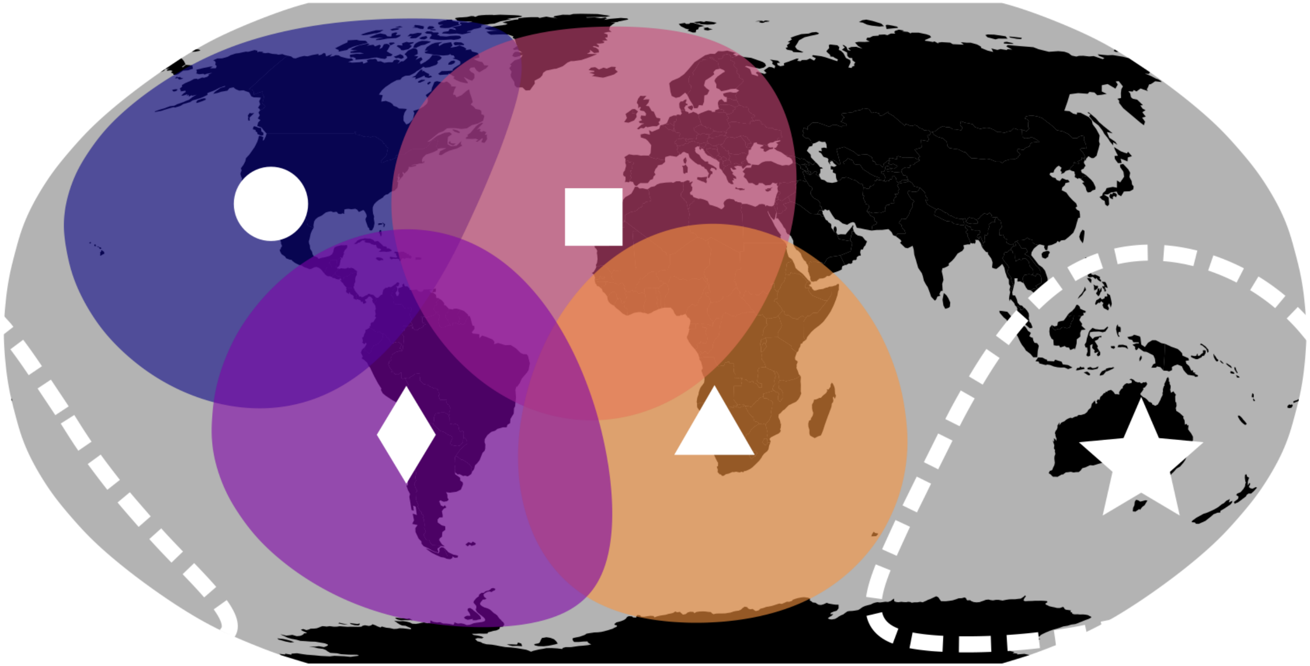
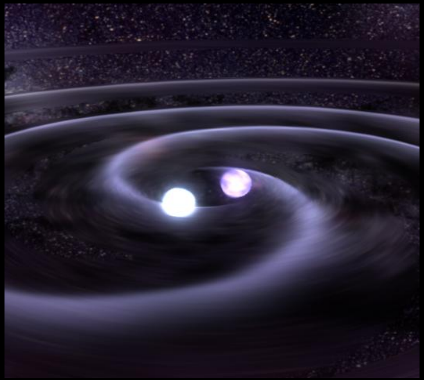
Towards a Network of Cherenkov Telescopes



Simon Lee, Sabrina Einecke, Gavin Rowell (October 2021)

Motivation

[NASA]



[NASA/Goddard Space Flight Center]

Instant followup and continuous monitoring of GeV/TeV gamma-ray sources

Especially useful for transient events, often varying over days/hours/seconds.

- AGN/Blazar flares
- Gamma-ray Bursts
- Binary Neutron Star mergers
- Novae!

...

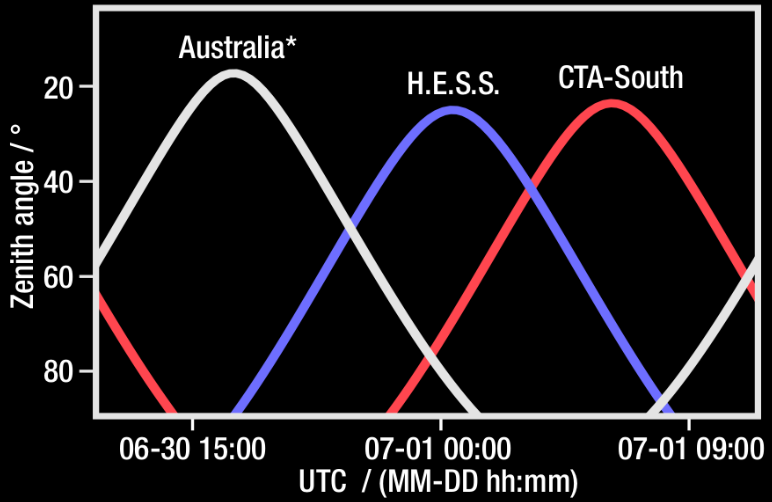
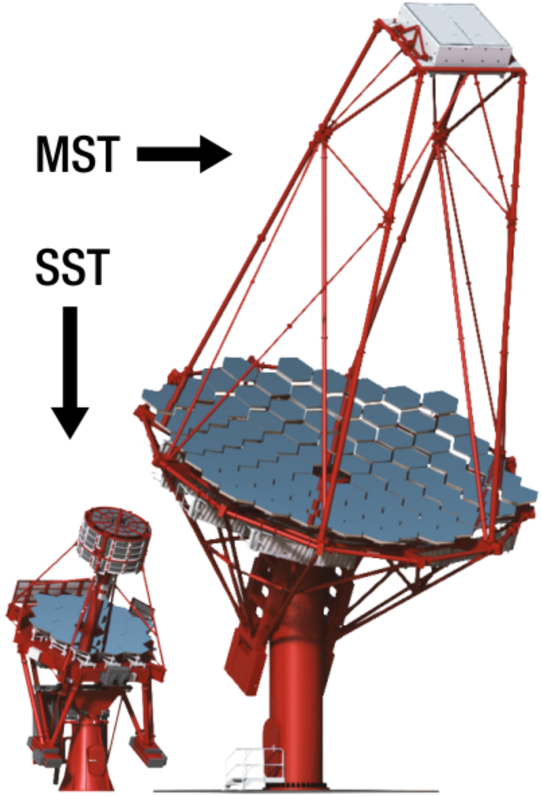


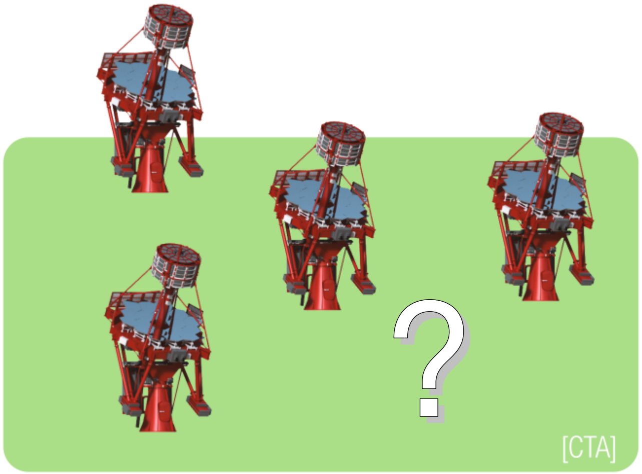
Figure 2: PKS 2005-489 blazar visibility from Australia (*Flinders Ranges) and other southern sites

Telescope configuration



cta-observatory.org/project/technology

What kind of array setup would be suitable for an Australian IACT array?

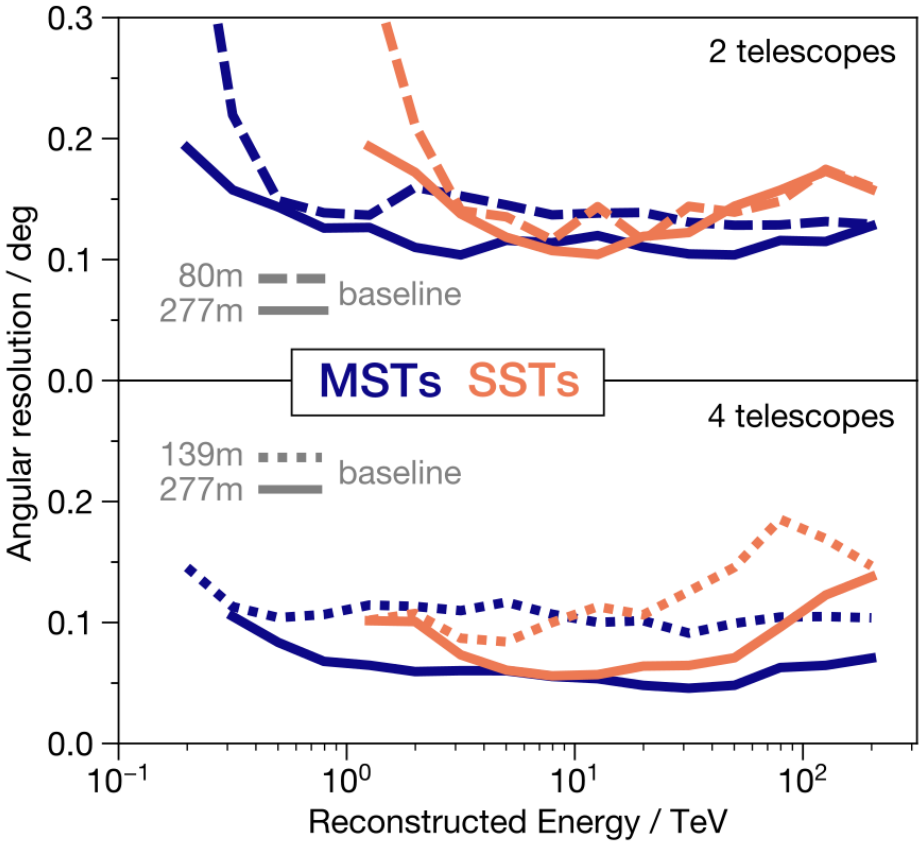


We studied:

- Altitude
  - 0m & 1000m
- Number of telescopes
  - 1 to 4
- Size of telescopes?
  - SST or MST
- Baseline?
  - 80m to 277m

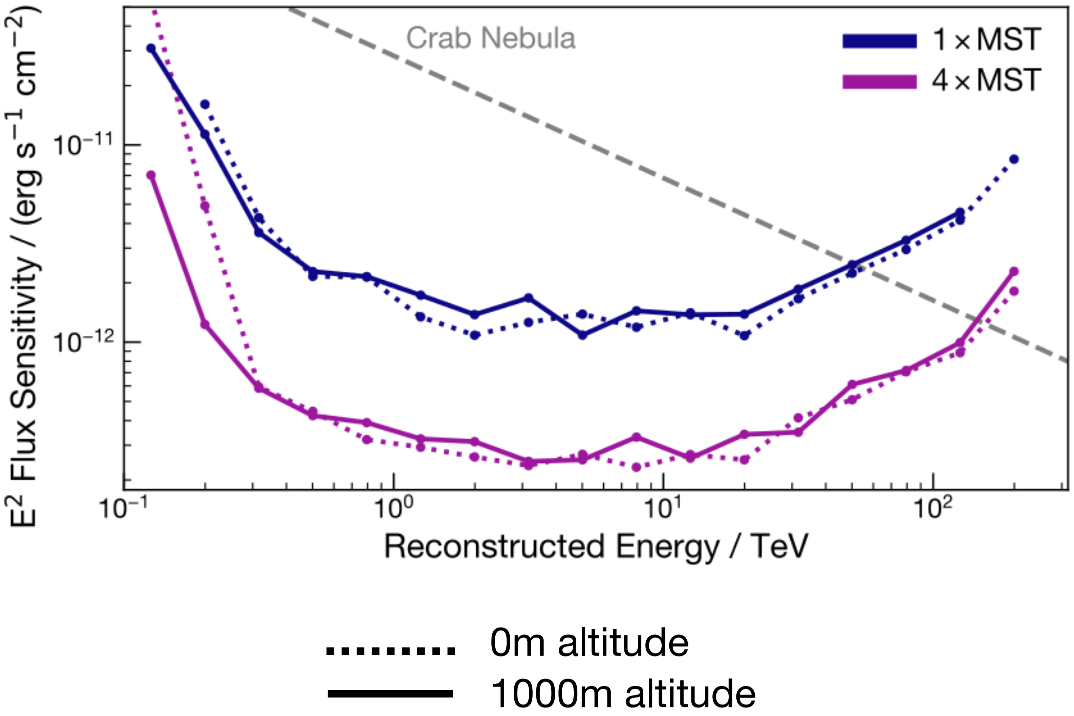
Array Performance

Results: Baseline distance



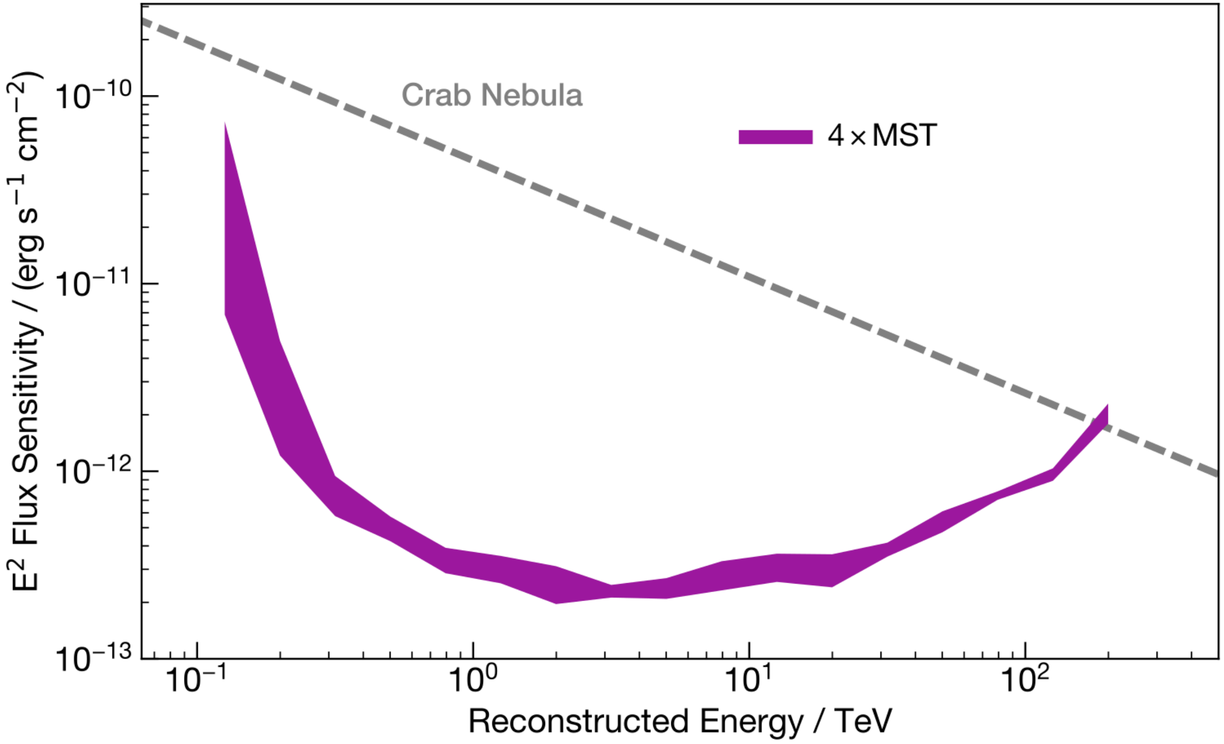
Wider baseline showed a big improvement in angular resolution, especially for 3+ telescope

Results: Altitude



1000m altitude showed a small improvement in energy threshold over 0m but otherwise the differences were negligable

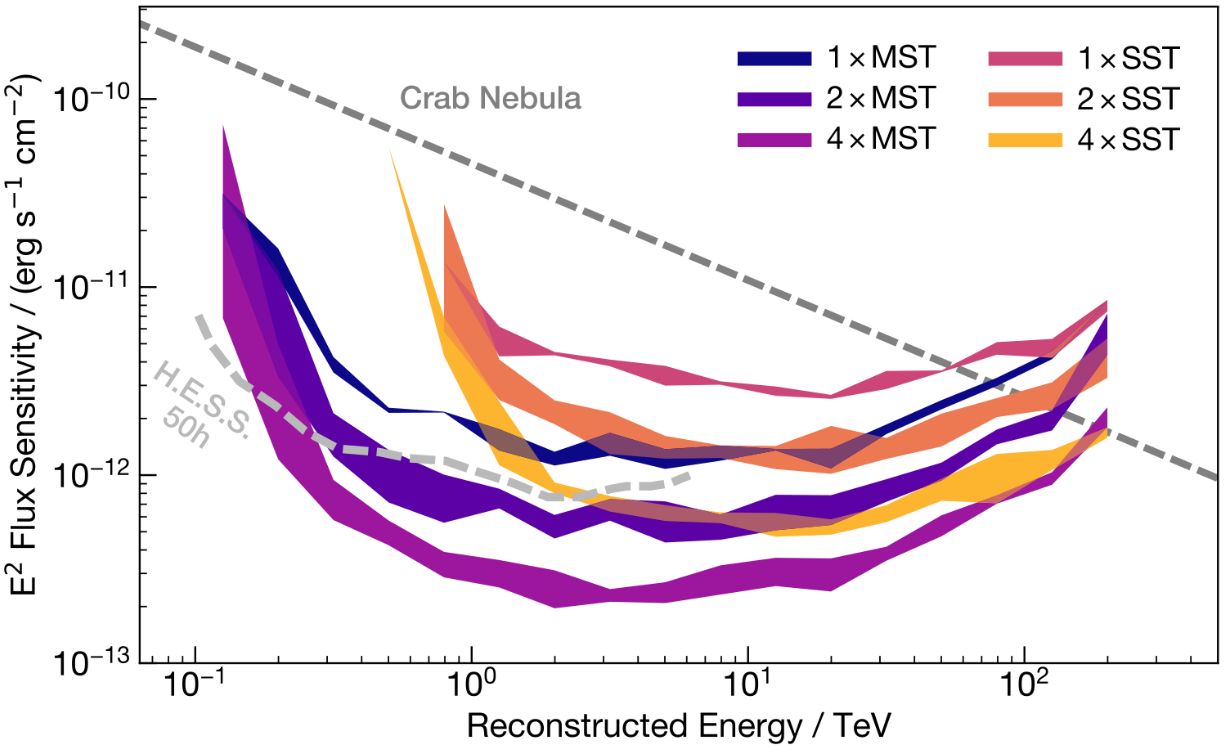
Results: Sensitivty band



This shows the range of sensitivities spanned by a 4 MST setups at different altitudes (0m & 1000m) and with different baselines (139m & 277m)

50 hour differential sensitivity as a function of energy. Bands show range for different site altitudes (0m and 1000m) and baseline distances (80m to 277m).

Results: Overview



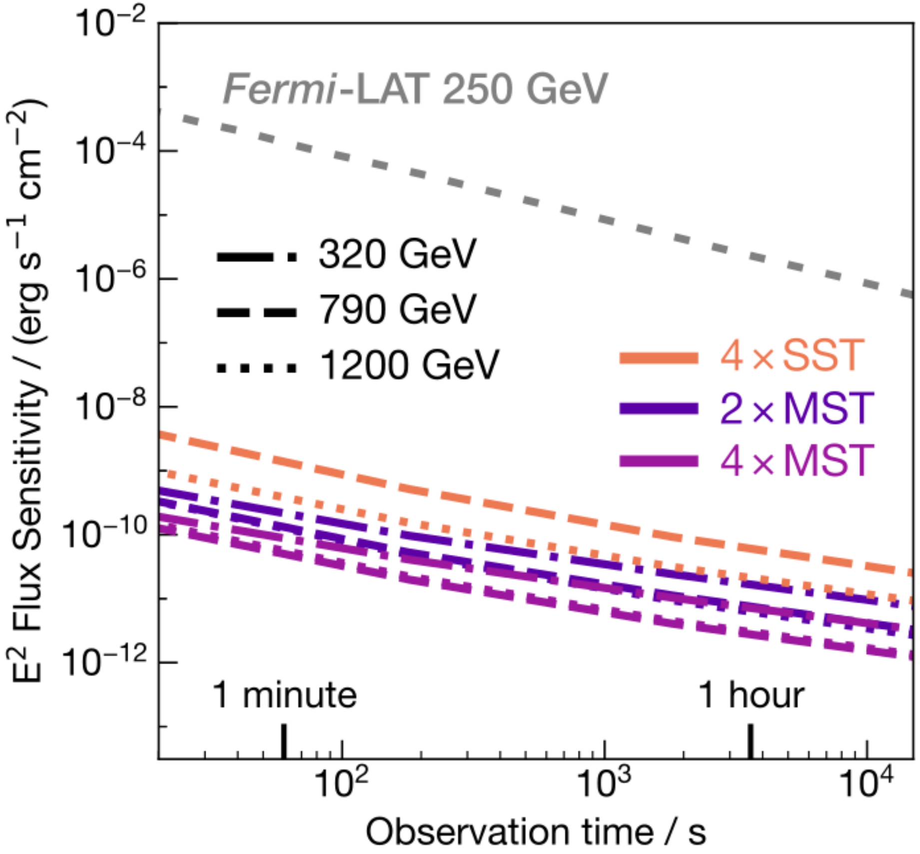
50 hour differential sensitivity as a function of energy. Bands show range for different site altitudes (0m and 1000m) and baseline distances (80m to 277m).

MST arrays achieved much lower energy thresholds, as expected.

Above the SST energy threshold the sensitivity starts to overlap.

Number and size of telescope are by far the most important factors.

Sensitivity vs Time

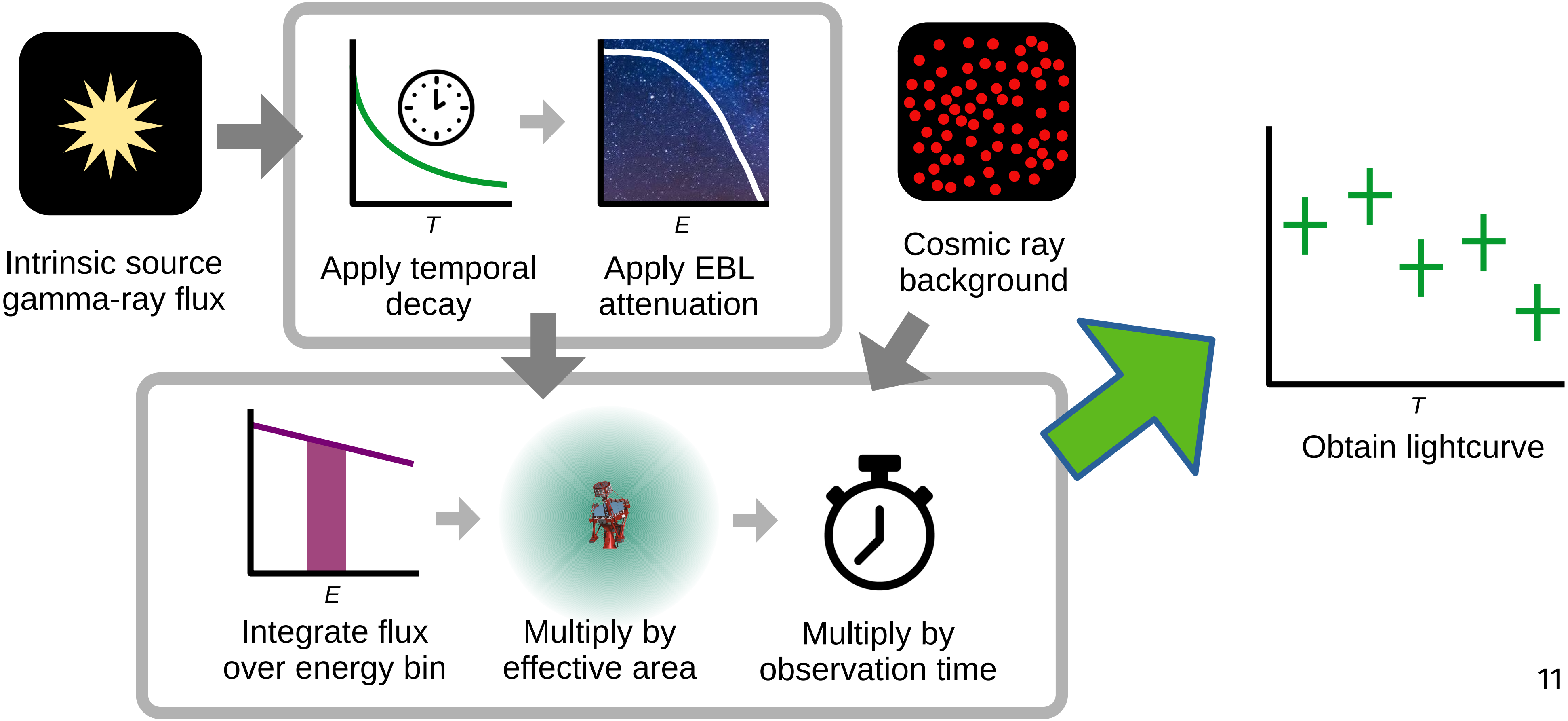


Showing the dimmest source detectable at 5 sigma for a given energy bin as a function of observation time

MSTs have an advantage over SSTs. The LAT on the *Fermi* satellite is shown for comparison

Observation simulations

Simulating a transient source

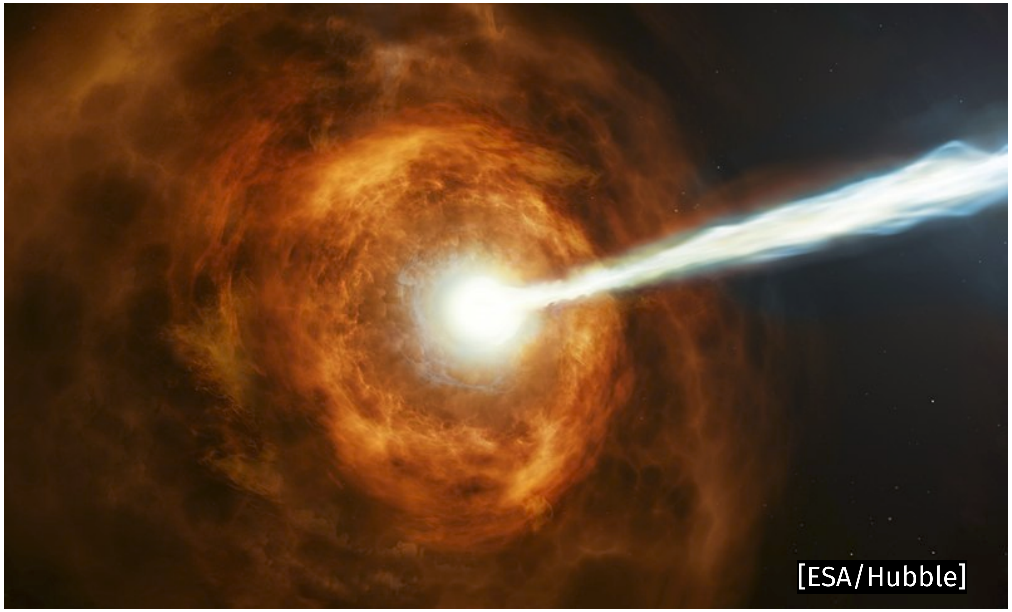


TeV GRB

- In 2019 MAGIC detected, for the first time ever, TeV gamma rays from GRB 190114C, with redshift $z \approx 0.4$
- In the window between 62 and 90 seconds after the burst, MAGIC measured its EBL-corrected flux as

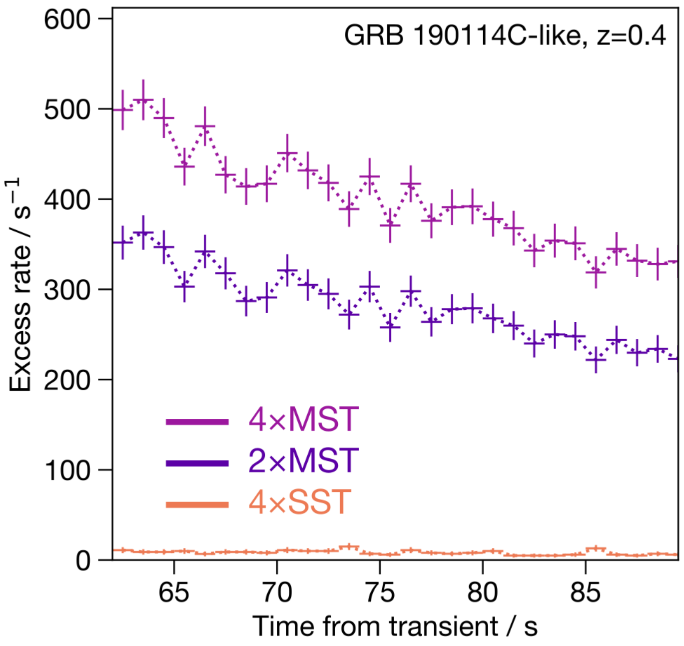
  $dN/dE = 1.95 \cdot 10^{-7}\ E^{-2.17}\ \mathrm{TeV}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

  with an assumed temporal flux decay relationship of $F(t) \propto t^{-1.2}$

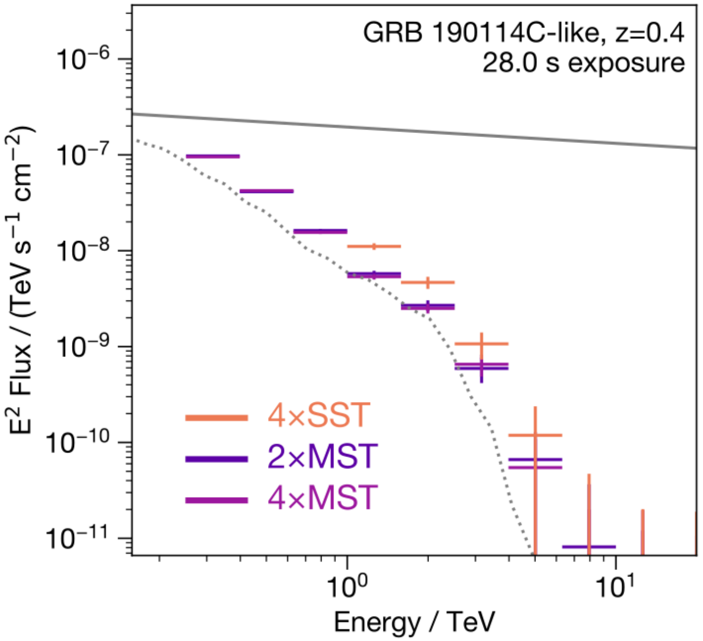

[ESA/Hubble]

nature MAGIC Collaboration (2019) https://www.nature.com/articles/s41586-019-1750-x

TeV GRB



Simulated lightcurves for GRB 190114C-like event



Reconstructed spectrum with intrinsic flux (solid) and flux after EBL absorption (dotted)

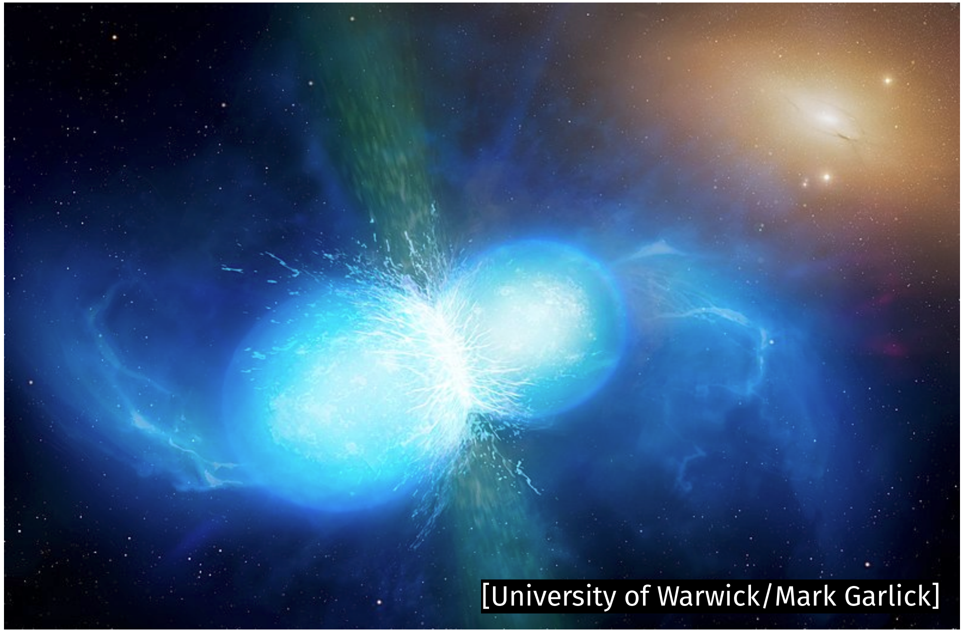
Short GRB

- In 2014 MAGIC observed a "short" GRB, likely the result of a Binary Neutron Star merger

- Scaling their model to their observed gamma-ray flux provides a flux of:

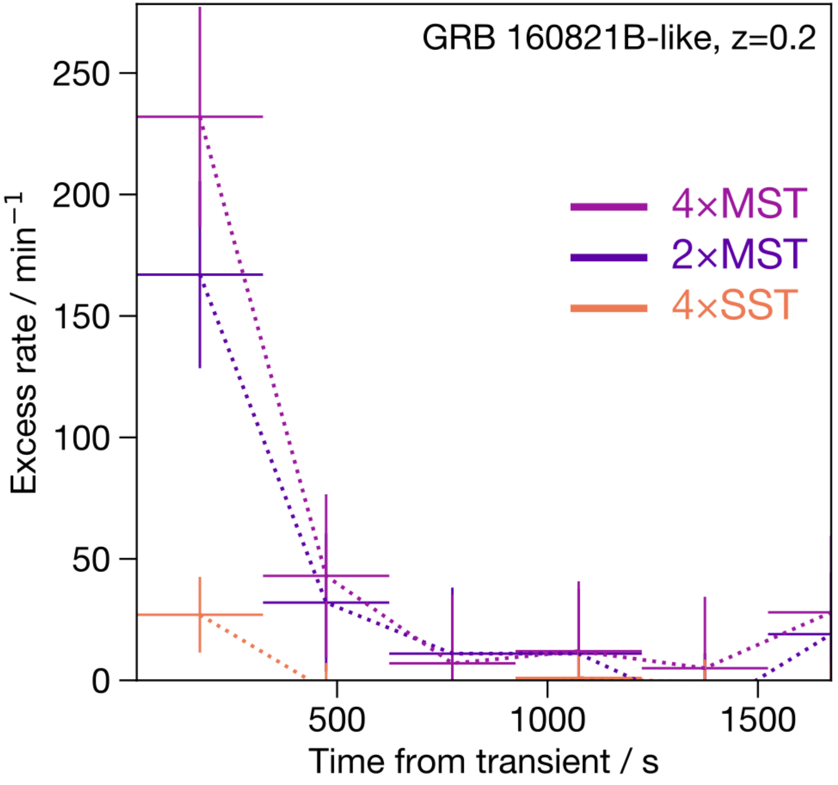
  $dN/dE \approx 4 \cdot 10^{-13}\, E^{-1.8}$ TeV^{-1} cm^{-2} s^{-1}

  with a measured temporal flux decay relationship of $F(t) \propto t^{-0.8}$



MAGIC Collaboration (2014) https://arxiv.org/abs/2012.07193

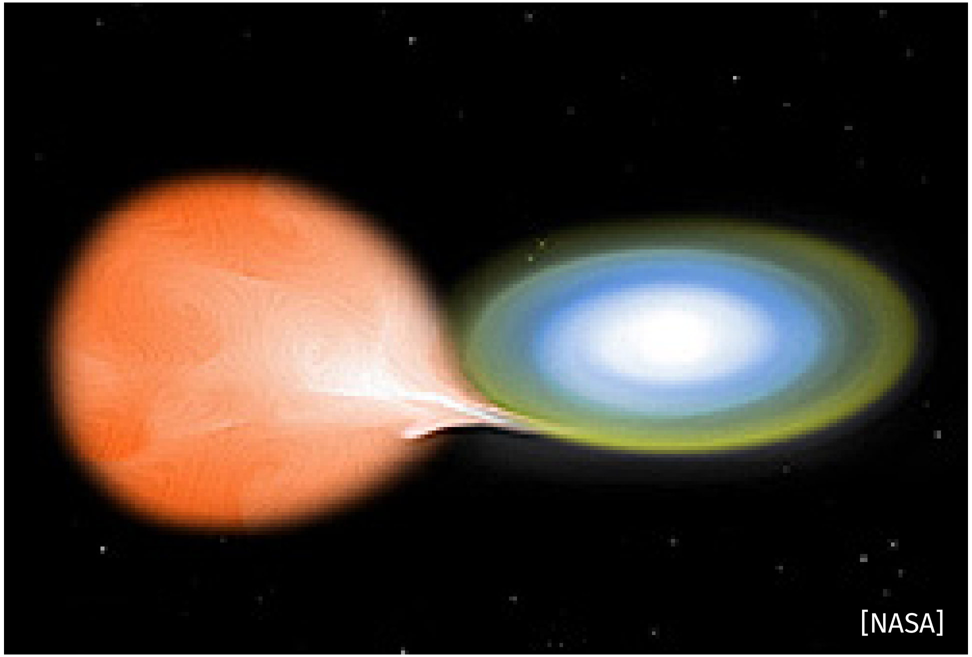
Short GRB



Simulated lightcurves for the short GRB 160821B

Nova

- In August 2021, for the first time ever, H.E.S.S. observed TeV gamma rays from a recurrent nova eruption
- We fit the flux normalisation and temporal decay constants to *Fermi*-LAT lightcurves and assumed a steep power law break above *Fermi*-LAT's energy range, in line with preliminary information from H.E.S.S.

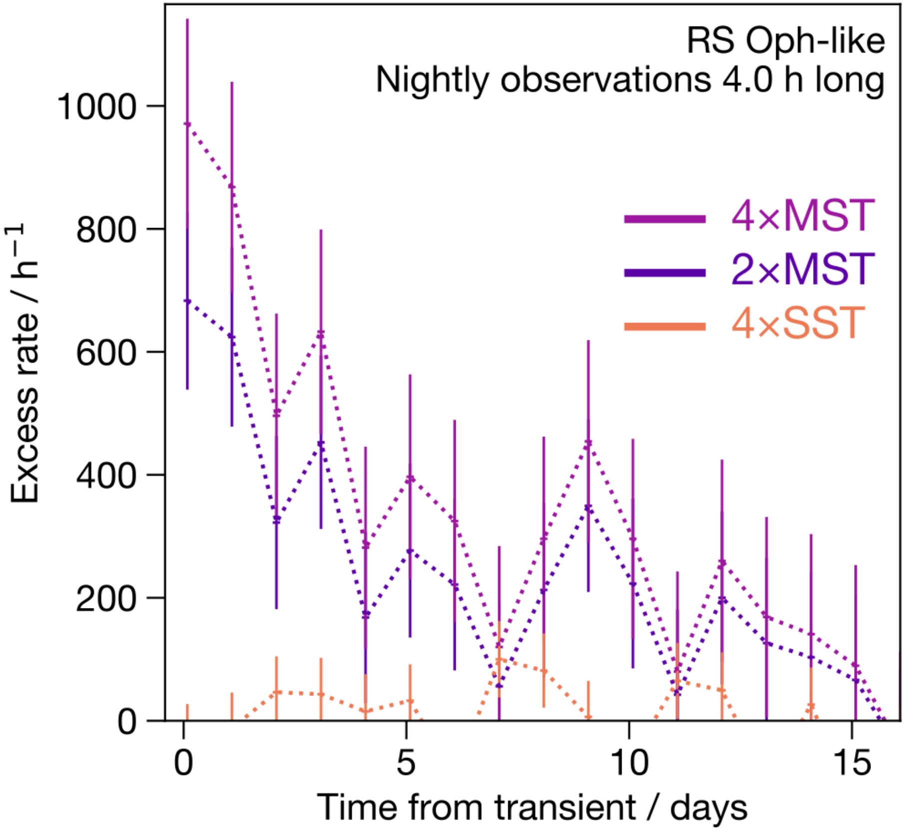


[NASA]

Fermi-LAT Collaboration (2021) https://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/

H.E.S.S. Collaboration (2021) https://www.astronomerstelegram.org/?read=14857

Nova



Simulated lightcurves for the eruption of the recurrent nova RS Ophiuchi

Summary

Publications of the Astronomical Society of Australia (PASA)
doi: 10.1017/pas.2021.xxx.

Performance of a Small Array of Imaging Air Cherenkov Telescopes sited in Australia

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Abstract

As TeV gamma-ray astronomy progresses into the era of the Cherenkov Telescope Array (CTA) there is a desire for the capacity to instantaneously follow up on transient phenomena and continuously monitor gamma-ray flux above 10^{12} eV. To this end, a worldwide network of Imaging Air Cherenkov Telescopes (IACT) is required to contribute triggers for CTA observations and provide complementary continuous monitoring. An IACT array based in Australia would contribute significant coverage of the Southern Hemisphere sky. Here we investigate the suitability of a small IACT array and how different design factors would influence its performance. Monte Carlo simulations were produced based on the Small Sized Telescope (SST) and Medium Sized Telescope (MST) designs from CTA. Key results included the up to two-fold improvement in angular resolution with wider baseline distances up to 277 m and the lower energy threshold achievable at 1000 m altitude. Additionally the ~300 GeV energy threshold of MSTs was more suitable for observing transients than the ~1.2 TeV threshold of SSTs. An array of four MSTs at 1000 m was estimated to provide a 5.9σ detection of an RS Ophiuchi-like nova eruption from a 4-hour observation. We conclude that a small array of four IACTs based on the CTA MST design at an Australian site would ideally complement the capabilities of CTA.

Keywords: Monte Carlo simulations – Cherenkov telescopes – IACT technique – gamma rays – cosmic rays

1 INTRODUCTION

Gamma-ray astronomy is a critical field for understanding the nature of extreme phenomena within and beyond our Galaxy. However, in the very-high-energy (VHE) regime (GeV to TeV) there is insufficient worldwide coverage to instantaneously follow-up on or monitor transient and variable sources over a 24-hour period.

Imaging Atmospheric Cherenkov Telescopes (IACTs), such as MAGIC, H.E.S.S, VERITAS, and FACT detect the Cherenkov radiation from extensive air showers generated by gamma rays interacting with the Earth's atmosphere. These telescopes can detect gamma rays with energies from tens of GeV to hundreds of TeV with an angular resolution down to ~0.05°. They are very sensitive compared to alternate methods, allowing for measurements of source flux variation with time bins sometimes as small as seconds. The next-generation Cherenkov Telescope Array (CTA) in its alpha configuration will have 13 IACTs at its Northern Hemisphere site and 51 at its Southern Hemisphere site. These will provide dramatic improvements to sensitivity across the VHE regime (CTA Consortium, 2018). The limitations of IACTs are their comparatively narrow field-of-view and their fundamentally optical detection method, which restricts observations to night time.

Water Cherenkov Detectors (WCDs) such as those used in HAWC, LHAASO, and the upcoming SWGO detect Cherenkov light from charged particles passing through large bodies of water instead of air. The largest benefits of this method are the very wide field-of-view achievable and the ability to run 24 hours a day, allowing for monitoring of many sources simultaneously for long periods of time. Compared to IACTs, WCDs are orders of magnitude less sensitive for a given observation time and their angular resolution quickly deteriorates below 10 TeV (Wang et al., 2018). This makes them less capable at detecting faint transients, reconstructing spectra for short-lived events, and monitoring flux variations on the scale of hours or minutes.

The Large Area Telescope (LAT) on the *Fermi* satellite directly detects gamma rays with a collection area of ~1 m^2. It has a wide field-of-view and can observe the whole sky multiple times per day as it orbits the Earth (Atwood et al., 2013). *Fermi*-LAT has provided many valuable insights, including the concurrent gamma-ray detections with multi-messenger transient events such as the gravitational wave GW170817 (Ajello et al., 2018)