Formation Of Hard Very High Energy Gamma-Ray Spectra Of Blazars Due To Internal Photon-Photon Absorption

Aharonian F. A., Khangulyan D., & Costamante L.
MNRAS, 387, 1206(2008)

May 14, 2009

Why do we need the internal absorption?

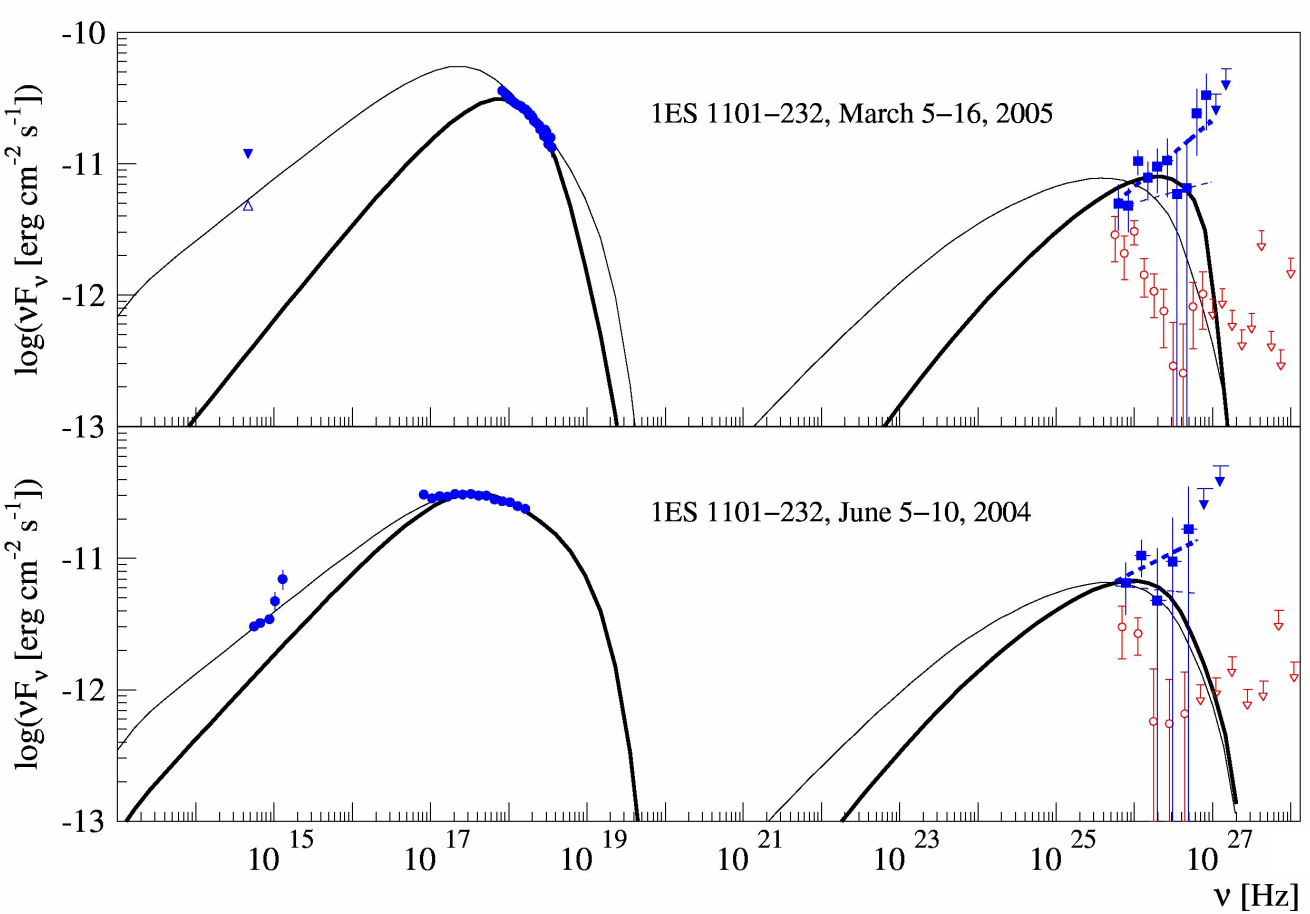
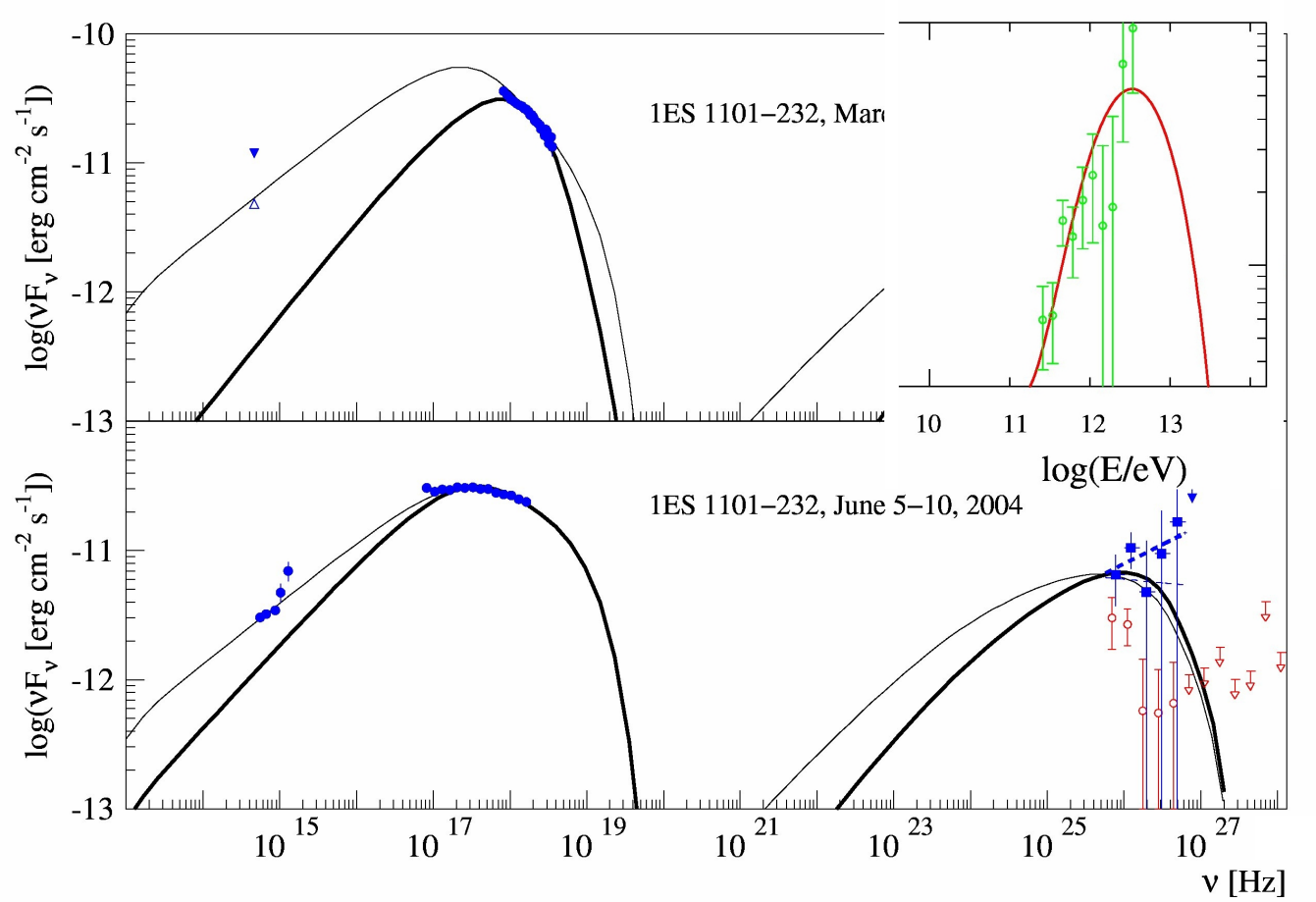


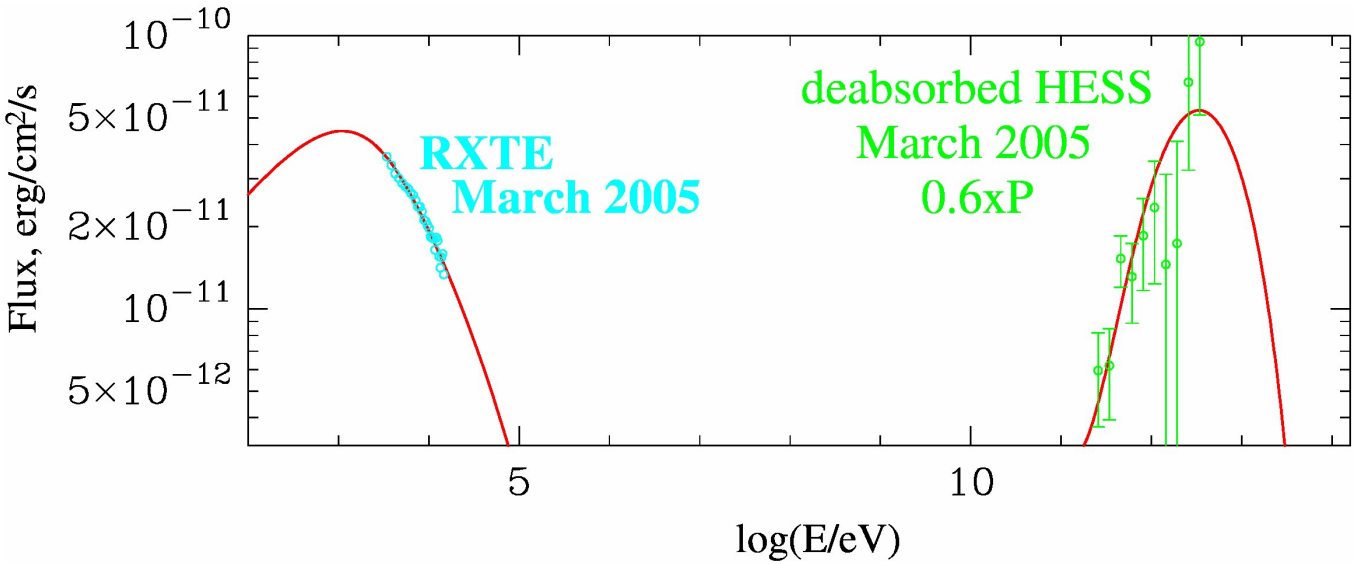
Figure: From 1ES 1101-232 Detection Paper (HESS, *A&A*,2007)

Why are we interested in the internal absorption?



With internal absorption correction

Common model for X-ray and TeV data?



The X-ray hump is not produced by the primary particles, but that is synchrotron emission of the gamma-gamma created pairs

Gamma-gamma absorption and AGN

- The VHE gamma-ray may be absorbed (e.g. Nikishov 1962)

$$\gamma + \epsilon_{\mathrm{EBL}} \Rightarrow e^{+} + e^{-}$$

- Direct measurements of EBL (e.g. Hauser&Dwek 2001) are complicated
- Theoretical predictions (e.g. Primack et al 2005, Franceschini et al 2008) are not robust

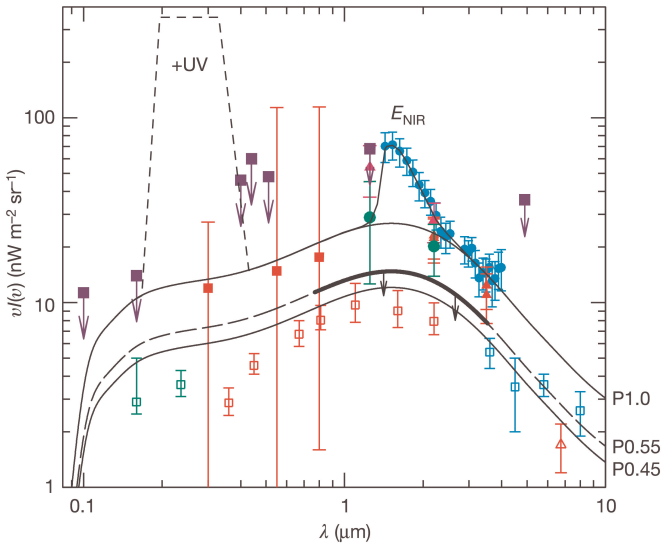


Figure: From HESS EBL paper (*Nature, 2006*)

EBL Correction of VHE Spectra

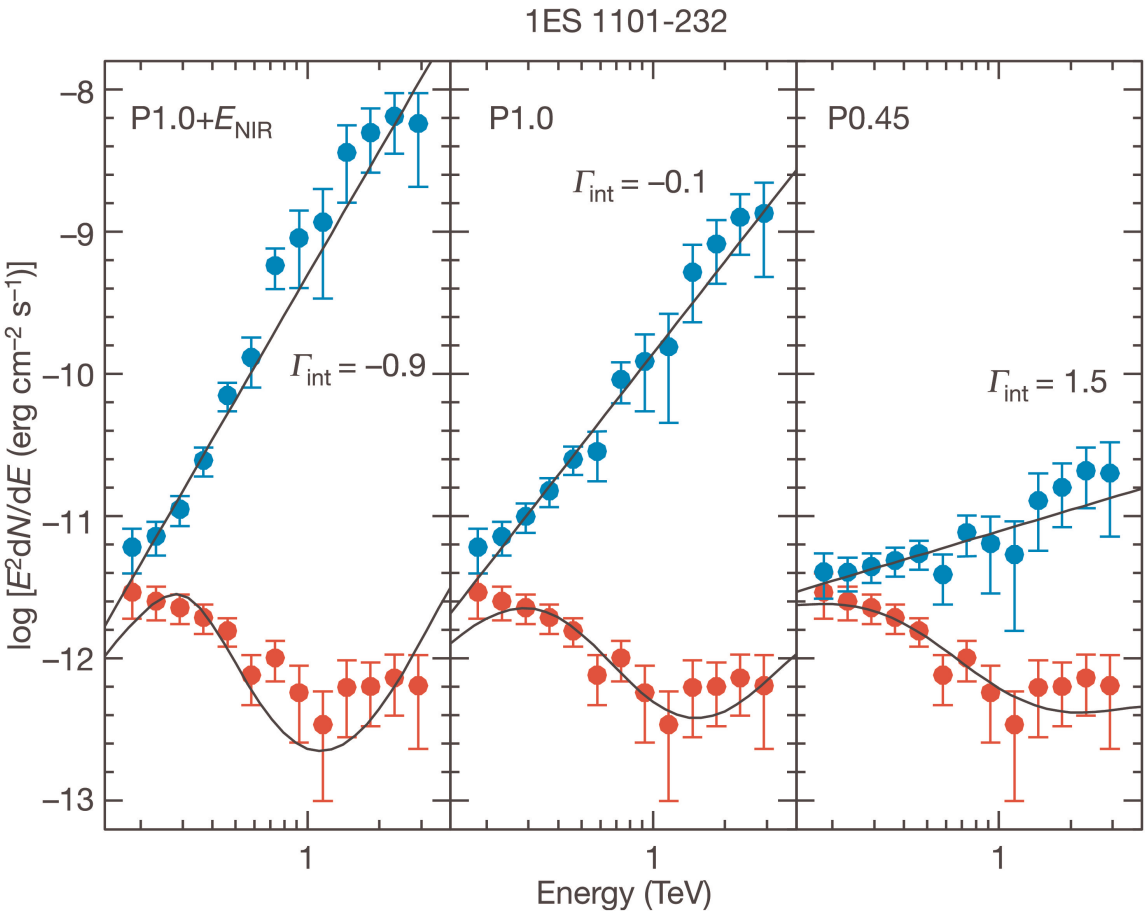


Figure: From HESS EBL paper (*Nature, 2006*)

EBL Crises?

- Hard intrinsic spectra? (e.g. Katarzynski et al 2006, Böttcher 2008, Tavecchio et al 2009)
- Lorentz invariance violation? (e.g. Kifune 1999)
- Oscillation of gamma-ray?
- Additional absorption?

EBL Crises: Hard Intrinsic Spectra?

(see Böttcher 2008, Tavecchio et al 2009)

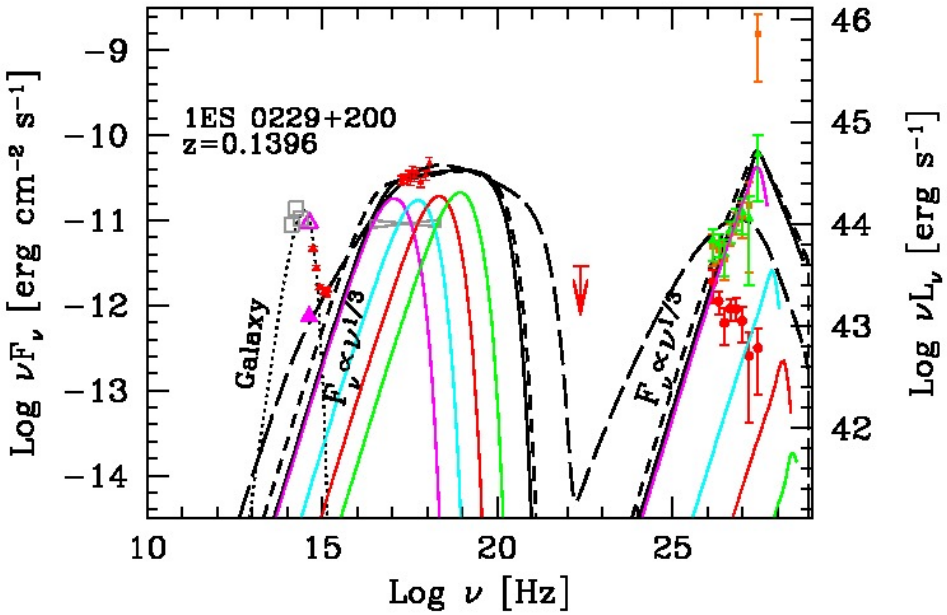


Figure: From Tavecchio et al 2009

EBL Crises: Hard Intrinsic Spectra?

This scenarios may produce hard intrinsic TeV spectra with photon indexes up to 1.5 (Böttcher, 2008) and 2/3 (Tavecchio et at, 2009). But

- Levenson& Wright, ApJ(2008) moved the lower limit at $3.6\mu\mathrm{m}$ from $5.4\mathrm{nW}/\mathrm{m}^2/\mathrm{sr}$ to $9.0 + 1.7 - 0.9\mathrm{nW}/\mathrm{m}^2/\mathrm{sr}$. This requires harder intrinsic spectra (see also Krennrich et al, 2009)
- Both scenarios require very slow cooling regime $\Longrightarrow$ NO VARIABILITY

Internal Absorption

The γ–γ optical depth

$$\tau = \int dl \int d\epsilon \sigma \, n_{\rm ph}$$

The cross section

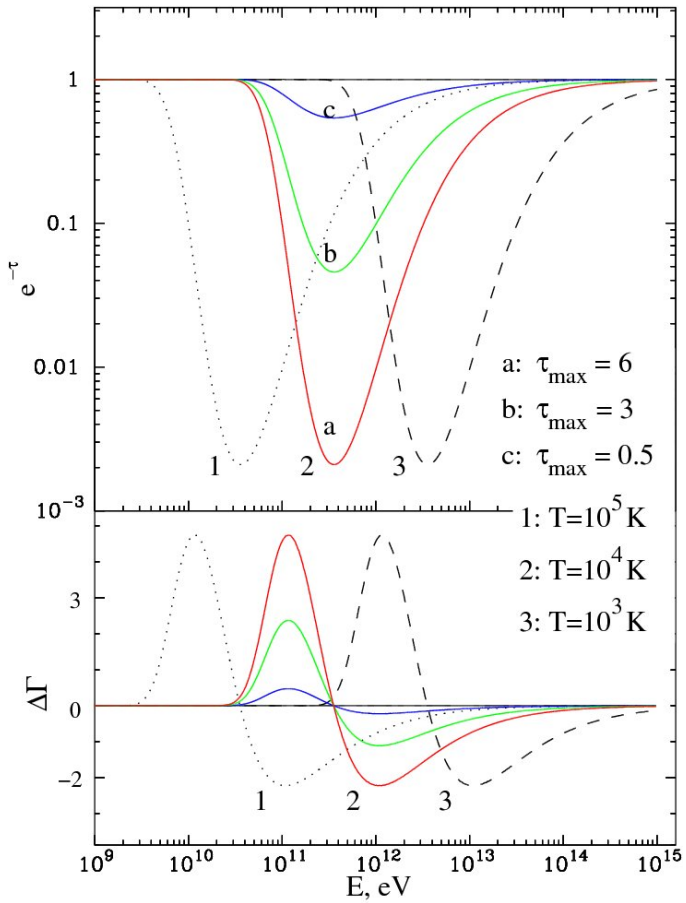
$$\sigma_{\rm max} \sim 0.2\sigma_{\rm T} \quad @ \quad E_\gamma \epsilon \sim 1{\rm TeV}\,1{\rm eV}$$

Thus the photon density

$$n \sim 4 \cdot 10^8 \tau_5 R_{17}^{-1} \quad [{\rm cm}^{-3}]$$

Luminosity

$$L = 2 \cdot 10^{43} \tau_5 R_{17} E_{0.1}^{-1} \quad [{\rm erg/s}]$$



Internal Absorption+EBL

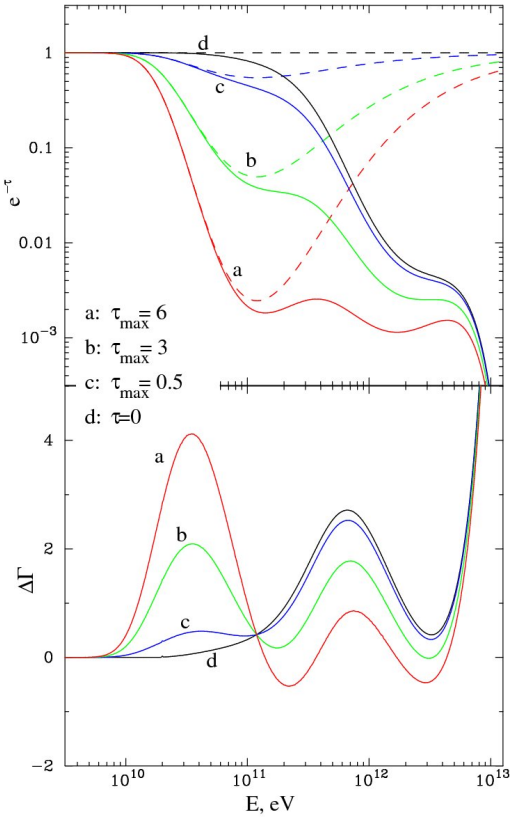


Figure: P0.7

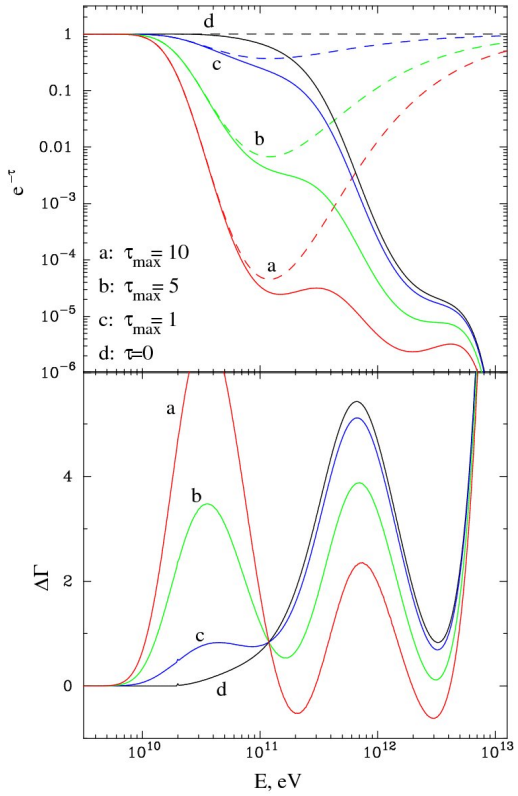


Figure: P1.4

Electromagnetic Cascade

pair production

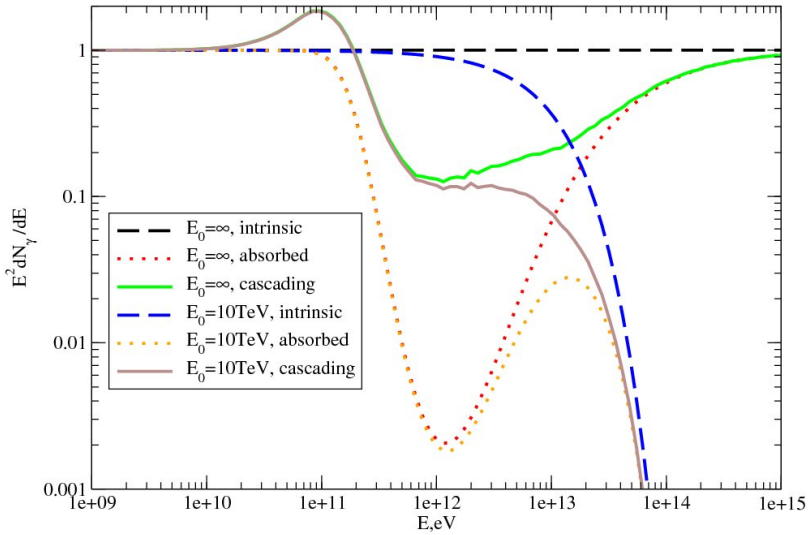
$$\gamma + \epsilon \longrightarrow e^+ + e^-$$

IC scattering

$$e^{\pm} + \epsilon \longrightarrow \gamma + e^{\pm}$$

Suppress the EMC!

- Absorption outside the production region
- Strong B-field



Radiative Mechanisms

- Leptons (if B-field is weak)
- *pp*

$$t_{\rm pp} = 10^{15} n^{-1} \Rightarrow n \sim 5 \cdot 10^{12} \delta^{-1} \Rightarrow E_{\rm kin} \sim 10^{55}\ {\rm erg}$$

- $p\gamma$

$$\frac{\sigma_{\rm p\gamma}}{\sigma_{\gamma\gamma}} = 10^{-3} \Rightarrow \gamma \gg 10 \,{\rm and}\, F_\nu \sim 10^{-11}\ {\rm cm^{-2} s^{-1}}$$

- p-synchrotron

$$B \gg 10\ {\rm G} \Longrightarrow E_{\rm B} \sim 2 \cdot 10^{48} {\rm erg}$$

$$E_\gamma \lesssim 10\,{\rm TeV}$$

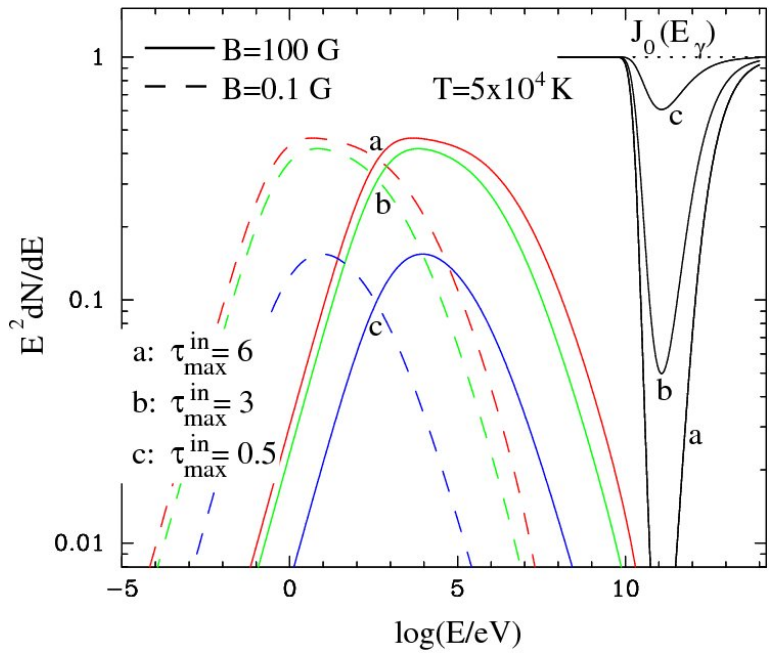
Does the scenario require a bigger energy budget?

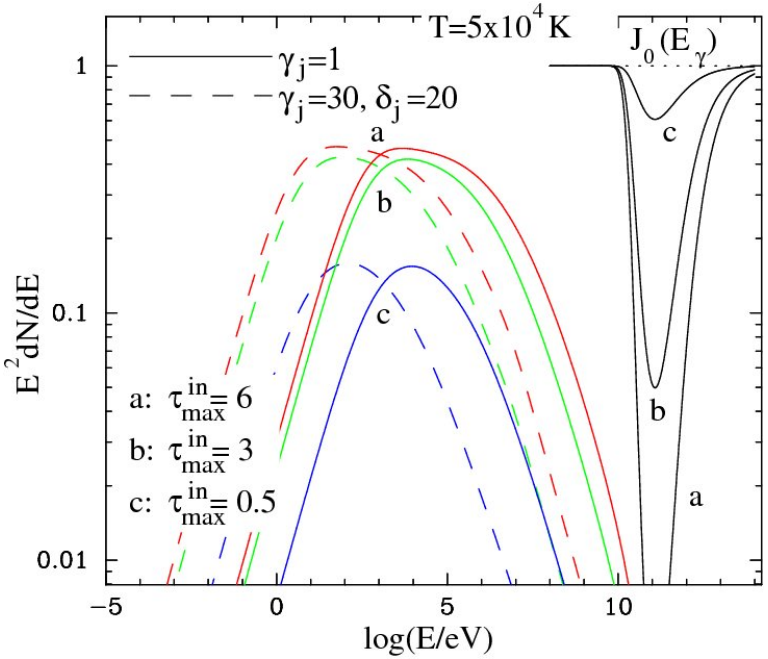
- YES
  The internal absorption may harder the VHE part of a spectra. This increase the energy budget by a factor $3 - 10$ only (not $e^{\tau_{max}}$!)
- NO
  If one is comparing the energy requirement for TWO models which explain the HARD intrinsic spectrum, then the internal absorption scenario requires rather SMALL energy budget!

Finally, $L \sim 10^{41}$ erg/s in M87 (HESS paper)

Radiation of Secondary Pairs

$$h\nu_{\max} \sim BT^{-2}\left(\frac{\delta}{\gamma^2}\right)$$





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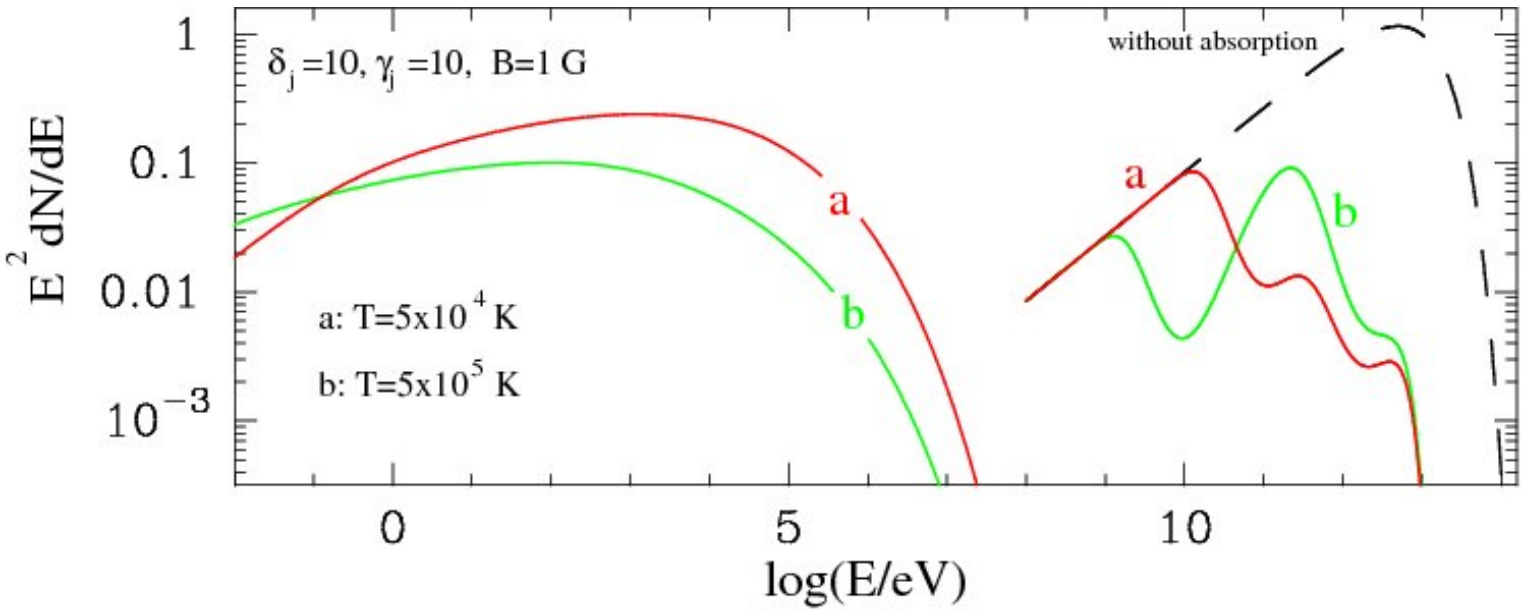

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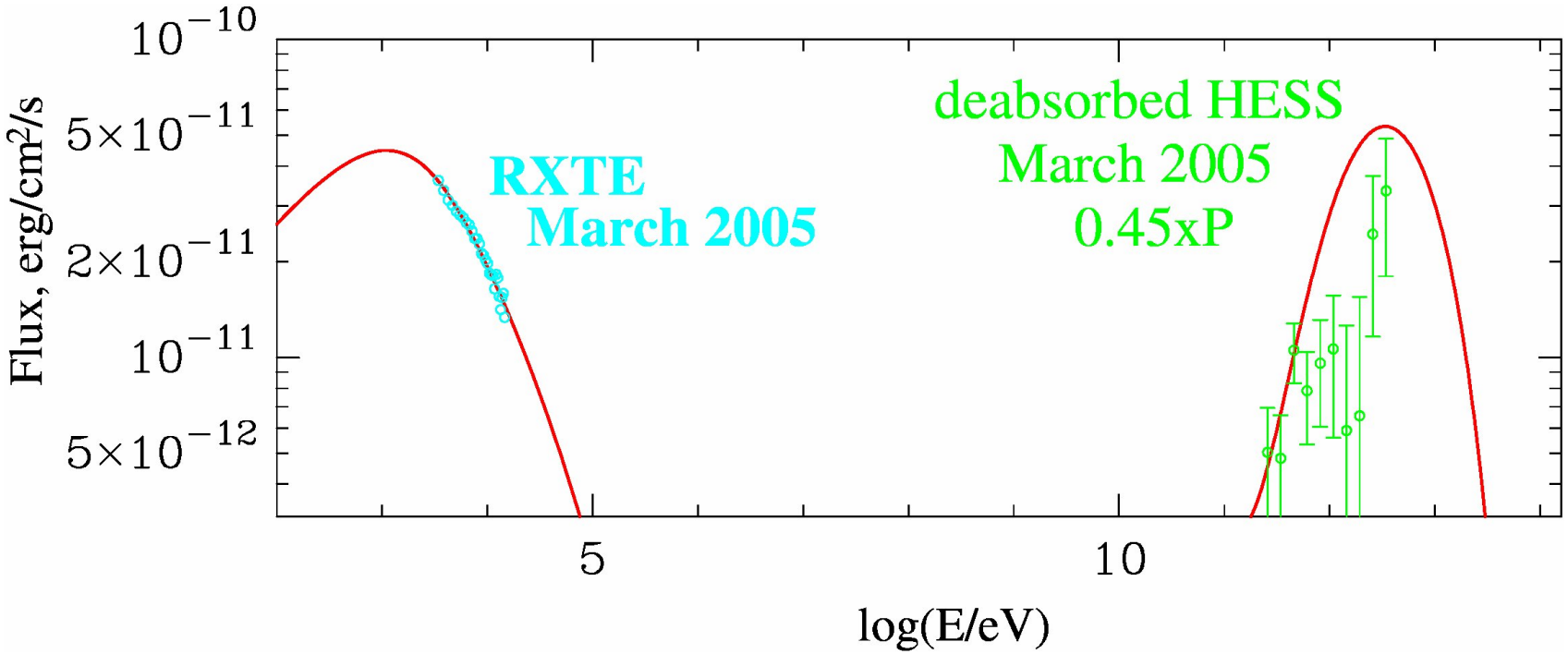

Figure: Intrinsic spectrum $E^{-2.5}e^{-E/1\,TeV}$

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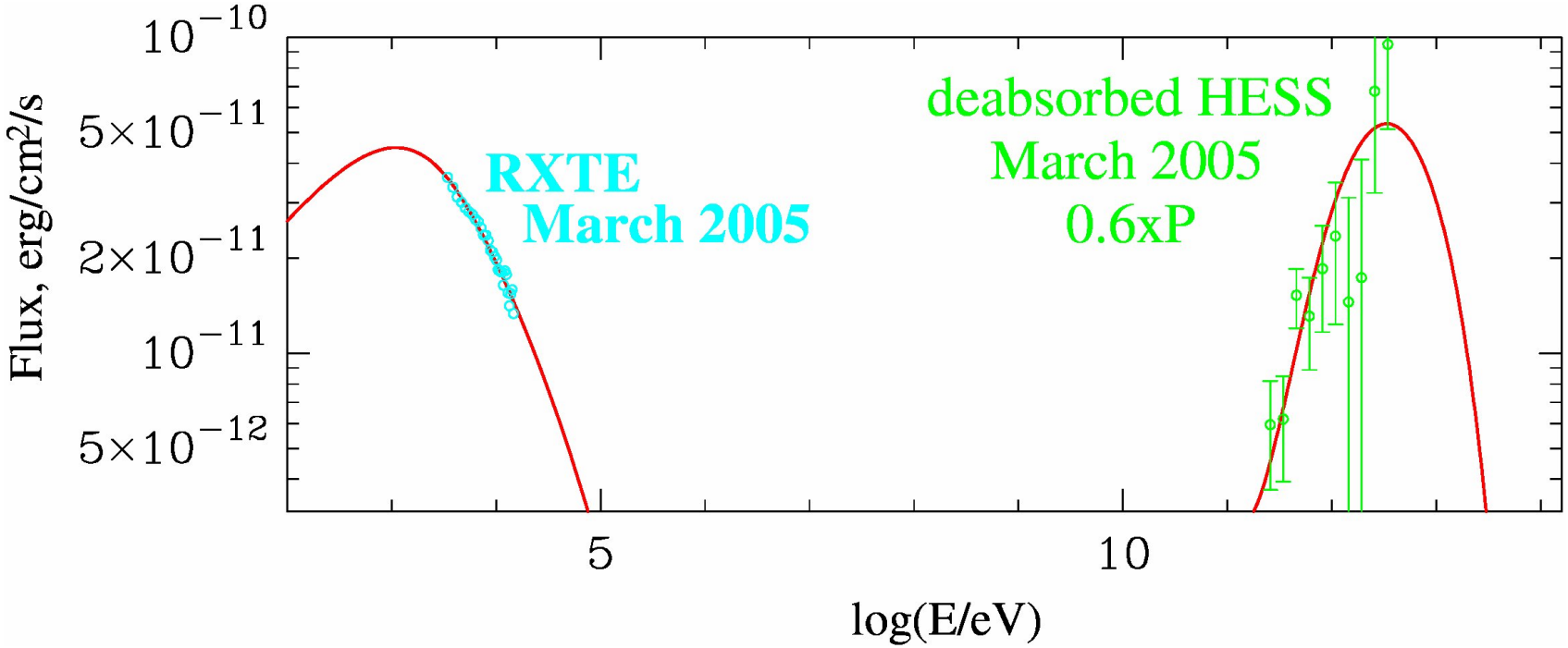

Figure: Intrinsic spectrum $E^{-2.5}e^{-E/1\,TeV}$

Summary

- Rather low luminosity target photon fields are sufficient for significant internal absorption. In some cases there are observational indications for presence of such fields(Urry and Padovani 1995; Celotti et al 1998; Pian et al 2005)
- Internal absorption may significantly harder the VHE spectrum
- If so: the constraints on ELB (HESS EBL paper; Mazin and Raue 2007) from VHE observations should be relaxed
- If so: the X-ray component may be explained as synchrotron radiation of secondary pairs