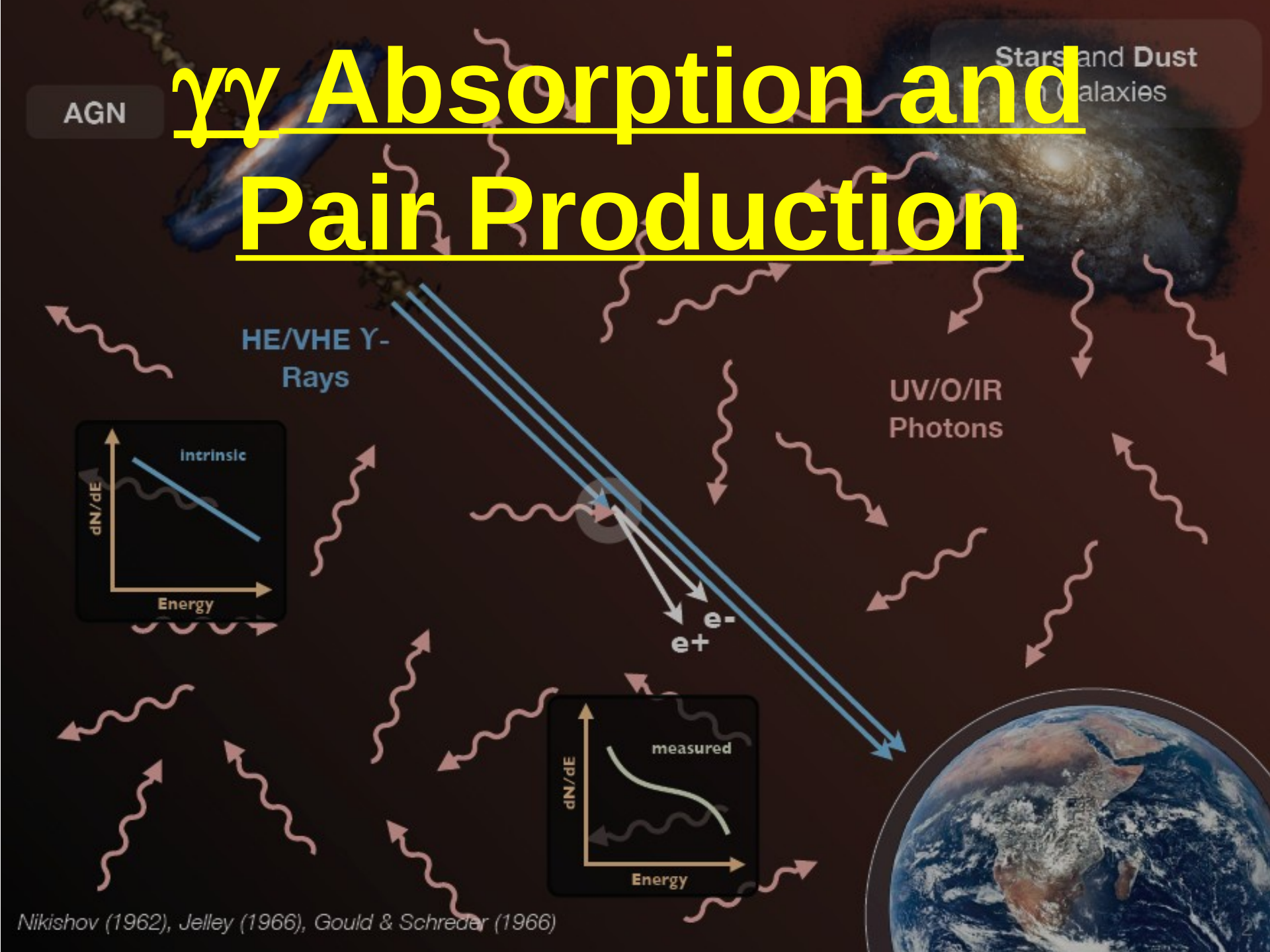
γγ Absorption and Pair Production

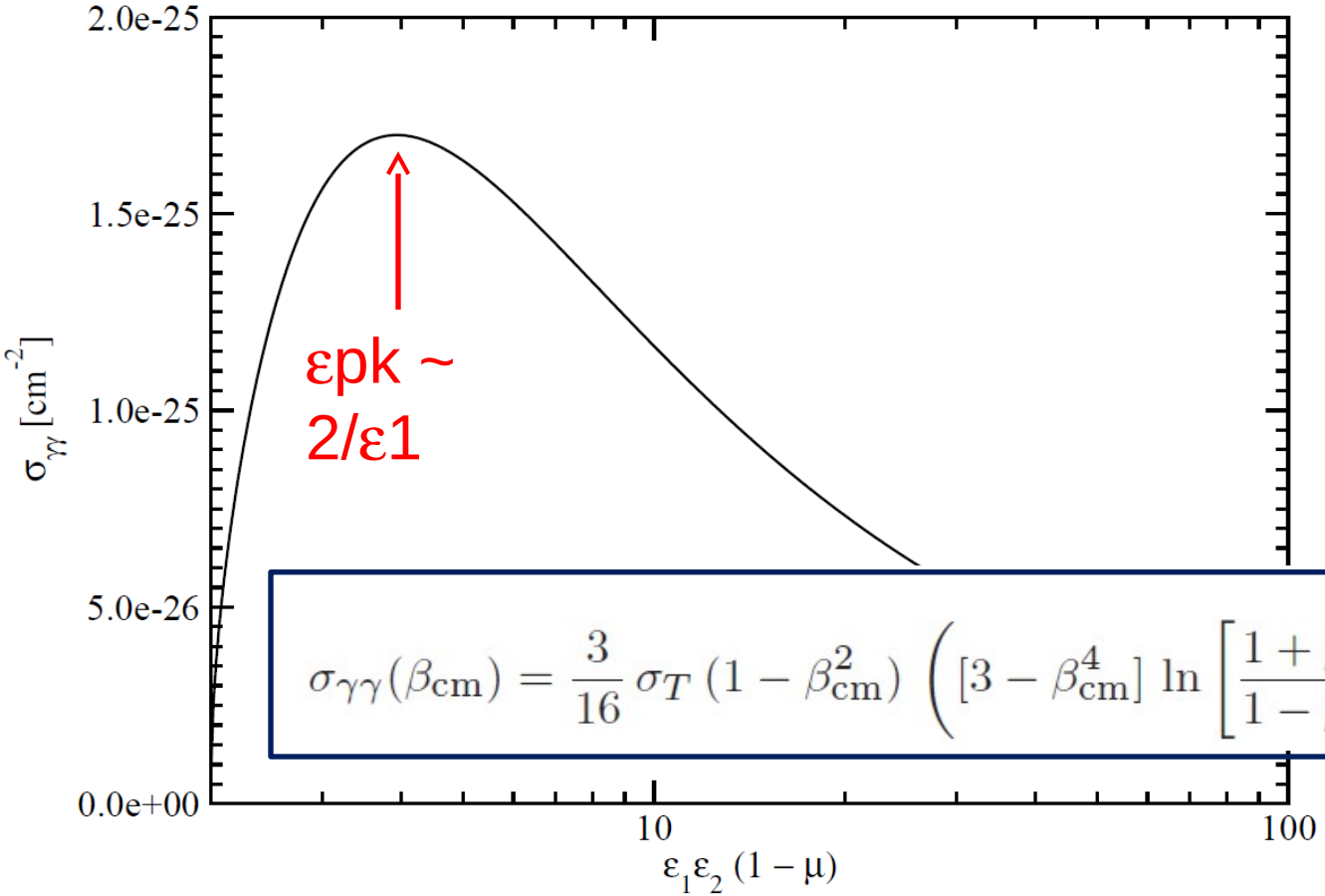


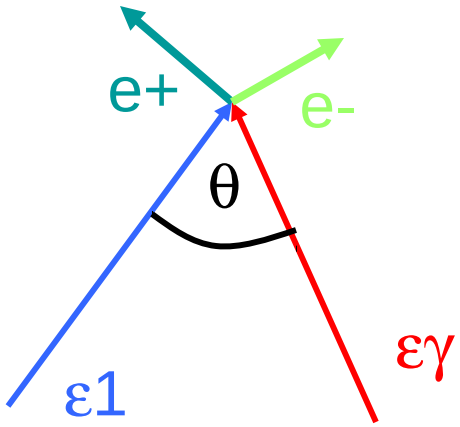
Nikishov (1962), Jelley (1966), Gould & Schreder (1966)

γγ Absorption and Pair Production

Threshold energy εthr of a γ-ray to interact with a background photon with energy ε1:

$$\varepsilon_{thr} = \frac{2}{\varepsilon_1 (1 - \cos\theta)}$$





$$\sigma_{\gamma\gamma}(\beta_{cm}) = \frac{3}{16}\,\sigma_T\,(1-\beta_{cm}^2)\left([3-\beta_{cm}^4]\,\ln\left[\frac{1+\beta_{cm}}{1-\beta_{cm}}\right] - 2\,\beta_{cm}\,[2-\beta_{cm}^2]\right)$$

$\gamma\gamma$ Absorption

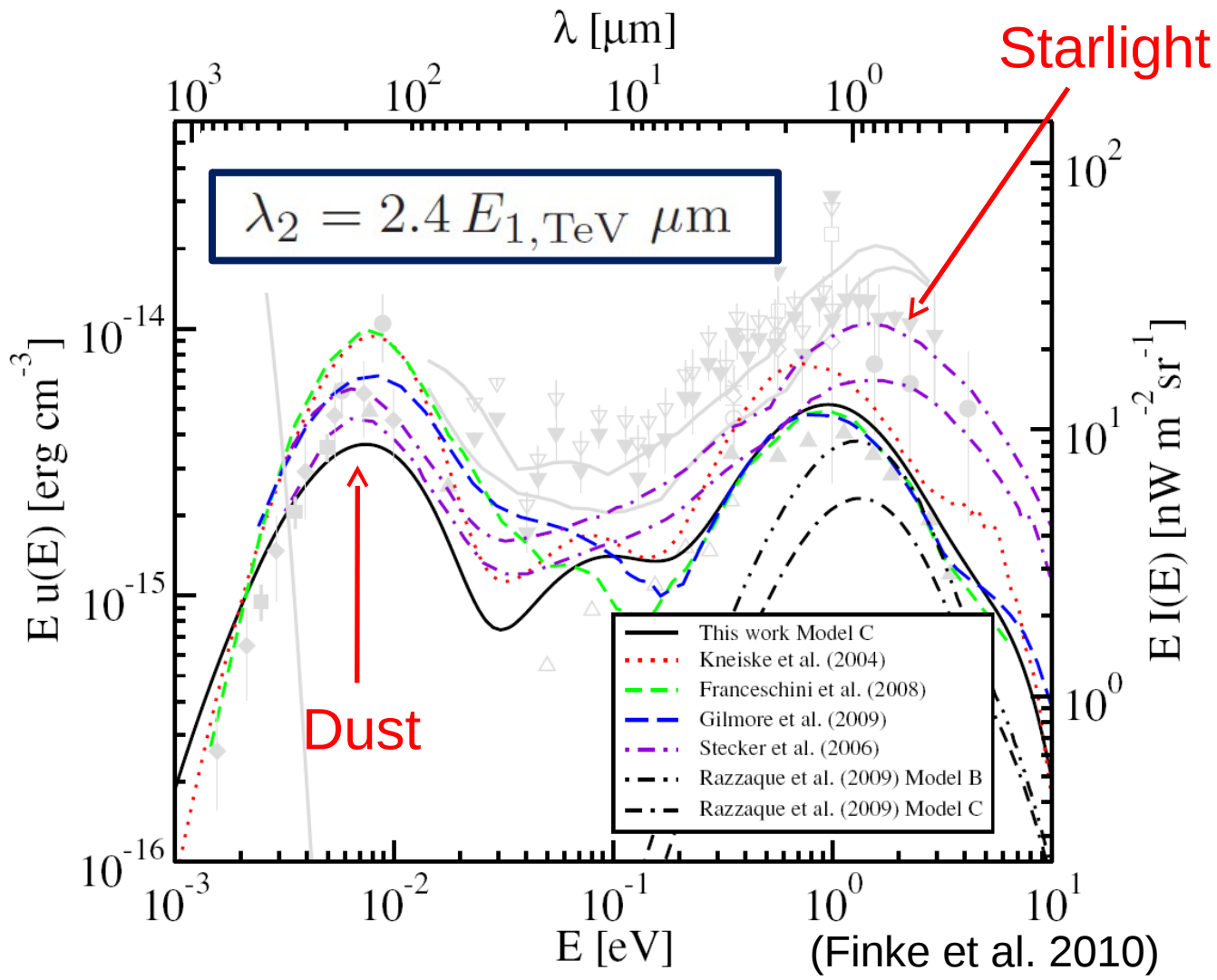
Delta-Function Approximation:

$$\sigma^{\delta}_{\gamma\gamma}(\epsilon_1, \epsilon_2) = \frac{1}{3}\,\sigma_T\,\epsilon_1\,\delta\left(\epsilon_1 - \frac{2}{\epsilon_2}\right)$$

VHE gamma-rays interact preferentially with IR photons:

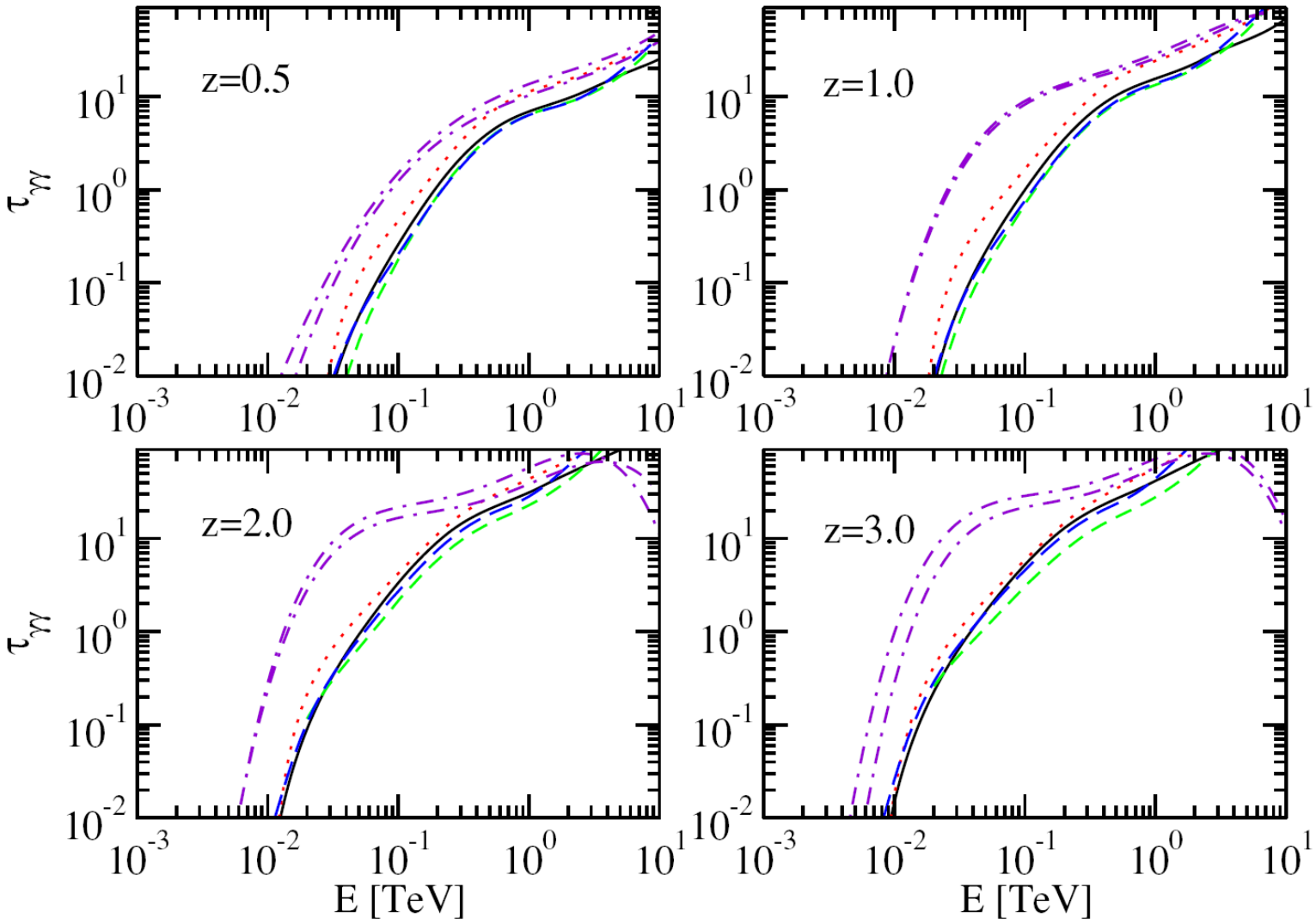
$$\lambda_2 = 2.4\,E_{1,\mathrm{TeV}}\ \mu\mathrm{m}$$

Spectrum of the Extrgalactic Background Light (EBL)



(Finke et al. 2010)

EBL Absorption



(Finke et al. 2010)

γγ Absorption Intrinsic to the Source

Importance of intrinsic γγ-absorption is estimated by the Compactness Parameter:

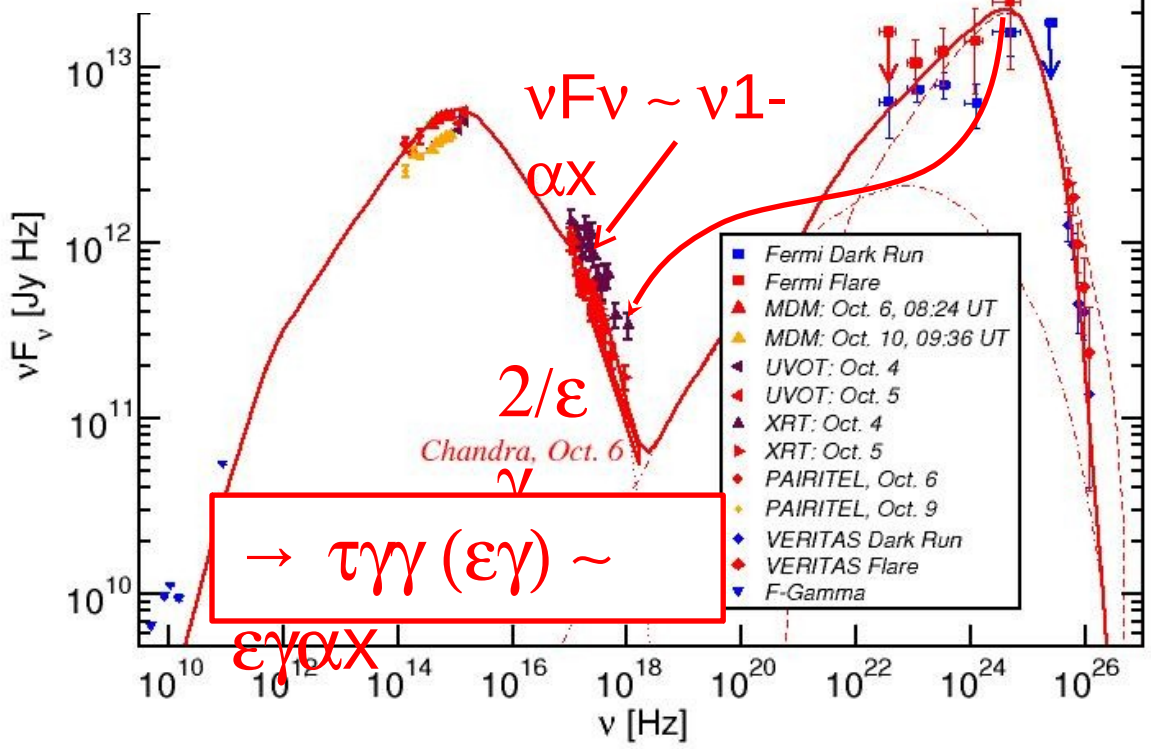
$$\ell = \frac{L_\gamma \, \sigma_T}{4 \, \pi \, R \, \langle \epsilon \rangle \, m_e c^3}$$

Radiation Transfer Equation gives:

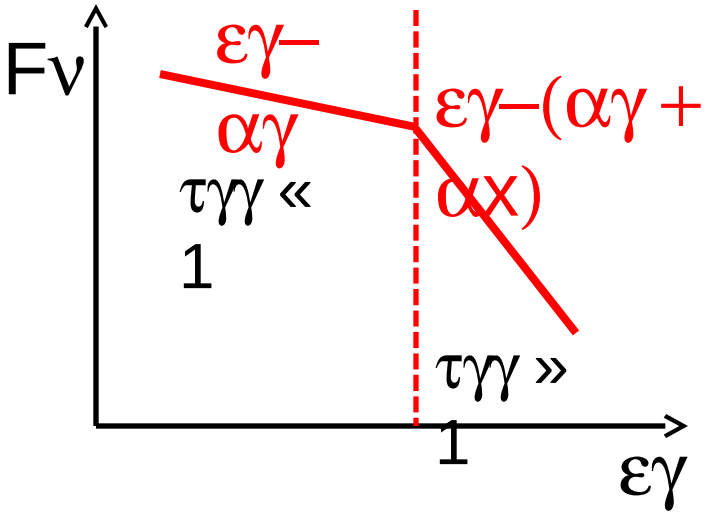
$$F_\nu^{\rm obs}(\epsilon) \approx F_\nu^{\rm int}(\epsilon) \, \frac{1 - e^{-\tau_{\gamma\gamma}(\epsilon)}}{\tau_{\gamma\gamma}(\epsilon)} \approx \begin{cases} \text{Fvint} & \text{if} \quad \tau\gamma\gamma \ll 1 \\ \text{Fvint} / \tau\gamma\gamma & \text{if} \quad \tau\gamma\gamma \gg 1 \end{cases}$$

γγ-Absorption Internal to the Source

$$\sigma^{\delta}_{\gamma\gamma}(\epsilon_1,\epsilon_2) = \frac{1}{3}\,\sigma_T\,\epsilon_1\,\delta\left(\epsilon_1 - \frac{2}{\epsilon_2}\right)$$



Break in the γ-ray spectrum at (or beyond) energy εγ → Limit on Doppler factor!



$$\delta \approx \left(10^{3\,\alpha_X}\,\frac{\sigma_T\,d_L^2}{3\,m_e\,c^4\,t_{\rm var}^{\rm obs}}\,F_{0-1}\,\frac{1-\alpha_X}{\epsilon_1^{1-\alpha_X}-\epsilon_0^{1-\alpha_X}}\,[1+z]^{2\,\alpha_X}\,E_{\rm GeV}^{\alpha_X}\right)$$

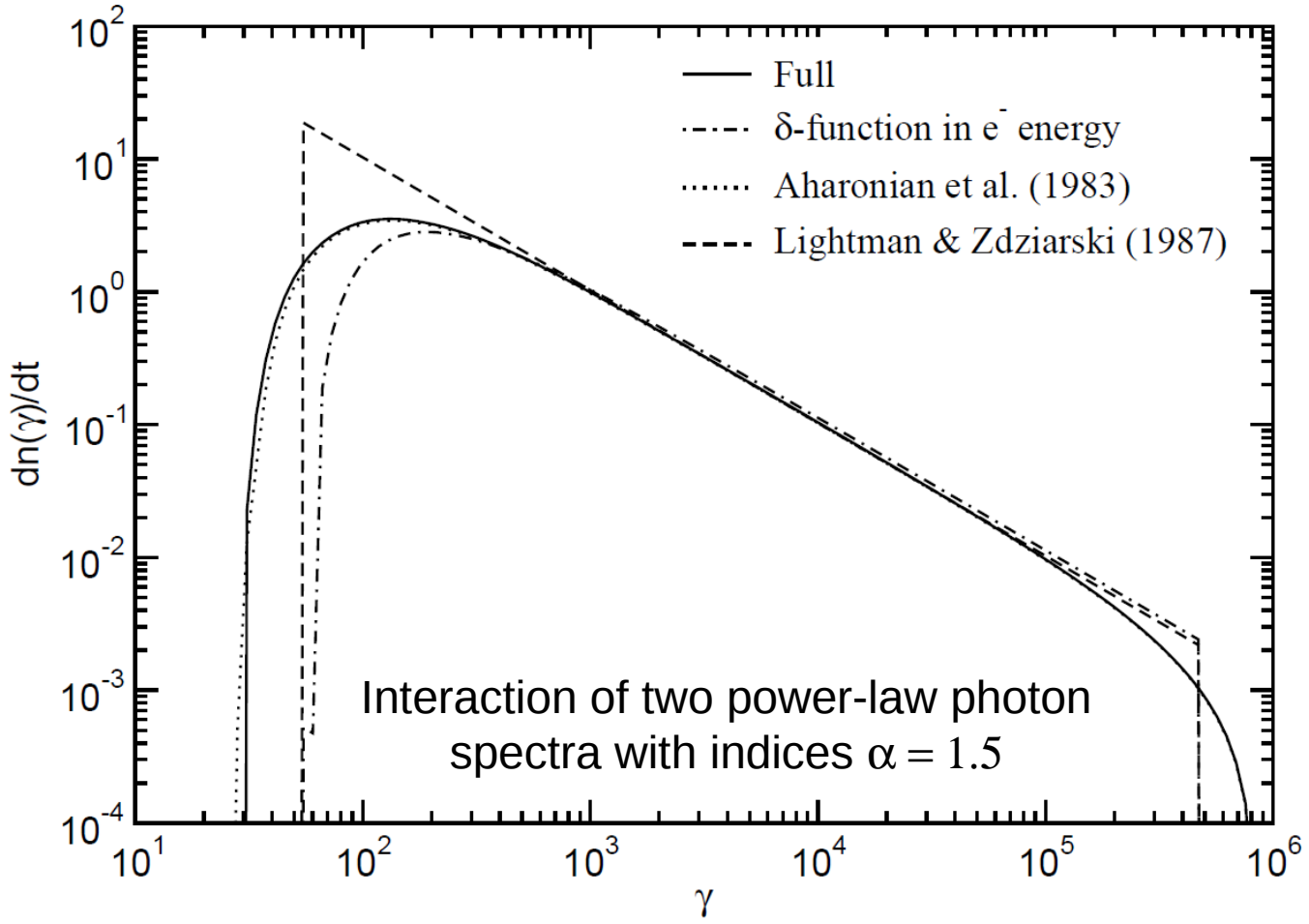
Pair Production Spectrum

Simplest approximation:

$\gamma+ = \gamma- = (\varepsilon 1 + \varepsilon 2)/2$

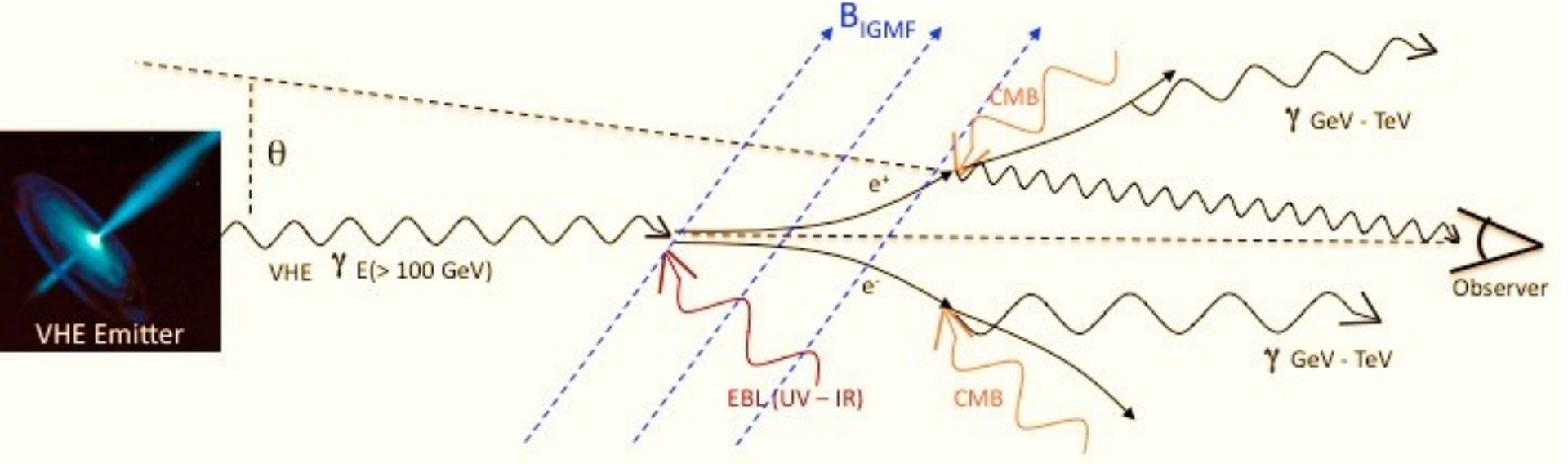
$$\dot{n}(\gamma)^{\mathrm{LZ}} \approx \eta(\alpha')\, c\, \sigma_T\, \frac{n_1(\epsilon_0)}{\epsilon_0}\, n_2\left(\frac{1}{\epsilon_0}\right)$$

$(\varepsilon 0 = 2\gamma)$



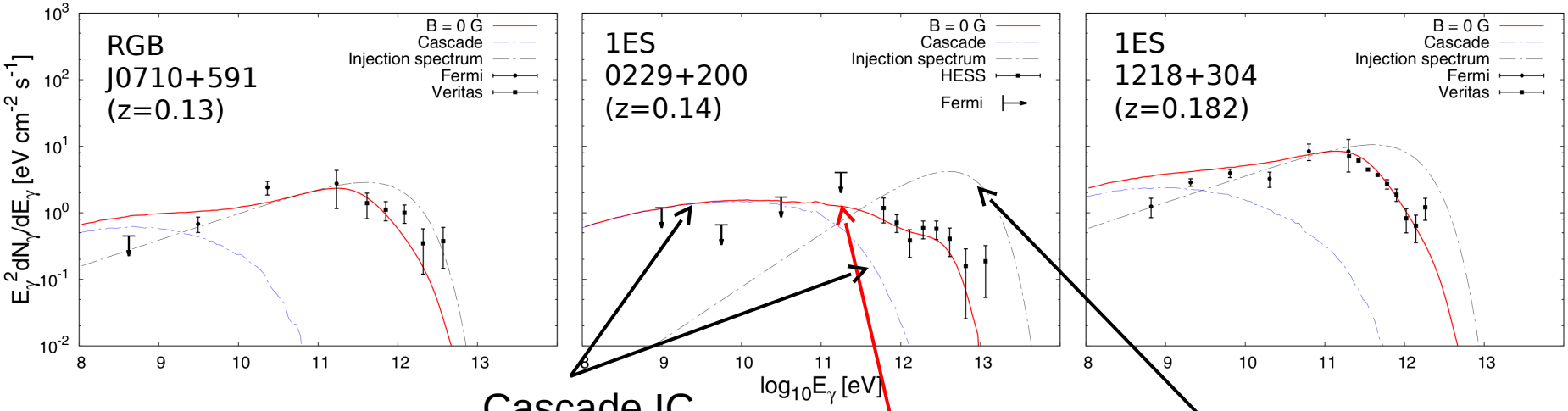
Pair Cascades

- The produced e+/e- may have enough energy to radiate new γ-rays (Compton), possibly with enough energy to be subject to γγ-absorption + pair production …



- (Deflected) IC cascades may be detectable in GeV γ-rays, lead to extended halos -> Limits on B-field

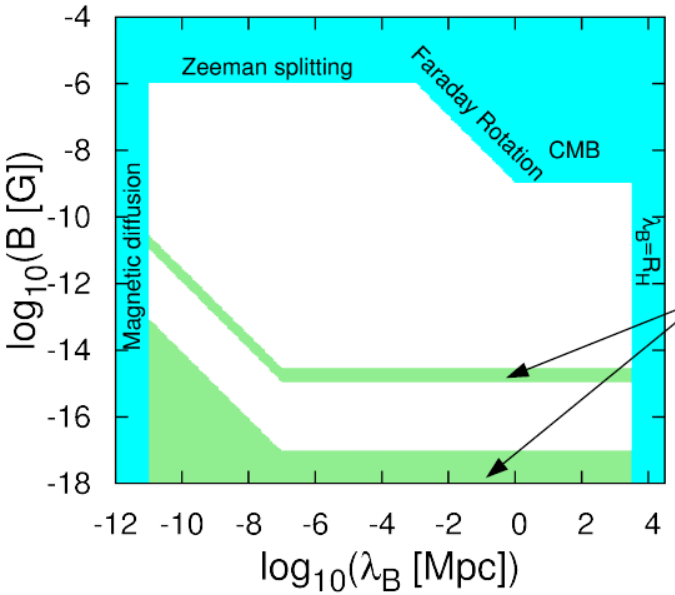
Magnetic-Field Limits



Cascade IC emission

EBL-absorbed γ-ray spectrum + cascade IC emission

Unabsorbed γ-ray spectrum



New exclusion regions from Blazar measurements

Several VHE (> 100 GeV) γ-ray blazars are not detected by Fermi (100 MeV – 100 GeV γ-rays)!