Intensity and origin of the extragalactic gamma-ray background between 100 MeV and 820 GeV

Gamma-ray Space Telescope

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on behalf of the Fermi LAT collaboration

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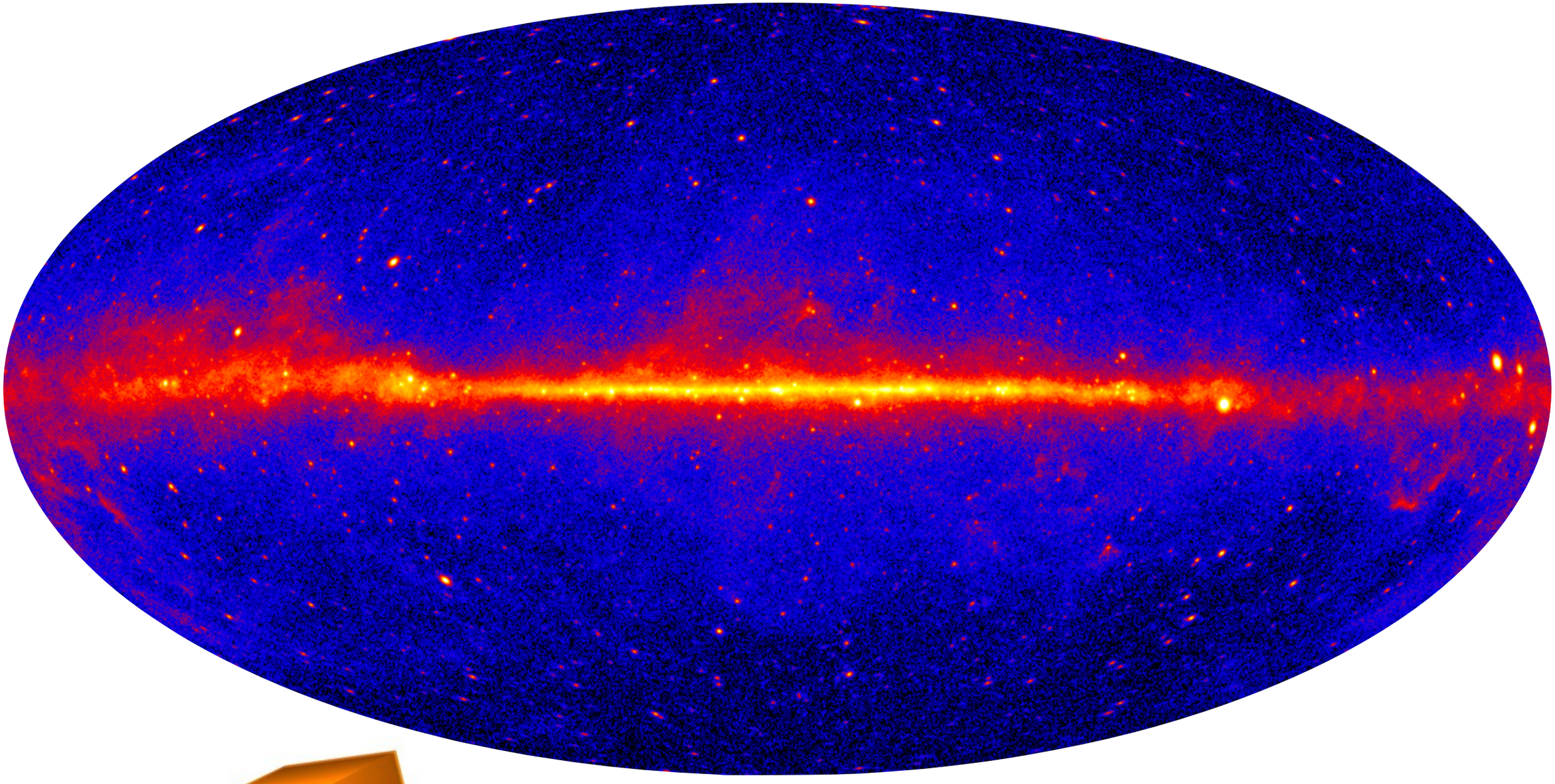
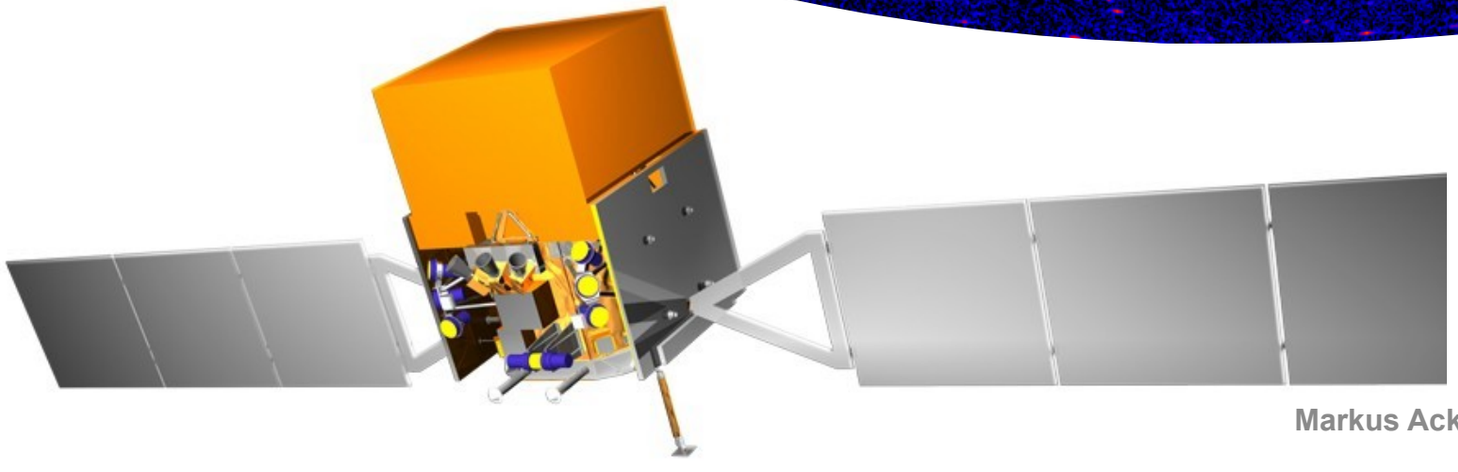
HELMHOLTZ ASSOCIATION

DESY

The Fermi LAT gamma-ray sky

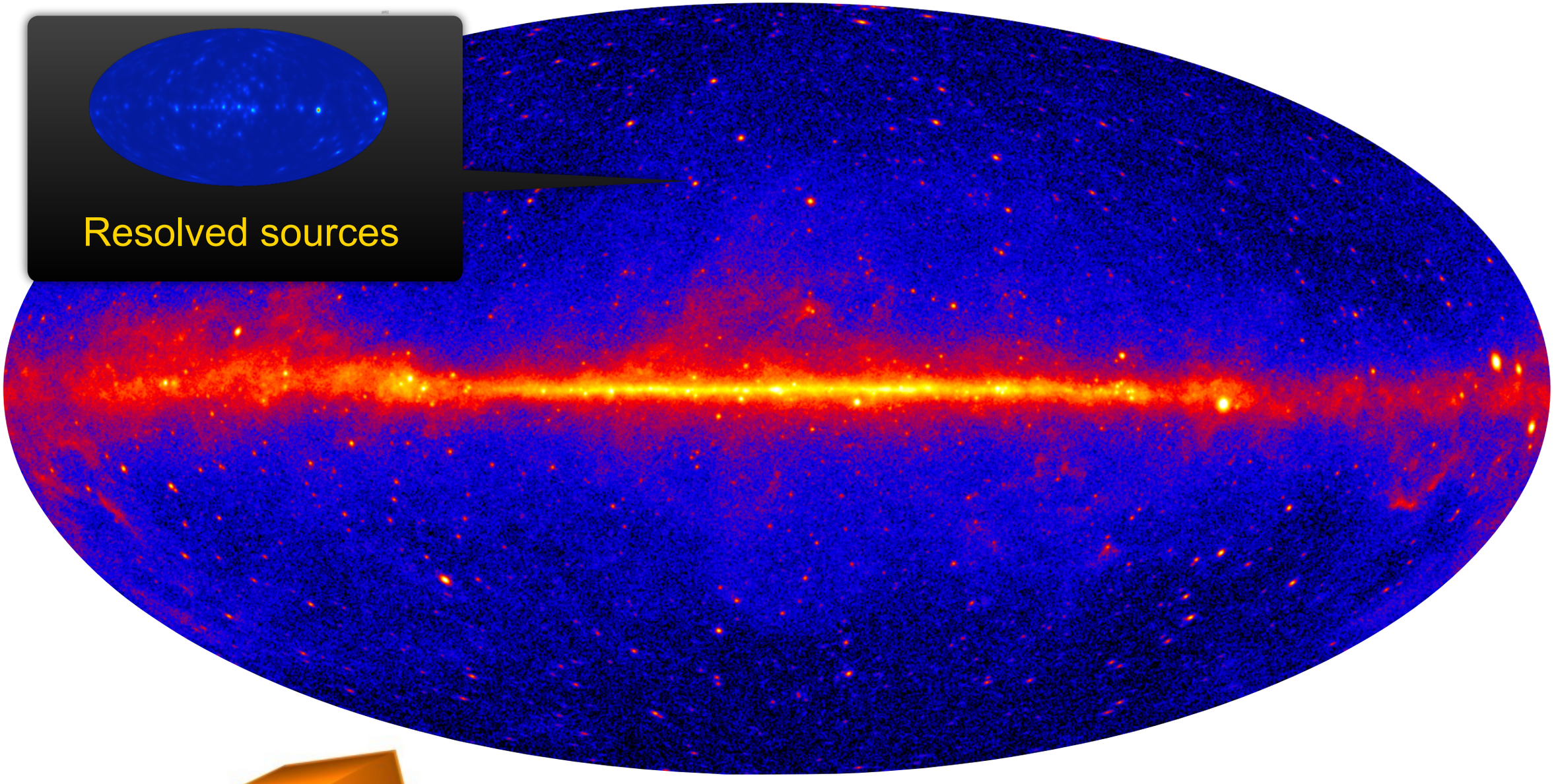
Fermi LAT, 4-year sky map, E > 1 GeV

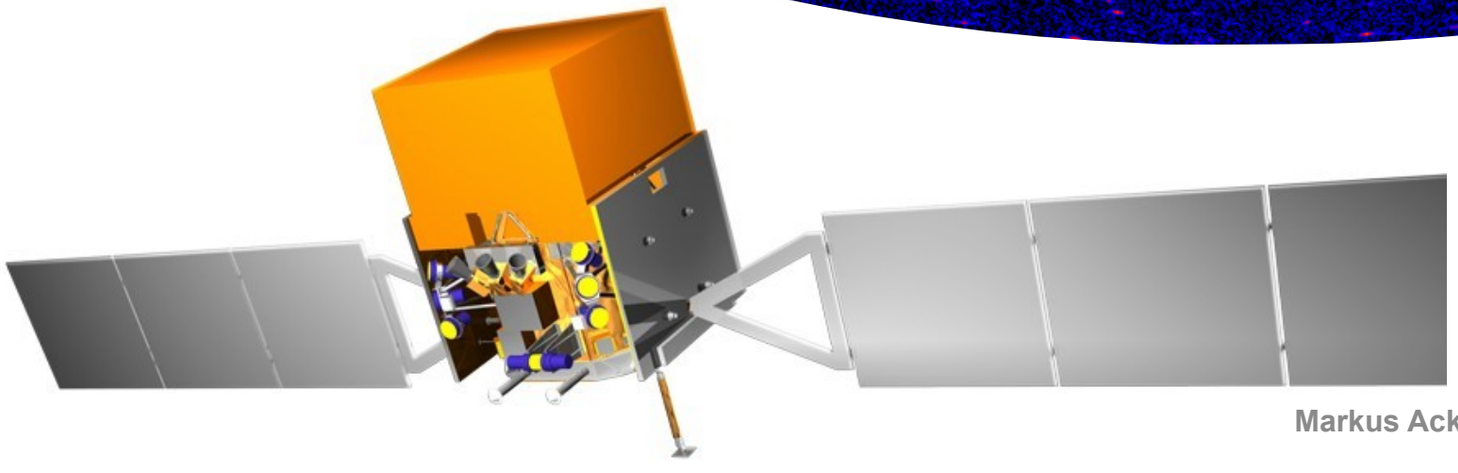




The Fermi LAT gamma-ray sky

Fermi LAT, 4-year sky map, E > 1 GeV





The Fermi LAT gamma-ray sky

Fermi LAT, 4-year sky map, E > 1 GeV

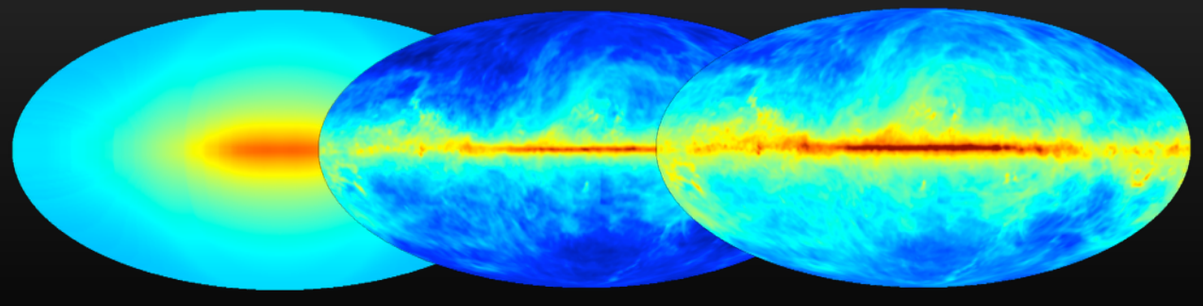
Resolved sources

Galactic diffuse emission

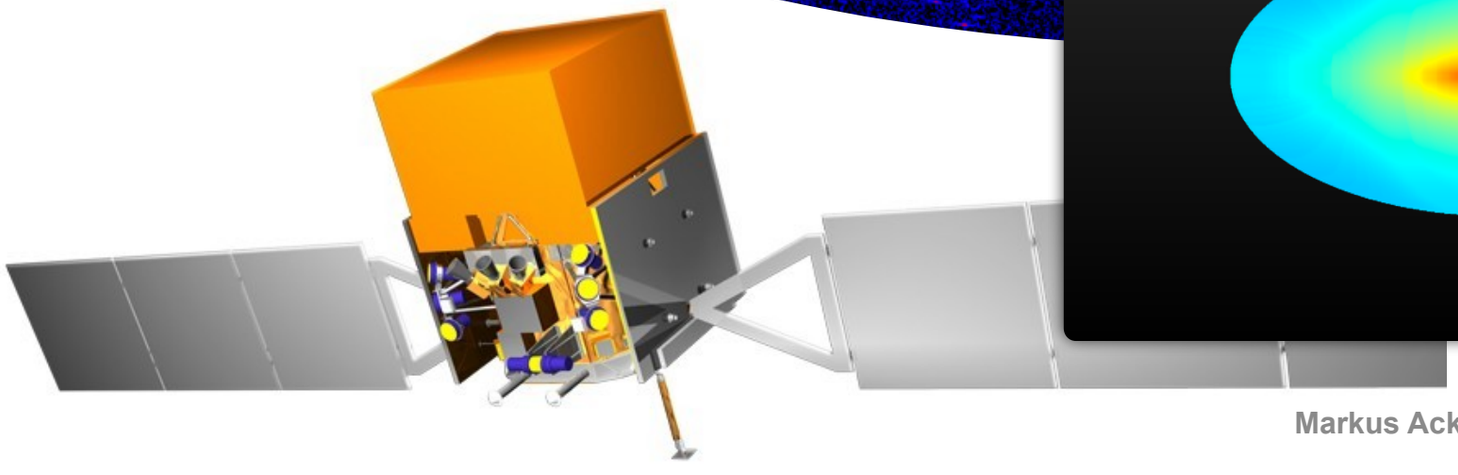
(CR interactions with the interstellar medium)

Inverse Compton

π^0-decay

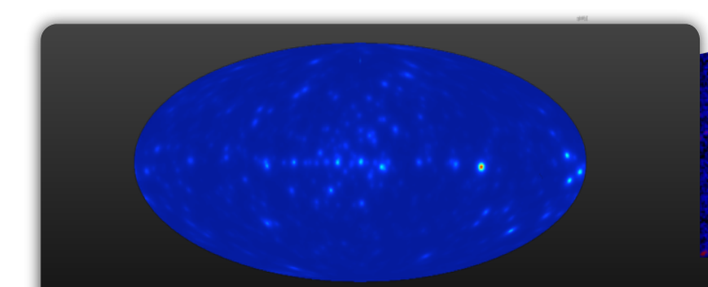


Bremsstrahlung



The Fermi LAT gamma-ray sky

Fermi LAT, 4-year sky map, E > 1 GeV



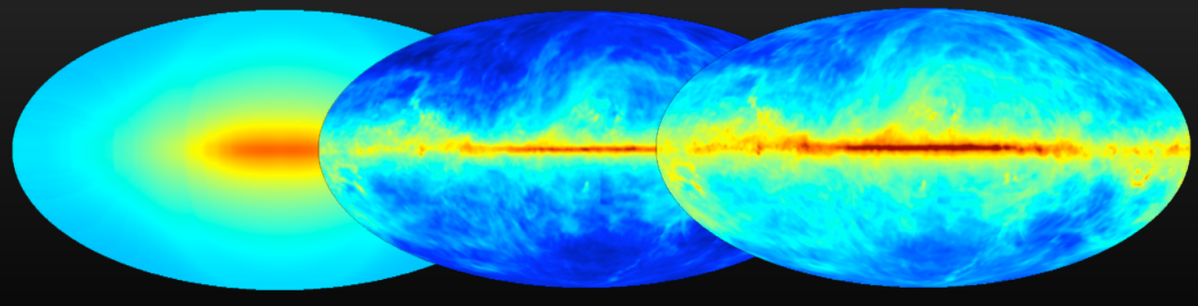
Resolved sources

Isotropic diffuse emission (IGRB)

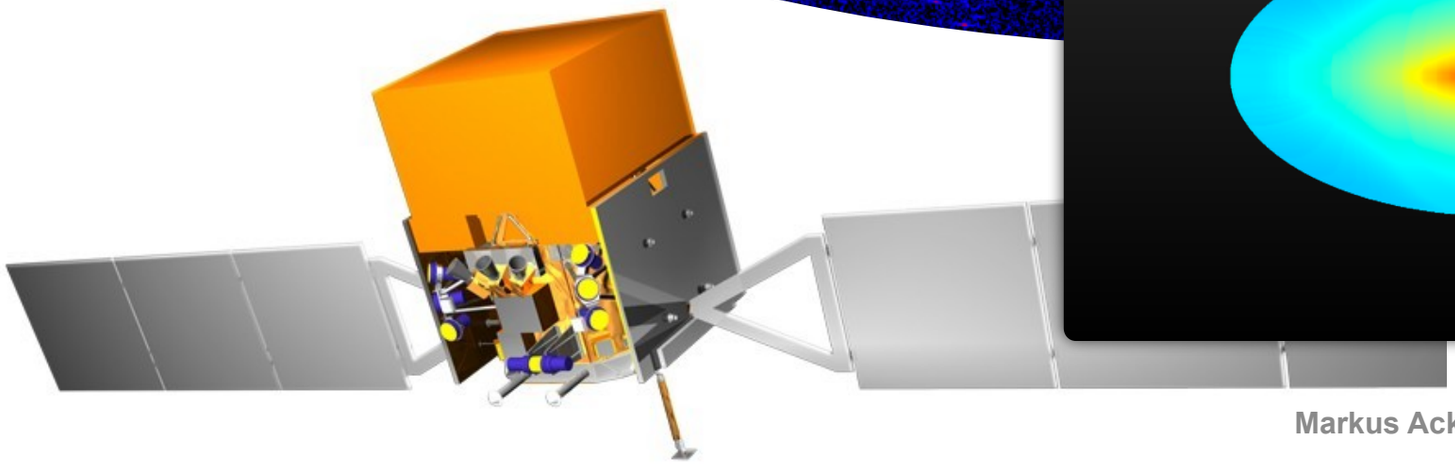
Galactic diffuse emission
(CR interactions with the interstellar medium)

Inverse Compton

π^0-decay

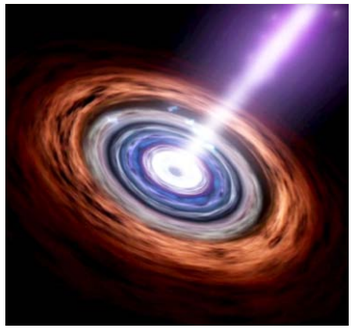


Bremsstrahlung



The origin of the IGRB in the LAT energy range

Undetected sources



Blazars

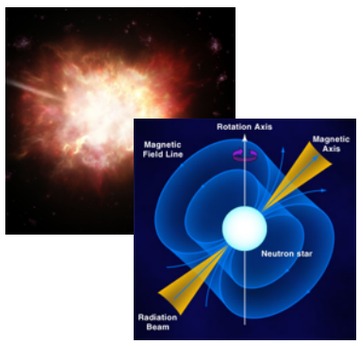
- Dominant class of LAT extra-galactic sources.
- Estimated EGB contributions ranging from 20% - 100%.

Radio galaxies

- 27 sources listed in 2FGL.
- 25% - 50 % contribution to EGB expected (large uncertainties!).

Star-forming galaxies

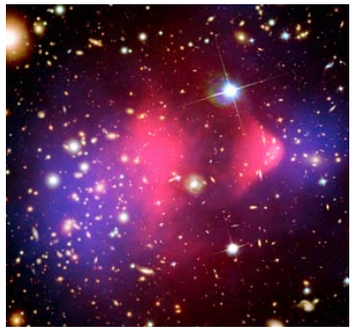
- Several galaxies outside the local group resolved by LAT.
- Significant contribution to EGB expected.



GRBs + High-latitude pulsars

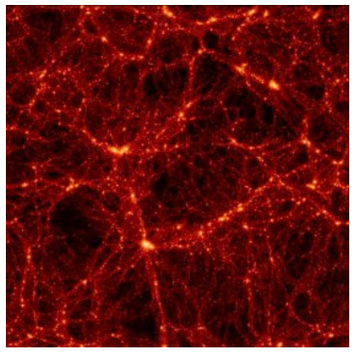
- Small contributions expected.

Diffuse processes



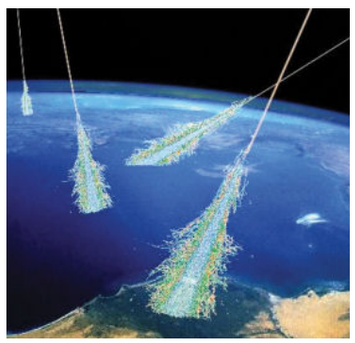
Intergalactic shocks

- Widely varying predictions of EGB contribution ranging from 1% to 100%.



Dark matter annihilation

- Potential signal dependent on nature of DM, cross-section and structure of DM distribution.



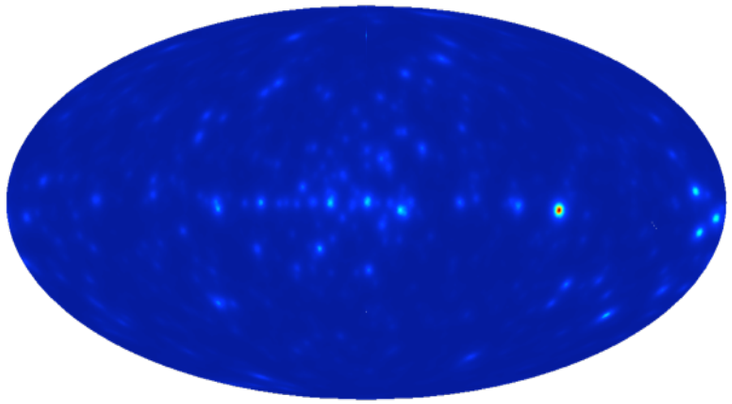
Interactions of UHE cosmic rays with the EBL

- Strongly dependent on evolution of UHECR sources.
- 1% - 100% of EGB emission.

Isotropic Galactic contributions

- Contributions from an extremely large Galactic electron halo.
- CR interaction in small solar system bodies.

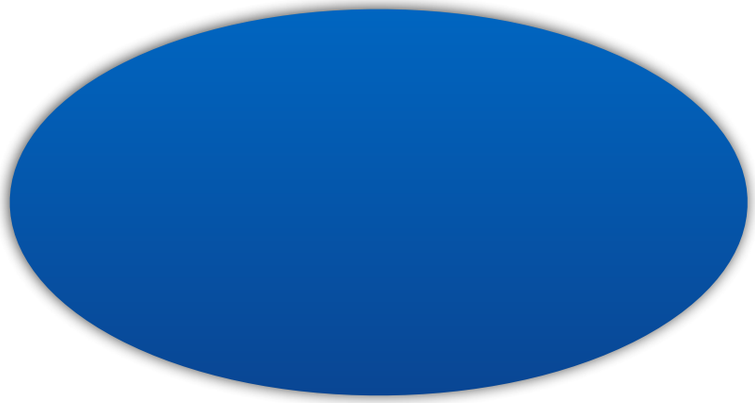
The isotropic and the total extragalactic background



Resolved sources

Intensity that can be **resolved into sources** depends on:

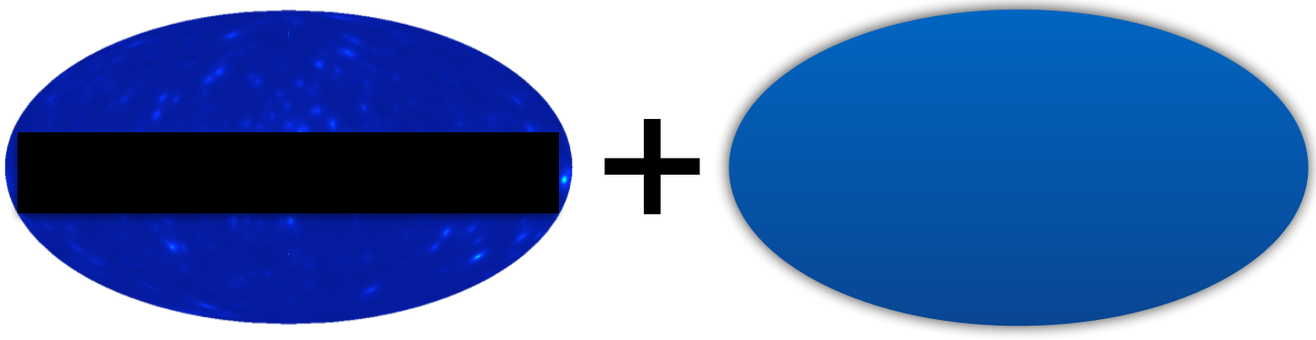
- the sensitivity of the instrument.
- the exposure of the observation.



Isotropic γ-ray background (IGRB)

→ The **isotropic γ-ray background** depends on the sensitivity to identify sources.

→ Important as an **upper limit on diffuse processes.**

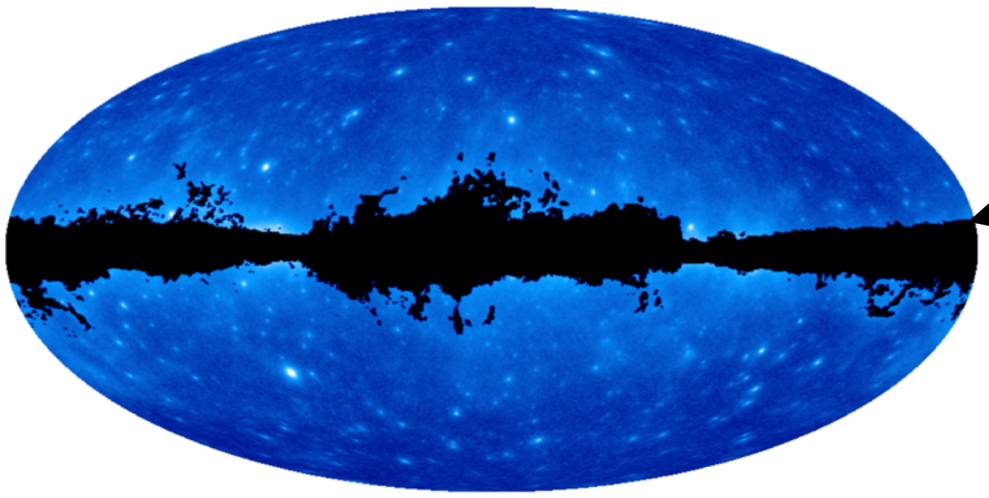


Total extragalactic γ-ray background (EGB)

→ **The total extragalactic γ-ray background** is instrument and observation independent.

→ Useful for **comparisons with source population models**.

Derivation of the isotropic gamma-ray background



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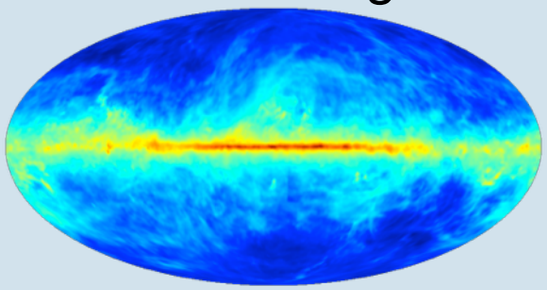
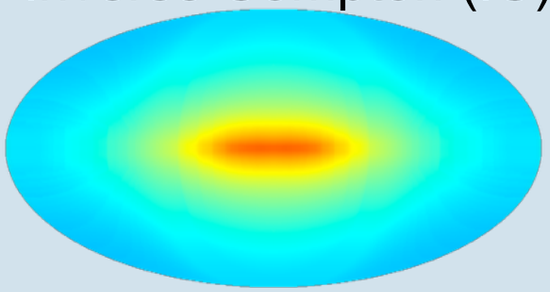
Not used in this analysis:

> Galactic plane
> Regions with dense molecular clouds
> Regions with non-local atomic hydrogen clouds

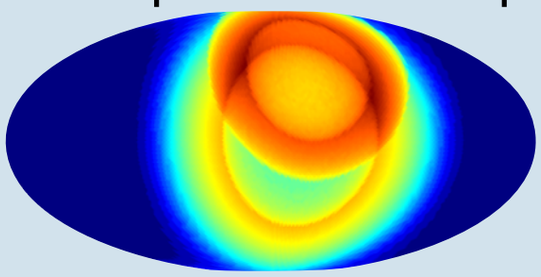
Interstellar gas



Inverse Compton (IC)



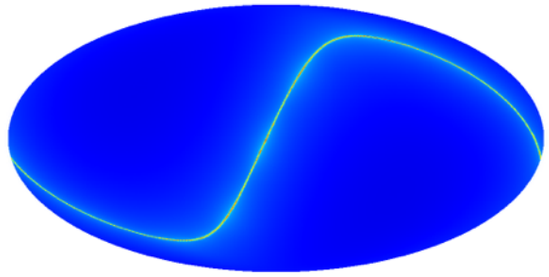
Loop I / Local Loop



Galactic diffuse emission

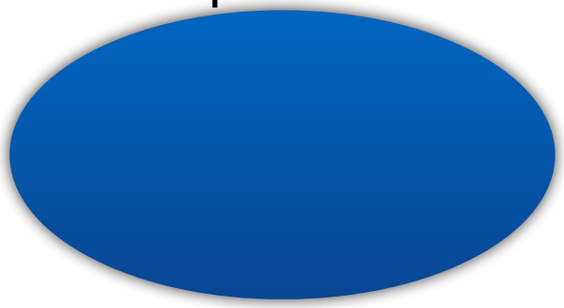
+

Solar disk and IC



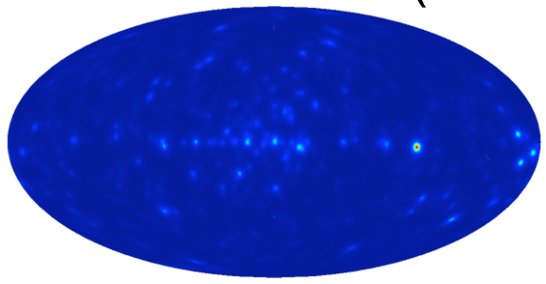
Isotropic emission

+



Resolved sources (2FGL)

+



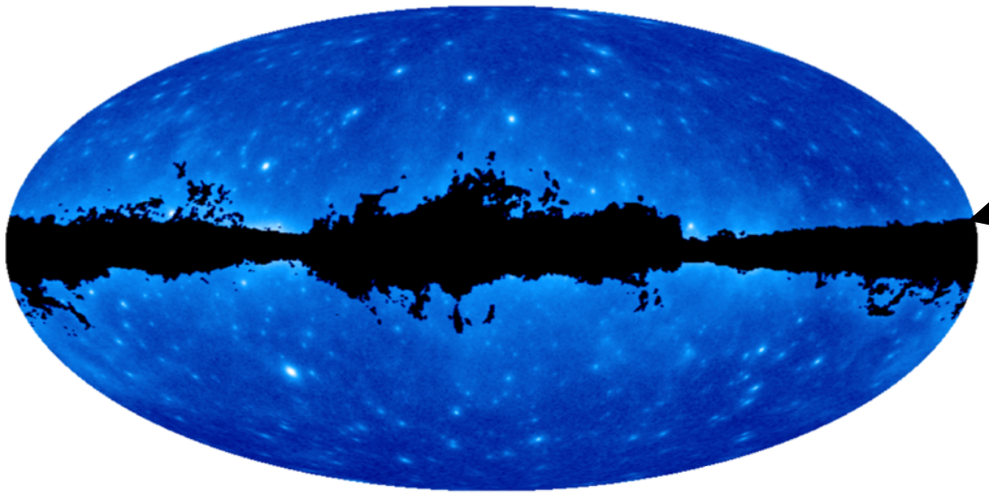
Low-energy analysis (100 MeV - 13 GeV)

> **High-statistics** regime.
> Intensity of **all components** is fitted in each energy band.

High-energy analysis (13 GeV - 820 GeV)

> **Low-statistics** regime
> **Only resolved sources** and **isotropic emission** are fitted in each energy band.

Derivation of the isotropic gamma-ray background



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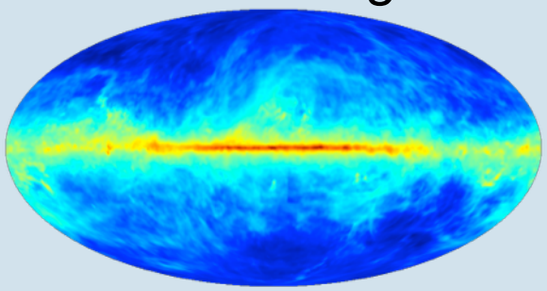
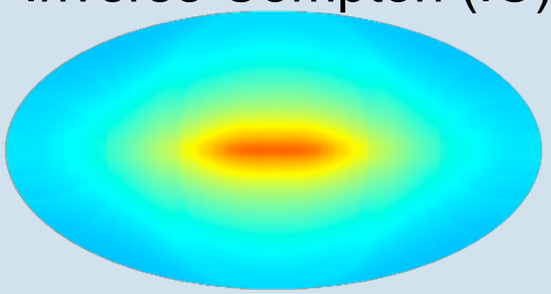
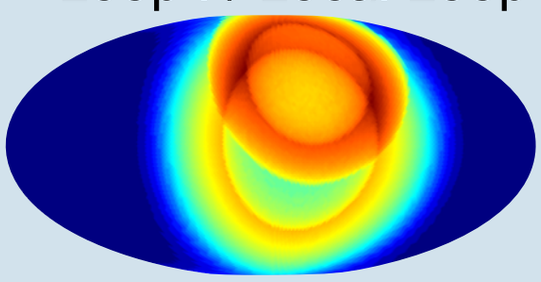
Interstellar gas



Inverse Compton (IC)



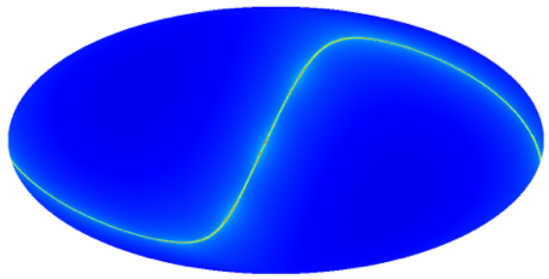
Loop I / Local Loop



Galactic diffuse emission

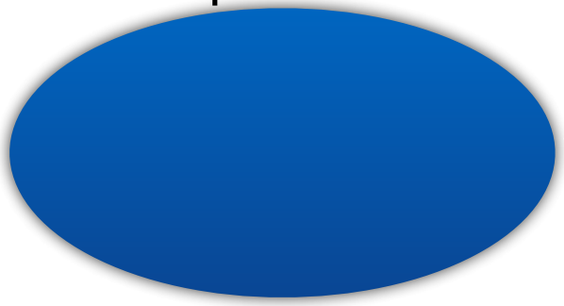
\+

Solar disk and IC



Isotropic emission

\+



Resolved sources (2FGL)

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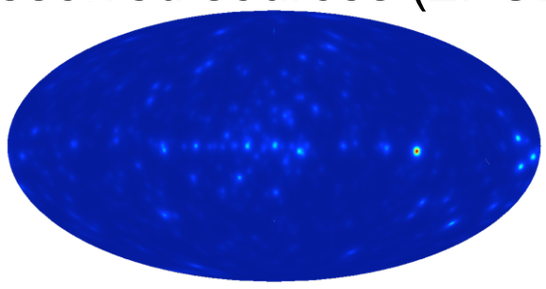
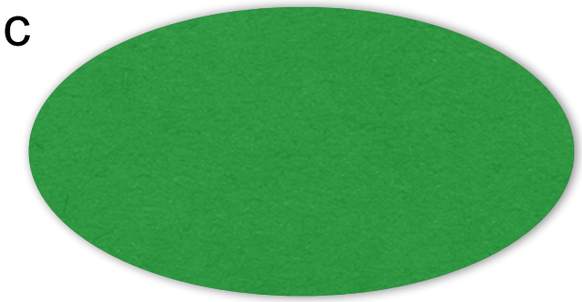
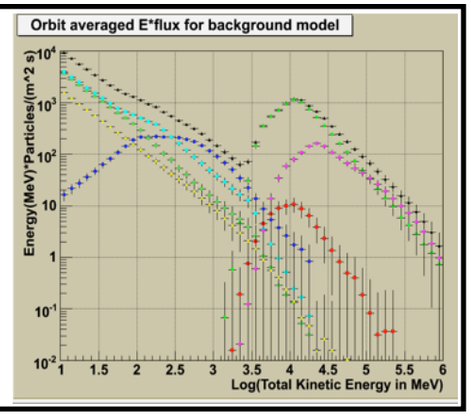


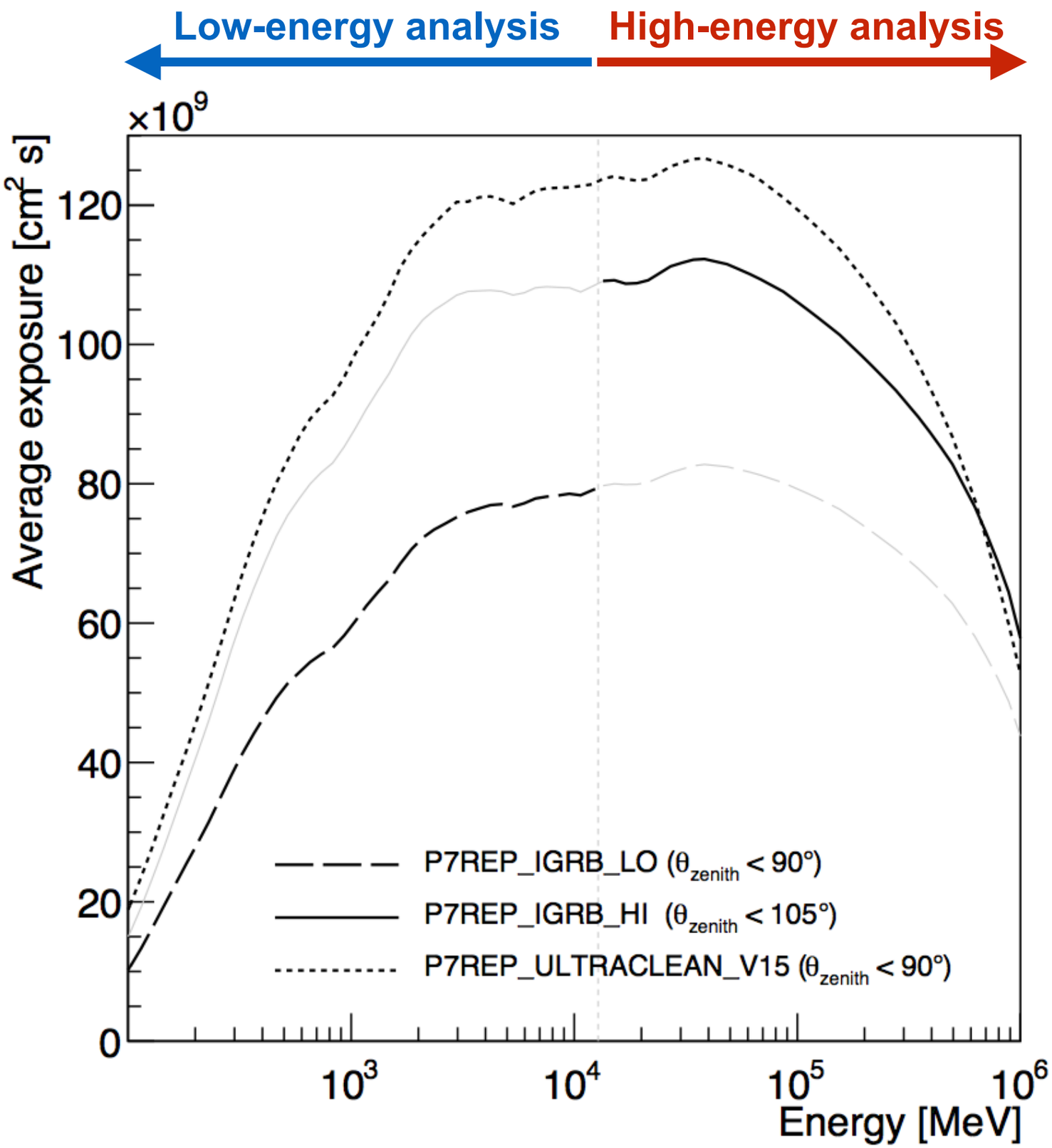
Isotropic γ-ray back-ground (IGRB)



Contami-nation from CR induced background



New event classifications for the EGB analysis



> Publicly available LAT event classes (P7ULTRACLEAN) have **insufficient background rejection** for this study at very low and very high energies.

> **New high-purity event classes** developed for this analysis.

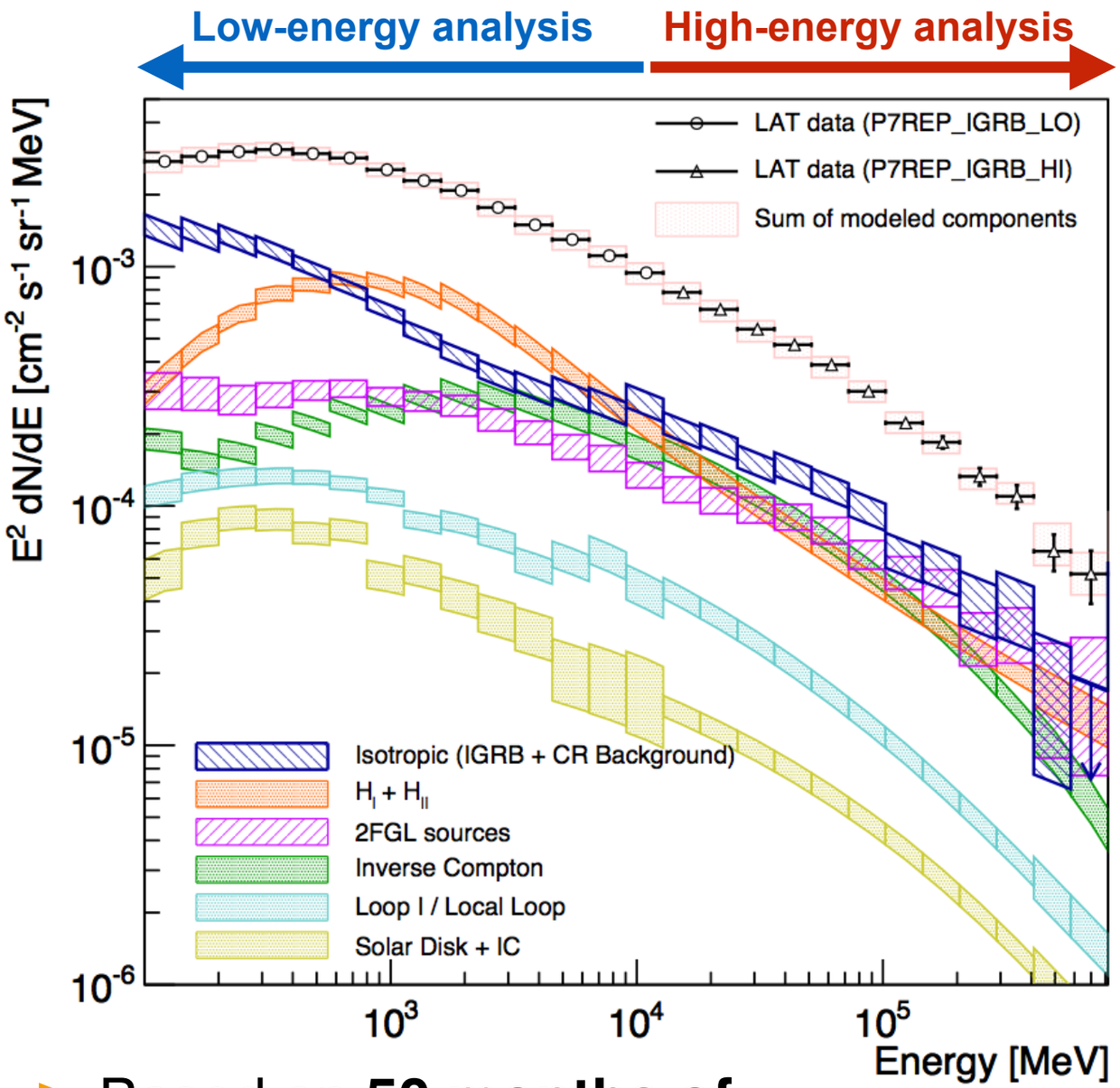
> P7REP_IGRB_LO

- Optimized to reject secondary CR background at low energies

> P7REP_IGRB_HI

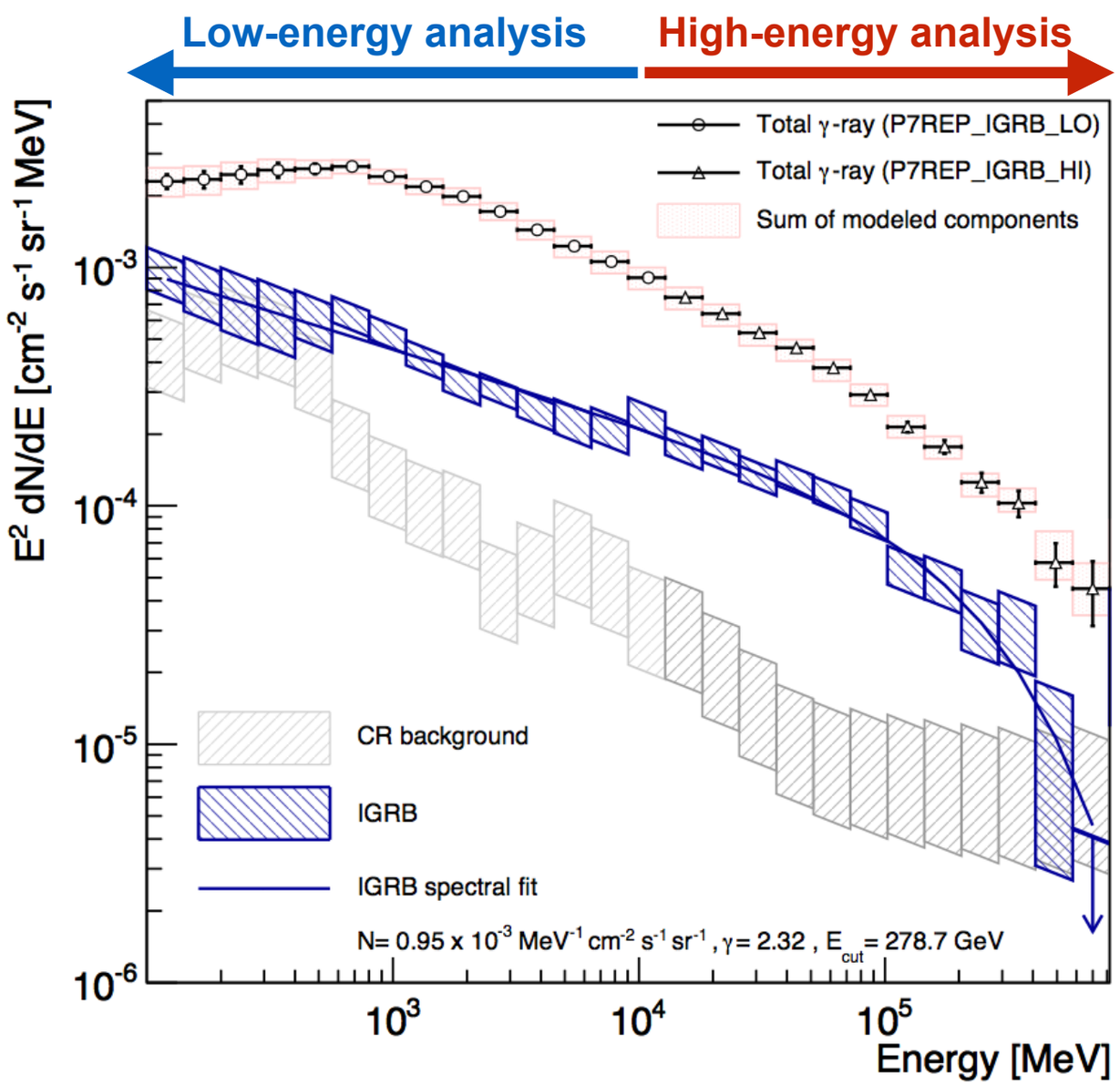
- Optimized to reject primary CR background while retaining high statistics

Results from the IGRB fit

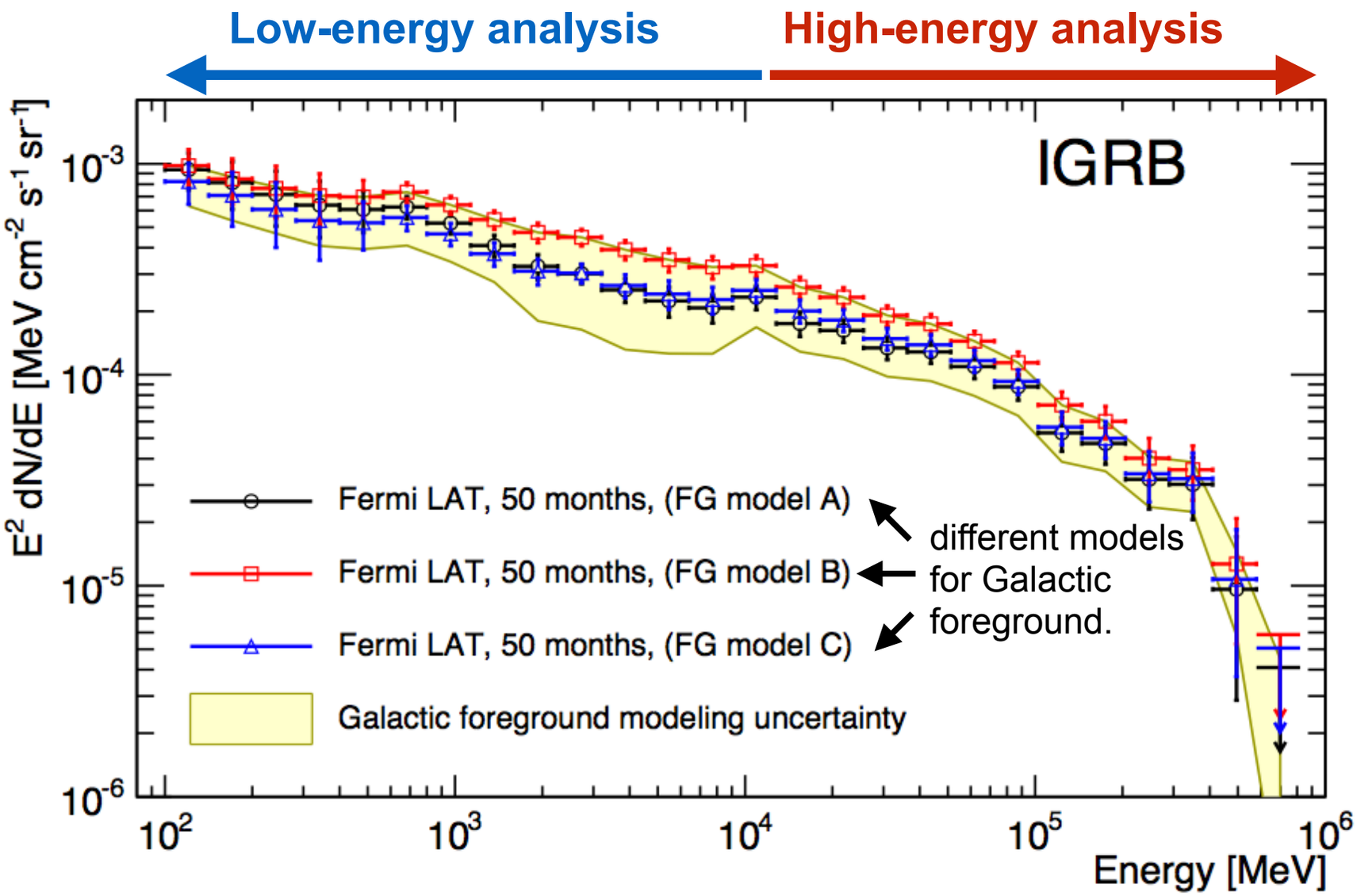


- Based on **50 months of reprocessed LAT data**.
- **Average intensities** (|b| > 20°) attributed to model templates.
- **Baseline foreground model** used.

- **IGRB and CR contributions** to isotropic emission
- **Spectral fit of IGRB** by power-law with exponential cutoff.



The IGRB spectrum



> **Error bars**:

statistical error

\+ syst. error from effective area parametrization

\+ syst. error from CR background subtraction

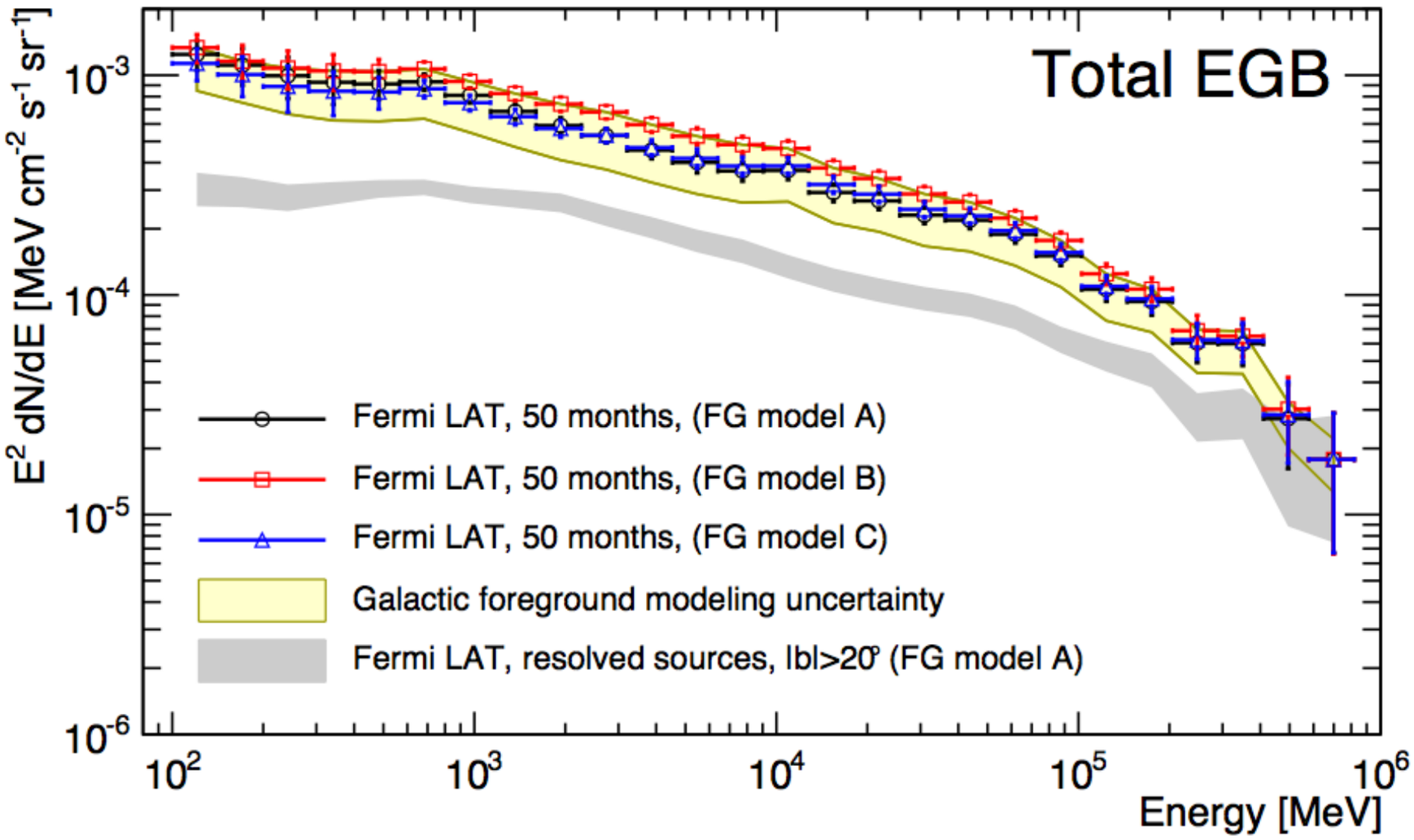
> **Yellow band:** systematic uncertainties from foreground model variations.

> **IGRB spectrum** can be parametrized by single power-law + exponential cutoff.

> Spectral index **~ 2.3** , cutoff energy **~ 250 GeV.**

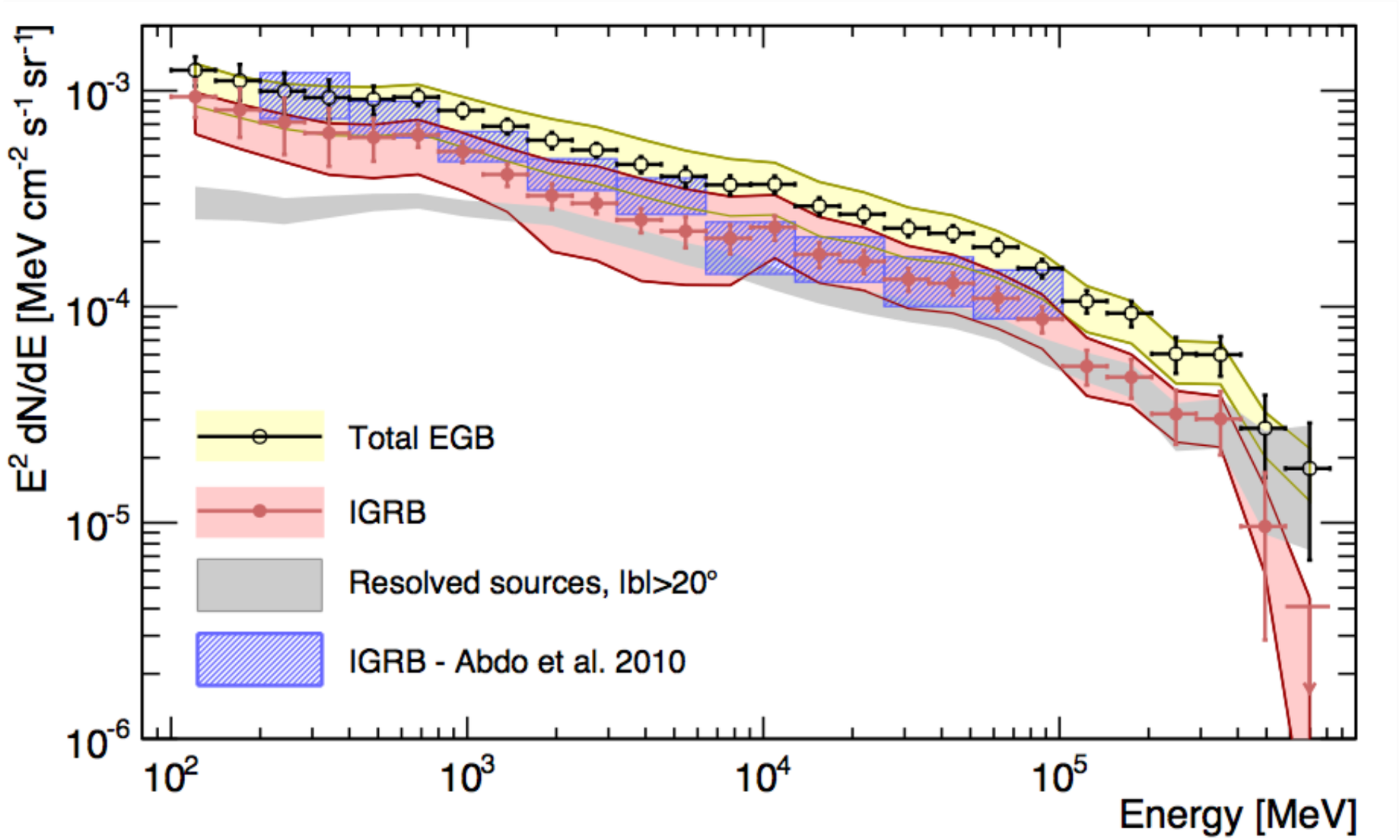
> It is **not compatible with a simple power-law** ($\chi^2 > 85$).

The total extragalactic background



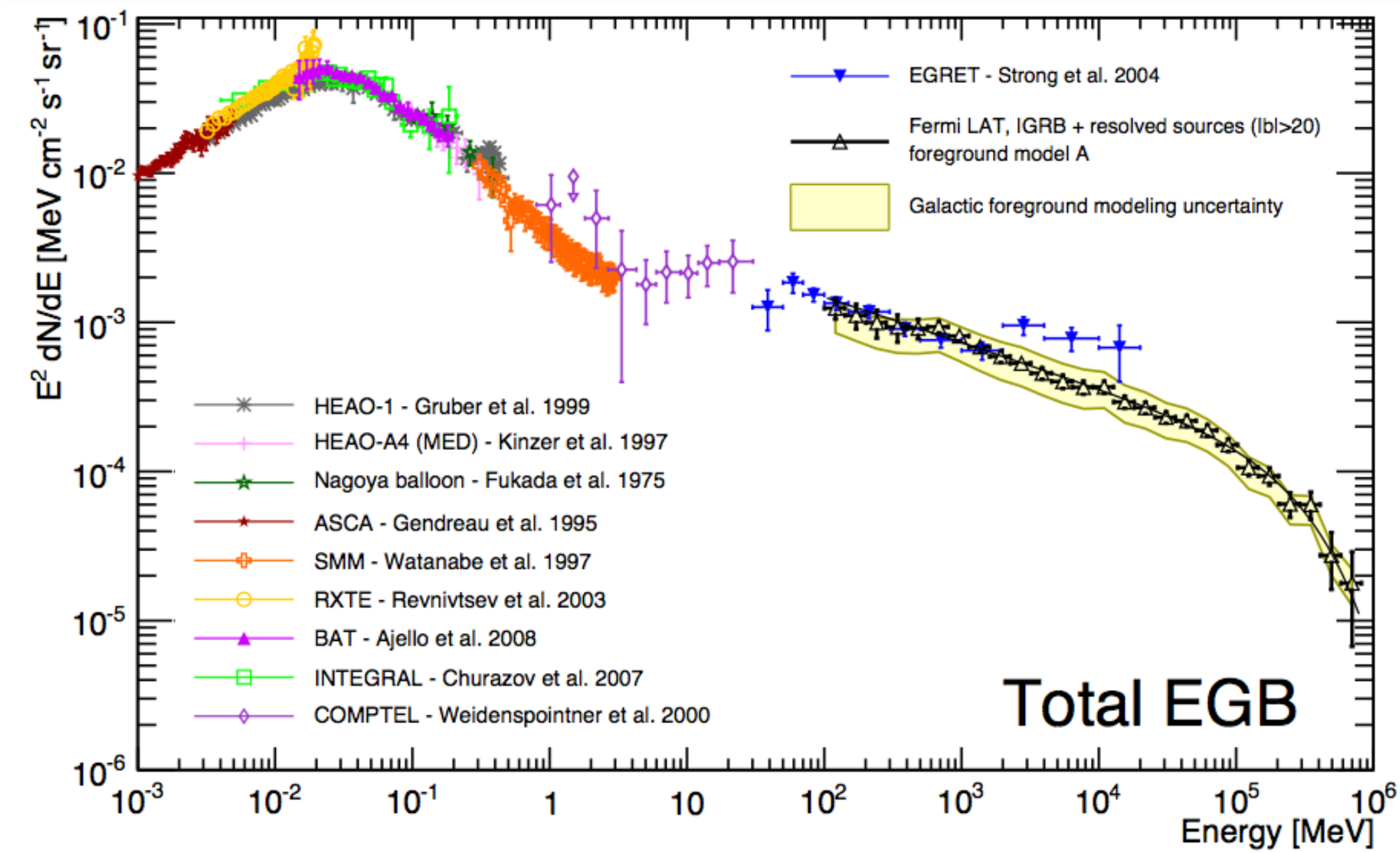
- **Sum of the intensities** of IGRB and the resolved high-latitude sources.
- Contribution of high-latitude Galactic sources **<< 5%.**
- Spectrum can be parametrized by **power-law with exponential cutoff**.
- Spectral index **~ 2.3**, cutoff energy **~ 350 GeV.**

Comparison of LAT IGRB and EGB measurements



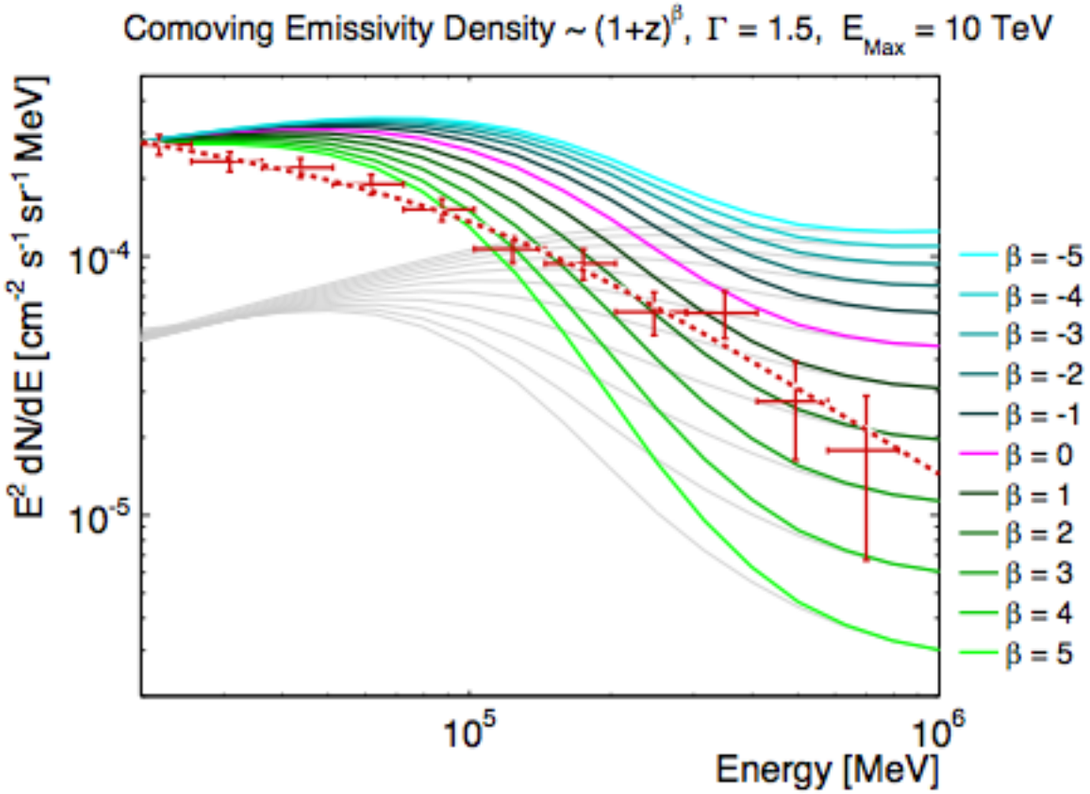
- Comparison for **baseline diffuse model**.
- **Integrated intensity** of IGRB about **30% below** measurement in Abdo et al. 2010.
- **Compatible** within systematic uncertainties.
- **Main differences:** Improved diffuse foreground and CR background models.

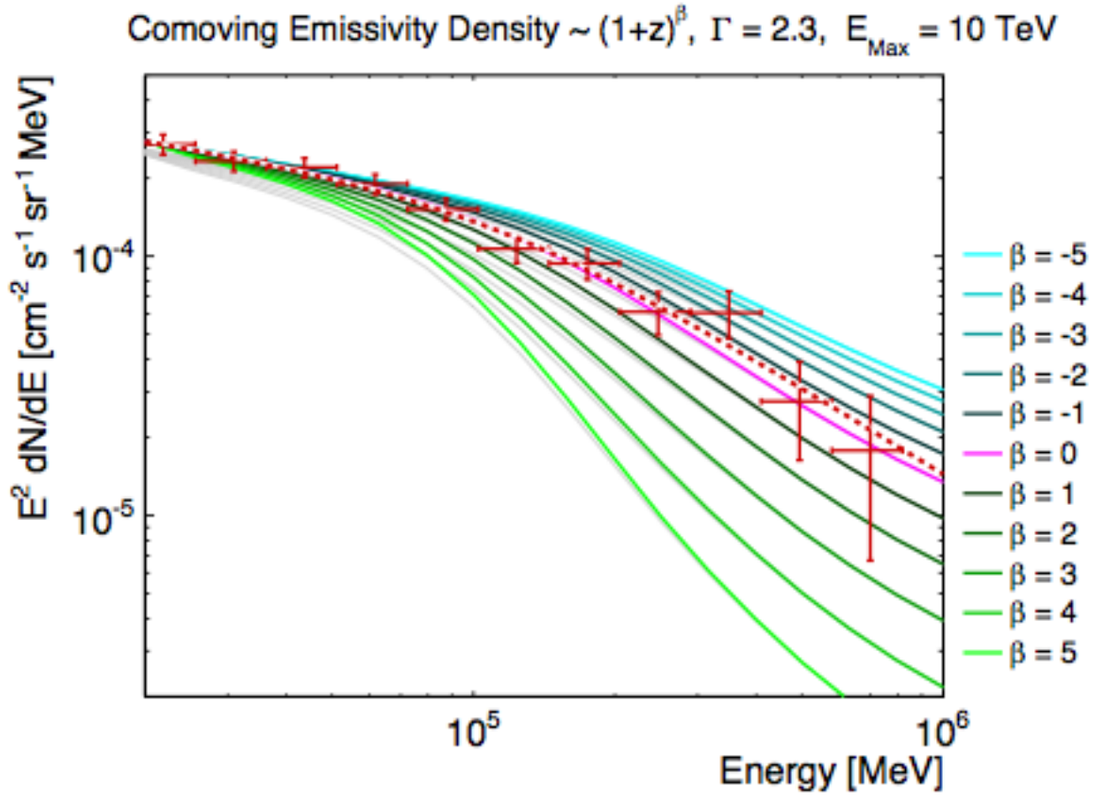
Comparison to other experiments



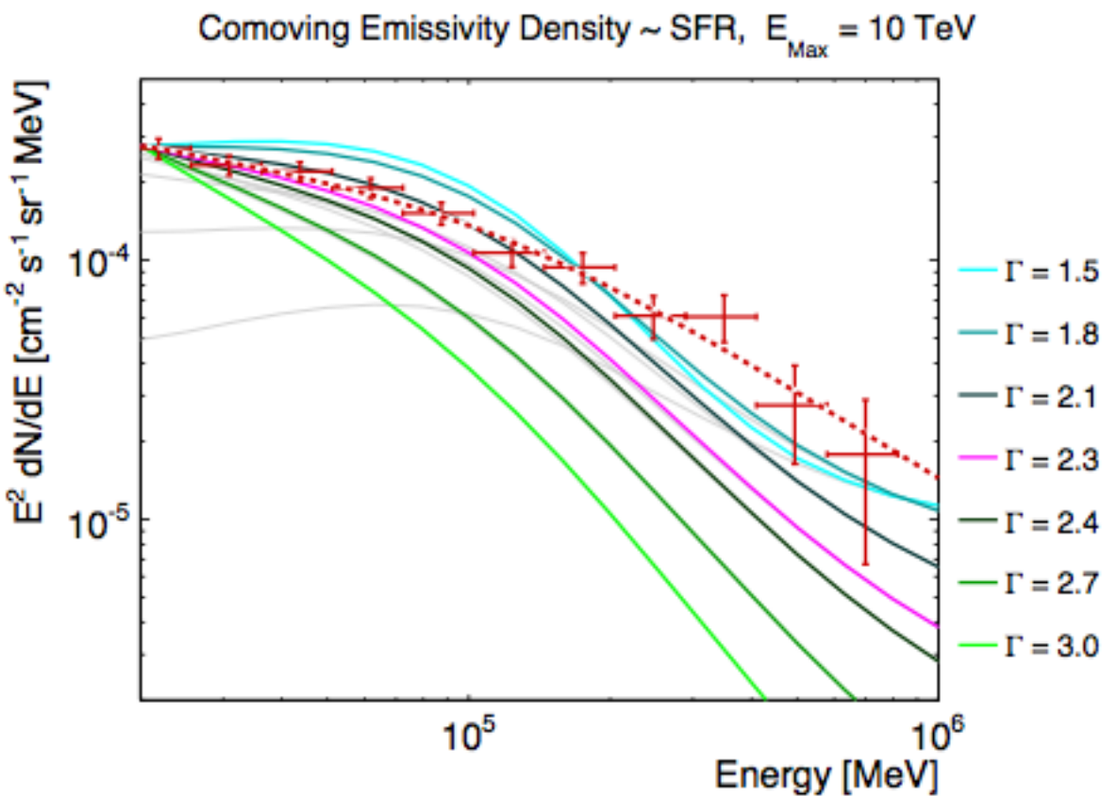
- Cosmic x-ray and gamma-ray background now **measured over 9 orders of magnitude in energy**.
- Is the observed cutoff compatible with an absorption feature ?

The shape of the high-energy IGRB spectrum





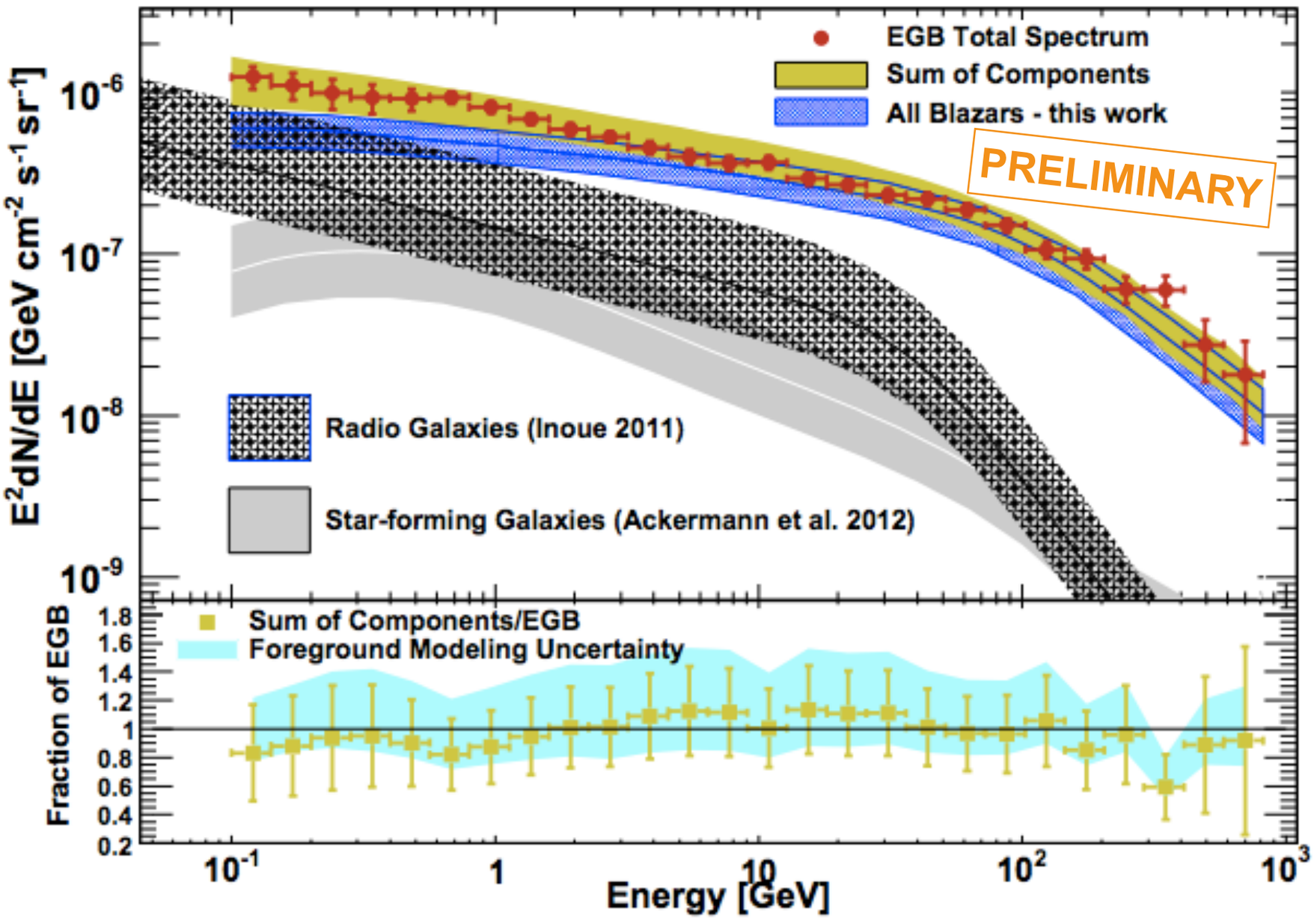
Franceschini et al., 2008 EBL model



- **Simple population** of sources with **power-law spectrum** with index Γ
- Luminosity or density evolution ~ $(1+z)^{\beta}$ or following star-formation rate
- Observed EGB spectrum is **compatible with single population of sources** with power-law spectrum (Γ=2.3) and no evolution (β=0).

Source populations contributing to the EGB

submitted to ApJL



- … but **reality** might be **more complex**.
- **Multiple populations might contribute** to explain the observed spectrum.
- Blazars seem to dominate above few GeV.

Summary

- The spectrum of the isotropic and total extragalactic gamma-ray background was **measured between 100 MeV and 820 GeV**.
  - Energy range of measurement in Abdo et al. 2010 extended by more than an order of magnitude.
  - Paper accepted by ApJ (The Fermi LAT Collaboration, arXiv:1410.3696).

- **The IGRB spectrum** can be described over the full energy range by a simple power law of **index ~2.3** with an **exponential cutoff at ~250 GeV.**

- **First clear evidence** for cutoff at high energies.

- **The shape of the cutoff** is compatible with expectations due to **absorption** of the gamma rays in the **extragalactic background light**.

- **Uncertainty in diffuse foreground modeling** is the **largest systematic uncertainty** for the IGRB measurement. Future work needs to address this.