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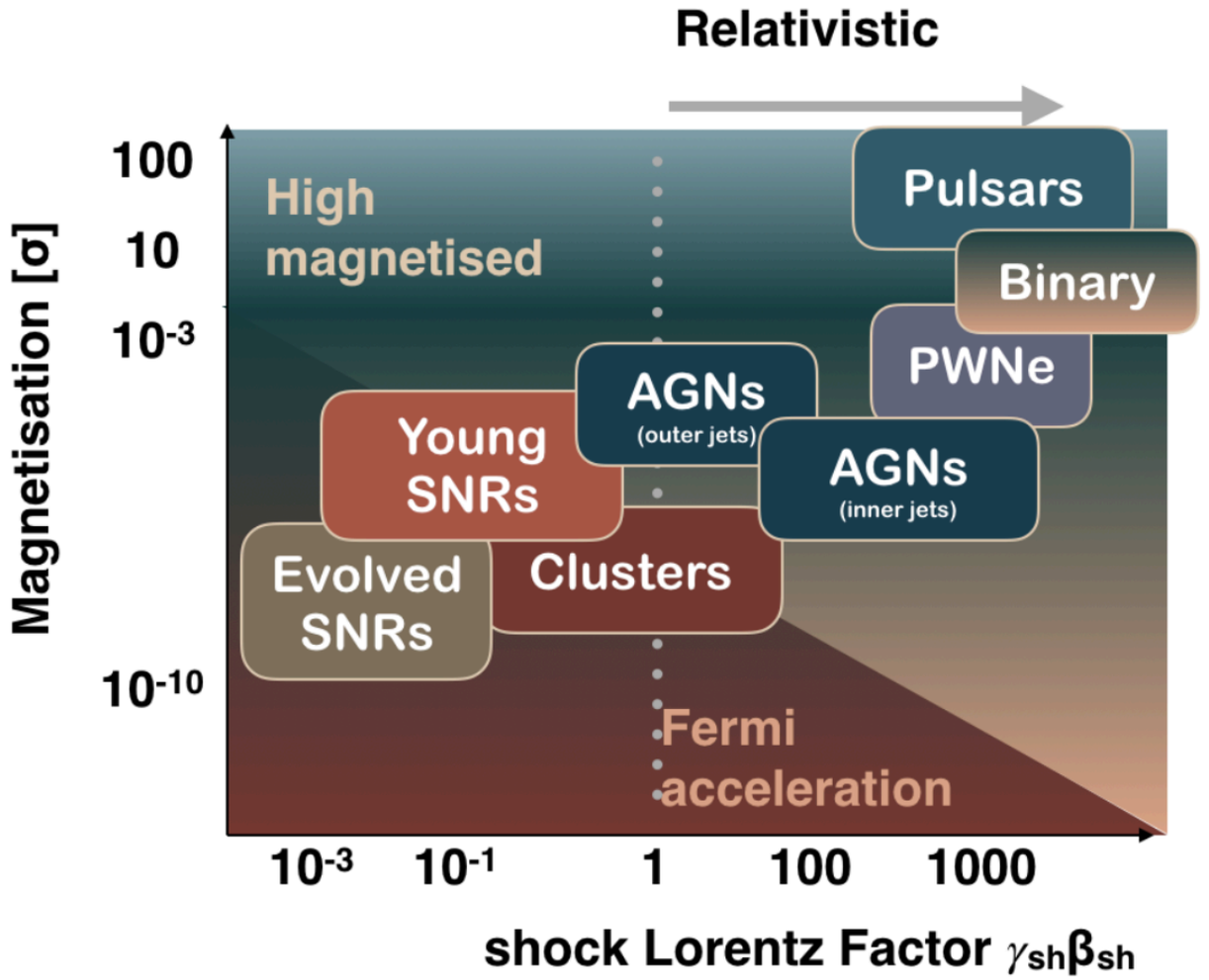
Gamma-ray Astrophysics

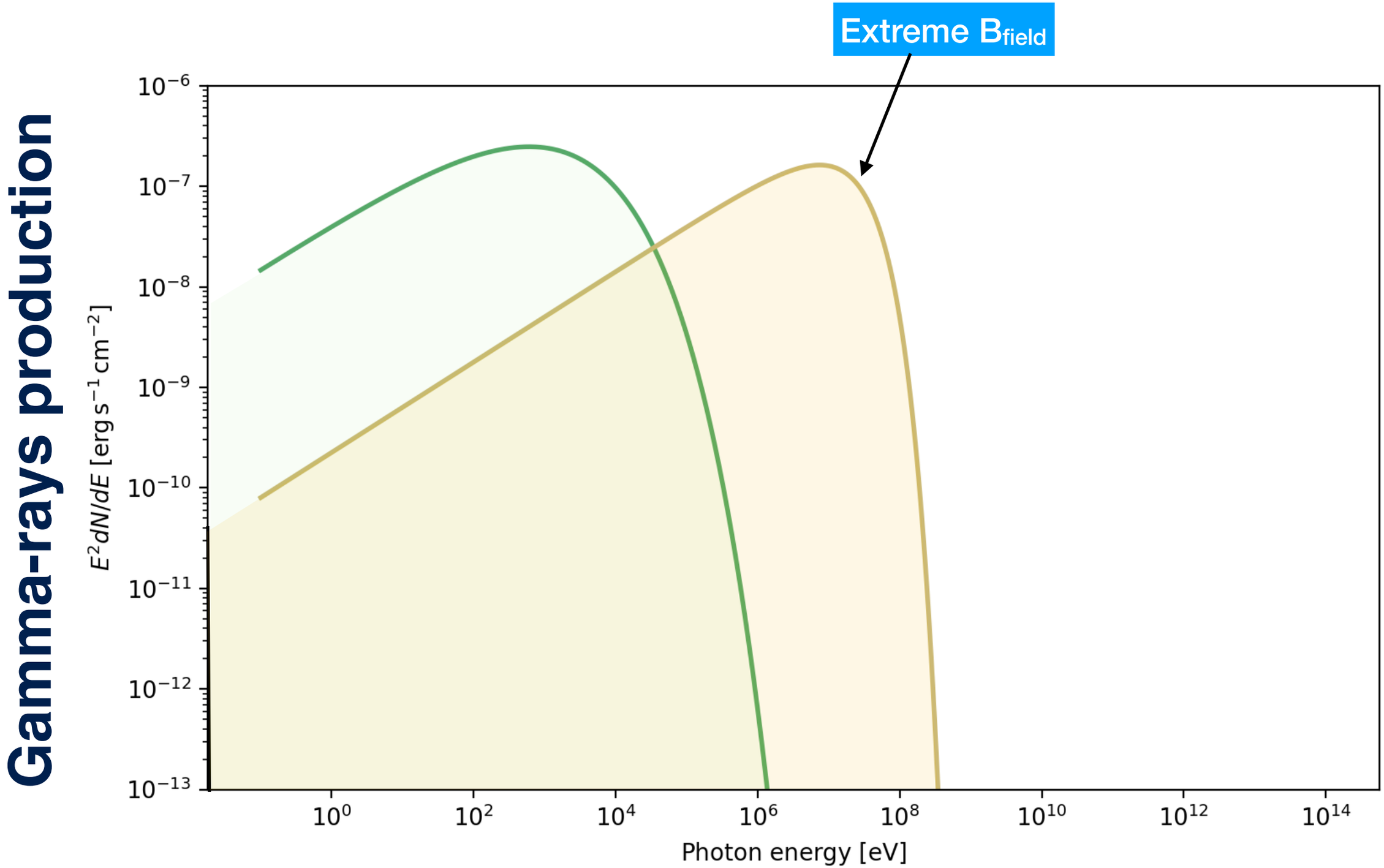
Emma de Oña Wilhelmi, DESY-Zeuthen & ICE (CSIC/IEEC)

Gamma-ray Astronomy

- To radiate high-energy gamma-ray, particles (electrons and hadrons) have to be accelerated to energies of 100 TeV or more:
  - ➡ Huge gravitational, magnetic and electric fields
  - ➡ Very dense background radiation relativistic bulk motions (black hole jets and pulsar winds)
  - ➡ Shock waves (SNRs), highly excited (turbulent) media, etc...



Synchrotron: Need magnetic field => Radio/X-ray Synergies



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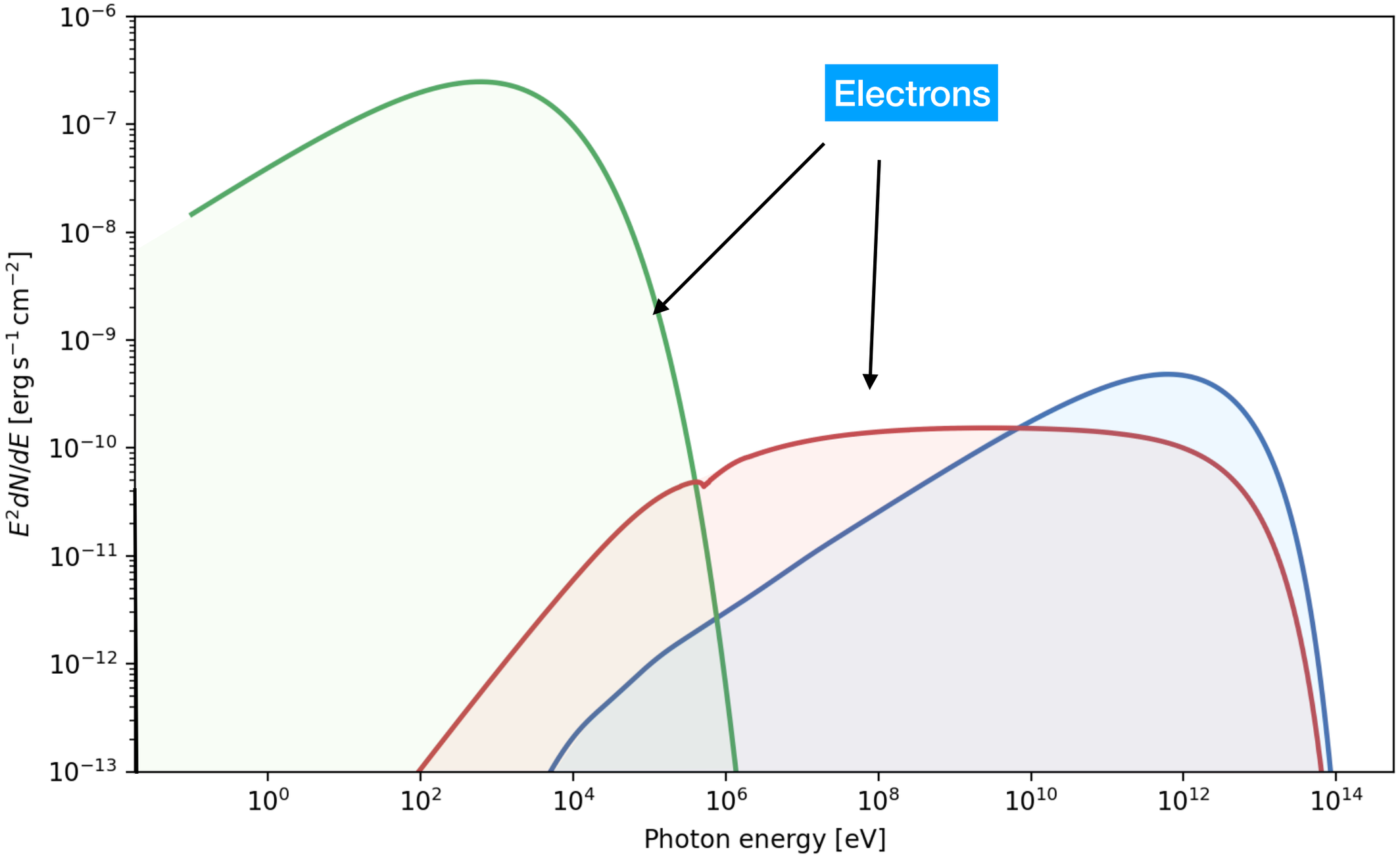
Inverse Compton: Need soft FIR, NIR, CMB photon fields

Bremsstrahlung: Need dense media

Gamma-rays production



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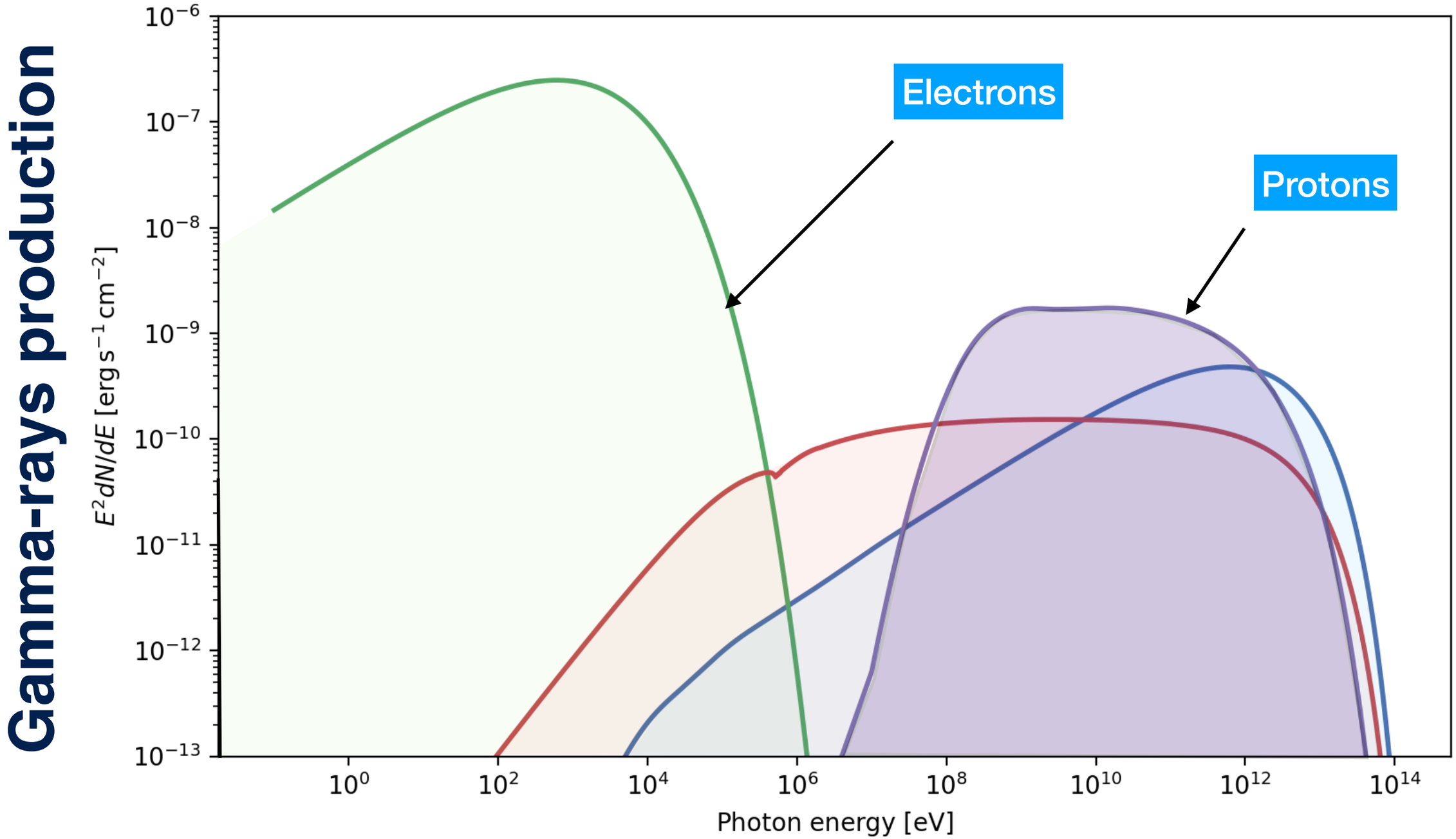

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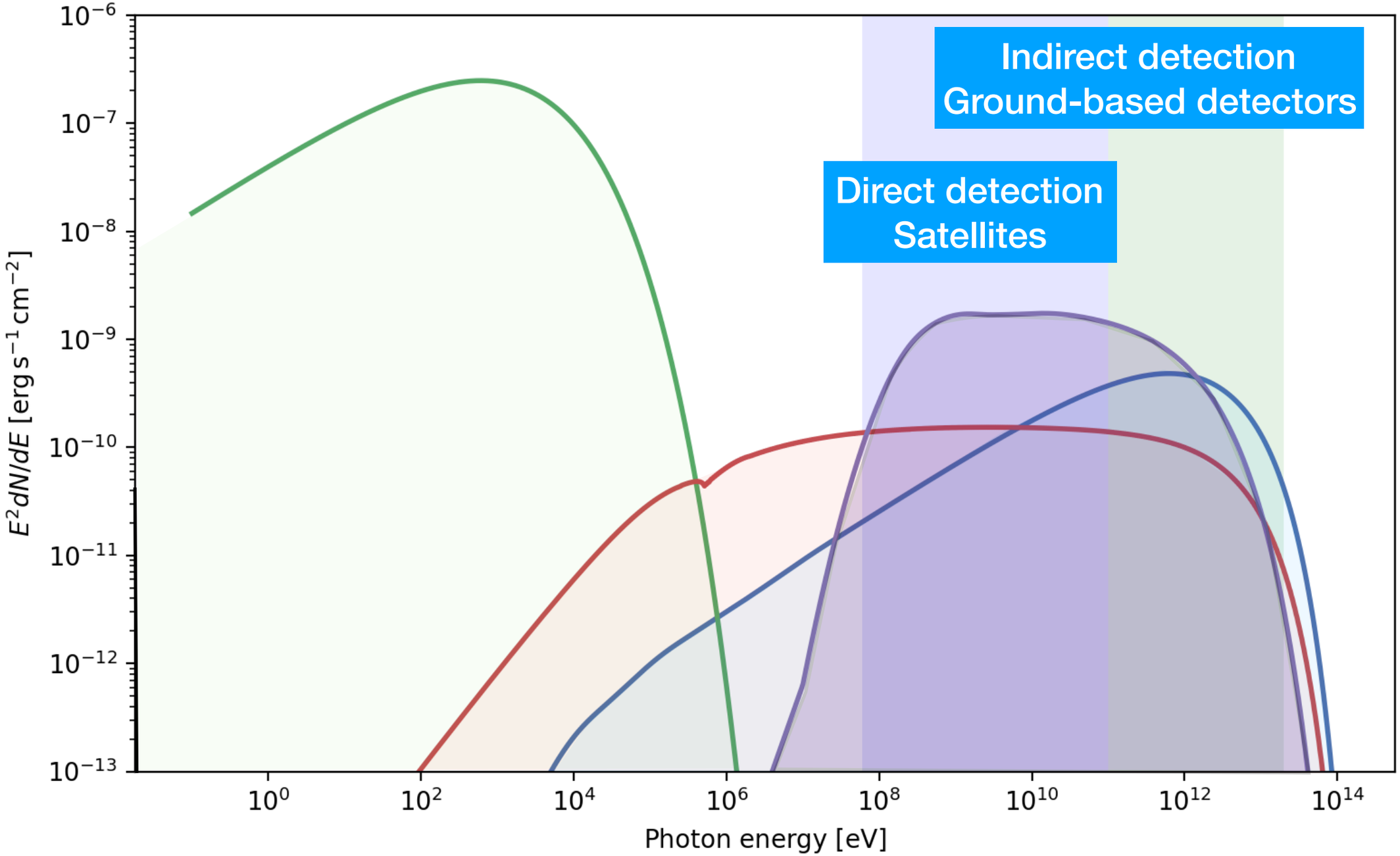
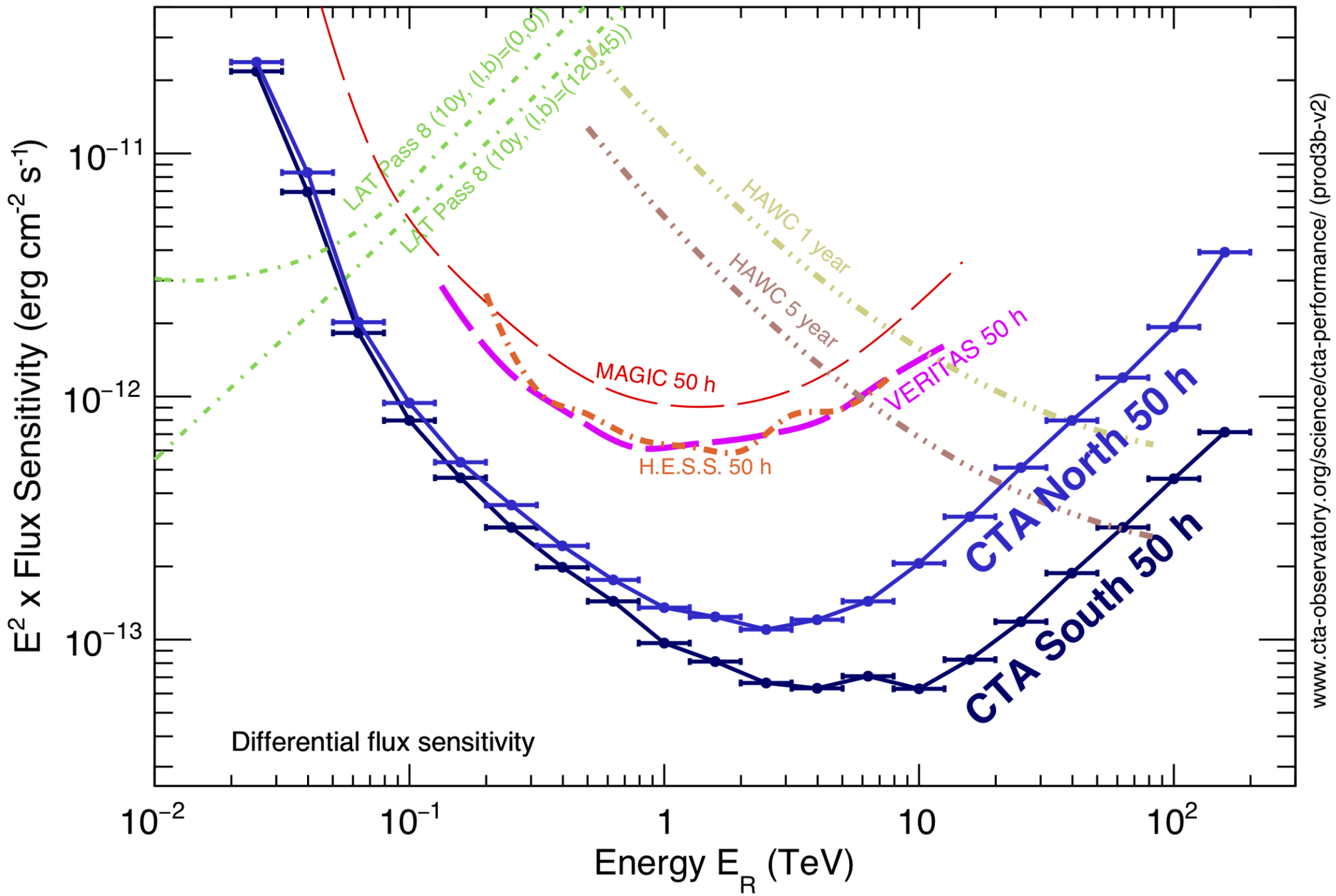


Detection of gamma-rays



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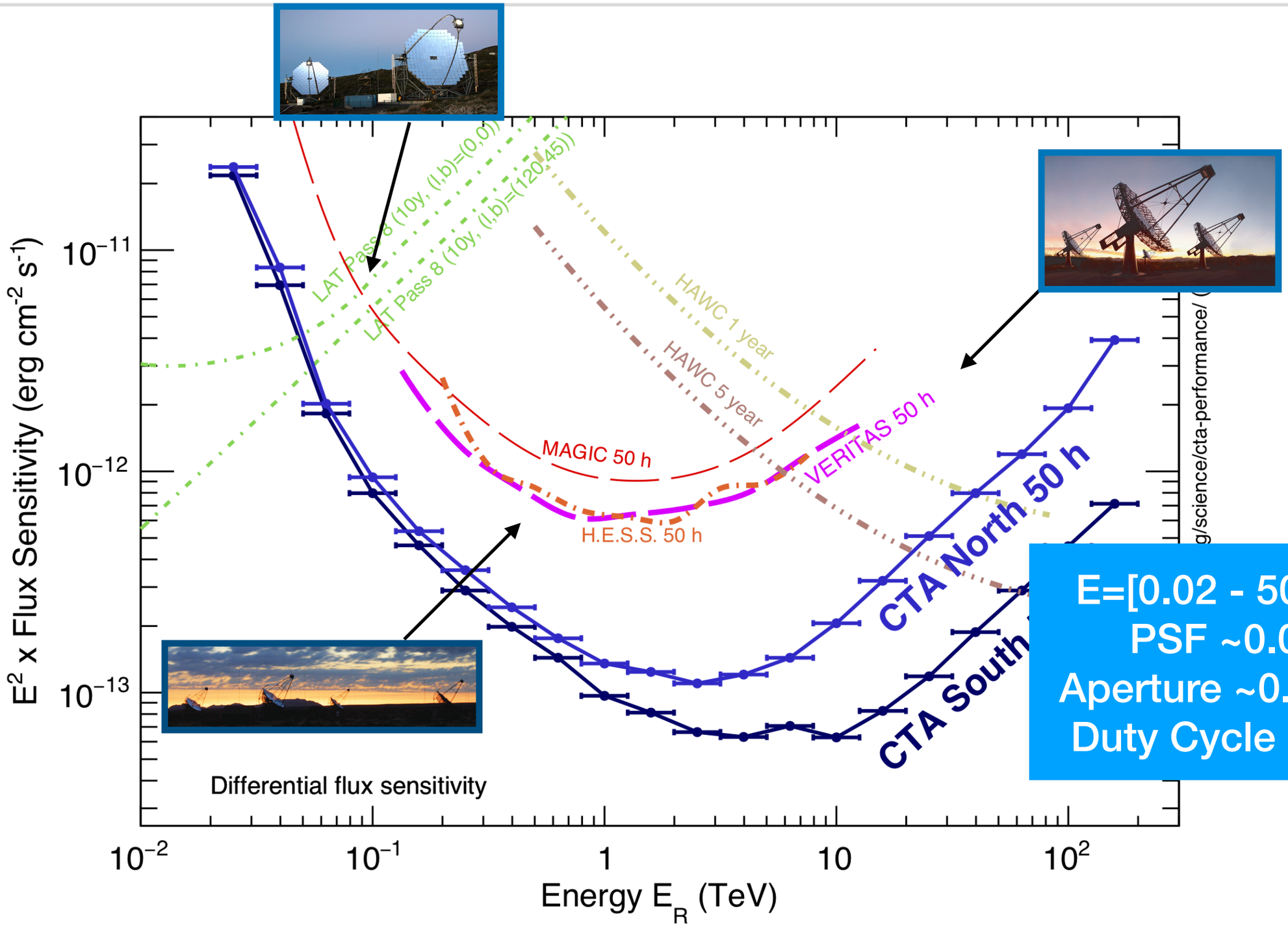


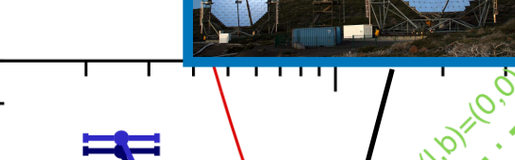
IACTs

E=[0.02 - 50] TeV
PSF ~0.05°
Aperture ~0.003 sr
Duty Cycle ~10%

Detection of gamma-rays

E=[10 - 100] TeV
PSF ~0.3-0.7º
Aperture > 2 sr
Duty Cycle ~90%

Particle Det



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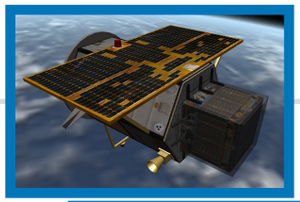
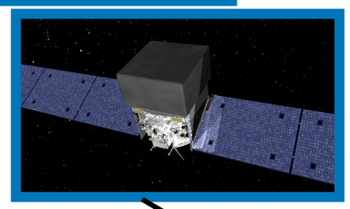
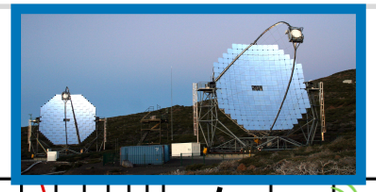
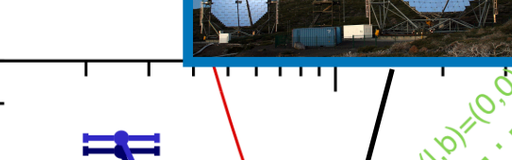






Satellites

E=[100MeV - 100 GeV]
PSF ~0.1-3º
Aperture > survey
Duty Cycle ~95%



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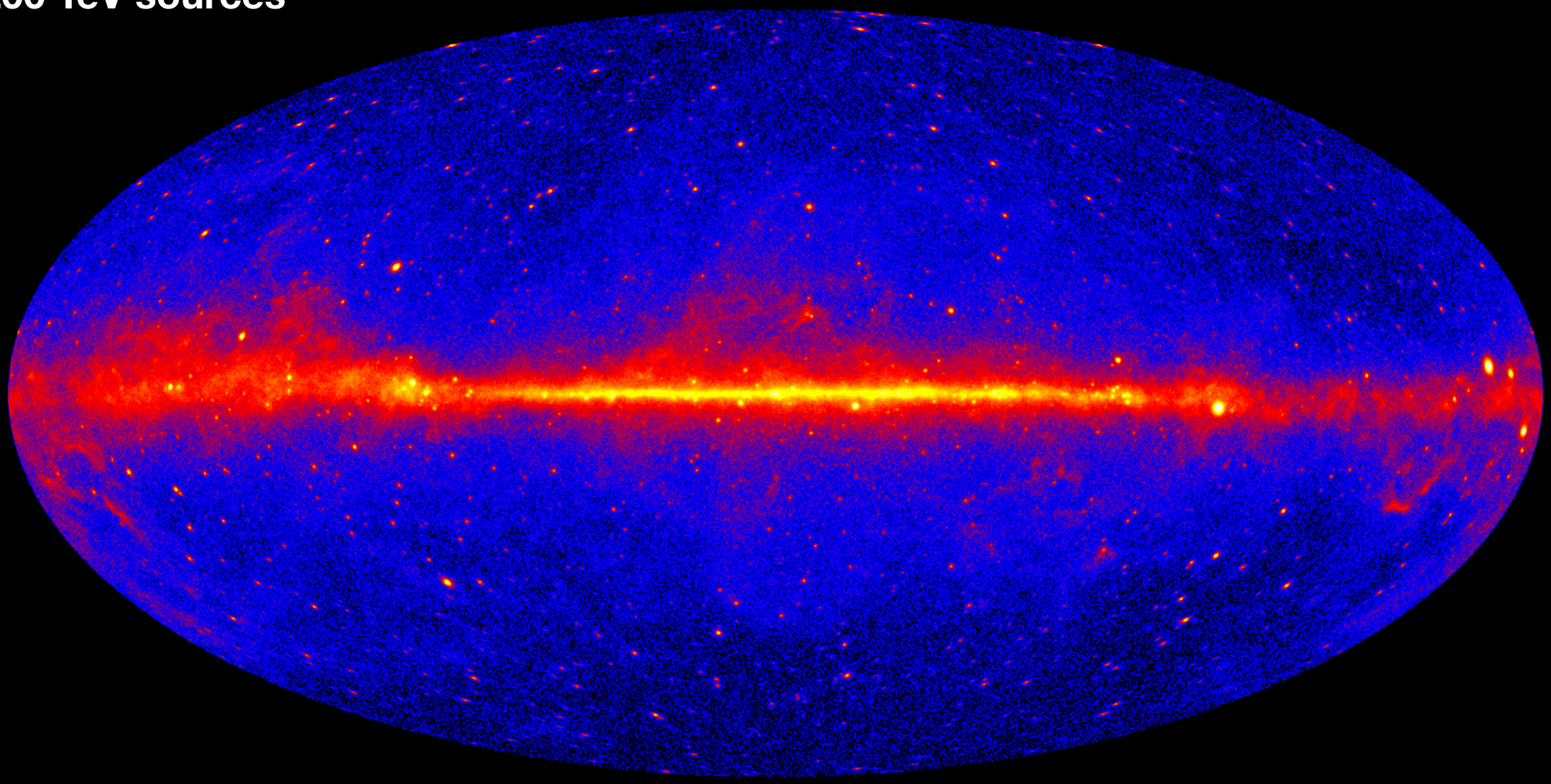
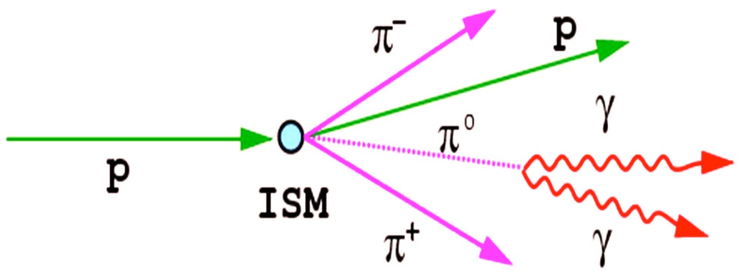
The Sky in Gamma-rays

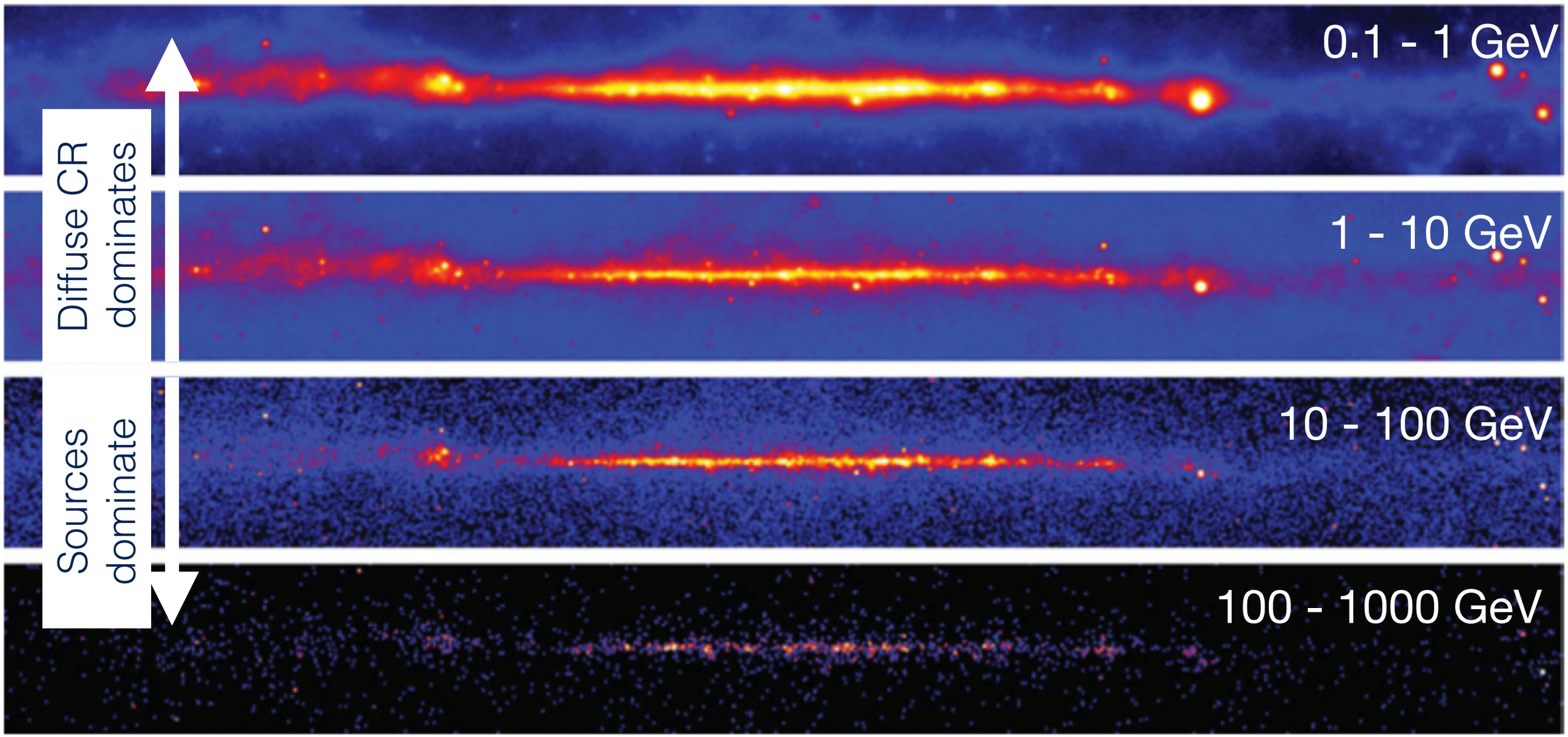
~3500 GeV sources
~200 TeV sources

Fermi LAT 5 years



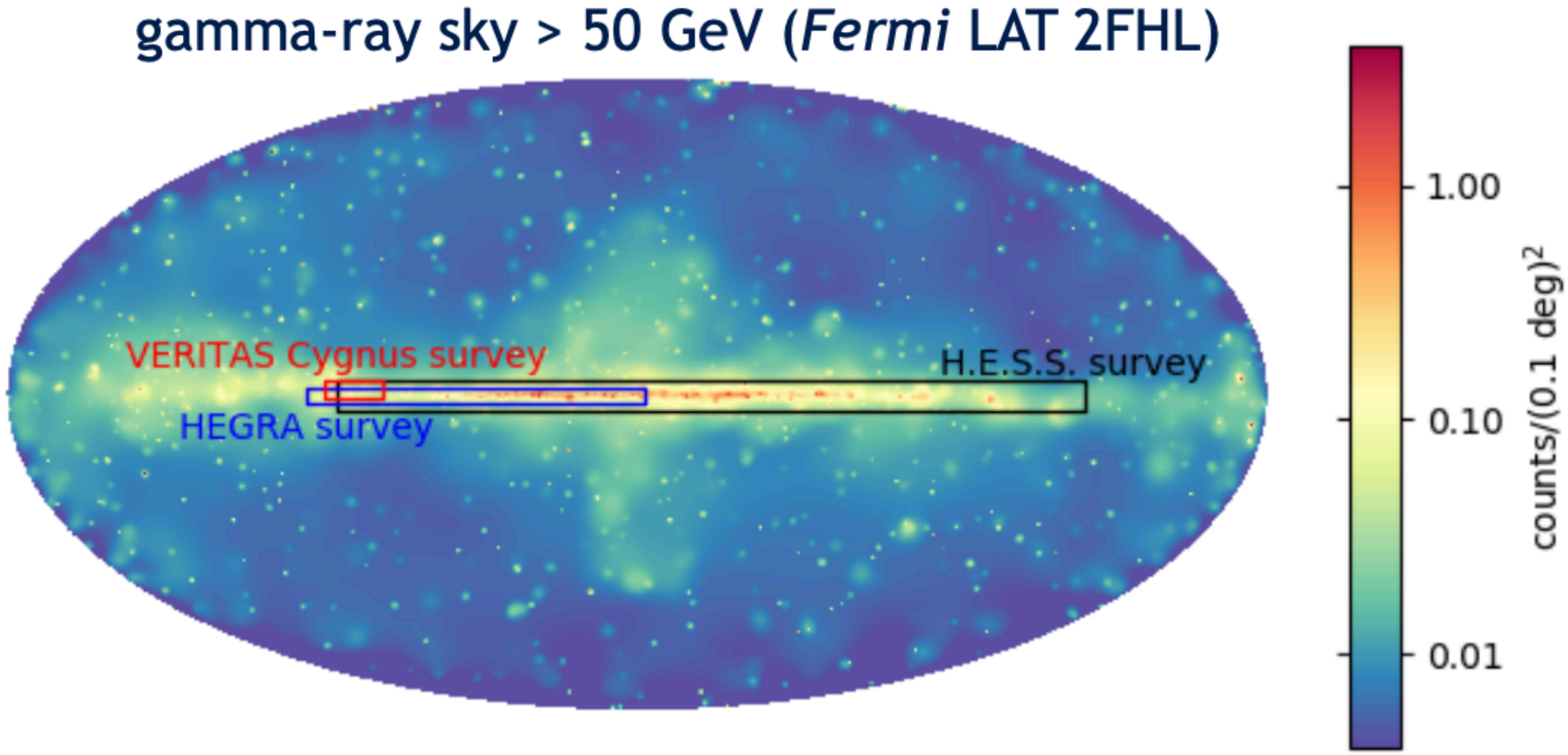


Sources + Diffuse Emission

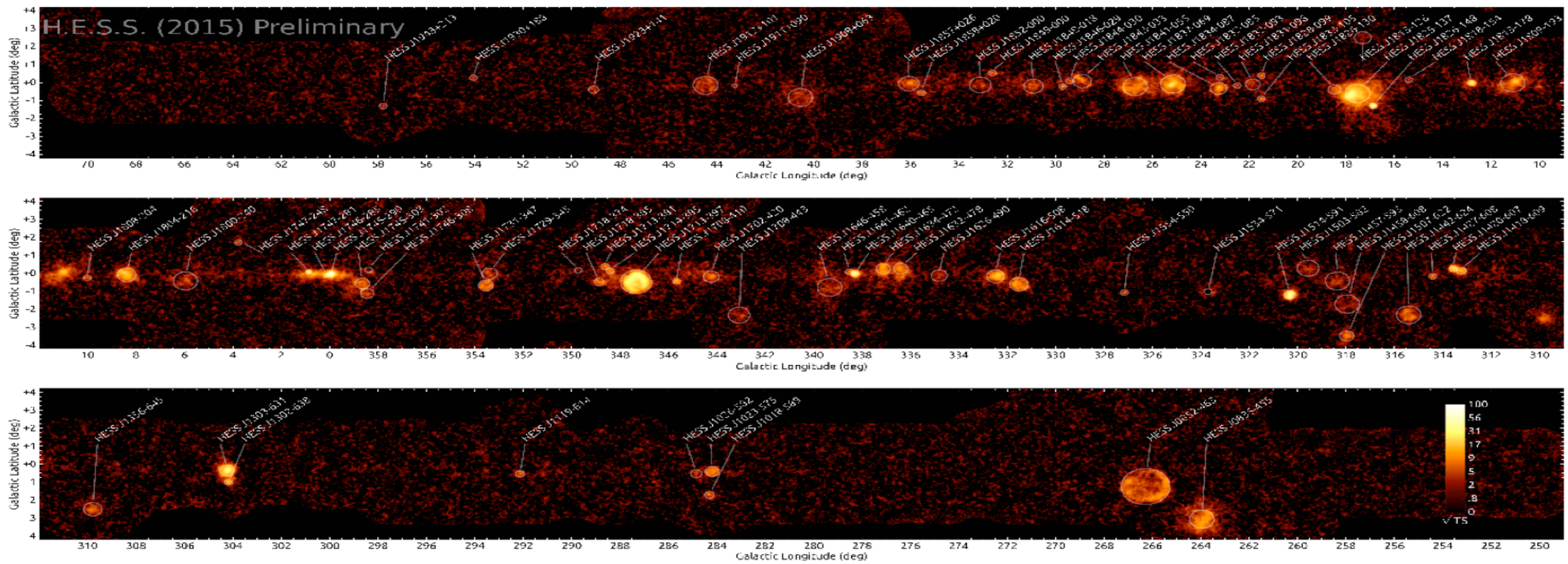


CR Standard Paradigm : E_{kin} ~10^{51} erg/SN, rate=2-3 century
=> 10% to sustain the **10^{41} erg CR**

Large Structures:
* Fermi bubbles
* Galactic Center
* Resolved Srcs



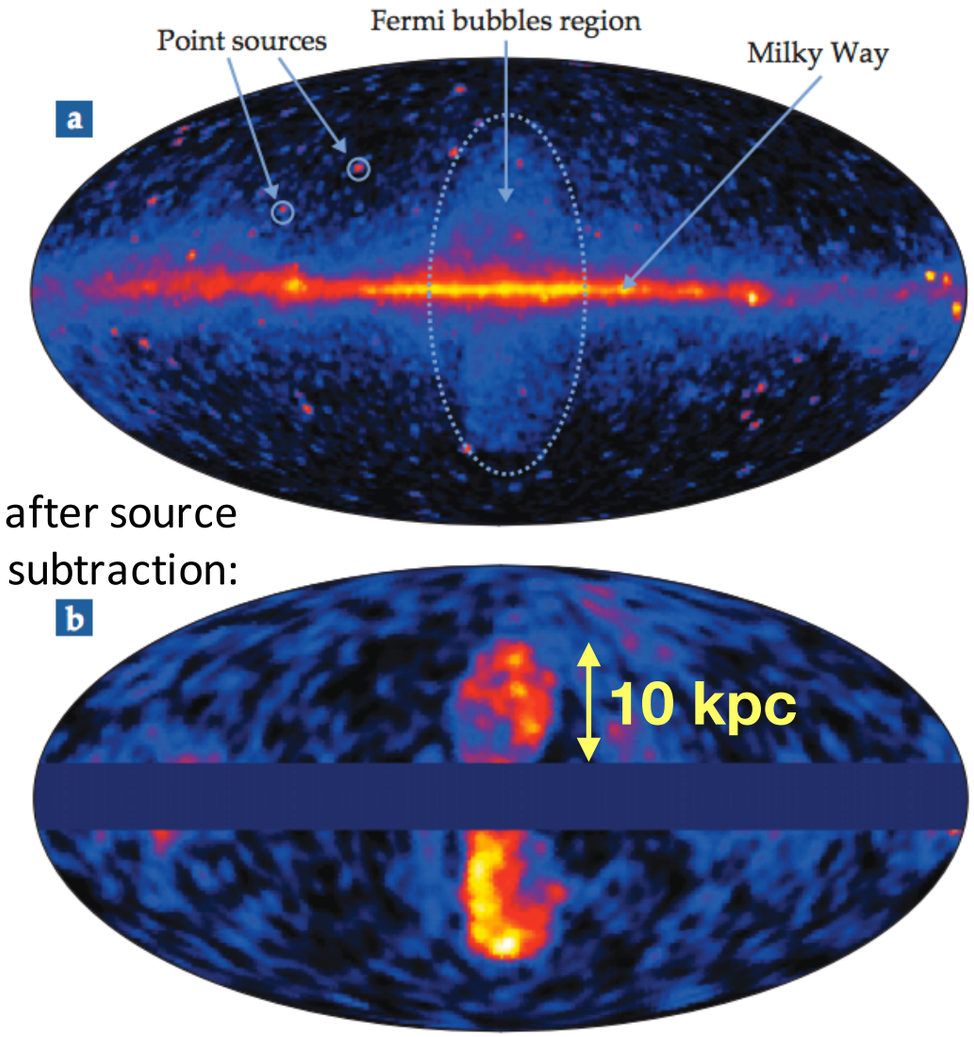
H.E.S.S. Galactic Plane Survey

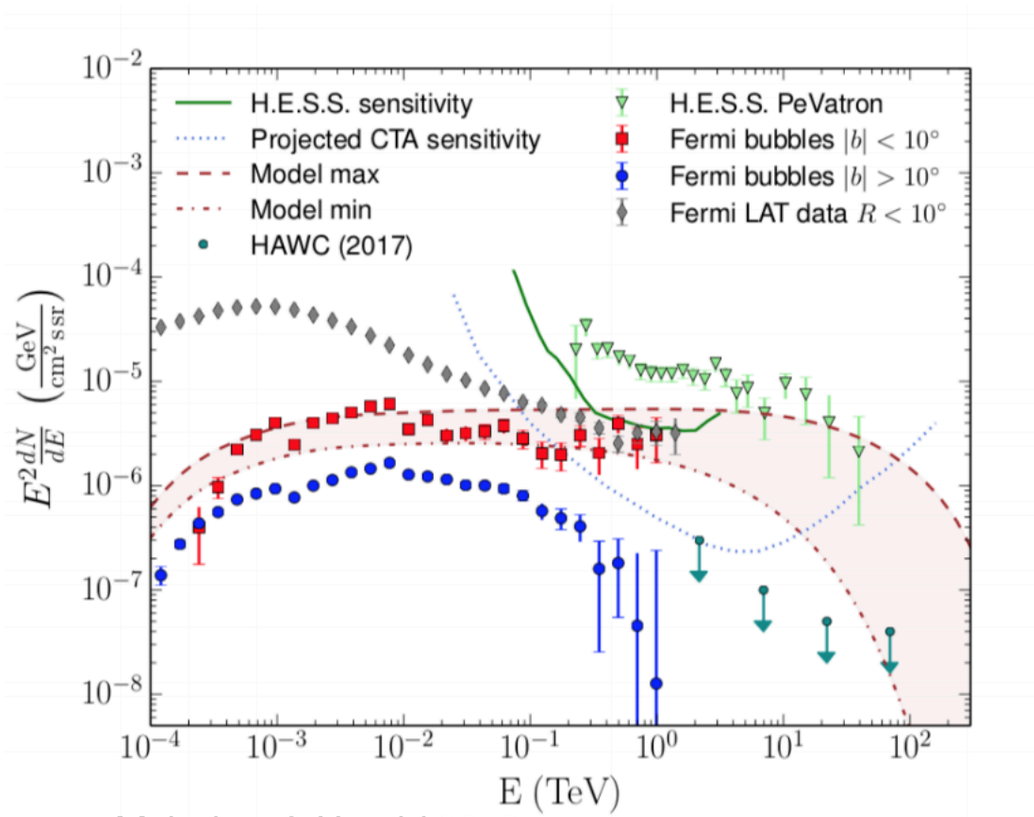


Large HE Structures in the Galaxy

- **The Fermi Bubbles:** Large γ-ray emitting structures extending below and above the Milky Way plane from the galactic center
- E~10^{56}erg: how is the outflow connected to the Gal Center?

Physics Today, 67 (2014)





Malyshev & Herold 2018

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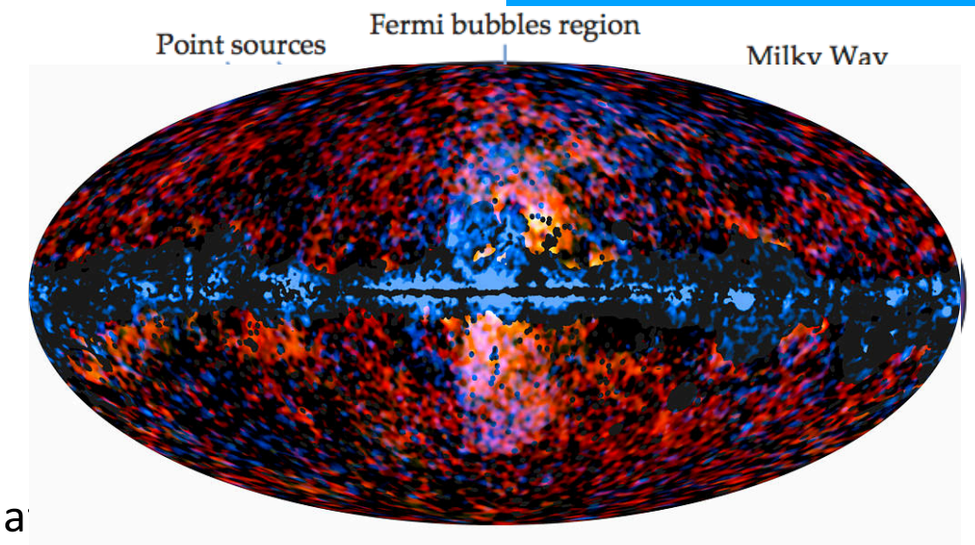
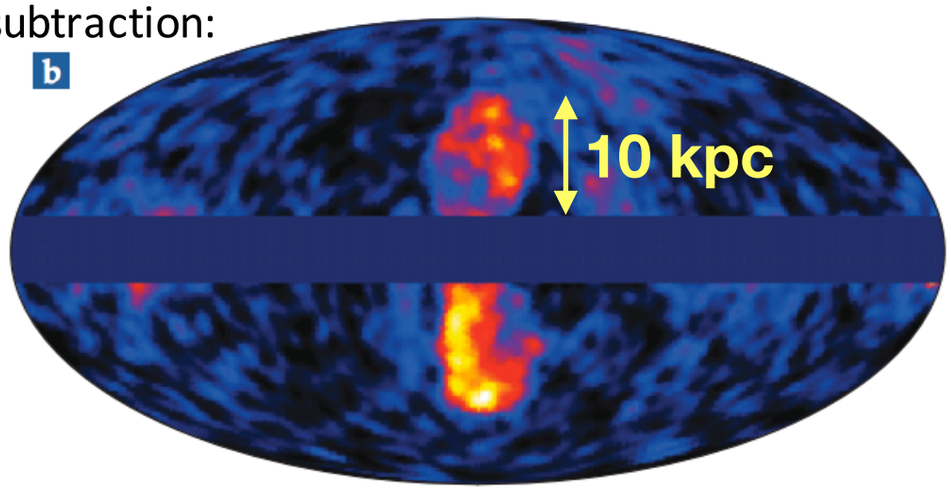
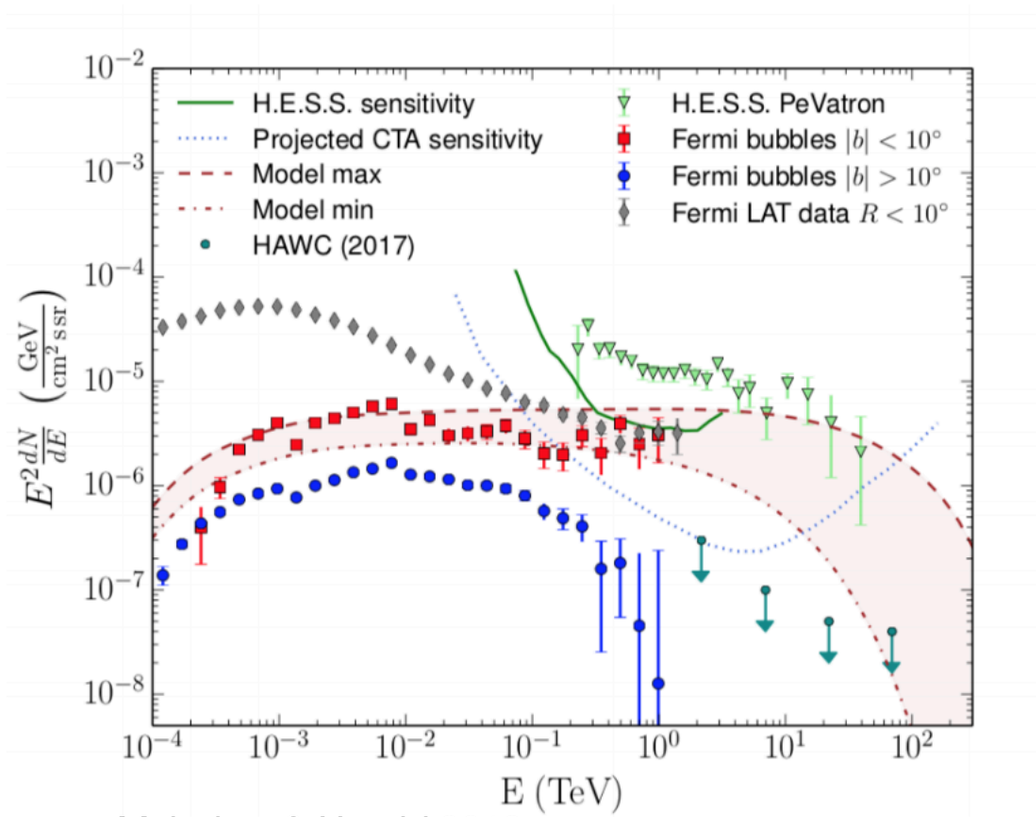
Planck (red & yellow)



a

subtraction:





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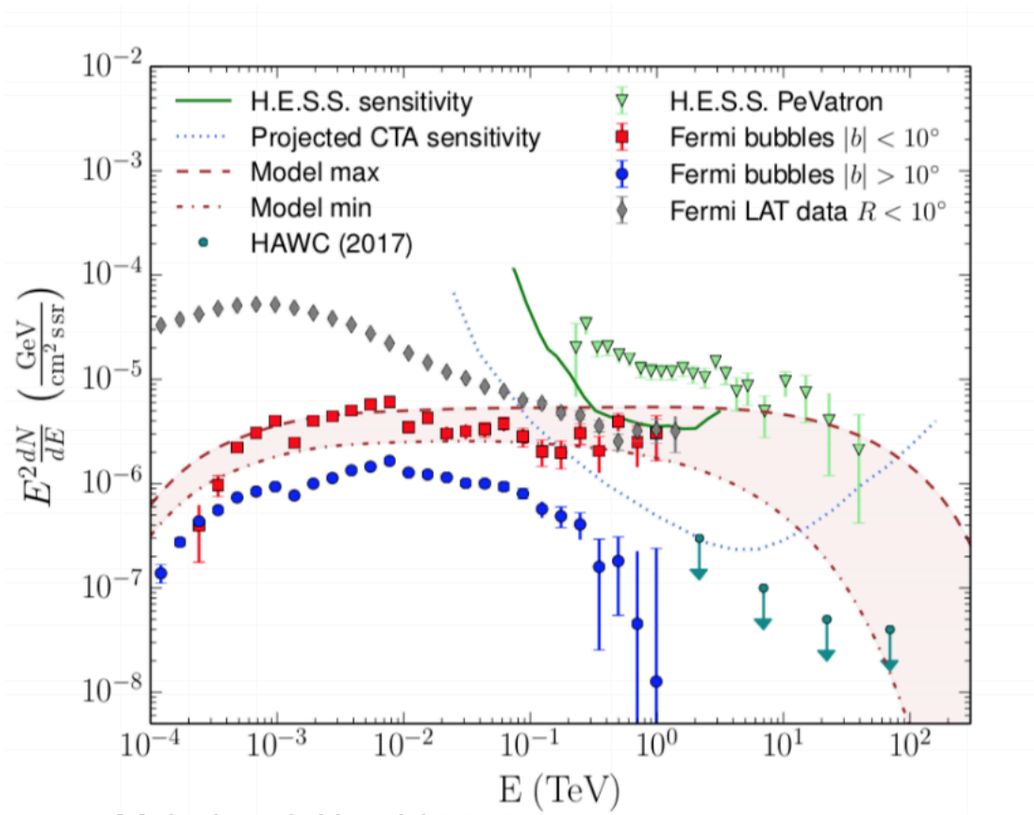
Leptonic Scenarios:

Explain the low energy emission
BUT short cooling time @ TeV (~Myr)
10 kpc size => v_{exp} ~ 10,000 km/s

Hadronic Scenarios:

Powered by ~few x 10^{39}erg CRs (SF in the GC?)
Need target gas: few Gyr to establish steady state on hot gas phase



Malyshev & Herold 2018

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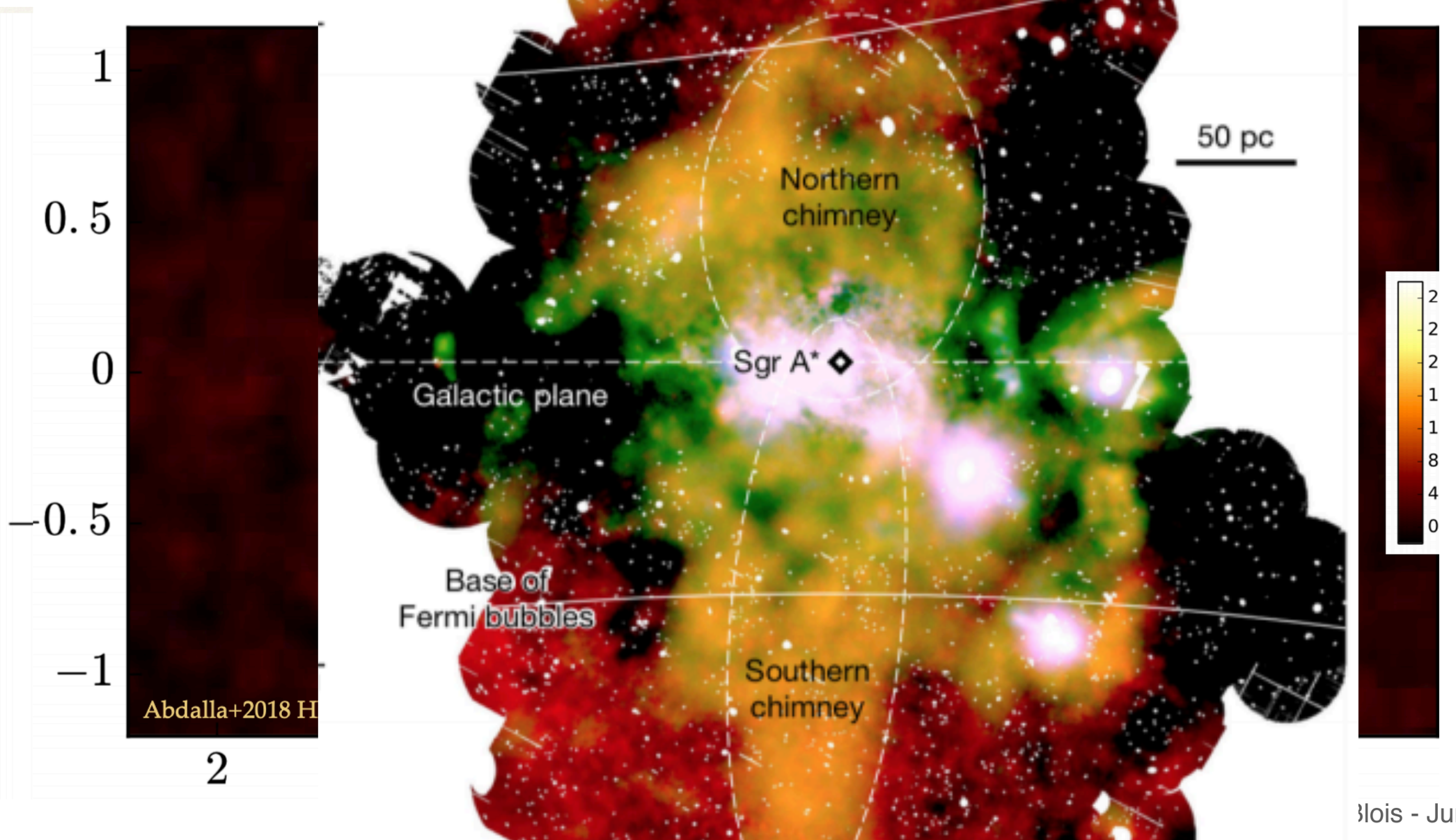
– **The Fermi Bu** g
below and ab r
– E~10^{56}erg: hc



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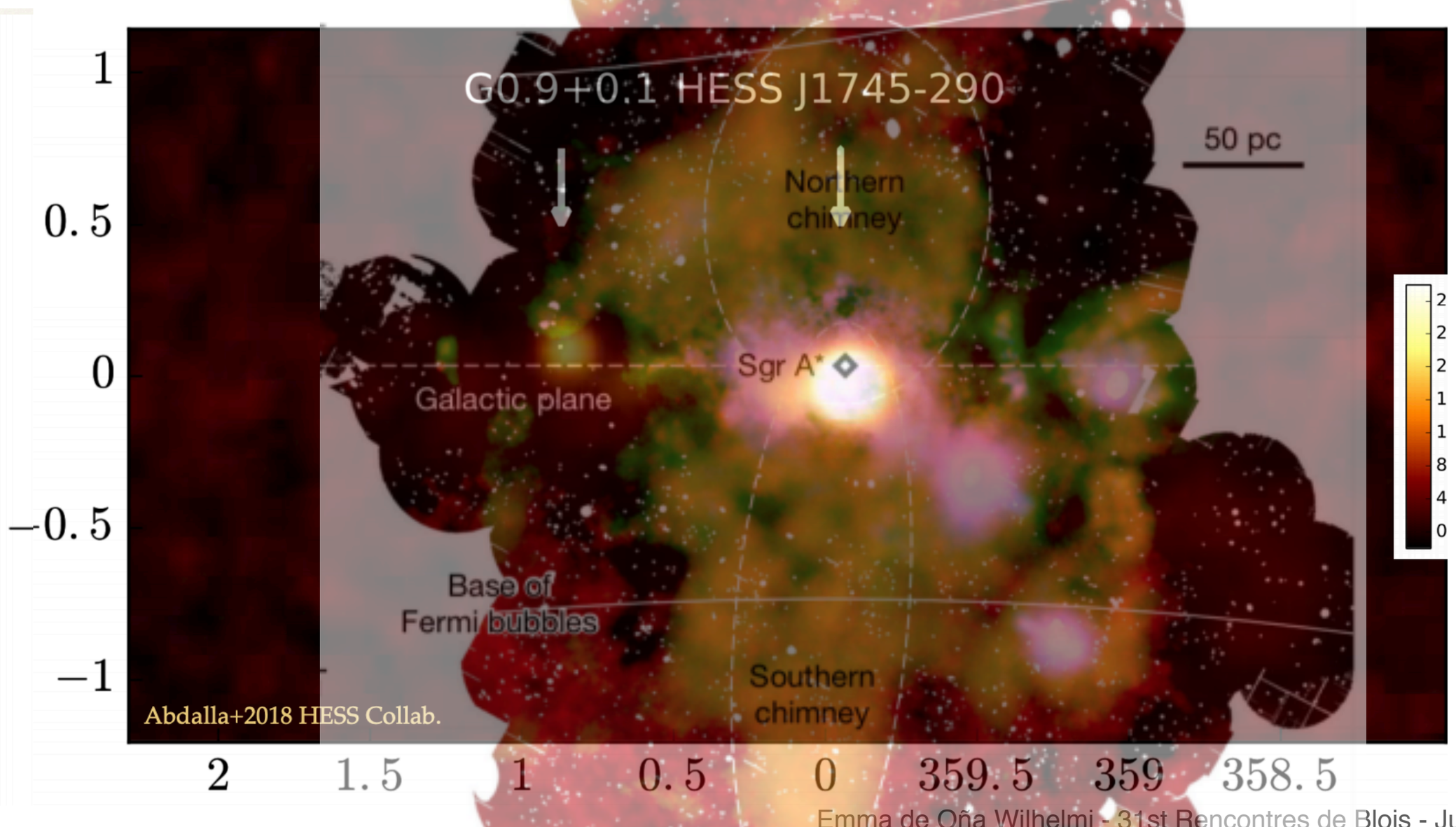

Large HE Structures in the Galaxy

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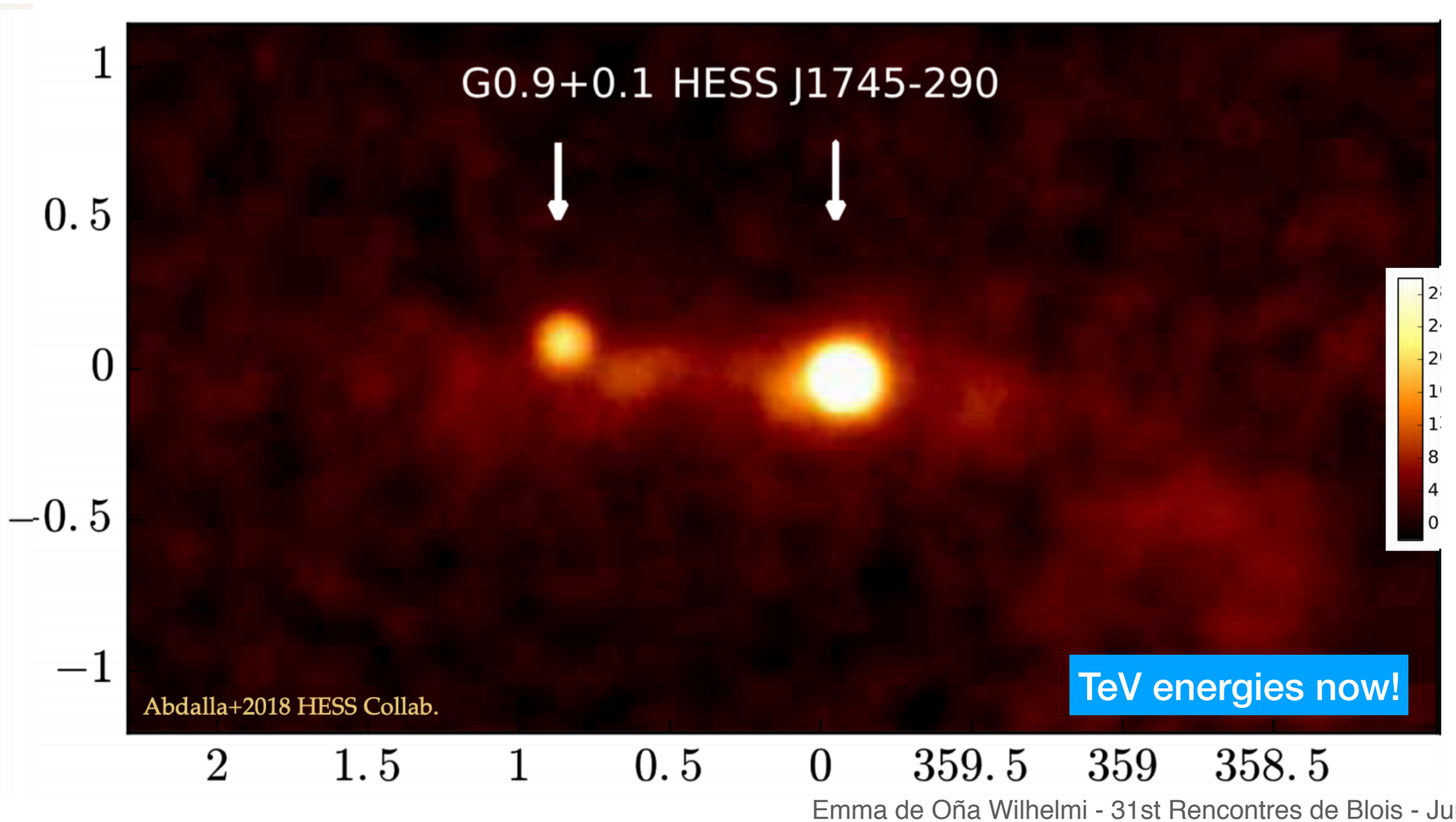

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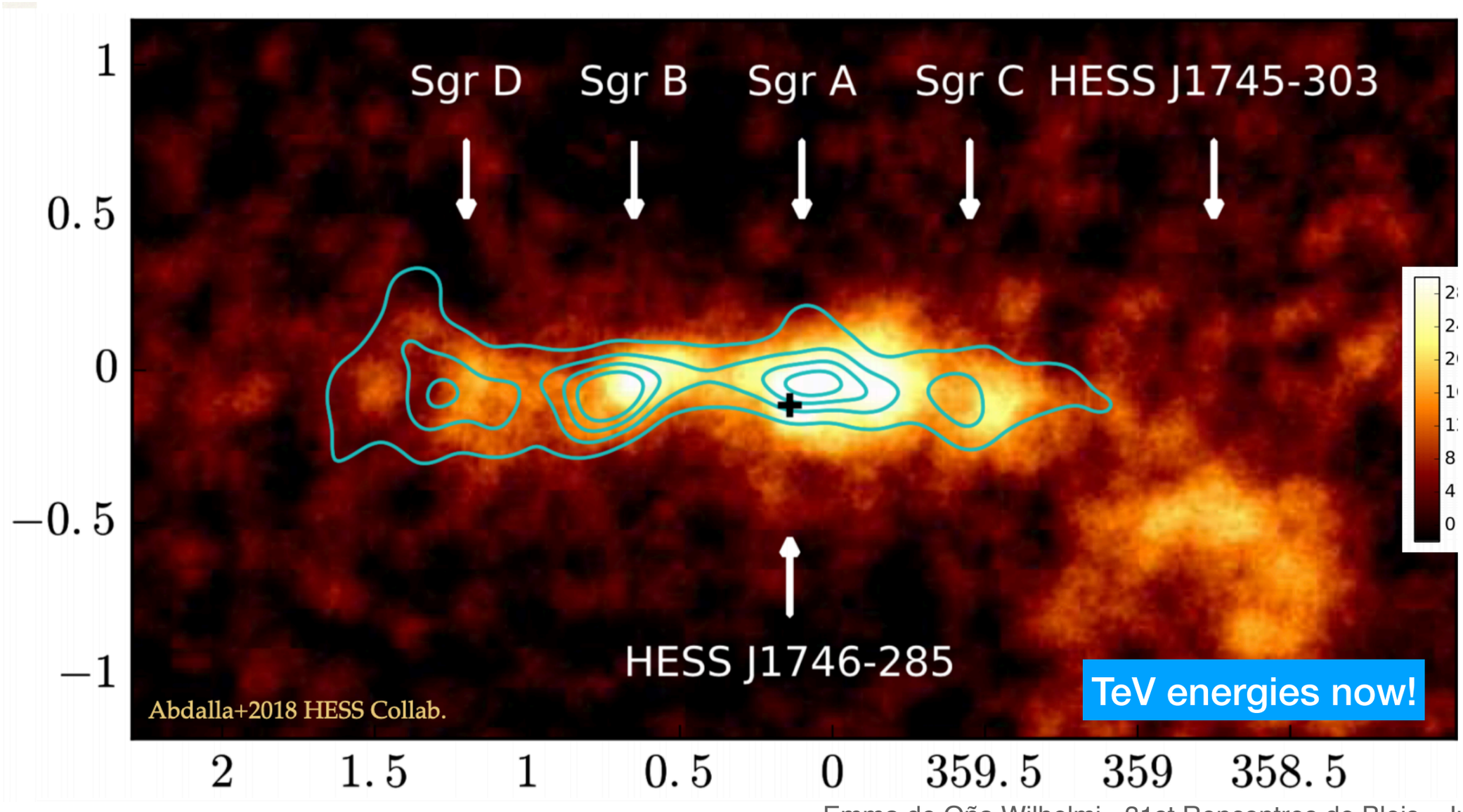

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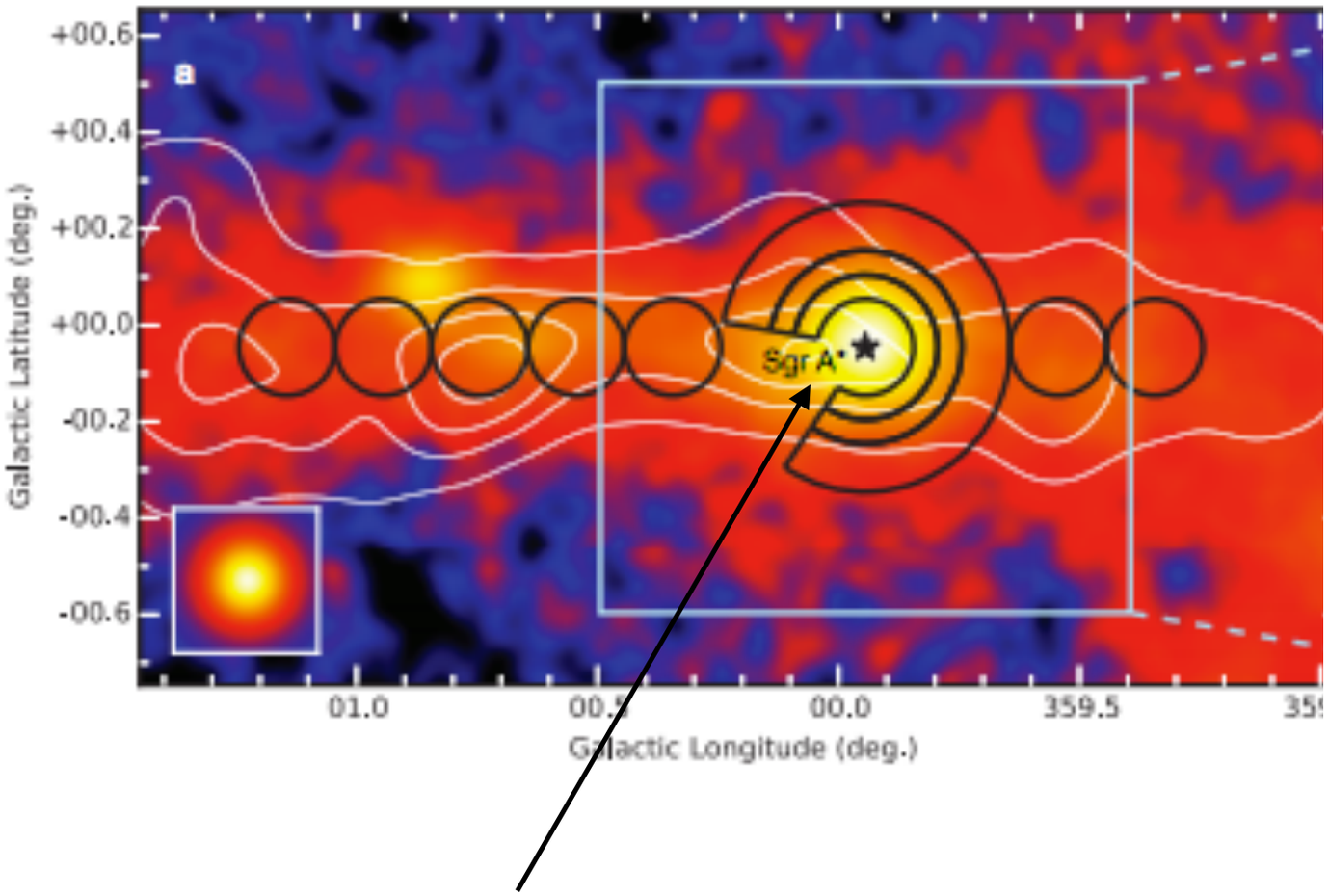

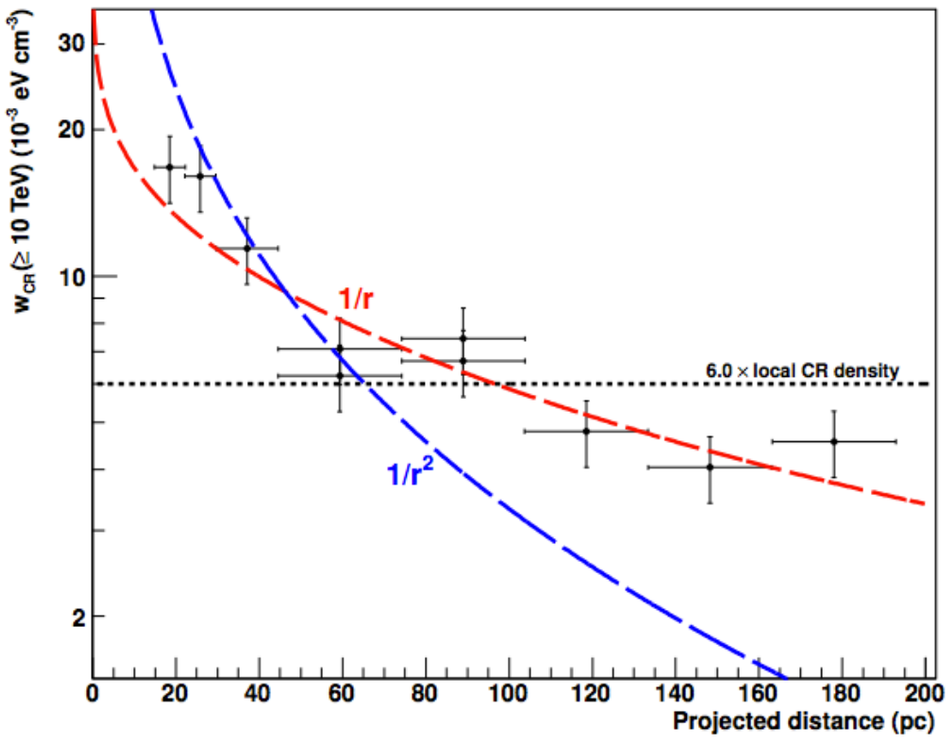

~5-10% of Galaxy's current star formation

1/r	continuous source
1/r^2	wind or ballistic motion
constant	burst like source

Large HE Structures in the Galaxy

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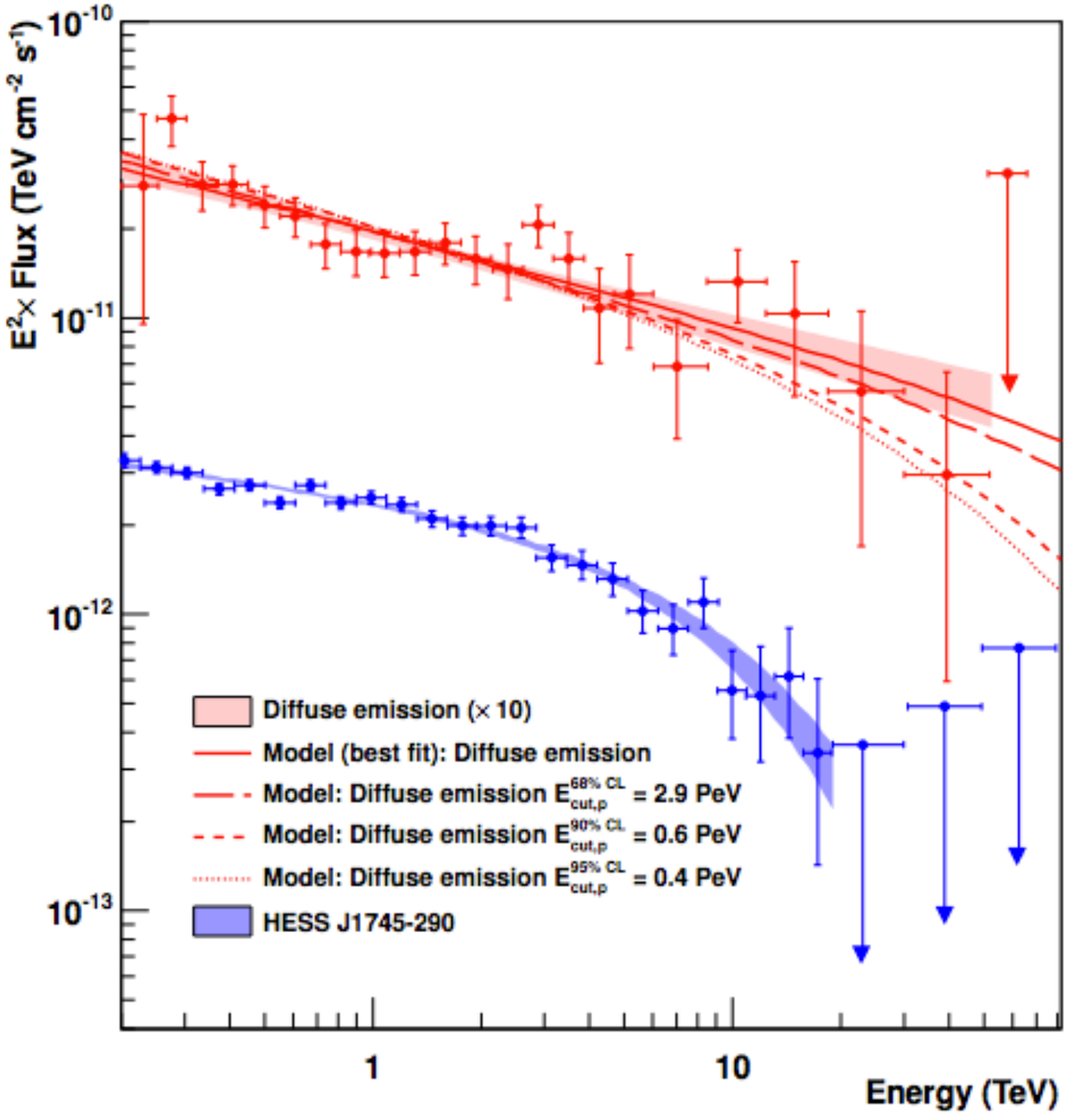
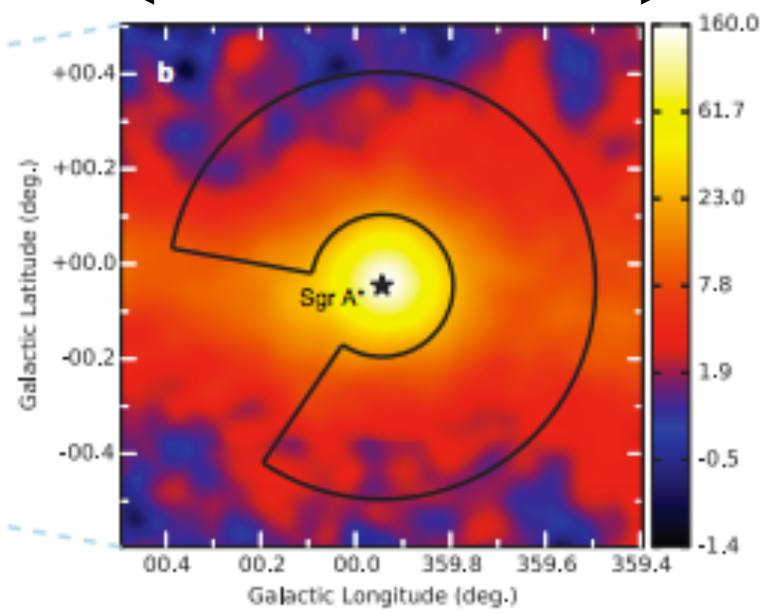


~70 pc



First PeVatron in the Galaxy

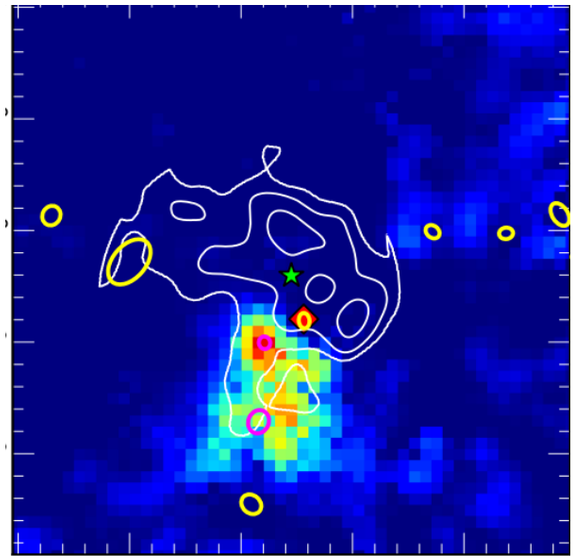
$W_{CR}=10^{49}$ erg

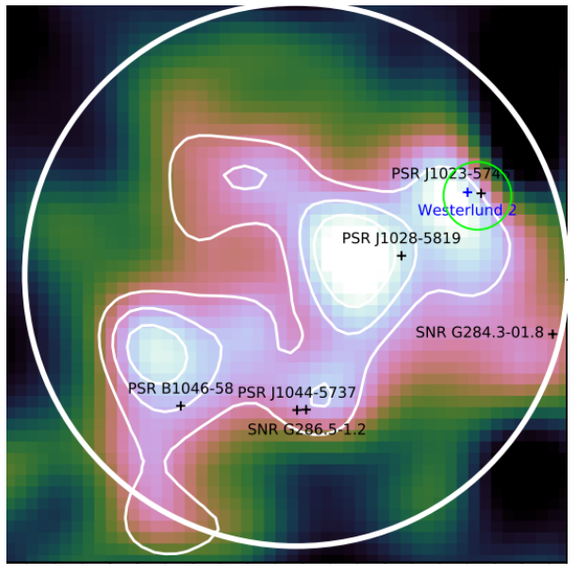
Connected to the GC?

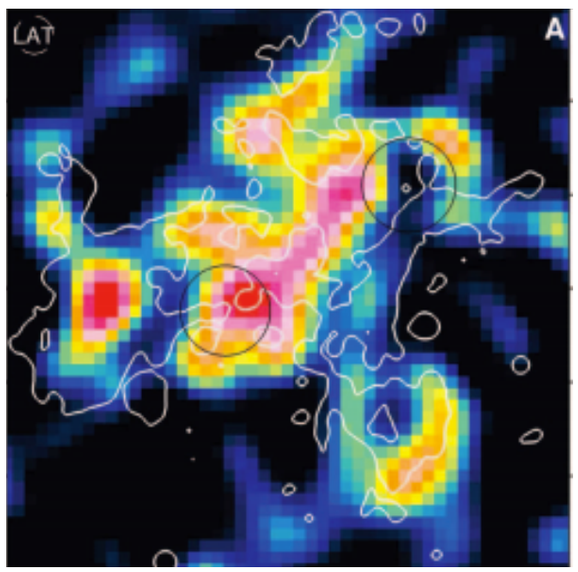
Large HE Structures in the Galaxy

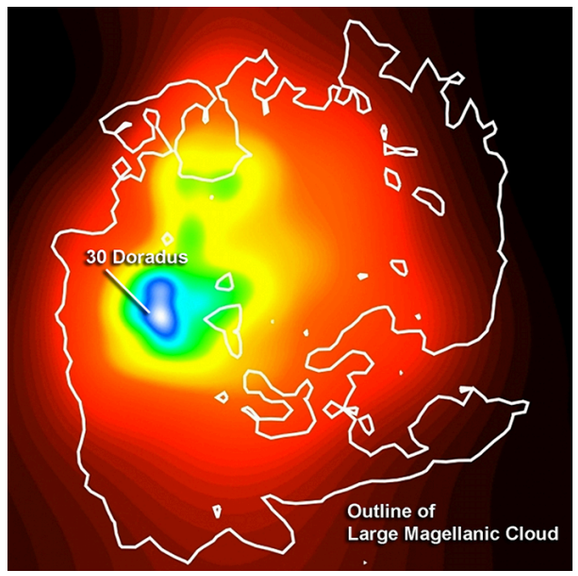
– **Stellar Clusters:** Energy reservoir ~$10^{38\text{-}39}$ erg over ages of T≥10^{6} years

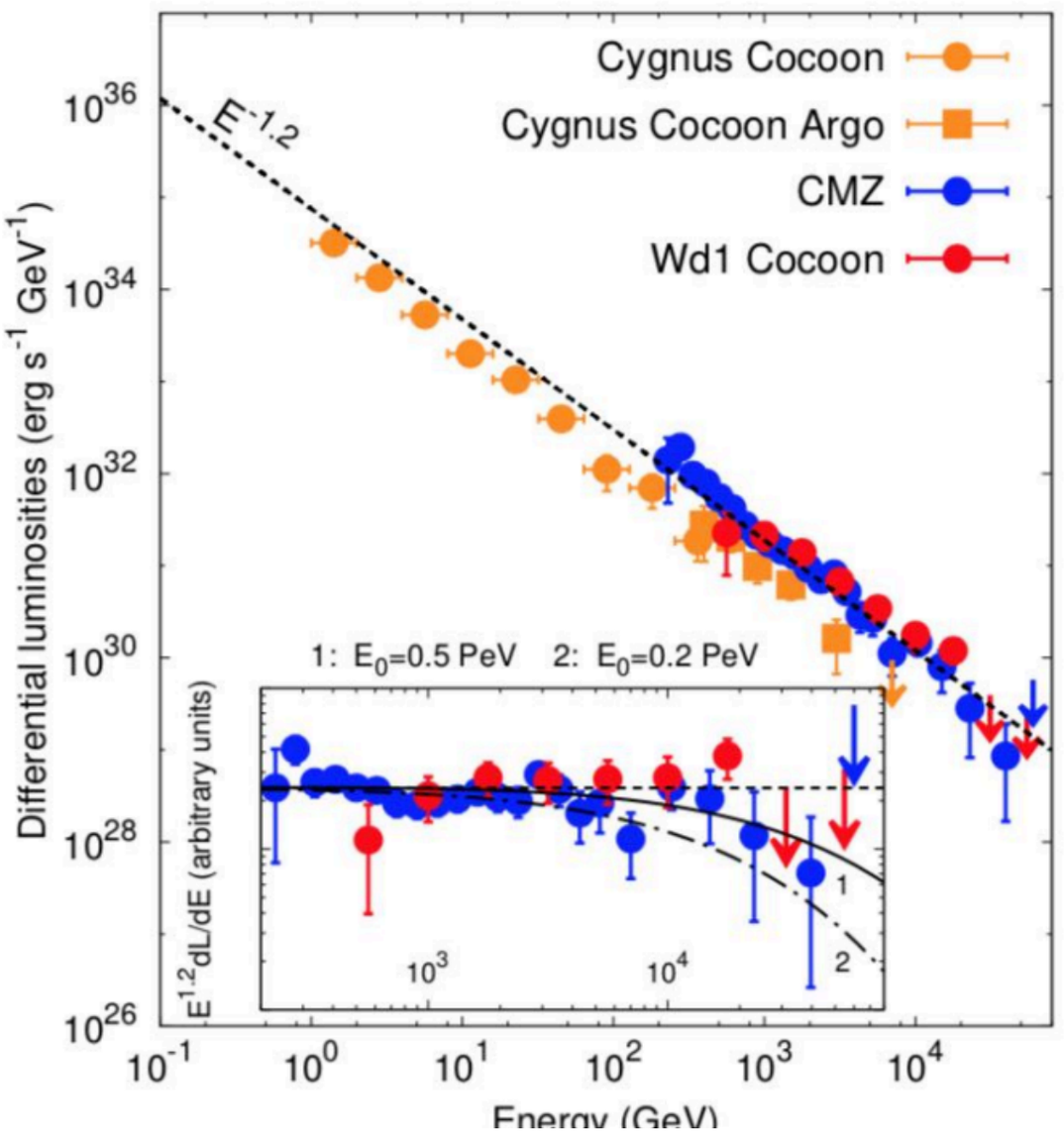
~few degree











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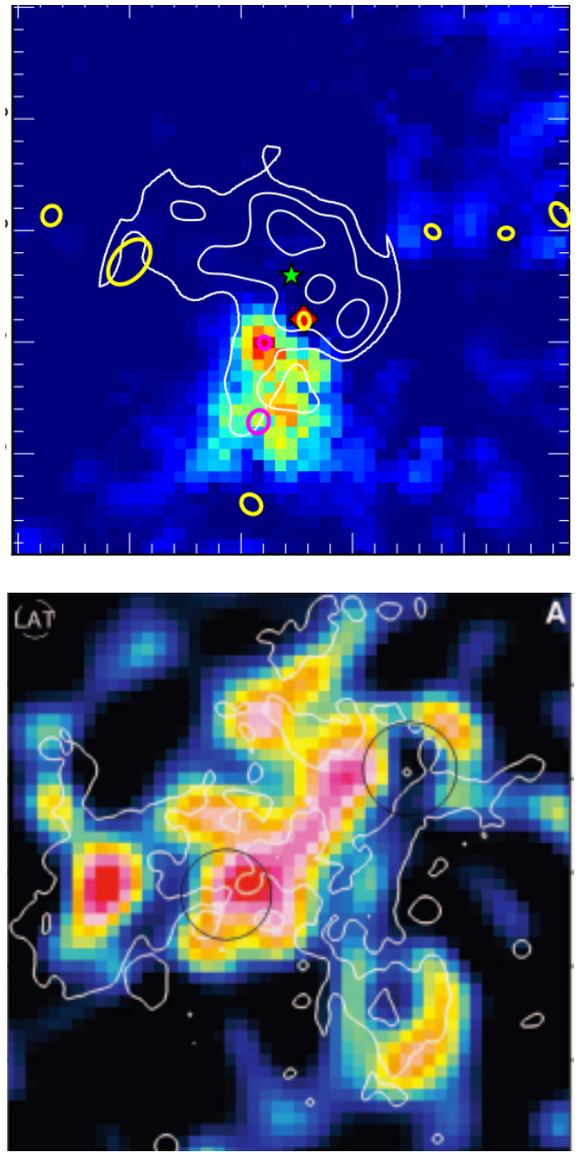
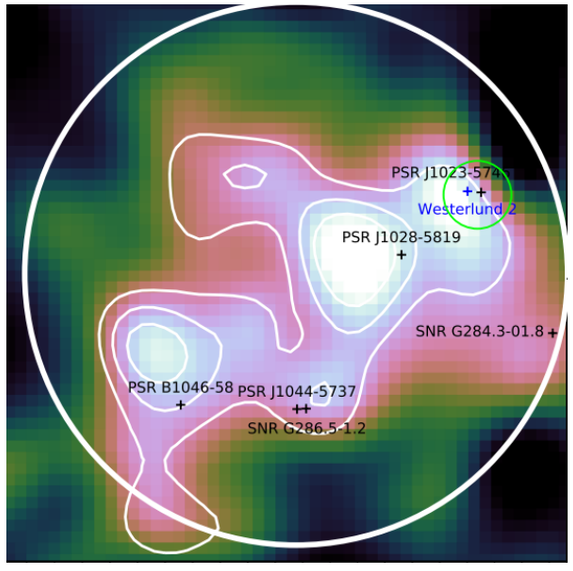
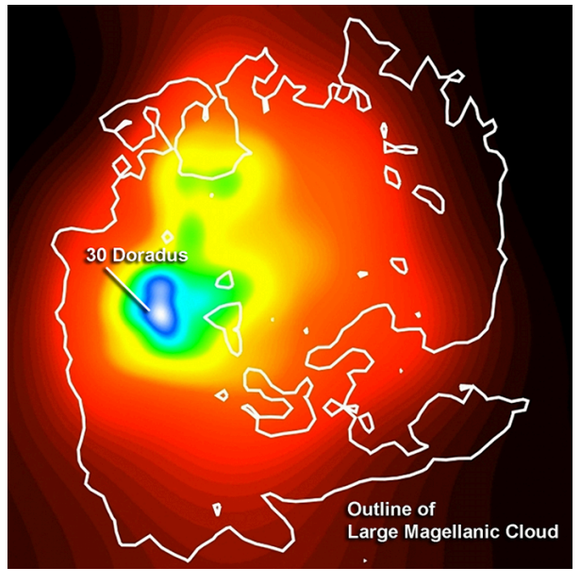
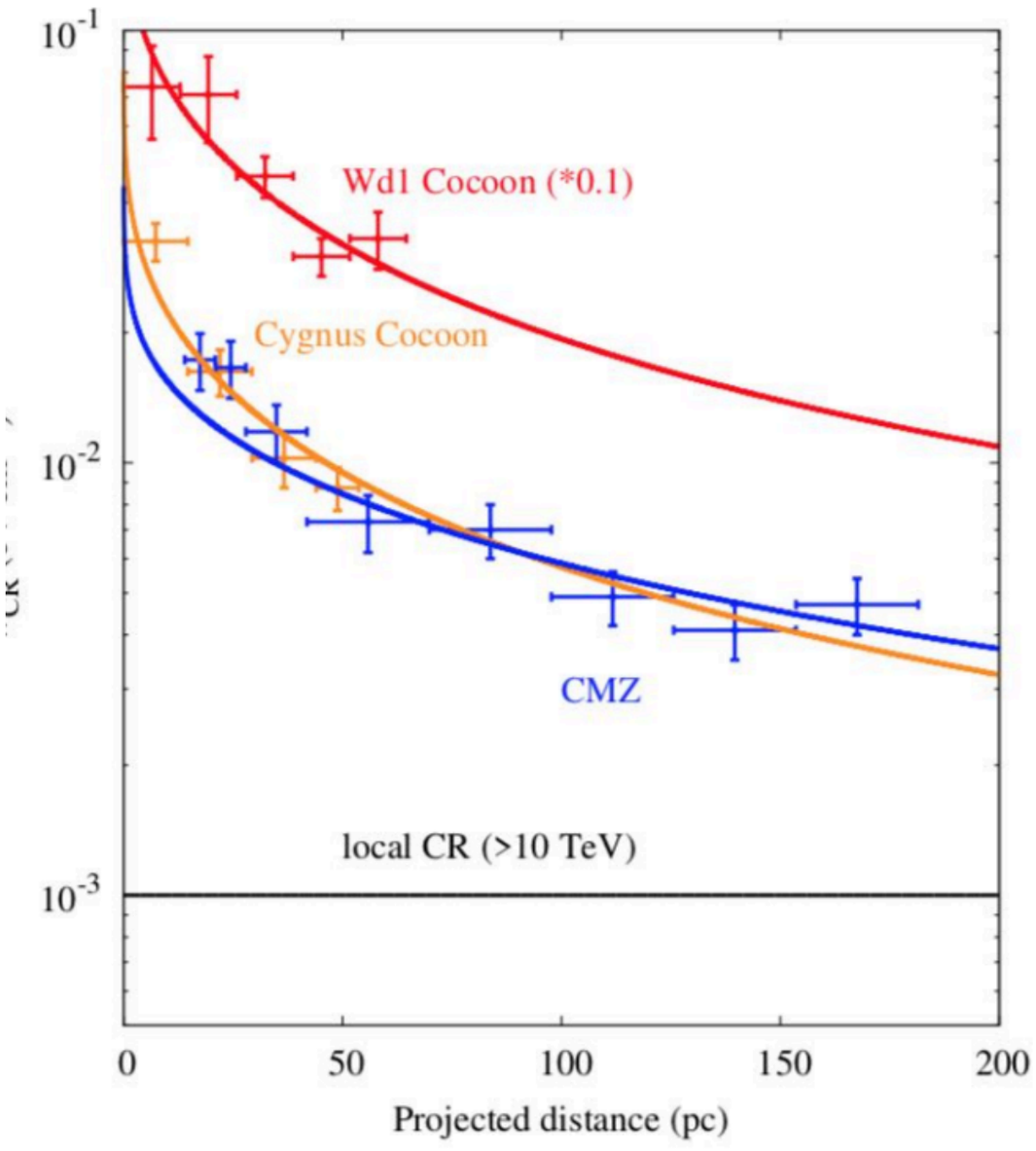
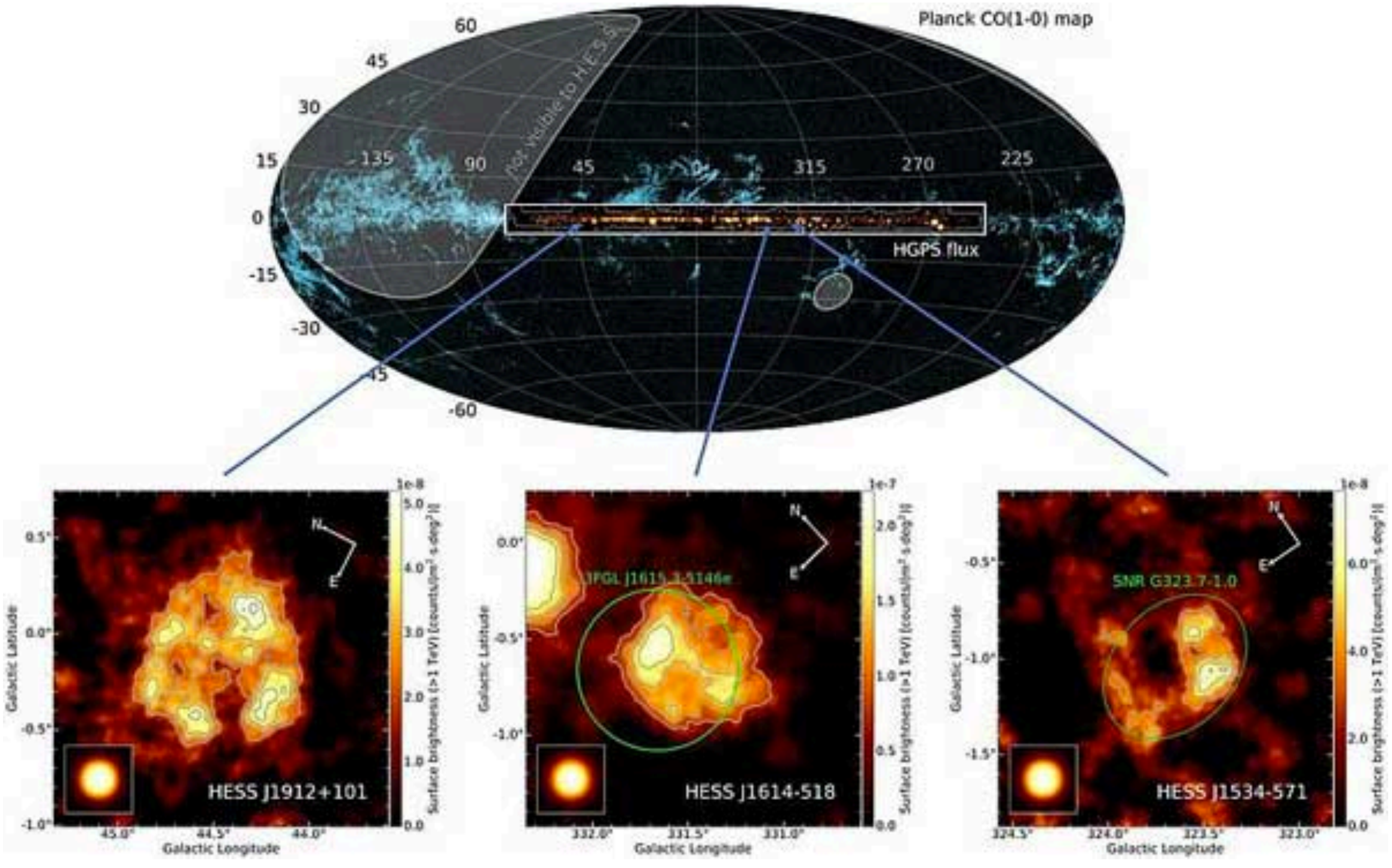








Large and resolved Structures in the Galaxy



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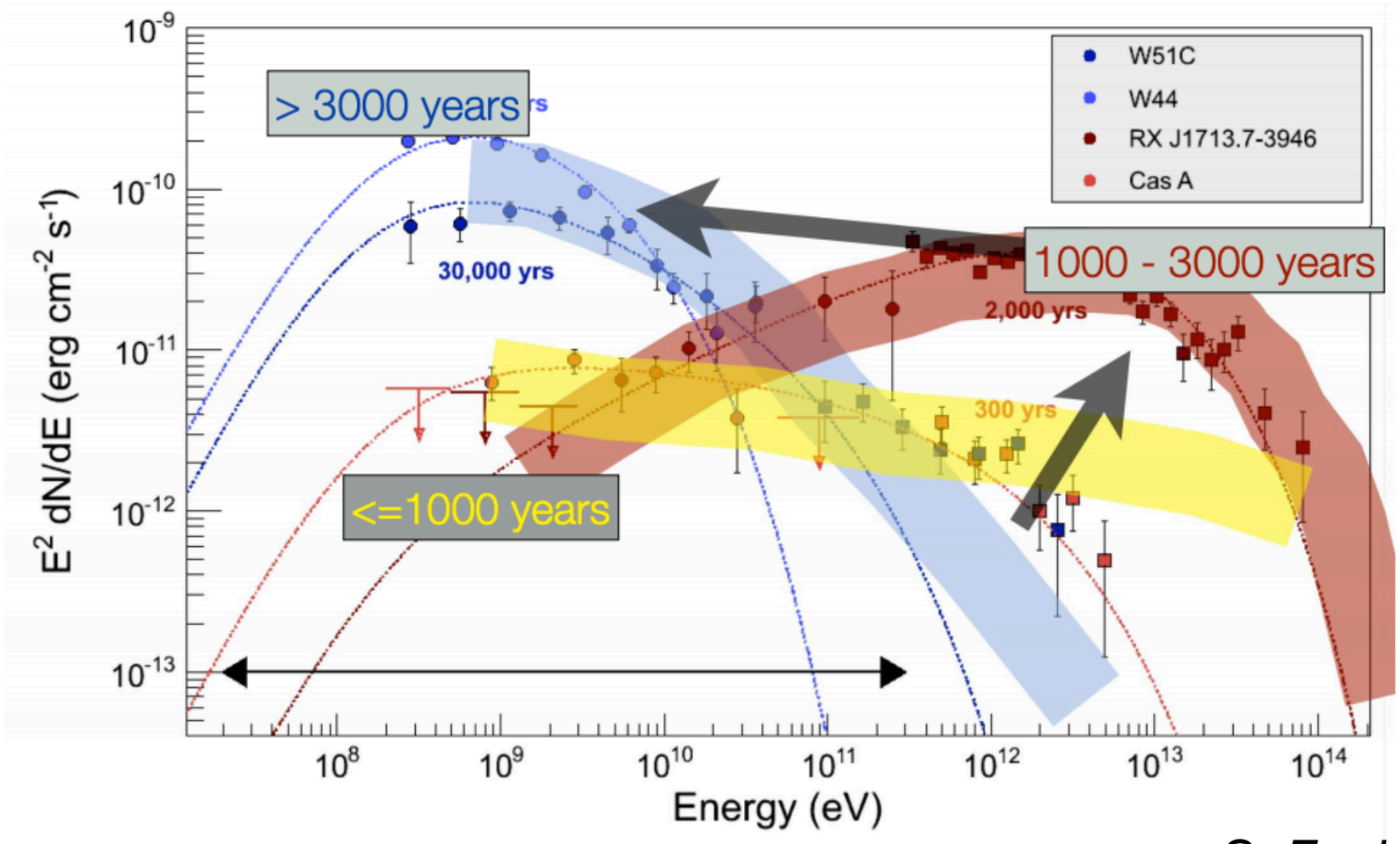

S. Funk

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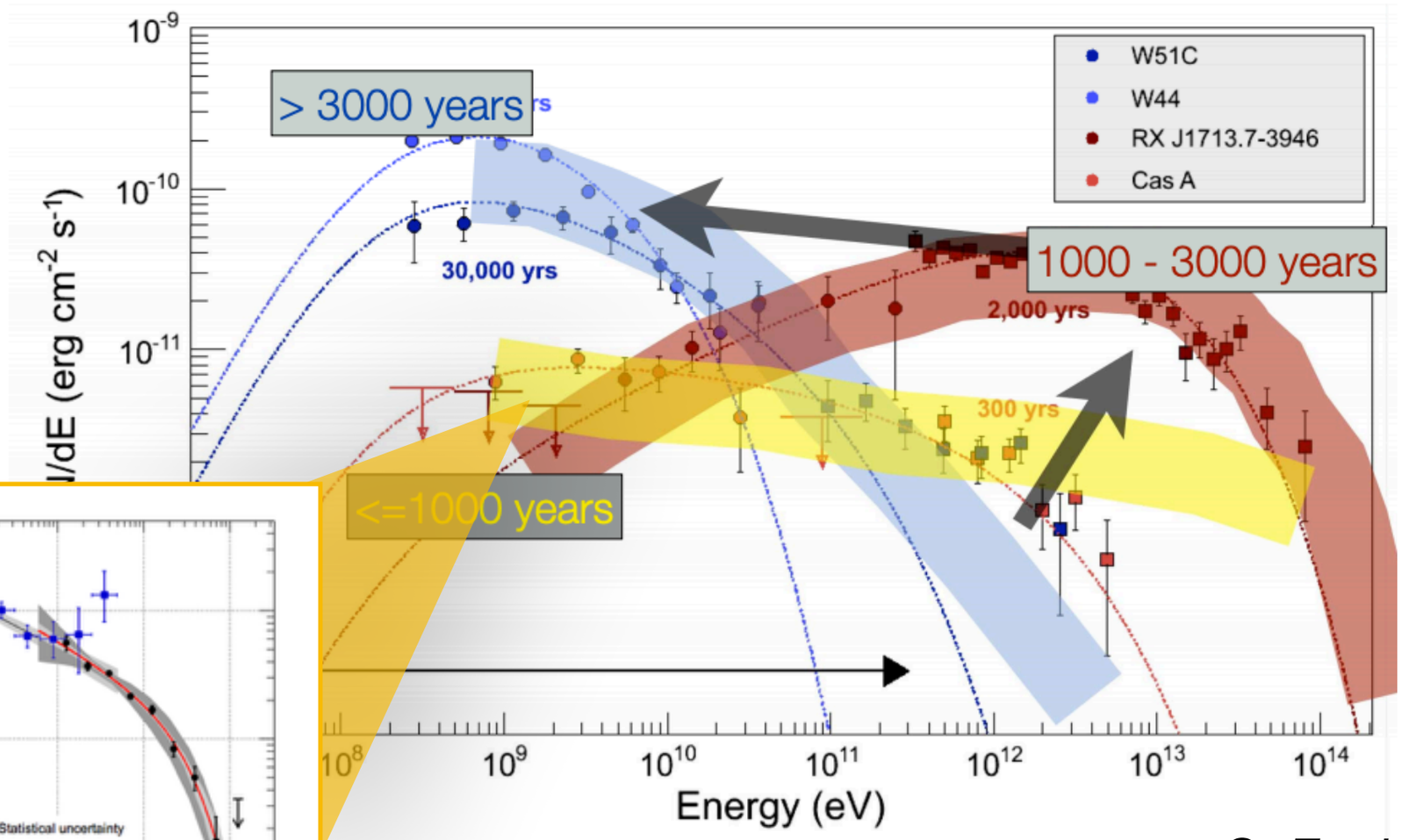

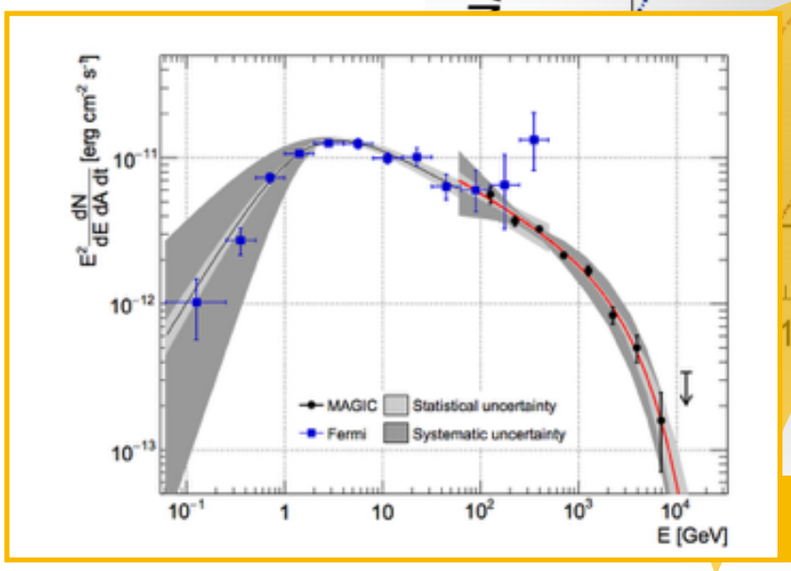

Low Ecut

S. Funk

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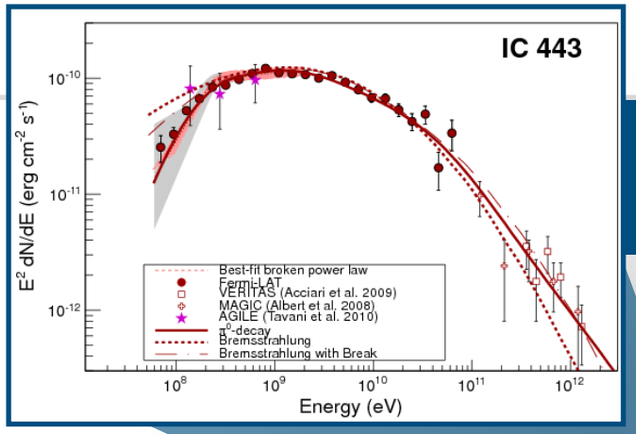
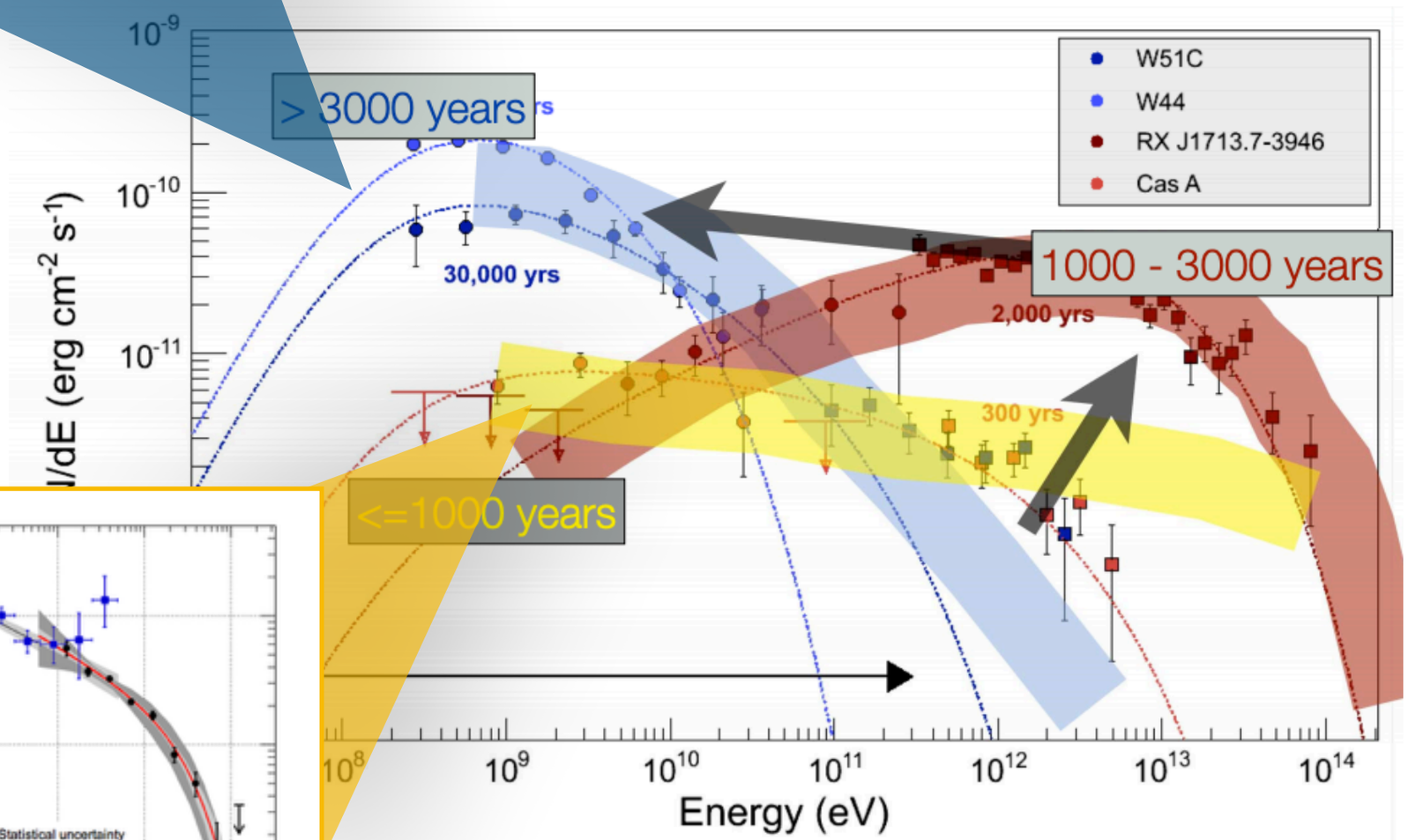


π-peak detected => hadrons!



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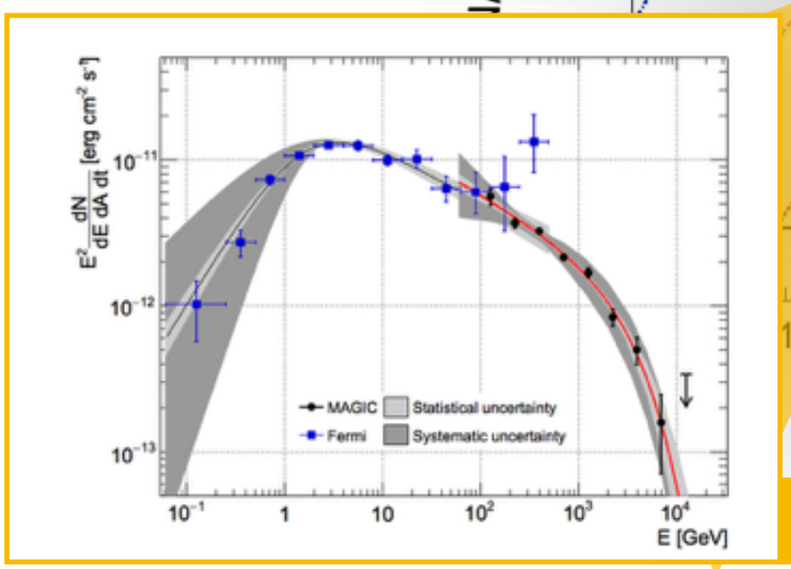

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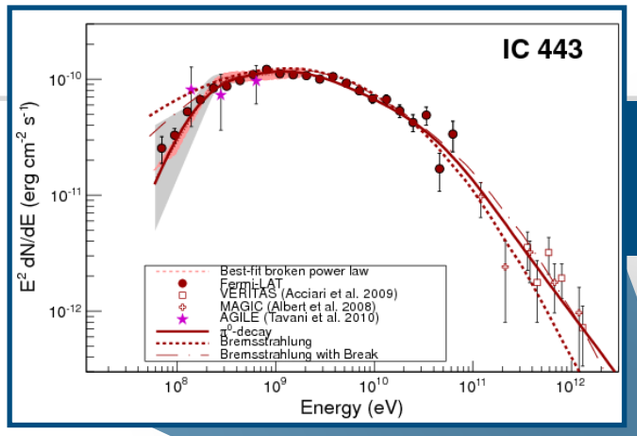

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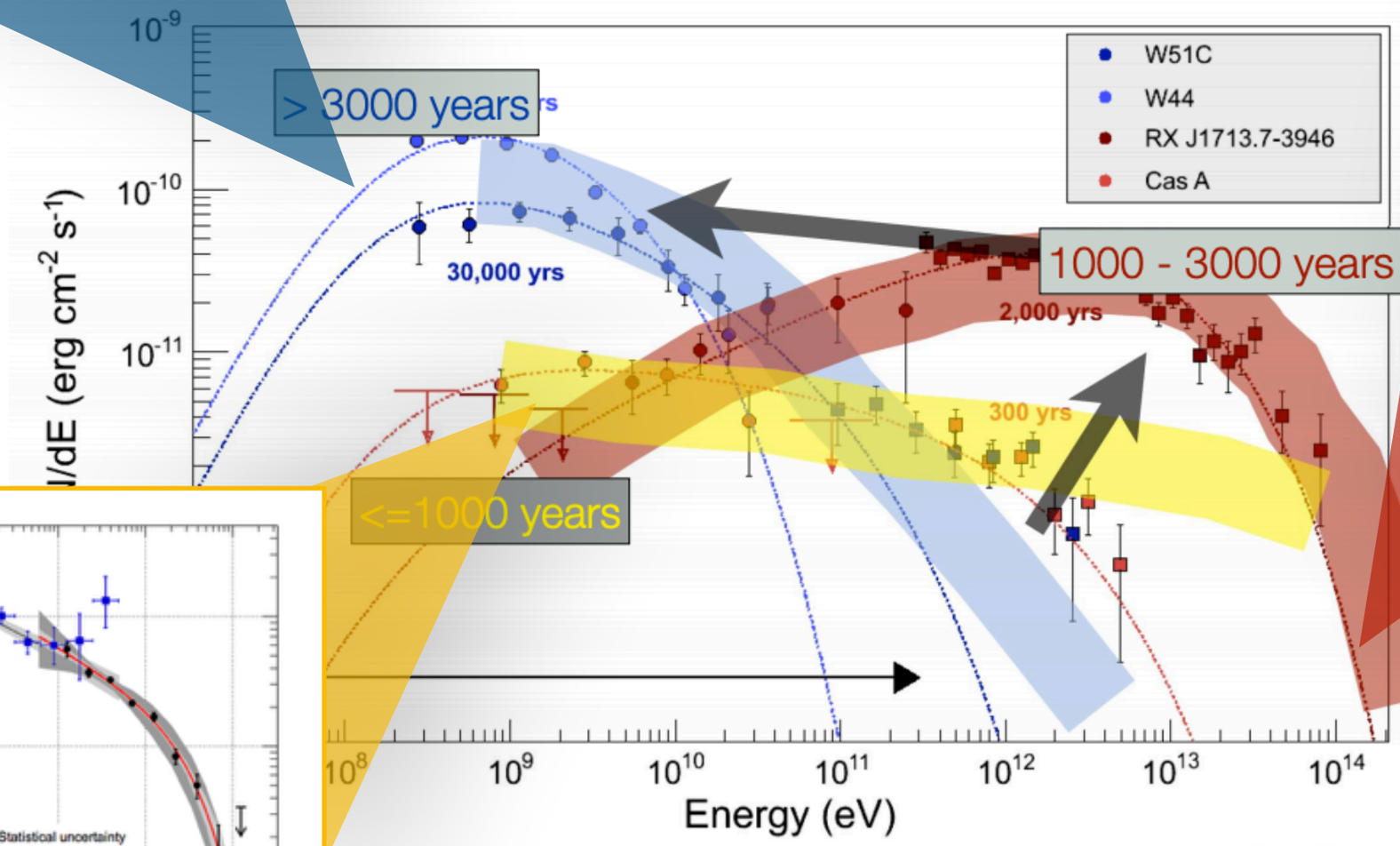

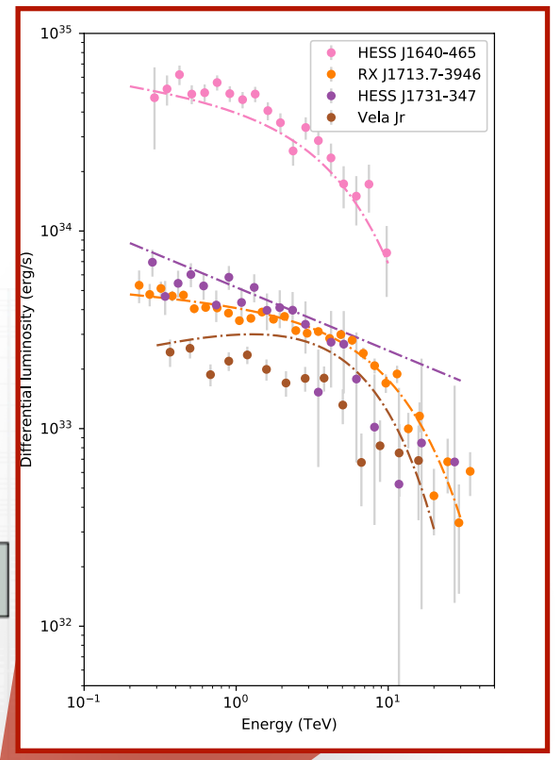

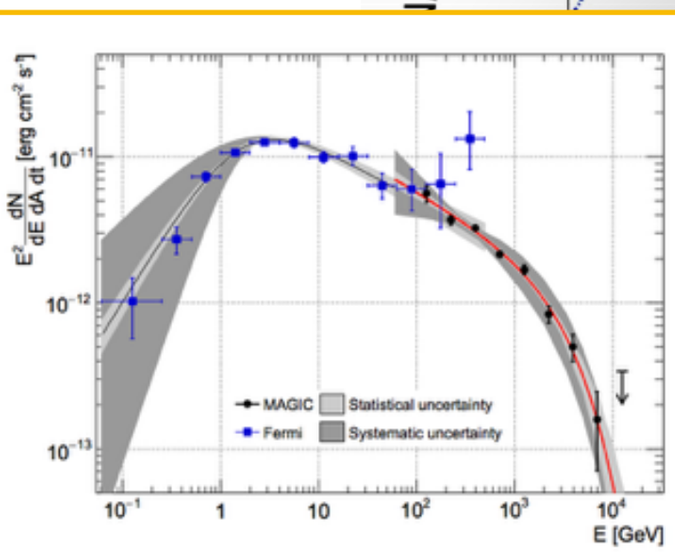

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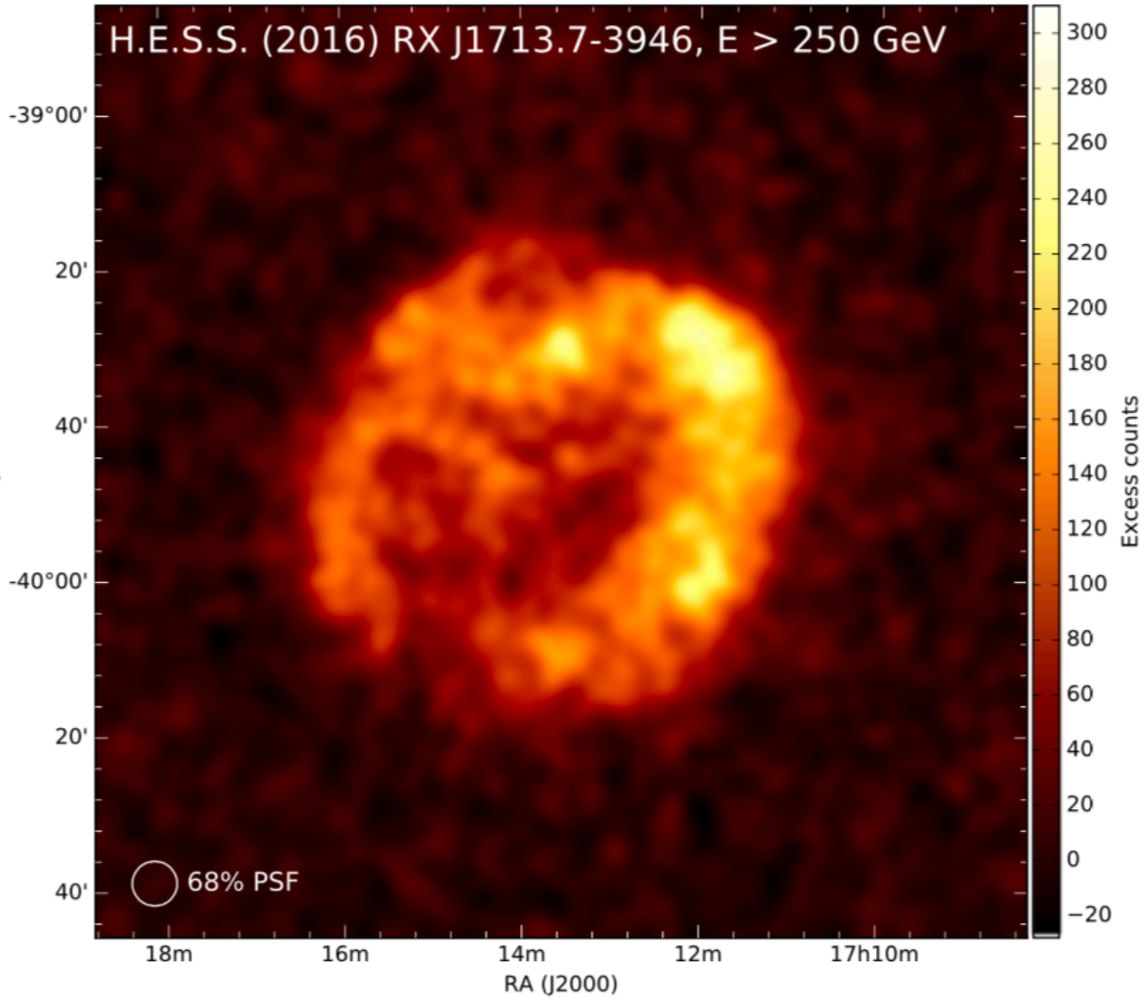
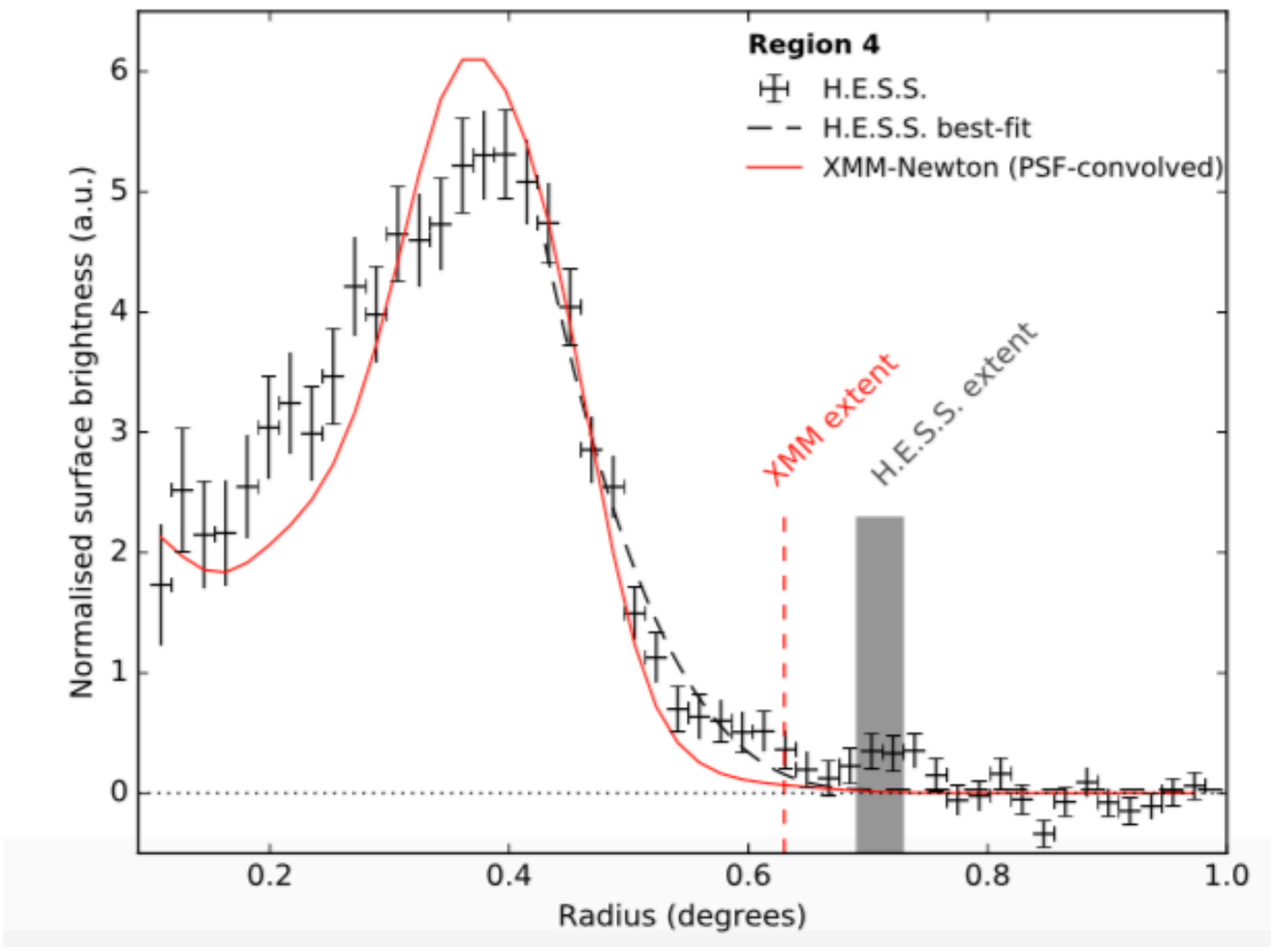
S. Funk

Large and resolved Structures in the Galaxy

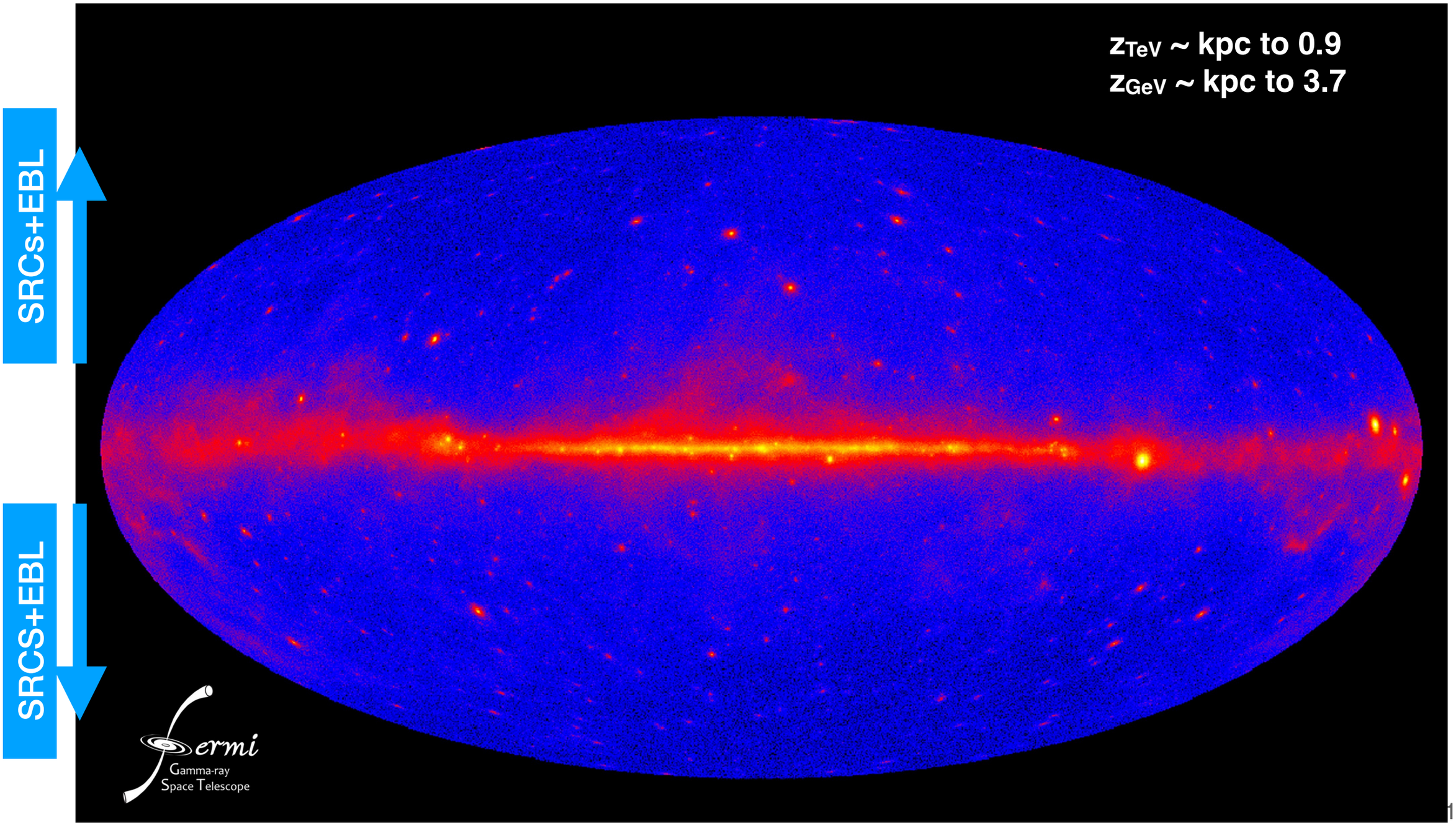




HESS, 2017

The Extragalactic Sky

- Extreme Large Fluxes - Large cosmological distances - Fast Variability



The Extragalactic Sky

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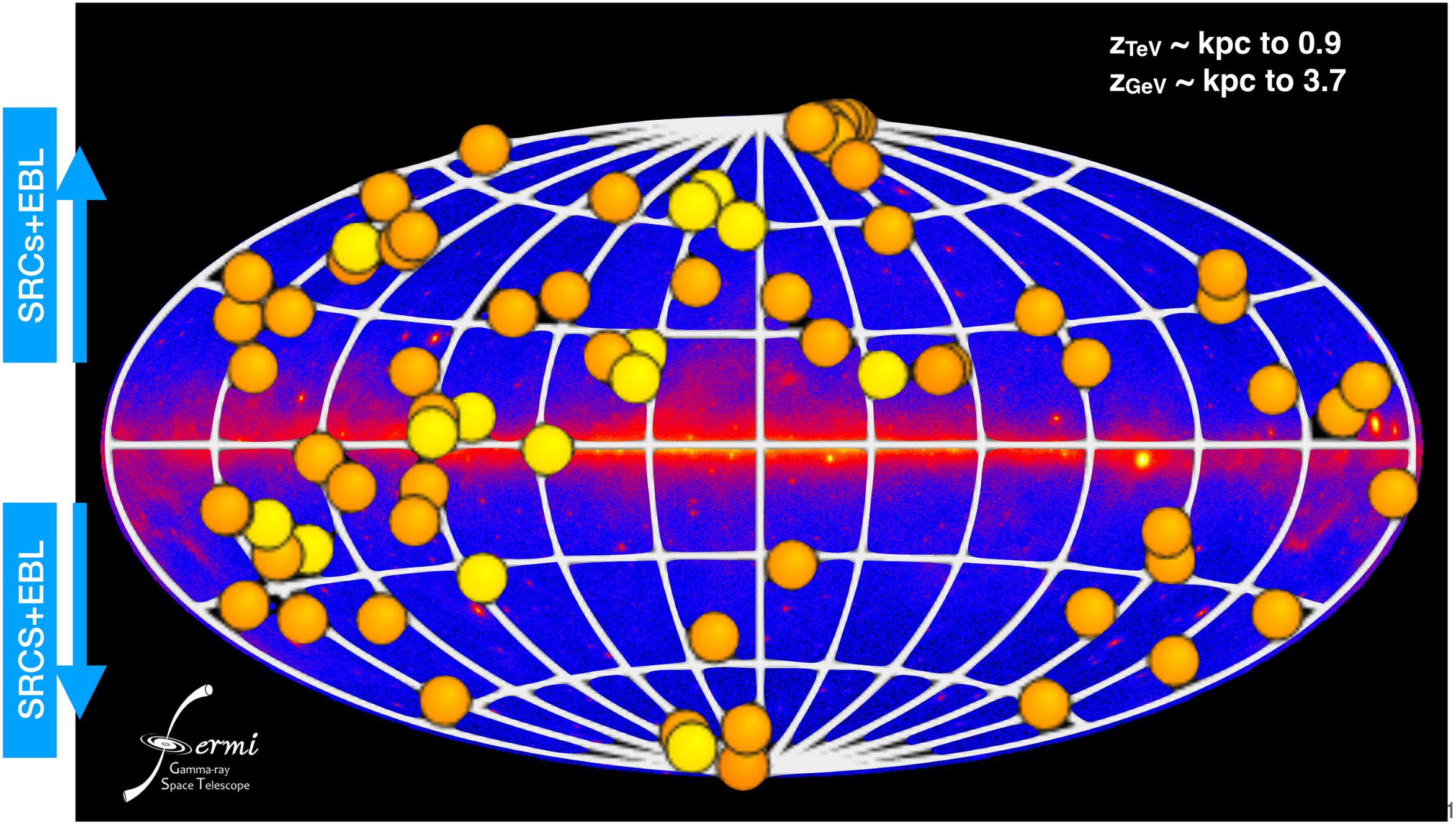
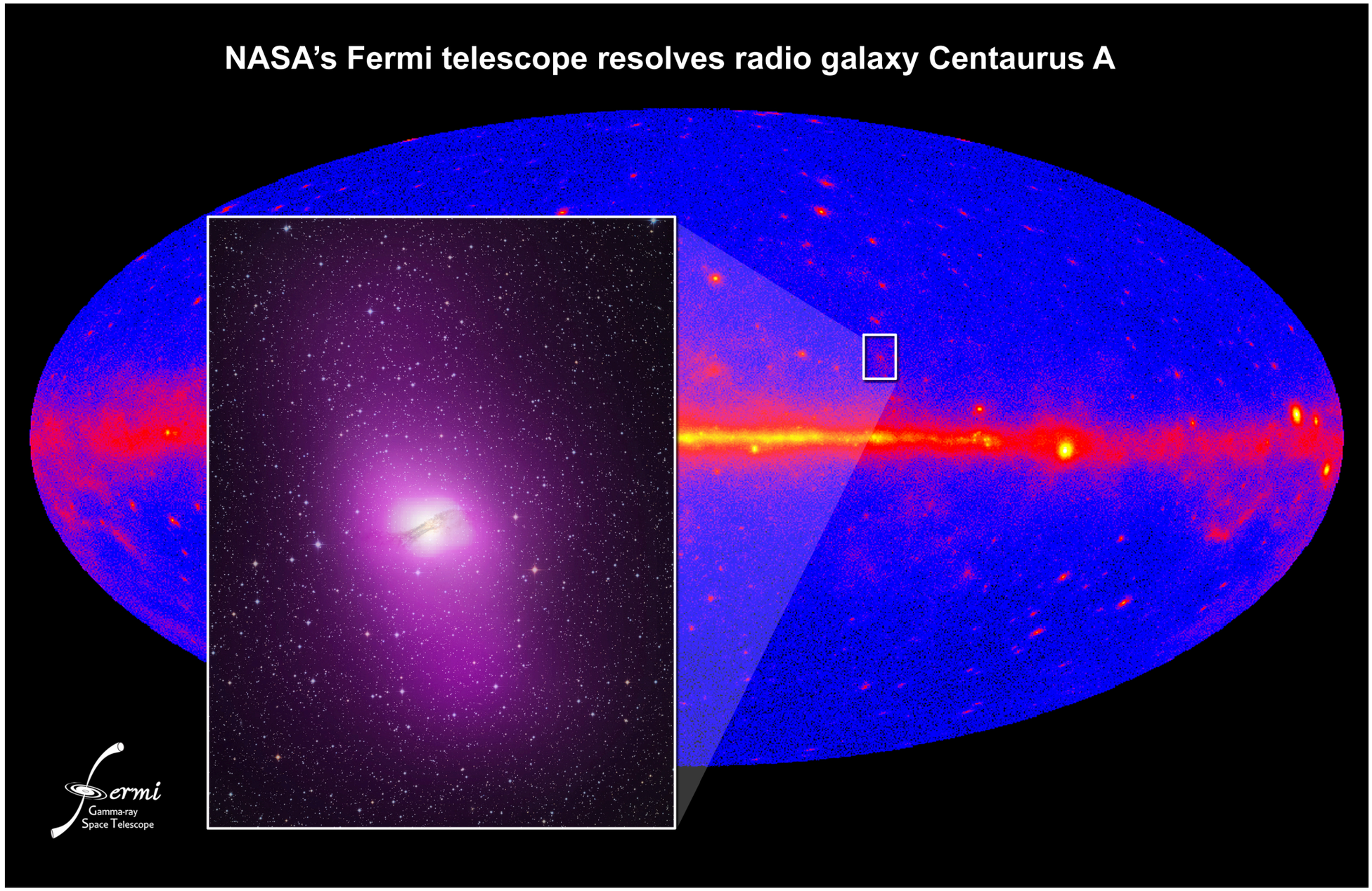


The Extragalactic Sky: Large Structures!



The Extragalactic Sky: Large Structures!

– HESS detected an extended source on the direction of the inner jets

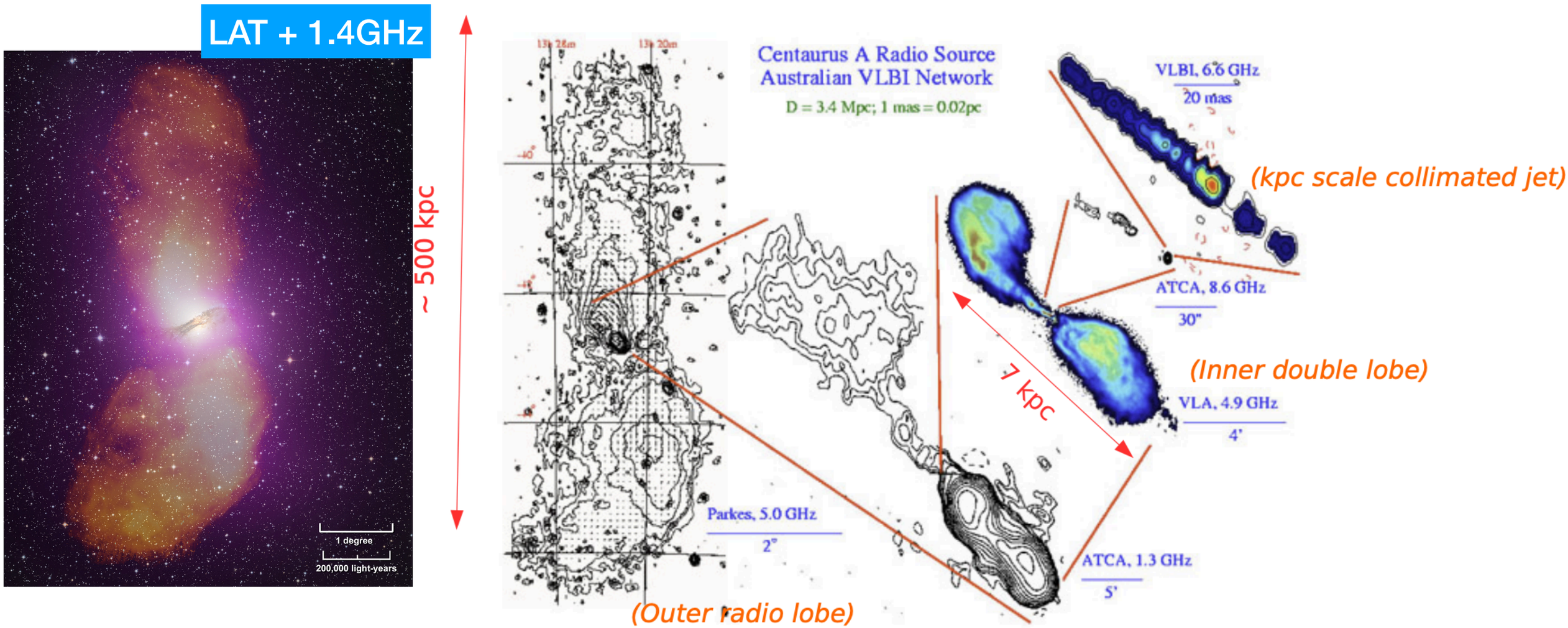


Image credit: ATNF/CSIRO

– Similar problems like the ones in the Fermi bubbles case

The Extragalactic Sky: Large Structures!

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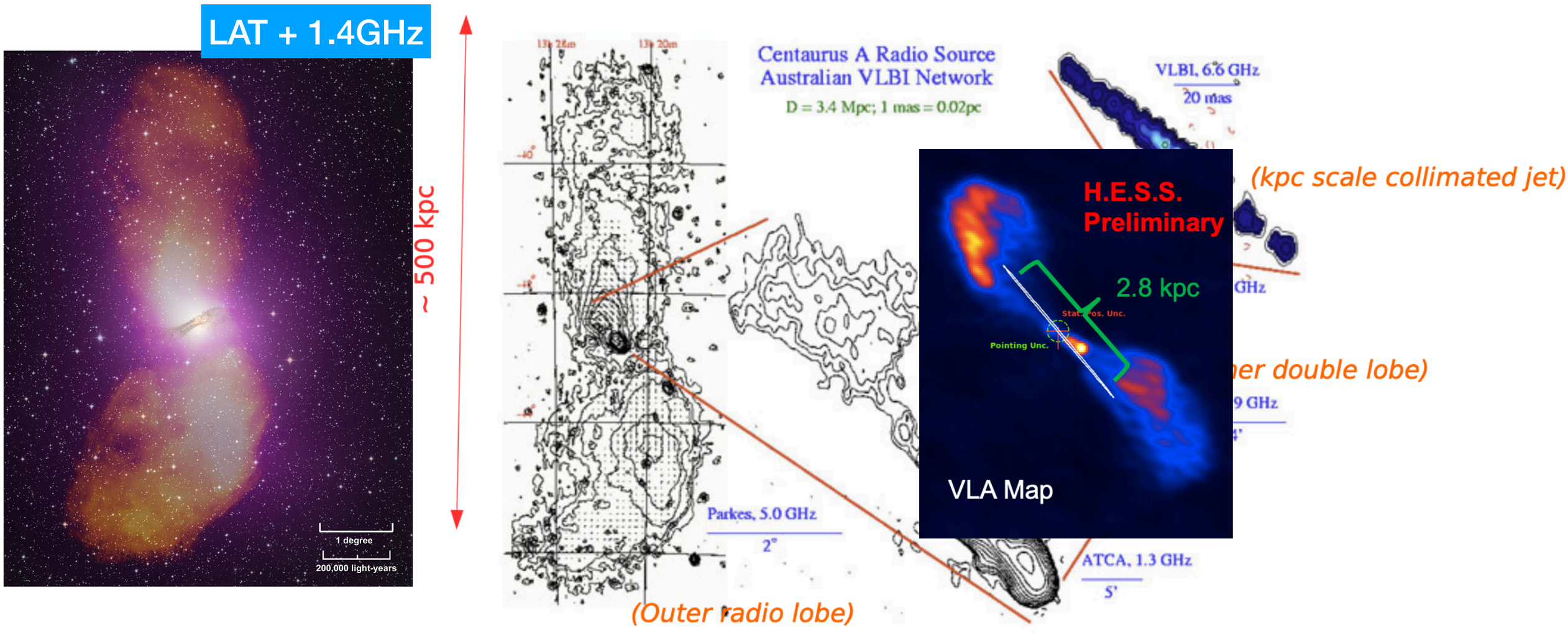
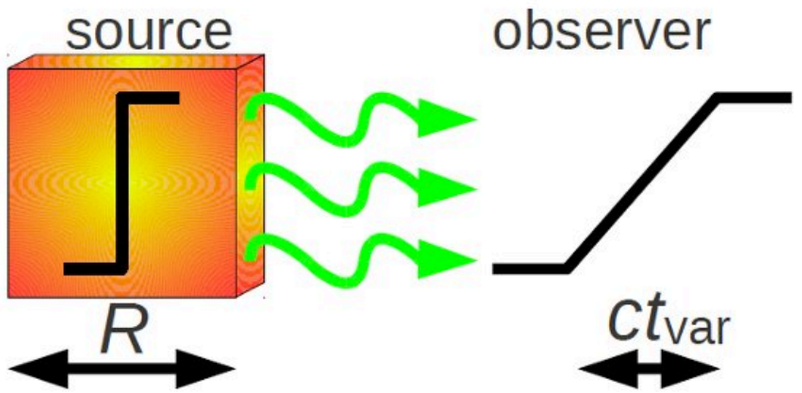


Image credit: ATNF/CSIRO

– Similar problems like the ones in the Fermi bubbles case

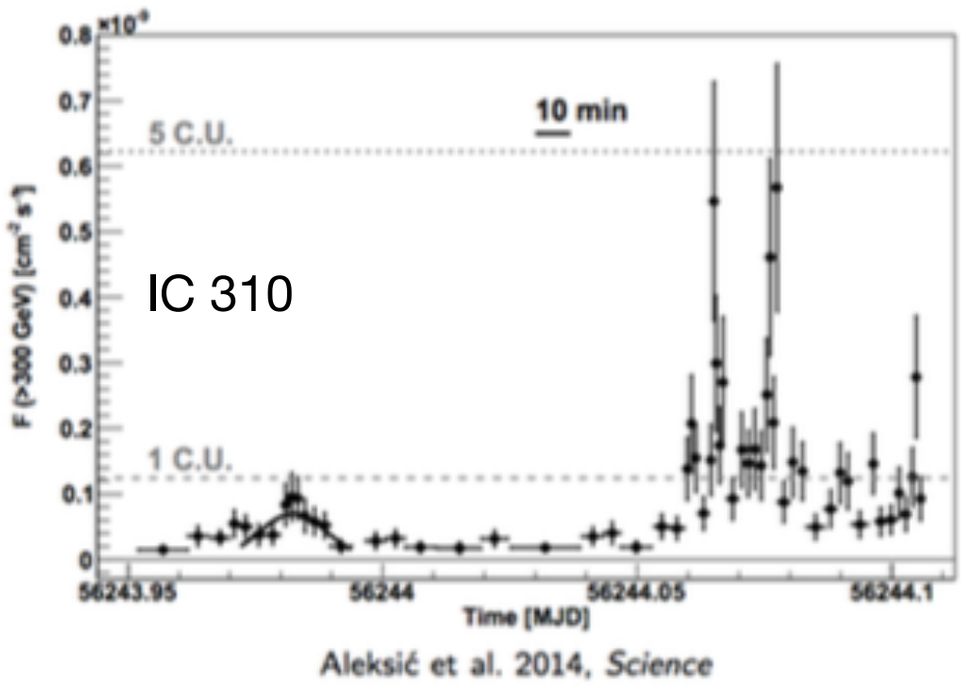
The Extragalactic Sky

– Fast, Far and Strong:
  Temporal variability down to minutes: ct << $r_{Schwarzschild} = 2GM/c^2$



$$R \leqslant \frac{\delta}{1+z} ct_{\rm var}$$

$t_{\rm var} \sim 10$ min $\quad z < 1 \quad$ and $\quad \delta \simeq 10 \quad$ gives $\quad R \leqslant 2 \times 10^{14}$ cm



Aleksić et al. 2014, *Science*

The Extragalactic Sky

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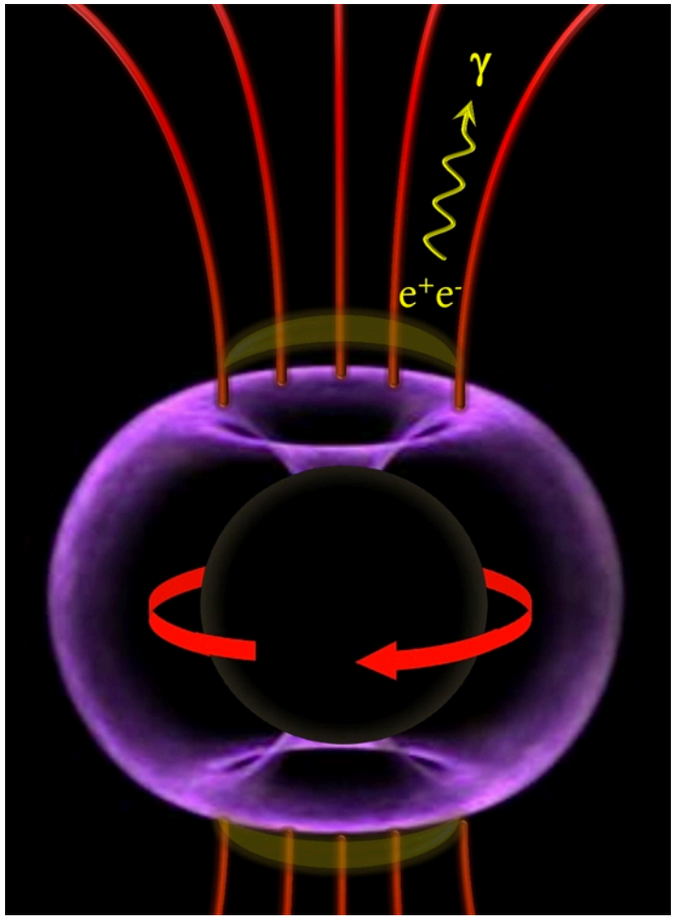
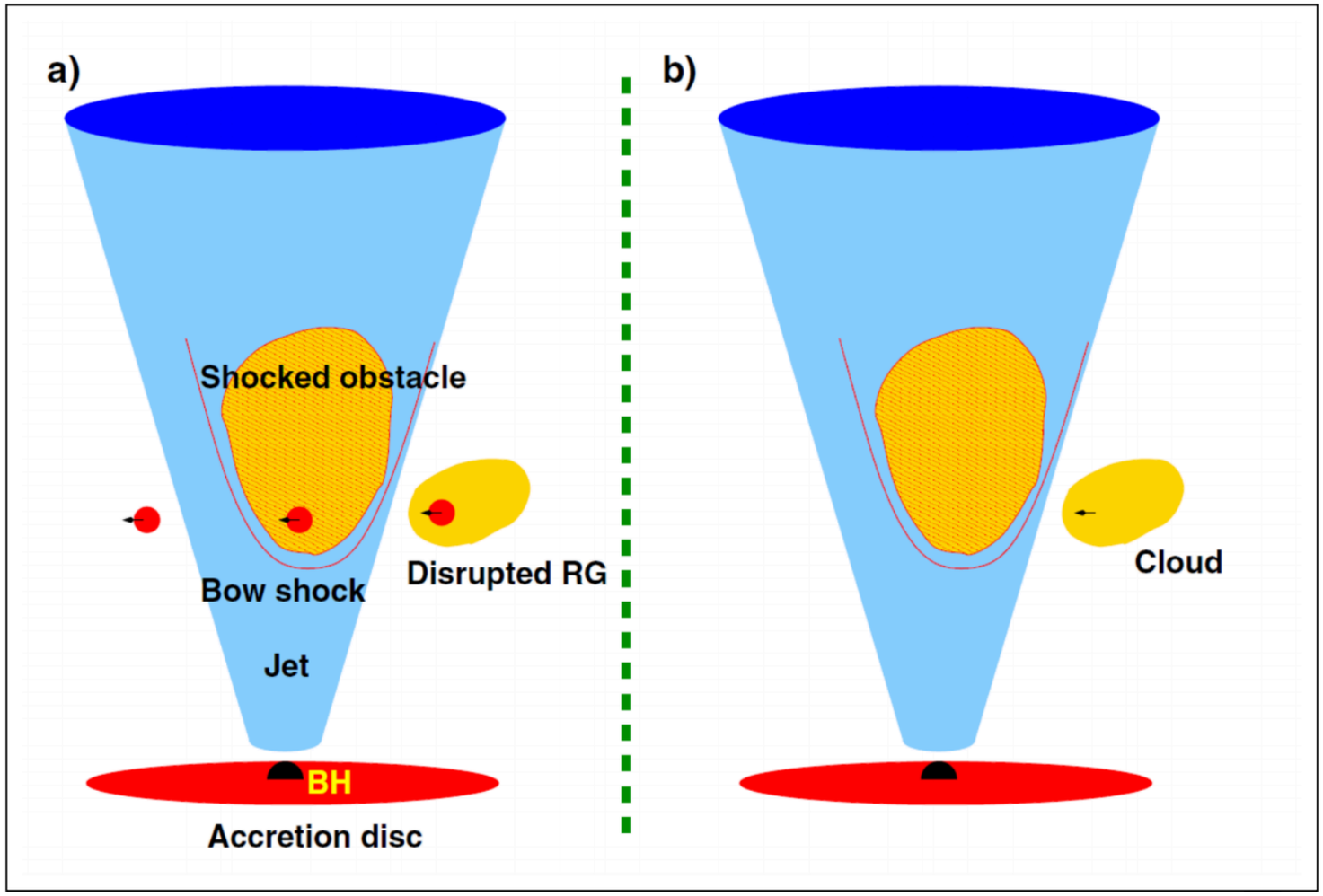


MAGIC, 2018

thunderstorm?



Barkov et al, 2016

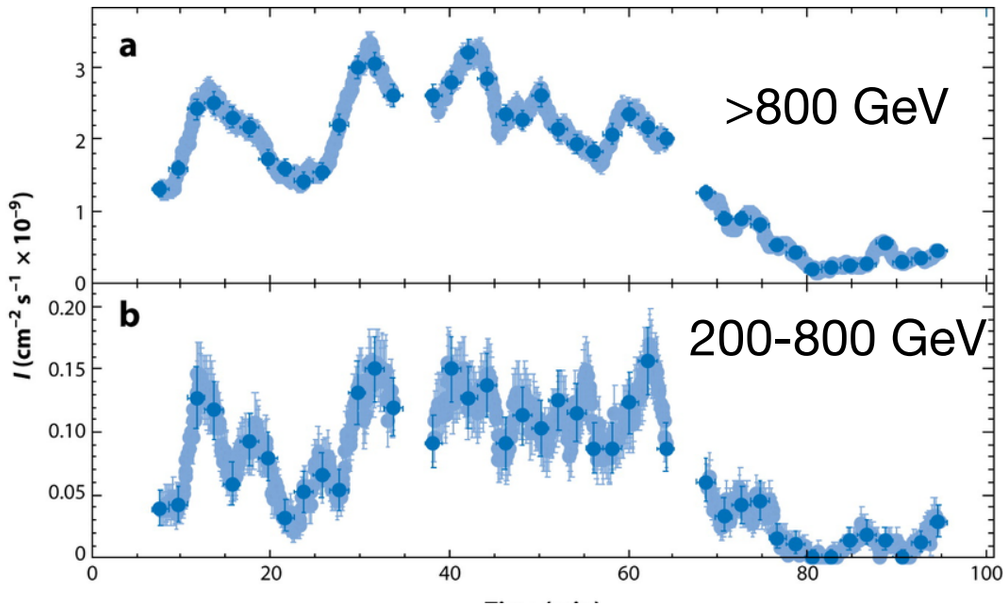
We need MWL observations to pin-point the acceleration region (i.e. ETH!)

The Extragalactic Sky

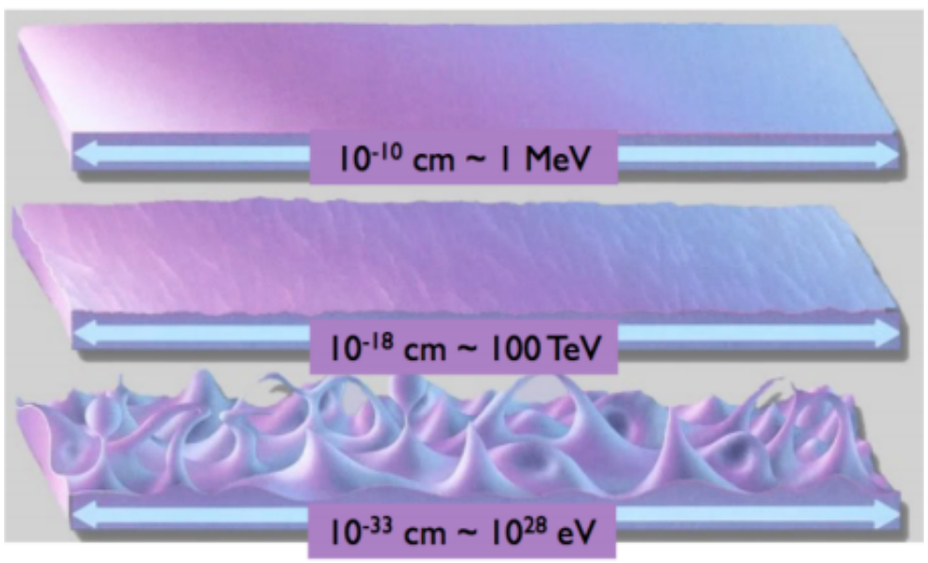
– Fast, Far and Strong:
Temporal variability down to minutes
=> Allow us to put limits on QG LIV

$$v = c\left(1 \pm \xi\left(\frac{E}{M_P}\right) \pm \zeta\left(\frac{E}{M_P}\right)^2 \pm \ldots\right)$$

- Access to Planck scale via large distances and/or high energies
- GRBs, AGN flares or PSRs provide good test-benches
- Different objects probe different phase space

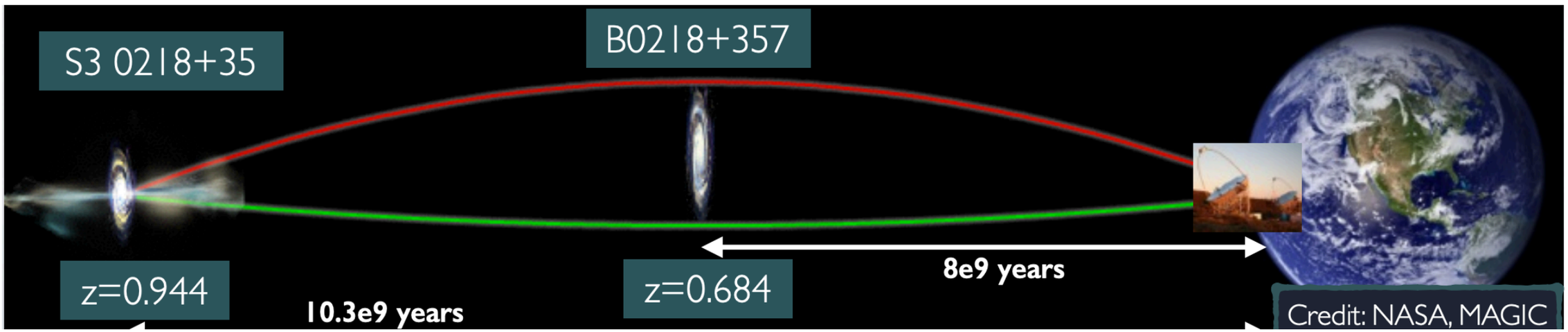


Source family	d [pc]	E [GeV]	δt [s]	Expected limits E_{QG1} [GeV]	E_{QG2} [GeV]
GRB	10^{10}	10^{1}	$10^{0} - 10^{2}$	$10^{17} - 10^{19}$	$10^{9} - 10^{10}$
AGN	10^{8}	10^{4}	$10^{2} - 10^{5}$	$10^{15} - 10^{18}$	$10^{9} - 10^{11}$
Pulsar	10^{3}	10^{2}	$10^{-4} - 10^{-2}$	$10^{17} - 10^{19}$	$10^{10} - 10^{11}$



The Extragalactic Sky

– Fast, Far and Strong:
  Reaching Cosmological distances (Gravitational Lenses)



Different behaviour than in radio: different emission region?

The Extragalactic Sky

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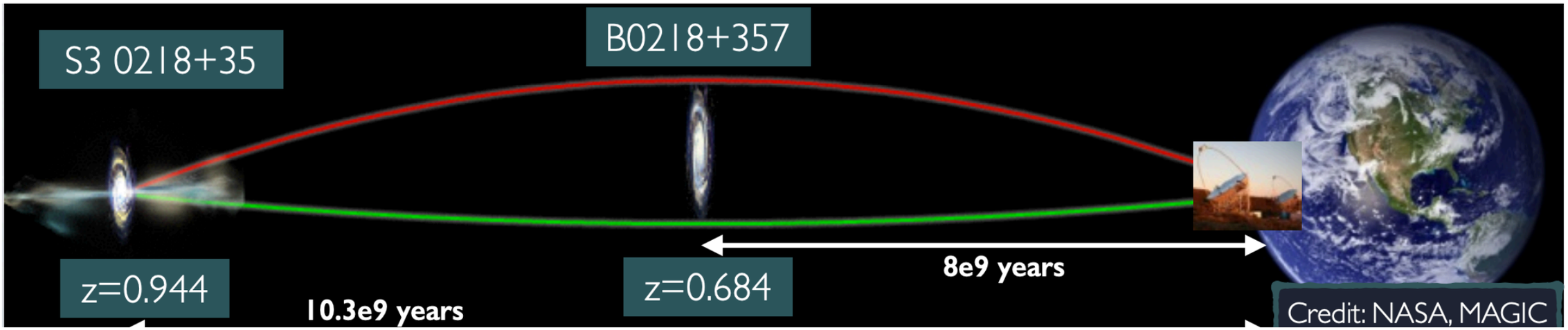
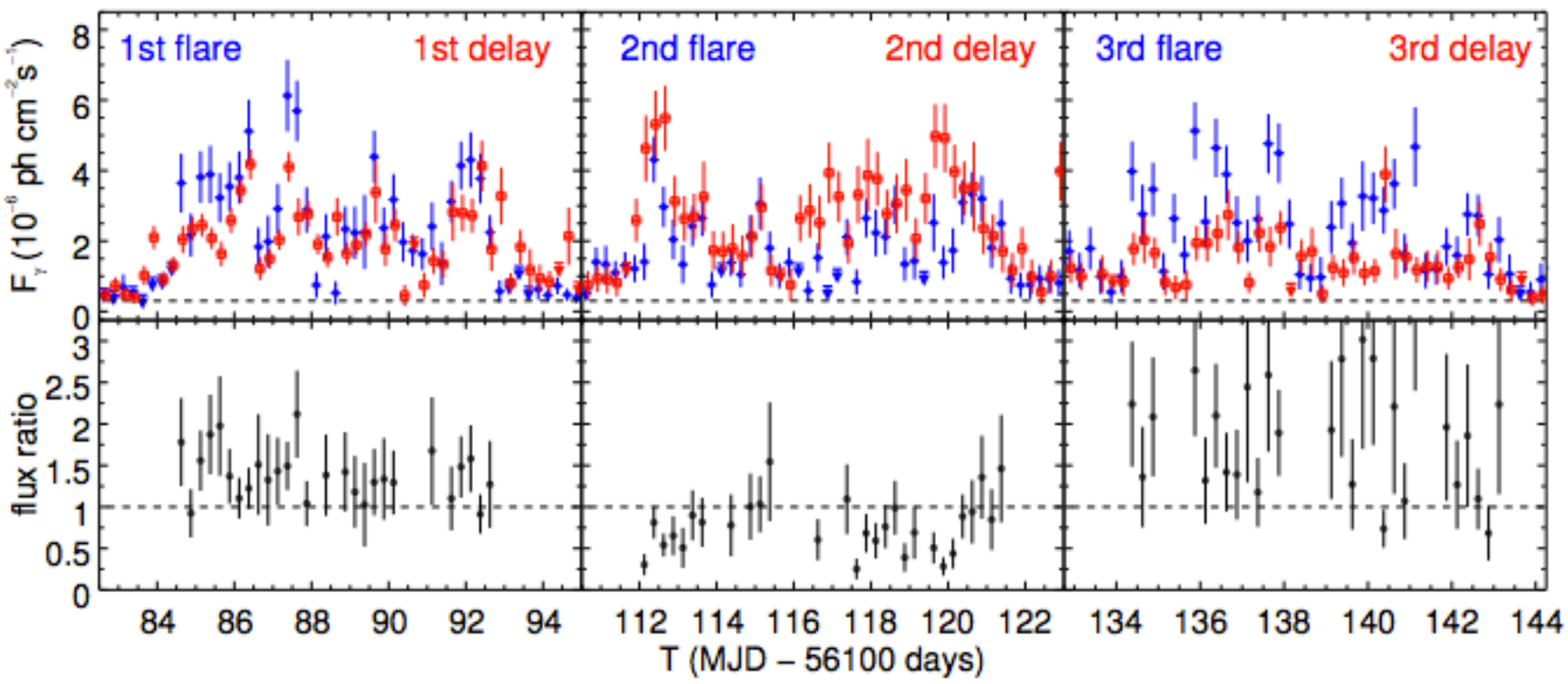




Different behaviour than in radio: different emission region?

The Extragalactic Sky

Gamma-ray Bursts

Jet collides with ambient medium (external shock wave)

Colliding shells emit low-energy gamma rays (internal shock wave)

High-energy gamma rays

X-rays

Visible light

Radio

Slower shell

Faster shell

Low-energy gamma rays

Black hole engine

Prompt emission

Afterglow

The Extragalactic Sky

– Fast, Far and Strong:
  First detections of GRBs above >100 GeV

GRB 180720B

50sec after Swift-Bat alert

[Previous | Next | ADS]

First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

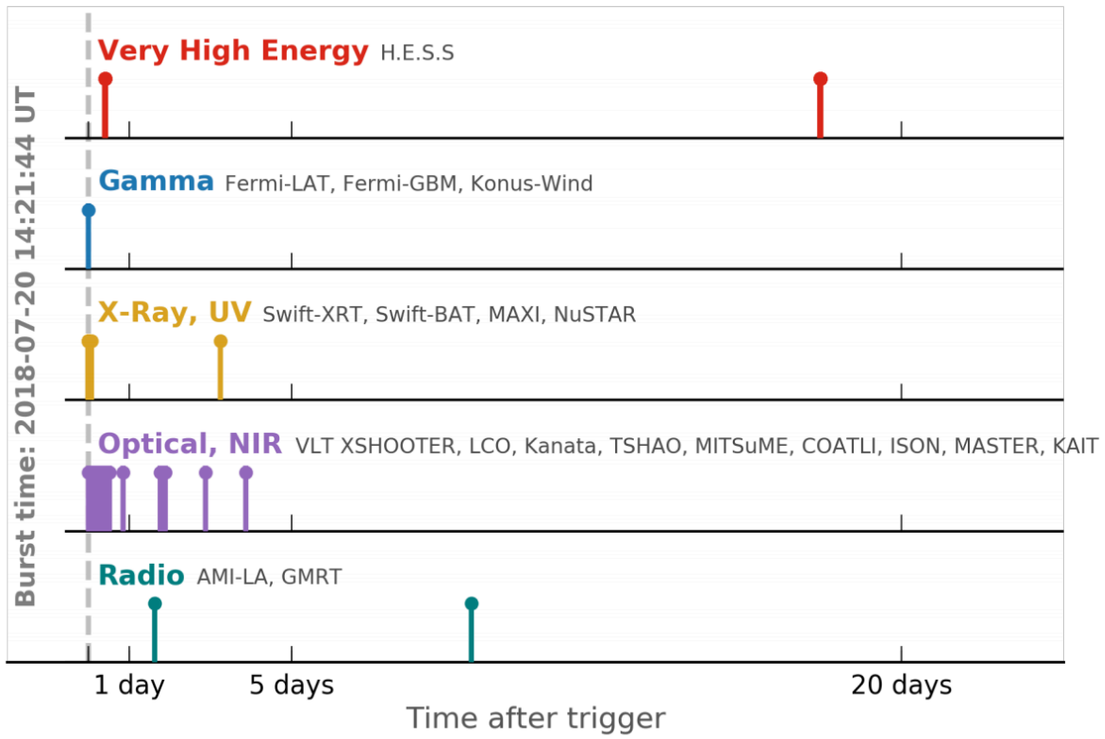
ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
*on **15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

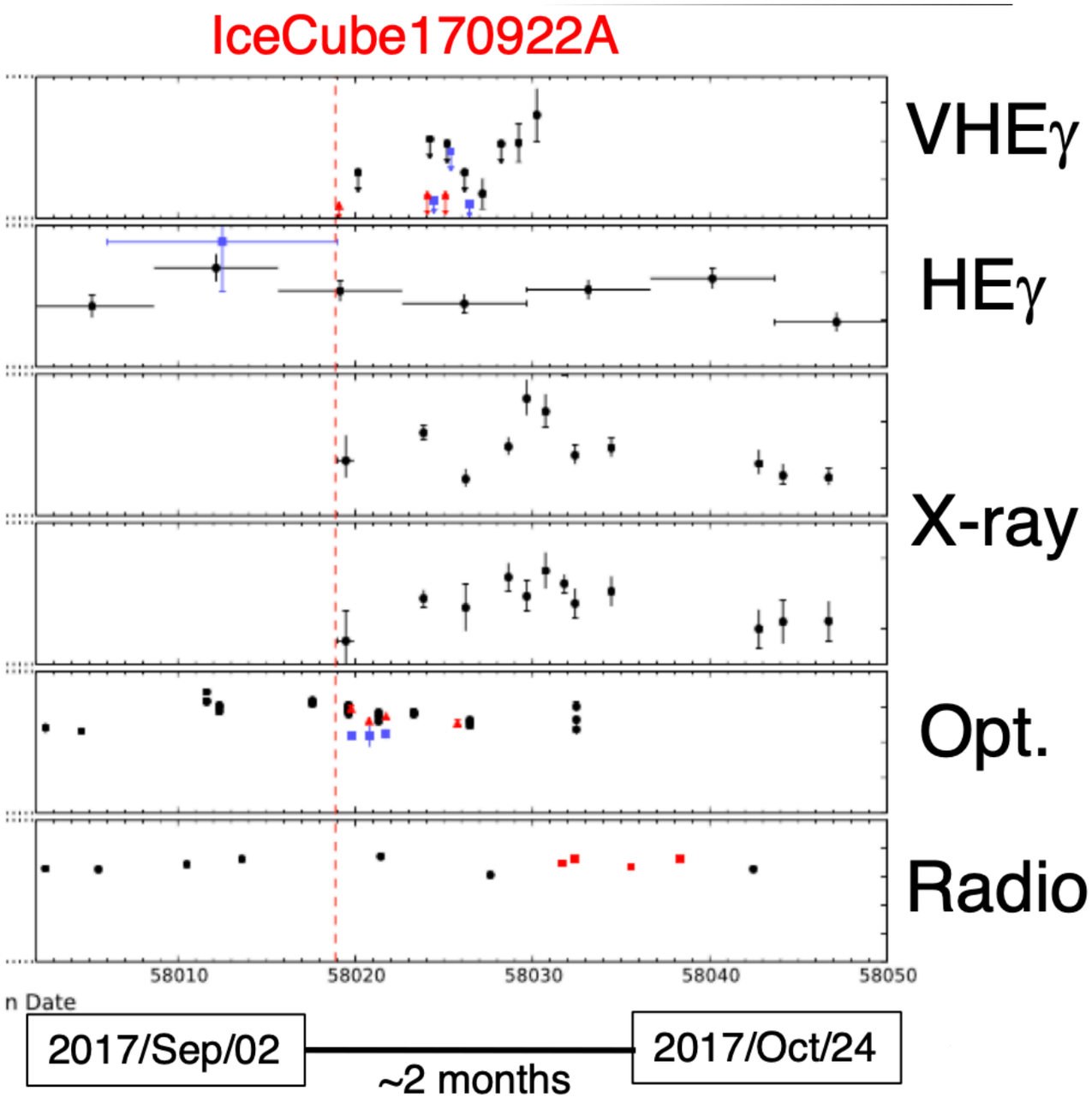
Tweet

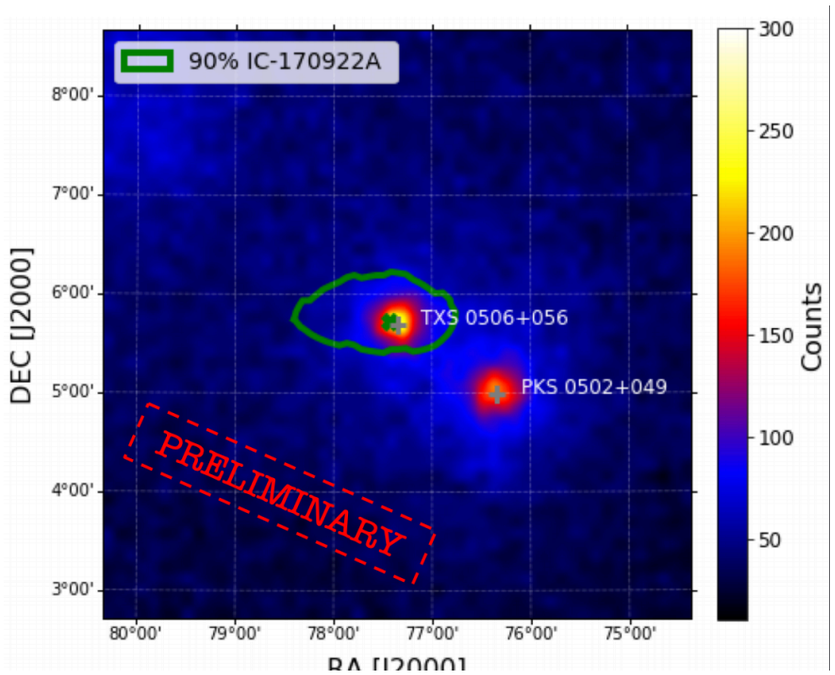
The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a

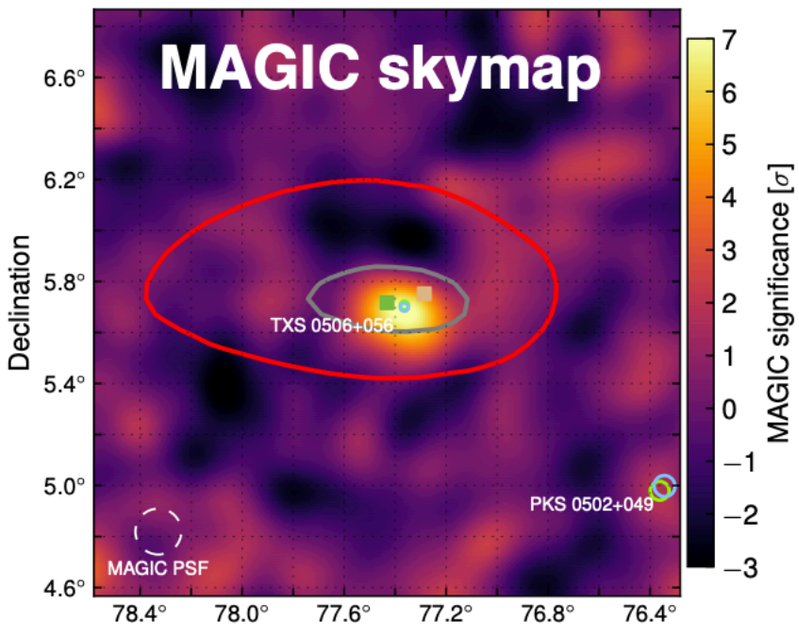


Hunting also the EM counterapart at TeV of GWs!

Gamma-ray / Neutrino Source: TXS 0506+056







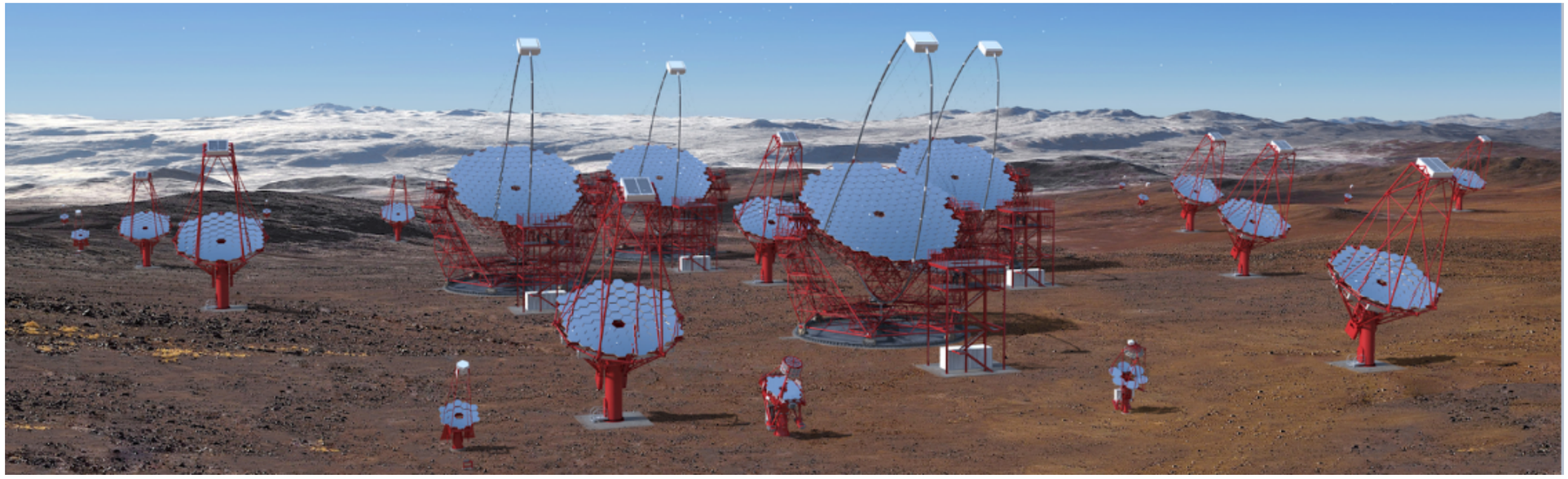
Ansoldi et al, 2018

Summary

- More than 200 sources discovered at TeV energies in the last 10 years, and ~3500 between 100 MeV and 300 GeV
- In the TeV regime, we are moving from a ‘discovery mode’ to a more detailed study of sources and population
- The hunting for PeVatrons is still ongoing, are we getting any closer? New surprises: The standard steady candle is not so standard nor so steady anymore!
- The extragalactic sky is highly variable - more sophisticated models are needed to explain the light-curves and spectra
- A large number of new incognitos - we need better sensitivity, better angular and energy resolution -> next generation of Cherenkov telescopes

The Cherenkov Telescope Array

South: 99 telescopes spread out over ~5 km² (70 SSTs, 25 MSTs, 4 LSTs)

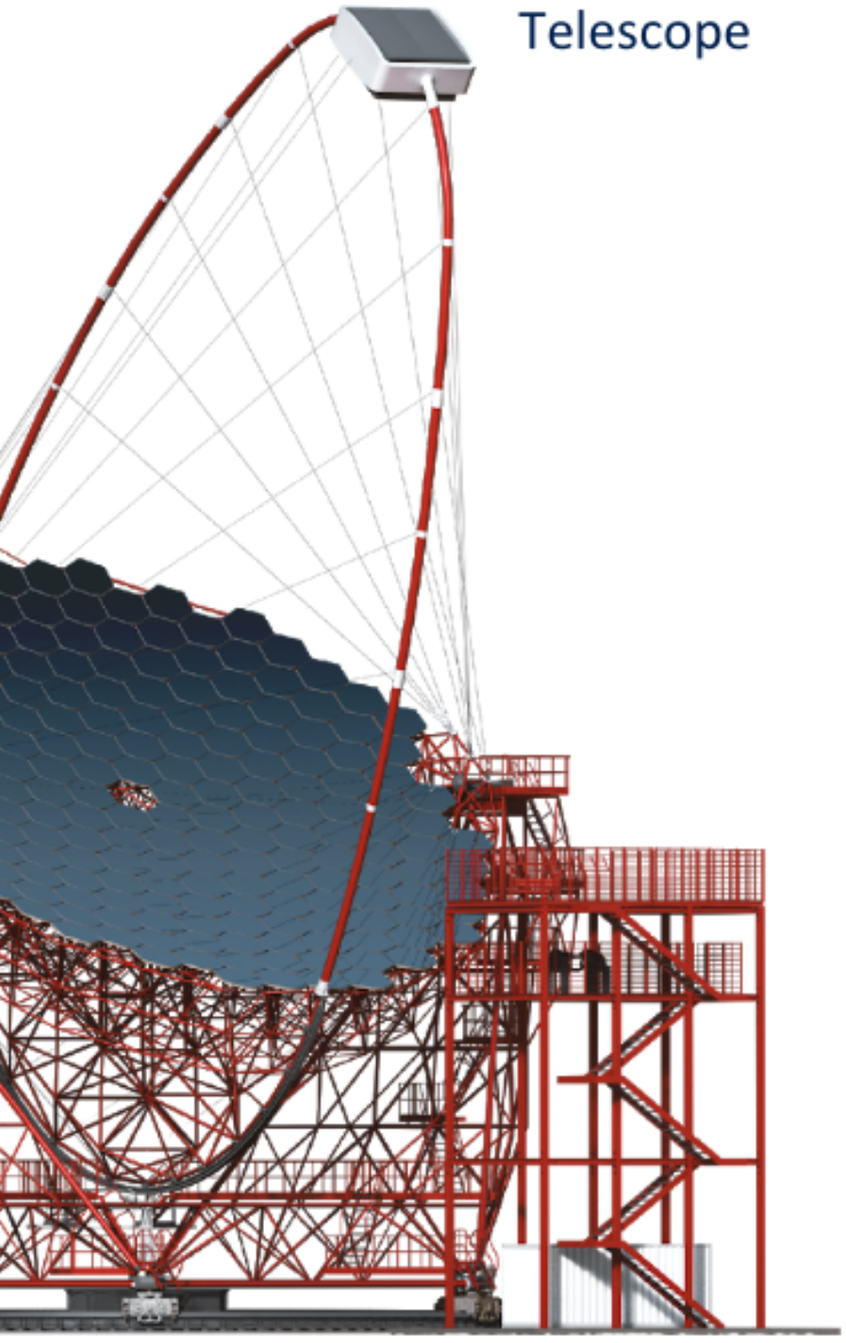


North: 19 telescopes spread out over ~1 km² (15 MSTs, 4 LSTs)

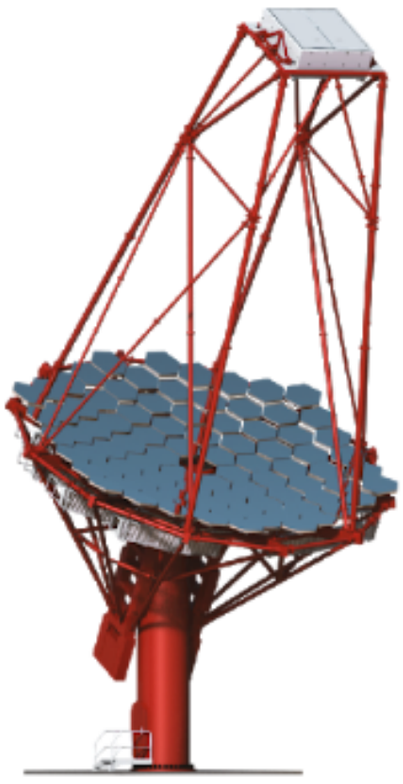
Telescopes

Three classes of telescope are required to cover the full energy range of CTA (20 GeV – 300 TeV)

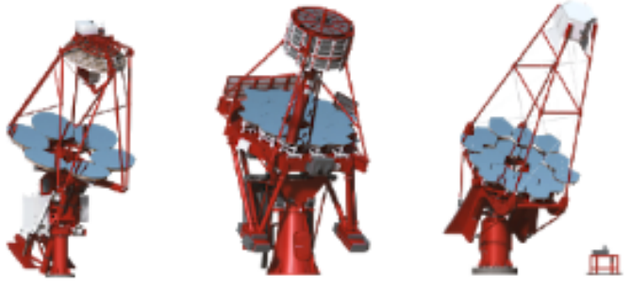
Large-Sized Telescope



Medium-Sized Telescope



Small-Sized Telescope



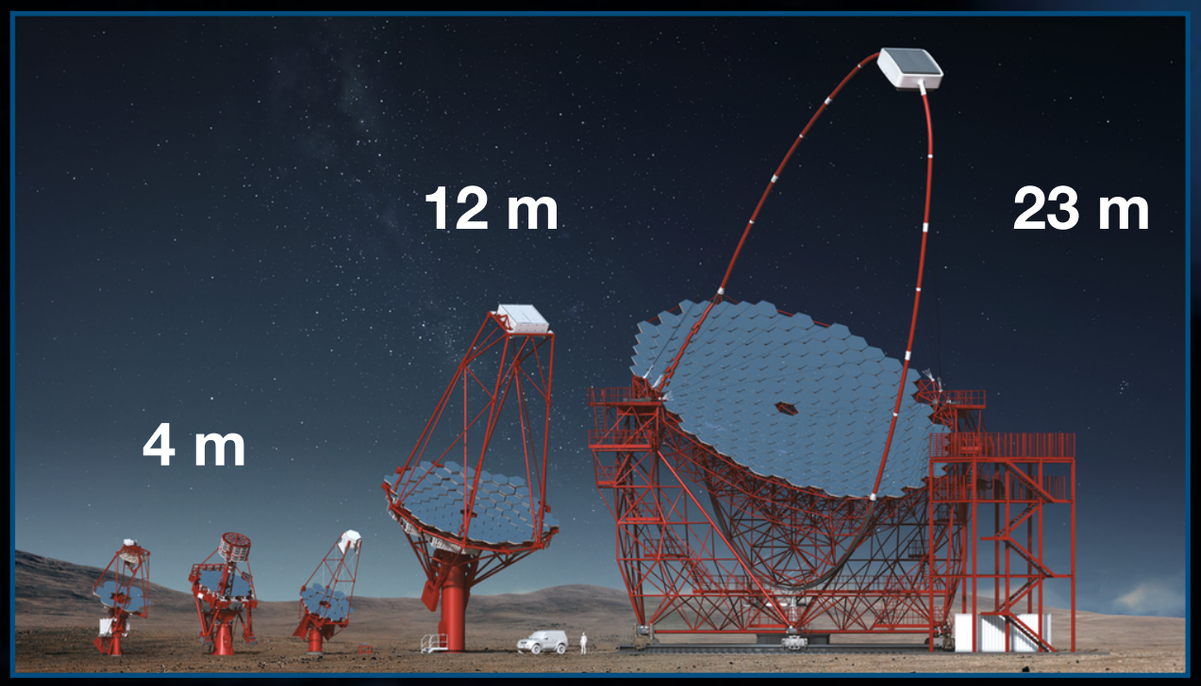
(Rendering credit: Gabriel Pérez Diaz, IAC)

Boosting:

- Increase sensitivity by up to a factor ~6 at 1 TeV
- Increase the detection area for transients and at the highest energies
- Increase the angular resolution and maintaining a large FoV

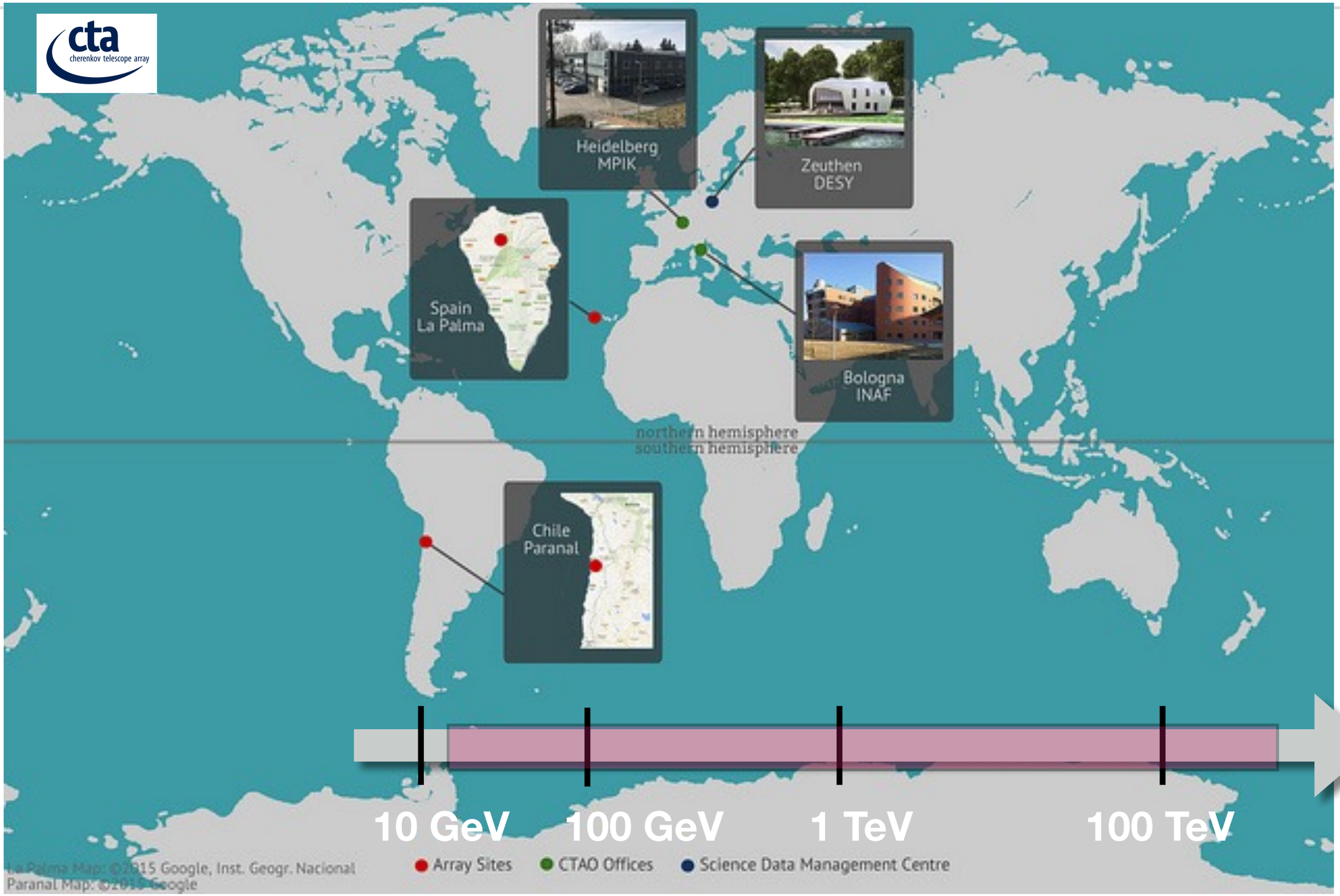
New:

- Energy coverage from tens of GeV and beyond 100 TeV (~300 TeV)
- 2 Sites, flexibility of operation, allowing for sub-arrays and multi-mode
- Operate as an observatory



Thanks!

The Cherenkov Telescope Array



Two Arrays: Two Eyes on the Sky

Array Coordinates
Latitude: 24° 41' 0.34" South
Longitude: 70° 18' 58.84" West

CTA South
Chile, Paranal

~5 km²

area covered by the array of telescopes

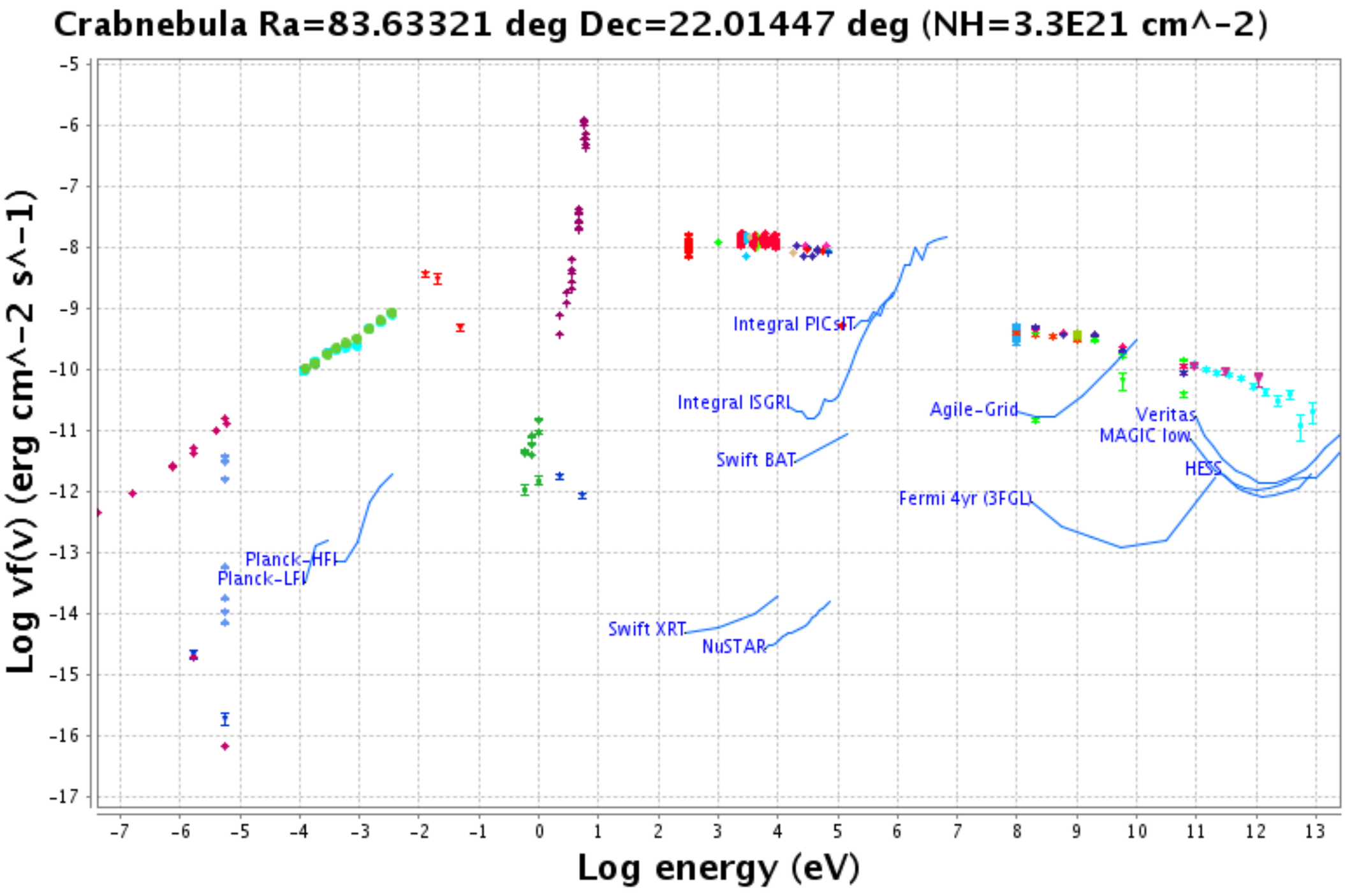
CTA North
Spain, La Palma

~0.5 km²

area covered by the array of telescopes

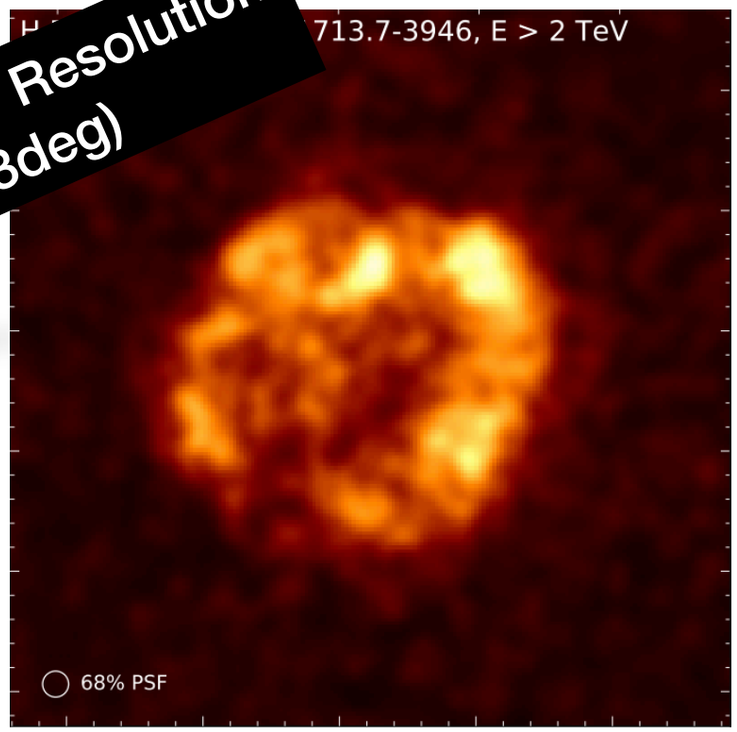
Array Coordinates
Longitude: 17° 53' 31.218" West
Latitude: 28° 45' 43.7904" North

Detection of gamma-rays

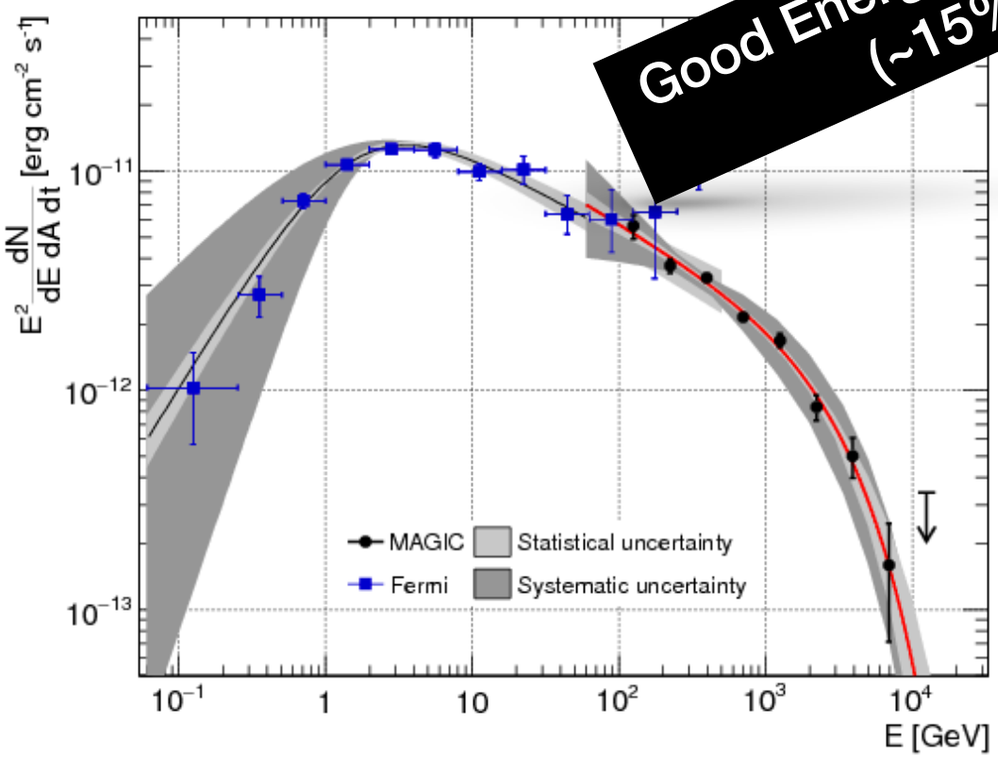


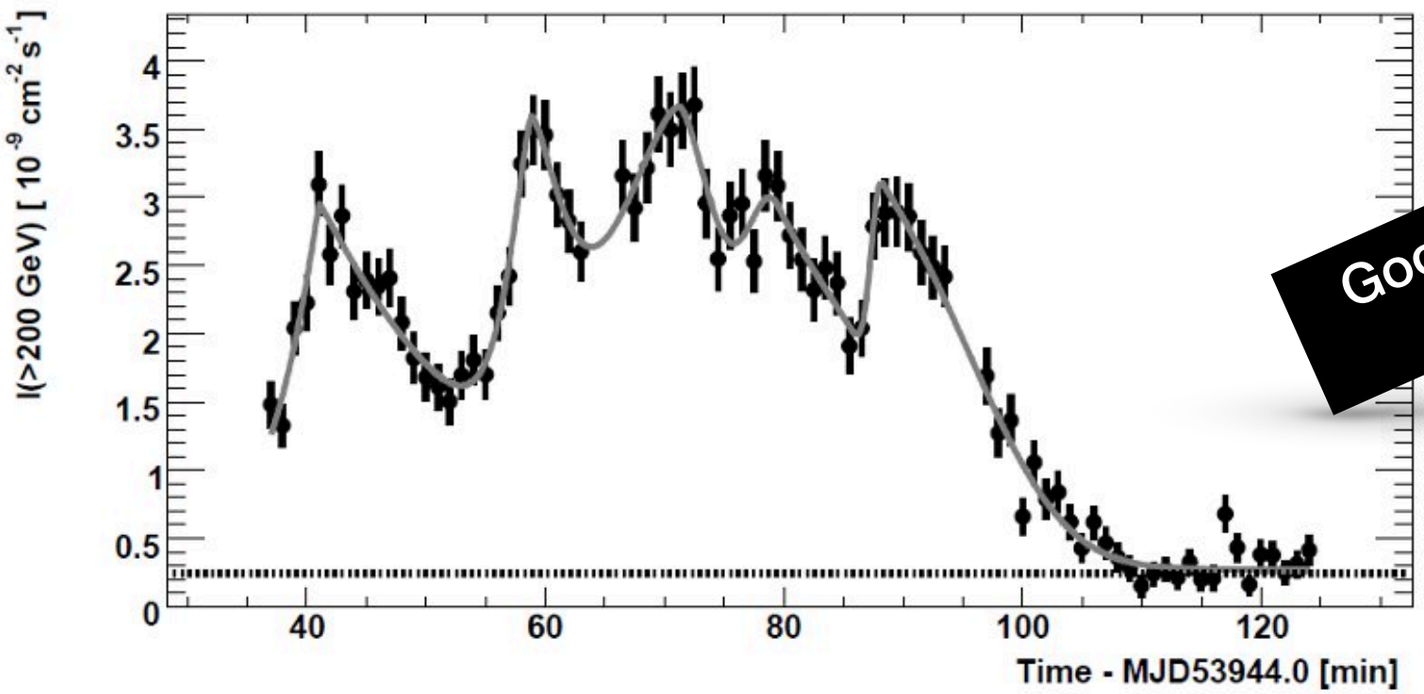
Detection of gamma-rays

Good Angular Resolution (~0.03deg)



Good Energy Resolution (~15%)





Good Time Resolution (~min)