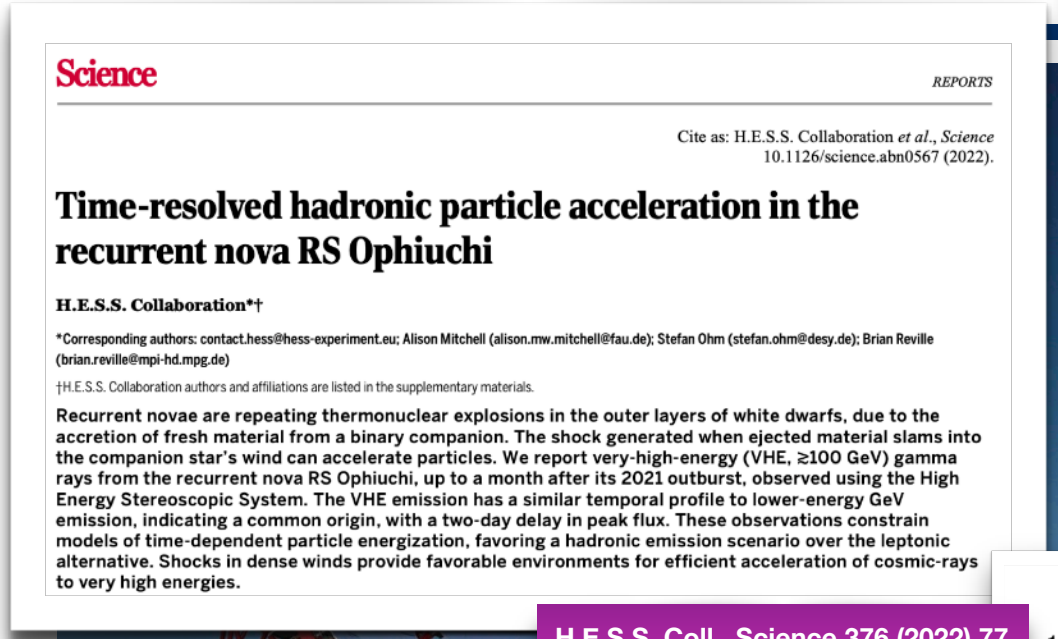
- 1764 pixel (7.7º FoV)
- 250 MHz sampling rate
- fully digital trigger/readout

ECAP:

- tests/characterisation of photon detector planes
- camera module assembly
- calibration/science verification of FlashCam prototype in H.E.S.S.

Cherenkov cameras - FlashCam

ECAP contributions to CTA



Science

REPORTS

Cite as: H.E.S.S. Collaboration *et al.*, *Science* 10.1126/science.abn0567 (2022).

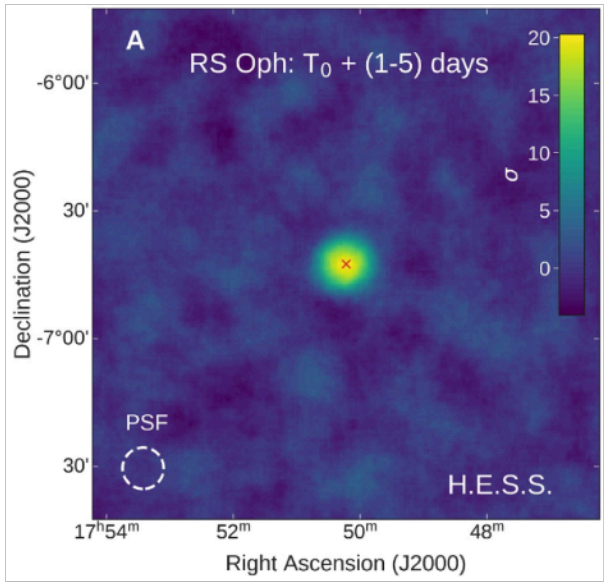
Time-resolved hadronic particle acceleration in the recurrent nova RS Ophiuchi

H.E.S.S. Collaboration*†

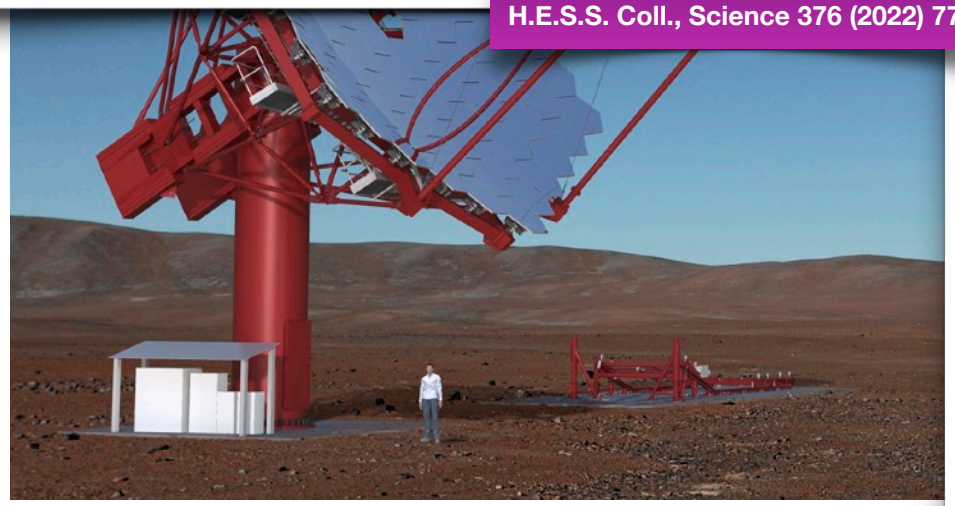
*Corresponding authors: contact.hess@hess-experiment.eu; Alison Mitchell (alison.mw.mitchell@fau.de); Stefan Ohm (stefan.ohm@desy.de); Brian Reville (brian.reville@mpi-hd.mpg.de)

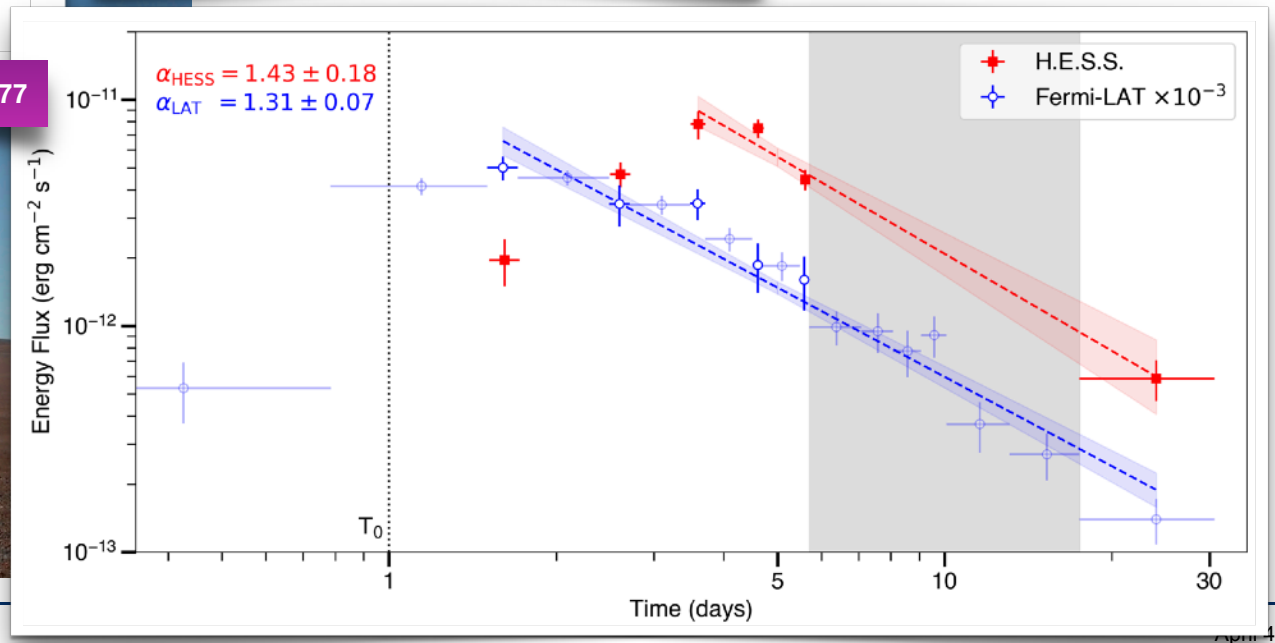
†H.E.S.S. Collaboration authors and affiliations are listed in the supplementary materials.

Recurrent novae are repeating thermonuclear explosions in the outer layers of white dwarfs, due to the accretion of fresh material from a binary companion. The shock generated when ejected material slams into the companion star's wind can accelerate particles. We report very-high-energy (VHE, ≥100 GeV) gamma rays from the recurrent nova RS Ophiuchi, up to a month after its 2021 outburst, observed using the High Energy Stereoscopic System. The VHE emission has a similar temporal profile to lower-energy GeV emission, indicating a common origin, with a two-day delay in peak flux. These observations constrain models of time-dependent particle energization, favoring a hadronic emission scenario over the leptonic alternative. Shocks in dense winds provide favorable environments for efficient acceleration of cosmic-rays to very high energies.



H.E.S.S. Coll., Science 376 (2022) 77



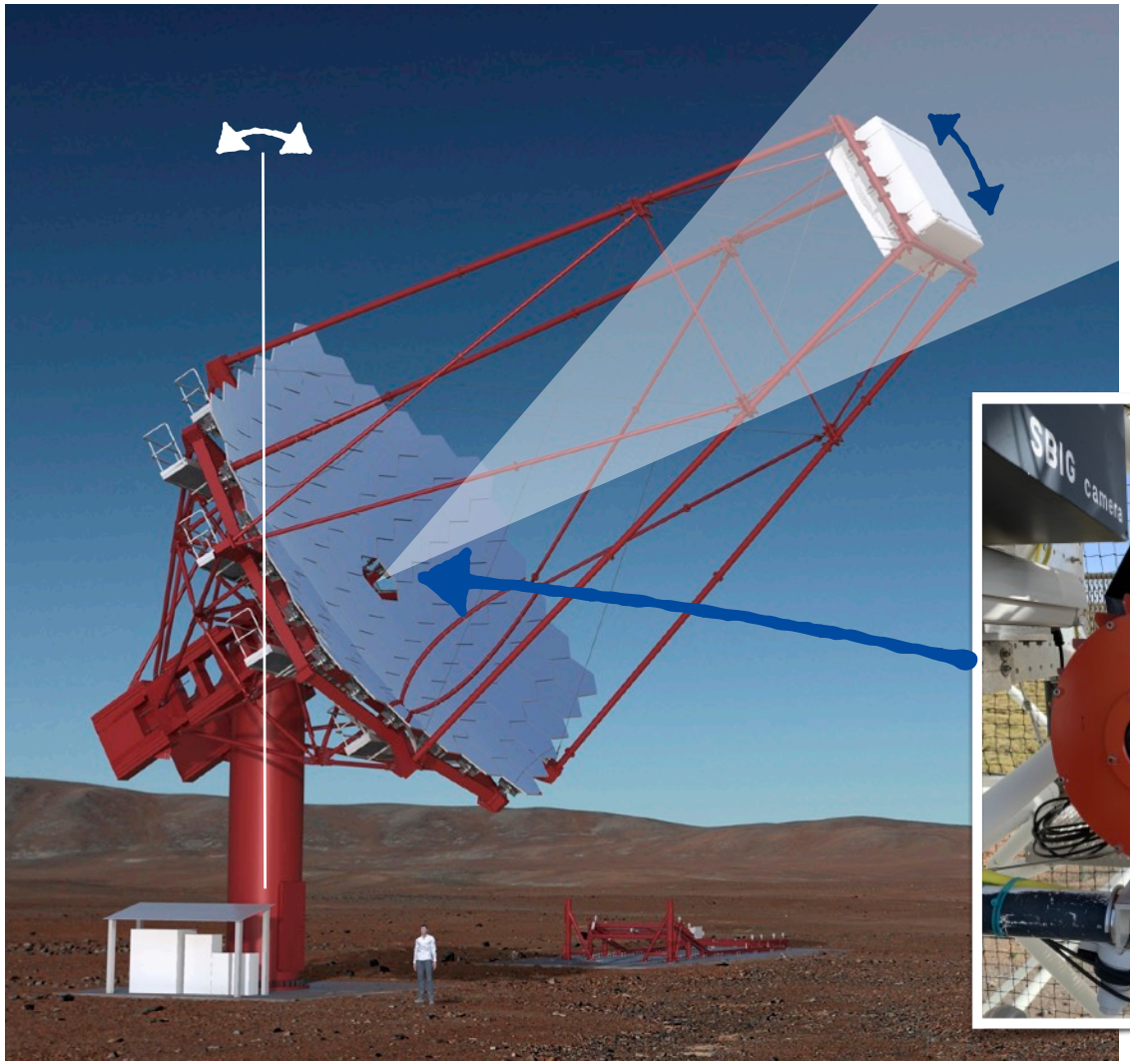


2021 outburst of recurrent nova RS Ophiuchi

- follow-up of optical outburst with H.E.S.S.
- particle acceleration to multi-TeV energies within days
- plausibly proton/ion acceleration dominates over electrons

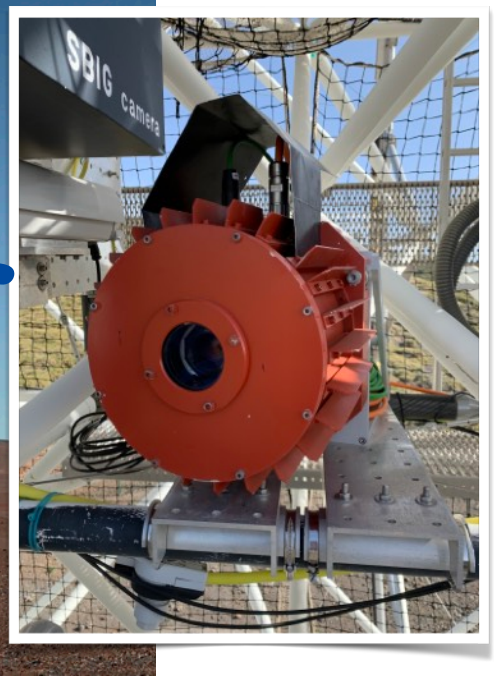
Telescope precision pointing

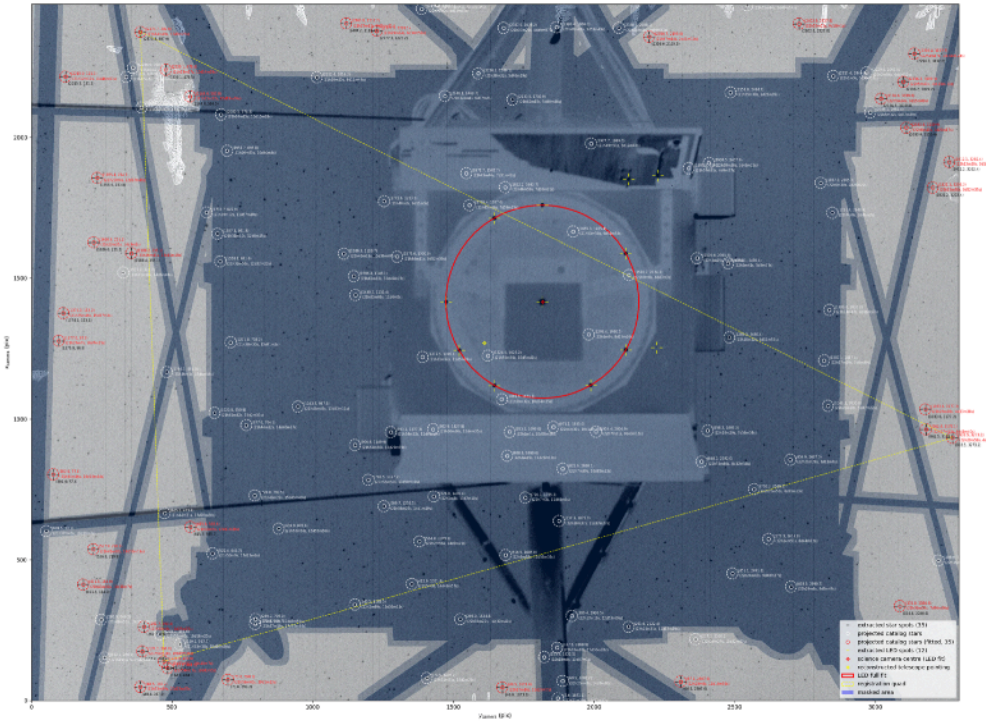
ECAP contributions to CTA



Calibration of telescope pointing to 5” precision

- camera hardware development
- camera mass production + tests
- steering software
- calibration algorithms
- observatory integration





Telescope precision pointing

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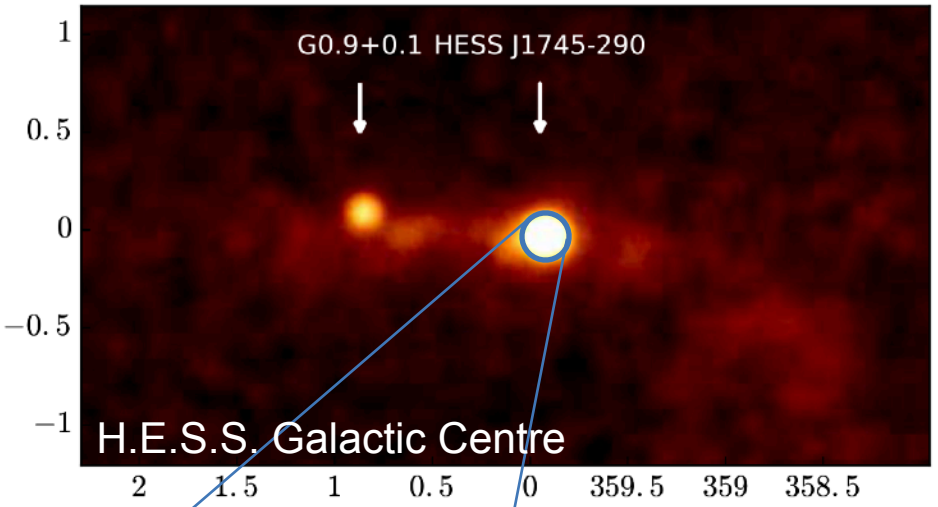
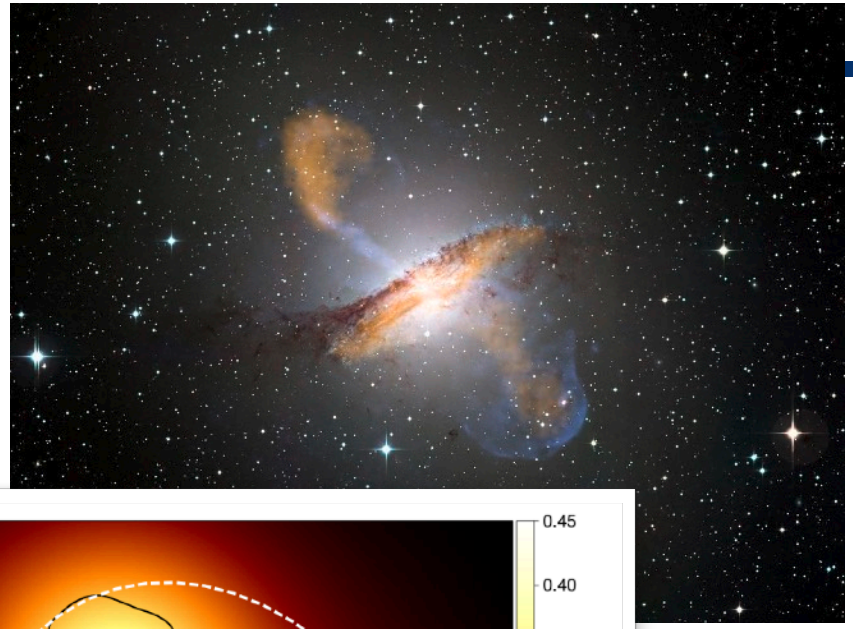
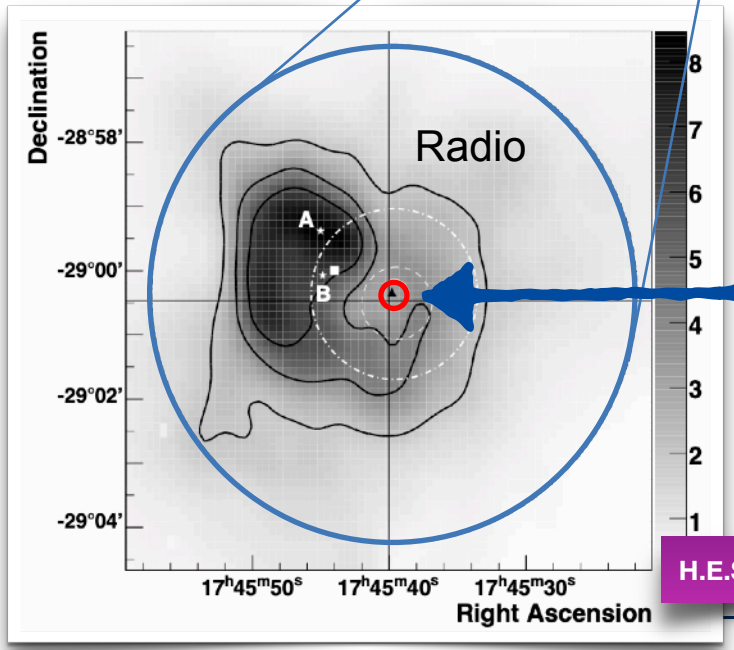
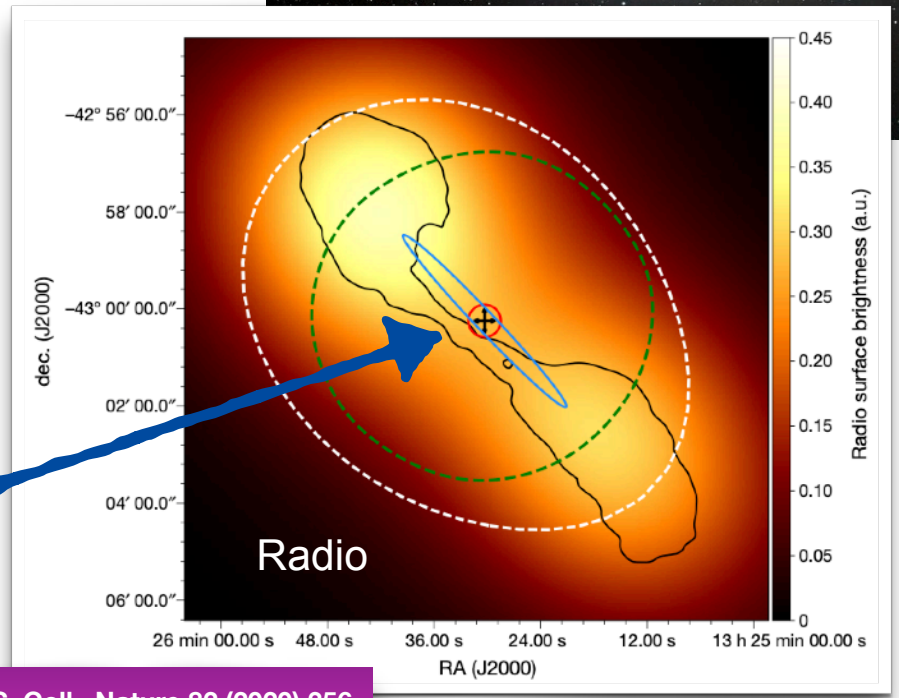






Precision source localisation & extension:

- TeV particle acceleration within 6'' of BH **Sgr A***
- TeV particle acceleration in **Cen A's jets**

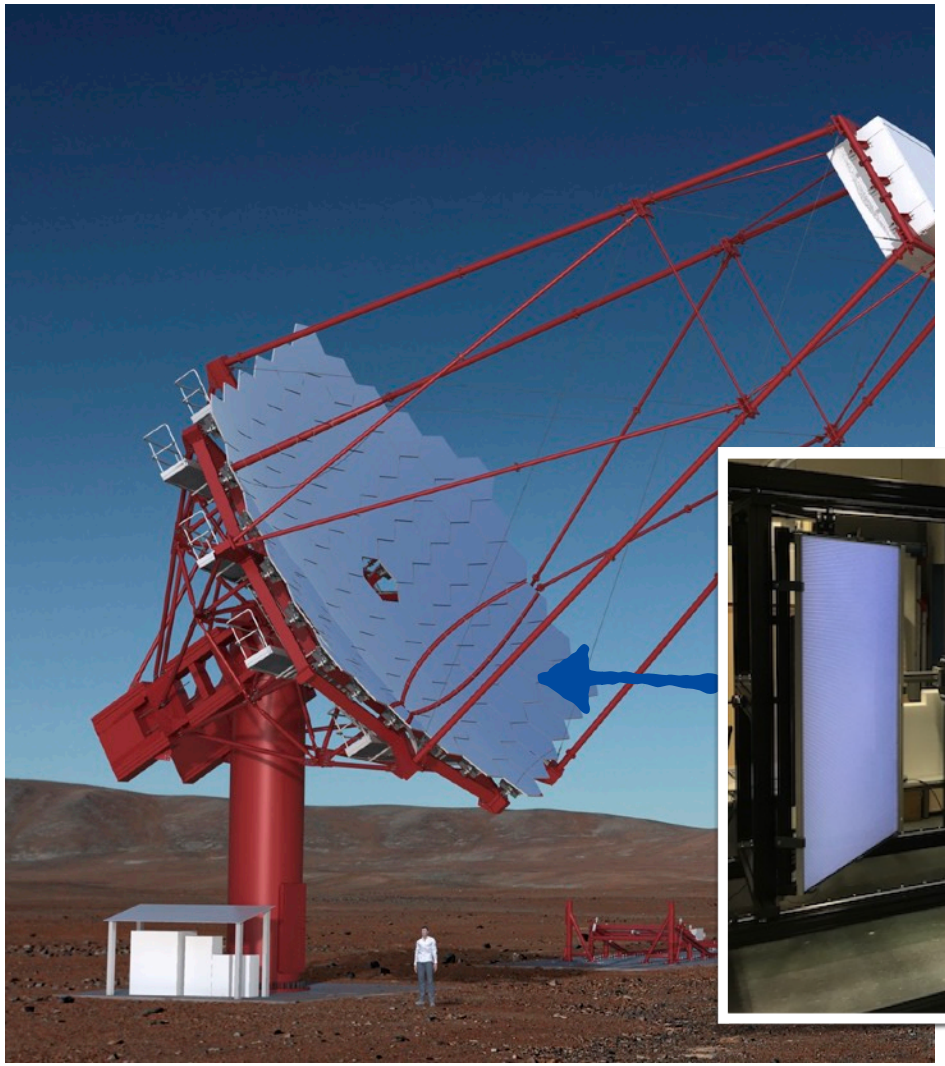


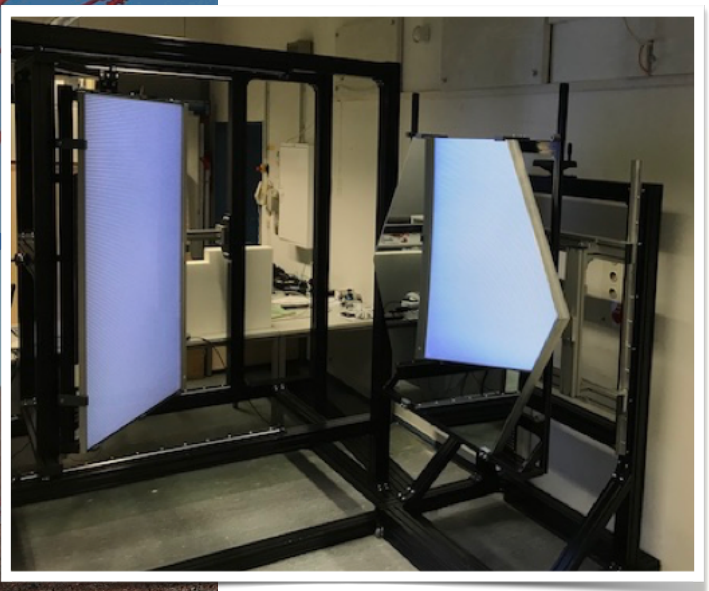
H.E.S.S. Coll., MNRAS 402 (2010) 1877

H.E.S.S. Coll., Nature 82 (2020) 356

Mirror surface measurements

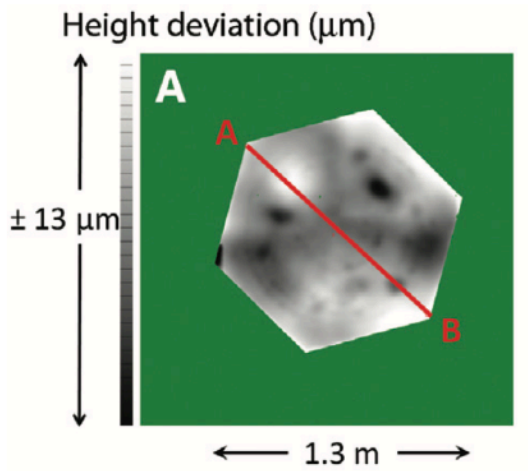
ECAP contributions to CTA

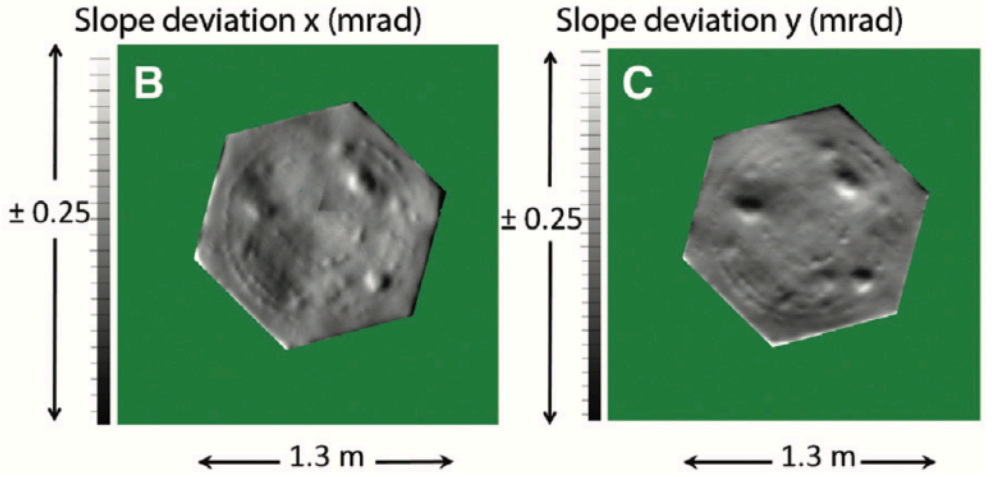




Test stands for fast surface inspections

- fast + robust deflectometric technique (PMD)
- local measurement of surface slope
- arc-second precision
- ray-tracing to assess mirror focal distance and point spread function



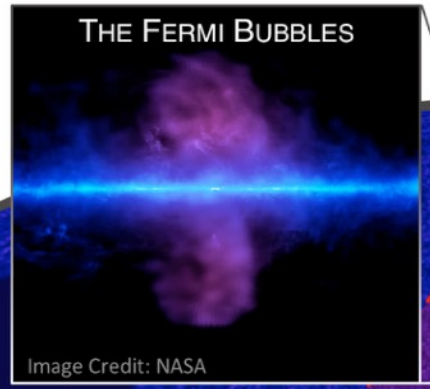


The Southern Wide-field Gamma-ray Observatory

A gamma-ray survey instrument in the southern hemisphere

Southern Hemisphere:
no TeV survey instrument so far

SWGO would
- complement HAWC
- complement CTA-S



The Southern Wide-field Gamma-ray Observatory

A gamma-ray survey instrument in the southern hemisphere

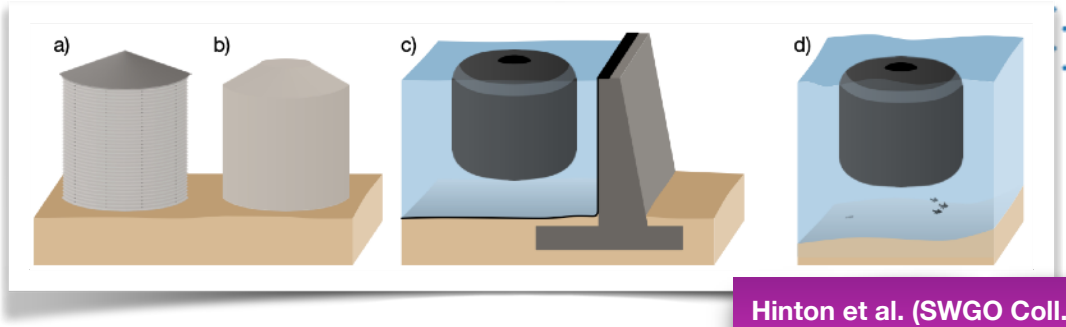
SWGO
The Southern Wide-field
Gamma-ray Observatory

dense
core array

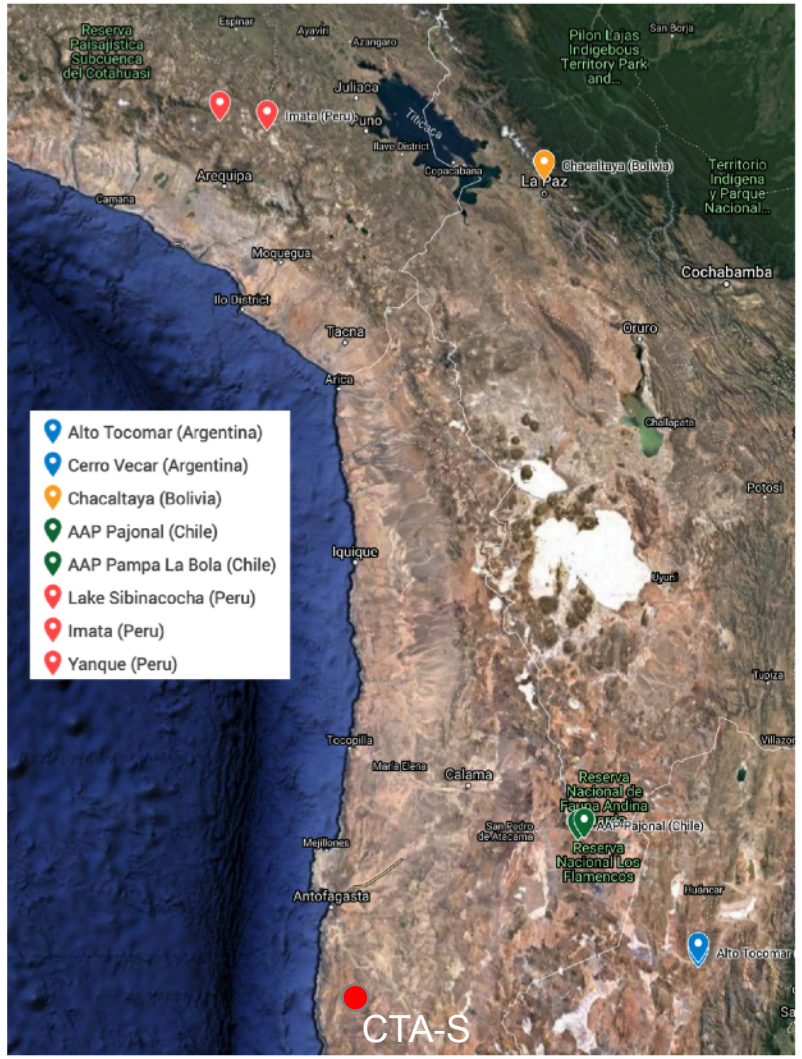
sparse
outer array

Reference configuration:

- 6600 water Cherenkov detectors
- 240.000 m² array footprint
- 4.700 m altitude



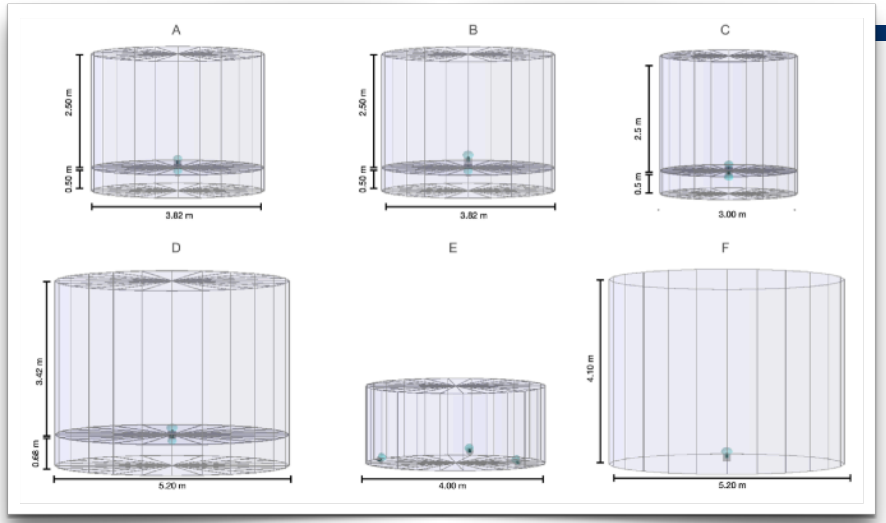
Hinton et al. (SWGO Coll.) ICRC 2021

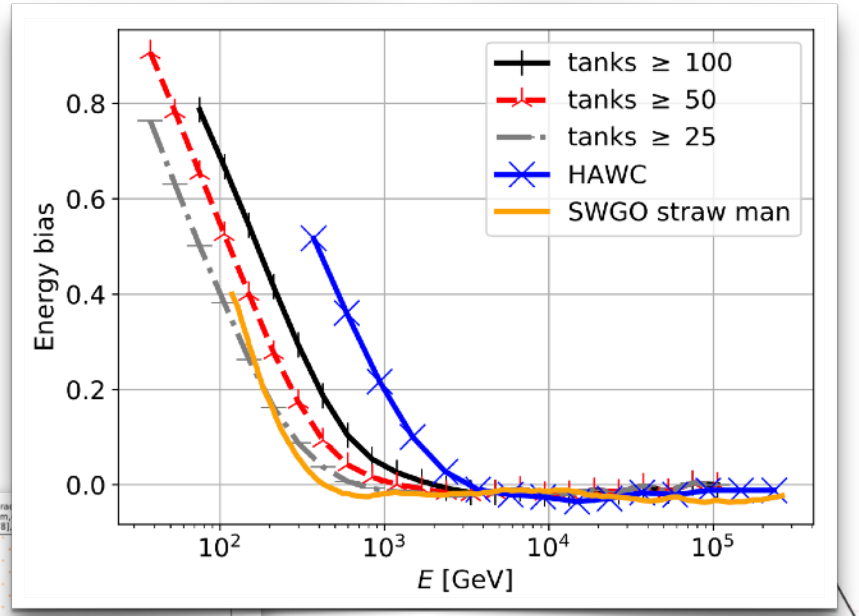


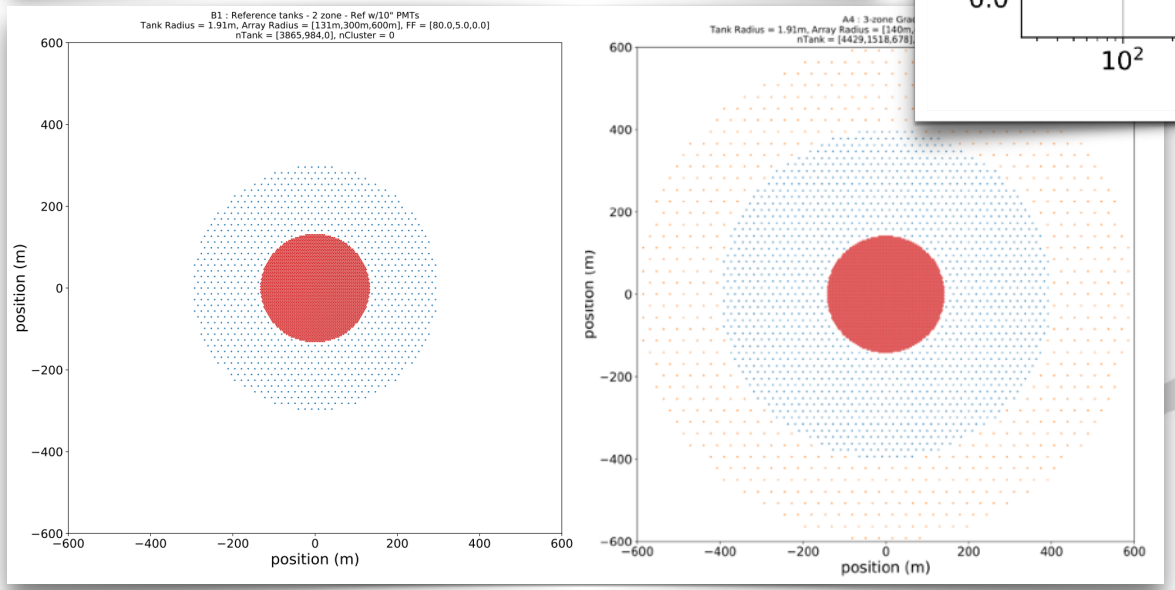
Site shortlisting
in progress

Reconstruction and Array Optimisation

ECAP contributions to SWGO

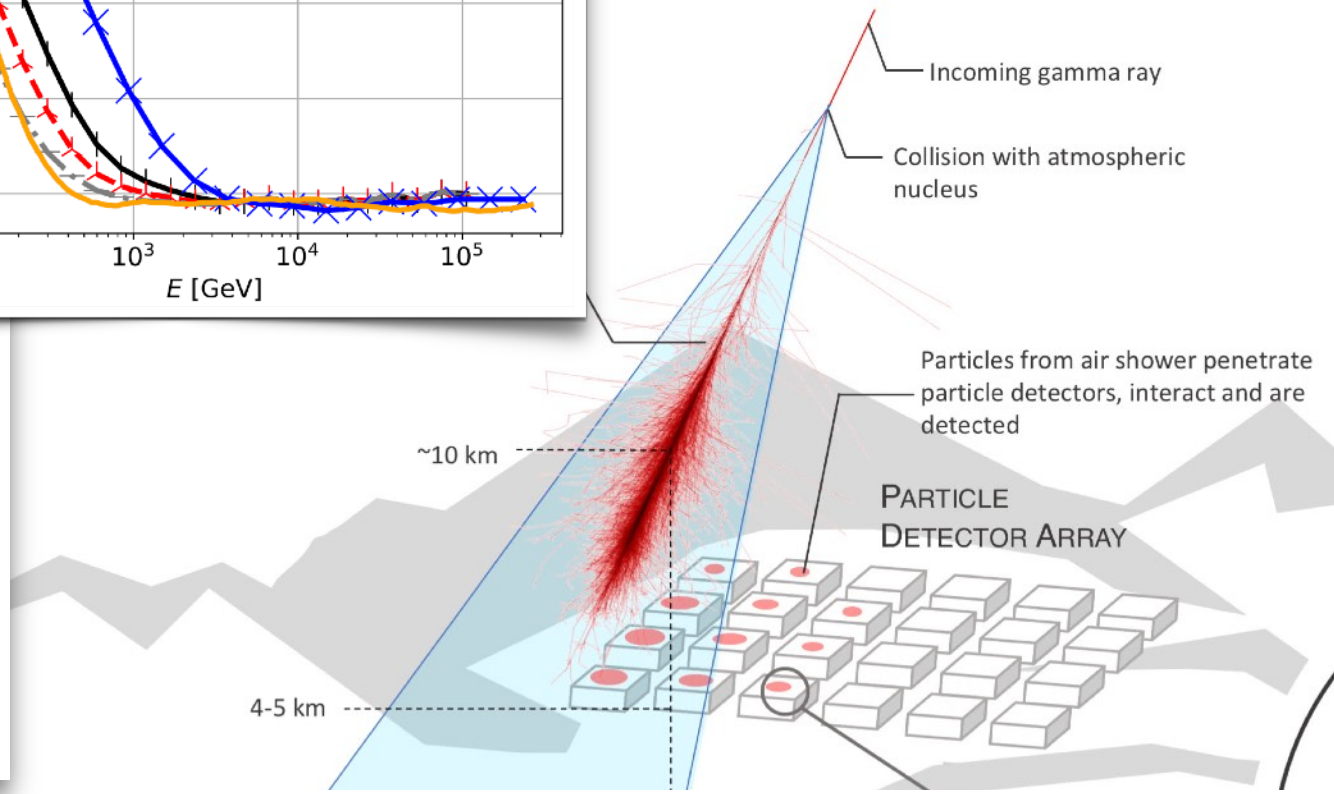






ECAP:

- event reconstruction
- array performance optimisation
- pathfinder array



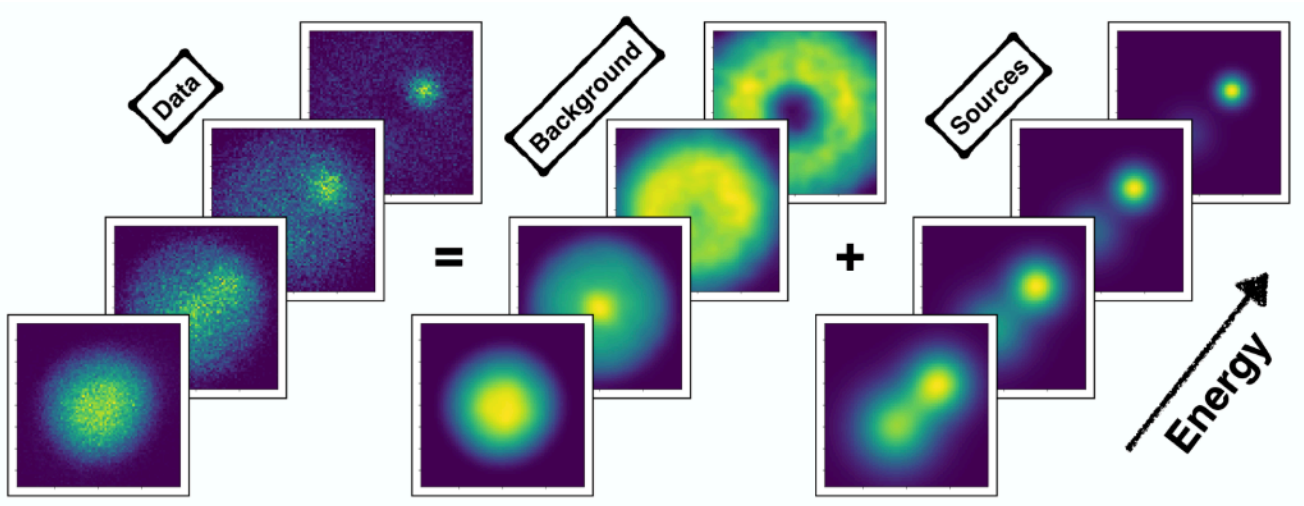
Gammapy: Analysis Software for Gamma-ray Astronomy

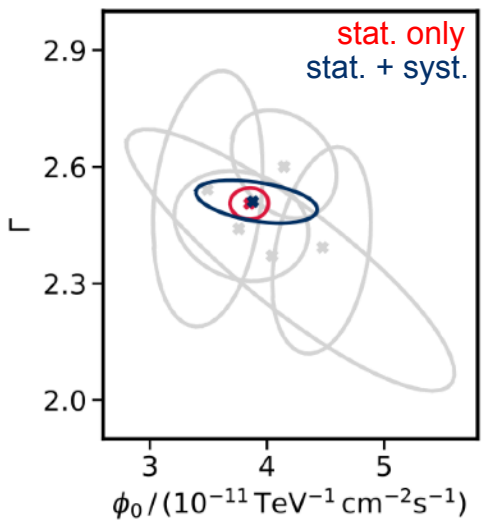
Towards joint instrument analysis

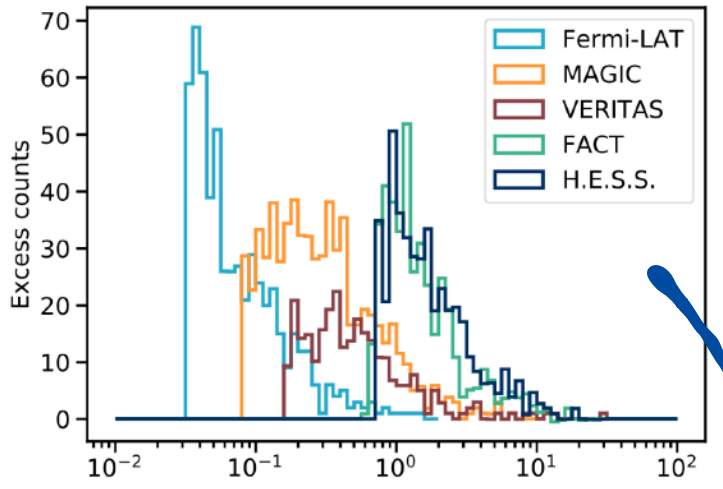
A **Python** package for **gamma-ray** astronomy

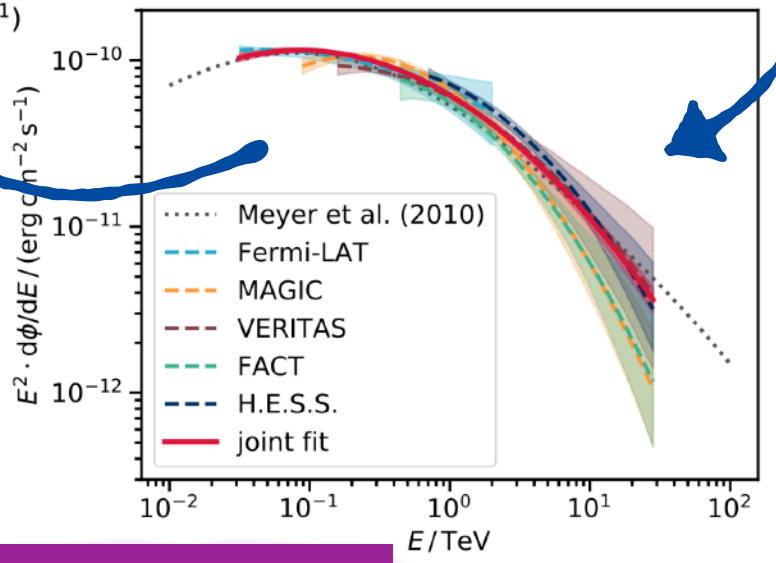
- open source, community developed
- chosen as core of CTA science tools
- H.E.S.S. open science package of choice

- multi-instrument analysis
- fit of physical models directly to data
- consistent treatment of statistics and systematics





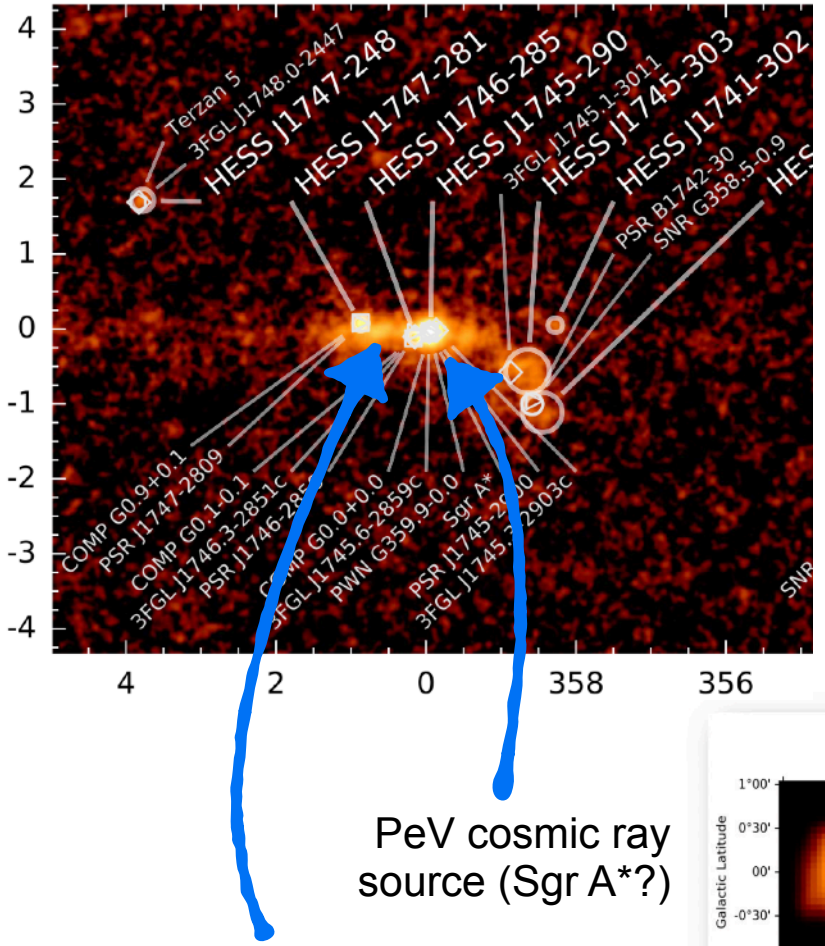




Nigro et al. A&A 625 (2019) A10

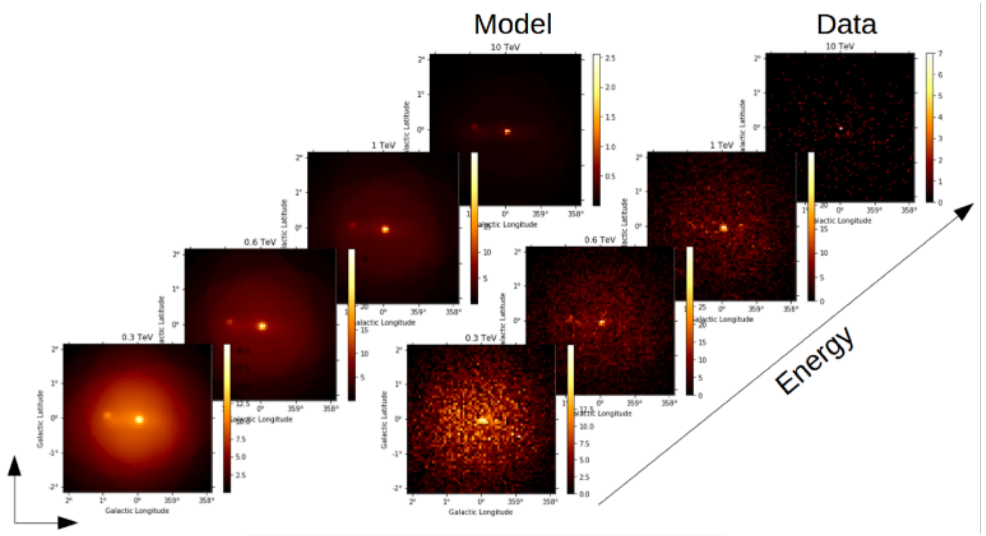
Analyses of complex regions

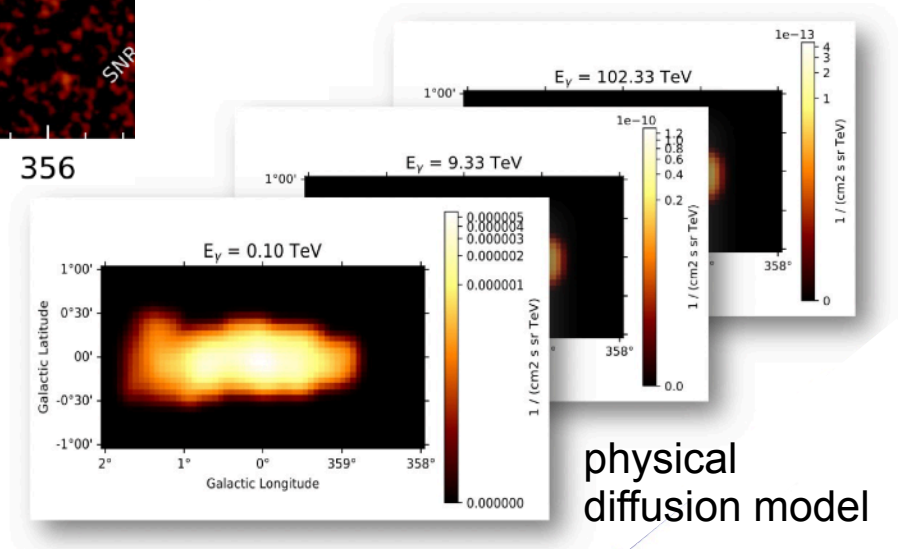
Galactic Centre with H.E.S.S.



PeV cosmic ray source (Sgr A*?)

diffuse emission from cosmic ray-gas collisions



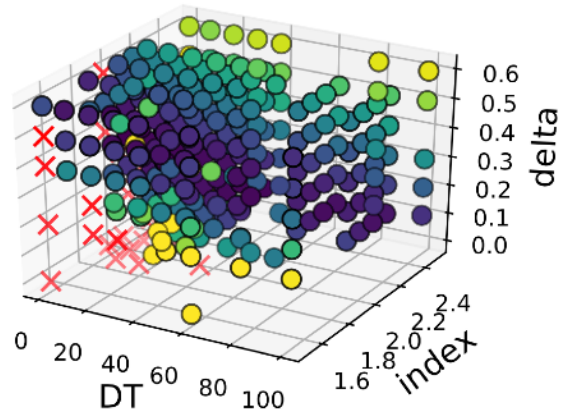


physical diffusion model

ECAP:

common analysis of Fermi-LAT and H.E.S.S. data

- origin of central source of PeV cosmic rays
- diffusion properties in central molecular zone
- mixing of cosmic rays into Galaxy
- origin of Fermi bubbles
- dark matter searches



ECAP

- strong involvement in leading running and up-coming gamma-ray observatories
- contributions to instrument building, calibration, reconstruction, analysis
- increasing focus on joint multi-wavelength/multi-messenger analysis

Thanks for your attention.