MAX-PLANCK-GESELLSCHAFT

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New Limits On The Density Of The Extragalactic Background Light From The Spectra Of All Known TeV Blazars

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Spectral Energy Distribution of the EBL

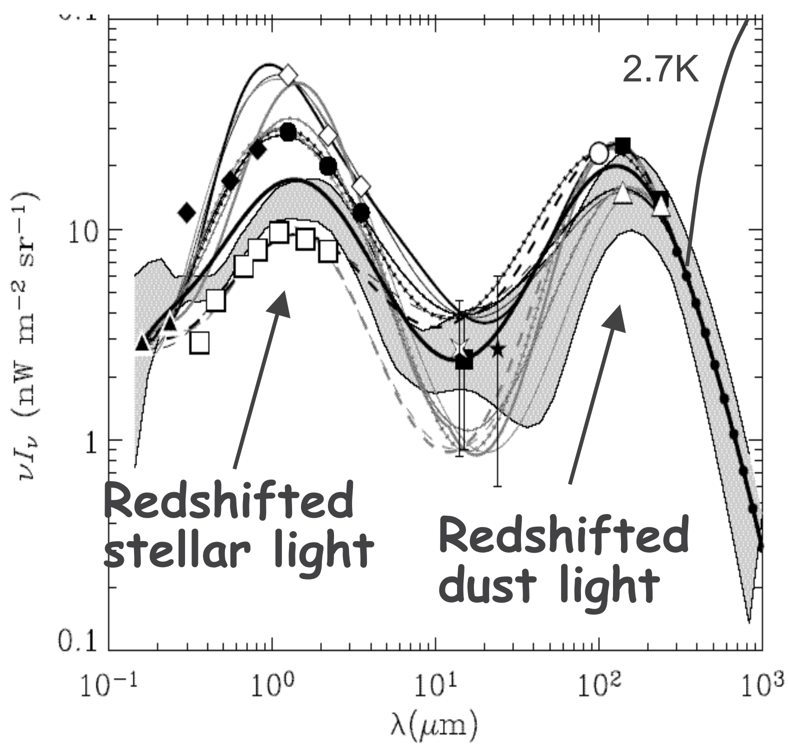
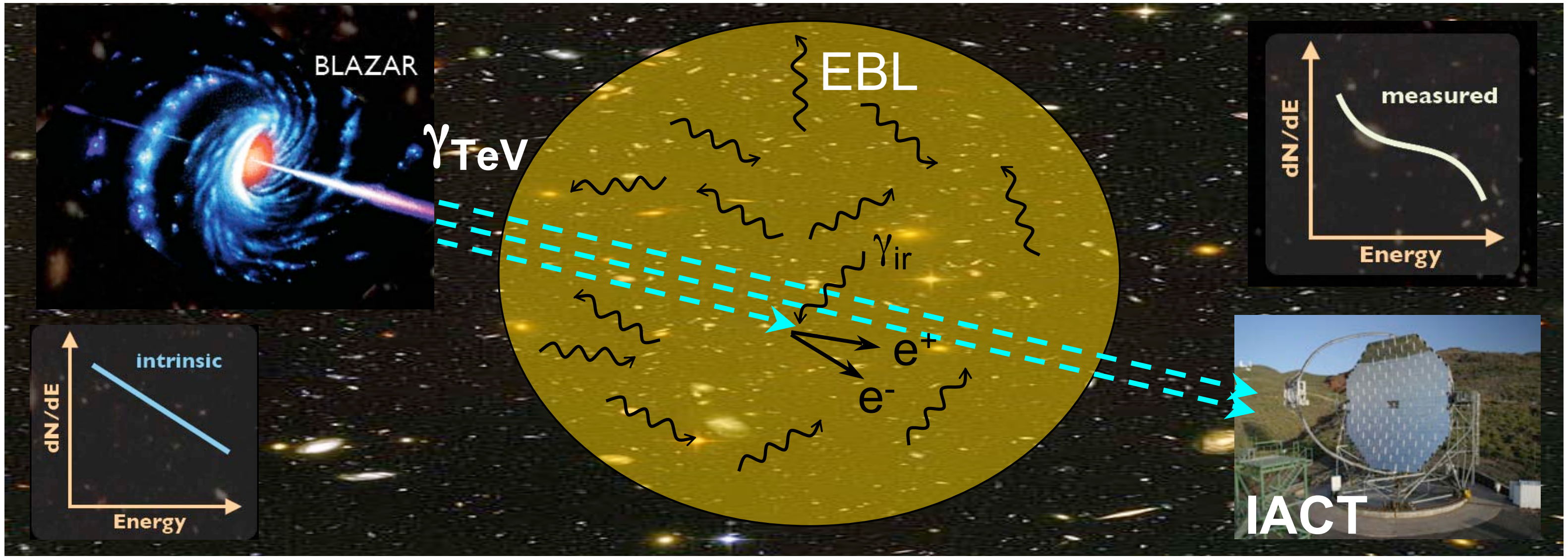


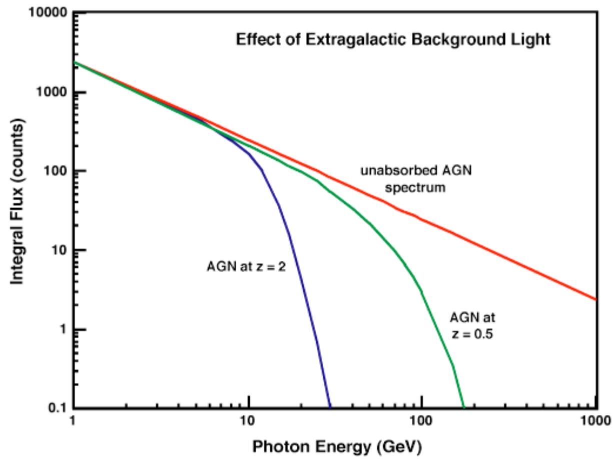
Figure adapted from Dwek&Krennrich (2005)

- Unique imprint of the history of the universe
- Test of star formation and galaxy evolution models
- Cosmological evolution models have to explain current EBL
- Opacity source of GeV-TeV photons

Attenuation of GeV-TeV photons



- Direct measurements of the EBL in UV to IR are difficult (foregrounds)
- TeV photons are attenuated via pair production with UV to IR photons from the EBL
- Imprint of the EBL density and shape in the measured TeV spectra



Generic EBL limits from TeV blazars

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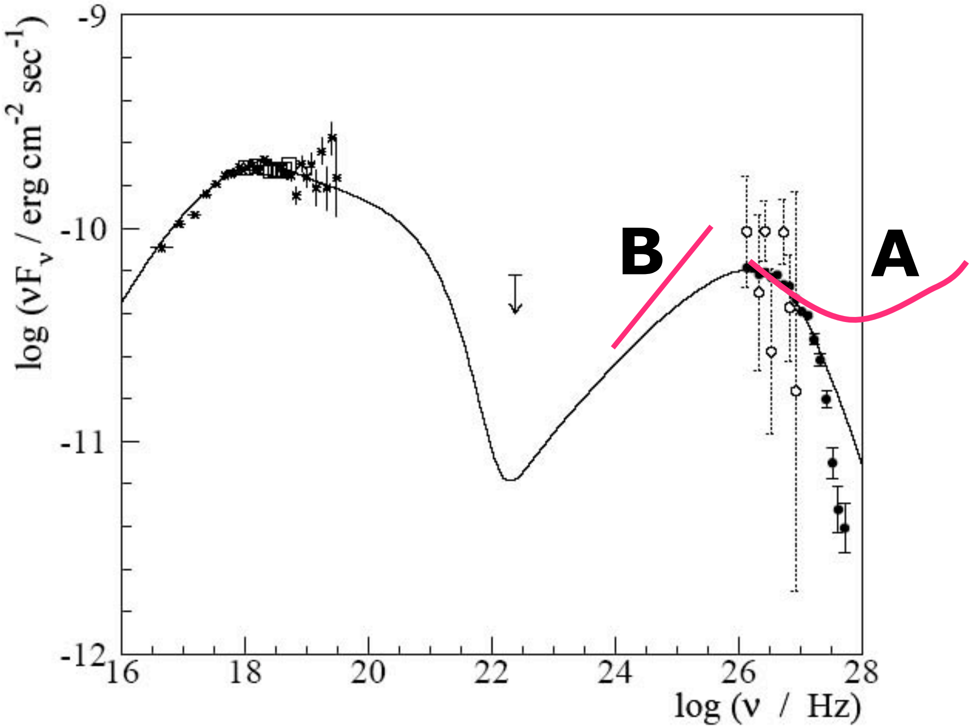
Problems for TeV blazars

- A: TeV crisis (pile-up at high energies)
- B: Too hard spectra (spectral index < 1.5)



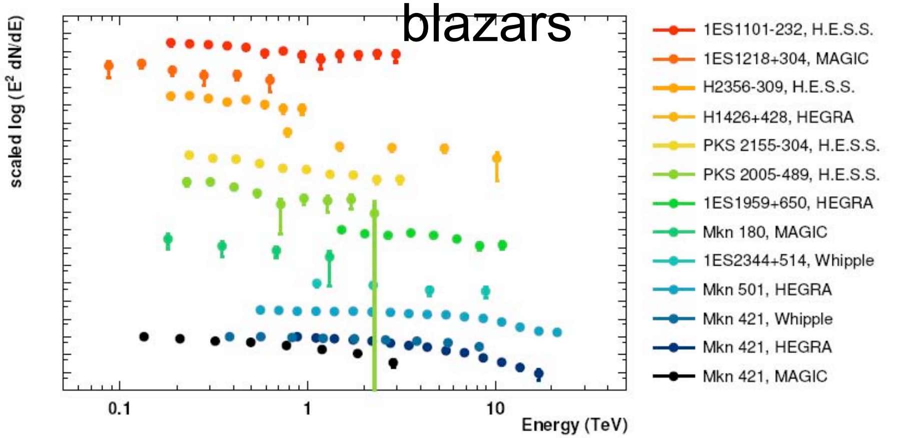
This study

1. Provide limits on the EBL density, which do not rely on a predefined shape or model
2. Treat all TeV blazars in a consistent way, using generic assumptions about the intrinsic spectrum and statistical evident exclusion criteria
3. Use spectral data from all detected TeV blazars to:

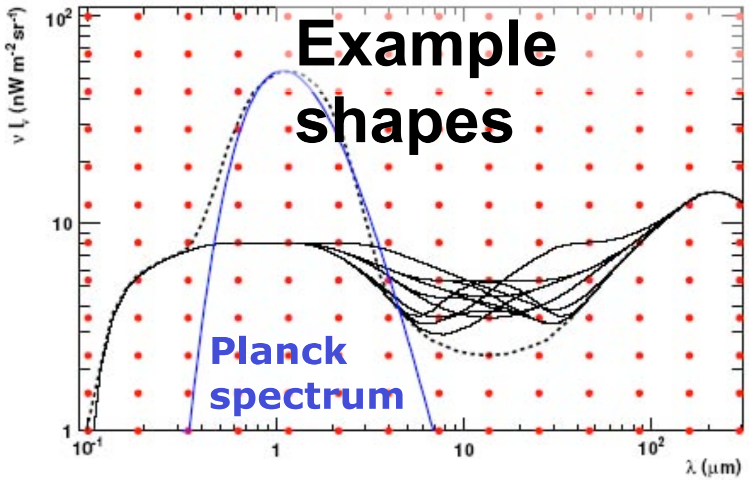
   a) **Derive upper limits on the EBL from individual spectra**

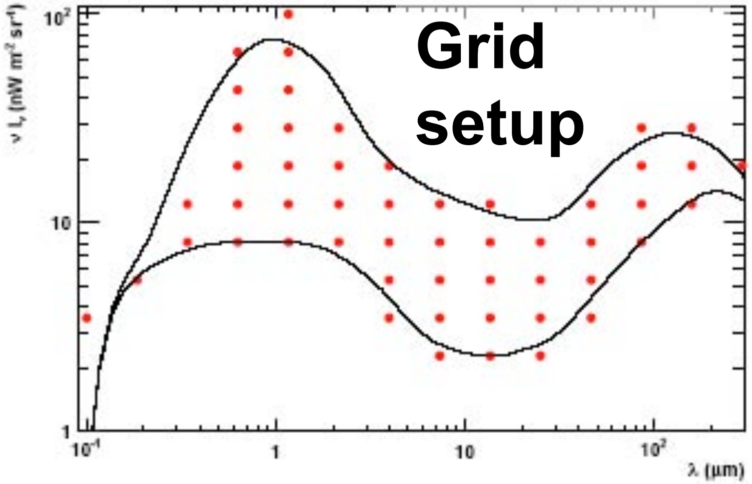
   b) **Combine these results to a single robust on the EBL for a wide wavelength range**

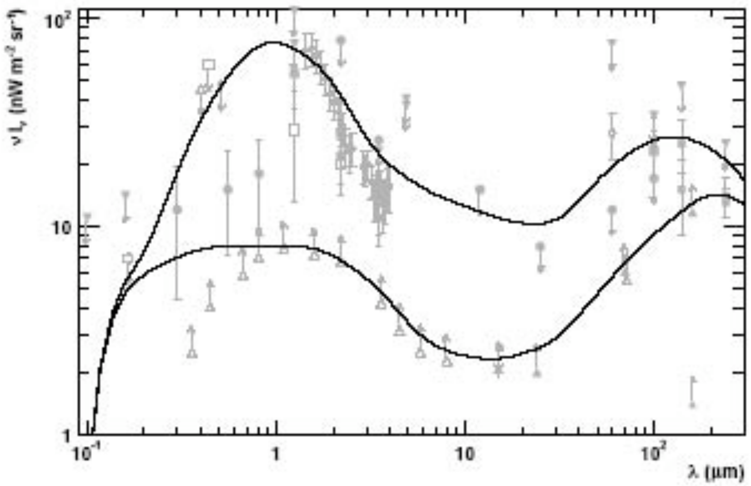
Scaled spectra of the used TeV blazars



The technique: Grid Scan







- Shapes constructed using not-interpolating splines (superposition of smooth gauss-like base functions)
- Highest shape on the level of the existing upper limits
- Lowest shape on the level of the existing lower limits
- 8,064,000 shapes to test

Exclusion criteria

Find analytical expression for the intrinsic spectrum, evaluate fit parameters:

- Fitted photon index Γ is outside of allowed range
- Or: significant pile-up at high energies

Statistical tools:

- Likelihood ratio test to determine a "better" function
- Conservative error on spectral index Γ: $\Gamma + \sigma_\Gamma + \sigma_{sys} < \Gamma_{max}$

2 Scans

At least part of TeV blazar spectrum: $dN/dE \sim E^{-\Gamma}$

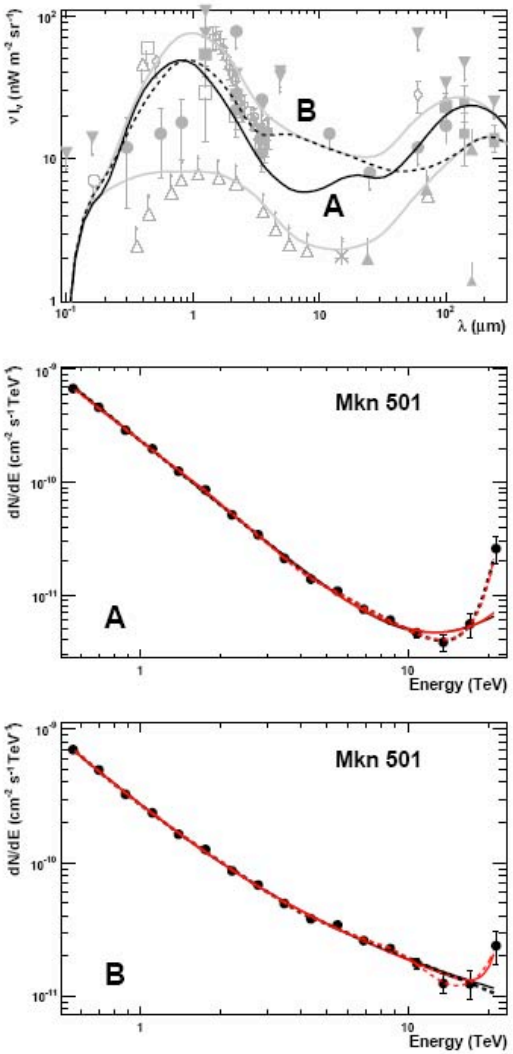
Realistic Scan: $\Gamma < 1.5$

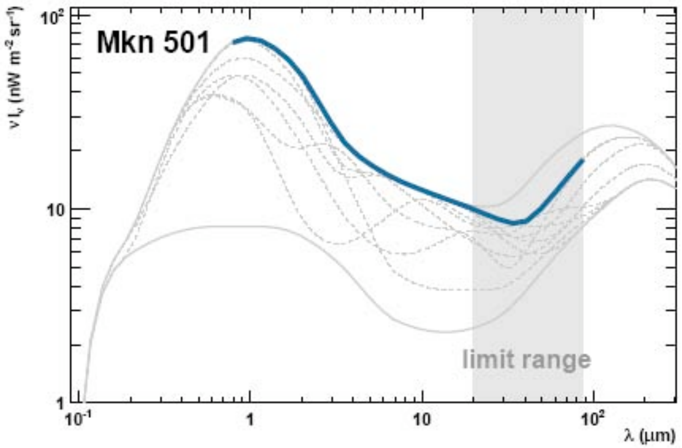
Based on classical shock acceleration, taking maximum electron spectral index $\alpha=2$

Extreme Scan: $\Gamma < 2/3$

Based on extreme SSC assumptions that almost monoenergetic electrons (heavily truncated electron-spectrum) are responsible for the γ-emission

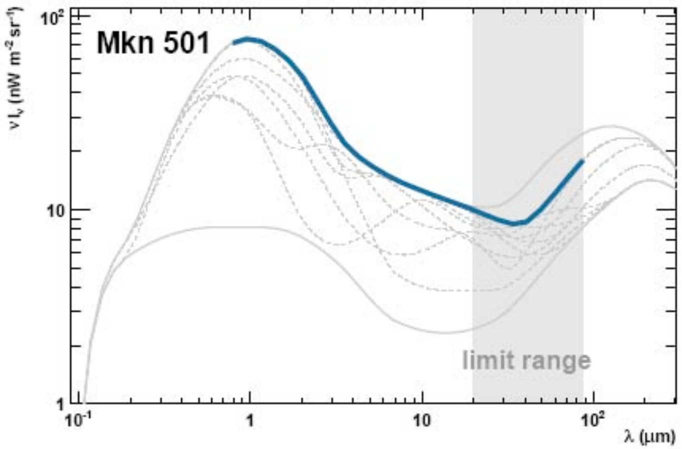
Prototype of close by sources: Mkn 501

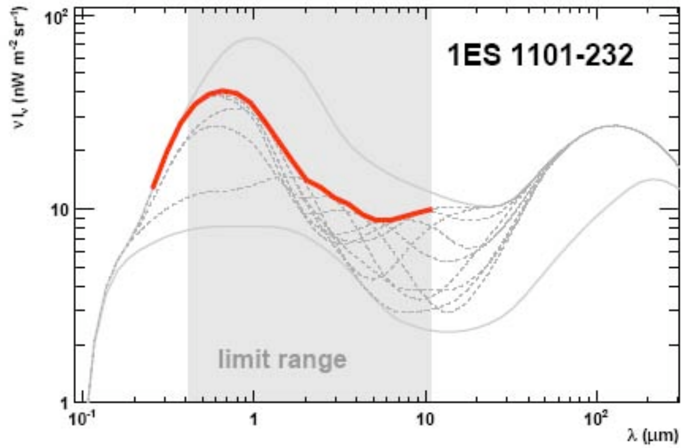


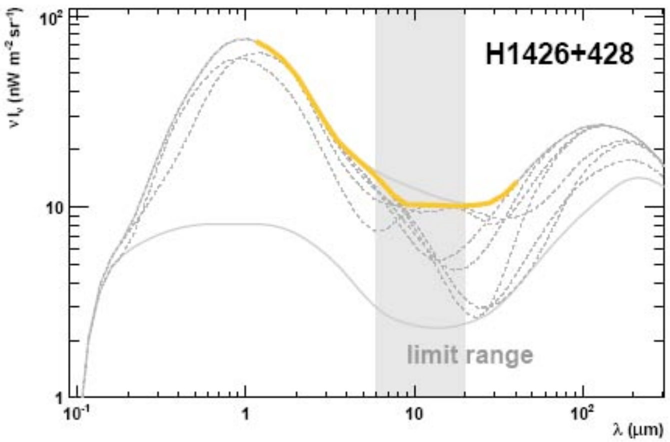


- 7766674 shapes excluded out of 8064000
- Excluded area is small because certain **types** of EBL shapes allowed independent on the level

Realistic Scan: $\Gamma > 1.5$







Results from the prototypes:

- Mkn 501: 7766674 shapes excluded out of 8064000: 96.30 %
- H1426+428: 69.09 % excluded
- 1ES 1101-232: 95.57 % excluded

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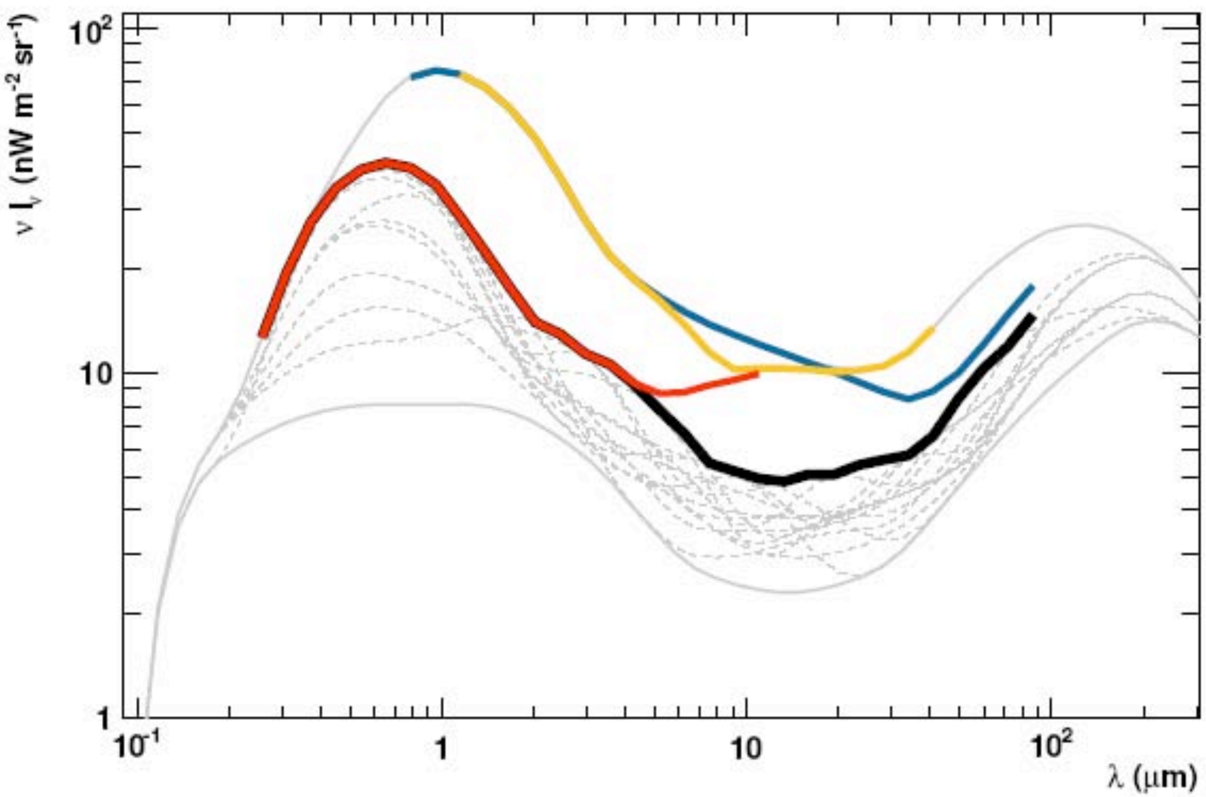
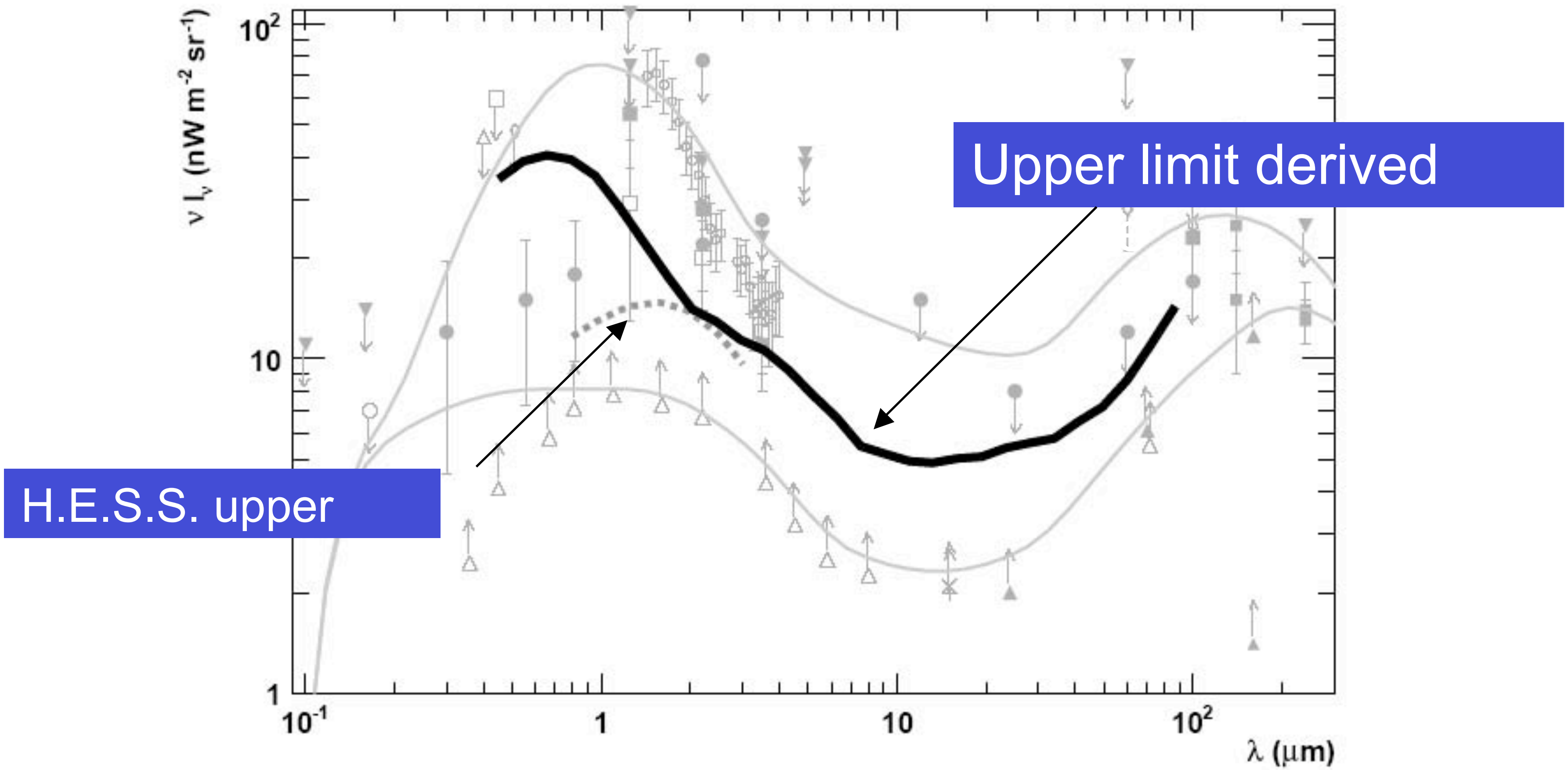
Combined results: realistic scan

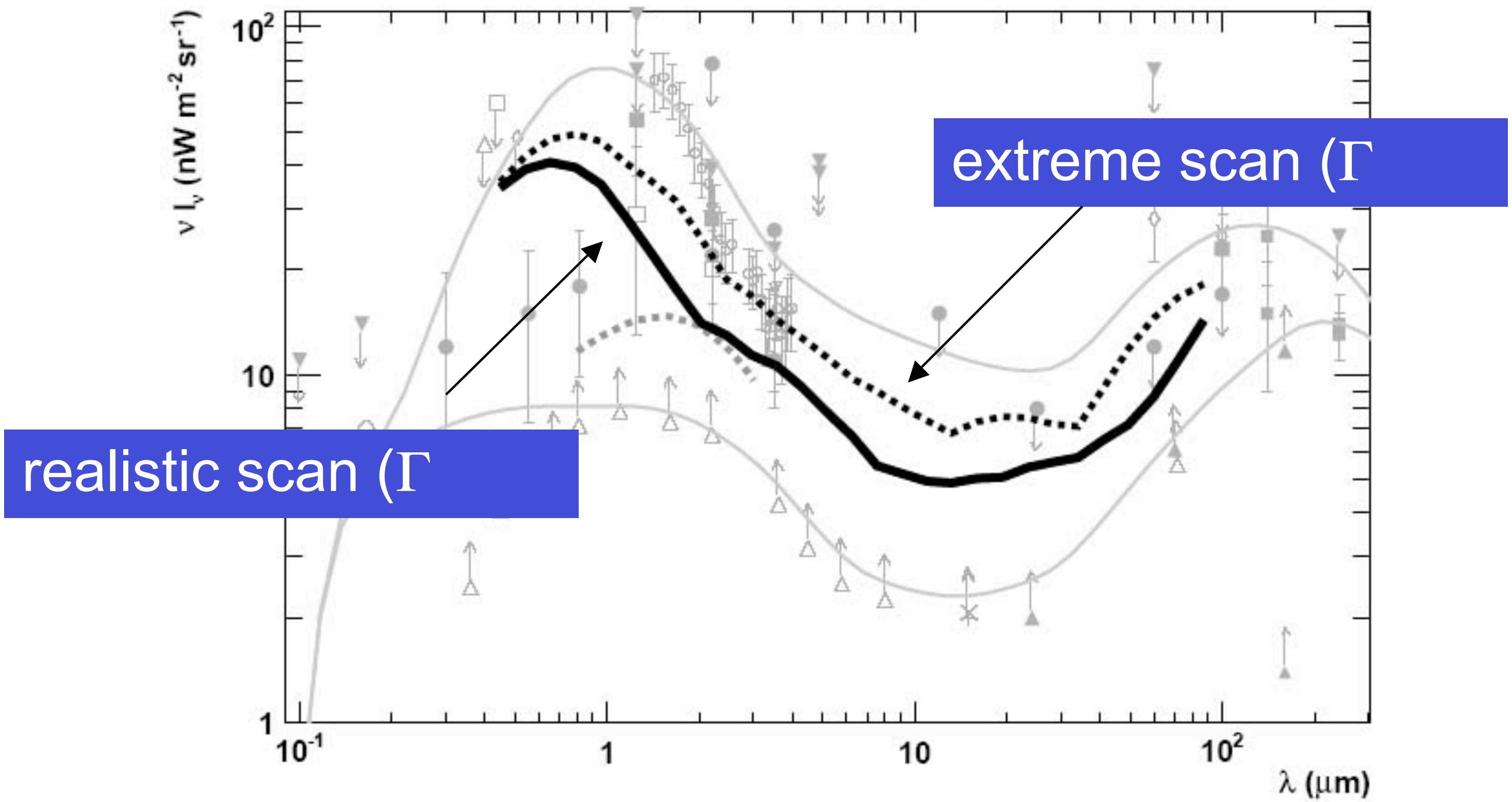


Upper limit is defined as an envelope of all allowed

Combined results: realistic scan



Combined results: extreme scan



Summary / Conclusions

- Strong limits from Optical to far IR using individual sources
- Much stronger limits after combining individual results
- Derived upper limits are conservative and robust for systematic effects (estimated to be 35 %)
- Submitted to A&A, astro-ph/0701694

Results can be interpreted in two ways:

- NIR excess not extragalactic and source counts resolved almost everything
- Blazar physics has to be reconsidered (improbable)

BACKUP

Systematic effects

- Grid setup. The minimum width of the EBL structures that can be resolved → 30%
- Evolution of EBL → 10% (at most)
- Absolute Energy scale of TeV blazars → 2-3%
- Numerical uncertainties while fitting → 1-2%

Overall error (quadratic sum) →

TeV blazar sample

- Select best statistics
- Select hardest among similar
- Select best coverage in energy

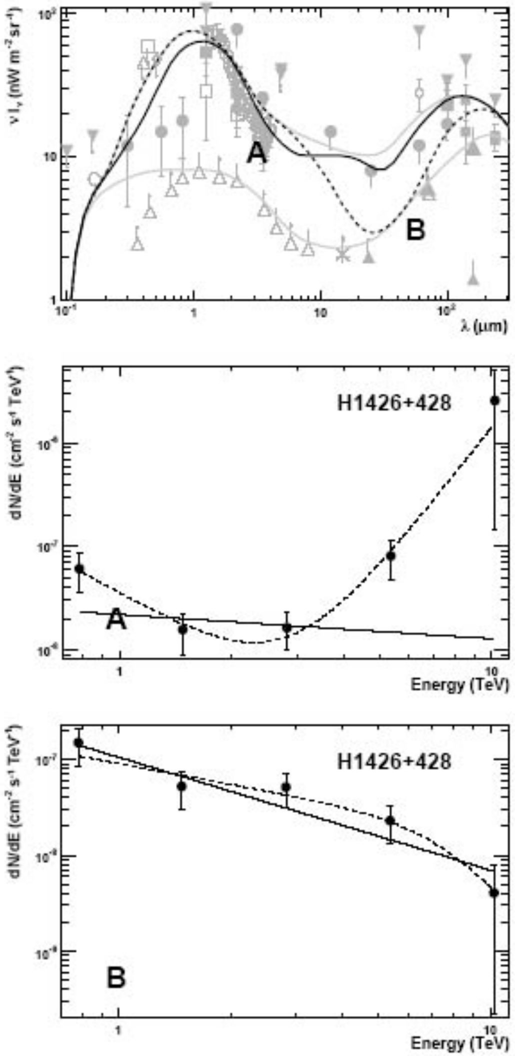
Source	Redshift	Experiment	Energy range (TeV)	Slope $\Gamma \pm \sigma_{st} \pm \sigma_{sy}$	Cut-off energy (TeV)	Reference
Mkn 421	0.030	MAGIC	0.10 – 3.0	$2.20 \pm 0.08 \pm 0.20$	1.44 ± 0.28	Albert et al. (2006c)
Mkn 421	0.030	HEGRA	0.70 – 18.0	$2.19 \pm 0.02 \pm 0.20$	$3.6 + 0.4 - 0.3$	Aharonian et al. (2002a)
Mkn 421	0.030	Whipple	0.35 – 0.90	$2.31 \pm 0.04 \pm 0.05$	——	Krennrich et al. (2002)
Mkn 501	0.034	HEGRA	0.50 – 22.0	$1.92 \pm 0.03 \pm 0.20$	6.2 ± 0.4	Aharonian et al. (1999)
1ES 2344+514	0.044	Whipple	0.80 – 11.0	$3.32 \pm 0.70 \pm 0.70$	——	Schroedter et al. (2005)
Mkn 180	0.045	MAGIC	0.14 – 1.5	$2.20 \pm 0.08 \pm 0.20$	——	Albert et al. (2006b)
1ES 1959+650	0.047	HEGRA	1.5 – 13.0	$2.83 \pm 0.14 \pm 0.08$	——	Aharonian et al. (2003a)
PKS 2005-489	0.071	H.E.S.S.	0.20 – 2.5	$4.0 \pm 0.4\ (\pm 0.2)$	——	Aharonian et al. (2005a)
PKS 2155-304	0.116	H.E.S.S.	0.20 – 3.5	$3.37 \pm 0.07 \pm 0.10$	——	Aharonian et al. (2005b)
H 1426+428	0.129	HEGRA	0.70 – 12.0	$2.6 \pm 0.6 \pm 0.1$	——	Aharonian et al. (2003c)
H 2356-309	0.165	H.E.S.S.	0.16 – 1.0	$3.06 \pm 0.21 \pm 0.10$	——	Aharonian et al. (2006b)
1ES 1218+304	0.182	MAGIC	0.08 – 0.7	$3.0 \pm 0.4 \pm 0.6$	——	Albert et al. (2006a)
1ES 1101-232	0.186	H.E.S.S.	0.16 – 3.3	$2.88 \pm 0.14 \pm 0.1$	——	Aharonian et al. (2006a)

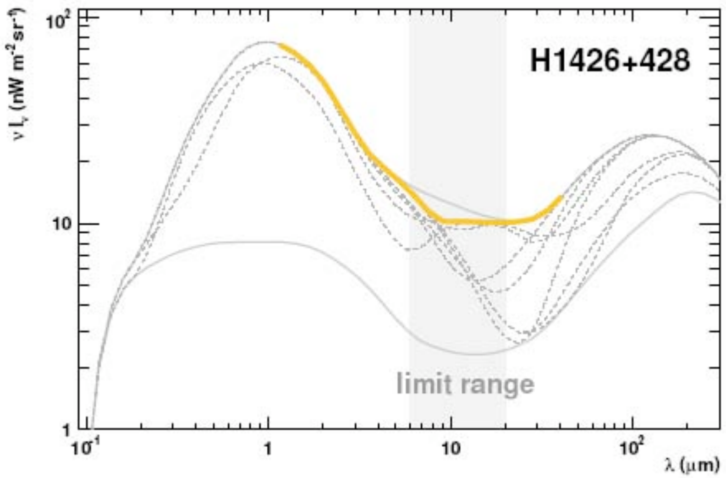
Fitting functions

In order to allow for multi-zone (multi-component) emission, breaks in spectrum are allowed

#	Description	Abbreviation	Formula $f(E) = dN/dE$	Parameters to evaluate
1	simple power law	PL	$N_0 E^{-\Gamma}$	χ^2, Γ^{PL}
2	broken power law with transition region	BPL	$N_0 E^{-\Gamma_1} \left[1 + \left(\frac{E}{E_b}\right)^f\right]^{\frac{\Gamma_1-\Gamma_2}{f}}$	χ^2, Γ_1^{BPL}, Γ_2^{BPL}
3	broken power law with transition region and super-exponential pile-up	BPLSE	$N_0 E^{-\Gamma_1} \left[1 + \left(\frac{E}{E_b}\right)^f\right]^{\frac{\Gamma_1-\Gamma_2}{f}} \exp\left(\frac{E}{E_{\mathrm{p}}}\right)$	χ^2
4	double broken power law with transition regions	DBPL	$N_0 E^{-\Gamma_1} \left[1 + \left(\frac{E}{E_{b1}}\right)^{f_1}\right]^{\frac{\Gamma_1-\Gamma_2}{f_1}} \left[1 + \left(\frac{E}{E_{b2}}\right)^{f_2}\right]^{\frac{\Gamma_2-\Gamma_3}{f_2}}$	χ^2, Γ_1^{DBPL}, Γ_2^{DBPL}, Γ_3^{DBPL}
5	double broken power law with transition regions and super-exponential pile-up	DBPLSE	$\mathrm{DBPL} \times \exp\left(\frac{E}{E_{\mathrm{p}}}\right)$	χ^2

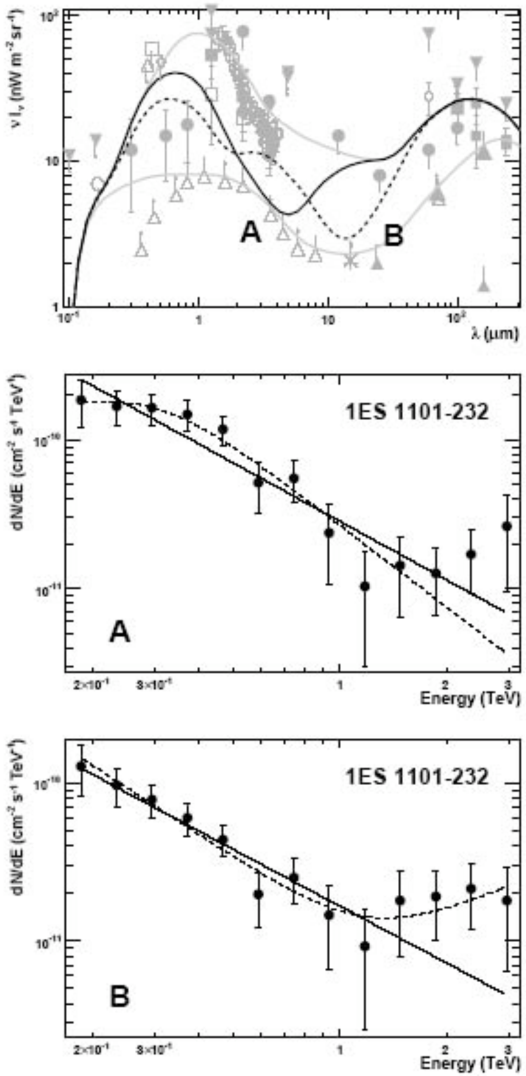
Intermediate distance: H1426+428



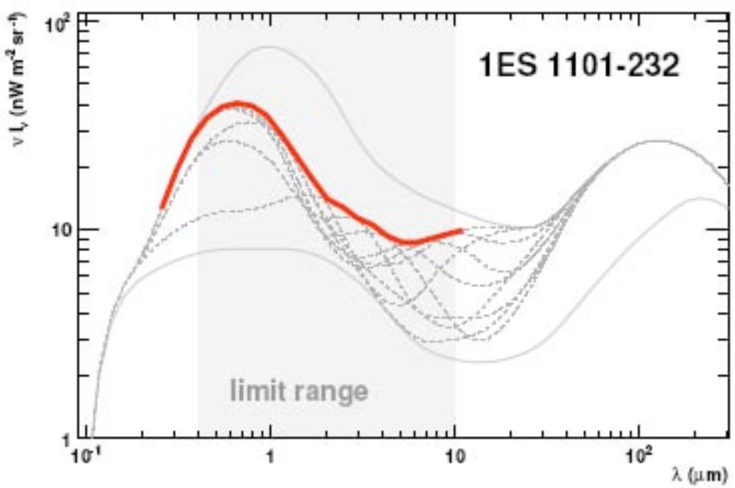


- 5571772 shapes excluded out of 8064000
- Excluded area is small because certain **types** of EBL shapes allowed independent on the level

Distant sources: 1ES1101-232



Generic EBL limits from TeV blazars



- 7706625 shapes excluded out of 8064000
- Excluded area is rather big; given the upper limit at 0.4μ m, the NIR excess is excluded

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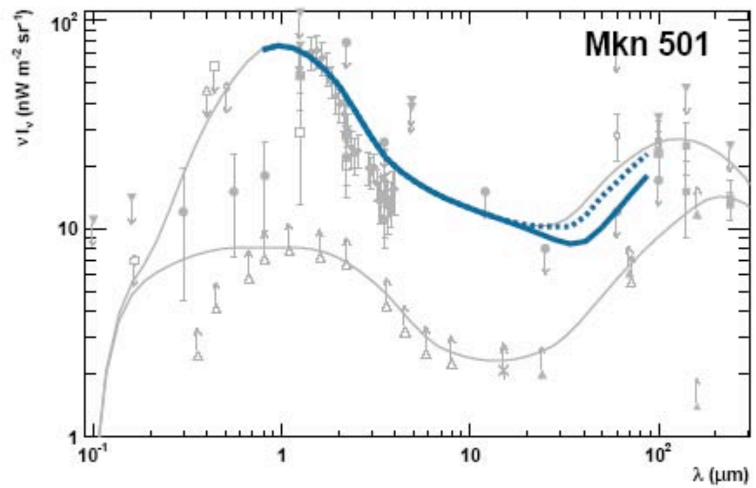
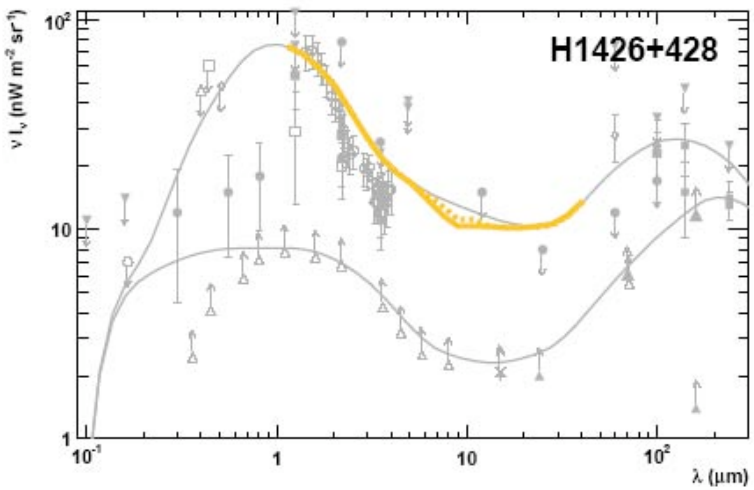
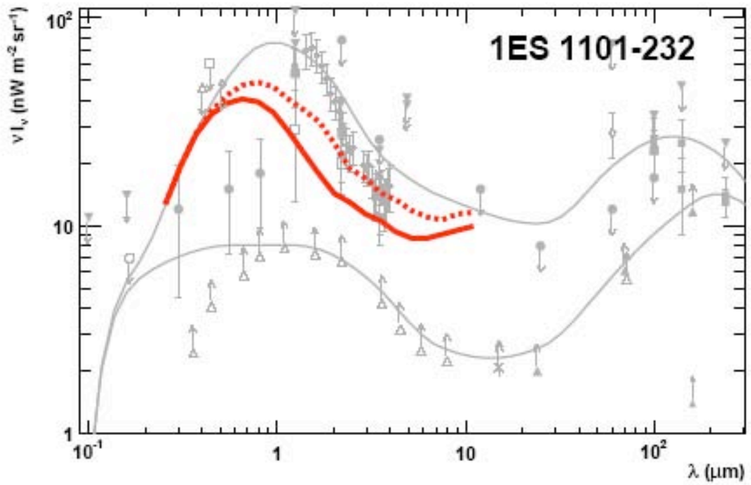
Extreme Scan: Γ > 2/3



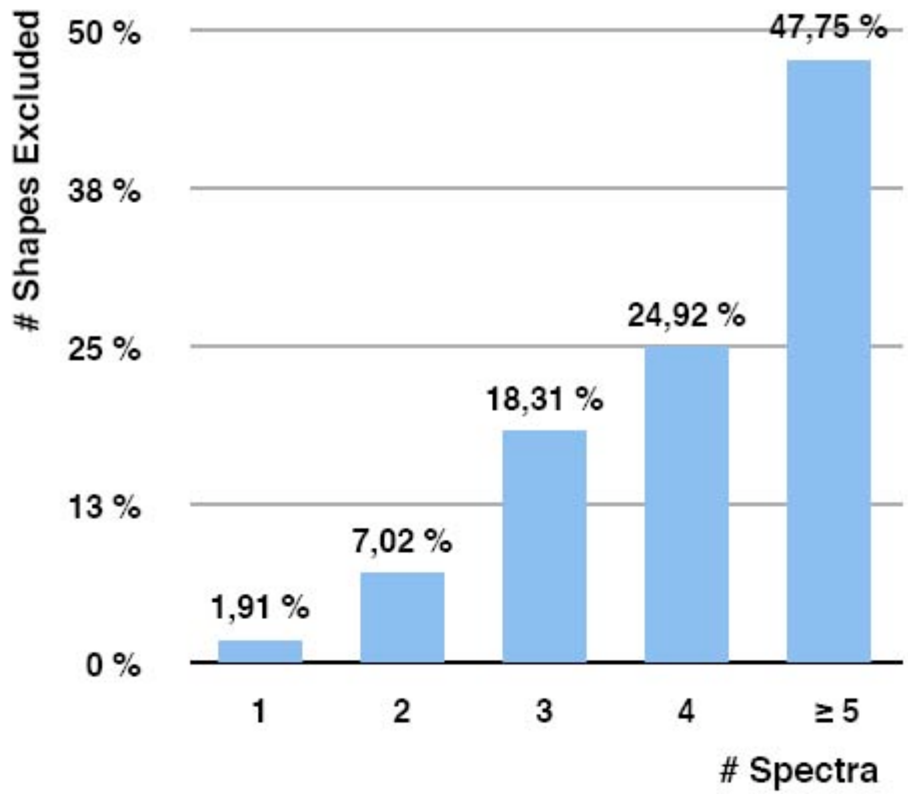




- Limits are (as expected) less restrictive. Still a very high number of excluded shapes
- NIR excess at 1μm is still excluded

Rejection statistics

50% of excluded shapes are excluded by 5 or more AGN spectra



high confidence of the derived