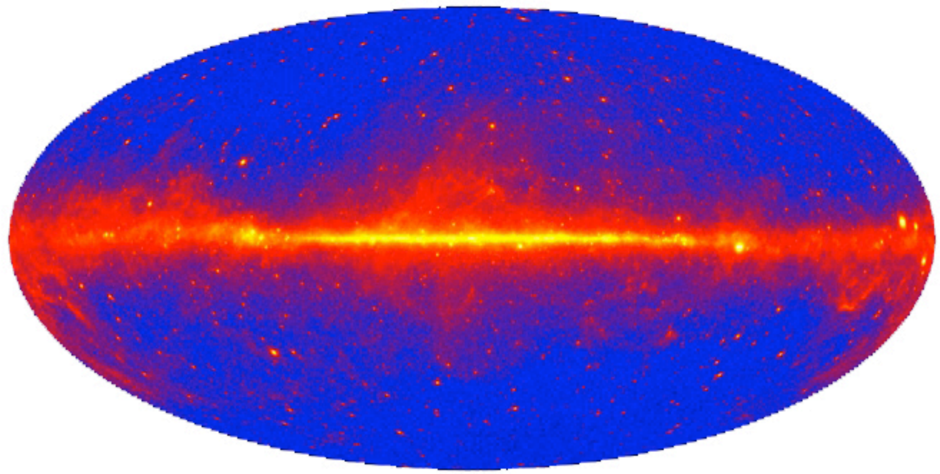
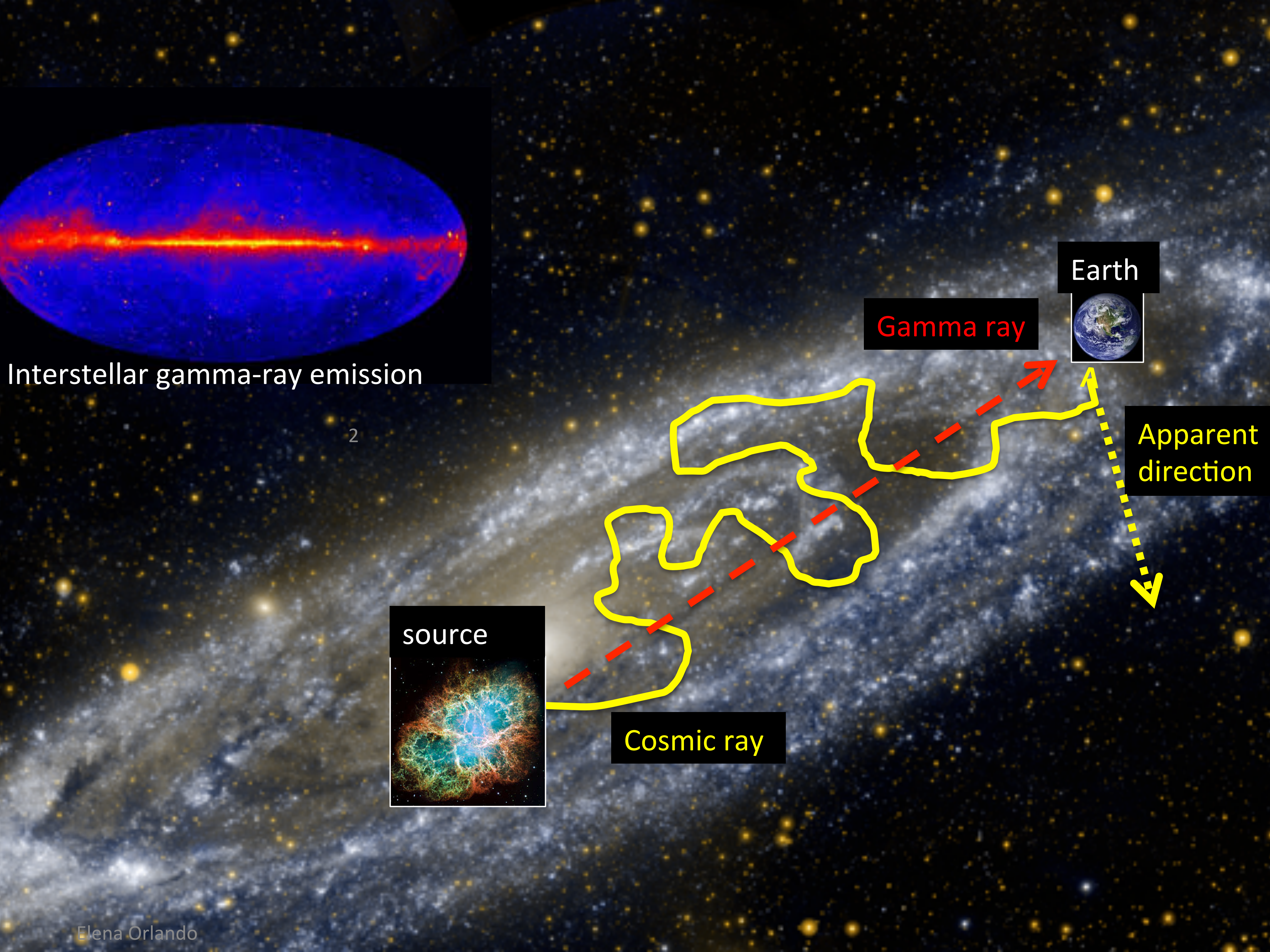


High and very-high energy gamma-ray observations of the Milky Way

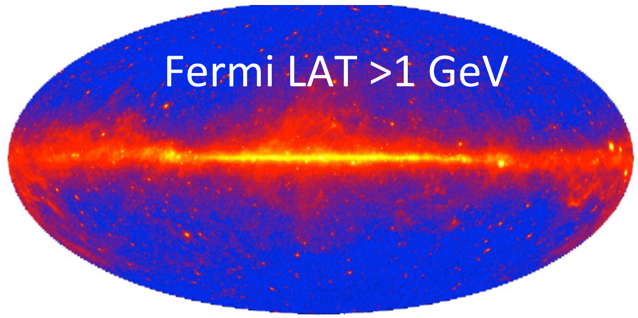
Elena ORLANDO
(Stanford University)

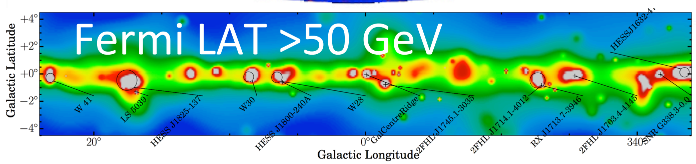
SciNeGHE 2016

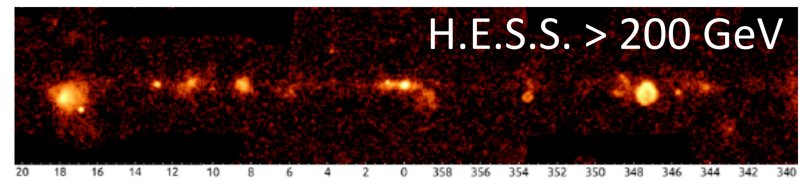
Pisa, 18 – 21 Oct 2016

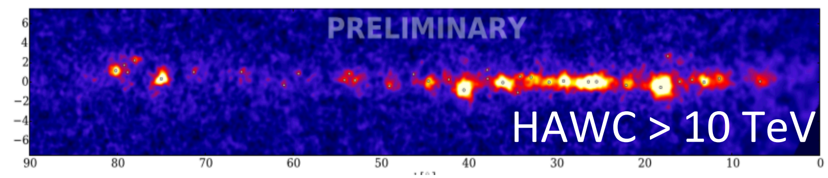

Interstellar gamma-ray emission
Earth
Gamma ray
Apparent direction
source
Cosmic ray
2
Elena Orlando

HE vs VHE









- Mostly interstellar diffuse emission ⟷ - Mainly sources

-

- Searching for faint sources depends on interstellar model and is challenging ⟷ - Searching for interstellar emission only after subtraction of sources in very bright regions and it is challenging

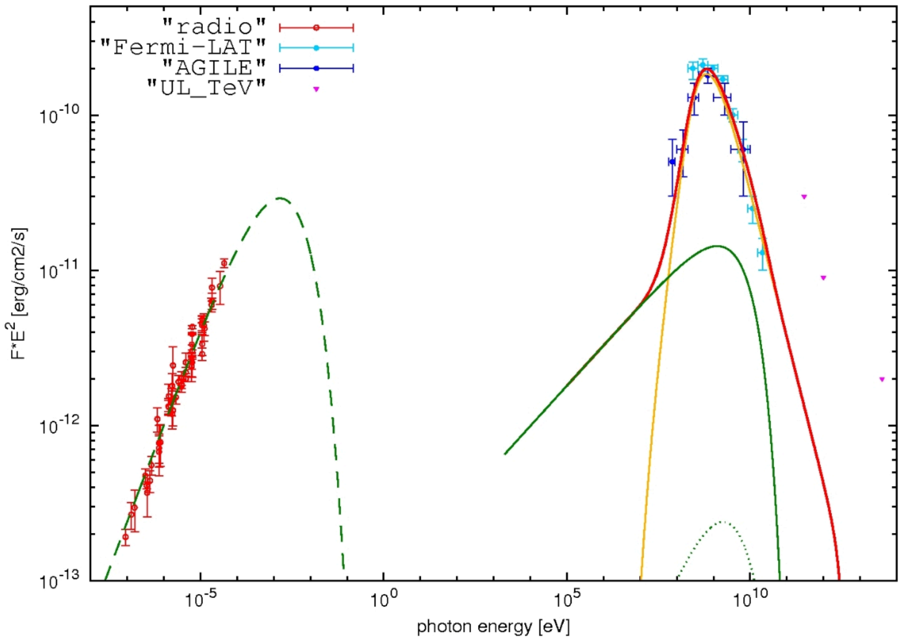
Sources

Freshly accelerated nuclei

Hadronic emission from accelerated protons in the **SNR W44** expanding in a dense medium

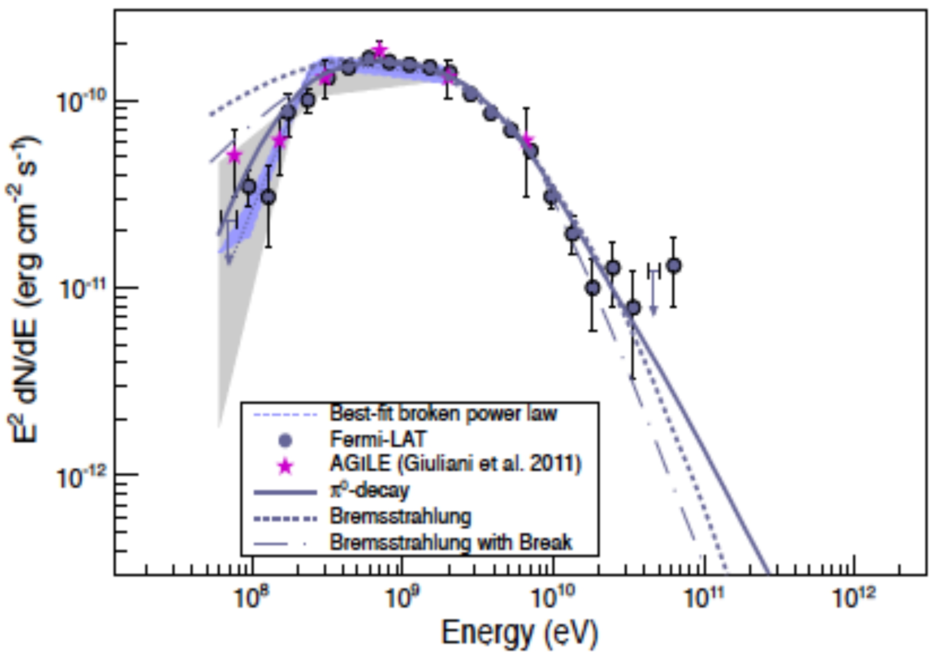
AGILE

Giuliani et al. 2011 ApJ 742L 30



FERMI-LAT

Ackermann at al. 2013 Science 339 807



See talk by F. de Palma on Friday

SNRs

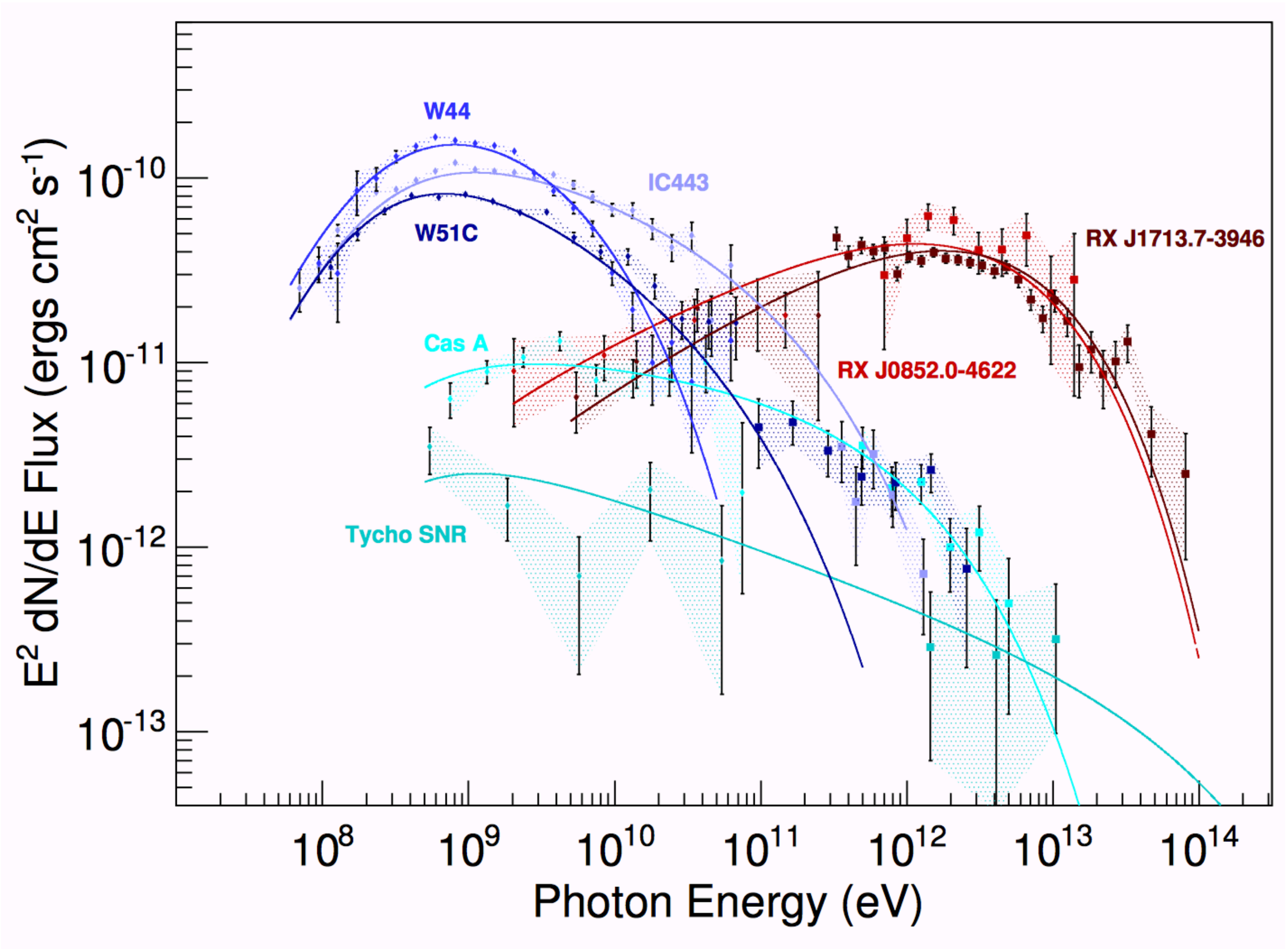
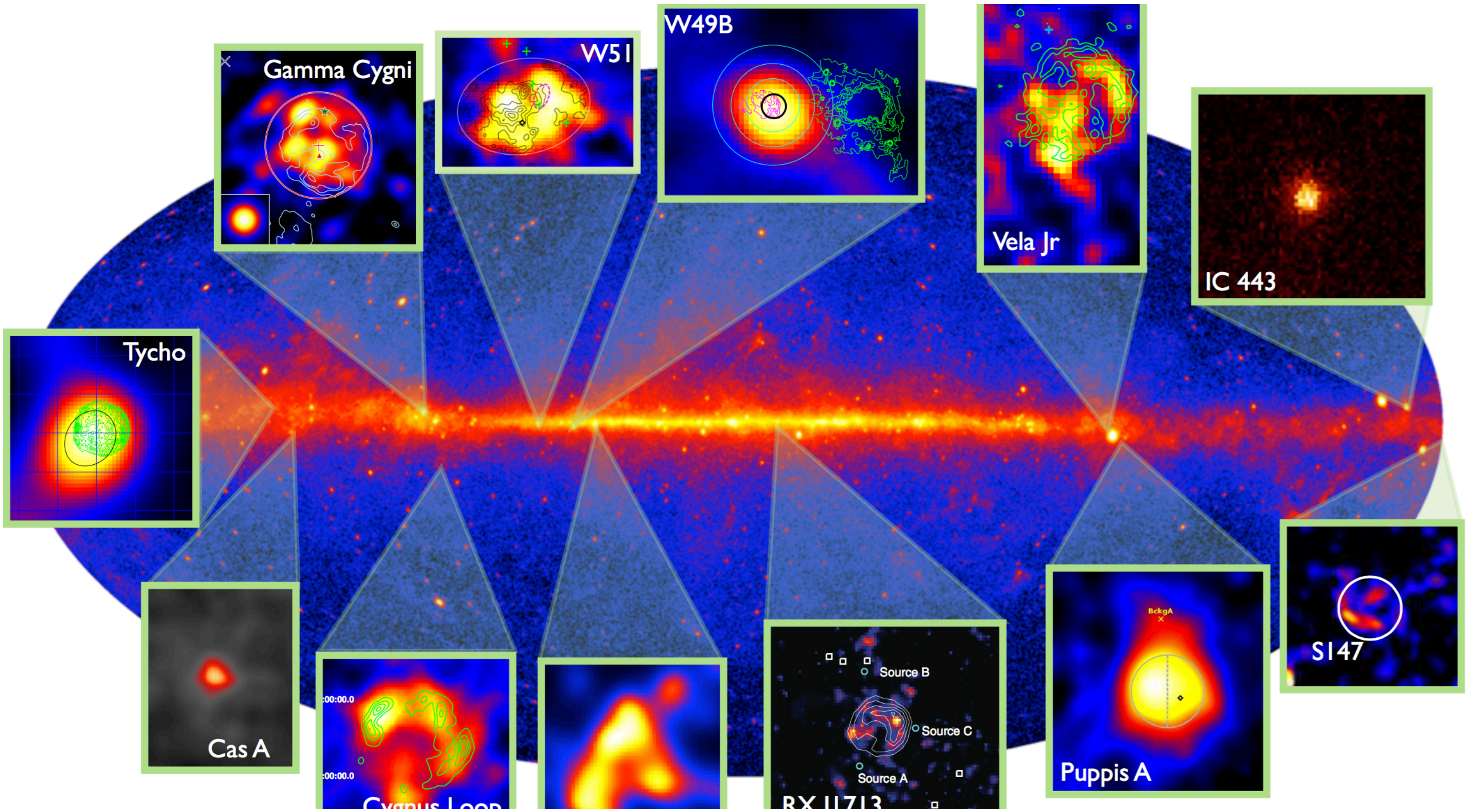


Figure from Funk. S., 2016, Ann. Rev. of Nuclear and Particle Science Vol. 65: 245-277

The first LAT SNR catalog

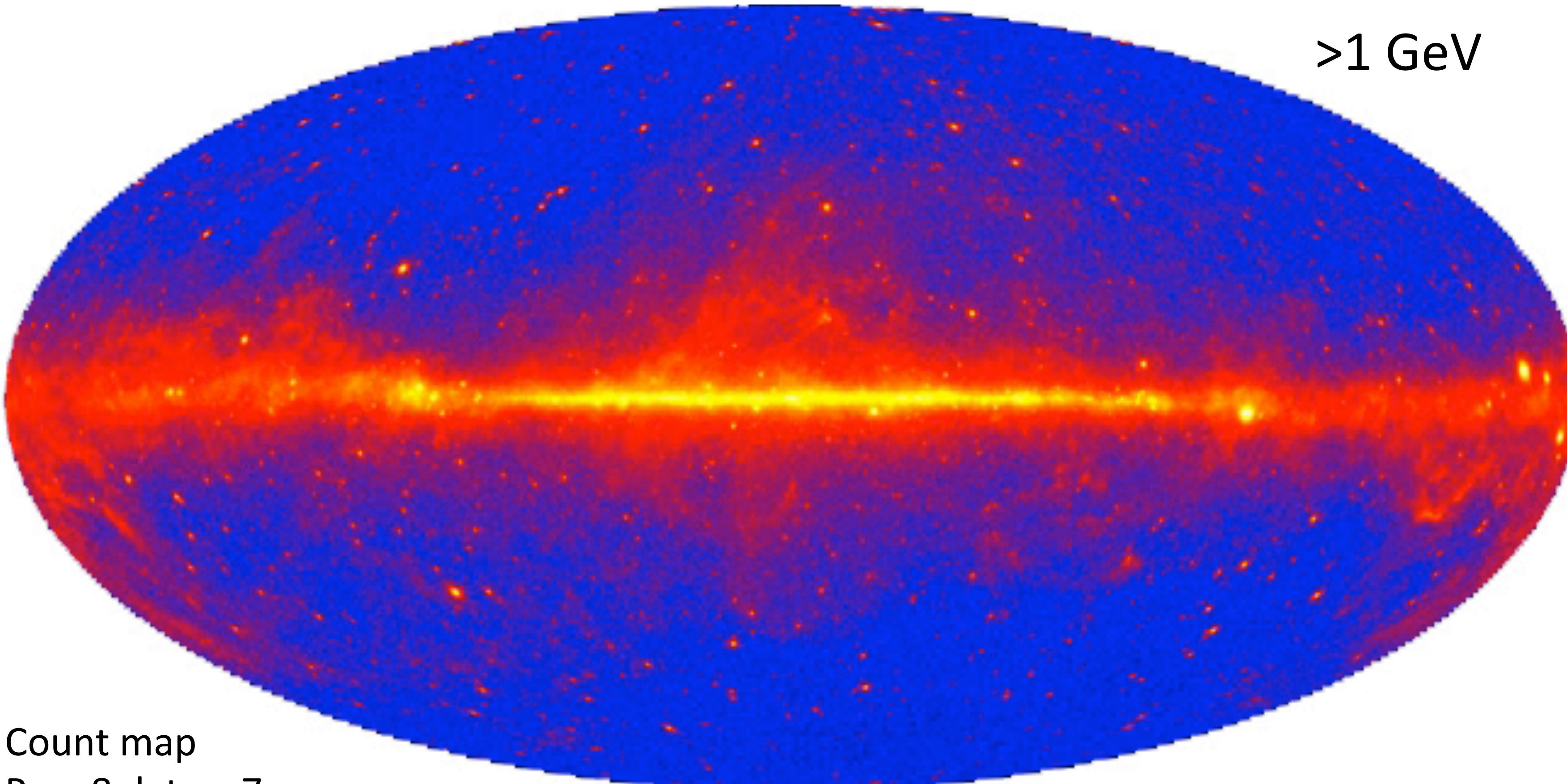


Acero et al. 2016 APJS Vol. 224, 1, 8

→ Candidate SNRs are within expectations if SNRs provide the majority of Galactic CRs

See talk by F. de Palma on Friday

The gamma-ray sky seen by Fermi LAT

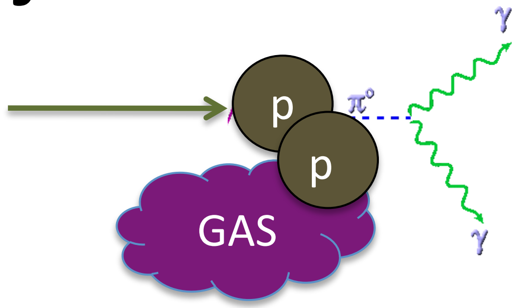


Count map
Pass 8 data – 7 years
Adaptively smoothed

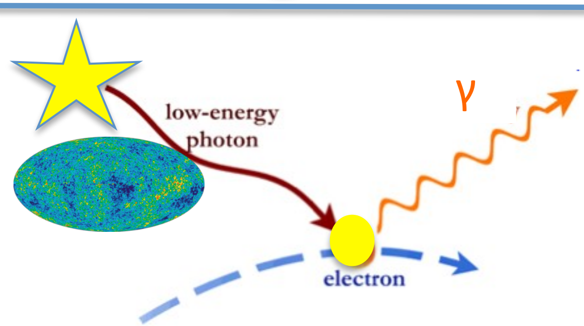
Credits: Fermi LAT collaboration

The interstellar emission

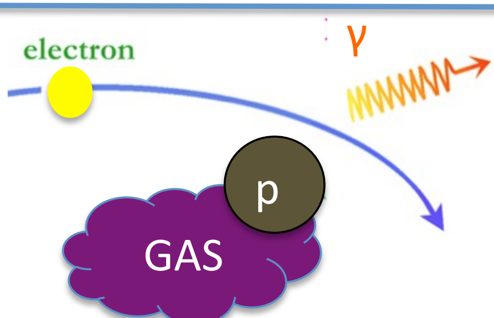
Major non-thermal emission mechanisms



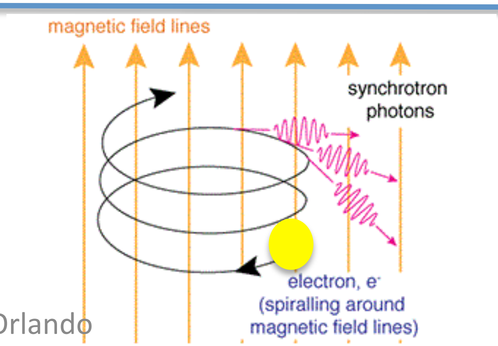
Pion decay



Inverse Compton

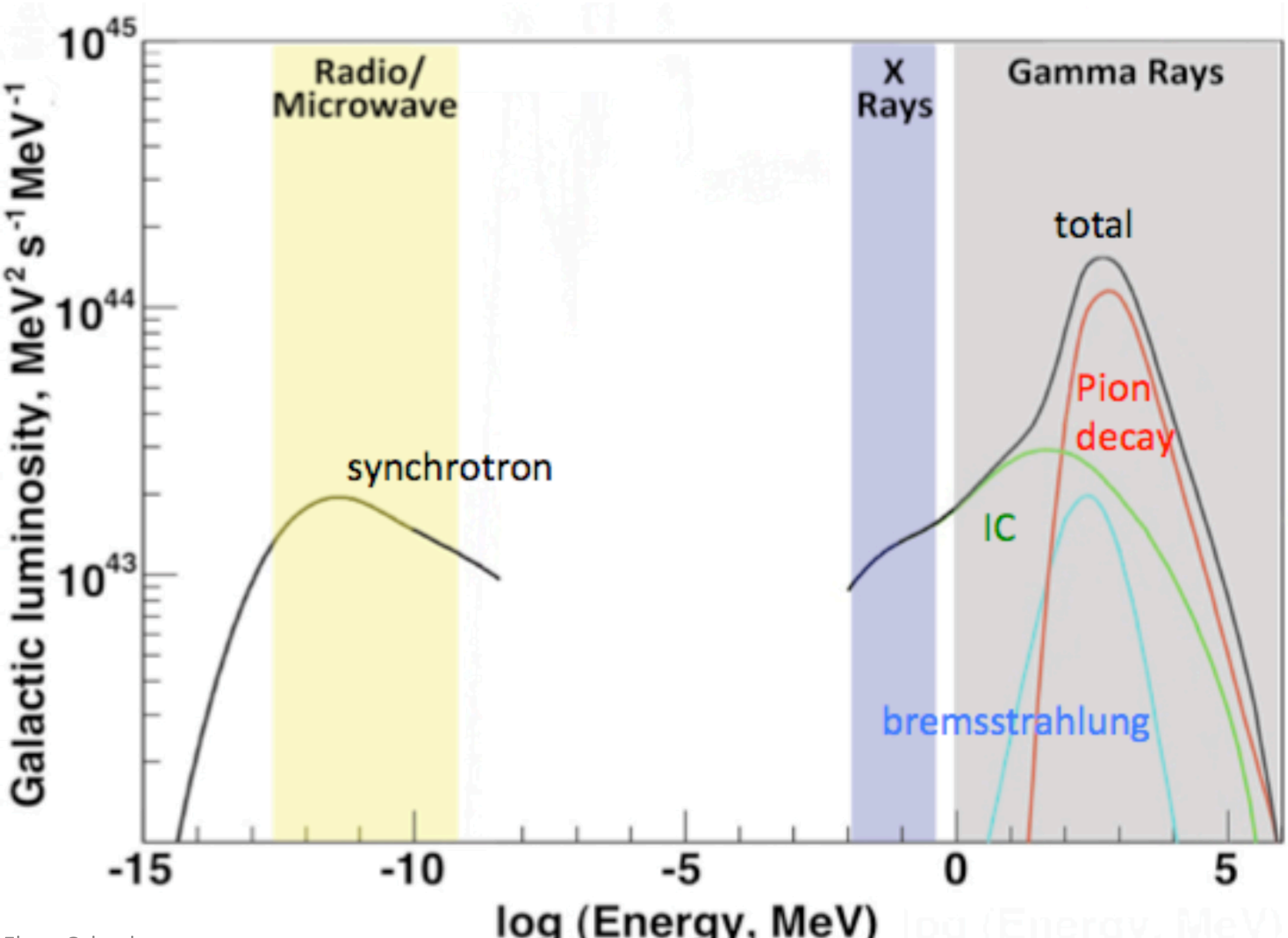


Bremsstrahlung



Synchrotron

Interstellar emission

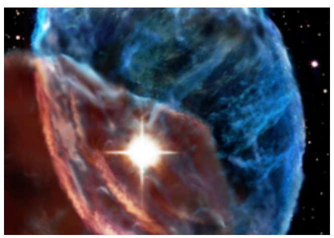


CR propagation models

http://*galprop.stanford.edu*

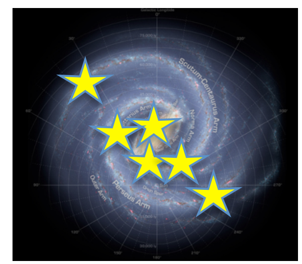
CR propagation codes such as GALPROP solve transport equation (energy losses, diffusion, acceleration, convection, fragmentation, radioactive decay) for all CR species.

INPUTS (also sources of uncertainties):

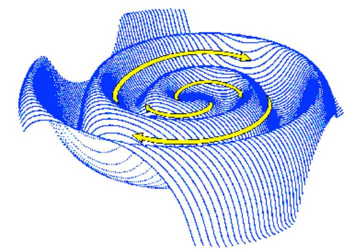


CR source distribution

Gas distribution



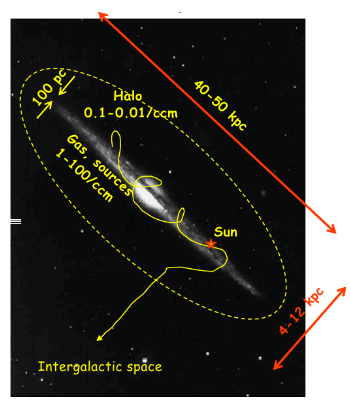
ISRF



Magnetic field

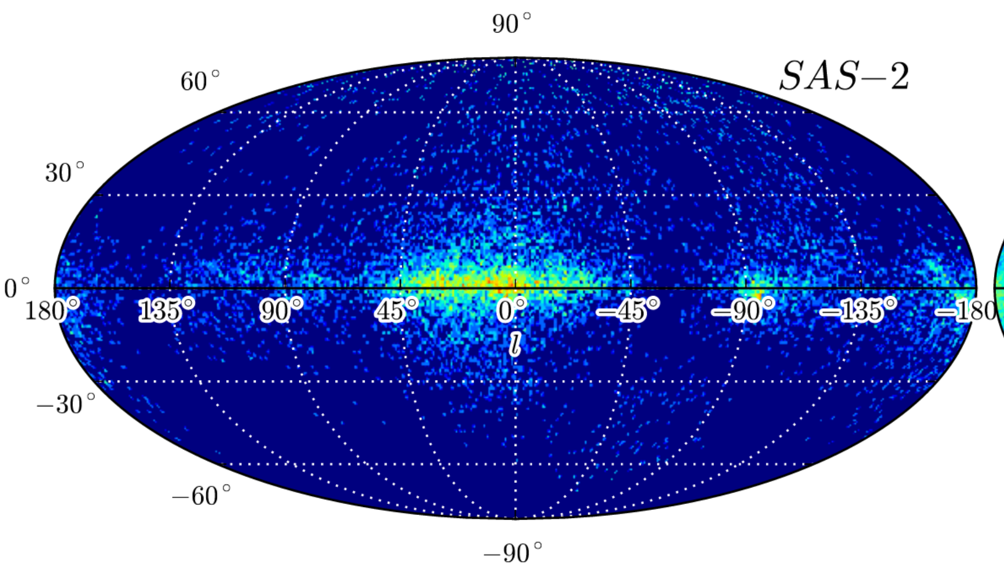
CR propagation parameters:

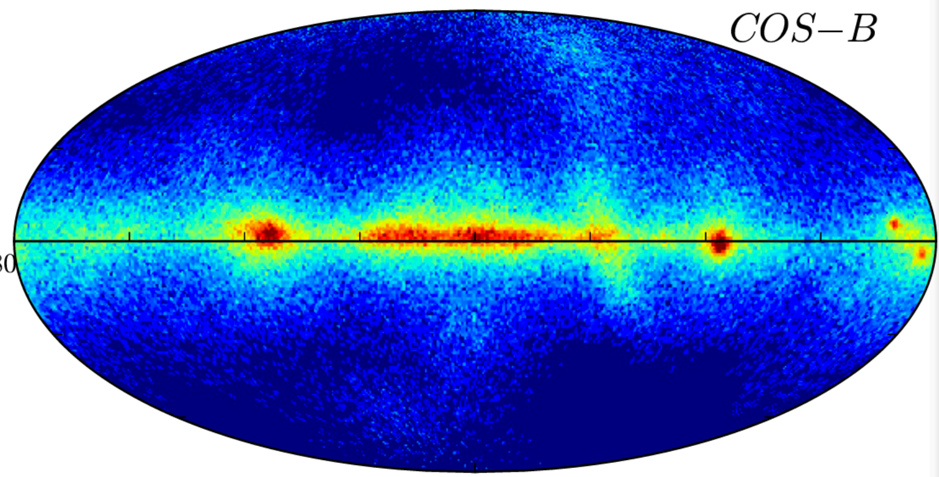
- Injection spectral indexes
- Halo size
- Solar modulation
- Diffusion coefficient
- Convection
- Reacelleration



The gamma-ray sky in the ‘70s

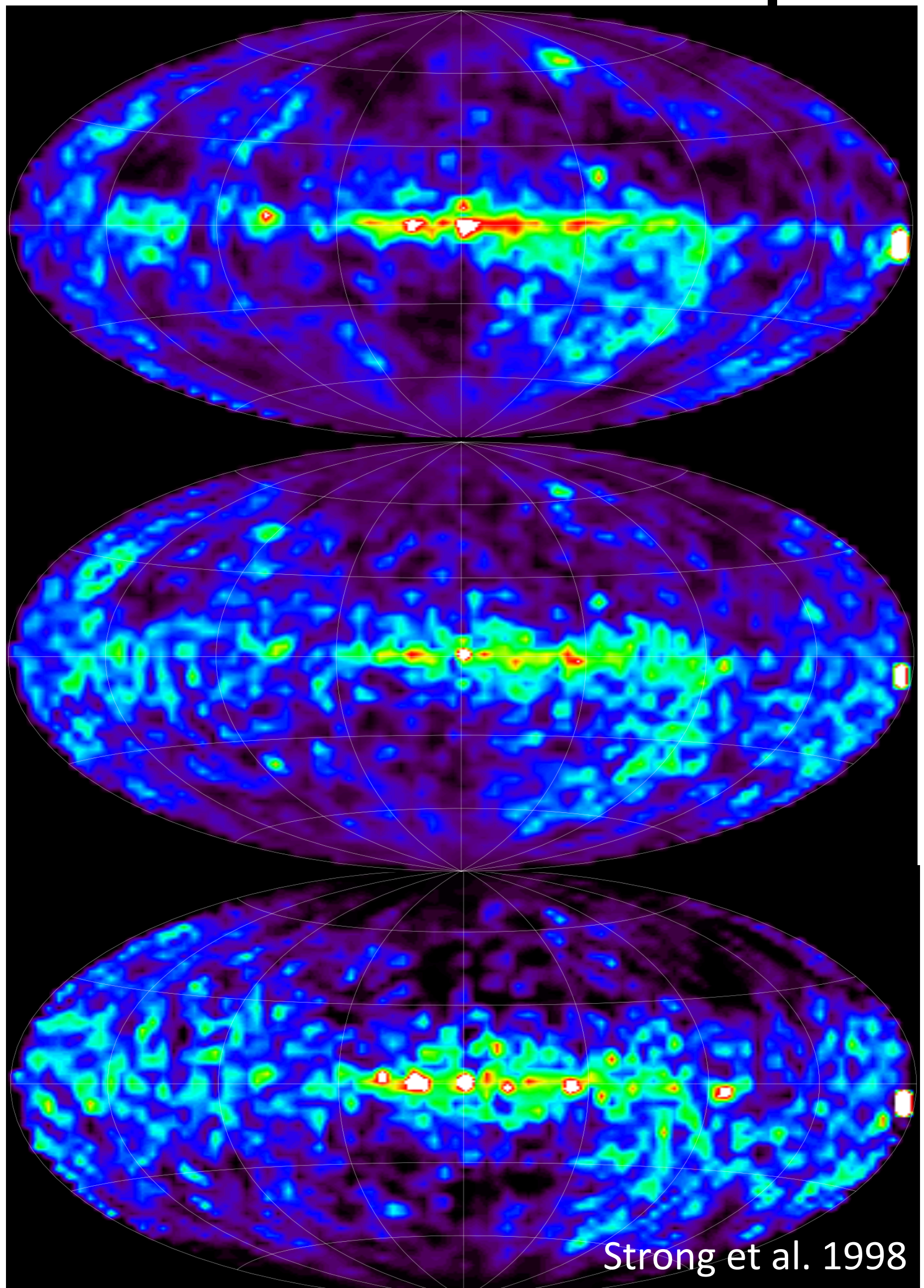
>50 MeV





from Acero et al. 2016 and NASA HEASARC

In the '90s: Comptel

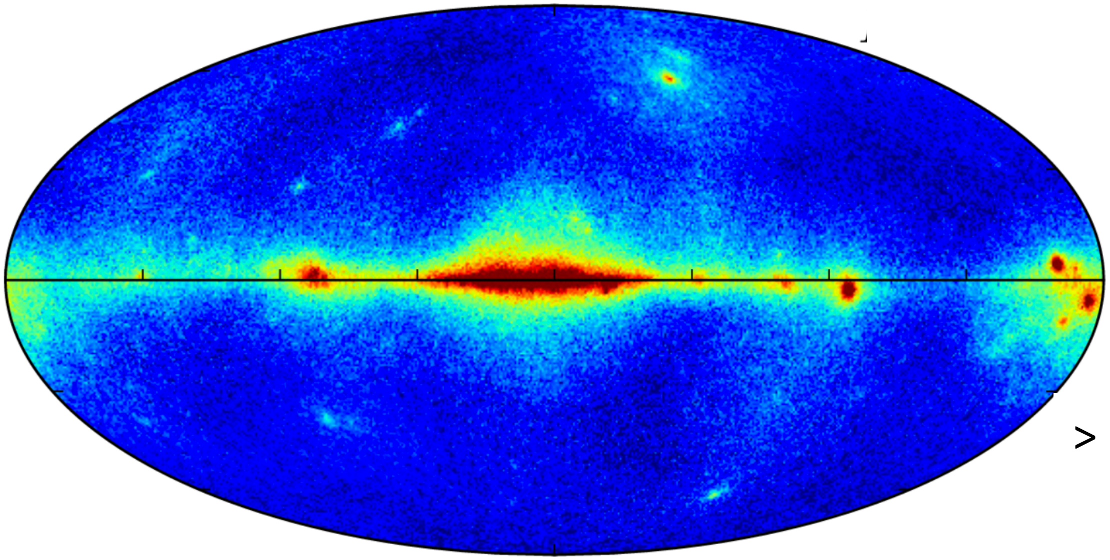


1 – 3 MeV

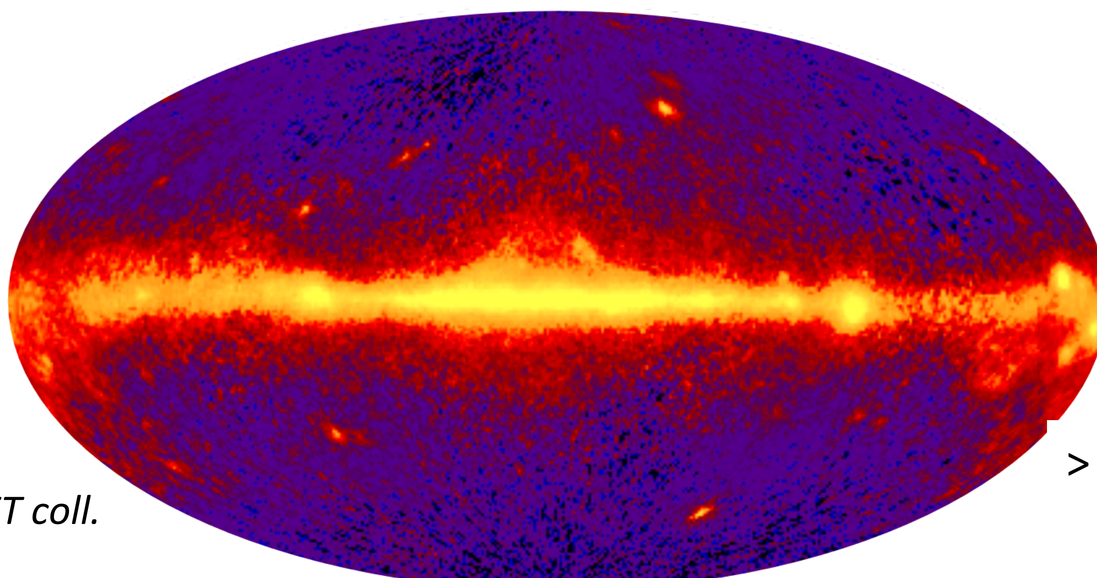
3 – 10 MeV

10 – 30 MeV

In the '90s: EGRET



> 50 MeV

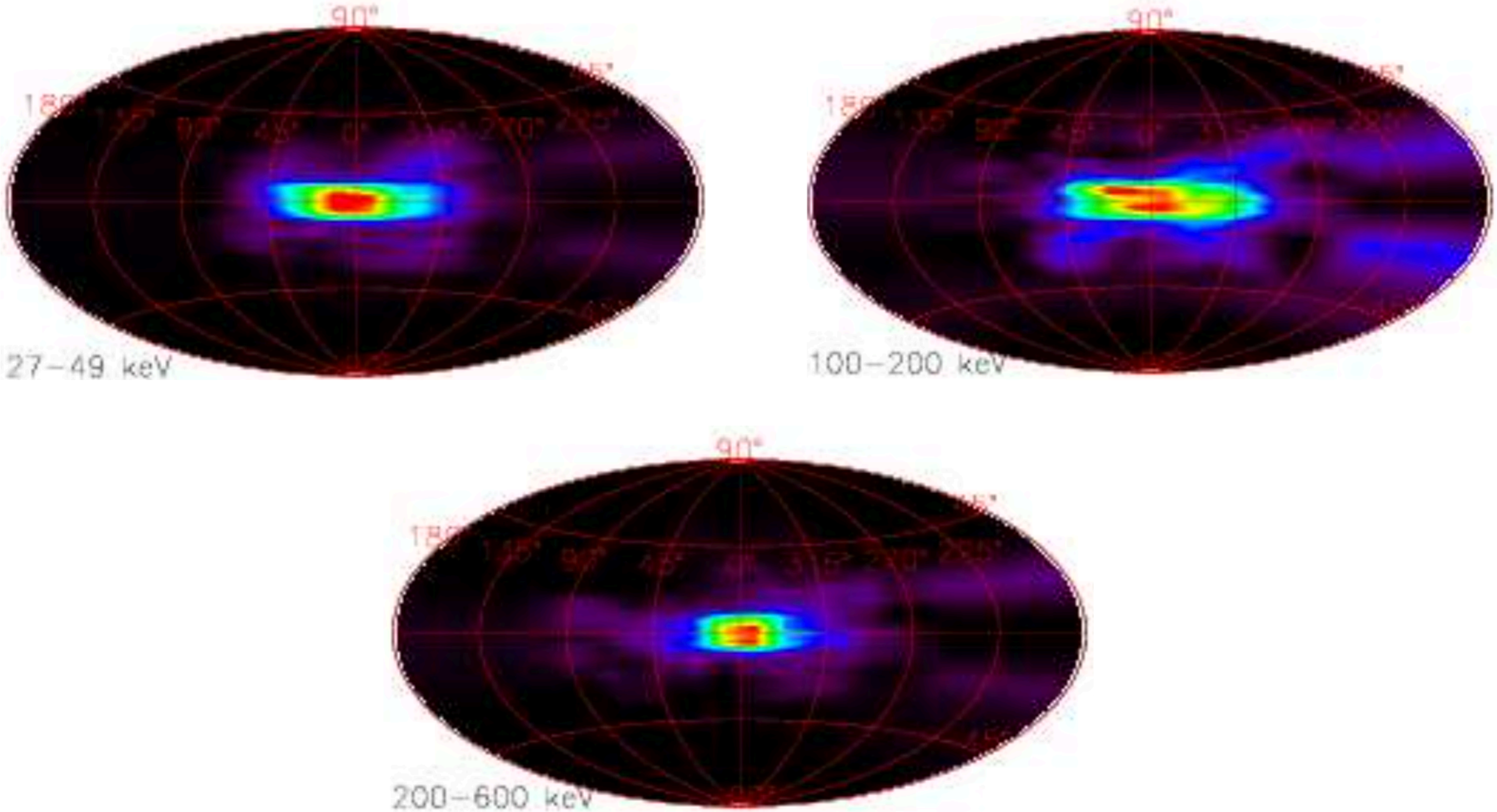


> 100 MeV

Credits: EGRET coll.

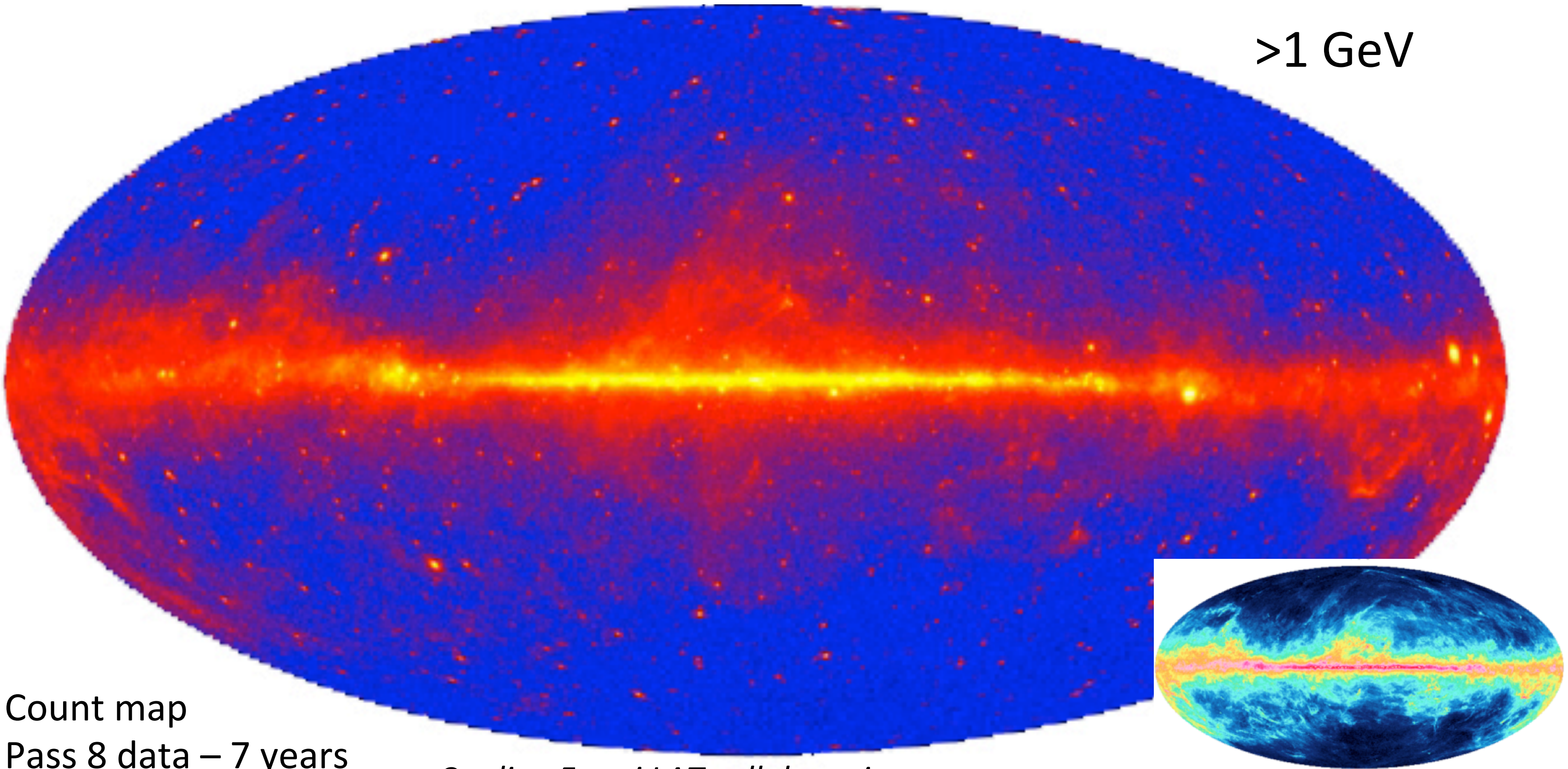
SPI: the sky from 30 KeV to 0.6 MeV

Bouchet et al., ApJ. (2011) 739,29



Inverse Compton emission with 2x CRe or 10X ISRF in the ridge

The gamma-ray sky seen by Fermi LAT

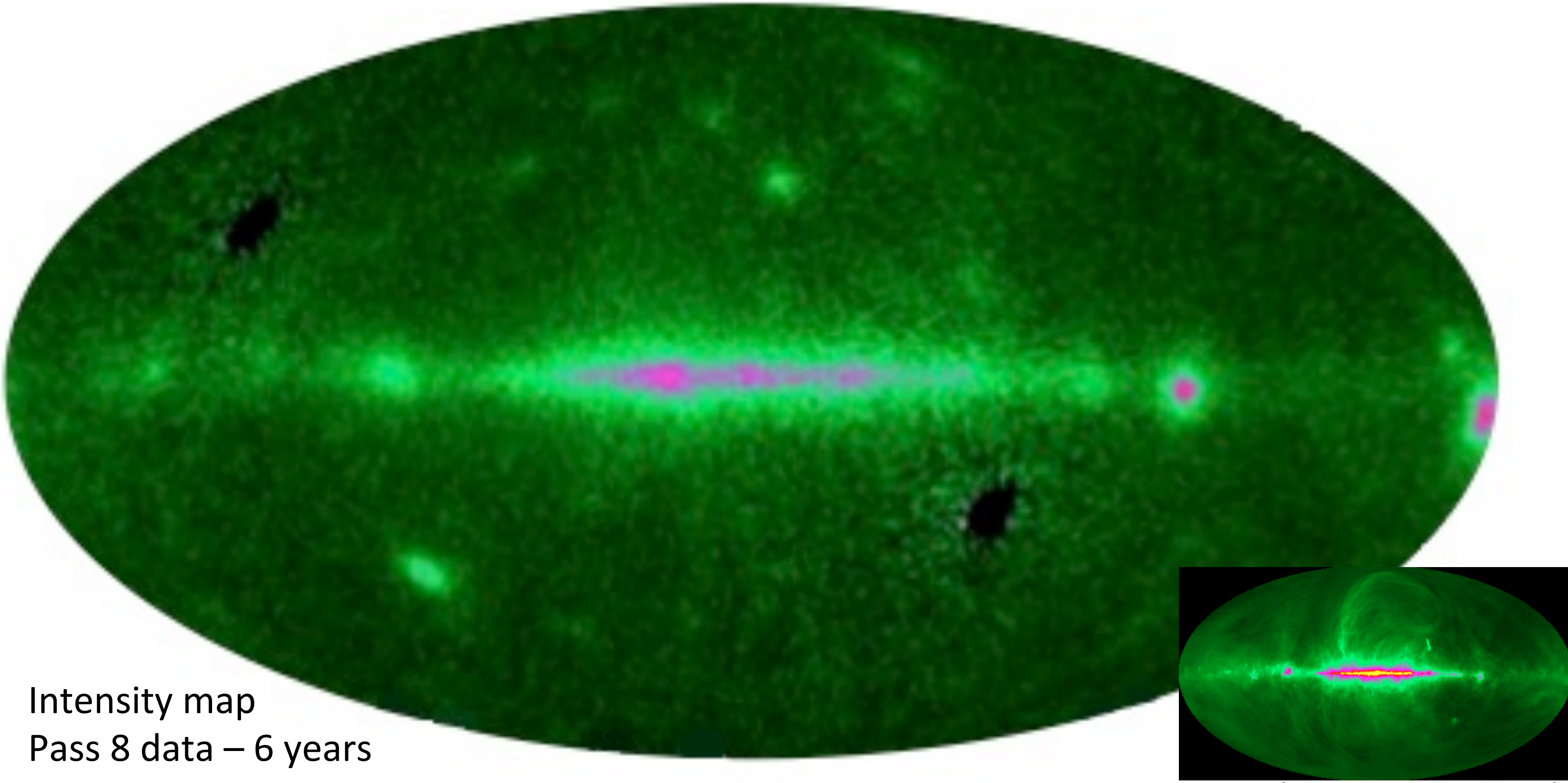


Count map
Pass 8 data – 7 years
Adaptively smoothed

Credits: Fermi LAT collaboration

Planck Coll. 2014 A&A 564, A45
353 GHz, dust map

Our Galaxy in gamma – 30÷80MeV

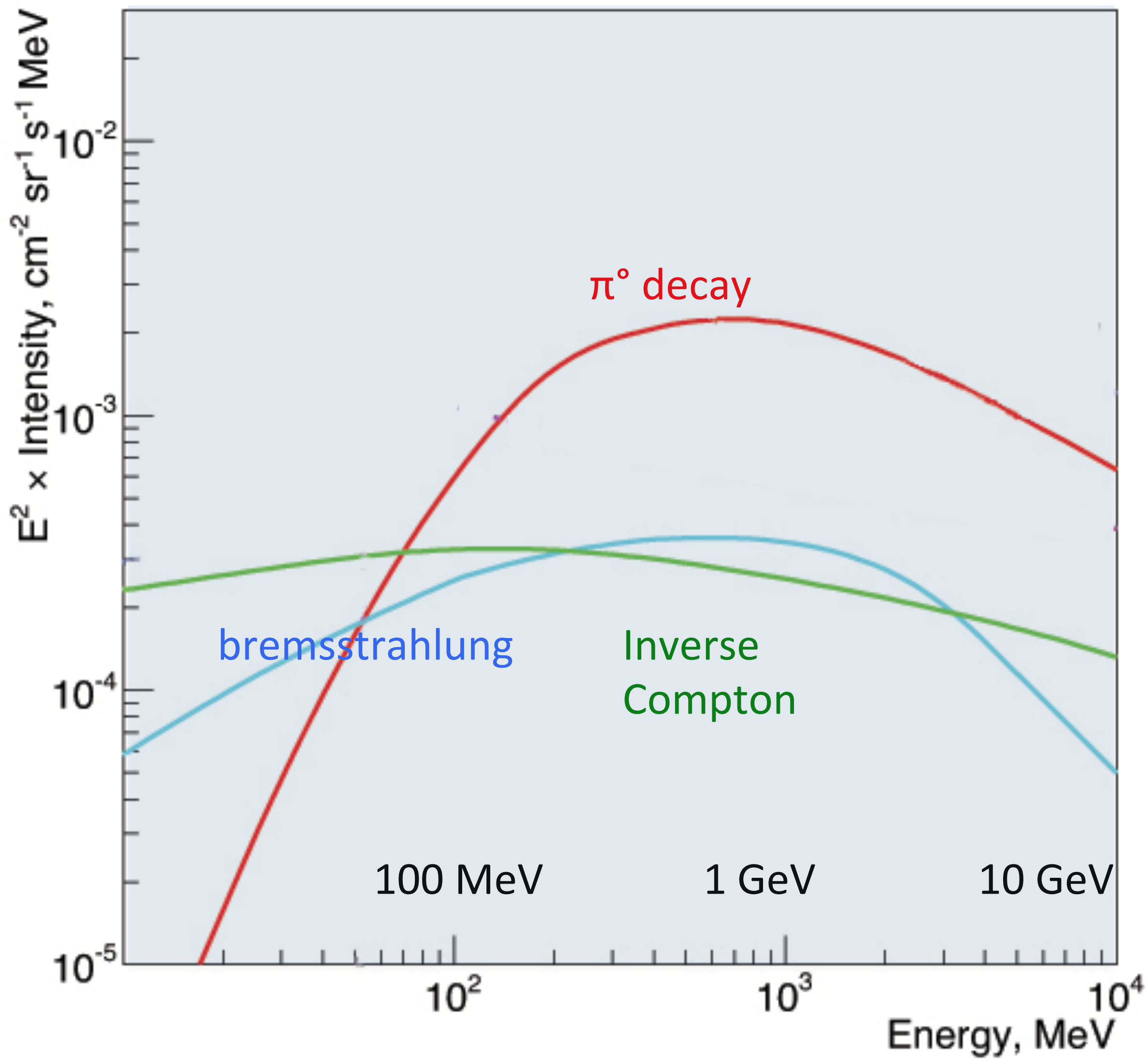


Intensity map
Pass 8 data – 6 years
Adaptively smoothed

Credits: Fermi LAT collaboration

408 MHz (Haslam et al 1981)

Example of gamma-ray spectrum

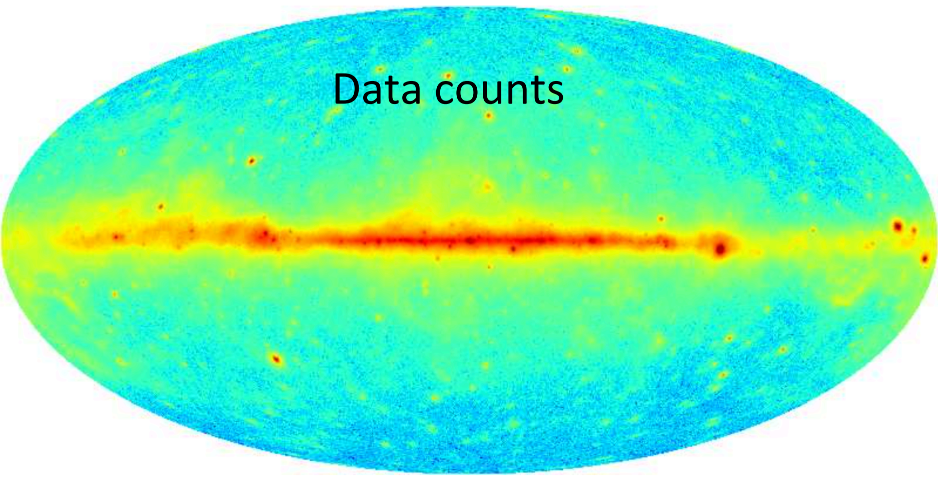


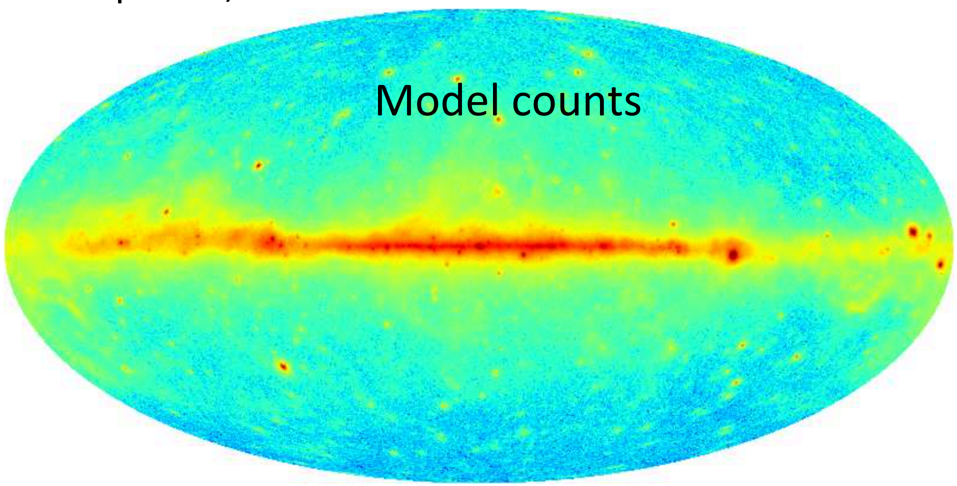
Spectral components depend on the CR spectra !

Relative intensities depend on the region of the sky !

CR propagation models

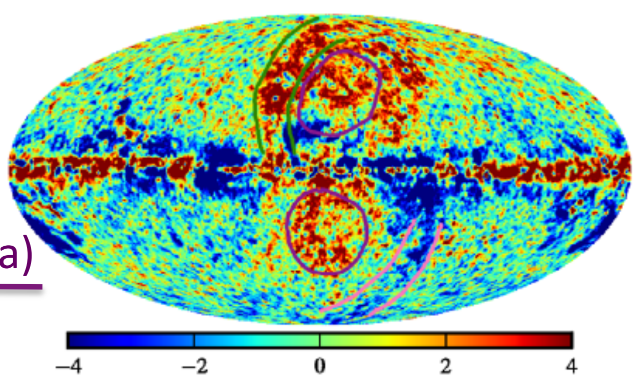
Ackerman et al. 2012 ApJ 750, 3





→ With CRs consistent with CR local measurements

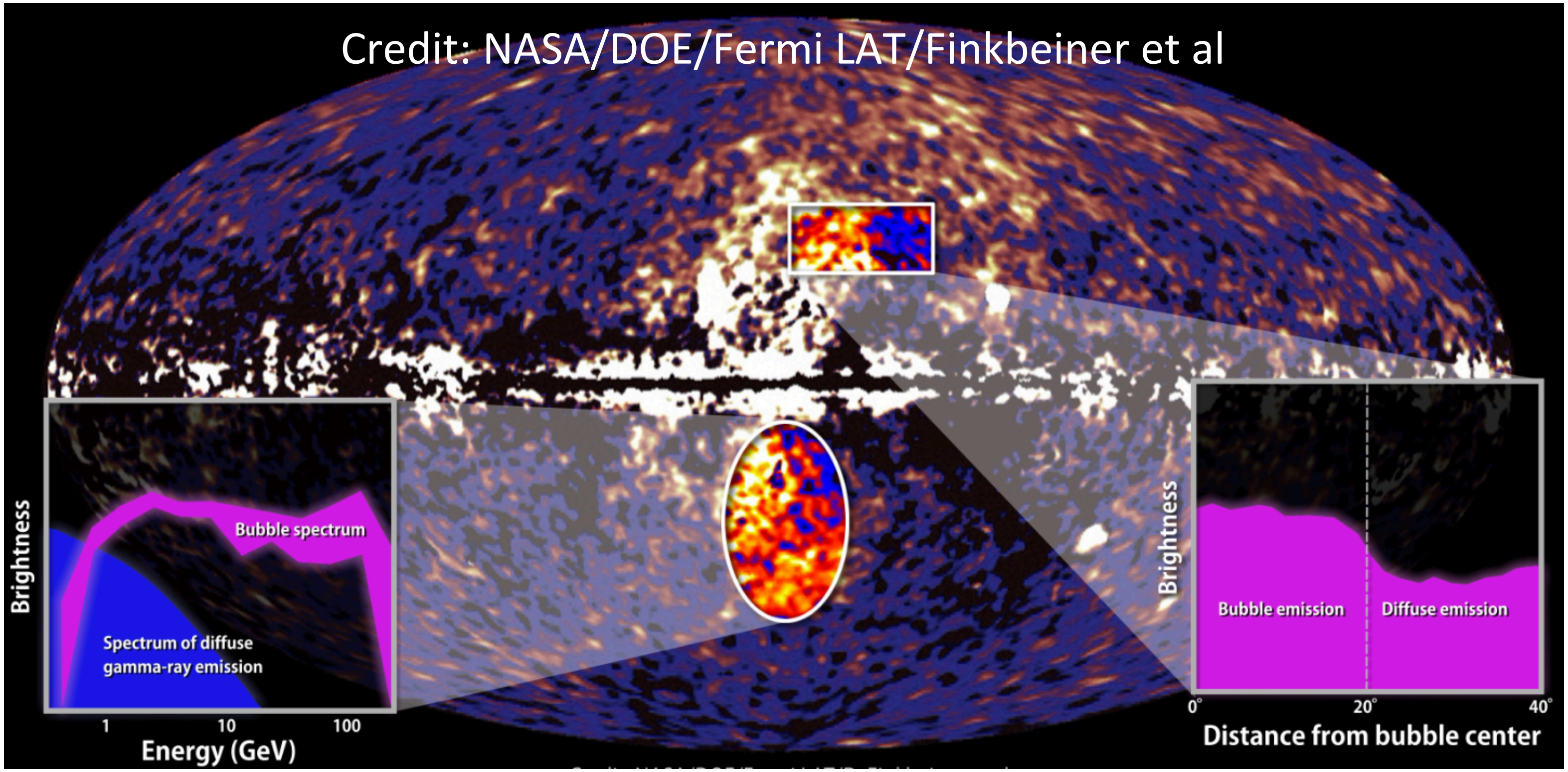
$\frac{\text{(model-data)}}{\text{model}}$



Excess:

- Outer Galaxy
- Fermi Bubbles?
- Inner Galaxy

CRs and the Fermi Bubbles



References: Dobler et al. 2010; Su et al 2010, 2012; ..; since then many studies including different wavelength (e.g. Carretti 2013, S-PASS; Dobler 2012, WMAP; Snowden 1997, Su 2012 ROSAT; Kataoka 2013, Tahara 2015, Suzaku, Planck coll 2013; …)

→ Both leptonic and hadronic models represent Fermi spectral data well

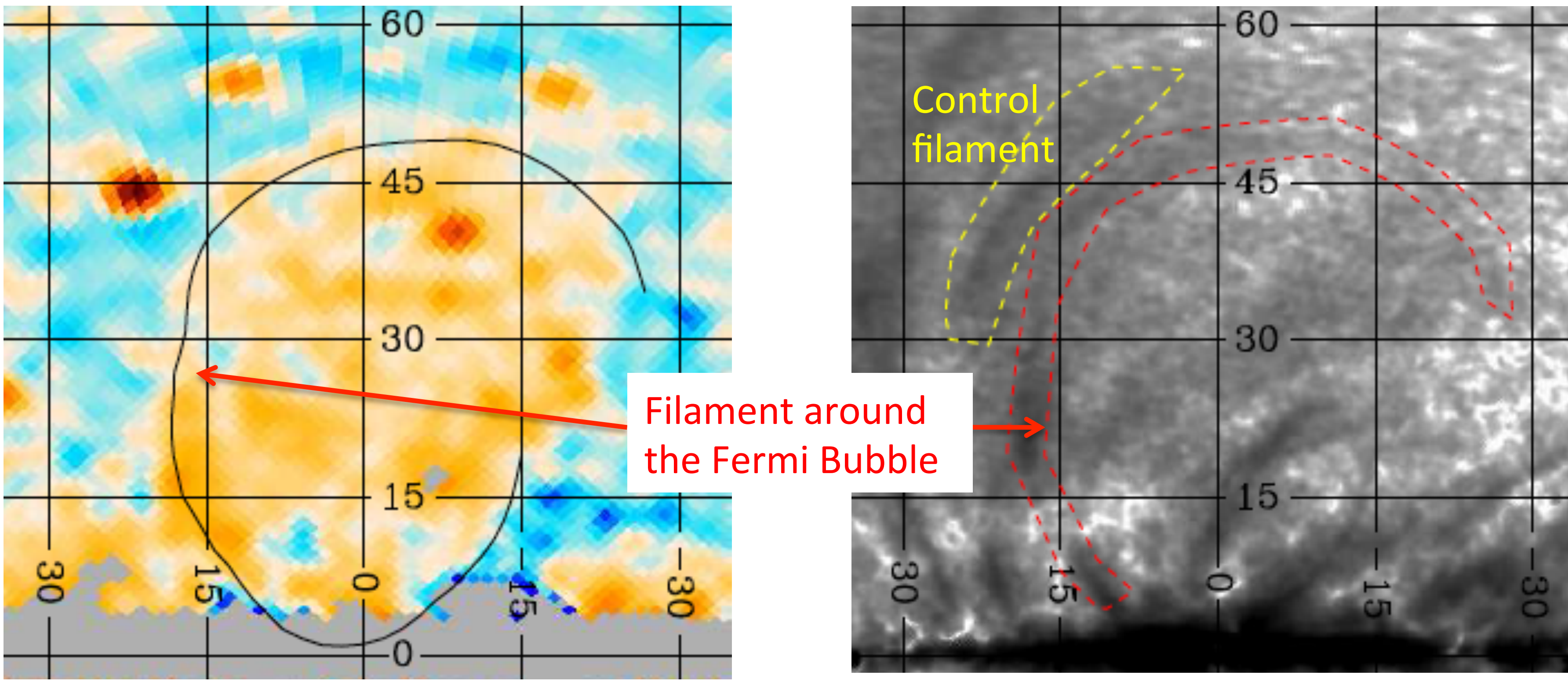
(Ackermann et al., 2014 ApJ 793, 64)

Planck polarization and Fermi Bubbles

Planck 2015 results. XXV

Fermi-LAT > 10 GeV from
Ackermann et al 2014 (dust subtracted)

Planck polarization map

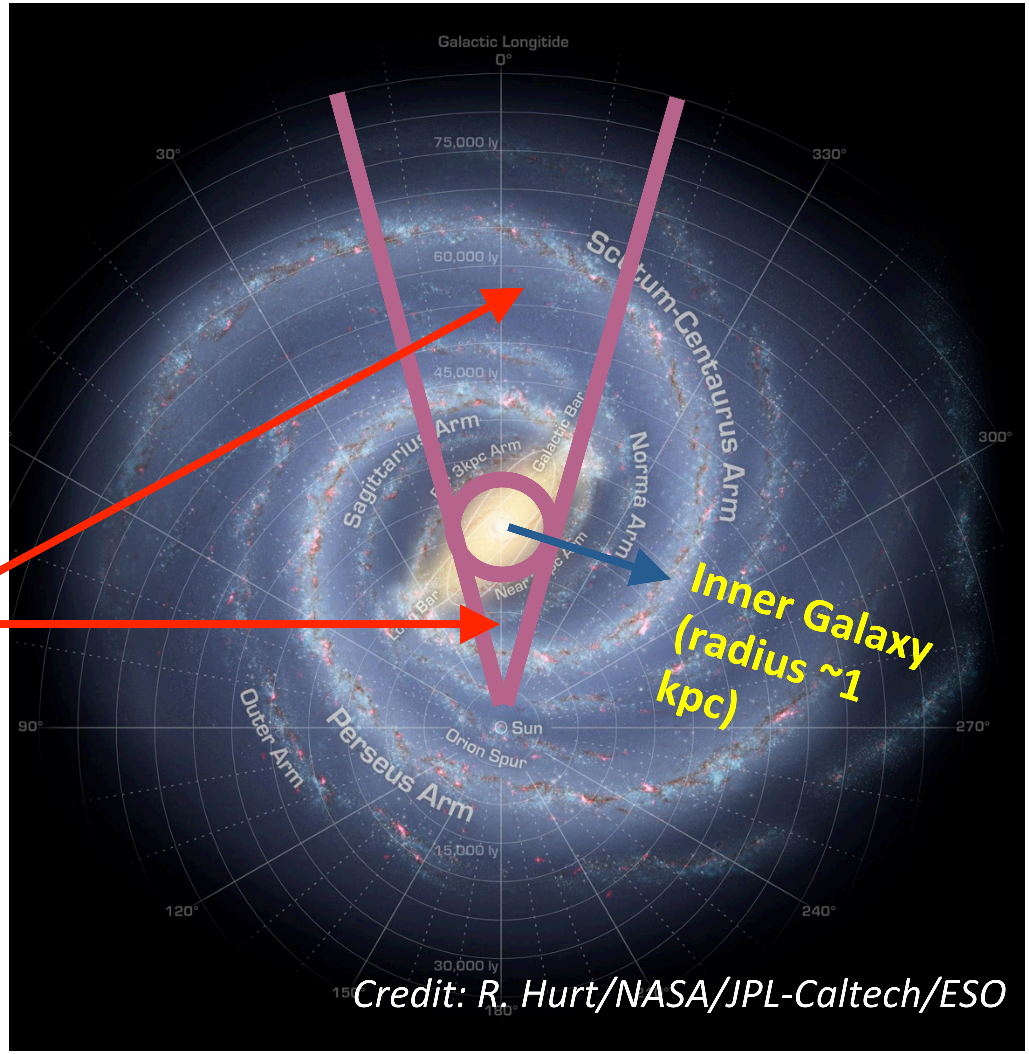


CRs in the inner Galaxy

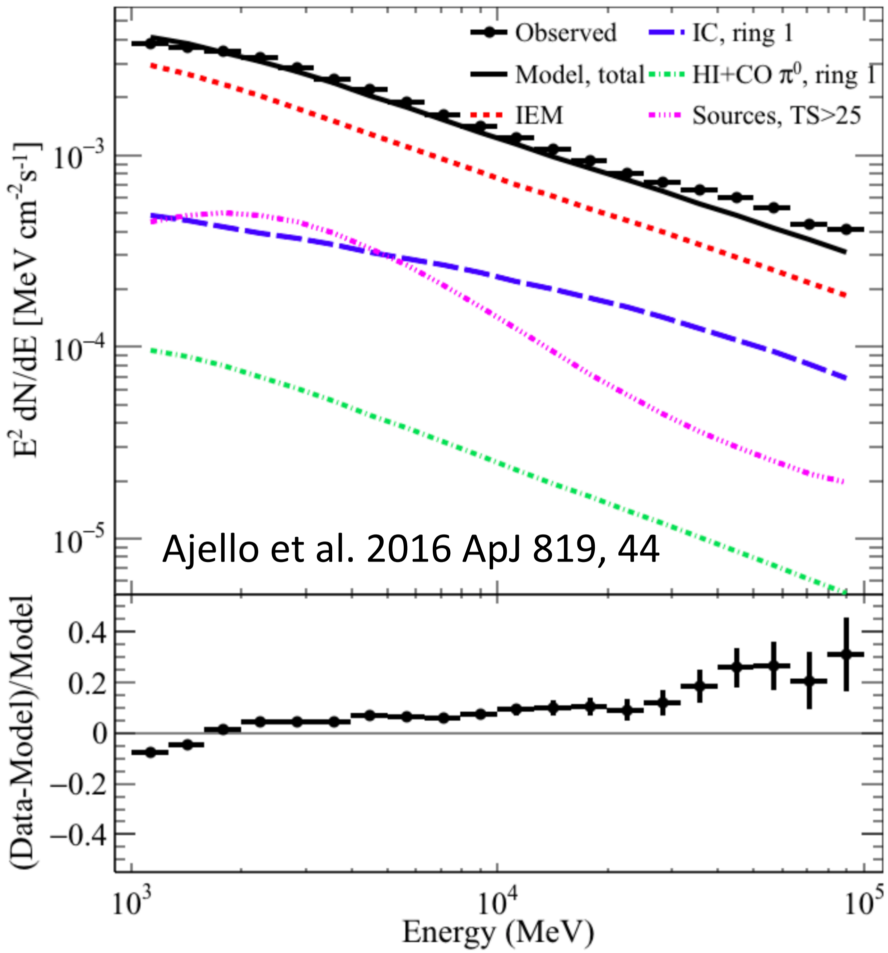
Hooper et all 2010, Goodenough et al. 2011, Abazajian et al. 2012, Hooper et al 2013, Gordon et al. 2013, Daylan eta al. 2014, Calore et al 2015; Mirabal (2013), Petrovic et al (2015), Cholis et al. (2015), Lee et al. 2016, Bartels et al. 2016, Brandt & Kocsis 2015, Carlson et al. 2016 etc

- CRs? - Unresoved sources? - Dark Matter?

Fore/background interstellar modeling is critical



CRs toward the Galactic center

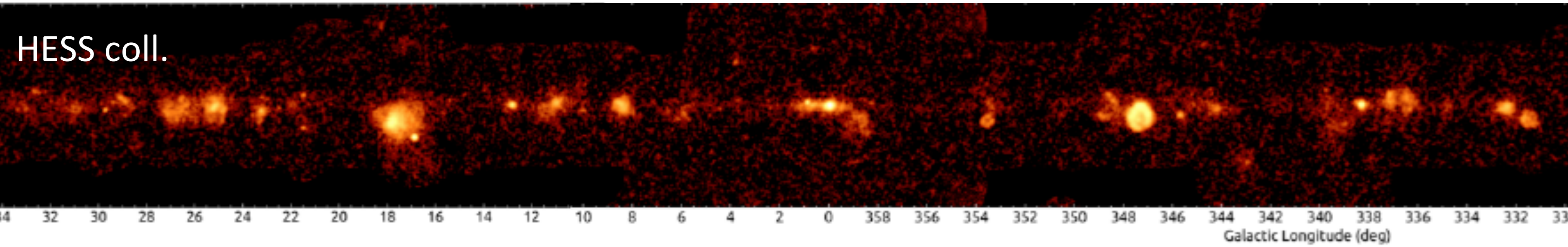


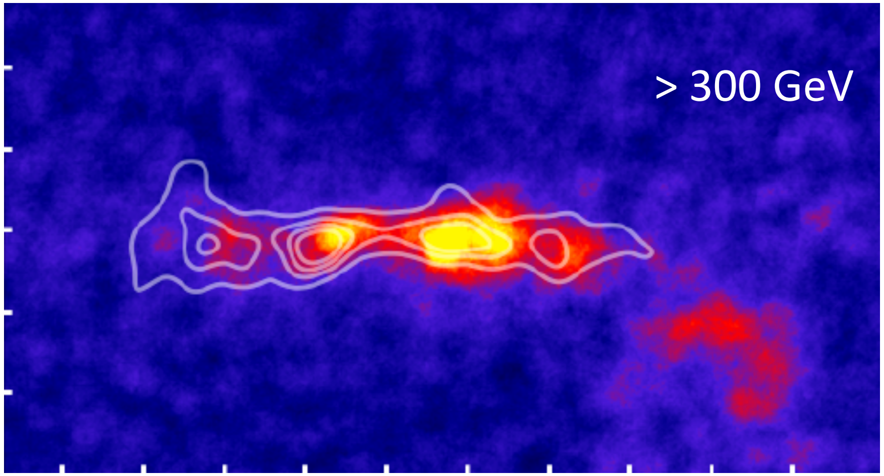
→ GeV excess with respect to usual interstellar models

→ IC dominant and enhanced (ISRF or CR electrons?)

Galactic plane above 200 GeV

H.E.S.S.



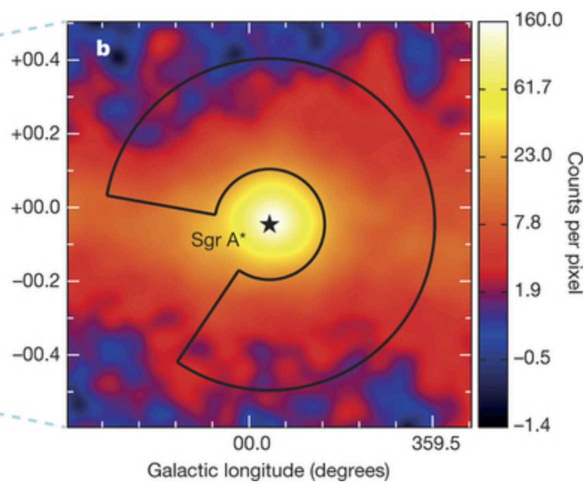


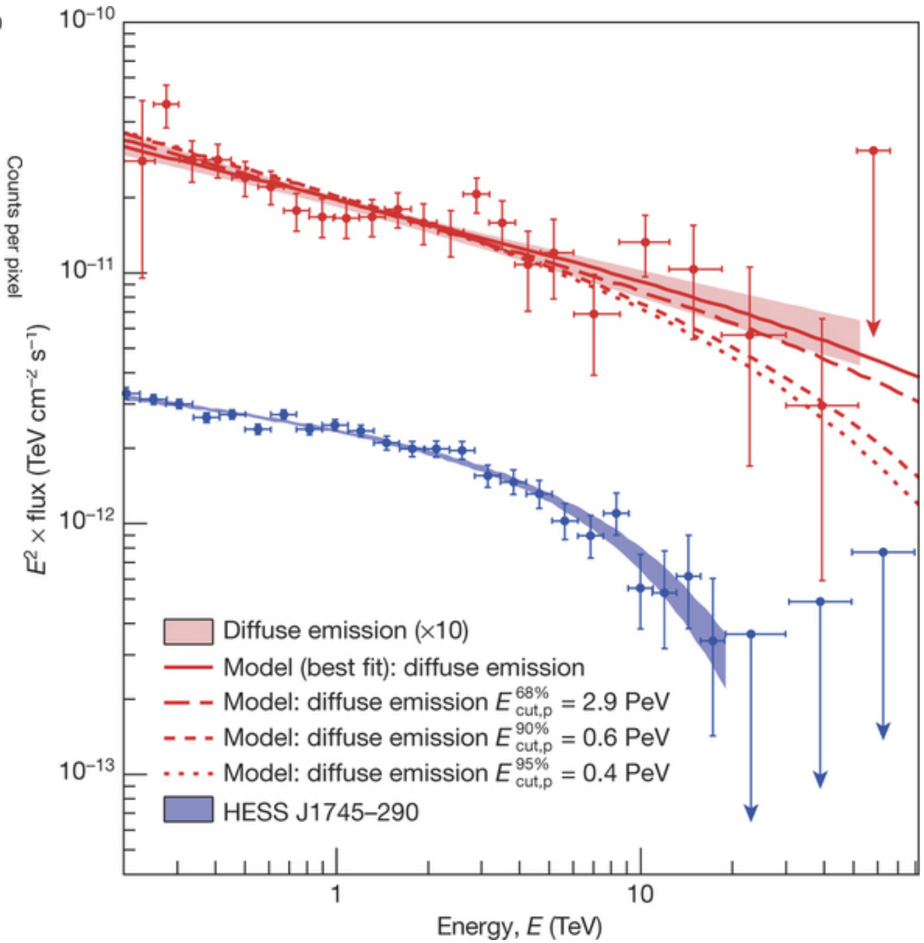
H.E.S.S. Coll. Nature (2016) 531, 476

Updated observations of the GC ridge: a fraction of emission is distributed like dense gas tracers (CR hadronic origin) -> info on CRs.

See talk by Dmitry Zaborov on Mon

Discovery of PeVatron protons

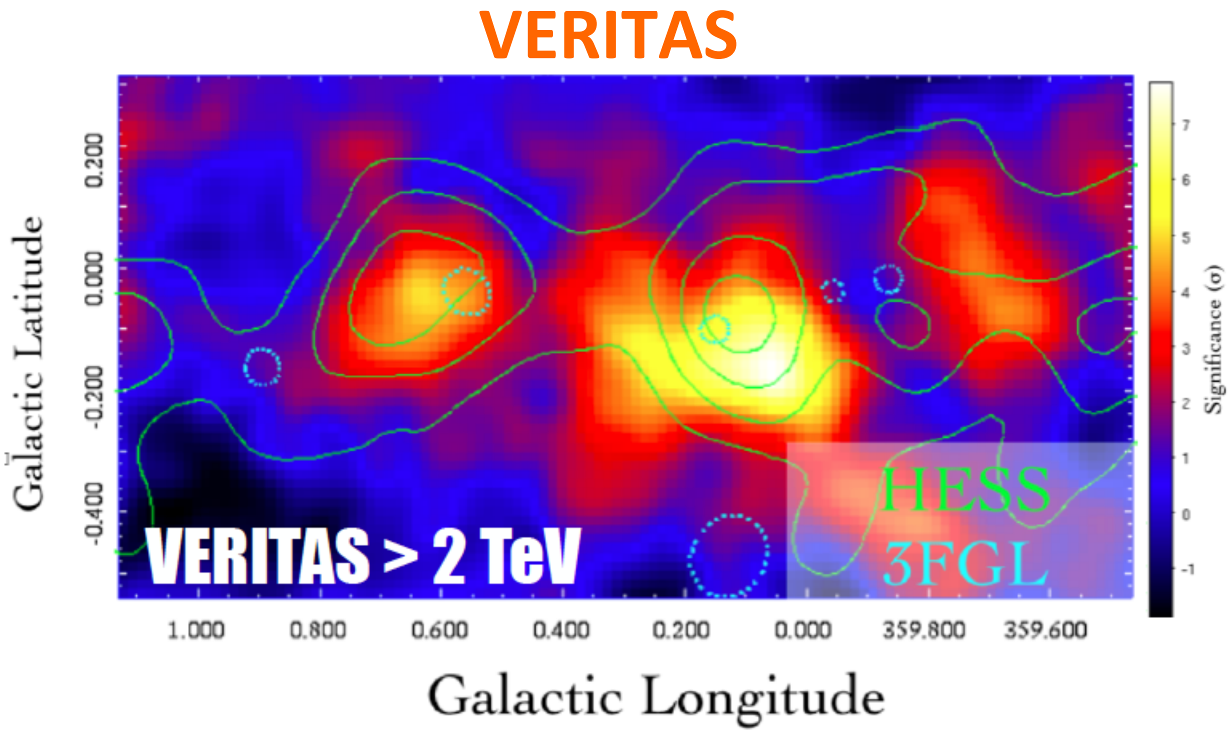




H.E.S.S. Coll.
Nature 2016

- Location of the CR source in the inner ~10 pc
- Radial profile of the emission is consistent with with CRs accelerated in BH diffusing away
- Diffuse emission possibly associated to Sgr A* activity in the last 10^6-10^7 yrs

Galactic Ridge above 2 TeV

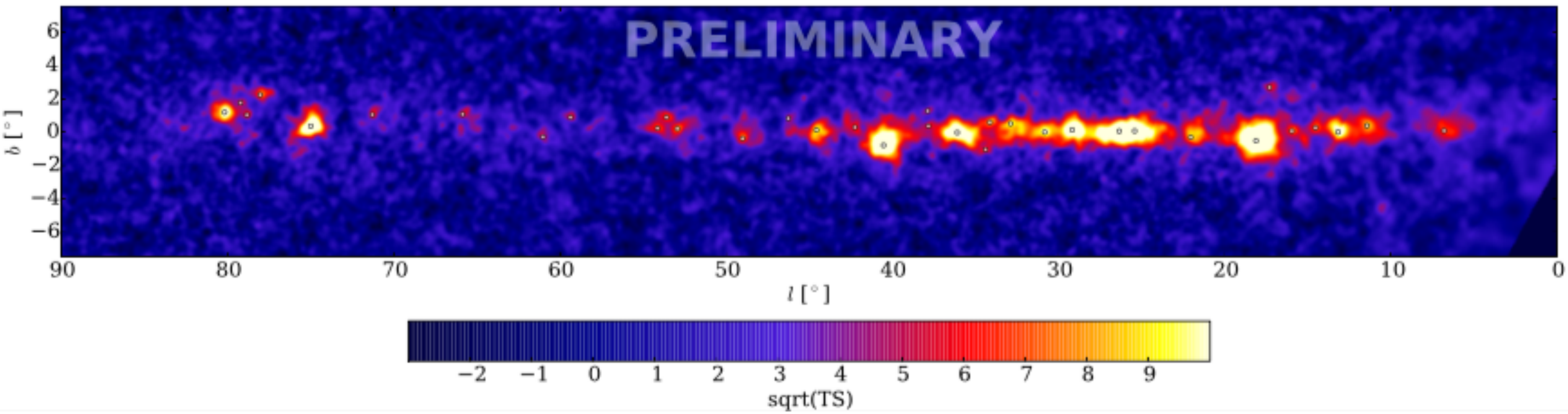


Archer et al. 2016

Residual emission after subtracting the sources overlaps the countour from H.E.S.S

See talk by Qi Feng on Mon

HAWC >10 TeV



Detections that are coincident with known TeV SNRs and PWN along the Galactic plane

Waiting for deeper observations of diffuse emission in different regions of the sky

See talk by Francisco Salesa Greus on Mon

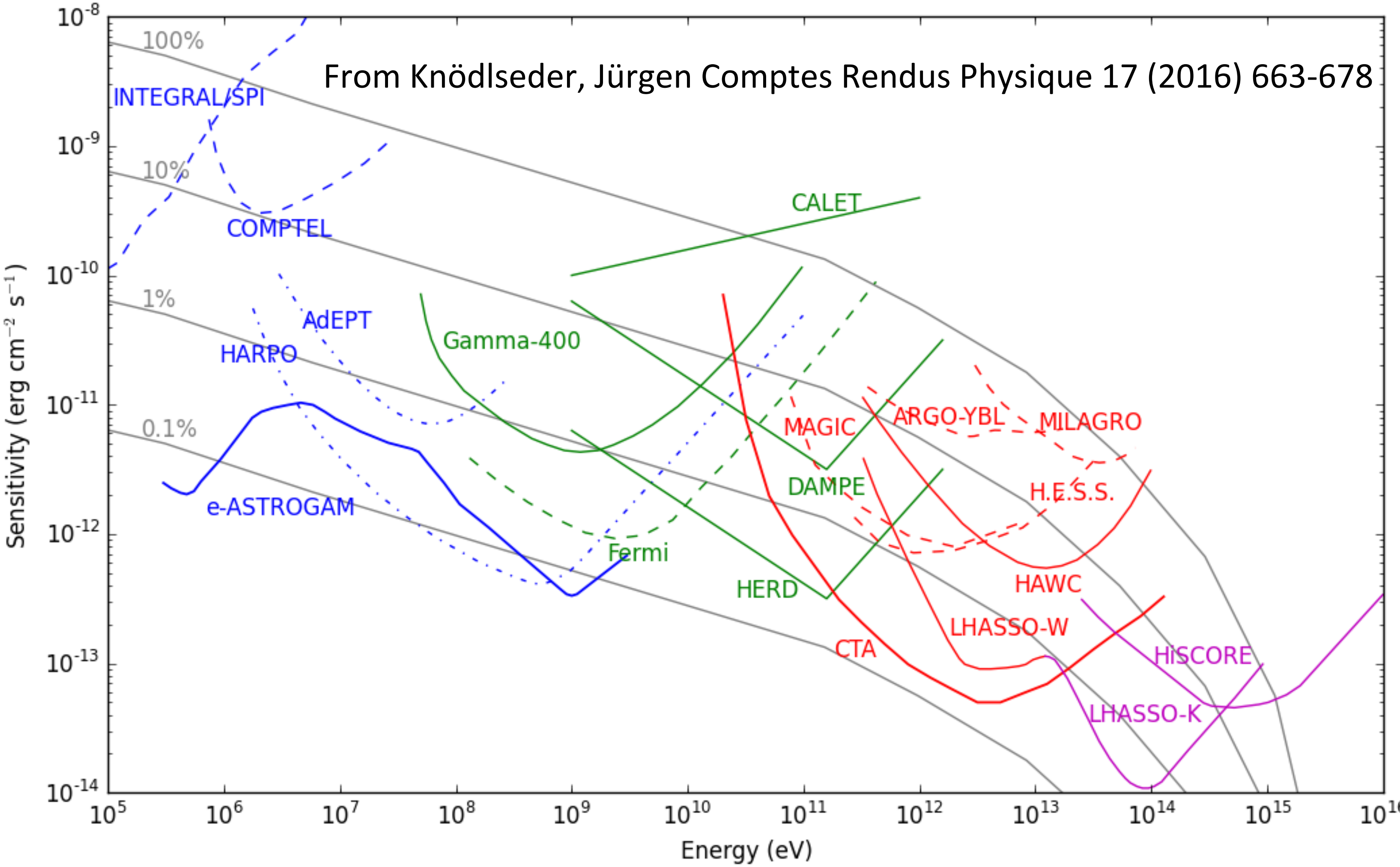
Still long-standing open questions:

1. What are all the Galactic sources producing CRs?

2. How CRs accelerate and propagate in the interstellar medium?

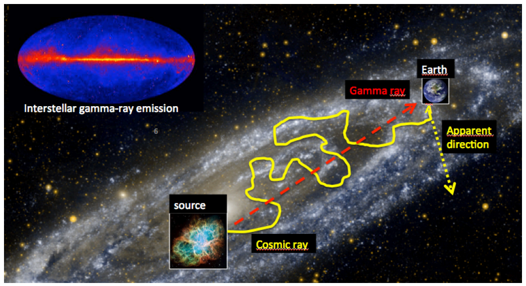
n. …

Present & future



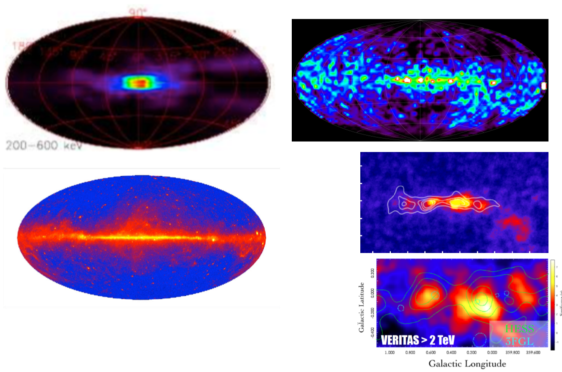
With upcoming mission will have a full and deeper coverage of the gamma-ray sky

Today you have seen



- CR sources
- Diffuse Interstellar emission and its uncertainties

-> many questions still open



From X to TeV energies diffuse emission is a common feature (also radio should be included for a complete picture)

Multiwavelengh observations and especially the advent of CTA + possible missions at MeV will answer open questions