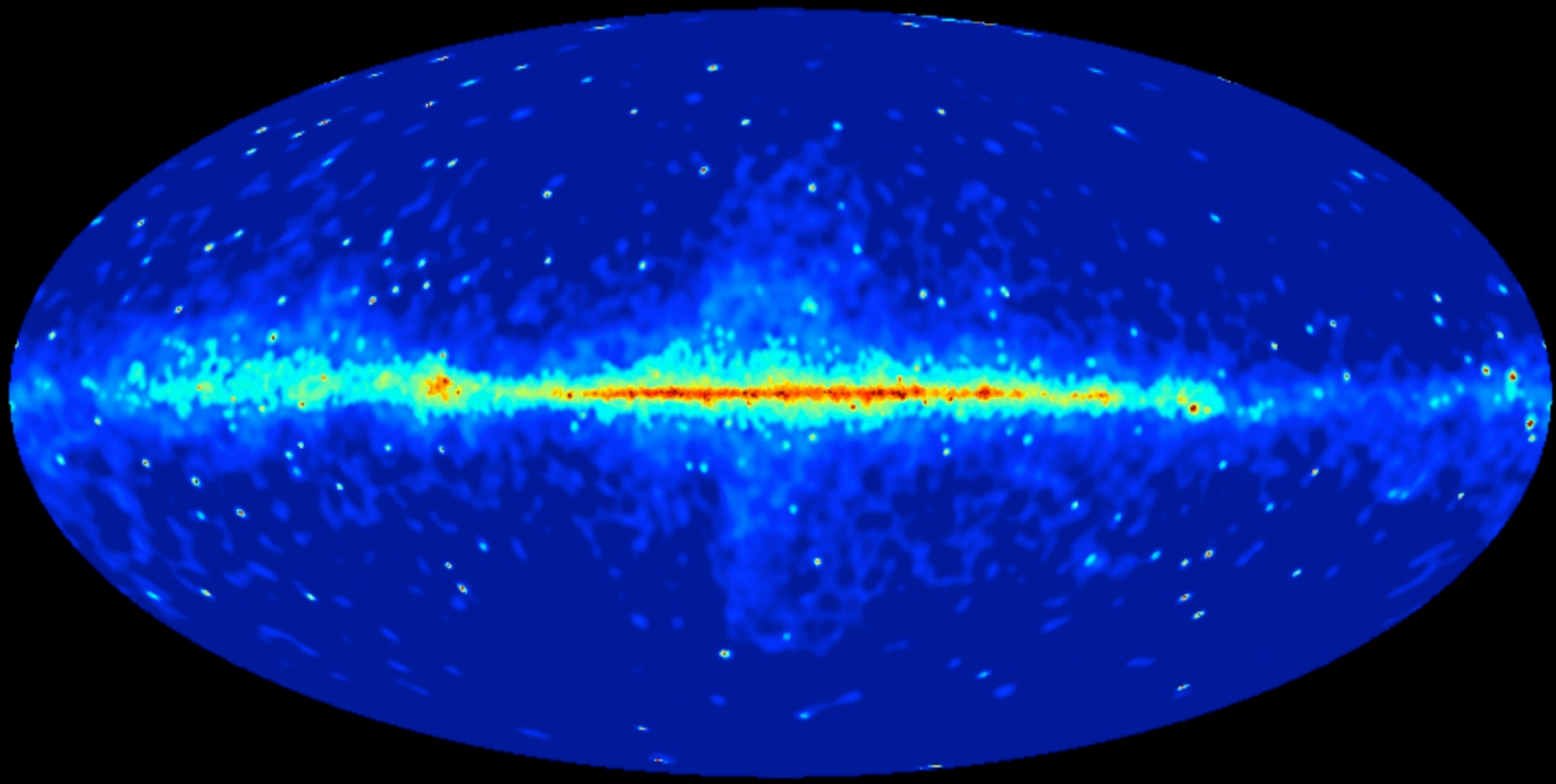
High-energy gamma-ray astronomy

Gernot Maier -- DESY

The high-energy gamma-ray sky

Fermi LAT 3-years
sky map > 10 GeV



>2500 sources @ MeV-GeV
>500 sources >10 GeV
>150 sources >100 GeV

supernova remnants, pulsars, pulsar wind nebulae, binary systems, massive star clusters, starburst galaxies, active galactic nuclei (mostly blazars), gamma-ray bursts, nova, diffuse, dark matter, ...

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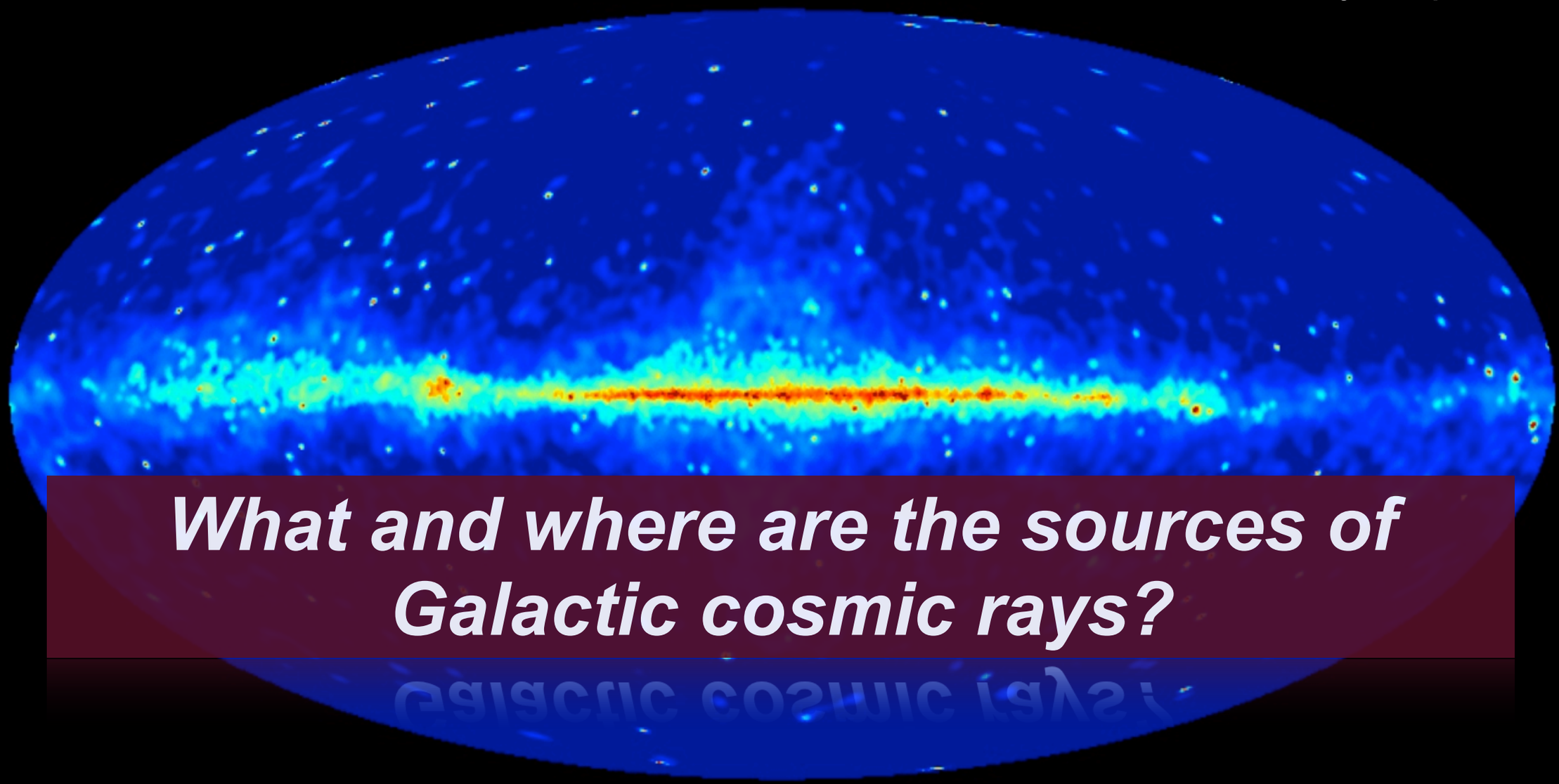


What and where are the sources of Galactic cosmic rays?

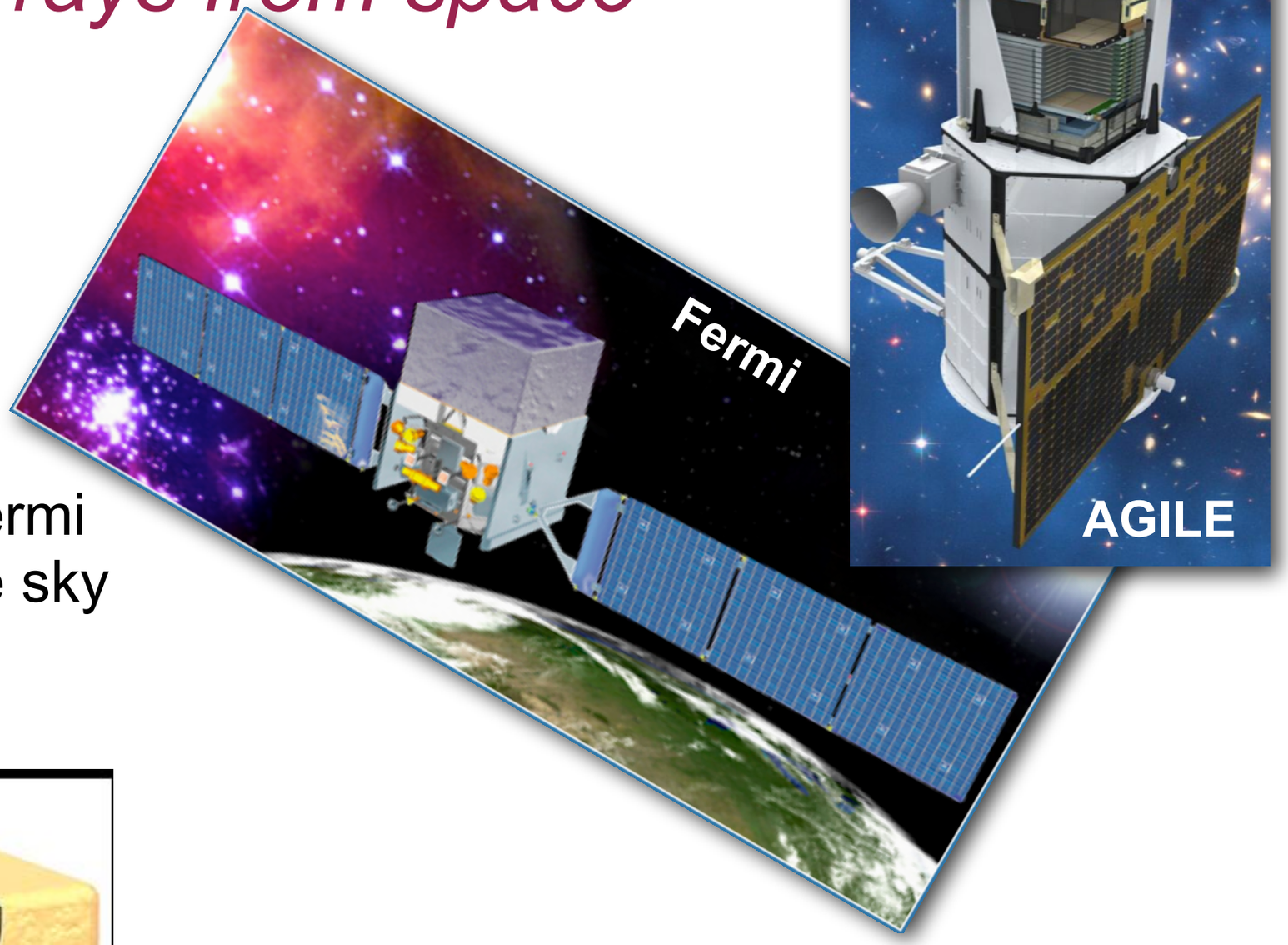
>2500 sources @ MeV-GeV
>500 sources >10 GeV
>150 sources >100 GeV

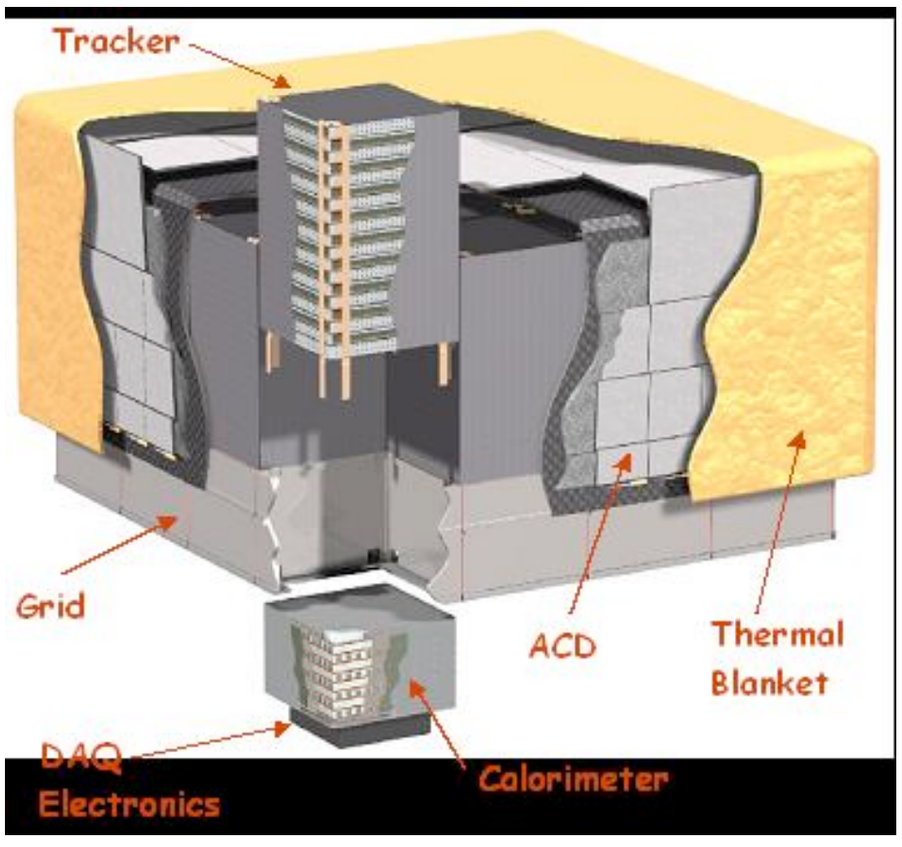
supernova remnants, pulsars, pulsar wind nebulae, binary systems, massive star clusters, starburst galaxies, active galactic nuclei (mostly blazars), gamma-ray bursts, nova, diffuse, dark matter, ...

Observing gamma-rays from space

Fermi LAT:

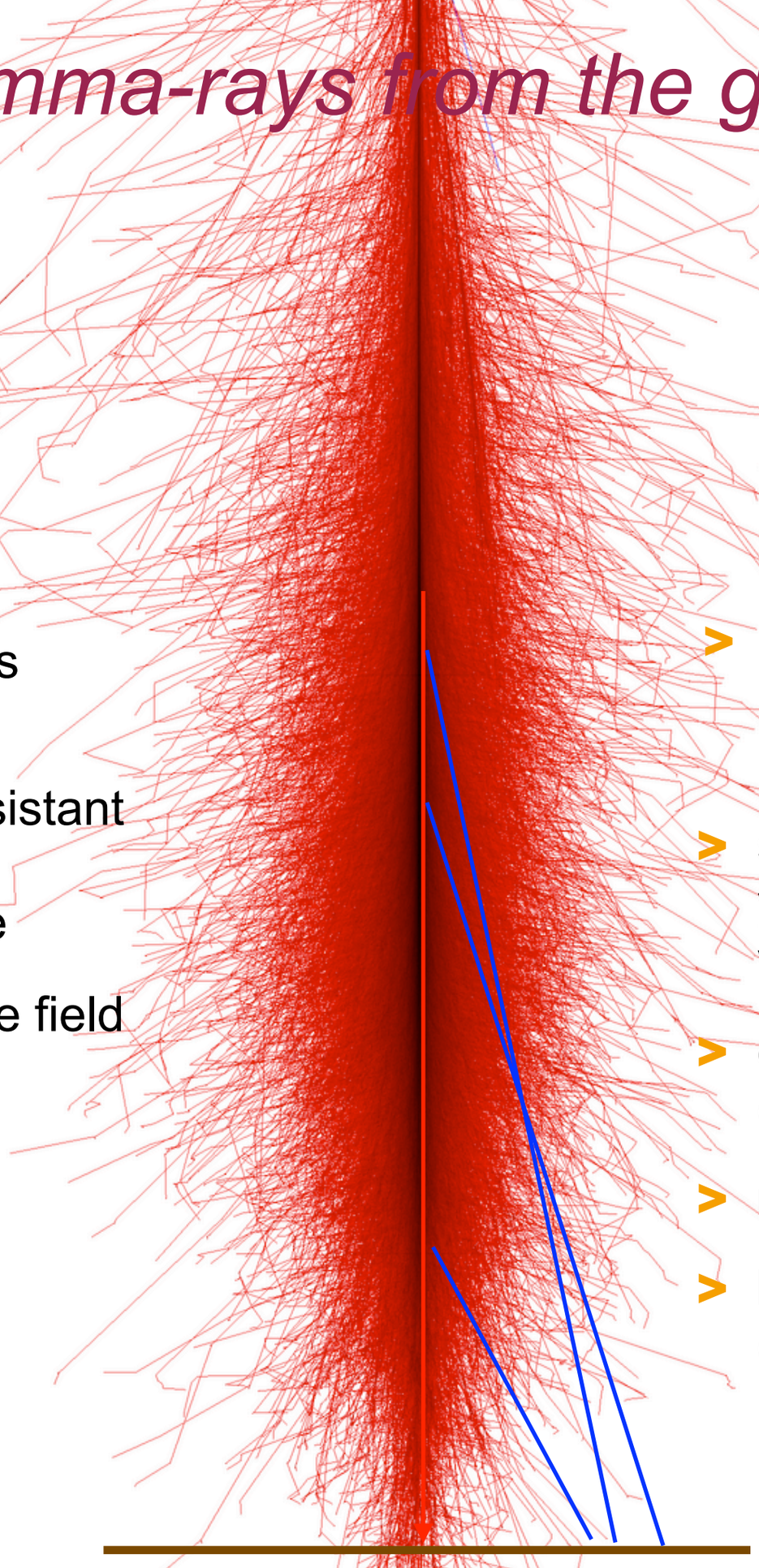
- launched in June 2008
- pair-conversion telescope
- mostly in survey mode: Fermi observes each point in the sky every three hours





- Energy range 20 MeV to 300 GeV
- LAT Effective area: ~0.7 m^2
- AGILE Effective area: ~0.07 m^2

Observing gamma-rays from the ground



Ground Arrays

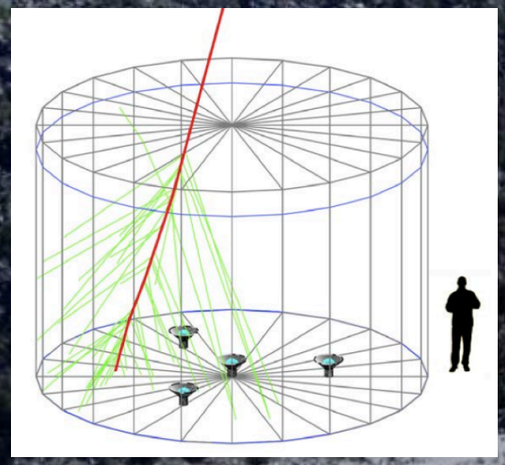
- measure the particles reaching the ground
- scintillator arrays, resistant plate carpets, water Cherenkov technique
- large duty cycle, large field of view
- survey mode
- large effective area (>10^4 m^2)

Cherenkov Arrays

- measure the Cherenkov light emitted by the shower particles
- small duty cycle (~1000h/ year) and moderate field of view
- excellent angular resolution (~0.03-0.1^0)
- mainly pointed observations
- large effective area (>10^5 m^2)

Ground-based observations: HAWC & Tibet ASγ & ARGO

Water Cherenkov Detector
Sierra Negra, Mexico (4150 m a.s.l.)
300 water tanks
>20,000 m^2 effective area
completed in August 2014
same sky as IceCube, VERITAS



see talks in
parallel sessions

Imaging Cherenkov Telescopes

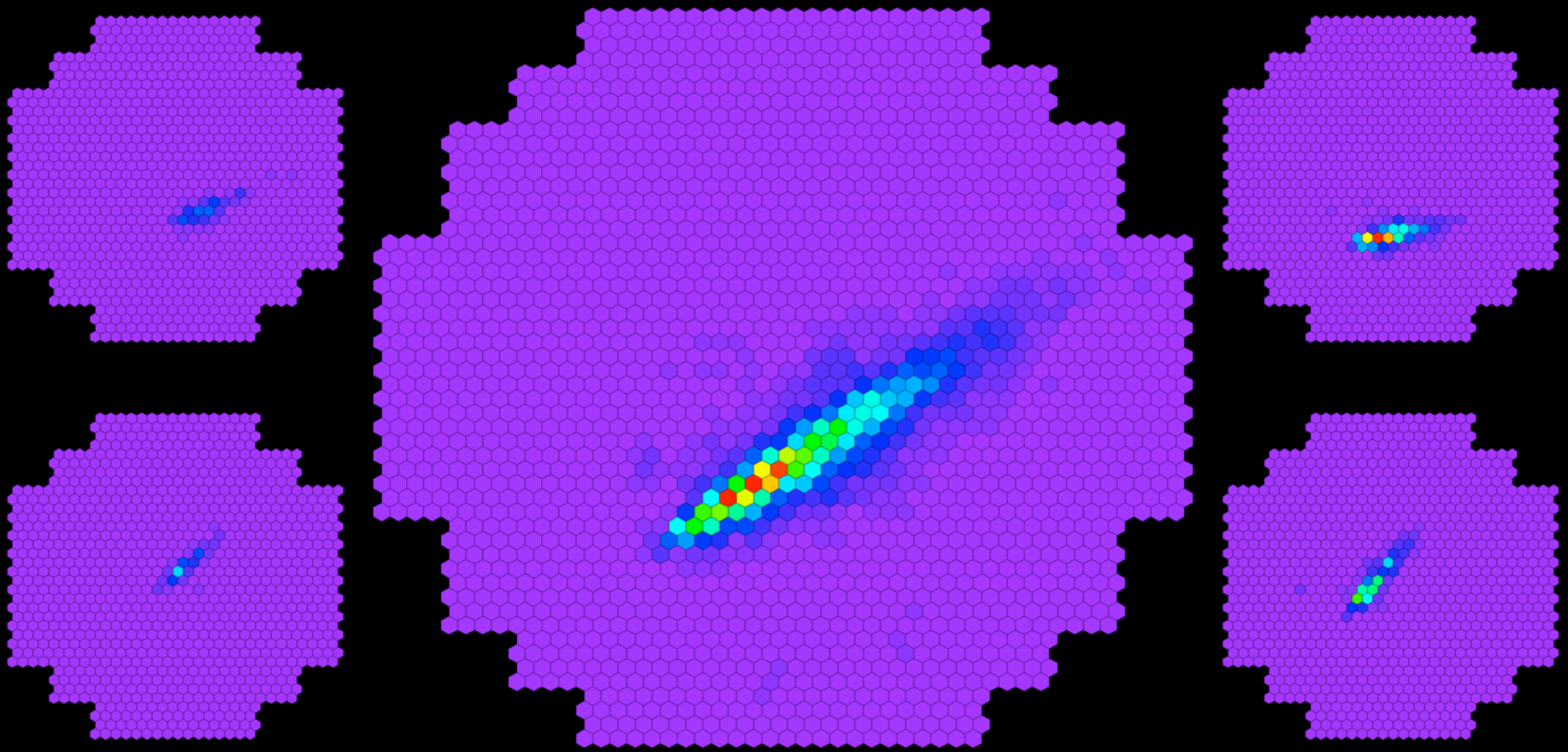
- major upgrades at all observatories for increased sensitivity and lower energy threshold
- MAGIC: 2nd telescope; upgrade of camera & readout in MAGIC I
- VERITAS: camera upgrade with high-efficiency PMTs; new trigger system
- H.E.S.S.: addition of a 28 m telescope

H.E.S.S.

H.E.S.S. collaboration

Imaging extensive air showers

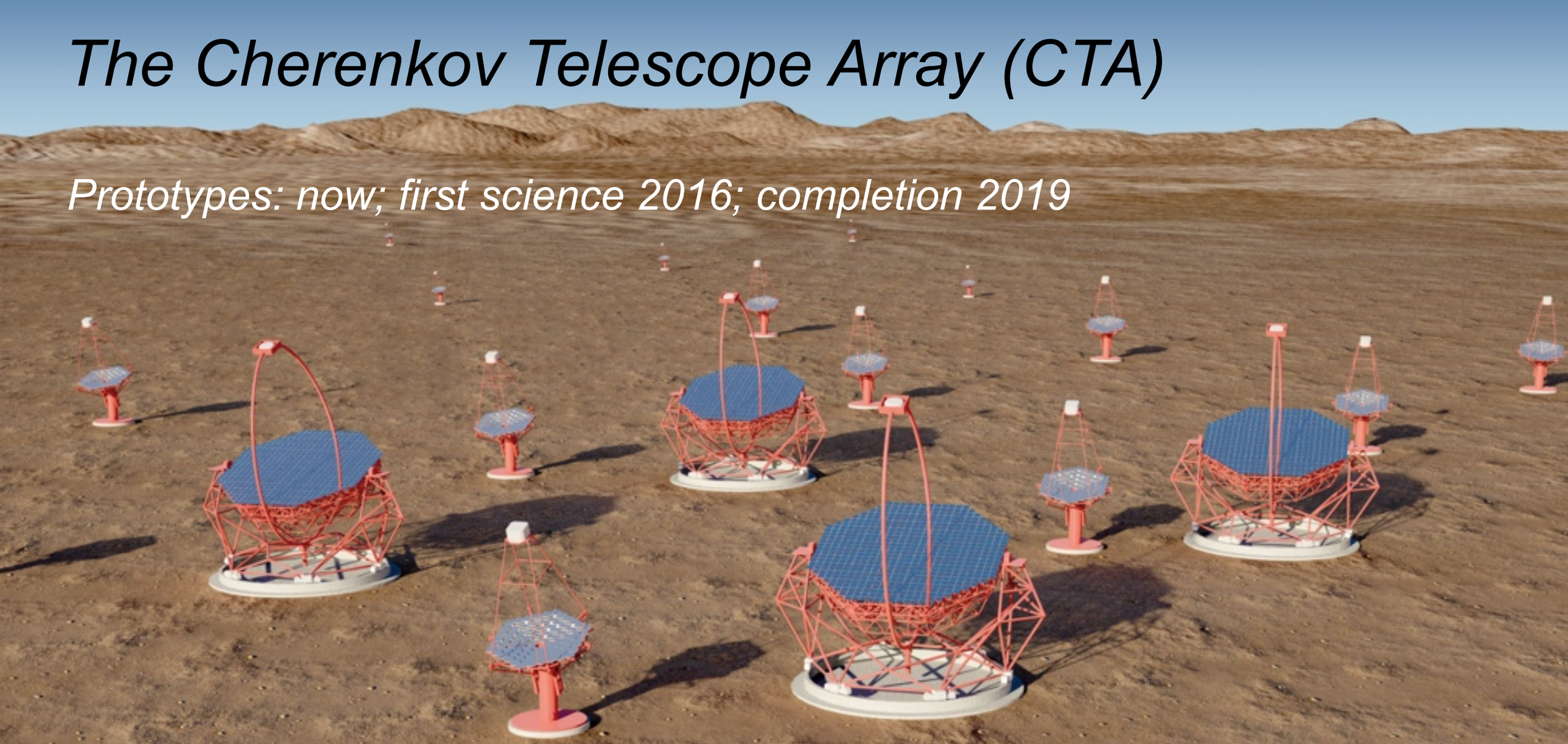
A shower seen by H.E.S.S.



H.E.S.S. collaboration

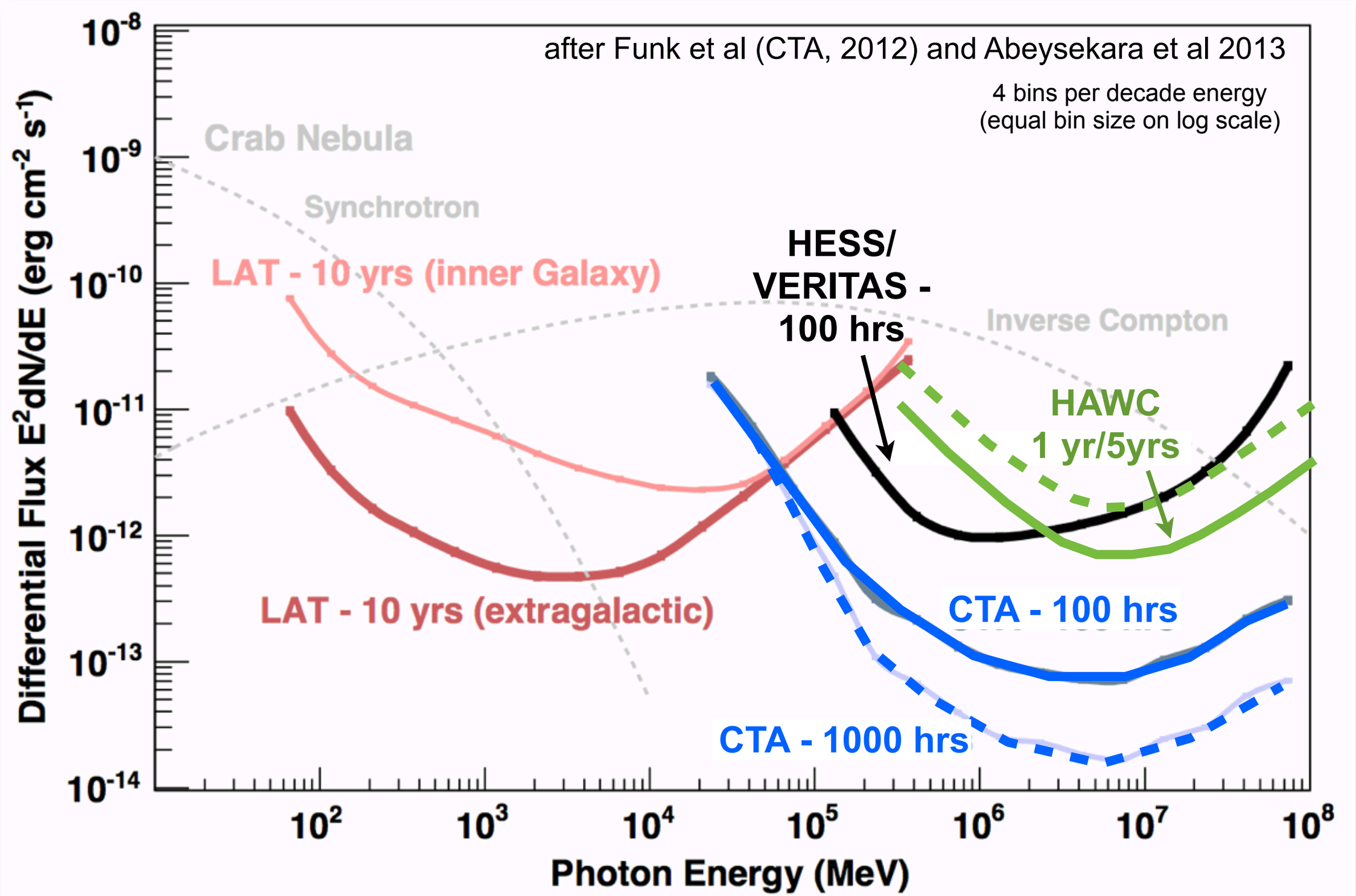
The Cherenkov Telescope Array (CTA)

Prototypes: now; first science 2016; completion 2019



Array of >50 telescopes (3 telescope types)
20 GeV to >300 TeV energy range
factor 10 improvement in sensitivity
significantly improved angular resolution
two observatories: North and South
Collaboration of ~1000 scientist

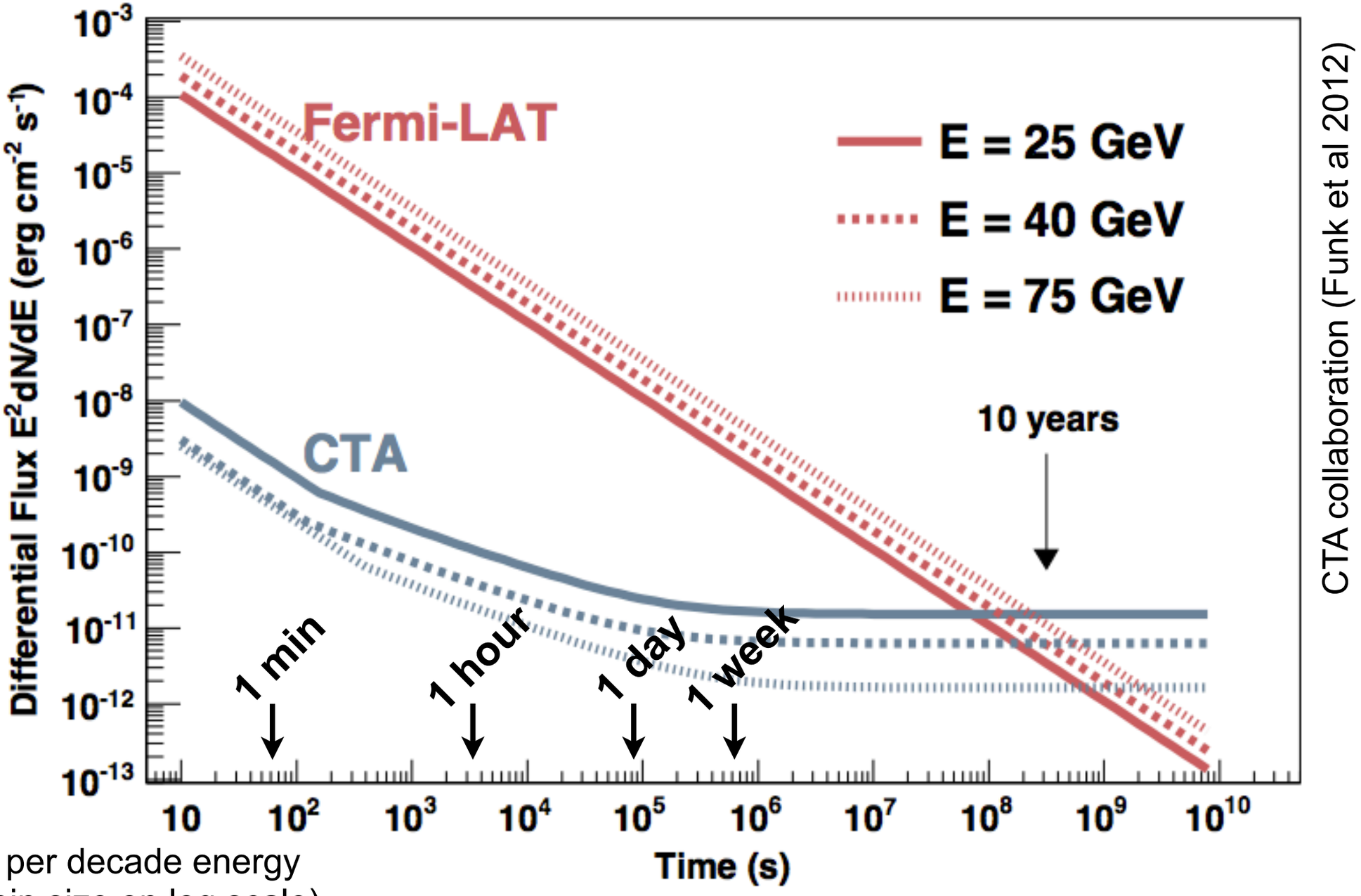
Differential Flux sensitivity



HAWC: 24/7 duty cycle; IACTS: 1200 hrs/year

Sensitivity to transients

effective areas: 1 m^2 (LAT) vs 10^4 m^2 (CTA at 40 GeV)



4 bins per decade energy
(equal bin size on log scale)

factor 1000 higher sensitivity of CTA for short (hours) transients

Are supernova remnants the sources of cosmic rays?

Are supernova remnants the sources of cosmic rays?

It is very hard to image a SNR which does not accelerate charged particles

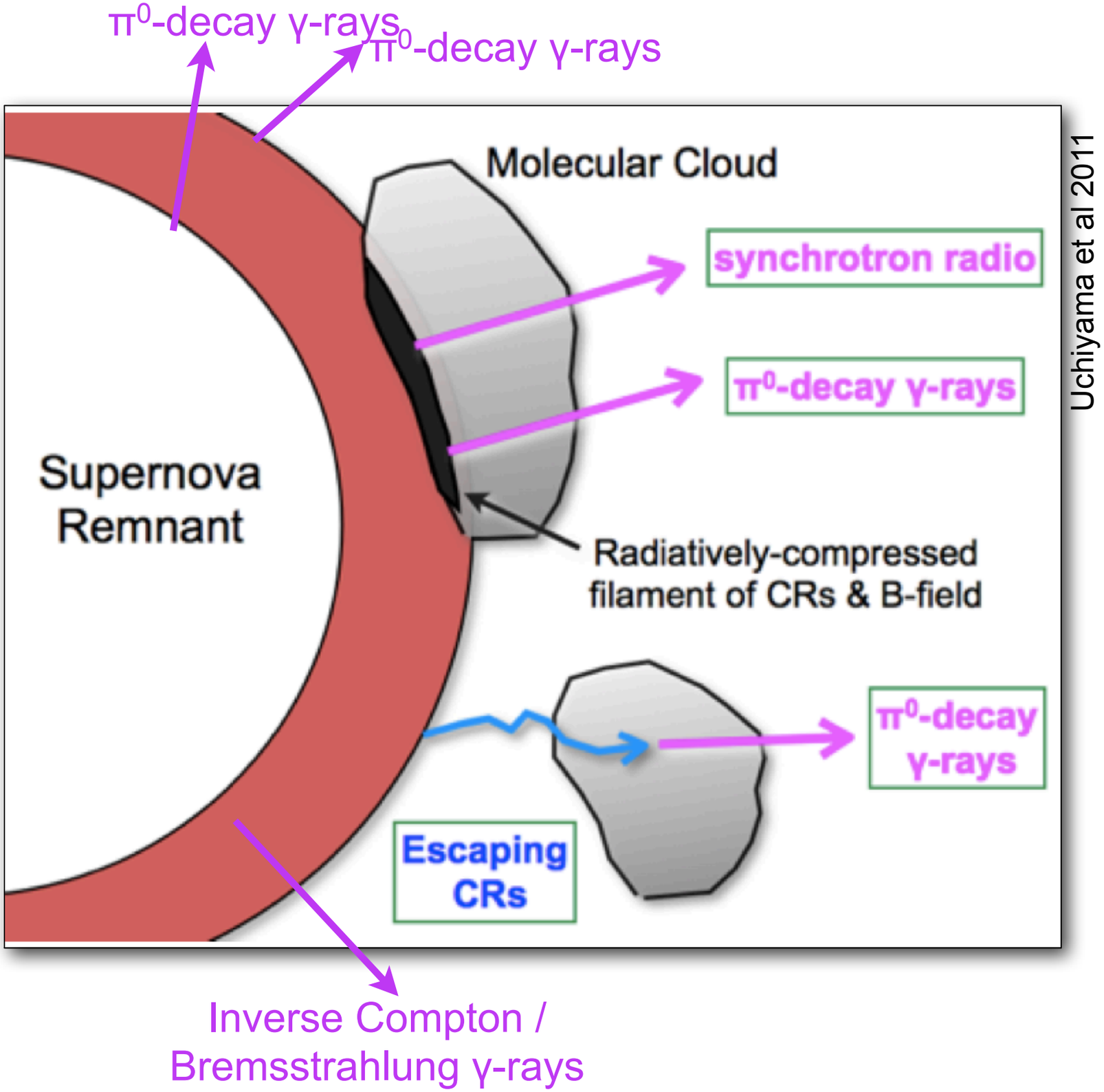
working theory: non-linear diffuse shock acceleration

energetics & numbers are ok
(3-30% of shock energy is converted into particle energies)

Are SNRs efficient accelerators?

Can they accelerate particles up to PeV energies?

Supernova remnants - γ-ray emission



Uchiyama et al 2011

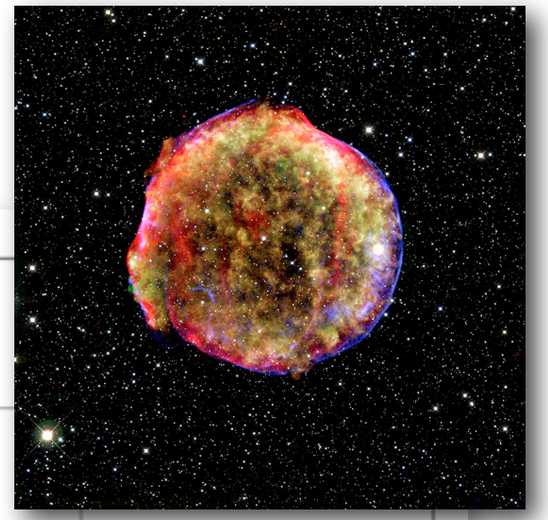
high proton visibility:
large gas densities

high lepton visibility:
low magnetic fields,
high photon fields

spectral information
imaging
multiwavelength
coverage

Tycho Supernova Remnant

Type Ia SNR; 1572



Protons up to 500 TeV

The unequivocal evidence of hadron acceleration in Tycho's Supernova Remnant

G. Morlino[1⋆], D. Caprioli[1]†,

[1] *INAF-Osservatorio Astrofisico di Arcetri, Largo E. Fermi, 5, 50125, Firenze, Italy*

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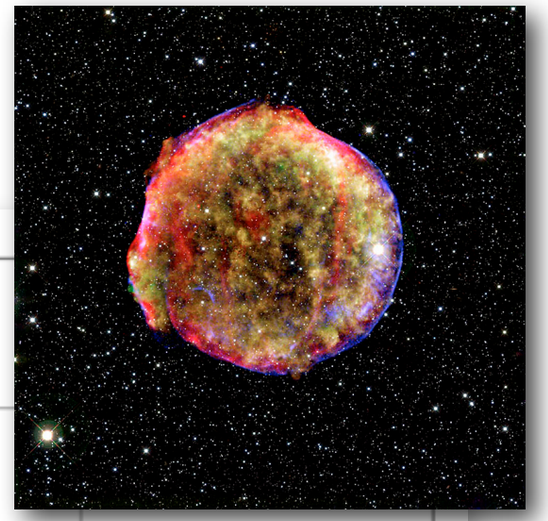

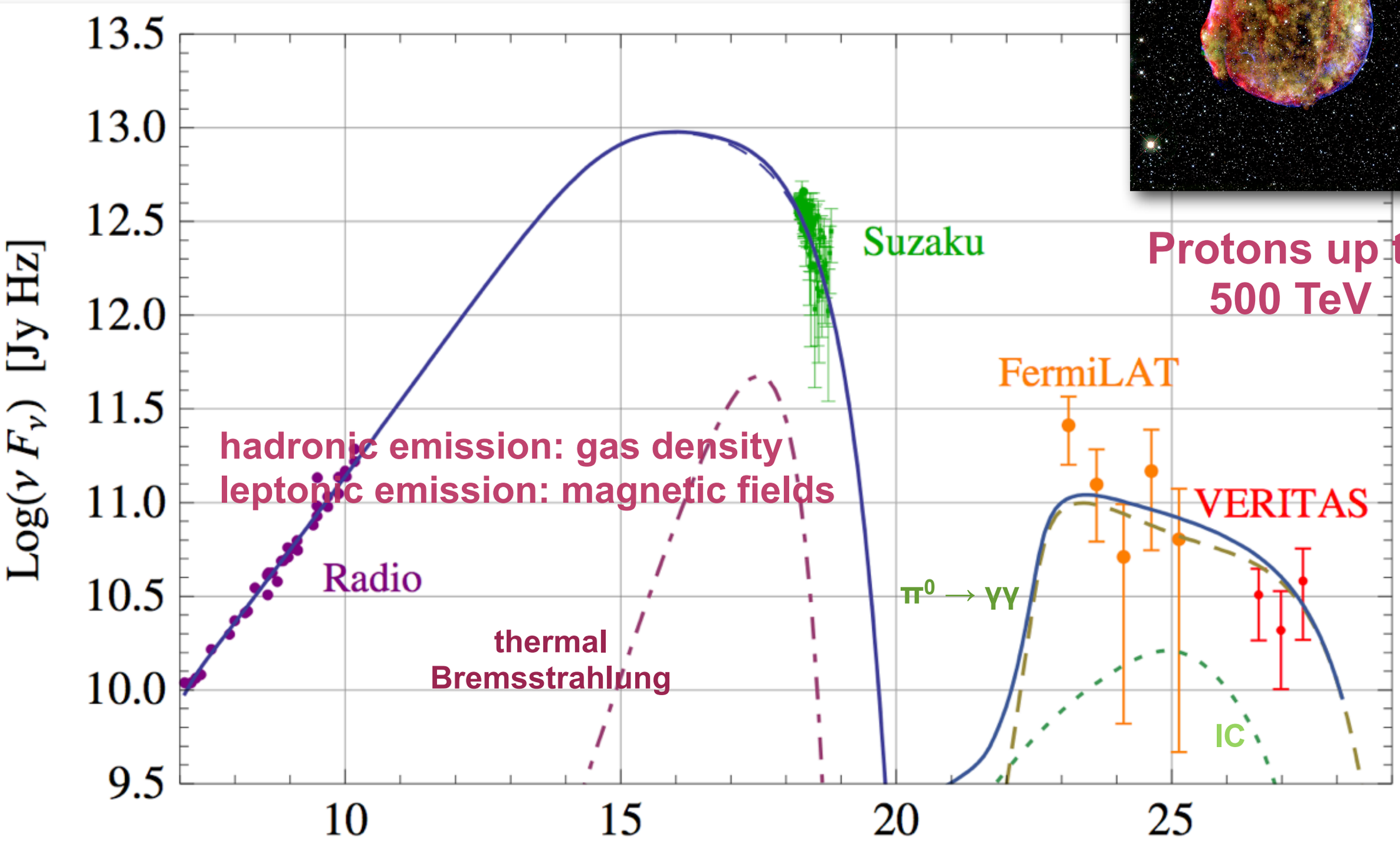

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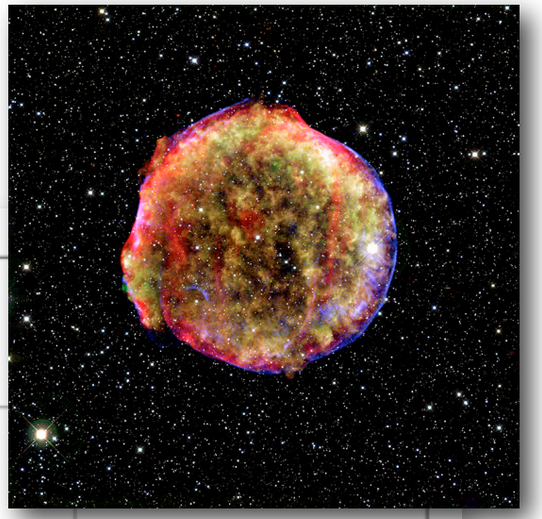
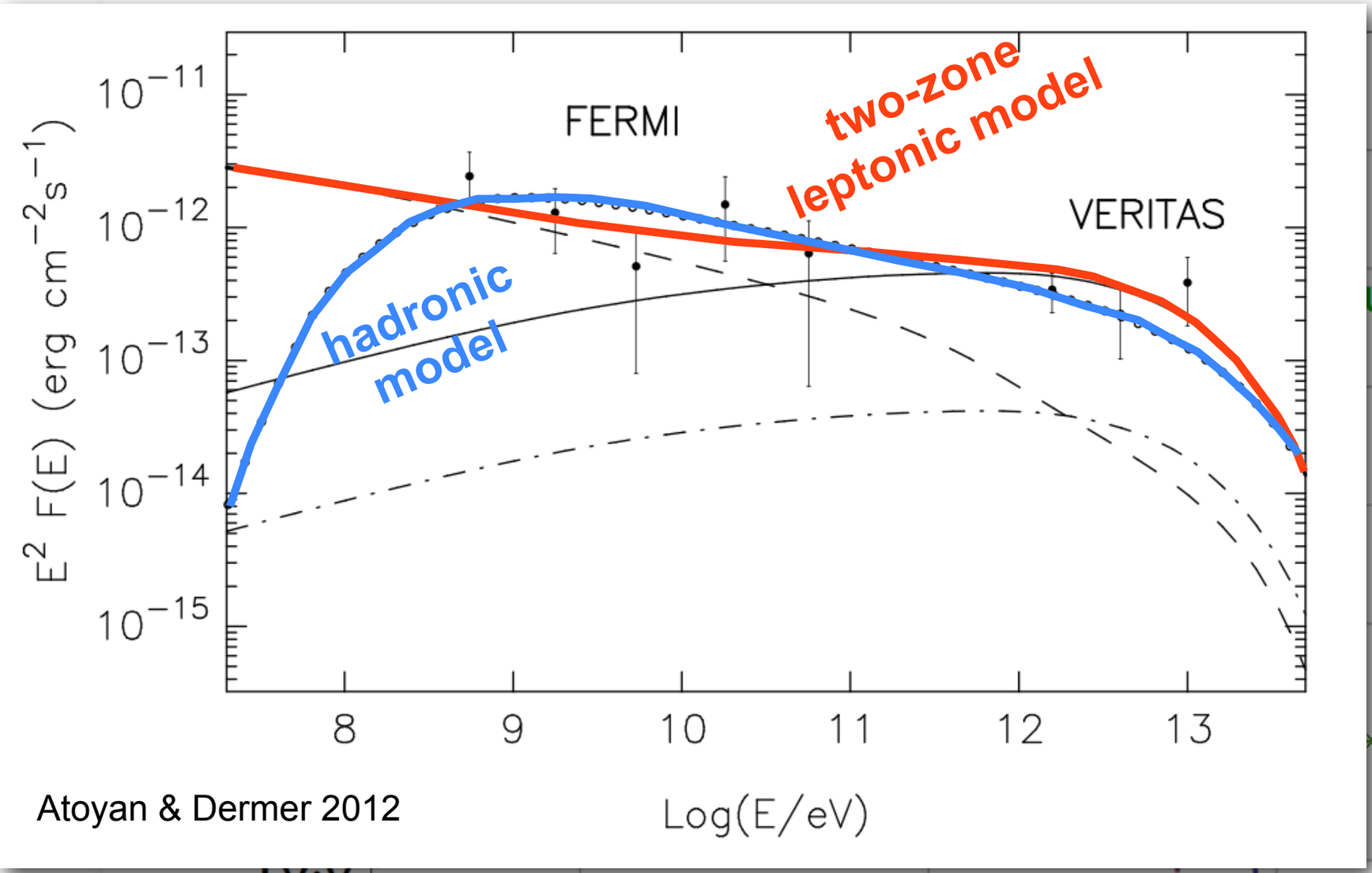
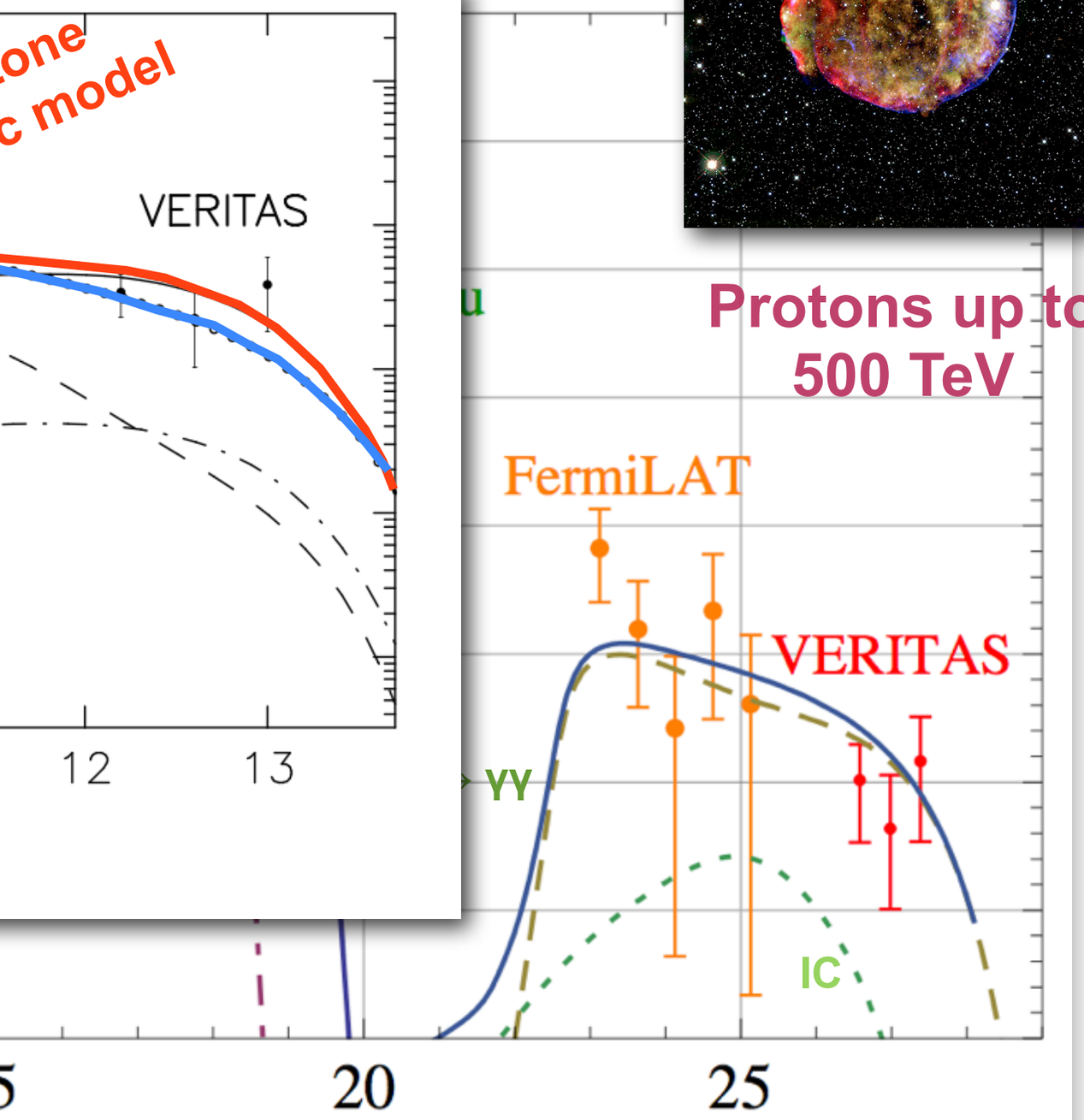




Atoyan & Dermer 2012



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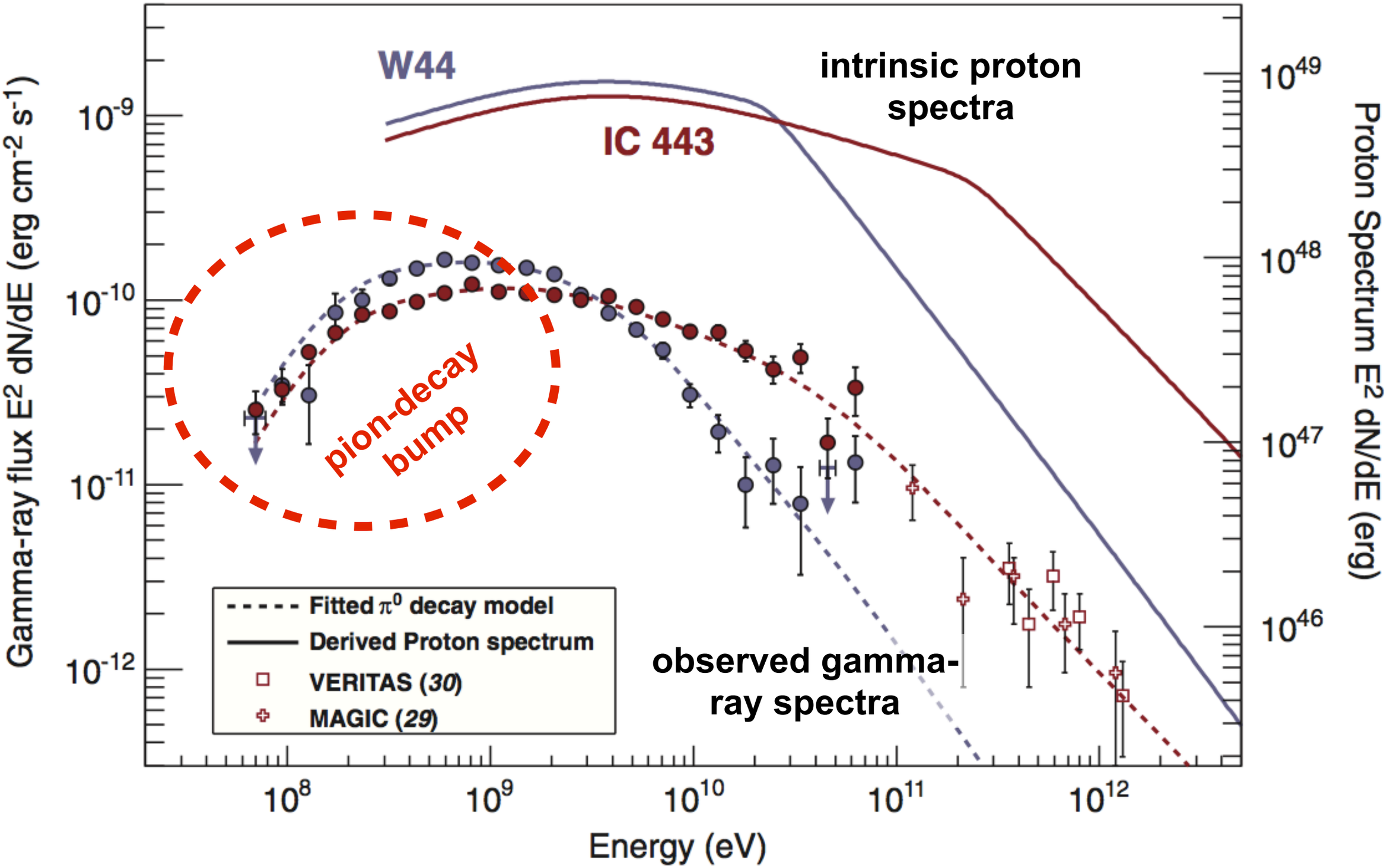
The Pion-Decay Signature

see also talk by S.Funk in yesterday's parallel session

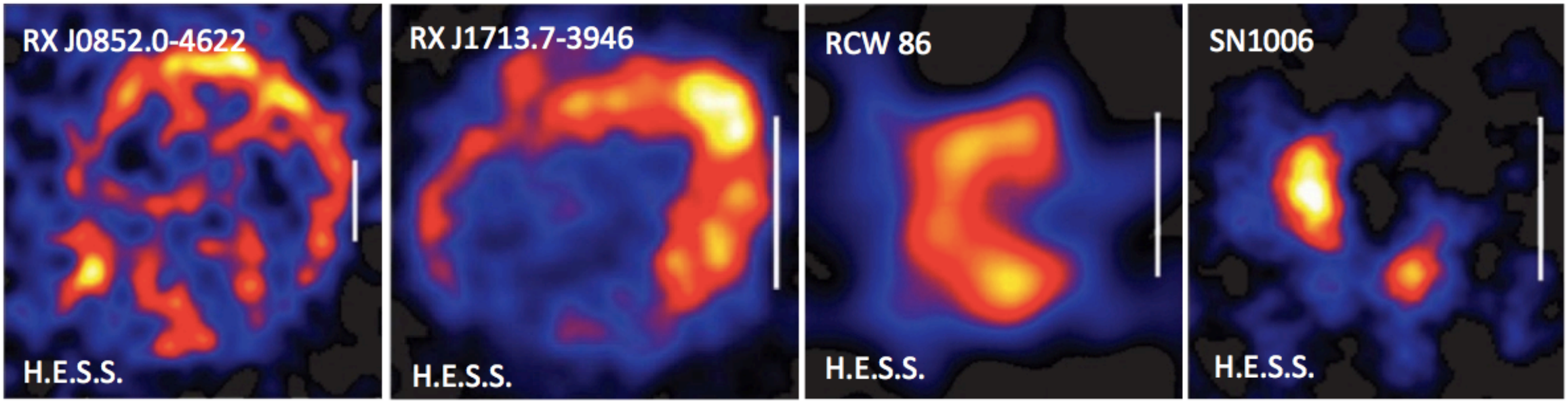
$\pi^0 \rightarrow \gamma\gamma$:
E_γ=67.5 MeV (rest frame of π^0)

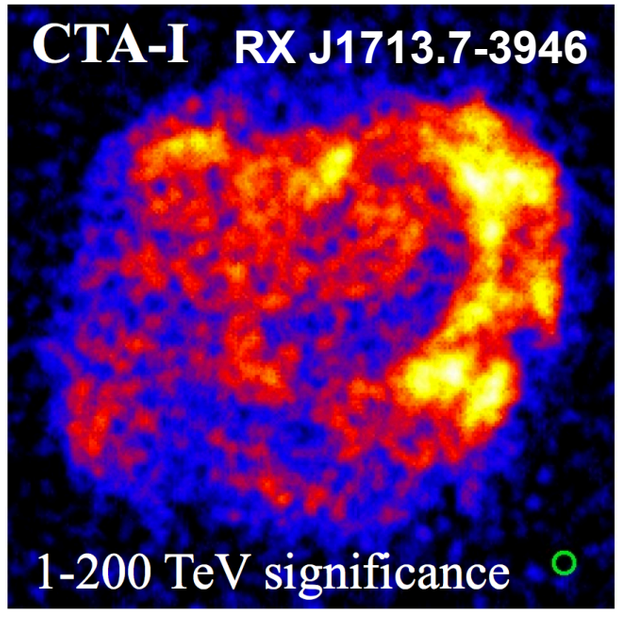


Fermi LAT collaboration 2013

Young supernova remnants

single objects vs population studies





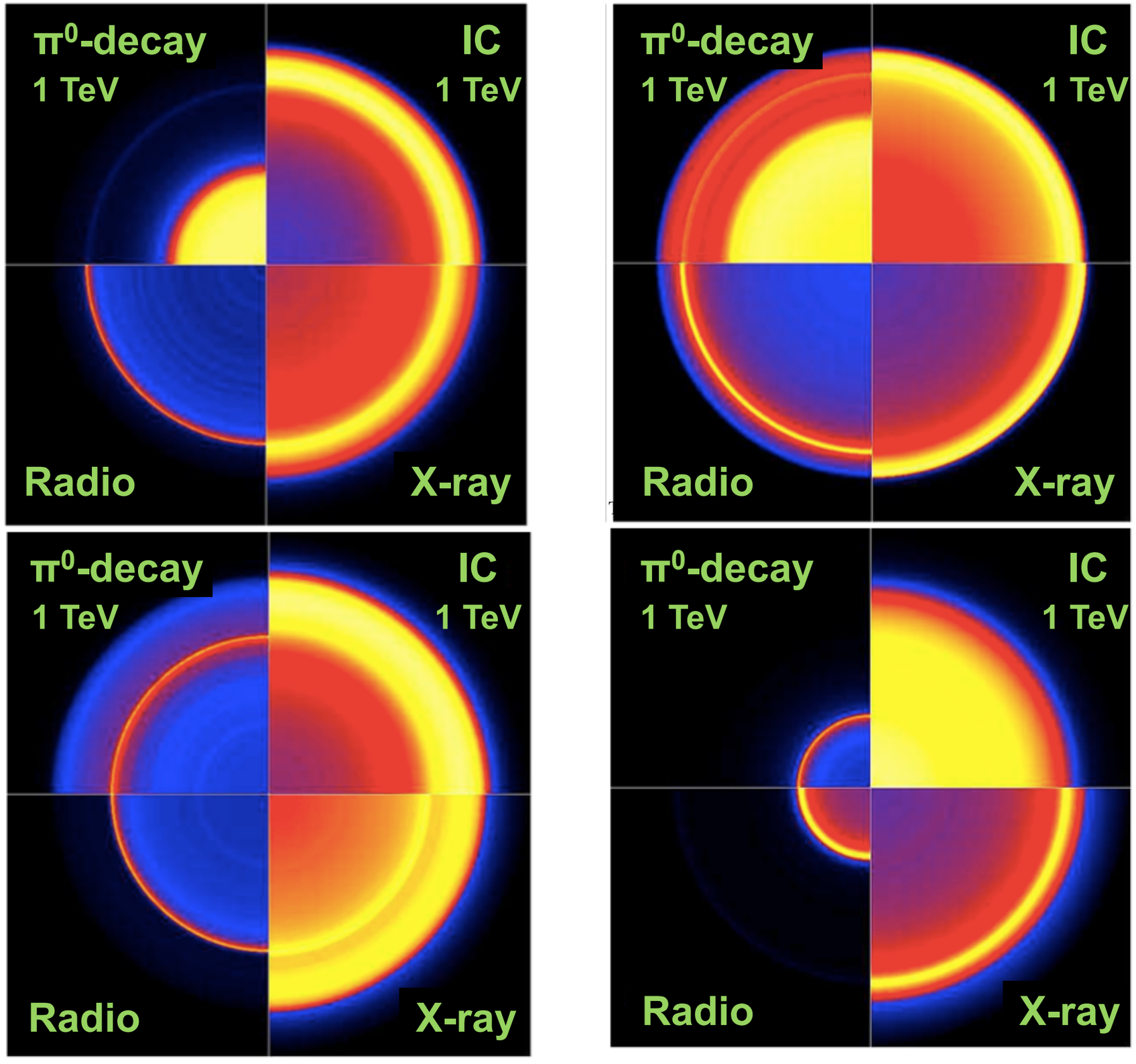
importance of progenitor, age, target material, magnetic fields

Young supernova remnants - modeling

400 years

2000 years

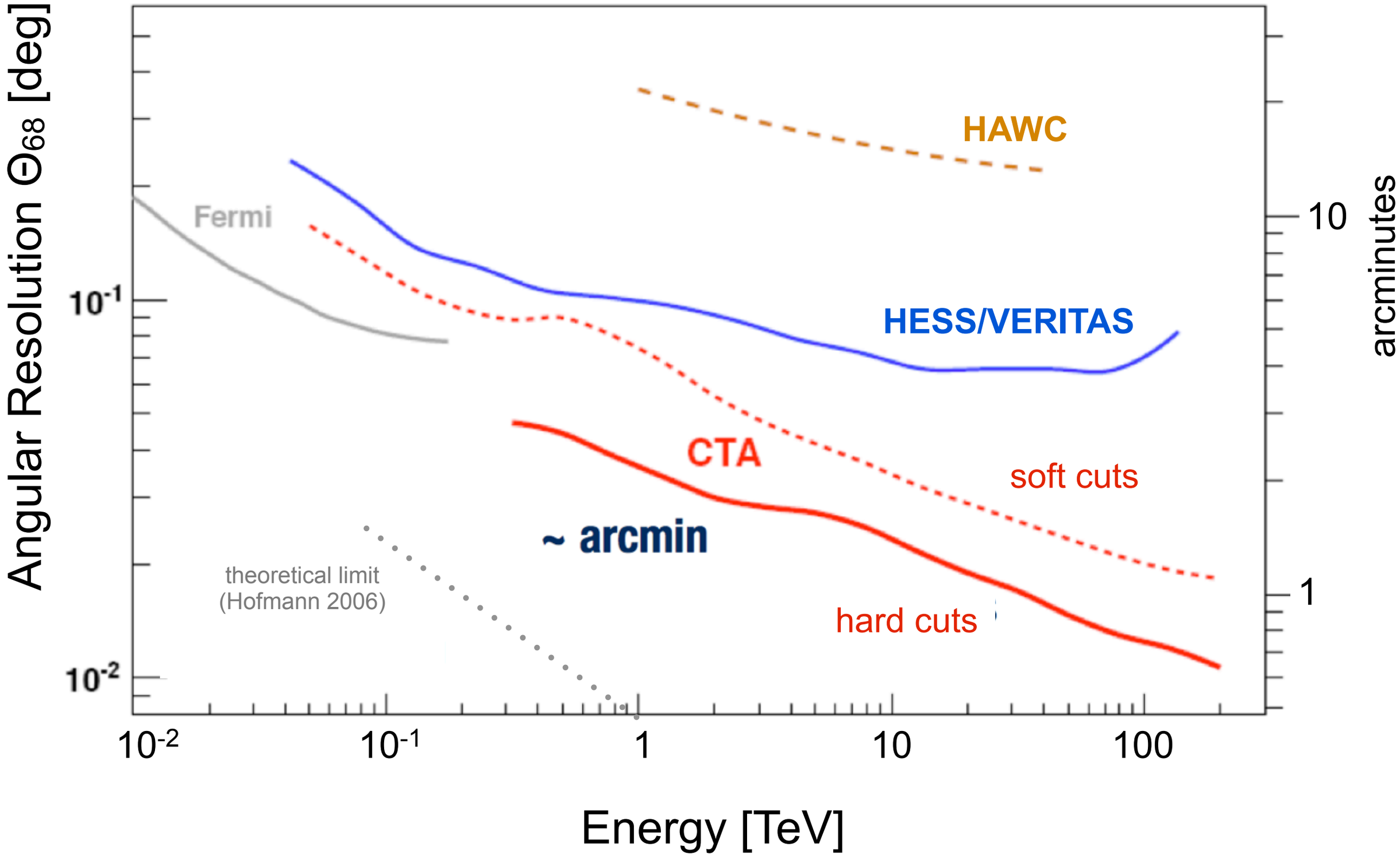
SNR Type Ic (Wolf Rayet, fast, low density wind)



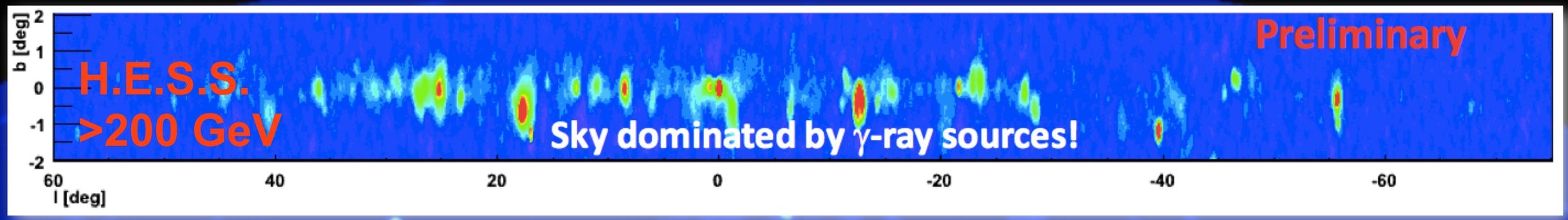
SNR Type IIb (Red SG, slow, high density wind)

Telezhinsky et al (2013)

Angular resolution



The diffuse component



Egberts et al 2013

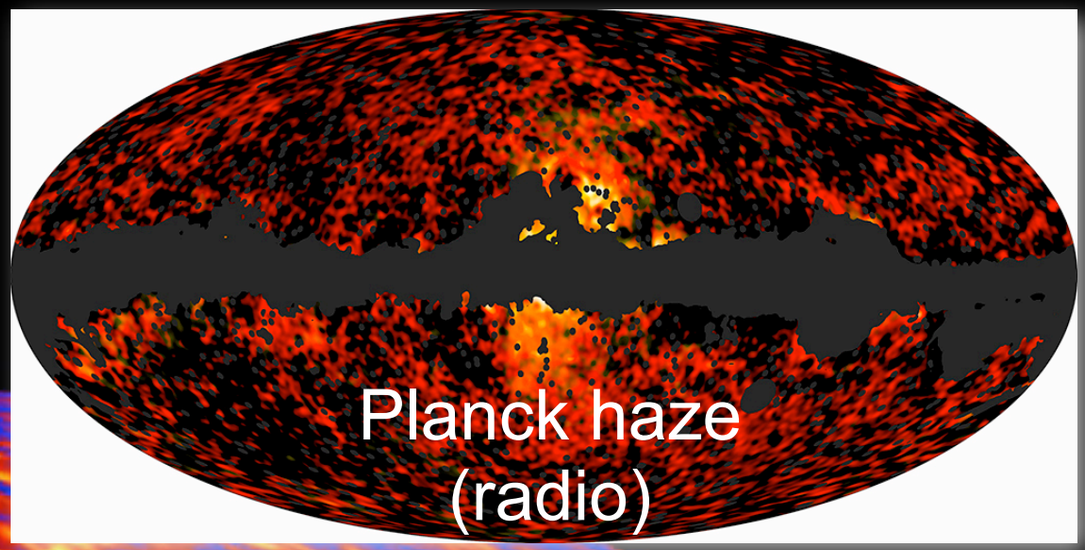
MeV-GeV sky dominated by diffuse background

Fermi LAT 3-years sky map > 10 GeV

Diffuse measurements:
- **cosmic ray content (p,e^-,..) and spatial distribution**
- **gas content**
- **CR diffusion in magnetic fields, convection, reacceleration**
- **unresolved sources**

The Fermi Bubbles

emission with harder spectrum than diffuse emission, cutoff at 150 GeV; sharp edges



Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

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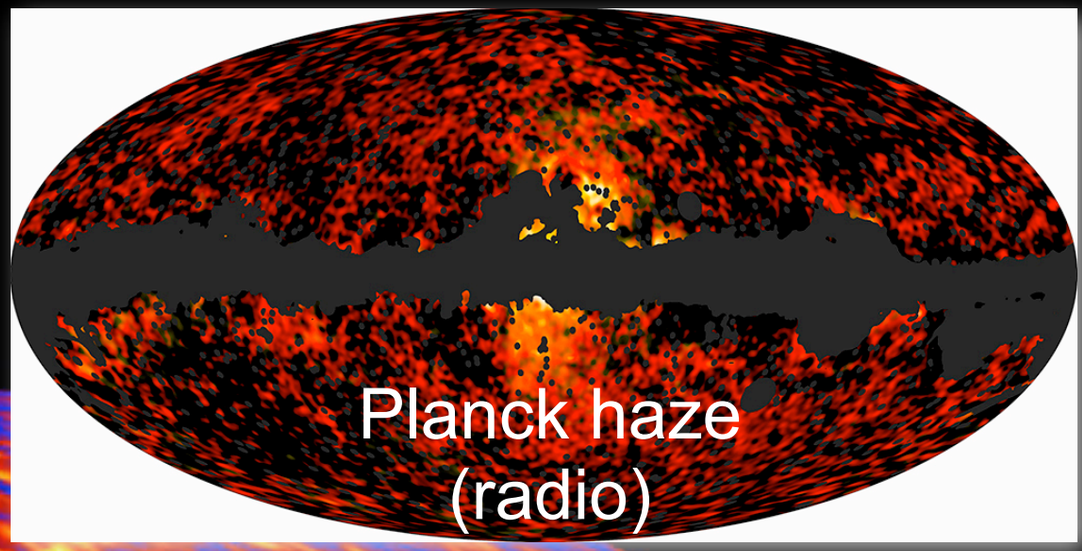
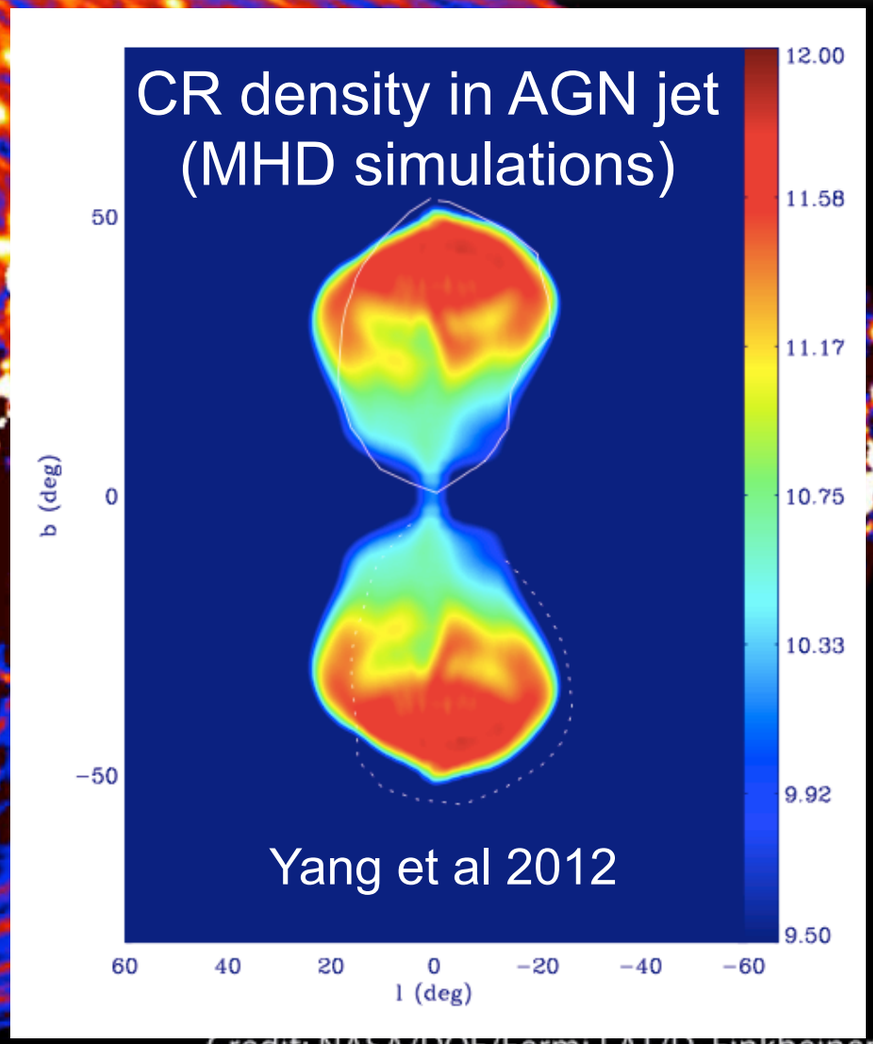


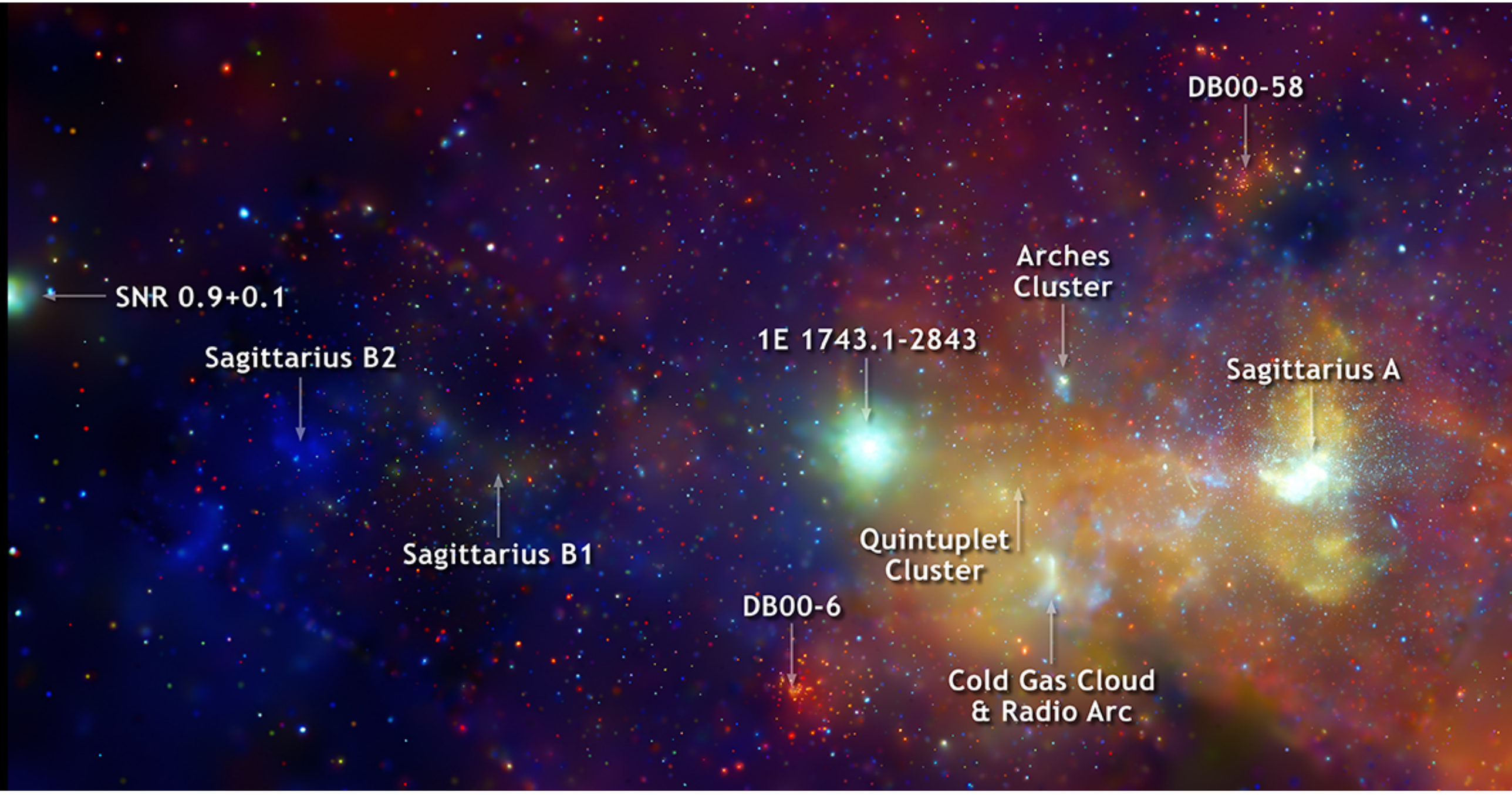
Scenarios

- AGN jet activity due to past accretion event
- starburst activity
- bipolar galactic wind
- signal of annihilating dark matter



Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

The Galactic Centre



Band	Telescope
X-ray	Chandra ACIS
Optical	Hubble Space Telescope NICMOS
Infrared	Spitzer Space Telescope IRAC

The Galactic Centre

H.E.S.S. CTA

point-like gamma-ray source
+ diffuse component
(no extension as expected
for most DM models)

DB00-58

Arches
Cluster

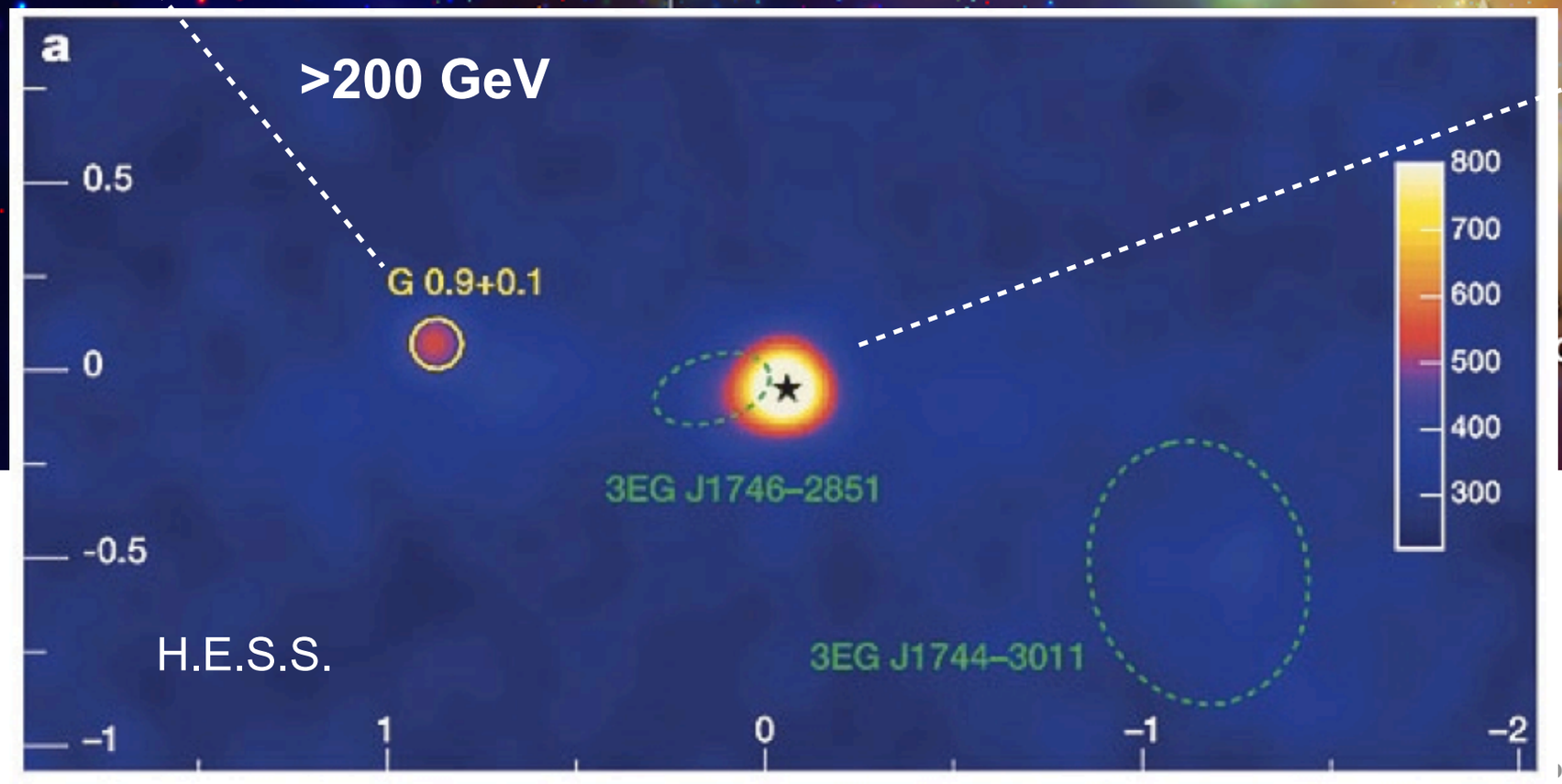
SNR 0.9+0.1

1E 1743.1-2843

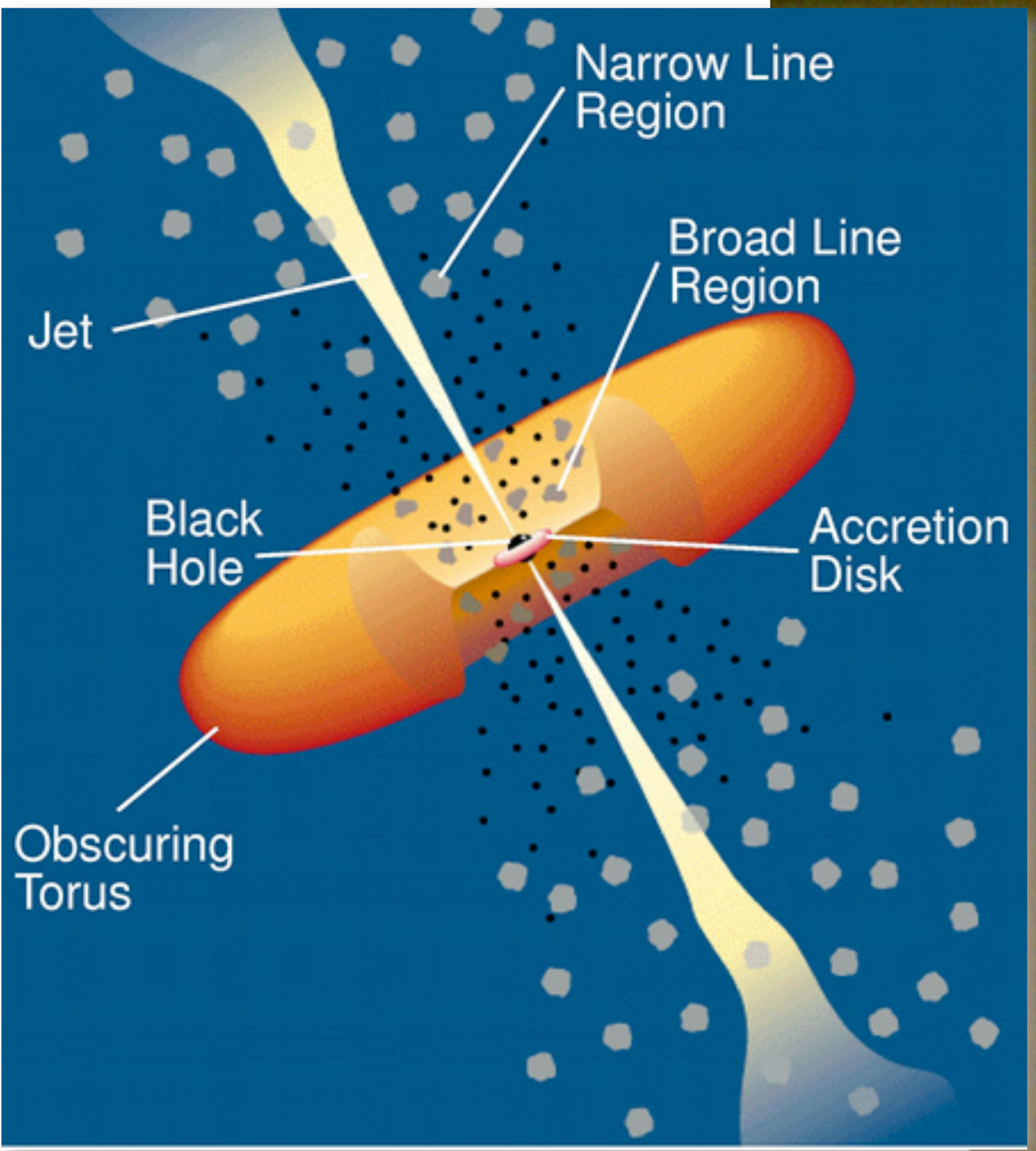
Sagittarius B2

Sagittarius A

Cloud
o Arc



Active Galactic Nuclei



AGN are strong gamma-ray emitter

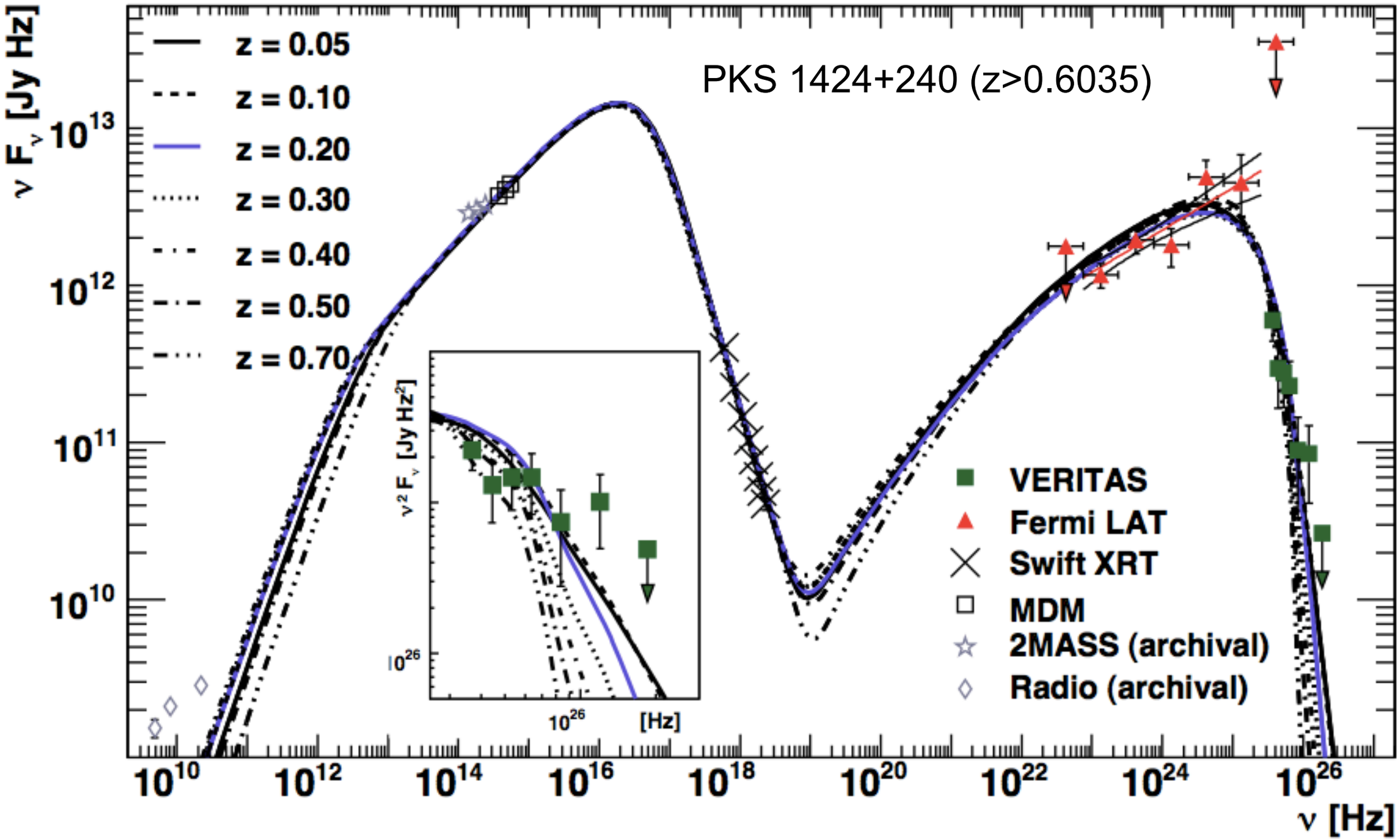
Where are particles accelerated (jet, close to black hole, ..)?

Are AGN the sources of ultra-high energy cosmic rays?

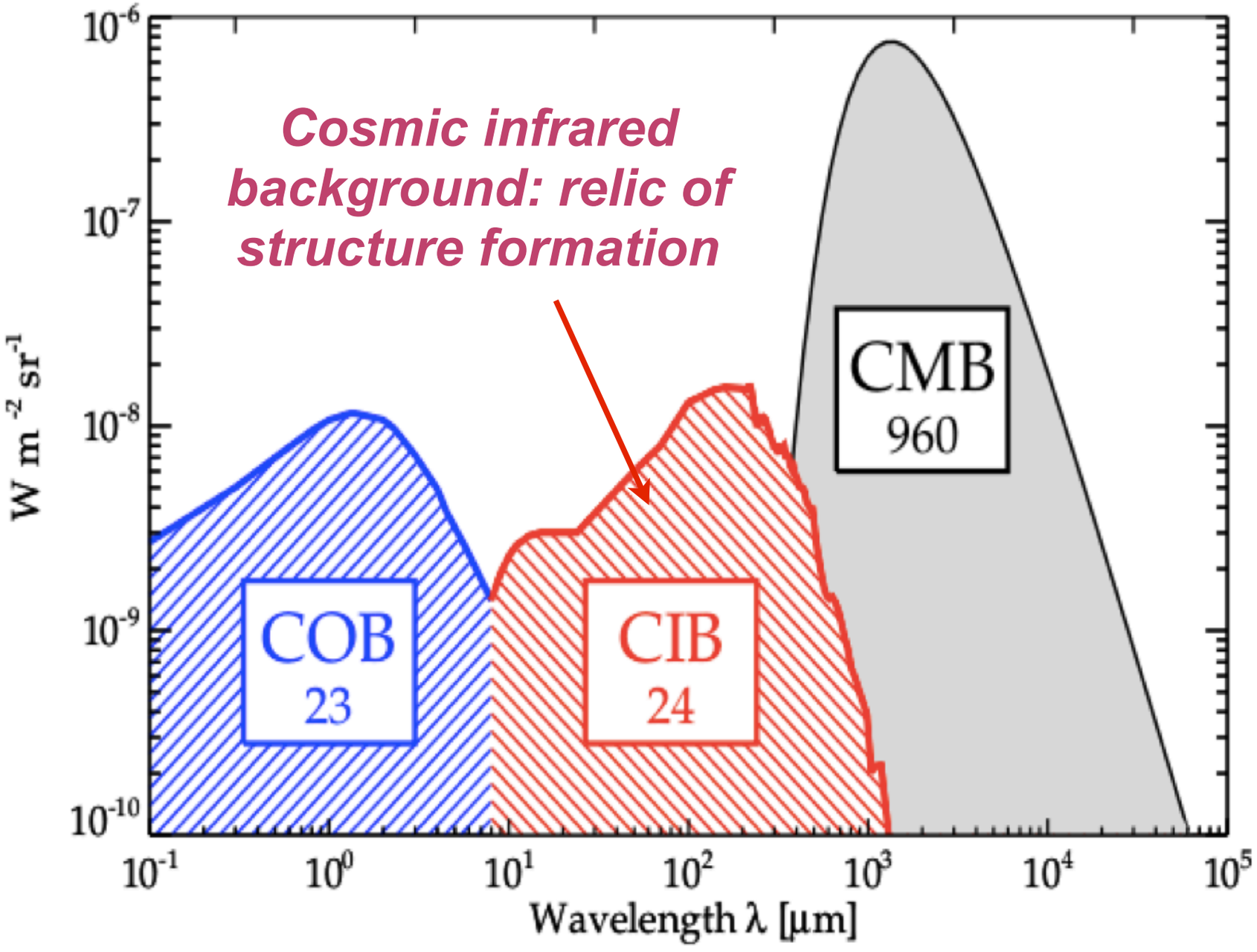
M87 by HST

Active Galactic Nuclei

easier explained by leptonic emission



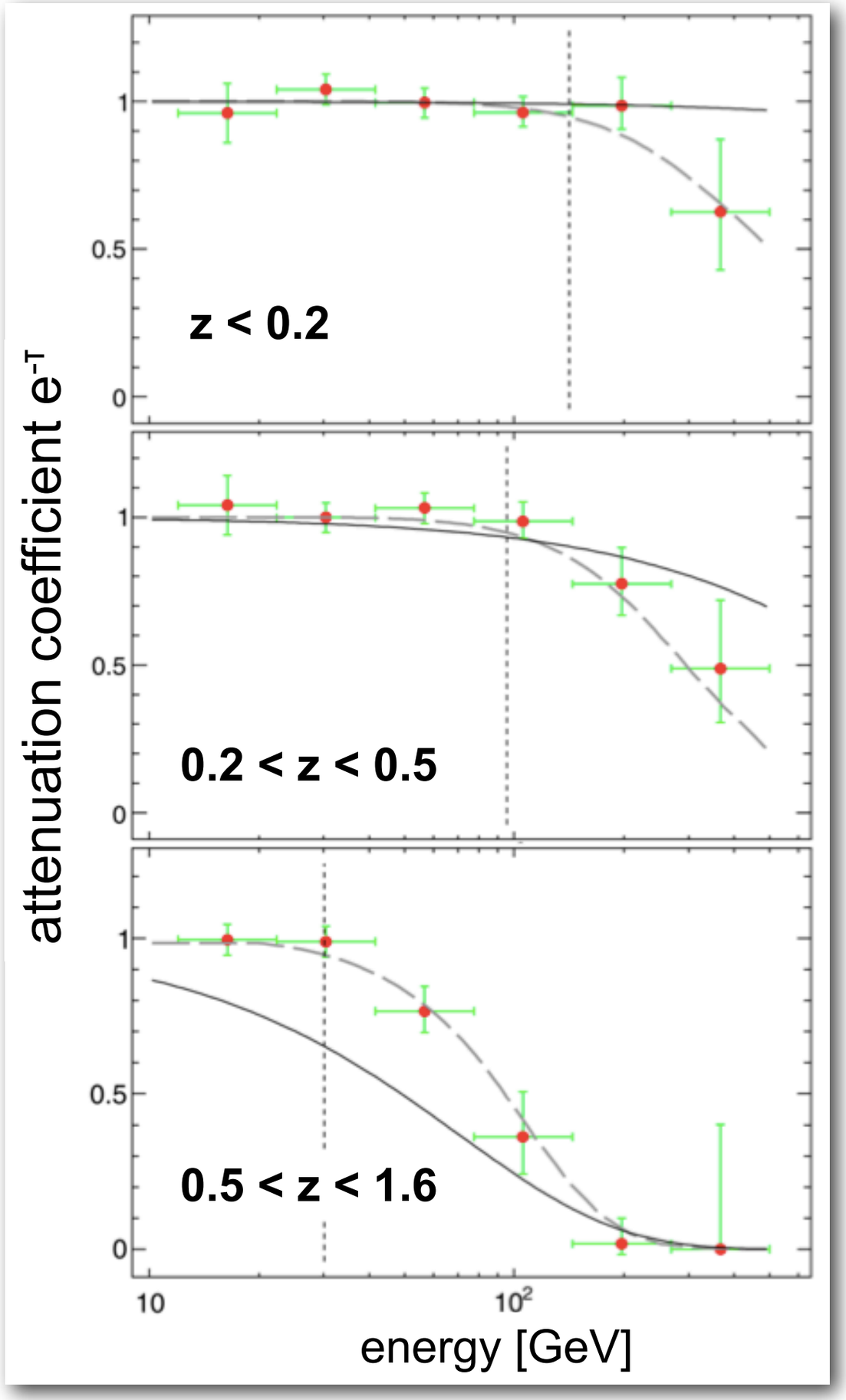
The extragalactic background light



Attenuation of high-energy gamma-rays:
$\gamma_{HE}\gamma_{EBL} \rightarrow e^+e^-$

expect a unique redshift-dependent imprint on γ-ray spectra

Measurement of the extragalactic background light

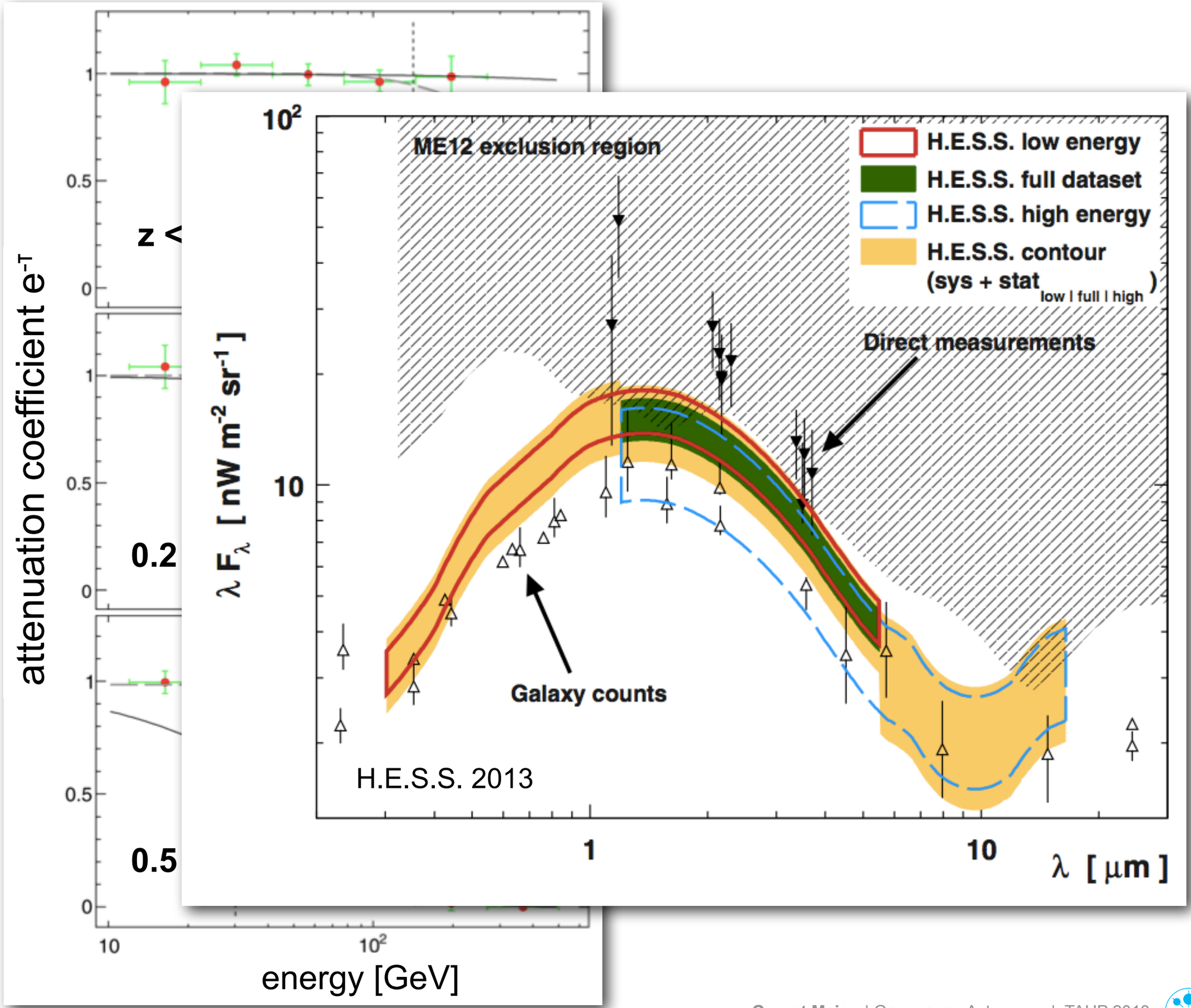


Ackermann et al 2012

look at a larger number of AGNs at different redshifts

assume intrinsic spectral smoothness

Measurement of the extragalactic background light



Gamma-ray Astronomy

- **astrophysics, cosmology and fundamental physics**
  - origin of Cosmic Rays, black hole accelerators
  - cosmology (extragalactic background light)
  - dark matter particles, Lorentz invariance, ...
- **second phase of H.E.S.S./MAGIC/VERITAS**
- **Fermi Large Area Telescope**
  expected to be operational at least +5 years
- **HAWC: survey of the northern sky**
  in construction; to be completed in 2014
- **x10 improvement:**
  The Cherenkov Telescope Array

stop....

Cosmic rays → Gamma rays

Cosmic rays
(p, He, .., Fe, e±)

matter, magnetic,
photon fields

Cosmic rays → Gamma rays

Cosmic rays
(p, He, .., Fe, e±)

matter, magnetic, photon fields

inverse Compton scattering

Bremsstrahlung

leptonic

hadronic

proton synchrotron

$p_{CR} + p \rightarrow p + \pi^{0/+/-} + ...$

$\hookrightarrow \gamma\gamma$

$p_{CR} + \gamma \rightarrow p + \pi^{0}$

$p_{CR} + \gamma \rightarrow p + \pi^{+/-}$

$\hookrightarrow \mu^{+/-}\nu$

$\hookrightarrow e^{+/-}...$

cascades/synchrotron

Cosmic rays → Gamma rays

Cosmic rays
(p, He, .., Fe, e±)

matter, magnetic, photon fields

inverse Compton scattering

Bremsstrahlung

leptonic

top down: decay, annihilation

hadronic

proton synchrotron

$p_{CR} + p \rightarrow p + \pi^{0/+/-} + ...$

↳ $\gamma\gamma$

$p_{CR} + \gamma \rightarrow p + \pi^{0}$

$p_{CR} + \gamma \rightarrow p + \pi^{+/-}$

↳ $\mu^{+/-}\nu$

↳ $e^{+/-}$...

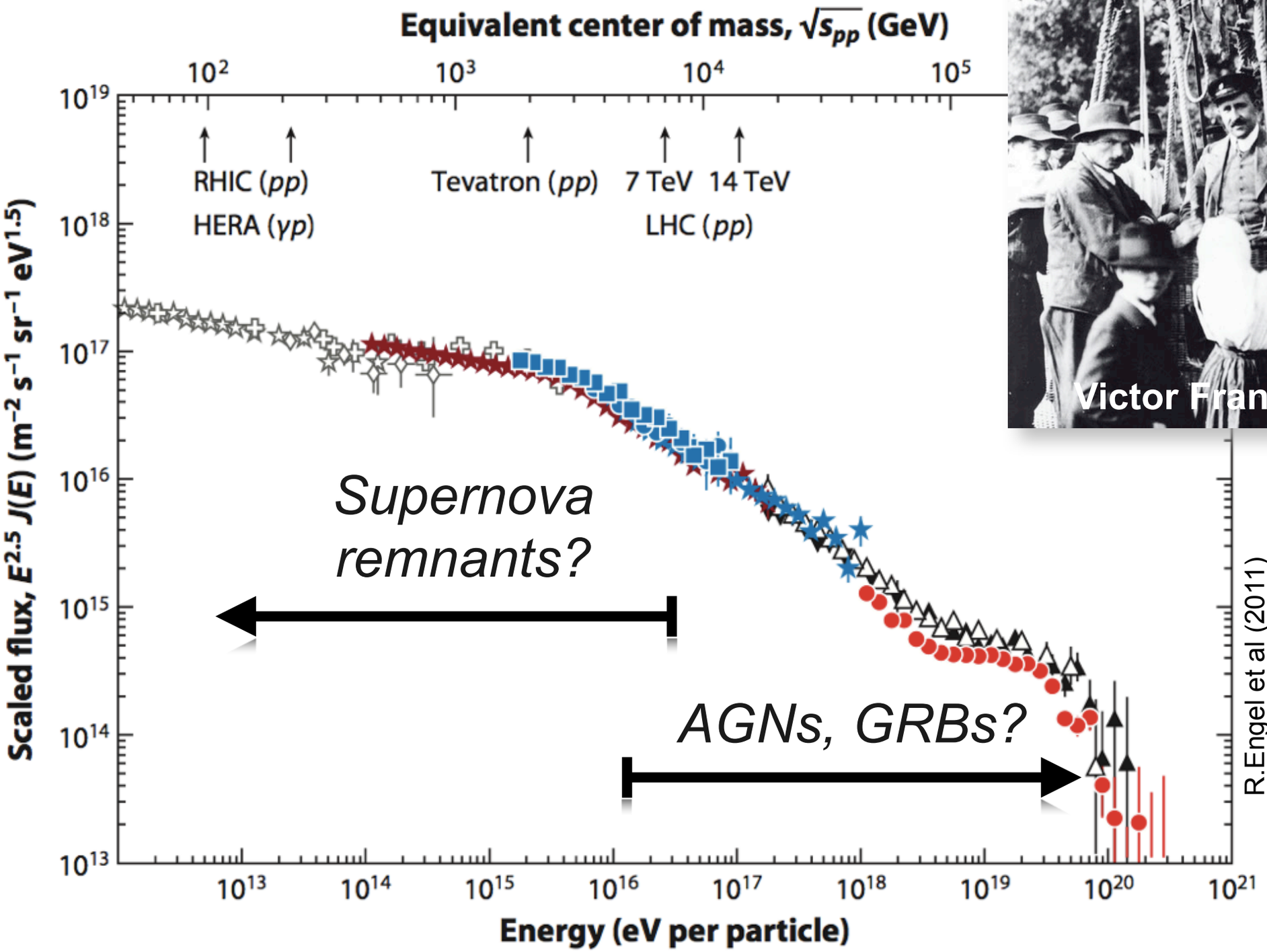
cascades/synchrotron

CTA midsize telescopes

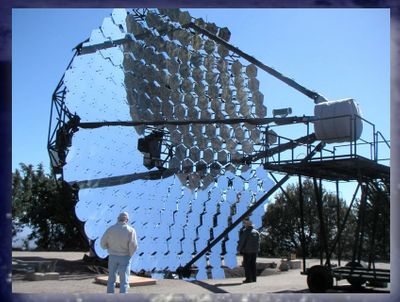
full-scale mechanical prototype (Berlin)

Dual-mirror telescope (prototype to be build in Az)

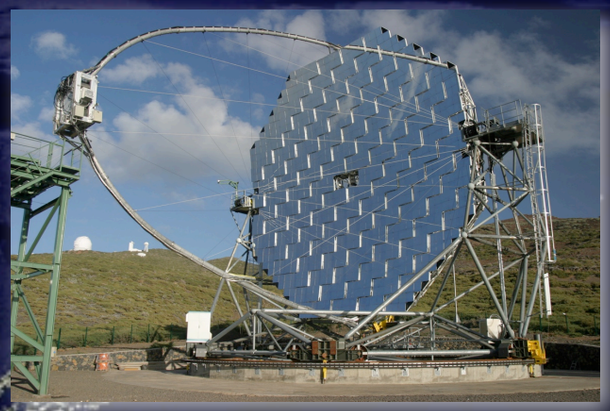
How do cosmic rays gain their energy? Where are they accelerated?



Observing gamma rays



Whipple



MAGIC

AGILE

Fermi LAT

VERITAS

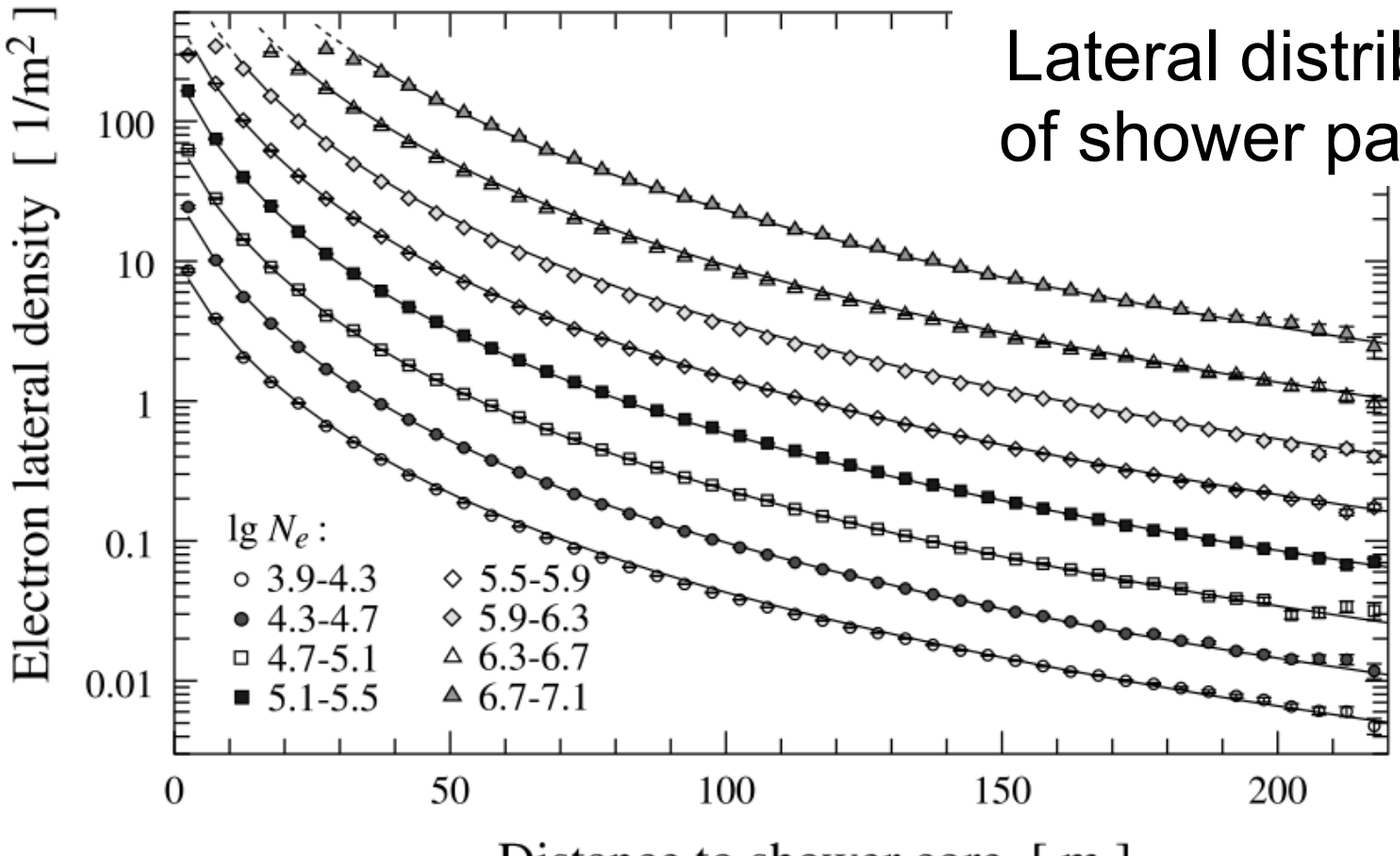
HAWC

Tibet ASγ/ARGO

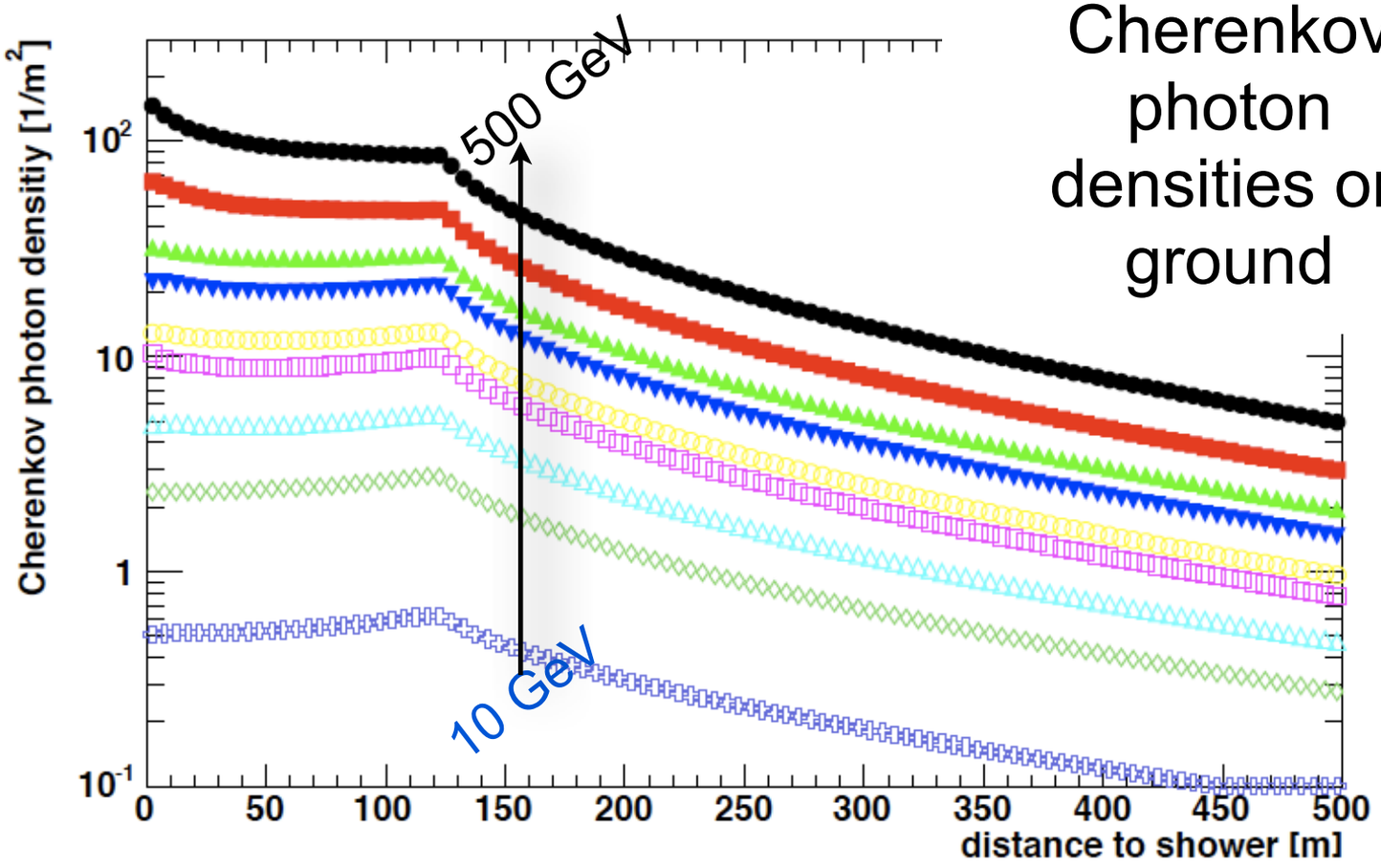
H.E.S.S.

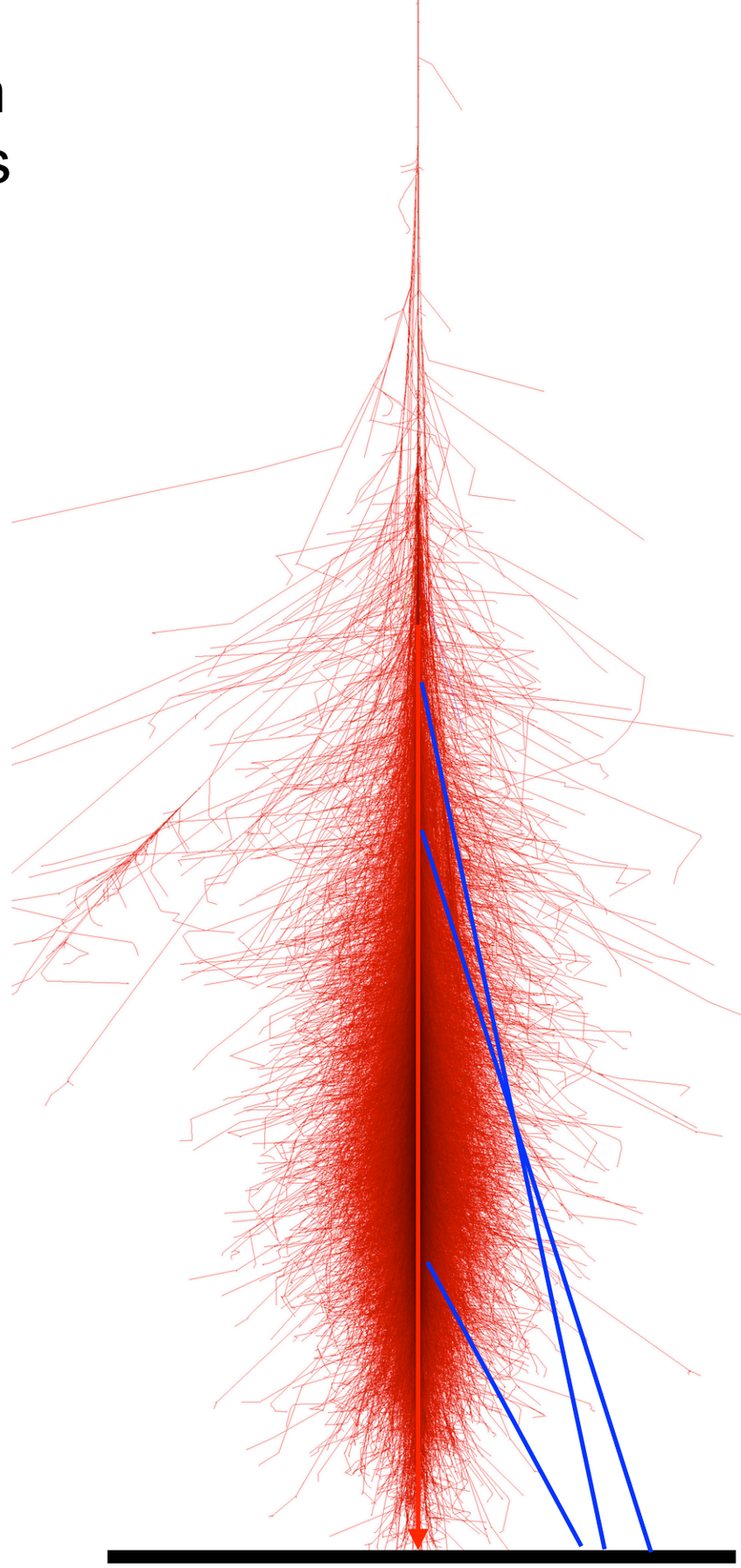
space based: 20 MeV - 300 GeV
ground based: 25 GeV - 1 PeV

Lateral distribution of shower particles

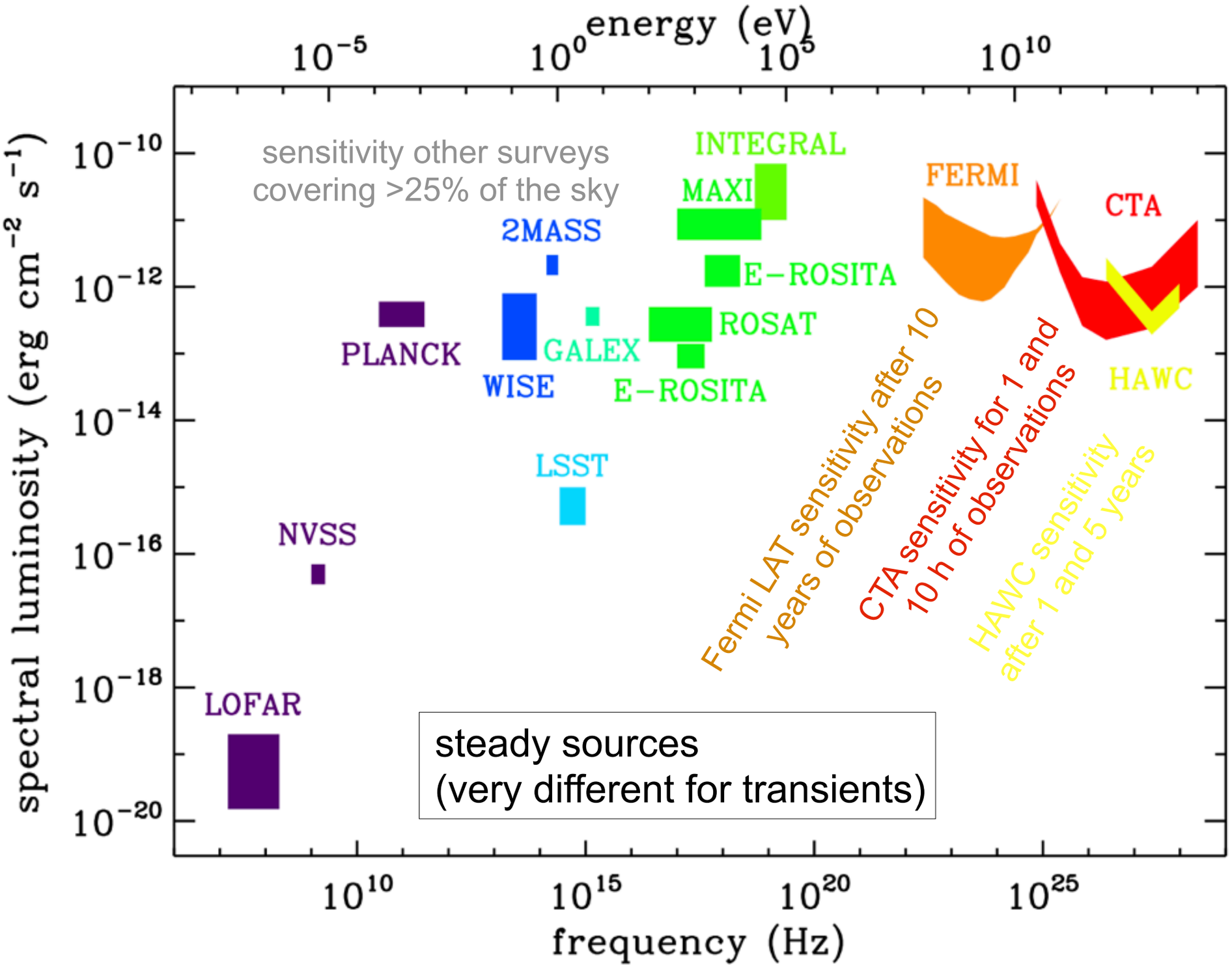


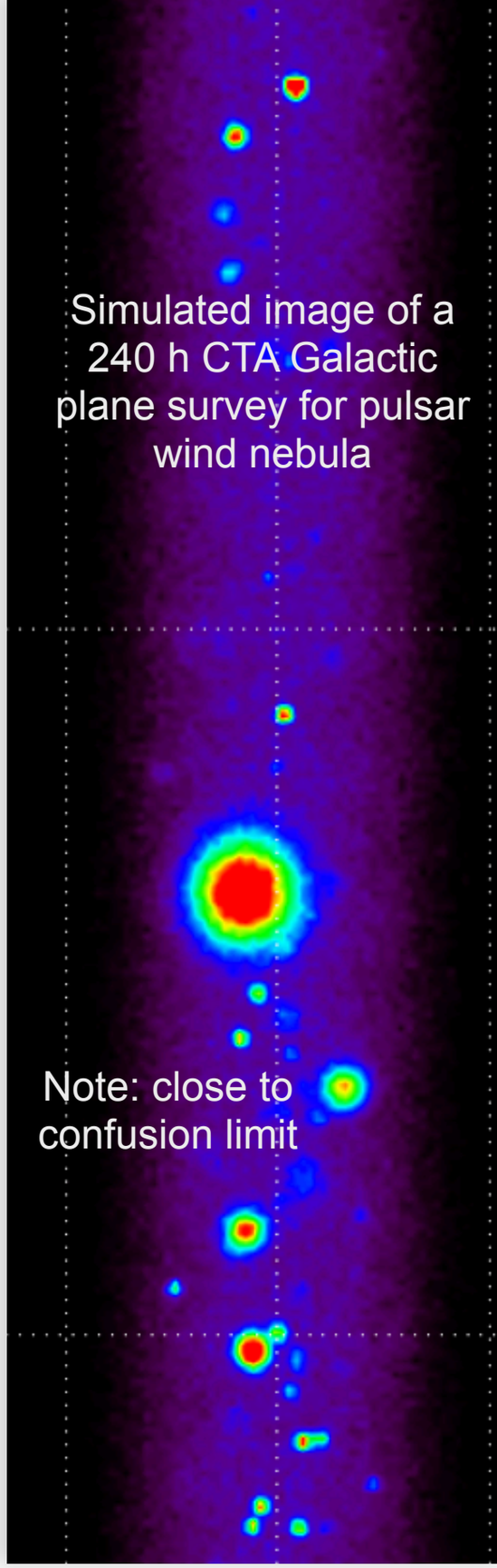
Cherenkov photon densities on ground





Survey sensitivity in the multi-wavelength context

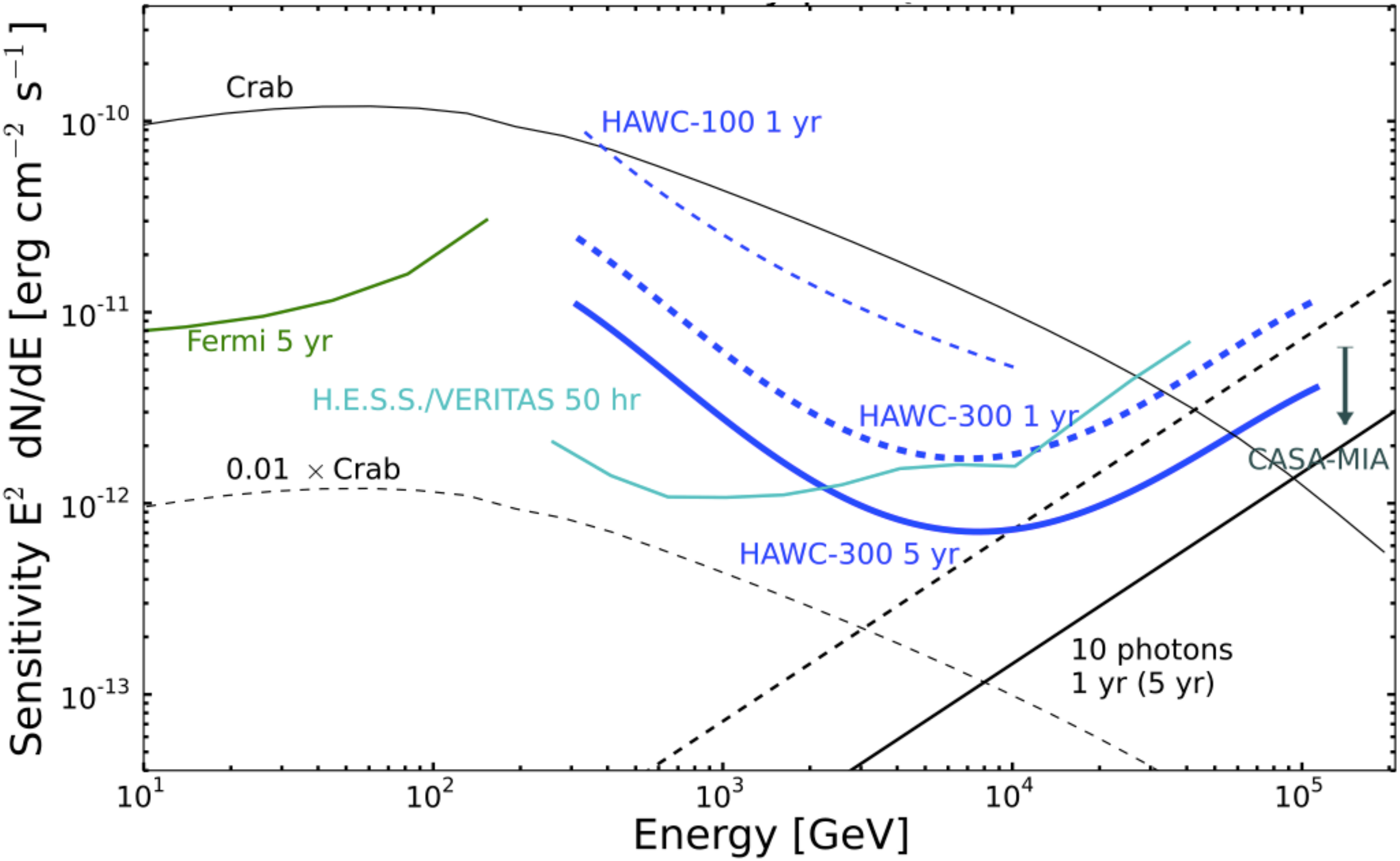




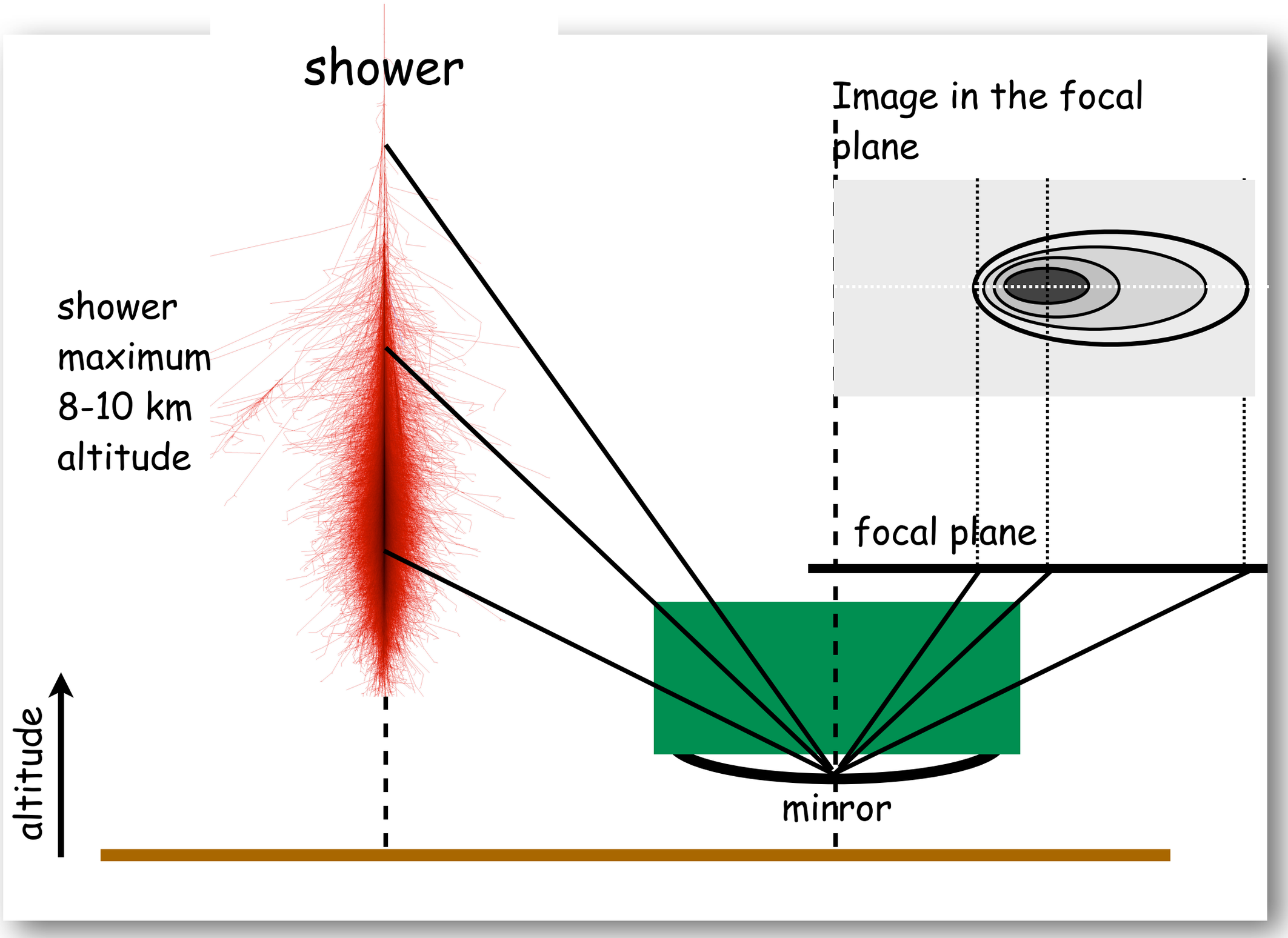
CTA (Dubus et al), astro-ph/12108.5686; 2012

Flux sensitivity

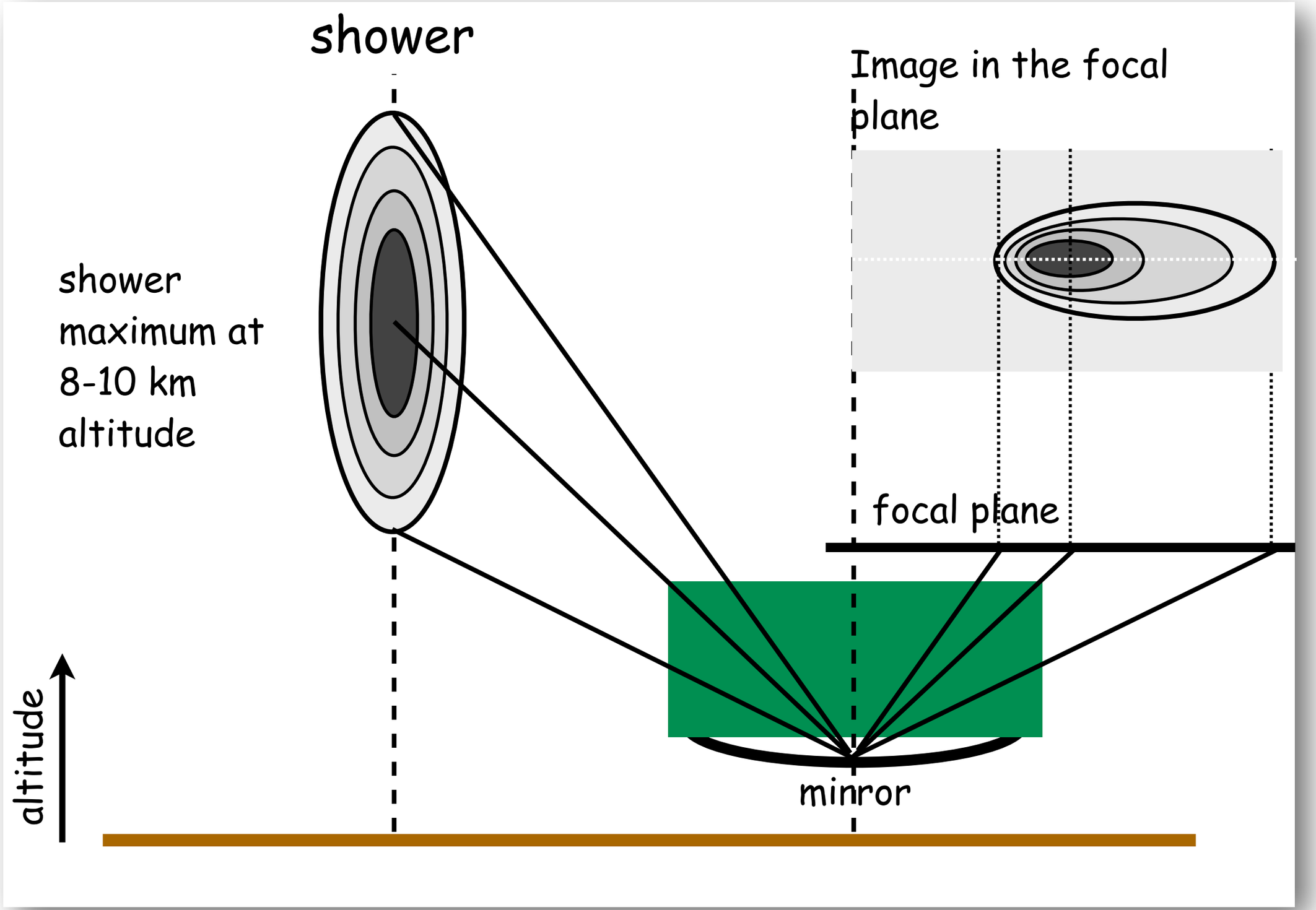
Abeysekara et al 2013



Imaging Atmospheric Cherenkov Telescopes

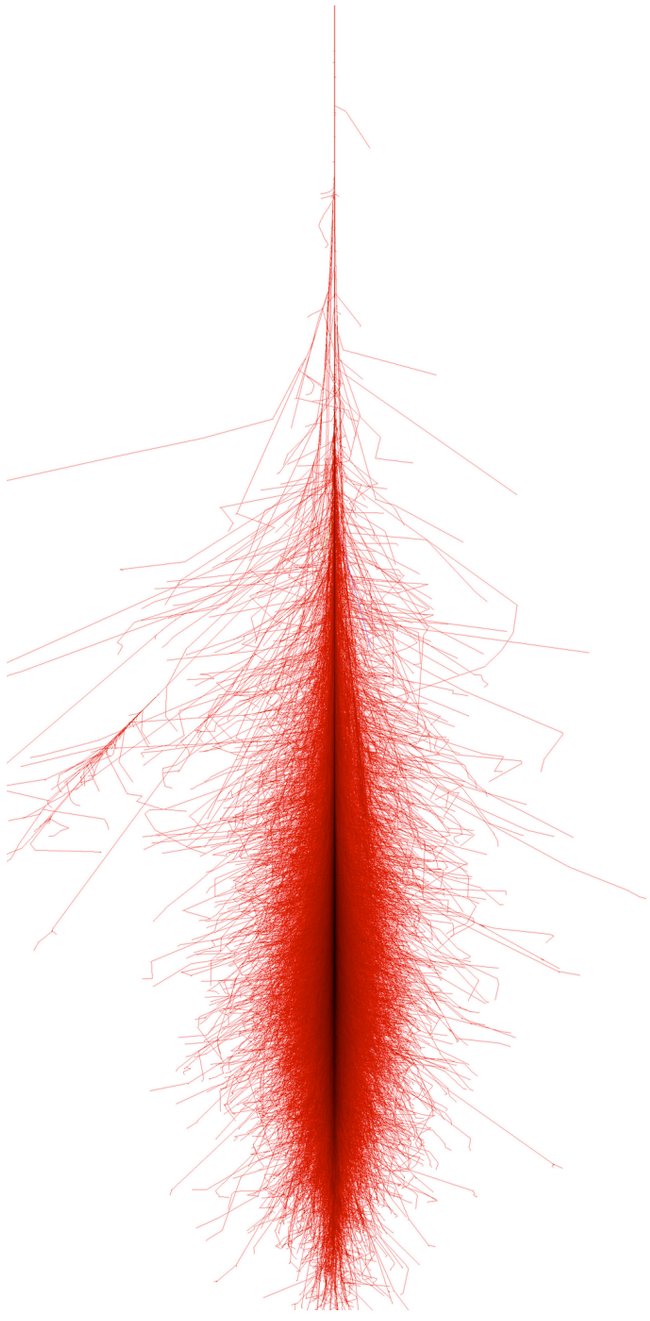


Imaging Atmospheric Cherenkov Telescopes

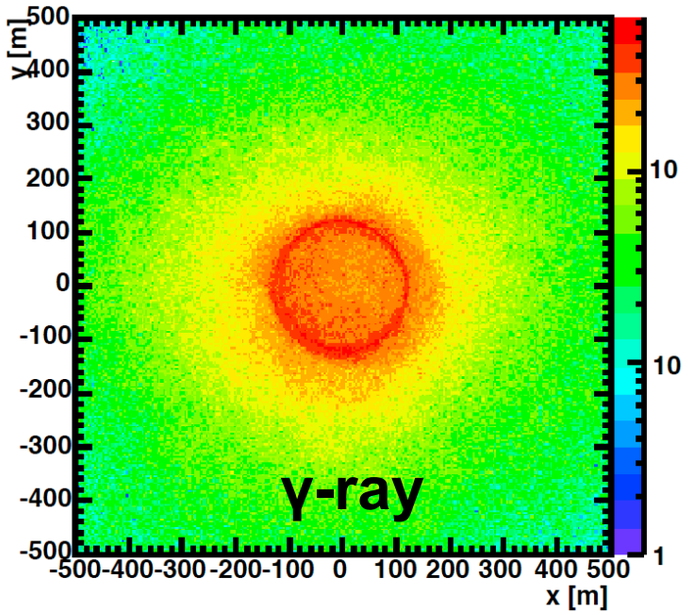


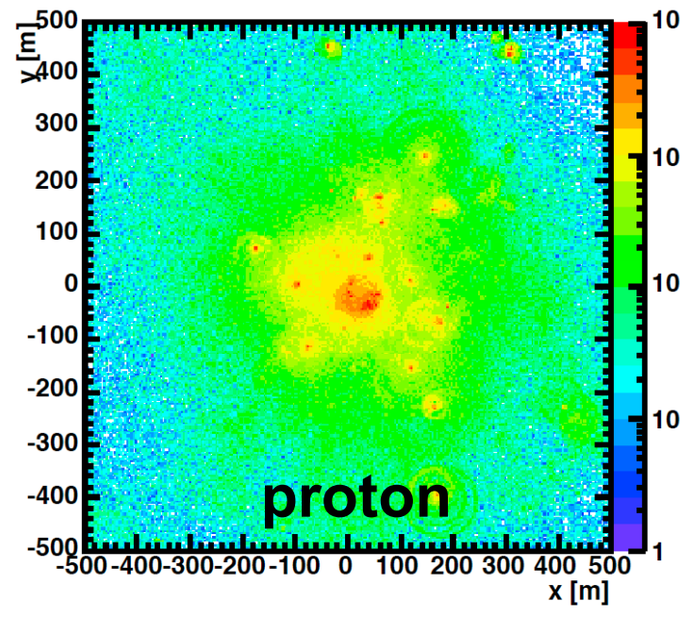
Proton vs Gamma-ray showers

γ-ray



Cherenkov photons on ground





proton