MAGIC observations of the February 2014 flare of 1ES 1011+496 and measurement of the Extragalactic Background Light density

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Outline

Extragalactic Background Light

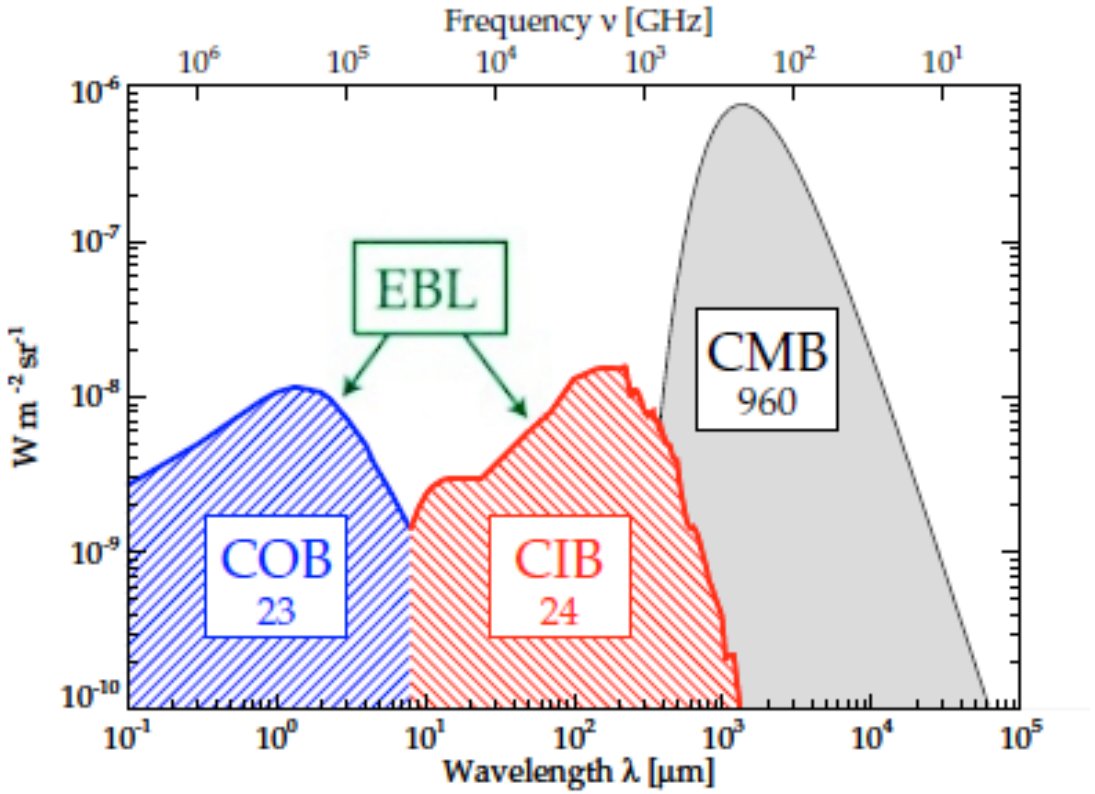
MAGIC Telescopes & Analysis

1ES 1011+496 exceptional flare

EBL measurement

Summary

Extragalactic Background Light (EBL)



Redshifted star light | Redshifted dust emission

adapted from Dole et al.

EBL [COB+CIB] ~ 5% of CMB

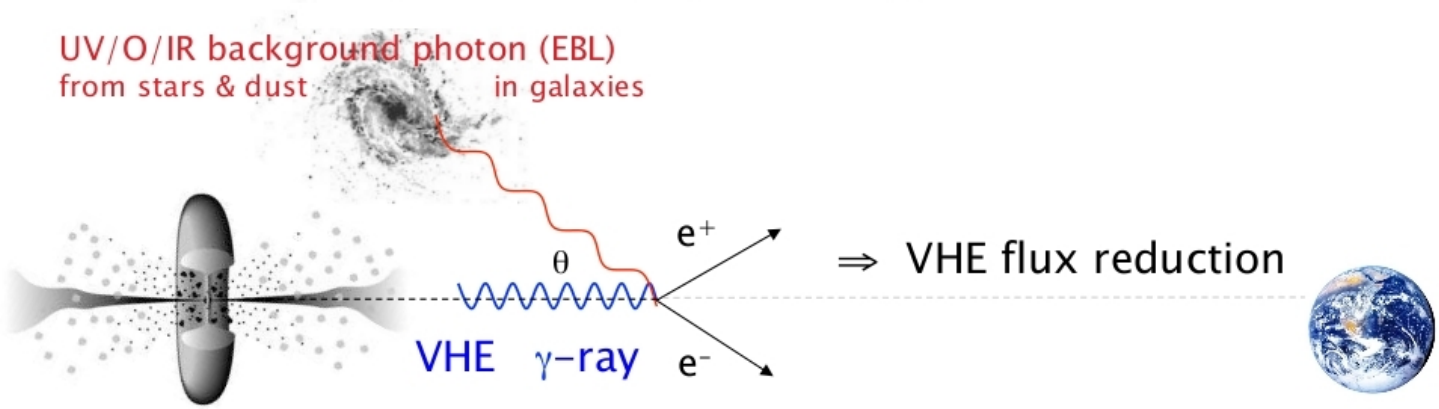
EBL: why is it important?

- Key information about evolution of the Universe
- EBL intensity is directly related to the cosmic star formation rate and stellar mass density today
- Most EBL intensity is supplied by massive stars
  - Supernova rate
  - Neutrino flux
- If the measured EBL intensity is higher than predicted by models
  $\Rightarrow$ Unknown radiation sources in the universe?

EBL: measurement techniques

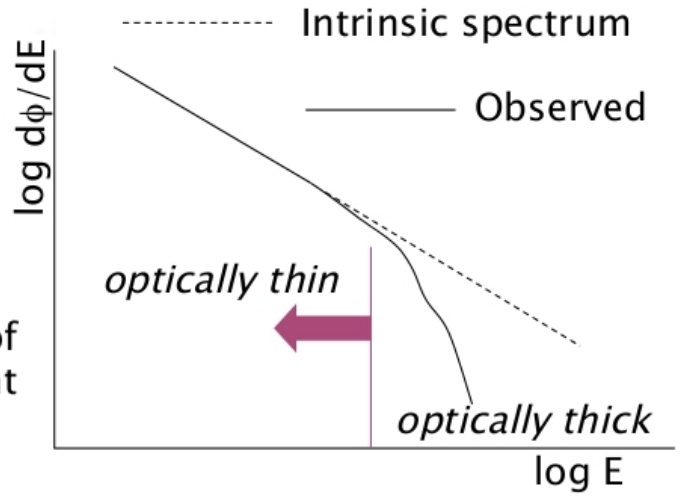
- Direct measurement is challenging
  - Zodiacal light (interplanetary dust)
  - Stellar and interstellar emission from Milky Way
- Robust lower limits from galaxy counts (from deep field HST images)
  - Account only for contributions of resolved sources
- **γ-rays can be used as a probe for measuring the EBL**
  - The observation of a blazar in flaring state at intermediate redshift ($z>0.1$) gives a opportunity to measure the impact of the (EBL) on the measured flux of γ-rays

VHE γ-ray propagation



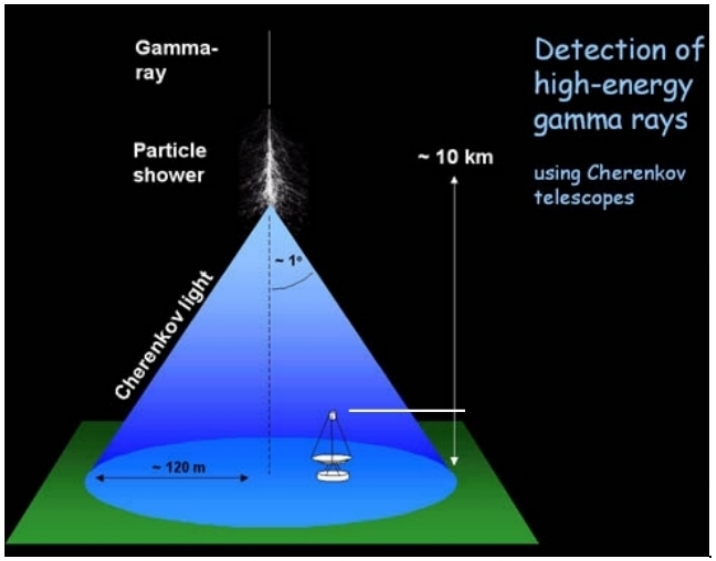
- observed flux: $e^{-\tau}$ × emitted flux
- τ : optical depth
- $\tau = \tau(E, z)$

VHE γ-rays can be used as a probe of Extragalactic Background Light



Cradit: Abelardo

MAGIC Telescopes

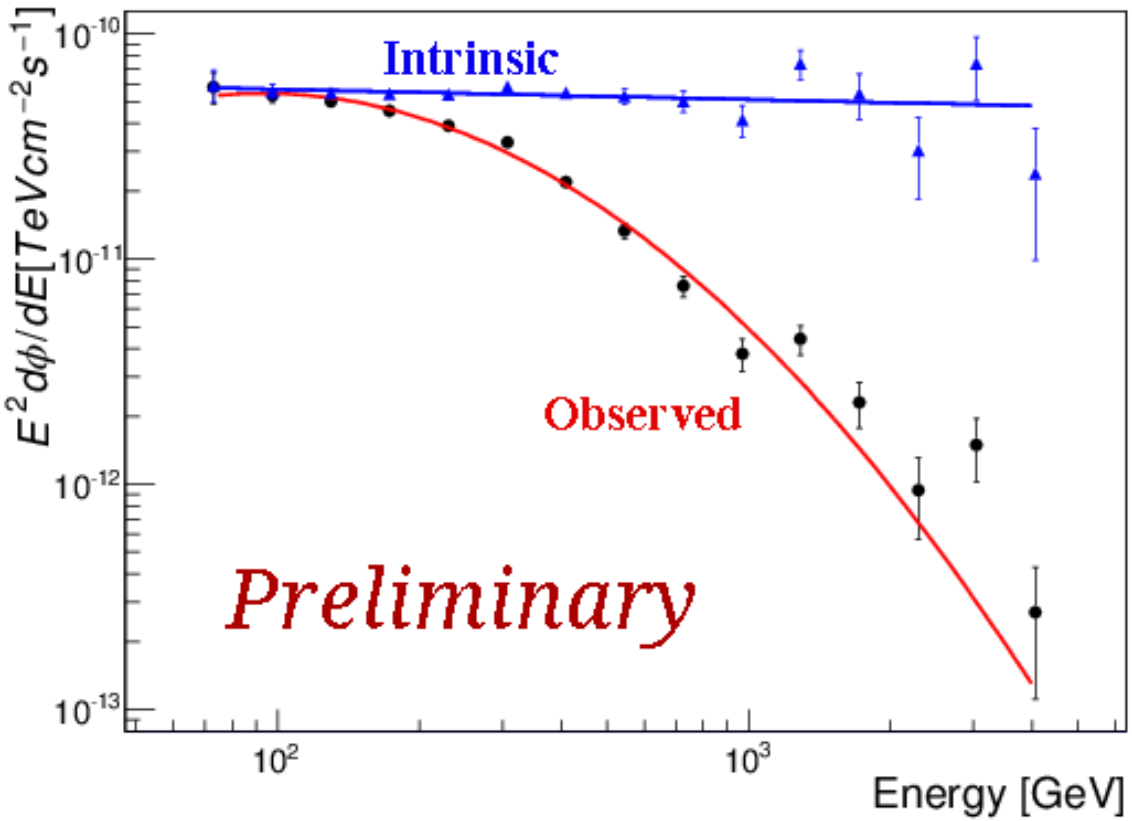


- Stereoscopic system of two 17m diameter Imaging Atmospheric Cherenkov telescopes (IACTs)
- Location: La Palma in Canary Island (28.75°N, 17.86°W, 2200m asl).
- Energy range 50 GeV-50 TeV.
- Integral sensitivity ((0.67 ± 0.04) % C.U. above 290 GeV in 50 hours
- Energy resolution $\Delta E/E \sim$ 15-25%

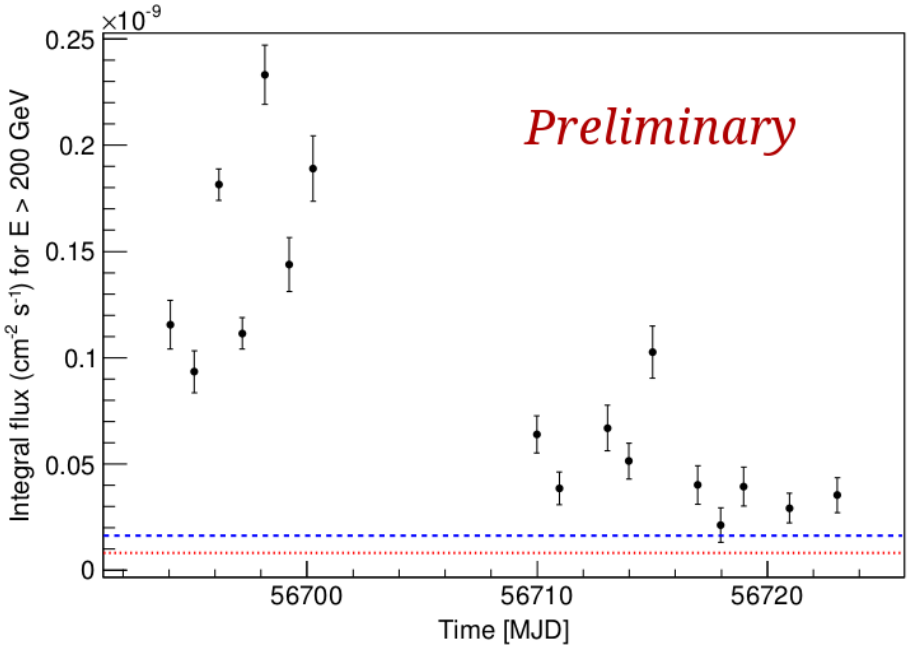
1ES 1011+496 exceptional flare

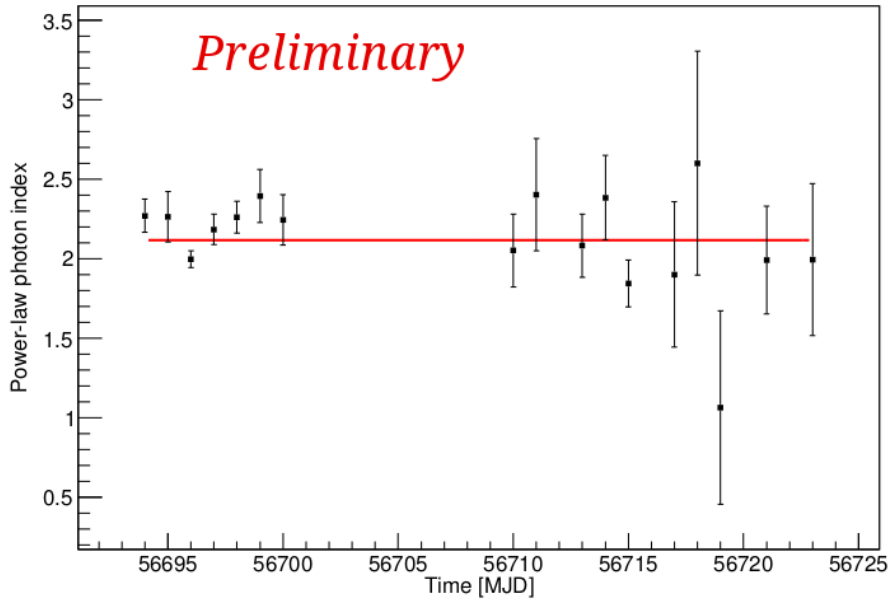
- RA: 10^h 15^m 04:1^s, DEC: $+49^\circ$ 26^m 01^s
- First detection at VHE with MAGIC in 2007
- High frequency peaked BL Lac (HBL) with redshift **z=0.212**
- On February 5th, following an alert issued by VERITAS, MAGIC observed 1ES 1011+496 in flaring state for 17 nights during February-March 2014 in the zenith range of $20^\circ - 56^\circ$ (11.8 hours of good quality data were collected).
- During this bright flare, flux exceed roughly 10 times than previously recorded flux ($\sim$7% Crab flux) [VERITAS+MAGIC (ATel#: 5887) and Fermi (ATel#:5888)].
- The 0.3-10 keV X-ray flux is at the highest level ever seen by Swift for this source [ATel#:5866]

Results: Average Spectral Energy Distribution during the flare



Results: Light curve (E > 200 GeV)



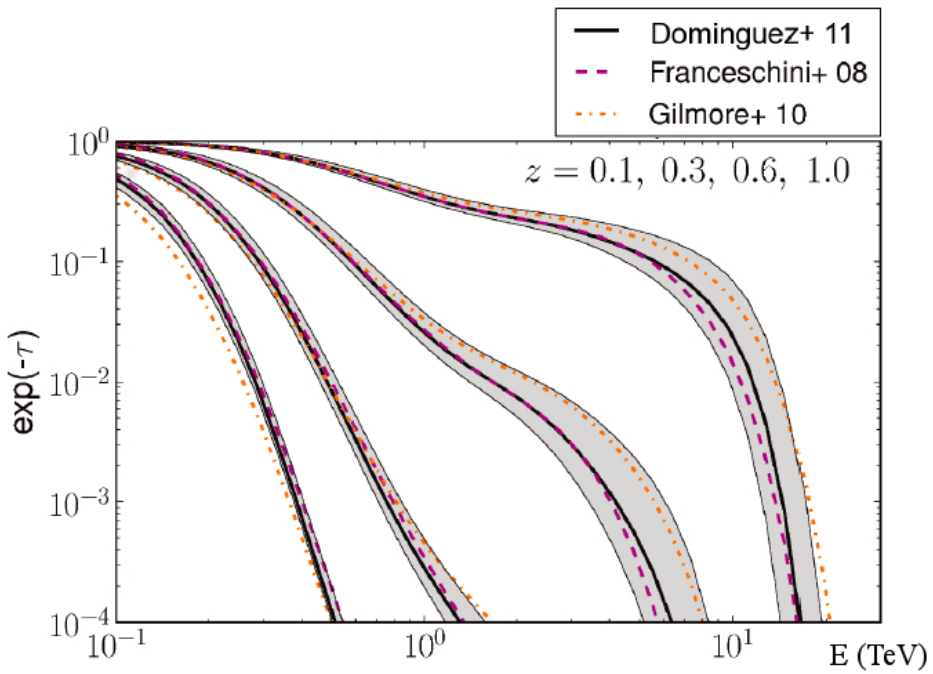


- Peak Flux (E > 200 GeV): (2.32±0.14) 10^{-10} cm^{-2} s^{-1}
- Blue line: Flux from 2007-2008
- Red line: Flux from 2011-2012

Distribution of the Intrinsic photon index assuming the Dominguez 2011 model. It shows the stability of the spectral shape during the flare.

EBL measurement: likelihood maximization method

- The technique is based in measuring a distinctive feature of the EBL imprint in the VHE γ-ray data (Abramowski et al. 2013)
- For our measurement we used as template the EBL model by Dominguez et al. 2011



- We assume the intrinsic spectrum can be described by one among a few simple, concave functions with no inflection points.

EBL measurement: likelihood maximization method

- The model for the intrinsic spectrum is modified by the effect of the EBL, scaled by a opacity normalization factor (Abramowski et al. 2013)

$$\frac{d\phi_{obs}(E)}{dE} = \frac{d\phi_{int}(E)}{dE} \times \exp(-\alpha \times \tau(E,z))$$

free parameter

from EBL model

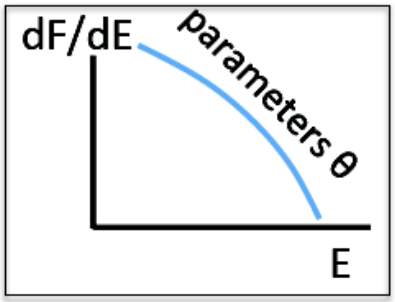
Name	Abbreviation	Formula
Power law	PWL	$\phi_0(E/E_0)^{-\Gamma}$
Log-parabola	LP	$\phi_0(E/E_0)^{-\Gamma-\beta\log(E/E_0)}$
Exponential cut-off power law	EPWL	$\phi_0(E/E_0)^{-\Gamma}\exp(-E/E_{cut})$
Exponential cut-off log-parabola	ELP	$\phi_0(E/E_0)^{-\Gamma-\beta\log(E/E_0)}\exp(-E/E_{cut})$
Super exponential cut-off power law	SEPWL	$\phi_0(E/E_0)^{-\Gamma}\exp(-(E/E_{cut})^{\gamma})$

EBL measurement method (forward folding)

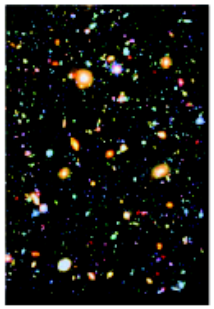
- The "forward folding" starts with the model of a smooth intrinsic spectrum.
- Then apply absorption using EBL model and given α
- Fold the resulting absorbed spectrum with the response of the MAGIC telescopes (migration matrix, effective area and effective time)
- Best-fit parameters for the intrinsic spectrum found by maximizing a Poissonian likelihood built from the ON- and OFF- event statistics vs. reconstructed energy
- The maximum likelihood is computed for each α from 0 to 2.5
- A likelihood ratio test is computed: $TS = 2log\left(\frac{L_\alpha}{L_{\alpha=0}}\right)$

Forward folding

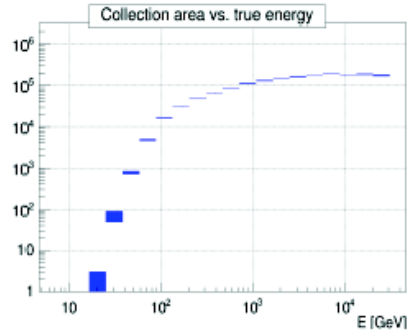
Spectrum



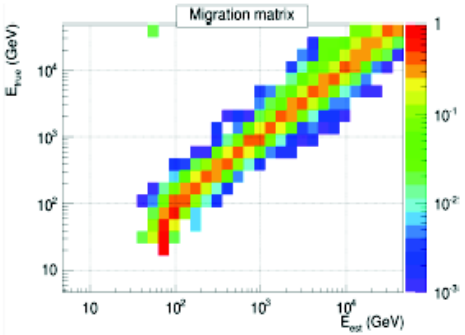
EBL(optional)



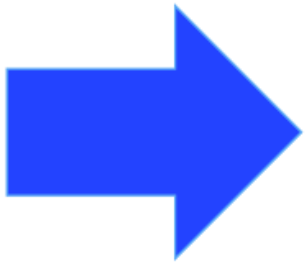
Effective Area



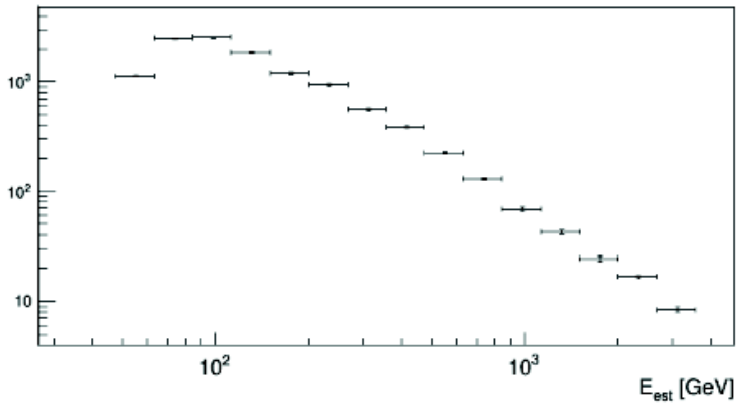
Migration matrix



Eff. time

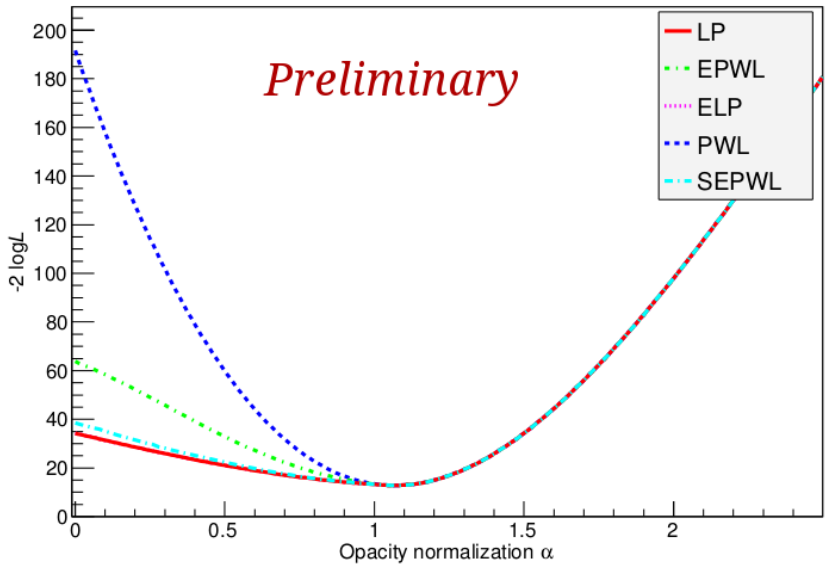


expected number of gammas (Poisson parameter)

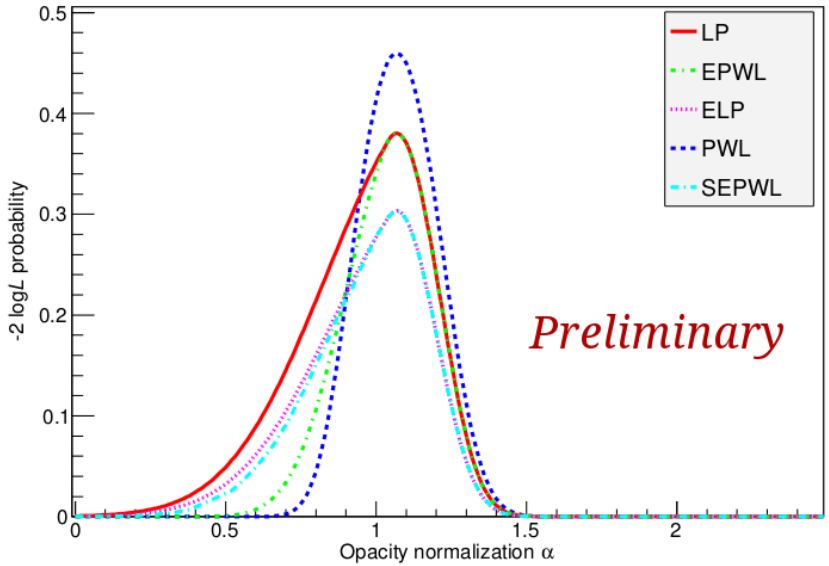


Results for likelihood test

$-2LogL$ distribution

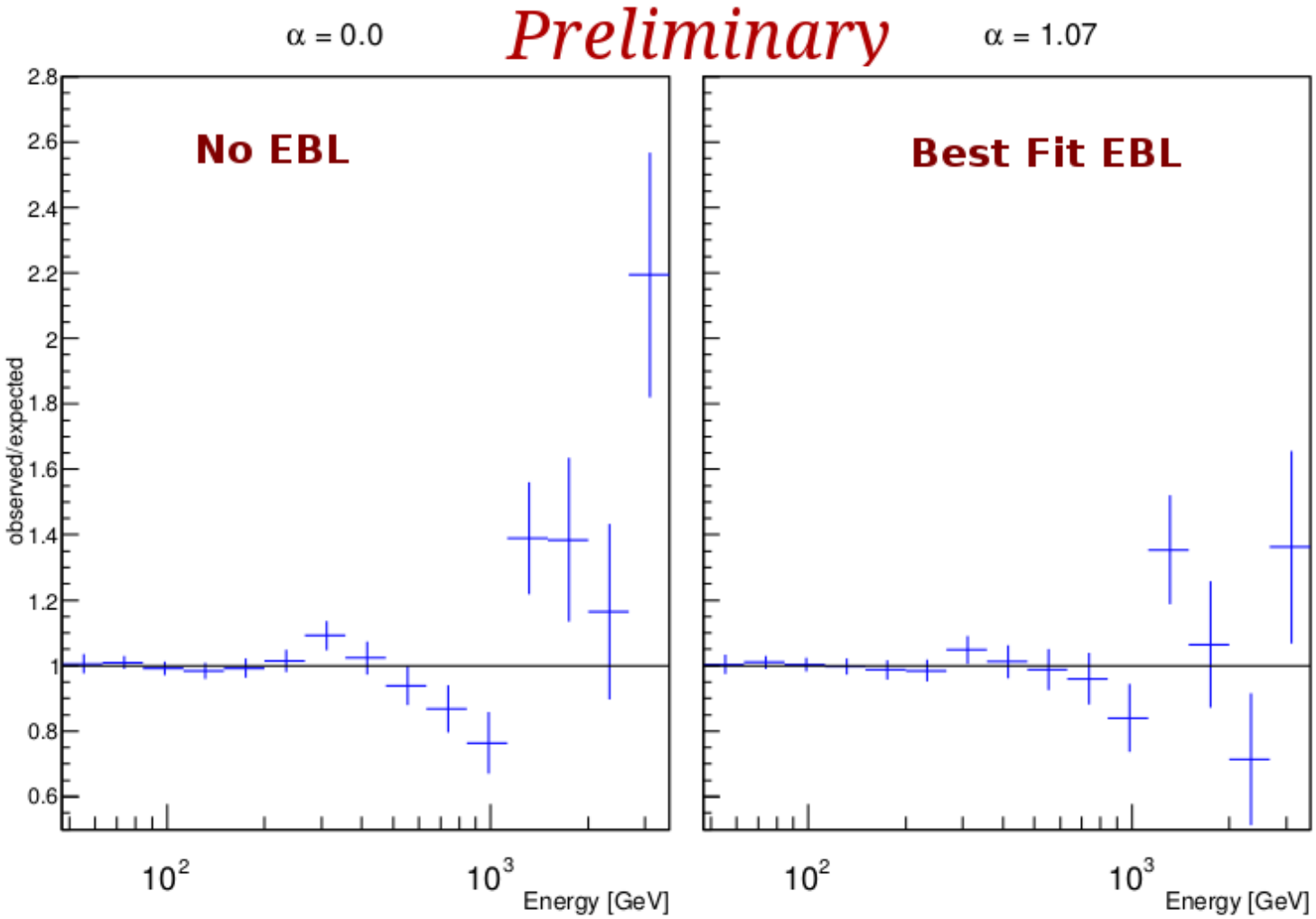


Probability distribution

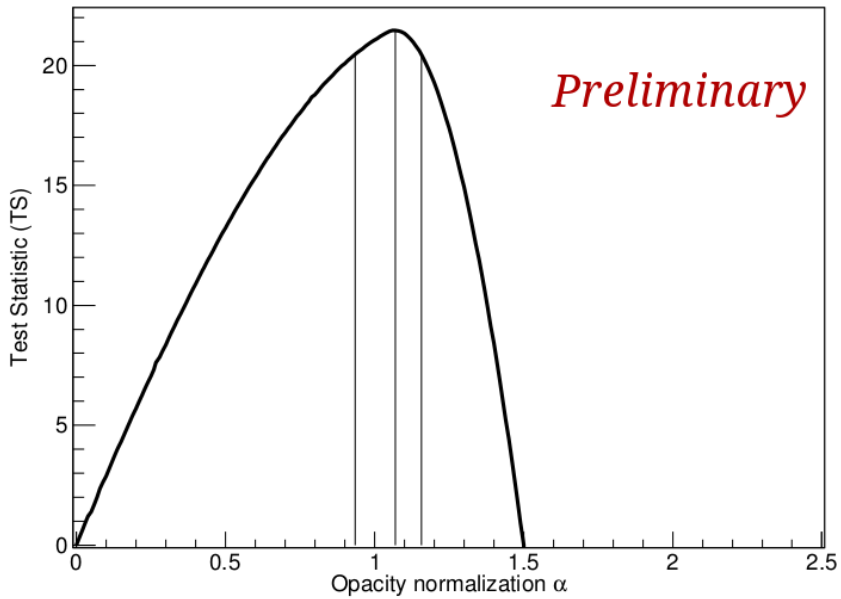


Although the PWL has the maximum fit probability, choosing it as model for intrinsic spectrum it would imply that all observed curvature comes solely from the EBL

Residuals (using log-parabola as a function for intrinsic spectrum)



Test Statistics distribution



The TS=-2log($L_\alpha/L_{\alpha=0}$) revealed that the EBL model by Dominguez et al. scaled by the opacity normalization factor (using only statistical uncertainties) α_0: $1.07^{+0.09}_{-0.13}$ (using Log Parabola as function for intrinsic spectrum) was preferred **over the null EBL hypothesis with a significance of 4.6σ**. Note that (The lines shown here are for $\pm 1\sigma$ i.e. $\Delta\mathrm{TS} = 1$

Systematic uncertainty

- The main source of systematic uncertainty in the MAGIC telescopes is the absolute energy scale which is estimated as 15%
- We modified the overall light collection efficiency of the instrument by changing the calibration factors and redid the full analysis
- The wider range of resulting α values for the estimated maximum systematic of $+15\%$ is taken as our final result as $\alpha_{(stat+sys)} = 1.07^{+0.24}_{-0.20}$

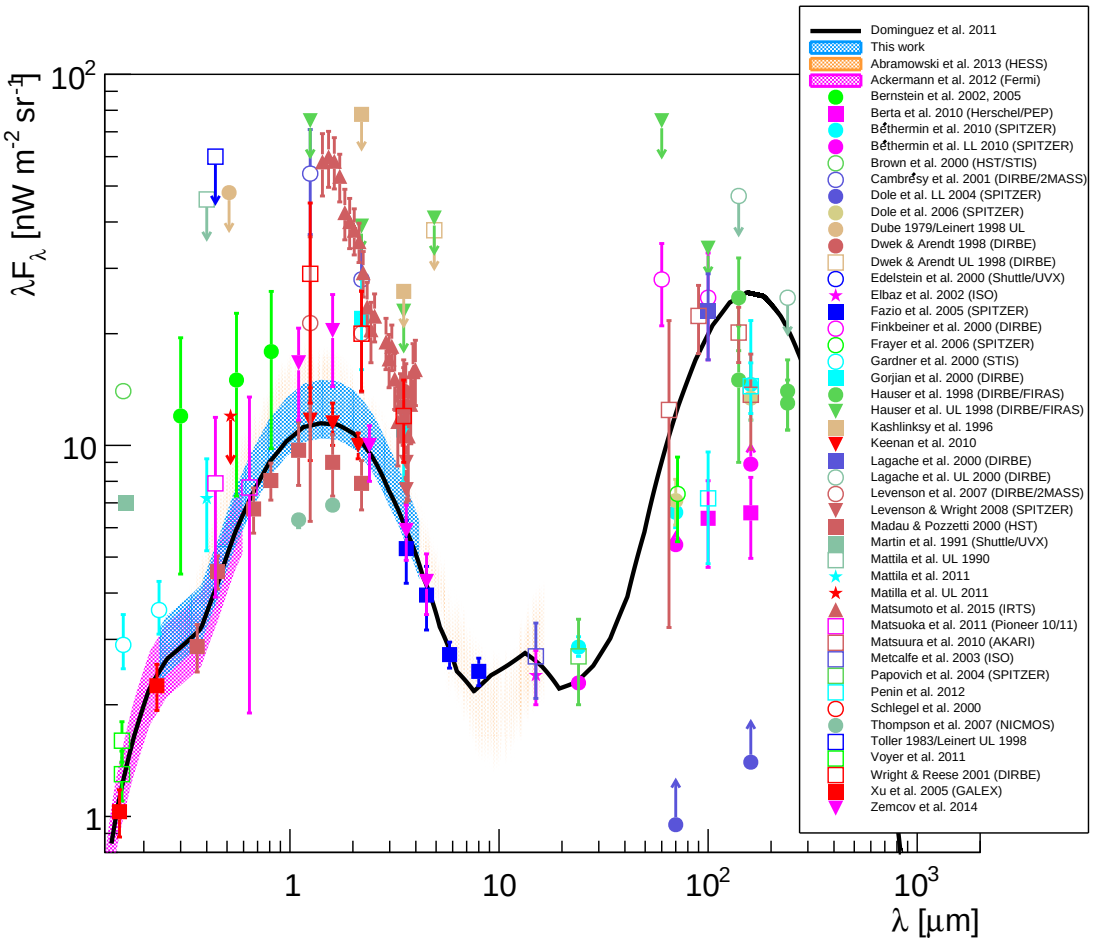
EBL Flux Density

- The relation of the energy E_γ of the γ-ray from the source with the EBL wavelength at the peak of the photon-photon cross section

$$\lambda_{EBL}(\mu\mathrm{m}) = 1.187 \times E_\gamma(\mathrm{TeV}) \times (1+z)^2$$

EBL Flux Density

- The wavelength covered is on the COB part of the EBL, with a peak density of $\lambda F_\lambda = 12.27^{+2.75}_{-2.29}$ nW m^{-2} sr^{-1} at 1.4 μm



Summary

- For 1ES1011+496, bright flare observed by MAGIC & VERITAS (VHE), Fermi (GeV) and Swift (X-ray) in Feb. 2014
- This was the first time to observe flare with such high flux from such a distant source around 1 TeV. Thus presented an opportunity to perform measurements of the EBL.
- With 1ES1011+496 spectra, we measured the EBL imprint with a significance of 4.6σ over the null EBL hypothesis with peak flux density $= 12.27^{+2.75}_{-2.29}$ nWm^{-2}sr^{-1} at 1.4μm
- We did not find any anomaly that could be attributed to sources of unknown origin
- The high redshift of the source and the strength and hardness of the flare makes this one of the most EBL- constraining individual VHE spectra recorded to date.

Thank You!

Back up

Signal scaling