Recent Highlights of Extragalactic GeV & TeV Gamma-ray Astronomy

Yoshiyuki Inoue

(KIPAC / SLAC / Stanford)

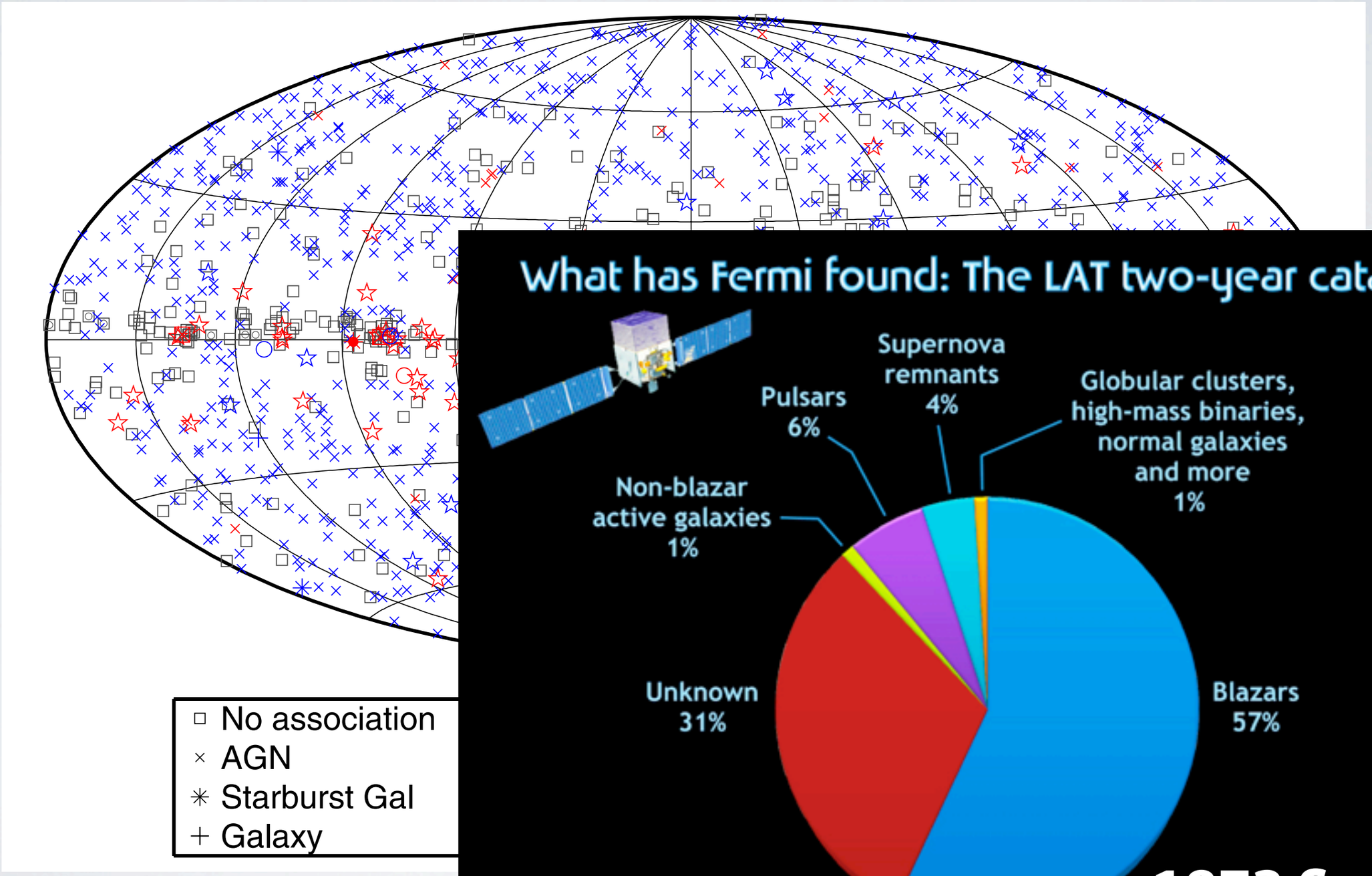
Extragalactic Gamma-ray Talks at TeVPA 2013

- Active Galactic Nuclei - H. Takami; X. Guan; E. Warren; D. Williams
- Gamma-Ray Bursts - T. Aune; D. Zaborov
- Diffuse Gamma rays - T. Venters; M. Ahlers
- Particle Acceleration - K. Kashiyama
- Optical Study - O. Kurtanidze
- Cosmology - A. Dominguez

Contents

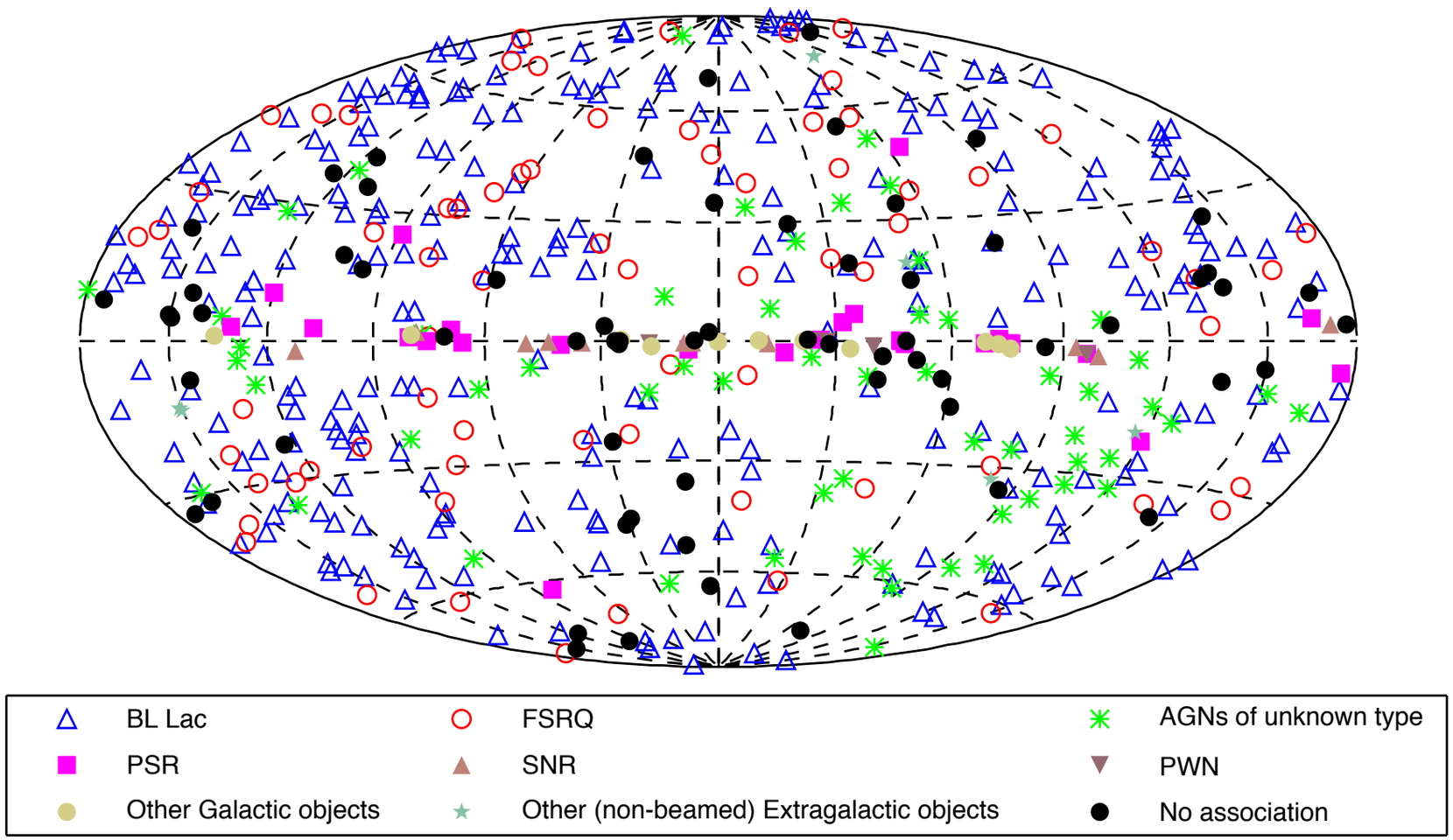
- Extragalactic GeV & TeV Gamma-ray Population
- Extragalactic Background Light
- Blazars
- Extragalactic Gamma-ray Background
- Gamma-Ray Bursts
- Summary

The Fermi/LAT two-year catalog above 100 MeV



Nolan+'12

The First Fermi/LAT Catalog above10 GeV

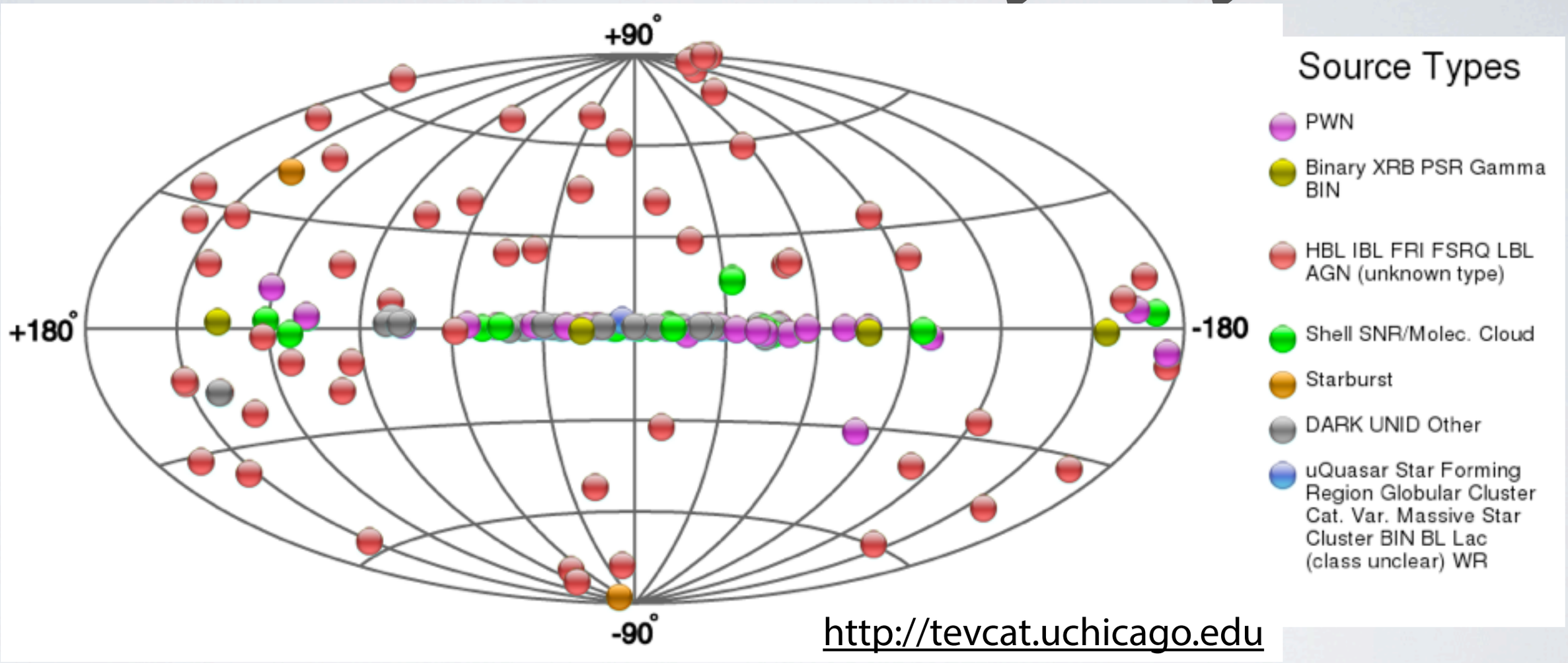


Class	#	Fraction of 1FHL (%)
Blazar BL Lac	259	50.4
Blazar FSRQ	71	13.8
Unknown type AGN	55	10.7
Pulsar	27	5.2
SNR	11	2.1
PWN	6	1.2
Other Galactic	11	2.1
Other extragalactic	9	1.8
Unassociated	65	12.7

Ackermann+'13

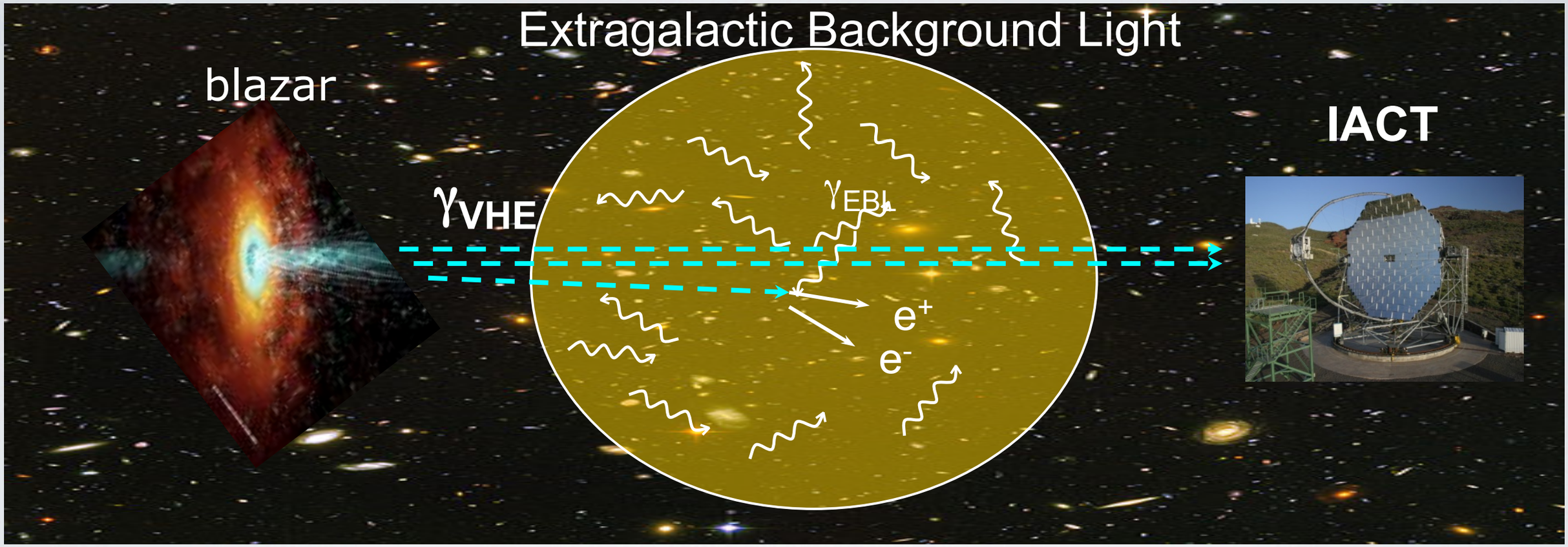
- 514 Sources (first 3 years)

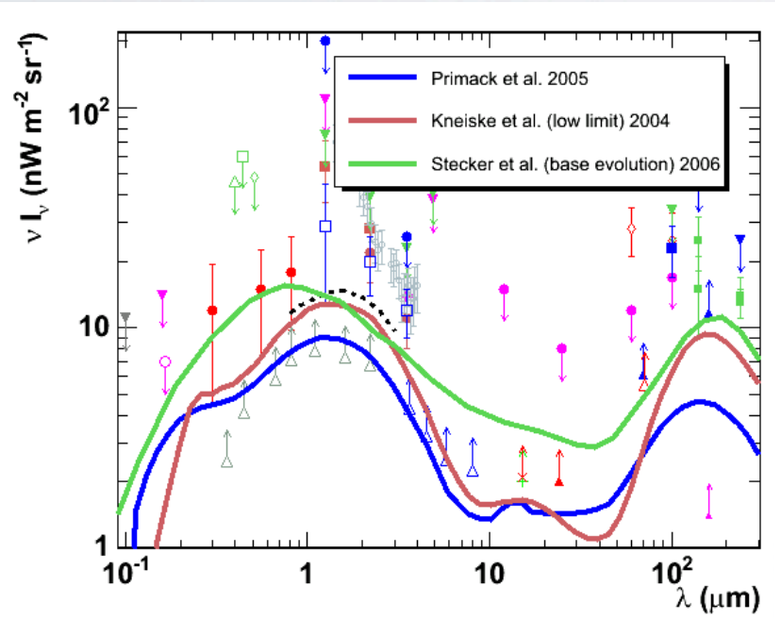
Very High Energy (VHE; >100 GeV) Gamma-ray Sky

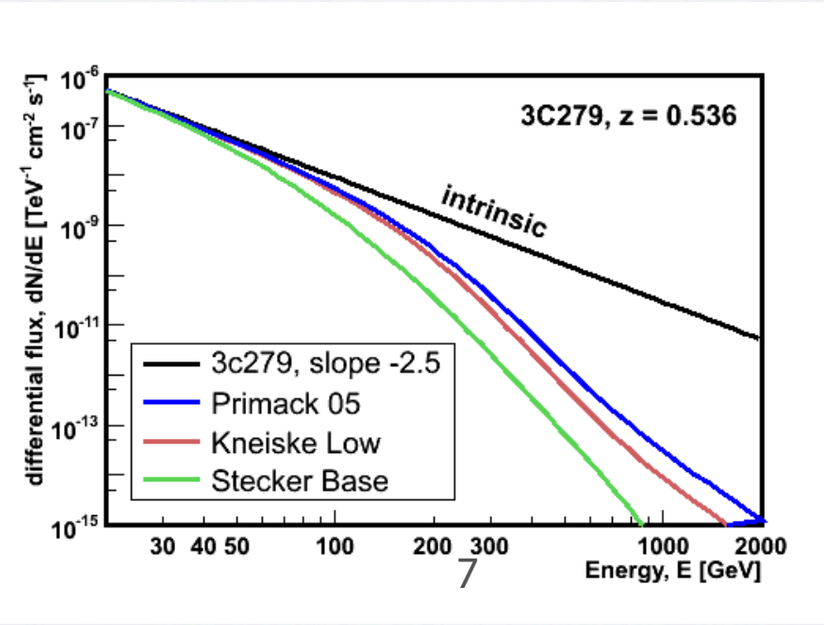


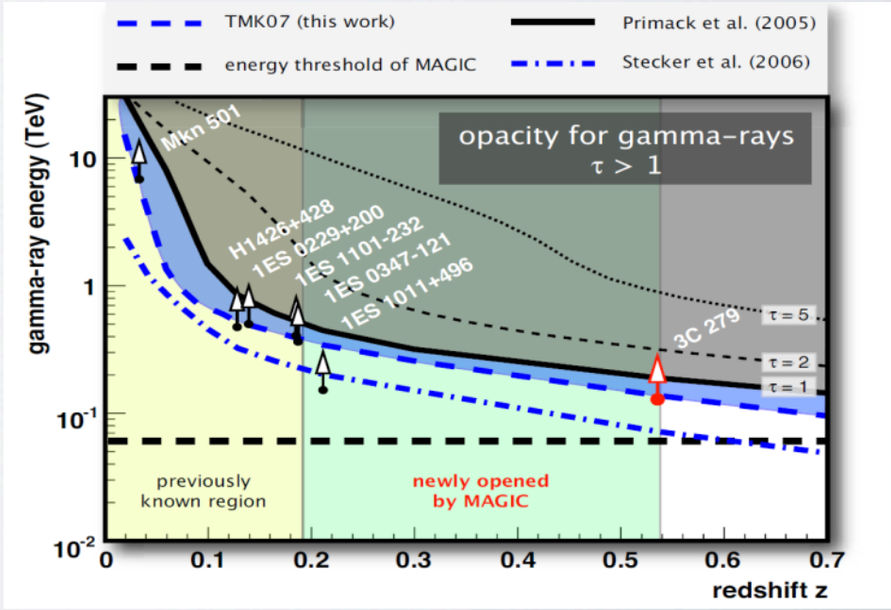
- 145 Sources
  - 3 FSRQs, 49 BL Lacs, 4 Radio Galaxies, 2 Starburst Galaxies

Gamma-ray Absorption by the Extragalactic Background Light (EBL)

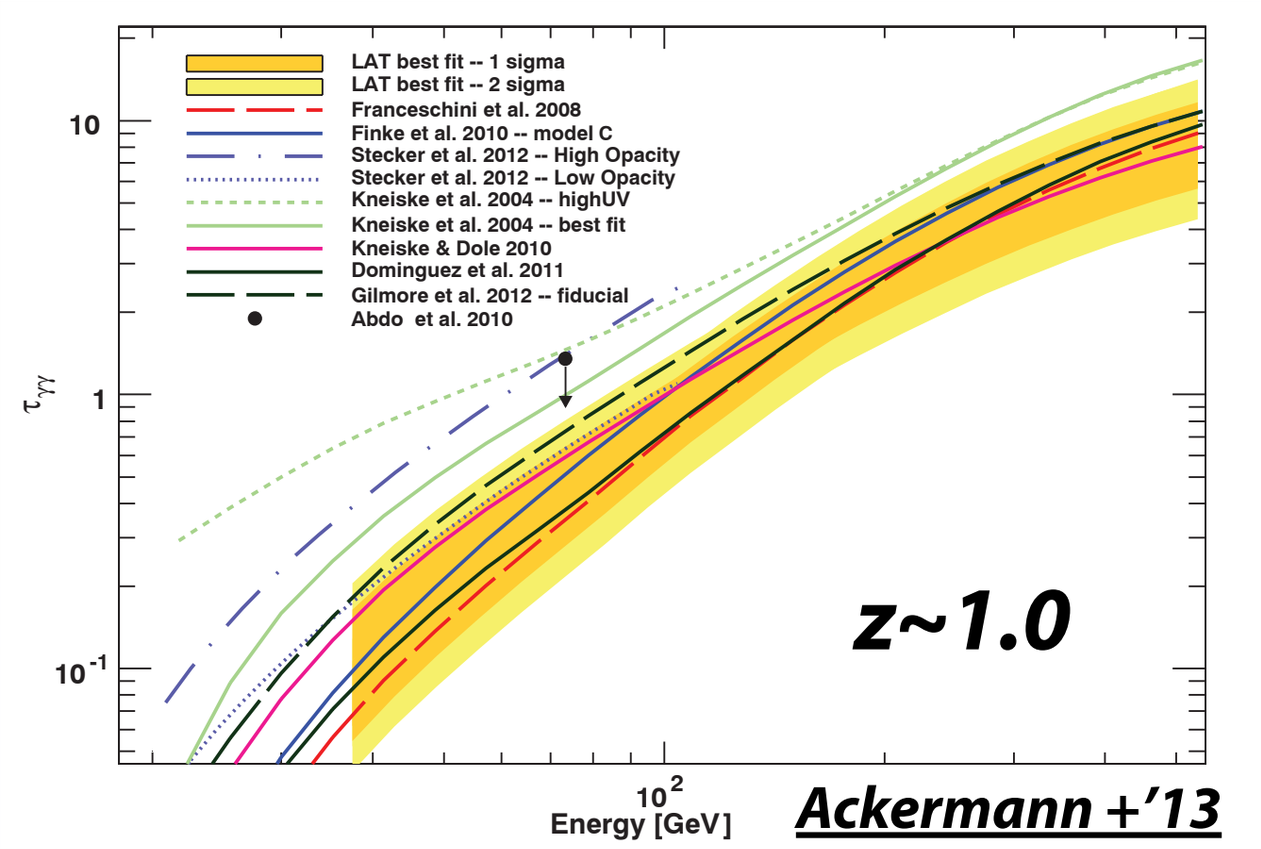




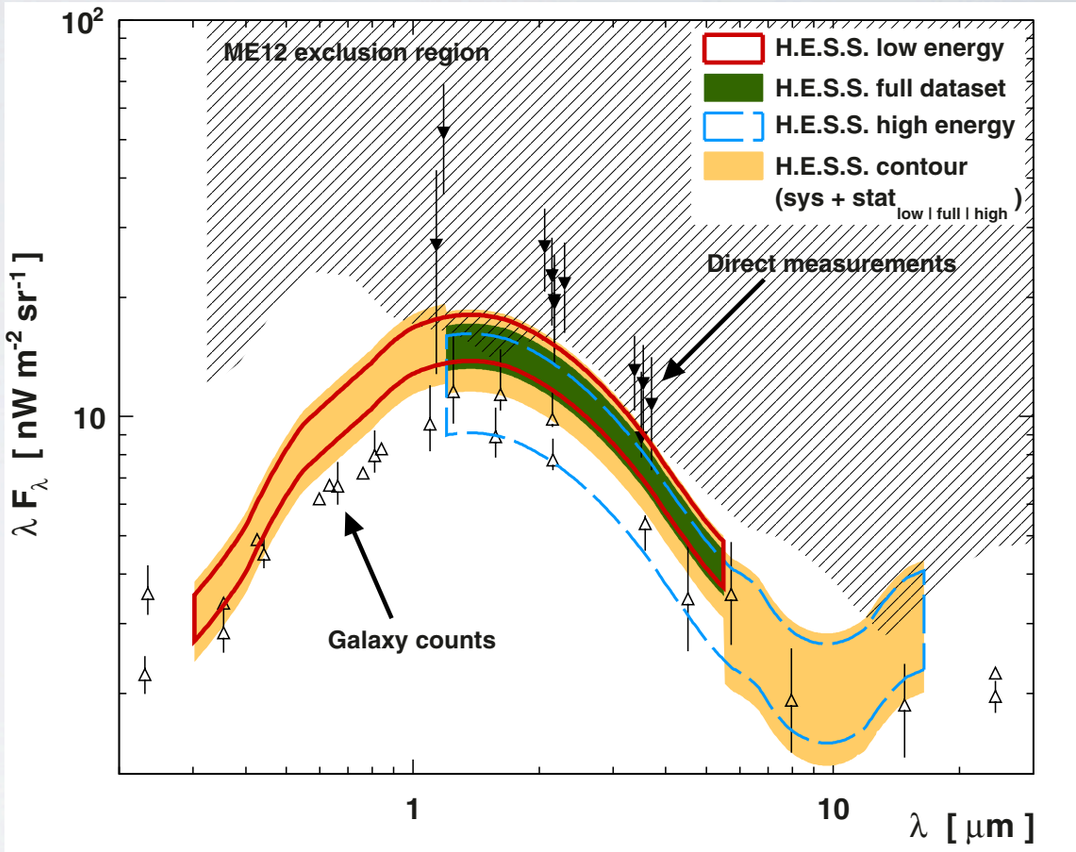




EBL Constraints from Gamma rays



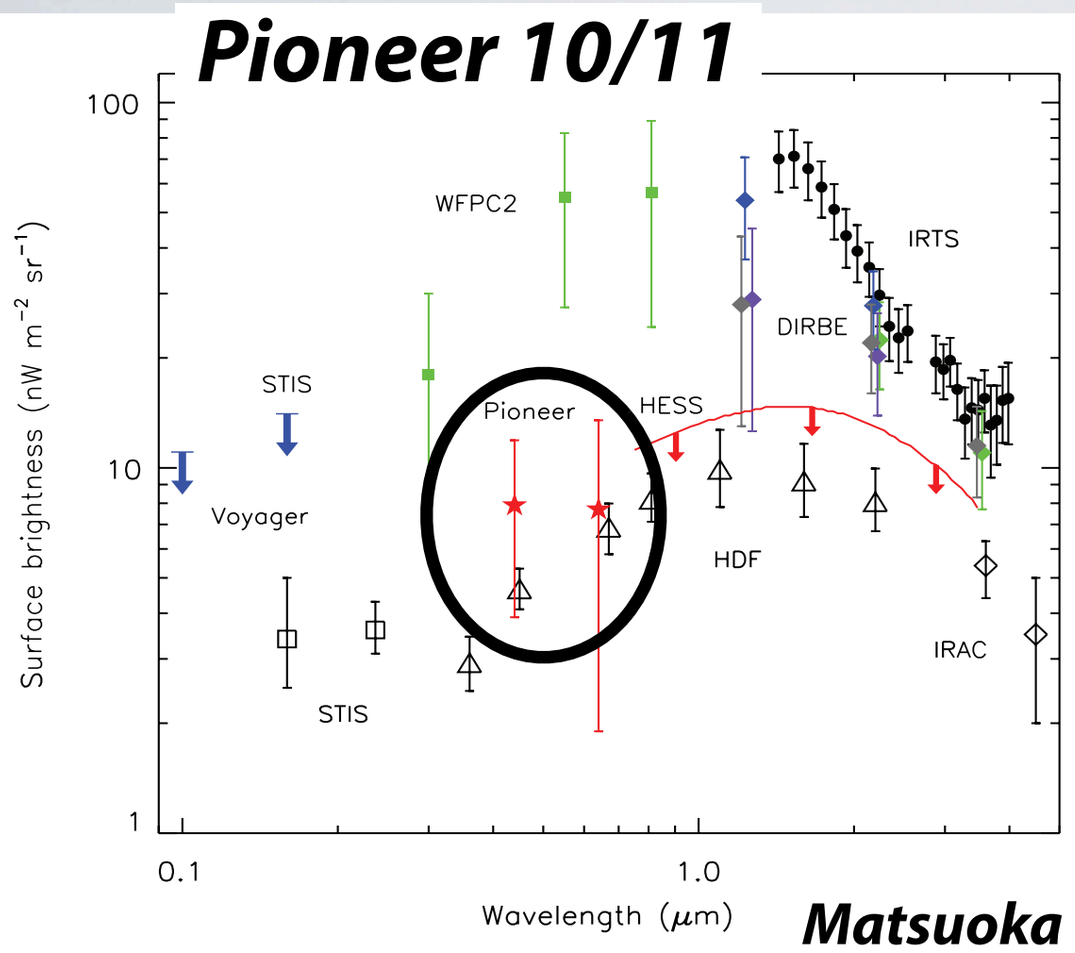
Ackermann +'13



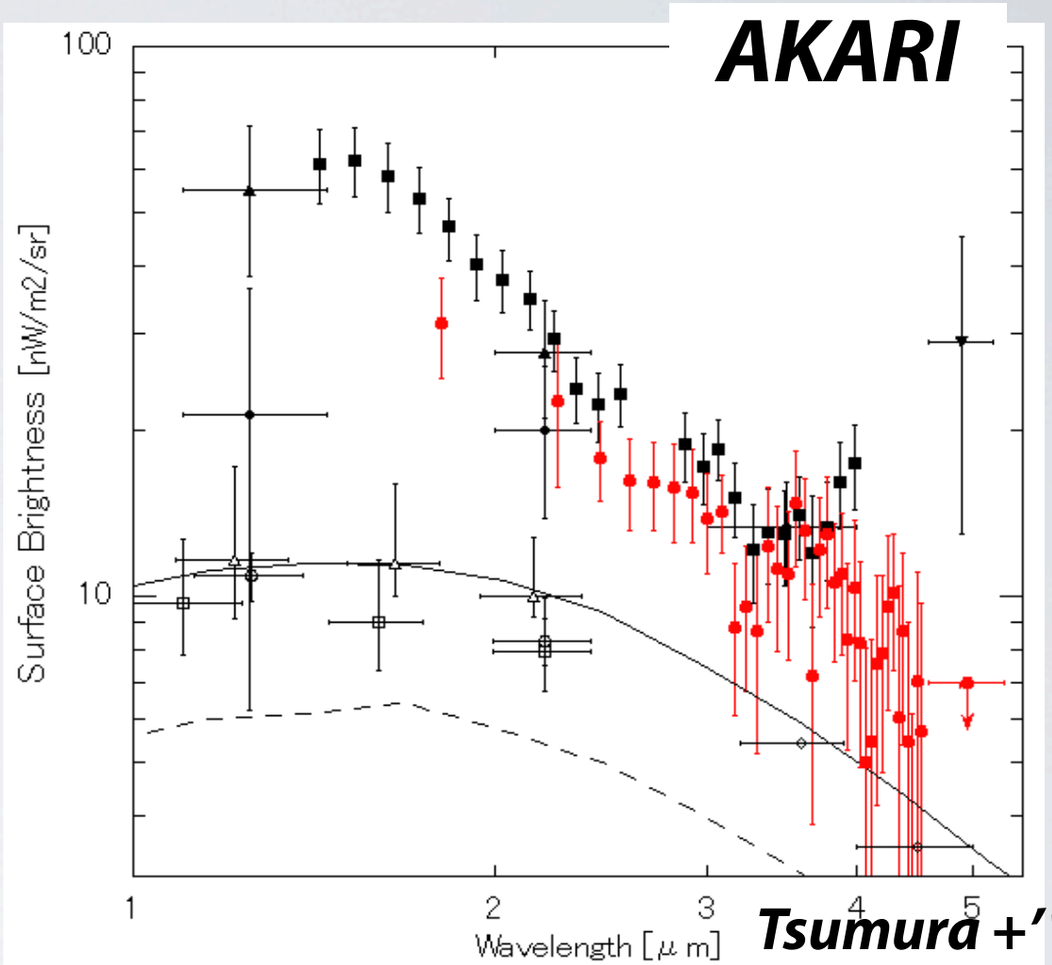
Abramowski +'13

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

Direct Measurements of EBL



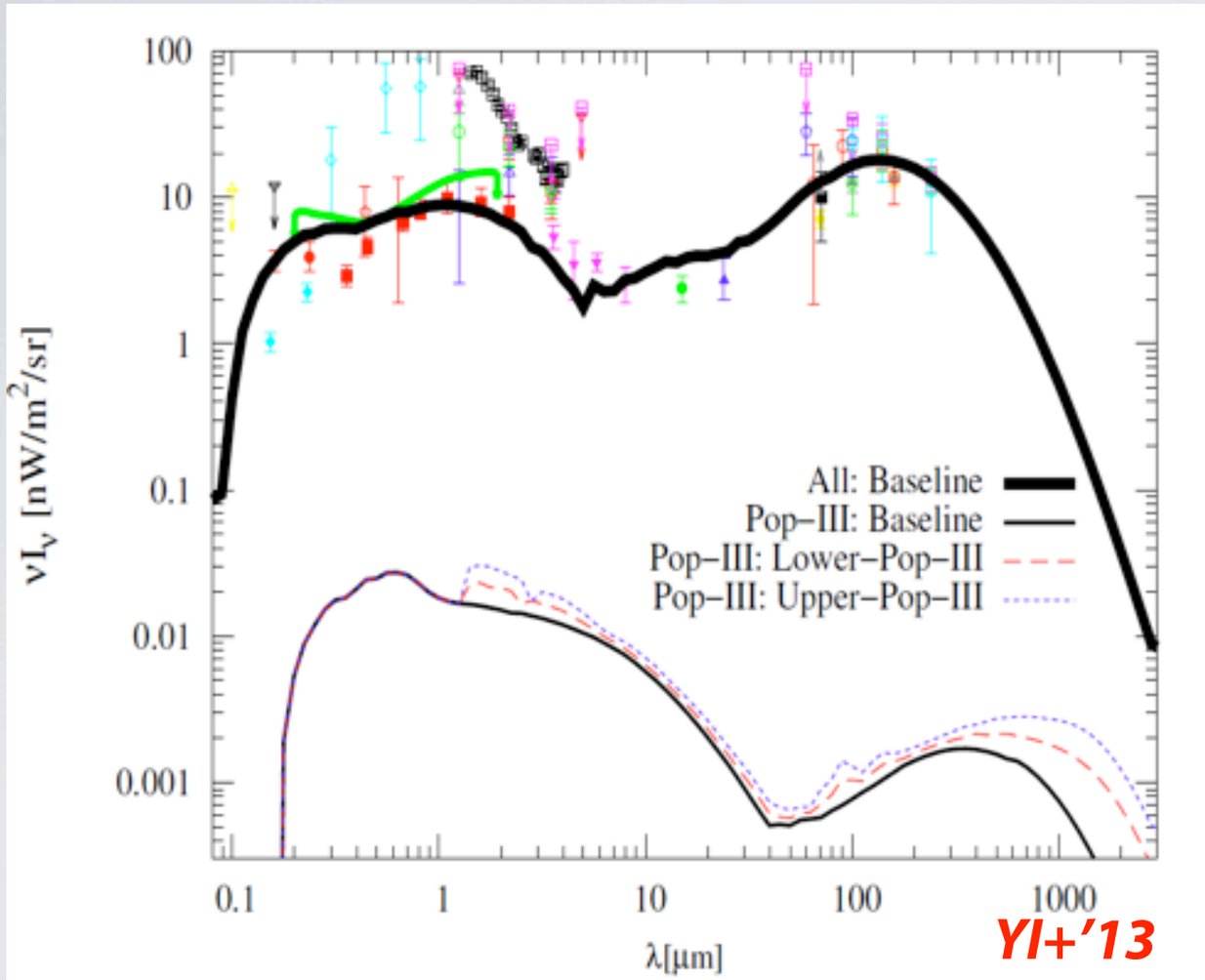
Matsuoka +'11

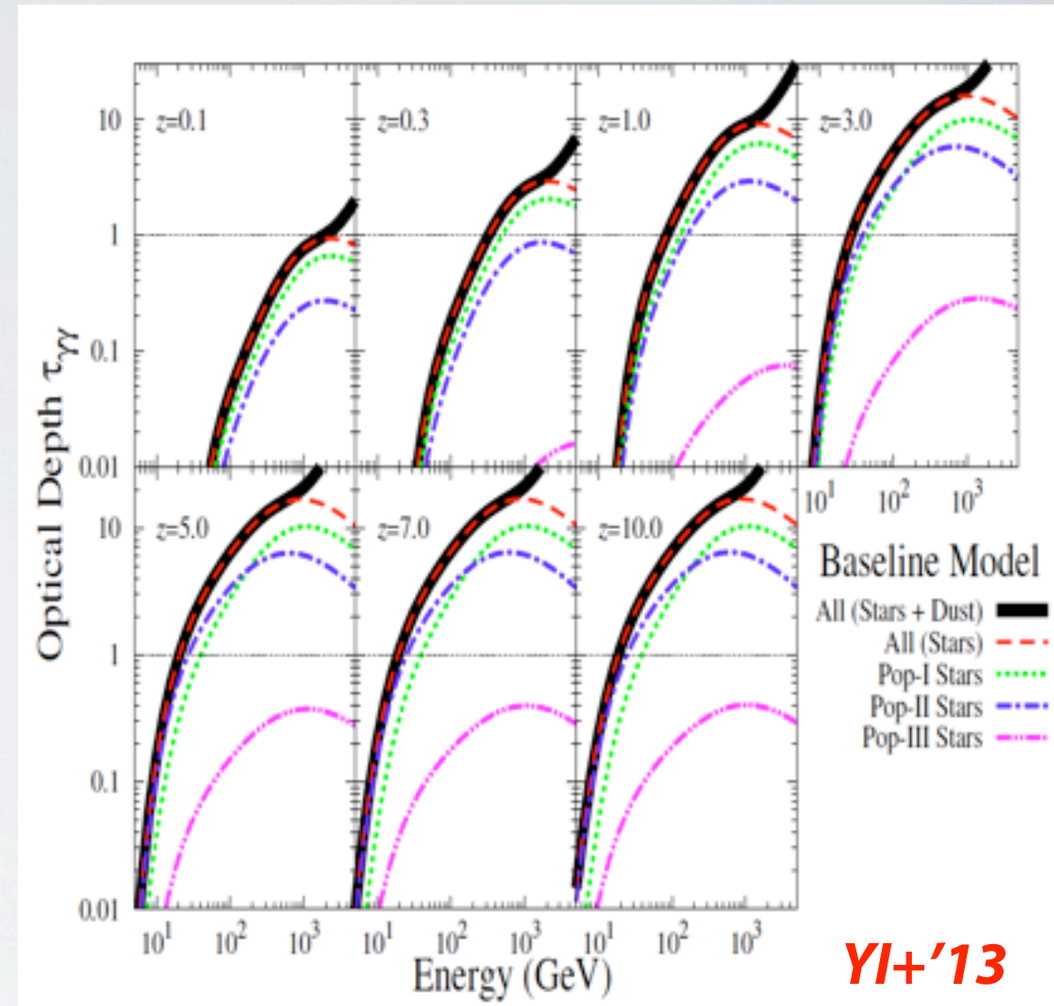


Tsumura +'13

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

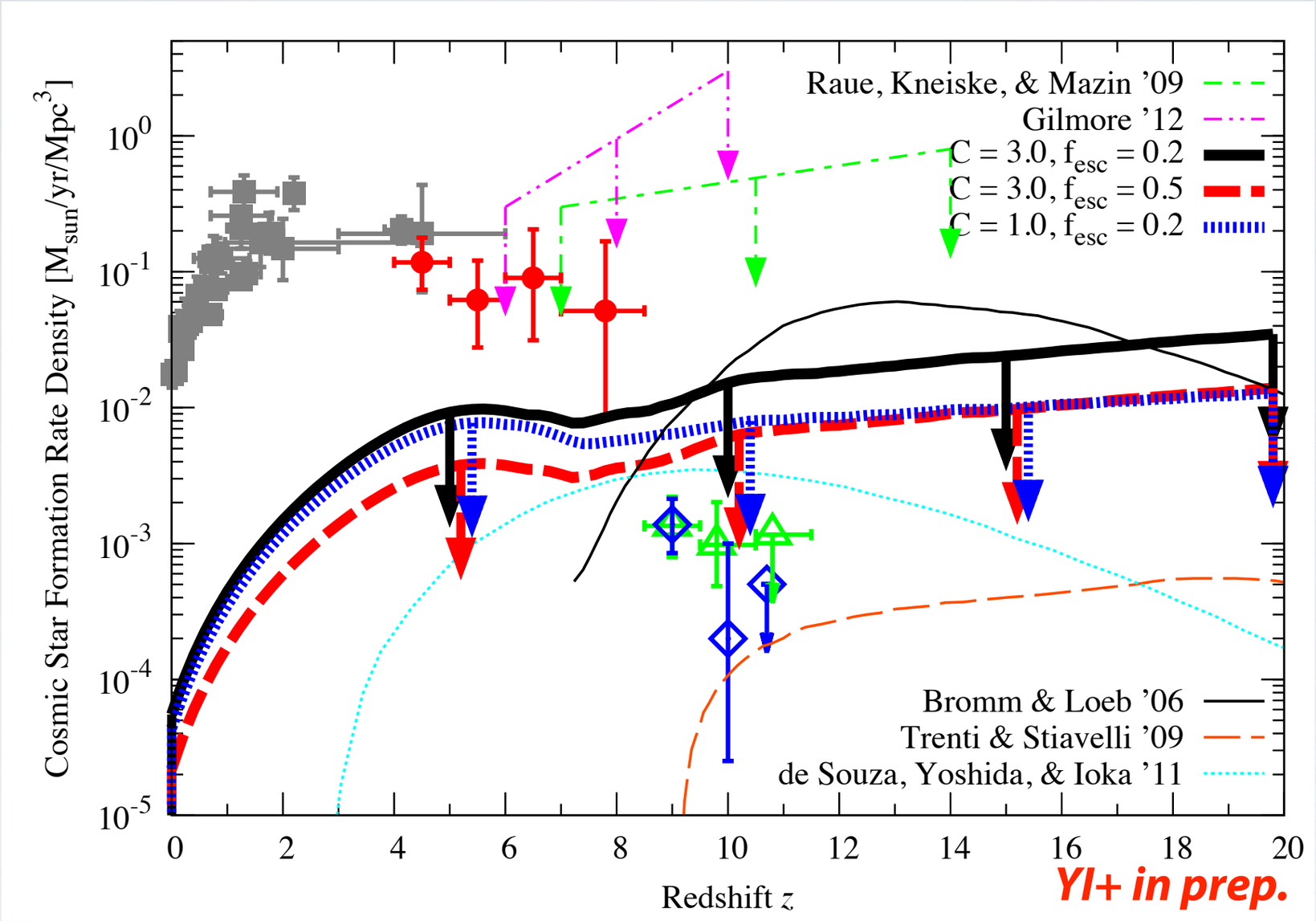
EBL Model with First Stars





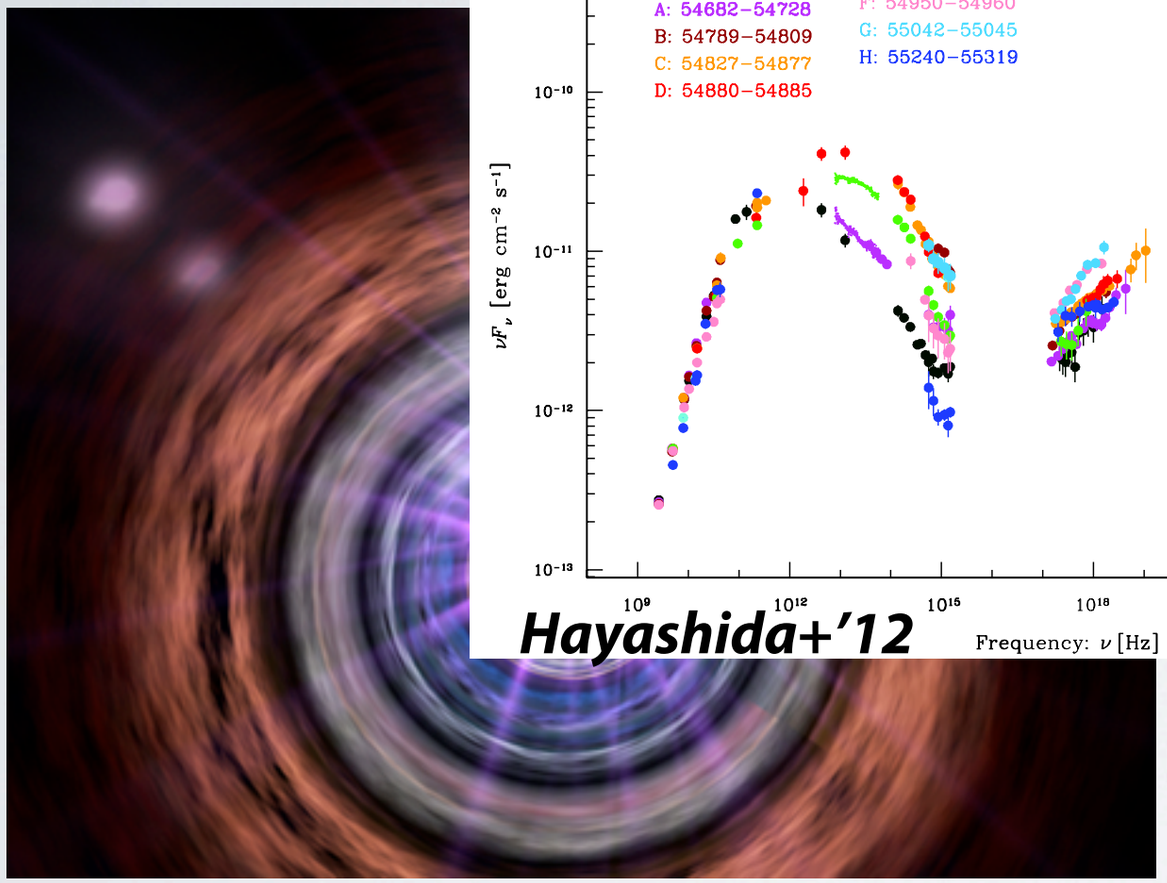
- An EBL model explaining galaxy formation and reionization data.
- First stars' contribution to EBL at z=0 is minor, and difficult to distinguish through gamma-ray attenuation even with high-z objects.

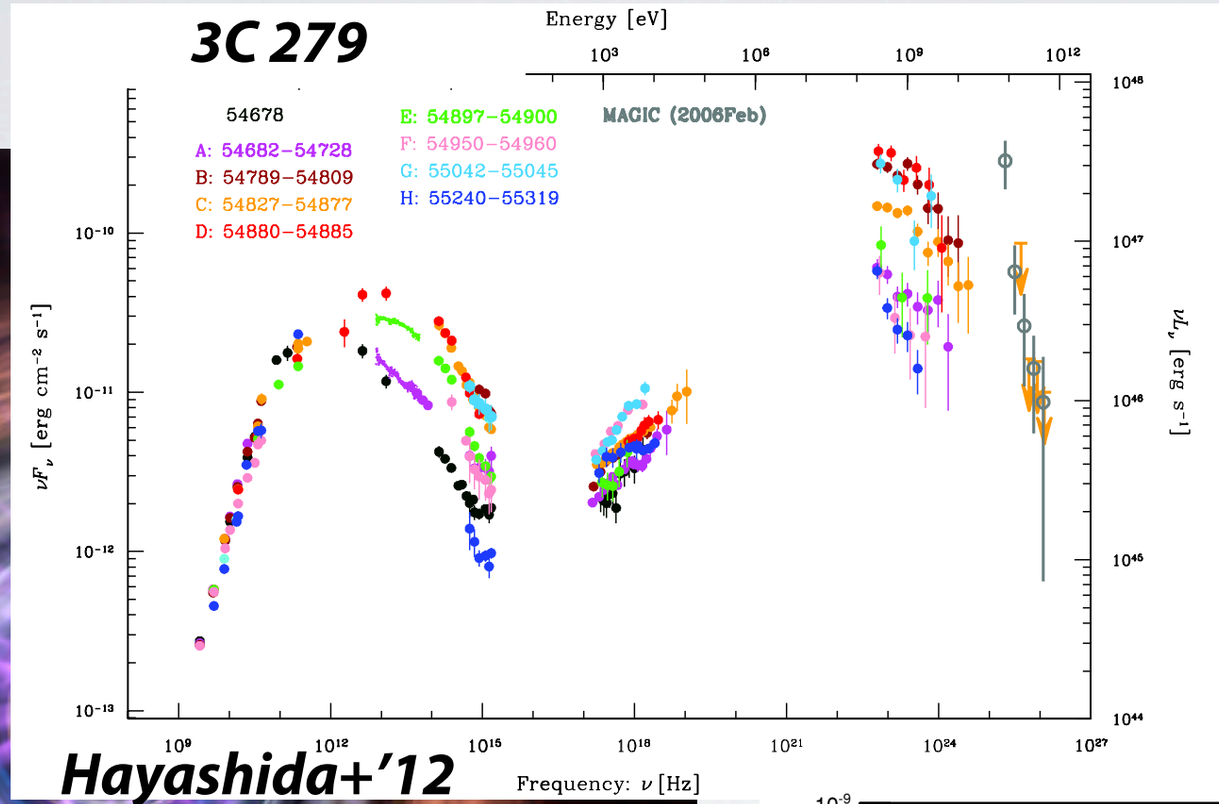
Constraints on First Stars

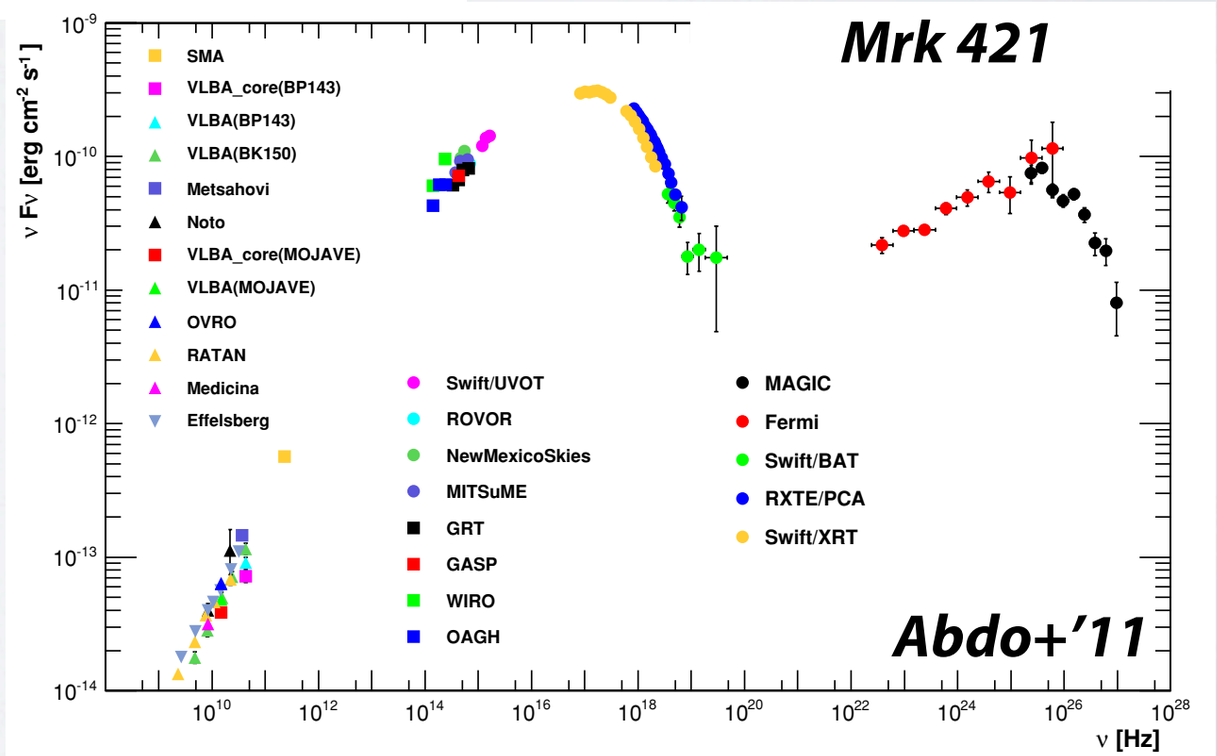


- Combining reionization (fraction of neutral hydrogen & the Thomson scattering optical depth) and distant gamma-ray data.

Blazars

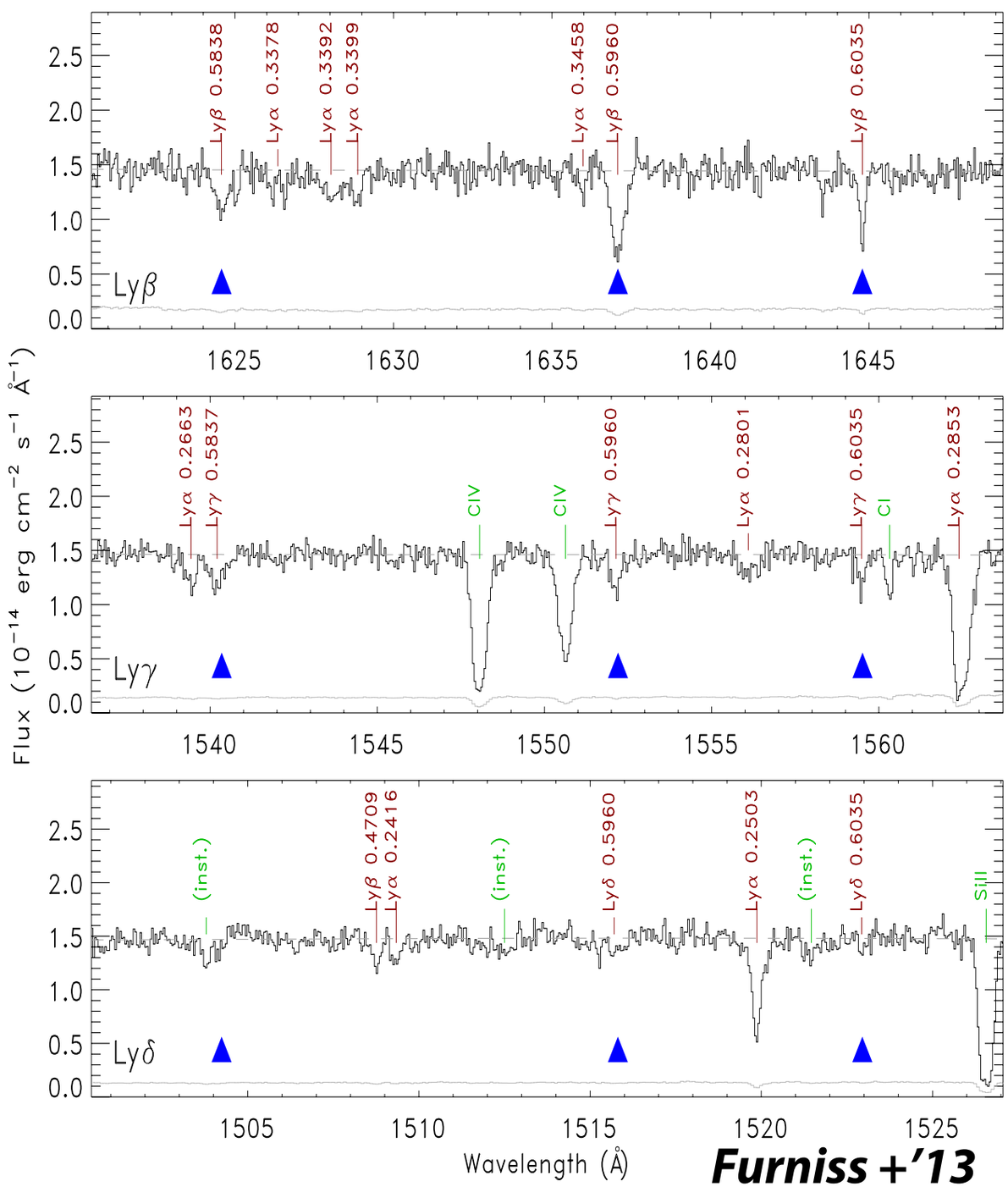



3C 279
Energy [eV]
MAGIC (2006Feb)
54678
A: 54682–54728
B: 54789–54809
C: 54827–54877
D: 54880–54885
E: 54897–54900
F: 54950–54960
G: 55042–55045
H: 55240–55319
νF_ν [erg cm^{-2} s^{-1}]
νL_ν [erg s^{-1}]
Frequency: ν [Hz]
Hayashida+'12


Mrk 421
SMA
VLBA_core(BP143)
VLBA(BP143)
VLBA(BK150)
Metsahovi
Noto
VLBA_core(MOJAVE)
VLBA(MOJAVE)
OVRO
RATAN
Medicina
Effelsberg
Swift/UVOT
ROVOR
NewMexicoSkies
MITSuME
GRT
GASP
WIRO
OAGH
MAGIC
Fermi
Swift/BAT
RXTE/PCA
Swift/XRT
νF_ν [erg cm^{-2} s^{-1}]
ν [Hz]
Abdo+'11

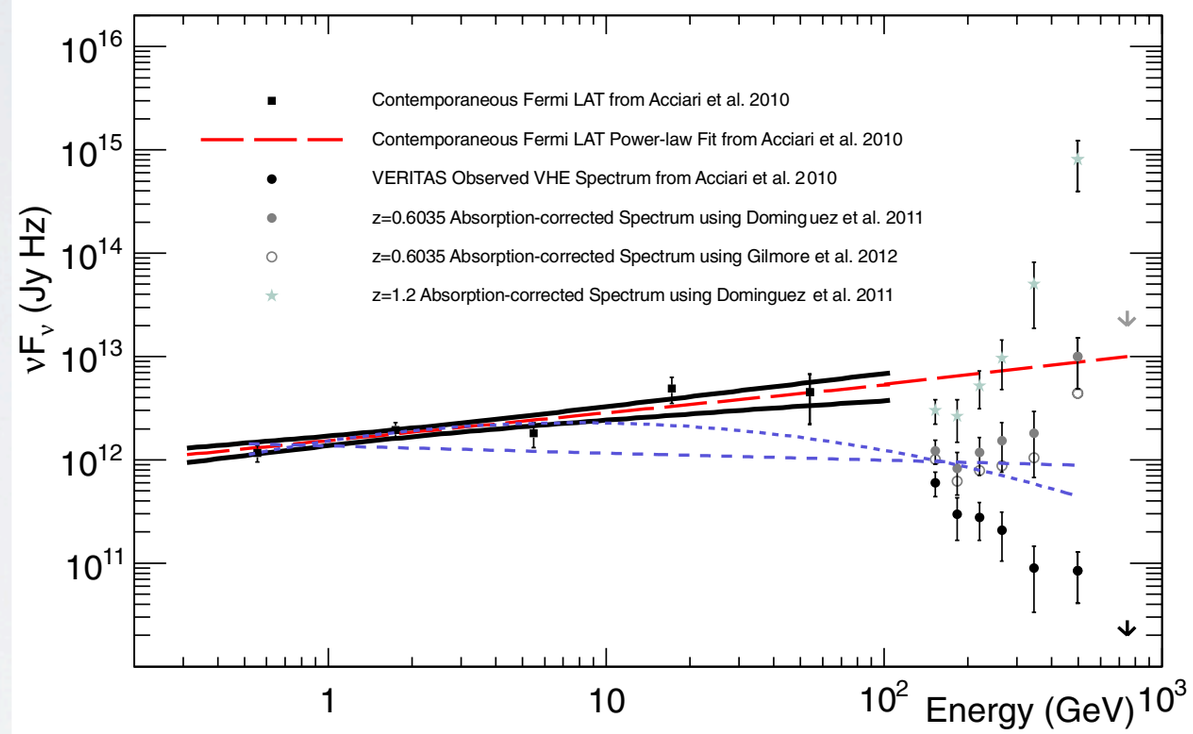
TeV blazar PKS 1424+240 at z > 0.6

Hubble/COS Spectra



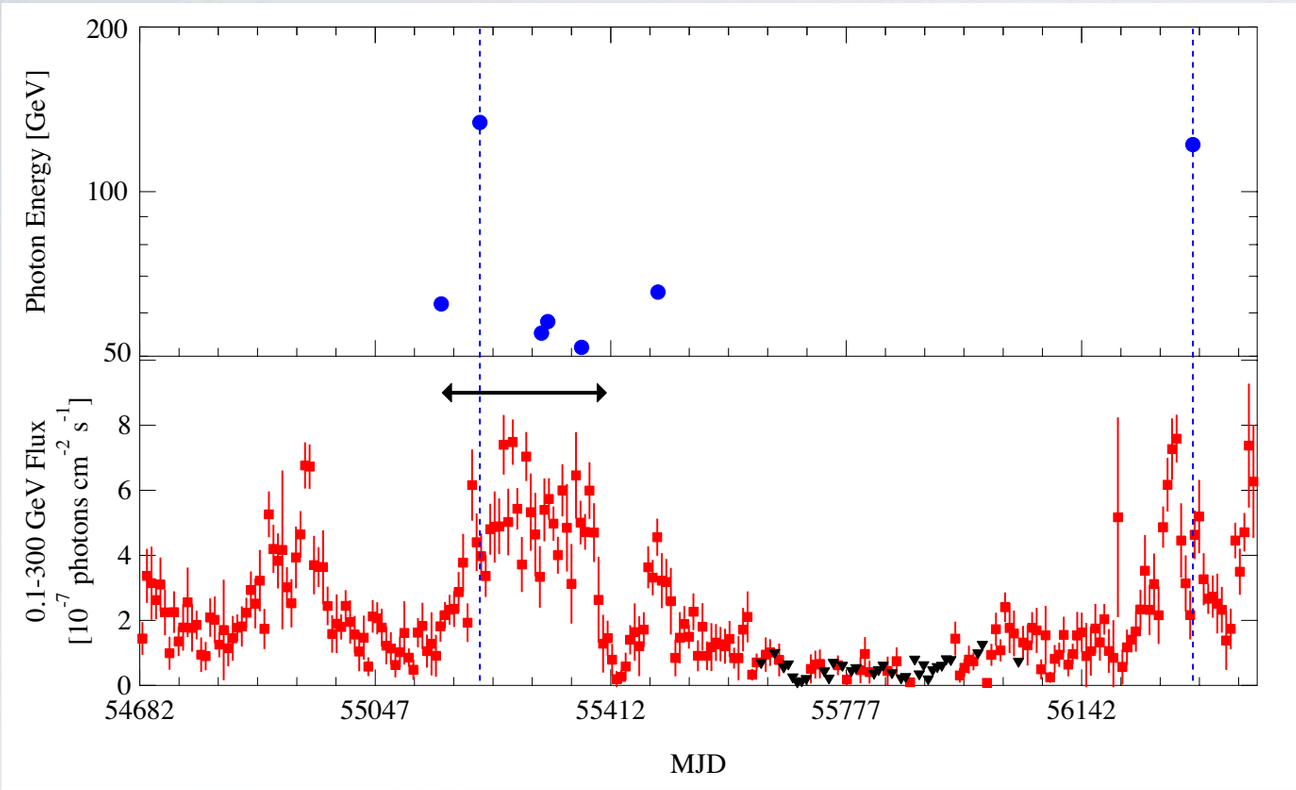
Furniss +'13

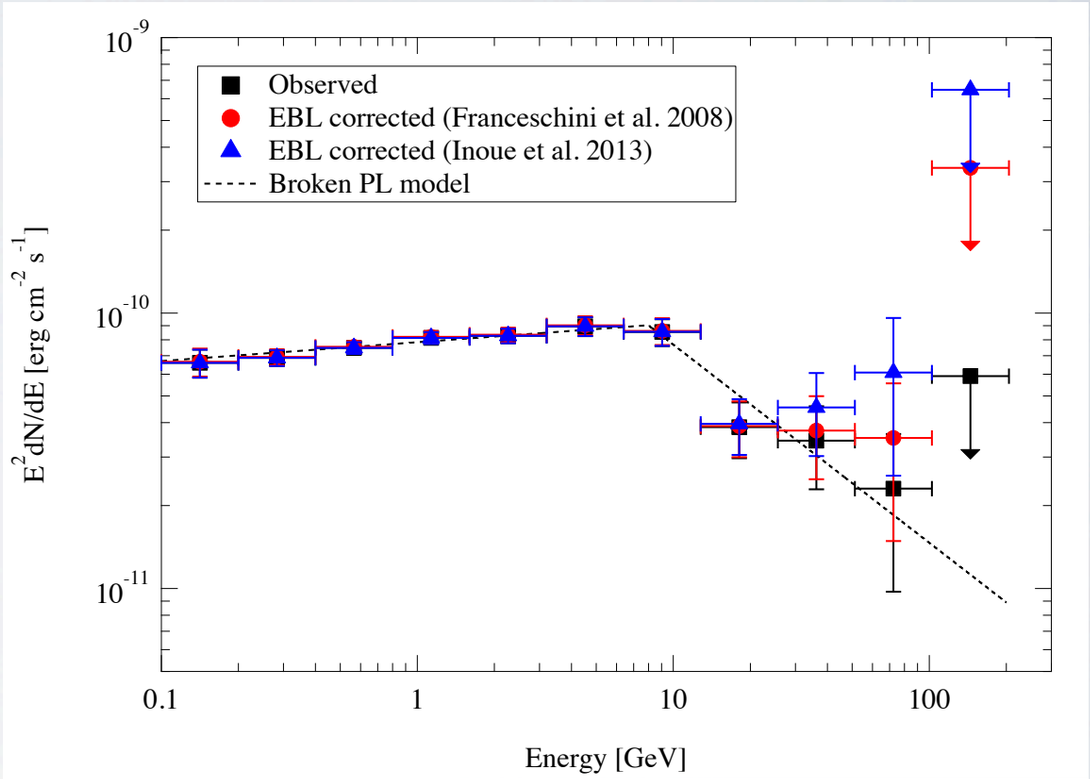
VHE SED with Fermi/LAT & VERITAS



- Intergalactic absorption put the redshift lower limit of z > 0.6035.
- Spectral hardening?
- ***See David Williams' talk (tomorrow)***

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

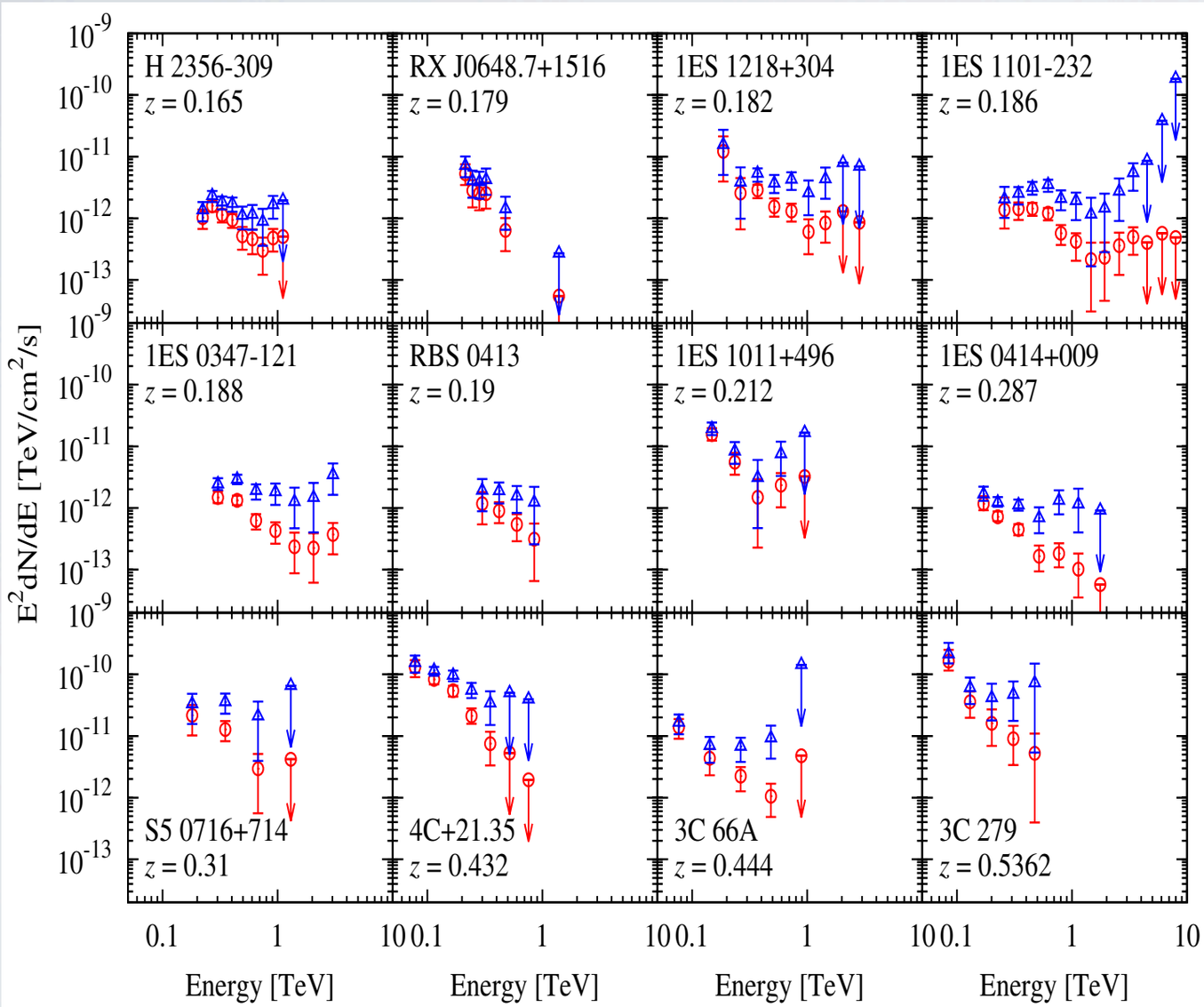




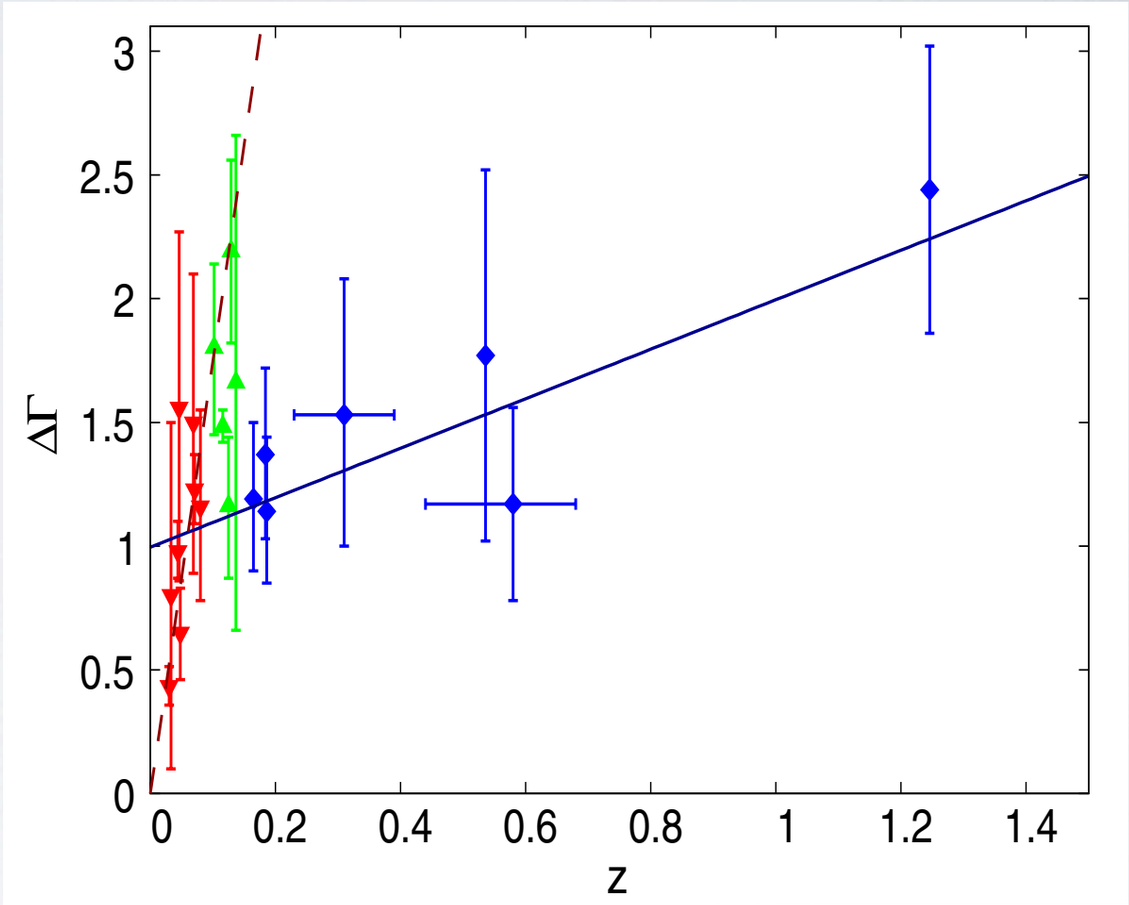
Tanaka, YI, +'13

- Detection of 2 VHE photons by Fermi/LAT at flaring states.
  - But, we did not find an exact correspondence to the peak of each flare.
- Hardening is seen in the EBL corrected spectrum.

VHE Spectral Hardening?



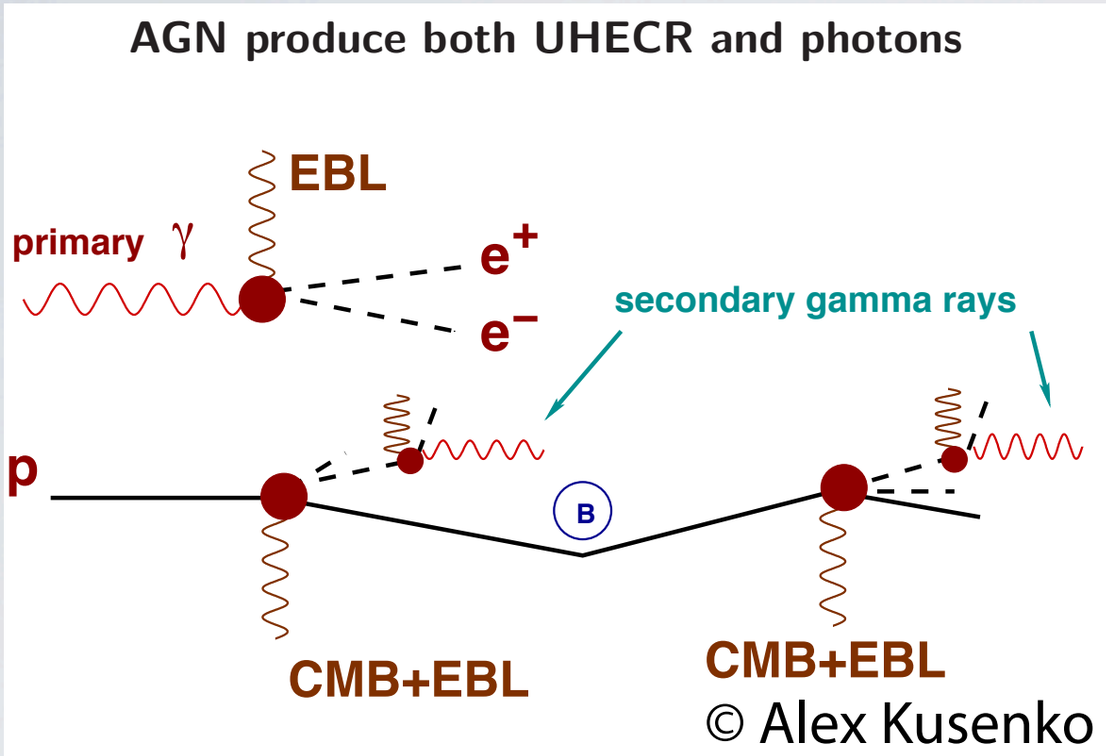
YI+'13

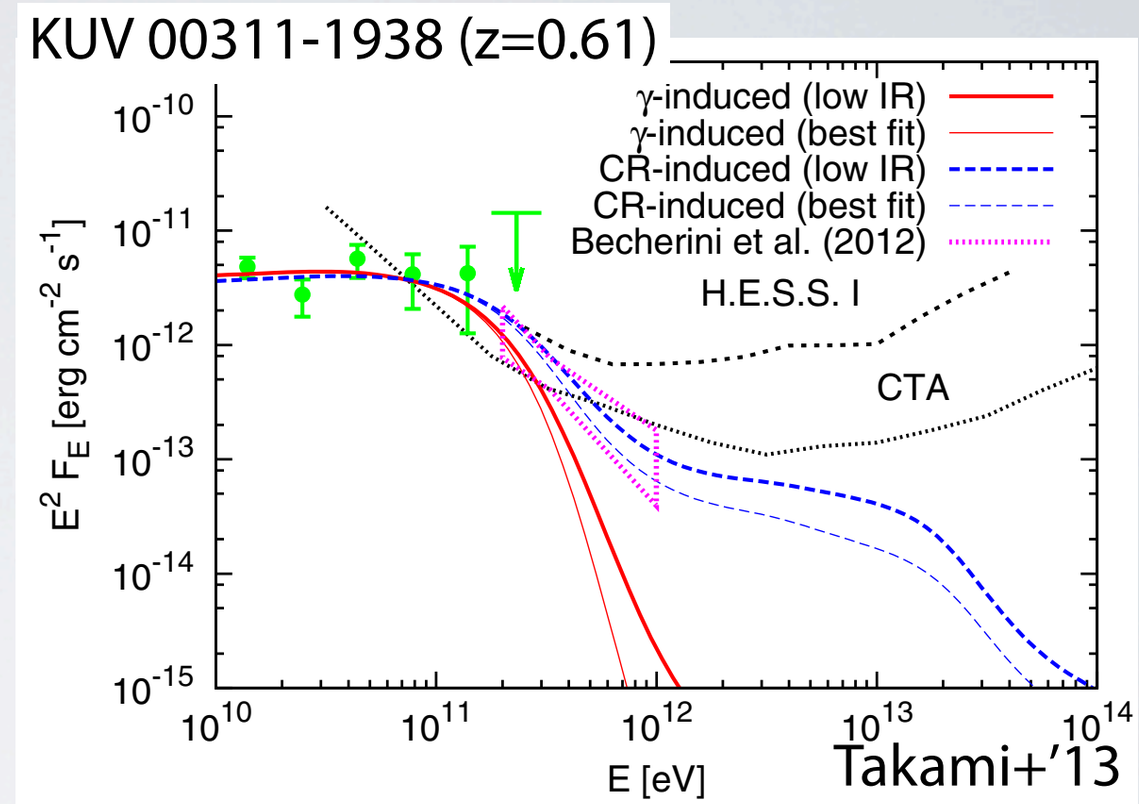


Essey & Kusenko '12

- Spectra of blazars at z > 0.15 show hardening.

Secondary Gamma Rays?





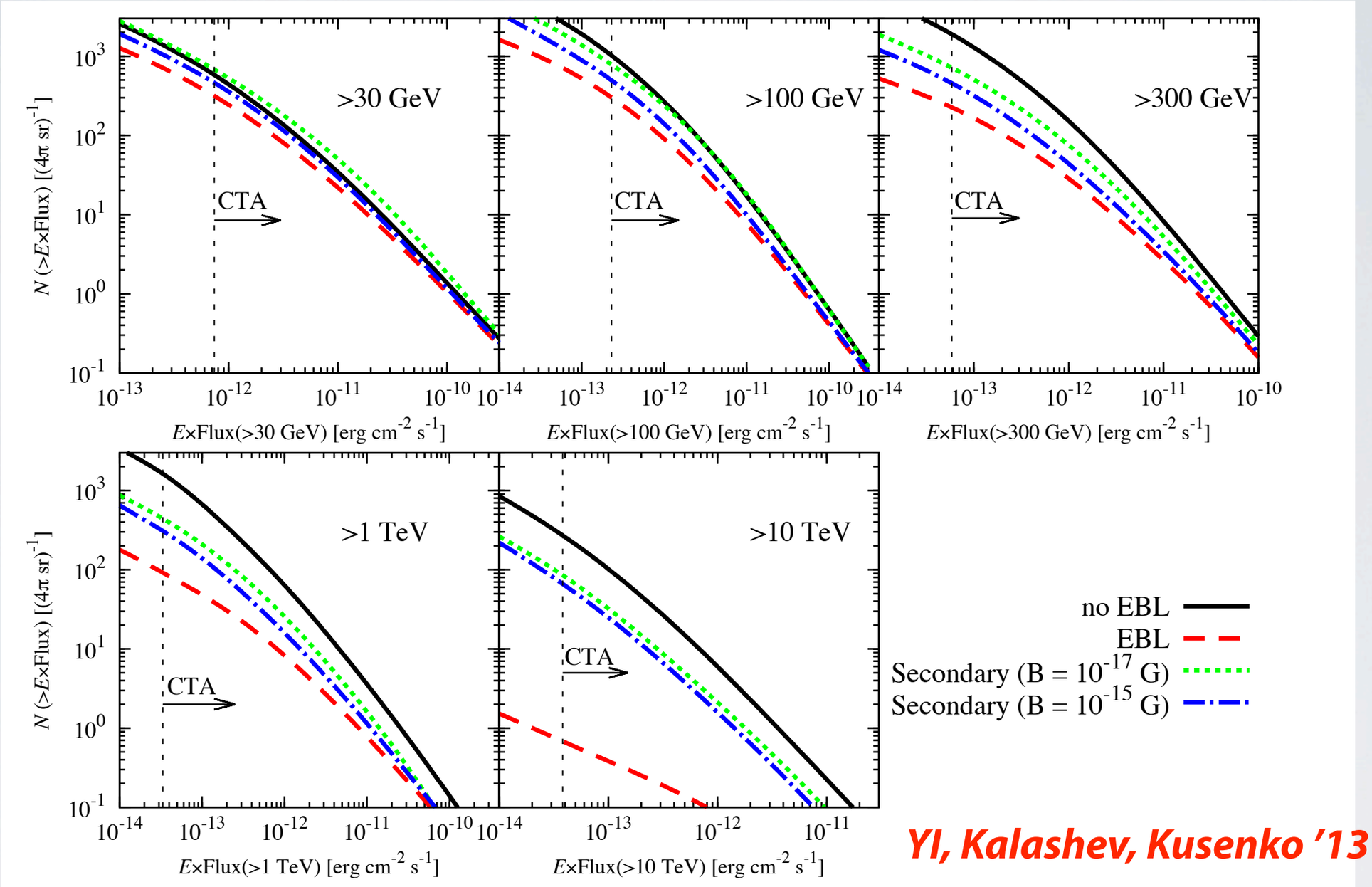
- Secondary gamma rays from cosmic rays along line of sight

  (Essey & Kusenko '10, Essey+'10, Essey+'11, Murase+'12, Takami+'13).

  - If this is the case, the intergalactic magnetic fields must be 10^{-17} ***G*** $< B_{IGMF} < 3 \times 10^{-14}$ ***G*** (Essey+'11).

- ***See Hajime Takami's and Warren Essey's talks (tomorrow)***

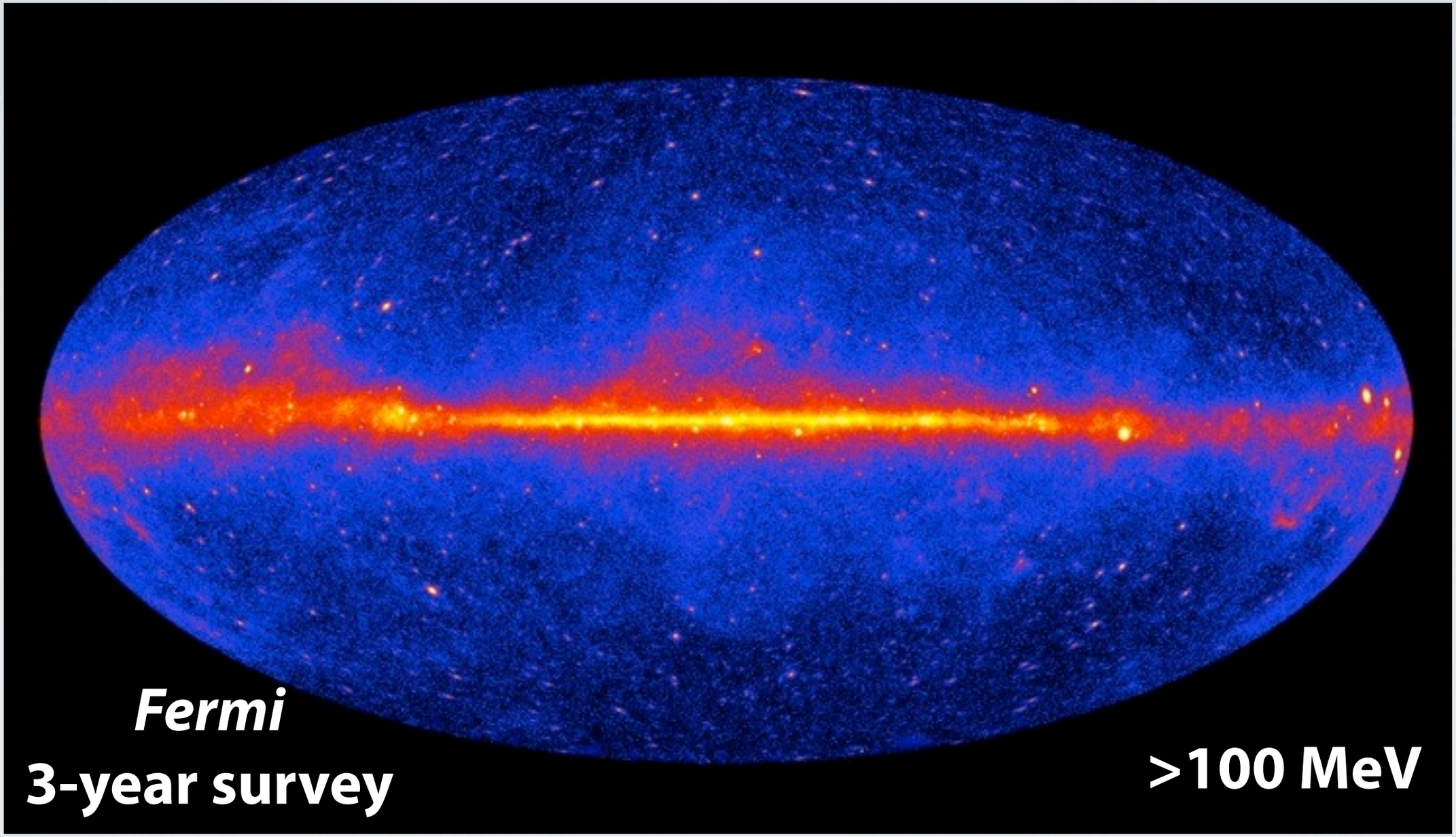
CTA Survey with secondary gamma rays



YI, Kalashev, Kusenko '13

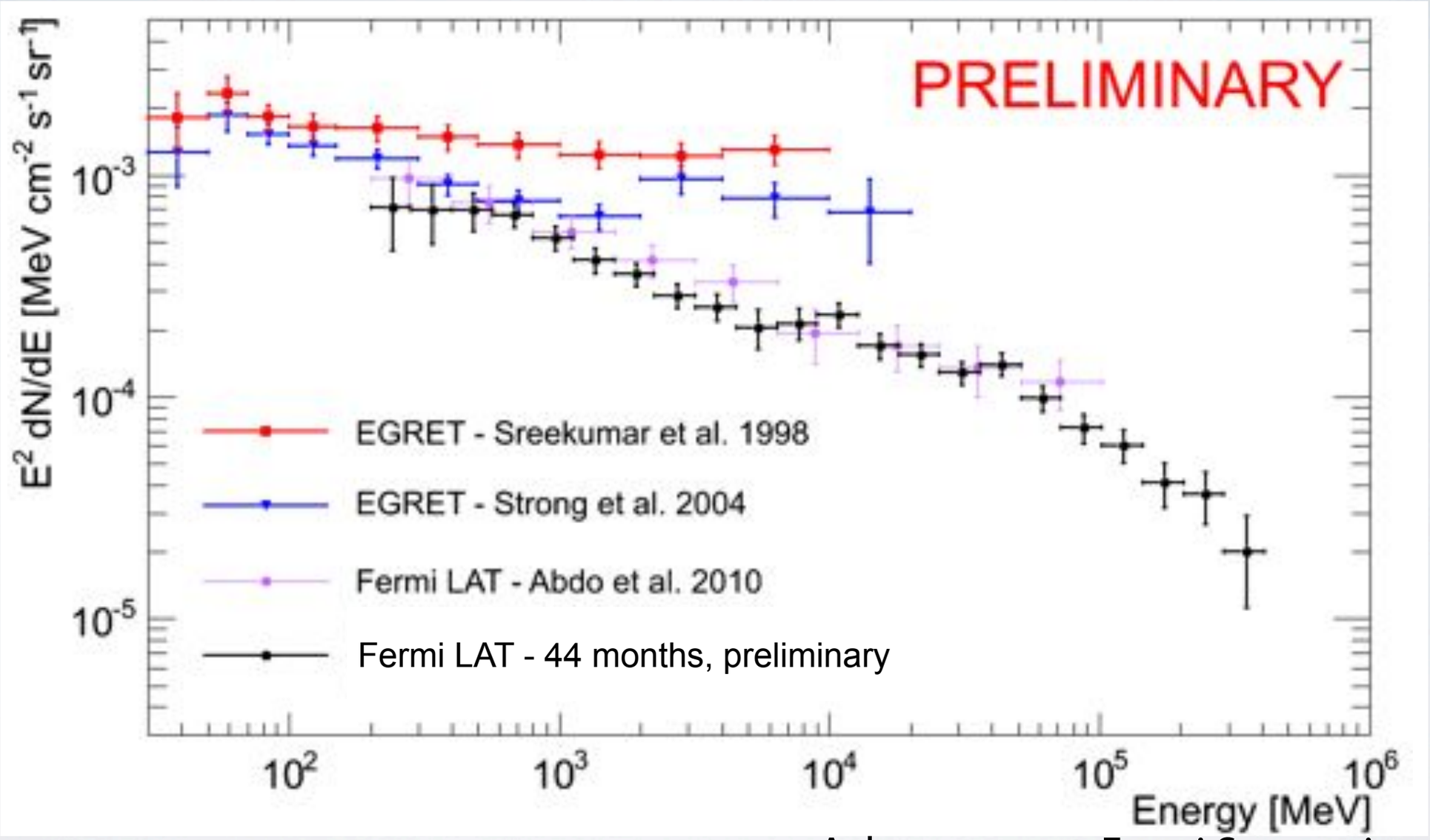
- Secondary gamma rays will enable us to detect a large number of blazars with CTA, especially at >1 TeV.

Extragalactic Gamma-ray Background



- Numerous sources are buried in the extragalactic gamma-ray background (EGB).

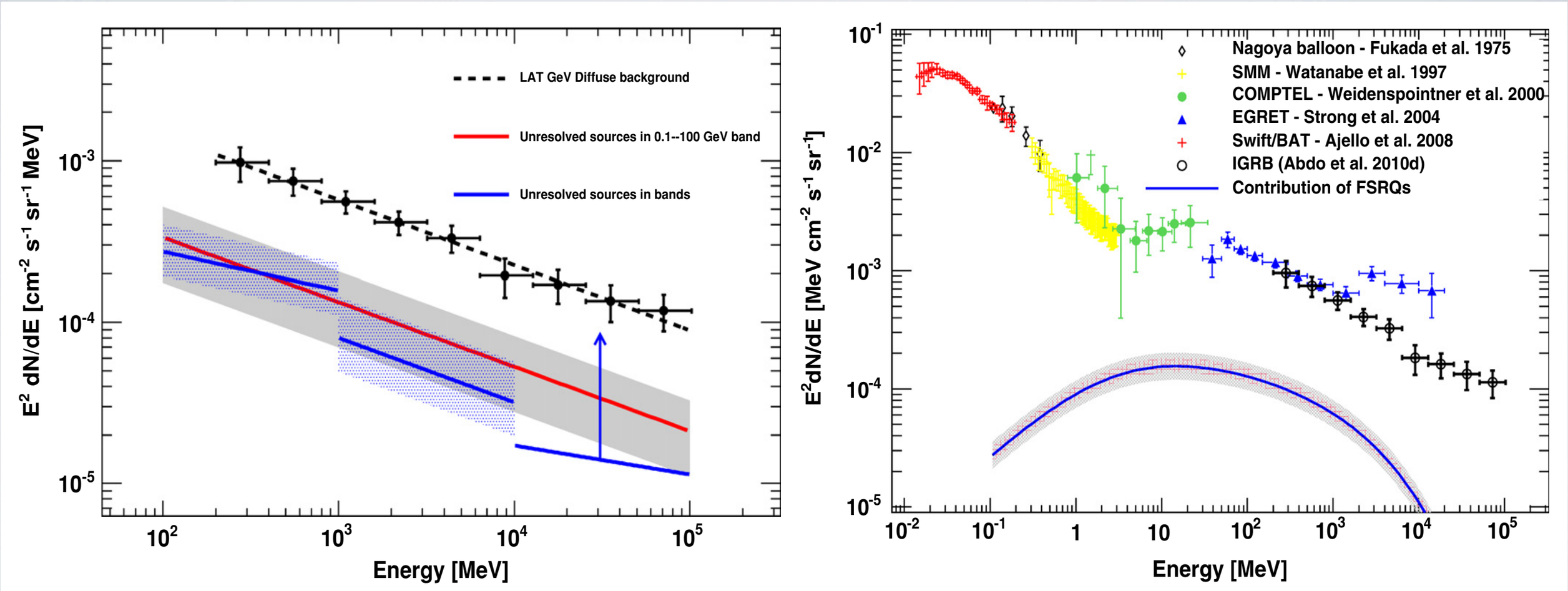
EGB Spectrum



Ackermann+@ Fermi Symposium

- Power-law spectrum up to ~400 GeV.

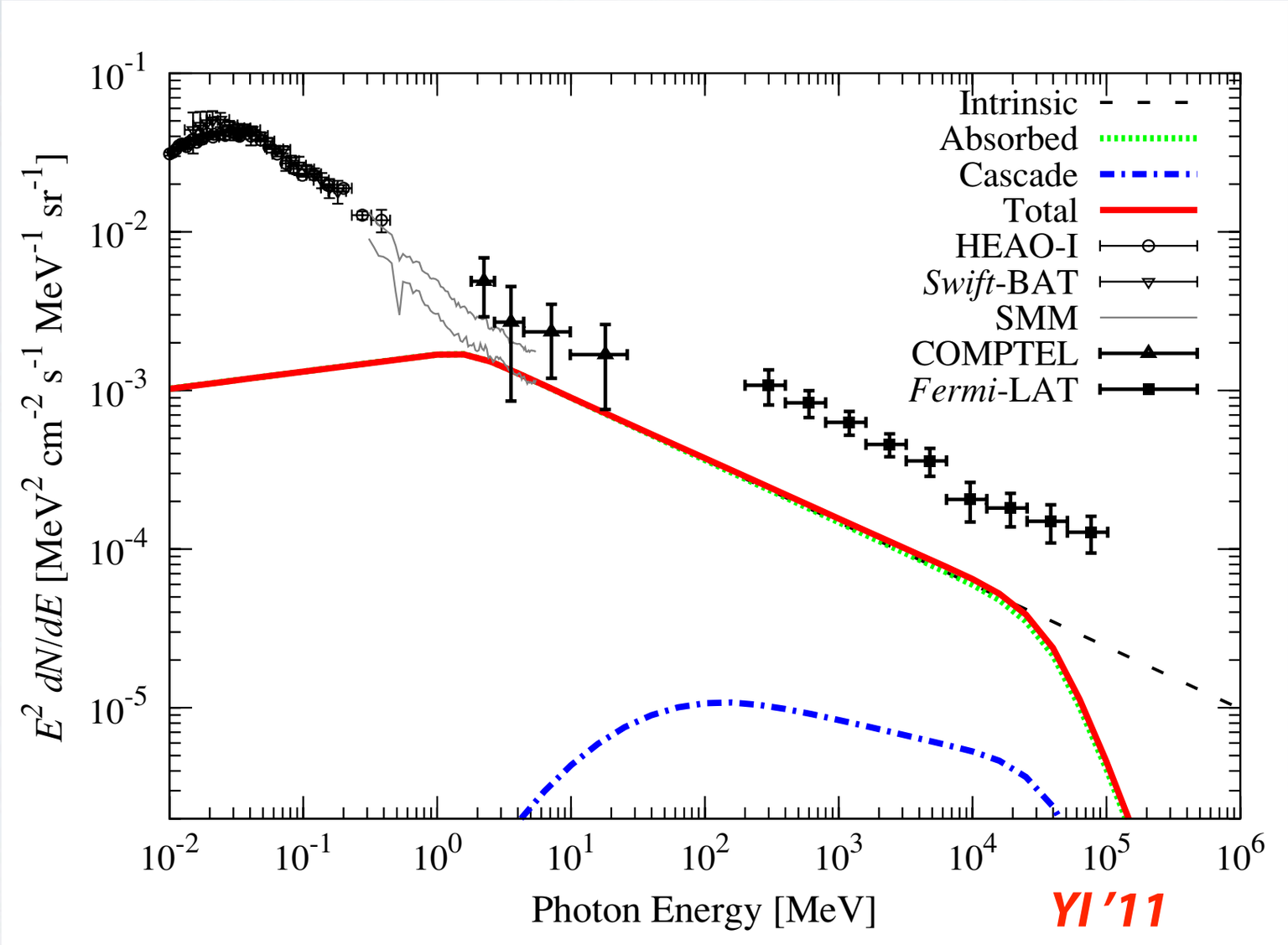
Blazars



- 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; ***Yl & Totani '09***; Abdo+'10; Stecker & Venters '10; Cavadini+'11, Abazajian+'11, Zeng+'12, Ajello+'12, Broderick+'12, Singal+'12, Harding & Abazajian '12

- Blazars explain 23± 5(stat) ±12 (sys) % of 0.1-100 GeV EGB
  - FSRQs explain $9.3^{+1.6}_{-1.0}$ (stat) ±3(sys) of 0.1-100 GeV EGB

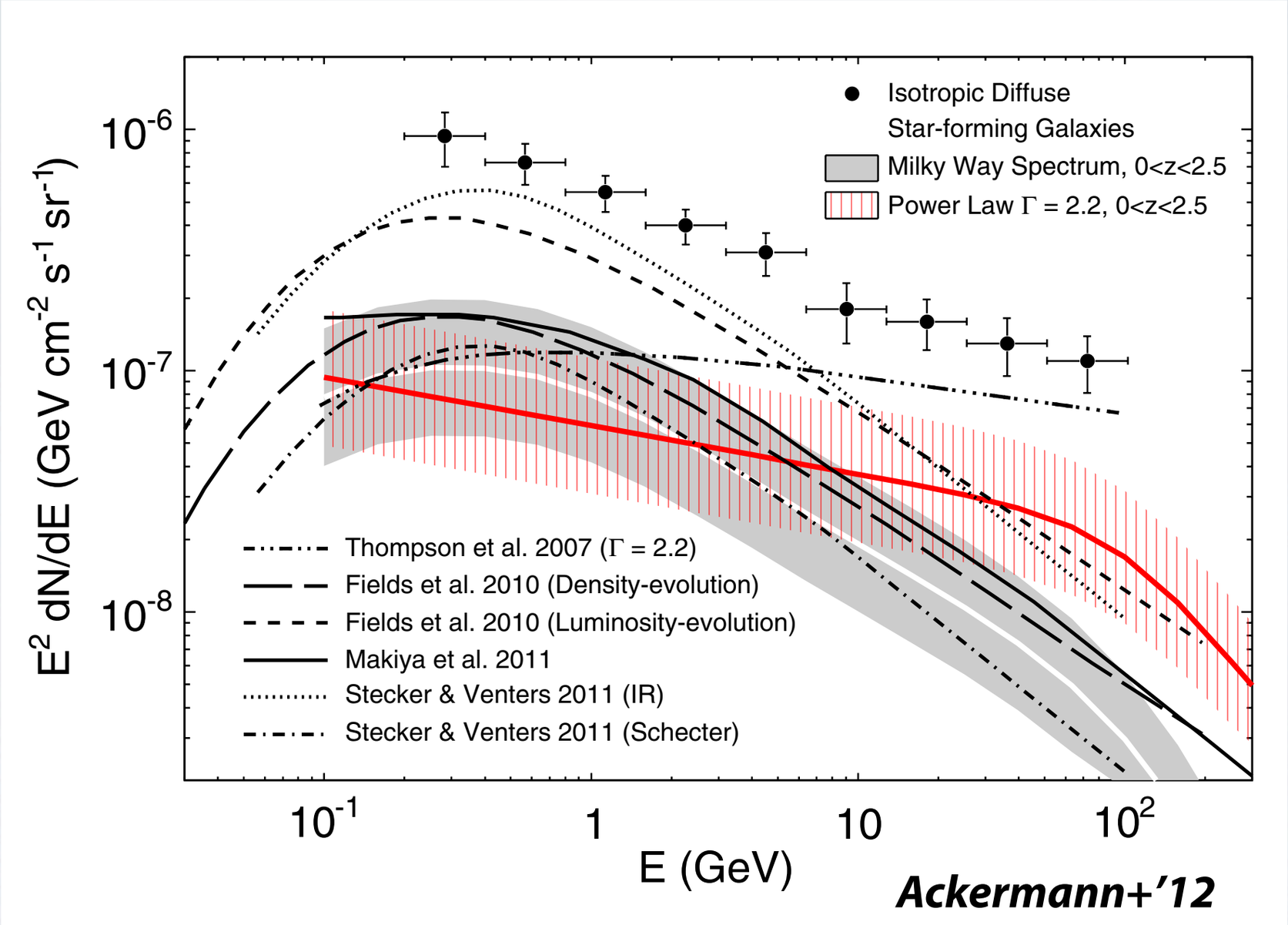
Radio Galaxies



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

- ~25% of EGB

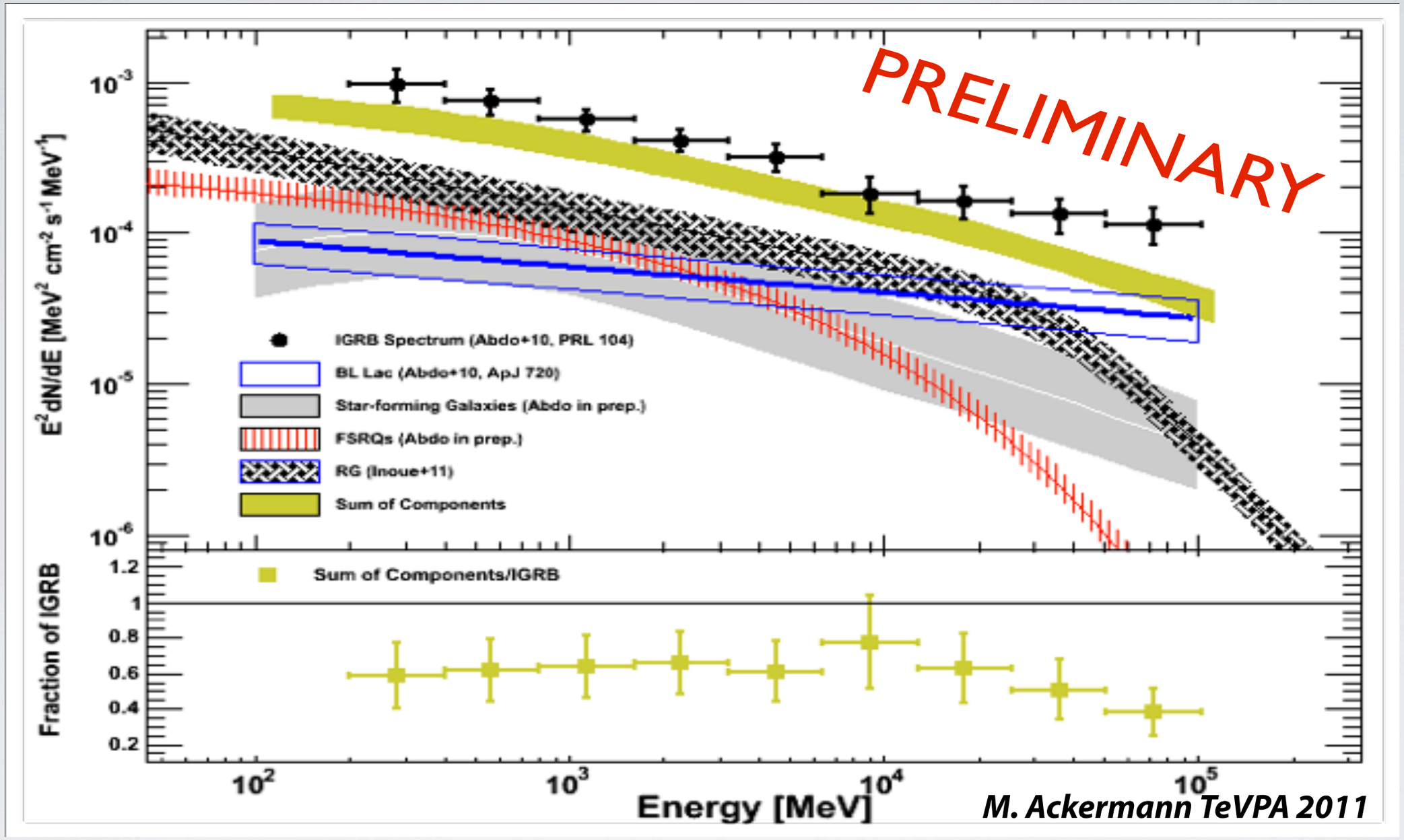
Starburst Galaxies



- 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

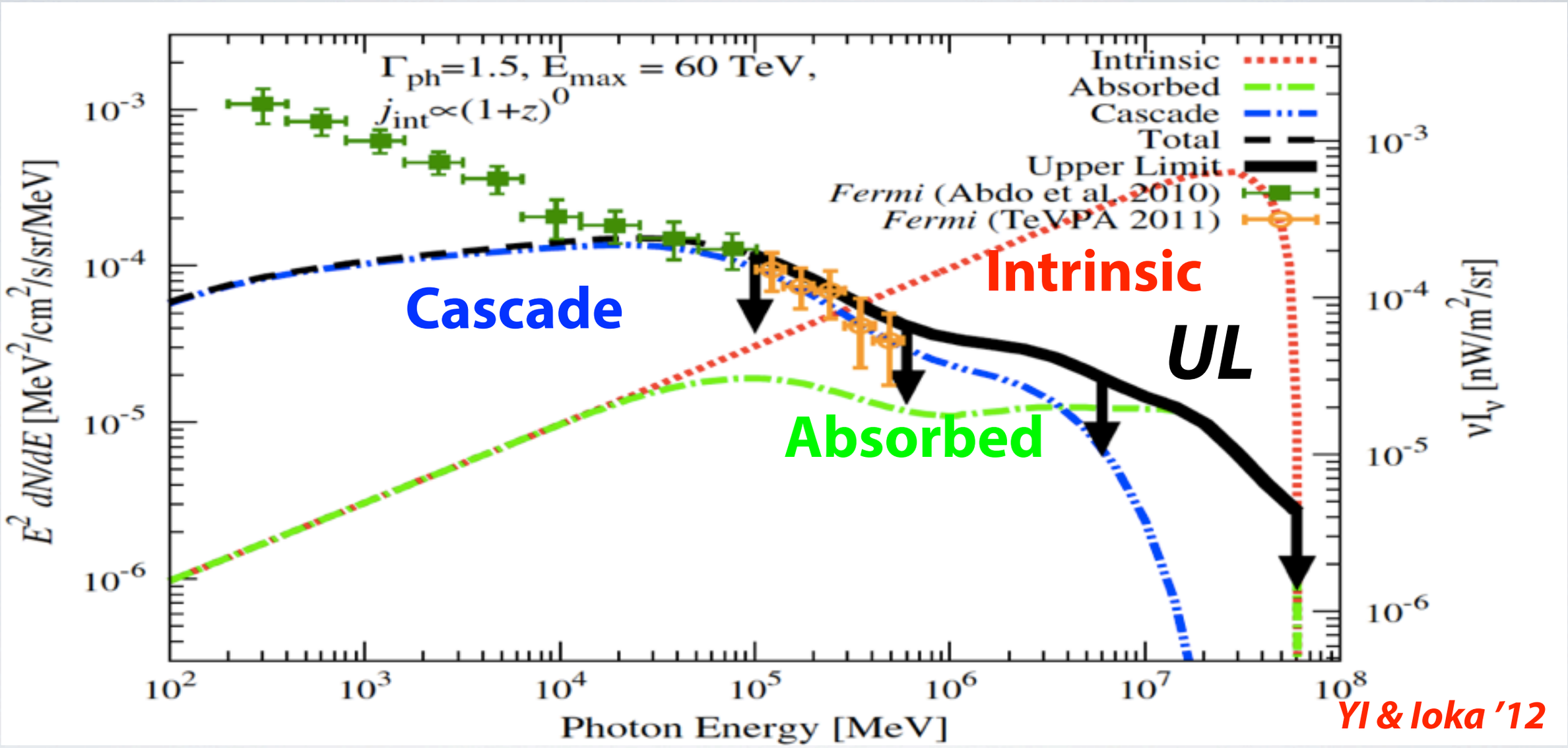
- 4 - 23% of EGB

Components of EGB



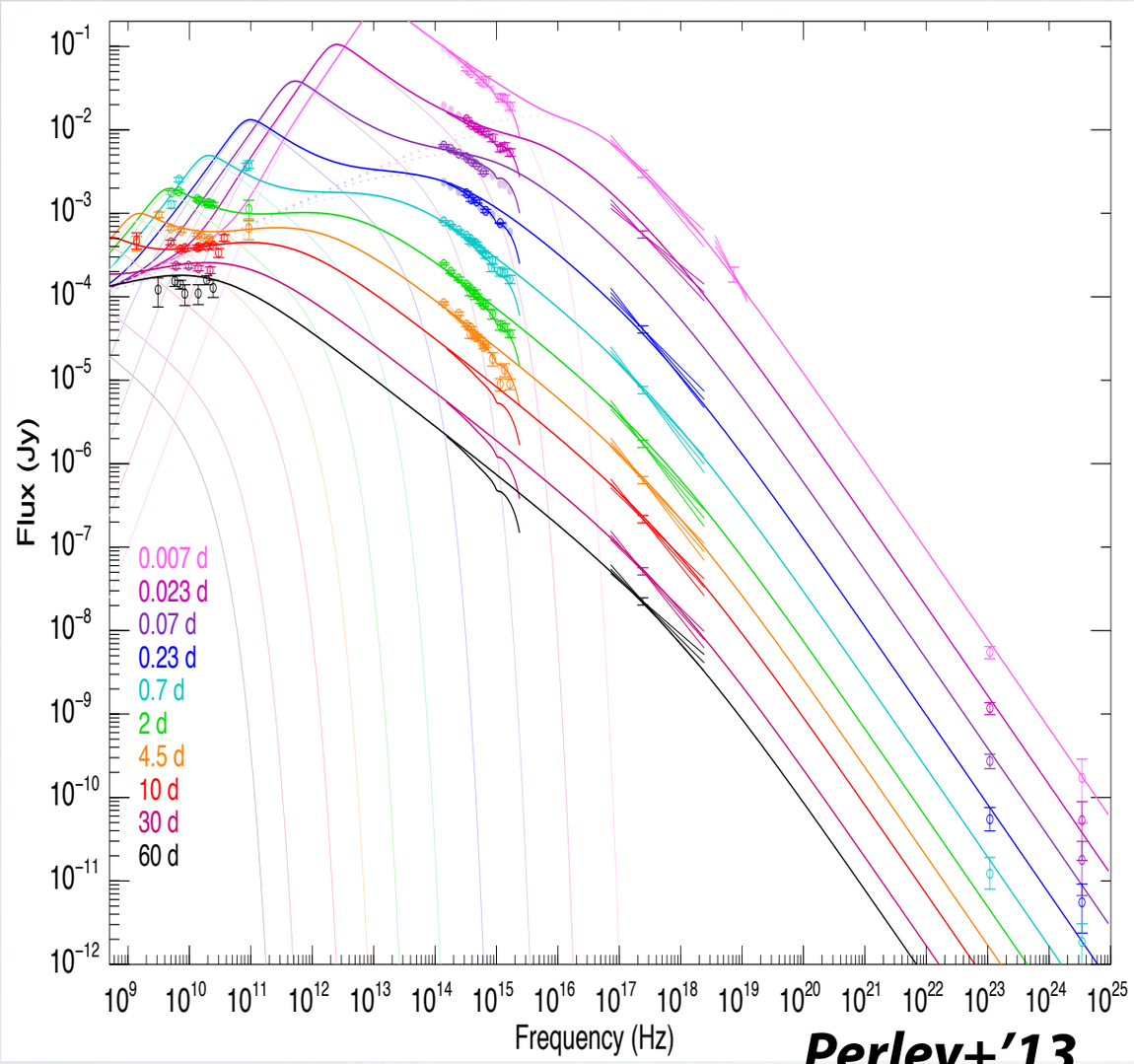
- FSRQs (Ajello+'12), BL Lacs (Abdo+'10), Radio gals. (Yl'11), Starburst gals. (Ackermann+'12) are guaranteed to contribute to EGB.

Upper Limit on EGB

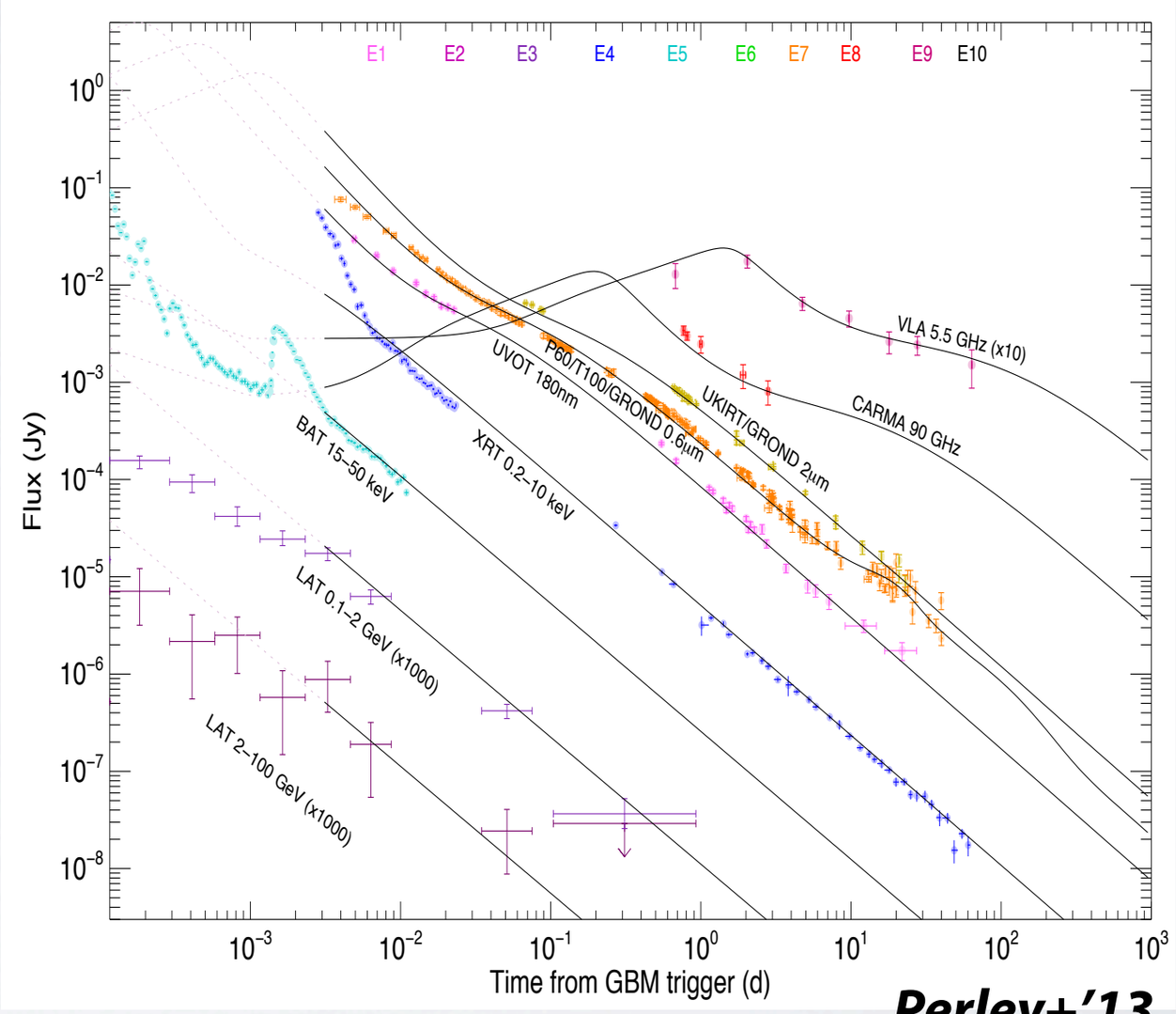


- Cascade component from VHE EGB can not exceed the Fermi EGB data (see also Murase+'12).
  - If we try to explain EGB at <10GeV by known sources, the observation violates the limit.

Brightest GRB: GRB 130427A



Perley+'13



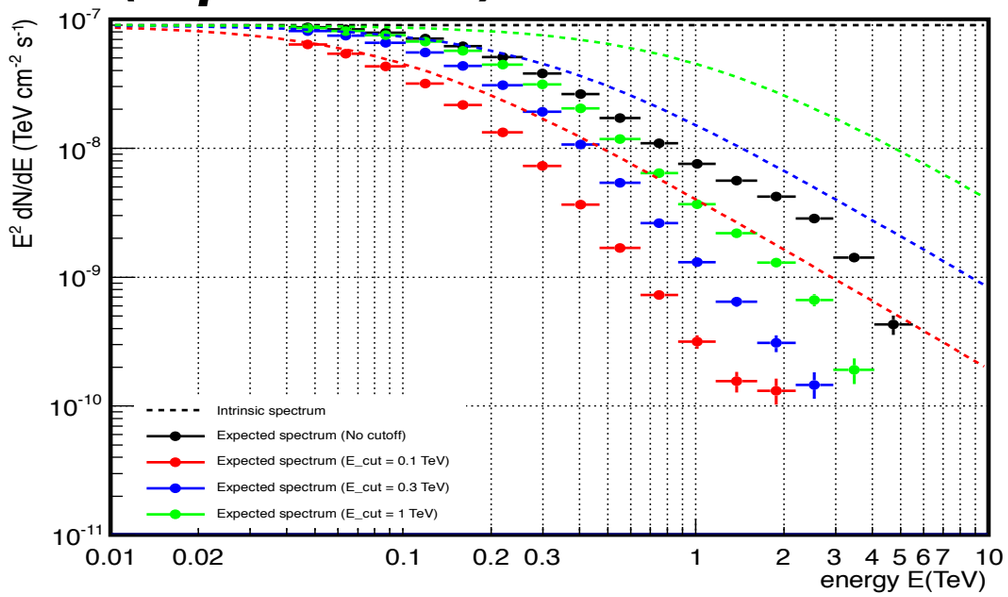
Perley+'13

- z=0.34
- Longest lasting GeV emission (~day)
- Highest energy photon (94 GeV)

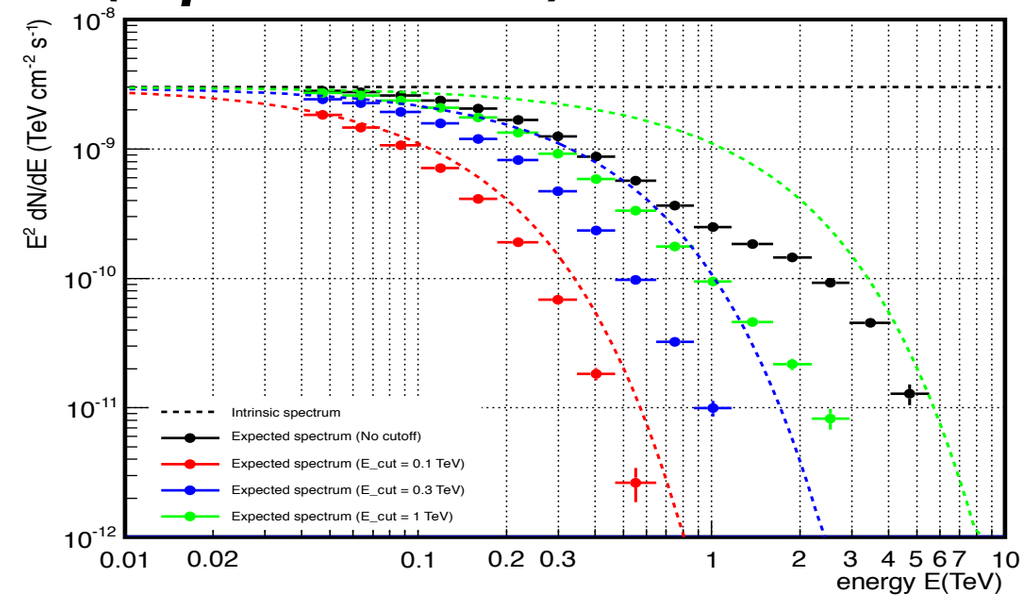
GRB 130427A and CTA: at 100s, 1 hr, 1 day, 10 days

- PL cutoff (steepening) at 100 s, (cutoff E = none, 0.1 TeV, 0.3 TeV, 1 TeV)
- PL cutoff (exponential) in afterglow phase, (cutoff E = none, 0.1 TeV, 0.3 TeV, 1 TeV)
- YI+'13 EBL (z=0.35), Spectra from Tam+'13, model from Granot+'08

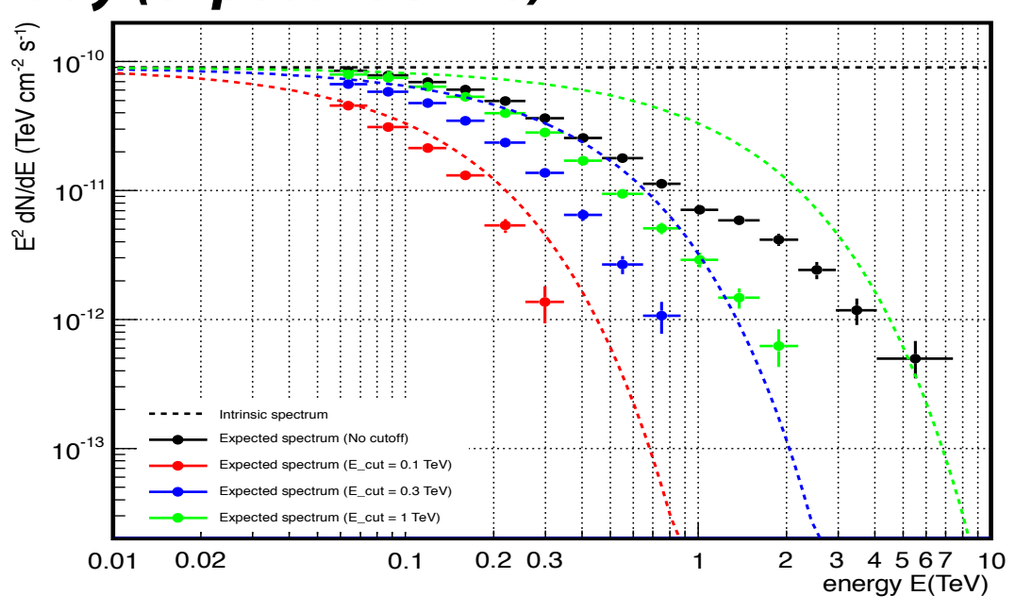
100 s (exposure 50s)



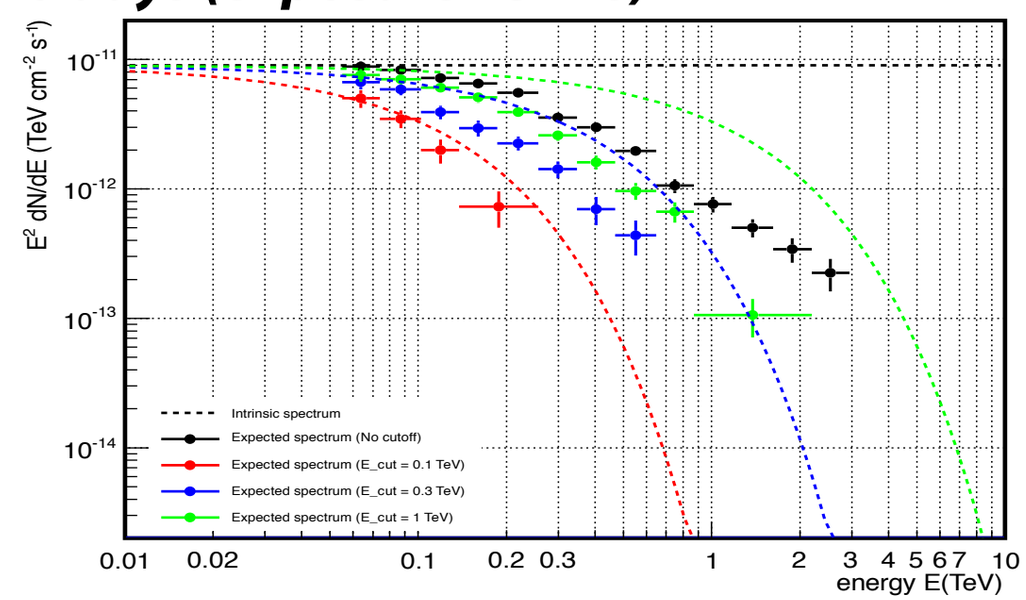
1 hr (exposure 30 min)



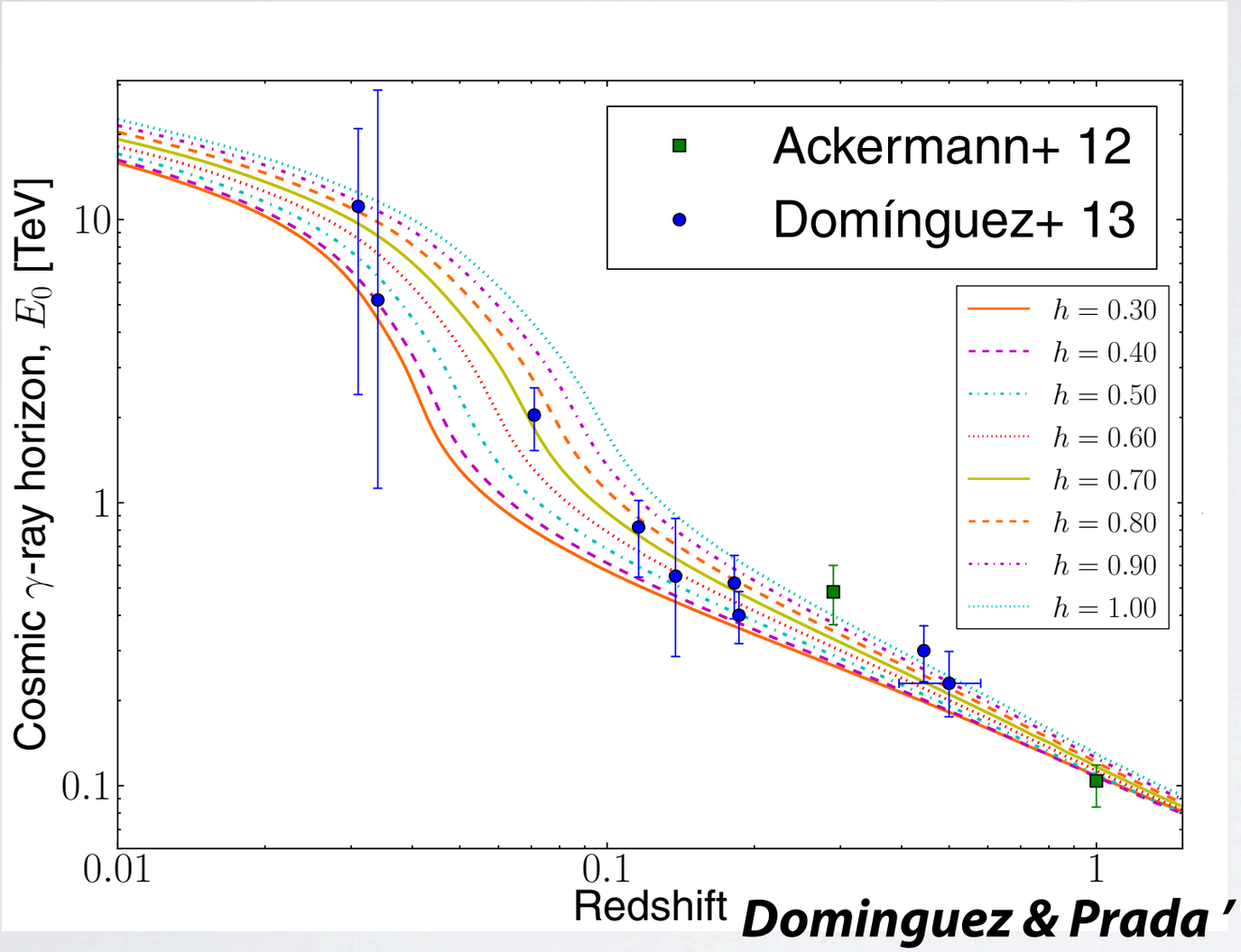
1 day (exposure 3 hrs)



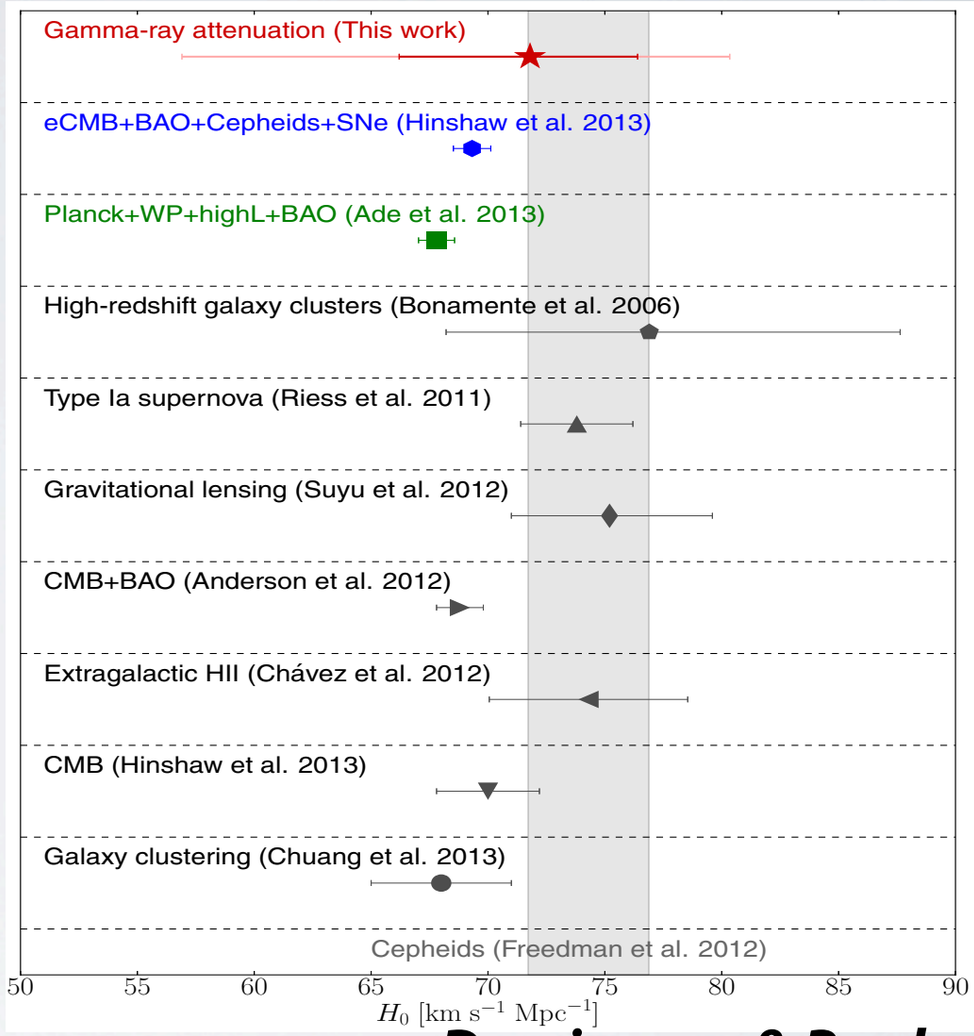
10 days (exposure 15 hrs)



Dark Energy & Gamma rays?



Dominguez & Prada '13



Dominguez & Prada '13

- Derive the cosmic expansion rate using gamma-ray horizon.
- Future data may allow to constrain cosmological parameters.
- ***See Alberto Dominguez's talk***

Summary

- 2000, 500, and 150 sources at >100 MeV, >10 GeV, and >100 GeV, respectively.
- Two distant VHE sources are newly found.
  - One is at $z > 0.6$ and the other is at $z \sim 1.1$.
- EBL corrected blazar spectra indicate a new component.
- The origin of EGB is now well understood; blazars, starbursts, & radio galaxies.
- We may be able to probe "Dark Energy" with gamma rays.