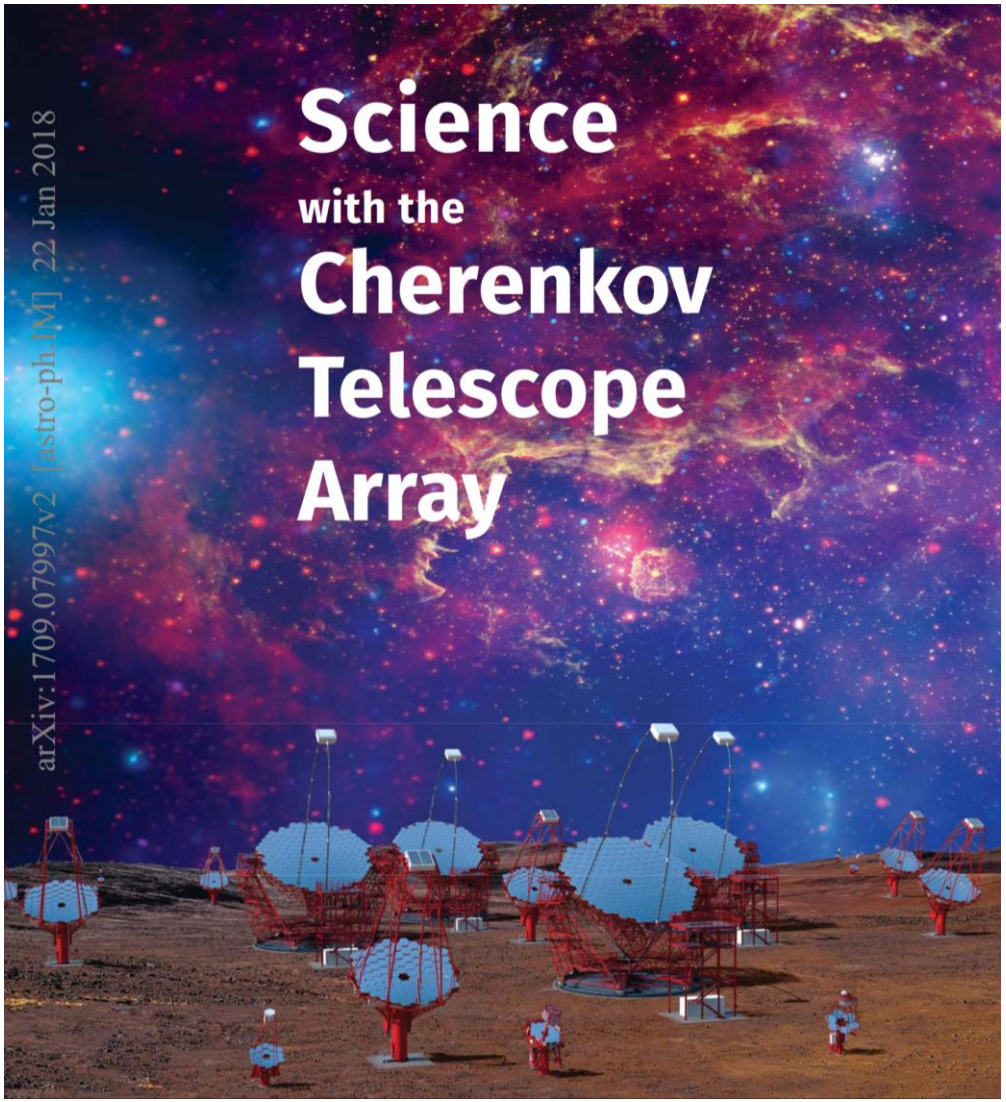
Cherenkov Telescope Array – status May 2023

- Introduction to CTA
- The Small Size Telescope and its camera
- Progress on CTA northern and southern sites
- Odds and ends
- Some CTA science
- Summary

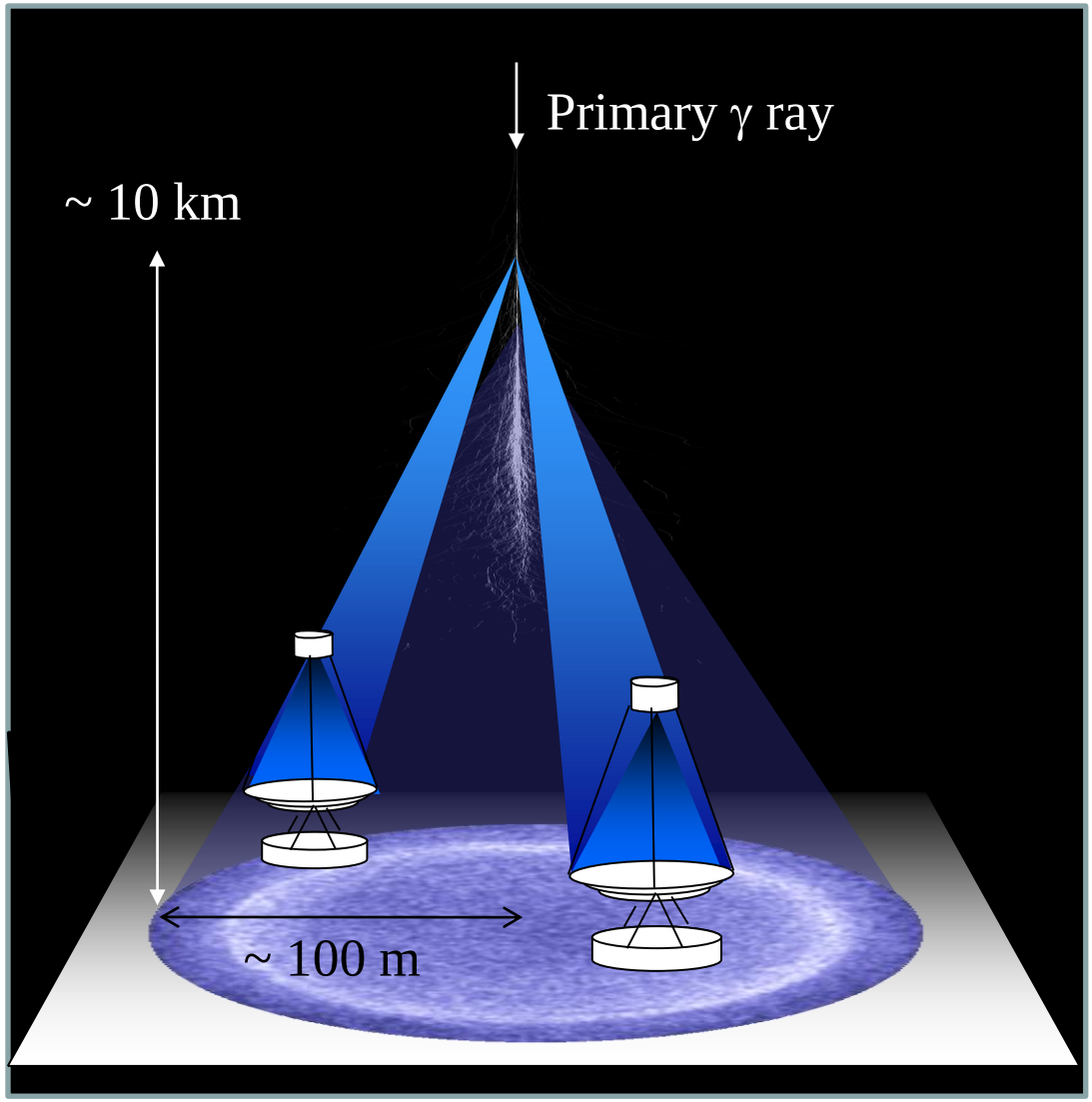
- CTA-UK:
  - Armagh Observatory
  - Durham
  - Leicester
  - Liverpool
  - Oxford



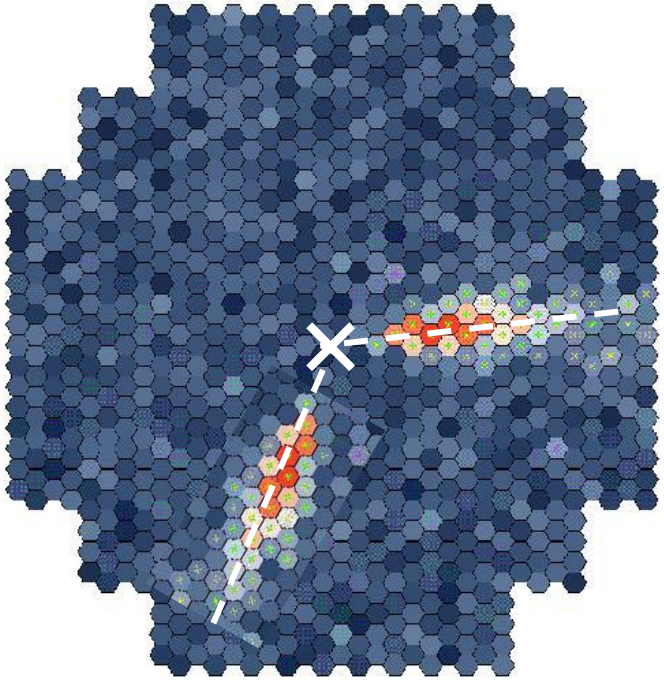
CTA and Liverpool according to ChatGPT

- Right: *The CTA will enable researchers to observe high-energy gamma rays with unprecedented sensitivity, providing insights into a wide range of astrophysical phenomena such as active galactic nuclei […] and the search for dark matter.*
- Wrong: *The array will consist of multiple telescopes […] divided into two types: the large-sized telescopes (LSTs) and the medium-sized telescopes (MSTs).*
- Right and wrong: *Liverpool has played a significant role in the development of the cameras for the CTA telescopes. The university's Astrophysics Research Institute has expertise in the design and construction of high-speed imaging cameras…*
- Unexpected degree of wisdom: *It's worth noting that the progress and timeline of large-scale scientific projects like the CTA can evolve […] consult other reliable sources for the most up-to-date information on its current status.*

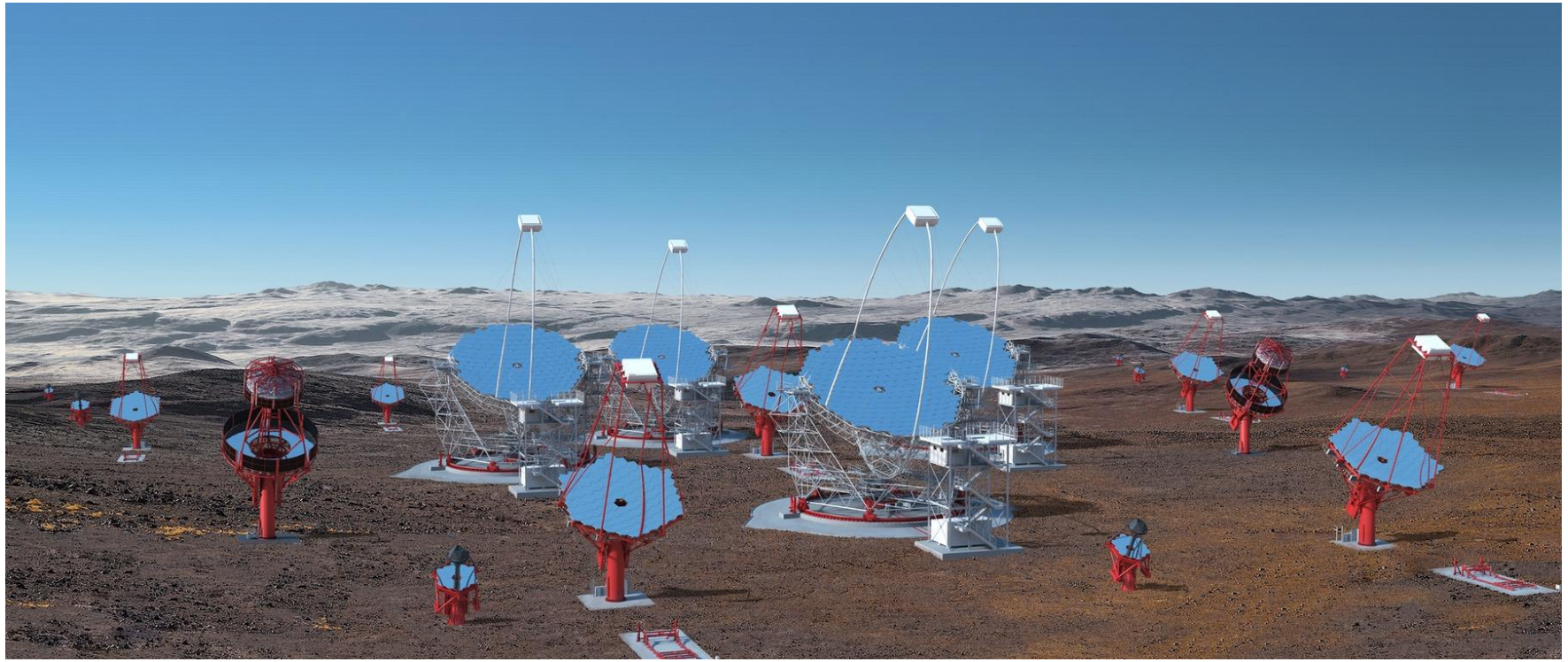
Introduction – detecting high energy γ rays



- Cherenkov light flash lasts ~ 10 ns.
- Detect with camera made of photomultipliers.
- Superimpose telescope images, find γ-ray source and intensity.



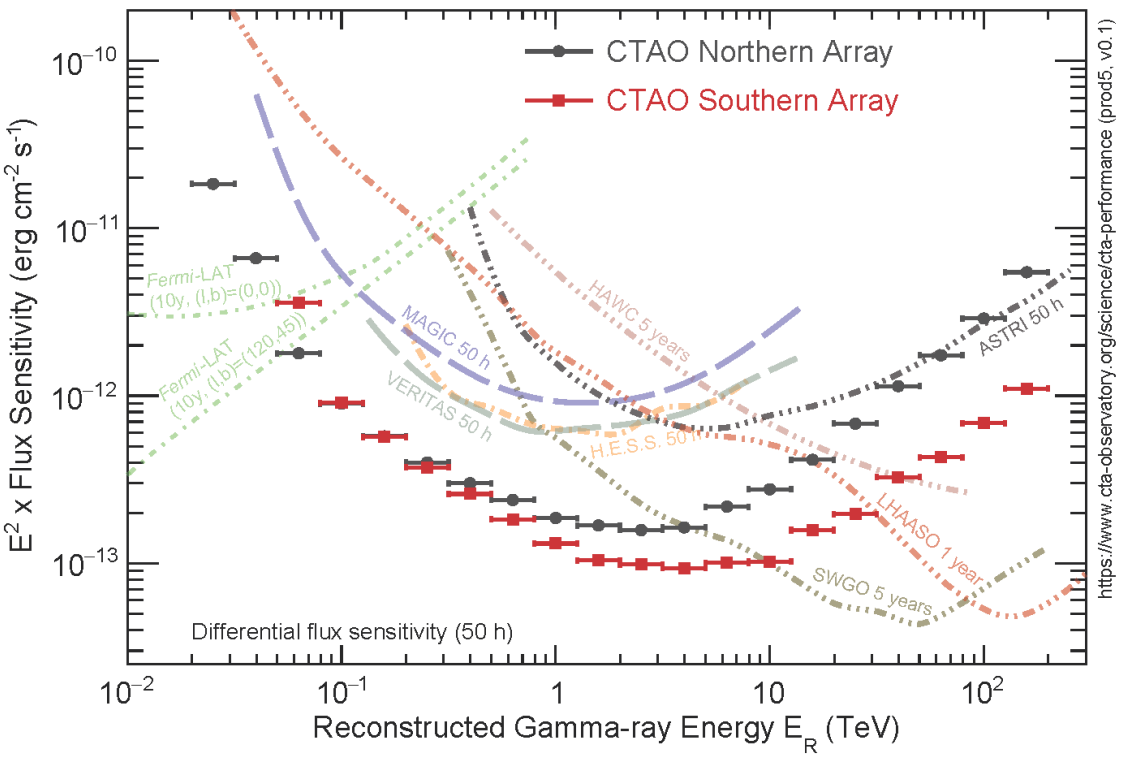
The Cherenkov Telescope Array



- CTA will use different telescope sizes on northern and southern sites to cover:
  - Low energy, 20 GeV…1 TeV, Large Size Telescopes, 23 m diameter.
  - Medium energy, 500 Gev…5 TeV, Medium Size Telescopes, 12 m diameter.
  - High energy, 1 Tev…300 TeV, Small Size Telescopes, 4.3 m diameter.

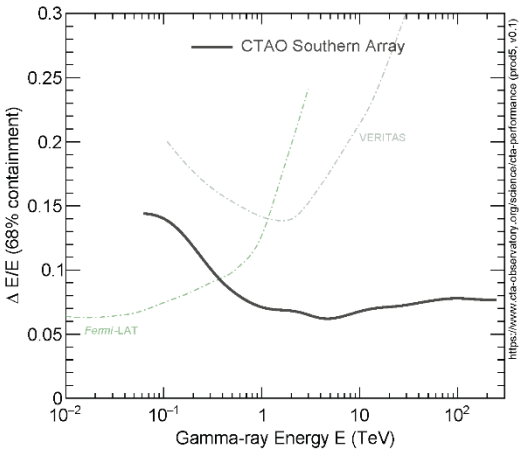
CTA performance

- CTA sensitivity:

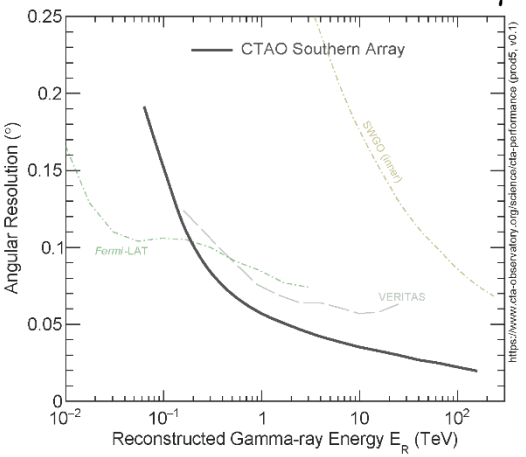


- Performance dominated by Small Size Telescopes at energies above 5 TeV.

- $\Delta E/E < 10\%$ for $E_\gamma > 1$ TeV.



- Ang. Res. $< 0.05°$ for $E_\gamma > 1$ TeV.



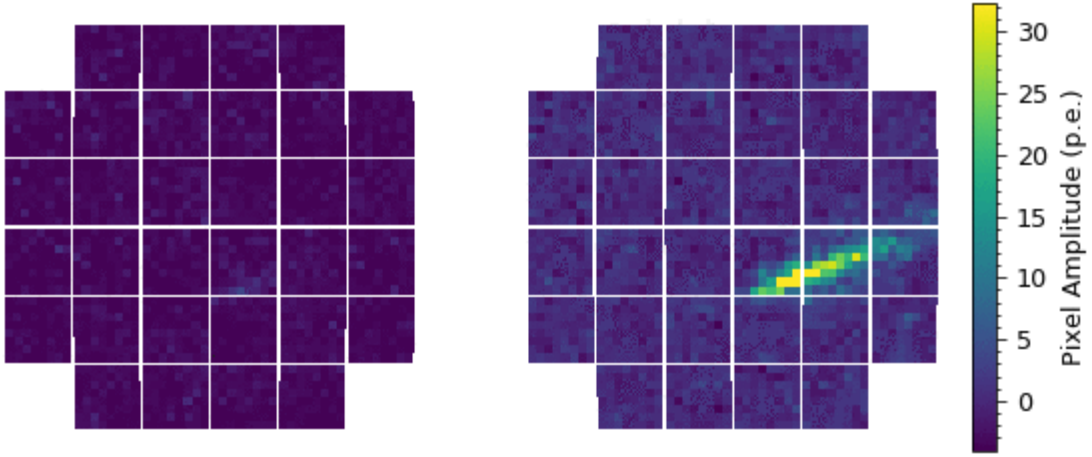
Small Size Telescope

- UK proposed use of Schwarzschild-Couder (dual mirror) optics for SSTs.
- Original optical design by Liverpool and Durham, later by Brera Observatory, Italy.
- Current design has:
  - Primary diameter 4.3 m.
  - Secondary diameter 1.8 m.
  - Focal length 2.15 m.
  - F = 0.5.
  - Focal plane diameter 0.4 m.
  - Field of view 9°.
- UK camera selected for SST after international review.

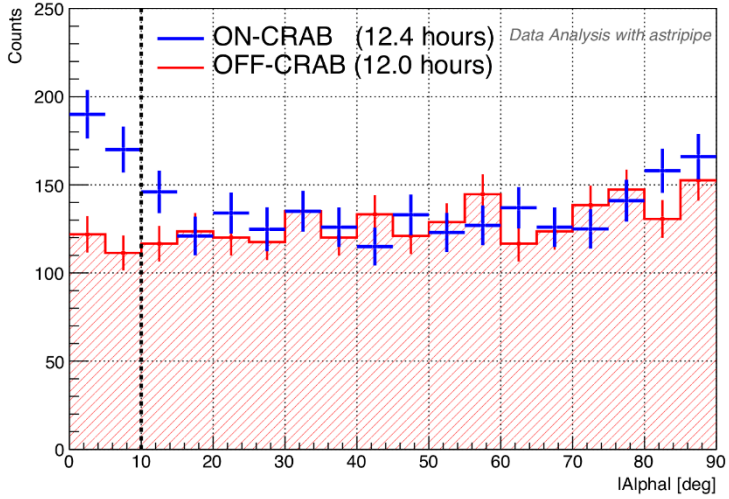
SST camera based on CHEC-S

- ASTRI telescope and CHEC-S camera at the Serra La Nave observatory in Etna, Sicily.

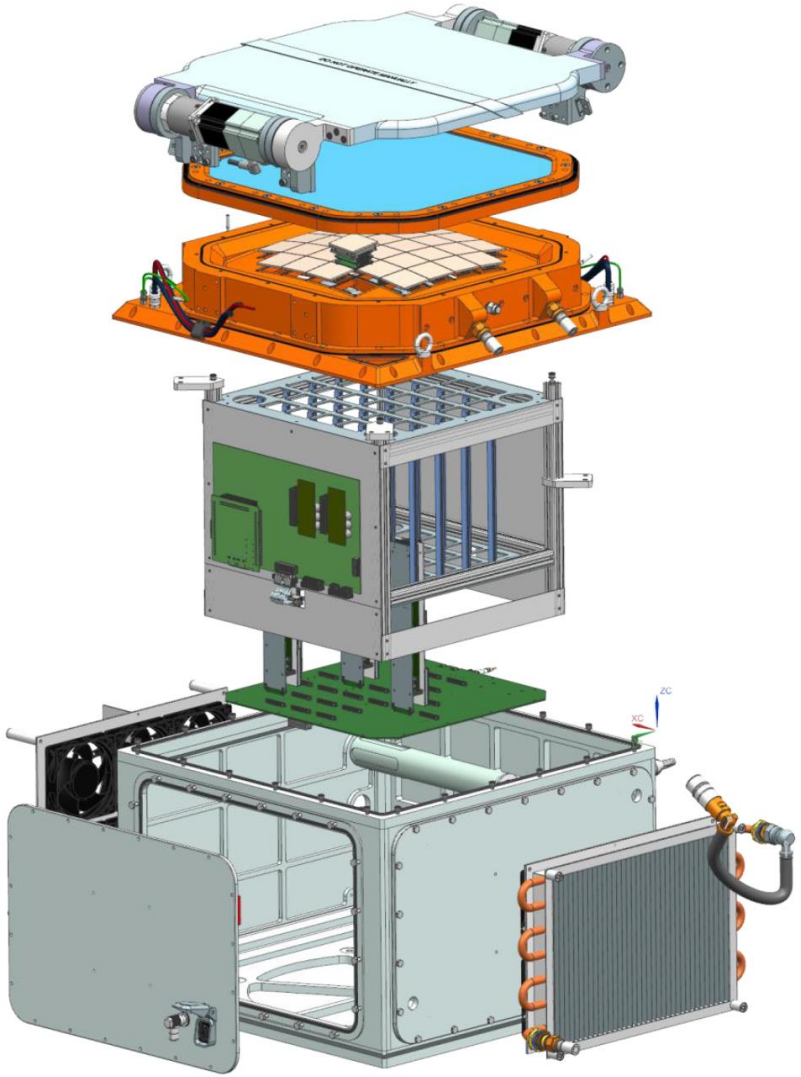
- Examples images, 1 ns time slices:



- First dual-mirror VHE detection of Crab nebula:

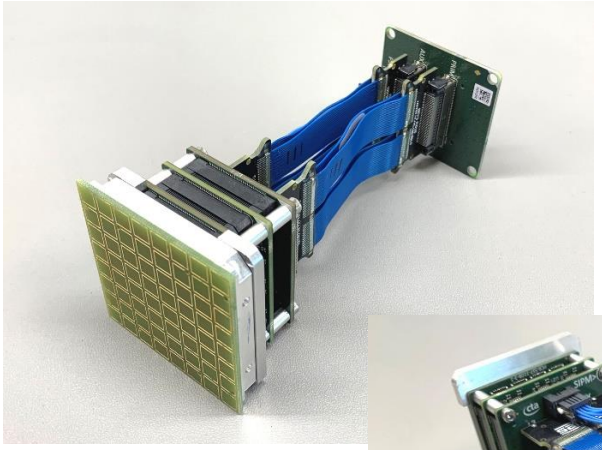


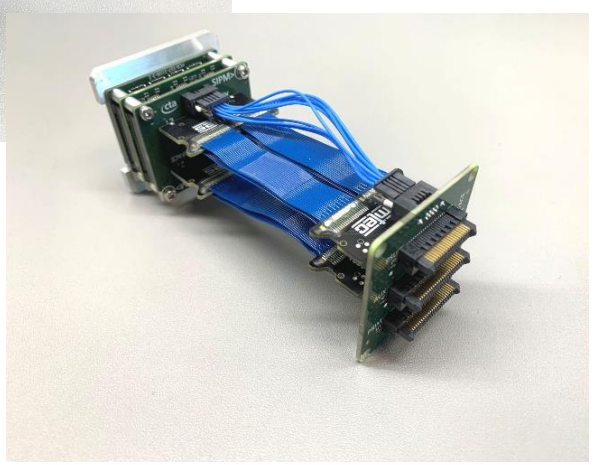
SST camera



Sensors

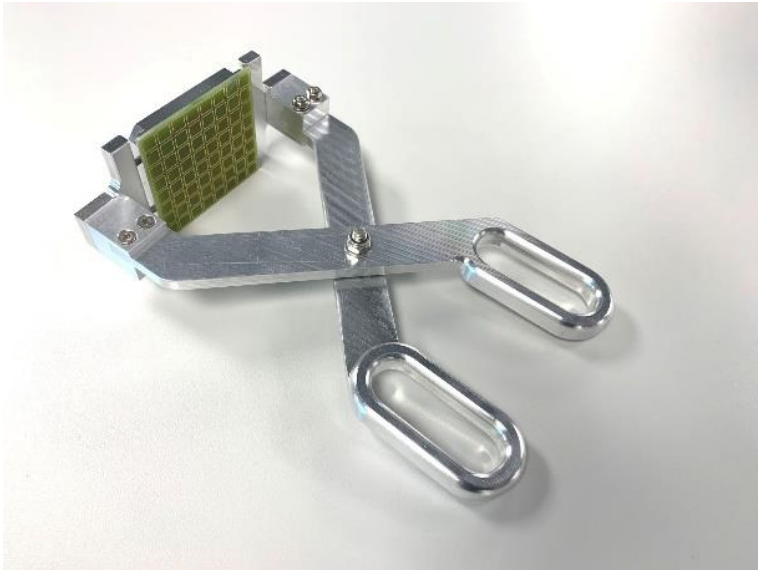
- Thirty-two tiles of 8×8 Hamamatsu SiPMs.
- Pixel size 5×5 mm^2.
- Delivery and test of production versions has started.



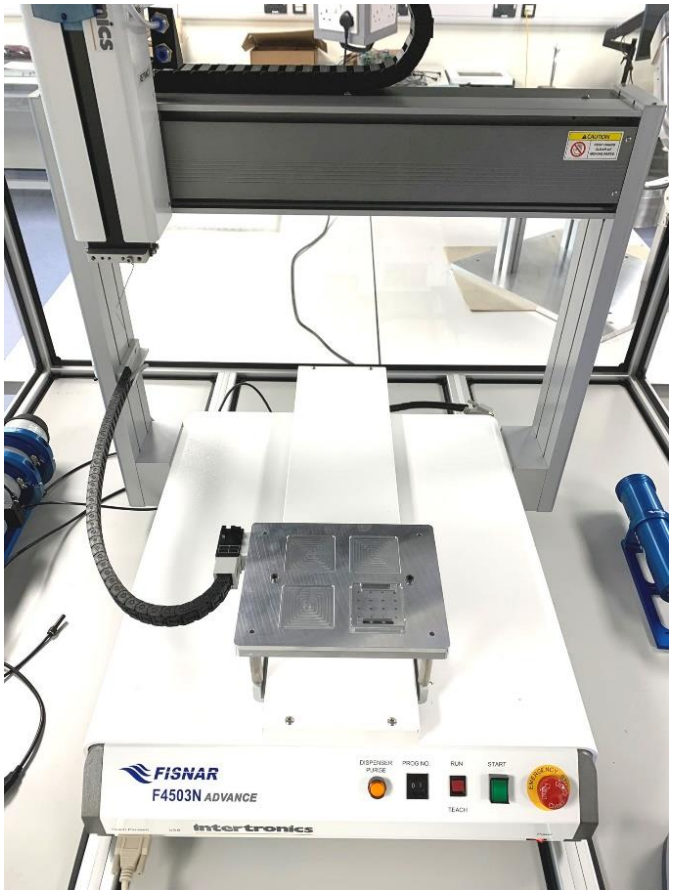


Sensor handling and tile assembly

- Cross talk due to photons scattering in SiPM resin coating was observed in CHEC-S, so SST-Cam uses uncoated silicon.
- Care needed in assembly!
- Handling jig constructed.

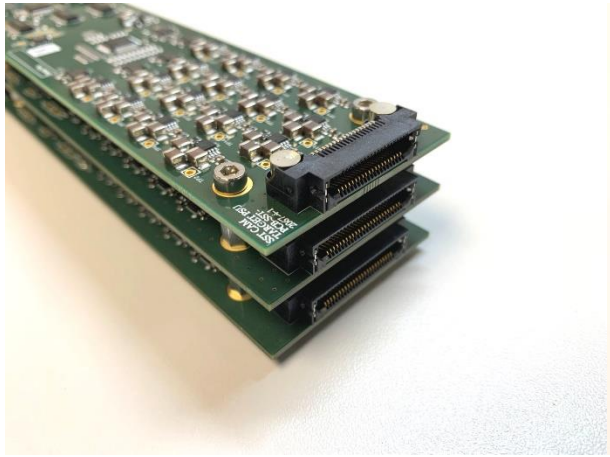


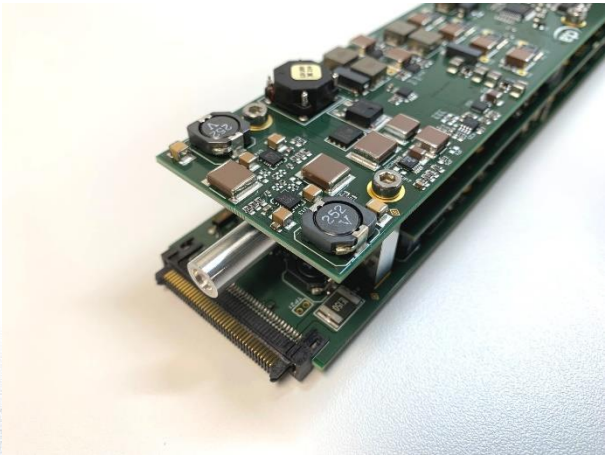
- Glue robot for attaching heart sinks to SiPMs set up.



Camera trigger and readout

- Trigger and readout (1 Gsample/s) using custom TARGET ASICS.
- First modules manufactured (UK contribution).

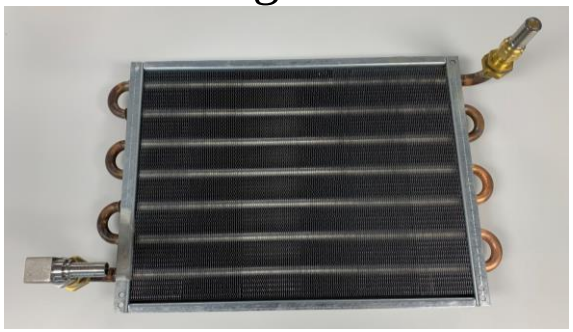




- Initial tests successful: no layout errors found.
- One chip on power board will be replaced with pin-compatible to better match voltage range required for new SiPMs.
- Preliminary waveforms observed.
- First investigations show improved gain matching w.r.t. CHEC-S due largely to individual pixel HV control.

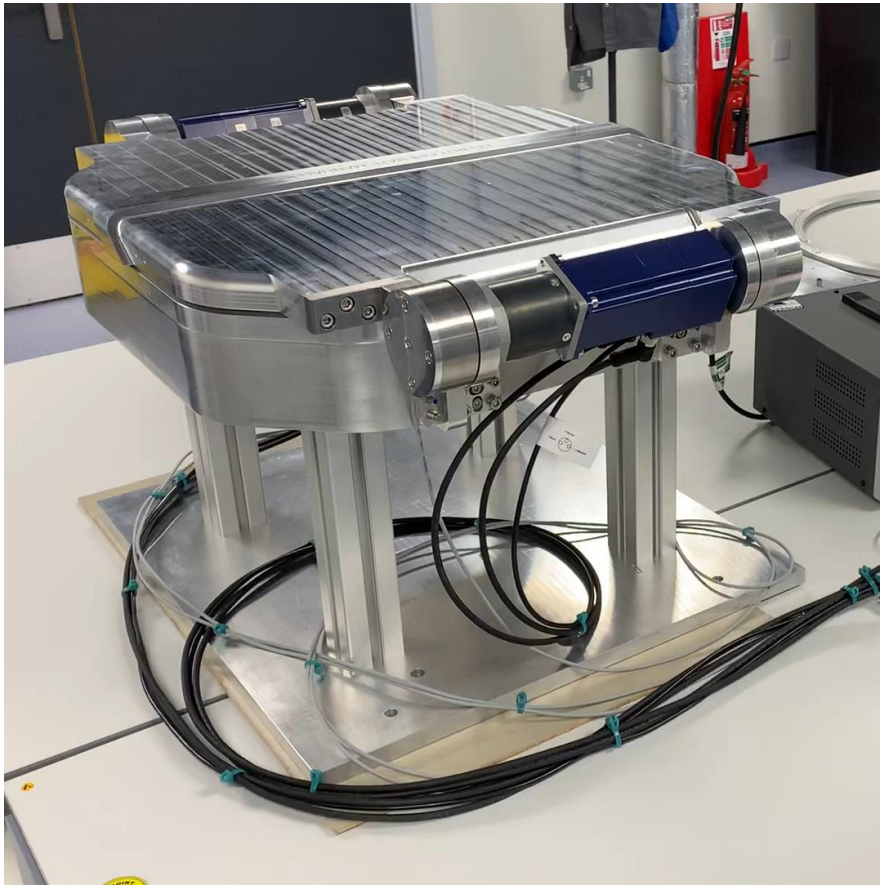
Camera mechanics

- First of production enclosures under construction.
- UK contributions to mechanics:
  - Heat exchangers



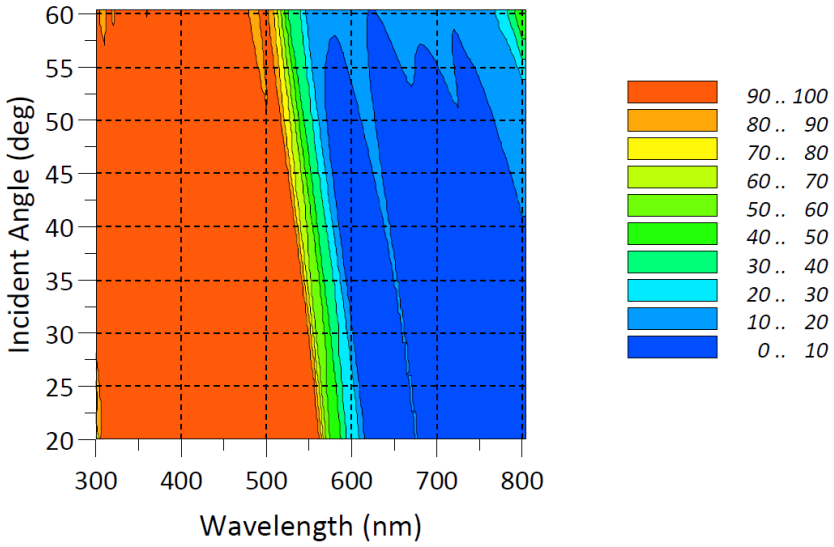
  - Fan banks…

- …and doors.

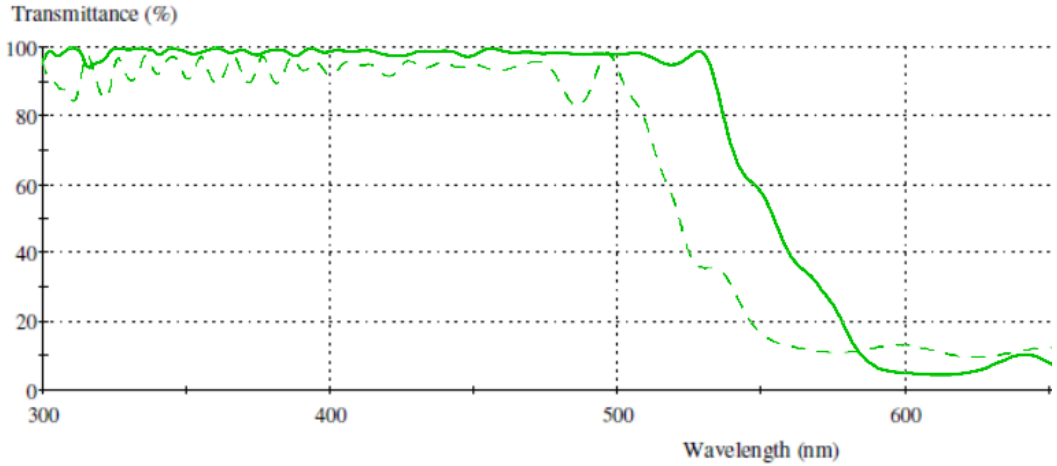


Camera calibration and windows

- UK will provide flashers for camera calibration.
- And quartz windows with coating that transmits UV/blue light and blocks IR (night sky background).
- Coating developed by Thin Metal Films, Basingstoke.



- "Needle" design consists of 81 layers (hafnia, silica…).
- Transmittance (mean polarisation): solid line at 20° incidence angle; dashed line at 60° incidence.



- Rear coating to prevent reflection of IR photons produced in SiPMs back onto camera.
- UK funding for camera windows agreed.

Southern site

- Paranal (European Southern Observatory, Atacama desert, Chile).
- Will construct 2 LSTs, 14 MSTs and 42 SSTs in alpha phase.
- Work on site has started: some roads constructed and connection to power grid underway.

Northern site and Data Centre

- Roque de los Muchachos Observatory, La Palma, Spain.
- Funding for 4 LSTs and 9 MSTs.
- First LST constructed and under test.

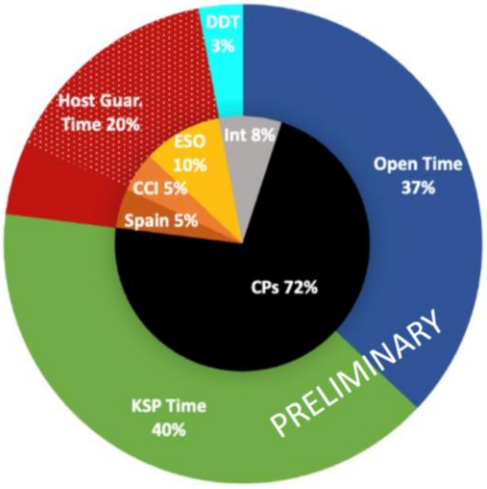
- CTA science data centre construction underway, ready for use Q3 2024.

Odds and ends

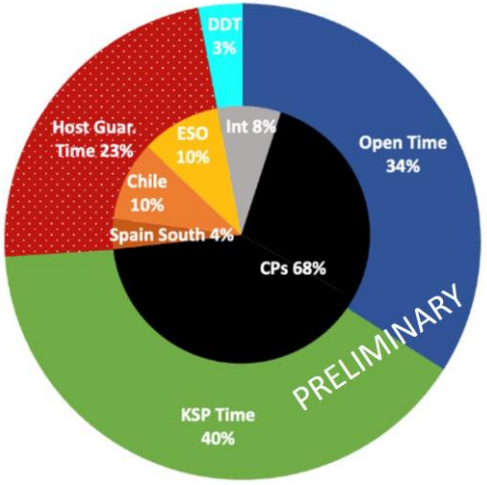
- Funding for CTA now in place.
- ERIC application in queue for sign-off by EU, announcement this summer.
- Lessons learned.
- Establishing international agreements necessary for CTAO in parallel with development of instrumentation has been difficult.

- *…every kind of peaceful cooperation among men [!] is primarily based on mutual trust and only secondly on institutions* (A. Einstein, Peace in the Atomic Era, 19/2/50.)
- E.g. of "peaceful cooperation", CTA observing time agreements:

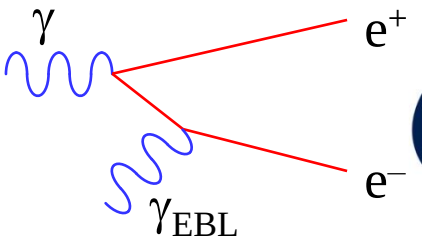
North



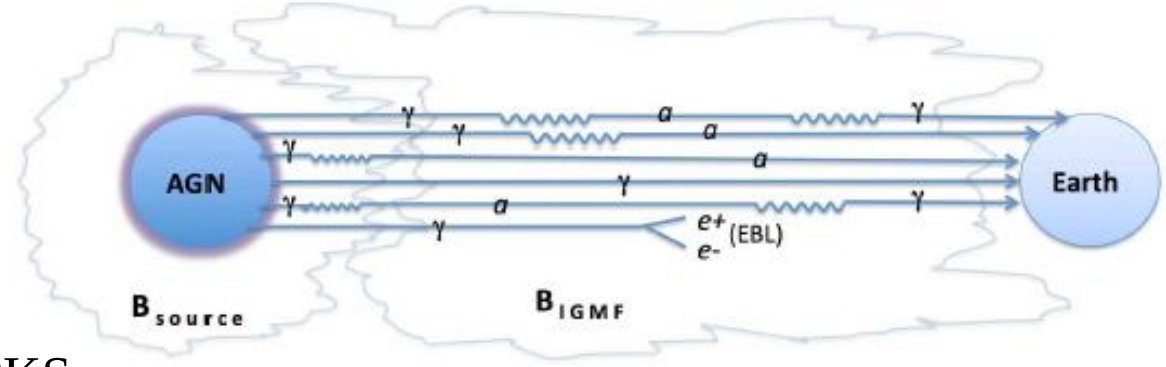
South

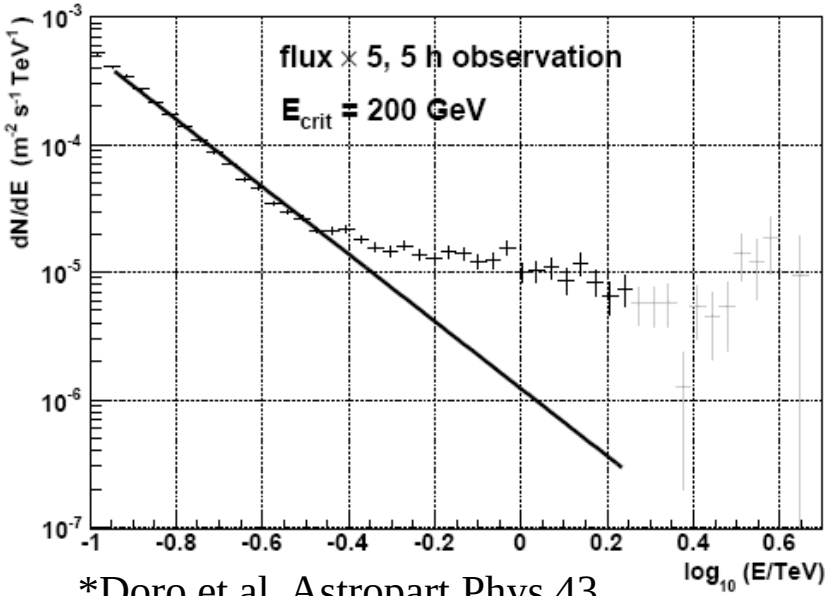


CTA science – searches for axions



- HE γ rays interact with EBL (for E_γ > 1 TeV) and CMB for E_γ > 100 TeV).
- Opacity of universe changes if there are axion-like particles.
- E.g. simulation of 5 h flare of PKS 1222+21, see change in spectrum*.

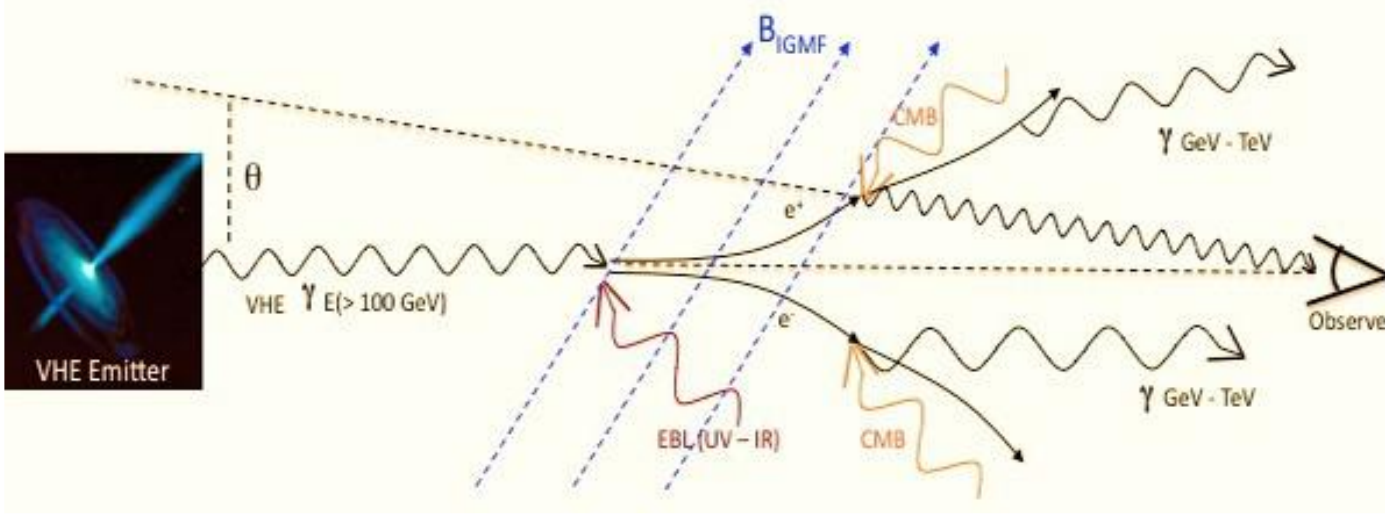


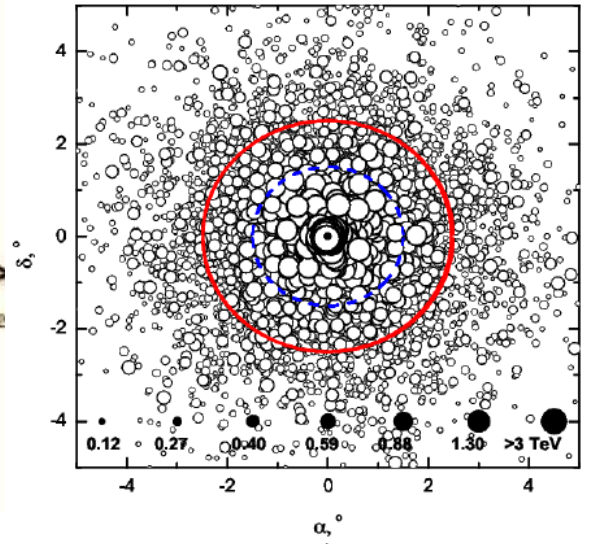


*Doro et al, Astropart Phys 43

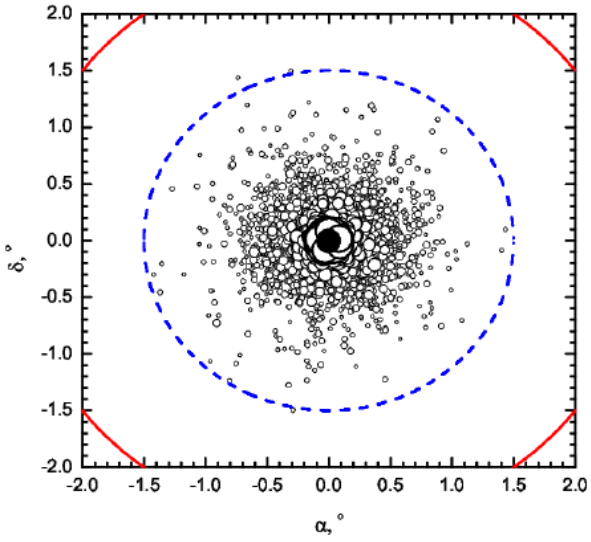
- Allows searches for ALPs in mass and coupling regions not otherwise accessible.
- Also provides a measurement of the EBL density.
- Allows inferences about first "population III" stars and the stellar formation rate, primordial black holes, and decays of exotic particles to photons in the early universe.

CTA science – Probing intergalactic magnetic fields with CTA





- Explore origin of magnetic fields in galaxies.
- Look for extended γ-ray emission and pair haloes associated with primary γ-ray source at 120 Mpc.
- Top Fig. IGMF 10^{-14} G, bottom IGMF 10^{-15} G.
- For lower fields, look for "pair echoes".



Summary

- CTA offers opportunity to study fundamental physics (WIMPs, axions, Lorentz invariance…) astrophysics (accel. of cosmic rays, extra-galactic background light, intergalactic B fields…).
- ASTRONET Science Vision and Infrastructure Roadmap 2022-2035 includes CTA as top priority new ground-based project.
- Funding in place, ERIC start this year, commissioning 2027…28.
- Liverpool contribution to SST-Cam as part of CTA-UK will ensure UK scientists have access to CTA data.