Blazars:

beams for astro & astroparticle physics

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INAF-OAB

Outline

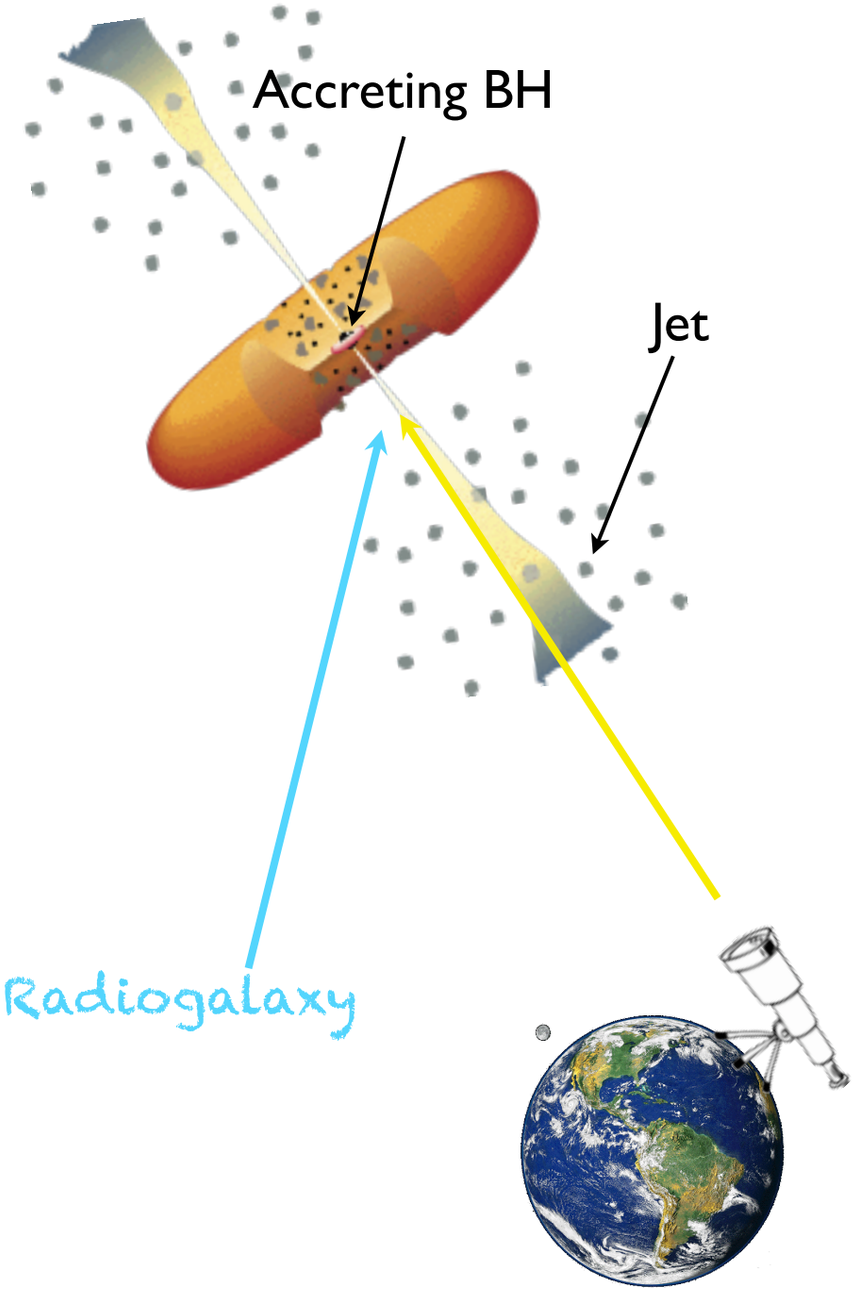
Introduction

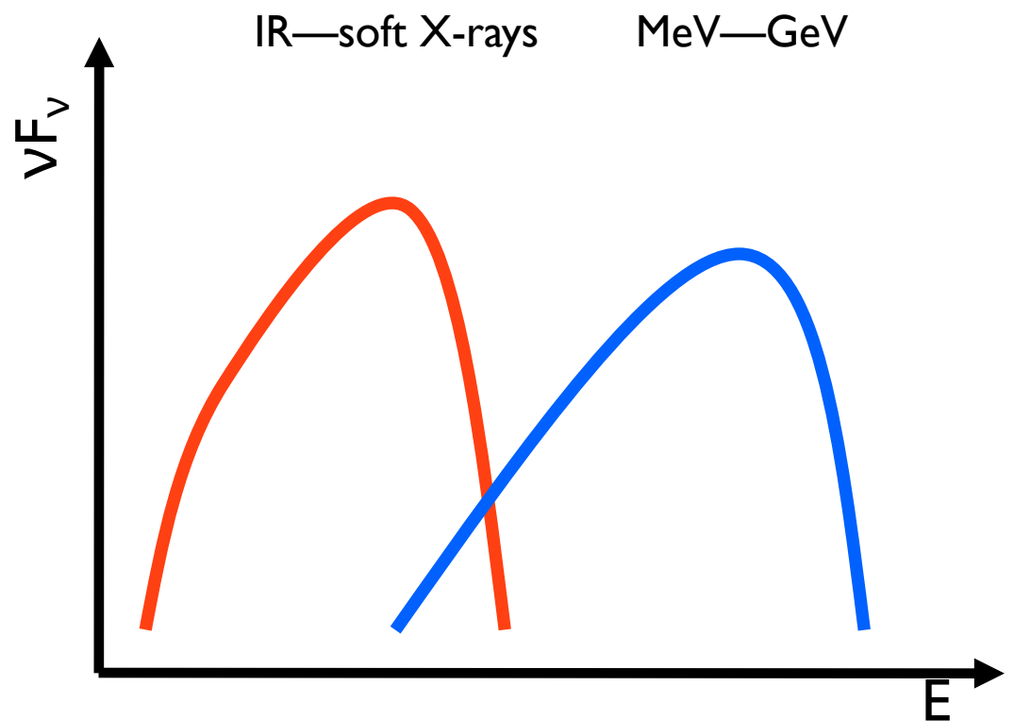
Current issues: location and dissipation

Structured jets: radiogalaxies & neutrinos

Extreme BL Lacs: UHECR, ALP & LIV

Blazars in a nutshell





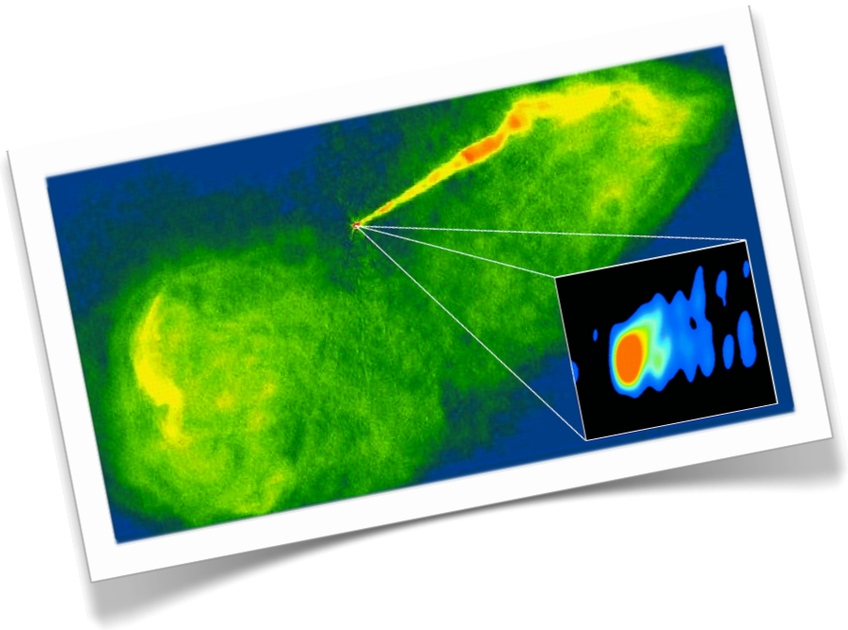
SED dominated by the relativistically boosted non-thermal continuum emission of the jet.

$$L_{\rm obs} = L'\delta^4 \qquad \delta = \frac{1}{\Gamma(1-\beta\cos\theta_{\rm v})}$$

Synchrotron and IC in leptonic models.

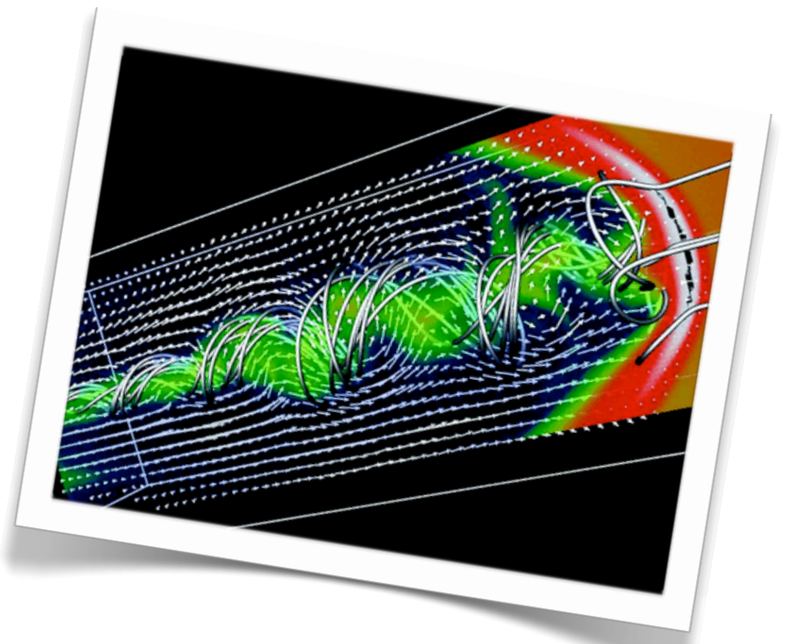
Also hadronic scenarios (synchrotron or photo-meson emission)

Blazars: jet physics

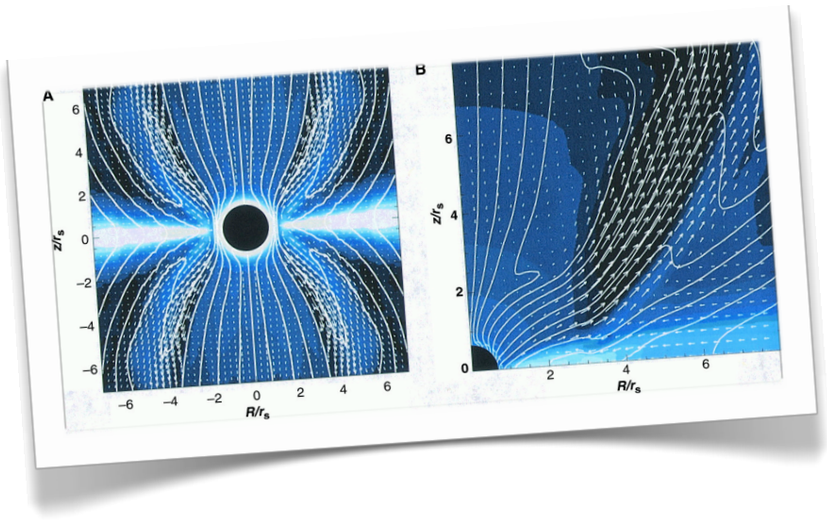


Jet speed,
composition,
power

G. Ghisellini & T. Sbarrato talks

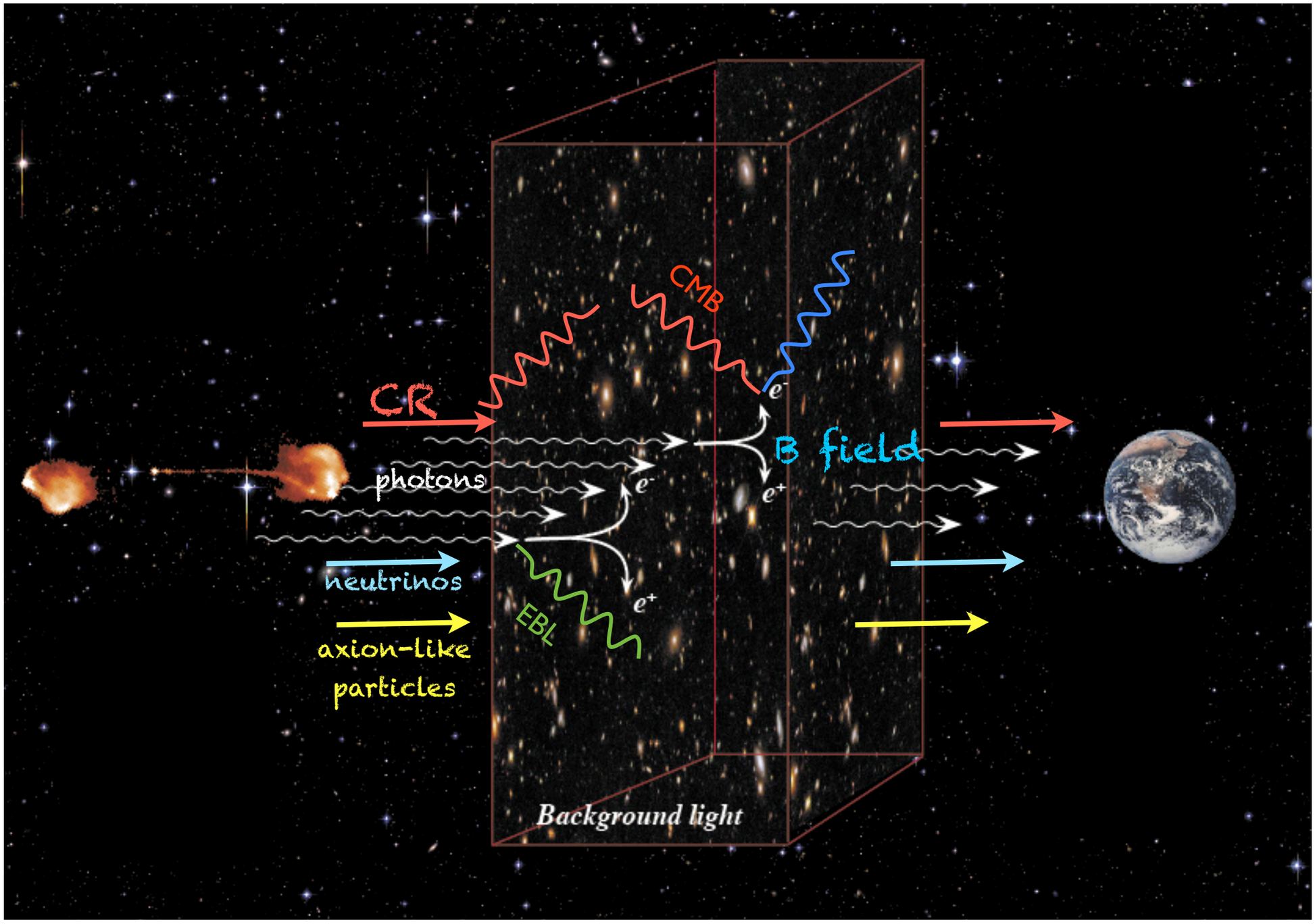


Magnetic fields,
particle acceleration



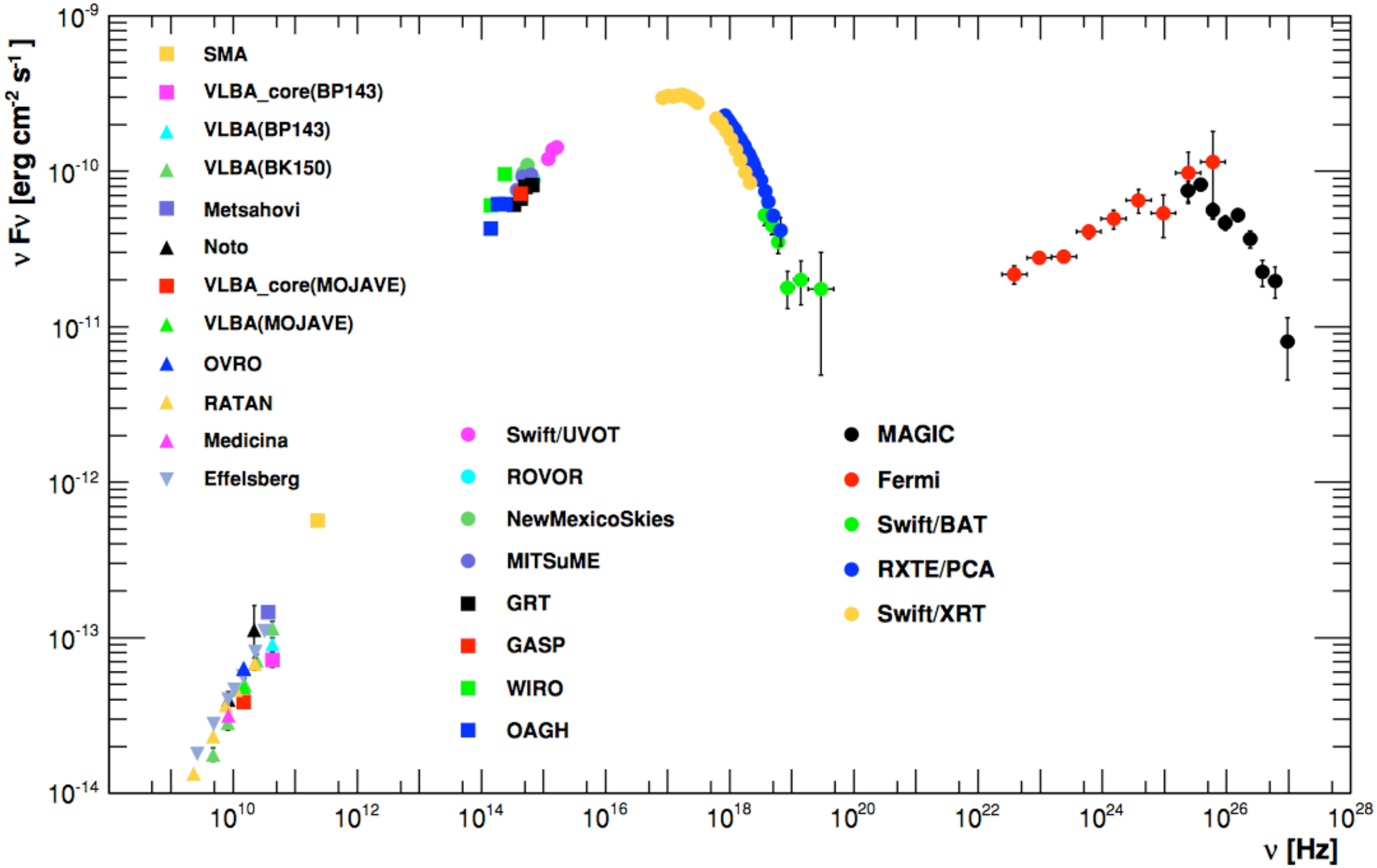
Formation, collimation,
acceleration

Blazars: high-energy particle beams



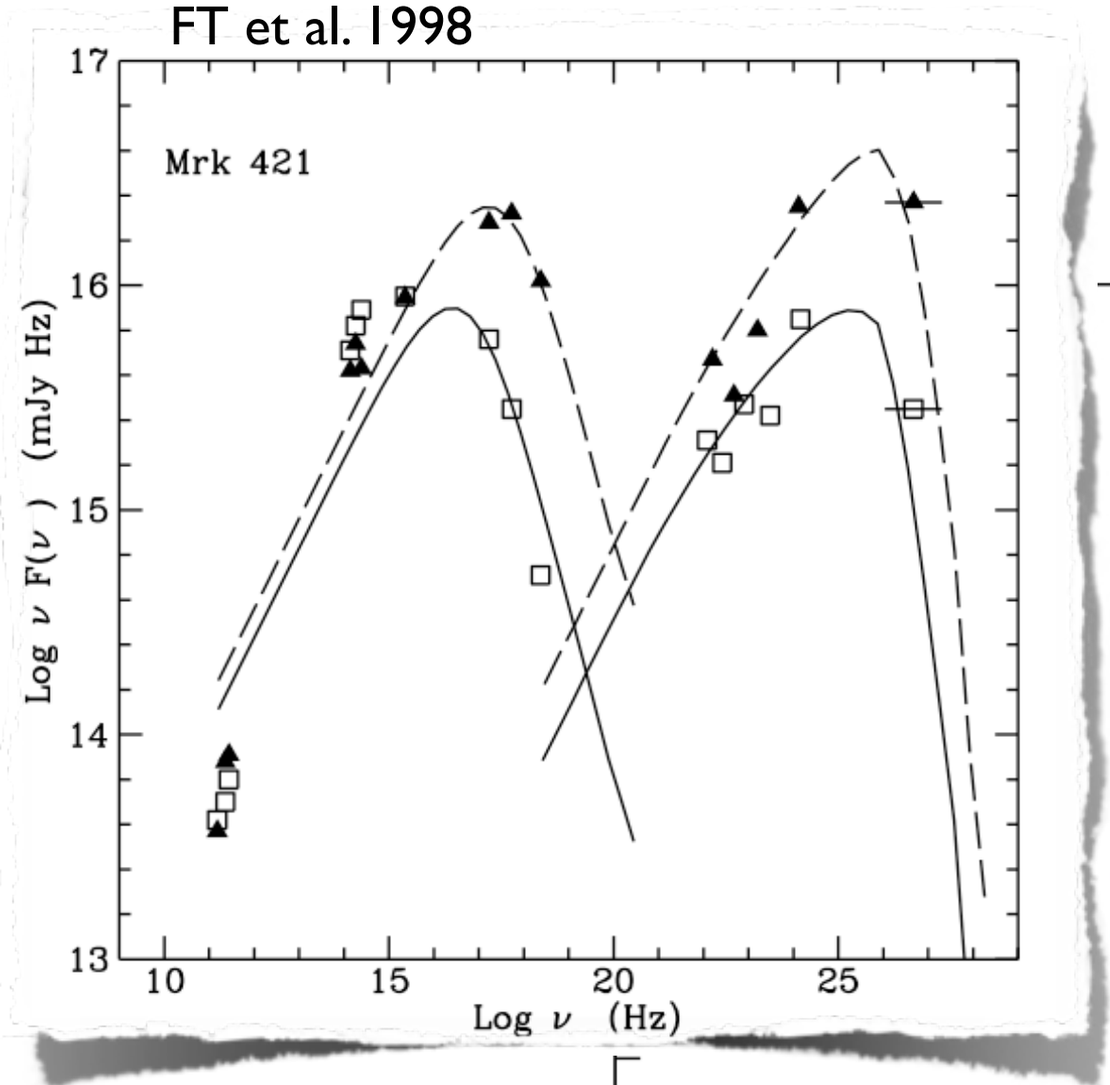
The golden era

Abdo et al. 2011

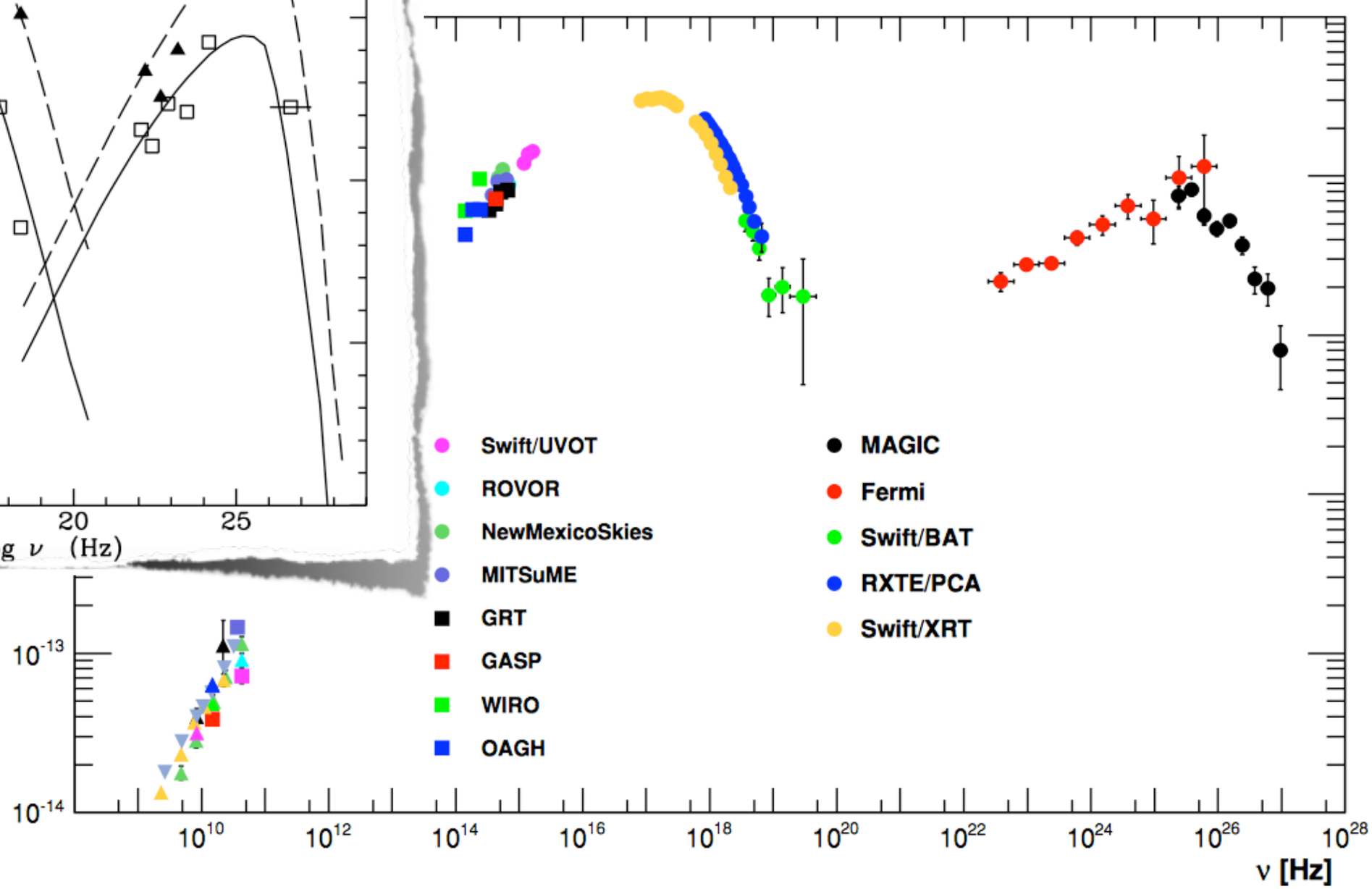


The golden era

FT et al. 1998

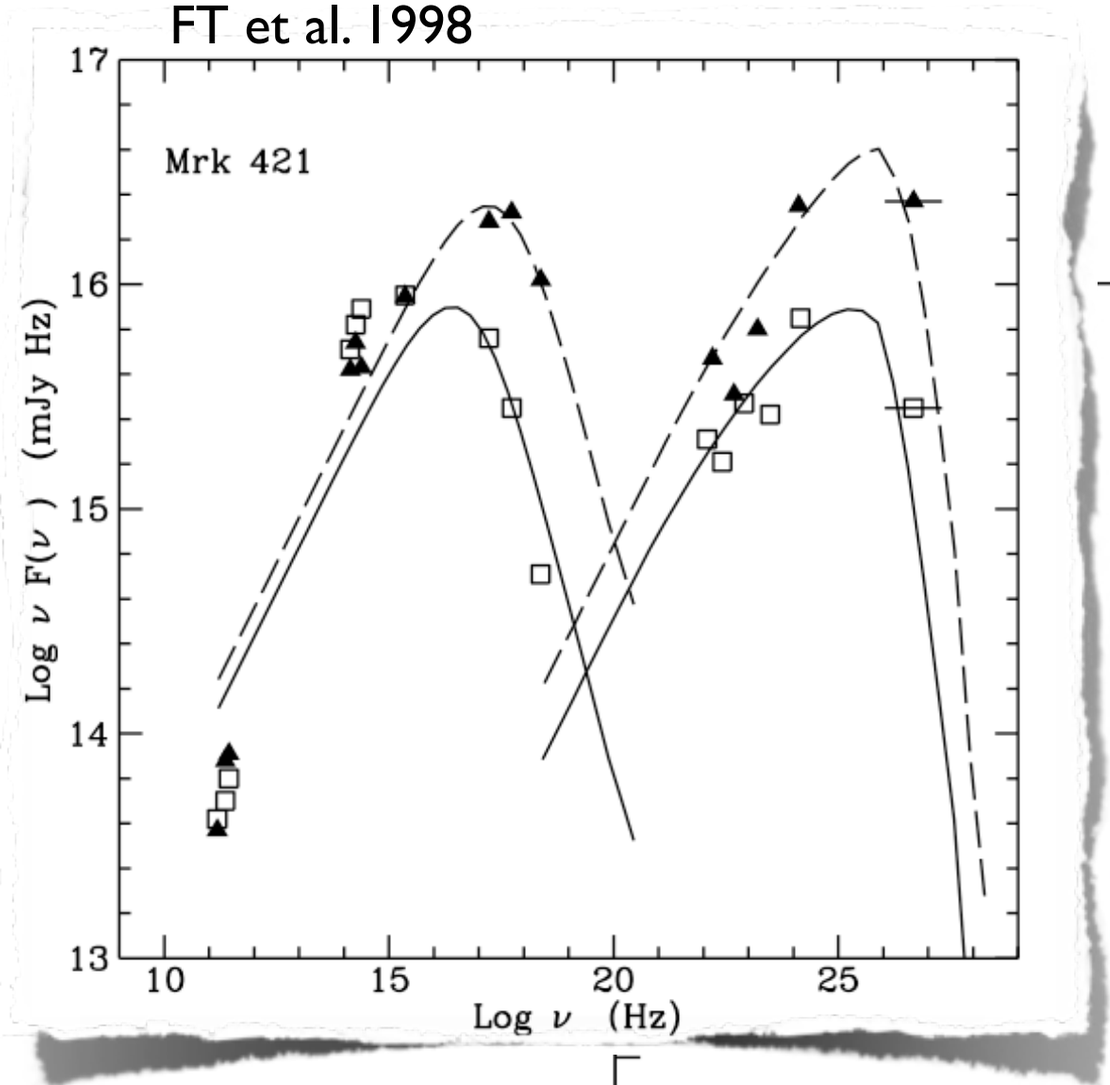


Abdo et al. 2011

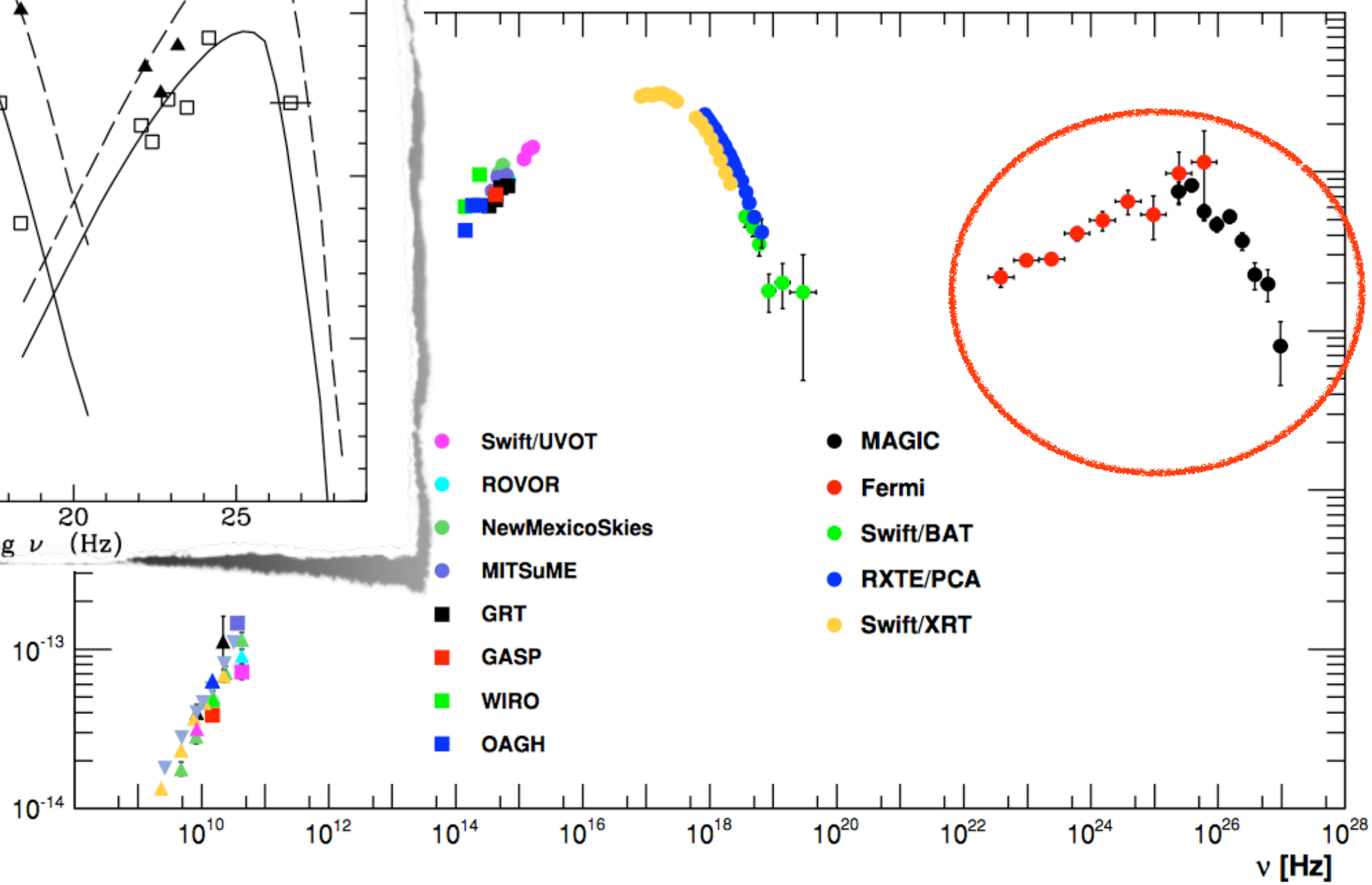


The golden era

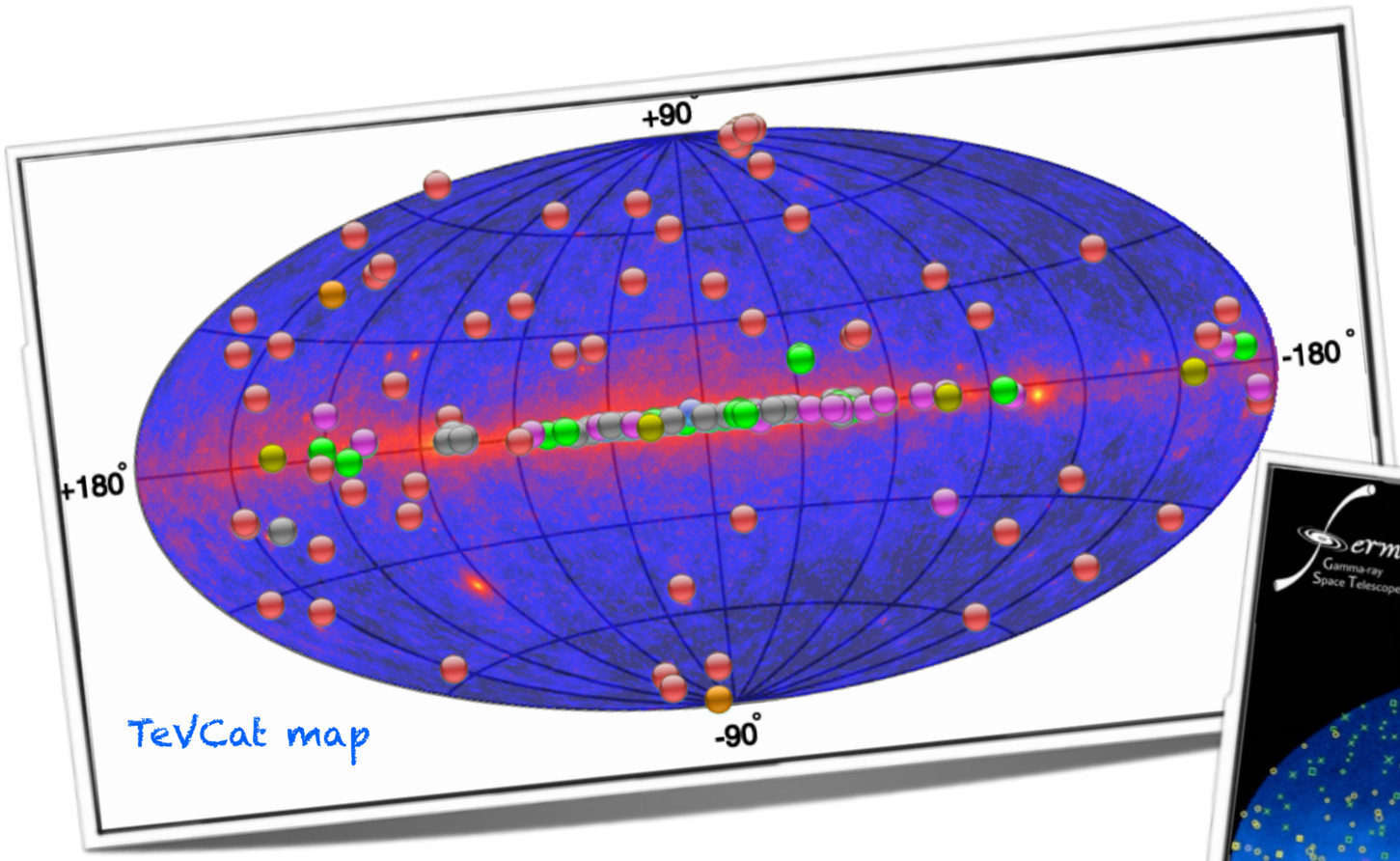
FT et al. 1998



Abdo et al. 2011



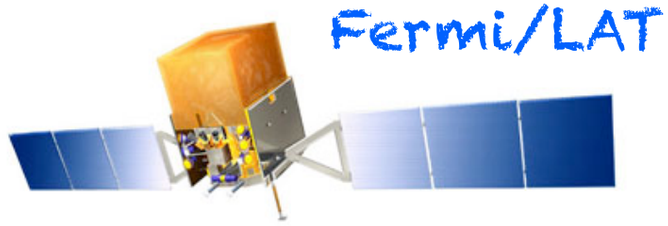
The golden era



TeVCat map

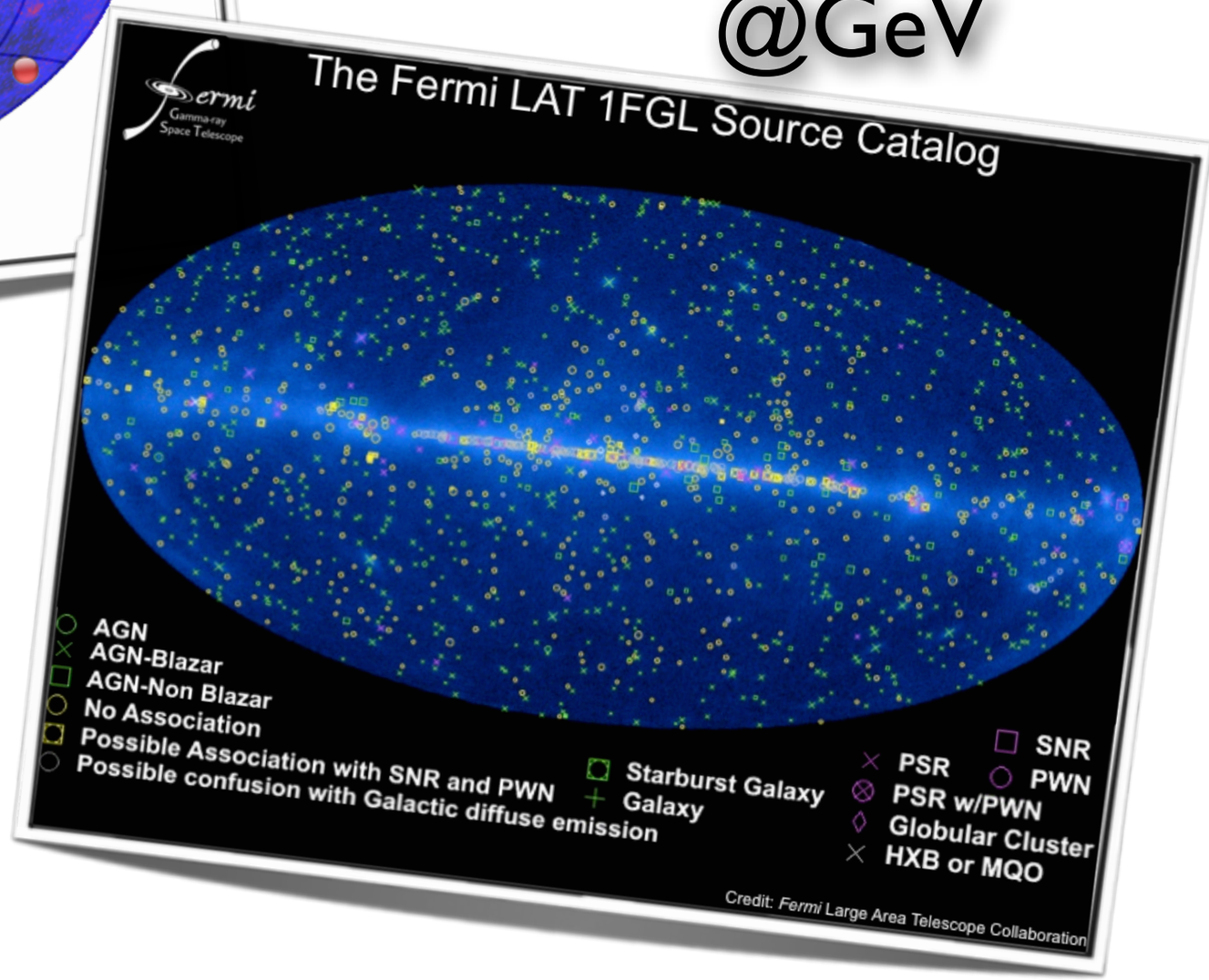
@TeV

Cherenkov Arrays

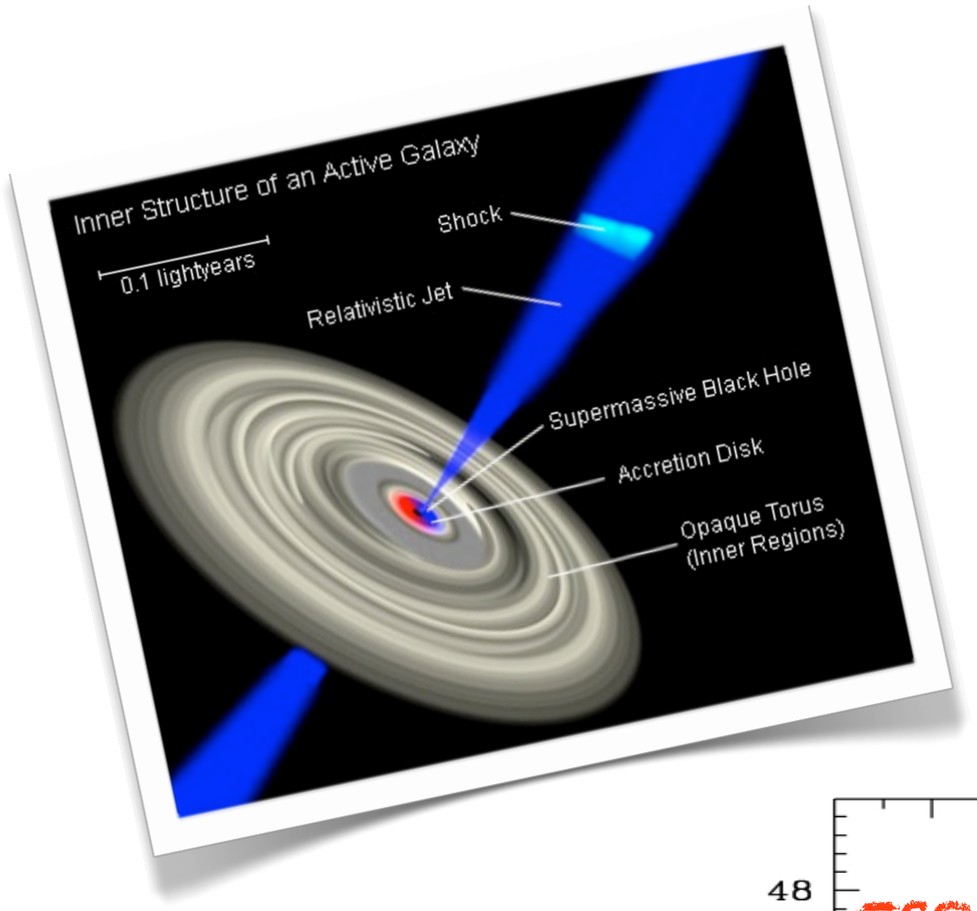


Fermi/LAT

@GeV



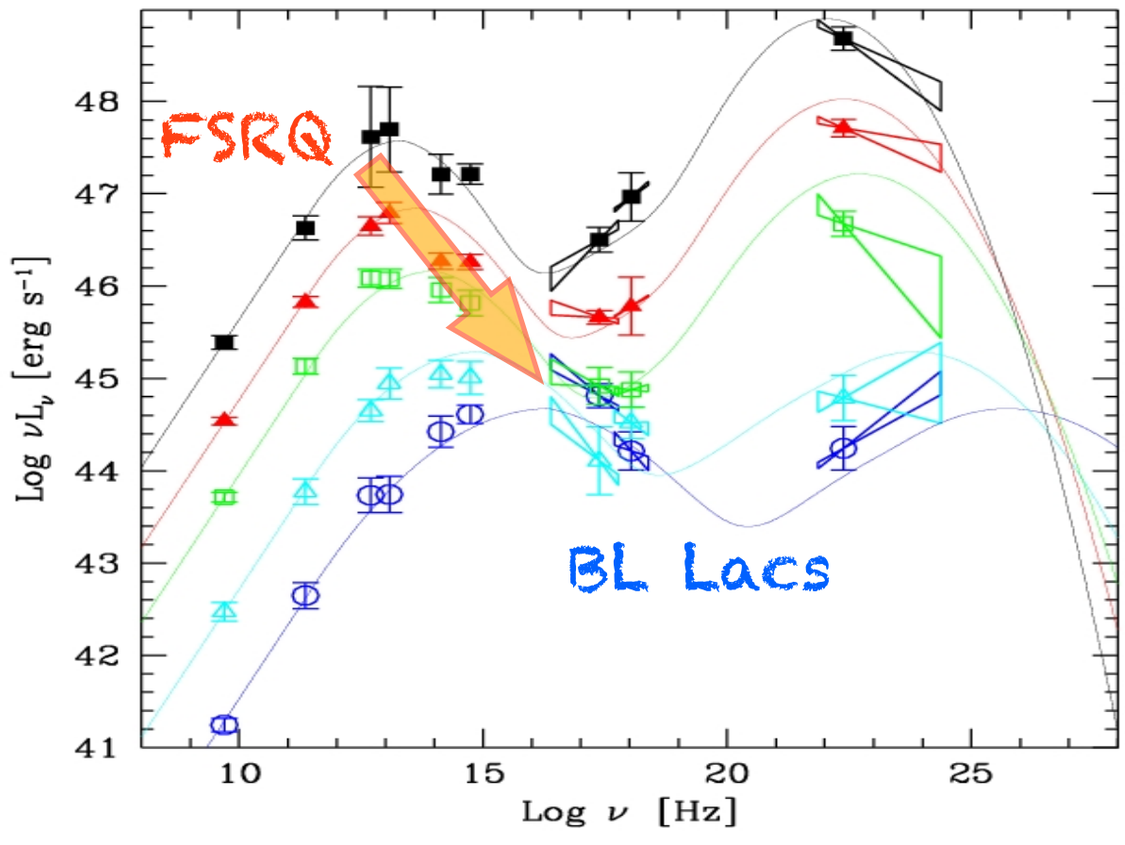
Blazars: basic phenomenology



Blazars occur in two flavors:

FSRQ: high power, thermal optical components

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

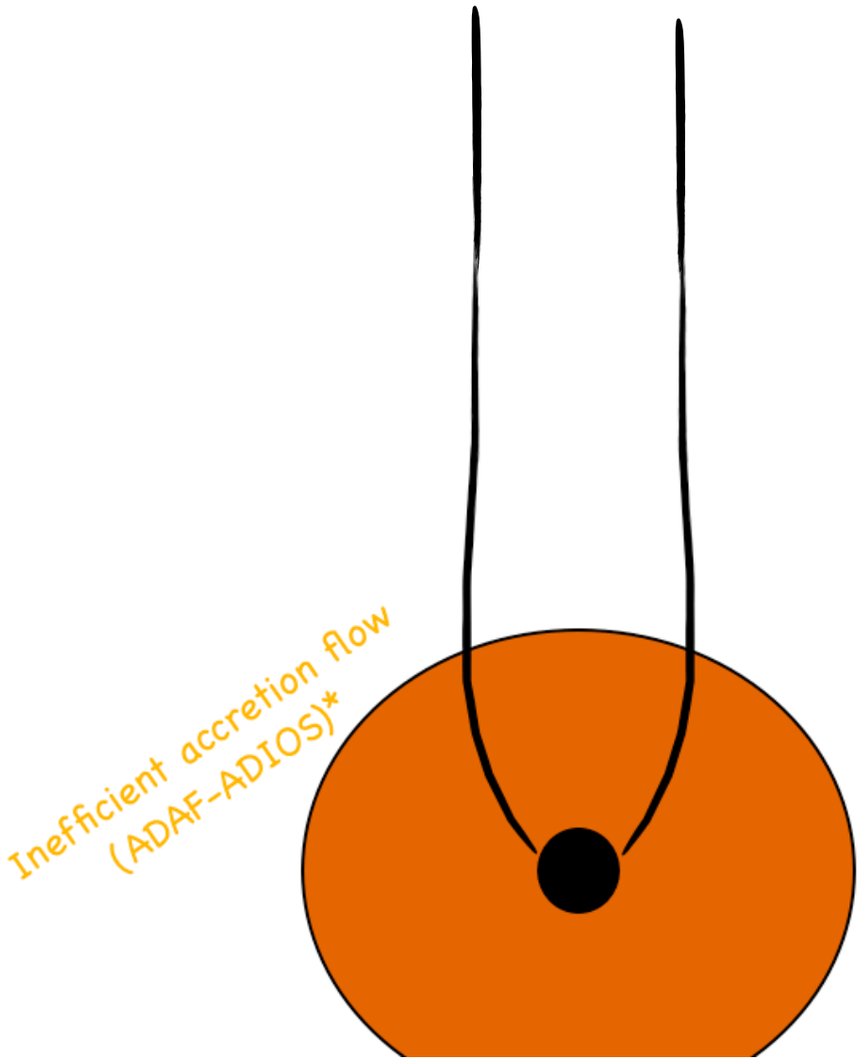


The "blazar sequence"

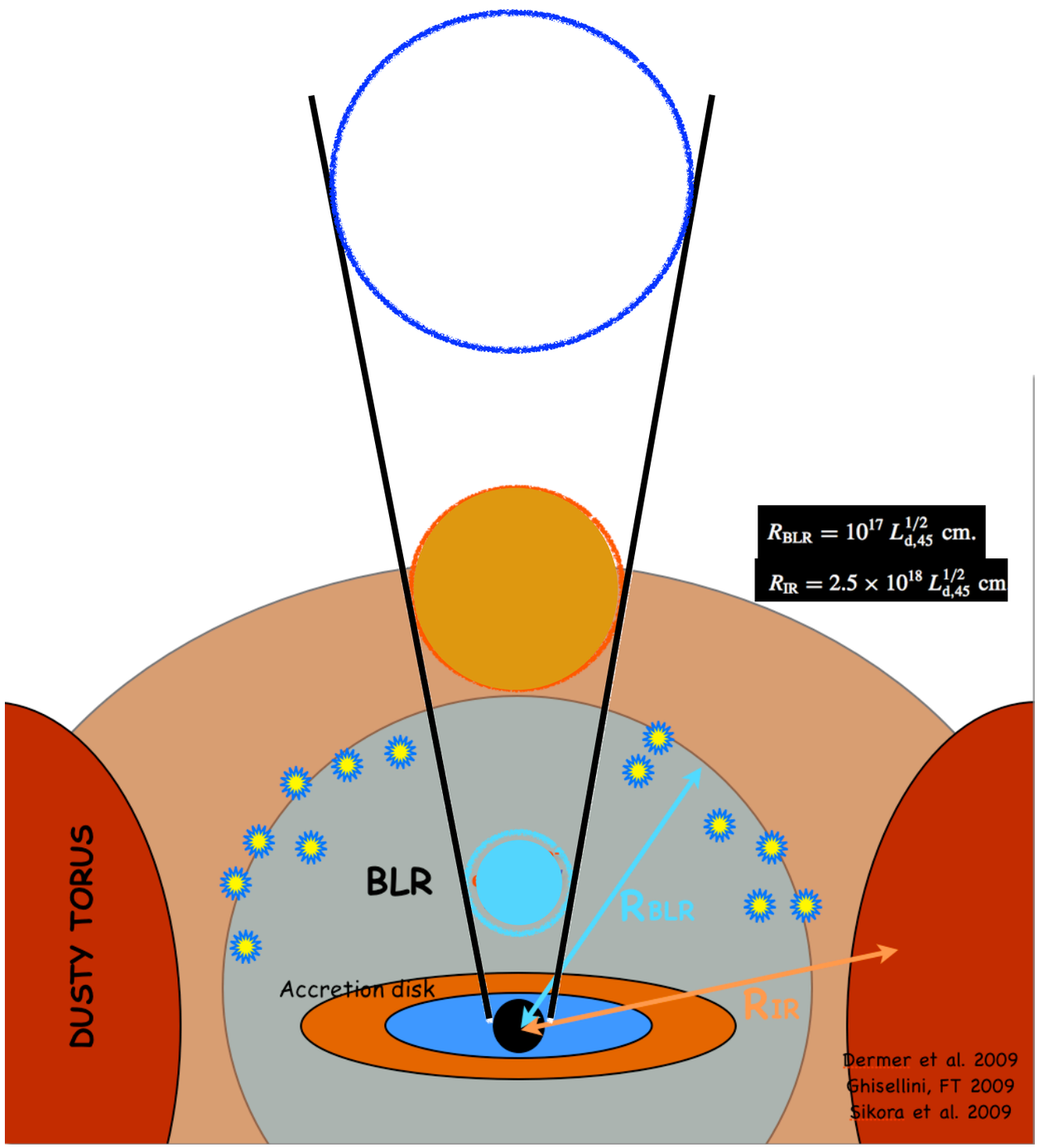
Fossati et al. 1998

Blazars: current discussions

BL Lacs: “naked” jets

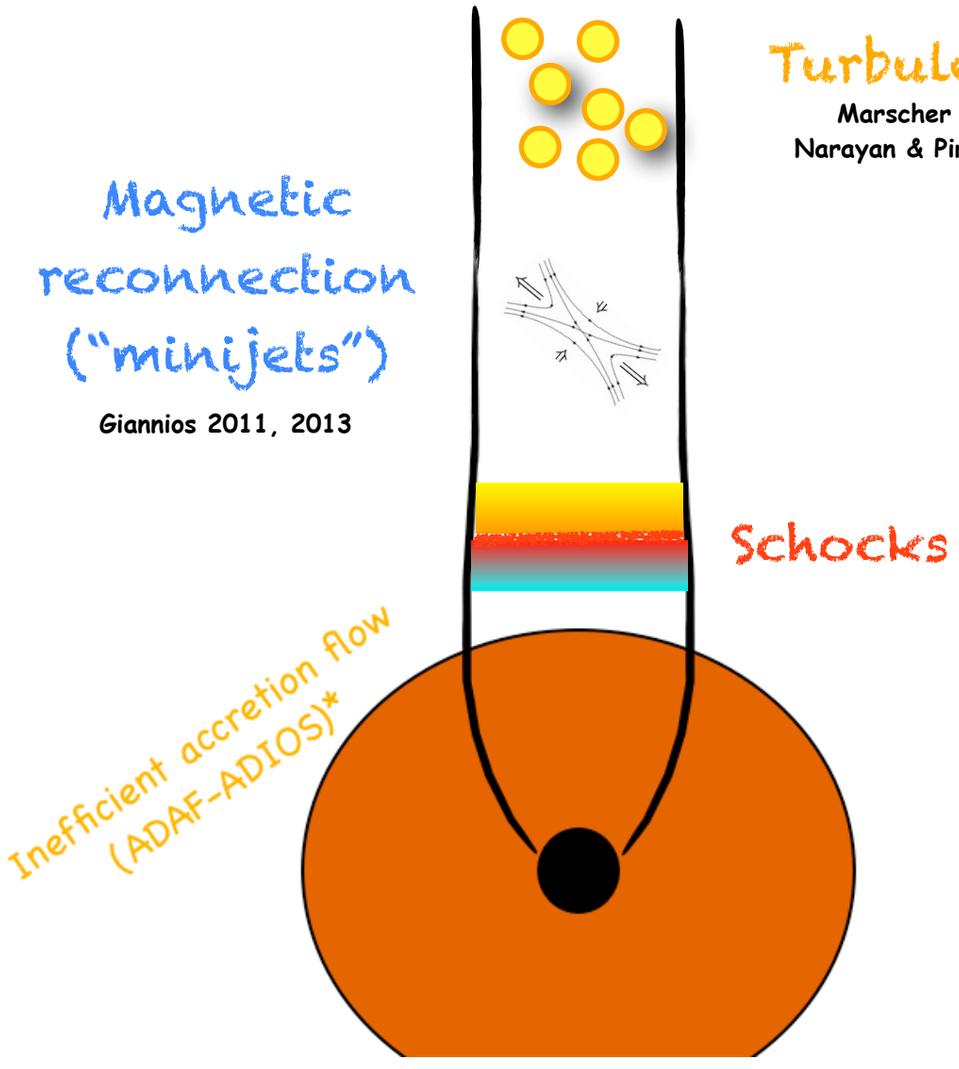


FSRQ: “dressed” jets

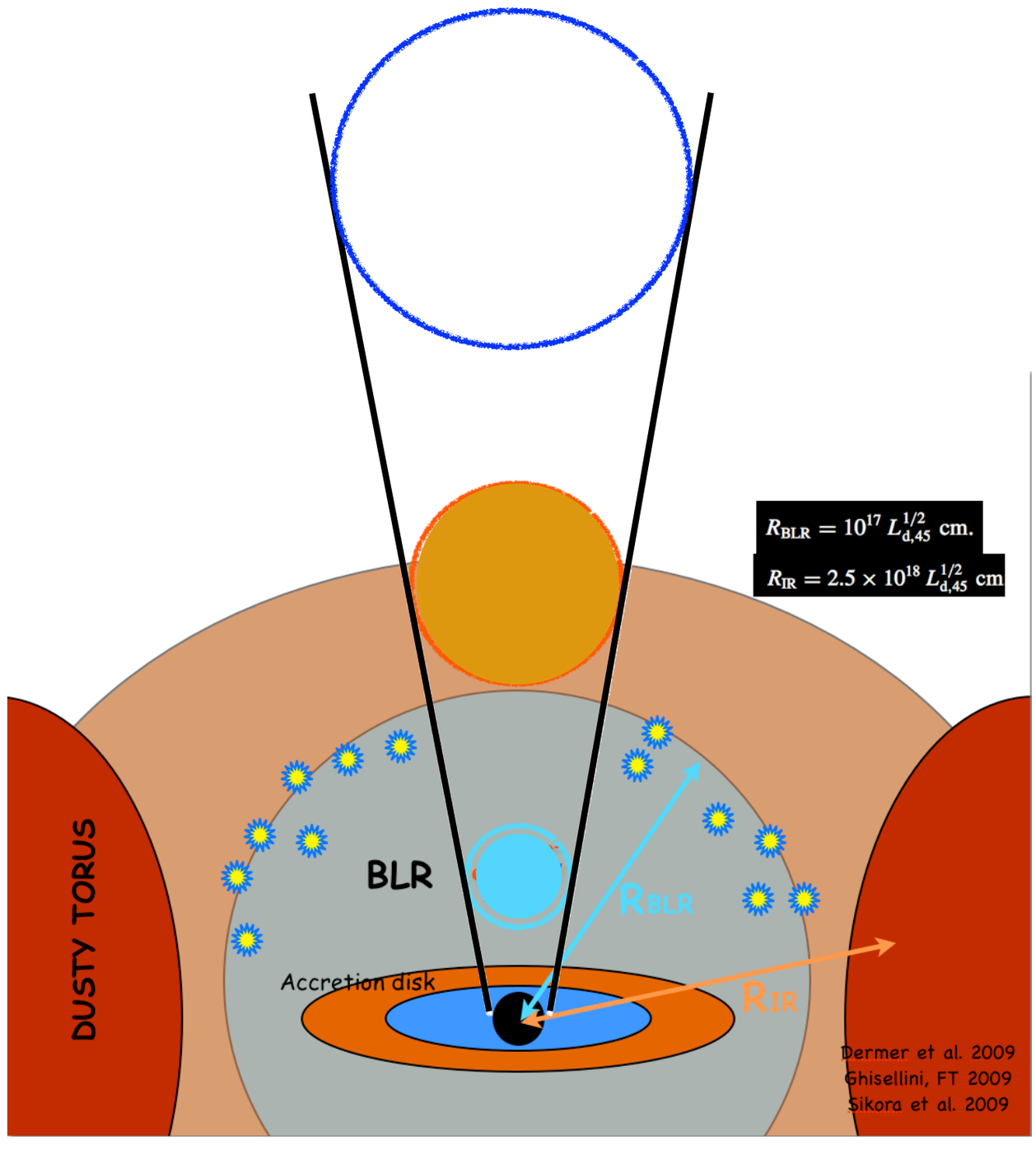


Blazars: current discussions

BL Lacs: "naked" jets

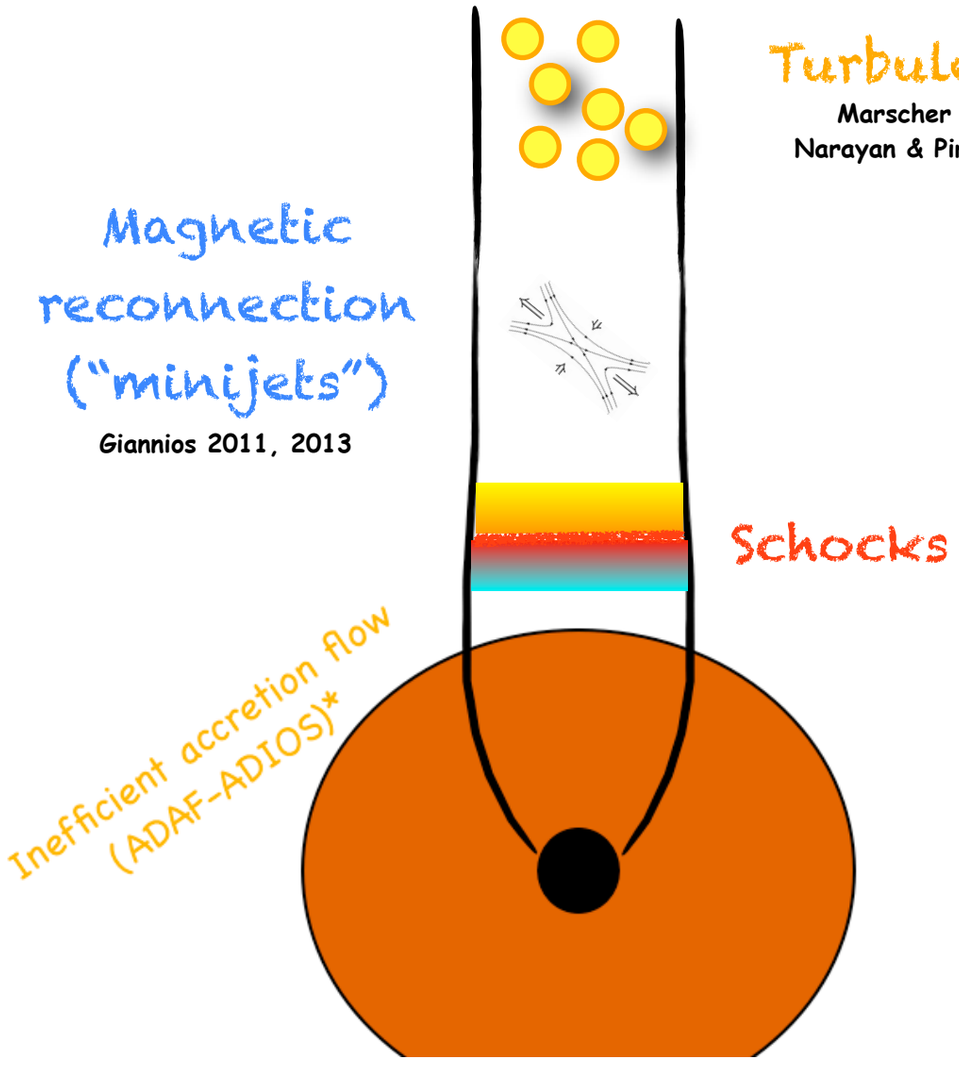


FSRQ: "dressed" jets

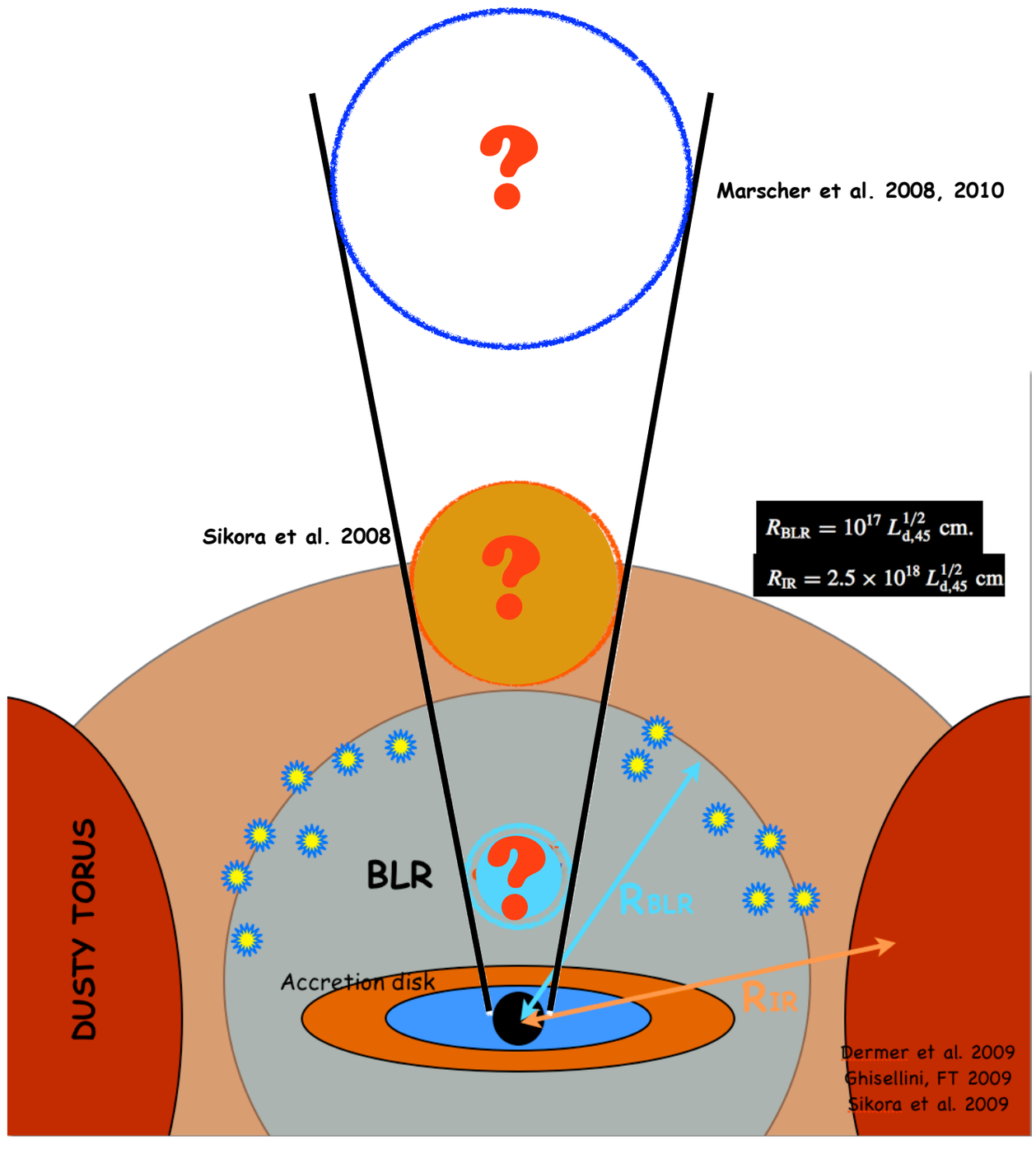


Blazars: current discussions

BL Lacs: "naked" jets

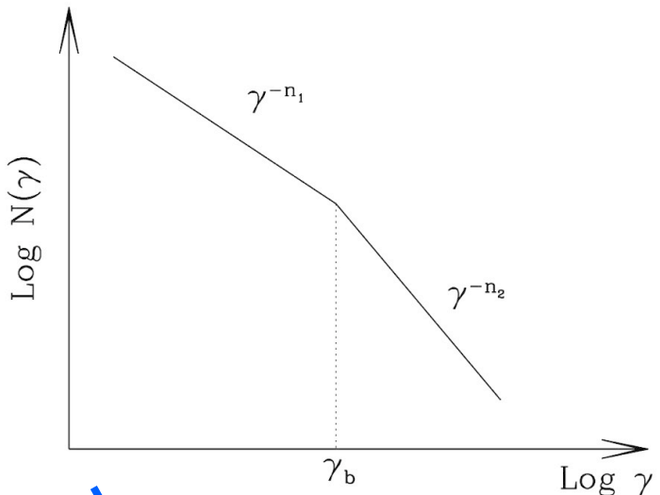


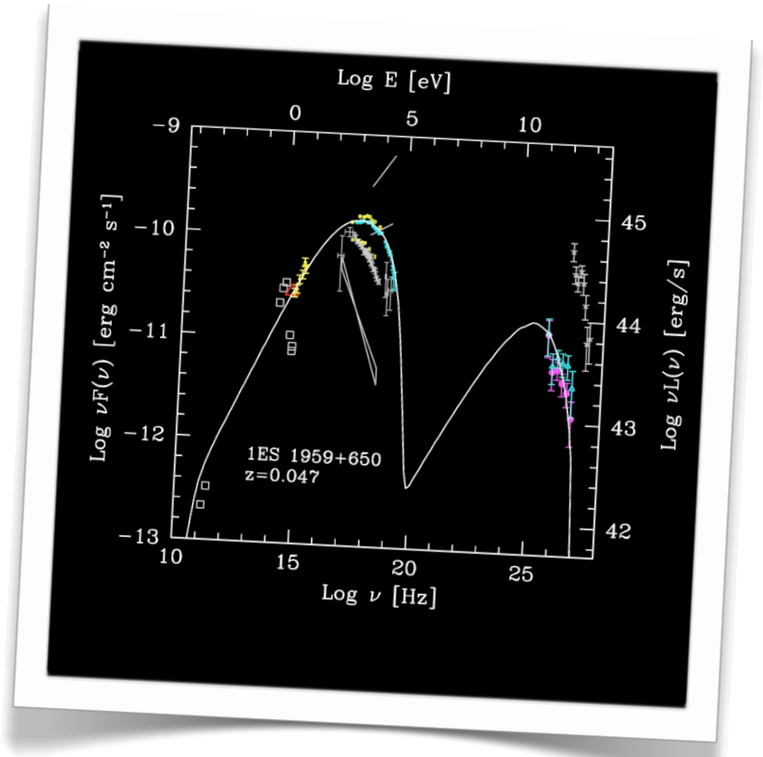
FSRQ: "dressed" jets



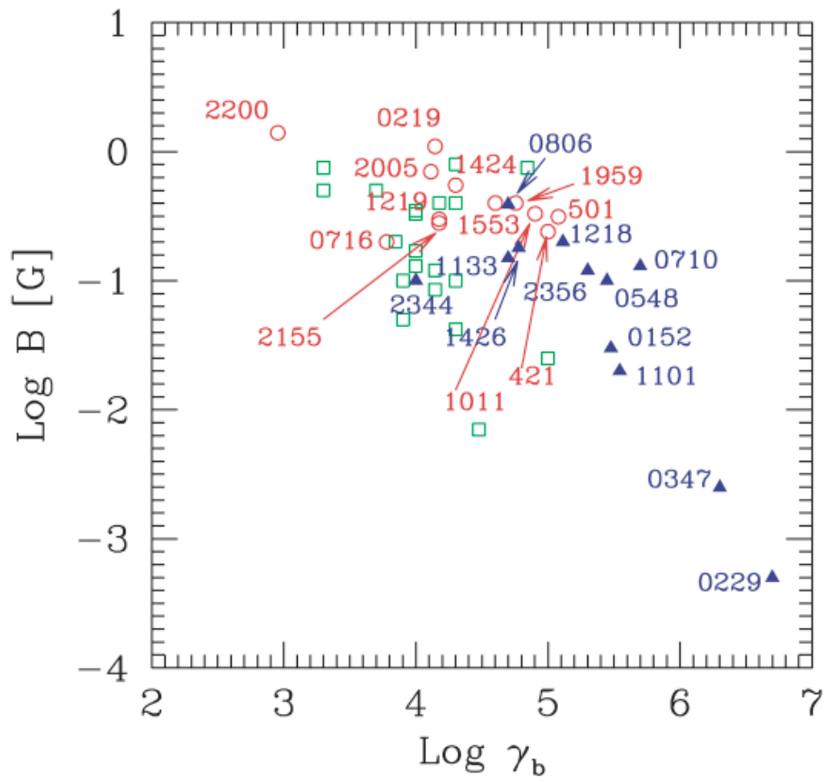
L. Pacciani talk

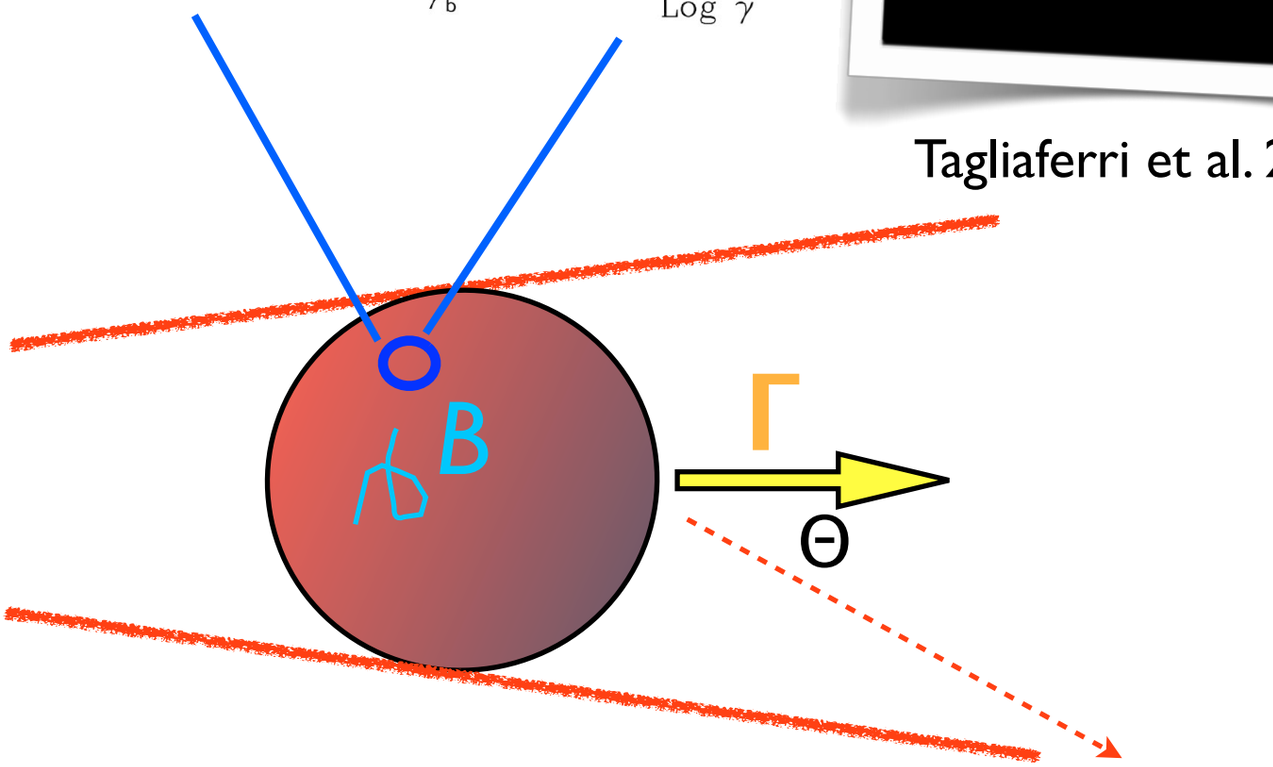
BL Lacs: the one zone model



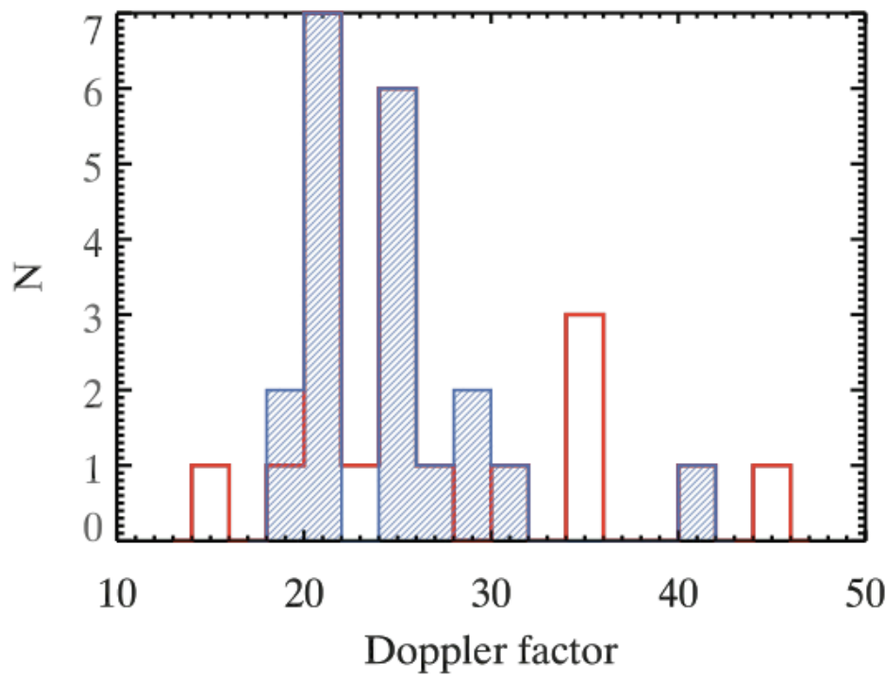


Tagliaferri et al. 2009



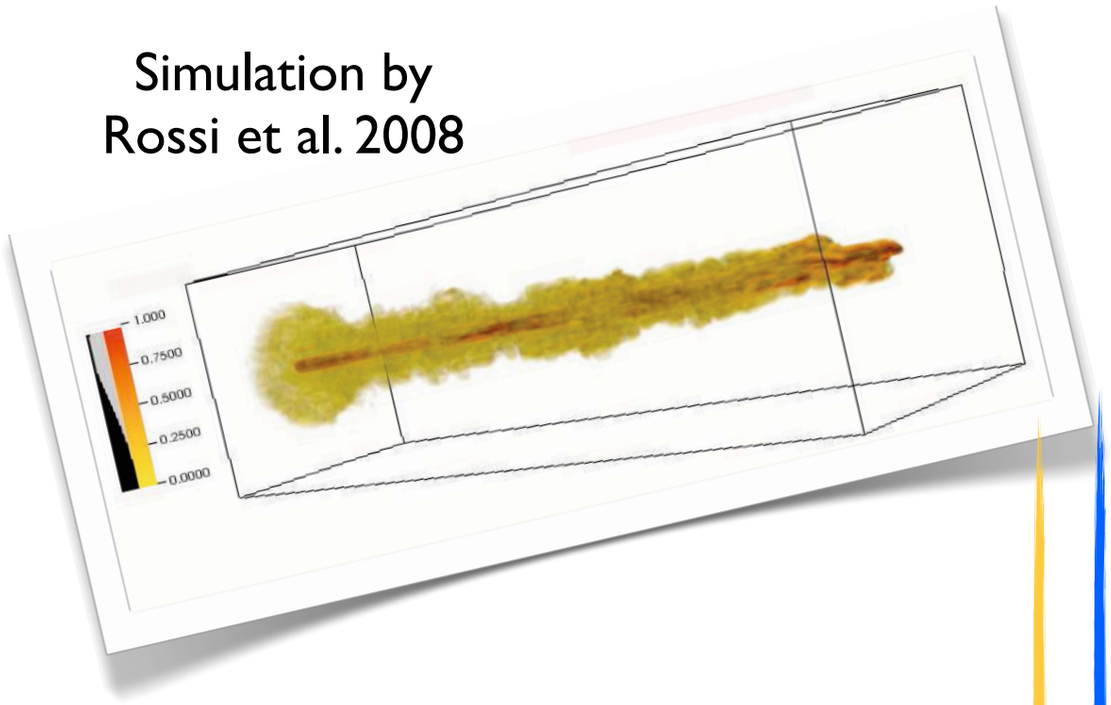


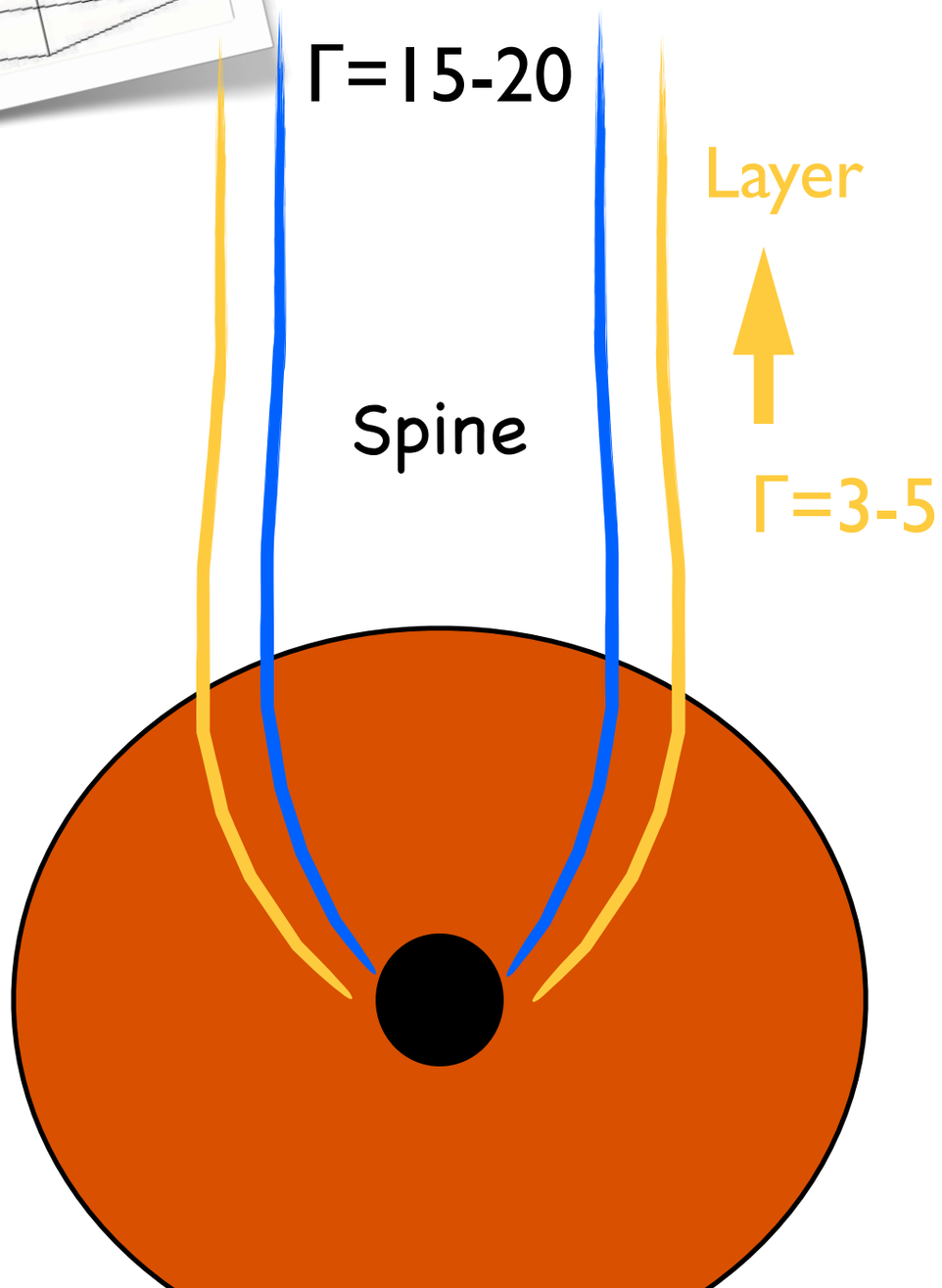
FT et al. 2010



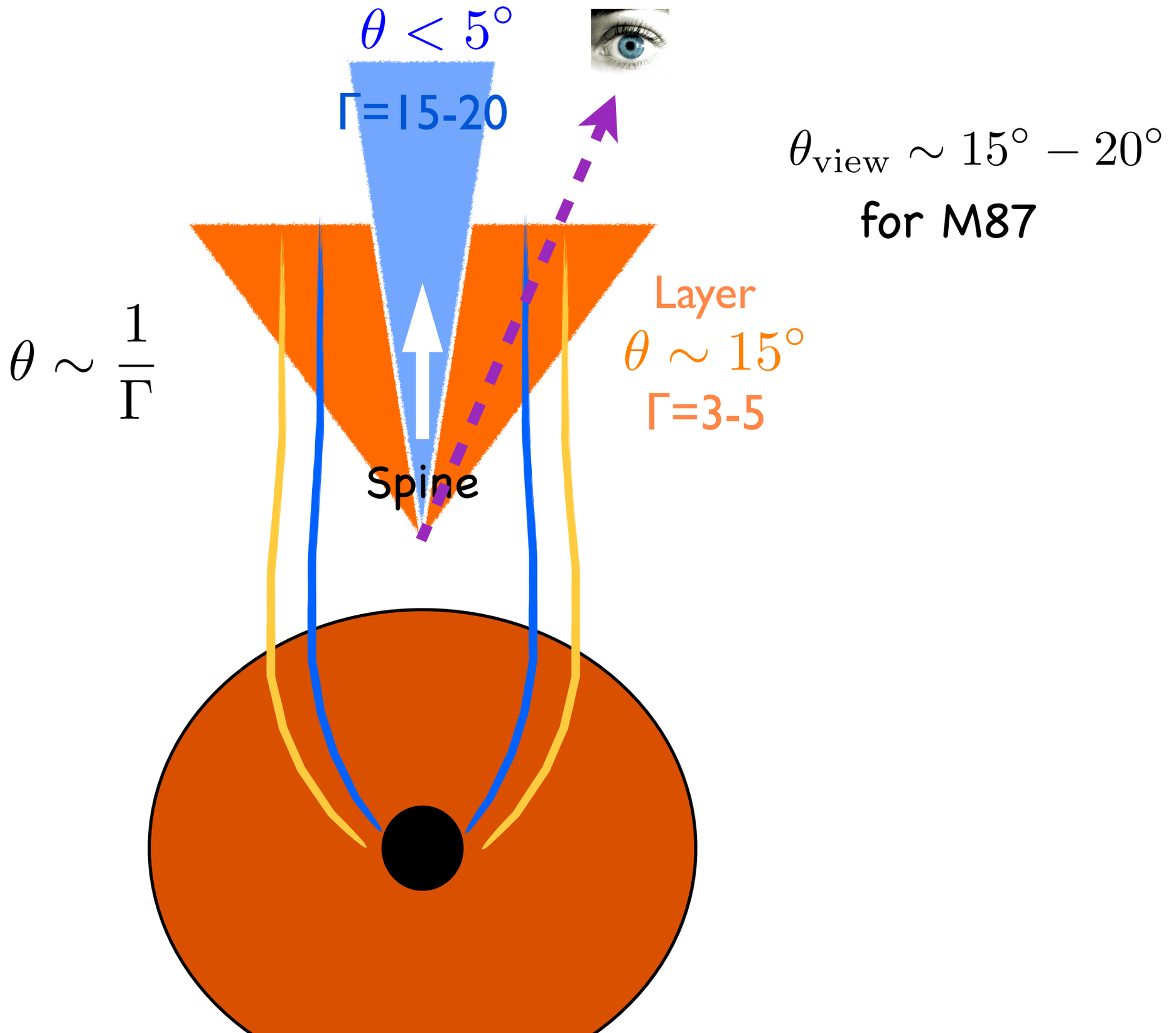
BL Lacs: the structured jet model

Simulation by
Rossi et al. 2008





Structured jets



$\theta_{\rm view} \sim 15^\circ - 20^\circ$

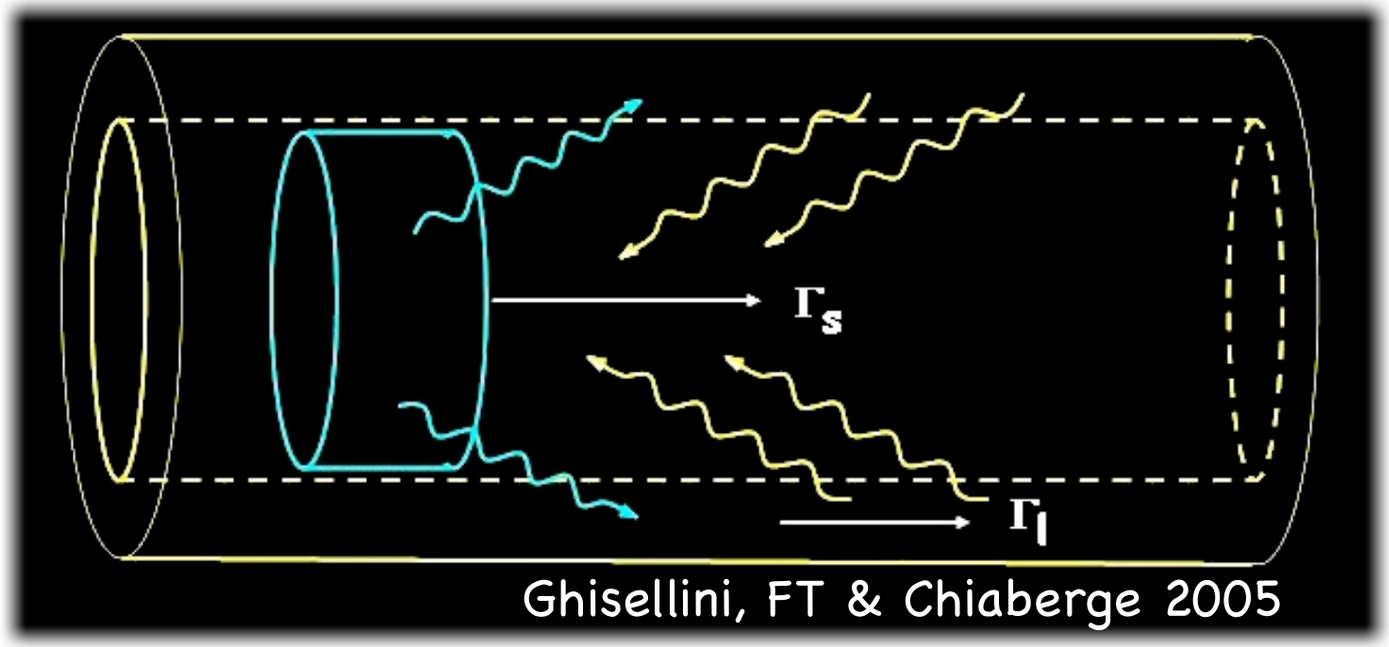
for M87

Structured jets

$$\Gamma_{\rm rel} = \Gamma_{\rm s}\Gamma_{\rm l}(1-\beta_{\rm s}\beta_{\rm l})$$

$$U' \simeq U\Gamma_{\rm rel}^2$$

$$L_{\rm IC} \propto U'$$

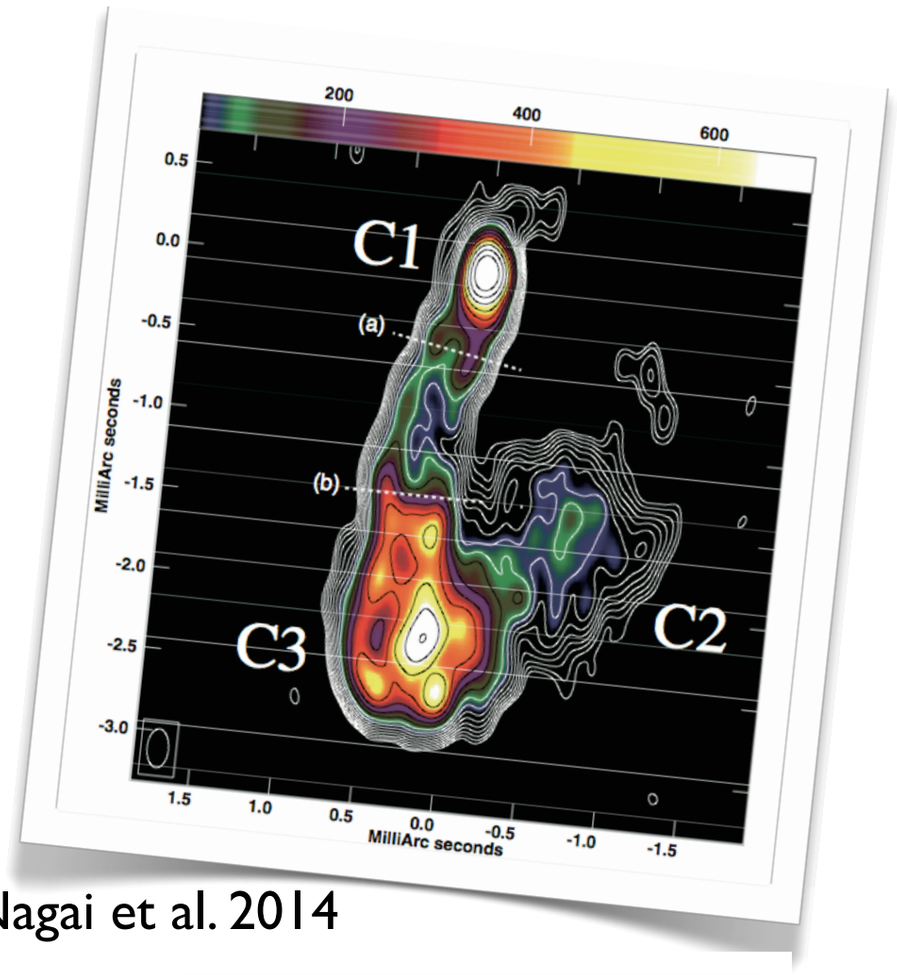


★ The spine sees an enhanced U_{rad} coming from the layer

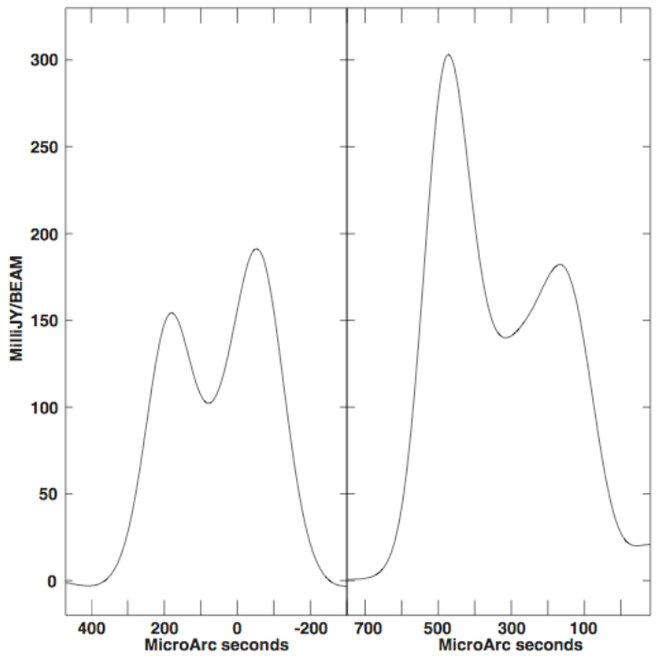
★ Also the layer sees an enhanced U_{rad} coming from the spine

The IC emission is enhanced w.r.t. to the one-zone model

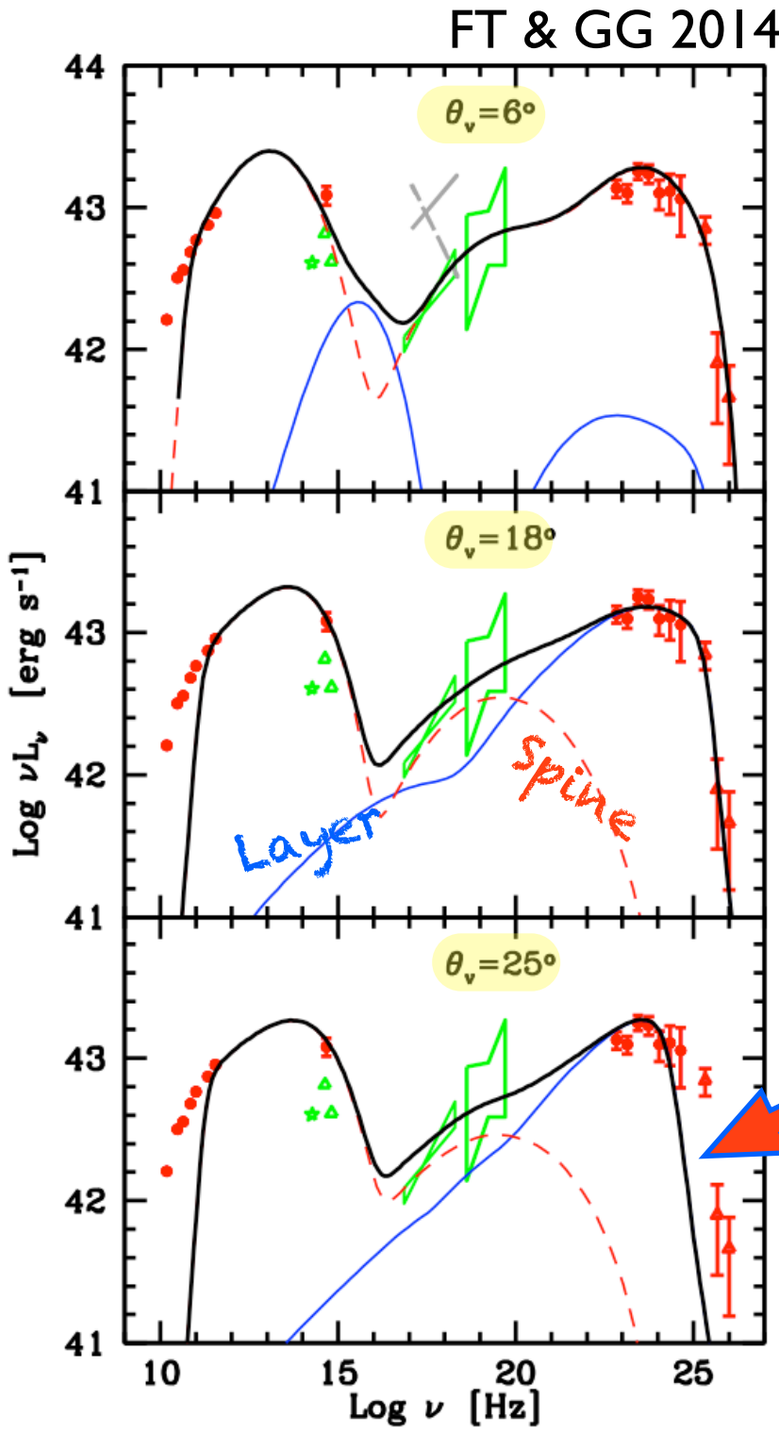
Structured jets: radiogalaxies



Nagai et al. 2014



FT & GG 2014



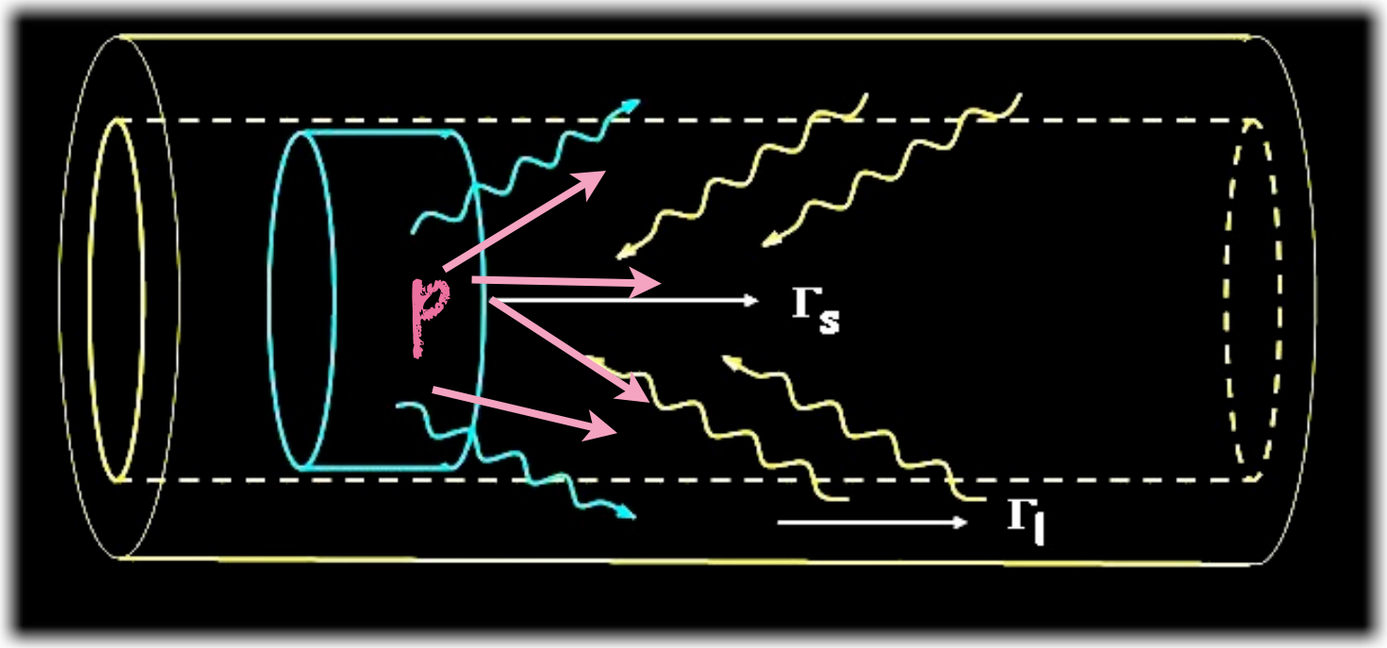
NGC 1275

Absorbed E>50 GeV

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

Structured jets: neutrinos

FT et al. 2014



$$p + \gamma \rightarrow n + \pi^+$$

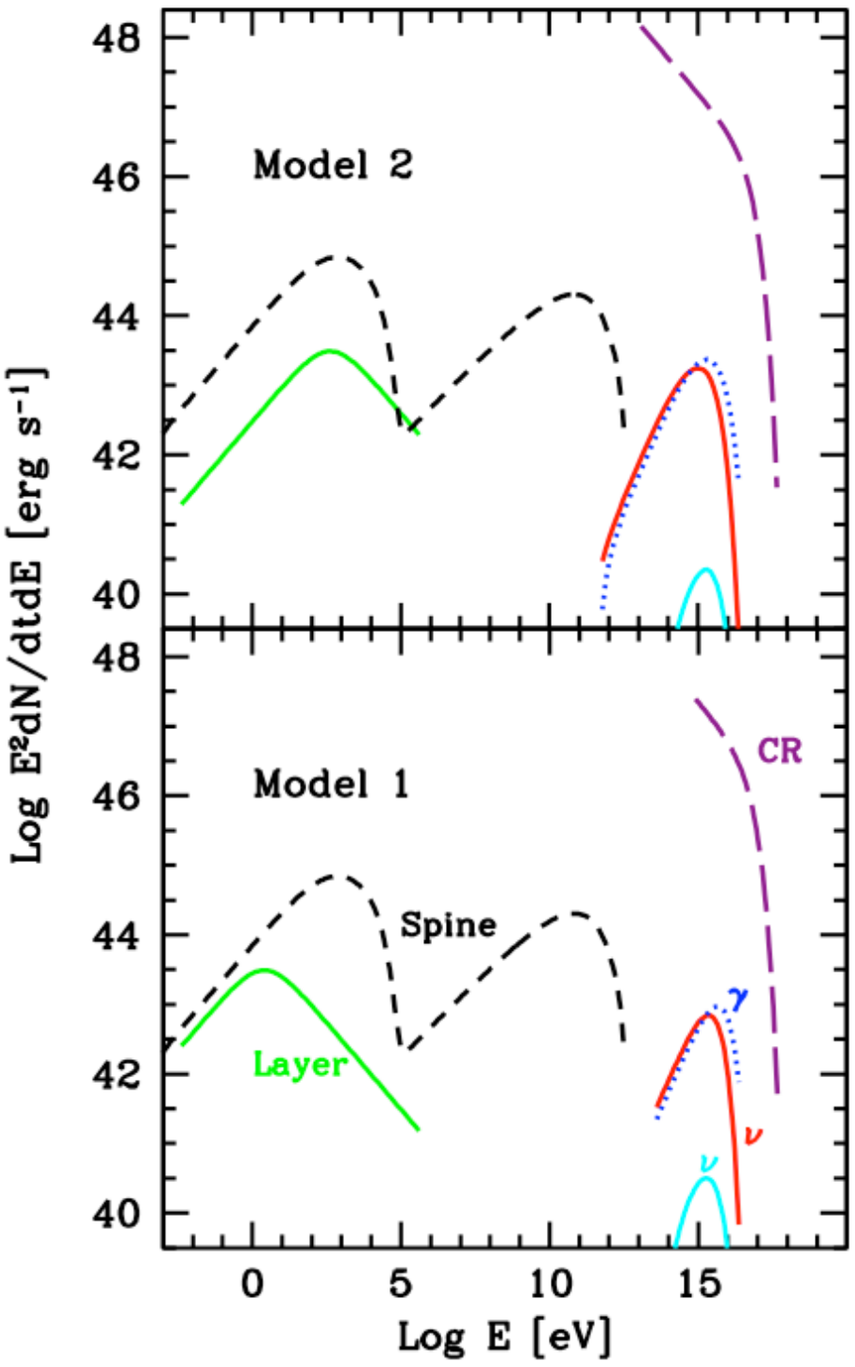
$$p + \gamma \rightarrow p + \pi^0$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \bar{\nu}_e + \bar{\nu}_\mu + \nu_\mu$$

$$\pi^0 \rightarrow 2\gamma$$

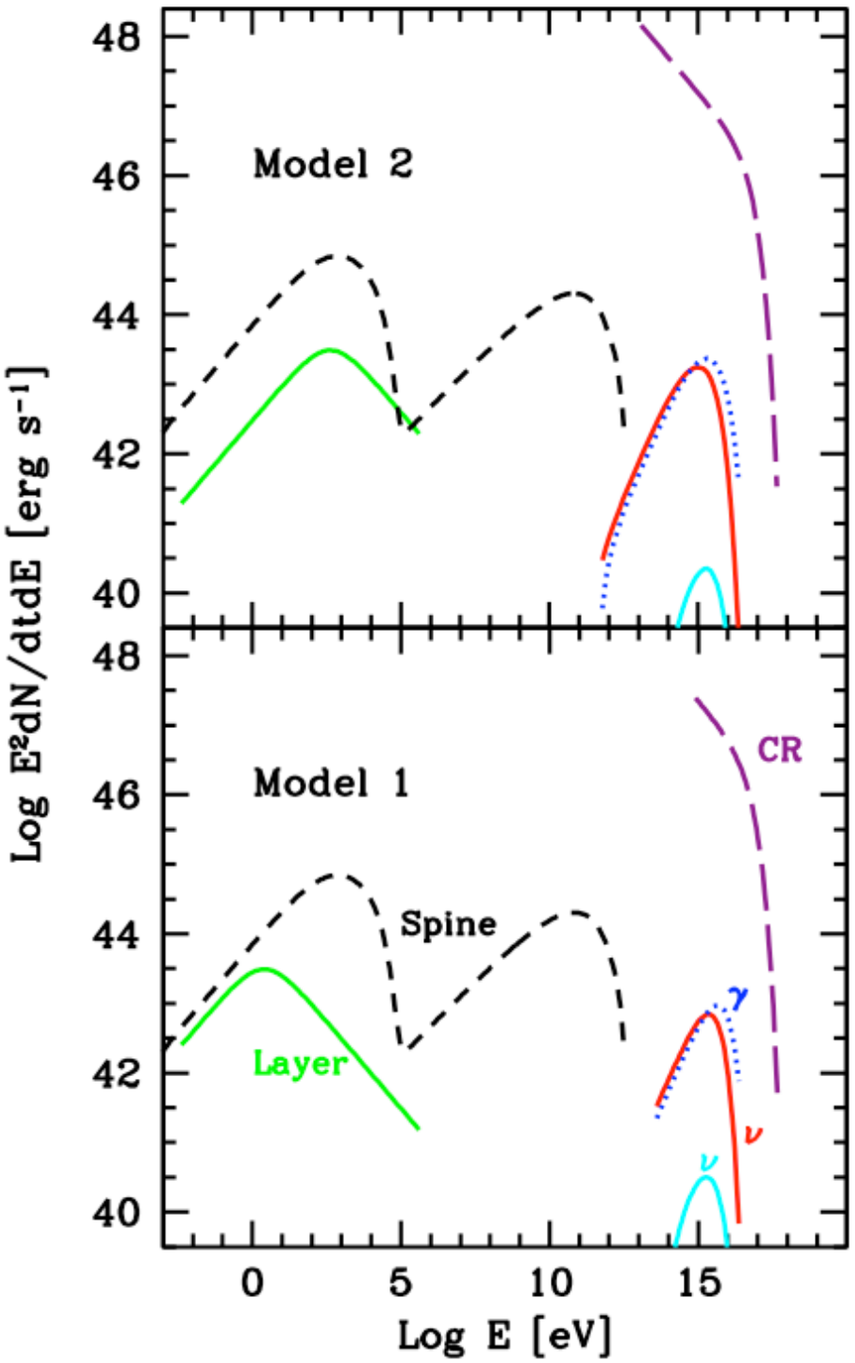
Structured jets: neutrinos

FT et al. 2014



Structured jets: neutrinos

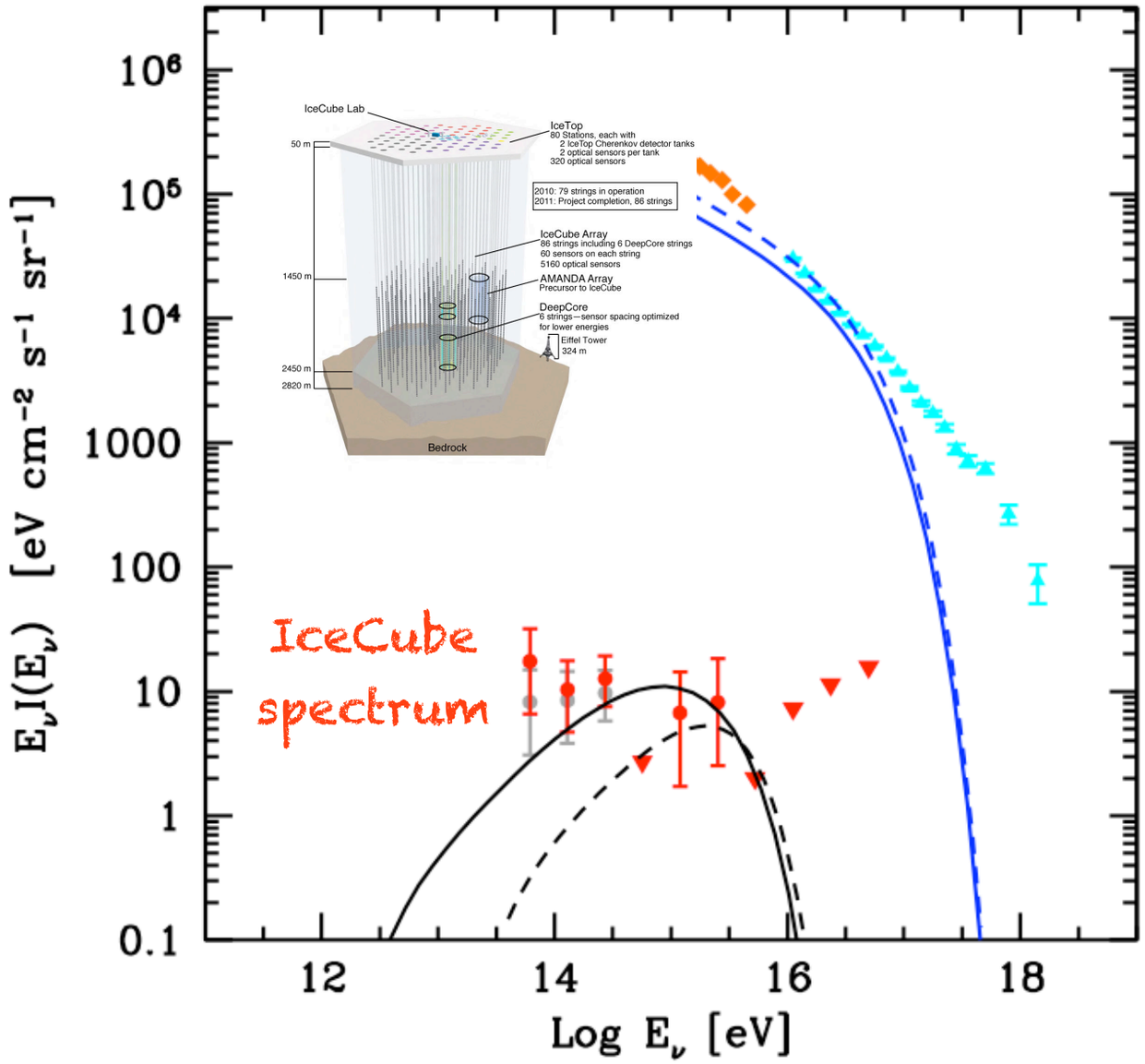
FT et al. 2014



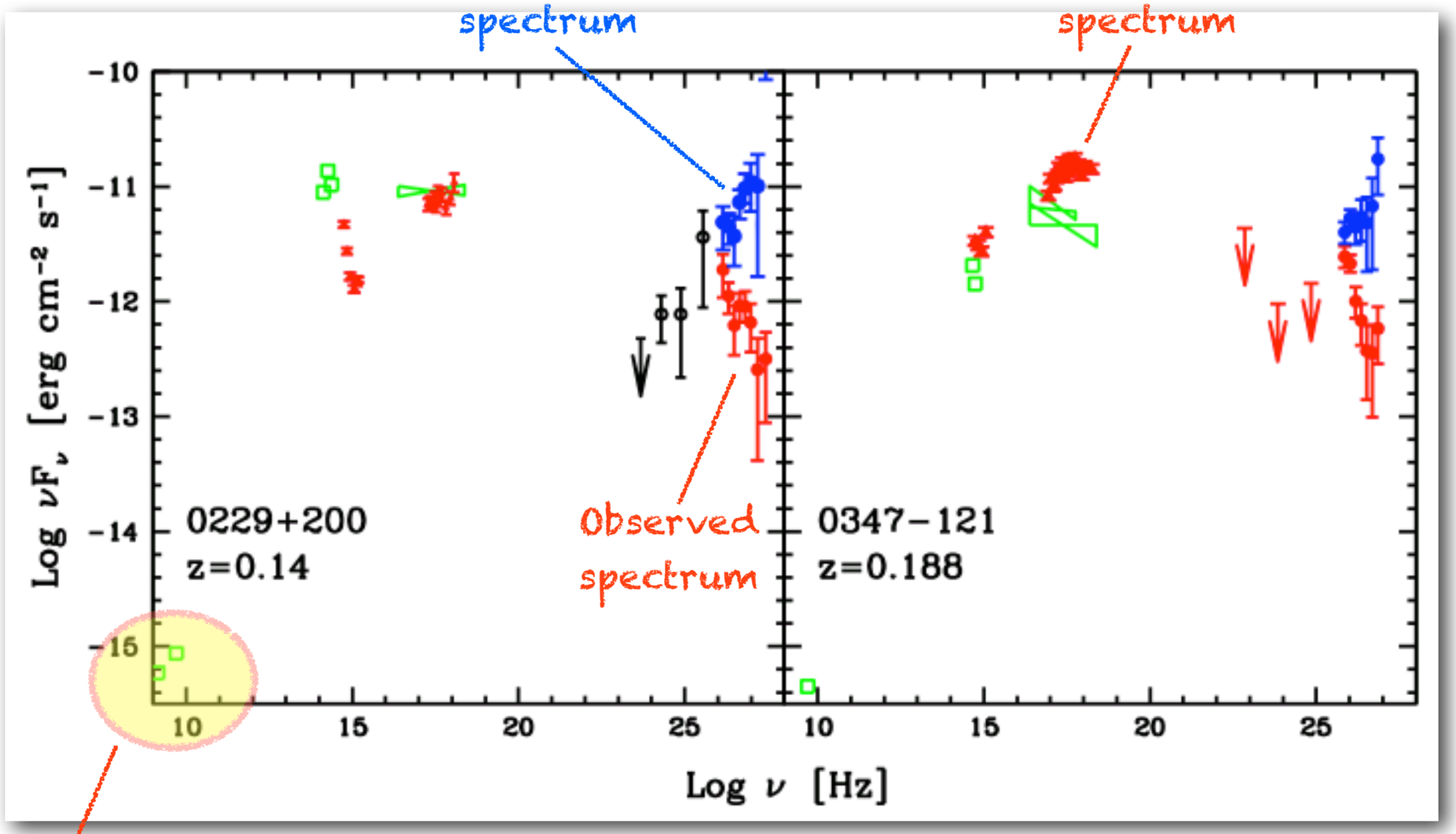
Cumulative emission assuming a fast evolution of HBL

$$N(z) = N_o(1+z)^{-6}$$

Ajello et al. 2014



Extreme BL Lacs



Very low radio power (very compact)

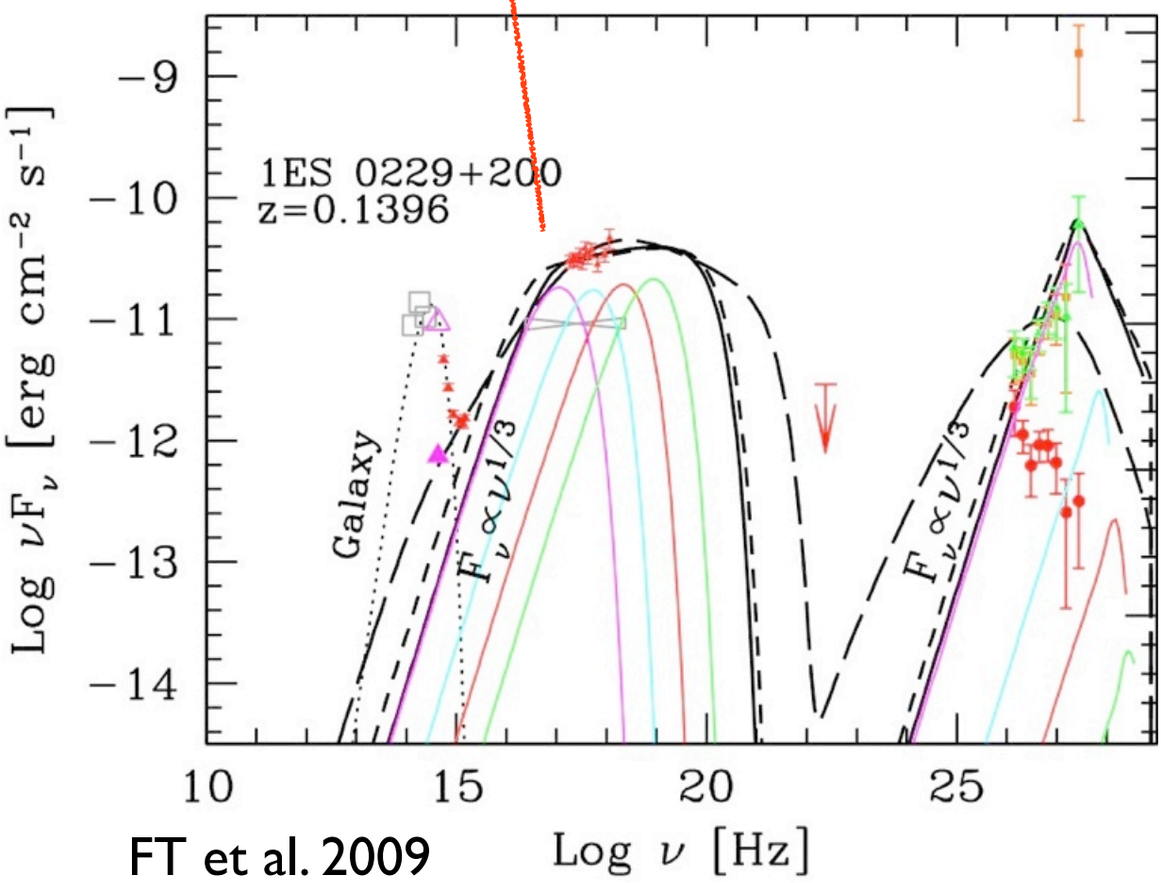
Very hard X-ray and gamma-ray (deabsorbed) spectra

Rather modest variability

Extreme BL Lacs

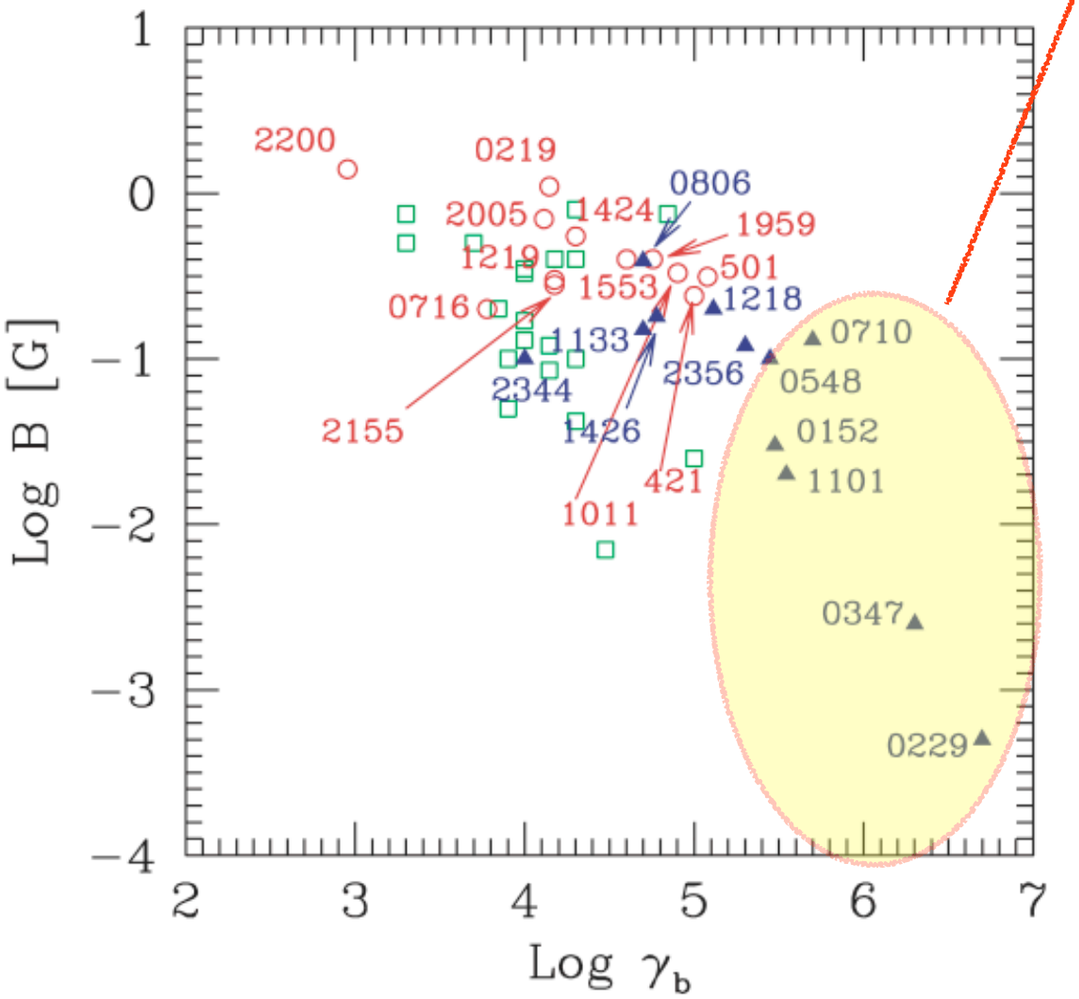
after Costamante et al. 2001

Large minimum electron energy



FT et al. 2009

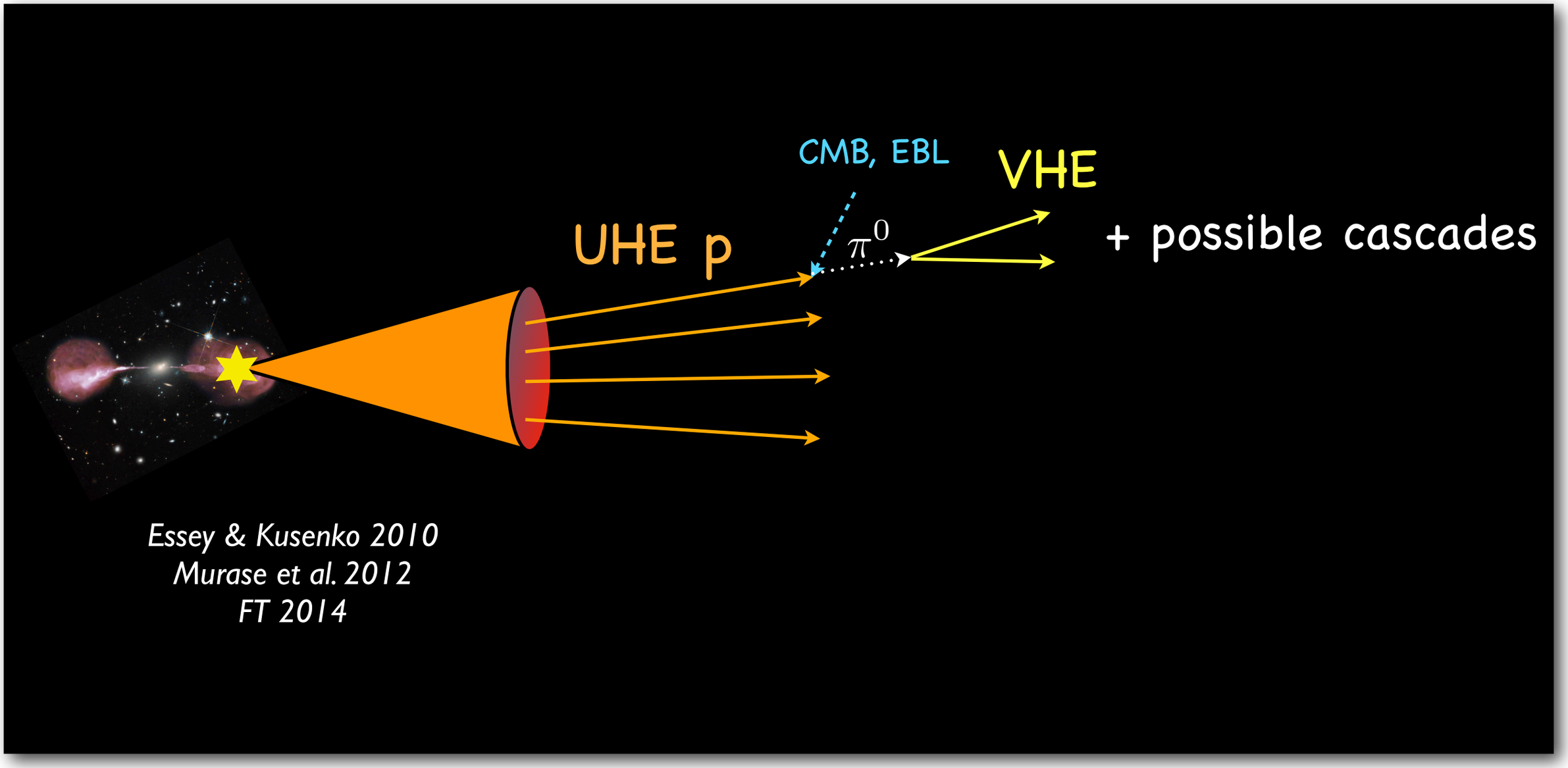
Very low B
Large energies



Acceleration process?

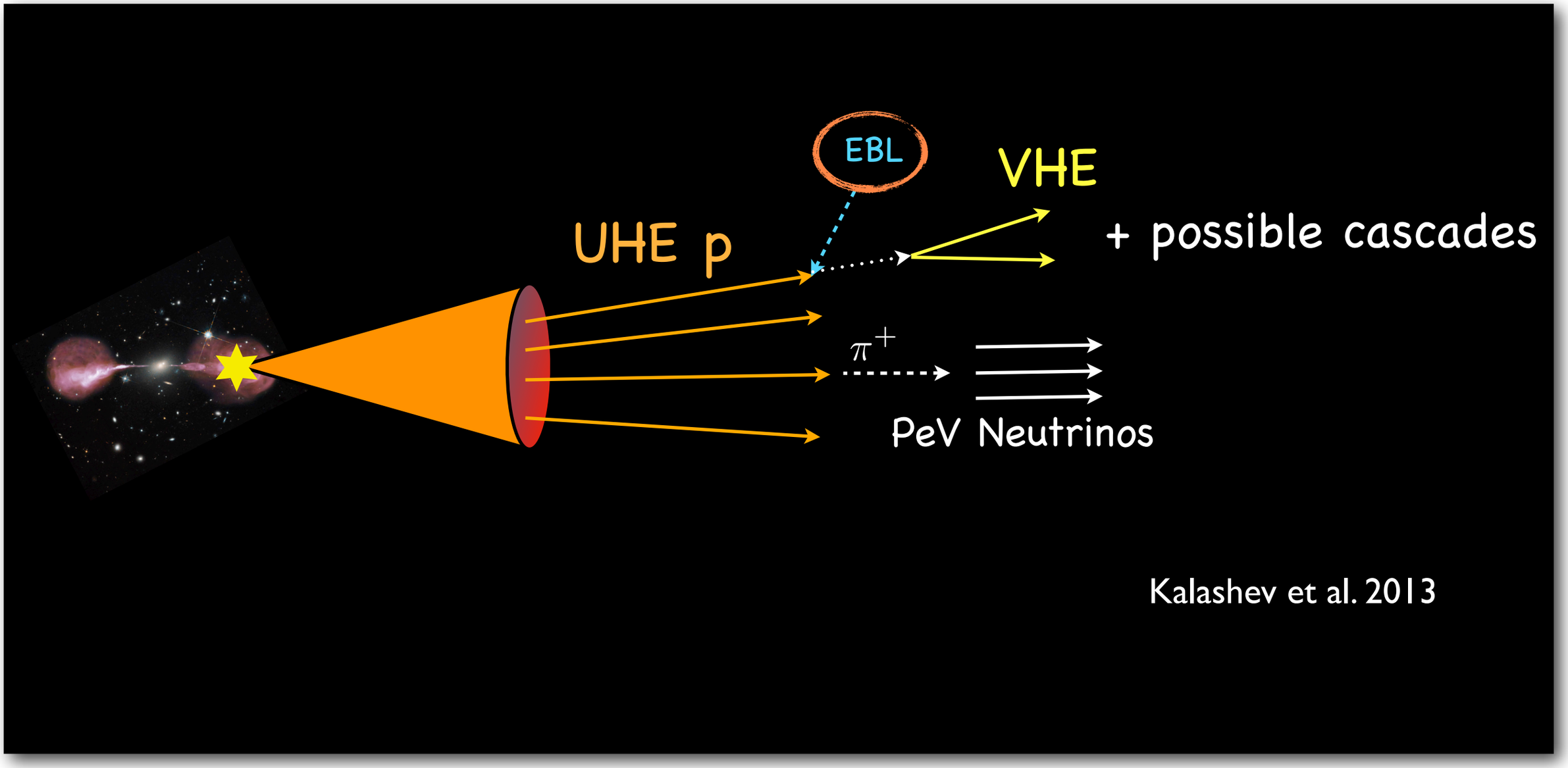
Why slowly variable?

Proton beams?



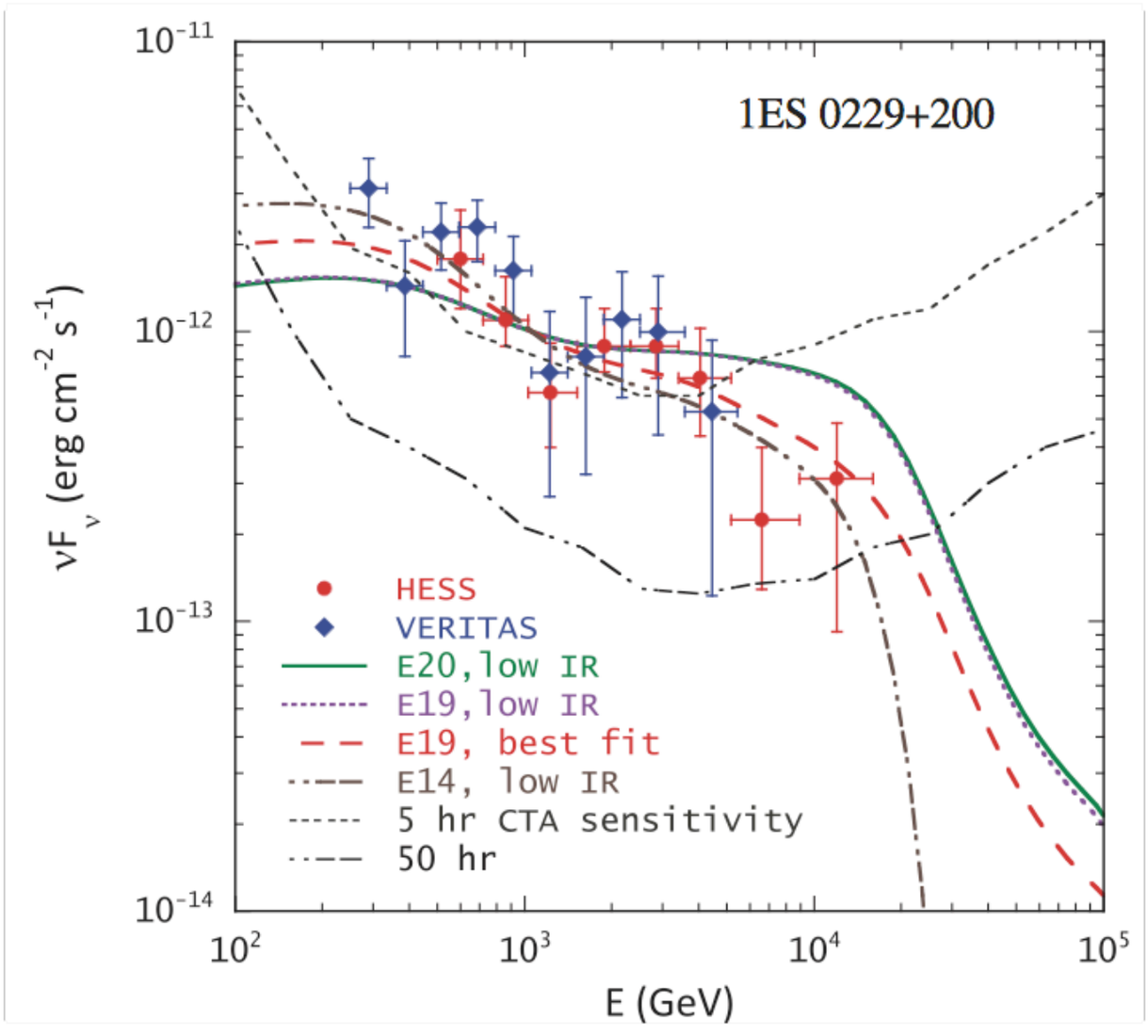
Essey & Kusenko 2010
Murase et al. 2012
FT 2014

Proton beams?



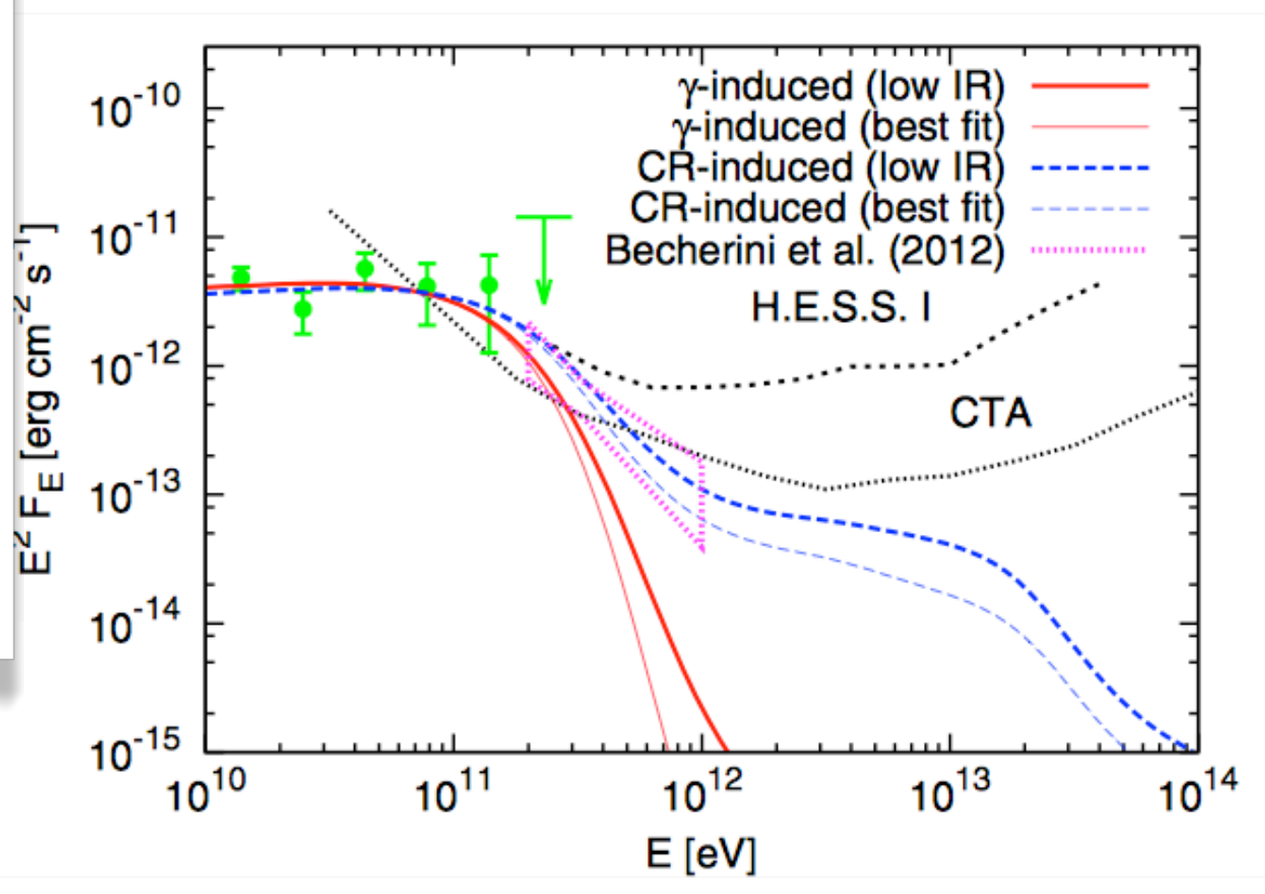
Proton beams?

Murase et al. 2012



To be observed with CTA

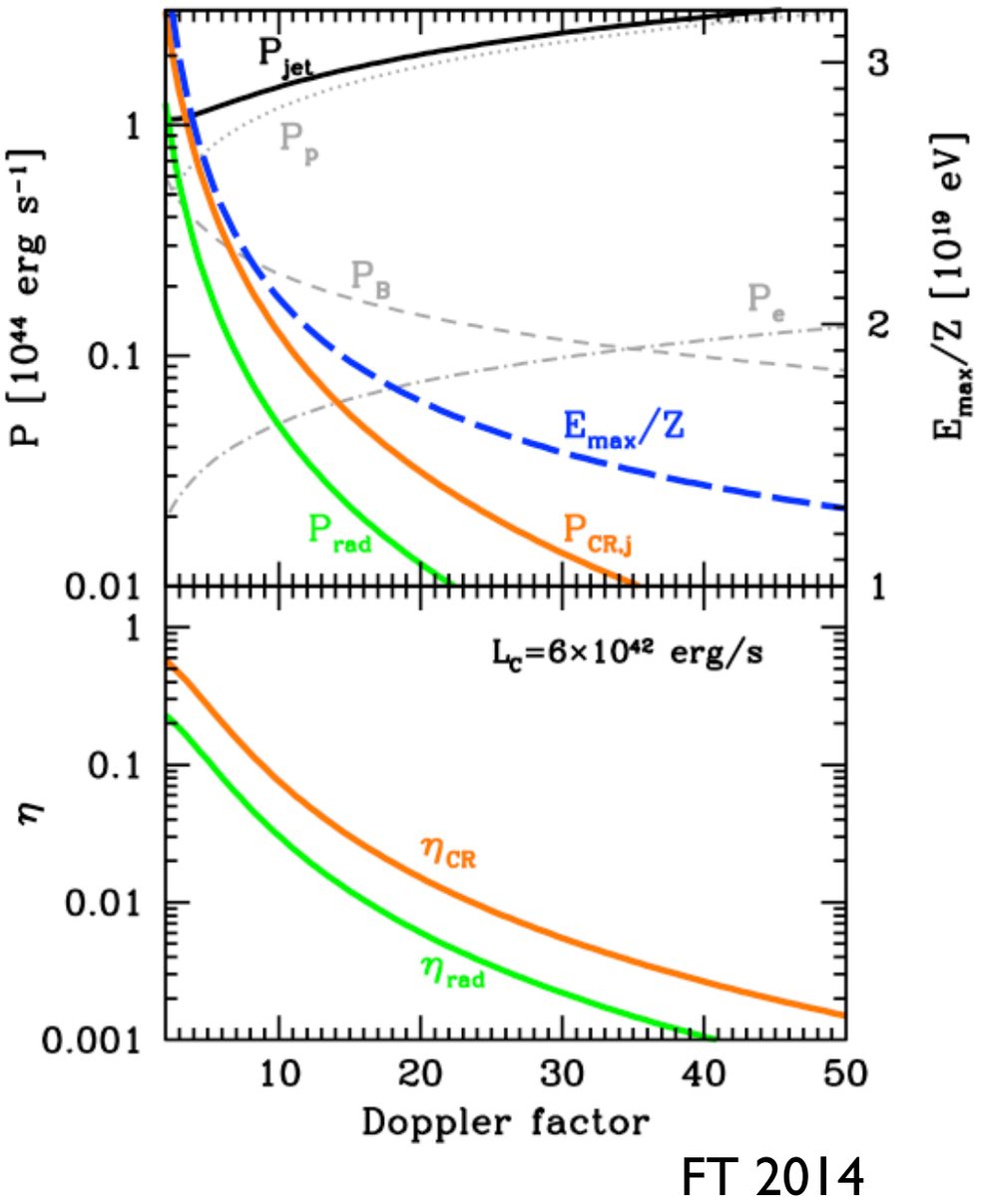
Takami et al. 2013



Misaligned EHBL: UHECR sources?

$$E_{UHECR} > 10^{19}\ \mathrm{eV}$$

$$E_{\max} = ZeBR\Gamma$$ ← Emission model



FT 2014

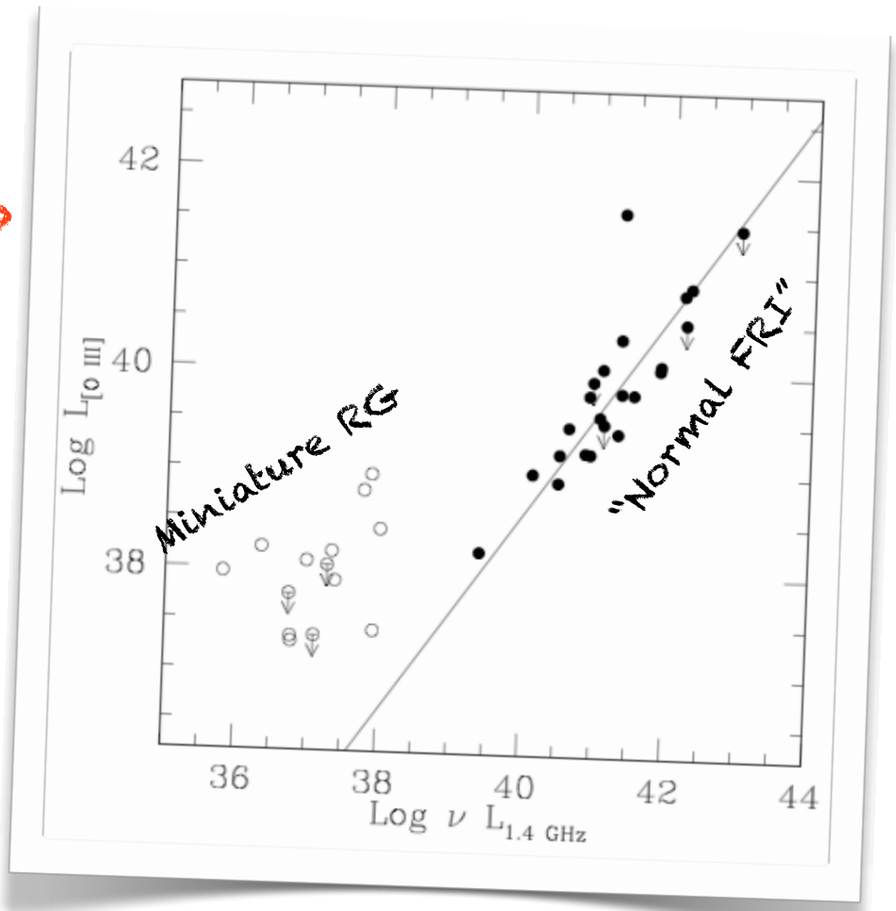
NO EHBL within the GZK radius (~100 Mpc)

Parent population (misaligned EHBL)?

$$L_{\rm r} \lesssim 10^{40}\ \mathrm{erg\ s^{-1}}$$

"Miniature" radio-galaxies?

Baldi & Capetti 2009



Outlook

Blazar jets: emission region(s)
dissipation/acceleration process(es) (magnetic, shock, turb.)

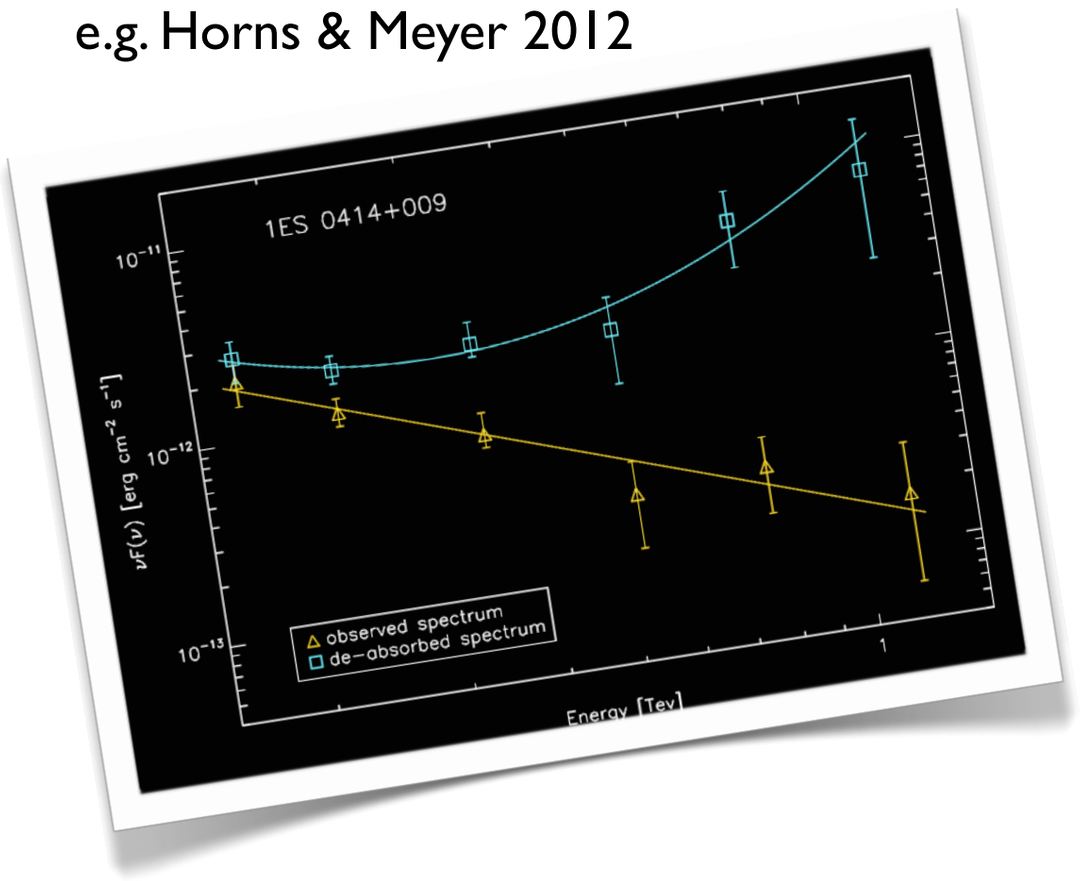
Structured jets: radiogalaxies
neutrinos
powerful jets (FRII)?

Extreme BL Lac: why are they so different?
UHECR sources?
parent population?

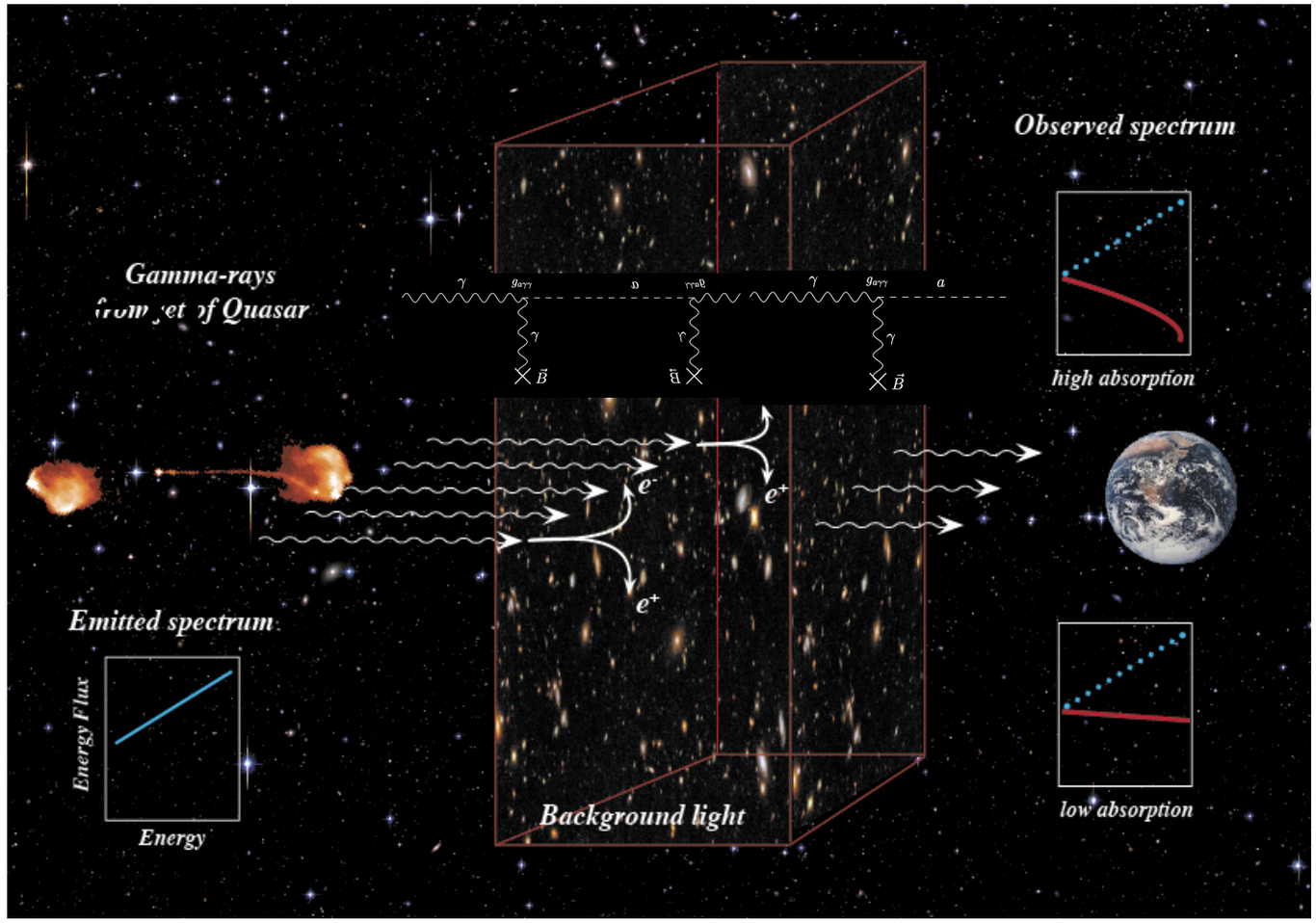
Thank you!

Cosmic opacity anomaly: ALP

e.g. Horns & Meyer 2012



e.g. De Angelis et al. 2011



Cosmic opacity anomaly: LIV

LIV induces an affective mass for the photon

$$\beta_\gamma = 1 - \left(\frac{E_\gamma}{M_{LVn}}\right)^n \quad ; \quad m_\gamma^2 = -\frac{E_\gamma^{2+n}}{M_{LVn}^n},$$

Modification of threshold for pair production at high E

LIV induces suppression of EBL-opacity

ASTRI/CTA Mini-Array

Fairbairn+ 2014

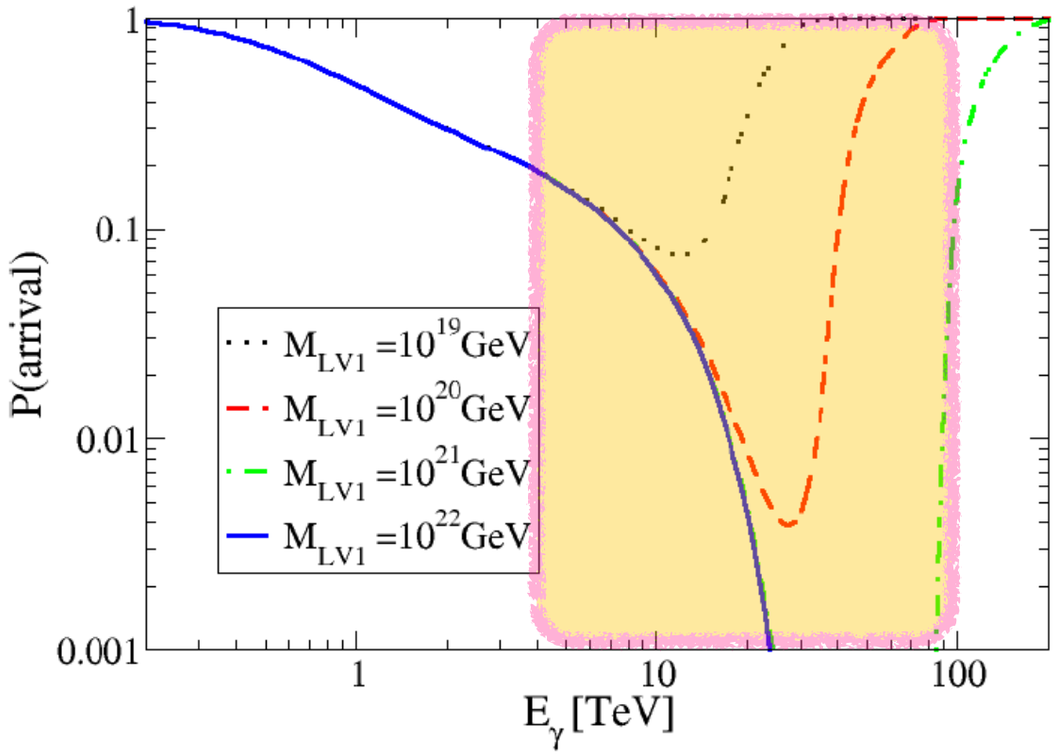
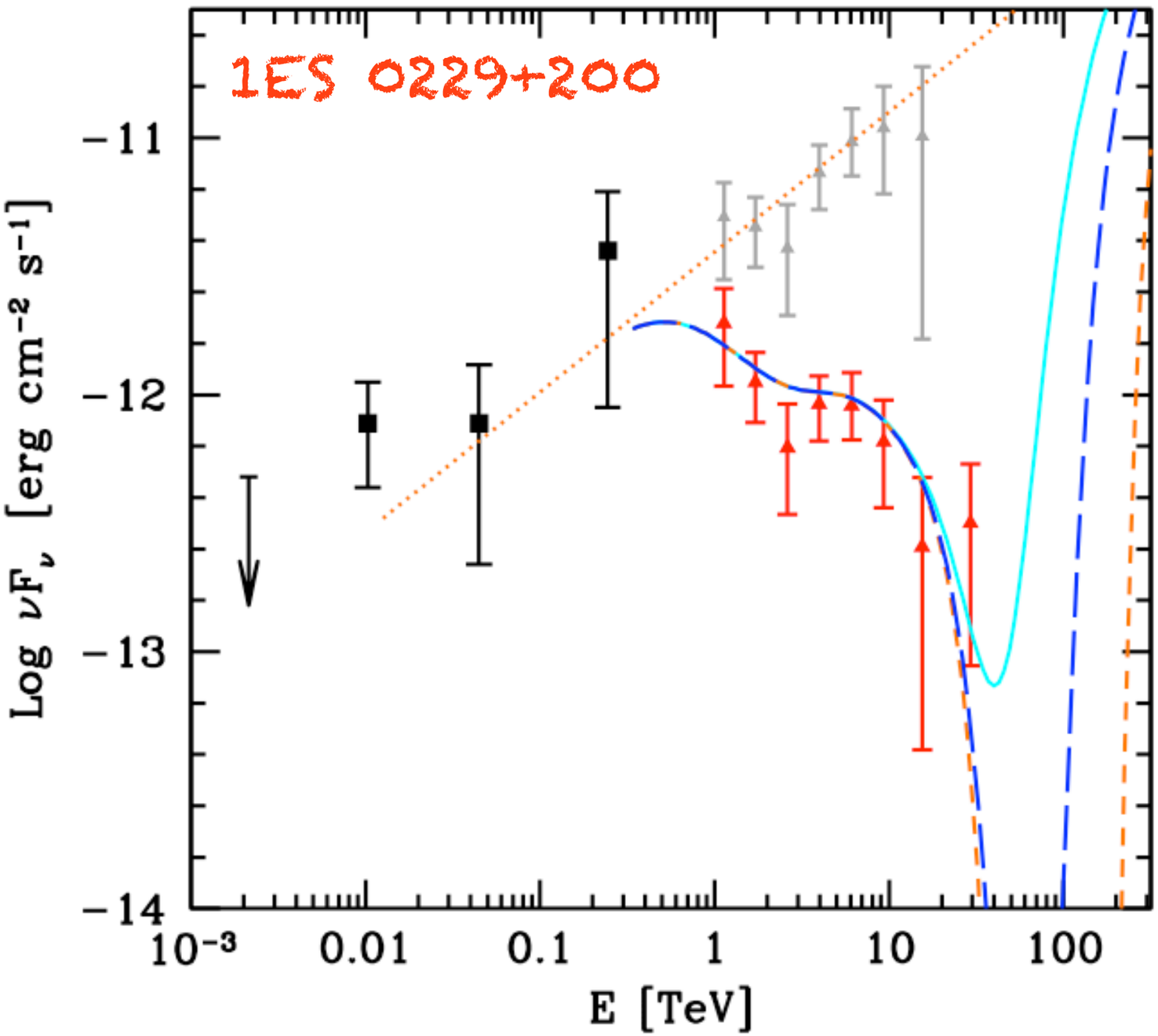


Figure 2. *The arrival probability of a photon emitted from a hypothetical source at redshift $z = 0.05$ as a function of energy. The different curves represent different values of the Lorentz-violating scale M_{LV1}. VHE photons with energies $\gtrsim 100$ TeV can travel through the CMB effectively unimpeded.*

Cosmic opacity anomaly: LIV



Intermezzo

neutrino production in a nutshell

relativistic protons

$$p + \gamma \to n + \pi^+$$

$$p + \gamma \to p + \pi^0$$

pion decay

$$\pi^+ \to \mu^+ + \nu_\mu \to e^+ + \bar{\nu}_e + \bar{\nu}_\mu + \nu_\mu$$

$$\pi^0 \to 2\gamma$$

$\sigma_{p\gamma} \simeq 3.4 \times 10^{-28}\,\mathrm{cm}^2$

$$E_{\rm th} = \frac{2 m_p m_\pi + m_\pi^2}{4\epsilon} \simeq 7 \times 10^{16} \left(\frac{\epsilon}{\rm eV}\right)^{-1} \,\mathrm{eV}$$

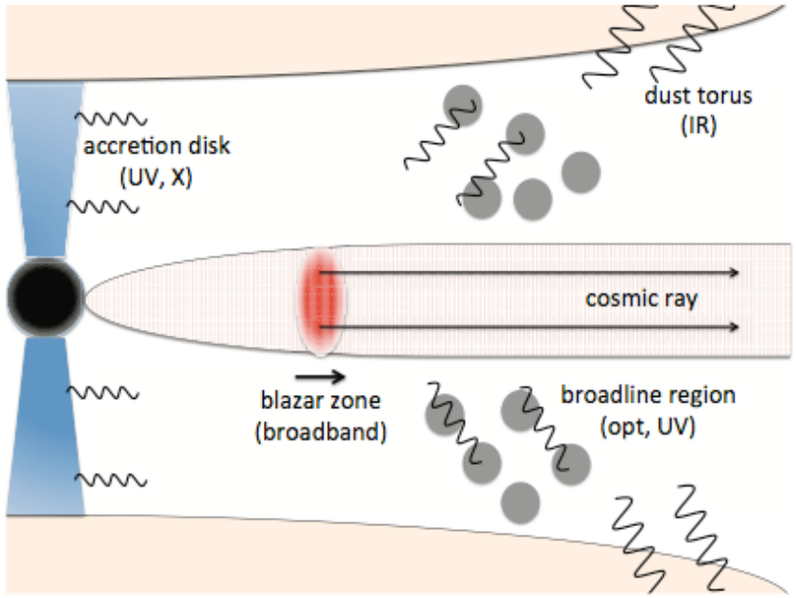
$$E_\nu \simeq 0.05 E_p$$

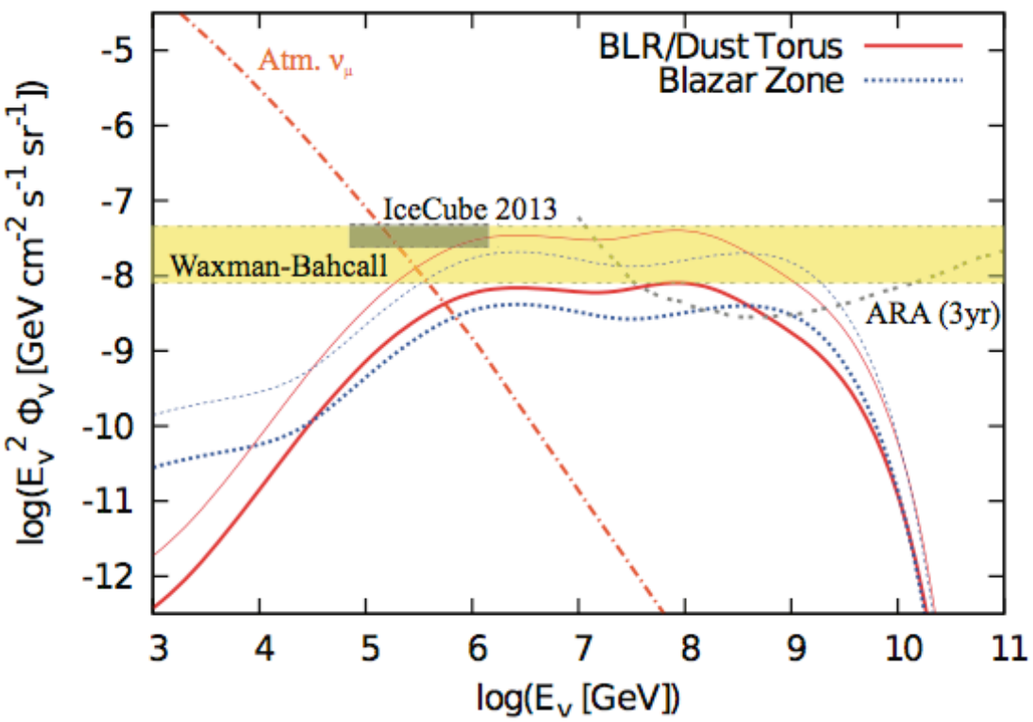
$$E_\gamma \simeq 0.1 E_p$$

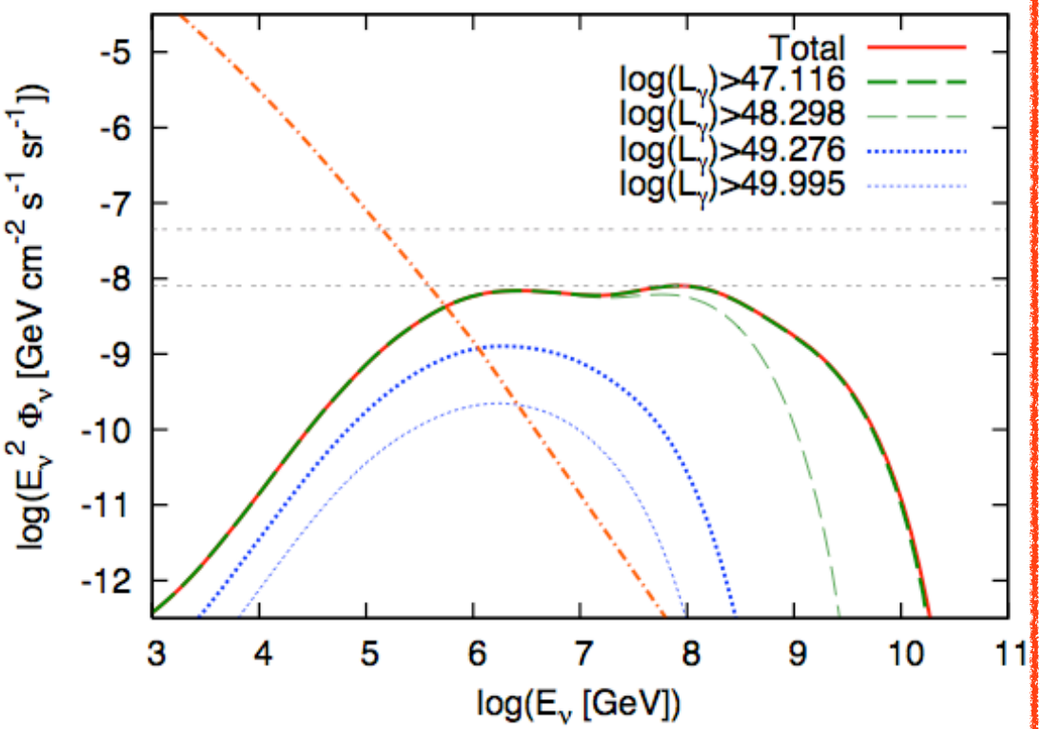
Neutrinos from FSRQ?

Strong correlation expected!

Murase, Inoue & Dermer 2014



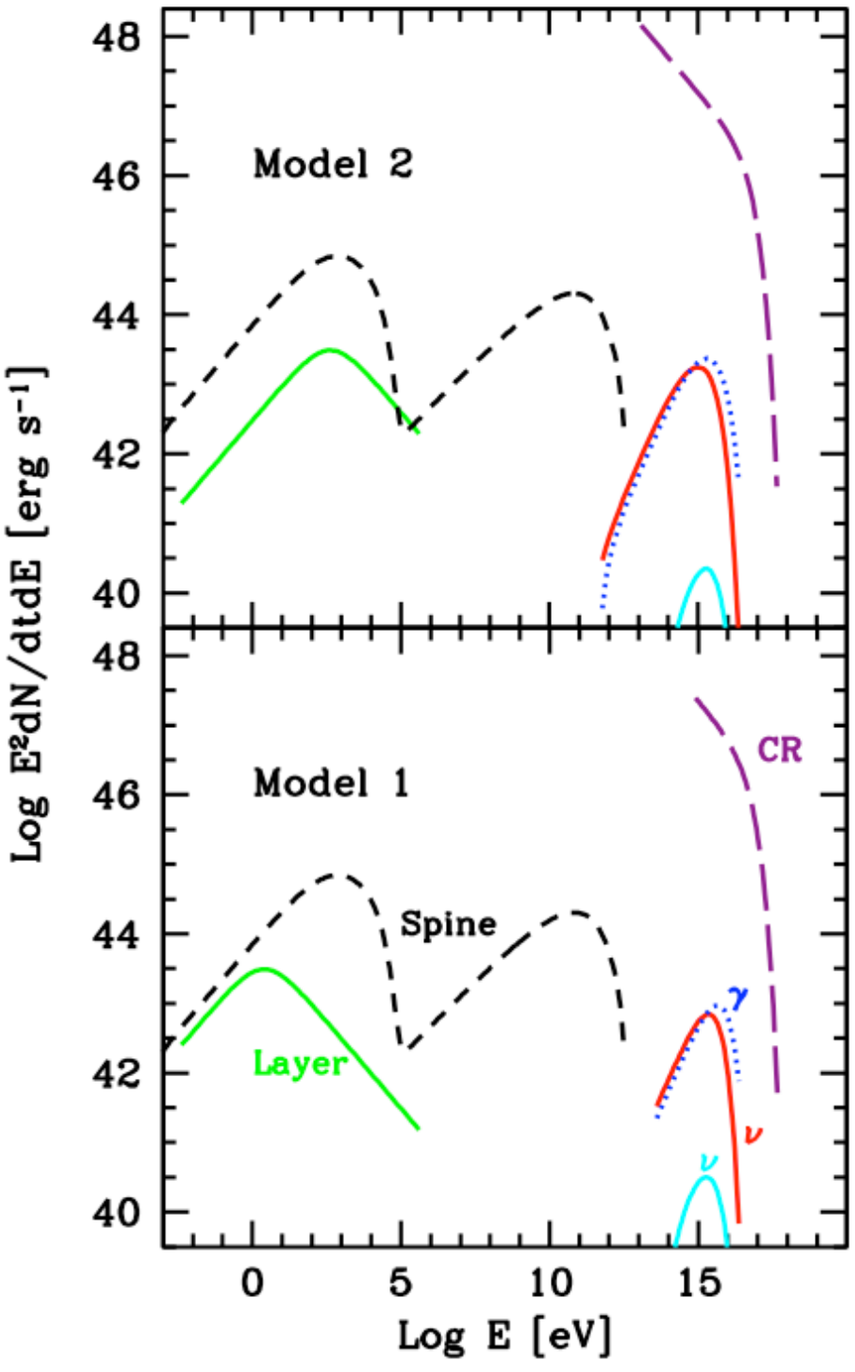


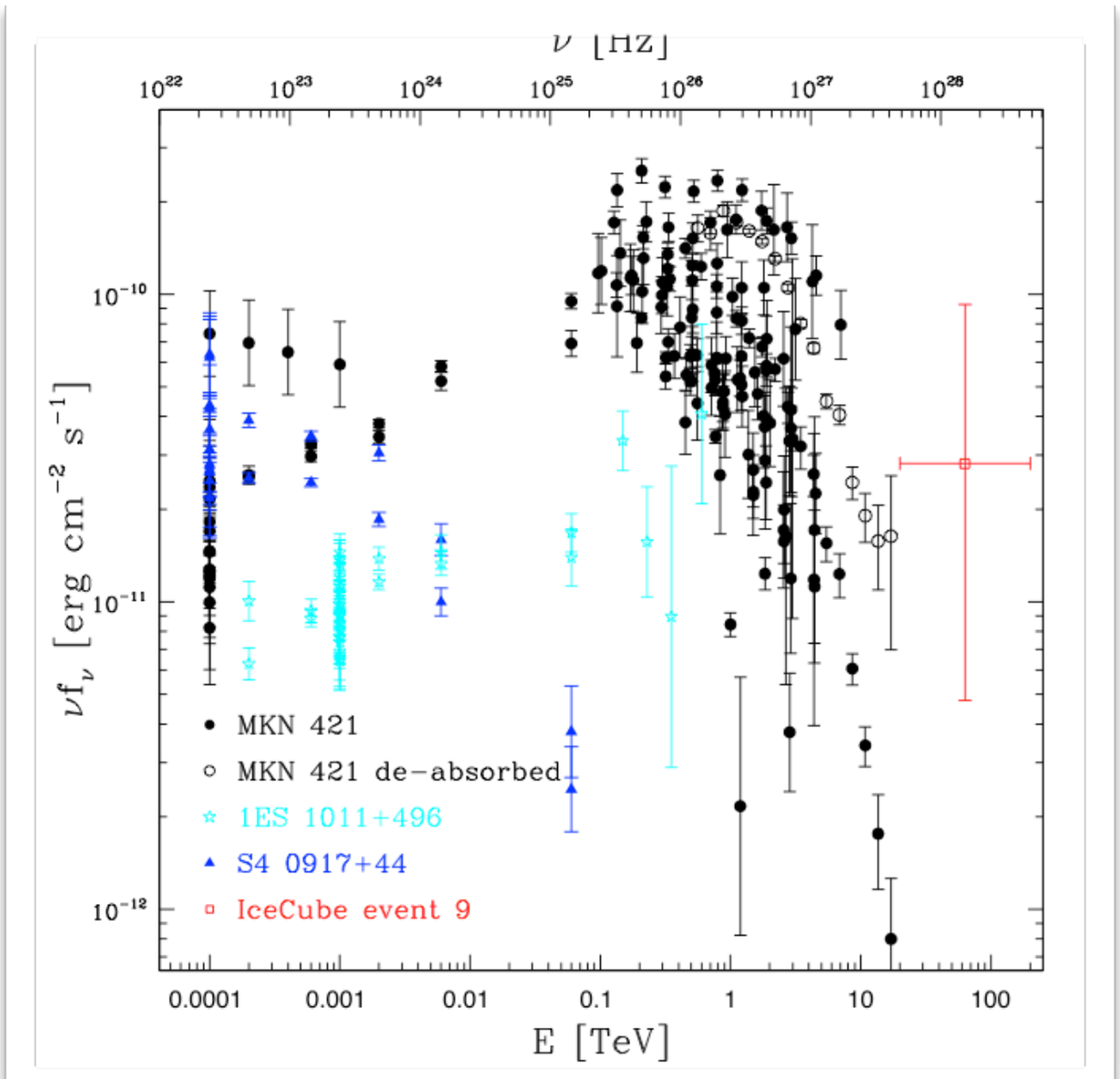


$L_\gamma^{\rm th}[\mathrm{erg\ s^{-1}}]$	$N_{\rm AGN}(>L_\gamma^{\rm th})$
$10^{45.740}$	741
$10^{45.983}$	725
$10^{47.116}$	614
$10^{48.298}$	84
$10^{49.276}$	0.54
$10^{49.995}$	0

Structured jets: neutrinos

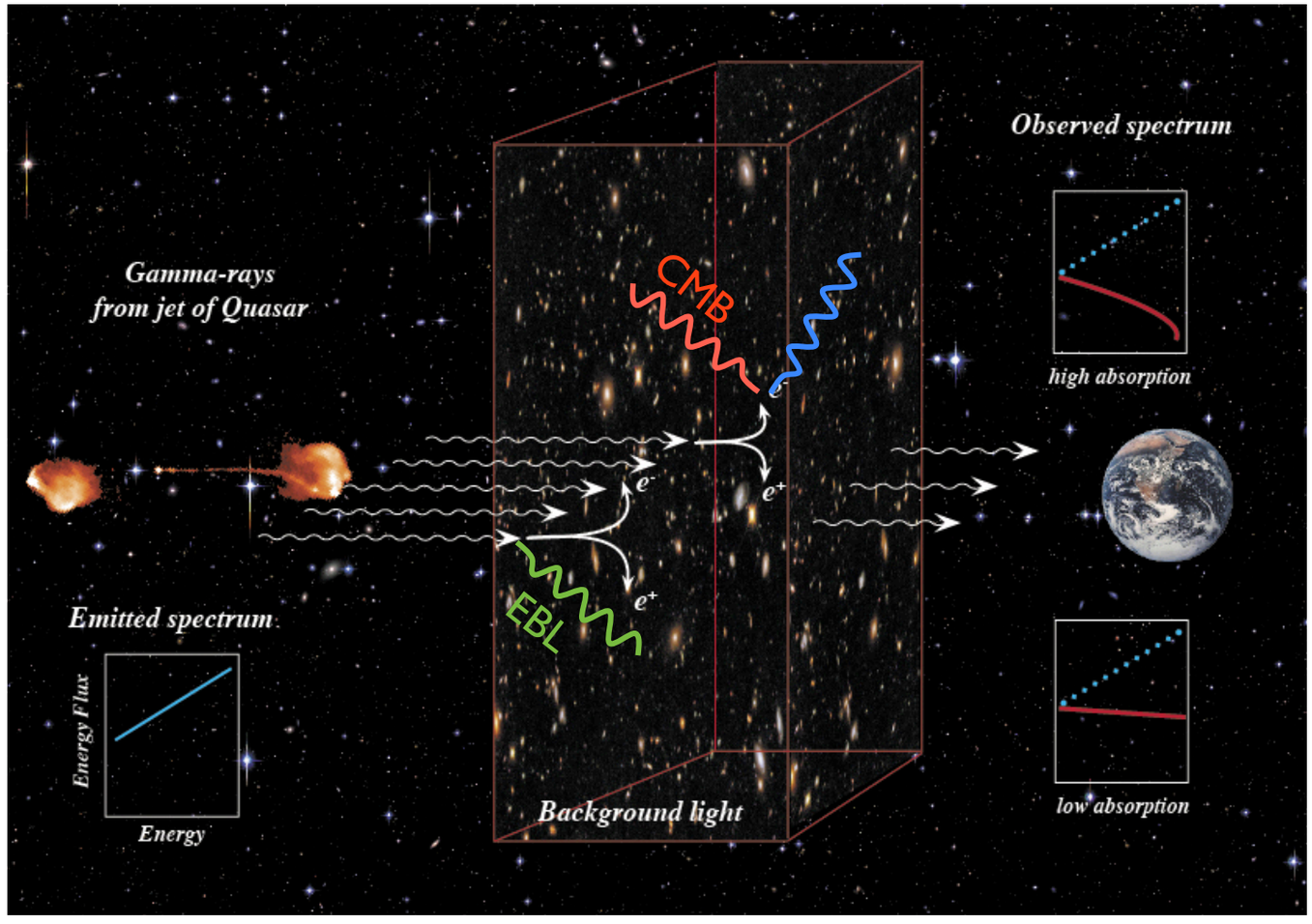
FT et al. 2014

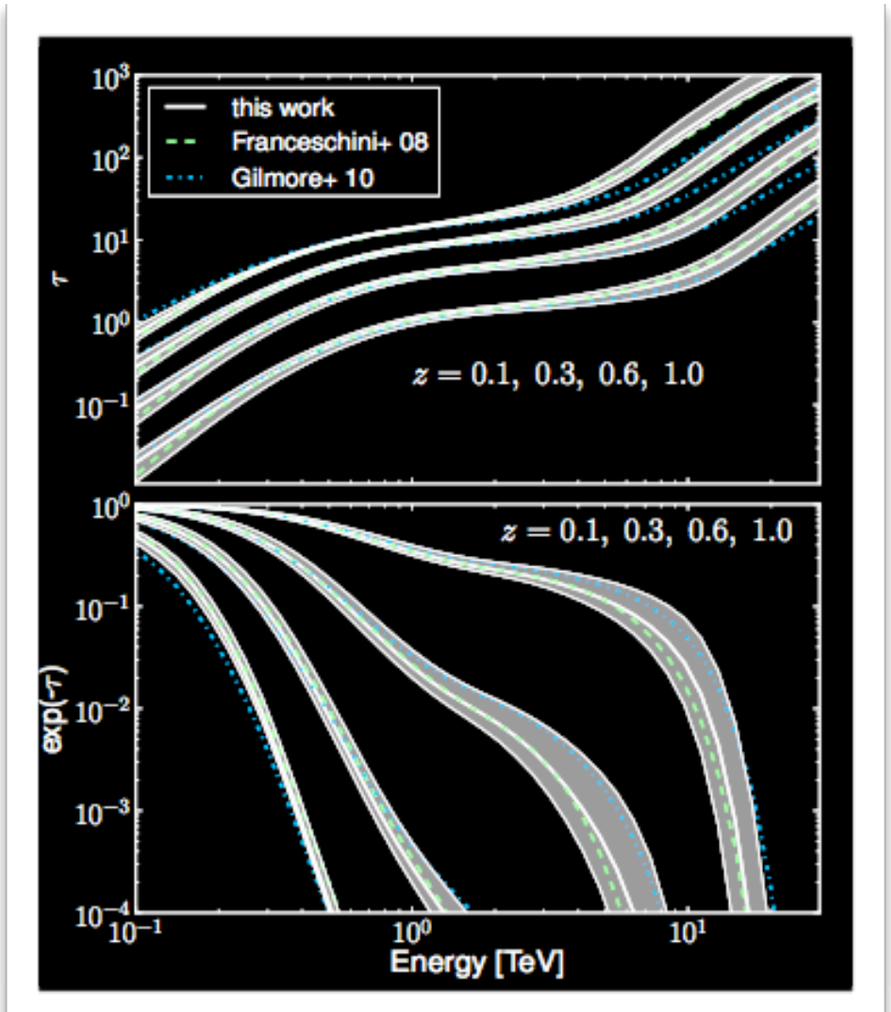




Padovani & Resconi 2014

Propagation: EBL absorption





Dominguez et al. 2011

Structured jets