Constraints on the extragalactic background light using TeV gamma-ray spectra

- Introduction
- TeV gamma spectra measured with HEGRA
- (Impact of 60 μm measurement)
- Constrains on the minimum of EBL in Mid-IR
- "Cap" impact for H 1426+428 (with update)
- Conclusion

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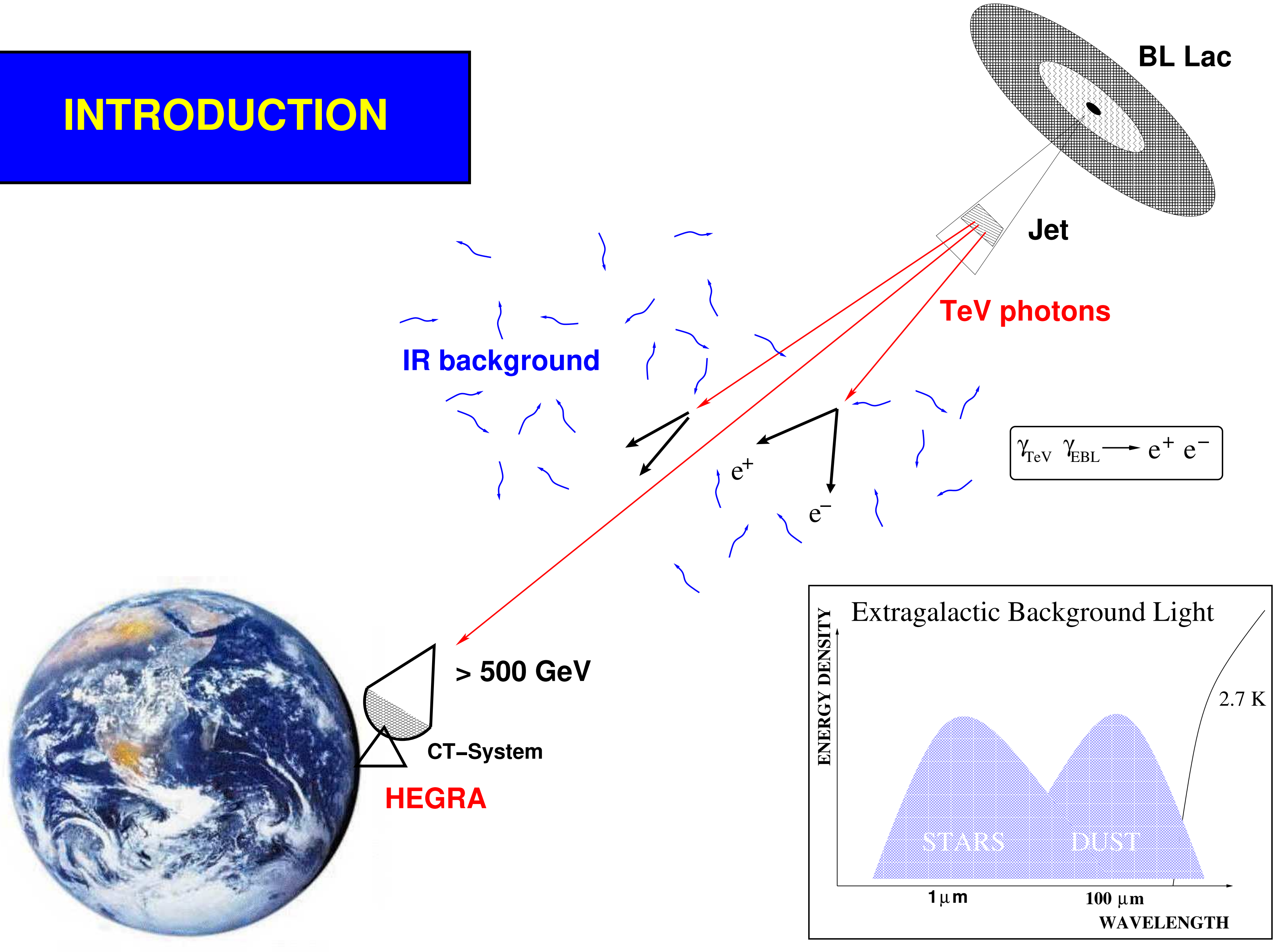
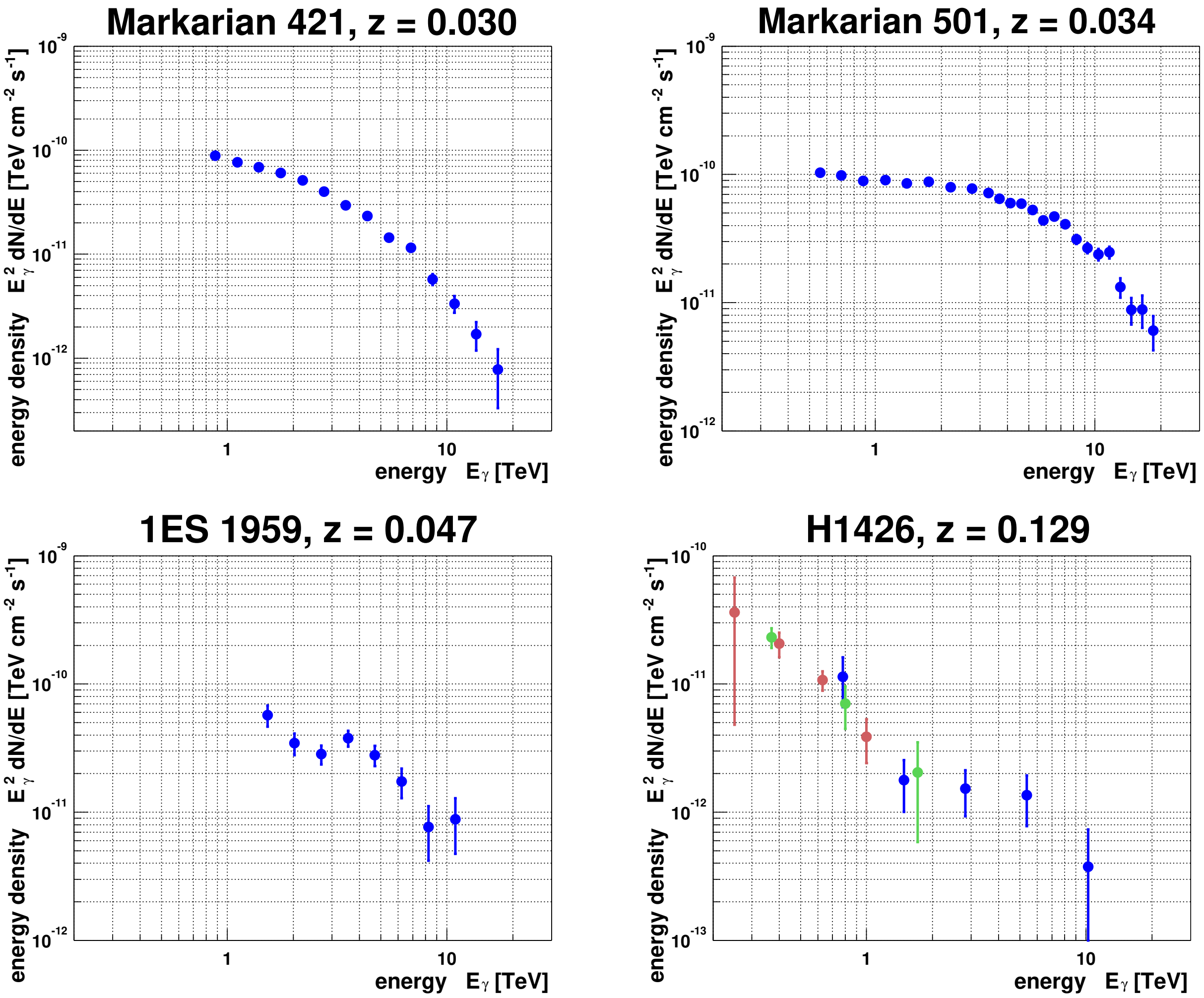
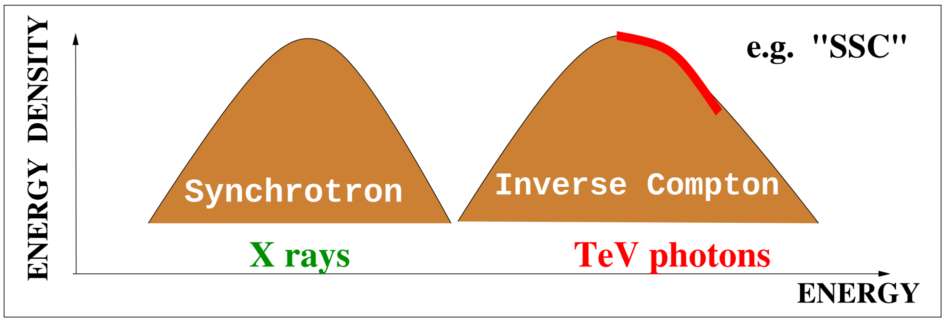
INTRODUCTION



Measured spectra of extragalactic TeV gamma-sources



measured spectra



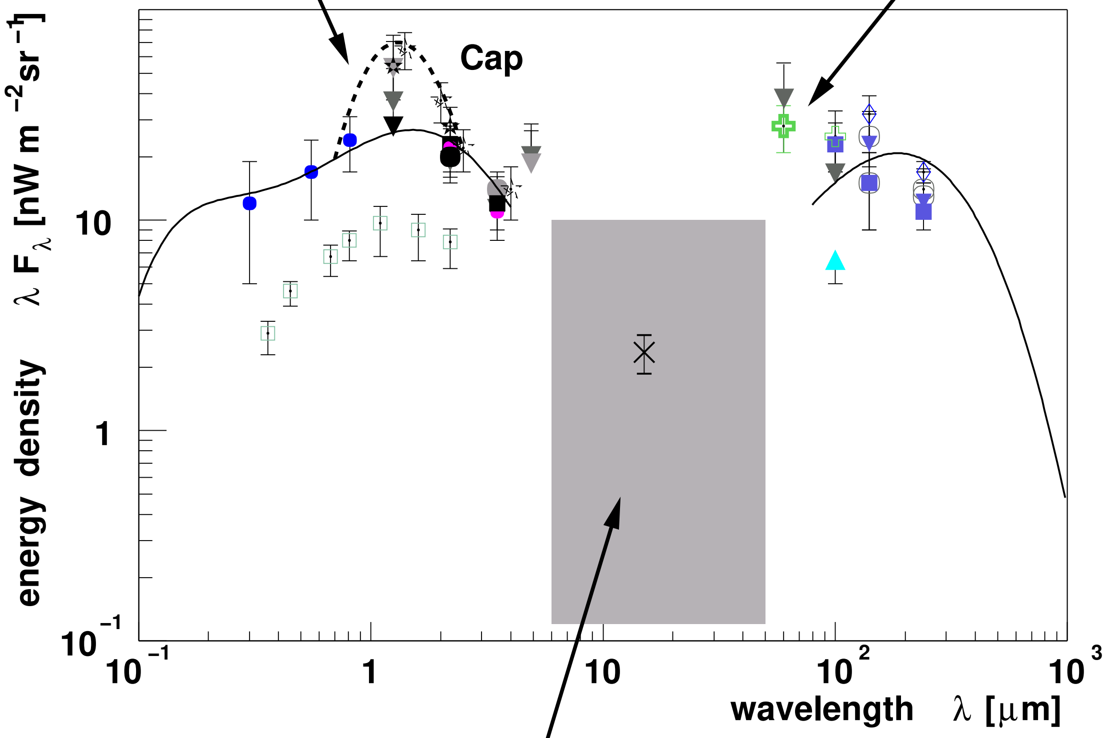
assumed initial spectrum

Topics of this work

topic 1:

Finkbeiner at 60 microns

topic 3: Cap impact



topic 2: position of minimum

Strategy to constrain EBL

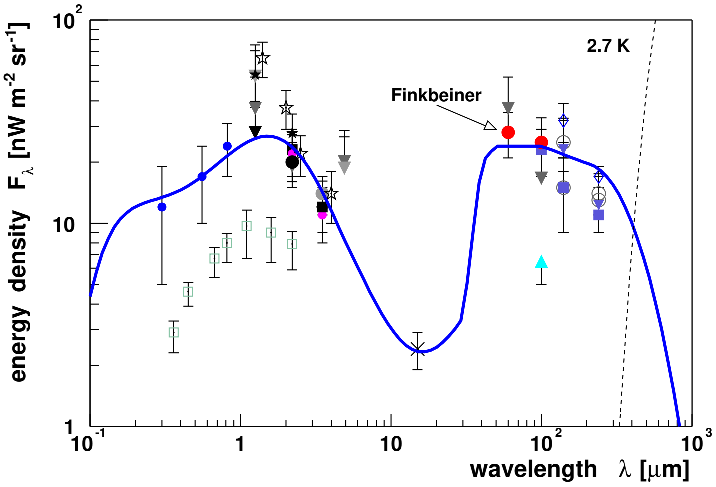
Steps:

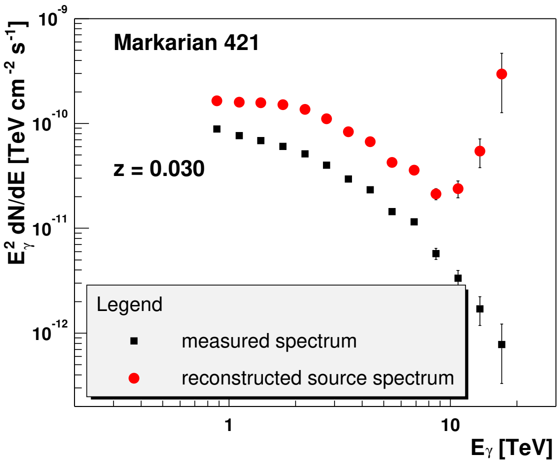
- measure TeV spectrum
- assume an EBL shape
- calculate the optical depth
- reconstruct TeV source spectrum
- physical constaints of reconstructed TeV source spectrum
- upper limits on EBL

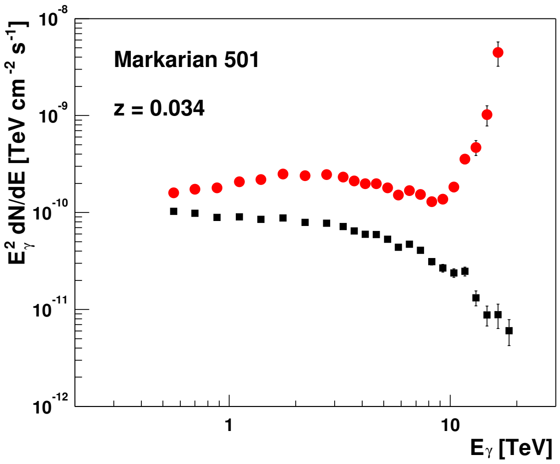
Difficulties:

- need to keep some EBL parts fixed
- what is physically possible for TeV source spectra?

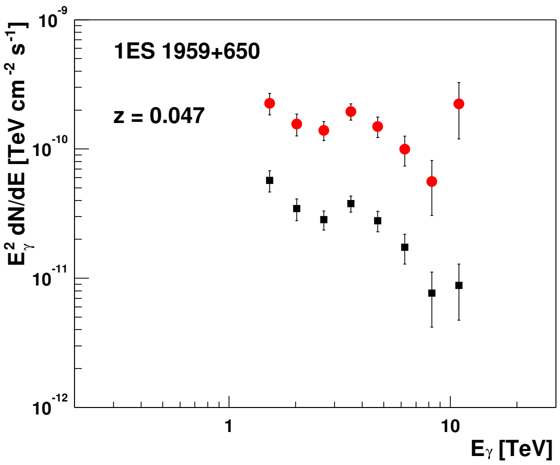
Topic 1: Finkbeiner at 60 μm $\longrightarrow$ TeV crisis

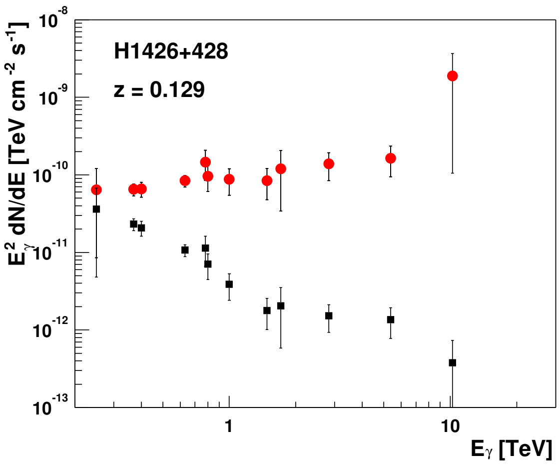






$\longrightarrow$ Markarian objects: TeV-crisis



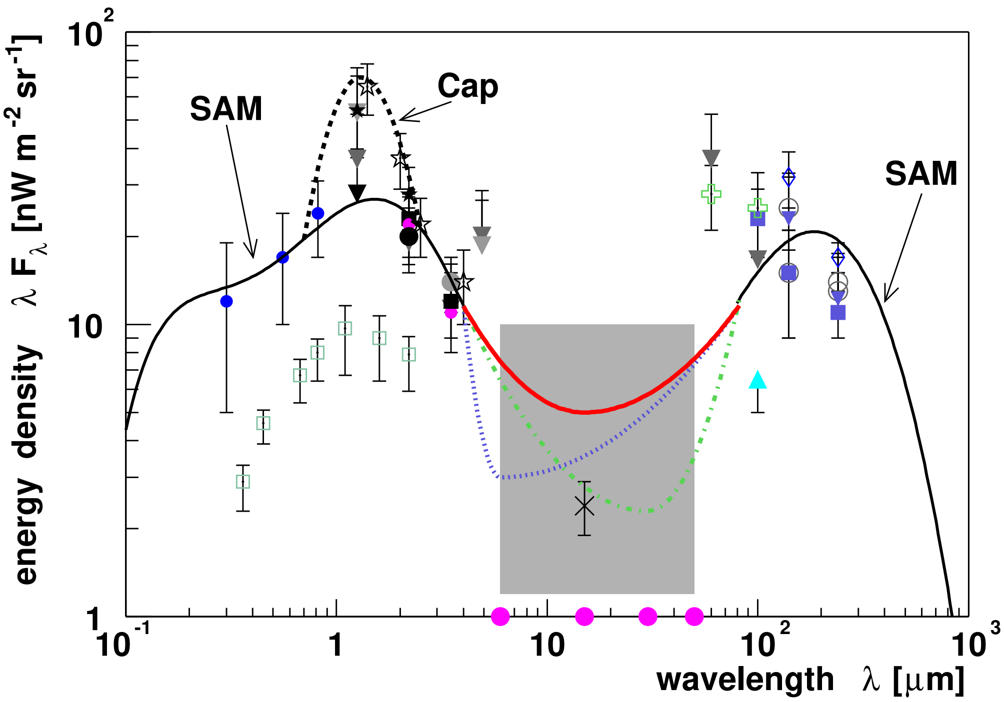


$\longrightarrow$ 1ES1959 and H1426: tentative crisis

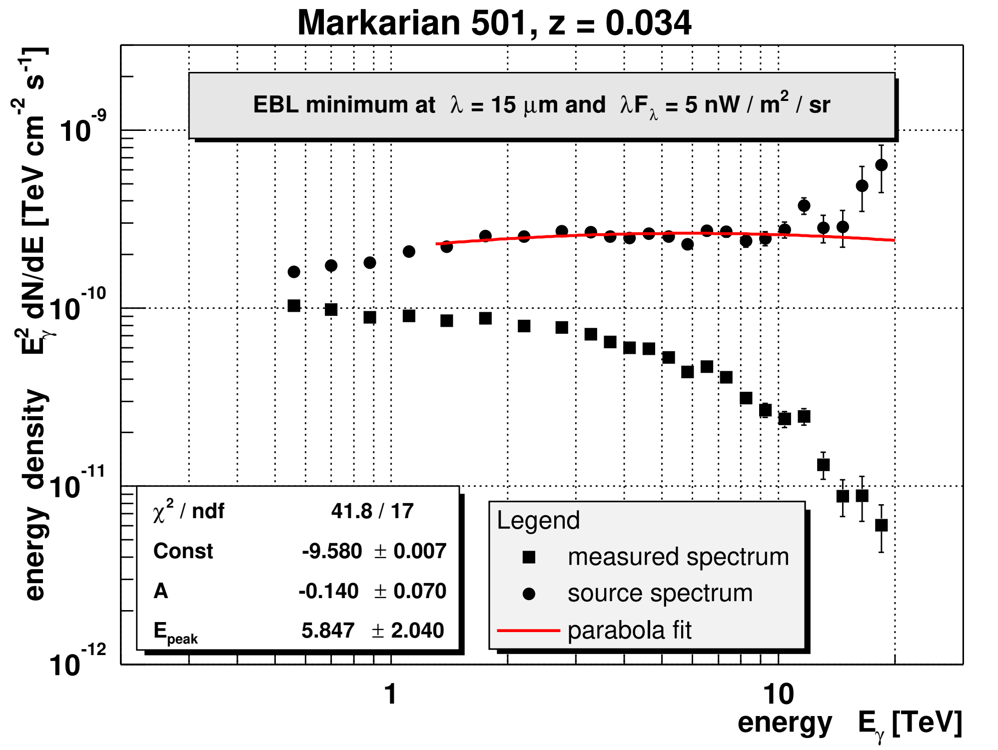
$\boxed{\Longrightarrow \text{Finkbeiner at 60 } \mu\text{m is very unlikely}}$

Topic 2: Constraining Minimum in MID-IR

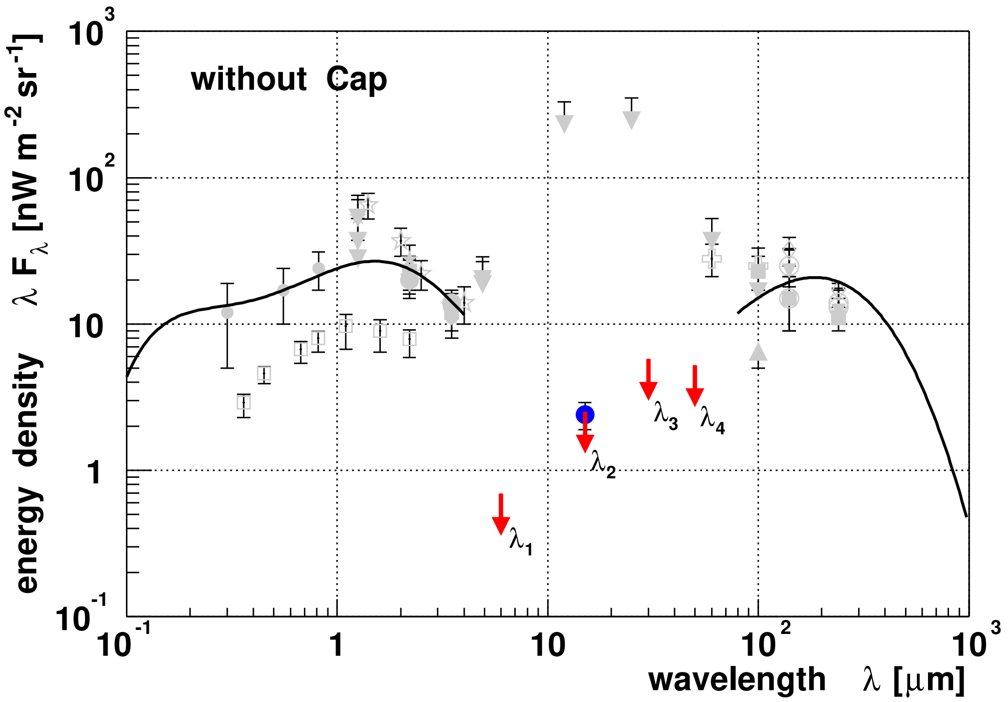
1. choose an EBL shape (SAM: semi analytical model)



2. calculate optical depth for TeV photons
3. reconstruct source spectrum
4. fit reconstructed source spectrum: $\longrightarrow$ get χ^2
5. if χ^2 OK (within 99% c.l.) then EBL shape accepted



Constraints on EBL from Markarian 501



	upper limits (99% c.l.) on EBL [nWm^{-2}sr^{-1}]			
Minimum at:	**6 μm**	**15 μm**	**30 μm**	**50 μm**
SAM shape	**0.69**	**2.51**	5.75	5.25
SAM + "Cap" shape	**0.36**	**1.45**	6.31	6.31

lower limit from ISOCAM at 15 μm:

Metcalfe *et al.* (2003), `astro-ph/0305400`

(2.7 ± 0.62) nW m^{-2} sr^{-1}

- red: strong conflict
- blue: possible conflict

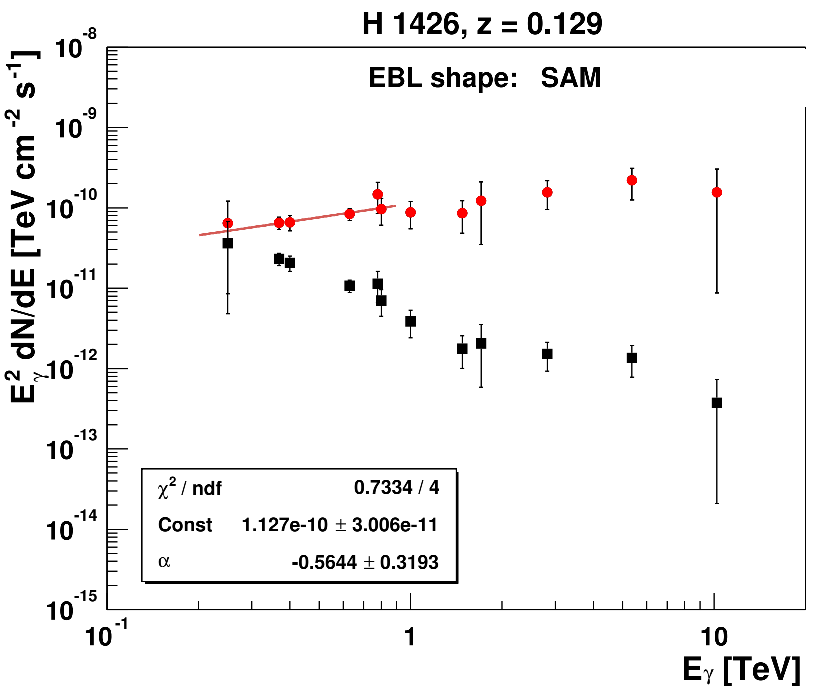
$\Longrightarrow$ Minimum at $\lambda > 15\,\mu$m

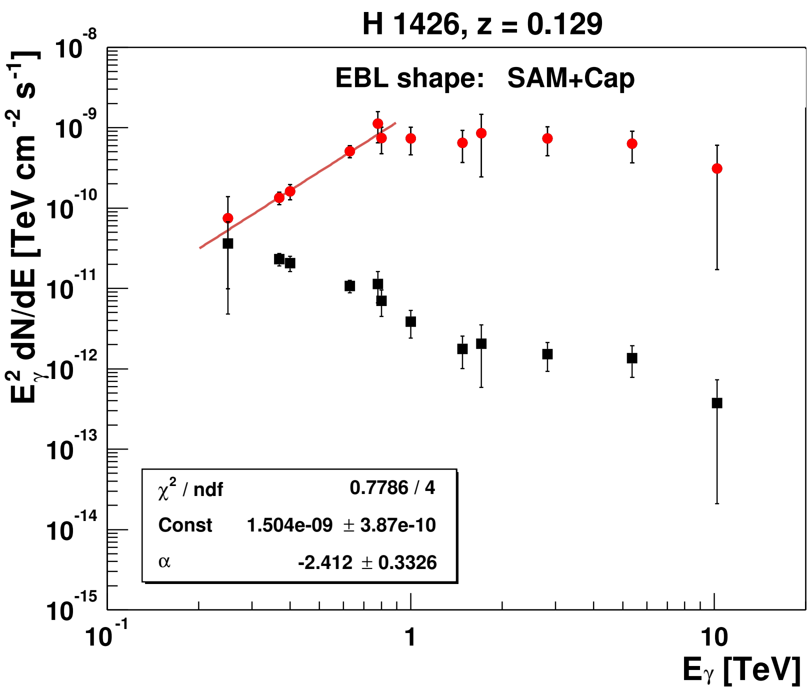
Topic 3: Cap impact – the case of H 1426+428

Theoretical values for rising spectra near maximum:

- hadronic models (π^0-decay): $\alpha \approx -1$
- leptonic models (SSC): $\alpha \approx -0.5$ (L. Costamante, priv. communication)

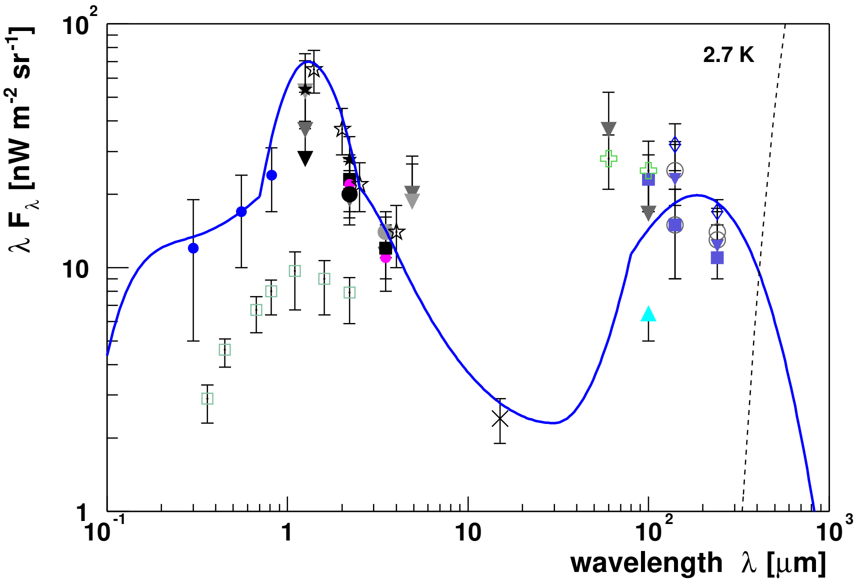
$$E^2 \frac{\mathrm{d}N}{\mathrm{d}E} = Const\, E^{-\alpha}$$

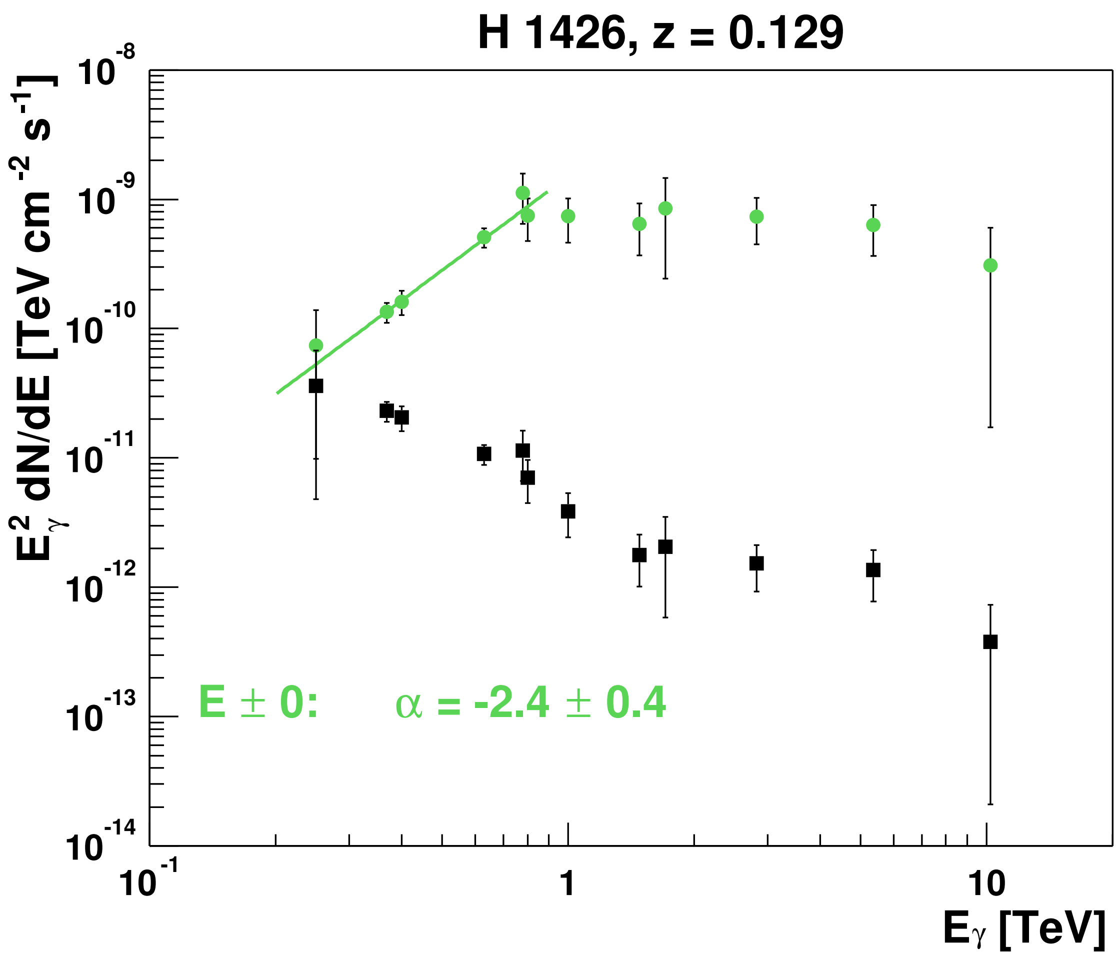


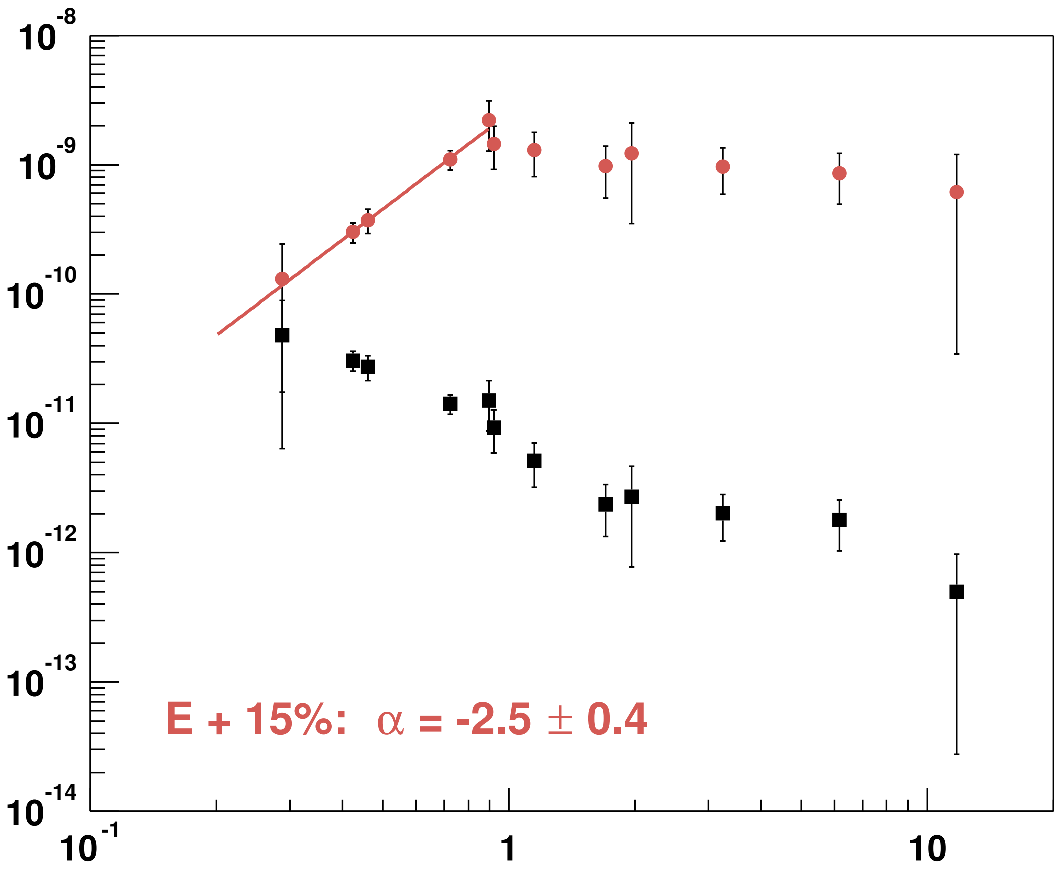


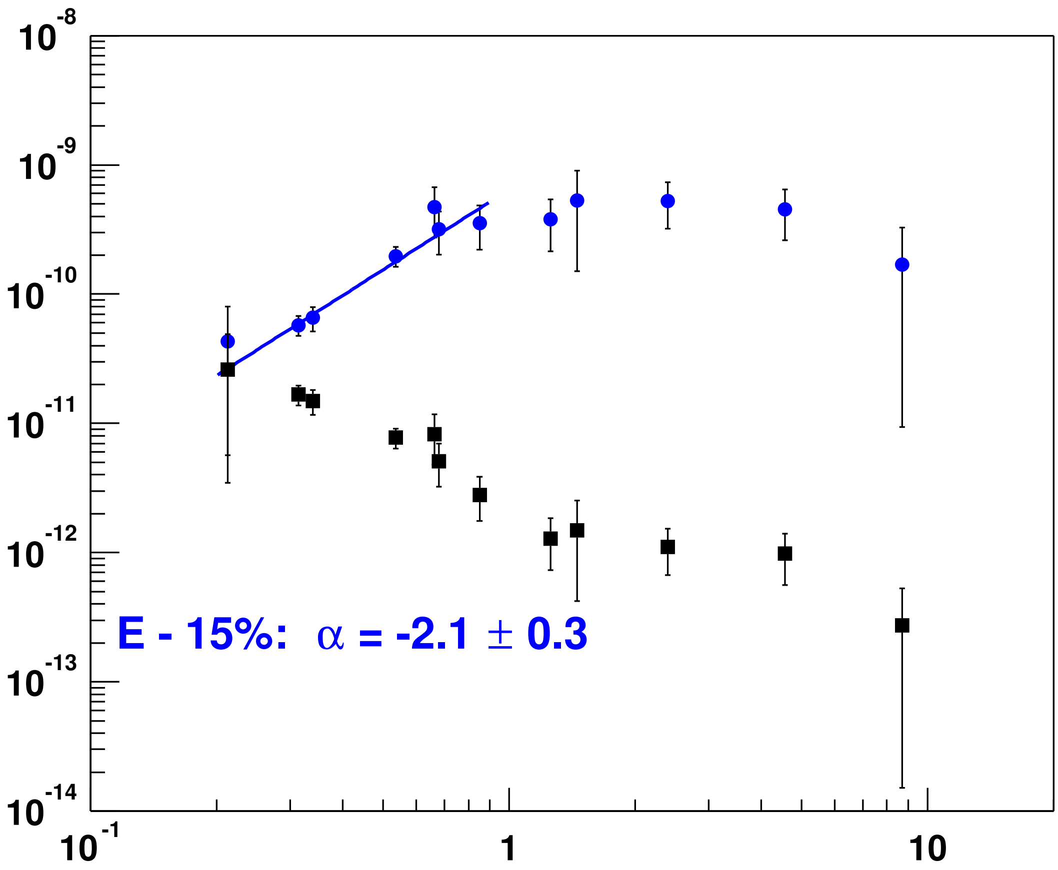
from H 1426 $\longrightarrow$ if “Cap” then spectrum too hard

Update I: Impact of absolute uncertainty of the energy scale of 15%



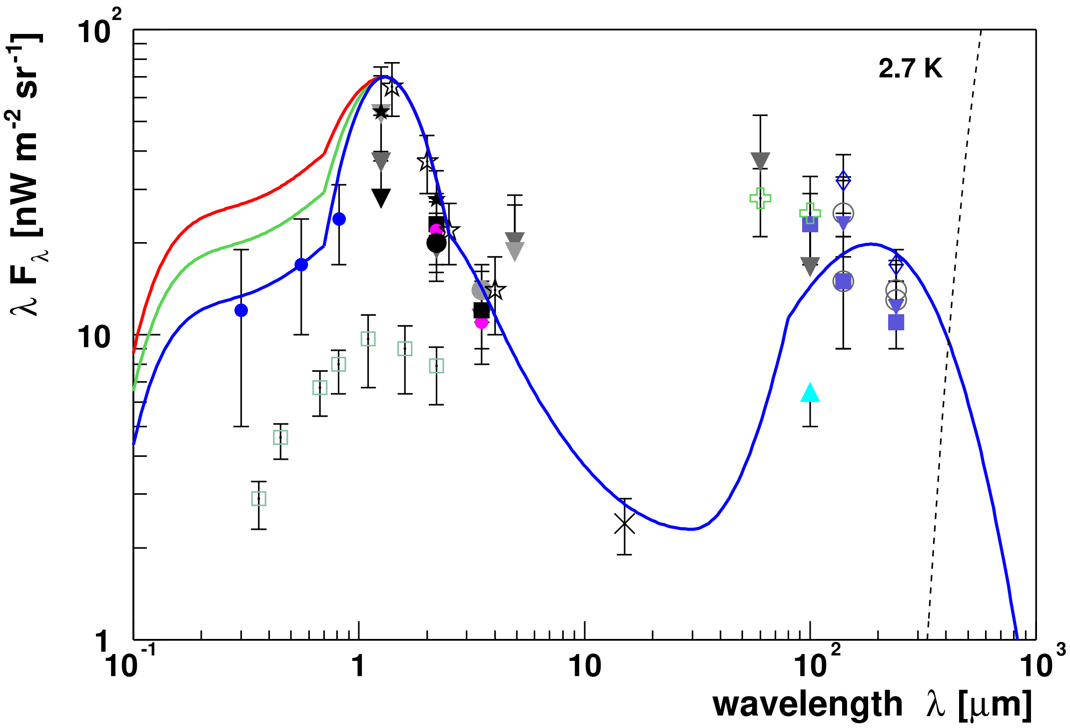


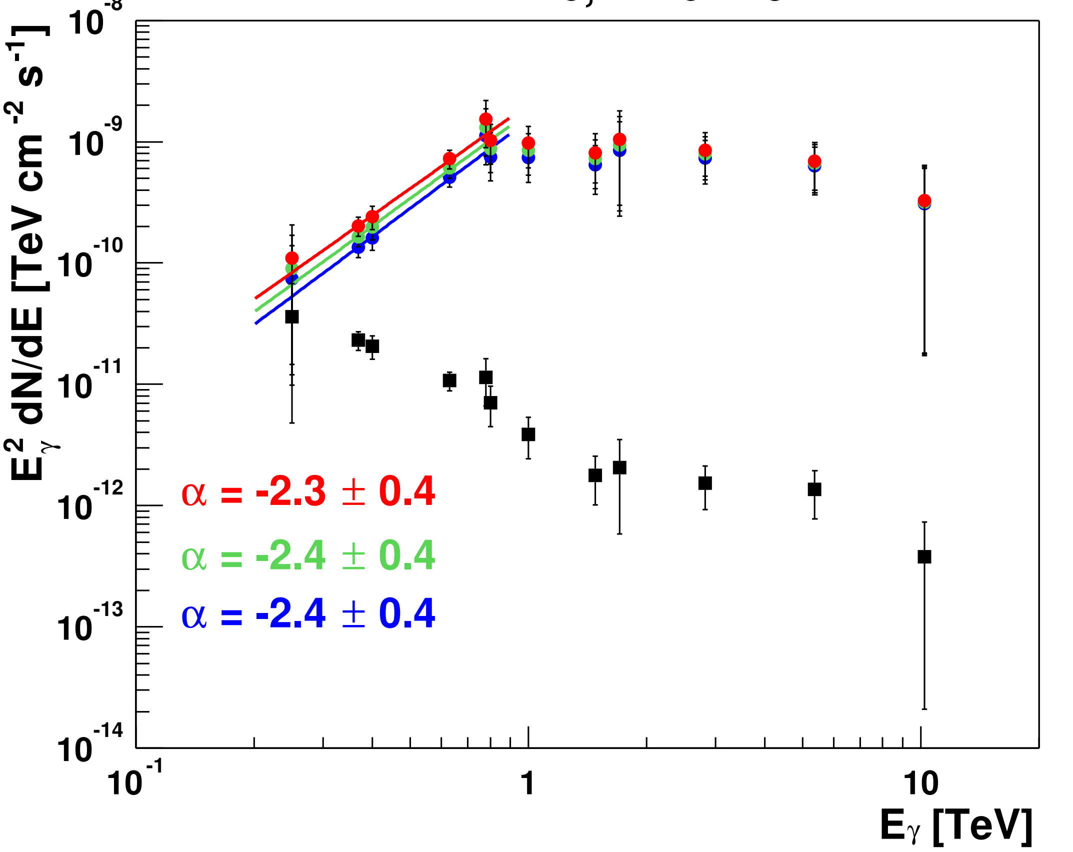

10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-1
1
10
E + 15%: α = -2.5 ± 0.4



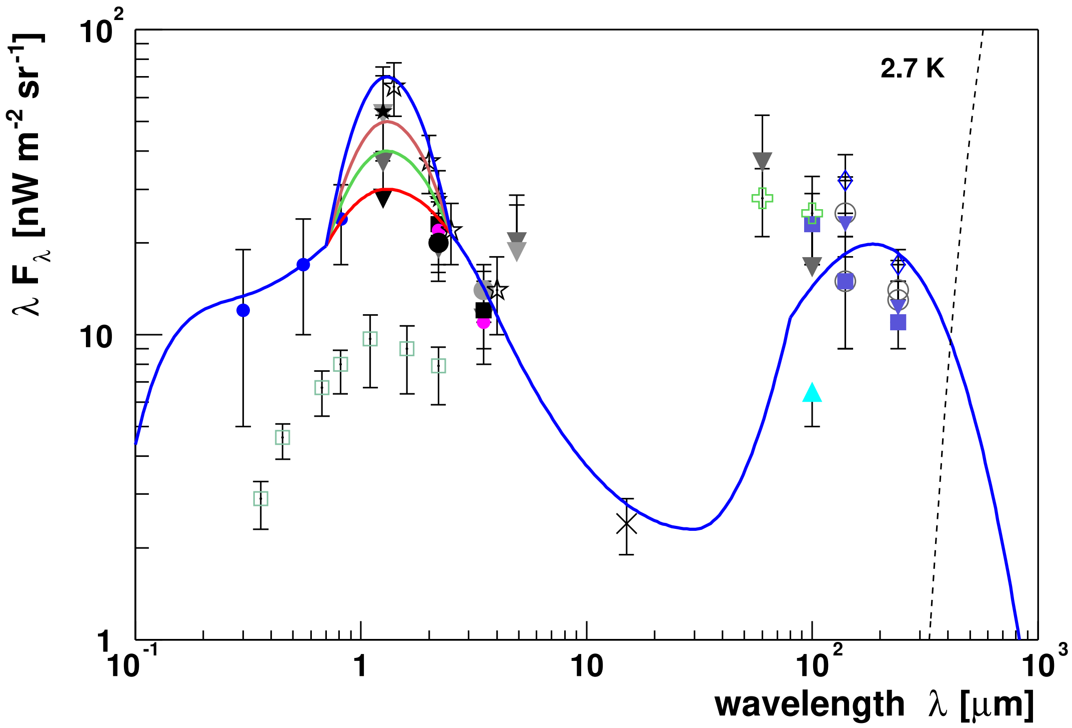
E - 15%: α = -2.1 ± 0.3
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-1
1
10

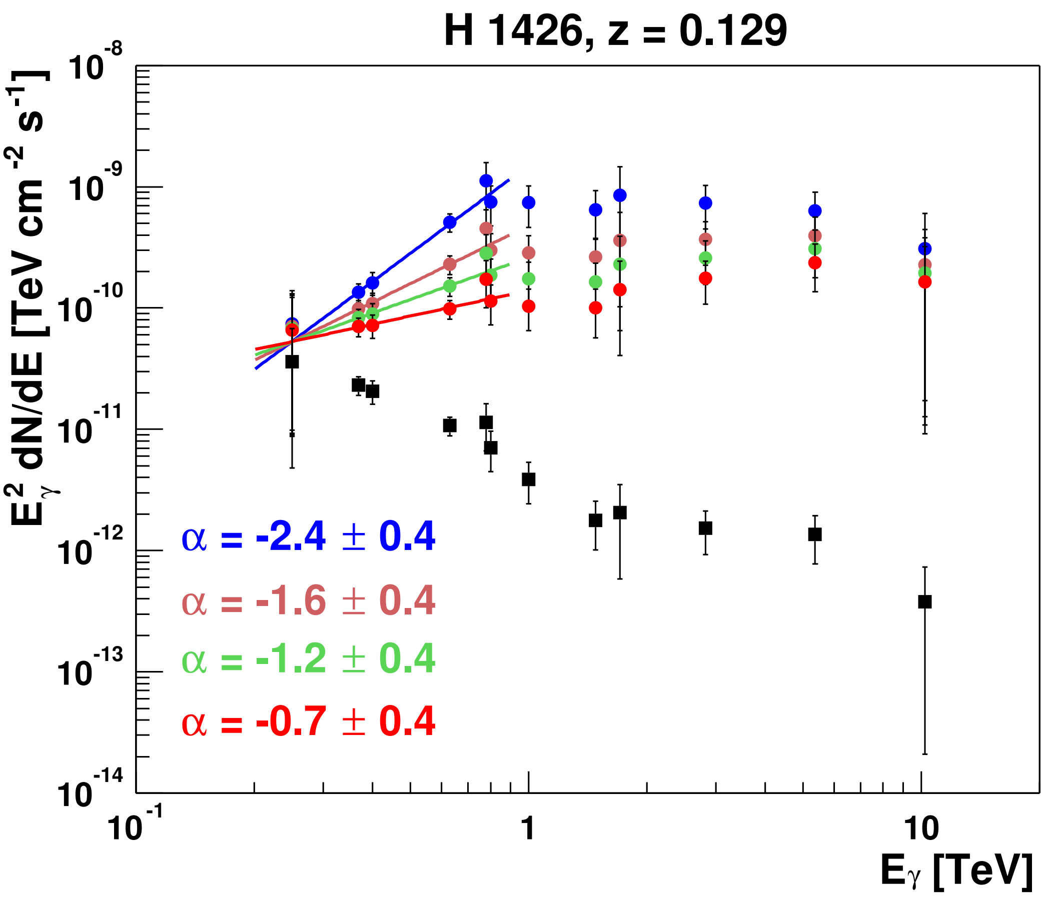
Update II: Impact of UV-opt part of EBL



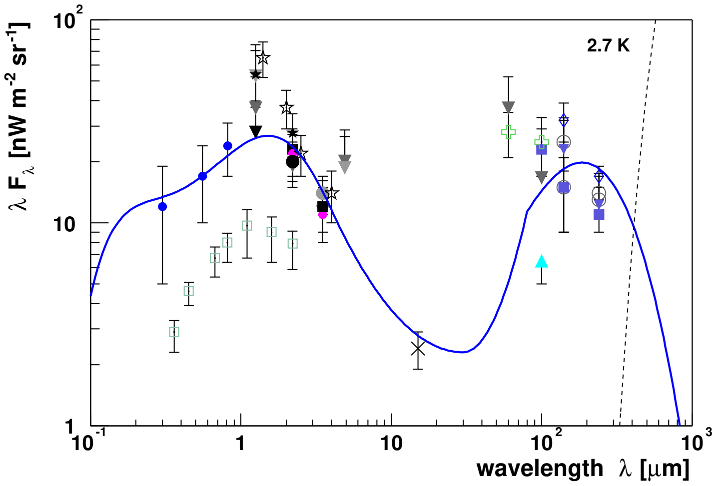


Update III: Impact of the height of the Cap

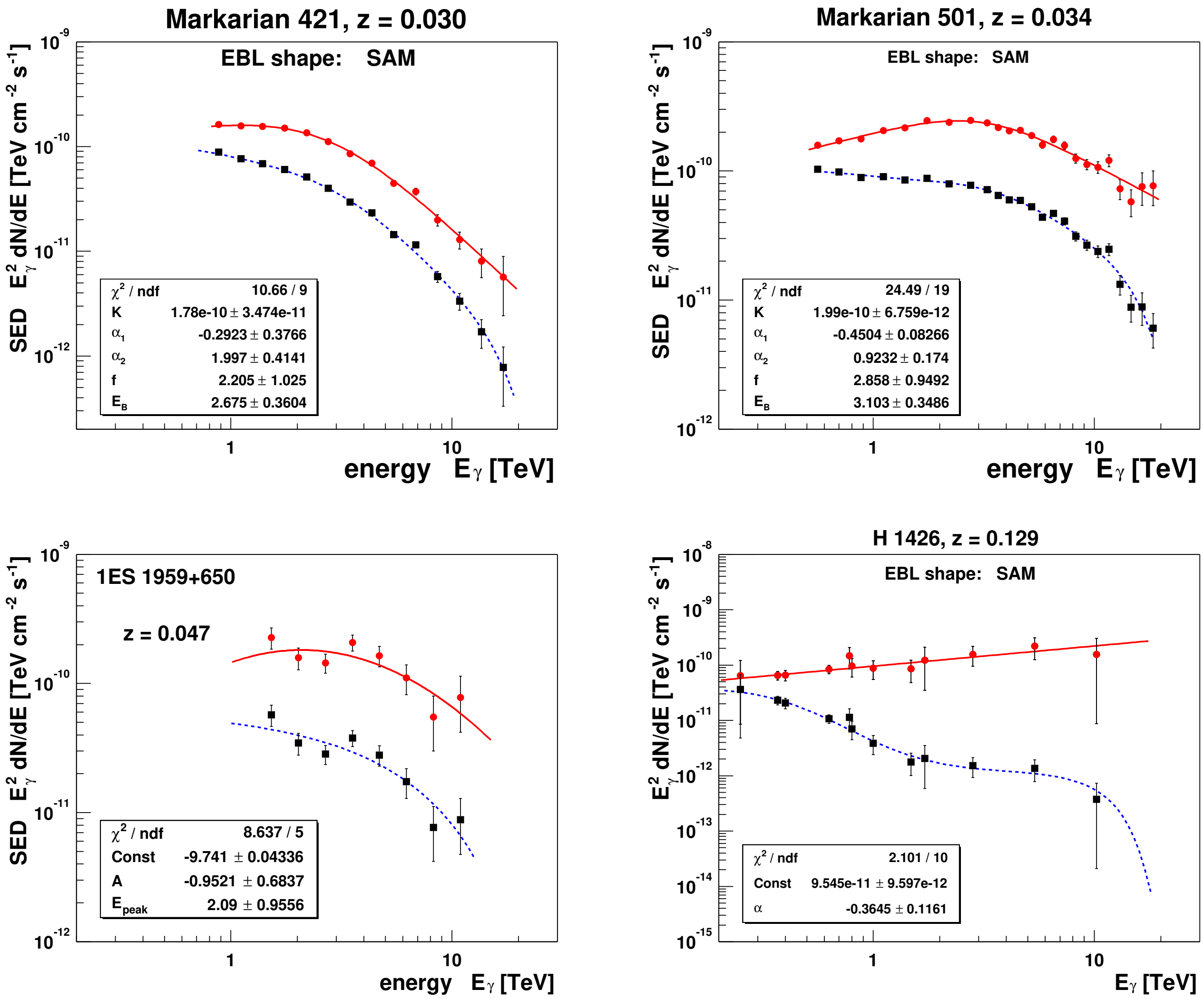




Example: EBL shape fitting all TeV-spectra well



- no Finkbeiner at 60 μm
- minimum at $\lambda > 15\,\mu$m
- no "Cap"

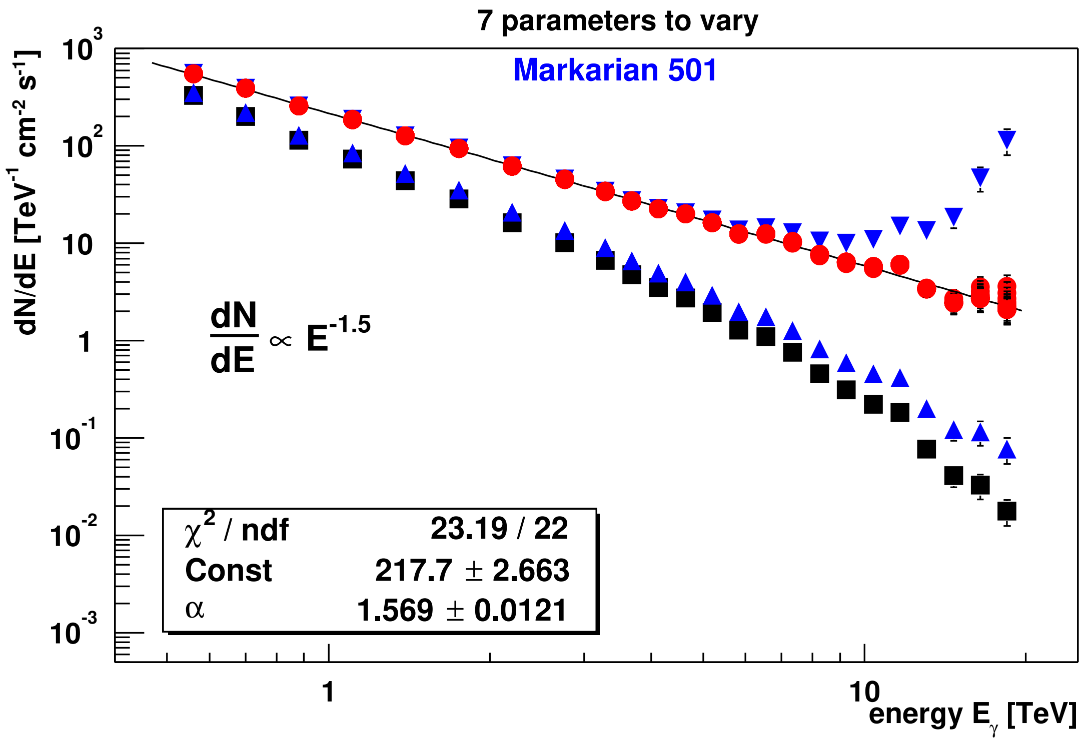


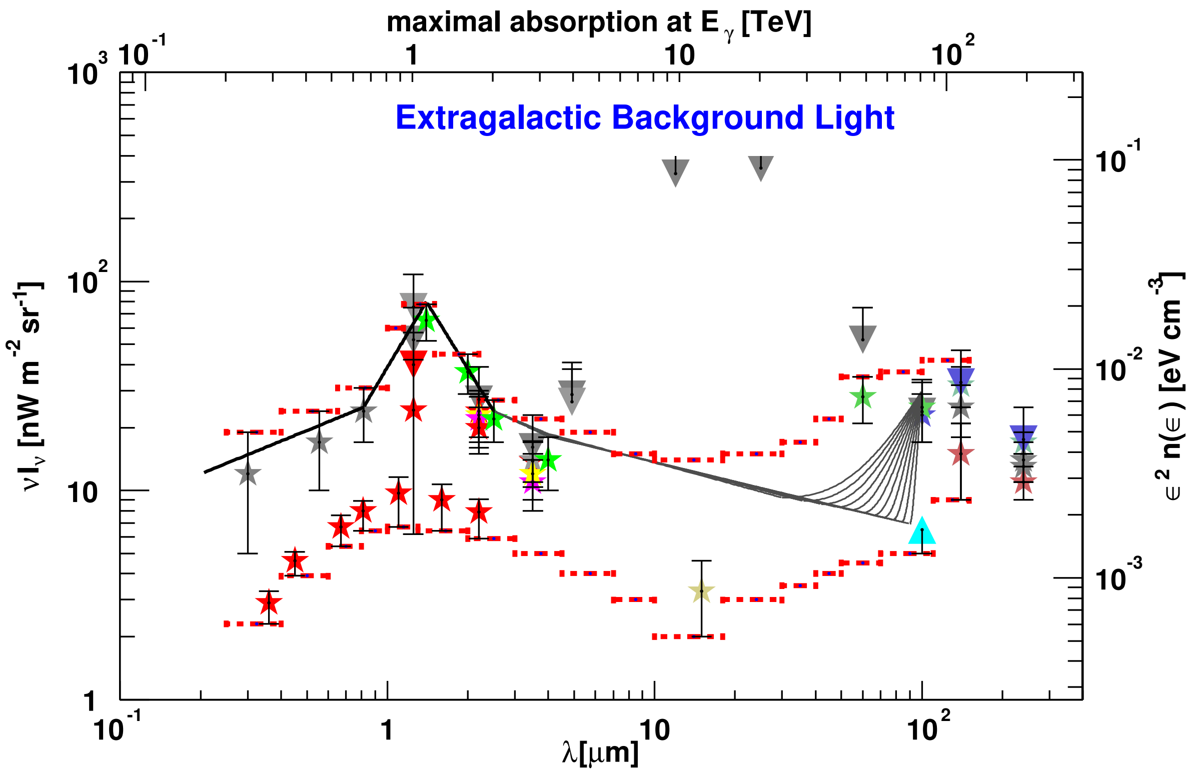
Conclusion and Outlook

- TeV γ-astronomy provides strong constraints to EBL density
- Finkbeiner at 60 μm is very unlikely
- Minimum of the mid-IR valley at $\lambda > 15\,\mu$m
- "Cap" around $1\,\mu$m is unlikely
- Statistics is still low

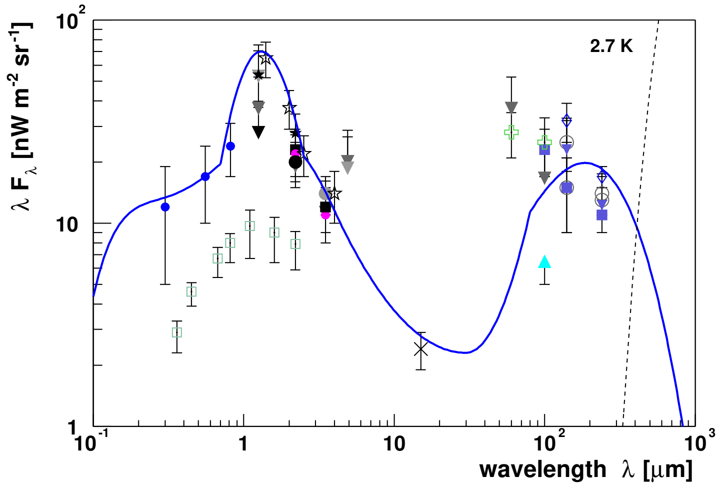
- Next Generation of Cherenkov Telescopes:
  H·E·S·S, MAGIC, VERITAS, CANGAROO
  $\rightarrow$ will provide <u>more</u> TeV γ-sources
  with <u>higher</u> statistics
- 0.3 to 3 TeV spectra could "measure" Cap

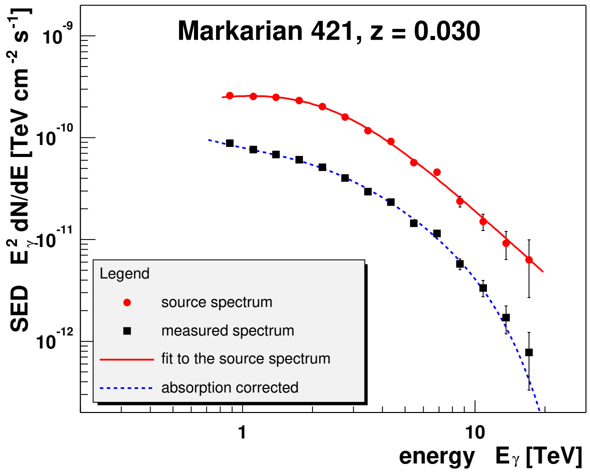
Strategy A

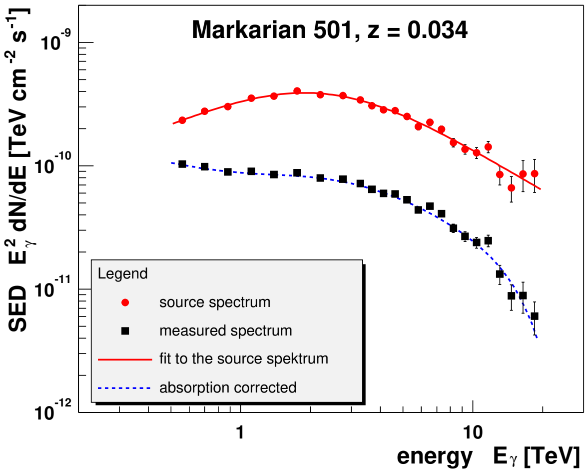

7 parameters to vary
Markarian 501
dN/dE [TeV^{-1} cm^{-2} s^{-1}]
$\frac{dN}{dE} \propto E^{-1.5}$
χ^2 / ndf 23.19 / 22
Const 217.7 ± 2.663
α 1.569 ± 0.0121
energy E_γ [TeV]

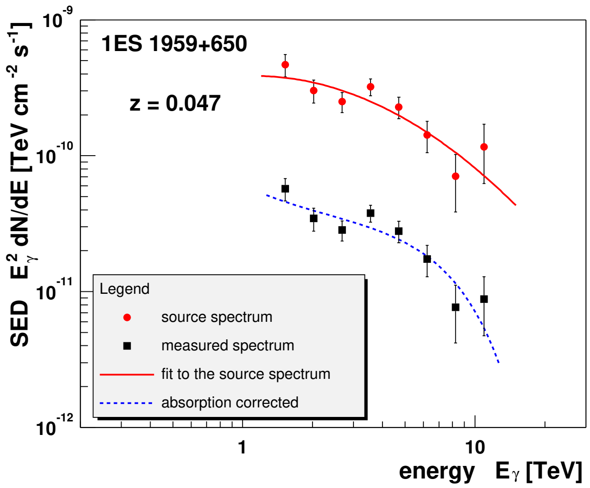

maximal absorption at E_γ [TeV]
Extragalactic Background Light
νI_ν [nW m^{-2} sr^{-1}]
ϵ^2 n(ϵ) [eV cm^{-3}]
λ[μm]

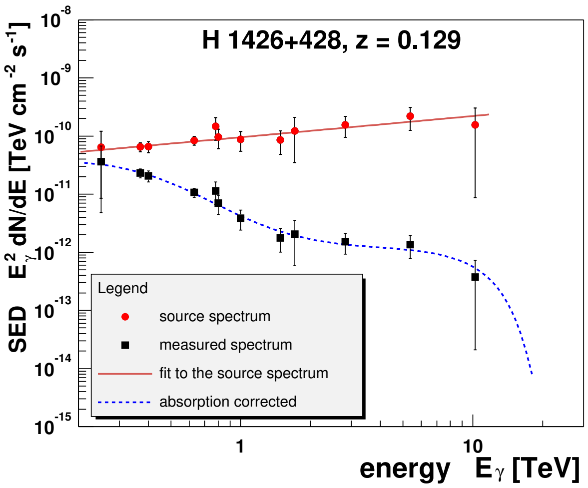
Example: EBL shape fitting all TeV-spectra well











Calculation of the optical depth $\tau(E)$

Absorption:

- Pair production $\boxed{\gamma_{\text{TeV}}\,\gamma_{\text{EBL}} \longrightarrow e^+e^-}$
- $\tau(E,\, z_s) =$

$$\frac{c}{H_0}\int_0^{z_s} dz\, \frac{(1+z)^2}{\sqrt{(1+z)^3\,\Omega_{\text{m}}+\Omega_\Lambda}} \int_{-1}^{1} d\mu\, \frac{1-\mu}{2} \int_{\epsilon_t}^{\infty} d\epsilon\, n(\epsilon,z)\,\sigma_{\gamma\gamma}(\epsilon,E,\mu,z)$$

$\mu := \cos(\theta)$

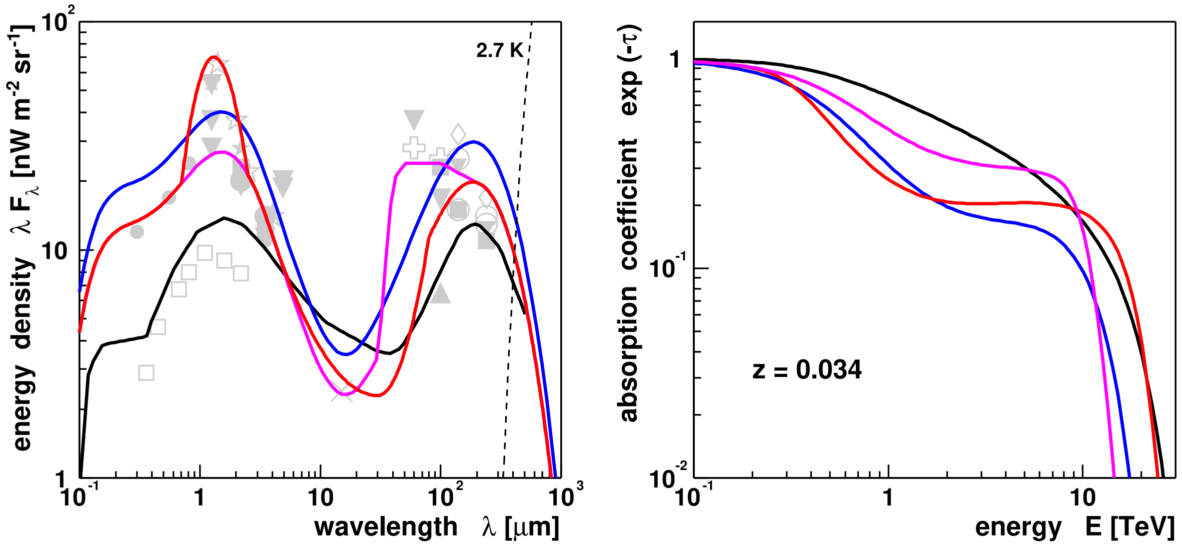
- Maximum pair production: $\lambda_{EBL} \approx 1.24\, \frac{E_{\text{TeV}}}{1\ \text{TeV}}\ \mu\text{m}$

Took into account:

- expansion of the universe:
  $E \longrightarrow E(1+z),\ \epsilon \longrightarrow \epsilon(1+z),\ n(\epsilon) \longrightarrow n(\epsilon)\,(1+z)^3$
- flat universe, cosmological constant $\Lambda \neq 0$

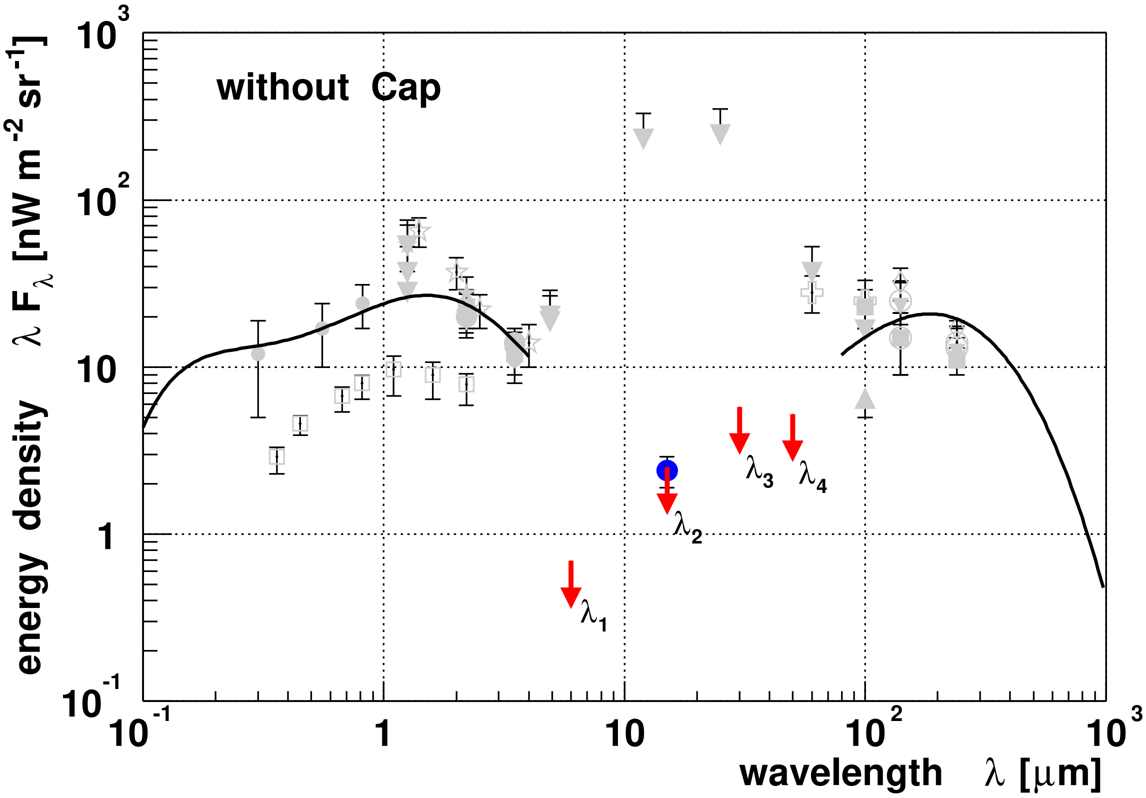
Dependencies:

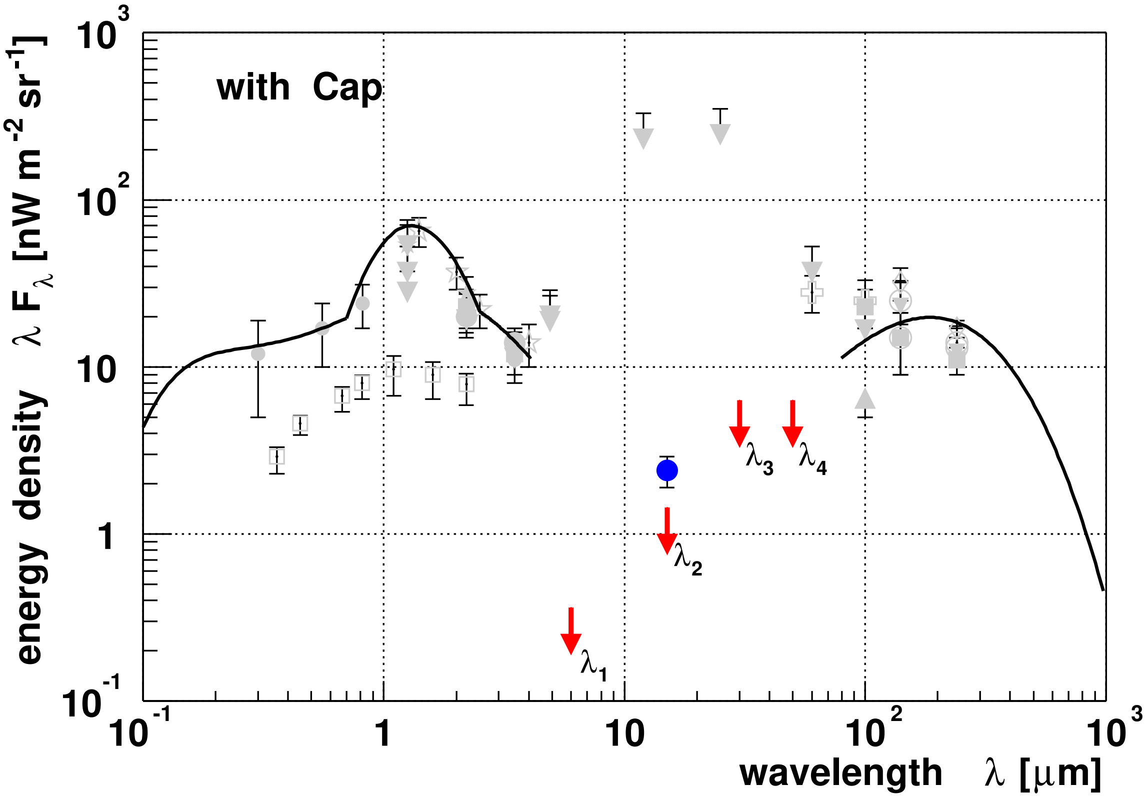
- cosmological parameters: $H_0,\ \Omega_m,\ \Omega_\Lambda$
  $H_0 = 72\,\text{Mpc s}^{-1}\,\text{km}^{-1},\ \Omega_m = 0.3,\ \Omega_\Lambda = 0.7$
- form and height of EBL spectrum $n(\epsilon)$



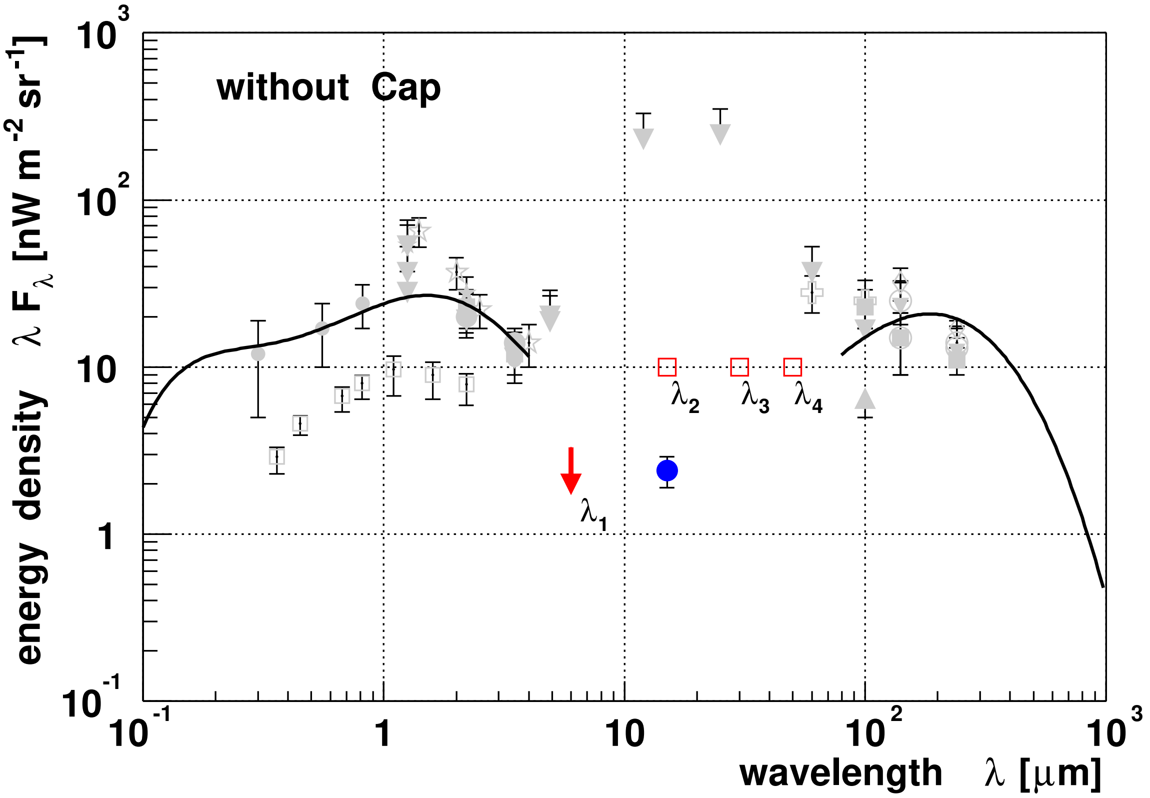
TeV source spectrum: $\boxed{F_{init}(E) = \exp(\tau)\cdot F_{meas}(E)}$

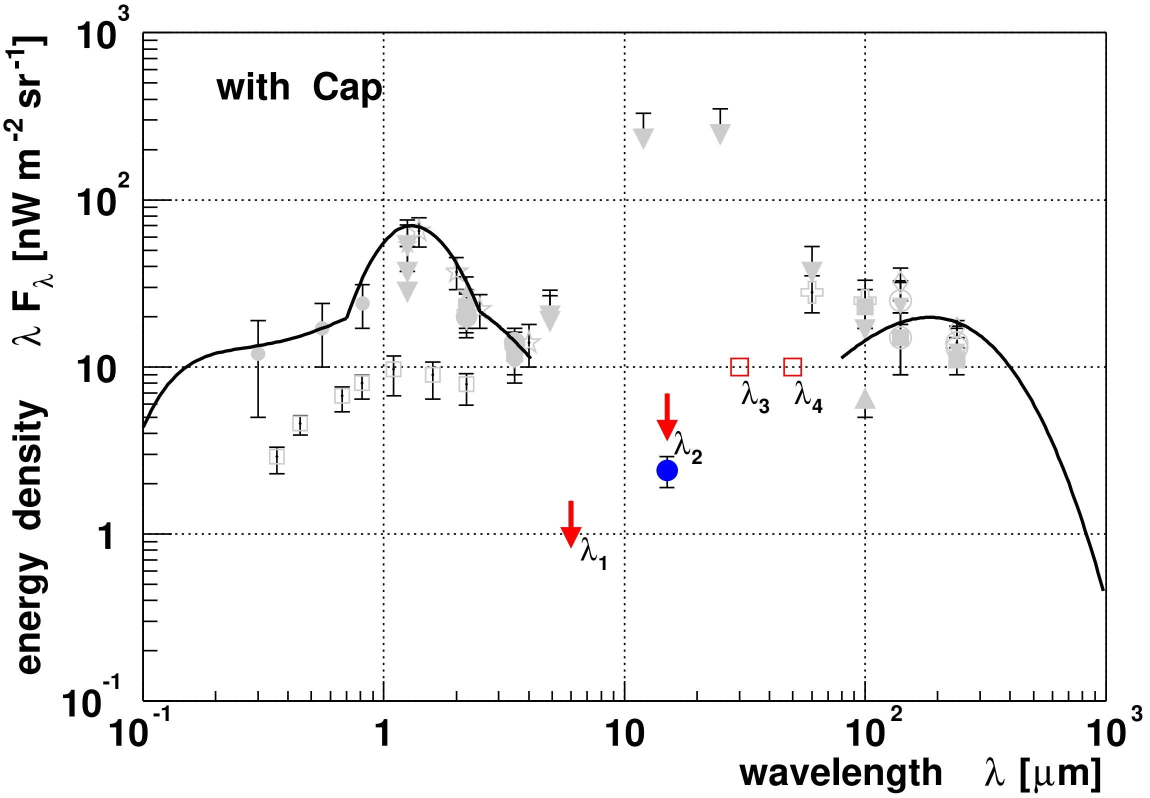
Constraints on EBL from Markarian 501



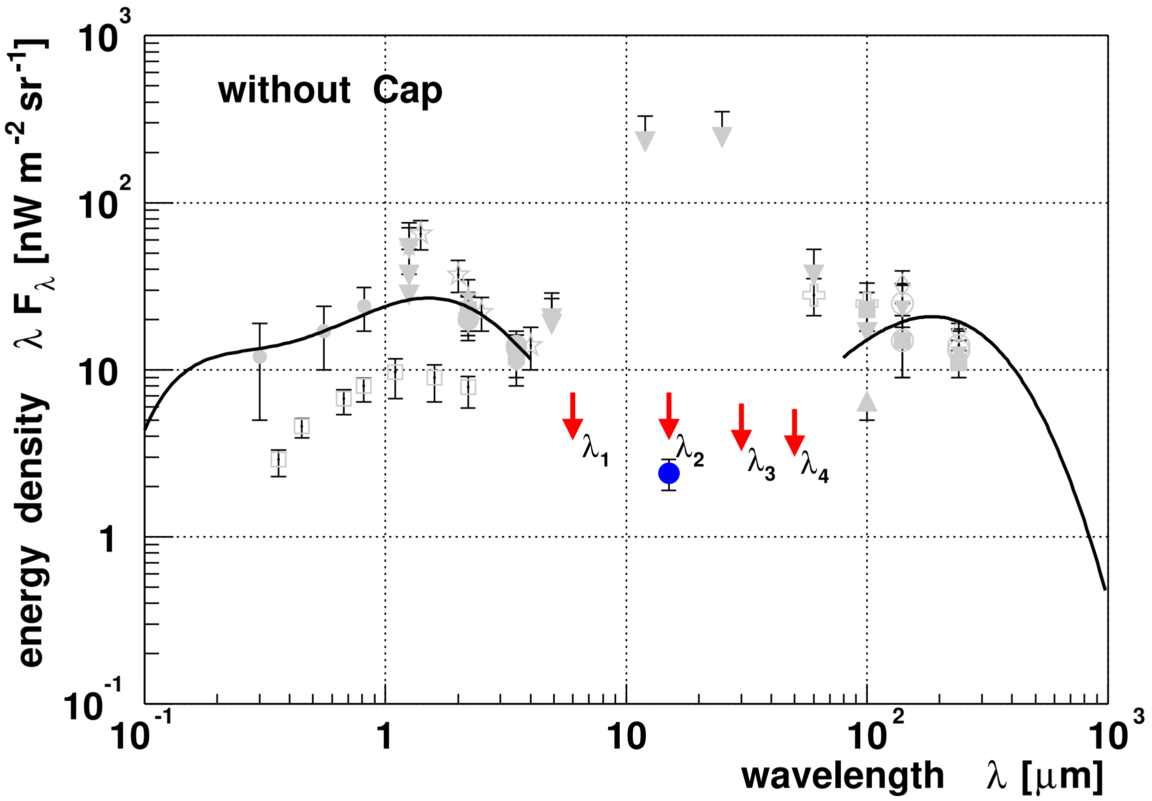


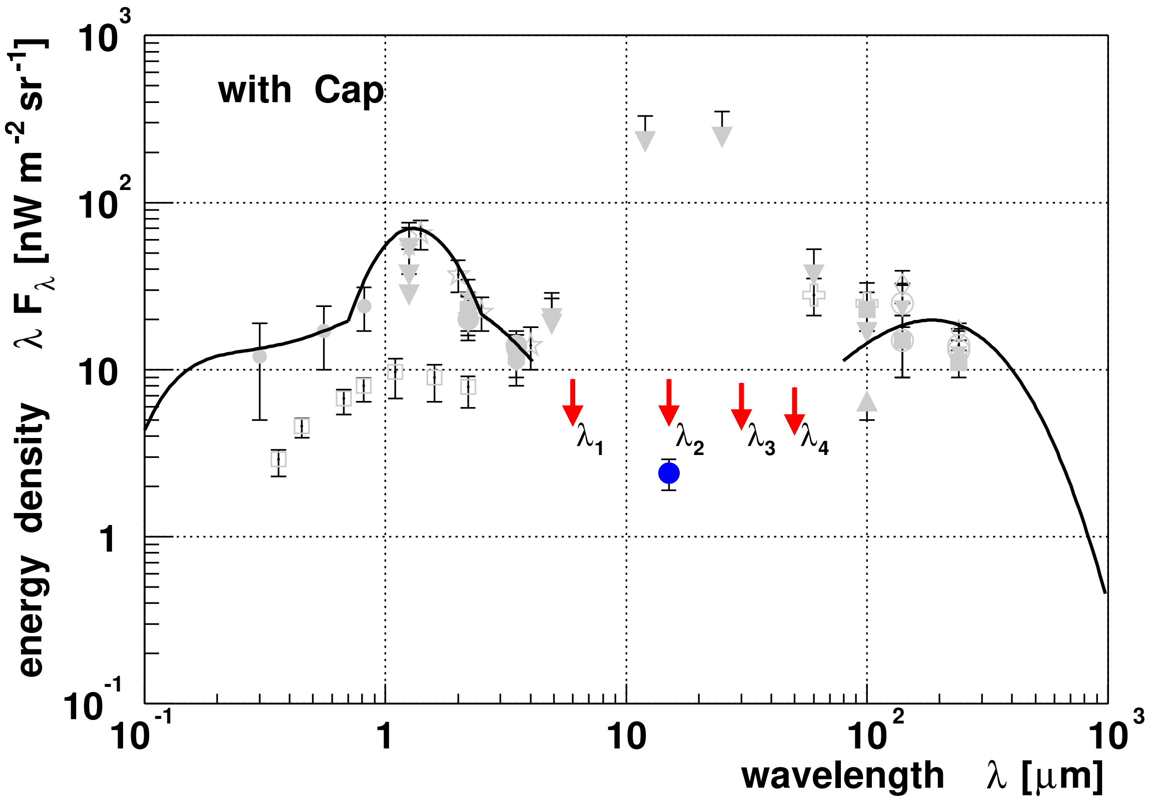
Constraints on EBL from Markarian 421





Constraints on EBL from H1426+428





Summary of Upper Limits on EBL minimum

	upper limits (99% c.l.) on EBL SAM shape [$\mathrm{nWm^{-2}sr^{-1}}$]			
Minimum at	**Mrk 421**	**Mrk 501**	**1ES 1959**	**H 1426**
6 μm	3.31	**0.69**	—	7.3
15 μm	—	**2.51**	—	7.3
30 μm	—	**5.75**	—	6.3
50 μm	—	**5.25**	—	5.8

	upper limits (99% c.l.) on EBL SAM+„Cap“ shape [$\mathrm{nWm^{-2}sr^{-1}}$]			
Minimum at	**Mrk 421**	**Mrk 501**	**1ES 1959**	**H 1426**
6 μm	1.58	**0.36**	—	8.8
15 μm	6.92	**1.45**	—	8.8
30 μm	—	**6.31**	—	8.3
50 μm	—	**6.31**	—	7.8

lower limit from ISOCAM at 15 μm:
Metcalfe *et al.* (2003), astro-ph/0305400
(2.7 ± 0.62) nW m^{-2} sr^{-1}

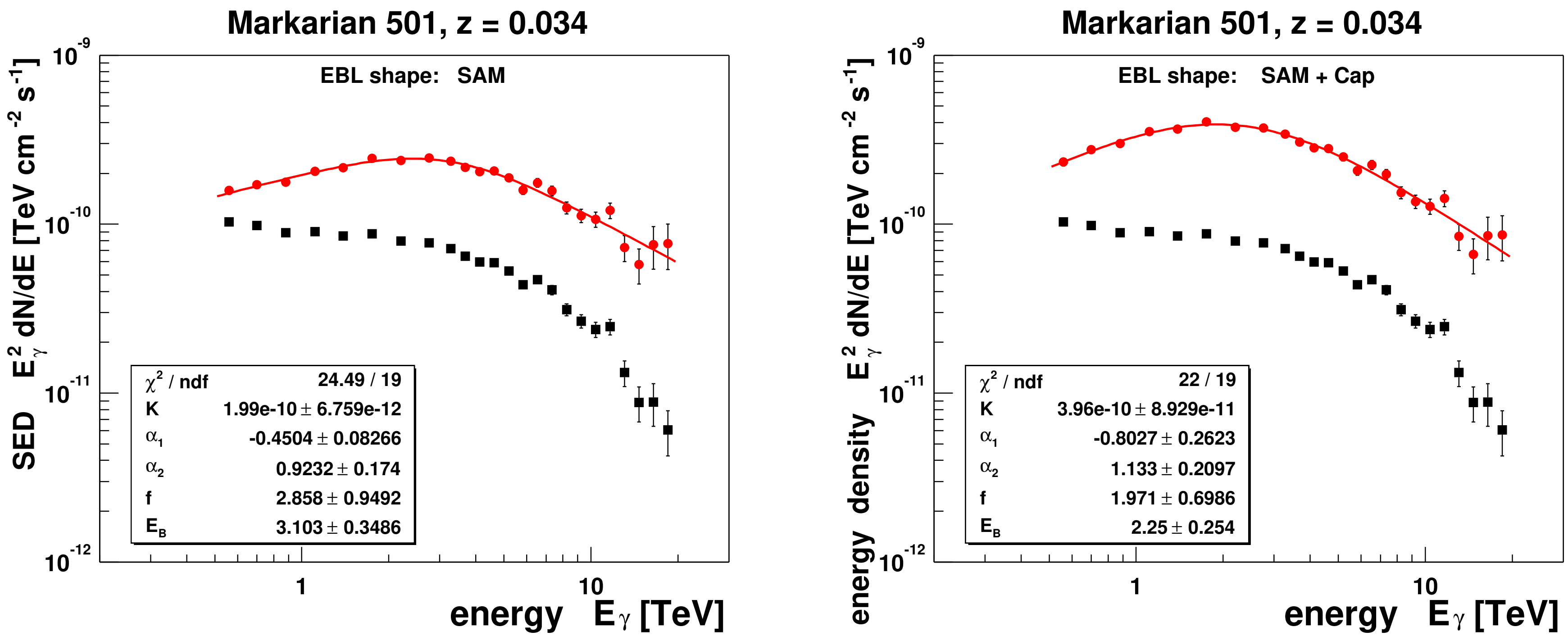
- red: strong conflict
- blue: possible conflict

Topic 3: “Cap” impact – spectrum too hard?

Theoretical values for rising spectra near maximum:

- hadronic models (π^0-decay): $\alpha_1 \approx -1$
- leptonic models (SSC): $\alpha_1 \approx -0.5$ (L. Costamante, priv. communication)

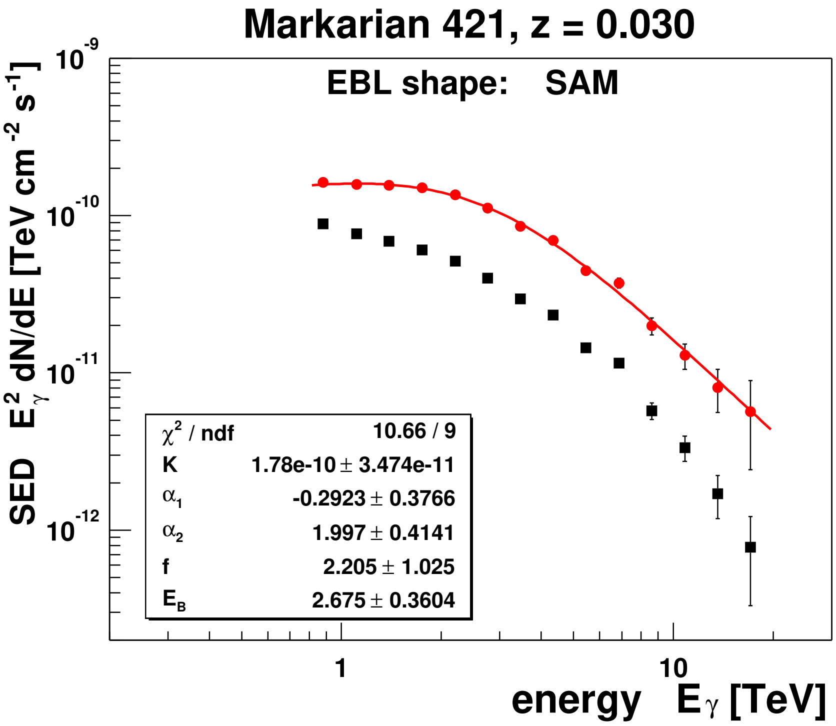
Fit method: $$E^2 \, \frac{\mathrm{d}N}{\mathrm{d}E} = K \, E^{-\alpha_1} \left(1 + \left(\frac{E}{E_B}\right)^f\right)^{(\alpha_1-\alpha_2)/f}$$

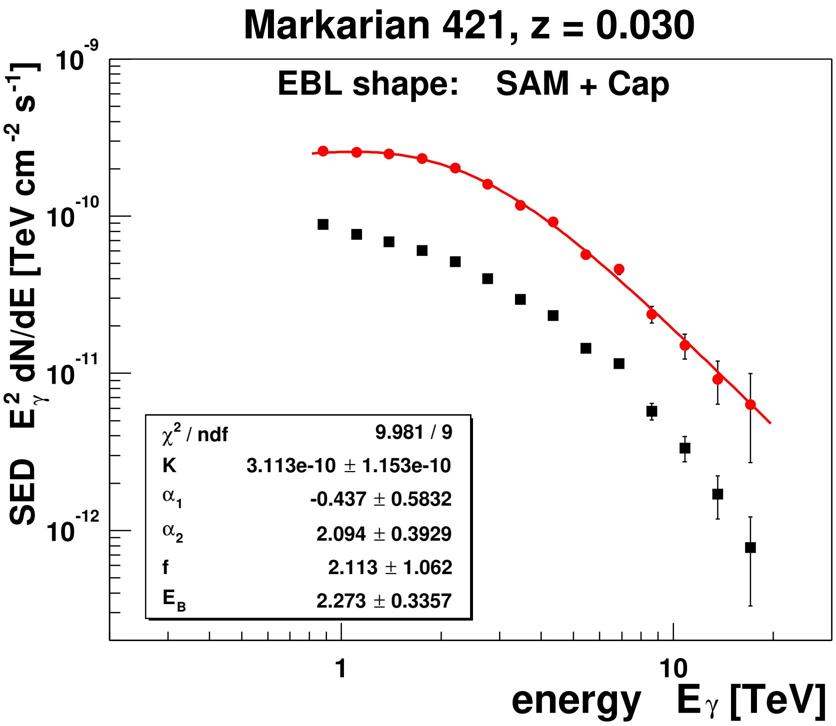


from Mrk 501 $\longrightarrow$ no evidence for too hard spectrum

“Cap” impact: Markarian 421

$$E^2\,\frac{\mathrm{d}N}{\mathrm{d}E} = K\,E^{-\alpha_1}\left(1+(\frac{E}{E_B})^f\right)^{(\alpha_1-\alpha_2)/f}$$

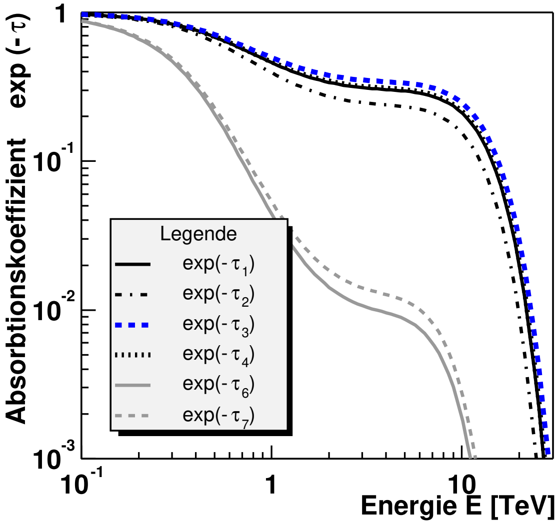


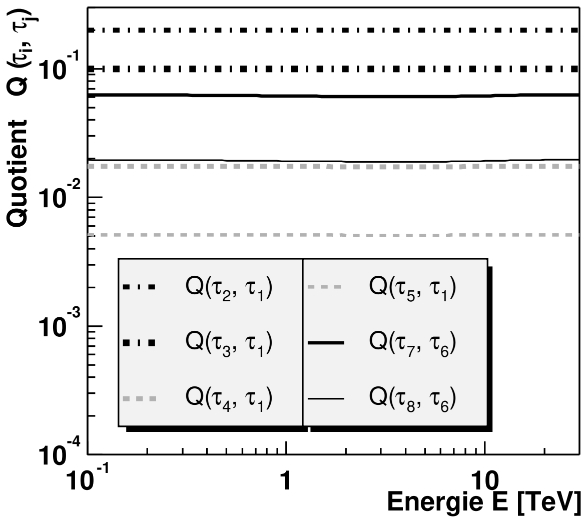


$\longrightarrow$ no evidence for too hard spectrum

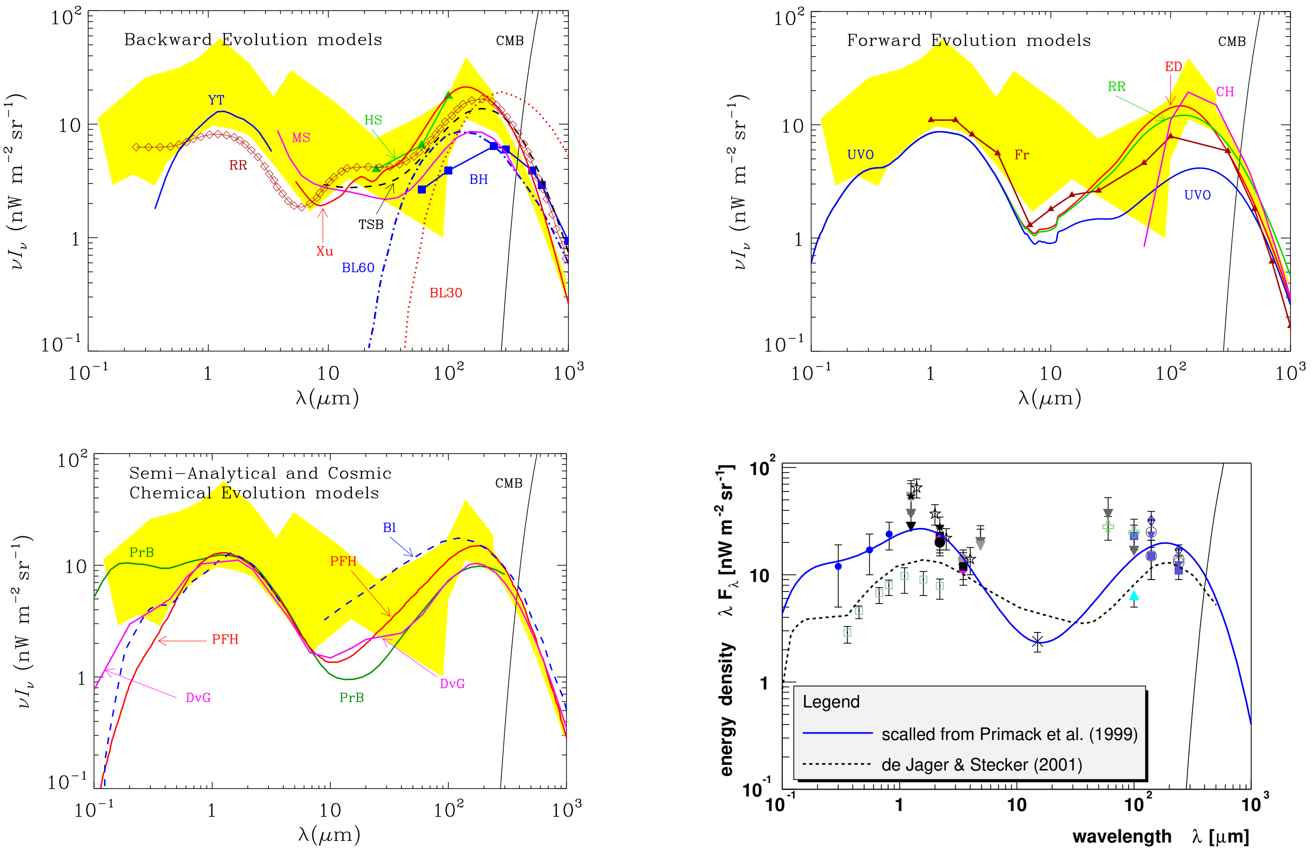
Dependencies

	find in plots below	redshift z	Hubble constant H_0	Ω_Λ	Ω_m
impact of H_0	τ_1	0.034	72 km/s/Mpc	0.7	0.3
	τ_2		60 km/s/Mpc		
	τ_3		80 km/s/Mpc		
impact of the desity parameters	τ_4	0.034	72 km/s/Mpc	0.0	1.0
	τ_5			0.5	0.5
	τ_6	0.129	72 km/s/Mpc	0.7	0.3
	τ_7			0.0	1.0
	τ_8			0.5	0.5





Extragalactic Background Light: Models



- no unique solution
- models differ significantly
- models predict 10 – 50% less EBL than observed
- lack of information in mid infrared,
  only lower limit at 15 μm from ISOCAM
- Finkbeiner at 60 μm too high to be EBL only?