The EBL imprint on H.E.S.S. blazar spectra

Jonathan Biteau, B. Giebels, D. A. Sanchez and M. Raue for the **H.E.S.S. collaboration**

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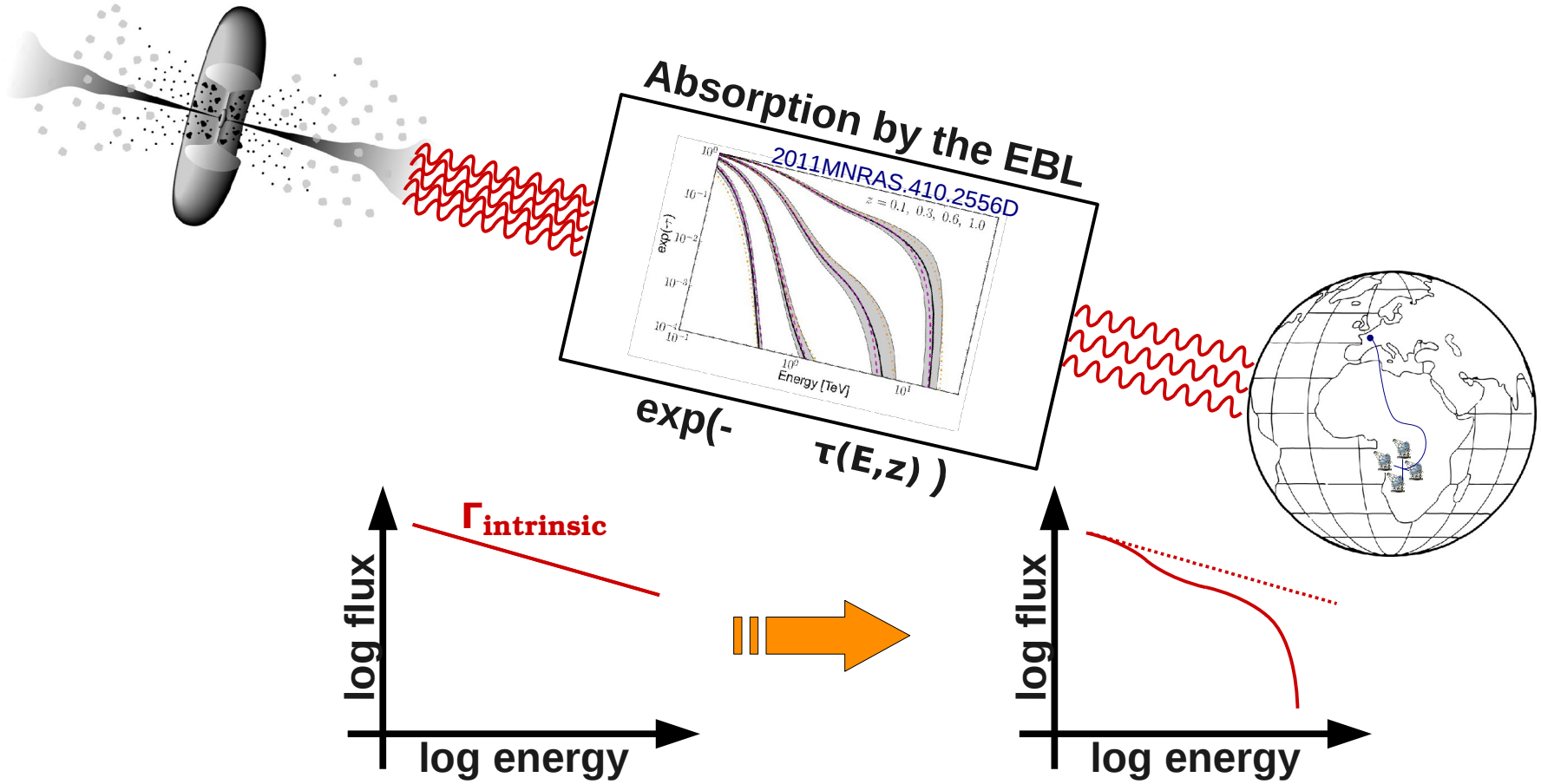
Constraints on the EBL with VHE blazars



So far

- **Power law** spectrum (no curvature)
- $\Gamma_{intrinsic}$ > 1.5 or $\Gamma_{intrinsic} > \Gamma_{Fermi\text{-}LAT}$

⇒ **Upper limit on the EBL density**

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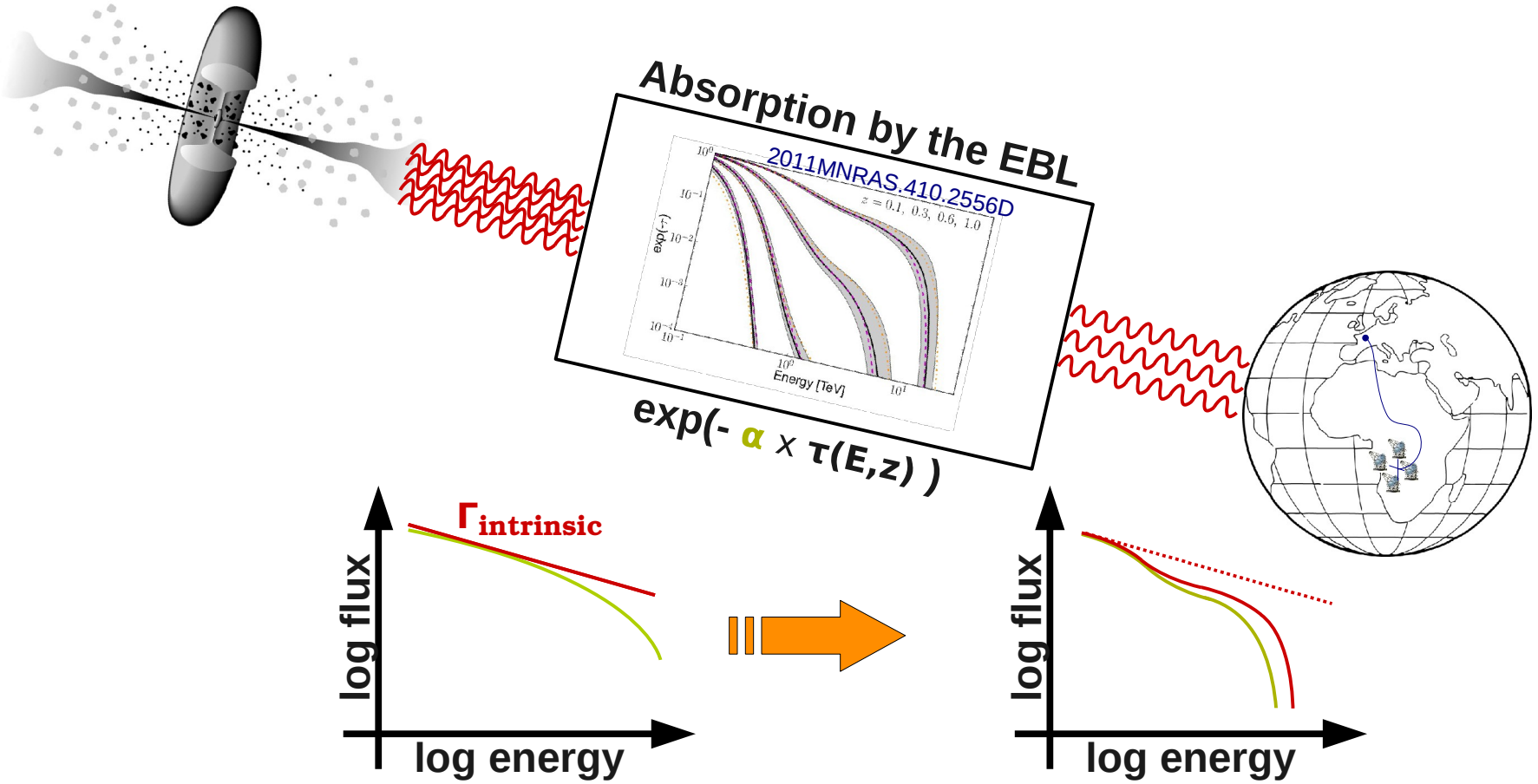

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This work

- **Curvature** allowed, **free parameters**
- Parametrization of the EBL optical depth via a **scaling factor α**
- Fit of a **large VHE data set**

⇒ **Measurement of the EBL density**

A large set of extragalactic VHE γ-rays

GAMMA-RAY ASTRONOMY

Catching photons from hell

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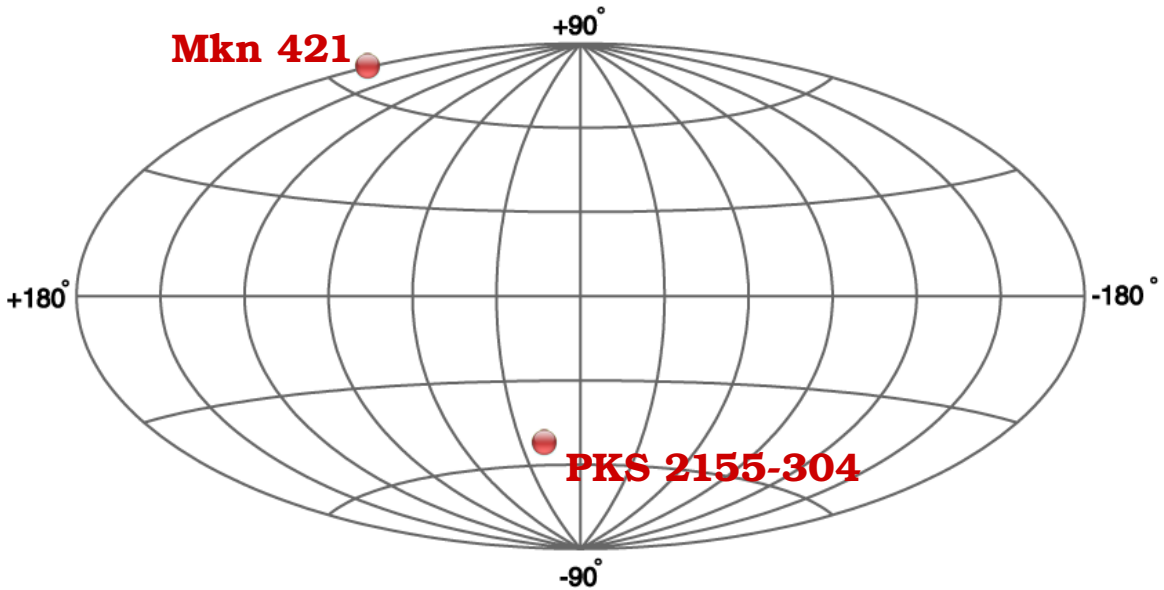

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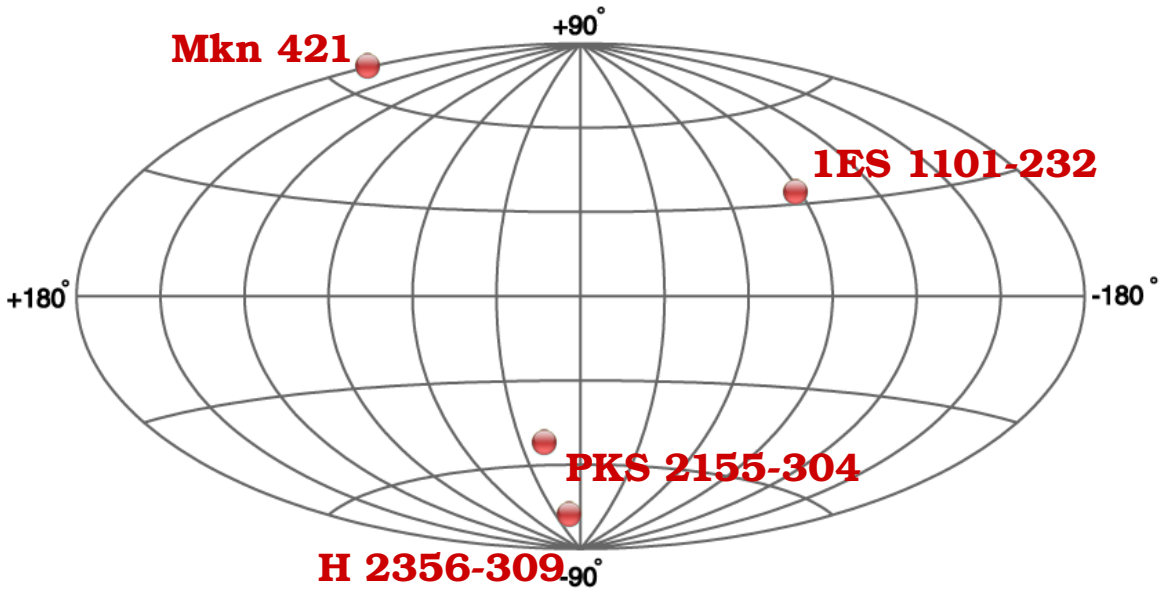

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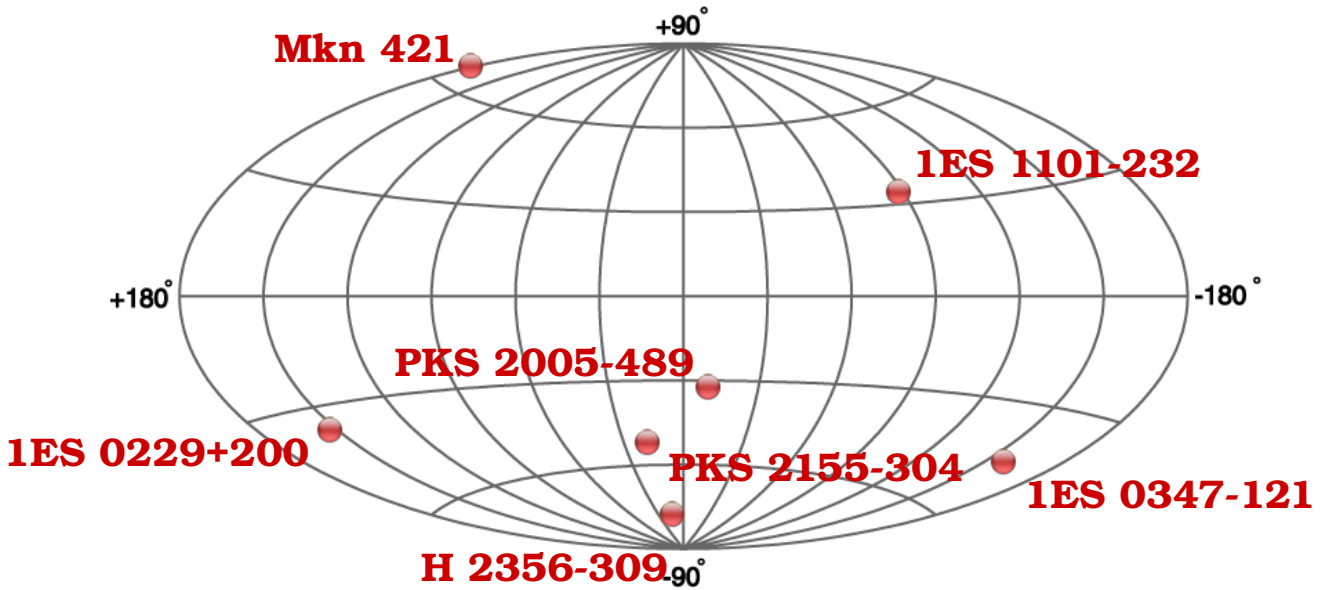

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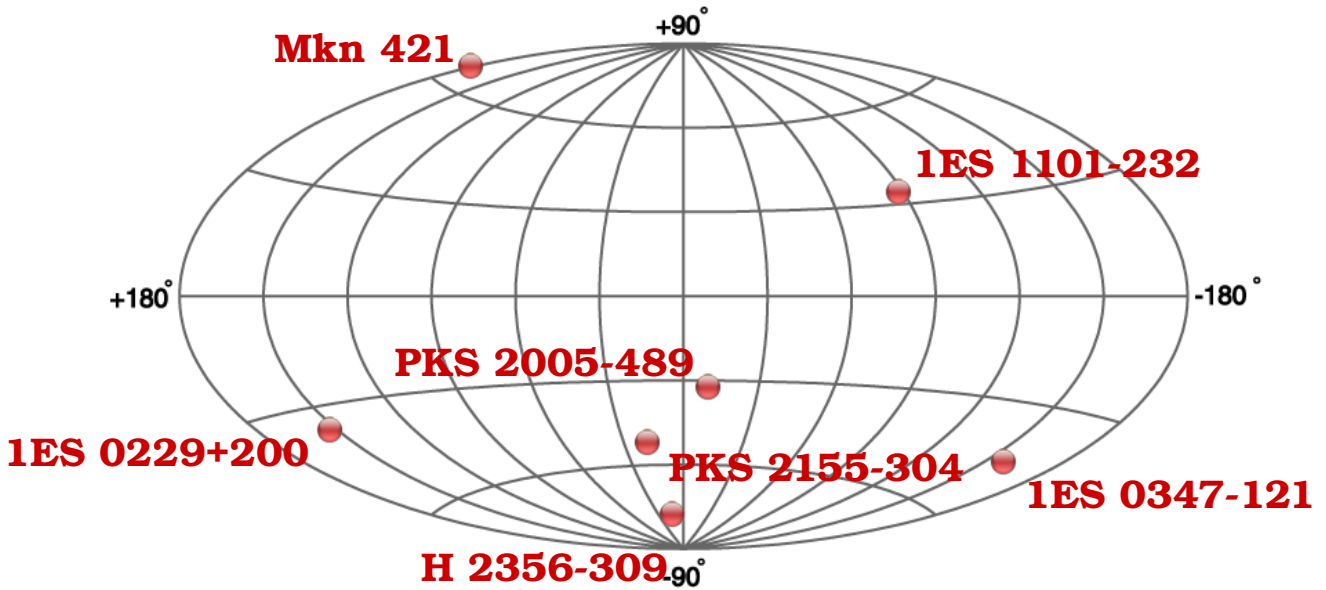

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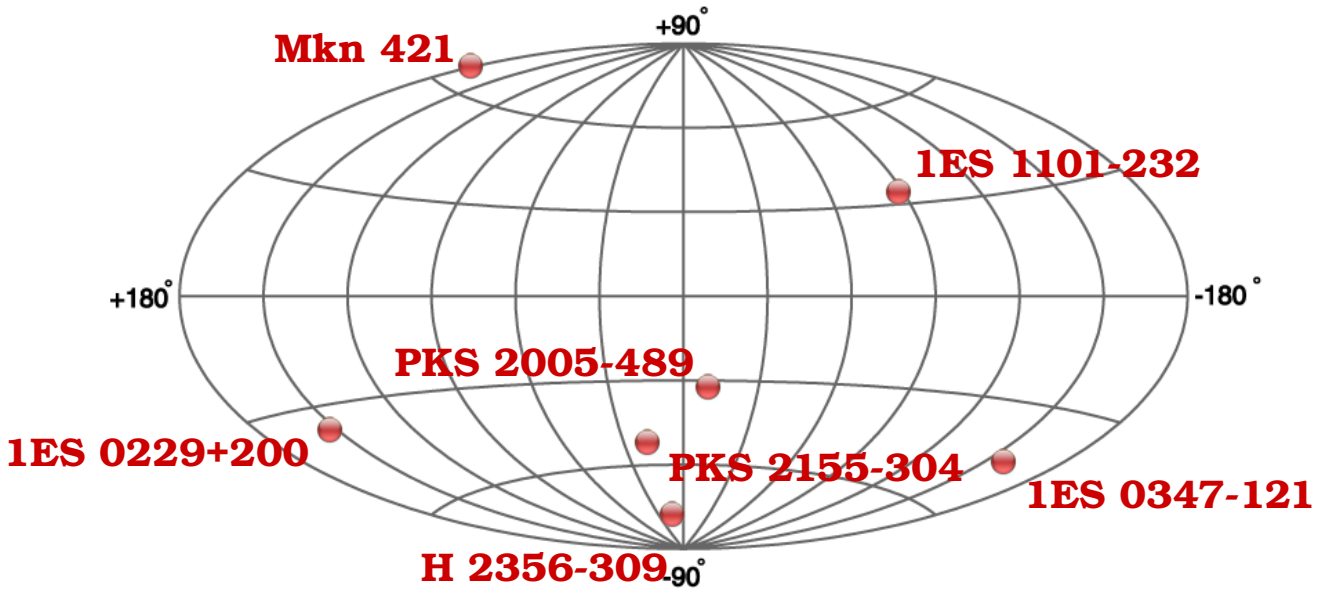

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Data sets on highly significant sources were divided and sorted by flux level

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Hypotheses and spectral analysis

$$\boxed{\phi_z(E)} = \boxed{\phi_{\mathrm{int}}^{\alpha}(E)} \times \boxed{\exp(-\boxed{\alpha} \times \tau(E, z, n))}$$

observed **intrinsic** **EBL absorption**

Same parametrization as in Abdo et al. 2010, ApJ, 723, 1082

Fermi Large Area Telescope Constraints on the Gamma-ray Opacity of the Universe

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Aim : Fit of the scaling factor α combining data sets

Hypotheses :

- **Template EBL model : Franceschini et al., 2008, A&A, 487, 837**
  Extragalactic optical-infrared background radiation, its time evolution and the cosmic photon-photon opacity,
- **Intrinsic spectrum described with :**

Name	Abbrev.	Function
Power law	PWL	$\phi_0 (E/E_0)^{-\Gamma}$
Log parabola	LP	$\phi_0 (E/E_0)^{-a-b\log(E/E_0)}$
Exponential cut-off power law	EPWL	$\phi_0 (E/E_0)^{-\Gamma} \exp(-E/E_{\text{cut}})$
Exponential cut-off log parabola	ELP	$\phi_0 (E/E_0)^{-a-b\log(E/E_0)} \exp(-E/E_{\text{cut}})$
Super exponential cut-off power law	SEPWL	$\phi_0 (E/E_0)^{-\Gamma} \exp(-(E/E_{\text{cut}})^{\gamma})$

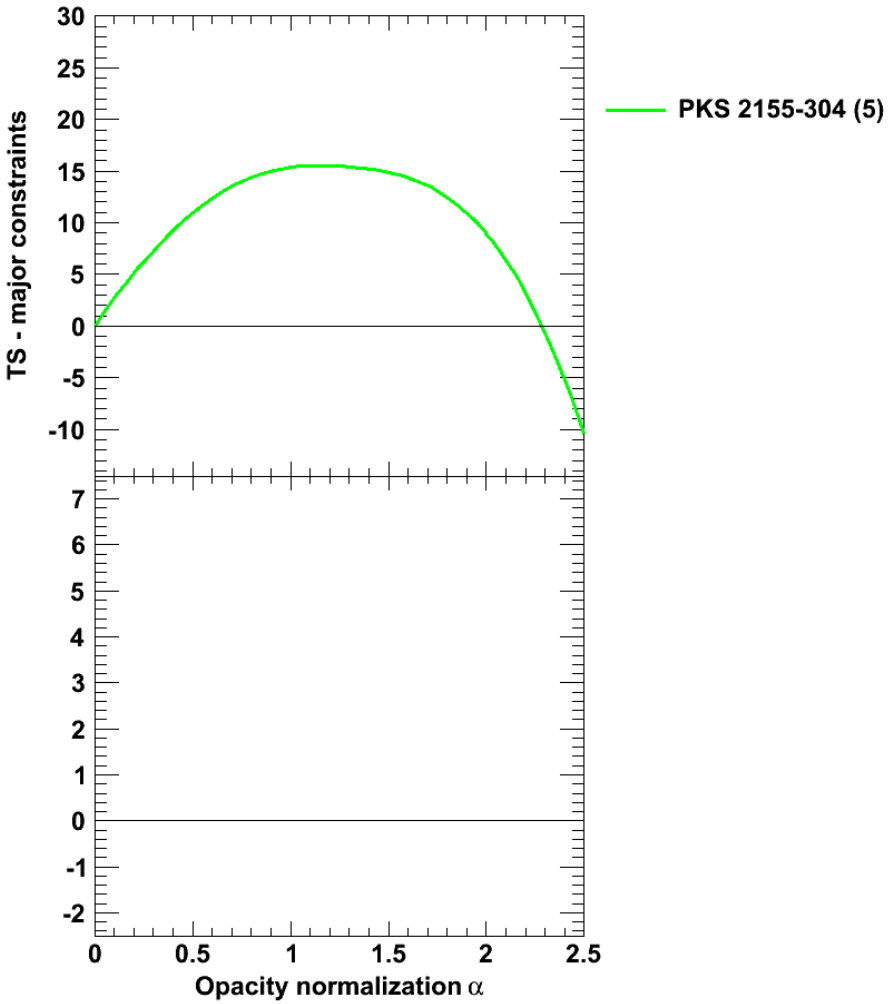
Method :

- **Likelihood profiles for each {data set, spectral model}**
- **Selection of the spectral model with the largest χ^2 probability**

Stacking : sum of the likelihood profiles

Null hypothesis : no EBL, i.e. α=0

$$\mathrm{TS} = 2\log\left[\mathcal{L}(\alpha)/\mathcal{L}(\alpha=0)\right]$$



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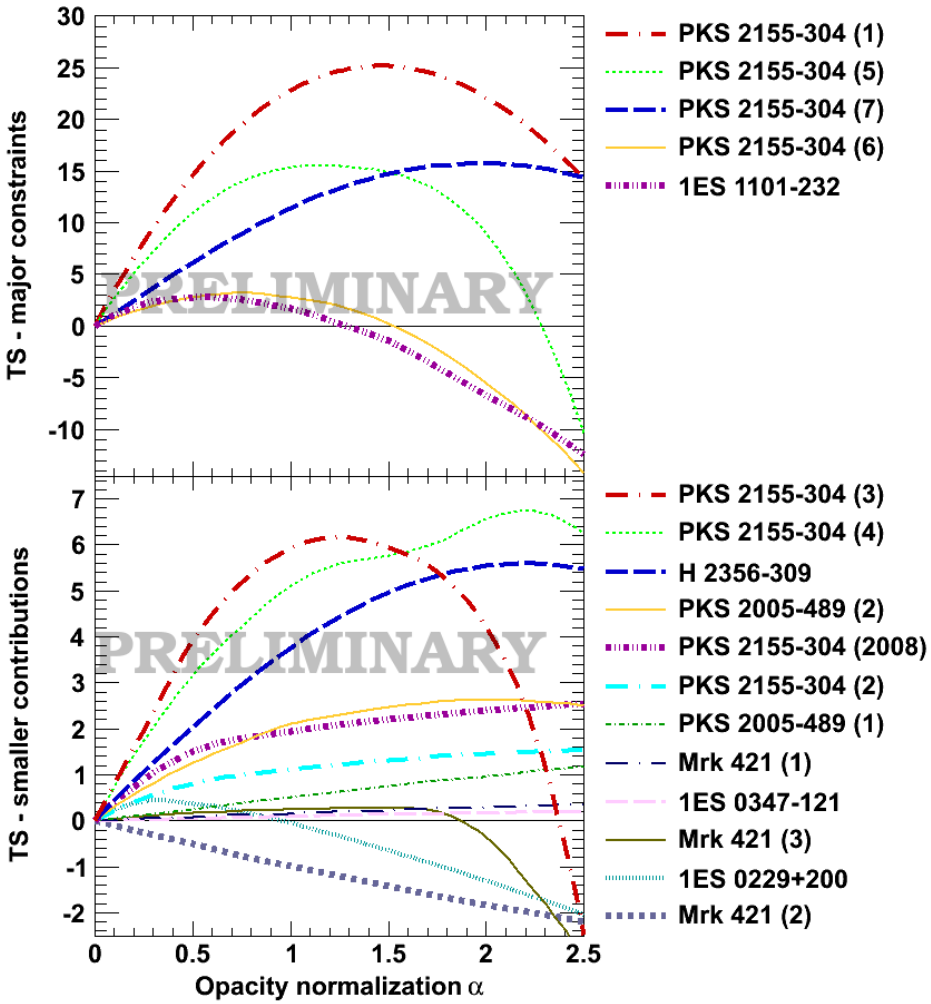

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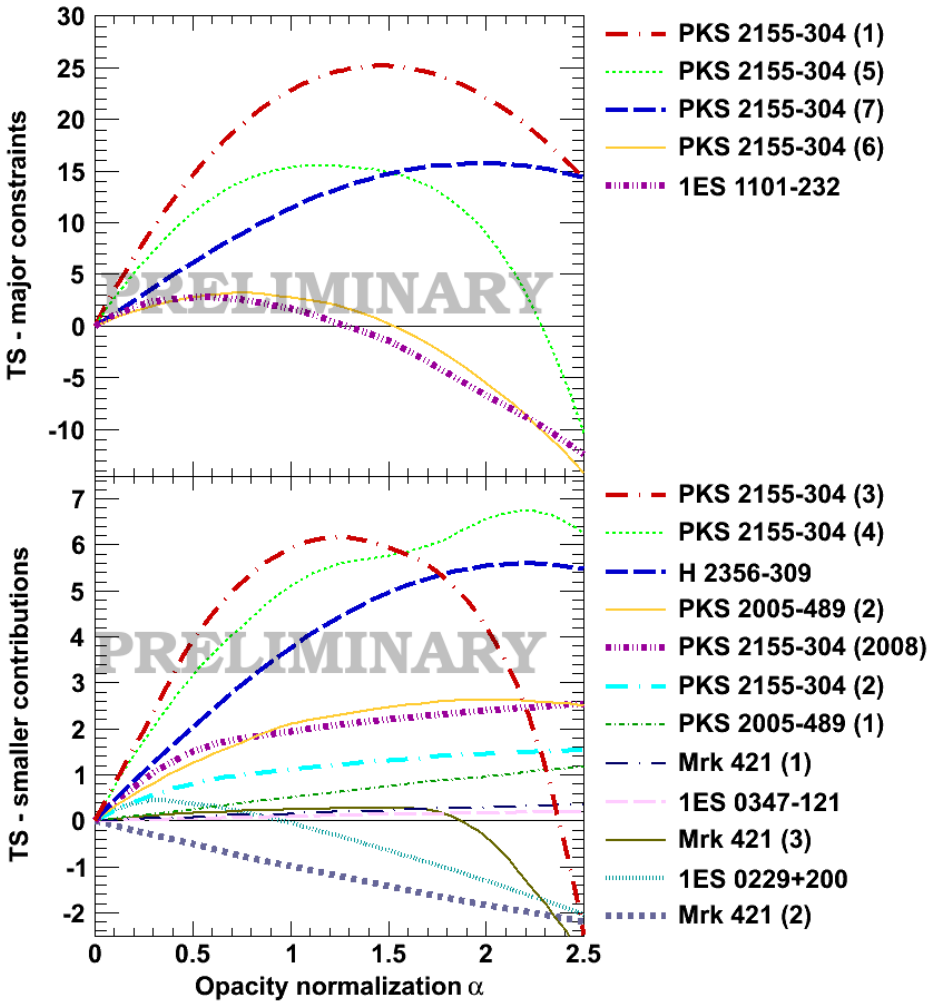

combining the individual TS

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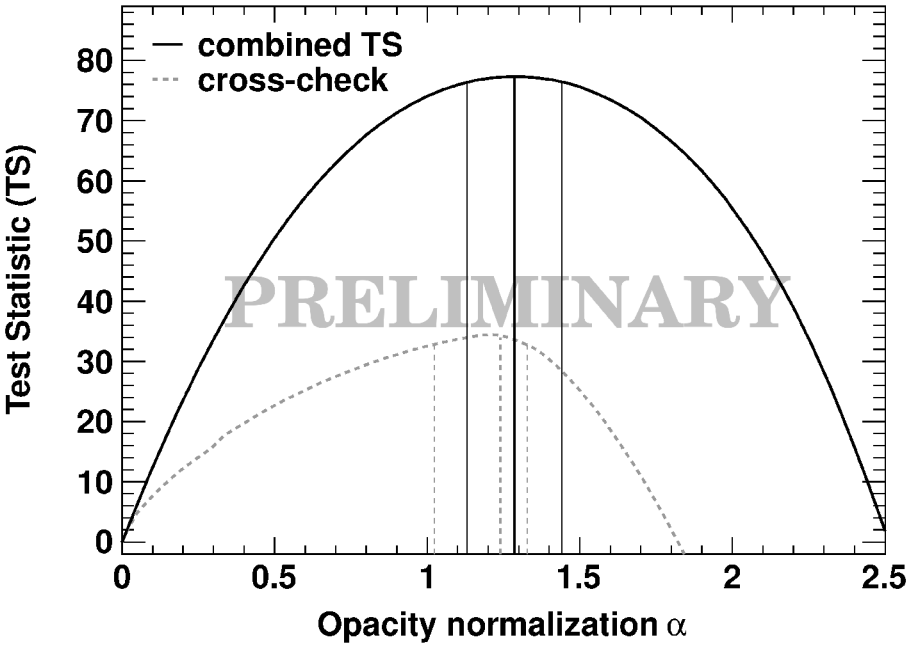

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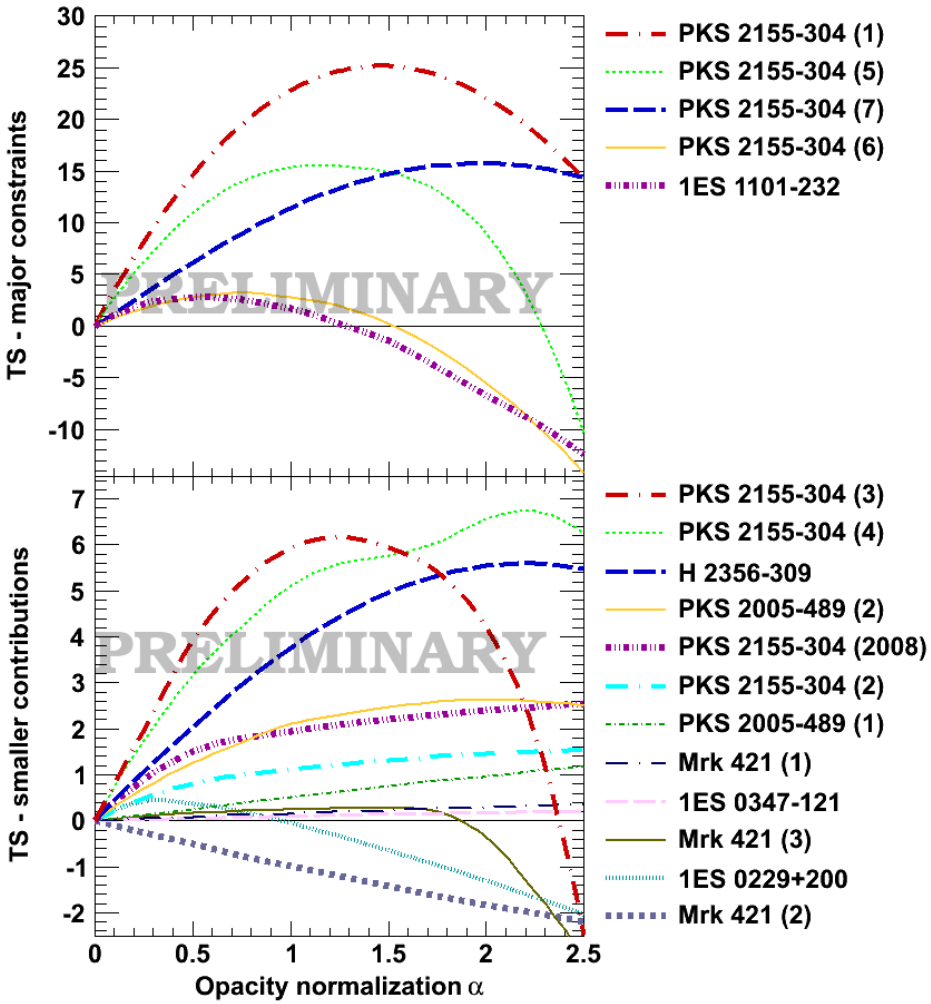

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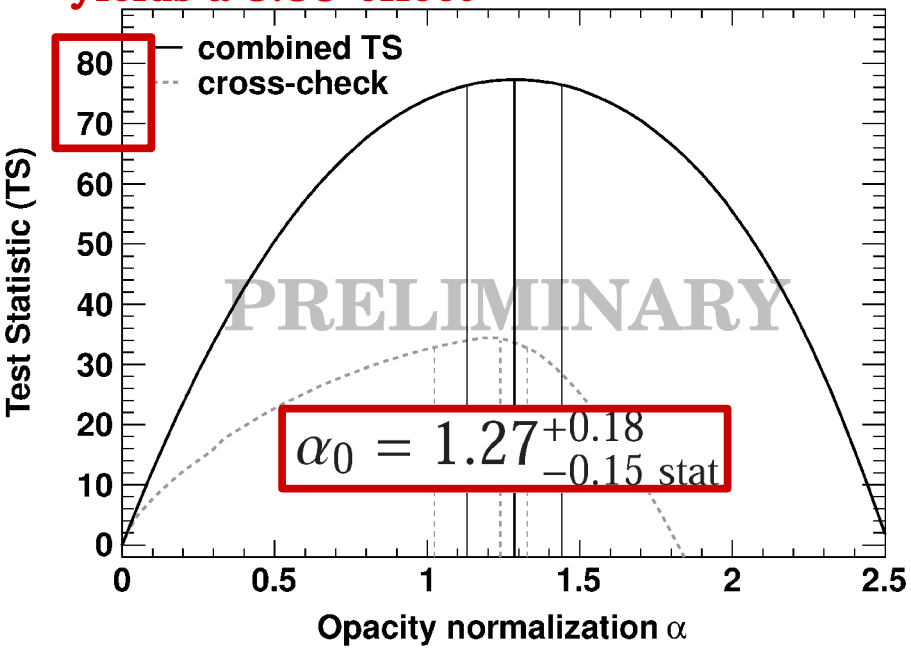
yields a 8.8σ effect



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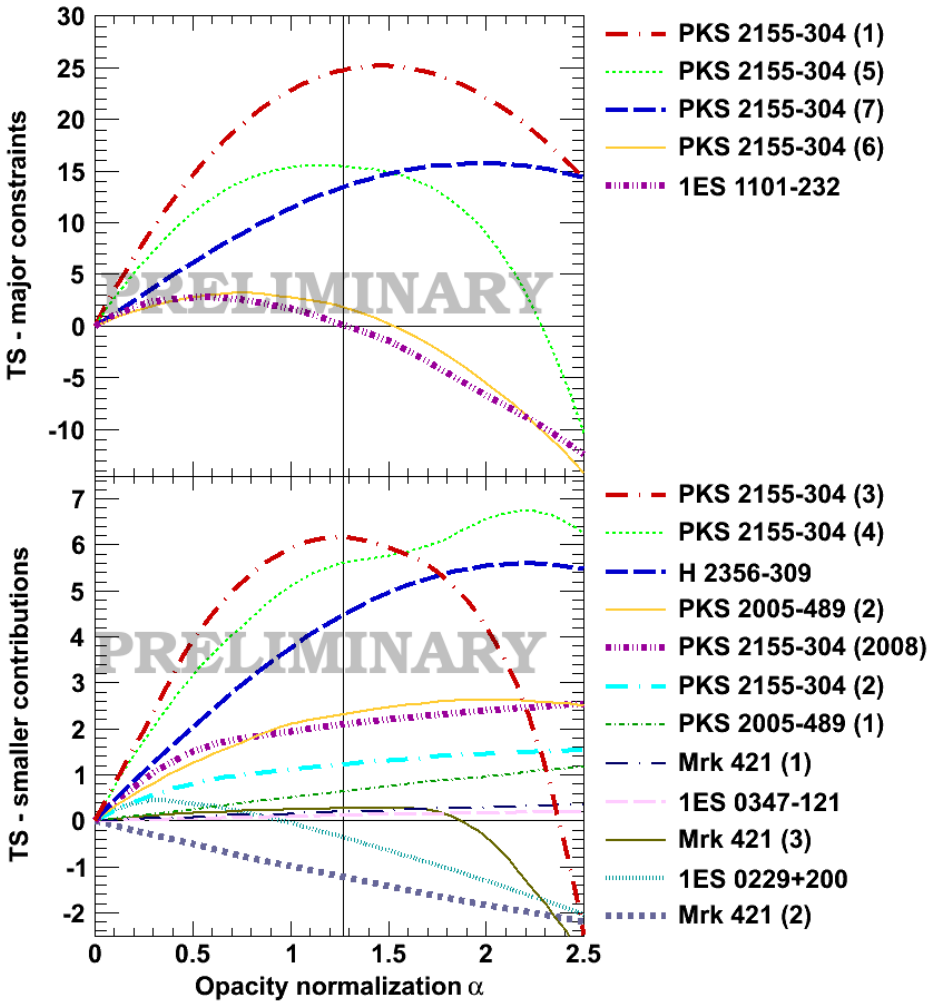

No outlier

No significant variation over redshift

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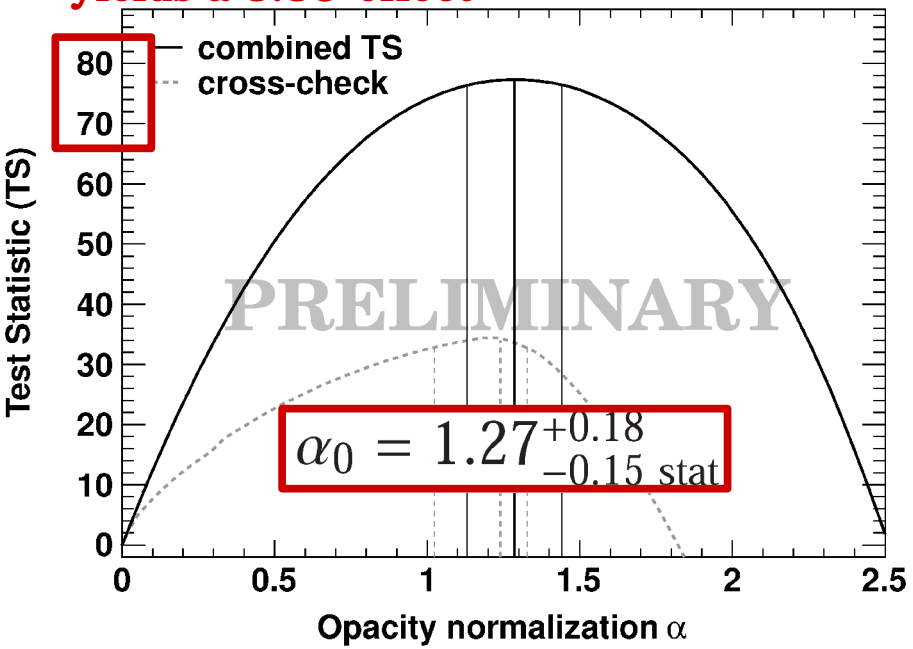

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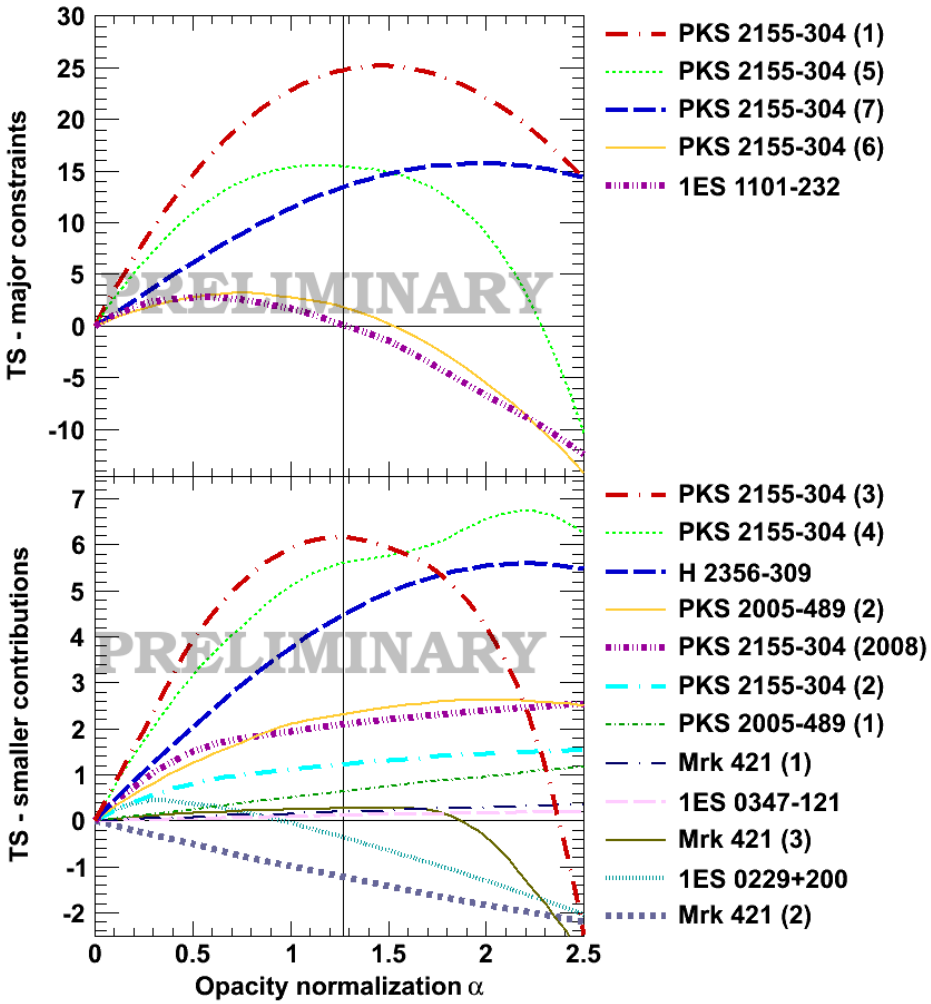

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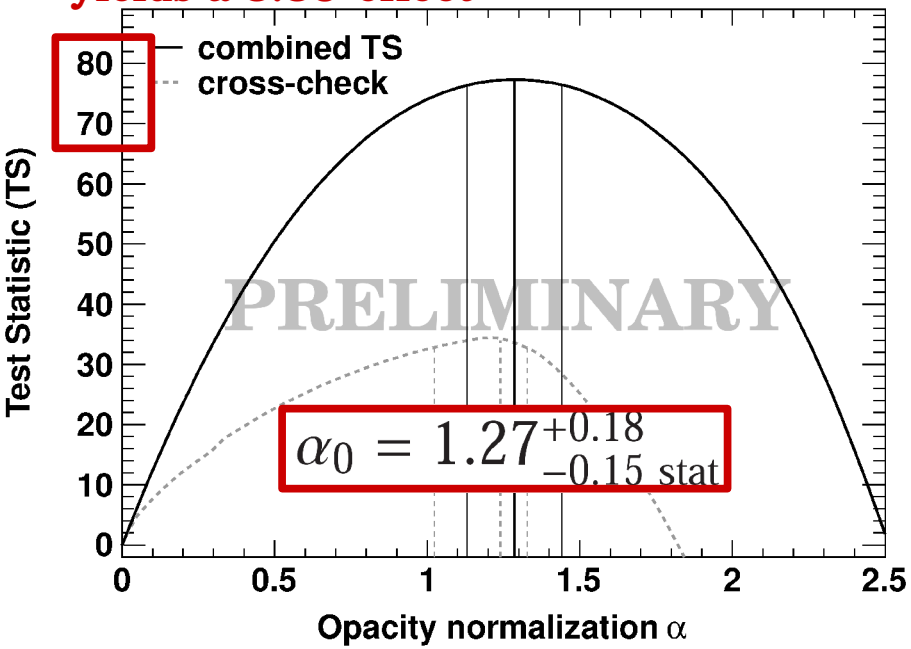
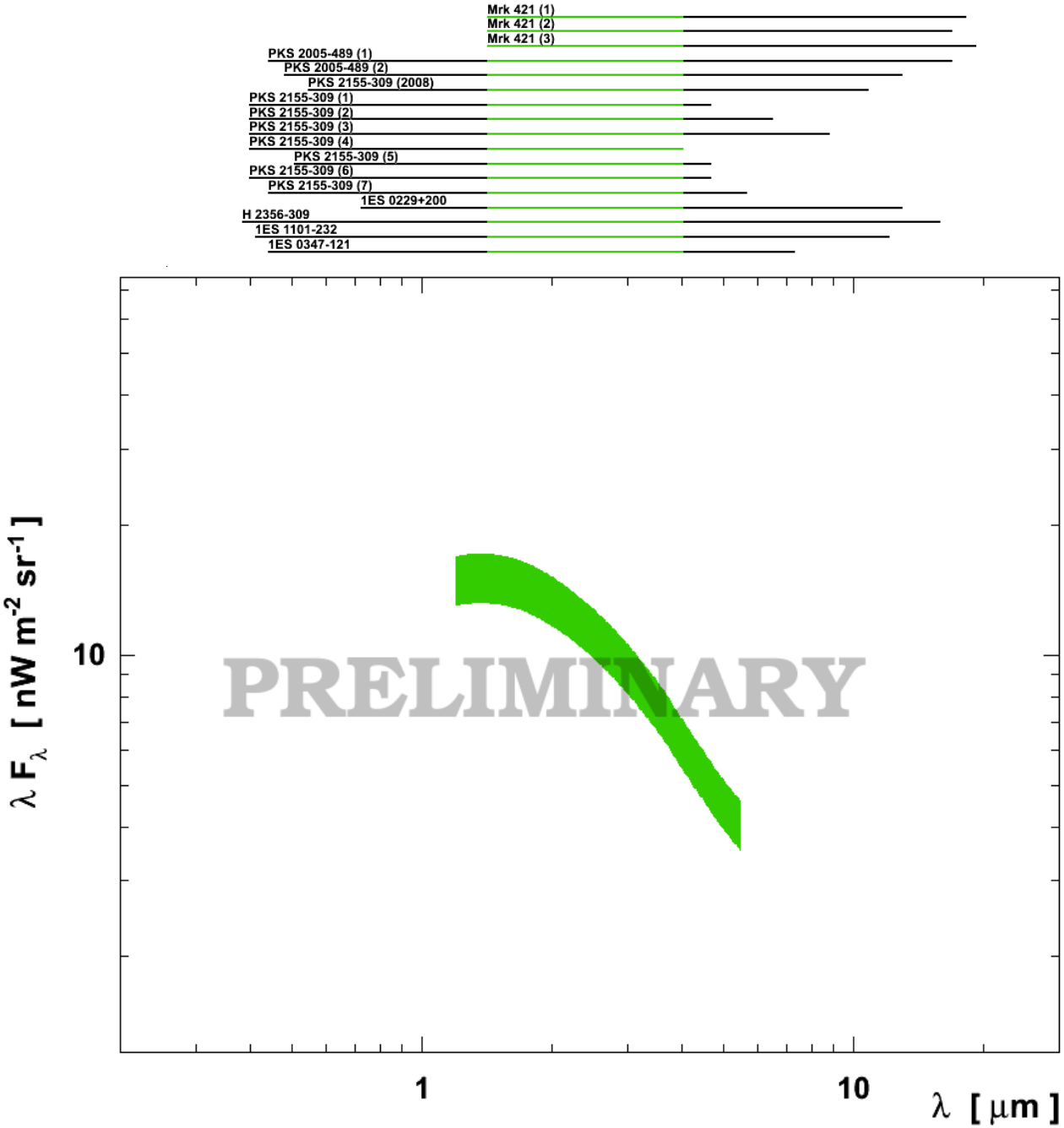
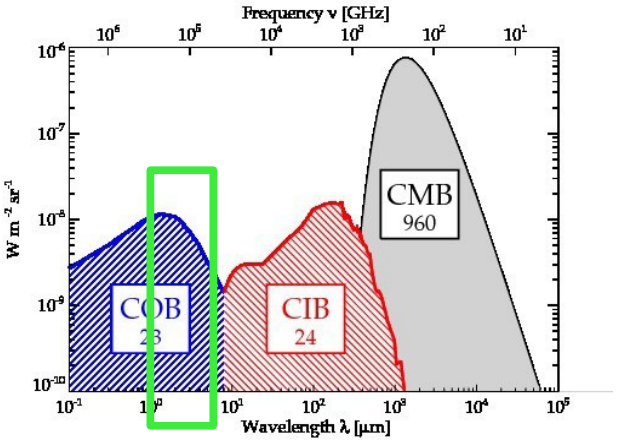


Sources of systematics	Estimated systematics
Analysis chain	0.21
Intrinsic model	0.10
EBL model	0.06
Energy scale	0.05
Total	**0.25**

Full study of the systematics

In astrophysical/cosmological terms





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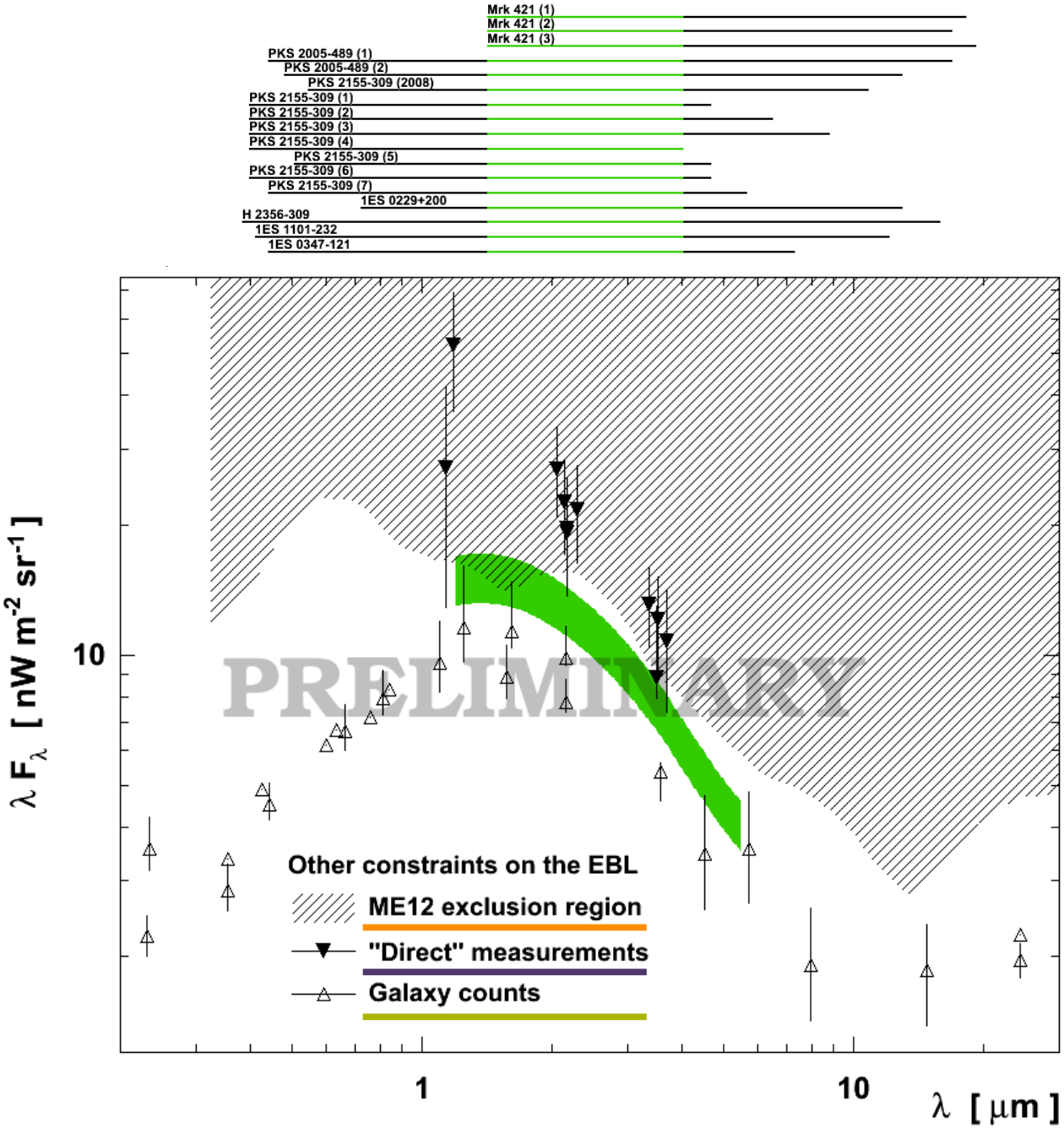

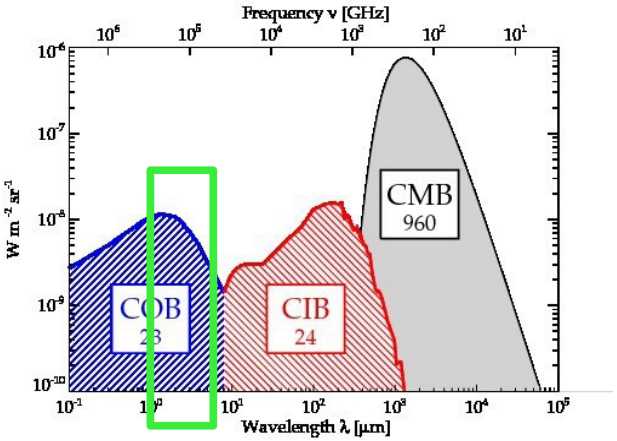

Good agreement with TeV UL

Good agreement with direct measurements (upper limits)

Good agreement with galaxy counts (lower limits)

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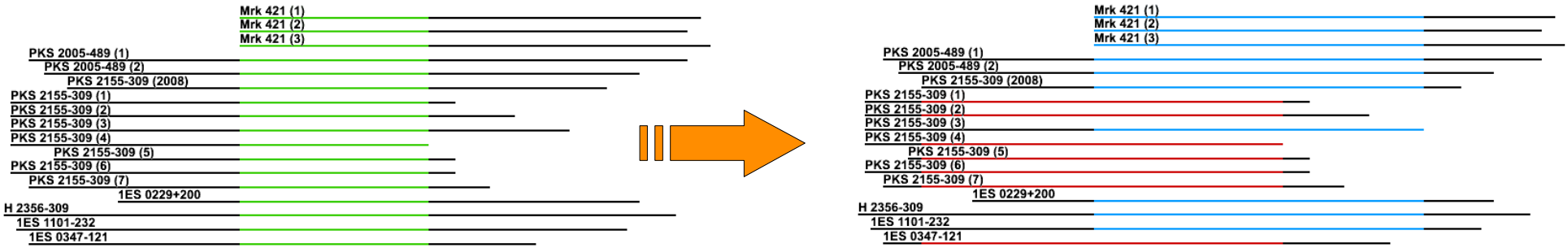

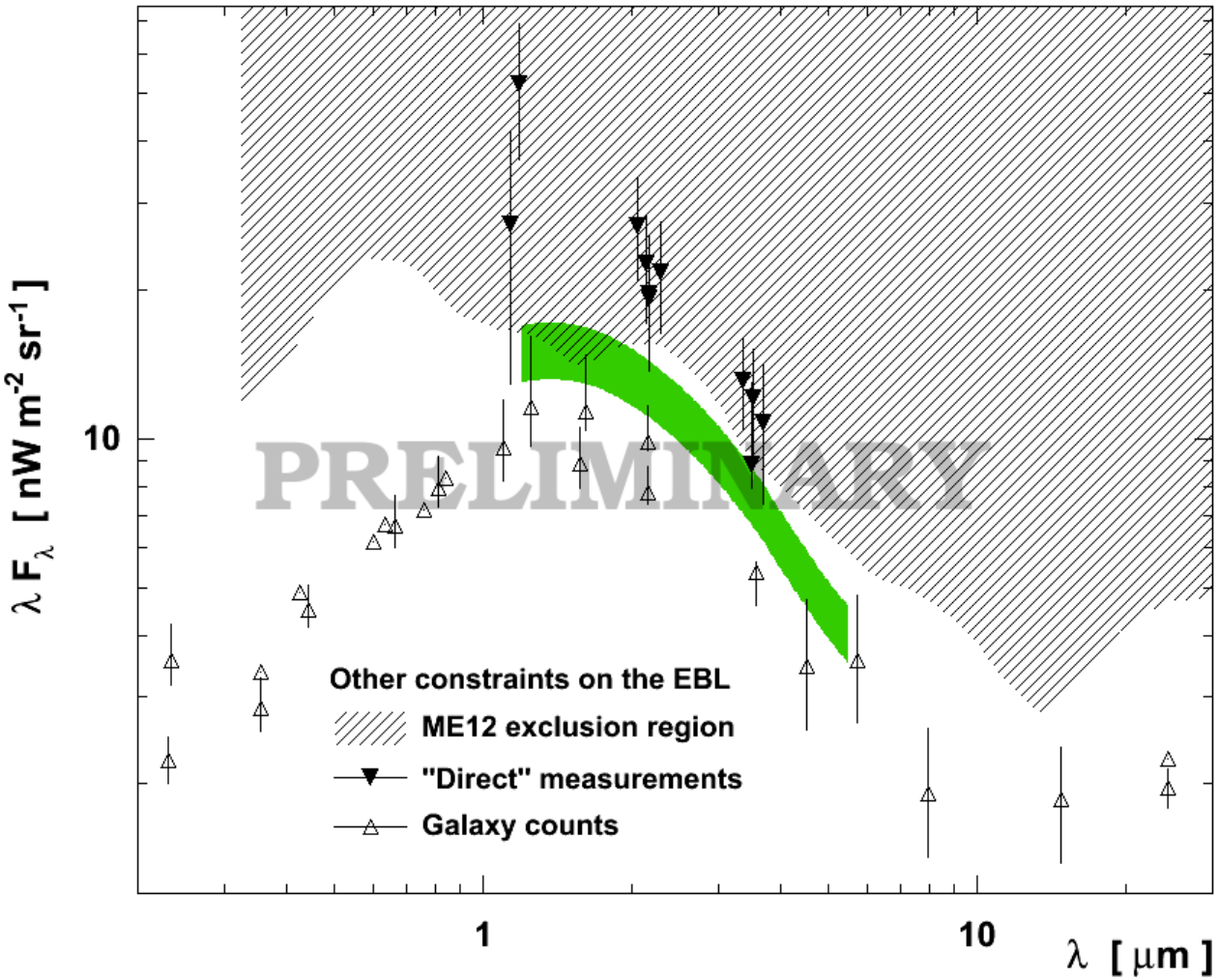

Enough data to split in two groups

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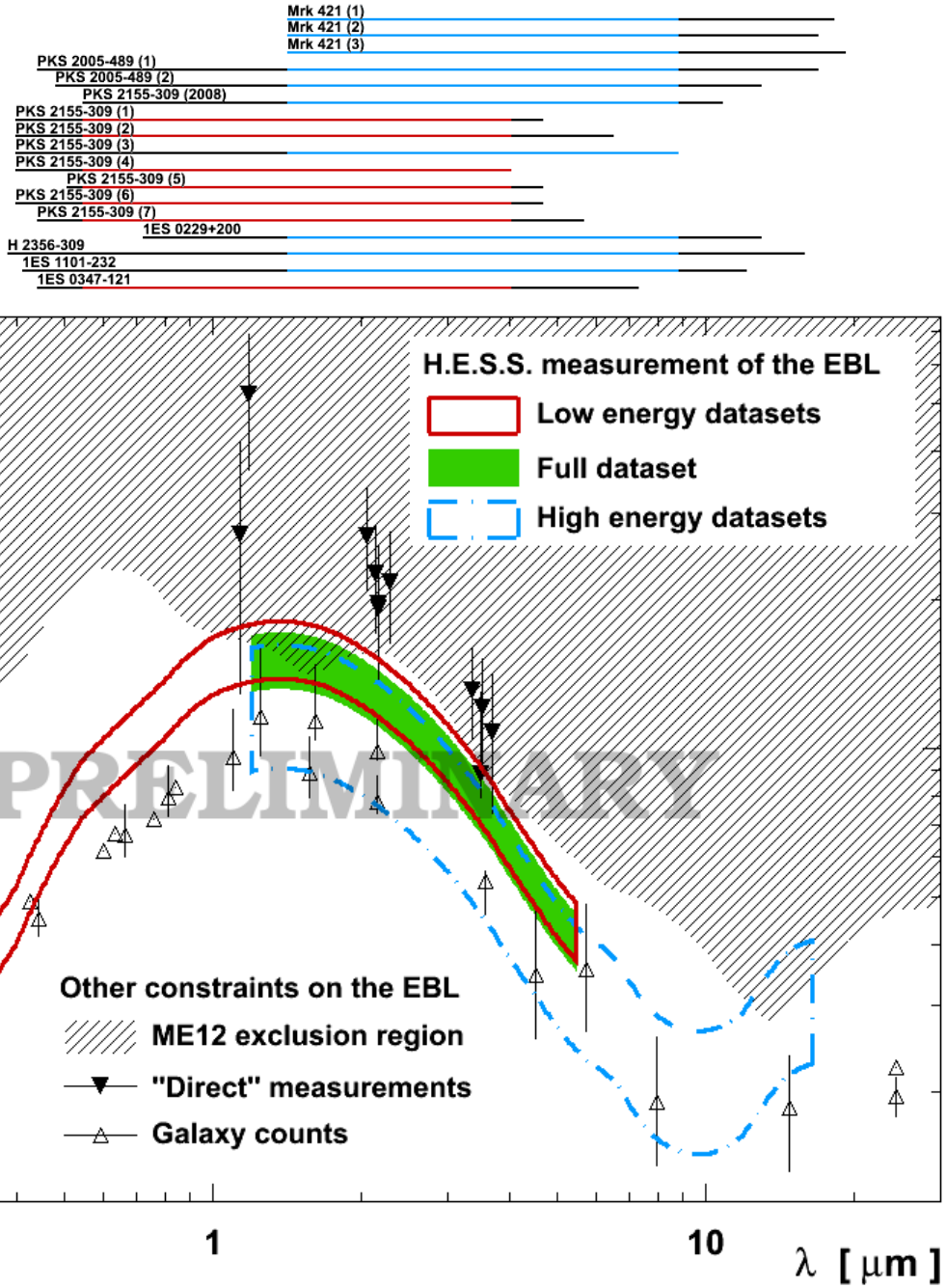
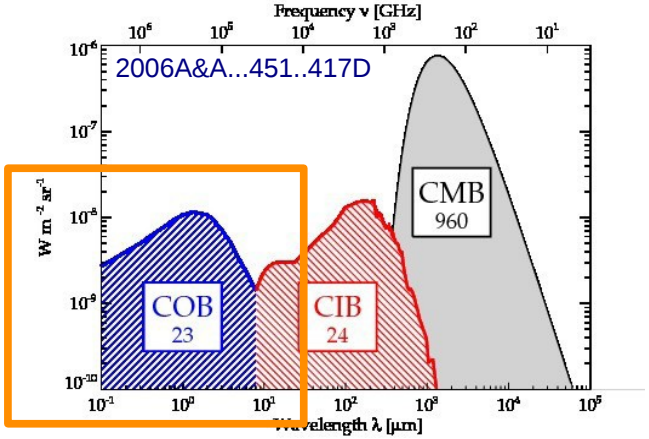
In astrophysical/cosmological terms





Full coverage of the COB, the first EBL bump.

Good agreement with TeV UL

Good agreement with direct measurements (upper limits)

Good agreement with galaxy counts (lower limits)

Conclusion and perspectives

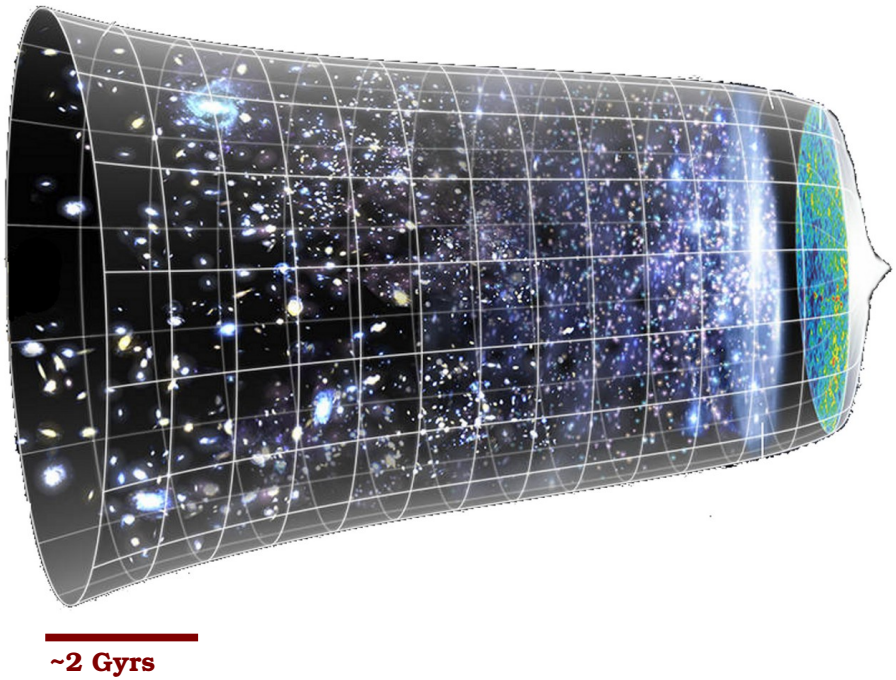
Conclusion :

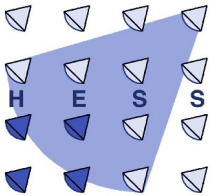
- **1st significant detection of the EBL signature in γ-ray spectra**
  → at the ~9σ level
- **New method to constrain the EBL flux density**
  → probe of ~2 decades of wavelengths

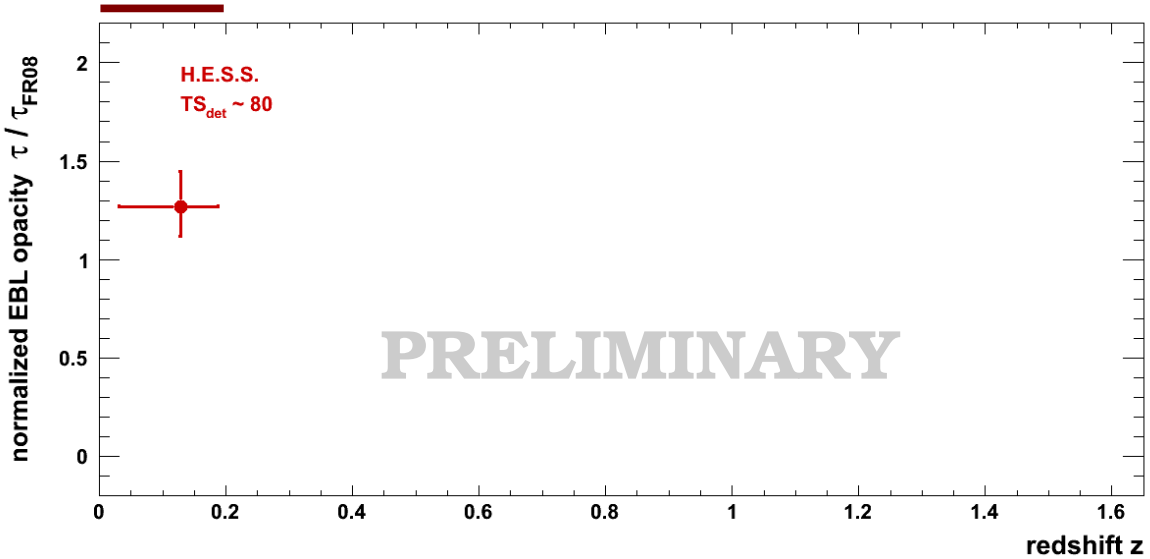
Perspectives :

- **Keep on monitoring with H.E.S.S.**
  → increase the statistics on the bright sources / flaring events
  → increase the number of sources
- **Lower the energy threshold with H.E.S.S. II**
  → direct probe of the unabsorbed part of the spectrum (low z)
  → search for higher z sources

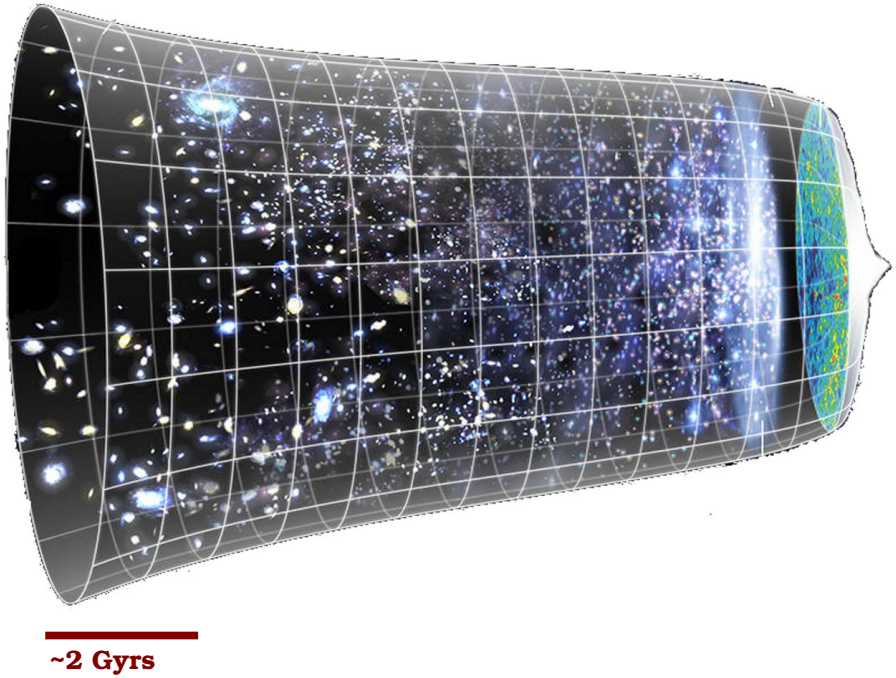
What for higher redshifts ?

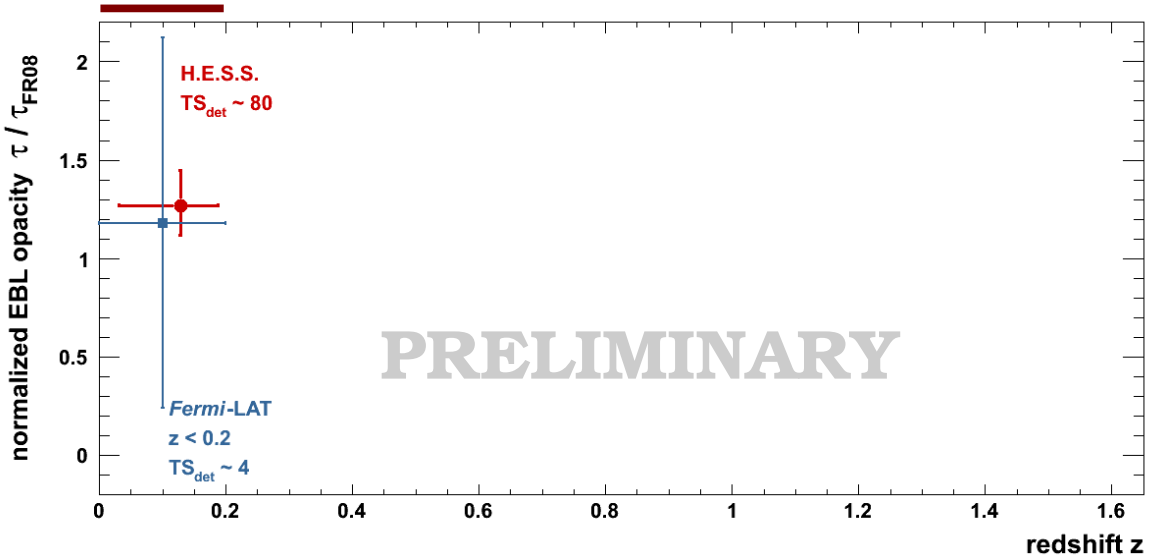




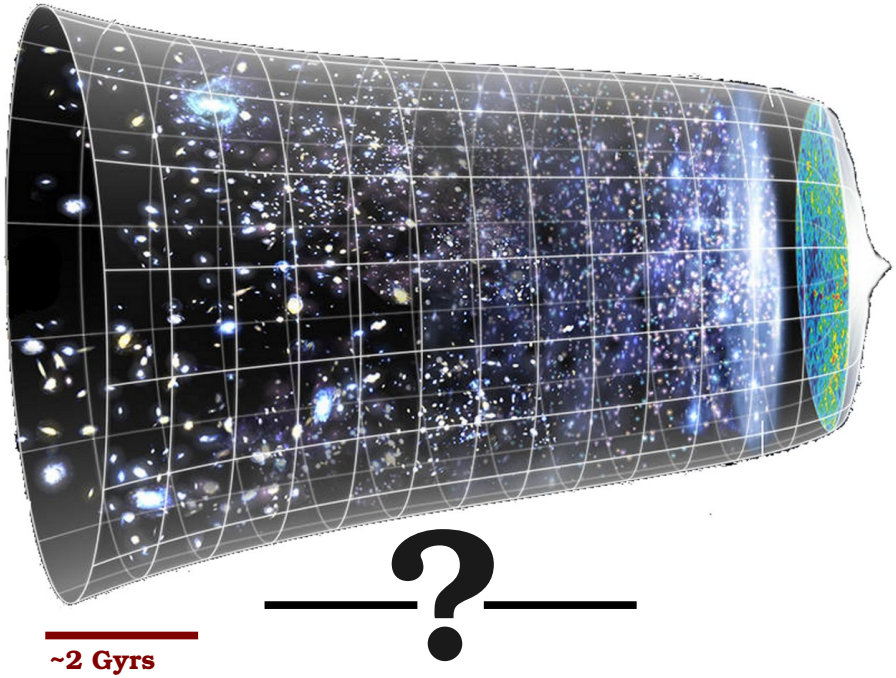


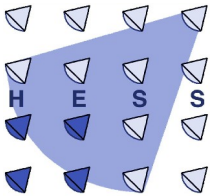
What for higher redshifts ?

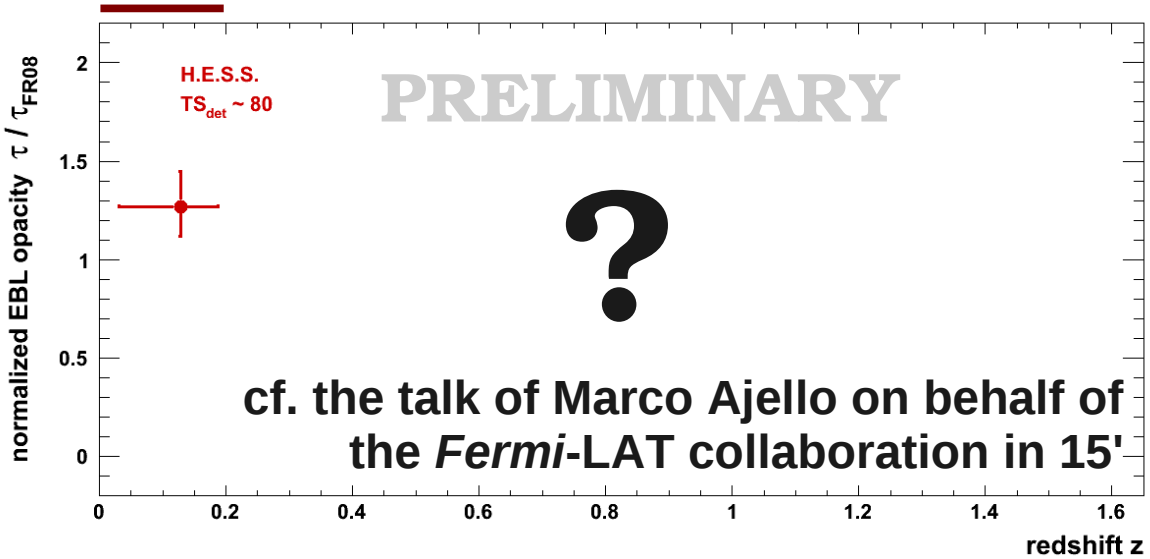




What for higher redshifts ?



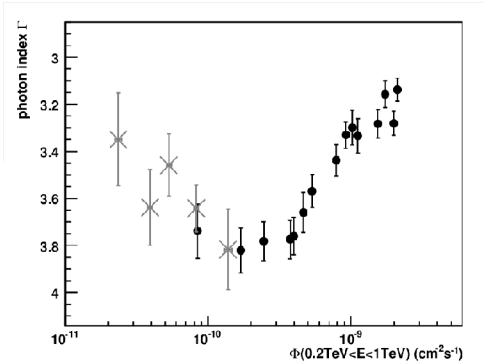




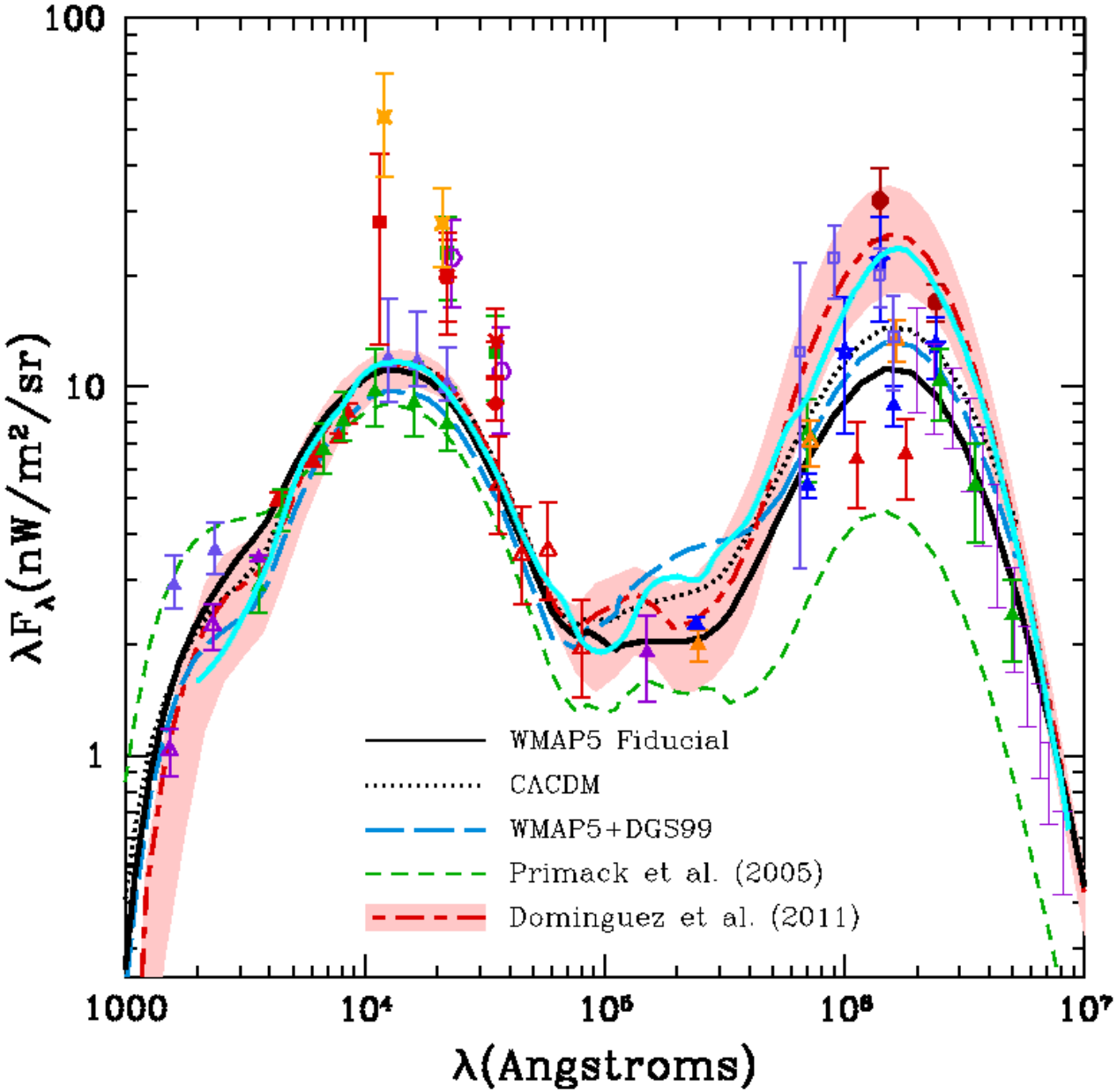
Backup 1

Source	z	N_γ	σ	$E_{\min} - E_{\max}$ [TeV]	$\lambda_{\min} - \lambda_{\max}$ [μm]	Spectral model	$\chi^2(\alpha_0)$ / dof
Mrk 421 (*1*)	0.031	3381	96.7	0.95 – 41	1.2 – 49	ELP	21.5 / 31
Mrk 421 (*2*)	0.031	5548	135	0.95 – 37	1.2 – 44	ELP	46.8 / 30
Mrk 421 (*3*)	0.031	5156	134	0.95 – 45	1.2 – 53	ELP	34.8 / 28
PKS 2005-489 (*1*)	0.071	1540	25.3	0.16 – 37	0.22 – 44	LP	49.5 / 60
PKS 2005-489 (*2*)	0.071	910	28.9	0.18 – 25	0.25 – 30	LP	31.8 / 46
PKS 2155-304 (*2008*)	0.116	5279	99.2	0.13 – 19	0.30 – 23	ELP	21.9 / 37
PKS 2155-304 (*1*)	0.116	3499	93.0	0.13 – 5.7	0.19 – 6.8	PWL	32.3 / 31
PKS 2155-304 (*2*)	0.116	3470	116	0.13 – 9.3	0.19 – 11	SEPWL	25.3 / 28
PKS 2155-304 (*3*)	0.116	9555	186	0.13 – 14	0.19 – 17	SEPWL	35.2 / 31
PKS 2155-304 (*4*)	0.116	4606	132	0.18 – 4.6	0.19 – 5.5	SEPWL	19.1 / 21
PKS 2155-304 (*5*)	0.116	11901	219	0.13 – 5.7	0.27 – 6.8	SEPWL	24.3 / 27
PKS 2155-304 (*6*)	0.116	6494	166	0.15 – 5.7	0.19 – 6.8	LP	29.2 / 21
PKS 2155-304 (*7*)	0.116	8253	191	0.20 – 7.6	0.22 – 9.0	SEPWL	13.6 / 13
1ES 0229+200	0.14	670	12.6	0.29 – 25	0.45 – 30	PWL	60.1 / 60
H 2356-309	0.165	1642	21.2	0.11 – 34	0.18 – 40	LP	70.2 / 61
1ES 1101-232	0.186	1268	17.8	0.12 – 23	0.20 – 27	PWL	62.6 / 69
1ES 0347-121	0.188	604	13.5	0.13 – 11	0.22 – 13	ELP	31.7 / 35

- **splitting of the data sets to minimize the intrinsic scatter as** 2010A&A...520A..83H **(HESS collaboration)**
  - ✶**7 data sets on PKS 2155-304**
  - ✶**3 data sets on Mkn 421**
  - ✶**2 data sets on PKS 2005-489**



Backup 2

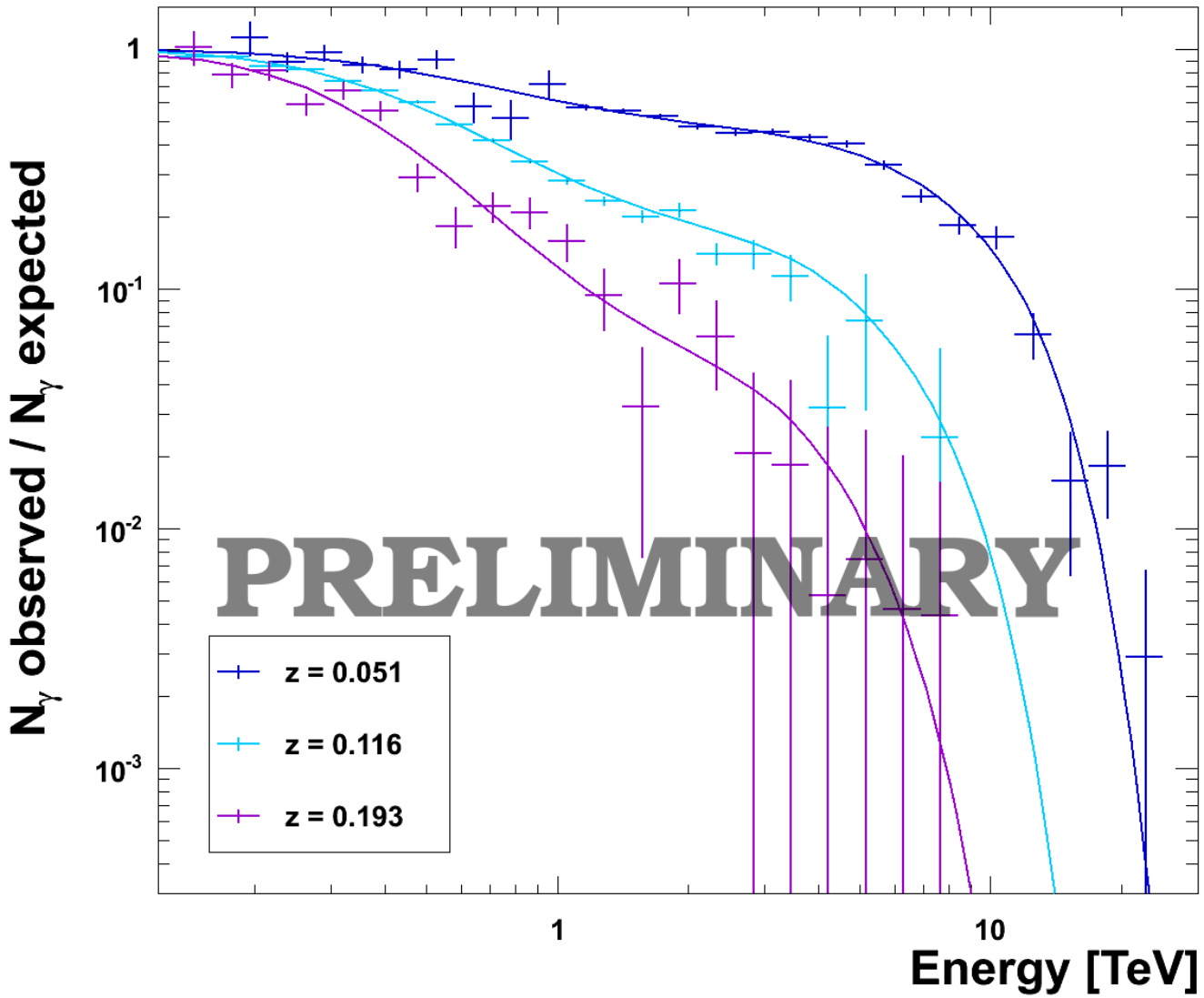


Extracted from Gilmore et al. 2012

Semi-analytic modelling of the extragalactic background light and consequences for extragalactic gamma-ray spectra

Franceschini 2008 added in cyan

Backup 3

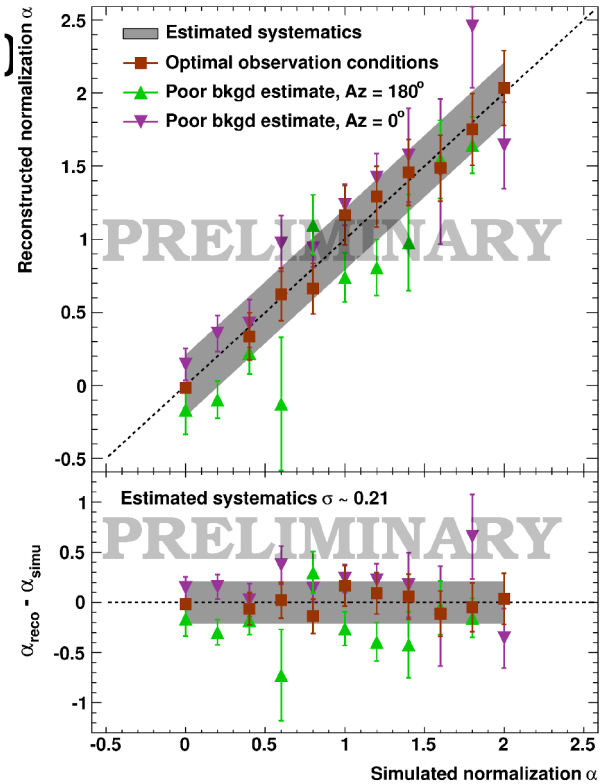


Number of events observed / number of events expected without EBL

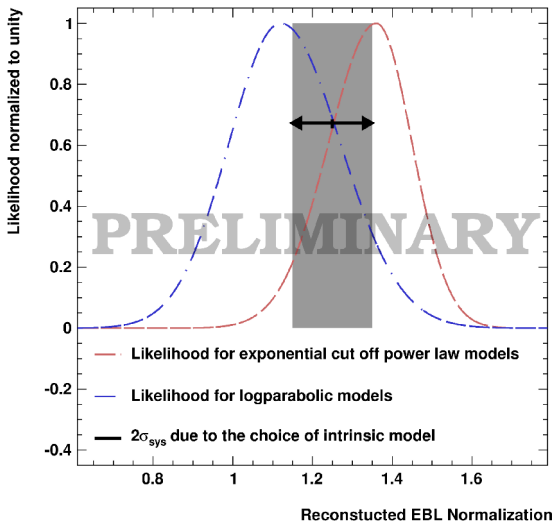
Data sets grouped by redshift.

Backup 4

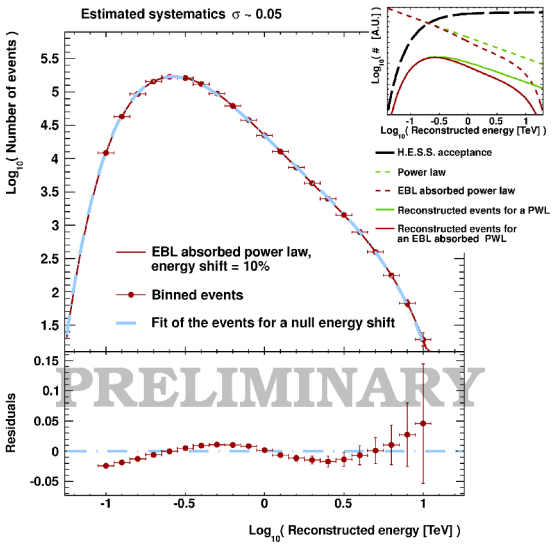
1)



2)



3)



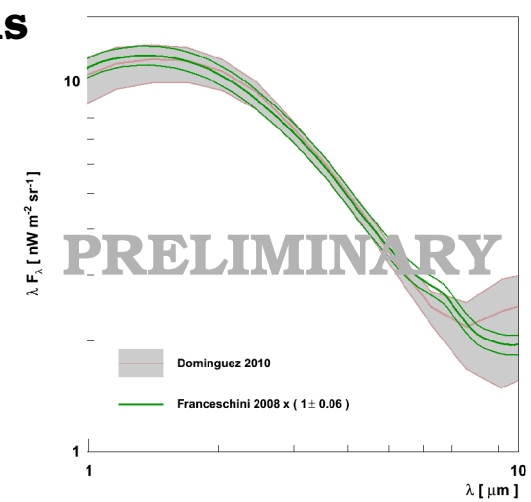
1) Monte Carlo simulated events, filtered to reproduce the EBL absorption.

2) Testing the procedure of choice of the most conservative intrinsic model with the data

3) Energy scale (10% shift in energy).

Choice of the EBL template (FR08 - DOM11)

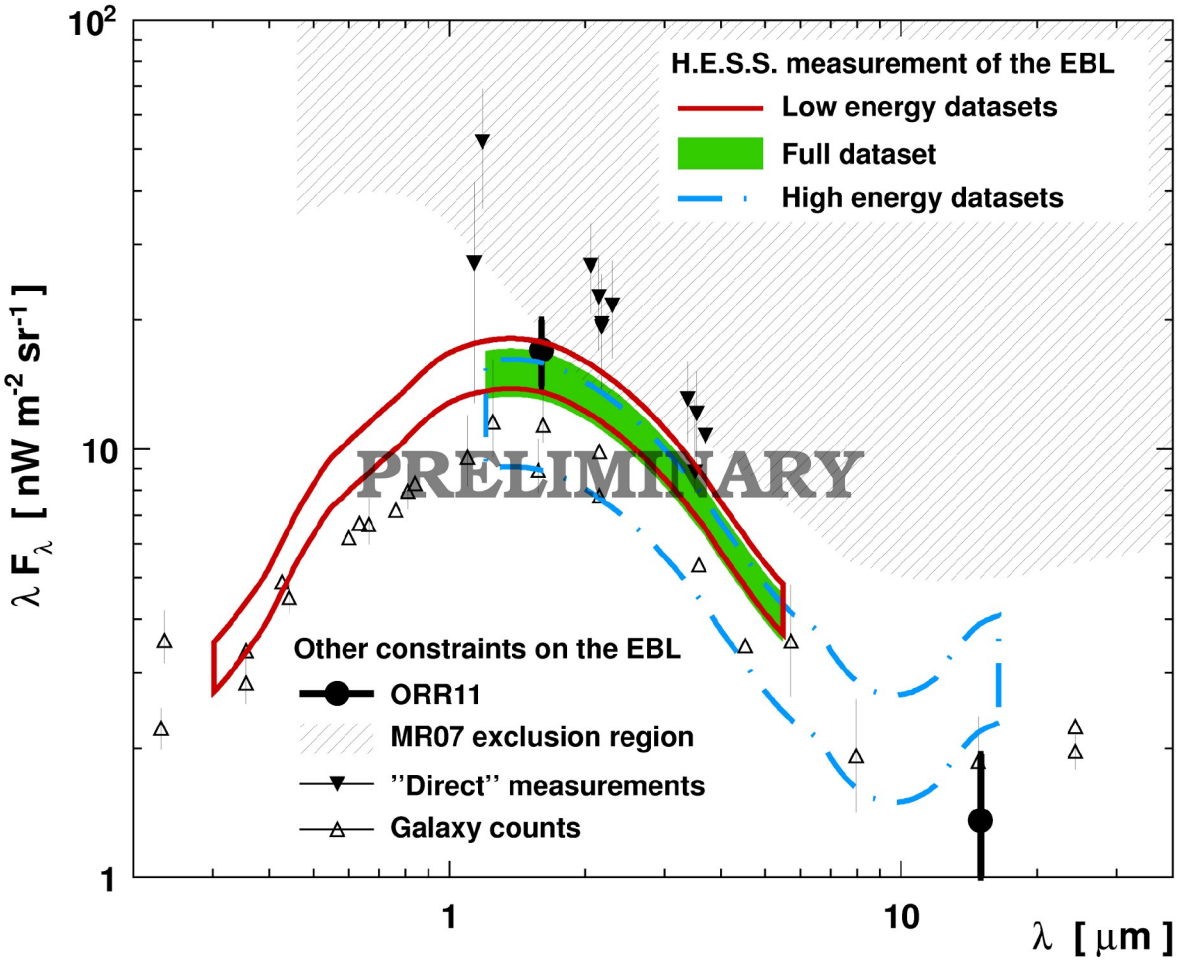
3) bis



Sources of systematics	Estimated systematics
Analysis chain	0.21
Intrinsic model	0.10
EBL model	0.06
Energy scale	0.05
Total	**0.25**

Backup 5

Other constraints :



Backup 6

Why selecting the model with the largest χ^2 probability ?

Because it ensures that all the intrinsic curvature is accounted for (and that it does not mimic the curvature due to the EBL extrinsic effect)

→ conservative approach

With the "usual" criterion : select the model with one extra parameter if it is significantly preferred (e.g. at the 2σ level), one changes the models of :

```
1ES 0347-121 :            ELP   -> PWL
H 2356-309 :              LP    -> PWL
Mrk 421 (1) :             ELP   -> PWL
Mrk 421 (3) :             ELP   -> EPWL
PKS 2155-304 (2008) :     ELP   -> PWL
PKS 2155-304 (2) :        SEPWL -> LP
PKS 2155-304 (3) :        SEPWL -> LP
PKS 2155-304 (4) :        SEPWL -> PWL
PKS 2155-304 (5) :        SEPWL -> LP

All data-sets : Detection significance = 14.3 sigma / alpha = 1.46 +/- 0.11
```

Our approach selects the model with more curvature (ensures we do not overestimate the EBL effect), the drawback being a diminished significance.