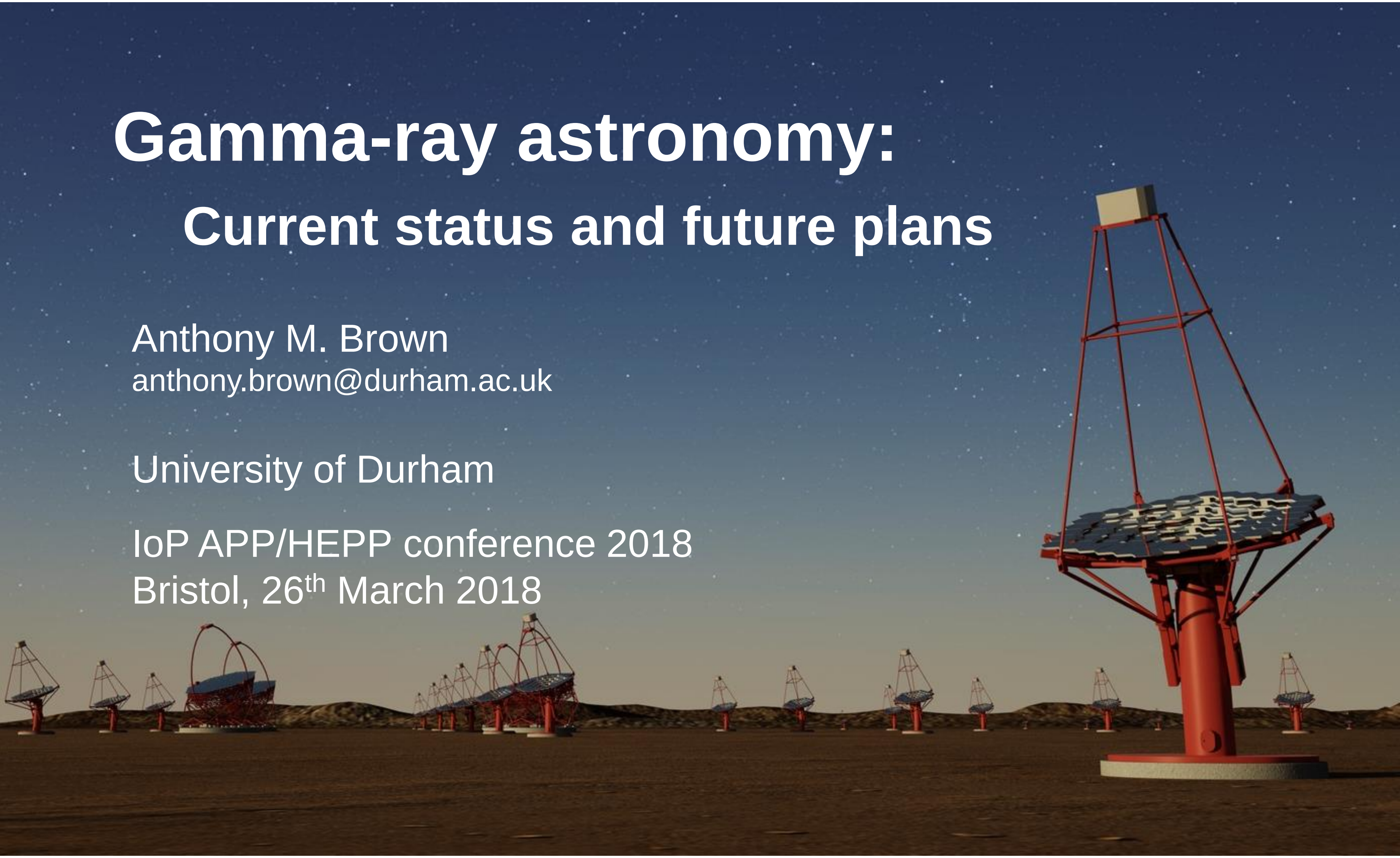

Gamma-ray astronomy:

Current status and future plans

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IoP APP/HEPP conference 2018

Bristol, 26th March 2018

For the next 25 minutes

- Where it all started.
- Why gamma-rays? - our motivation.
- Space-based gamma-ray astronomy
  - *Fermi*-LAT and how it works.
  - Some of *Fermi's* amazing results.
- Ground-based gamma-ray astronomy
  - The technique.
  - Current instruments and their stunning results
  - What is the Cherenkov Telescope Array (CTA)?
  - The challenges CTA presents us with…

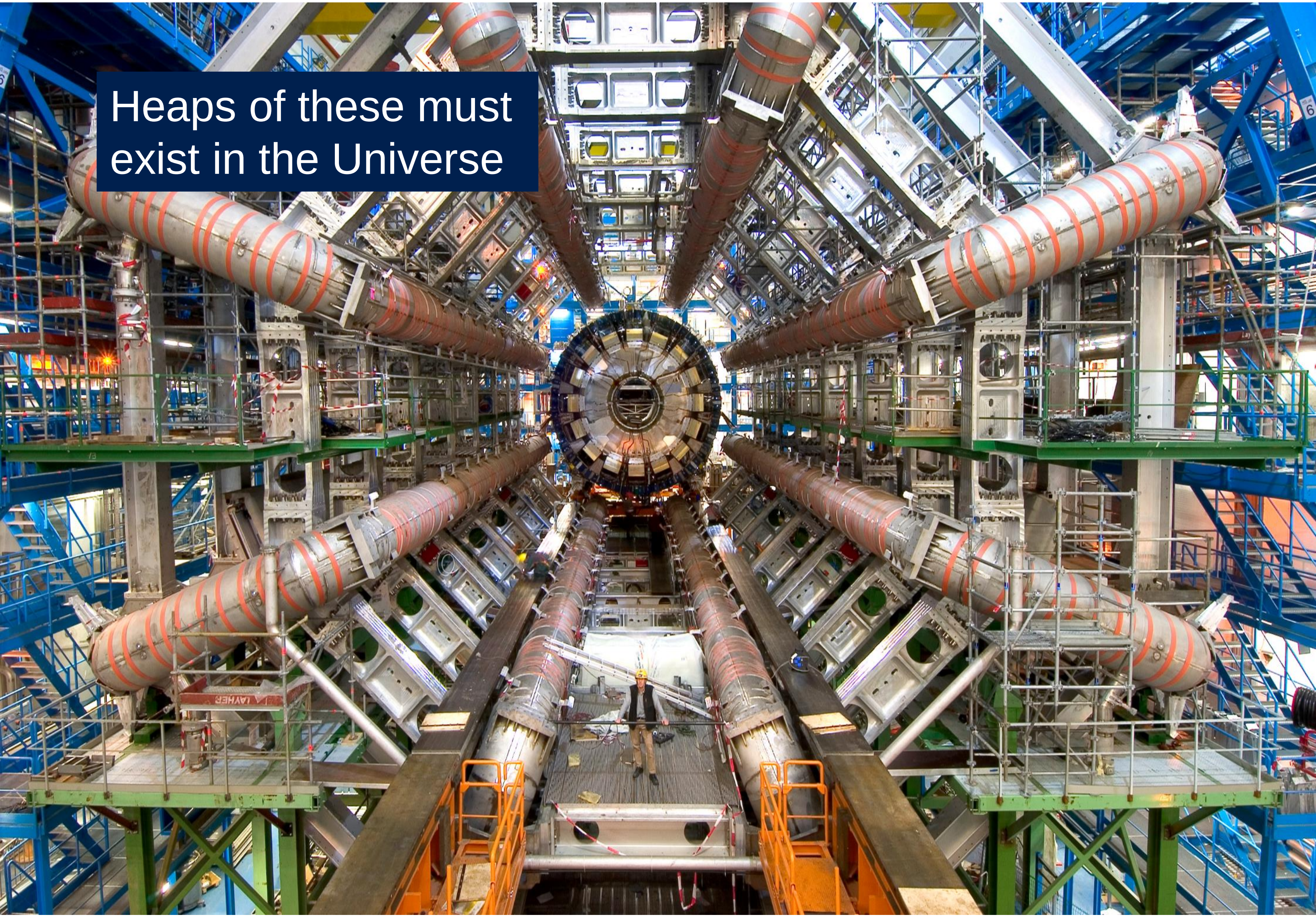
…And how we aim to solve them!

It started with cosmic rays...

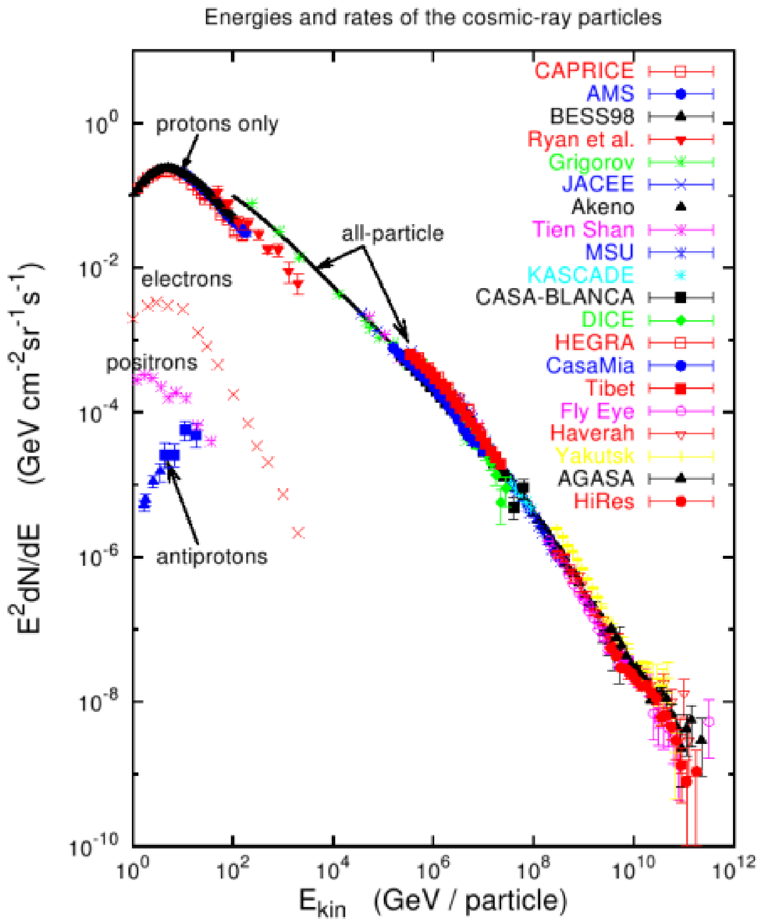
1909 Wulf
1911 Pacini
1912 Hess

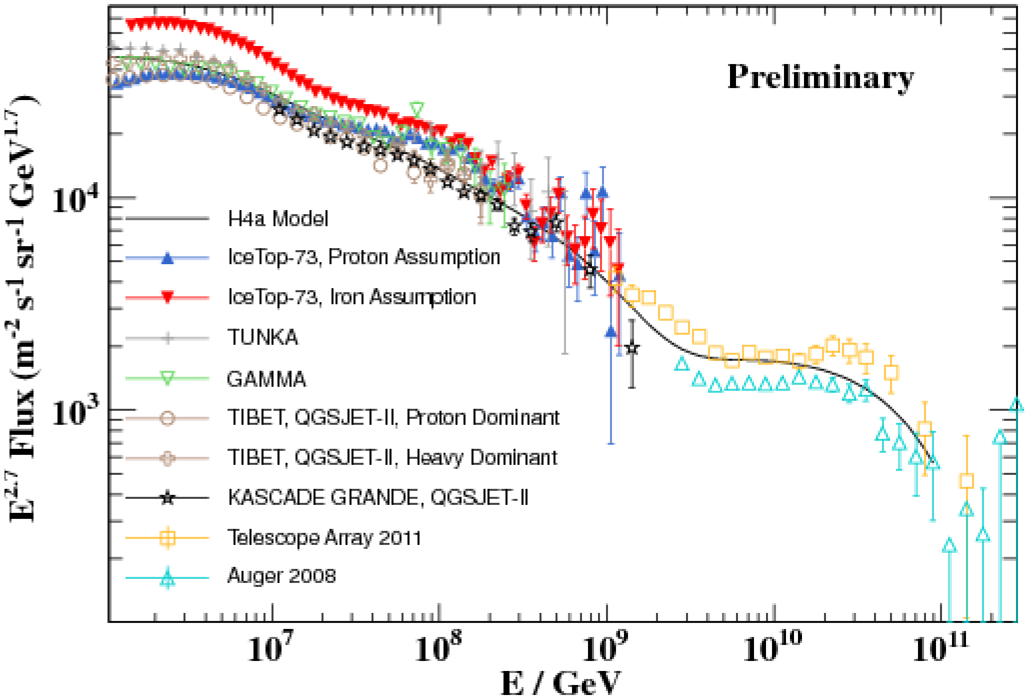
All measured variation in ionization as a function of altitude

Evidence pointed to a source of charged particles, some with enormous energy, outside of our atmosphere
=> Cosmic rays!


Heaps of these must exist in the Universe

Cosmic ray spectrum

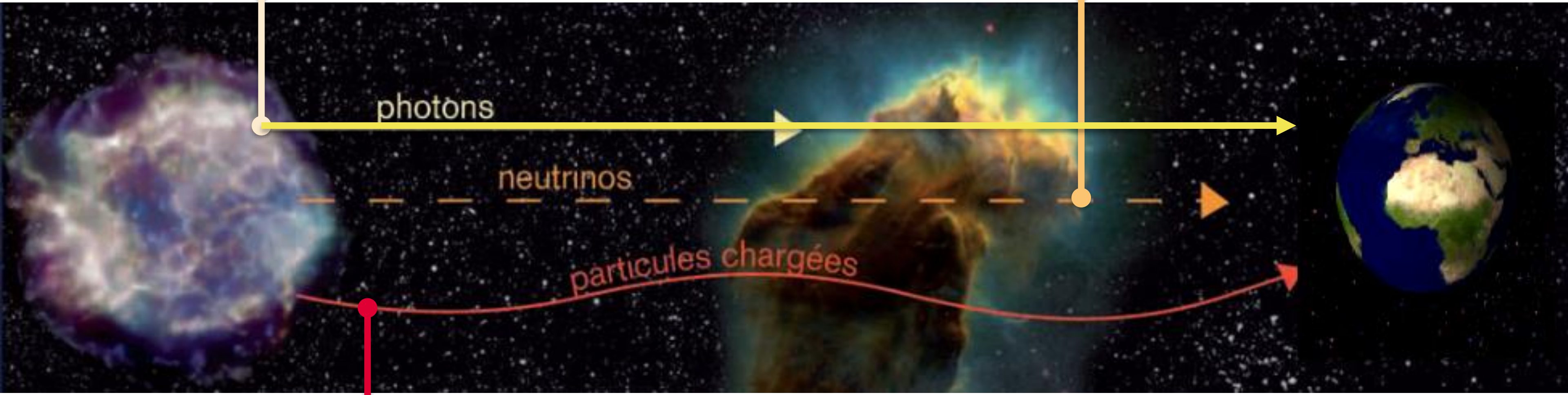




Finding the source of CRs

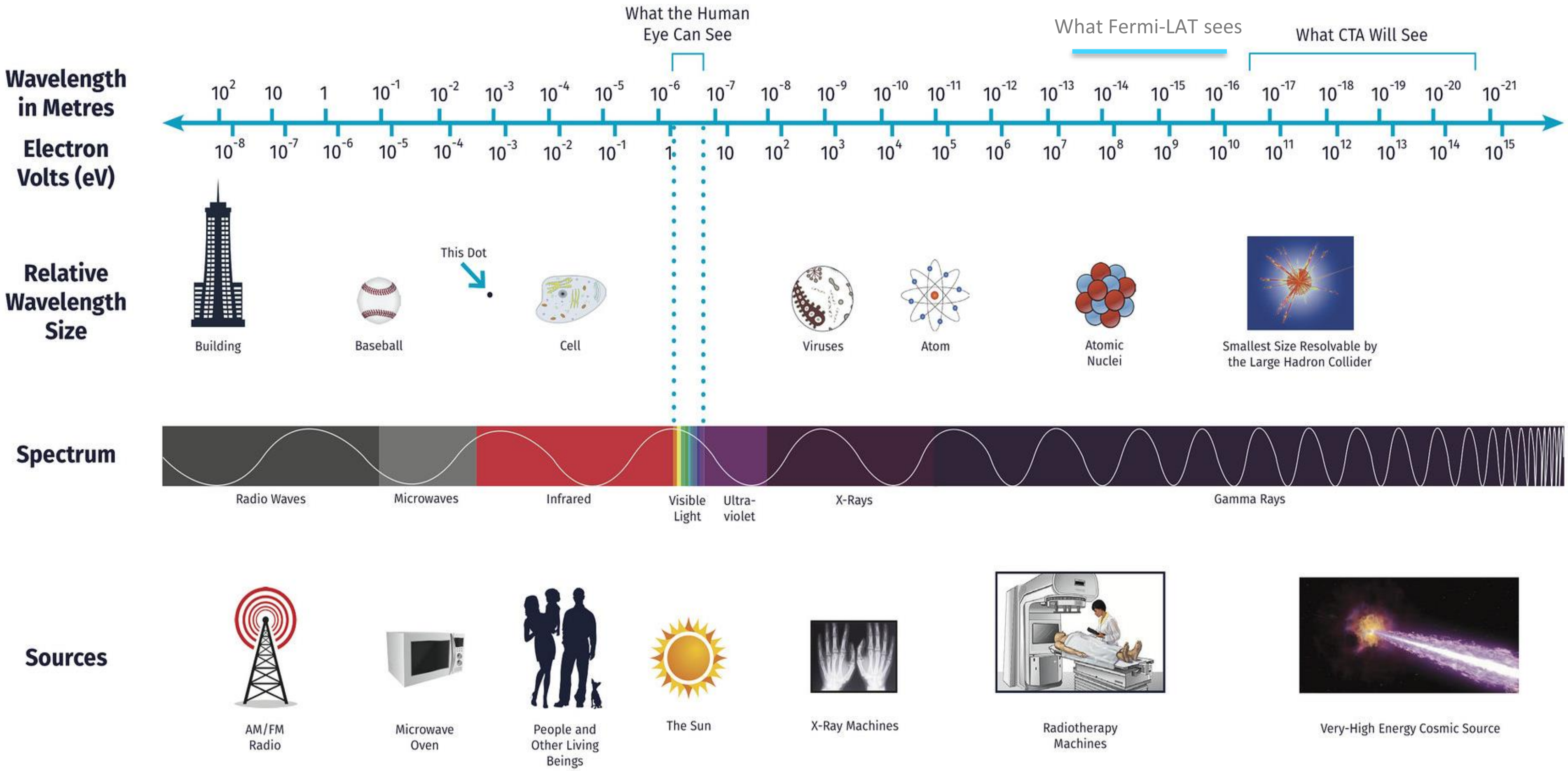
Gamma-rays travel from the CR source and you don't need a cubic kilometre of Antarctic ice to detect an astronomical signal

Neutrinos rarely interact with stuff, so they are difficult to actually detect

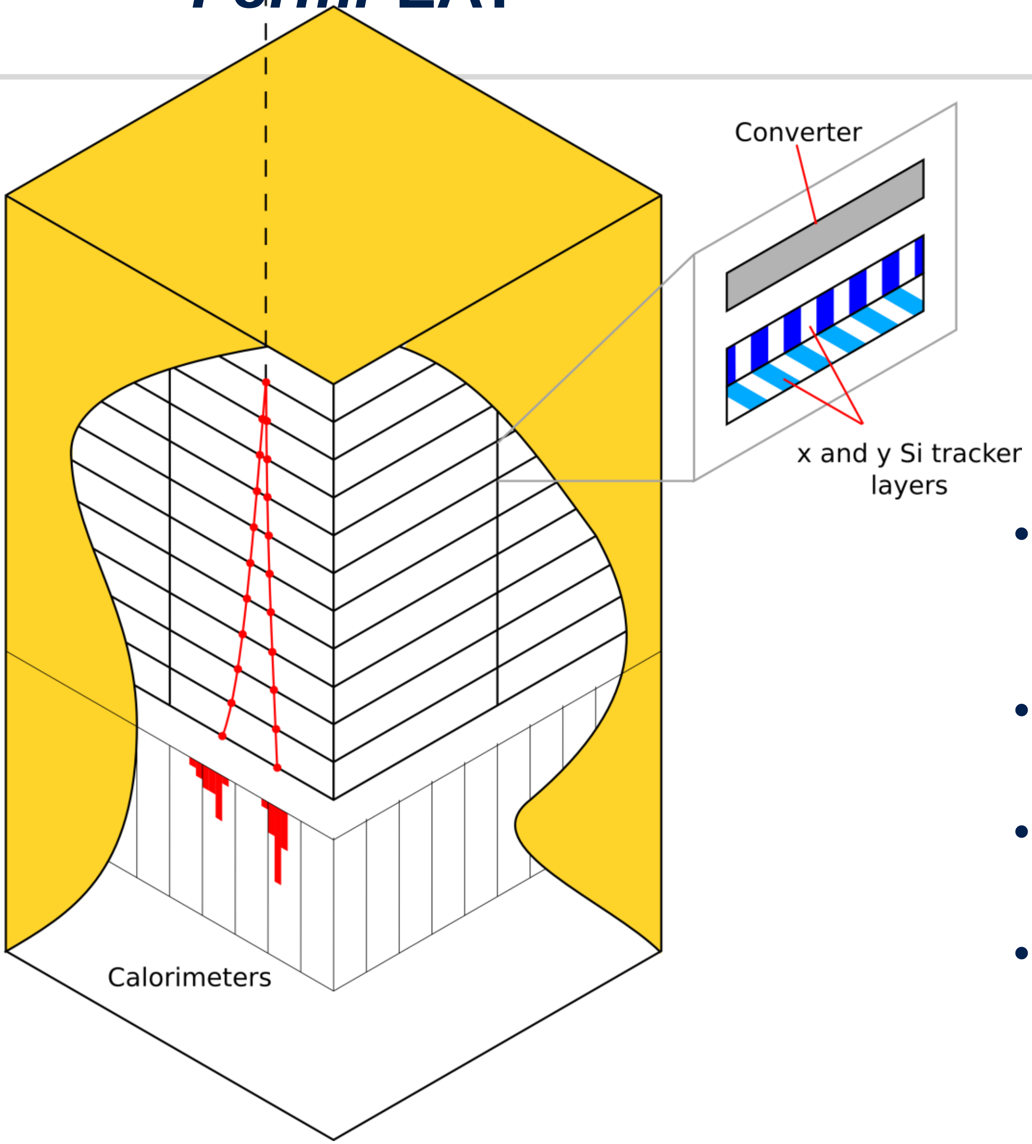


Charged particles' paths are bent by magnetic fields

Gamma-ray astronomy



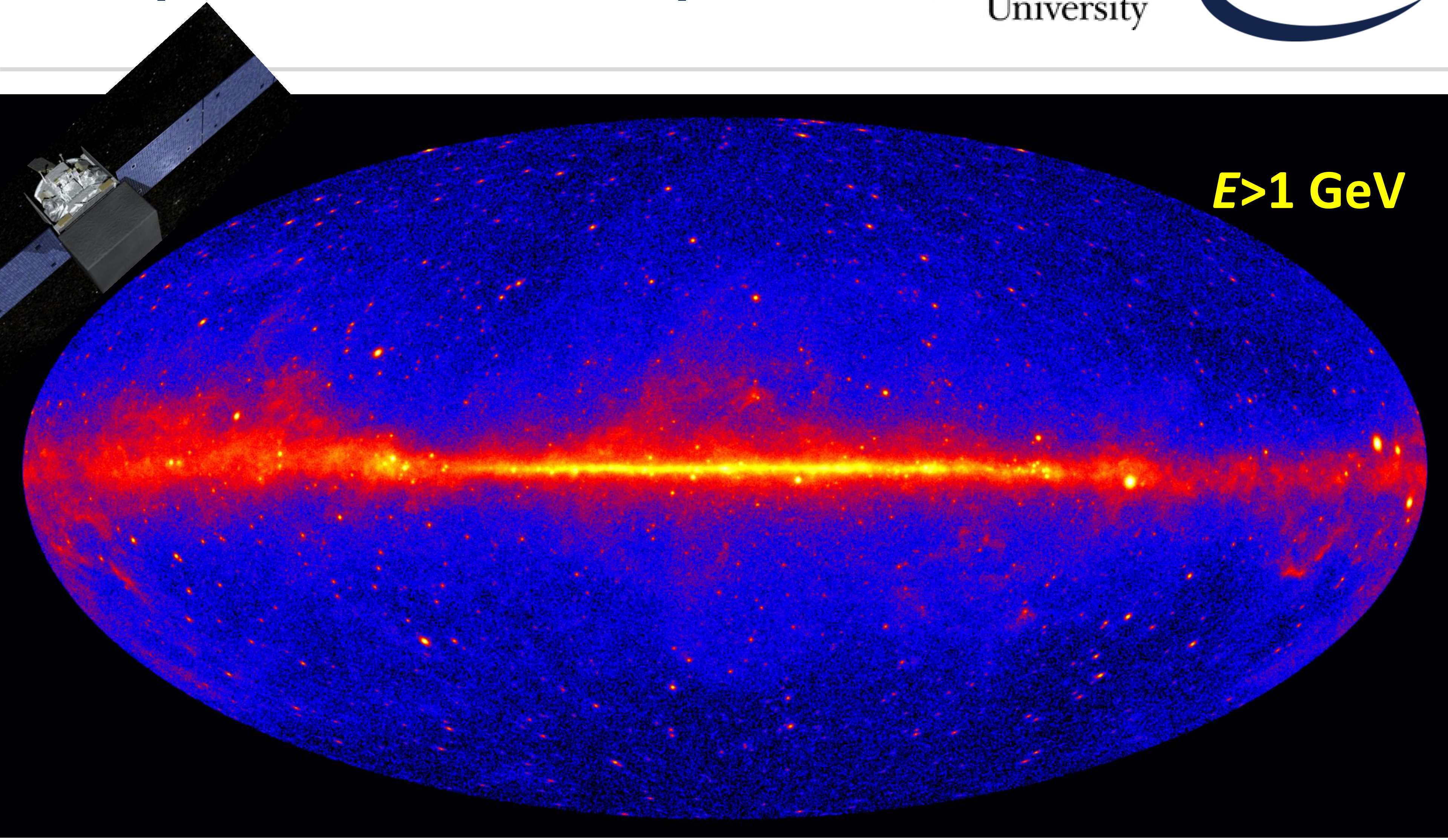
Space-based telescope: *Fermi*-LAT



Essentially the LAT detector is a particle physics detector in space.

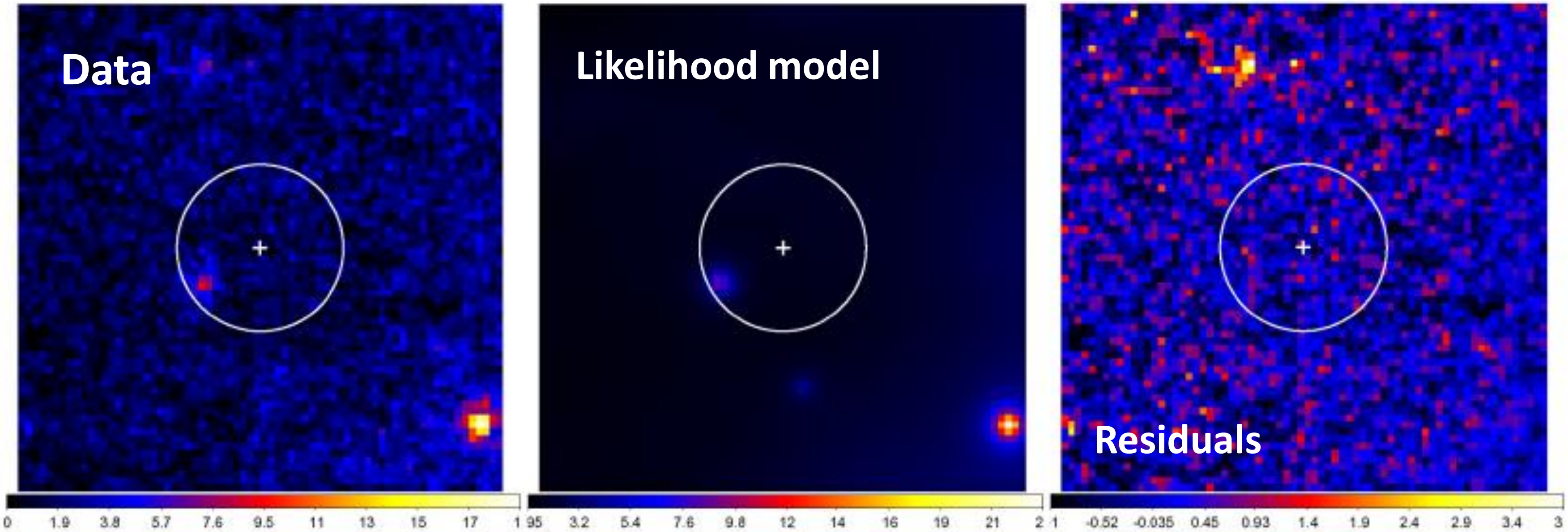
- Doesn't observe the gamma-rays directly, just the by-products of their absorption.
- Studies 60-2000 MeV photons
- 0.8 deg ang. Res. Above 1 GeV
- LAT scans the sky every 3 hours (for the last 9.5 years)

Space-based telescopes



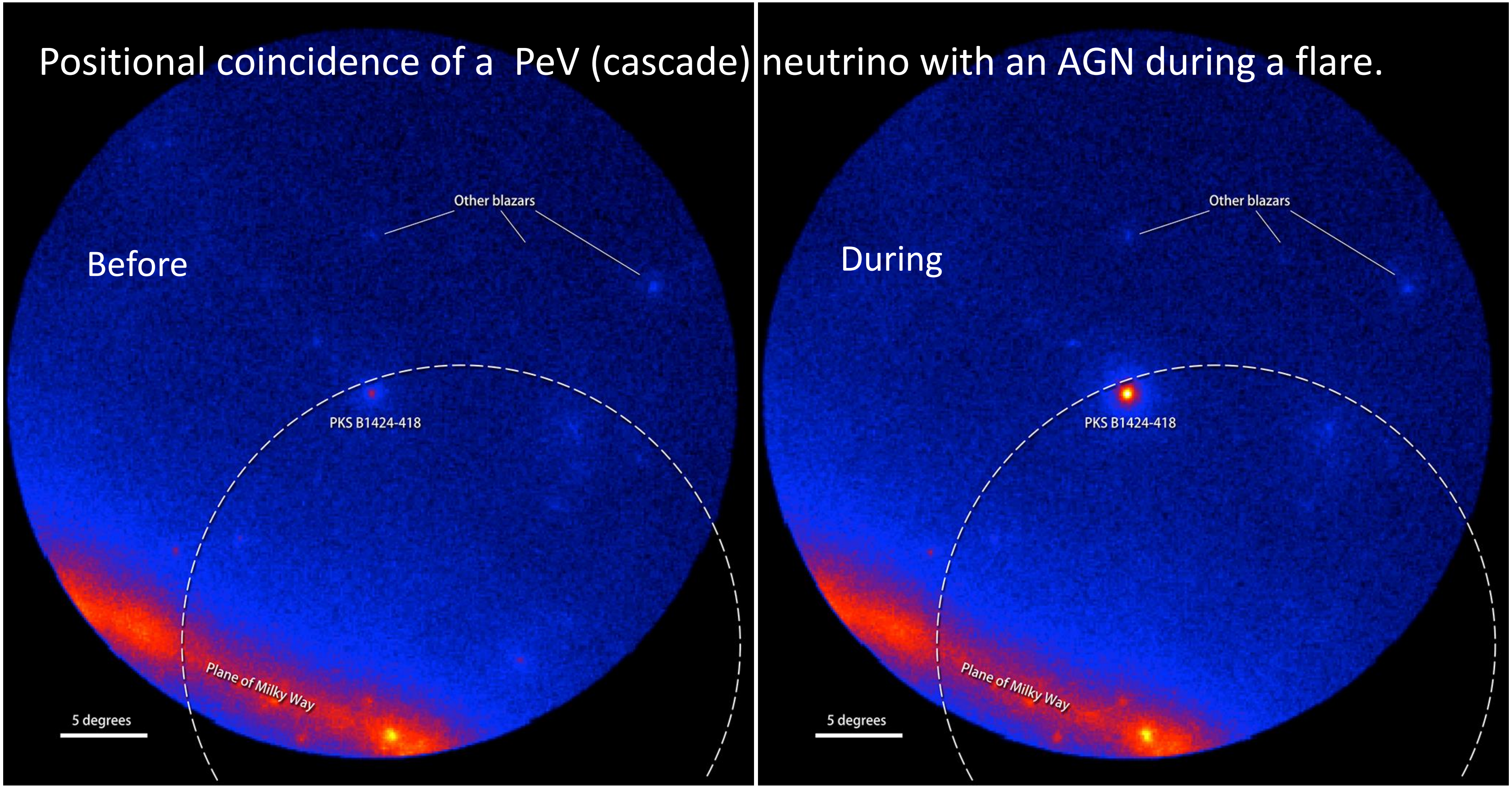
Gamma-rays & neutrinos

- The continual scanning-mode of LAT's operation allows us to search for the progenitors of transient events => ideal when searching for the sources of IceCube's astrophysical neutrinos.



Brown, Adams & Chadwick, 2015, MNRAS, 451, 323

Gamma-rays & neutrinos



Kadler et al., 2016, Nat.Phys., 12, 8

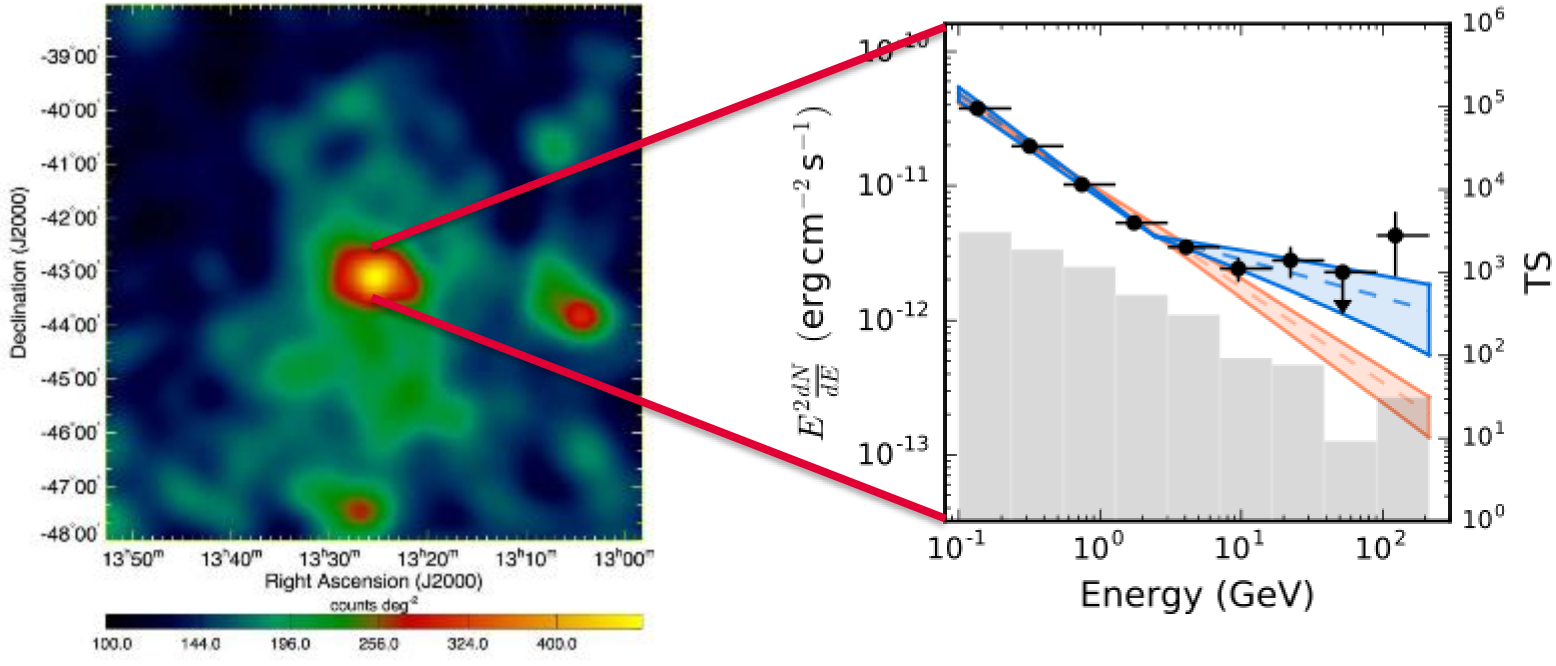
Gamma-rays & neutrinos

- September 2017 saw the **track-like** EHE neutrino spatially **and** temporally coincident with a flaring AGN, detect by both space-based and (some but not all) ground-based gamma-ray telescopes…

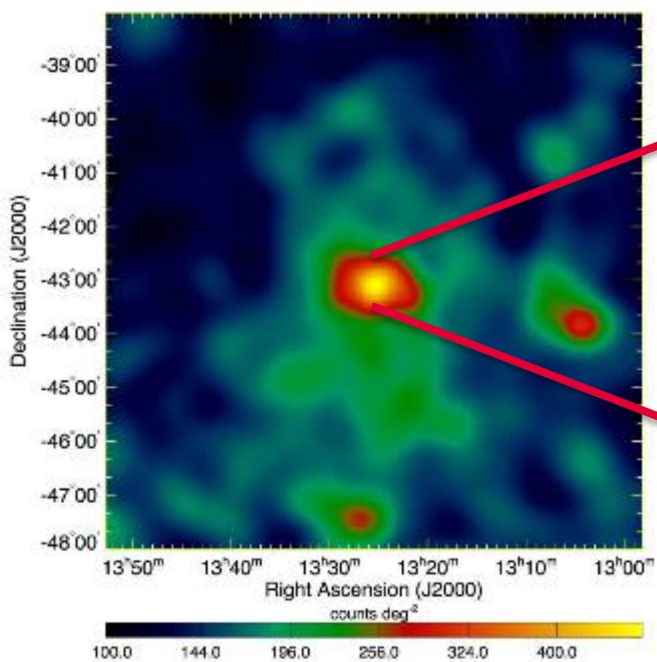
….. Publication expected soon, so watch this space!

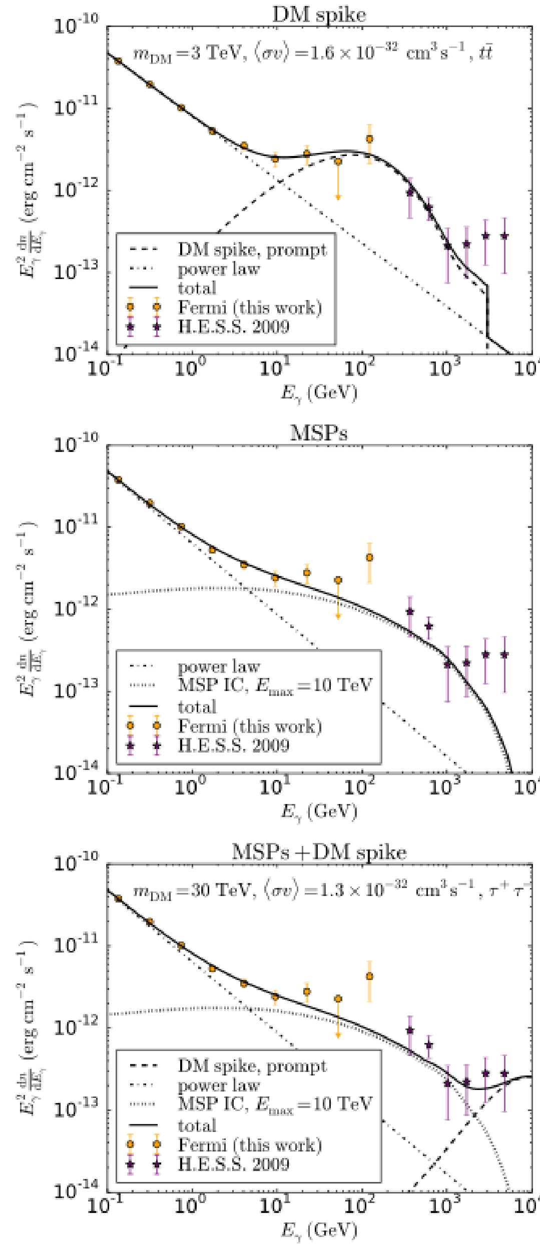
AGN: Centaurus A

- Statistically significant spectral hardening that cannot be explained with standard AGN emission models used to date.



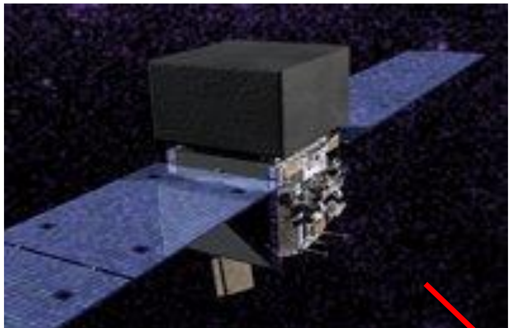
AGN + DM: Cen A





Brown et al., 2017, Phys.ReV.D, 95, 3018

However, there are LAT limitations: Effective area



1m^2

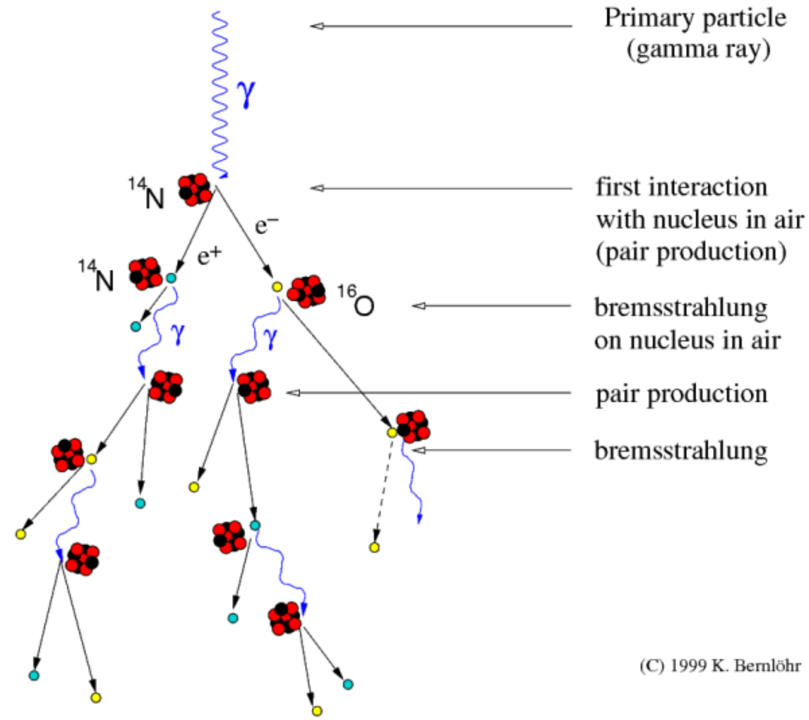
Gamma-rays are rare. And they get rarer as you go higher in gamma-ray energy.

>10^{4}m^2

Extended Air Showers

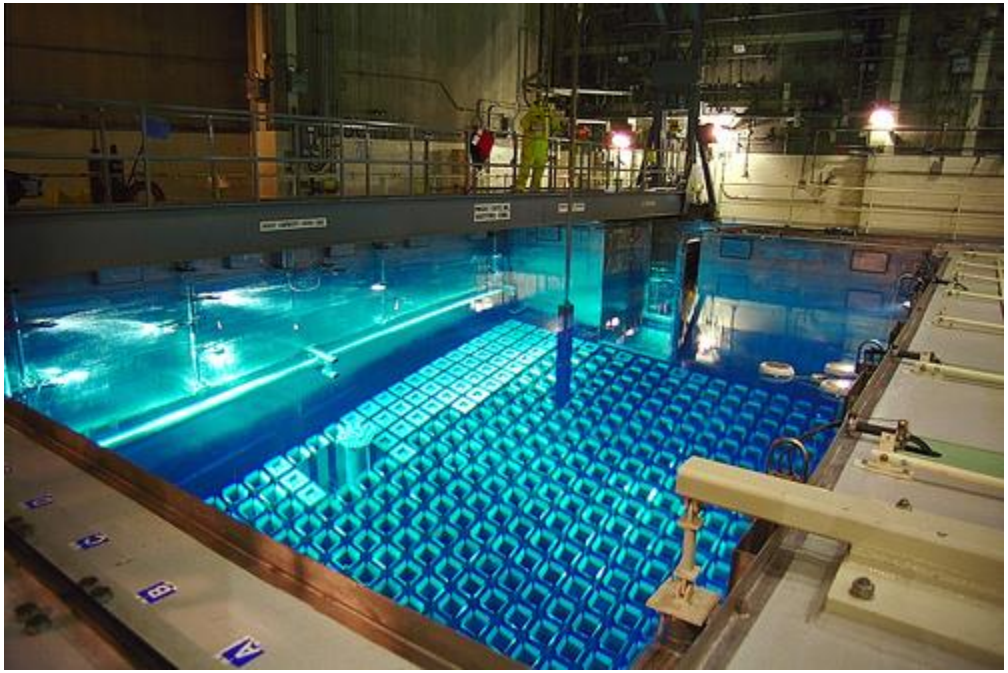
- The earth's atmosphere is opaque to gamma-rays
- The absorption of gamma-rays starts a cascade event known as an extended air shower
- Observe this air shower and we can (indirectly) observe the gamma-rays

Development of gamma–ray air showers

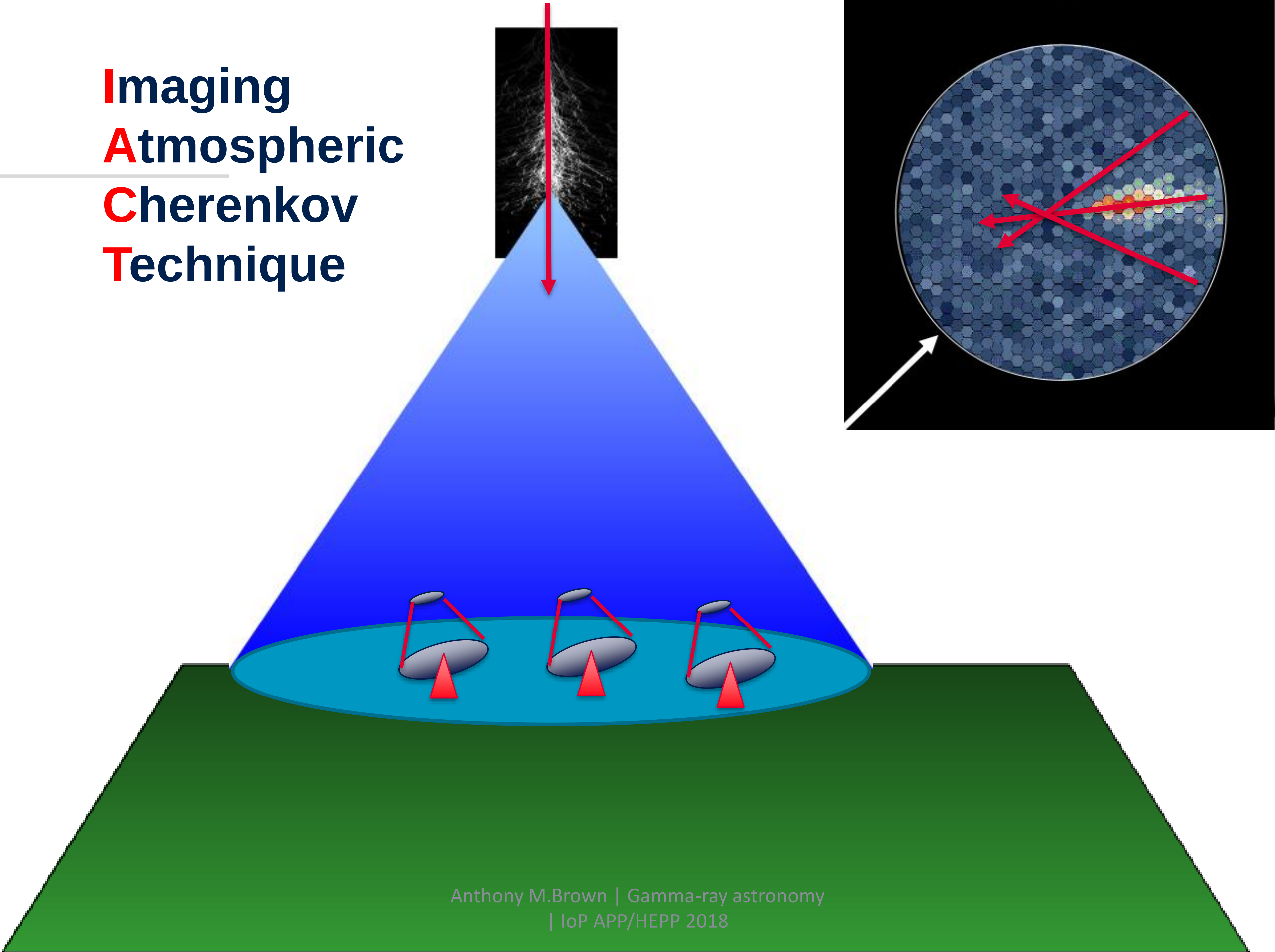


Cherenkov Radiation

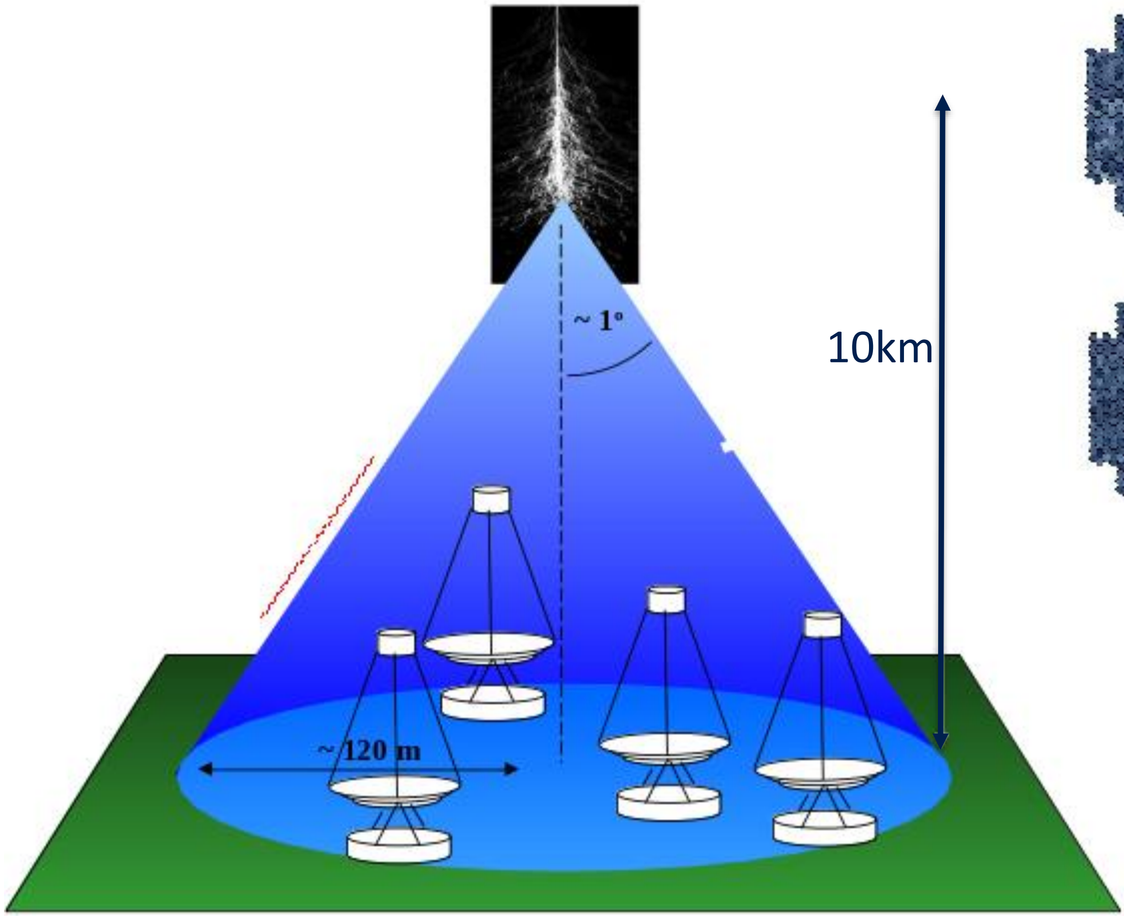
Charged particles travelling faster than the phase-velocity of light in a di-electric medium will emit light. This light is referred to Cherenkov

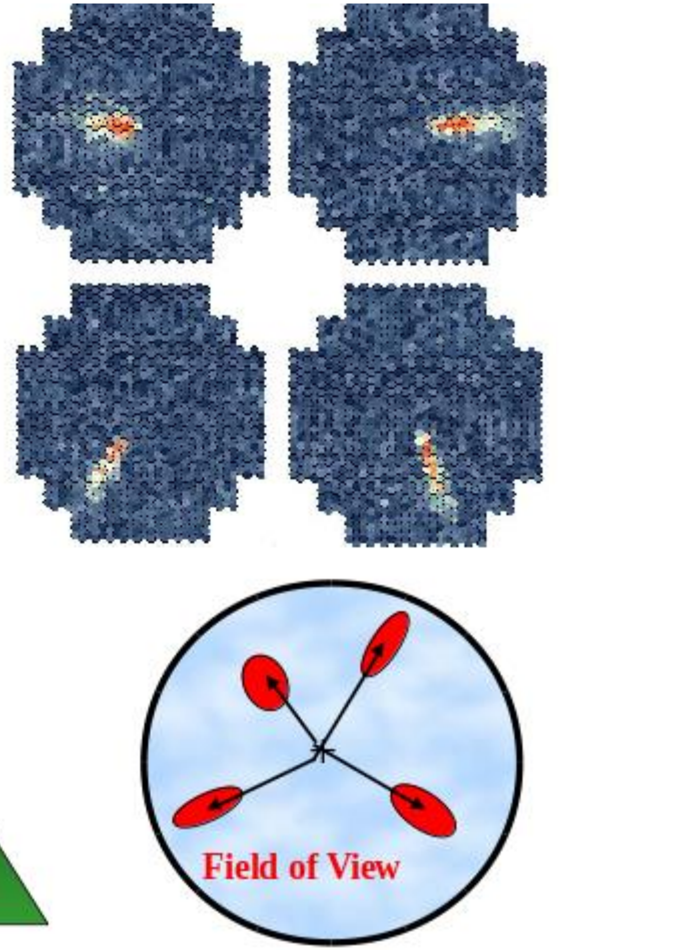


Imaging Atmospheric Cherenkov Technique

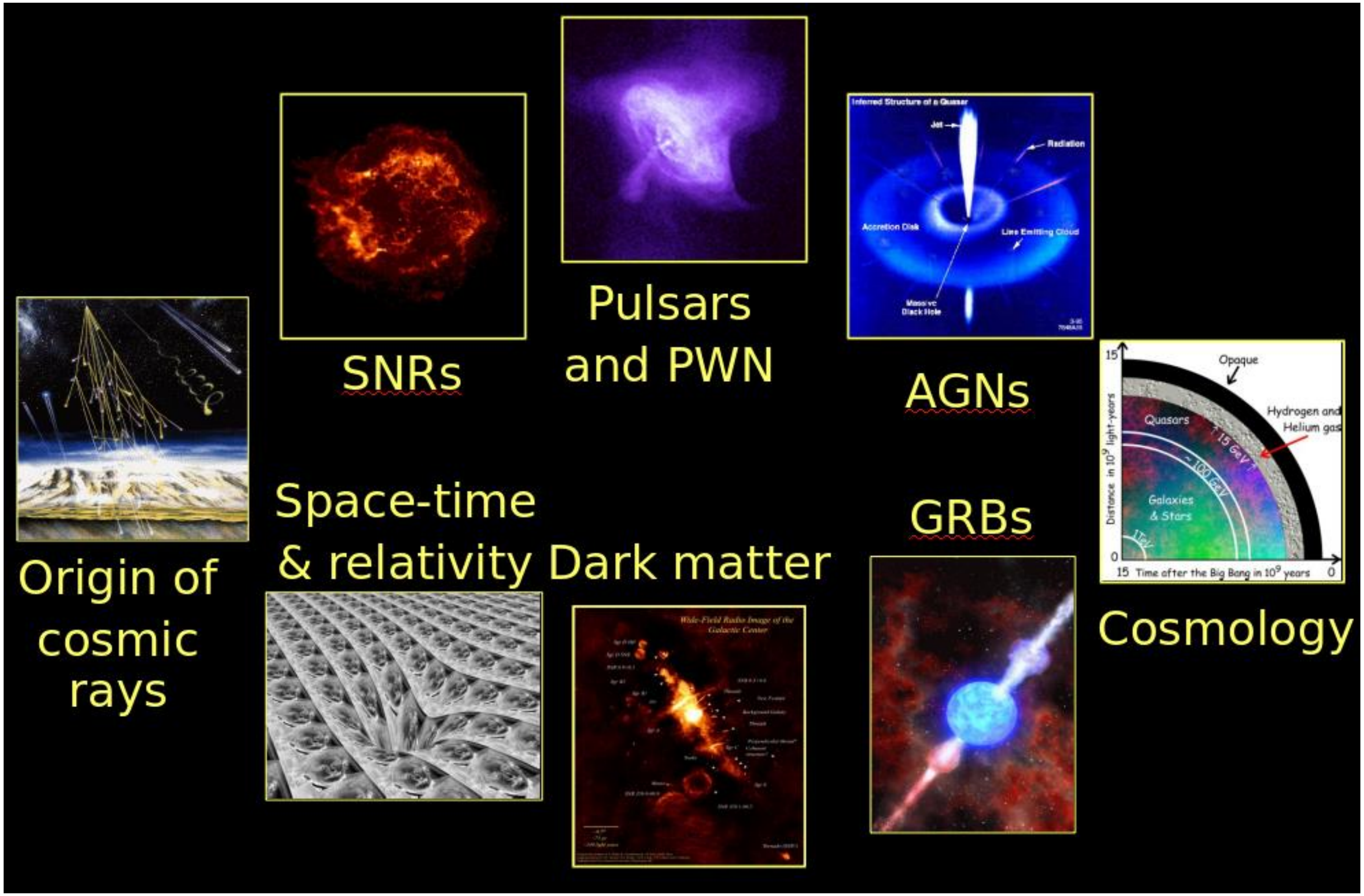


Stereoscopic IACT



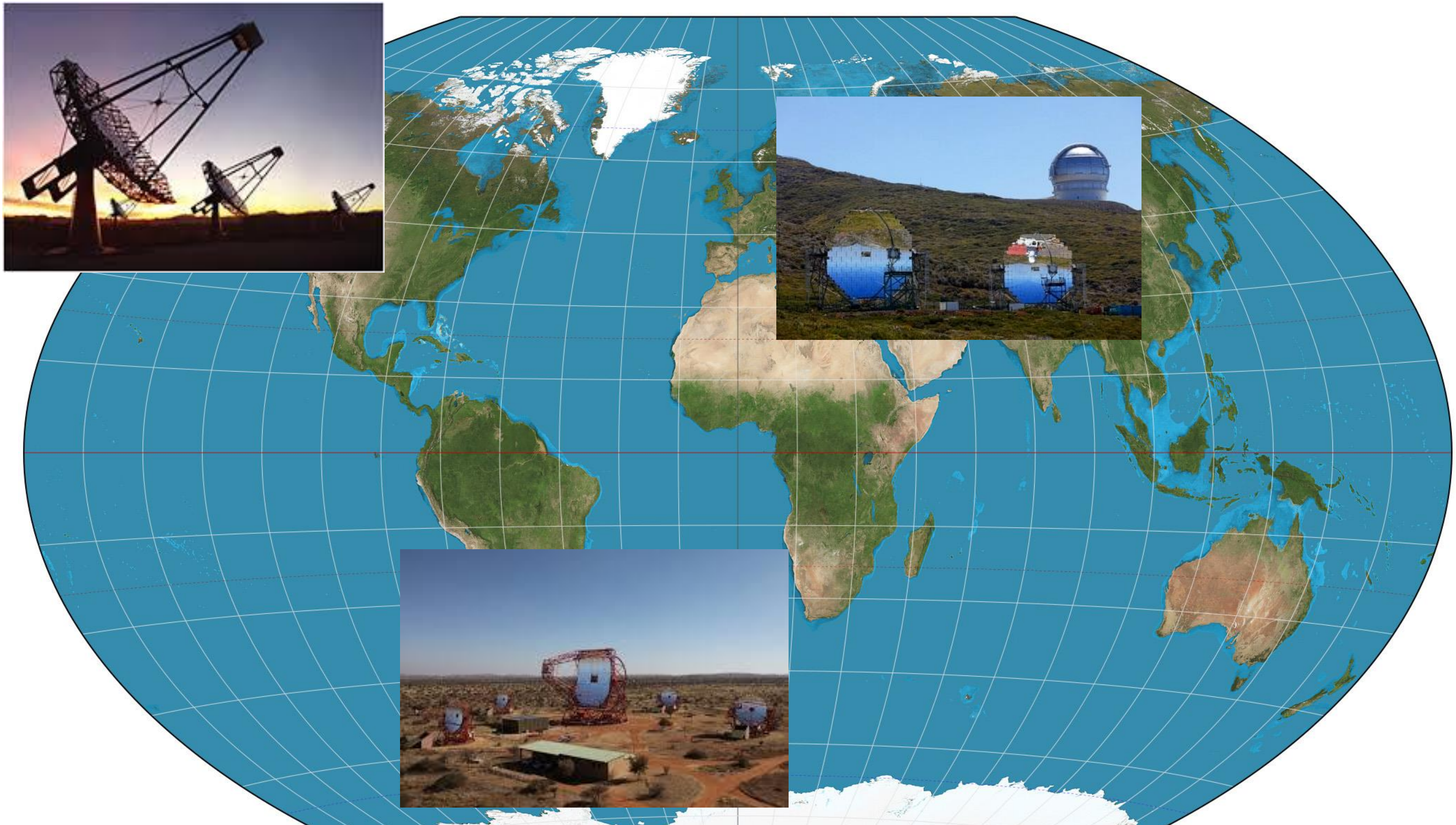


Possible Science

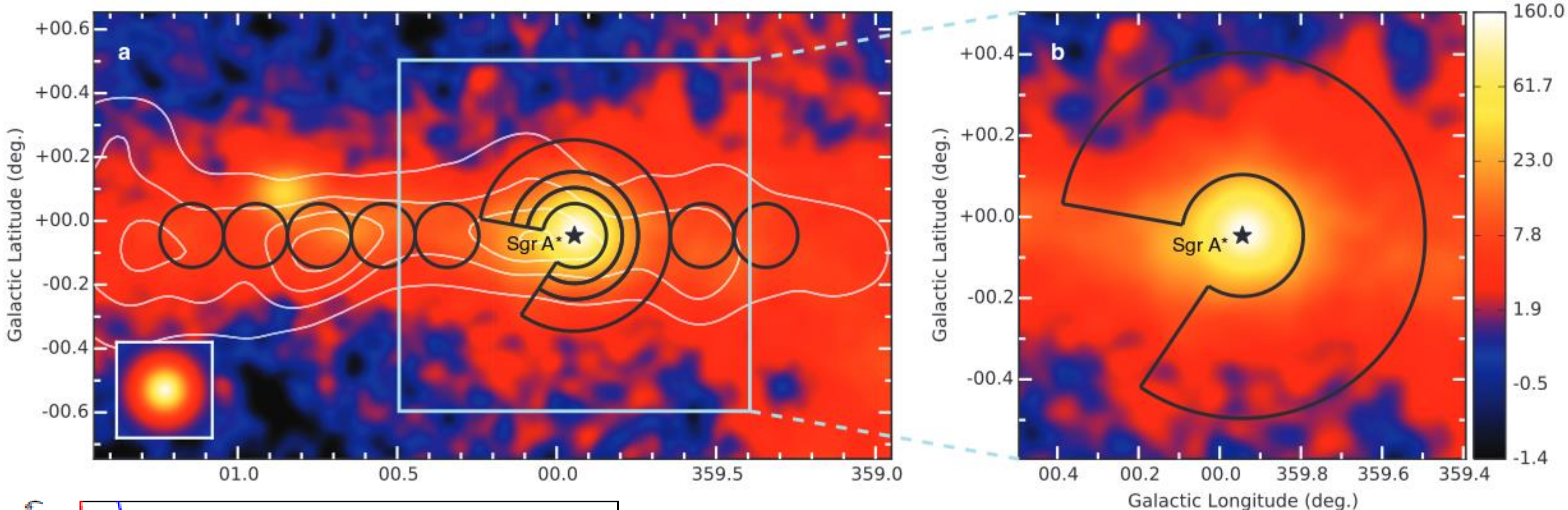


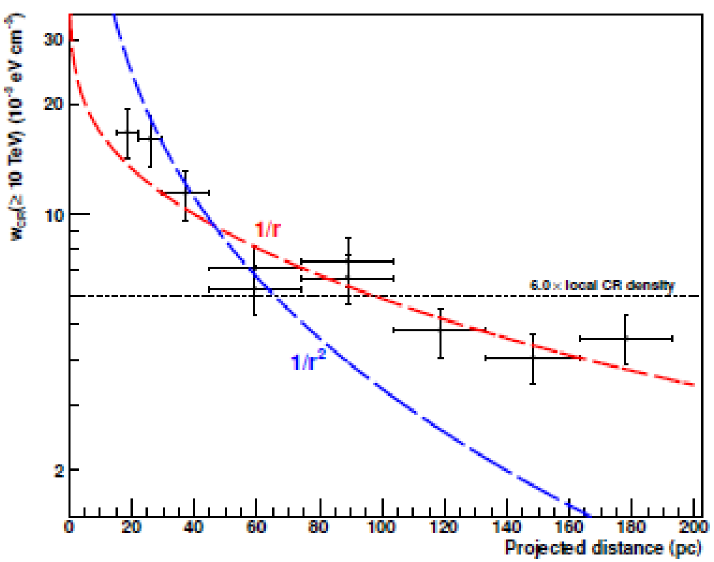
White paper on CTA Science cases can be found at arxiv:1709.07997

Current IAC Telescopes



Galactic Pevatron…





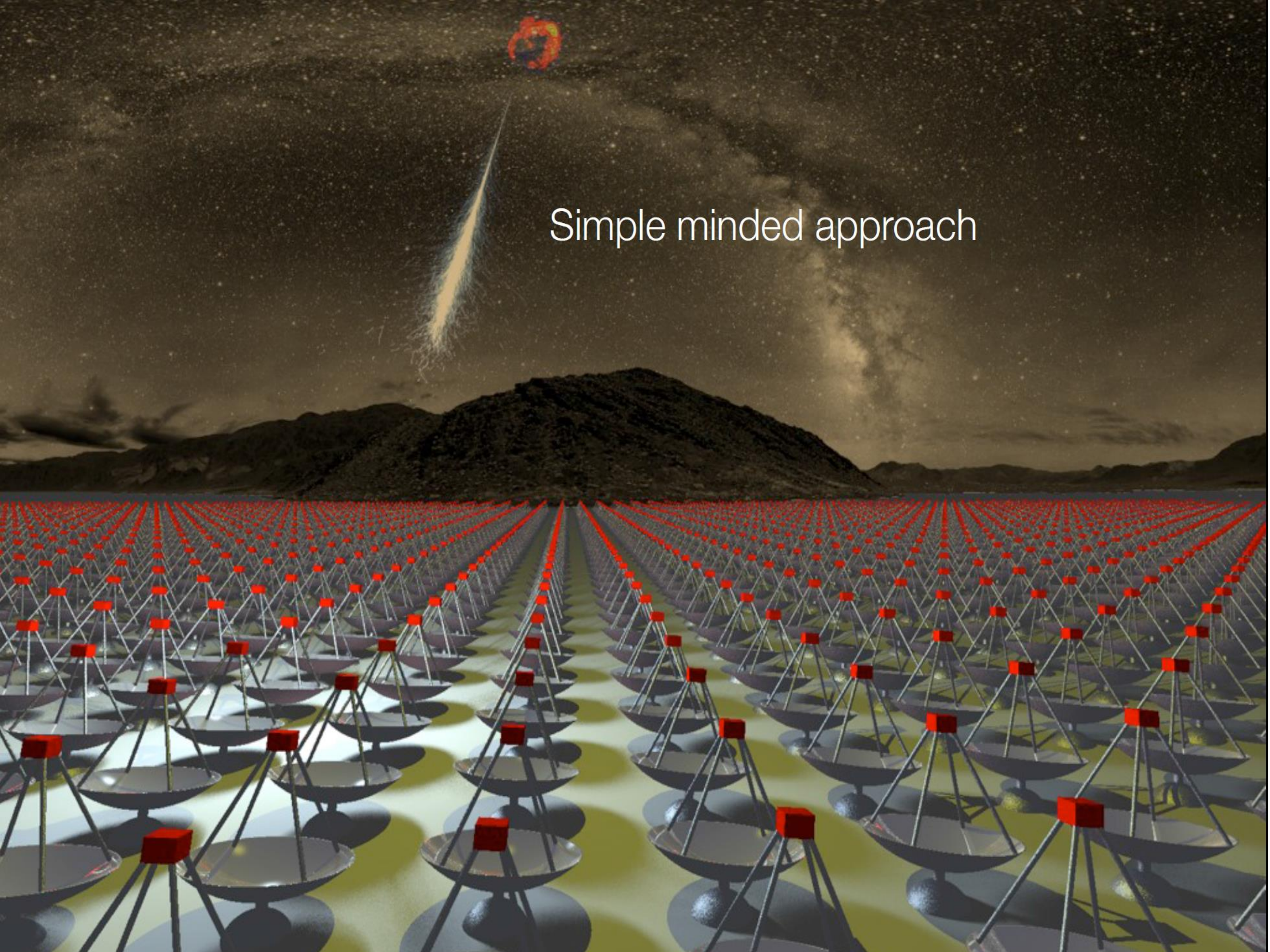
10 years of HESS observations of the Galactic centre reveals that the gamma-ray flux drops as 1/r from Sgr A*.

=> source of diffuse emission is due to persistent CR emission from SgrA*

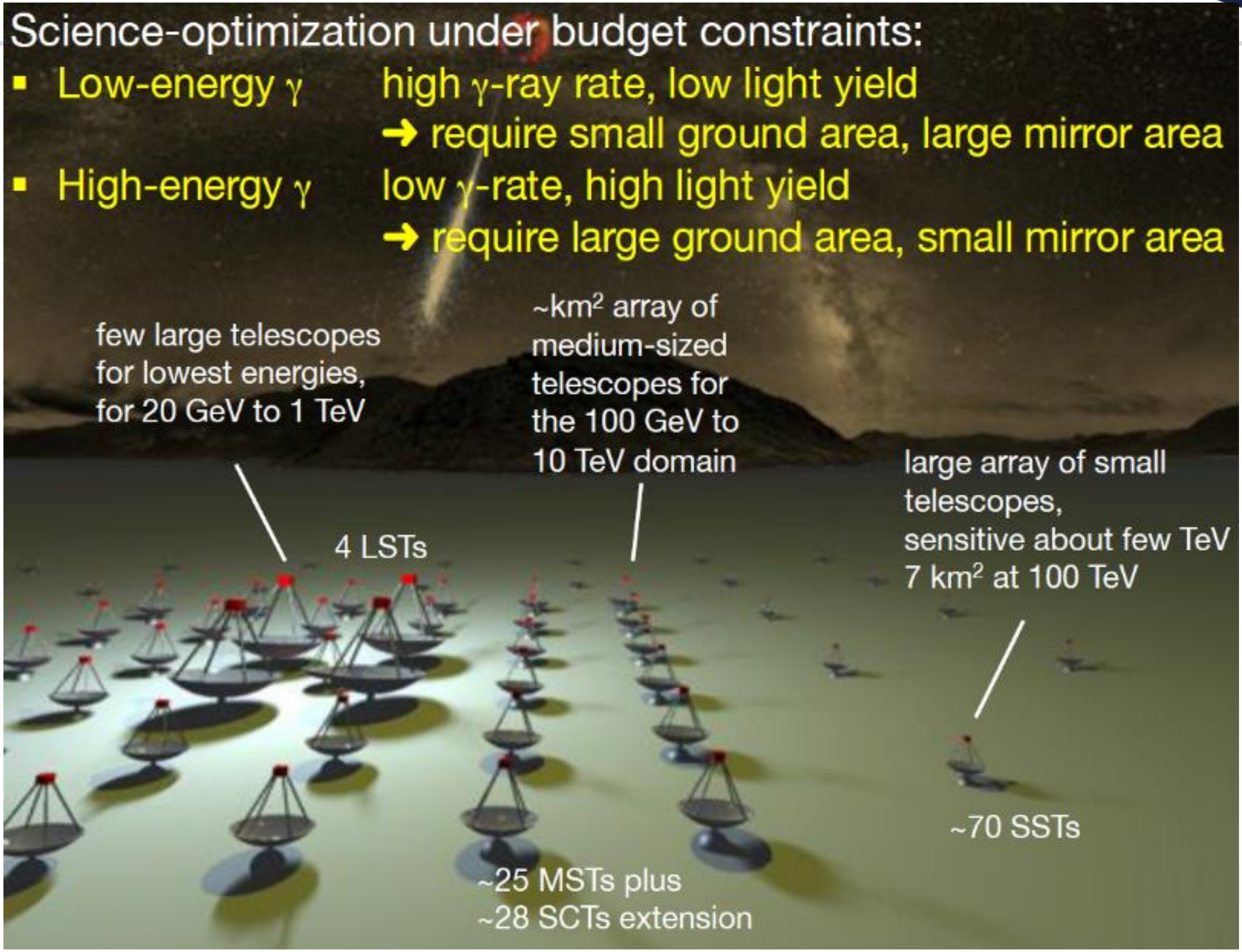
(HESS collab., 2016, Nature, 531, 476)

The next big step

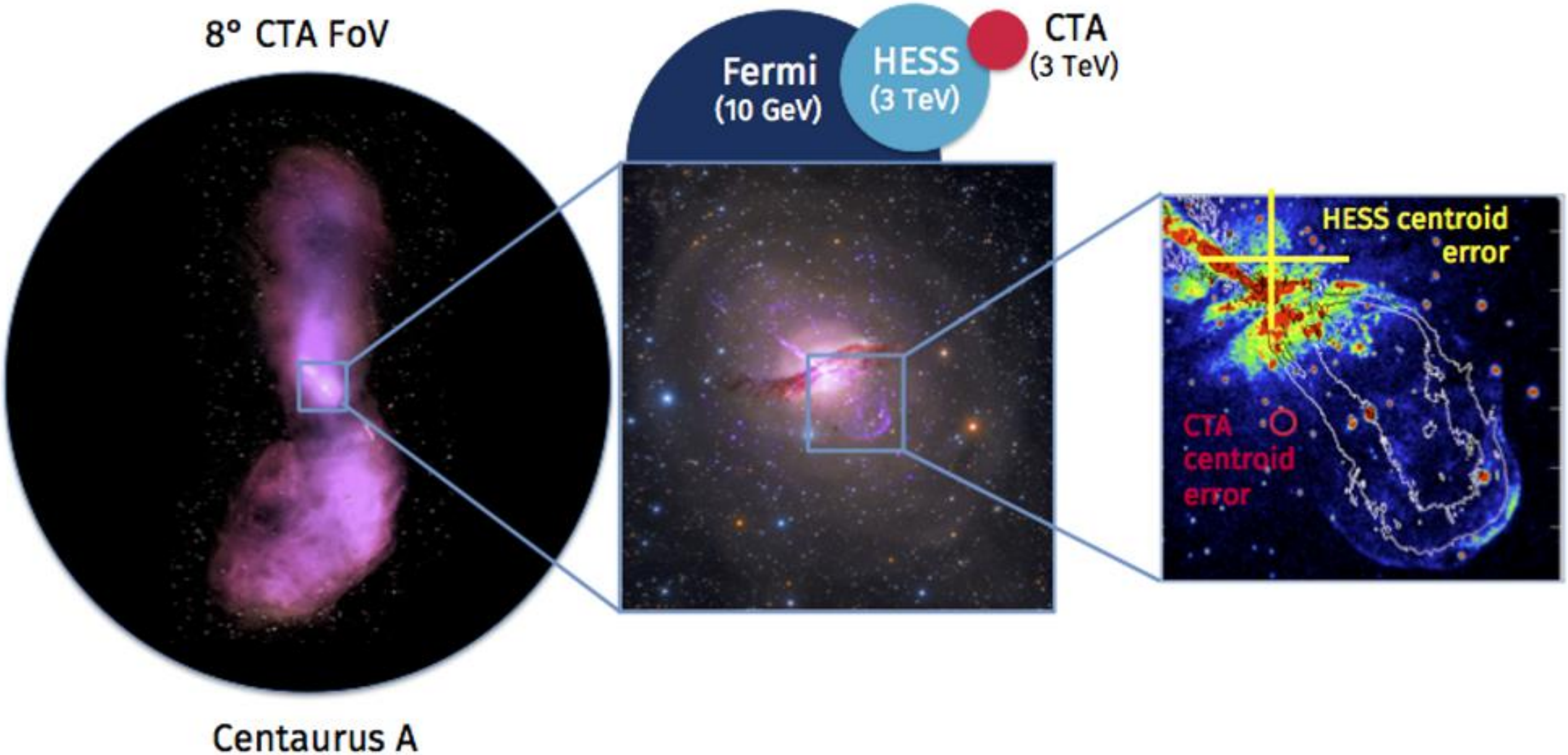
- The current generation of ground-based gamma-ray telescopes have been operating >15 years, time to think about the next step….
- We set ourselves the goals of
  - An order of magnitude improvement in performance
  - A larger energy range (lower threshold and higher maximum)
  - All sky coverage
  - Observatory operation, ie, open to a large community of astronomers, not just those in CTA.


Simple minded approach

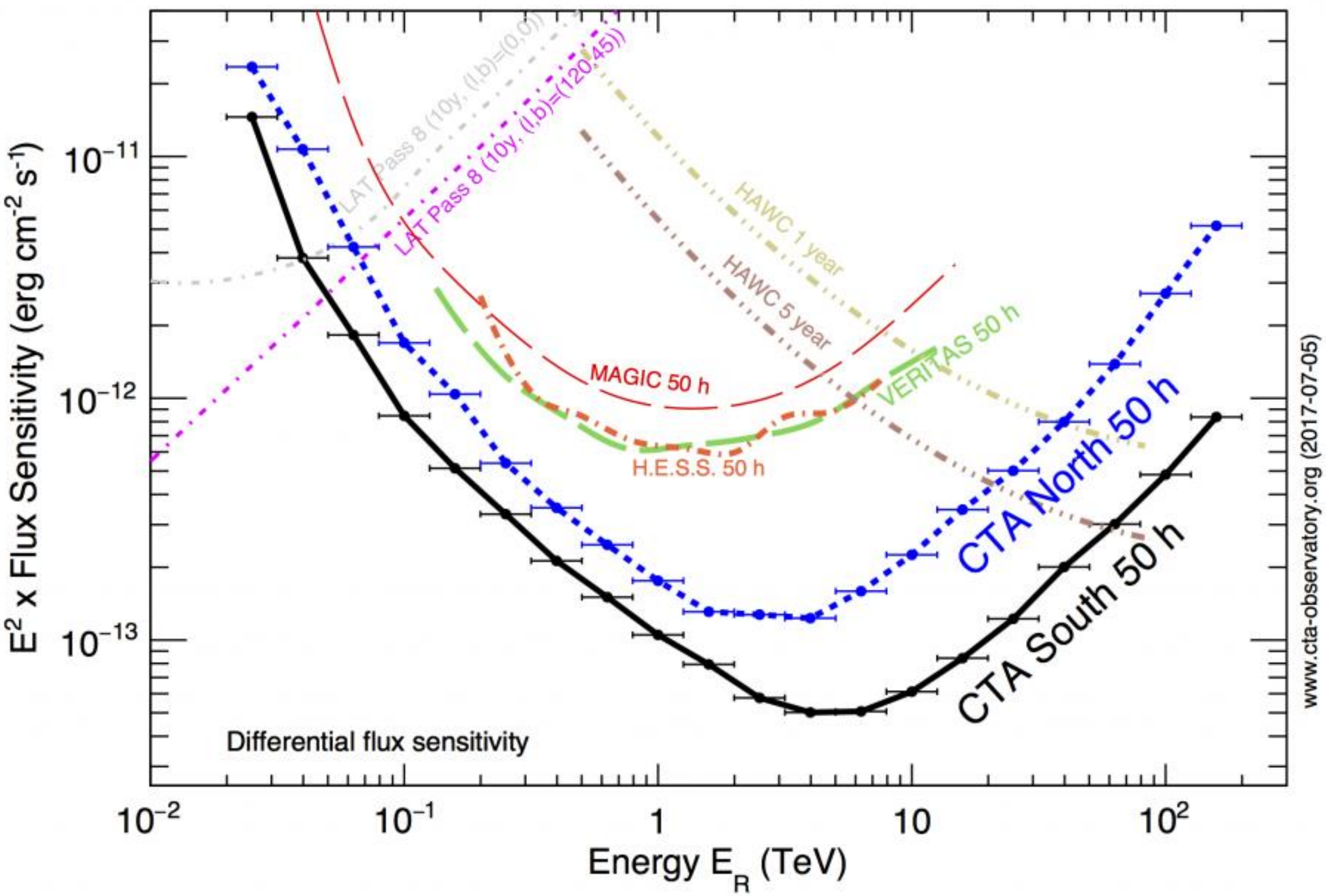
The Cherenkov Telescope Array



CTA Angular Resolution

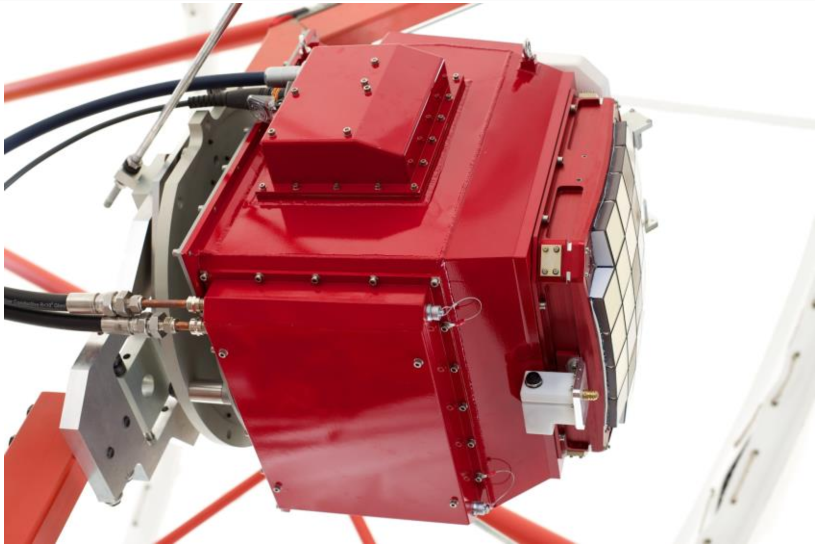


CTA Sensitivity

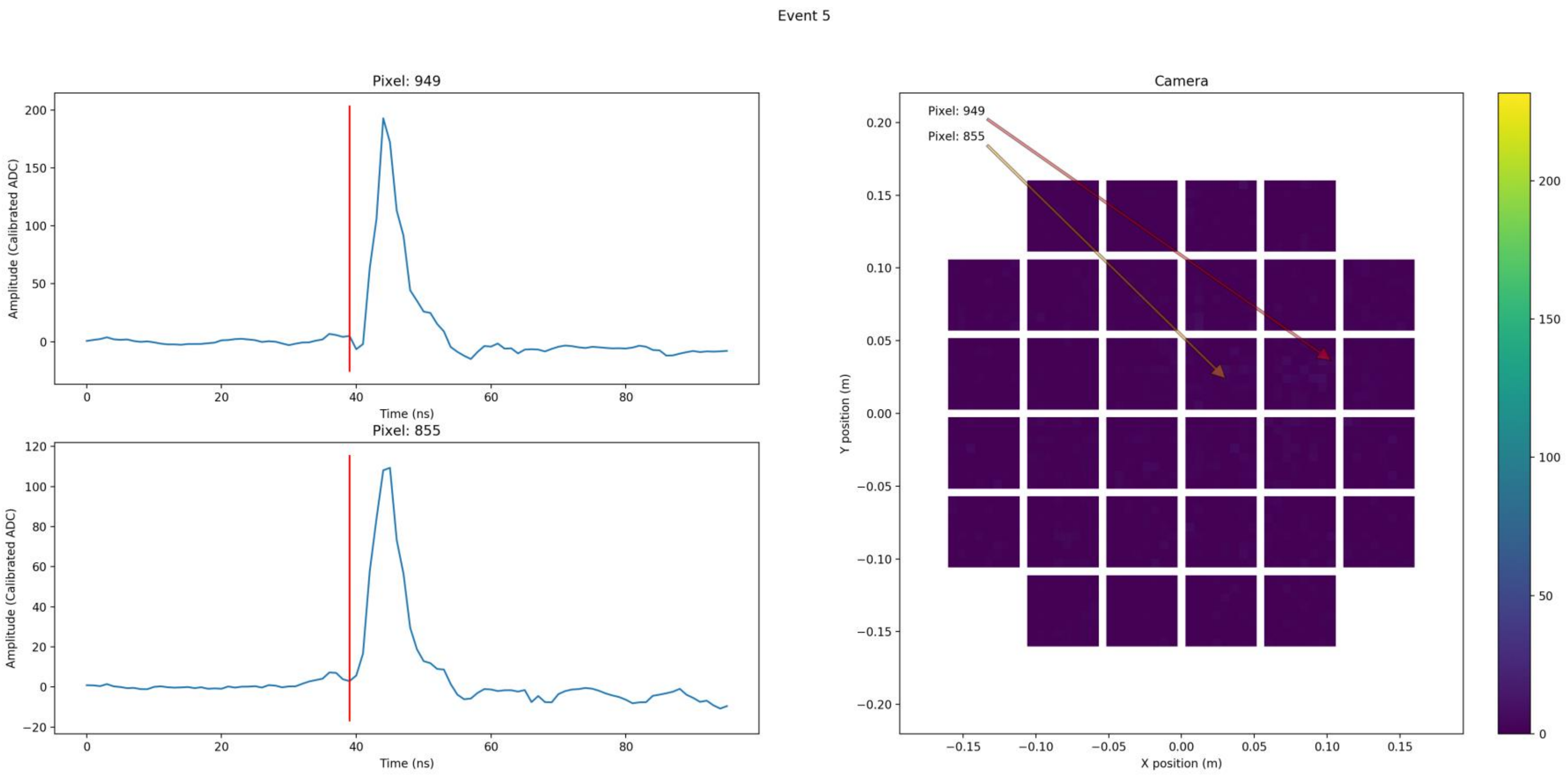


UK contribution: SSTs

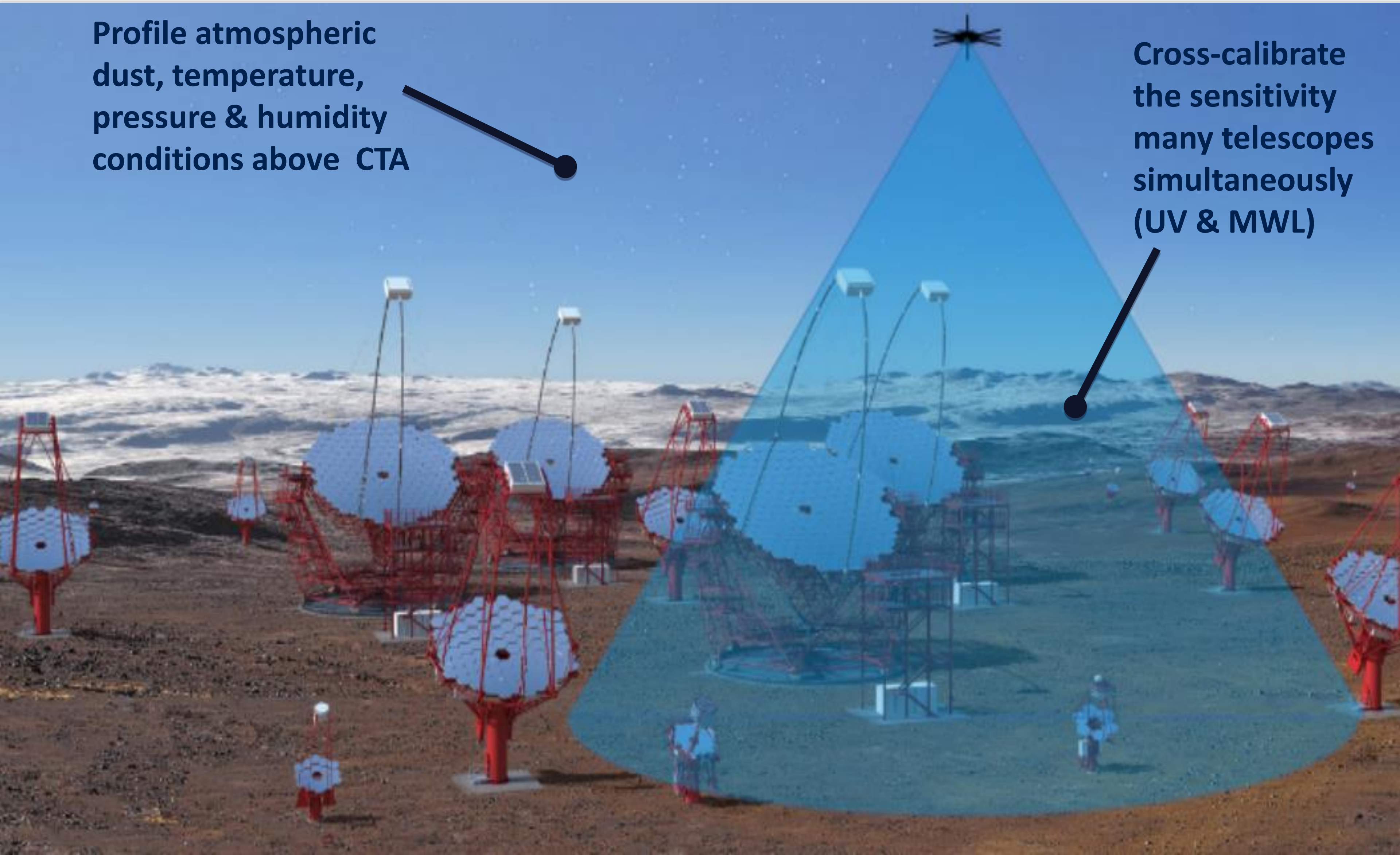
- Expect ~70 on southern site
- GCT is a dual mirror SST prototype
- British (+ collaborators) contribution is a dual-mirror telescope called the GCT
  - Primary hardware effort (Durham, Leicester, Liverpool, Oxford) is on the camera plus some work on mirror design
  - Scientific interest in Edinburgh, Hertfordshire, KCL, Liverpool John Moores, Nottingham, Sheffield & Southampton



First light for CTA

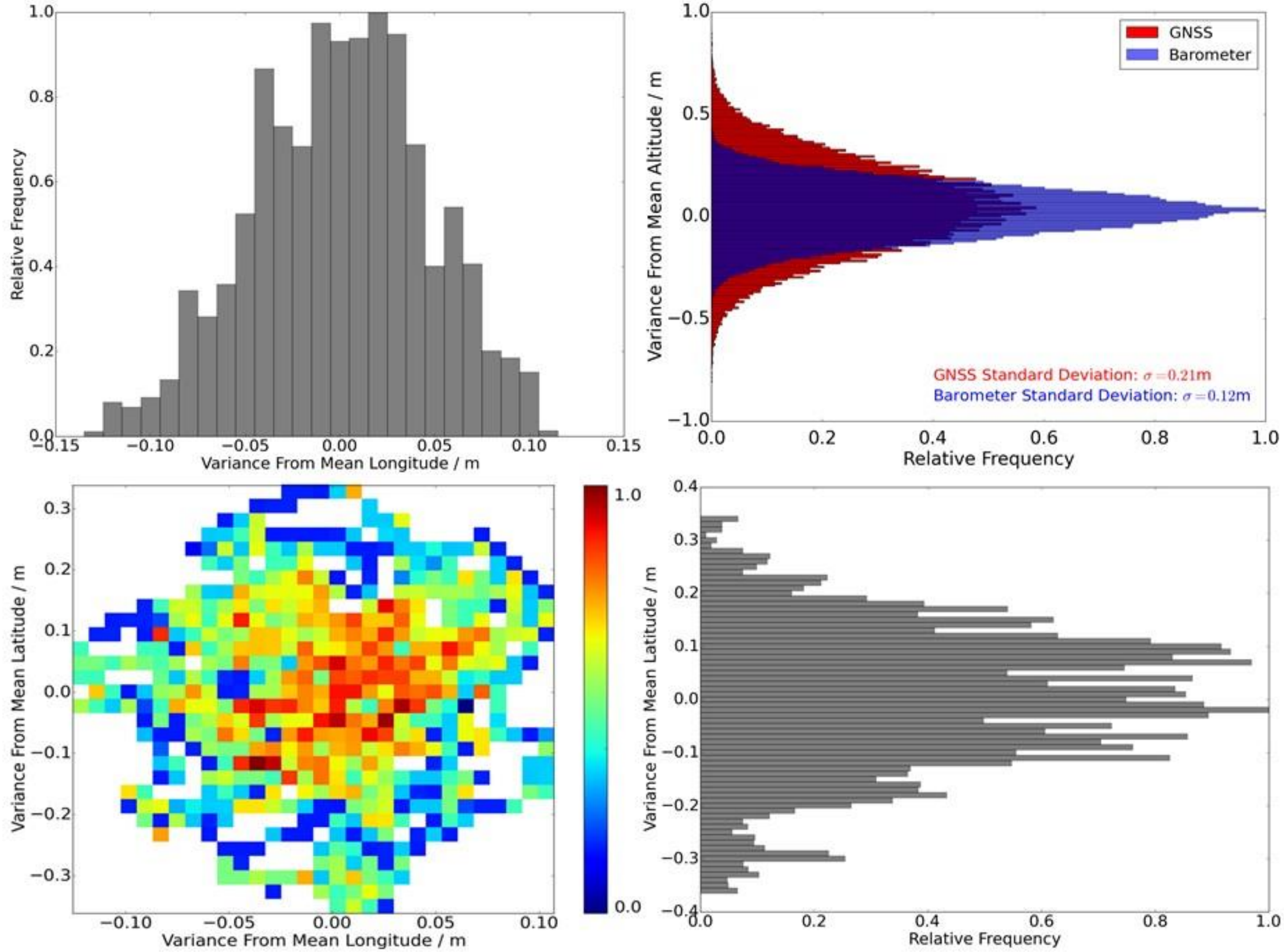


Other UK efforts: Airborne calibration



Preliminary Flight Tests

Horizontal & altitude stability

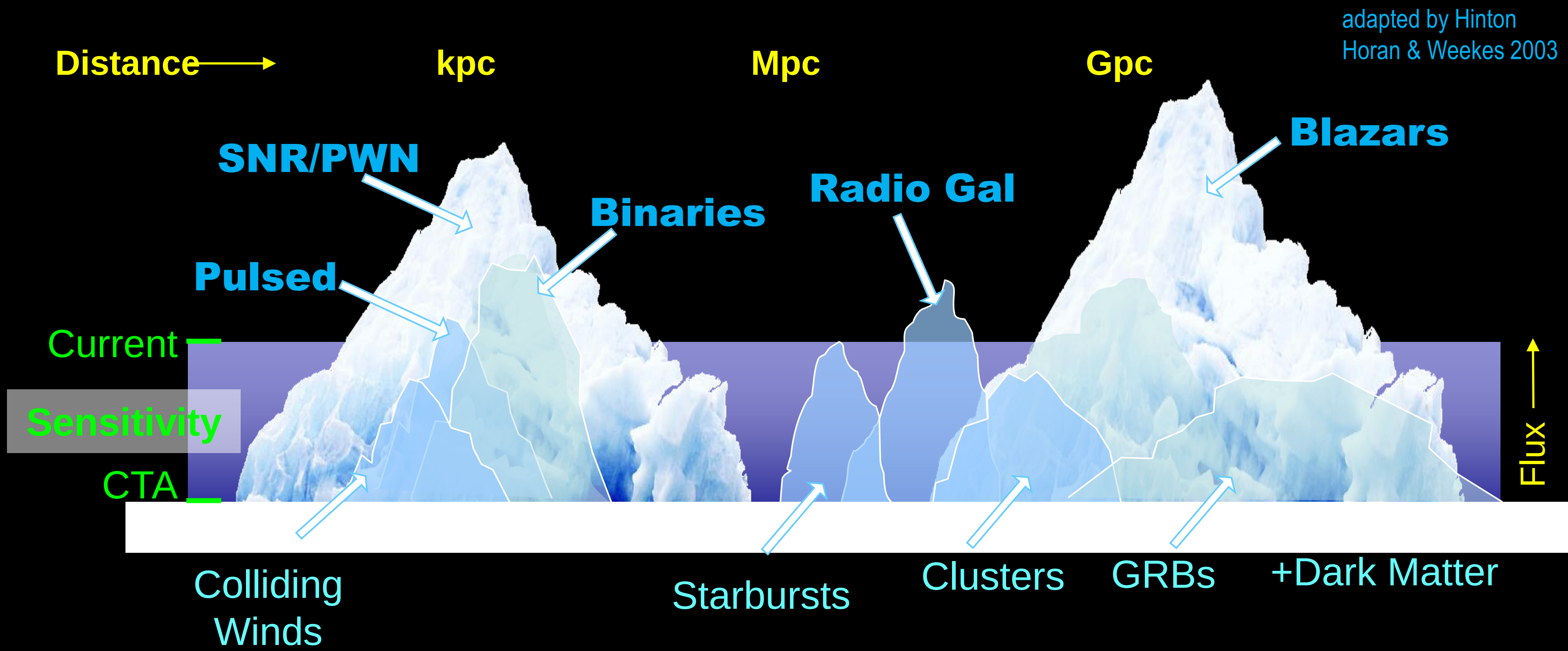


Take home points

- Gamma-ray astronomy allows us to probe the most extreme events in our Universe.
- *Fermi*-LAT has given us insights into these events with high-energy gamma-ray observations
- We expect the Cherenkov Telescope Array to give us unparalleled views of these events at very-high-energies.

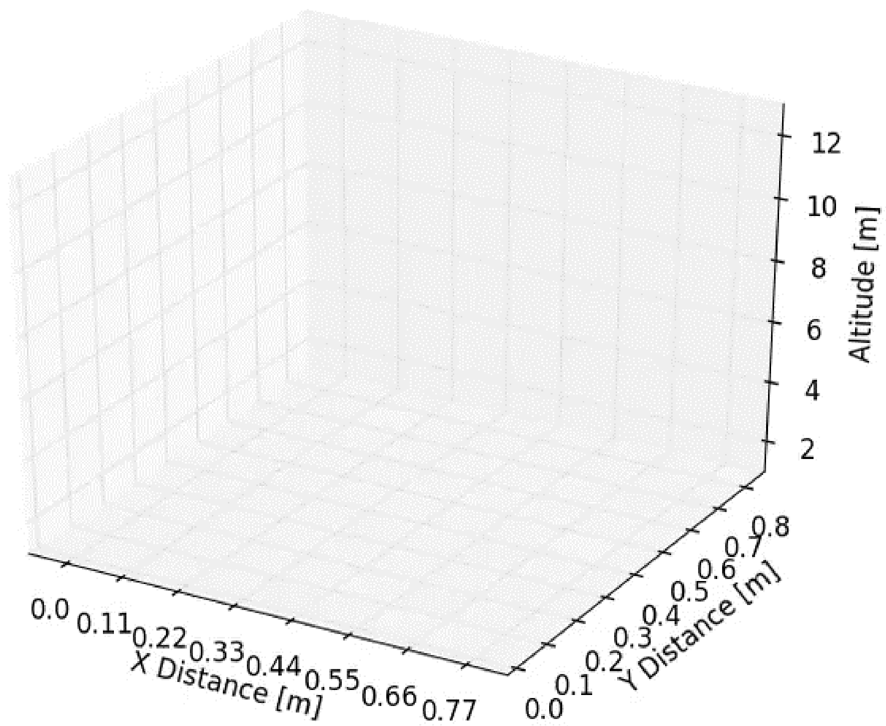
Keep up with CTA:
https://www.cta-observatory.org/ - you can subscribe to the newsletter
https://twitter.com/cta_observatory
https://www.facebook.com/ctaobservatory/

We are scratching the surface

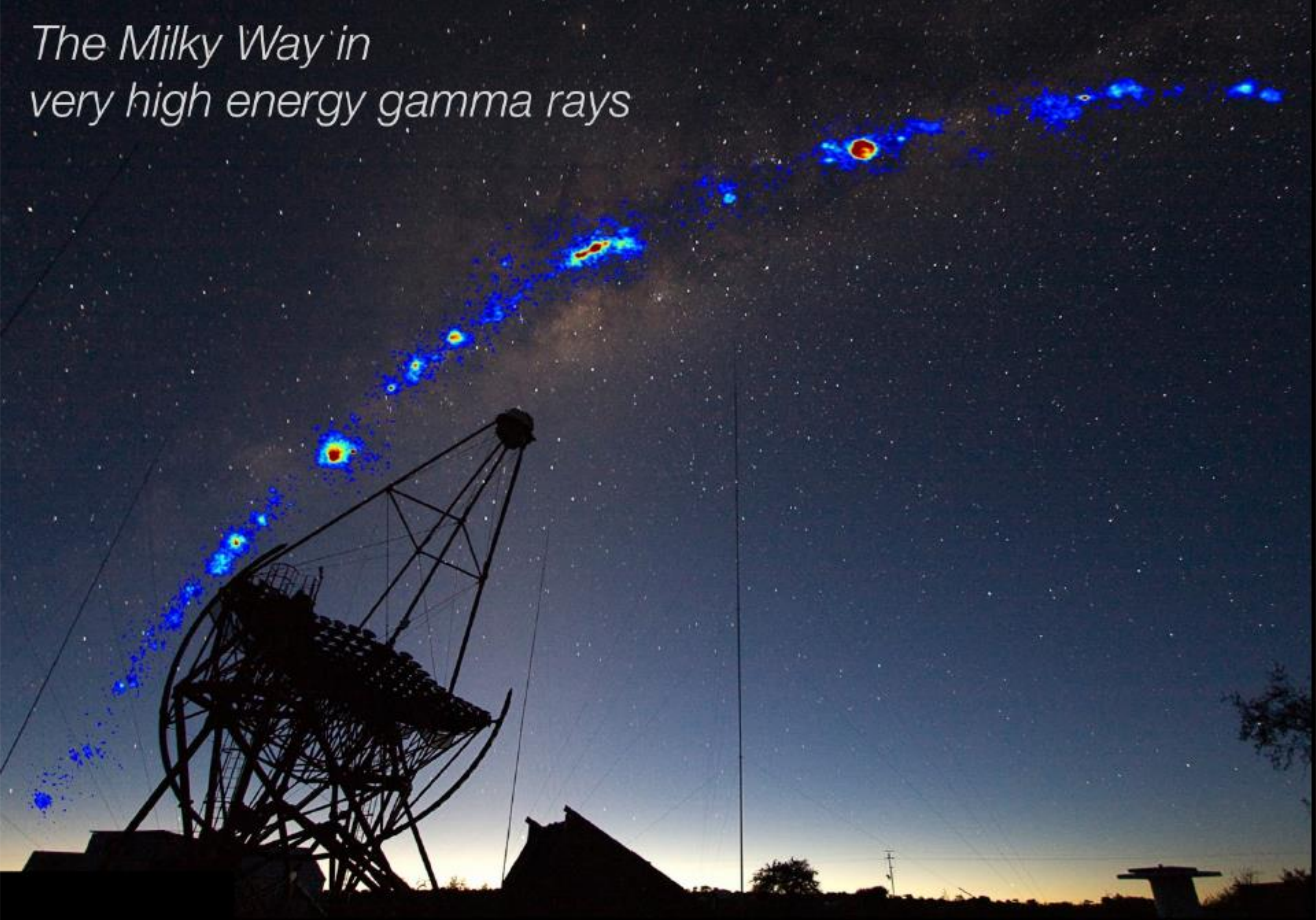


- **Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg**

Horizontal & altitude stability



The Milky Way in very high energy gamma rays



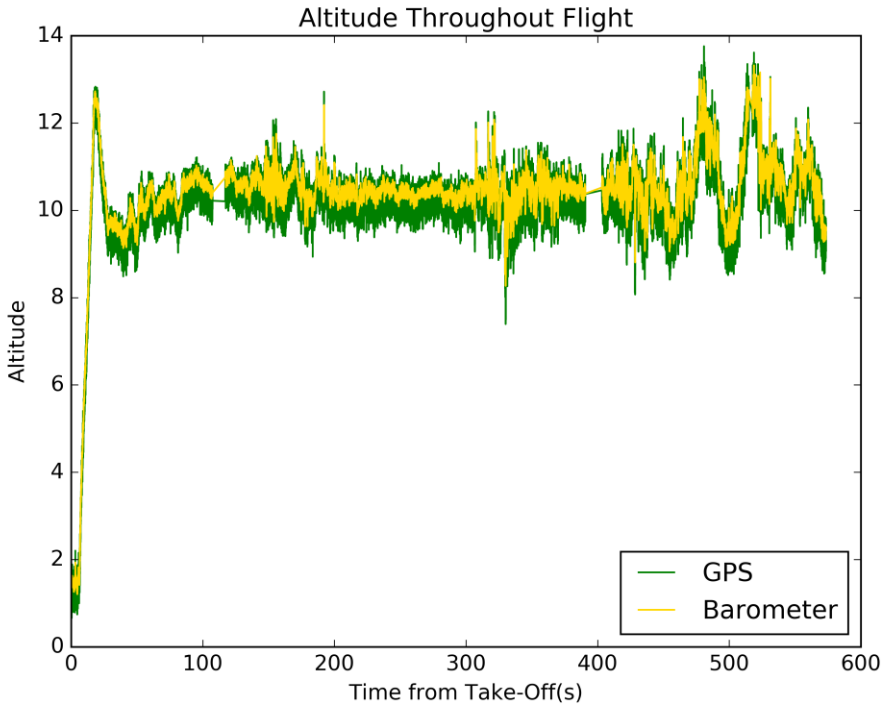
Goals for sys. uncertainty

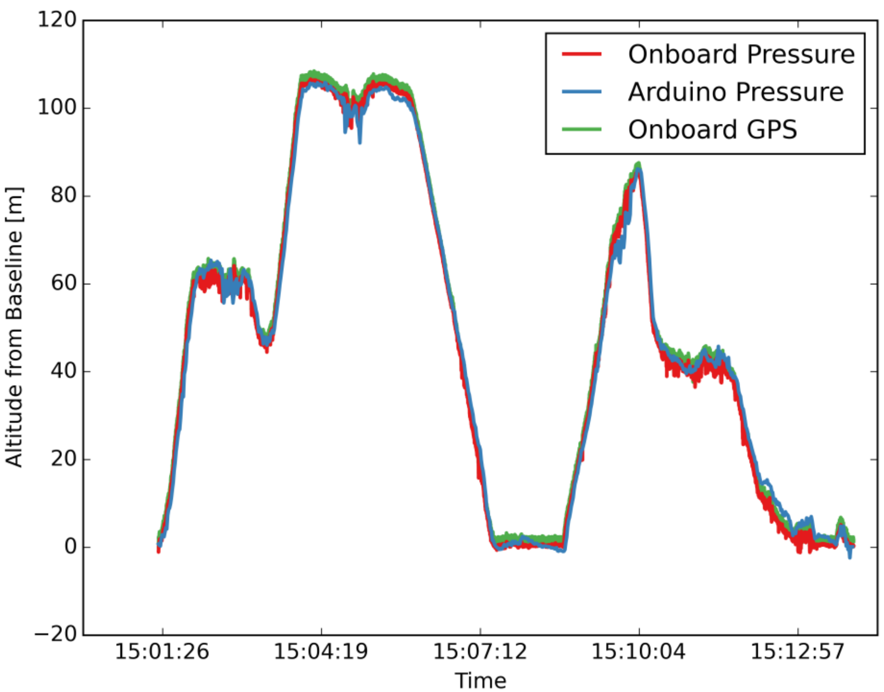
- To achieve these sensitivity & resolution goals, we have strict requirements for the systematic uncertainties of CTA.
  - Energy res. of a photon < 15%
  - Energy scale shift < 10%
  - Collection Area < 12%
  - Absolute intensity < 8%
- Quantifying these uncertainties requires multiple techniques and instruments.
  - Calibration is helped if a common light source illuminating

Achievable accuracy

Source of Uncertainty	Inter-calibration	Cross-calibration
Statistical	1%	1%
Light source stability	1%	1%
Absolute UAV position	<1%	<1%
Atmospheric extinction	1%	1%
Background light	<0.5%	<2%
Flat-fielding	5 – 8%	5 – 8%
Point Spread Function	2%	<5%
Aerosol Distribution	2%	2%
Total Uncertainty	6 – 8%	8 – 10%

Altitude Stability

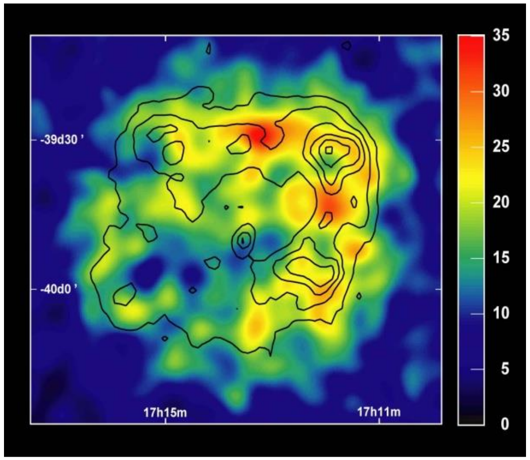


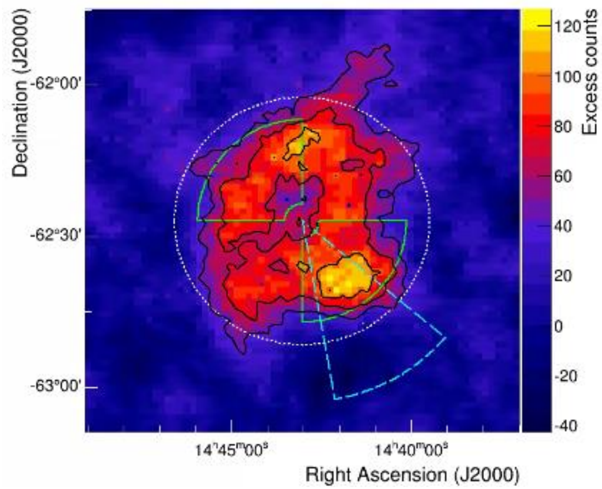


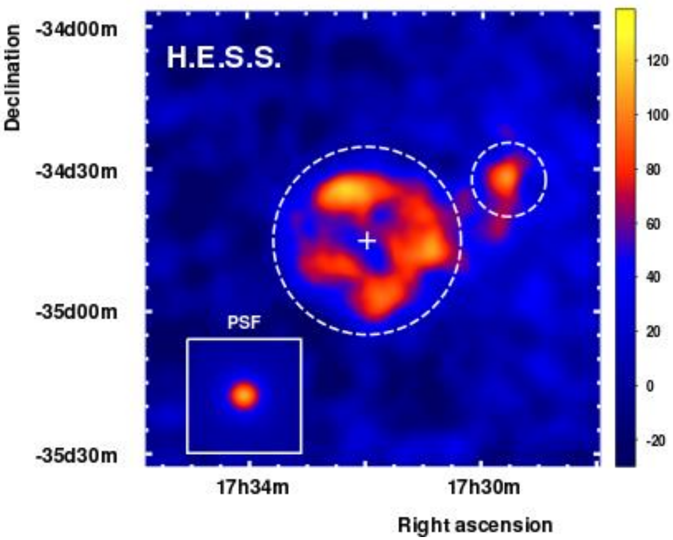
Altitude as given by an on board pressure sensor is more accurate than GNSS

Nonetheless, assuming h=1.3km, for an uncertainty of 1m in the altitude gives a 0.2% systematic uncertainty in the light intensity on the ground

Other CR sources…







- Structured VHE emission found in supernovae remnants: origin of CRs found? Not really…
  - Leptonic models
  - Hadronic models
- Both can explain (with varying degrees of success)
- Need the highest energy photons (*E*>10 TeV)
- Need improved resolution & sensitivity…

Why do we need a UAV?

- Understanding optical throughput is critical for us to achieve our goals for the systematic uncertainties of CTA.
- Considering effort has gone into investigating telescope optical cross-calibration methods:
  - Air showers: using CR, γ-ray or muon-ring observations
    - **'For free', with no loss of observing time**
    - **No multi-wavelength (MWL) information**
  - Instrumentation: design a calibration device (CLF or illuminator)
    - **Has MWL information**
    - **Restrictive hardware requirements or large amount of time needed to perform calibration**
- **The flexibility of a UAV platform allows us to fly a MWL calibration light source, with EAS timing characteristics, above CTA and simultaneously illuminate a large number of telescopes (and more!!)**