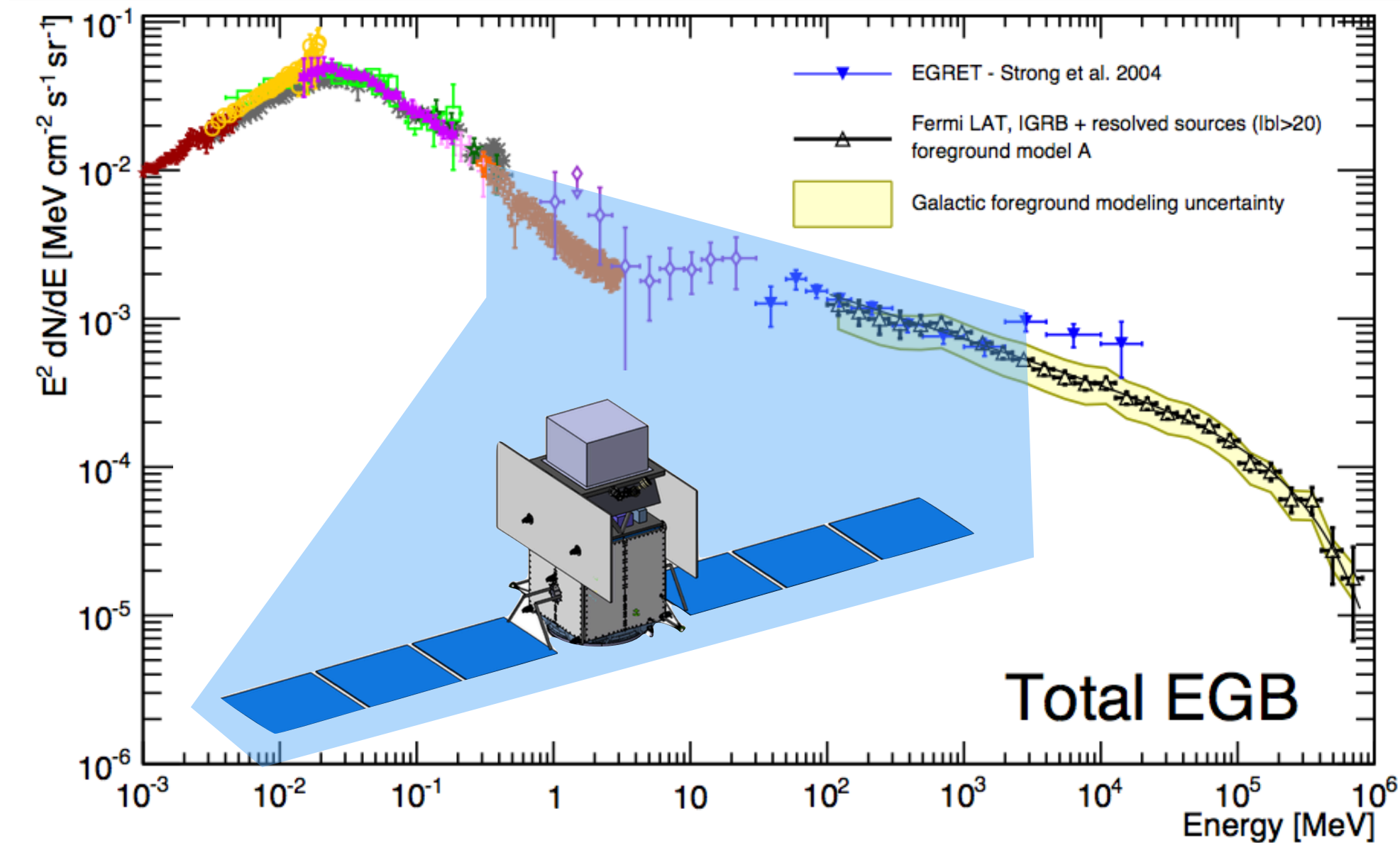


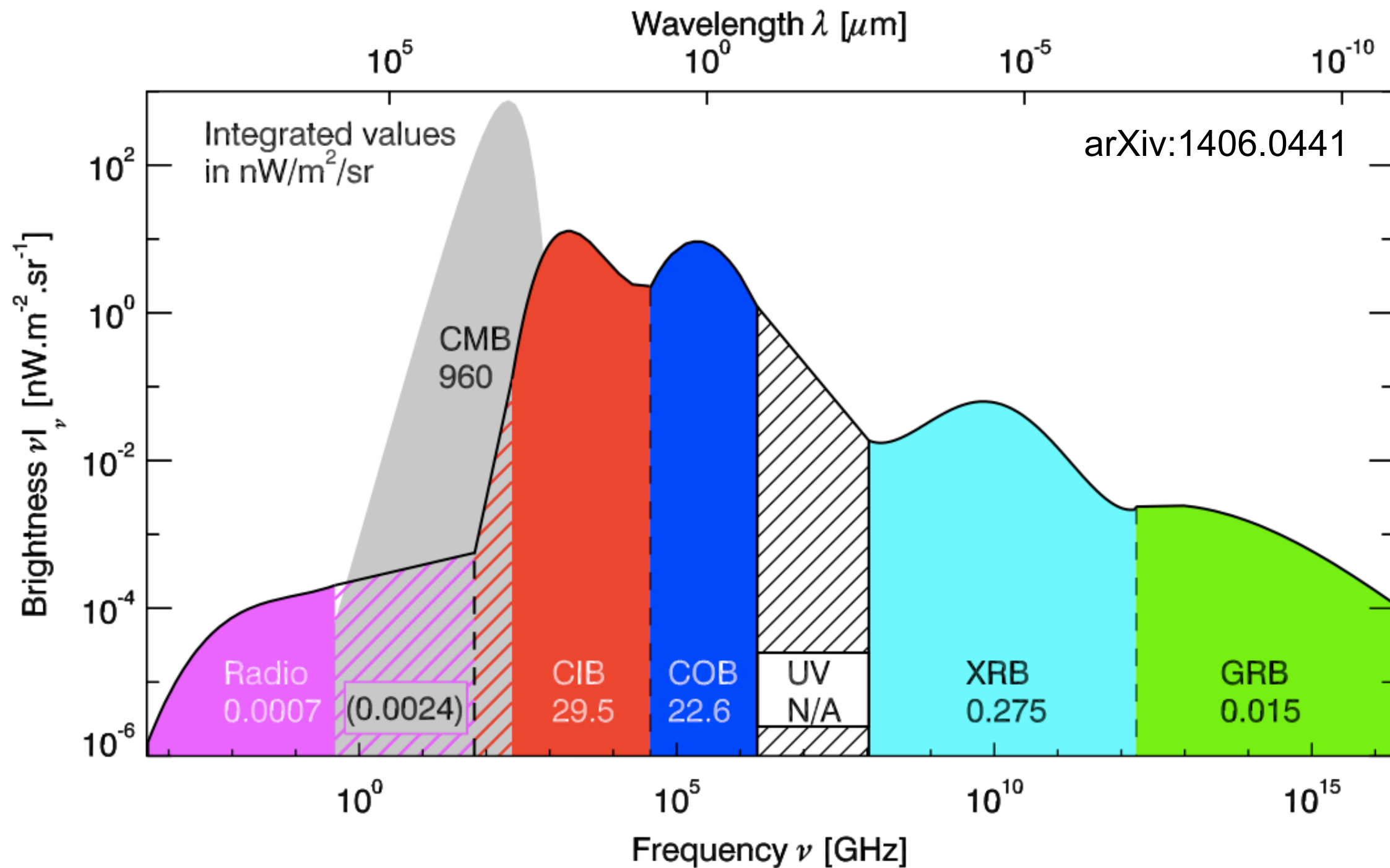
# The MeV extragalactic gamma-ray background



Markus Ackermann

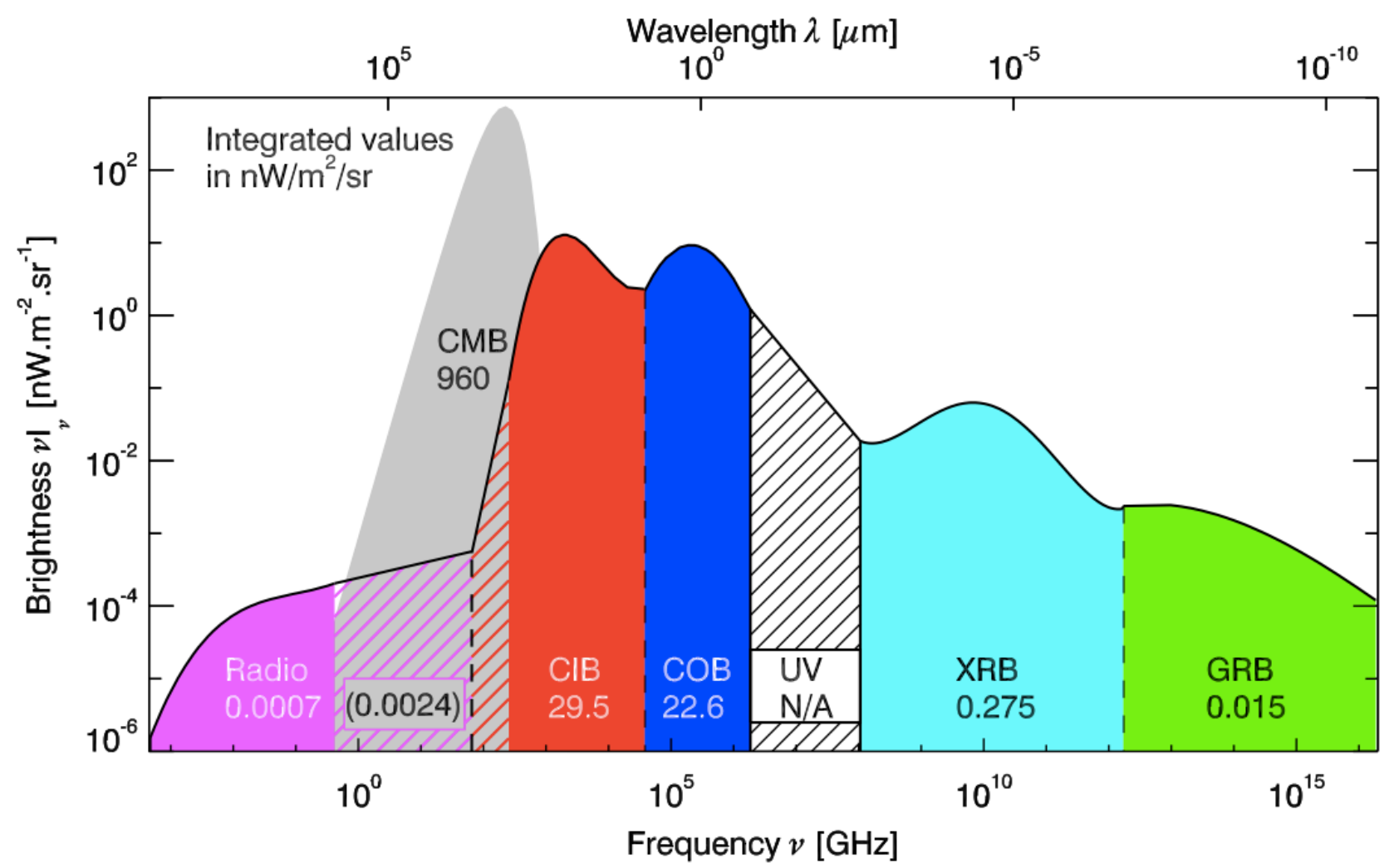
e-ASTROGAM Workshop  
Padova, 02.03.2017

# Extragalactic radiation backgrounds.

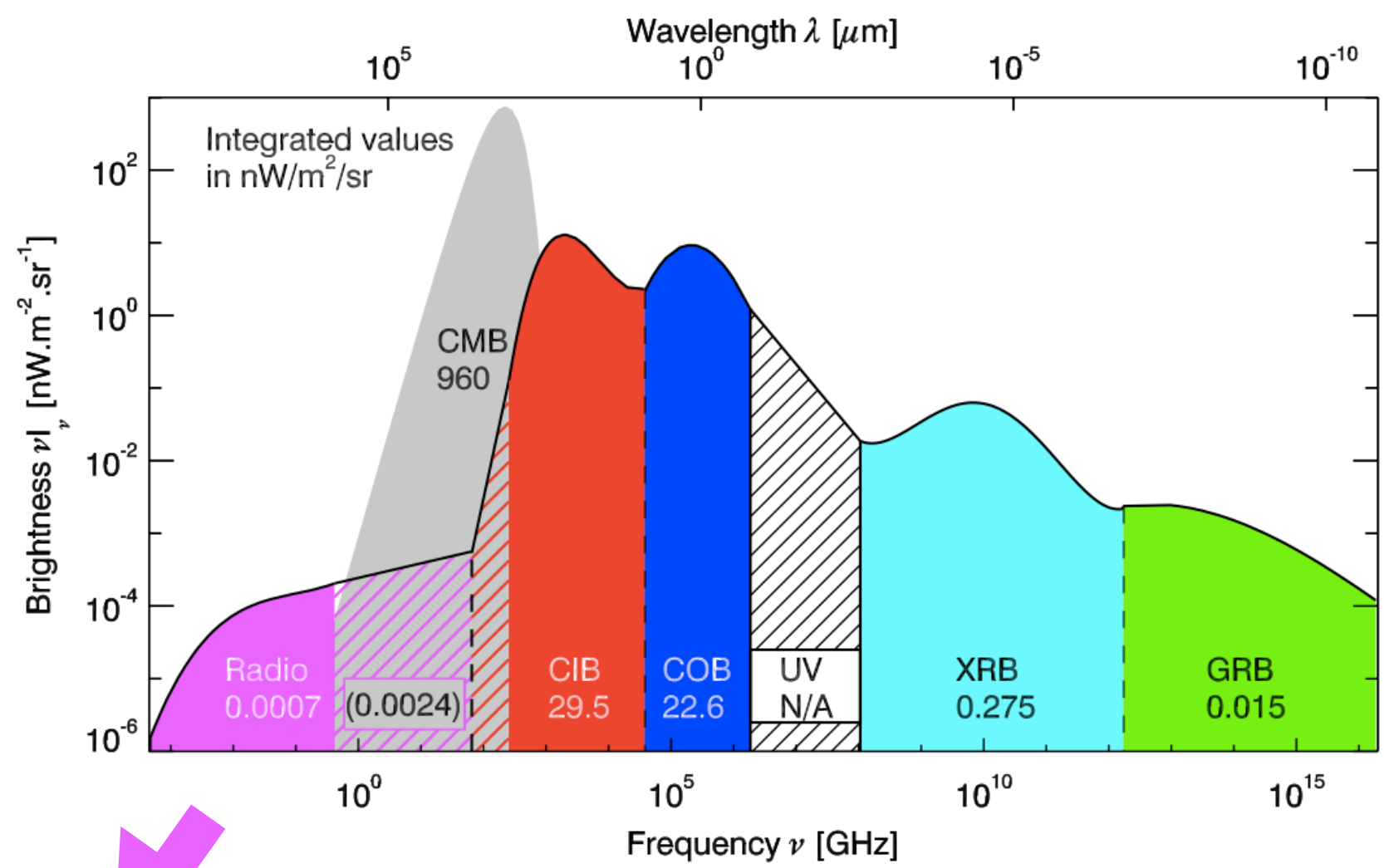


- > The universe is **full of radiation backgrounds** from radio to gamma rays.
- > Integrated emission of the visible universe in each waveband (after foreground subtractions).

# Origin of the radiation backgrounds.



# Origin of the radiation backgrounds.

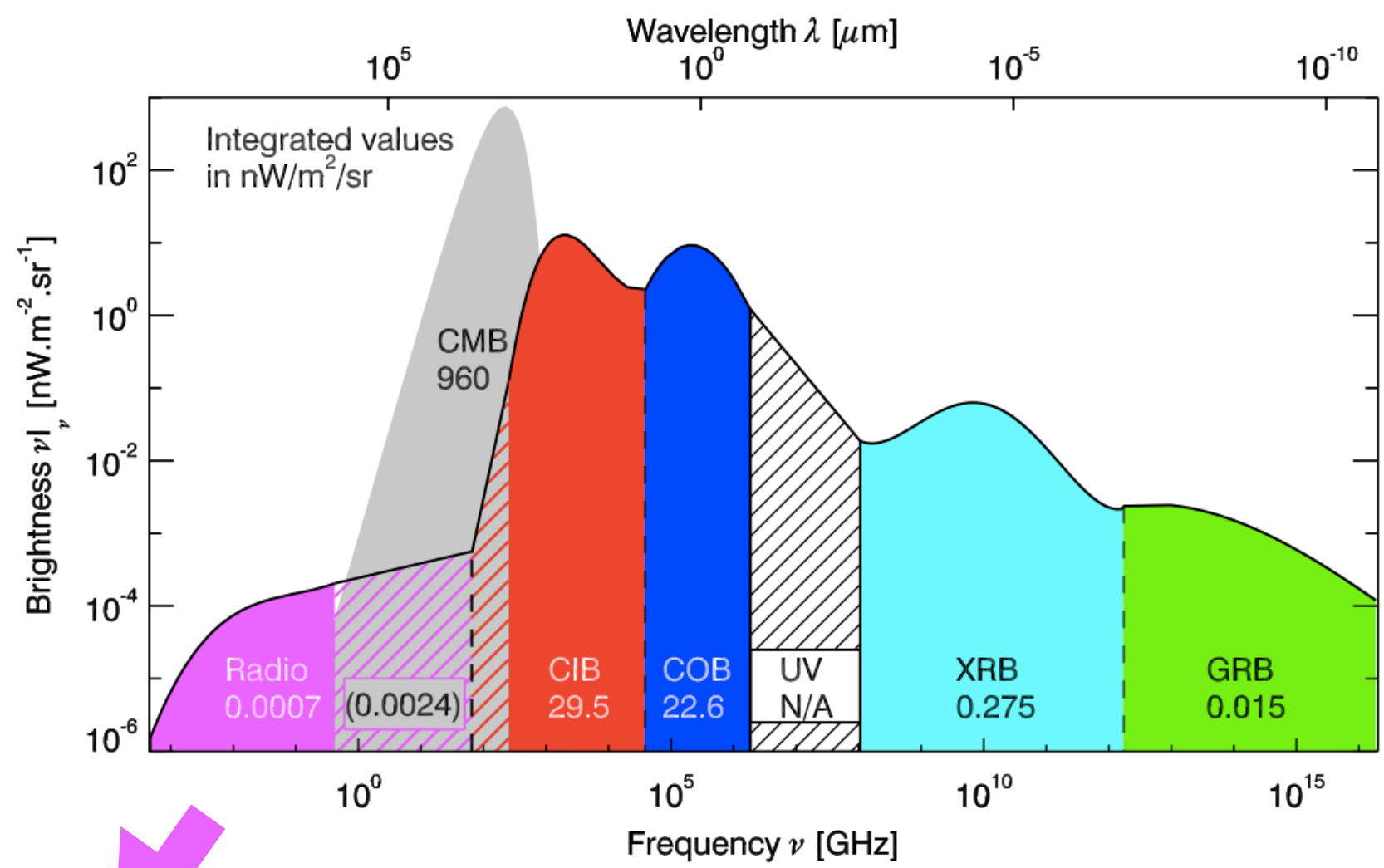


- synchrotron emission from galaxies & galactic cores.
- ???





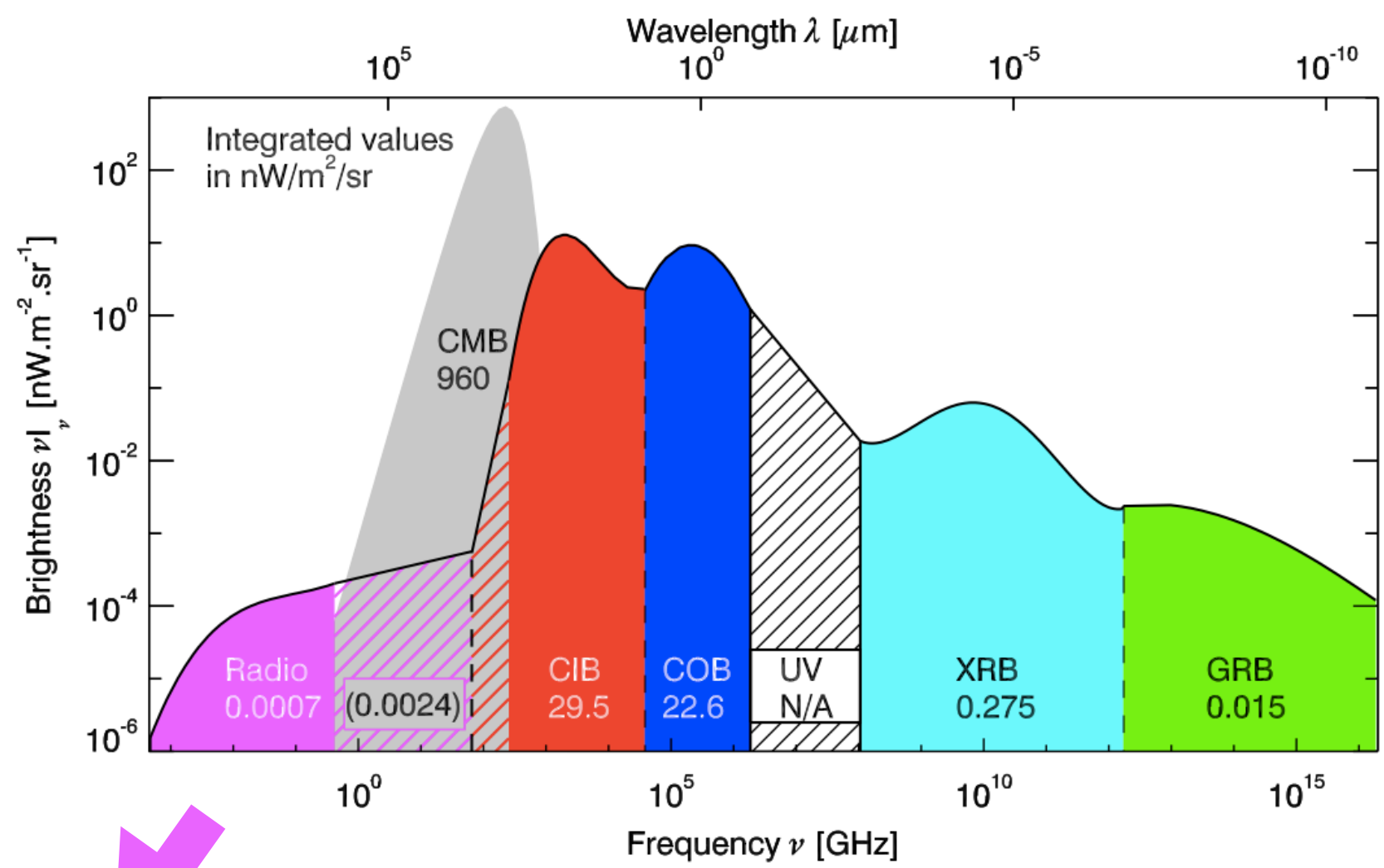
# Origin of the radiation backgrounds.



- synchrotron emission from galaxies & galactic cores.
- ???
- thermal emission from stars and dust
- possible small contribution from unknown stellar populations (e.g. Pop III stars)



# Origin of the radiation backgrounds.



- synchrotron emission from galaxies & galactic cores.

- ???

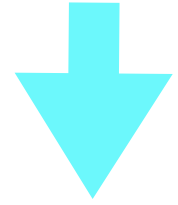
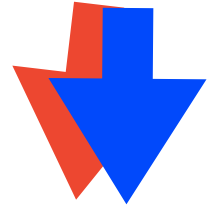
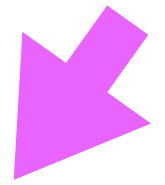
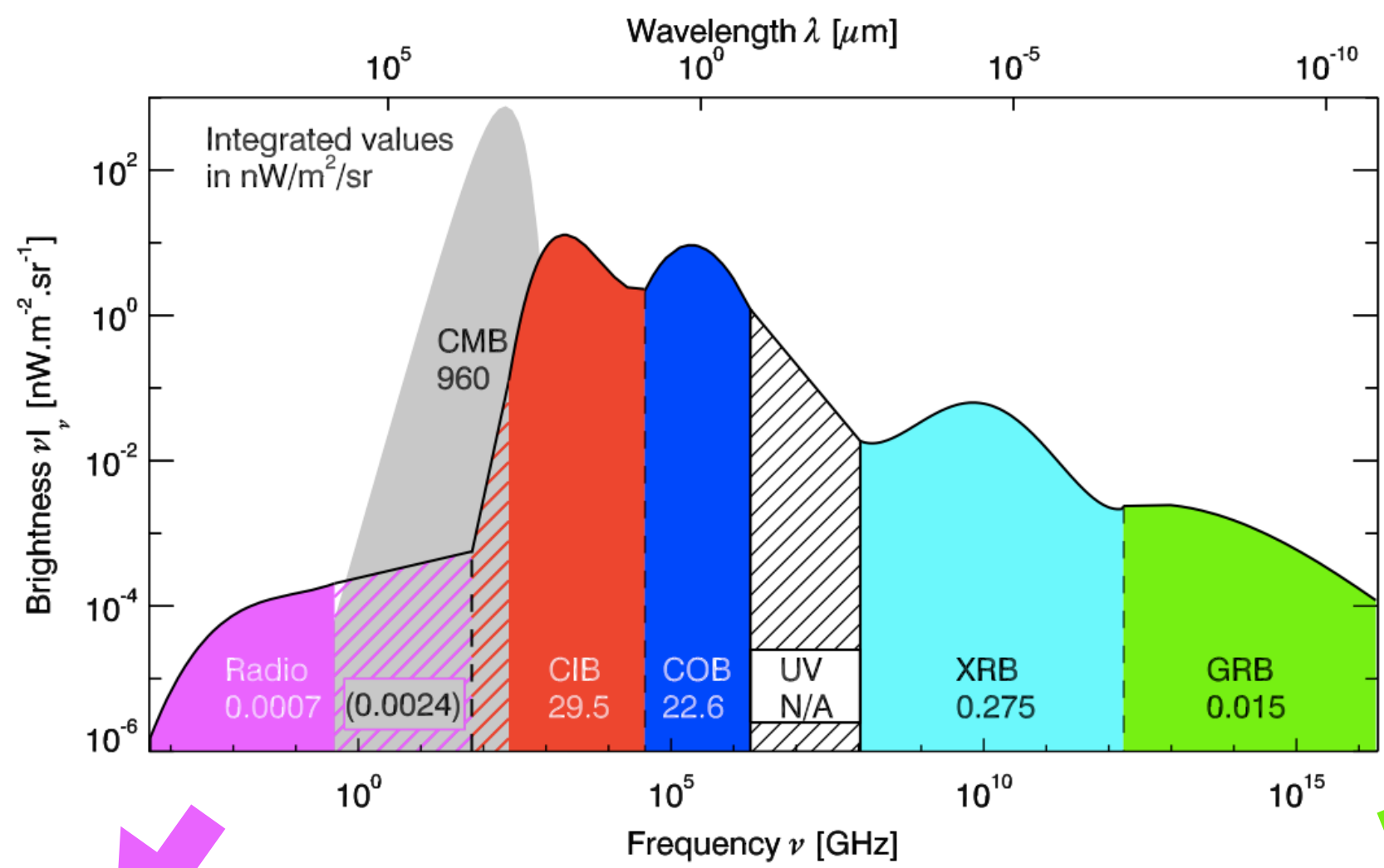
- thermal emission from stars and dust

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- accretion disks of active galactic nuclei (AGN)



# Origin of the radiation backgrounds.



- synchrotron emission from galaxies & galactic cores.
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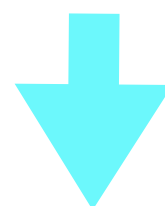
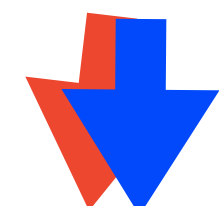
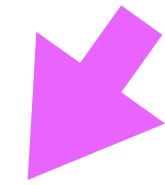
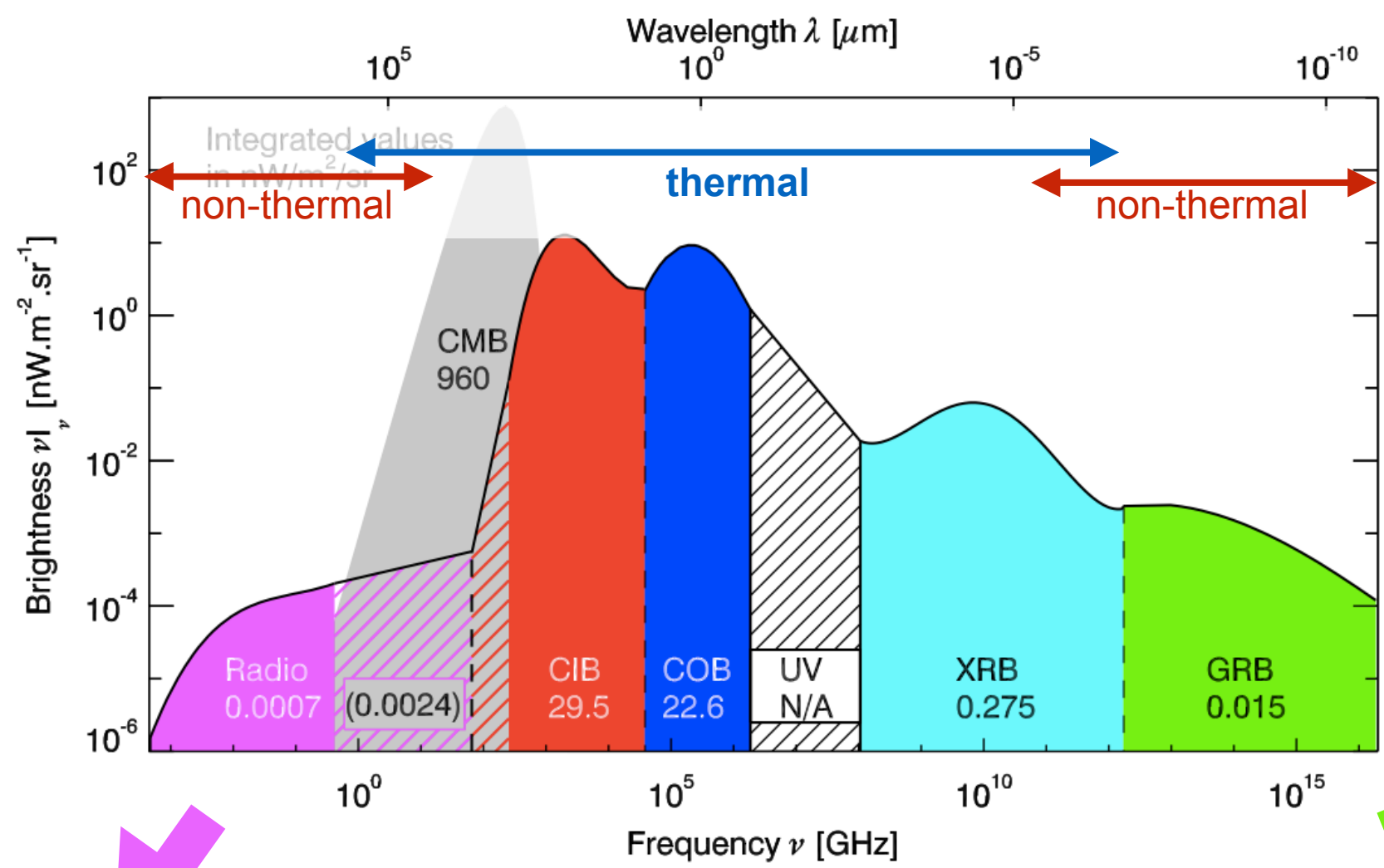
- thermal emission from stars and dust
- possible small contribution from unknown stellar populations (e.g. Pop III stars)

- accretion disks of active galactic nuclei (AGN)

- non-thermal emission from AGN and normal galaxies
- diffuse contributions from CR, dark matter ??



# Origin of the radiation backgrounds.



- synchrotron emission from galaxies & galactic cores.
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- possible small contribution from unknown stellar populations (e.g. Pop III stars)

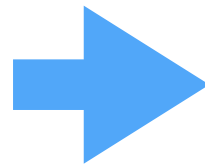
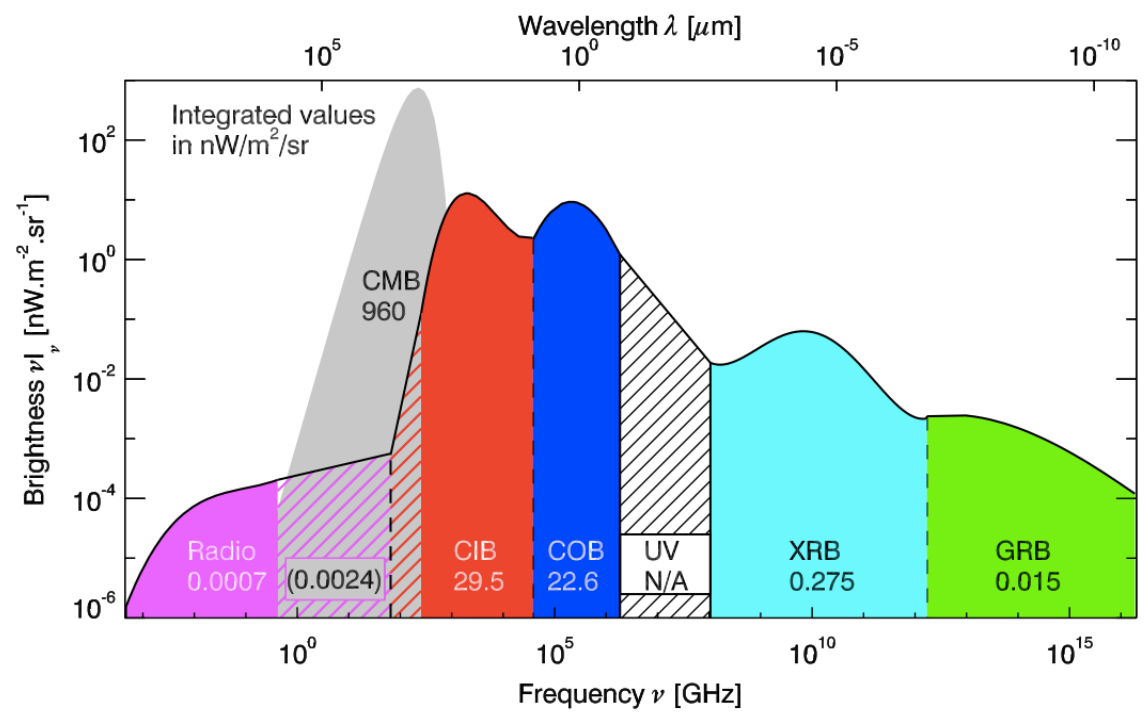
- accretion disks of active galactic nuclei (AGN)

- non-thermal emission from AGN and normal galaxies
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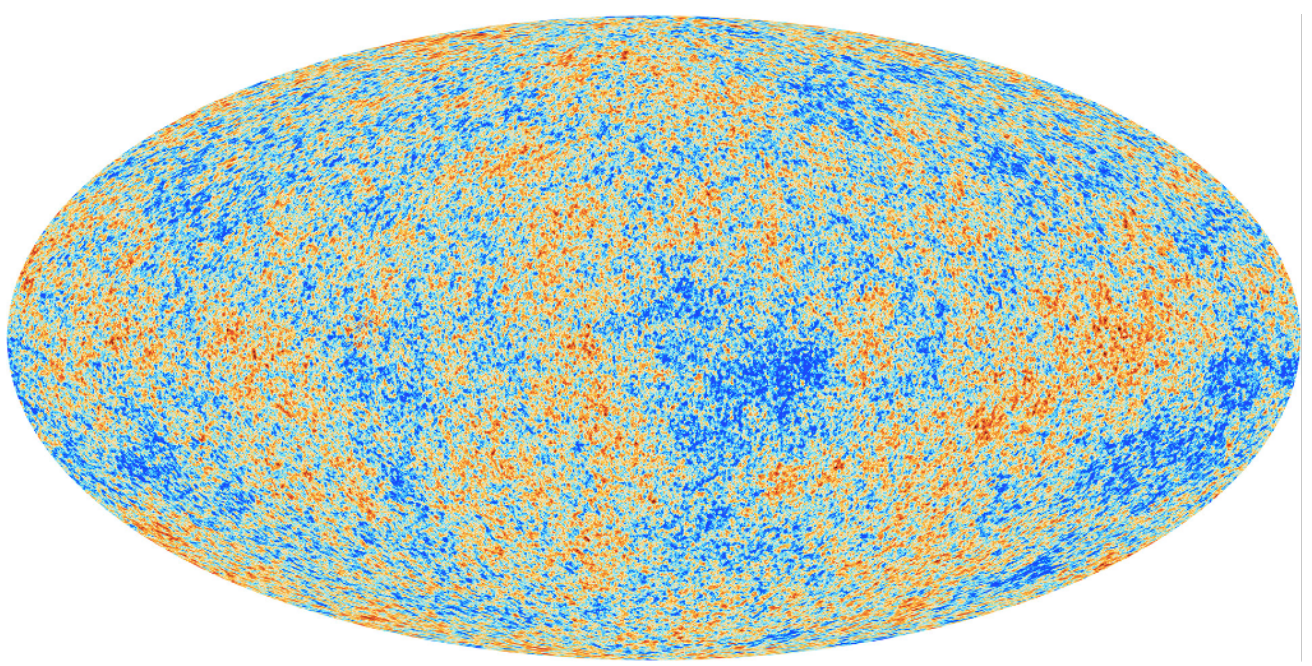
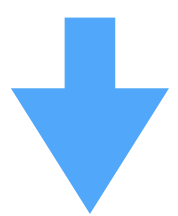




# Origin of the radiation backgrounds.



Known source populations



Diffuse radiation

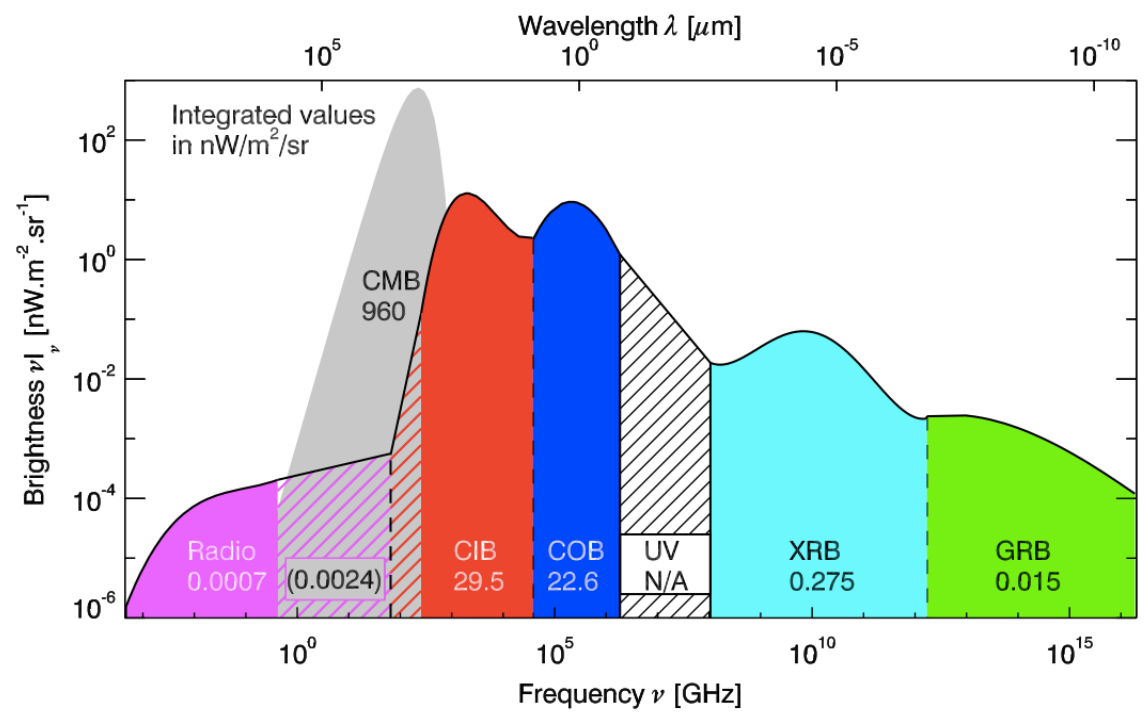


Sources too faint to be resolved.





# Features of the radiation background components.



- > Depends on sensitivity of available instruments
- > Derived from surveys and / or deep fields

## Resolved source populations

- > Constrained by total radiation background minus resolved source emission
- > Angular power spectrum of radiation background might help to identify origin

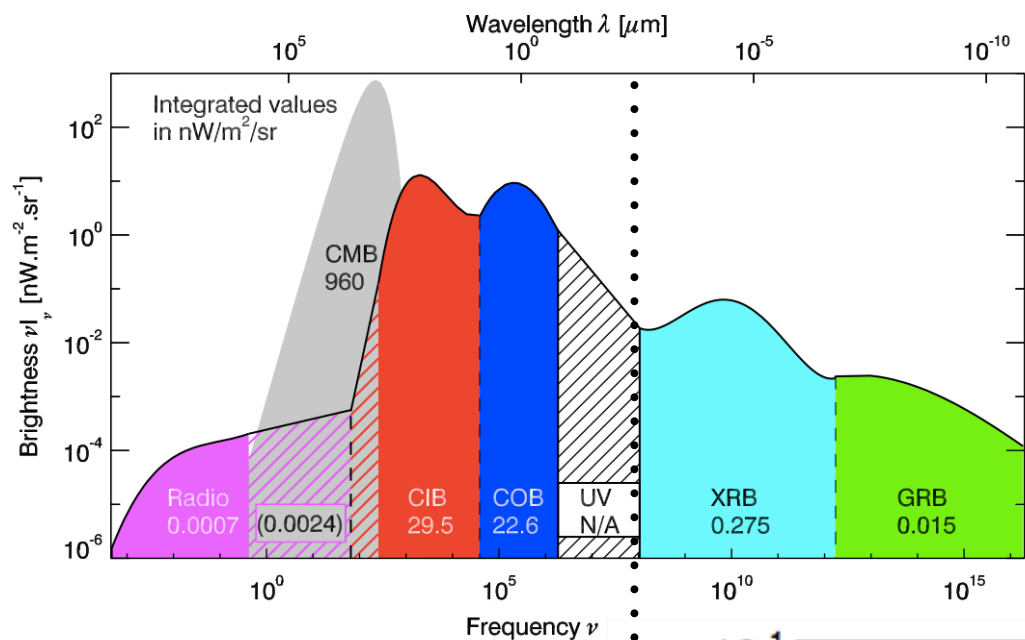
## Sources too faint to be resolved.

- > Particularly important for cosmology and particle physics
- > Radiation backgrounds are upper limit for photon emission from new physics processes.

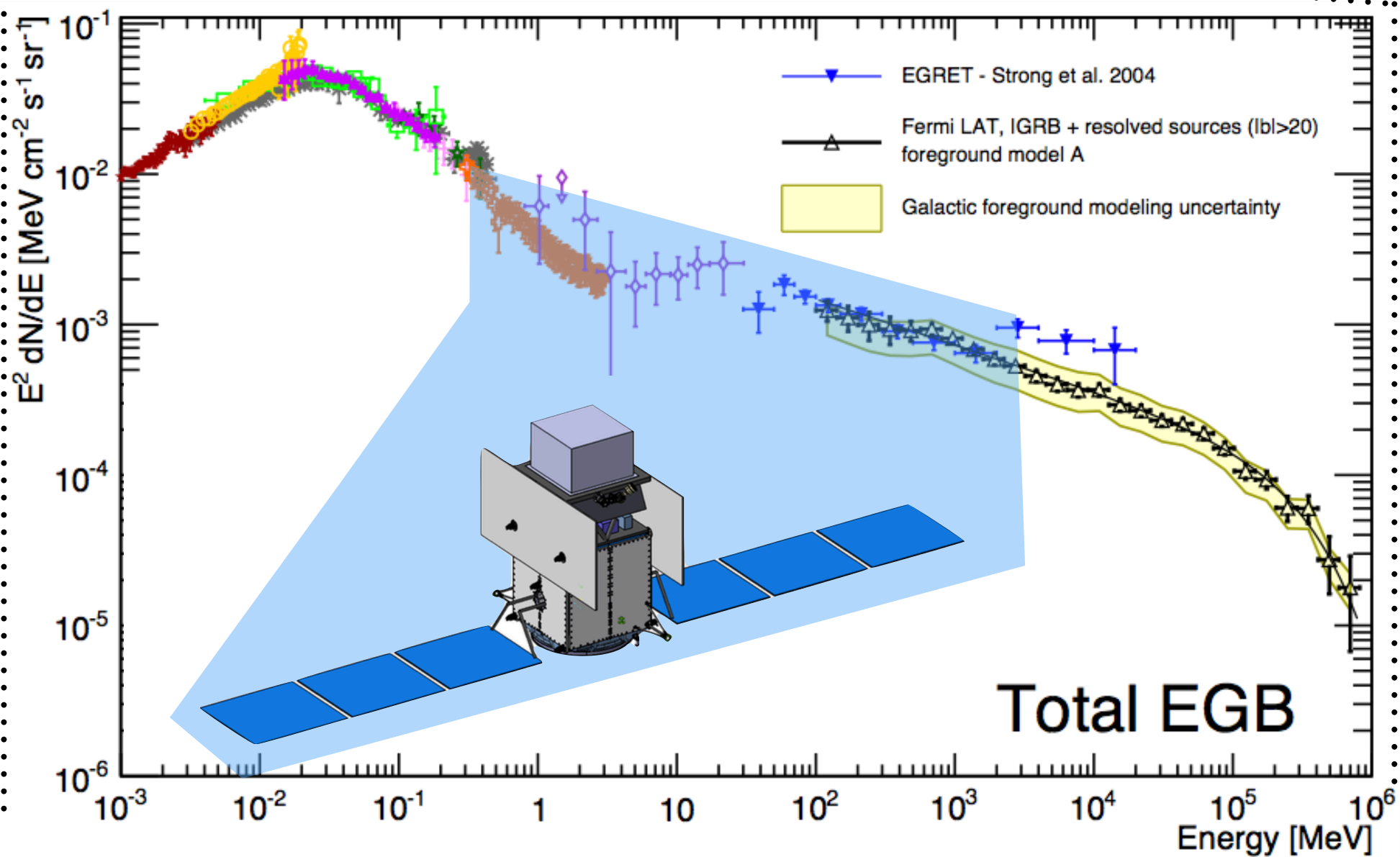
Diffuse radiation



# The extragalactic X-ray and gamma-ray background



> Poorly measured between 1 MeV and 100 MeV by COMPTEL and EGRET



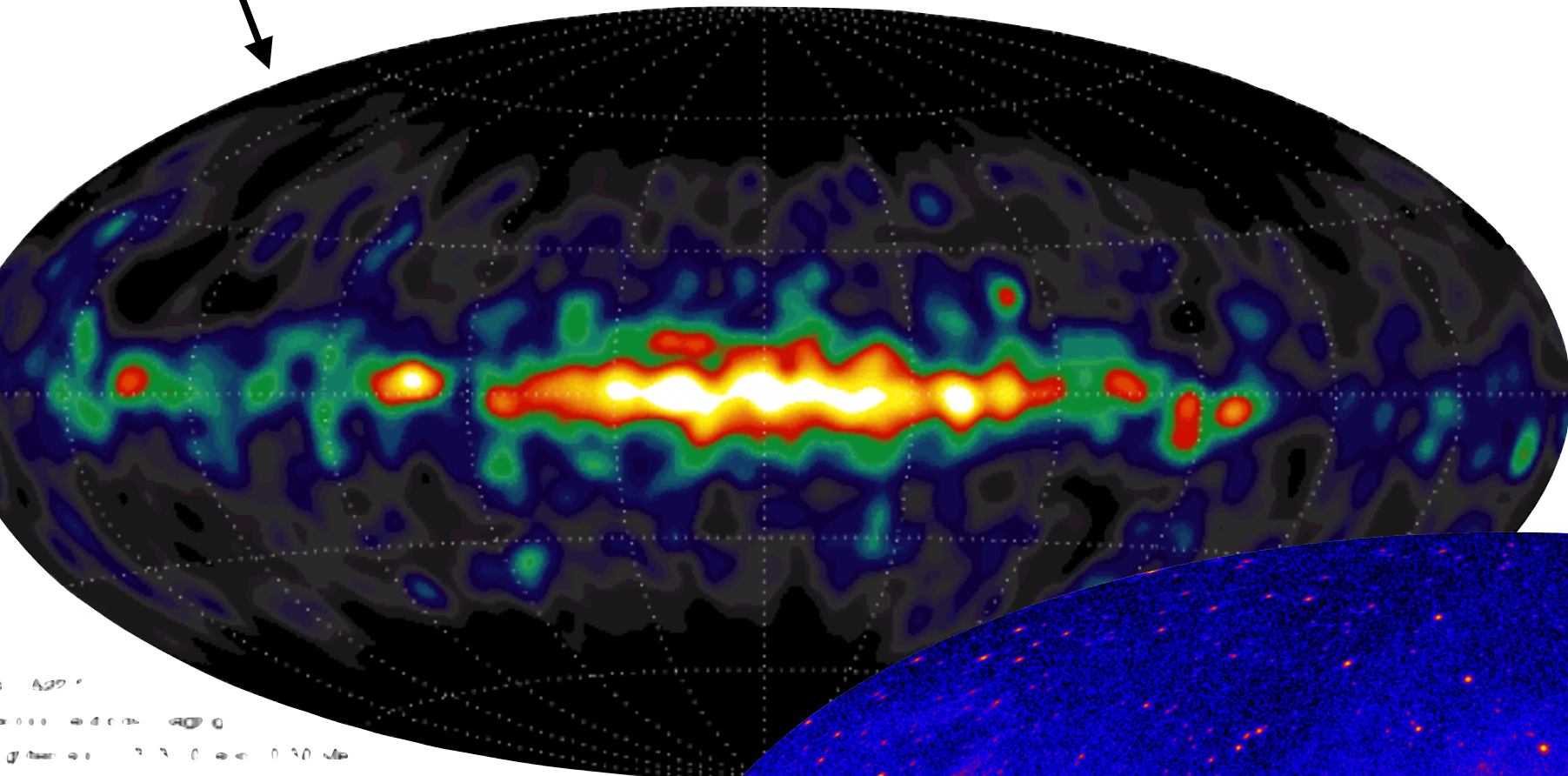


# Measuring the Spectrum of the Extragalactic Background

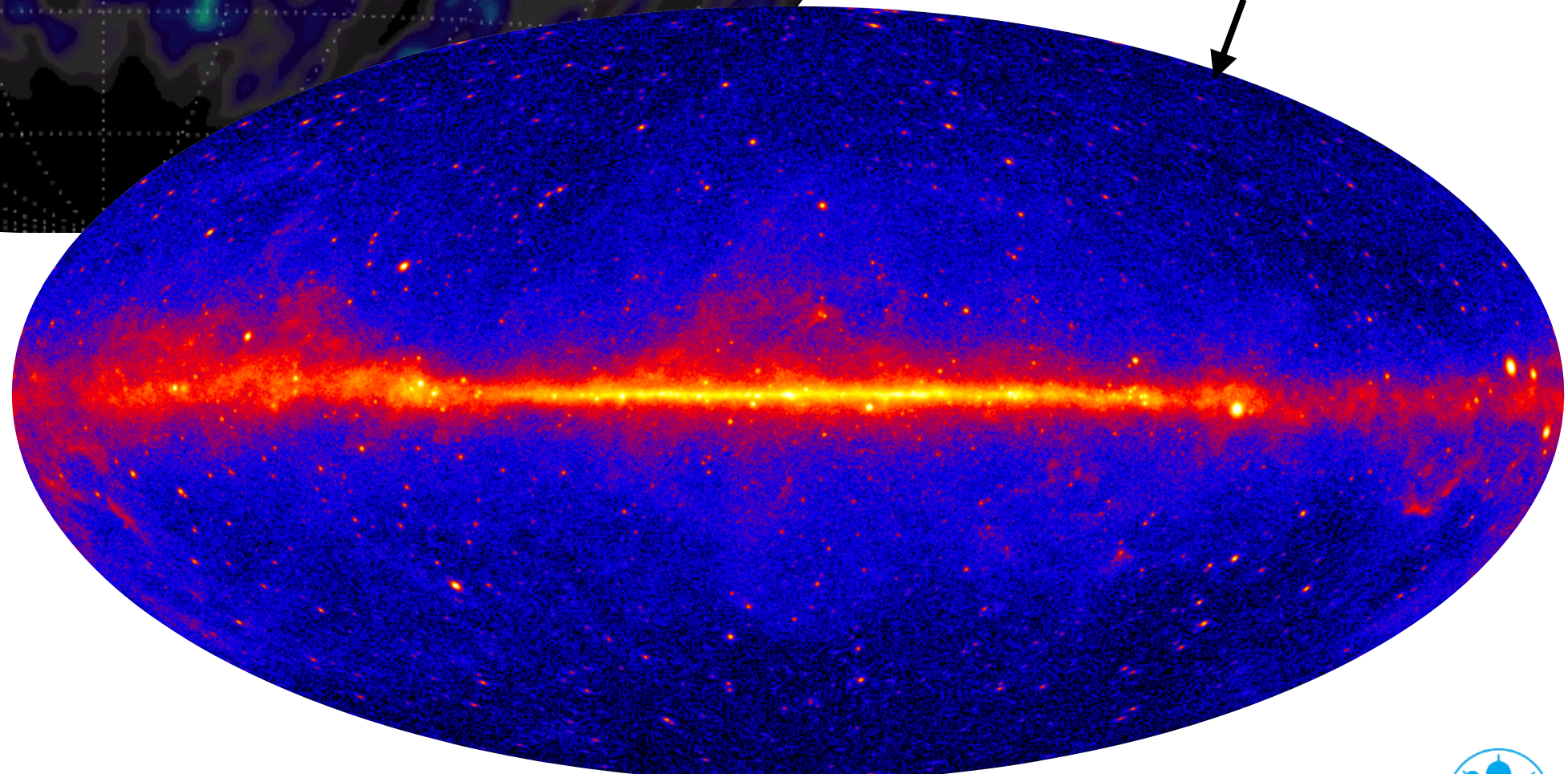


# The gamma-ray sky at MeV and GeV

COMPTEL 1-30 MeV



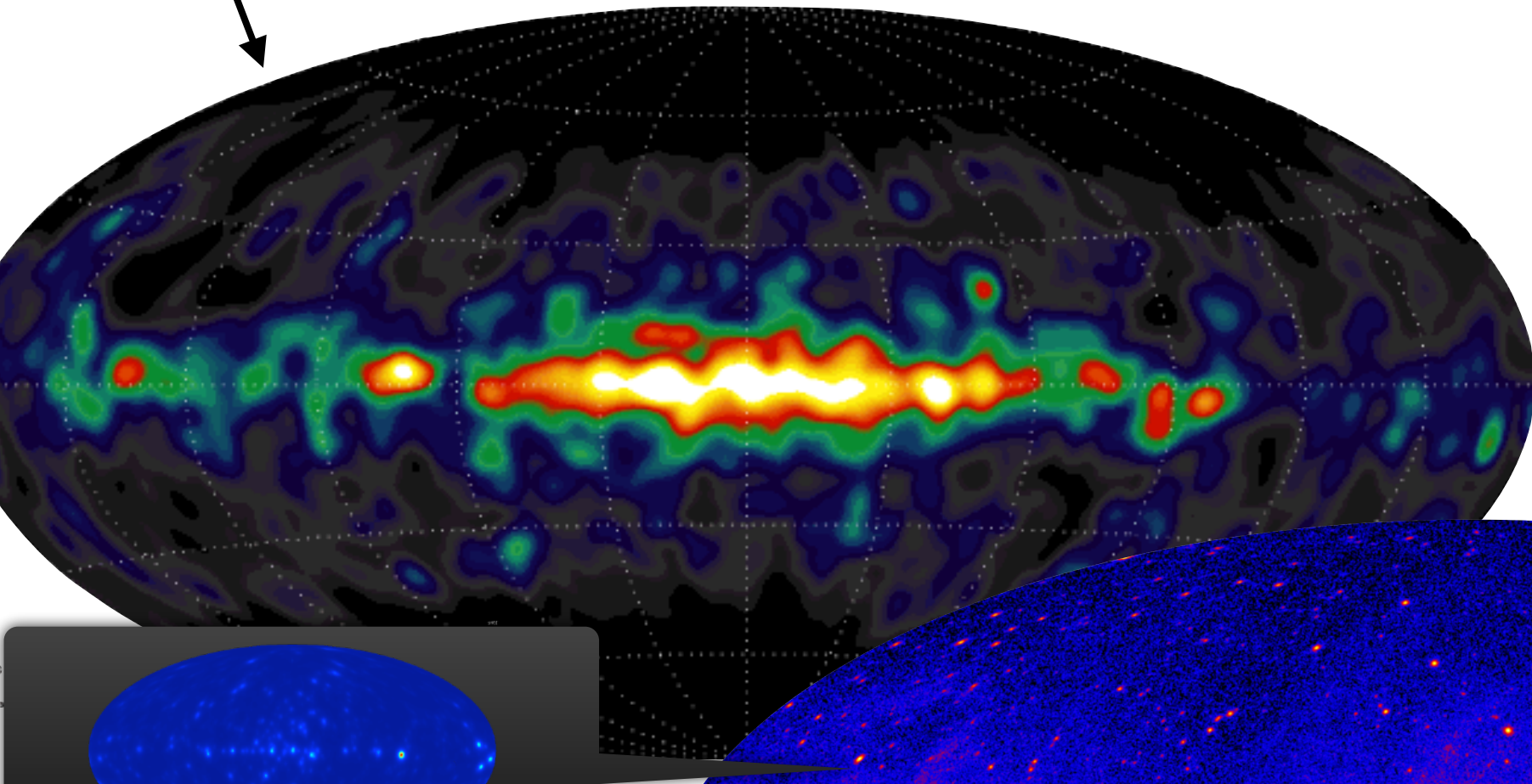
Fermi LAT  $E > 1$  GeV



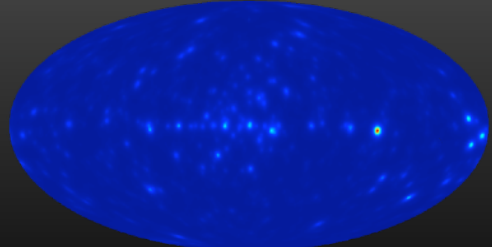
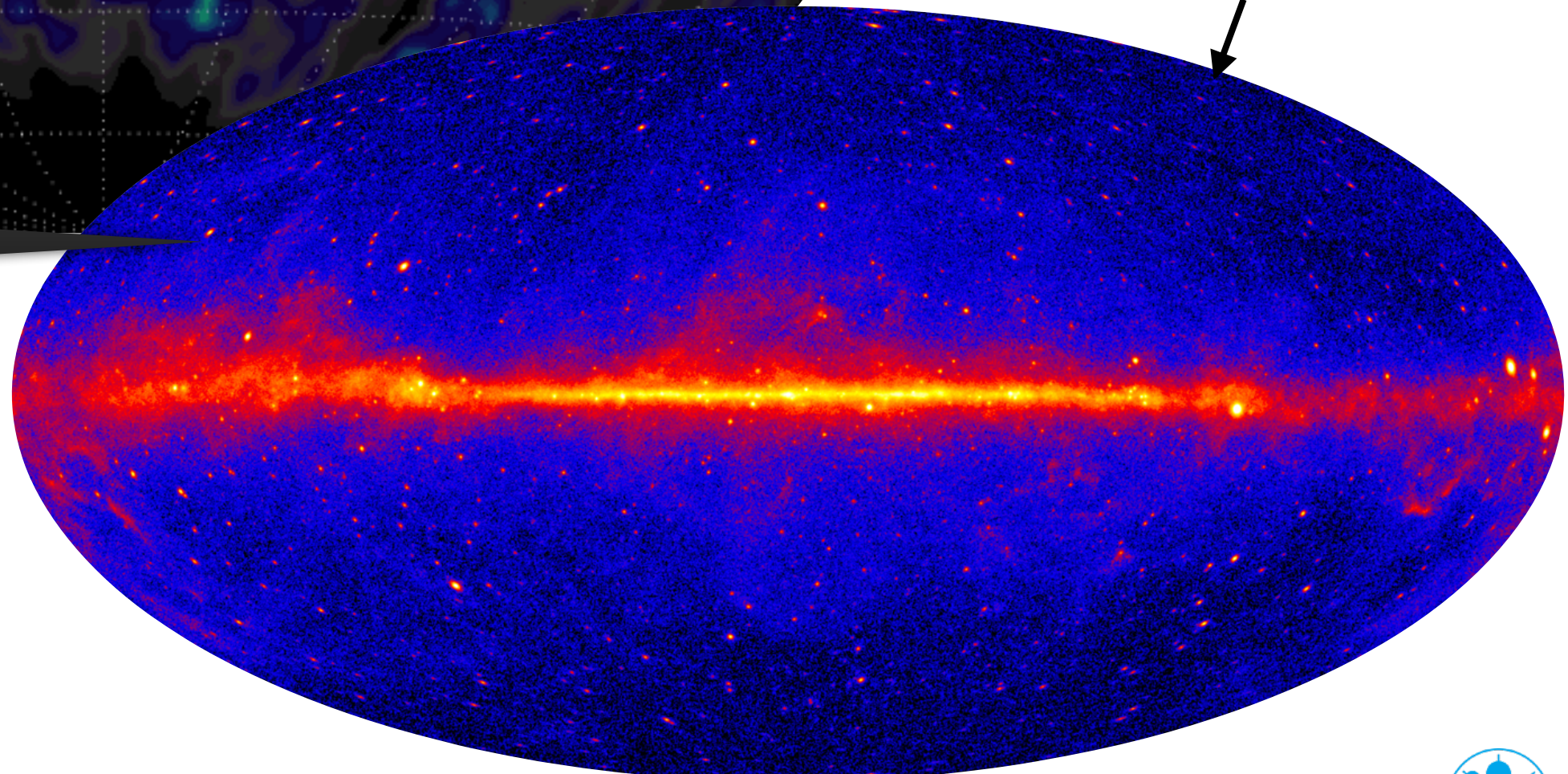


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Fermi LAT  $E > 1$  GeV

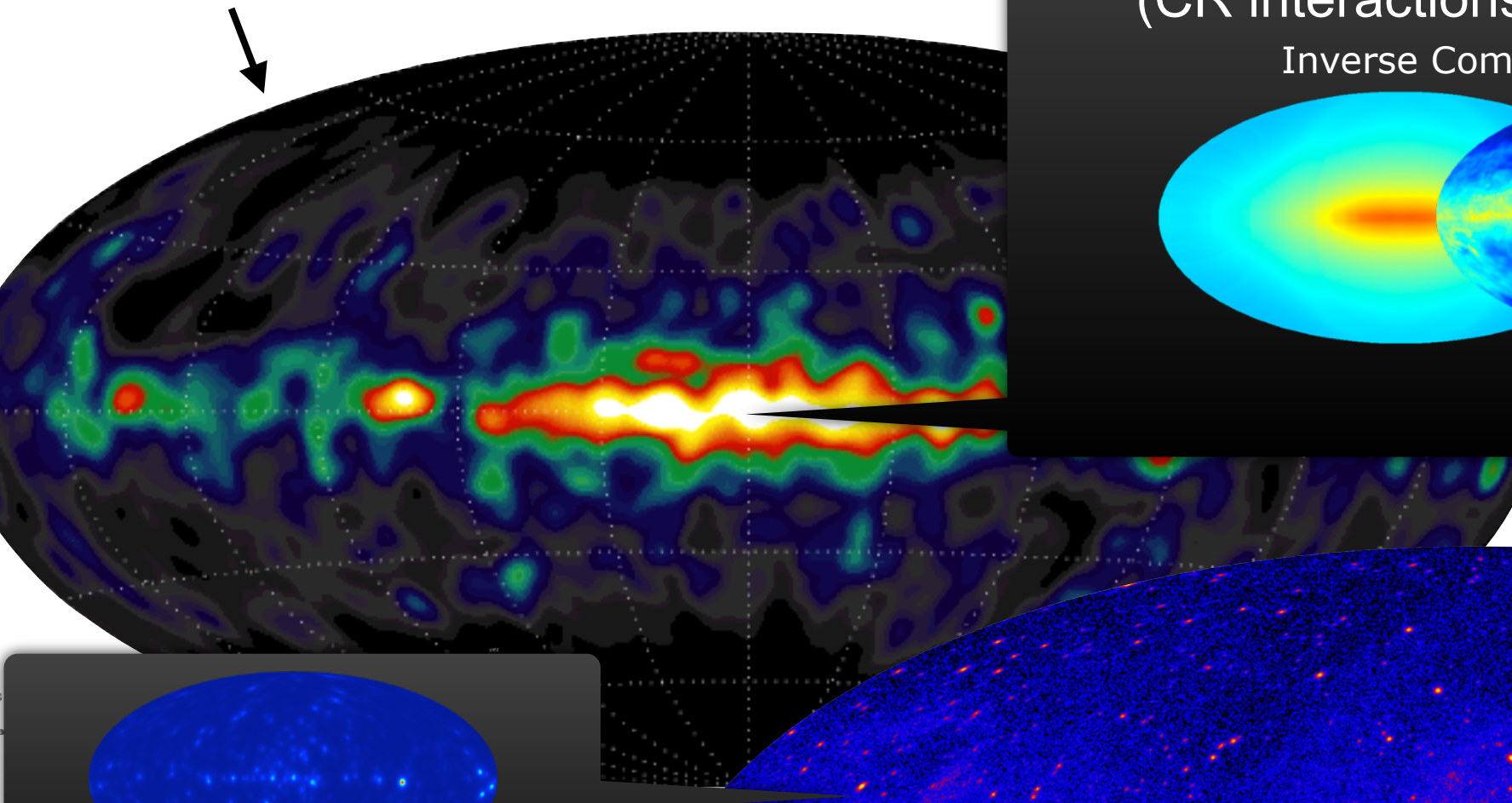


Resolved sources



# The gamma-ray sky at MeV and GeV

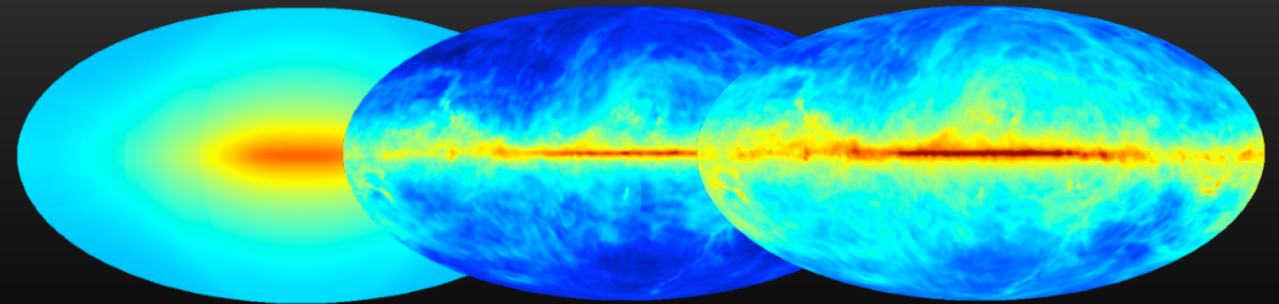
COMPTEL 1-30 MeV



Galactic diffuse emission  
(CR interactions with the interstellar medium)

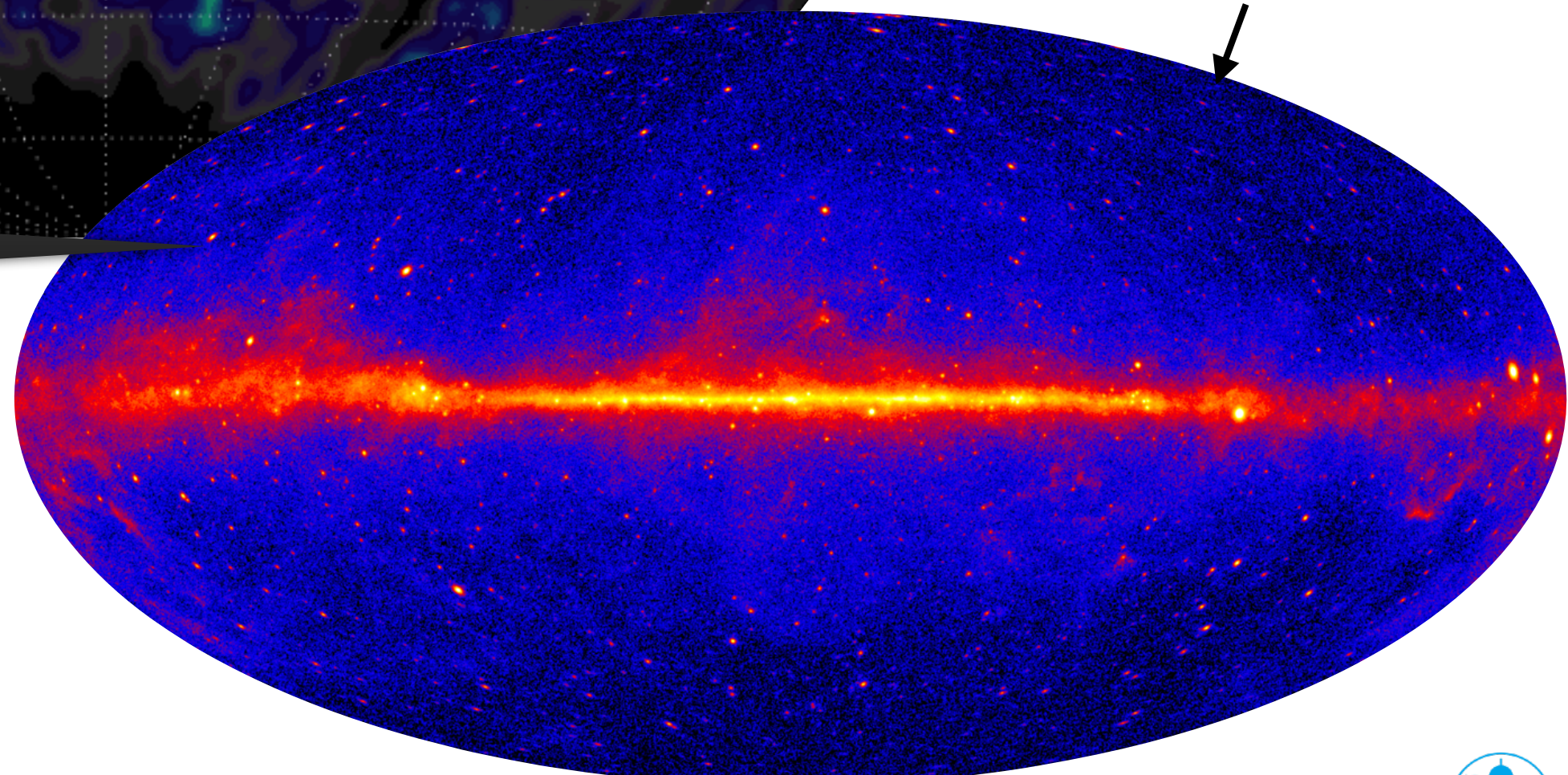
Inverse Compton

$\pi^0$ -decay

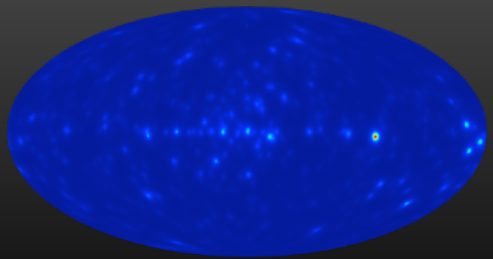


Bremsstrahlung

Fermi LAT  $E > 1$  GeV



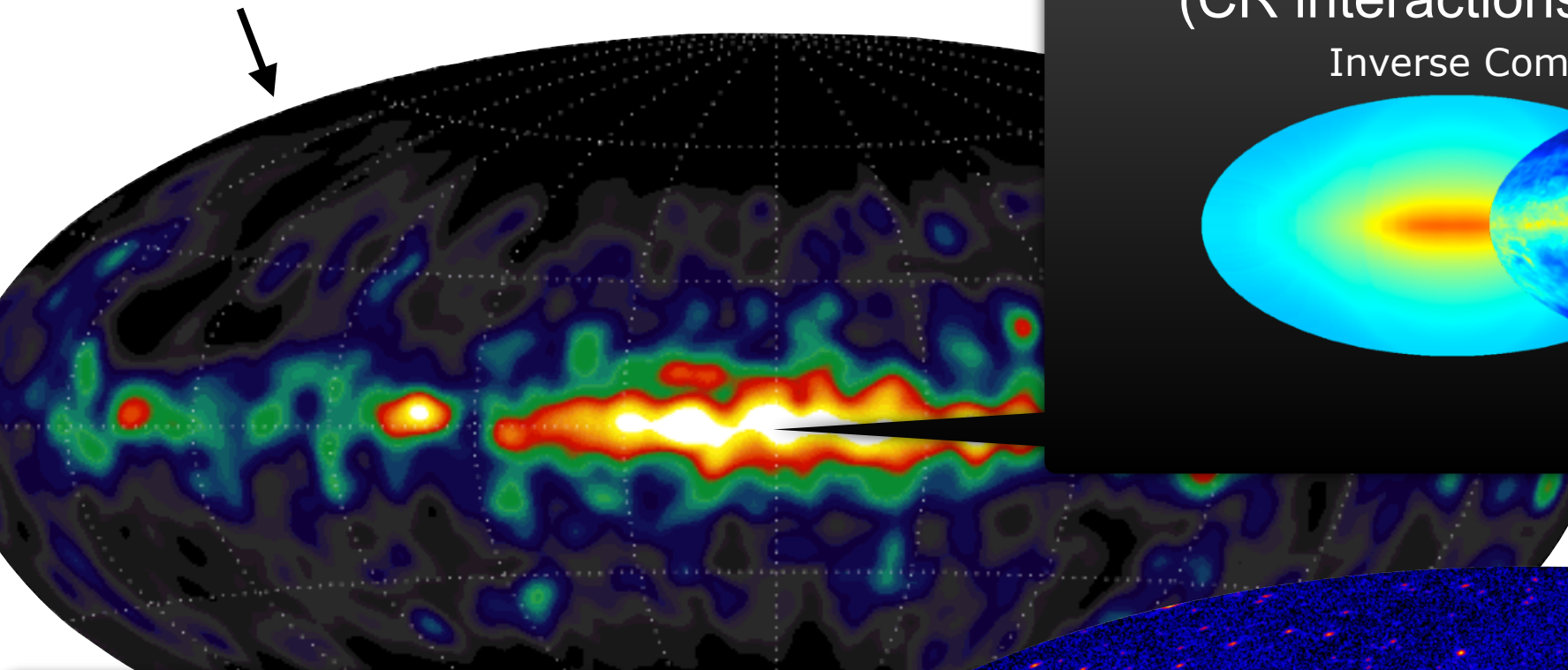
Resolved sources





# The gamma-ray sky at MeV and GeV

COMPTEL 1-30 MeV

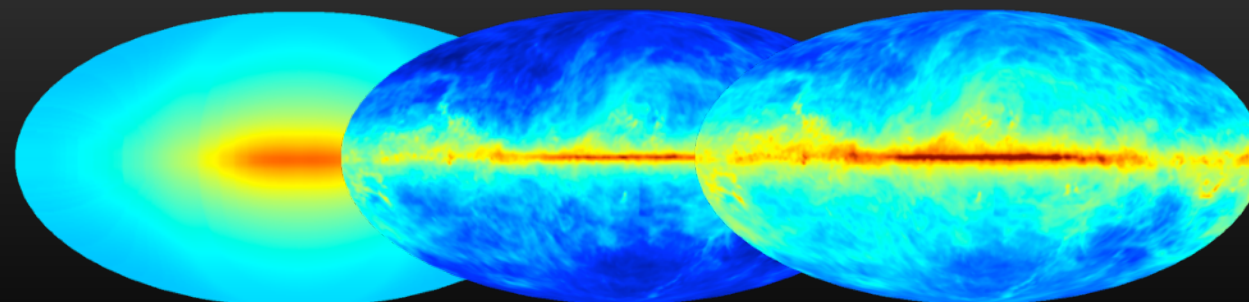


Resolved sources

Galactic diffuse emission  
(CR interactions with the interstellar medium)

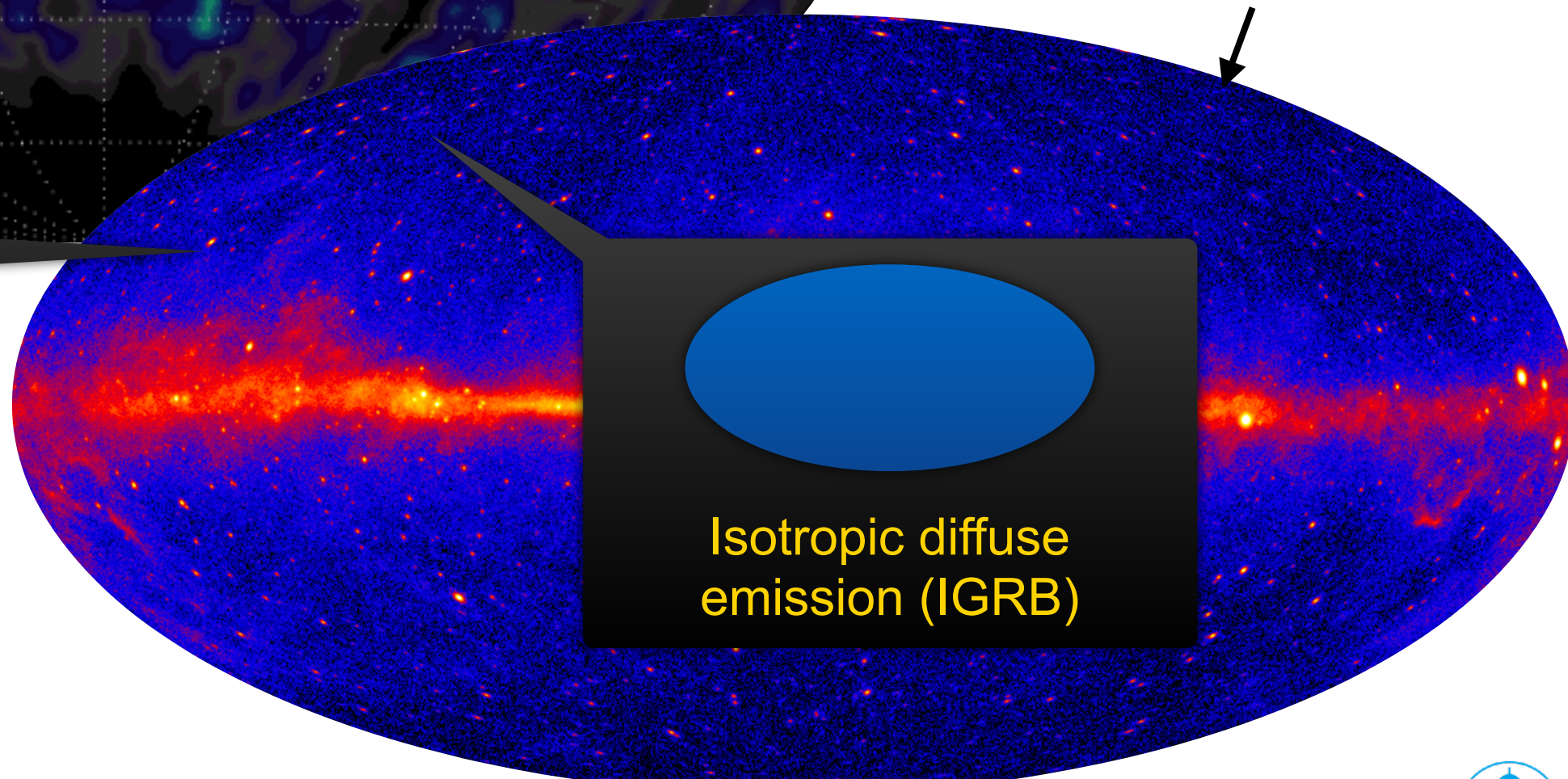
Inverse Compton

$\pi^0$ -decay



Bremsstrahlung

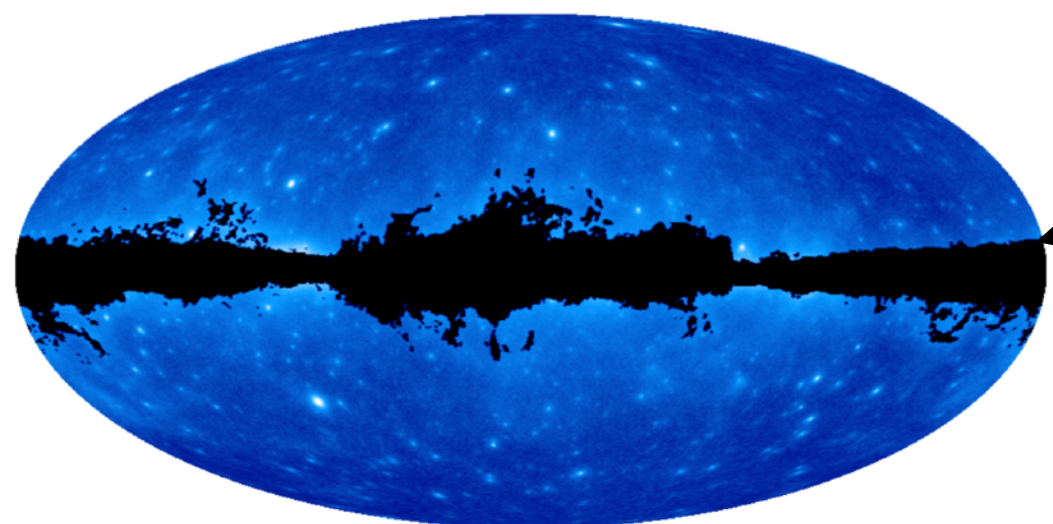
Fermi LAT  $E > 1$  GeV



Isotropic diffuse emission (IGRB)



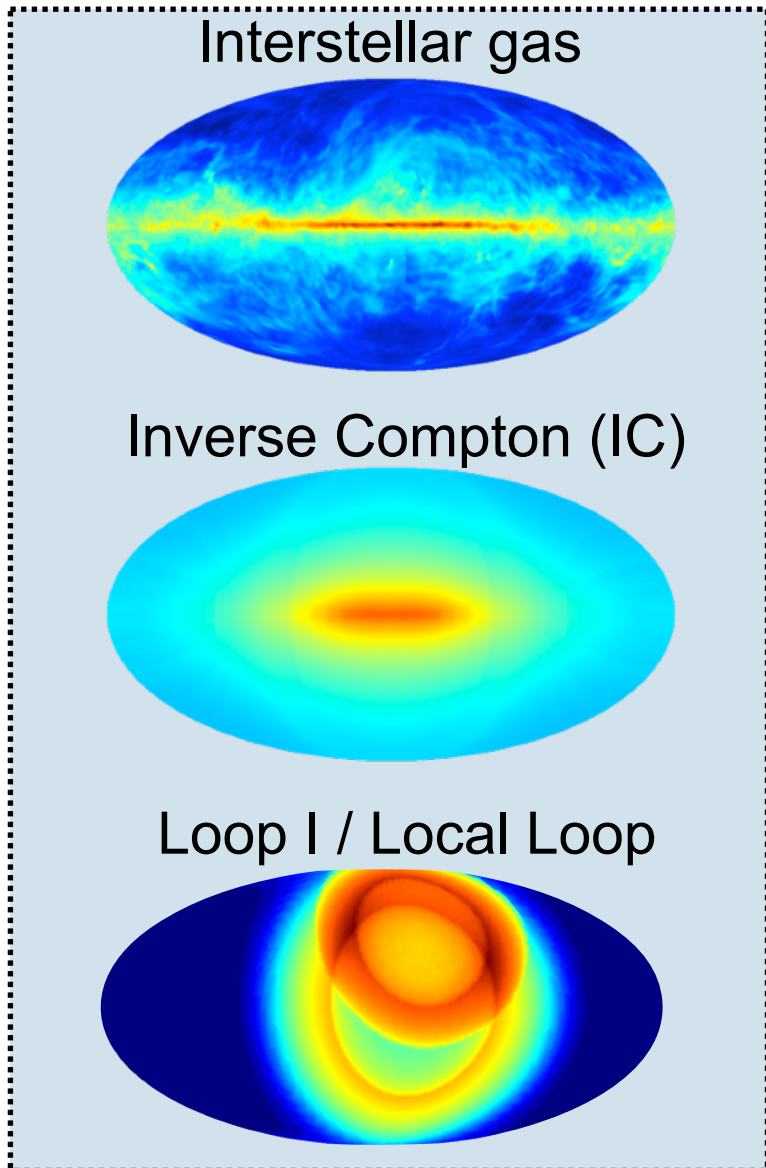
# Fermi LAT analysis of the isotropic gamma-ray background



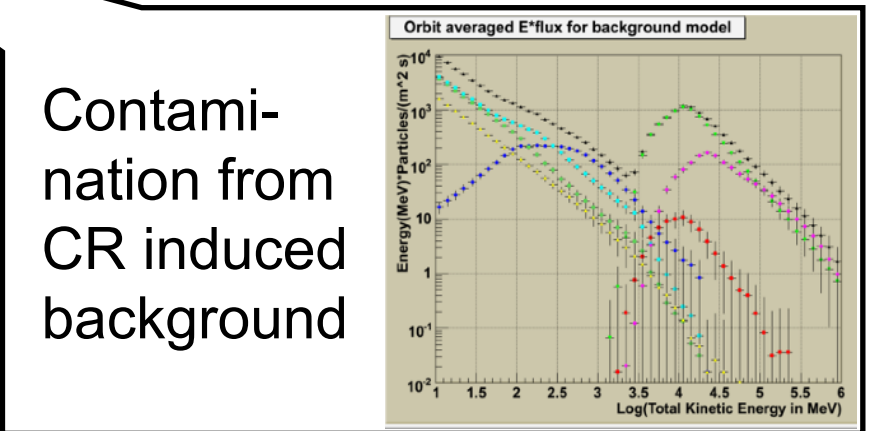
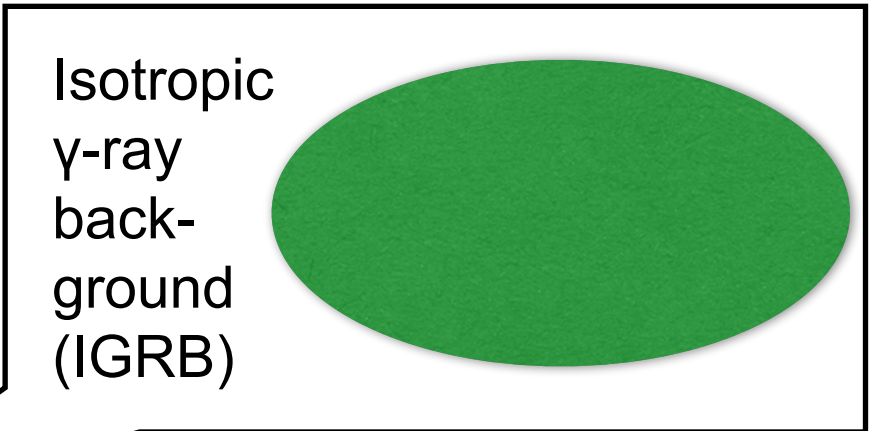
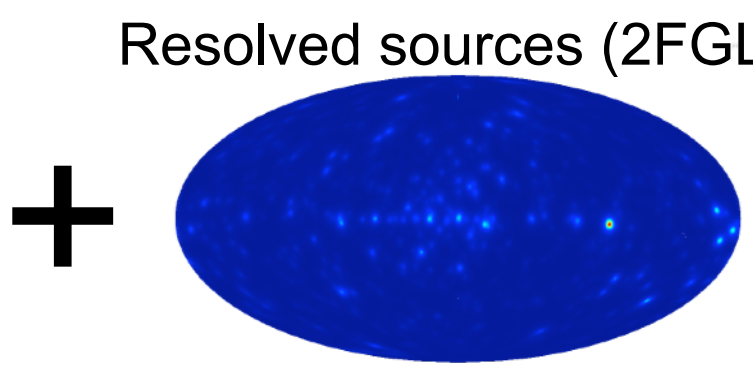
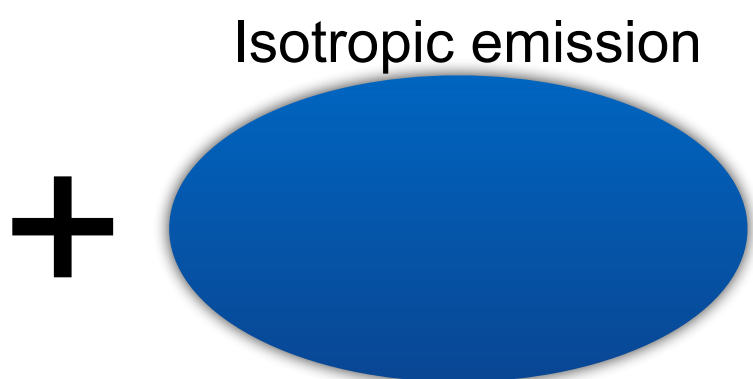
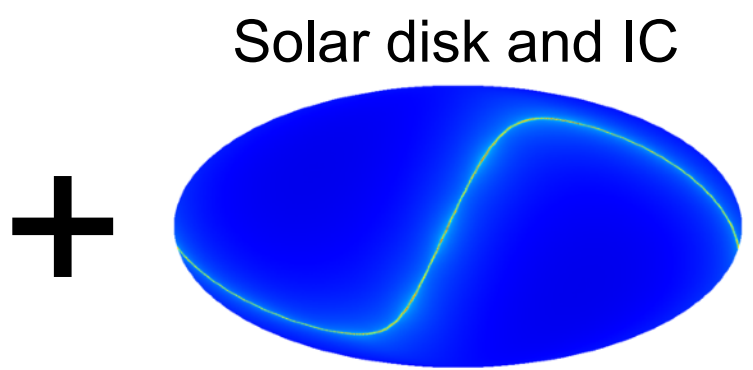
**Masked regions:**

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

=



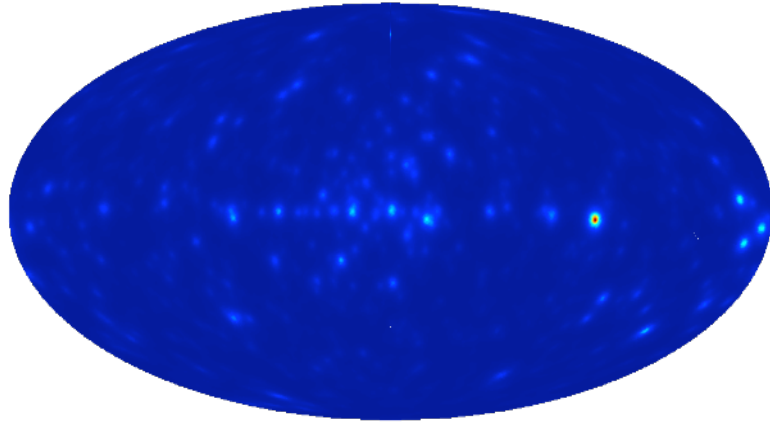
Galactic diffuse emission



Contami-  
nation from  
CR induced  
background



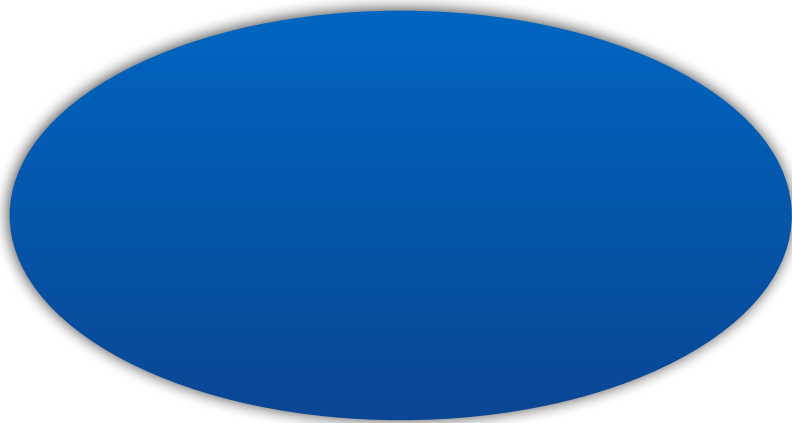
# The isotropic and the total extragalactic background



Resolved sources

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

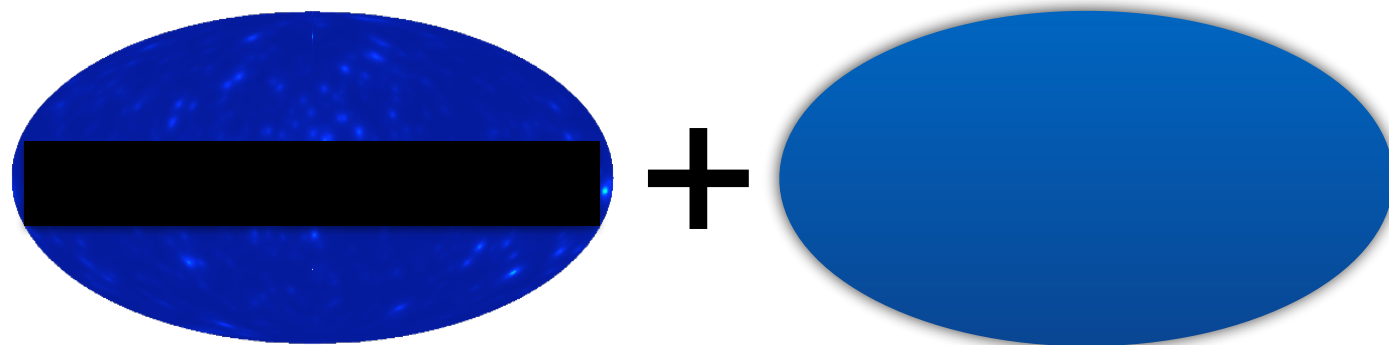
- the sensitivity of the instrument.
- the exposure of the observation.



Isotropic  $\gamma$ -ray background (IGRB)

→ The **isotropic  $\gamma$ -ray background** depends on the sensitivity to identify sources.

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



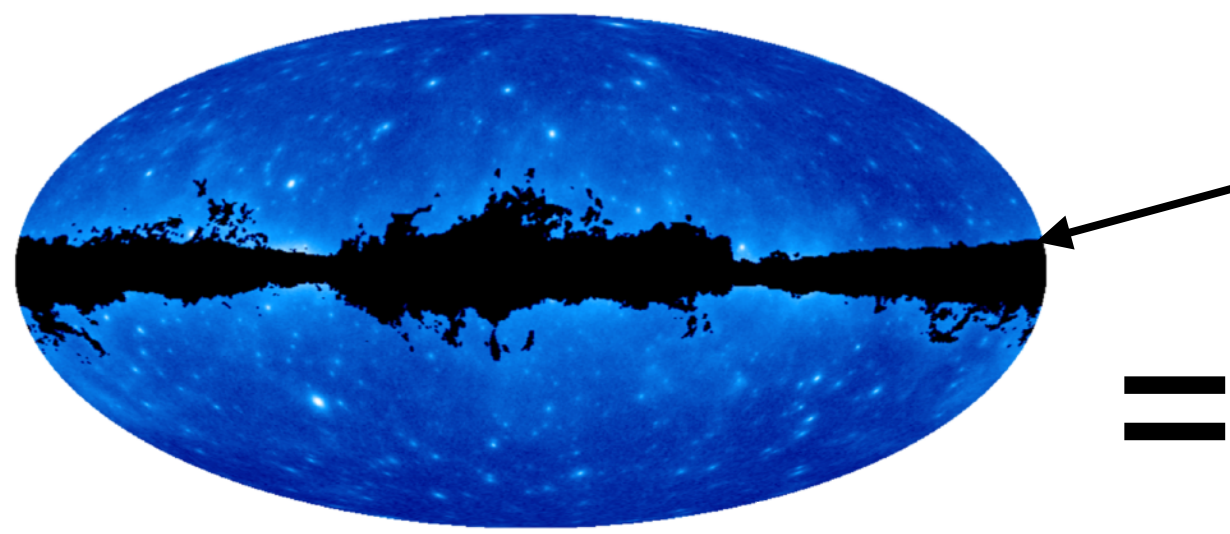
Total extragalactic  $\gamma$ -ray background (EGB)

→ The **total extragalactic  $\gamma$ -ray background** is instrument and observation independent.

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



# Derivation of the isotropic gamma-ray background.



- Not used in 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

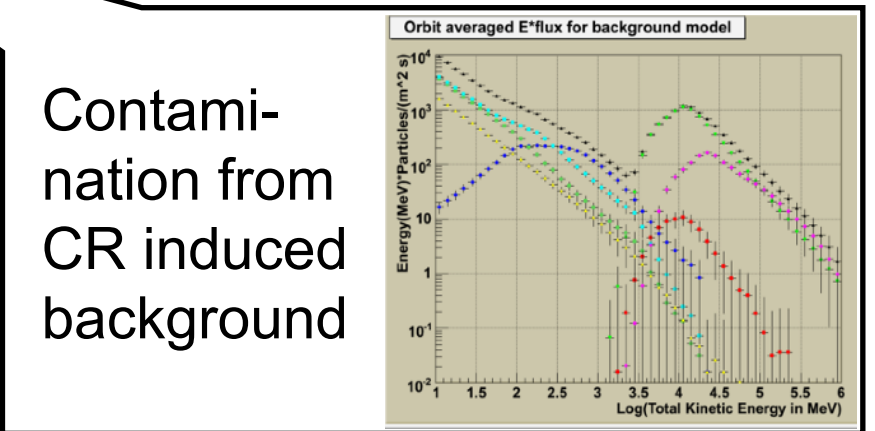
+

Isotropic emission

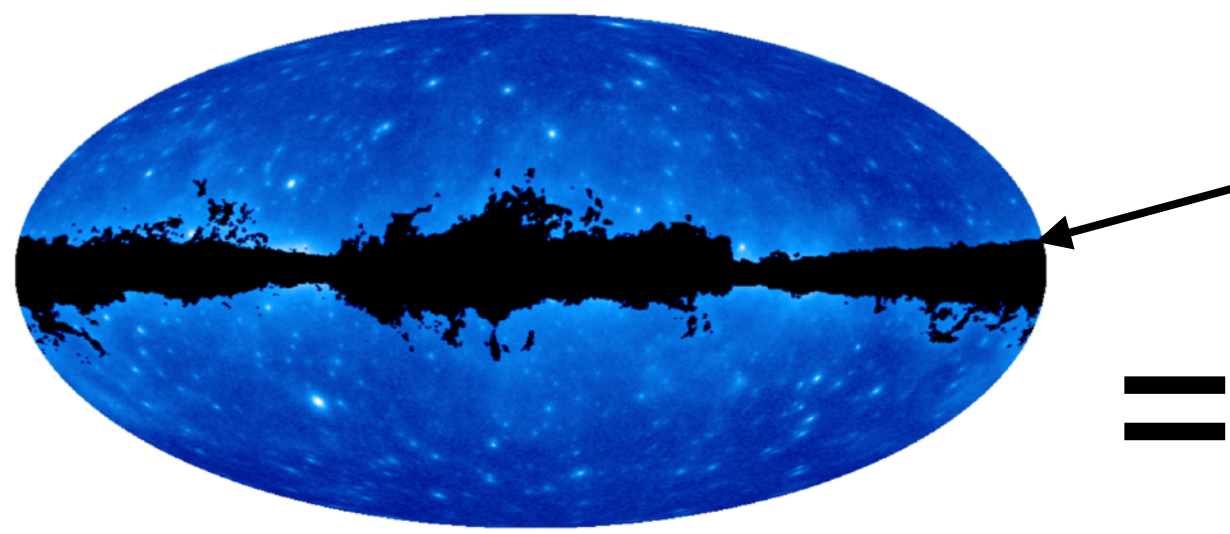
+

Resolved sources

Isotropic  $\gamma$ -ray background (IGRB)



# Derivation of the isotropic gamma-ray background.



- Not used in analysis:**
- > Galactic plane
  - > Regions with dense molecular clouds
  - > Regions with non-local atomic hydrogen clouds

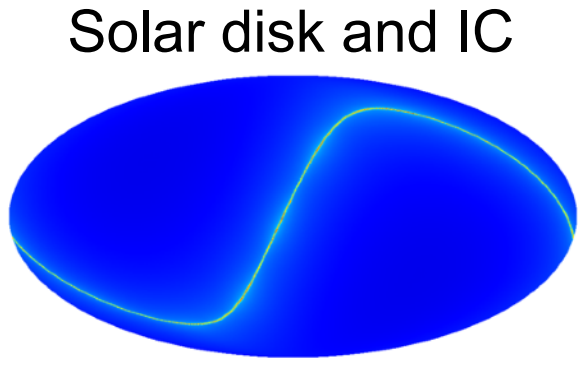
Galactic diffuse emission

Interstellar gas

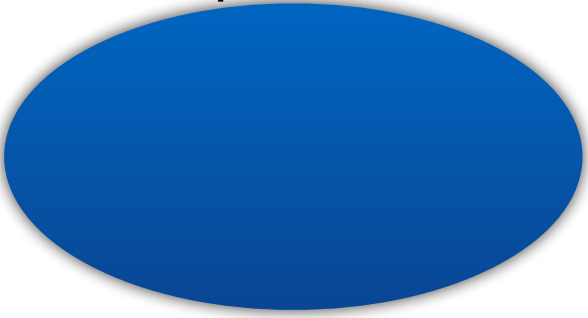
Inverse Compton (IC)

Loop I / Local Loop

+

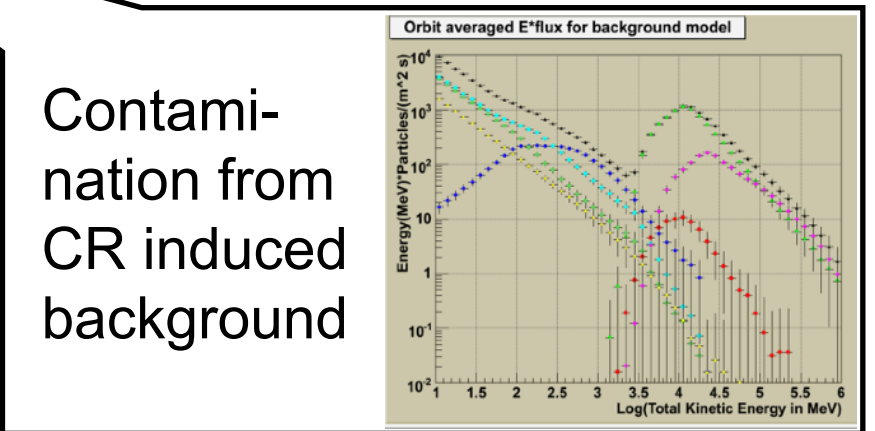


+



+

Isotropic  $\gamma$ -ray background (IGRB)



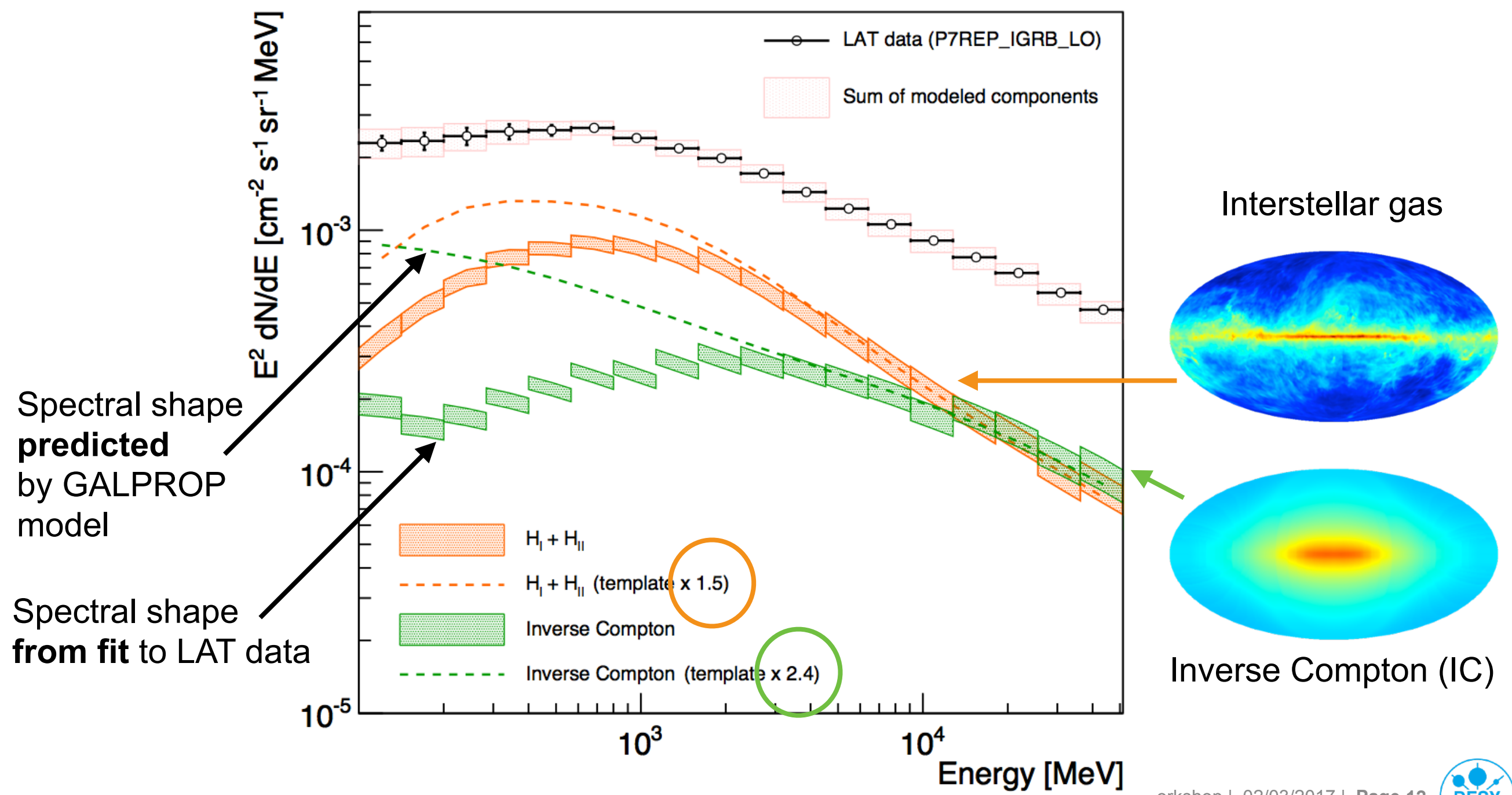
Galactic diffuse emission





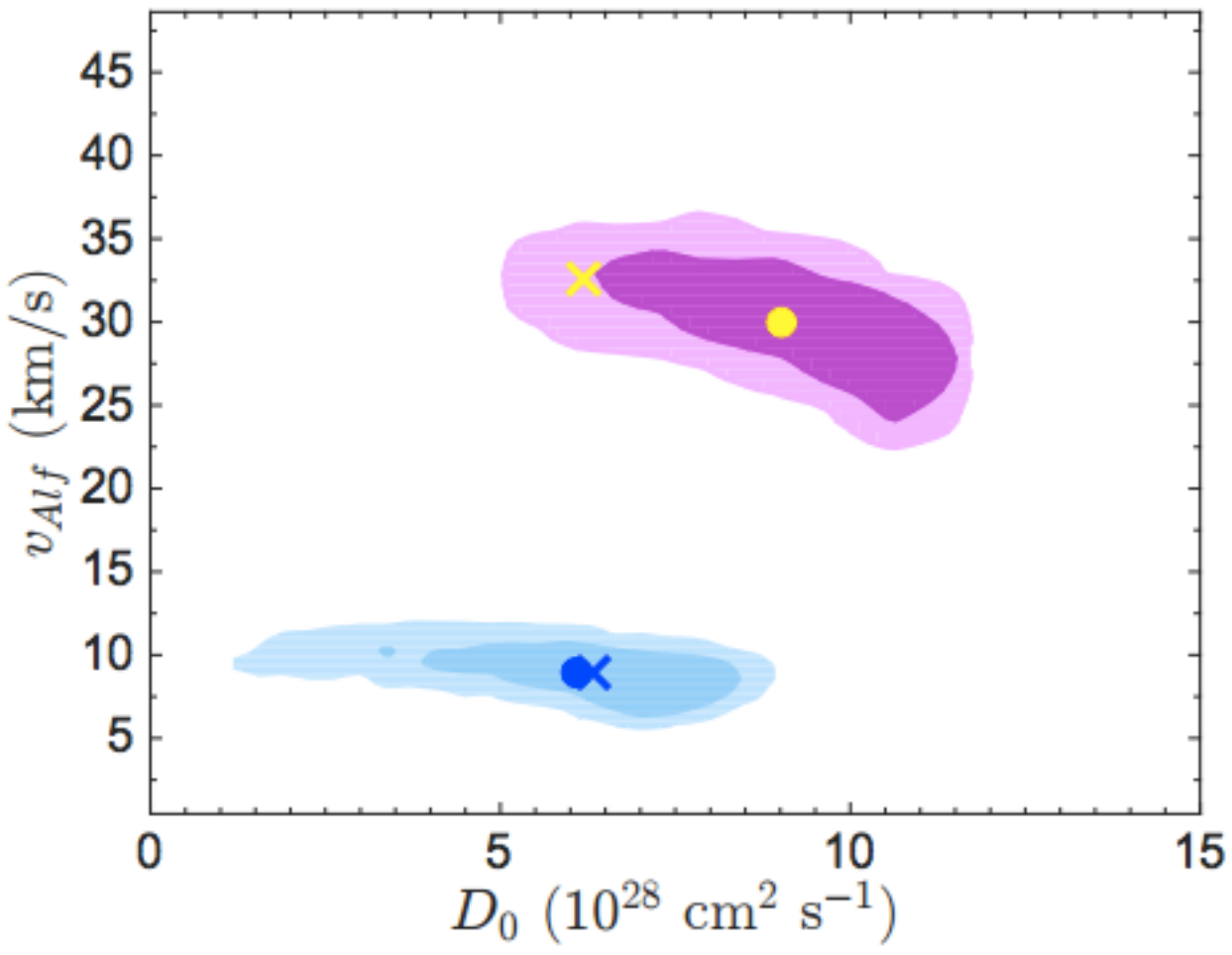
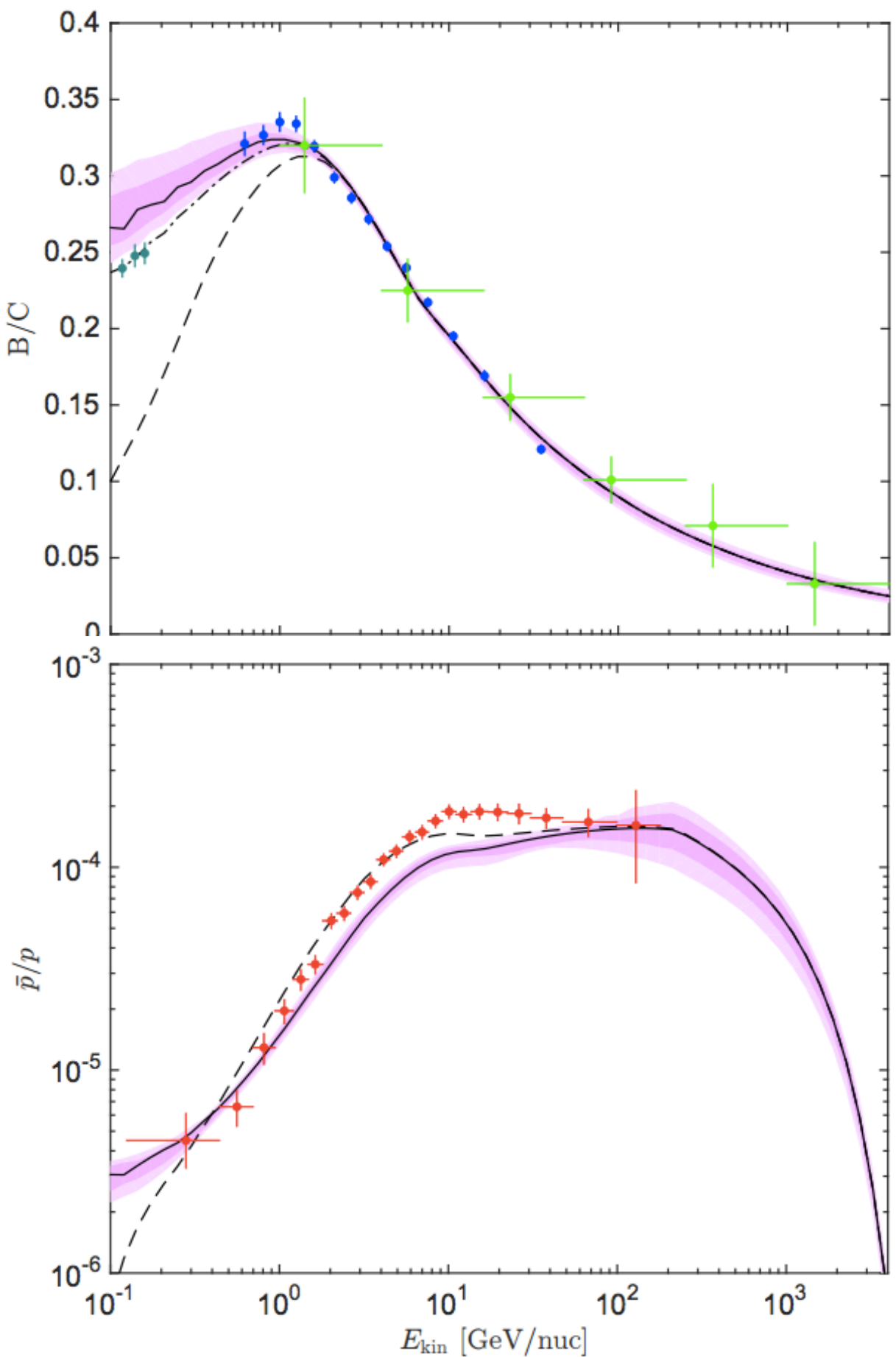
# Galactic diffuse foreground model.

- > **GALPROP** code used to produce **template maps** for diffuse Galactic emission.
  - Baseline model: CR injection/propagation scenario as in Ackermann et al. 2012
- > **Intensity** is derived from **fit to LAT data** in each energy band.



# Evidence from CR for more complex propagation scenarios

Johannesson et al., arXiv:1602.02243

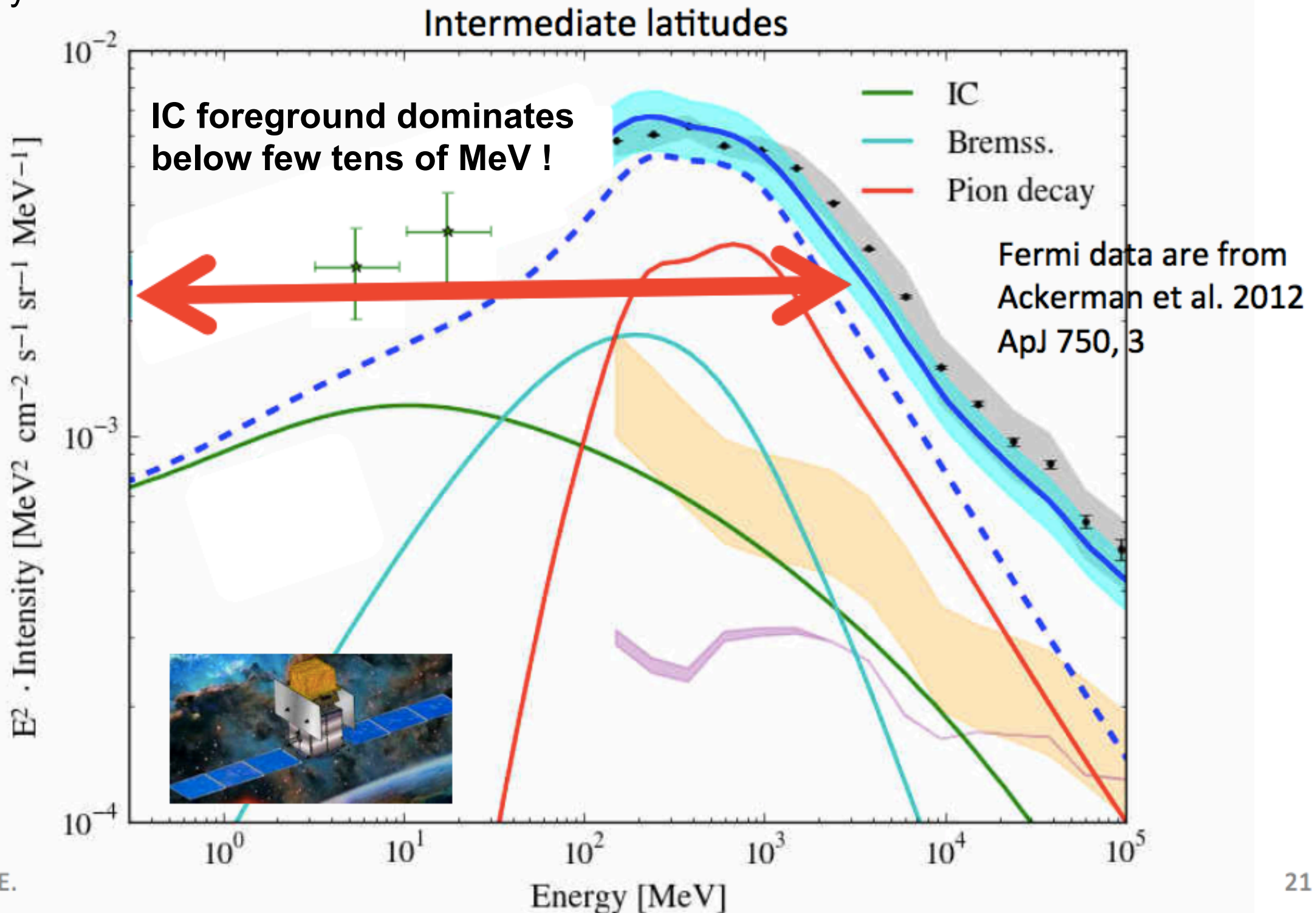


> A single set of (constant) propagation parameters cannot describe the light elements and B/C data simultaneously.

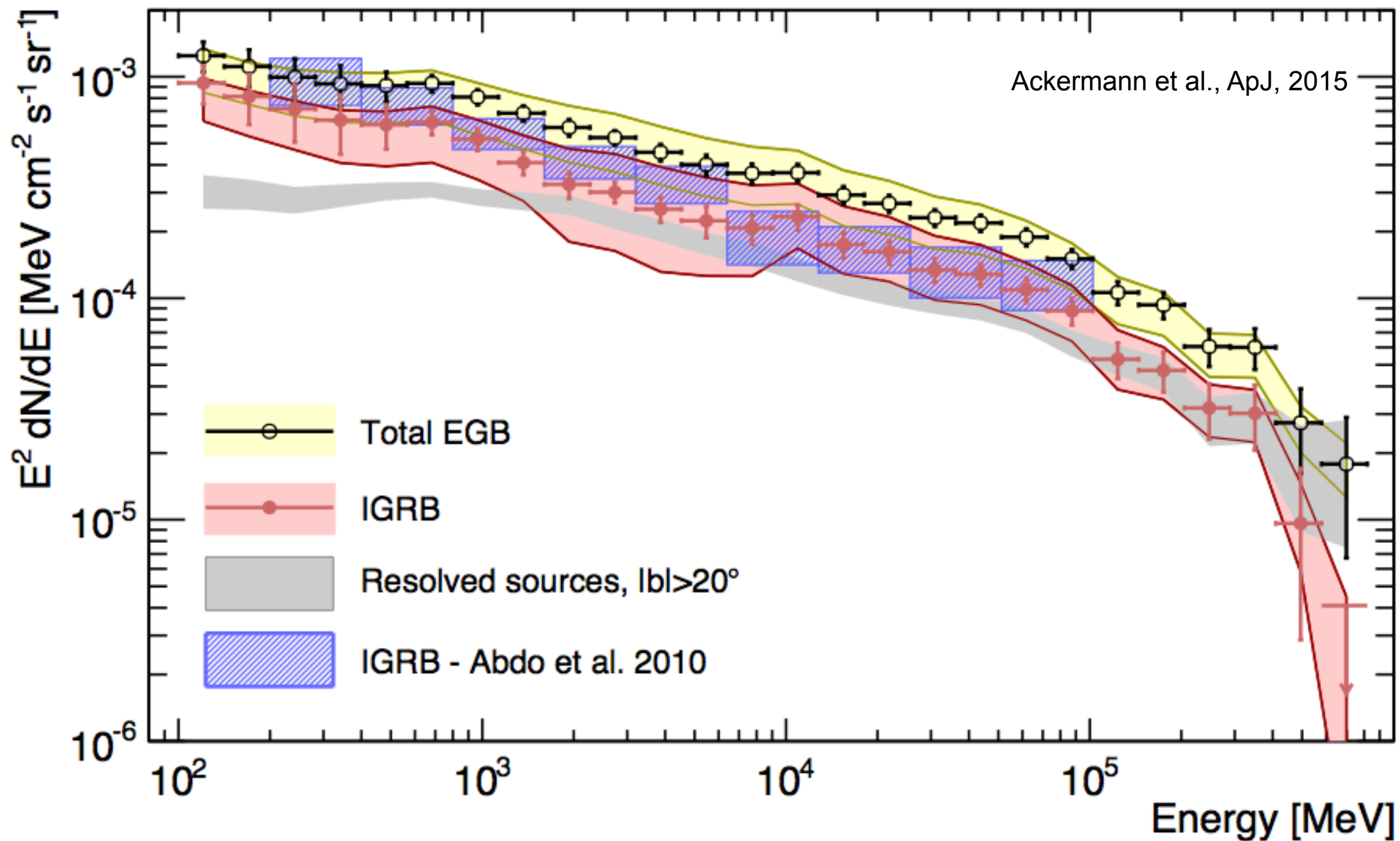


## Updated interstellar models, and predictions for e-ASTROGAM

Slide from Elena's talk yesterday



# Comparison of IGRB and EGB measurements above 100 MeV



- > **Total EGB = isotropic gamma-ray background + intensity of detected sources**
- > **Uncertainty from foreground modeling dominates**



# Understanding the origin of the Extragalactic Background





## Sources



### Blazars

- Dominant class of extra-galactic GeV / TeV sources.



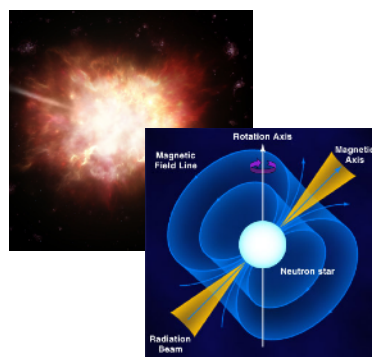
### Radio galaxies

- ~ 30 sources resolved by LAT
- Less luminous but more abundant than Blazars



### Star-forming galaxies

- Only few galaxies resolved in GeV band.
- Large number of sources → significant EGB contribution.



### GRBs + High-latitude pulsars

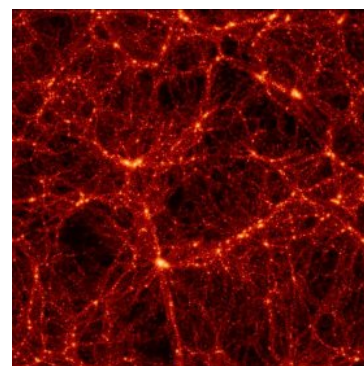
- Small contributions expected.

## Diffuse processes



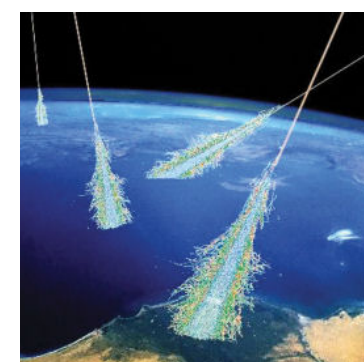
### Intergalactic shocks

- Small contribution on the level of few % expected.



### 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.
- large contributions possible (above few GeV)

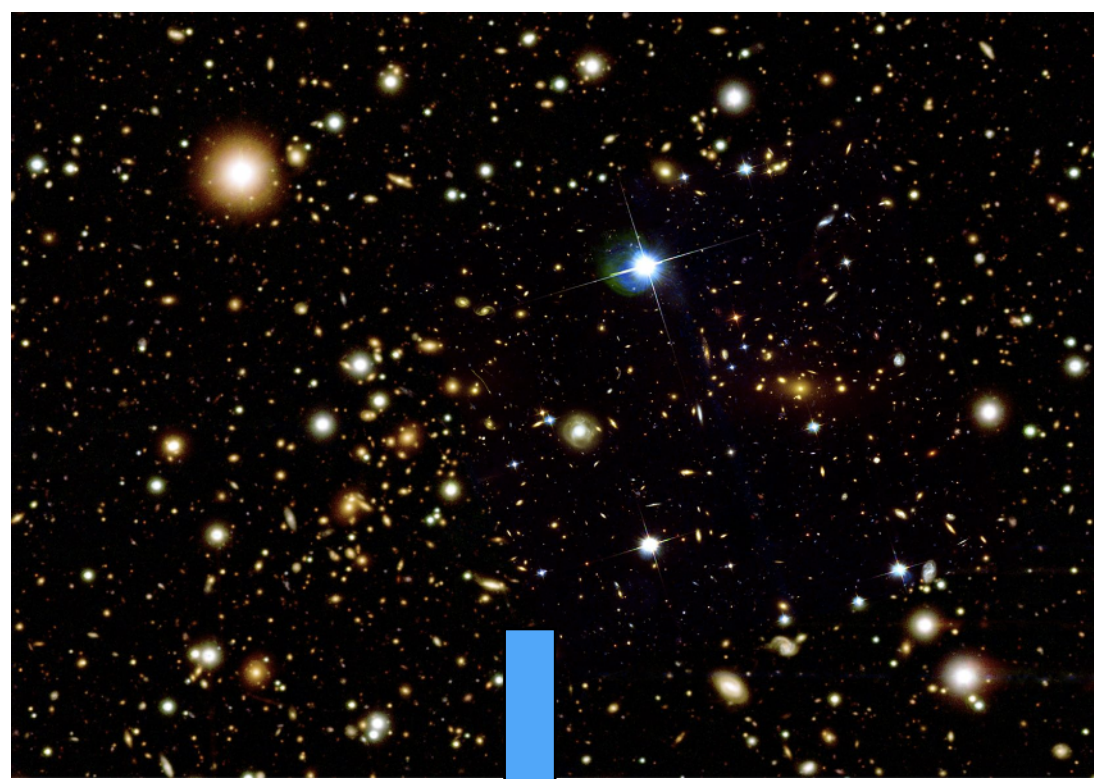
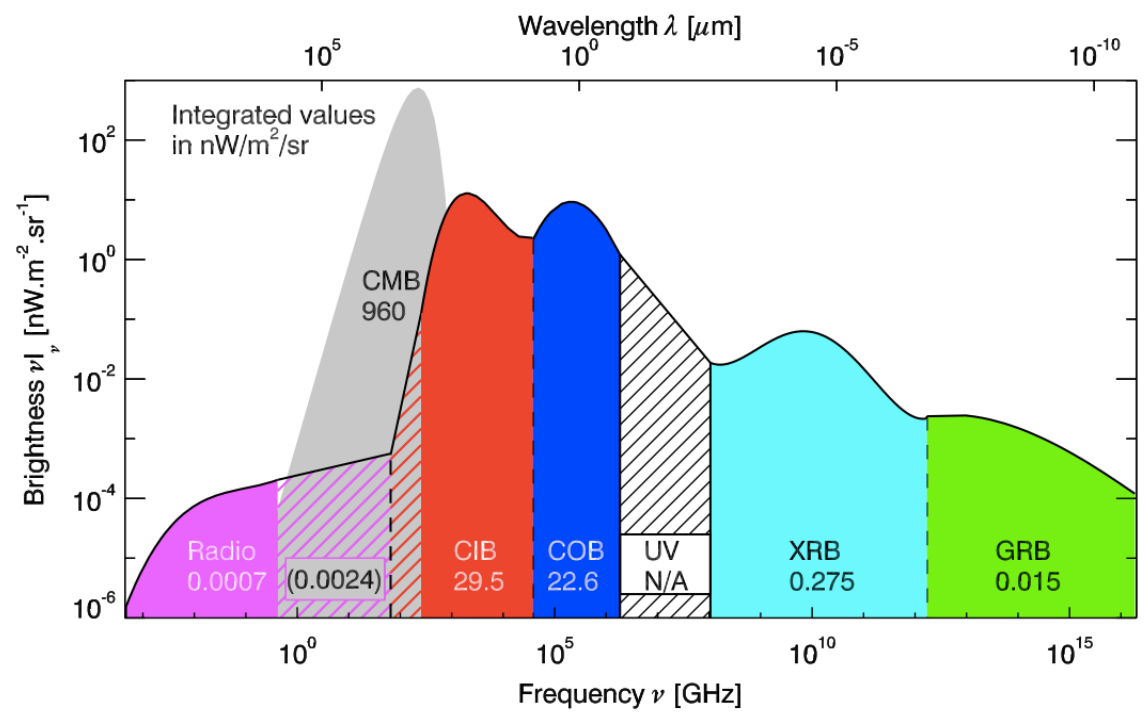


### Isotropic Galactic contributions

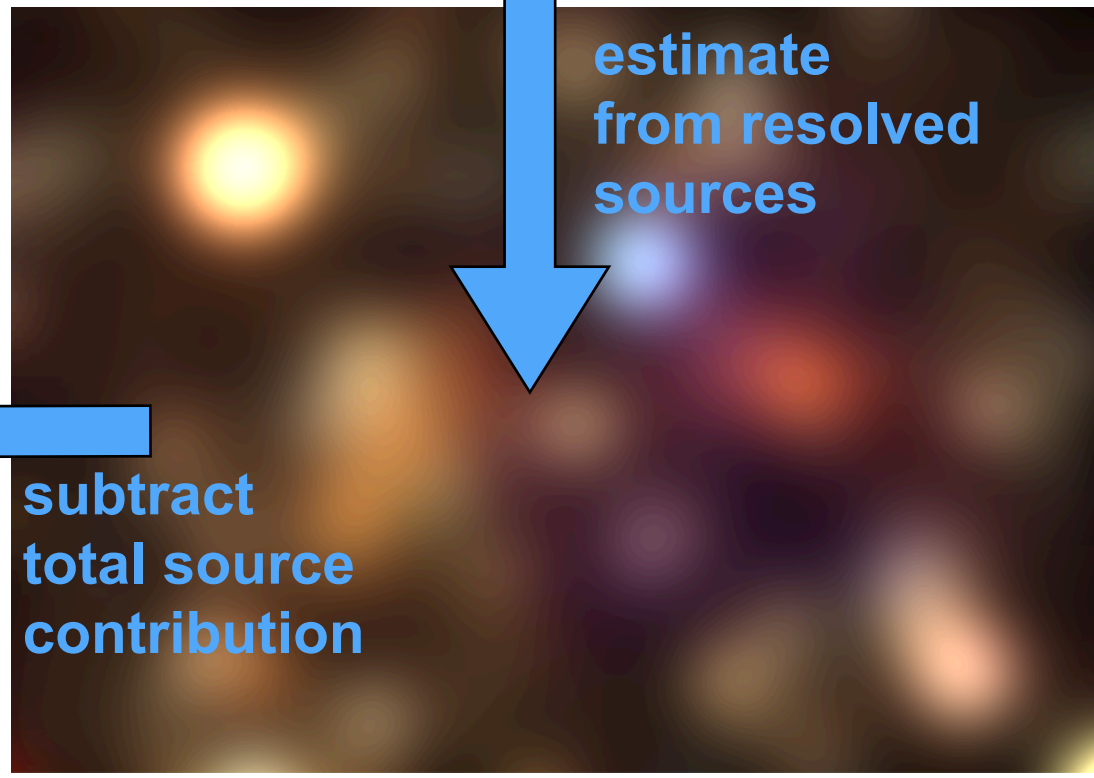
- Contributions from an extremely large Galactic electron halo / small solar system bodies.



# Origin of the radiation backgrounds.

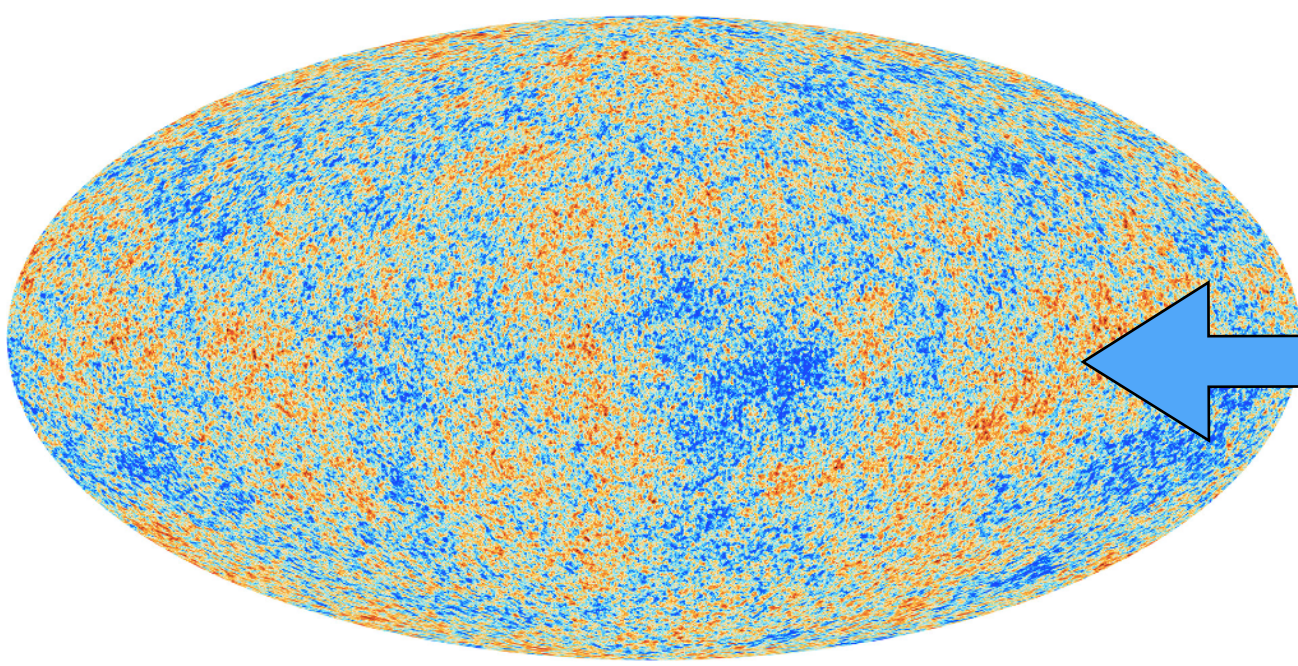


Known source populations



estimate from resolved sources

subtract total source contribution



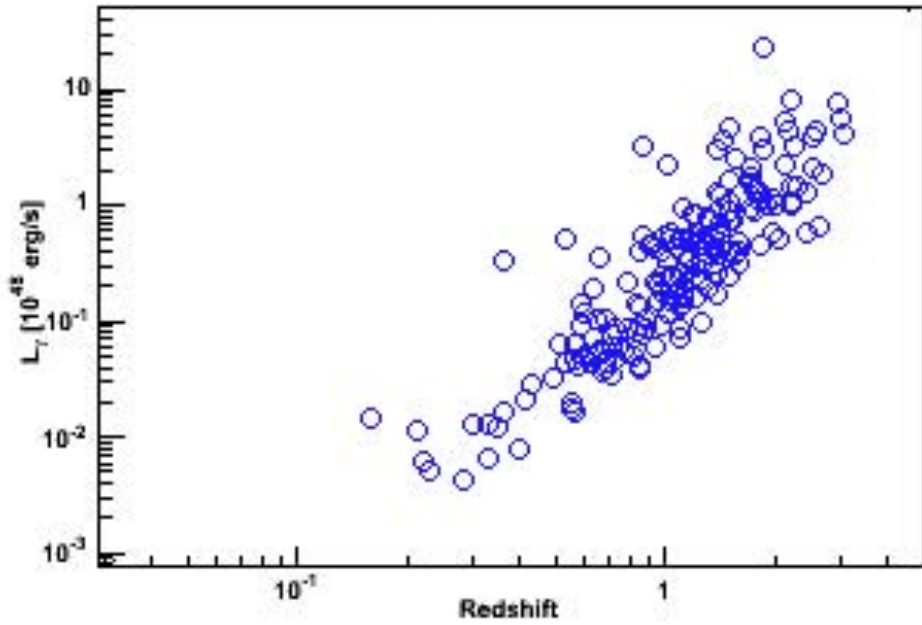
Diffuse radiation

Sources too faint to be resolved.



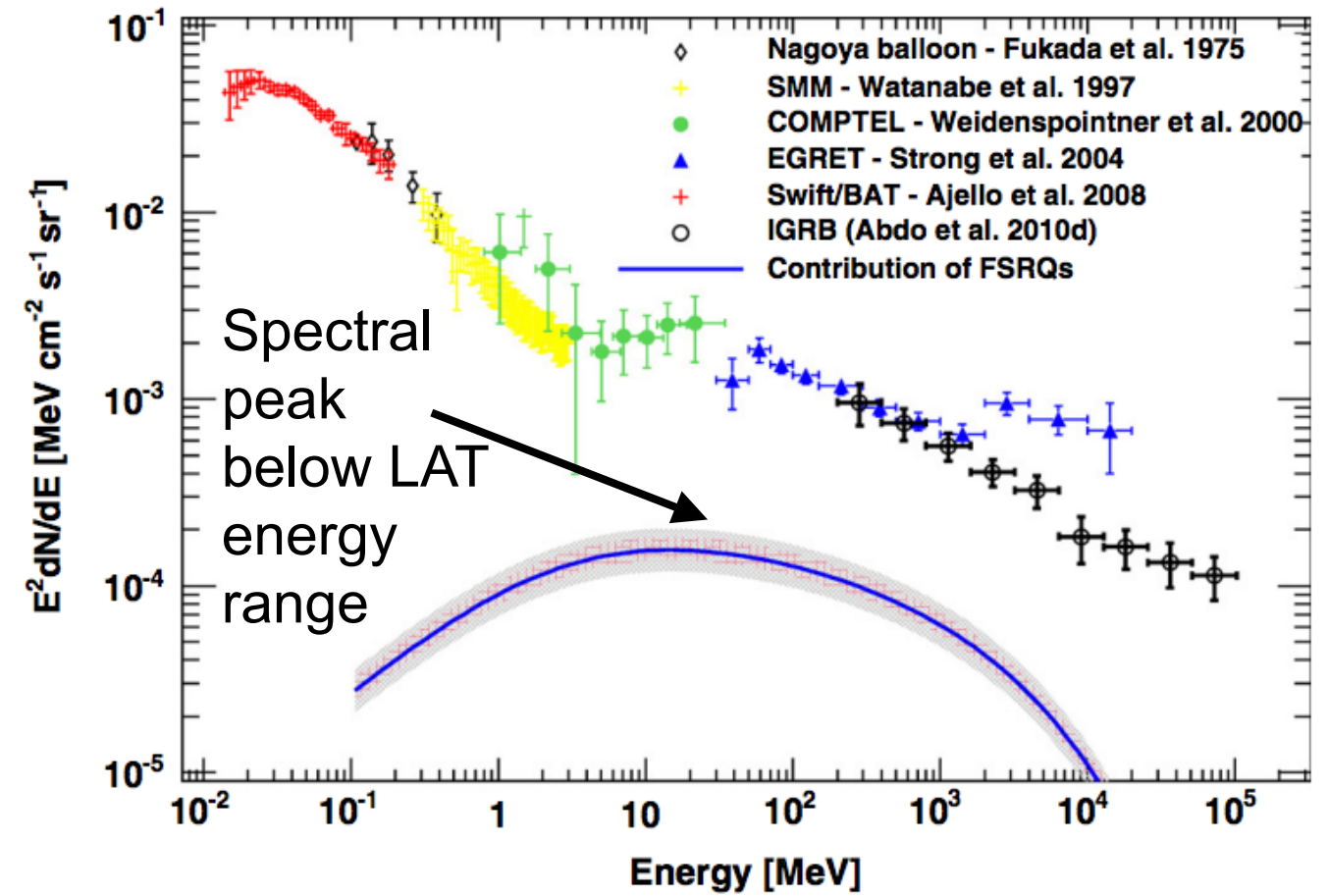
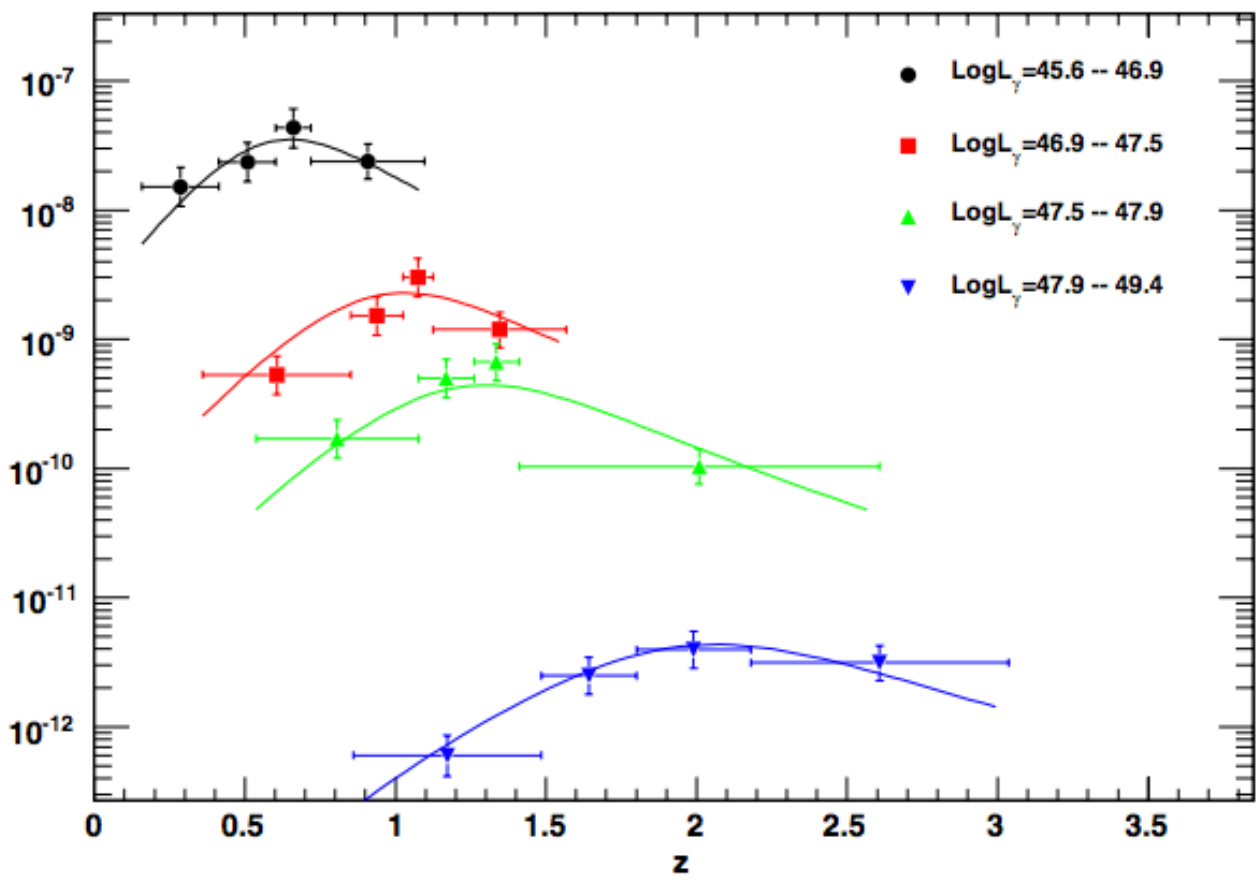


# Unresolved Blazars: FSRQ gamma-ray luminosity function.

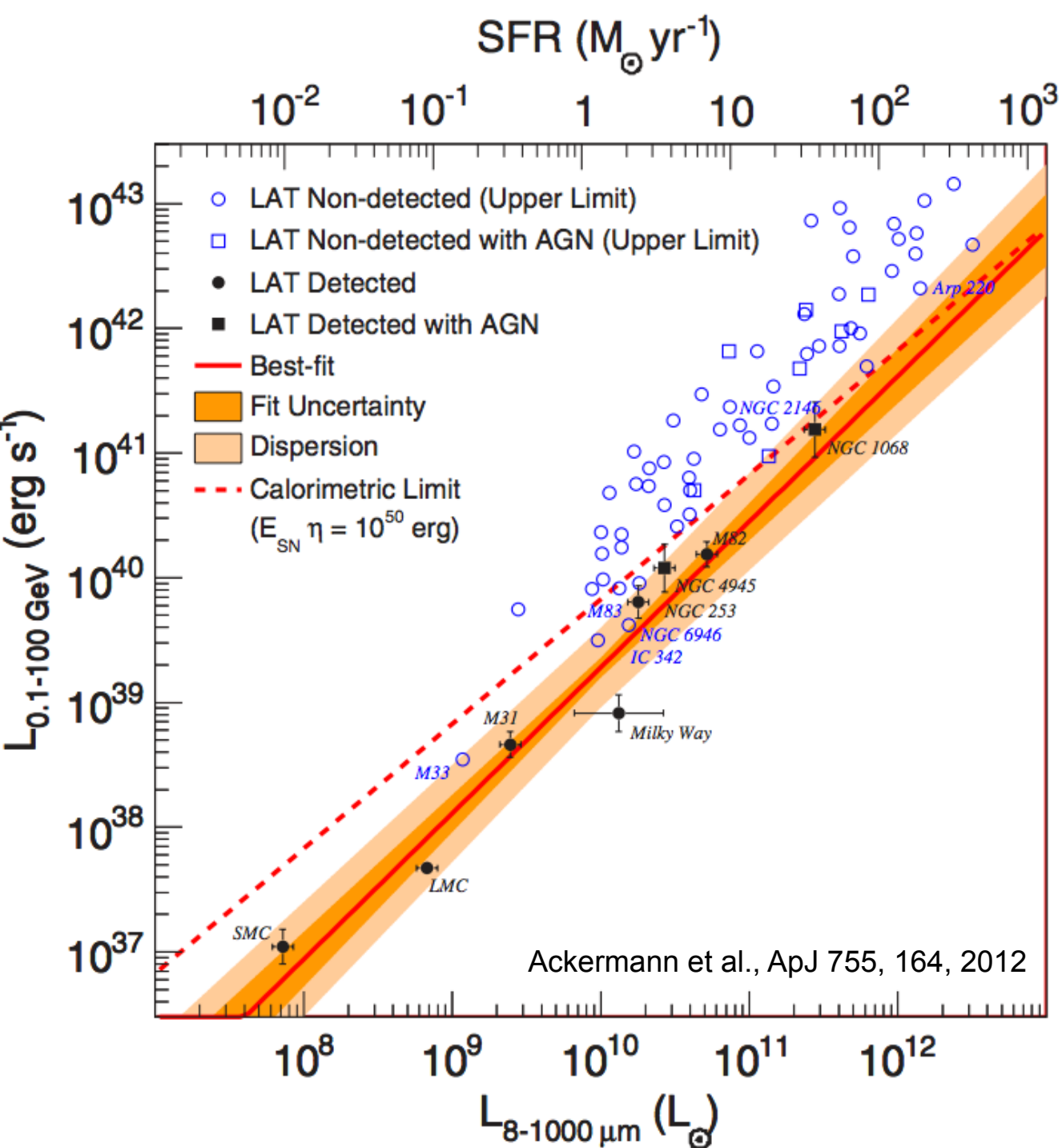
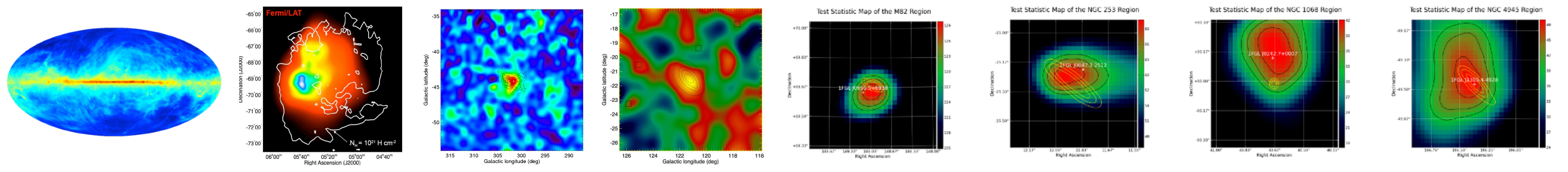


- > LAT resolved FSRQ population spans wide range in redshift and luminosity
- > Allows to build gamma-ray luminosity function (GLF) based on LAT data alone
- > Luminosity-dependent density evolution (LDDE) fits LAT population best
- > Prediction of EGB contribution based on GLF + spectral modeling

Ajello et al., ApJ 751, 108, 2012



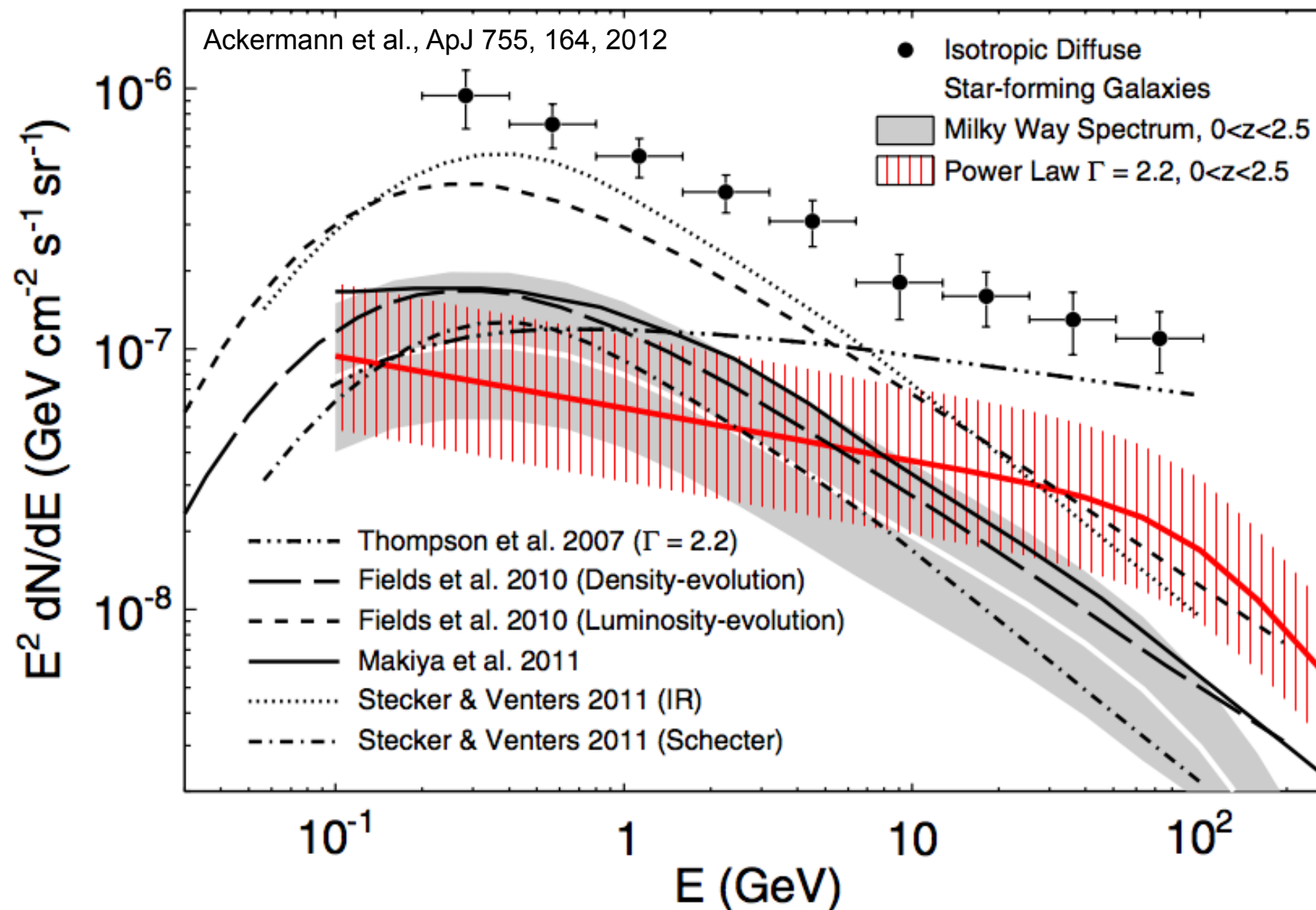
# Contributions of star-forming galaxies



- > Only 8 galaxies detected by the LAT
- > Almost linear correlation between gamma-ray luminosity and tracers of star formation
  - bolometric infrared luminosity
  - 1.4 GHz radio continuum emission
- > Detection + upper limits can be used to constrain correlation
- > Use gamma-ray / IR luminosity correlation to calculate EGB contribution based on IR luminosity function of galaxies.



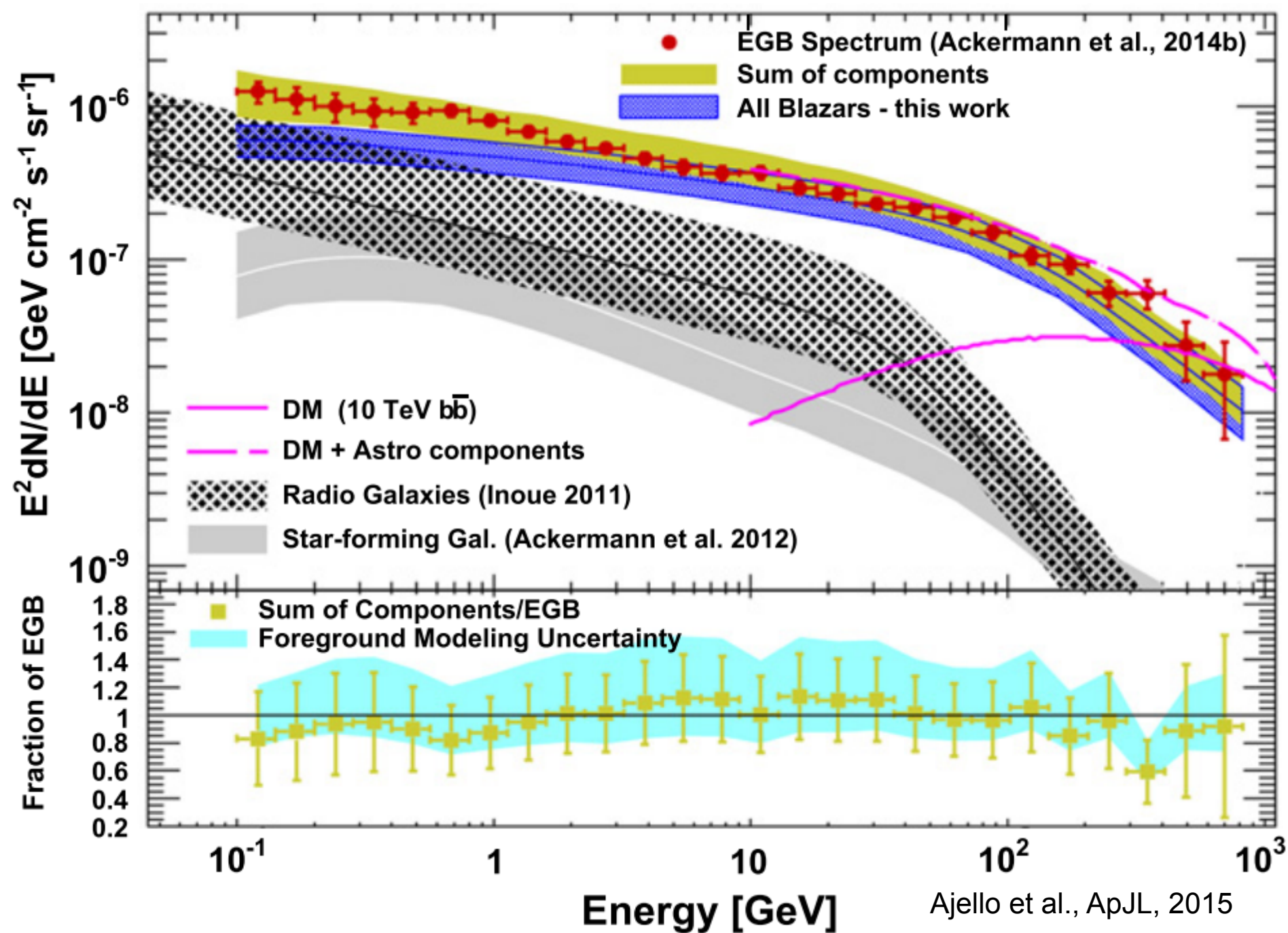
# Contributions of star-forming galaxies



- > Different population models predict different contributions to the EGB.
- > Measurement of spectral features in the 10 MeV - 200 MeV range would help to constrain these population models.



# Source population contributions to the EGB

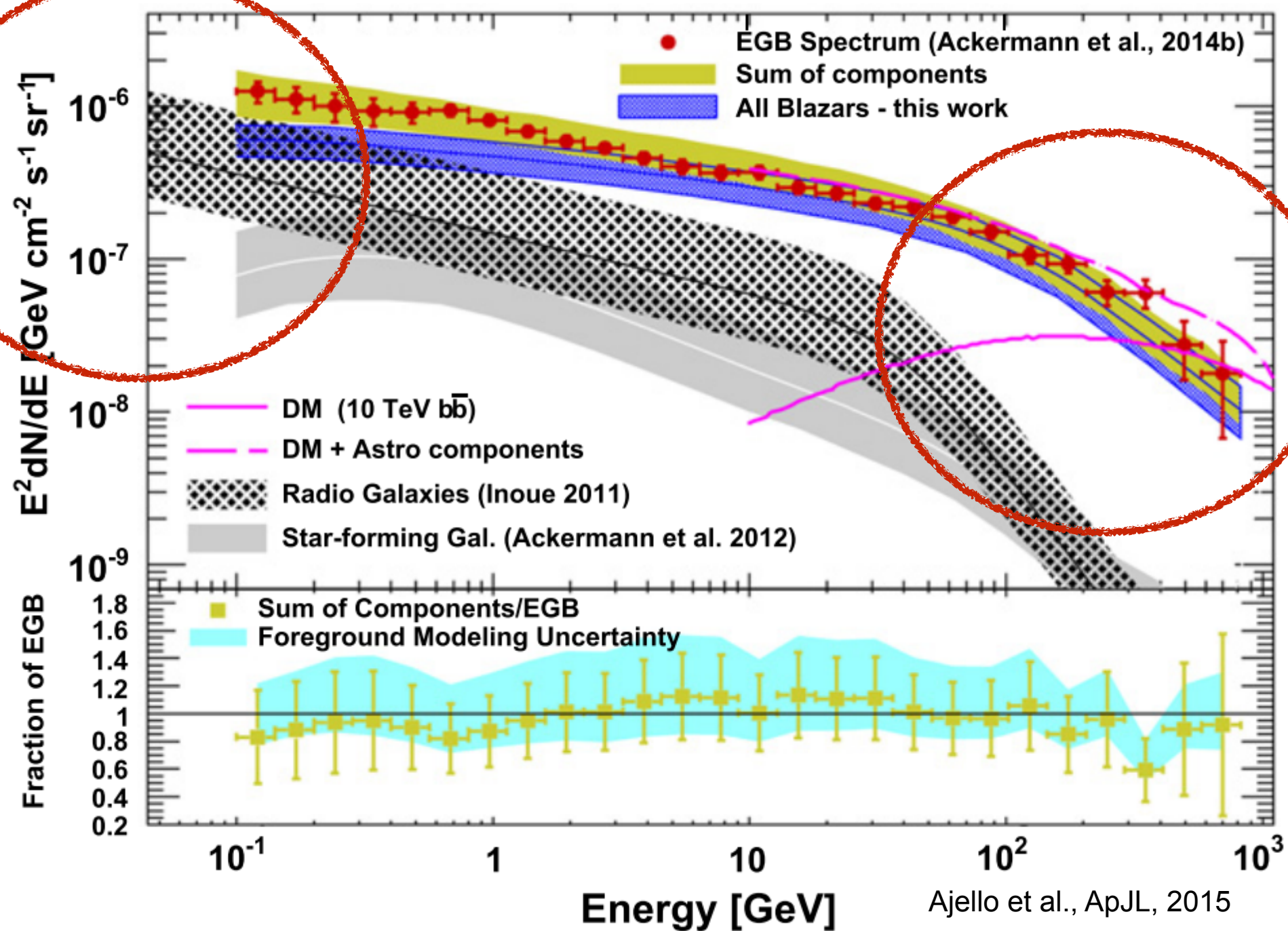


- > Observed extragalactic LAT source populations can account for the EGB intensity.
- > Significant uncertainties in modeling contributions.

# Source population contributions to the EGB

multiple contributions with large uncertainties

BLLac dominate

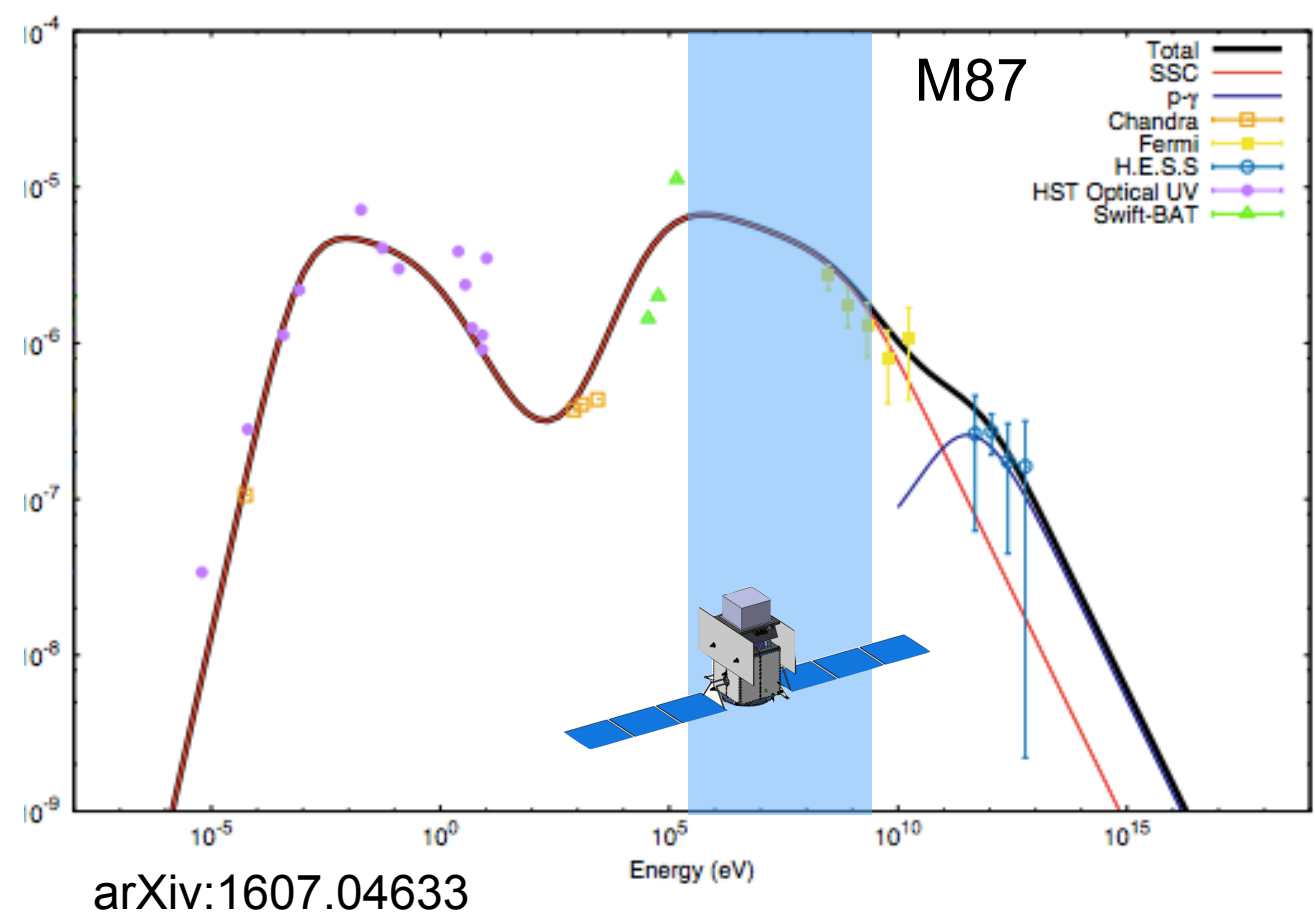
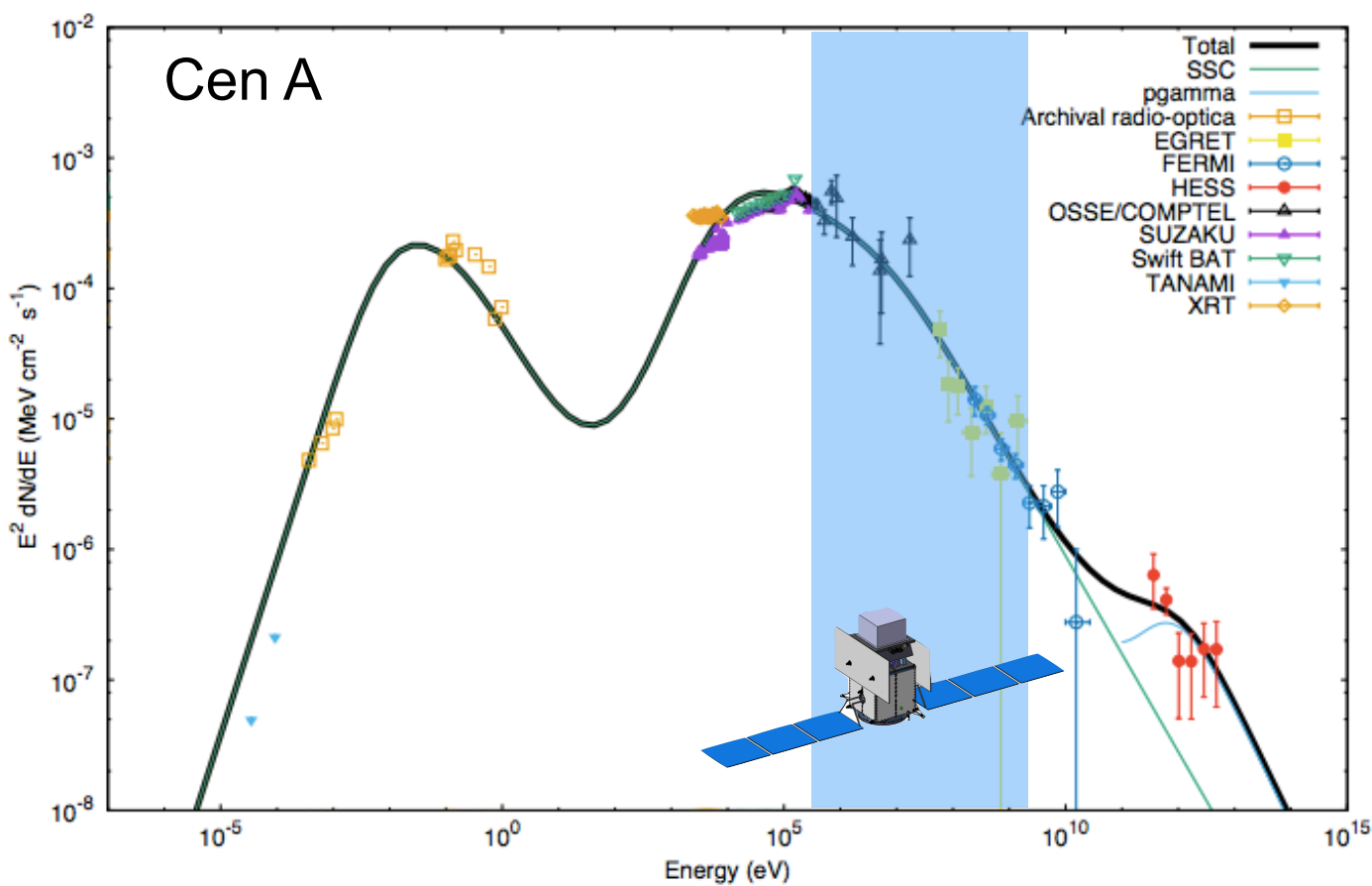


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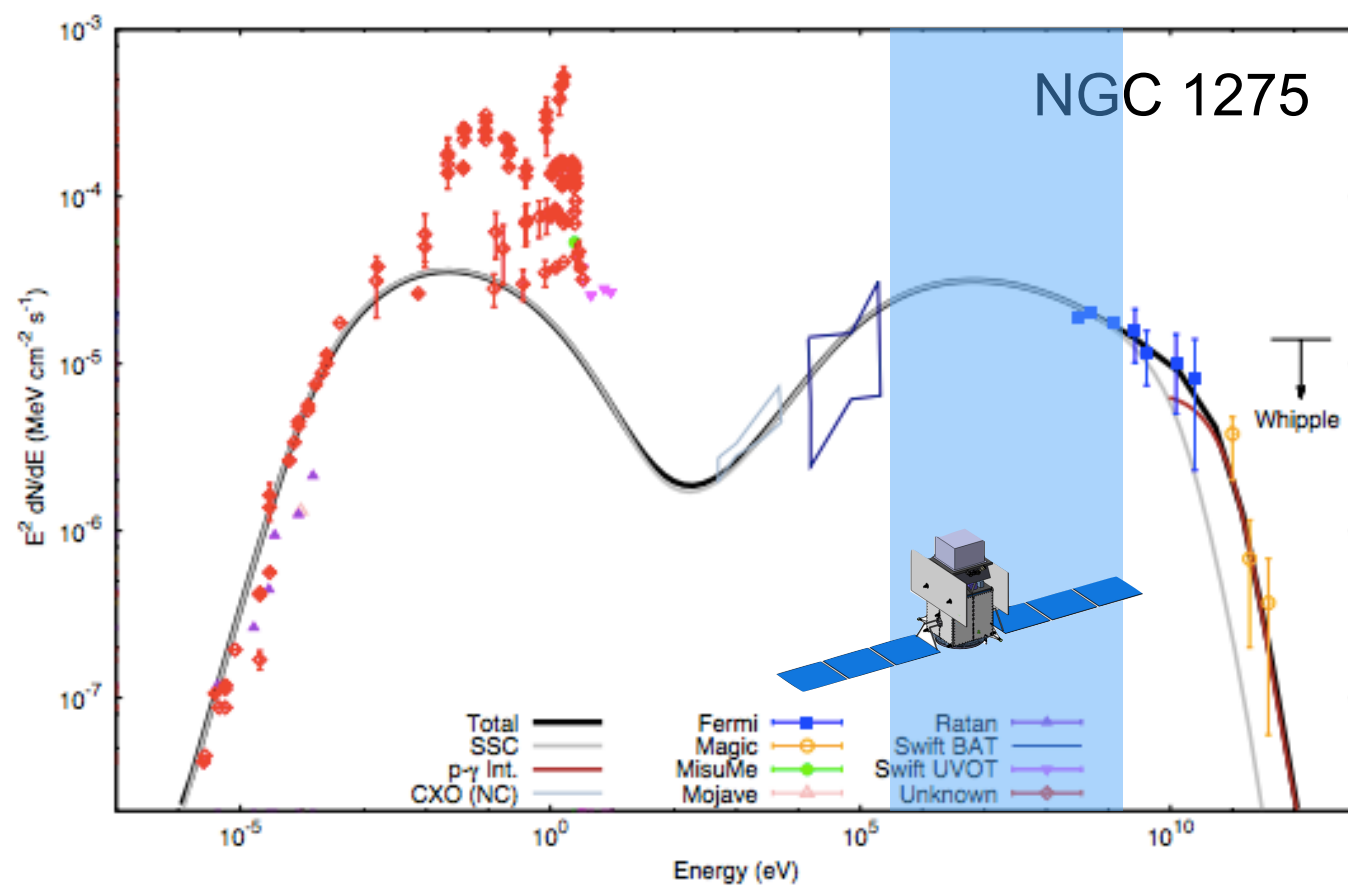




# Spectra of nearby radio galaxies

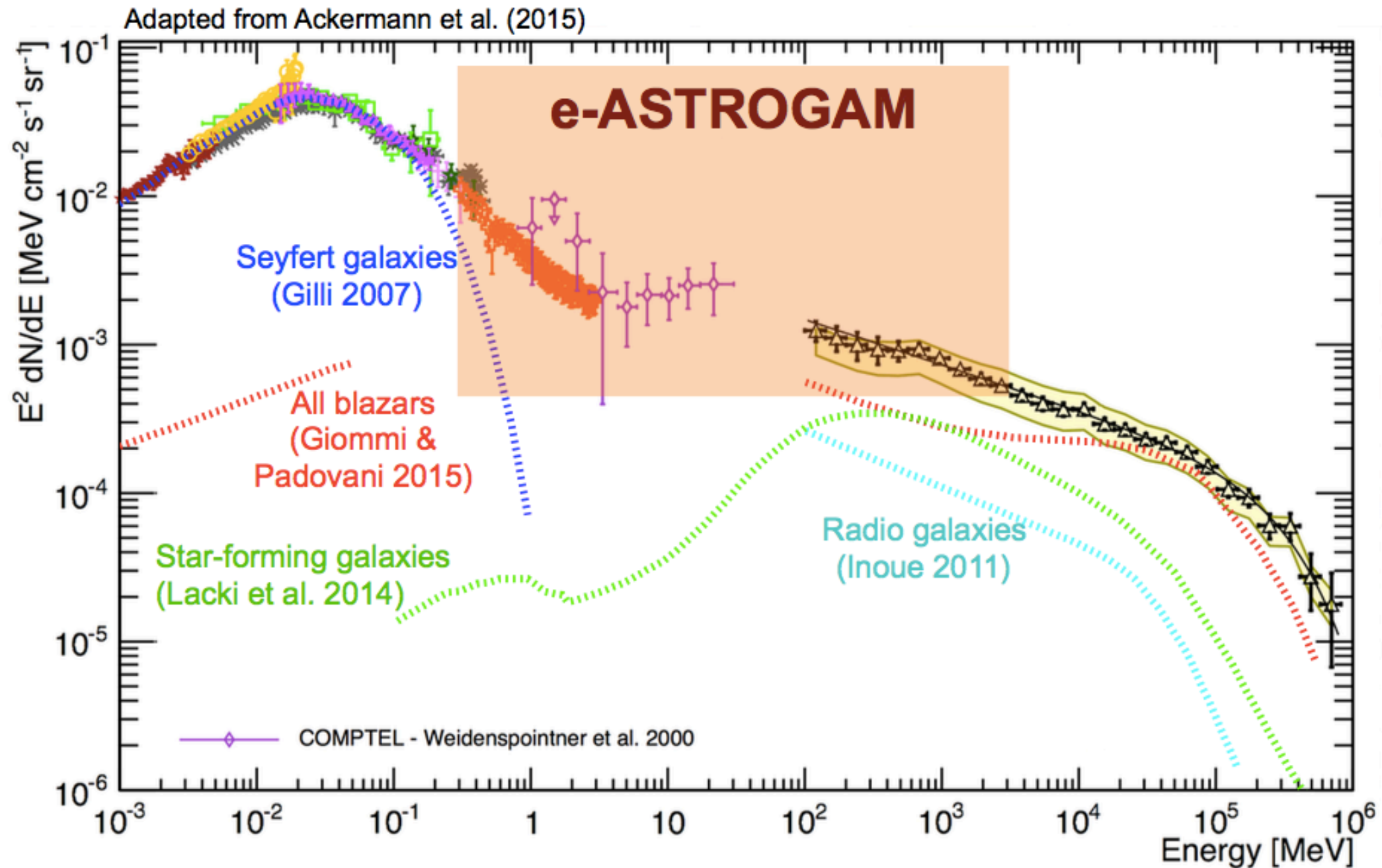


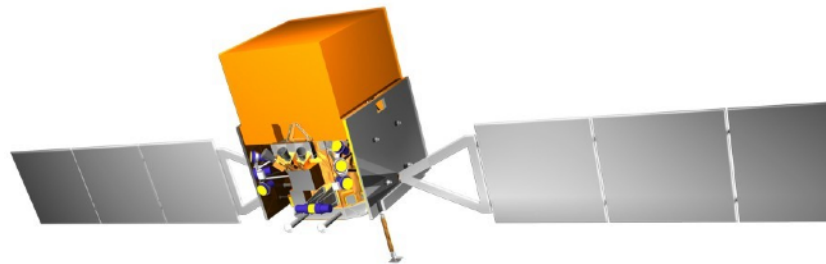
- Better spectral modeling of radio galaxy contributions
- Additional radio galaxy detections due to better e-ASTROGAM low-energy sensitivity (compared to Fermi LAT)
- Can give a handle to separate radio galaxy / star-forming galaxy contributions



# The extragalactic MeV background

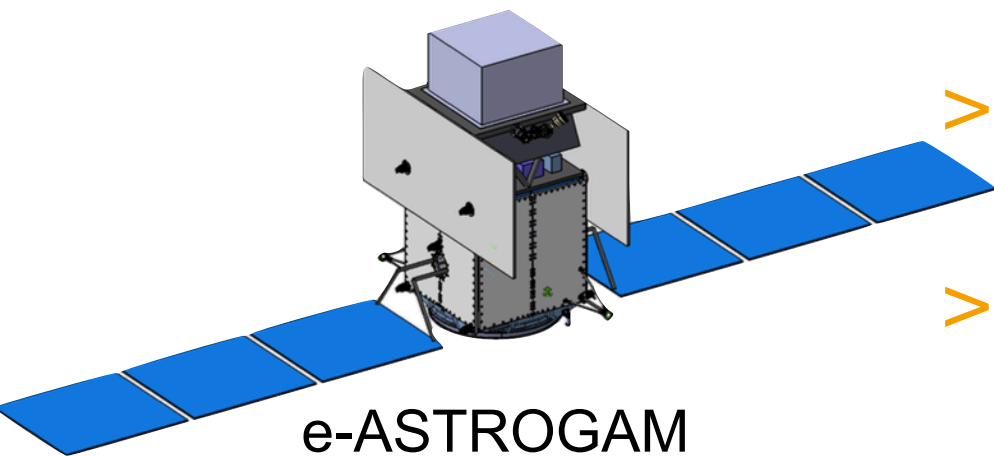
- > EGB contributions in MeV range widely unknown
- > There is room for surprises !





Fermi LAT

- > Cosmic x-ray and gamma-ray backgrounds have been measured over 9 orders of magnitude in energy.
- > Fermi LAT data enabled the most accurate EGB measurement between 100 MeV and 820 GeV.
- > BLLacs dominate the EGB above a few GeV, while multiple source populations contribute at low energies



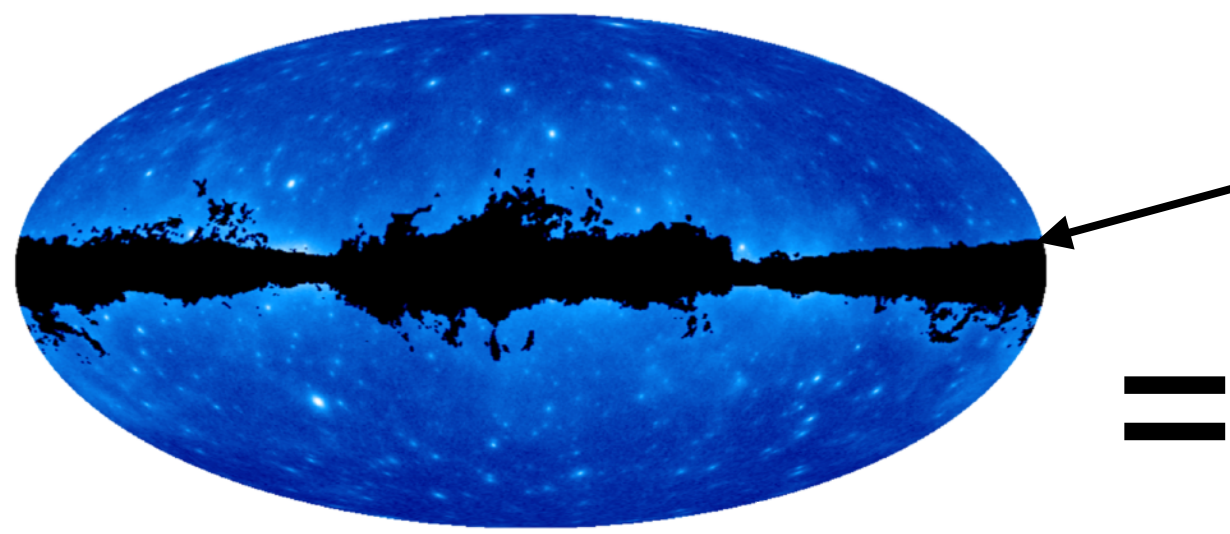
e-ASTROGAM

- > e-ASTROGAM would deliver a significant improvement of the EGB measurement between 0.3 MeV and 3 GeV.
- > Better constraints of Galactic foreground would also improve measurement in LAT energy range.
- > Potential spectral features in the MeV range would give important clues on the origin of the EGB.
- > Better determination of source population spectra improves modeling their contribution.

# Backup



# Derivation of the isotropic gamma-ray background.



- Not used in 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

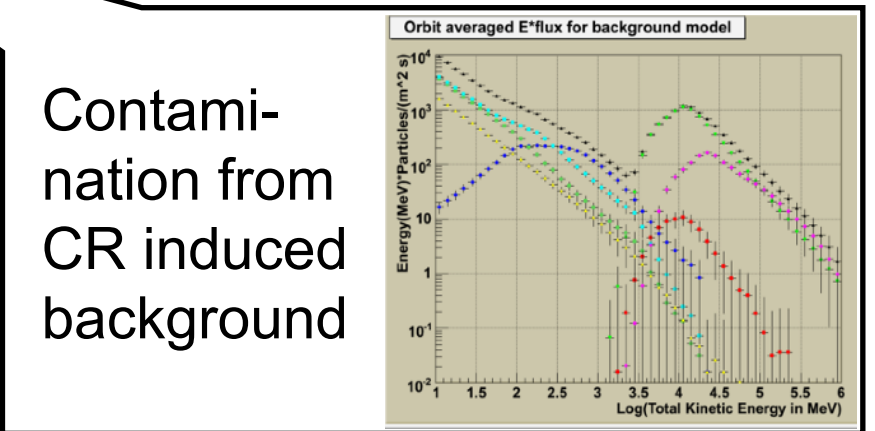
+

Isotropic emission

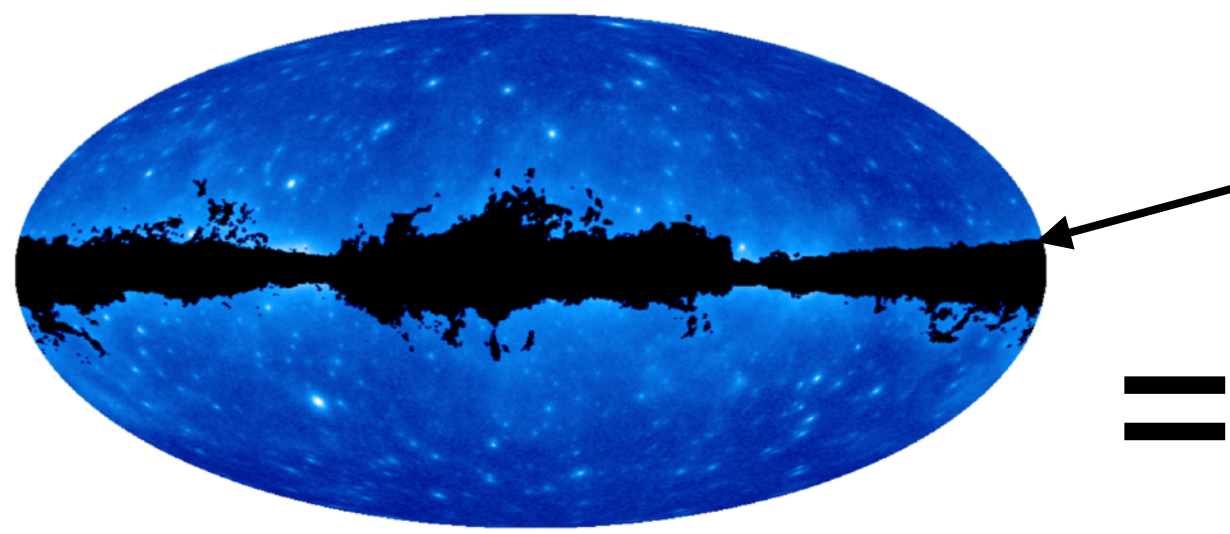
+

Resolved sources

Isotropic  $\gamma$ -ray background (IGRB)



# Derivation of the isotropic gamma-ray background.



- Not used in analysis:**
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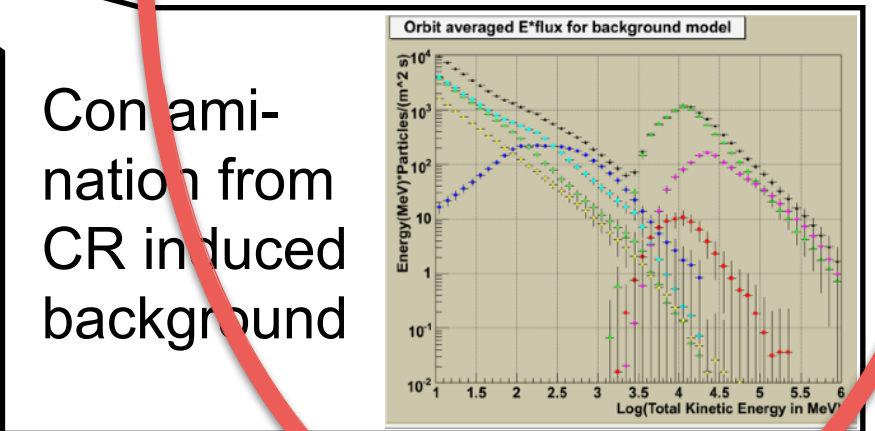
Galactic diffuse emission

Solar disk and IC

Isotropic emission

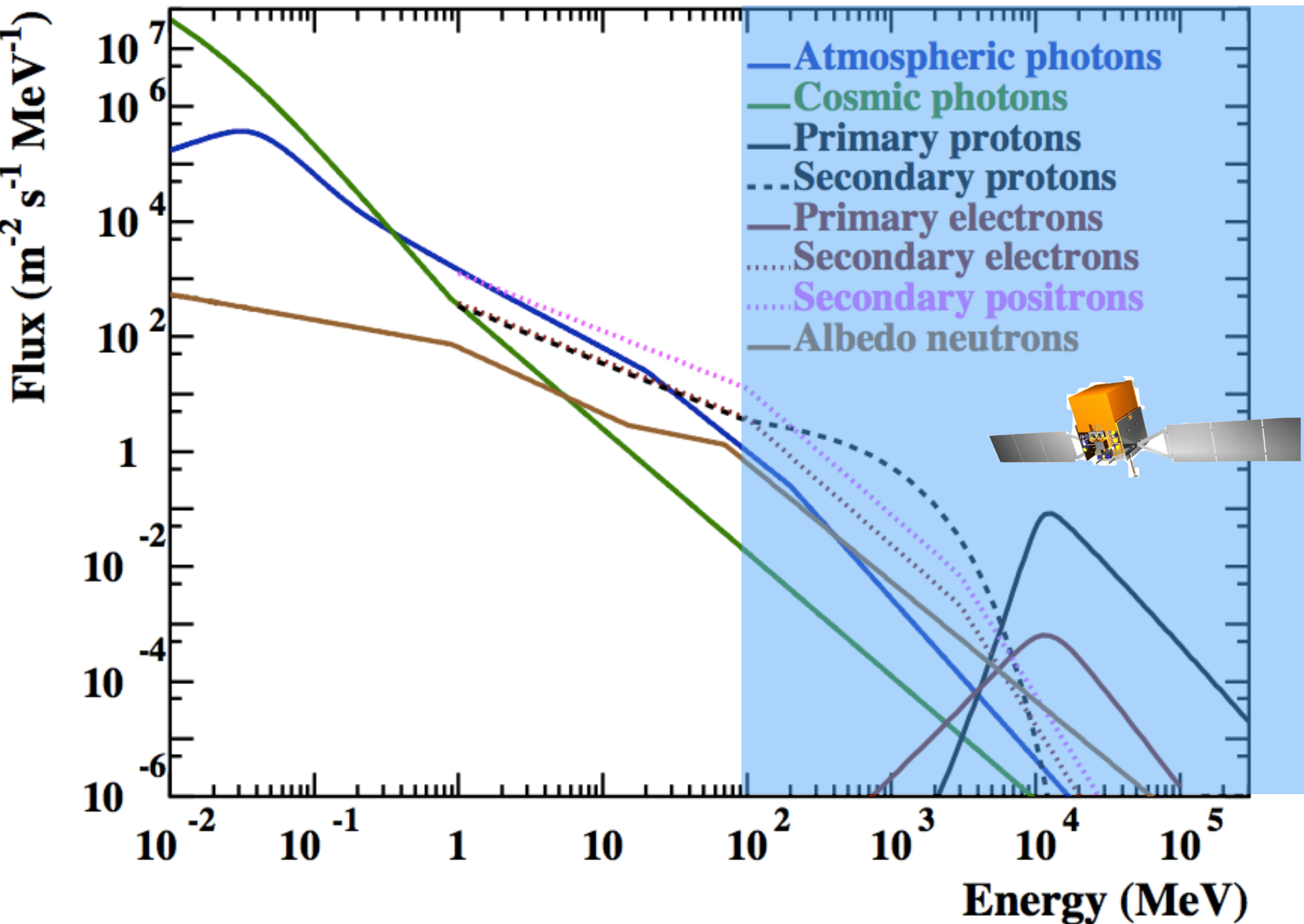
Resolved sources

Isotropic  $\gamma$ -ray background (IGRB)





# Backgrounds in the GeV regime

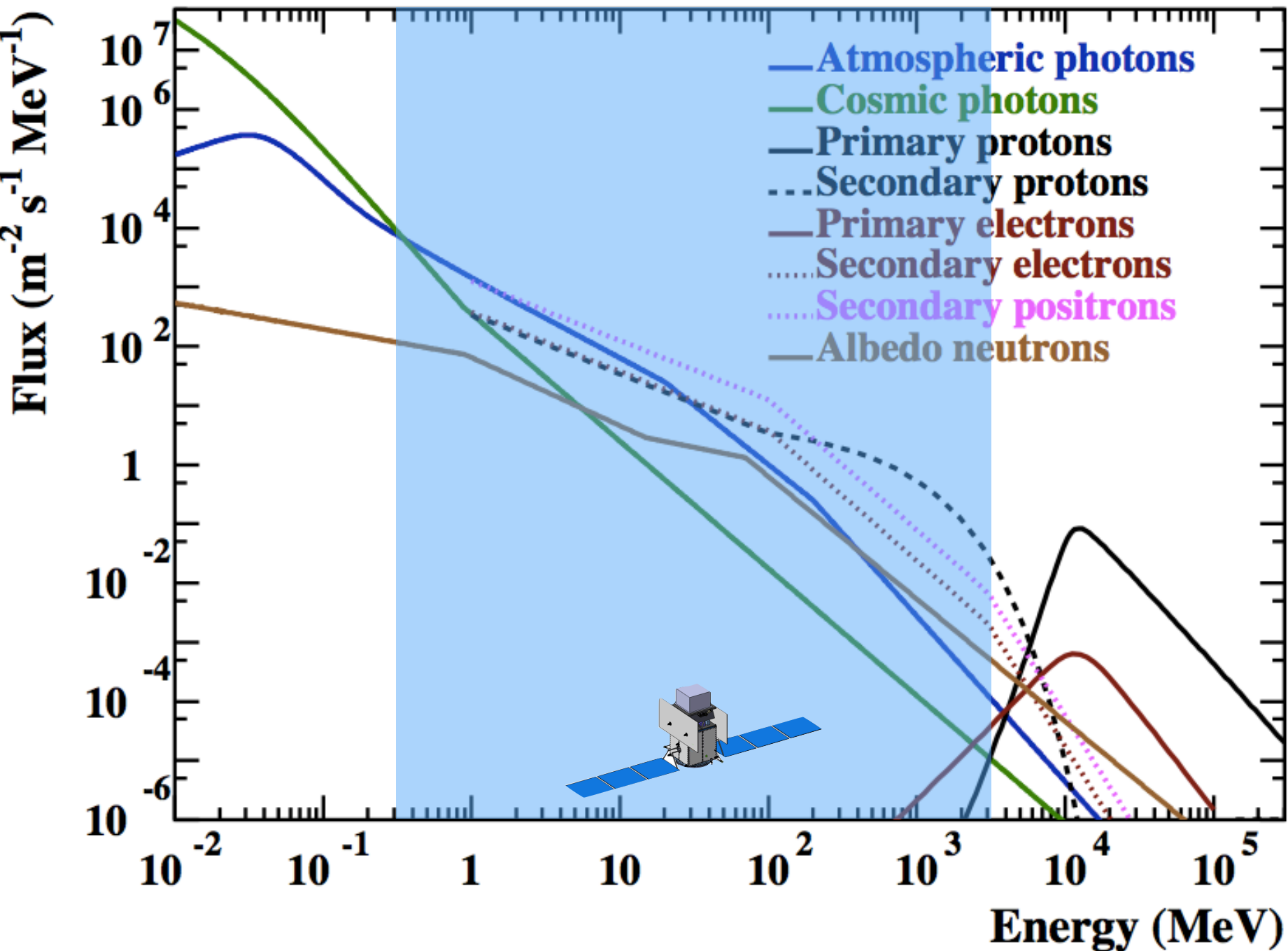


> In Fermi LAT energy range up to  $10^6$  times higher charged particle backgrounds than EGB intensity

> Lots of effort went into modeling and reducing CR background contaminations



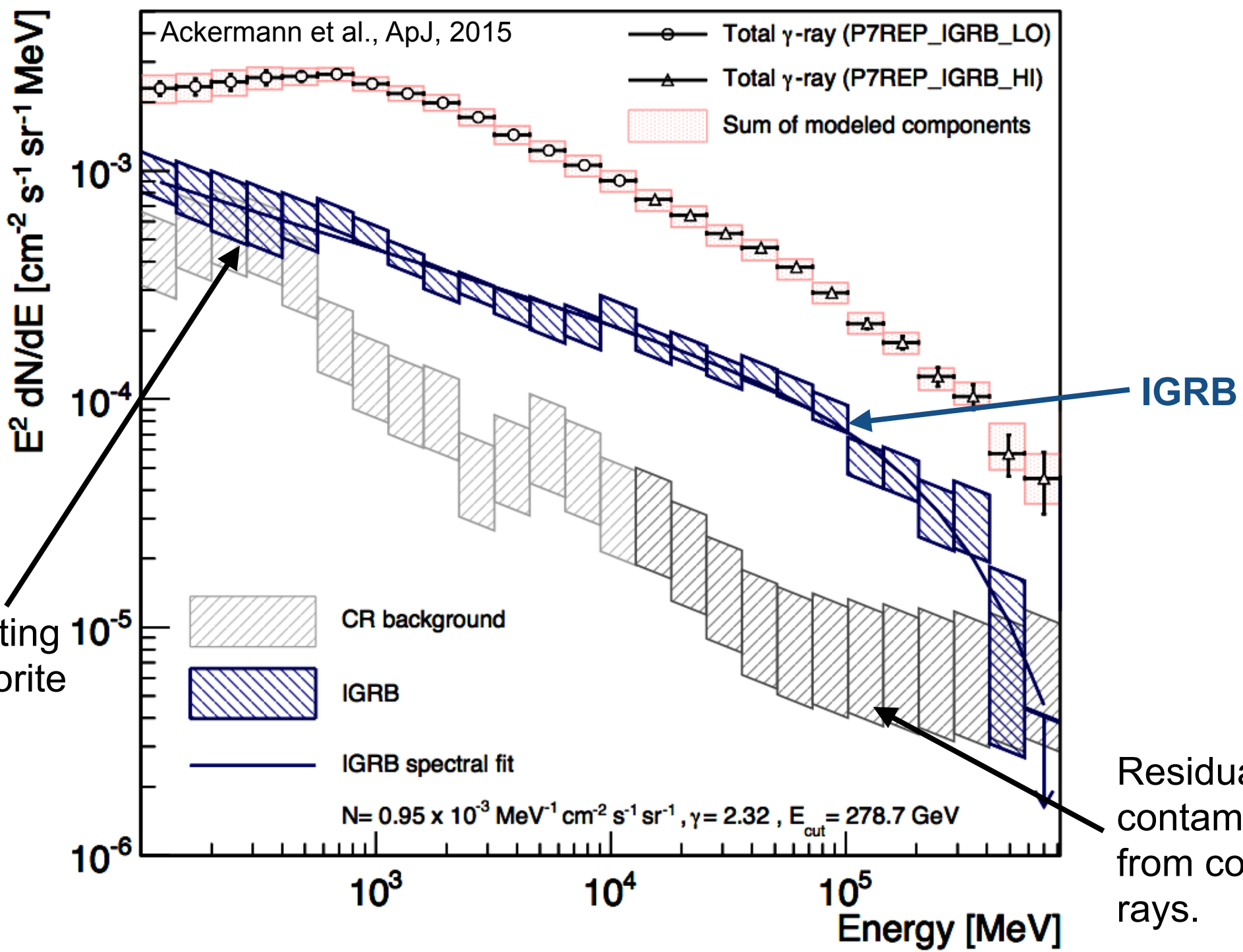
# Backgrounds in the MeV regime



- > Ratio between cosmic photons and backgrounds improves towards lower energies
- > Still efficient rejection of charged particle backgrounds necessary.

# Cosmic-ray contamination in high-purity event class

> Effective contamination from mis-classified CRs in comparison to IGRB intensity



Positrons annihilating in the micro-meteorite shield of the LAT: "irreducible background"

IGRB

Residual contamination from cosmic rays.

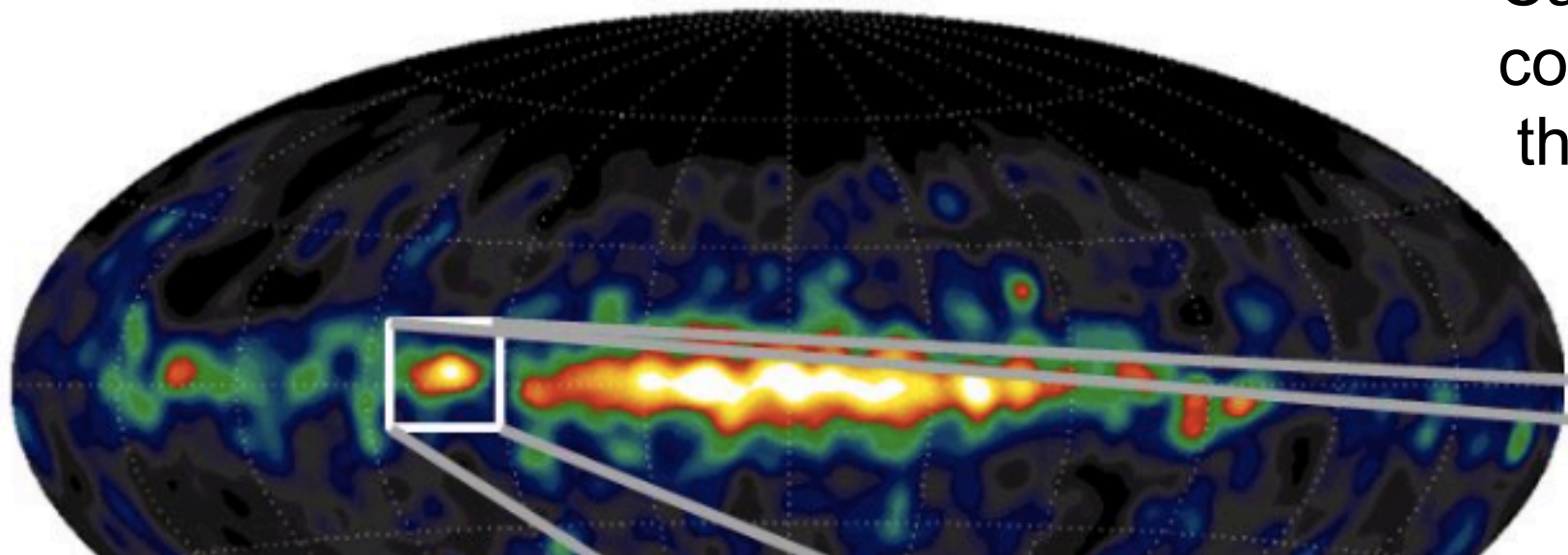


# EGB measurement and angular resolution

Improved angular resolution will help to:

- > Identify extragalactic sources
- > Calculate the contribution of the corresponding populations to the MeV EGB

COMPTEL 1-30 MeV



e-ASTROGAM (1-30 MeV)

