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(Werner-Heisenberg-Institut)

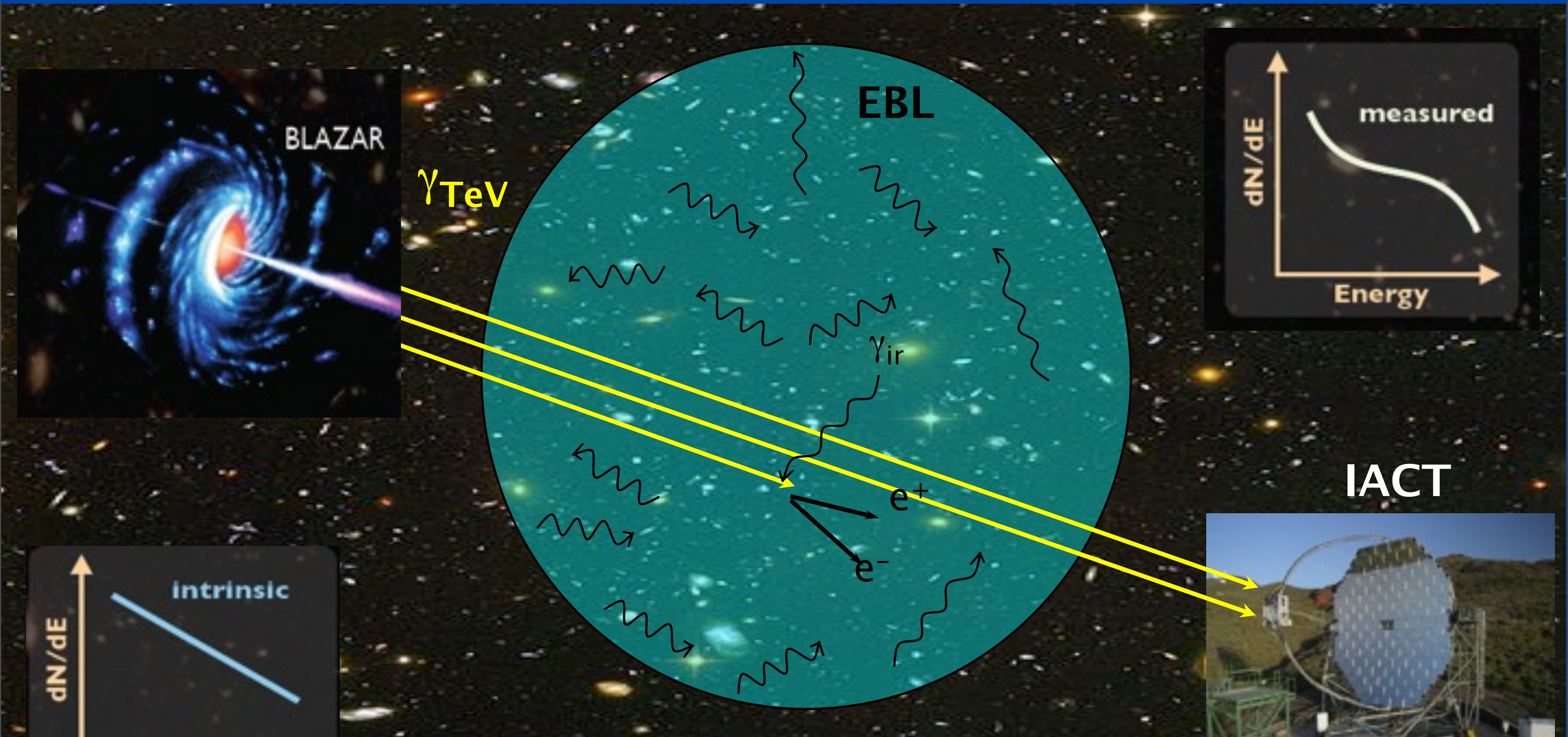
Constraints on Extragalactic Background Light using very high energy gamma rays

Daniel Mazin

IFAE, Barcelona

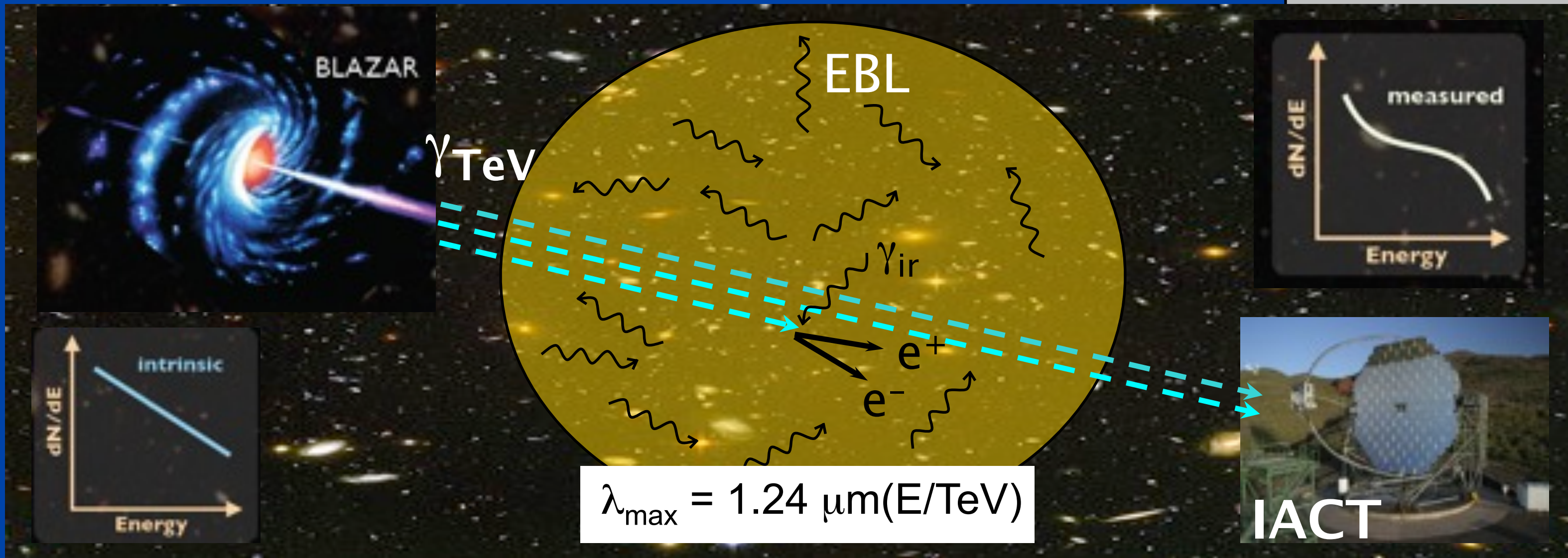
MPI for physics, Munich

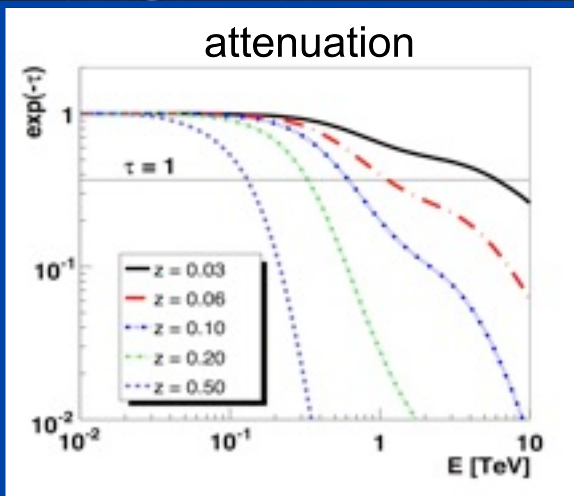
AGN emission passes through EBL

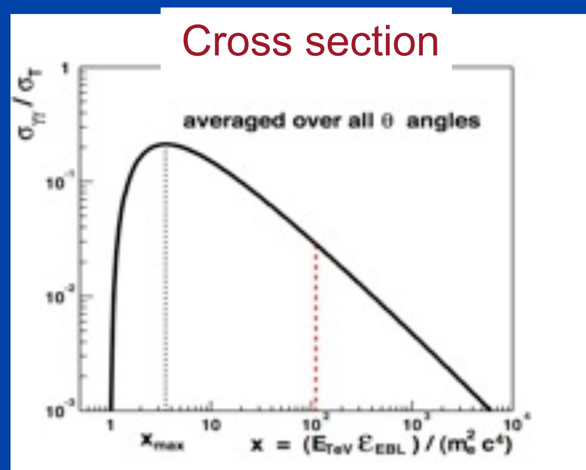


$\lambda_{max} = 1.24\ \mu m(E/TeV)$

AGN emission passes through EBL





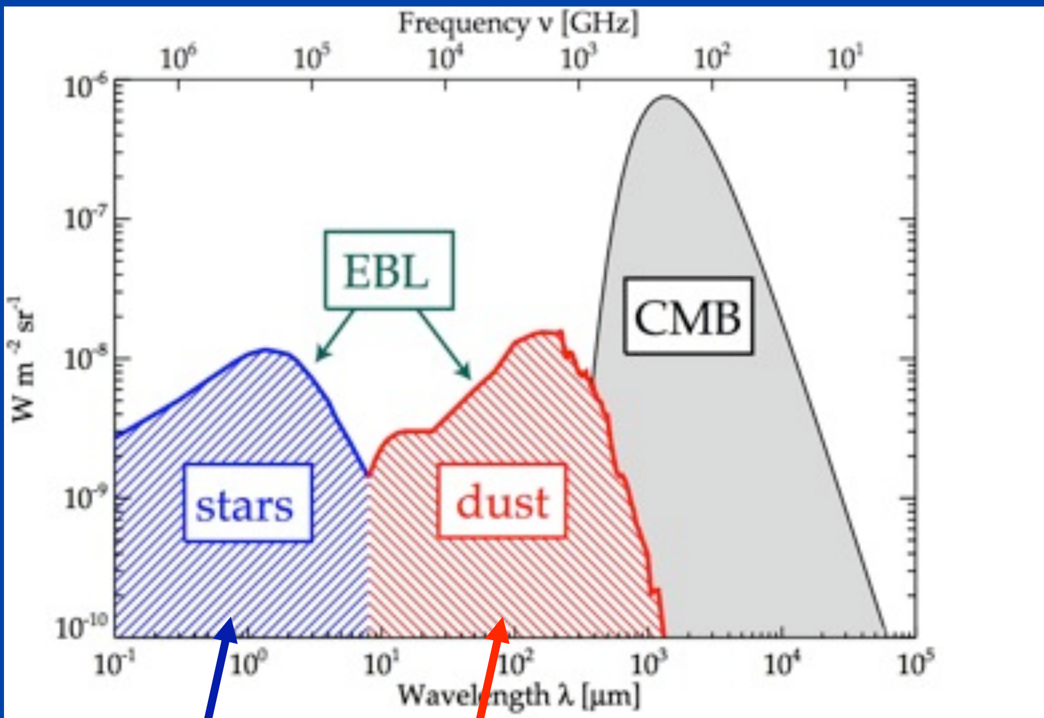


Contents

- Direct limits on Extragalactic Background Light (EBL)
- Blazars as probes of EBL
- limits on EBL (H.E.S.S. MAGIC, Fermi)
- Discussion of the limits
- Applications of the limits:
  - Pop III limits
  - halos: limits on the magnetic field

Extragalactic Background Light

Spectral Energy Distribution of the EBL



Redshifted star light

Redshifted dust emission

adapted from Dole et al.

- 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

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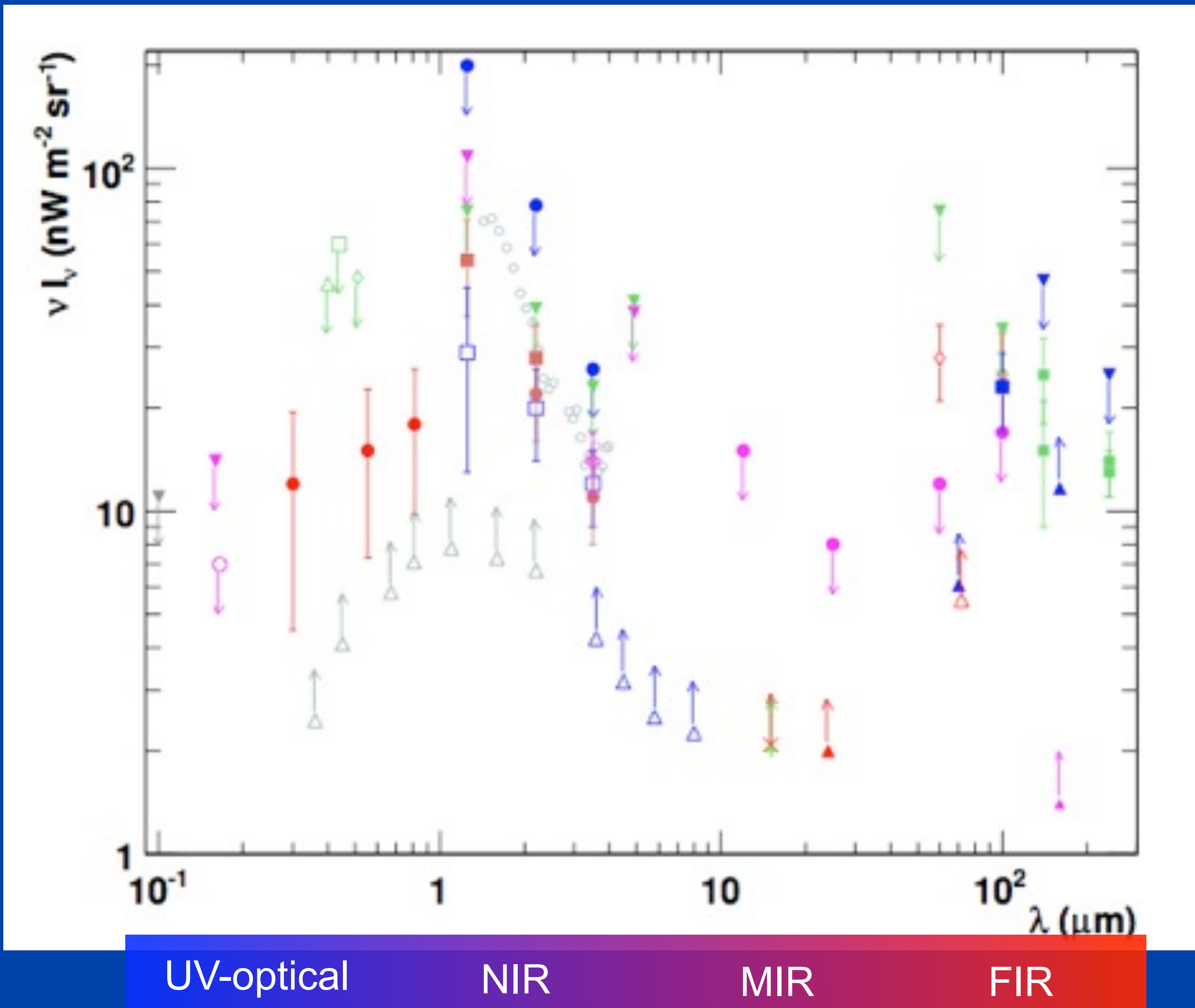
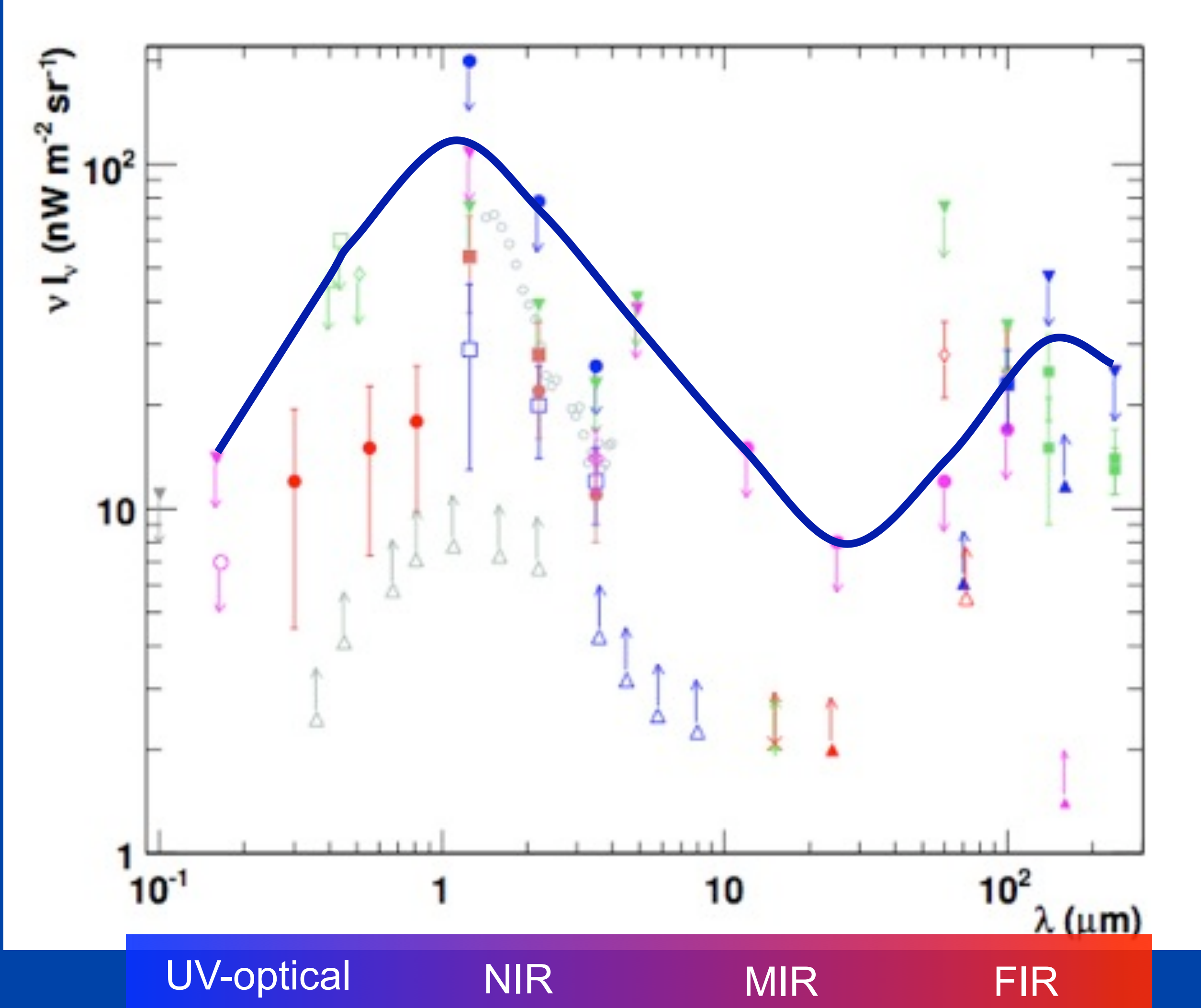
EBL: status of the measurements



- Direct measurements are difficult
- Lower limits from source counts and stacking
- Upper limits from fluctuation analyses and direct

EBL: status of the measurements



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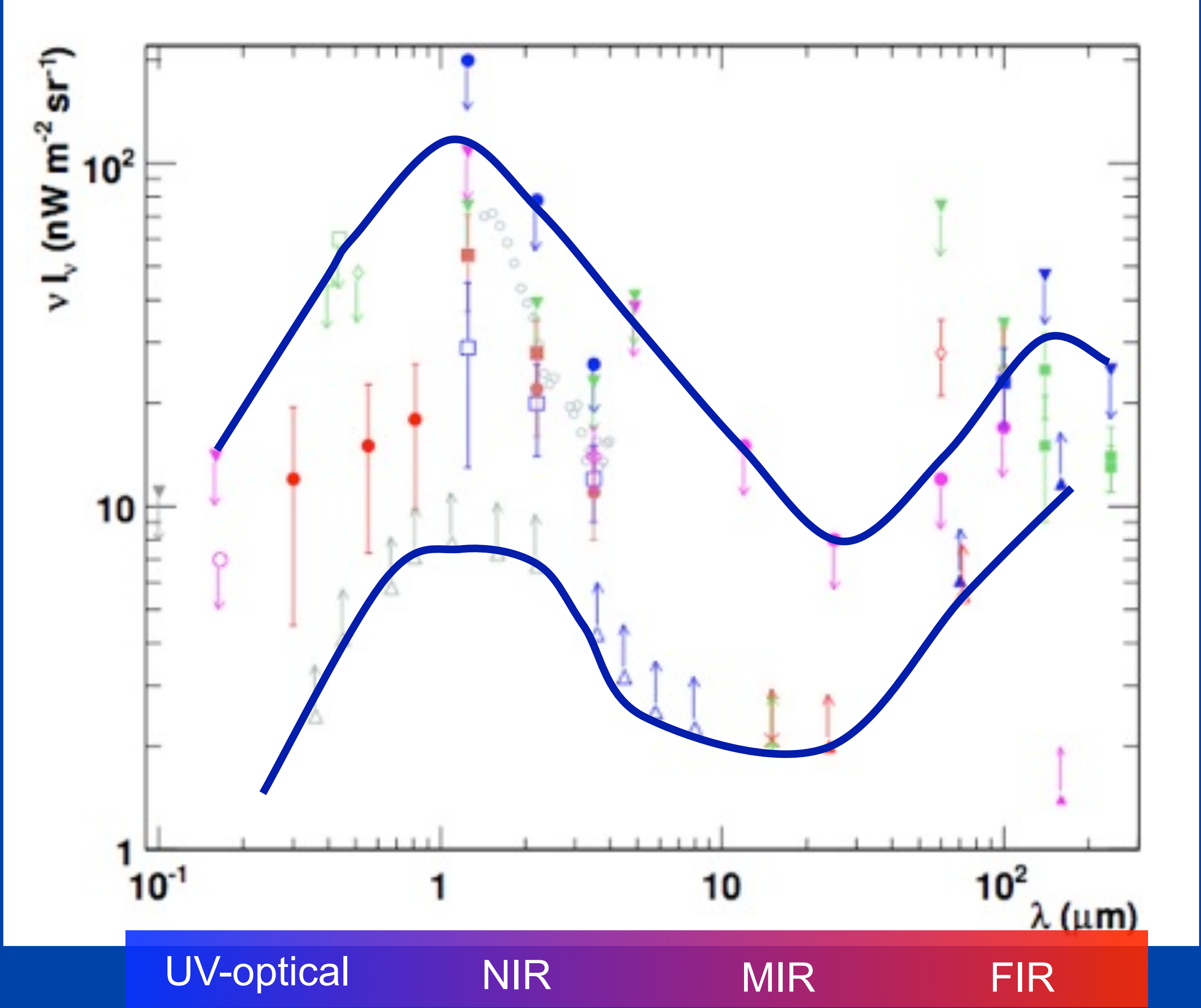

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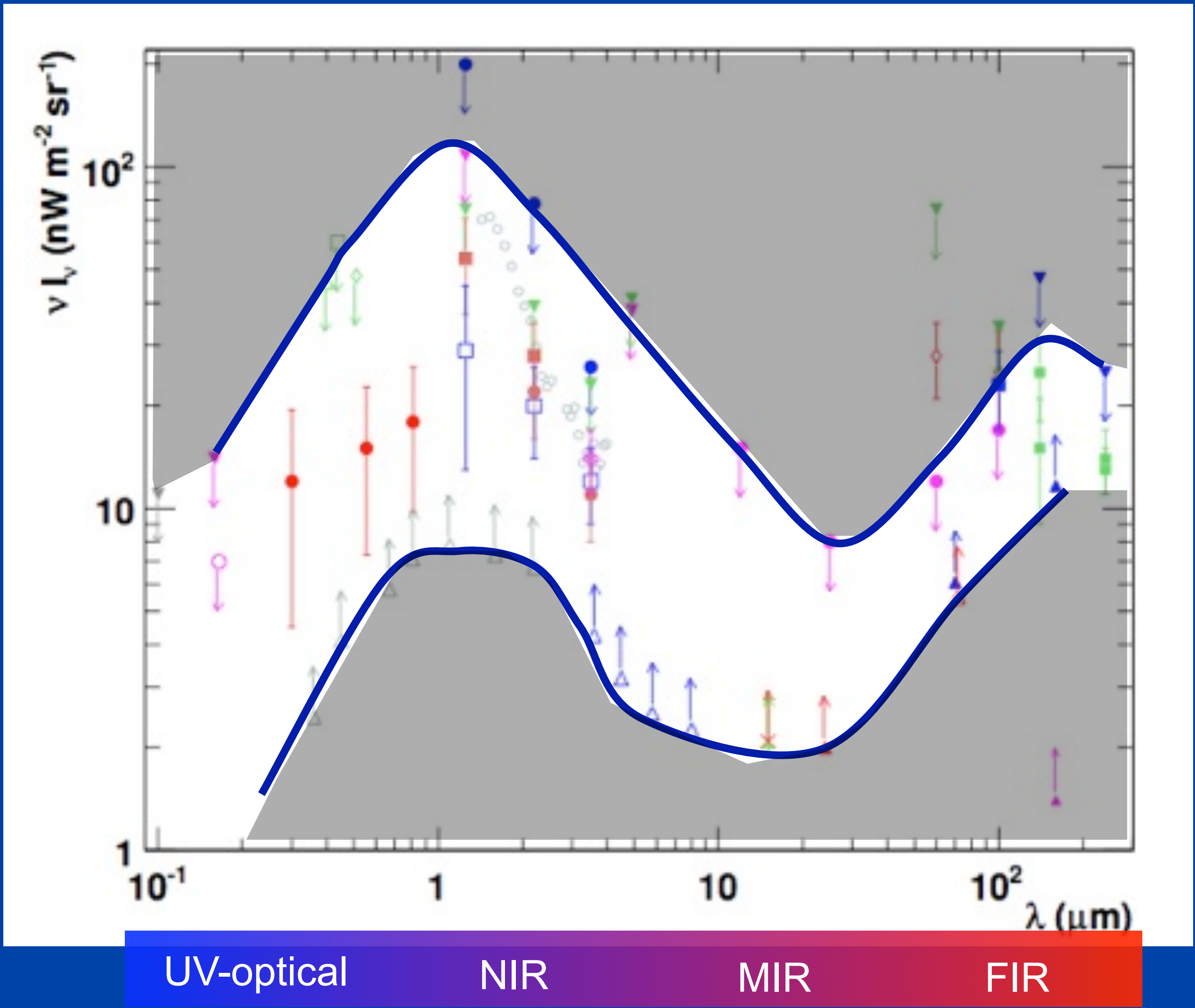

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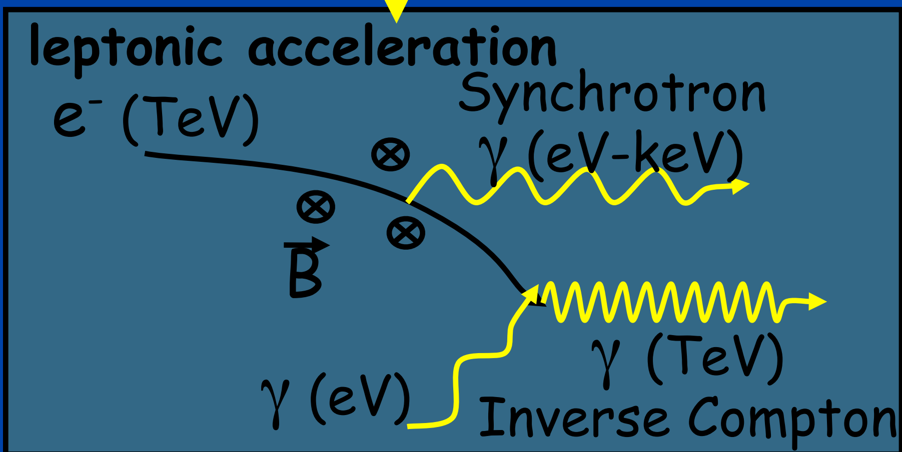
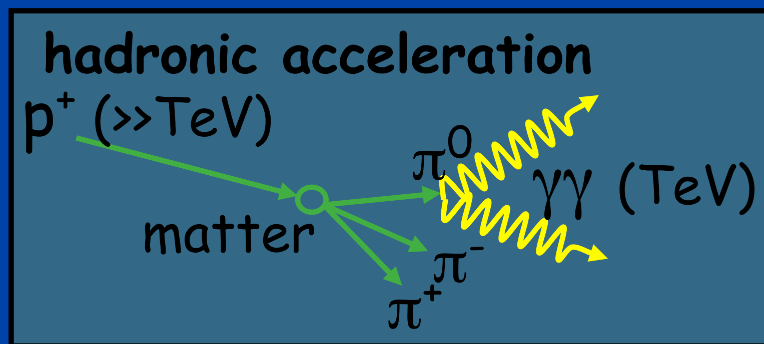
Blazars

Active Galactic Nuclei, TeV blazars

- Factories of violent, broad band (up to high energy) non-thermal radiation
- Blazars: relativistic plasma jet, highly variable
- TeV blazars (above 100 GeV): 20 out of 28 are HBL (High-peaked BL Lacertae)
- Models: leptonic vs. hadronic origin



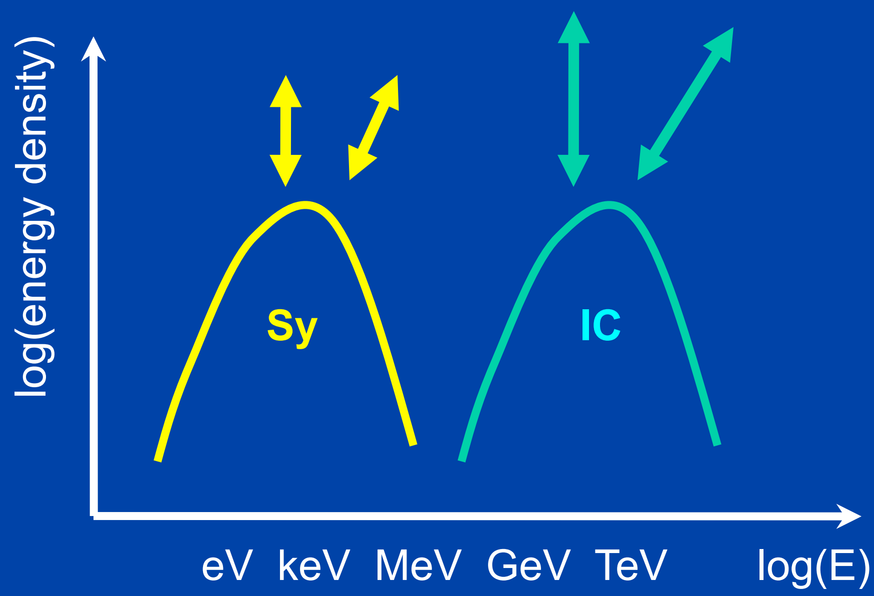


AGNs, TeV blazars, leptonic models

- leptonic models favored due to:
  - X-ray/TeV correlation found in some objects (Mkn501, Mkn421)
  - Fast flaring: down to minutes!
- We still do not know:
  - Variability scales
  - Other correlations
- Open questions:
  - Origin of γ-rays
  - Physical conditions in the jet
  - Reason for the variability
- No wonder: only 6 known VHE blazars in 2004
  - Now: around 40

Self-Synchrotron-Compton (SSC)

- Free parameters: electron spectrum, electron density, magnetic field, Doppler factor, size of the region



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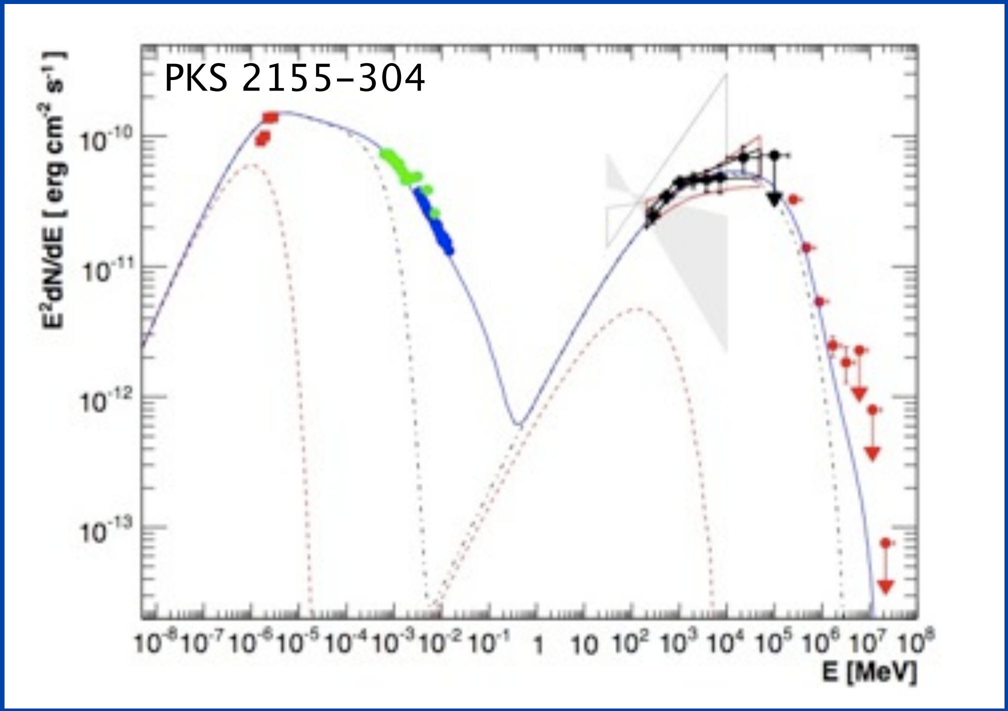
EBL constraints

Previous problems

- A: TeV crisis (pile-up at high energies)
- B: Too hard spectra (spectral index $\Gamma < 1.5$, defined in $dN/dE \sim E^{-\Gamma}$)



H.E.S.S. and FGST, arXiv:0903.2924

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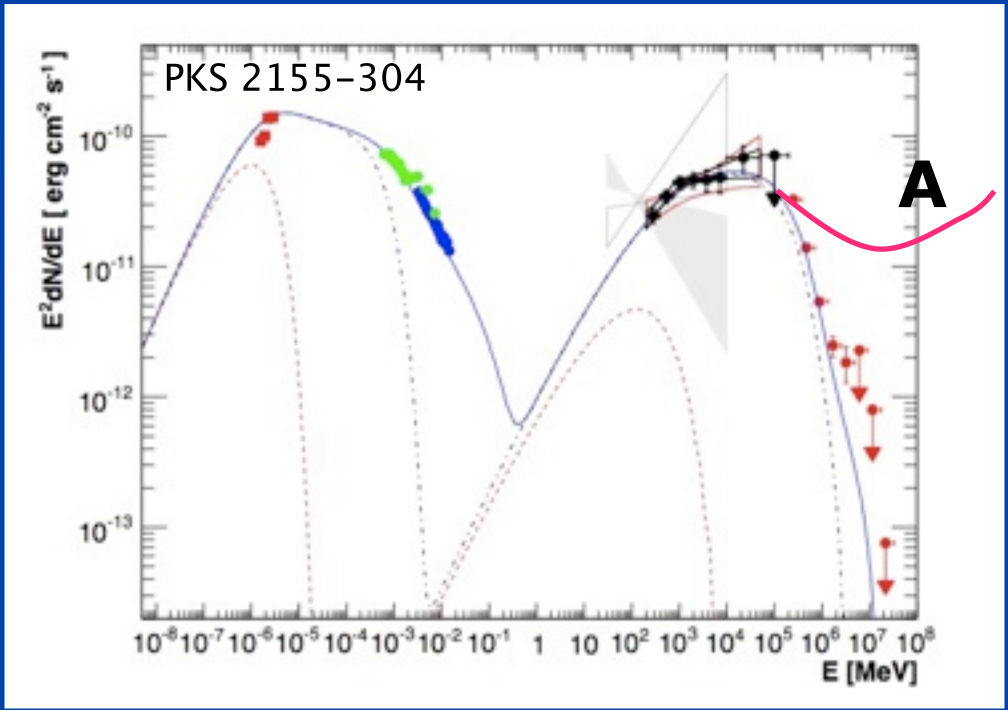

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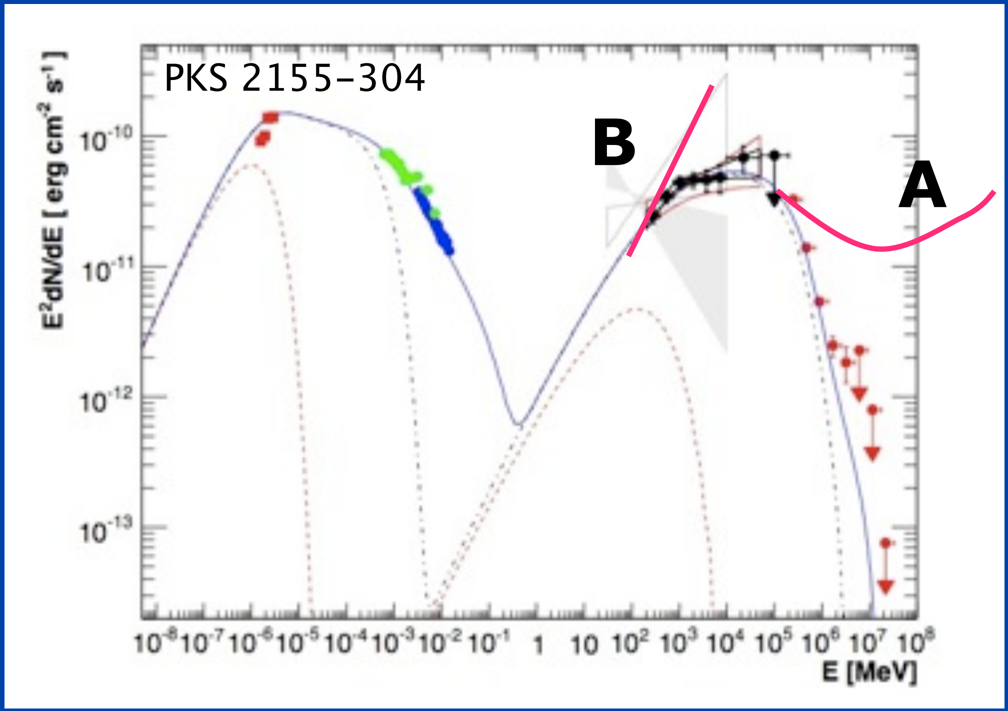

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IFAE

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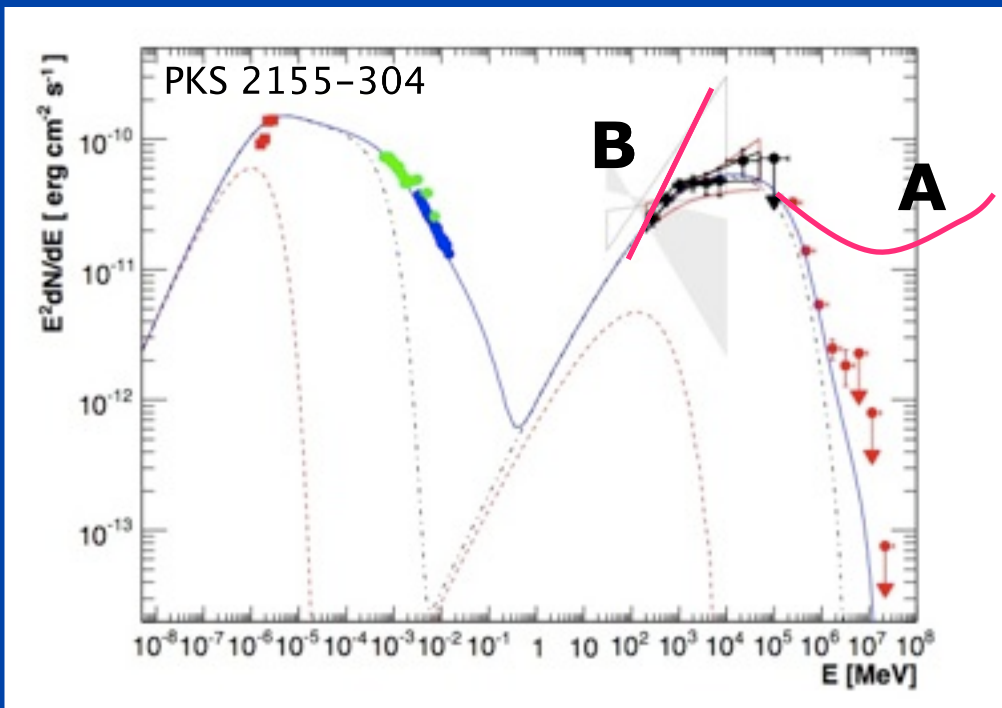

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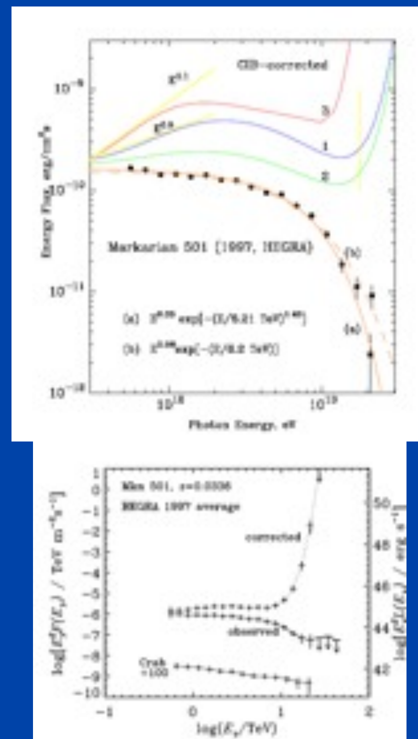
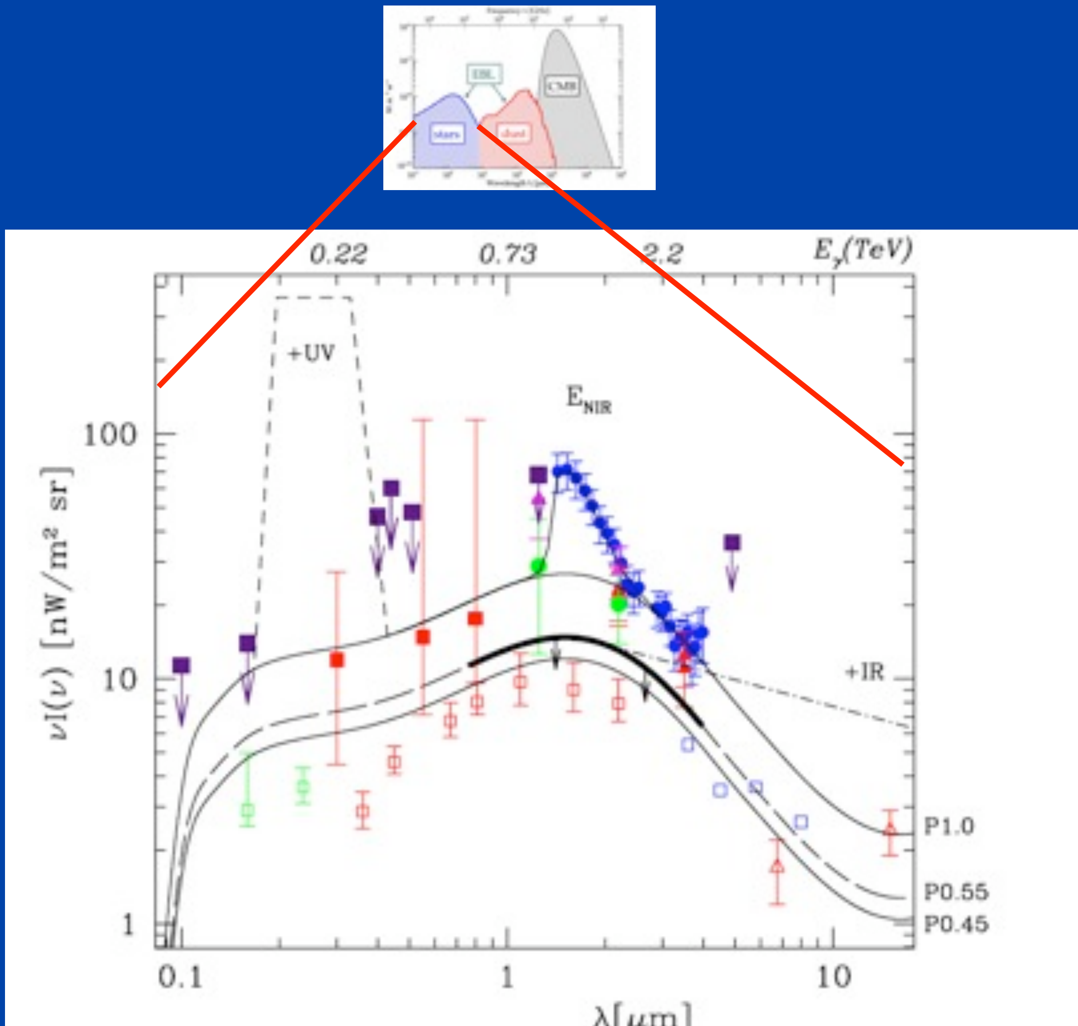


H.E.S.S. results 2006: 1ES1101-232 and H2356



- H.E.S.S. 2006
  - **Discovery of two distant blazars with hard VHE spectra**
  - **With the assumption F>1.5 constraints in the O-NIR**
- 1ES 0229+200
  - **z=0.114**
  - **Measured energy spectrum with Γ ~ 2.4 up to E > 10TeV**
  - **With the same argument, constraints in the MIR on the level of the source counts**

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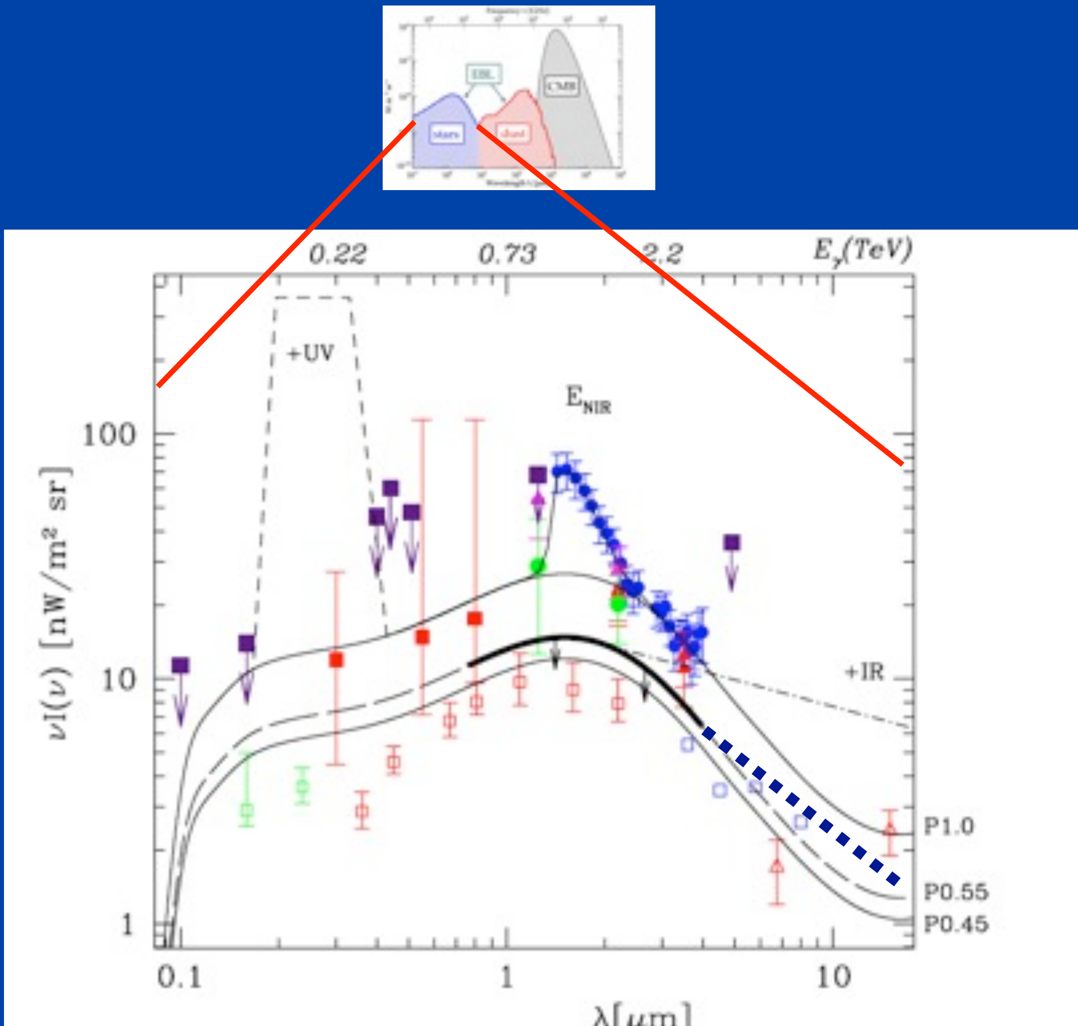

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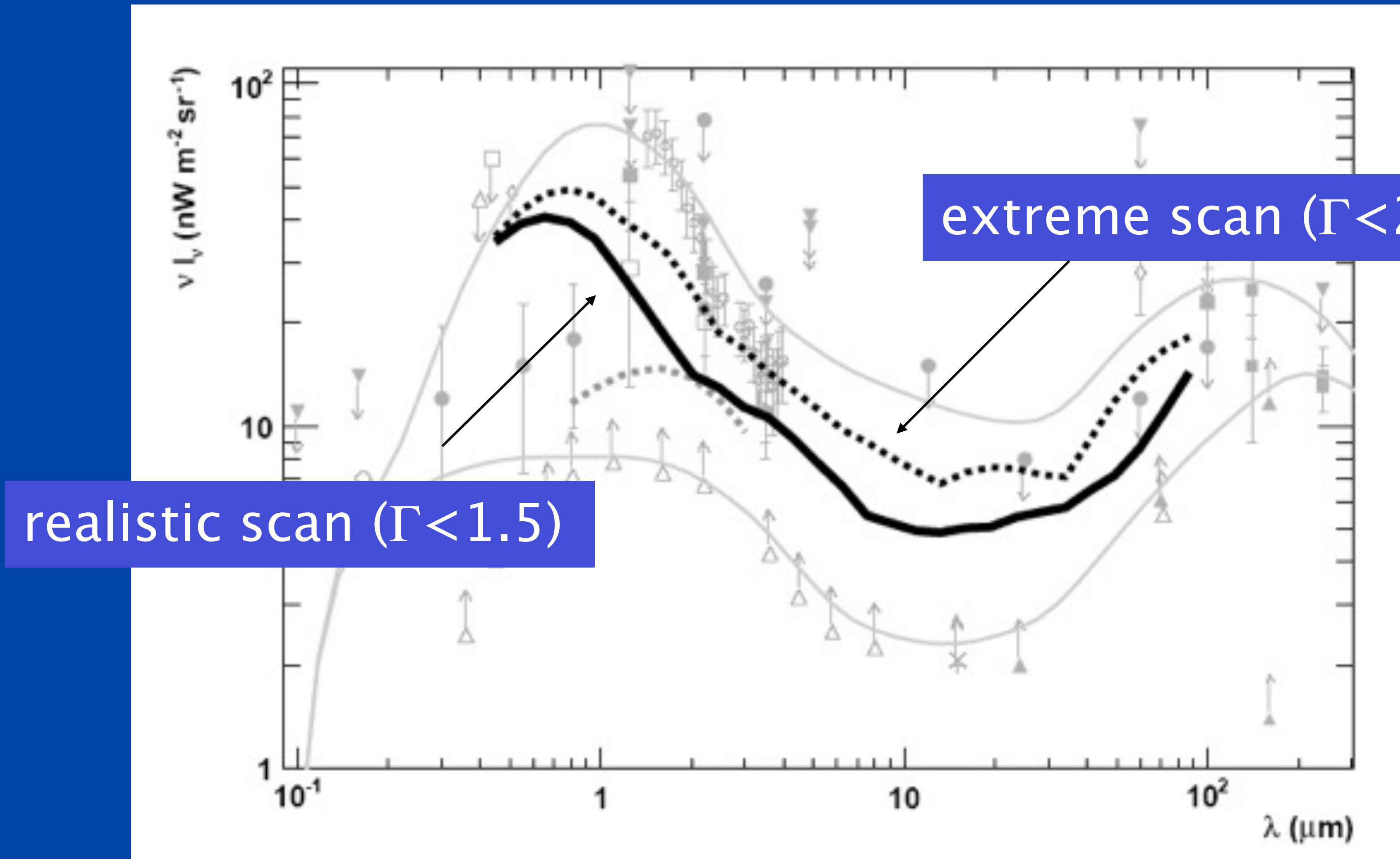
model independent constraints (2007)



Mazin & Raue, A&A 471, 439-452 (2007)

MAGIC 2008: EBL constraints from 3C279

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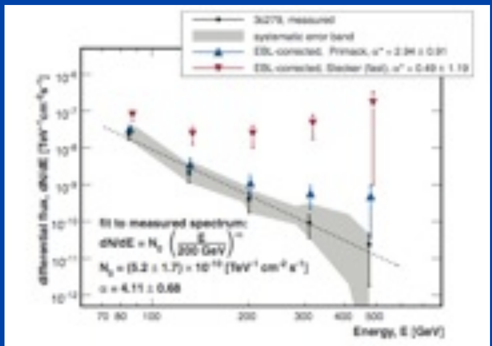
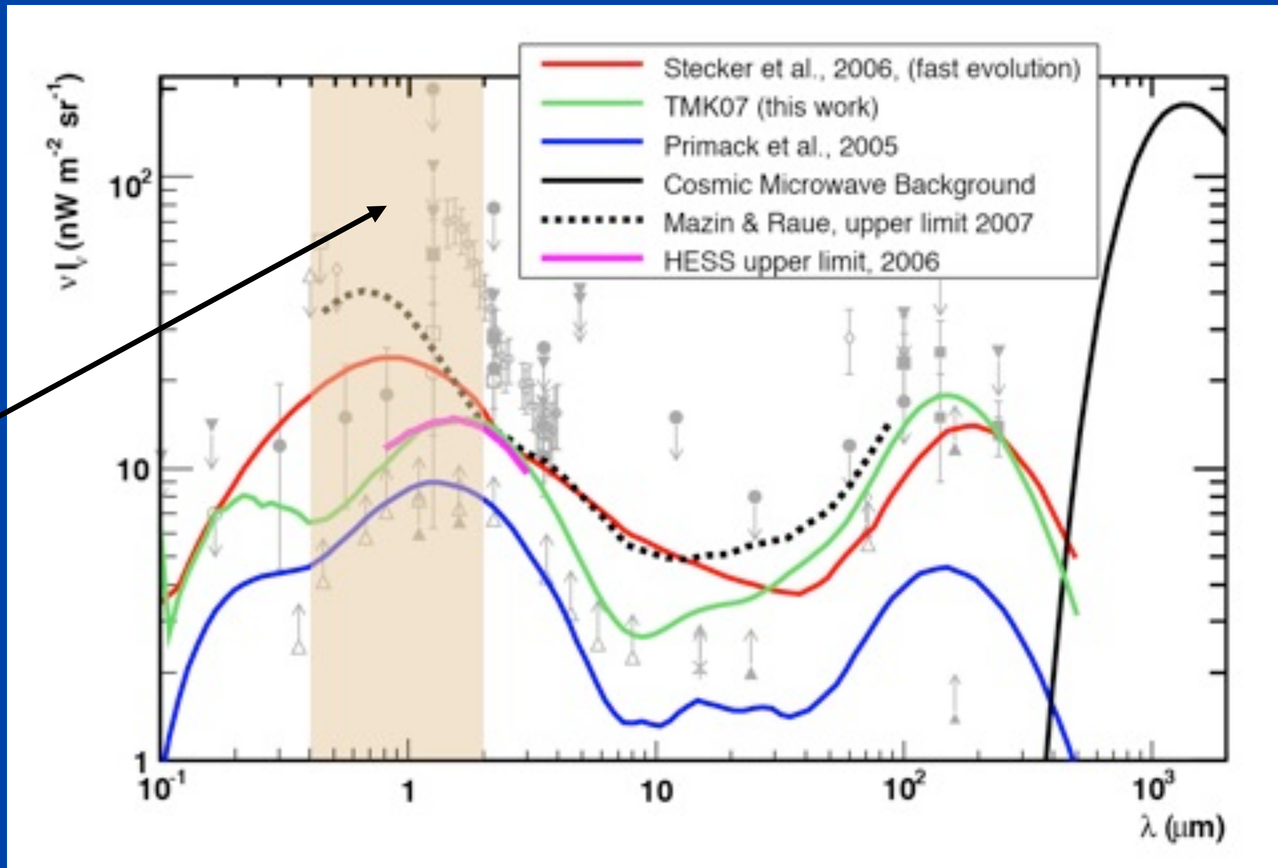




Probing new range of the EBL

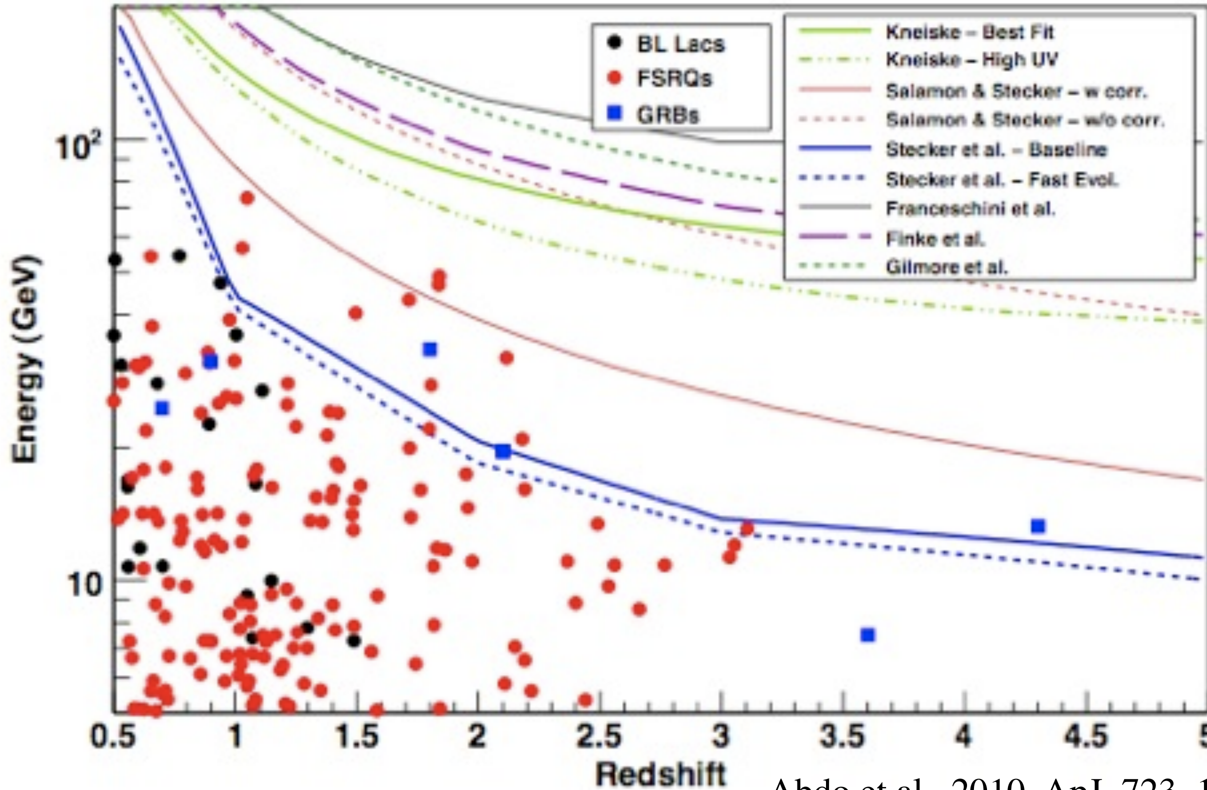
Green line: model of Kneiske et al., tuned to the 3C 279 spectrum using the $\Gamma=1.5$ criterion

Albert et al., Science (2008) 320, 1752

Fermi/LAT limits

- Highest energy photon method

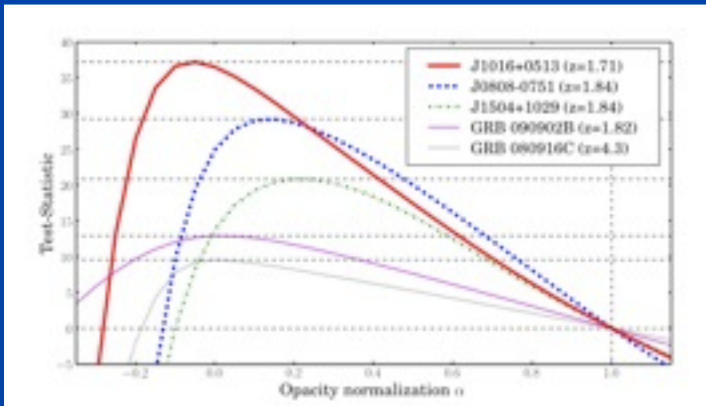
lines for optical depth tau =3



Abdo et al., 2010, ApJ, 723, 1082

Fermi/LAT limits

◉ Likelihood ratio technique



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- compares Null-hypothesis (L_0) with competitive model (L_1) to best represent data: $TS = -2 \times [\log(L_0) - \log(L_1)]$
- observed flux = $\exp[-\alpha \cdot \tau_{\gamma\gamma,model}(E,z)] \times F_{unabs}$
  with $\tau_{\gamma\gamma,model}$ = „baseline model" [Stecker etal (2006)]

Source	z	LRT Rejection Significance pre-trial	post-trial
J1147-3812	1.05	3.7σ	2.0 σ
J1504+1029	1.84	4.6σ	3.3 σ
J0808-0751	1.84	5.4σ	4.4 σ
J1016+0513	1.71	6.0σ	5.1 σ
J0229-3643	2.11	3.2σ	1.2 σ
GRB 090902B	1.82	3.6σ	1.9 σ
GRB 080916C	4.24	3.1σ	1.0 σ

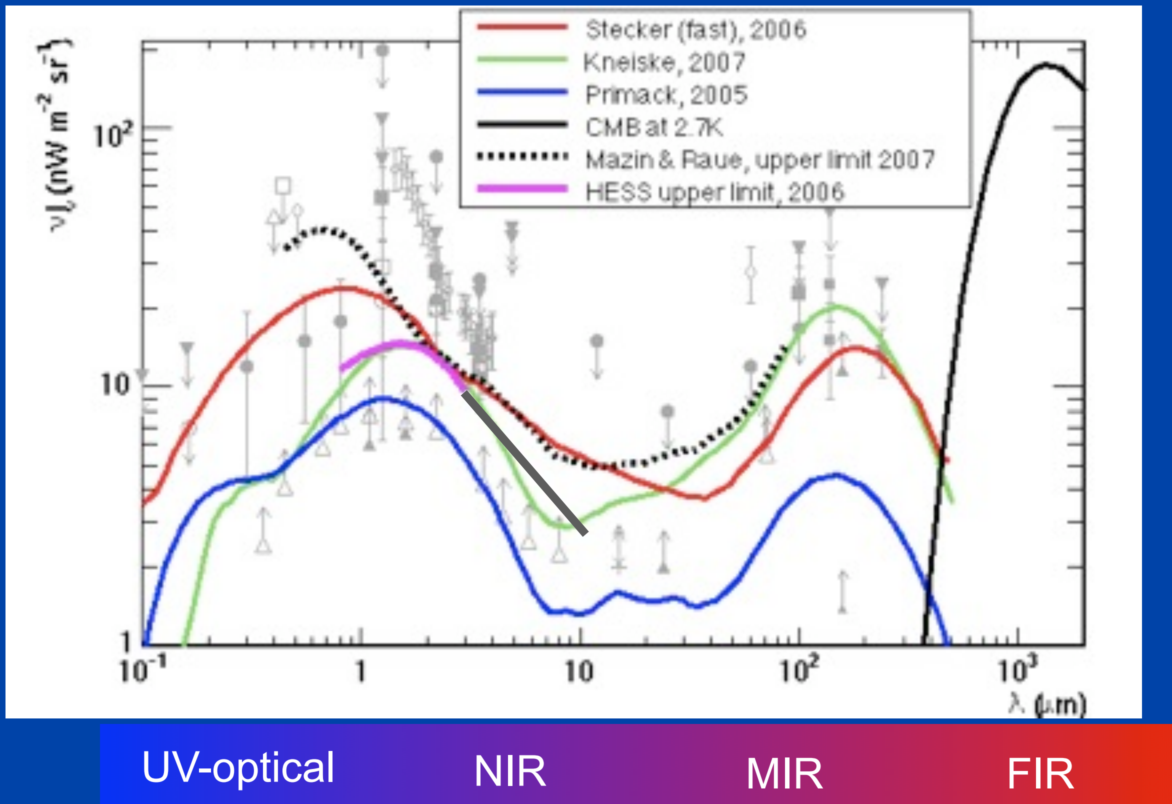
- *multi-trial effects:*
  $P_{post-trial} = 1 - (1 - P_{4\sigma})^{1/N}$
  with N ~ 200 trials

  $P_{4\sigma,post-trial} \sim 3\times10^{-7} \rightarrow 5.1\sigma$ pre-trial

"Baseline model" (Stecker etal 2006) significantly constrained by LRT.

◉ Conclusion: high EBL is excluded with high significance

EBL constraints from VHE γ-rays



- Upper limits using VHE spectra + assumptions about AGN physics
- Recent constraints are already very tight
- HESS II, MAGIC II and Fermi will remove these uncertainties
- Constraints above 10μm rely on a single measurement of Mkn 501 done by HEGRA in 1997: need more!
- References:
  - Aharonian et al, Nature440
  - Mazin&Raue, AA 471
  - Aharonian et al., AA 475
  - Albert et al., Science 320

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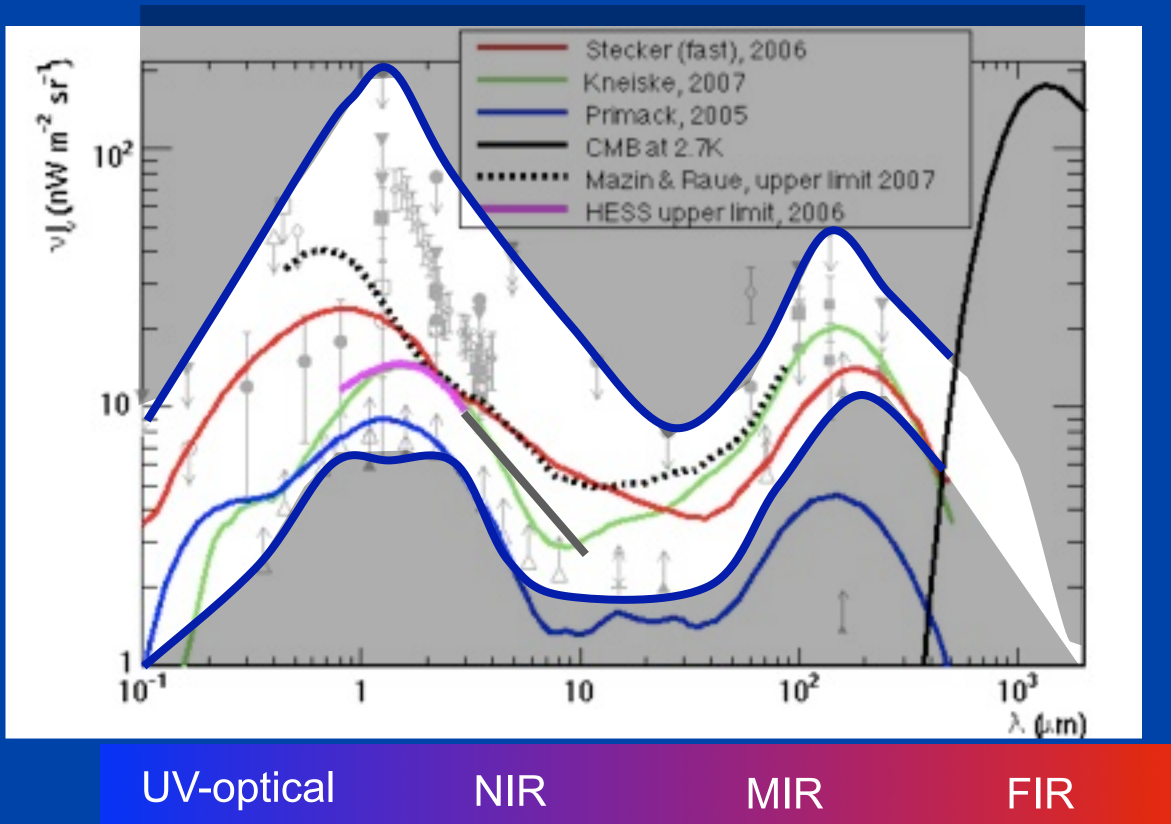

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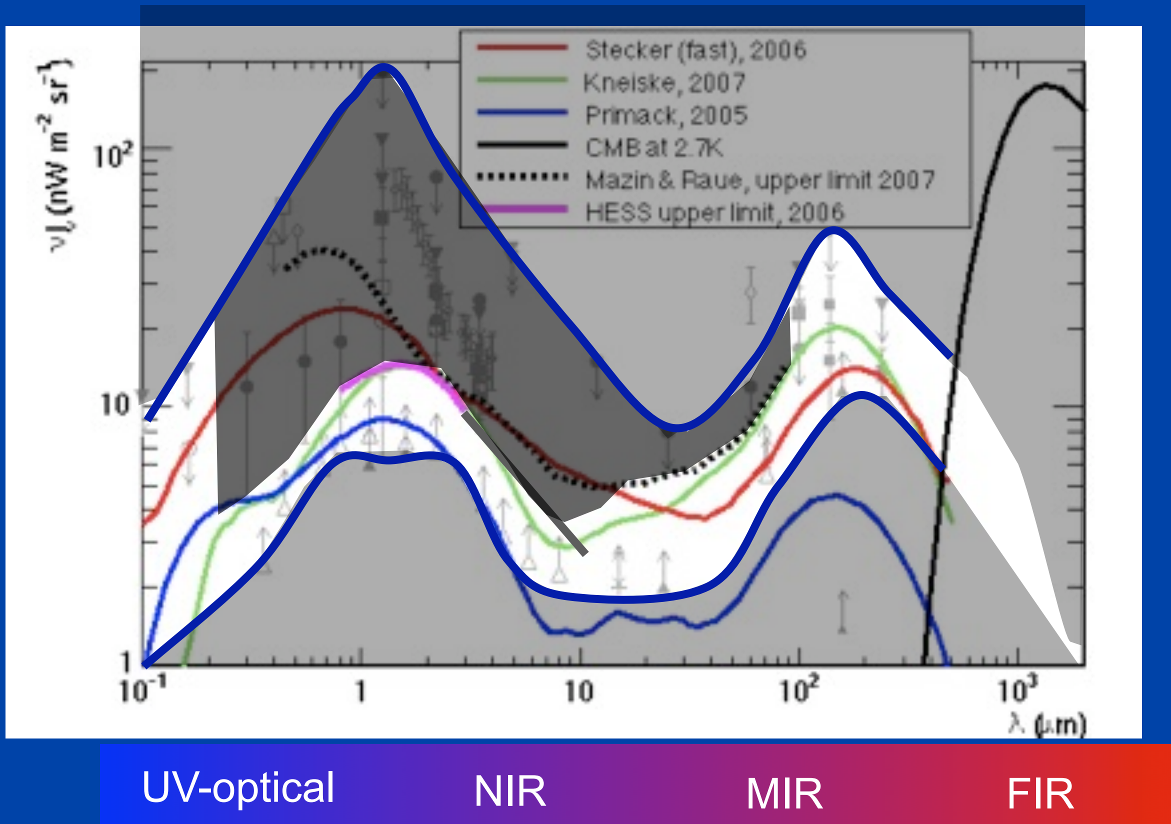

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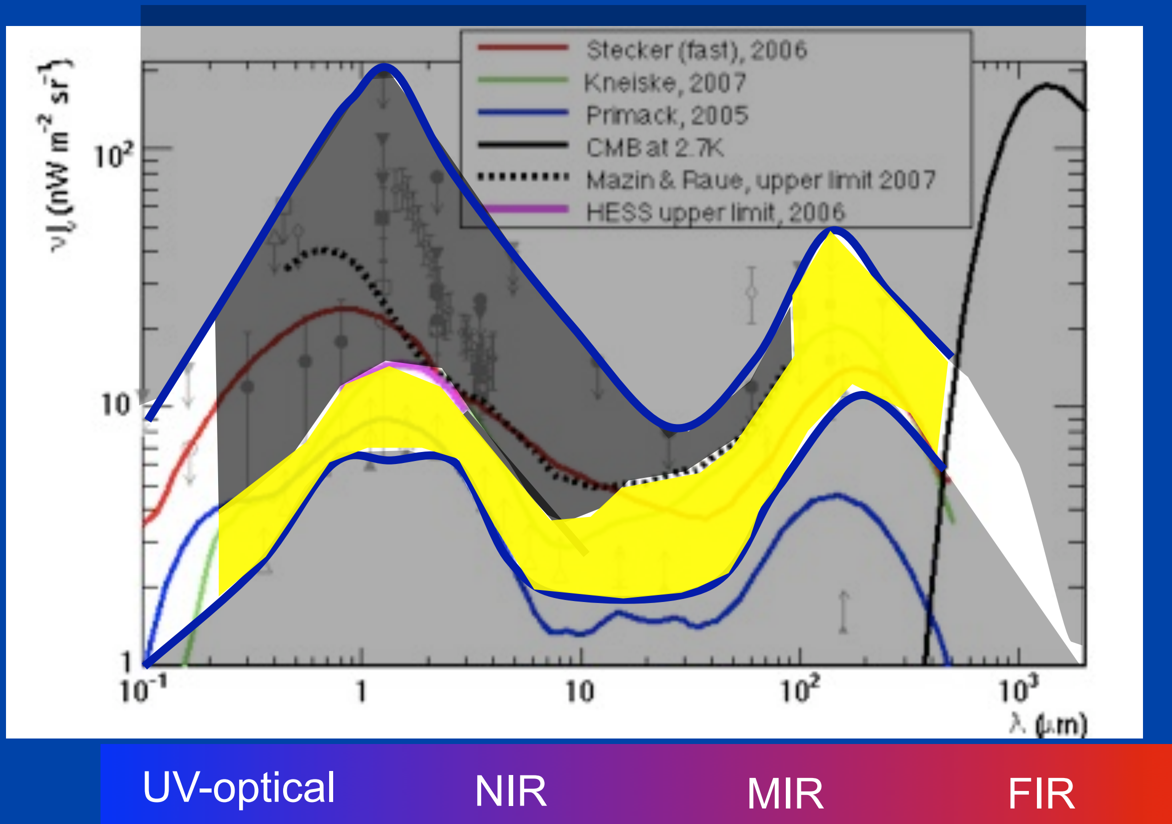

Newly excluded region

Still allowed EBL region

- Upper limits using VHE spectra + assumptions about AGN physics
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γ-ray horizon

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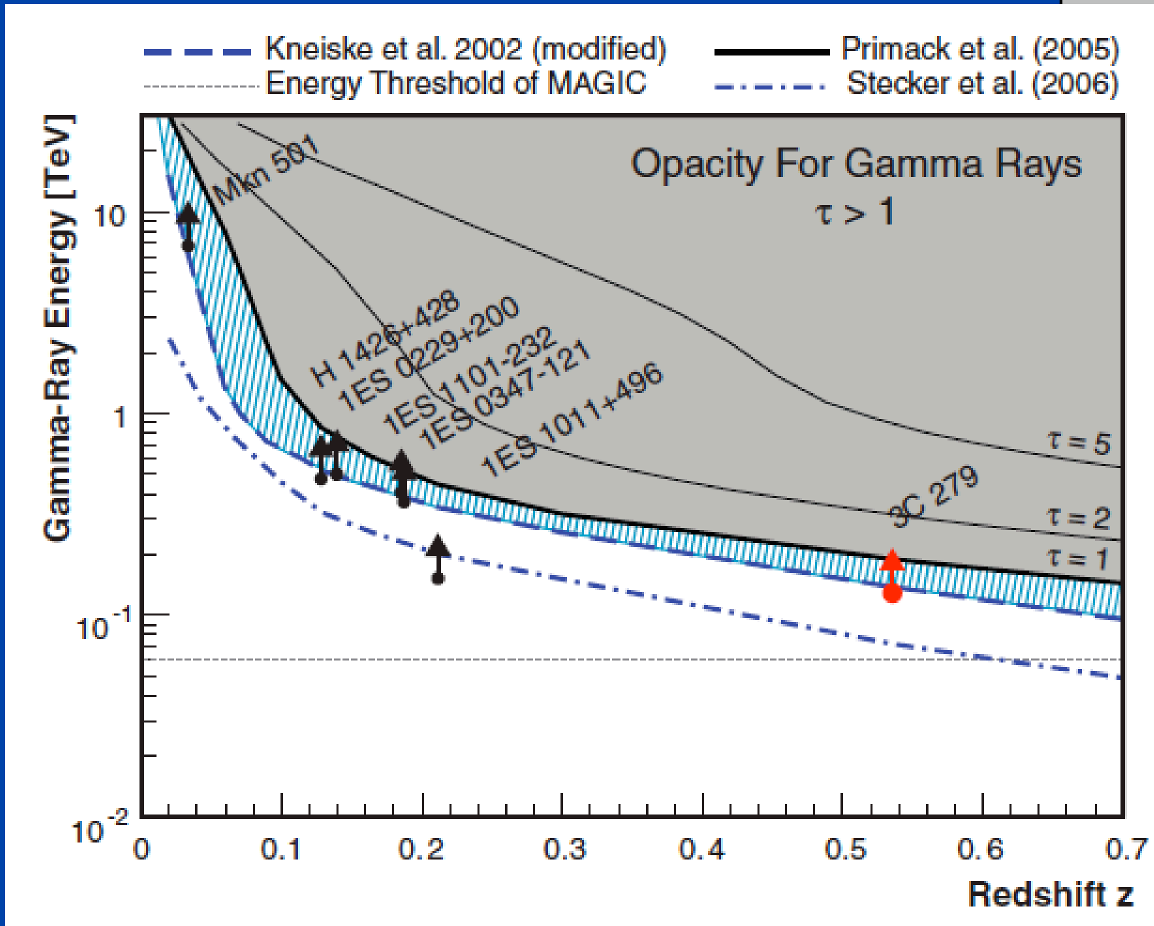

Only narrow band left between galaxy counts and the IACT constraints

Albert et al., Science (2008) 320, 1752

D. Mazin, Probing EBL with VHE γ-rays

15 December 2010, Paris

Wednesday, December 15, 2010

Recent EBL models

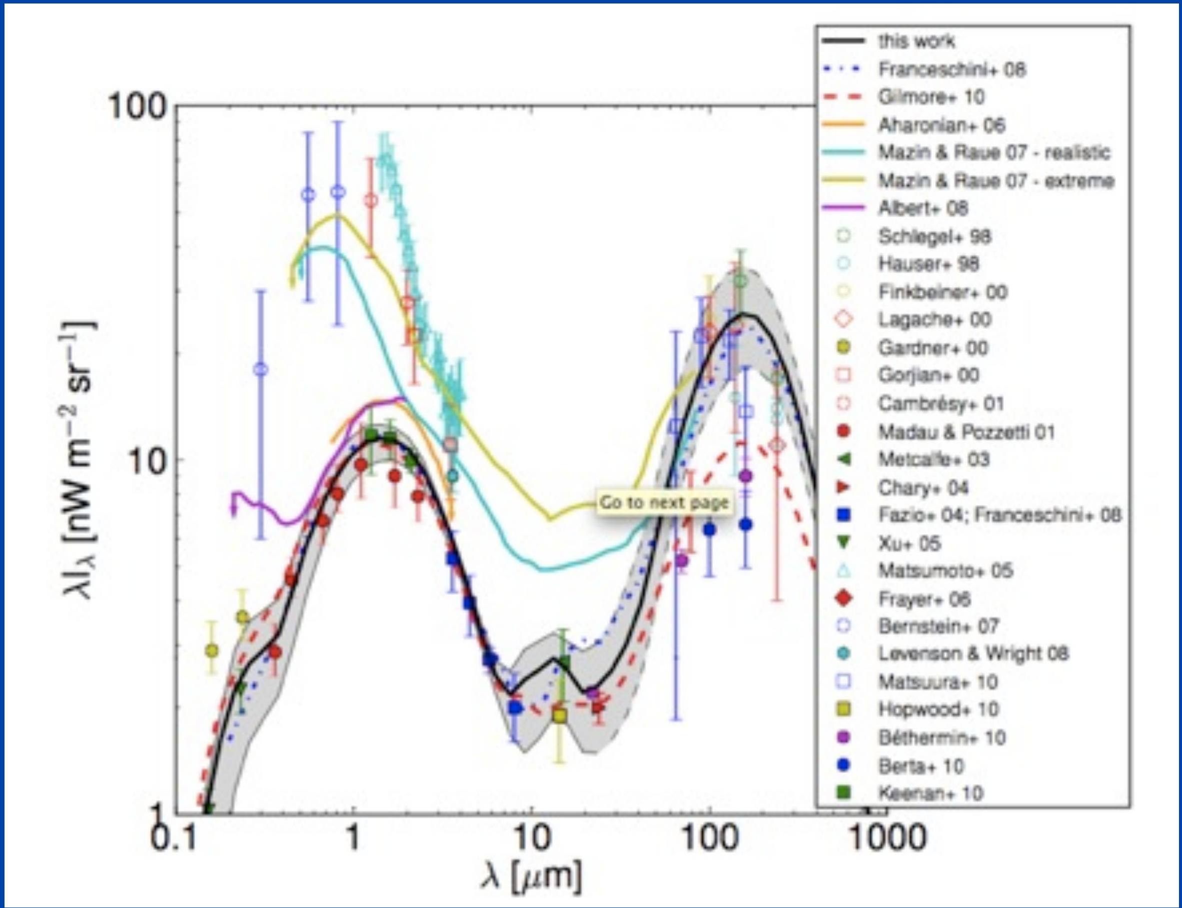

Fig from Dominguez et al, 2010, MNRAS, arXiv: 1007.1459

EBL, which are OK:

1. **Franceschini+08**
2. **Gilmore+09**
3. **Dominguez+10**
4. **Kneiske+10**
5. **Finke+10**

- Recent EBL models suggest low EBL level

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Discussion and application of the limits

Skepticism about EBL limits

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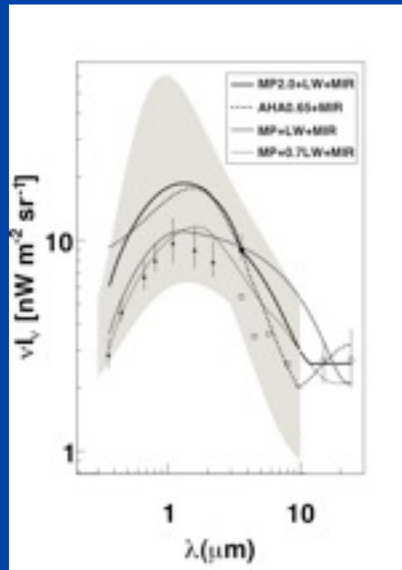
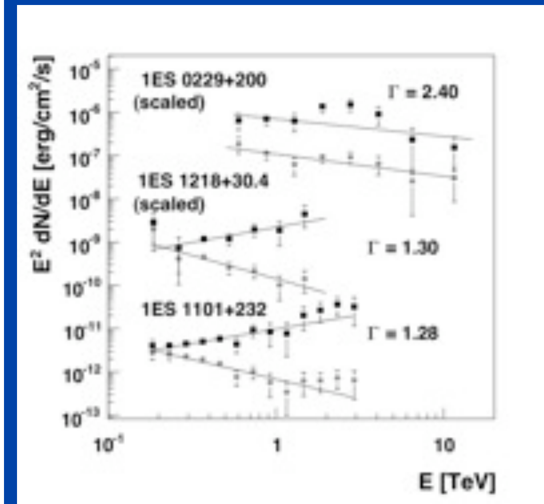
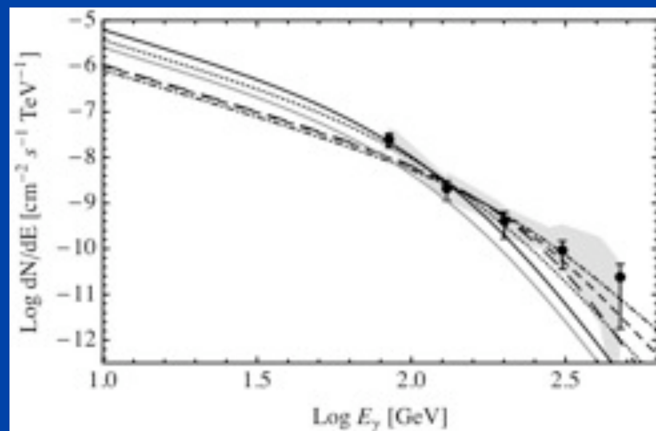
- Dwek, Krennrich & Imran (2008): even with low EBL, the spectra too hard!



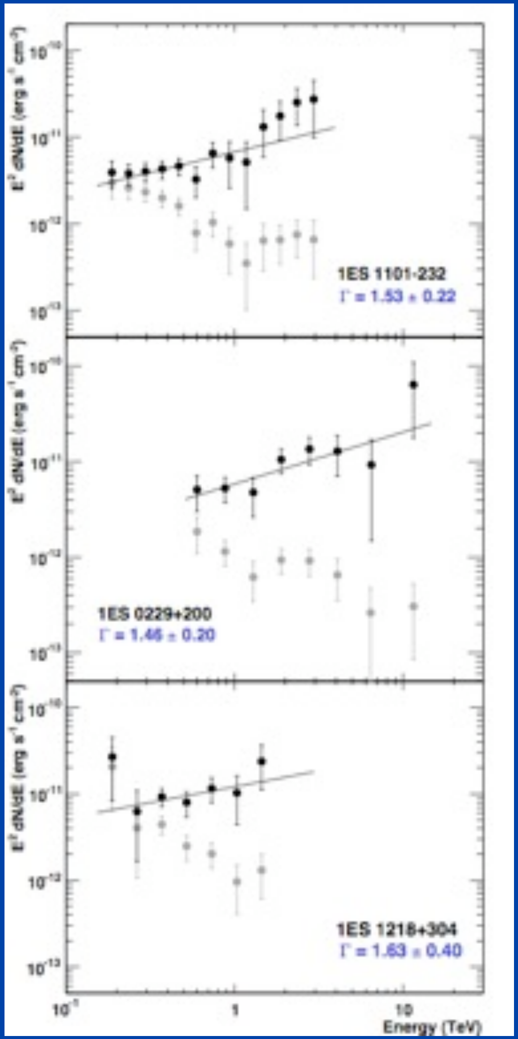


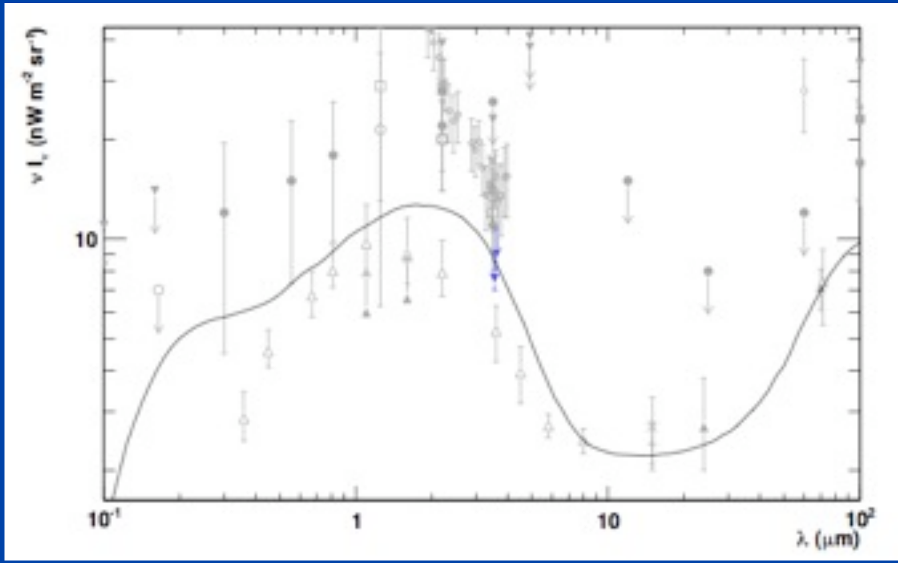
- Stecker & Scully 2009: even with high EBL, the spectra are OK!



discussion is ongoing ...

plots from Raue, 2009





- If the EBL is 30% above lower limits: spectra OK
- Statistical criteria: 2σ but results very consistent for already 7 different sources

Internal absorption - 1

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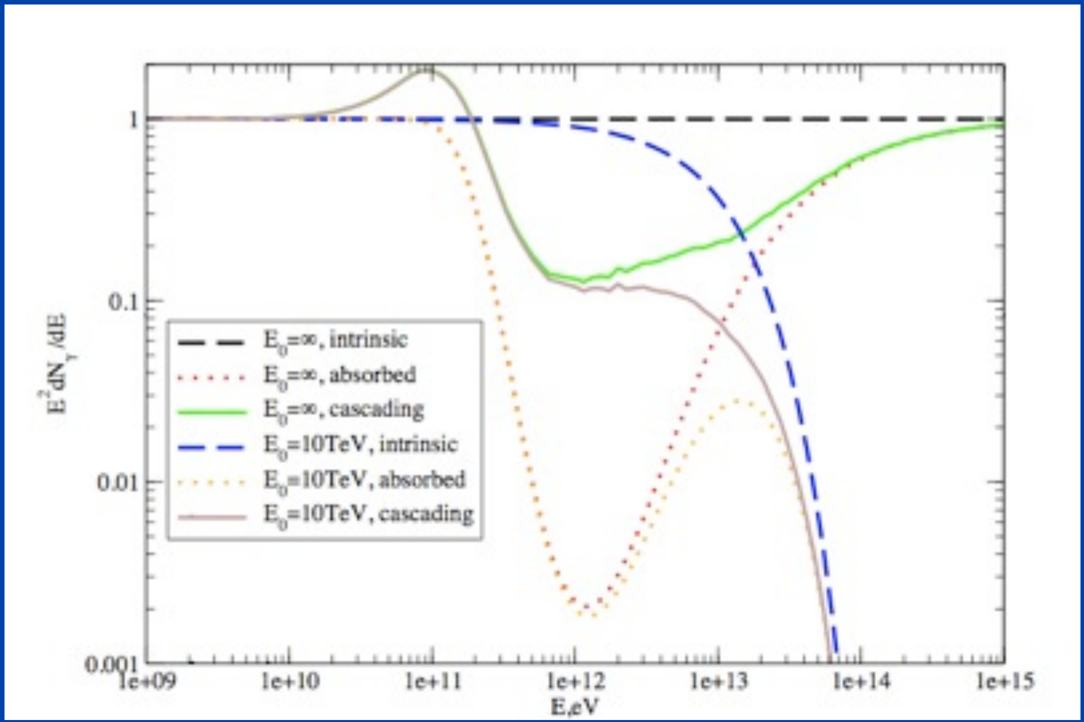
- internal absorption on narrow target fields may produce very hard observed spectra



Aharonian, Khangulyan & Costamante, 2008, MNRAS, 387, 1206

Internal absorption -2

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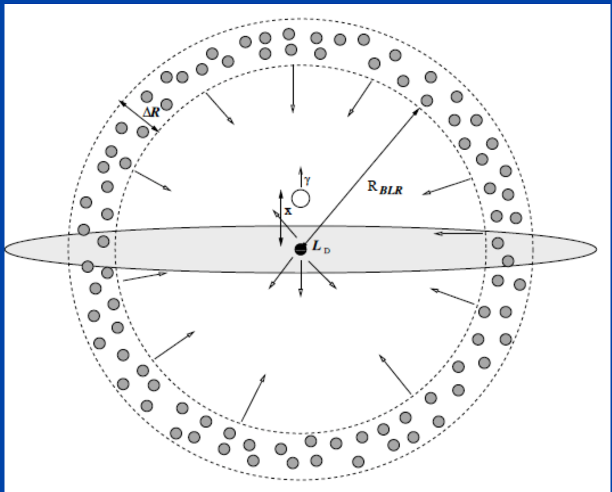
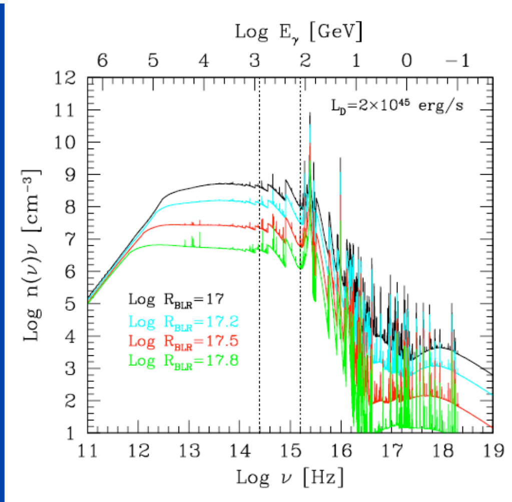
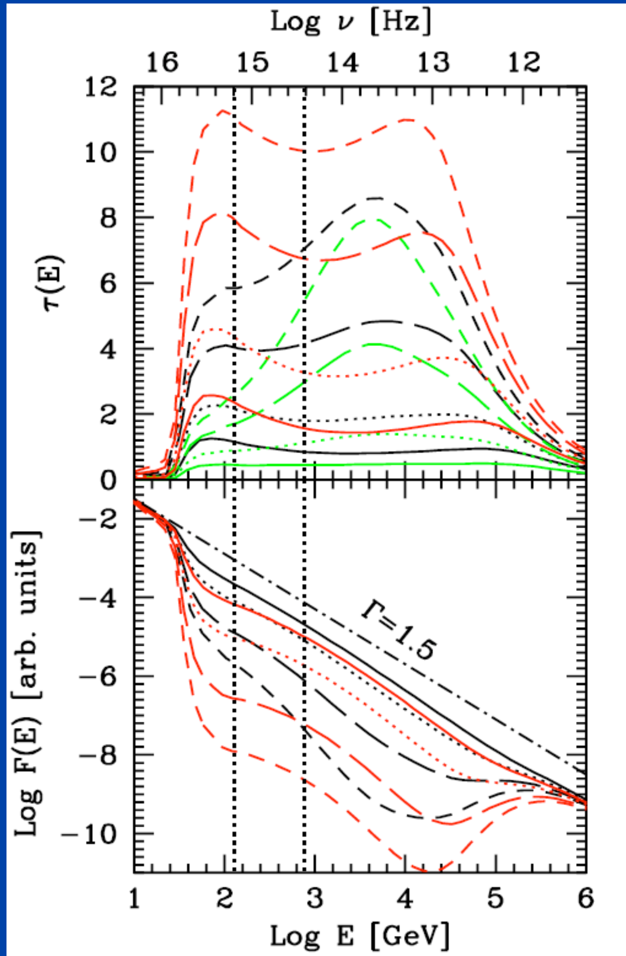
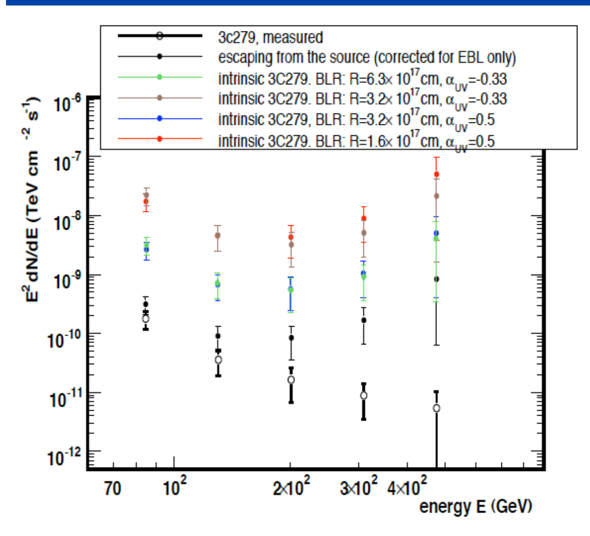




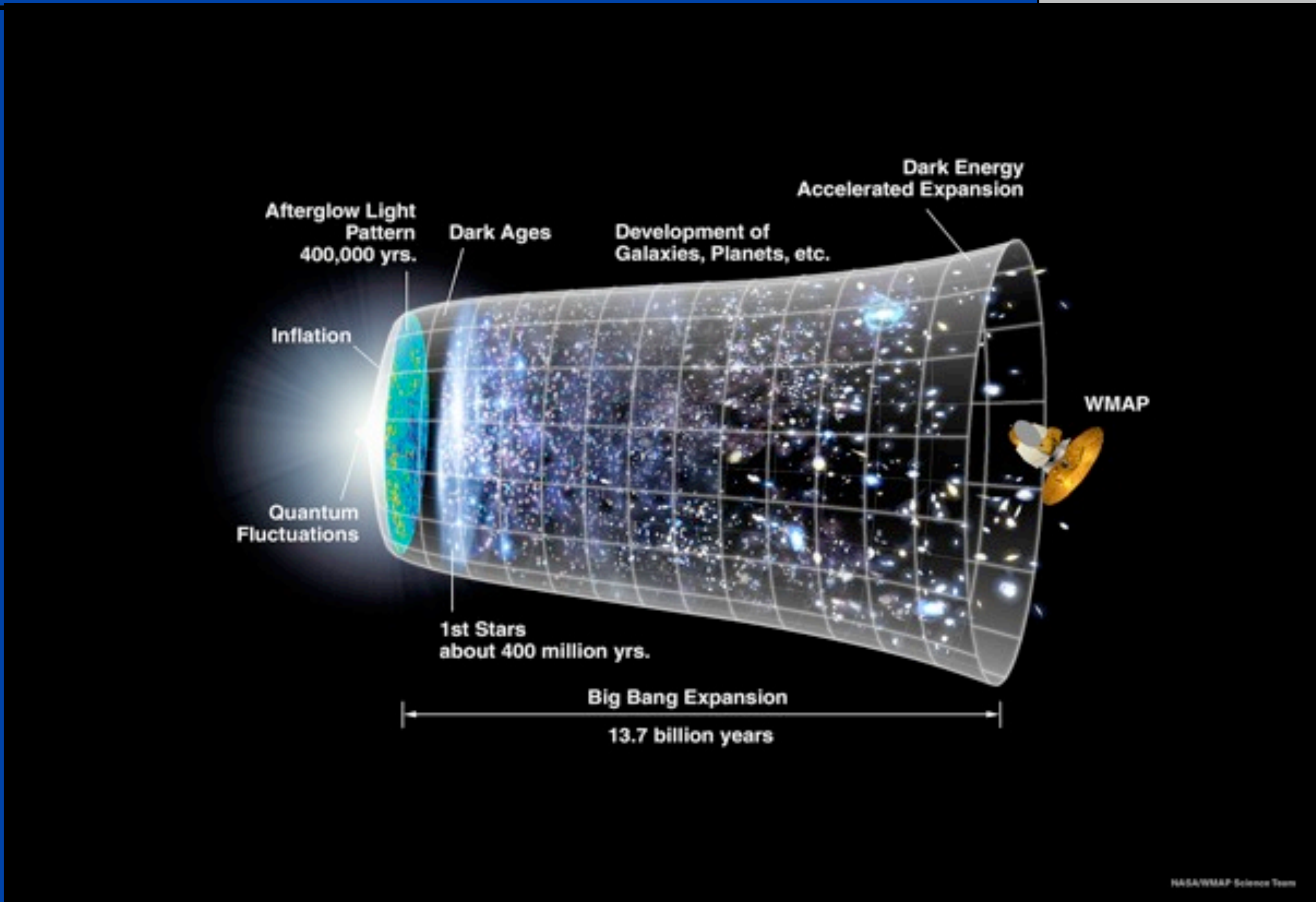




- BLR: spherical shell of thickness ΔR, negligible disk radiation
- Latest **CLOUDY** code, which includes not only lines but also continuum emission
- Moderate change of the VHE MAGIC spectrum
- No change of the EBL limits
- Details in **Tavecchio & Mazin, MNRAS 392 (2009) L40-L44**

With realistic Broad Line Regions and Disk re-emission: no change in the EBL limits

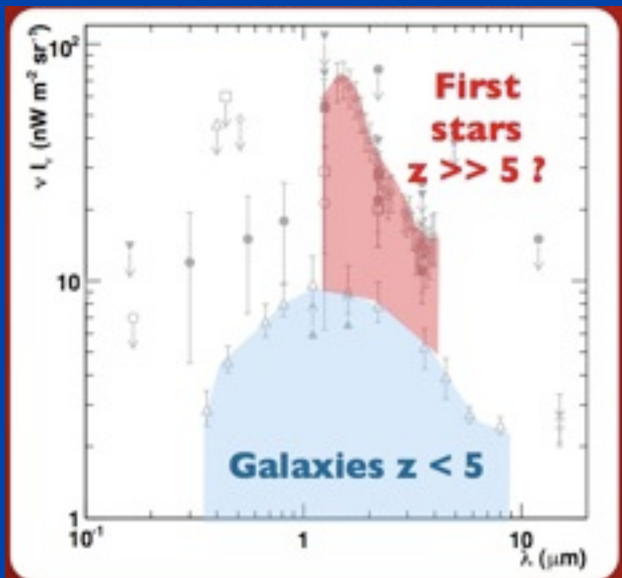
Population III stars

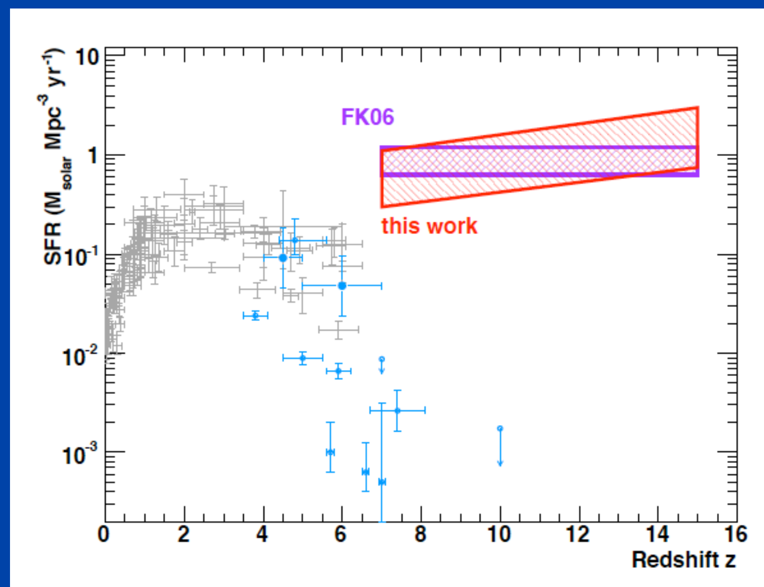


Population III stars

Raue, Kneiske & Mazin, A&A (2009), 498, 25–35, arXiv:0806.2574

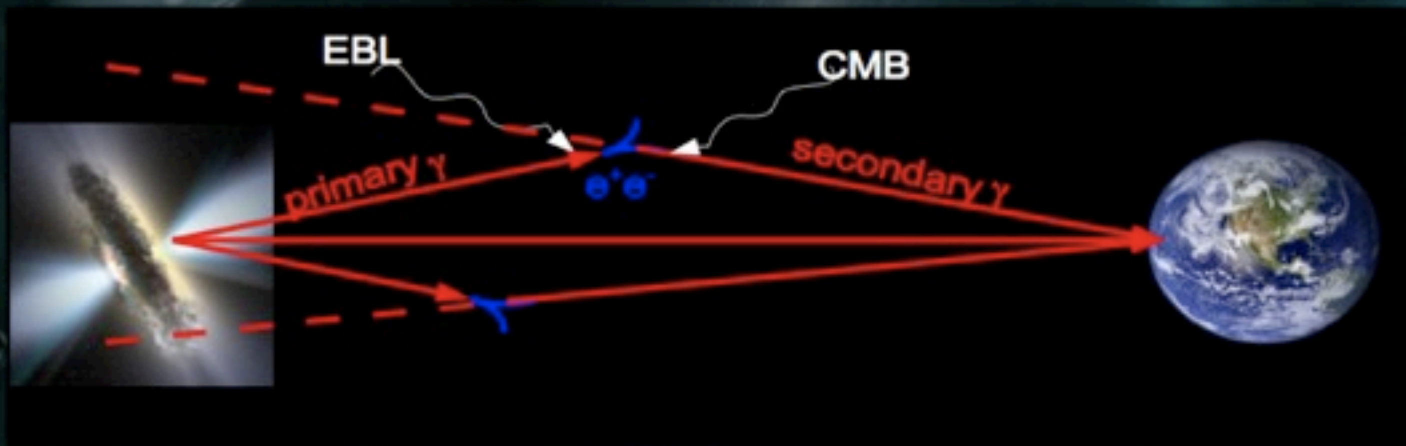
- used the recent EBL limits to derive constraints on the PopIII stars
- account for the time evolution of the emissivity of a stellar population
- results:
  - Zero metallicity stars: peak SFR of 0.6 - 3 $M_\odot$ / year (for z = 7 - 14)
  - Low metallicity stars: peak SFR of 0.3 - 1.5 $M_\odot$ / year (for z = 7 - 14)





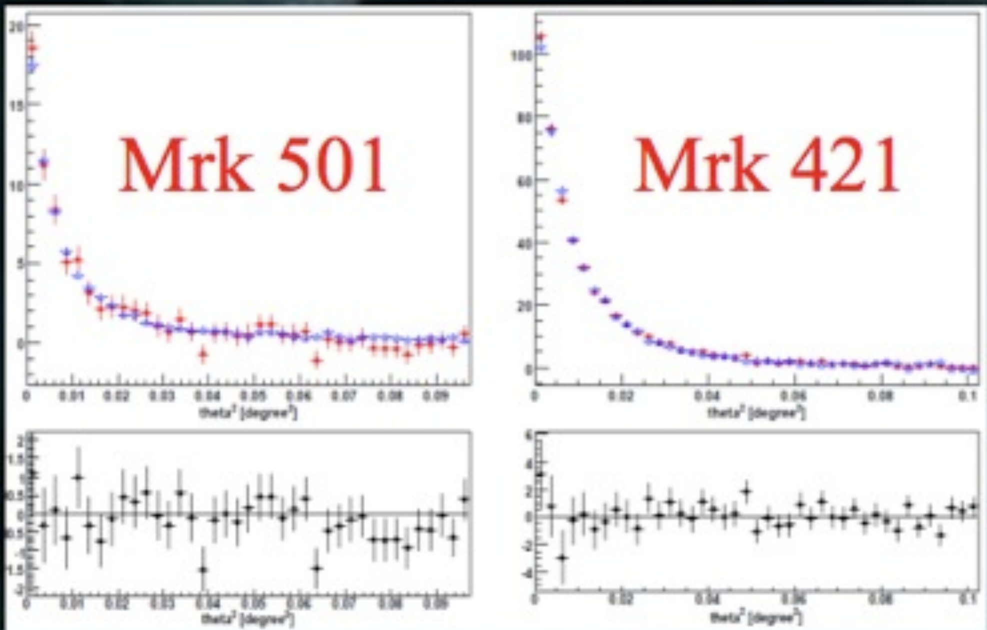
Halos

Search for an extended emission from Markarian 421 and 501 blazars



- Cascades (on the way to the observer) of VHE gamma-rays in the EBL/CMB radiation fields
- The trajectories of e^+e^- pairs are bend in the extragalactic magnetic field (EGMF) → an additional, extended emission component is possible.

no halos by MAGIC so far



Aleksic et al. 2010, A&A, 524, 77

- No extended emission was found, an upper limit of < 4% of the Crab Nebula flux was obtained

- Constraints for the existence of EGMF with strengths of: $4 \cdot 10^{-15} < B < 1.3 \cdot 10^{-14}$ G (for its correlation length » 30kpc) assuming comparable level of SED at 300 GeV and 20TeV 10

- see more in the next talk!

Conclusions / Outlook

- EBL carries essential cosmological information and is a source of VHE gamma-ray opacity
- VHE spectra put strong limits on the EBL density, suggesting an EBL on the level of galaxy counts
- Fermi/LAT confirms these limits with high confidence
- Recent EBL models favor low level EBL
- However, hard VHE gamma-ray spectra may still surprise us. If so:
  - possibly rare emission scenario
  - internal absorption
  - new physics (propagation of gamma-rays is not well understood)
- If EBL can be considered as resolved, the intrinsic VHE spectrum can be deduced and one can calculate the expected cascading emission for a given magnetic field strength
- Remaining issues for future:
  - disentangle AGN physics from propagation effects
  - provide beacons behind the main galaxy formation epoch (z>1)
  - measure Mid and Far-infrared EBL
  - independent distance measurements
    ➟ cosmology, Hubble parameter

backup

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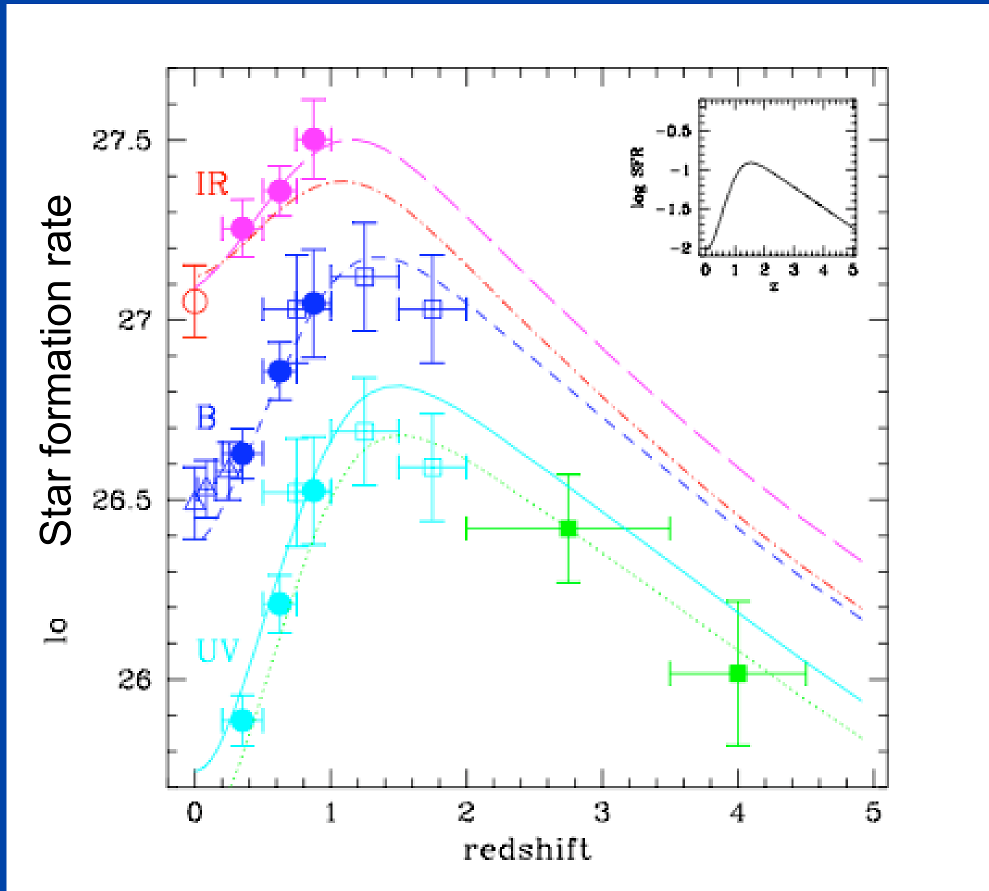
Future perspectives:

FGST, MAGIC II, H.E.S.S. II, CTA

Goal 1: EBL evolution

- Star and galaxy evolution is largely unknown
- Fermi (CTA) can measure blazar spectra up to redshift **z ~ 1 (z ~ 2)**
- Such sources are behind the main star formation epoch ➟ **beacons**
- Using sources with z<1, the EBL evolution can be resolved!
- Need >100 sources
- Need to know intrinsic evolution of the sources (see A. Reimer 07, but see good news from Fermi, S. Funk)



Madau, 1998

Goal 2: EBL at Mid- and Far-Infrared

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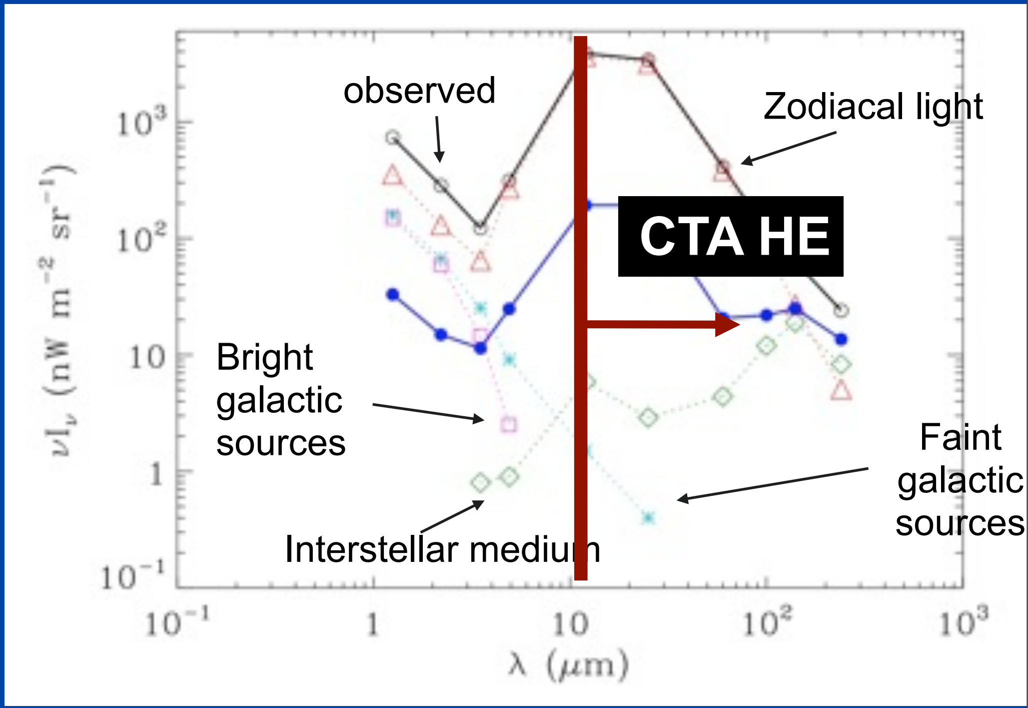
COBE data (Hauser & Dwek, 2001)

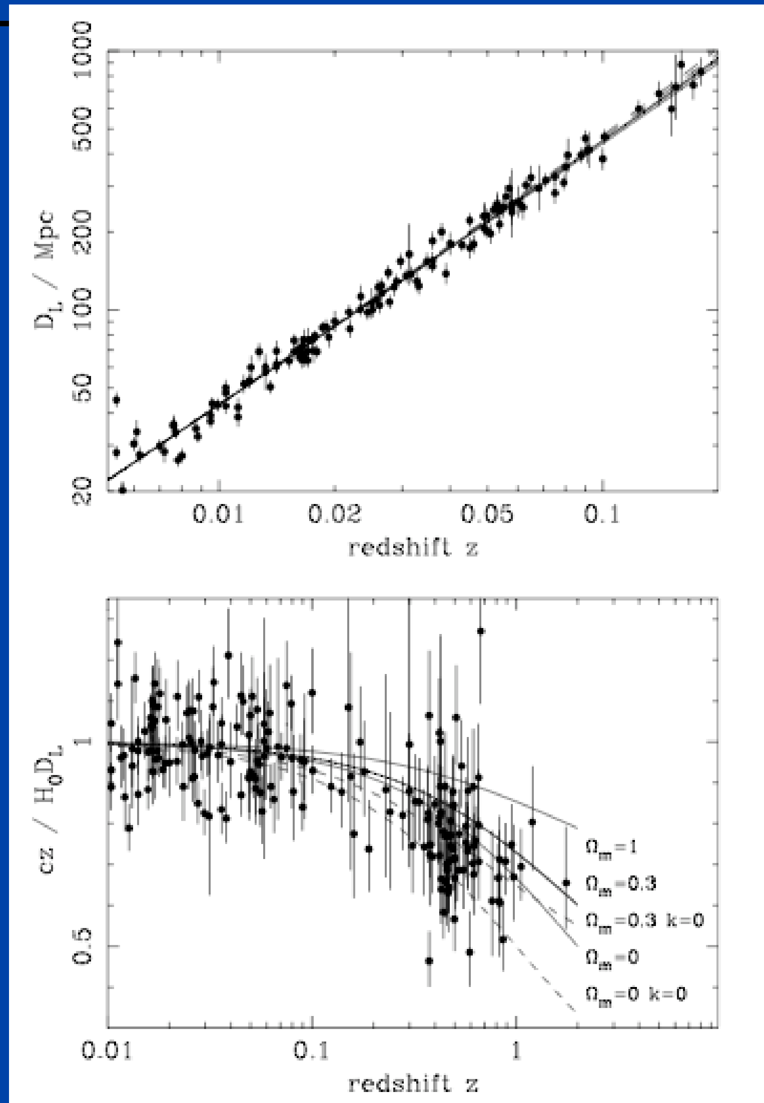


- EBL in mid- and far-infrared are crucial for understanding star and galaxy formation:
  - **How much dust?**
  - **What is dust contents?**
  - **How many galaxy populations?**
- No direct measurement in the near future
- CTA (high energy array!!) is the only experiment to test Mid + Far-Infrared
- Need a few sources (e.g. Mrk 501, PKS2155-304, H1426+428)

Goal 3: distance = Hubble parameter

Based on Blanch & Martinez, 2001

- If one knows
  - **Intrinsic AGN spectrum and**
  - **EBL density**
- determine distance to the sources using the EBL signature in the measured spectra
- Can cover range from z=0.004 to z > 1



Goal 3: distance = Hubble parameter

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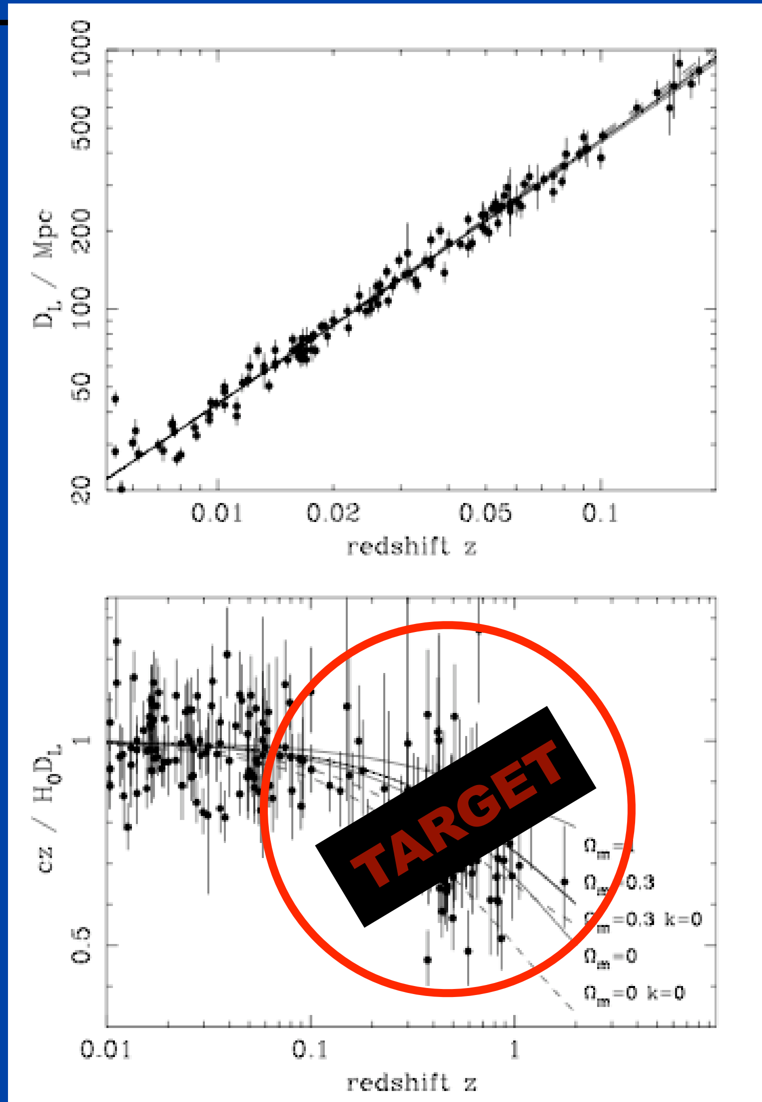
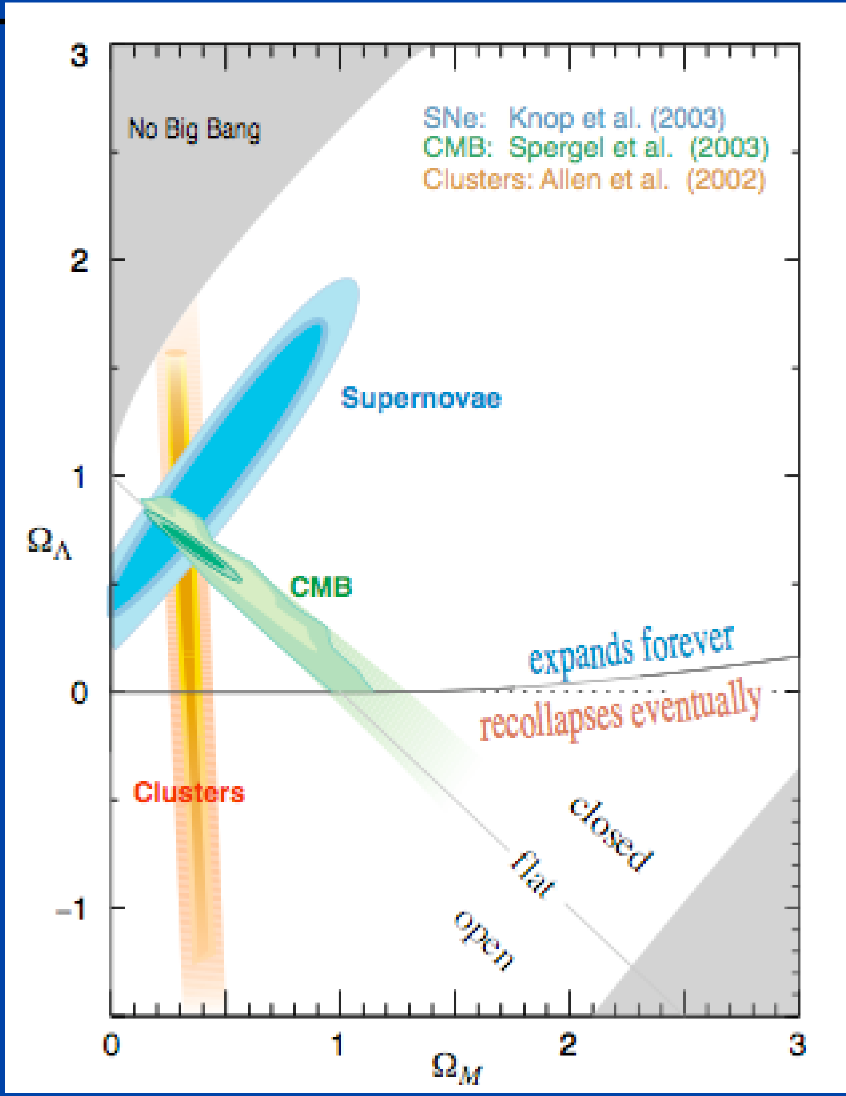


Goal 3: distance = Hubble parameter

Based on Blanch & Martinez, 2001

- Determination of cosmological parameters
- Independent method
- Required precision: 5-10% (in dz/z)
- High potential to determine evolution of Hubble parameter
- need >100 sources
- There are already some simplistic attempts to constrain H_0: Barrau et al. 08, Bi & Yuan 08



Goal 3: distance = Hubble parameter

Based on Blanch & Martinez, 2001

- o Determination of cosmological parameters
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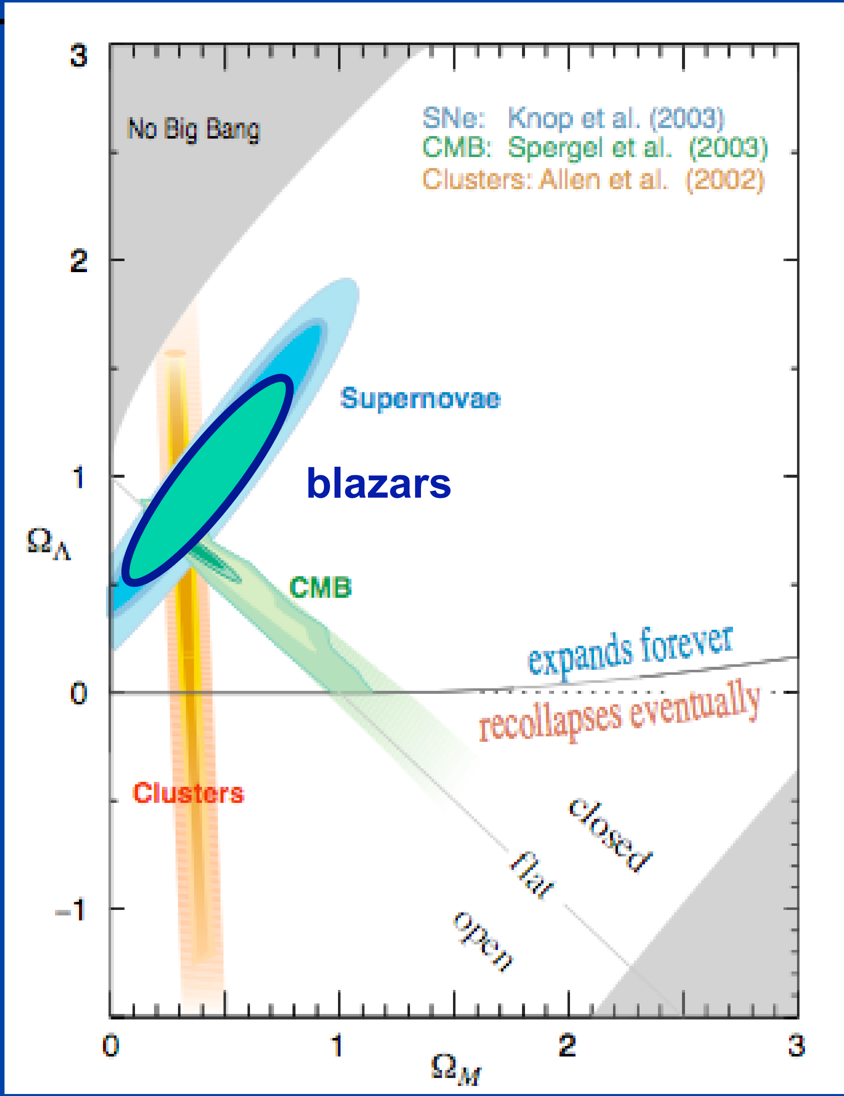
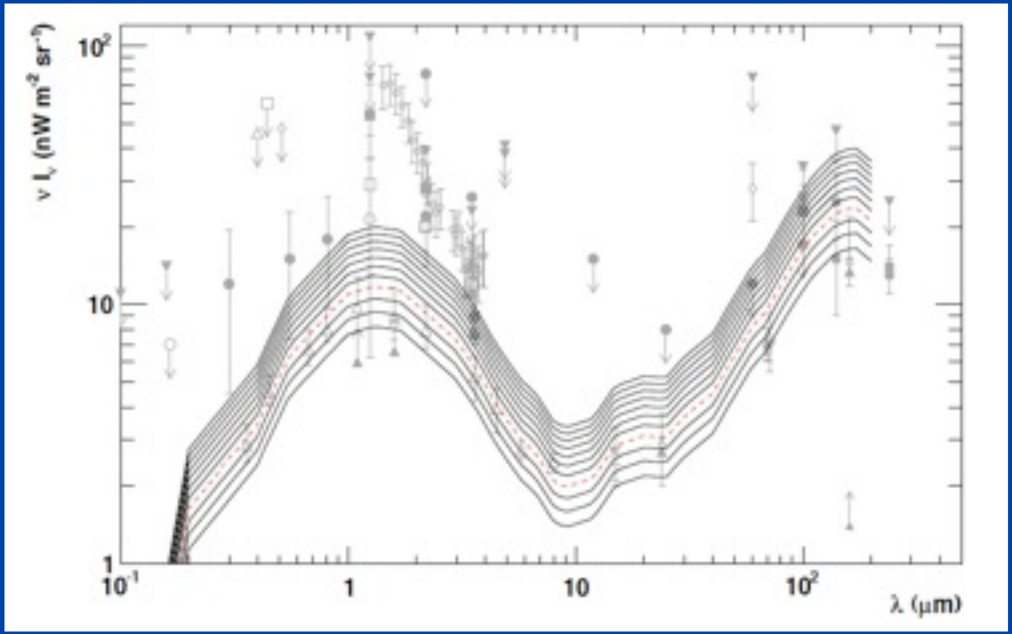
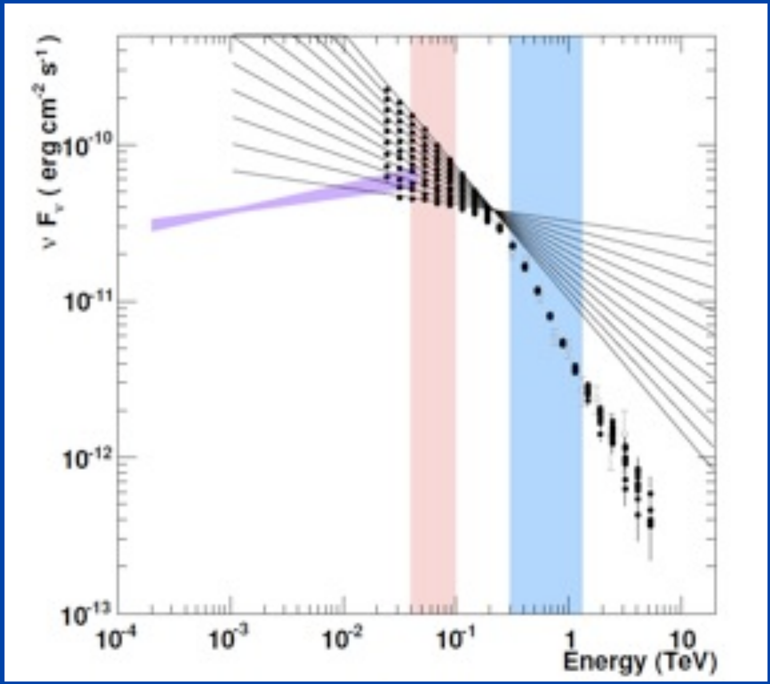


Low energies

- Franceschini 08 model
- scaling densities

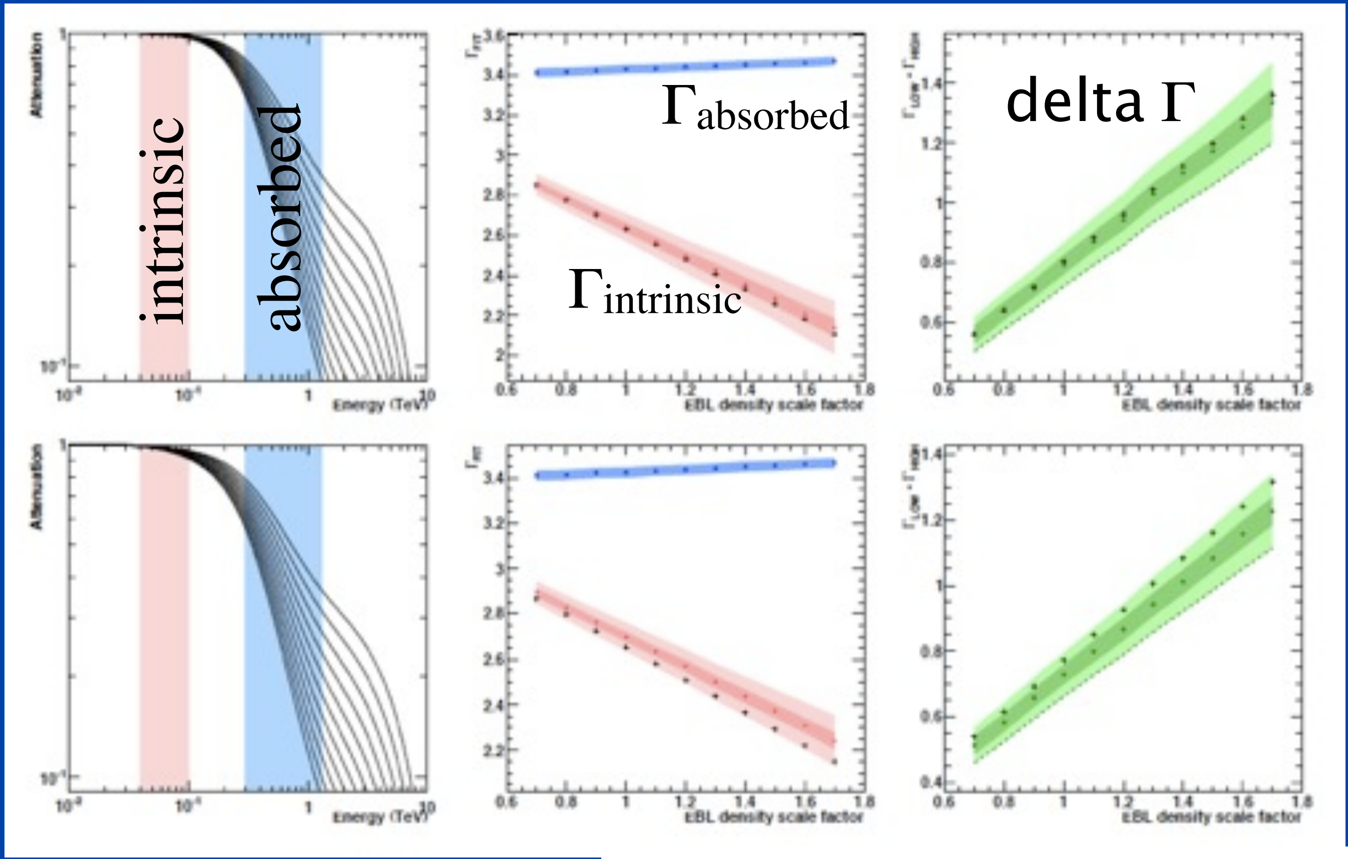


- PKS 2155-305



characterizing CTA

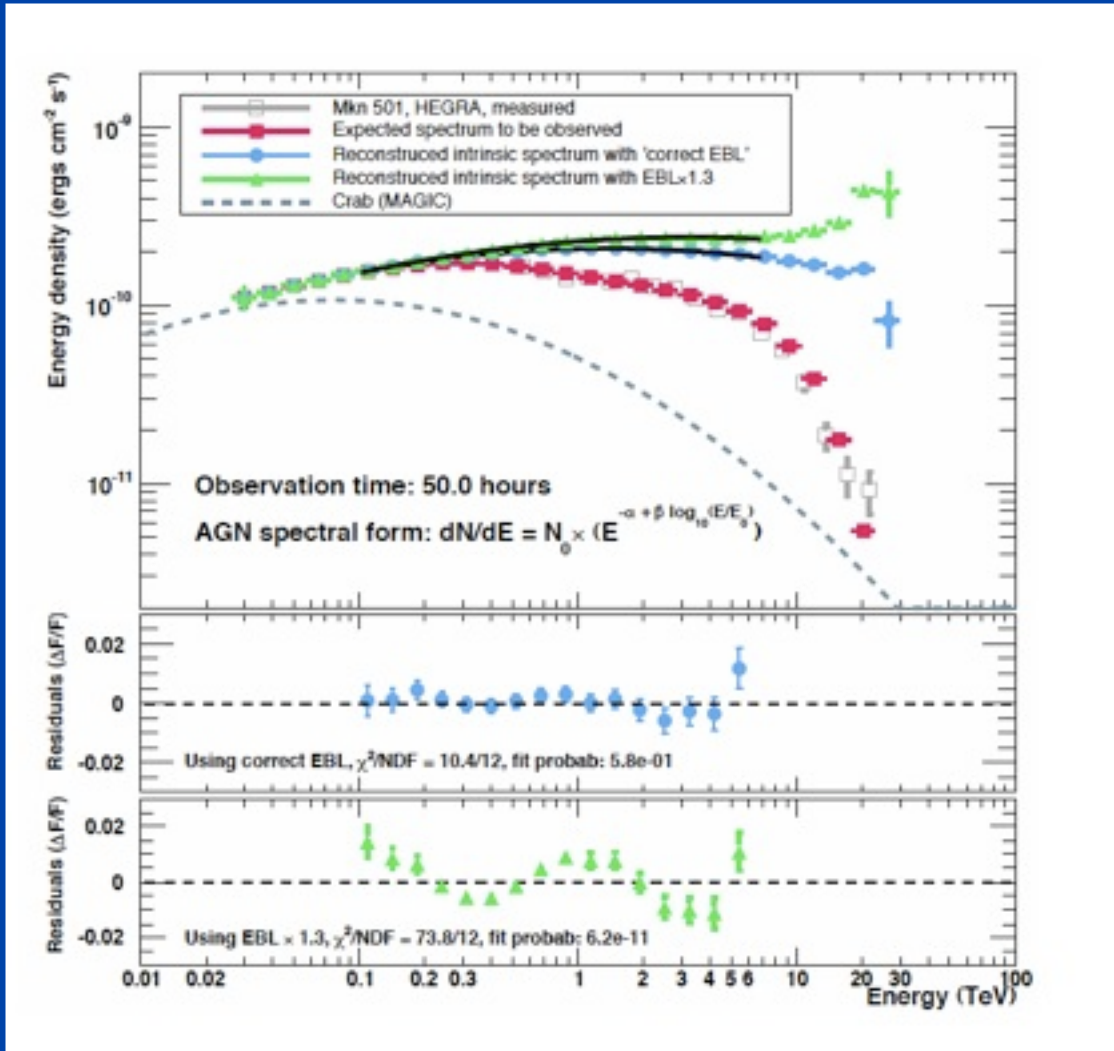
- simultaneous measurement of the intrinsic and absorbed parts of the spectrum



Raue & Mazin, Astrop Ph (2010) 34, 245

characterizing CTA (intermidiate energies)

- assume intrinsic spectrum of a known source during a flare
- simulate CTA spectrum
- de-absorb it using <u>correct</u> and <u>scaled</u> EBL
- check for wiggles in the spectrum



Raue & Mazin, Astrop Ph (2010) 34, 245

Taking into account internal absorption

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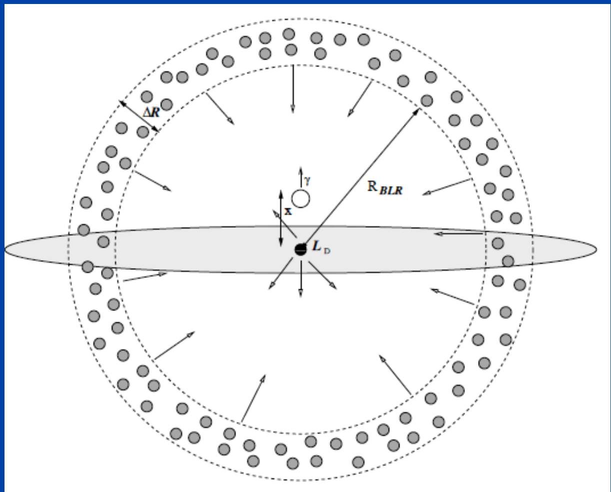
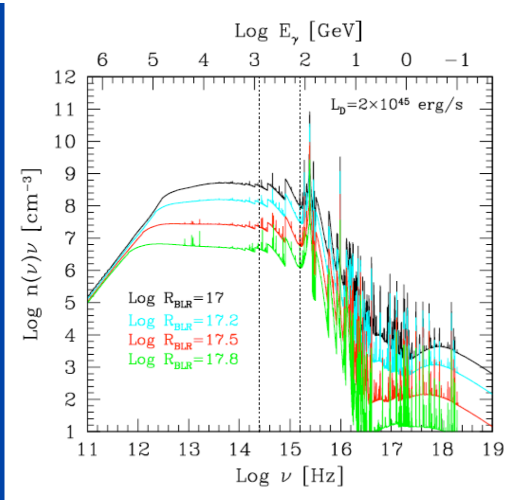
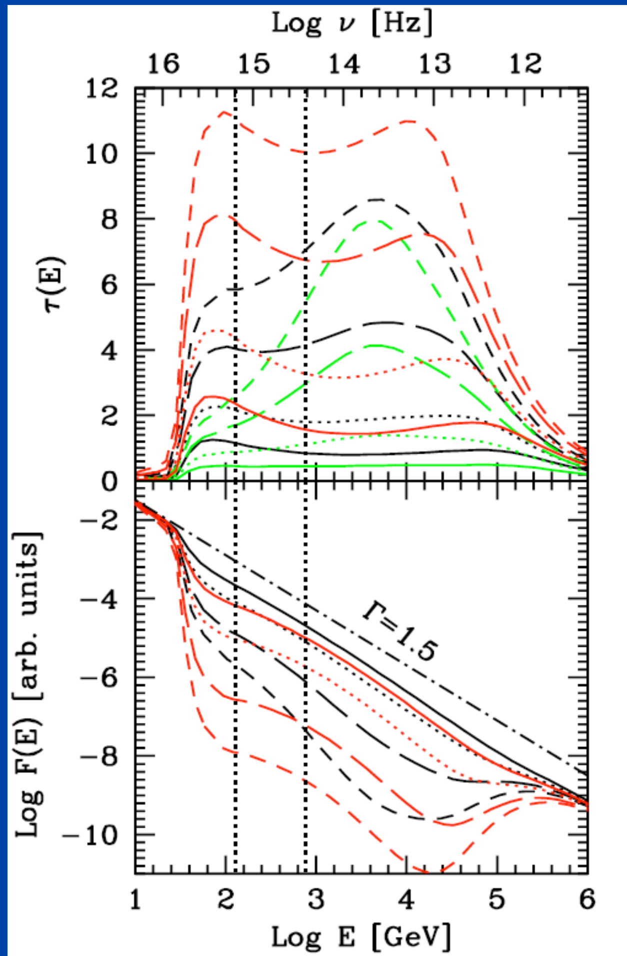
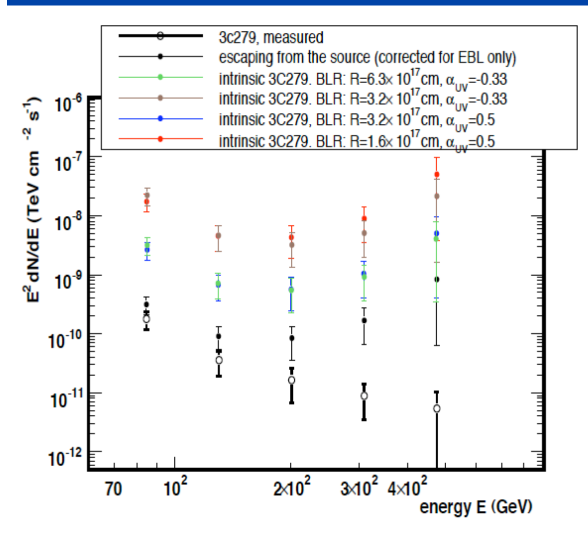








- BLR: spherical shell of thickness ΔR, negligible disk radiation
- Latest **CLOUDY** code, which includes not only lines but also continuum emission
- Moderate change of the VHE MAGIC spectrum
- No change of the EBL limits
- Details in **Tavecchio & Mazin, MNRAS 392 (2009) L40-L44**

D. M

With realistic Broad Line Regions and Disk re-emission: no change in the EBL limits

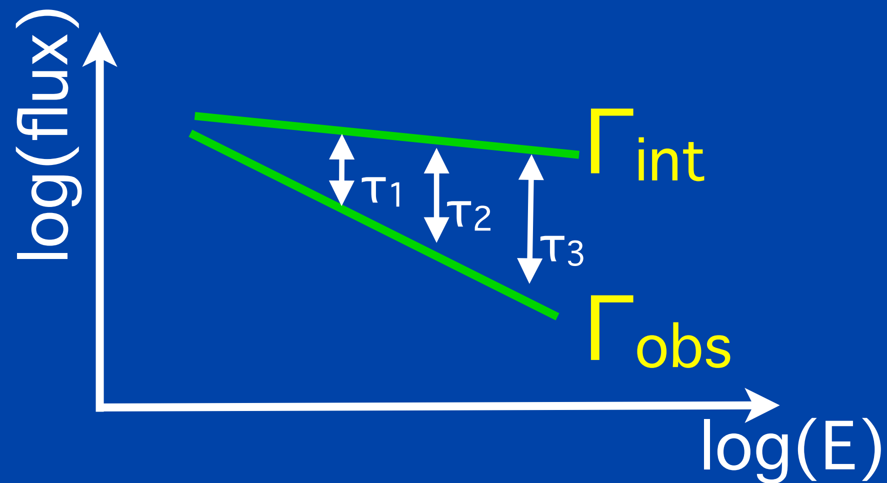
some more papers in last 2 years

- Finke, Justin D.; Razzaque, Soebur; ApJ (2009) 698, 1761-1766
- Georganopoulos, Markos; Finke, Justin D.; Reyes, Luis C., ApJL (2010) 714, L157-L161
- Mankuzhiyil, N., Persic, M., & Tavecchio, F. ApJL (2010) 715, L16-L20

Finke et al. ApJ (2009) 698, 1761-1766

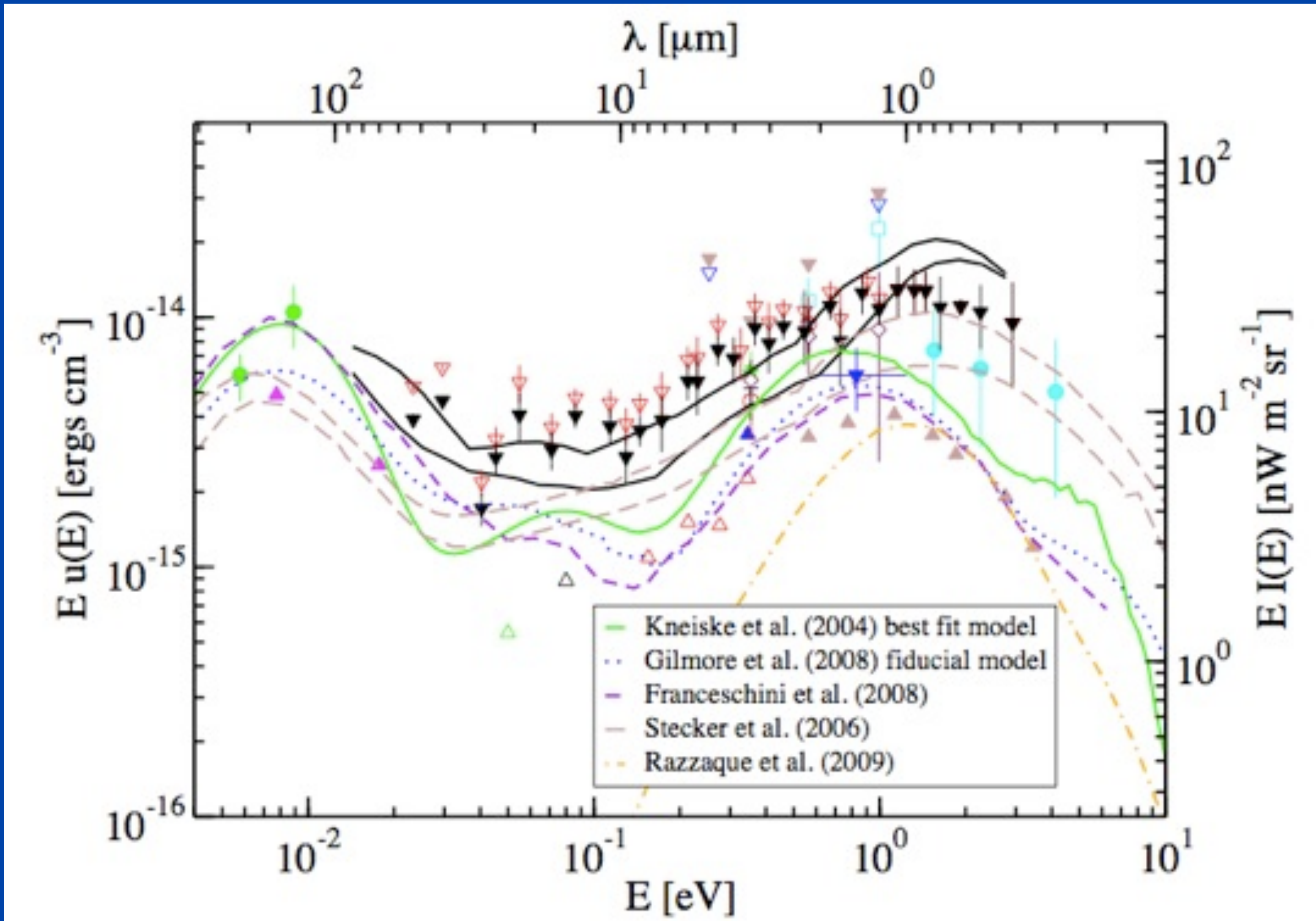
using Schroedter, M., ApJ (2005) 628, 617

- Fermi TeV BL Lacs indexes are 1.7-1.8, i.e. Γ=1.5 is safe (Γ=1.0 extreme)
- Assuming:
  - Observed and intrinsic spectra can be described by power laws with different photon indexes
  - EBL absorption is monochromatic
  - No EBL evolution (valid for nearby sources)
- Derive limits on EBL density from each blazar for each flux point



$$\epsilon'_* u'^{max}_{EBL}(\epsilon'_*; z \approx 0) = \frac{64 m_e c^2 H_0}{3 c \sigma_T z \bar{\phi}(2) \epsilon_1} \times \tau^{max}_{\gamma\gamma}(2/\epsilon'_*, z \approx 0)$$

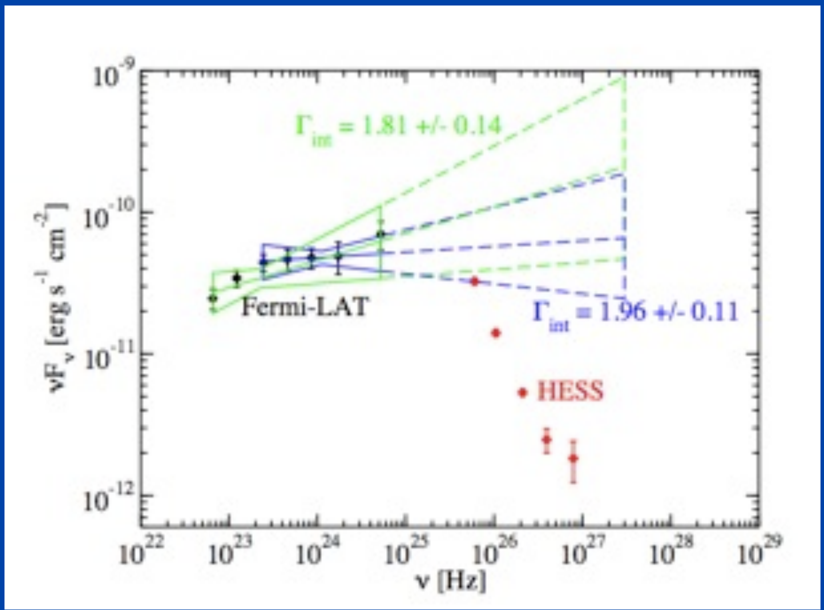
Finke et al. ApJ (2009) 698, 1761-1766

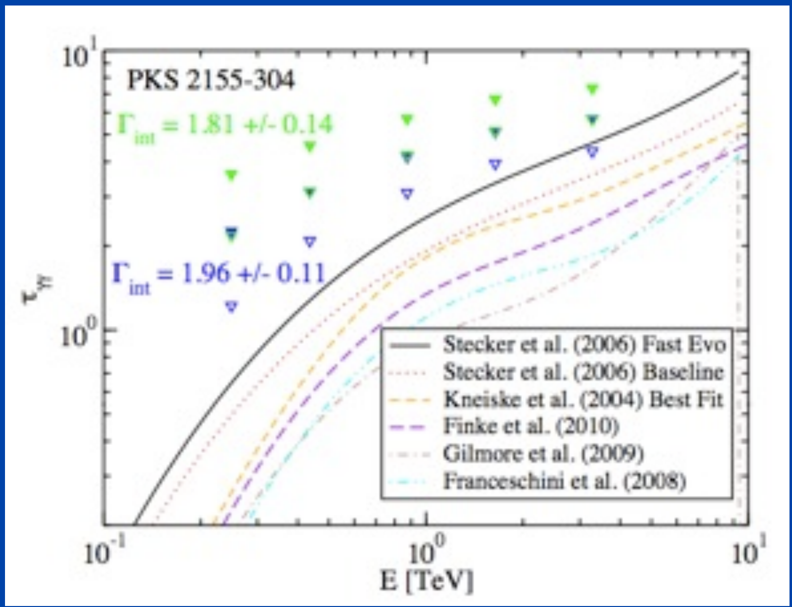


Wednesday, December 15, 2010

Georganopoulos, M. et al., ApJL (2010) 714, L157

- Extrapolate Fermi spectra into VHE band since it is un-attenuated in the LAT energy range
- Calculate max optical depth as a difference between the measured flux and the extrapolated one





Mankuzhiyil, N., Persic, M., & Tavecchio, F. ApJL (2010) 715, L16-L20

- Assume SSC model works for HBLs
- Take PKS2155 as an example
- multiwavelength SED fitting using χ2
- Derive optical depth (τ) from the best fit and also the uncertainty.