Lower and Upper Bounds on the Cosmic TeV Gamma-ray Background

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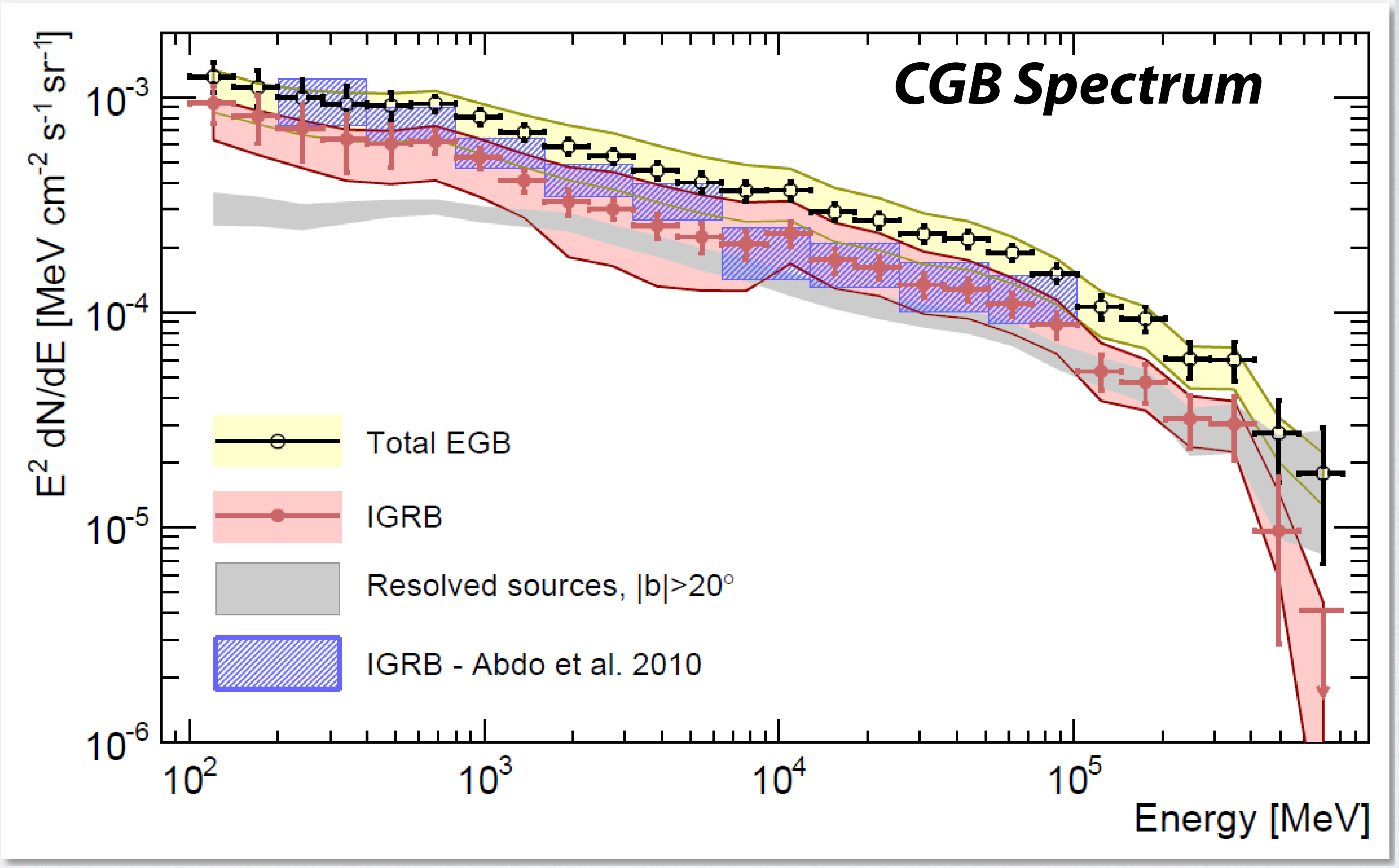
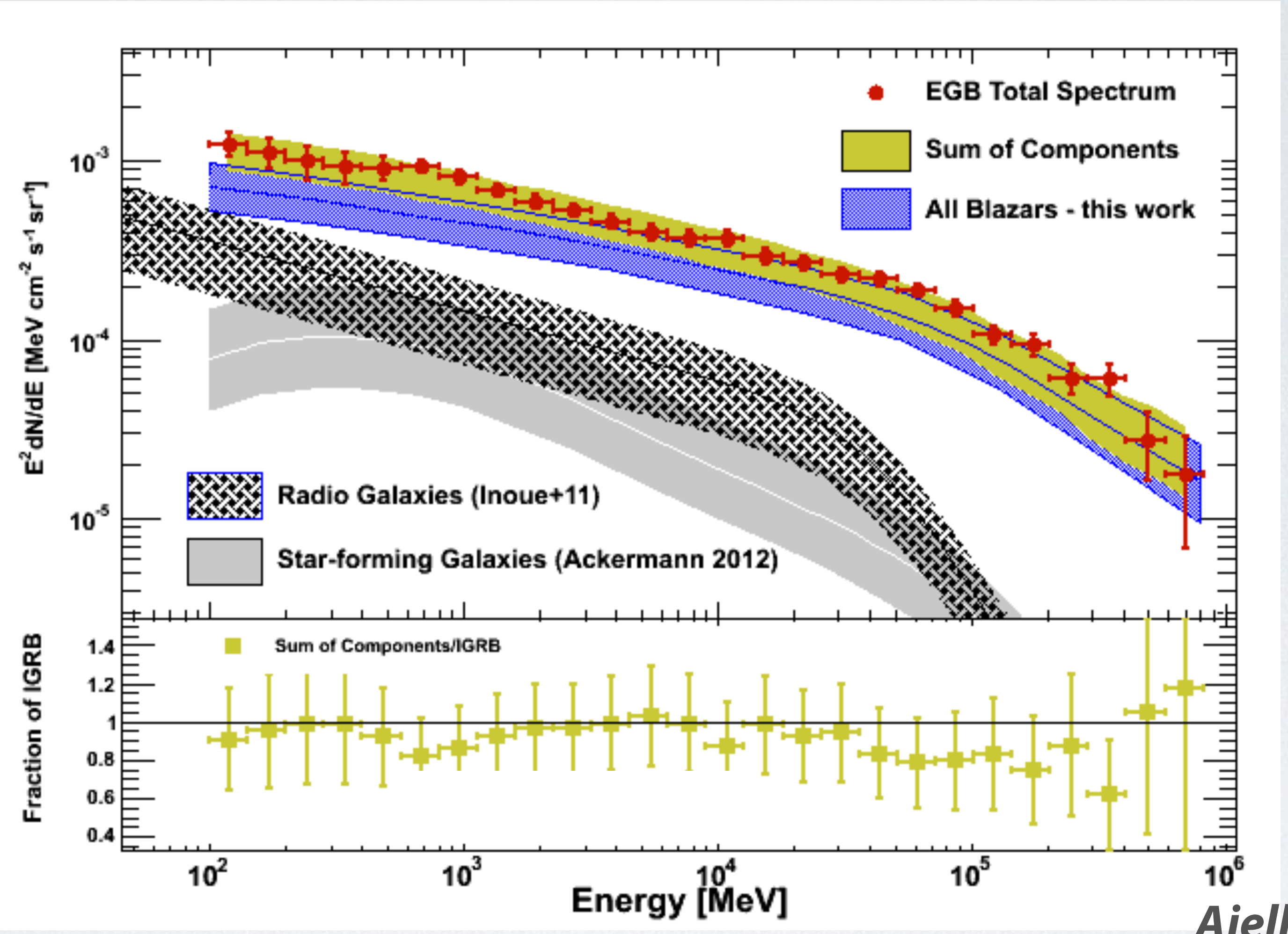
Cosmic Gamma-ray Background Spectrum at >0.1 GeV



Ackerman+'15

- Fermi has resolved 30% of the CGB at ~1 GeV and more at higher energies (see Di Mauro's talk).

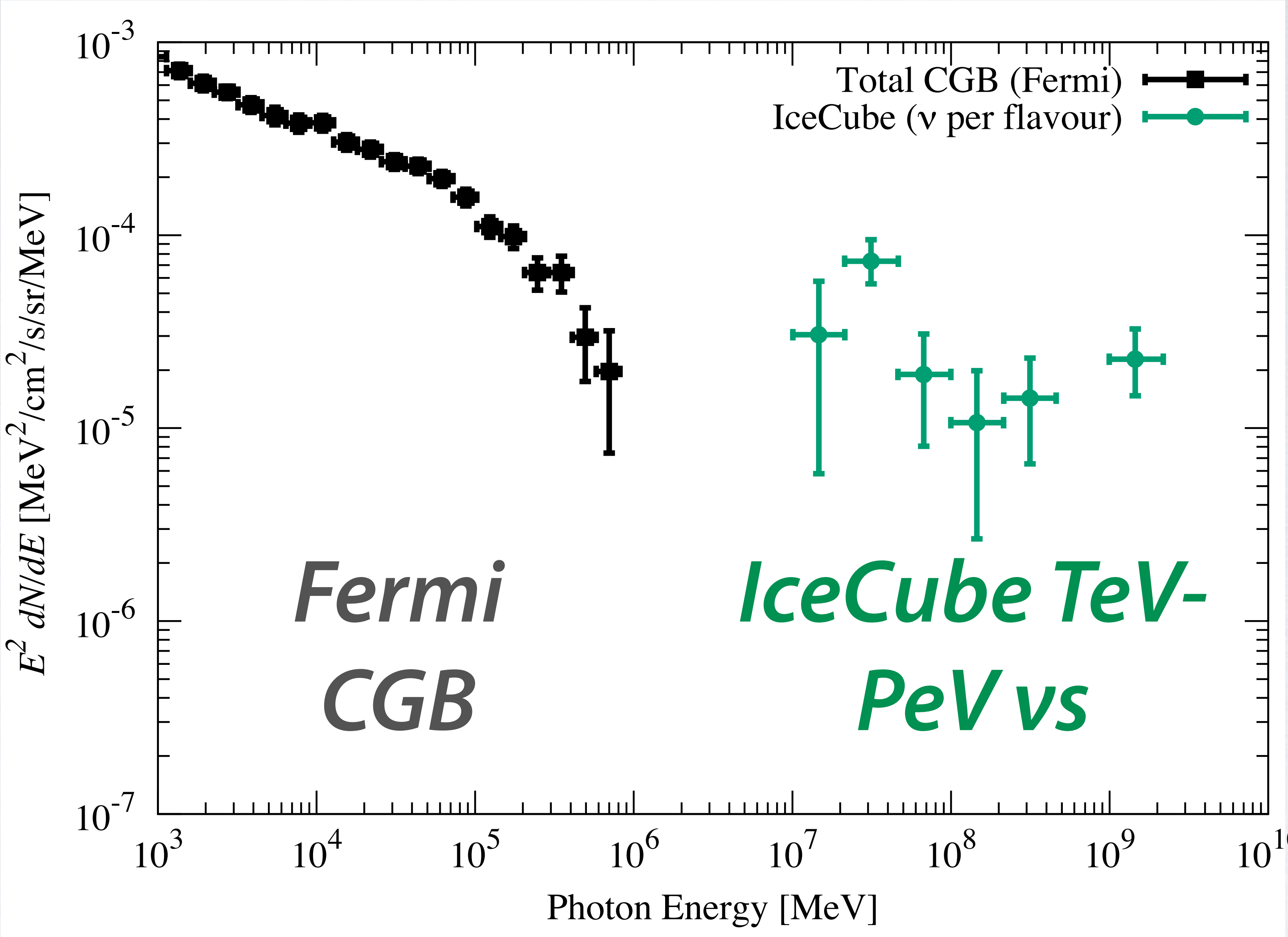
Components of the Cosmic GeV Gamma-ray Background



Ajello, YI +'15

- Blazars (Ajello+'15), Radio gals. (YI'11), & Star-forming galaxies (Ackermann+'12) make up almost 100% of CGB from 0.1-1000 GeV.
- Next frontiers will be
    - Anisotropy (e.g. Ando & Komatsu '06, Ackermann+'11, Camero+'13, Shirasaki+'14)
    - Cosmic MeV Gamma-ray Background (e.g. YI+'08, Ajello+'09, YI+'13)
    - **Cosmic TeV Gamma-ray Background (This talk)**

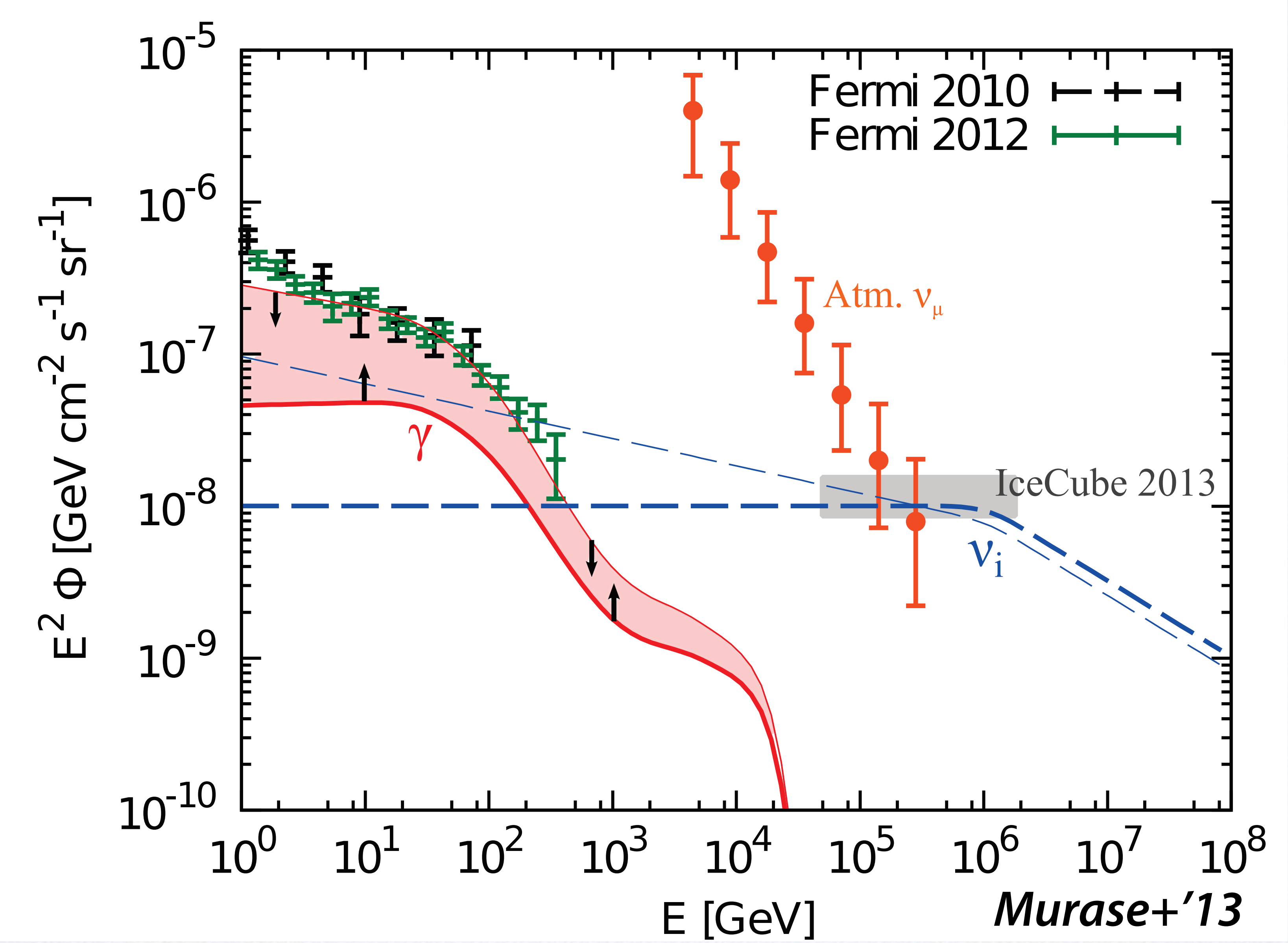
Cosmic TeV Gamma-ray Background



- Above 1 TeV, there is no gamma-ray data, though it is important for neutrino studies.

- extragalactic ***pp*** scenario for IceCube events is constrained by the CGB (Murase+'13; Bechtol+'15).

Cosmic TeV Gamma-ray Background



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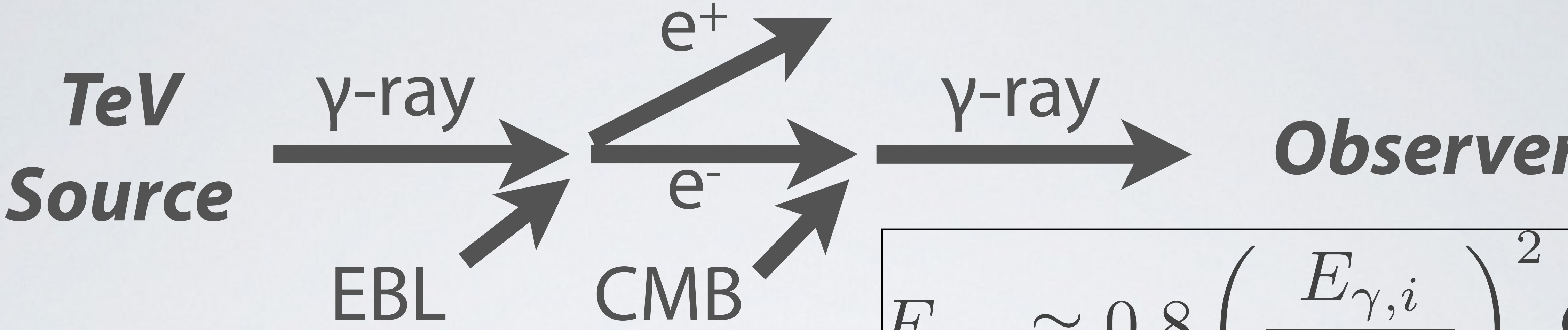
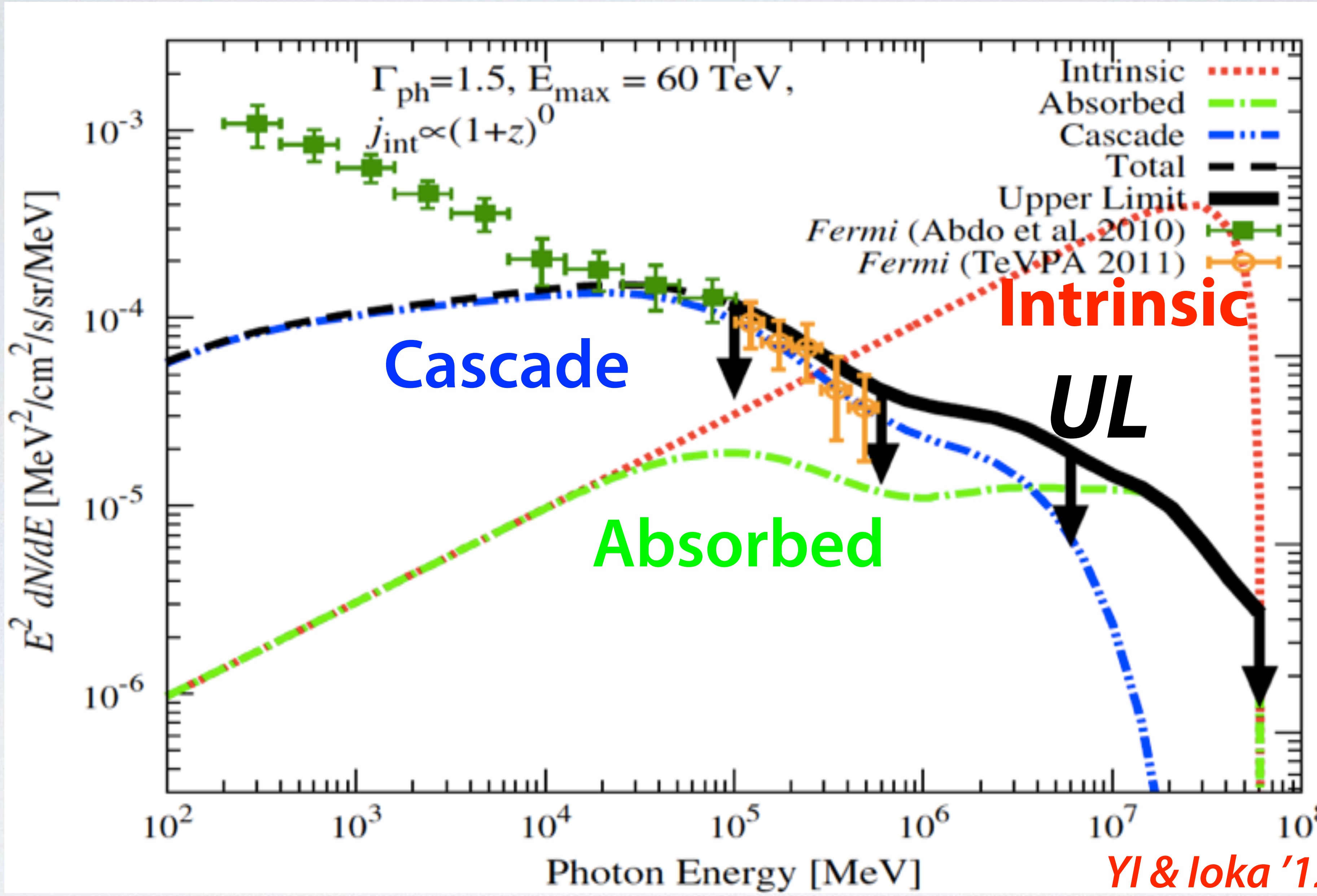
GeV-TeV Gamma-ray Connection: Cascade



$$\boxed{E_{\gamma,c} \approx 0.8 \left(\frac{E_{\gamma,i}}{1 \text{ TeV}} \right)^2 \text{GeV}}$$

- TeV gamma-ray photons are absorbed by EBL
- electron-positron pairs are created
- pairs scatter CMB via inverse-Compton process
    - 1 TeV (primary) -> ~1 GeV (secondary)
- Note: plasma instability may suppress the cascade
  (Broderick+'12, but see also Sironi & Giannios '14)

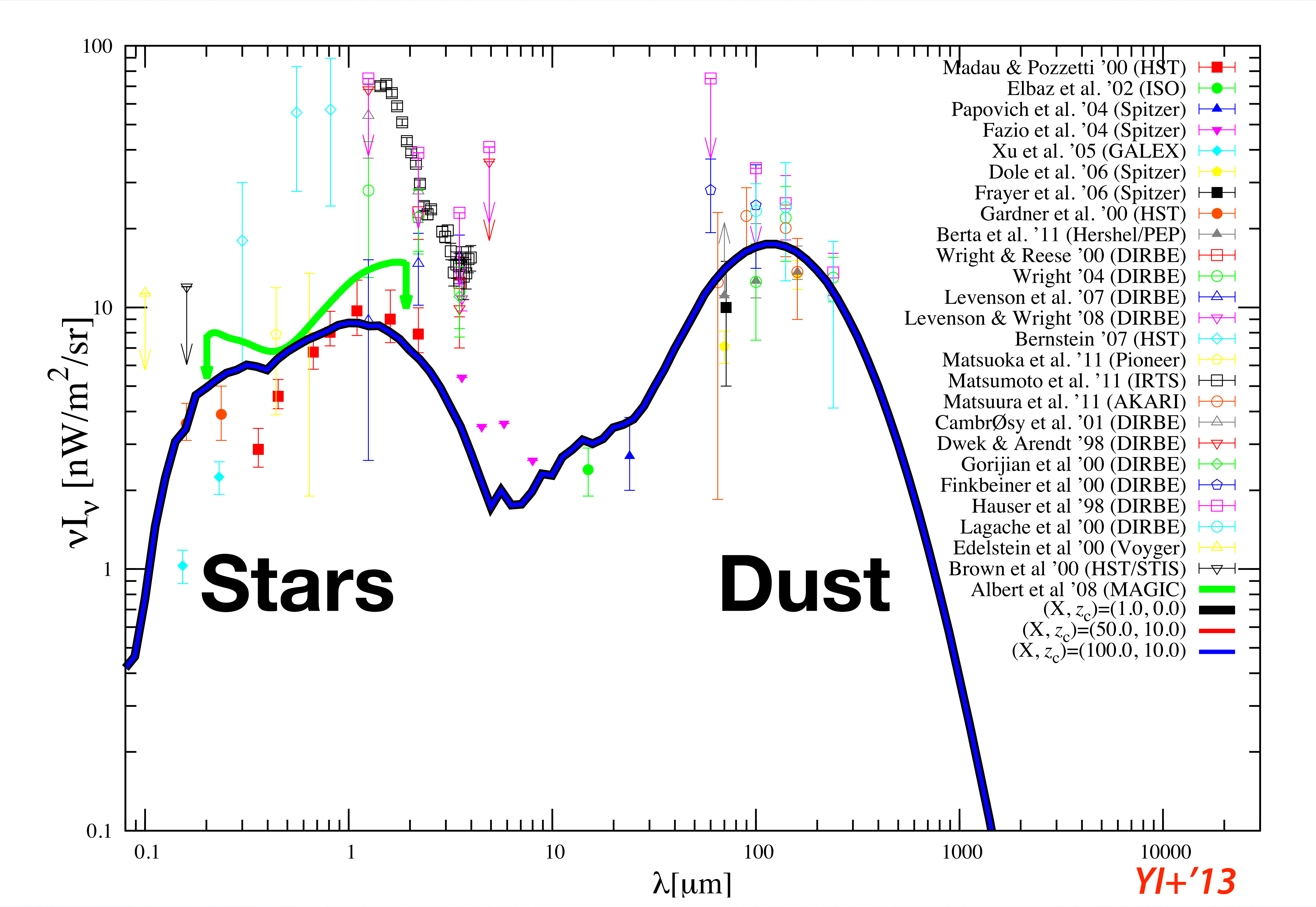
Upper Bound on the Cosmic Gamma-ray Background



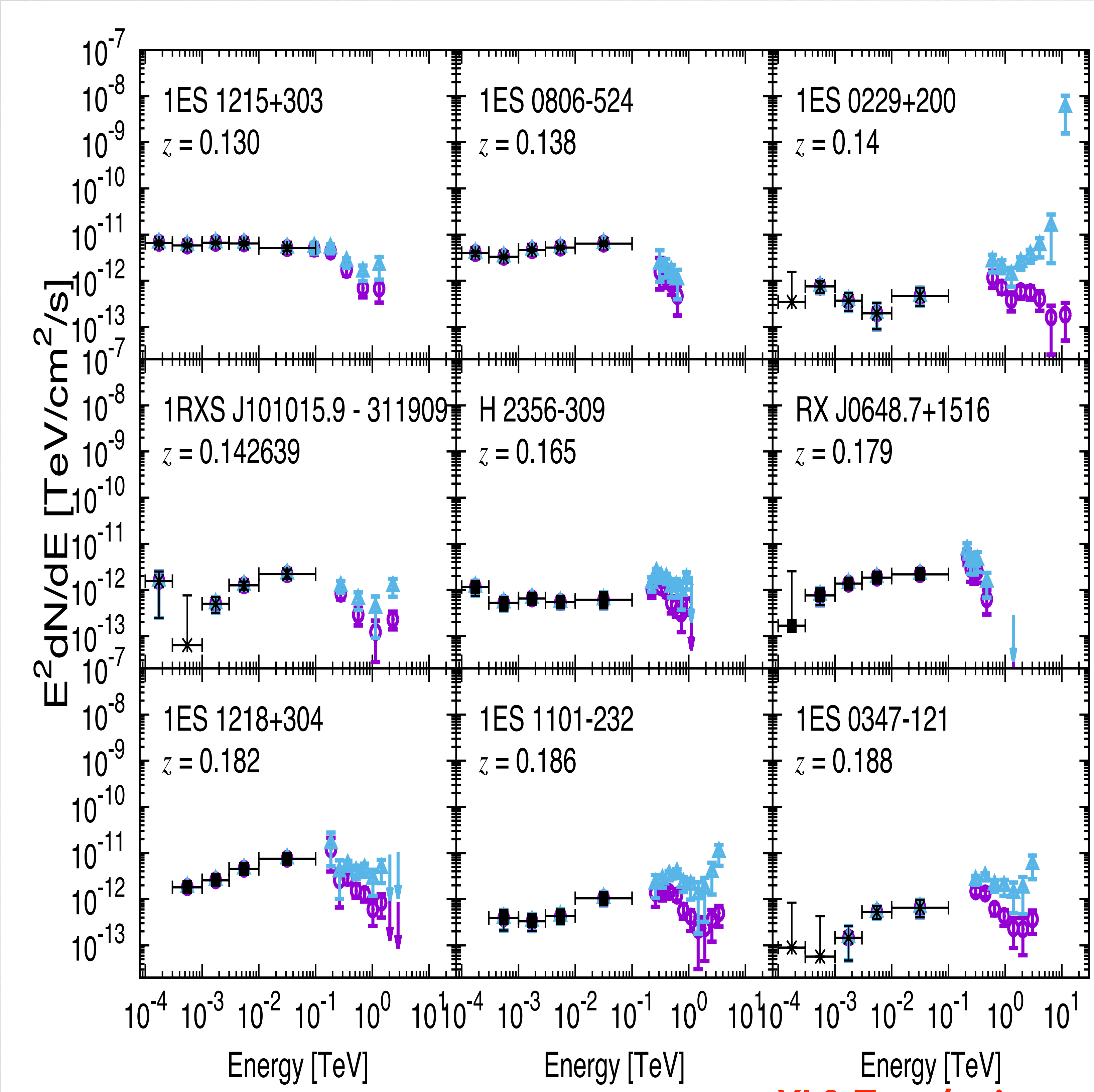
YI & Ioka '12

- Cascade component from the TeV background 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).

Galaxy Counts: Lower Bound on the Cosmic Optical/Infrared Background



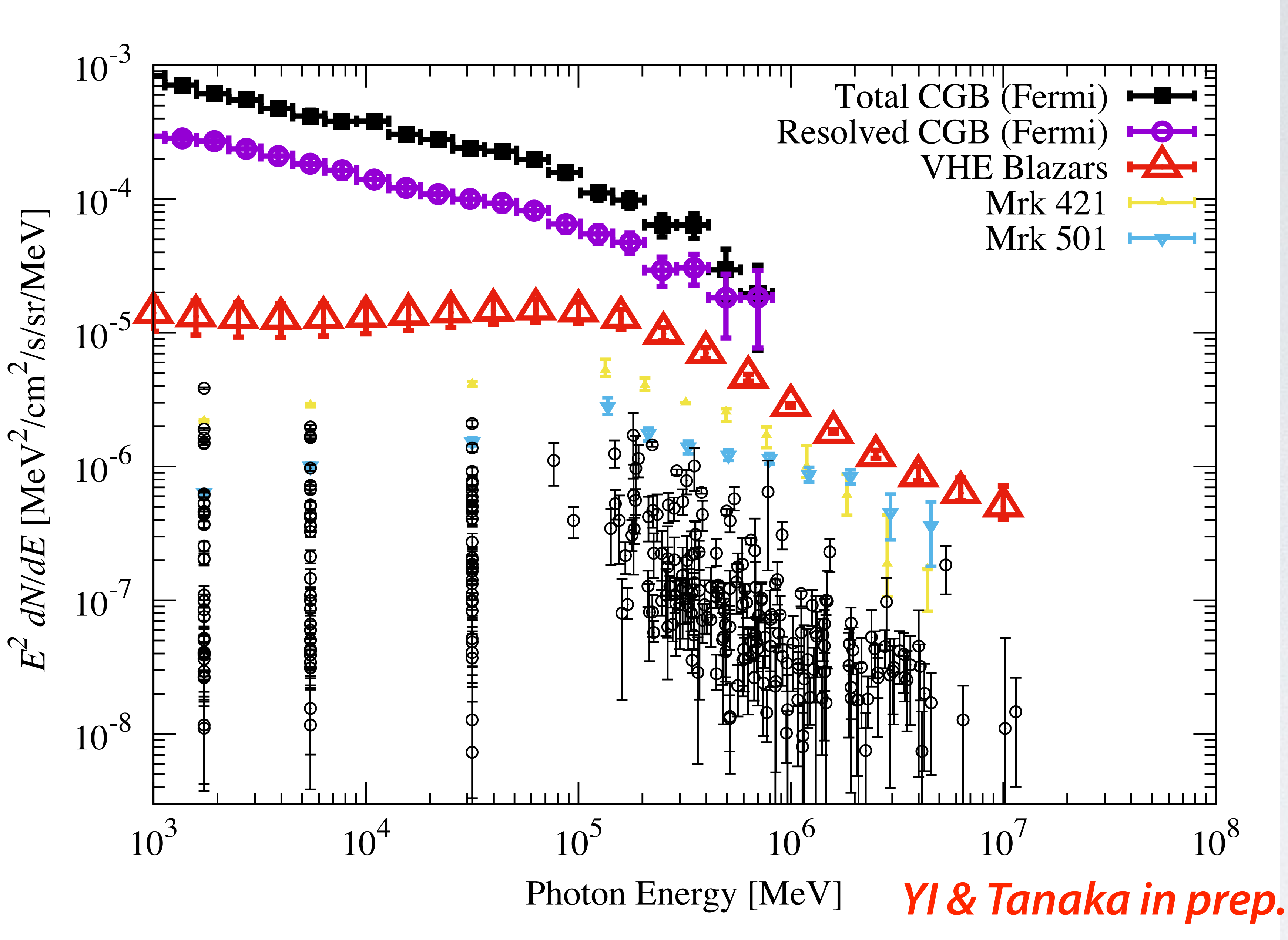
TeV blazar sample



YI & Tanaka in prep.

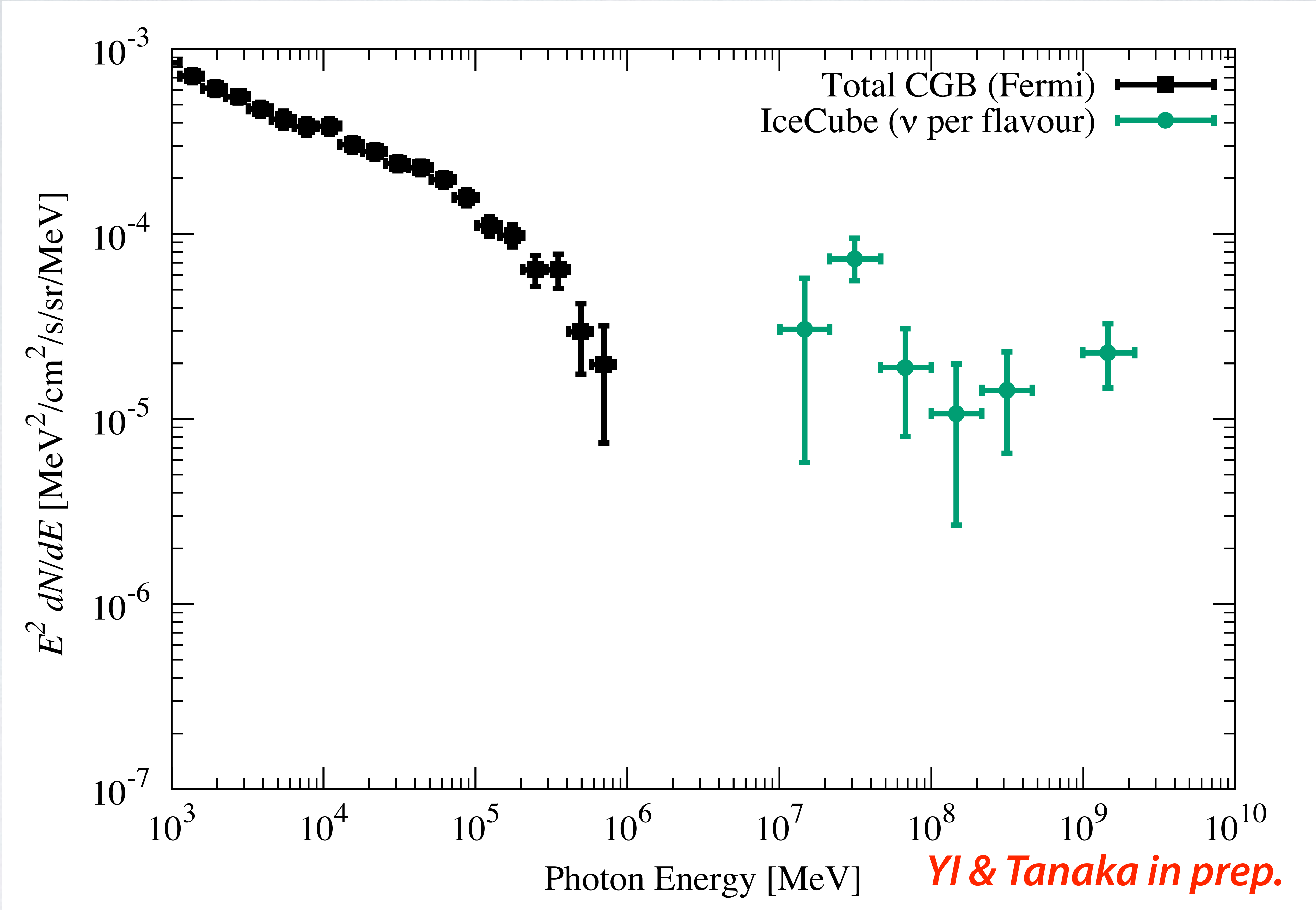
- Select 36 blazars the default TeVcat catalog.
  - Low-state data are available for 31/36.
- 3FGL SED data for the GeV data.
- Radio galaxies and star-forming galaxies are not included yet.

Lower Bound on the Cosmic Gamma-ray Background



- TeV blazar counts give lower limit on to the cosmic gamma-ray background.
- Fermi has resolved more portion of the TeV sky than IACTs do?
  - CTA survey will be important (YI, Totani, & Mori 10; Dubus, YI, +'13)

Bounds on the Cosmic TeV Gamma-ray Background



- Current limit at 0.3-10 TeV is

$$3 \times 10^{-5} \left(\frac{E}{100\mathrm{GeV}}\right)^{-1} [\mathrm{MeV/cm^2/s/sr}] < E^2 \frac{dN}{dE} < 5 \times 10^{-5} \left(\frac{E}{100\mathrm{GeV}}\right)^{-0.7} [\mathrm{MeV/cm^2/s/sr}]$$

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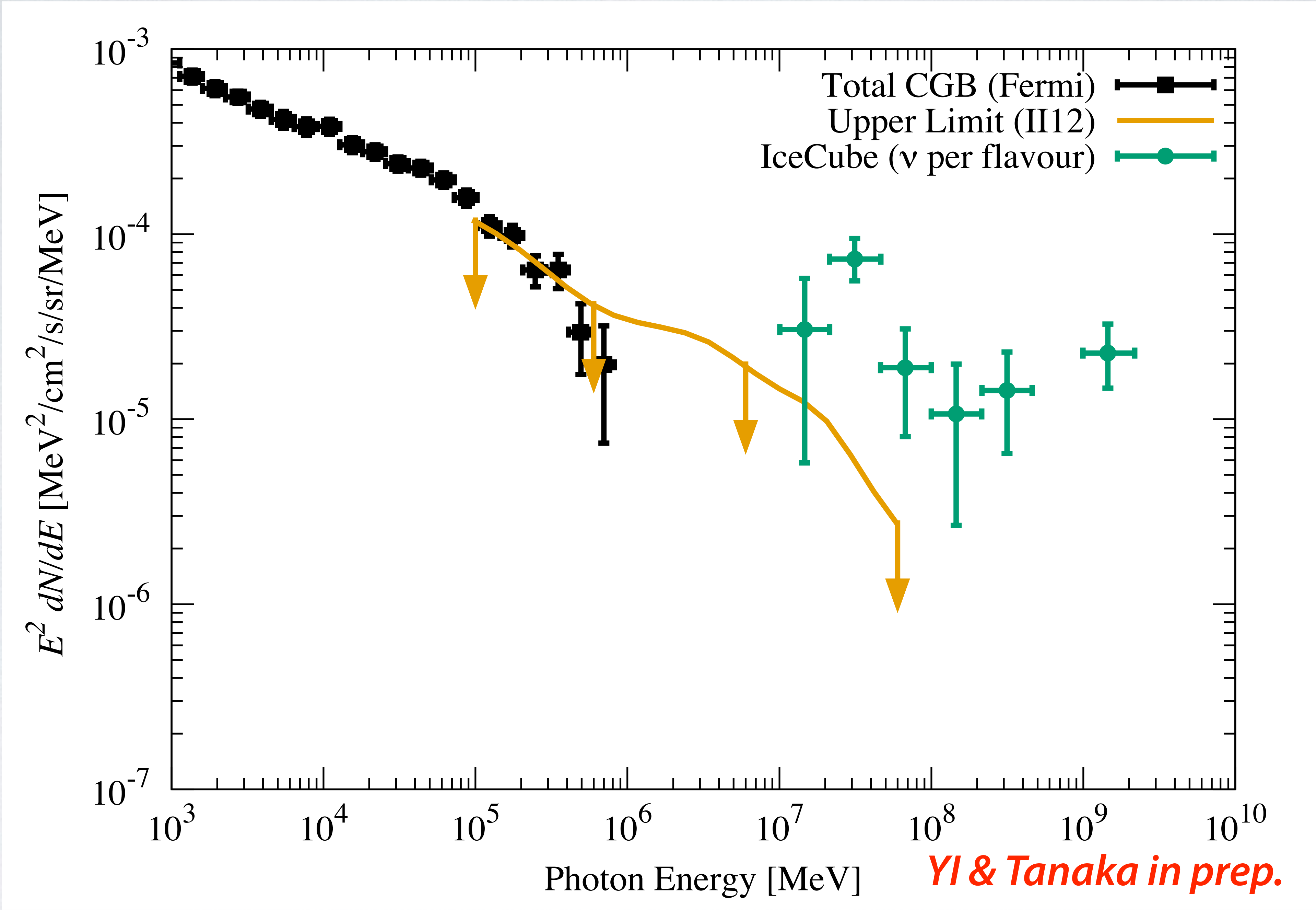

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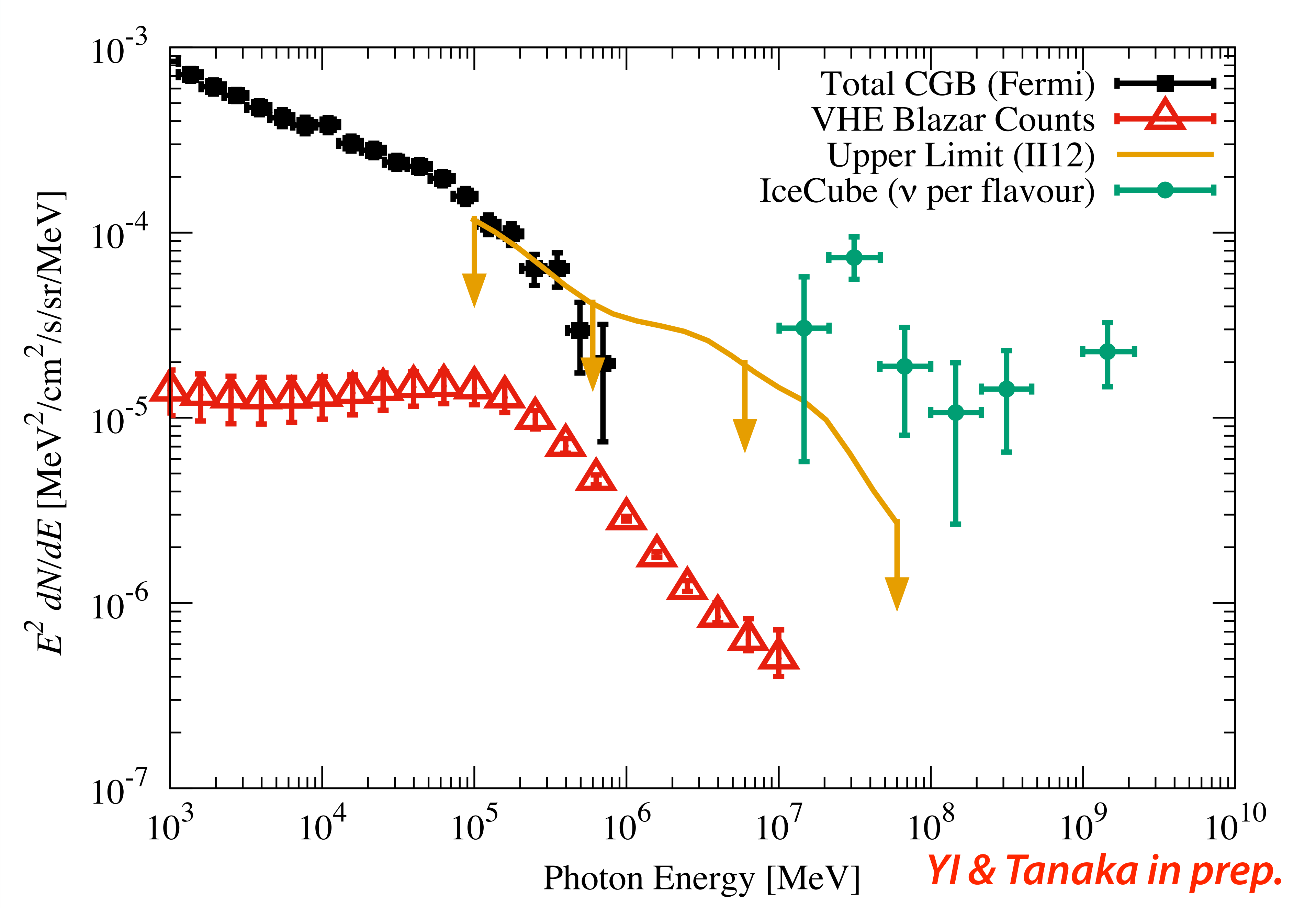

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Summary

- Cosmic TeV gamma-ray background is not well investigated yet.
- Current GeV gamma-ray background gives upper limits on the TeV gamma-ray background through the cascade argument
- Ensemble of low-state TeV blazar flux gives lower limit on to the cosmic gamma-ray background
- Current limit on the TeV background is

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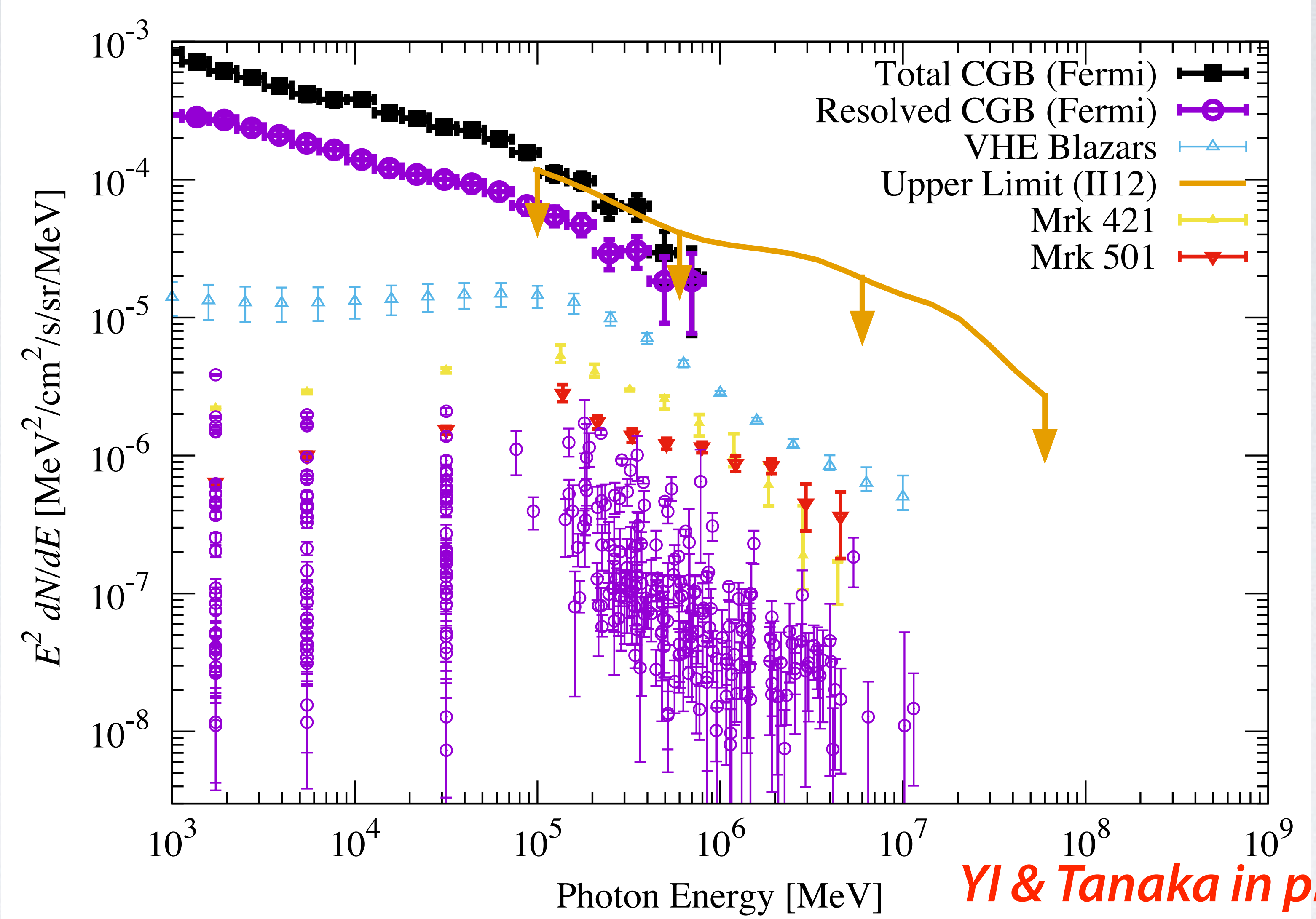
Lower Bound on the Cosmic Gamma-ray Background



YI & Tanaka in prep.

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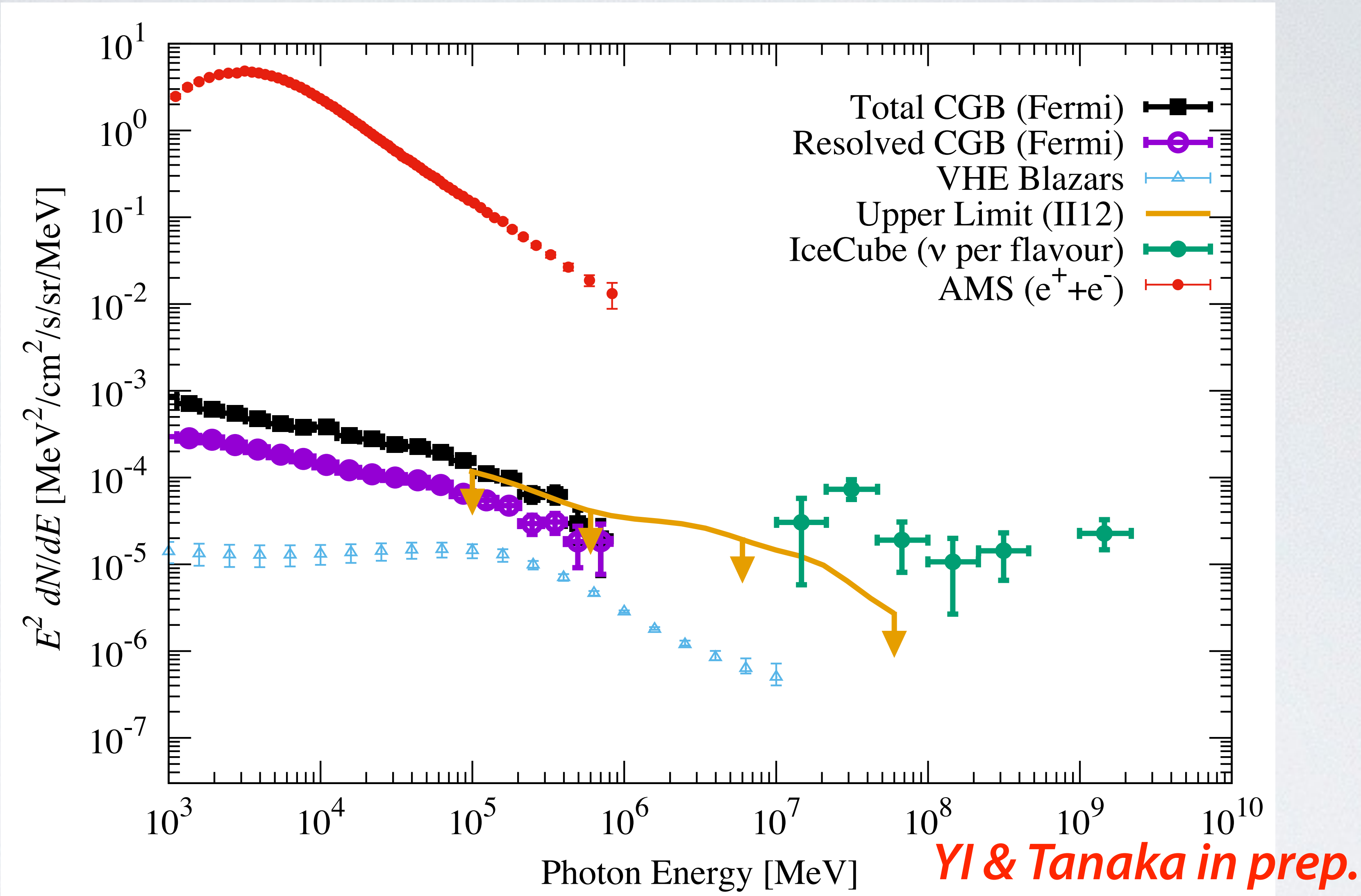

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VHE EGB Model

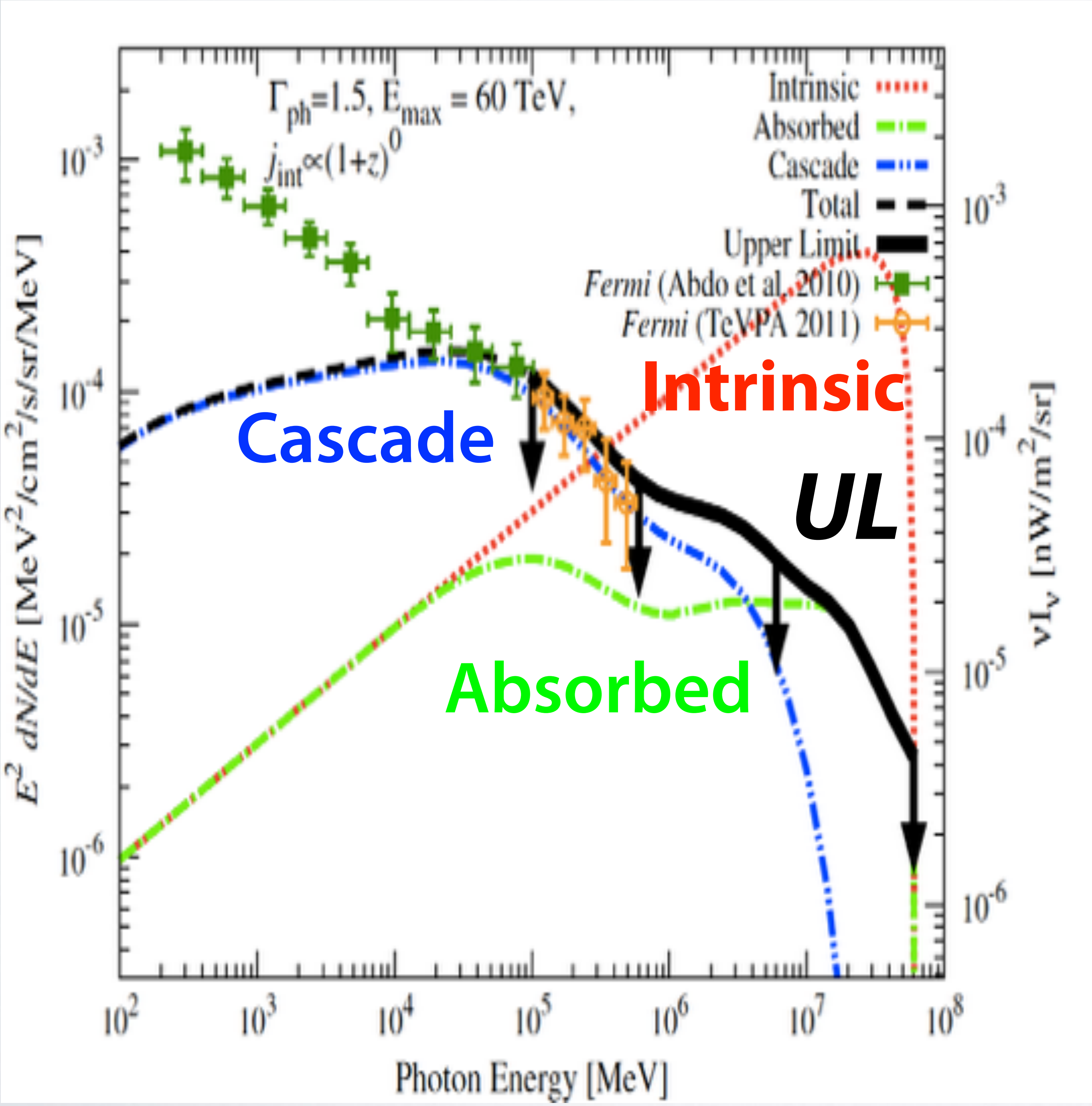
$$E^2 \frac{dN}{dE}(E_{\rm obs}) = \frac{cE_{\rm obs}^2}{4\pi} \int_0^{z_{\rm max}} dz \left| \frac{dt}{dz} \right| (1+z) \times \frac{dj}{dE_\gamma}[(1+z)E_{\rm obs}, z] \exp[-\tau_{\gamma\gamma}(E_{\rm obs}, z)],$$

$j = j_{\rm int} + j_{\rm cas}$ $\quad$ $\mathrm{MeV/s/MeV/cm^3}$

$$\frac{dj_{\rm int}}{dE_\gamma}(E_\gamma, z) = \begin{cases} j_0 E_\gamma^{-\Gamma_{\rm ph}} (1+z)^{\beta_{\rm evo}}, & E_\gamma \le E_{\rm max}, \\ 0, & E_\gamma > E_{\rm max}, \end{cases}$$

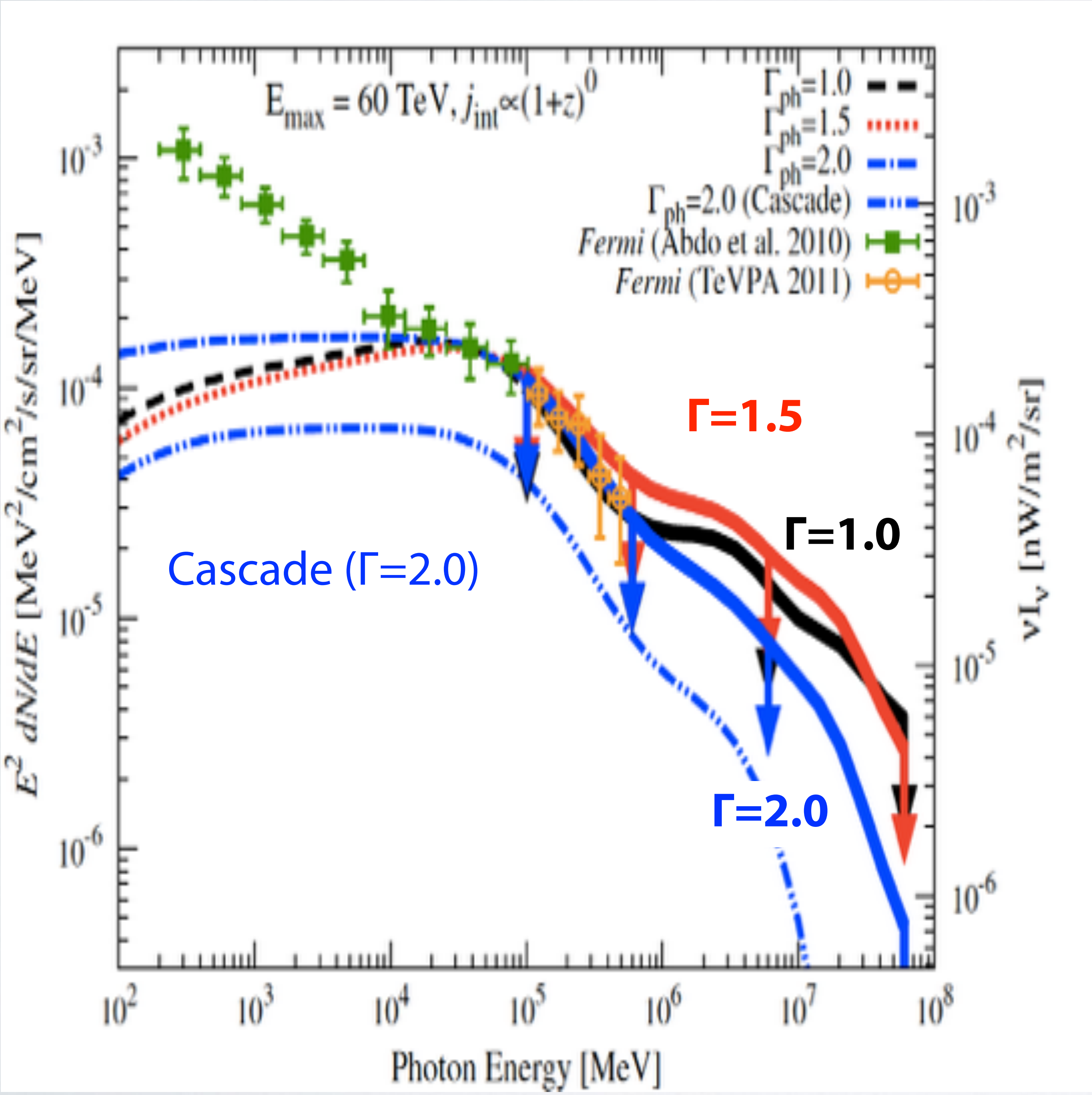
- Parameters are
  - β_{evo} : Cosmological evolution of number density
    - Most of known sources show $\beta_{evo} > 0$
  - E_{max} : Maximum energy
  - Γ_{ph} : Photon index

Upper Limit on EGB



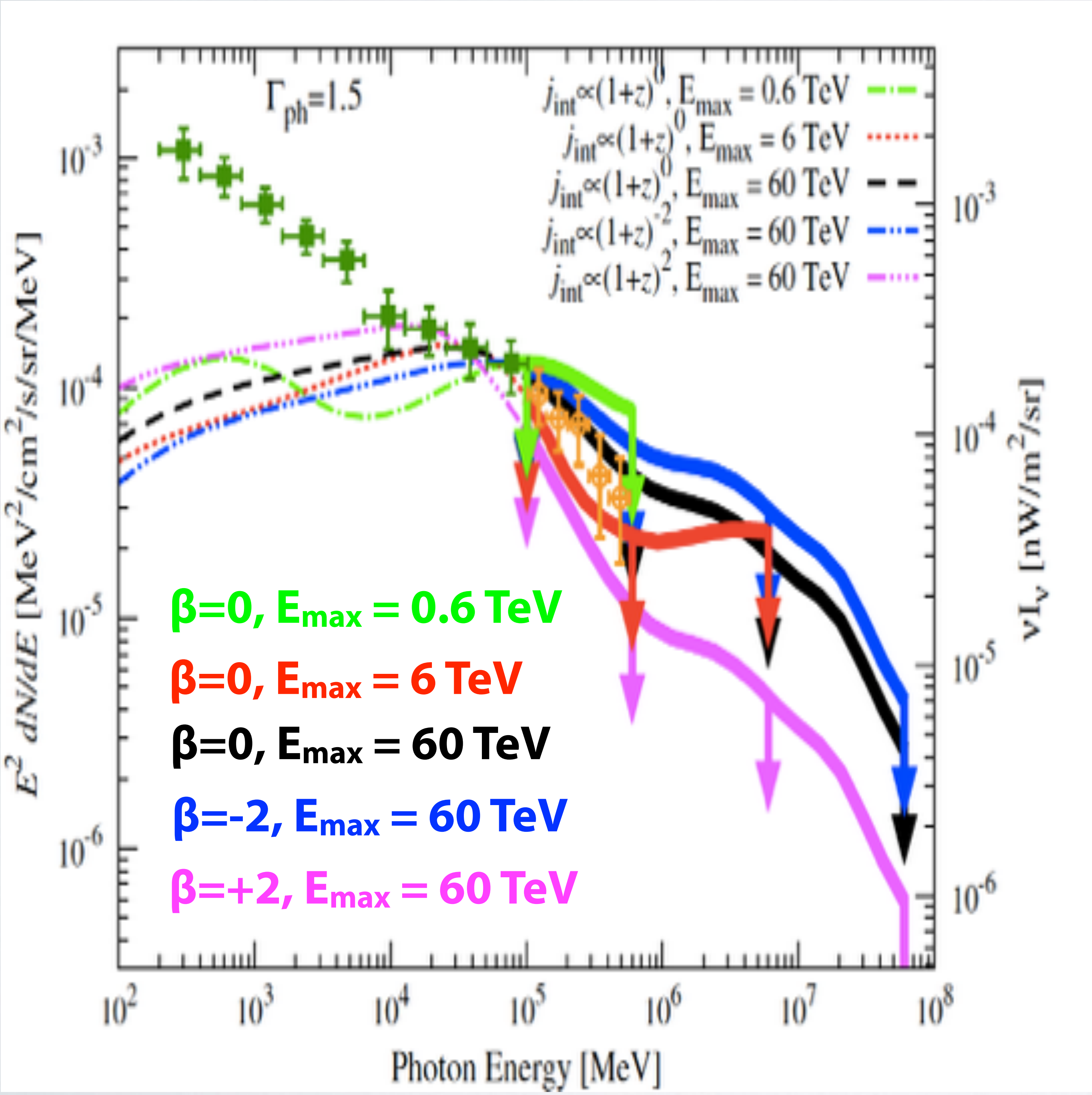
- β_{evo}=0 (no evolution)
- Γ_{ph}=1.5 (Fermi acc. limit)
- E_{max} = 60 TeV
- Normalization is fixed to the EGB data < 100 GeV.
- No known source classes included.
- Upper limit is consistent with the Fermi VHE EGB obs.
- UL: $E^2\frac{dN}{dE} < 1.1\times10^{-4}\left(\frac{E}{100\,\mathrm{GeV}}\right)^{-0.5}$ MeV/cm^2/s/sr

Different Photon Indices



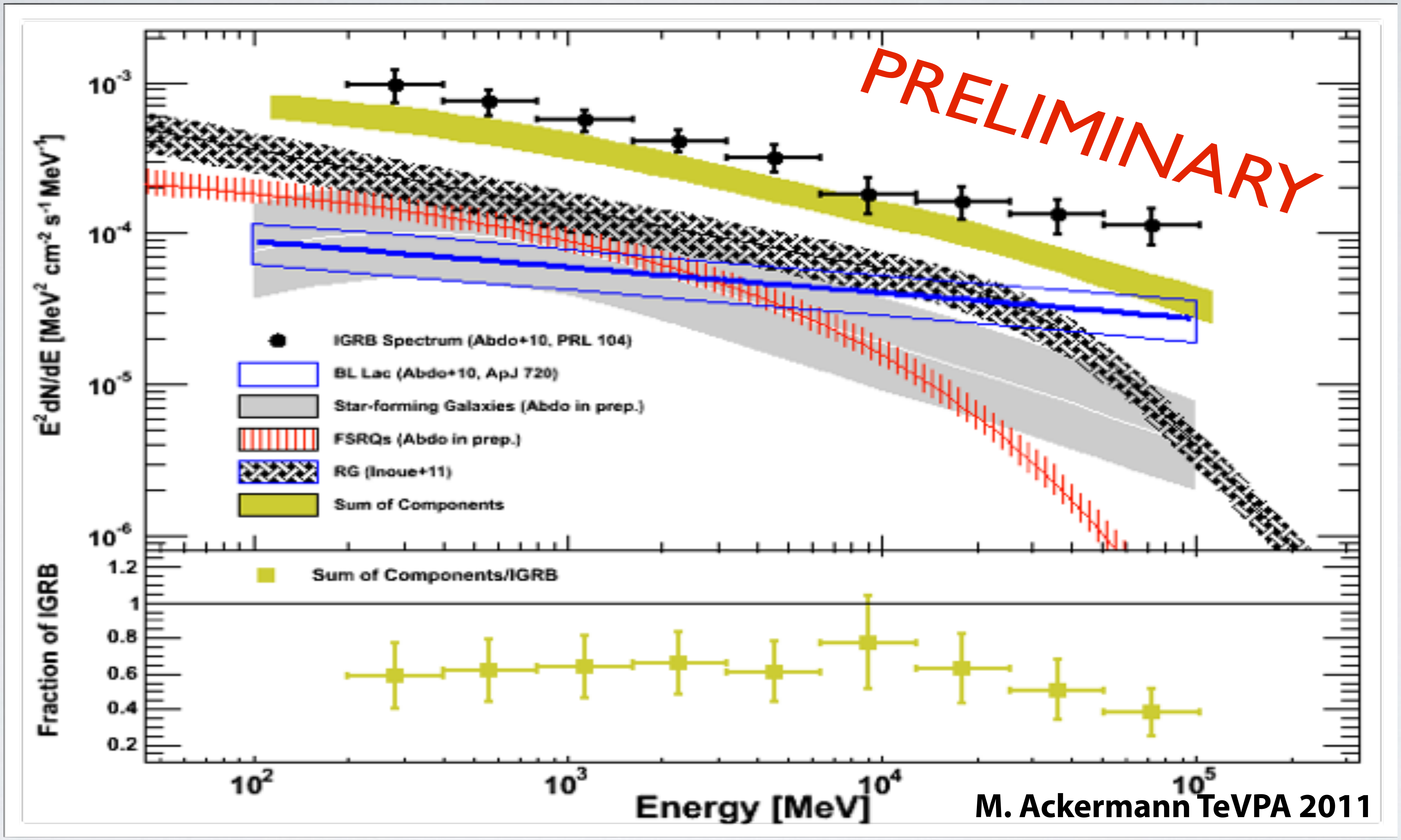
- Γ~1.5 is the most conservative.
- Harder spectral model is limited by the cascade.
- Softer spectral model is limited by the primary.

Different E_{max} and evolution



- β>0 violates the limit.
- β<0 eases the limit.
  - But, no known gamma-ray sources.
- low E_{max}(~sub-TeV) eases the limit.
- If cosmological,
  - sources should have a hard spectrum and show no or negative evolution.

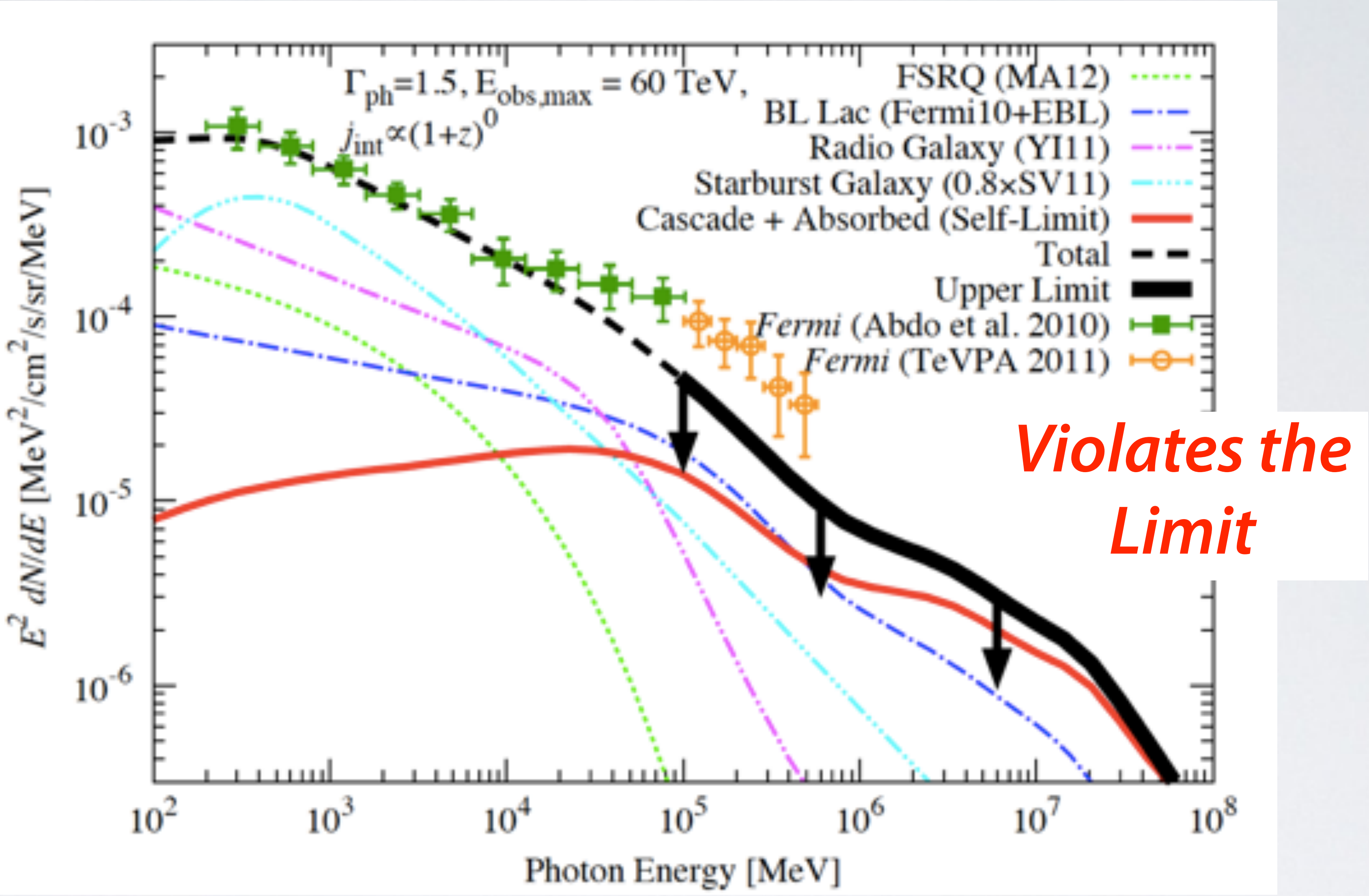
Components of EGB



- FSRQs (Ajello+'12), BL Lacs (Abdo+'10), Radio gals. (YI'11), Starburst gals. (Stecker & Venters '11, Ackermann+'12) are guaranteed to contribute to EGB.

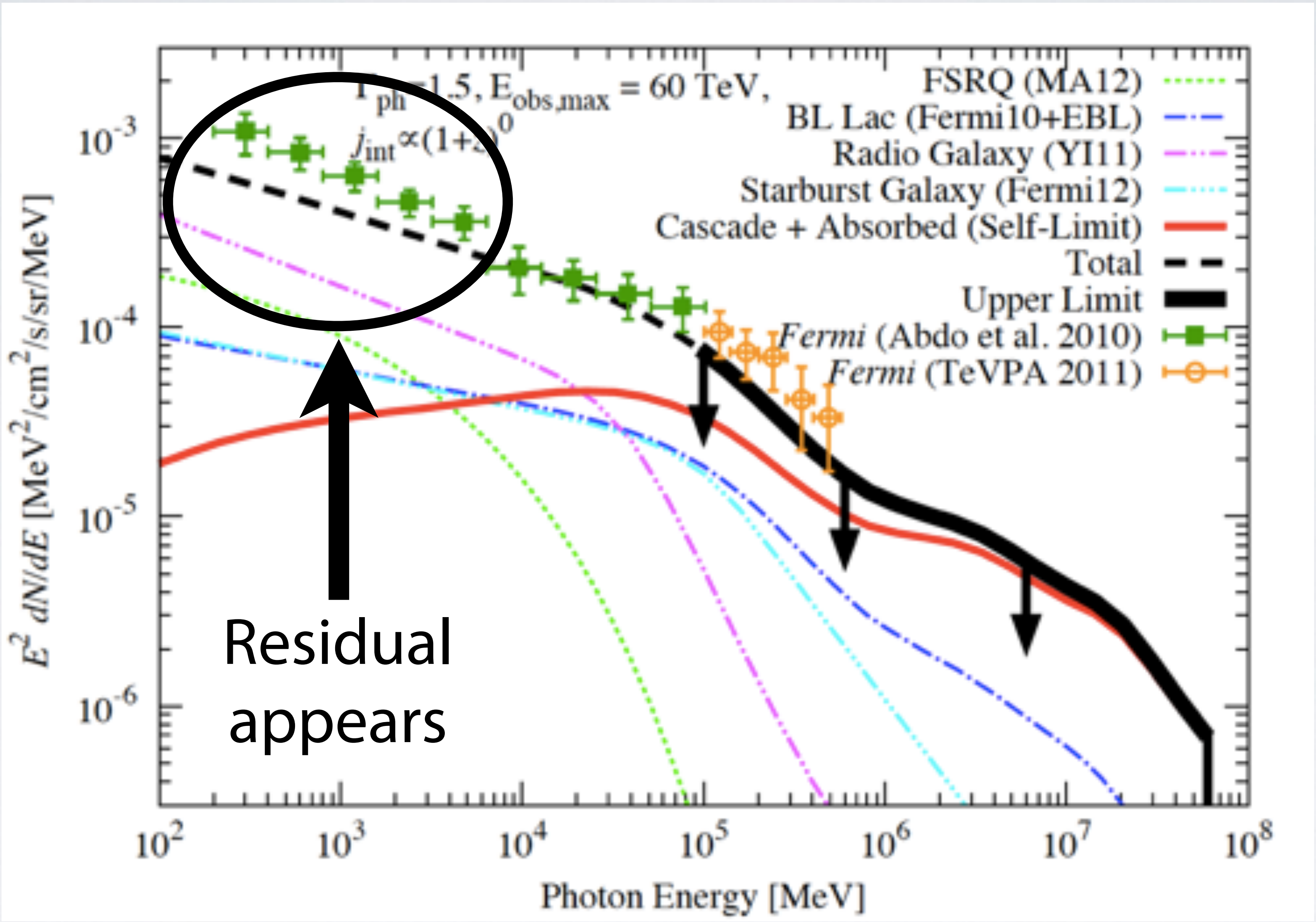
- We need to subtract them to evaluate the VHE EGB upper limit.

Upper Limit on EGB w/ known sources



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

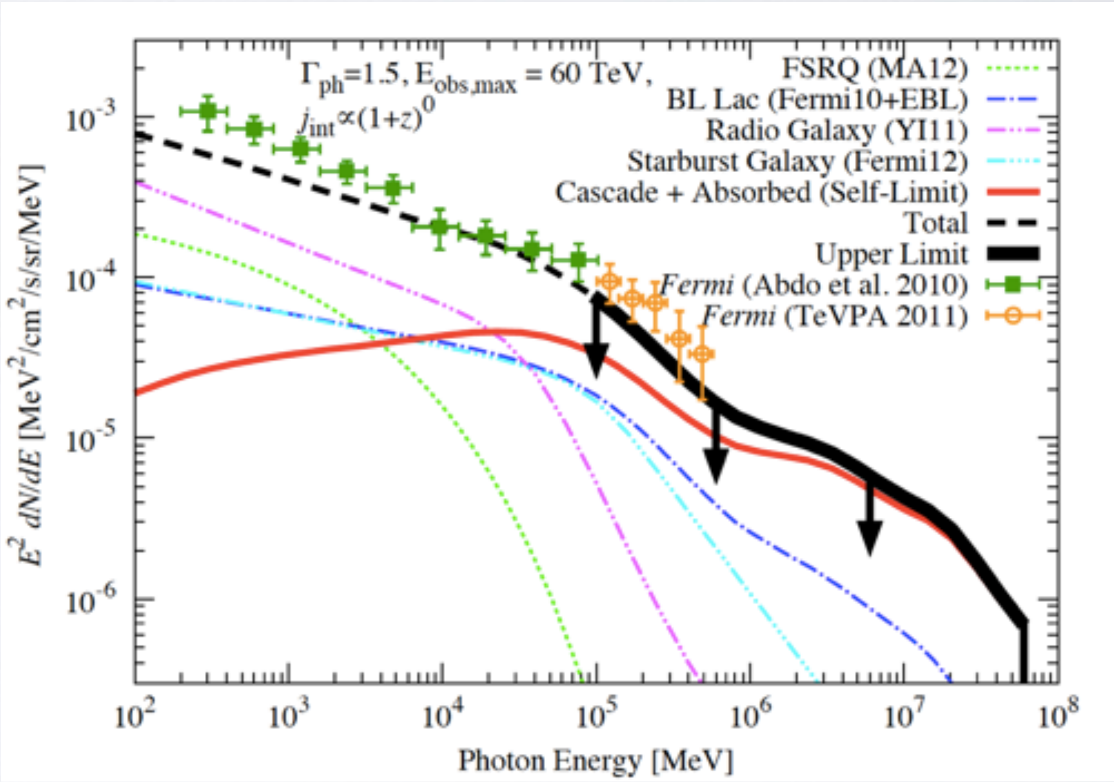
Upper Limit on EGB w/ other models



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

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