Cosmic Gamma-ray Background Radiation

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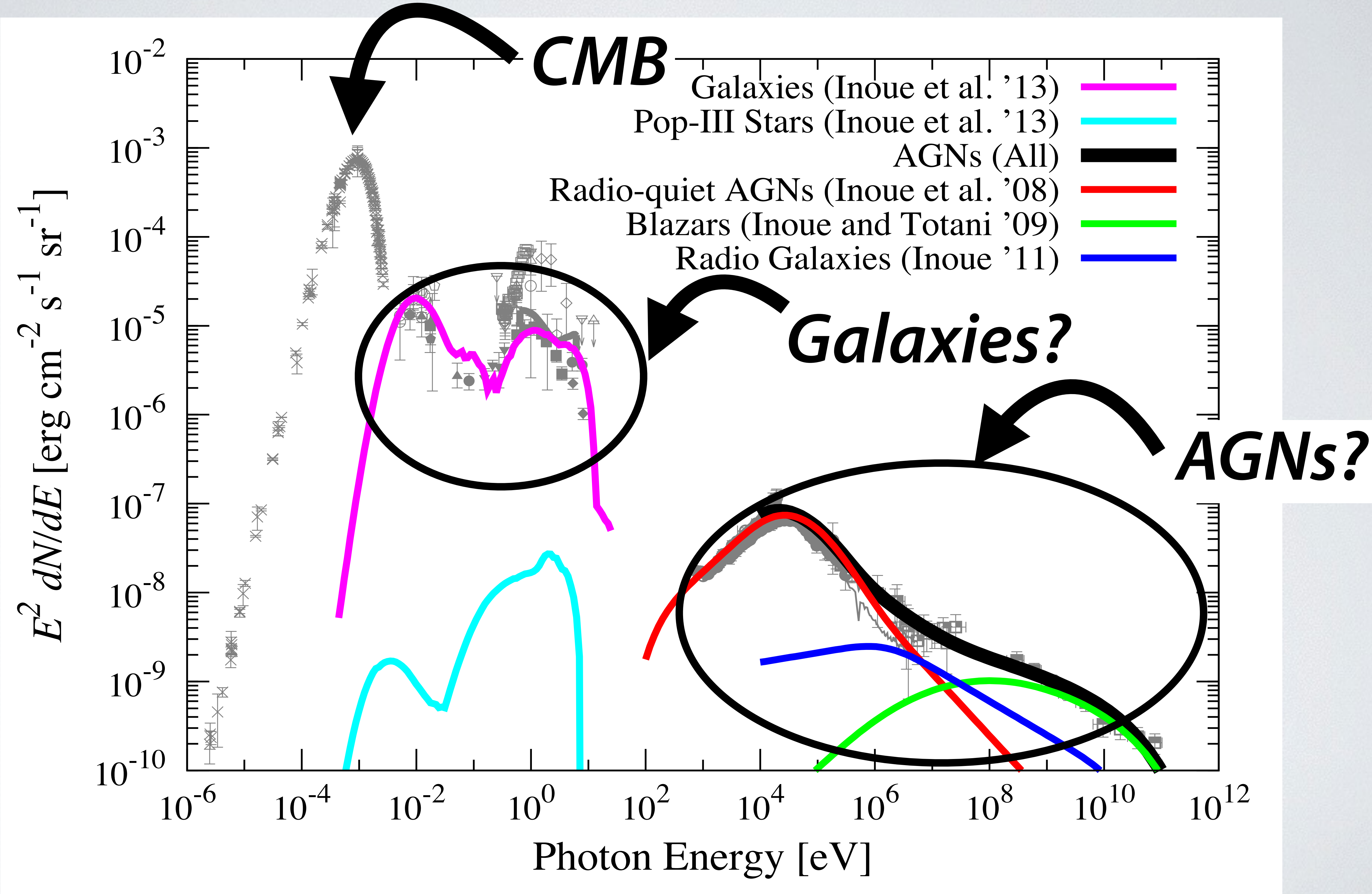
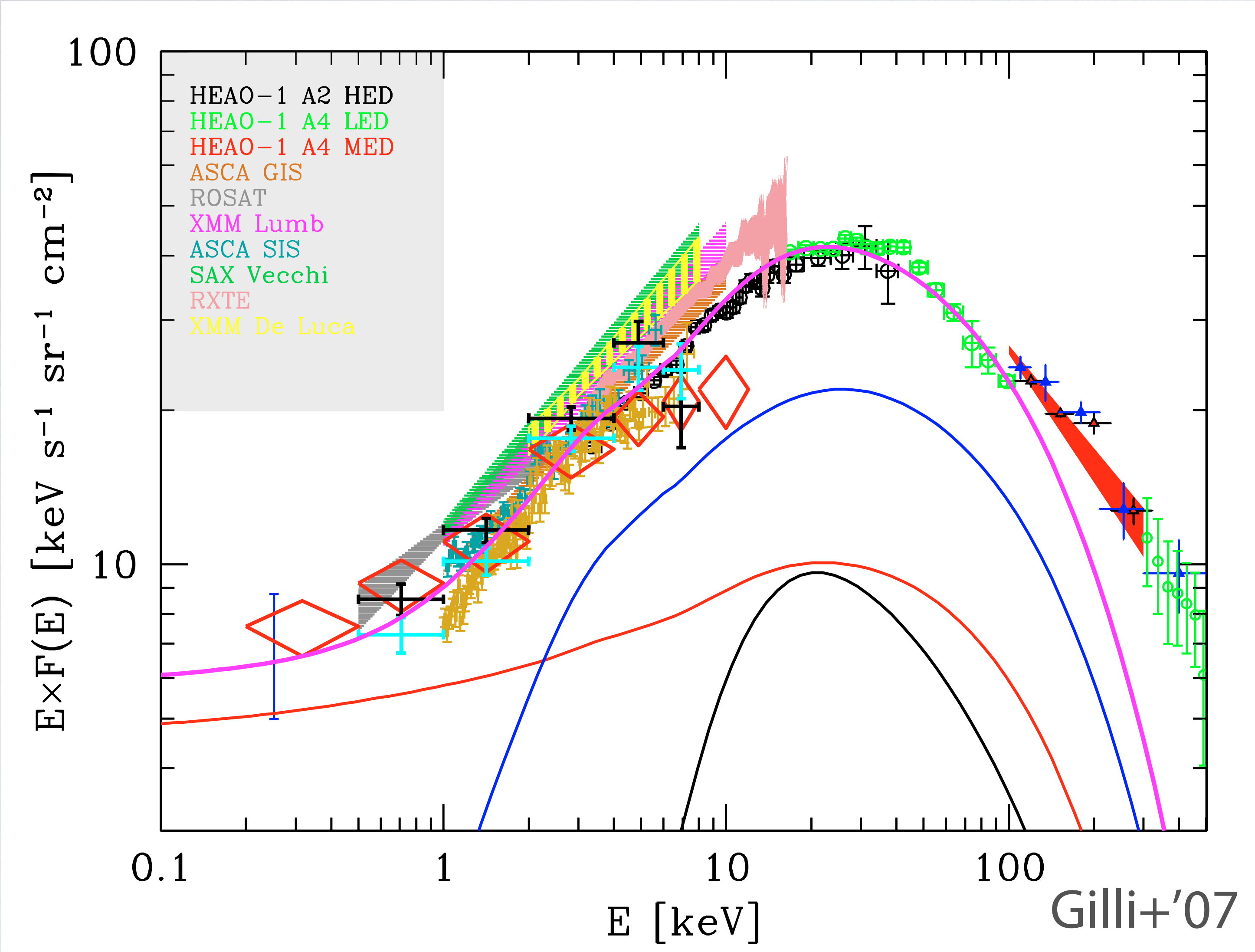
Cosmic Background Radiation Spectrum



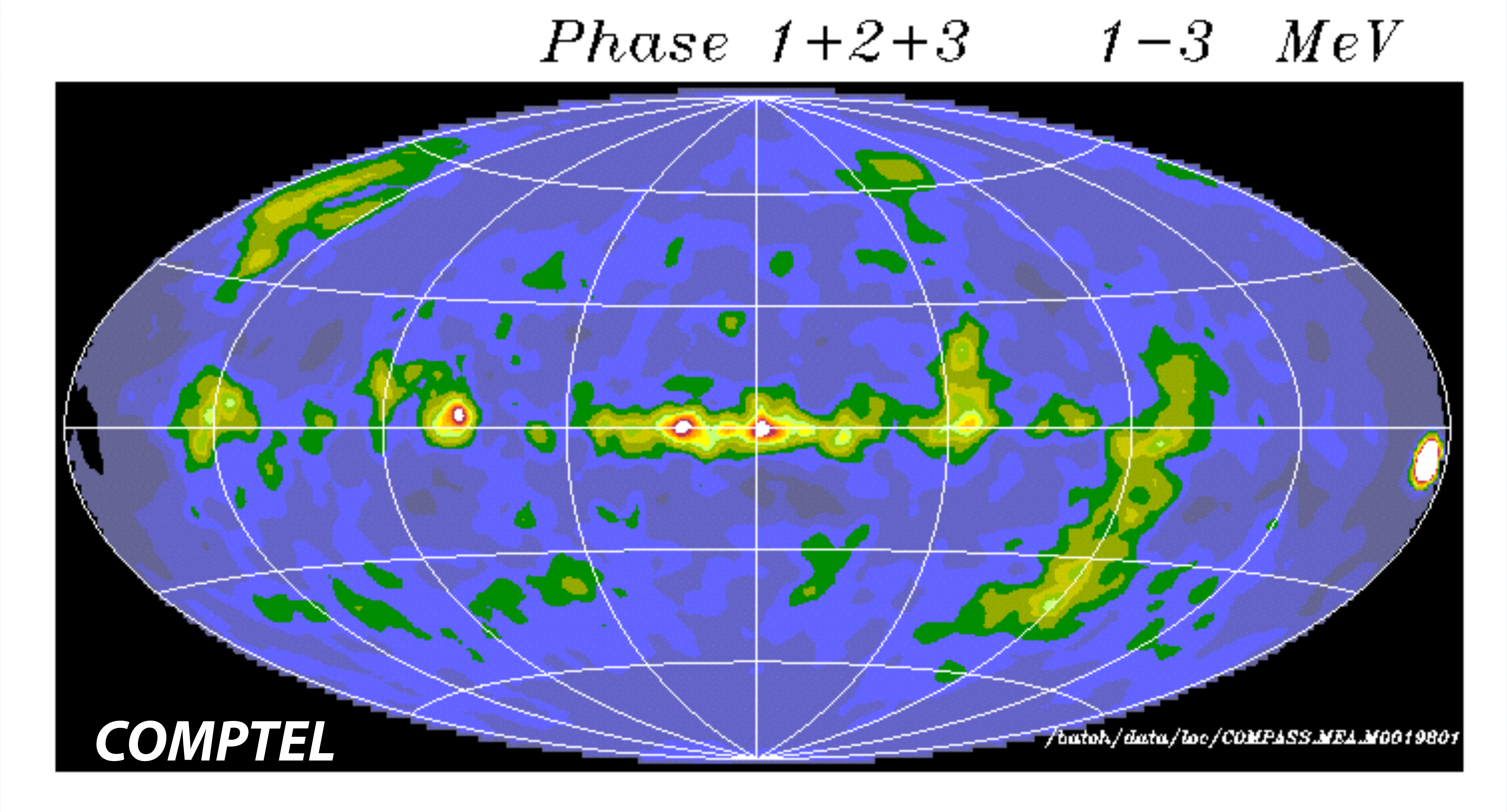
Cosmic X-ray Background (CXB)



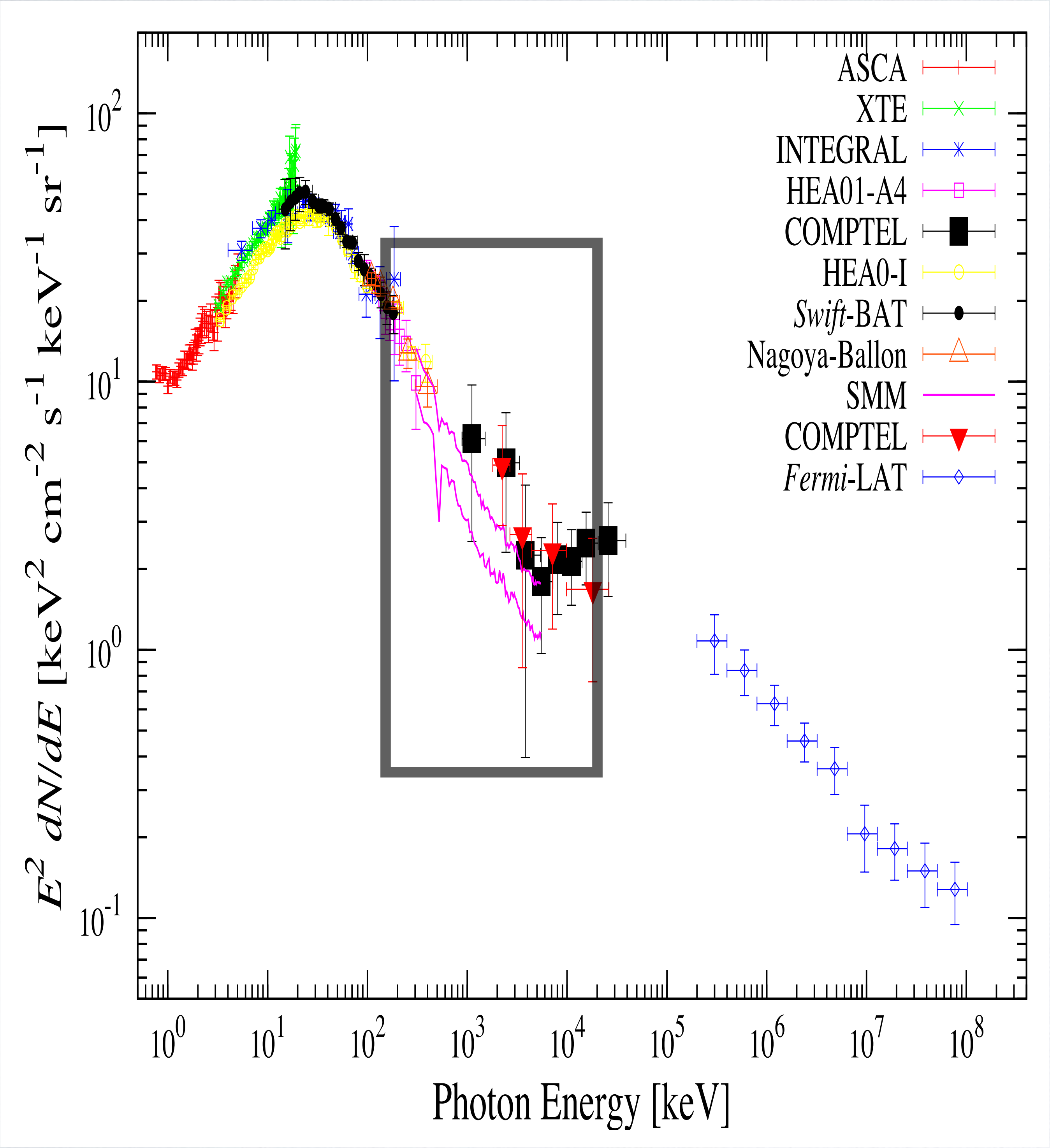
- The origin of CXB is thought to be Seyferts.
  - >90 % of CXB at 0.5-10 keV has been resolved.

- But, CXB above 10 keV is not well resolved.
  - Astro-H & NuSTAR will probe this.

Cosmic MeV Gamma-ray Background Sky

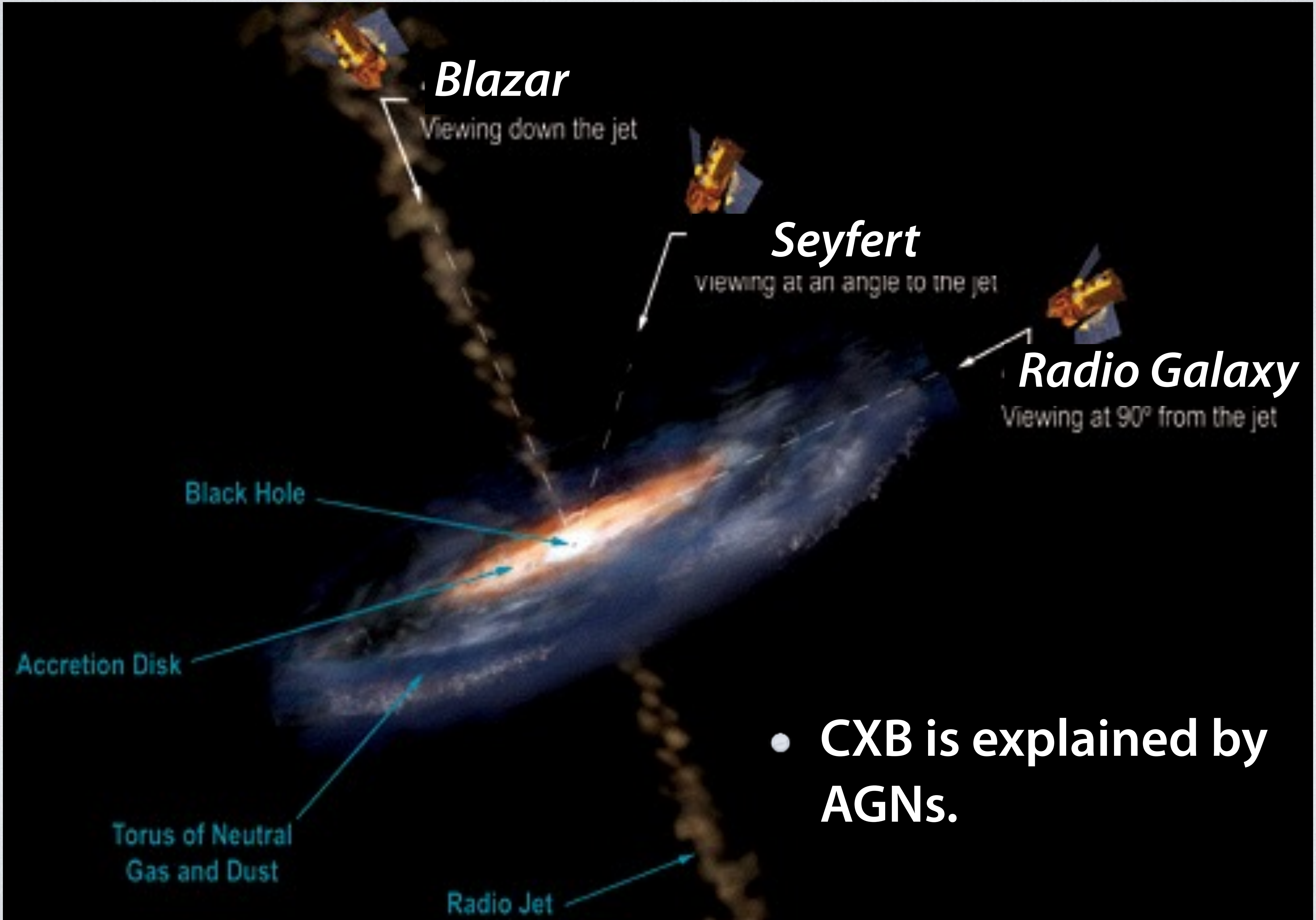


Cosmic MeV Gamma-ray Background Spectrum



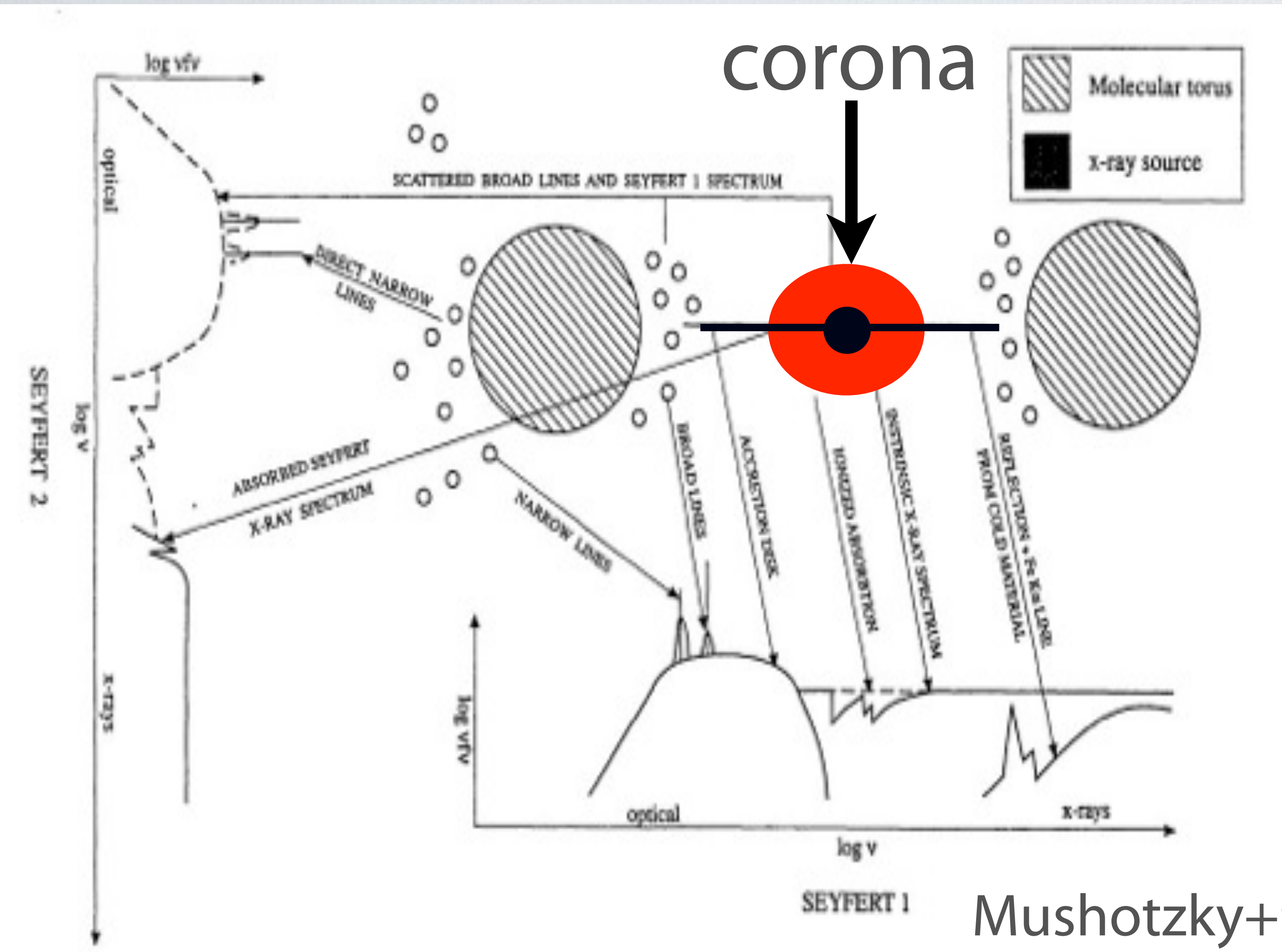
- The origin of cosmic X-ray background is thought to be active galactic nuclei (AGNs).
- Smooth connection to the cosmic X-ray background.
- Type Ia Supernovae? (e.g. Clayton+'75, Zdziarski+'96)
  - Insufficient (e.g. Strigari+'05, Horiuchi+'10)
- Radio galaxies? (e.g. Strong+'76)
  - Insufficient (e.g. Massaro & Ajello '11, YI'11)
- MeV Dark Matters? (e.g. Olive & Silk '85, Ahn & Komatsu '05, '06)
  - no natural DM particle candidates from particle physics

Active Galactic Nuclei (AGNs)

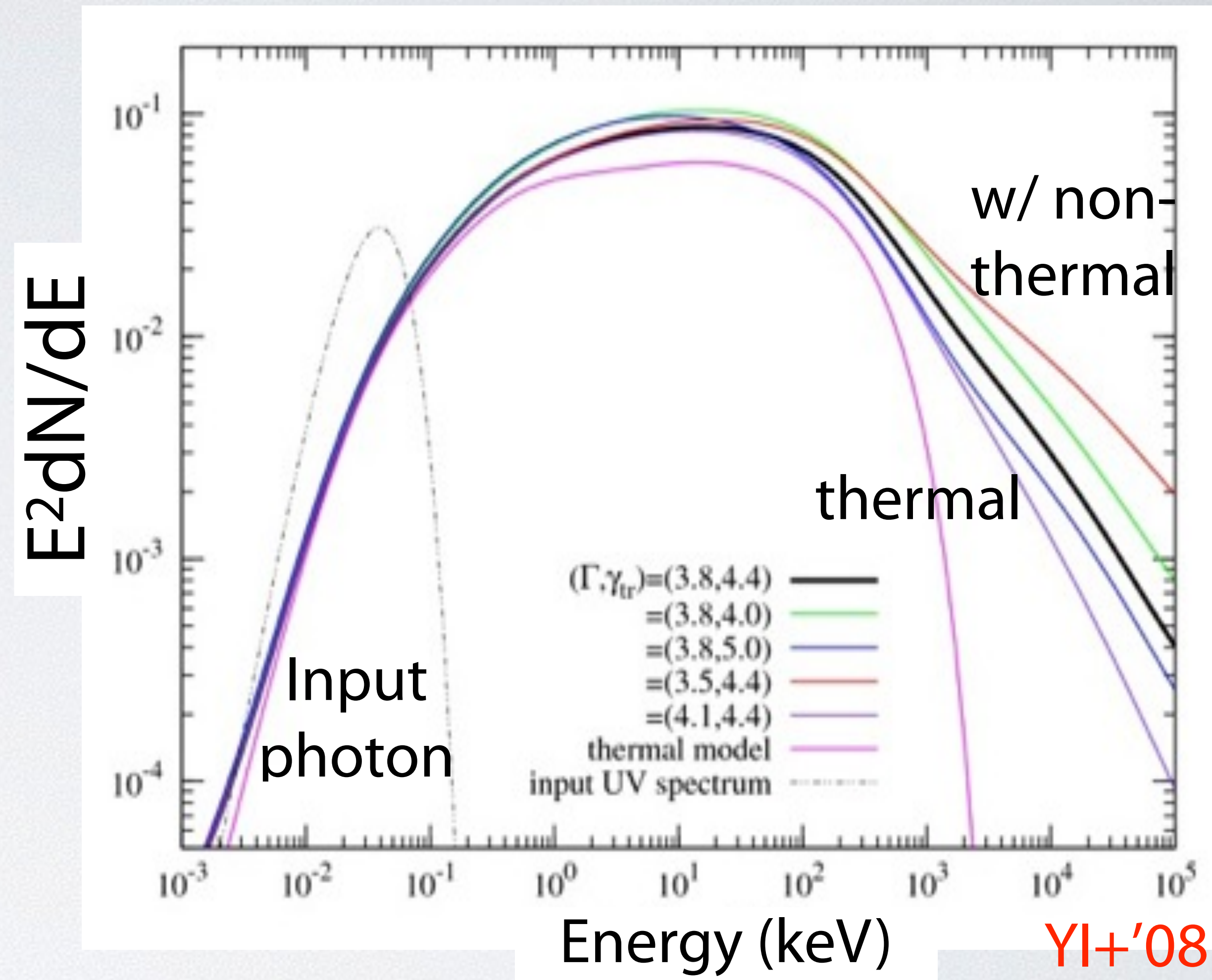


- **CXB is explained by AGNs.**

Hard X-ray Spectra (Seyfert)



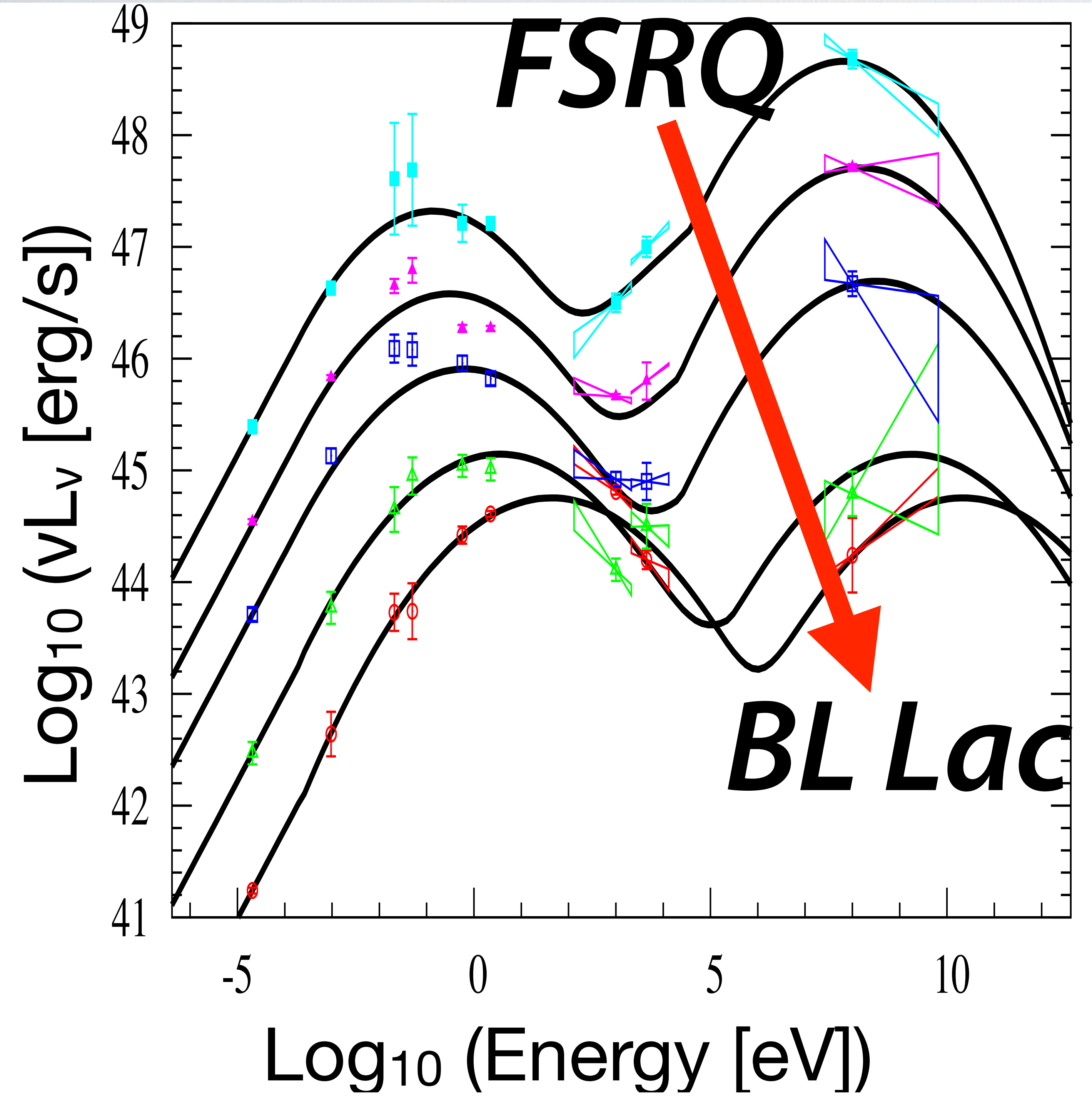
Mushotzky+93



YI+'08

- 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).
    - MeV power-law tail is observed in a Galactic X-ray binary (Cyg X-1).

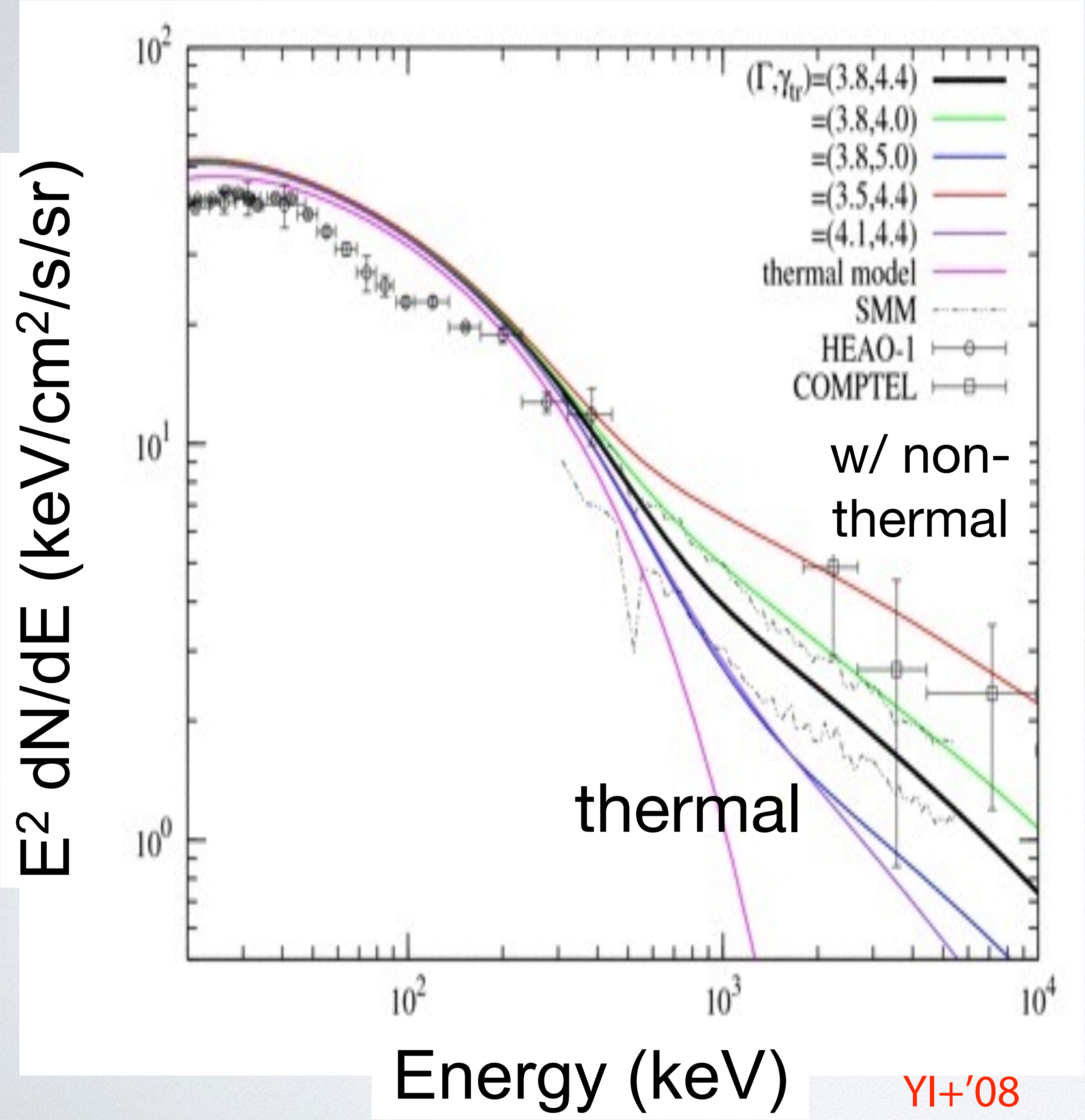
Typical Spectra (Blazar)



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)

Seyferts and Cosmic MeV Gamma-ray Background

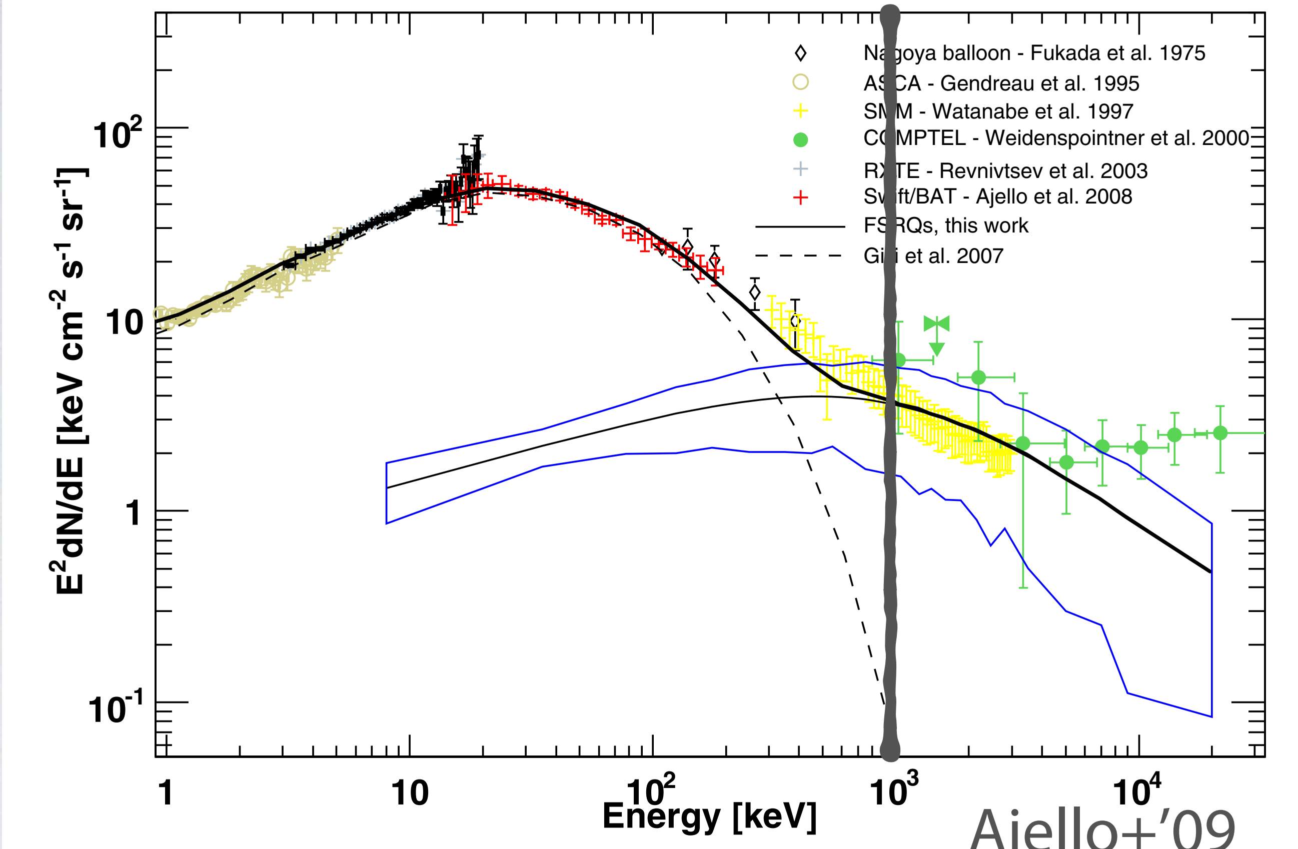


- Required non-thermal electron distribution is similar to that in solar flares and Earth's magnetotail

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

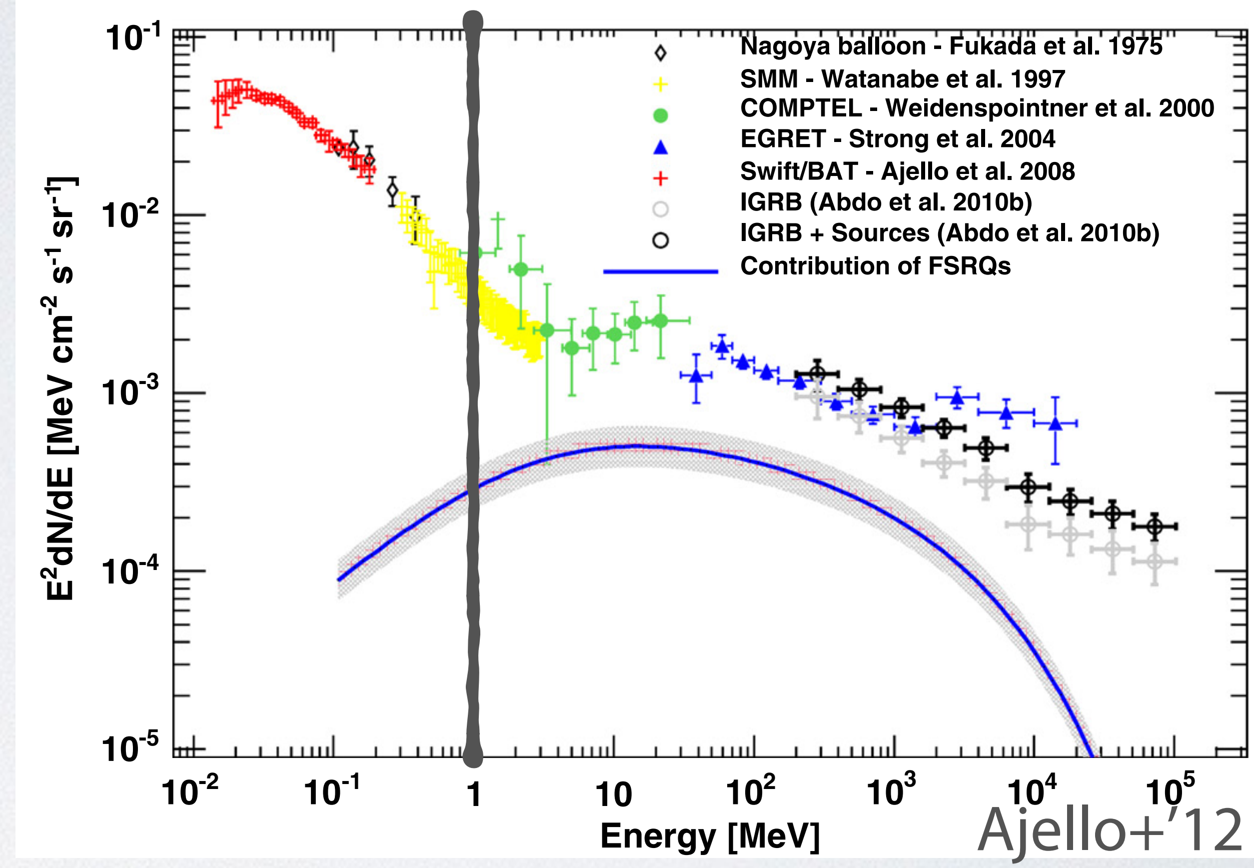
Blazars and Cosmic MeV Gamma-ray Background

Based on Swift-BAT



Ajello+’09

Based on Fermi-LAT

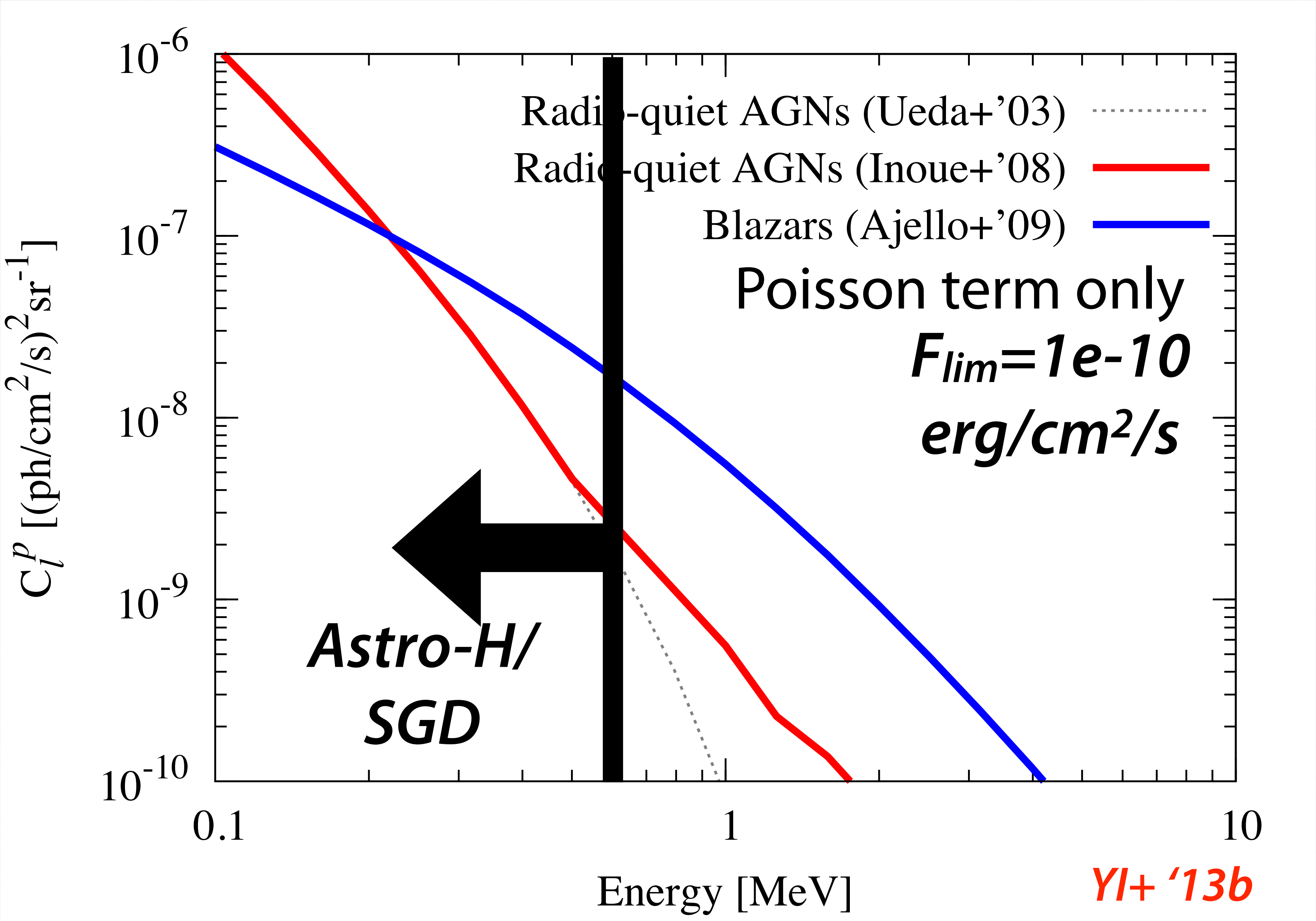


Ajello+’12

- FSRQs explain the GeV gamma-ray background with a peak at ~100 MeV (e.g. YI & Totani ’09, Ajello +’12)
- FSRQs need another peak at ~1 MeV to explain the MeV background.

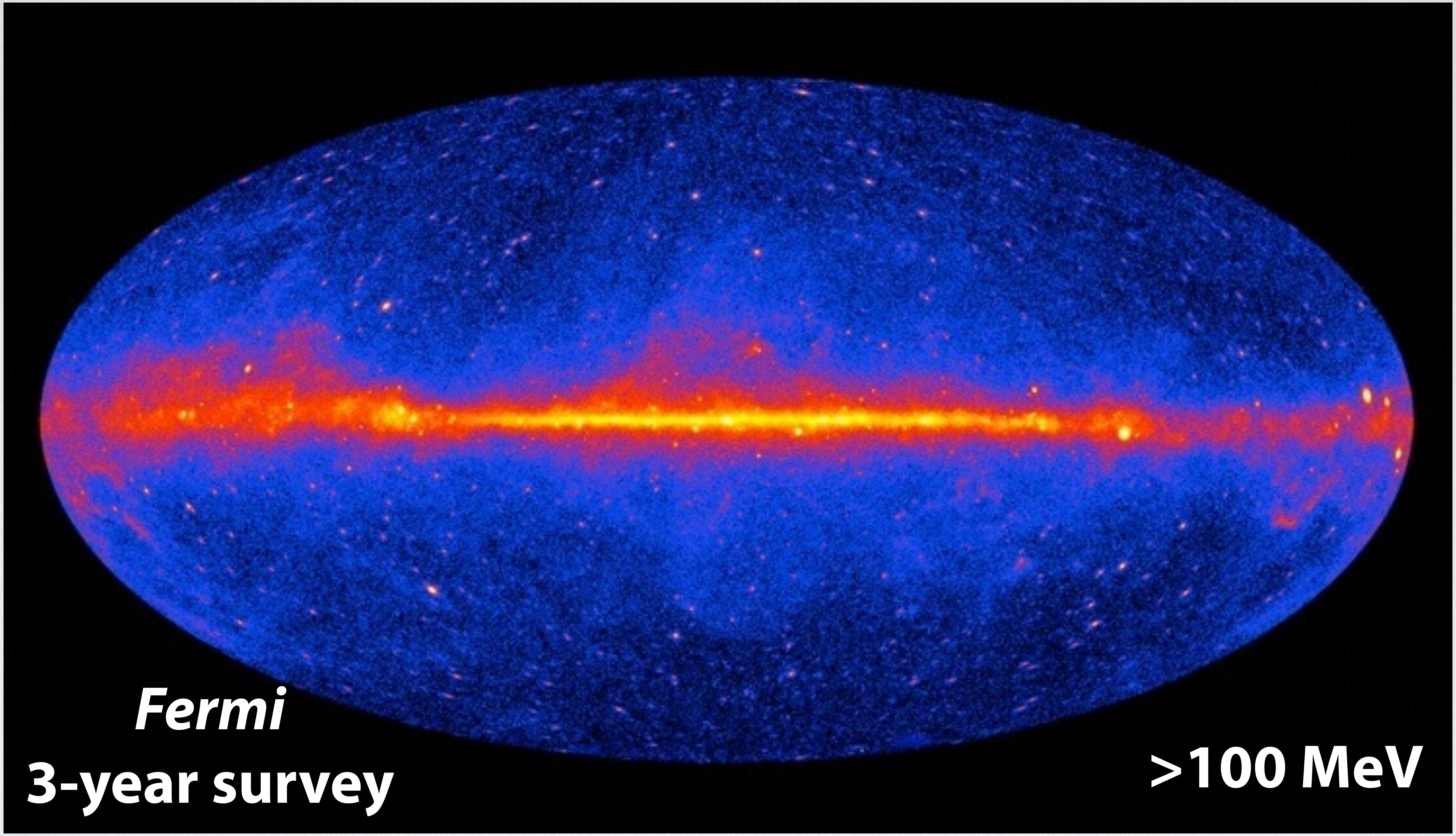
➡Two components in gamma-ray spectra?

Cosmic MeV Gamma-ray Background Anisotropy



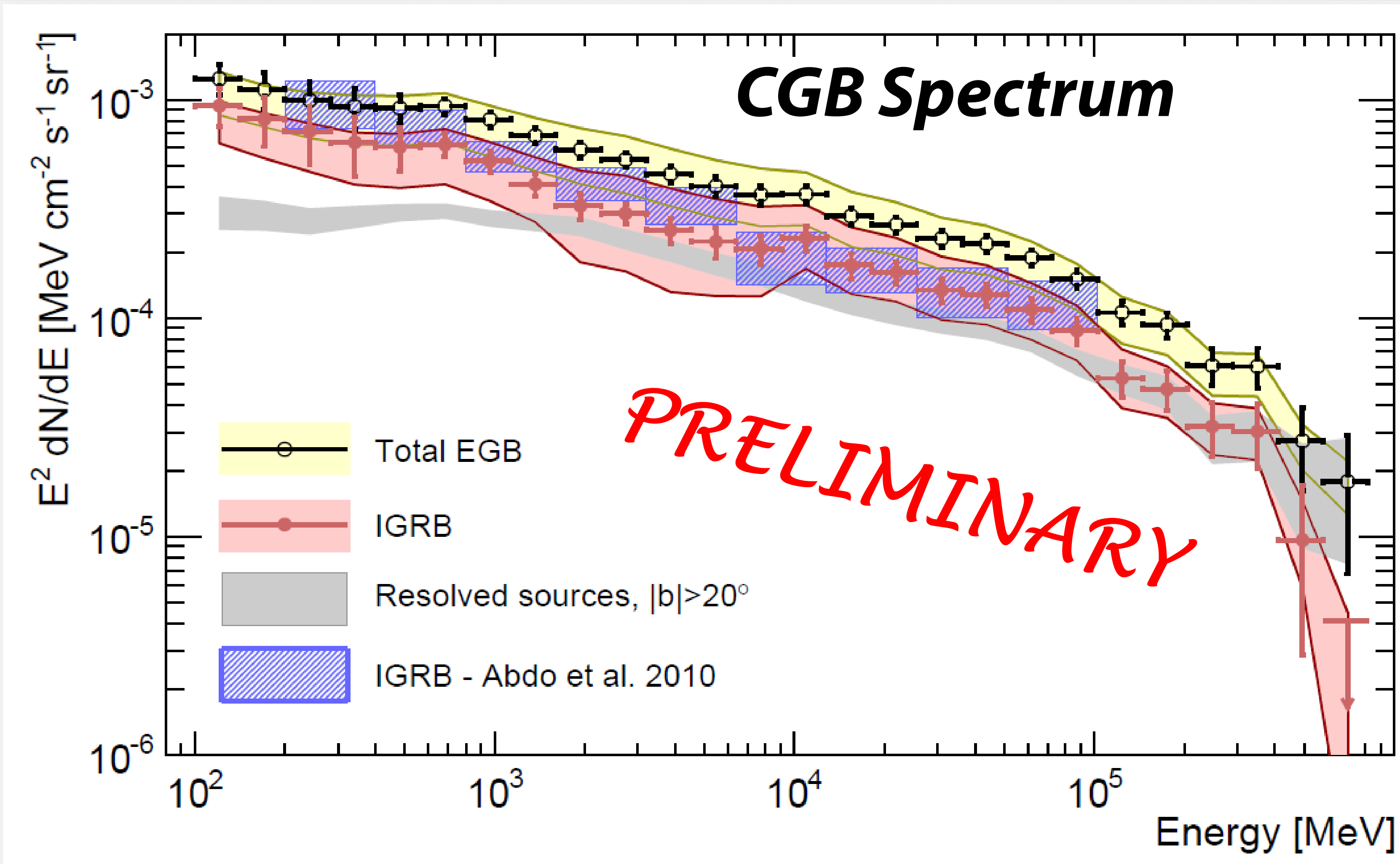
- Astro-H (SGD) / future MeV satellites will distinguish Seyfert & blazar scenarios through anisotropy in the sky.

Cosmic GeV Gamma-ray Background



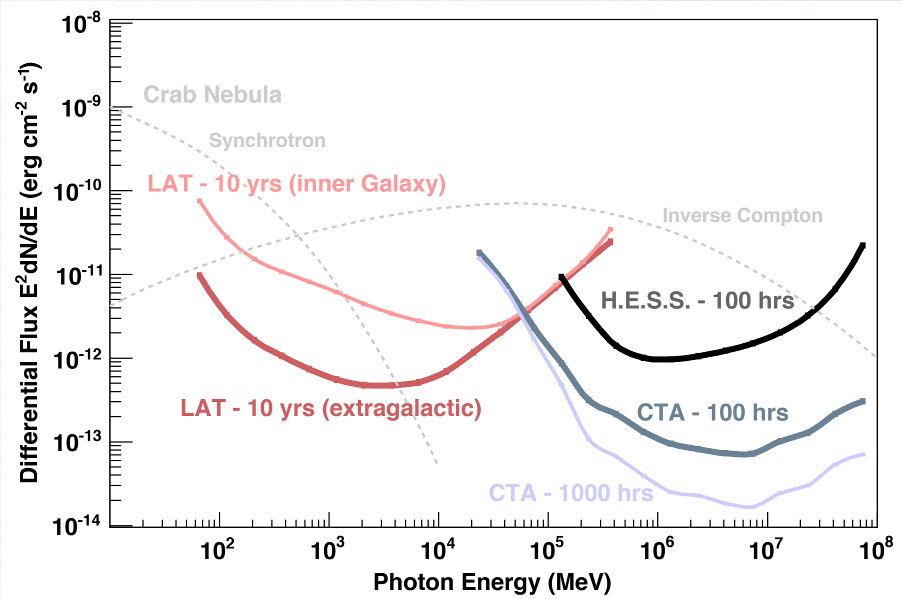
- Numerous sources are buried in the cosmic gamma-ray background (CGB).

Cosmic Gamma-ray Background Spectrum at >0.1 GeV



Bechtol+@ APS, HEM14

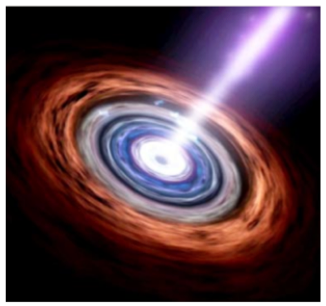
- Softening around ~400 GeV.
- Fermi resolves CGB more at higher energies?



Funk & Hinton '13

Possible Origins of CGB at GeV

Unresolved sources



Blazars

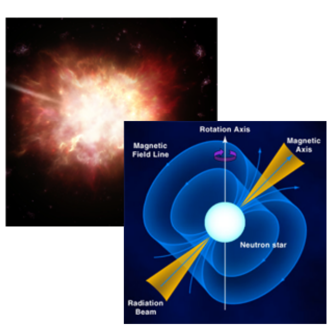
Dominant class of LAT extra-galactic sources. Many estimates in literature. EGB contribution ranging from 20% - 100%

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)



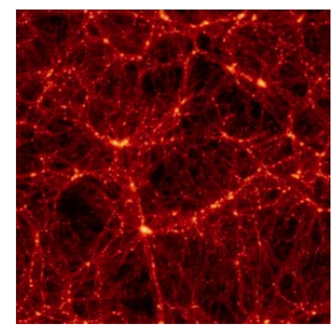
GRBs
High-latitude pulsars

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

Diffuse processes

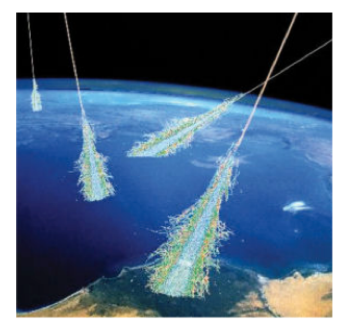
Intergalactic shocks

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

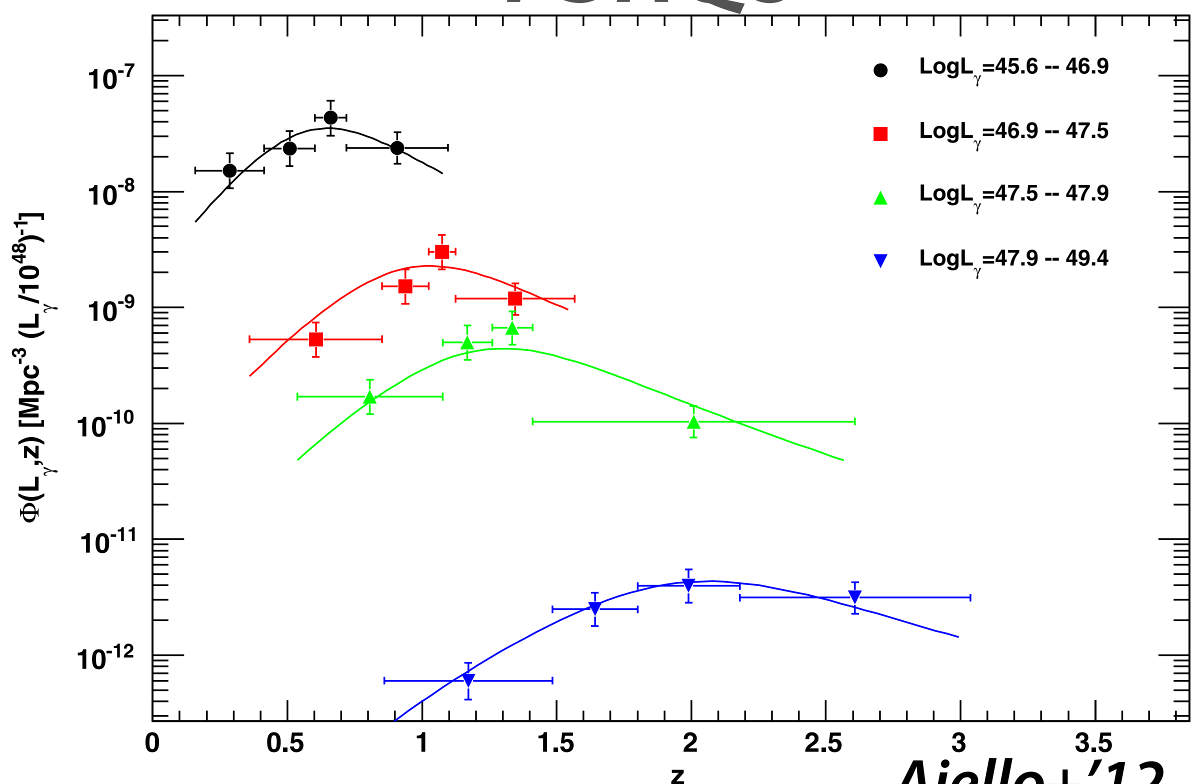
dependent on evolution of CR sources, predictions varying from 1% to 100 % (e.g. Kalashev et al. 2009)

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

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

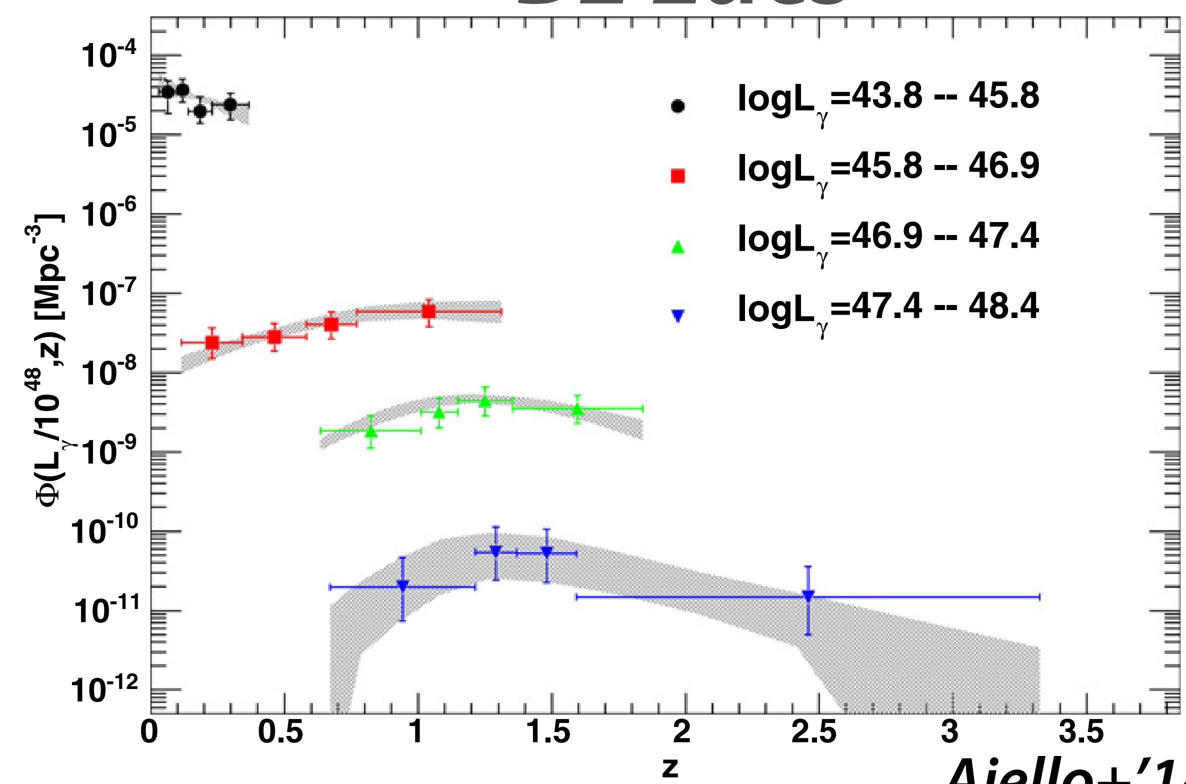
Cosmological Evolution of Blazars

FSRQs



Ajello+'12

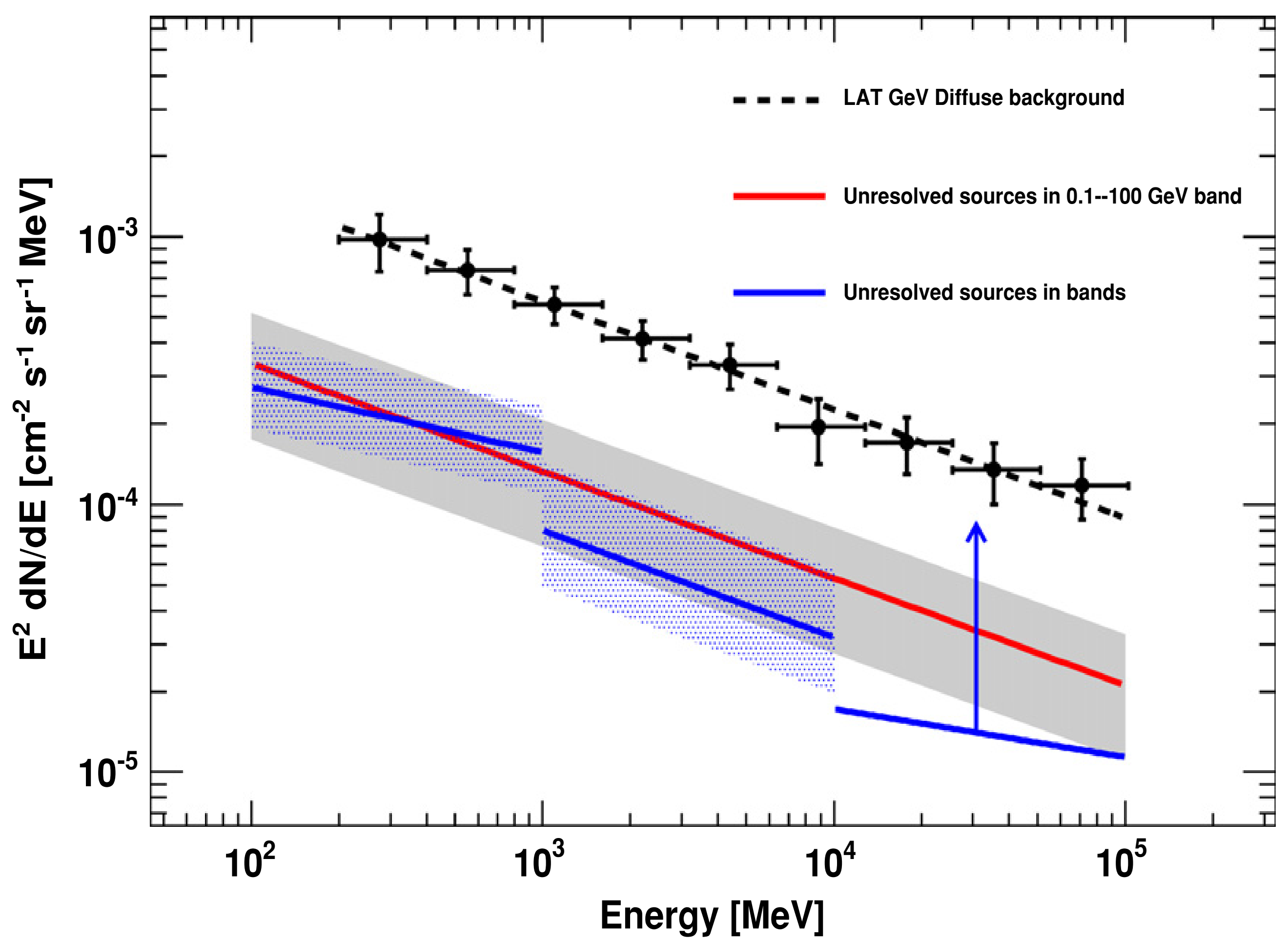
BL Lacs

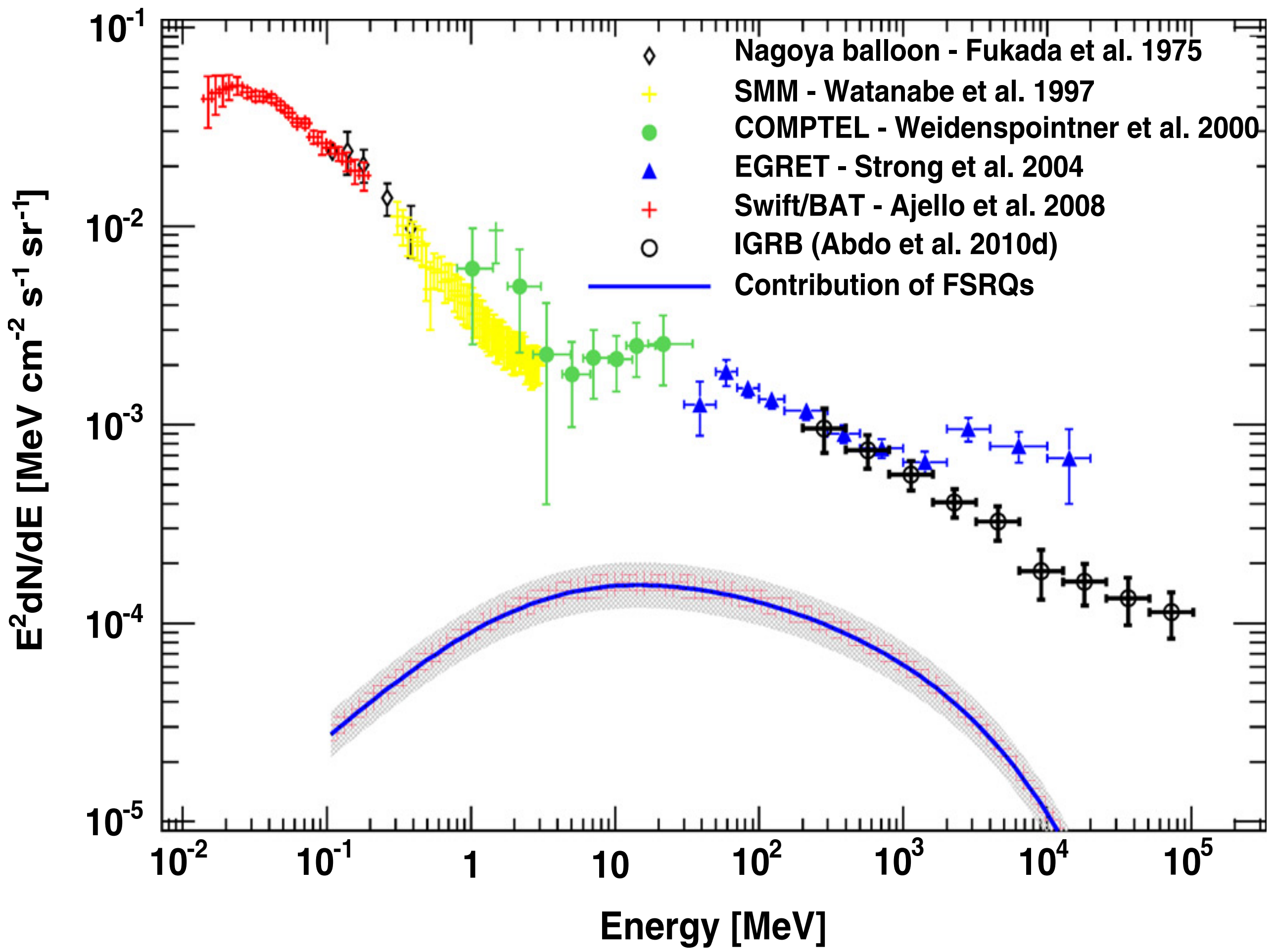


Ajello+'14

- FSRQs show positive evolution.
- LBLs & IBLs show positive evolution.
- HBLs show negative evolution.
    - Half of BL Lacs lack spectroscopic redshift information. Various redshift constraints are used.

Blazars

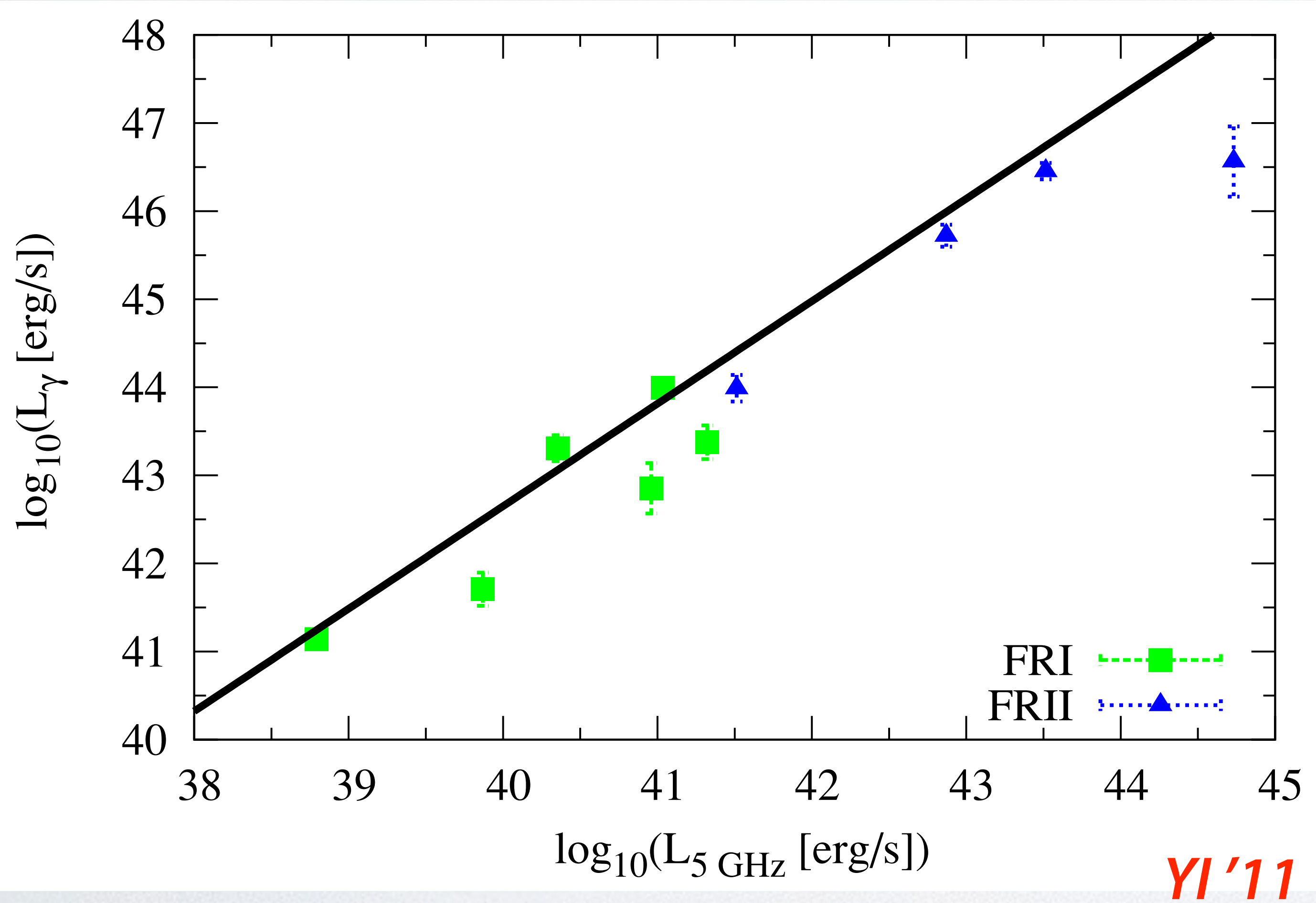


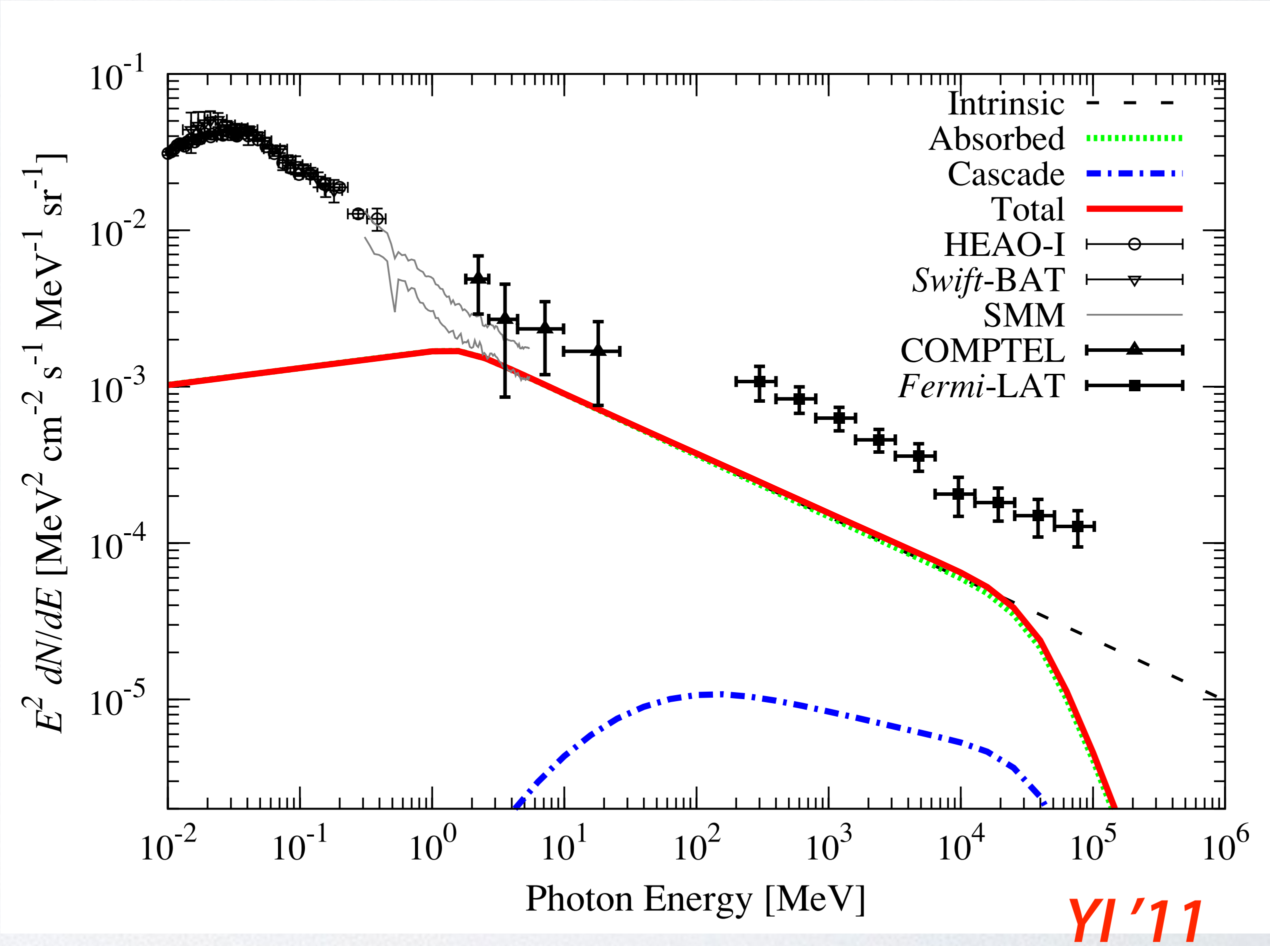


- Padovani+'93; Stecker+'93; Salamon & Stecker '94; Chiang + '95; Stecker & Salamon '96; Chiang & Mukherjee '98; Mukherjee & Chiang '99; Muecke & Pohl '00; Narumoto & Totani '06; Giommi +'06; Dermer '07; Pavlidou & Venters '08; Kneiske & Mannheim '08; Bhattacharya +'09; ***YI & Totani '09***; Abdo+'10; 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

- Blazars explain ~23% of 0.1-100 GeV CGB.
  - FSRQs explain ~9% of 0.1-100 GeV CGB.

Radio Galaxies



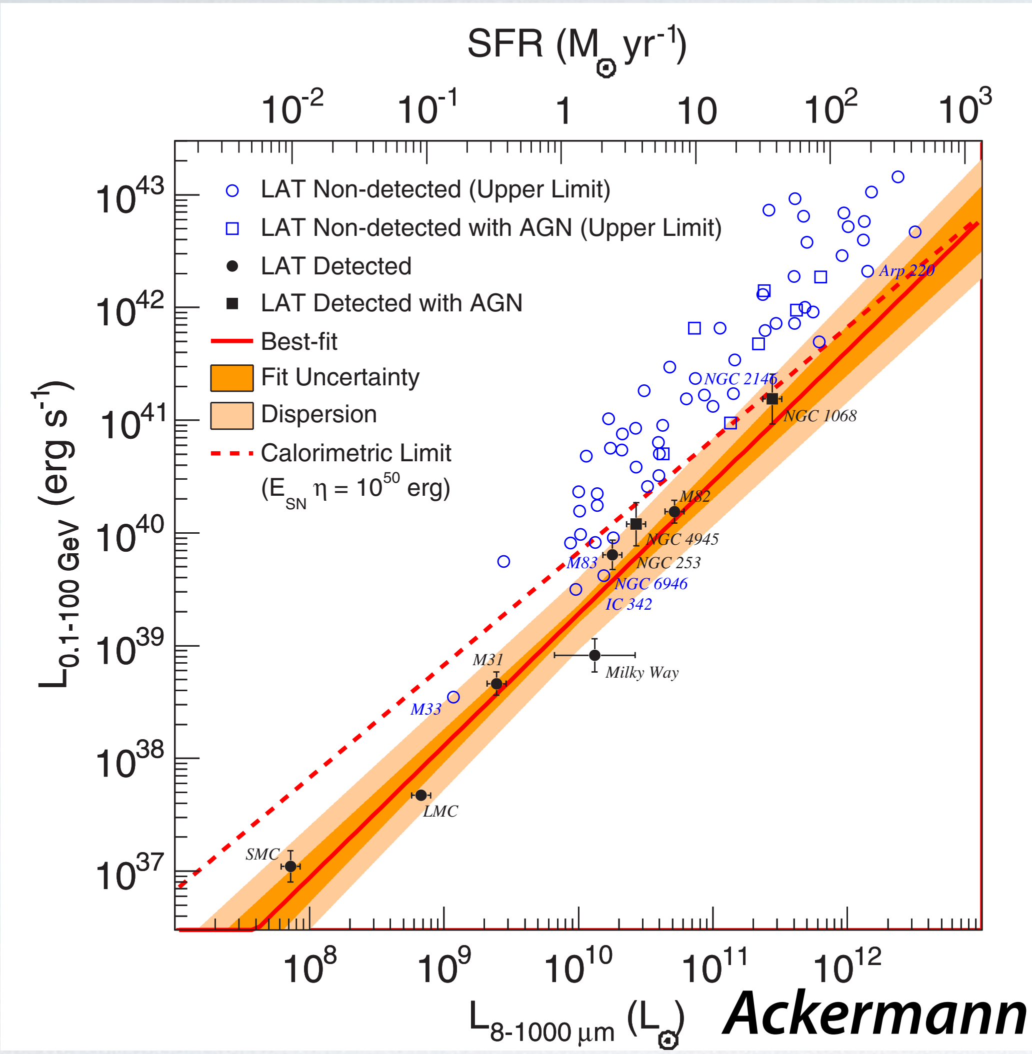


- Padovani+'93; ***YI '11***; Di Mauro+'13; Zhou & Wang '13

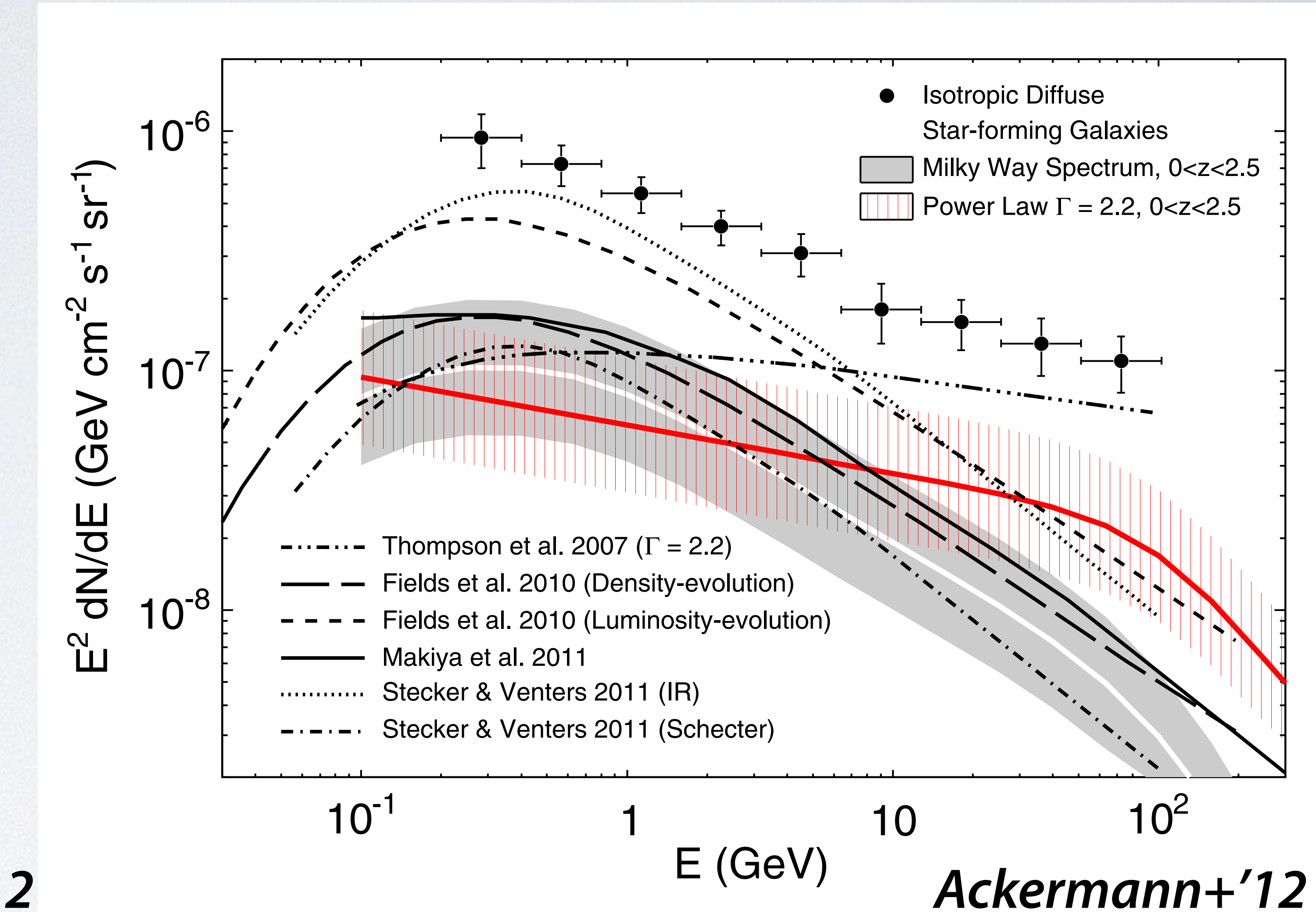
- Use gamma-ray and radio-luminosity correlation.

- ~25% of CGB

Star-forming Galaxies



Ackermann+’12



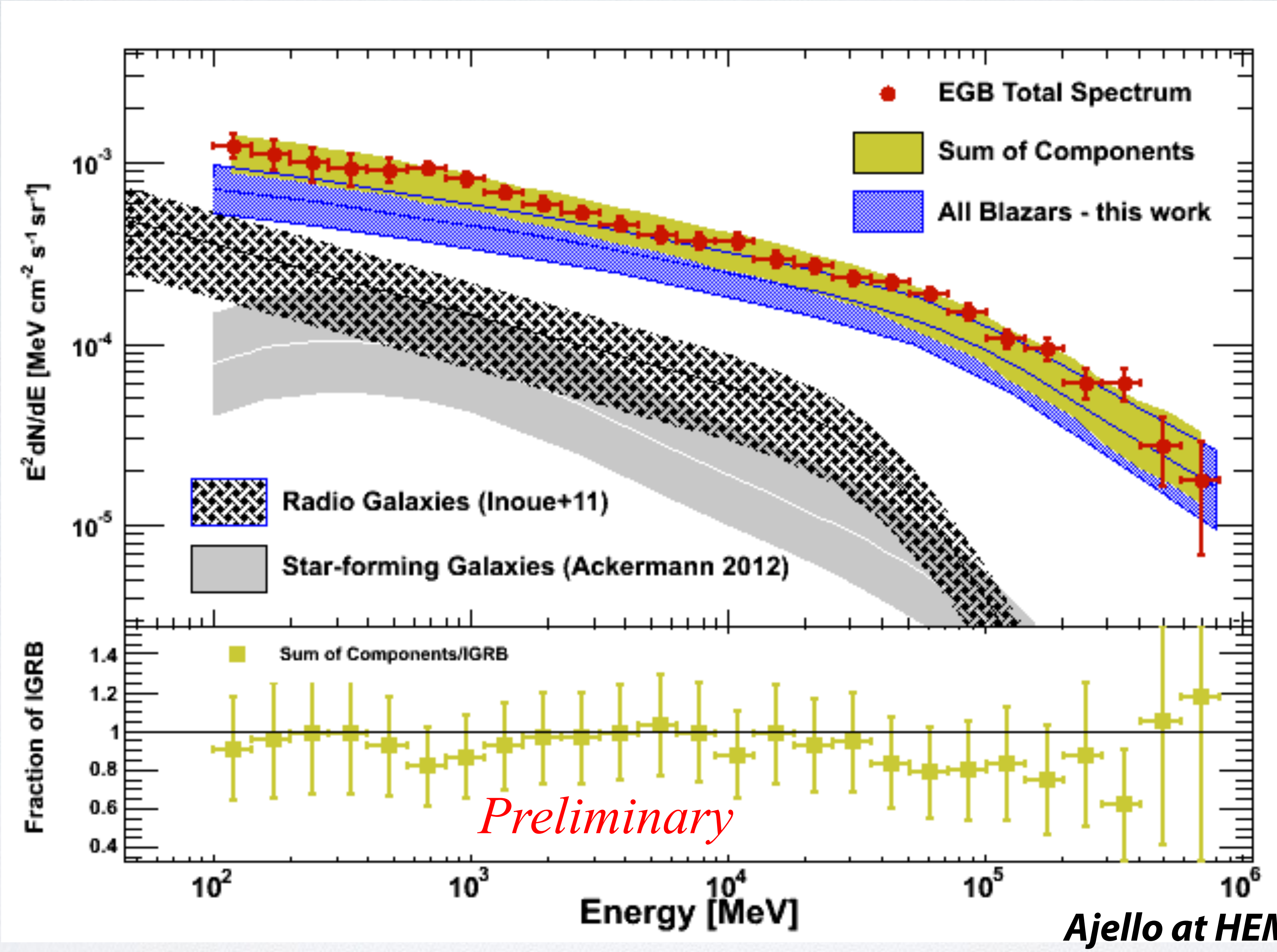
Ackermann+’12

- 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

- Use gamma-ray and infrared luminosity correlation

- 4 - 23% of CGB

Components of Cosmic Gamma-ray Background

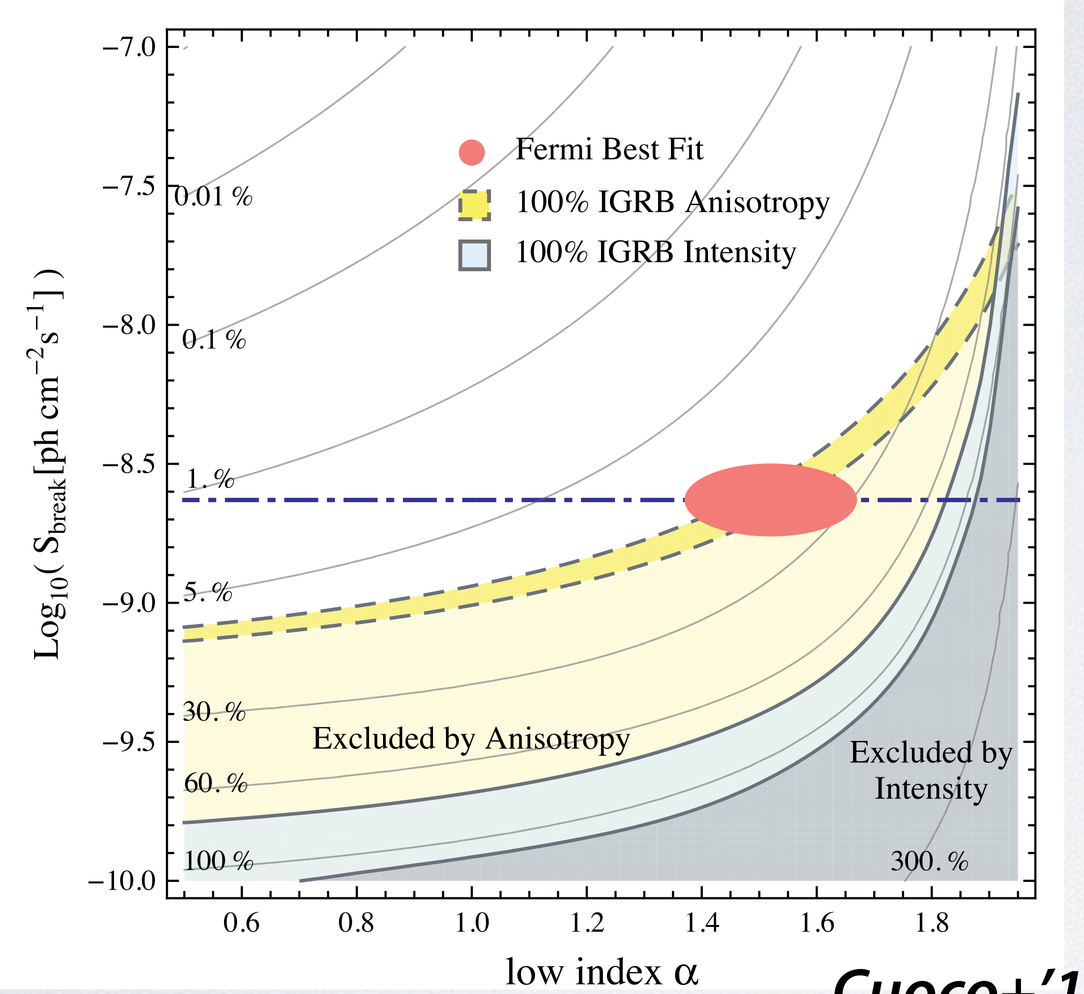


Ajello at HEM14

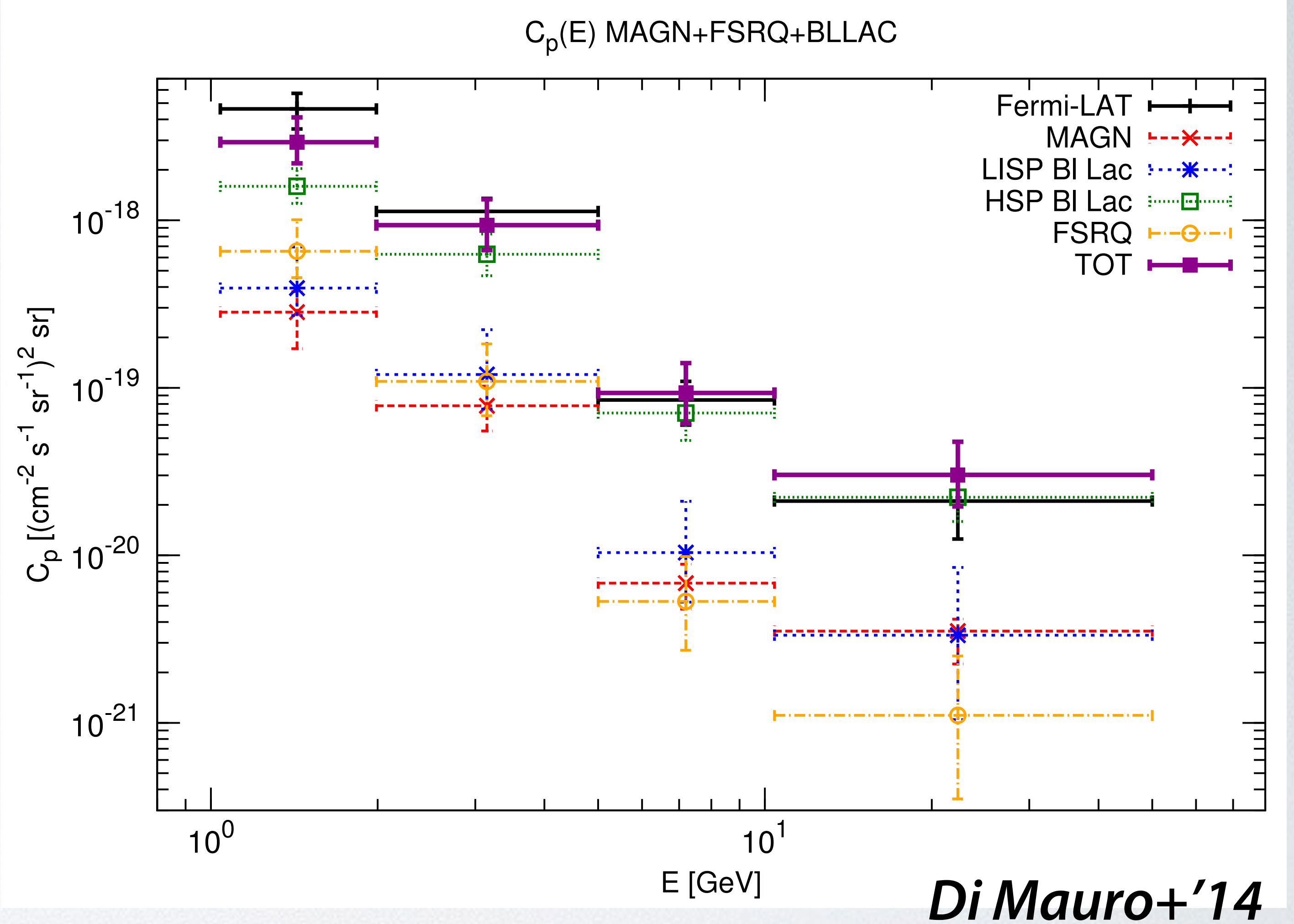
- FSRQs (Ajello+'12), BL Lacs (Ajello+'14), Radio gals. (YI'11), Star-forming gals. (Ackermann+'12) are guaranteed.

- little room for dark matters?

Anisotropy of Cosmic Gamma-ray Background



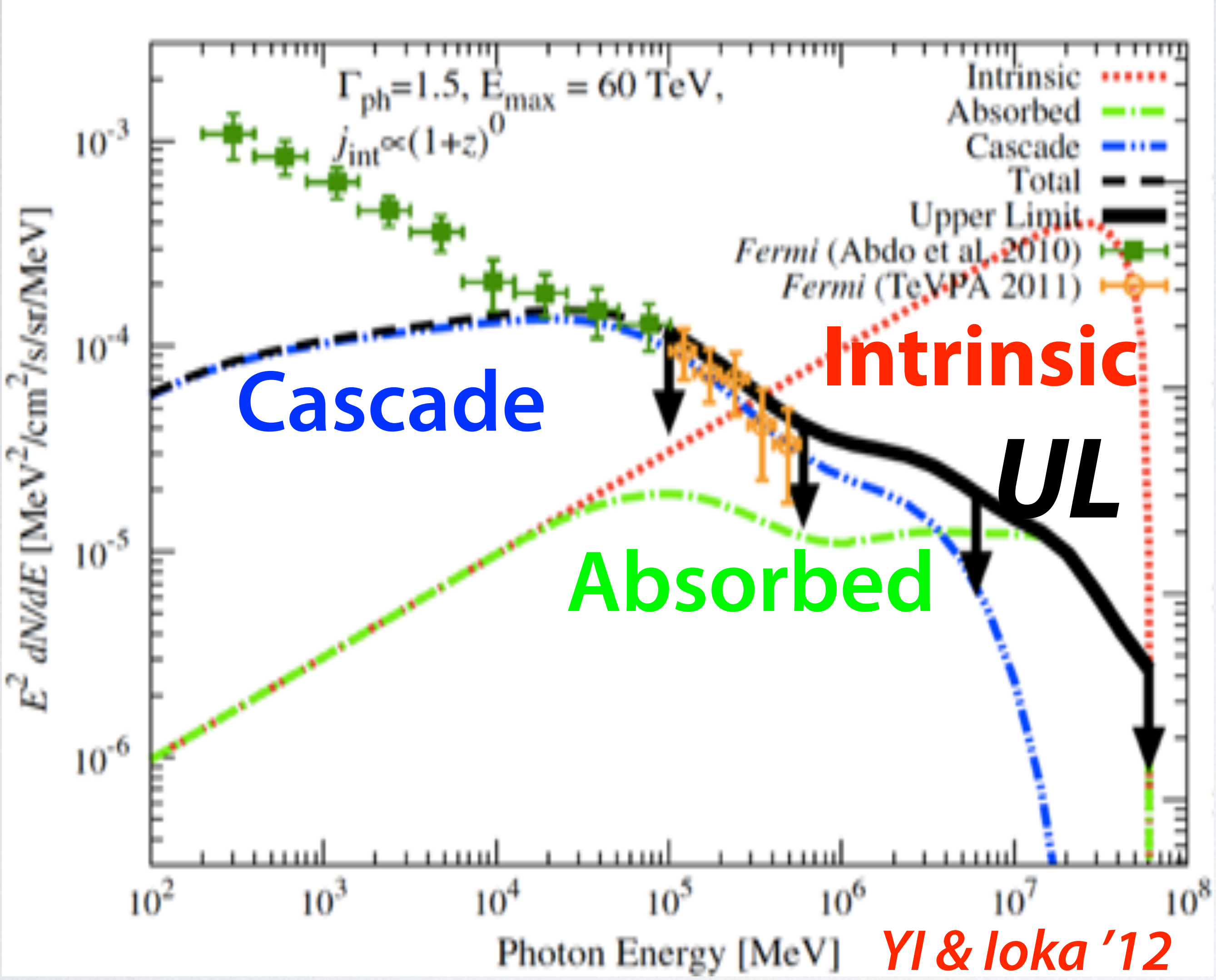
Cuoco+'12

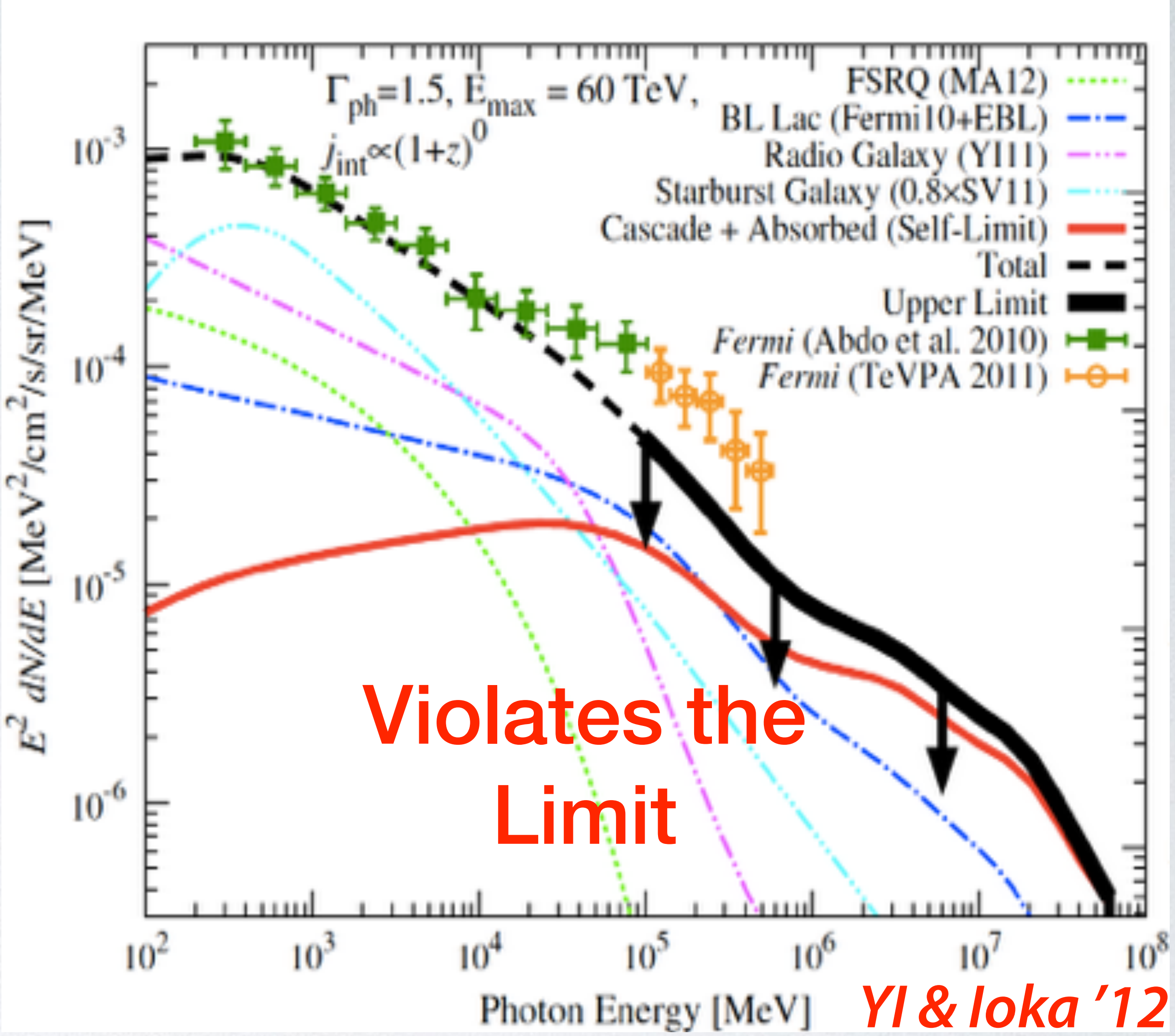


Di Mauro+'14

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

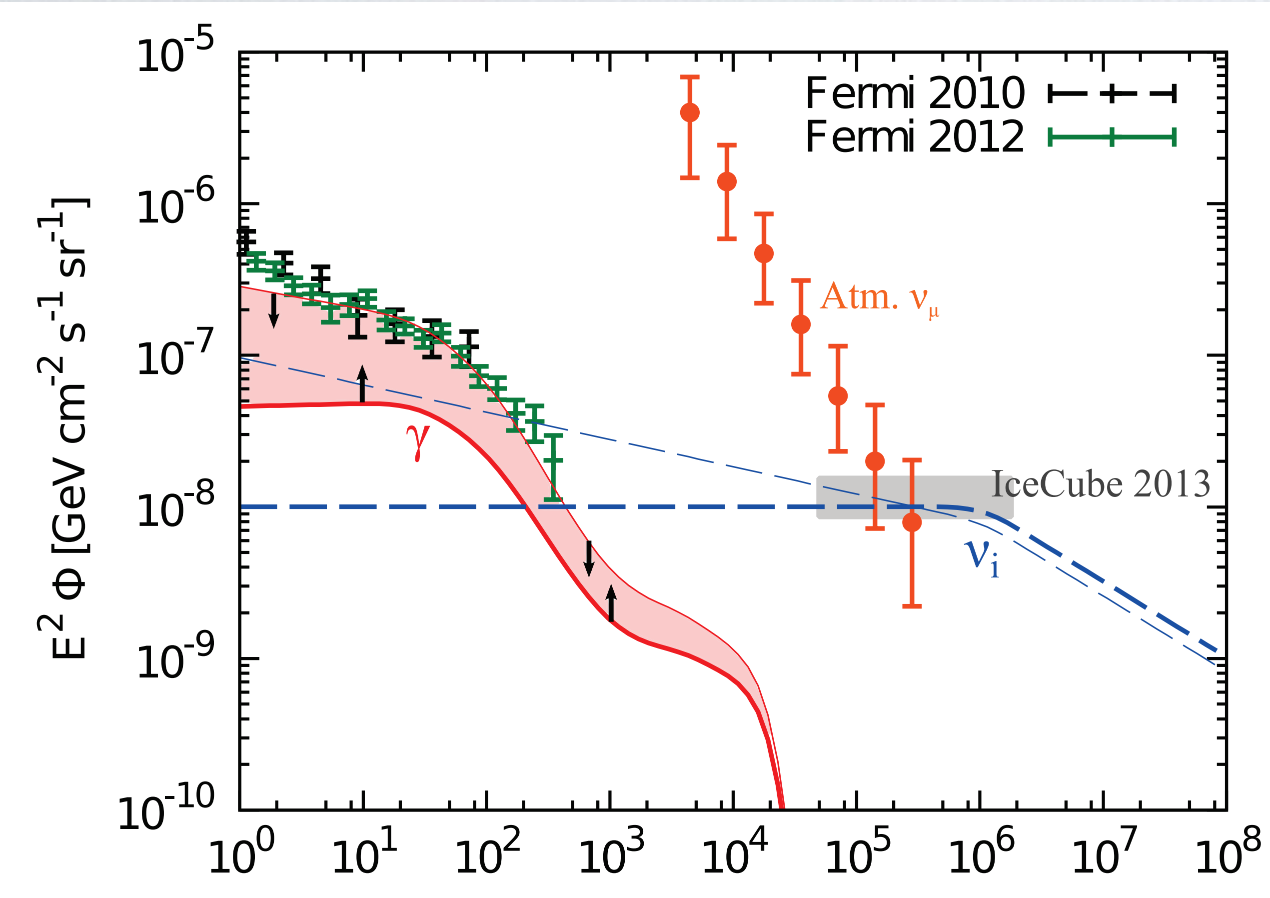
Upper Limit on Cosmic Gamma-ray Background



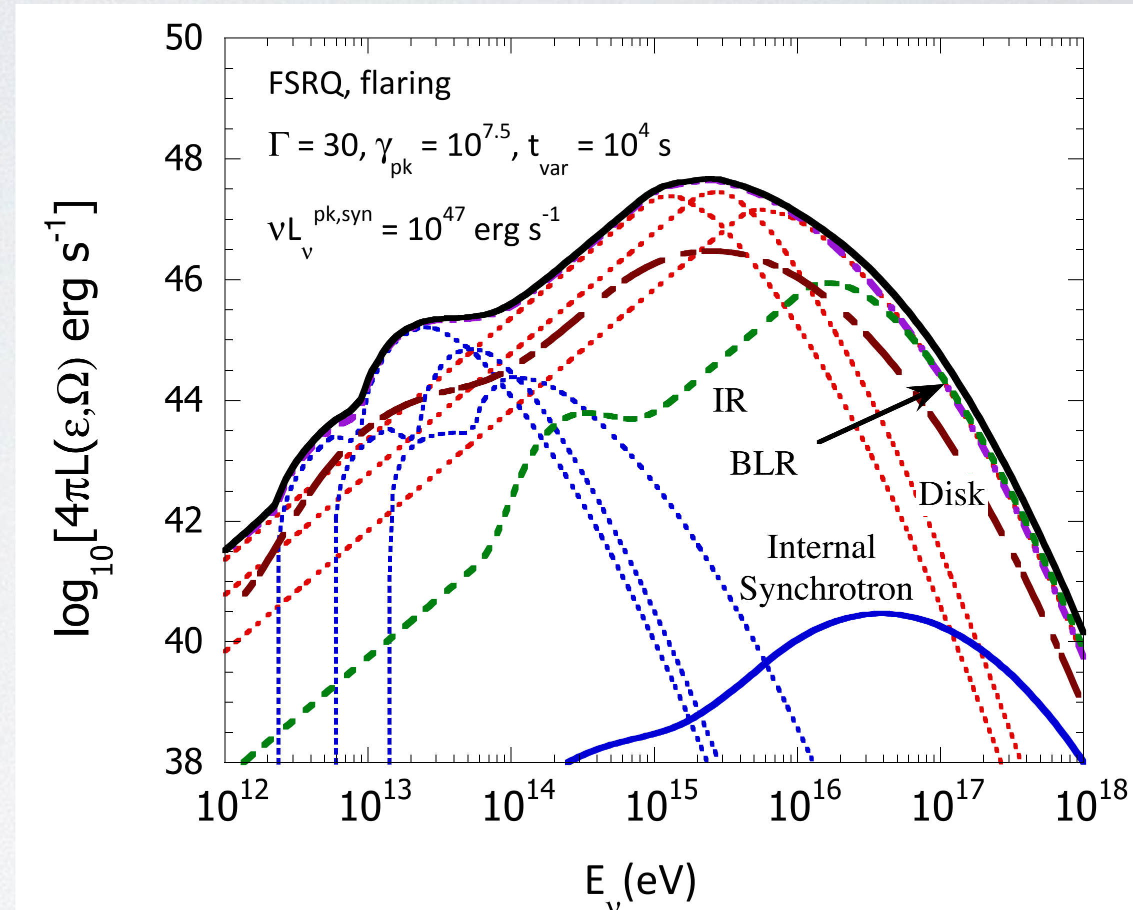


- Cascade component from VHE CGB can not exceed the Fermi data (see also Murase+'12).
  - Negative evolution is required.
  - If we try to explain CGB at <10GeV by known sources, the observation violates the limit.

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).

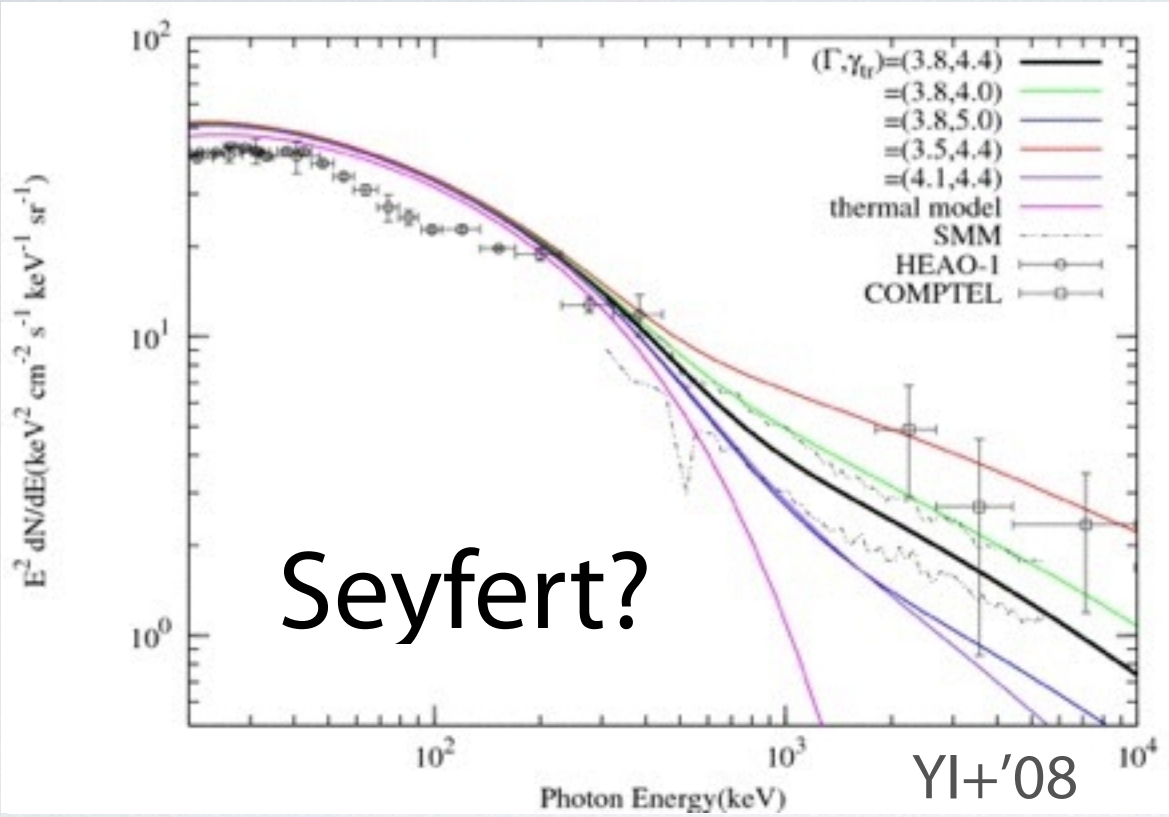
- Extragalactic pγ scenario (FSRQs) will have a low-energy cut-off feature at ~PeV (Murase, YI, & Dermer '14, Dermer, Murase, & YI '14).

Summary

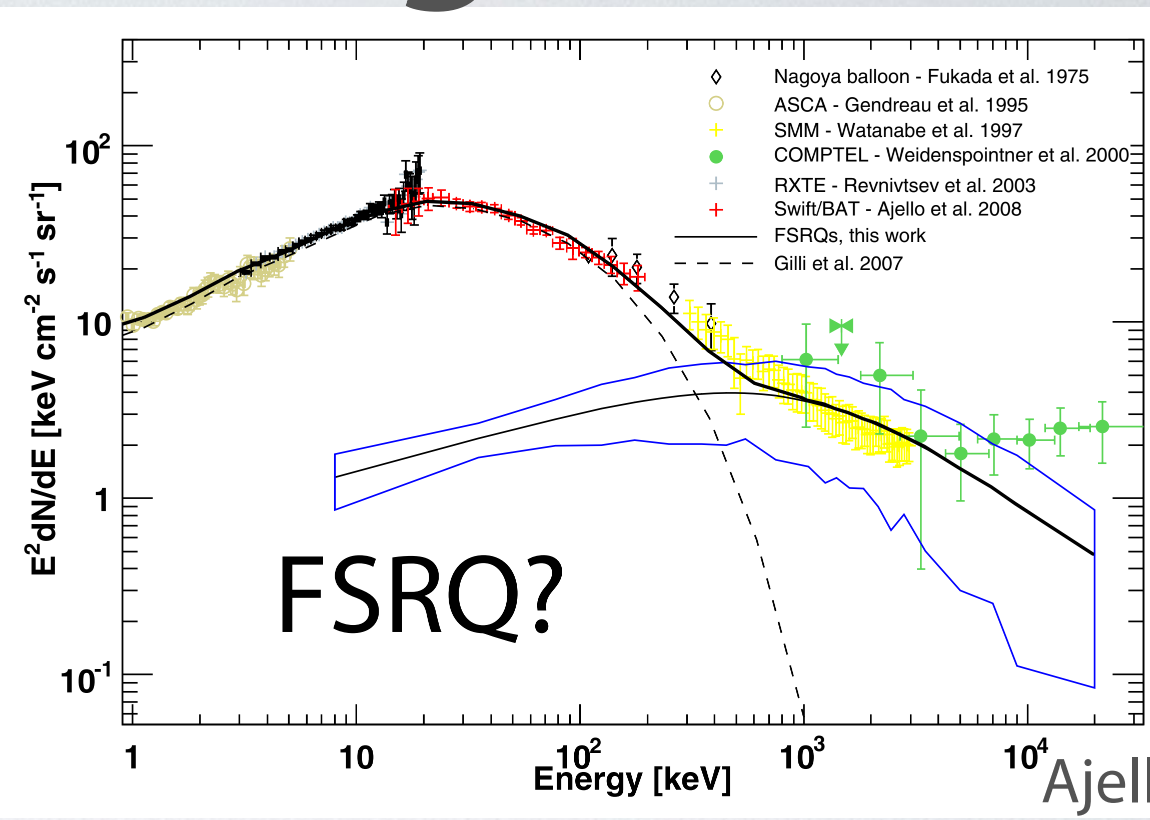
- CGB at MeV band may be come from blazars or Seyferts.
    - Anisotropy measurement will distinguish these two scenarios.
- CGB above >100 MeV is composed of blazars, radio galaxies, and star-forming galaxies.
    - Cascade emission put a strong limit on the origin of the VHE CGB.
    - Need to check consistency with IceCube neutrino measurements.

Backup

Cosmic MeV Background



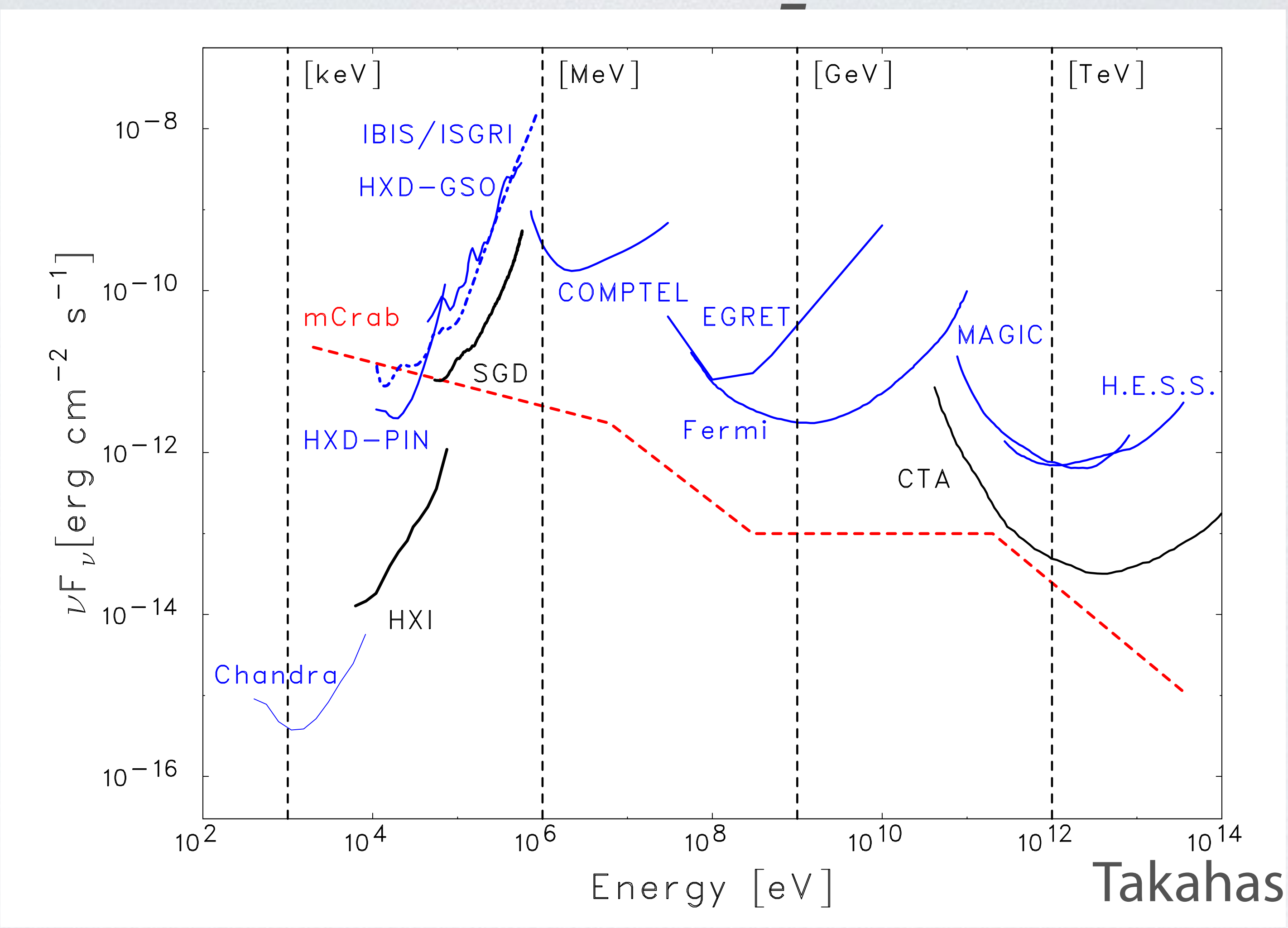
YI+’08



Ajello+’09

- Type Ia Supernovae? (e.g. Clayton+’75) -> not enough (e.g. Horiuchi+’09).
- Radio Galaxies? (e.g. Strong+’76) -> not enough (e.g. Massaro & Ajello ’11, ***YI’11***)
- MeV Dark Matters? (e.g. Olive & Silk ’85) -> Mass of DM candidates are mostly in GeV-TeV ranges
- Seyferts? (Schoenfelder ’78; ***YI+’08***) -> Magnetic Reconnection Heated Corona (Liu+’02)?
- FSRQs? (Ajello+’09) -> Two (MeV & GeV) components in gamma-ray spectra?

It is not easy to resolve the

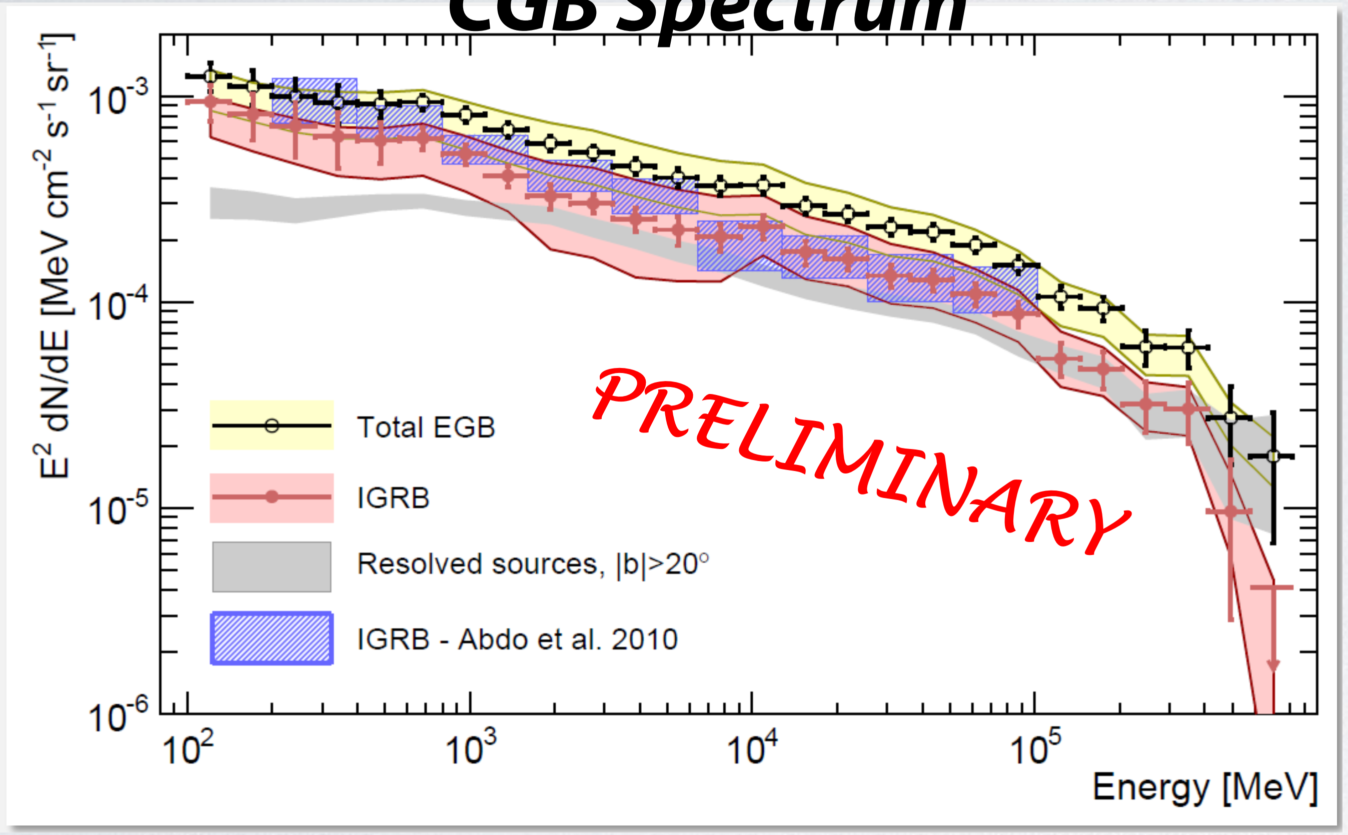


Takahashi+'13

- Answers are in "***Anisotropy***".
  - Cosmic background radiation is not isotropic.
  - There is anisotropy due to the sky distribution of its origins.

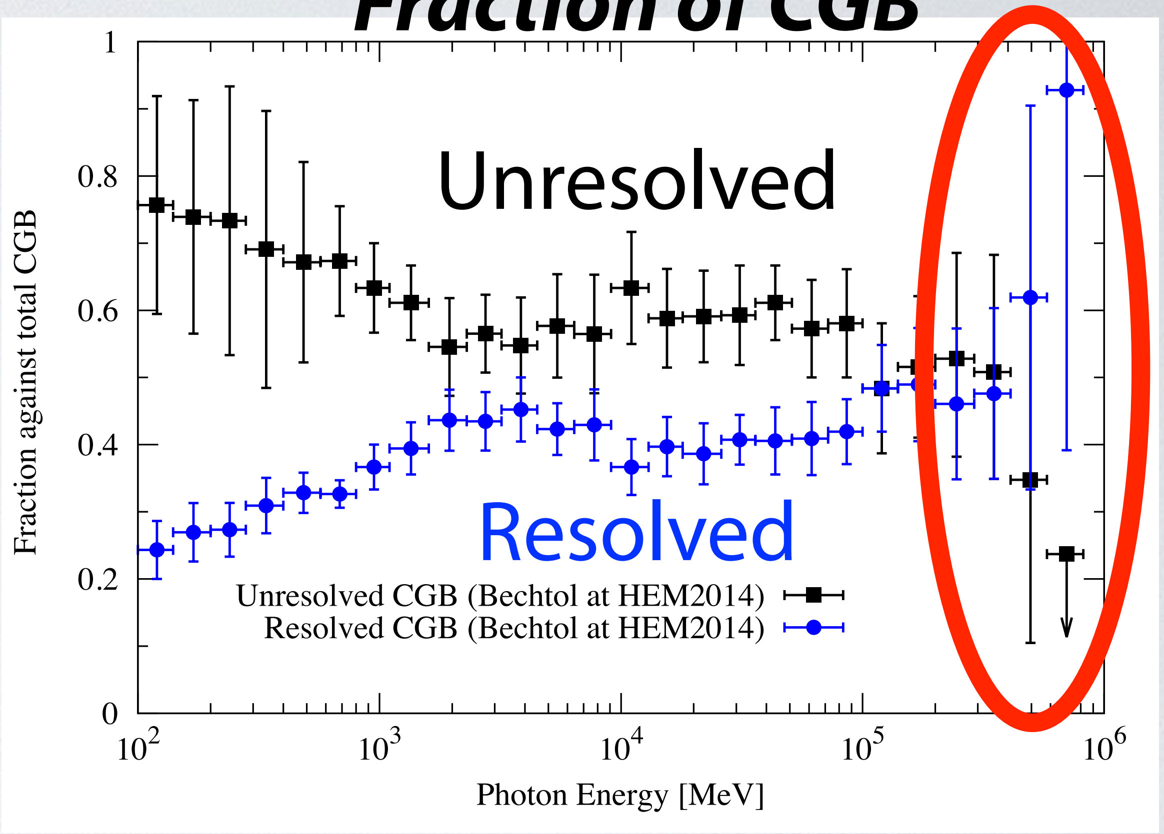
Cosmic Gamma-ray Background Spectrum

CGB Spectrum

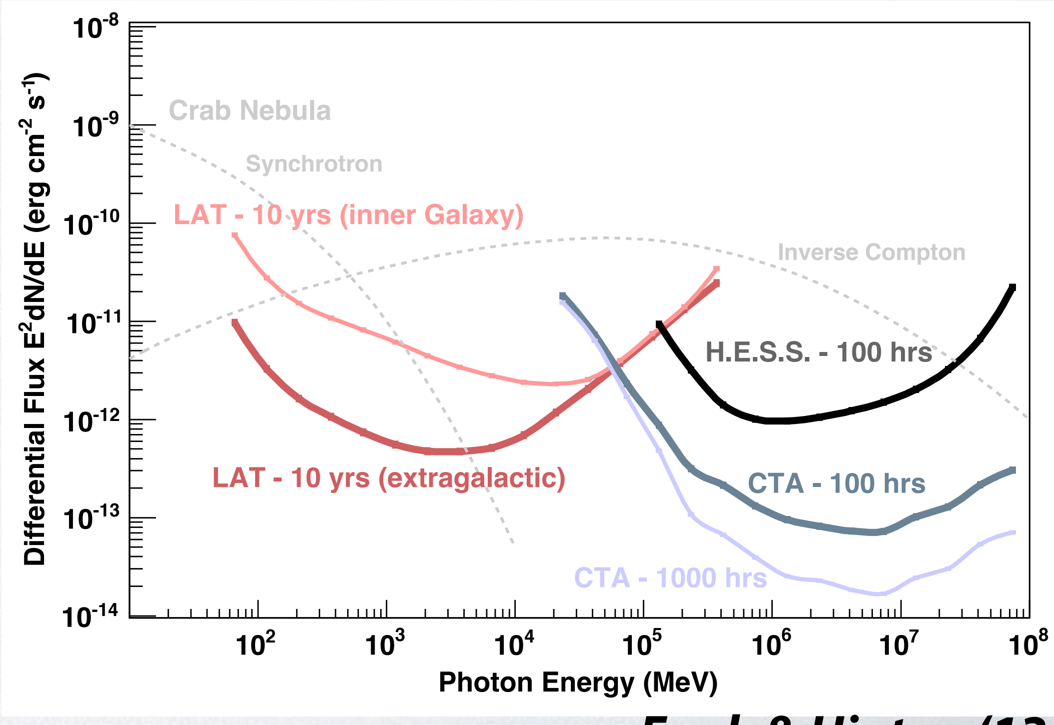


Bechtol+@ APS, HEM14

Fraction of CGB

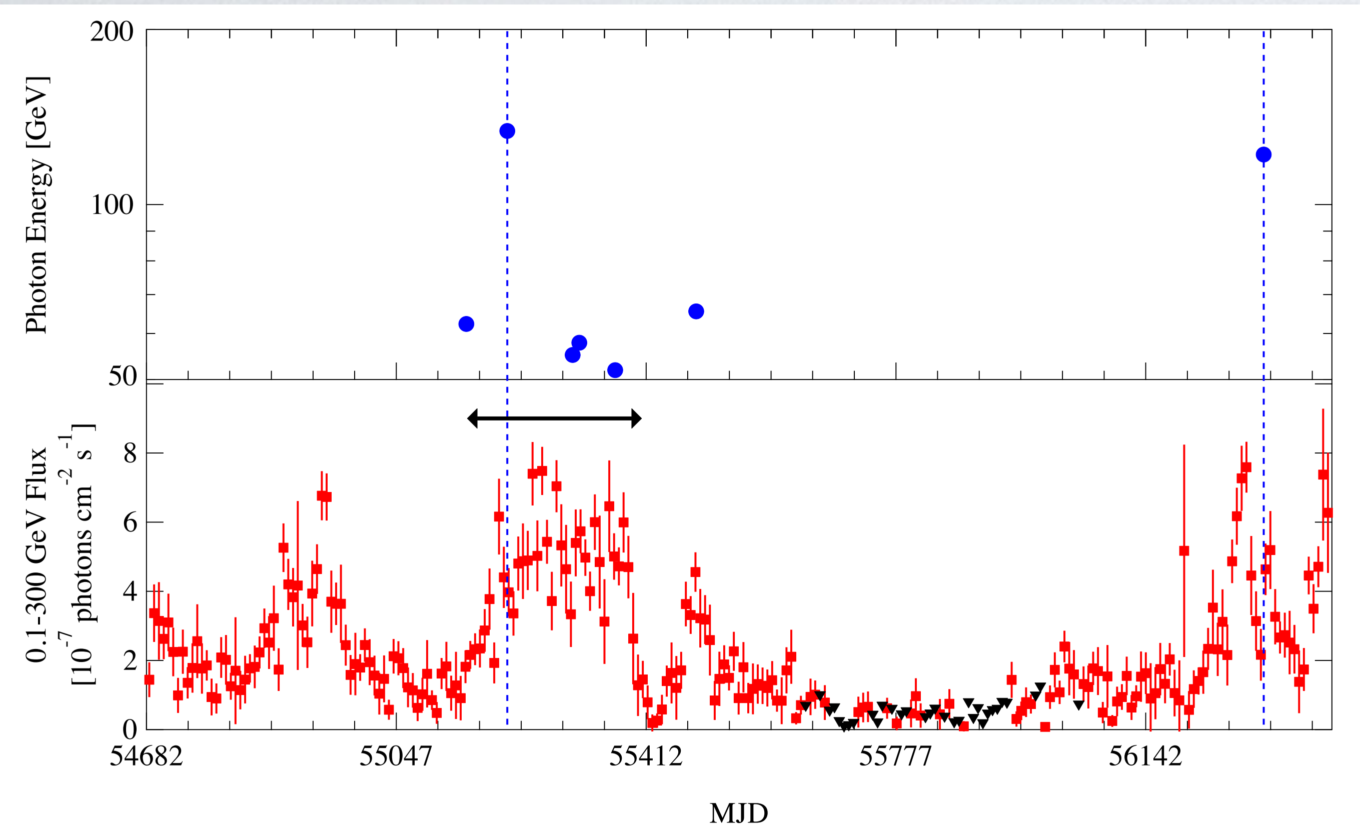


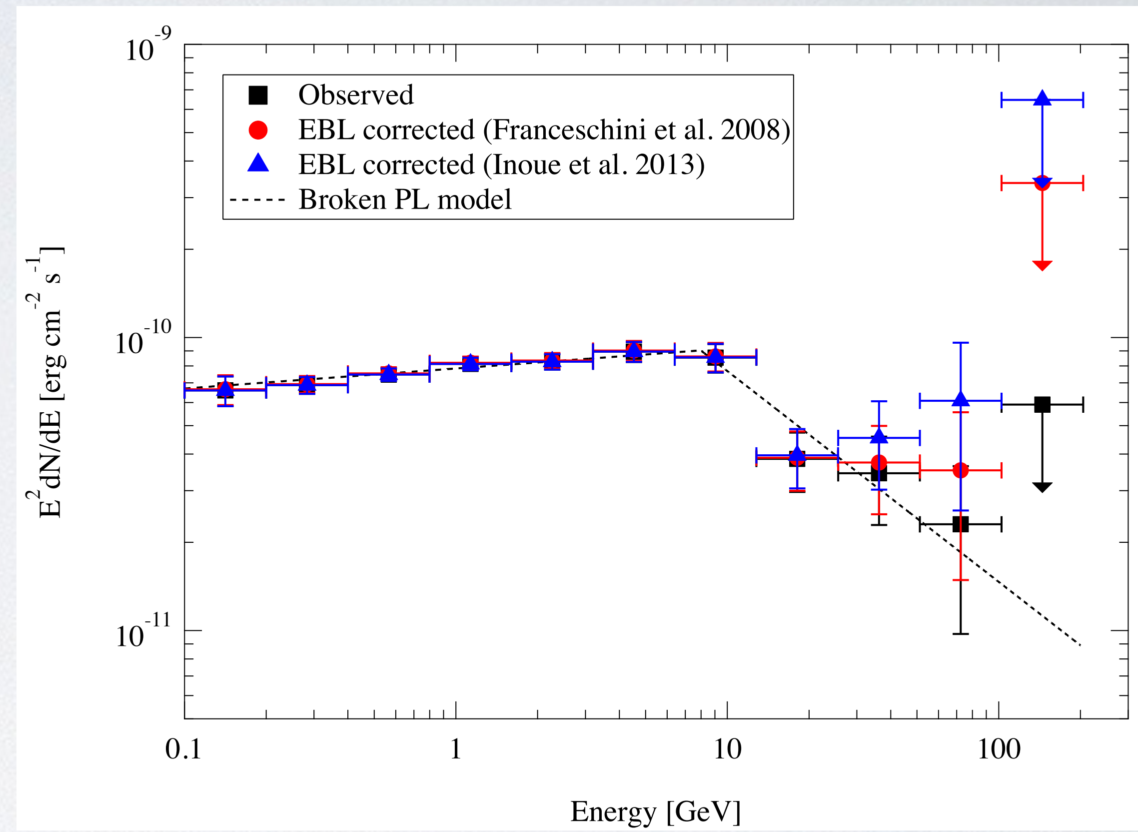
- Softening around ~400 GeV.
- Fermi resolves CGB more at higher energies?



Funk & Hinton '13

Two VHE (>100 GeV) gamma rays from PKS 0426-380 at z=1.1

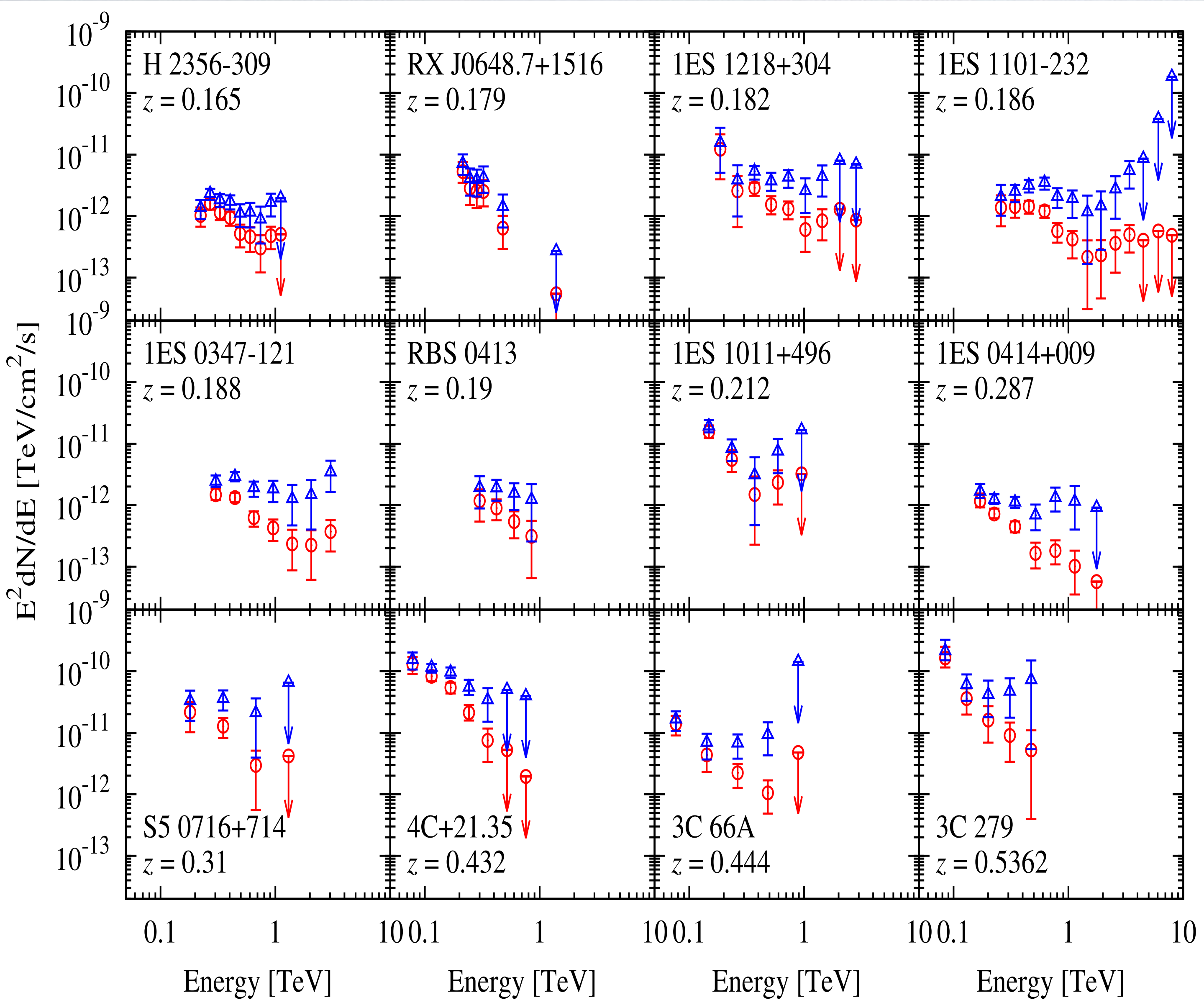




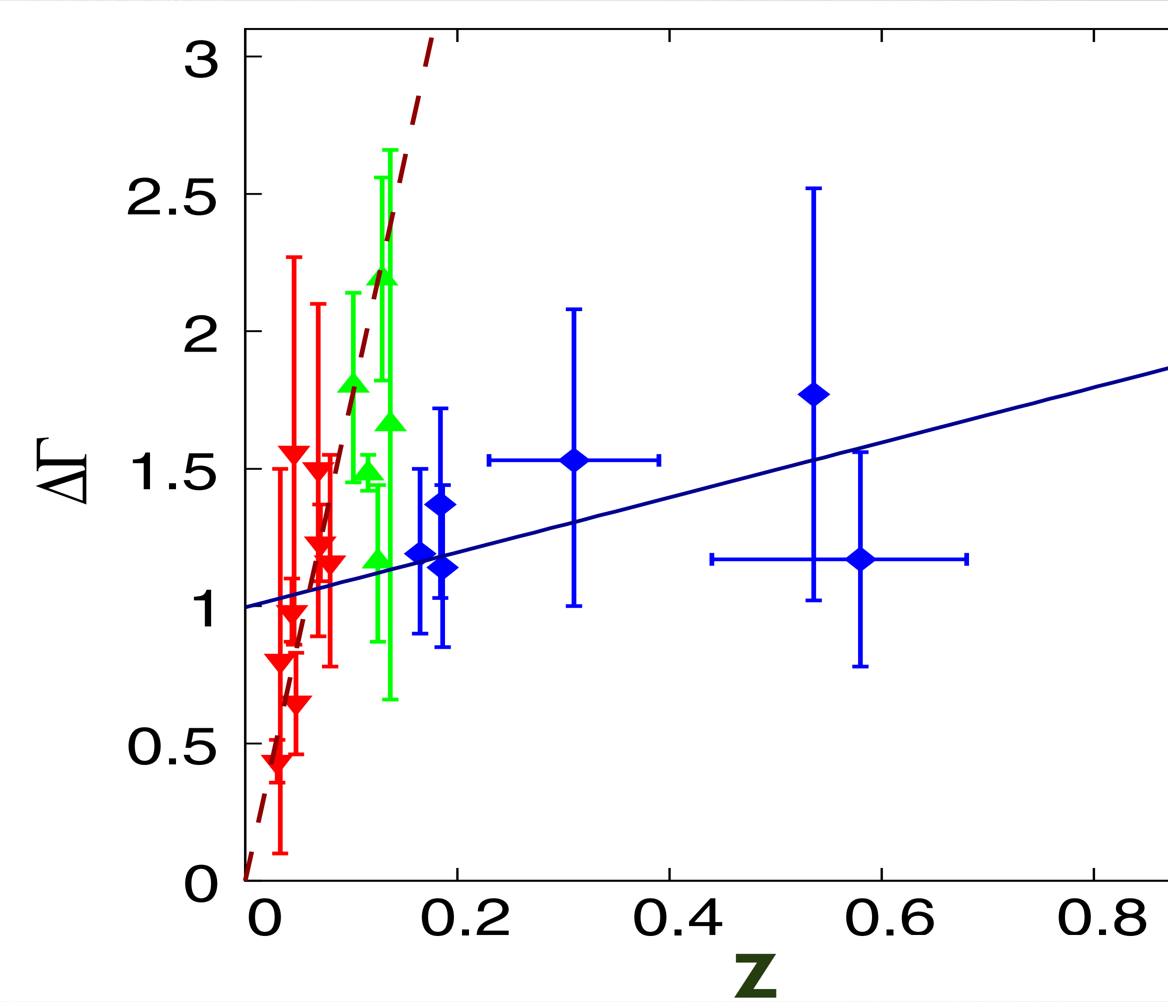
Tanaka, YI, +'13

- 2 VHE photons at flaring states, but not an exact correspondence to the peak of each flare.
- Spectral hardening from ~30 GeV.

Is VHE Spectral Hardening Universal?



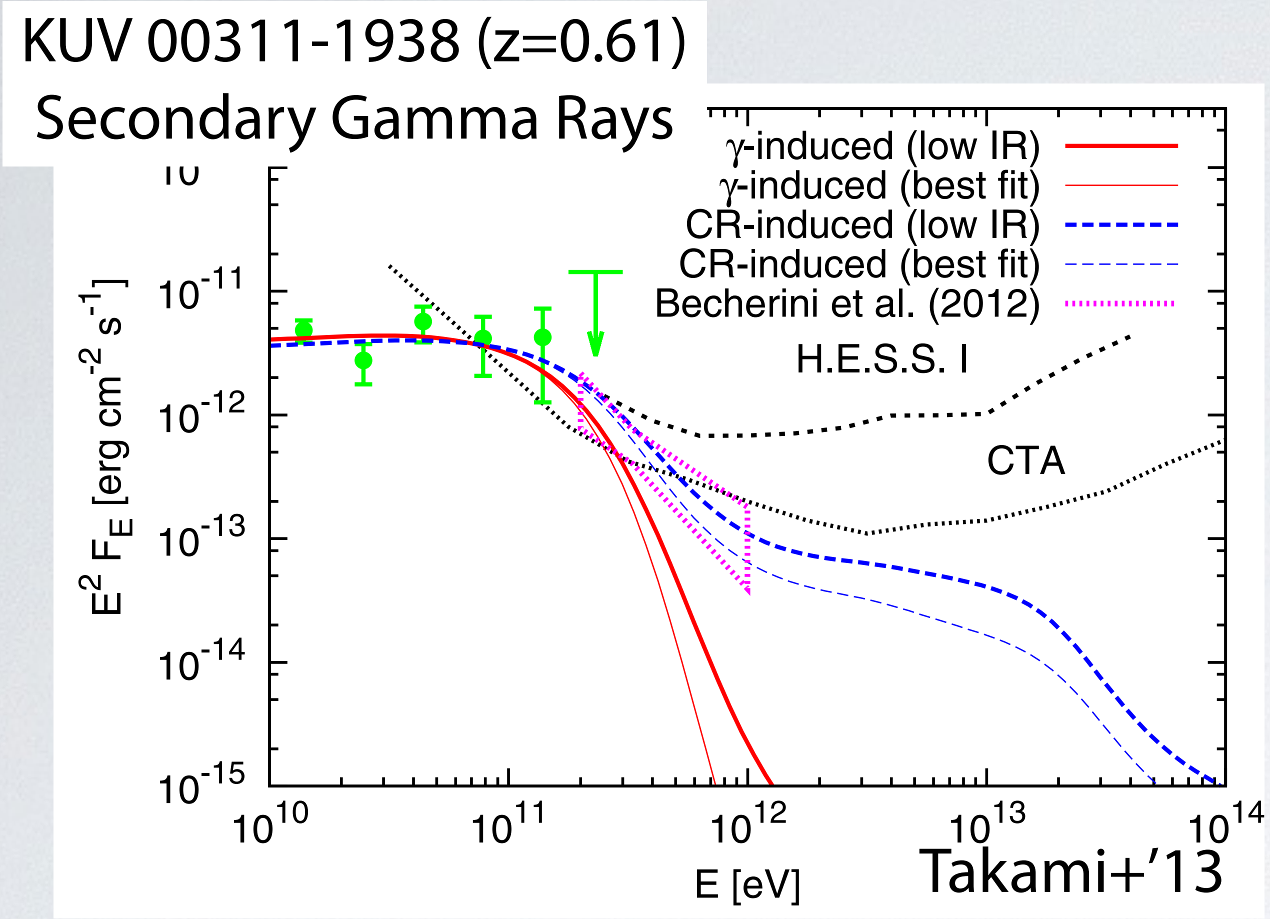
Yl+'13a

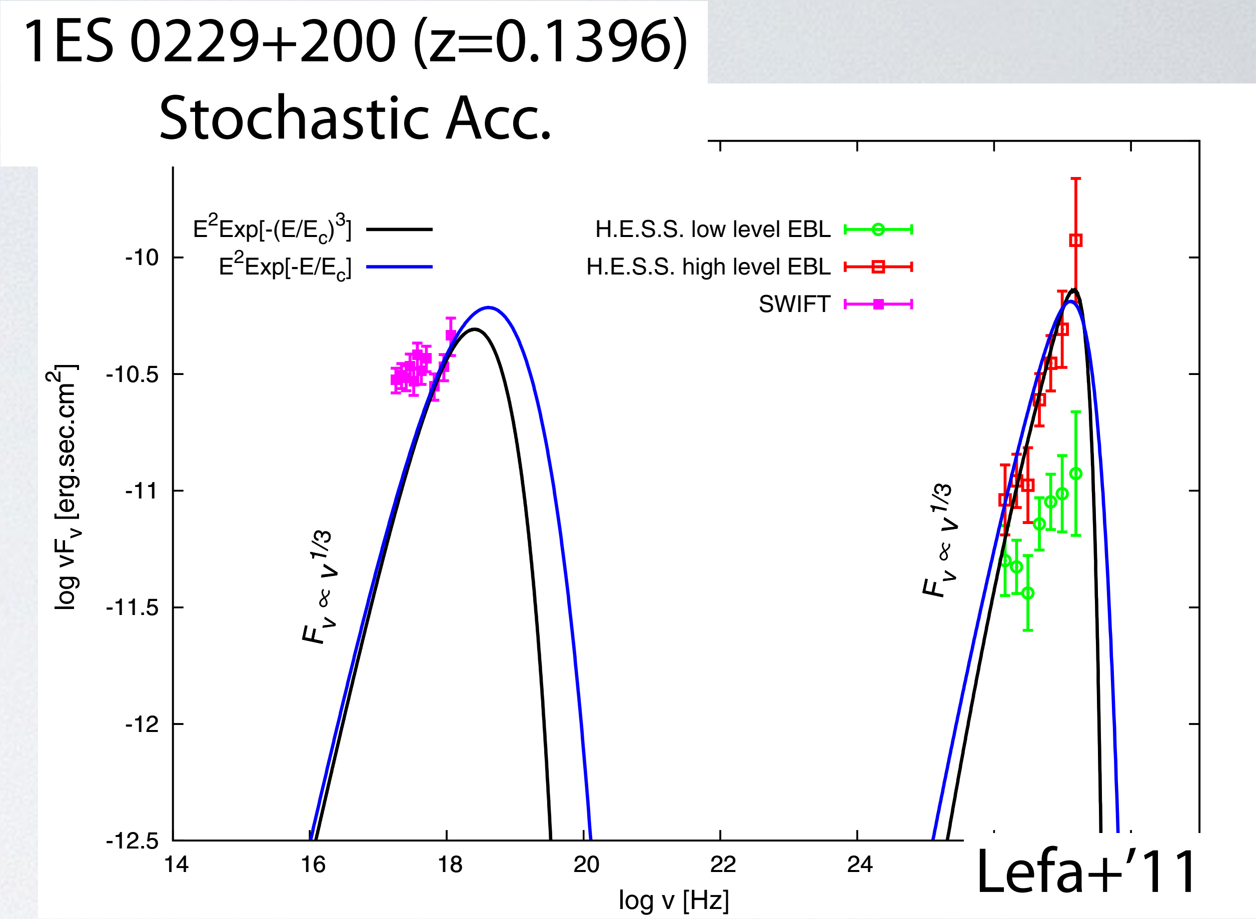


Essey & Kusenko '12

- Spectra of blazars at z > 0.15 show hardening from a few hundred GeV.

Secondary Gamma Rays? Stochastic Acceleration?

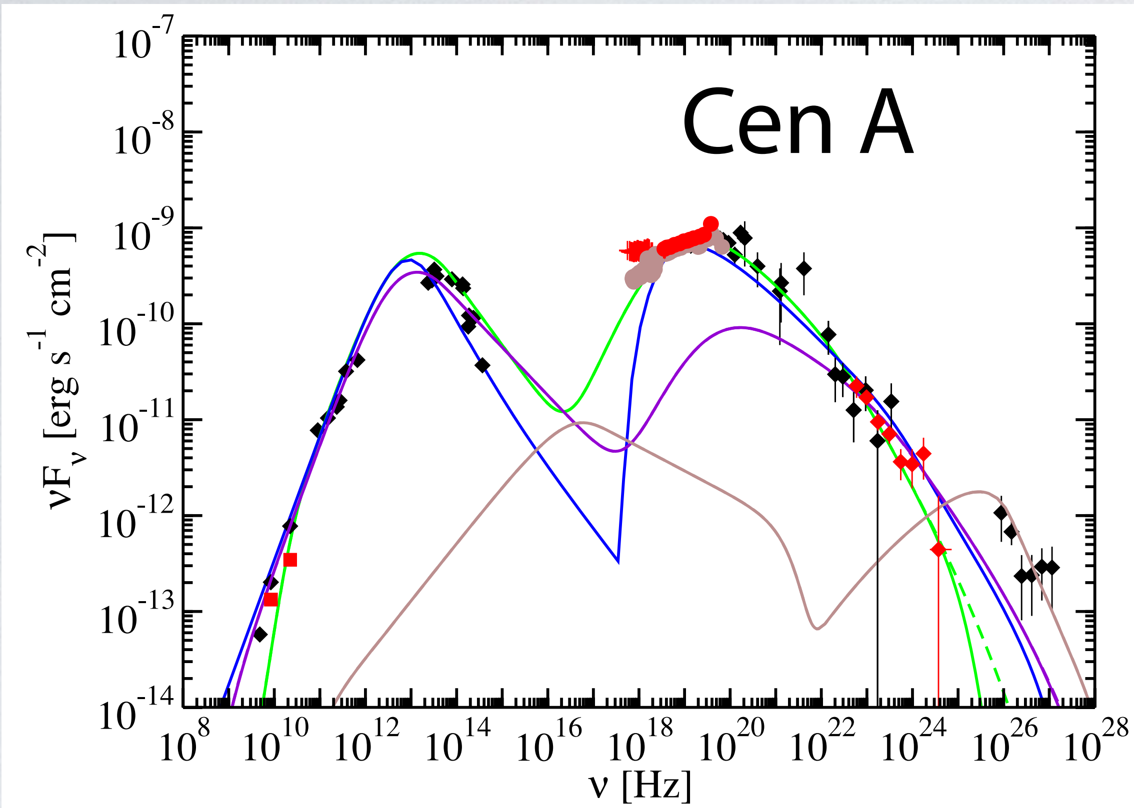




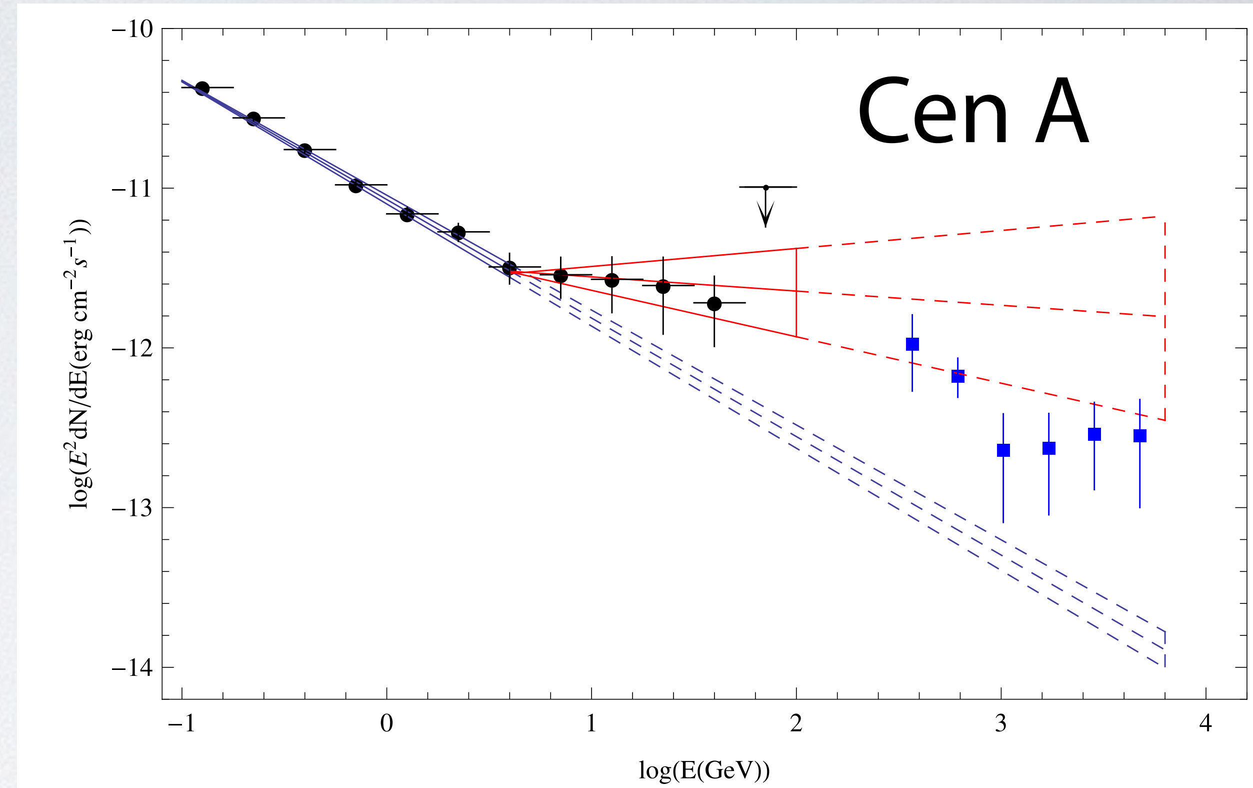
- Secondary gamma rays from cosmic rays along line of sight (Essey & Kusenko '10, Essey+'10, Essey+'11, Murase+'12, Takami+'13,YI+'14).

- Stochastic (2nd-order Fermi) acceleration (Stawarz & Petrosian '08, Lefa+'11).

Another component in radio galaxies



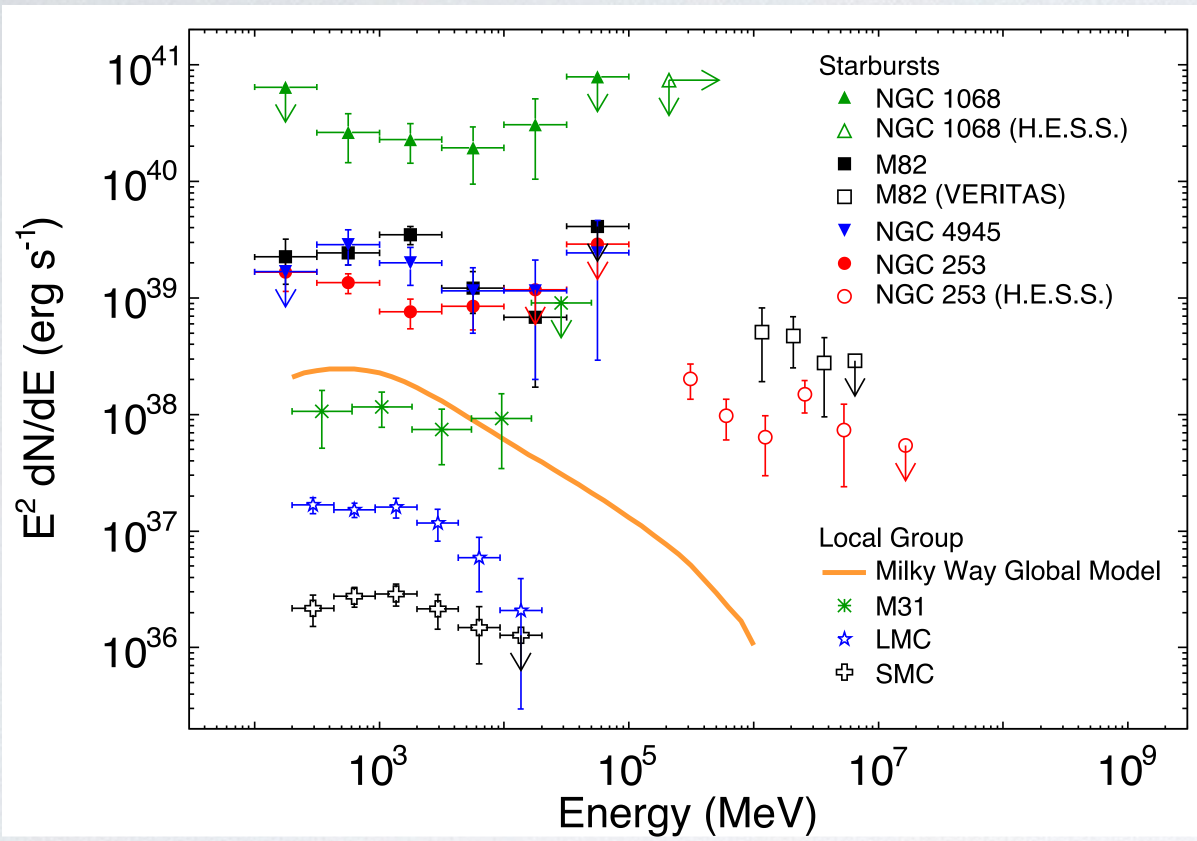
Abdo+'10



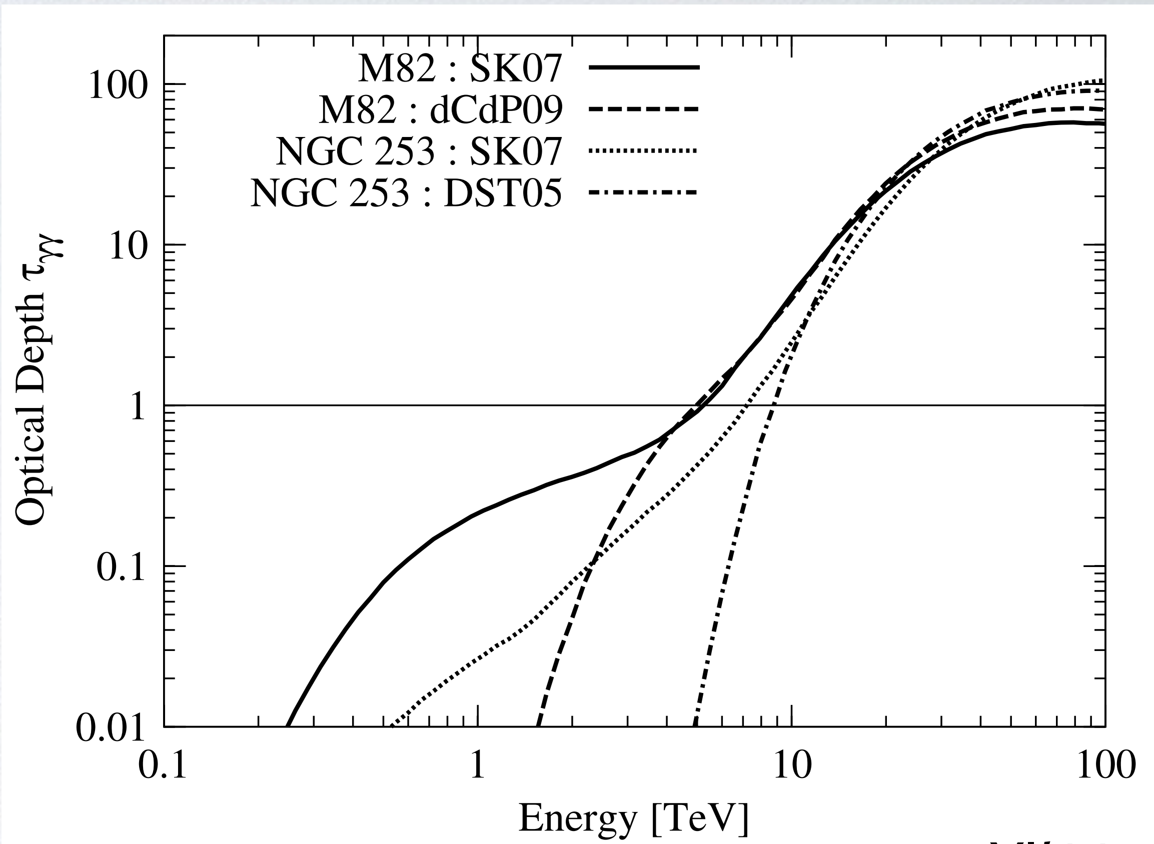
Sahakyan +'13

- Spectral hardening from ~4 GeV (Sahakyan+'13).
  - BH magnetosphere? multi components? hadronic? knots? cascade in torus? IC of host galaxy starlight?

Star Forming Galaxies



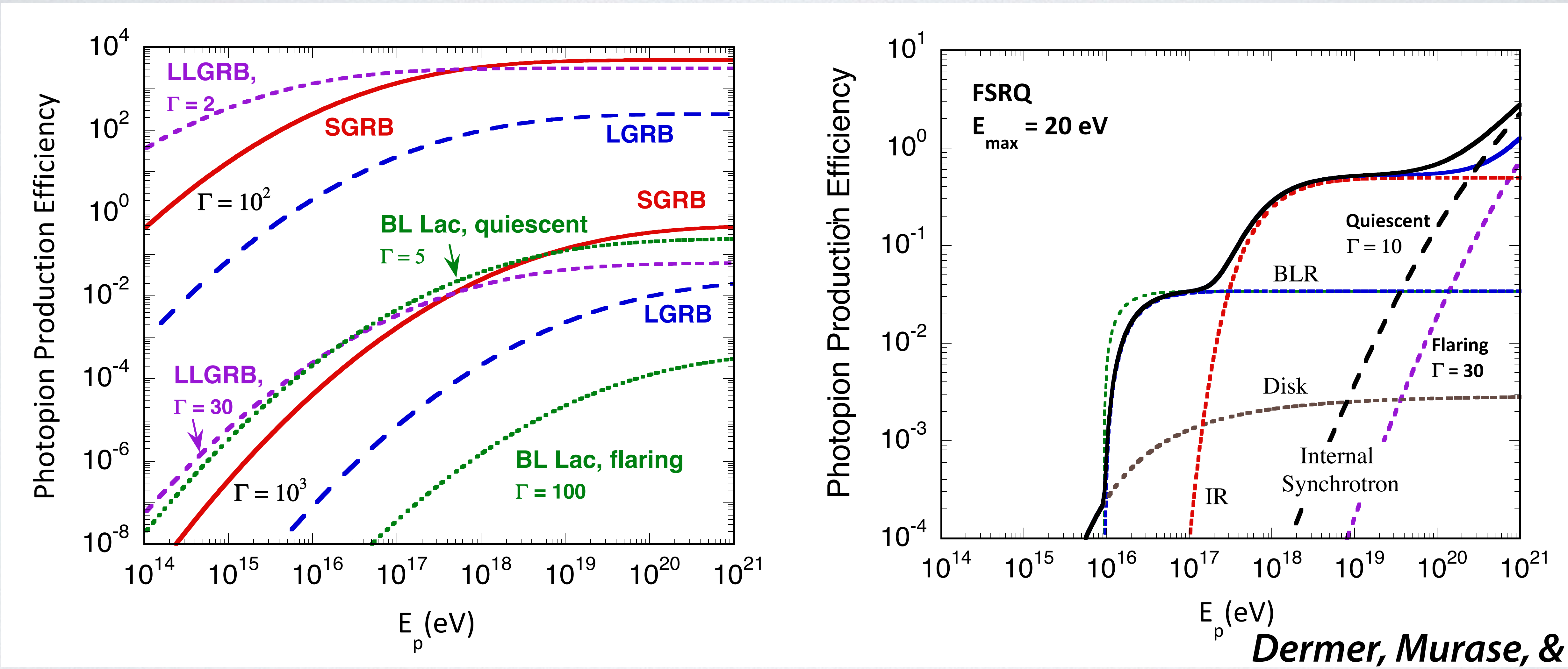
Ackermann+'12



YI'11

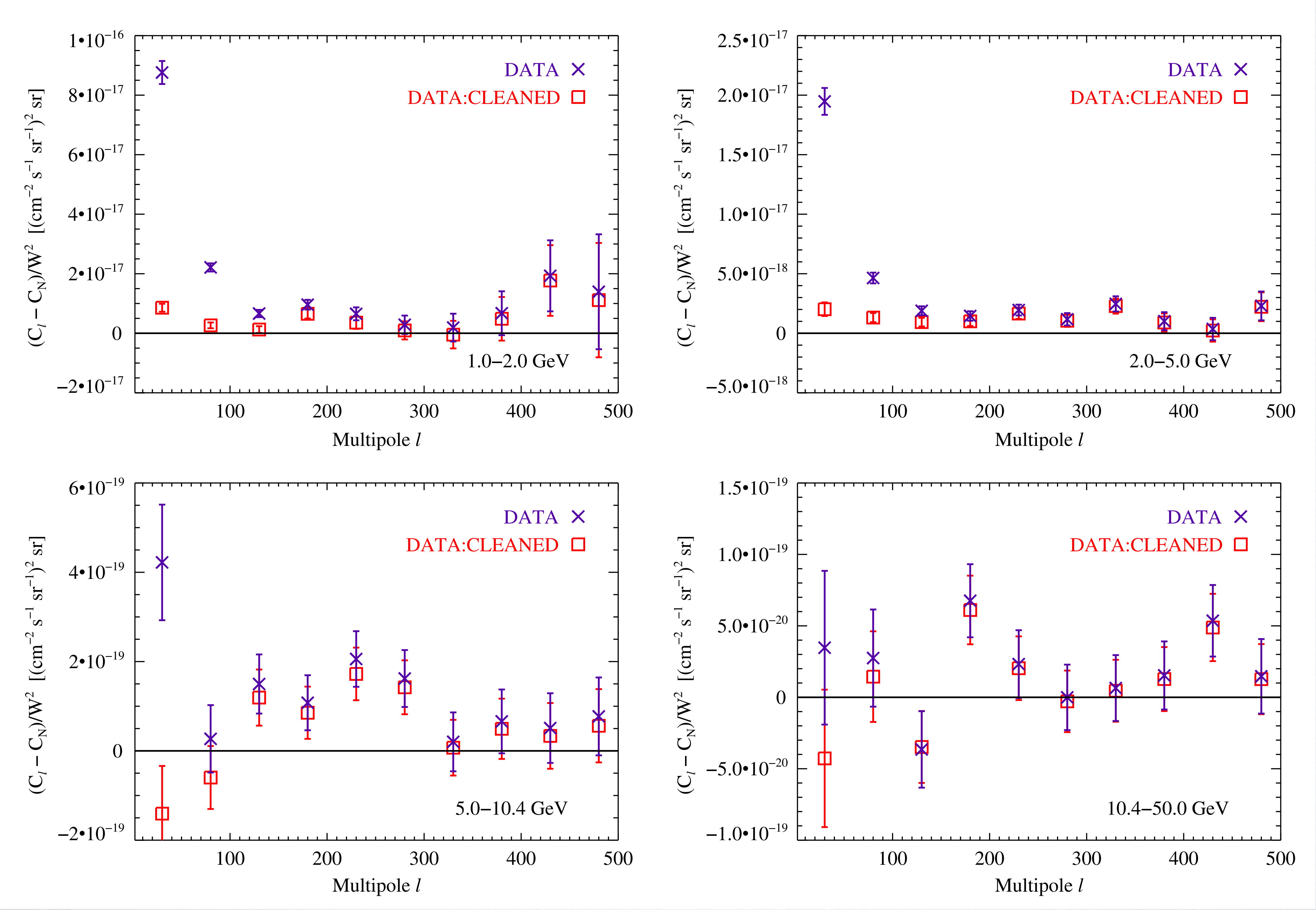
- Hadronic origin as same as our Galaxy.
- > a few TeV gamma rays may be internally absorbed.

Photopion Production Efficiency

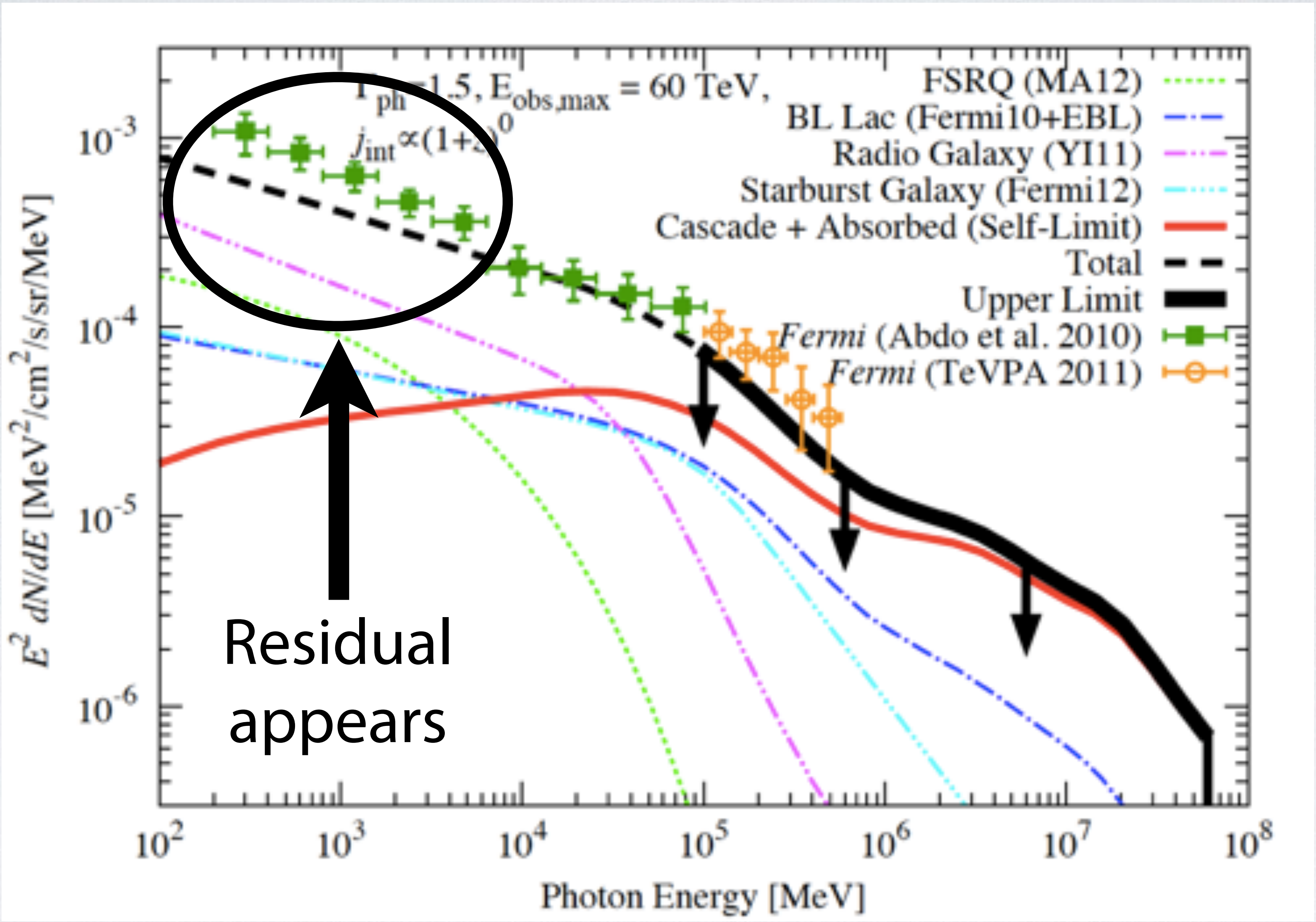


Dermer, Murase, & YI '13

Fermi did this for the GeV gamma-ray background

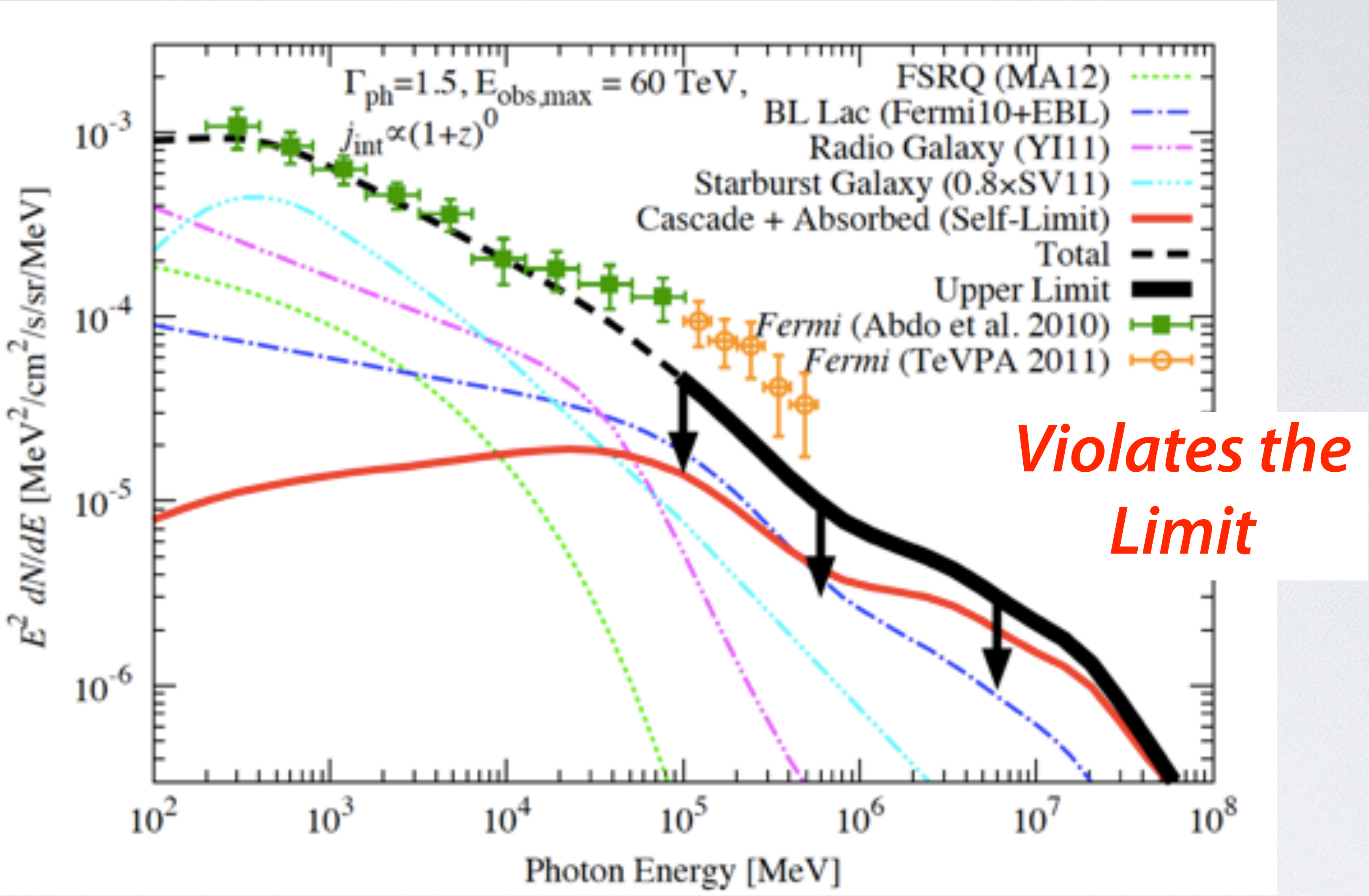


Upper Limit on EGB w/ other



- If we try not to violate the limit, residual appears at <10GeV.

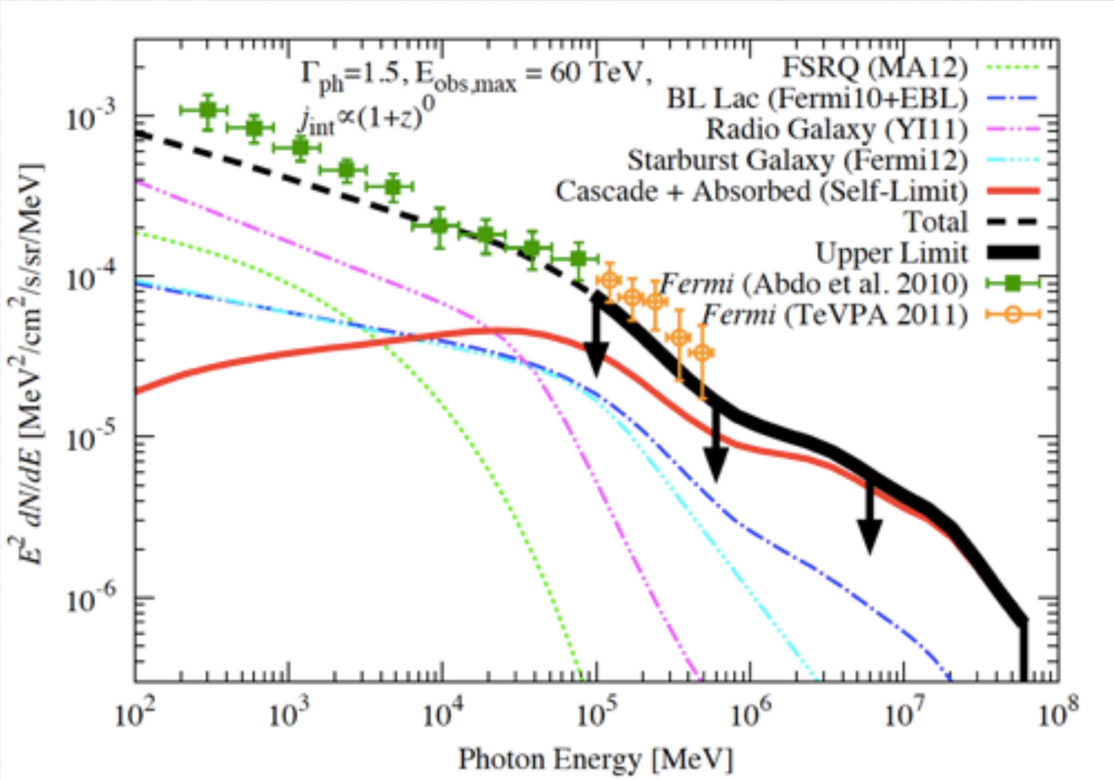
Upper Limit on EGB w/ known



- If we try to explain EGB at <10GeV, the observation violates the limit.
- UL: $E^2\frac{dN}{dE} < 4.5\times10^{-5}\left(\frac{E}{100\,\mathrm{GeV}}\right)^{-0.7}\mathrm{MeV/cm^2/s/sr}$

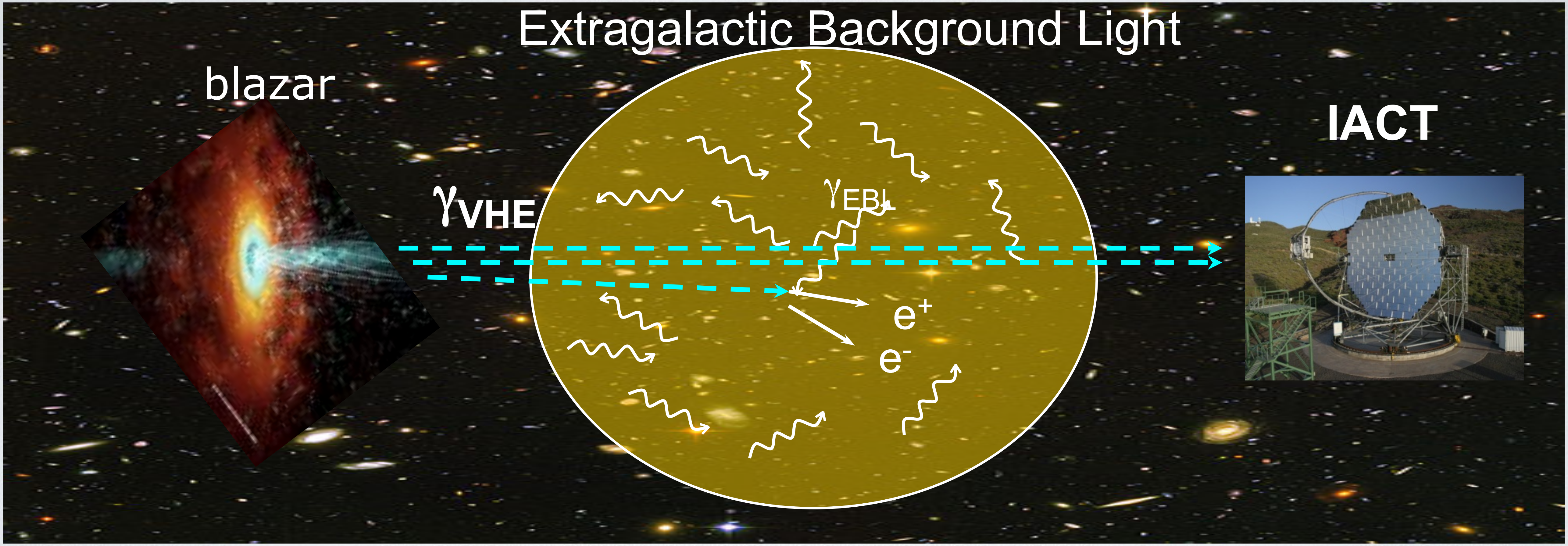
Possible Explanations

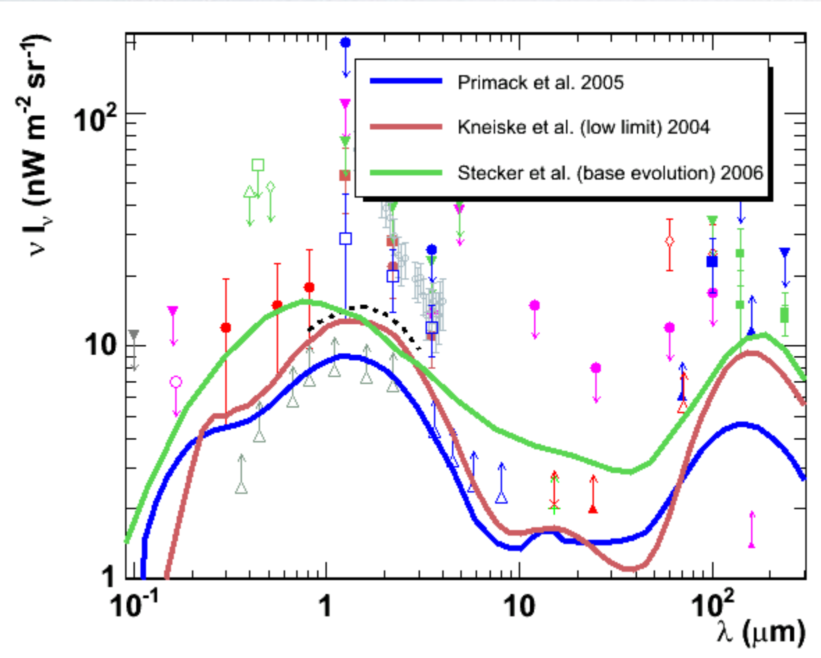
- Hard spectrum with sub-TeV E_{max} and $\beta<0$
  - No known sources. TeV HBL? Low-luminosity GRBs?
- New Physics: Axion or Lorentz invariance violation?
- Dark matter in local?
- ~GeV sources
  - pulsars? radio-quiet AGNs?
- Foreground uncertainty?
- See also Murase+'12

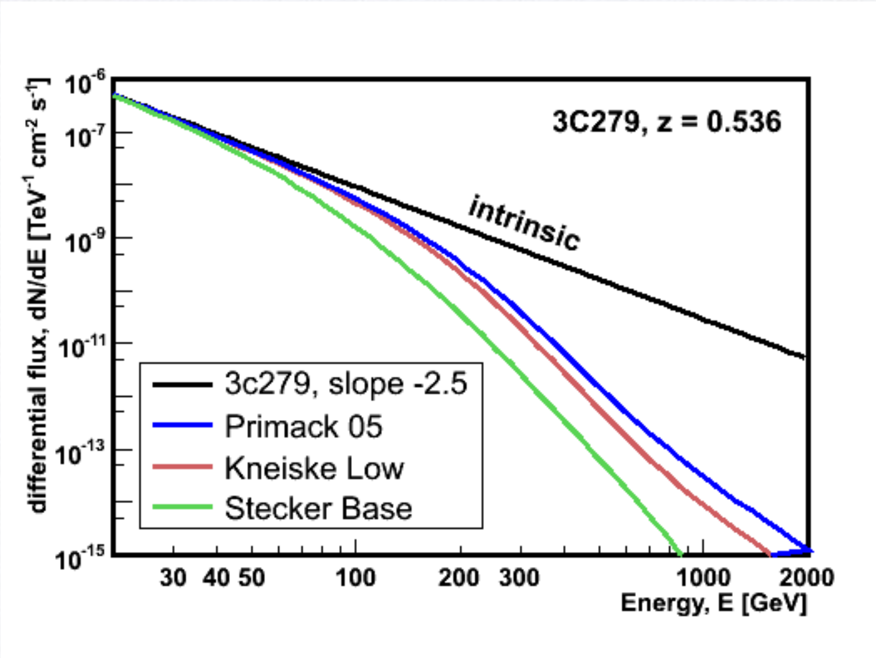


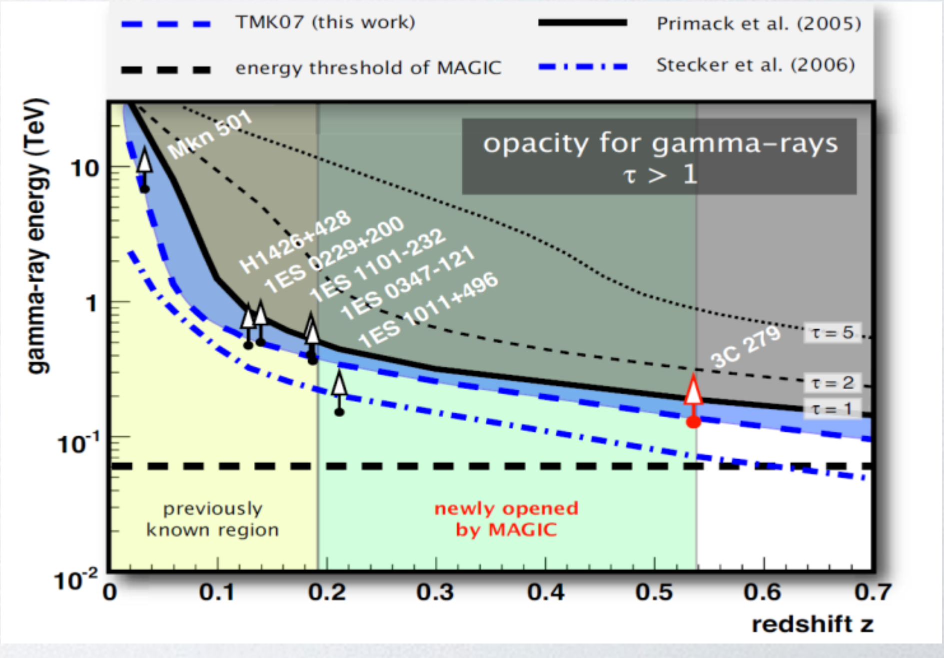
Our limit is useful for future: Fermi, CTA, & CALET

Gamma-ray Attenuation by Cosmic Optical & Infrared Background

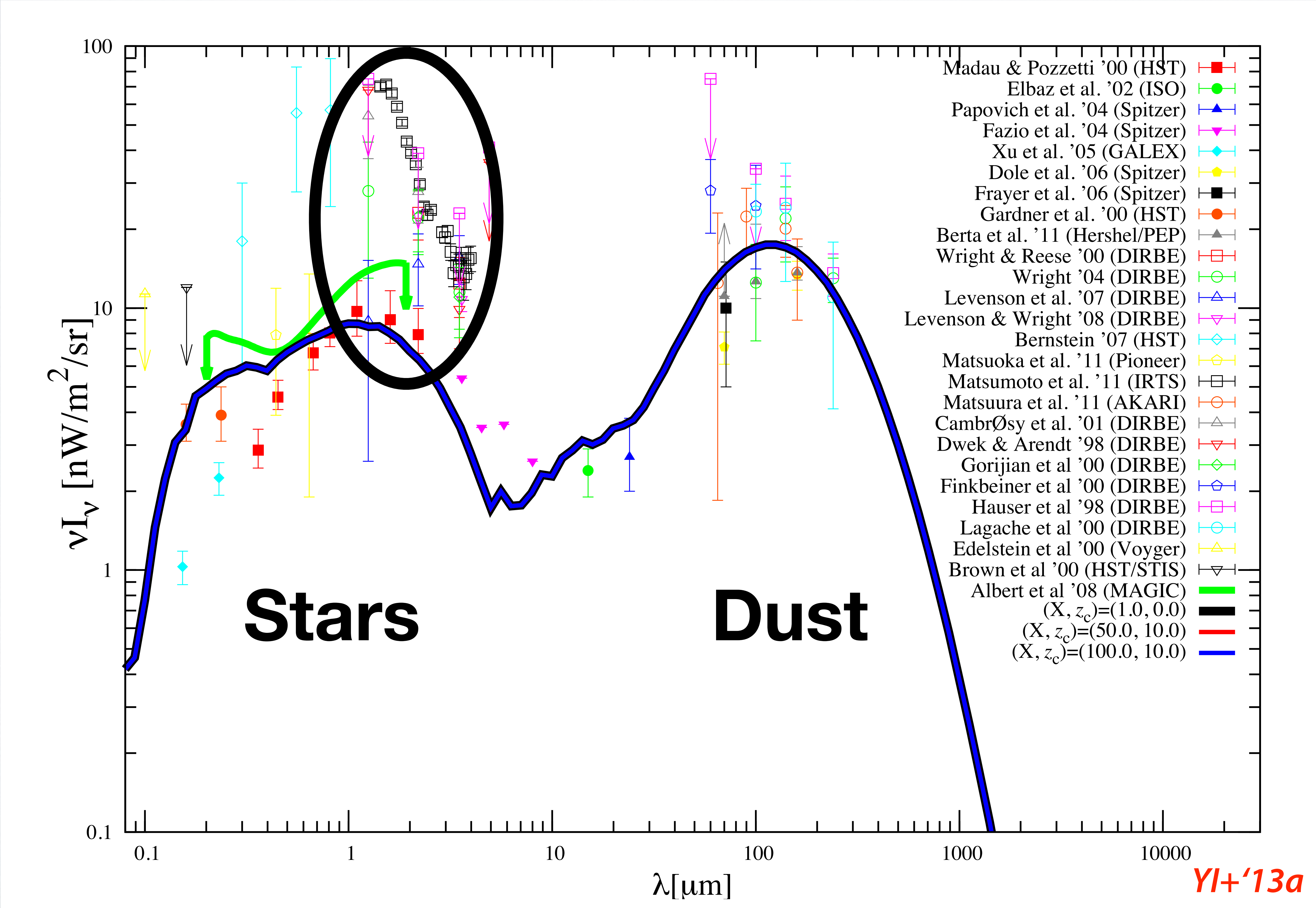






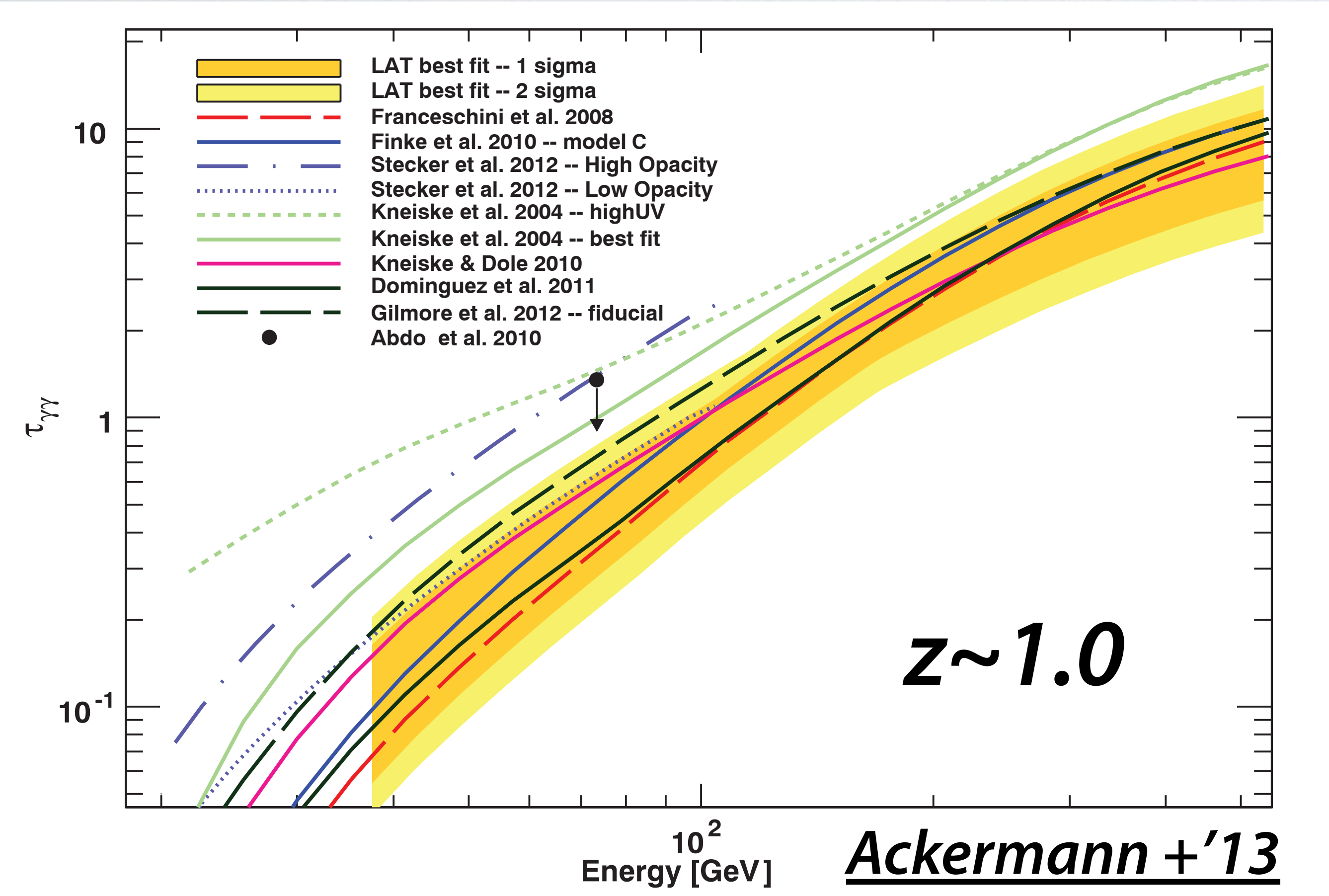


Cosmic Optical & Infrared Background (COB & CIB)

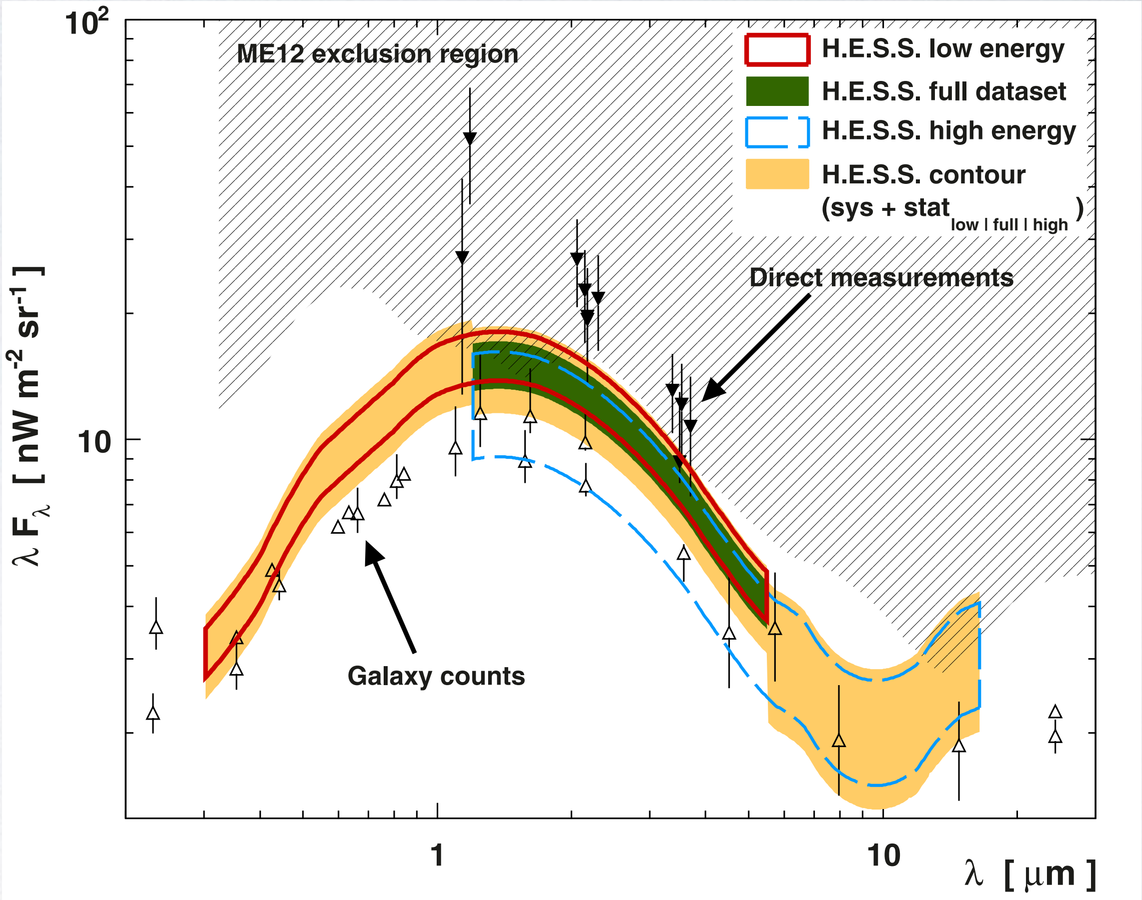


Yl+'13a

Constraints from Gamma rays



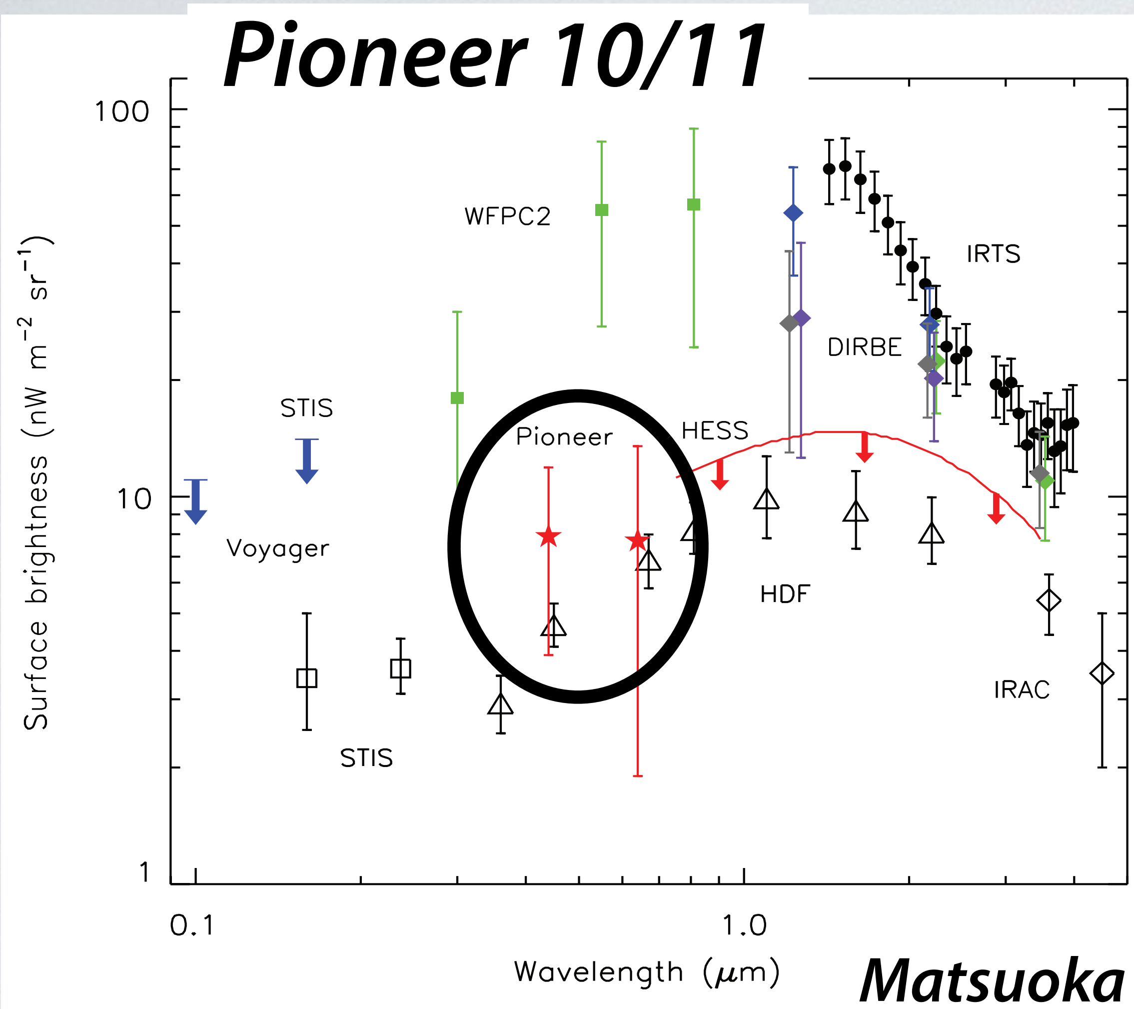
<u>*Ackermann +'13*</u>



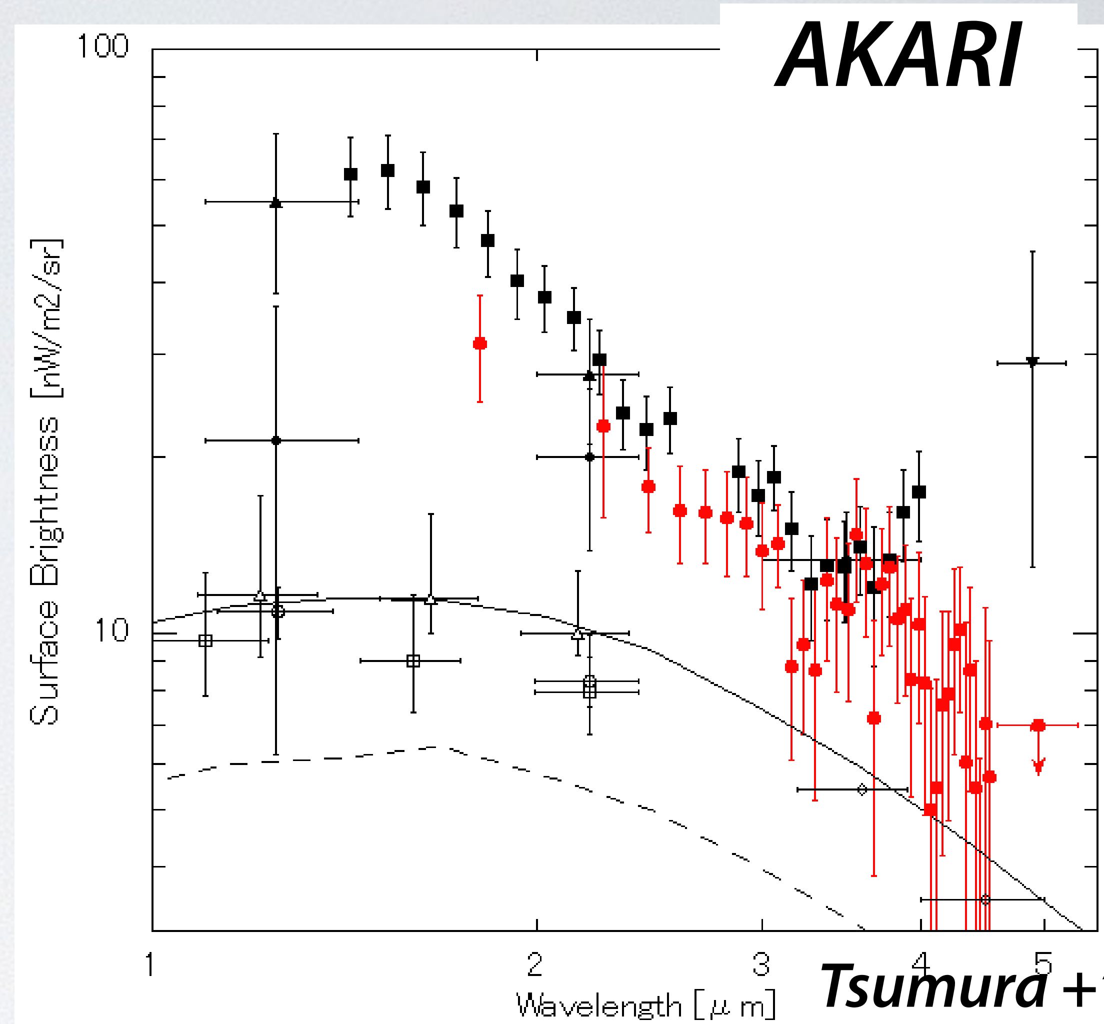
Abramowski +'13

- Fermi derived the COB opacity using the combined spectra of blazars (see also Gong & Cooray '13, Dominguez +'13).
- H.E.S.S. derived the COB intensity using the combined spectra of blazars.

Direct Measurements of COB & CIB



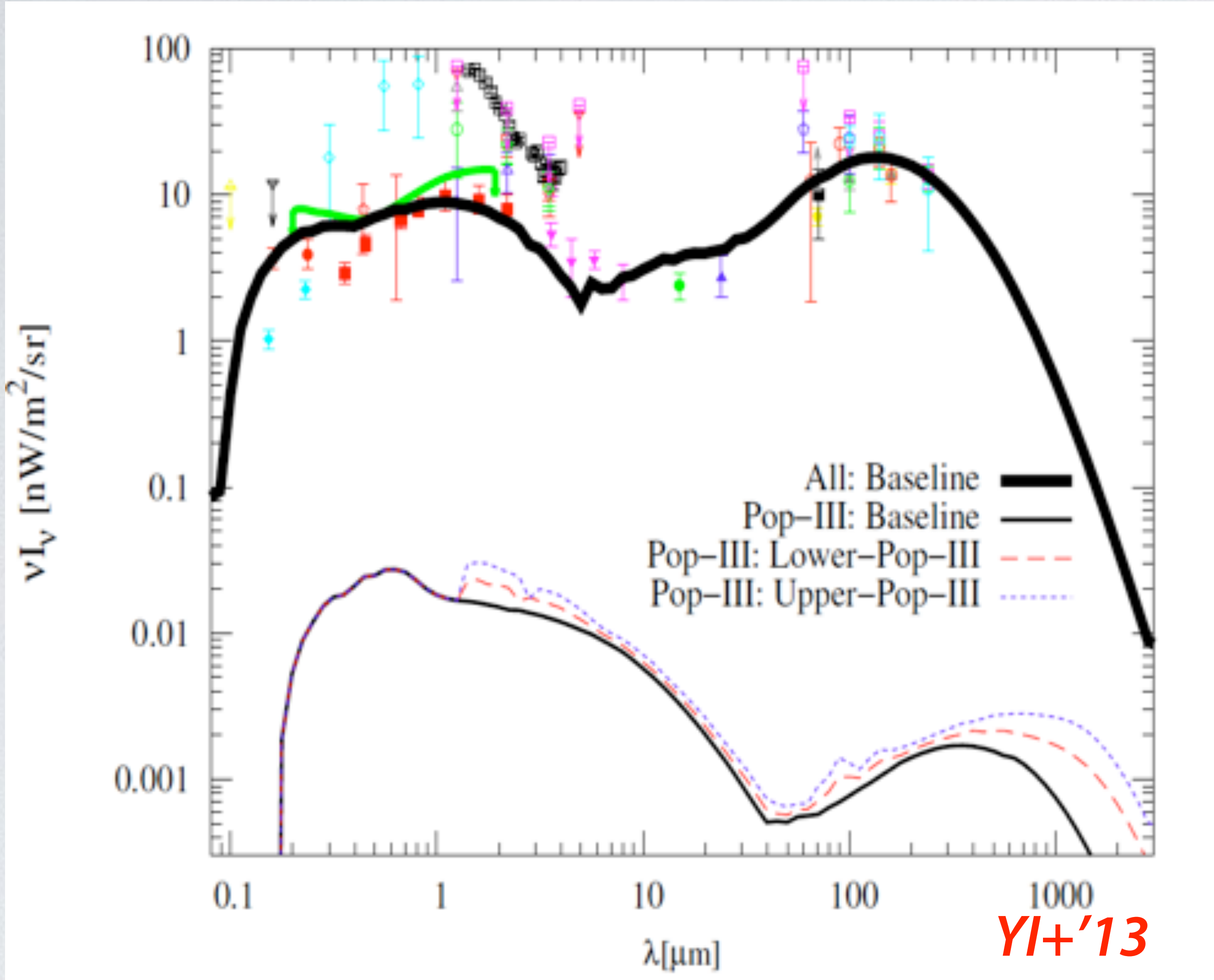
Matsuoka +'11

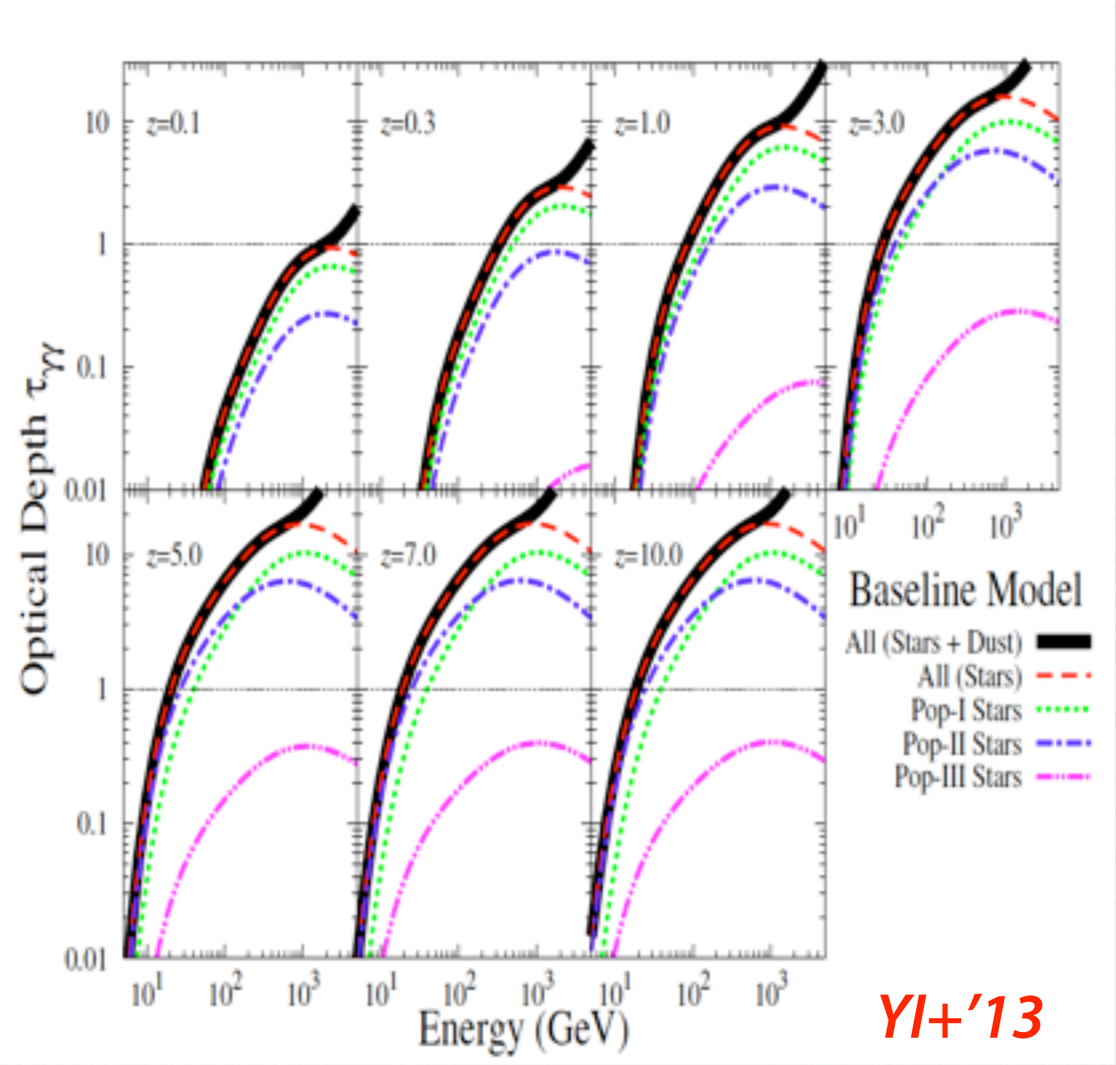


Tsumura +'13

- Pioneer 10/11 measurements are consistent with the galaxy count lower limit.
- But, recent AKARI measurement is consistent with IRTS.
  - Peak at near infrared?
  - CIBER rocket experiment will provide more information.

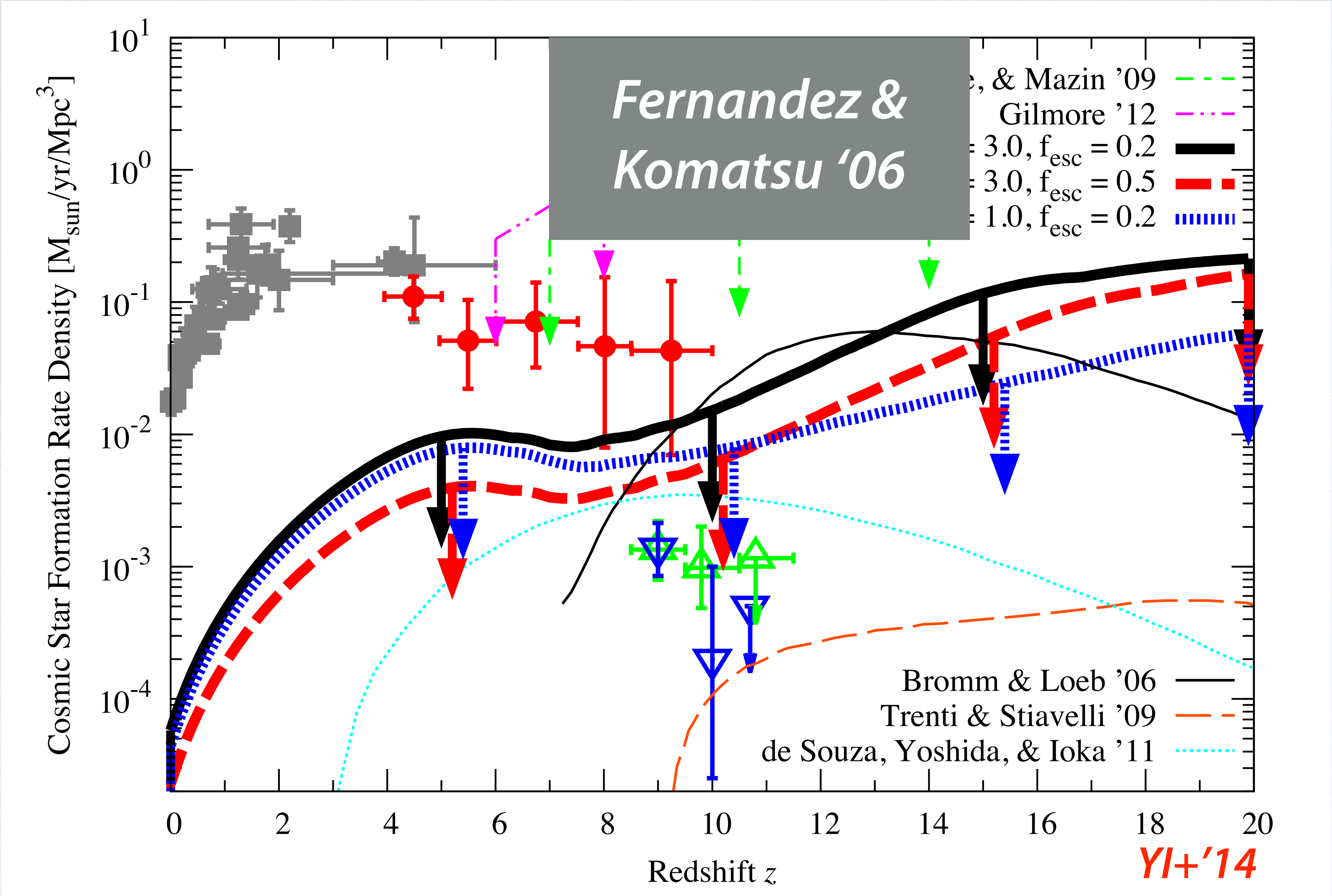
CIB Model with First Stars





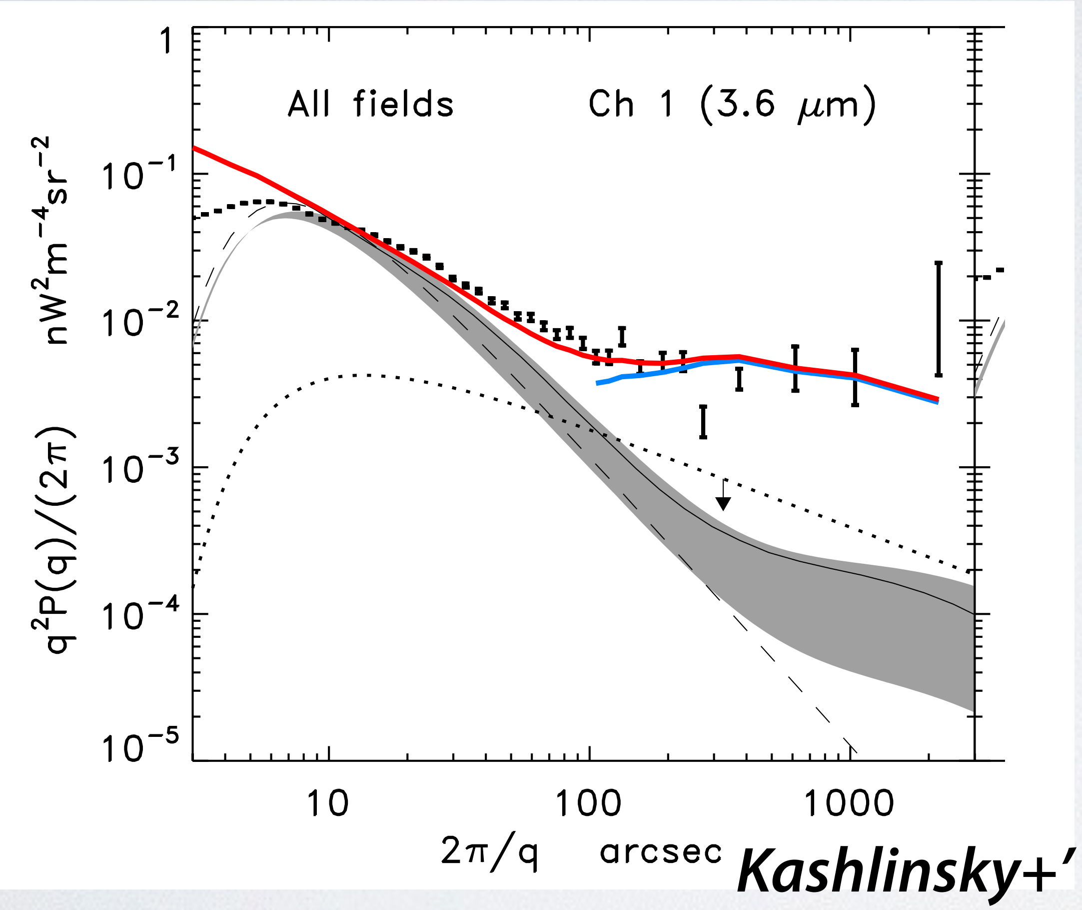
- First stars' contribution to EBL at z=0 is minor, and difficult to distinguish through gamma-ray attenuation even with high-z objects.

Constraints on First Stars

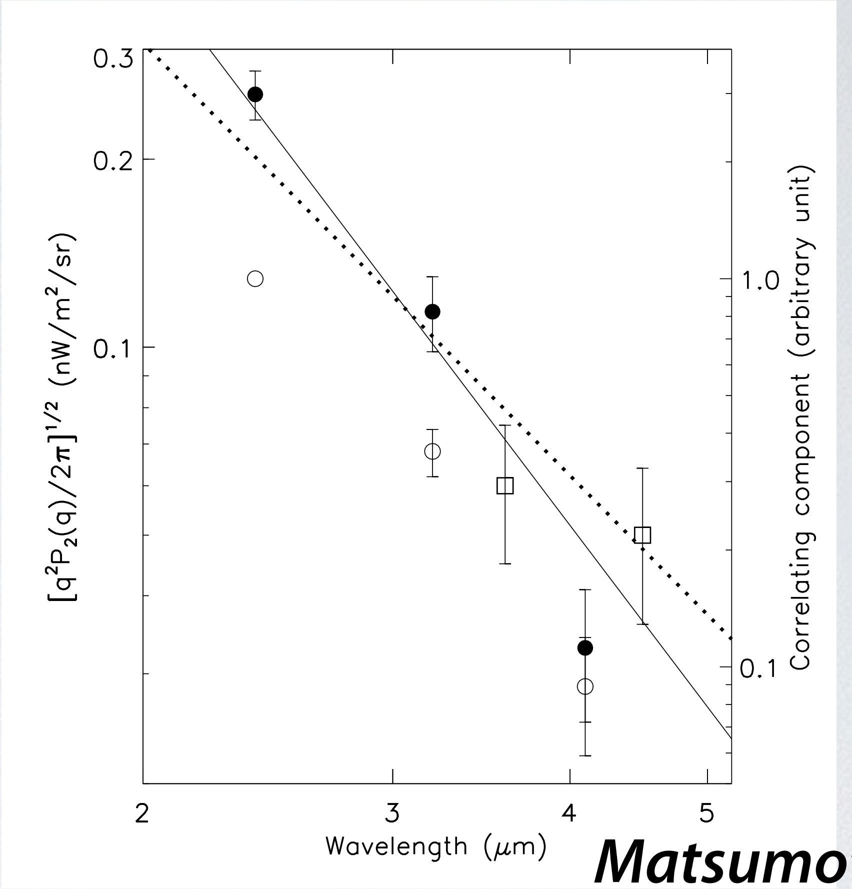


- Combining reionization and distant gamma-ray data (E<100 GeV).
- The required first star formation rate density is inconsistent with reionization data (e.g. Madau & Silk '05; YI+'14)

Excess in the NIR Sky Fluctuation



Kashlinsky+'12



Matsumoto +'11

- AKARI & Spitzer reported NIR background fluctuation at 2.4, 3.2, 3.6, 4.1 and 4.5 um (Kashlinsky+'05, '07, '12, Matsumoto+'11, Cooray+'12).
    - 15-20% of CIB fluctuation is correlated with CXB (Cappelluti+'13).
- The angular power spectrum at large scales is close to the shape of a Rayleigh-Jeans spectrum, λ^{-3} (Matsumoto+'11, Cooray+'12)