From one-zone to structured jet models

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Outline

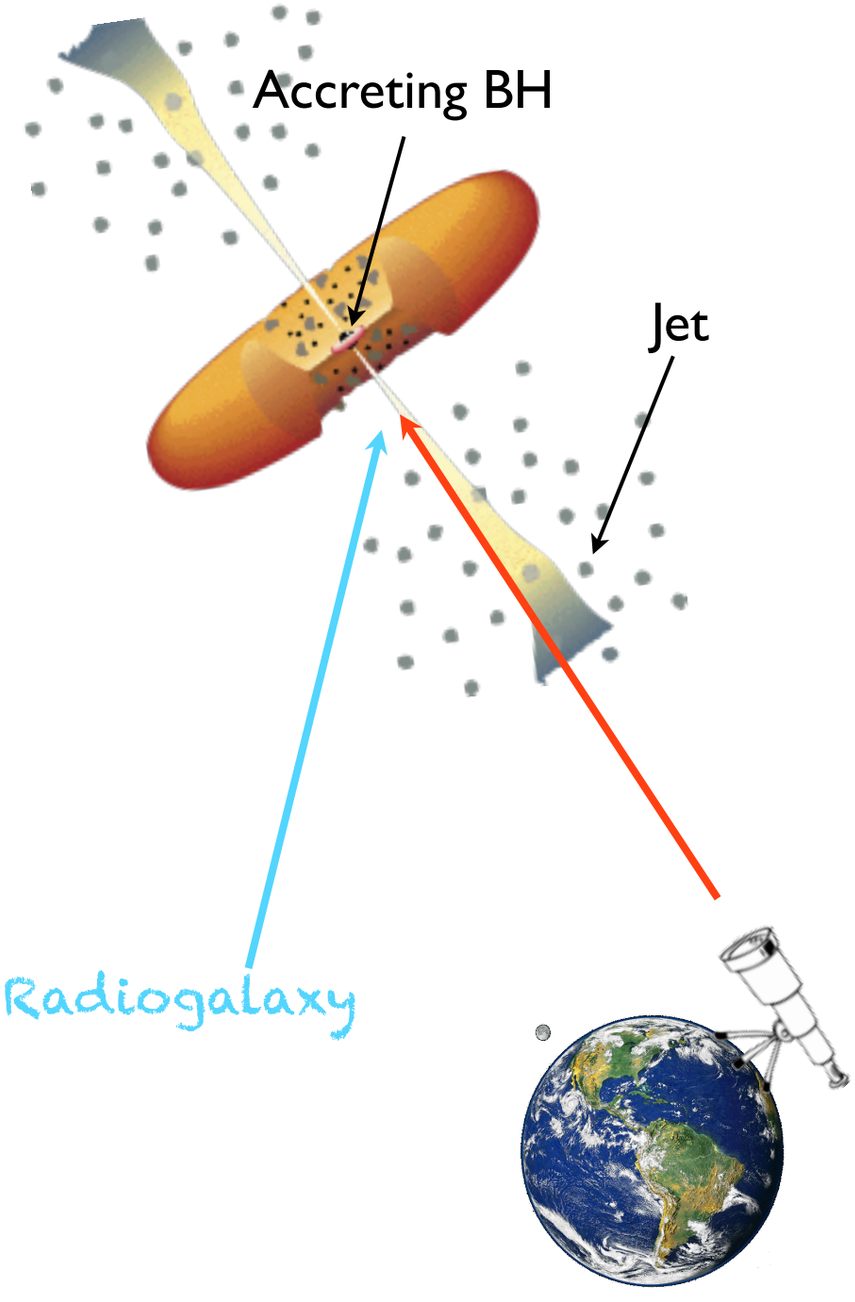
Introduction

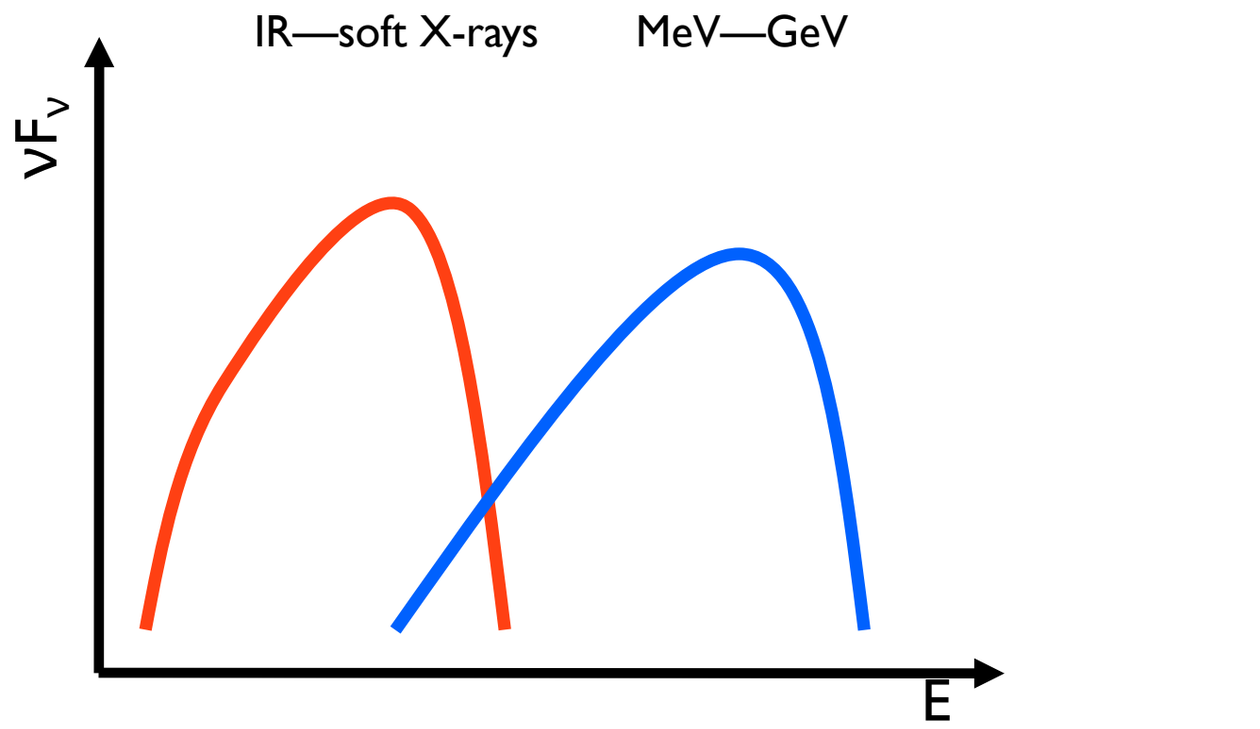
One-zone models: application and some problems

Multi-component models

Structured (spine-layer) models: misaligned jets

Blazars in a nutshell





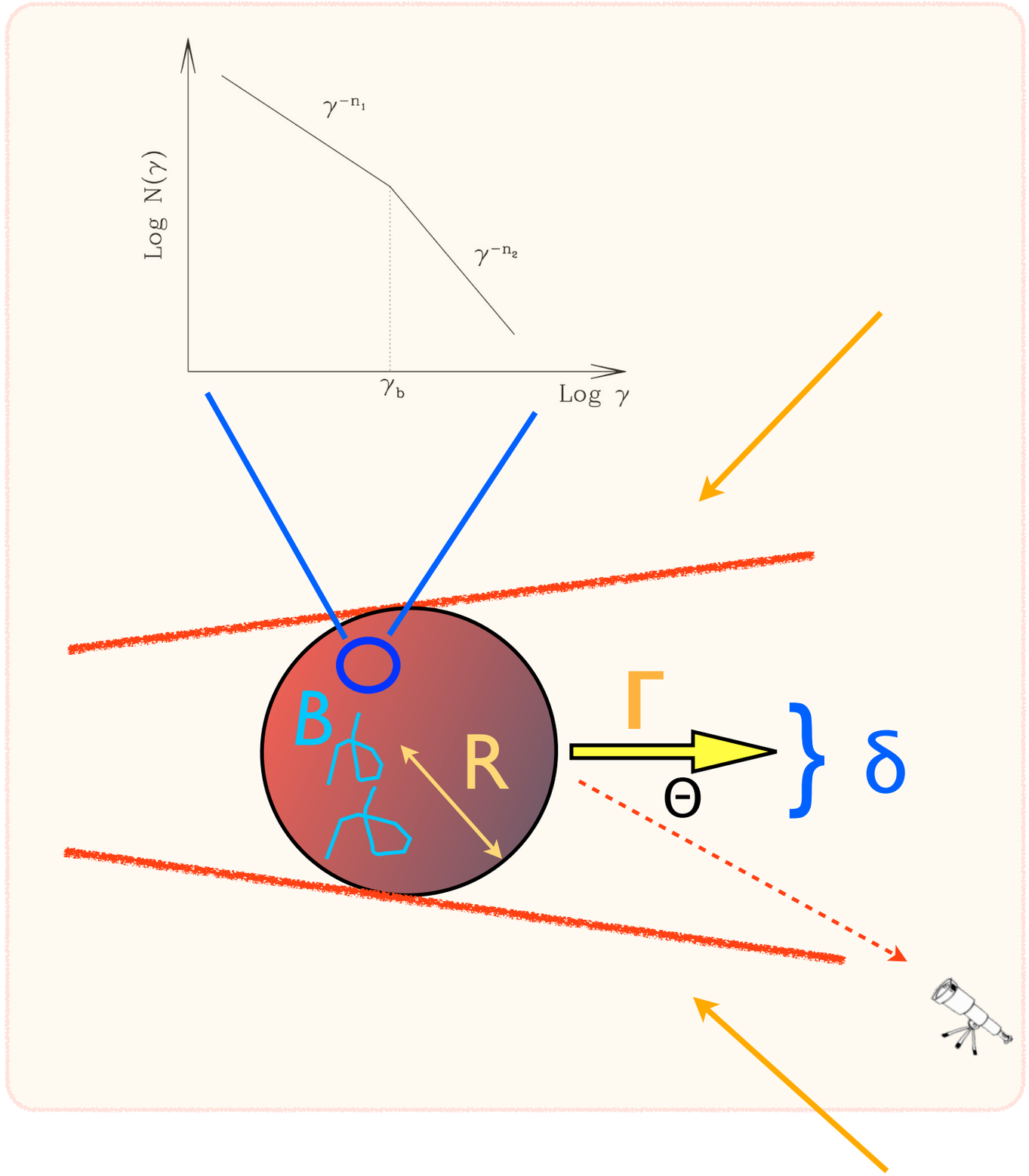
SED dominated by the relativistically boosted non-thermal continuum of the jet.

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

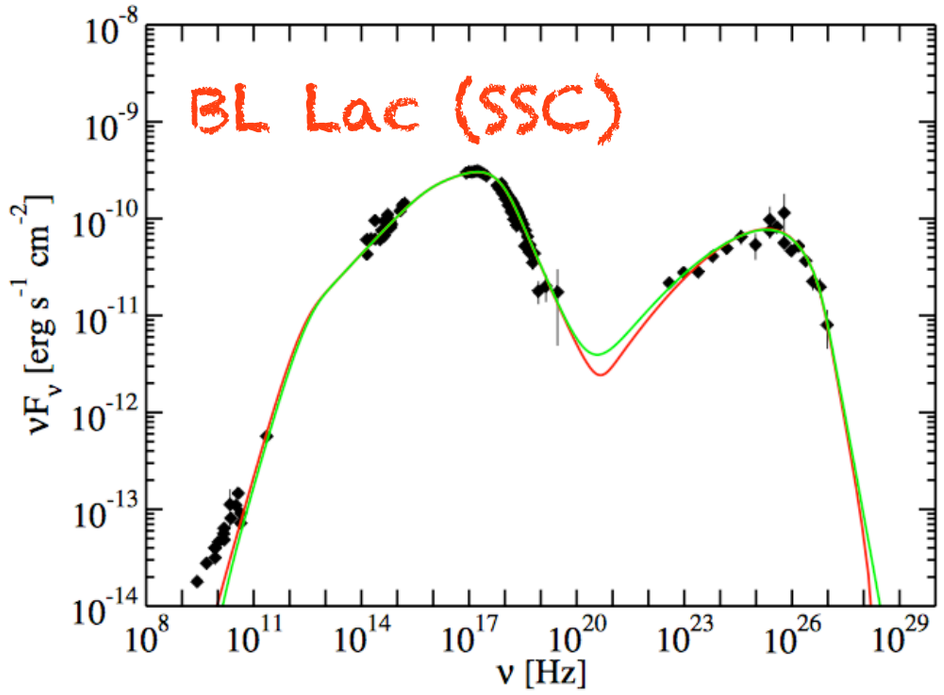
Synchrotron and IC in leptonic models.

Also hadronic scenarios
(synchrotron or photo-meson emission)

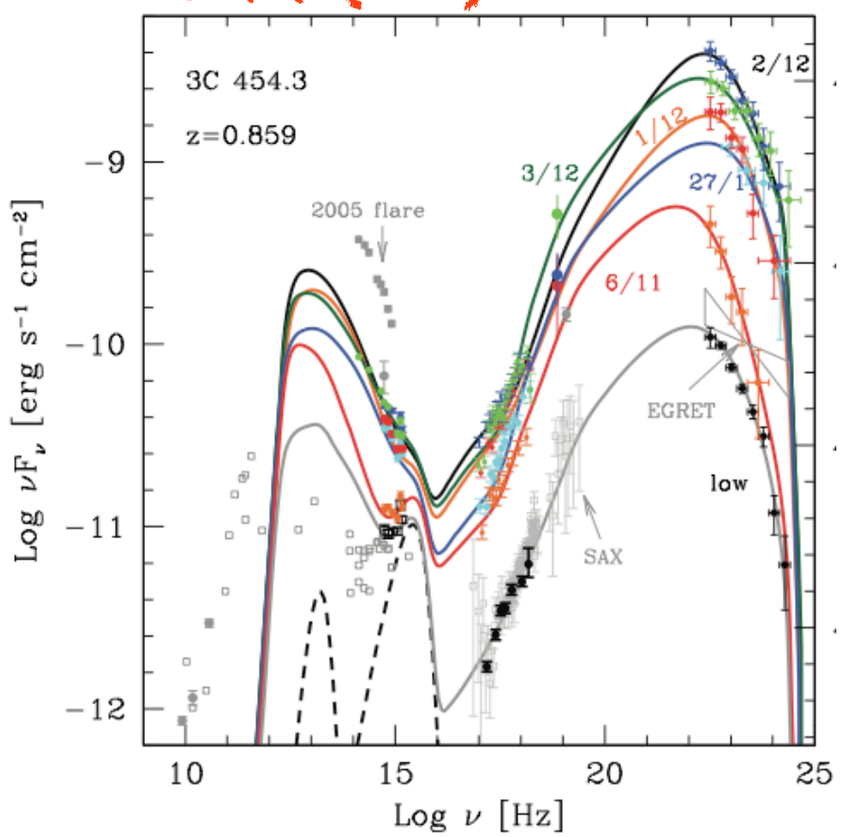
One-zone models



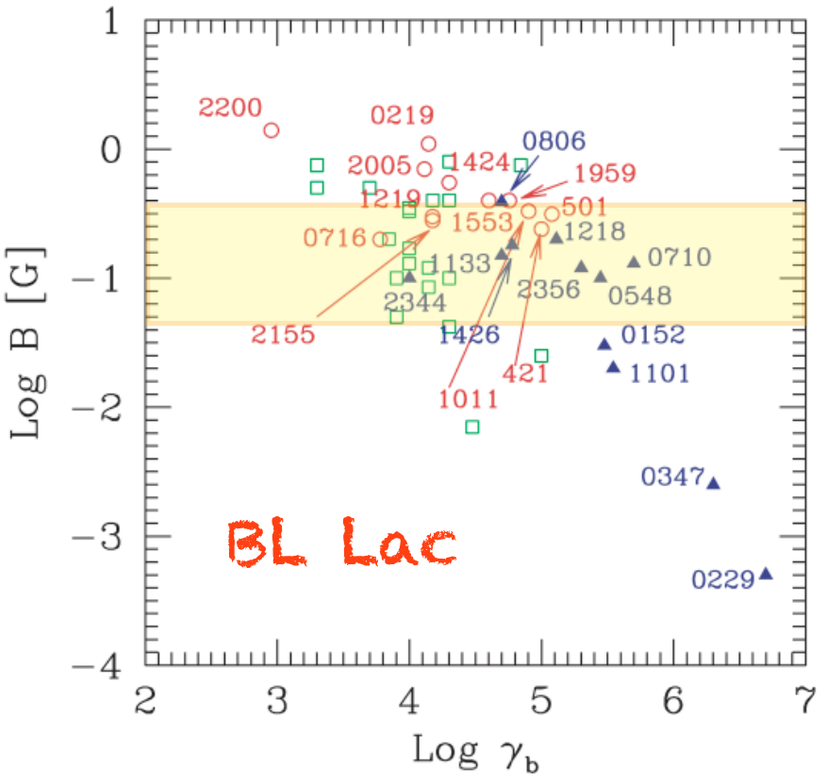
Abdo et al. 2011



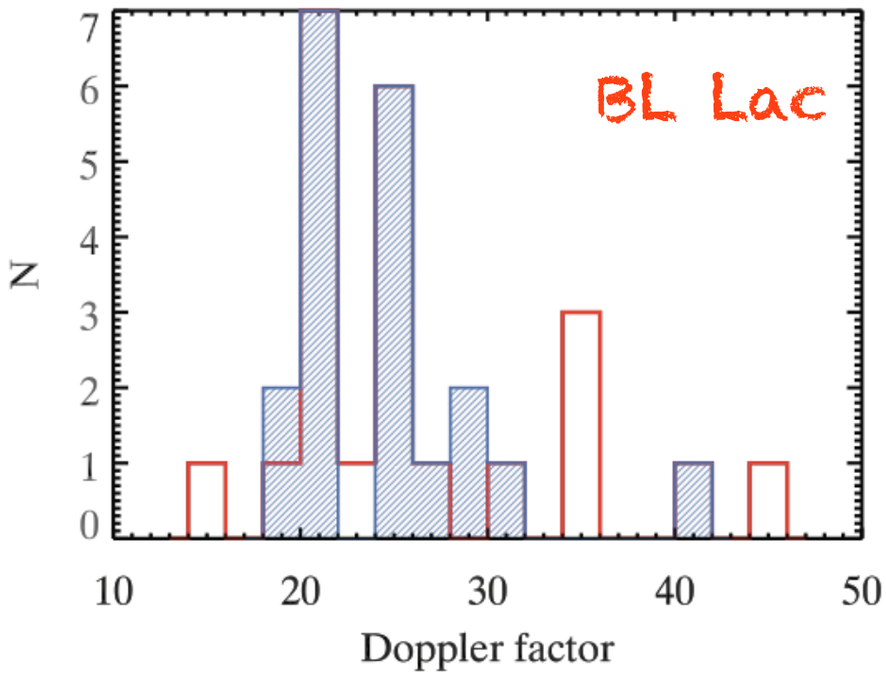
FSRQ (EC) Bonnoli et al. 2011



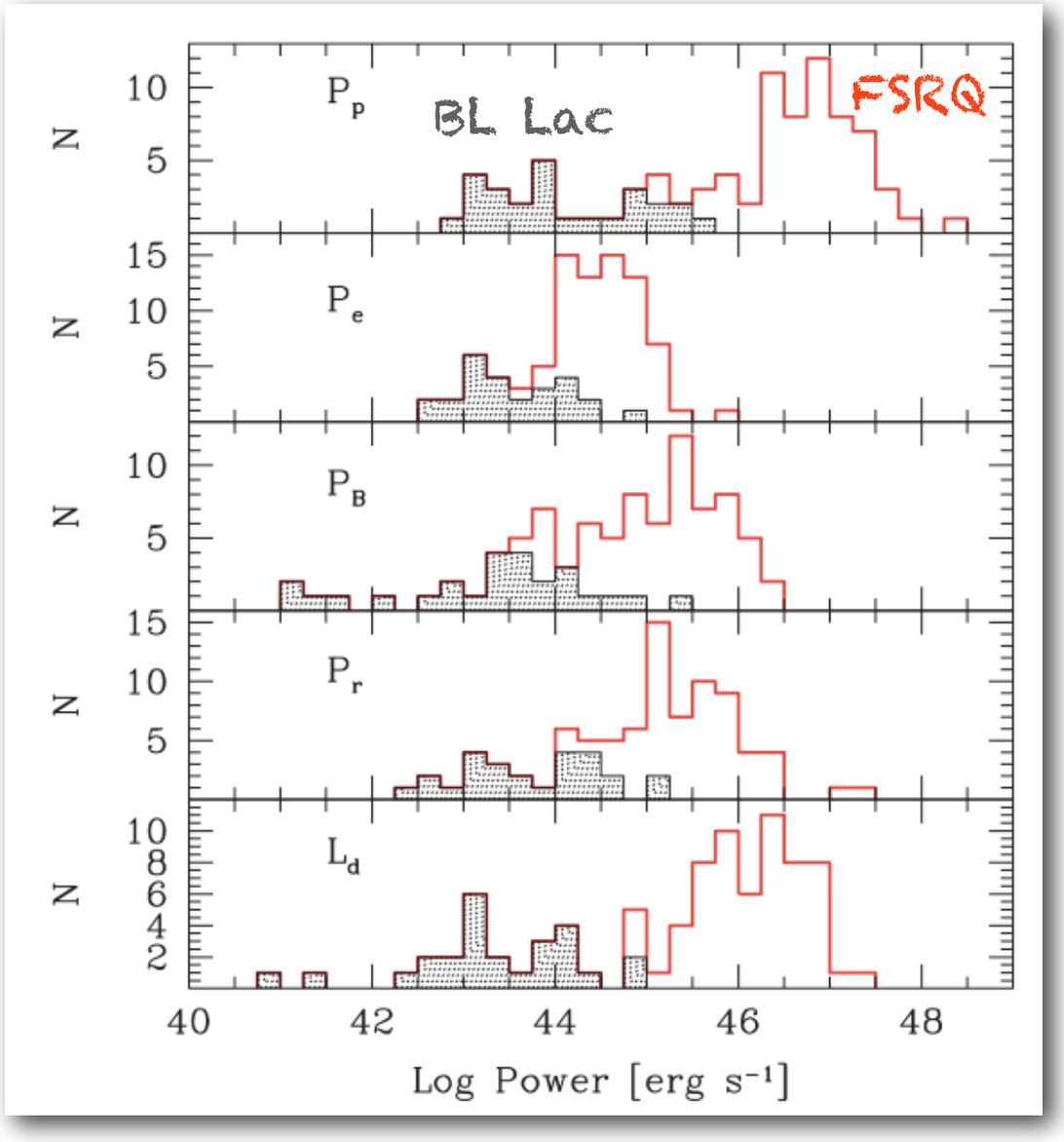
One-zone models



FT et al. 2010

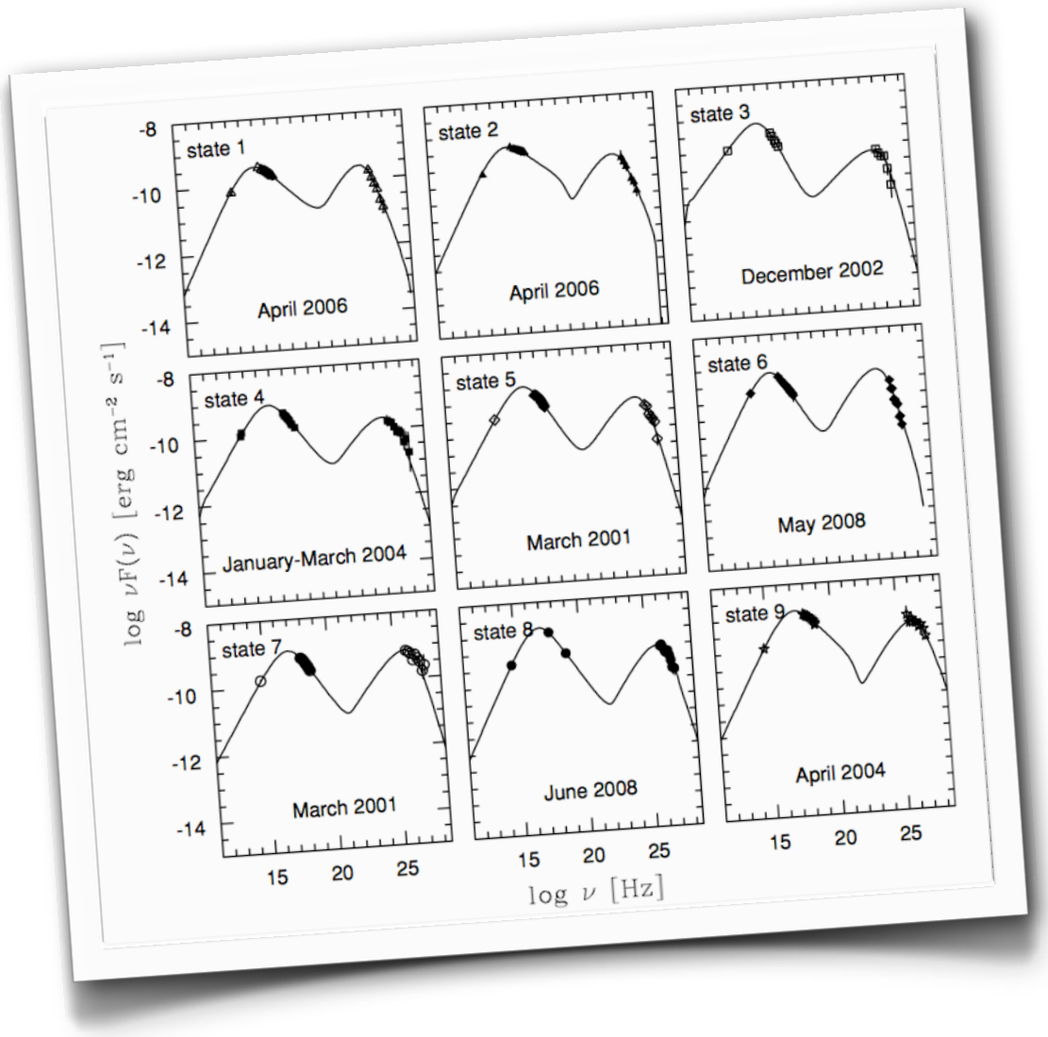


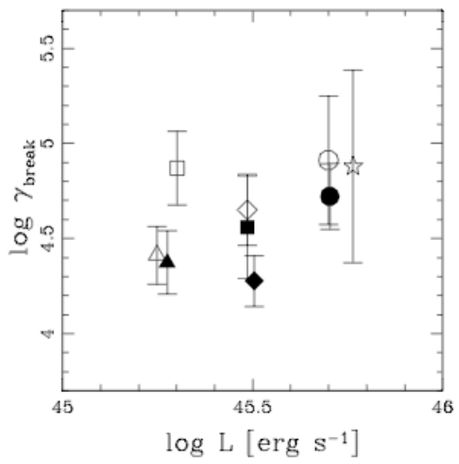
Ghisellini et al. 2010

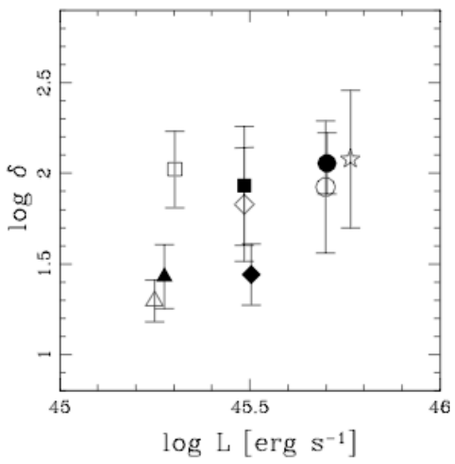


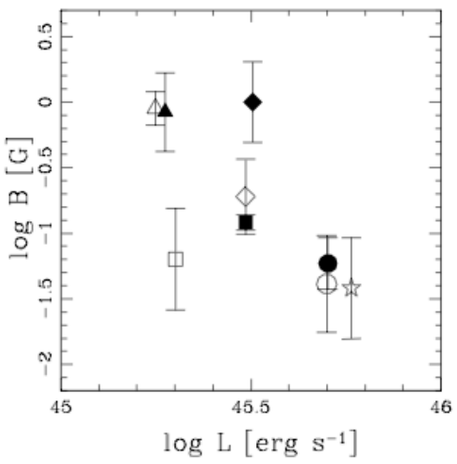
see G. Ghisellini's talk

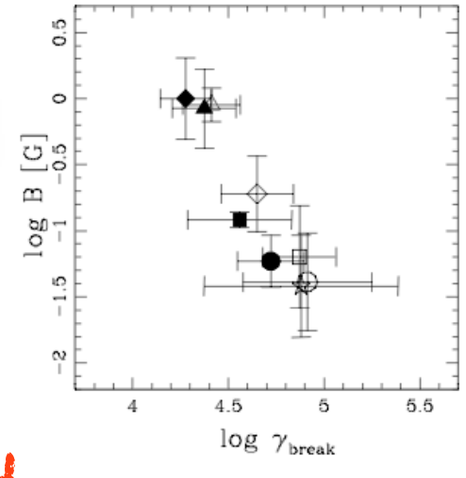
One-zone models: SSC

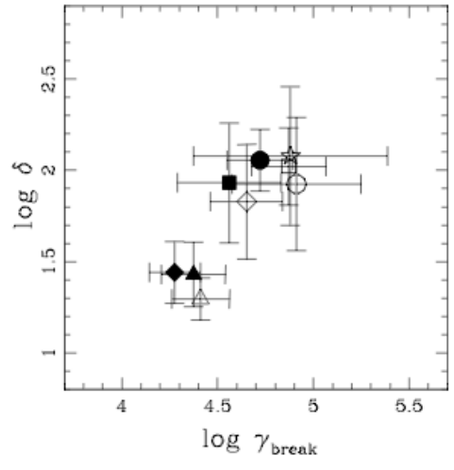


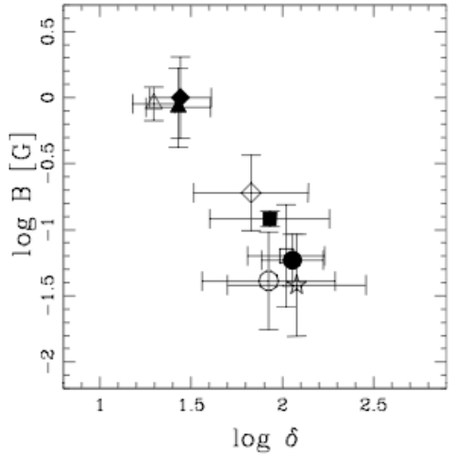












SSC: few parameters

Parameters uniquely fixed

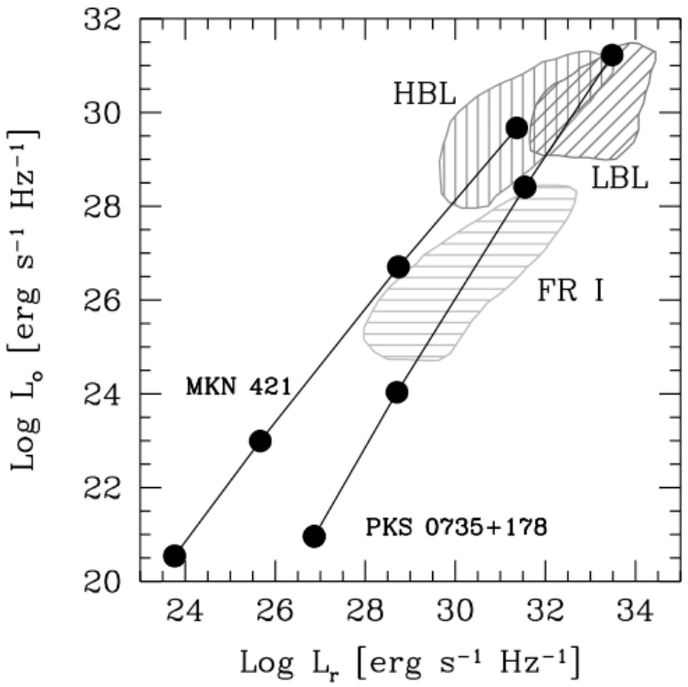
Automated fitting feasible

Mankuzhiyil et al. 2011,2012

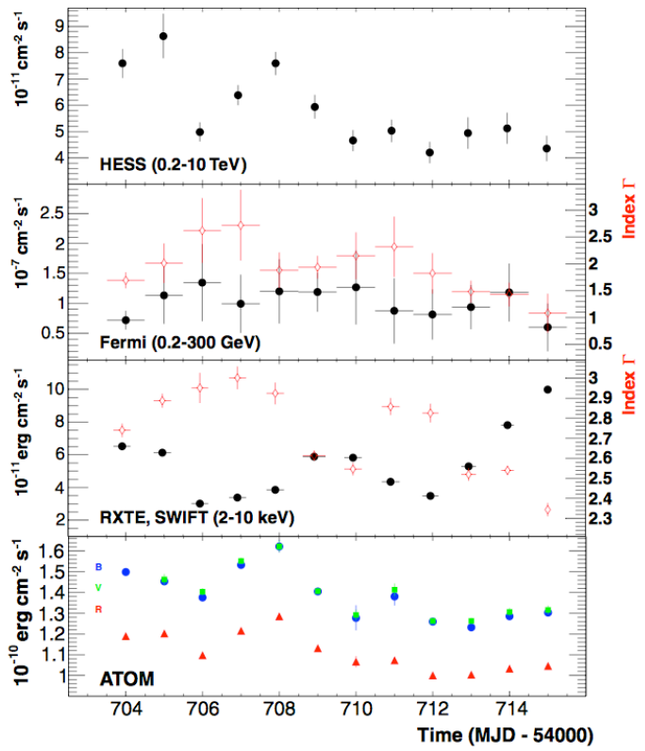
Some problems

Unification

Chiaberge et al. 2000
Meyer et al. 2011
Sbarrato et al. 2014
Georganopoulos & Kazanas 2004
Henry & Saugé 2006



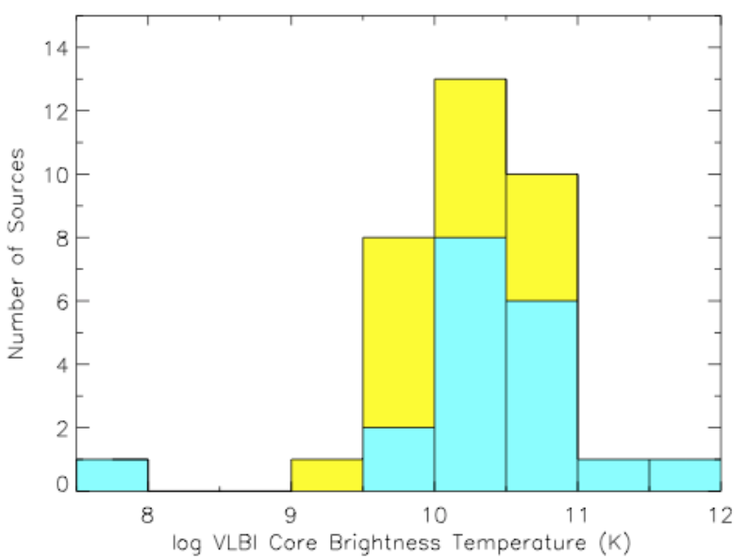
X-ray/TeV connection



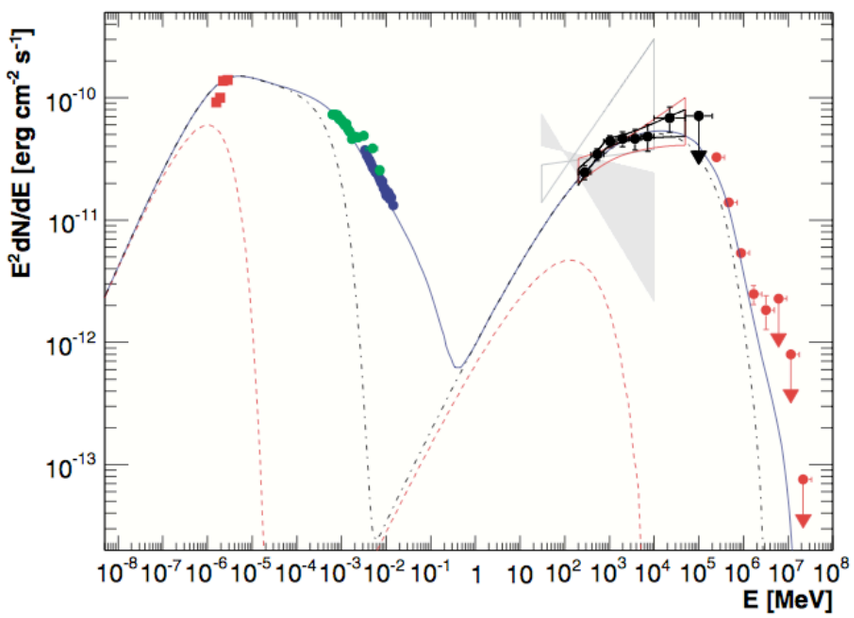
Aharonian et al. 2009
Aleksic et al. 2015

Velocity discrepancy

Contraddiction between large delta and small (v<c) VLBI apparent speeds and brightness T



Piner & Edward 2004, 2014
Georganopoulos & Kazanas 2004



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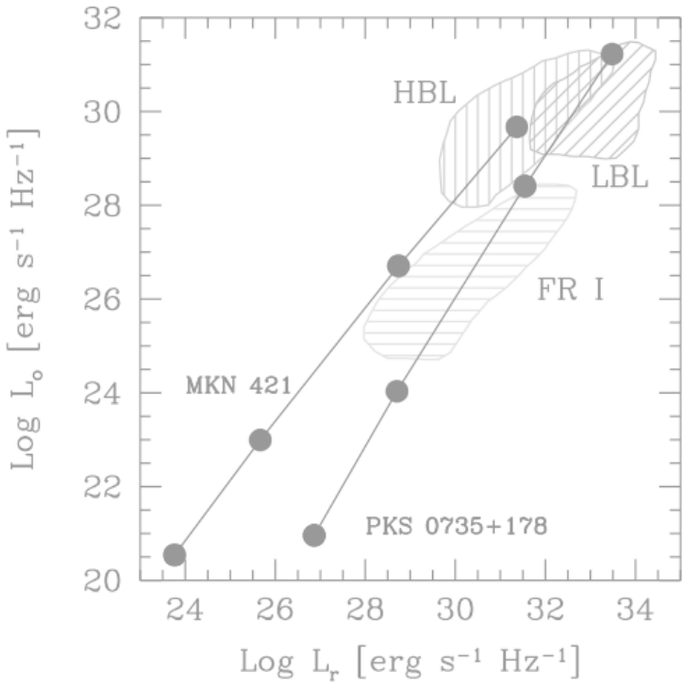

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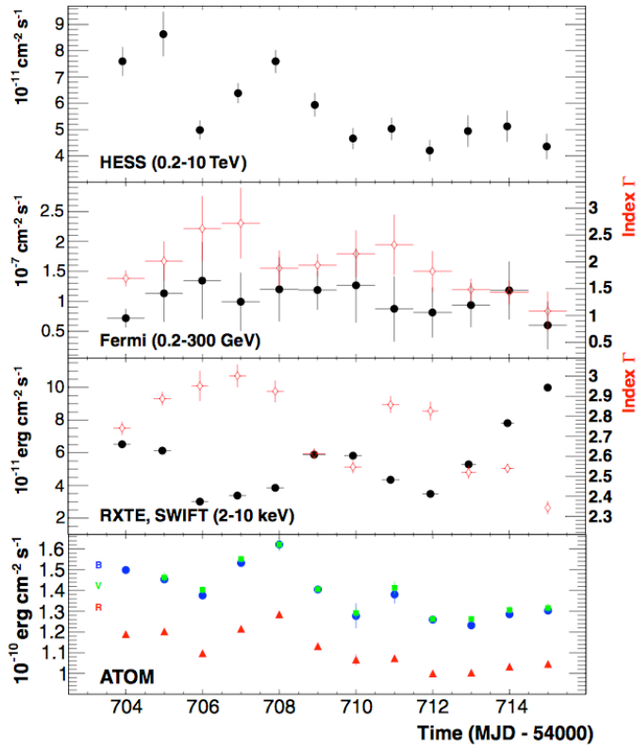

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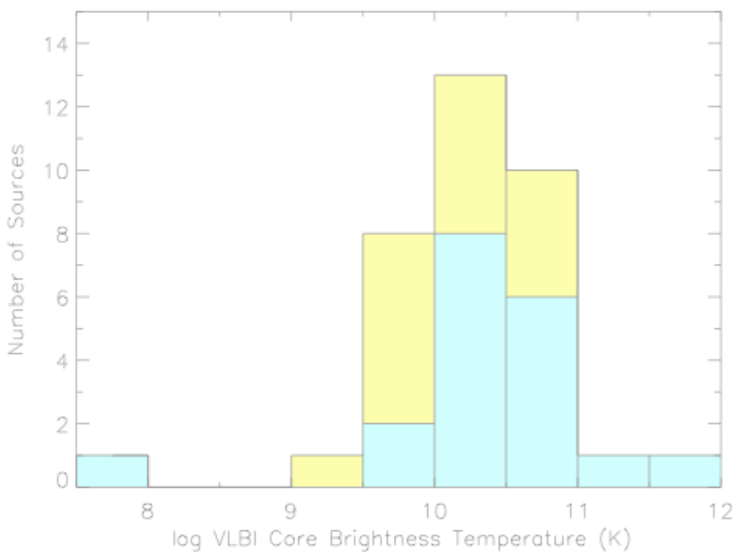

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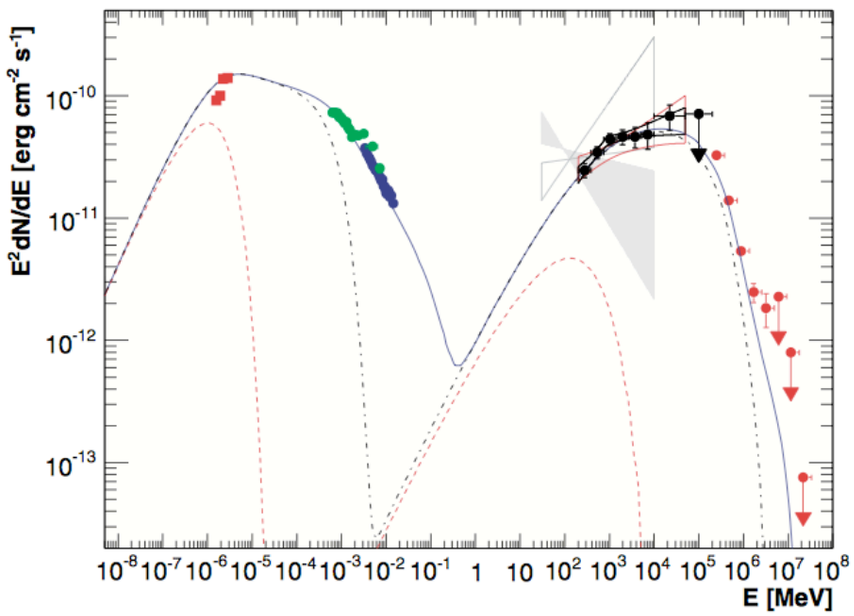
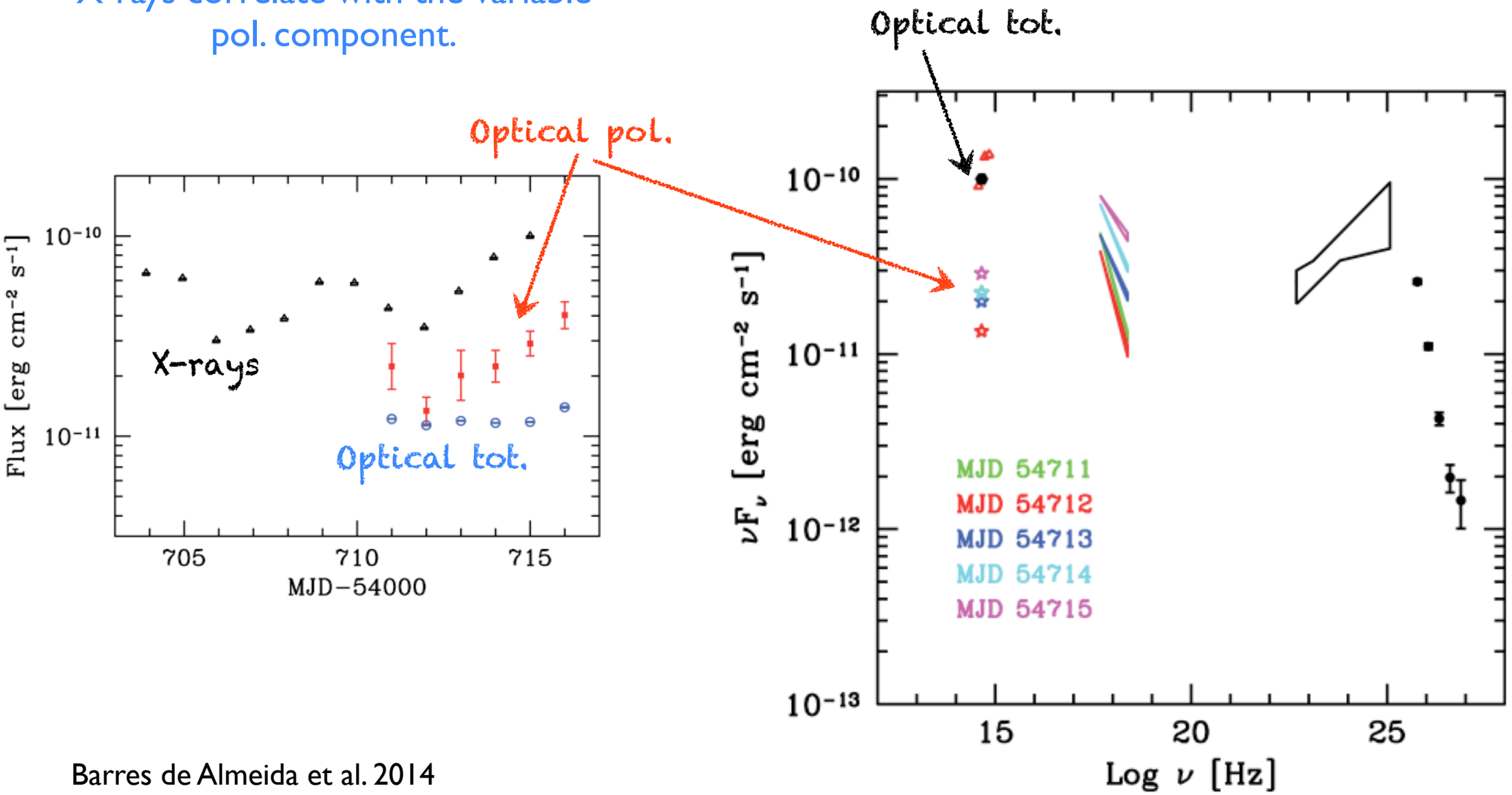


Multi-blob models

Evidence for two regions with different polarization behavior (BA 2010). X-rays correlate with the variable pol. component.

"Polarimetric tomography"



Barres de Almeida et al. 2014

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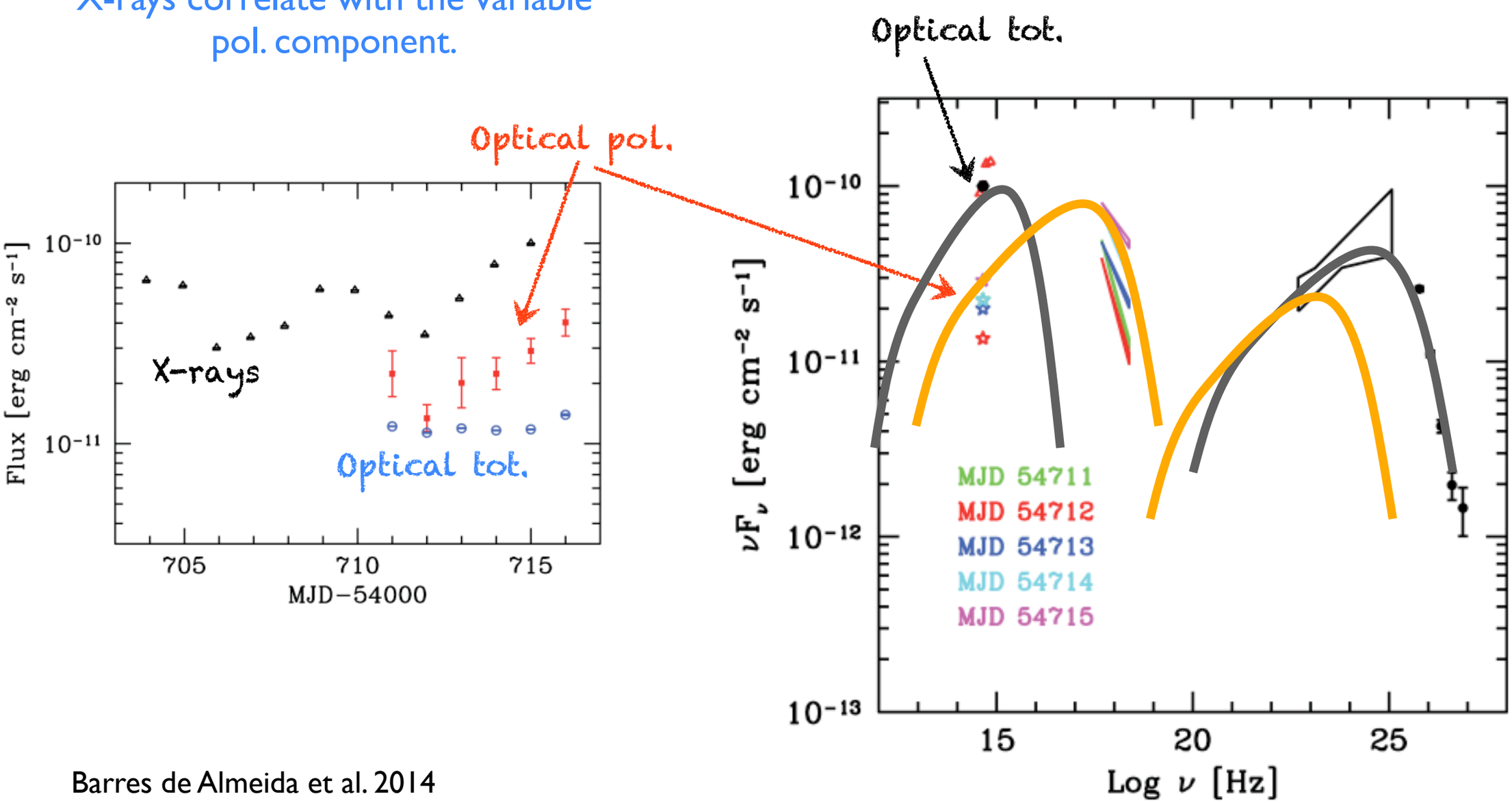
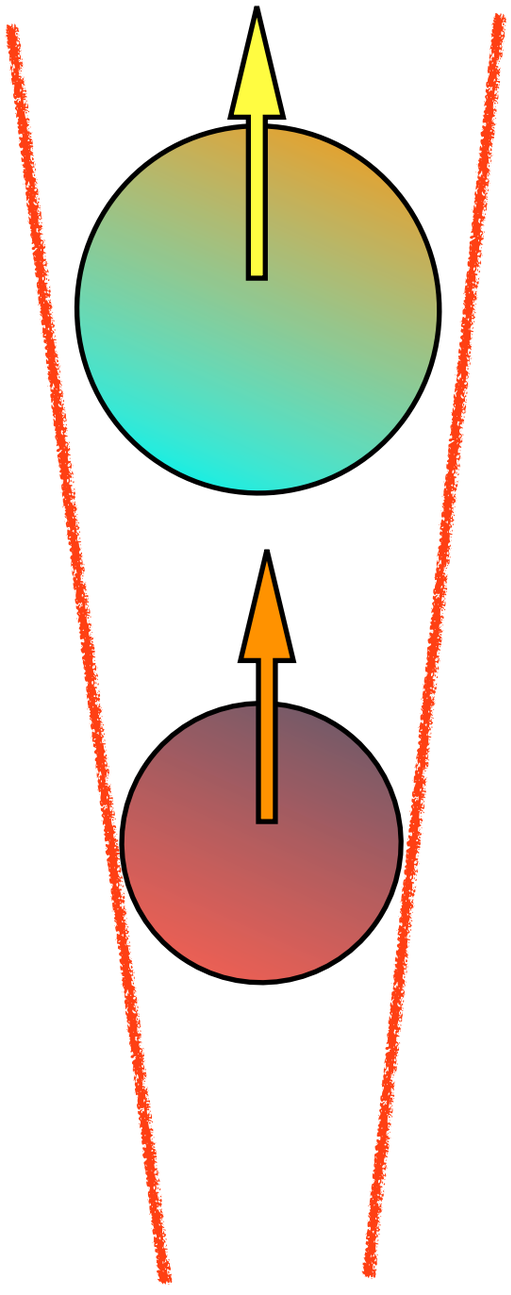
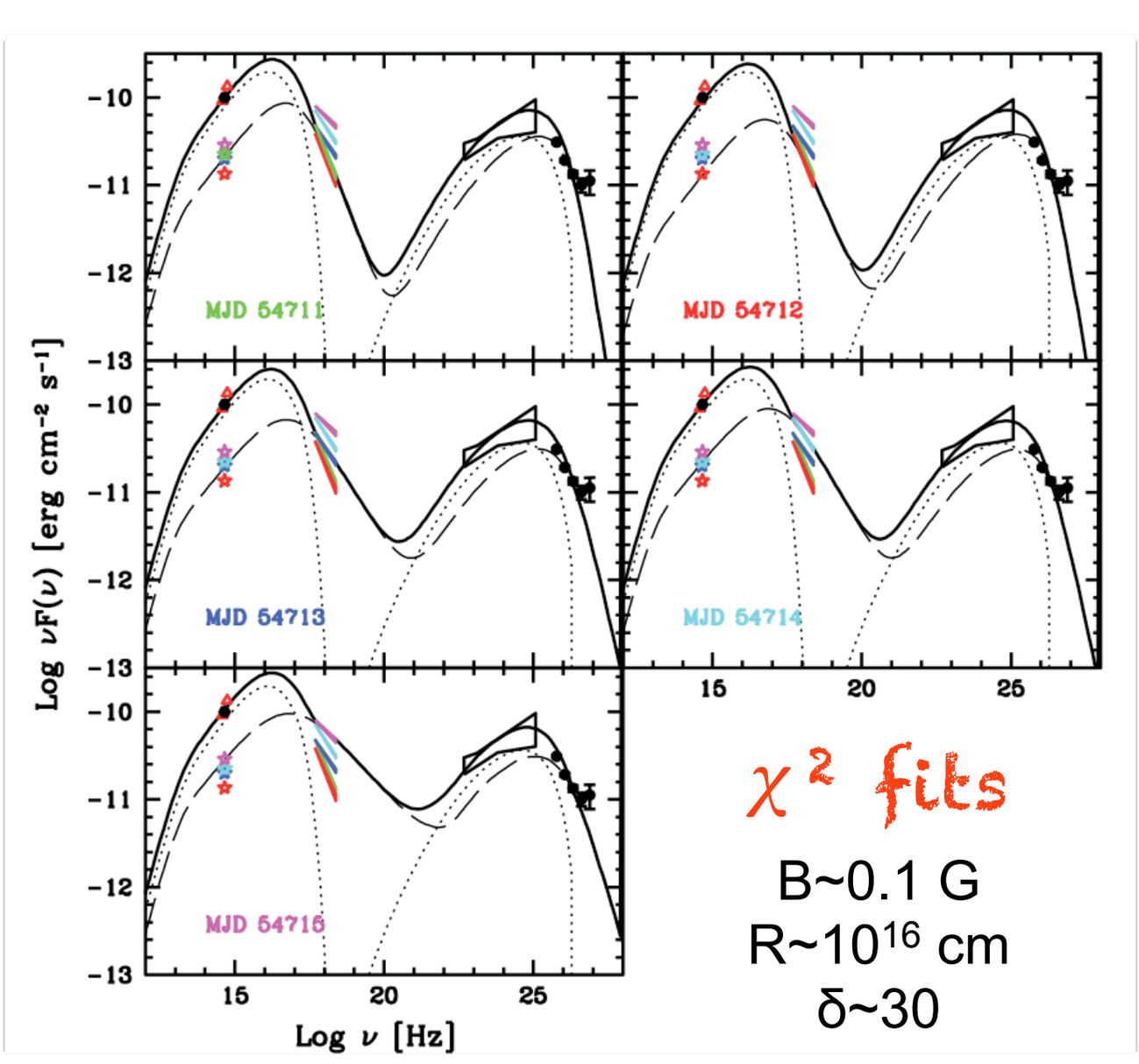


Barres de Almeida et al. 2014

Multi-blob models

Independent, not interacting, regions





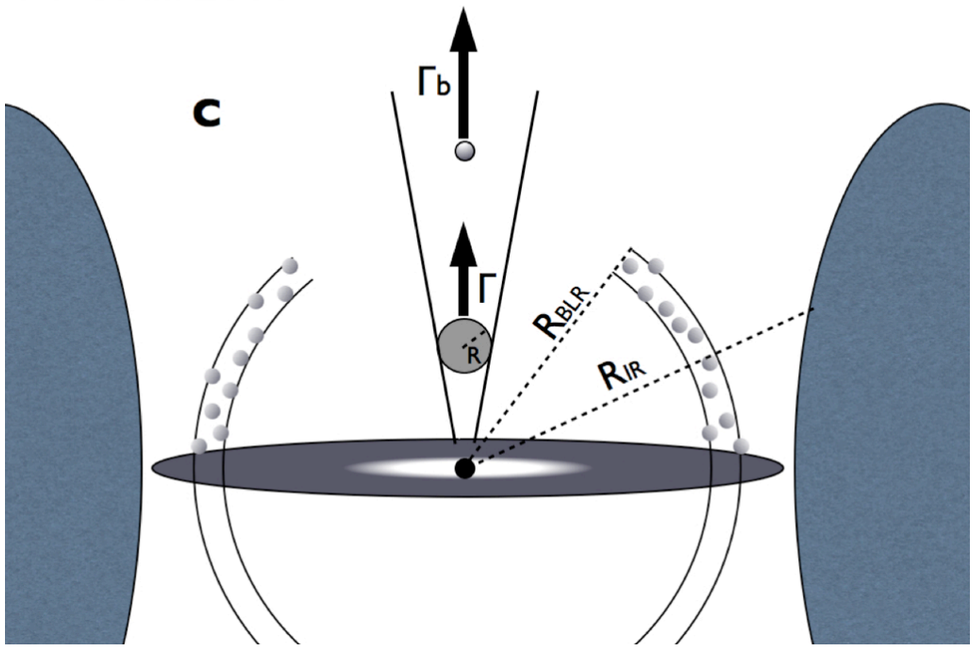
χ^2 fits

B~0.1 G
R~10^{16} cm
δ~30

Barres de Almeida et al. 2014

Multi-blob models

FT et al. 2011

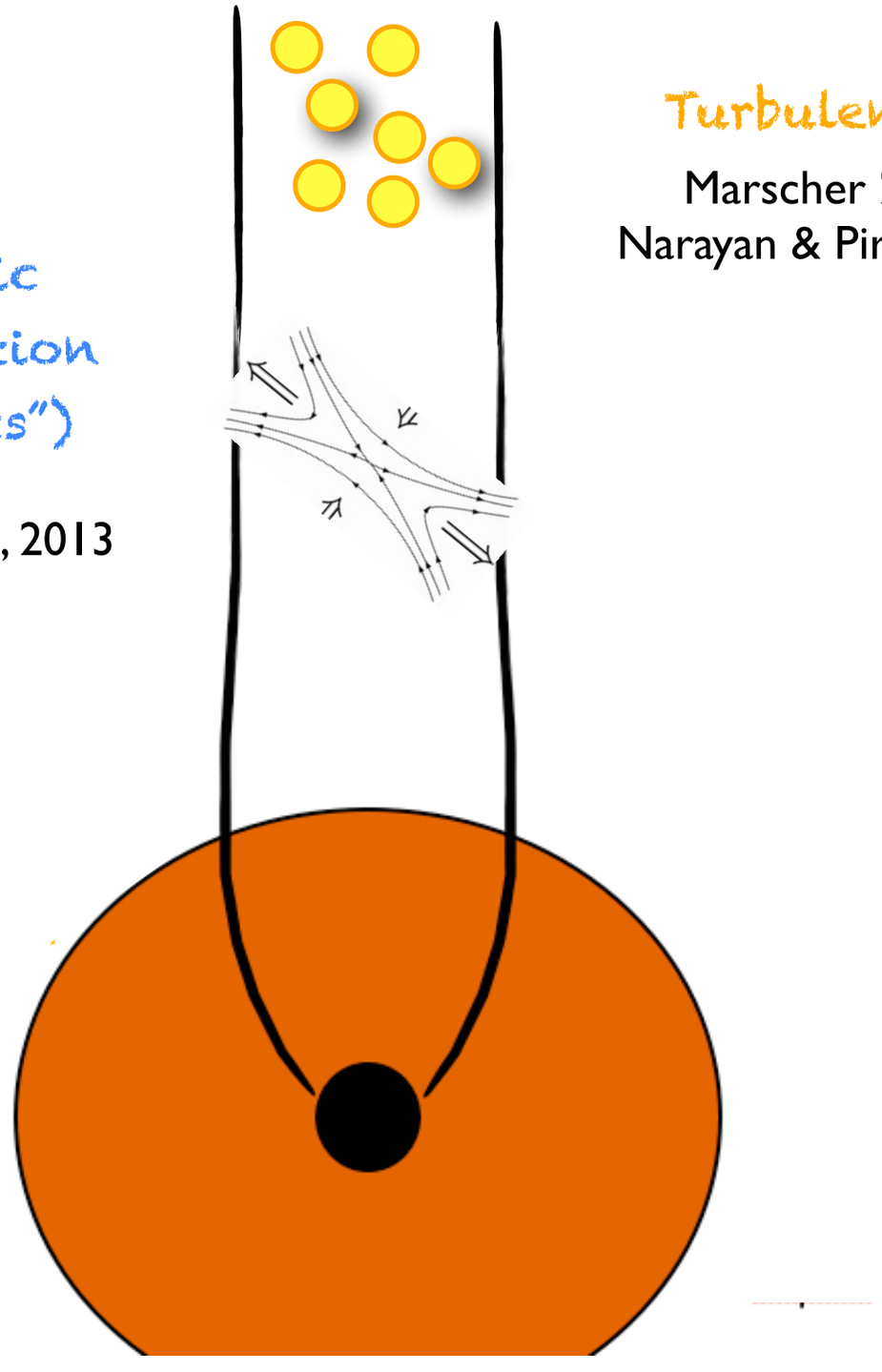


PKS 1222+200

FSRQ with (sub)TeV emission

Magnetic reconnection ("minijets")

Giannios 2011, 2013



Turbulence

Marscher 2014
Narayan & Piran 2012

Some problems

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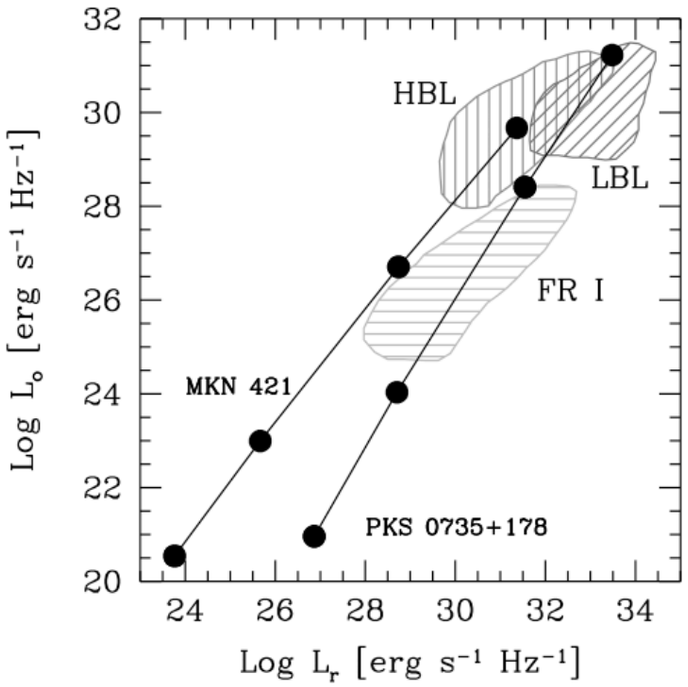

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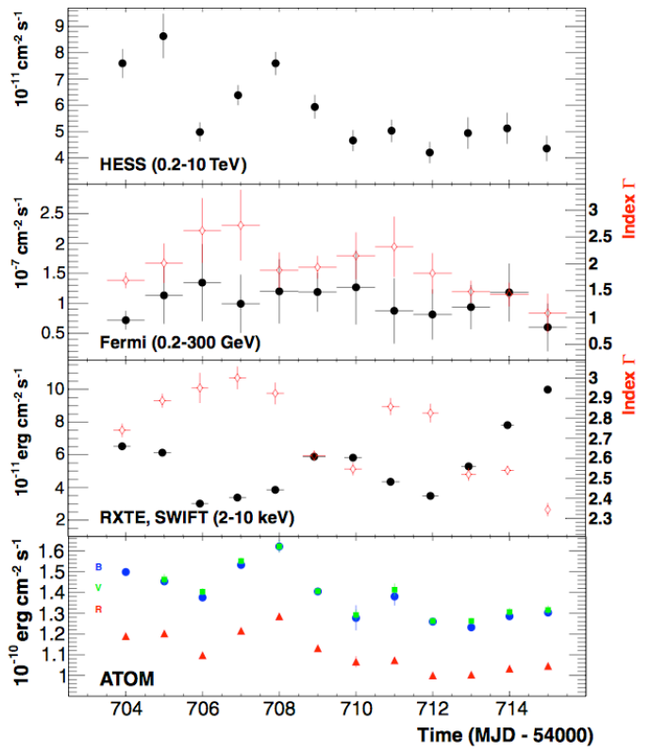

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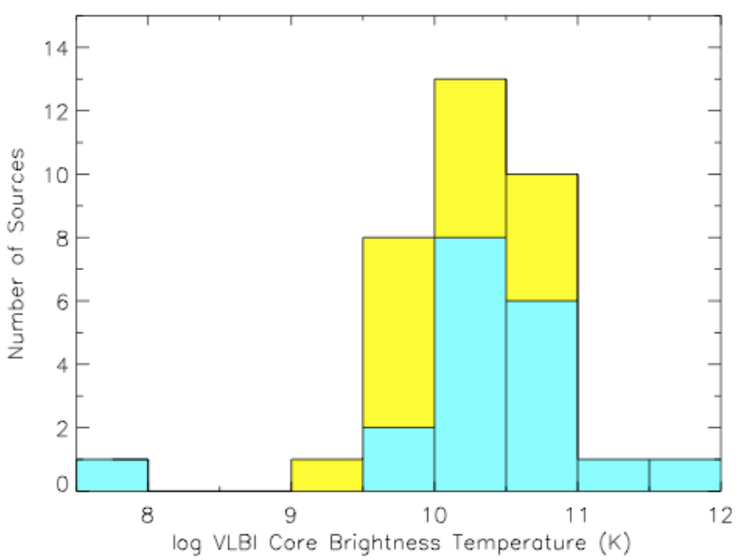

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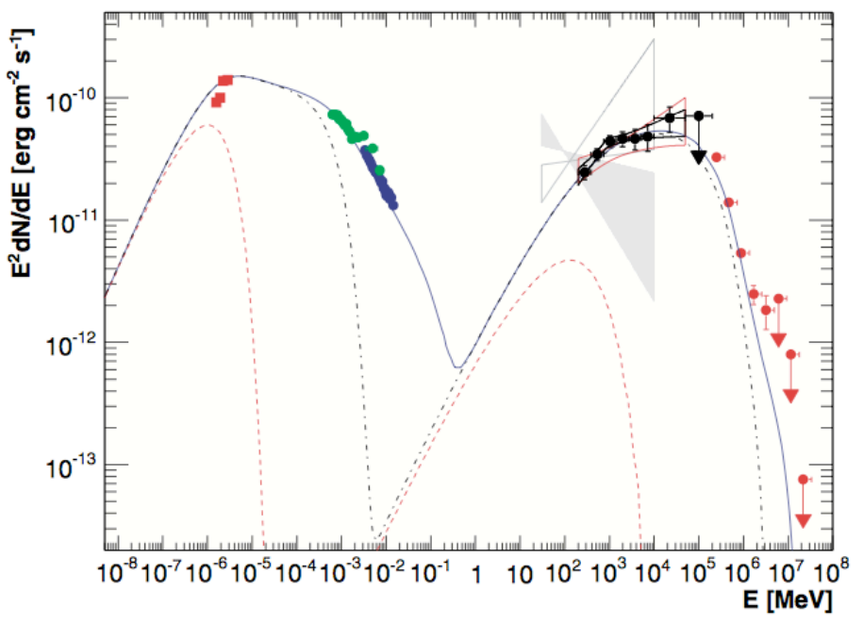
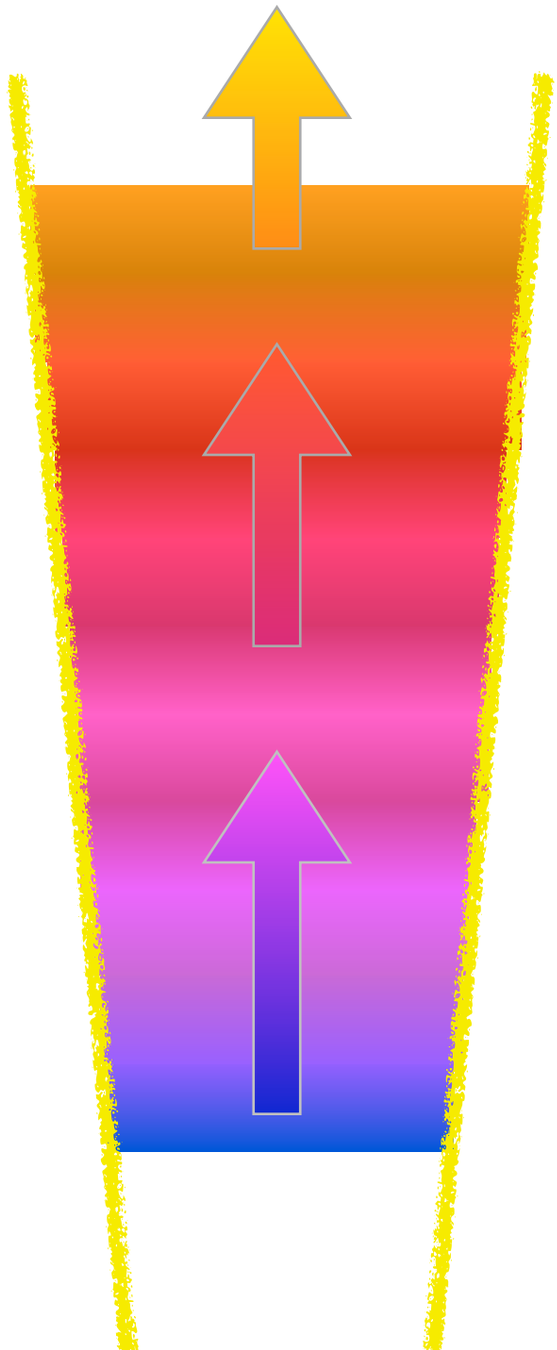


Decelerating jets

The inner/faster regions "see" boosted radiation from the outer/slower regions

Amplified IC



Γ=3-5

Γ=15-20

Georganopoulos & Kazanas 2003

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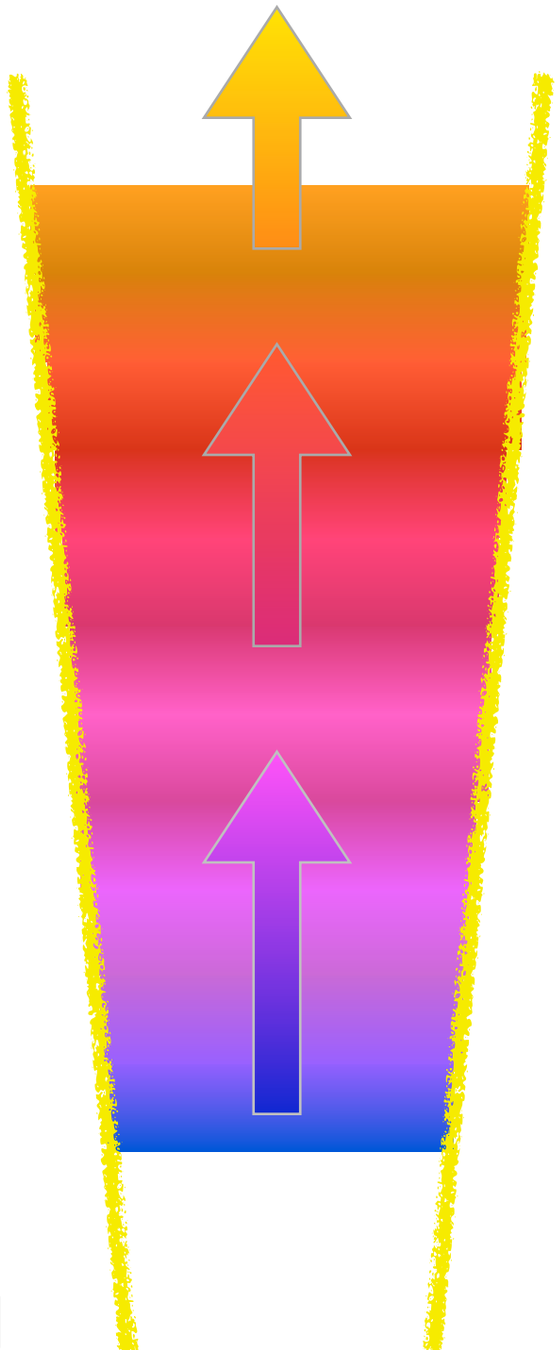


Γ=3-5

✔ Slow VLBI
✔ Unification

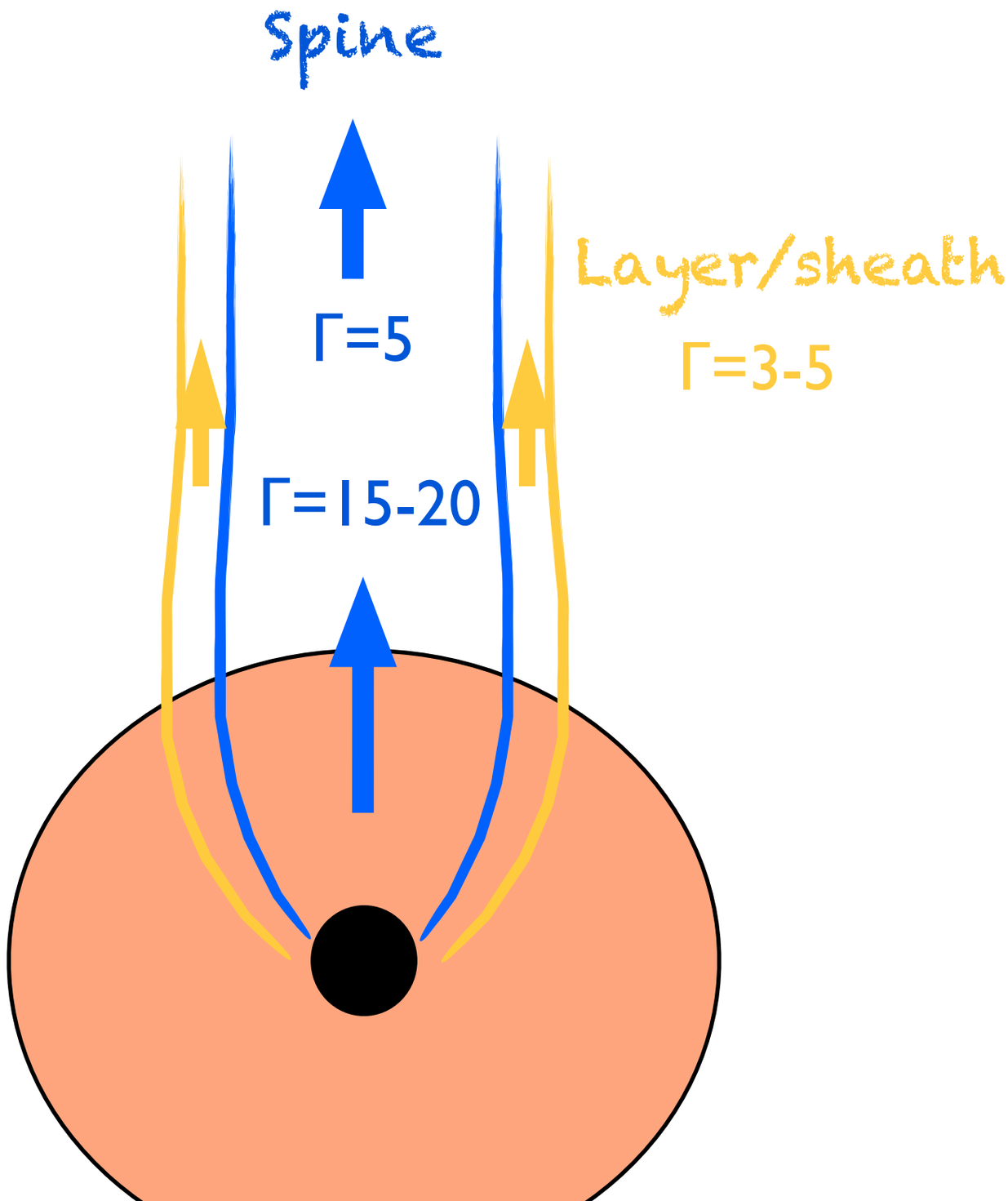
Γ=15-20

✔ Large Doppler factor

✘ Deceleration is postulated

Georganopoulos & Kazanas 2003

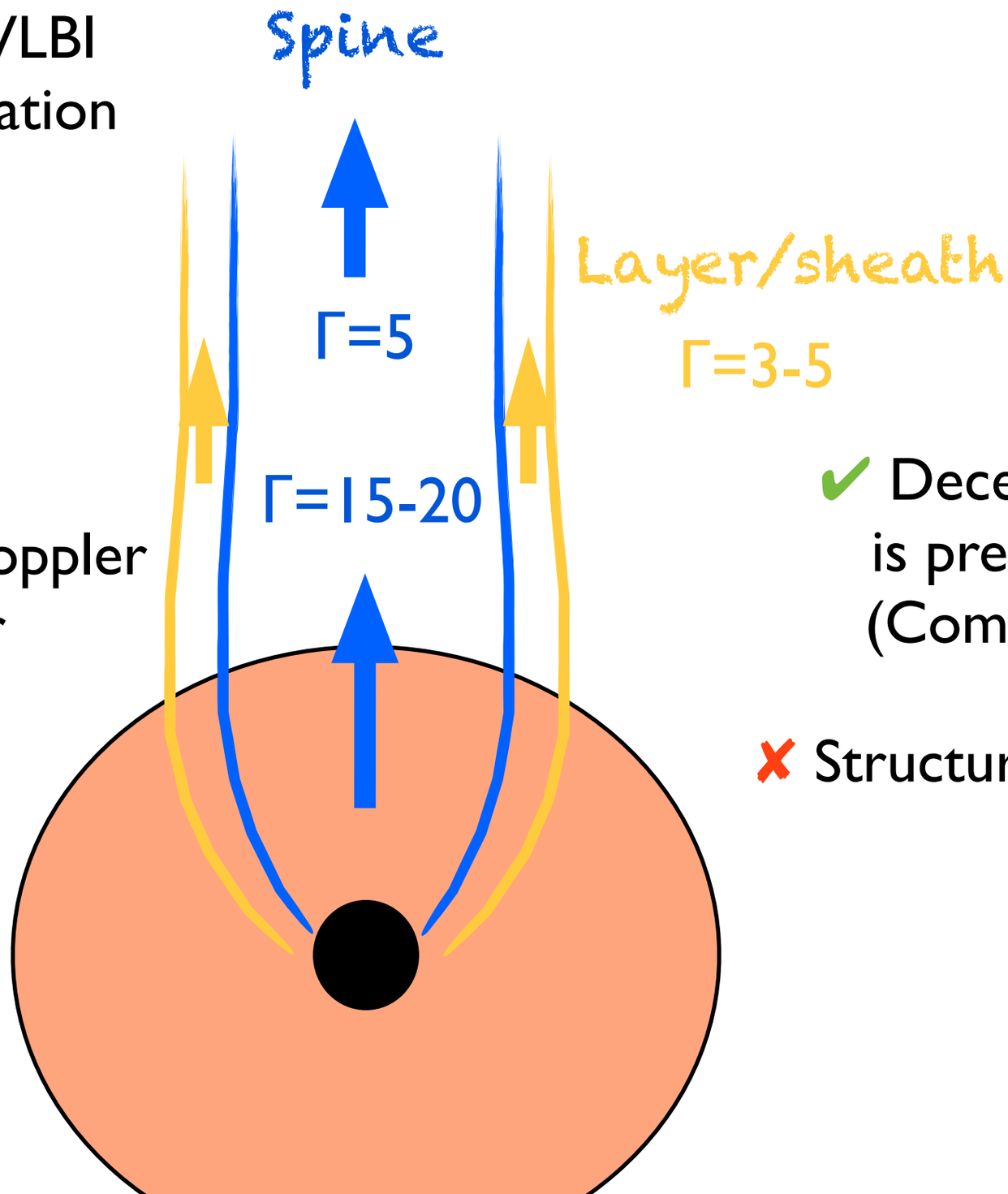
Structured jets



Ghisellini, FT and Chiaberge 2005
also Henri & Pelletier 1991

Structured jets

✔ Slow VLBI
✔ Unification



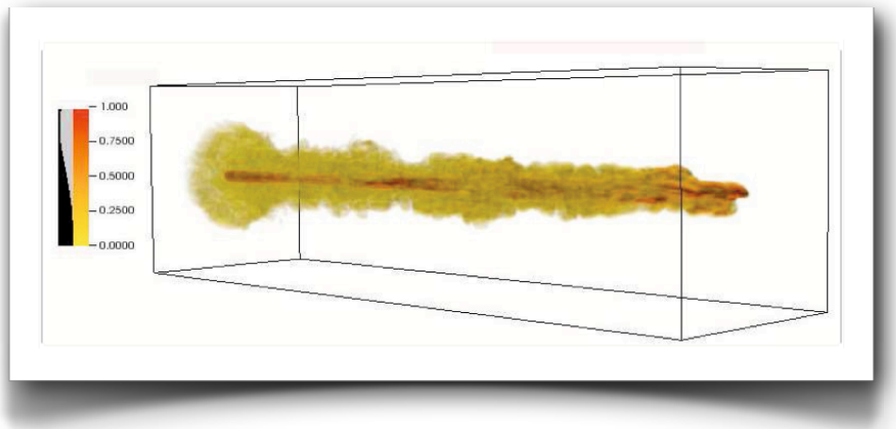
✔ Large Doppler factor

✔ Deceleration is predicted (Compton drag)

✘ Structure is postulated

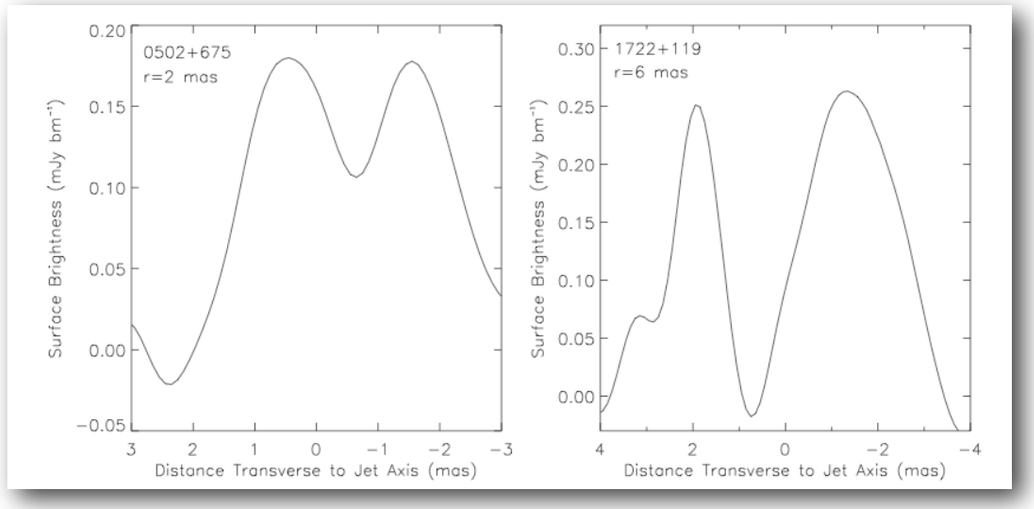
Ghisellini, FT and Chiaberge 2005

Structured jets



Simulations **predict spine-layer structure**

Entrainment/instability e.g. Rossi et al. 2008
Acceleration process e.g. McKinney 2006



Limb brightening
Mkn 501, Mkn 421, M87, NGC 1275

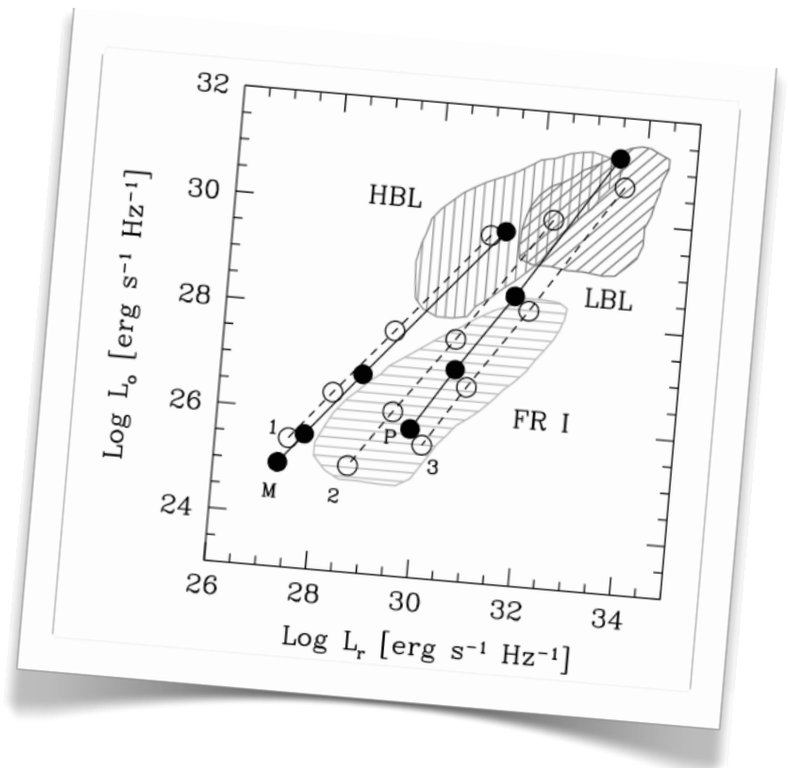
Laing 1996
Giroletti et al. 2004
Piner & Edwards 2014

Helical magnetic fields can mimic it!

Pushkarev et al. 2005
Clausen-Brown 2011
Murphy et al. 2013

Unification **requires velocity structures**

Chiaberge et al. 2000
Meyer et al.
Sbarrato et al. 2014

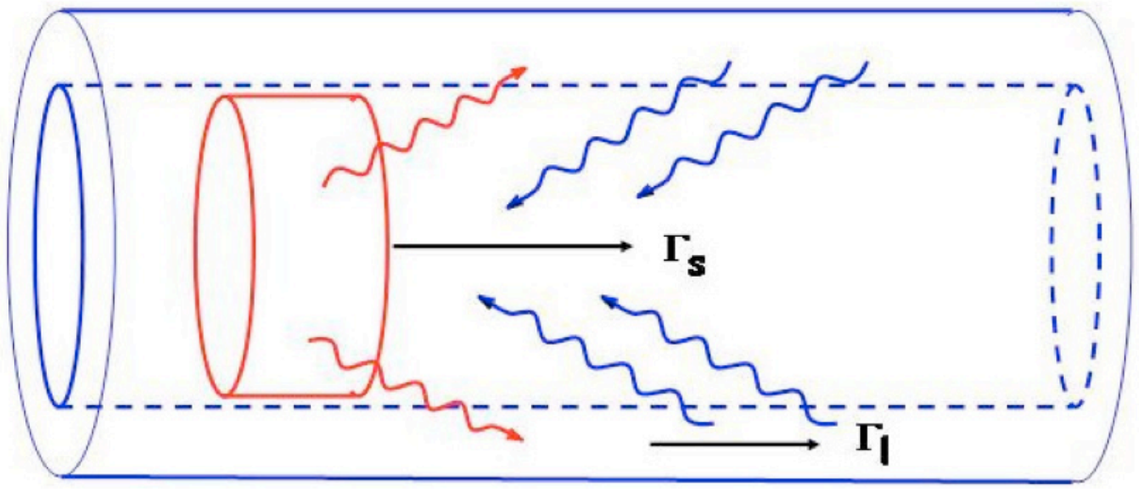


The spine layer model - 10 years after

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

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

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



Ghisellini, FT and Chiaberge 2005

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

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

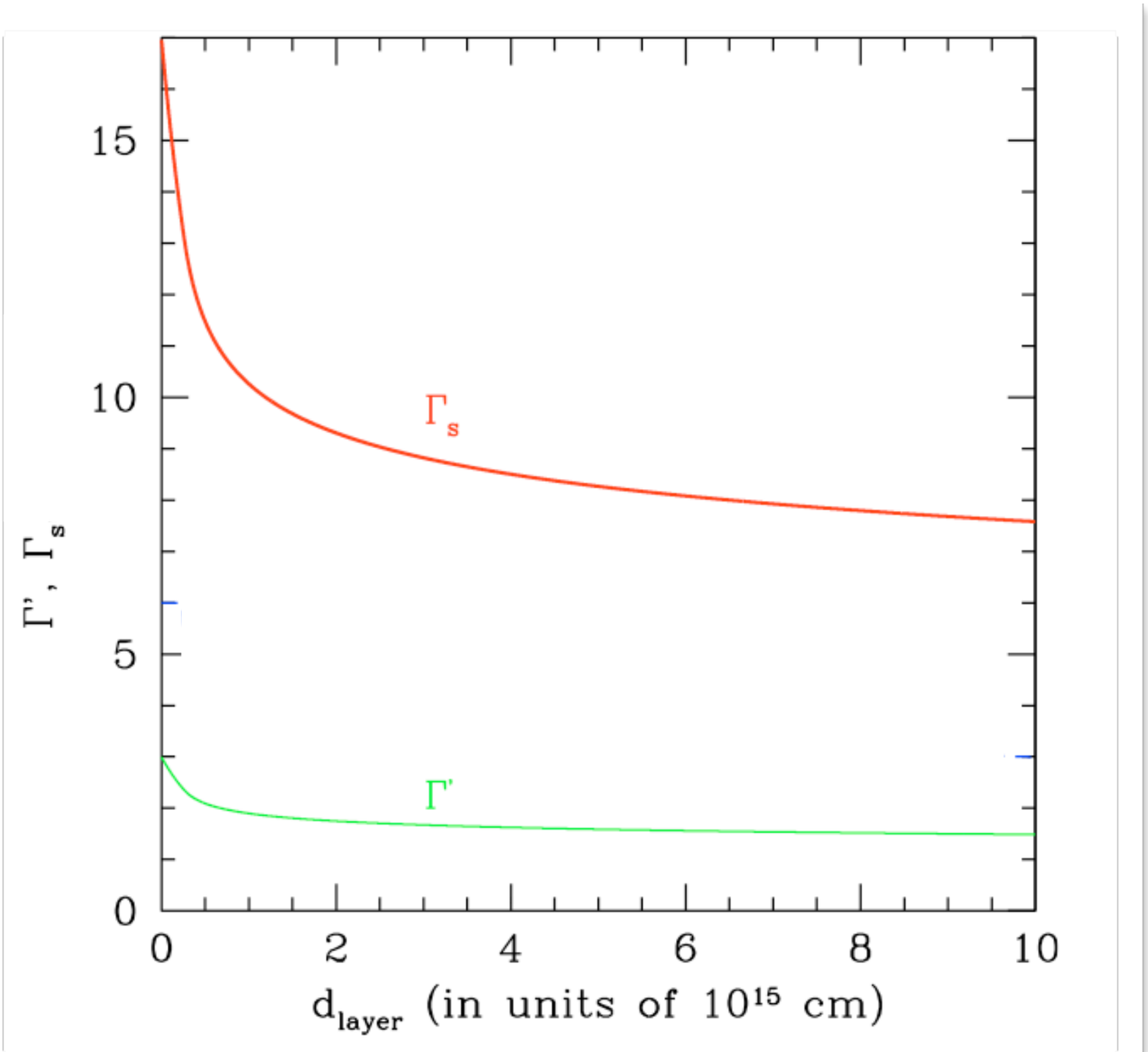
The IC emission is enhanced w.r.t. to the one-zone model

The IC emission is anisotropic in the layer spine-frame

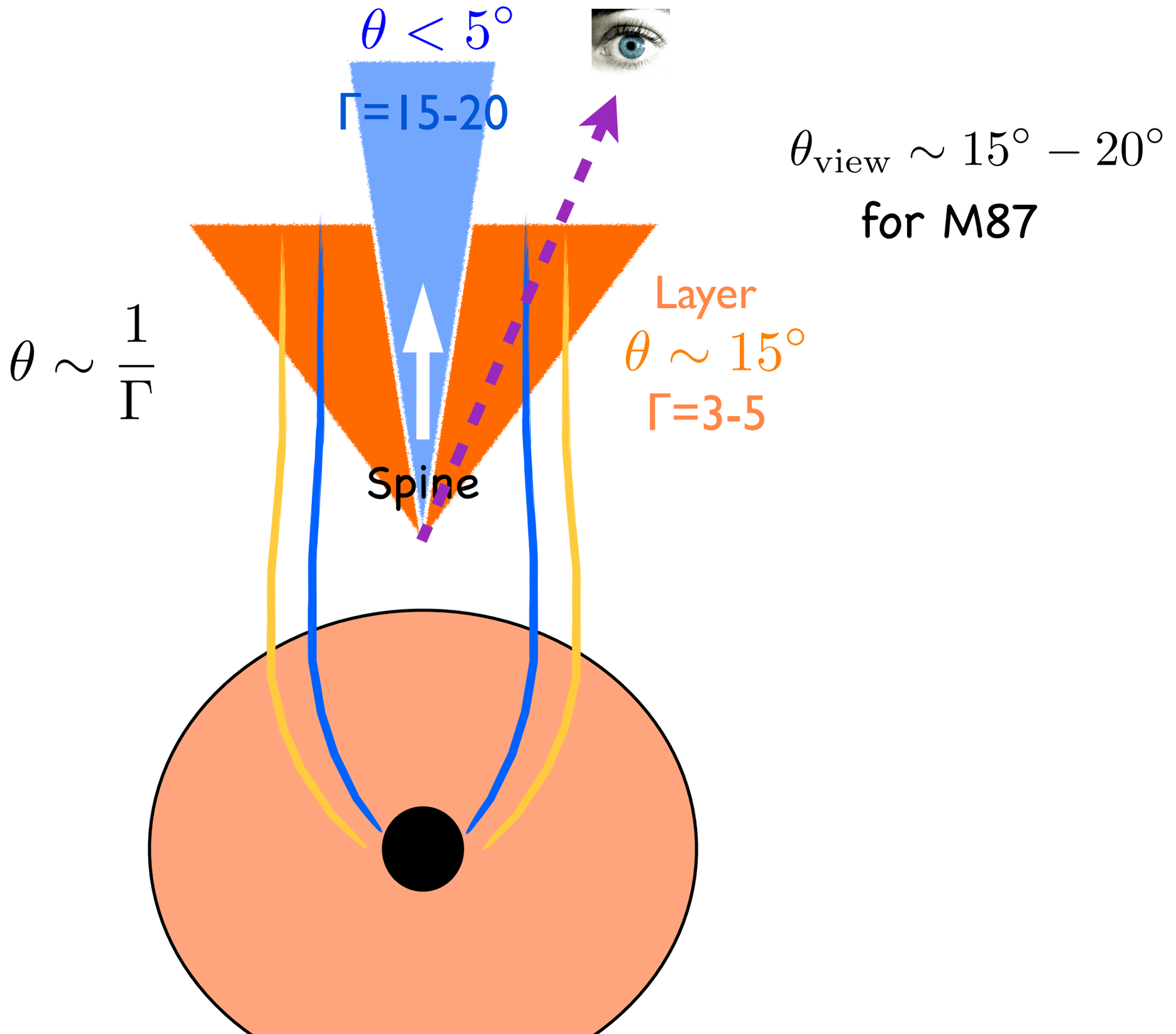
The spine layer model - 10 years after

Spine deceleration

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}t} = \frac{4}{3}\frac{\sigma_{\mathrm{T}} c N_{\mathrm{e}} U_{\mathrm{syn}} \langle\tilde{\gamma}^2\rangle_z}{N_{\mathrm{p}} m_{\mathrm{p}} c^2 + N_{\mathrm{e}}\langle\gamma\rangle m_{\mathrm{e}} c^2} = \frac{8}{9}\frac{\sigma_{\mathrm{T}} c N_{\mathrm{e}} U_{\mathrm{syn}} \langle\gamma^2\rangle \Gamma^2}{N_{\mathrm{p}} m_{\mathrm{p}} c^2 + N_{\mathrm{e}}\langle\gamma\rangle m_{\mathrm{e}} c^2}.$$



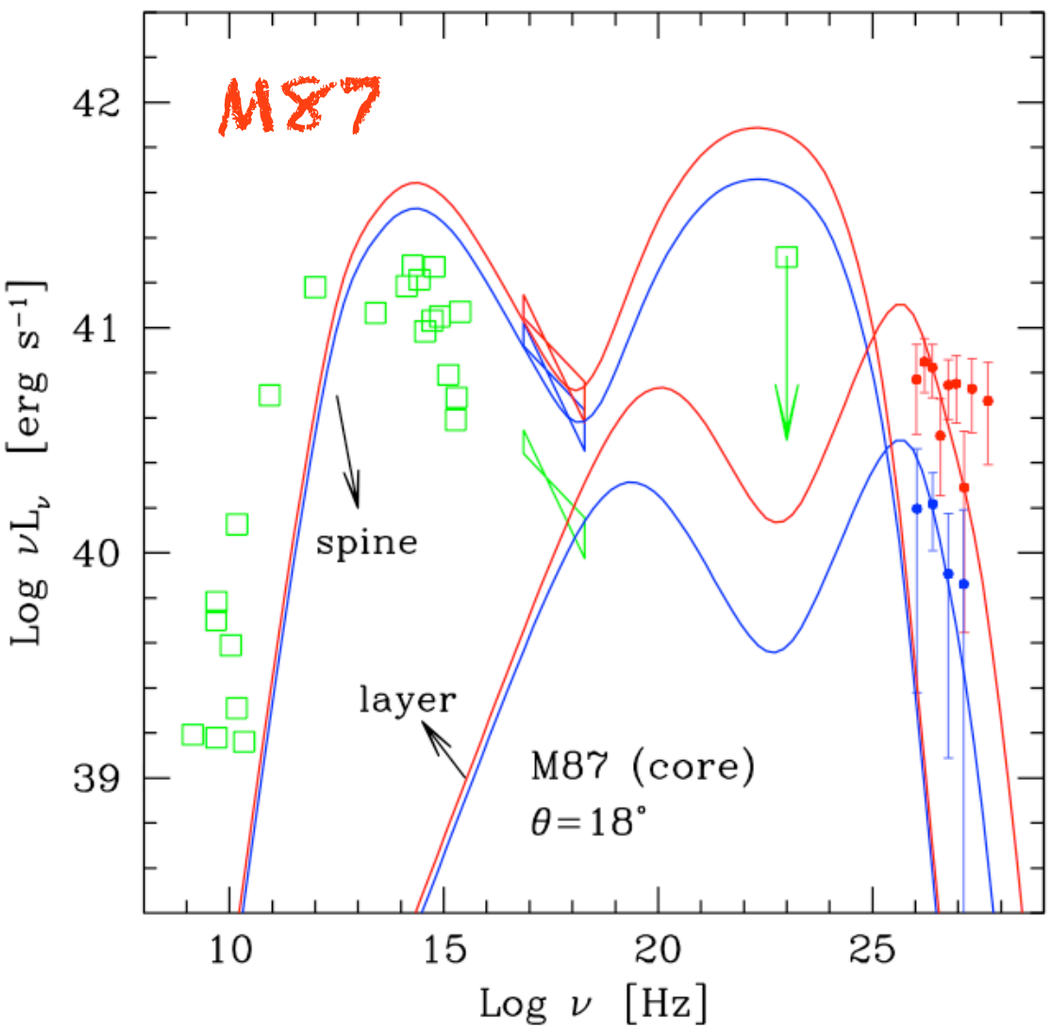
Structured jets and radiogalaxies



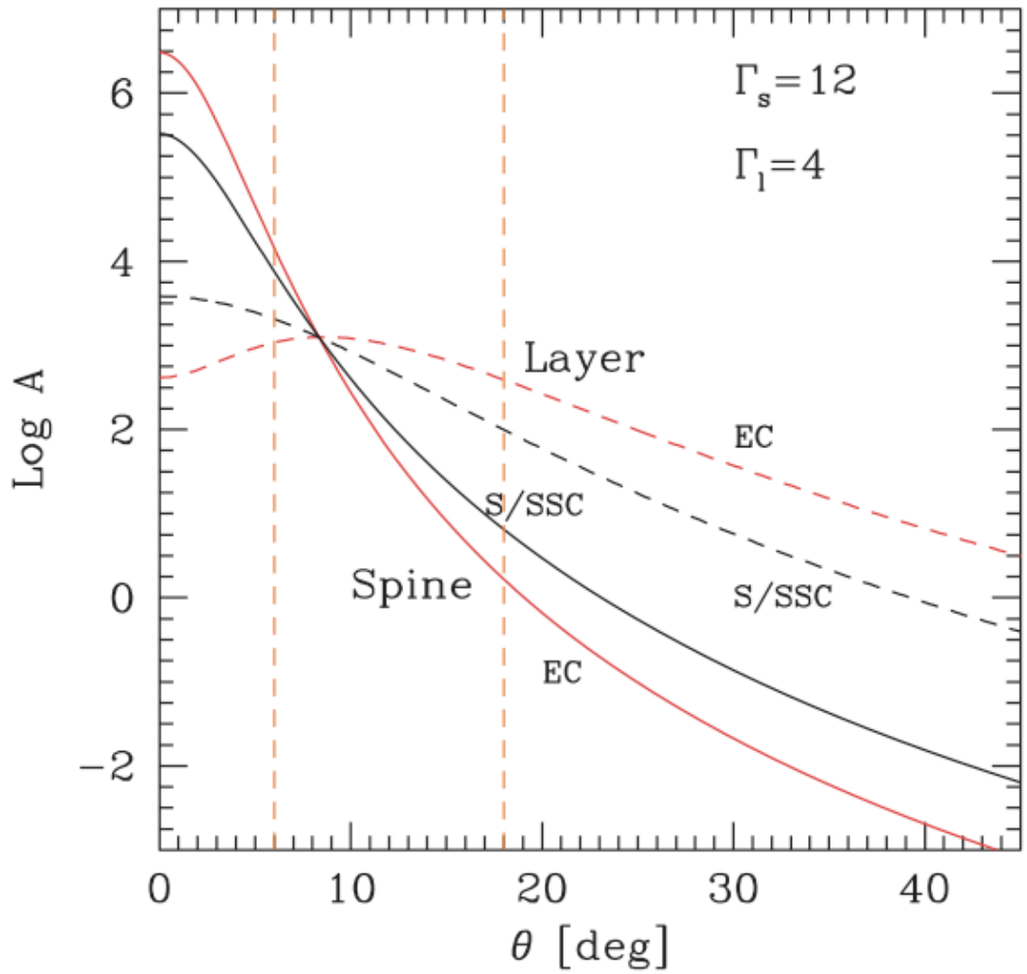
$\theta_{\rm view} \sim 15^\circ - 20^\circ$

for M87

Structured jets and radiogalaxies

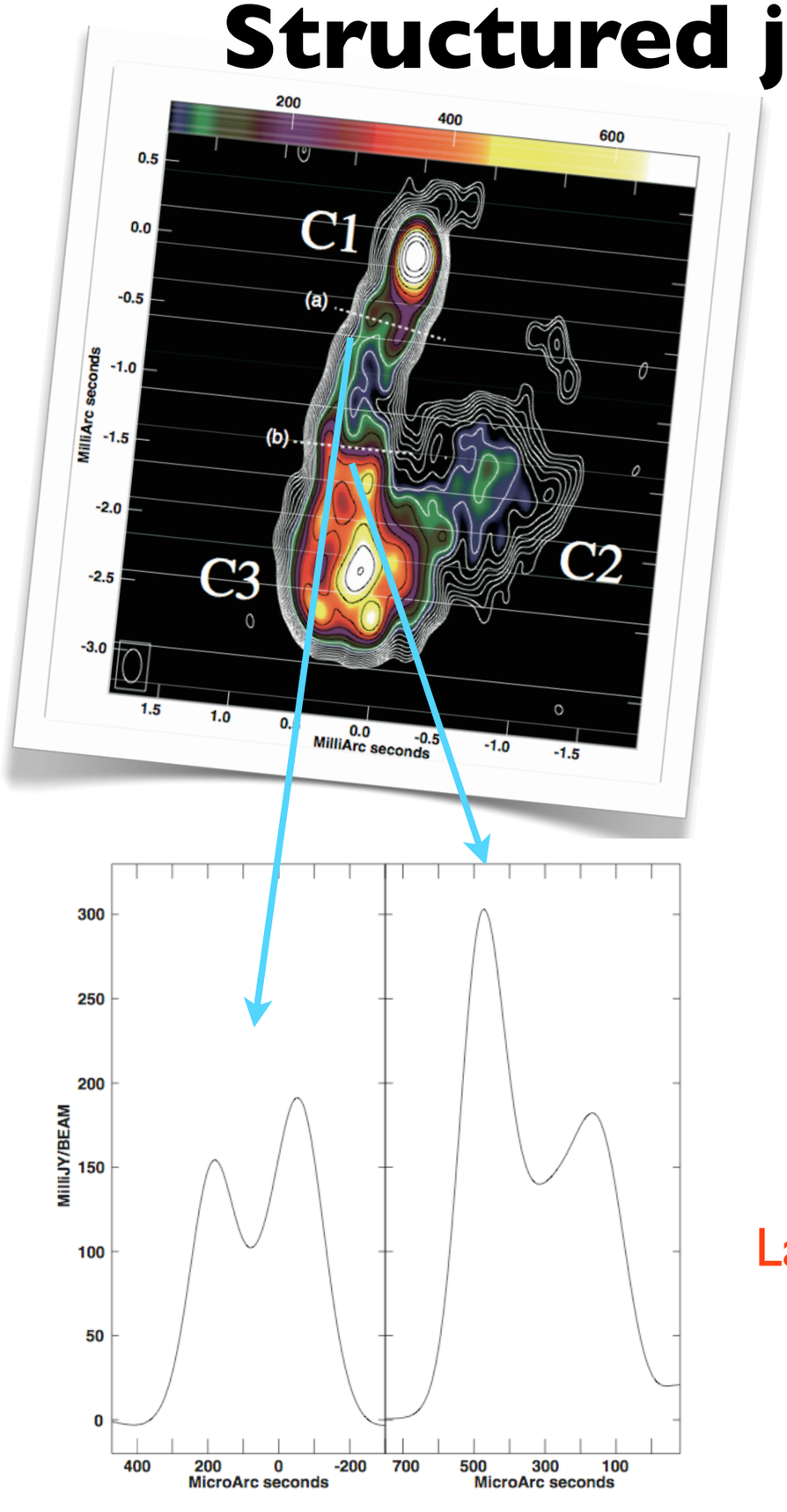


Amplification patterns



FT & Ghisellini 2008

Structured jets and radiogalaxies



NGC 1275

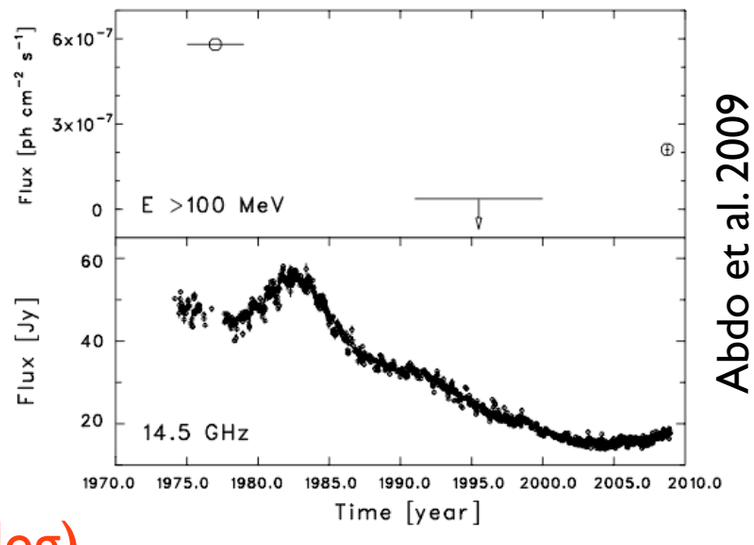
Nagai et al. 2014

Radio outburst in 2005

Limb brightening VLBA 43 GHz

Not present in the 1990s

Correlation with gamma-rays?



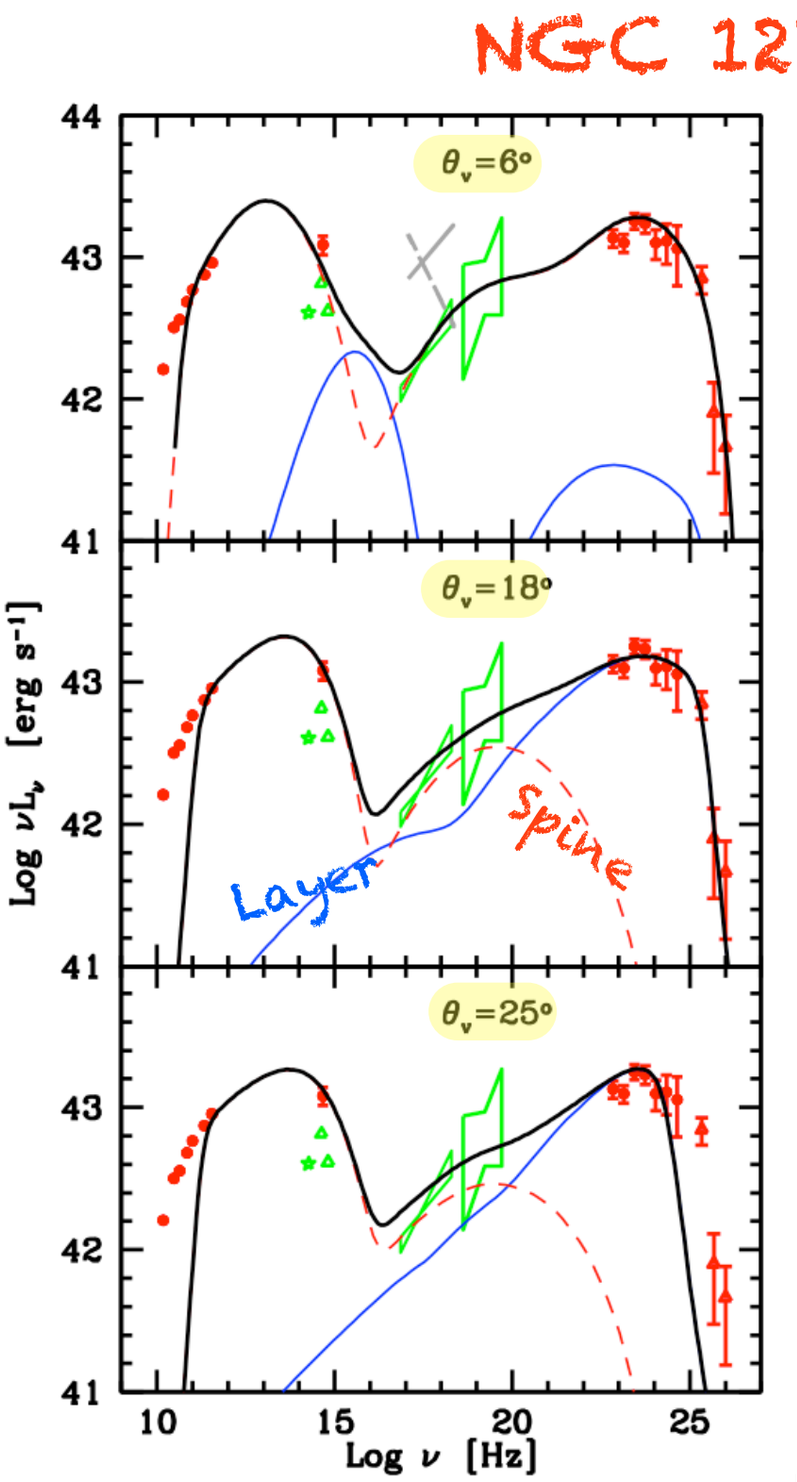
Abdo et al. 2009

Large viewing angle (θ~20 deg)

One-zone SSC excluded
(requires large beaming)

Aleksic et al. 2014

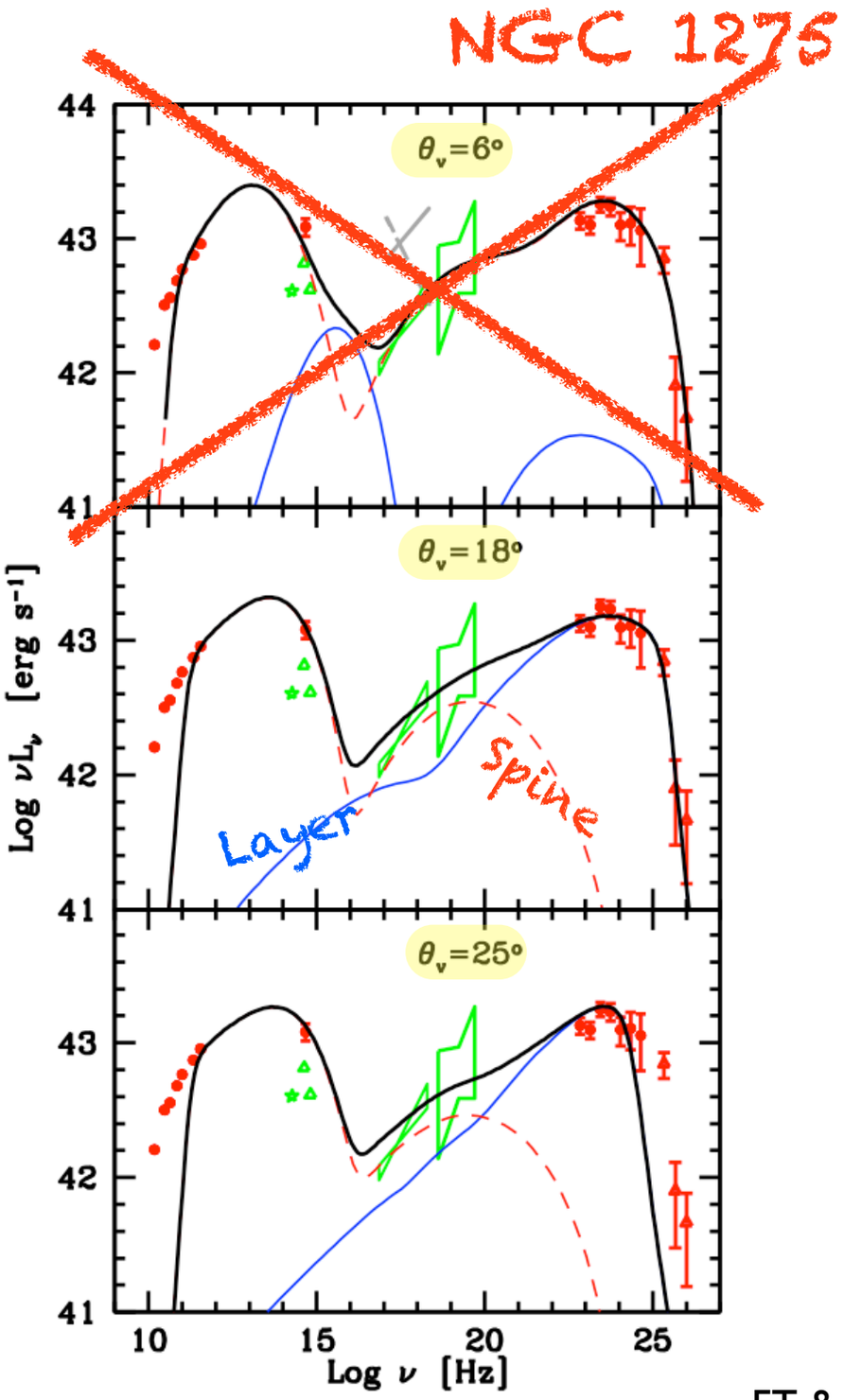
Structured jets and radiogalaxies



Emission from one region
possible only for small angles
(requires $\delta \gtrsim 4$)

FT & Ghisellini 2014

Structured jets and radiogalaxies

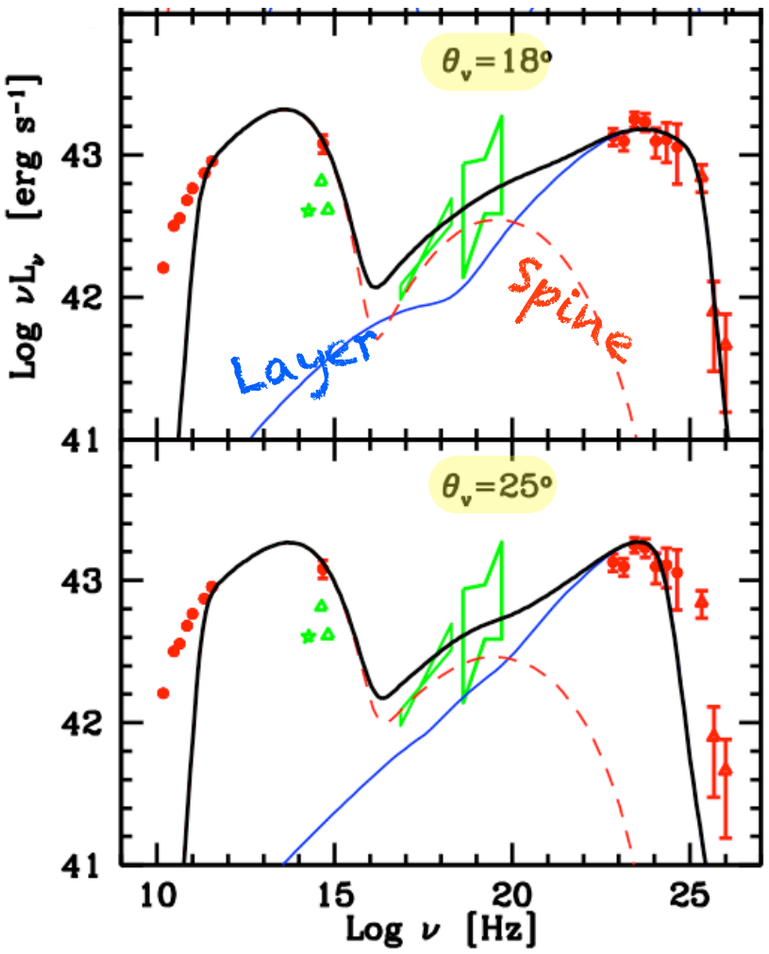


Emission from one region
possible only for small angles
(requires $\delta \gtrsim 4$)

FT & Ghisellini 2014

Structured jets and radiogalaxies

NGC 1275



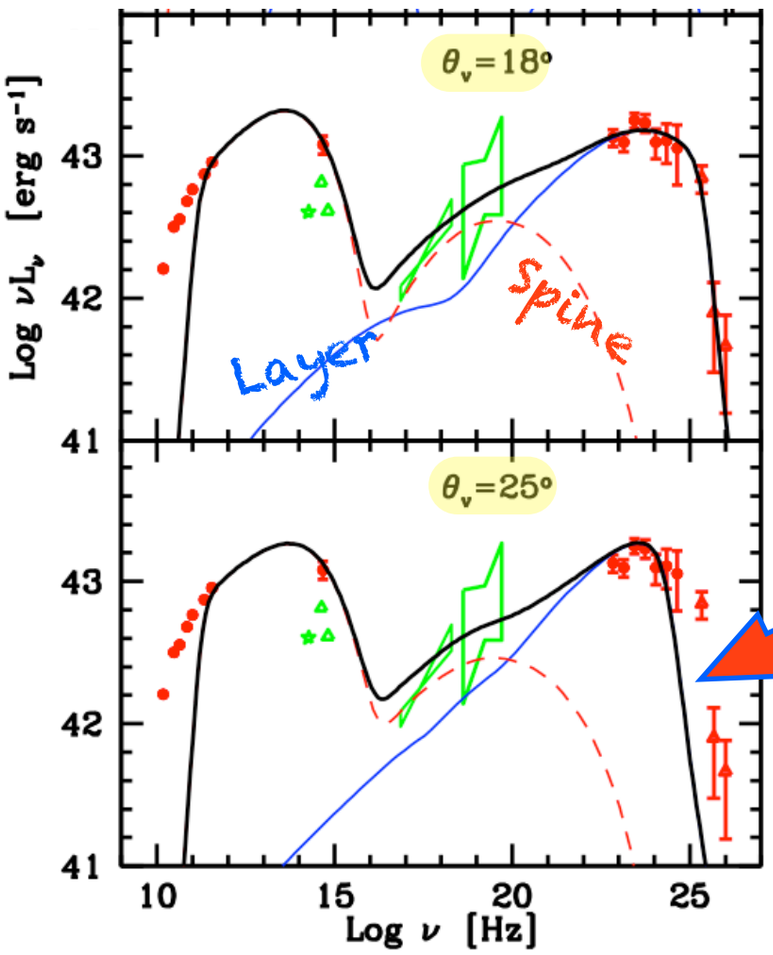
Spine: low energy peak $\Gamma_s = 10$

Layer: high energy peak $\Gamma_l = 4$

FT & Ghisellini 2014

Structured jets and radiogalaxies

NGC 1275



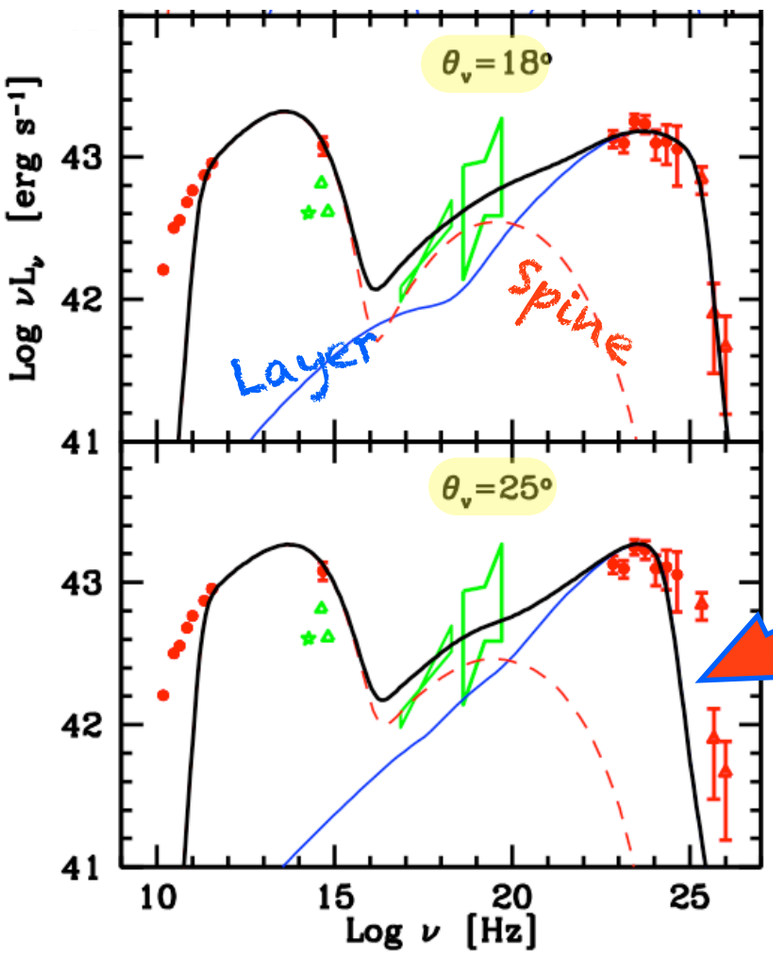
Absorbed E>50 GeV

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

FT & Ghisellini 2014

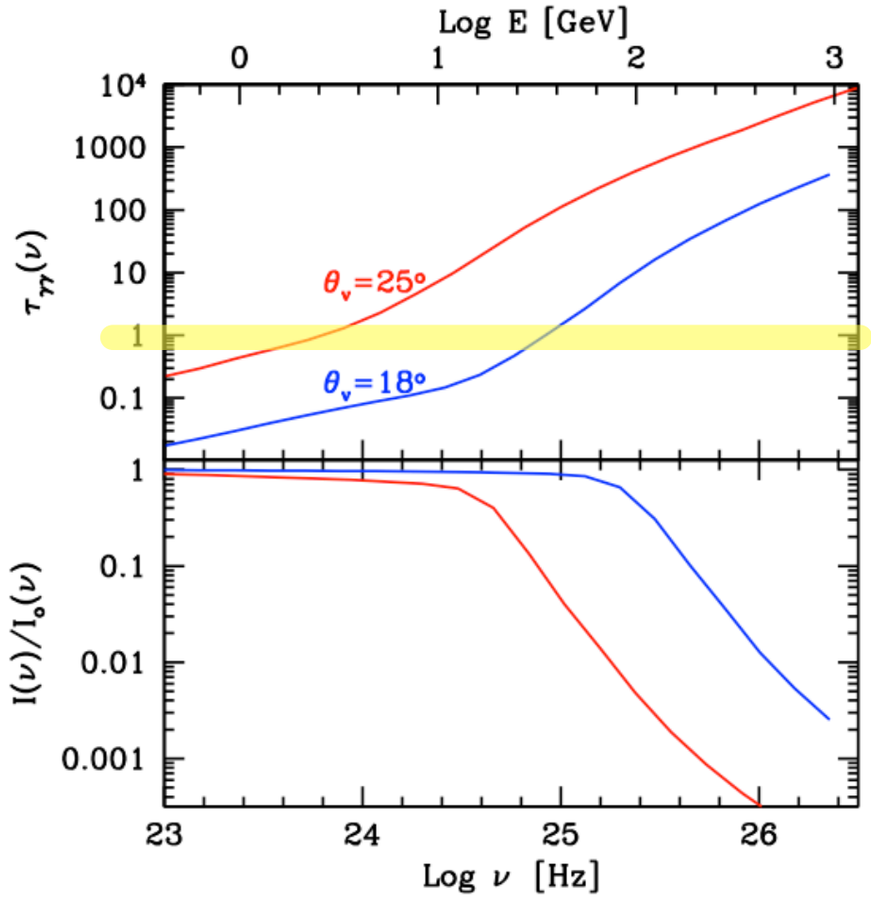
Structured jets and radiogalaxies

NGC 1275



Absorbed E>50 GeV

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



Larger angles

Smaller beaming

Larger comoving luminosity

Larger tau

FT & Ghisellini 2014

Structured jets and radiogalaxies

$\theta = 18^o$ *case*

Physical conditions

$$\frac{U_B}{U_{\rm rad}} = 7 \times 10^{-2}$$ Layer

[Dominated by spine radiation]

$$\frac{U_B}{U_{\rm rad}} = 3.7$$ Spine

Layer $\gamma_{\rm max} = 10^6$

(Stawarz & Ostrowski 2002)

Turbulent acceleration?

$$\gamma_{\rm eq} \simeq 10^8 \left(\frac{B}{\rm G}\right)^{-1/2} (1+\xi)^{-1/2} \qquad \xi = \frac{U_{\rm rad}}{U_B}$$

$\gamma_{\rm eq} \approx 10^7$ Pile-up?

Structured jets and radiogalaxies

$\theta = 18^o$ *case* Physical conditions

$$L_{\rm j} \approx L_B = 5 \times 10^{43}\ {\rm erg\,s^{-1}}$$ Layer

$$L_{\rm j} \approx L_p = 10^{47}\ {\rm erg\,s^{-1}}$$ Spine

Spine-layer: blazars

PKS 0521-36: a misaligned blazar?

Tentatively detected by EGRET

No beaming required

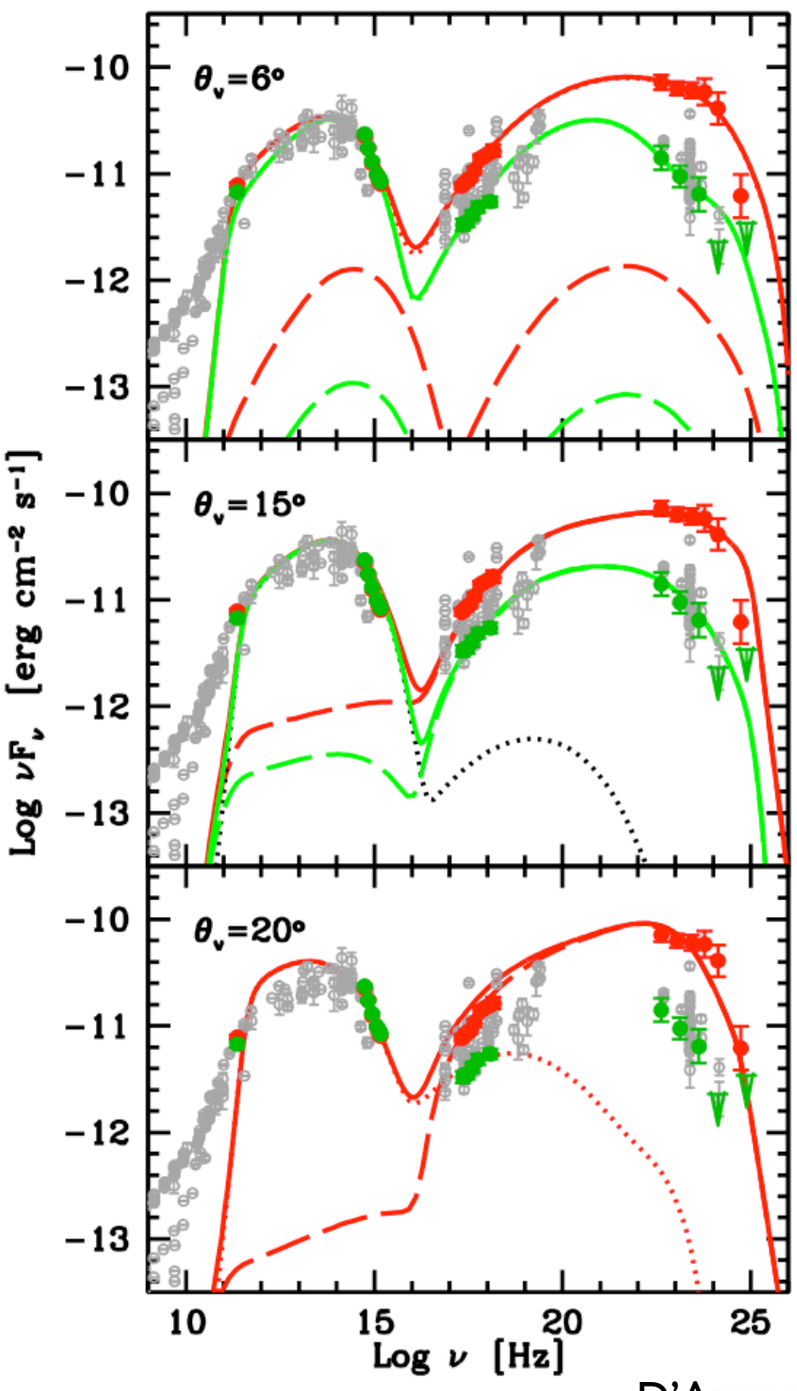
No superluminal speed

Large-scale optical/X-ray jet

→ Large angle ~20-30 deg (Pian et al. 1996, Giroletti et al. 2014)

Spine-layer: blazars

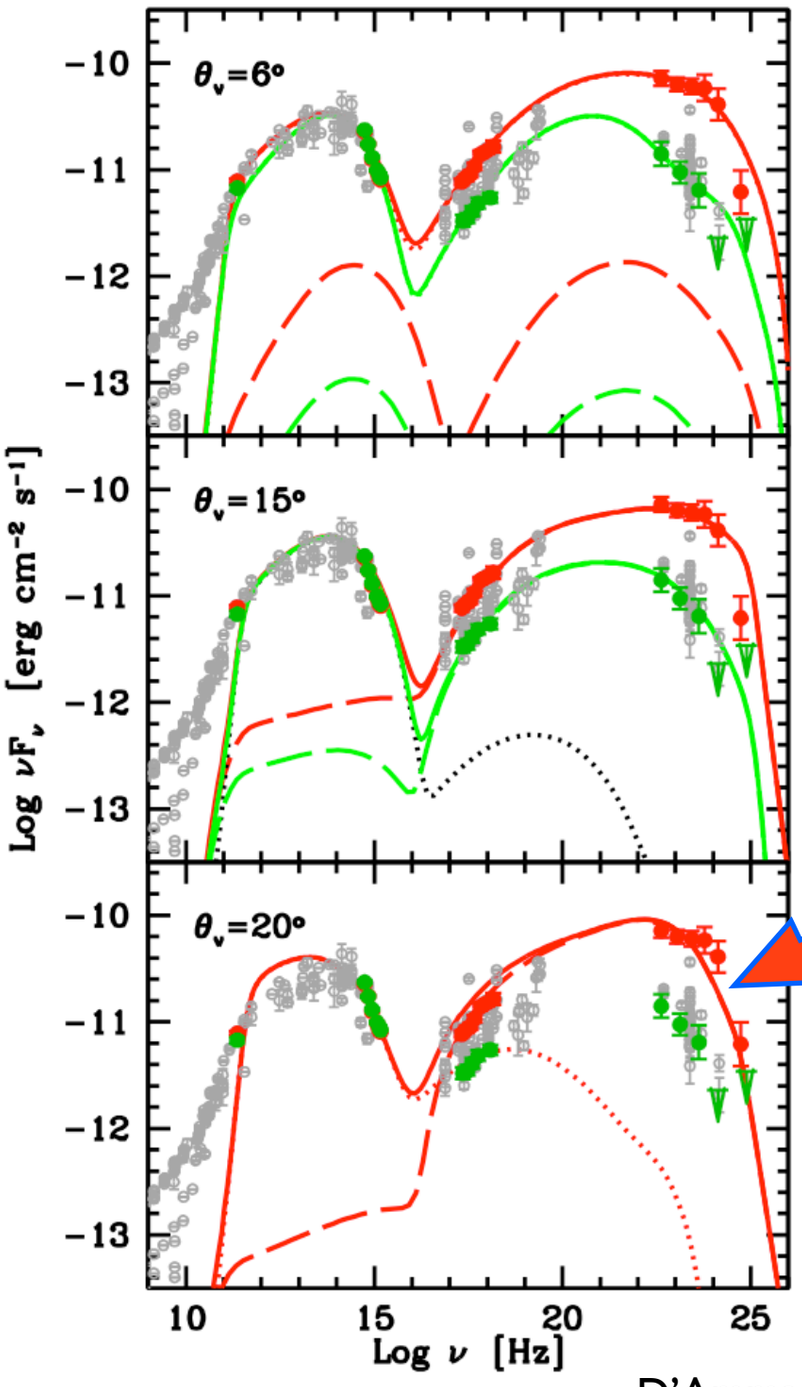
PKS 0521-36



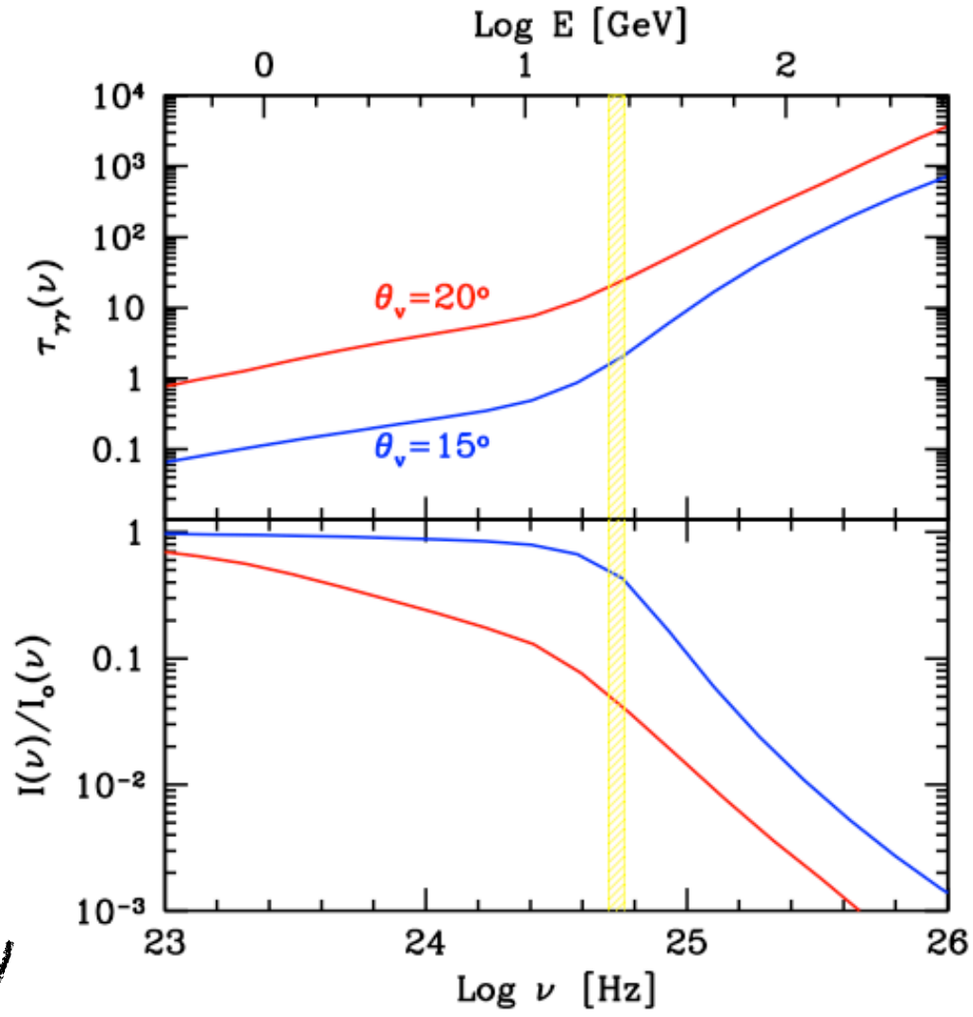
D'Ammando et al. 2015

Spine-layer: blazars

PKS 0521-36



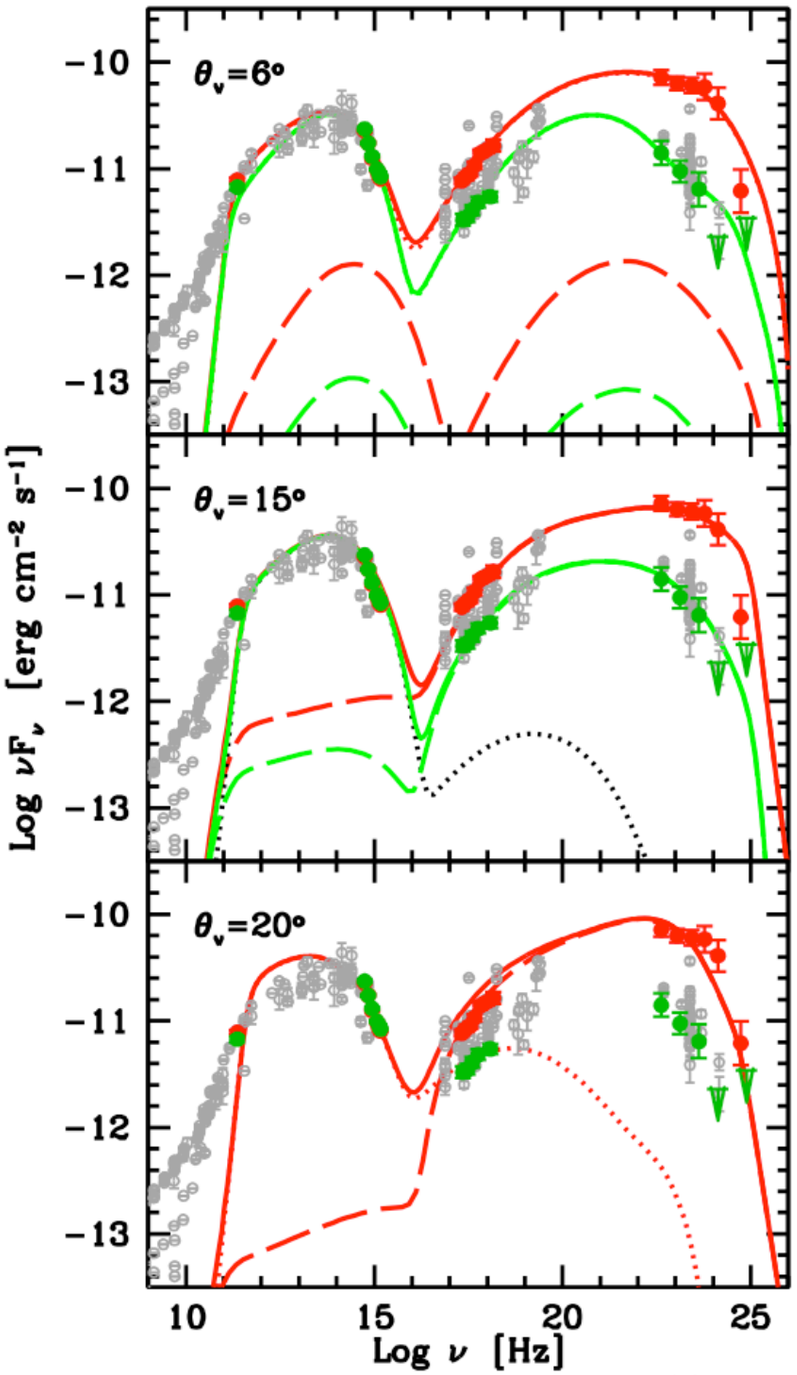
Absorbed E>100MeV



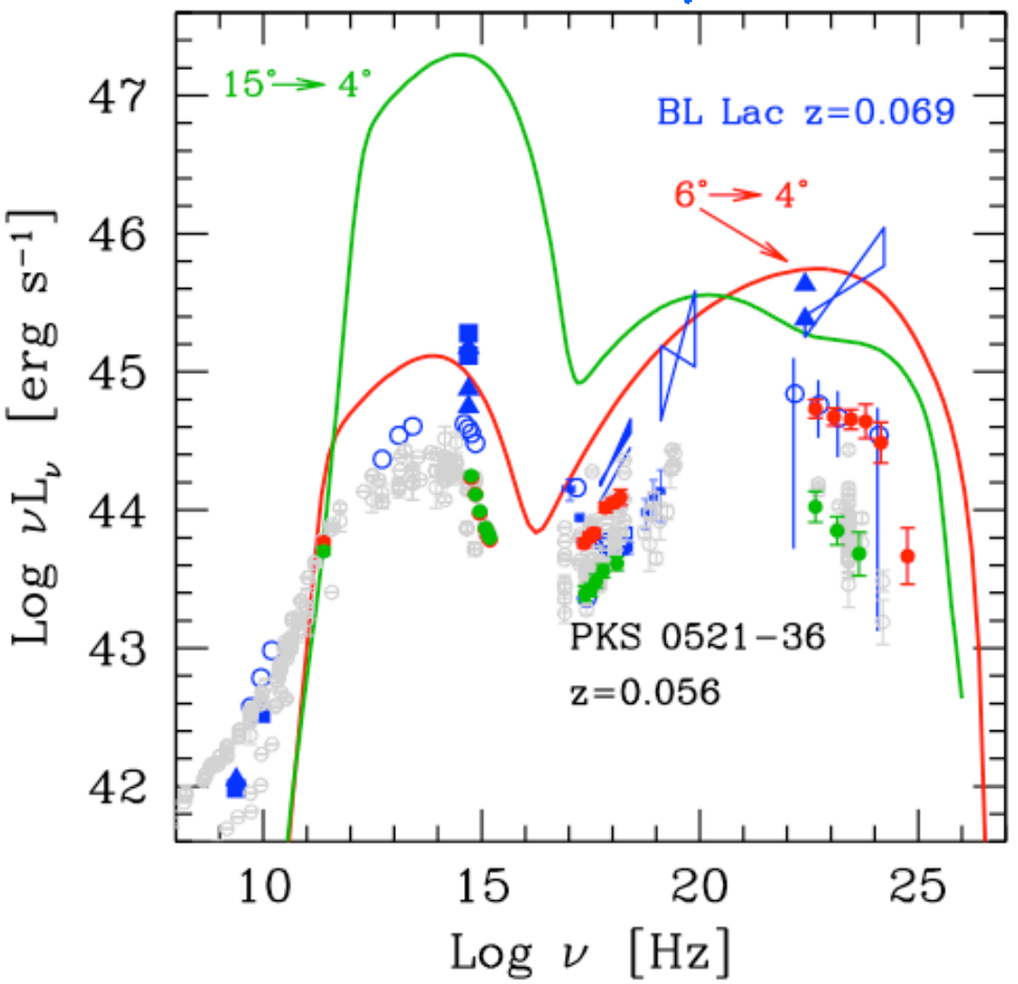
D'Ammando et al. 2015

Spine-layer: blazars

PKS 0521-36



A synchrotron-dominated counterpart?

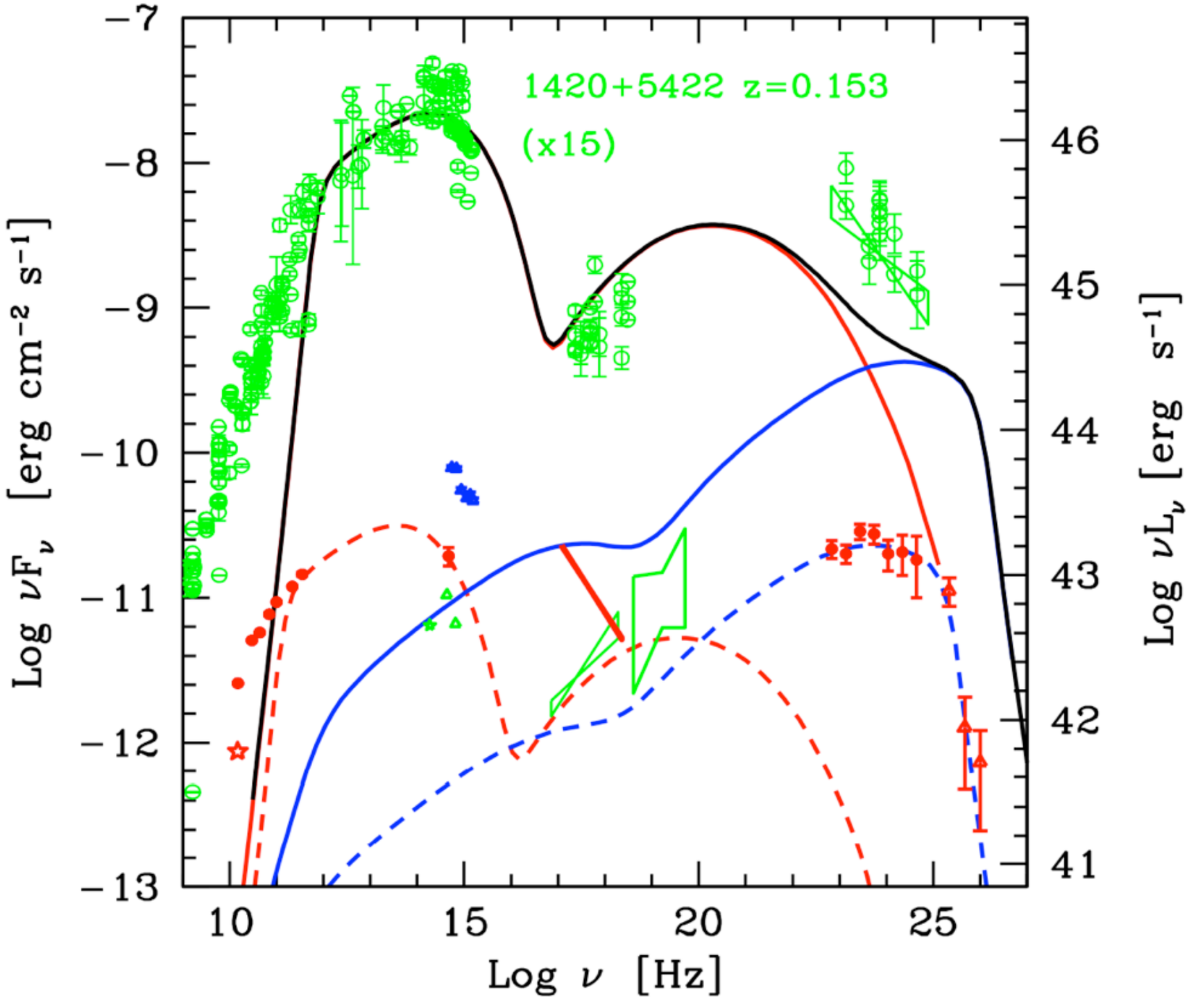


D'Ammando et al. 2015

Summary

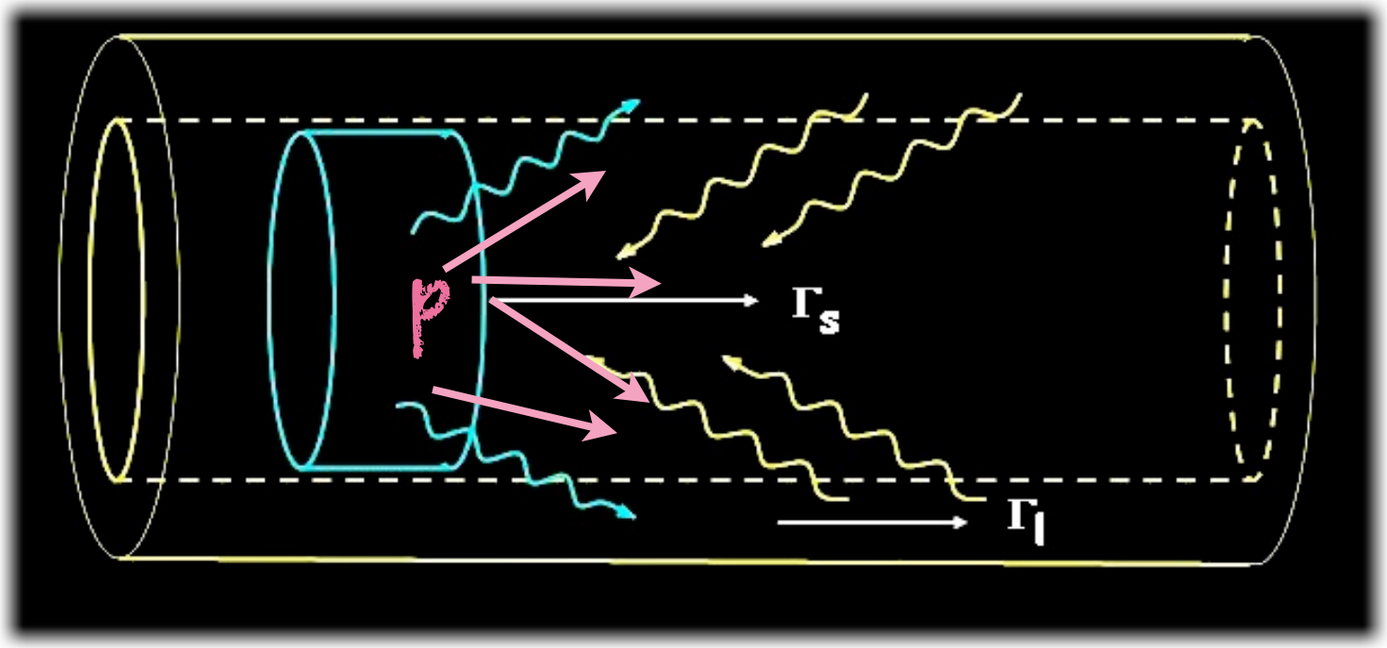
One zone: simple, good estimate of the parameters
problems with unification, small speed (TeV BL Lacs)
variability correlations

Structured jets: radiogalaxies and misaligned jets.
two-components required (low: spine, high: layer)


1420+5422 z=0.153
(x15)
Log νF_ν [erg cm⁻² s⁻¹]
Log νL_ν [erg s⁻¹]
Log ν [Hz]
−7
−8
−9
−10
−11
−12
−13
46
45
44
43
42
41
10
15
20
25

Structured jets: neutrinos

FT et al. 2014, 2015



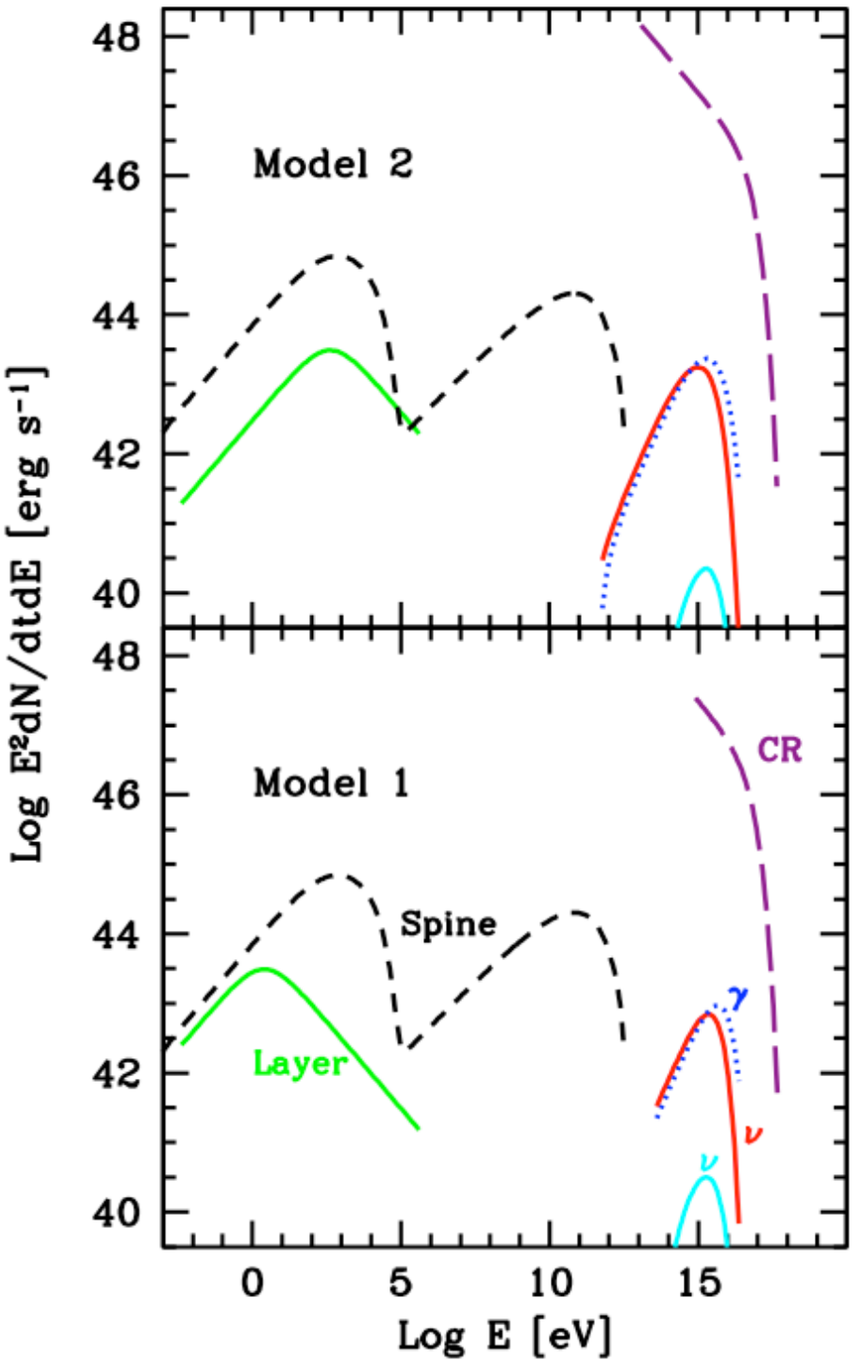
$$p + \gamma \to n + \pi^+$$

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

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

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

Structured jets: neutrinos



FT et al. 2014, 2015

Cumulative emission assuming a fast evolution of HBL

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

Ajello et al. 2014