Intergalactic Photon Backgrounds and Magnetic Fields (and γ rays)

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Penn State

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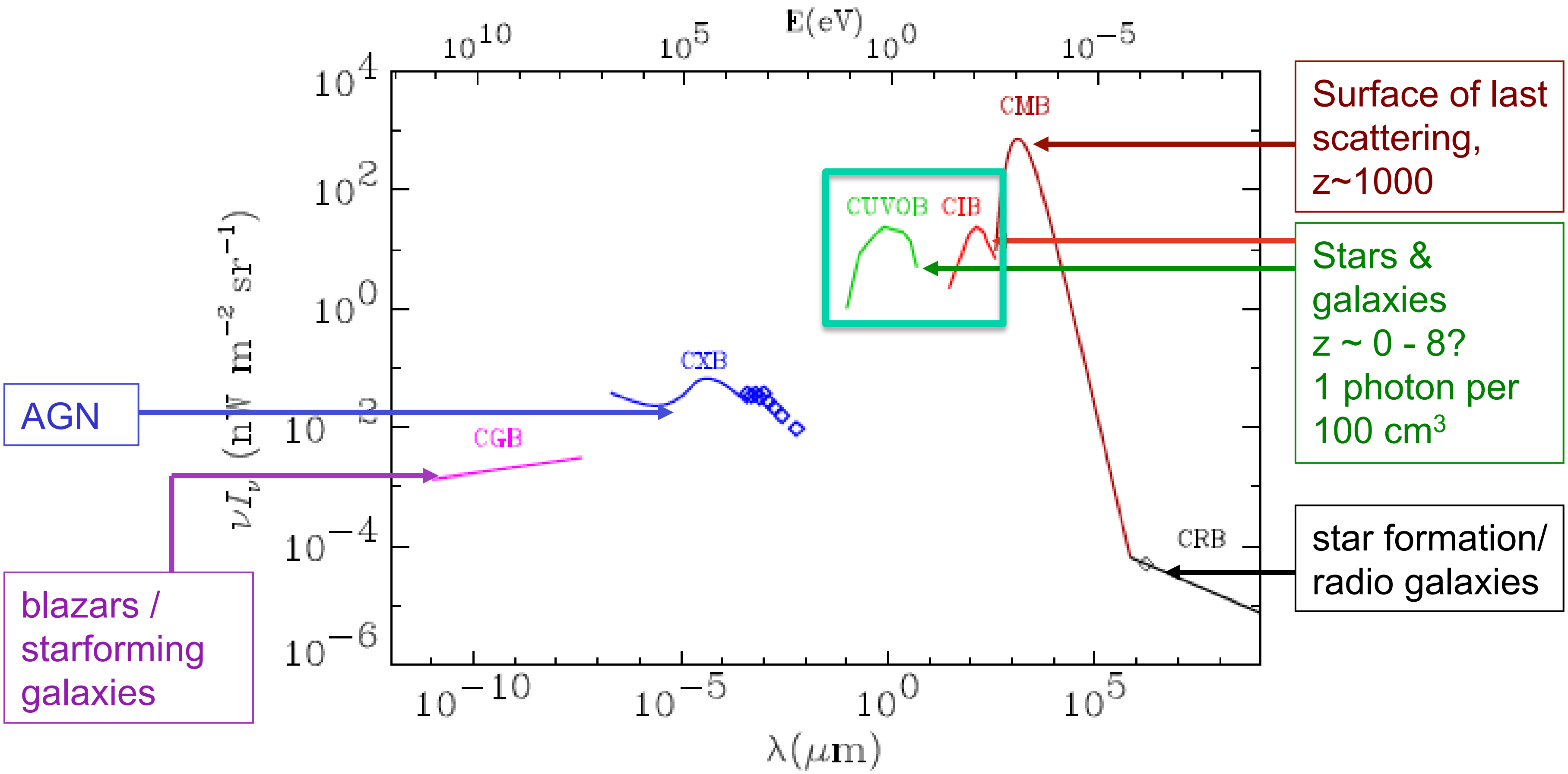
Extragalactic Background Light



Hauser & Dwek (2001), ARA&A, 39, 249

Outline

Part I: The Extragalactic Background Light (EBL)

Part II: The Intergalactic Magnetic Field (IGMF)

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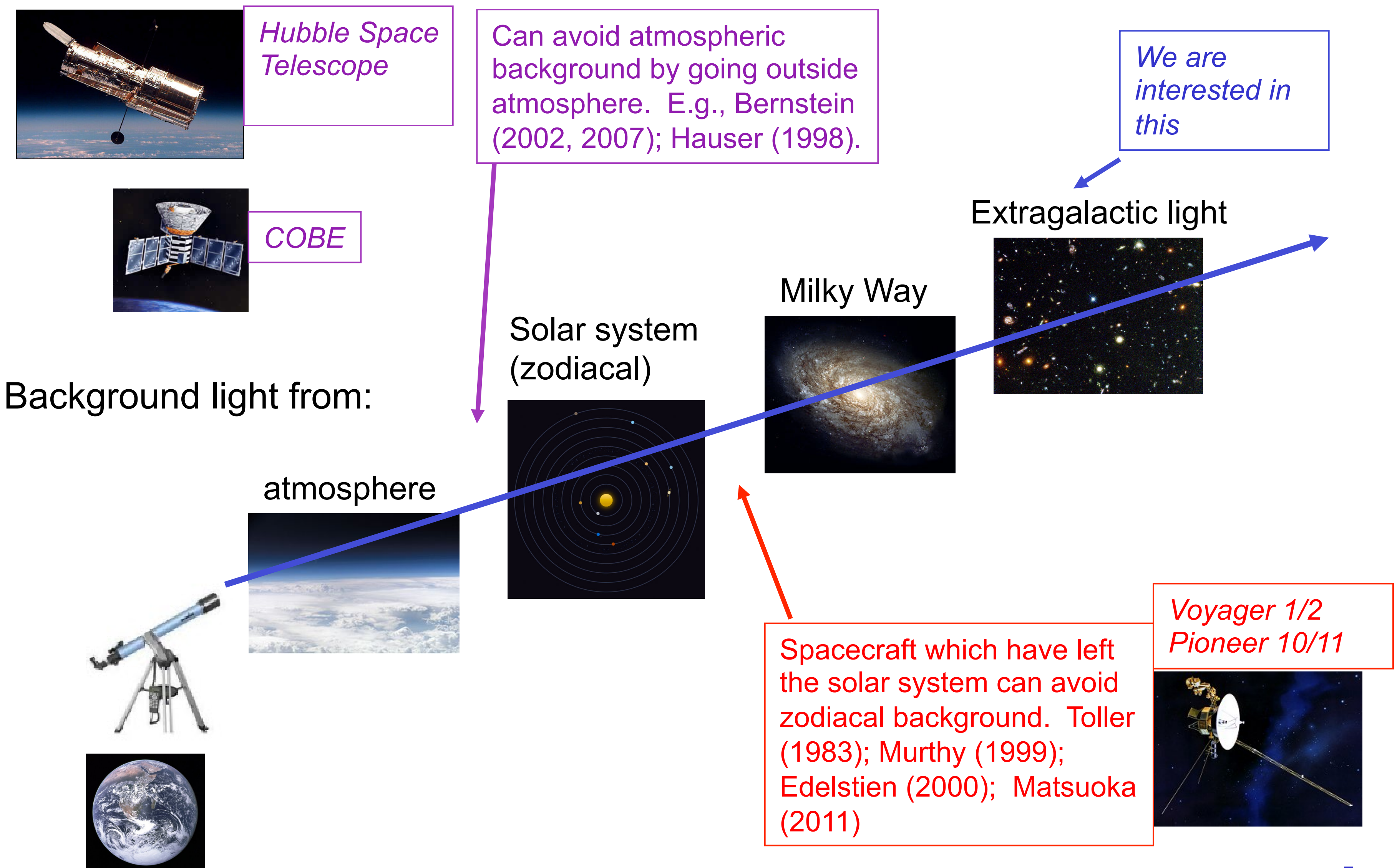
Part II: The Intergalactic Magnetic Field (IGMF)

Night Sky



Hubble Space Telescope
COBE
Can avoid atmospheric background by going outside atmosphere. E.g., Bernstein (2002, 2007); Hauser (1998).
We are interested in this
Extragalactic light
Milky Way
Solar system (zodiacal)
Background light from:
atmosphere
Spacecraft which have left the solar system can avoid zodiacal background. Toller (1983); Murthy (1999); Edelstien (2000); Matsuoka (2011)
Voyager 1/2
Pioneer 10/11

‘IR-UV’ Extragalactic Background Light

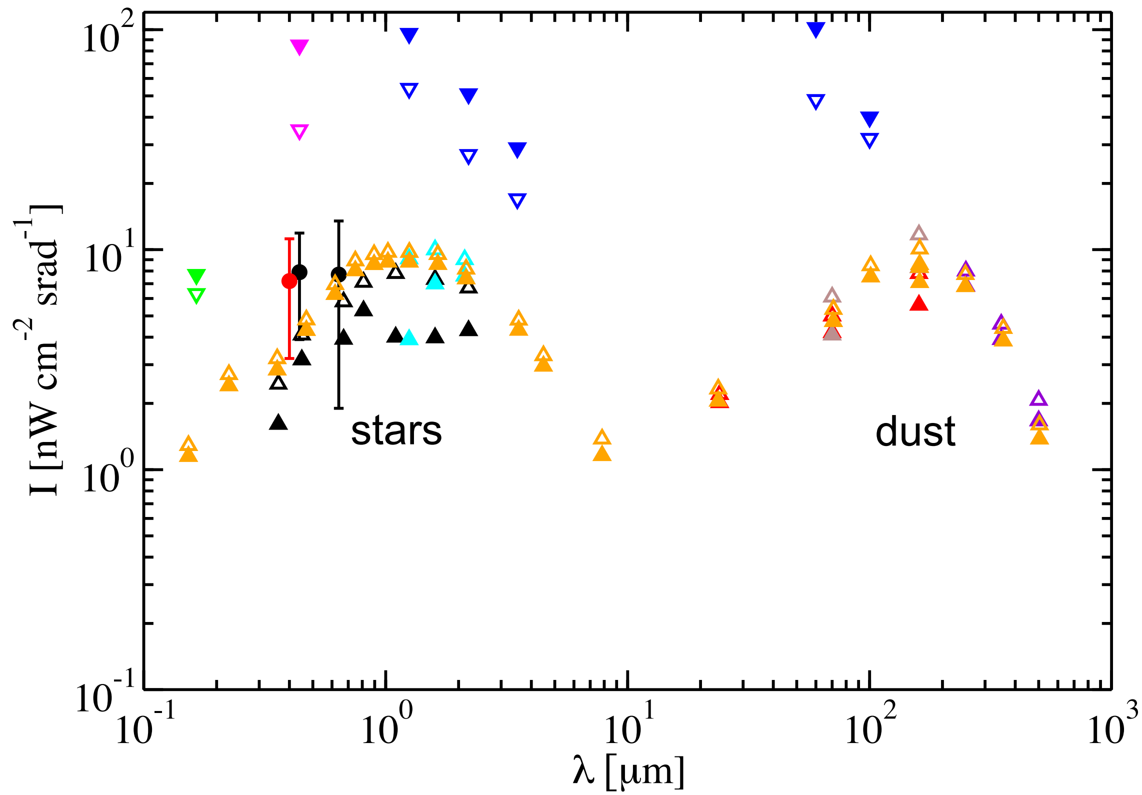
Summary of EBL observations / limits

Galaxy counts: add up light from all the galaxies seen in a certain region.

Problem: faint galaxies, and faint regions of brighter galaxies.

Results in lower limits.

1σ / 3σ limits



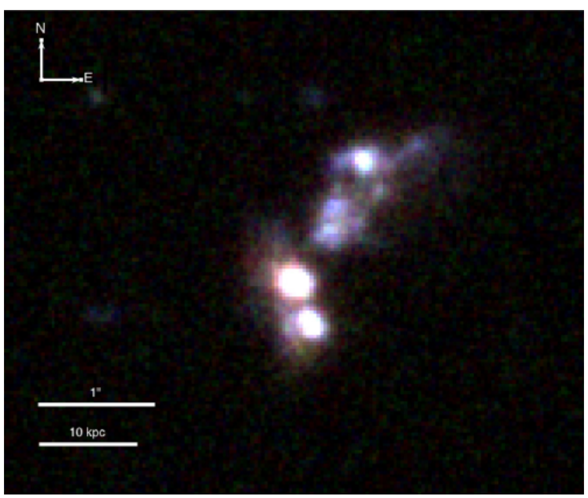
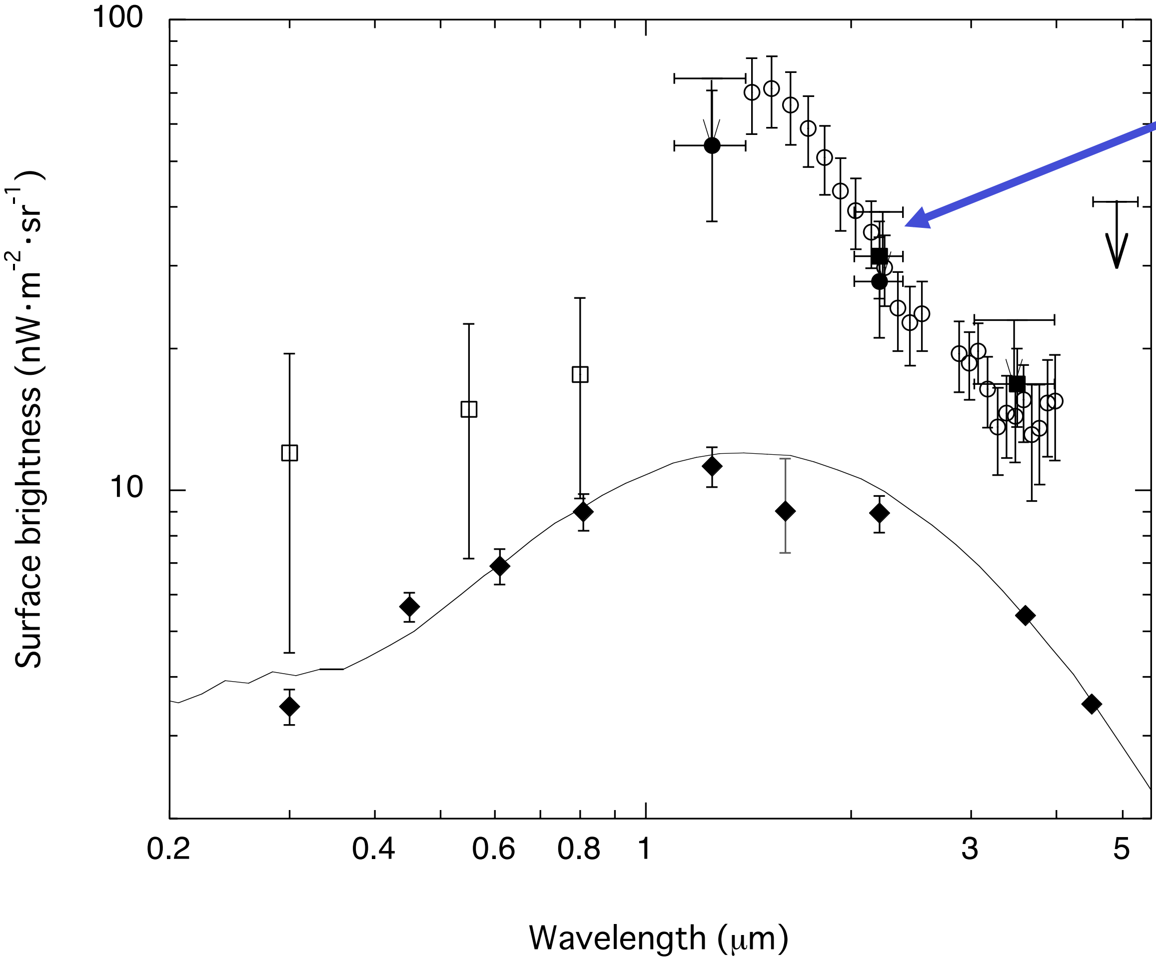


Image of faint galaxies with *HST*

Schawinski et al. (2011) ApJ, 743, L37

EBL and the first stars



Claimed Detection of EBL by Japanese IRTS.

Originating from the first stars in the universe?

This conflicts with models of galaxy formation and ionization.

Matsumoto et al. (2005) ApJ, 626, 31

Why do gamma-ray astronomers care about the IR-UV EBL?

EBL photons extinguish extragalactic gamma rays.

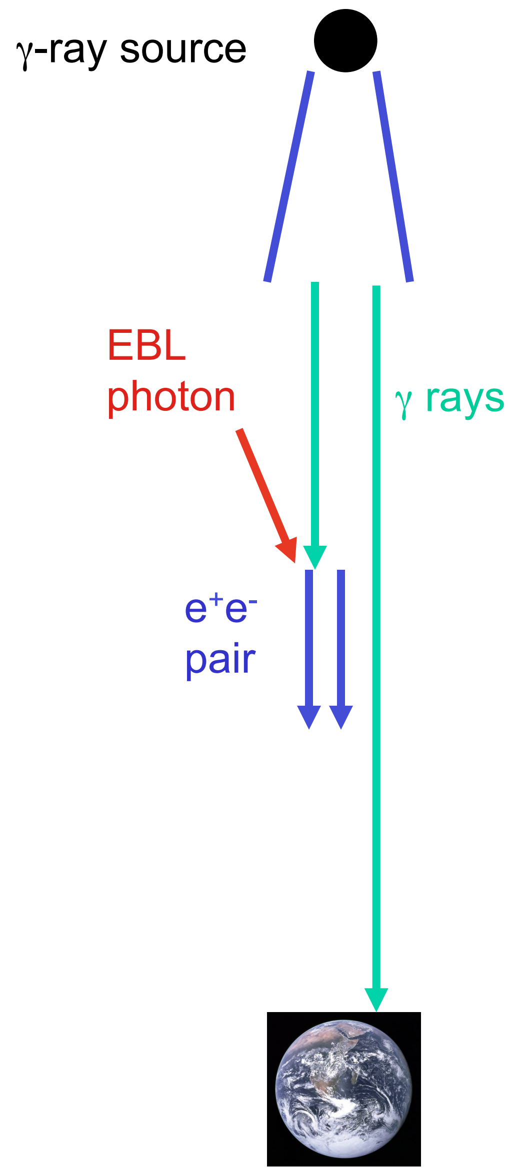
$\gamma_{ebl} + \gamma_{\gamma\text{-ray}} \rightarrow e^- + e^+$

Knowledge of the absorption effects due to EBL is necessary to infer the intrinsic spectra of extragalactic gamma-ray sources.

Gamma rays we see are attenuated by:

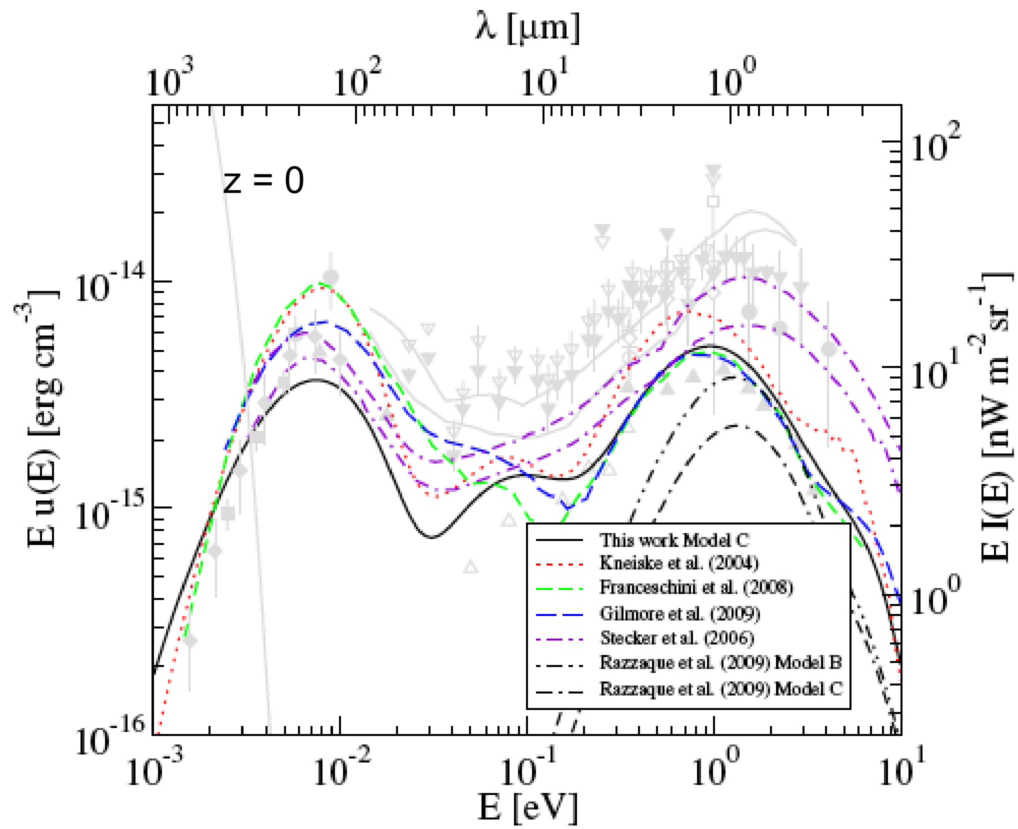
$$F_{obs} = F_{int} \exp[-\tau_{\gamma\gamma}(E, z)].$$

We want to create a model of the EBL to aid in our understanding of the γ-ray sources.



EBL Models

- Most recent models close to lower limits from galaxy counts

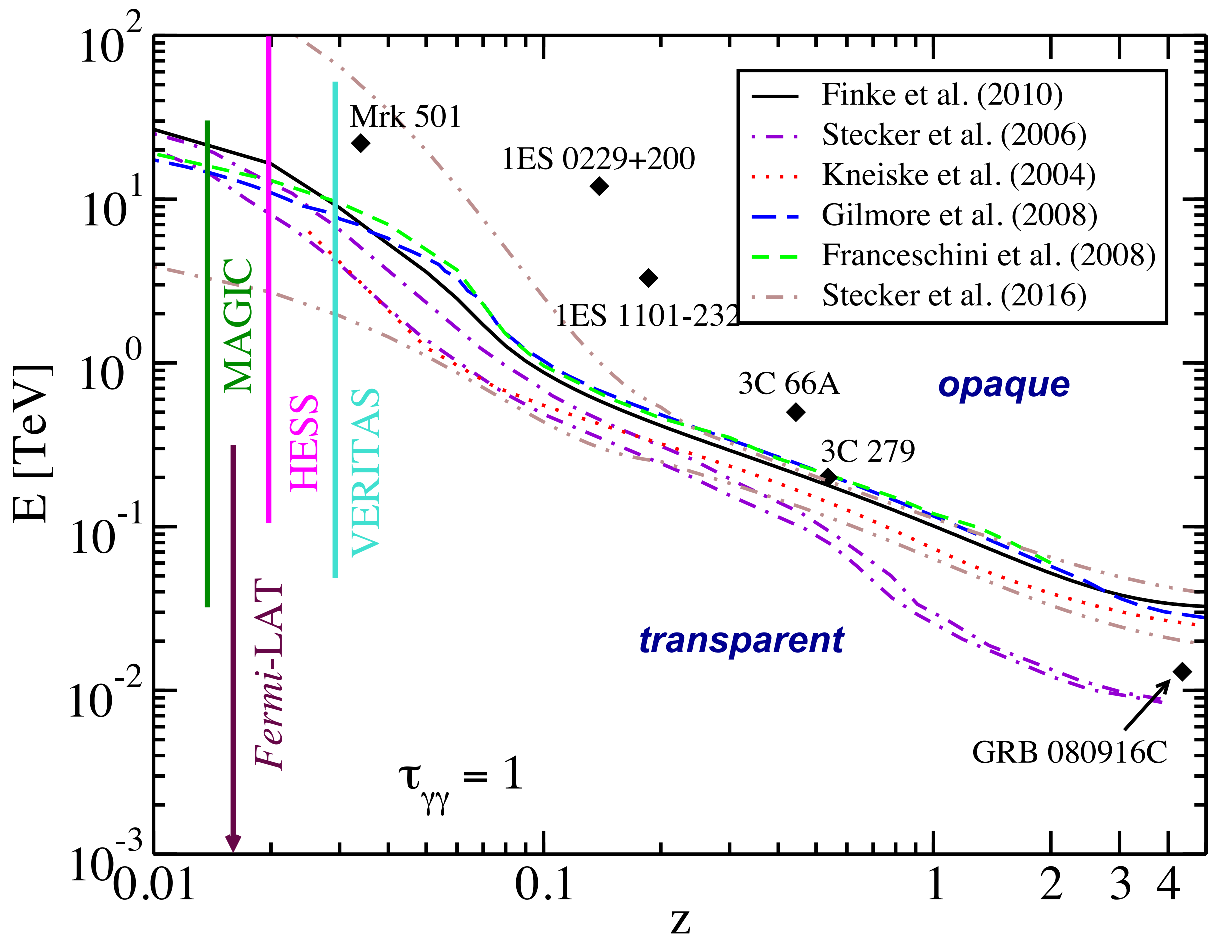


- Our EBL model available at:

http://www.phy.ohiou.edu/~finke/EBL

JF, Razzaque, & Dermer, (2010), ApJ, 712, 238
Razzaque, Dermer, & JF, (2009), ApJ, 697, 483

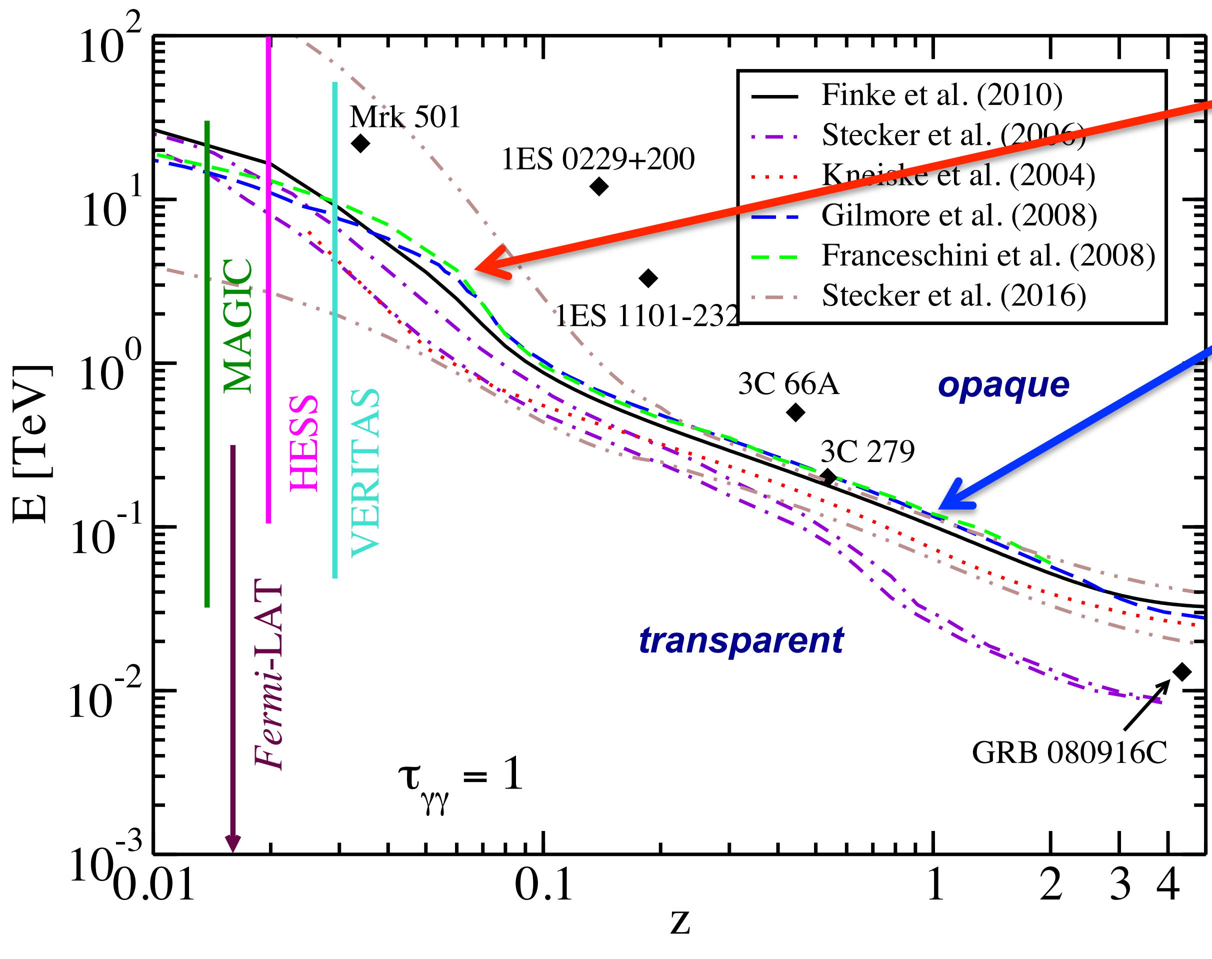
Cosmic Gamma-ray Horizon



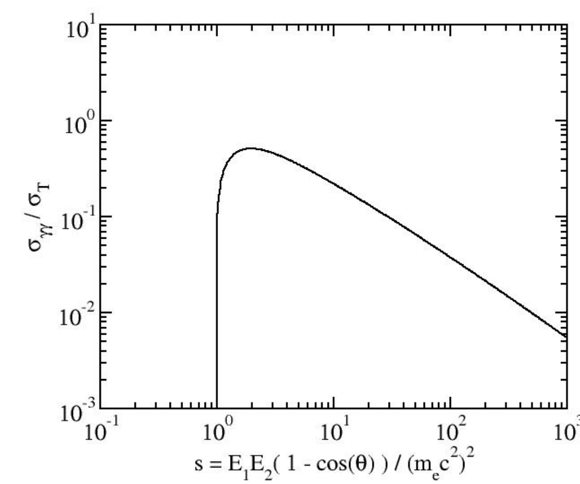
JF, Razzaque, & Dermer, (2010), ApJ, 712, 238

- Gamma rays we see are attenuated by:
  $F_{obs} = F_{int} \exp[- \tau_{\gamma\gamma}(E)]$.
- Energy where $\tau_{\gamma\gamma} = 1$ for a certain z.
- Highest energy photons labeled.
- Demonstrates TeV telescopes can be used to probe low-z, while LAT is sensitive to high-z.
- Universe transparent above ~ 10 GeV.

Cosmic Gamma-ray Horizon



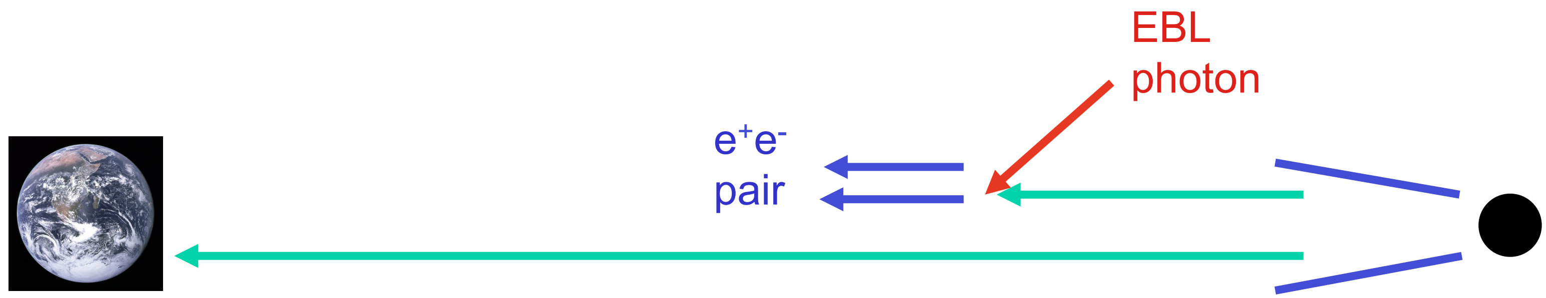
$$\lambda_{\max} = 47.5\,(1+z_{\rm src})\left[\frac{E_{\rm obs}}{\rm GeV}\right]\ \text{Å}\ .$$



JF, Razzaque, & Dermer, (2010), ApJ, 712, 238

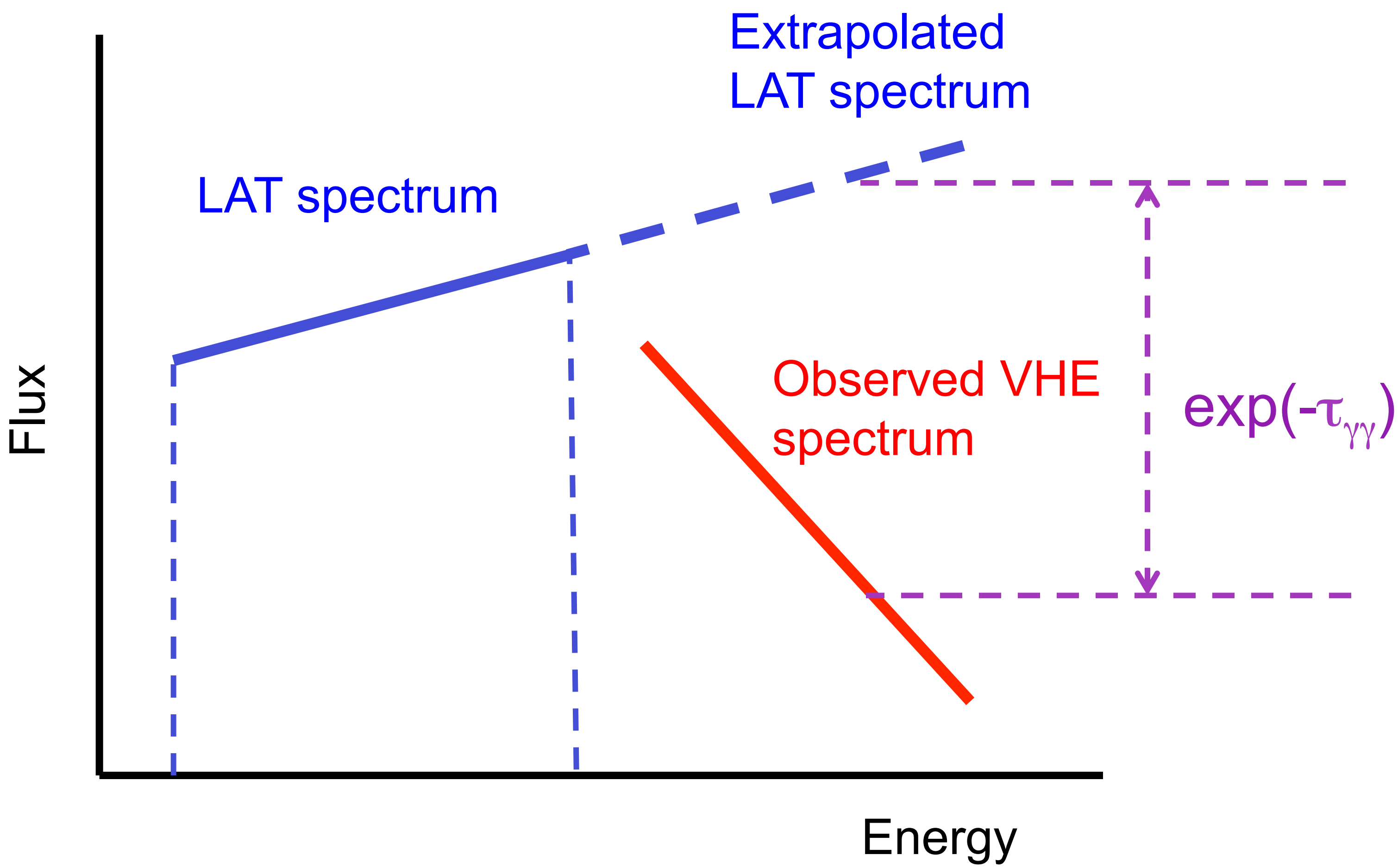
Untangling Intrinsic Brightness and Extinction

To study the EBL with γ-rays ($\tau_{\gamma\gamma}$), we need to know F_{int}. How can we determine the intrinsic γ-ray flux?



F_{obs} $\exp(-\tau_{\gamma\gamma})$ F_{int}

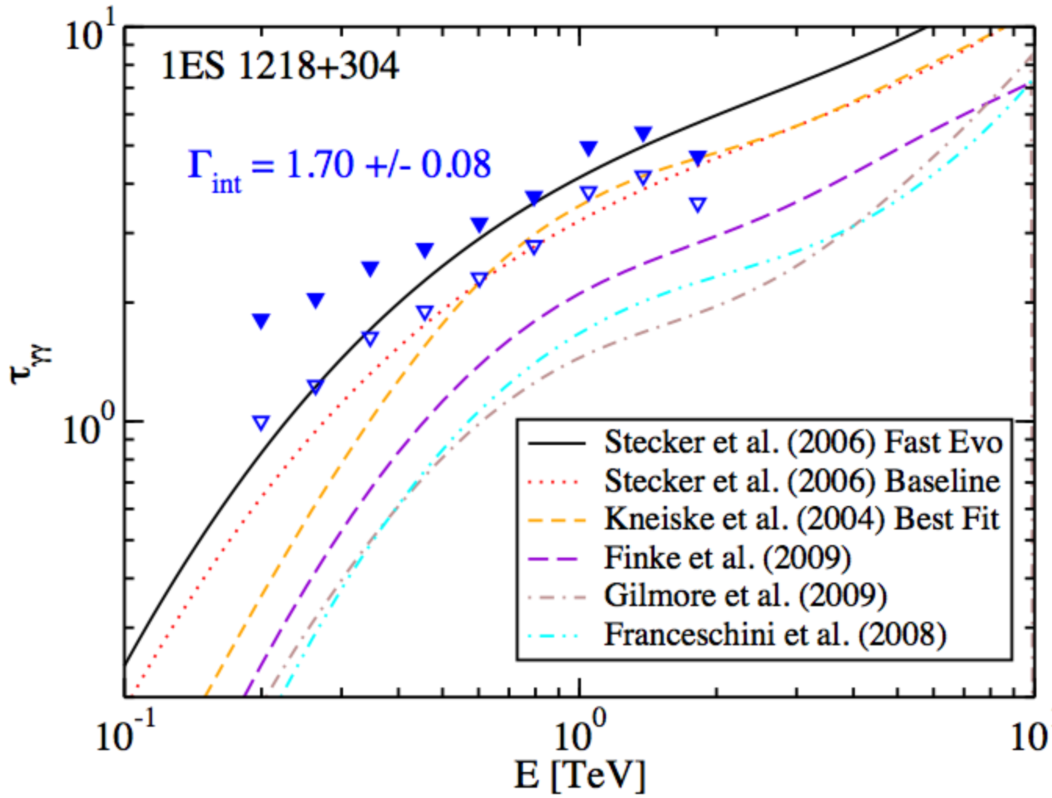
Combined LAT / ACT Constraints



Combined LAT / ACT Constraints

Results for 1ES 1218+304

- Empty symbols: 1 σ upper limits
- Filled symbols: 3 σ upper limits
- Stecker et al. (2006) fast evo. model ruled out at 4.7 σ
- Stecker et al. (2006) baseline model ruled out at 2.6 σ
- Kneiske et al. (2004) best fit model ruled out at 2.9 σ
- Other lower models allowed



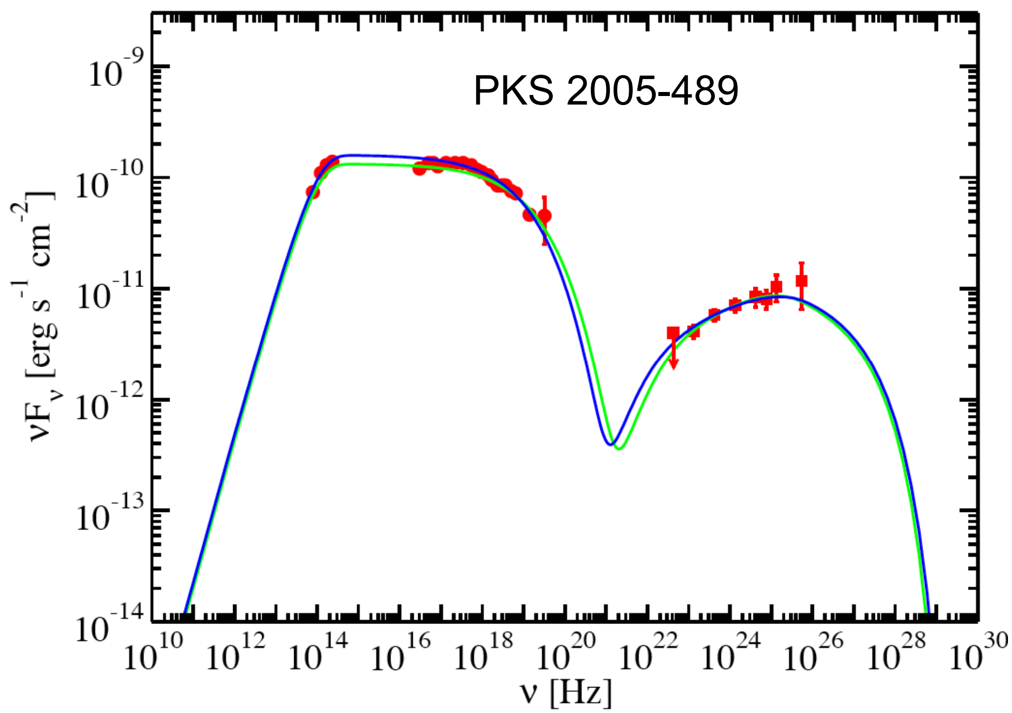
1σ and 3σ upper limits and model predictions

Georganopoulos, JF, & Reyes (2010), ApJ, 714, 157

Blazar Modeling

- Collect SED data sets on large sample of TeV blazars.
  - Includes 2FGL and Hard source list data.

- Model SED data from radio to LAT gamma-rays with synchrotron/ Synchrotron self-Compton model.
  - EBL γγ absorption is negligible at these energies.



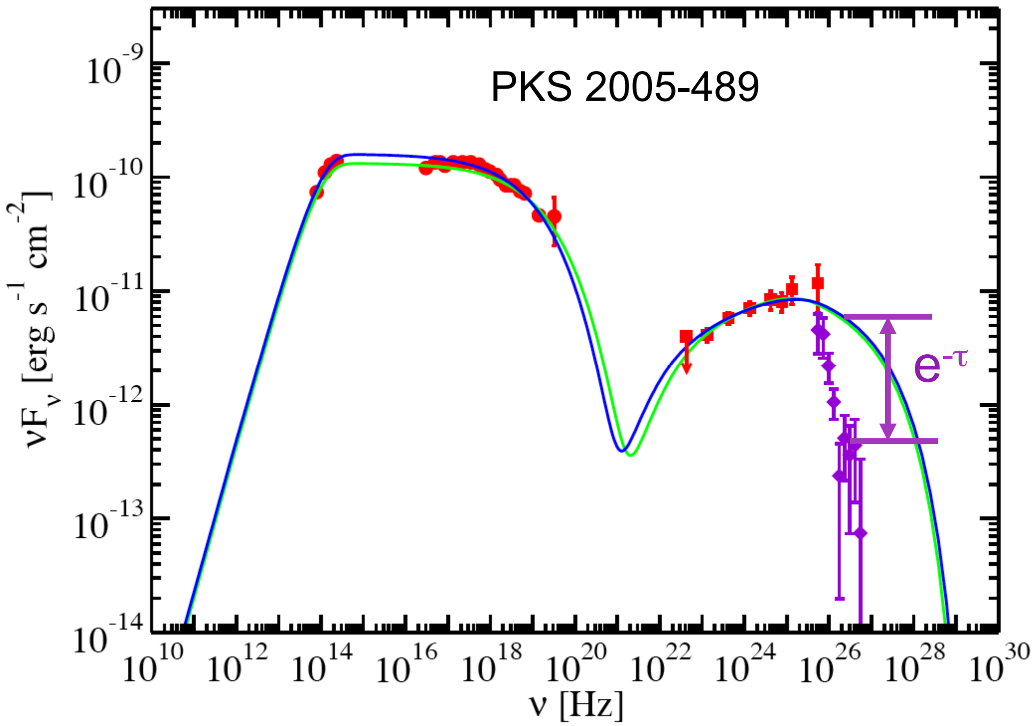
Dominguez, et al., (2013), ApJ, 770, 77

Blazar Modeling

- Collect SED data sets on large sample of TeV blazars.
  - Includes 2FGL and Hard source list data.

- Model SED data from radio to LAT gamma-rays with synchrotron/SSC model.
  - EBL γγ absorption is negligible at these energies.

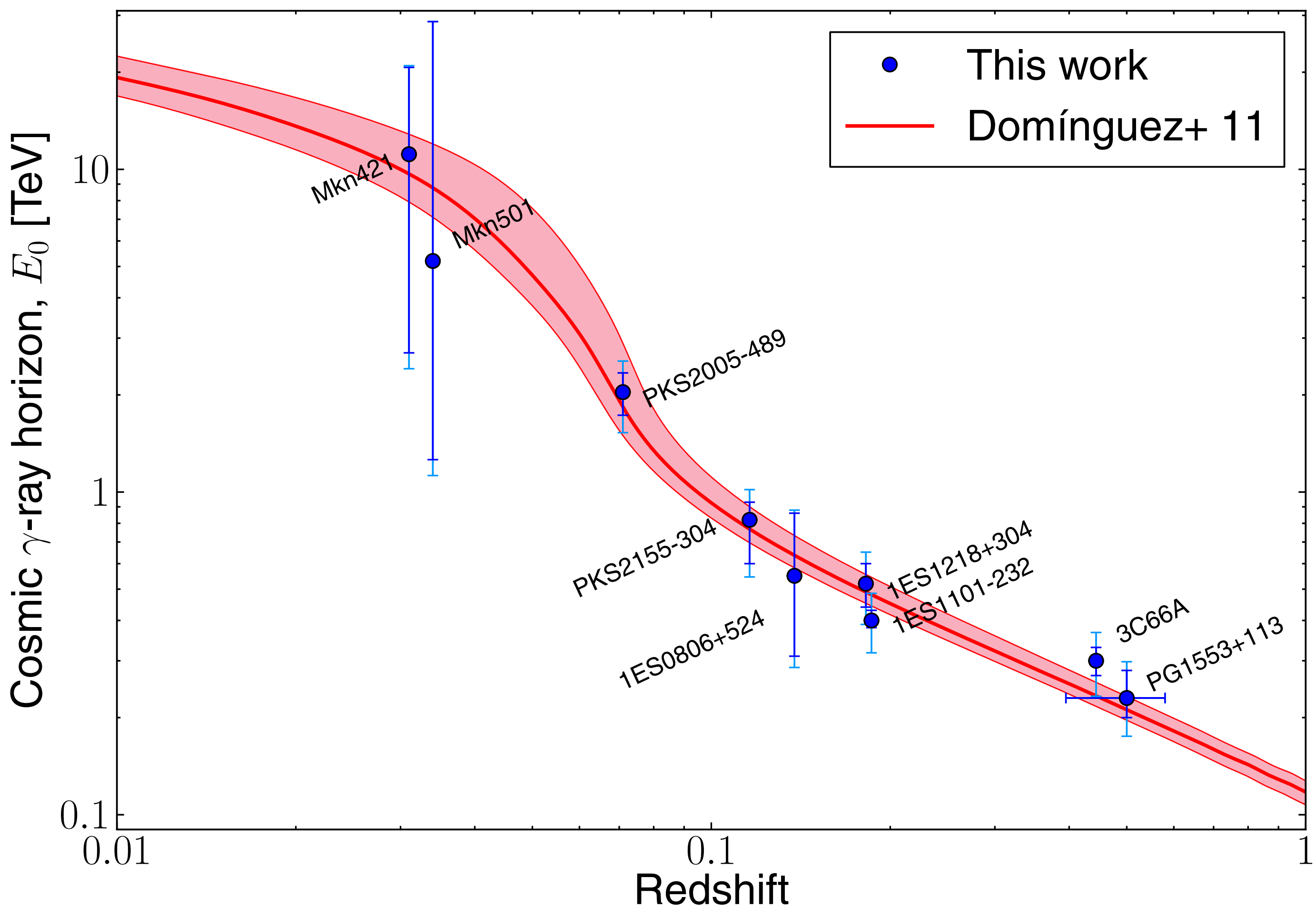
- Compare model prediction at TeV energies with observed TeV points to determine EBL absorption.
  - $F_{obs} = \exp(-\tau_{\gamma\gamma})\, F_{model}$



Dominguez, et al., (2013), ApJ, 770, 77

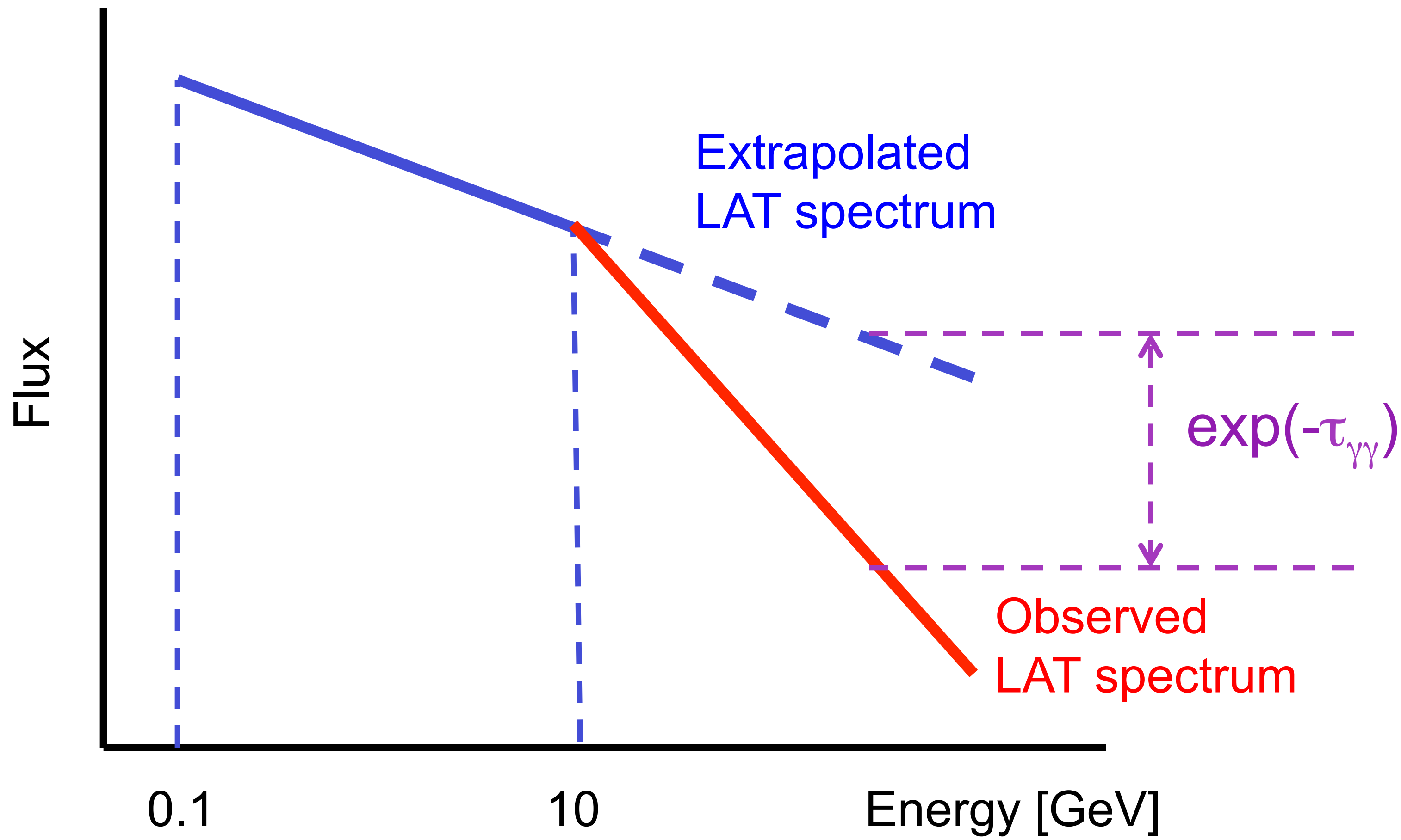
Blazar Modeling

Results: Good agreement with models



Dominguez, et al., (2013), ApJ, 770, 77

EBL Constraints with the Fermi LAT



EBL Constraints with the Fermi LAT

Constraints from blazars and GRBs			Stecker et al. (2006) "baseline model"	
Blazar/GRB	z	E_{max} [GeV]	Rejection significance HEP	Rejection significance LRT
J1147-3812	1.05	73.7	3.2σ	3.7σ
J1504+1029	1.84	48.9	4.1σ	4.6σ
J0808-0751	1.84	46.8	4.5σ	5.4σ
J1016+0513	1.71	43.3	3.3σ	6.0σ
J0229-3643	2.11	31.9	2.9σ	3.2σ
GRB 090902B	1.82	33.4	3.7σ	3.6σ
GRB 080916C	4.24	13.2	3.4σ	3.1σ

Combining results, Stecker et al. (2006) baseline model rejected at >11σ significance.
All lower opacity models tested are allowed thus far.

Abdo et al. (2010), ApJ, 723, 1082

EBL Constraints with the Fermi LAT

The passage of time changes things: 150 BL Lacs, 3.8 years of data. Many more photons at greater than 10 GeV thanks to lower background at high energies.

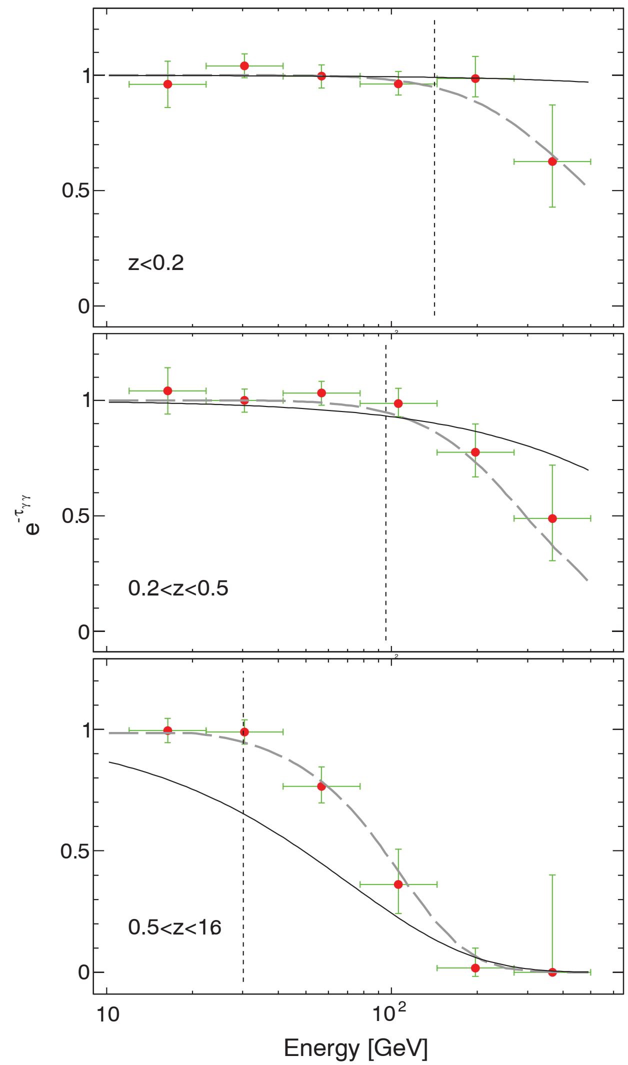
Model[a]	Significance of b=1 Rejection[e]
Stecker et al. (2006) – fast evolution	17.1
Stecker et al. (2006) – baseline	15.1
Kneiske et al. (2004) – high UV	5.9
Kneiske et al. (2004) – best fit	3.2
Gilmore et al. (2012) – fiducial	1.9
Primack et al. (2005)	1.2
Dominguez et al. (2011)	1.1
Finke et al. (2010) – model C	1.0
Franceschini et al. (2008)	0.9
Gilmore et al. (2012) – fixed	0.7
Kneiske & Dole (2010)	0.6
Gilmore et al. (2009) – fiducial	0.6

Rejected > 5σ (17.1, 15.1, 5.9)

Allowed (1.9 – 0.6)

Ackermann et al. (2012), Science, 338, 1190

EBL Constraints with the Fermi LAT



z < 0.2

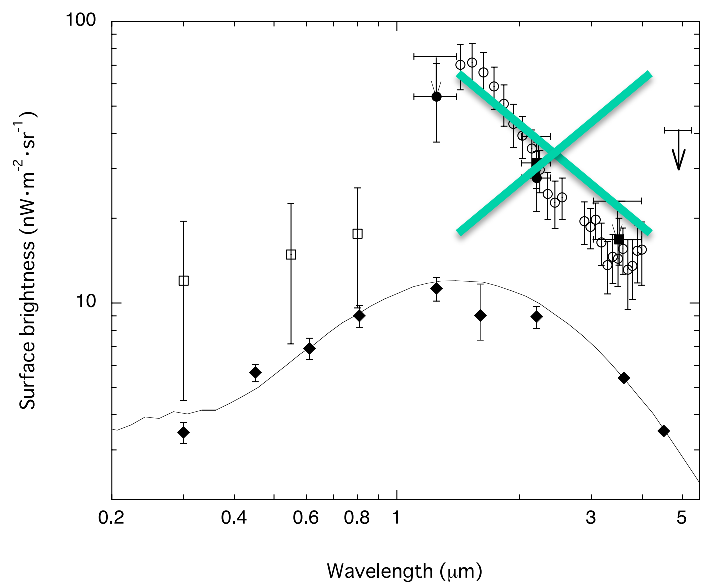
0.2 < z < 0.5

0.5 < z< 1.6

Ackermann et al. (2012), Science, 338, 1190

Absorption by EBL has been detected!

There does not seem to be any room for Pop 3 stars as claimed by Matsumoto et al. (2005).



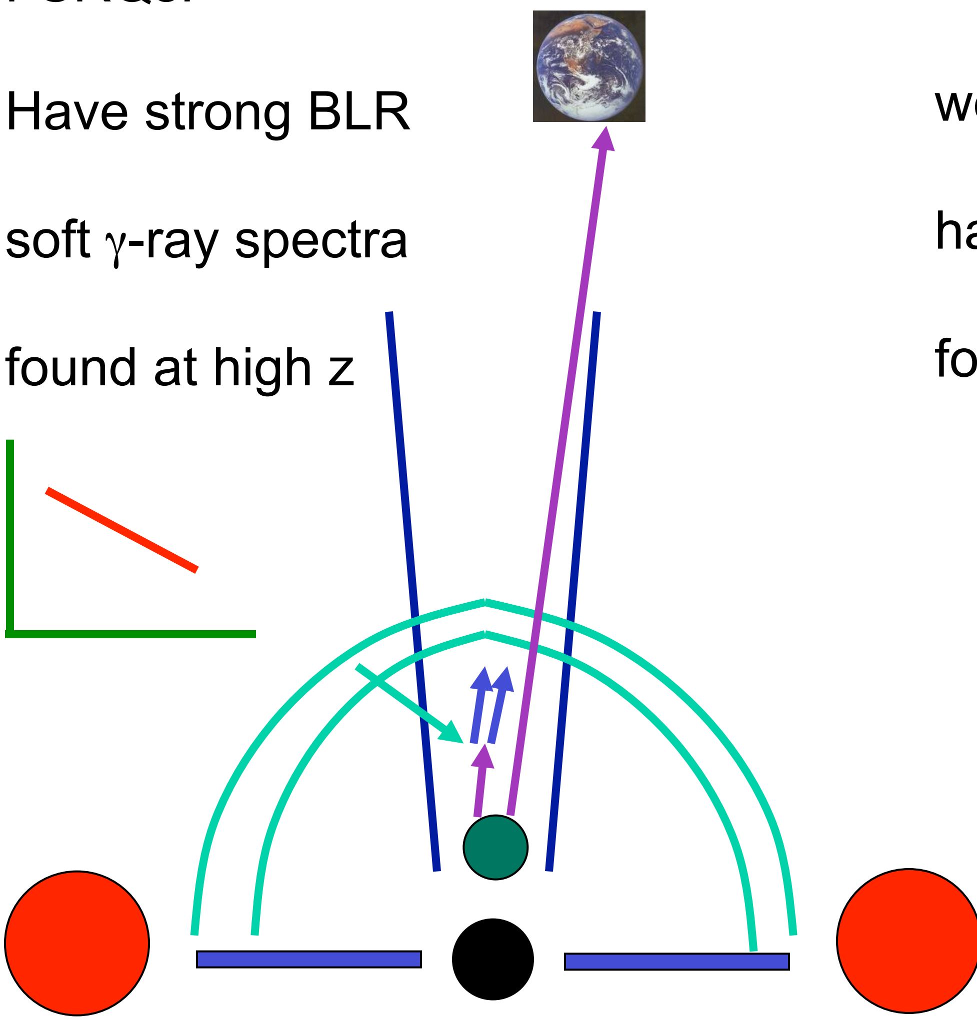
Blazar sources

FSRQs:

Have strong BLR

soft γ-ray spectra

found at high z

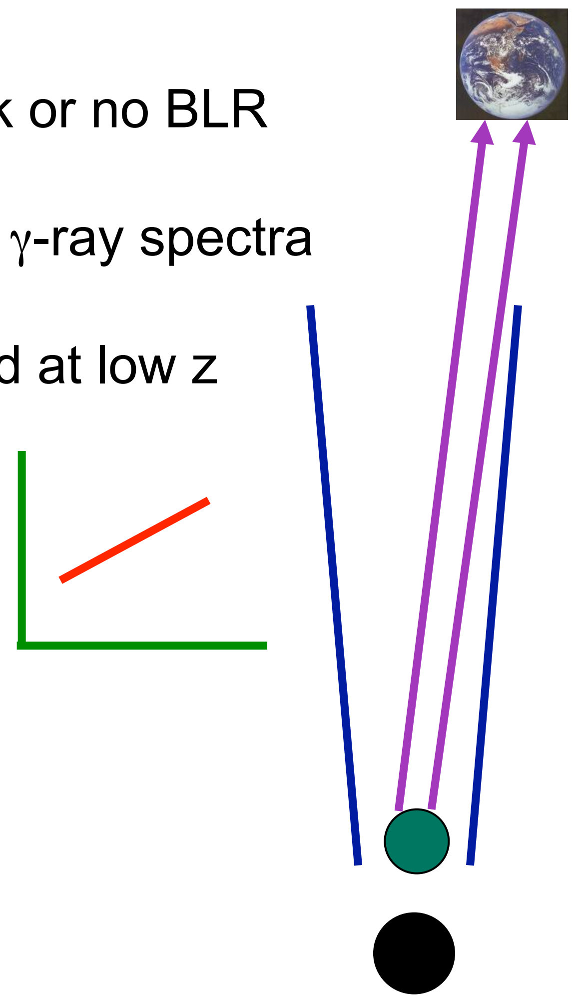


BL Lacs:

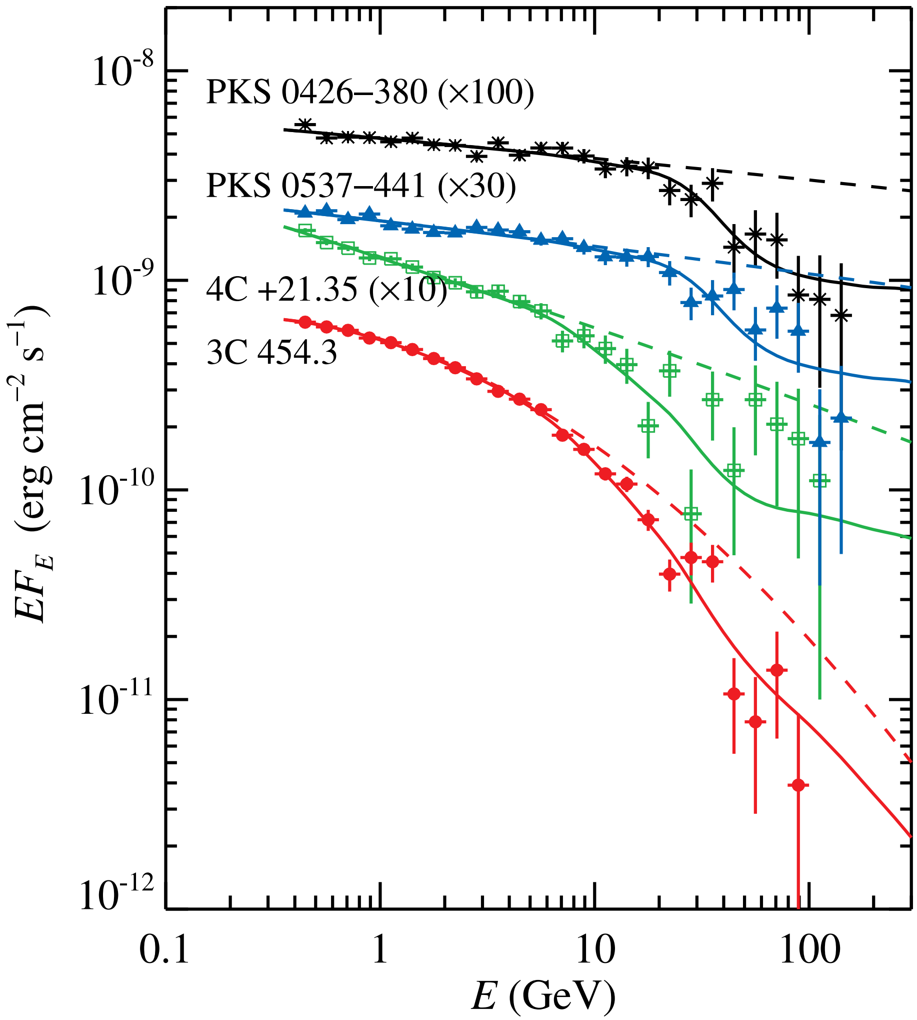
weak or no BLR

hard γ-ray spectra

found at low z



EBL Constraints with the Fermi LAT



Stern & Poutanen et al. (2014), ApJ, 794, 8
(Predicted by Reimer 2007, ApJ, 665, 1023)

LAT spectra of FSRQs do seem to have absorption feature from Lyα.

This existence of this feature is subtle and controversial. Modeling it hampers using FSRQs for studying the EBL.

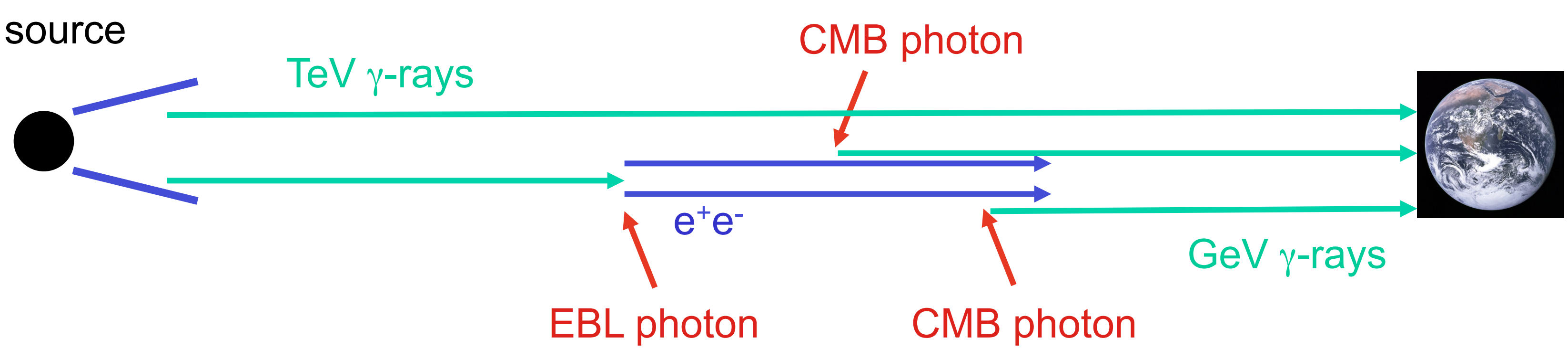
Outline

Part I: The Extragalactic Background Light (EBL)

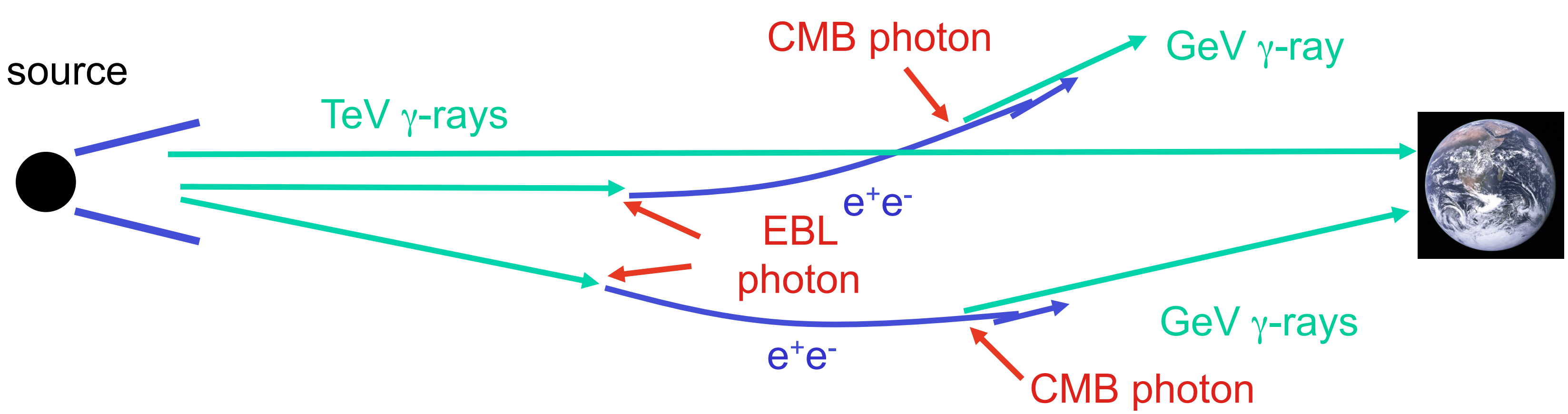
Part II: The Intergalactic Magnetic Field (IGMF)

EBL pair cascade

No Intergalactic Magnetic Field



Non-zero Intergalactic Magnetic Field



GeV γ-rays delayed due to greater distance traveled

Intergalactic Magnetic Field

Two broad categories for generating IGMF:

Astrophysical: Motion of plasma from outflows from first stars, AGN, or galaxies separates electrons and protons, which creates electric and magnetic fields.

Result: IGMF only in galaxy clusters, along filaments, or where matter is found.

Cosmological: Plasma motion in early universe, during phase transitions or era of inflation

Results: IGMF throughout universe, including in voids.

e.g., Neronov & Semikov (2009, Phys Rev D, 80, 123012)

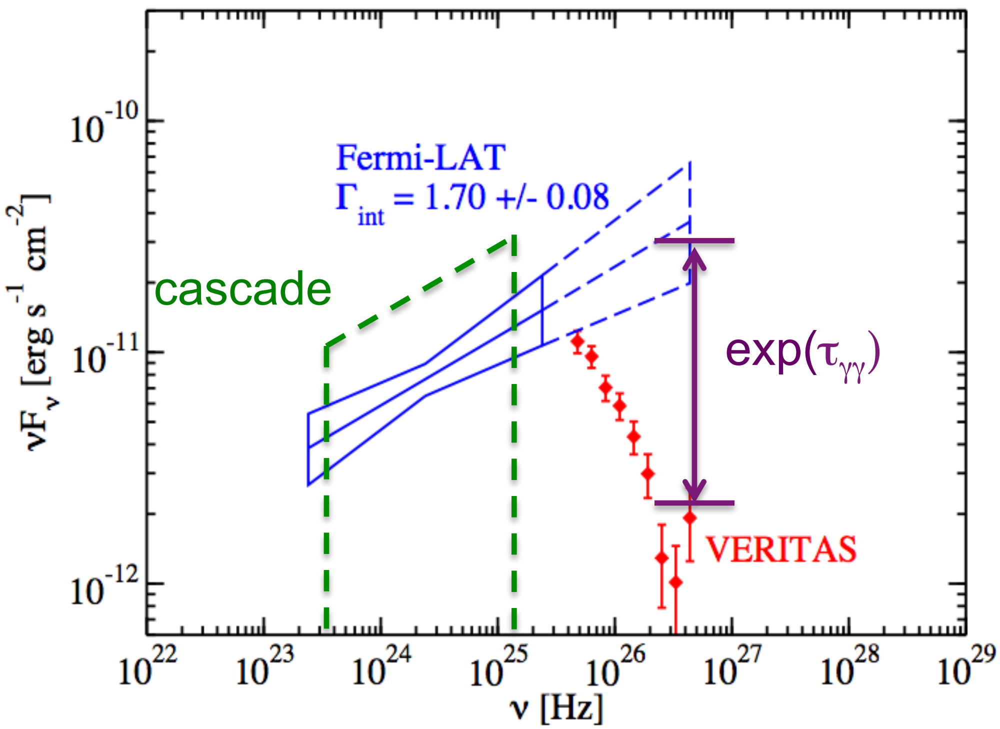
Intergalactic Magnetic Field

A number of authors have used gamma-ray observations to constrain the IGMF:

Neronov & Vovk 2010, Science, 328, 72
Tavecchio et al. (2010, MNRAS, 406, 70
Essey et al. 2011, Aph, 35, 135
Dermer et al. (2011), ApJ, 733, L21

Rule out low B fields

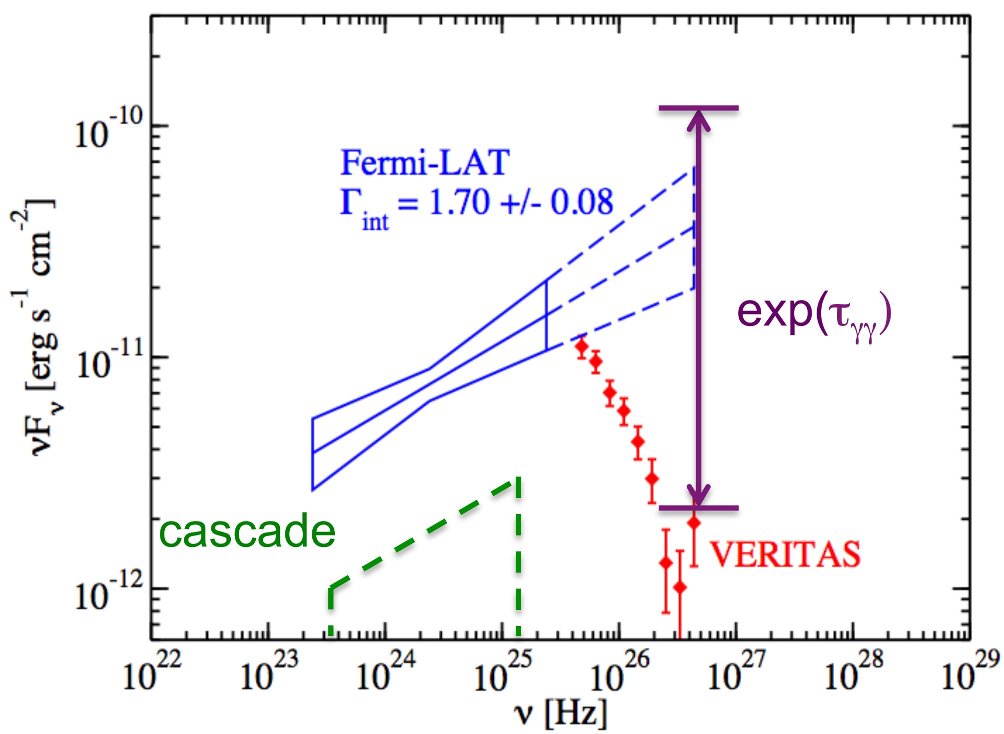
- If B-field is ***low***, cascade will be ***large***.
- Cascade can't be above observed LAT flux



Georganopoulos, JF, & Reyes (2010), ApJ, 714, 157

Rule out High B fields

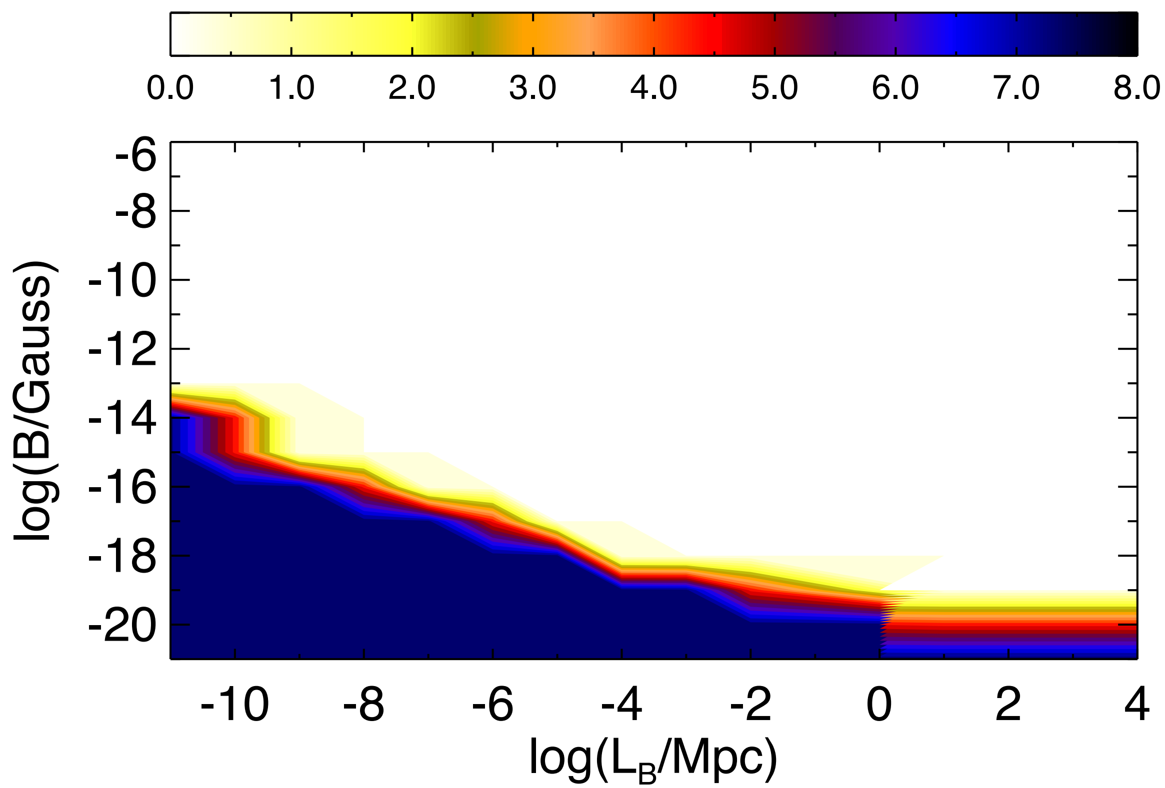
- If B-field is ***high***, cascade will be ***small***.
- If deabsorbed TeV points are above extrapolated LAT spectrum, the model is ruled out ***unless*** the cascade is significant fraction of the LAT flux.



Georganopoulos, JF, & Reyes (2010), ApJ, 714, 157

Cascade Calculation

- Combined results for 5 sources
- Conservative results: assumes sources have been creating TeV γ-rays for 3 years
- Use Finke et al. (2010) EBL model
- Low ***B*** ruled out at 7.1σ
- High ***B*** not ruled out



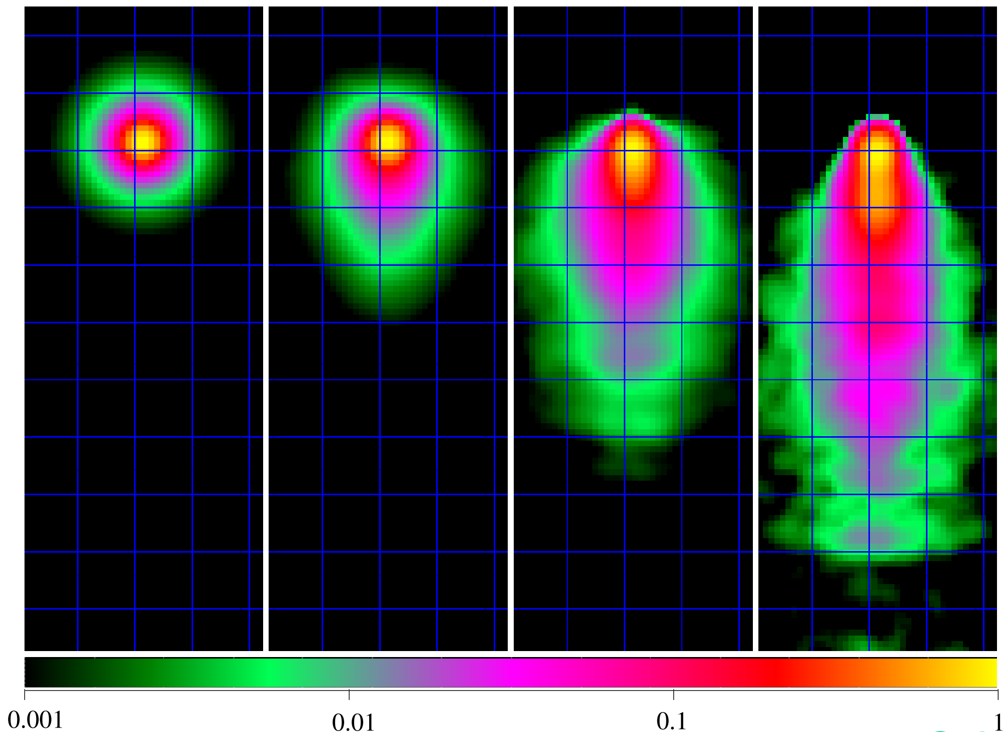
JF et al. (2015), ApJ, 814, 20

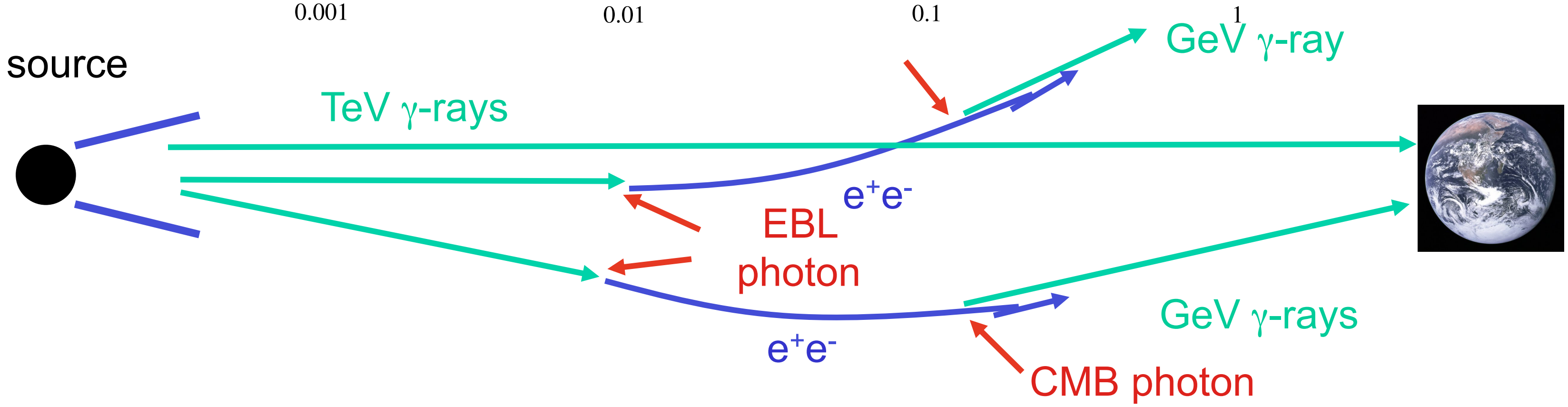
Implications

IGMF filling factor > 60% (Dolag et al. 2011)

Cosmological models for IGMF generation favored over astrophysical models

The future: resolved halos?





Neronov et al. (2010), ApJ, 719, L130

The future: CTA

2 sites:
northern: (Canary Islands, 19 telescopes of 0.4 km^2)
southern (Chile, 100 telescopes over 4 km^2)
Construction finished ~ 2024

Summary

EBL:

- Most recent EBL models give results close to EBL lower limits from galaxy counts.

- High opacity models (Stecker et al. 2006 models) ruled out at high redshifts from the UV EBL (high mass stars) by the Fermi-LAT (Abdo et al. 2010) and) at lower redshifts from mid-IR are with the LAT + VERITAS spectrum of 1ES 1218+304 (Georganopoulos et al. 2010).

- SED modeling gives results consistent with most EBL models that predict low opacity (Dominguez et al. 2013)

IGMF:

- Robust constraint of IGMF to B > 10^{-19} G.

- Cosmological models for IGMF generation favored over astrophysical models

Extra Slides