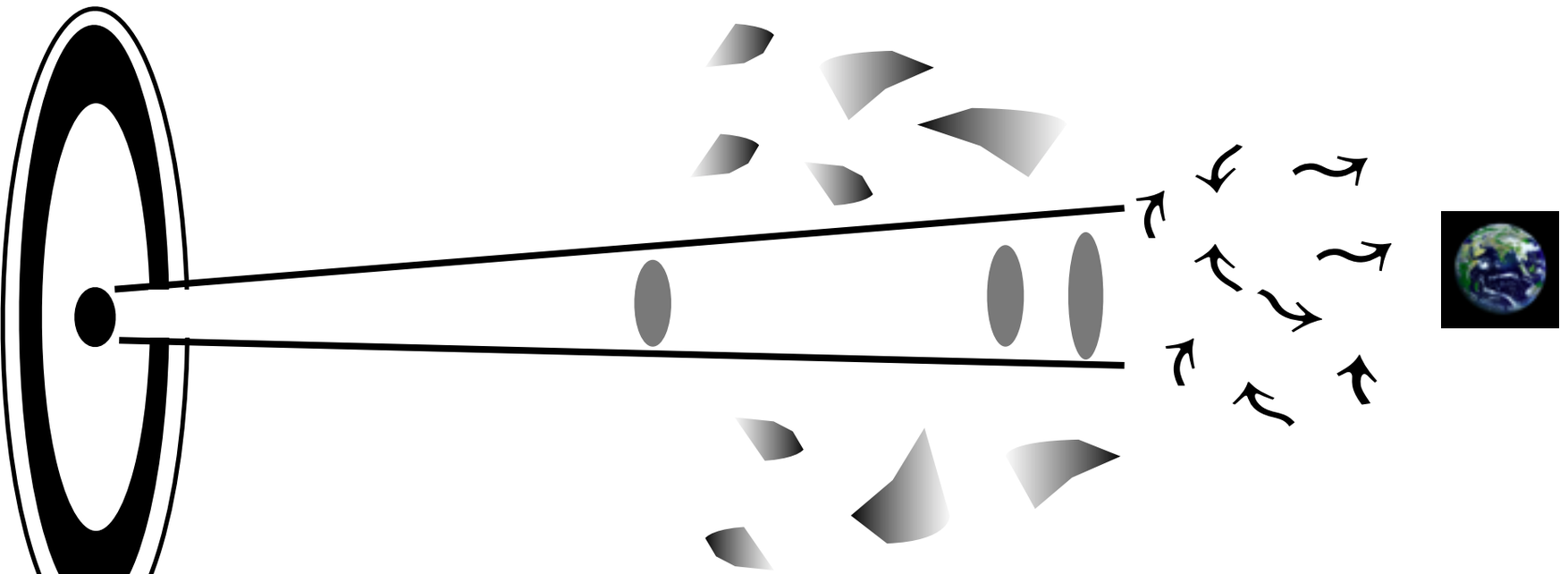
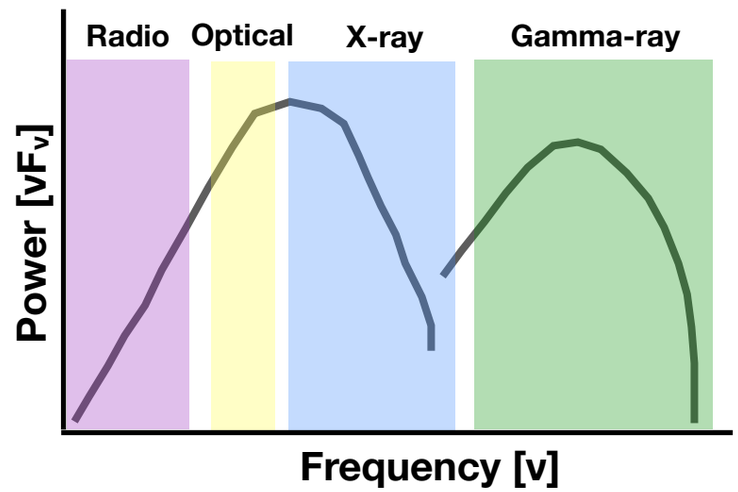
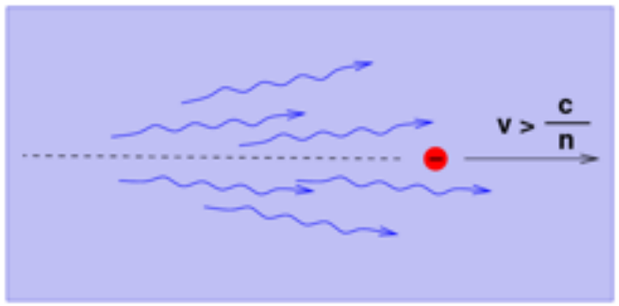
VERITAS Observations of Very High Energy Blazars and Potential for Cosmological Insight





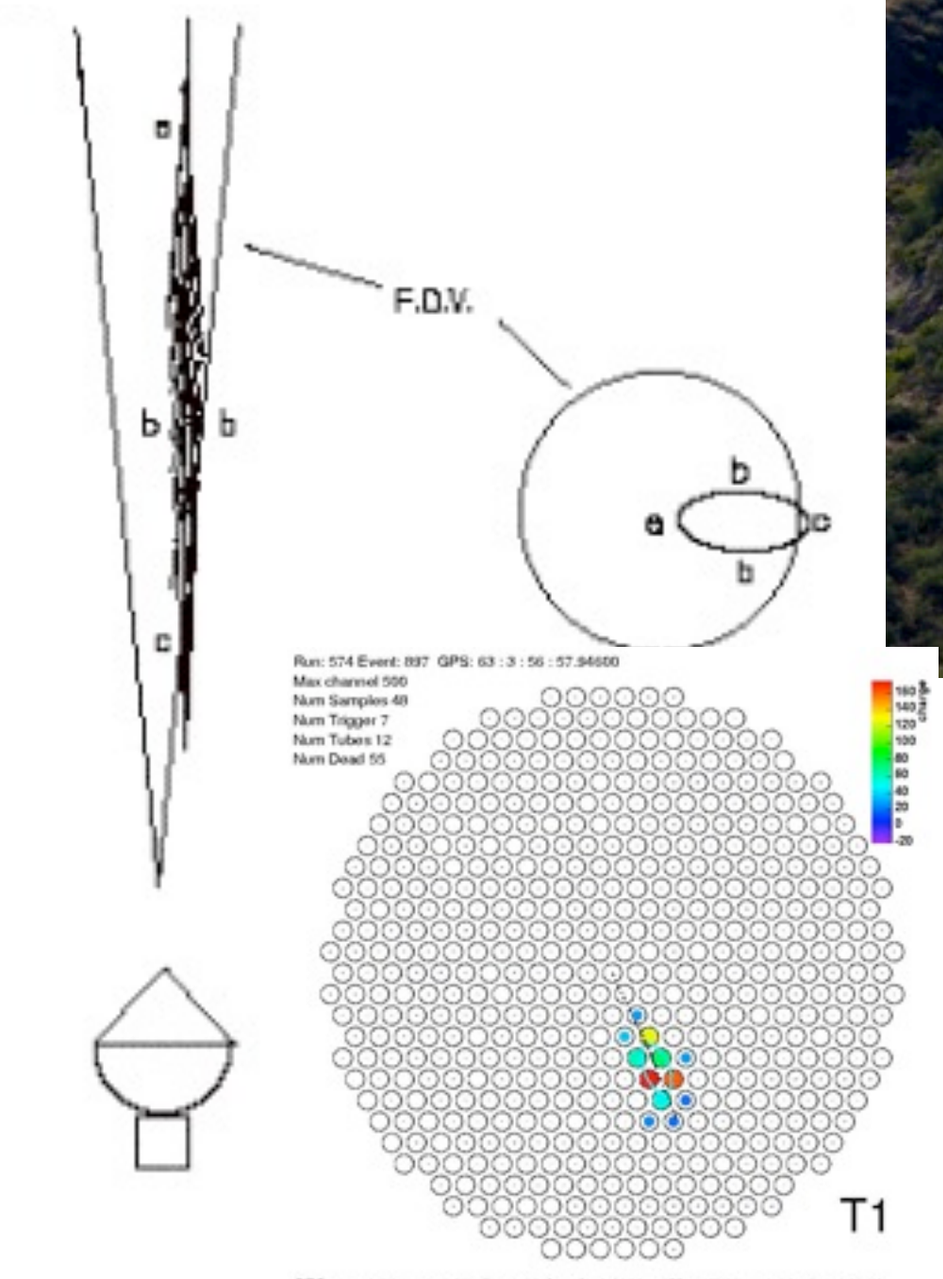
Amy Furniss for the VERITAS Collaboration

5th International Fermi Symposium
October 2014
Nagoya, Japan



VERITAS

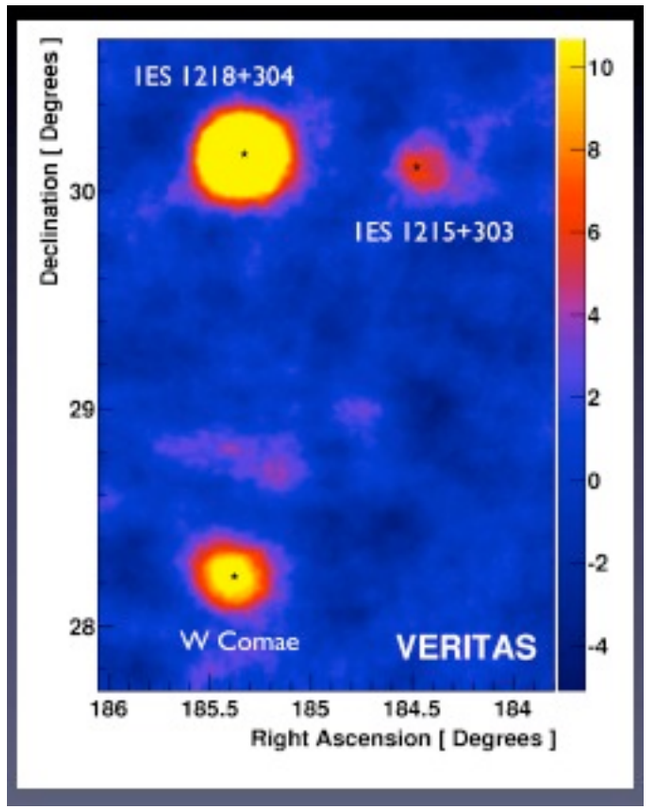
Very High Energy
γ_E>100 GeV



- **~70 GeV - 30 TeV**
- **15–20% energy resolution**
- **0.1° angular resolution**
- **Detect 1% Crab in < 30 hrs**
- **Upgrade complete: trigger (2011) and camera (2012)**

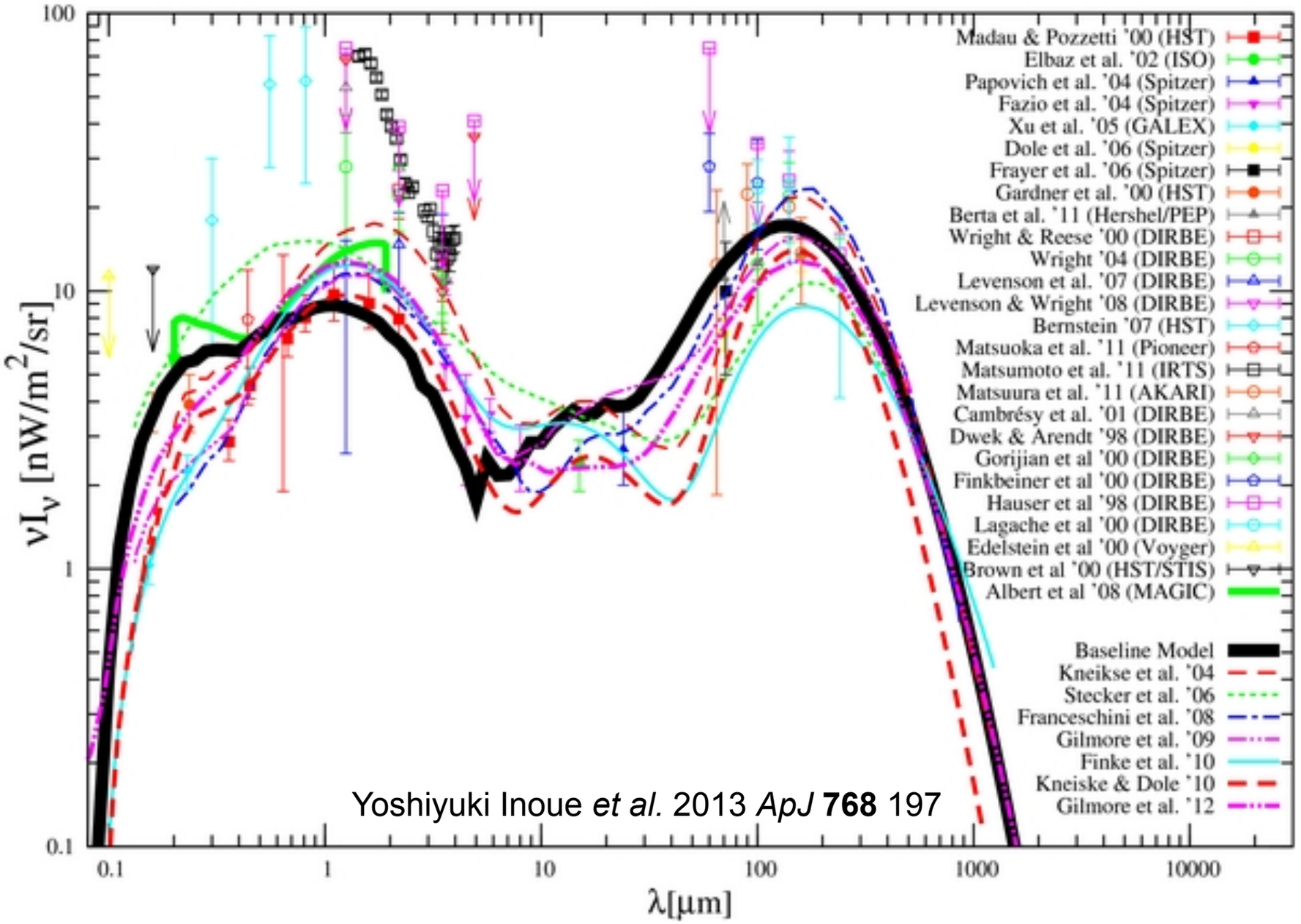
Using the VHE Blazar Catalog

- Particle Physics and Fundamental Laws
  - Particle processes at the highest energies
  - Lorentz invariance
  - Origin of ultra high energy cosmic rays
- Cosmology
  - Extragalactic background light density
  - Magnitude of the intergalactic magnetic field
- Black holes
  - Supermassive black holes
  - Jet physics
  - Evolution
  - Environment

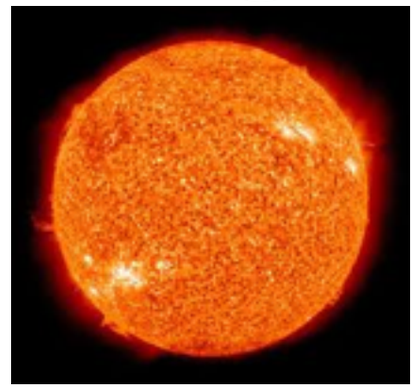


Extragalactic Background Light

The sum of the emitted and reprocessed starlight since the beginning of the Universe

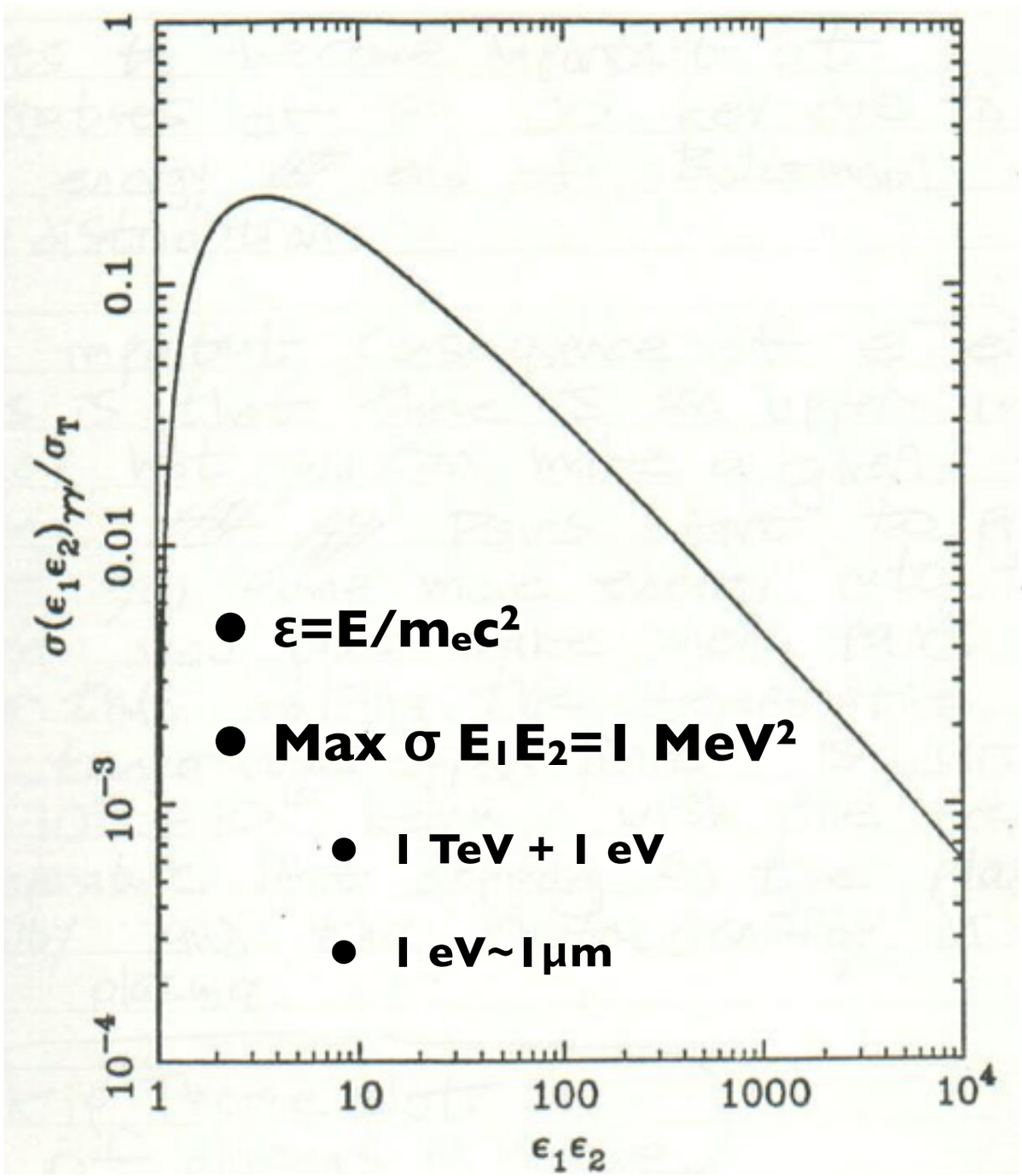


Yoshiyuki Inoue *et al.* 2013 *ApJ* **768** 197

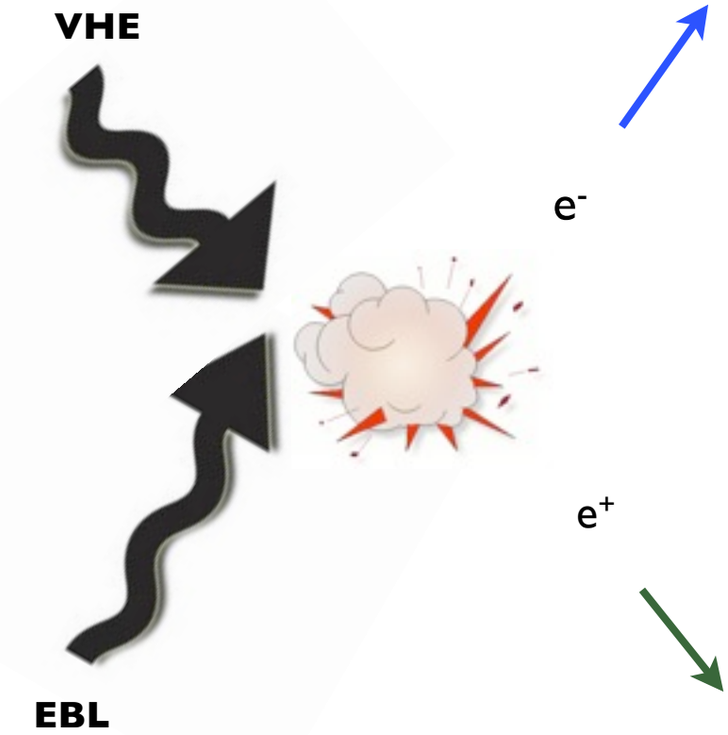


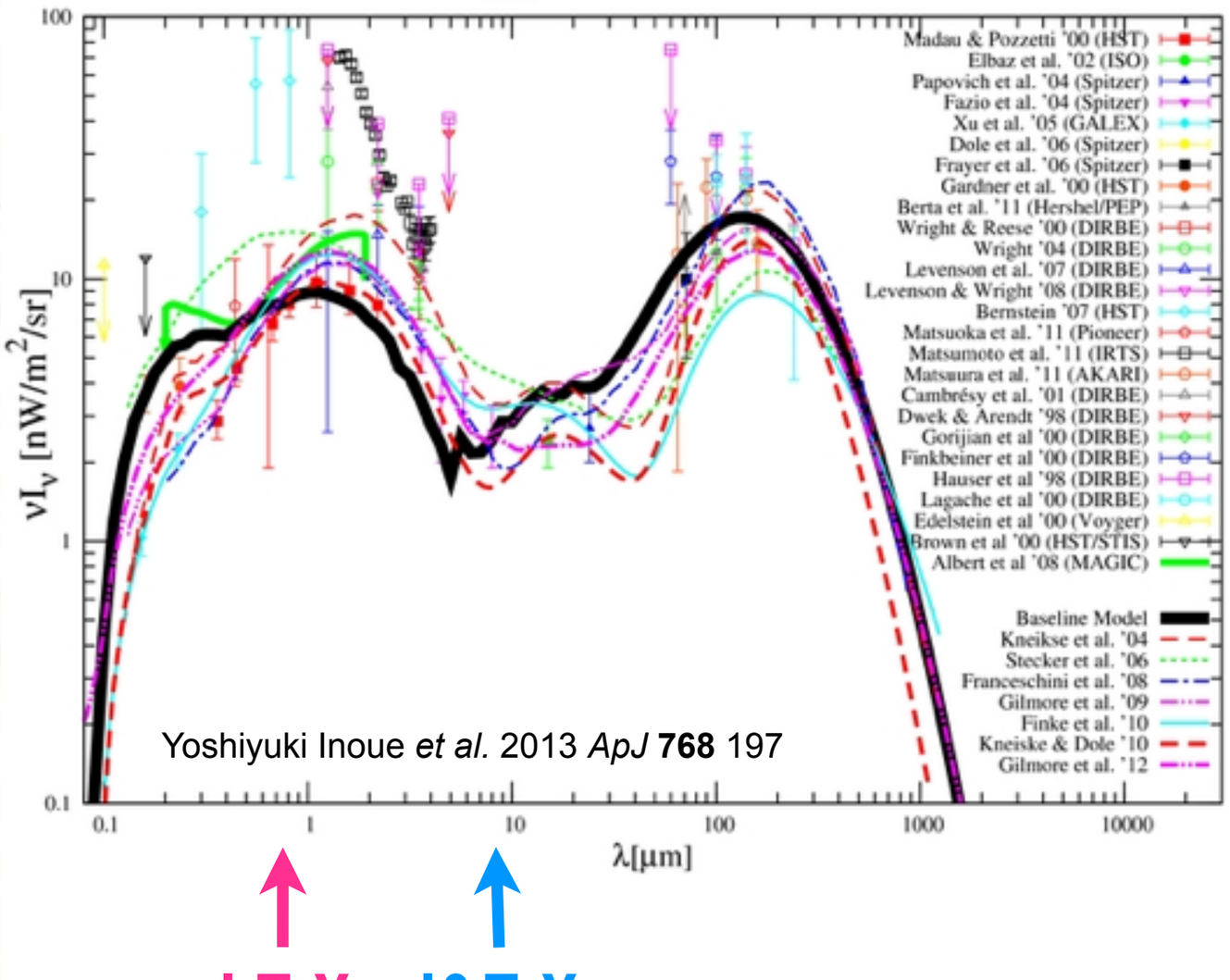
Difficult to observe directly due to strong foreground sources....

Photon-Photon Pair Production



- $\varepsilon = E/m_e c^2$
- Max σ E_1E_2=1 MeV^2
  - 1 TeV + 1 eV
  - 1 eV~1μm





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1 TeV 10 TeV

Observable Effect of VHE/ EBL Photon-Photon Pair Production

$$F_{obs} = F_{int} e^{-\tau(z,E)}$$

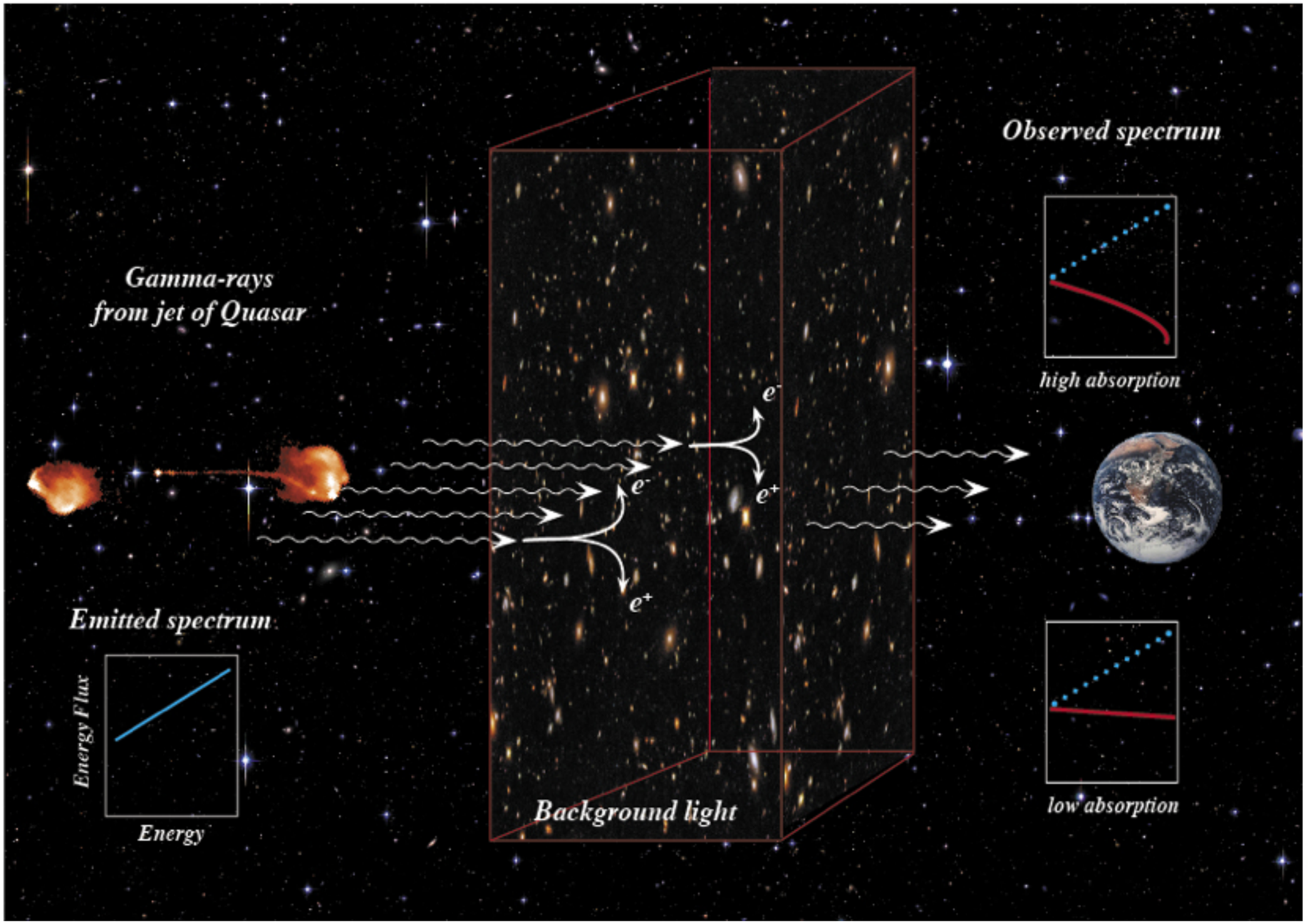
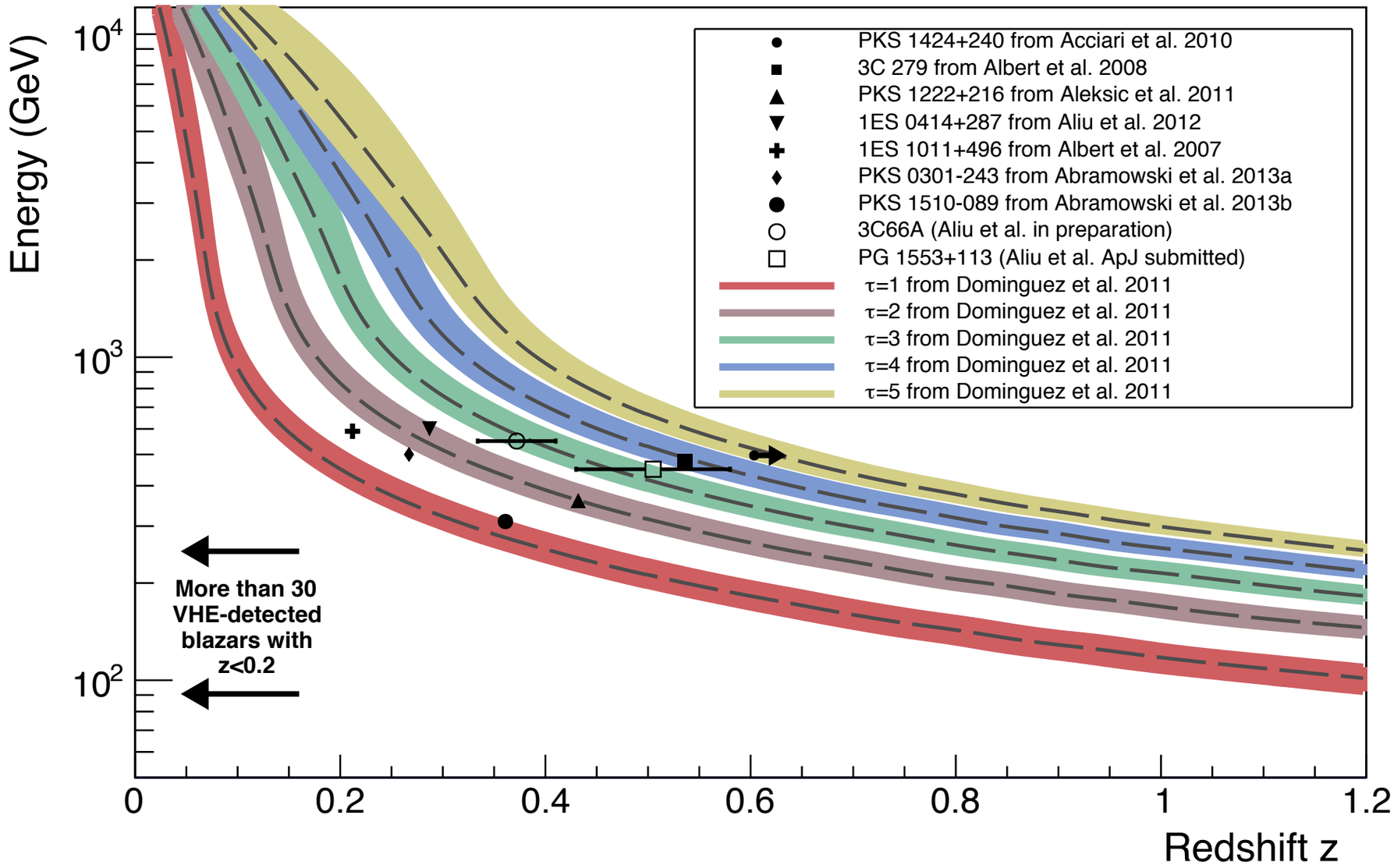


Image courtesy of cta cherenkov telescope array

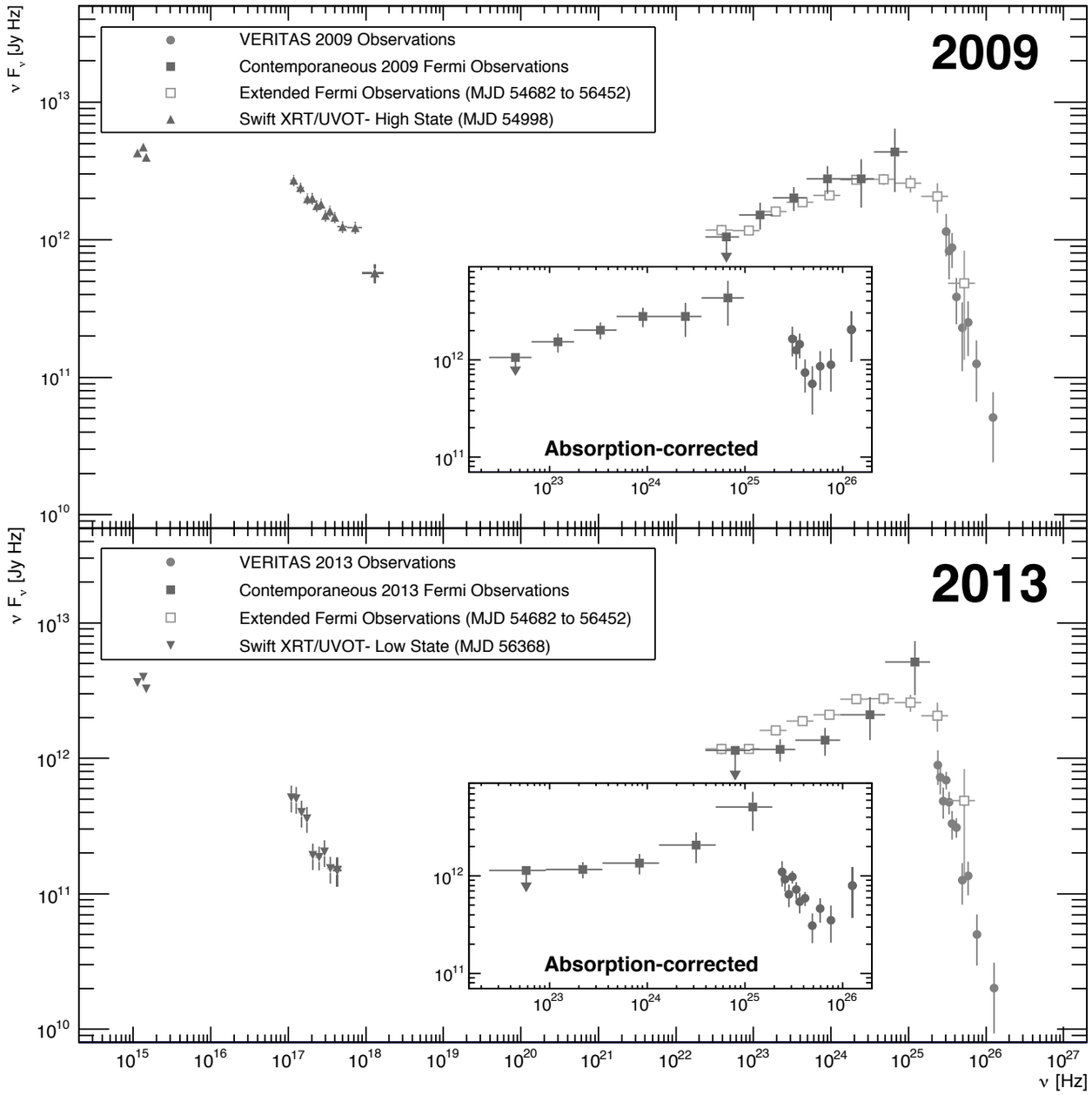
The Gamma-ray Horizon

- EBL opacity curves (Dominguez et al. 2011)
- PKS 1424+240 probes an opacity of τ>5
- 3C 66A and PG 1553+113 also pushing up in opacity
- S3 0218+35 @ z=0.944 detected by MAGIC between 100-200 GeV probes < τ~2.5



PKS 1424+240

- Blazar detected < 750 GeV @ z>0.6035
- Relative high state in 2009, low state in 2013
- Flux is lower in 2013 by about a factor of 2
- Both absorption-corrected spectra show low-significance indication of hardening at high energy
- Inconclusive whether the high energy (>310 GeV flux) is variable, (5.6±3.6) vs. (3.6±1.8) x 10^{-9} m^{-2} s^{-1}
- Lower state in 2014 as compared to 2013 - analysis ongoing

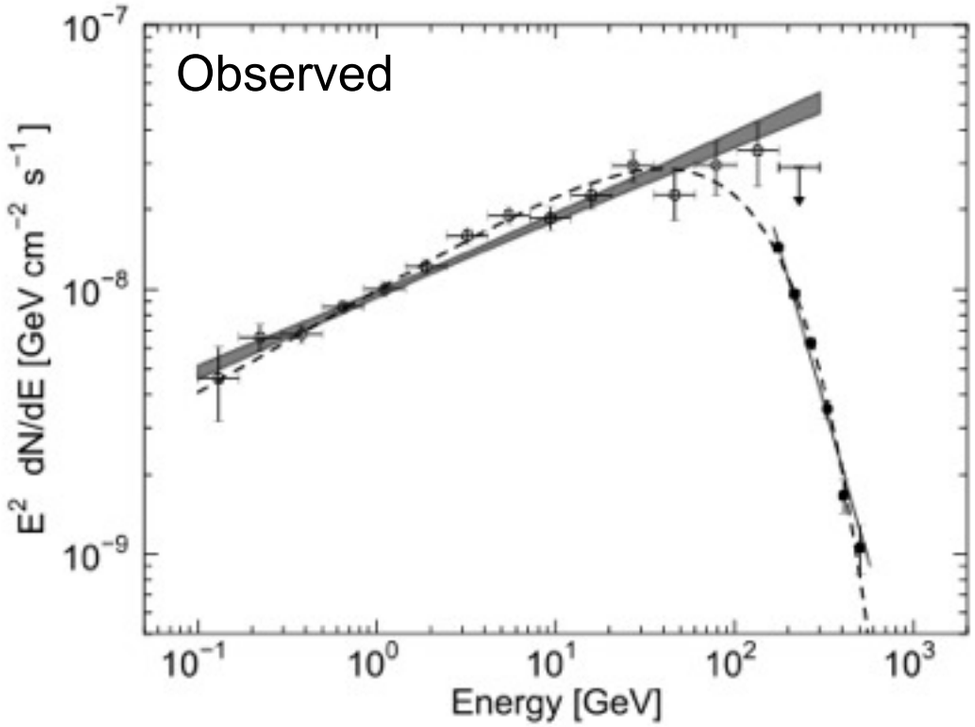


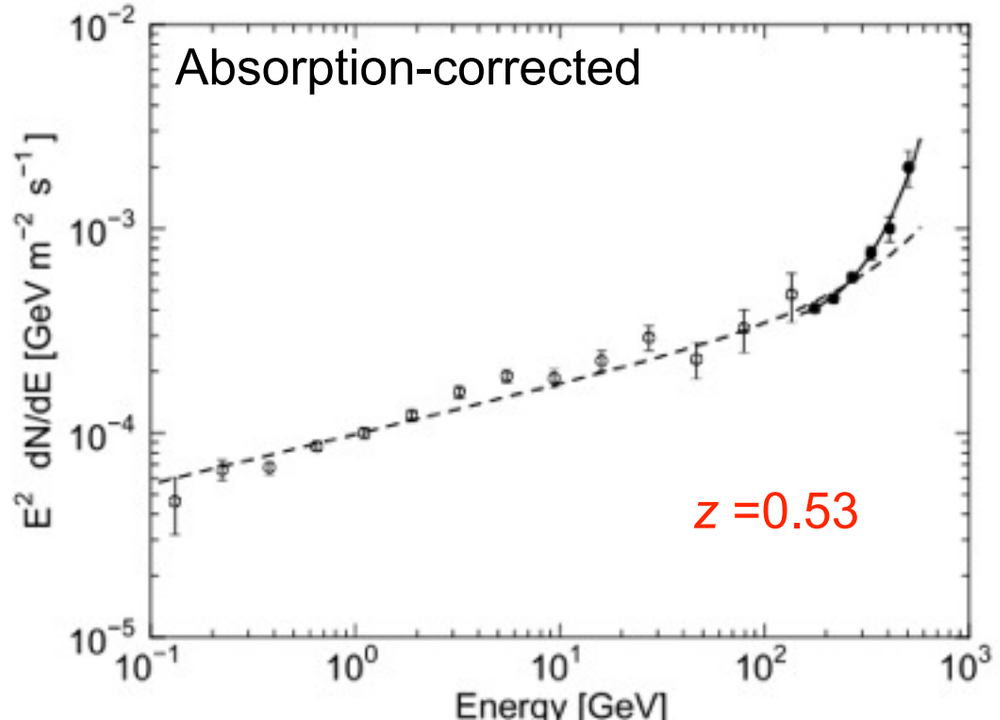
Figures from S. Archambault et al. 2014 (VERITAS Collaboration), ApJL 785, L16

PG 1553+113

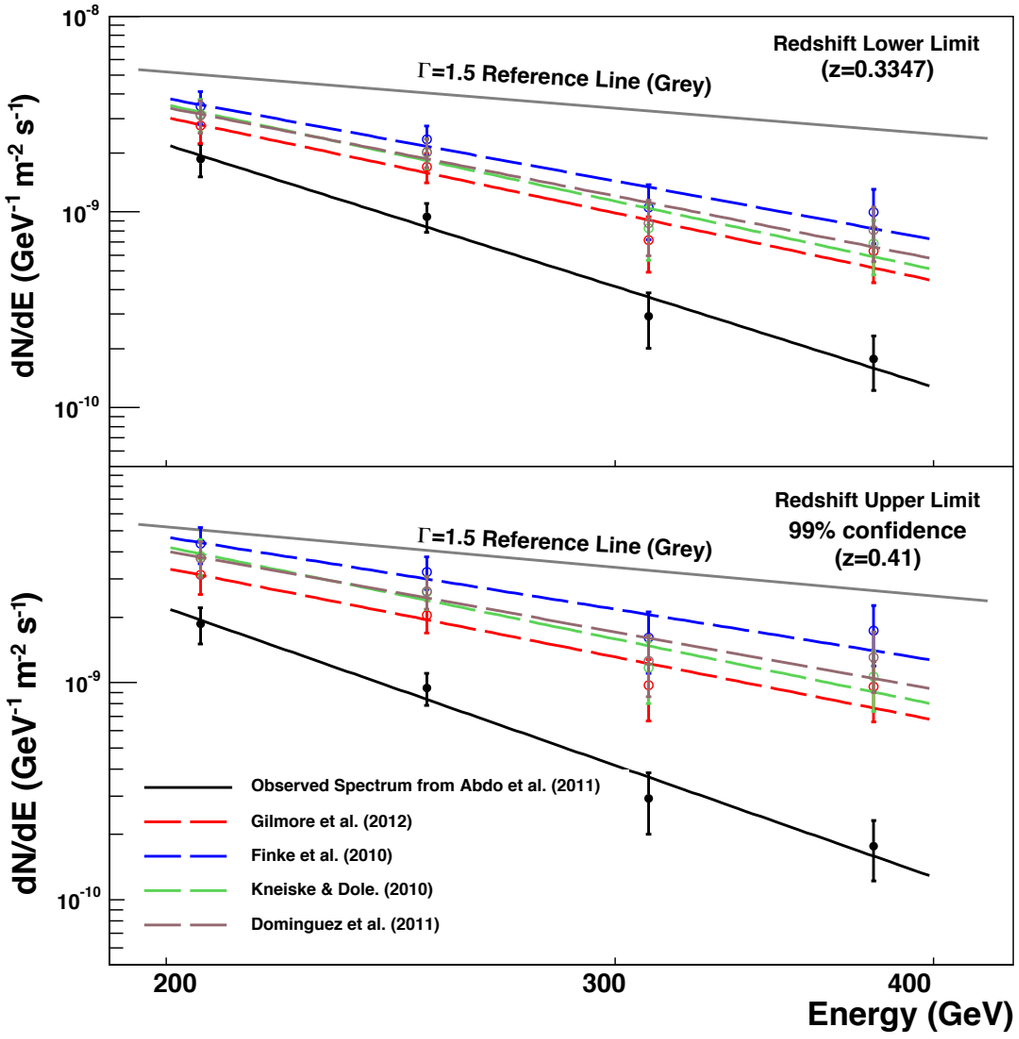
- Blazar detected between 160 and 560 GeV
- 0.395 ≤ *z* < ~0.58 from far UV observations
- 80 Hours of data from May 2010 to June 2012 show steady emission
- 7% Crab
- Place limits on the EBL or z assuming intrinsic emission does not show spectral hardening

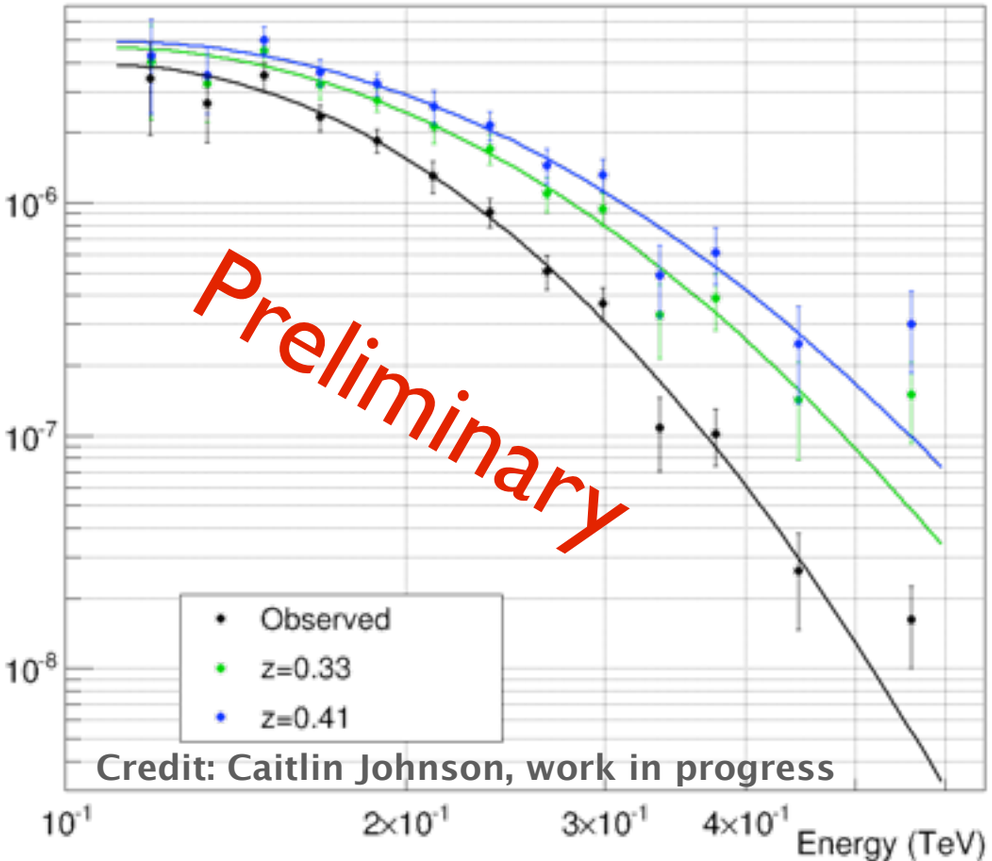
E. Aliu et al. (VERITAS Collaboration) ApJ accepted





3C 66A





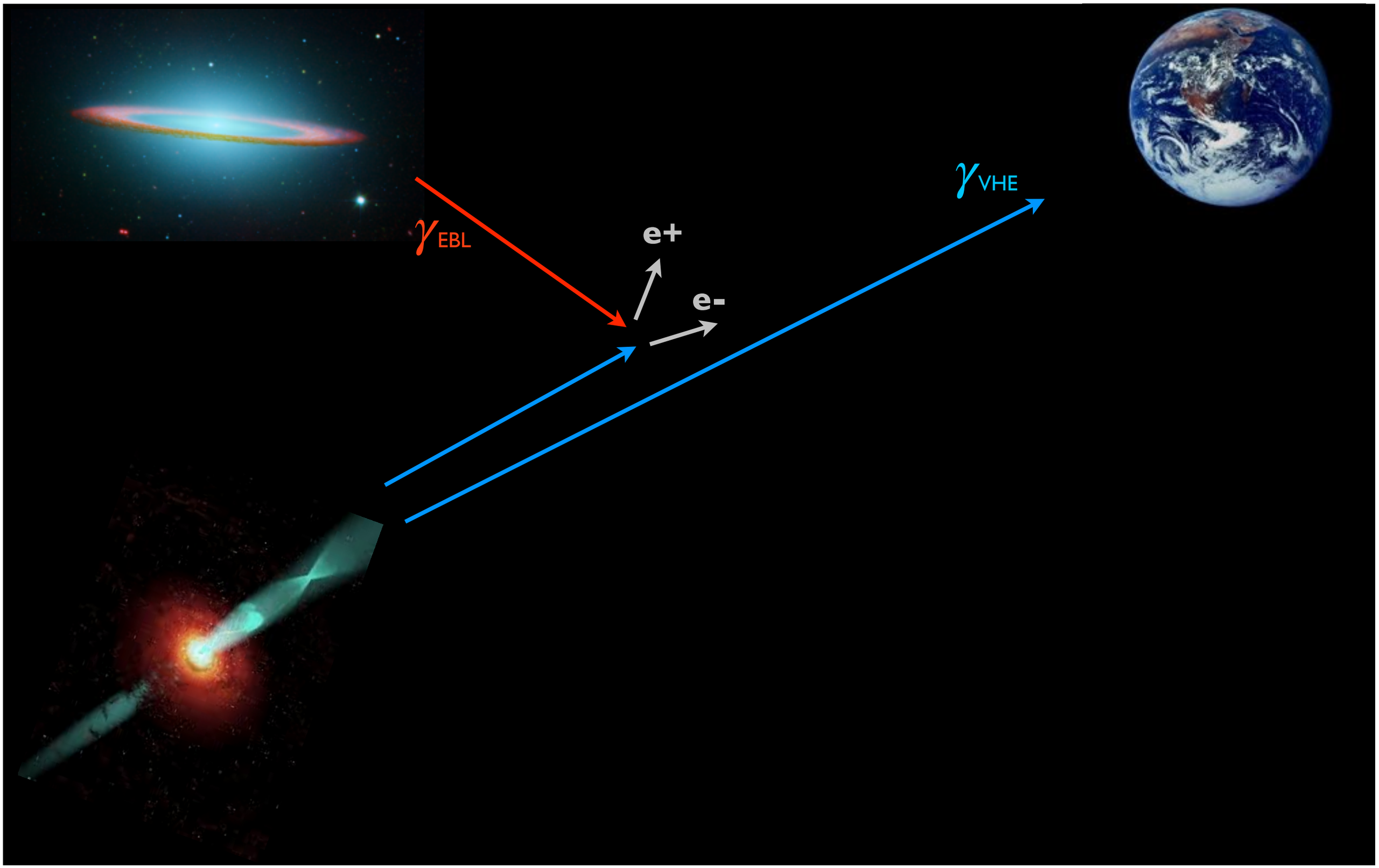
- Blazar detected to 600 GeV
- $0.33 < z < 0.41$ from far UV observations (HST)
- Flaring period in 2008 (3 nights, 6 hours of observations)
- VERITAS data from 2007–2013 (65 hours)
- Spectra absorption-corrected according to Gilmore et al., 2009 EBL model
- Continuing observations (20+ hours per year)

Possible Mechanisms for Spectral Hardening

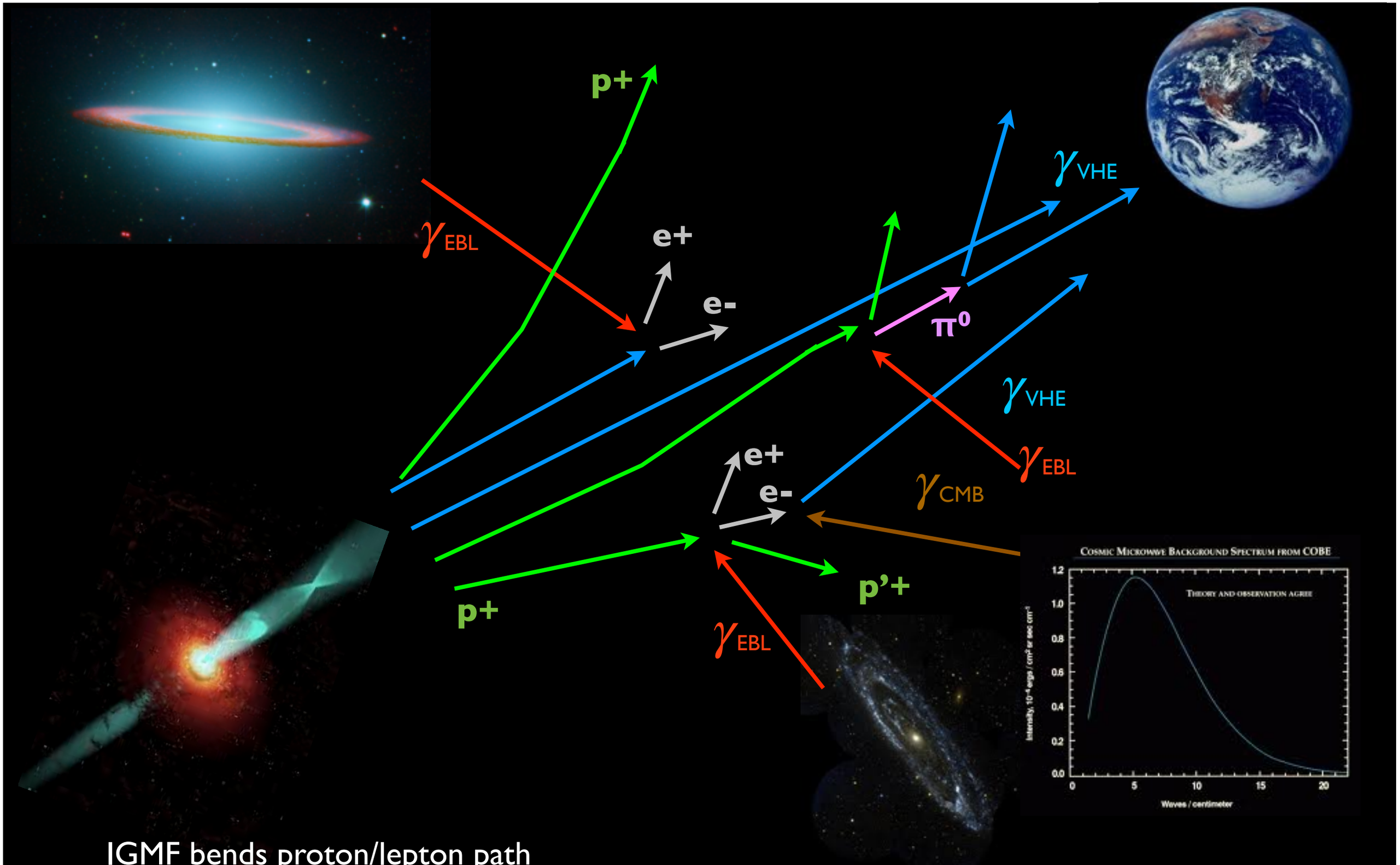
- Assumed EBL-model density, evolution or spectral shape is incorrect
- Lorentz invariance violation
- Gamma rays oscillate into axion-like particles
- Observation of secondary emission from extragalactic cosmic ray propagation

Commonly Applied Assumption

Intrinsic VHE photons+EBL



Cosmic-ray Contribution?



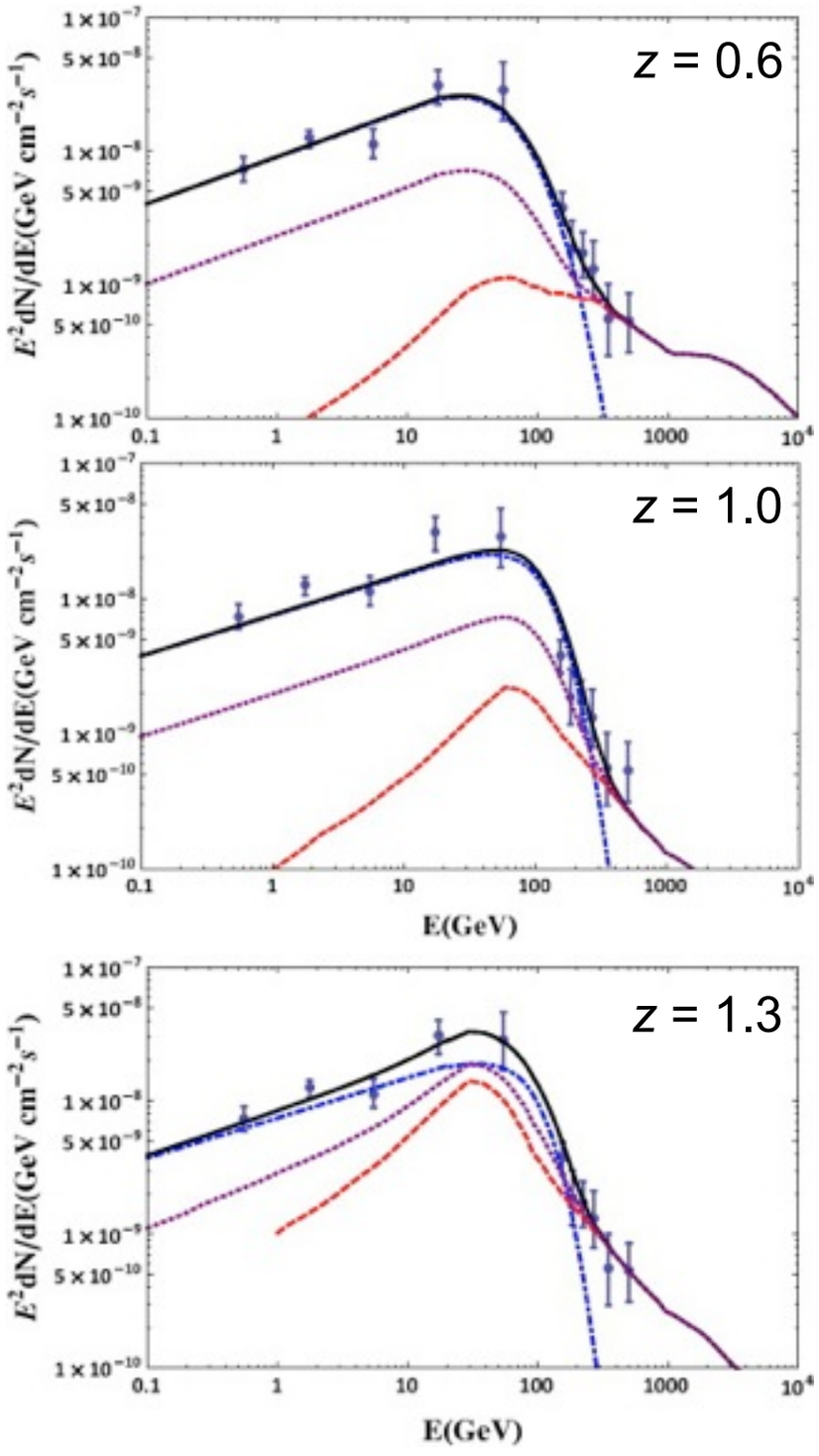
IGMF bends proton/lepton path

Take-home Message

- The very-high-energy γ-ray emission from extragalactic sources can be affected by
  - Absorption by the extragalactic background light — details depend on H_0 and star-formation history
  - Secondary γ-ray production from UHECR along line of sight
- Its a challenge to separate from intrinsic source properties from the possible secondary contributions
  - Progress can be made through use of multiple sources, improved instrument sensitivity, and deep observations
  - VERITAS blazar observation plan concentrates on sources with potential to add to this study

UHECR from PKS 1424+240?

- Assumptions:
  - Secondary gamma rays produced closer to Earth in cascades of UHECR
    - IGMF of order 10^{-15} G
- Hard secondary component should not show rapid variability



W. Essey & A. Kusenko 2014, ApP 57-58, 32.