Photon-ALP conversions inside AGNs

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Outline

Introduction: photon-ALPs conversion in blazars

The blazar environment: jet, galaxy, cluster

Results

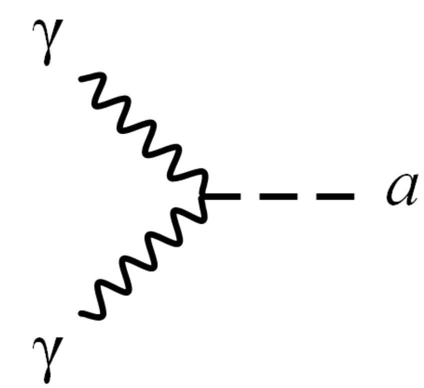
ALPs: Motivations

- Axion: pseudo-scalar boson expected in the PQ mechanism for solving the "strong CP problem"
- Axion-like particles (ALPs): light (pseudo)scalar particles expected in several extensions of SM
- Possible DM candidate.

Beyond the SM at low energies

ALPs: phenomenology

The ALP Lagrangian:



mass

$\equiv g_{a\gamma\gamma}$

$$\mathcal{L}^0_{\rm ALP} = \frac{1}{2}\,\partial^\mu a\,\partial_\mu a - \frac{1}{2} m^2 a^2 + \frac{1}{M}\mathbf{E}\cdot\mathbf{B}\,a\ ,$$

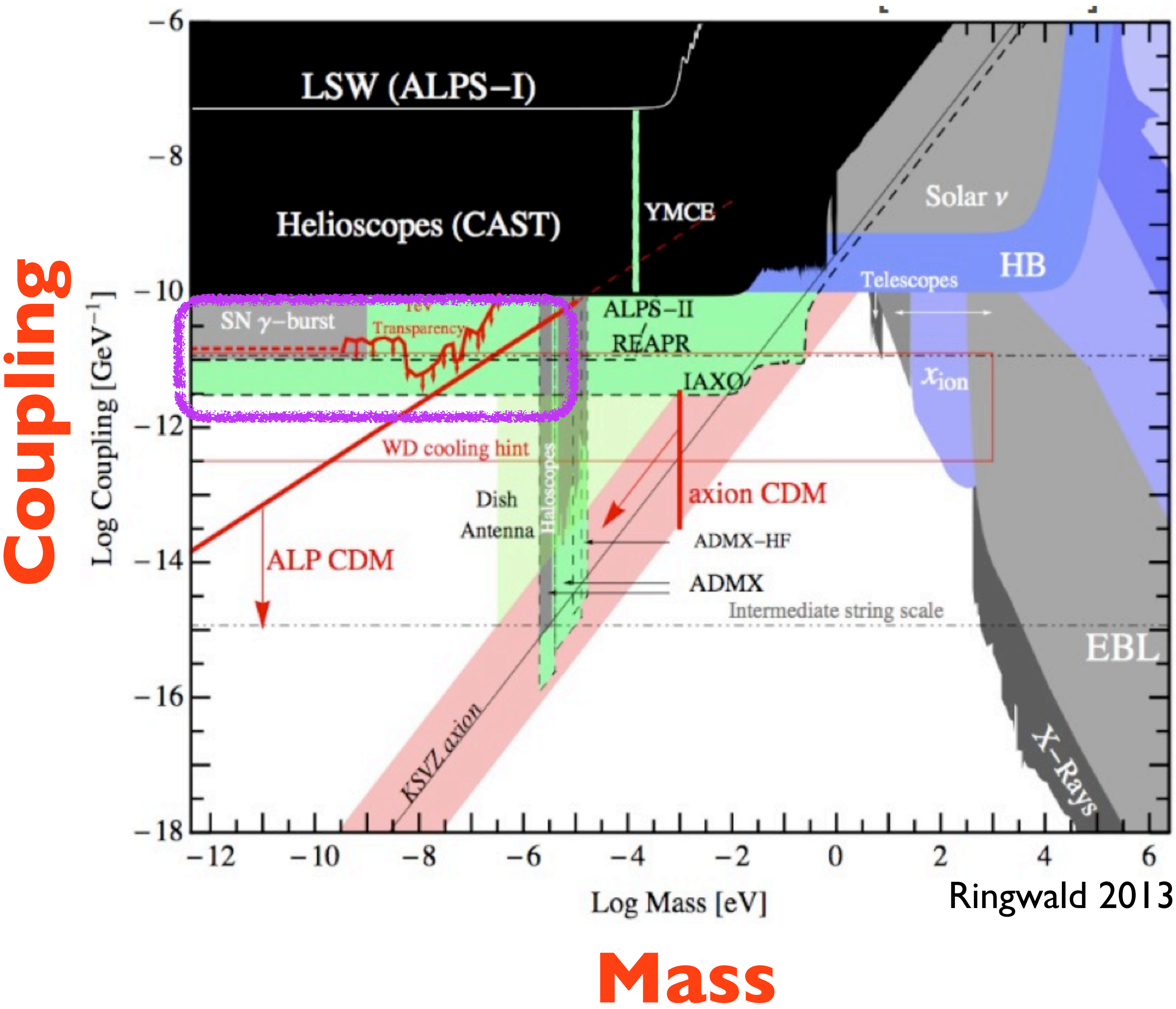
coupling term

In the following
$m=10^{-9}$ eV
$M=10^{11}$ GeV

Only the "transverse" B-field relevant for conversion

Only 1/2 of unpolarized photons couples to ALPs

ALPs: phenomenology



Ringwald 2013

In the following
$m=10^{-9}$ eV
$M=10^{11}$ GeV

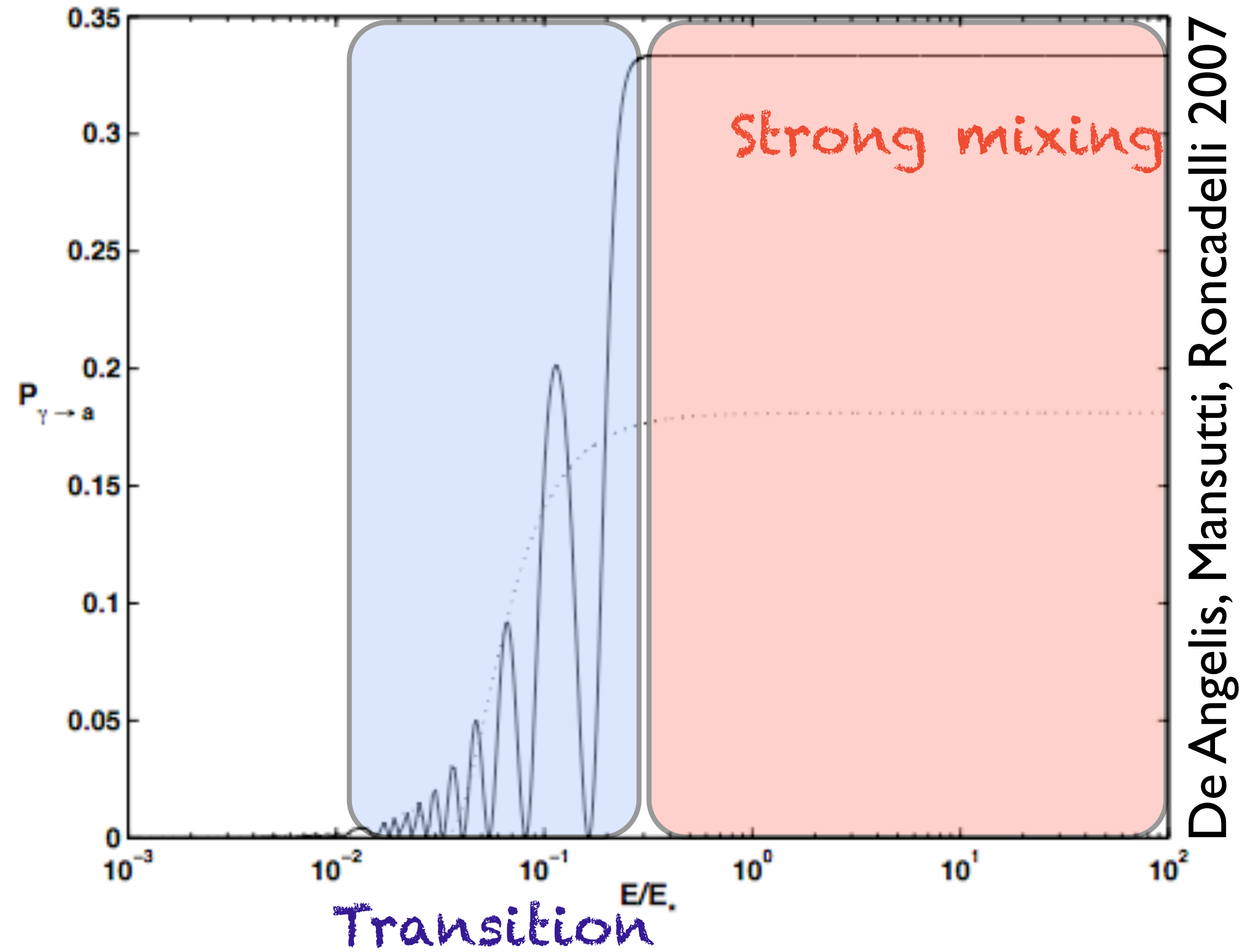
ALPs: phenomenology

Photon-ALP conversion in a B-field

$$P_{\gamma \to a}(E) = \left(\frac{g_{a\gamma\gamma} B_T}{\Delta_{\rm osc}(E)} \right)^2 \sin^2 \left(\frac{\Delta_{\rm osc}(E)\, y}{2} \right)$$

$$\Delta_{\rm osc}(E) \equiv \left[\left(\frac{m^2 - \omega_{\rm pl}^2}{2E} \right)^2 + g_{a\gamma\gamma}^2 B_T^2 \right]^{1/2}$$

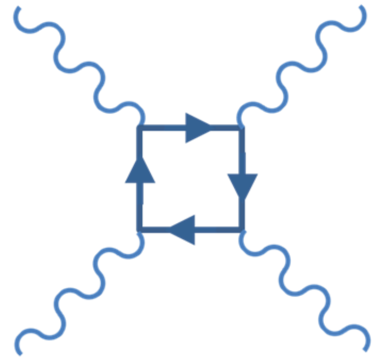
Strong mixing regime:
P maximal and E-independent



$$E_L \simeq 25 \left| \left(\frac{m}{10^{-10}\,{\rm eV}} \right)^2 - 0.13 \left(\frac{n_e}{{\rm cm}^{-3}} \right) \right| \left(\frac{G}{B_T} \right) \left(\frac{M}{10^{11}\,{\rm GeV}} \right) {\rm eV}$$

ALPs: phenomenology

Vacuum polarization
QED effect



Effective lagrangian: $\mathcal{L}_{\rm HEW} = \frac{2\alpha^2}{45 m_e^4} \left[\left(\mathbf{E}^2 - \mathbf{B}^2 \right)^2 + 7 \left(\mathbf{E} \cdot \mathbf{B} \right)^2 \right]$

Dominates above: $E_H \simeq 2.1 \left(\frac{G}{B_T} \right) \left(\frac{10^{11}\ \mathrm{GeV}}{M} \right) \mathrm{GeV}$

Not relevant for small (<10^{-6} G) B in clusters/ intergalactic space but not negligible in jets (B~1 G)

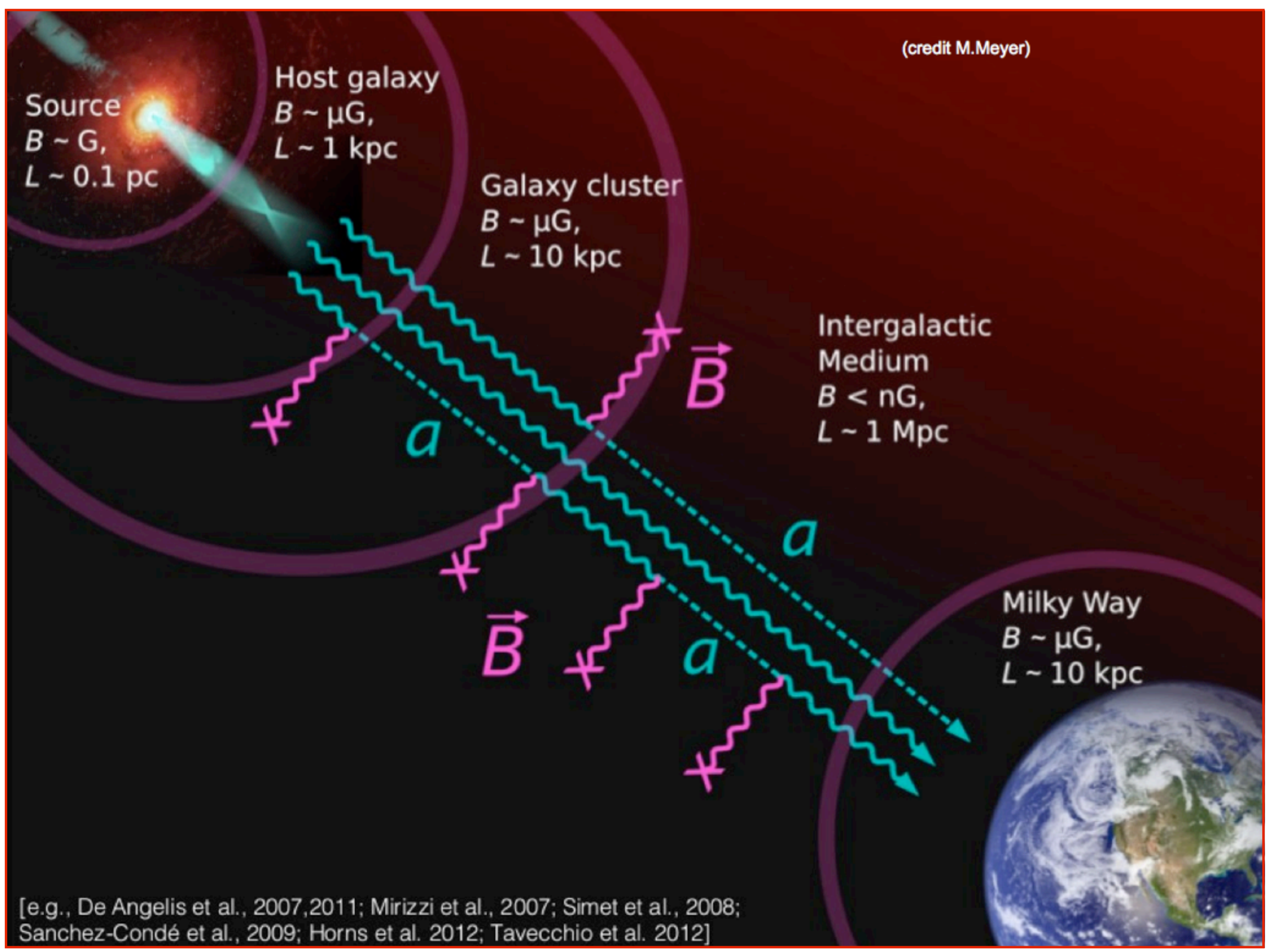
Relevance for VHE

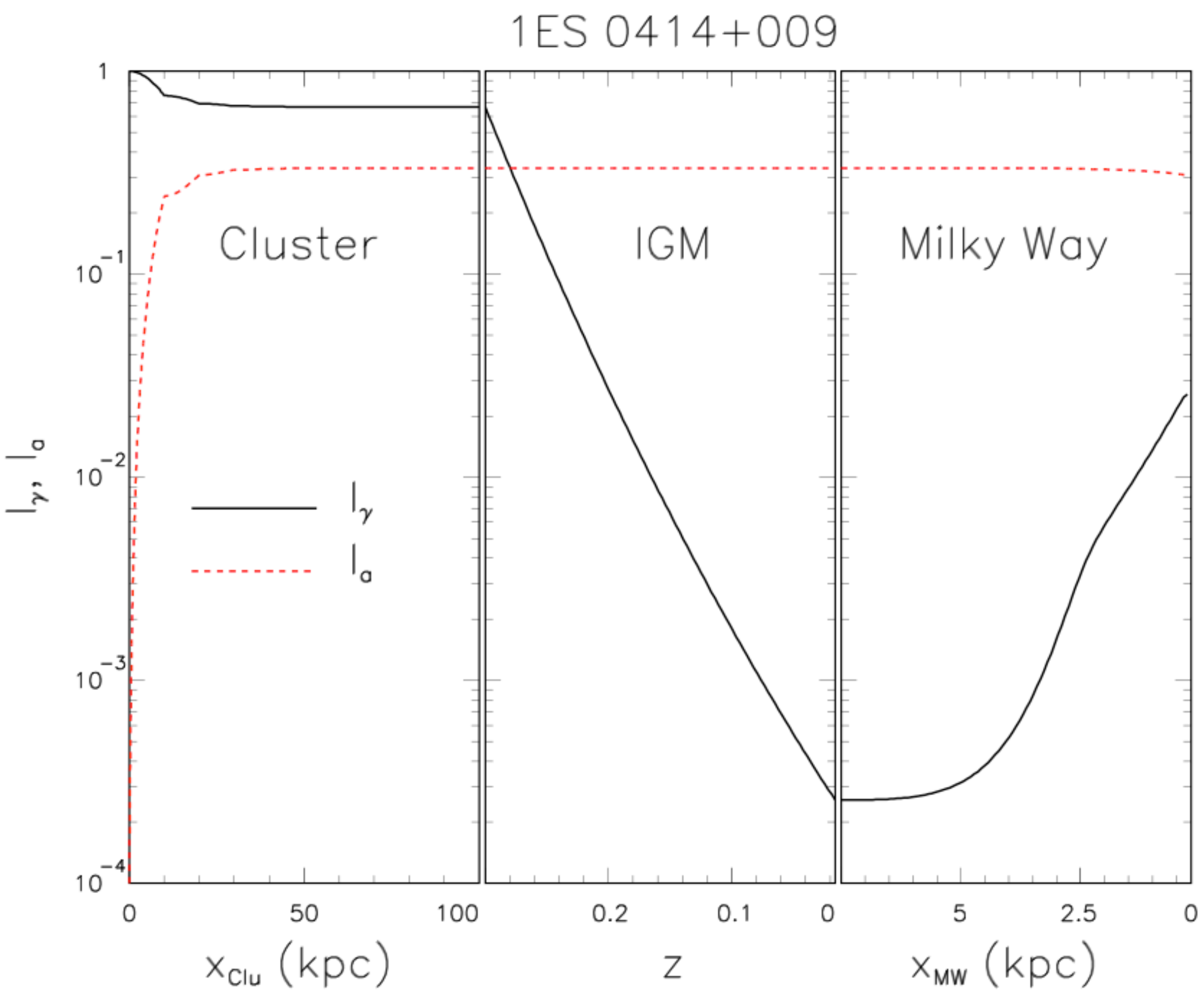
VHE gamma rays absorbed by intervening extragal. UV-IR background (EBL) or within the source

$$F_{\rm obs}(E) = F(E)e^{-\tau_{\gamma\gamma}(E)}$$

Photon-axion-photon conversion can modify the effective optical depth

More important for tau>1 (optically thick regime)





Horns et al. 2013

Model of the source

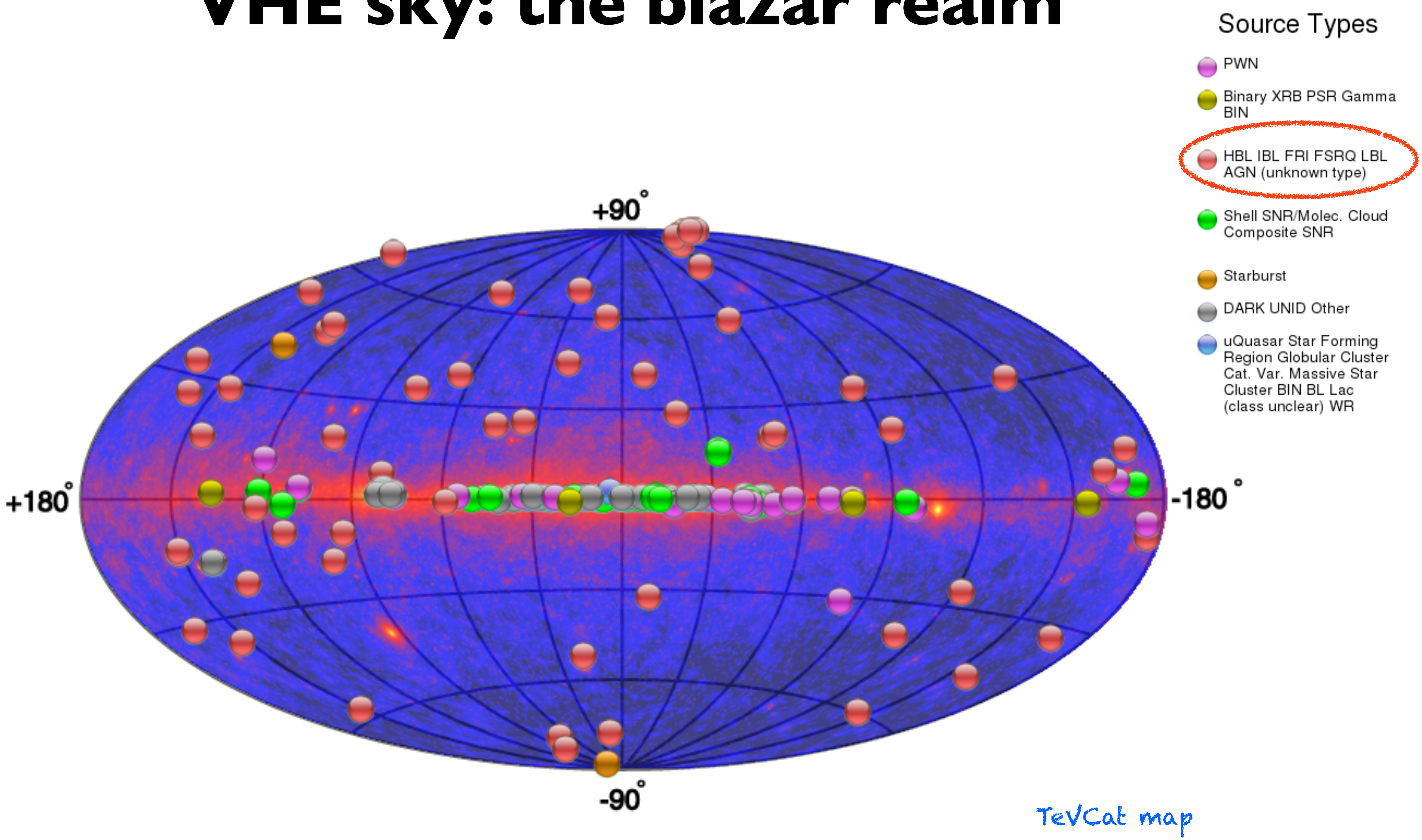
Conversion/reconversion in the AGN environment, intergalactic space and Milky Way rather well studied

(e.g., Hooper & Serpico 2007, De Angelis et al. 2008, 2011, Horns et al. 2013).

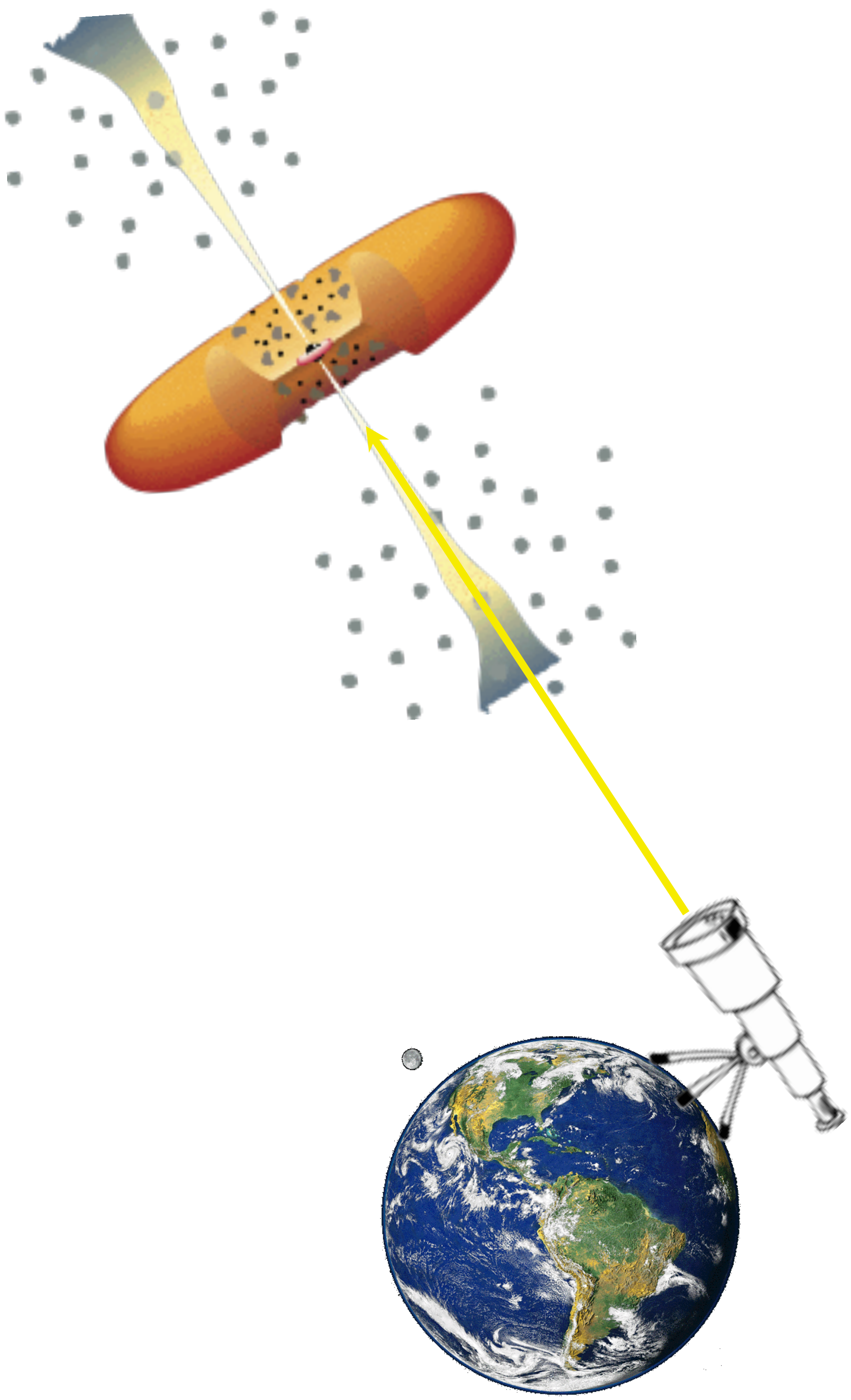
Detailed/realistic calculation of conversion in the source still lacking.

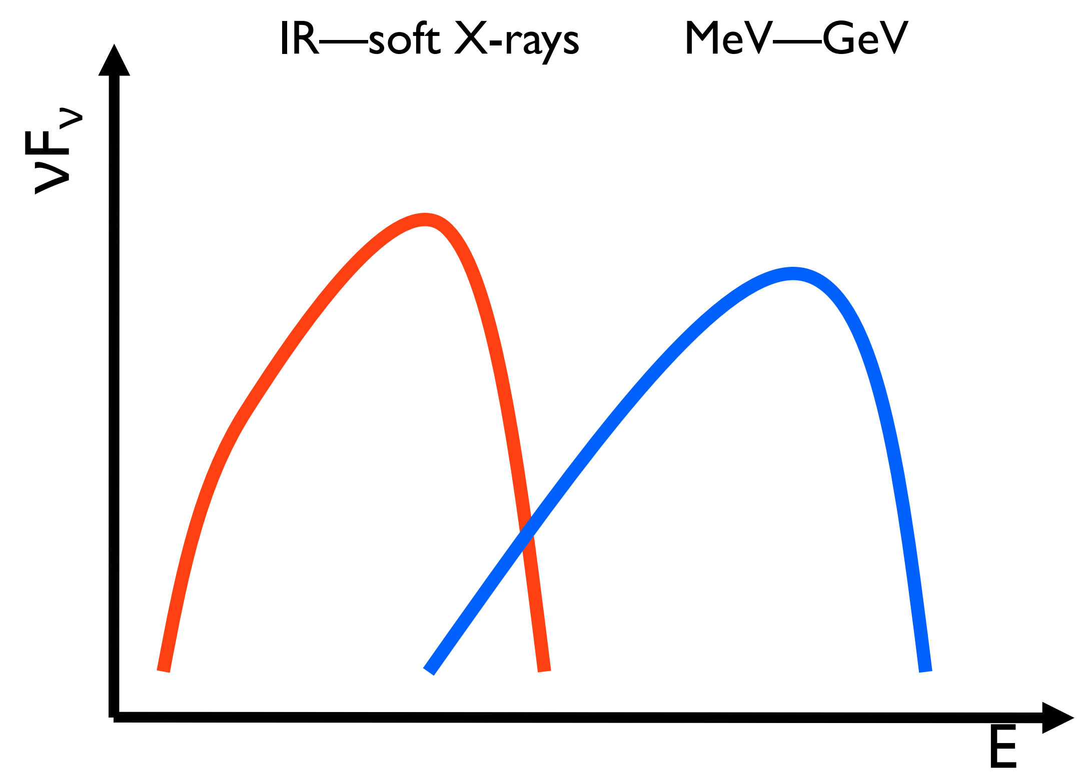
Often simplistic assumptions (e.g., maximal conversion).

VHE sky: the blazar realm



Blazars: phenomenology



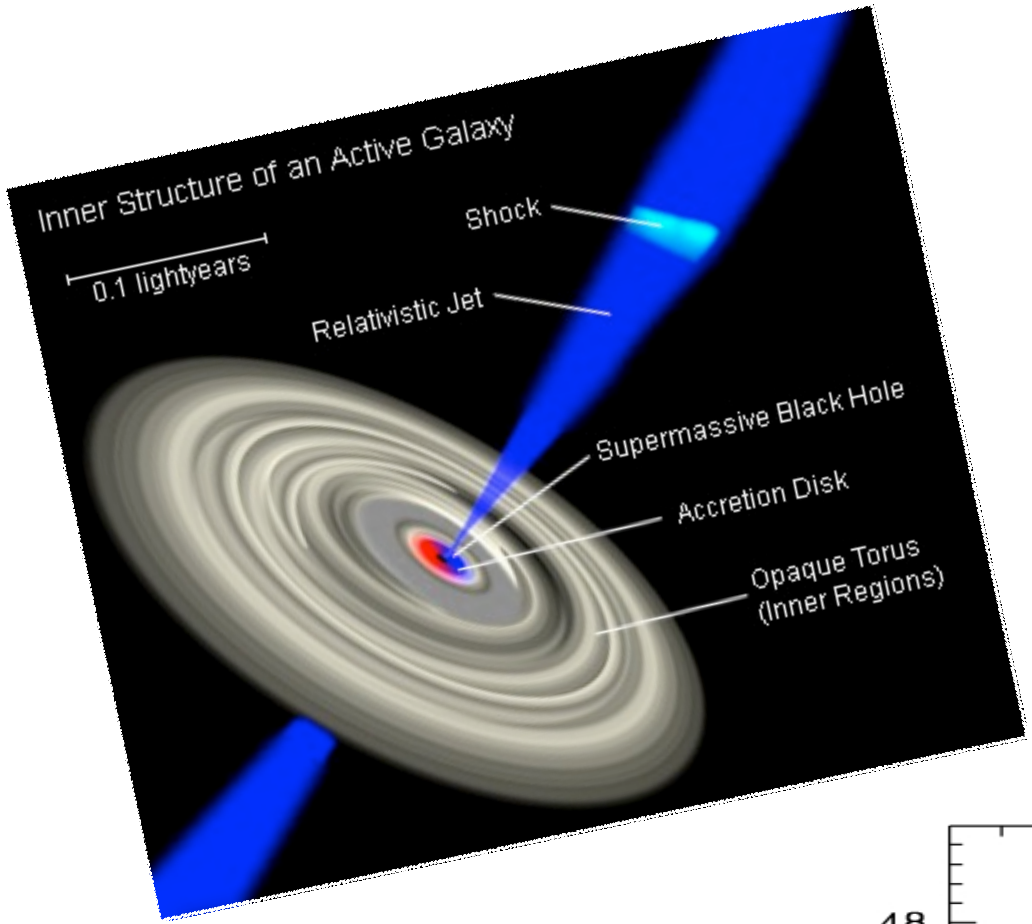


SED dominated by the <u>relativistically boosted</u> non-thermal continuum emission of the jet.

Synchrotron and IC in leptonic models.

Also hadronic scenarios are considered

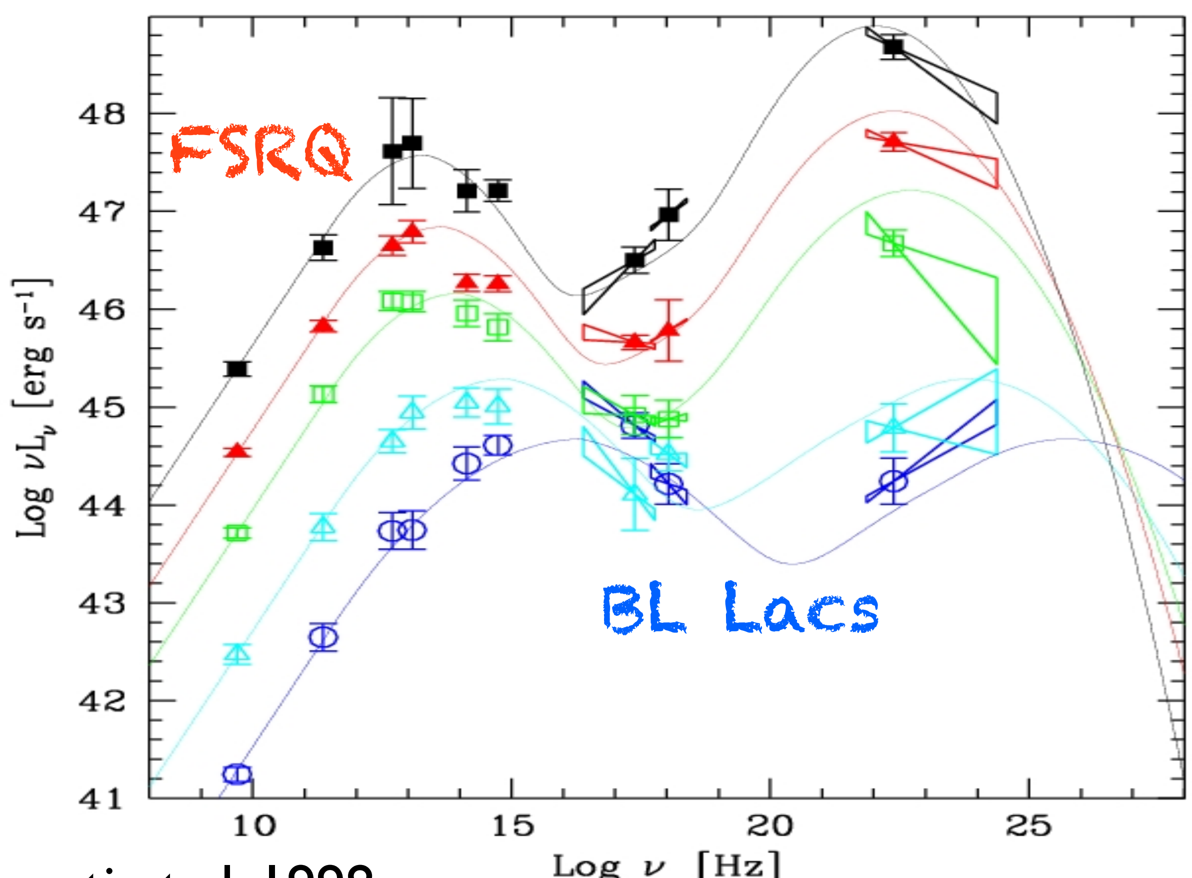
Blazars: phenomenology



Blazars occur in two flavors:

FSRQ: high power, thermal optical components

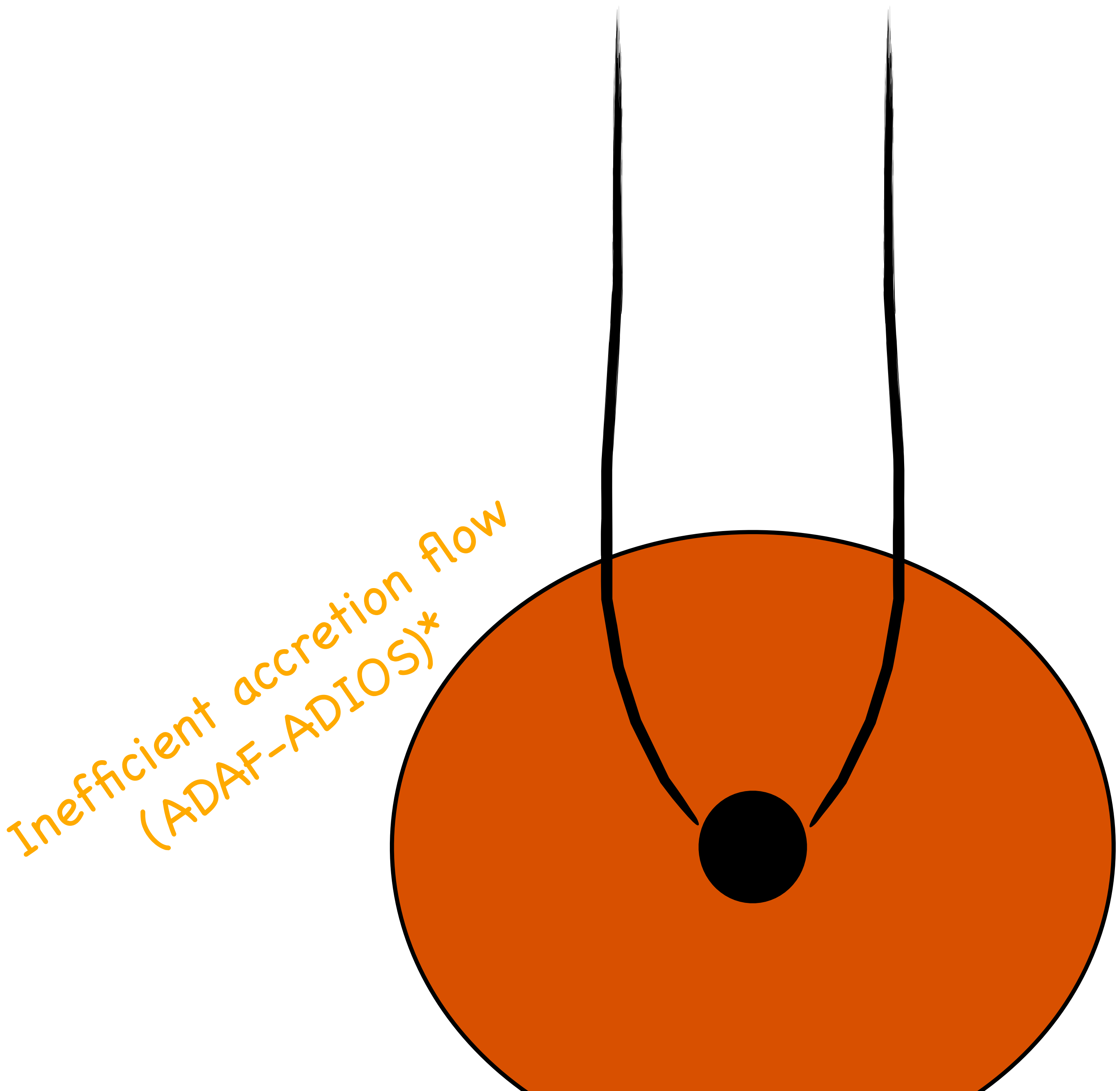
BL Lacs: low power, lack of important thermal comp.



Fossati et al. 1998

The blazar sequence

BL Lacs: "naked" jets

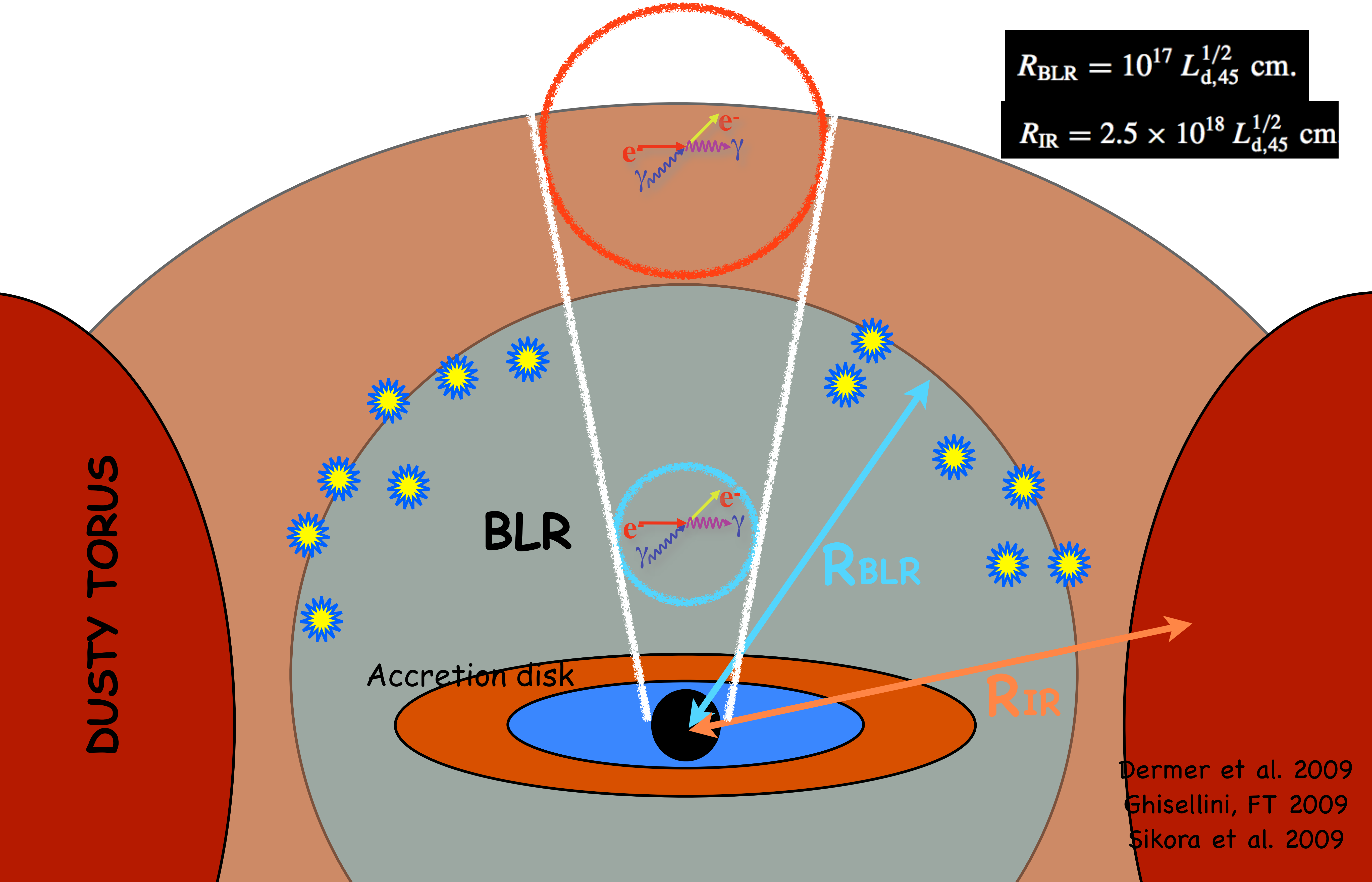


*but see Raiteri et al. 2009
Capetti et al. 2010 for BL Lac itself

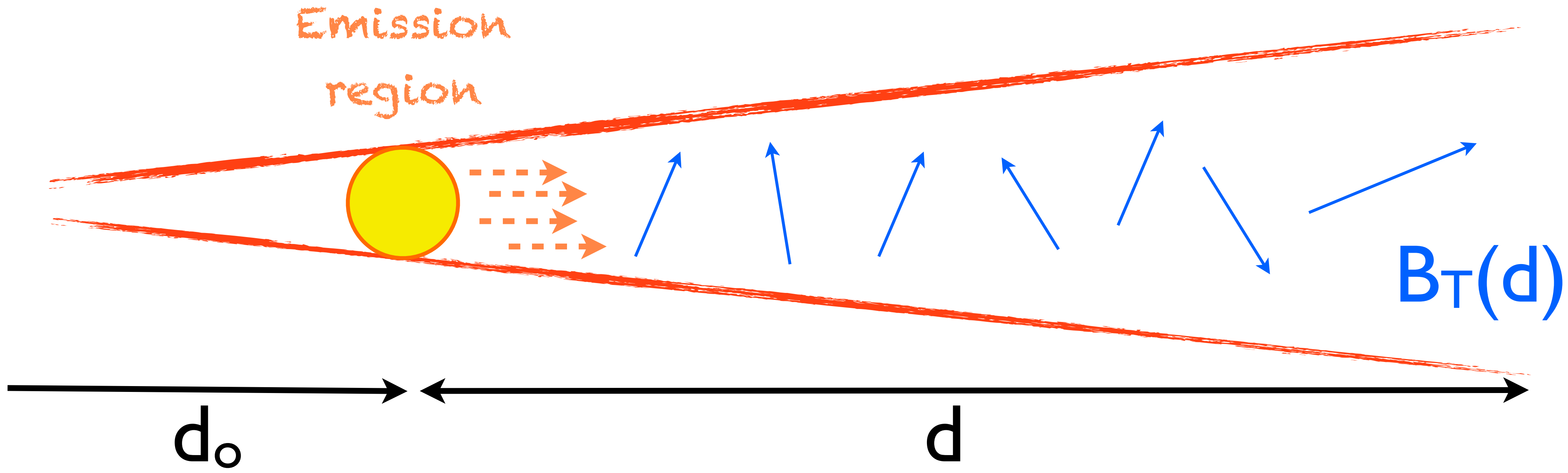
FSRQ: “dressed” jets

$$R_{BLR} = 10^{17}\, L_{d,45}^{1/2} \text{ cm.}$$

$$R_{IR} = 2.5 \times 10^{18}\, L_{d,45}^{1/2} \text{ cm}$$



Set-up I: jet



Set-up I: jet

BL Lacs: short jets
no hot spot/lobes

d~1 kpc
(e.g. Giroletti et al. 2004)

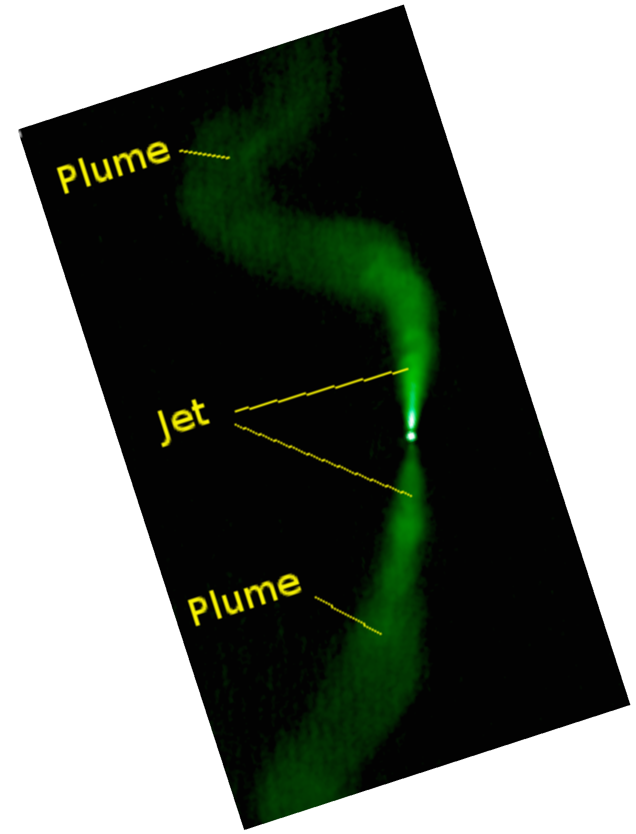
Magnetic field ordered,
predominantly tranverse

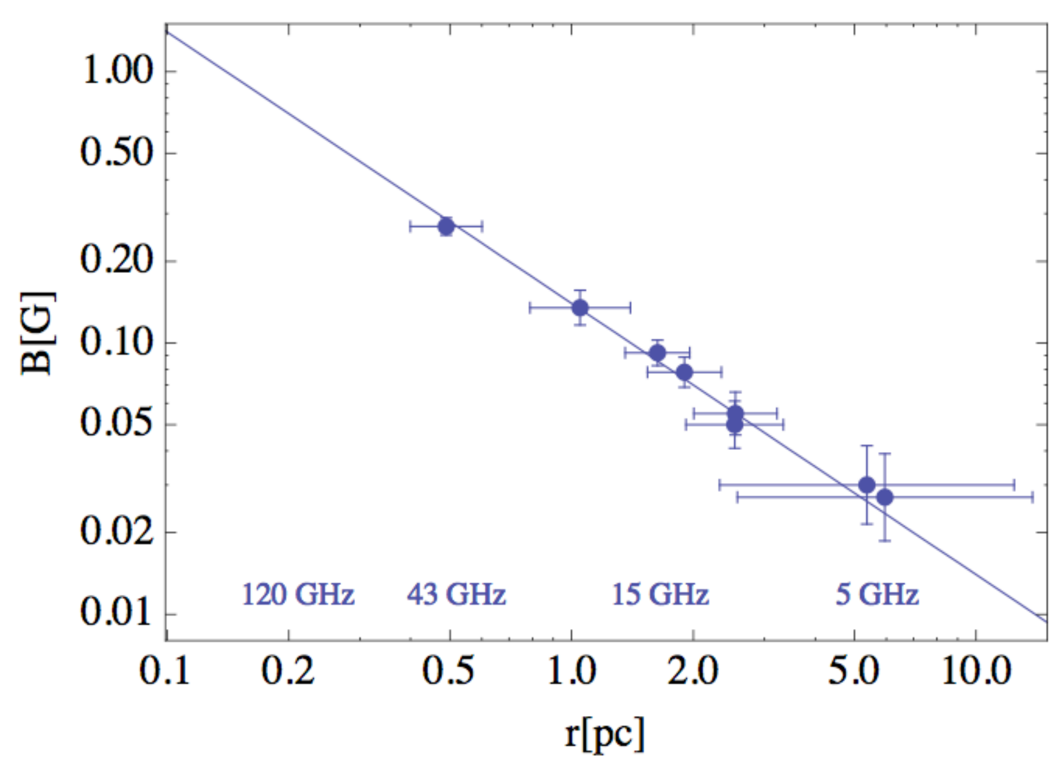
$$B_T(d) = B_T(d_o)\left(\frac{d}{d_o}\right)^{-1}$$

$$B_T(d_o) \simeq 0.1 - 1\ \mathrm{G}$$

Jet comoving frame

Jet Lorentz factor 15





O'Sullivan & Gabuzda 2009

Set-up I: jet

FSRQ: long jets
hotspots/lobes

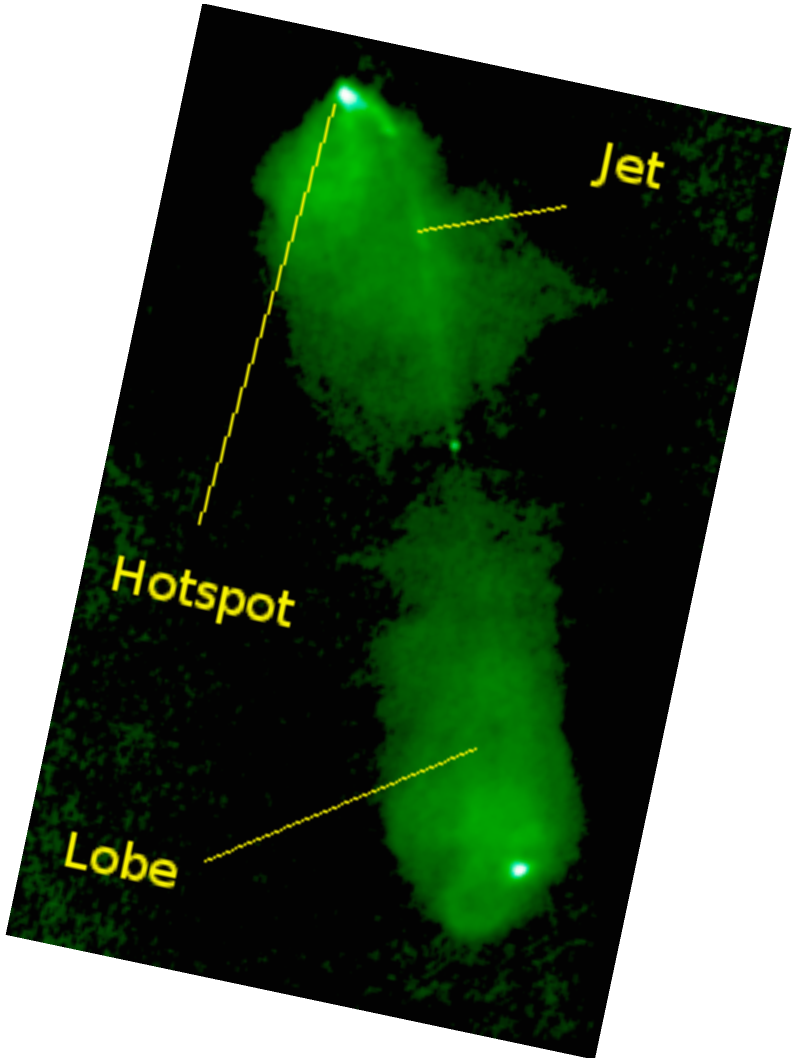
d~0.1-1 Mpc

Magnetic field?
No preferred orientation

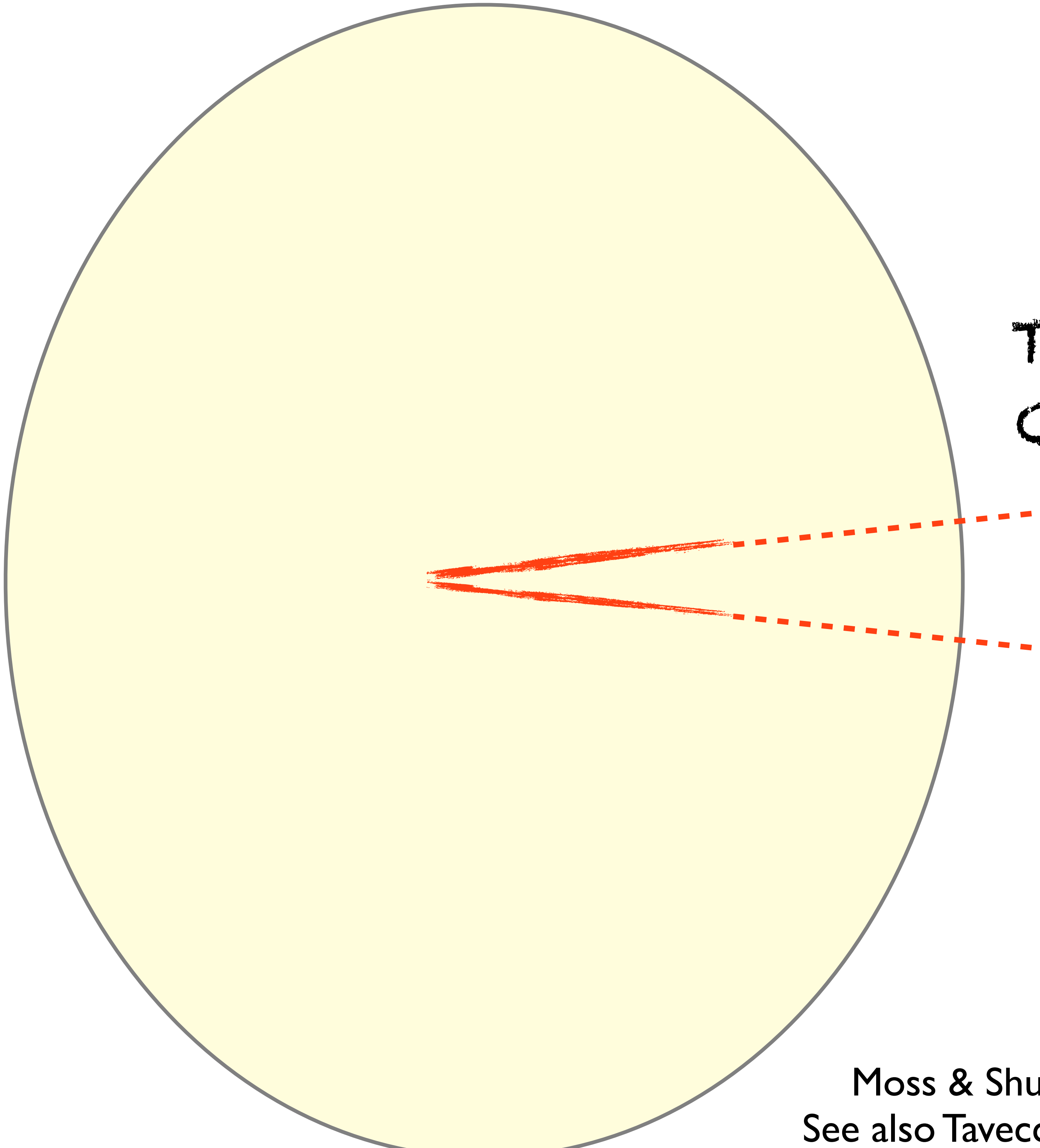
$$B_T(d) = B_T(d_o)\left(\frac{d}{d_o}\right)^{-1}$$

$$B_T(d_o) \simeq 1 - 5\ \mathrm{G}$$

Jet comoving frame
Jet Lorentz factor 10



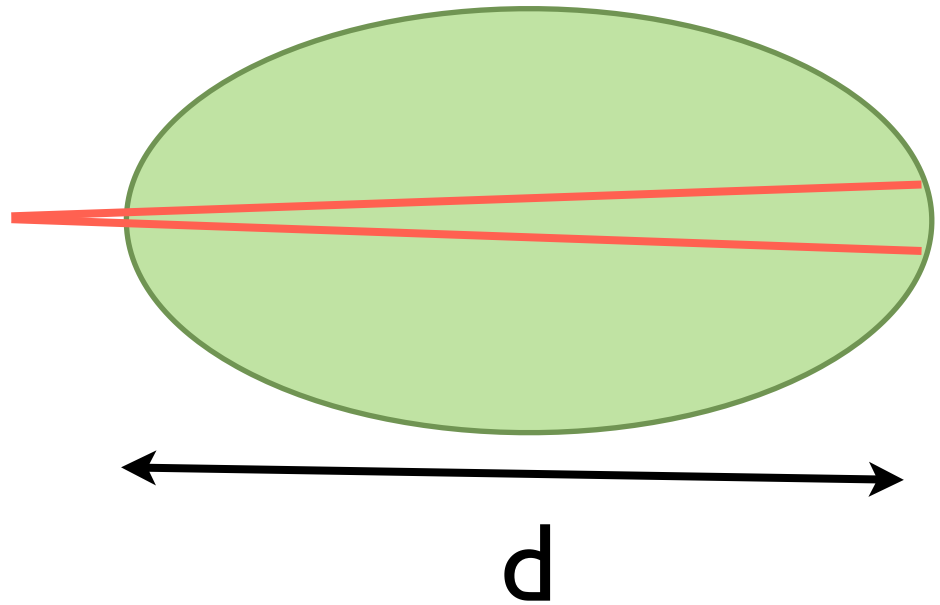
Set-up II: host galaxy



Giant elliptical galaxy
Turbulent magnetic field
Coherence length~150 pc
B~5 microG

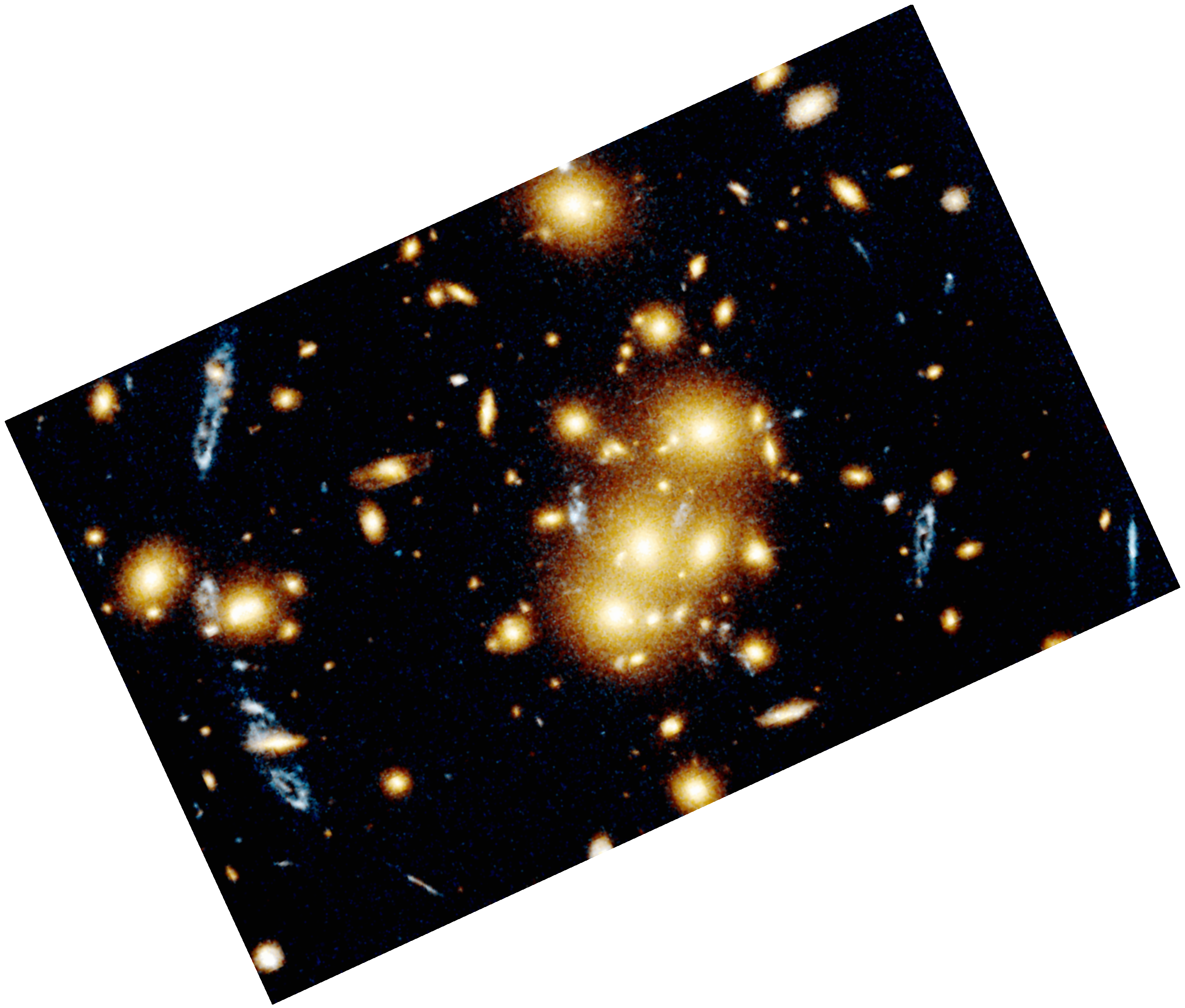
Moss & Shukurov 1996
See also Tavecchio et al. 2012

Set-up III: radio lobe (FSRQ)



Turbulent magnetic field
Coherence length ~ 10 kpc
Intensity ~ 10 microG
d~100 kpc

Set-up IV: cluster



BL Lacs reside in poor cluster (A0)

Few of them in reacher environments

neglected

See Horns et al. 2013

Set-up V: absorption in FSRQ

$$\gamma + \gamma \rightarrow e^{\pm}$$

Details in
G. Galanti's talk
tomorrow

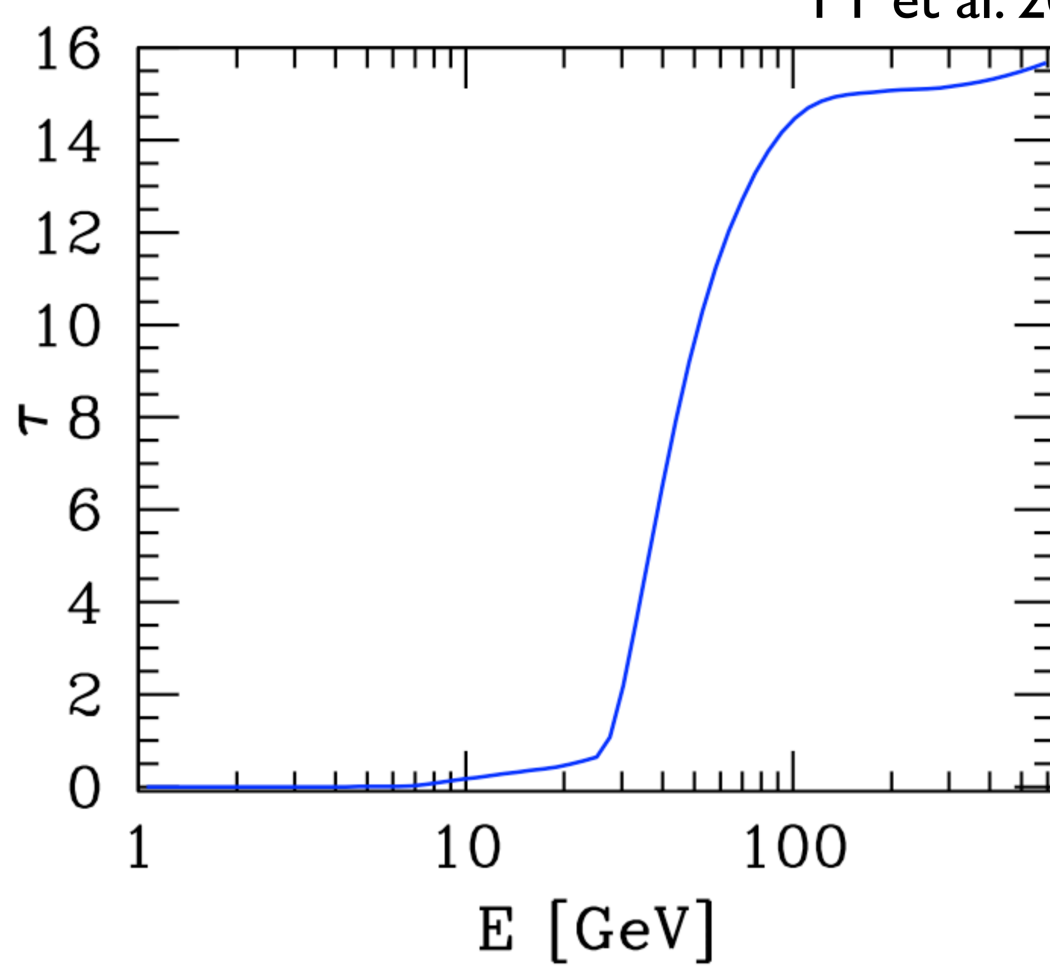
Threshold: $E\epsilon > m_e^2 c^4$ (head-on collision)

$$\epsilon(E) \simeq \left(\frac{500\,\mathrm{GeV}}{E}\right)\,\mathrm{eV}$$

Negligible in BL Lacs
(no external radiation field)

Huge in FSRQ above 30 GeV

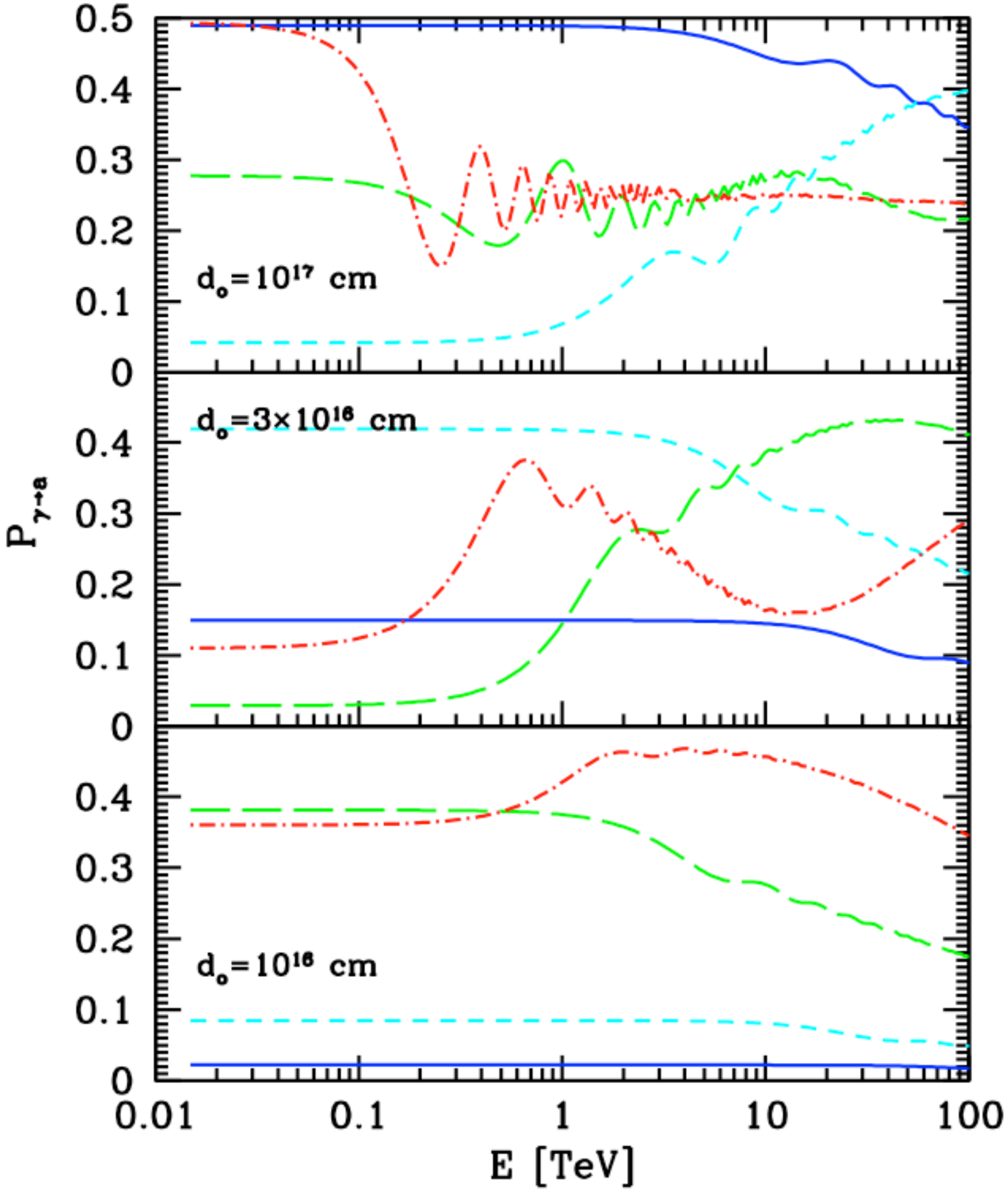
FT et al. 2012



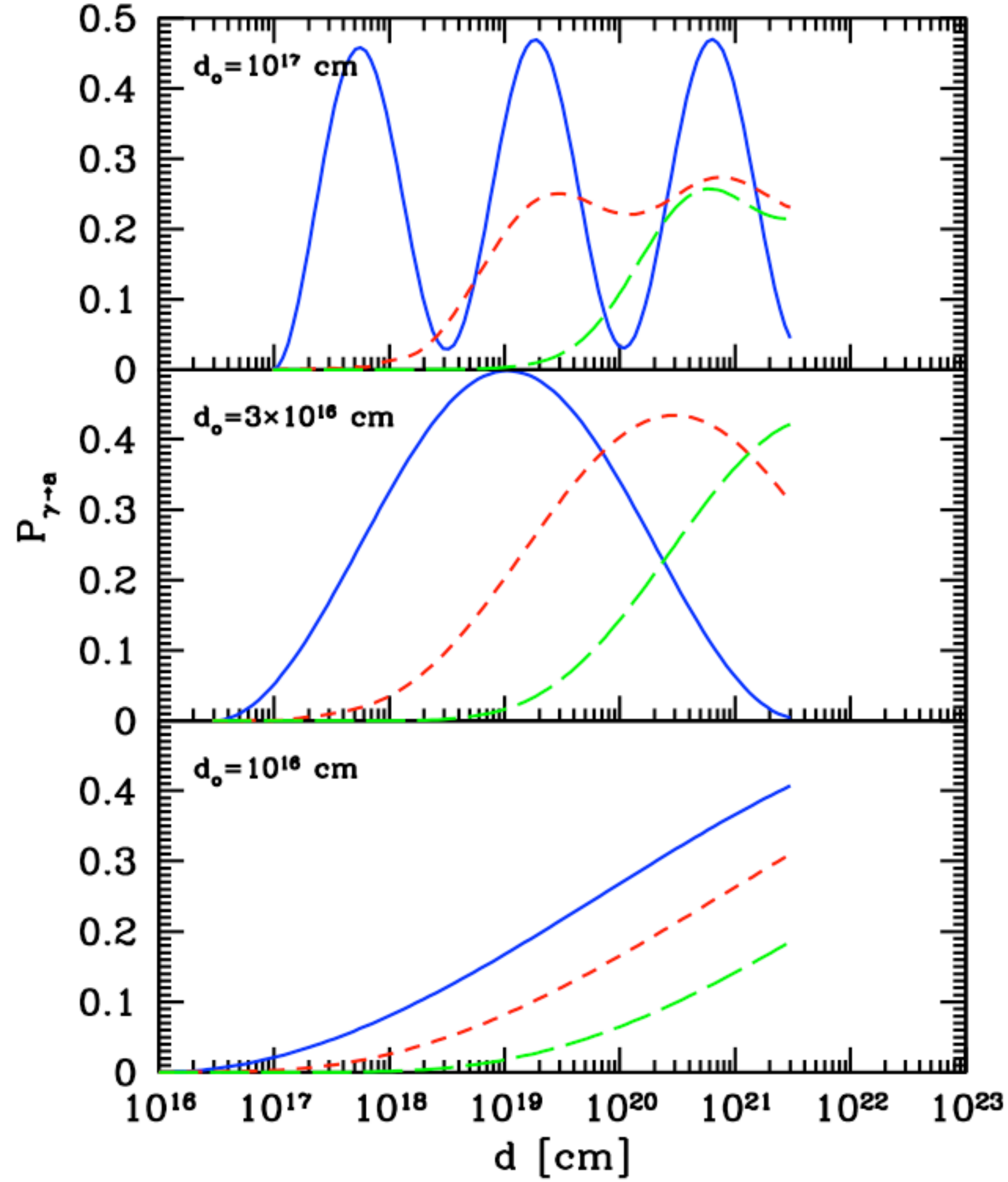
Results

BL Lacs: jet

B_0=0.1,0.2,0.5,1 G



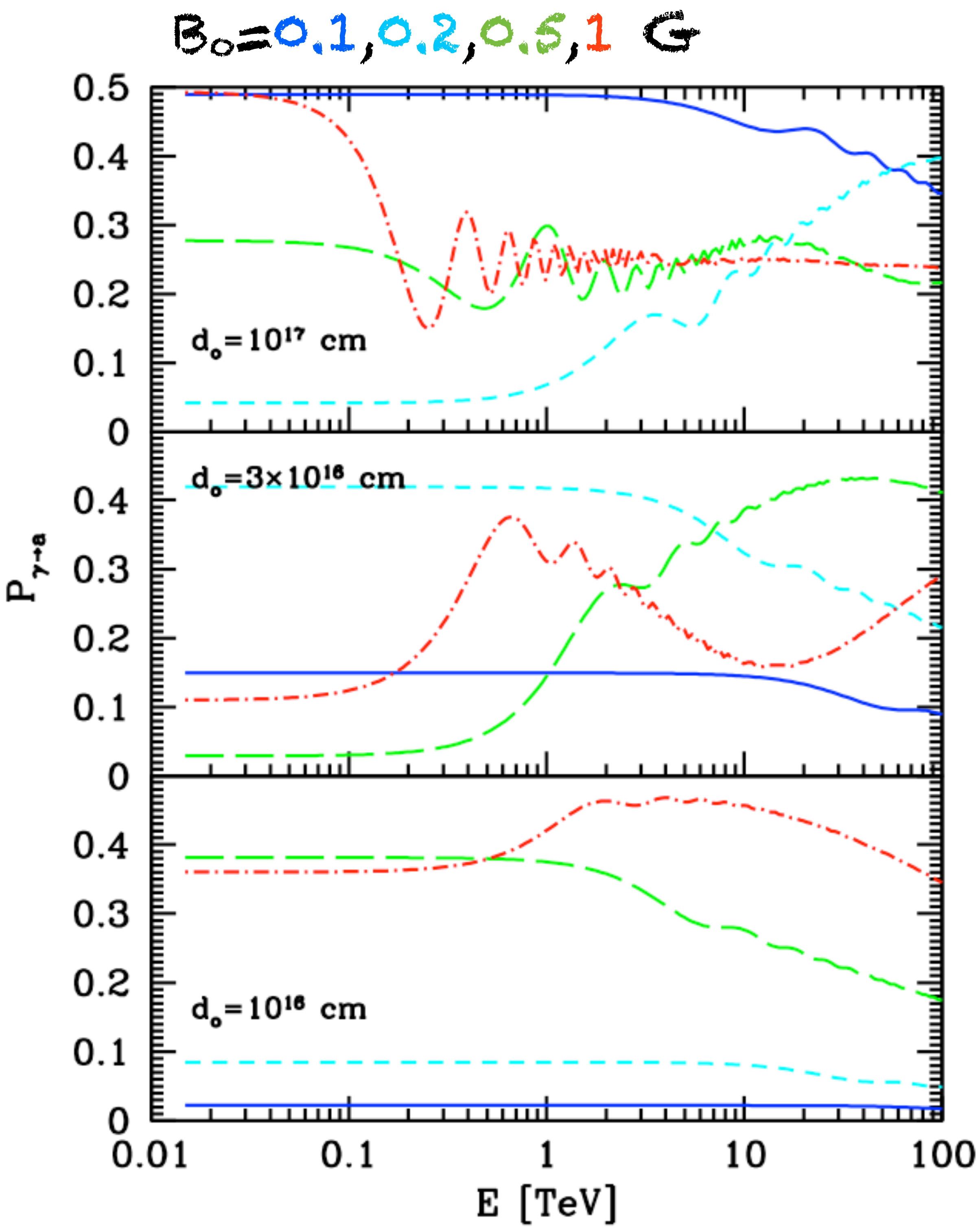
E=0.15,7.5,150 TeV B=0.5 G

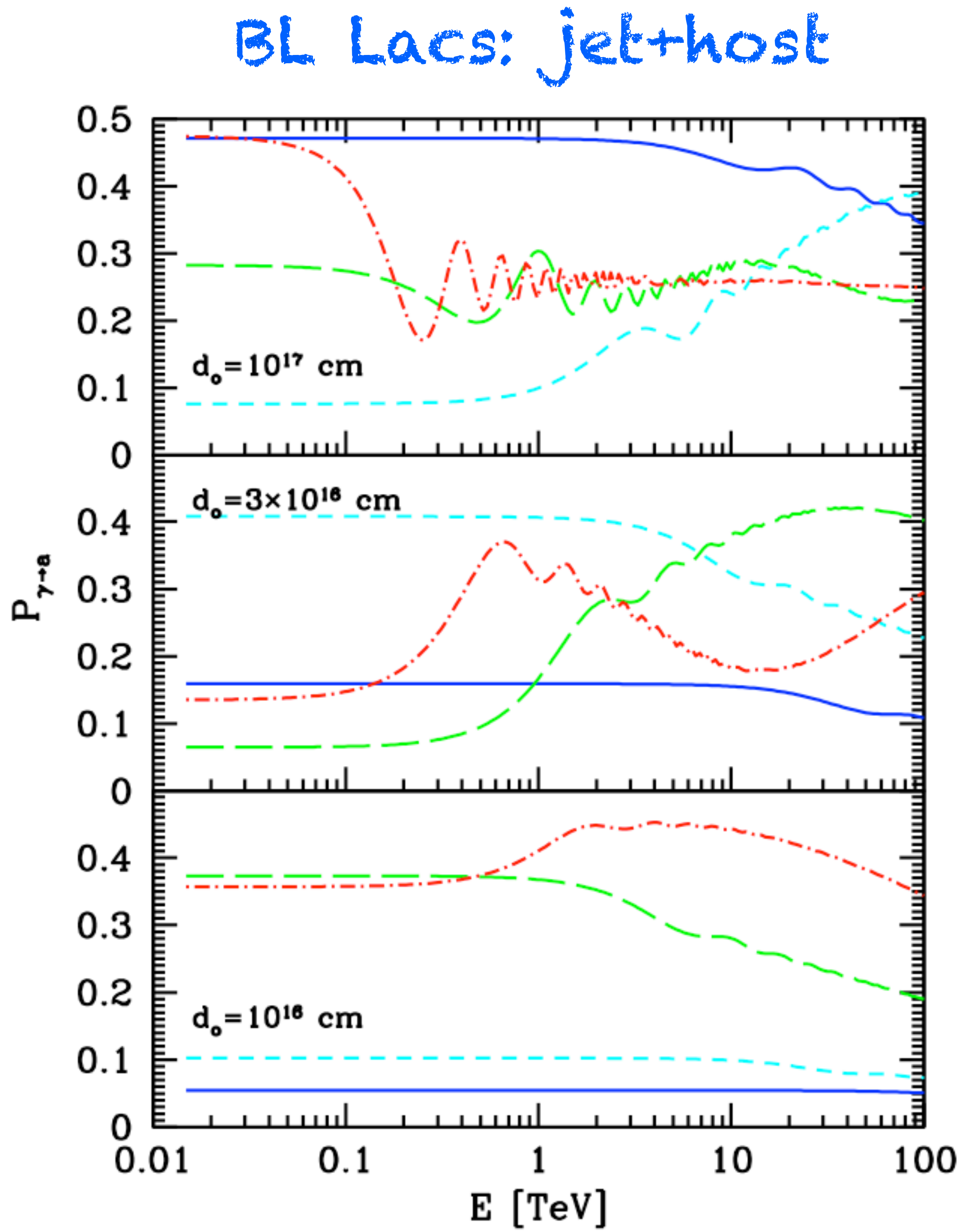


Ljet=0.5 kpc

FT et al., in prep

Results





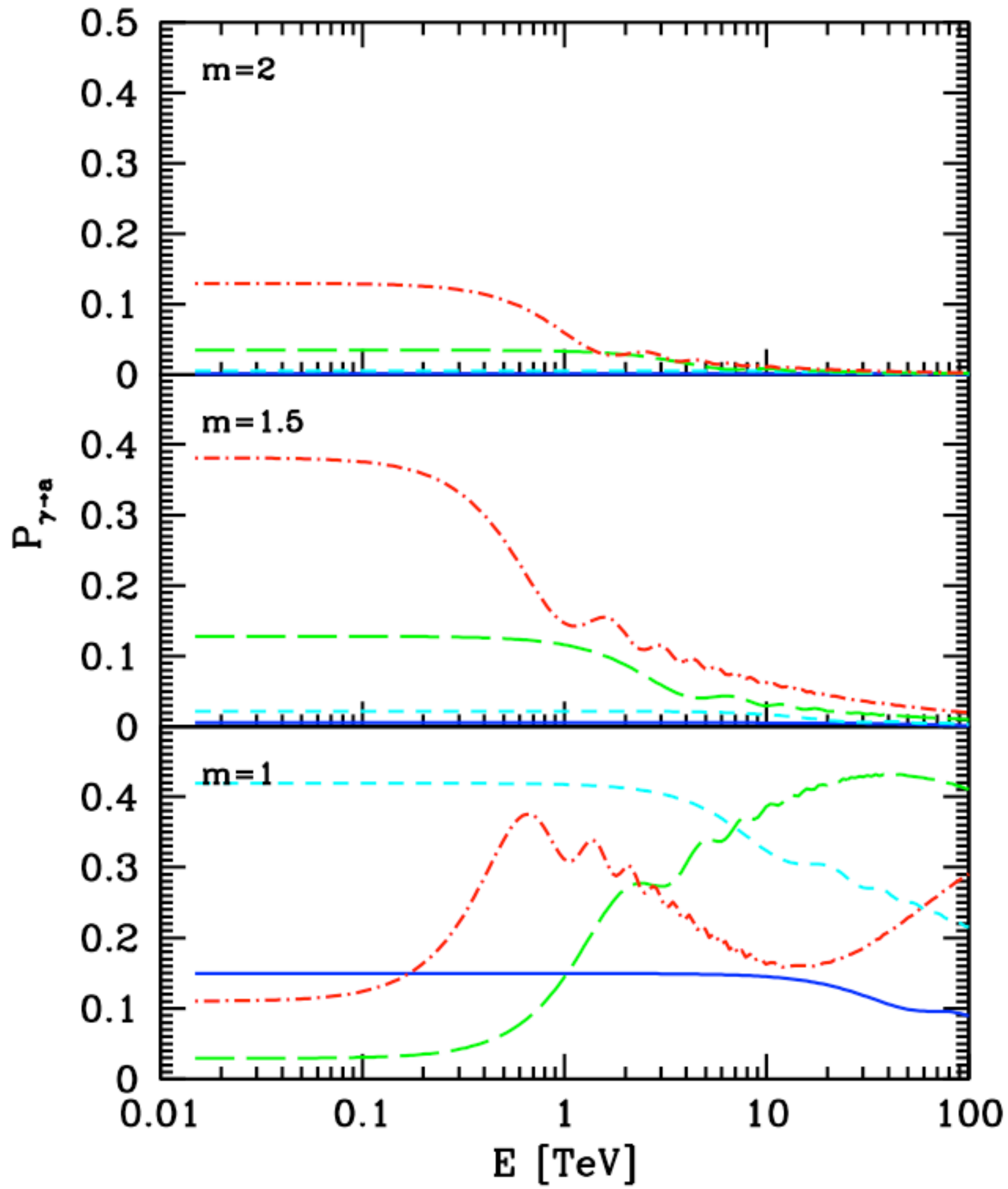
Ljet=0.5 kpc

FT et al., in prep

Results

B_o=0.1,0.2,0.5,1 G

Dependence on the slope

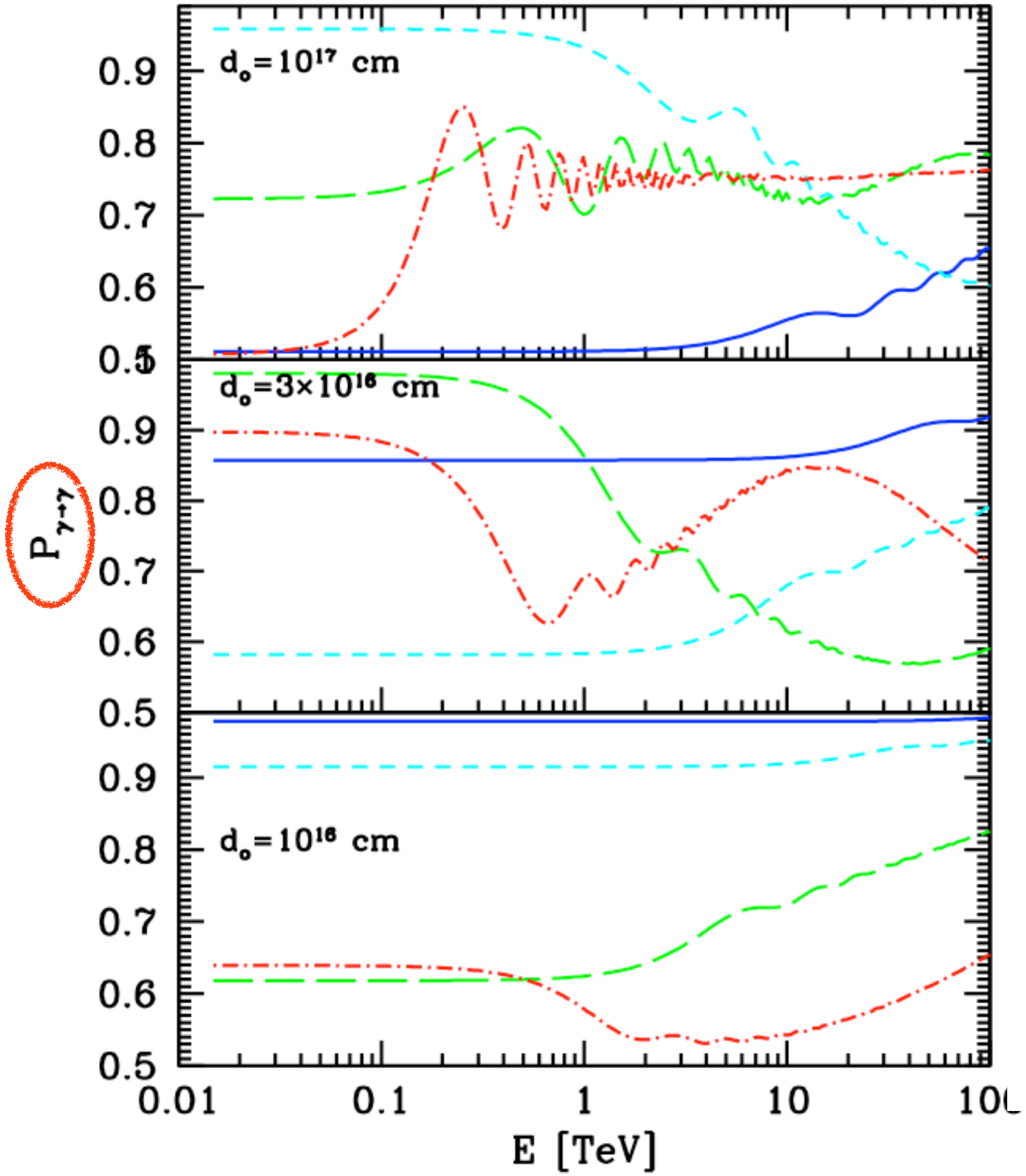


$$B_T(d) = B_T(d_o)\left(\frac{d}{d_o}\right)^{-1}$$

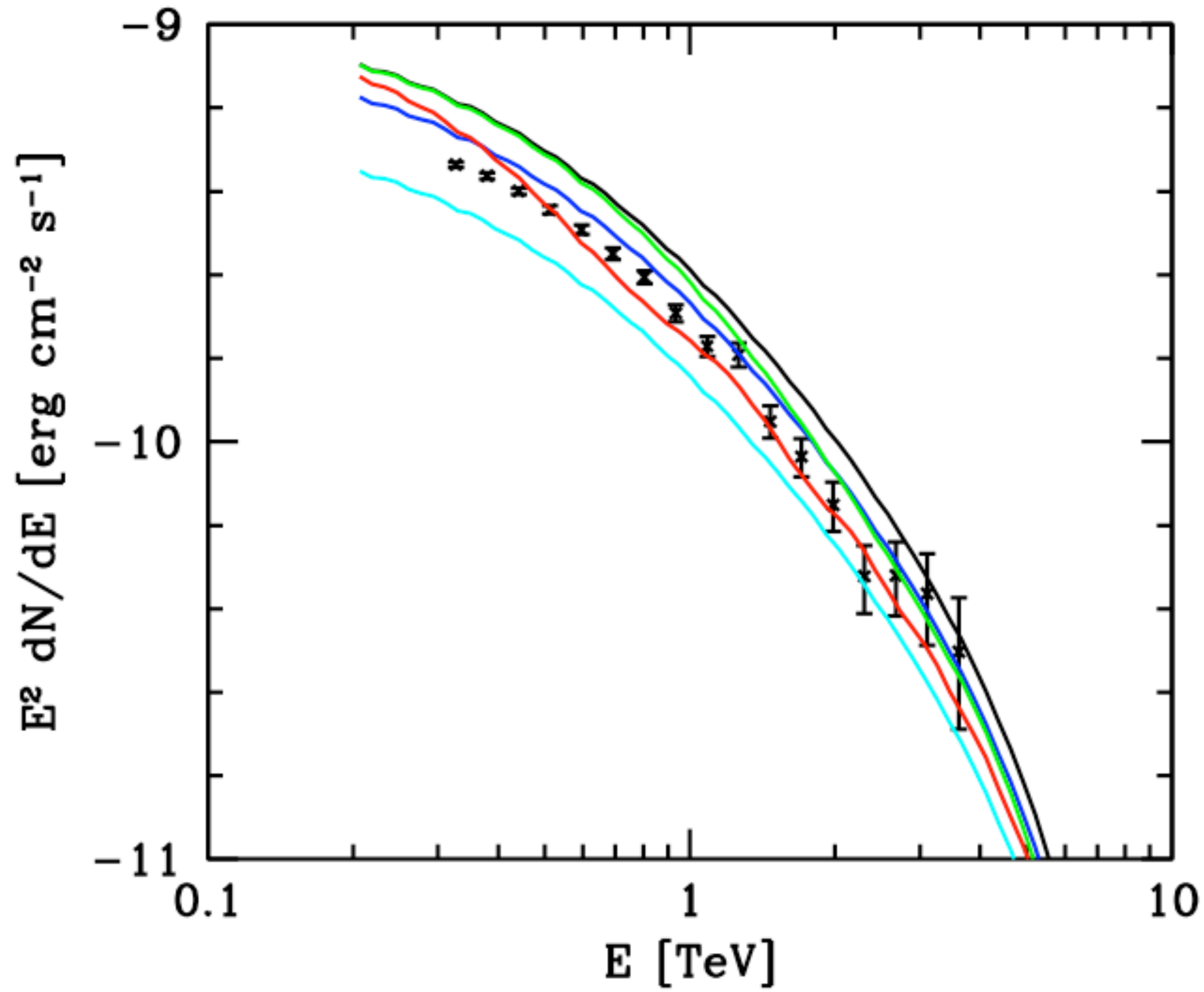
Ljet=0.5 kpc

FT et al., in prep

Results



Can we detect "wiggles" in the VHE spectrum of BL Lacs?

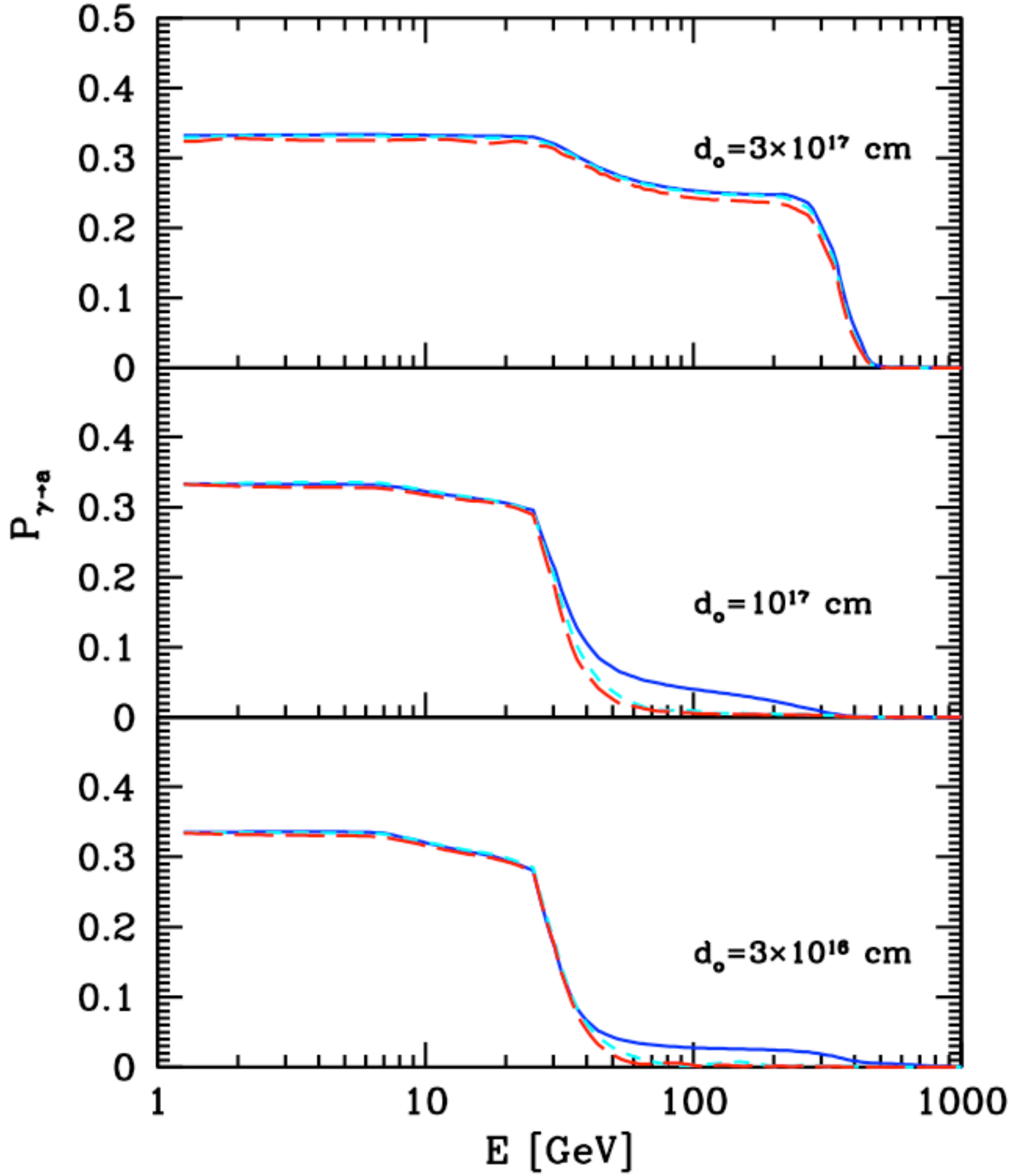


Results

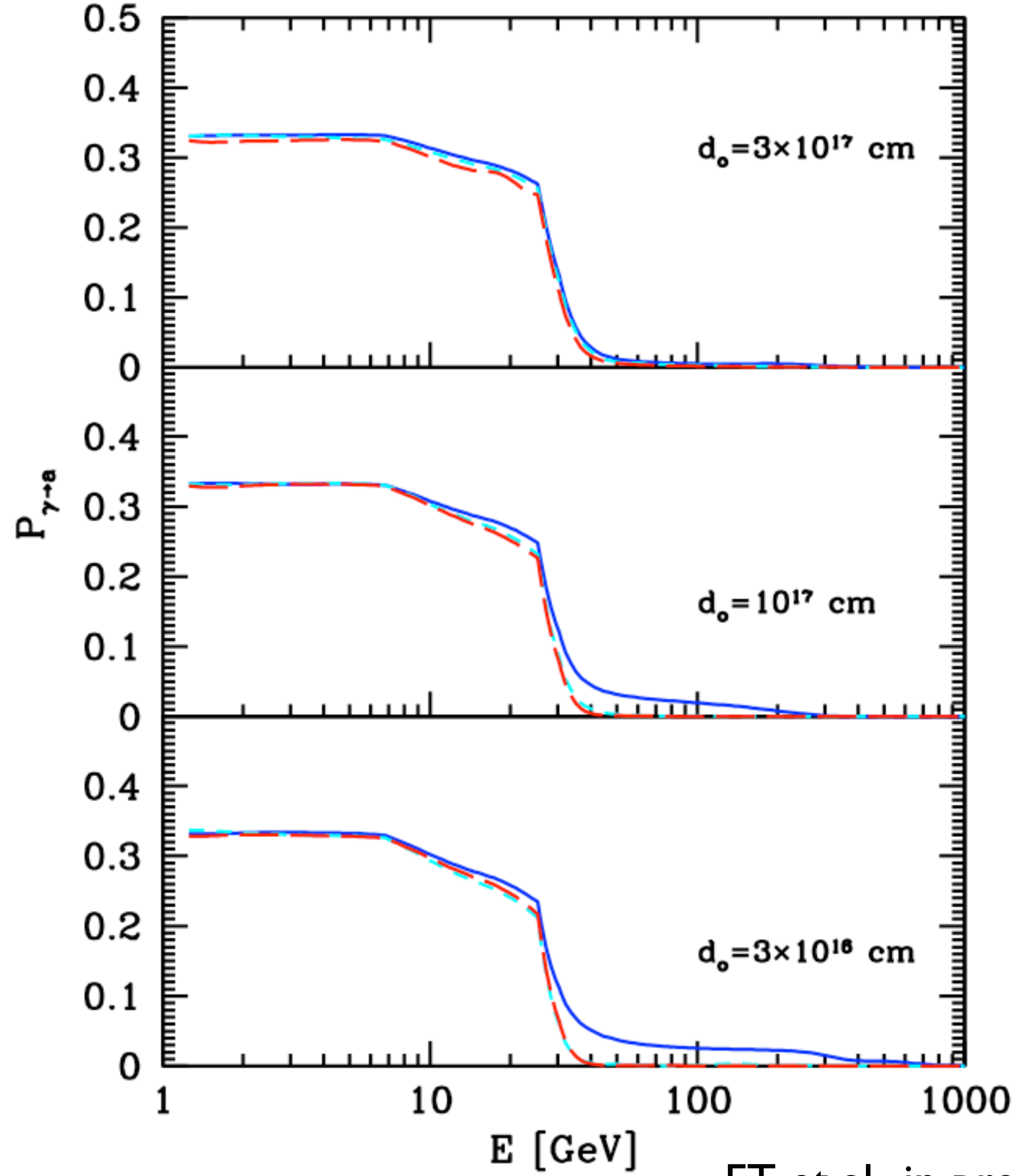
B_0=1,3,5 G

FSRQ

$L_{disk}=3\times10^{45}$ erg s^{-1}



$L_{disk}=1.5\times10^{46}$ erg s^{-1}



FT et al., in prep

Conclusions

BL Lacs:

conversion probability vs energy rather complex
Strongly dependent on position/magn. field

FSRQ:

more regular behaviour of P(E)
huge absorption dumps conversions above 20-30 GeV

Thank you!