Cosmic "Gamma-ray" Background Radiation

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- Cosmic ***GeV*** gamma-ray background
- Cosmic ***MeV*** gamma-ray background
- Cosmic ***TeV*** gamma-ray background
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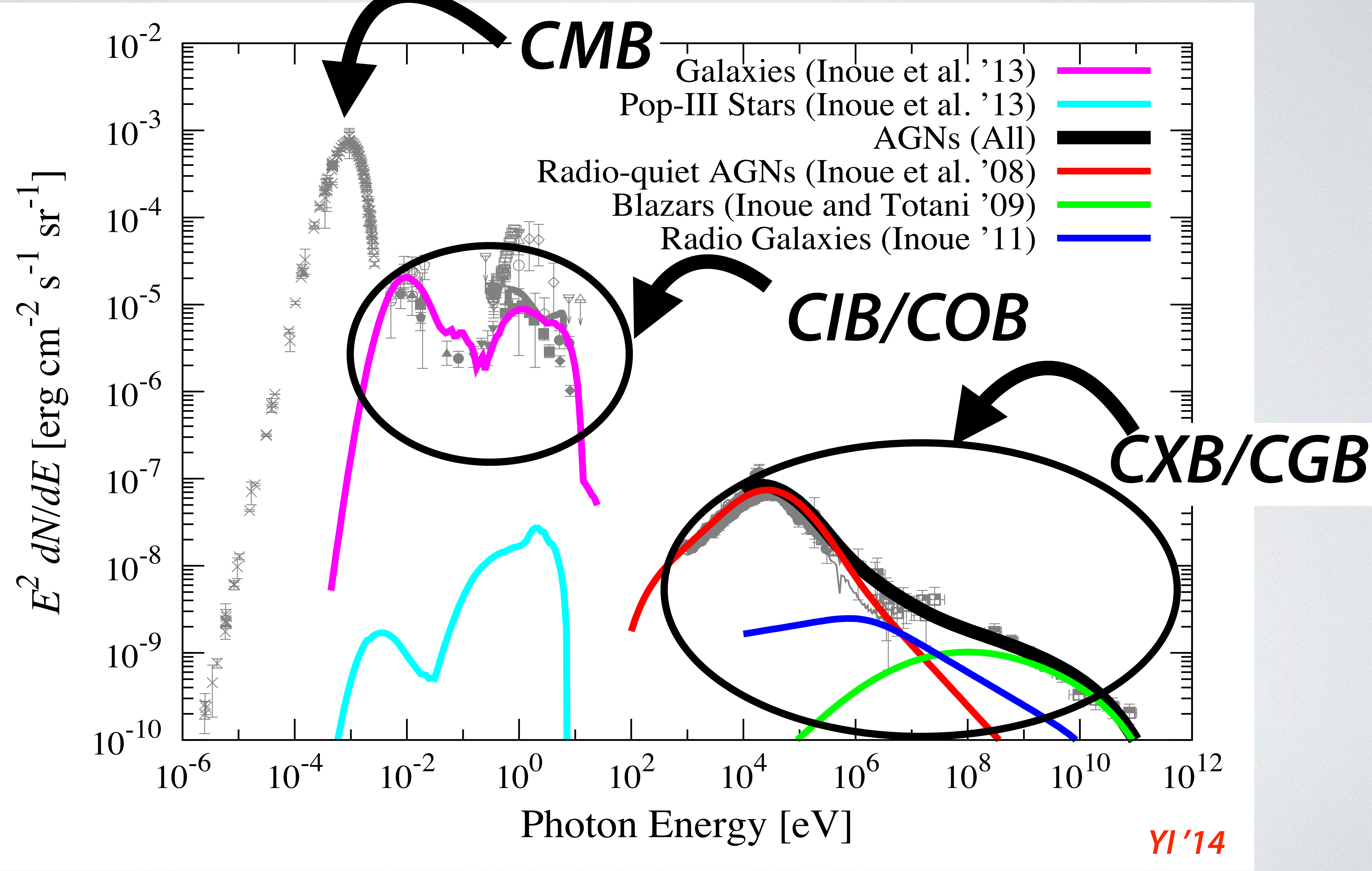
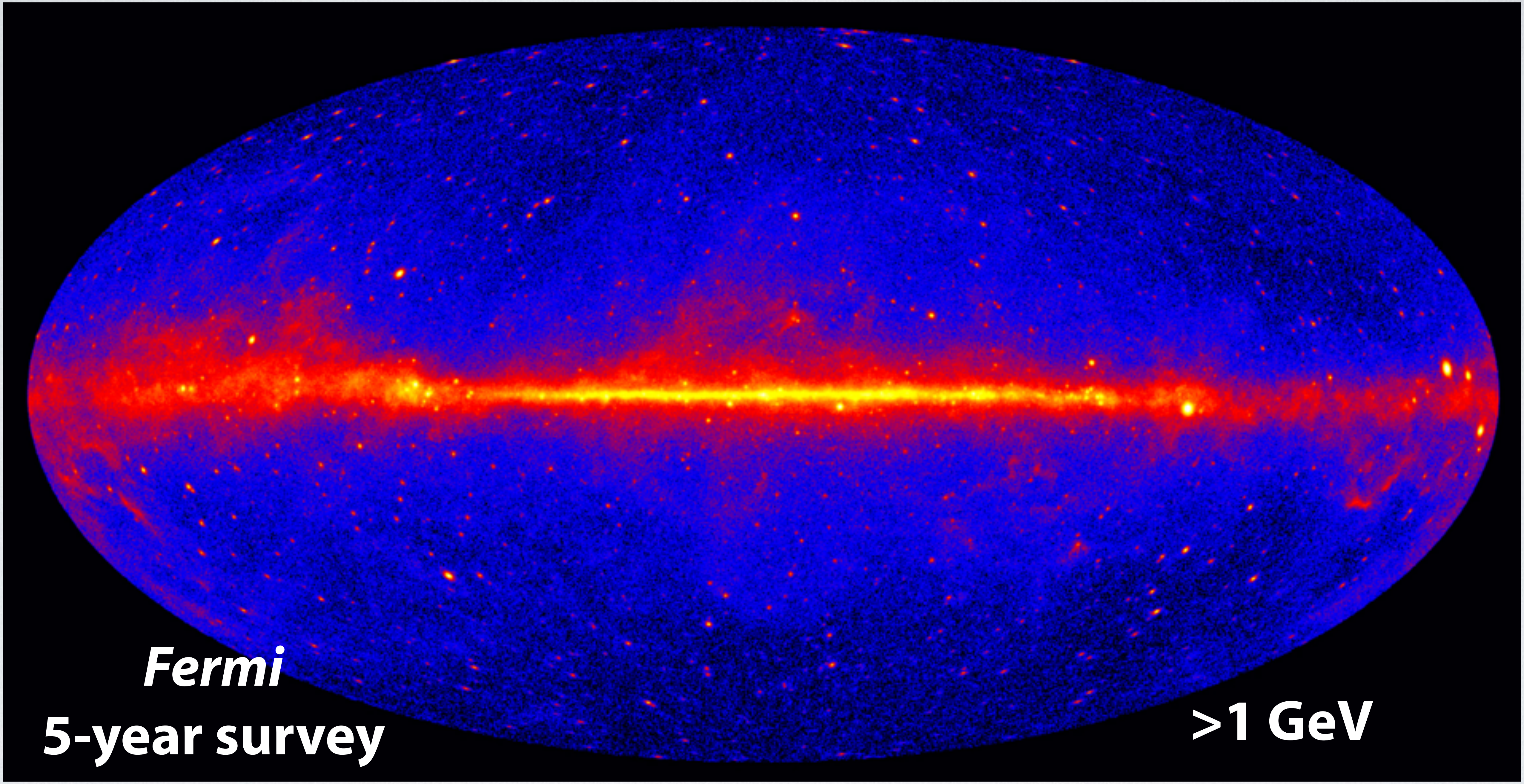
Cosmic Background Radiation Spectrum

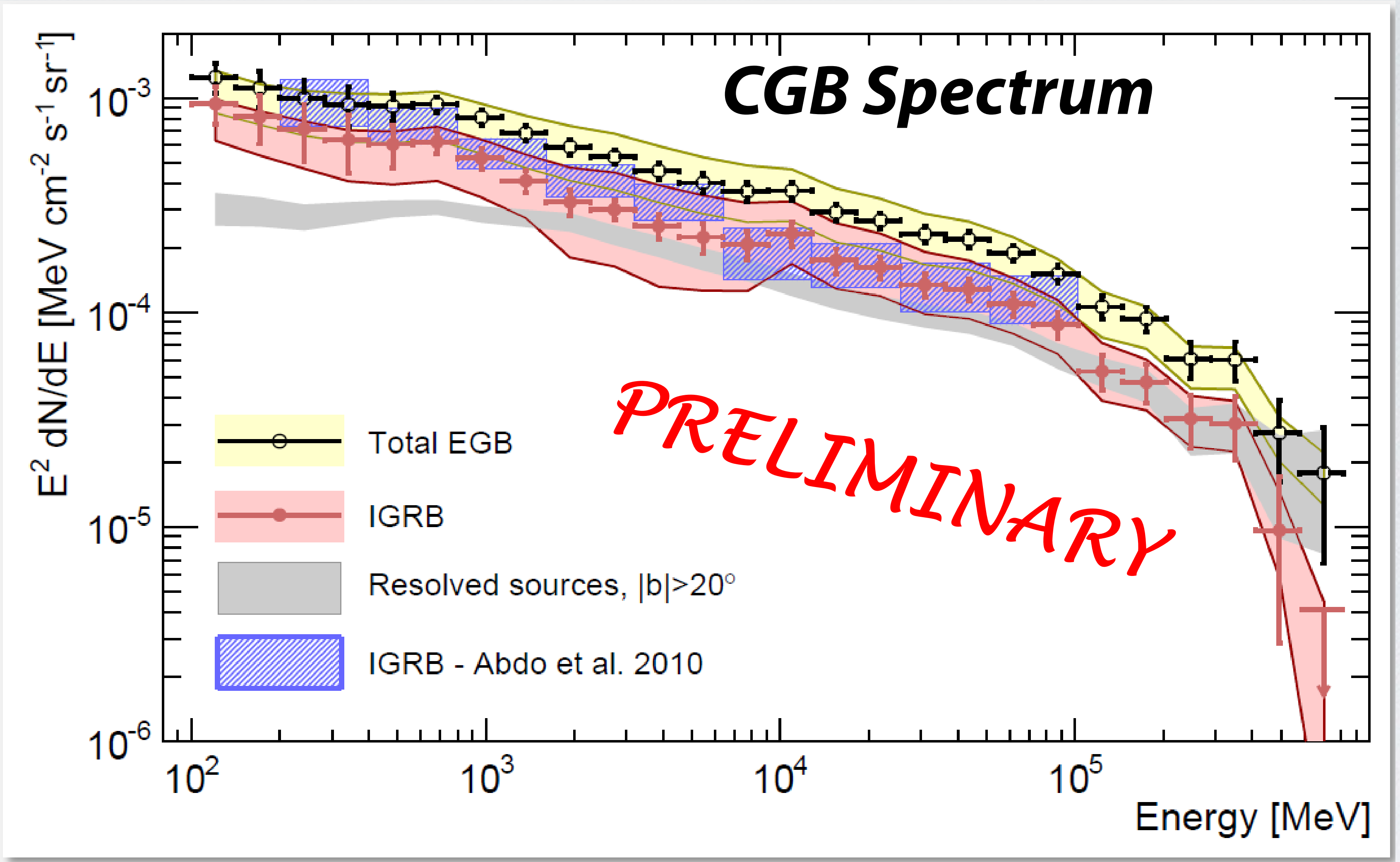


Cosmic Gamma-ray Background



- Numerous sources are buried in the cosmic gamma-ray background (CGB).

Cosmic Gamma-ray Background Spectrum at >0.1 GeV

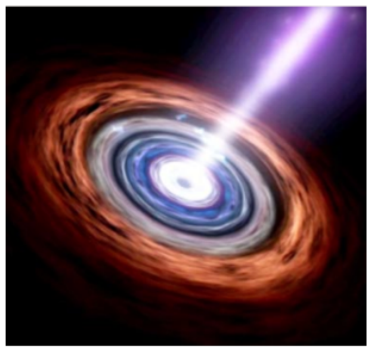


Ackerman+'15

- Softening around ~250 GeV.
- Fermi has resolved 30% of the CGB at ~1 GeV and more at higher energies.

Possible Origins of CGB at GeV

Unresolved sources



Blazars

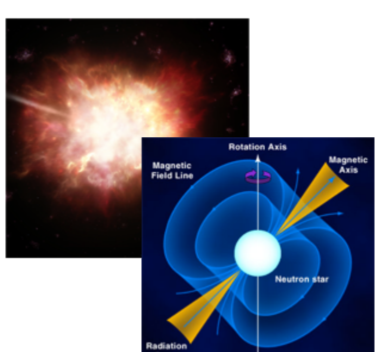
Dominant class of LAT extra-galactic sources. Many estimates in literature. EGB contribution ranging from 20% - 100%

Non-blazar active galaxies

27 sources resolved in 2FGL ~ 25% contribution of radio galaxies to EGB expected. (Inoue 2011)

Star-forming galaxies

Several galaxies outside the local group resolved by LAT. Significant contribution to EGB expected. (e.g. Pavlidou & Fields, 2002)



GRBs

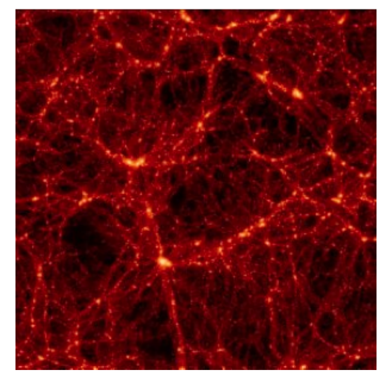
High-latitude pulsars

small contributions expected. (e.g. Dermer 2007, Siegal-Gaskins et al. 2010)

Diffuse processes

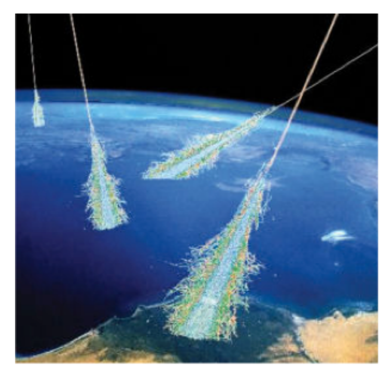
Intergalactic shocks

widely varying predictions of EGB contribution ranging from 1% to 100% (e.g. Loeb & Waxman 2000, Gabici & Blasi 2003)



Dark matter annihilation

Potential signal dependent on nature of DM, cross-section and structure of DM distribution (e.g. Ullio et al. 2002)



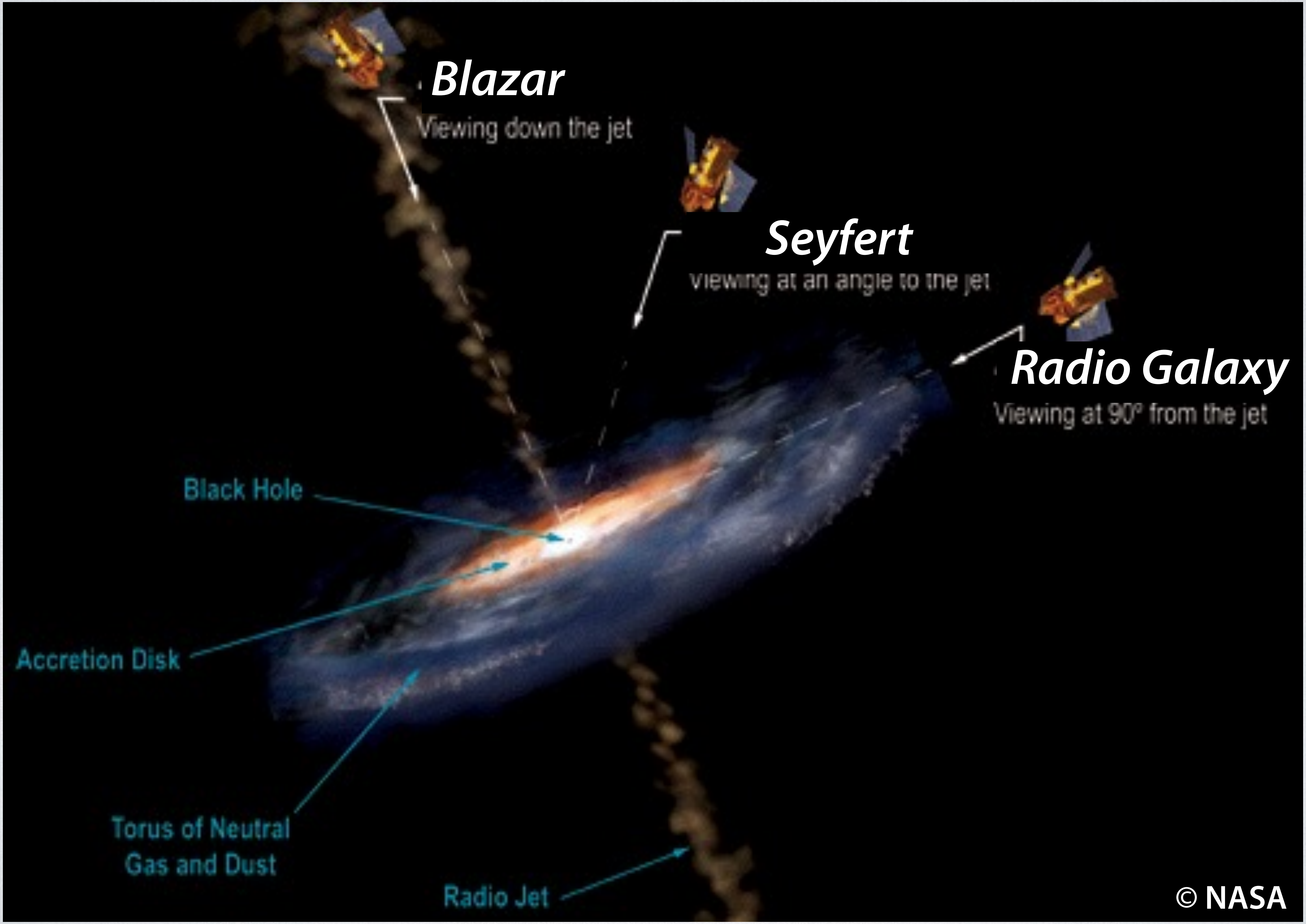
Interactions of UHE cosmic rays with the EBL

dependent on evolution of CR sources, predictions varying from 1% to 100 % (e.g. Kalashev et al. 2009)

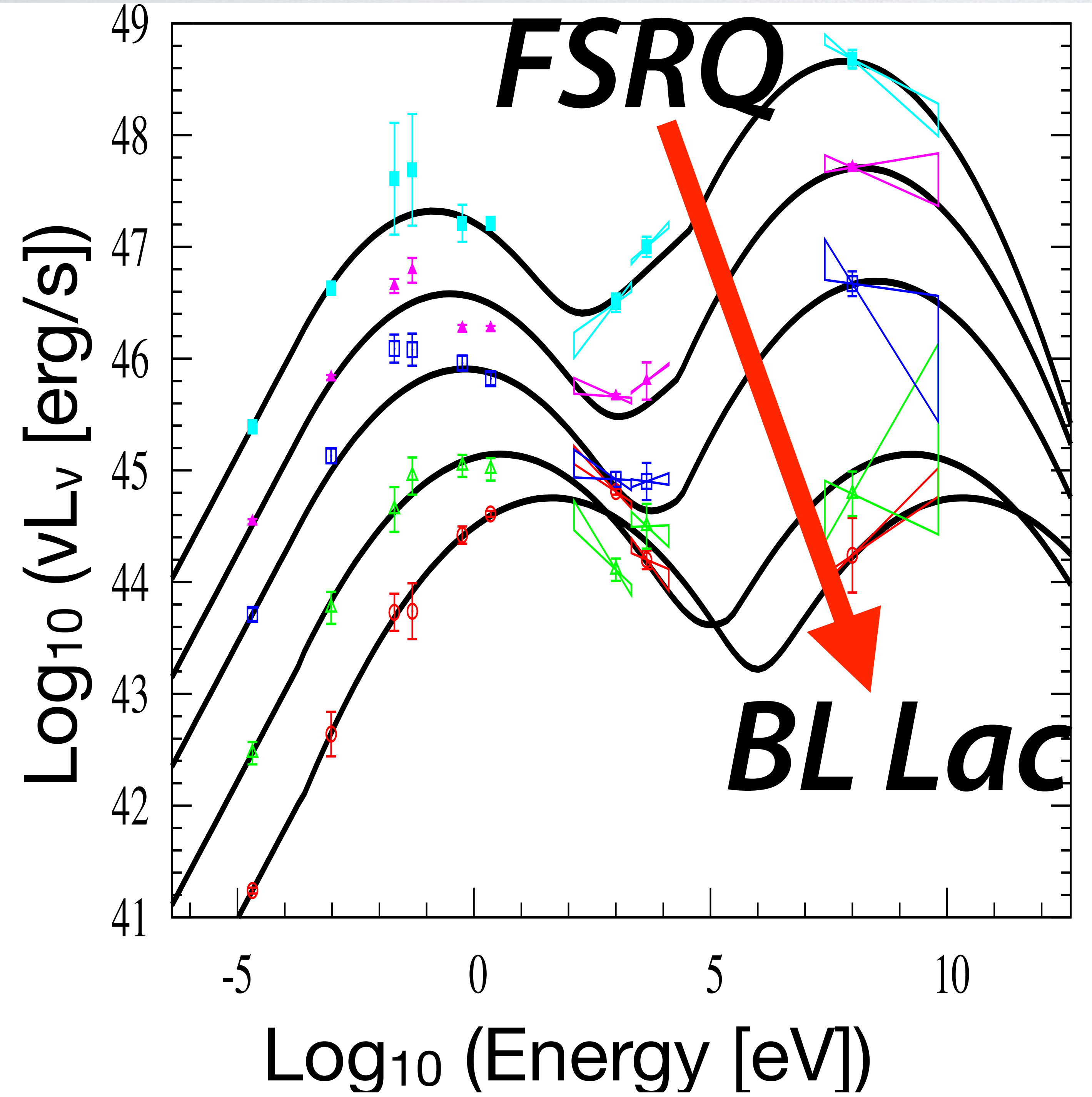
Extremely large galactic electron halo (Keshet et al. 2004)

CR interaction in small solar system bodys (Moskalenko & Porter 2009)

Active Galactic Nuclei (AGNs)



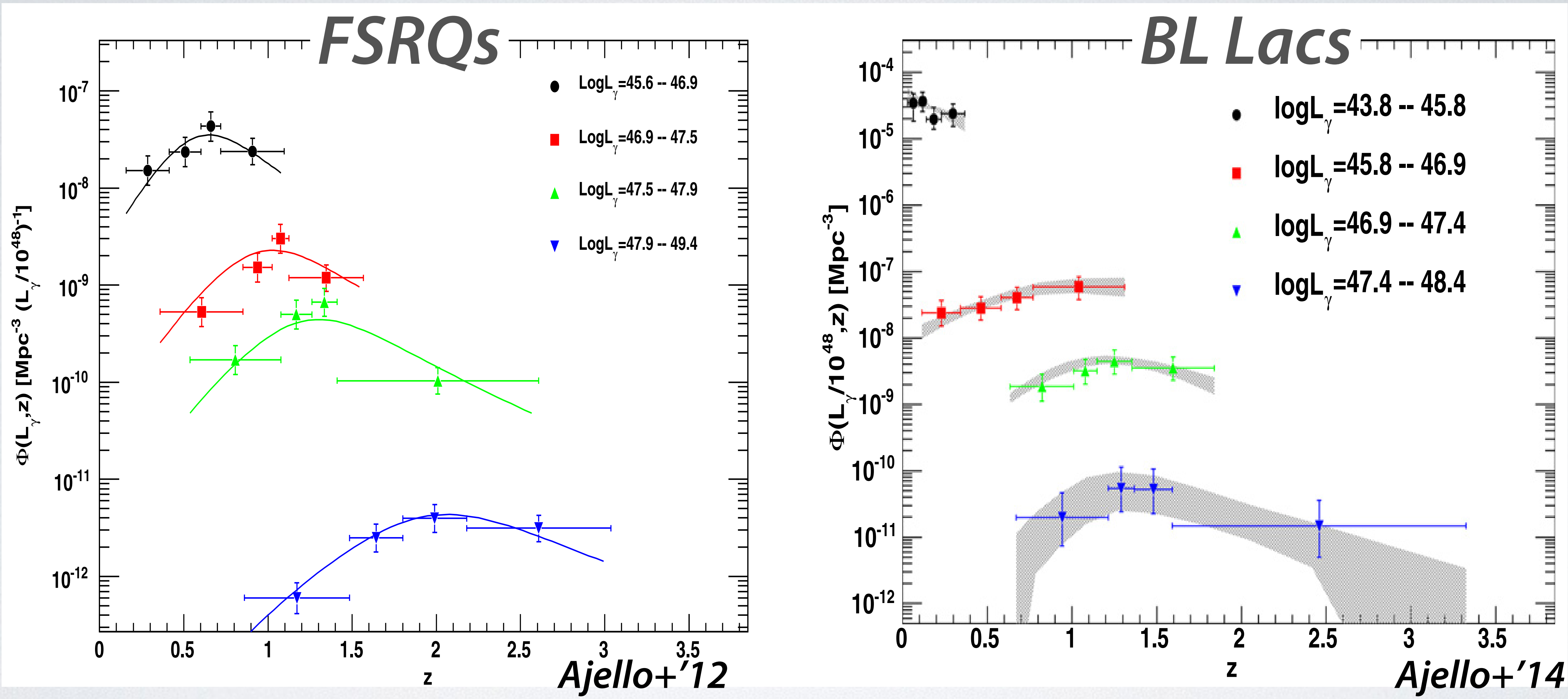
Typical Spectra of Blazars



Fossati+'98, Kubo+'98,
YI & Totani '09

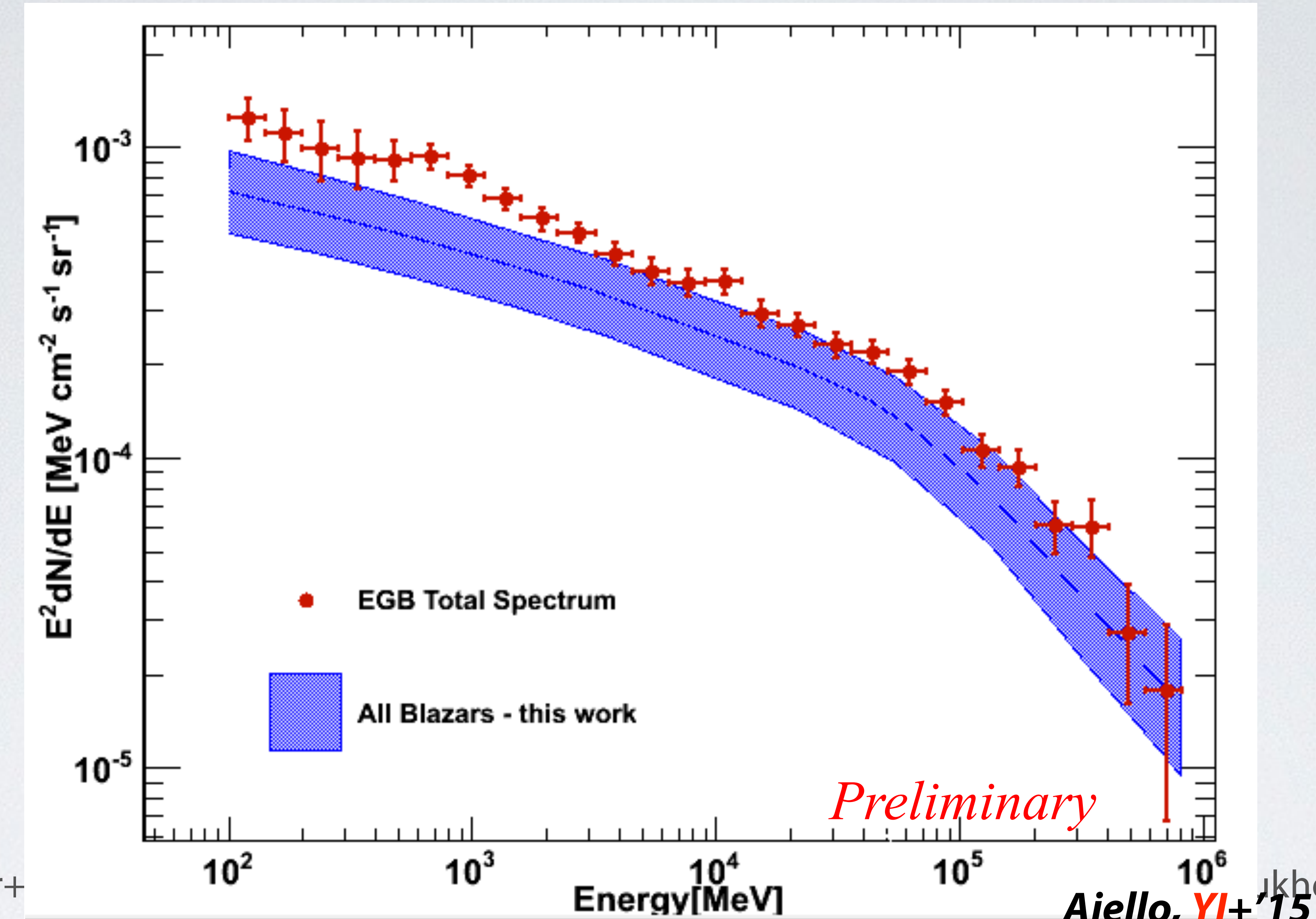
- Non-thermal emission from radio to gamma-ray
- Two peaks
  - Synchrotron
  - Inverse Compton
- Luminous blazars (Flat Spectrum Radio Quasars: FSRQs) tend to have lower peak energies (Fossati+'98, Kubo+'98)

Cosmological Evolution of Blazars



- FSRQs, luminous BL Lacs show positive evolution.
- low-luminosity BL Lacs show negative evolution unlike other AGNs.

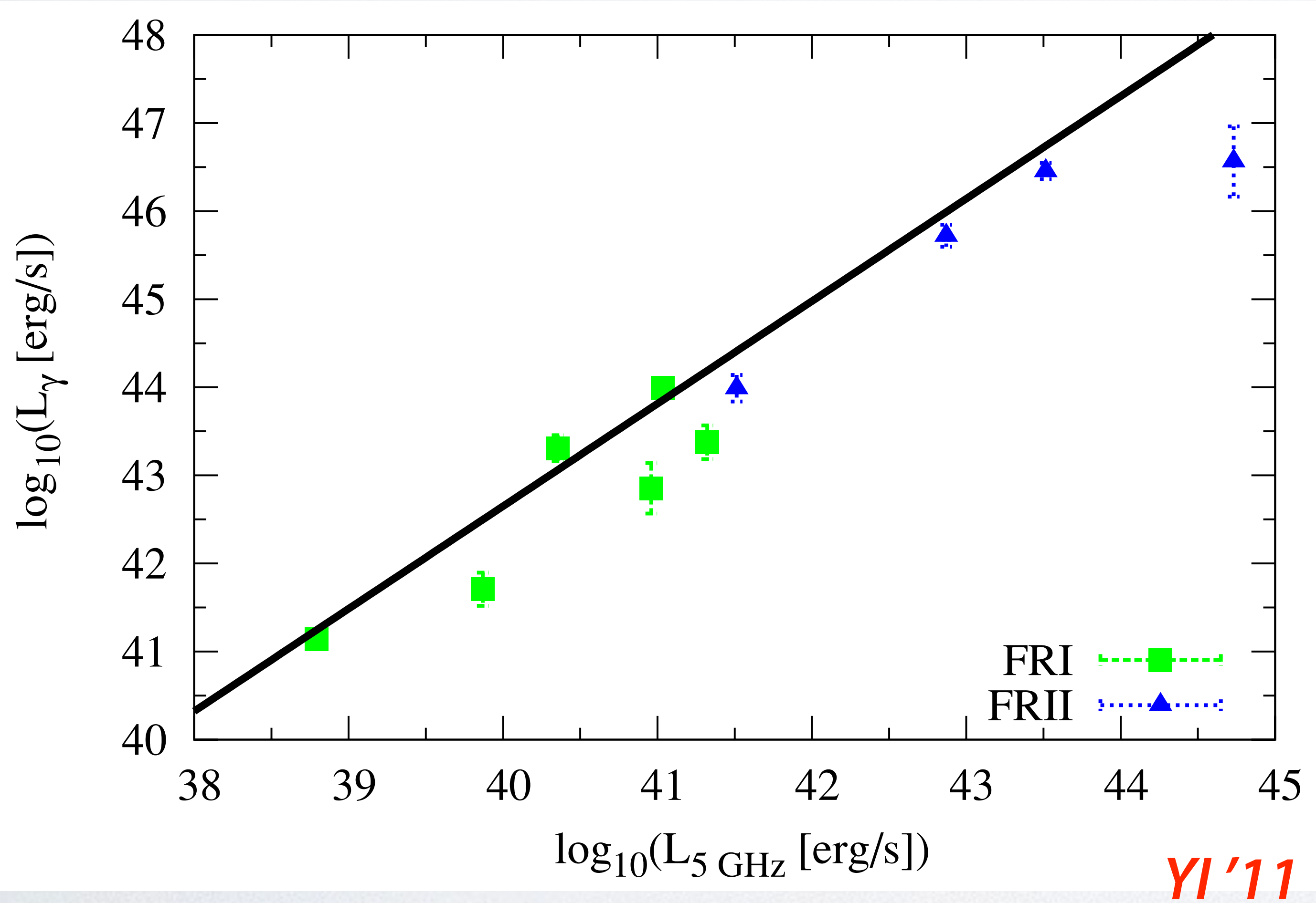
Blazar contribution to CGB

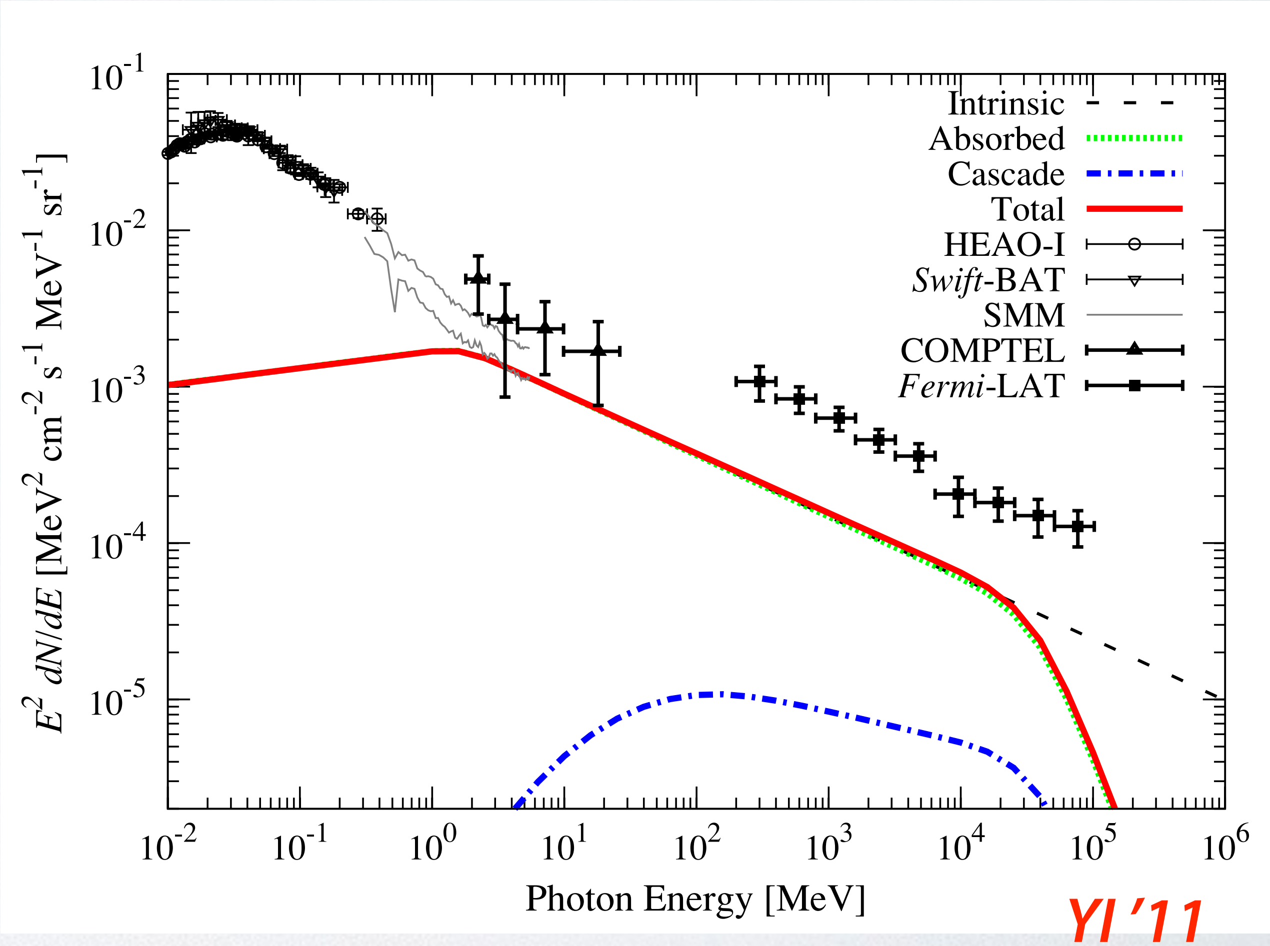


- Padovani+'93; Stecker+ … ukherjee '98; Mukherjee & Chiang '99; Muecke & Pohl '00; Narumoto & Totani '06; Giommi +'06; Dermer '07; Pavlidou & Venters '08; Kneiske & Mannheim '08; Bhattacharya +'09; ***YI & Totani '09***; Abdo+'10; Stecker & Venters '10; Cavadini+'11, Abazajian+'11, Zeng+'12, Ajello+'12, Broderick+'12, Singal+'12, Harding & Abazajian '12, Di Mauro+'14, Ajello+'14,Singal+'14, Ajello, YI, +'15,

- Blazars explain ~50% of CGB at 0.1-100 GeV.
  - explain ~100% of CGB at >100 GeV.

Radio Galaxies

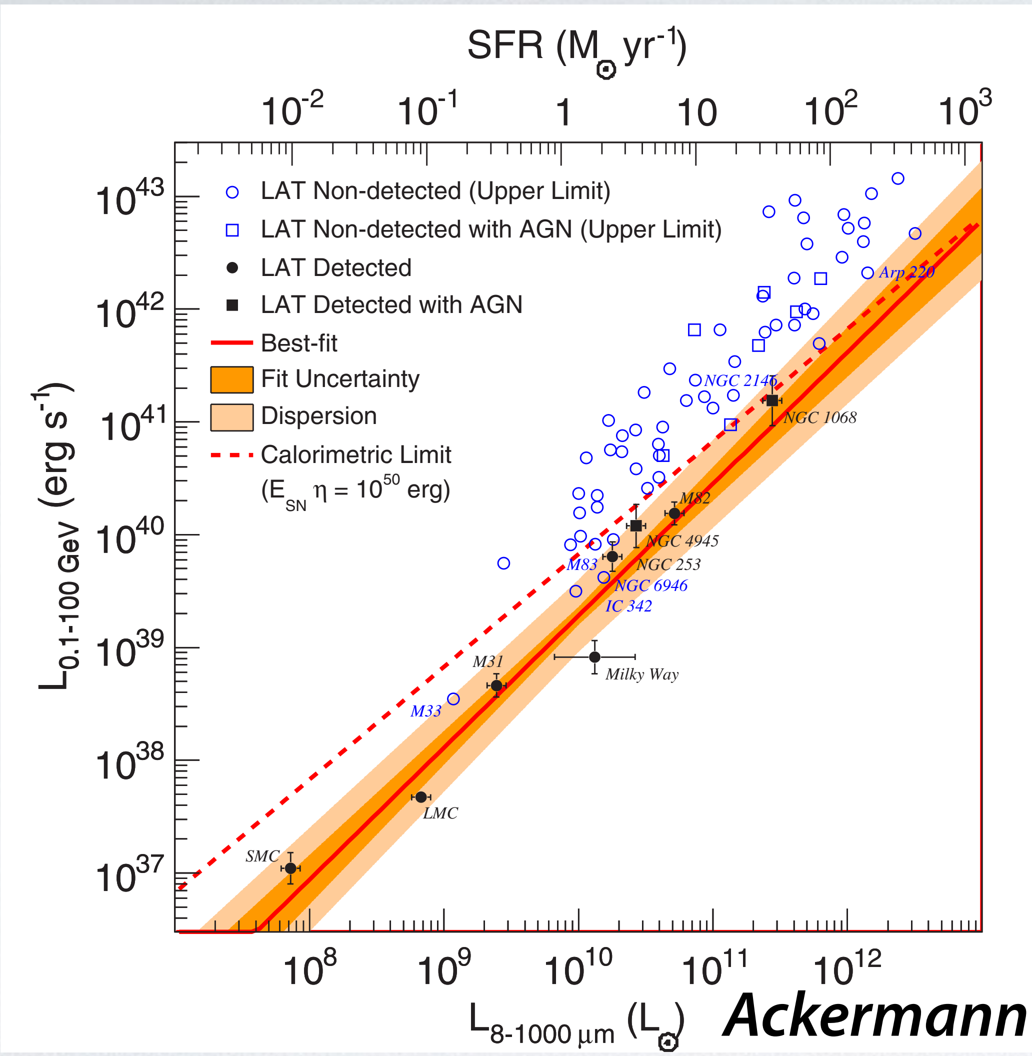




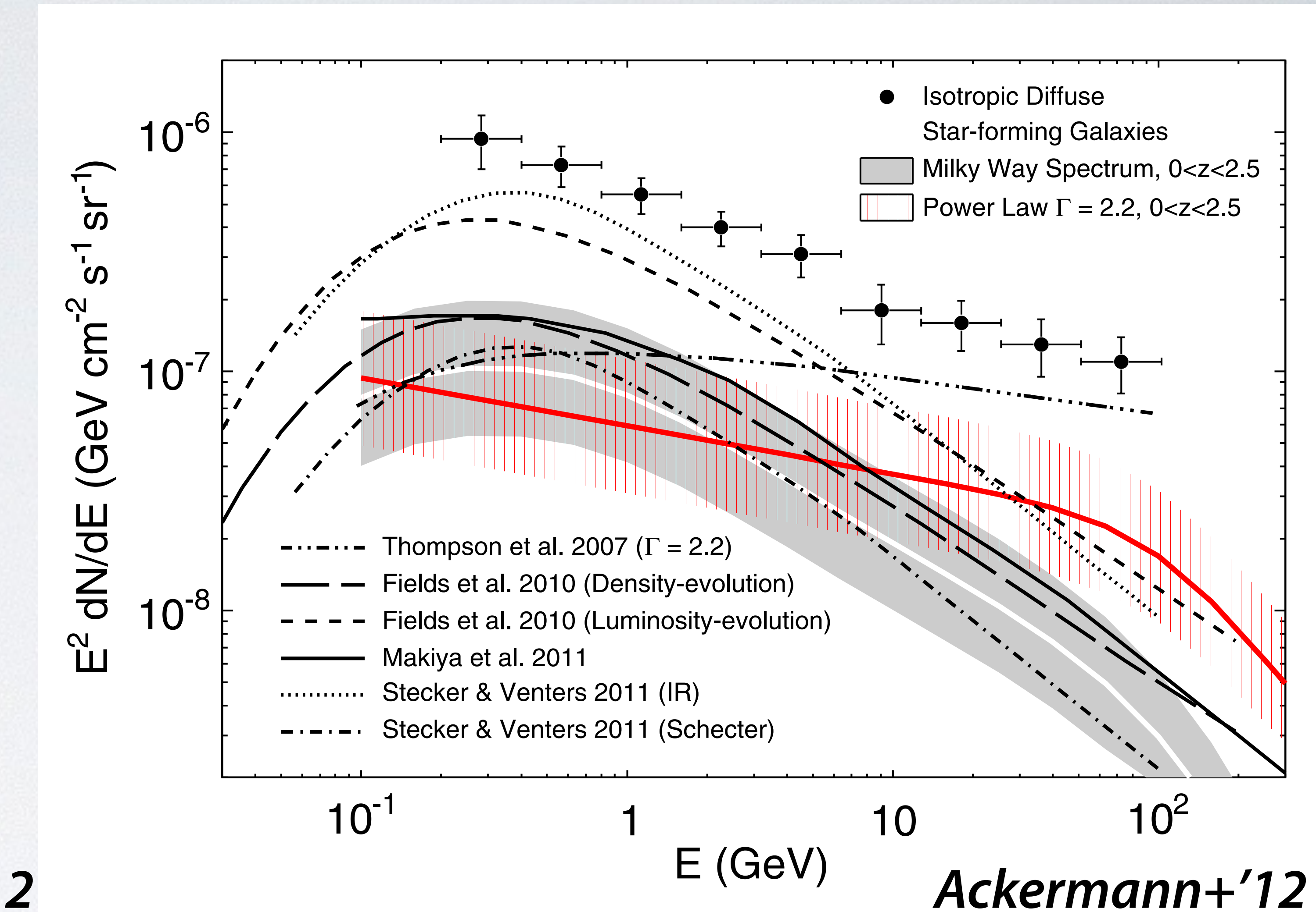
- Strong+'76; Padovani+'93; ***YI '11***; Di Mauro+'13; Zhou & Wang '13

- Use gamma-ray and radio luminosity correlation.
- ~20% of CGB at 0.1-100 GeV.
- But, only ~10 sources are detected by Fermi.

Star-forming Galaxies



Ackermann+'12



Ackermann+'12

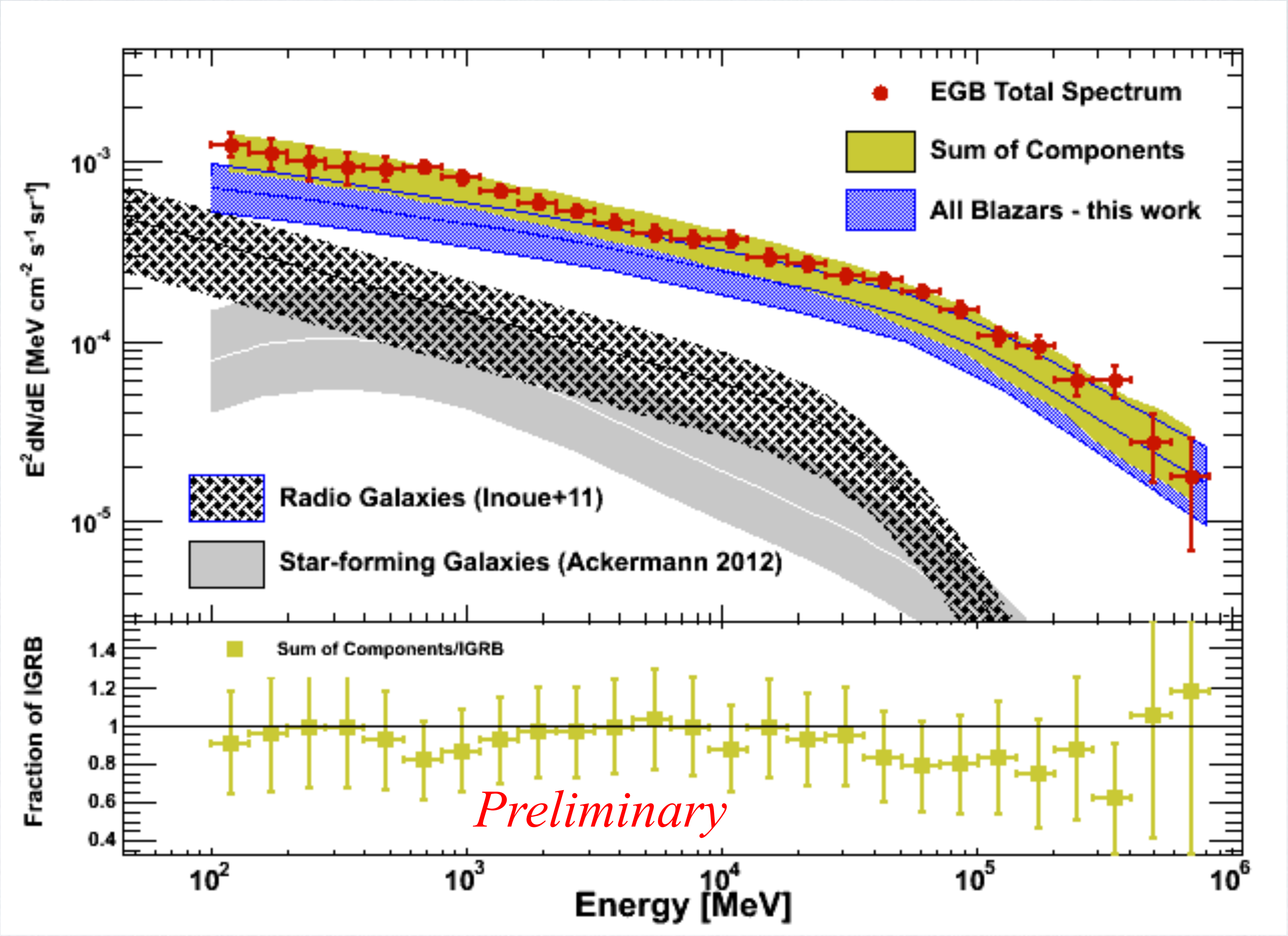
- Soltan '99; Pavlidou & Fields '02; Thompson +'07; Bhattacharya & Sreekumar 2009; Fields et al. 2010; Makiya et al. 2011; Stecker & Venters 2011; Lien+'12, Ackermann+'12; Lacki+'12; Chakraborty & Fields '13; Tamborra+'14

- Use gamma-ray and infrared luminosity correlation

- ~10-30% of CGB at 0.1-100 GeV.

- But, only ~10 sources are detected by Fermi.

Components of Cosmic Gamma-ray Background



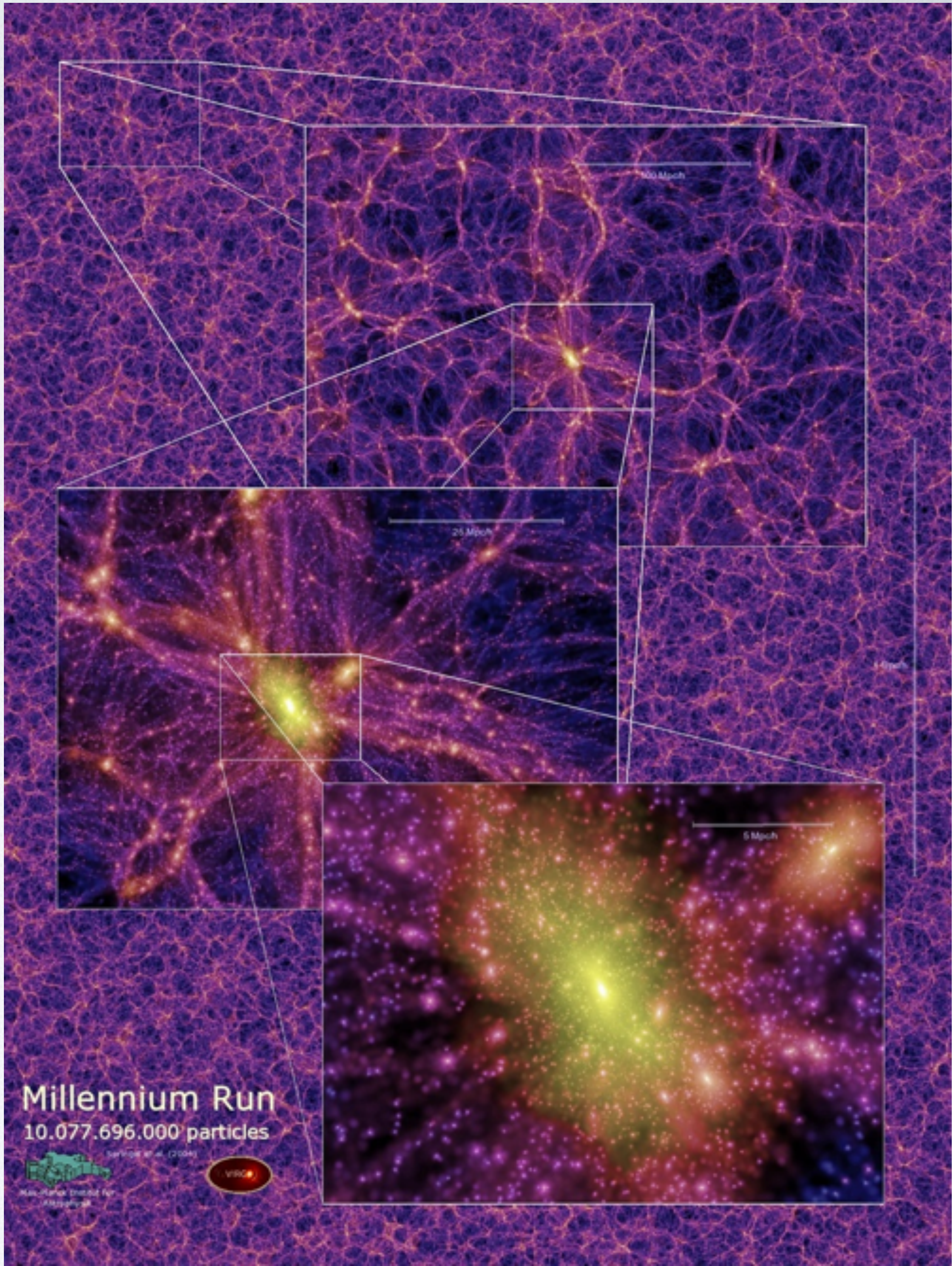
Ajello, YI +'15

- FSRQs (Ajello+'12), BL Lacs (Ajello+'14), Radio gals. (YI'11), & Star-forming gals. (Ackermann+'12) makes almost 100% of CGB from 0.1-1000 GeV.

Dark Matter Contribution to the CGB

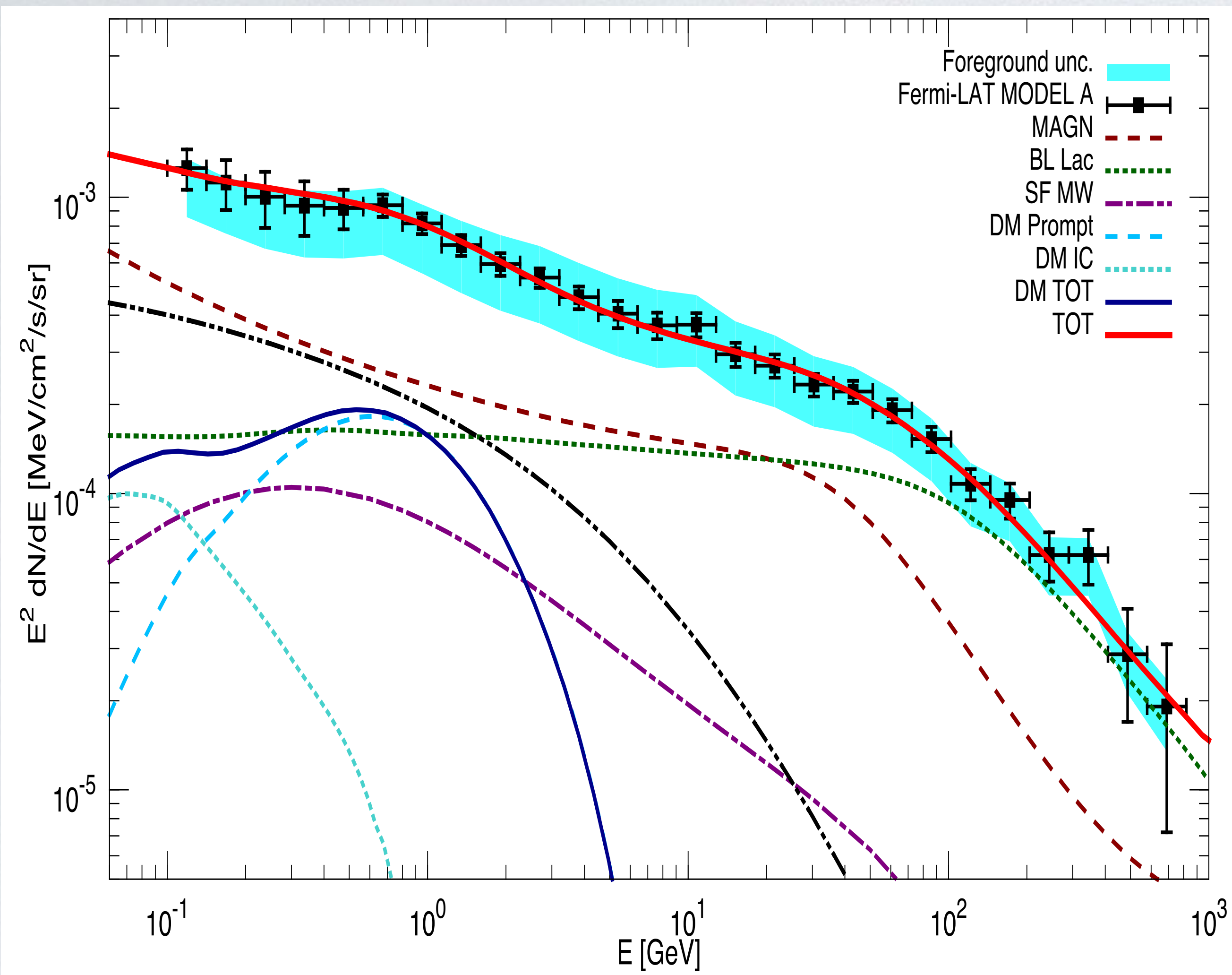
- Dark matter particles should have been annihilating/decaying since the beginning of the universe.
  - The annihilation flux depends on the square of density.

$$I_\gamma(\hat{n}) \propto \frac{\langle \sigma v \rangle}{m_\chi^2} \int d\chi \; \rho_\chi^2(\chi \hat{n})$$



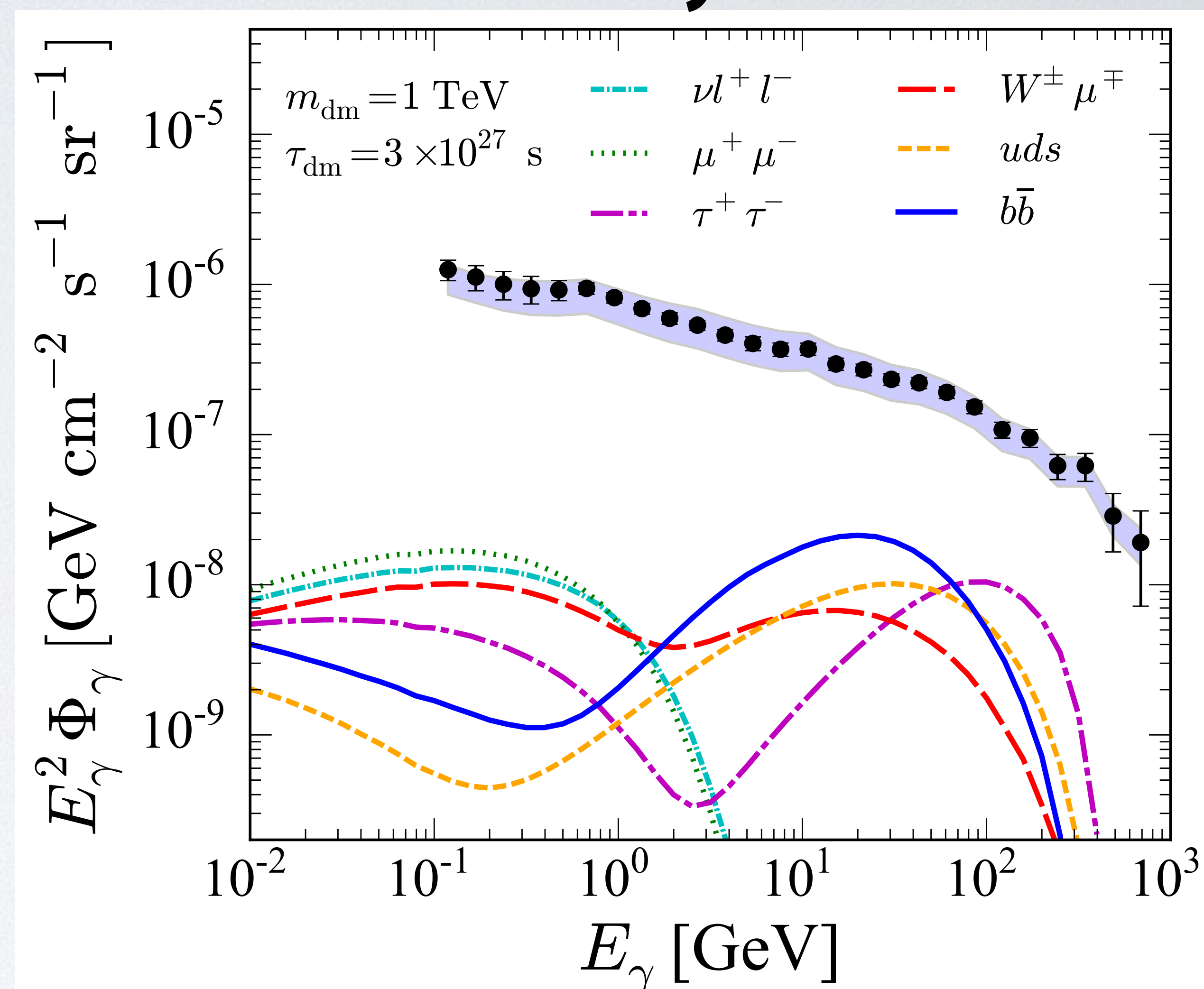
CGB spectrum from DM particles

Annihilation



Di Mauro+'15

Decay

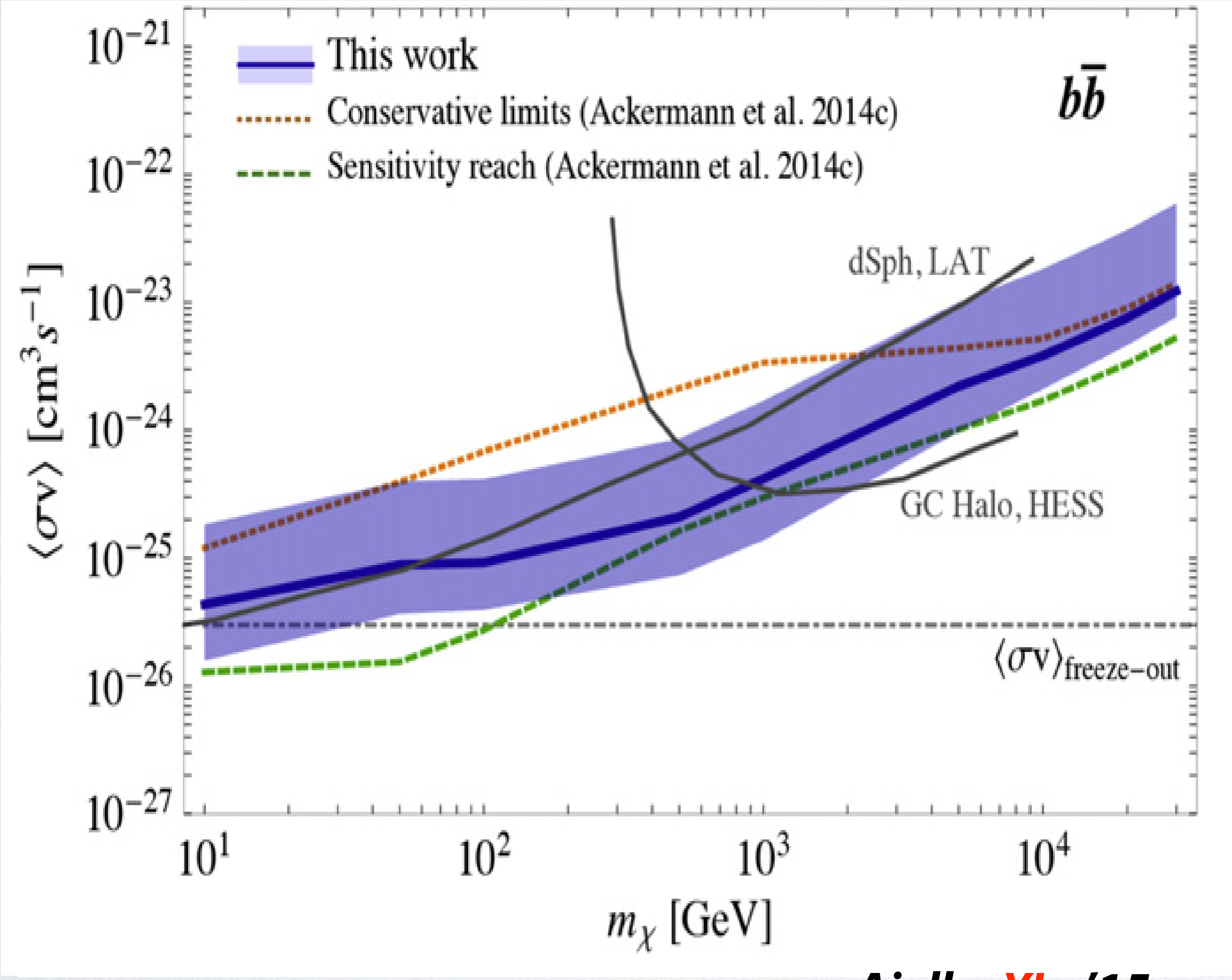


Ando & Ishiwata '15

- DM annihilation/decay creates a feature in the spectrum.

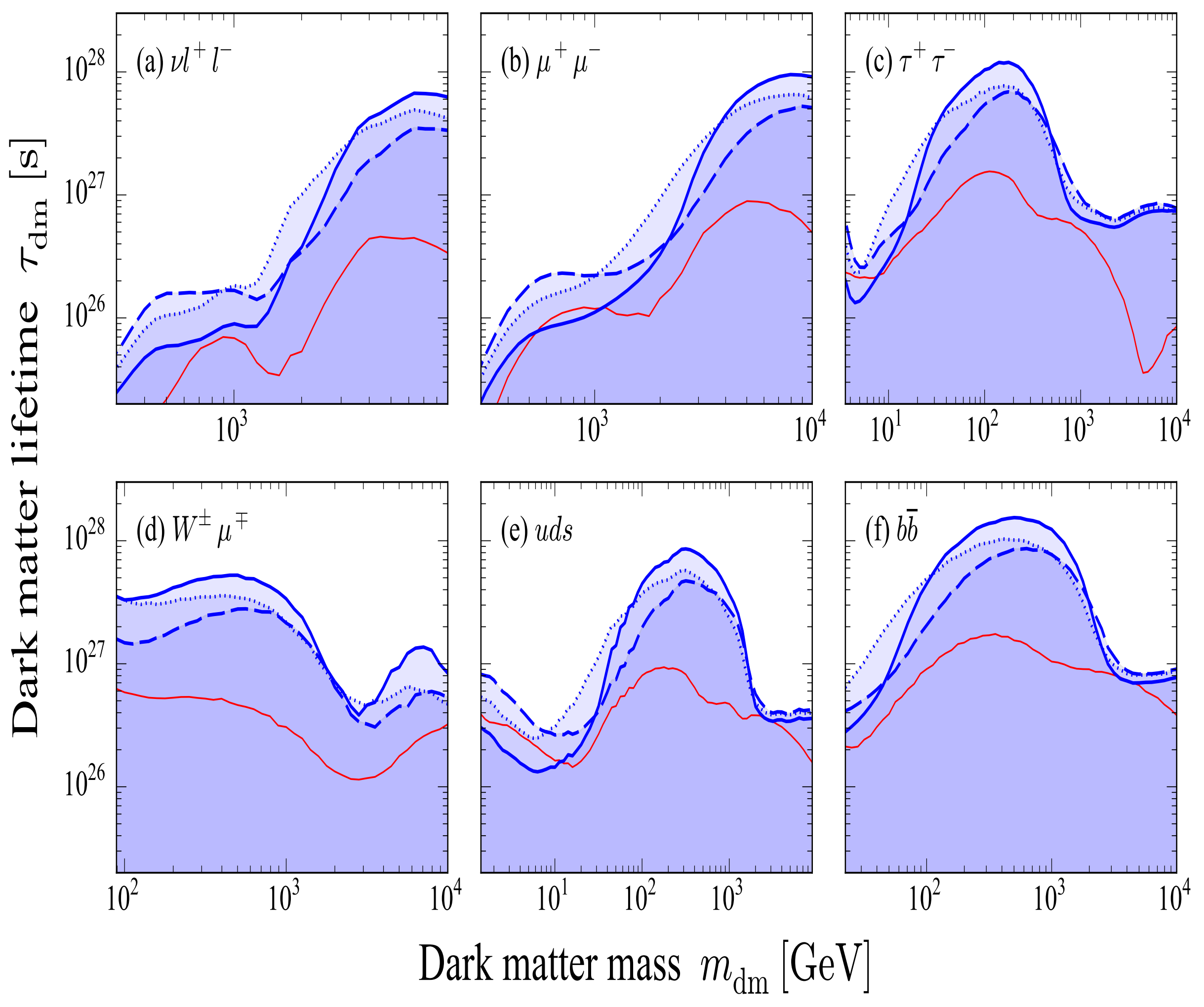
Constraints on DM parameters

Annihilation



Ajello, YI +'15

Decay



Ando & Ishiwata '15

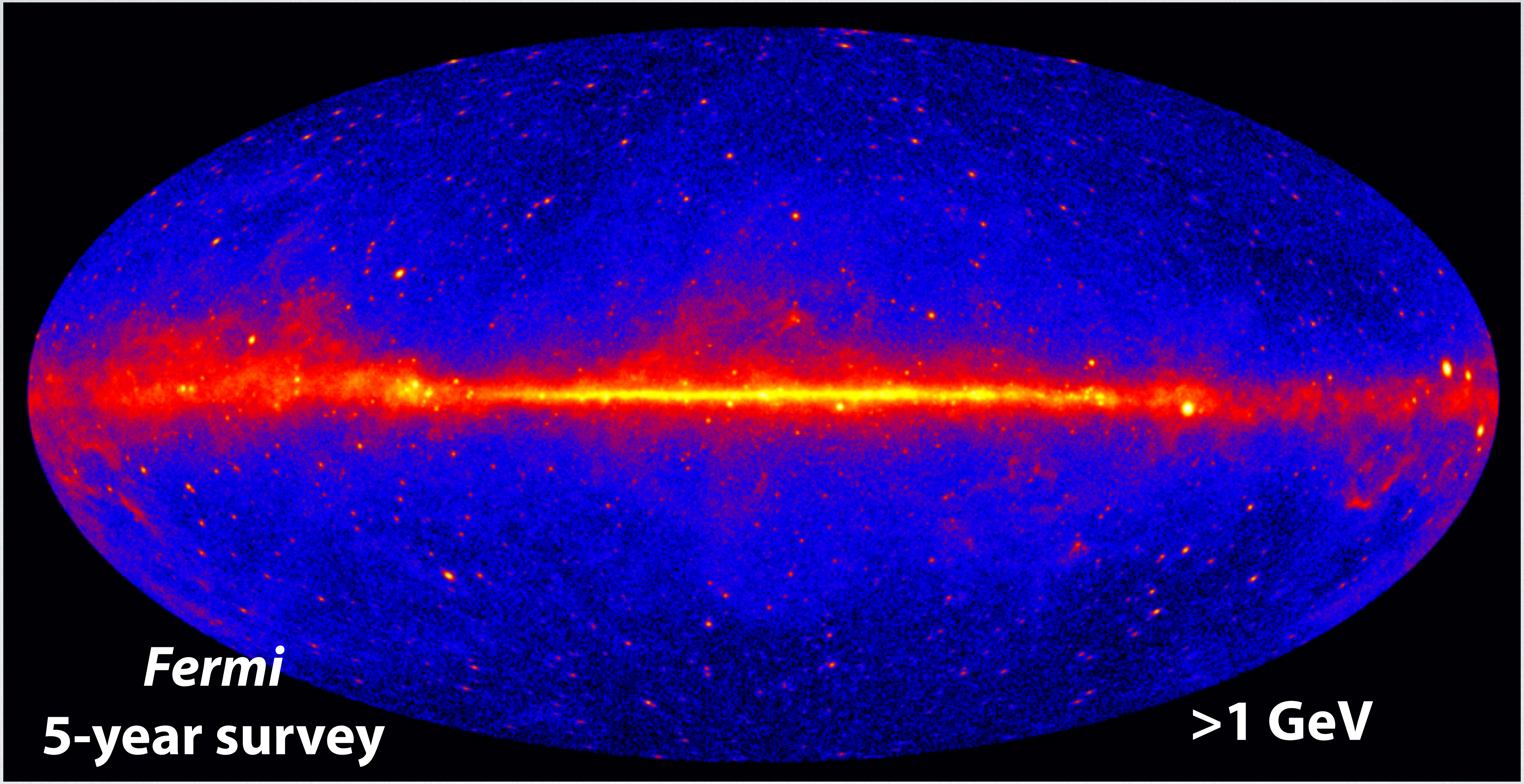
- Annihilation: comparable to dwarfs
- Decay: > 10^{27}s

Future CGB studies

- Cosmic ***MeV*** Gamma-ray Background
  - Origins are still unknown.
- Cosmic ***TeV*** Gamma-ray Background
  - Connection to the IceCube TeV-PeV neutrinos
- ***Anisotropy*** of Cosmic GeV Gamma-ray Background
  - Searching Dark Matter signature

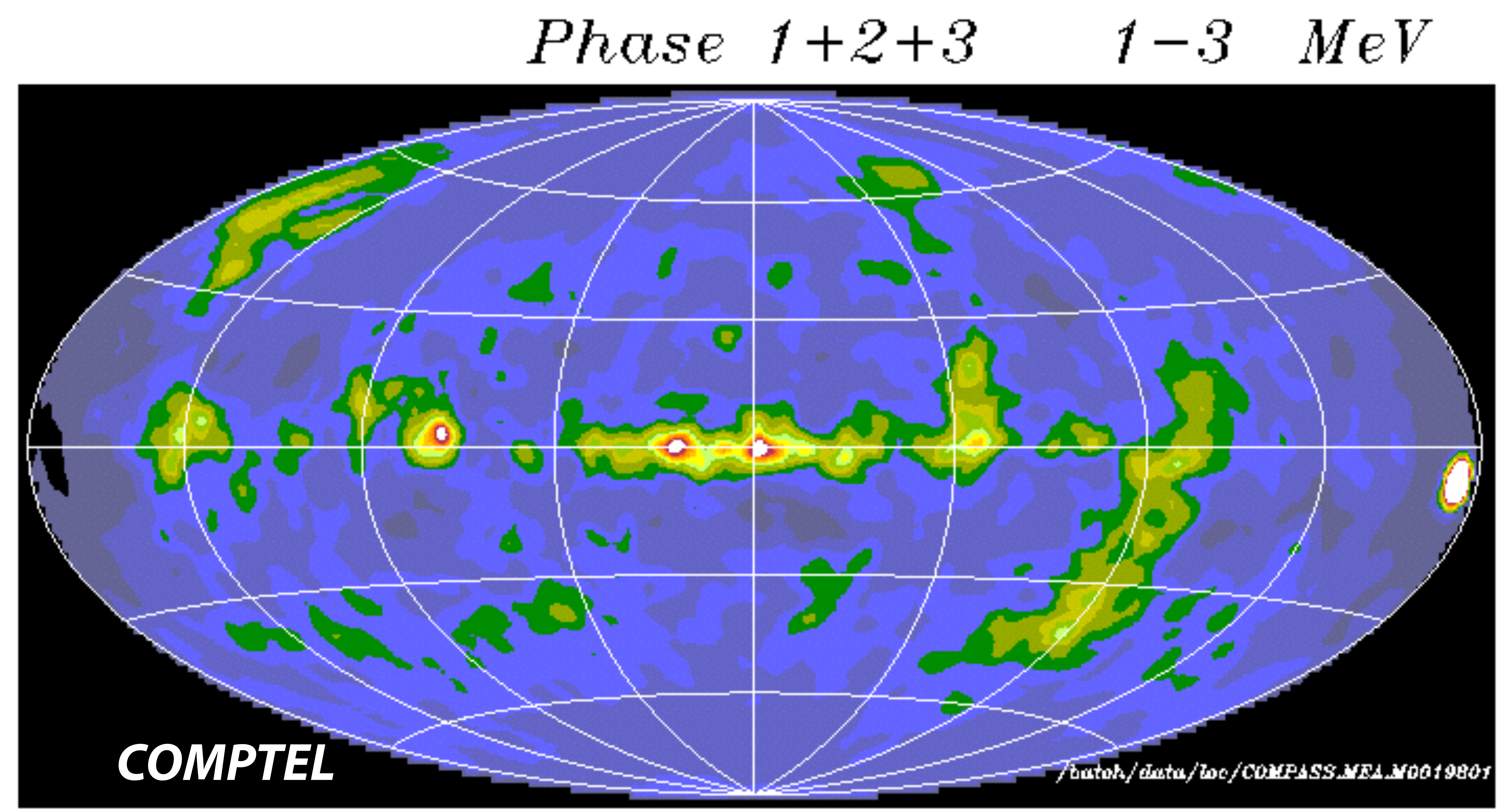
Cosmic MeV Gamma-ray Background

Cosmic Gamma-ray Background

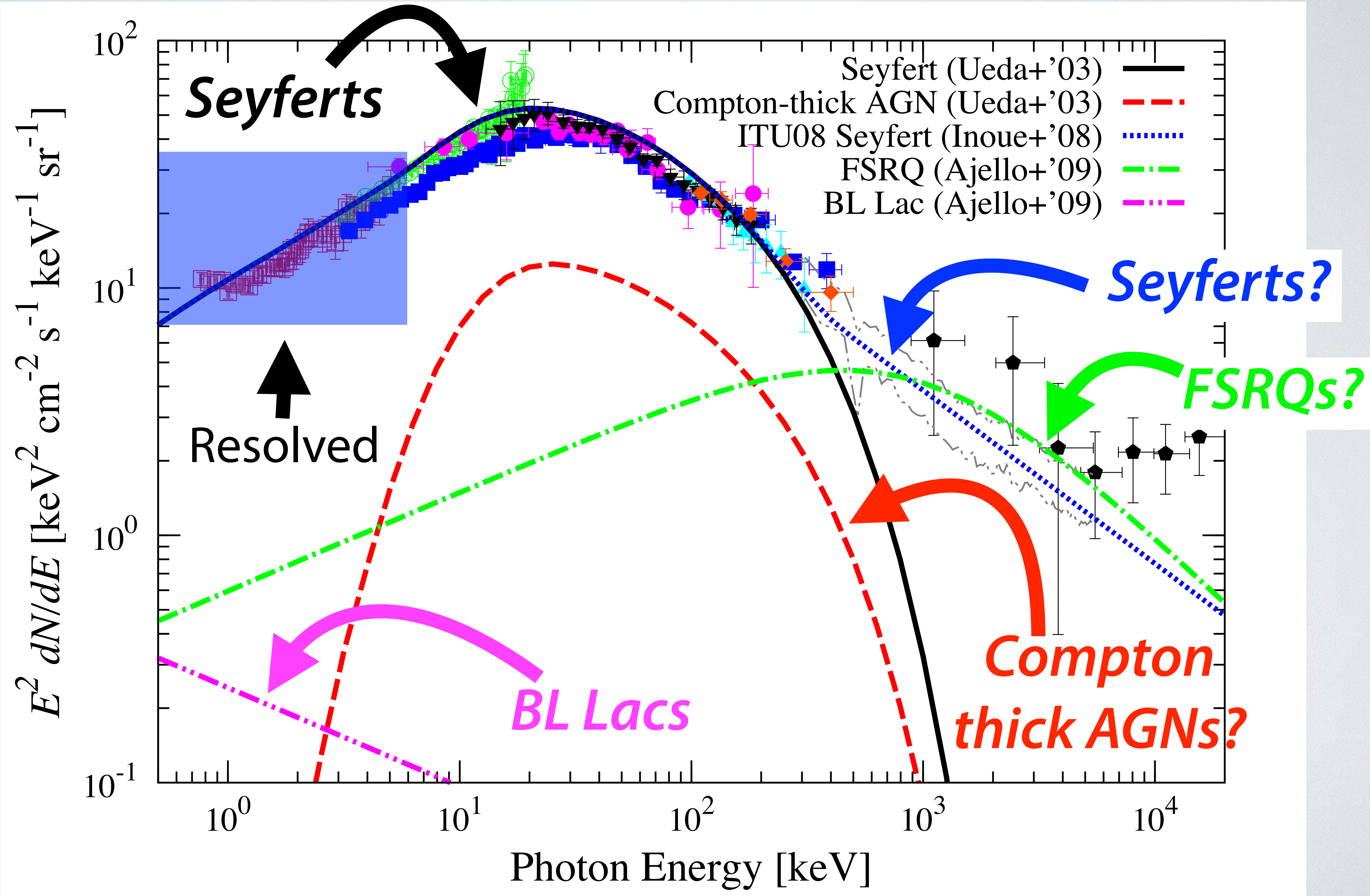


- Numerous sources are buried in the cosmic gamma-ray background (CGB).

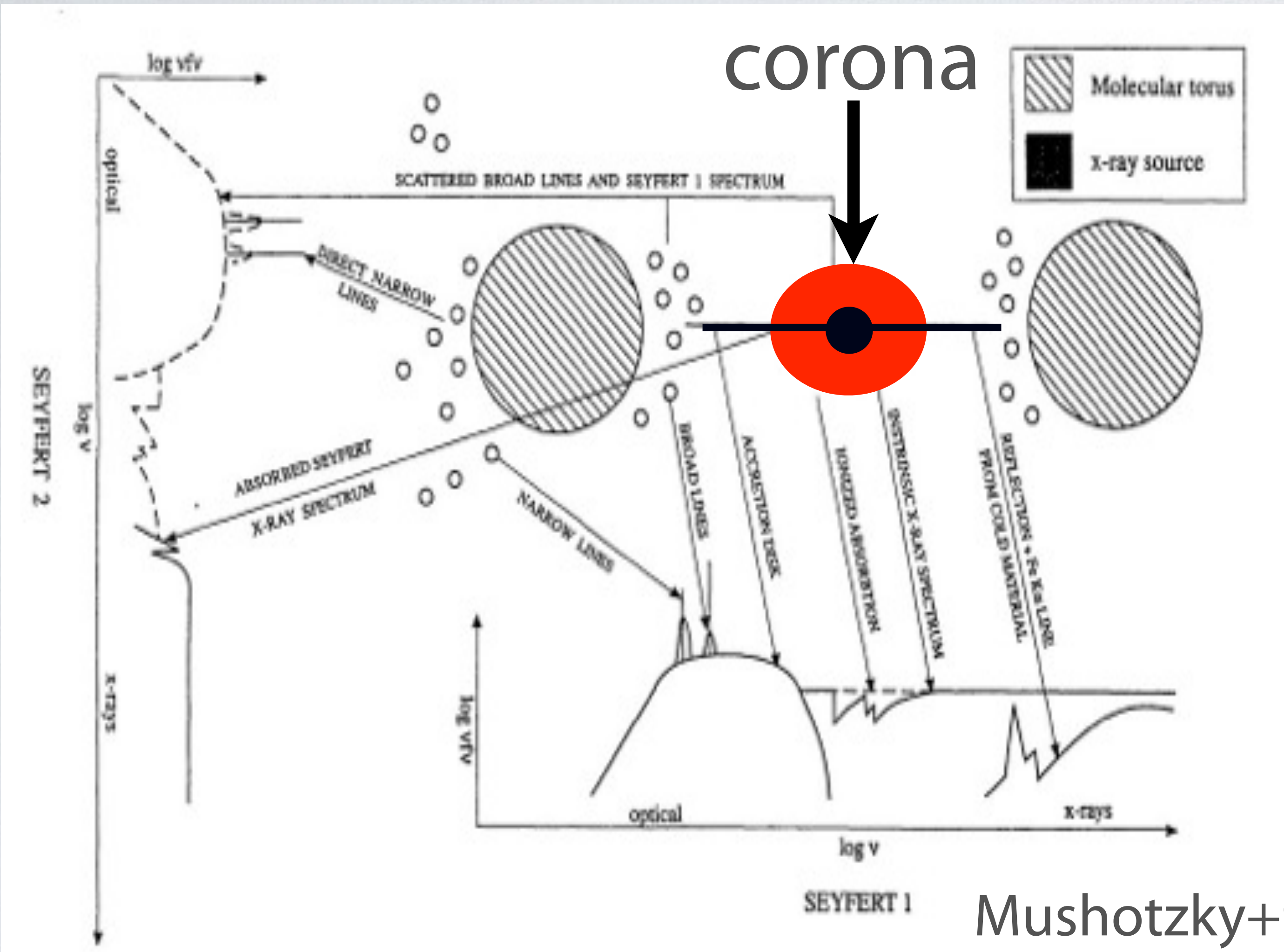
Sky in MeV Gamma rays

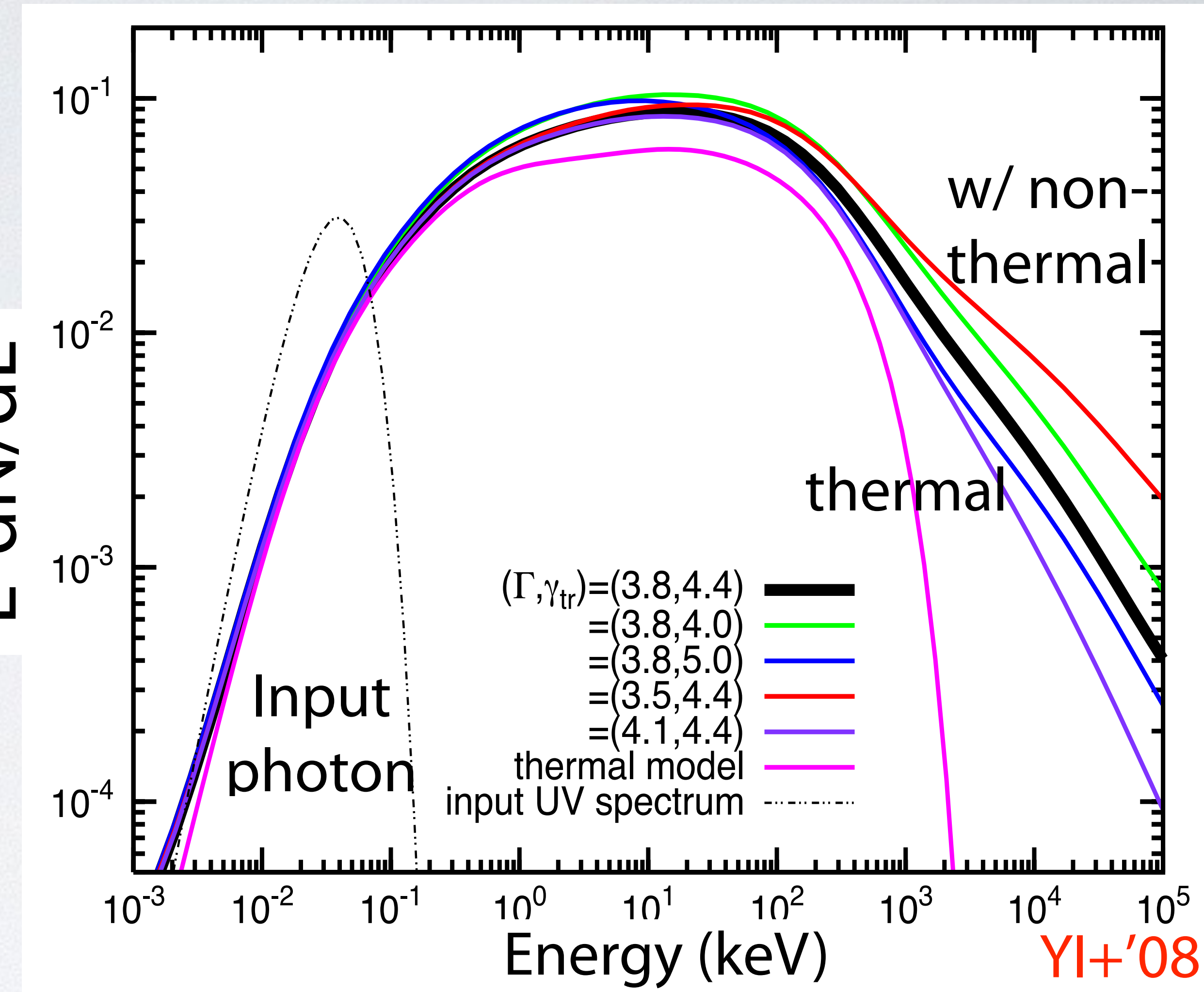


Cosmic X-ray/MeV Gamma-ray Background



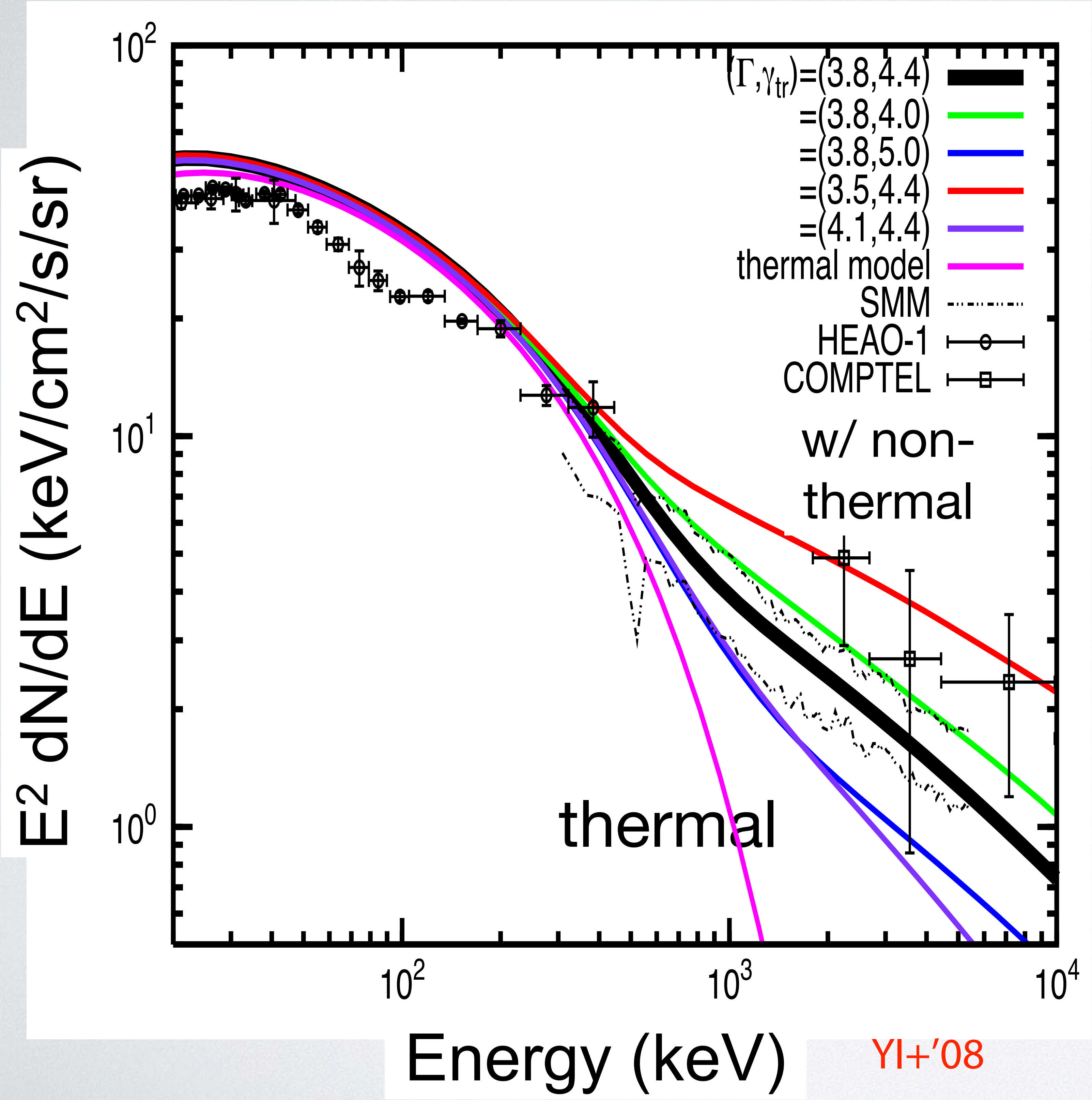
Hard X-ray Spectra (Seyfert)





- Comptonization in a hot corona above the disk.
- If non-thermal electrons exist in a corona, non-thermal tail is expected (e.g. YI+ '08).

Seyferts and Cosmic MeV Gamma-ray Background



YI+'08

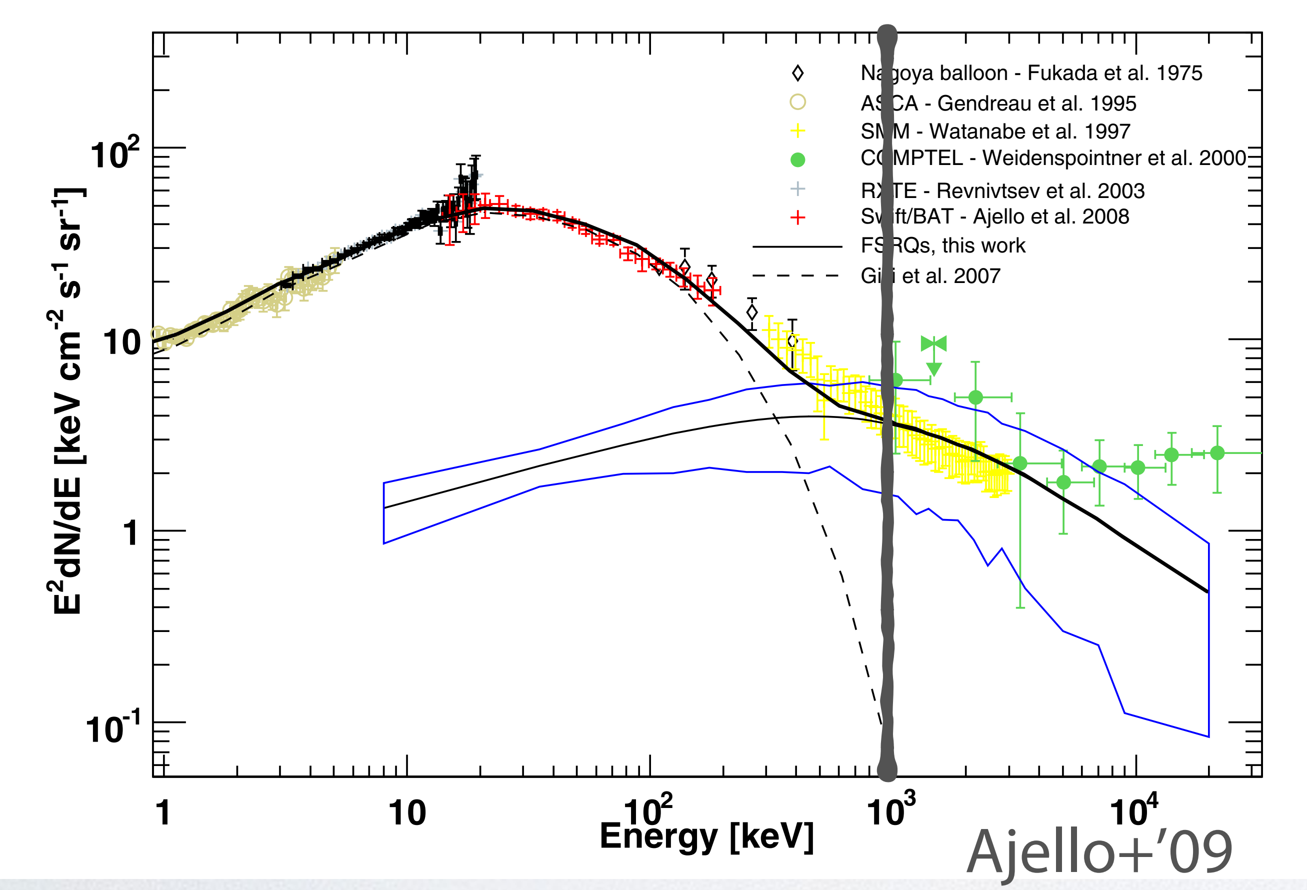
- Required non-thermal electron distribution is similar to that in solar flares and Earth's magnetotail

  ➡Magnetic reconnection-heated corona?
  (Liu, Mineshige, & Shibata '02)

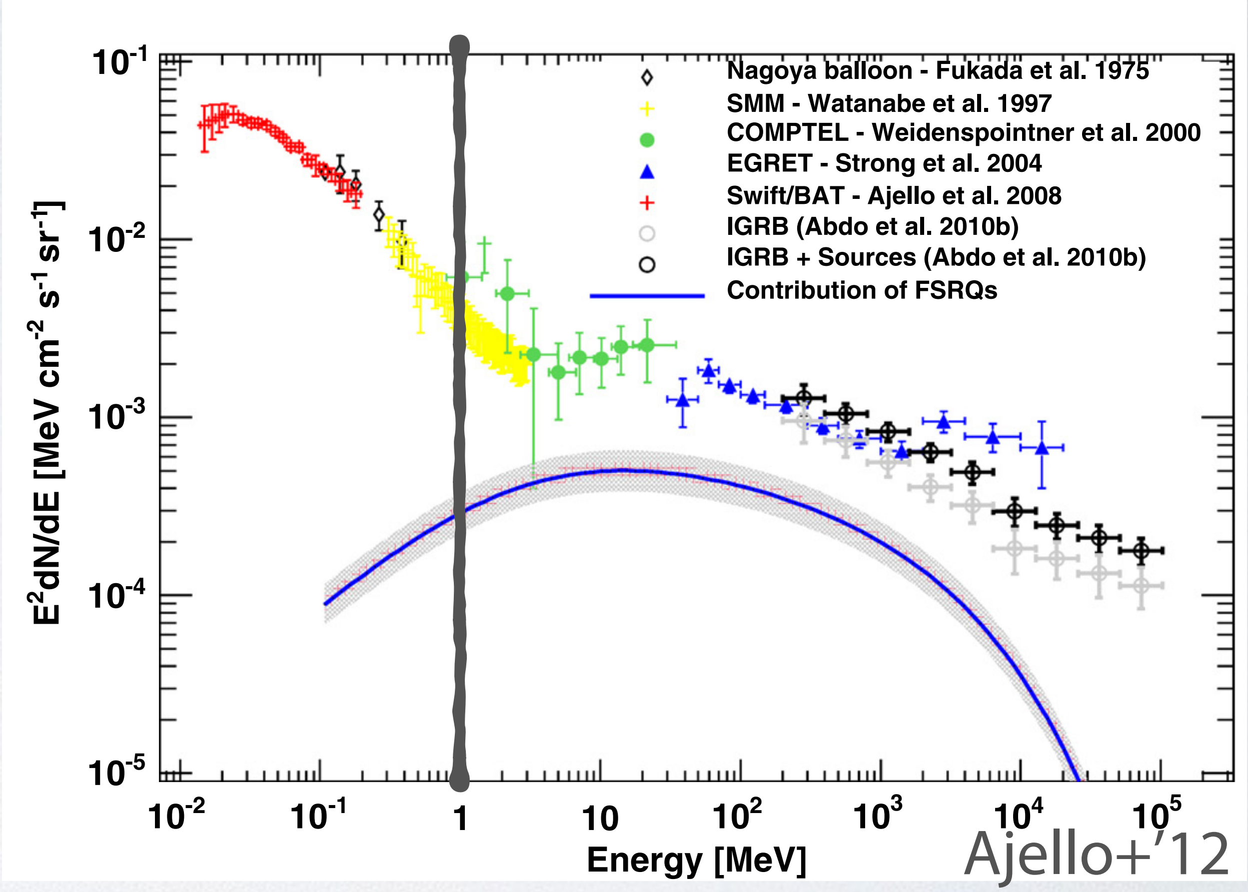
- ALMA may probe the corona heating scenario (YI & Doi '14).

Blazars and Cosmic MeV Gamma-ray Background

Based on Swift-BAT



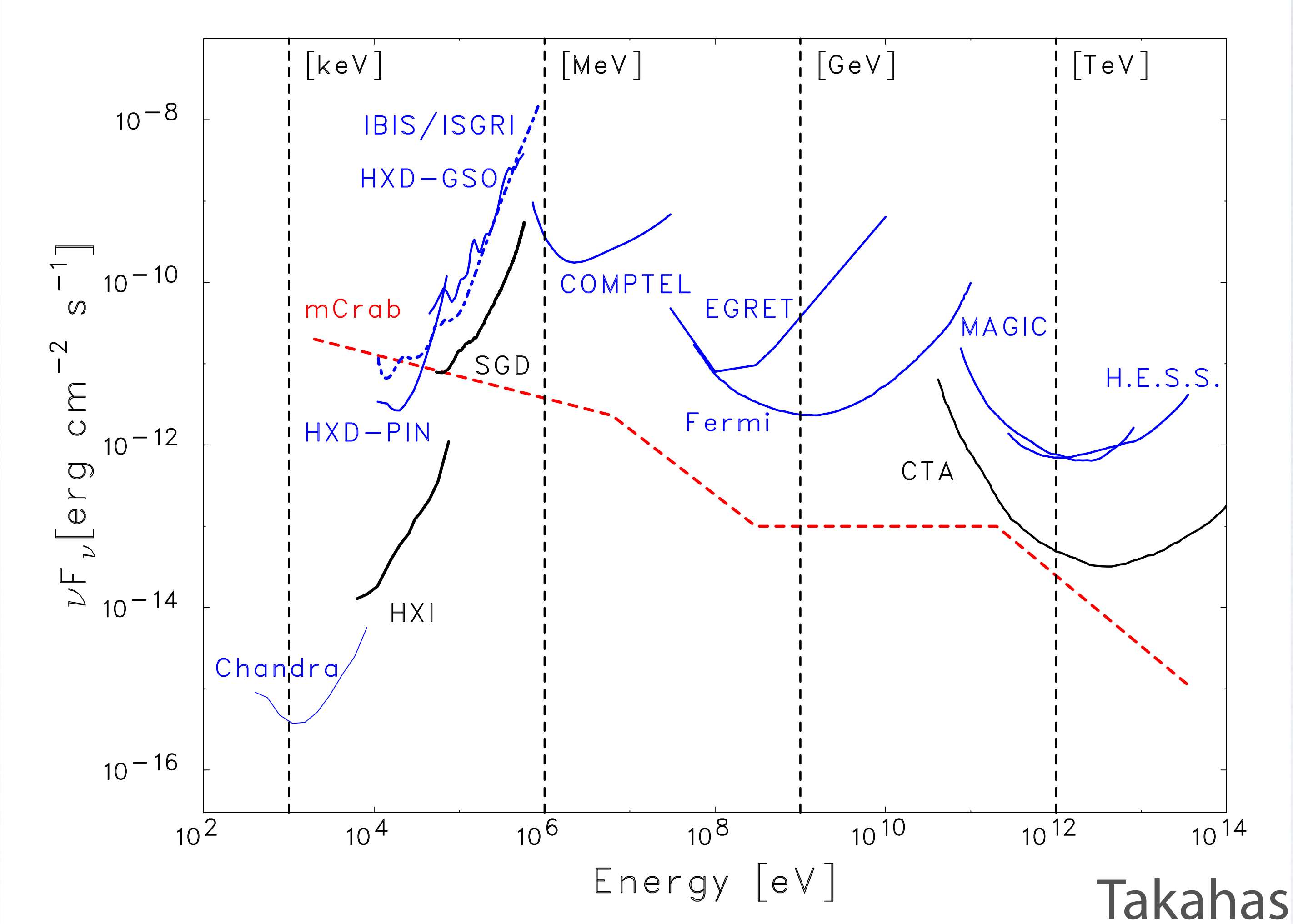
Based on Fermi-LAT



- FSRQs contribute to the GeV background with a peak at ~100 MeV (e.g. YI & Totani '09, Ajello +'12)
- FSRQs could explain the whole MeV background (Ajello+'09)

➡Two components in gamma-ray spectra or two FSRQ populations?

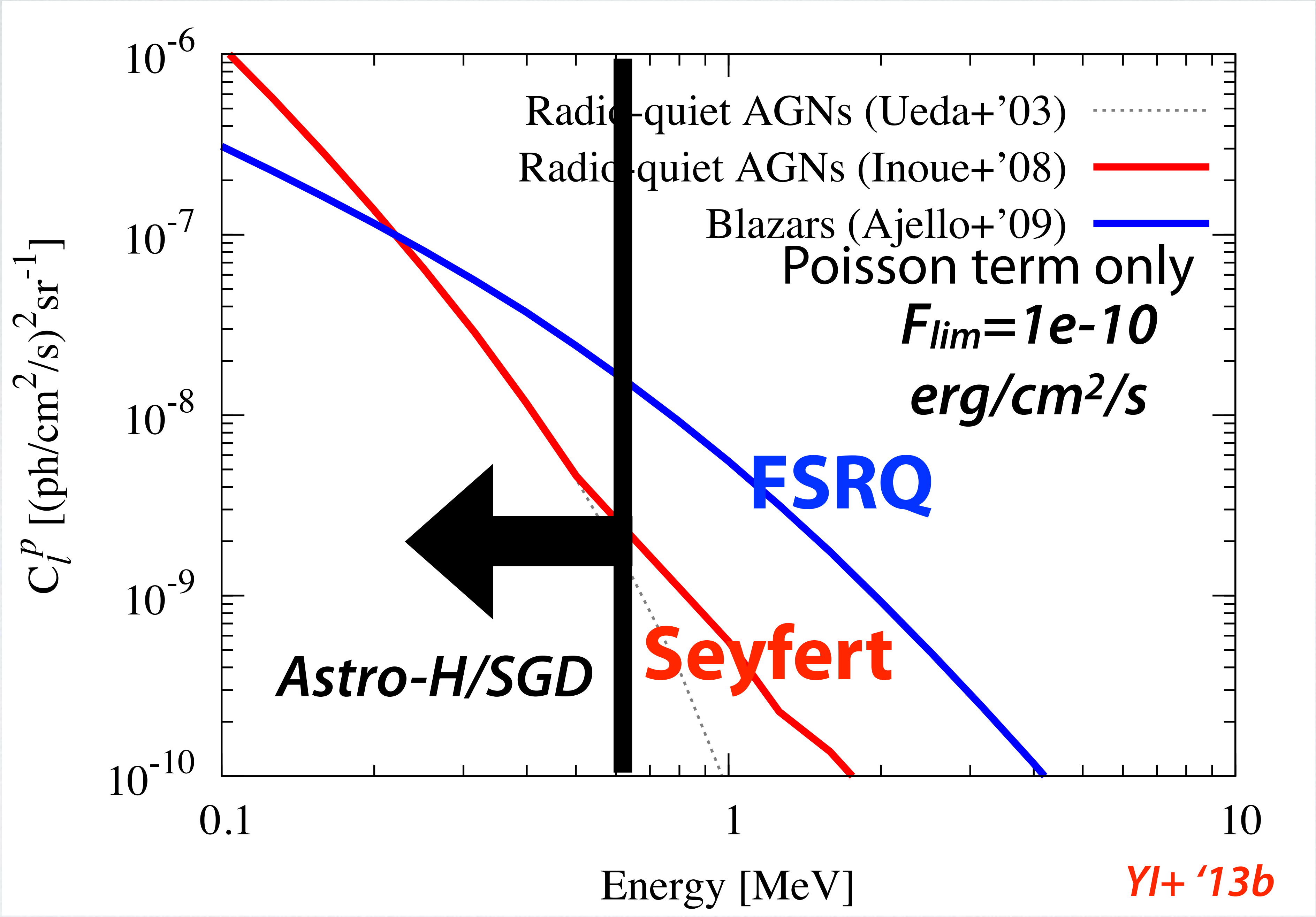
It is not easy to resolve the MeV sky.



Takahashi+'13

- Even achieving the sensitivity of 10^{-11} erg/cm^2/s, it is hard to resolve the MeV sky (***YI+'15***).
- Answers are in "***Anisotropy***".
    - Cosmic background radiation is not isotropic.
    - There is anisotropy due to the sky distribution of its origins.

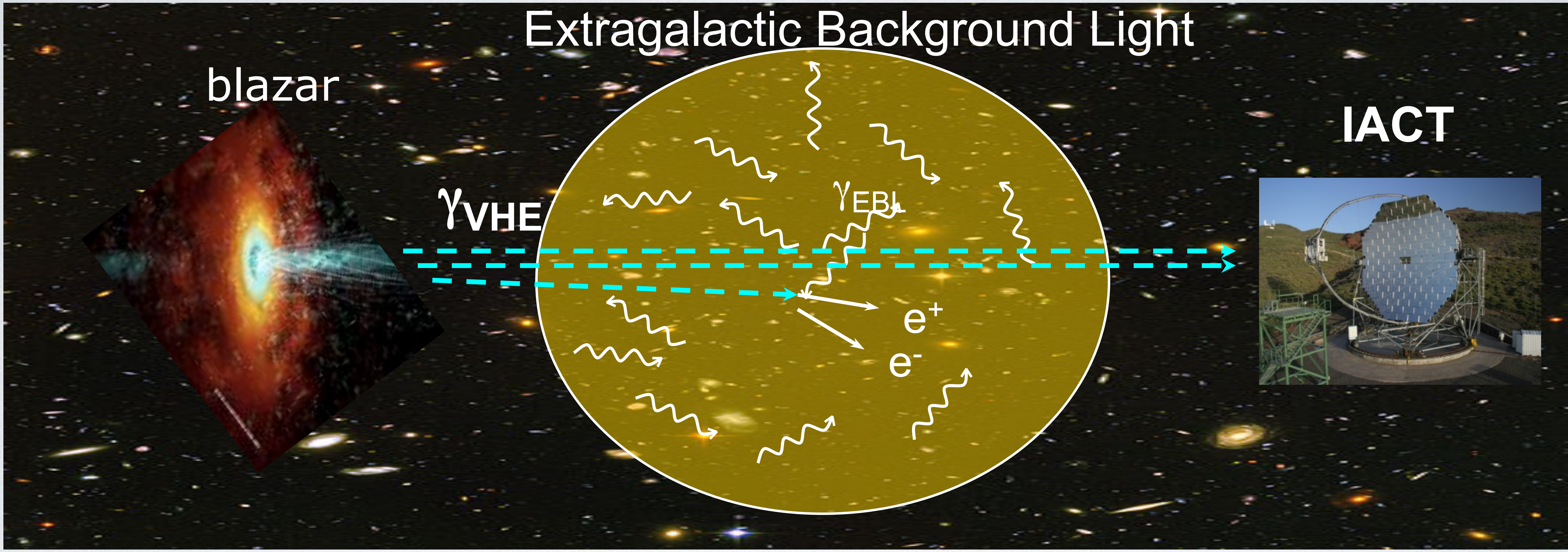
Cosmic MeV Gamma-ray Background "Anisotropy"

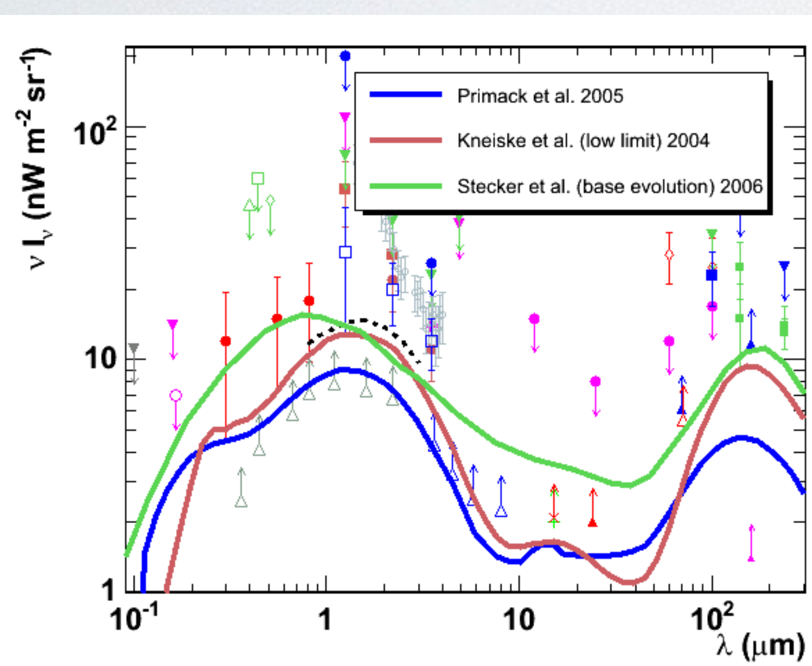


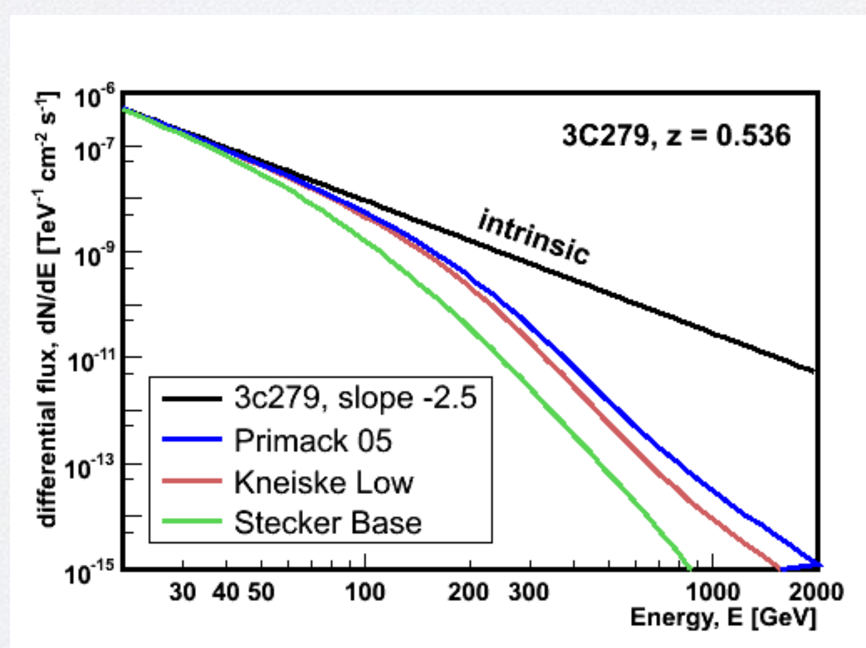
- Astro-H (SGD) / future MeV satellites will distinguish Seyfert & blazar scenarios through anisotropy in the sky.

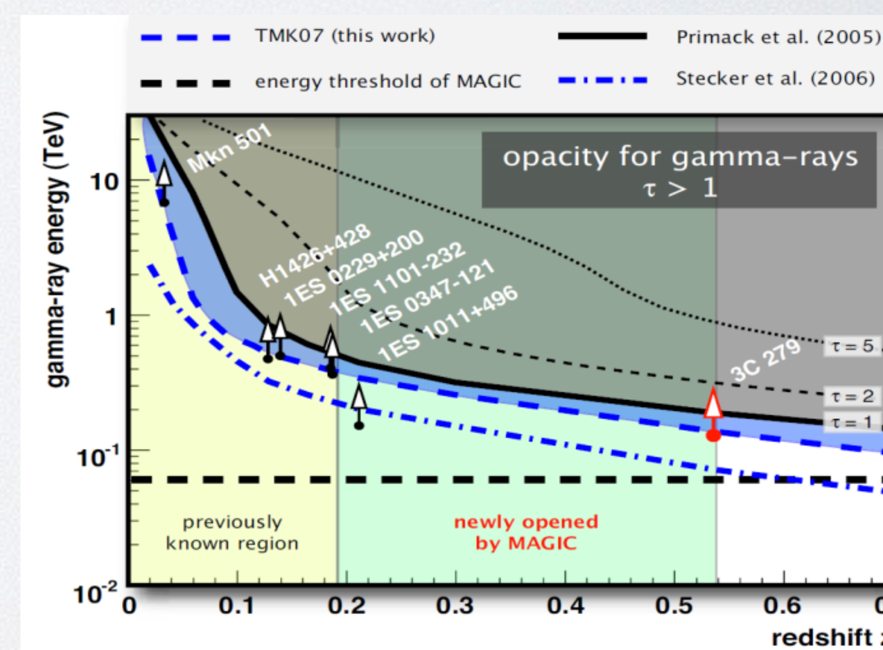
Cosmic TeV Gamma-ray Background

Gamma-ray Attenuation by Cosmic Optical & Infrared Background

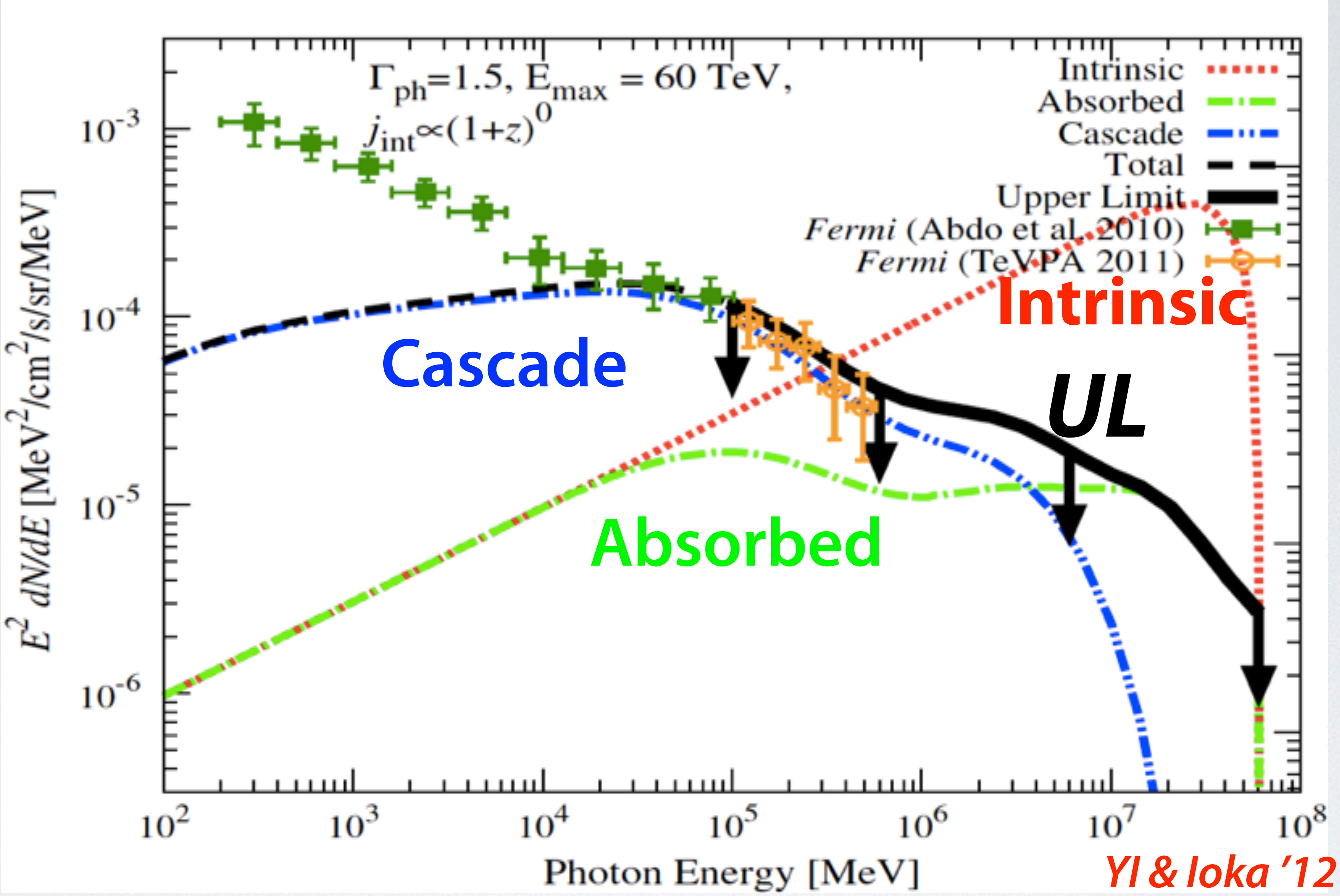






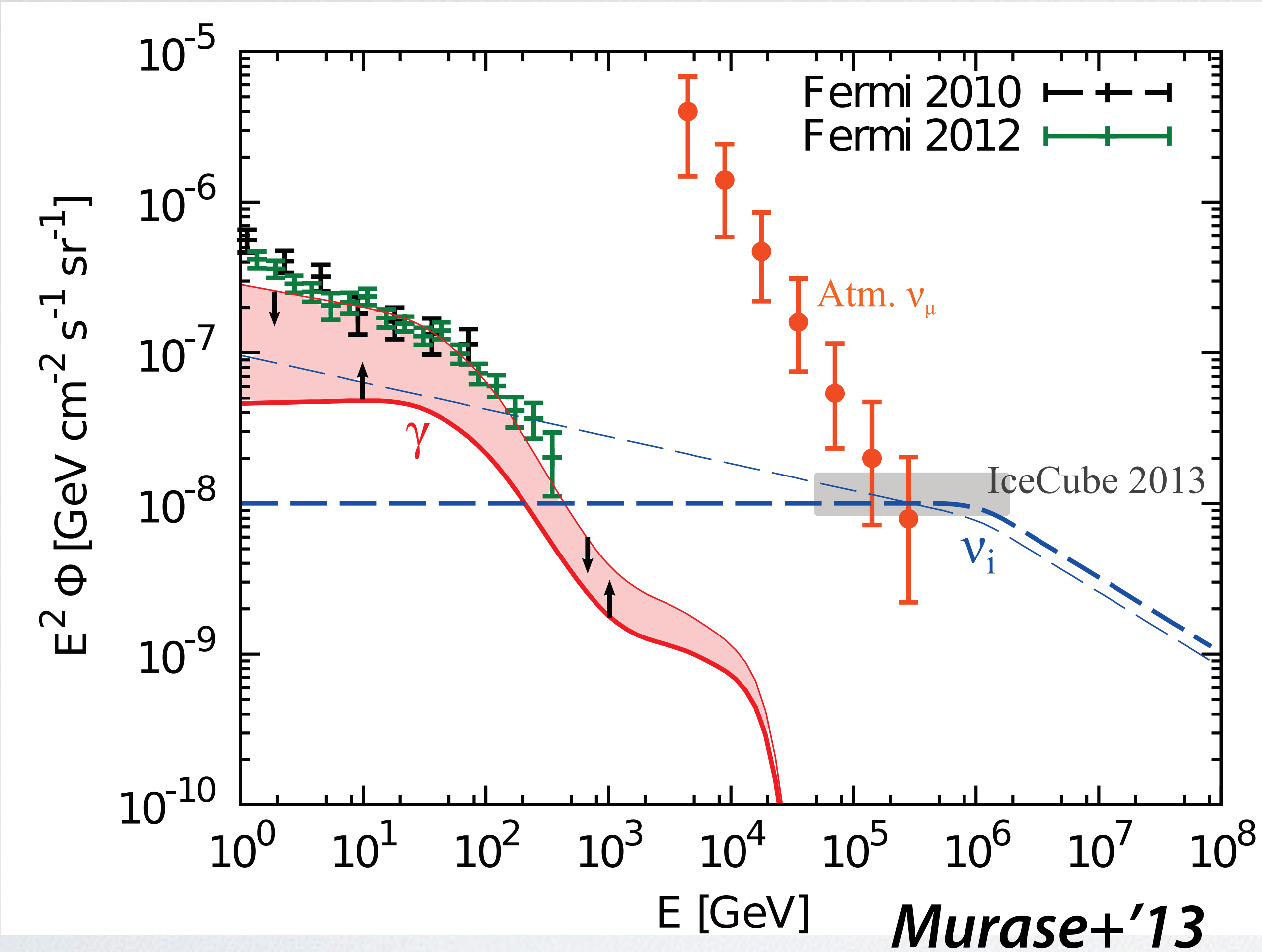


Upper Limit on Cosmic Gamma-ray Background

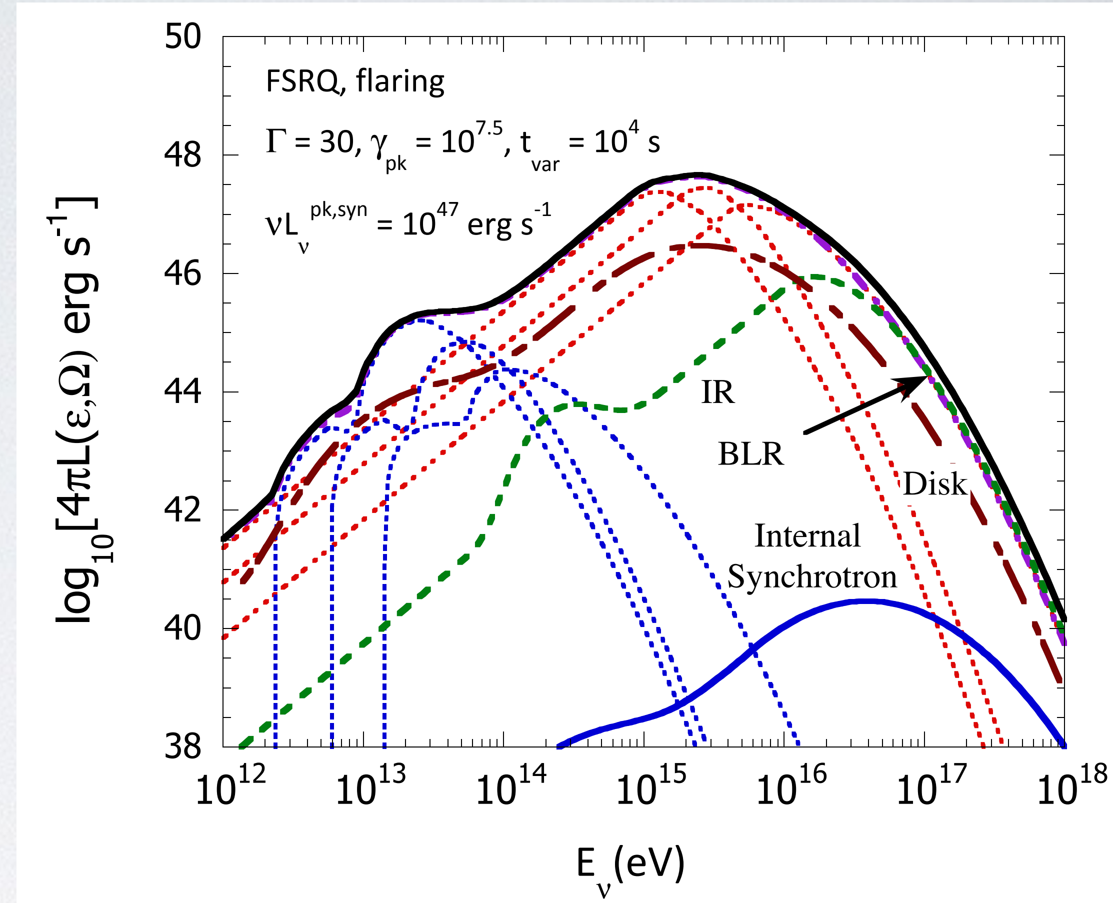


- Cascade component from VHE CGB can not exceed the Fermi data (Coppi & Aharonian '97, YI & Ioka '12, Murase+'12, Ackermann+'14).
  - No or negative evolution is required -> low-luminosity BL Lacs show negative evolution (Ajello+'14).

IceCube Neutrinos and Cosmic Gamma-ray Background



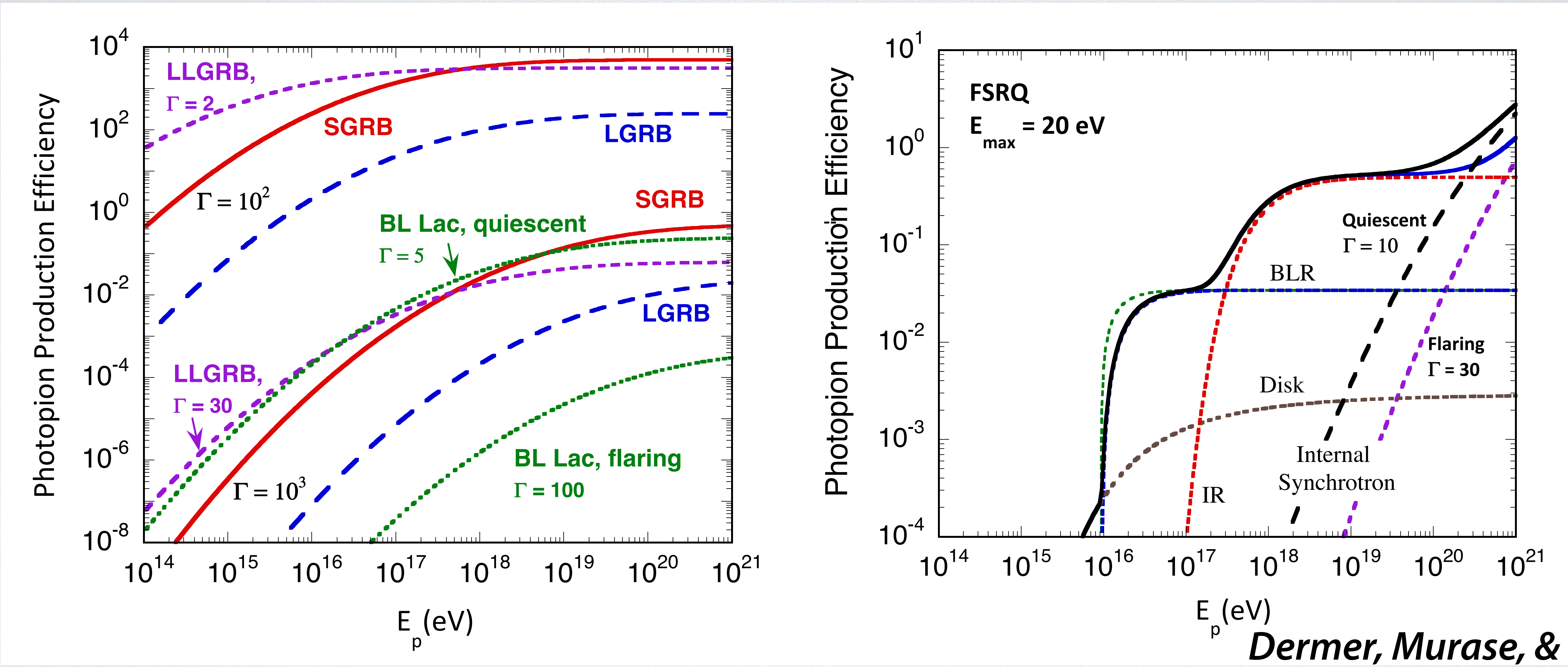
Murase+'13



Dermer, Murase, & YI '13

- Extragalactic ***pp*** scenario (galaxies or clusters) for IceCube events will provide 30-100 % of CGB (Murase+'13).
- Extragalactic ***pγ*** scenario (e.g. FSRQs) depends on the target photon spectra (e.g. Murase, YI, & Dermer '14, Dermer, Murase, & YI '14).

Photopion Production Efficiency

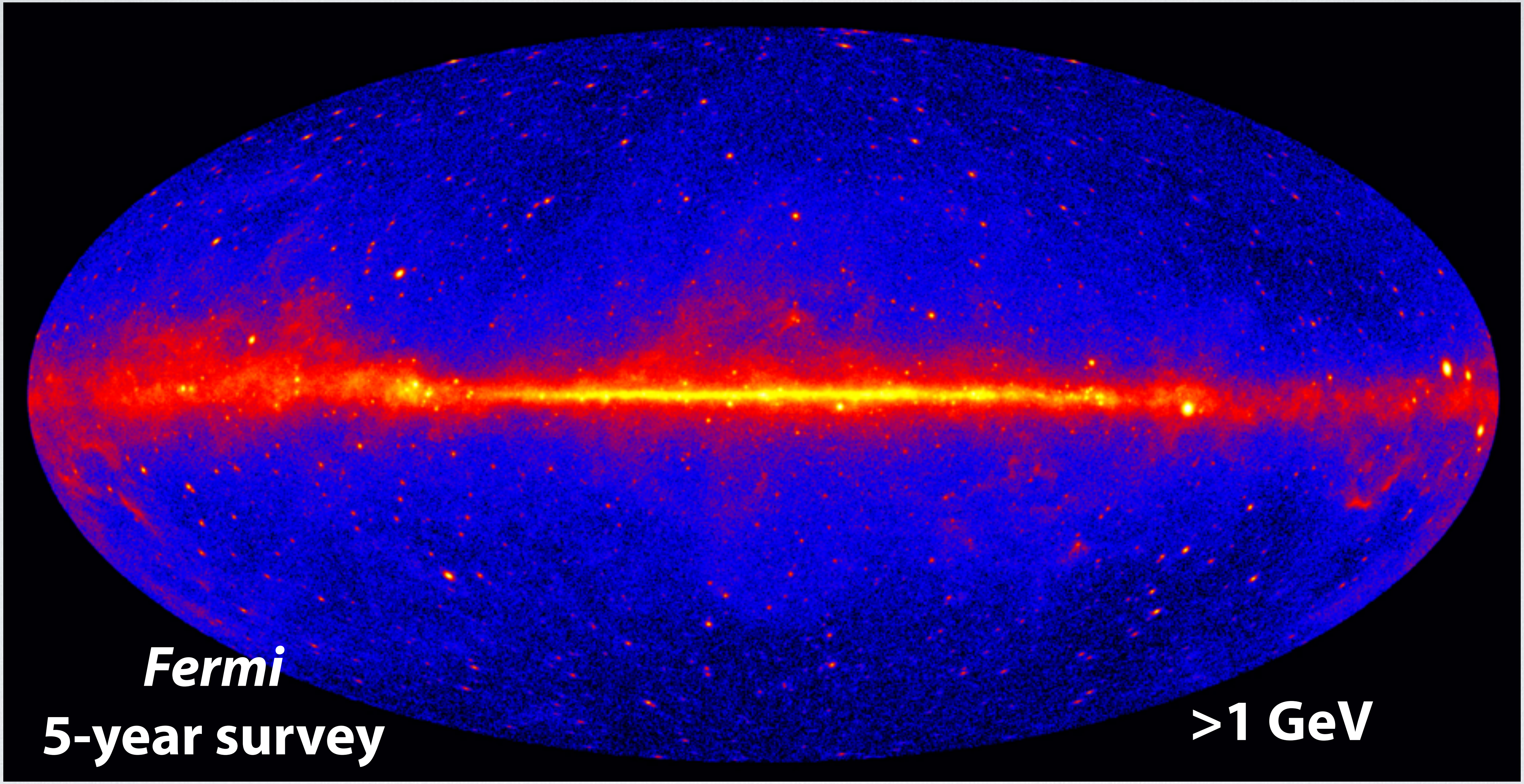


Dermer, Murase, & YI '13

- BL Lacs are inefficient neutrino factory
- FSRQs will have a lower cutoff at ~1 PeV.

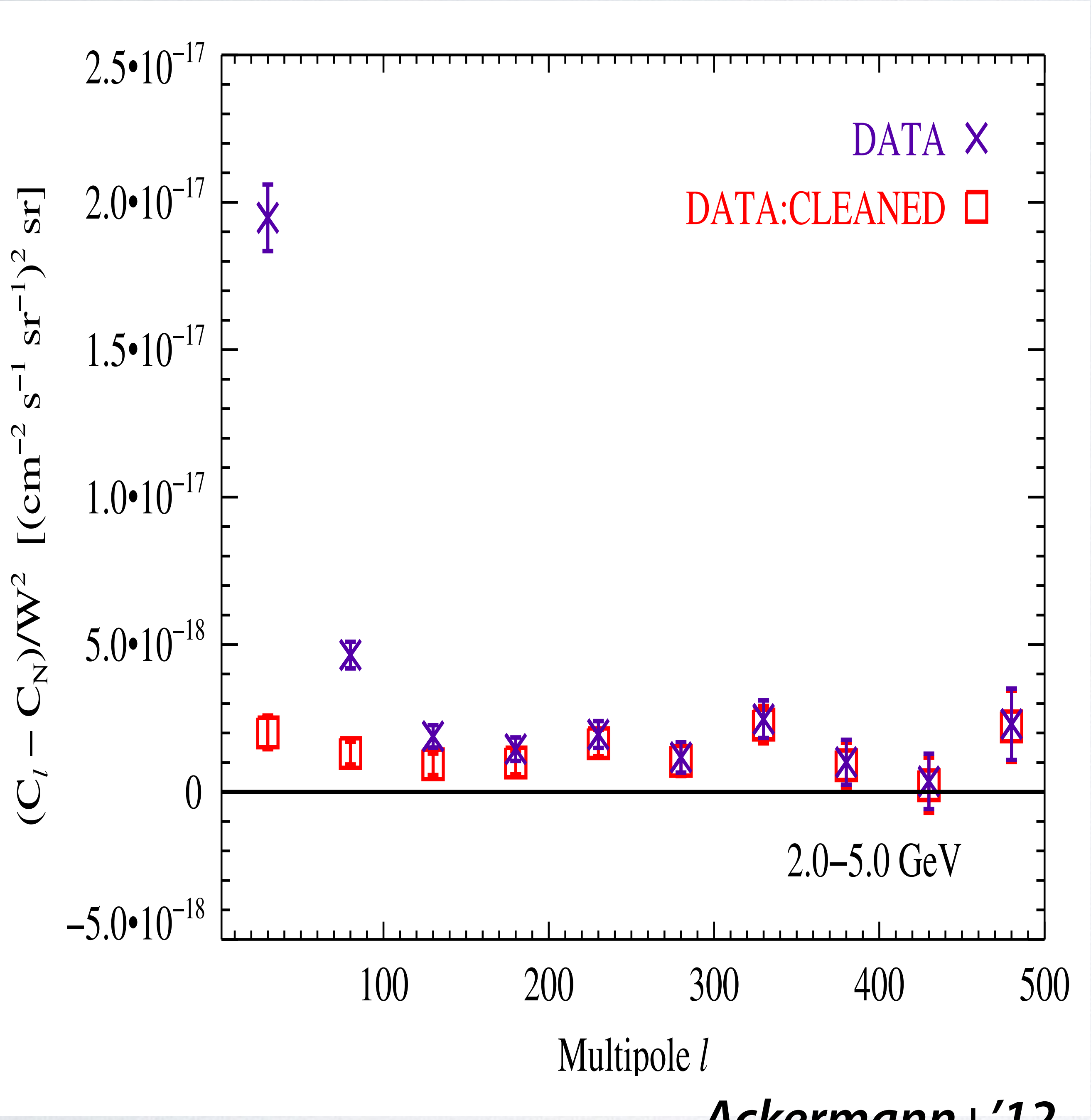
Anisotropy of Cosmic Gamma-ray Background

Anisotropy



- use the direction information of incoming gamma rays.

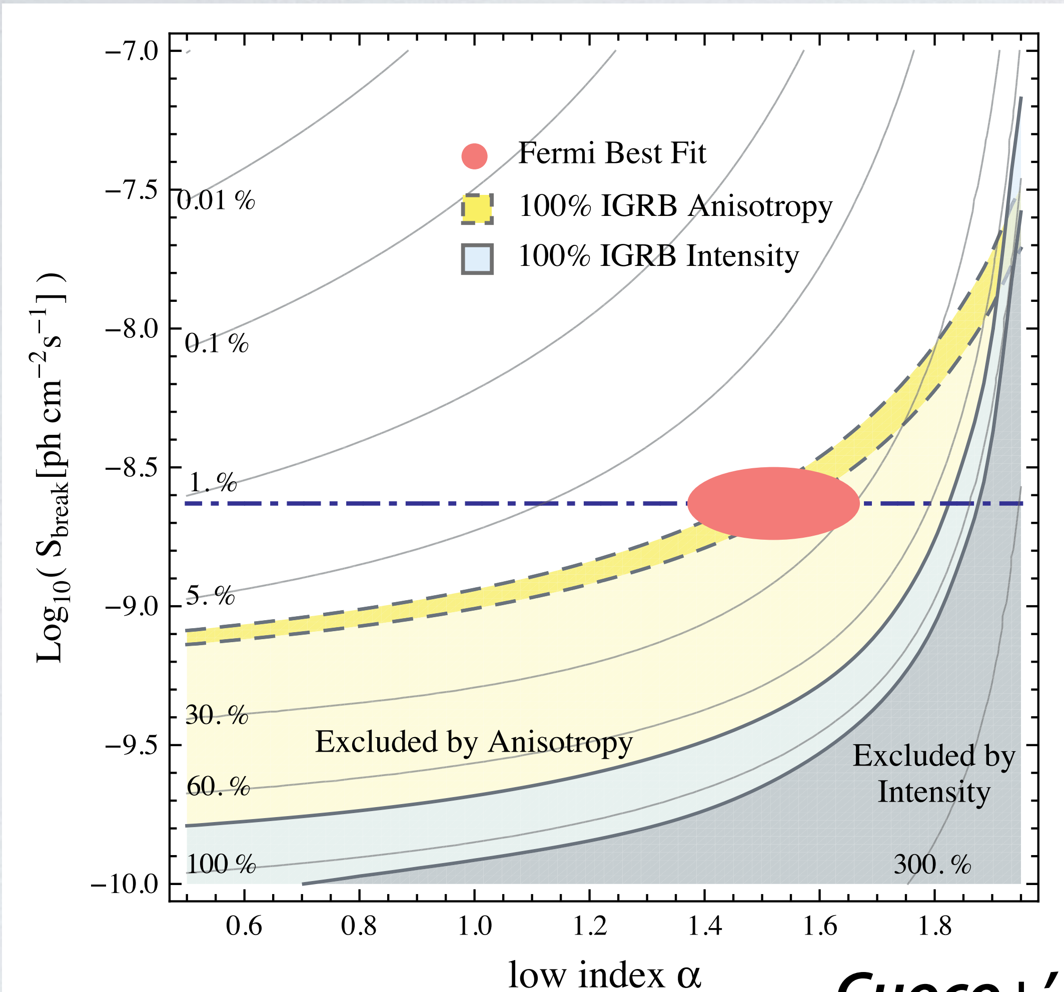
Observed Anisotropy of the CGB



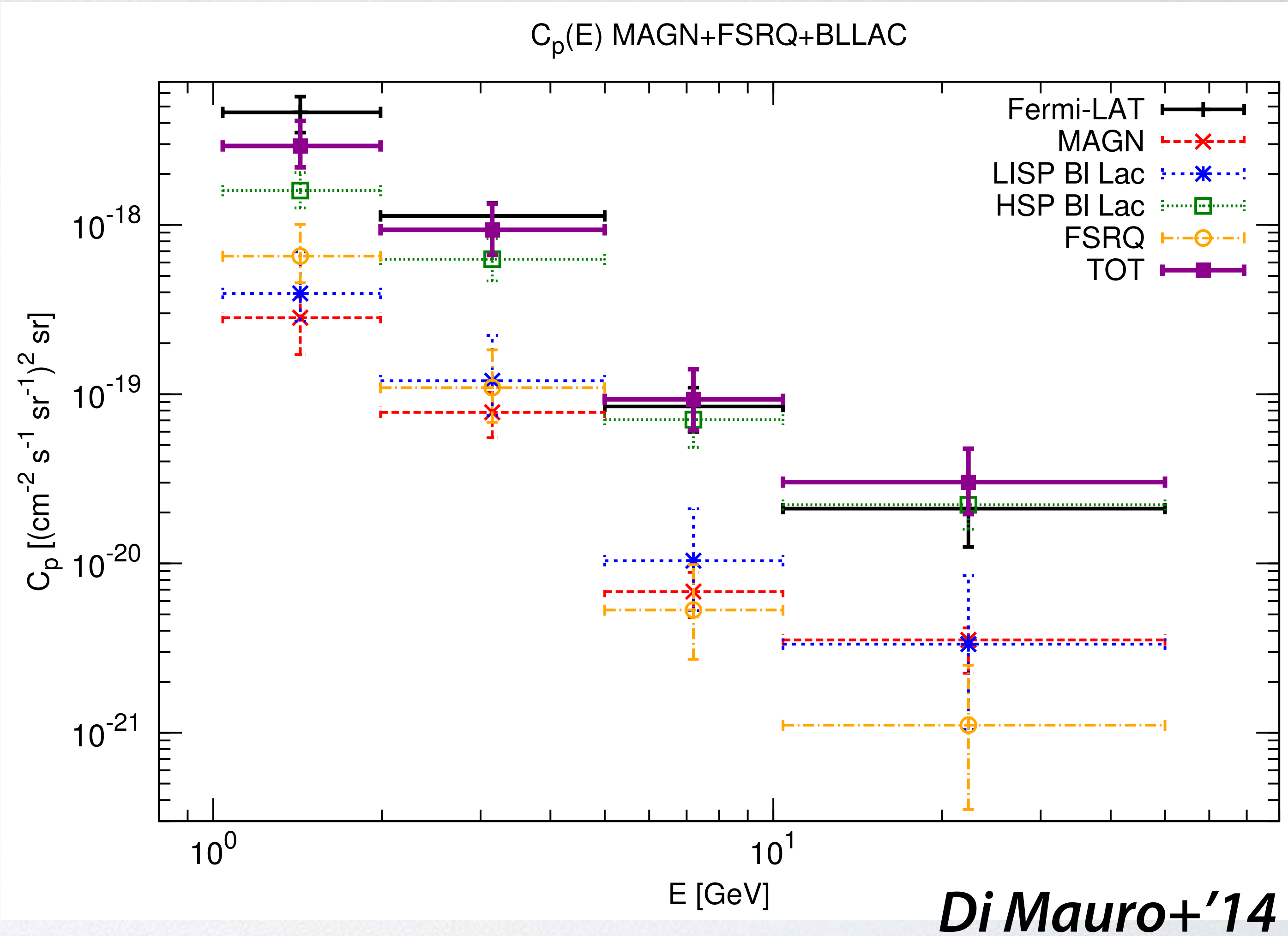
Ackermann+'12

- Fermi found anisotropy of the CGB
  - constant excess at 100<l<500
- consistent with blazars' contribution.

Anisotropy of Cosmic Gamma-ray Background



Cuoco+'12

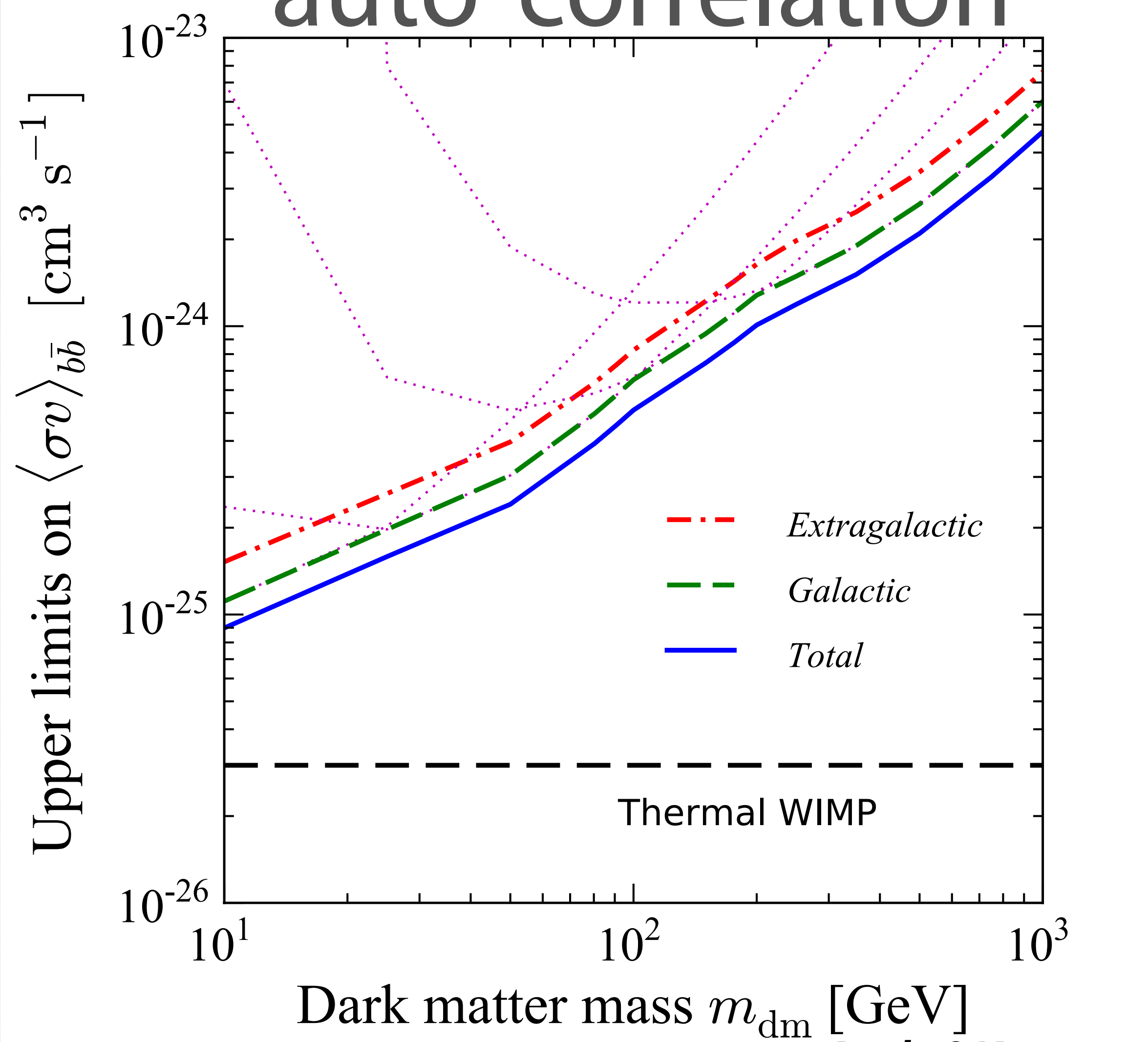


Di Mauro+'14

- Anisotropy puts strong constraints on the evolutionary models of blazars (Cuoco+'12, Harding & Abazajian '13).
- CGB anisotropy is well explained by known radio-loud AGN populations (Di Mauro+'14).

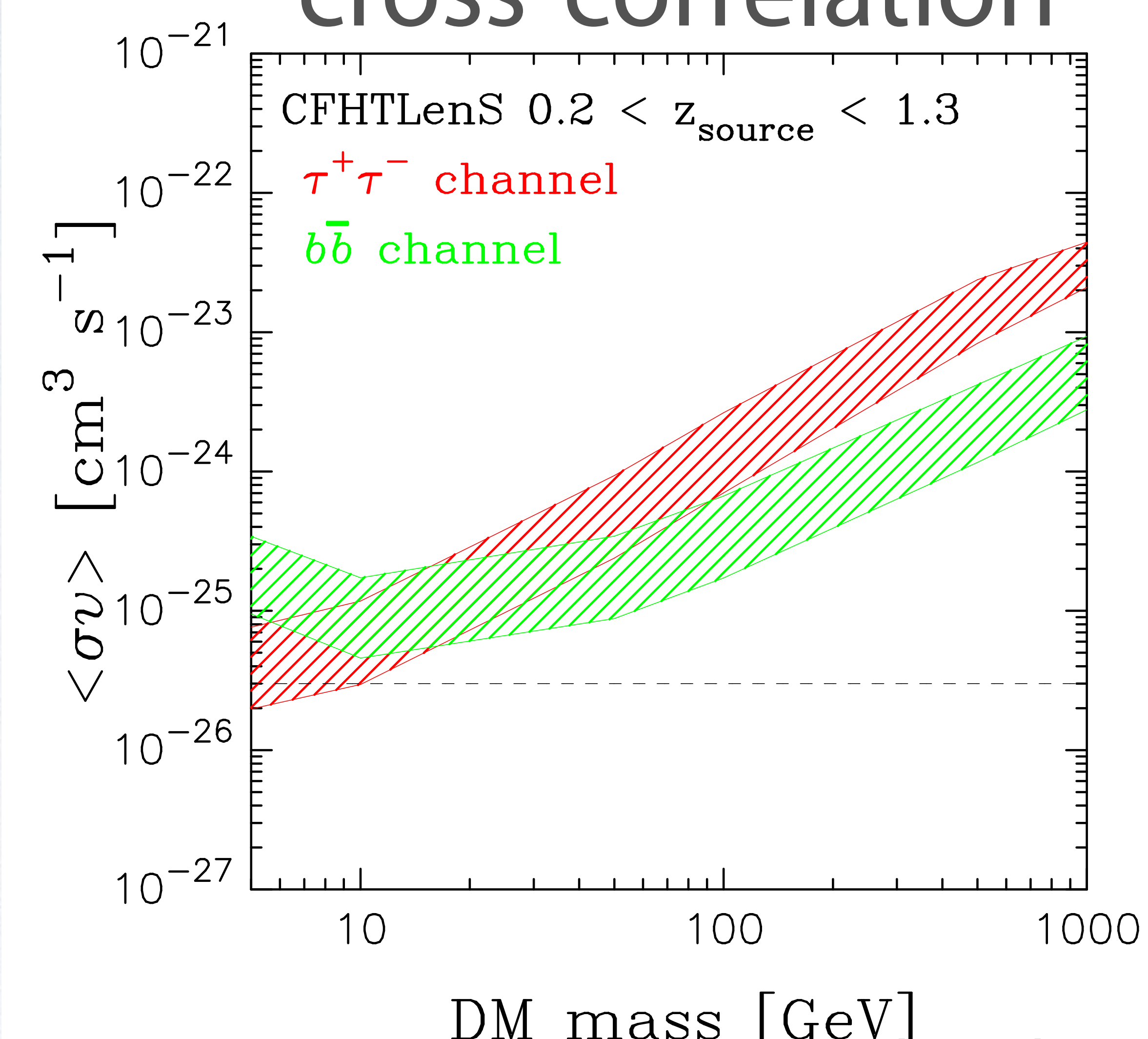
Anisotropy & Dark Matter

auto-correlation



Ando&Komatsu '13

cross-correlation



Shirasaki+'14

- Angular power spectra of CGB is a powerful tool to constrain the DM properties (e.g. Ando & Komatsu '06, '13).

- Cross-correlation between cosmic shear and CGB will be a new powerful tool (e.g. Camera+'13, Shirasaki+'14).

Summary

- CGB at GeV band is composed of blazars, radio galaxies, and star-forming galaxies.
- CGB at MeV band may be come from blazars or Seyferts.
  - Anisotropy measurement will distinguish these two scenarios.
- CGB at TeV band is constrained by CGB at GeV band through cascade emission.
  - Need to check consistency with IceCube neutrino measurements.
- Anisotropy of the CGB is a powerful tool to probe gamma-ray signatures from DM