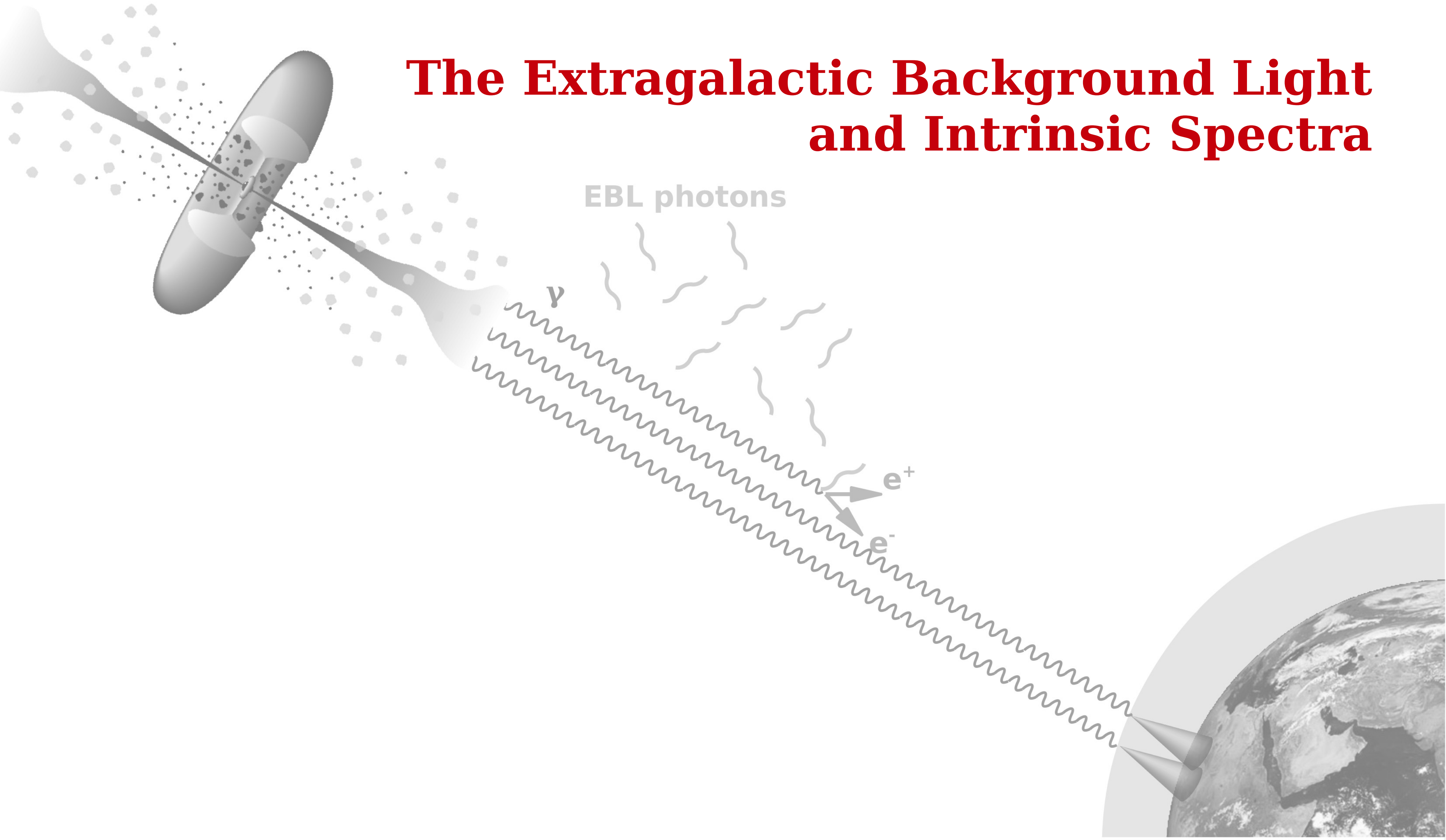
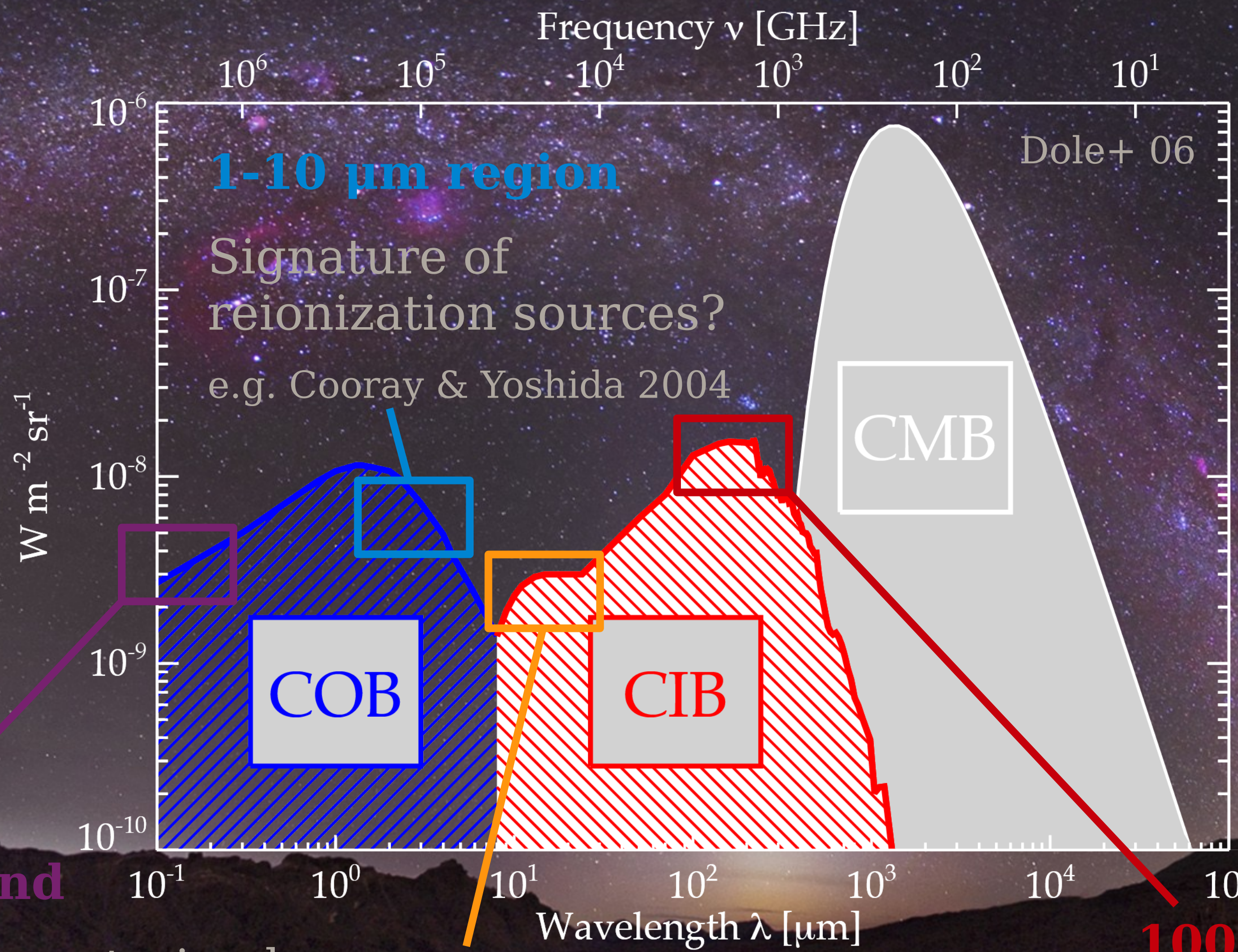
The Extragalactic Background Light and Intrinsic Spectra



Some open questions on the EBL



1-10 μm region

Signature of reionization sources?

e.g. Cooray & Yoshida 2004

UV background

Largely underconstrained by theory and experiments

e.g. Haardt & Madau 2012

10-30 μm region

Amount of polycyclic aromatic hydrocarbons?

e.g. Dominguez+ 2011

100 μm region

Census of the CIB sources up to high z ?

e.g. Viero+ 2015

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The EBL imprint on gamma-ray spectra

$$\underbrace{\tau(E,z)}_{\text{gamma}} = \underbrace{\int_0^z \mathrm{d}z' \frac{\mathrm{d}l}{\mathrm{d}z}(z')}_{\text{cosmo}} \underbrace{\int_0^{+\infty} \mathrm{d}\epsilon \; n(\epsilon, z')}_{\text{astro/cosmo}} \underbrace{\int_{-1}^{1} \mathrm{d}\mu \frac{1-\mu}{2} \sigma_{ee}(\epsilon, E \times (1+z'), \mu)}_{\text{particle physics}}$$

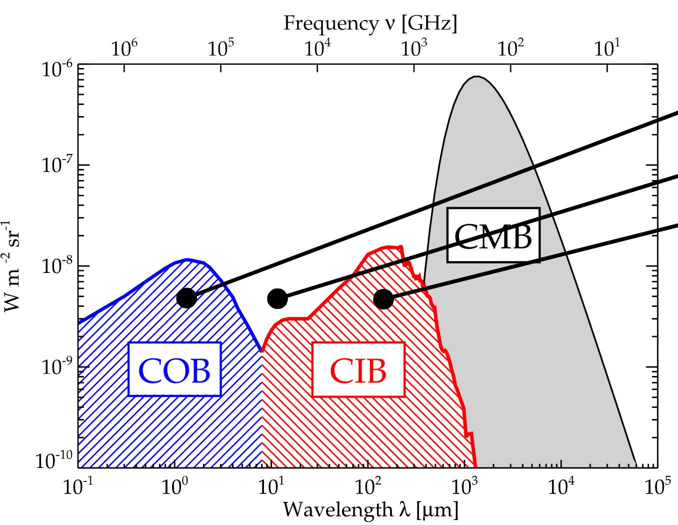
gamma | cosmo | astro/cosmo | → particle physics term maximum for E_γ [TeV] ~ 1/ε [eV] ~ λ [μm]

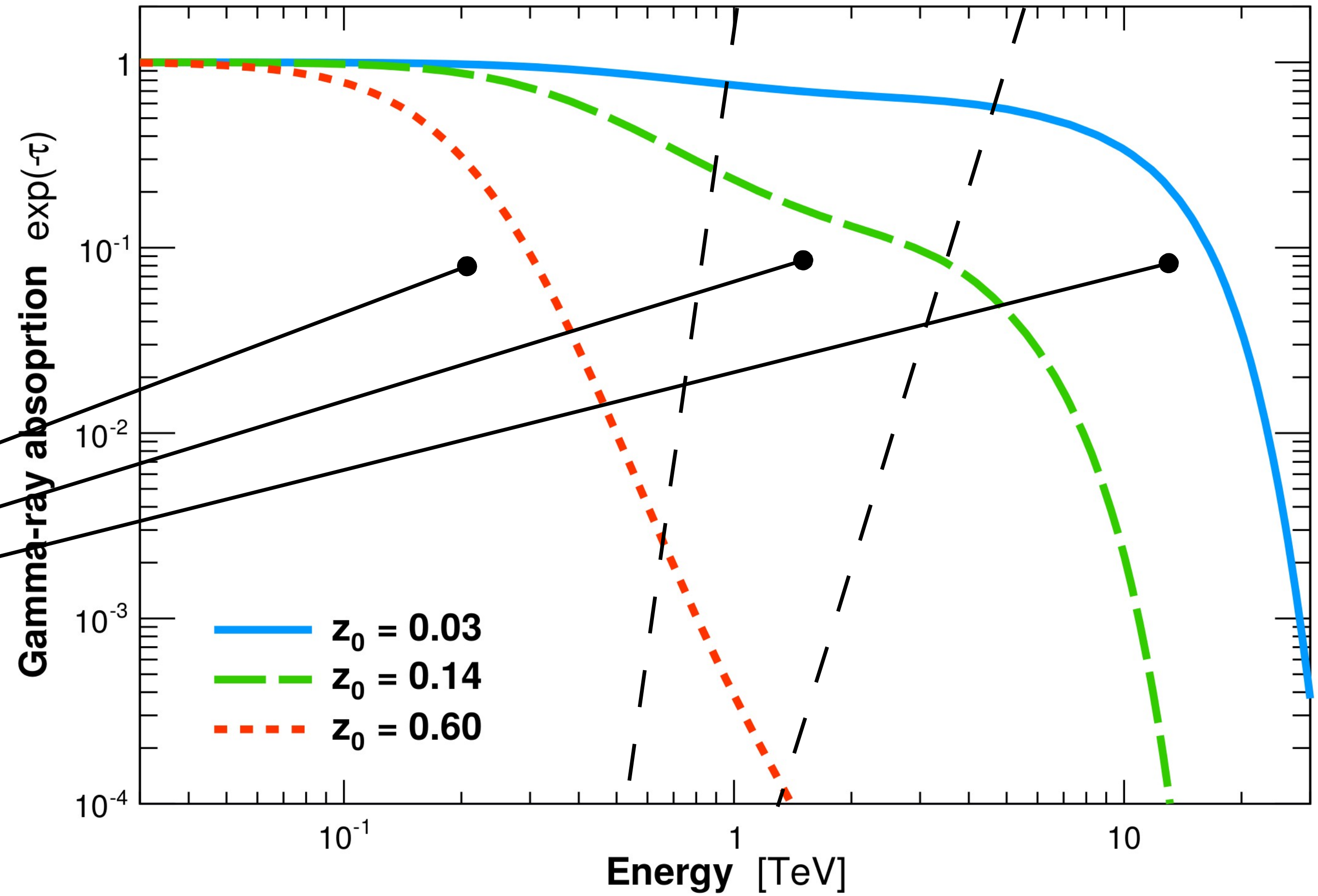
Gamma-ray disappearance imprints the spectra > 100 GeV

z<0.05: mostly CIB

z>0.3: mostly COB

E- + z-dependencies
→ reco of the EBL at z=0
and evolution





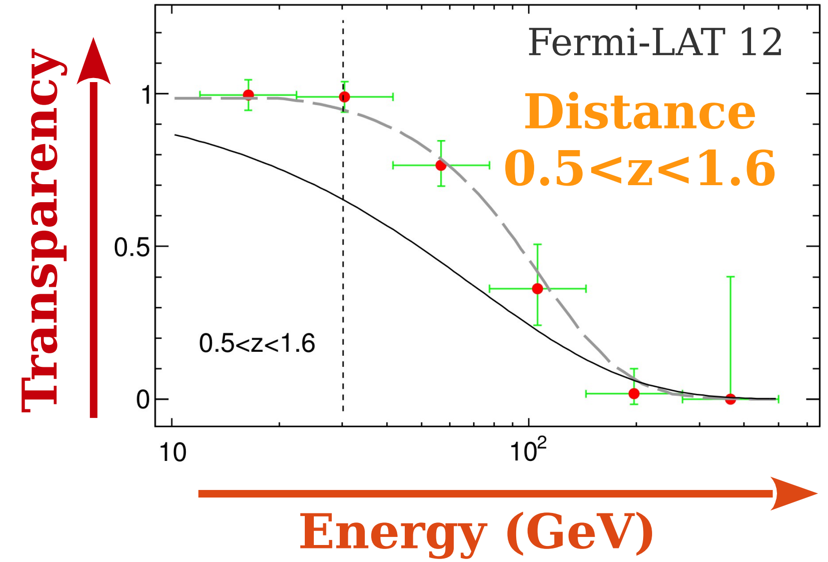
Scaling the optical depth

Joint fit of EBL and intrinsic emission

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

Accounting for intrinsic curvature if needed

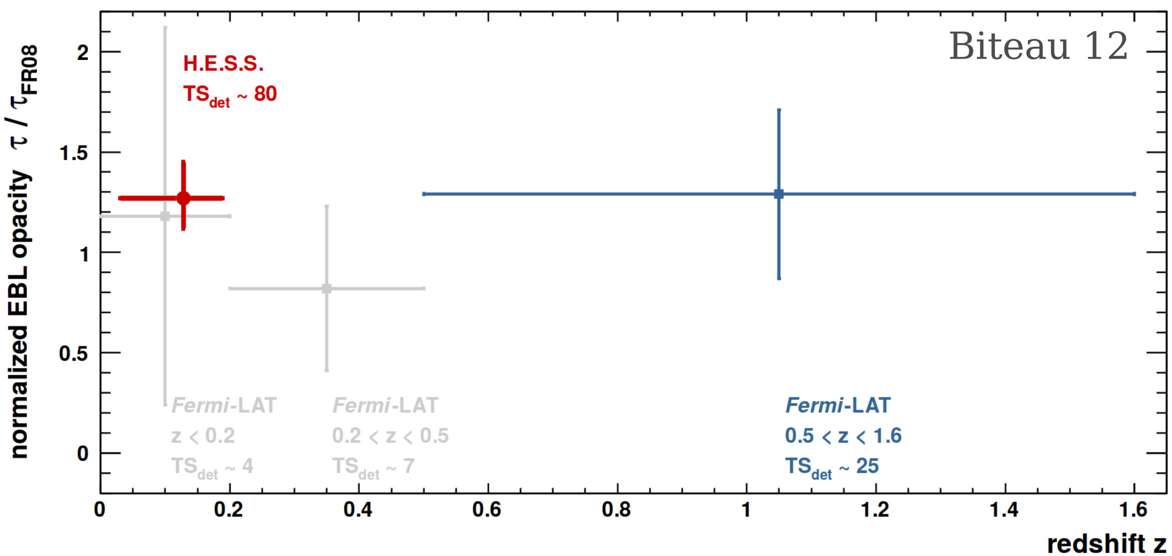
Question to investigate: which criteria?

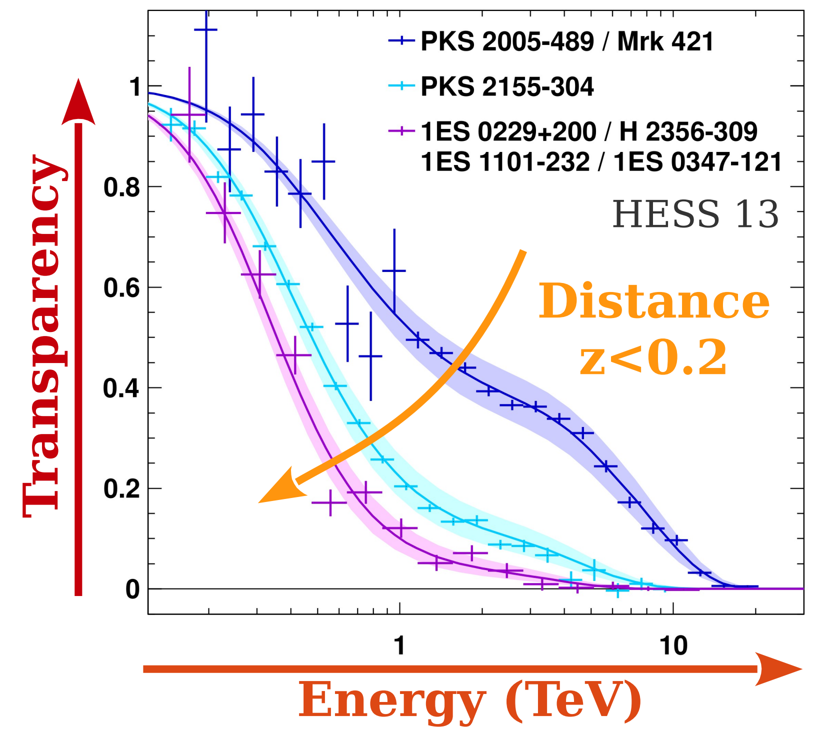


Fit of the normalization factor α

e.g. with likelihood profile techniques

Method used by Fermi-LAT, H.E.S.S., MAGIC

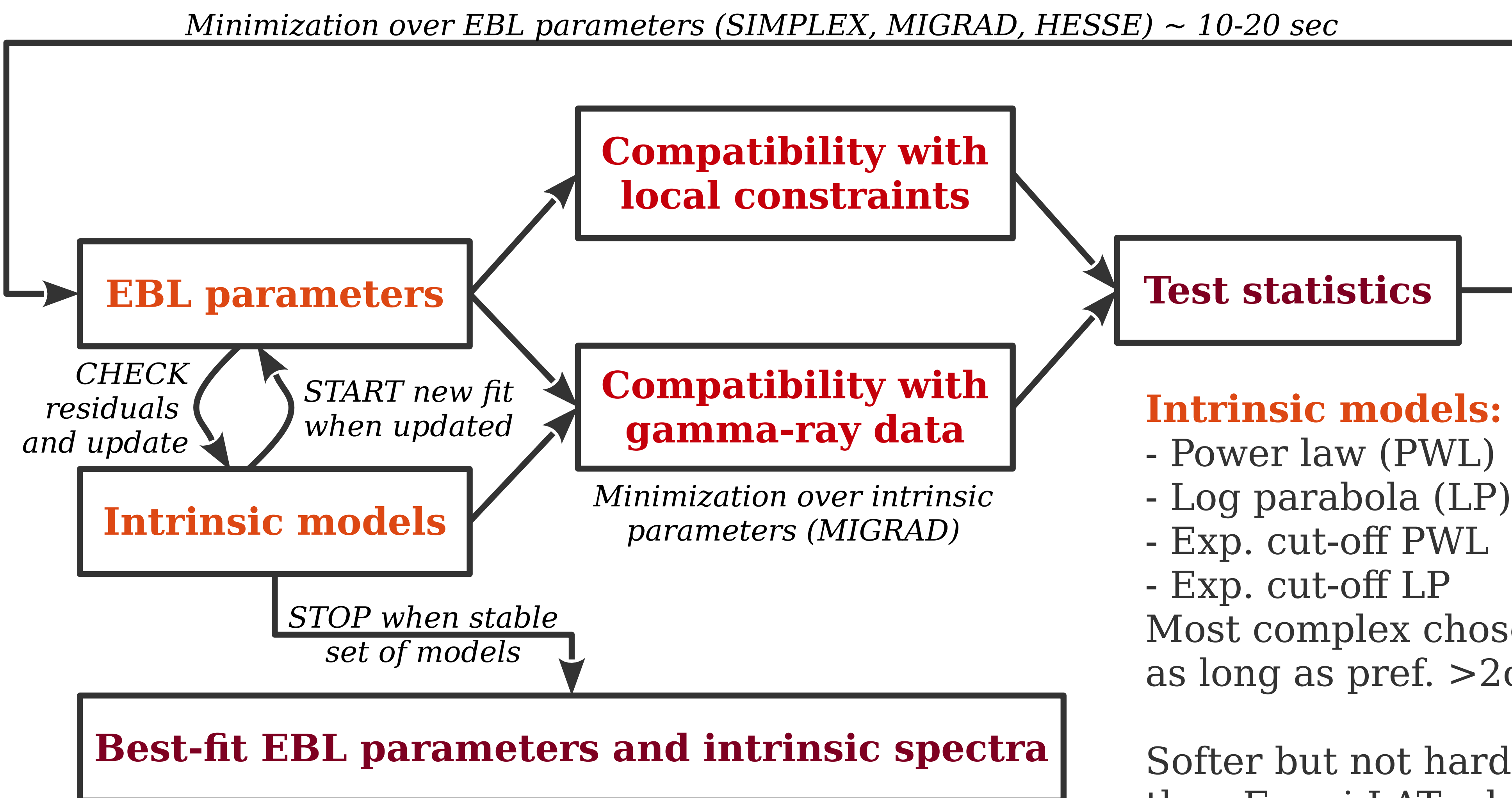




Example of a step further

Fitting algo. accounting for gamma-ray data and local EBL constraints:

Biteau & Williams 2015



Intrinsic models:

- Power law (PWL)
- Log parabola (LP)
- Exp. cut-off PWL
- Exp. cut-off LP

Most complex chosen as long as pref. $>2\sigma$

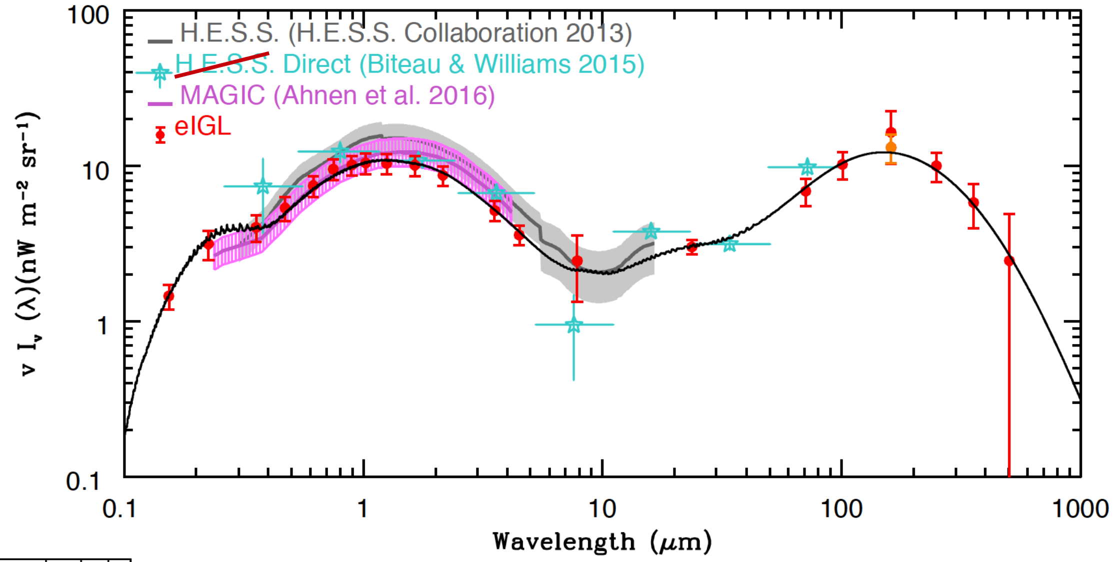
Softer but not harder than Fermi-LAT when contemporaneous

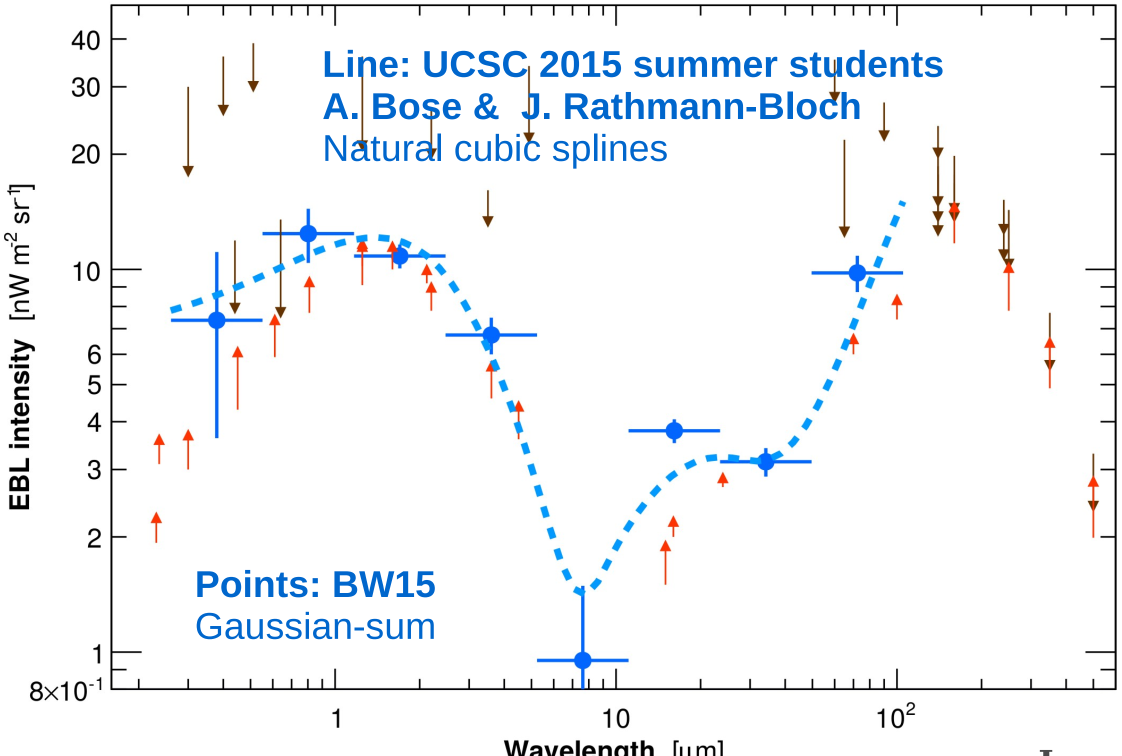
High-Accuracy EBL Spectrum

BW 15 results:
gamma rays + galaxy counts as lower limits

. COB (0.1 - 8 μm): 36±11 nW m^{-2} sr^{-1}

. CIB (8 - 1000 μm): 25.9±3.4 nW m^{-2} sr^{-1}





Driver+ 16 results:
galaxy counts as measurements

. COB (0.1 - 8 μm): 24±4 nW m^{-2} sr^{-1}

. CIB (8 - 1000 μm): 26±5 nW m^{-2} sr^{-1}

We have reached the 20% accuracy level from NUV to FIR!

→ Era of fine structure testing

→ Systematics in the method?

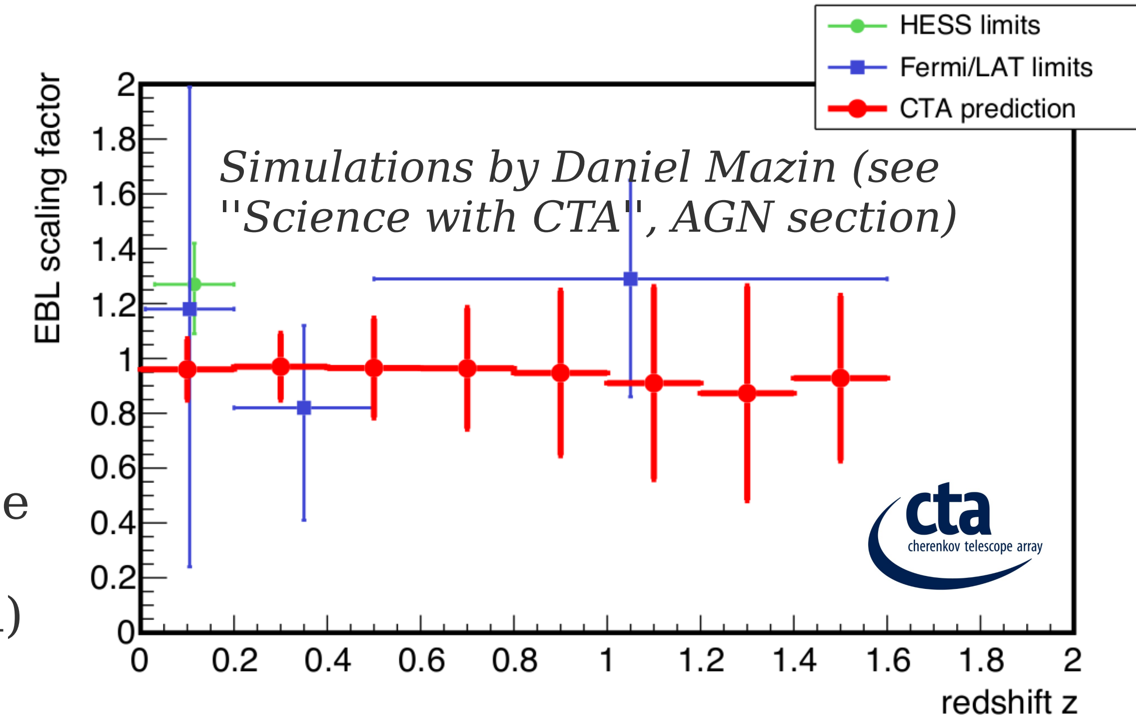
Some short-term goals for the EBL & IntSpec tasks

Reproduce Daniel's study

Intrinsic spectra: list of Fermi-LAT sources with extrapolated spectra (which cut-off or curvature?)

EBL: reconstruction of the scaling factor for various models

Analysis: ability to jointly fit multiple intrinsic spectra together with the EBL parameters (e.g. normalization)



Build a solid selection method for the intrinsic spectral model

List possible methods on the market and identify a simulation strategy to asses the impact of using this or that method

Build the tools to compute the optical depth vs E and z

Based on n(E,z), on $n(E_0,z=0) \times f(z)$

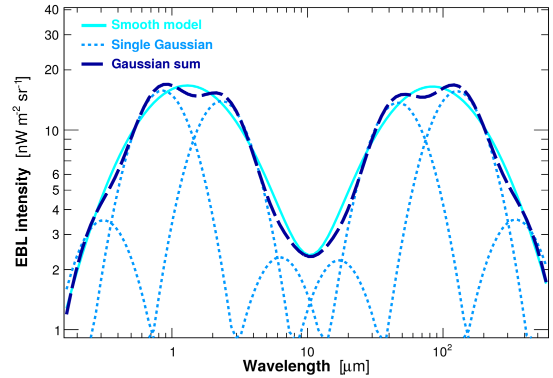
Go further if we can: build a generic model parametrization

Backup

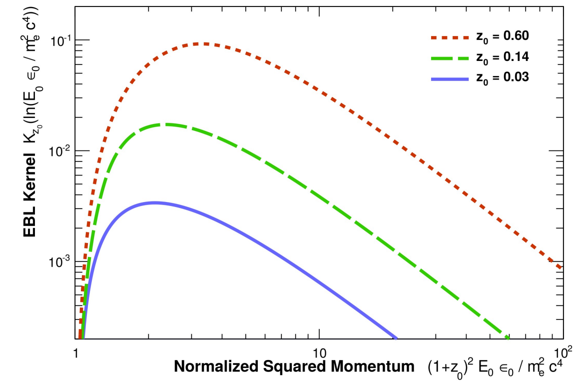
Model-Independent Gamma-ray Constraints

If Target density(ϵ_0, z_0) = Target density$(\epsilon_0, z_0=0)$ x Evolution(z_0), then

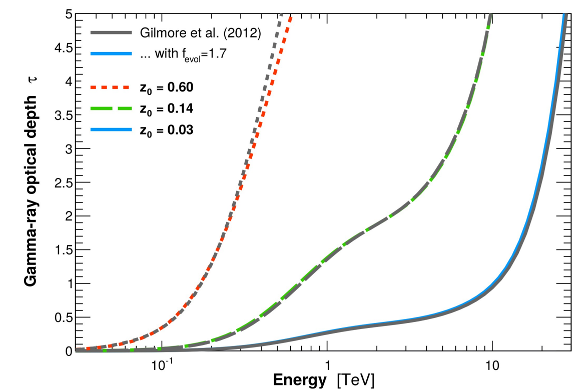
$\tau(E_0, z_0) = 3\pi\sigma_T / H_0 \times E_0 / m^2c^4 \times$

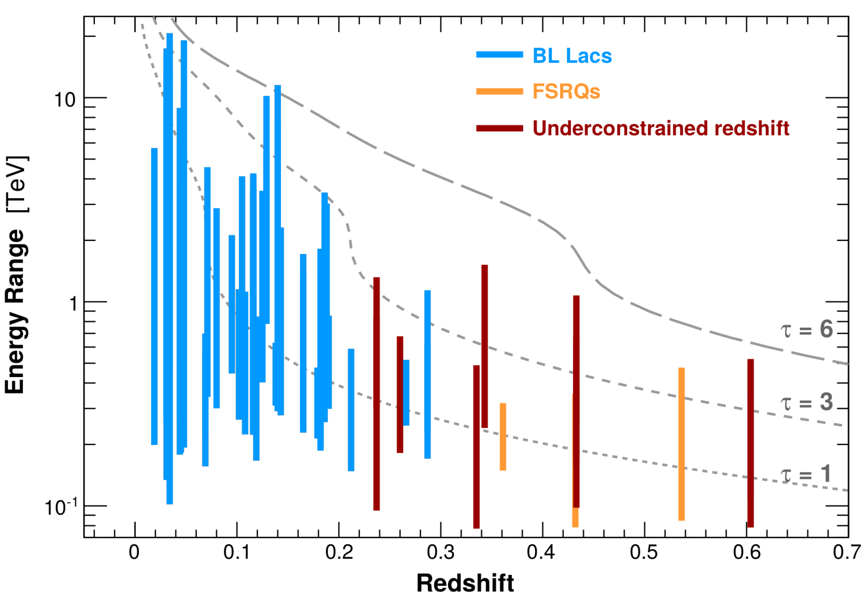


$\otimes$



Decoupling hypothesis: impact on τ of about ~2%





Dataset

. 86 TeV spectra from 32 known-z BL Lacs
. GeV spectral index when contemporaneous

Hypotheses

. TeV softer than GeV
. smooth concave spectrum at the source

“Dark patches” observations

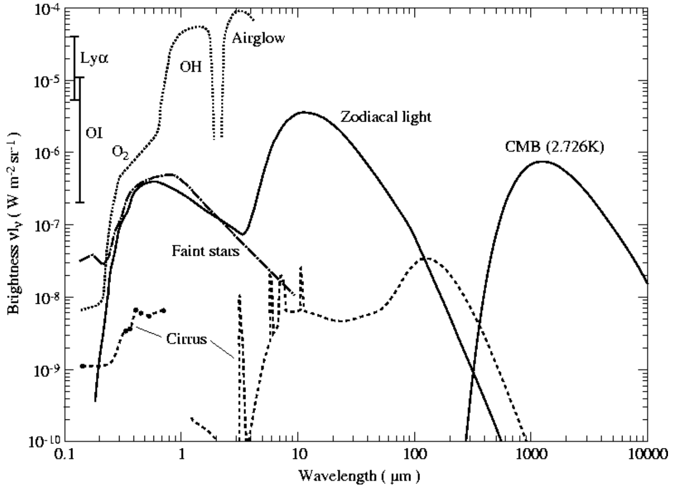
Direct measurement of the night-sky brightness

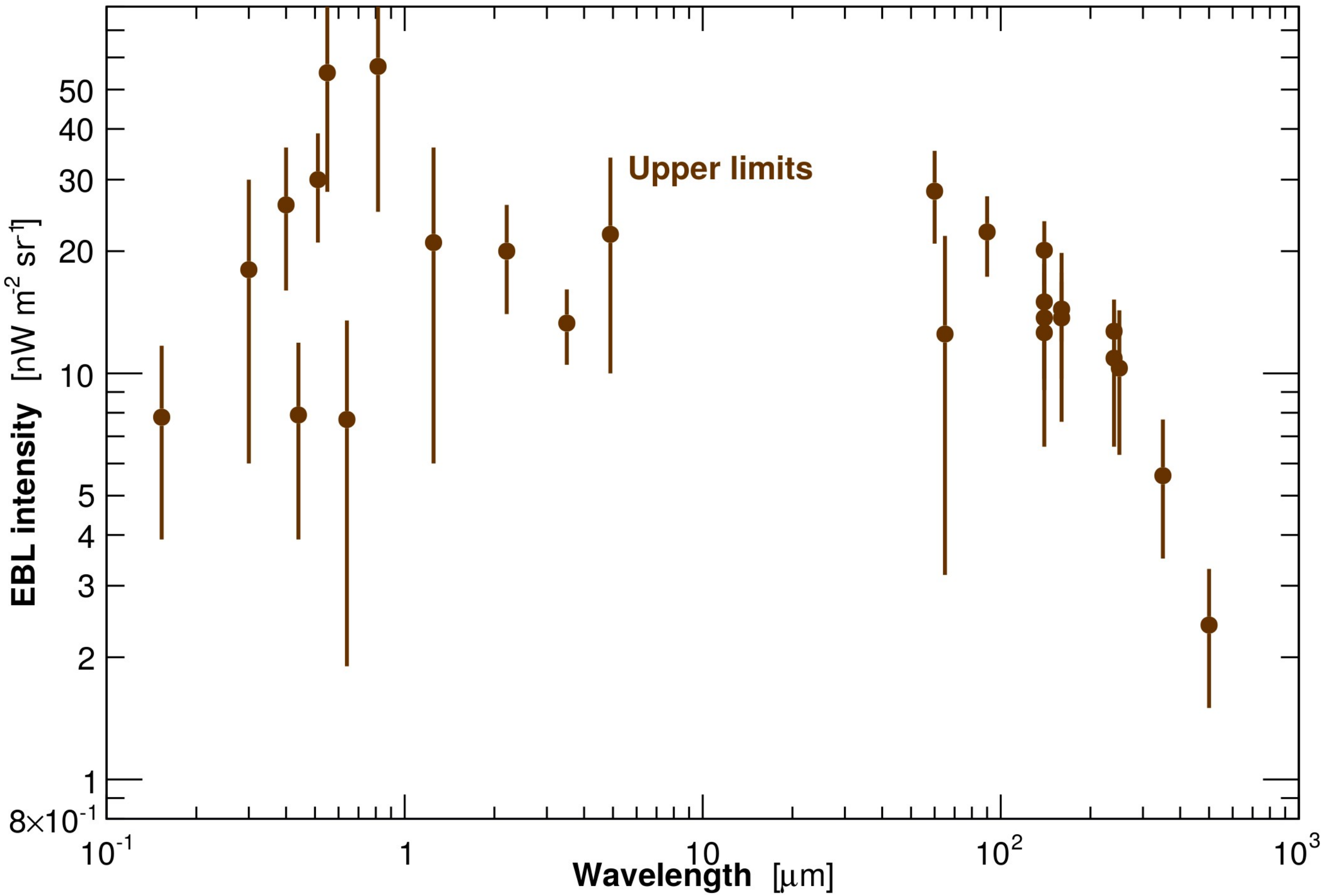
But bright local environment (e.g. zodiacal light) suggests foreground contamination, particularly for the COB → overestimation of the EBL.

> 100 μm: cleaner

COBE (FIRAS/DIRBE) measurements less prone to contamination

Leinert+ 1998

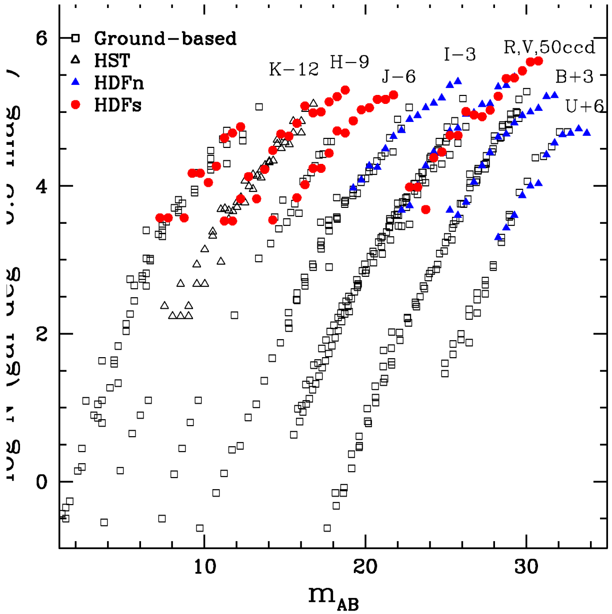




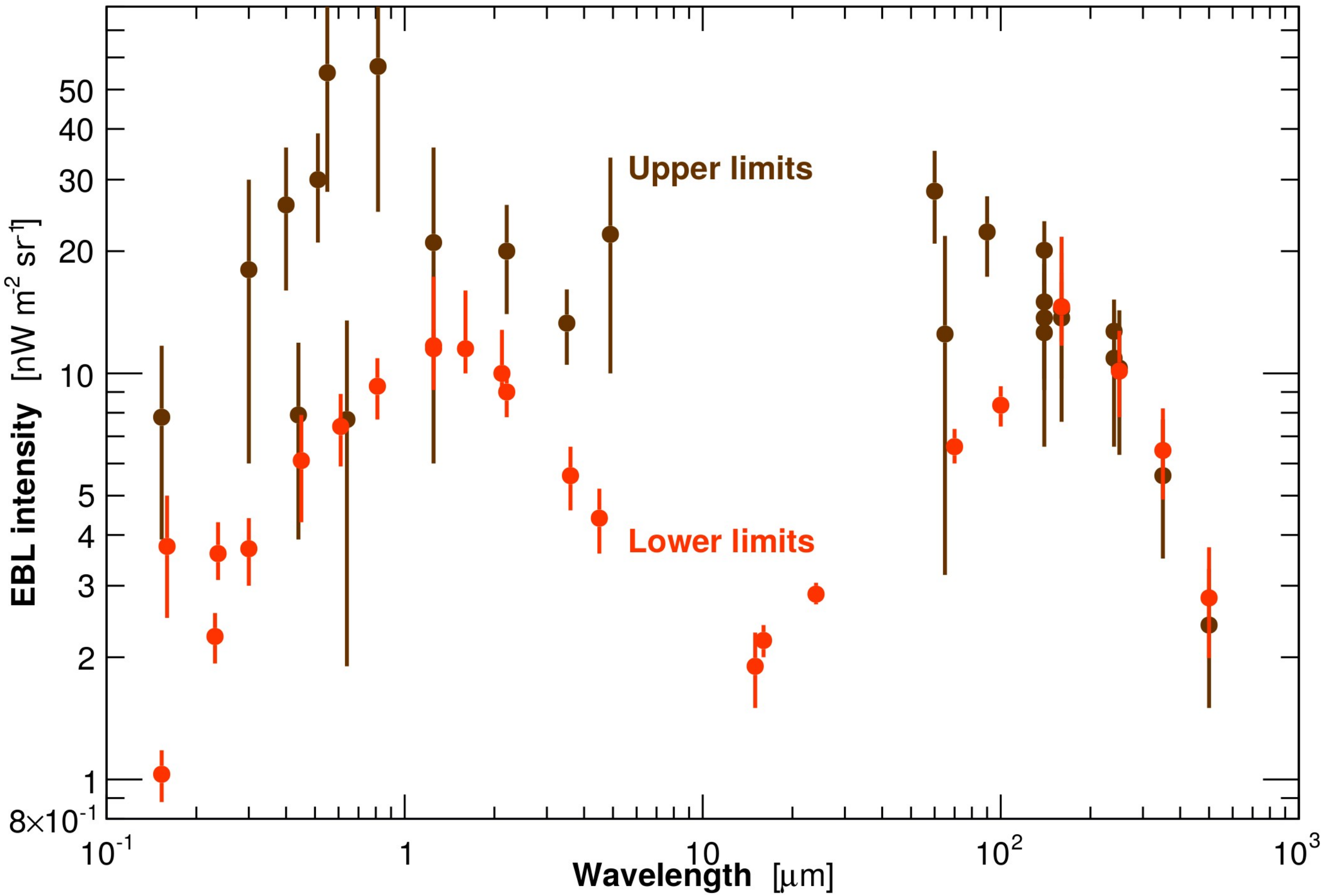
Galaxy Counts

Counting the number of objects per magnitude band

Faint end of the distribution function must drop below a given slope for the integral to converge (completeness). Does not account for unknown populations of sources or truly diffuse component → underestimation.



Madau & Pozetti 2000



+ stacking e.g. Viero +13

+ fluctuations e.g. Zemcov +14

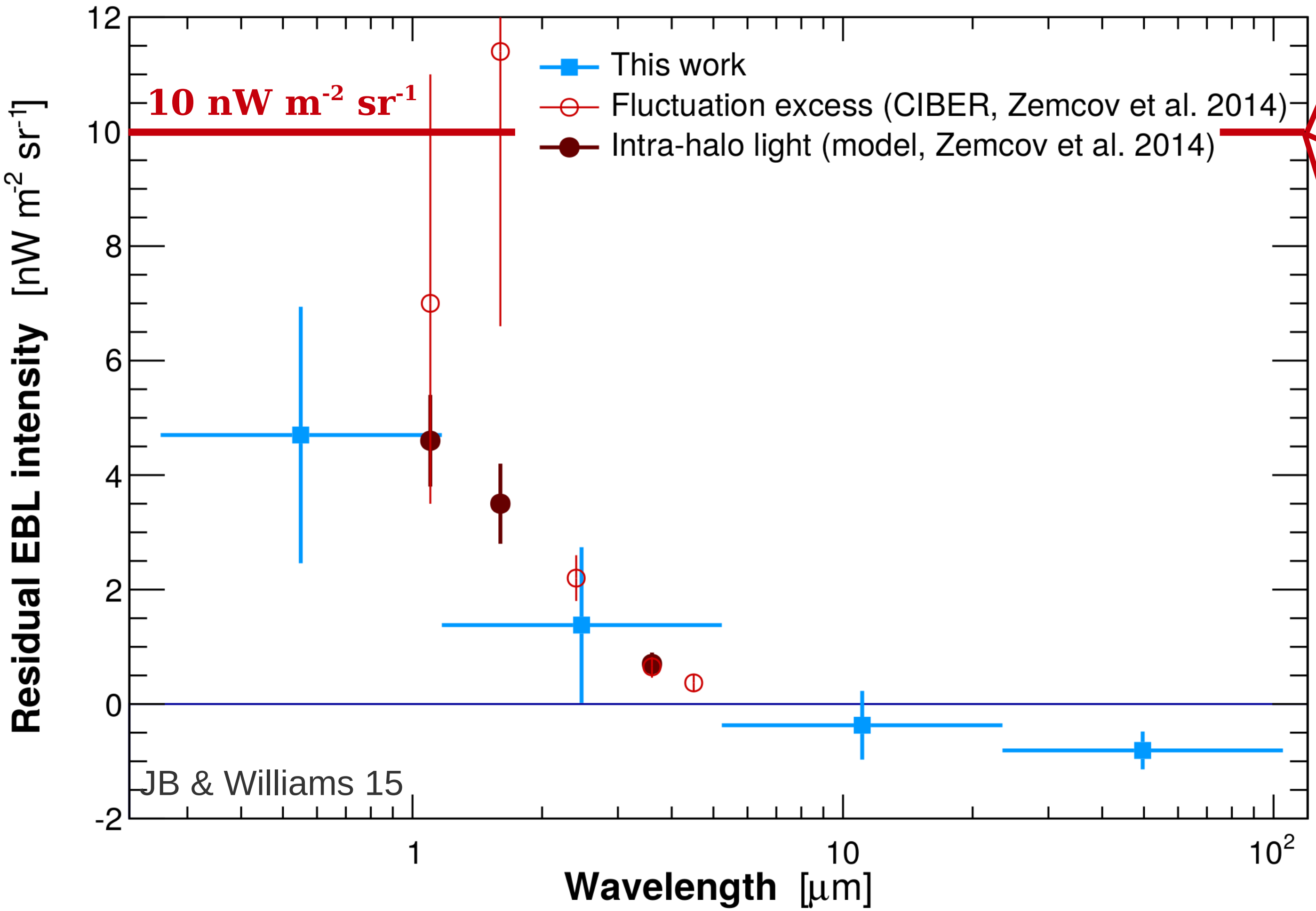
Unresolved Sources & Reionization

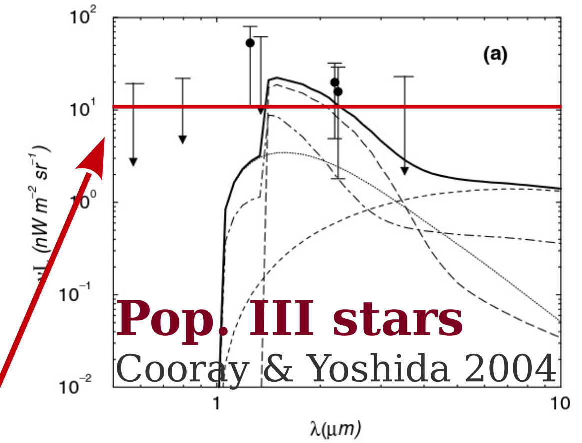
Method: gamma-ray inferred EBL – galaxy counts

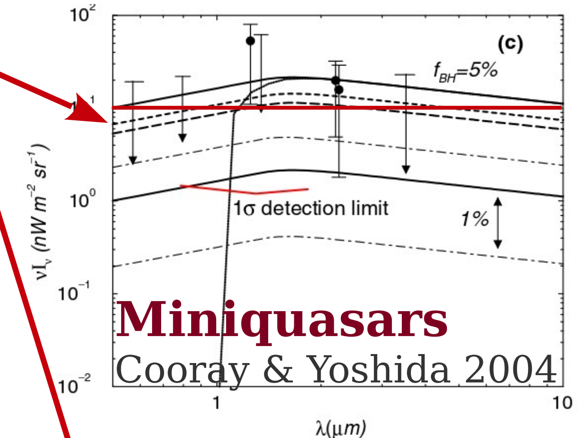
. Using the EBL derived with gamma-ray data only

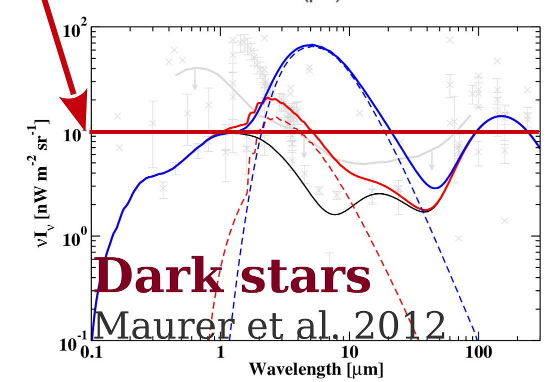
Results:

. Optimistic models of reionization rejected
. Room left for fluctuation excesses (IHL, CIBER)

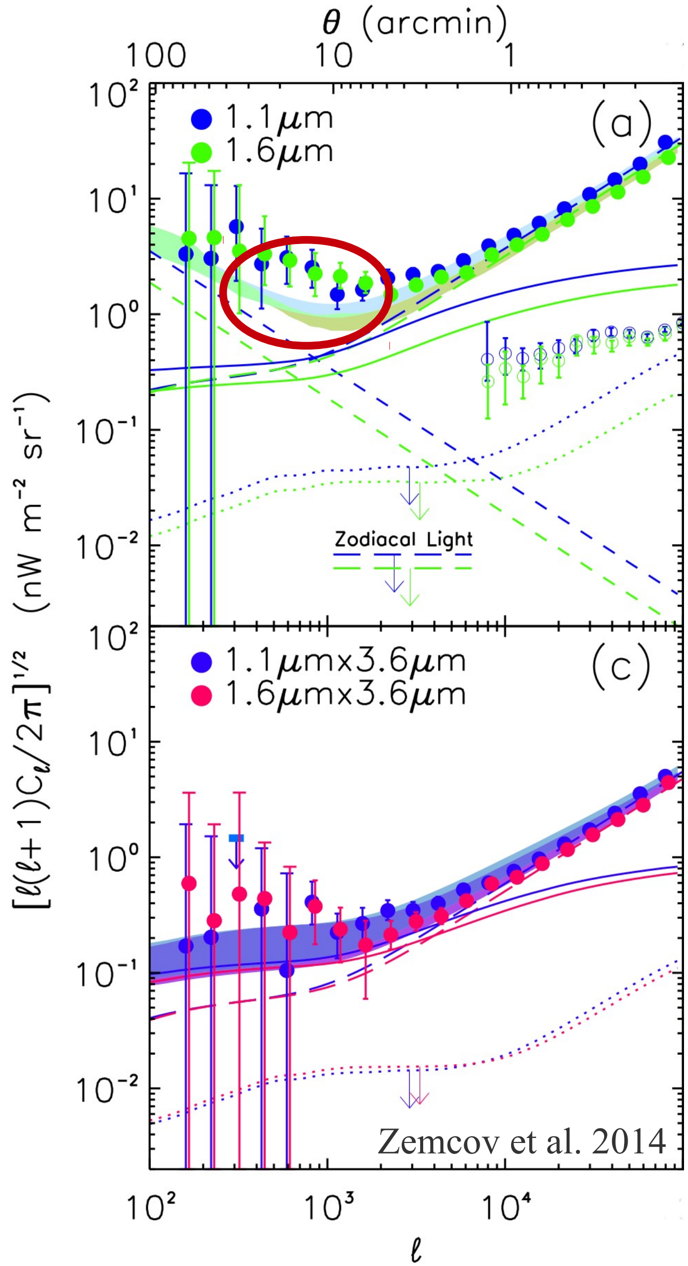








A word about CIBER



Other means of detection: 2^{nd} moment (fluctuations) instead of 1^{st} moment (brightness)

A fluctuation excess in NIR ?
Science publication in November 2014

Attributed to IHL
- Diffuse galactic light below l<500
- Low-z galaxies above l>2000
- Unknown excess in between to which intra-halo light from stars stripped from their parent galaxies could contribute.

Excess fluctuations → EBL intensity

Table 1. Contributions to near-infrared EBL anisotropy and intensity. At each wavelength, we list the measured fluctuation amplitude at large angular scales; the model-dependent ratio of EBL intensity to EBL anisotropy; the IGL determined by previous measurements; the ratio of the IHL and IGL intensities; and finally, the inferred total background intensity from both components. We also list the background intensity that would arise assuming the measured fluctuations are entirely due to high-redshift EOR galaxies.

λ (μm)	Measured $\delta\lambda I_\lambda$* (nW m^{-2} sr^{-1})	$\frac{\lambda I_{\lambda,IHL}}{\delta\lambda I_\lambda}$	$\lambda I_{\lambda,IHL}$‡ (nW m^{-2} sr^{-1})	$\lambda I_{\lambda,IGL}$§ (nW m^{-2} sr^{-1})	$\frac{\lambda I_{\lambda,IHL}}{\lambda I_{\lambda,IGL}}$	$\lambda I_{\lambda,IHL} + \lambda I_{\lambda,IGL}$ (nW m^{-2} sr^{-1})	$\lambda I_{\lambda,EOR}$‖ (nW m^{-2} sr^{-1})
1.1	$1.4^{+0.8}_{-0.7}$	5	$7.0^{+4.0}_{-3.5}$	$9.7^{+3.0}_{-1.9}$	0.7	$16.7^{+5.0}_{-4.0}$	28
1.6	$1.9^{+0.9}_{-0.8}$	6	$11.4^{+5.4}_{-4.8}$	$9.0^{+2.6}_{-1.7}$	1.3	$20.4^{+6.0}_{-5.1}$	38
2.4	0.32 ± 0.05†	7	2.2 ± 0.4	$7.8^{+2.0}_{-1.2}$¶	0.3	$10.0^{+2.0}_{-1.3}$	6.4
3.6	$0.072^{+0.019}_{-0.021}$	9	$0.65^{+0.17}_{-0.19}$	5.2 ± 1.0	0.1	5.9 ± 1.0	1.4
3.6#	$0.049^{+0.021}_{-0.007}$	9	$0.44^{+0.19}_{-0.06}$	5.2 ± 1.0	0.1	5.6 ± 1.0	1.0
4.5	0.053 ± 0.023†	7	0.37 ± 0.16	3.9 ± 0.8	0.1	4.3 ± 0.8	1.0

*RMS fluctuation amplitude computed as averages of measured data over 500 < l < 2000, except for those marked †, which are determined at l = 3000 using fainter mask cuts due to restricted field size (see also note ‖). ‡The IHL background from the product of columns 2 and 3. §The IGL background as compiled by (*28*). ‖Computed EOR background assuming EOR fluctuations with $\lambda I_\lambda/\delta\lambda I_\lambda$ = 20. ¶Determined at *K* band corresponding to 2.2 μm. #Computed using the measurements of (*6*) averaged over 500 < l < 5000.