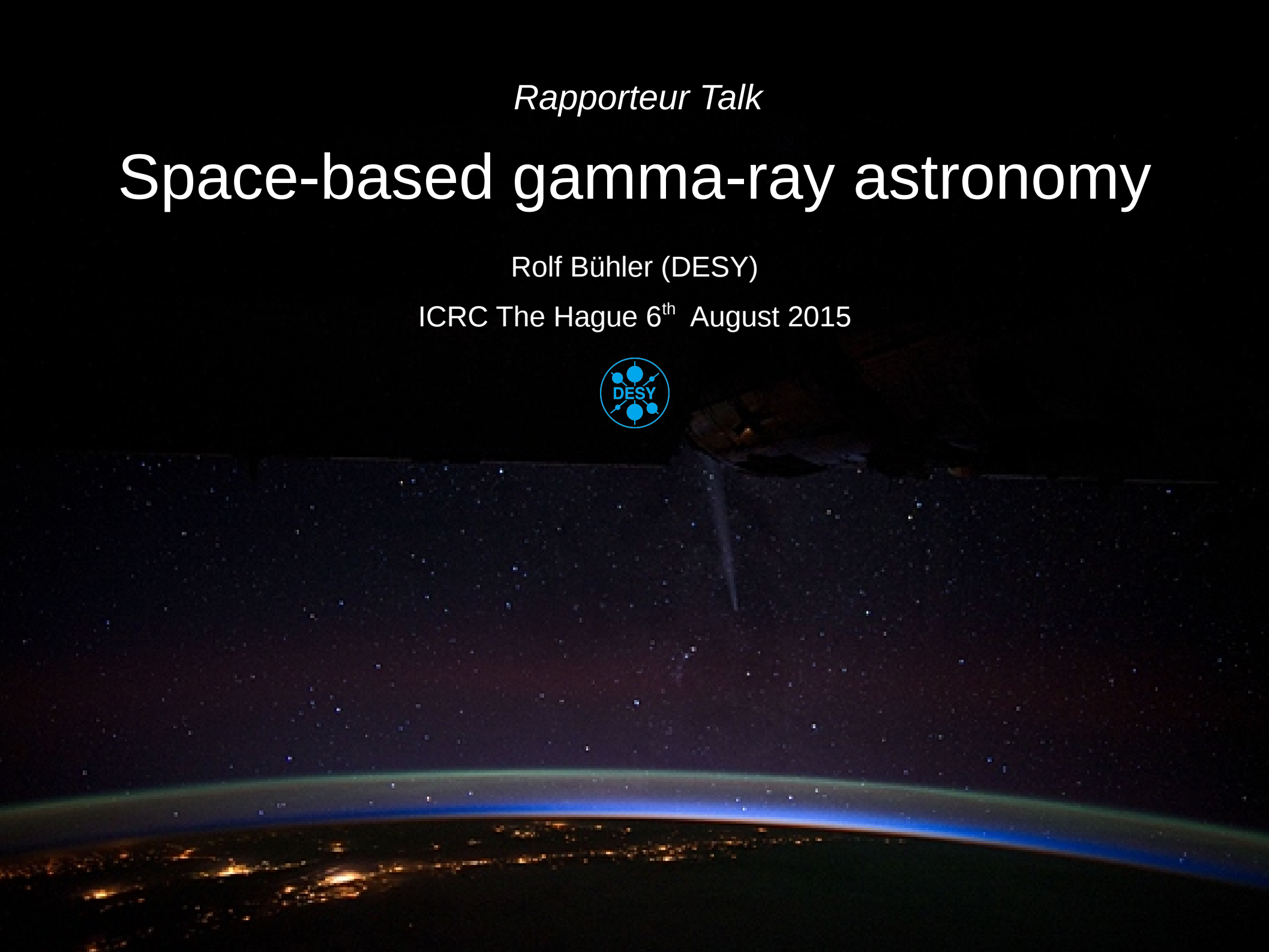
Rapporteur Talk

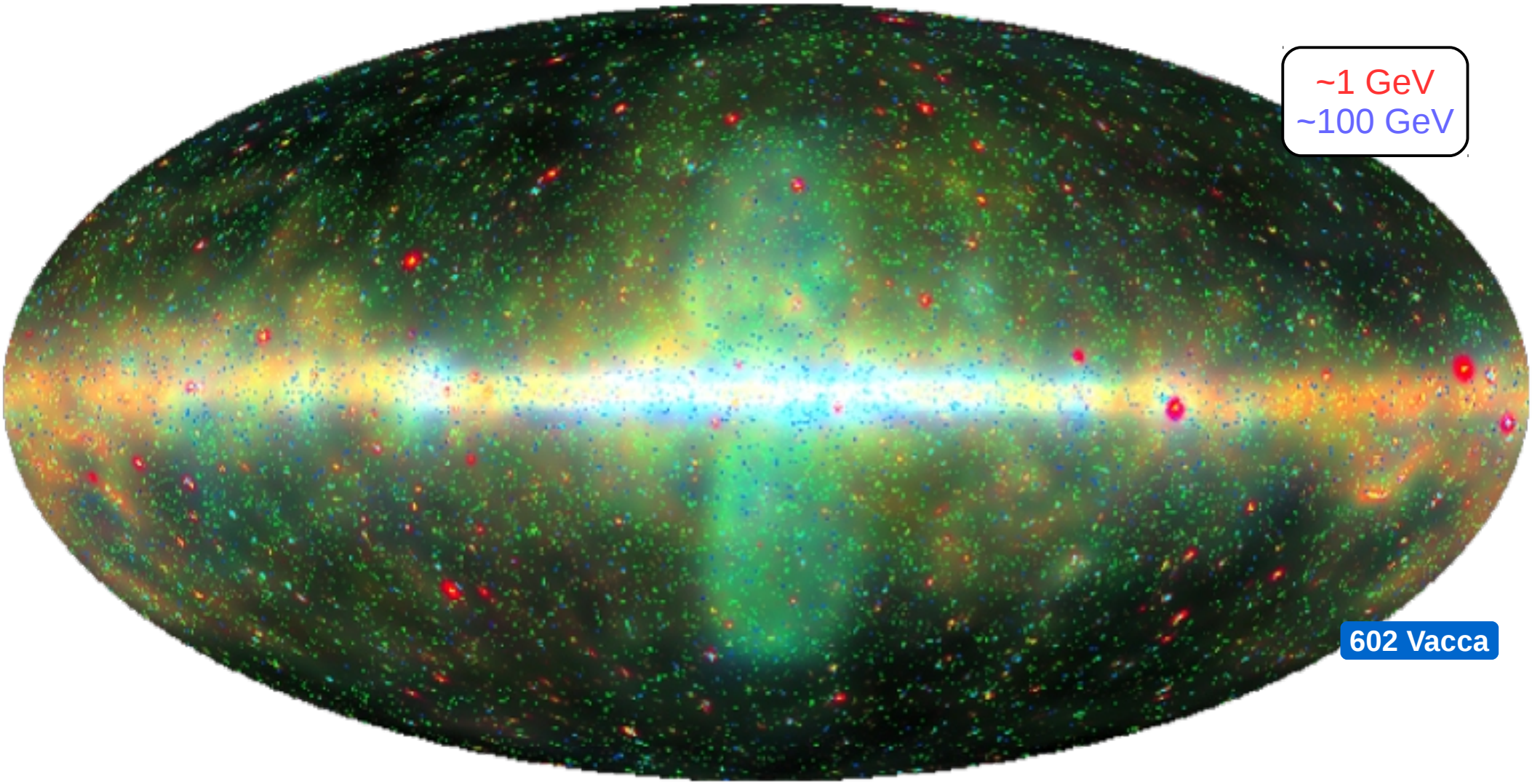
Space-based gamma-ray astronomy

Rolf Bühler (DESY)

ICRC The Hague 6th August 2015

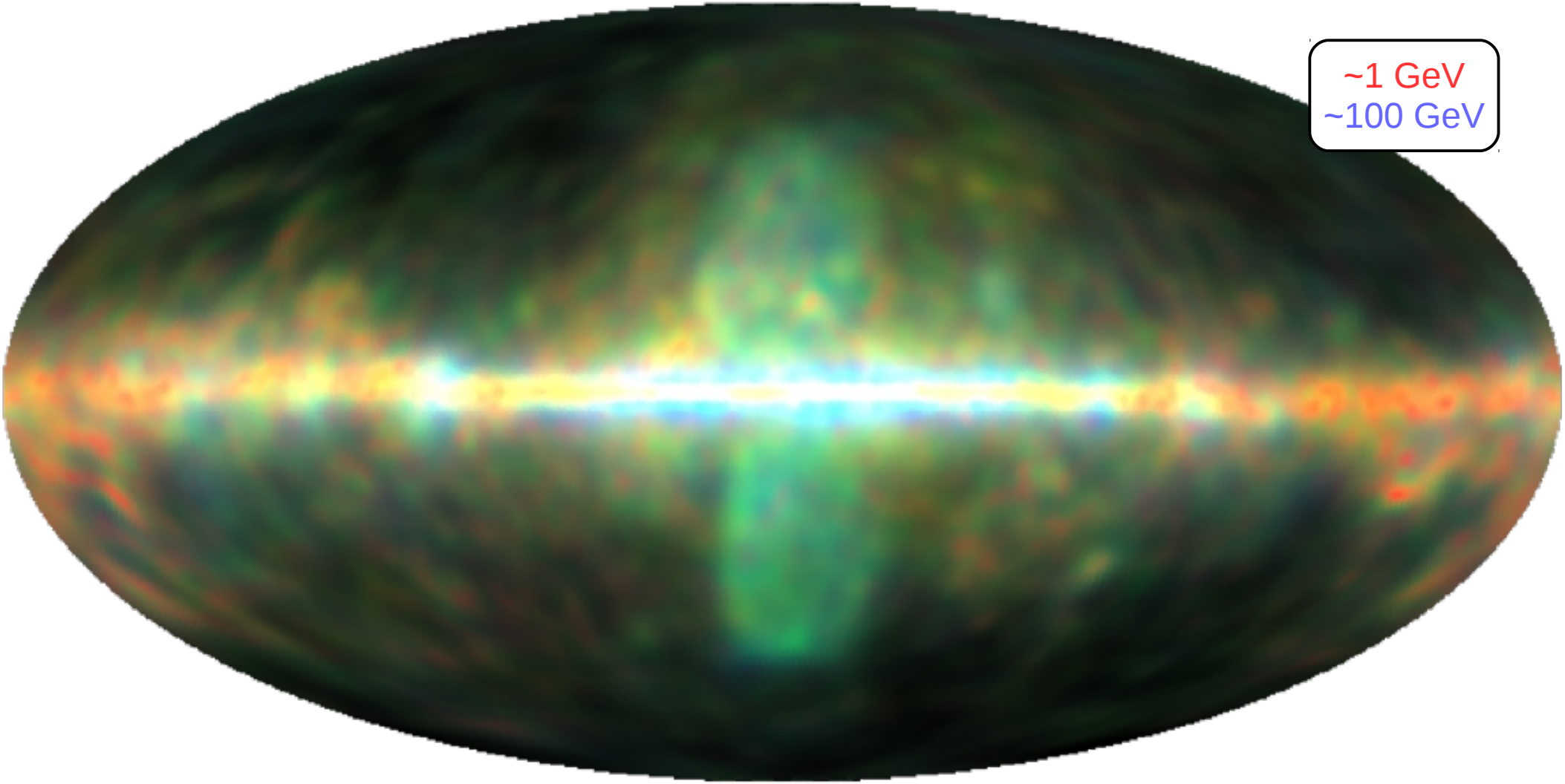


The γ-ray sky



D³PO decomposes Fermi-LAT sky into point and diffuse sources

Diffuse γ-ray emission



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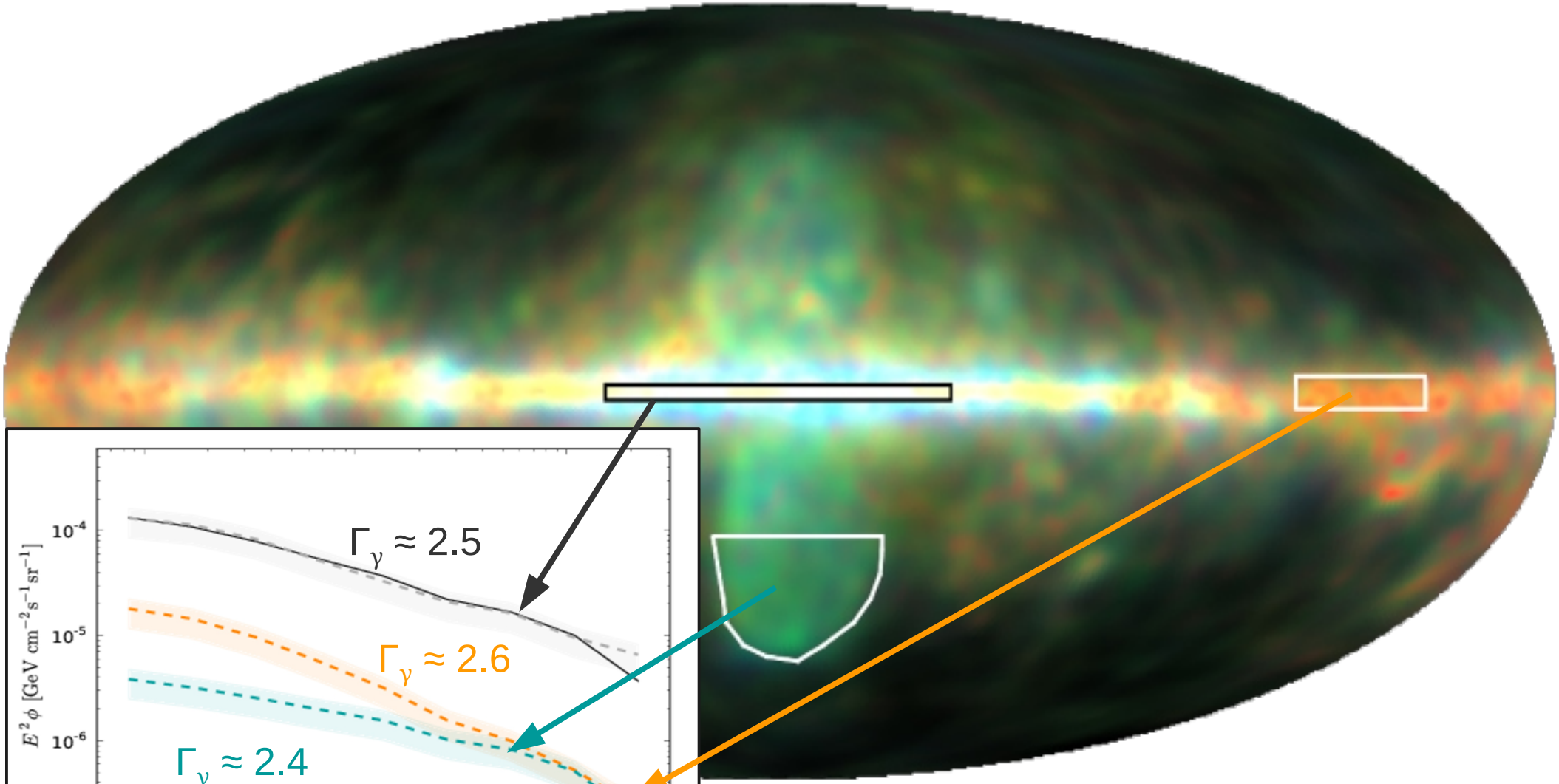
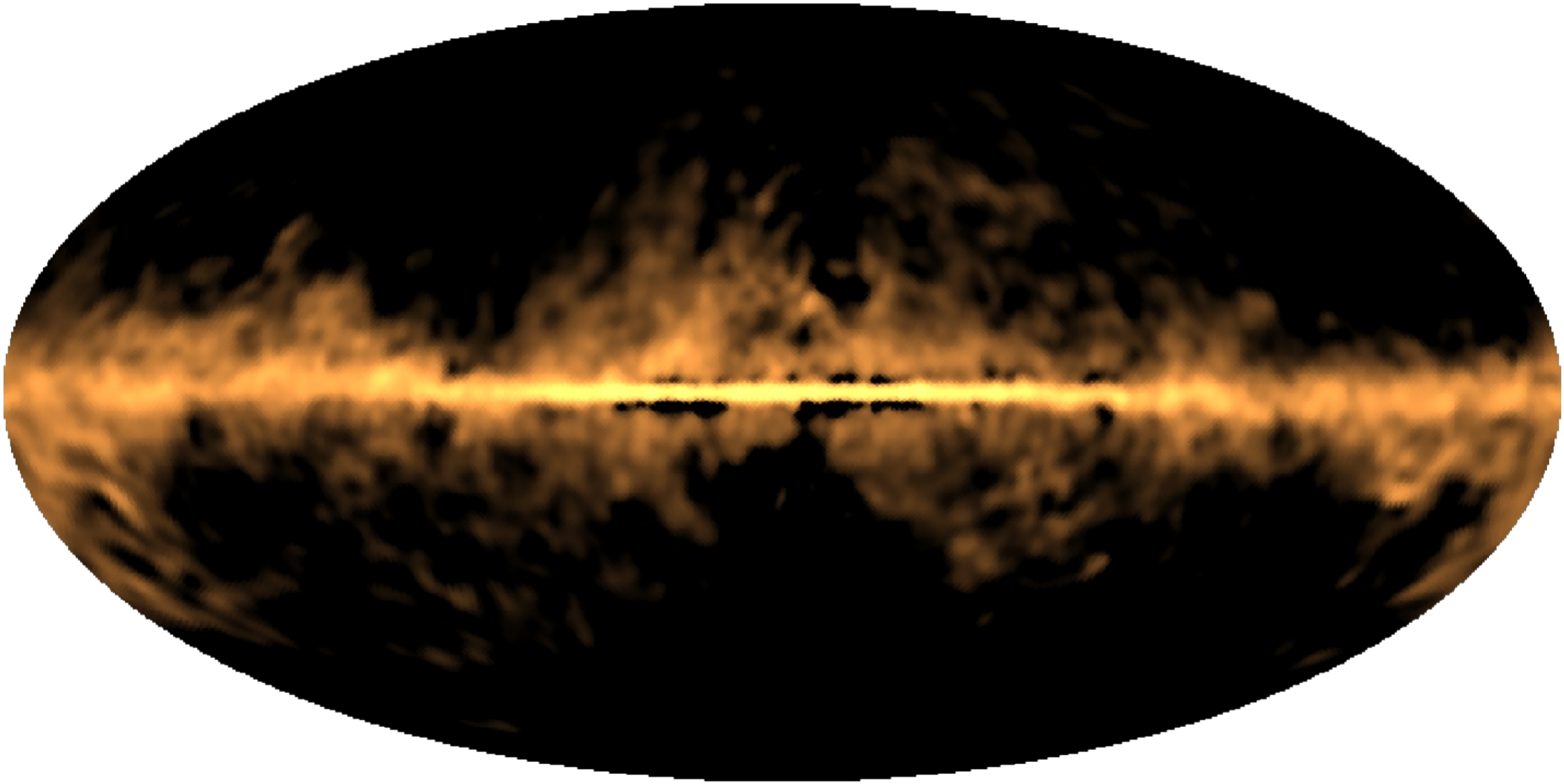
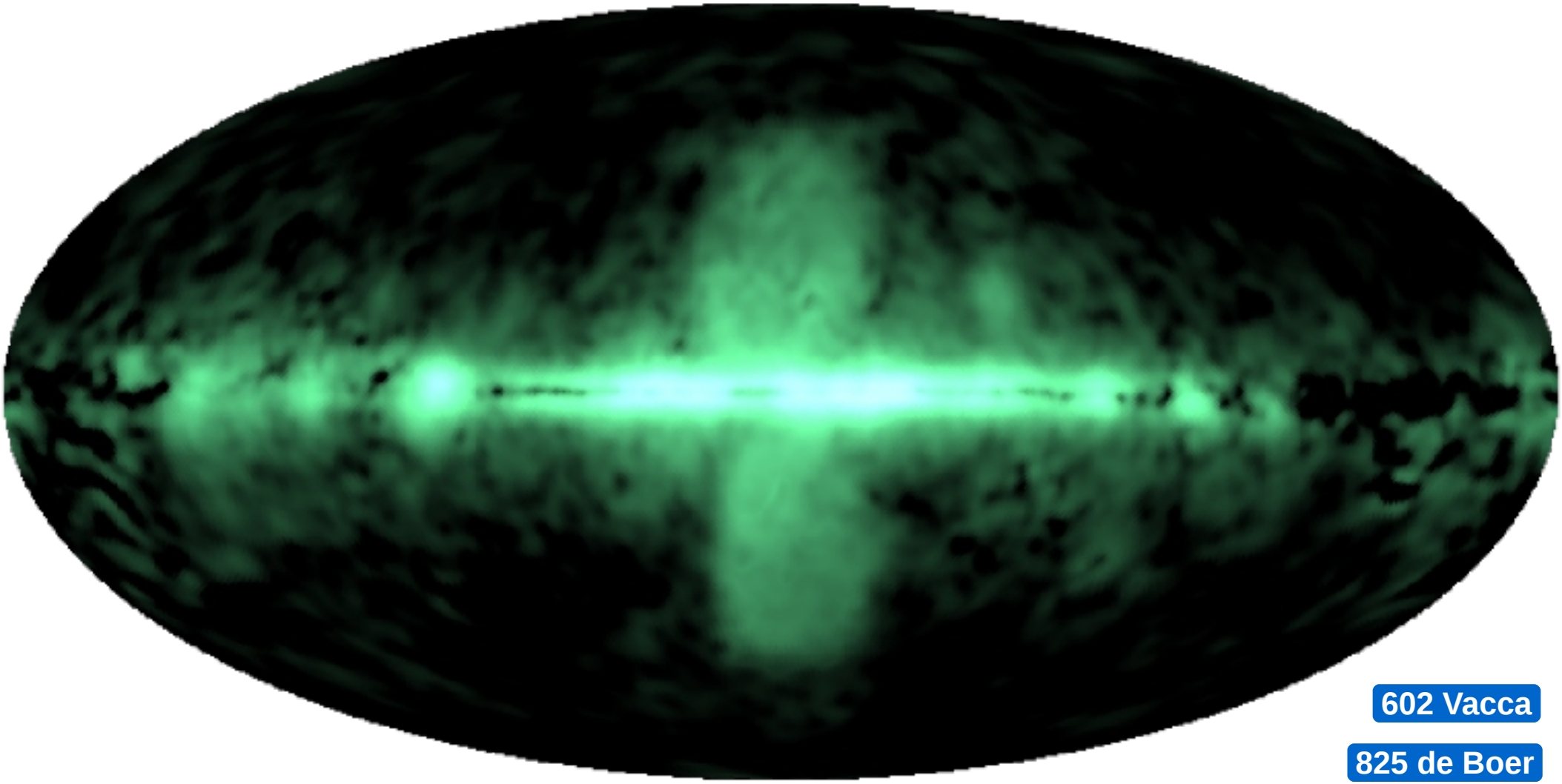


Soft diffuse component



Traces dust in first approximation – concentrated in the plane

Hard diffuse component

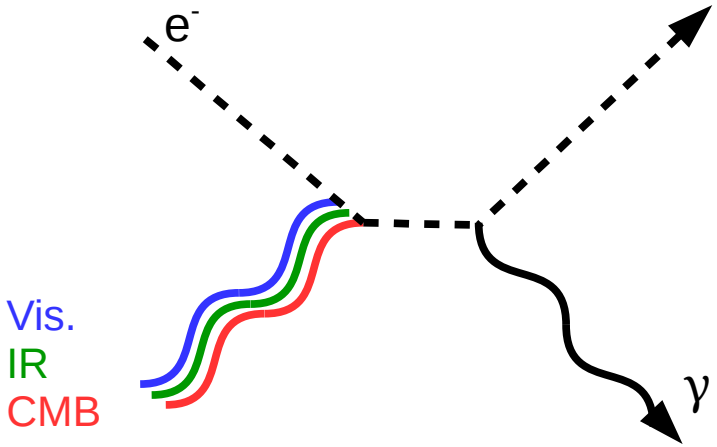


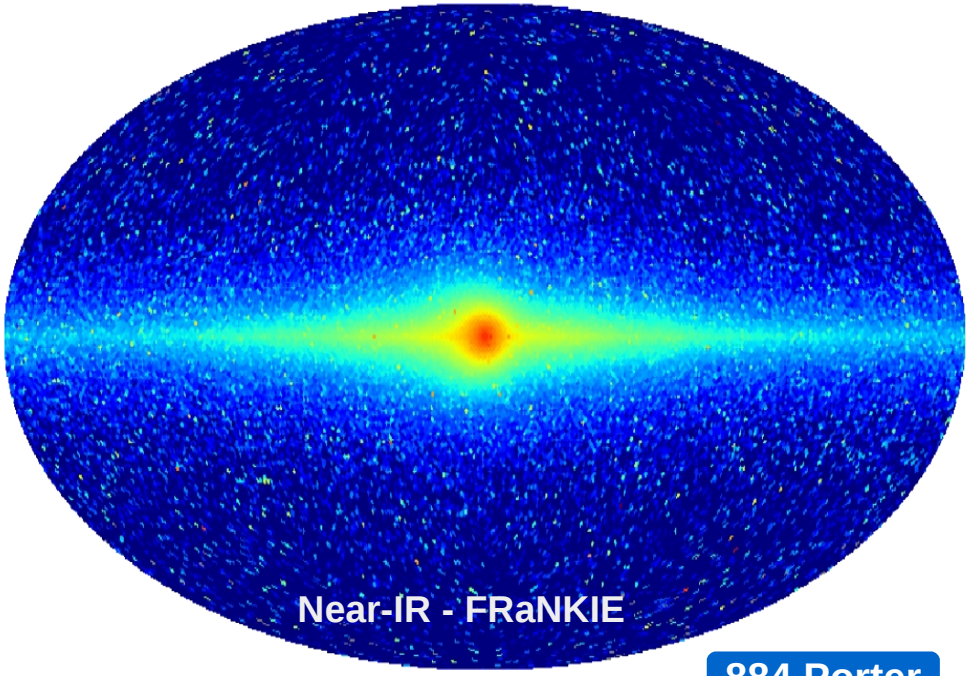
602 Vacca

825 de Boer

Extends to higher galactic latitudes – prominent “Fermi Bubbles”

Inverse Compton γ-rays





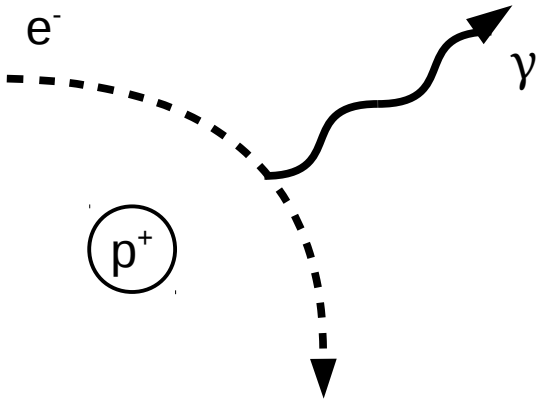
$$\Gamma_\gamma \approx \frac{\Gamma_e + 1}{2}$$

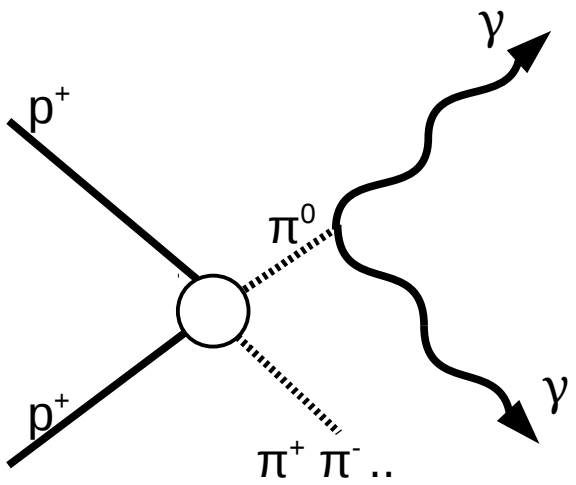
$$E_{\gamma,TeV} \approx 33\, E_{e,TeV}^2\, E_{T,eV}$$

1) Electron of ≈ 5 GeV – 5 TeV

2) Hard spectrum ($\Gamma_\gamma \approx 2.3$ for local $\Gamma_e \approx 3.3$)

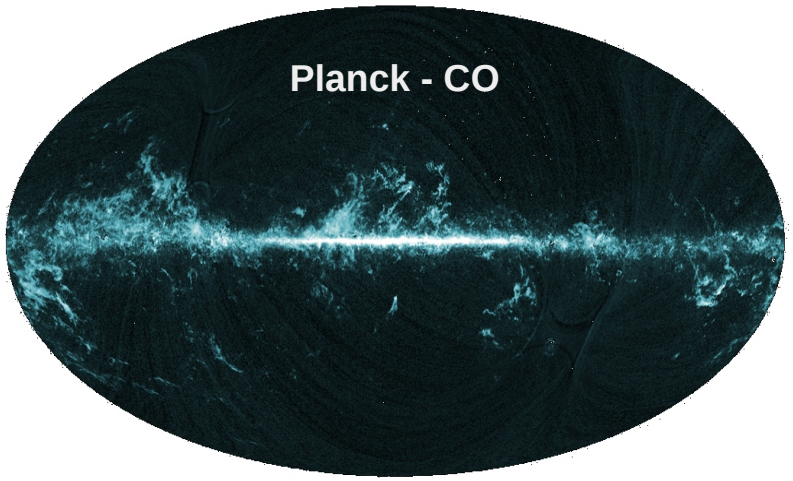
Bremsstrahlung and π^0 decay γ-rays





$$E_\gamma \approx 0.1 - 0.3\, E_{p,e}$$

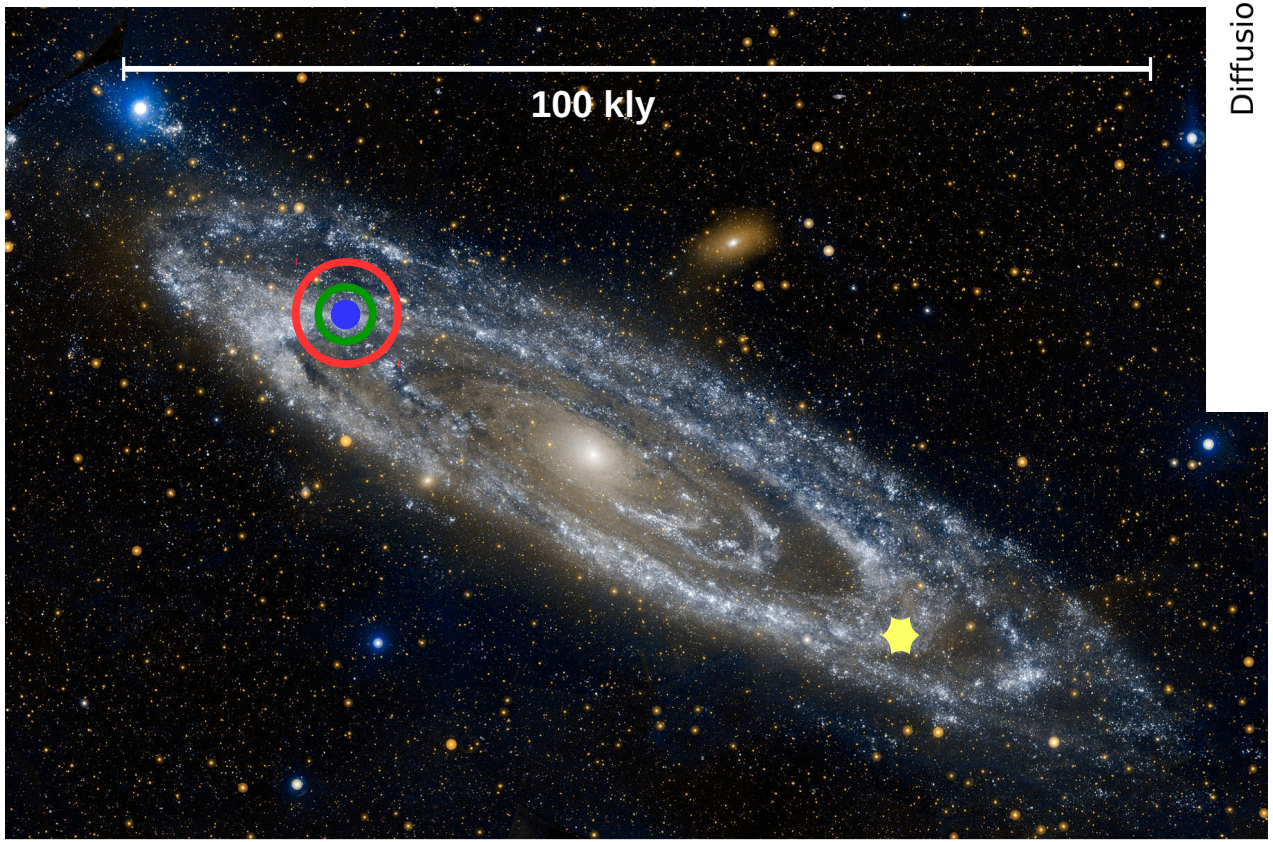
$$\Gamma_\gamma \approx \Gamma_{p,e}$$

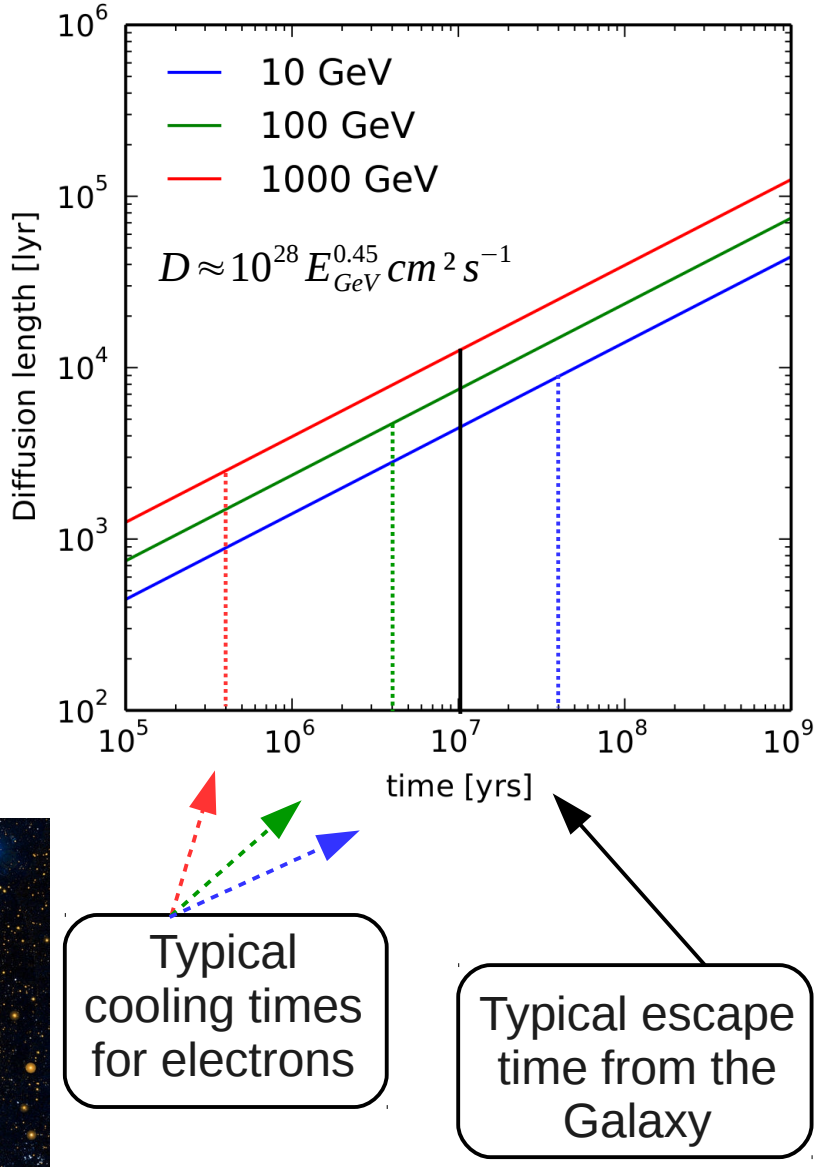


1) Protons (electrons) of ≈ 3 GeV – 1 TeV
2) Softer spectrum (local $\Gamma_p \approx 2.7$)
3) Strong concentration in galactic plane

Cosmic-ray propagation

To first oder: At γ-ray energies 1-100 GeV we observe a “rather localized” cosmic-ray density





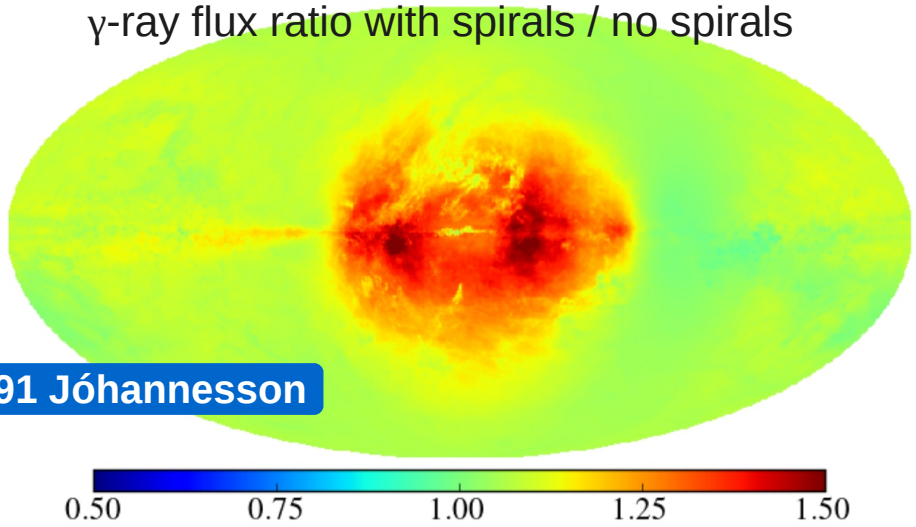
Cosmic-ray propagation

Cosmic-ray propagation codes GALPROP, PICARD, DRAGON increasingly realistic. Take into account:

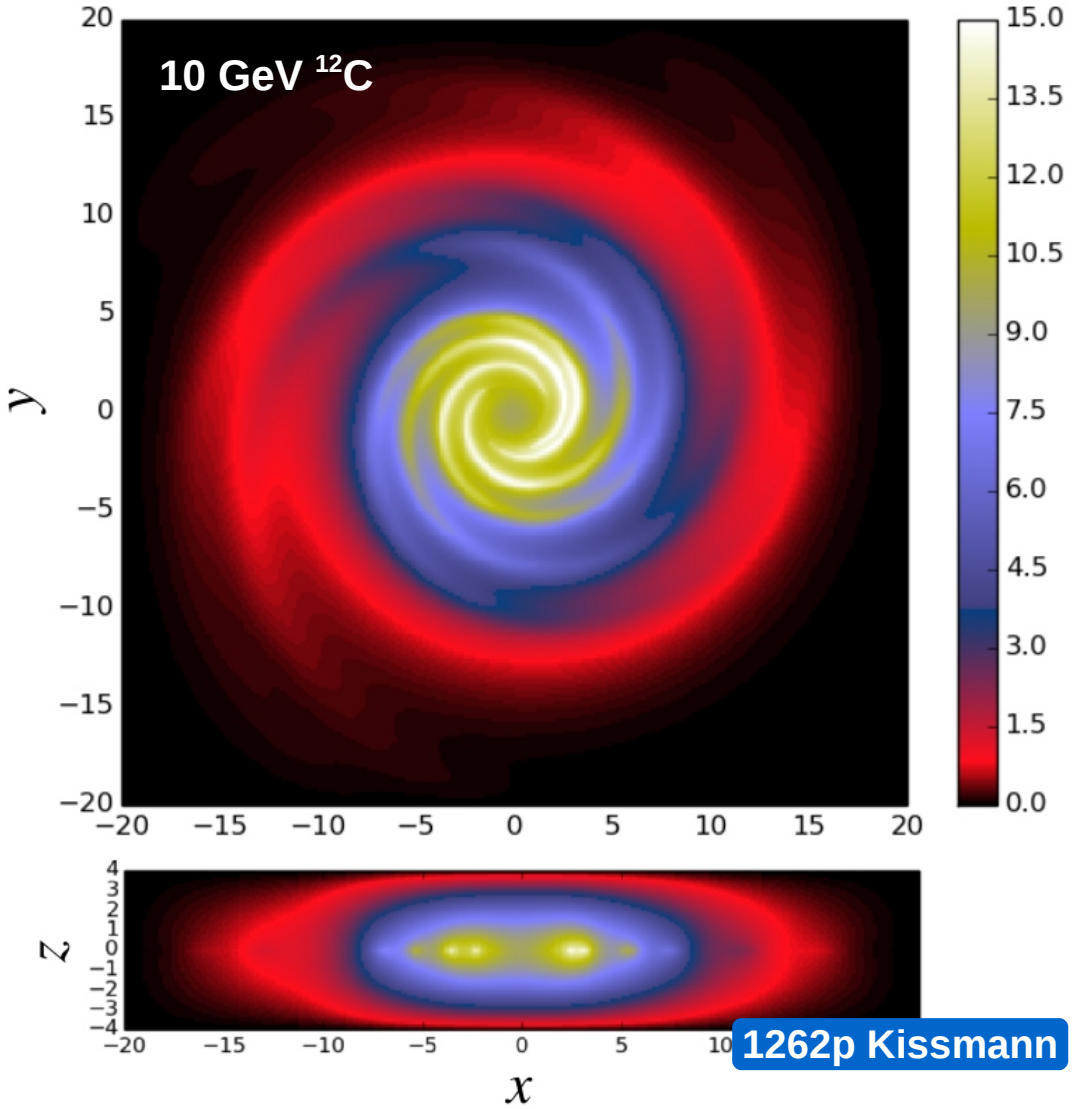
- 3D spiral arm structure
- Anisotropic diffusion

398 Moskalenko **1207 Orlando** **228 Gaggero**

γ-ray flux ratio with spirals / no spirals



691 Jóhannesson



1262p Kissmann

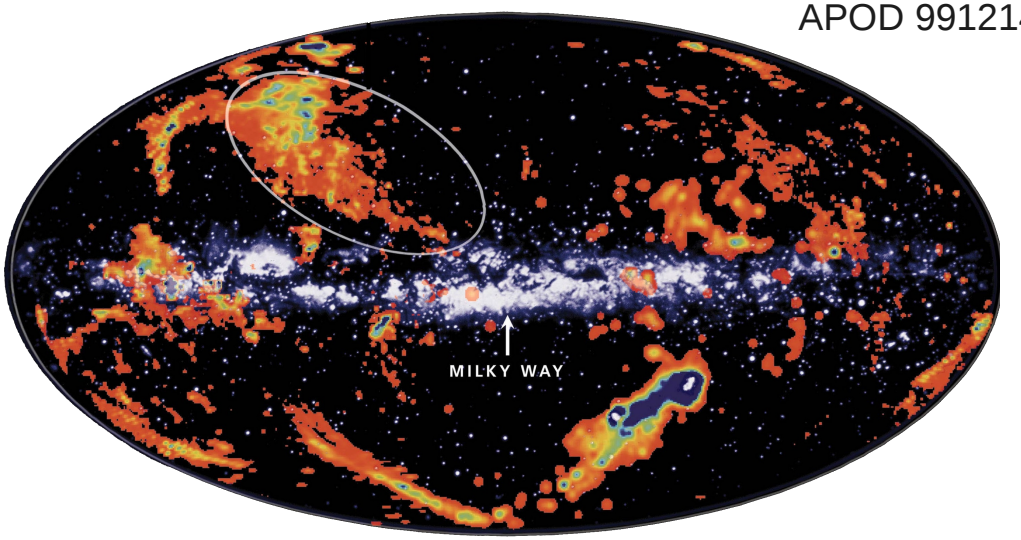
Cosmic-ray propagation

Emissivity = γ-ray flux / mass

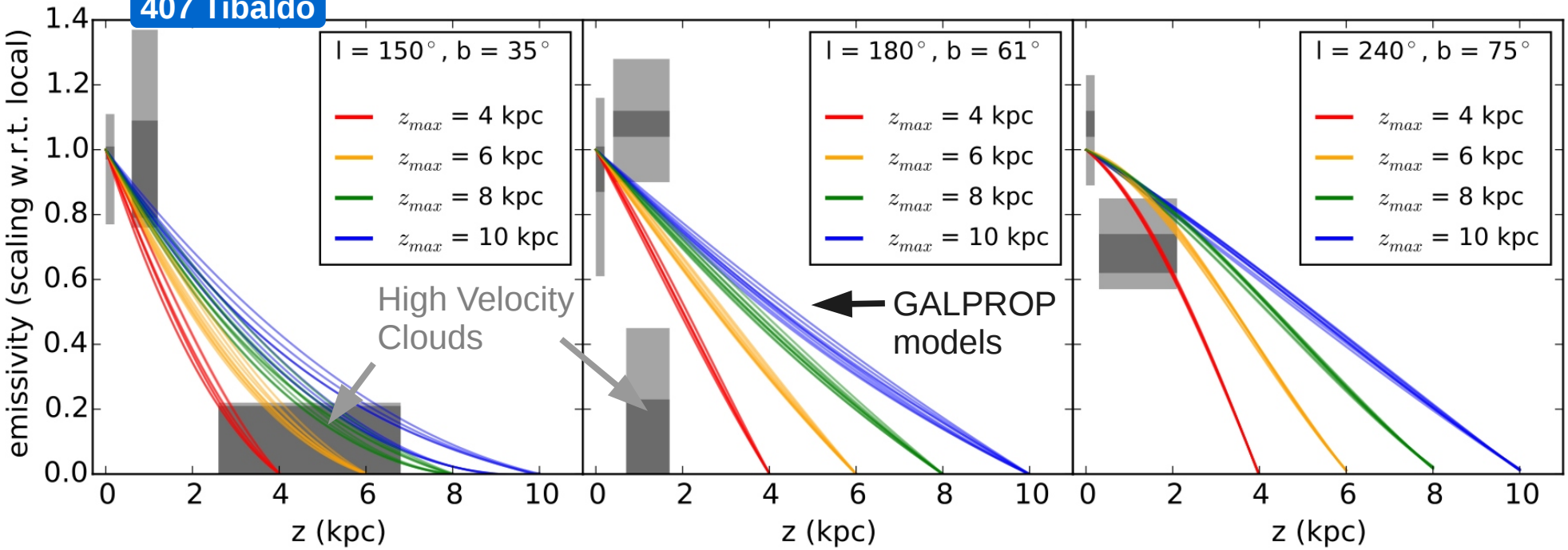
Reveals cosmic-ray density, decreasing above the galactic disk

545 Strong

High Velocity Clouds
APOD 991214



407 Tibaldo

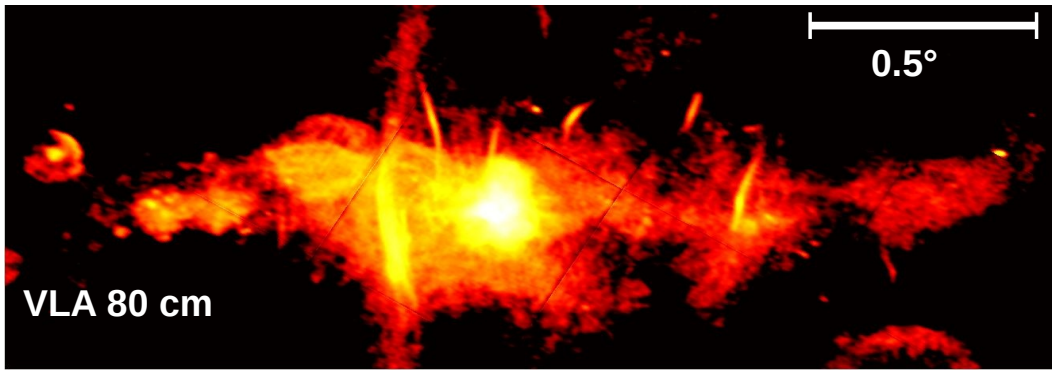


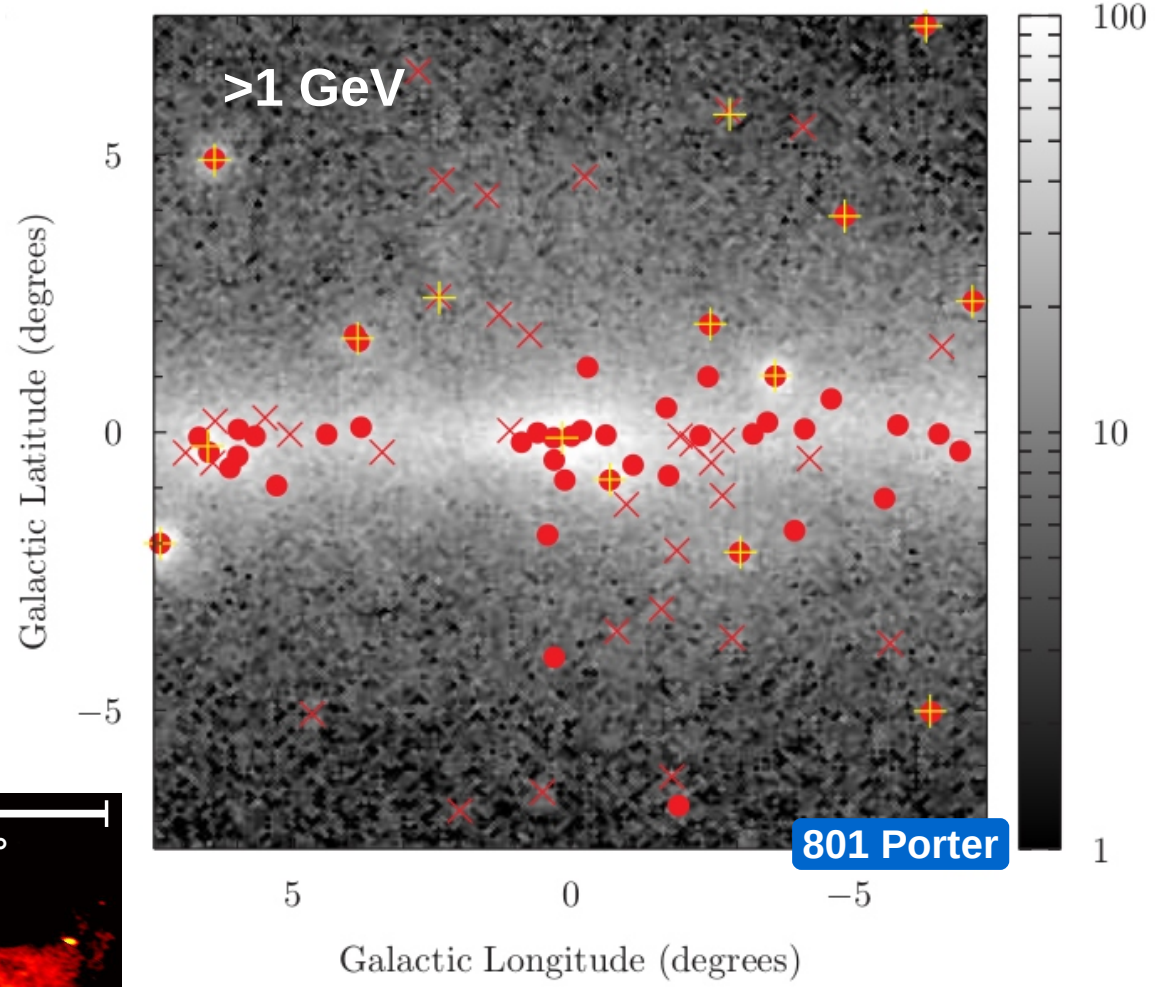
The Galactic center

One of the most interesting and complicated regions.
<u>Standard diffuse model not applicable</u>

Derive point source catalog from wavelet transforms

1234 Weniger





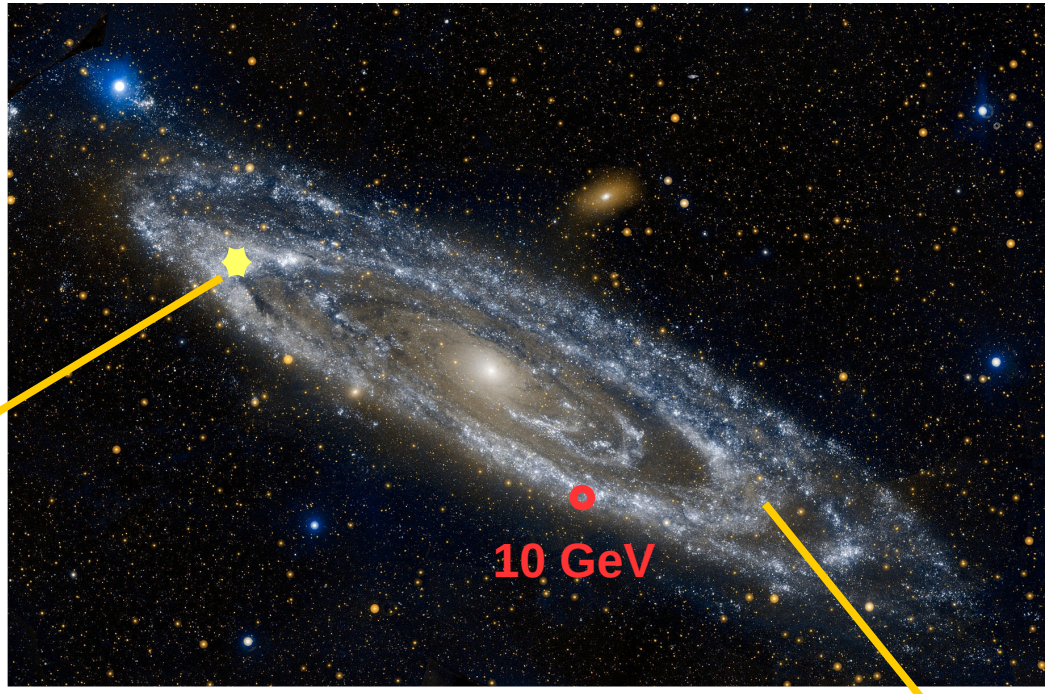
The GeV Excess

Excess above what?

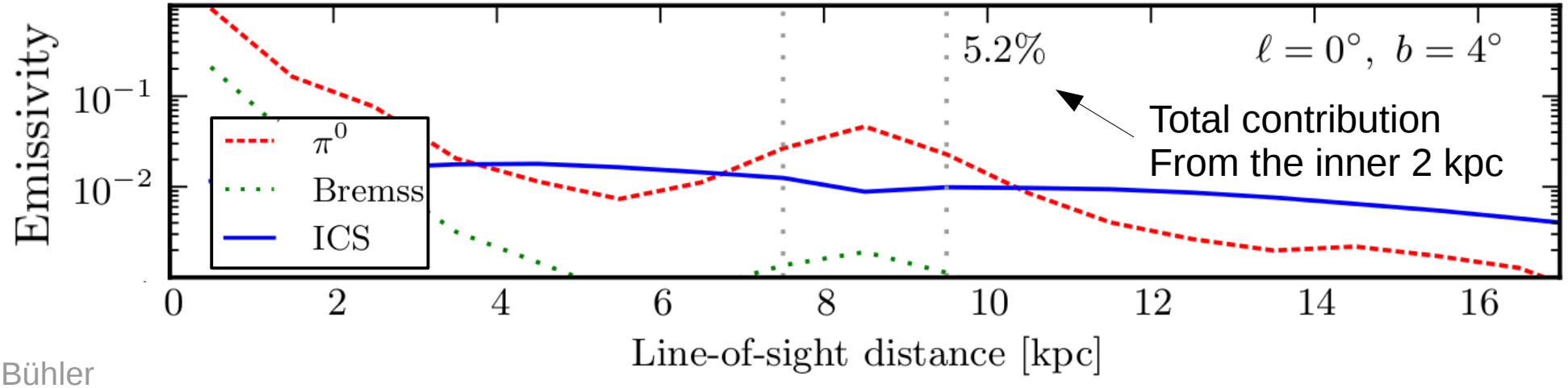
Predictions from cosmic-ray propagation codes constrained mainly by local observations

Consistently found by many authors

1140 Calore



2.6 GeV, Calore et al. JCAP 03 (2015)



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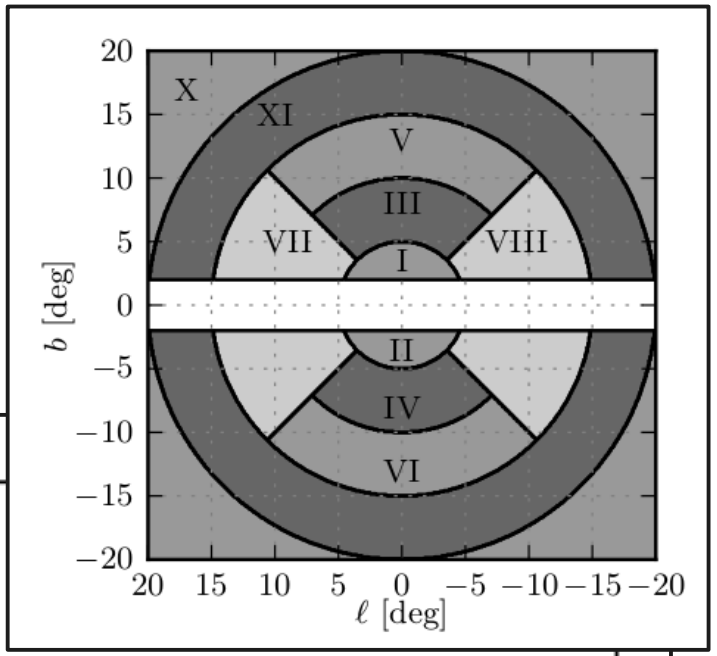

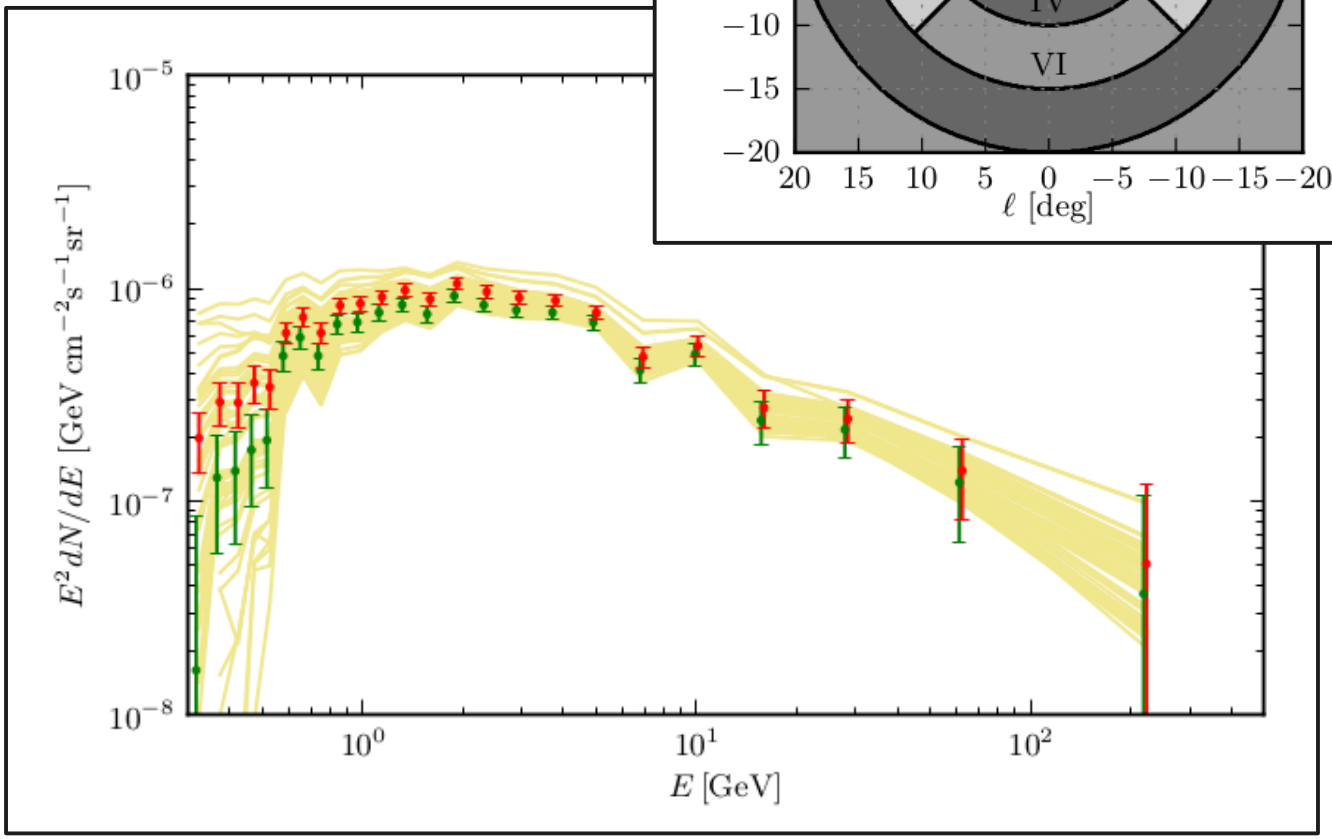

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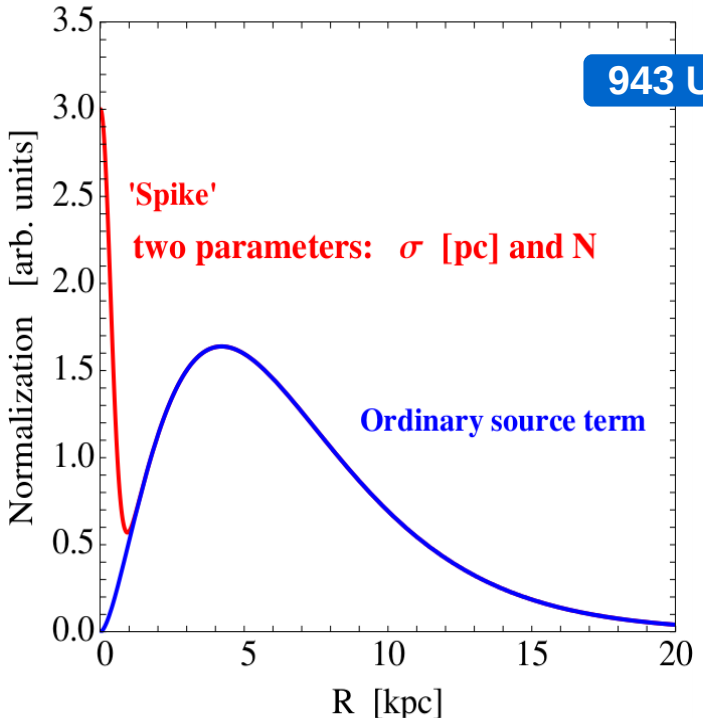
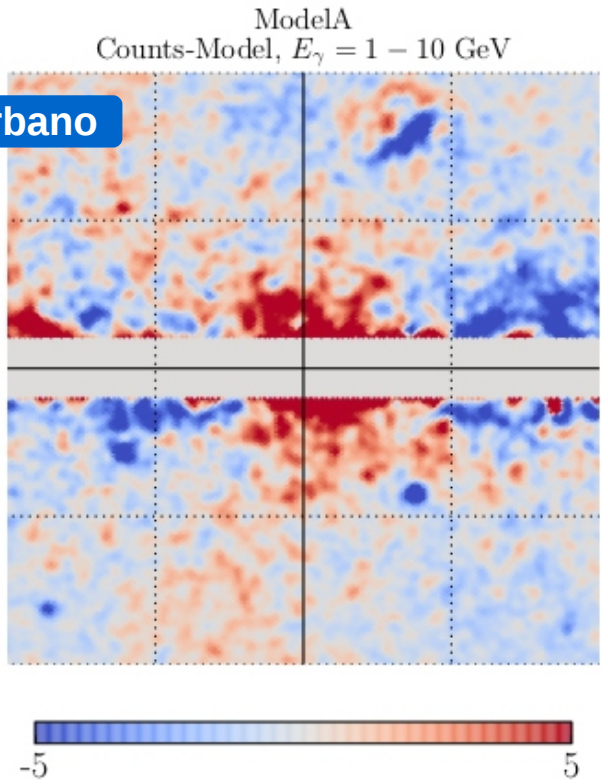
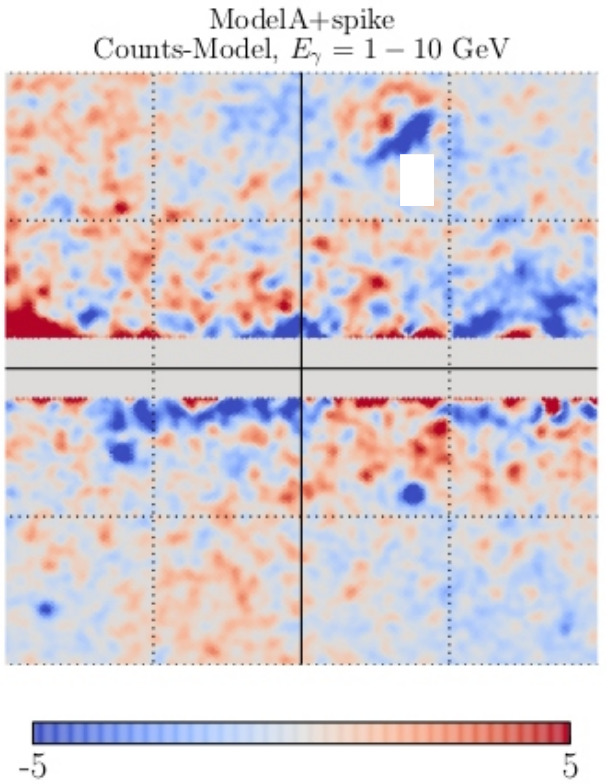


943 Urbano





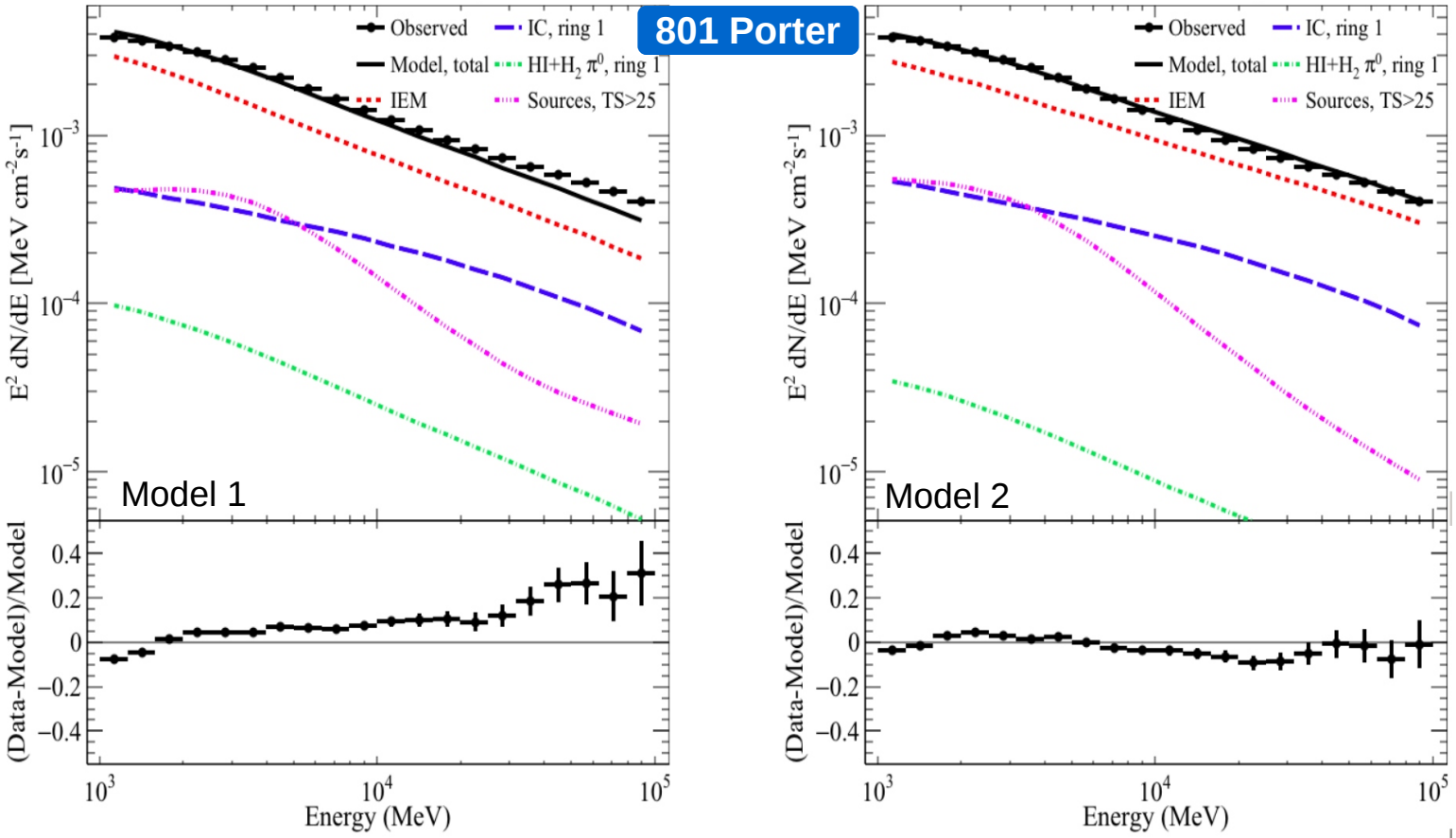
Models: source distribution, anisotropy, photon fields etc. ? 228 Gaggero 1304 Tuffs

Population of unresolved Millisecond pulsars ? 1234 Weniger

Activity of the central black hole ? 431 Macias 1140 Calore

Dark Matter ? Not covered here, see 1392 Cirelli 1174 Wood

The GeV excess



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Fermi Bubbles

Might me connected to WMAP/Planck haze

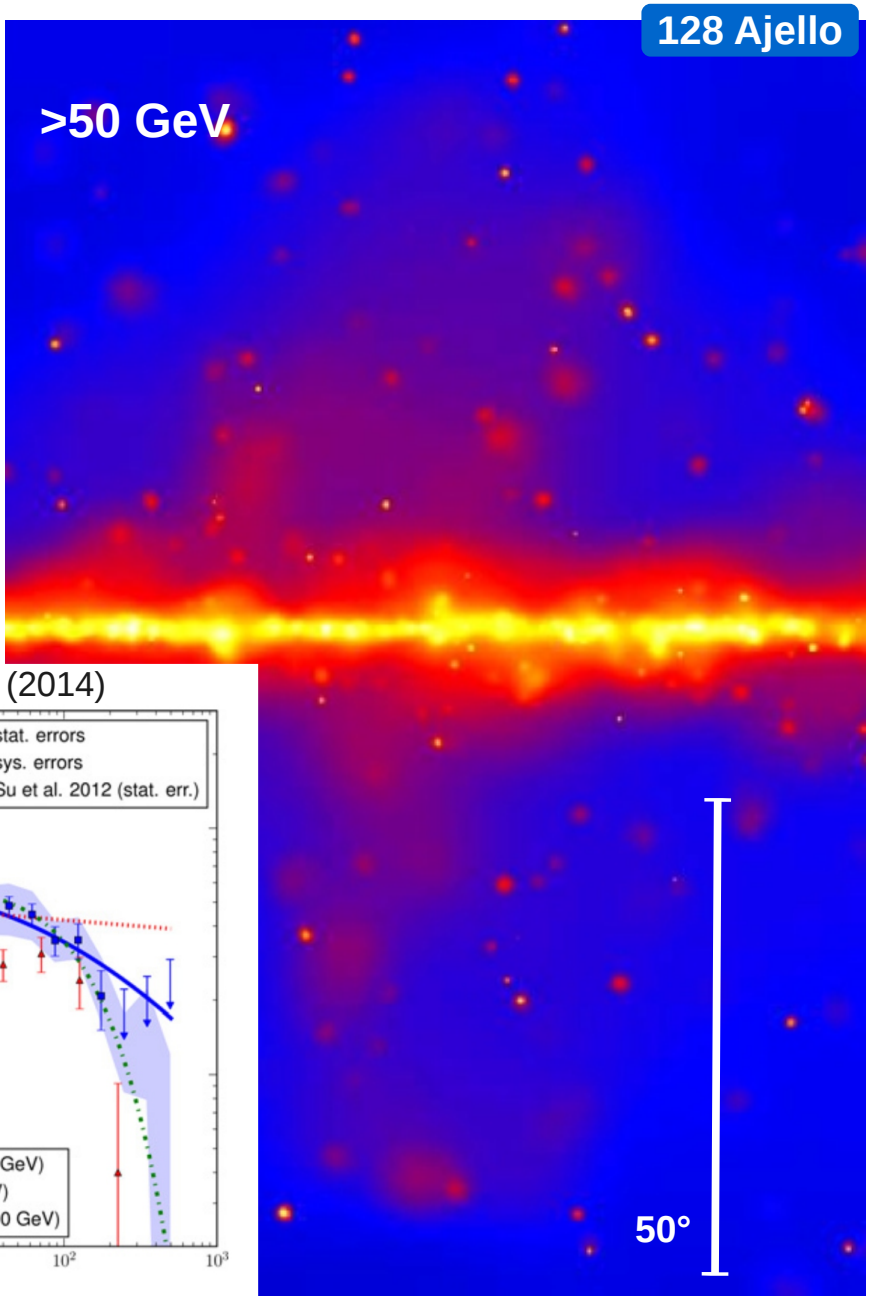
<u>γ-ray emission leptonic or hadronic</u>?

Leptonic requires burst injection (e.g. from Sgr A*) or re-acceleration to avoid cooling

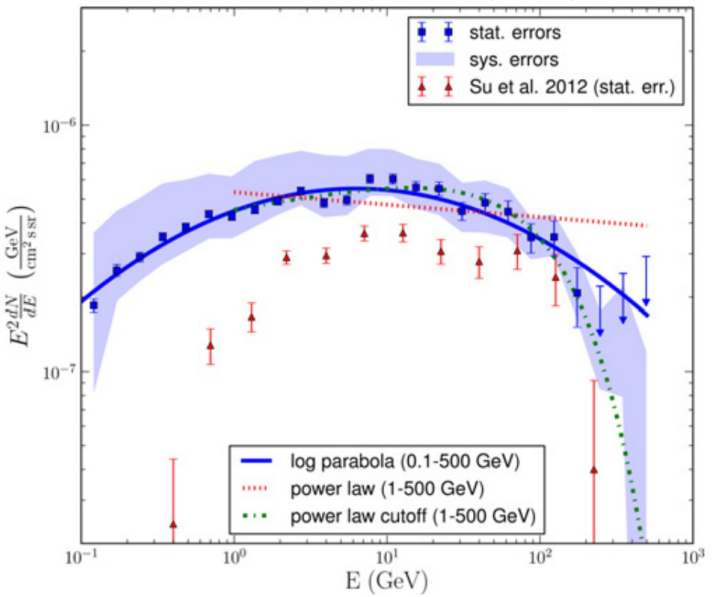
e.g.
Guo and Mathews ApJ 759 (2011)
Mertsch and Sarkar PRL 107 (2011)

Steady hadronic emission injected e.g. by star formation winds

825 de Boer **792 Crocker**



Ackermann et al. ApJ 793 (2014)



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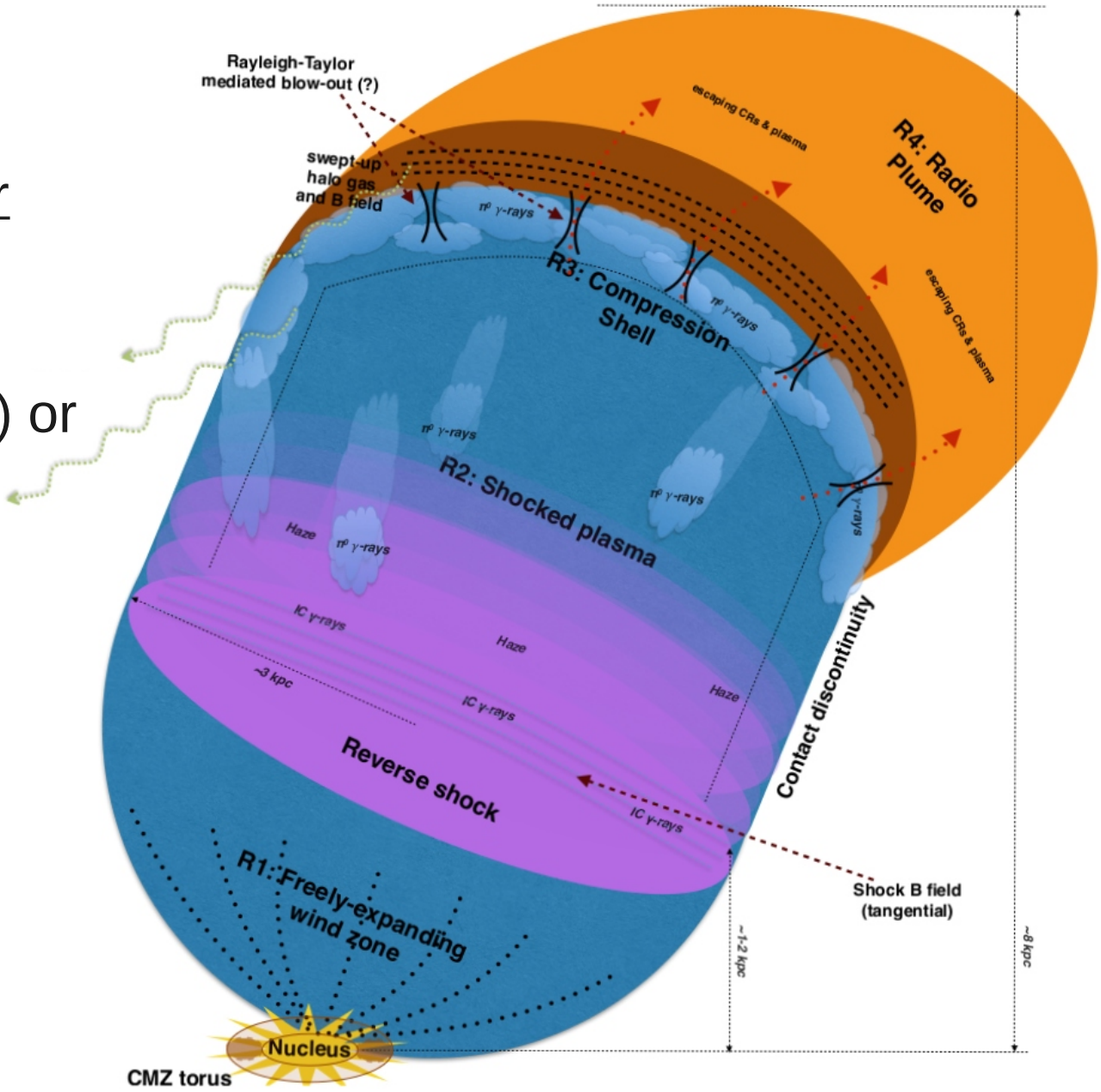
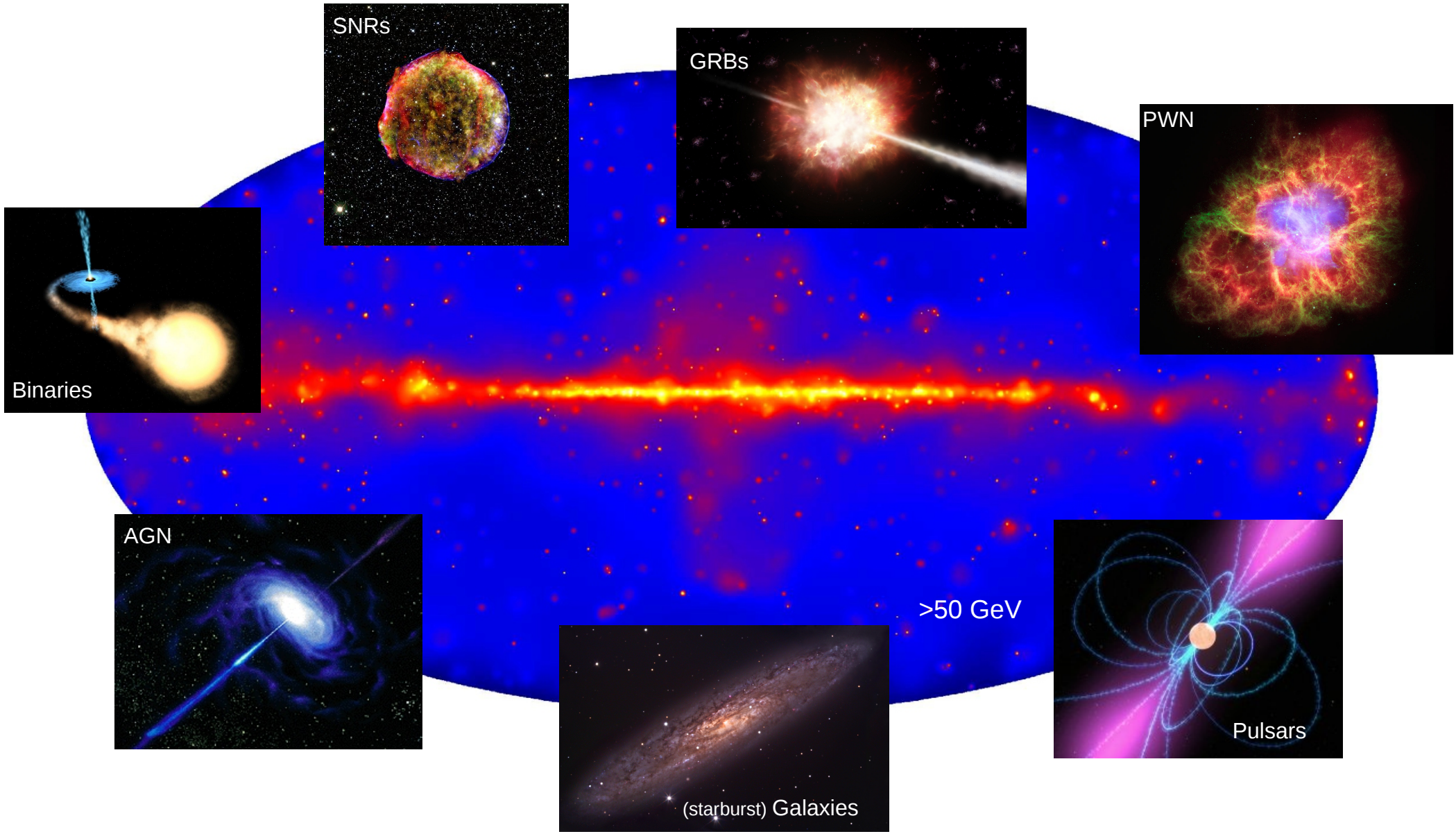


Cosmic Accelerators



The “era of catalogs”

3FGL catalog 4 yrs >100 MeV

1050 Ballet

D³PO 6.5 yrs >600 MeV

602 Vacca

Catalogs for population:

- Active Galactic Nuclei

  Based on 3FGL

  1236 Gasparrini **783 Brown**
- Super Novae Remnants

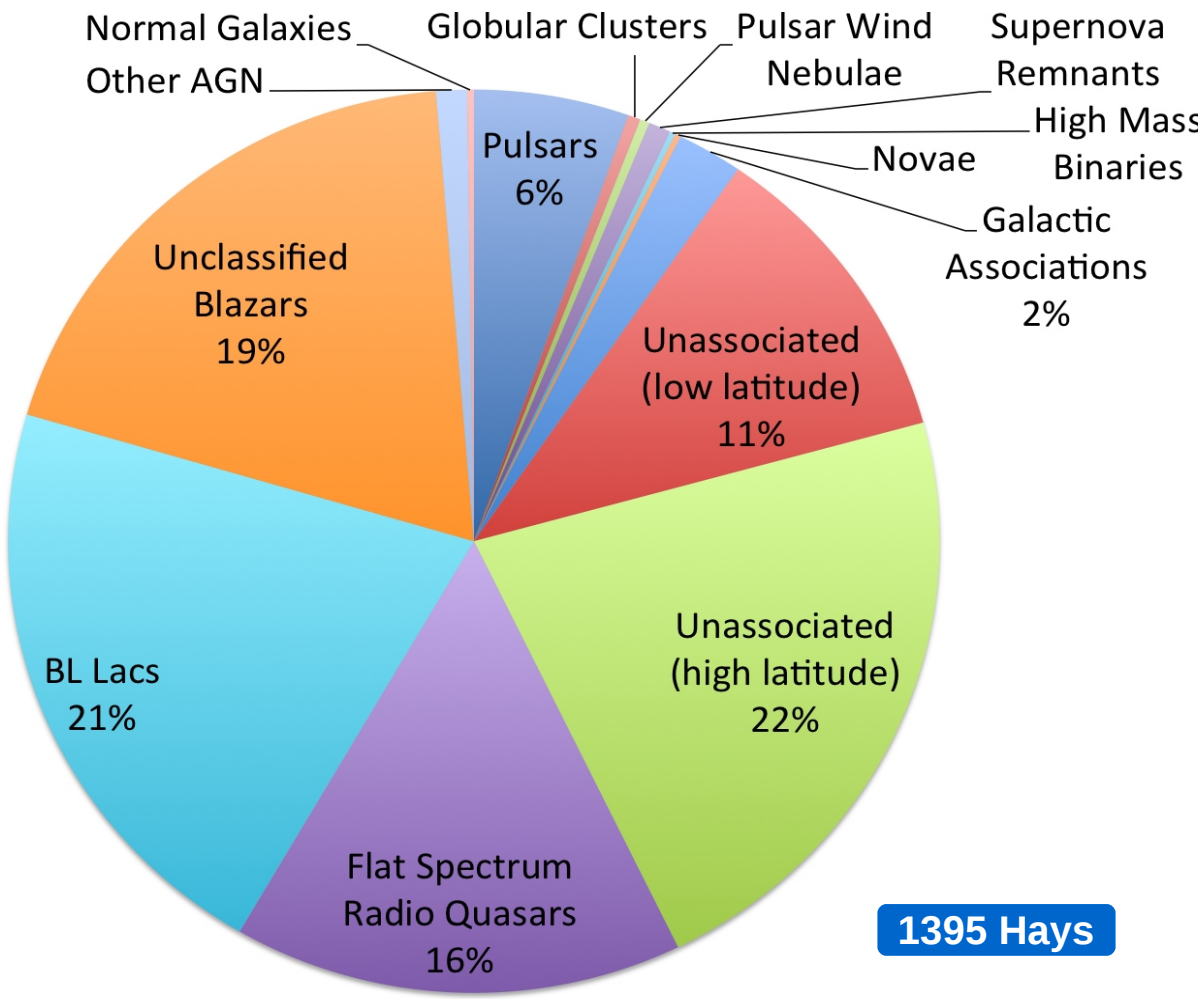
  3.5 yrs >1GeV

  259 De Palma **798 De Palma**
- Gamma-ray Bursts

  GBM > 20 keV LAT >100 MeV

  728 Bissaldi
- Millisecond Pulsars

  1019 Renault-Tinacci

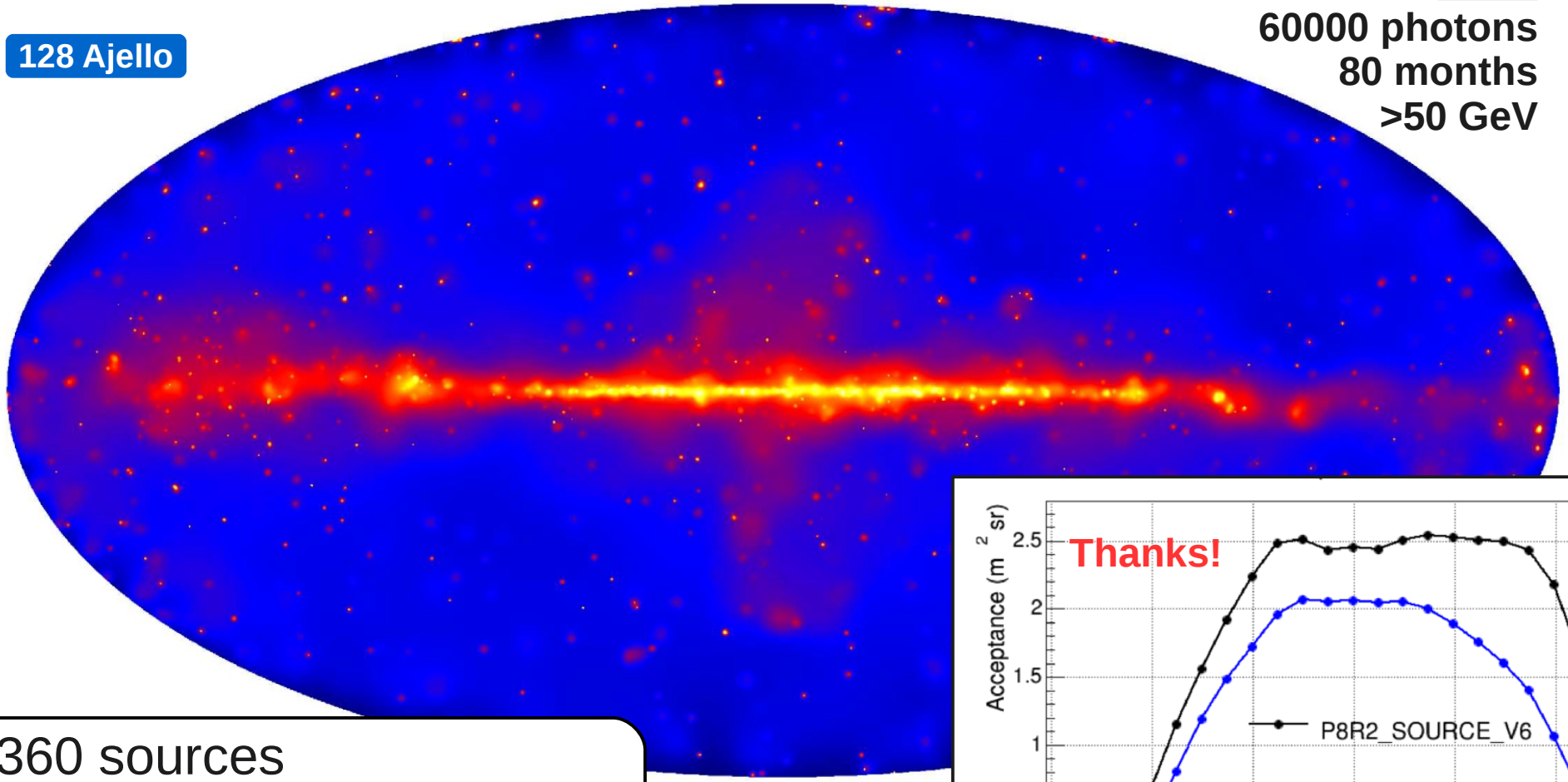


1395 Hays

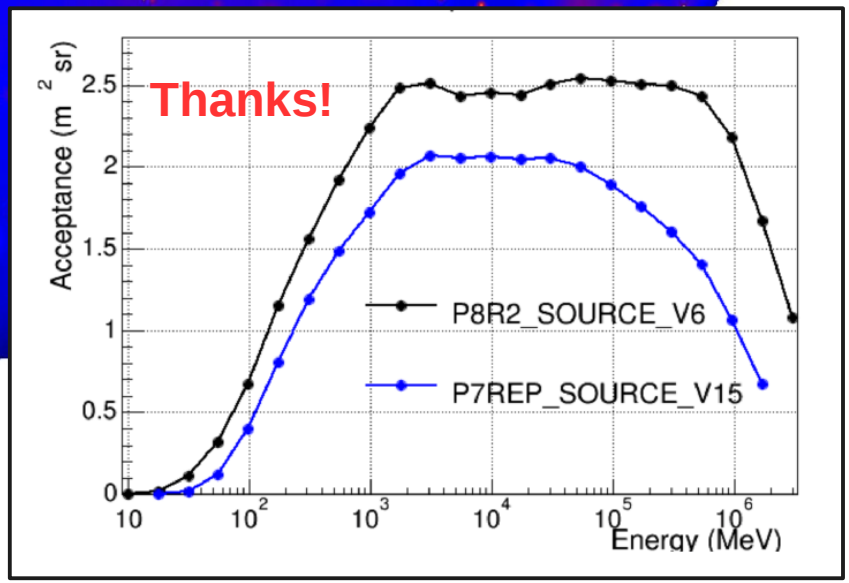
Hard sources catalog

2FHL
60000 photons
80 months
>50 GeV

128 Ajello



360 sources
78 detected also by IACTs
57 new sources



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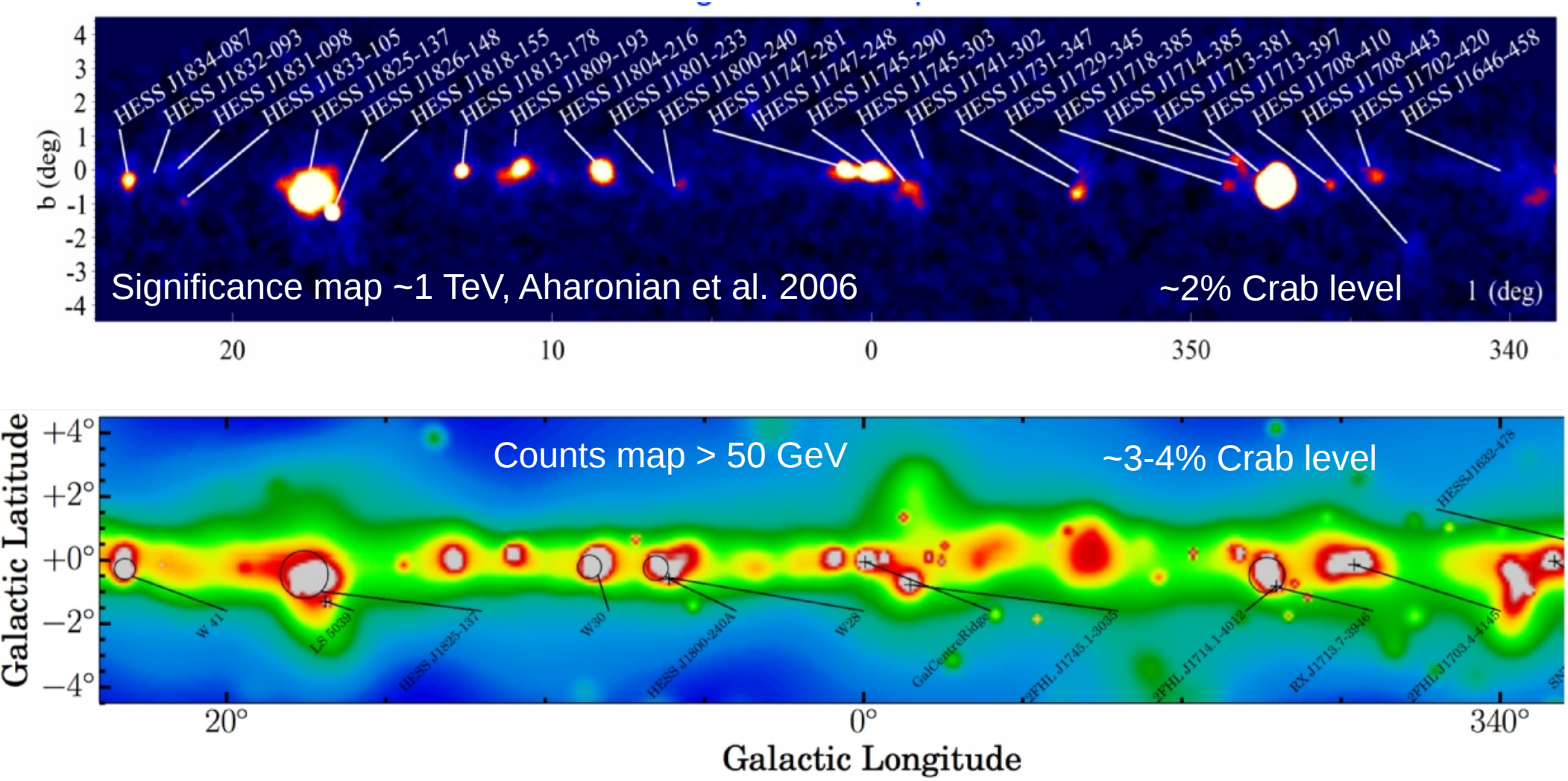


Five new extended sources in the plane

Super Novae Remnants

γ-rays hadronic or leptonic?

RCW 86 leptonic models preferred

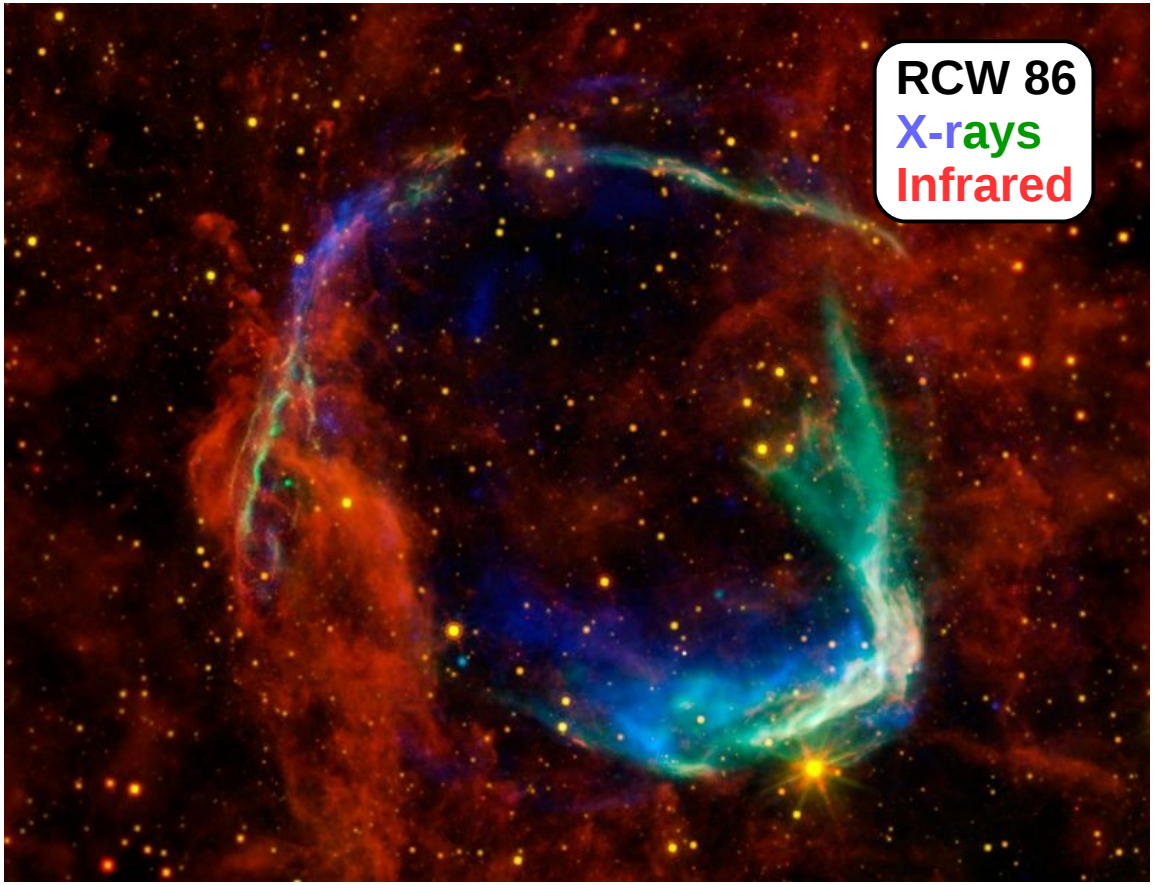
423 Condon

W51C and W49B show “pion bump”, hadronic origin preferred

1311 Jogler **1136 Brun**

SNRs accelerate both, what dominates in γ-rays depends on environment and age of the system

259 De Palma



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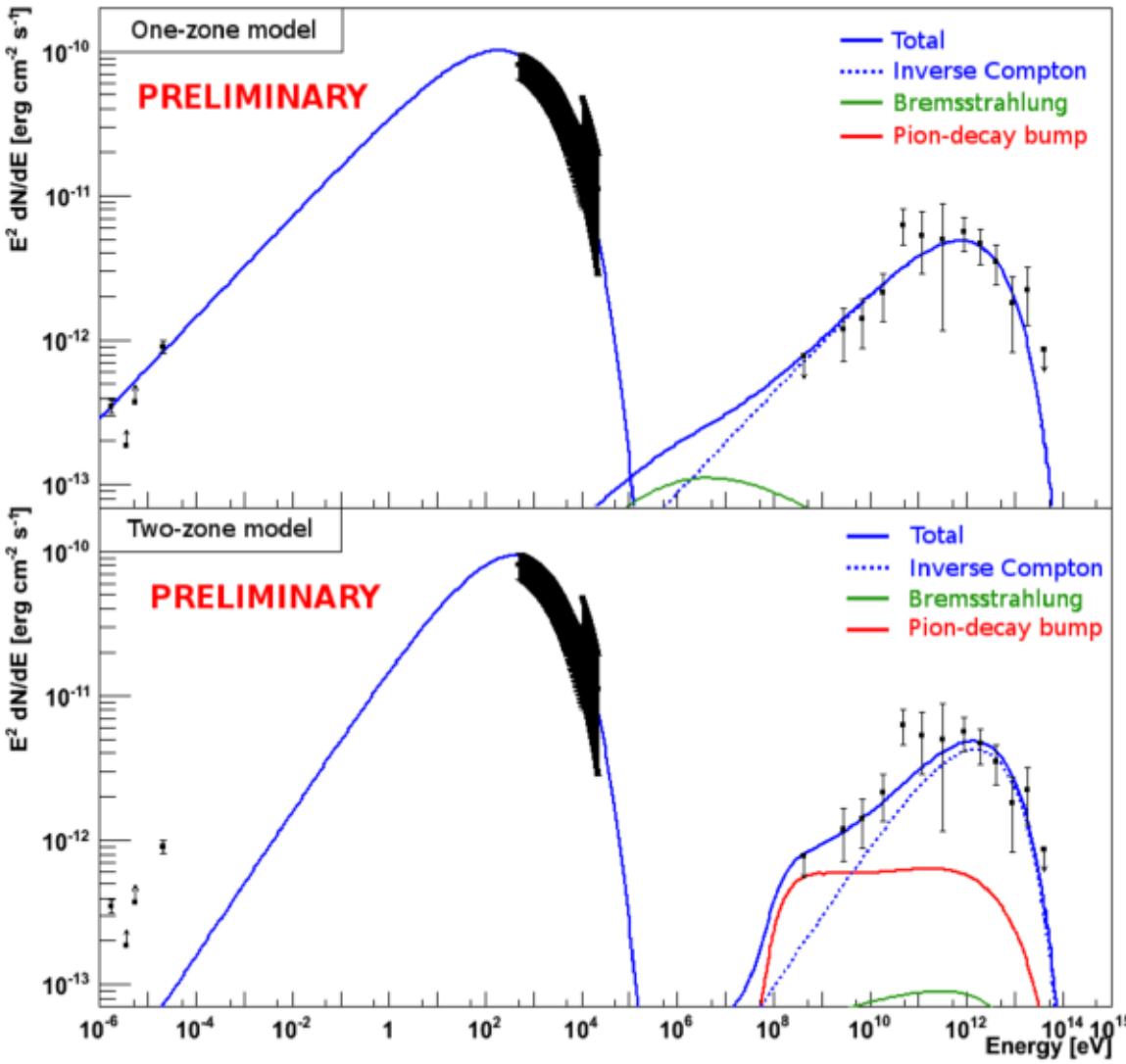

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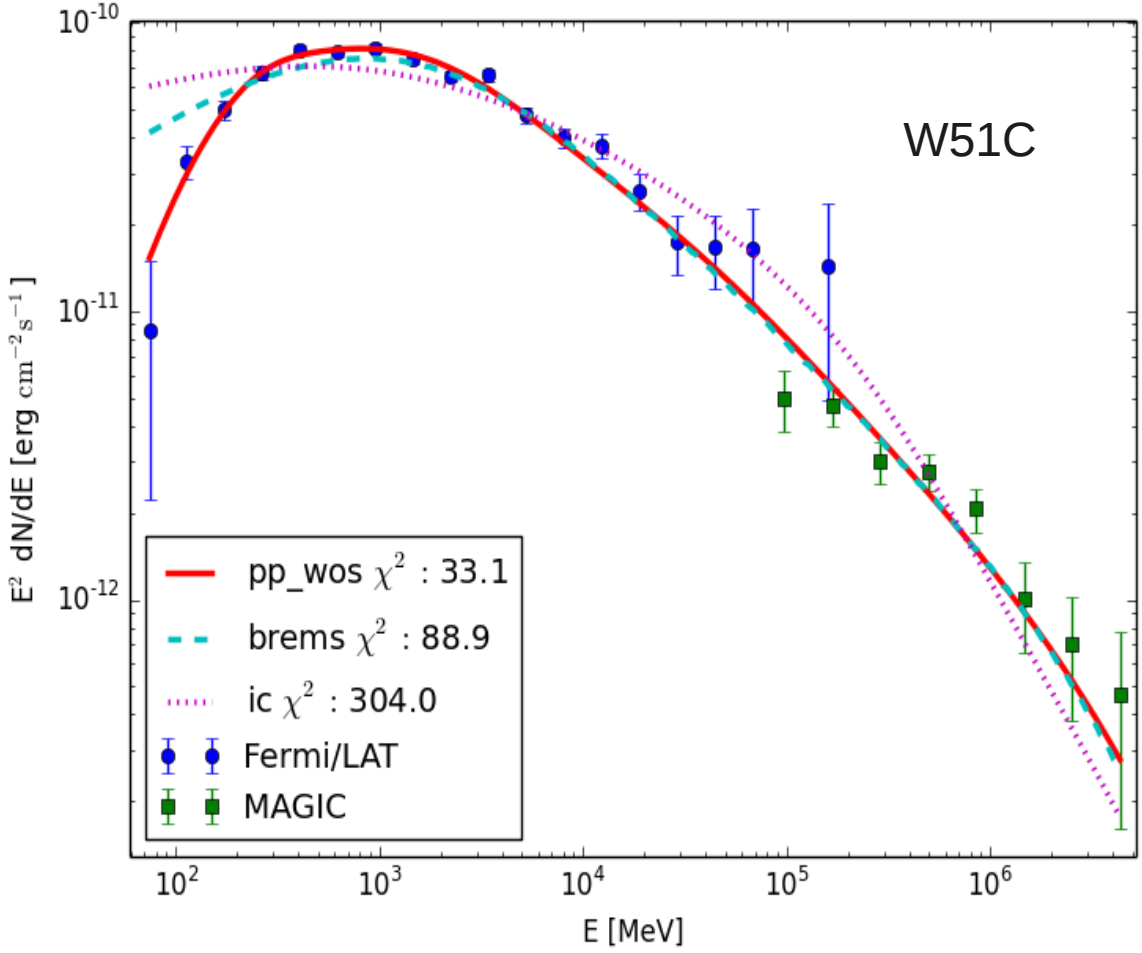
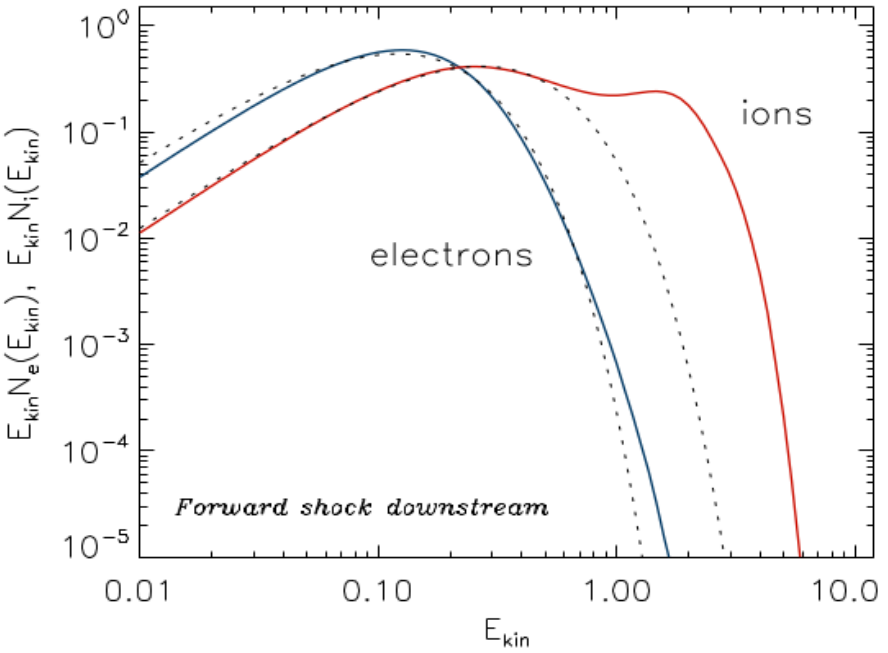


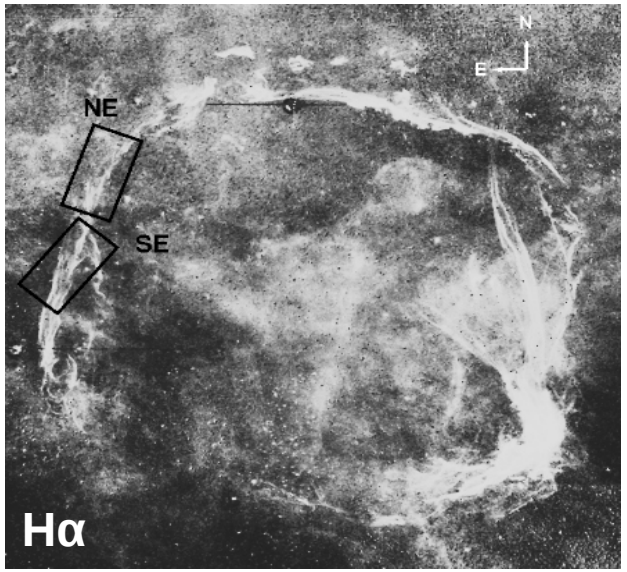
Theory of SNR shocks

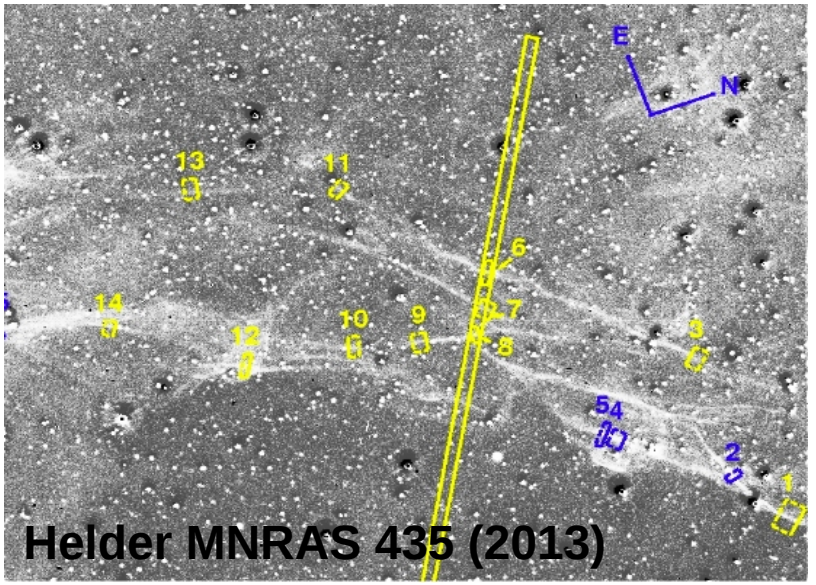
Simulations of perpendicular shocks in young SNR with Particle in Cell

455 Pohl **1385 Caprioli**

MHD simulations: cosmic-ray energy measure with Hα downstream temperature lower in inhomogeneous medium **316 Shimoda**







Nova Cen 2013
Beta Cen
Alpha Cen
Centaurus
APOD 131207

Binary systems

Six novae detected to date

Duration ~week, logParabola spectrum with peak at ~1GeV

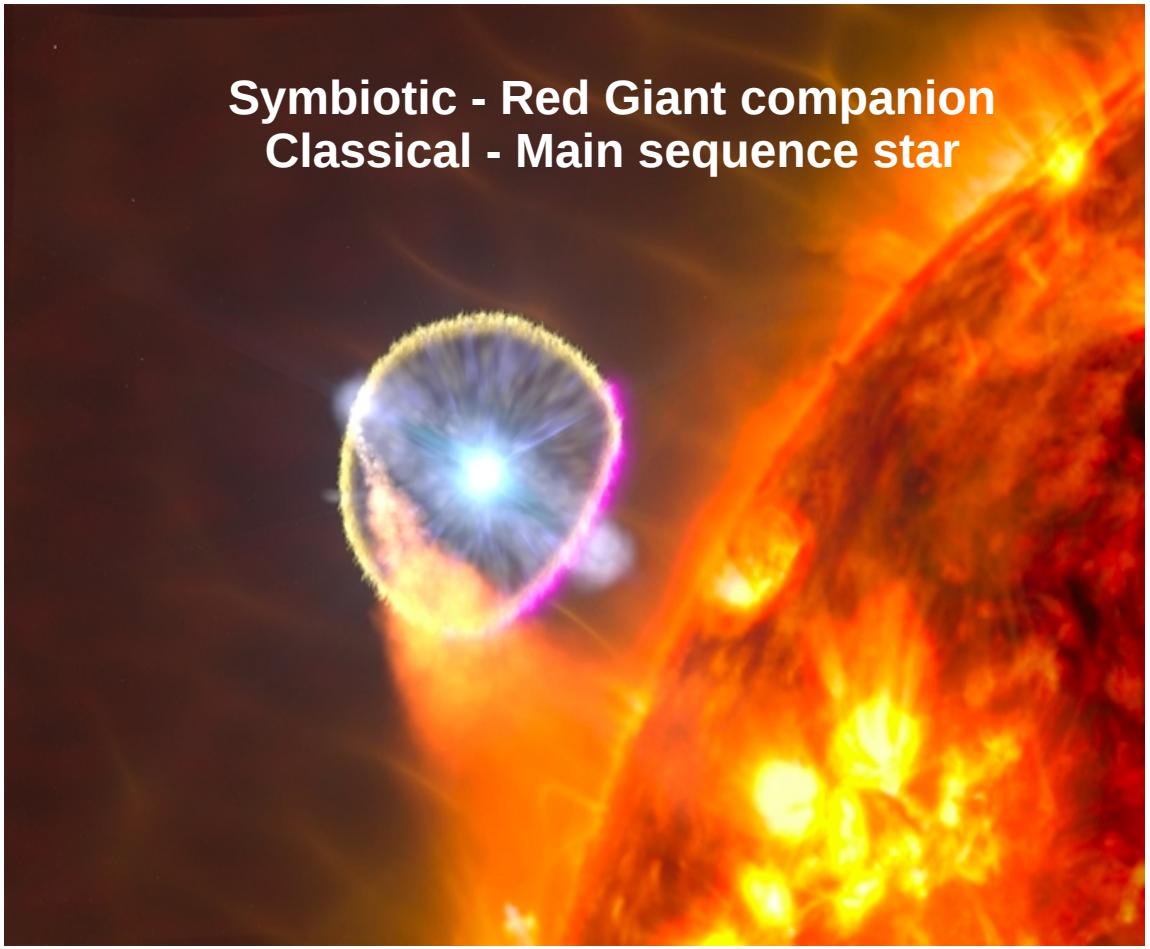
1249 Cheung

Eta Carinae only colliding wind binary in γ-rays

O-star 30 $M_\odot$ orbiting LBV 120 $M_\odot$

Hadronic and leptonic emission might dominate at different orbital phases

1020 Zabalza **1243 Reimer**



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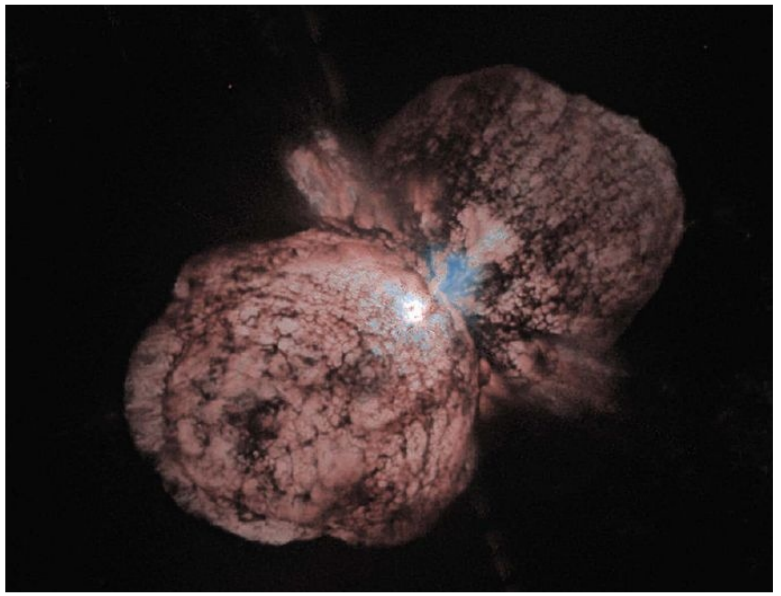
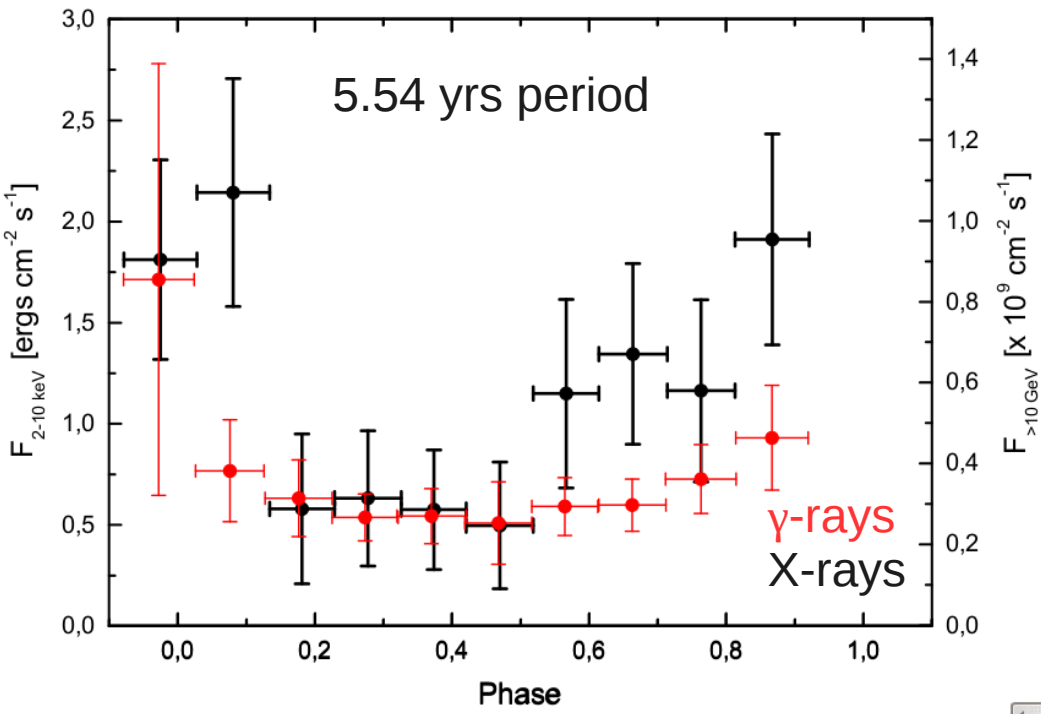




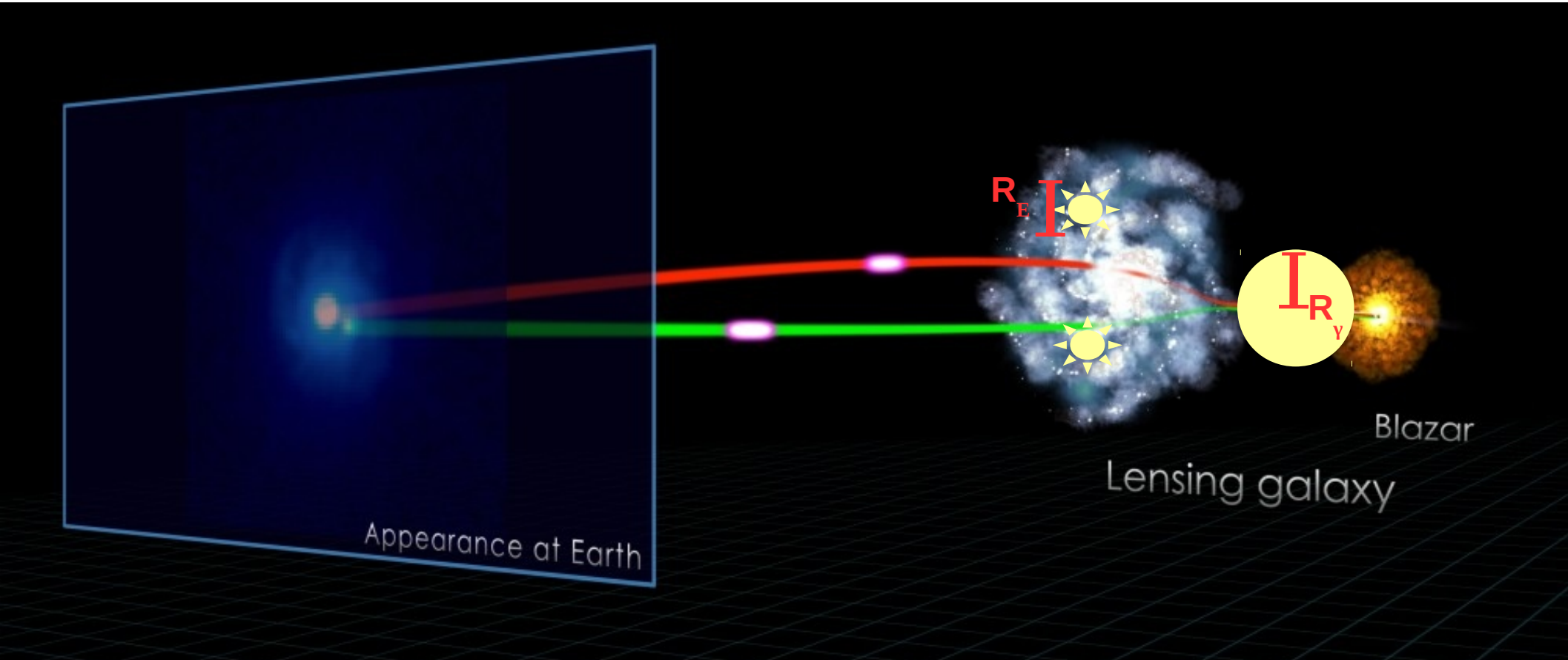
Lensed Active Galactic Nuclei

Micro-lensing in strongly gravitationally lensed galaxy B0218+357 constraint on emission region size

1224 Buson

$$R_{\gamma,proj} \lesssim R_E(M_\odot) \simeq 3 \times 10^{16}\ \mathrm{cm}$$

Vovk & Neronov arxive 1507.01092 (2015)



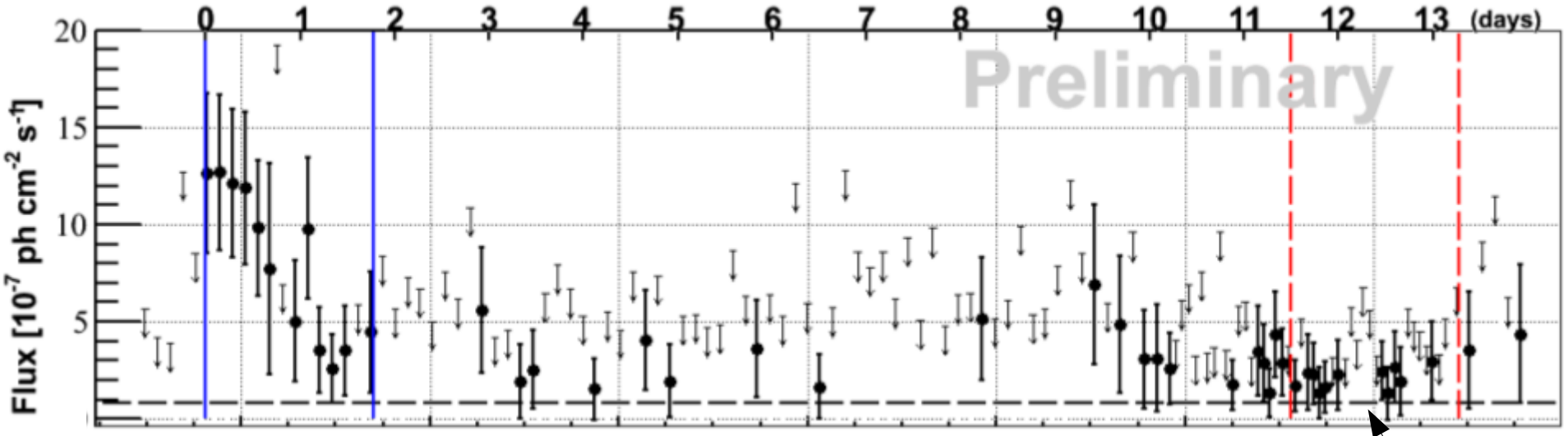
Lensed Active Galactic Nuclei

Micro-lensing in strongly gravitationally lensed galaxy B0218+357 constraint on emission region size

1224 Buson

$$R_{\gamma,proj} \lesssim R_E(M_\odot) \simeq 3 \times 10^{16}\ \mathrm{cm}$$

Vovk & Neronov arxive 1507.01092 (2015)



11.46 ± 0.16 days established in 2012 with flux ratio 1:1

MAGIC detection see next talk

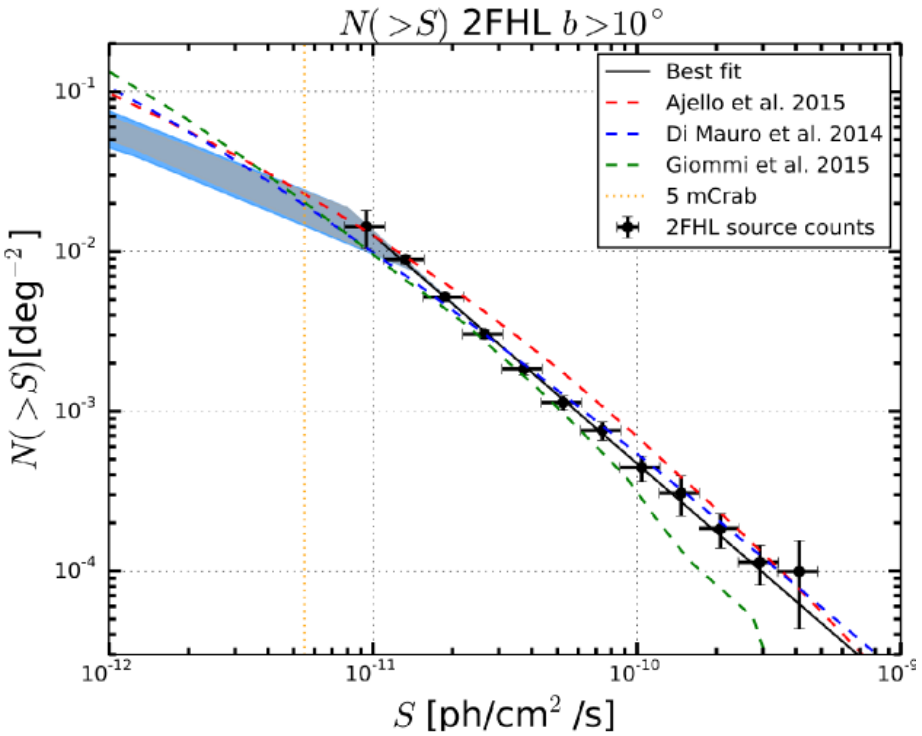
Isotropic ν's and γ-rays

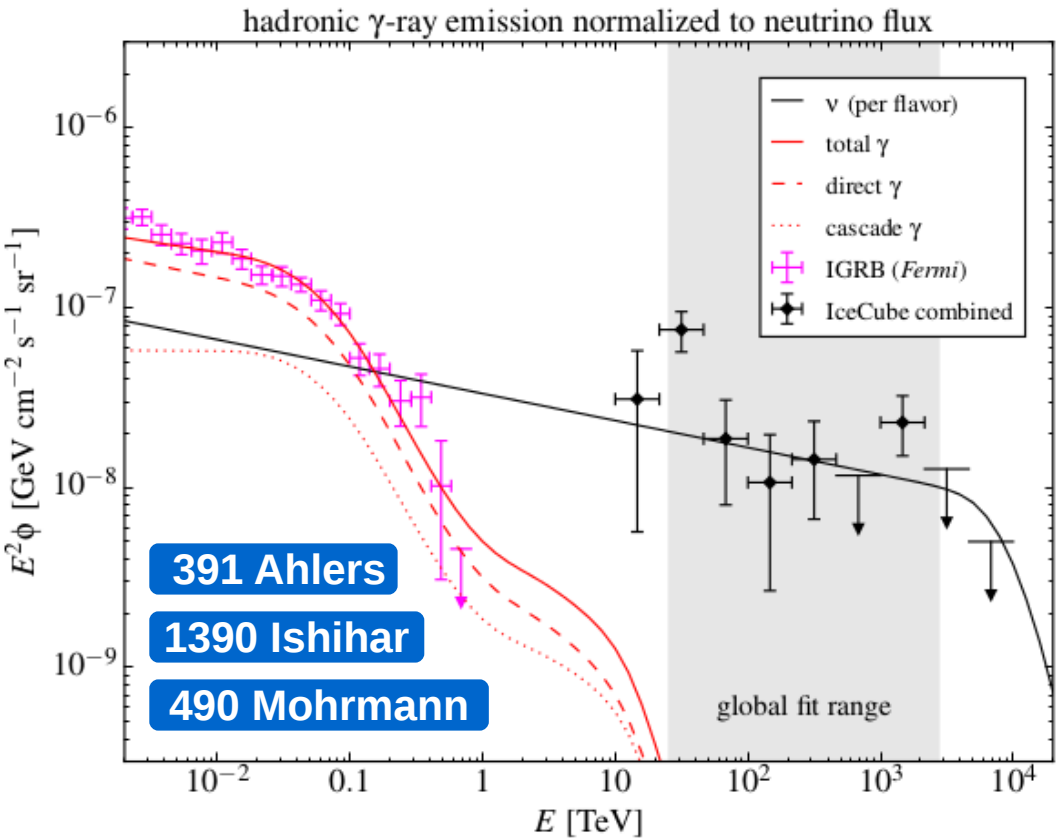
If ν's from p-p interactions tight relation between ν's and γ-ray emission

$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu$$

AGN responsible for the Extrapolating the logN/logS distribution **128 Ajello**





Future Mission

ComPair
1078 Mc Enery
1210 Moiseev

Aimed for 20's

SMILE
991 Komura

two successful balloons

Gas-TPC, 1° PSF in reach

POLAR
775 Kole

Launch 2016

50-500 keV

PANGU
386 Wu

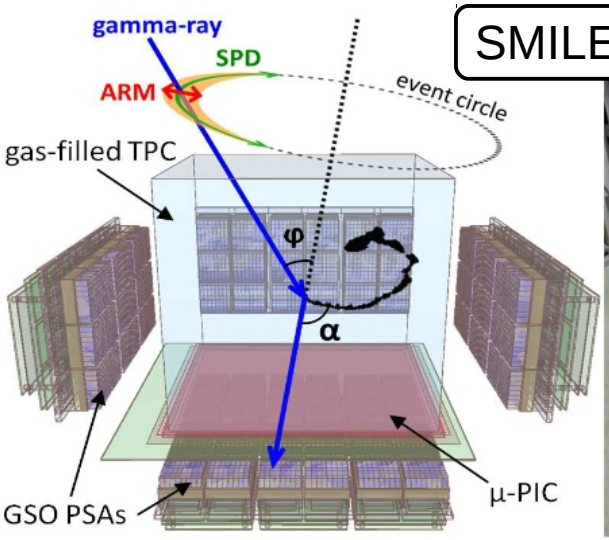
Gamma-400
1062 Topchiev

CALLET / DAMPE

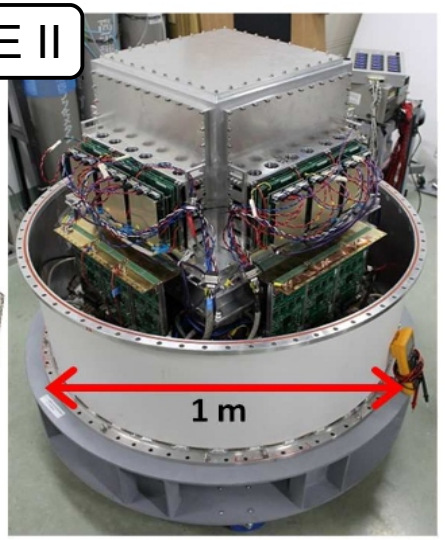
Will fly within a year

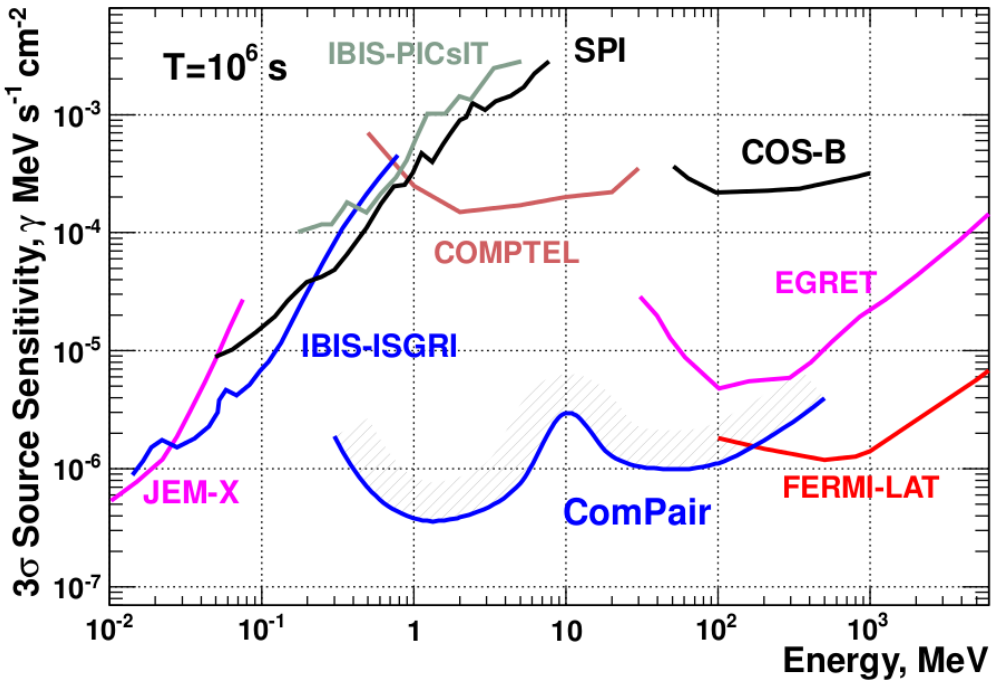
Specialized on $e^{+/-}$

727 Cannady
381 Wu
430 Torii
981 Gallo



SMILE II





Summary

New views on our inner galaxy (Center, Bubbles), revealing cosmic ray accelerators and transport in previously unconstrained regimes.

Era of Catalogs: population studies on most source classes. High energy catalog the first with new instrument response, more to come

Super Novae accelerate protons and electrons, γ-ray emission depends on environment

Lenzed blazars giving new views into γ-ray emission regions

Witnessing the birth of multi-messenger astronomy

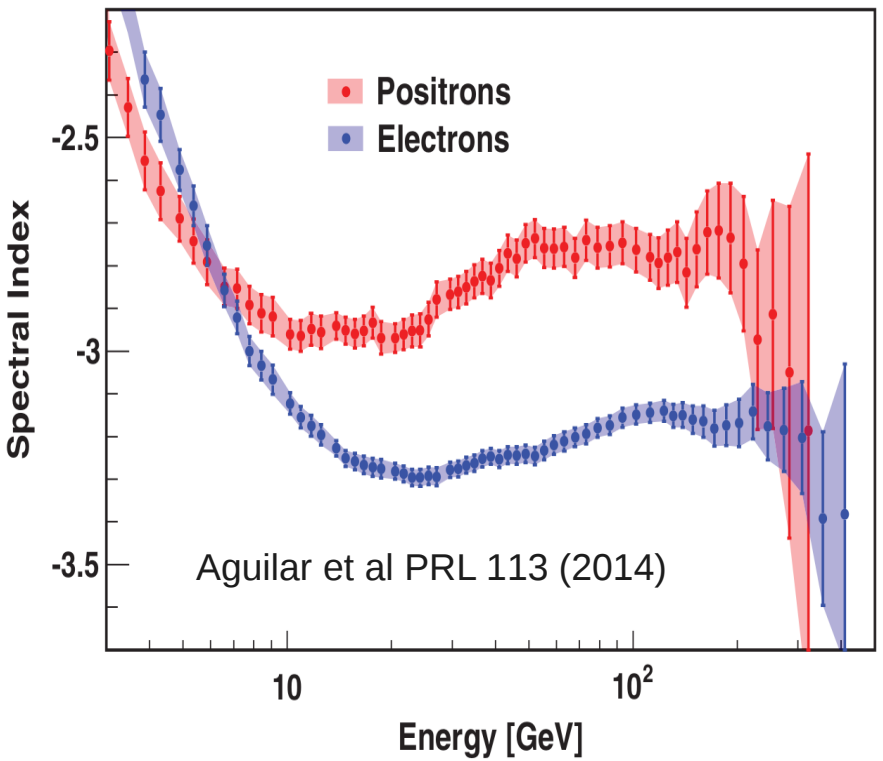
New instruments are being developed. The main goals are to close the MeV gap and improve angular resolution

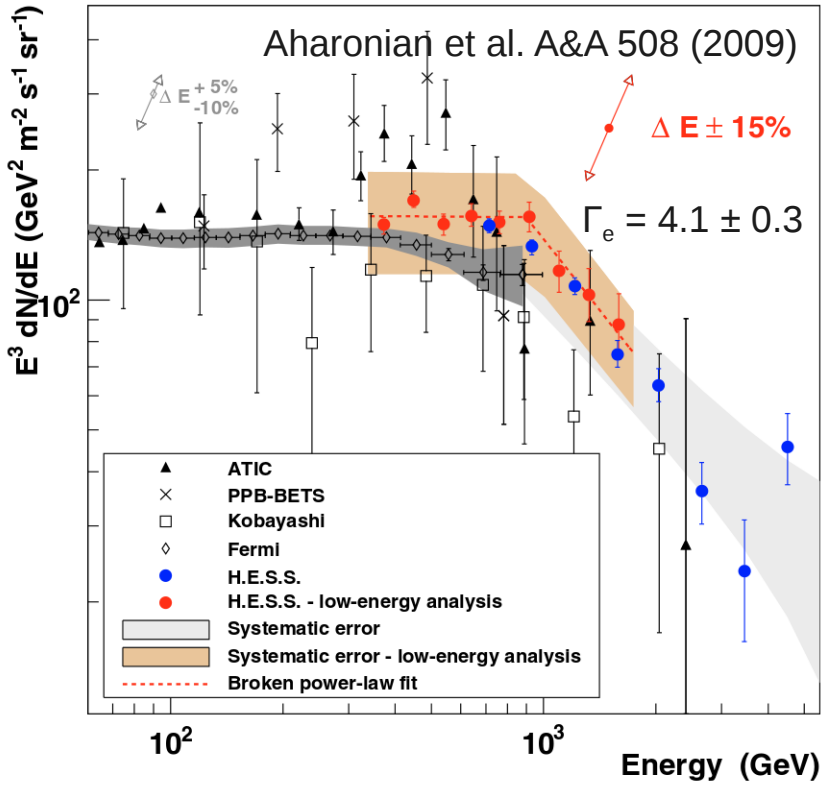
Topics not covered

- Gamma-Ray Bursts — 728 Bissaldi
- AGN with ultra fast outflows — 242 Tomono
- Symmetry in Blazars — 1087 Kenji
- Halo in M87 — 1141 Pshirkov
- Pulsars above the break — 770 Bochenek
- Dark Matter halos — 1343 Nieto
- Constraints on UHECR — 856 Kagaya
- Rossetta and Orion Nebula — 77 Lamanna
- Supernovae — 86 Franckowiak
- Millisecond Pulsars — 1252 Laffon — 25 Bednarek
- Observing the Moon — 77 Loparco
- GBM multi-messenger — 1081 Connaughton
- Hubble constant — 246 Dominguez
- GeV spectra of blazars — 998 Reimer
- Vela pulsar — 364 Pivato
- LAT below 100 MeV — 988 Desgardin
- Sgr B complex — 69 Ruizhi
- Flares from the Sun — 1114 Pesce-Rollins
- SS433/W50 — 620 Bordas
- Line in Mrk 876 — 620 Bordas
- ^{26}Al in our Galaxy — 102 Bouchet

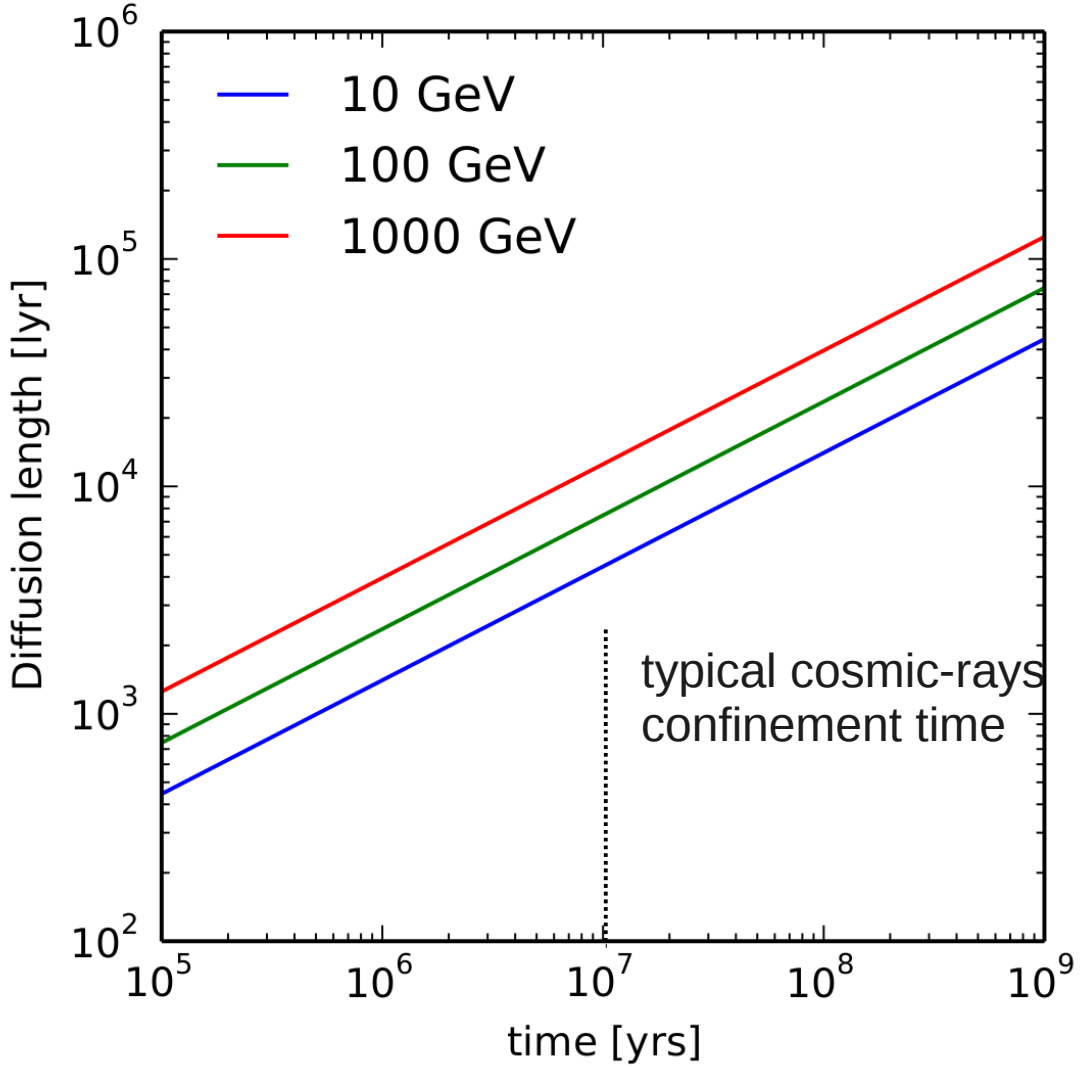
Backup slides

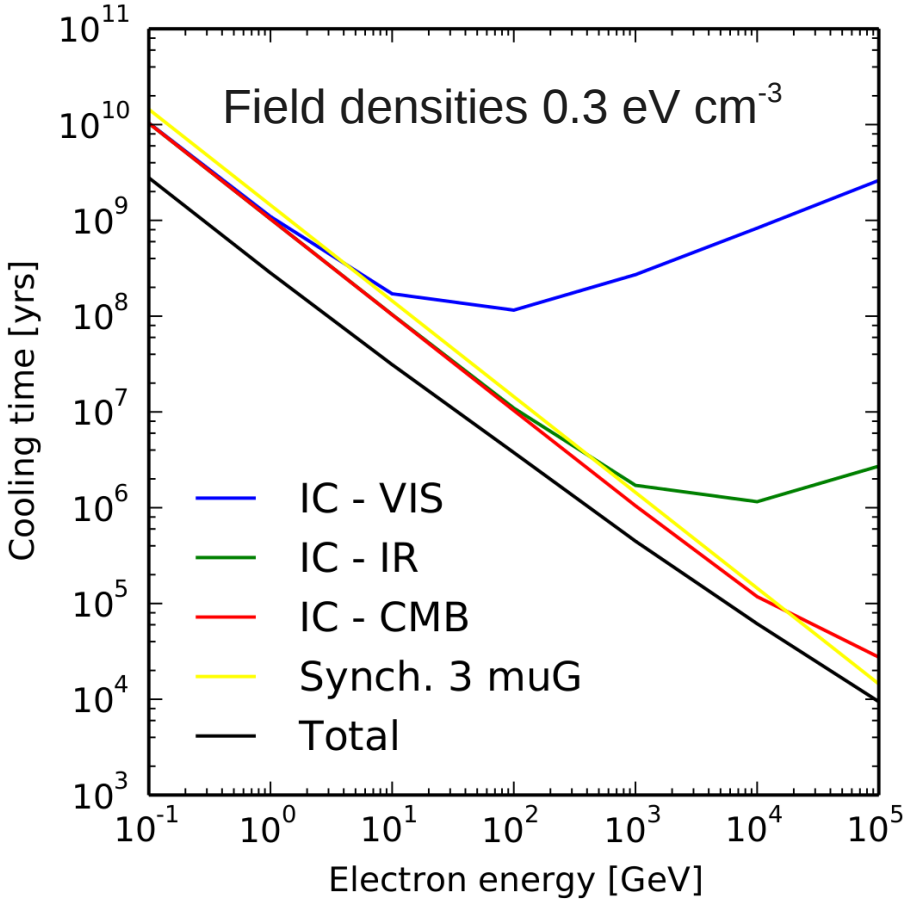
Electron spectra



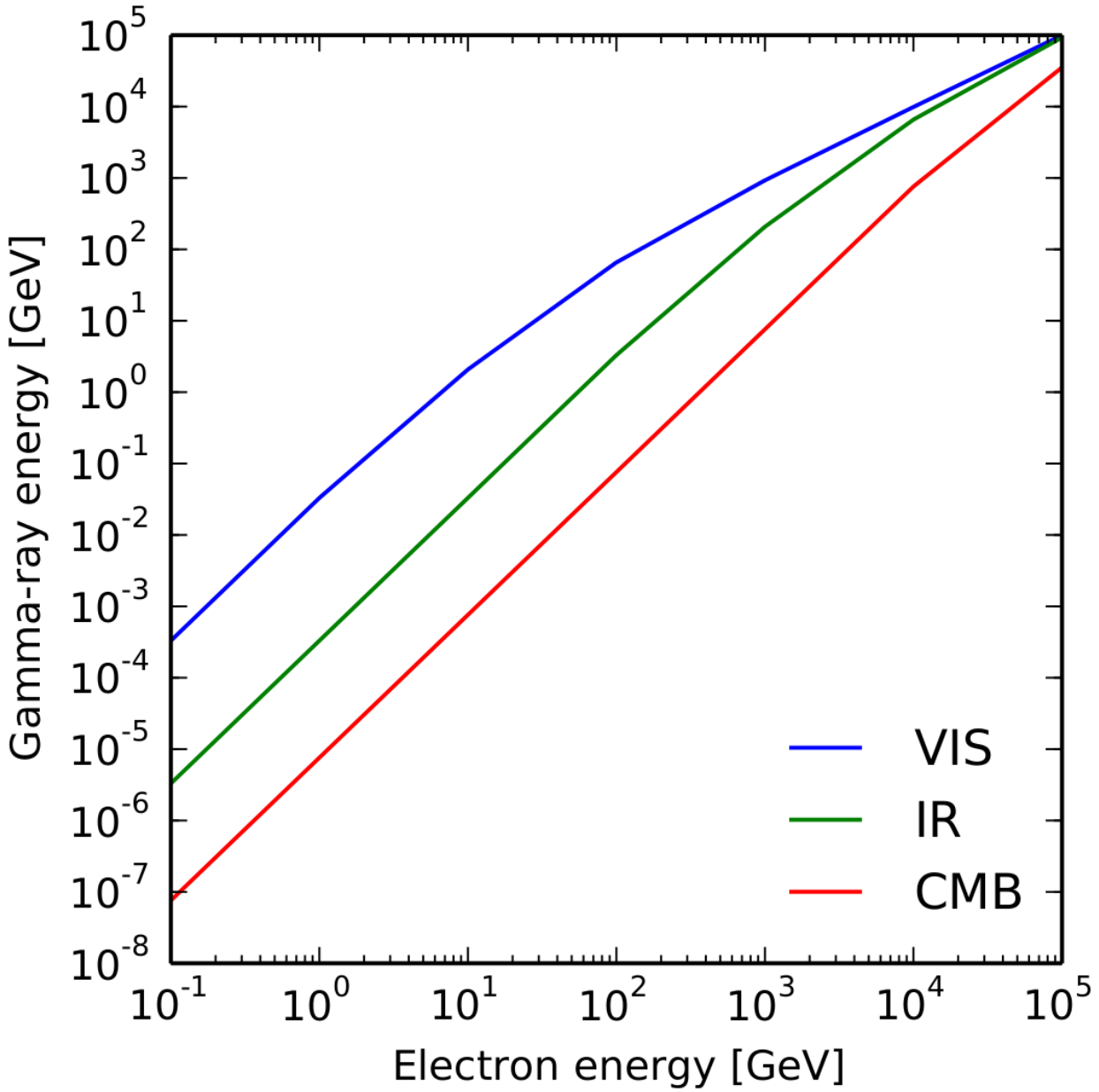


Time scales





$$R_{diff} \approx \sqrt{0.7\, E_{GeV}\, t_{yrs}}$$

Hinton & Hofmann ARAA 47 (2009)

Inverse Compton fields