Measurement of the Extragalactic Background Light with VERITAS

Elisa Pueschel for the VERITAS collaboration
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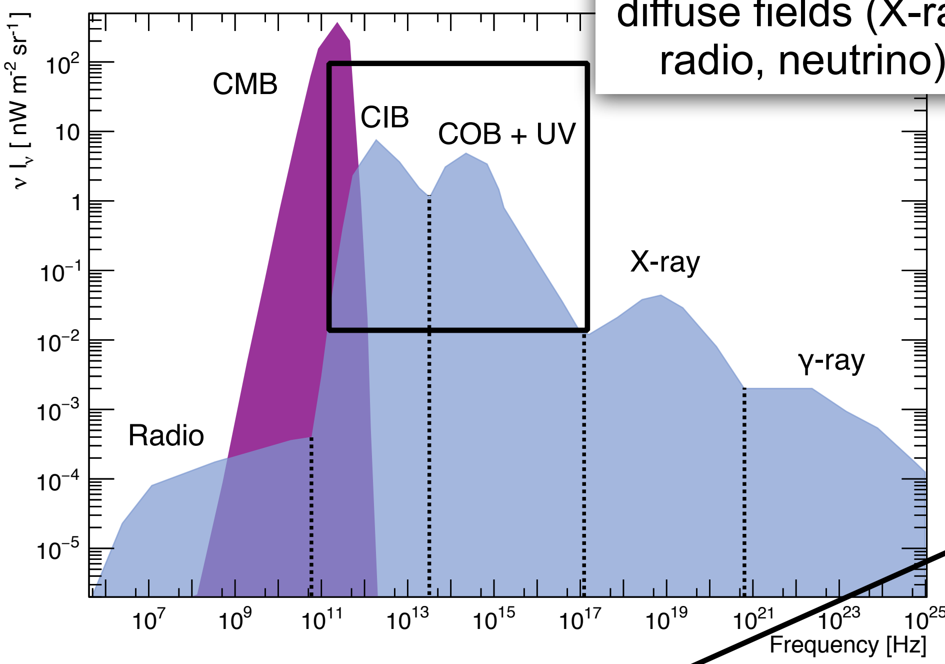
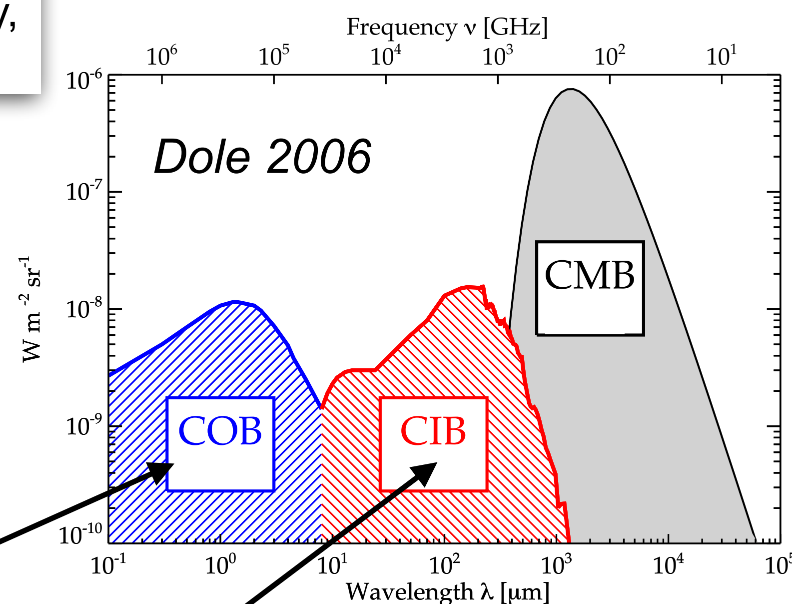
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES
HELMHOLTZ Young Investigators

Extragalactic Background Light

Light from reionization, star formation, galaxy evolution, emission by active galactic nuclei

*Connection to other diffuse fields (X-ray, radio, neutrino)



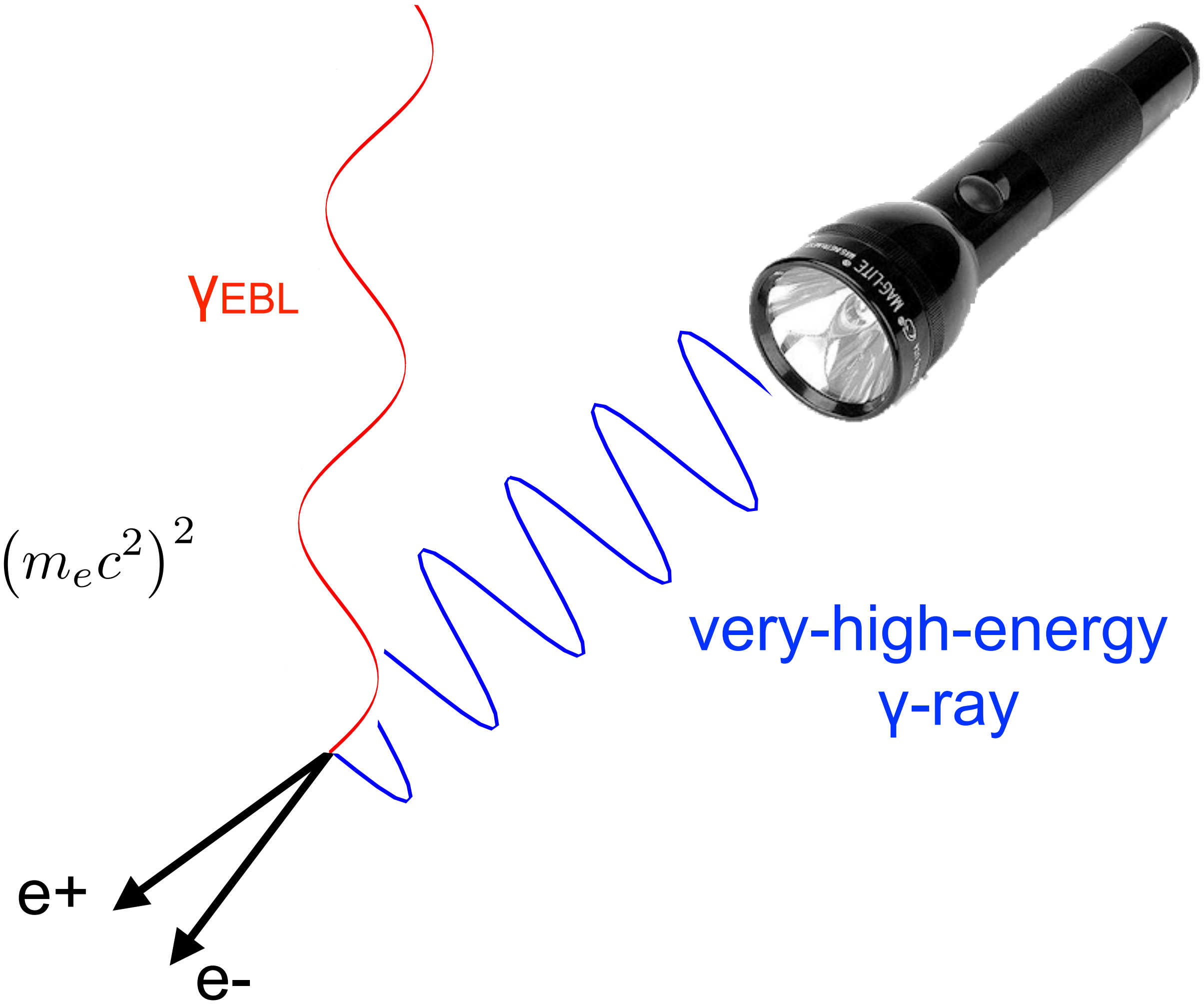


- COB = **Cosmic optical** background
- Light from stars, galaxies, etc

- CIB = **Cosmic infrared** background
- Light reprocessed by dust

Indirect Measurements of EBL with Gamma-ray Emitters

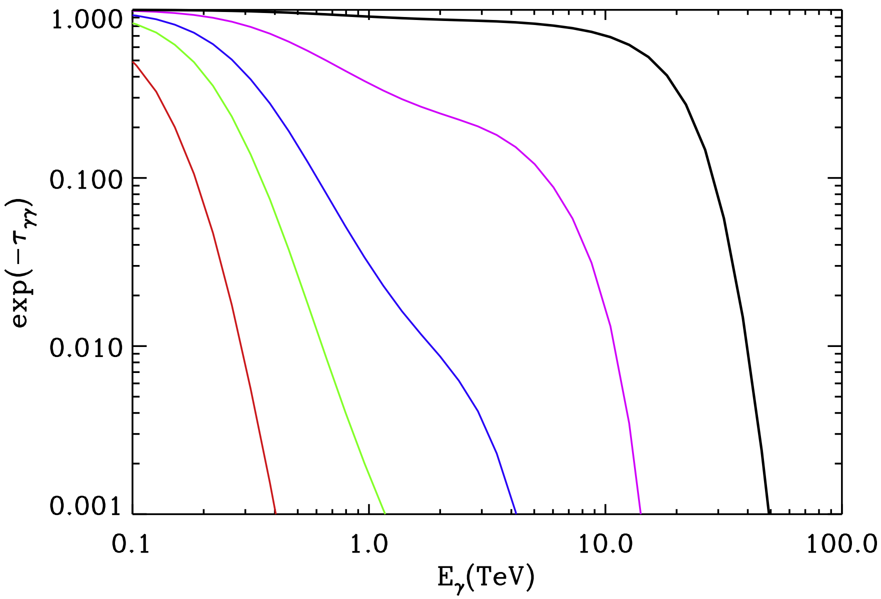
$$E'_{\gamma}\epsilon'_{\mathrm{EBL}} \geq \left(m_e c^2\right)^2$$

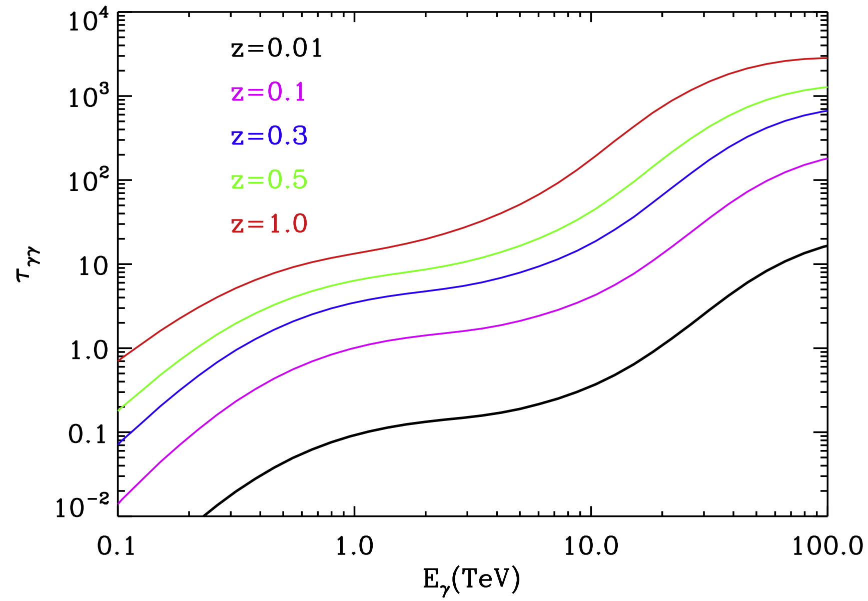


Photons from distant gamma-ray sources interact with **EBL photons** via **pair production**, VHE γ-ray flux attenuated

TeV Transparency

- Optical depth τ increases with **energy** and **redshift**
  - Depends on γγ interaction cross-section and number density of EBL photons (product integrated over distance, energy and angle)



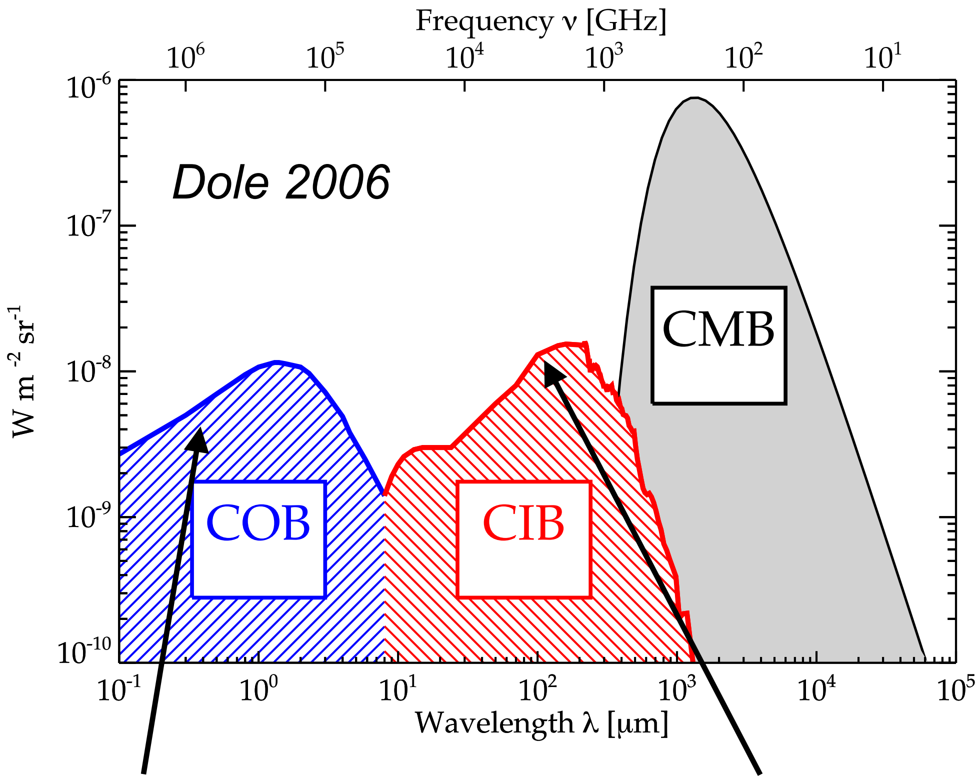


Dwek & Krennrich 2013

To probe full EBL spectrum, need gamma-ray sources emitting to **high energies**, located out to **large distances**

Probing the EBL Spectrum

$$\lambda_{\rm EBL} \simeq 0.5 - 5\,\mu{\rm m} \times \left(\frac{E_\gamma}{1\,{\rm TeV}}\right) \times (1+z)^2$$



Dominated by distant sources

Dominated by (relatively) nearby and “extreme” sources

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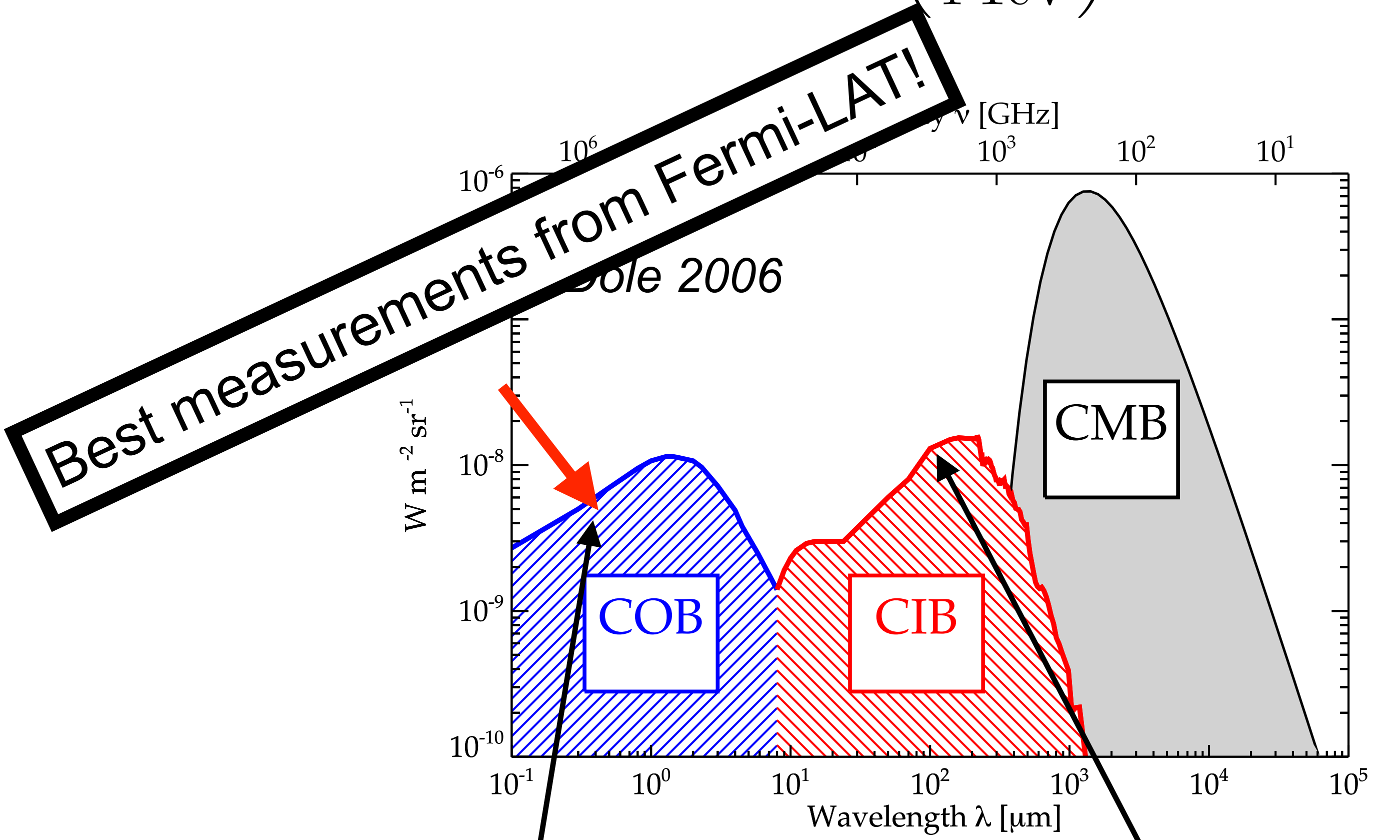
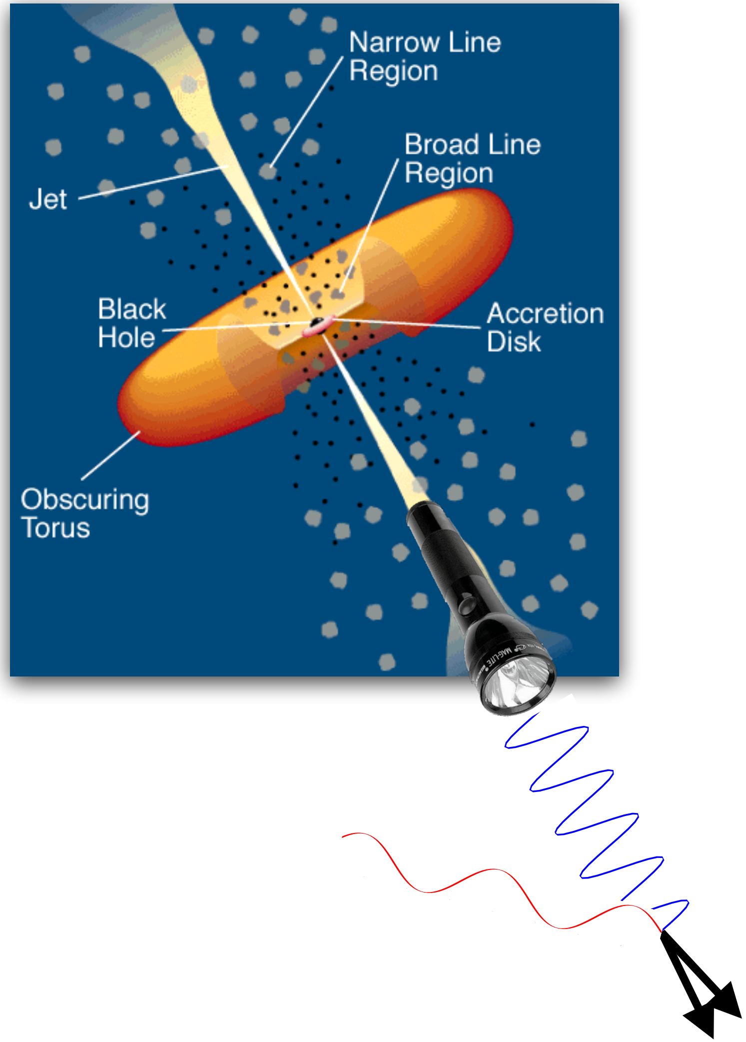


Dominated by distant sources

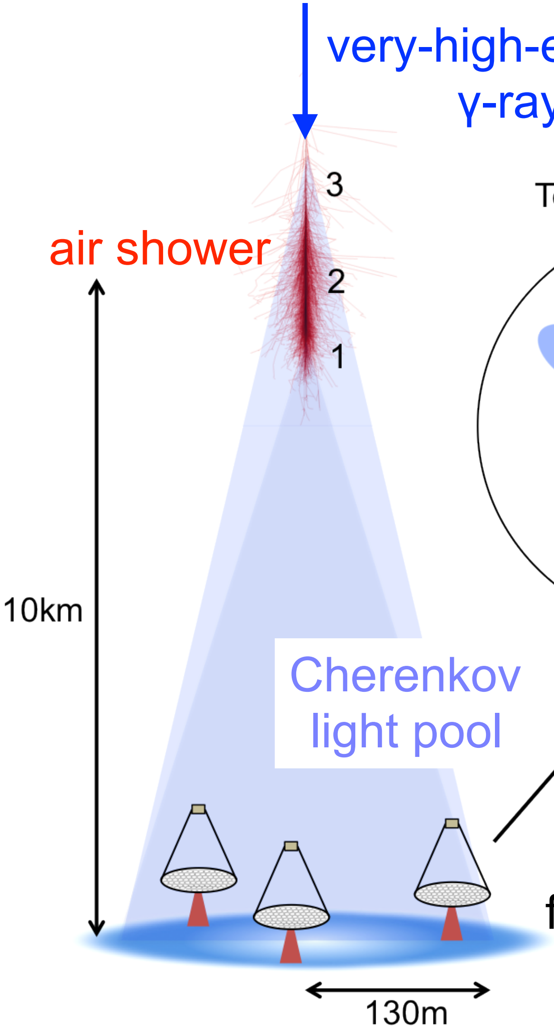
Dominated by (relatively) nearby and “extreme” sources

EBL Measurements with Blazars

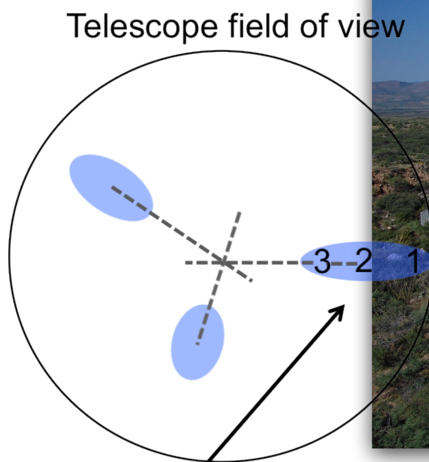


- Gamma-ray emission to > 1 TeV
- Detected to high redshifts (e.g. PKS 1424+240 @ z=0.604)
- Confounding factors
  - Intrinsic spectral curvature/cut-offs
  - Extreme flux variability, spectral variability
  - Redshift measurements

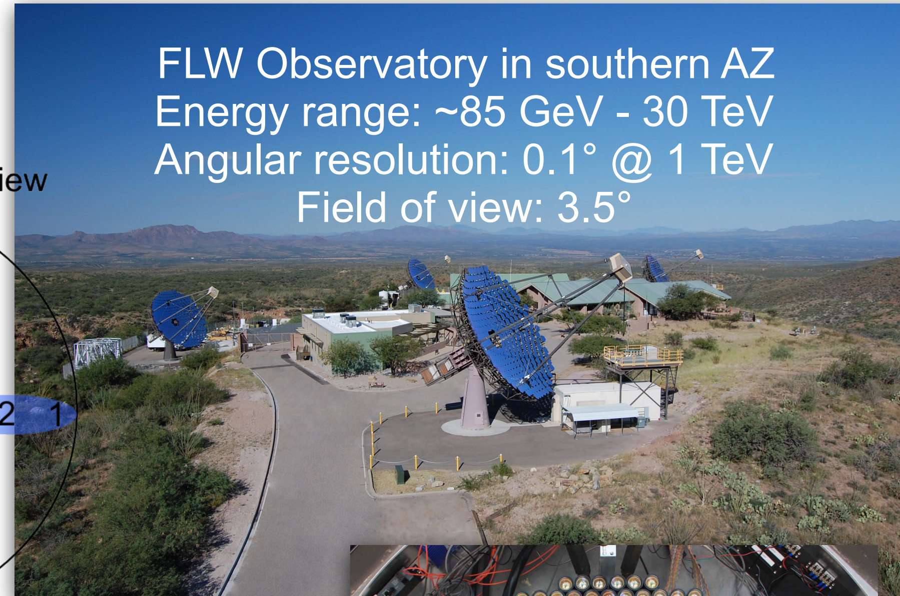
VERITAS Instrument

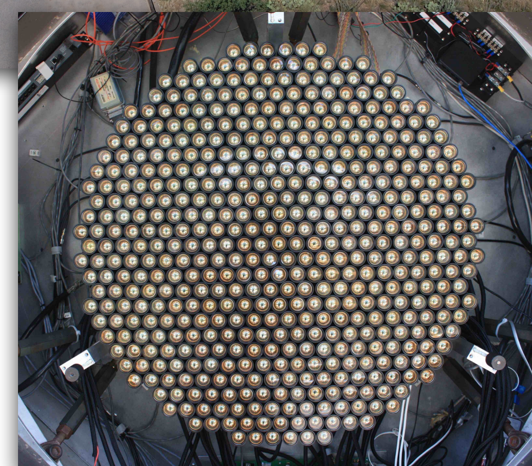


Credit: J. Holder



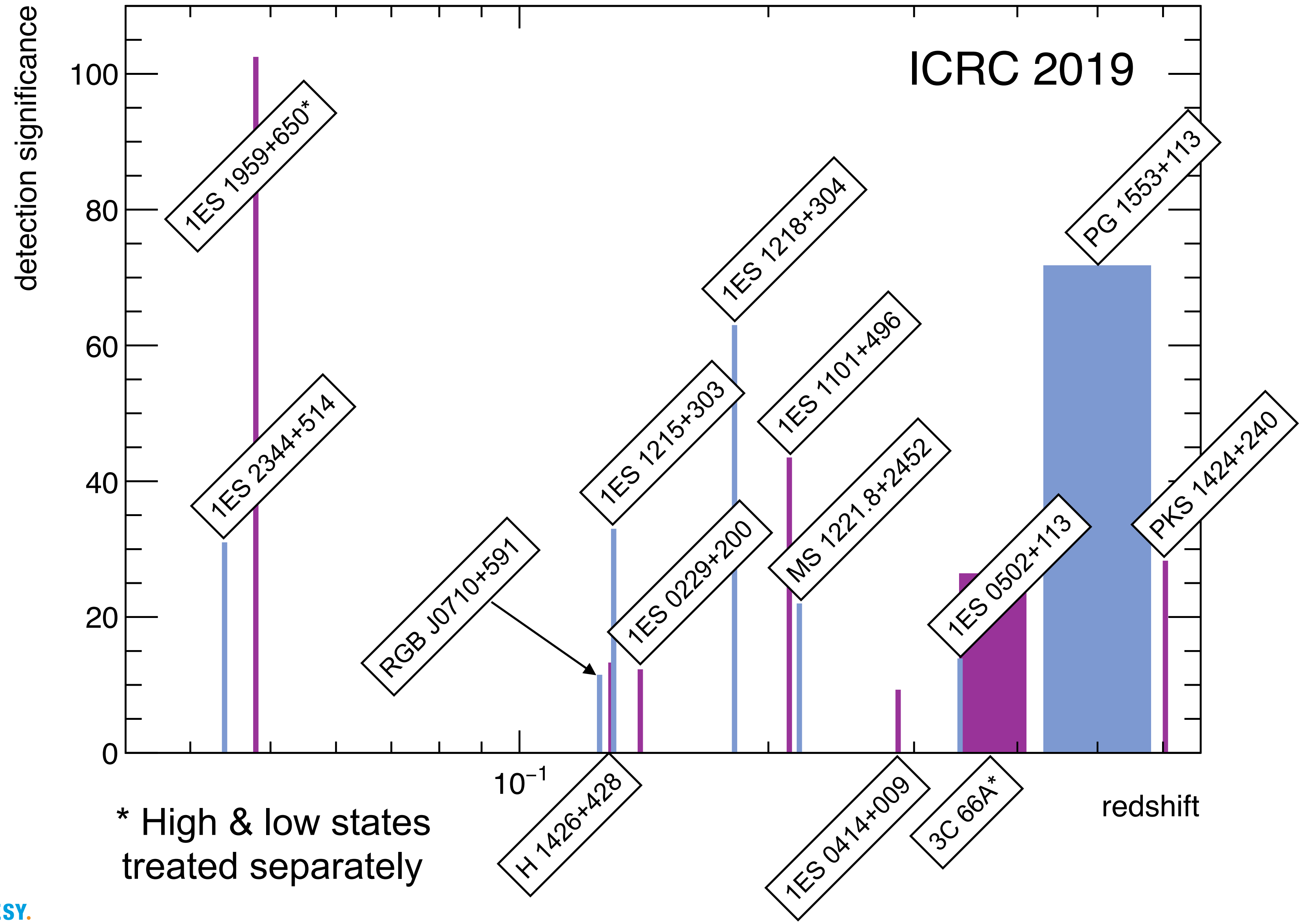
Multiple telescopes
for stereoscopic imaging





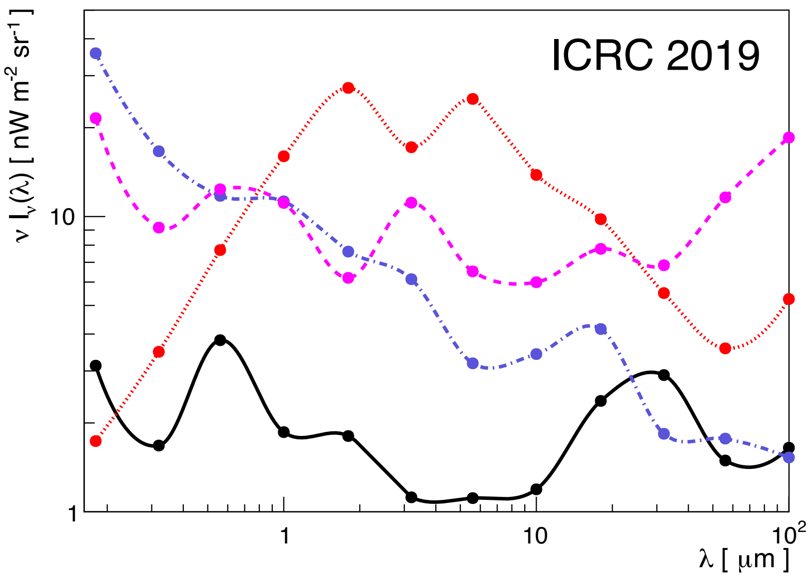
Photomultiplier tube cameras
for faint & fast signal

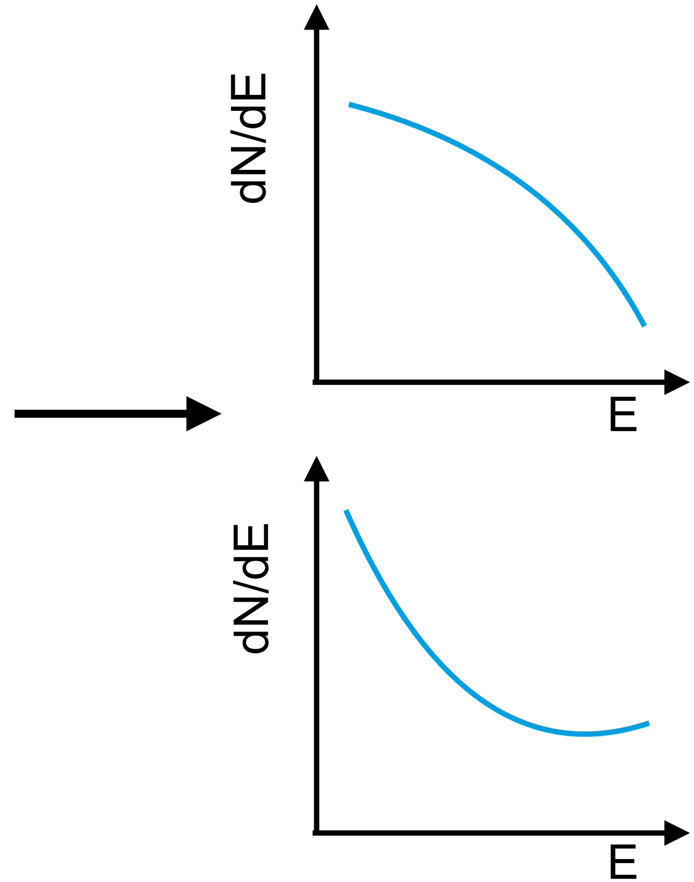
VERITAS source sample



* High & low states treated separately

VERITAS EBL Measurement



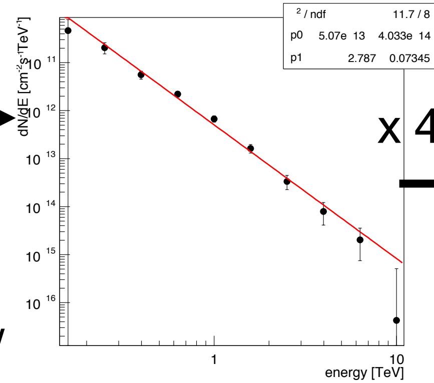


- Generic EBL shapes @ z=0
- Redshift evolution tuned to track theoretical models
- Calculated opacities used to correct observed spectra

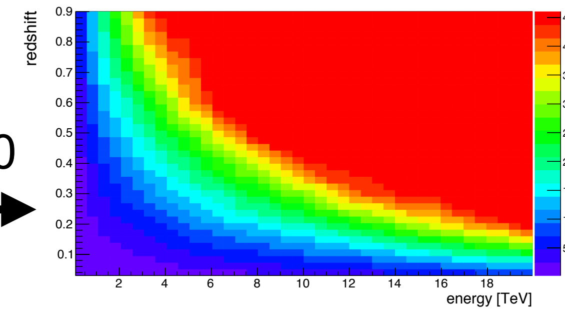
VERITAS EBL analysis

Input:
Observed spectrum
Opacity graphs
Weight file

Fit observed spectrum w. power law flag if good



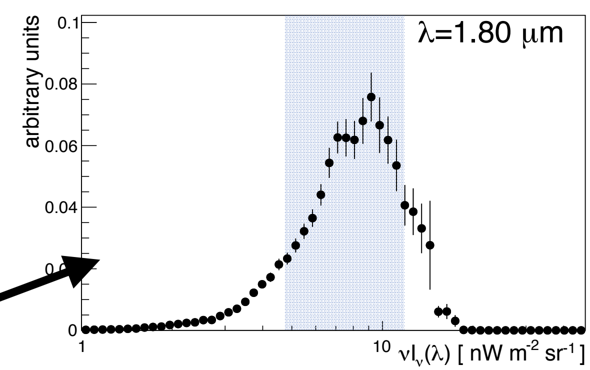
x 480 000



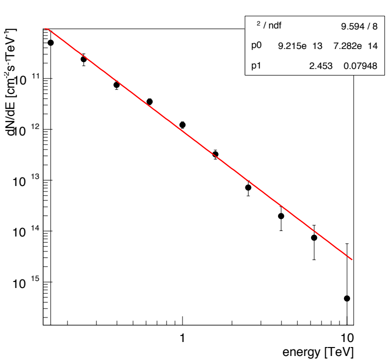
Interpolate to find τ for source redshift, energy of spectral points

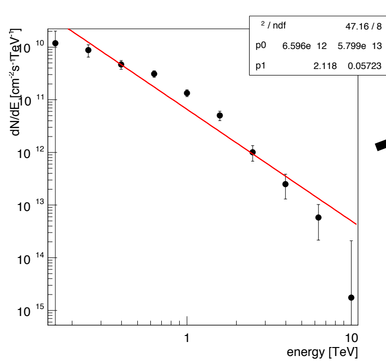
x 480 000

480 000 entries



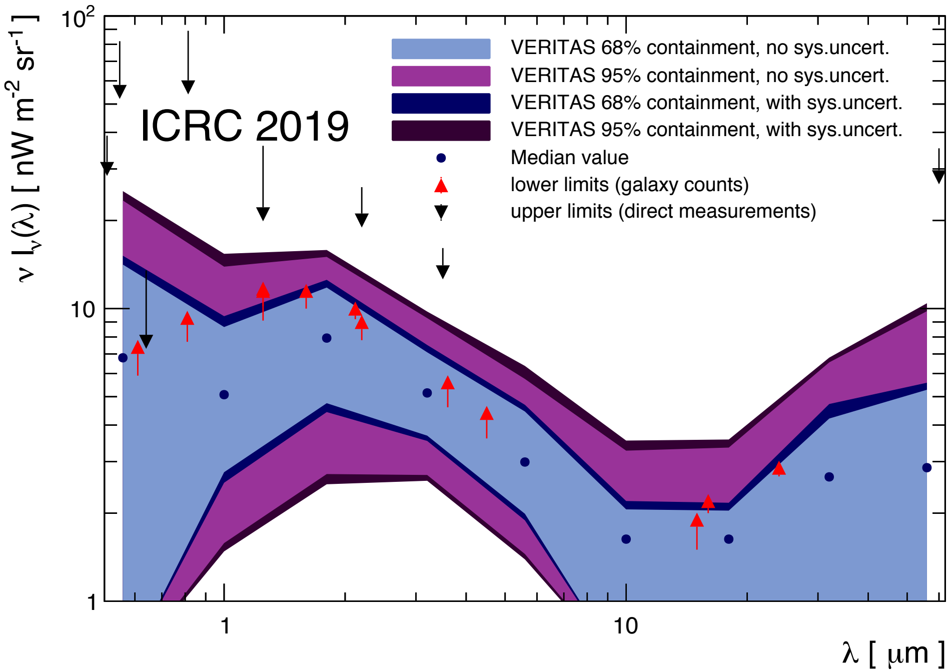
Fit deabsorbed spectrum
Power law only if observed fit by PL
Otherwise PL, PL+exp. cutoff, log parabola
Require $\Gamma_{deabs} > 1.0$





Output: $\exp(-\chi^2/2)$-weighted distribution of model intensities at different λ_{EBL}

Systematic uncertainties & stability

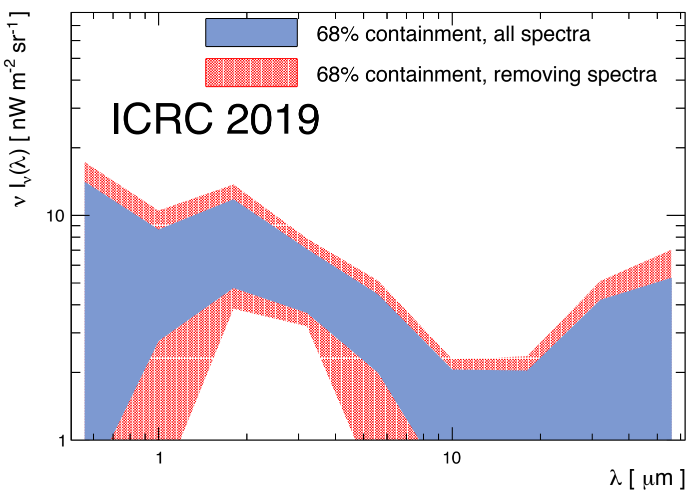


Systematic uncertainties

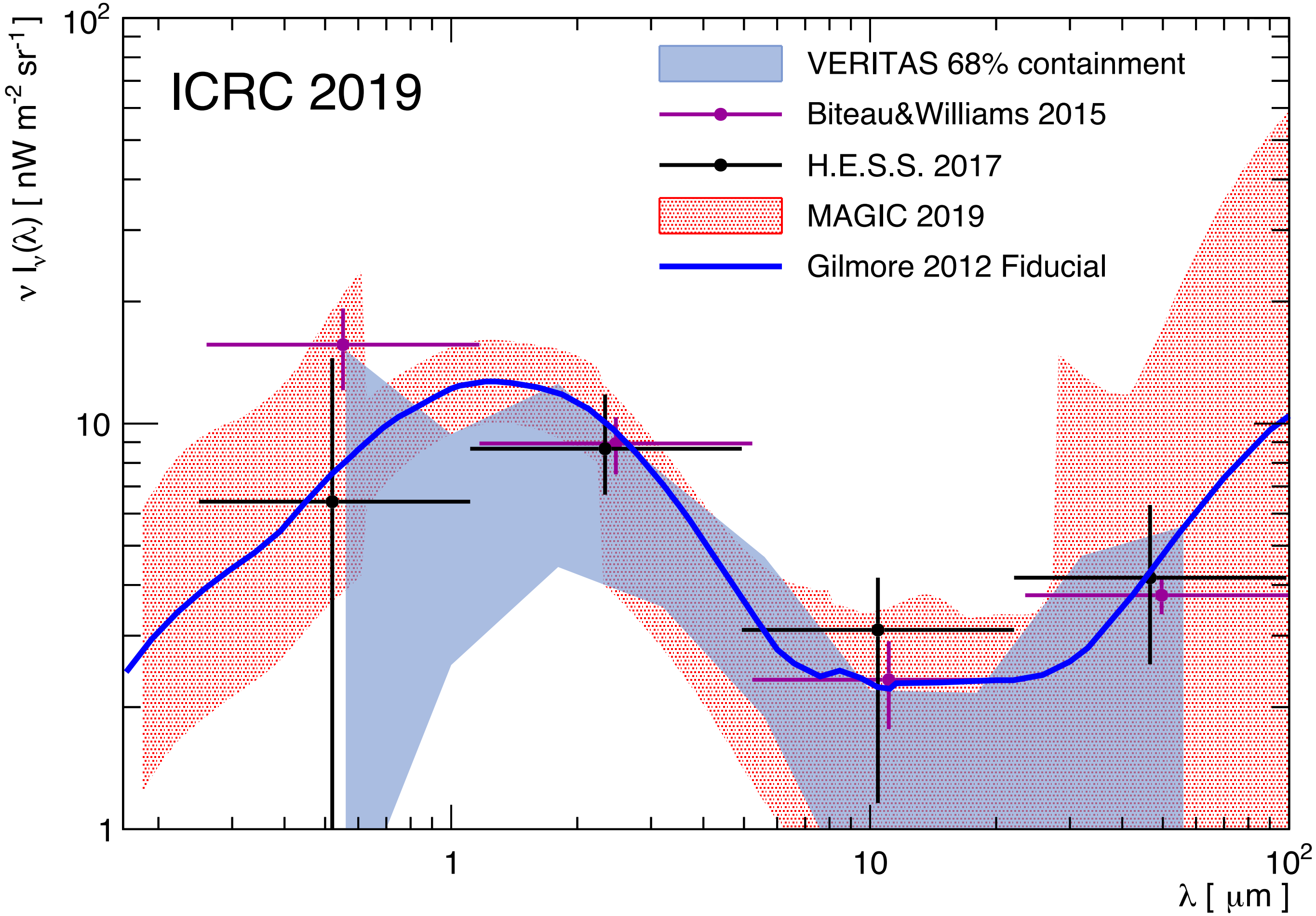
- Number of EBL shapes considered
- Energy scale uncertainty
- Uncertainty in redshift evolution
- Sources with uncertain redshift

Robustness check

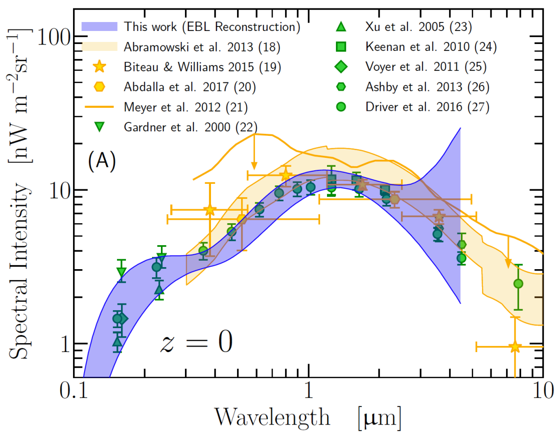
- Remove sources one by one

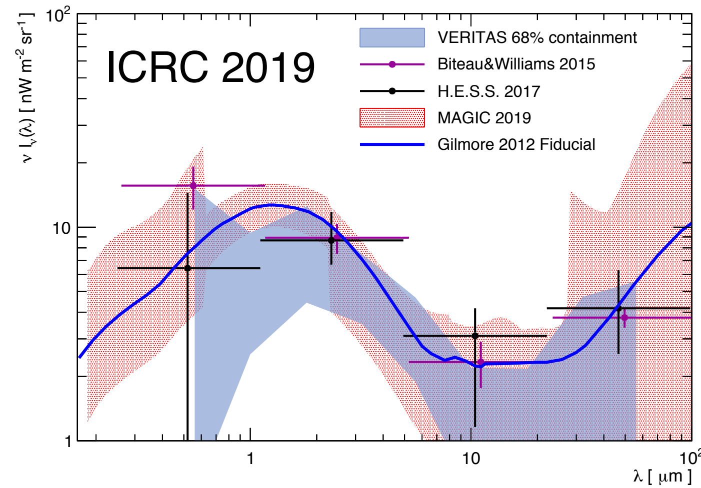


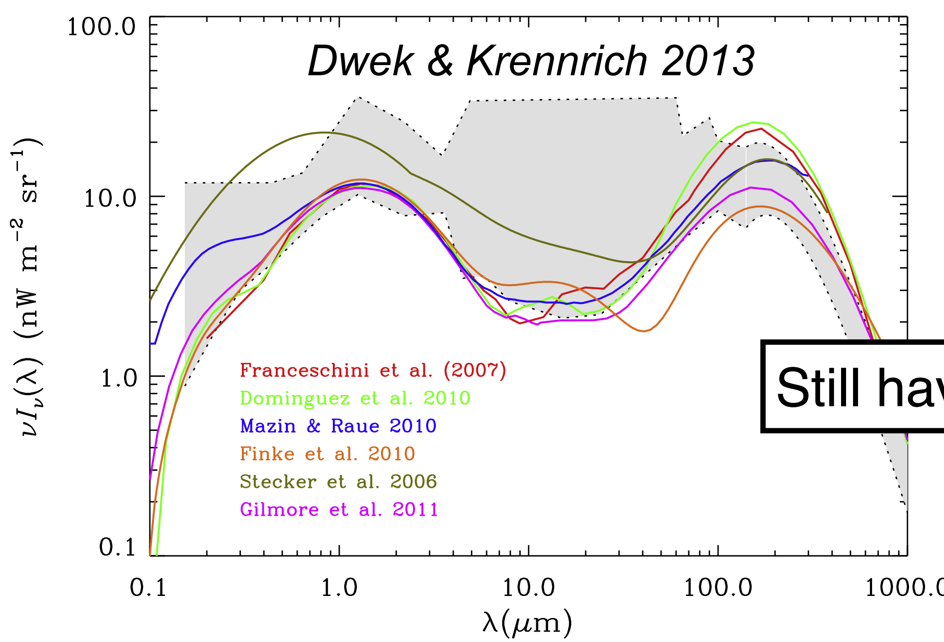
VERITAS EBL Measurement in Context



Is the EBL resolved?







Still have work to do at large λ_{EBL}

Conclusions

- New VERITAS EBL measurement based on ~10 years of blazar observations
- VERITAS measurement consistent with lower limits on EBL intensity from **galaxy counts**
- VERITAS measurement consistent with **theoretical predictions** and **other gamma-ray measurements**
- What now?
  - **Longest wavelengths** still loosely constrained
  - Bright, nearby sources (Markarians, M87 flares?)