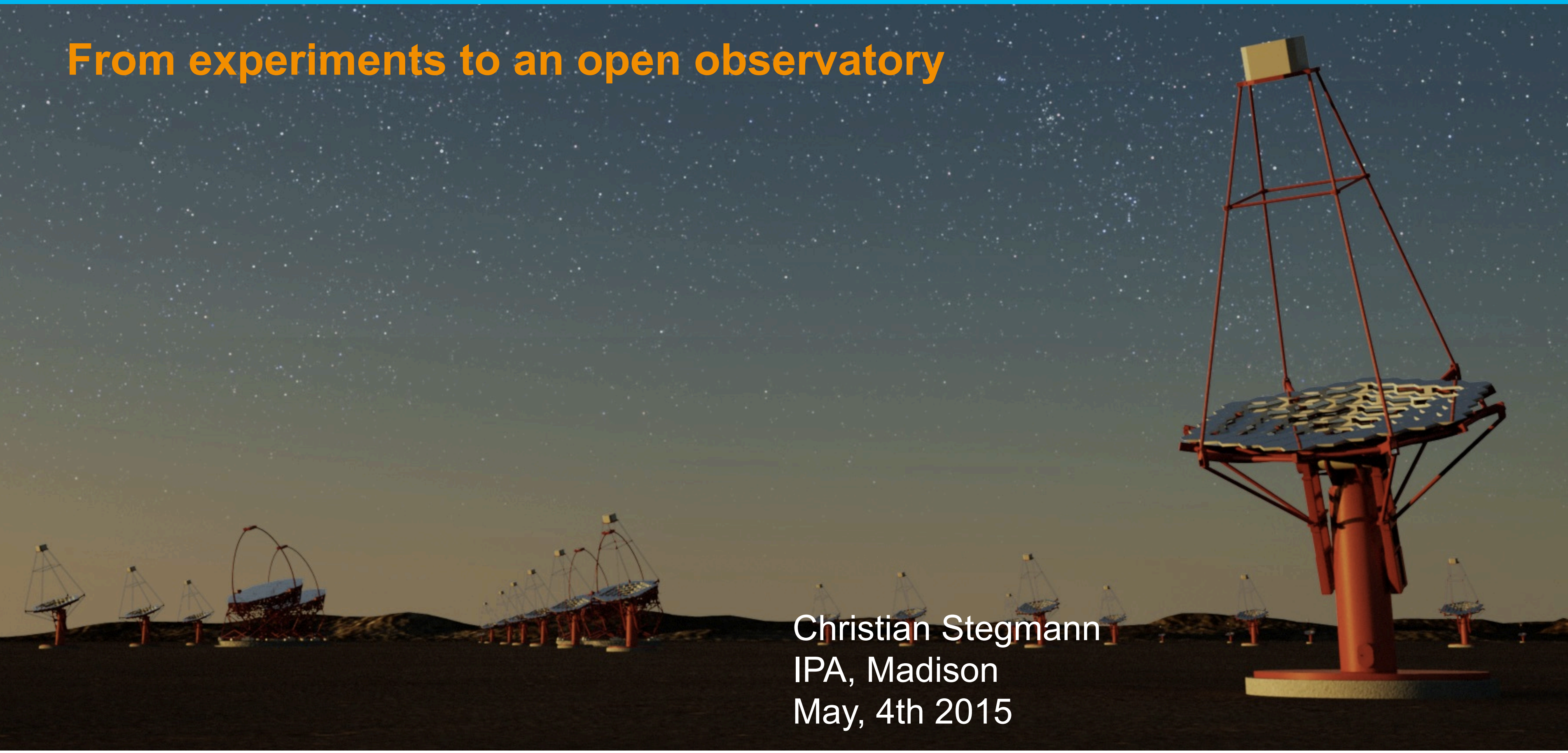
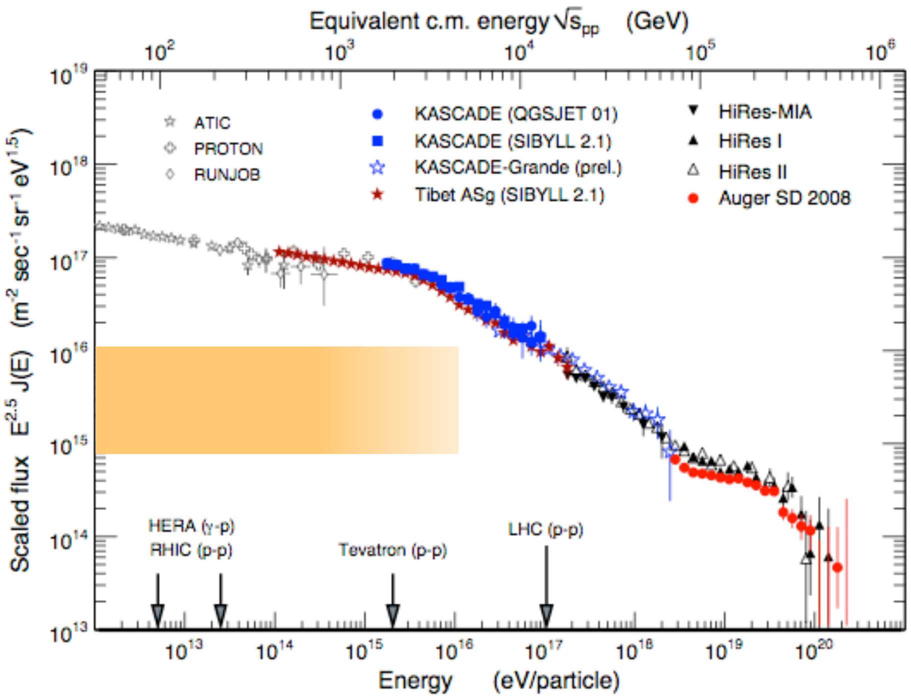
The Future of Gamma-ray Astronomy with Air Cherenkov Telescopes .

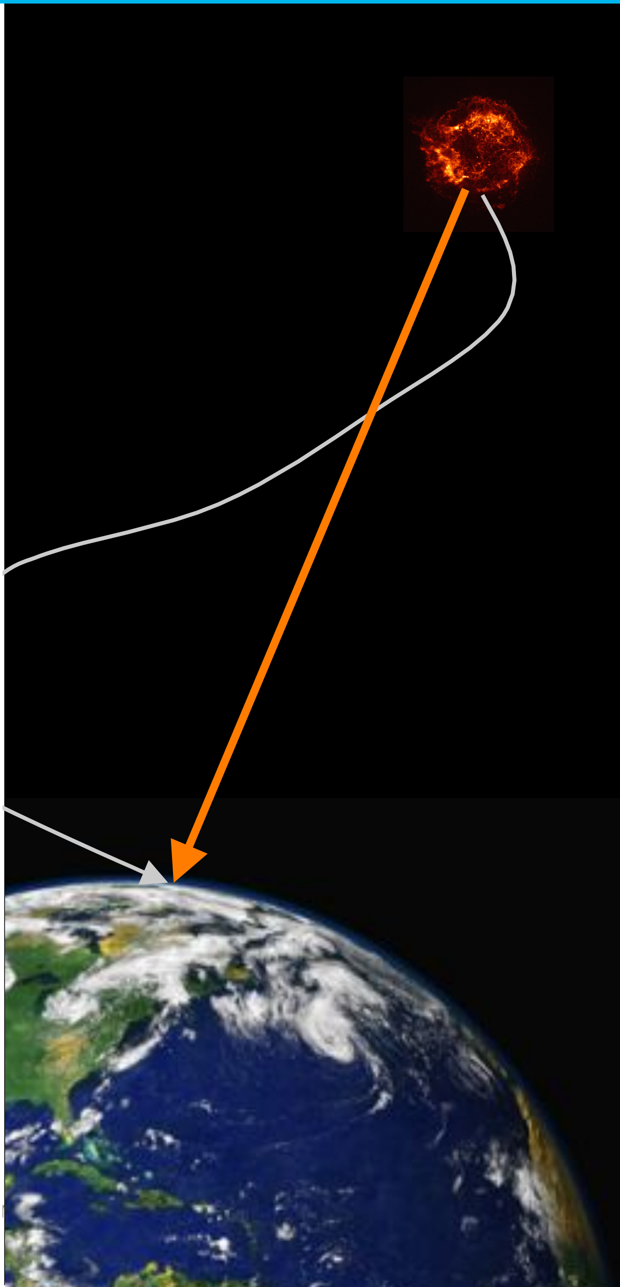


From experiments to an open observatory

Christian Stegmann
IPA, Madison
May, 4th 2015

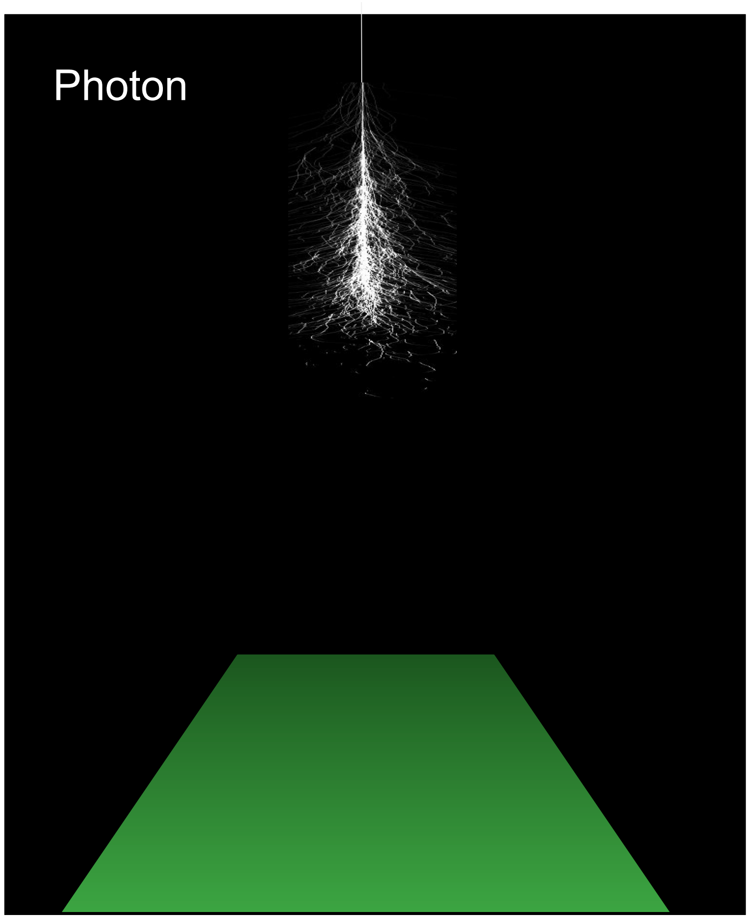
Gamma rays – Messengers from the High Energy Universe



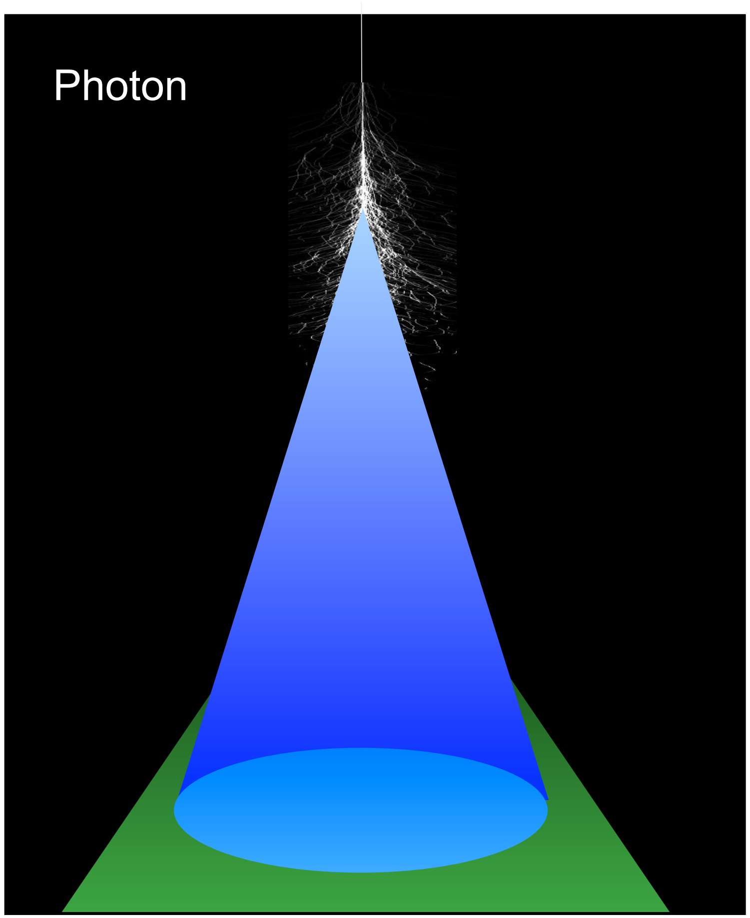


- Gamma rays are excellent tracers of the acceleration sites of ultra-relativistic cosmic rays
- Production
  - protons: pion-decay: $\pi^0 \rightarrow \gamma\gamma$
  - electrons: Inverse Compton Scattering: $e^{\pm}\gamma \rightarrow e^{\pm}\gamma$

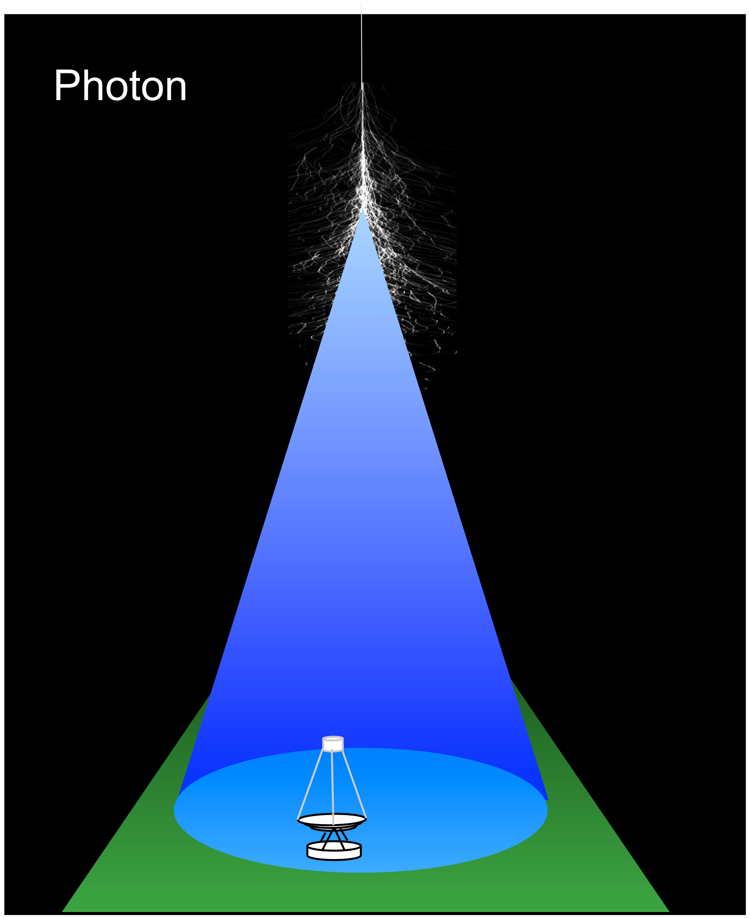
How to measure gamma-rays from the ground?

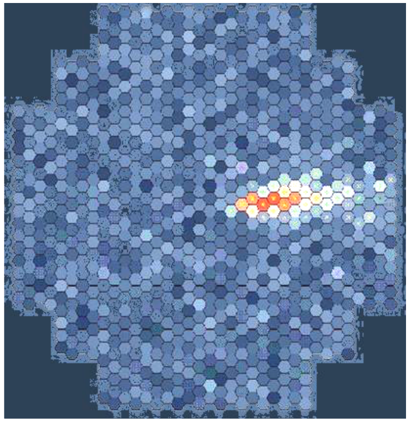


How to measure gamma-rays from the ground?



How to measure gamma-rays from the ground?





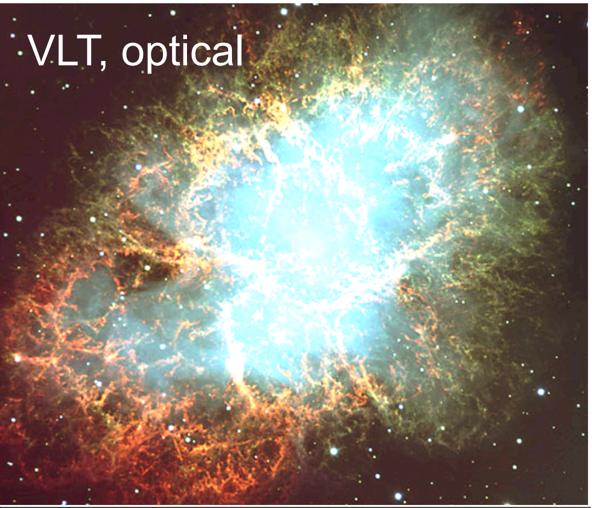
Camera image

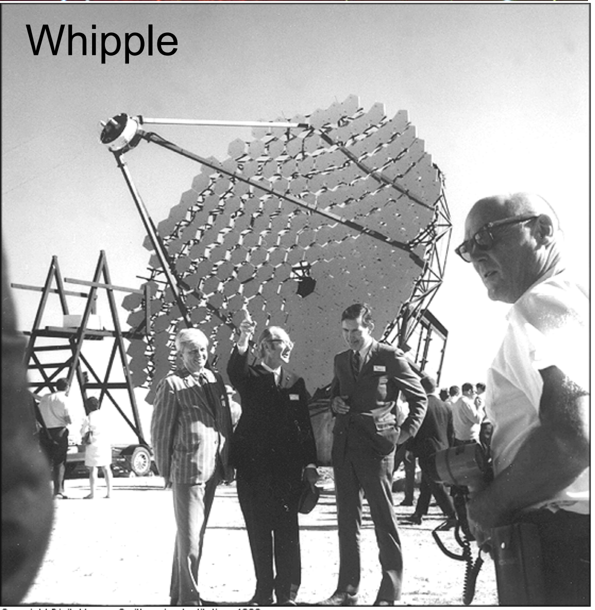
Intensity → Energy

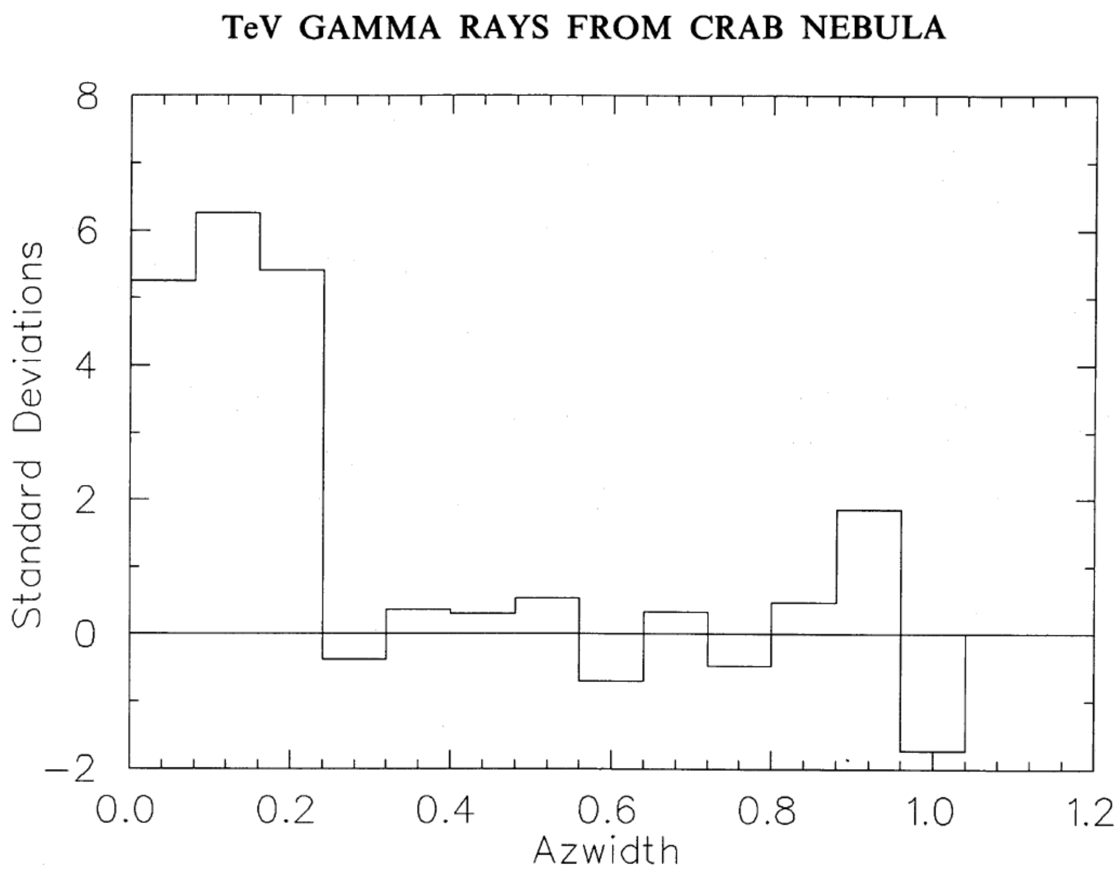
Orientation → Direction

Shape → Primary particle

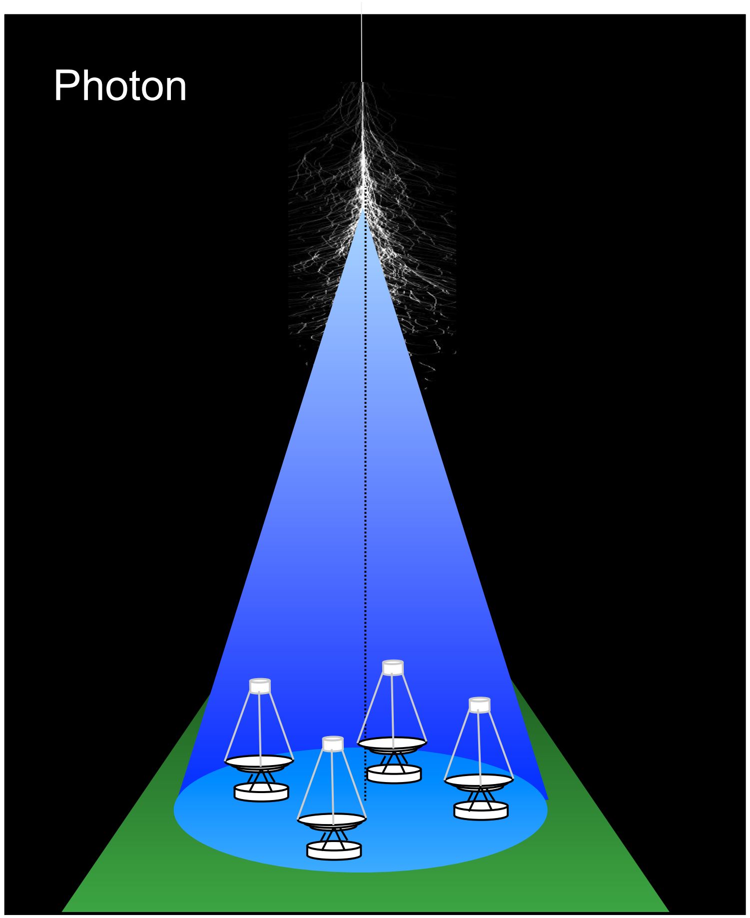
1989: The first VHE gamma-ray source

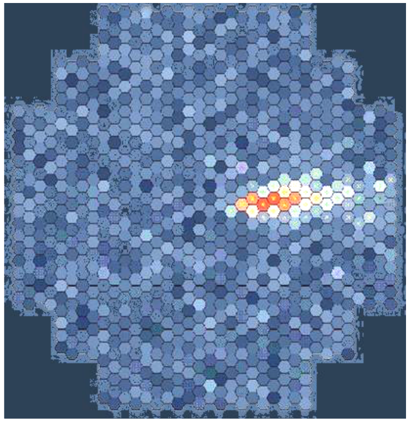




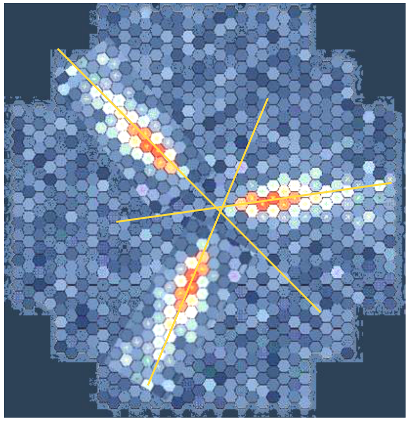


How to measure gamma-rays from the ground?





Single telescope event



3 telescope image in common camera plane

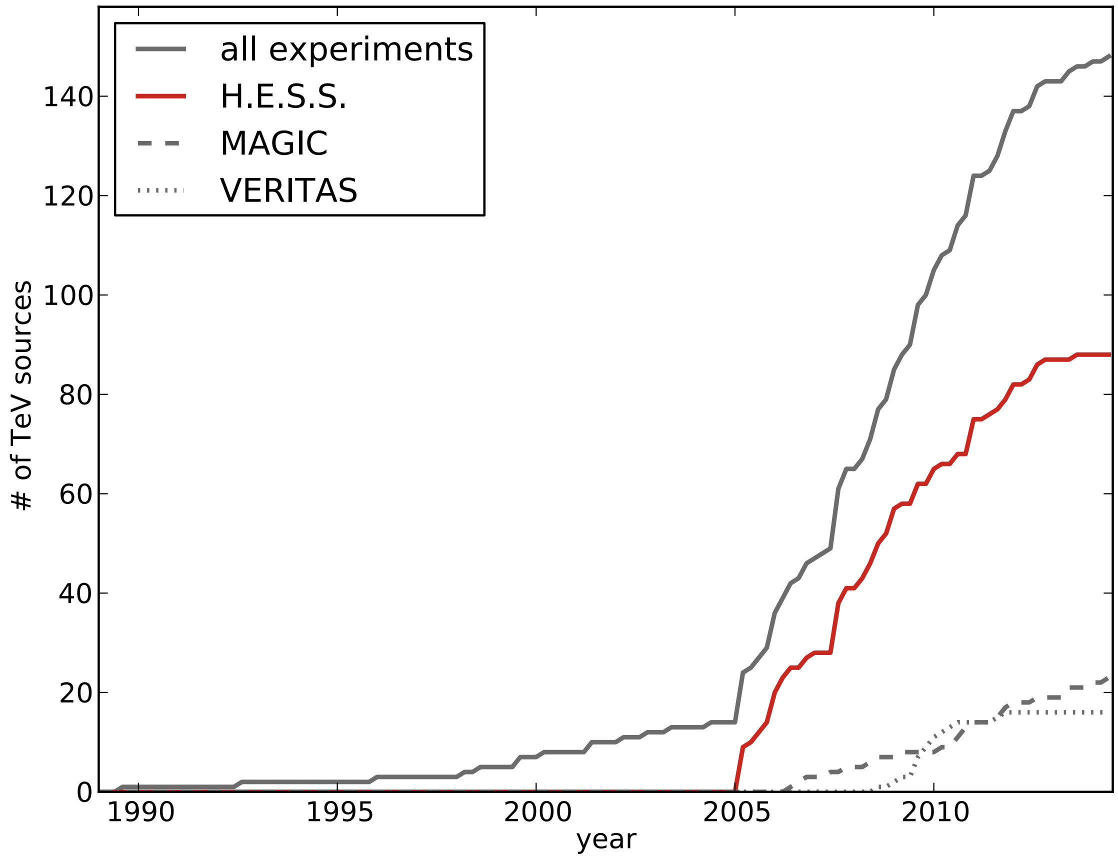
Intensity → Energy

Orientation → Direction

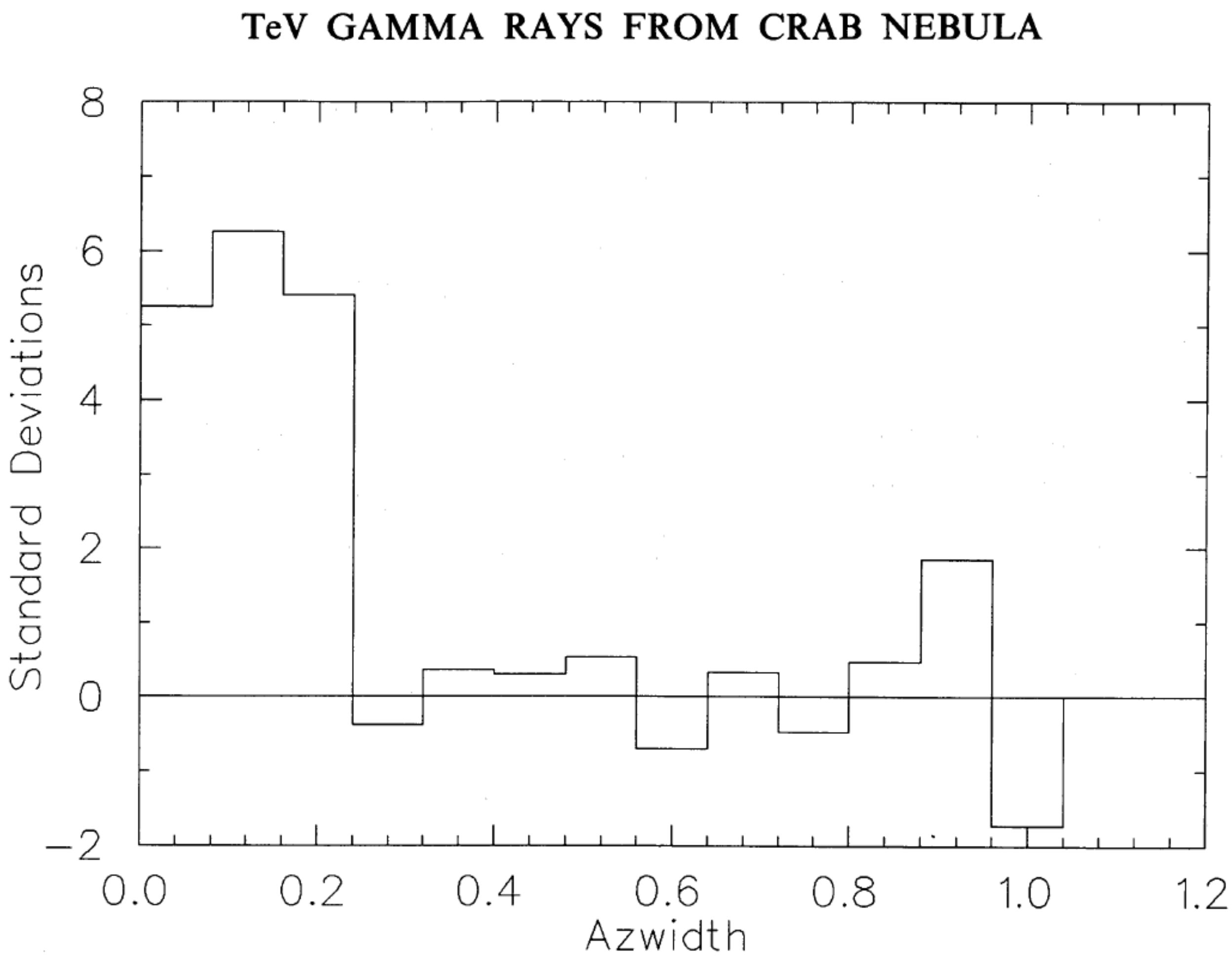
Shape → Primary particle

Gamma-ray astronomy – 3rd generation experiments

Number of sources



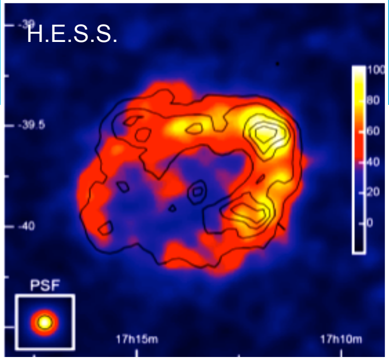
Data quality



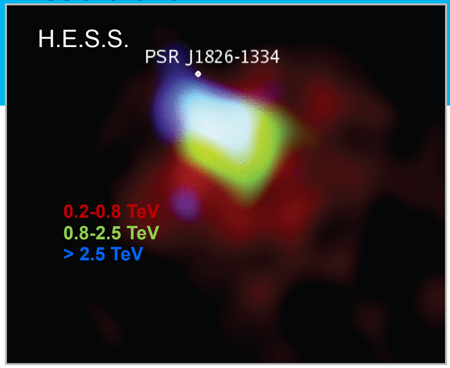
Data quality today

- Morphologies
  - spacial
  - energy-dependent
- Periodicities/Variability
  - from ms to years
- Energy-coverage
  - over several decades
- Source position
  - on the arc-second level

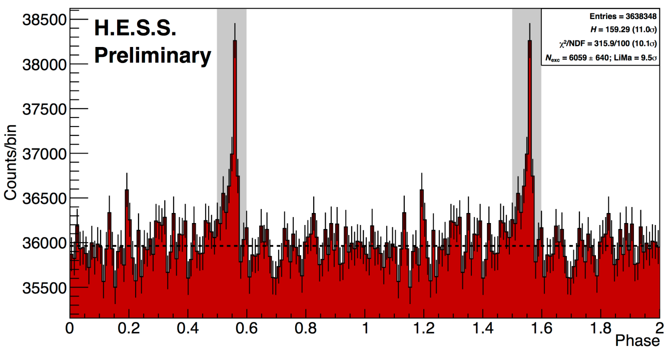
RX J1713-3946



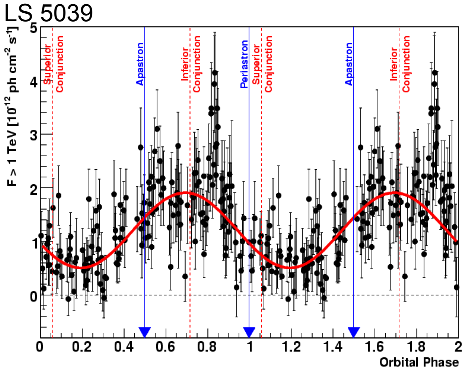
HESS J1825-137



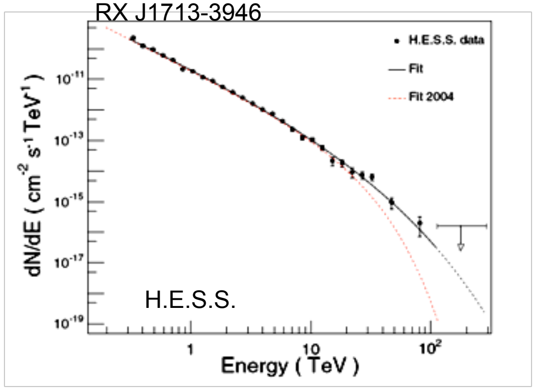
Vela pulsar



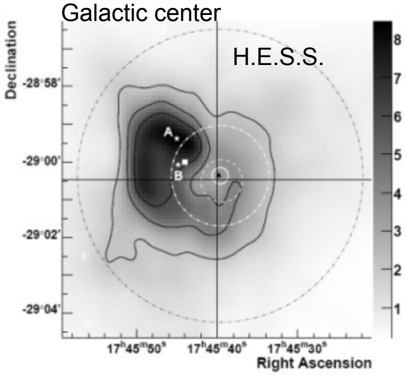
LS 5039

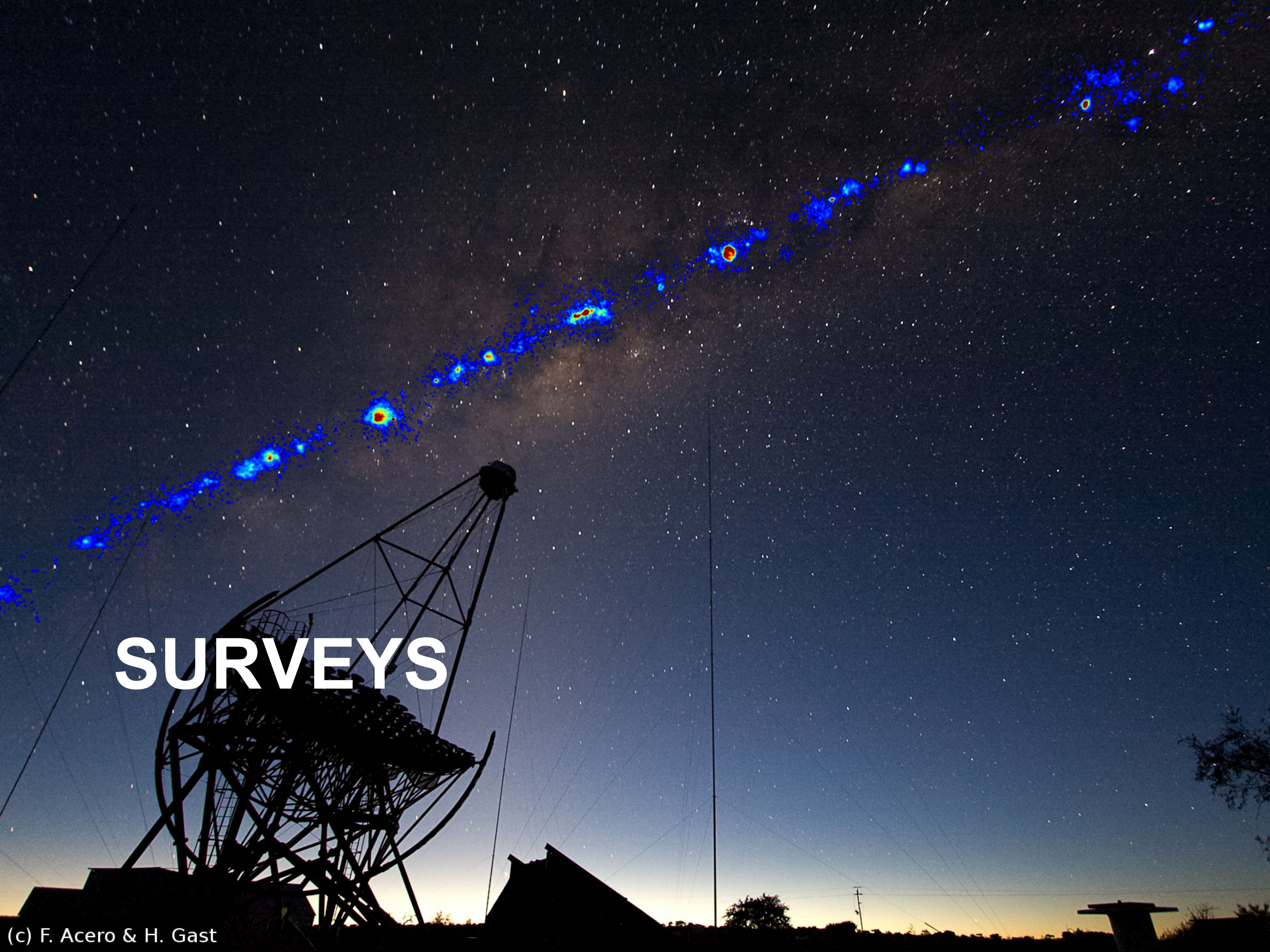


RX J1713-3946

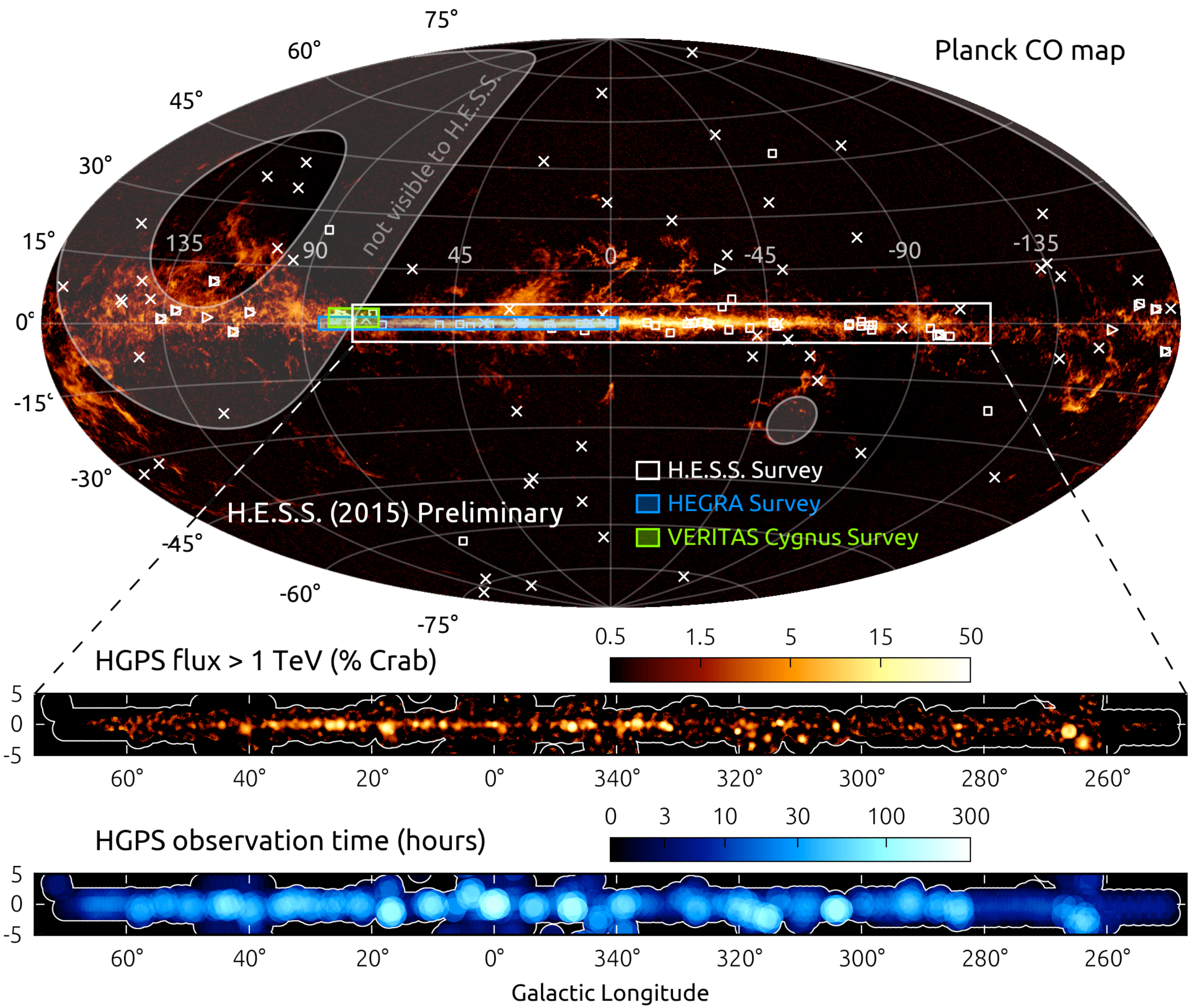


Galactic center

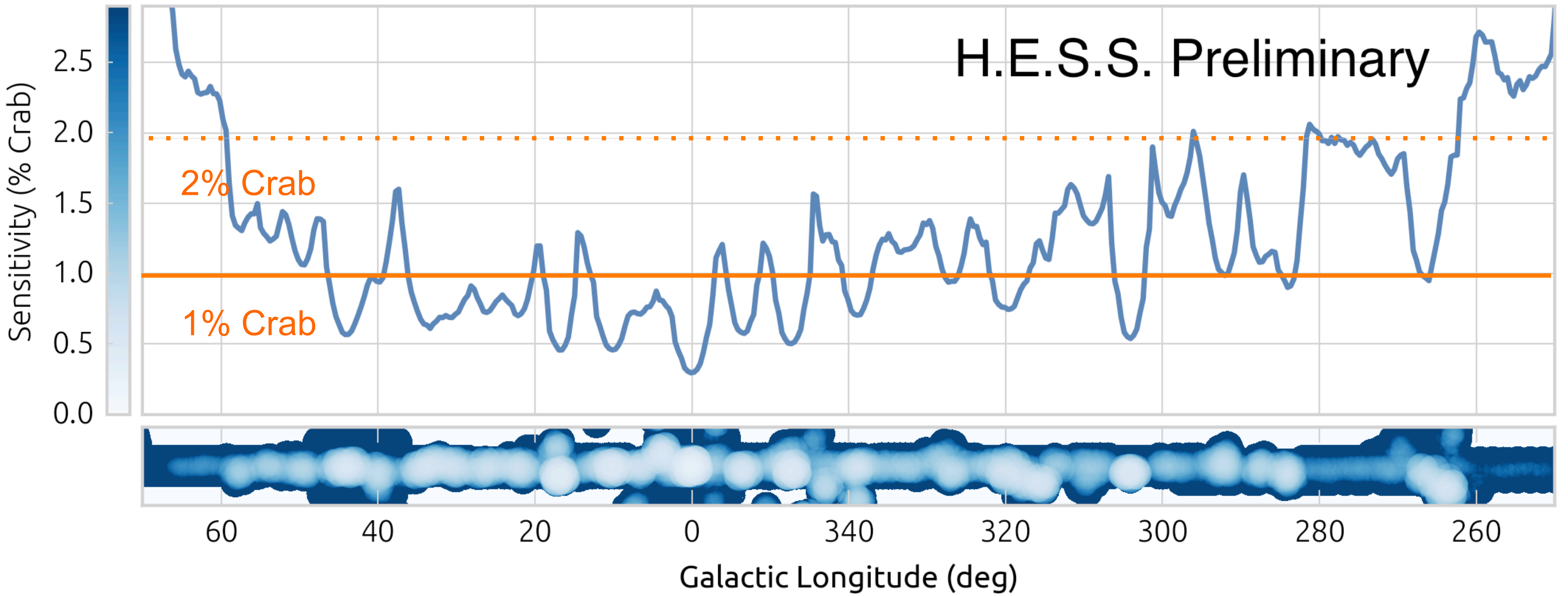



SURVEYS
(c) F. Acero & H. Gast

Galactic Plane Surveys



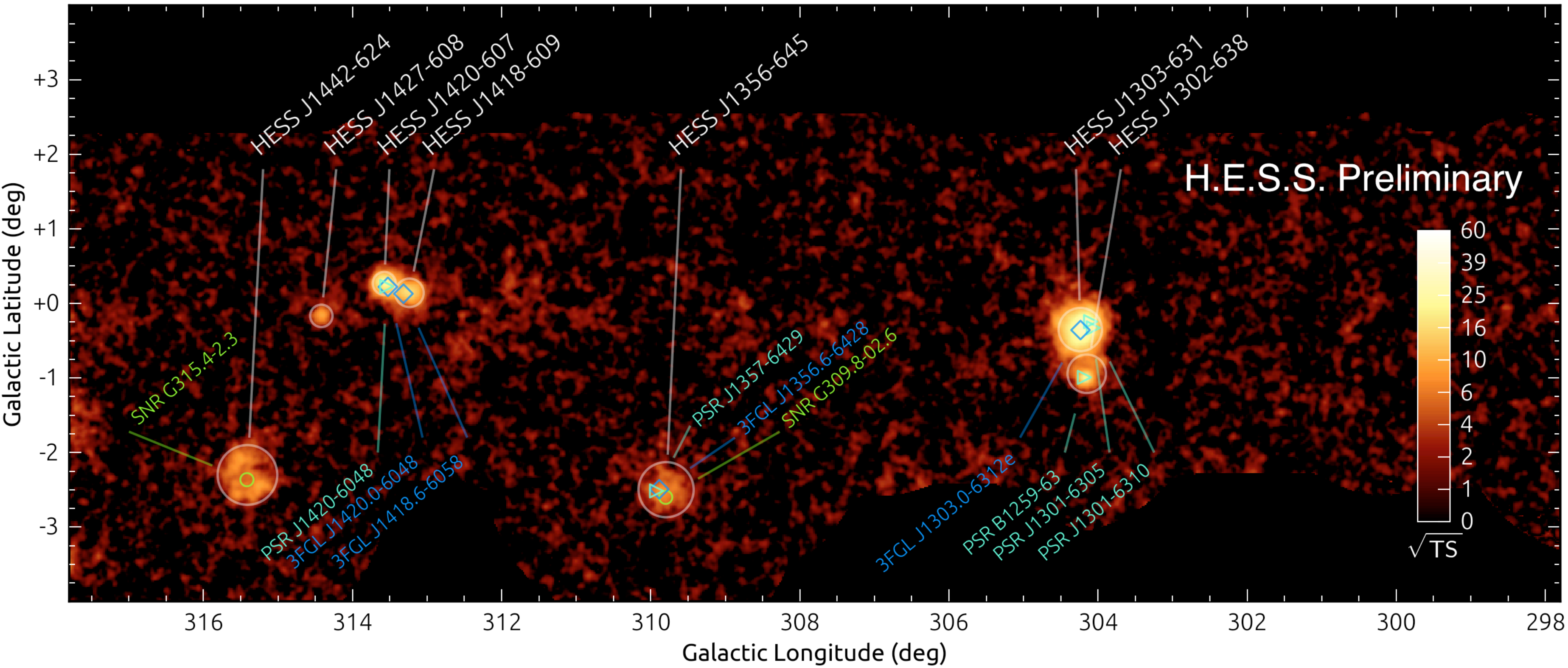
H.E.S.S. Galactic Plane Surveys



> 2673 hours of high-quality data, taken in the years 2004 to 2013.

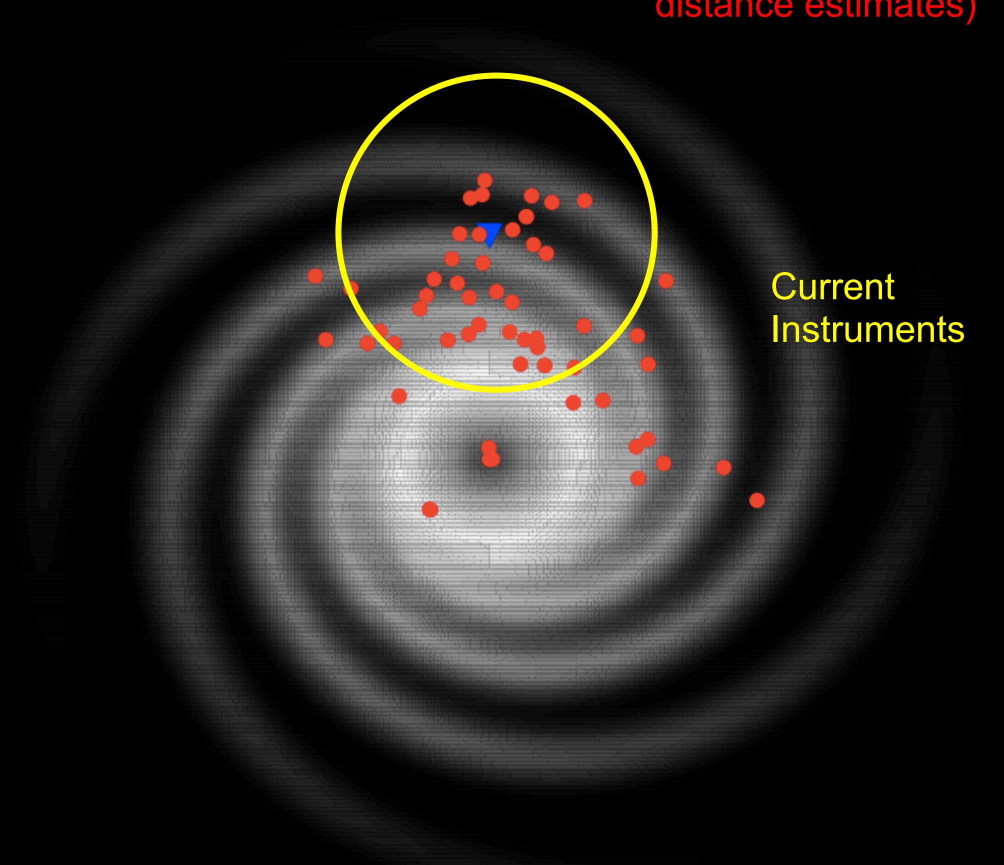
- Longitude l = 250 to 65 degrees, latitude |b| < 3.5 degrees
- Sensitivity for the detection of point-like sources is at the level of 2% Crab or better

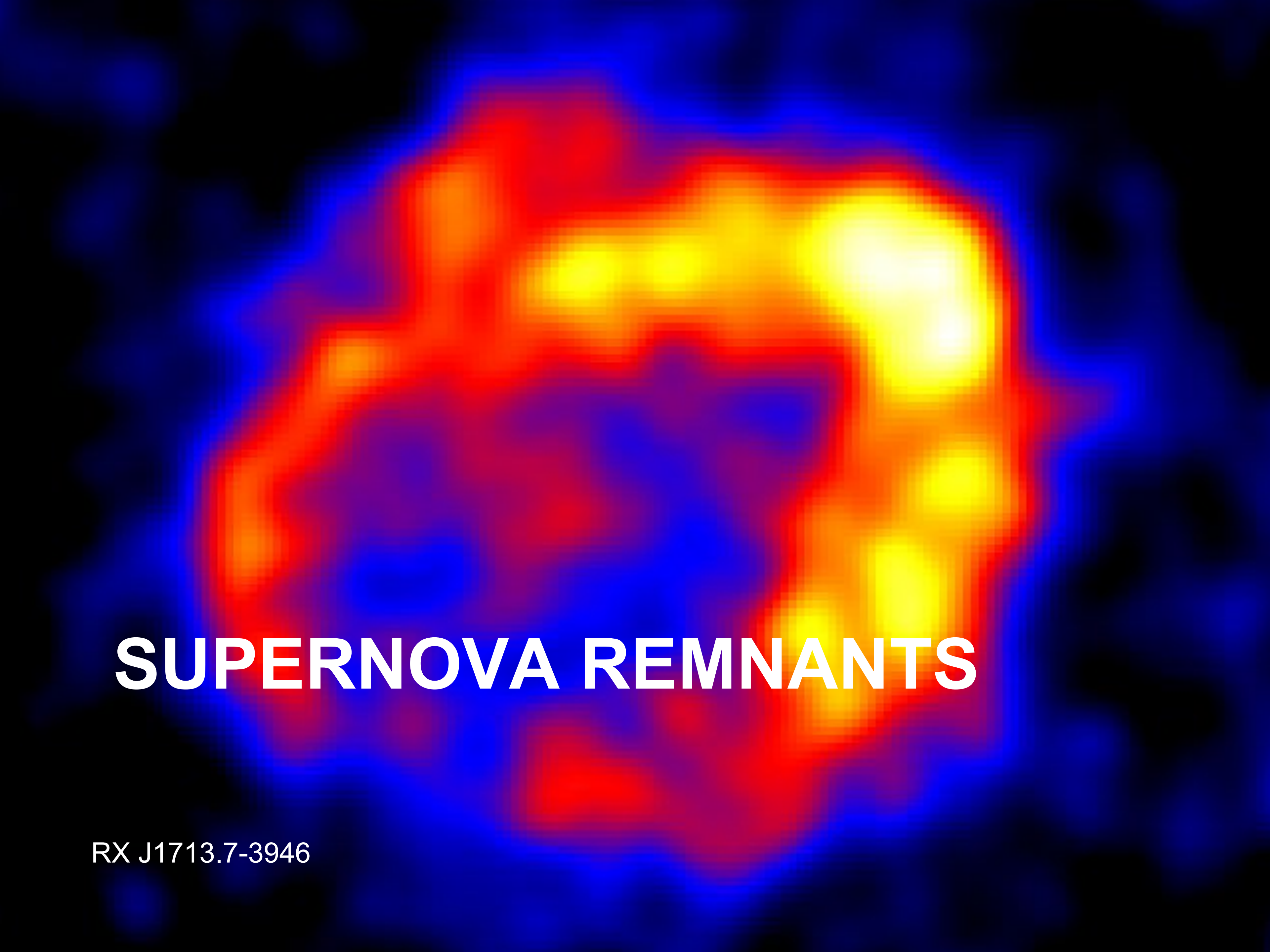
H.E.S.S. galactic plane survey



- Source extraction with automatic pipeline
- Likelihood fit of emission by multiple Gaussian components plus diffuse background, Overlapping emission components combined
- 66 VHE sources + 11 complex sources (e.g. shell SNR) excluded from pipeline

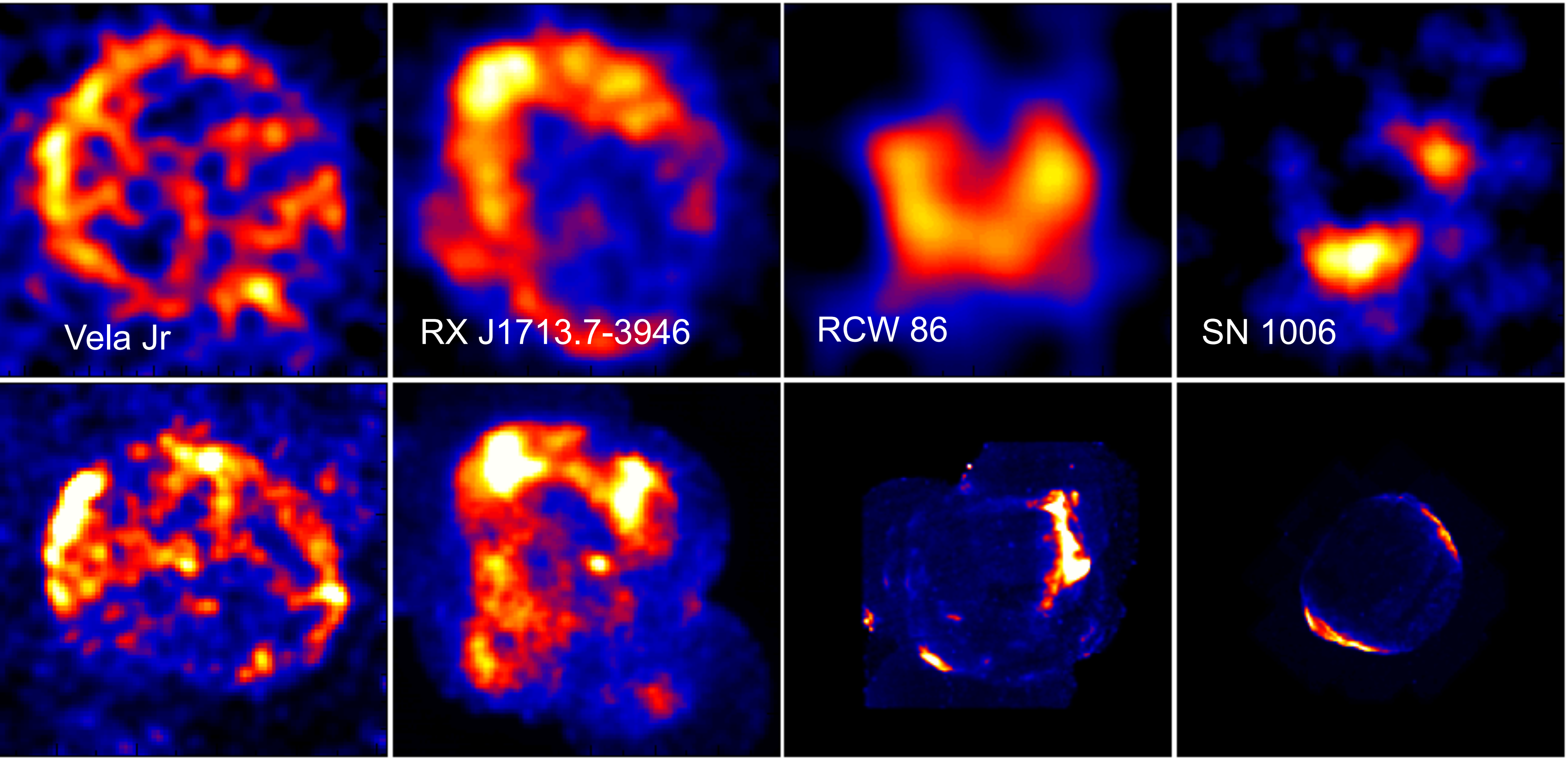
2% Crab Sensitivity




SUPERNOVA REMNANTS
RX J1713.7-3946

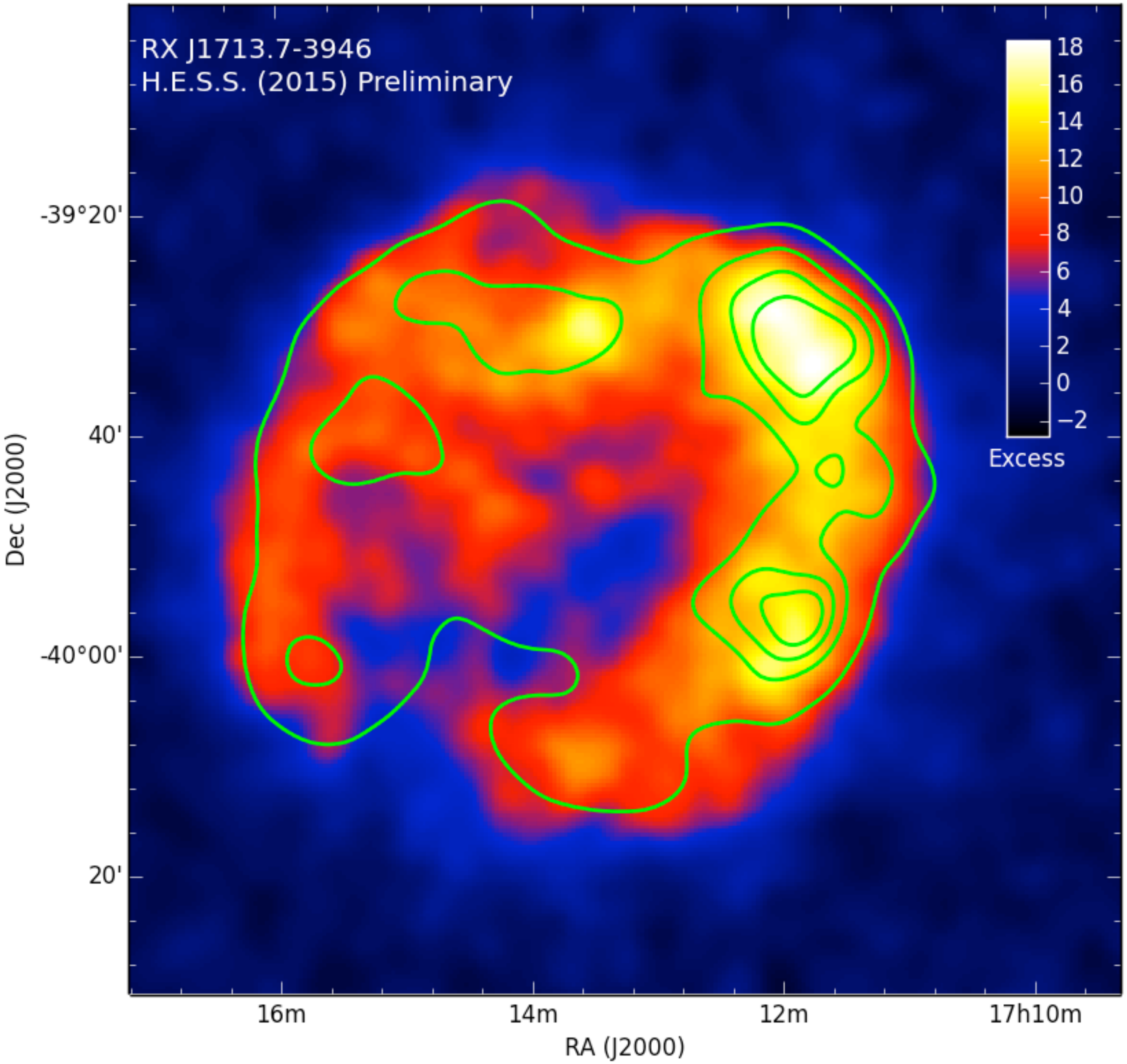
Examples of Supernova Remnants

Gamma rays



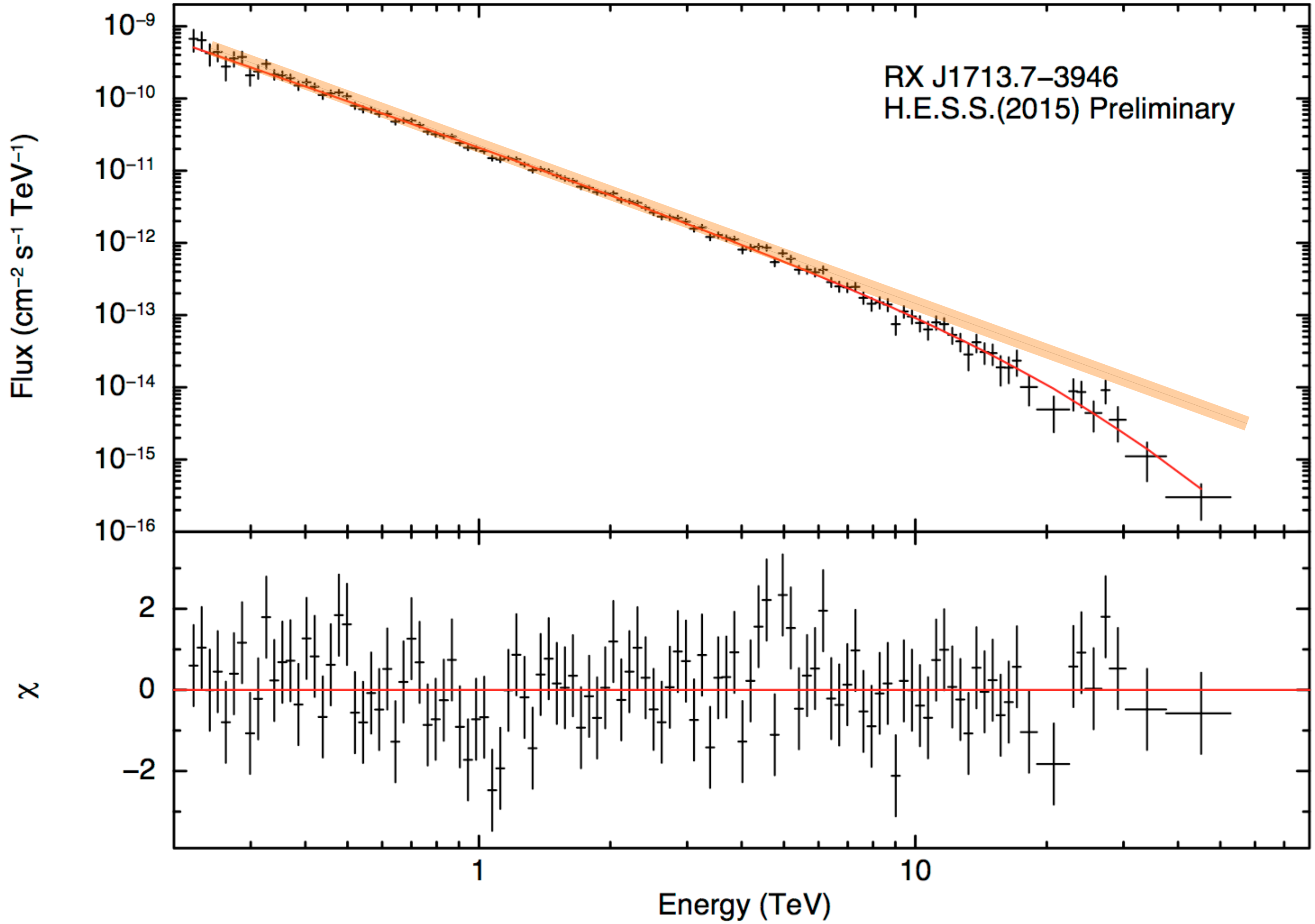
X rays

RX J1713.7-3946: Details of gamma-ray emission

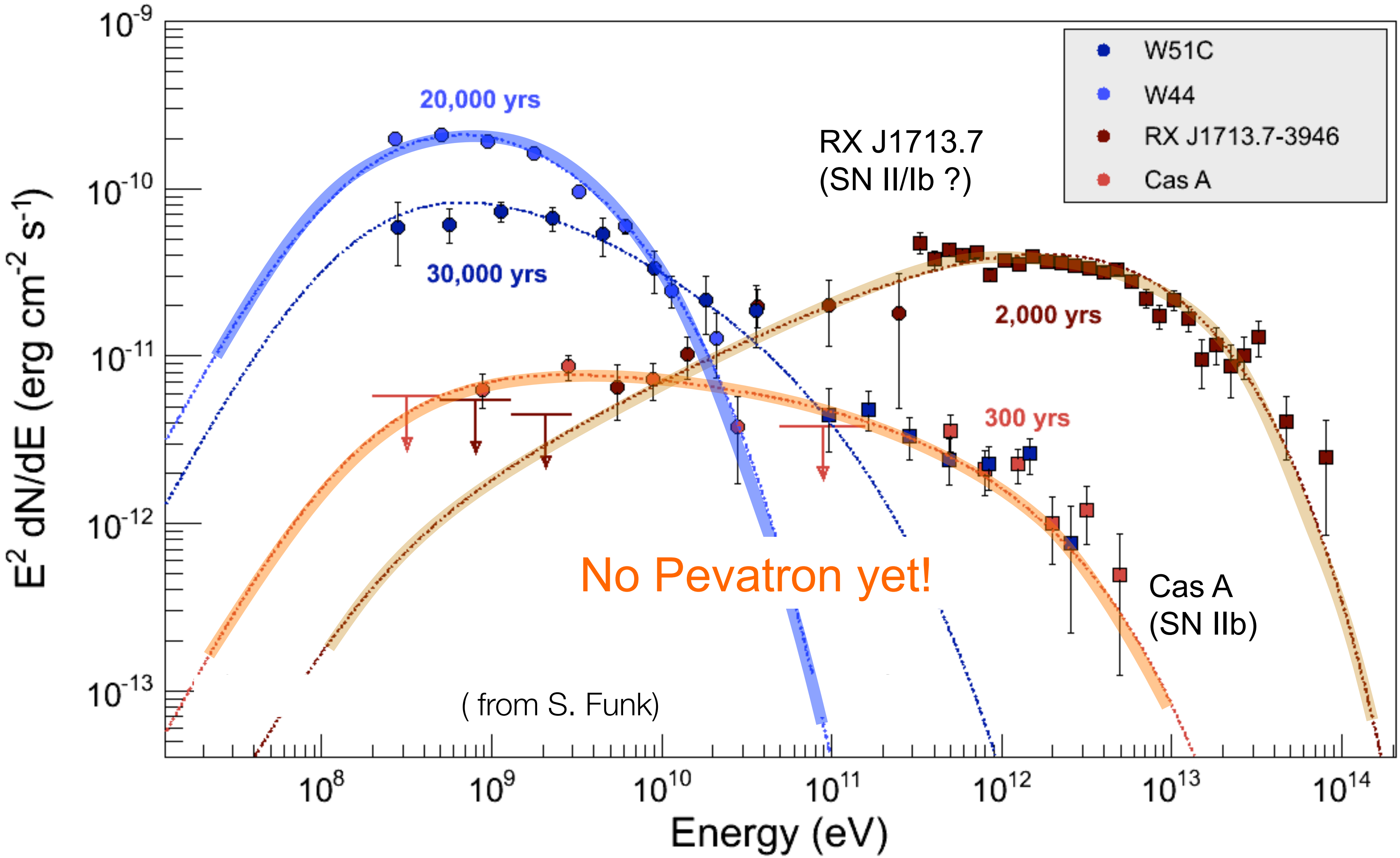


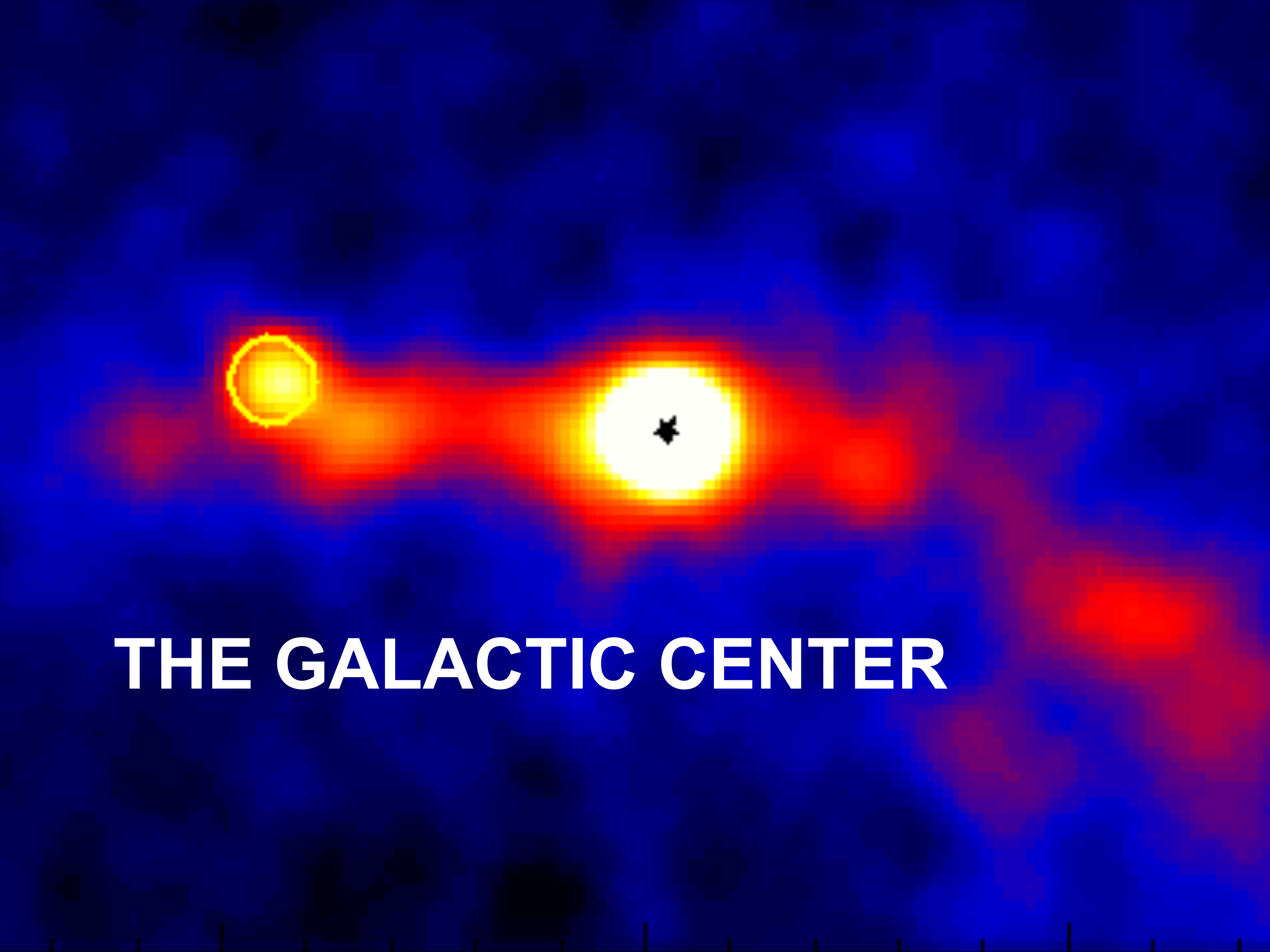
- High precision morphology
- Comparison of TeV and X-ray morphology

RX J1713.7-3946: Energy Spectrum



Evolution of Supernova Remnants?

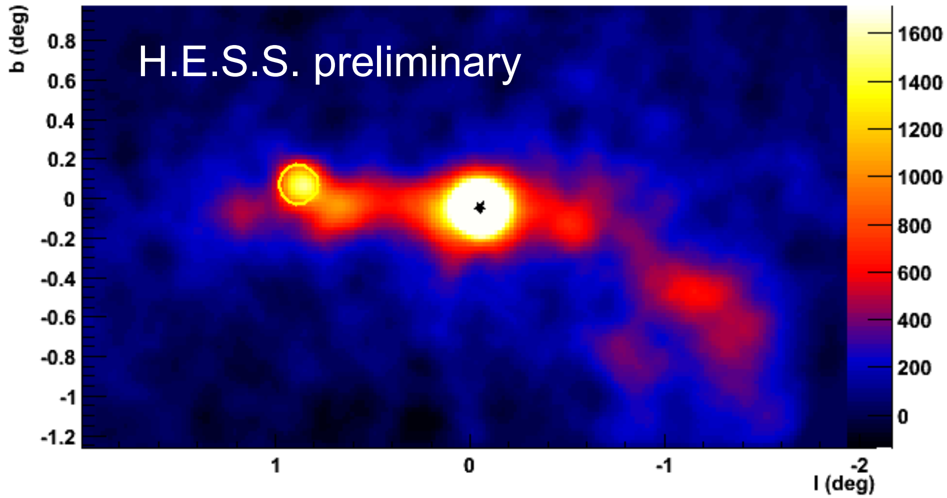


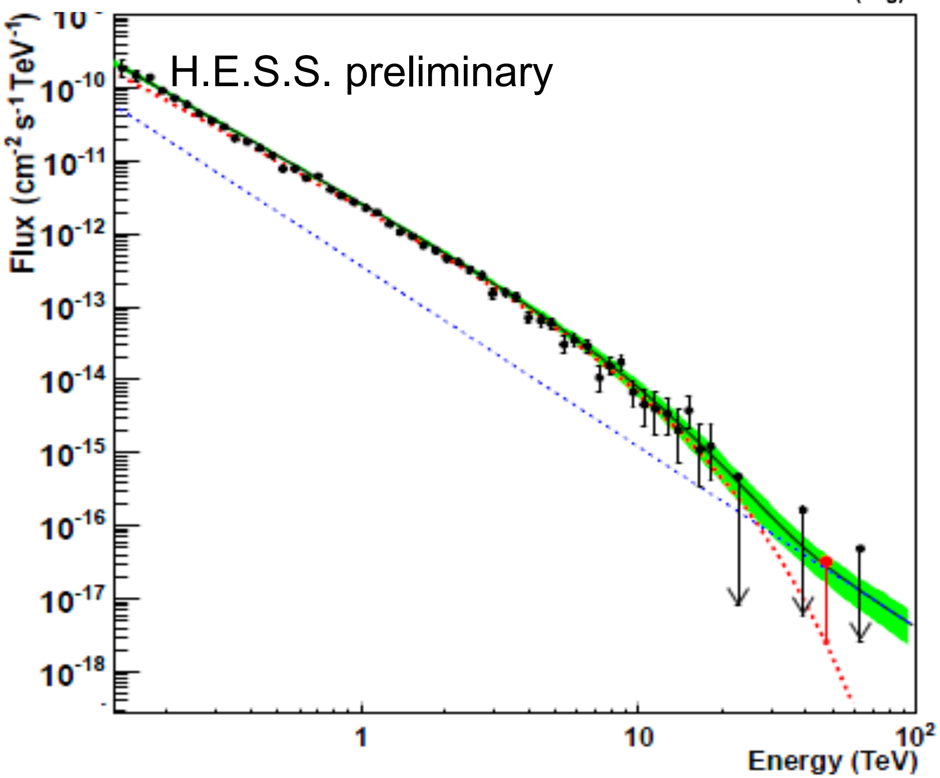

THE GALACTIC CENTER

The Galactic Centre at E > 200 GeV

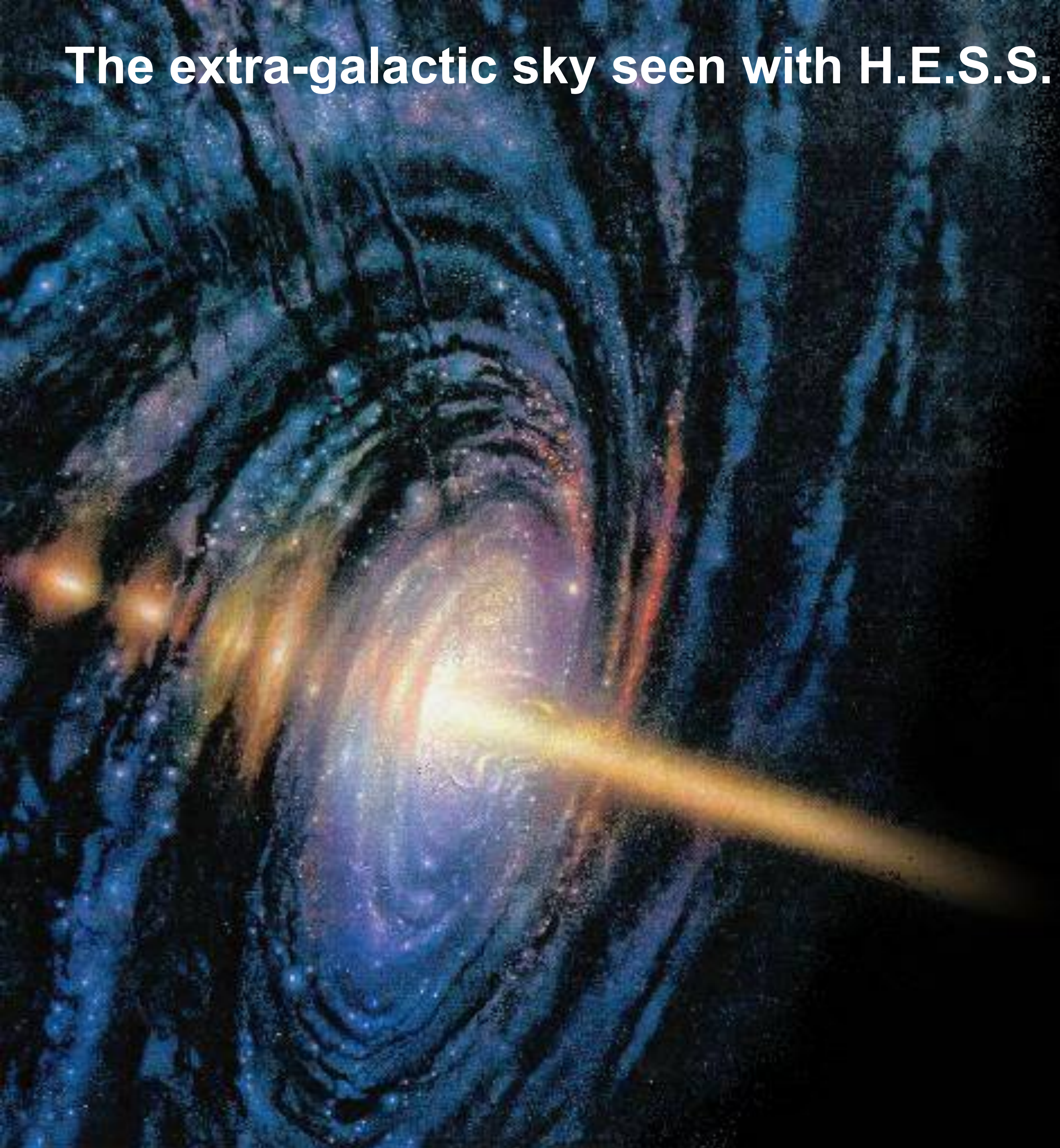
- > Intrinsic GC source spectrum
  - has a stronger cut-off ~ 7 TeV
- > Spectrum of diffuse emission
  - shows no indication of a cut-off below 25 TeV and
  - follows a power-law up to at least 50 TeV

→ Indication of a central source accelerating protons to energies > 500 TeV ?

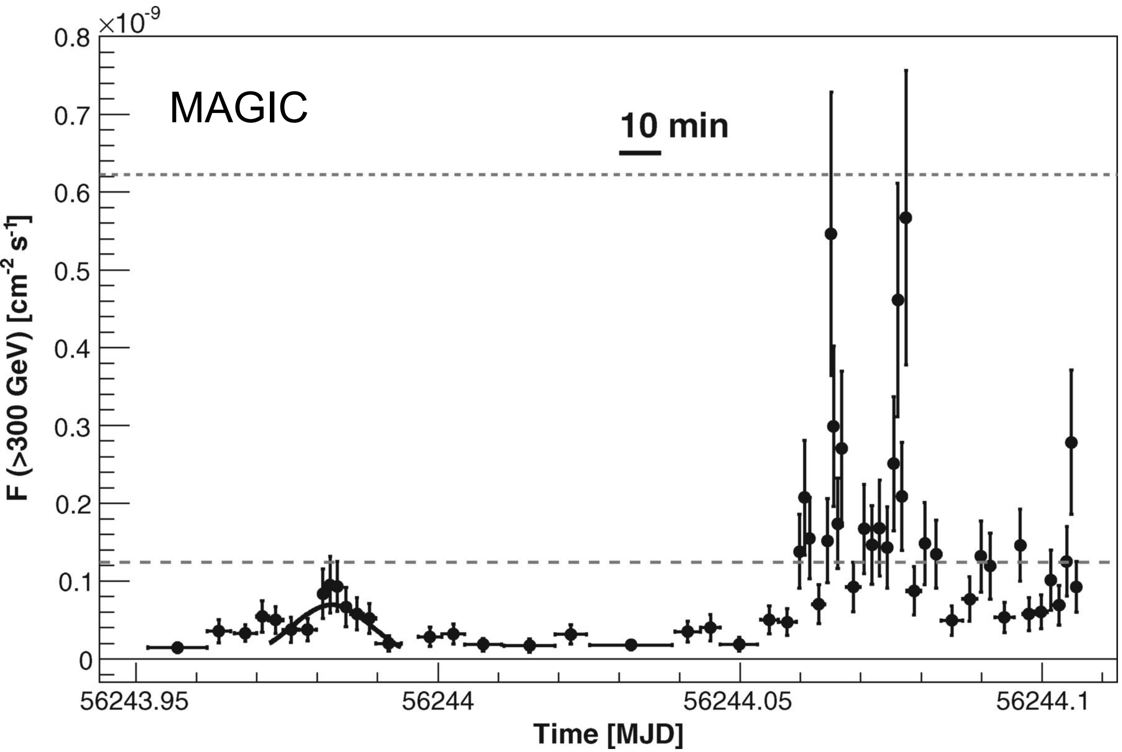


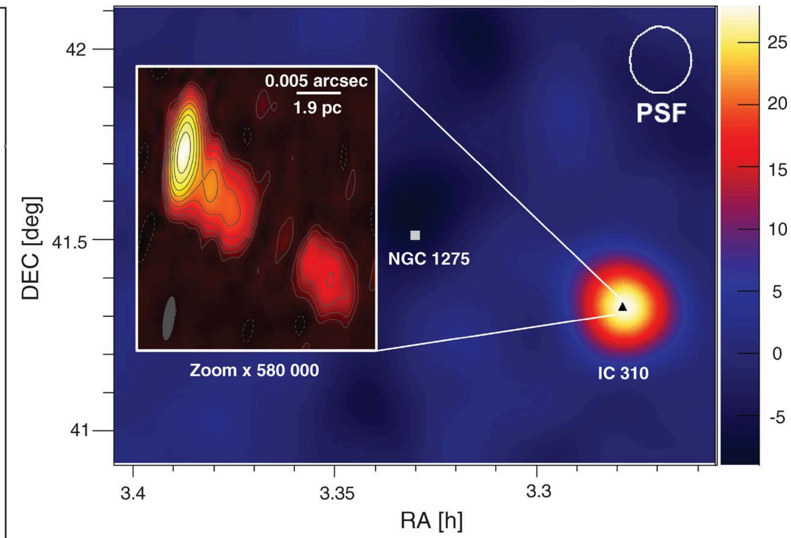


The extra-galactic sky seen with H.E.S.S.



Time Variability: IC 310

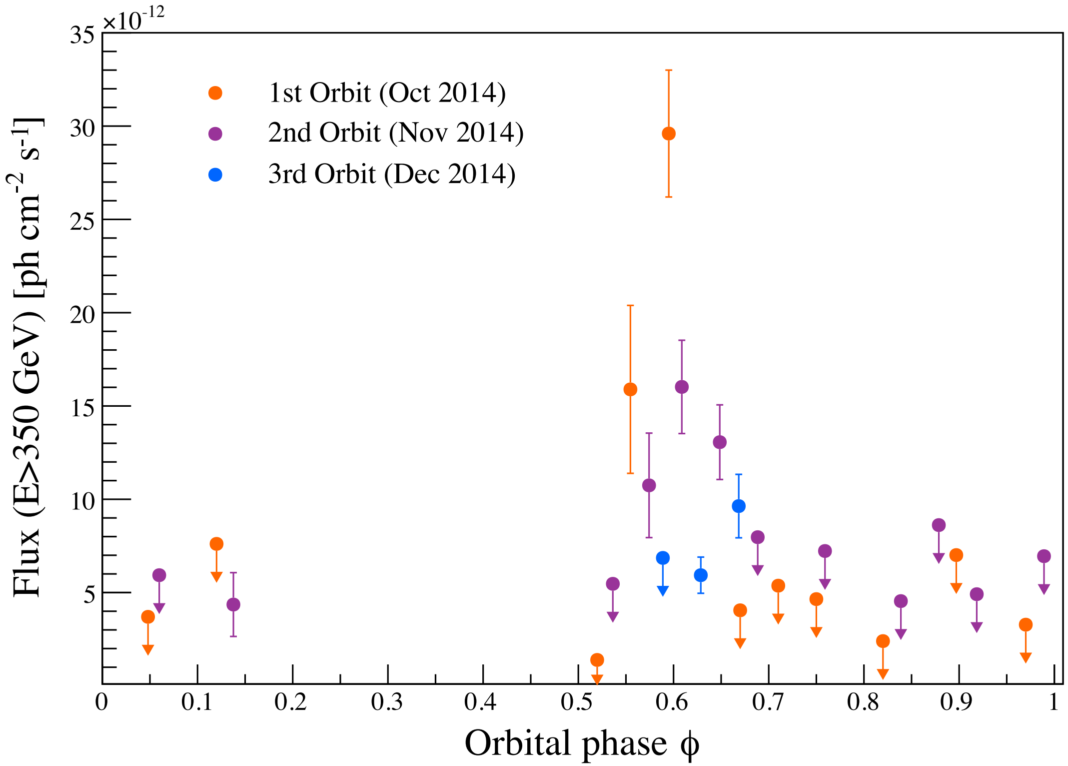




Science *346 (6213)*

- The closest blazar (z=0.019)
  - Previously thought to be a (large viewing angle) radio galaxy, new: VLBI jet
- Extreme variability seen with MAGIC
  - Despite larger jet viewing angle ~15°

Historically bright flares of LS I +61 303 in 2014



VERITAS Detection of Historically Bright TeV Flares From LS I +61 303

ATel #6785; *Jamie Holder (for the VERITAS Collaboration)*
*on **5 Dec 2014; 19:56 UT***
Credential Certification: Jamie Holder (jholder@physics.udel.edu)

Subjects: Optical, Ultra-Violet, X-ray, Gamma Ray, >GeV, TeV, VHE, Binary

Referred to by ATel #: 6786

Tweet 4 Recommend 4

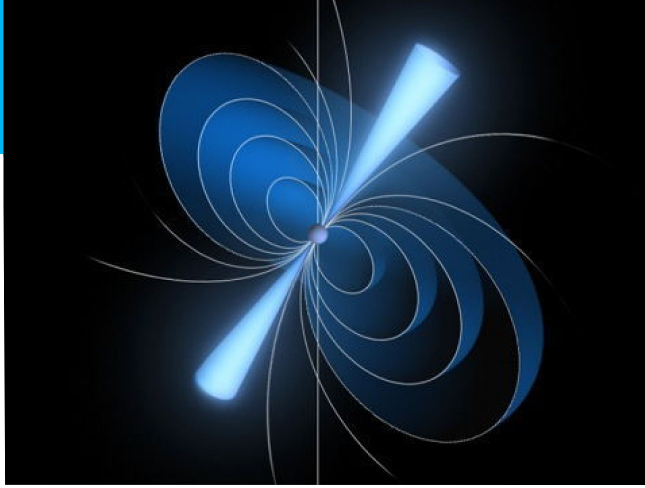
The VERITAS collaboration reports the detection of brief and intense gamma-ray flaring activity from the binary system LS I +61 303. The flares occurred over a sharply defined phase range (from phase 0.55 to 0.65) during two orbital cycles in October and November 2014. If the source behaves similarly over the next orbit, this represents an unprecedented opportunity to study the high energy processes in this enigmatic system.

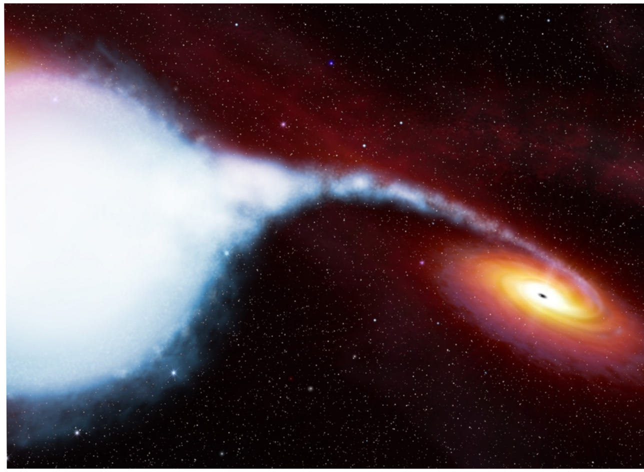
As a part of a multi-wavelength campaign with VERITAS, Swift-XRT, Ritter Observatory, and Fermi-LAT, VERITAS has been monitoring the known TeV binary source LS I +61 303 (orbital period of ~26.5 days) since October 16, 2014 (MJD 56946). In preliminary analysis, we have detected the source at a statistical significance of >15 sigma in ~20 hours of observations. During these observations, LS I +61 303 displayed relatively short (1-2 days duration), bright TeV flares with a flux peak above 25% of the Crab Nebula flux (>300 GeV). In both orbital periods sampled, these flares were centered on orbital phase = 0.6. Historically, the source has presented a flux level of 5-15% of the Crab Nebula during its active phases, making these flares the brightest ever detected from this source.

- VERITAS monitoring of the binary system LS I +61 303
- Peak flux above 25% Crab
- Contemporaneous light curves from Swift-XRT (0.3-10 keV) and Fermi-LAT (0.3-300 GeV) do not show evidence for similarly high emission

Many more science…

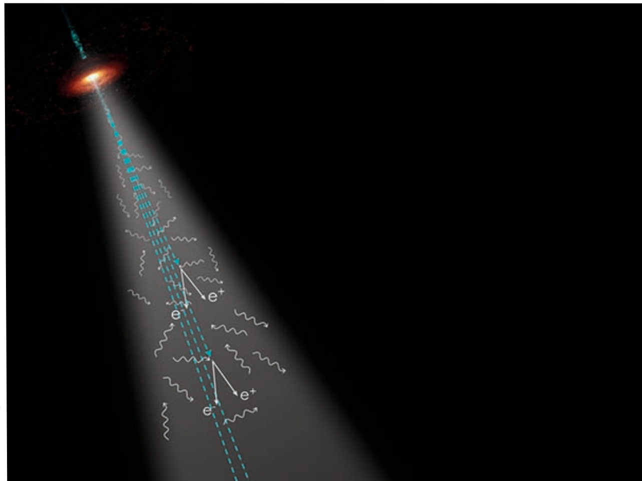
- Imaging of cosmic particle acceleration sites
- Physics of pulsars and pulsar winds
- Binary systems
- …





- Properties of AGN
- Probing the extragalactic background light
- …

- Limits on dark matter and new physics
- …



- **We just see the tip of the iceberg**

How to do better?

> More events

- more photons = better spectra, images, fainter sources

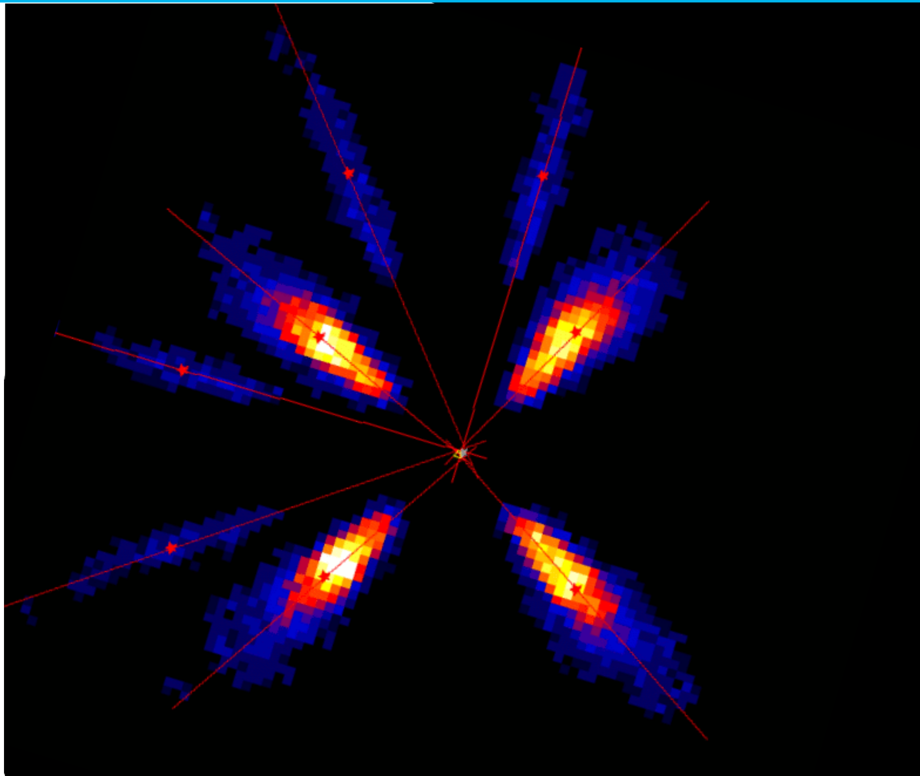
→ **larger collection area for gamma-rays**

> Better events

- more precise measurements of atmospheric cascades and hence primary gammas

→ **improved angular resolution**

→ **improved background rejection power**



Simulation: Superimposed images from 8 cameras

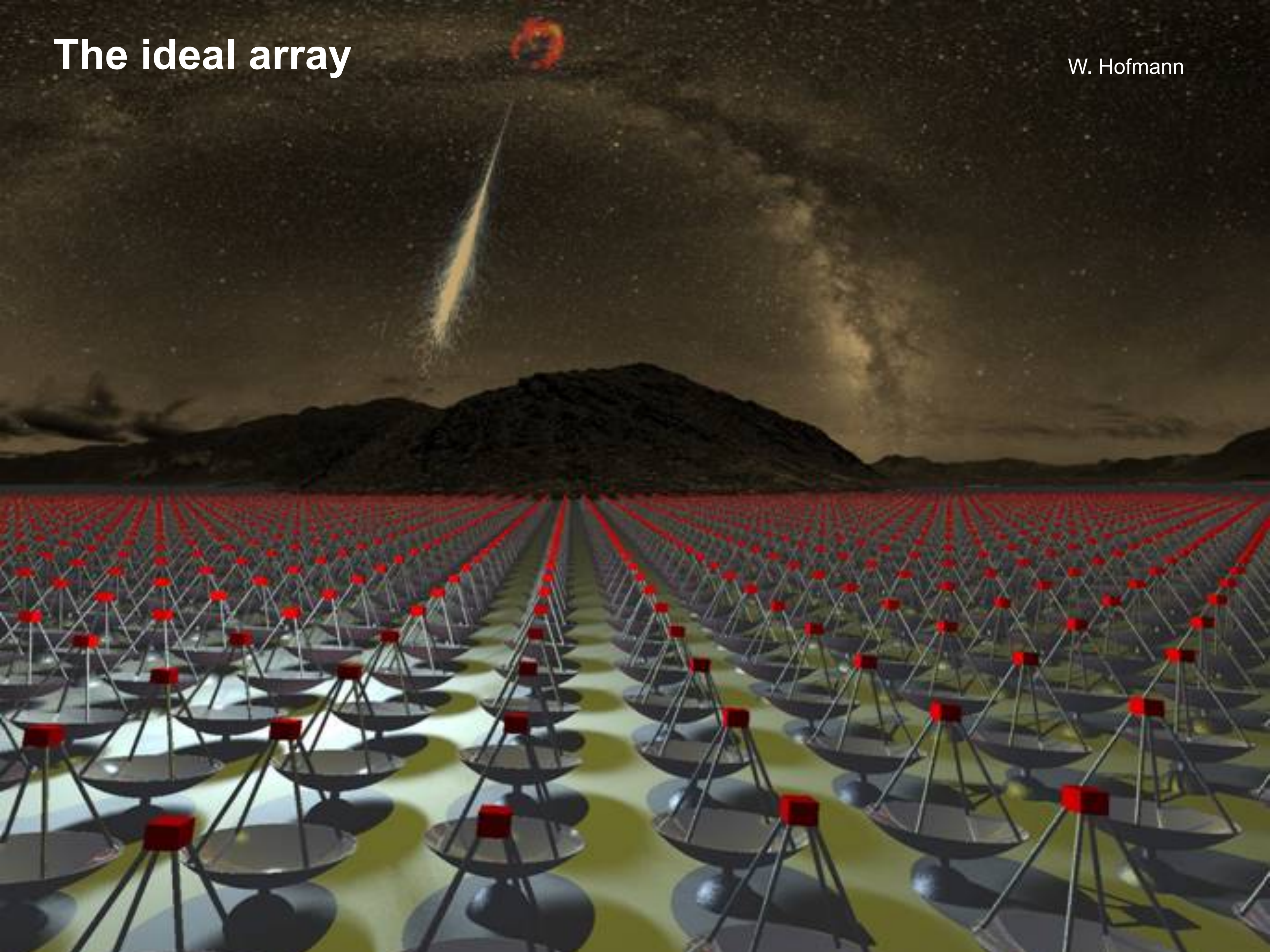
→ **More telescopes!**

cta

cherenkov telescope array

The ideal array

W. Hofmann



The affordable compromise

W. Hofmann

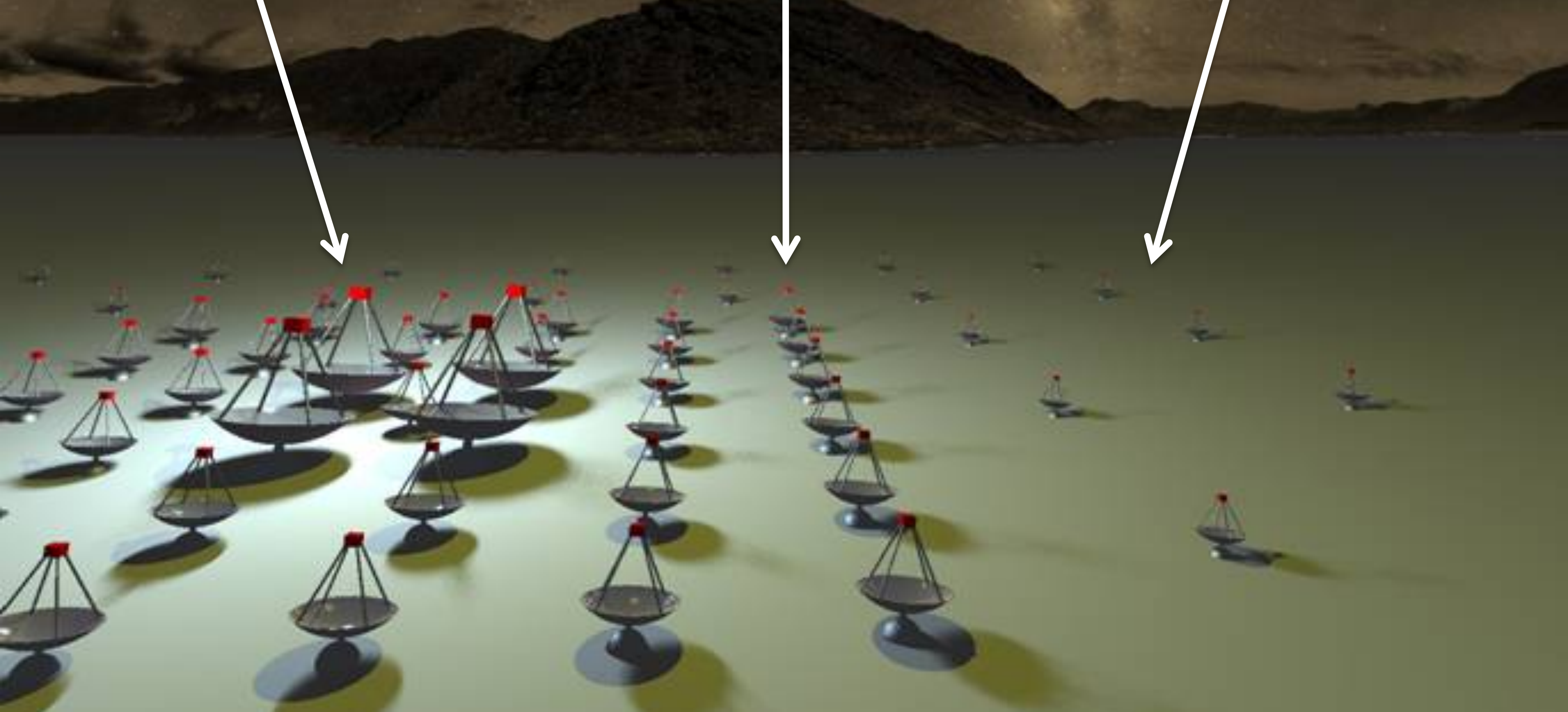
The affordable compromise

W. Hofmann

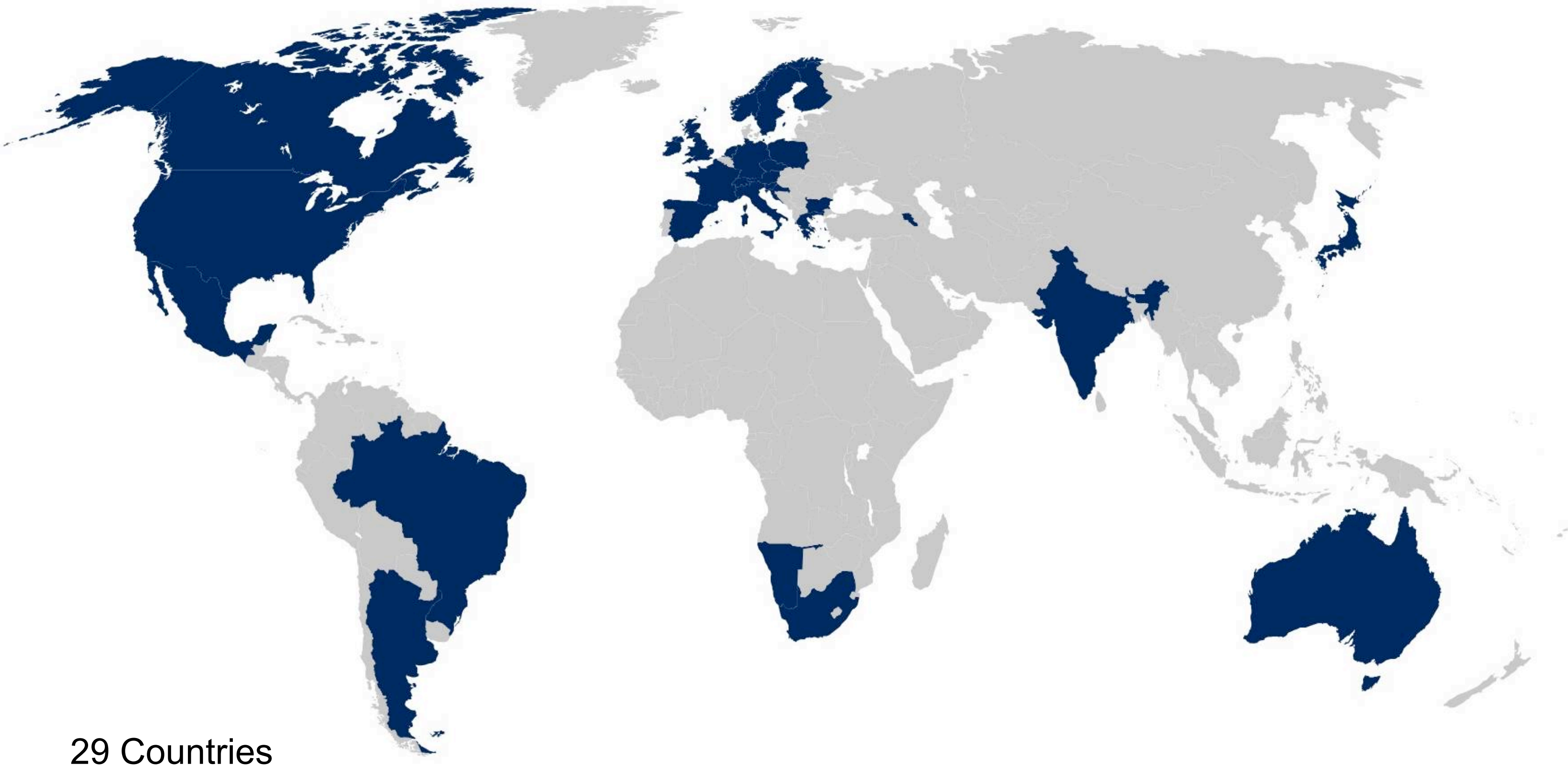
Low energy section
Energy threshold of some 10 GeV

Medium energy section
mCrab sensitivity in the 100 GeV – 10 TeV domain

High energy section
10 km^2 area at multi-TeV energies



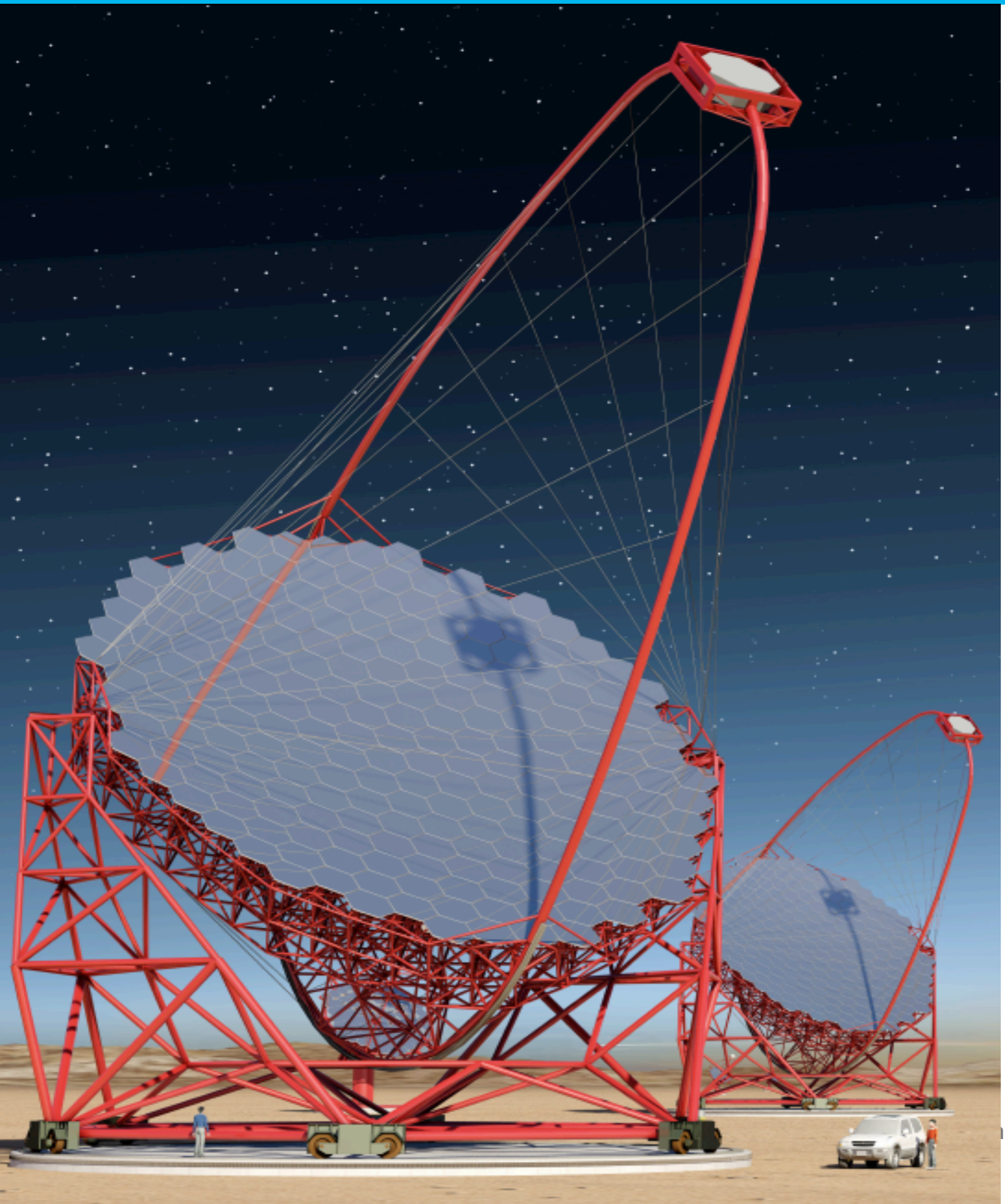
CTA: A Worldwide Consortium



29 Countries
178 Institutes
1187 Members

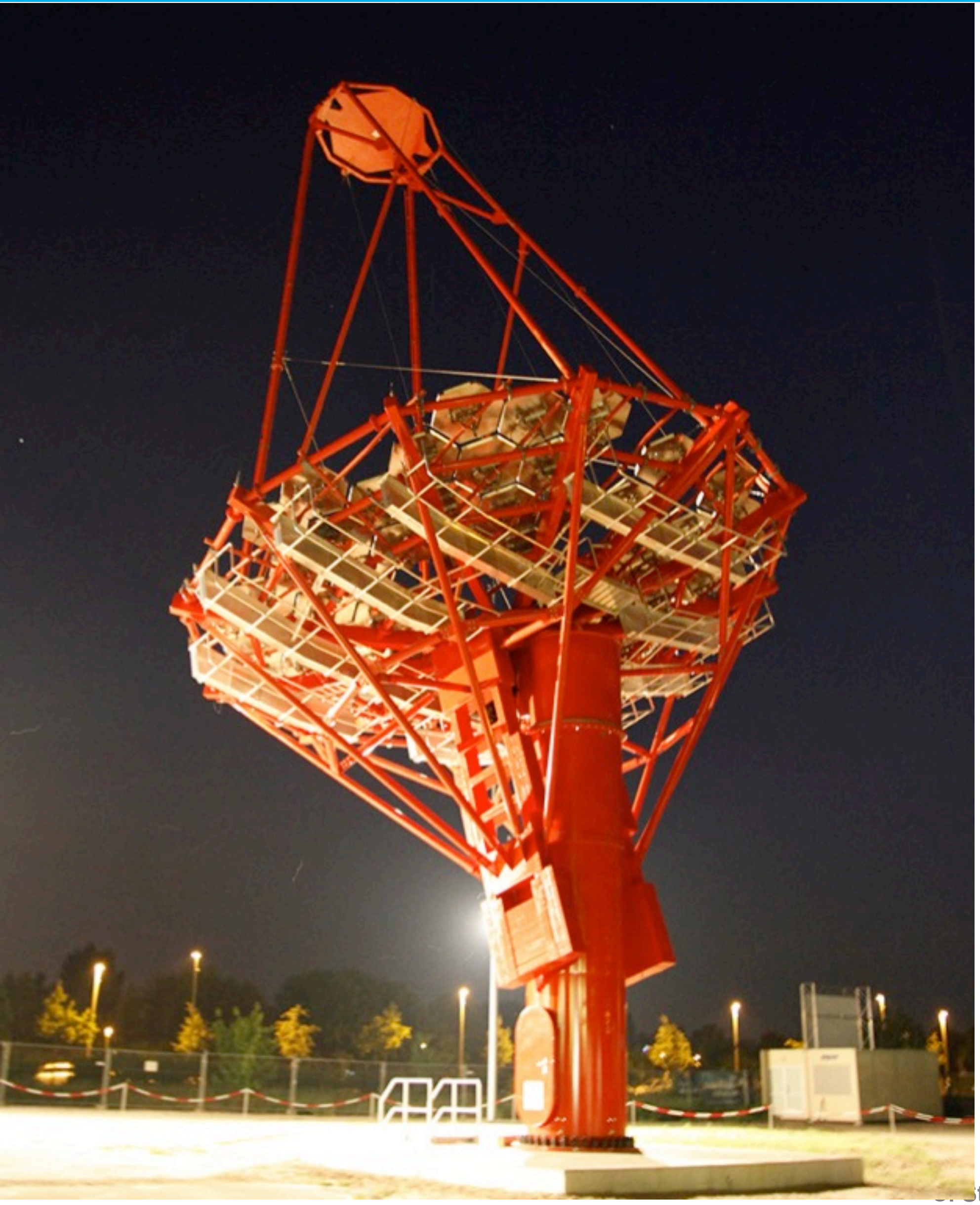
Site selection

Large Size Telescopes LST



- Structure
  - 23 m diameter (389 m^2)
  - 28 m focal length
  - 1.5 m mirror facets
- Camera
  - 4.5° field of view
  - 0.1° PMT pixels
  - Camera ∅ over 2 m
- Carbon-fiber structure for 20 s positioning
- **4 LSTs on South site**
- **4 LSTs on North site**
- **Prototype = 1st telescope**

Medium Size Telescopes MST



MST prototype in Berlin

> Structure
- 12m diameter (100 m^2)
- 16 m focal length
- 1.2 m mirror facets

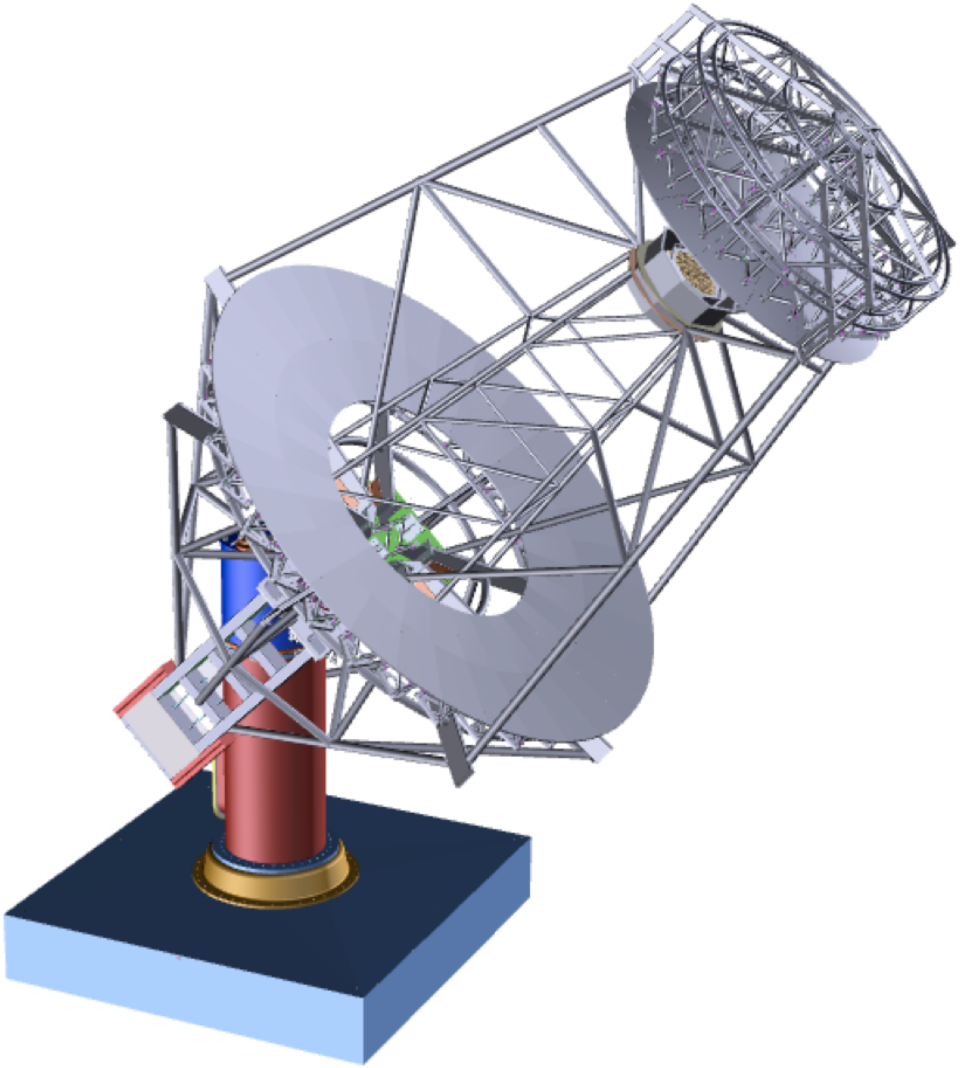
> Camera
- 8^o field of view
- ~2000 x 0.18^o PMT pixels

> **25 MSTs on South site**

> **15 MSTs on North site**

> **Prototype operational**

Medium Size Telescopes (MST) with dual mirror



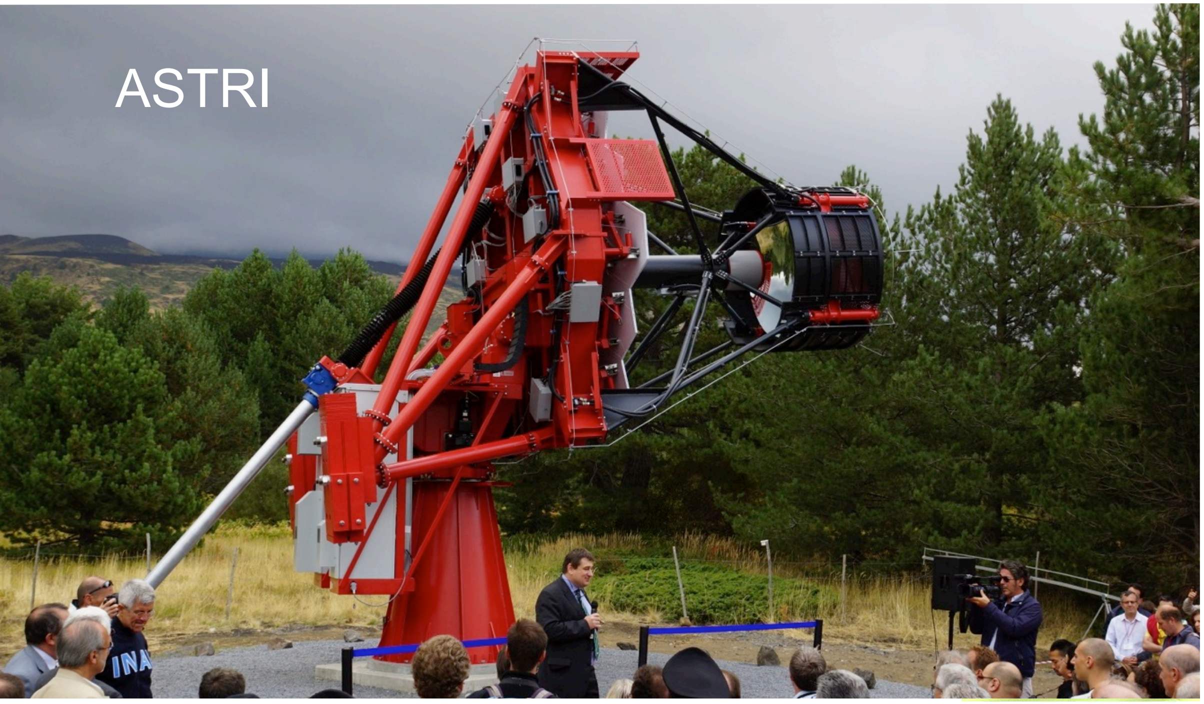
- **Structure**
  - 9.7 m primary
  - 5.4 m secondary
  - 40 m^2 eff. coll. area
  - PSF better than 4.5' across 8^o fov
- **Camera**
  - 8^o field of view
  - **11328 x 0.07^o SiPMT pixels**
- **Extend South array by adding 24 SCTs**

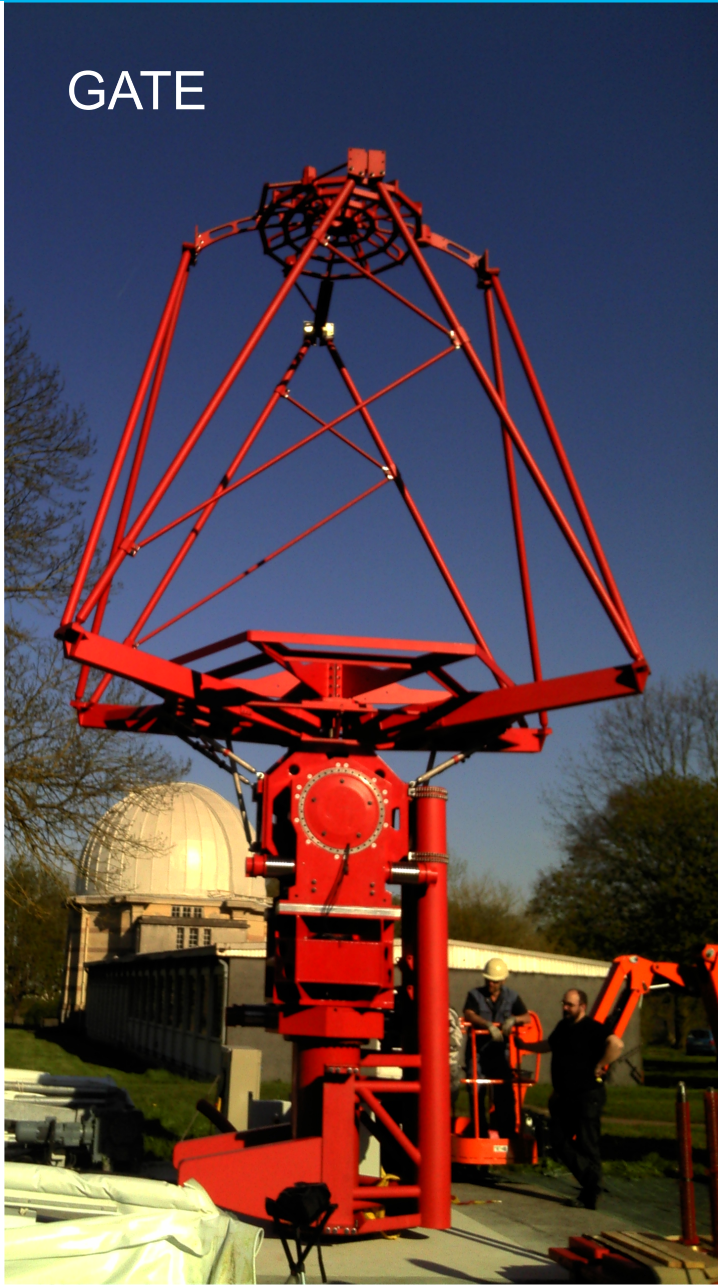
➜ increased γ-ray collection area and γ-ray angular resolution

Small Size Telescopes

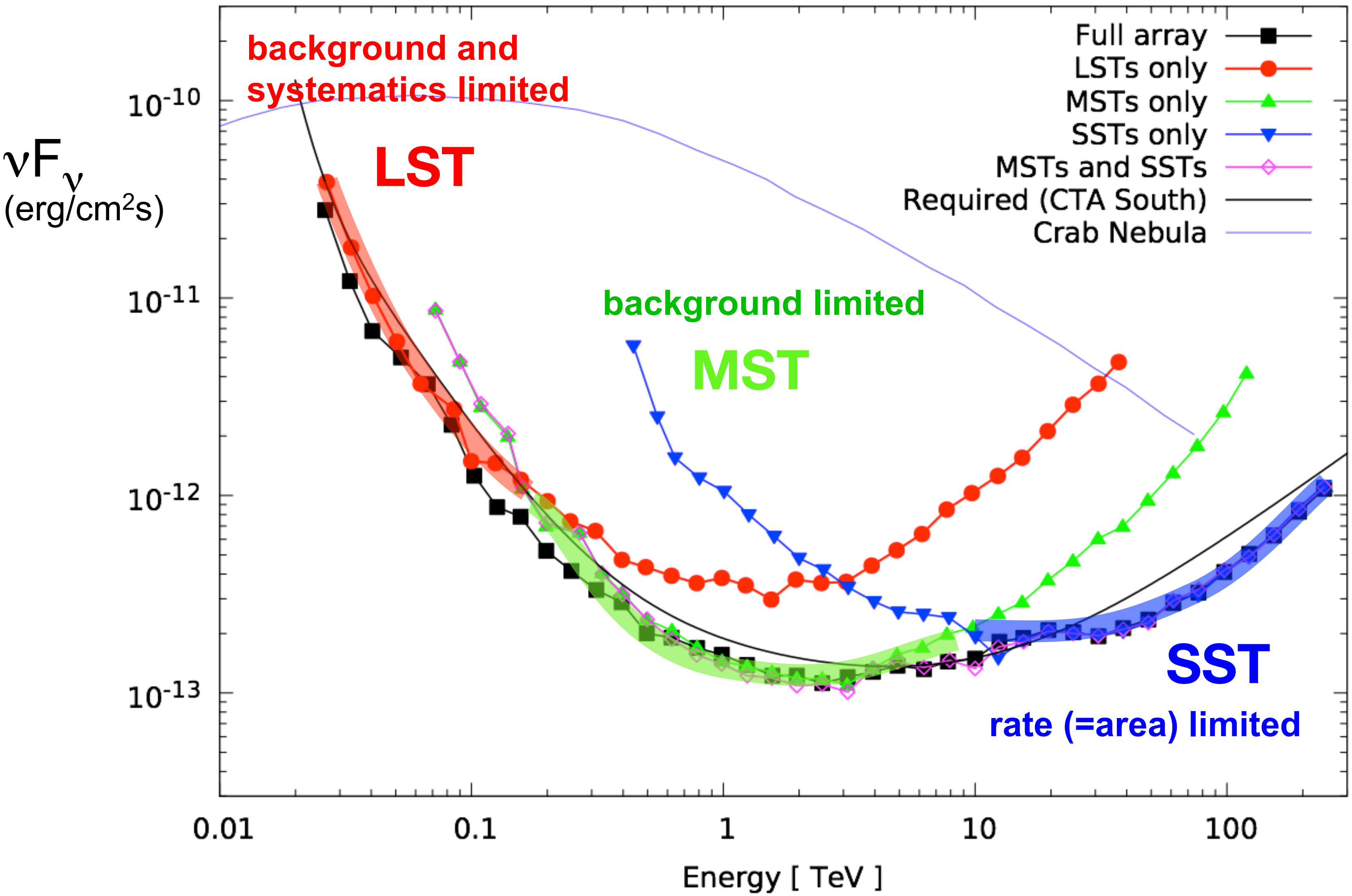
- **70 SSTs for South site**
- Different designs under consideration
- Single mirror design
  - SST-1M
- Dual mirror design
  - ASTRI
  - GATE

SST Prototypes





Sensitivity



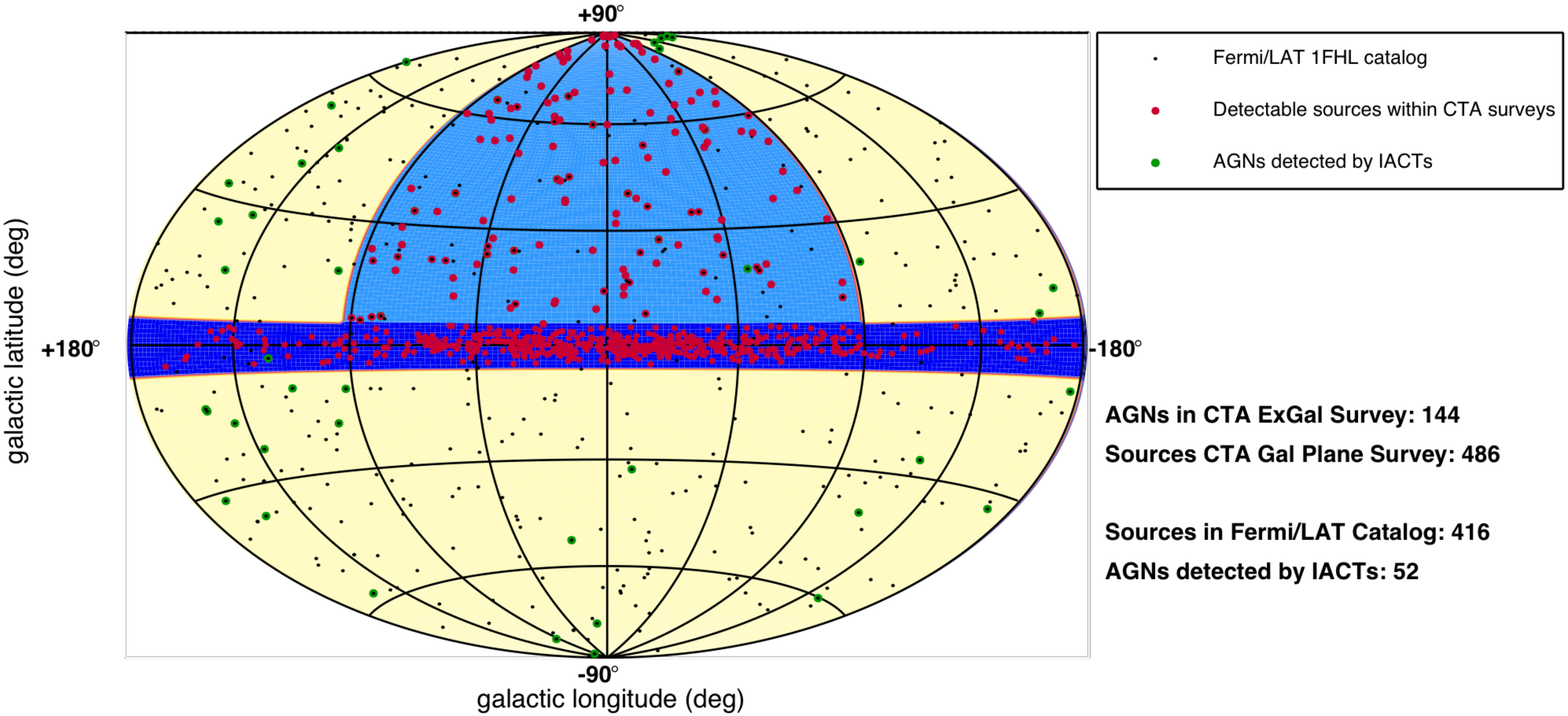
Science drivers for CTA

- Theme 1: Cosmic Particle Acceleration
  - How and where are particles accelerated?
  - How do they propagate?
  - What is their impact on the environment?
- Theme 2: Probing Extreme Environments
  - Processes close to neutron stars and black holes?
  - Processes in relativistic jets, winds and explosions?
  - Exploring cosmic voids
- Theme 3: Physics Frontiers – beyond the SM
  - What is the nature of Dark Matter? How it is distributed?
  - Is the speed of light a constant for high energy particles?
  - Do axion-like particles exist?

Key Science Questions and Key Science Projects

Theme		Question	Dark Matter Programme	Galactic Centre	Galaxy Clusters	LMC Survey	Active Galaxies	Star-forming Systems	Galactic Plane Survey	Extreme Accelerators	Transients	Extragalactic Survey	Cygnus Region
Understanding the Origin and Role of Relativistic Cosmic Particles	1.1	What are the sites of high-energy particle acceleration in the universe?		✔	✔✔	✔✔	✔	✔	✔✔	✔	✔✔	✔✔	✔
	1.2	What are the mechanisms for cosmic particle acceleration?		✔		✔	✔✔	✔	✔	✔✔	✔✔		✔
	1.3	What role do accelerated particles play in feedback on star formation and galaxy evolution?		✔	✔	✔	✔	✔✔					✔
Probing Extreme Environments	2.1	What physical processes are at work close to neutron stars and black holes?		✔		✔	✔✔		✔	✔✔			✔
	2.2	What are the characteristics of relativistic jets, winds and explosions?		✔		✔	✔✔		✔	✔✔	✔✔	✔	✔
	2.3	How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?					✔✔				✔	✔	
Exploring Frontiers in Physics	3.1	What is the nature of Dark Matter? How is it distributed?	✔✔	✔✔	✔	✔							
	3.2	Are there quantum gravitational effects on photon propagation?					✔✔			✔	✔✔		
	3.3	Do Axion-like particles exist?					✔✔				✔	✔	

Survey Sensitivity



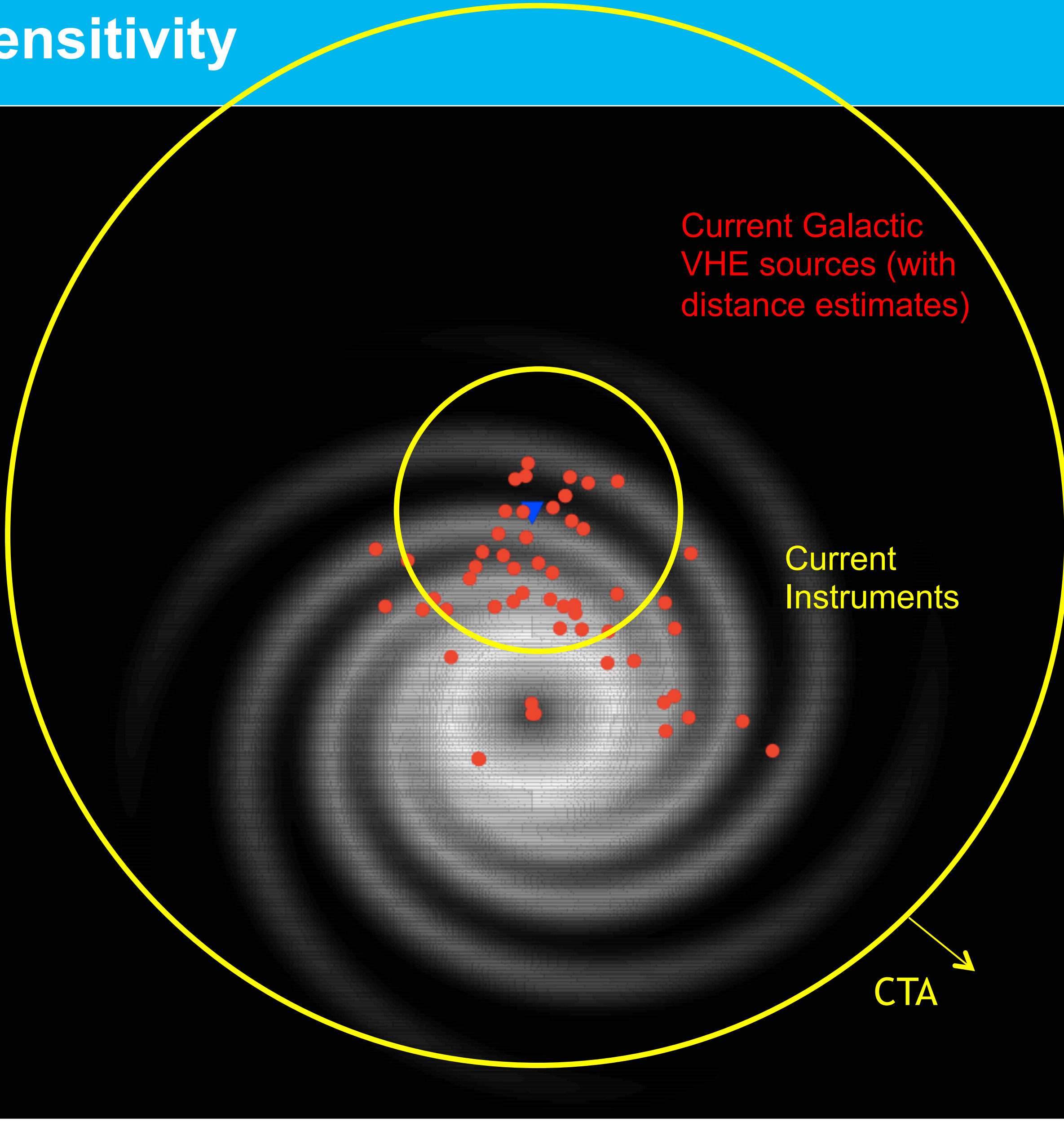
AGNs in CTA ExGal Survey: 144

Sources CTA Gal Plane Survey: 486

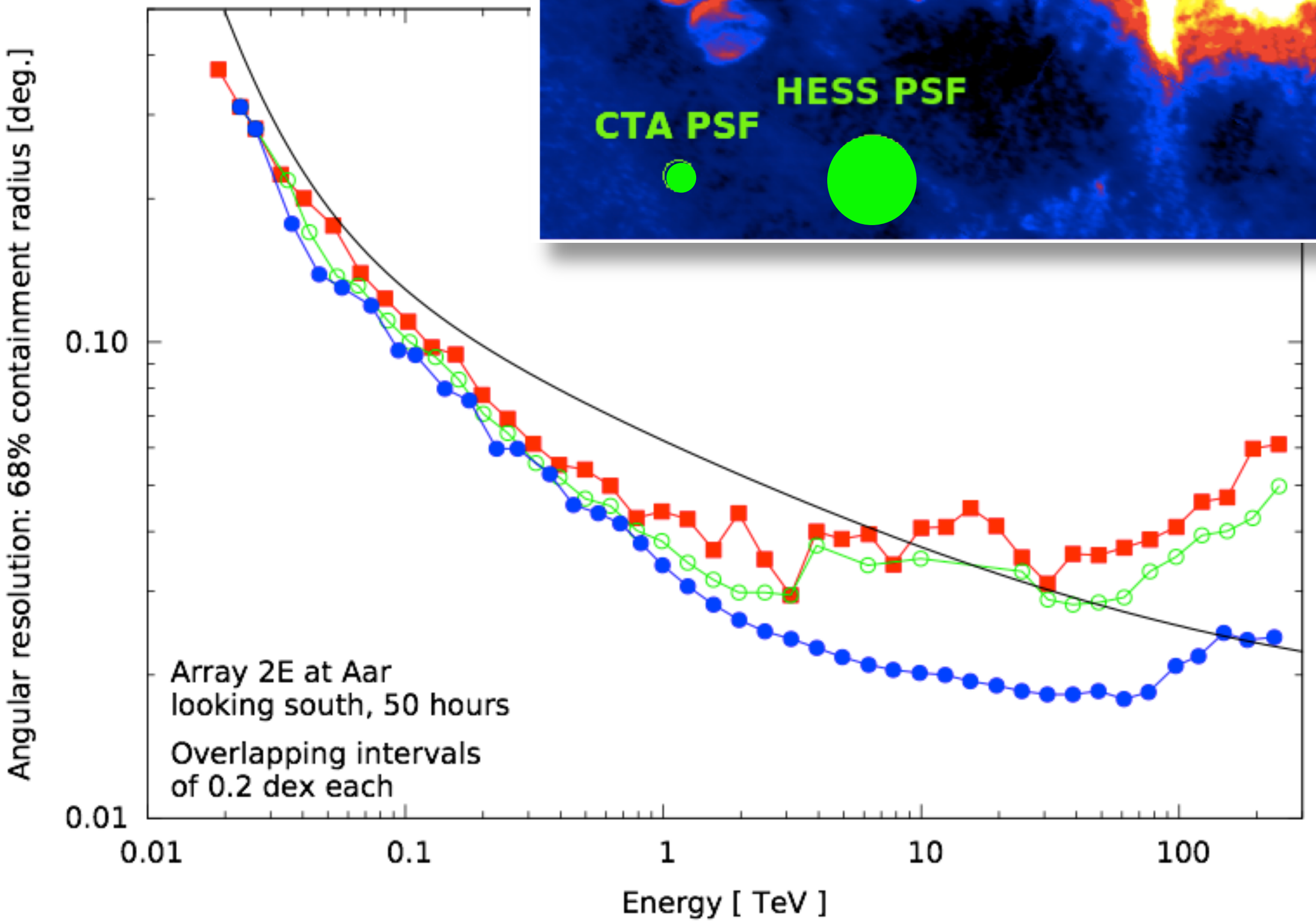
Sources in Fermi/LAT Catalog: 416

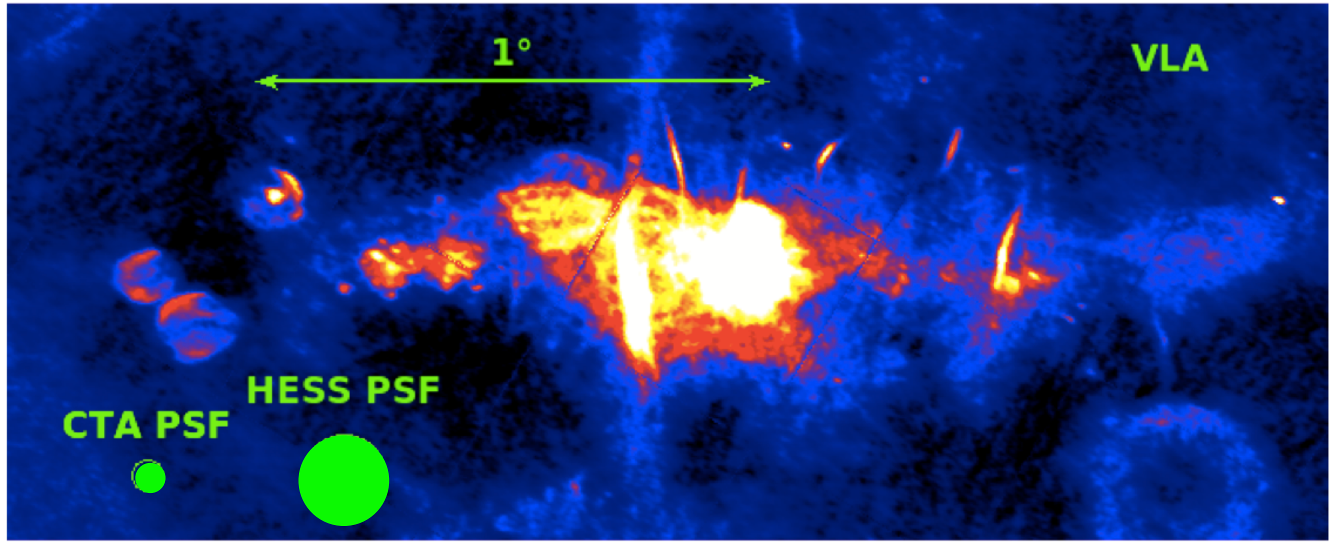
AGNs detected by IACTs: 52

mCrab Sensitivity



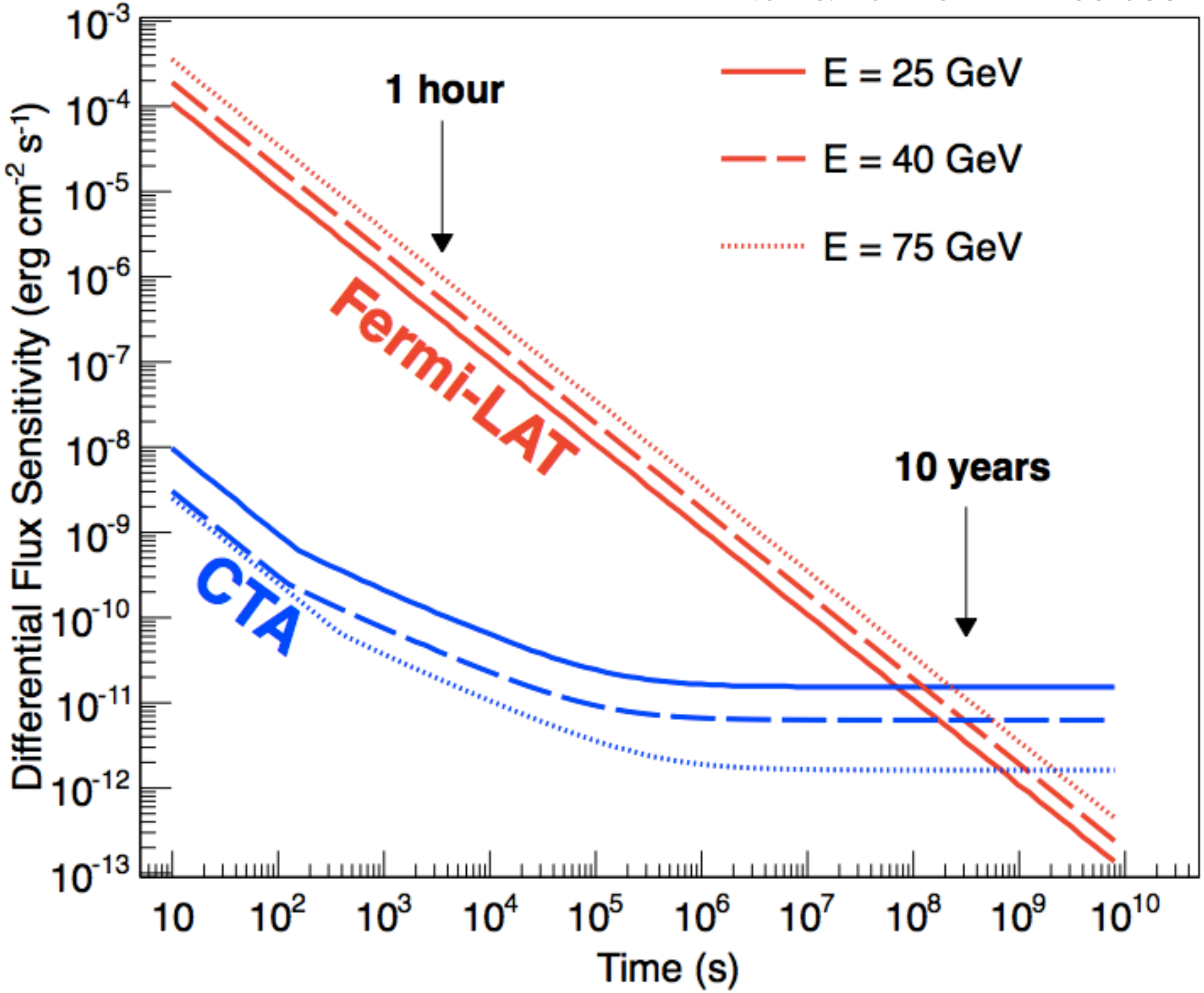
Angular Resolution



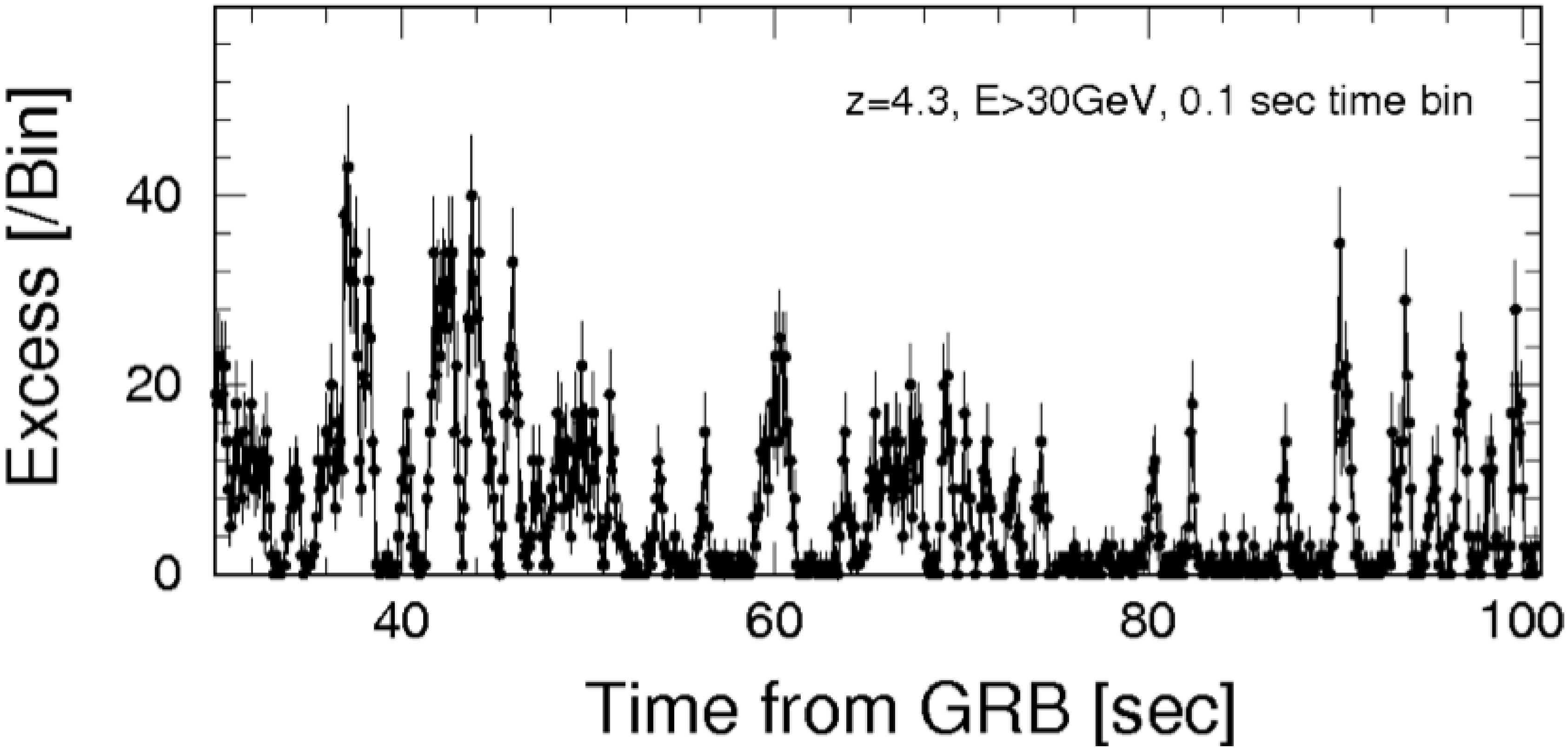


Transients with CTA

Hinton & Funk arXiv:1205.0832

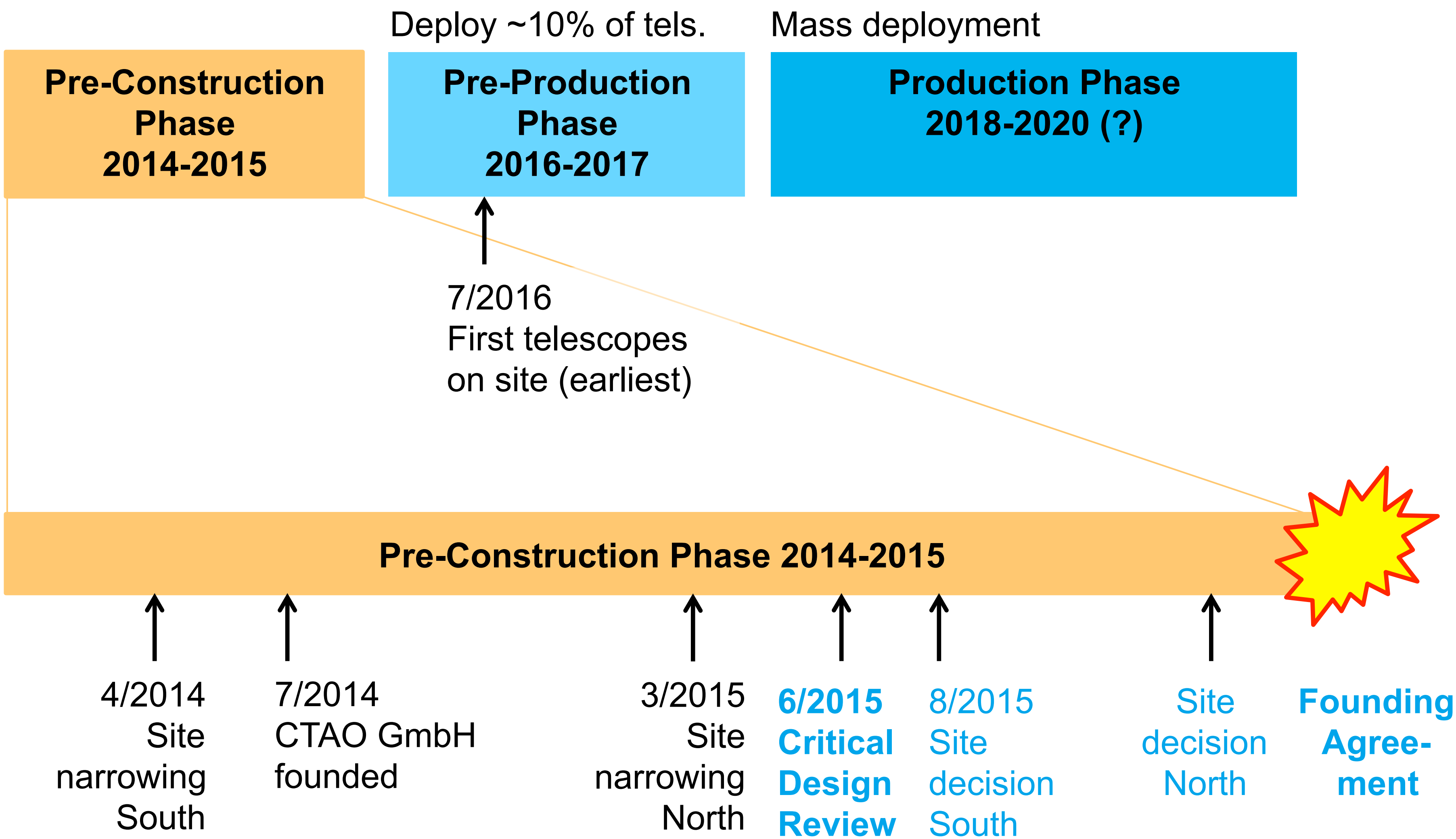


Gamma Ray Bursts (E>30 GeV)



from
Gamma-Ray Burst Science in the Era of Cherenkov Telescope Array
(Astroparticle Physics special issue article)
Susumu Inoue et al., arXiv:1301.3014

Schedule


Deploy ~10% of tels.
Mass deployment
Pre-Construction Phase 2014-2015
Pre-Production Phase 2016-2017
Production Phase 2018-2020 (?)
7/2016 First telescopes on site (earliest)
Pre-Construction Phase 2014-2015
4/2014 Site narrowing South
7/2014 CTAO GmbH founded
3/2015 Site narrowing North
6/2015 Critical Design Review
8/2015 Site decision South
Site decision North
Founding Agree-ment

CTA – the Cherenkov Telescope Array

- A huge improvement in all aspects of performance
  - A factor ~10 in sensitivity, much wider energy coverage, much better resolution, field-of-view, full sky, …
- A user facility / proposal-driven observatory
  - With two sites with a total of >100 telescopes
- A 29 nation ~€200M investment project
  - Including everyone from H.E.S.S., MAGIC and VERITAS

This is the future of ground based gamma-ray astronomy with Air Cherenkov Telescopes