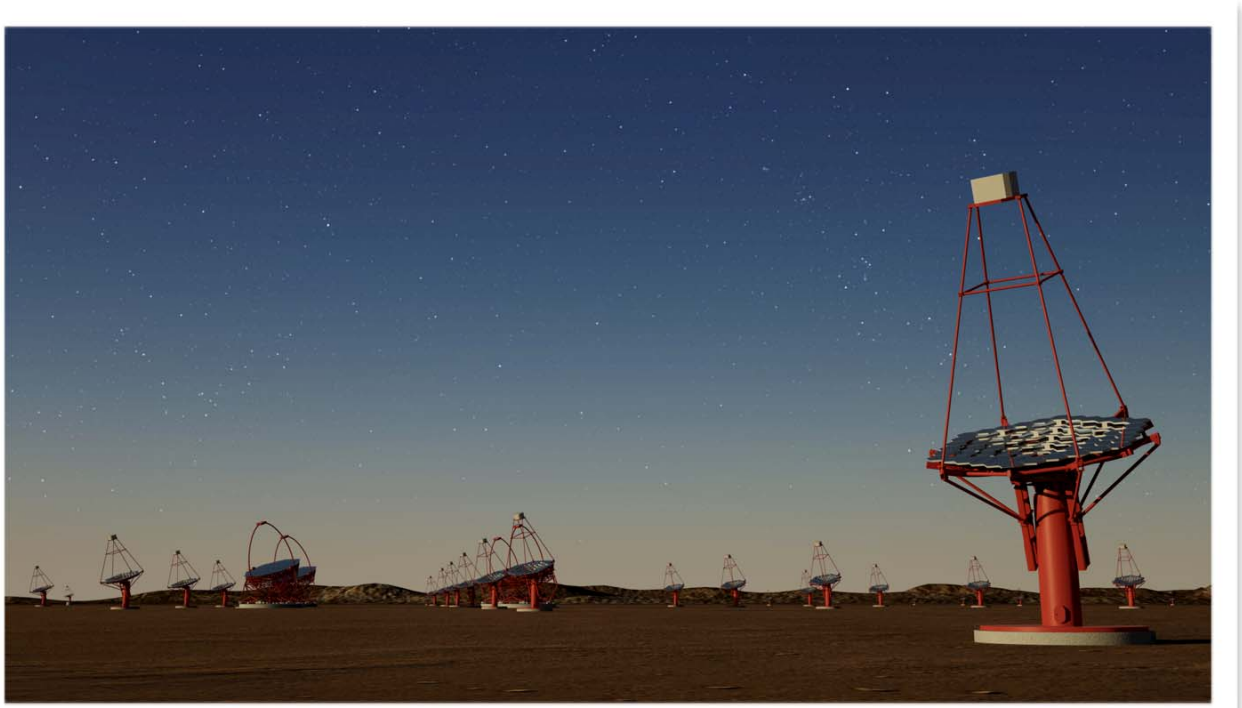


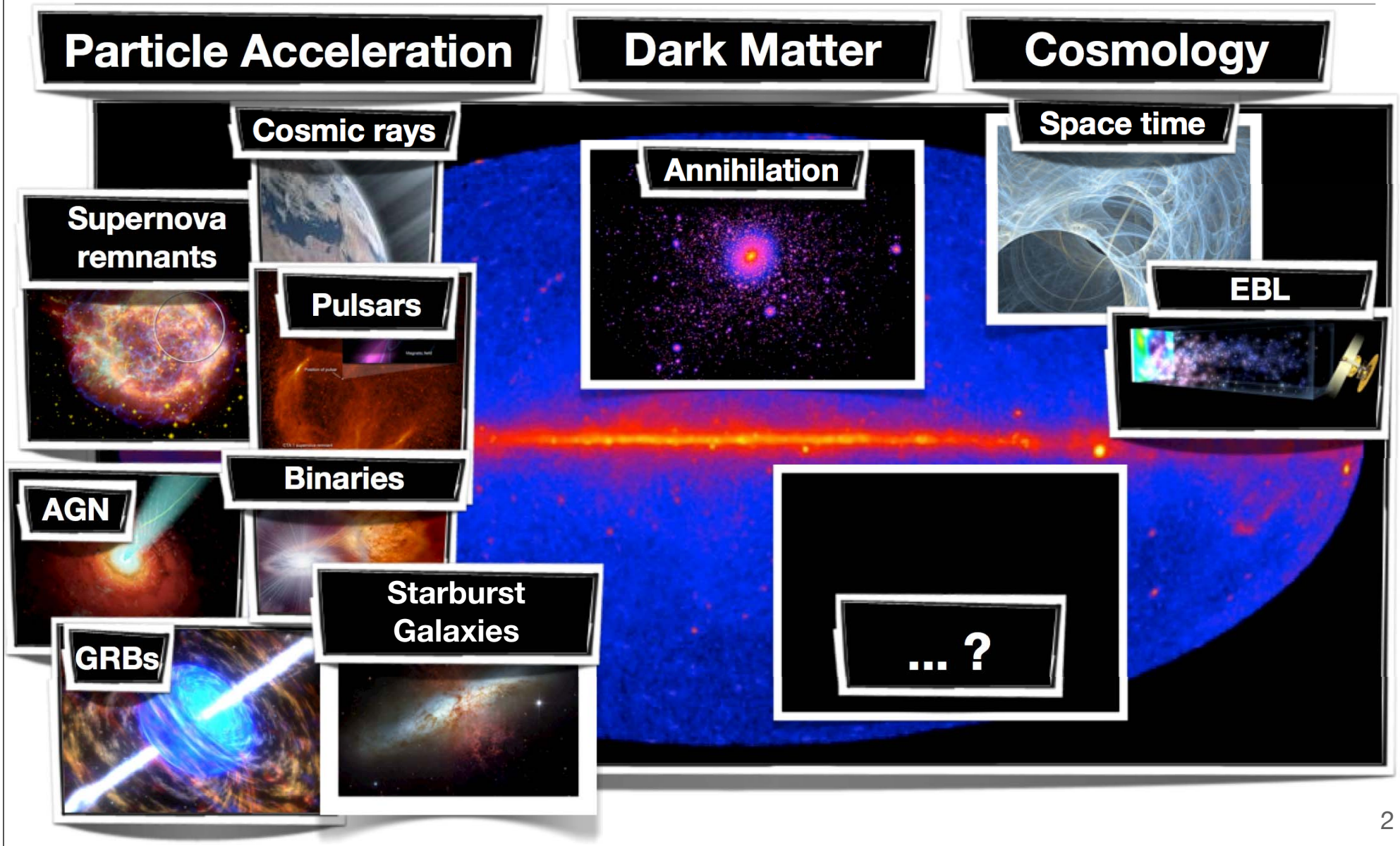
CTA Science and Project Overview

CTA and the origin of cosmic rays

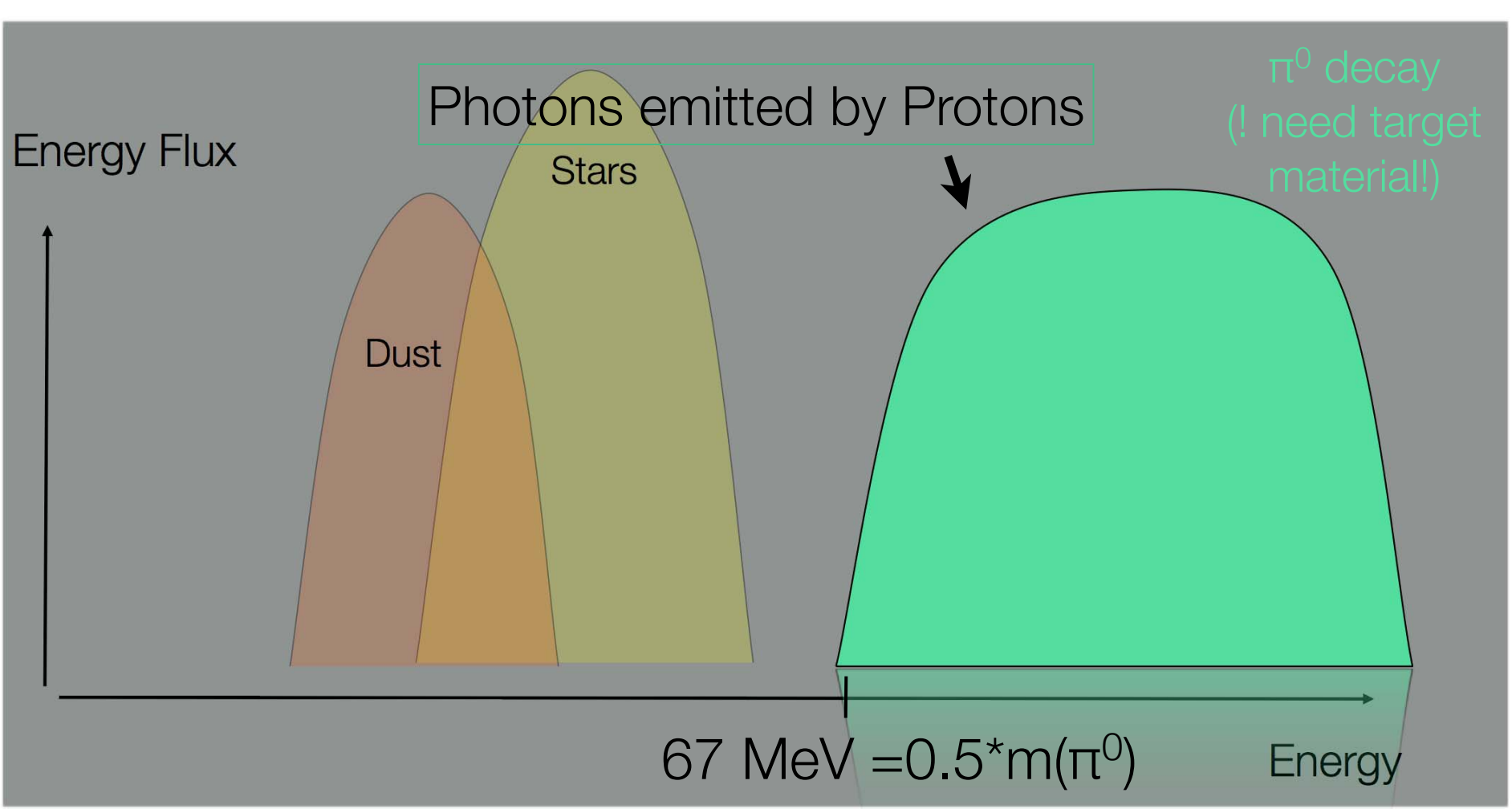
Stefan Funk

KIPAC KAVLI INSTITUTE FOR PARTICLE ASTROPHYSICS AND COSMOLOGY

Gamma-ray particle astrophysics



Photon emission by accelerated charged particles



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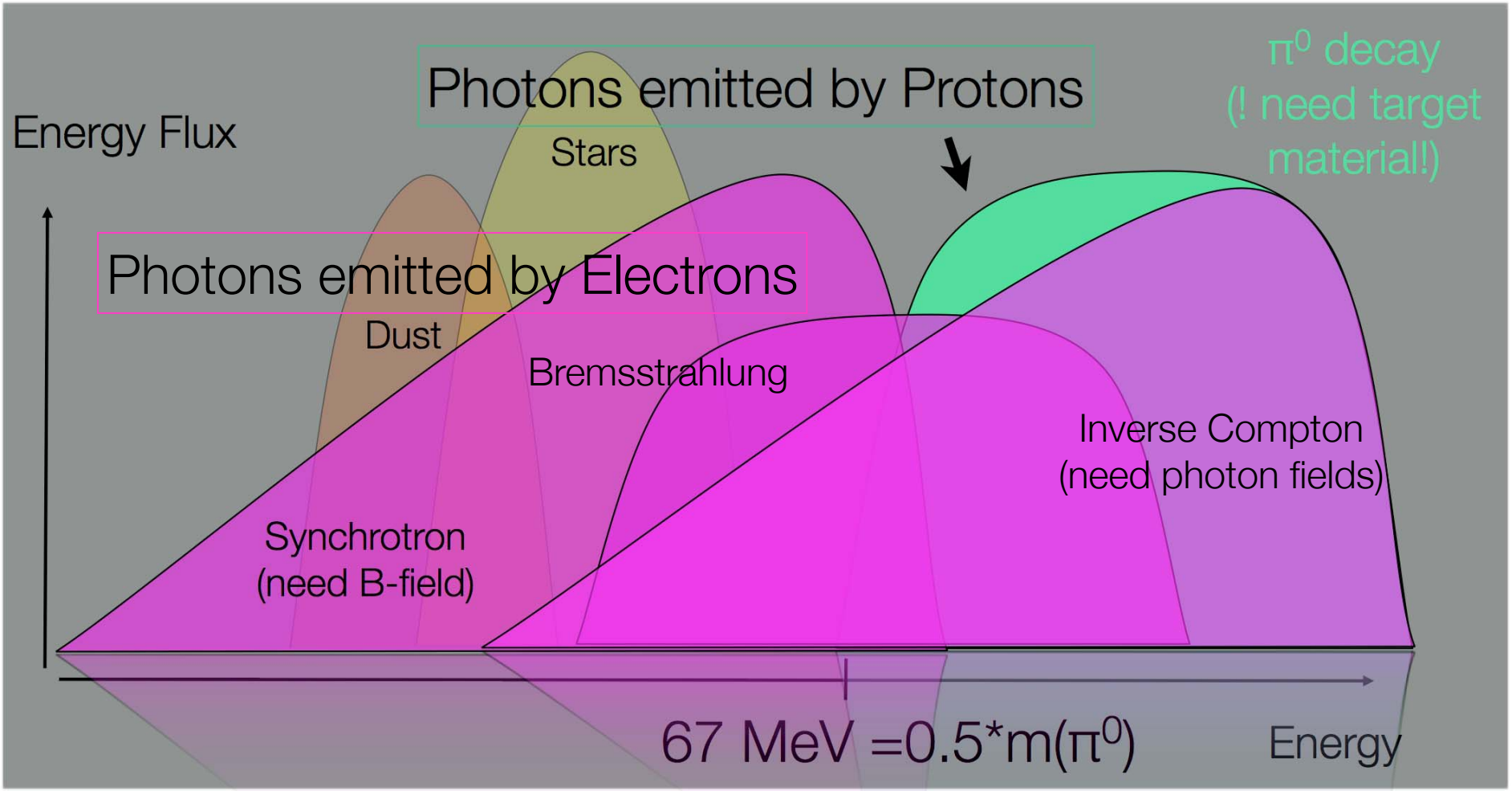

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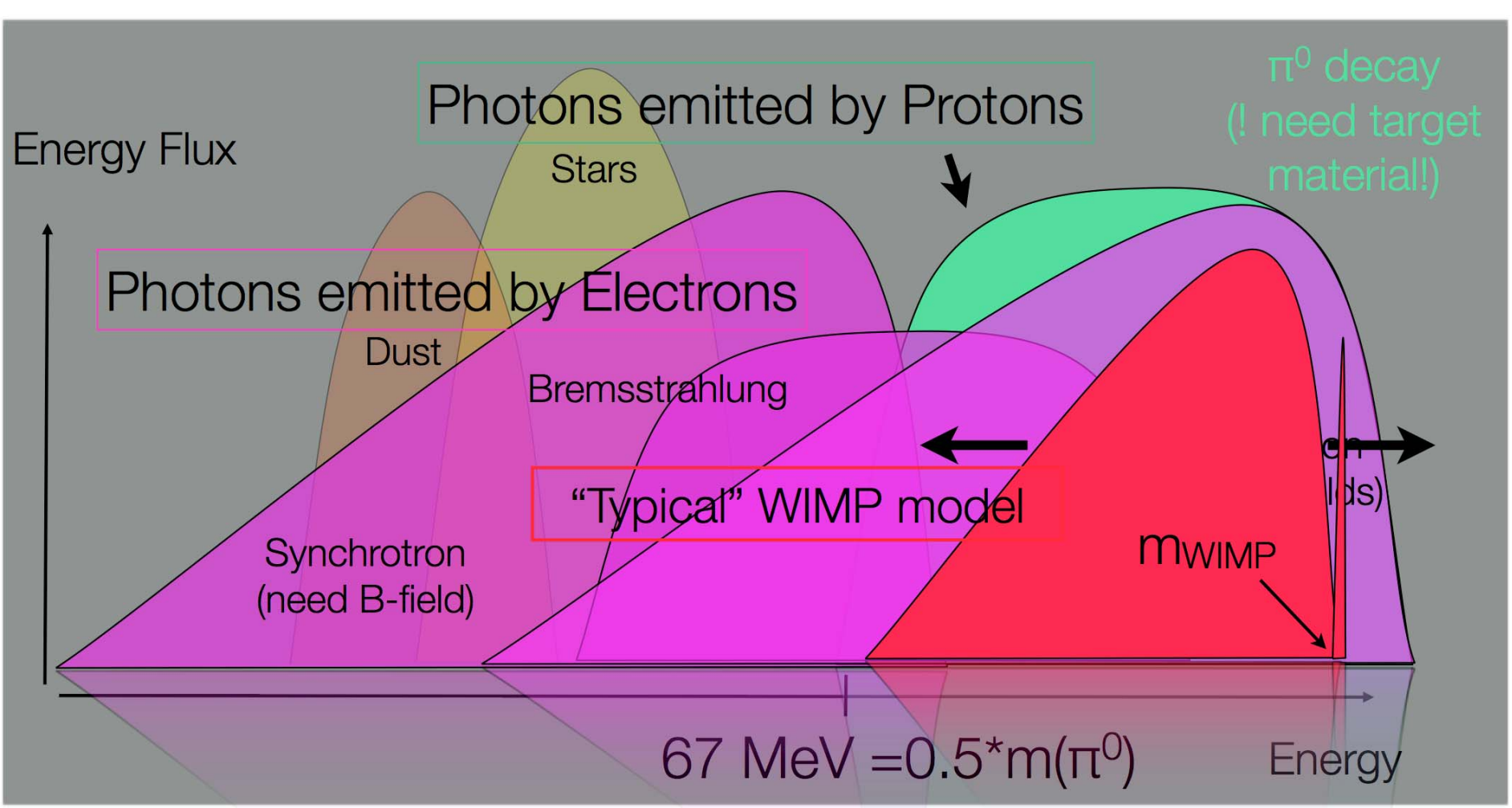
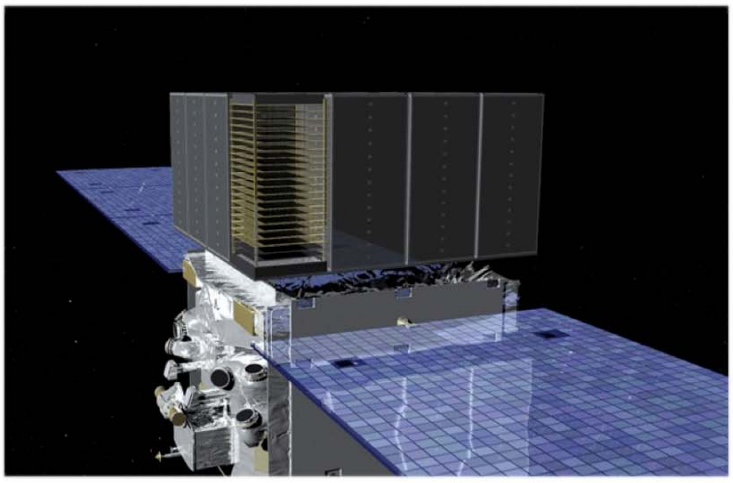
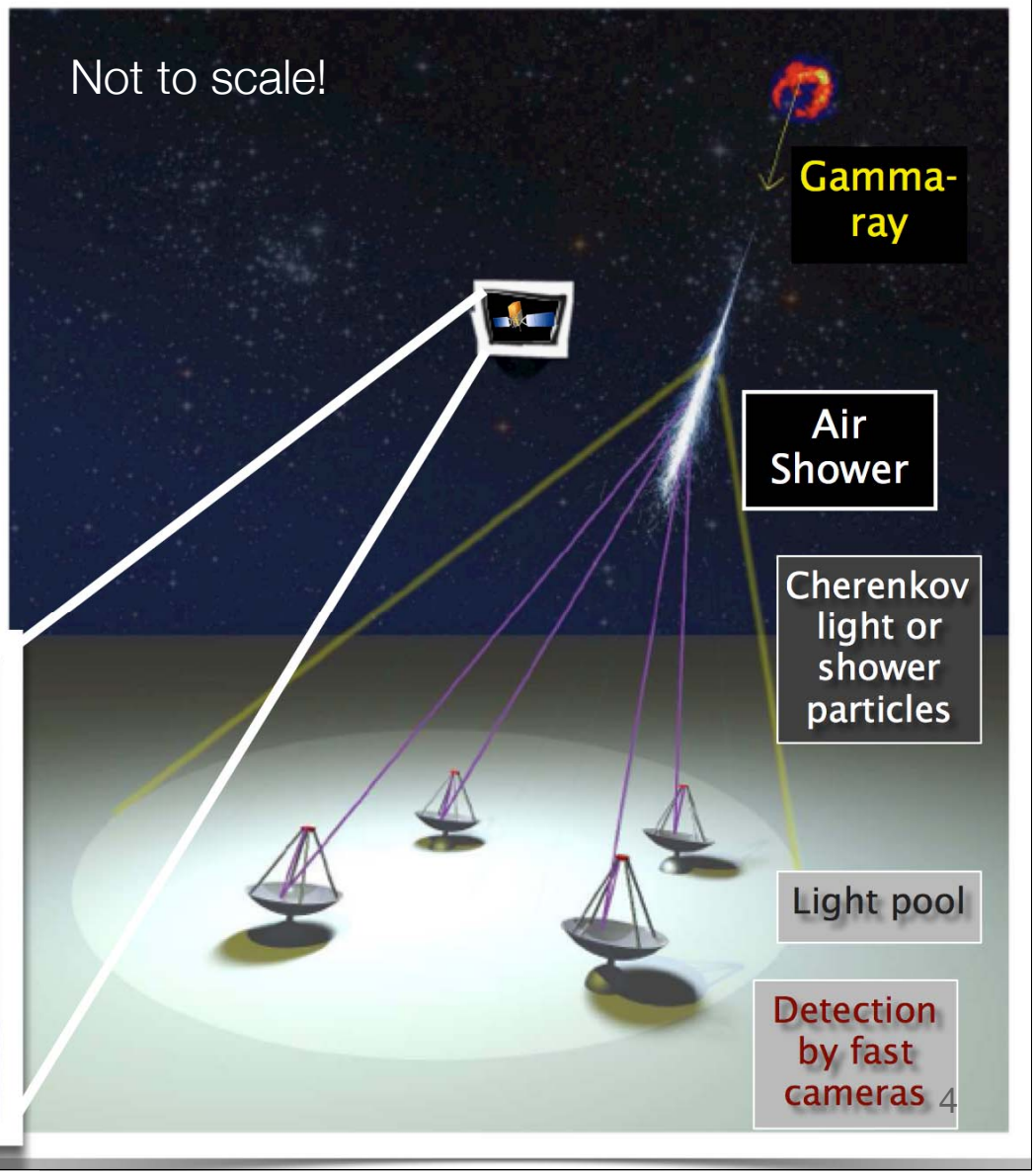


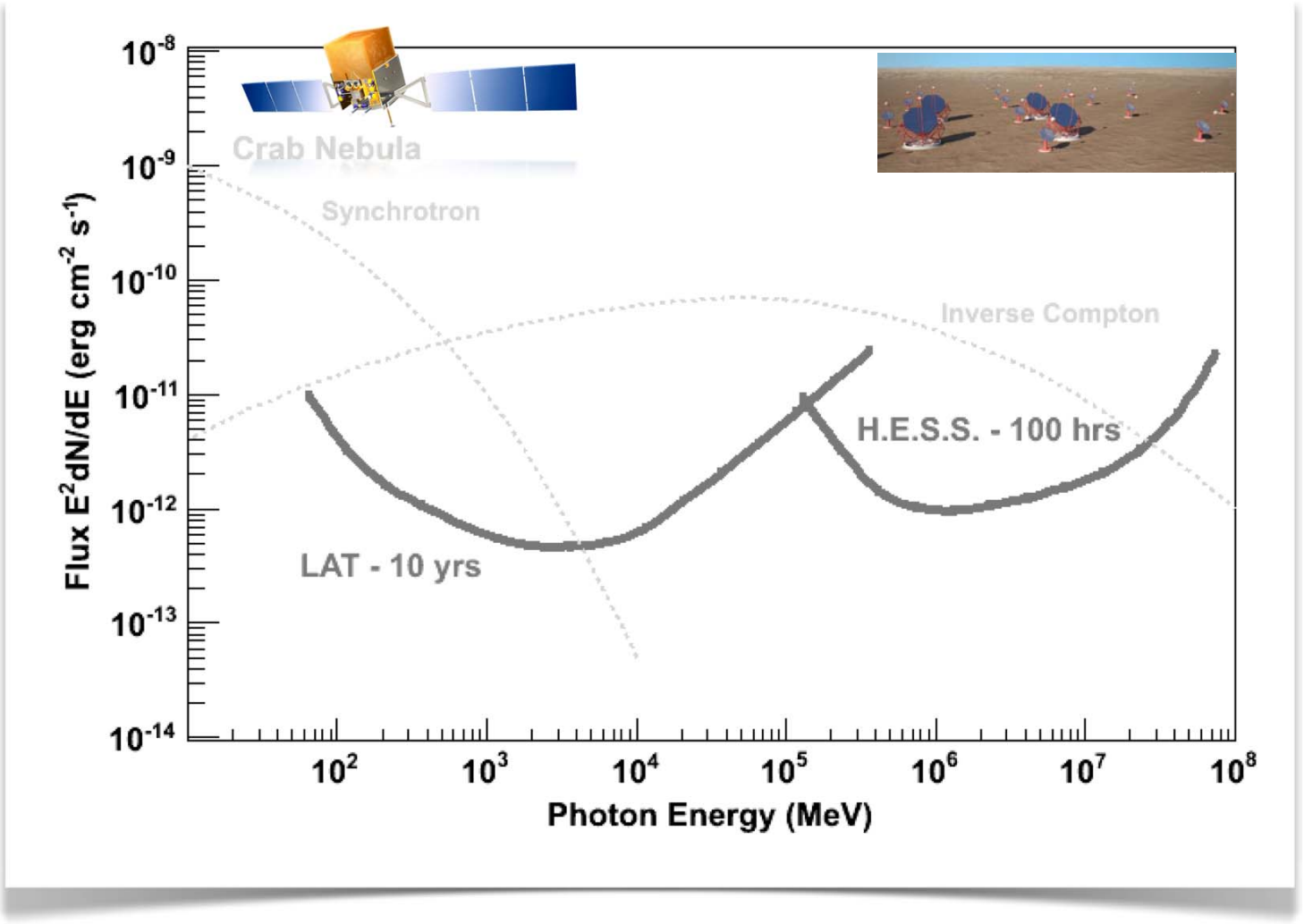
Detection of γ-rays

- Put instrument outside of the atmosphere (Fermi-LAT)
  - Ideal for lower-energy ($dN/dE \sim E^{-\alpha}$)
- Use atmosphere as part of the detector
  - Only realistic way to increase area

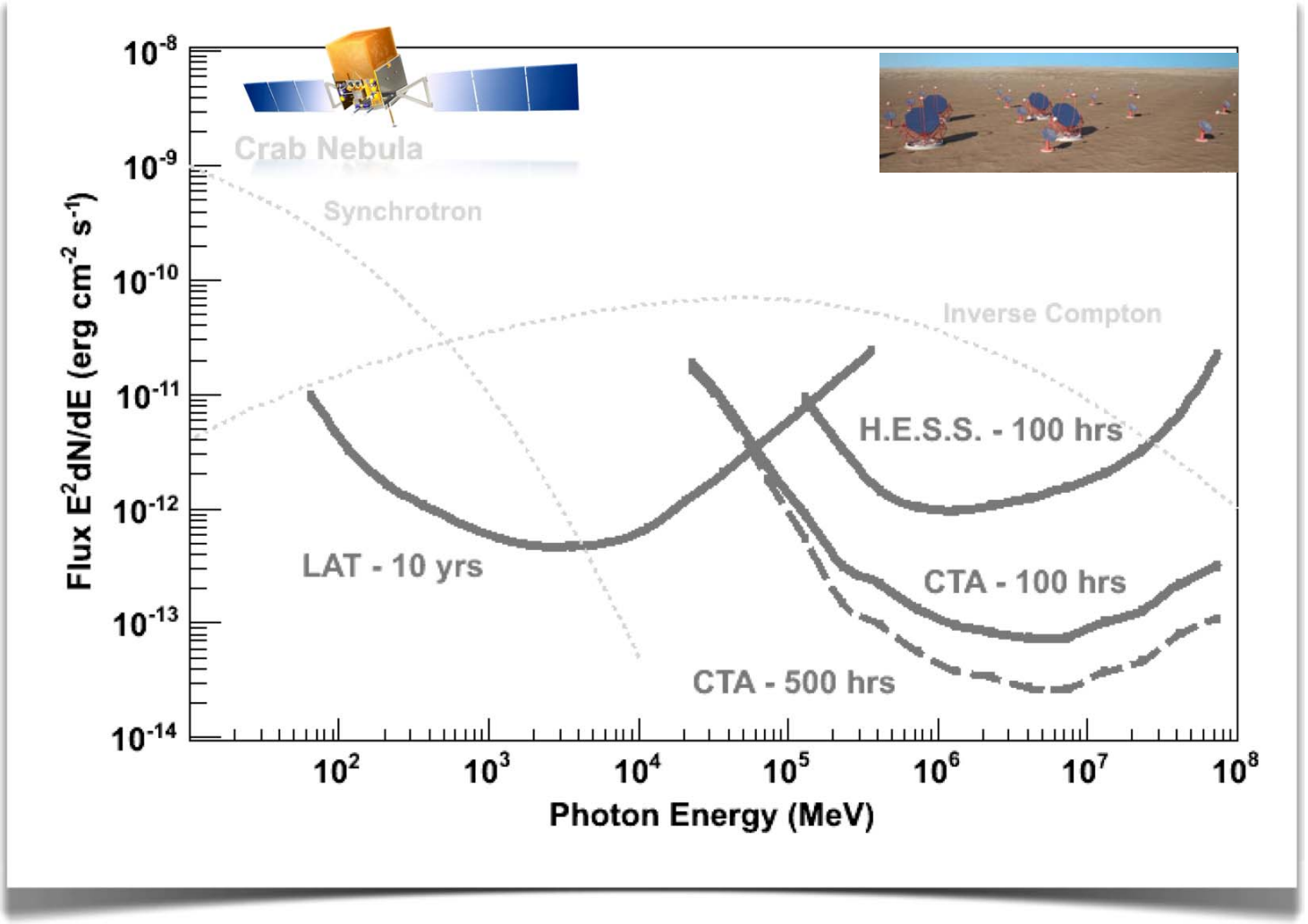




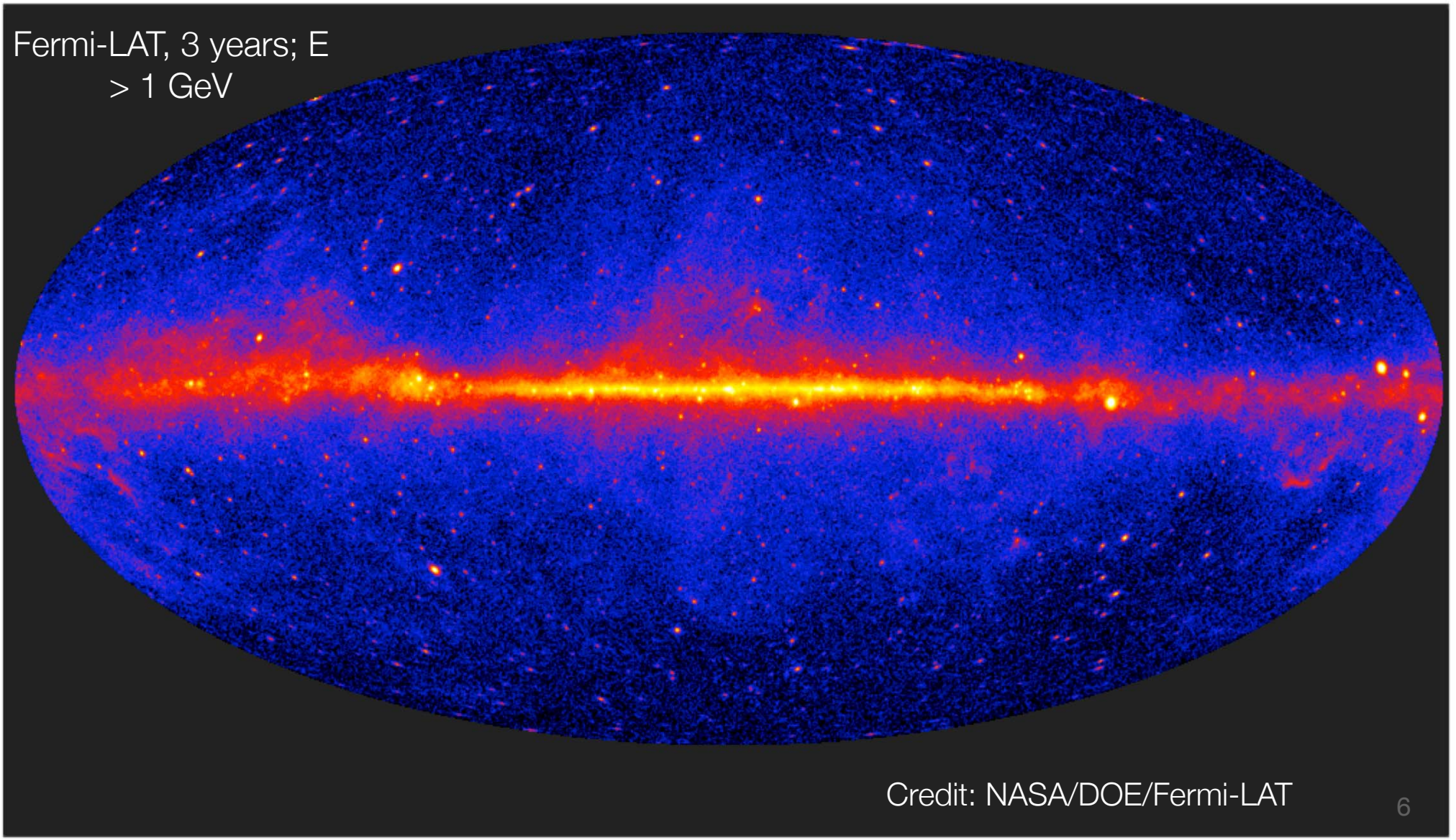
Spaced-based and ground-based instruments



Spaced-based and ground-based instruments

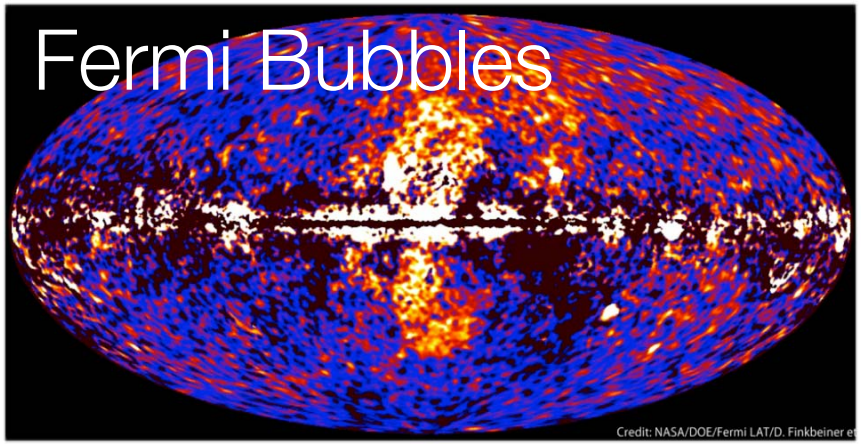


What a factor 30 improvement in sensitivity gets you

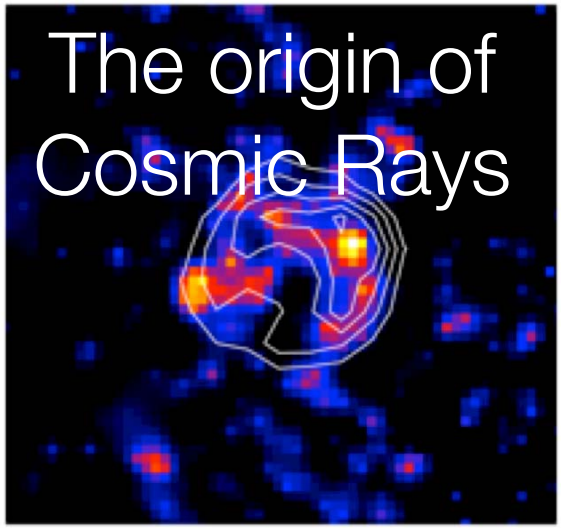


The four most exciting results of the last years*

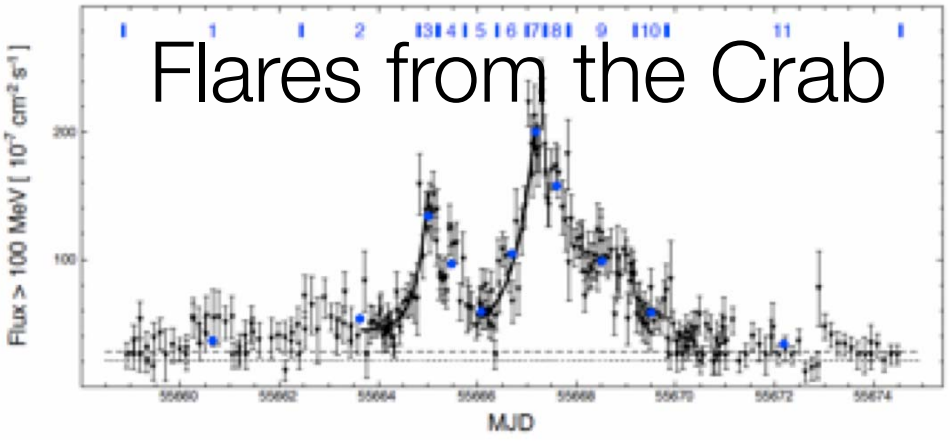
Fermi Bubbles



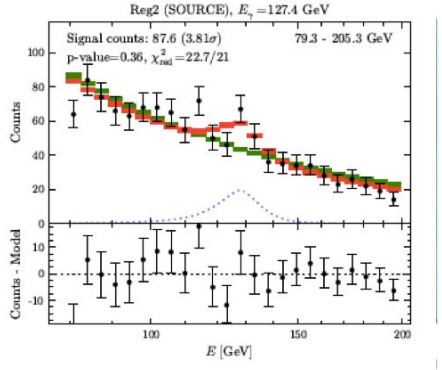
The origin of Cosmic Rays

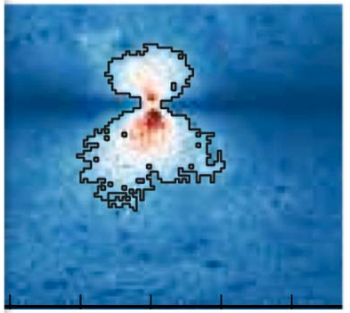


Flares from the Crab



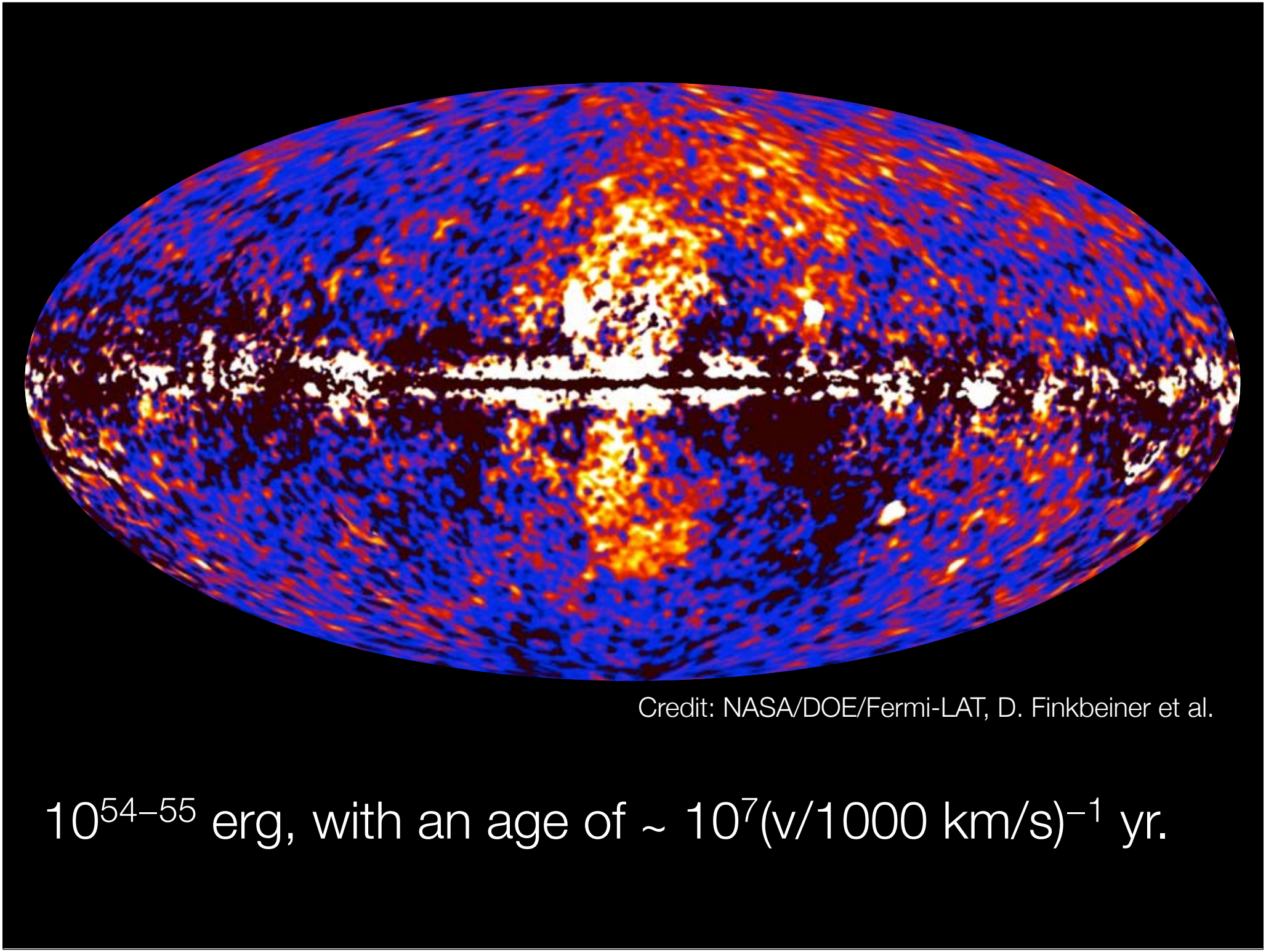
A line at 130 GeV?





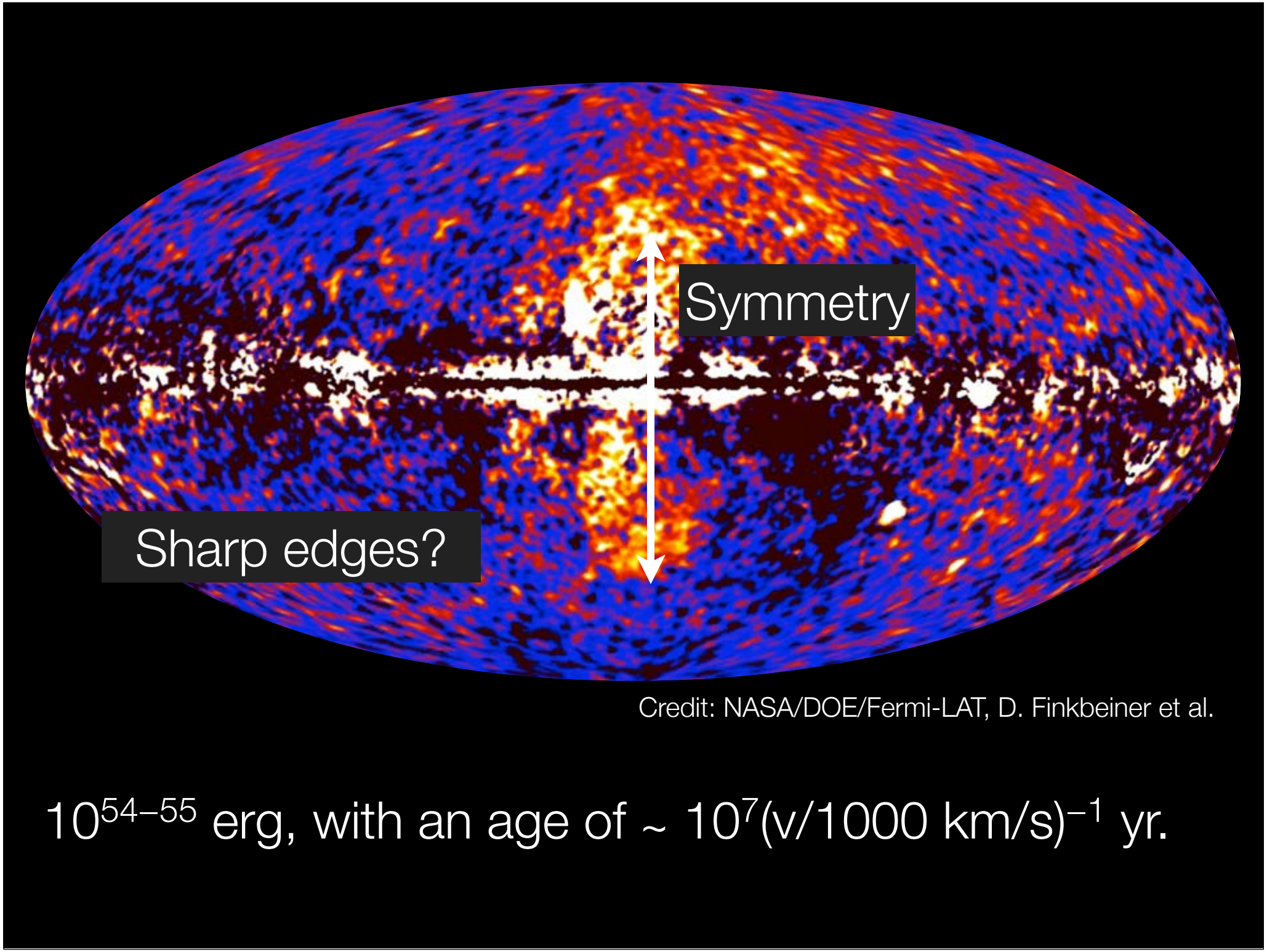
*Utterly personal and biased view

The Fermi Bubbles



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

10^{54-55} erg, with an age of ~ $10^{7}(v/1000\ \mathrm{km/s})^{-1}$ yr.



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

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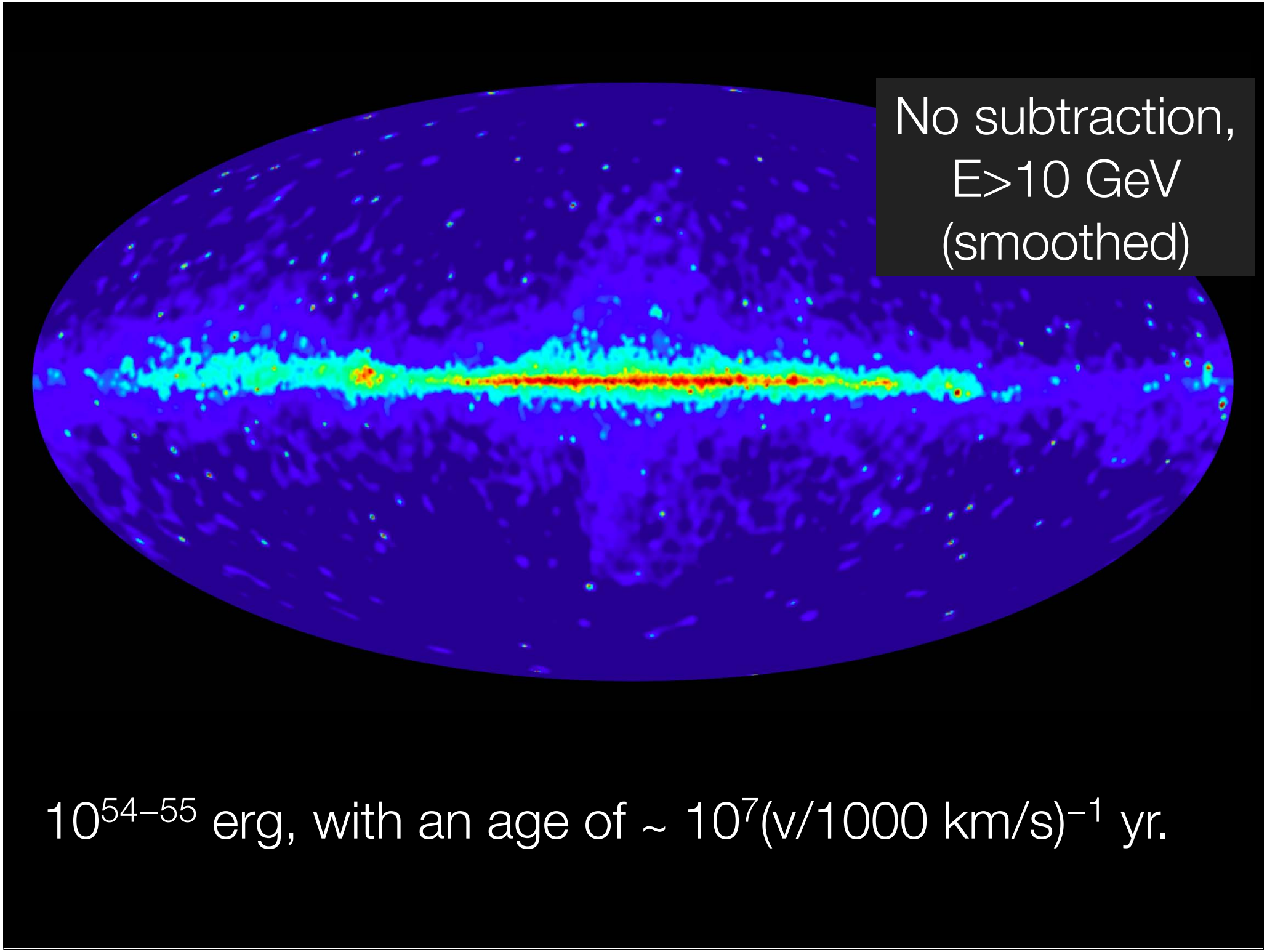

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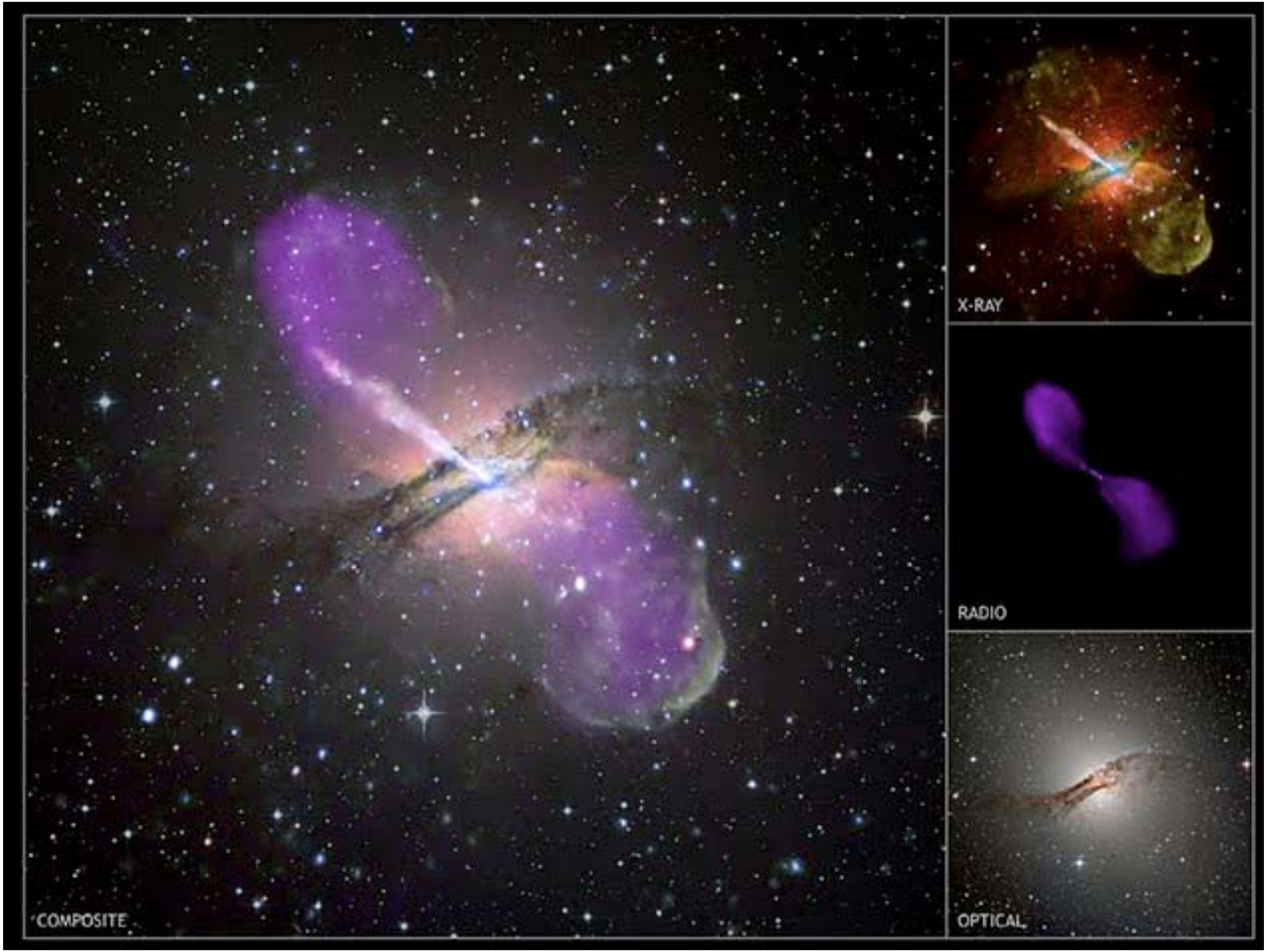
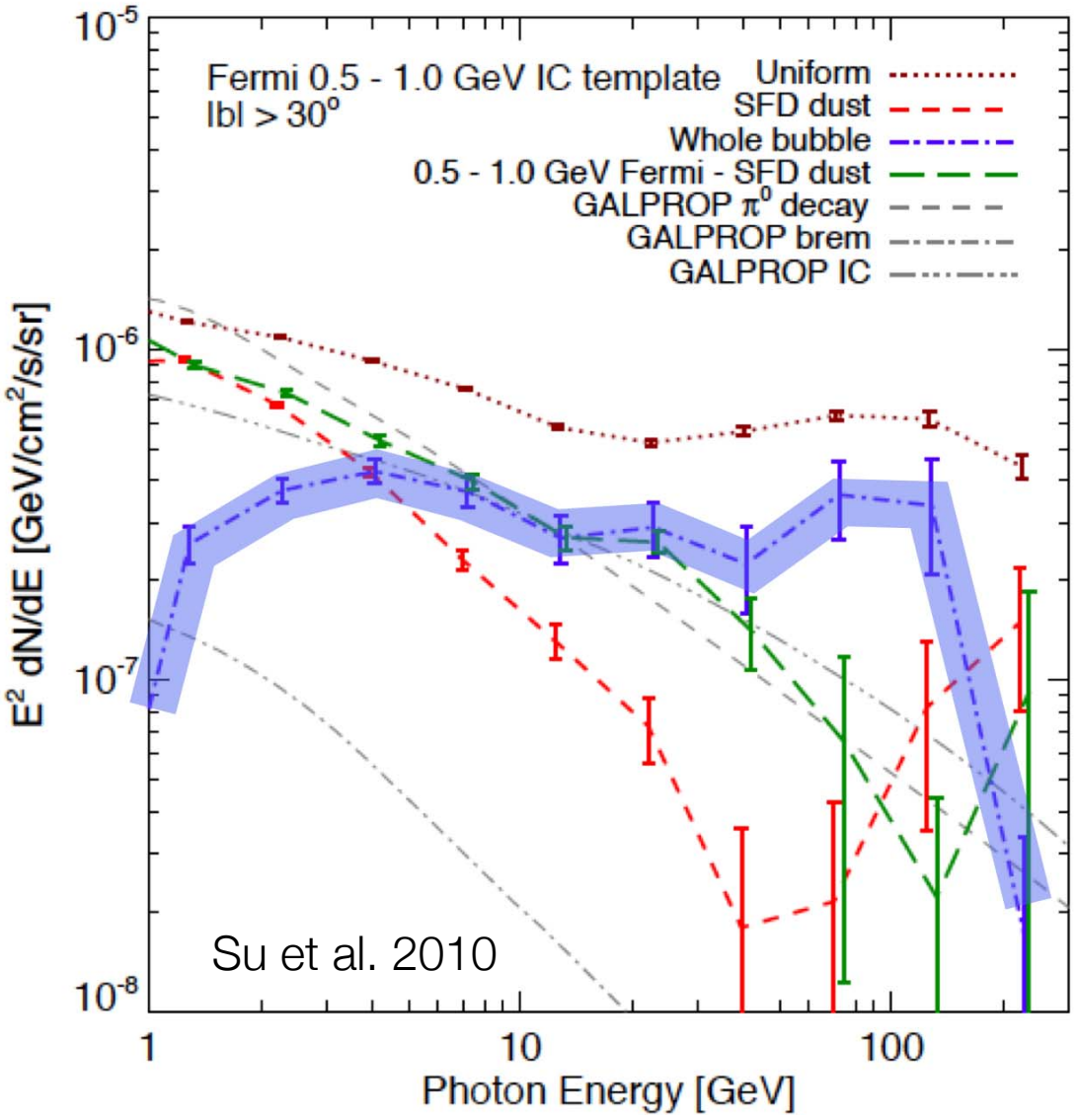

COMPOSITE
X-RAY
RADIO
OPTICAL

Properties of bubbles

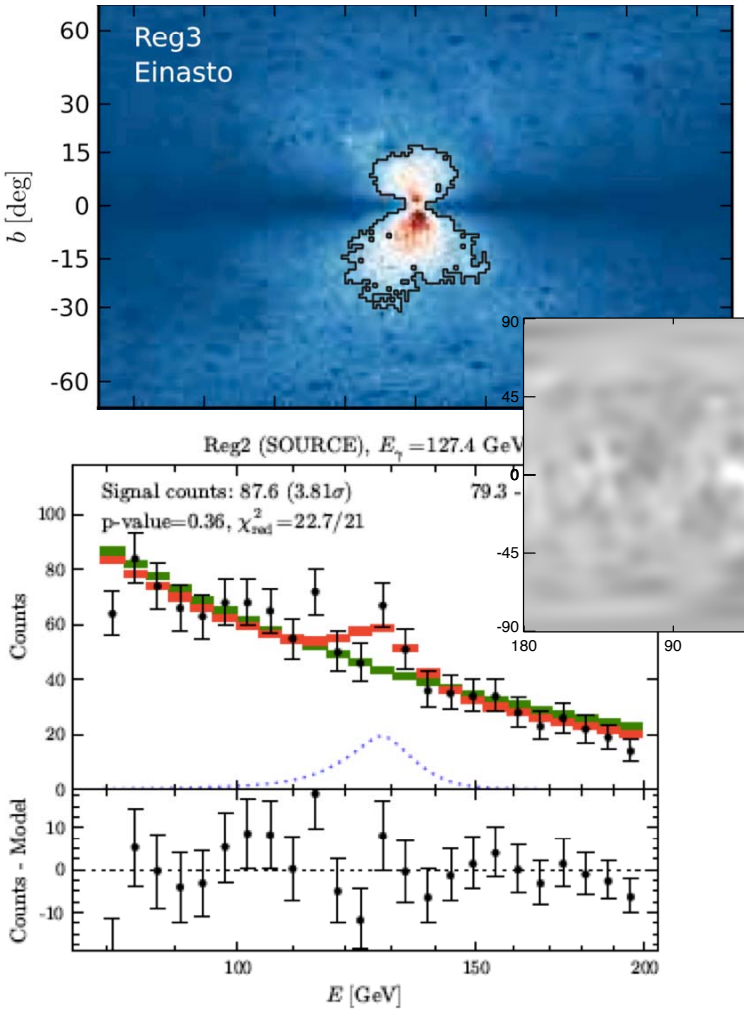
- Emission up to 100 GeV. 1.5 years of data did not allow a statement beyond that energy
- Will be interesting to check with CTA - but detection might be very challenging.
- Fermi keeps accumulating data.



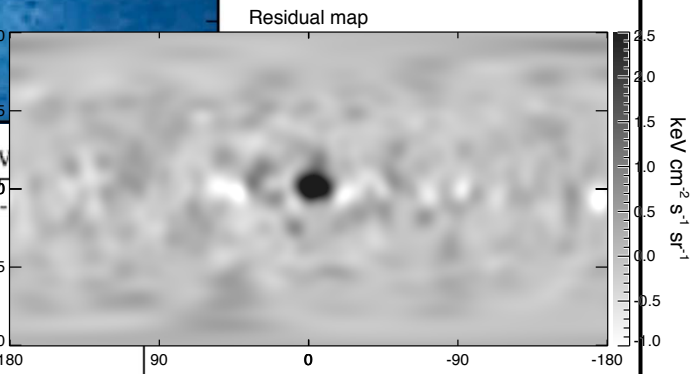
The 130 GeV line

The 130 GeV line?

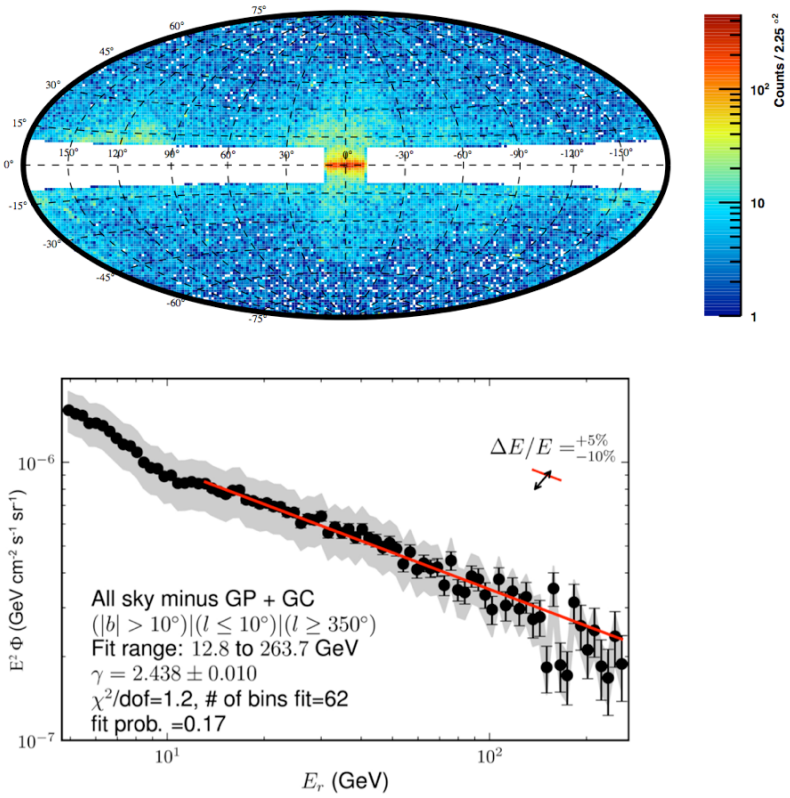
Weniger (2012)



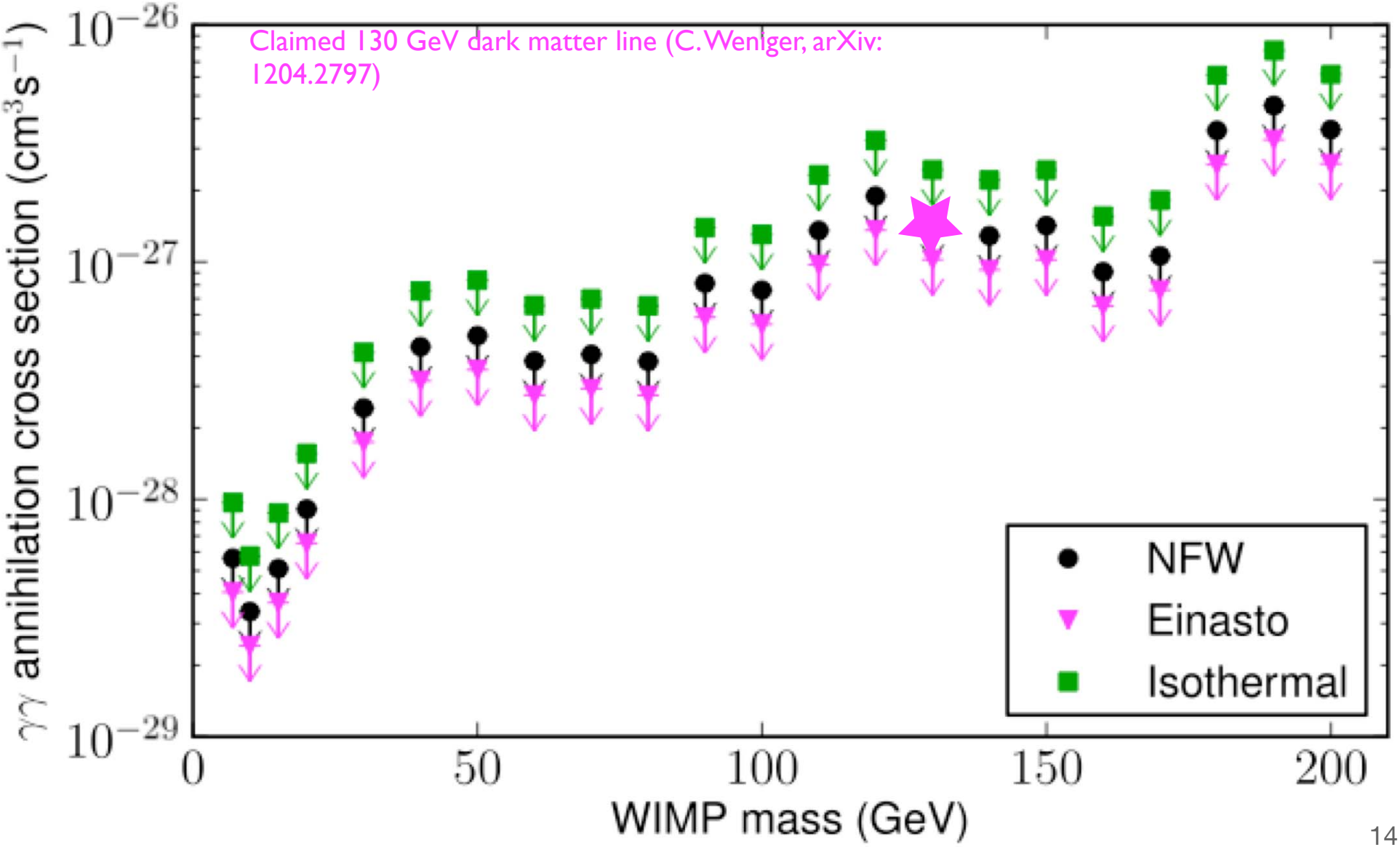
Su et al. (2012)



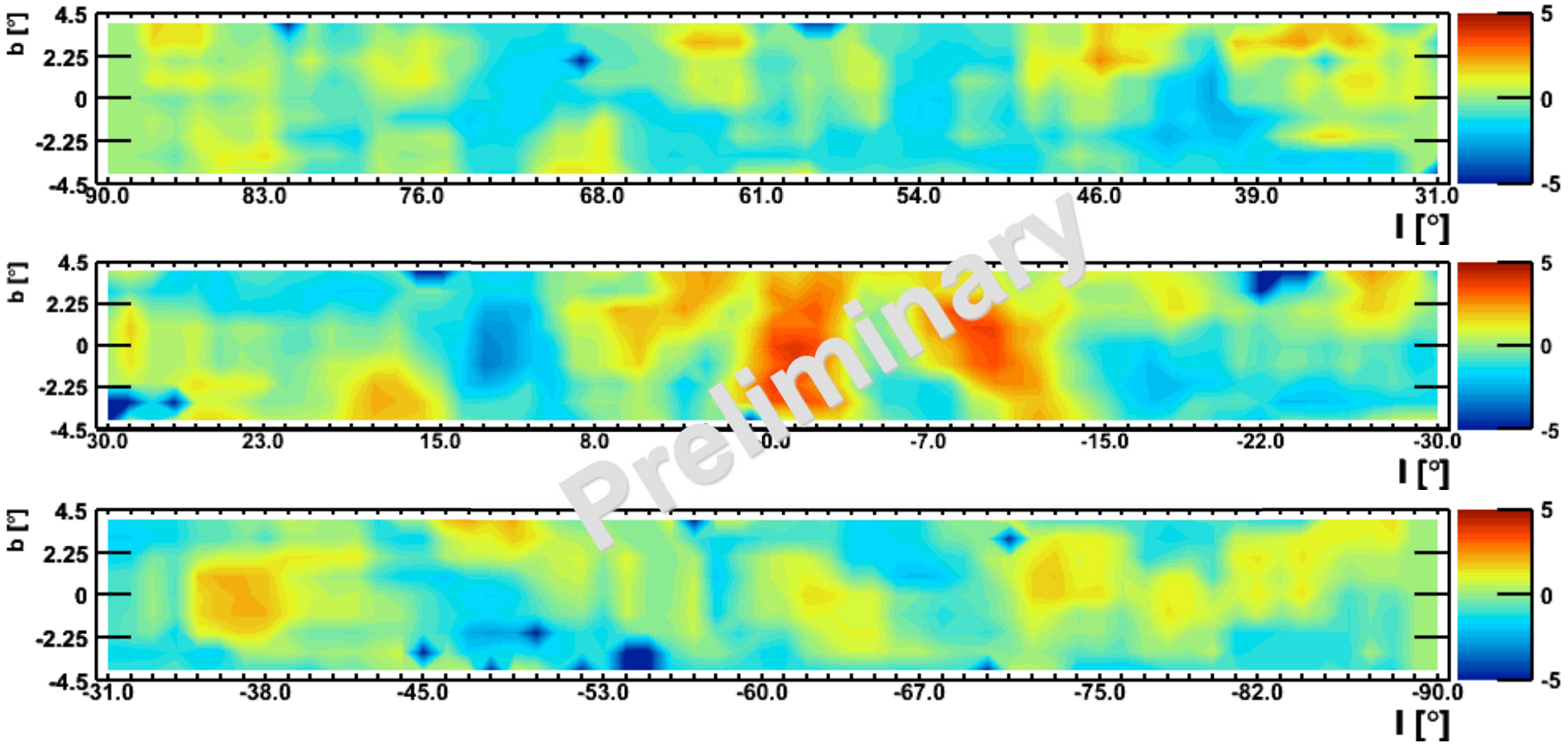
Fermi LAT Collaboration, Phys. Rev. D (2012)



The 130 GeV line?

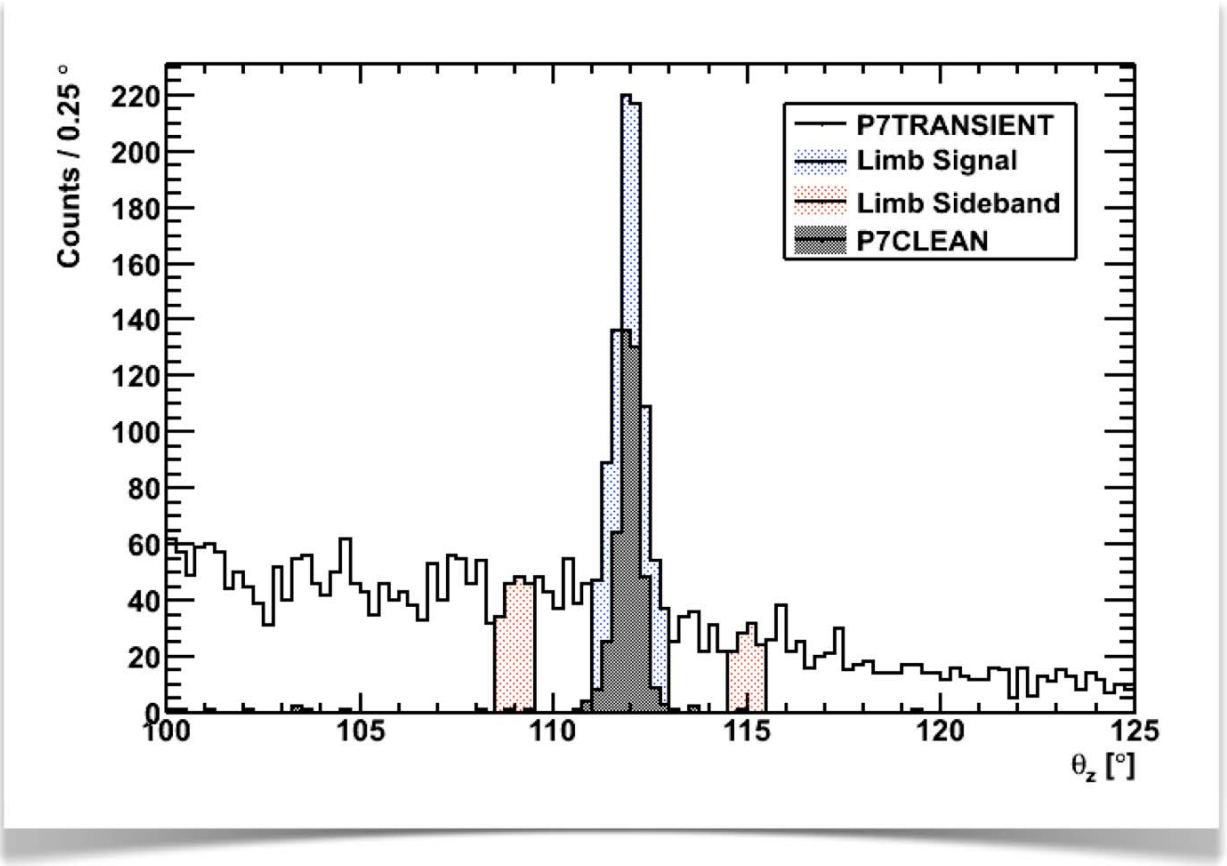


Fitted Excesses Along the Plane at 130GeV



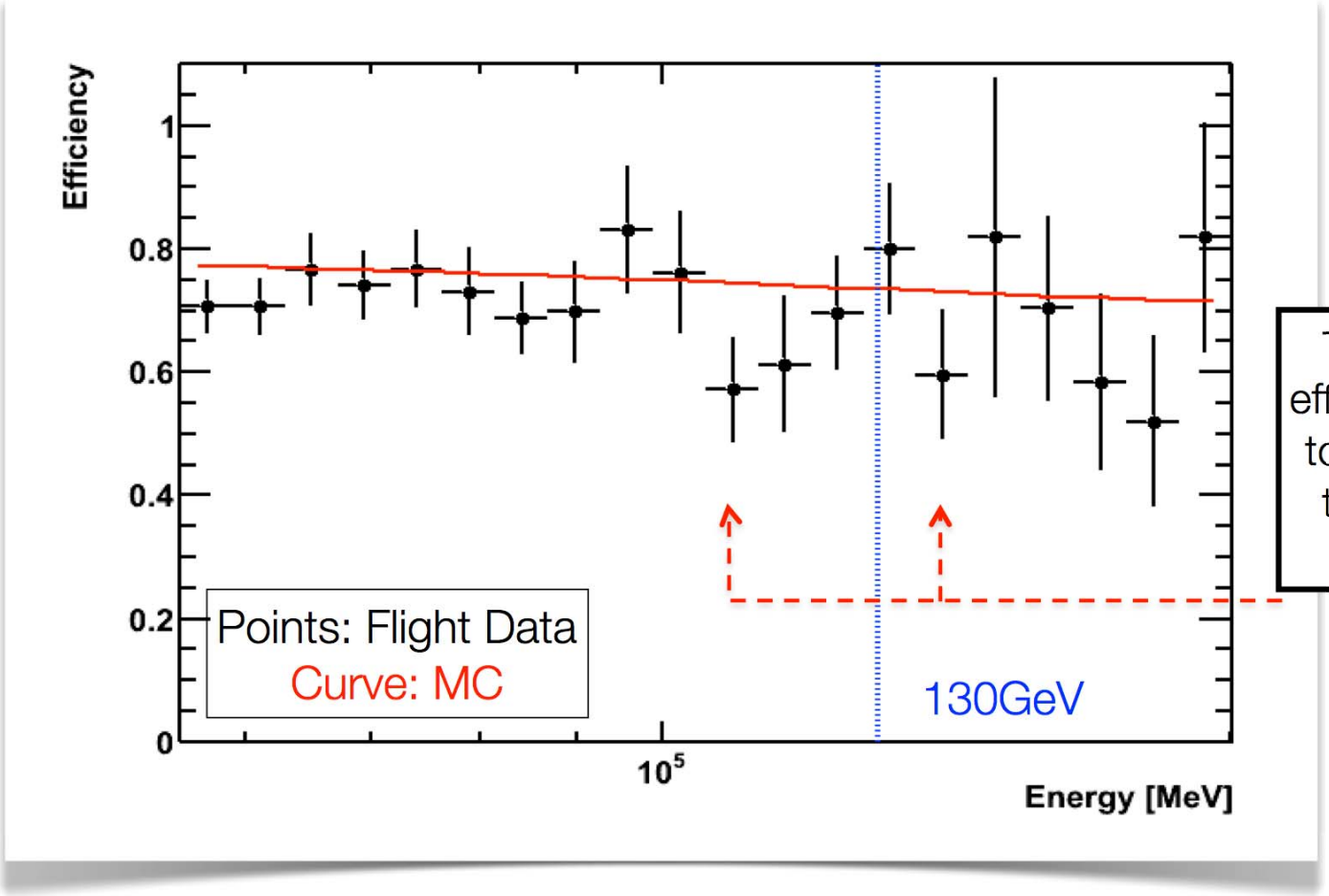
- The excesses near GC at 130 GeV are among the largest at any energy (for 4°x4°), and stand out particularly for 8-16° scales.

Measuring Efficiency with the Earth Limb



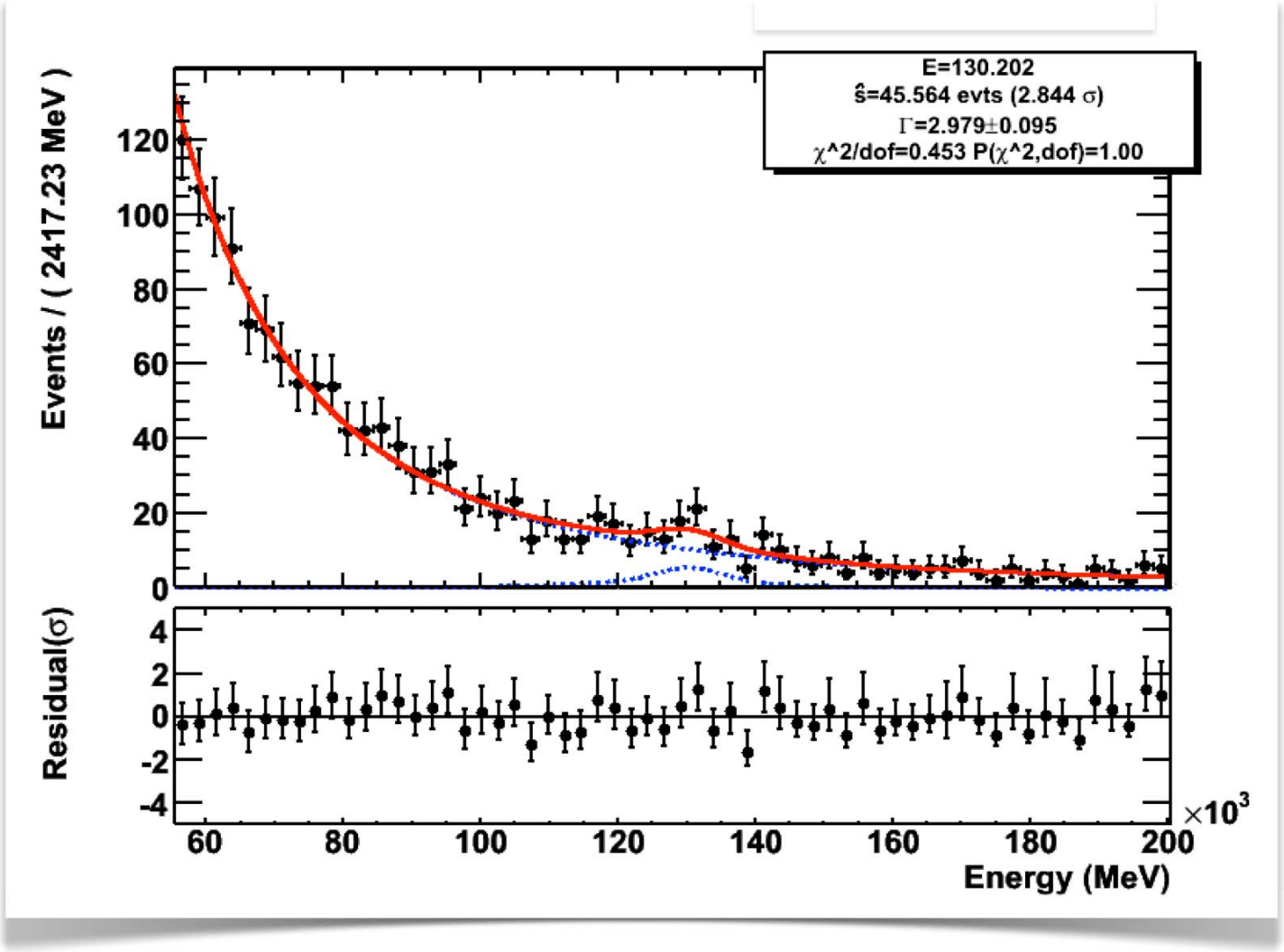
- The Earth Limb is unique in that it can be seen in loose cuts at high energies (P7_TRANSIENT). This allows us to use it to measure efficiencies for tighter event classes as a function of energy.

P7TRANSIENT to P7CLEAN Efficiency



- The efficiency at ~115 GeV is 0.57/0.75 = 0.75 percent of the MC prediction. This would imply a 30% boost in signal at 130GeV relative to the prediction from nearby energy bins.

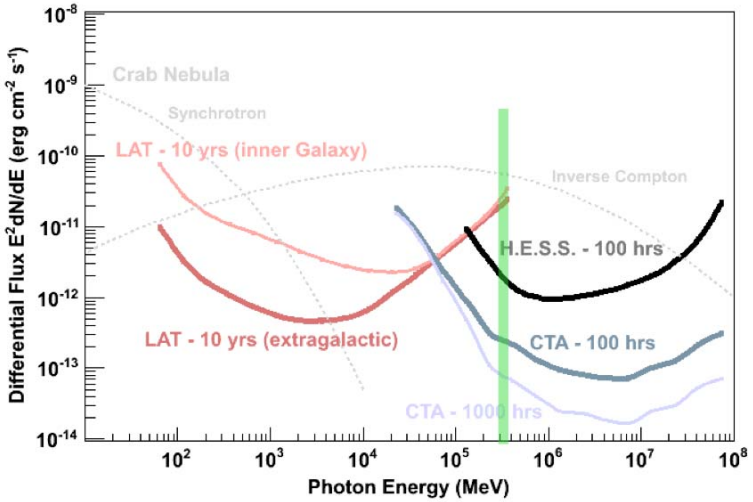
Fitting the Earth Limb

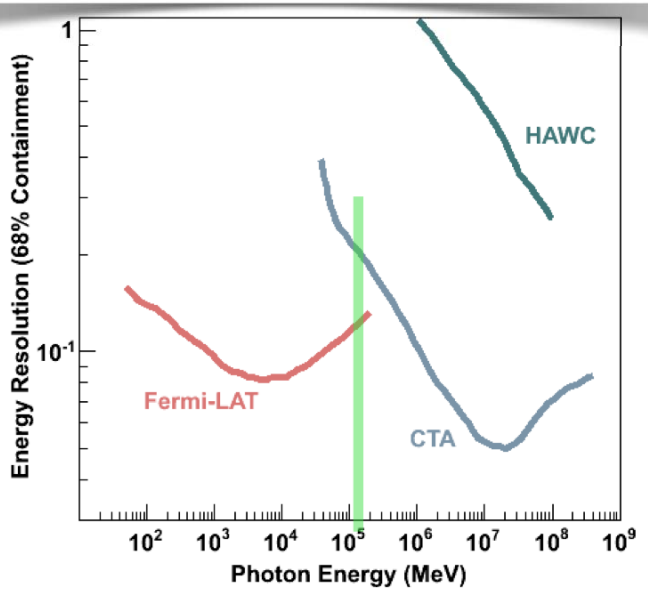


- The fit to Earth Limb data results in a 2.84σ signal

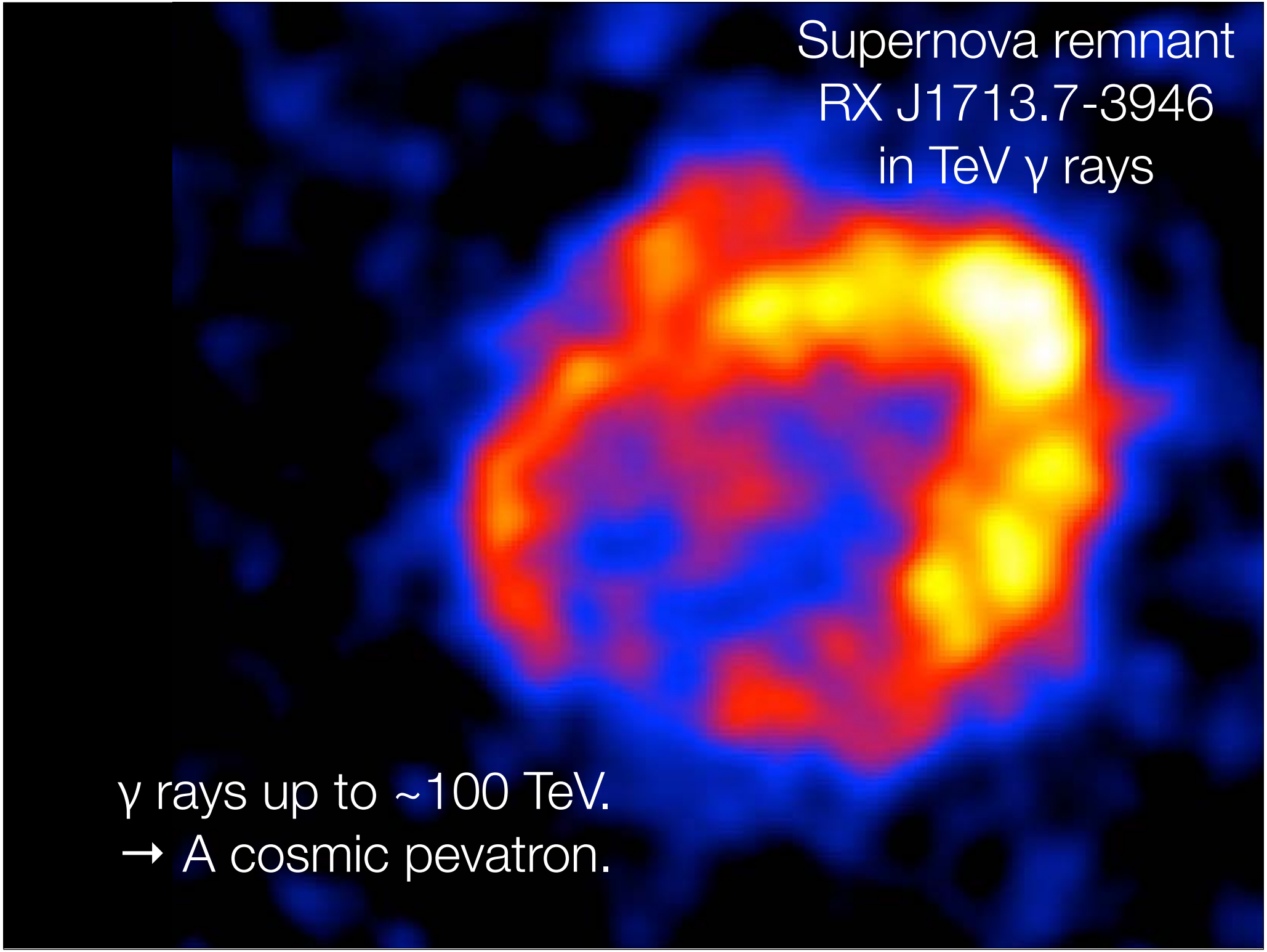
CTA and the 130 GeV line

- Fermi-LAT will gather a factor of ~2-3 more data during its lifetime
- Updated event reconstruction (Pass 8) might help to answer the question about instrumental effects
- CTA at 130 GeV: much better point-source sensitivity (but that does not help much here), but significantly worse energy resolution.

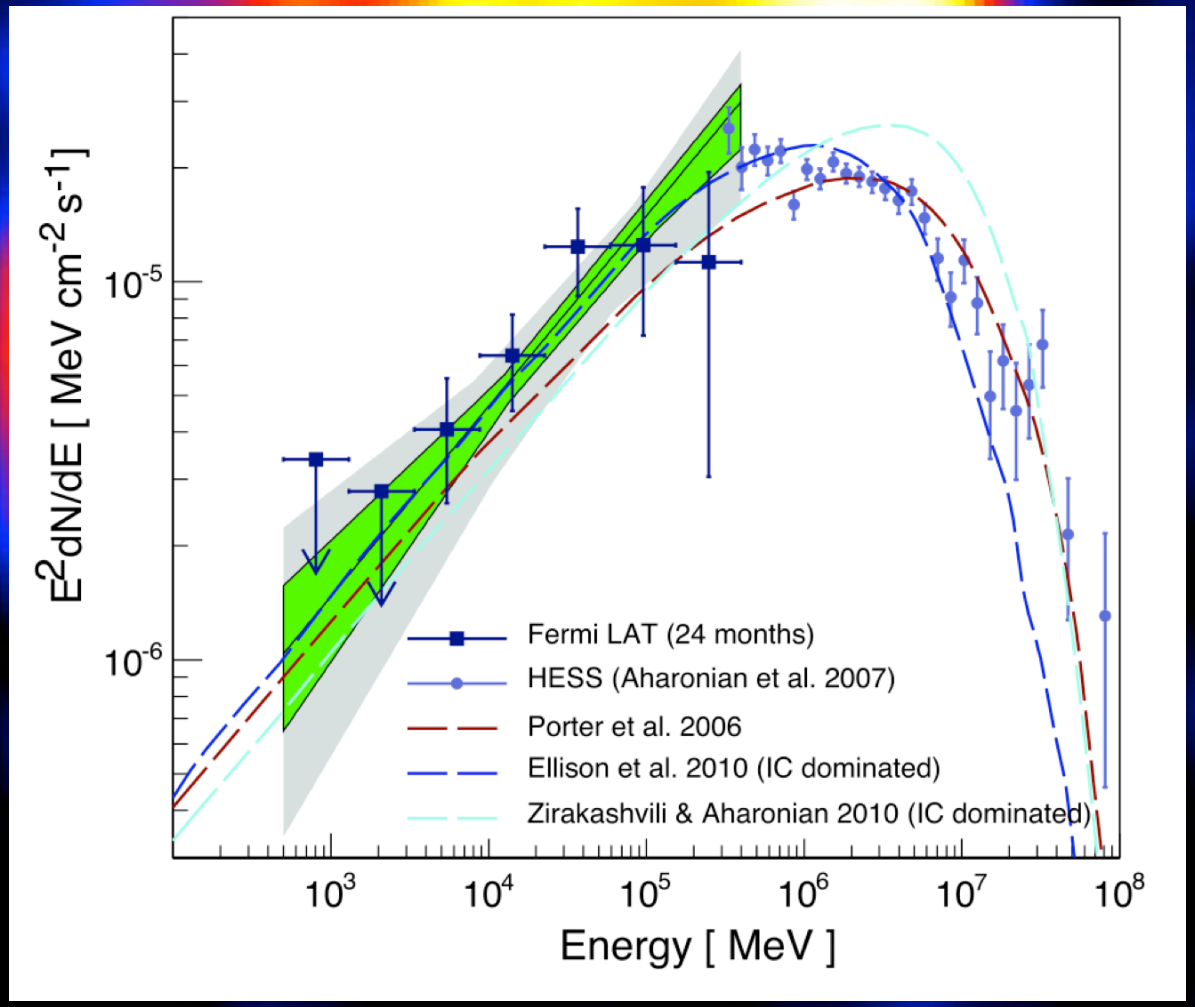




The Origin of Cosmic Rays


Supernova remnant
RX J1713.7-3946
in TeV γ rays
γ rays up to ~100 TeV.
→ A cosmic pevatron.

Spectra look as if gamma rays are created by electrons Compton-upscattering ambient photons



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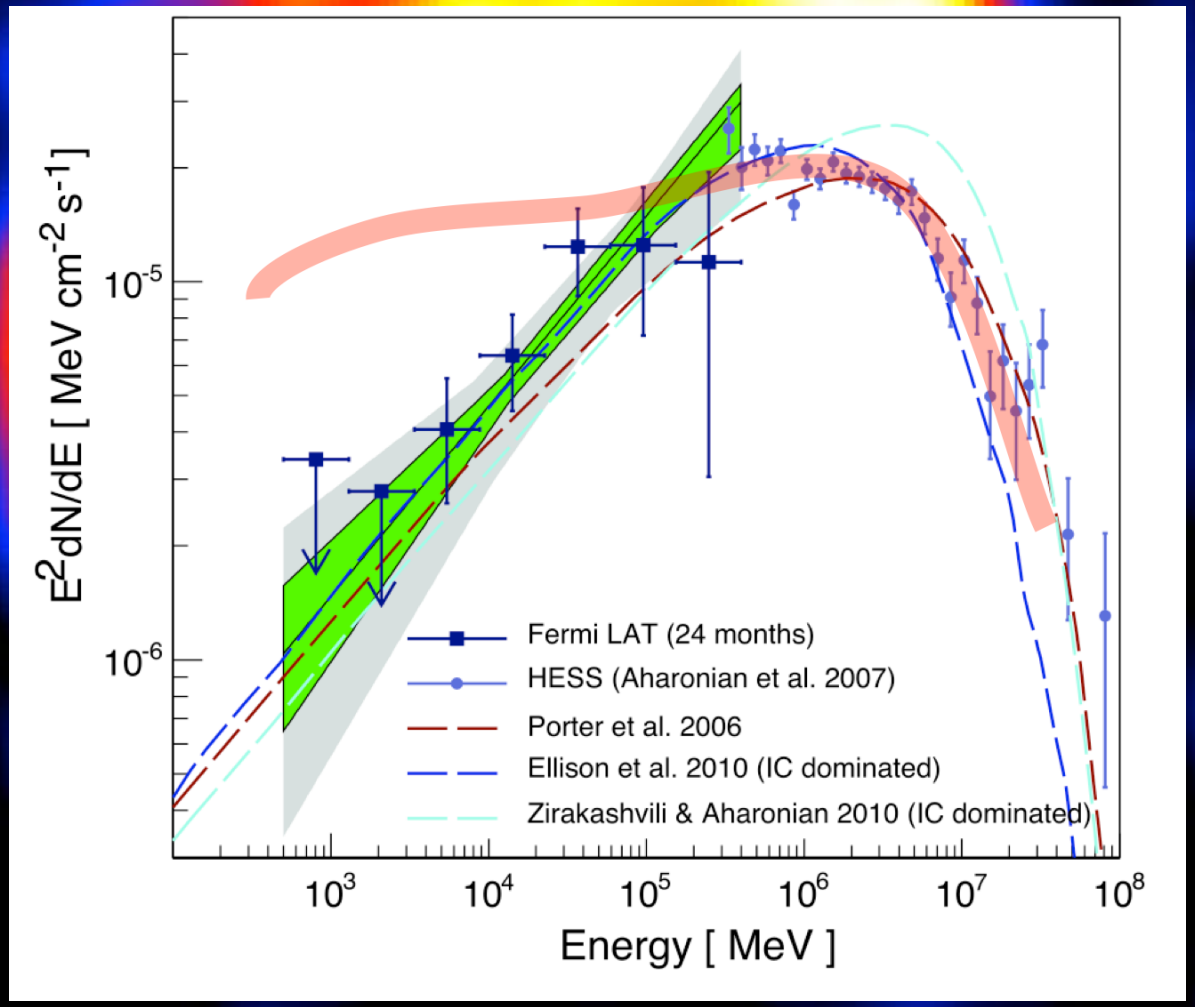
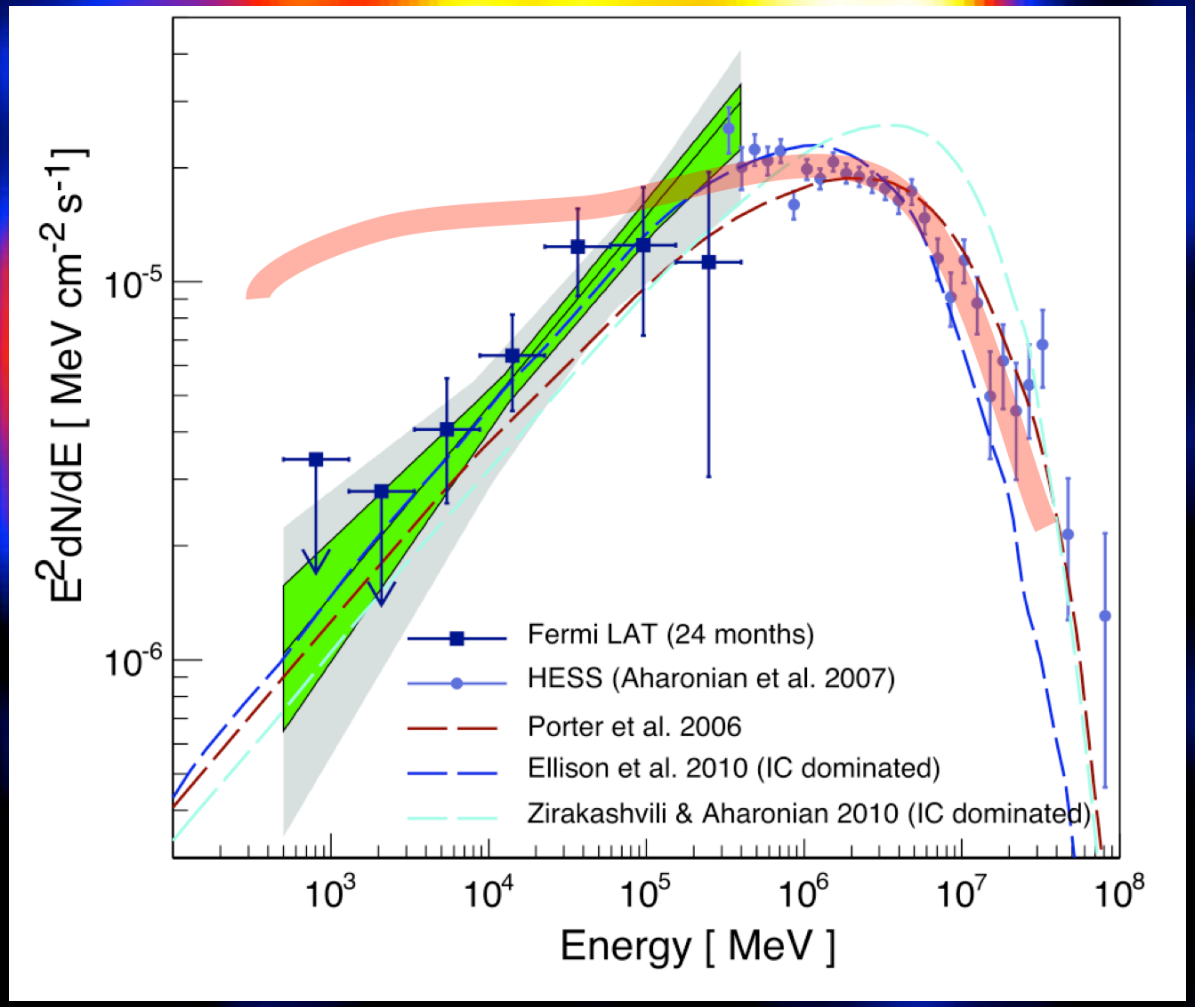


Spectra look as if gamma rays are created by electrons Compton-upscattering ambient photons

Protons “invisible” because of lack of target material?



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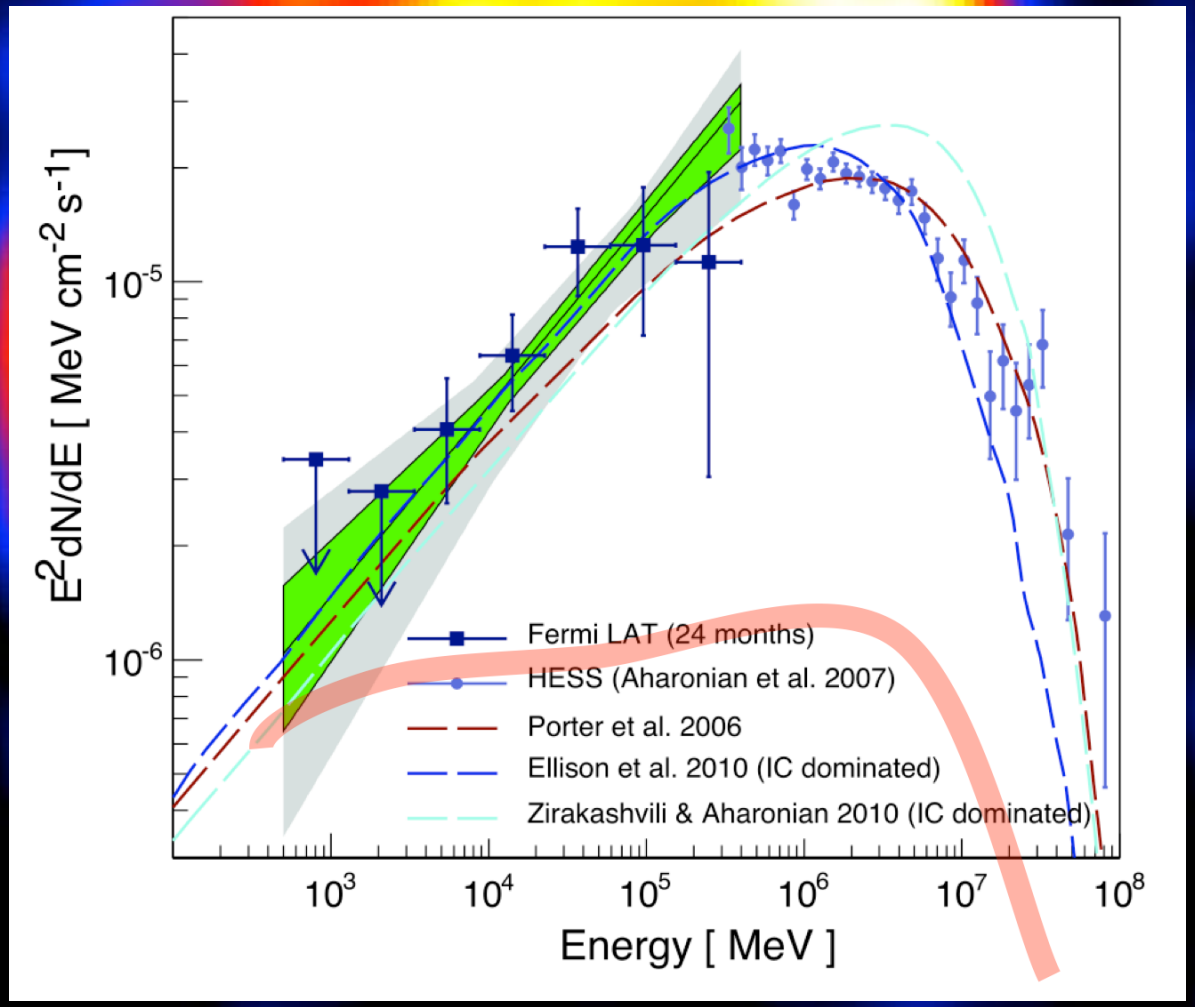
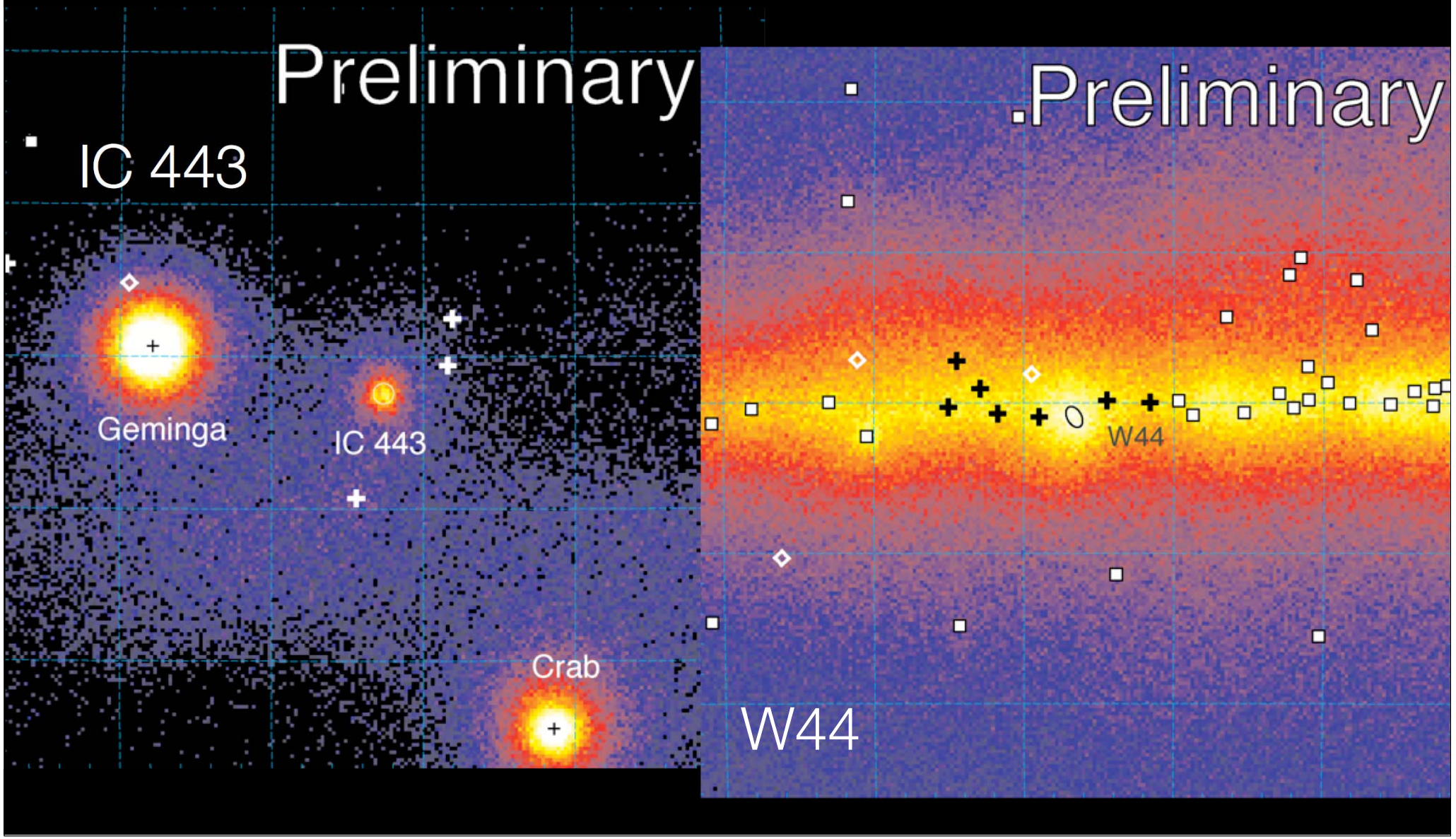
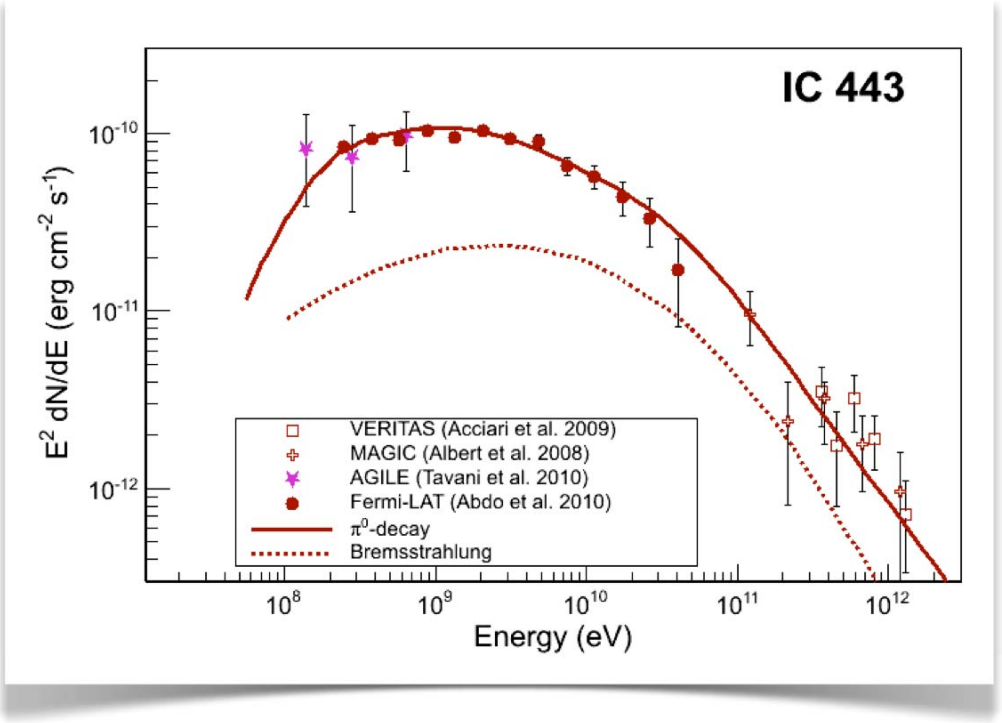


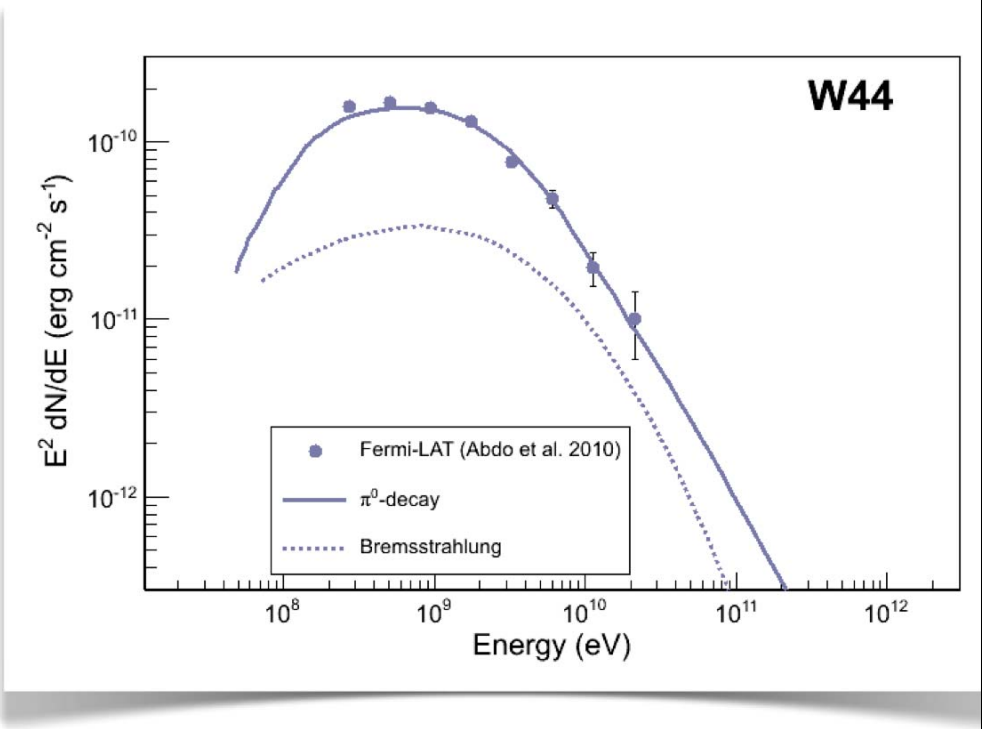
Mid-aged remnants interacting with molecular clouds



Mid-aged remnants interacting with clouds

Earlier results (using only 1 year of data)





- One year of data: Spectra show cutoffs in the 1-10 GeV range.
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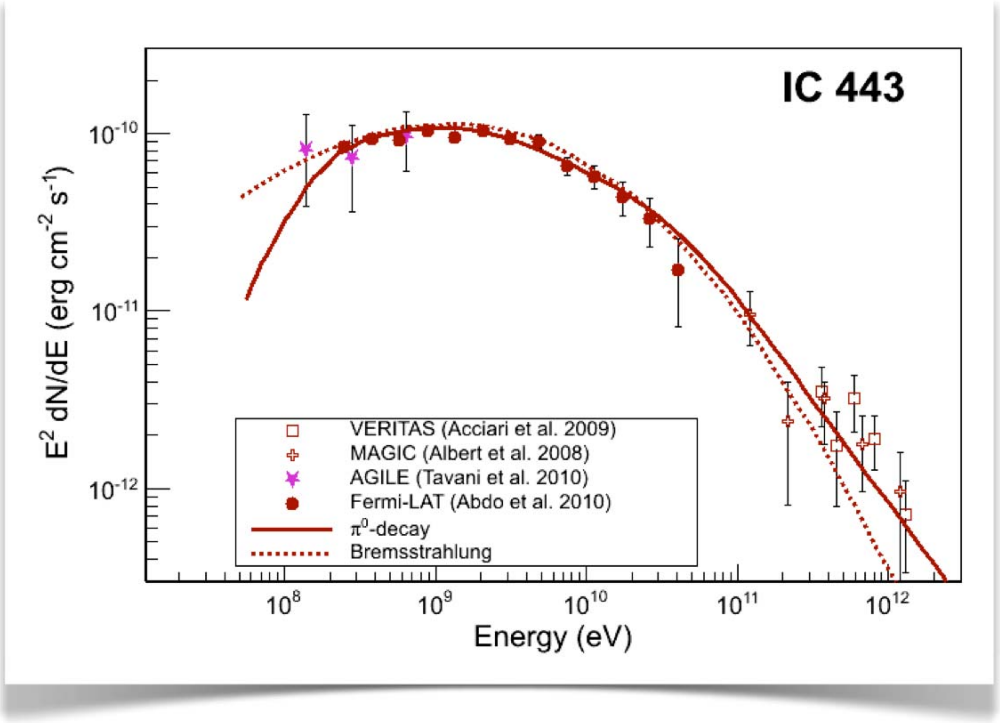

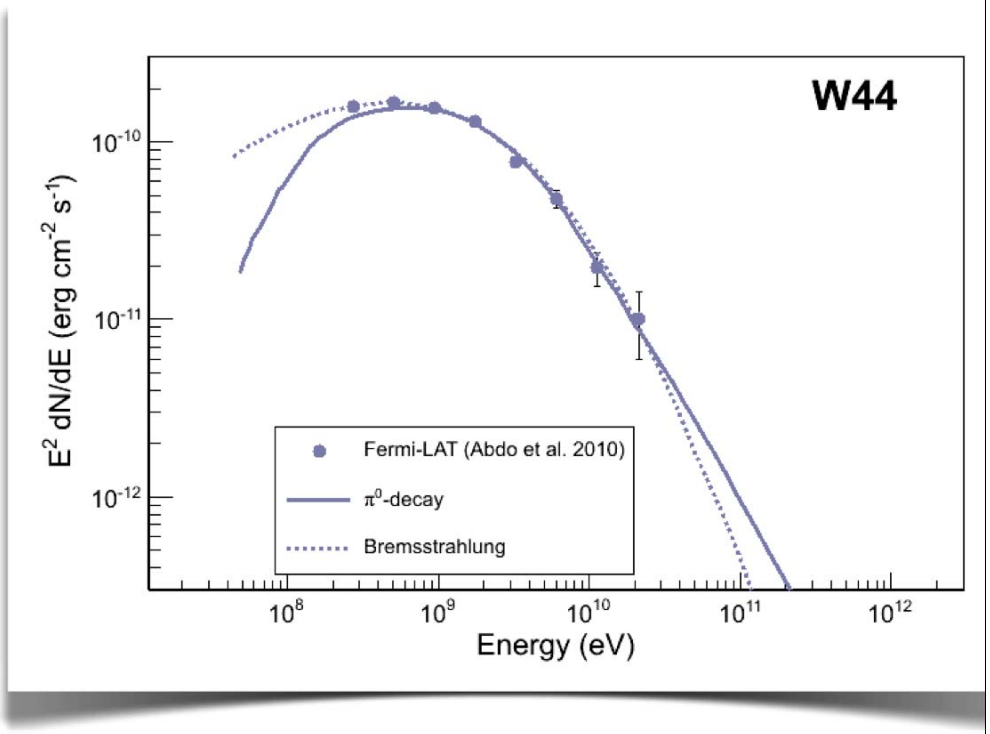

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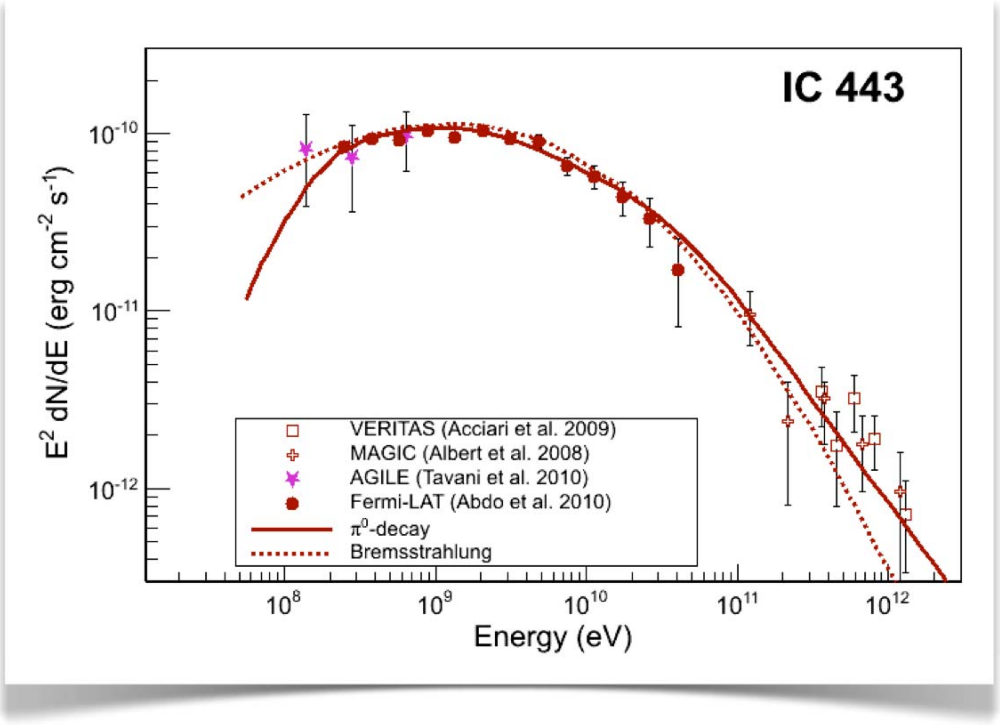

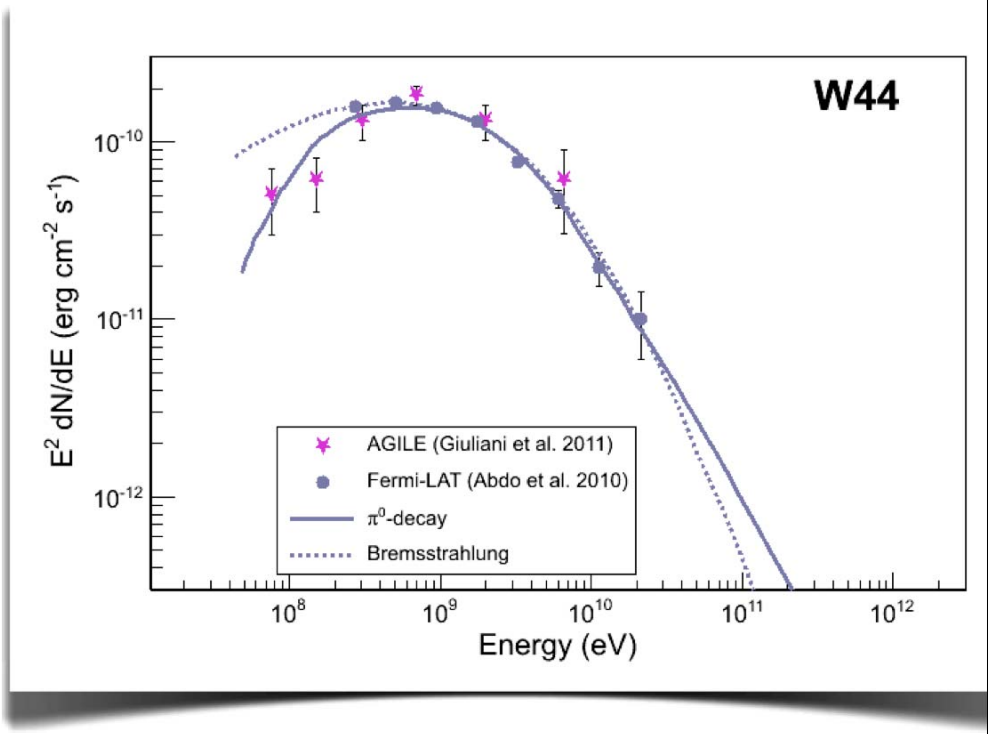

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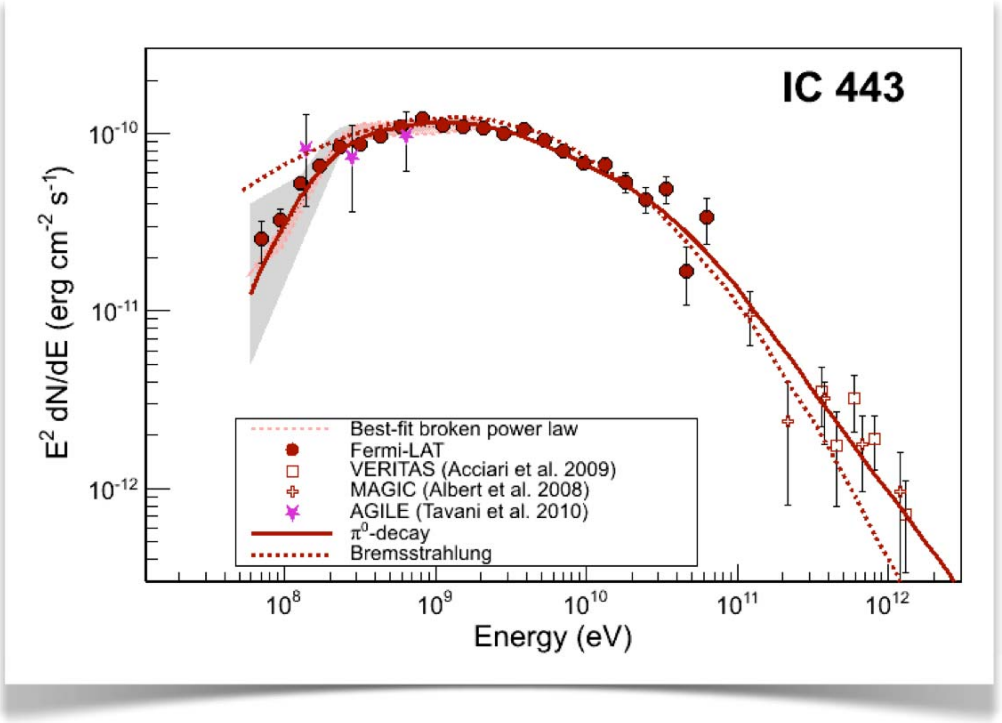
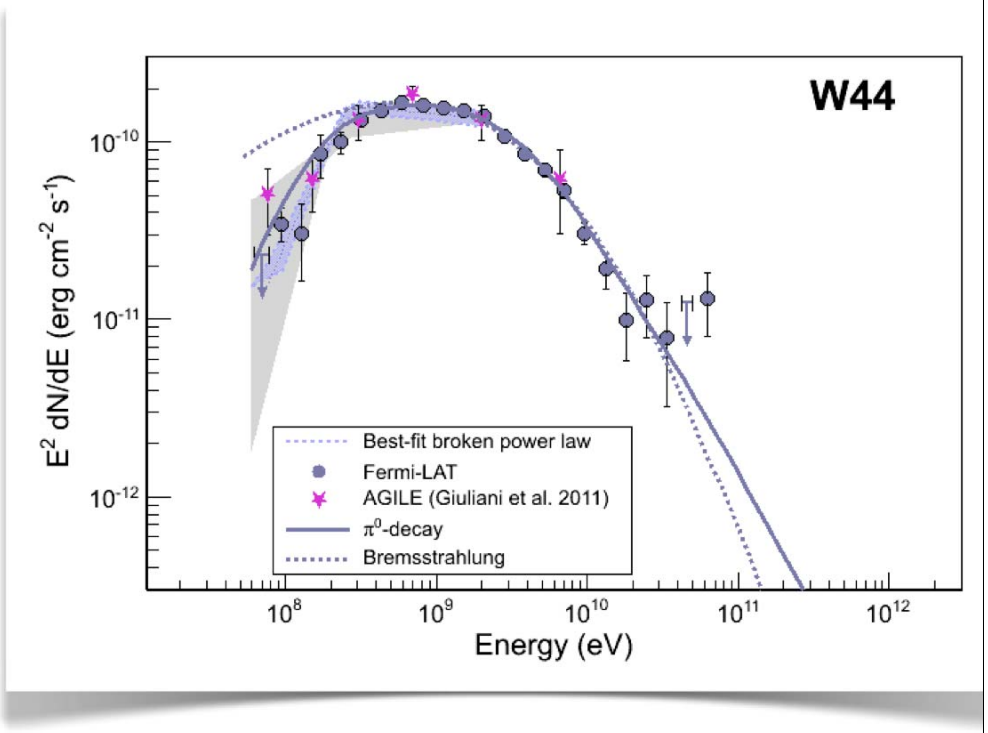
Mid-aged remnants interacting with clouds

4 years of data





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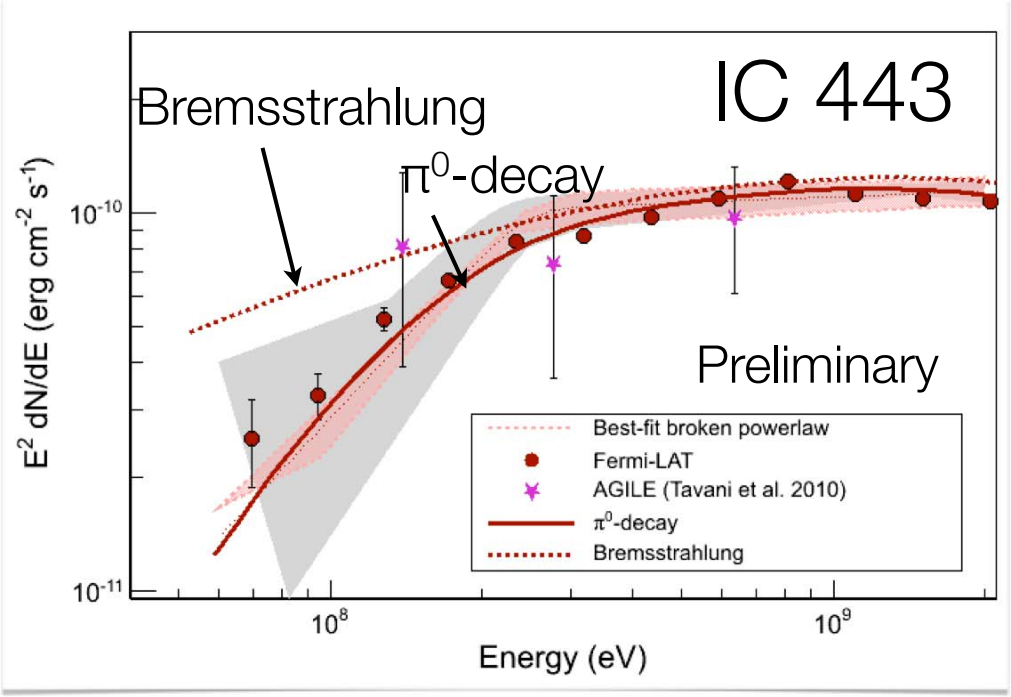
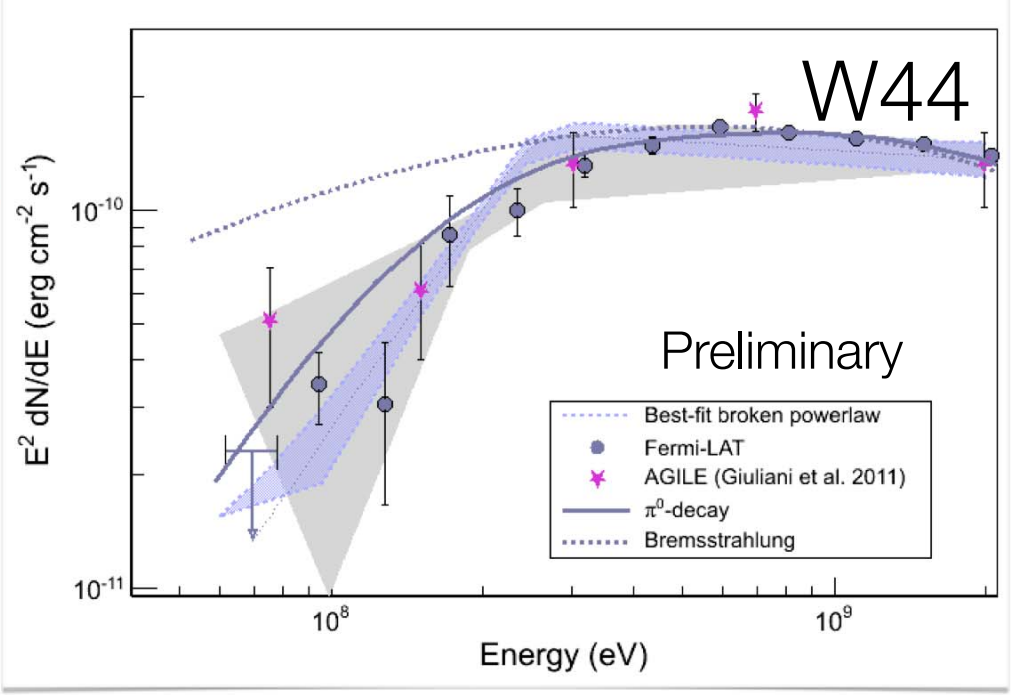
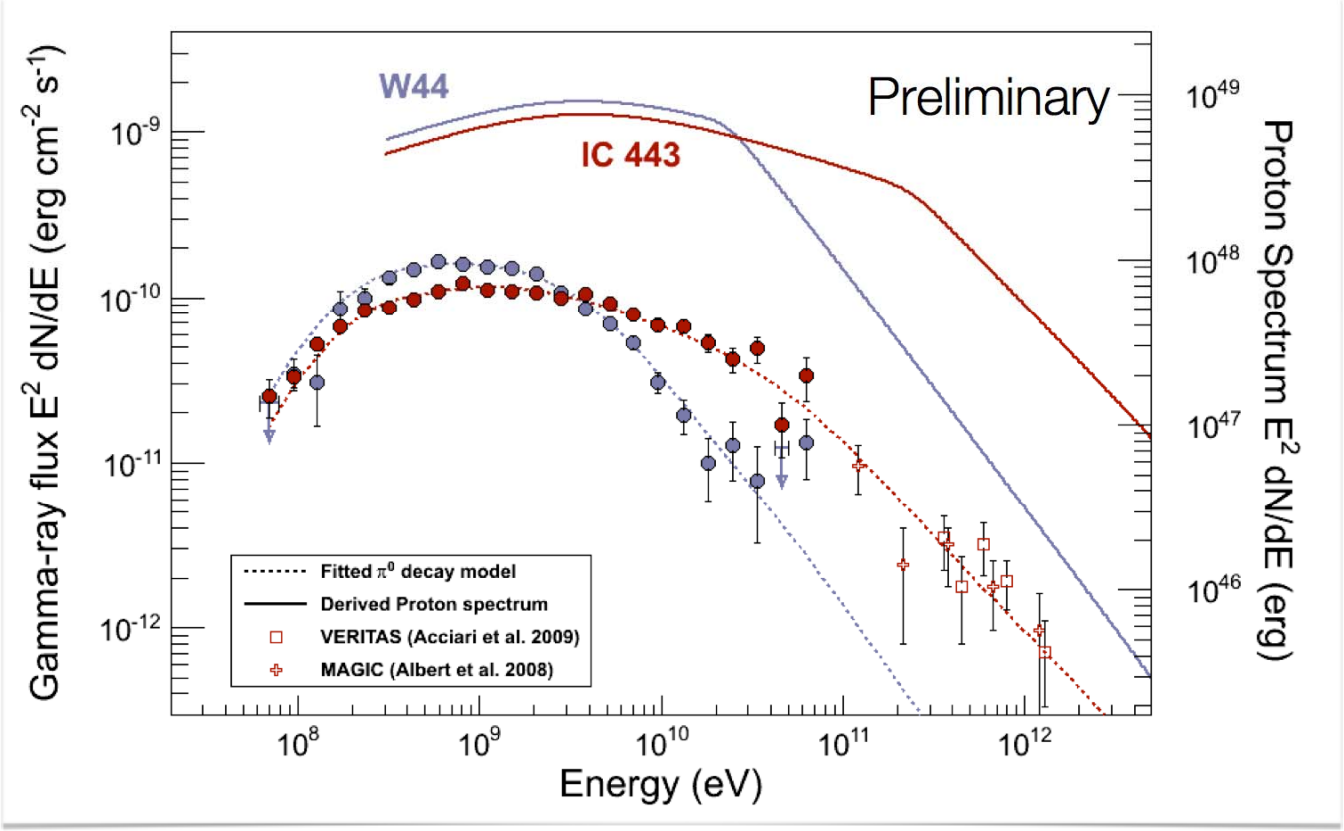
Pion-decay gamma rays (at last)





- Turnover matches what is expected from pion-decay
- Error band from evaluating different diffuse models
- Best-fit Bremsstrahlung model shows less steep decline

For the first time “measure” proton spectrum in SNRs

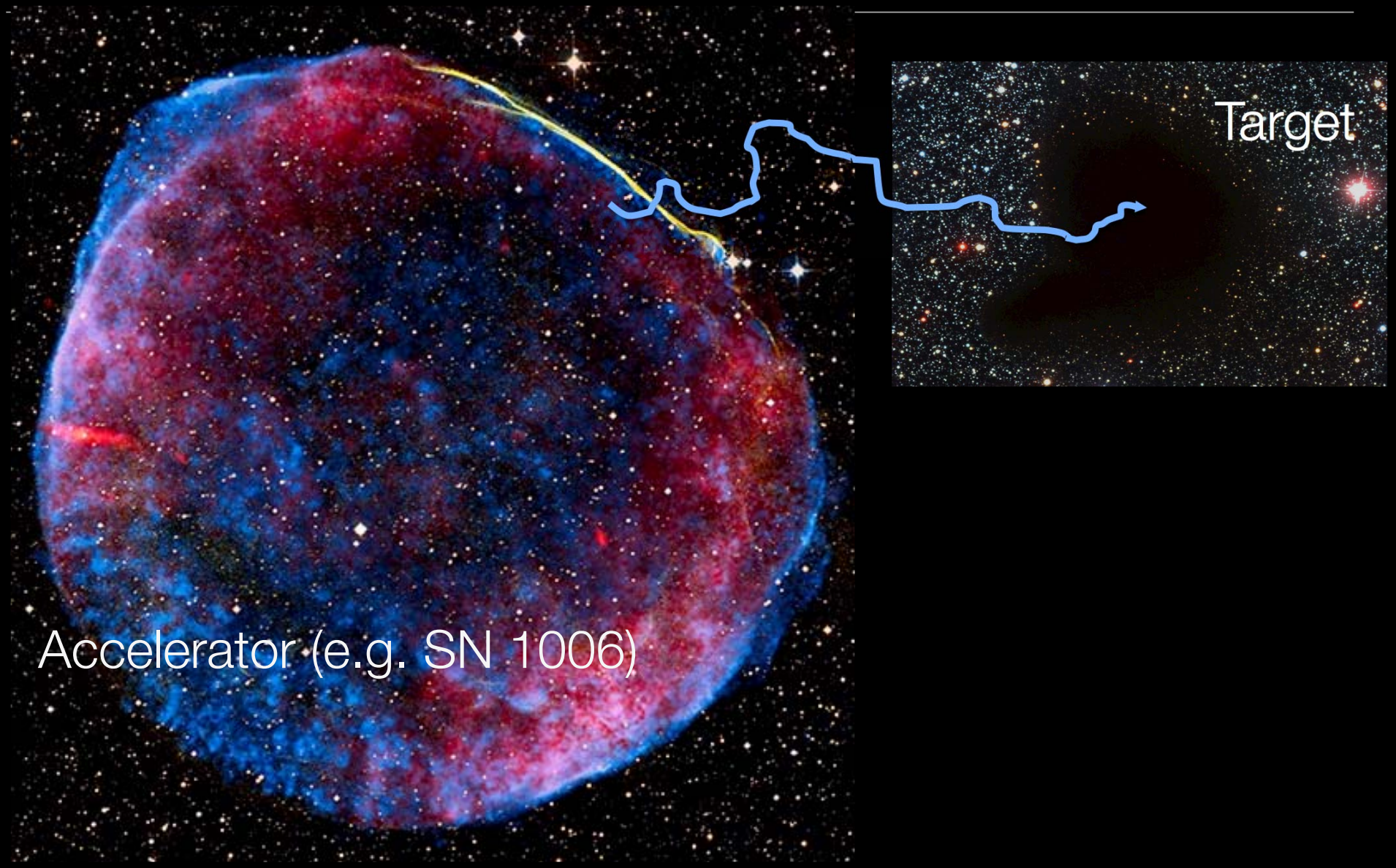


$$\frac{dN_p}{dp} \propto p^{-s_1}\left[1+\left(\frac{p}{p_{\rm br}}\right)^{\frac{s_2-s_1}{\beta}}\right]^{-\beta}$$

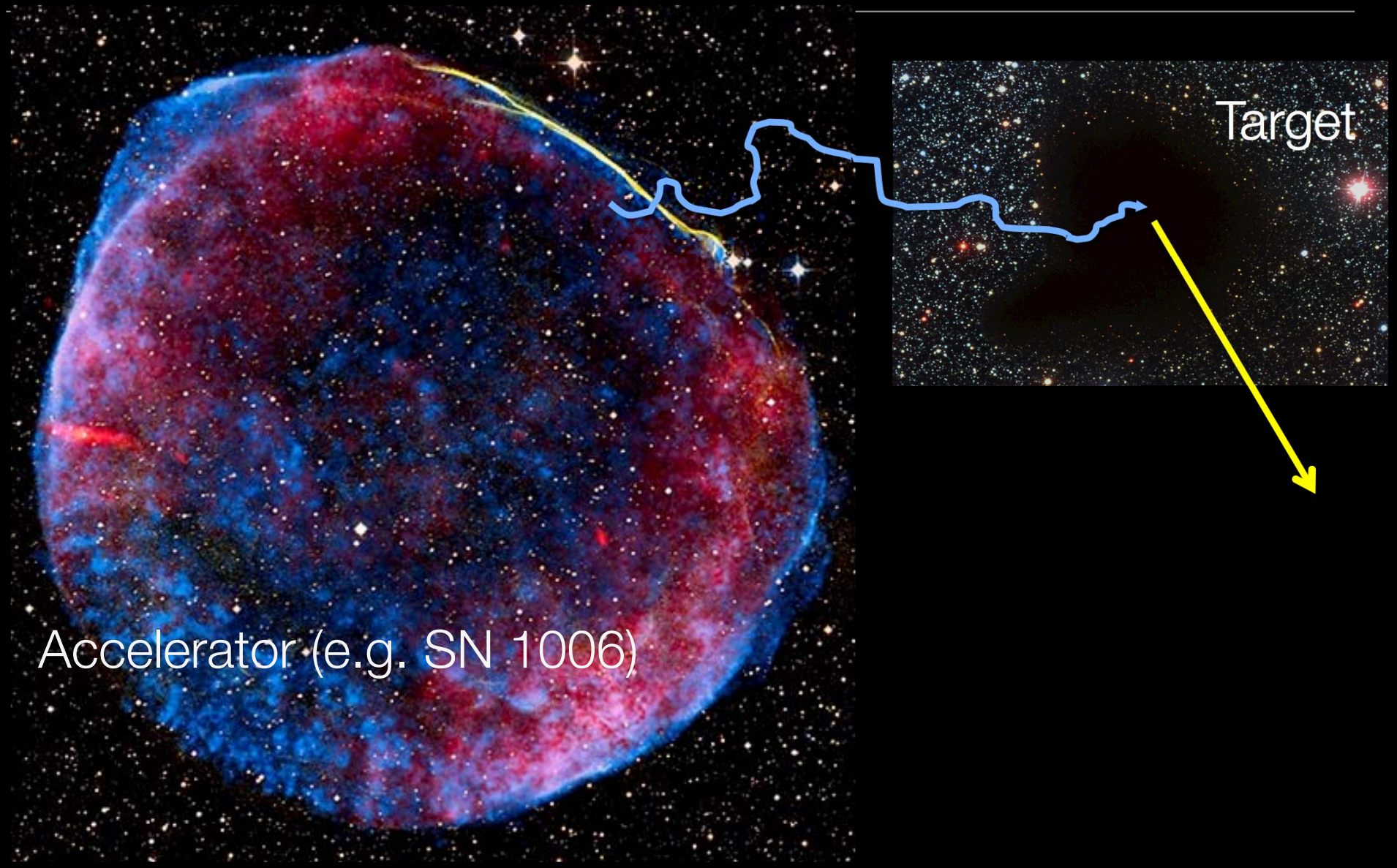
- CR efficiency ~5%. Strongly depends on assumed density
- Reason for high-energy break not fully understood

Probing escape and propagation of Cosmic Rays

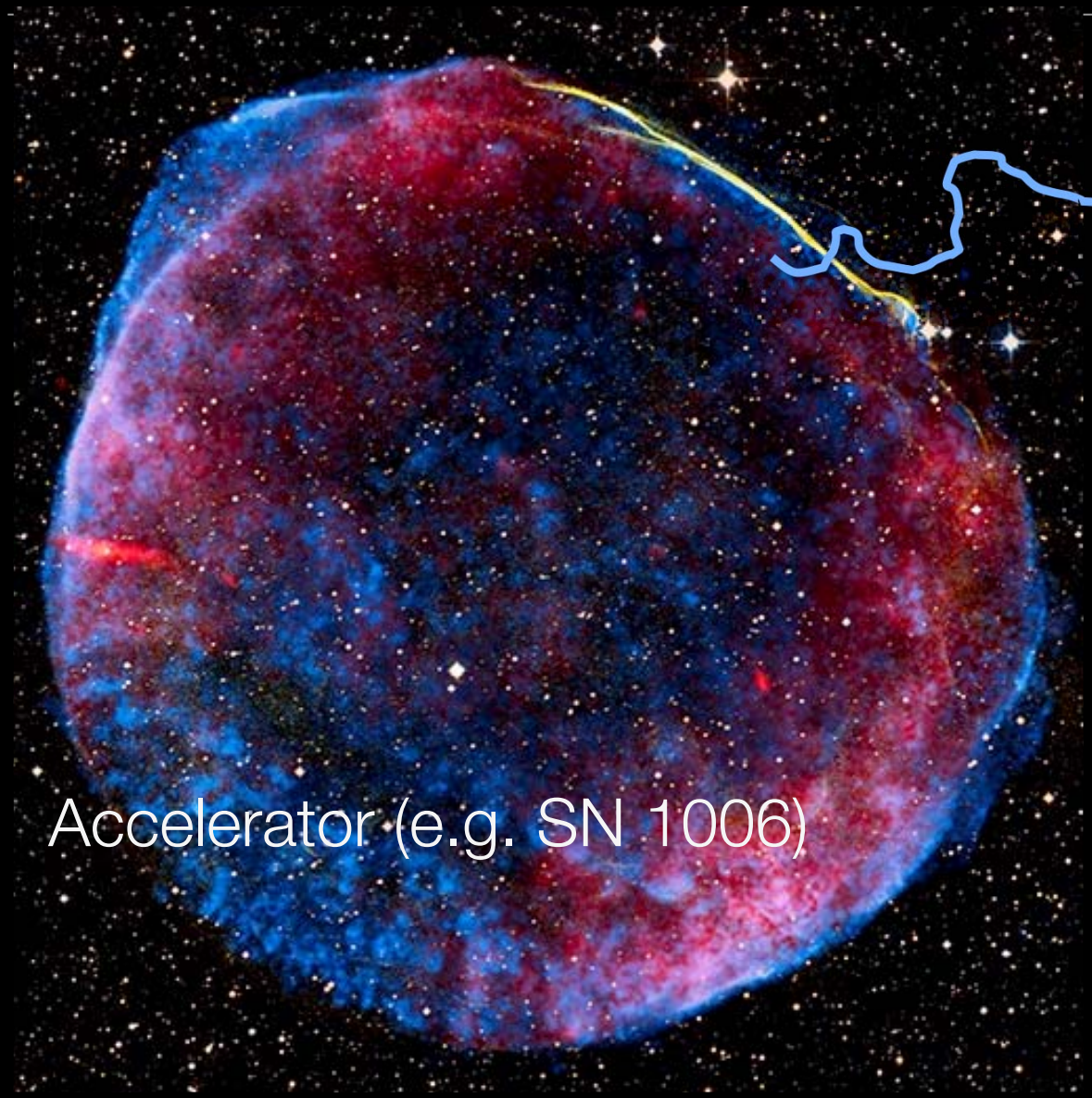
Probing escape and propagation of Cosmic Rays

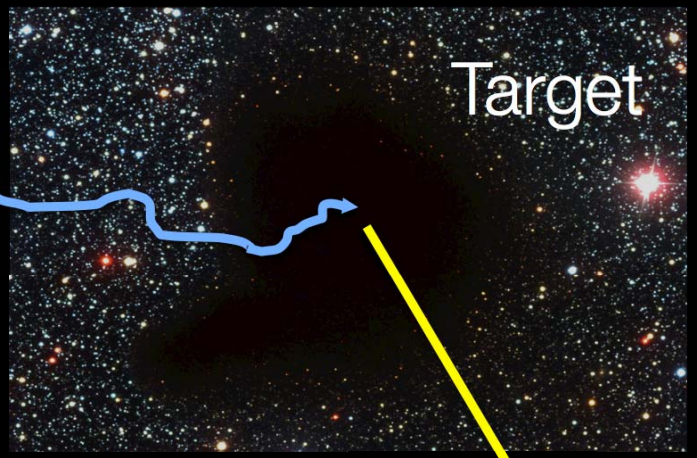


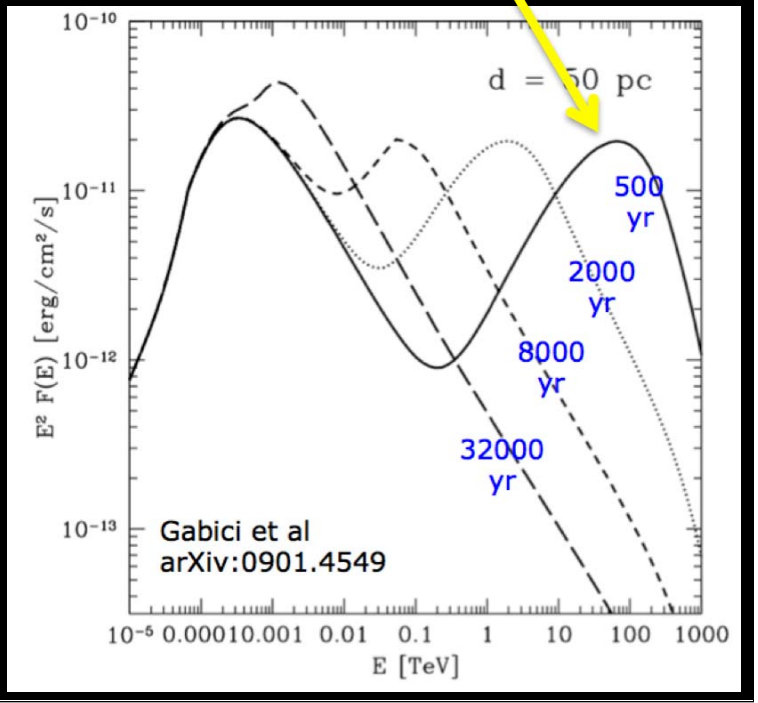
Probing escape and propagation of Cosmic Rays

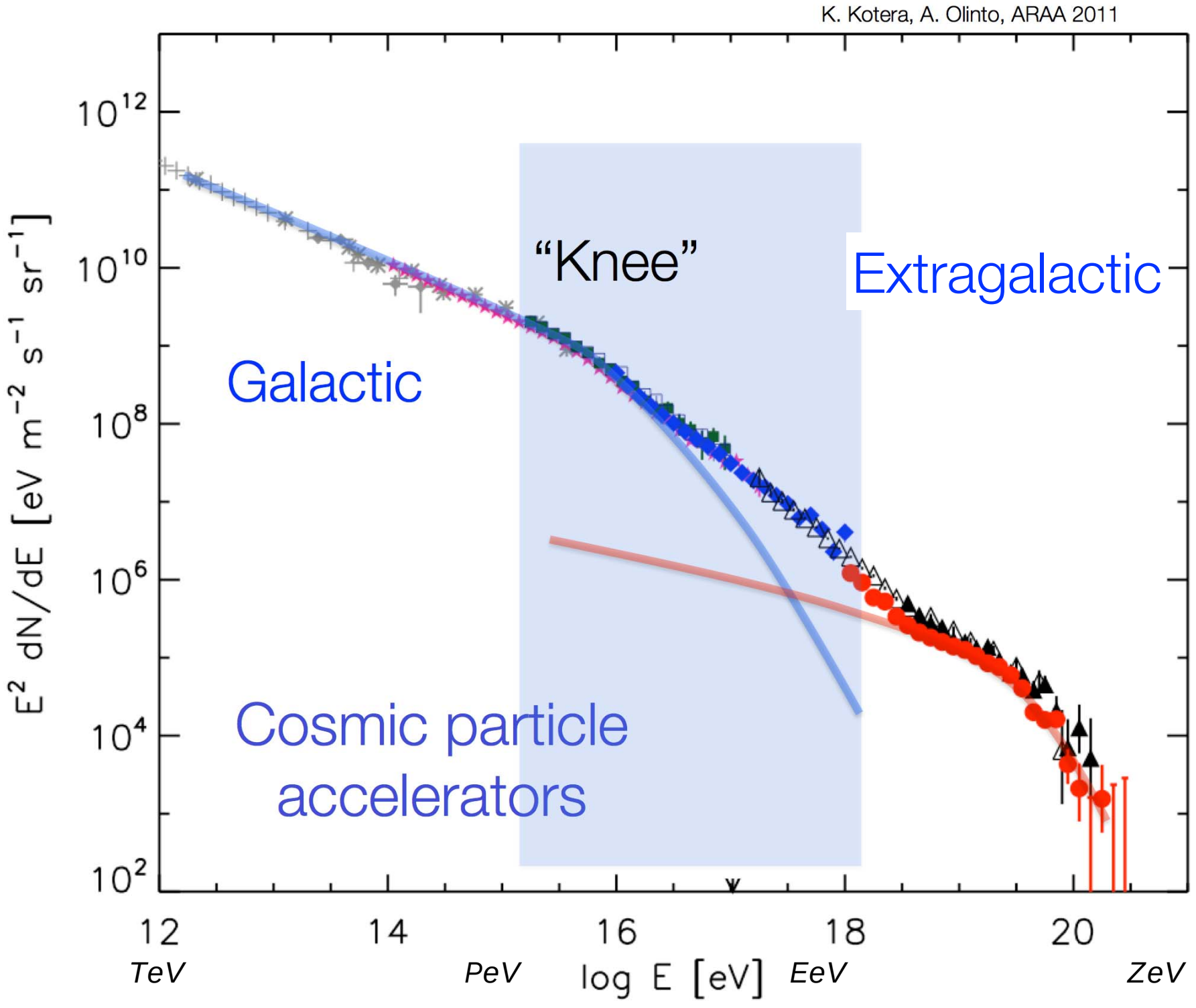


Probing escape and propagation of Cosmic Rays





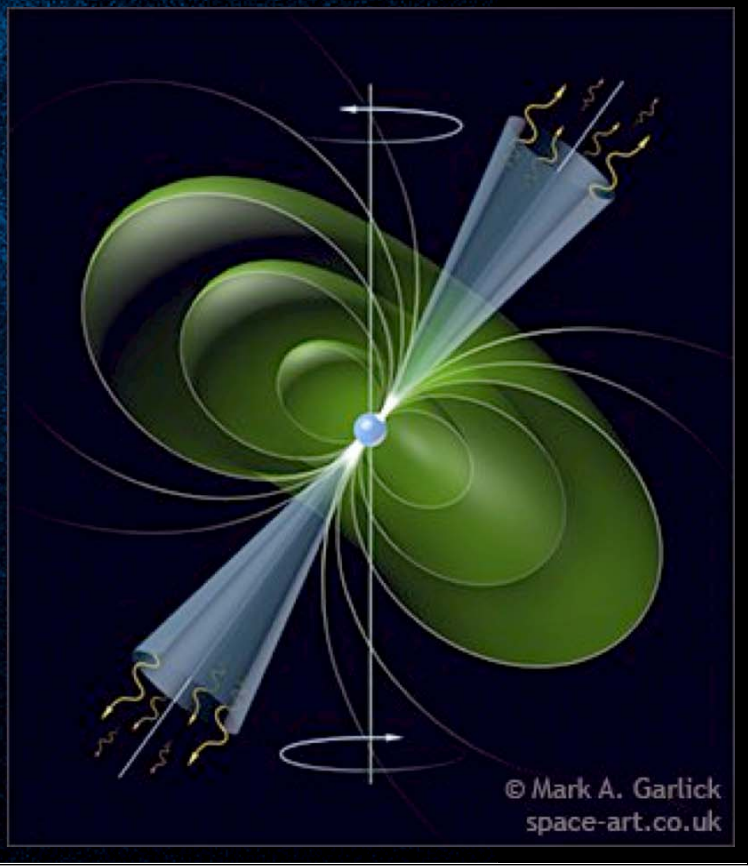



K. Kotera, A. Olinto, ARAA 2011
"Knee"
Extragalactic
Galactic
Cosmic particle accelerators
E^2 dN/dE [eV m^{-2} s^{-1} sr^{-1}]
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
12
14
16
18
20
log E [eV]
TeV
PeV
EeV
ZeV

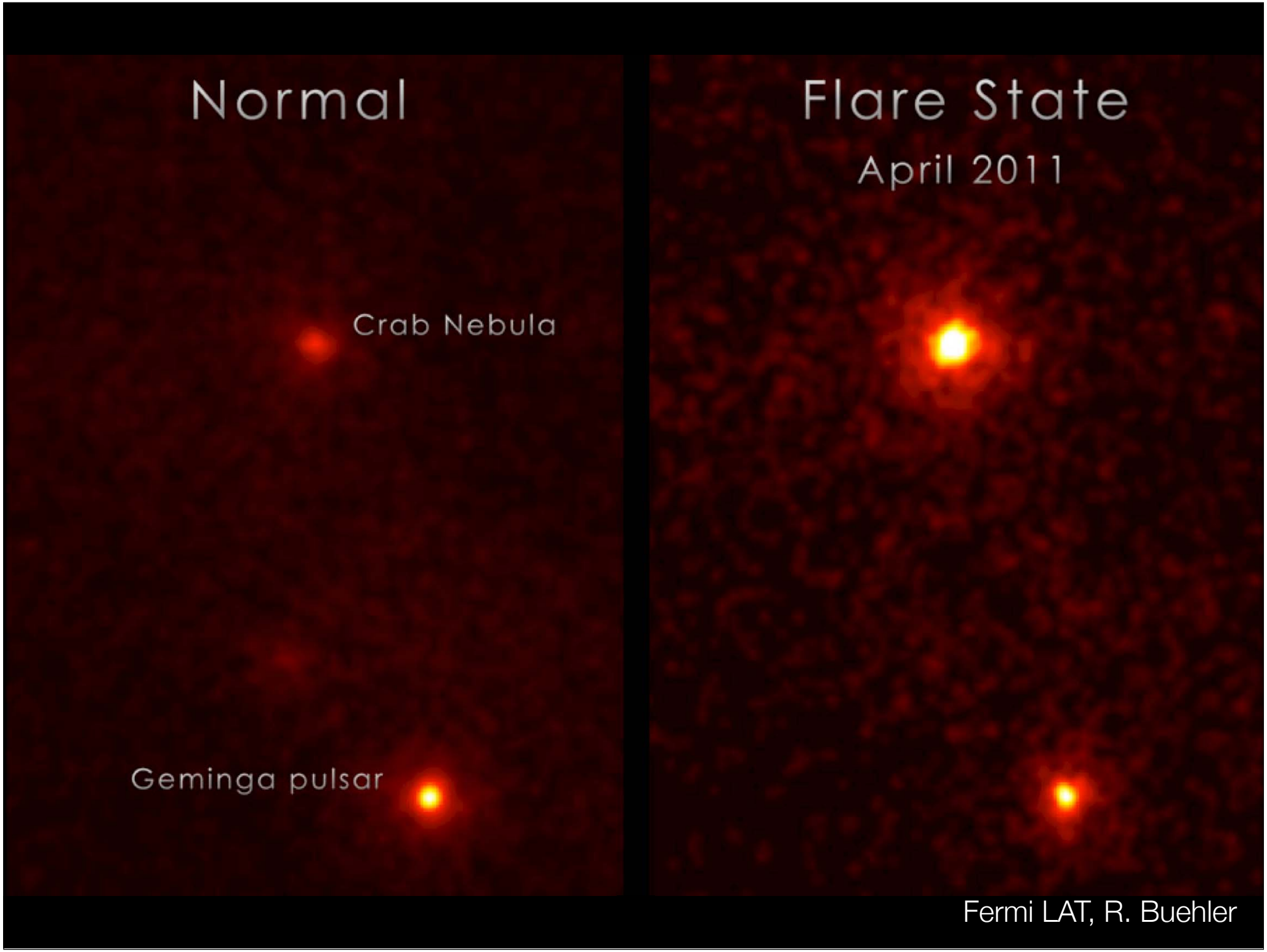
Crab Nebula Chandra X-ray

F. D. Seward, W. H. Tucker, R. A. Fesen

Alternatives to shock acceleration: Unipolar inductor mechanism



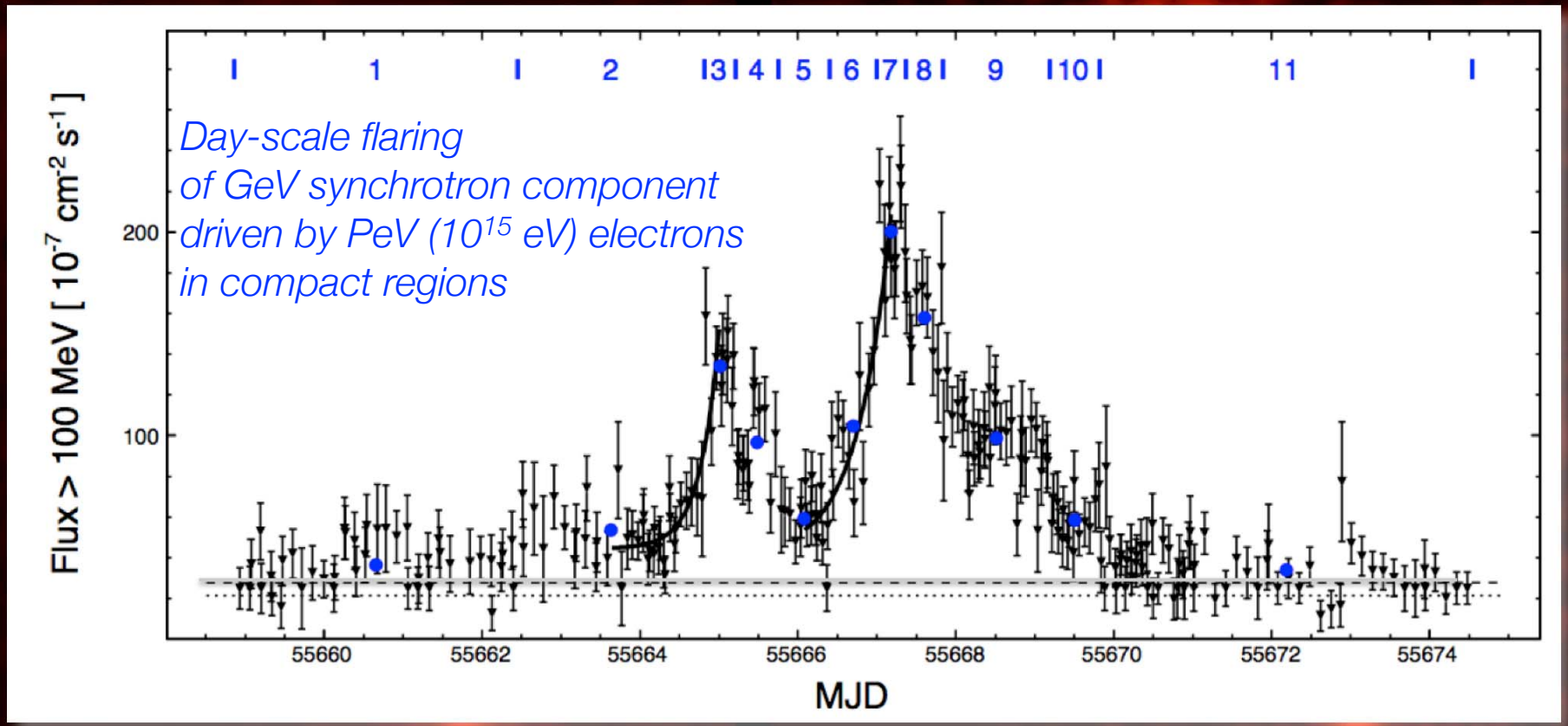
- Pulsed emission from pulsar magnetosphere
- Steady emission from extended electron nebula


Normal
Crab Nebula
Geminga pulsar
Flare State
April 2011
Fermi LAT, R. Buehler

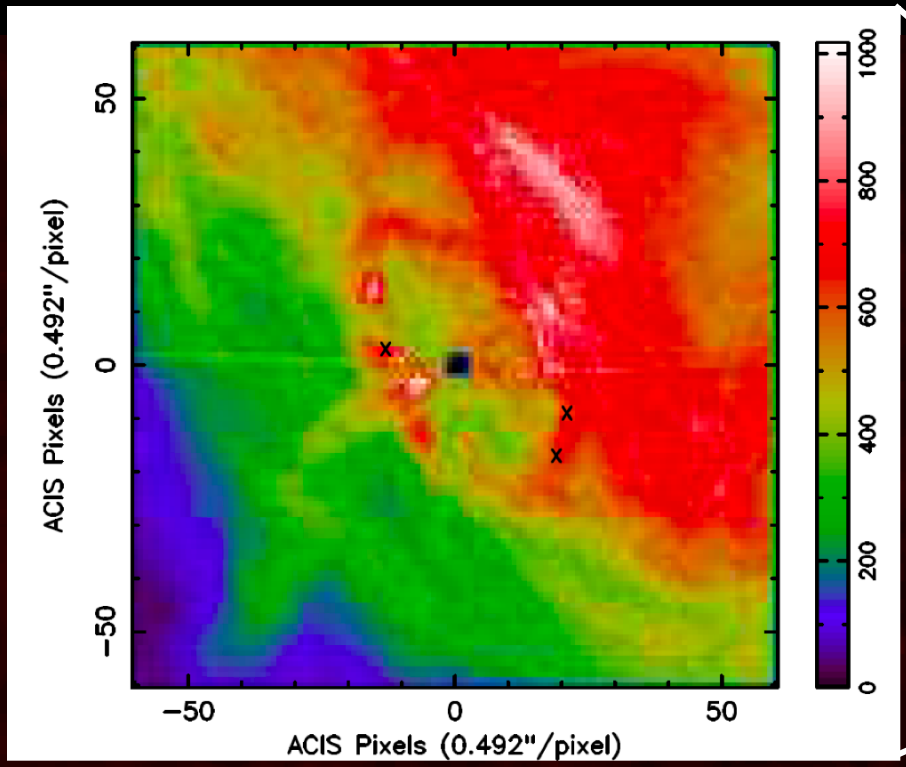
Normal

Flare State

April 2011



Fermi LAT, R. Buehler

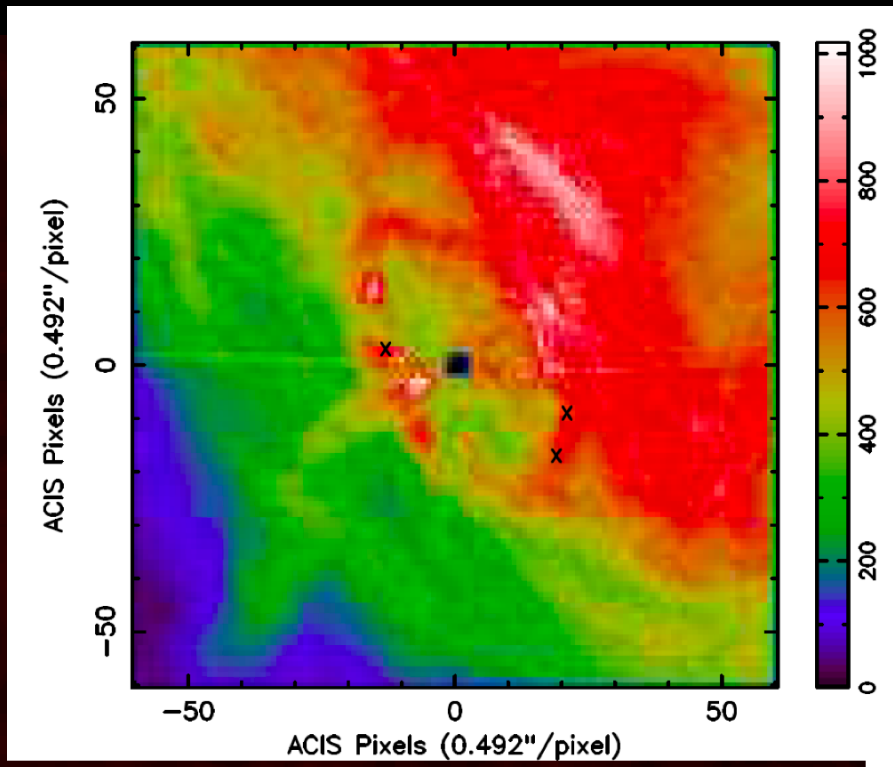


Flare State

April 2011

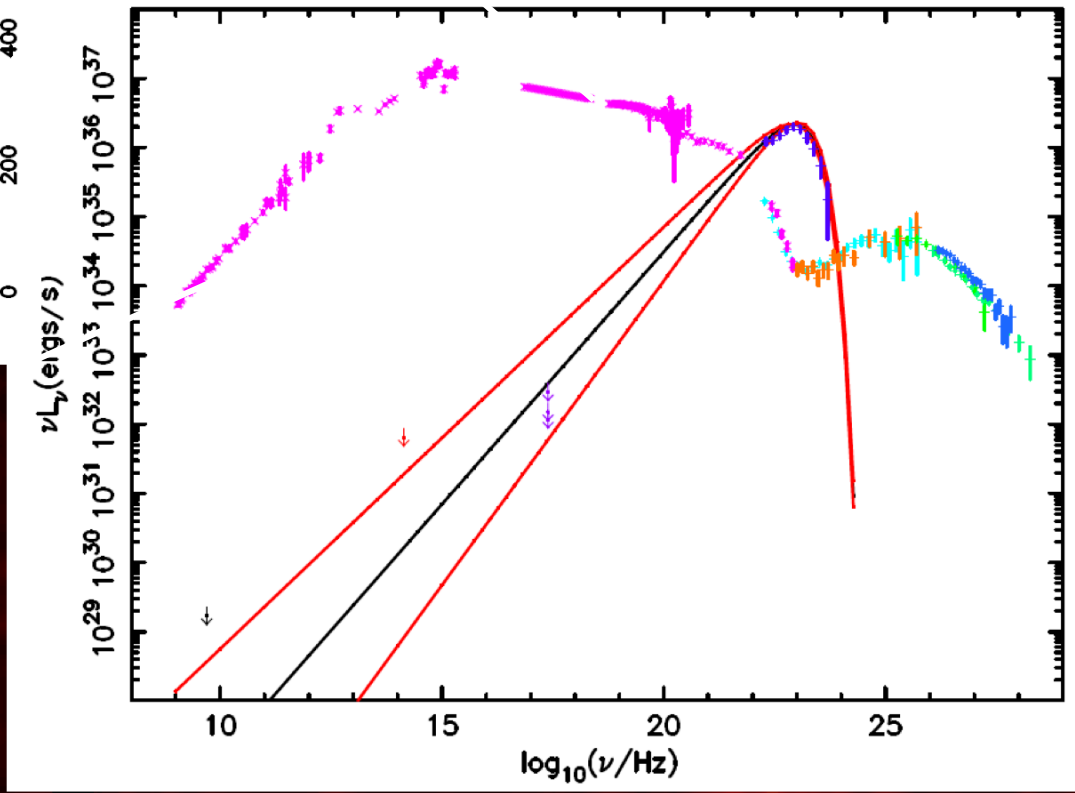
Geminga pulsar

Fermi LAT, R. Buehler



Flare State

April 2011

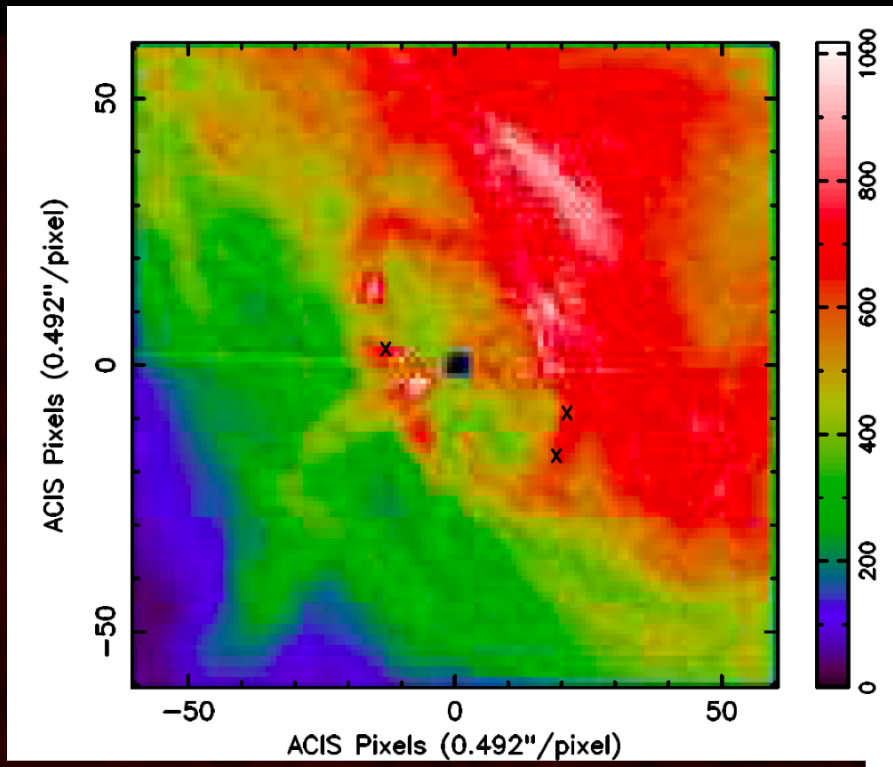


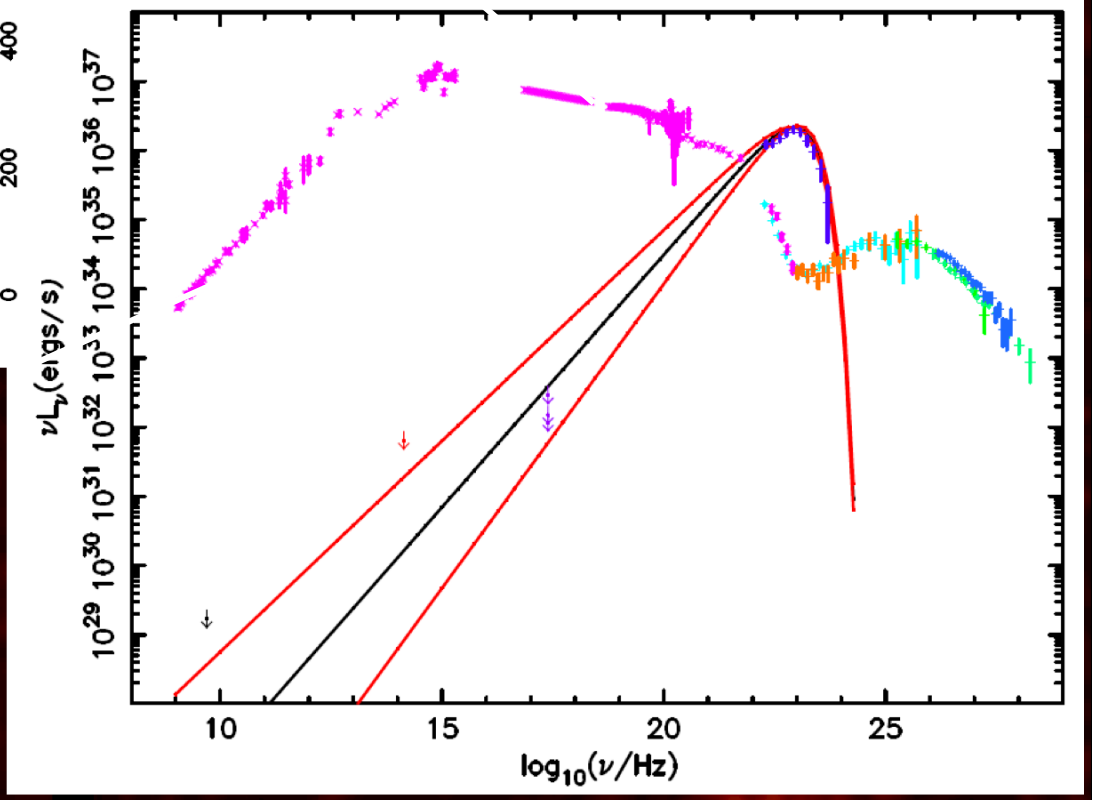
Geminga pulsar

Fermi LAT, R. Buehler

Flare State

April 2011





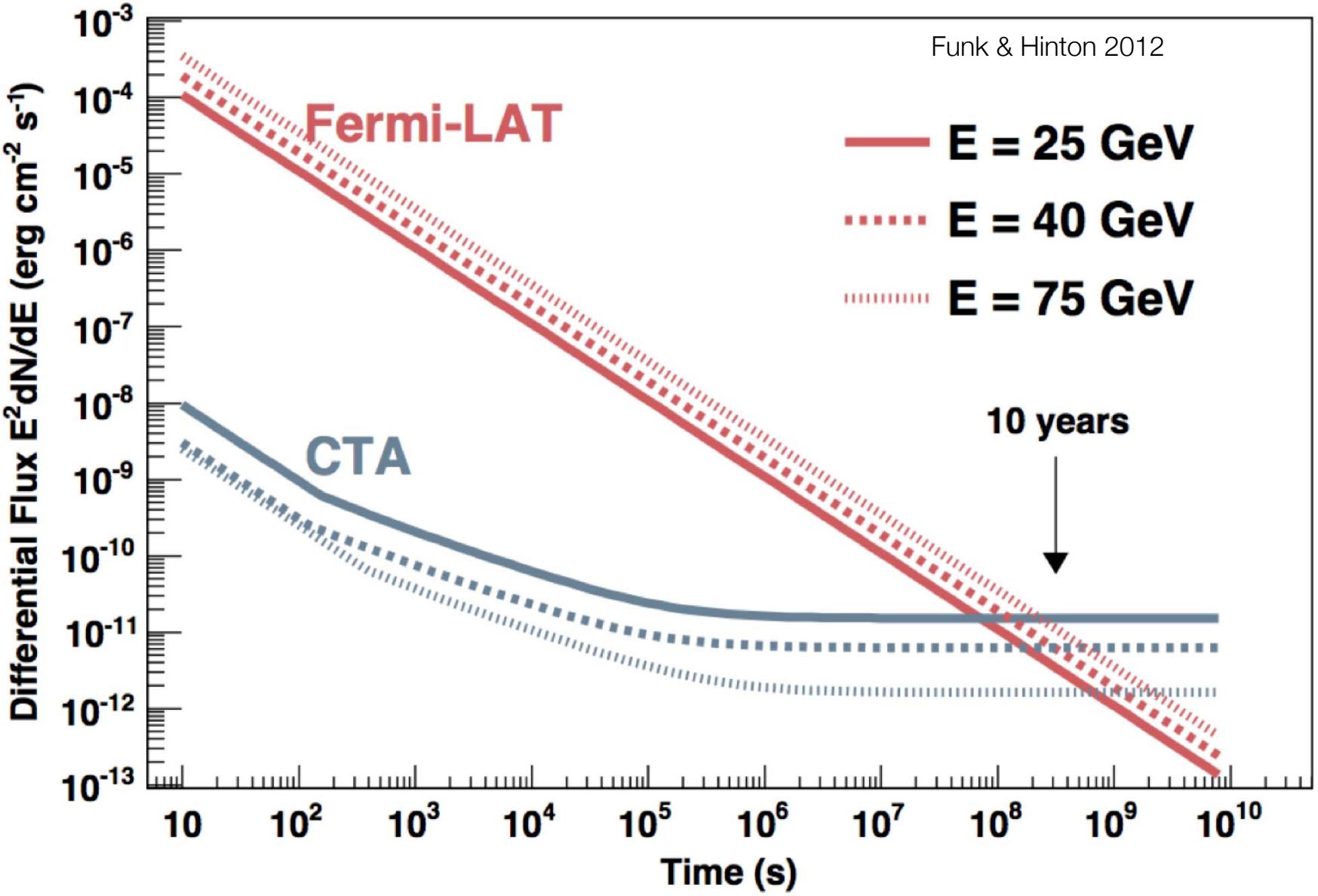
Geminga pulsar

similar flares predicted

in 100 TeV range

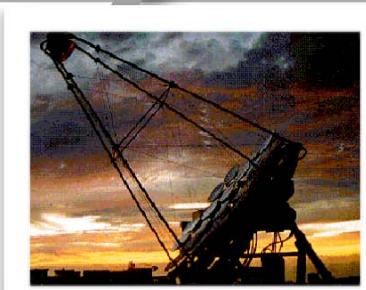
Fermi LAT, R. Buehler

CTA versus Fermi – transient sources



The Evolution

Whipple:
Imaging principle
Large dish



HEGRA:
Stereoscopy

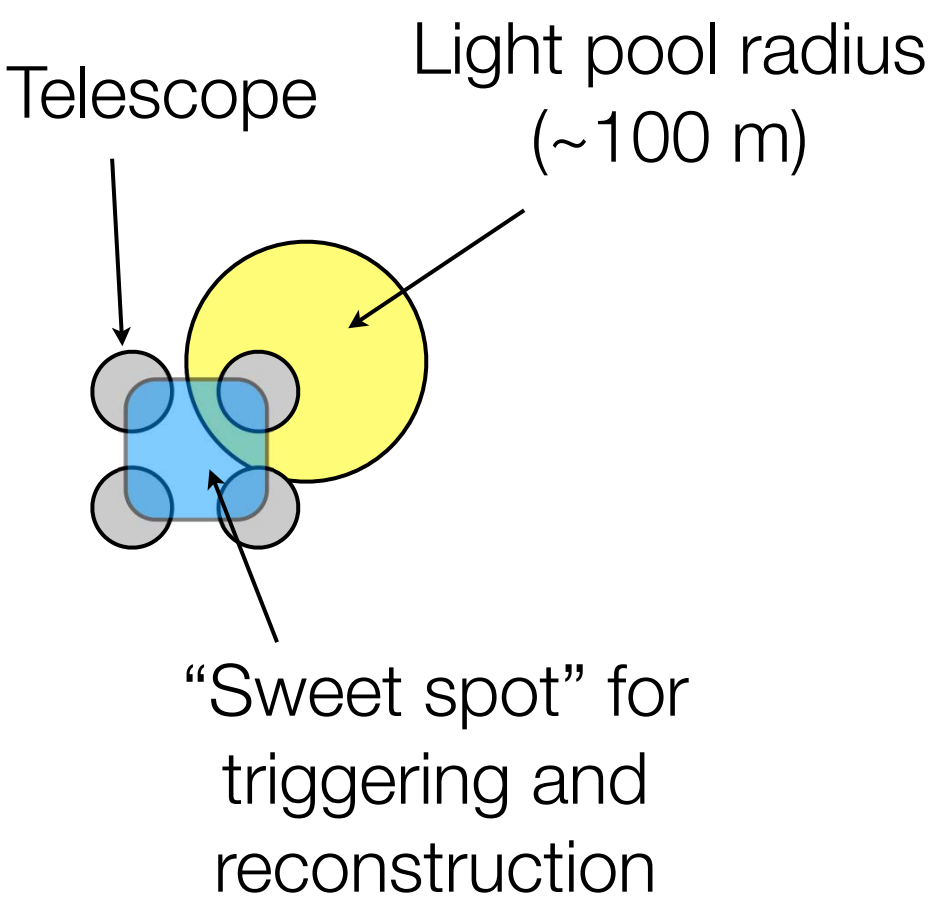
CAT:
Small pixels

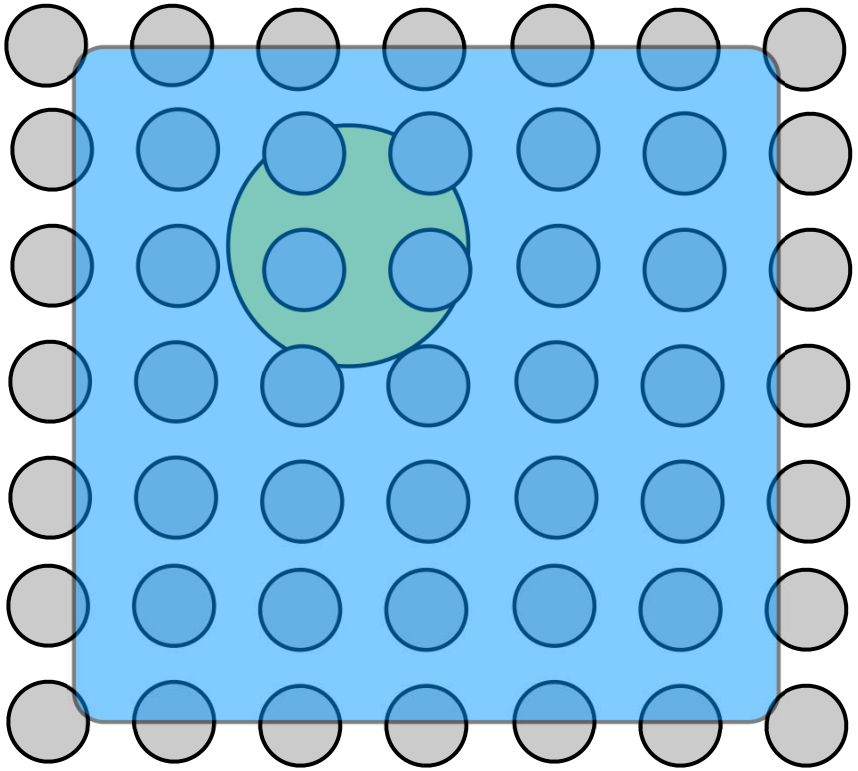
H.E.S.S.
VERITAS
MAGIC

CTA: Lots of Telescopes

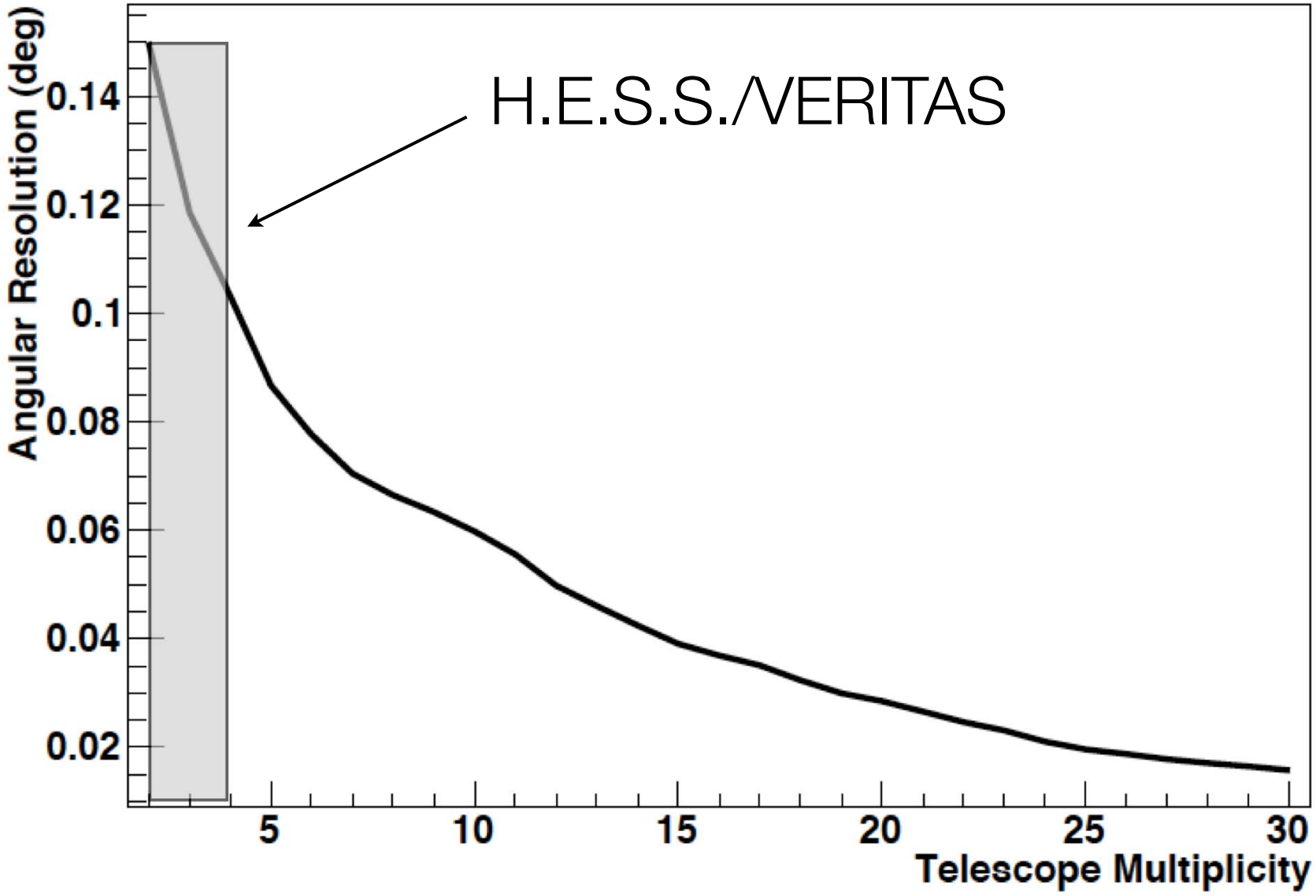
The concept of CTA

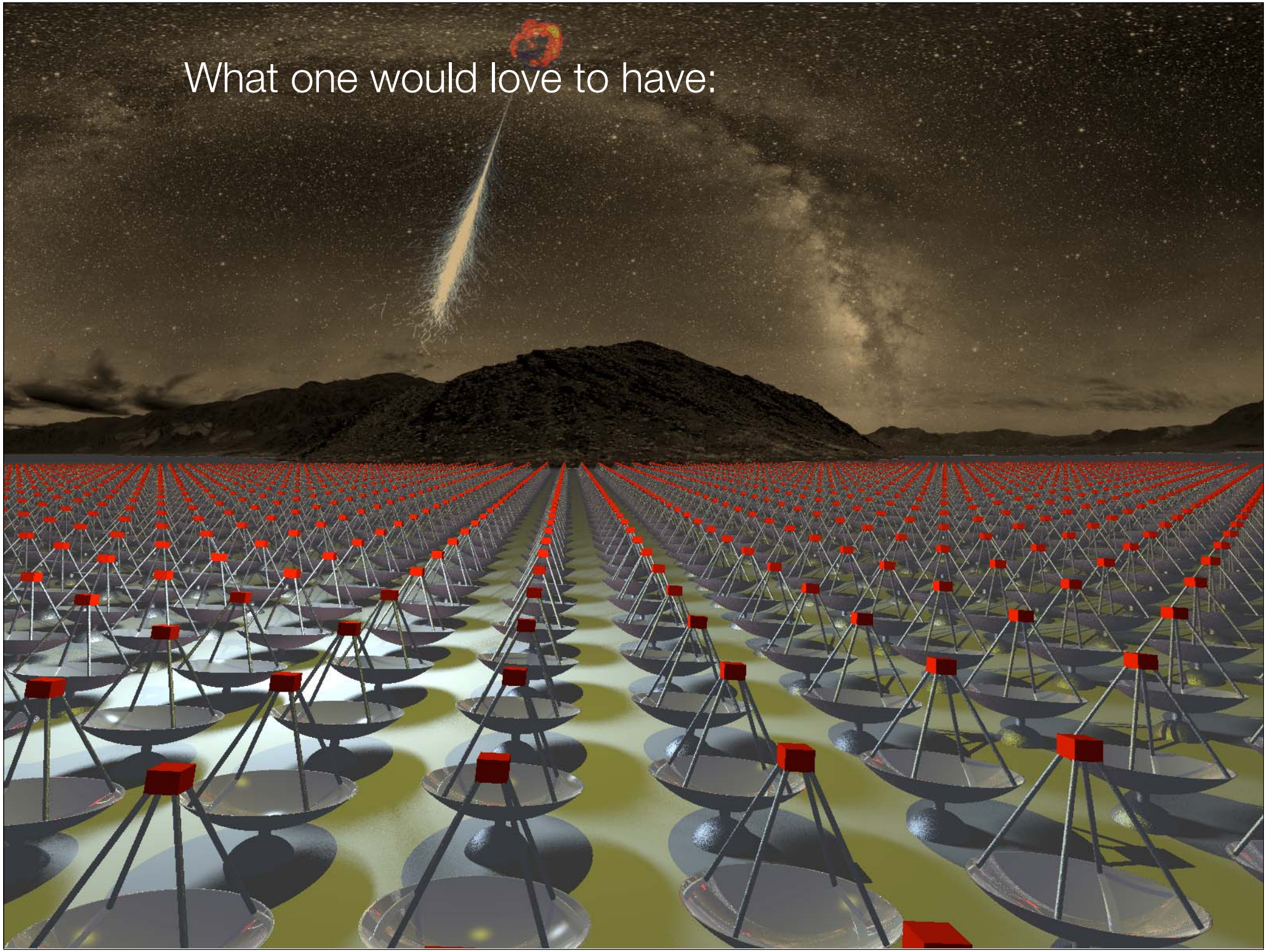
- Fraction of “contained events” significantly increases

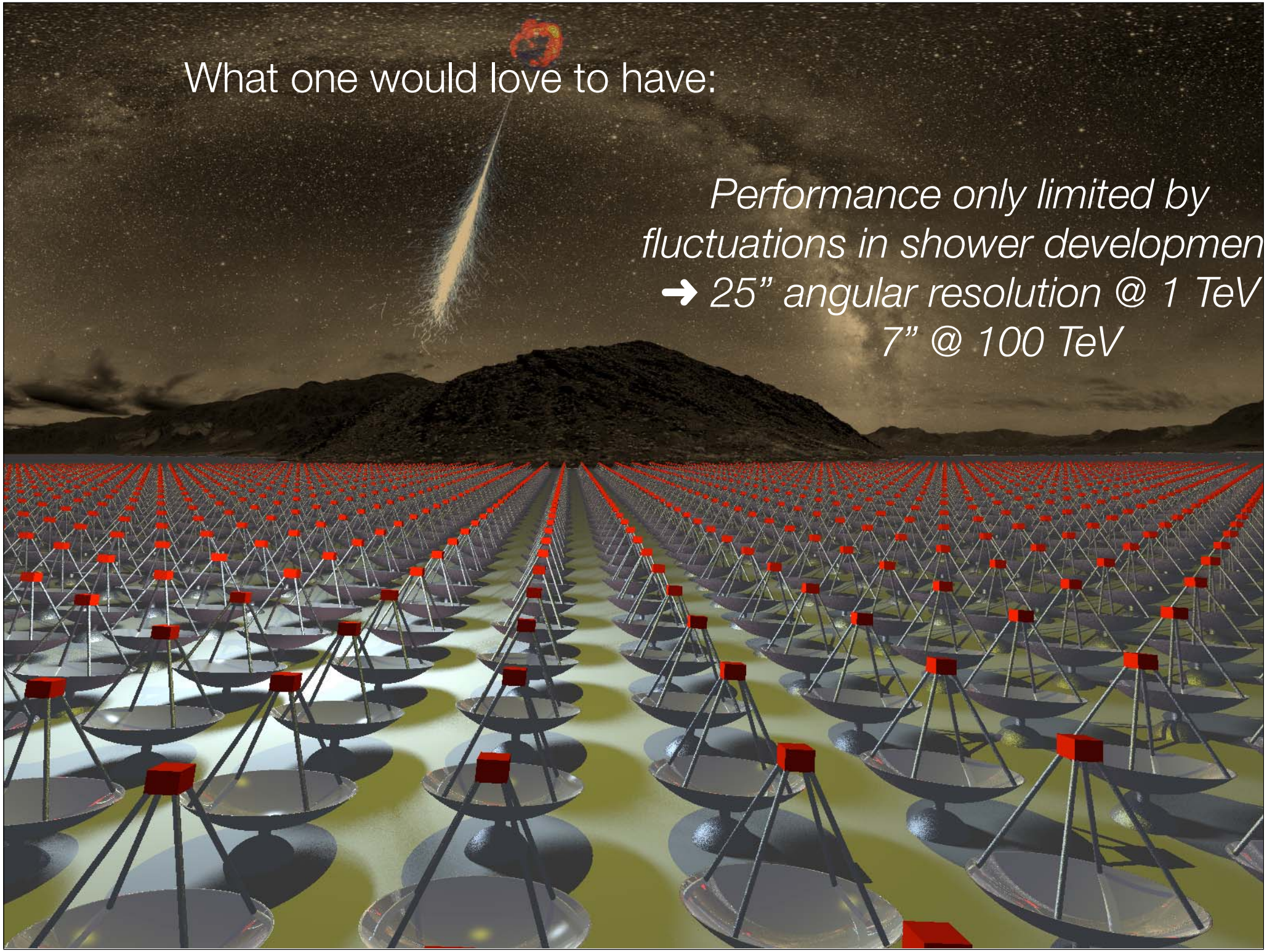




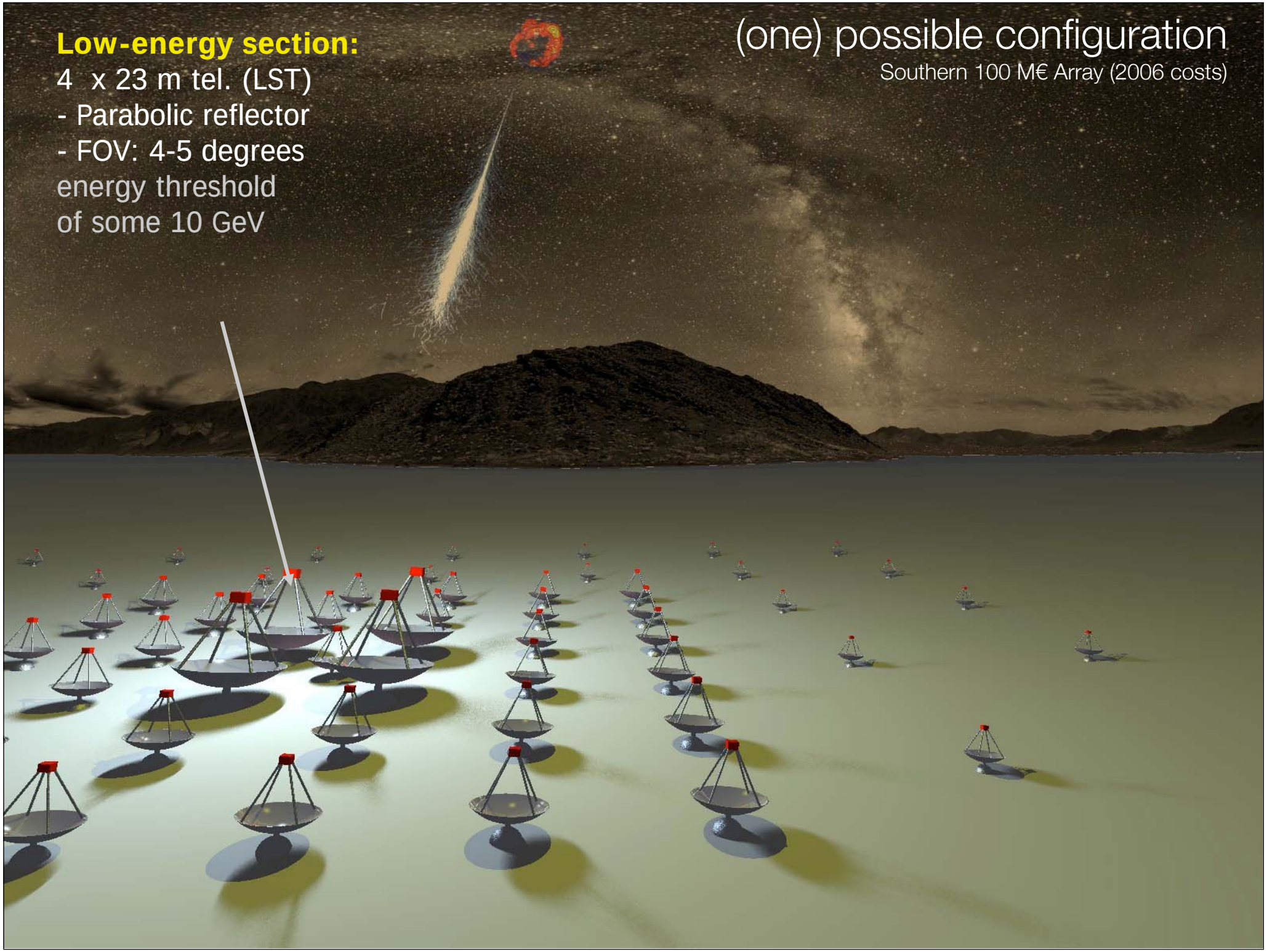
Strong implications for instrument properties




What one would love to have:

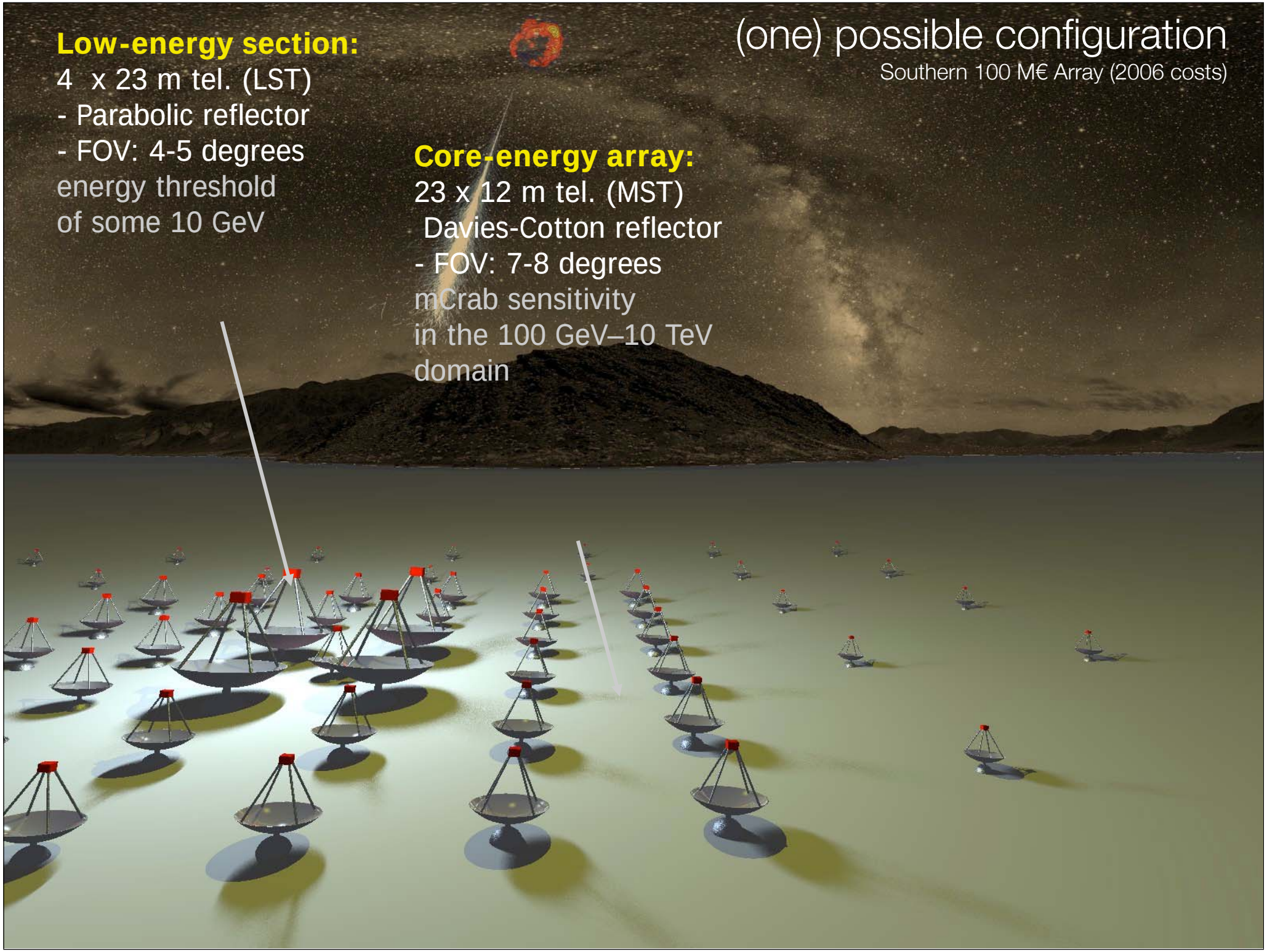

What one would love to have:
Performance only limited by fluctuations in shower developmen
➜ *25” angular resolution @ 1 TeV*
7” @ 100 TeV

What one can (hopefully) afford:


Low-energy section:
4 x 23 m tel. (LST)
- Parabolic reflector
- FOV: 4-5 degrees
energy threshold
of some 10 GeV
(one) possible configuration
Southern 100 M€ Array (2006 costs)

(one) possible configuration

Southern 100 M€ Array (2006 costs)



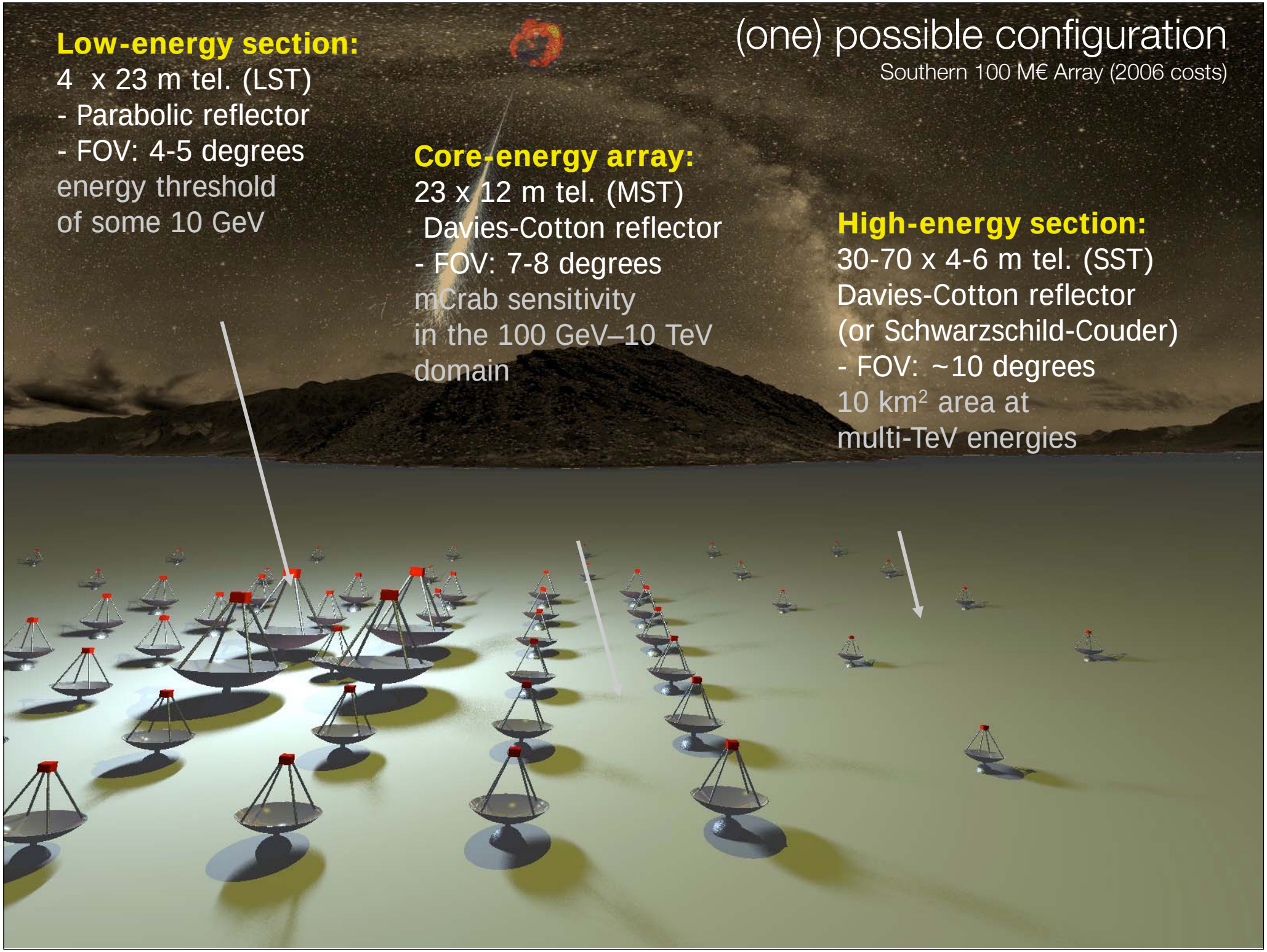
(one) possible configuration

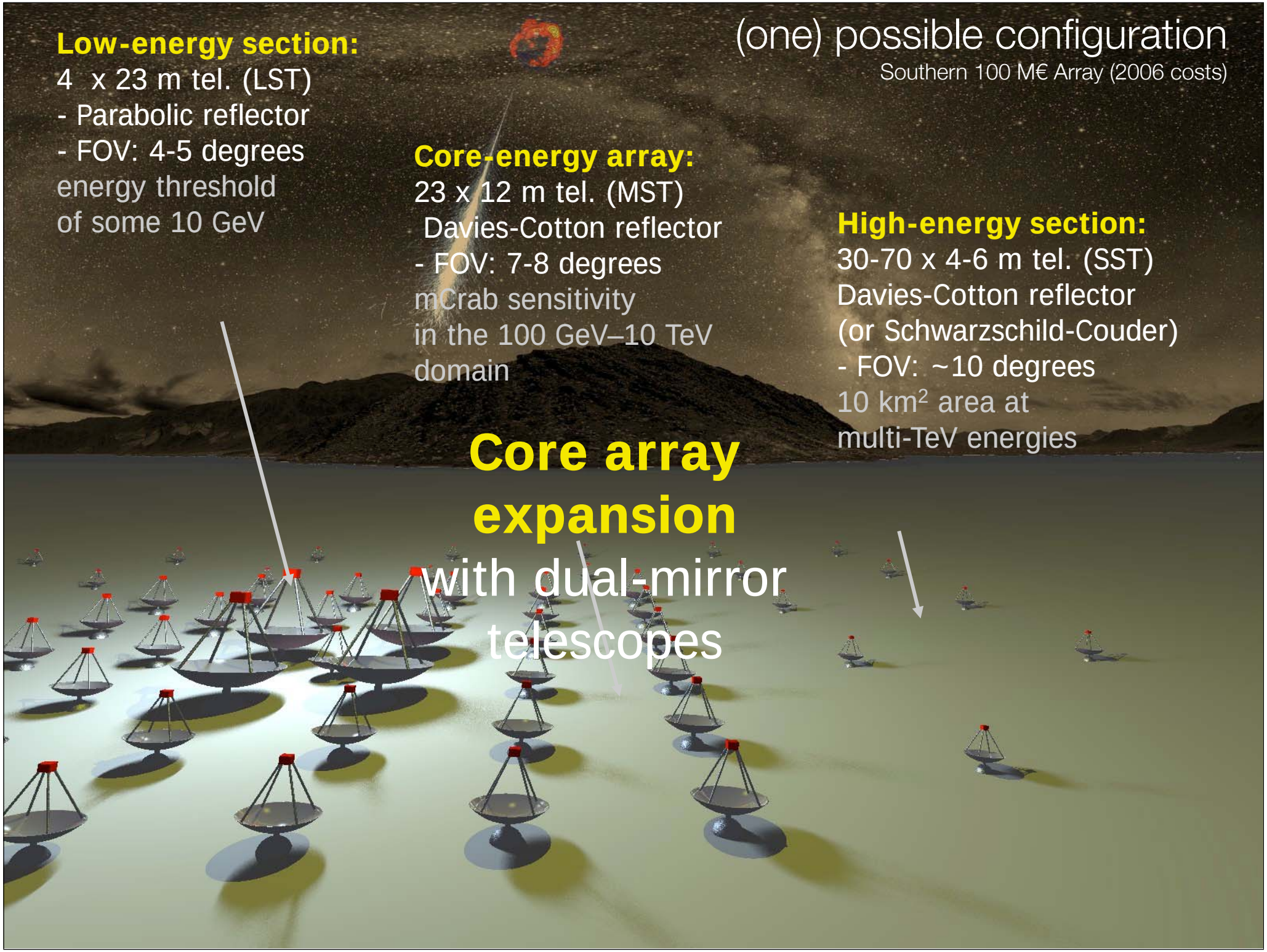
Southern 100 M€ Array (2006 costs)

Low-energy section:
4 x 23 m tel. (LST)
- Parabolic reflector
- FOV: 4-5 degrees
energy threshold
of some 10 GeV

Core-energy array:
23 x 12 m tel. (MST)
Davies-Cotton reflector
- FOV: 7-8 degrees
mCrab sensitivity
in the 100 GeV–10 TeV
domain

High-energy section:
30-70 x 4-6 m tel. (SST)
Davies-Cotton reflector
(or Schwarzschild-Couder)
- FOV: ~10 degrees
10 km^2 area at
multi-TeV energies

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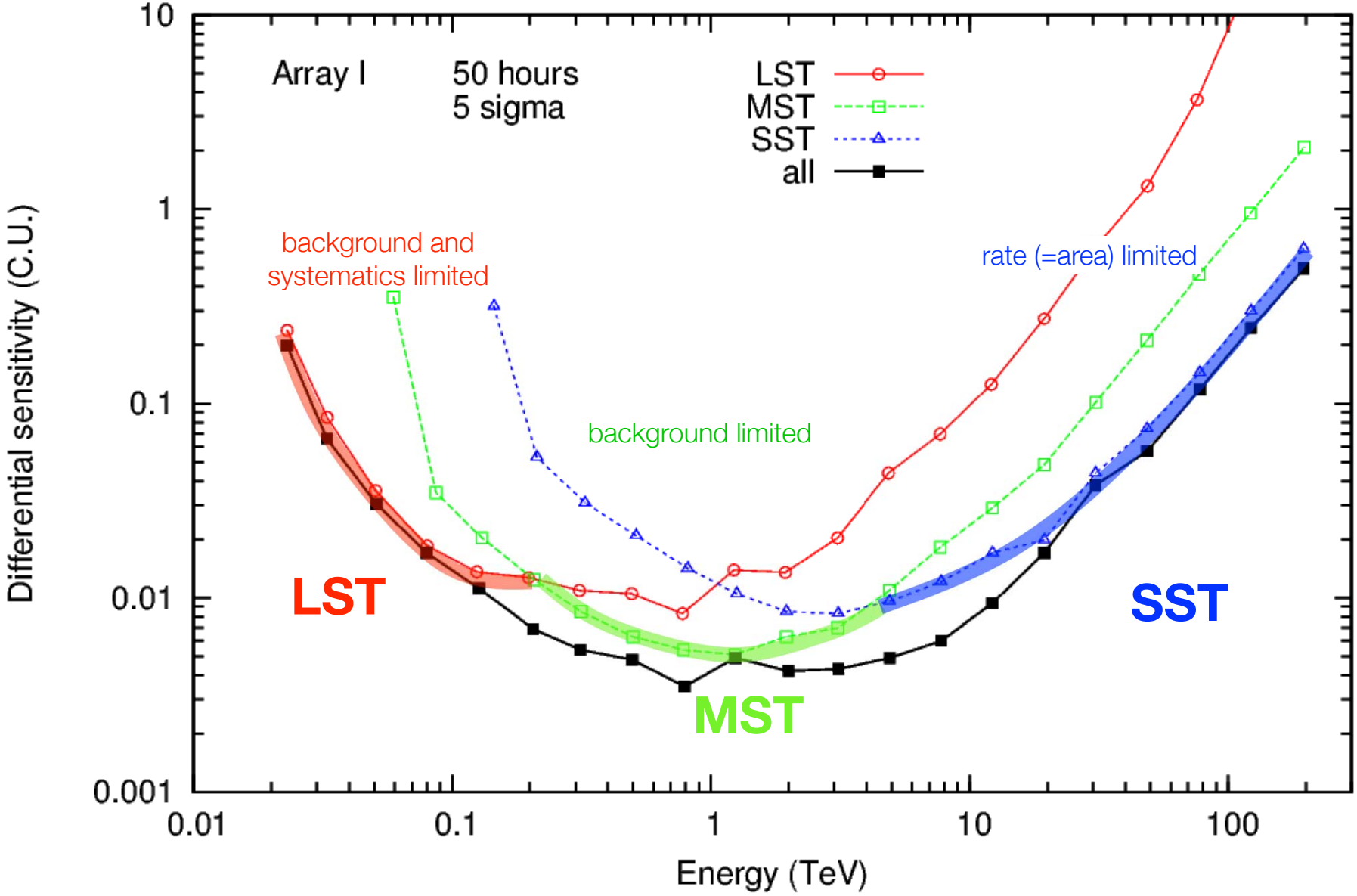
Davies-Cotton reflector
(or Schwarzschild-Couder)
- FOV: ~10 degrees
10 km² area at
multi-TeV energies
Core array
expansion
with dual-mirror
telescopes

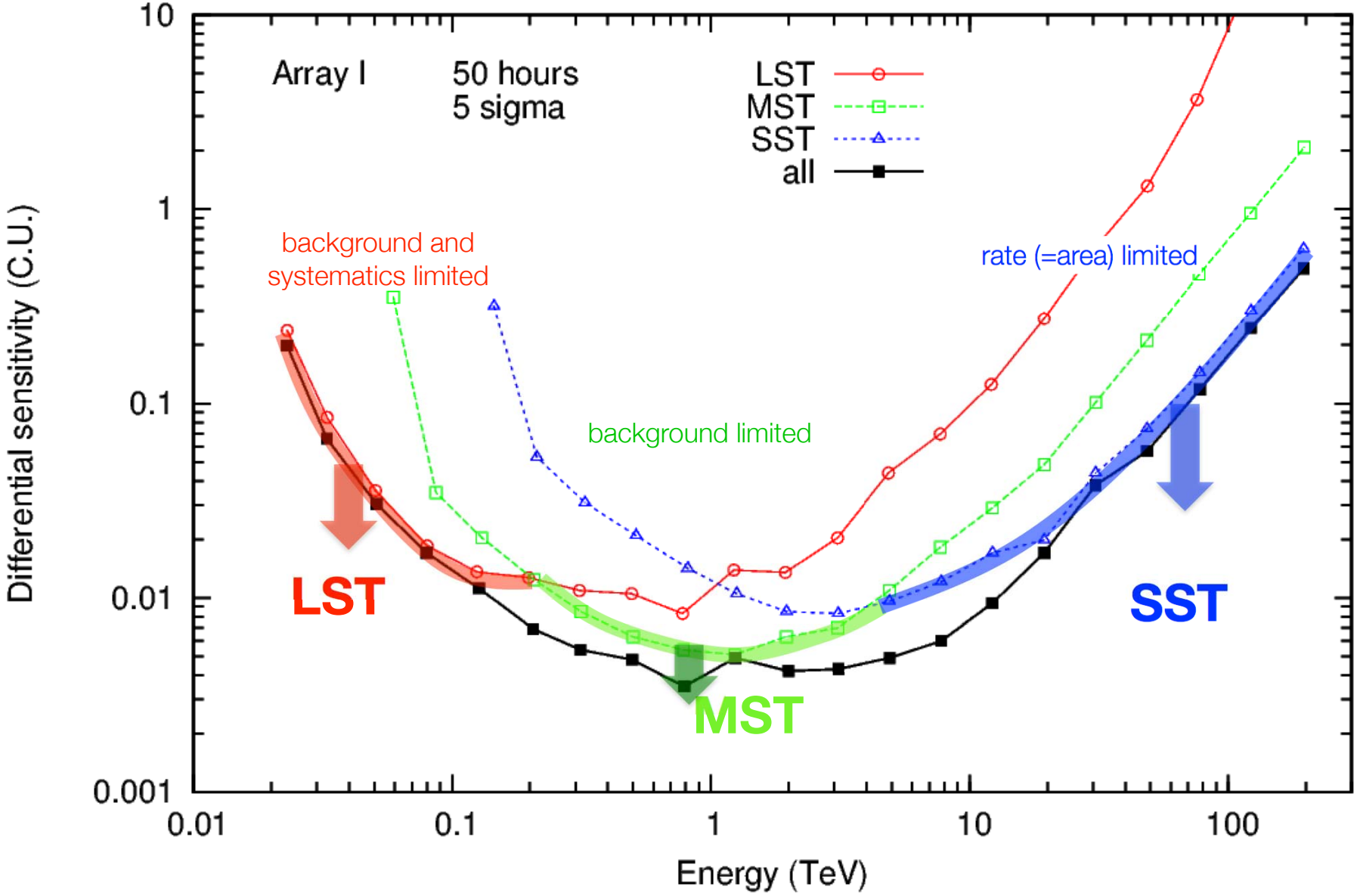
Sensitivity (in units of Crab flux)

for detection in each 0.2-decade energy band



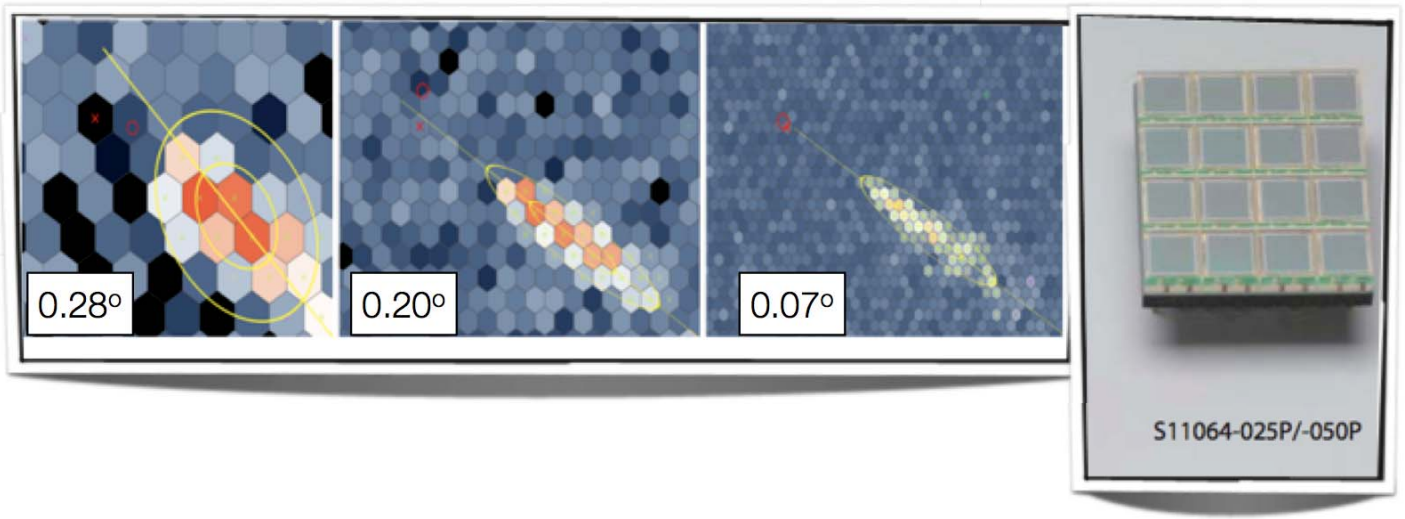
Sensitivity (in units of Crab flux)

for detection in each 0.2-decade energy band



Dual-mirror telescope system

Fine Pixelation:

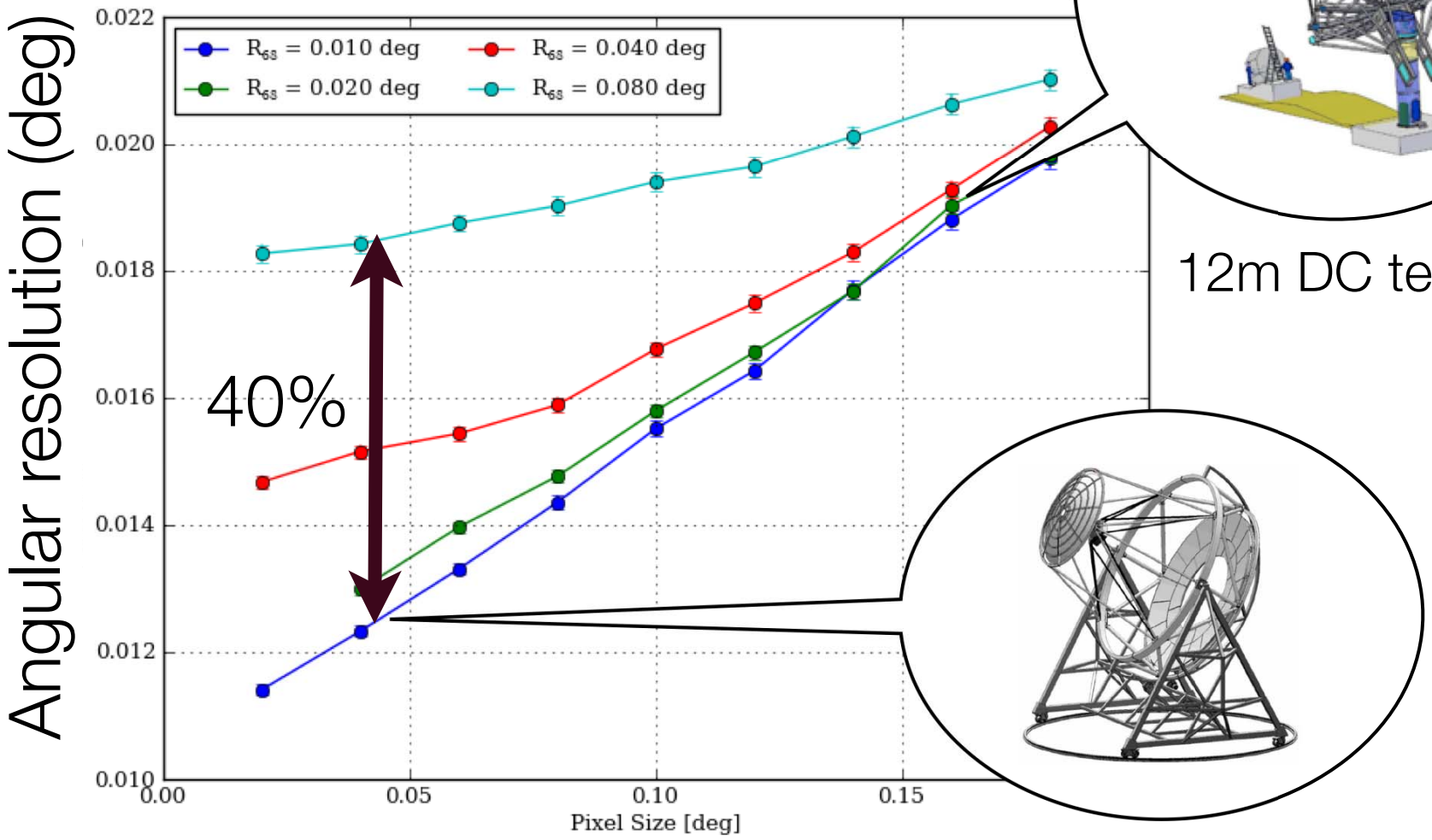


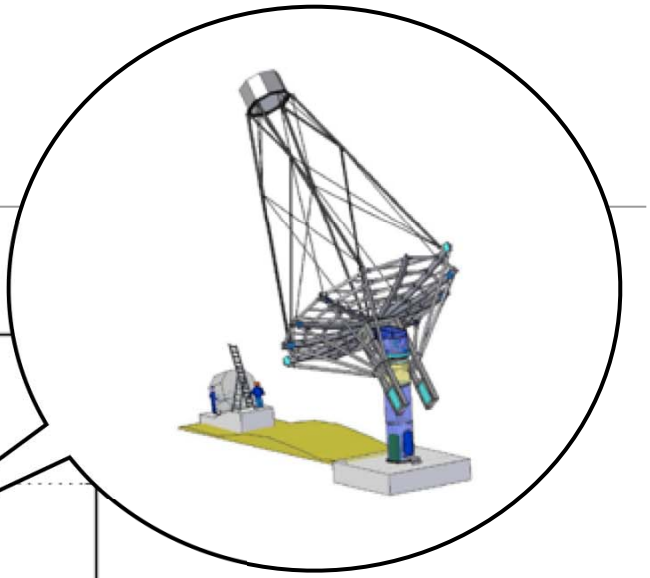
Vassiliev et al. 2007

9.5 m primary

- Main motivation:
  - Decrease camera size (0.7x0.7m versus 3x3m)
  - Decrease (physical and angular) pixel size (MaPMTs or SiPMTs)
  - Comes at expense of light-collection area (~x2) and complexity of mechanical structure

Performance enhancement





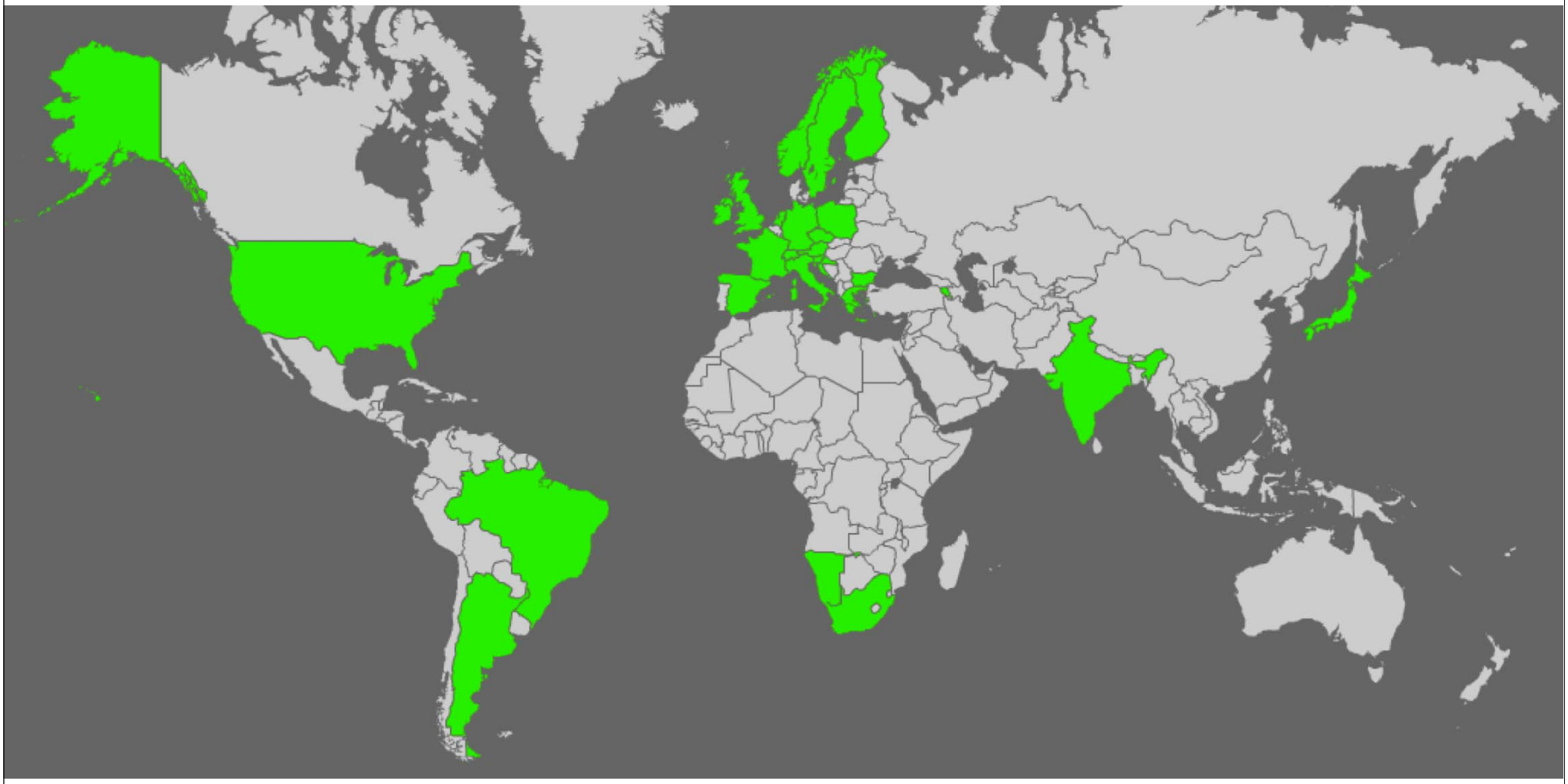
12m DC telescope

9.5m SC telescope

WHO

CTA Members: 26 Countries

~1000 scientists and engineers from >100 institutions



Argentina, Armenia, Austria, Brazil, Bulgaria, Czech Republic, Croatia, Finland, France, Germany, Greece, India, Italy, Ireland, Japan, Namibia, Netherlands, Norway, Poland, Slovenia, Spain, South Africa, Sweden, Switzerland, UK, USA

CTA

Buenos Aires
CTA
de los tra
CTA

The future in
very high energy
gamma ray astronomy
cta
cherenkov telescope array
Perfect mix of guaranteed science and discovery potential
Safe extrapolation of proven technologies, well-predictable performance
Supported by a large and diverse community
Highly ranked by major science roadmaps
Aim for deployment over 5 years – 2014-2018