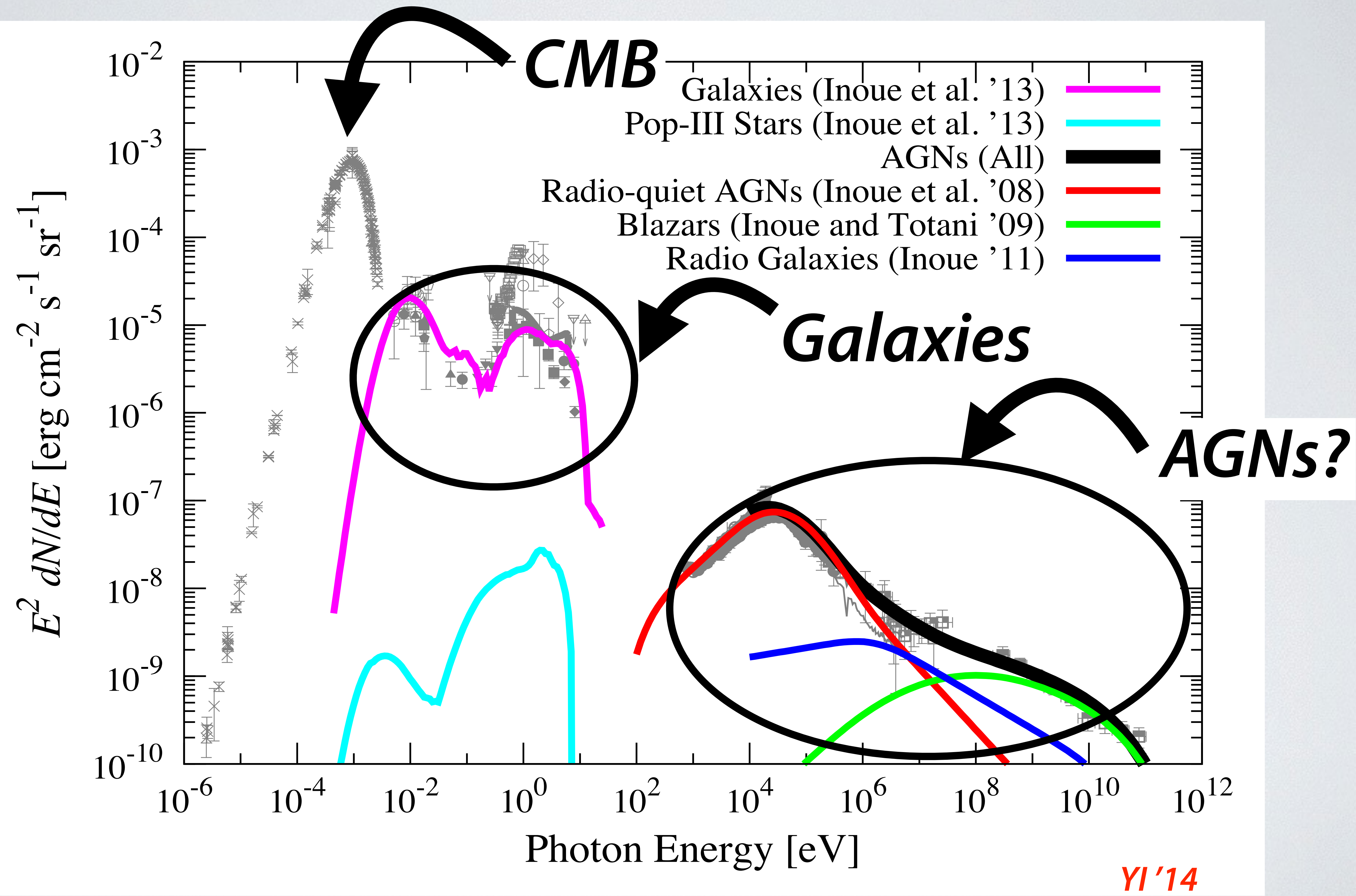
Gamma-ray Blazars and the Cosmic Background Radiation

Yoshiyuki Inoue
(JAXA International Top Young Fellow)

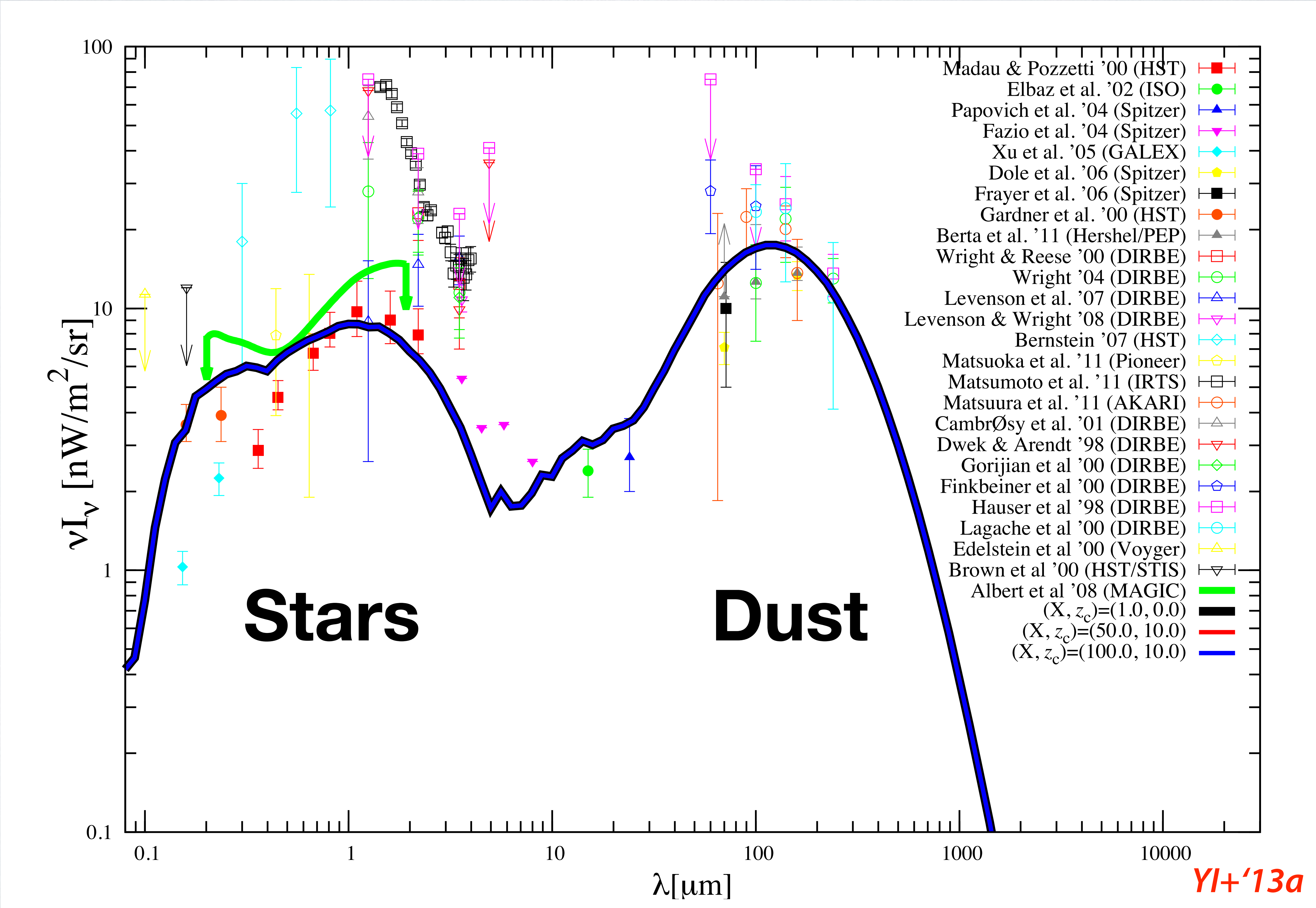
PACIFIC 2015, Tahiti, 2015-09-15

Cosmic Background Radiation

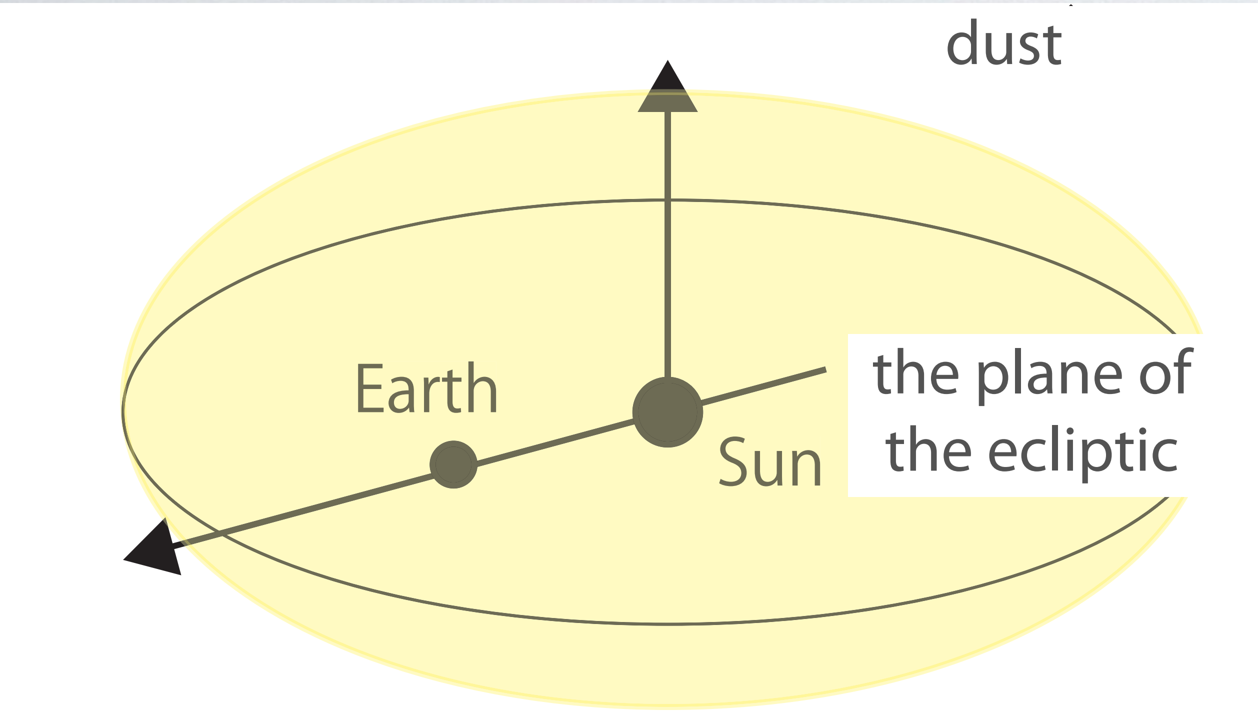


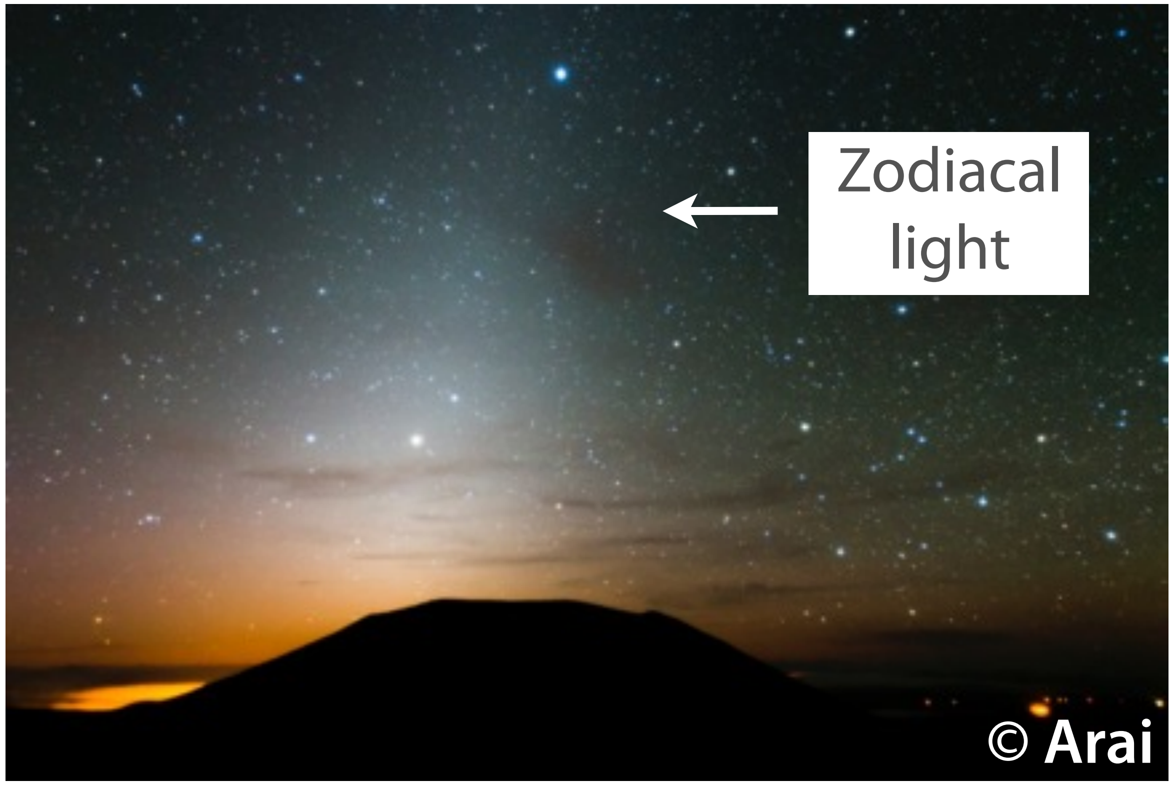
Cosmic Infrared Background

Cosmic Optical & Infrared Background (COB & CIB)



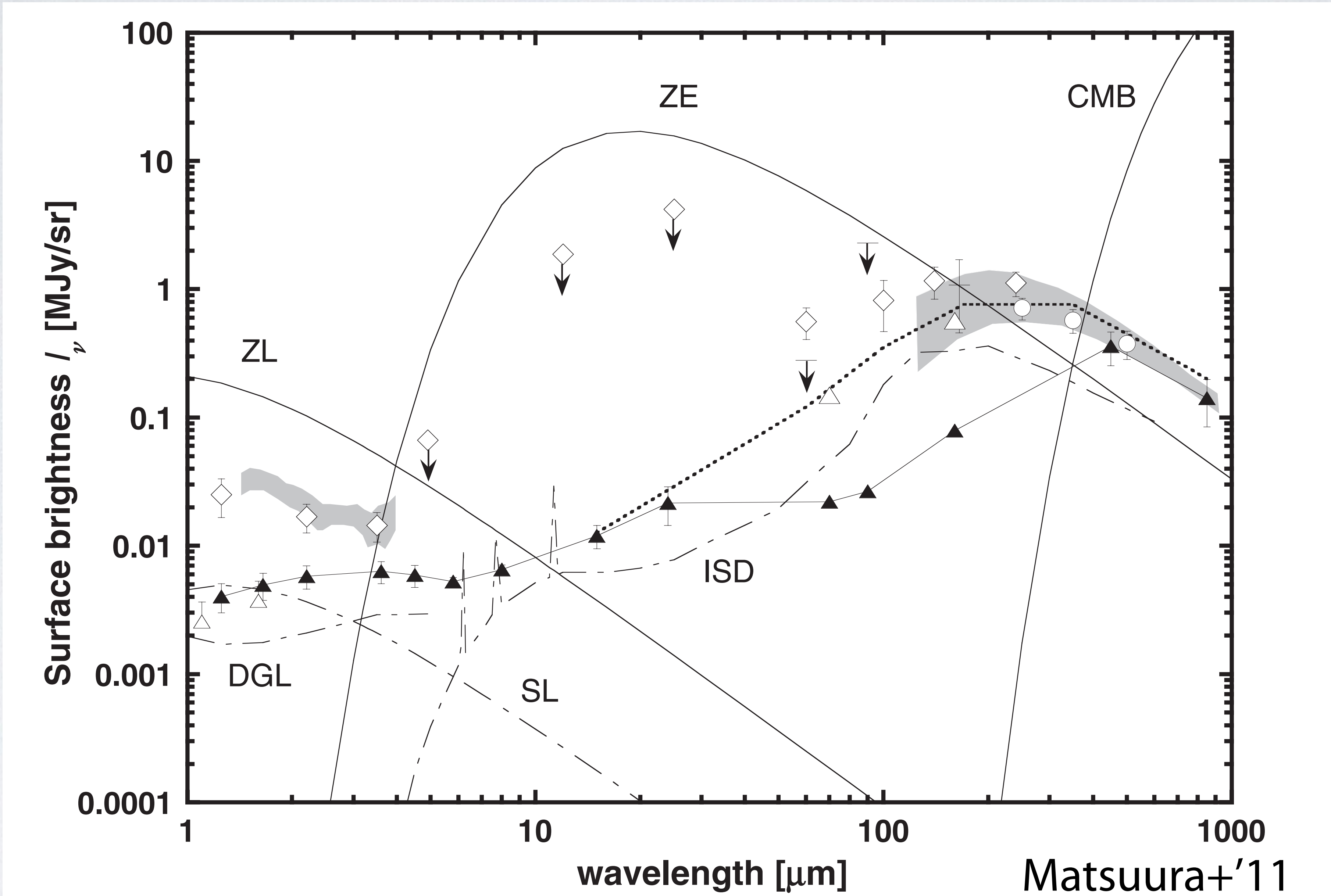
Zodiacal Light





- Scattered solar emission by interplanetary dust (NIR)
- Interplanetary dust distribute around the plane of the ecliptic
- Brightest foreground emission for the COB/CIB measurement

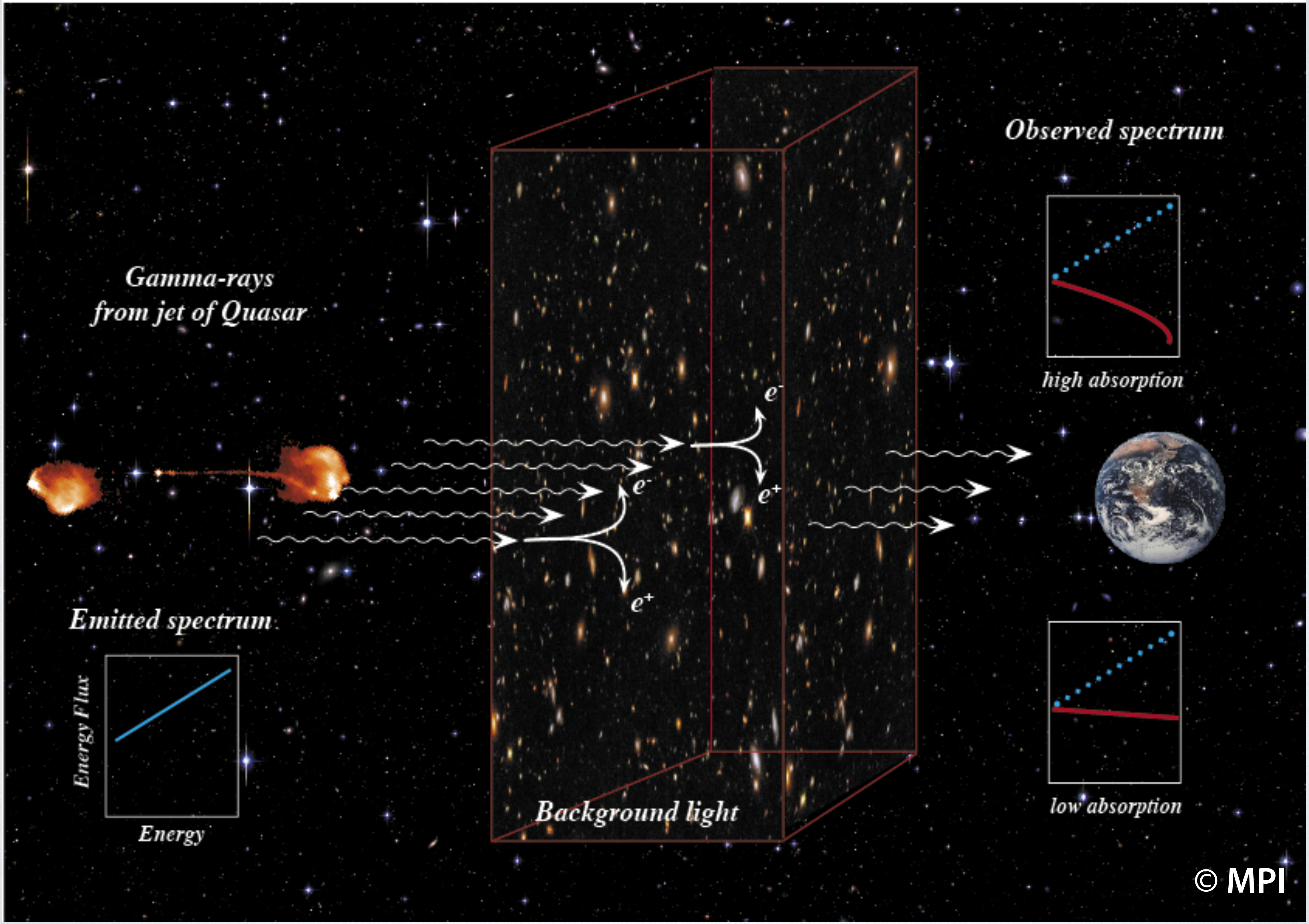
Foregrounds for COB & CIB



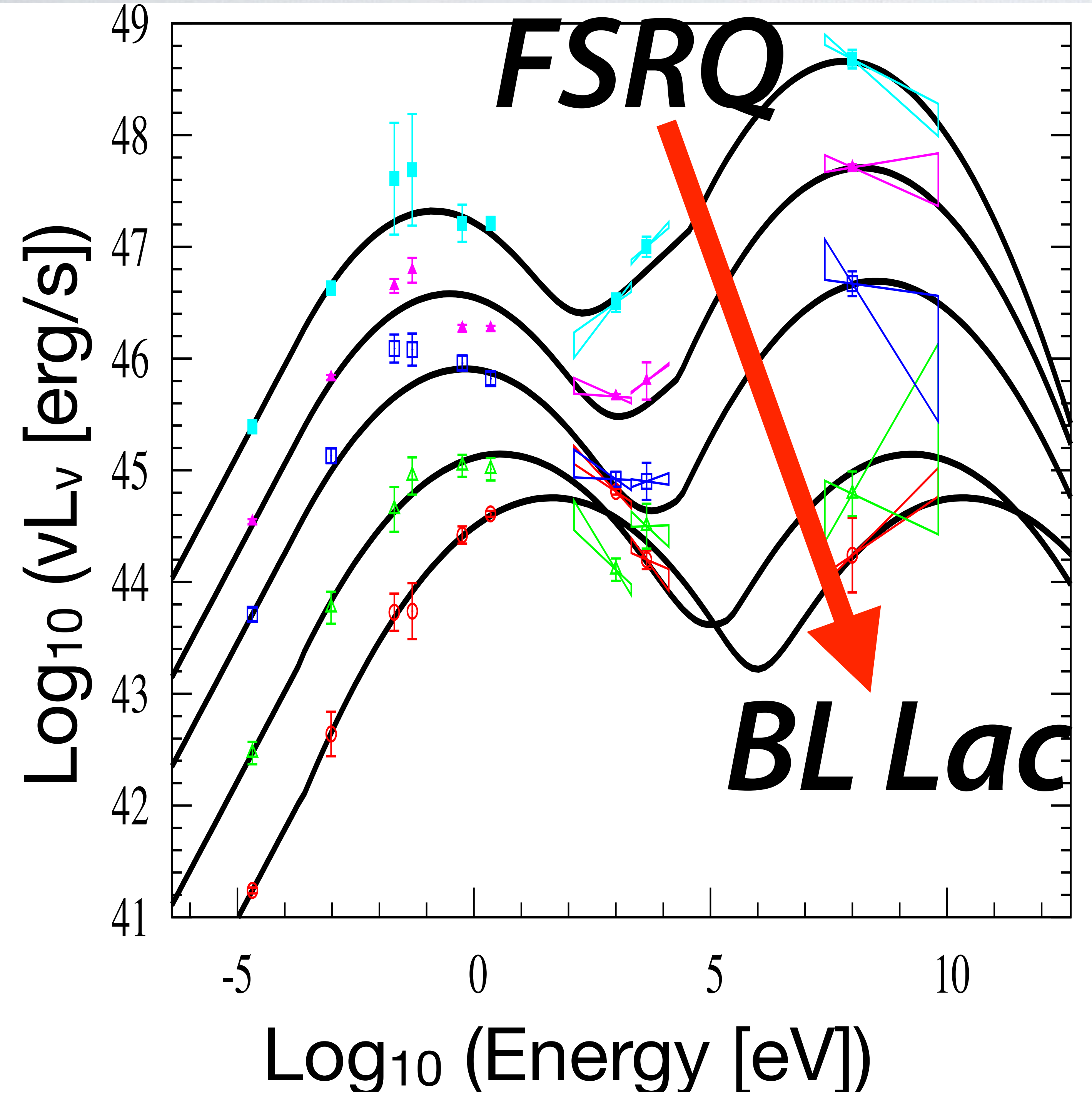
Matsuura+'11

- Foreground: Zodiacal light, Diffuse galactic light, Star light.

Gamma-ray Attenuation by The Cosmic Optical & Infrared Background



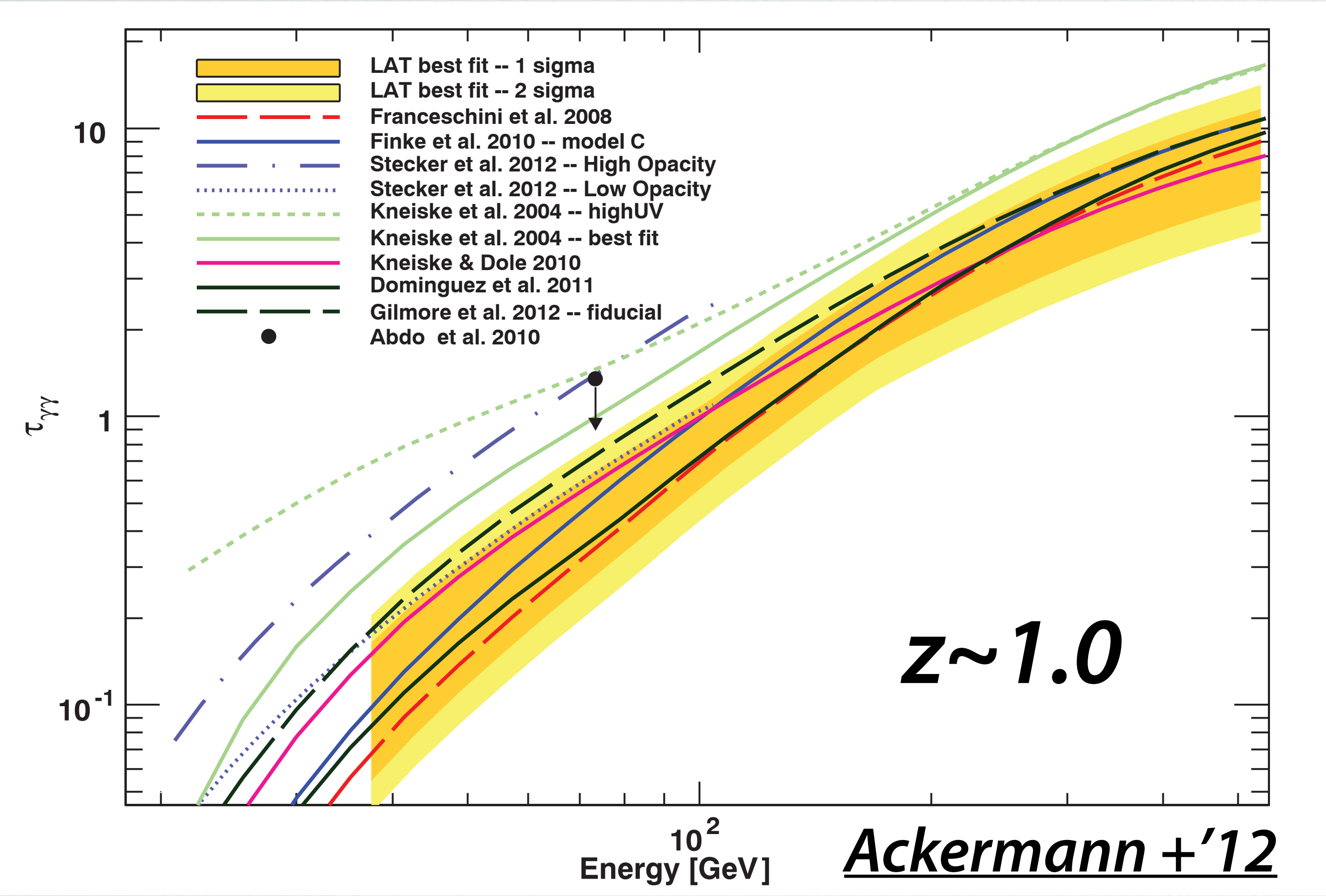
Typical Spectra of Blazars



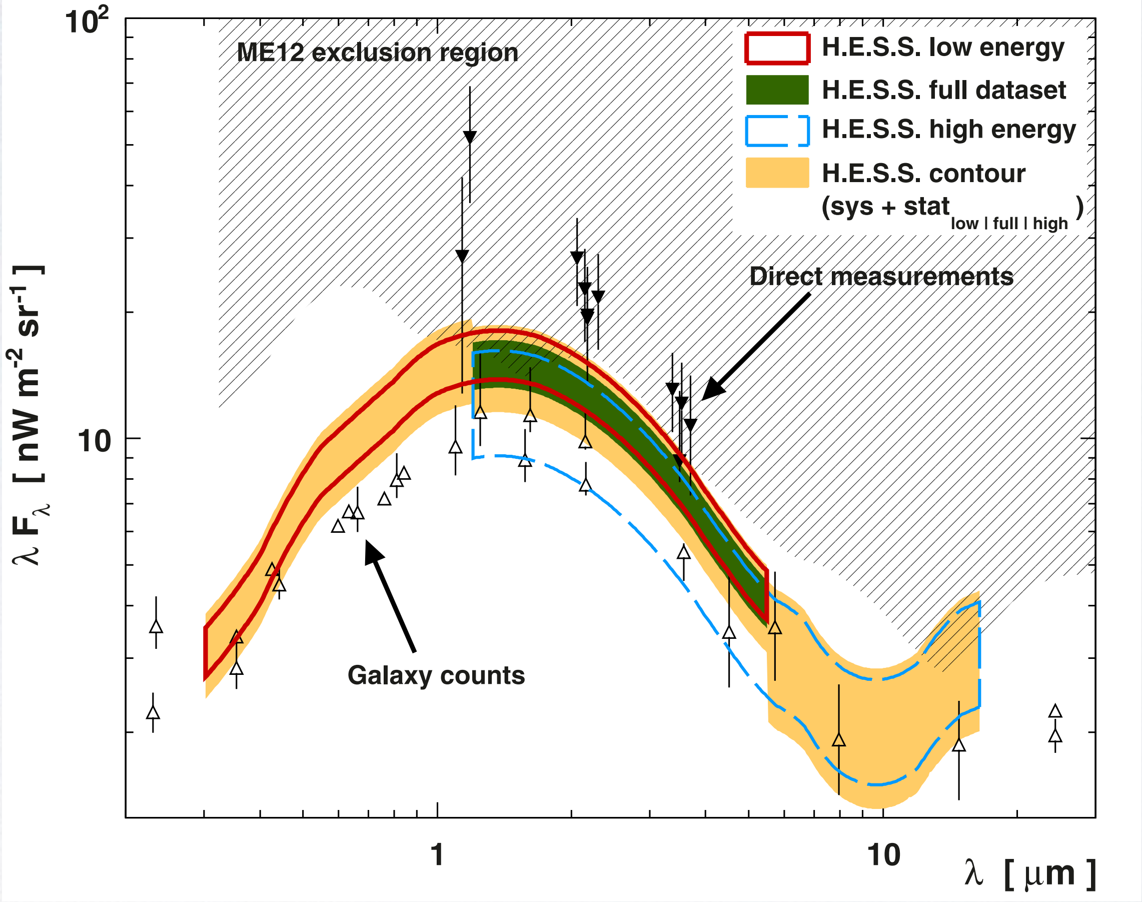
Fossati+'98, Kubo+'98,
YI & Totani '09

- 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)

Constraints from Gamma rays



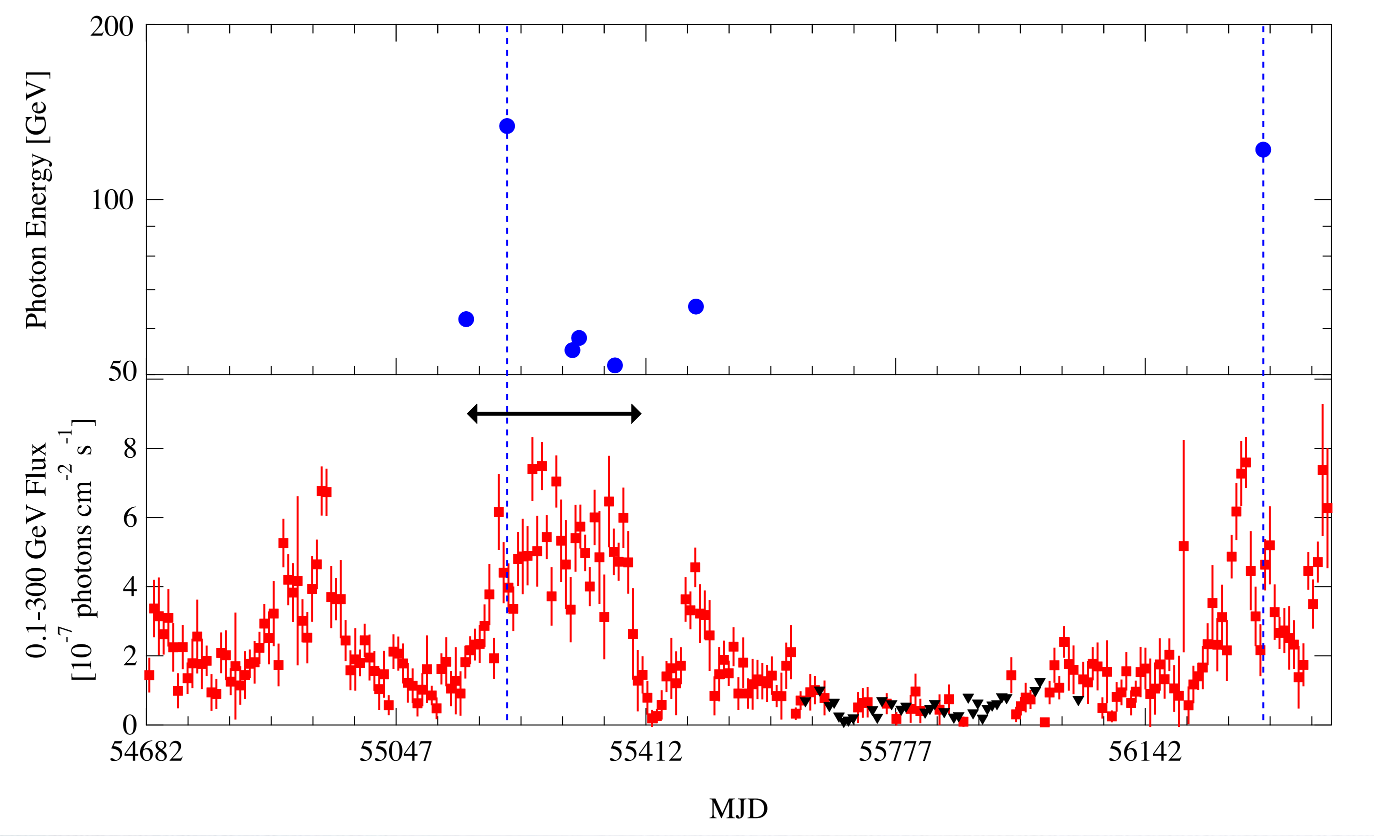
Ackermann +'12

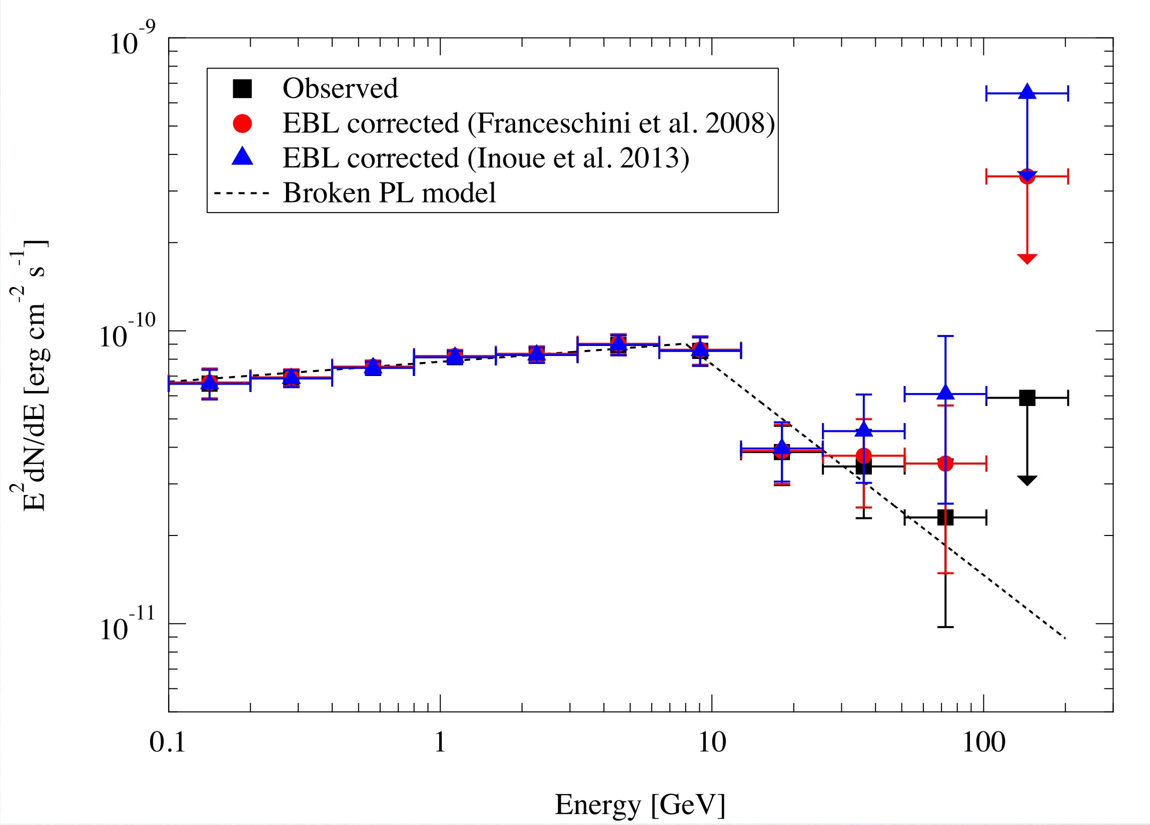


Abramowski +'13

- 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/CIB intensity using the combined spectra of blazars.
- Assume 1) no pile-up in the TeV band & 2) extrapolation from unattenuated spectra.

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

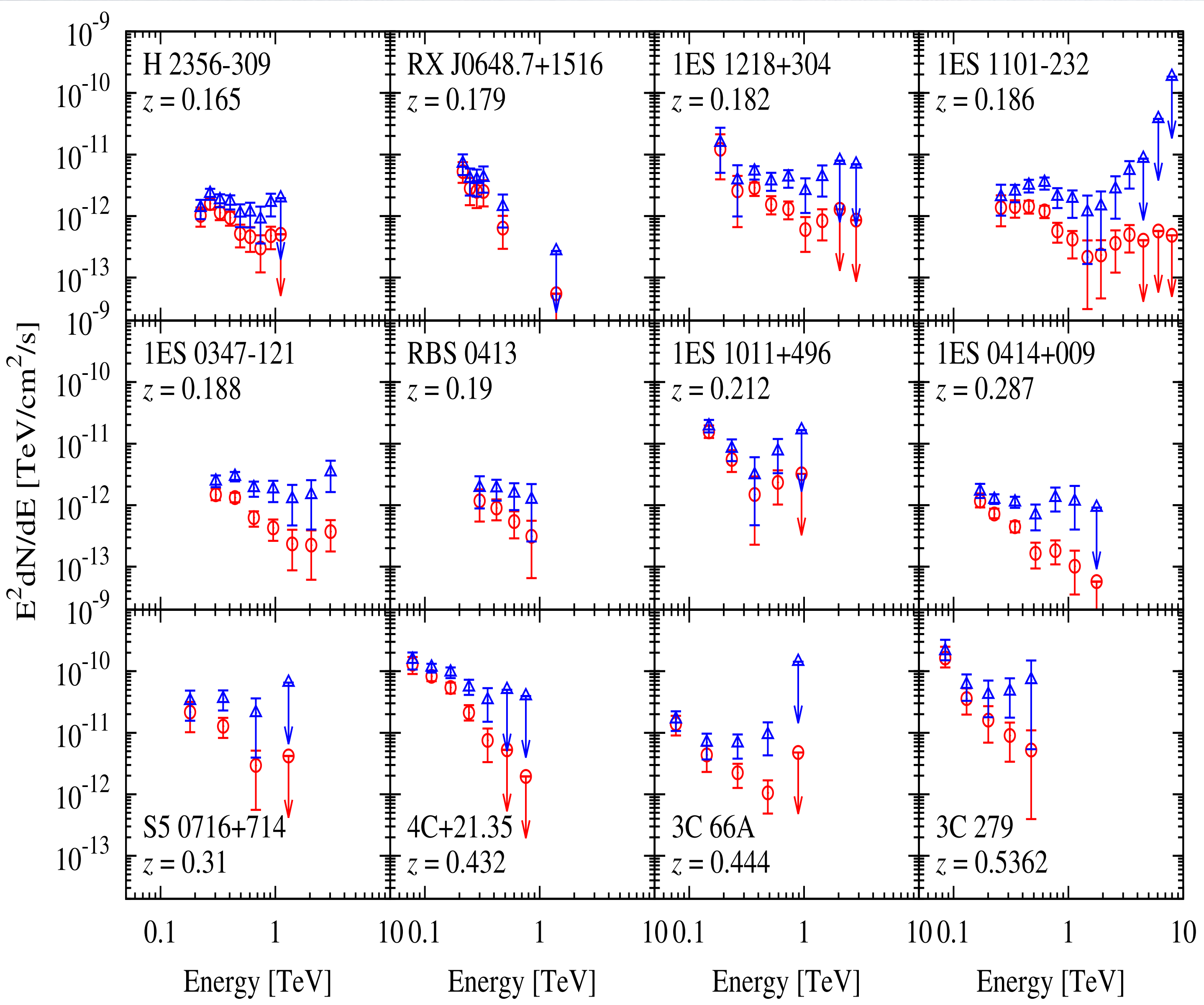




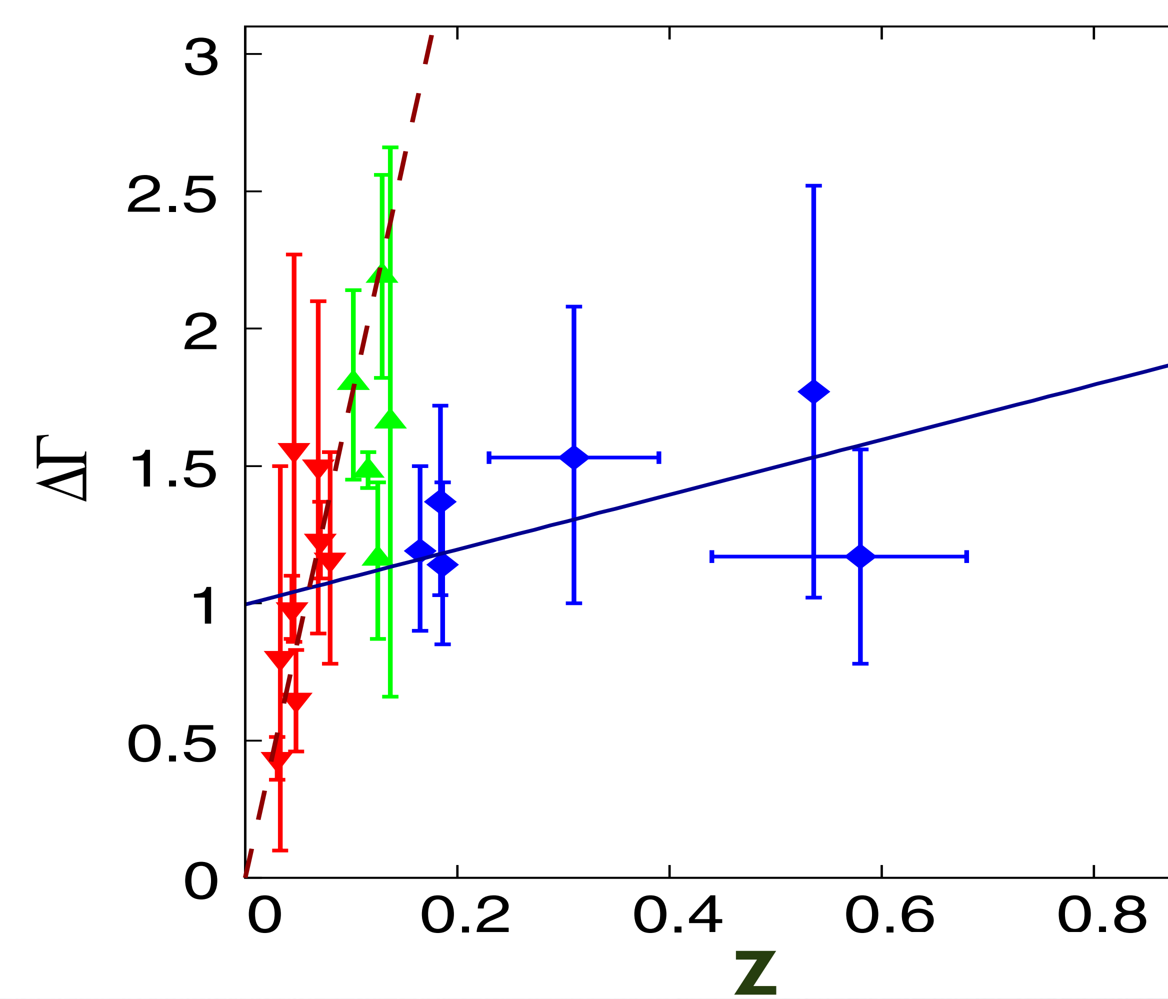
Tanaka, YI, +'13

- 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?



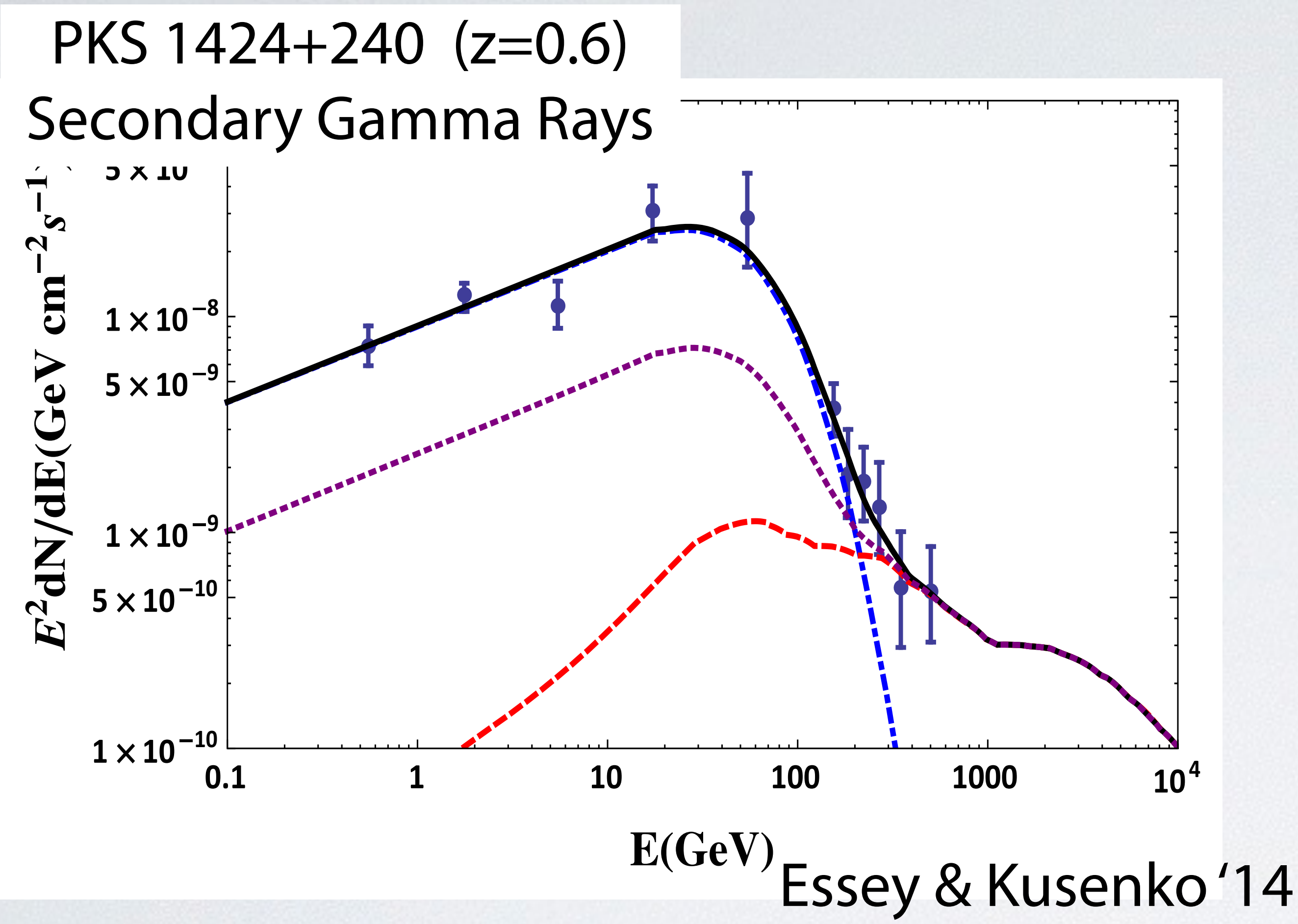
Yl+'13a

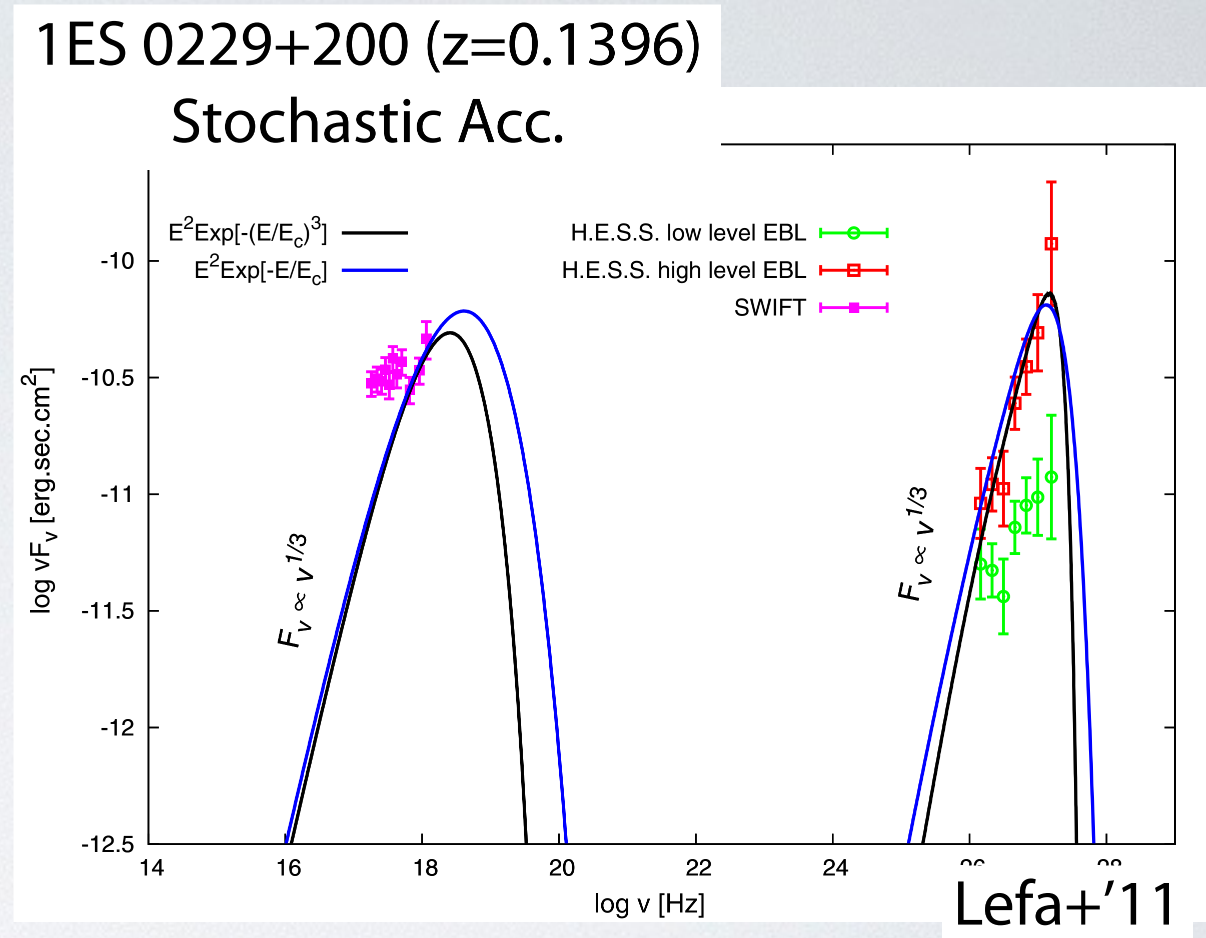


Essey & Kusenko '12

- It "seems" TeV blazars show spectral hardening.

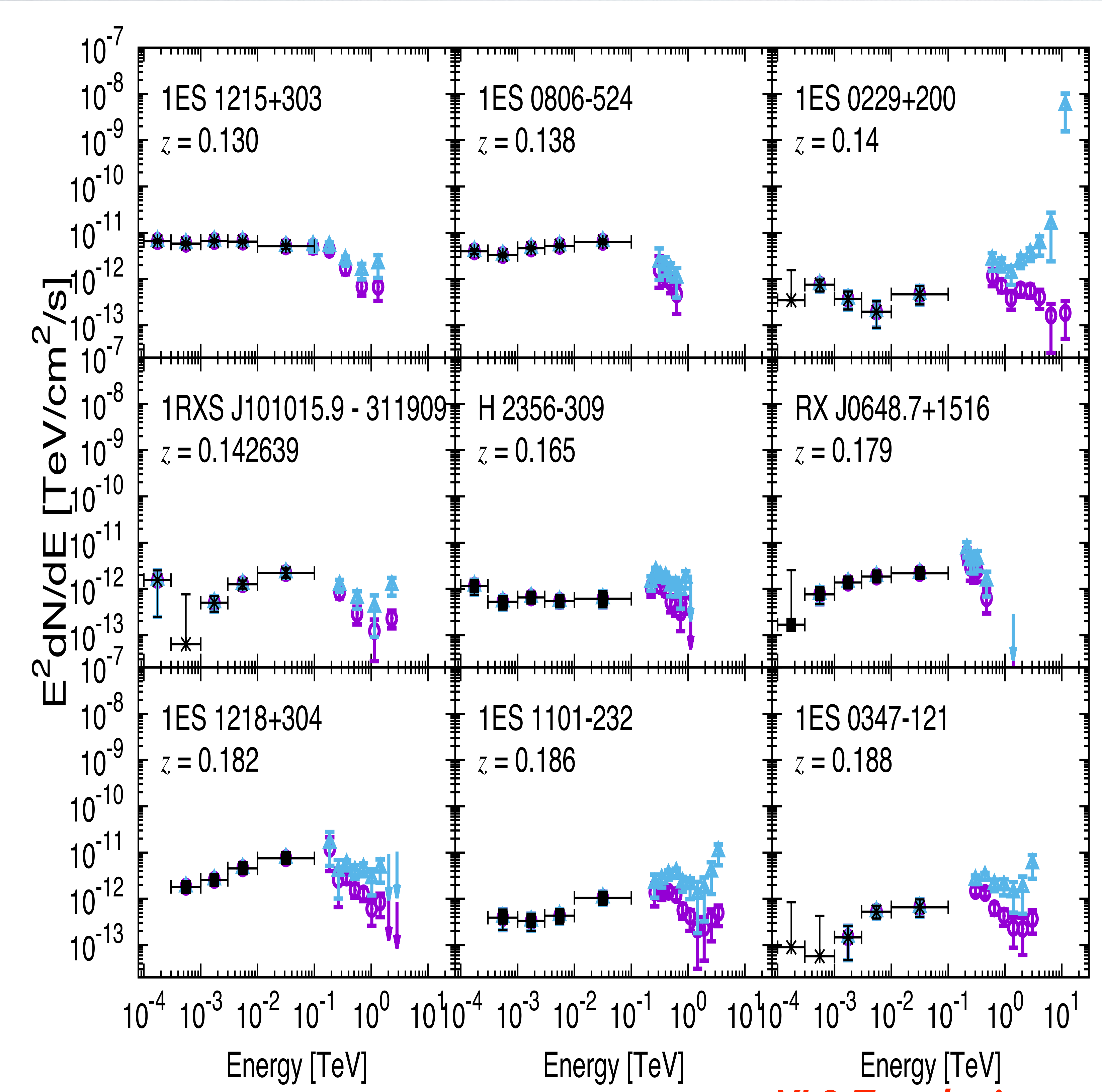
What is the origin of the hardening?





- Secondary gamma rays from cosmic rays along line of sight (Essey & Kusenko '10, Essey+'10, Essey+'11, Murase+'12,Takami+'13).
    - Observed GeV-TeV photon index dependence on redshift will be different from simple CIB attenuation (Essey & Kusenko '12).
- Stochastic acceleration (Stawarz & Petrosian '08, Lefa+'11).
- Lepto-hadronic emission (Cerutti+'14).

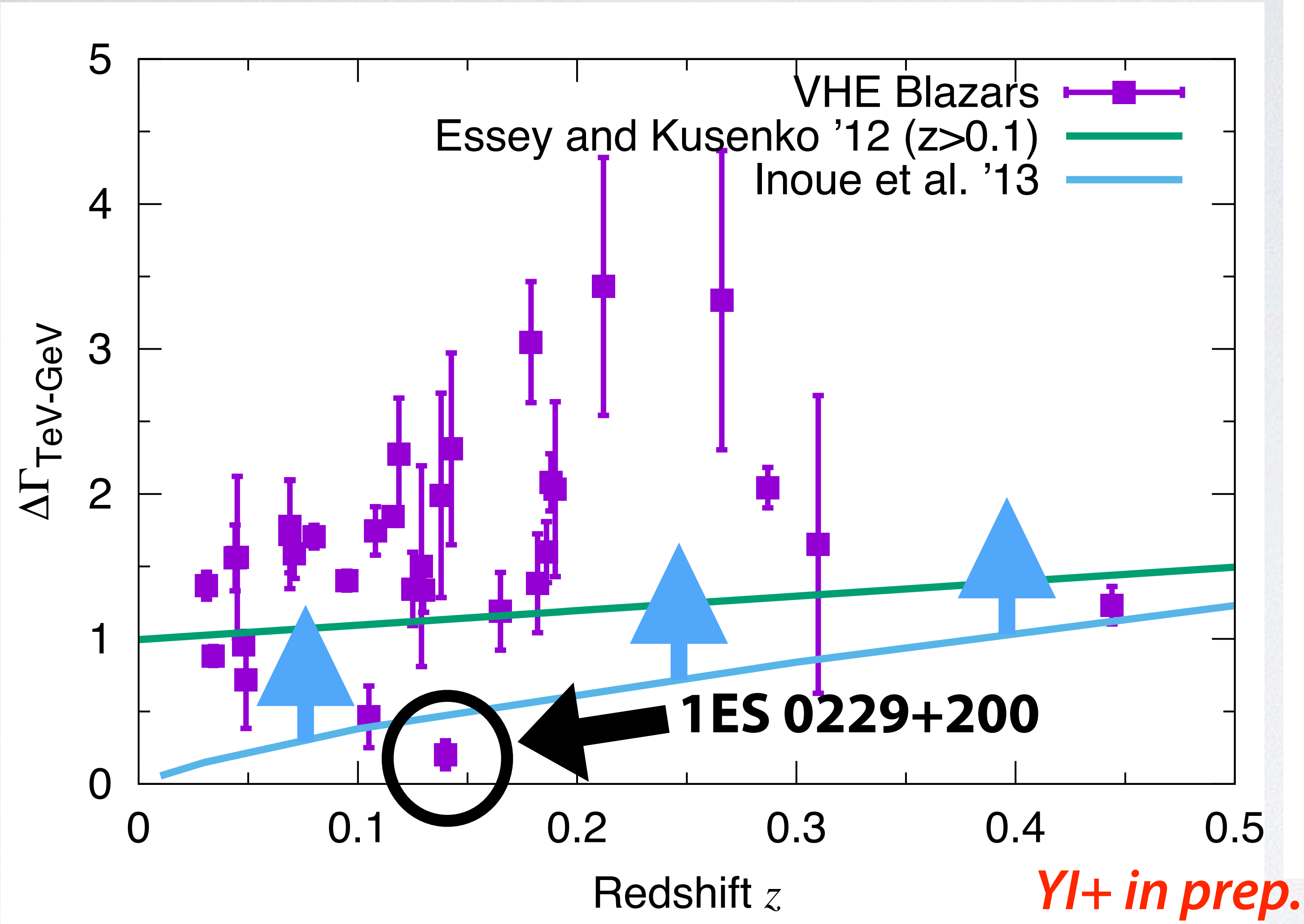
TeV blazar sample

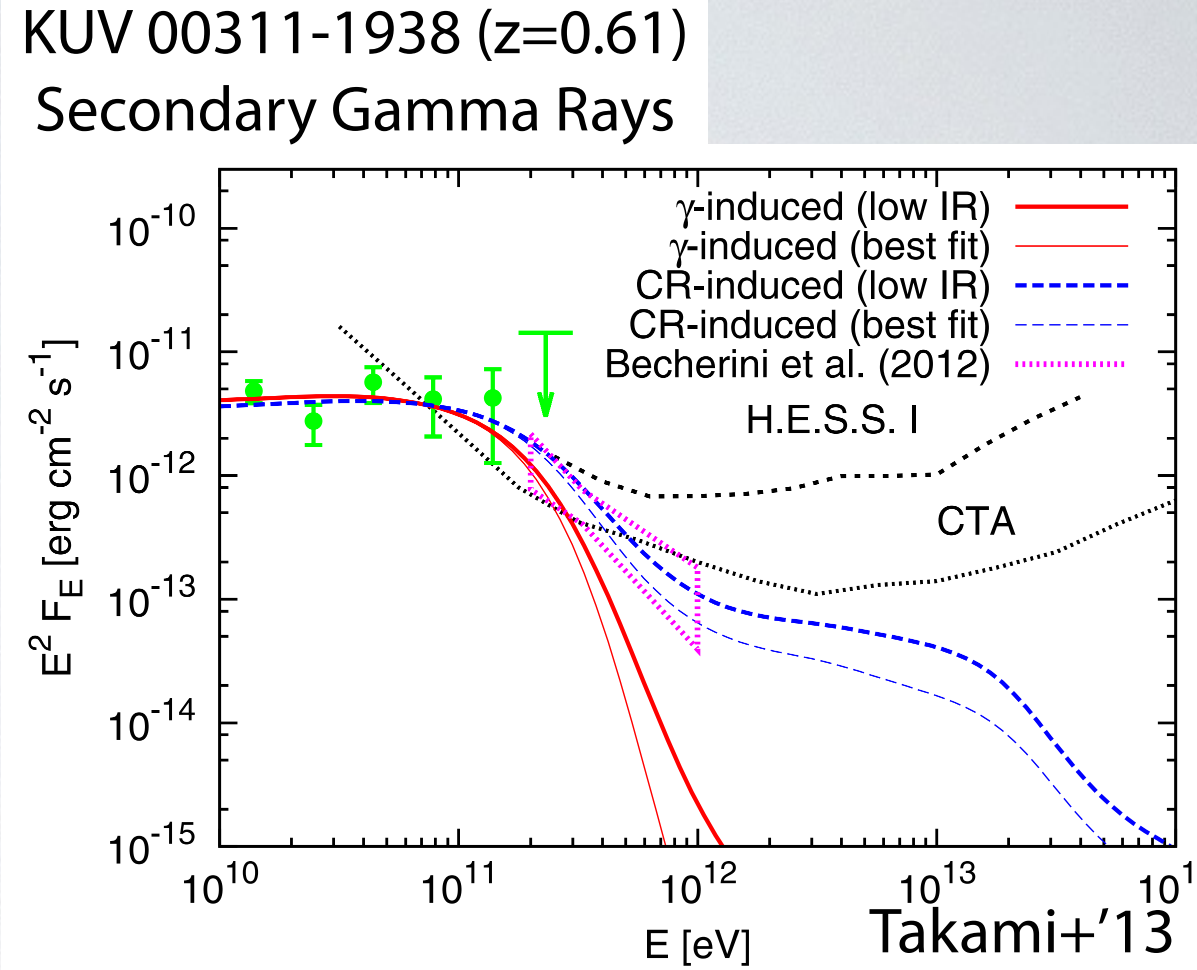


YI & Tanaka in prep.

- Select 36 blazars with z from the default TeVcat catalog.
- Low-state data are available for 31/36.
- 3FGL SED data.
- CIB correction by YI+'13.
- Systematic jet parameter study w/ MWL data is also on-going.

GeV-TeV index dependence on redshift

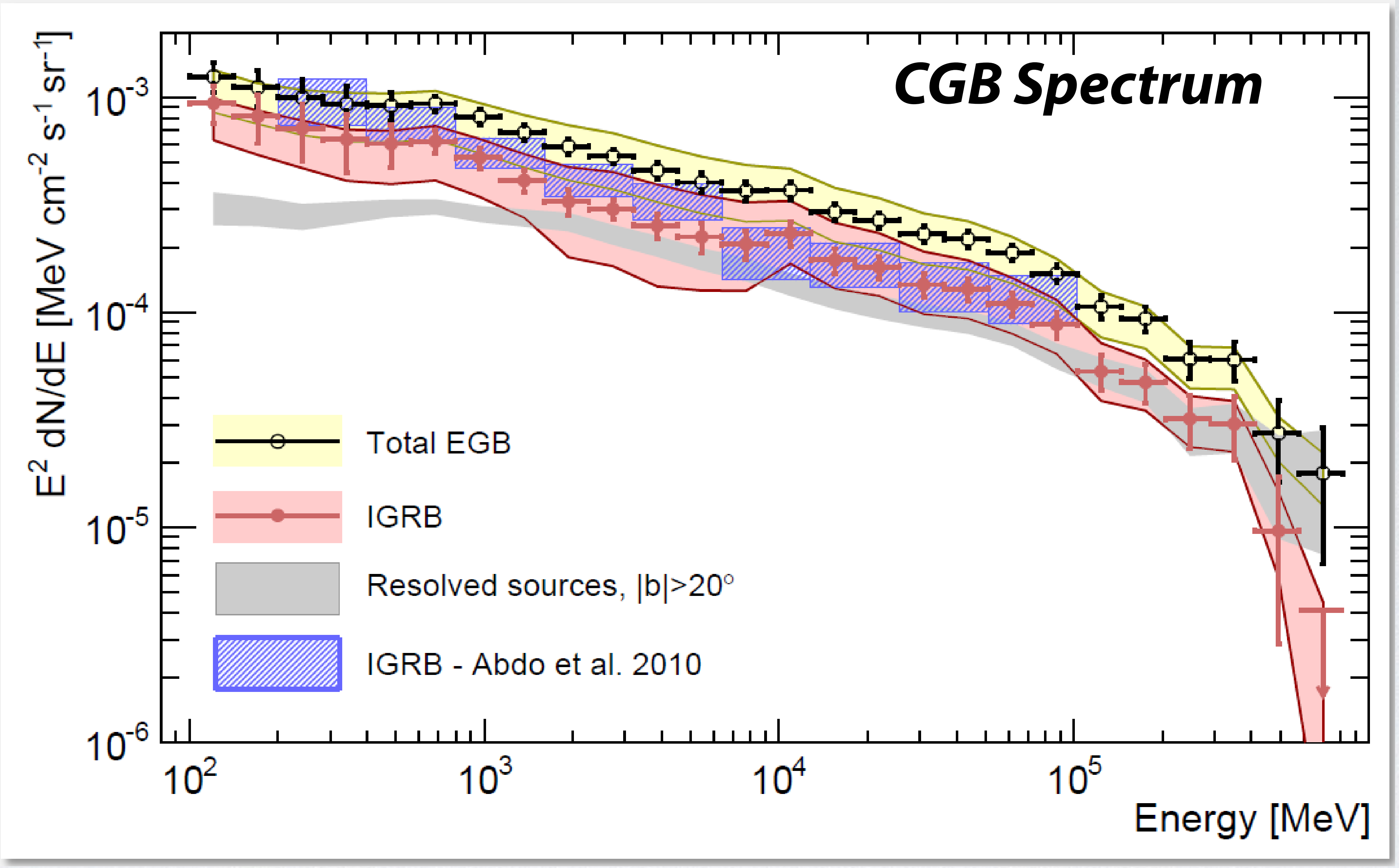




- No clear correlation (see also Sanchez+'13).
  - But, 1ES 0229+200 seems to be peculiar.
- additional components at TeV band are not significantly seen via F-test. No sources with P(F)<0.05.
- Future test by CTA is necessary (e.g. Takami+'13, YI+'14b).

Cosmic Gamma-ray Background

Cosmic Gamma-ray Background Spectrum at >0.1 GeV

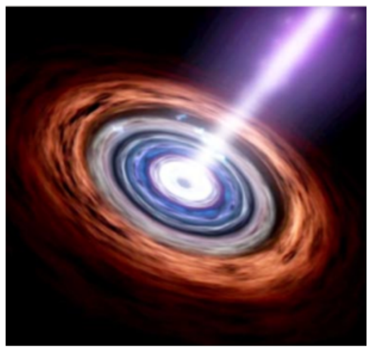


Ackerman+'15

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

Possible Origins of CGB at GeV

Unresolved sources



Blazars

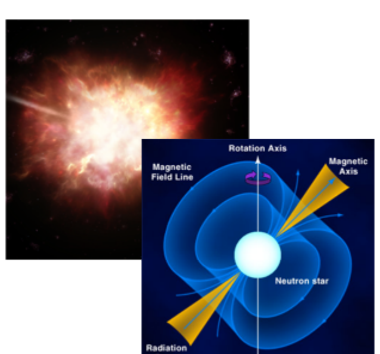
Dominant class of LAT extra-galactic sources. Many estimates in literature. EGB contribution ranging from 20% - 100%

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)



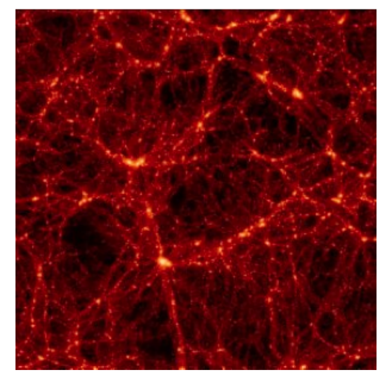
GRBs
High-latitude pulsars

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

Diffuse processes

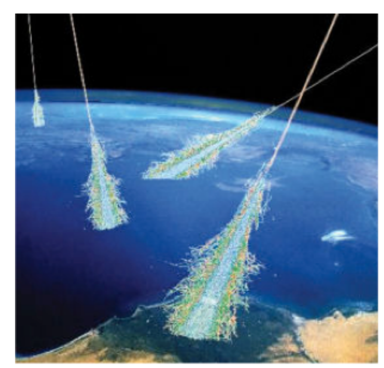
Intergalactic shocks

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)



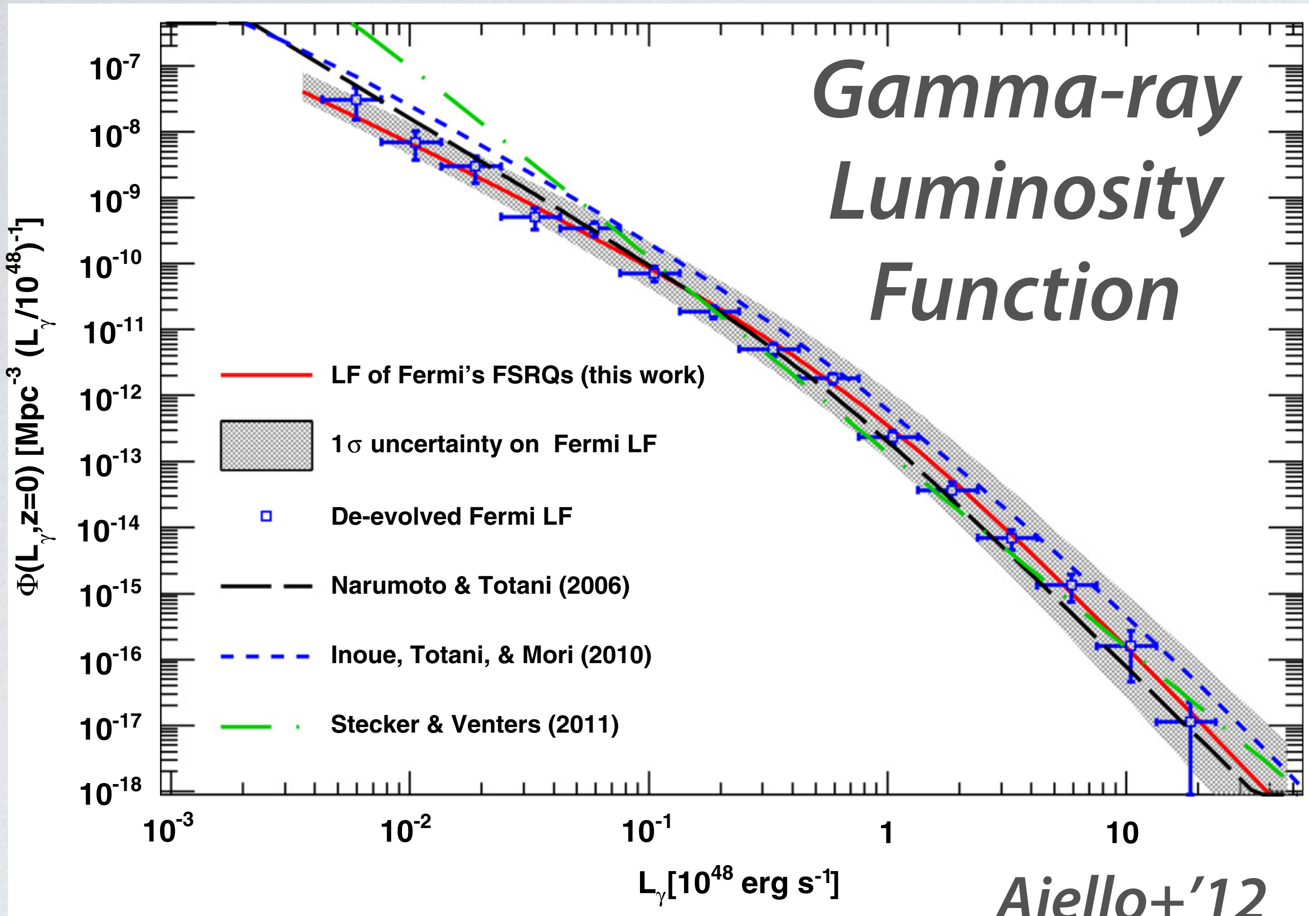
Interactions of UHE cosmic rays with the EBL

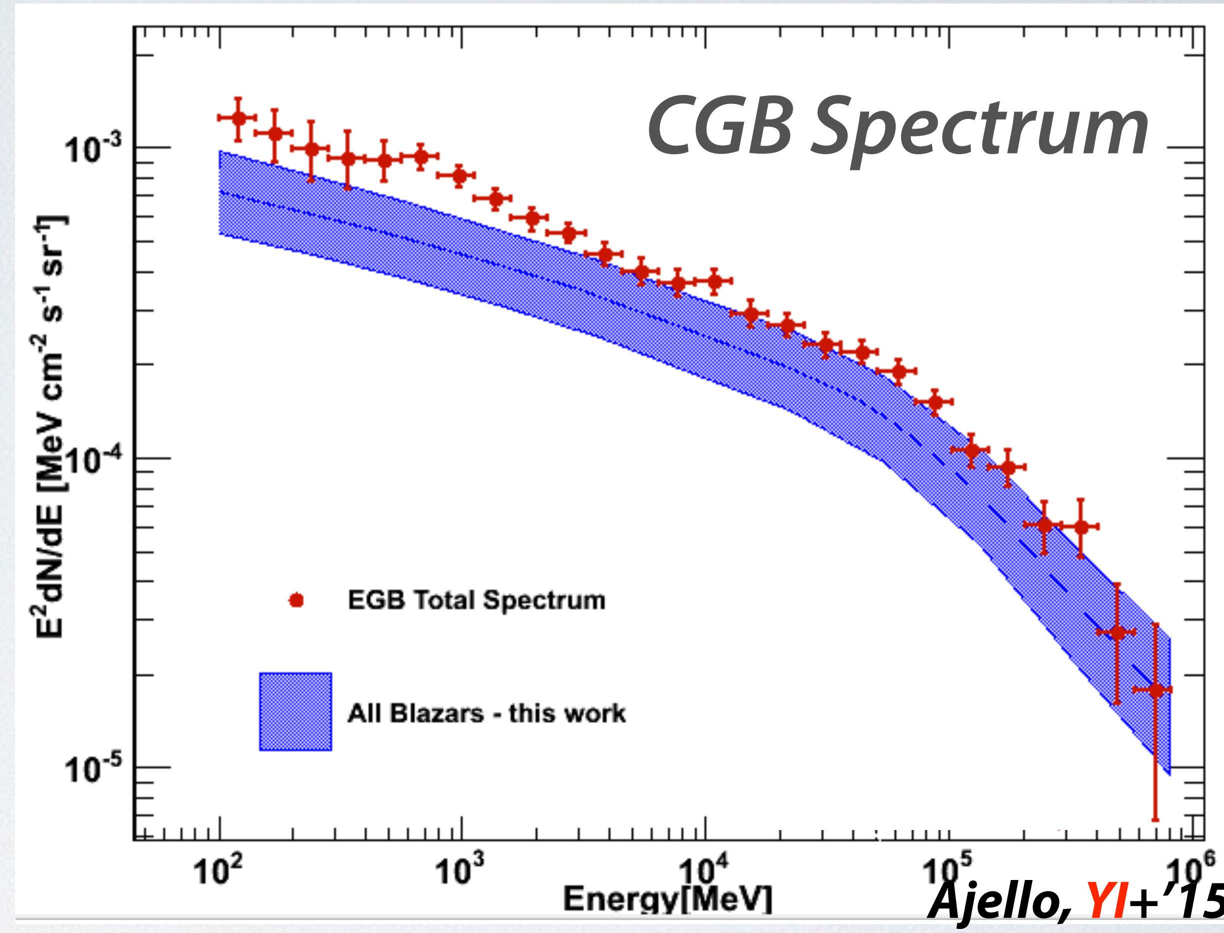
dependent on evolution of CR sources, predictions varying from 1% to 100 % (e.g. Kalashev et al. 2009)

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

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

Blazar contribution to CGB

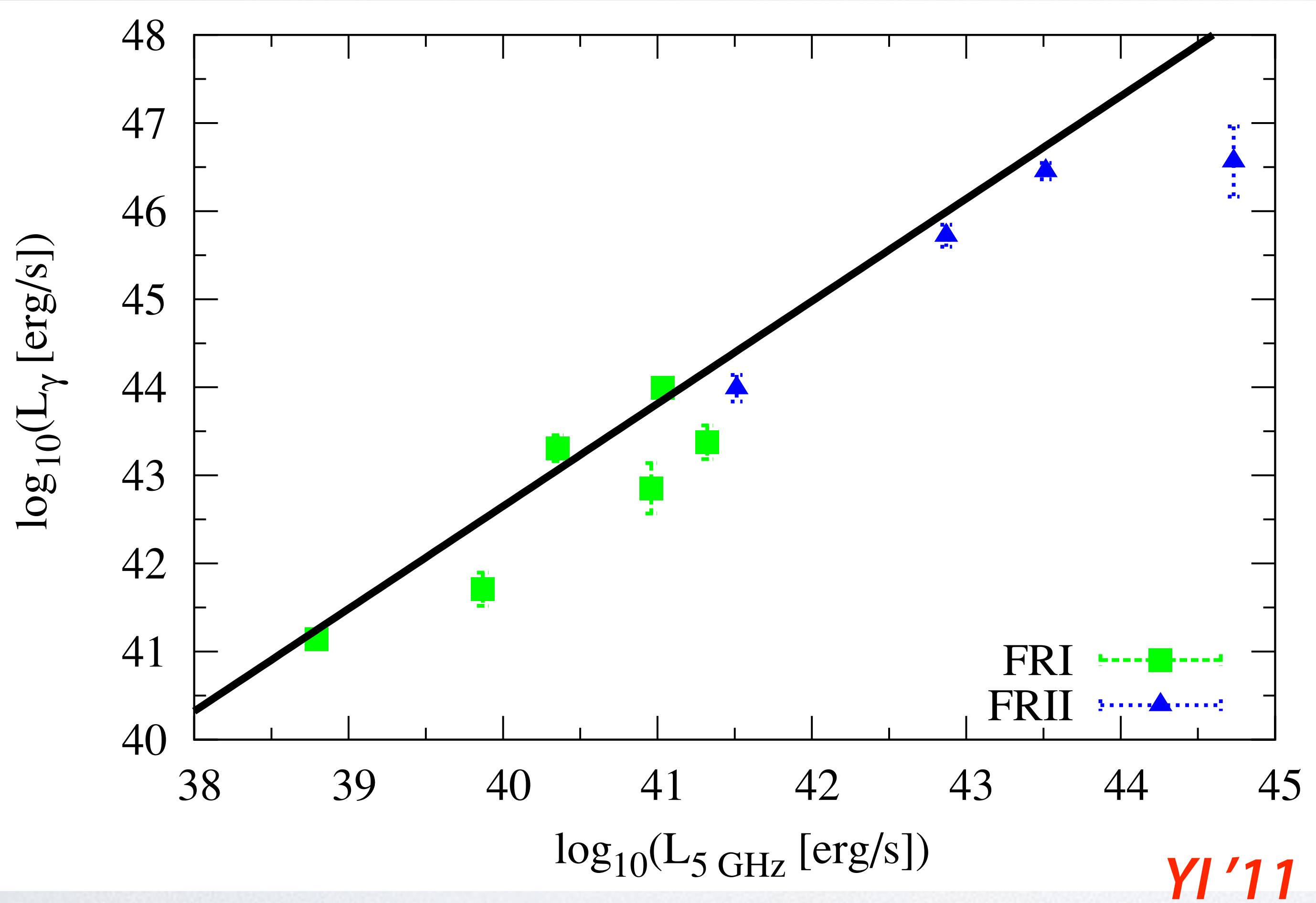


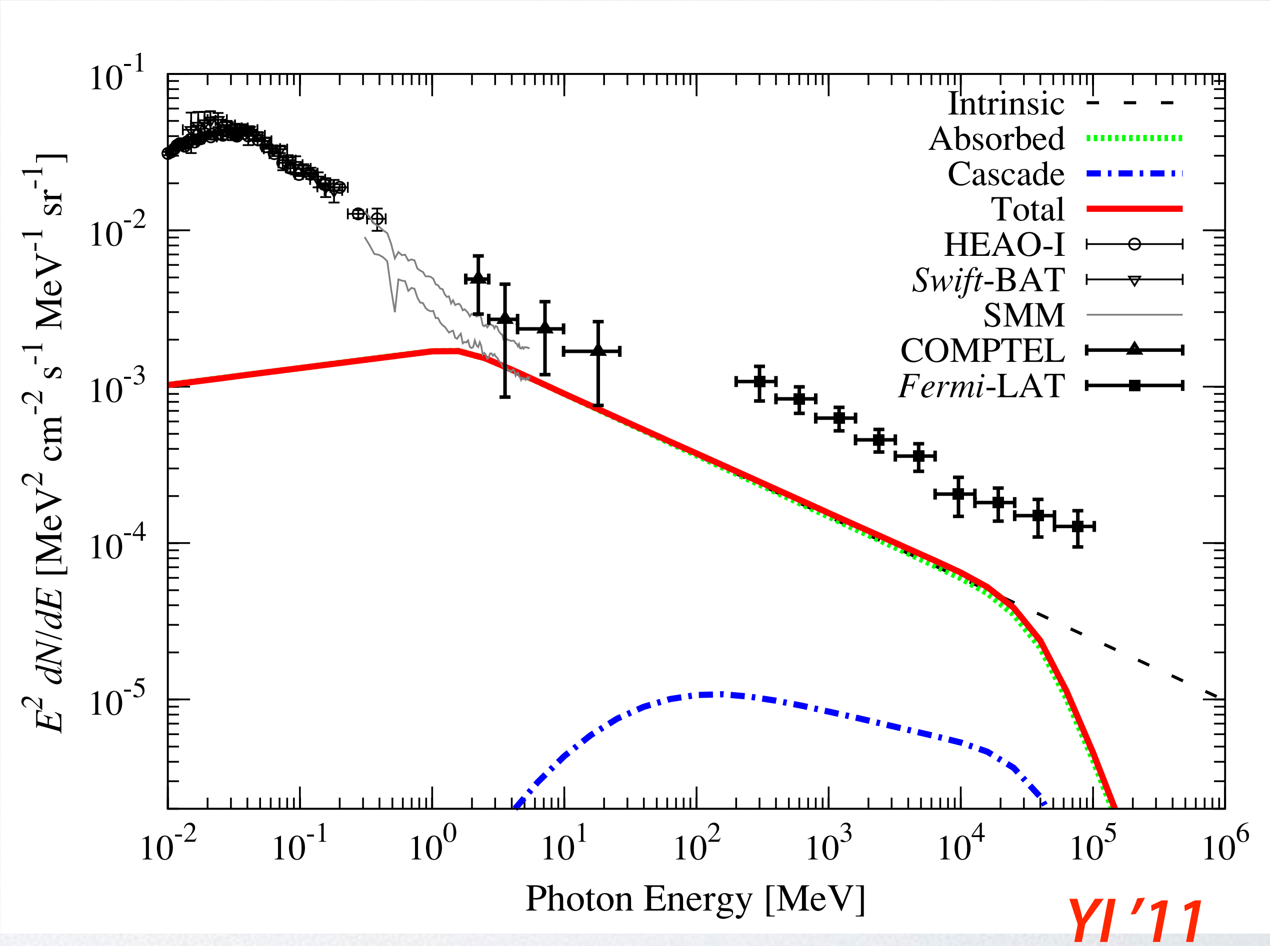


- Padovani+'93; Stecker+'93; Salamon & Stecker '94; Chiang + '95; Stecker & Salamon '96; Chiang & Mukherjee '98; Mukherjee & Chiang '99; Muecke & Pohl '00; Narumoto & Totani '06; Giommi +'06; Dermer '07; Pavlidou & Venters '08; Kneiske & Mannheim '08; Bhattacharya +'09; ***YI & Totani '09***; Abdo+'10; 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, Ajello, YI, +'15,

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

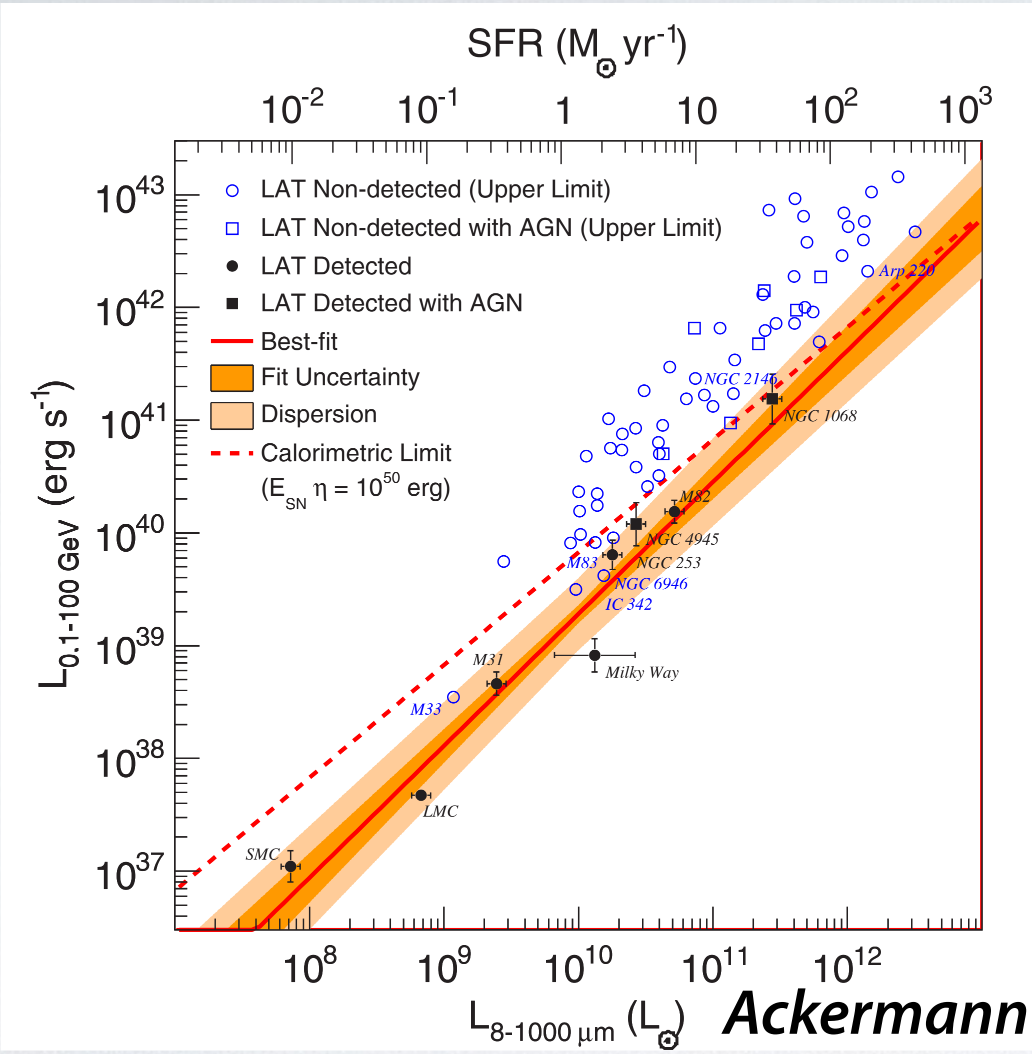
Radio Galaxies



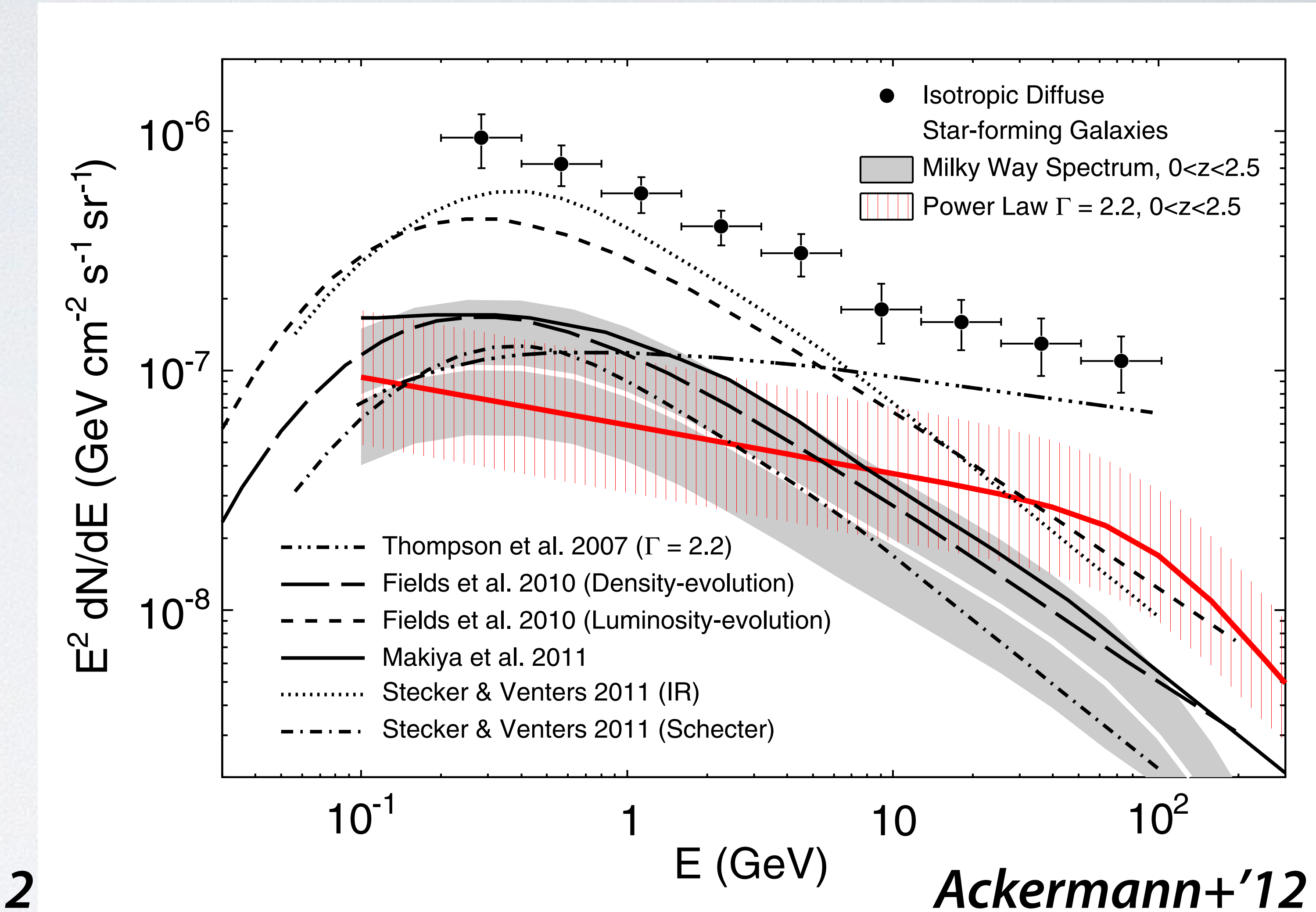


- Strong+'76; Padovani+'93; ***YI '11***; Di Mauro+'13; Zhou & Wang '13
- Use gamma-ray and radio luminosity correlation.
- ~20% of CGB at 0.1-100 GeV.

Star-forming Galaxies



Ackermann+'12



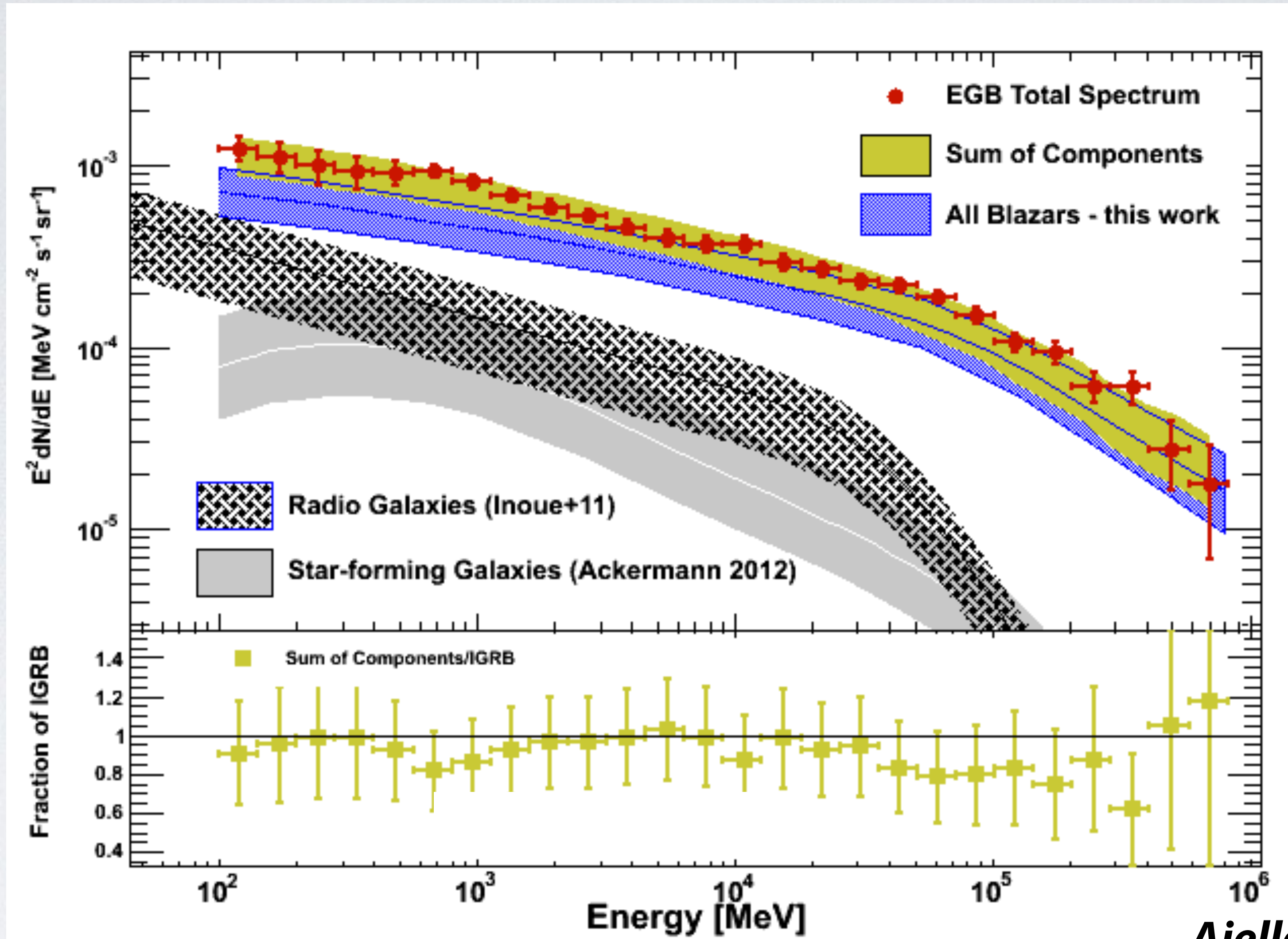
Ackermann+'12

- 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.

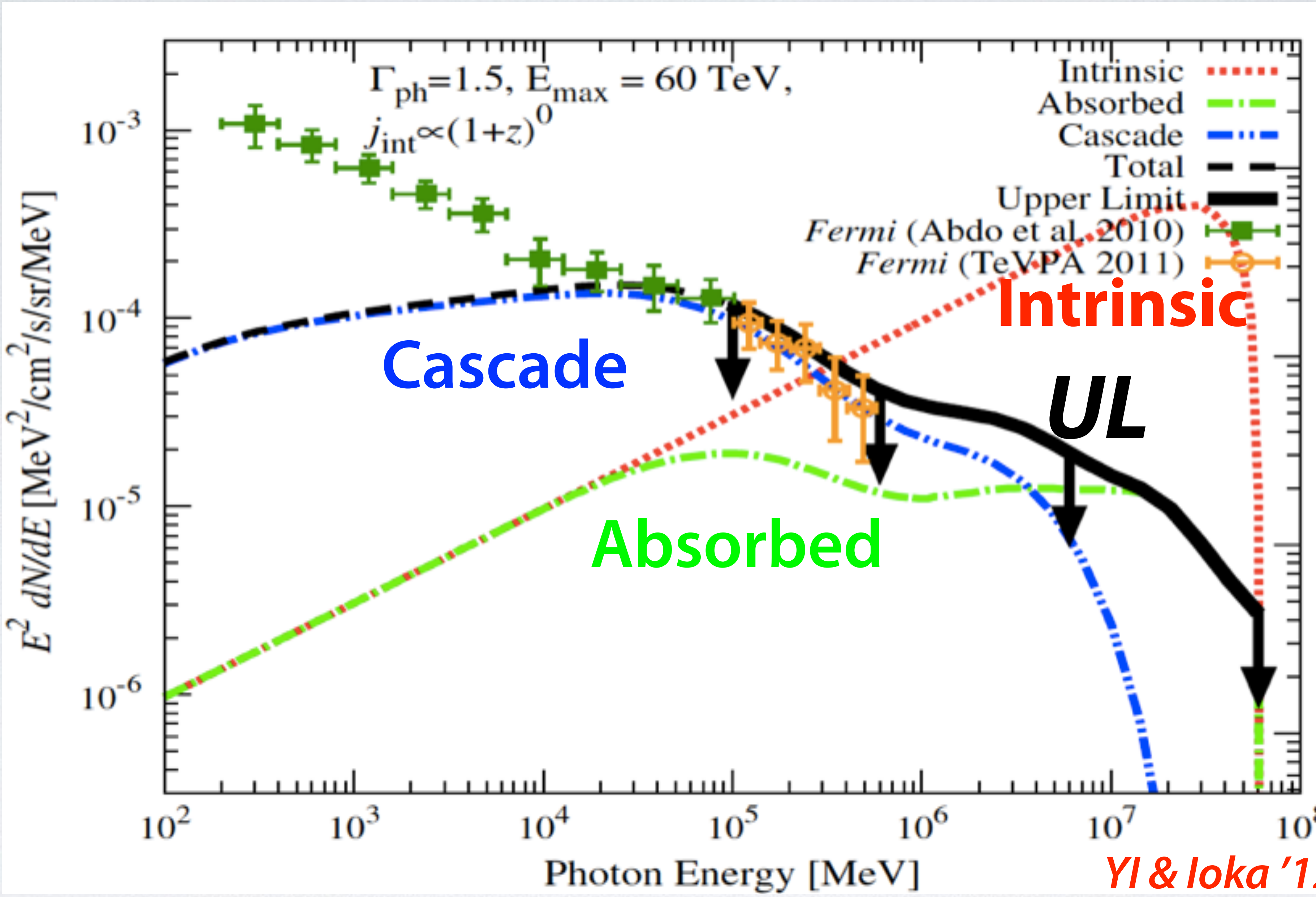
Components of the Cosmic Gamma-ray Background



Ajello, YI +'15

- Blazars (Ajello+'15), Radio gals. (YI'11), & Star-forming galaxies (Ackermann+'12) make up almost 100% of CGB from 0.1-10^3 GeV.
- But,,,
  - # of detected radio gals. and star-forming gals. is ~10.
  - TeV spectra of blazars are not well established. Redshifts of ~50% of BL Lacs are not measured.

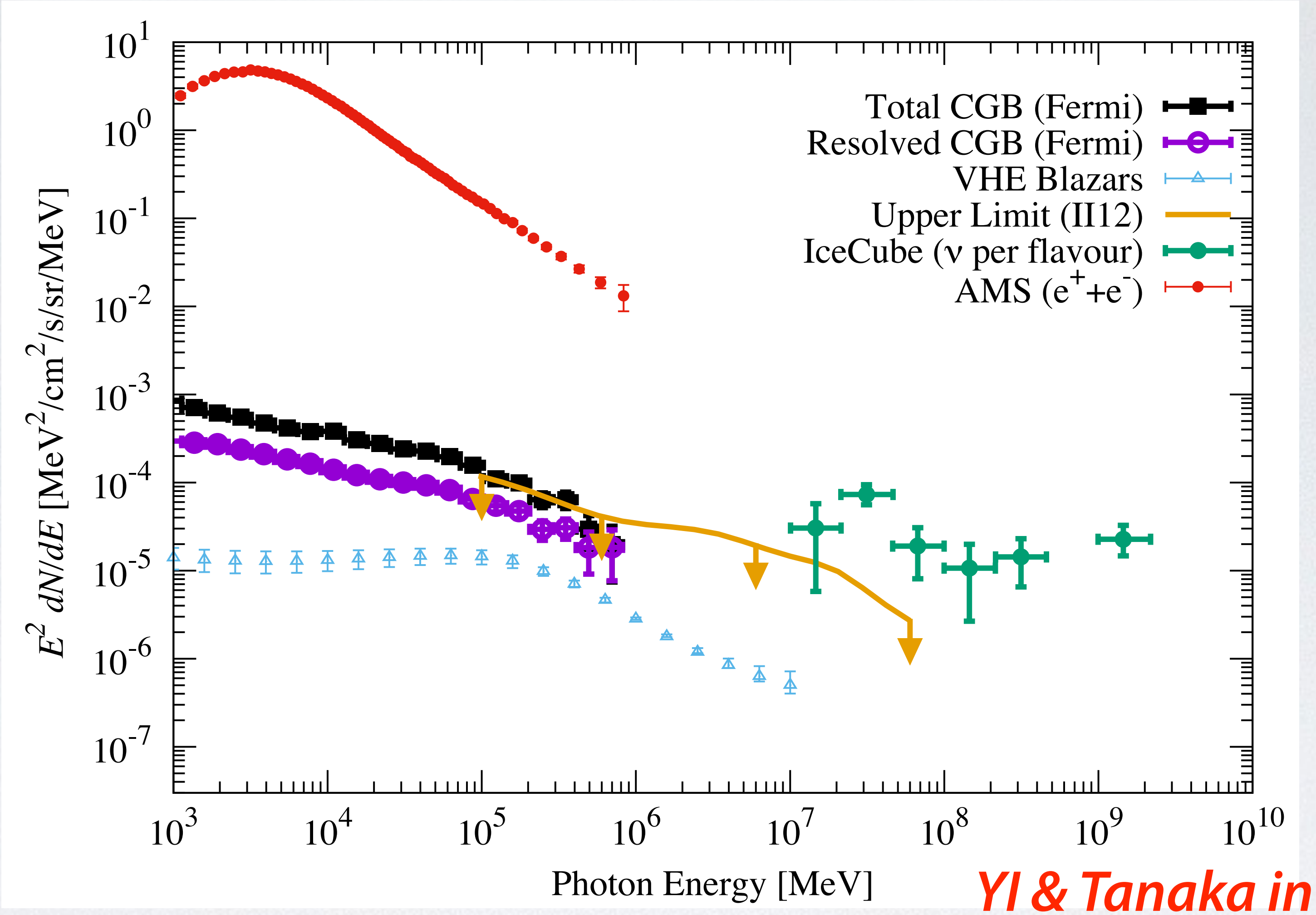
Upper Bound on the Cosmic TeV Gamma-ray Background



YI & Ioka '12

- 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).

Cosmic TeV Gamma-ray Background



YI & Tanaka in prep.

- The TeV blazar data give lower limit on to the cosmic gamma-ray background.
  - Current limit at 0.3-10 TeV is

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

- Fermi has resolved more portion of the TeV sky than IACTs do?
- Need to remove ~3 orders higher electron background to detect the CGB with CTA.

Summary

- We have not understood blazar emission mechanism to constrain the cosmic infrared background from gamma-ray observations
  - New emission mechanisms: secondary gamma rays, stochastic acceleration, lepto-hadronic emission…
  - At least, the GeV - TeV index distribution of blazars has no correlation.
- The cosmic GeV gamma-ray background is from blazars, radio galaxies, and star-forming galaxies
  - Current GeV & TeV observations give strict constraints on the cosmic TeV gamma-ray background.