EBL constraints using TeV blazars observed with the MAGIC telescopes

Gaia Vanzo,
Instituto de Astrofísica de Canarias, Universidad de La Laguna

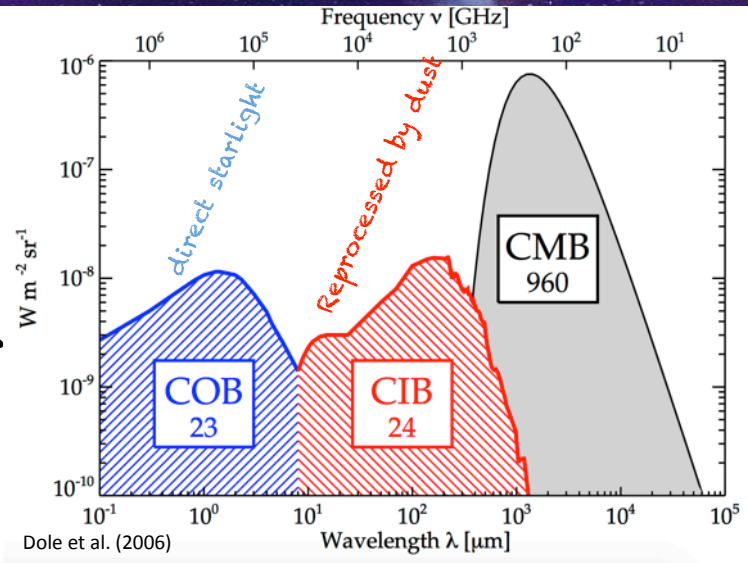
A. Domínguez, V. Fallah Ramazani, T. Hassan, D. Mazin, A. Moralejo, M. Nievas Rosillo, E. Prandini, J. Sitarek, M. Vázquez Acosta
for the MAGIC collaboration

MAGIC

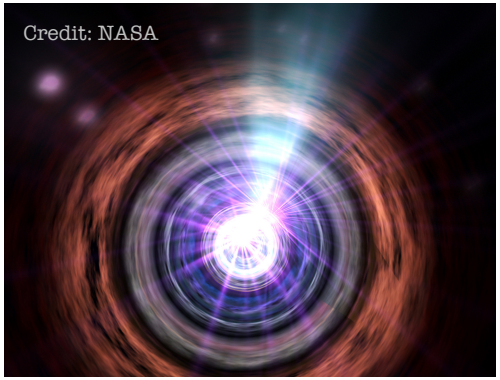
ULL Universidad de La Laguna

EBL
Extragalactic Background Light

- Holds crucial information about
  - -Star Formation Rate
  - -Galaxy Evolution
  - -**essential for full energy balance of the Universe**

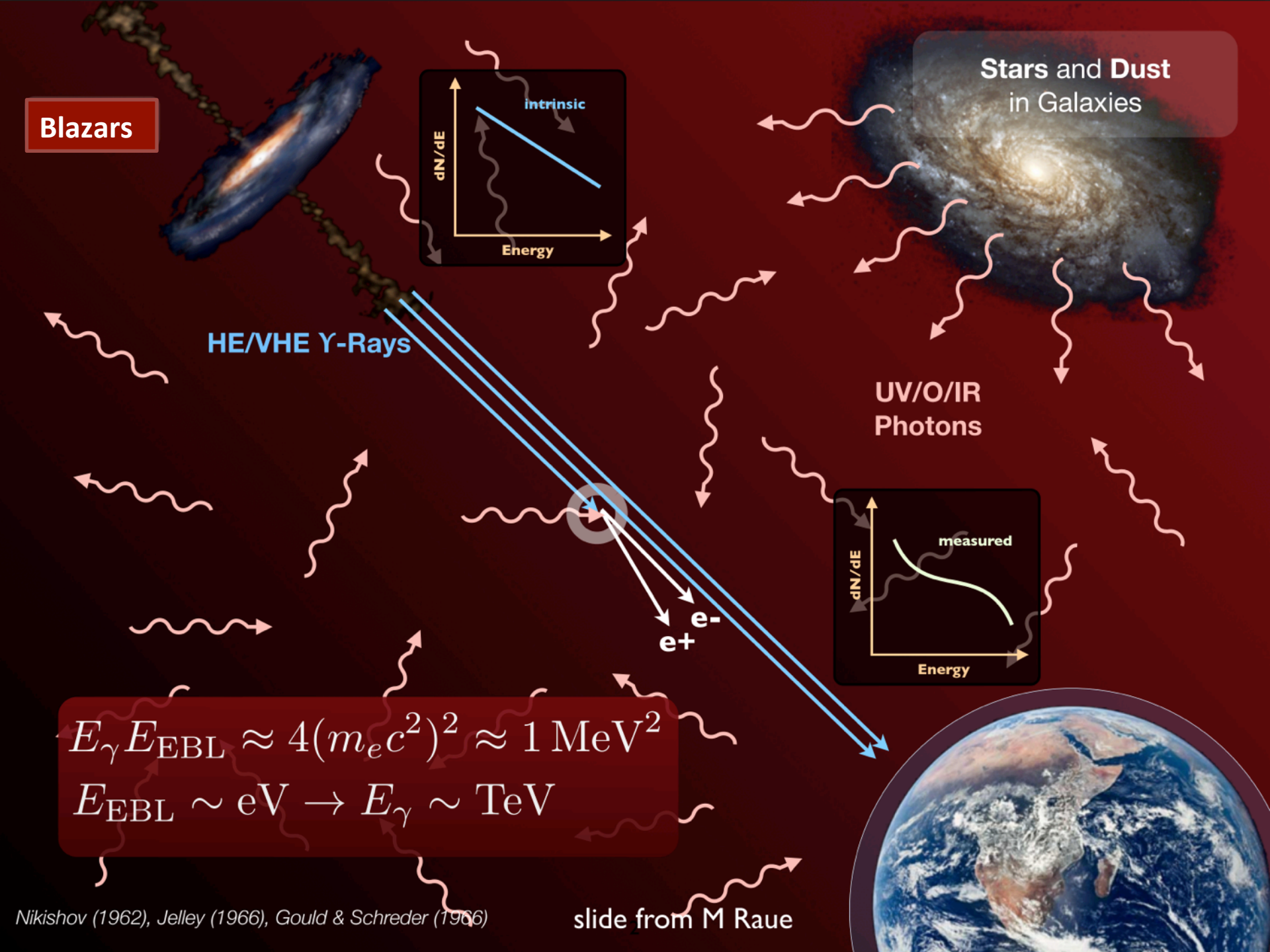


- Direct measurements are complicated by the presence of the <u>zodiacal light + foreground emission</u>



as <u>indirect measurements</u>

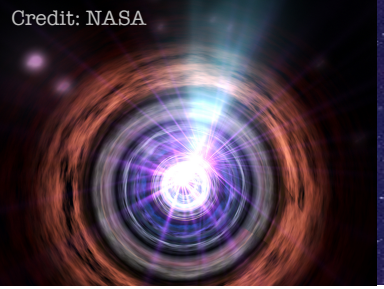
Can use **blazars**


Blazars
Stars and Dust
in Galaxies
intrinsic
dN/dE
Energy
HE/VHE Y-Rays
UV/O/IR
Photons
e+
e-
measured
dN/dE
Energy
$E_\gamma E_{\rm EBL} \approx 4(m_e c^2)^2 \approx 1\,{\rm MeV}^2$
$E_{\rm EBL} \sim {\rm eV} \rightarrow E_\gamma \sim {\rm TeV}$
Nikishov (1962), Jelley (1966), Gould & Schreder (1966)
slide from M Raue

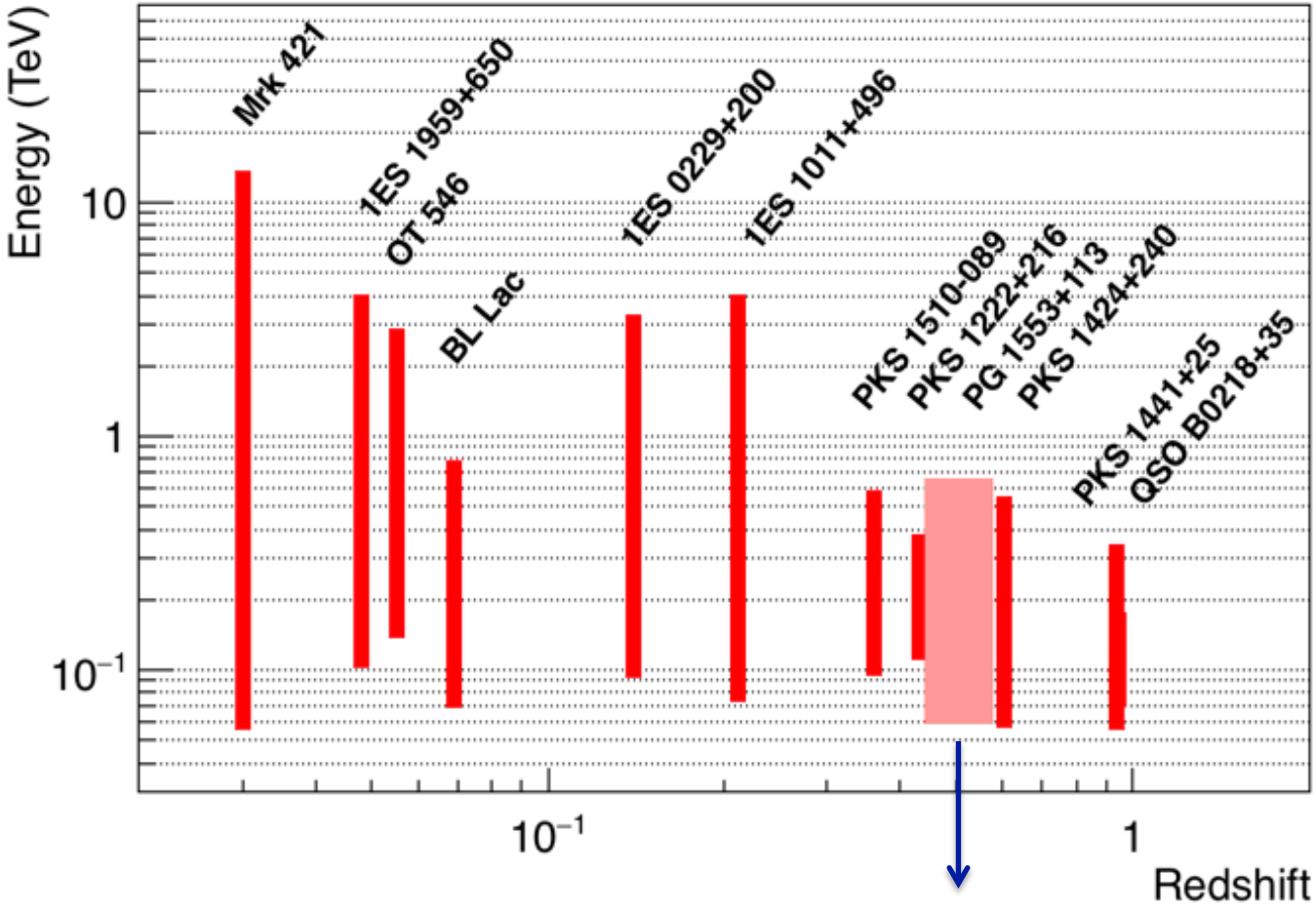
the Major Atmospheric Gamma-ray Imaging Cherenkov telescopes

- At the **Roque de Los Muchachos Observatory**, Canary Islands, Spain
- Stereoscopic system of two 17-m Cherenkov telescopes
- $E_\gamma > 50$ GeV, $\Delta E/E \approx 15 - 23\%$
- FoV 3.5°, angular resolution ≈ 0.1°
- Sensitivity: 1.45% Crab Flux in 50 h above 100 GeV (Aleksić et al, 2016)


THE MAGIC APPROACH

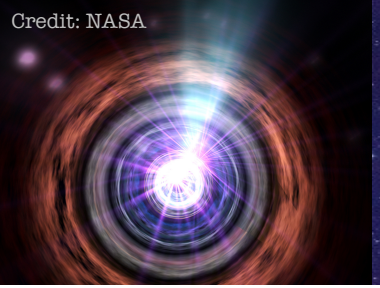


The data sample

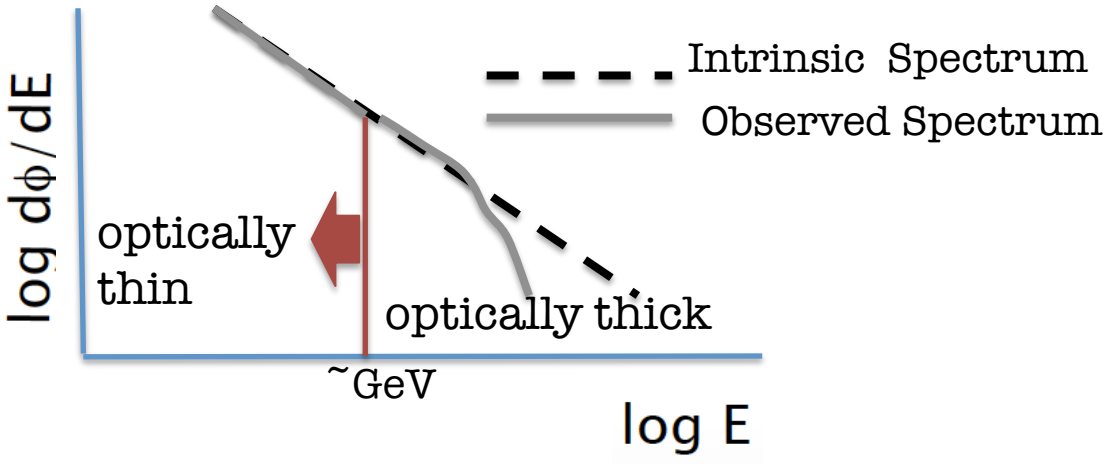


- ✓ 32 spectra of **12 blazars**, mainly in <u>flaring state</u>
- ✓ **316 hours** of data
- ✓ $0.03 < z < 0.944$

$0.43 < z < 0.6$
treated as a nuisance parameter

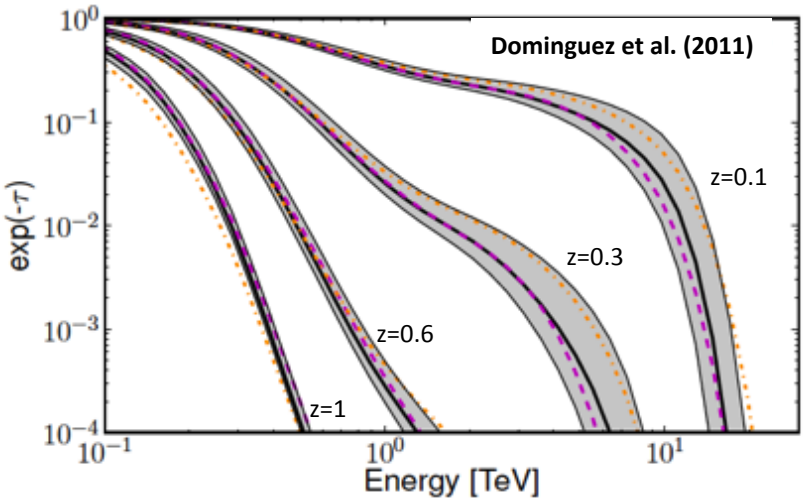


EBL and blazars' spectra



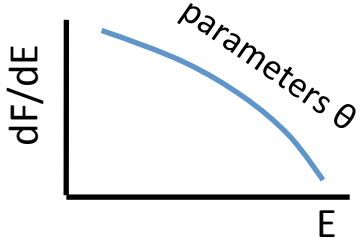
$$\left(\frac{d\phi}{dE}\right)_{\text{observed}} = \left(\frac{d\phi}{dE}\right)_{\text{intrinsic}} e^{-\tau(E,z)}$$

optical depth: τ



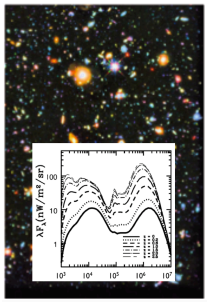
Maximum Likelihood Method

Intrinsic Spectra



×

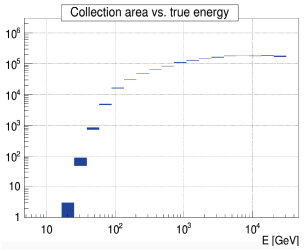
EBL model



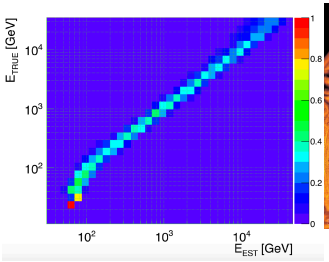
×

MAGIC instrumental response

eff. Area



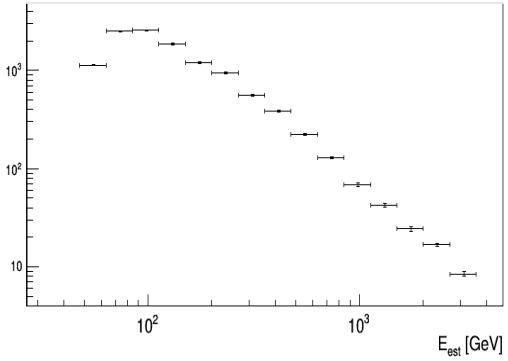
Mig. Matrix



eff. time

=

Expected #gamma (Poisson parameter)



Compared with the observed #gamma through **Maximum likelihood Method**

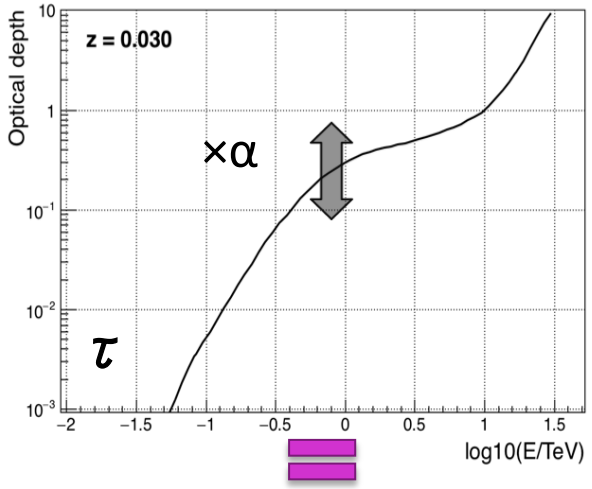
- ✓ **Free parameters in the fit: Intrinsic Spectra & scale of EBL model**
- ✓ Poisson parameters of the background in each E_{est} bin are treated as nuisance

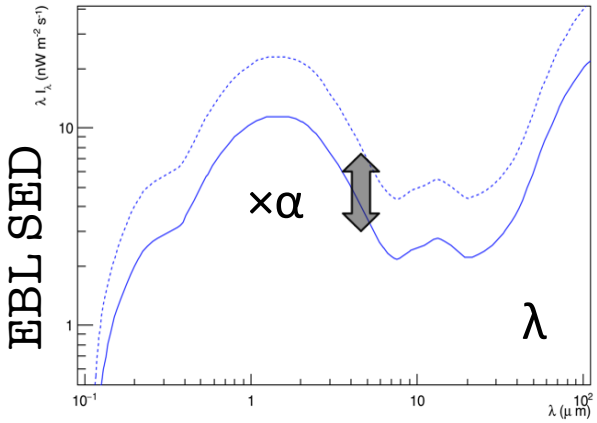
Free parameters: EBL scale α

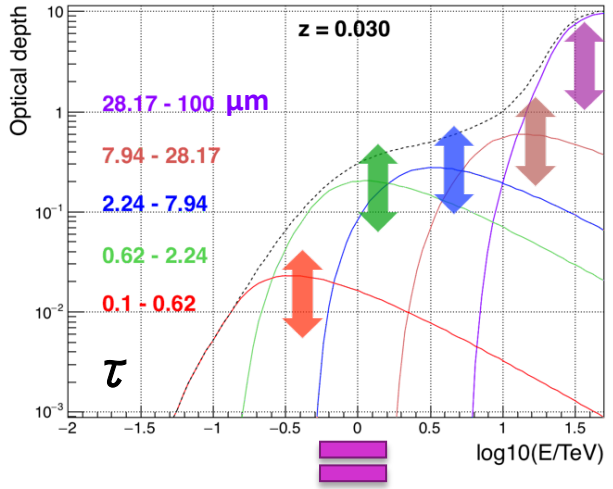
$$\left(\frac{d\phi}{dE}\right)_{\text{observed}} = \left(\frac{d\phi}{dE}\right)_{\text{intrinsic}} e^{-\alpha\tau(E,z)}$$

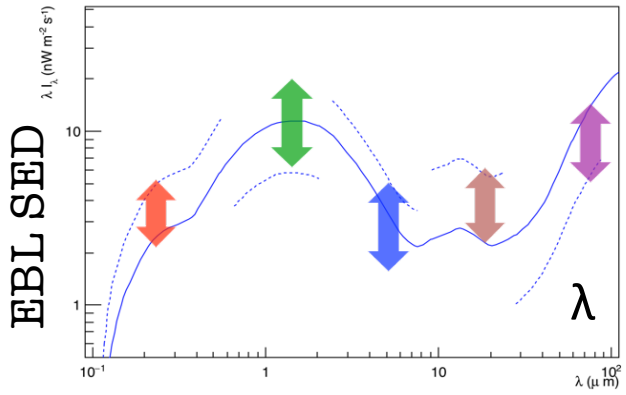
1 single free EBL parameter: α **vs** 5 free EBL parameters:

λ resolved EBL measurements



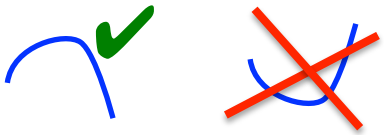






Free parameters: intrinsic spectra

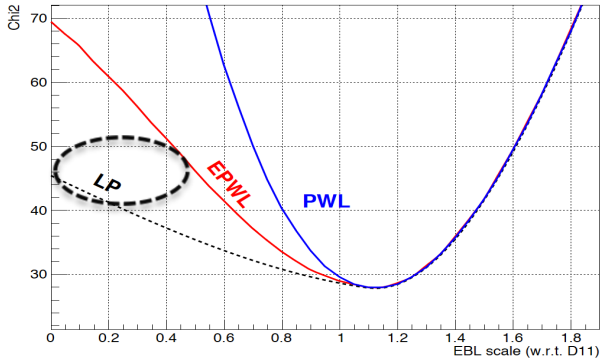
- **simple CONCAVE functions**



		#free parameters
-**PWL**	~~Power-law~~; excluded, to avoid that all the curvature of the spectra is attributed to EBL	
-**EPWL**	Power-law with exponential cut-off	(3)
-**SEPWL**	Power-law with sub/super-exponential cut-off	(4)
-**LP**	Log Parabola	(3)
-**ELP**	Power-law with exponential cut-off	(4)

- **best P-value requested for each spectrum**

If two functions have the same p-value, we chose the one with flatter χ^2 profile to be conservative




MAGIC RESULTS

Measured EBL scaling factor: MAGIC only

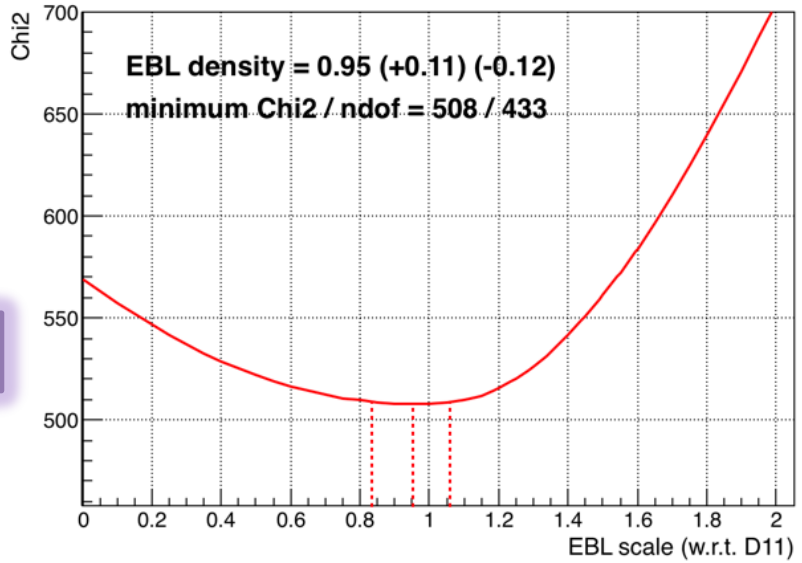
- only statistical errors:

EBL Scale α = 0.95 (+0.11) (-0.12)$_{stat}$

- statistical & systematic* errors:

EBL Scale α = 0.95 (+0.19) (-0.15) stat+syst

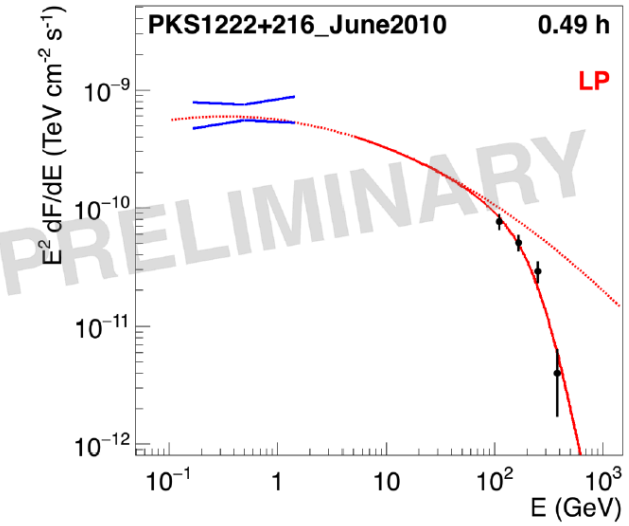
χ^2 profile vs. scaling factor α relative to Domínguez2011 EBL model



- **Results compatible with Dominguez'2011 model**

* The dominant systematics come from overall light scaling (±15%) and different selection on intrinsic spectra

Measured EBL scaling factor: MAGIC + Fermi



Fermi-LAT observes in the optically thin part of the spectrum, so it is little affected by EBL absorption

flux and photon index from Fermi contemporaneous data (Pass-8) used to constrain the intrinsic spectrum

only statistical errors:

EBL Scale α = 0.95 (+0.07) (-0.06) **stat**

- Use of Fermi reduces stat. uncertainty from ≈ 12% to ≈ **7%**

statistical+ systematic errors:

EBL Scale α = 0.95 (+0.28) (-0.26) **stat+syst**

- Respect to MAGIC only fit, systematic uncertainties increase

Measured EBL scaling factor α Different EBL models

PRELIMINARY

EBL model	MAGIC-only	MAGIC + Fermi-LAT
Domínguez' 2011 (D11)	$0.95\ (+0.11, -0.12)_{stat}$	$0.91\ (+0.07, -0.06)_{stat}$
Franceschini' 2008	$1.00\ (+0.11, -0.12)_{stat}$	$0.94\ (+0.07, -0.06)_{stat}$
Gilmore' 2012 fiducial	$0.98\ (+0.11, -0.12)_{stat}$	$0.95\ (+0.07, -0.08)_{stat}$

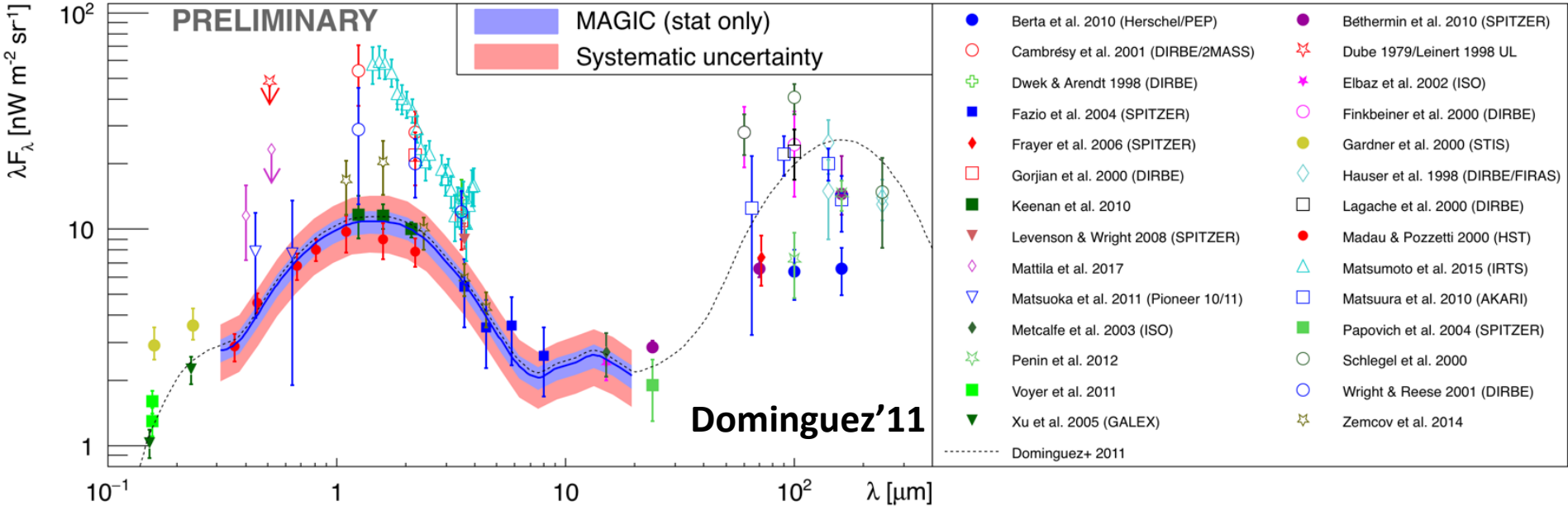
Data can not discriminate among state-of-the-art EBL models

P-values of the fit are low: $\sim 8\times10^{-3}$ and $(4-8)\times10^{-5}$.

Maybe due to: too simple spectral models, hidden point-wise systematics, imperfect EBL templates

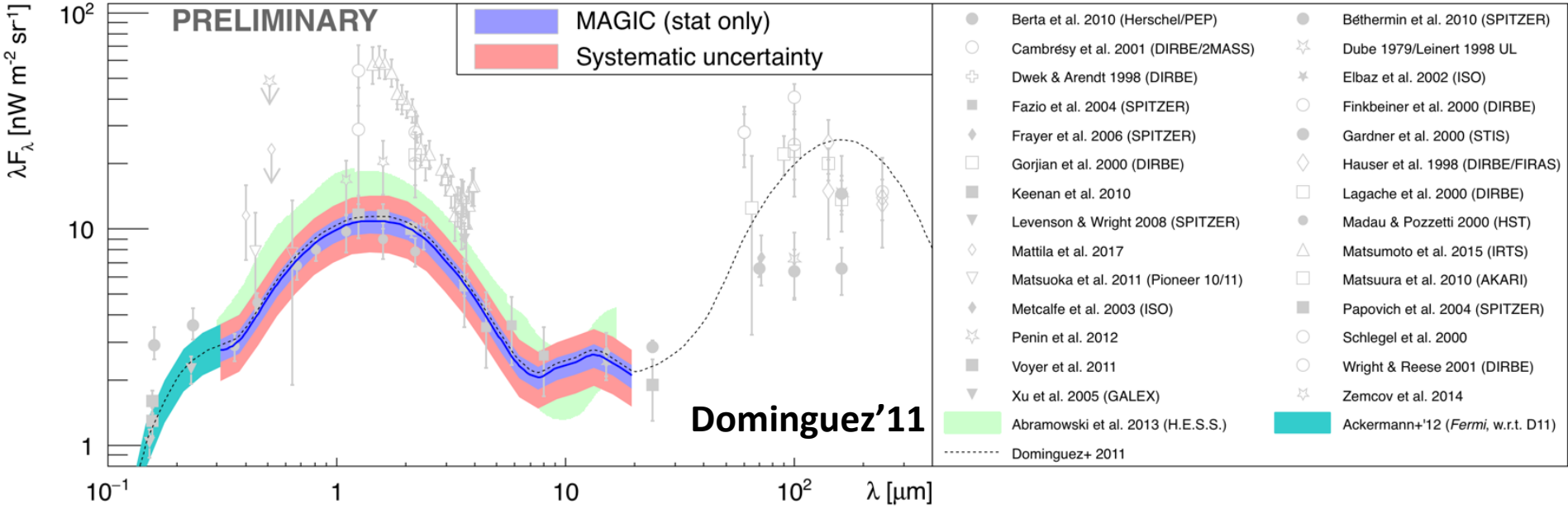
EBL measurement: MAGIC only

MAGIC measurements compared with measurements from galaxy counts (filled dots) and direct measurements (empty dots)

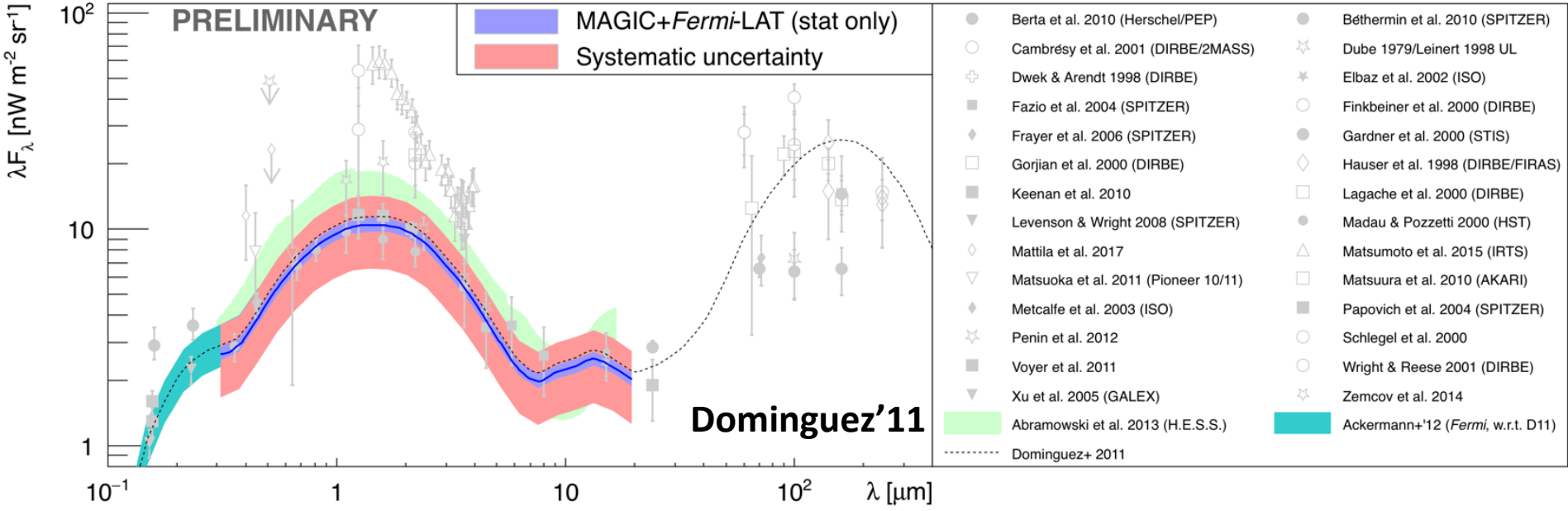


EBL measurement: MAGIC only
Comparison to other experiments

MAGIC measurements compared with **FERMI** and **HESS** measurements:

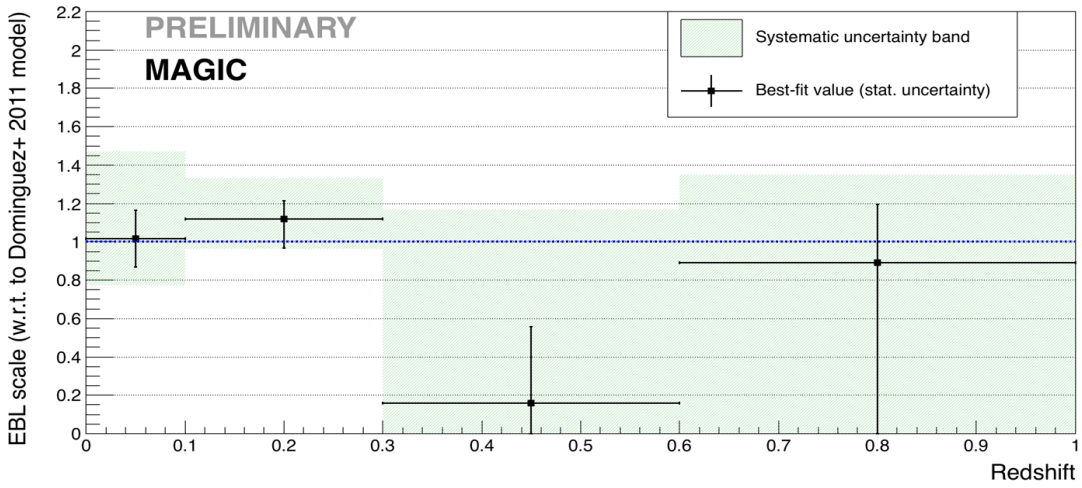


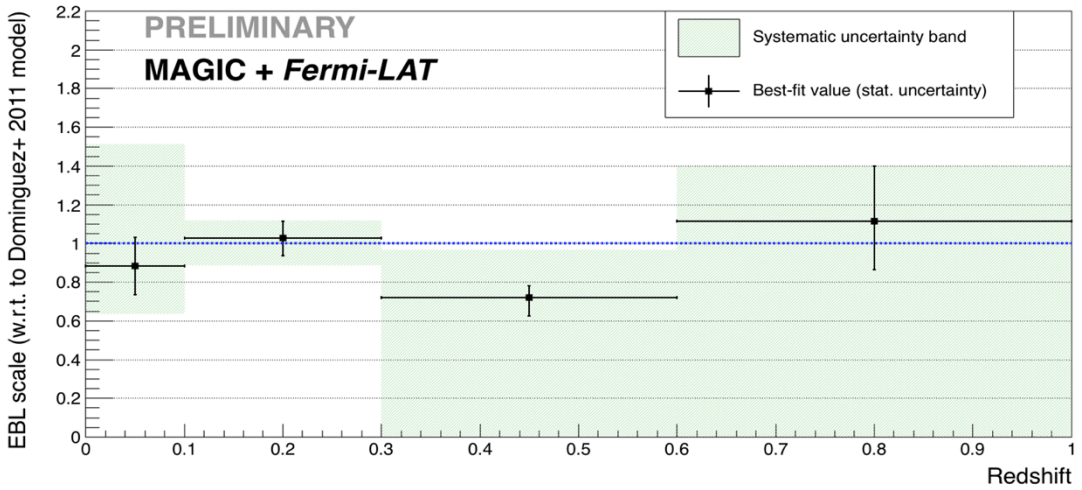
EBL measurement: MAGIC + Fermi



EBL scaling factor α vs z

Dominguez'11

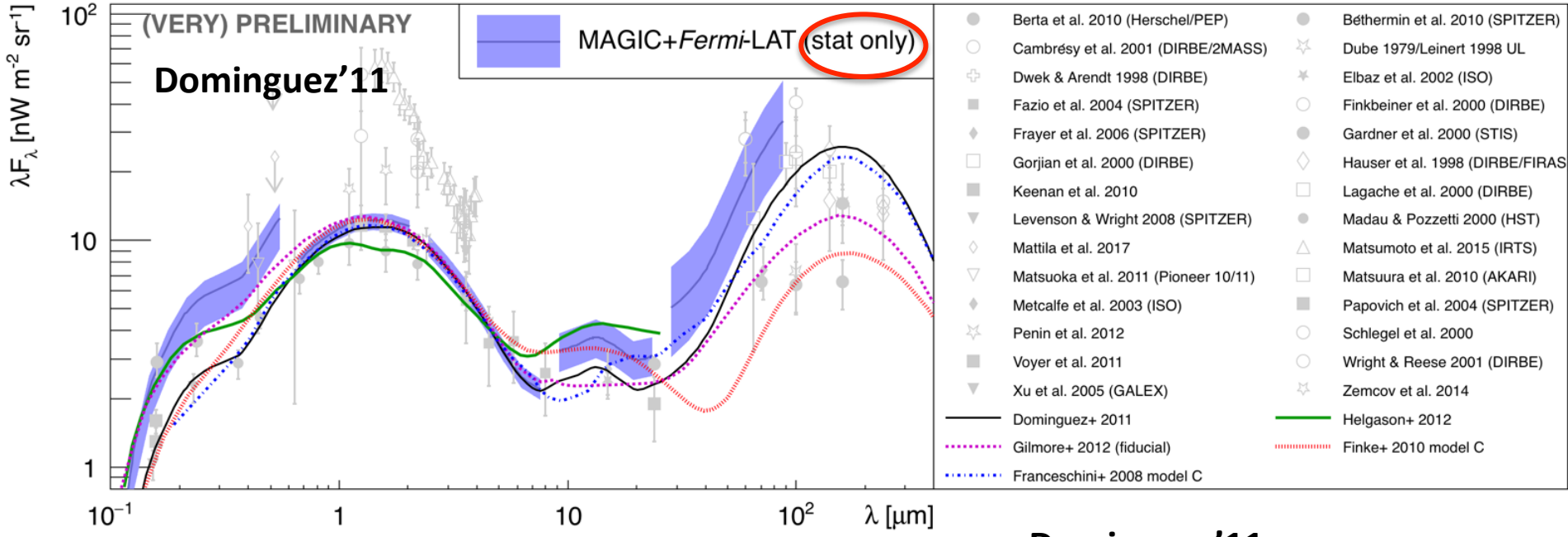




- No trend in scaling factors vs. z
- **z > 0.3**: when considering systematics, there are no lower constraints

effect of EBL cannot be distinguished from intrinsic softening

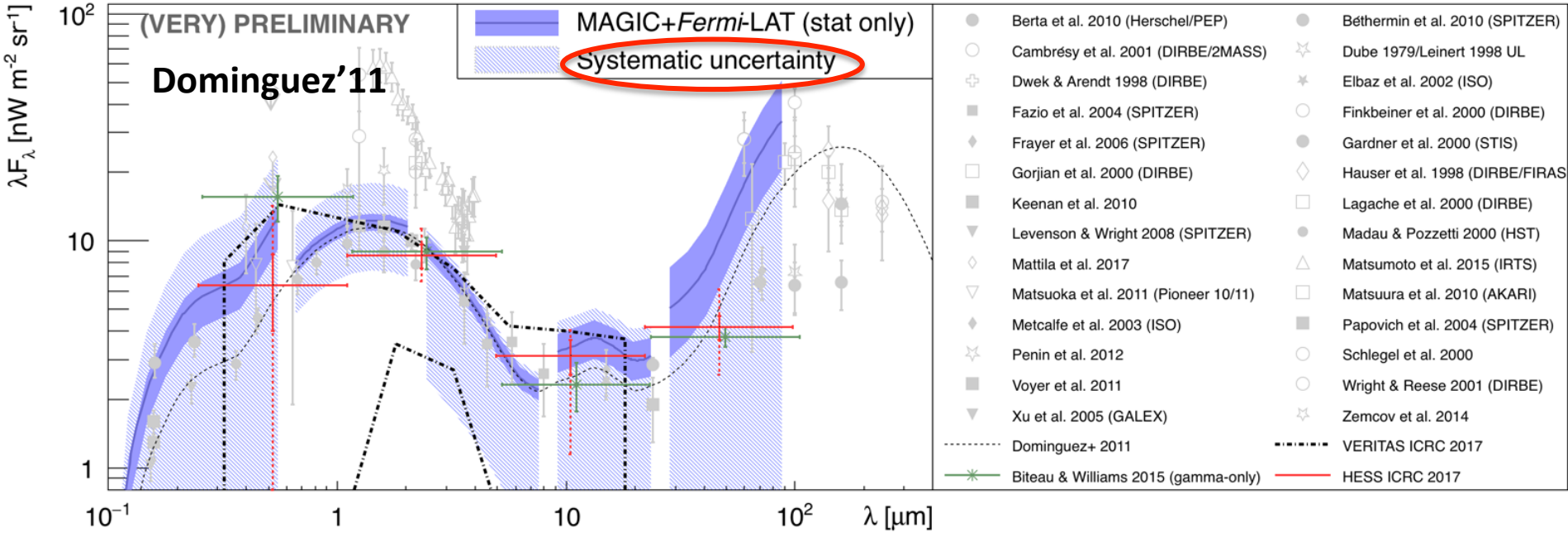
λ-resolved EBL measurement: MAGIC + Fermi (stat.only)



Dominguez'11

- Using same spectral model as previous analysis
- **$\lambda < 0.6$ μm** : compatible within ~2σ with Dominguez'11;

λ-resolved EBL measurement: MAGIC + Fermi (stat. + syst.)



- Including systematics the measurement $\lambda < 0.6$ μm is consistent
- improvement of systematics in progress

Summary

- Data: **MAGIC** observations of 12 blazars in z = 0.030 – 0.944, 316 h of observation & optionally contemporaneous **Fermi-LAT** data

- Results:: **data compatible with state of the art EBL models.** No trend with source redshift

- Best-fit values: within ≈10% of galaxy counts data (& 1-σ upper bound within 40%)

- **First time lambda-resolved EBL measurements were done!**

Thank you :)

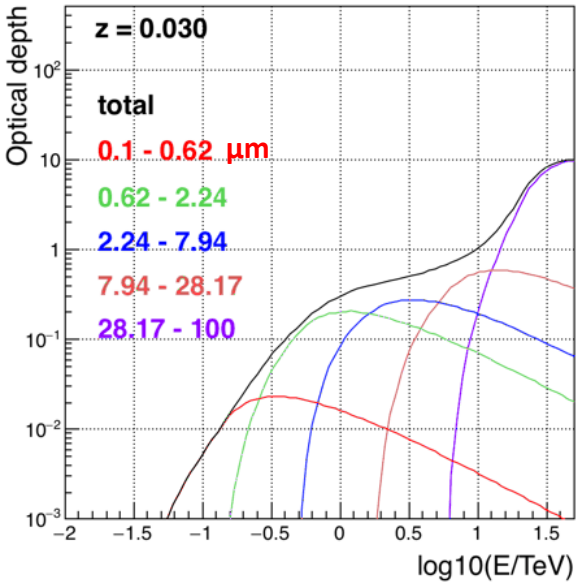
-BACK UP-

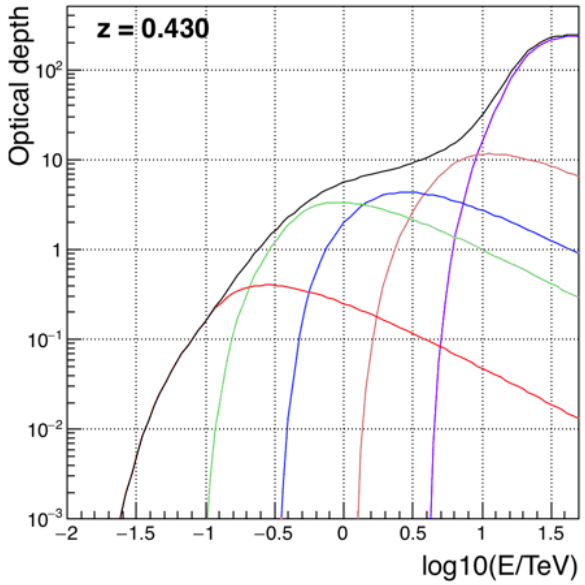
Data sample: the blazars

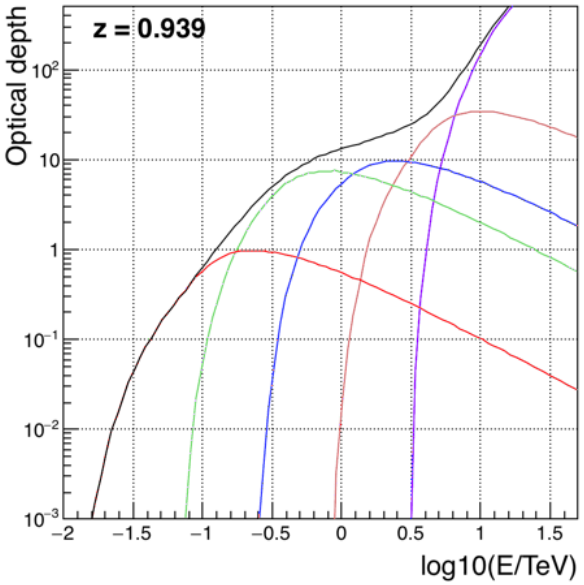
Source	type	redshift	period	observation time (h)
Markarian 421 (15 spectra)	HBL	0.030	20130410 - 19, 20140426	43.8
1ES 1959+650	HBL	0.048	20151106 - 18	4.8
OT 546 (1ES 1727+502)	HBL	0.055	20151012 - 20151102	6.4
BL Lacertae	IBL	0.069	20150615	1.0
1ES 0229+200	HBL	0.14	2012 - 2015	105.2
1ES 1011+496	HBL	0.212	20140206 - 20140307	11.8
PKS 1510-089 (2 spectra)	FSRQ	0.361	20150518-19, 20160531	5.0
PKS 1222+216	FSRQ	0.432	20100618	0.5
PG 1553+113 (5 spectra)	HBL	0.43 - 0.58	2012 - 2016	66.4
PKS 1424+240 (2 spectra)	HBL	0.604	2014 - 2015	49.1
PKS 1441+25	FSRQ	0.939	20150418 - 20150423	20.1
QSO B0218+35	FSRQ	0.944	20140725 - 20140726	2.1

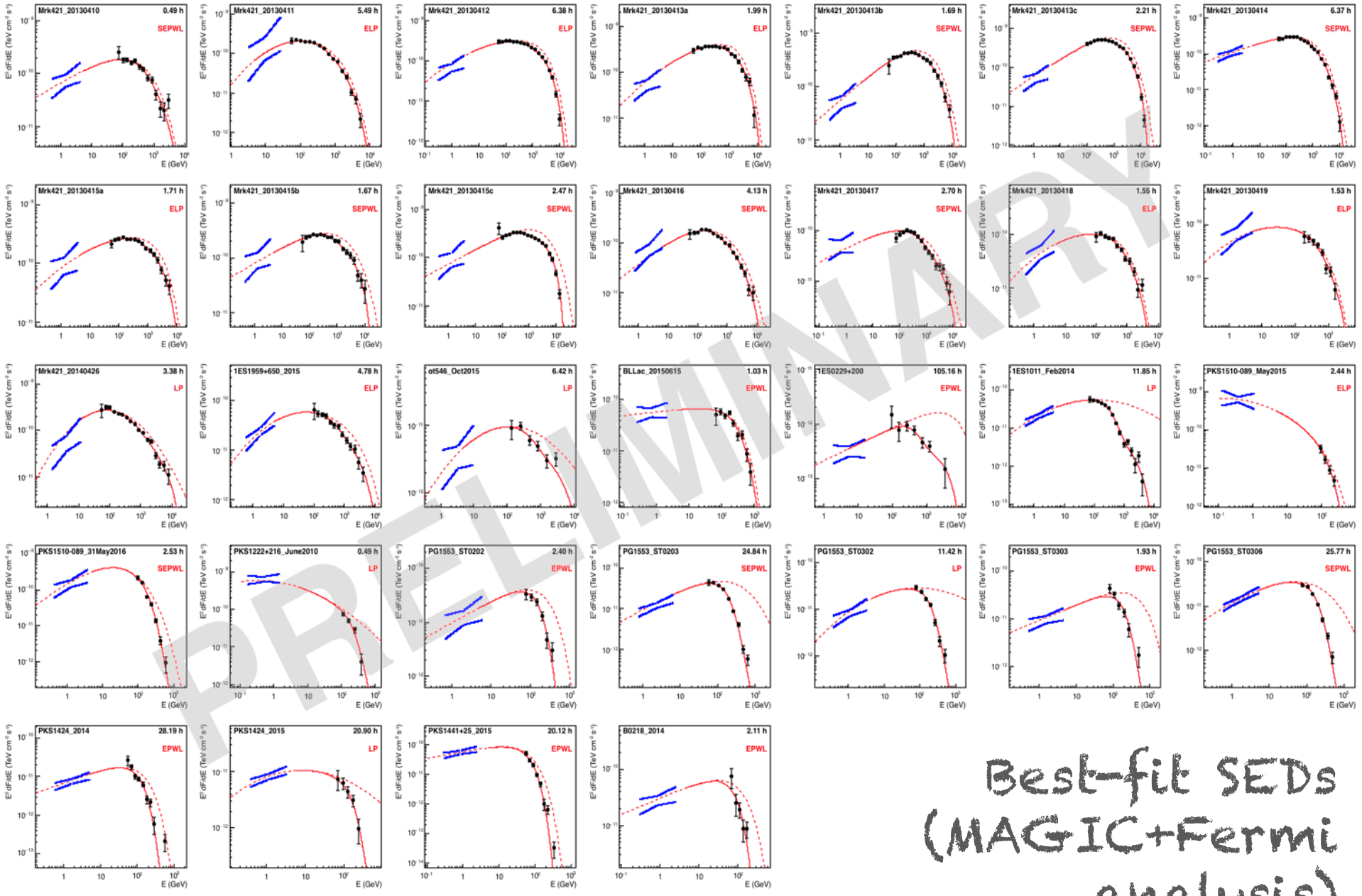
Table 1: *List of the 32 MAGIC spectra used in the determination of the EBL density.*

Optical depth: λ-resolved EBL measurement









PRELIMINARY

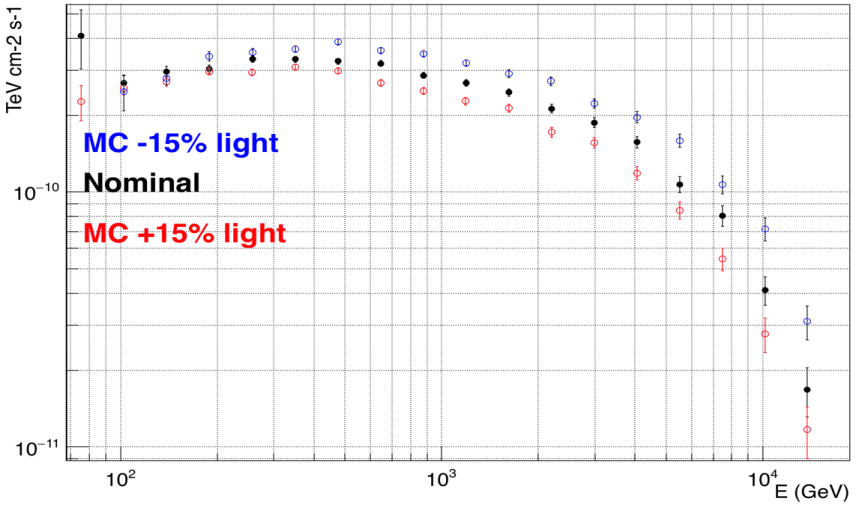
Best-fit SEDs (MAGIC+Fermi analysis)

Systematic uncertainties

To asses systematic, following approach:

- to test average miscalibration: re-analysed data with modified assumption on total light (atmosphere+telescopes)

  scaled light by ±15% *for all spectra*



- Allowed different selection of intrinsic spectrum:

  - selected **PWL**, when it provided best P-value (12 cases for the MAGIC-only analysis)

  - used models which best fit the *observed* spectra – i.e., most degenerate with the EBL imprint