Variability of blazars:

probe of emission regions and acceleration processes

-The telling tale of PKS 1222+216-

F.Tavecchio
INAF-OAB
Italy

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Outline

Preamble: the standard view of FSRQs

Inner vs outer emission scenarios

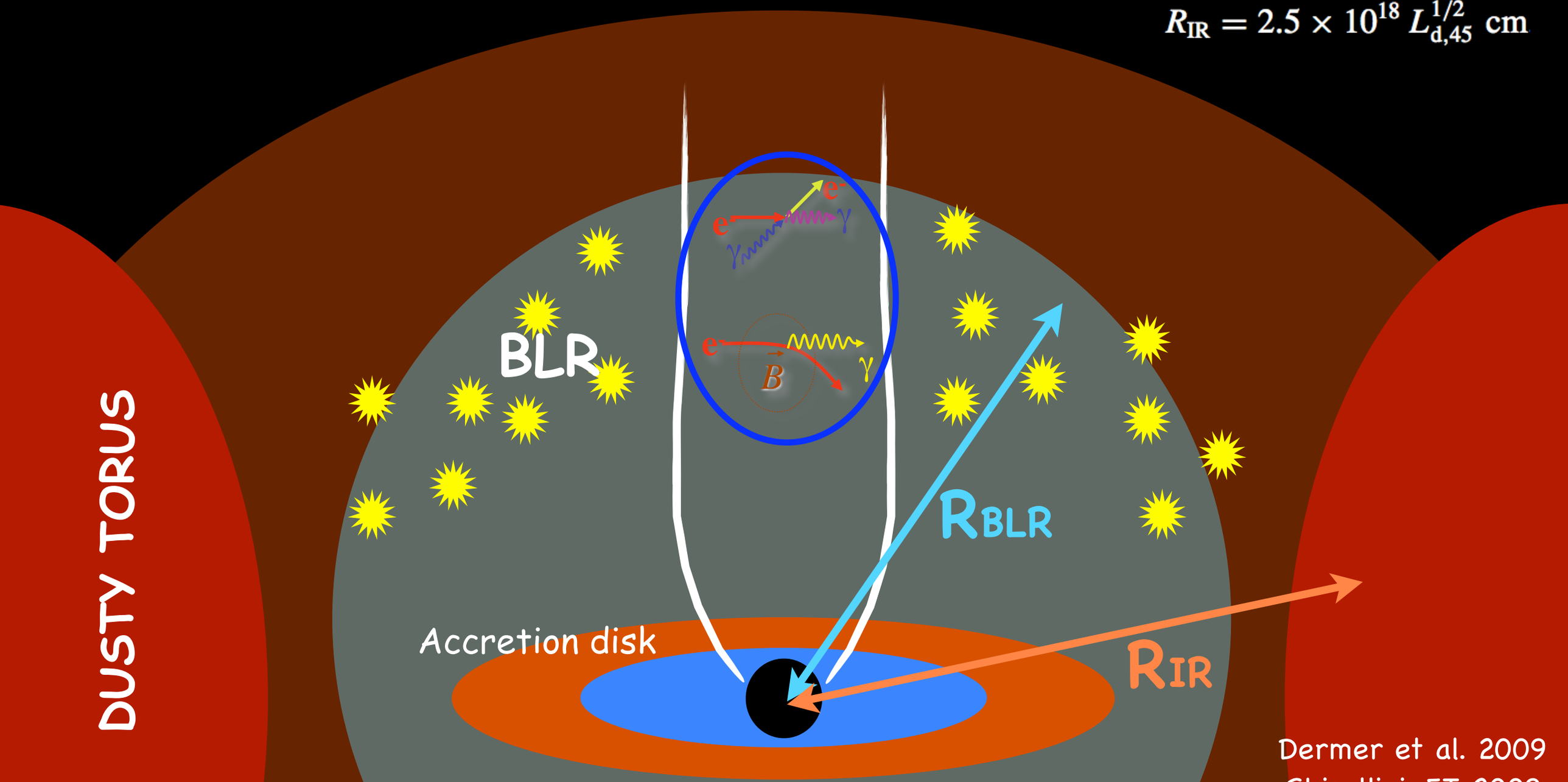
The GeV-TeV flare of PKS 1222+216

Interpretations

Preamble: setting the stage

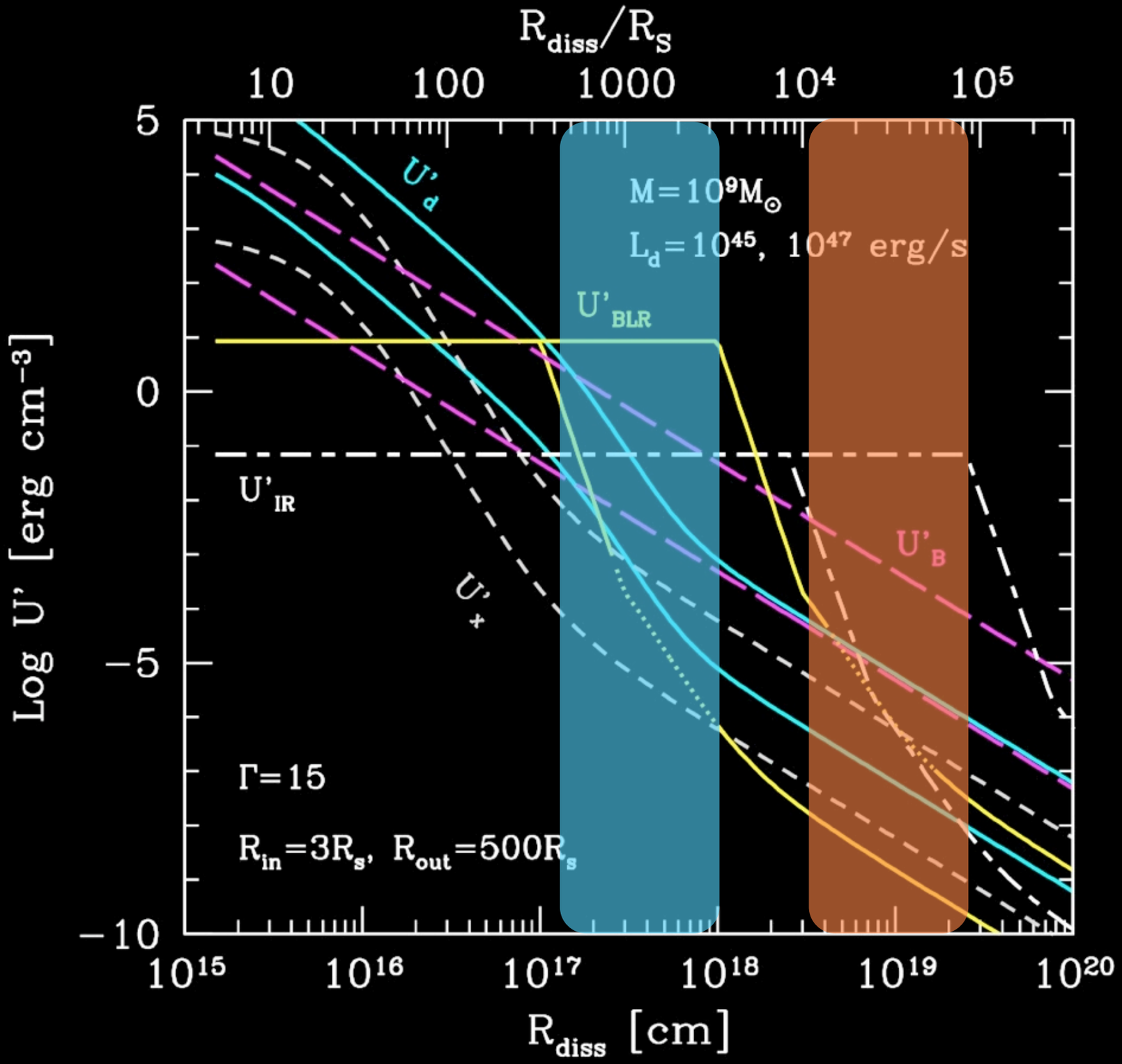
$$R_{\rm BLR} = 10^{17}\, L_{\rm d,45}^{1/2}\ {\rm cm}.$$

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

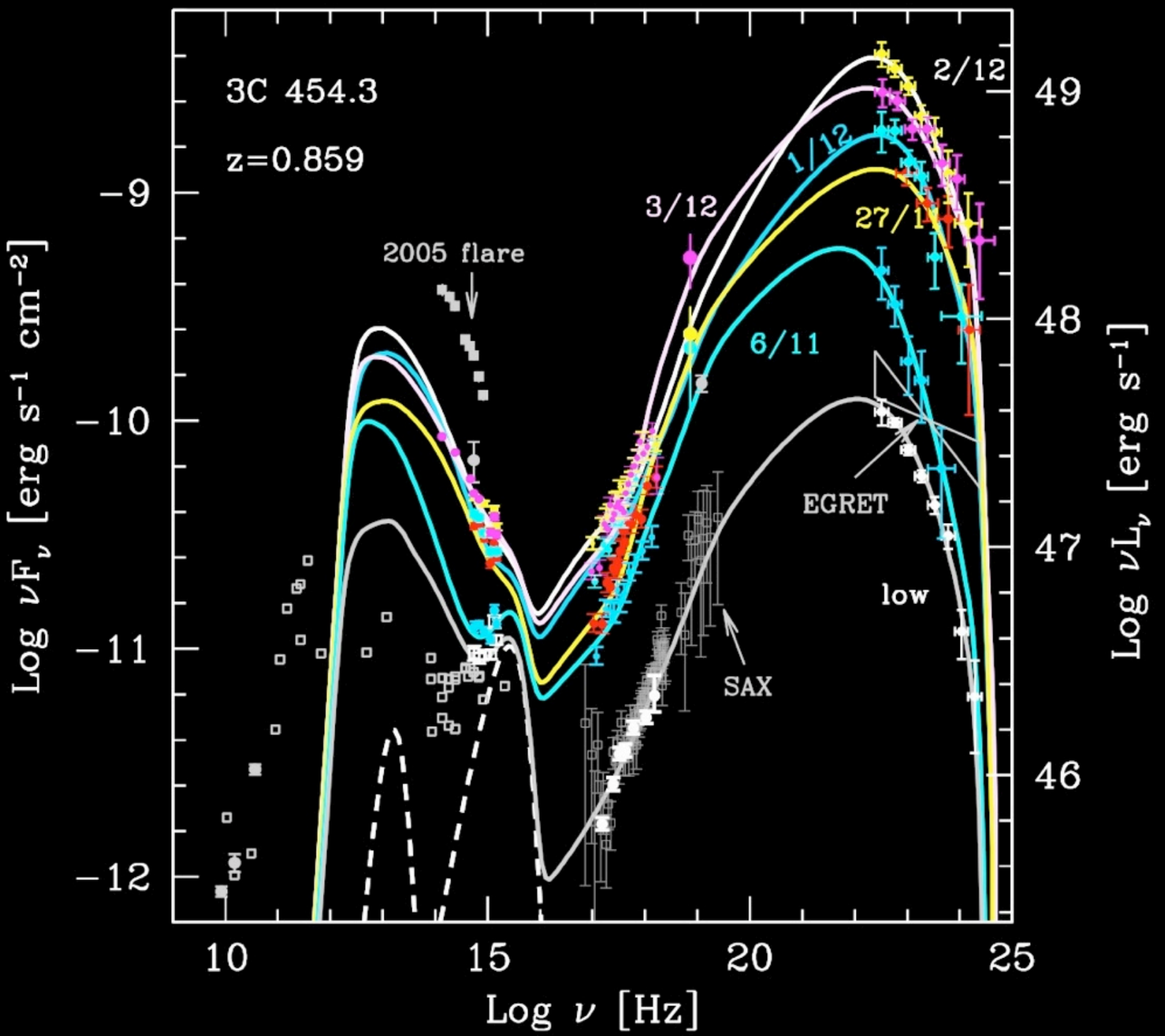


Dermer et al. 2009
Ghisellini, FT 2009
Sikora et al. 2009

Energy densities



Emission within R_{BLR}

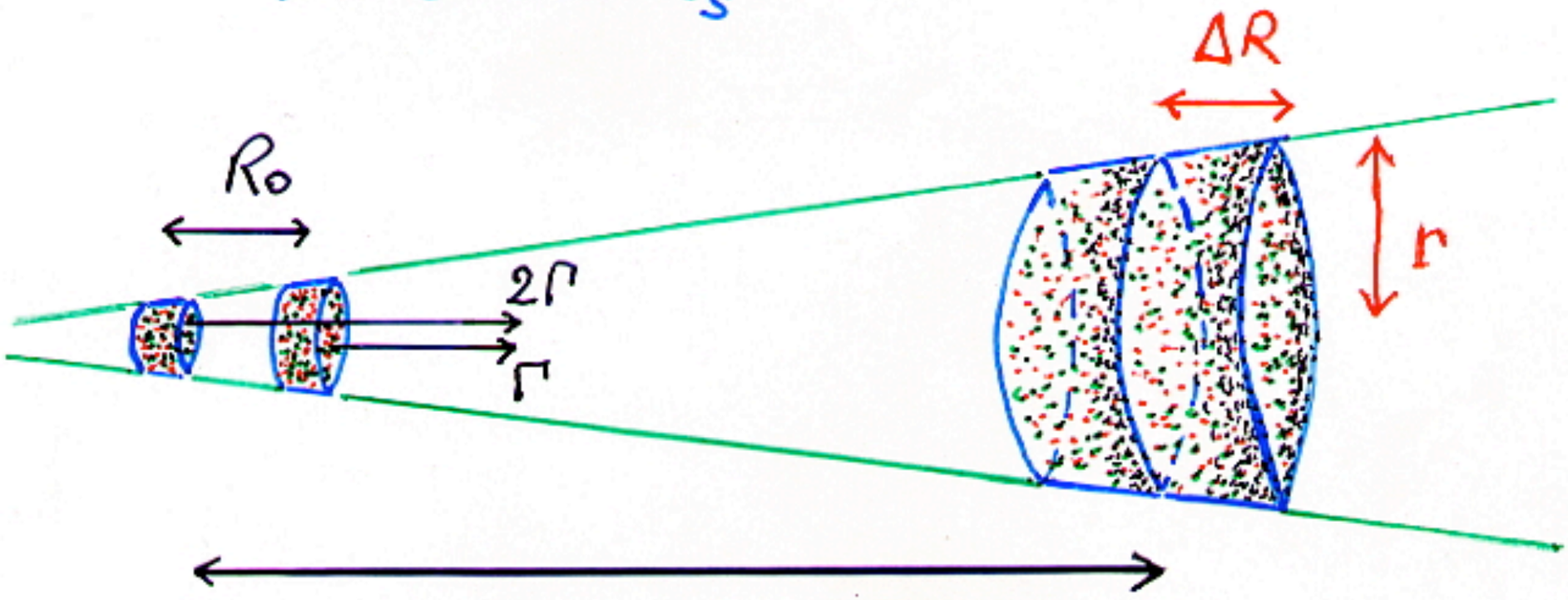


Bonnoli et al. 2011

Rees 1978 for M87

Internal shocks

Discoutinuous ejections of blobs with differeut Γ_s

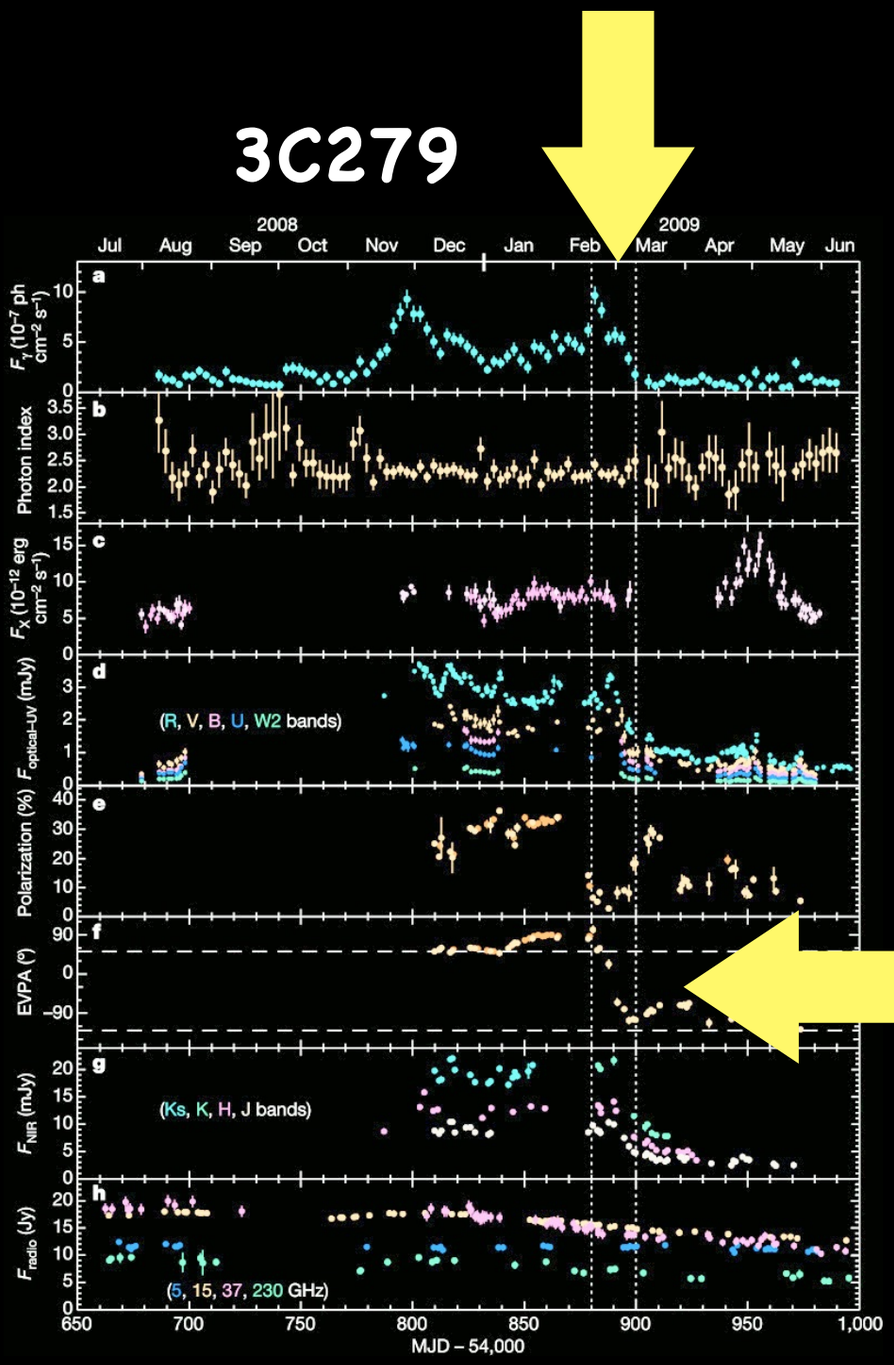


$$R_{Diss} \cong R_o \Gamma^2$$

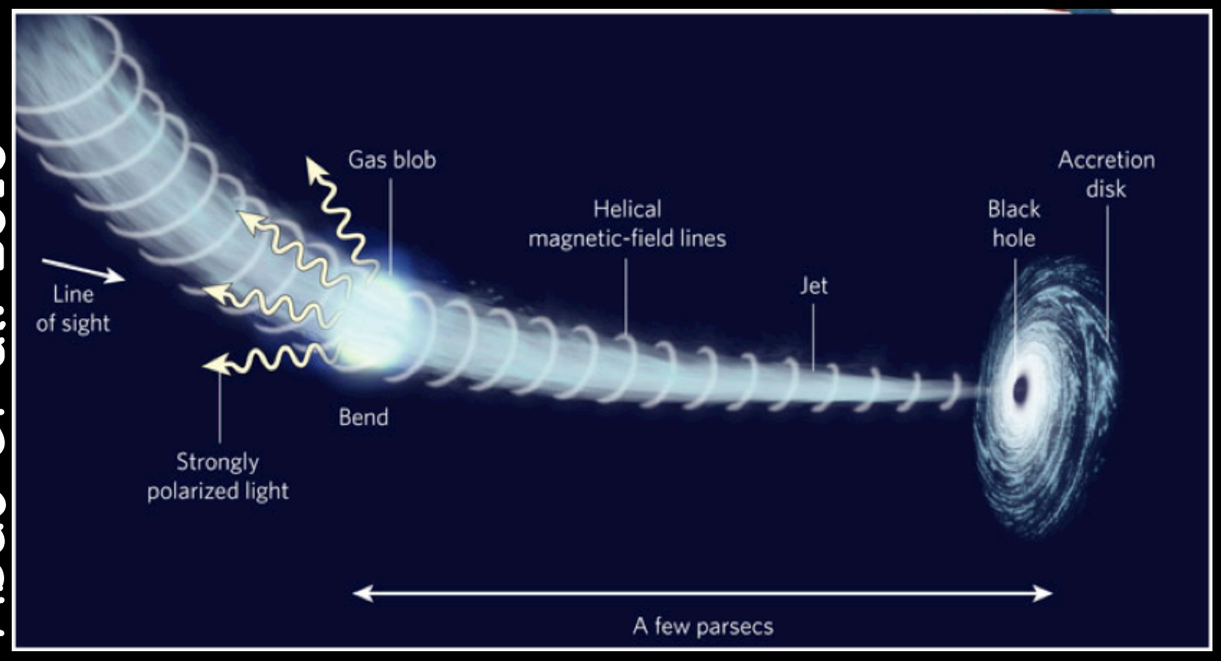
Emission at pc-scale?

Variability timescale: days!

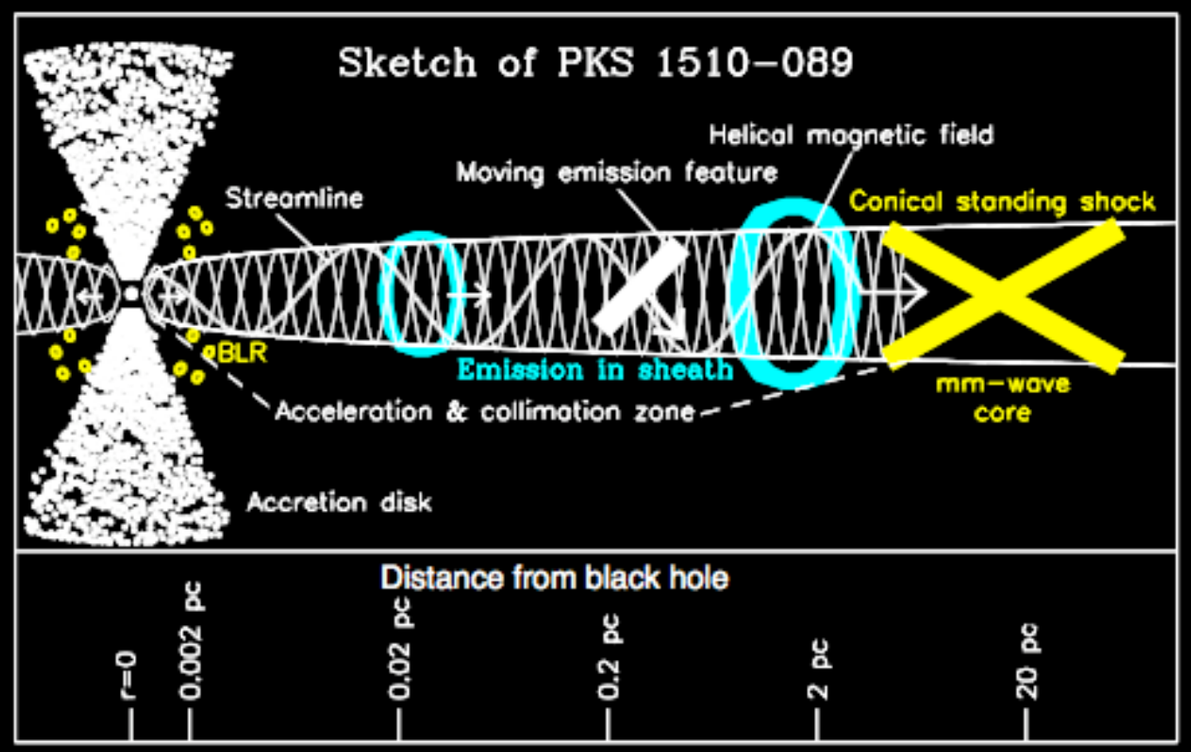
3C279



Abdo et al. 2010

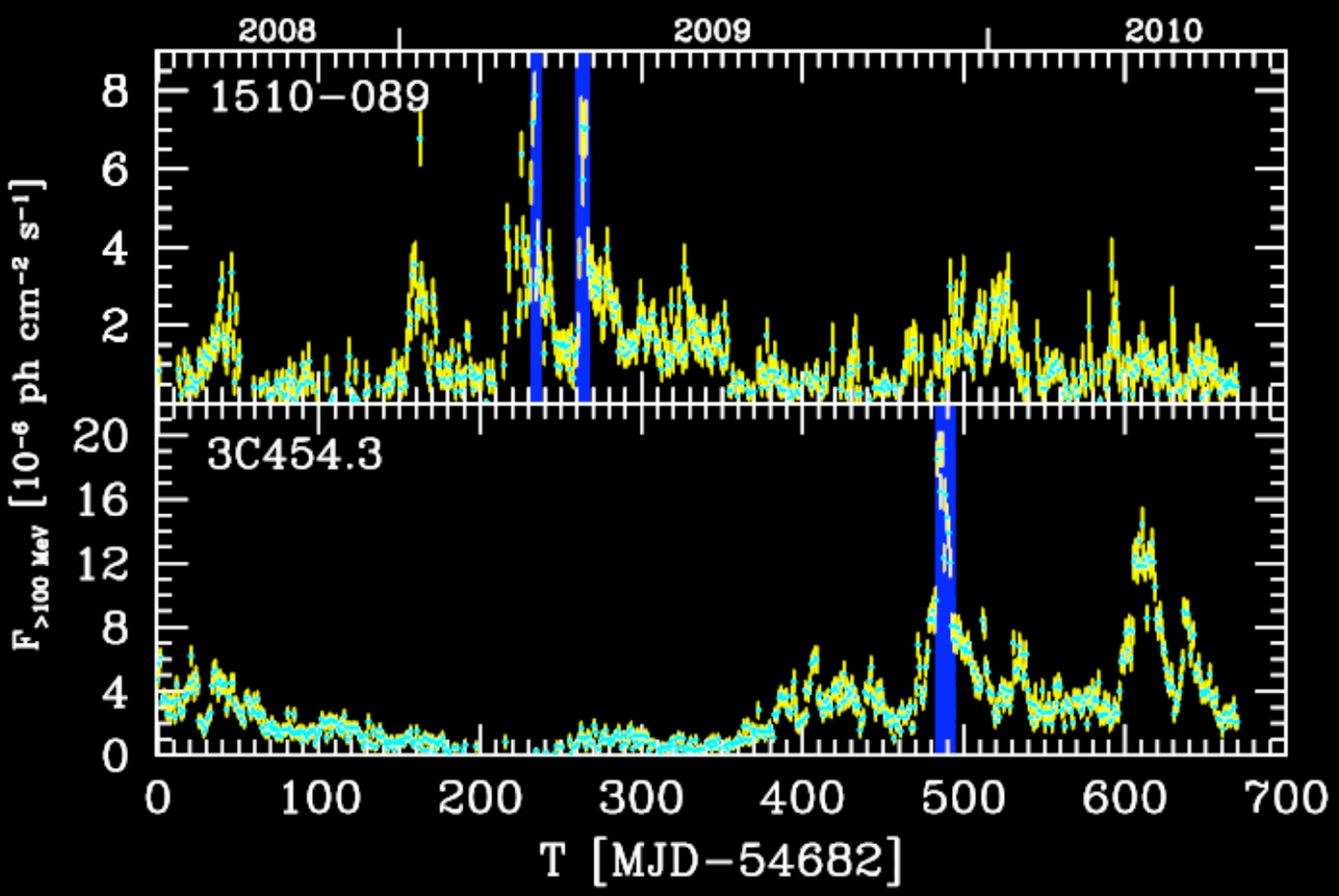


Marscher et al. 2008



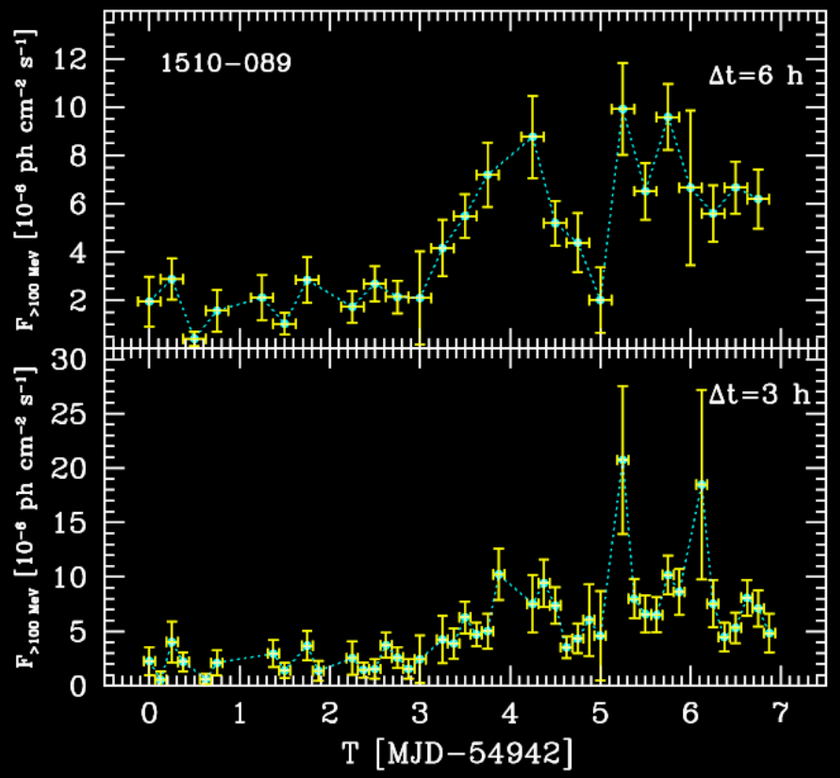
Rapid gamma-ray variability!

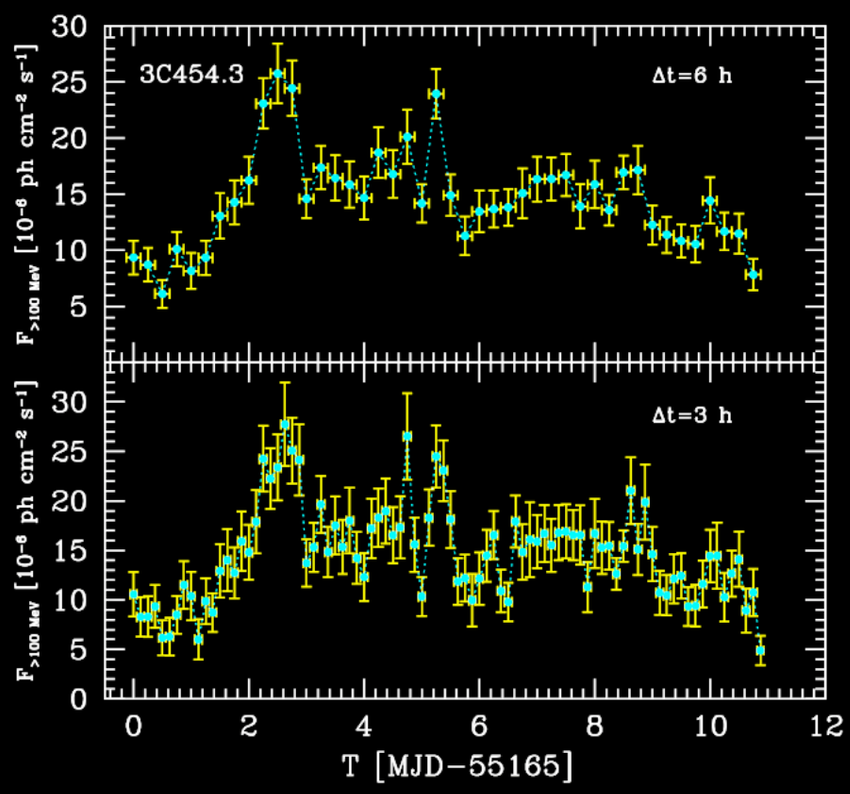
LAT lightcurve



FT et al. 2010

See also Foschini et al. 2011
Abdo et al. 2010





Rapid gamma-ray variability!

$$R < c t_{\rm var} \frac{\delta}{1+z} \simeq \frac{6.5\times10^{15}}{1+z} \left(\frac{t_{\rm var}}{6\,{\rm h}}\right) \left(\frac{\delta}{10}\right) \ {\rm cm}$$

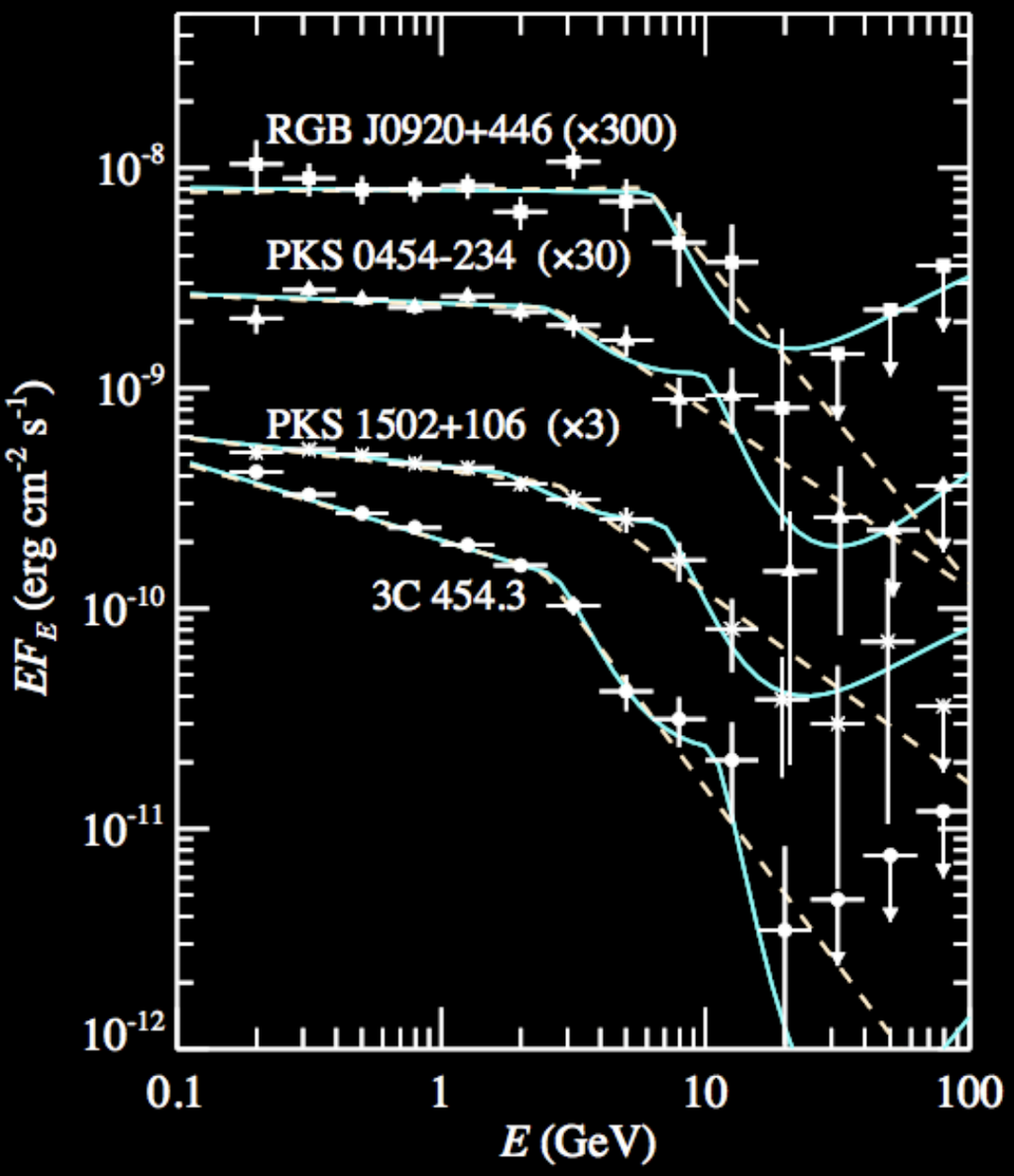
IF $d \simeq \frac{R}{\theta_{\rm j}}$ **Conical geometry**

$$d < c t_{\rm var} \frac{\delta}{1+z} \theta_{\rm j}^{-1} \simeq \frac{6.5\times10^{16}}{1+z} \left(\frac{t_{\rm var}}{6\,{\rm h}}\right) \left(\frac{\delta}{10}\right) \left(\frac{\theta_{\rm j}}{0.1}\right)^{-1} \ {\rm cm}$$

i.e. inside the BLR

Doppler factor is not expected to be > 30 (e.g. Abdo et al. 2010)

GeV spectral breaks



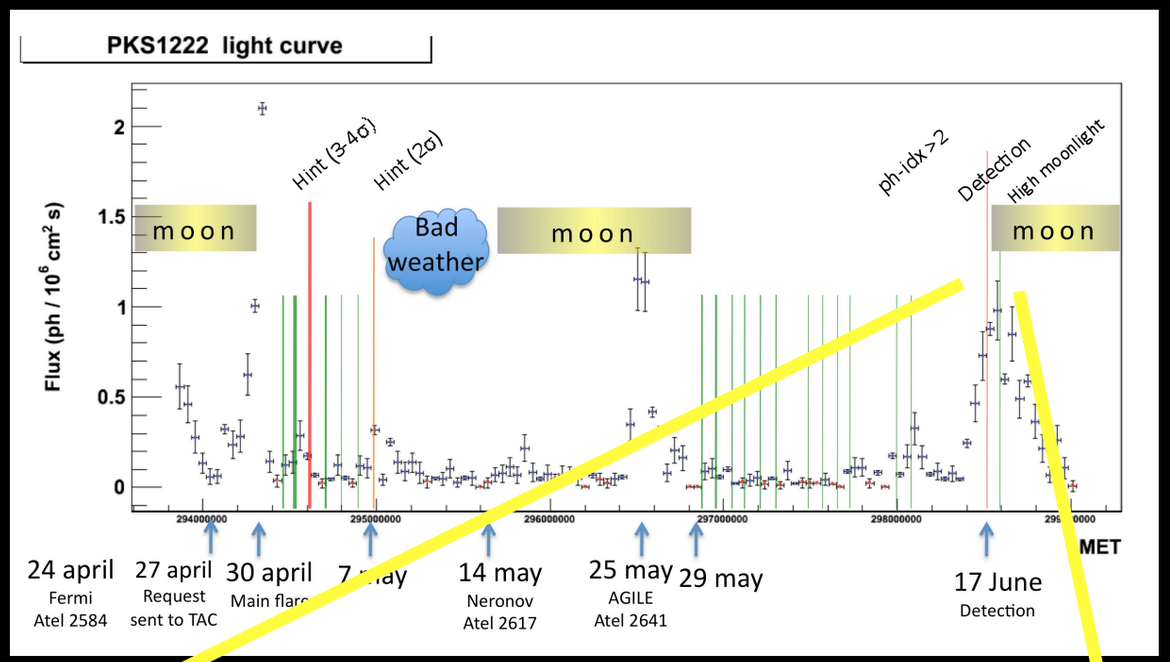
Breaks due to absorption inside BLR?

Poutanen & Stern 2011
Stern & Poutanen 2012

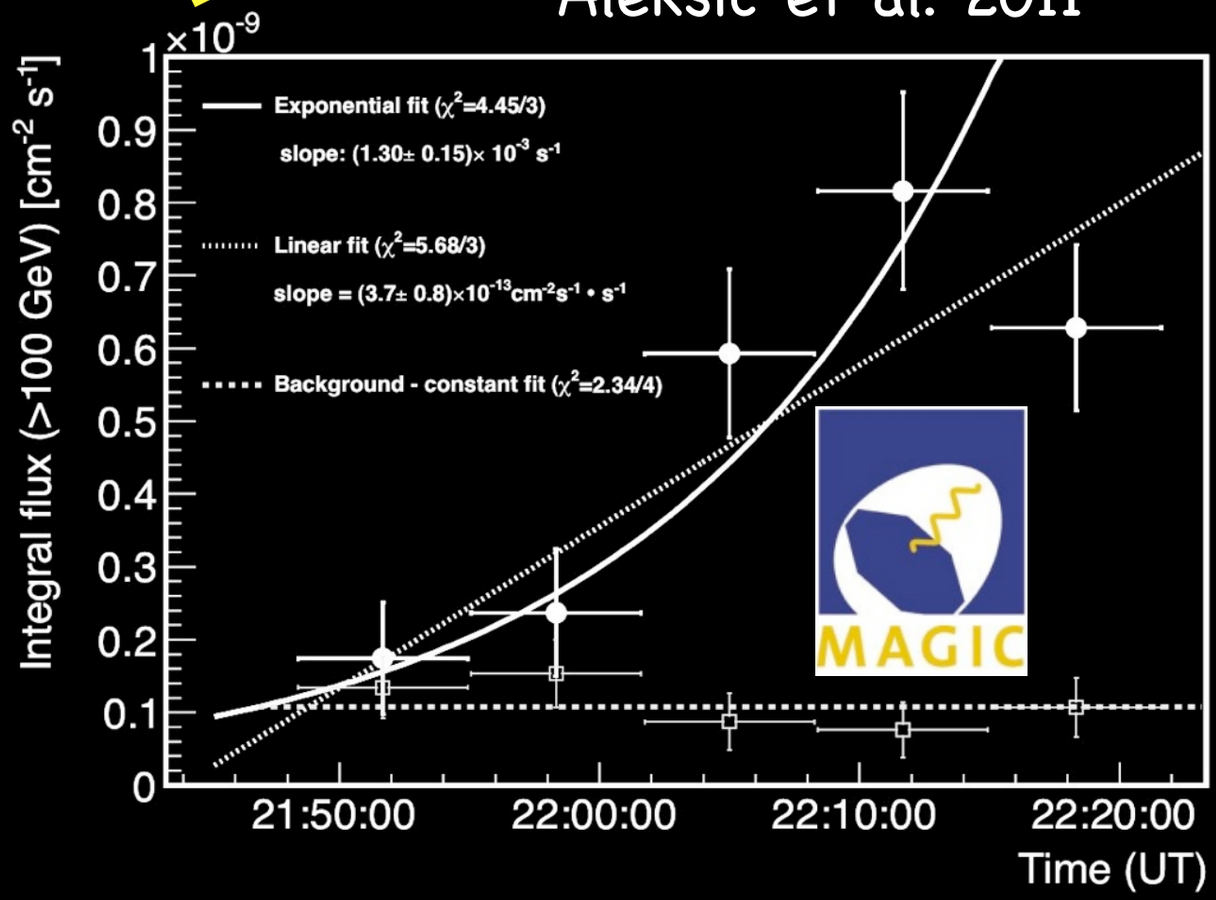
The strange case of PKS 1222+216

$t_{double} \sim 10$ min!

$$R < ct_{\rm var}\frac{\delta}{1+z} \simeq 1.2\times10^{14}\left(\frac{\delta}{10}\right)\ {\rm cm}$$



Aleksic et al. 2011



Ultra-rapid variability

$$R < ct_{\rm var}\frac{\delta}{1+z} \simeq 1.2\times10^{14}\left(\frac{\delta}{10}\right)\ {\rm cm}$$

IF $d \simeq \frac{R}{\theta_{\rm j}}$ **Conical geometry**

$$d < ct_{\rm var}\frac{\delta}{1+z}\theta_{\rm j}^{-1} \simeq 1.2\times10^{15}\left(\frac{t_{\rm var}}{10\,{\rm min}}\right)\left(\frac{\delta}{10}\right)\left(\frac{\theta_{\rm j}}{0.1}\right)^{-1}\ {\rm cm}$$

i.e. inside the BLR

Doppler factor is not expected to be > 30

d=0.22 pc = $R_{\rm BLR}$

$$\theta_{\rm j} \simeq 1.7\times10^{-4}\left(\frac{t_{\rm var}}{10\,{\rm min}}\right)\left(\frac{\delta}{10}\right)$$

Location of VHE emission? Arduous inside BLR!

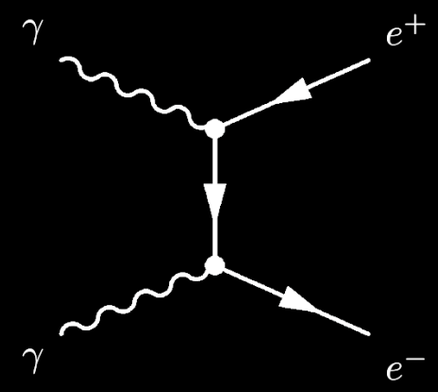
Strong absorption
(E>30 GeV within BLR, E>1 TeV outside)
(e.g. Liu et al. 2008, Reimer 2007, FT & Mazin 2009, Poutanen & Stern 2010)

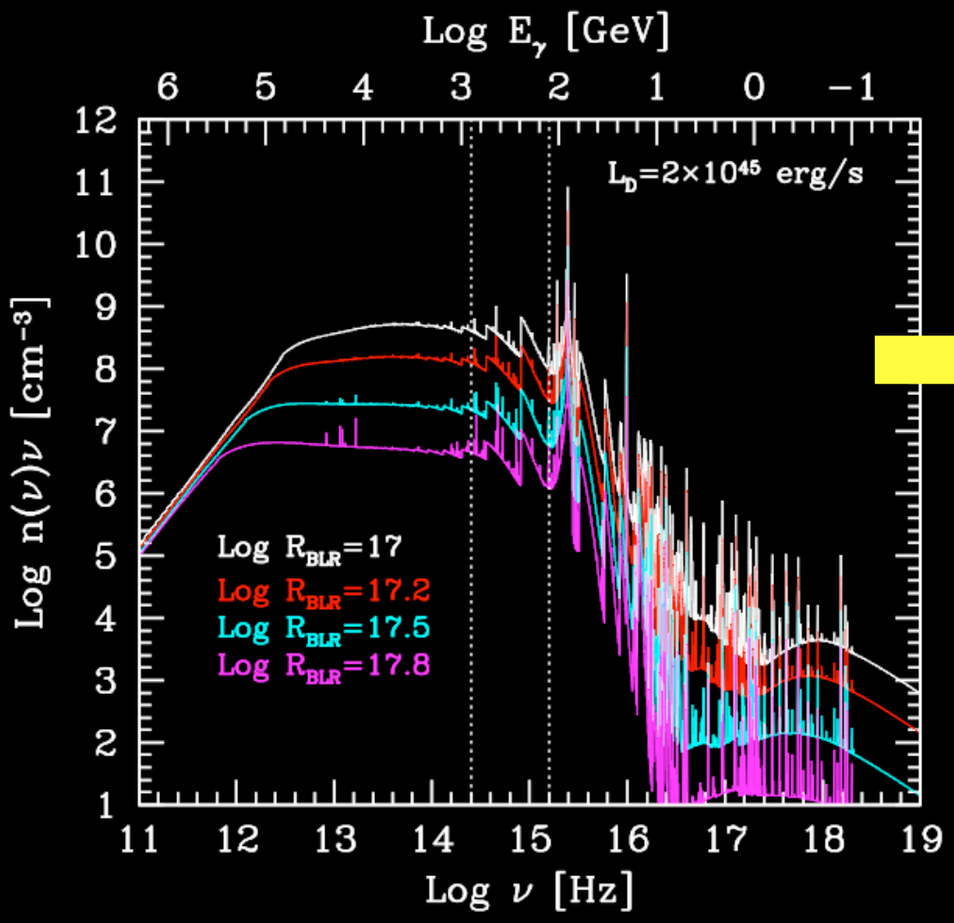
Decline of the IC scattering efficiency
(e.g. Albert et al. 2008, FT & Ghisellini 2008)

General

Model dependent
(not applicabile to hadronic)

Huge optical depth of BLR

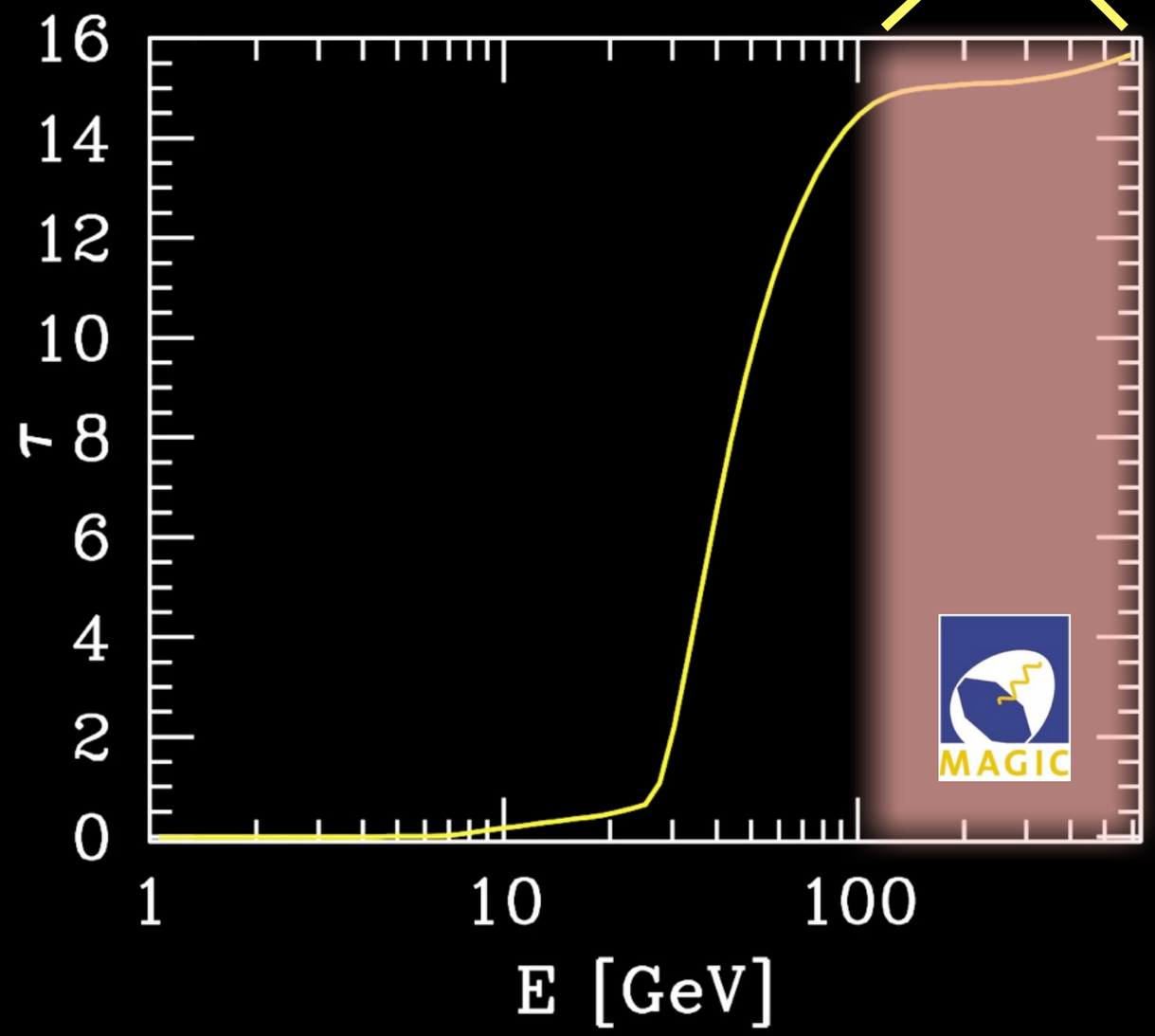




FT & Mazin 2009

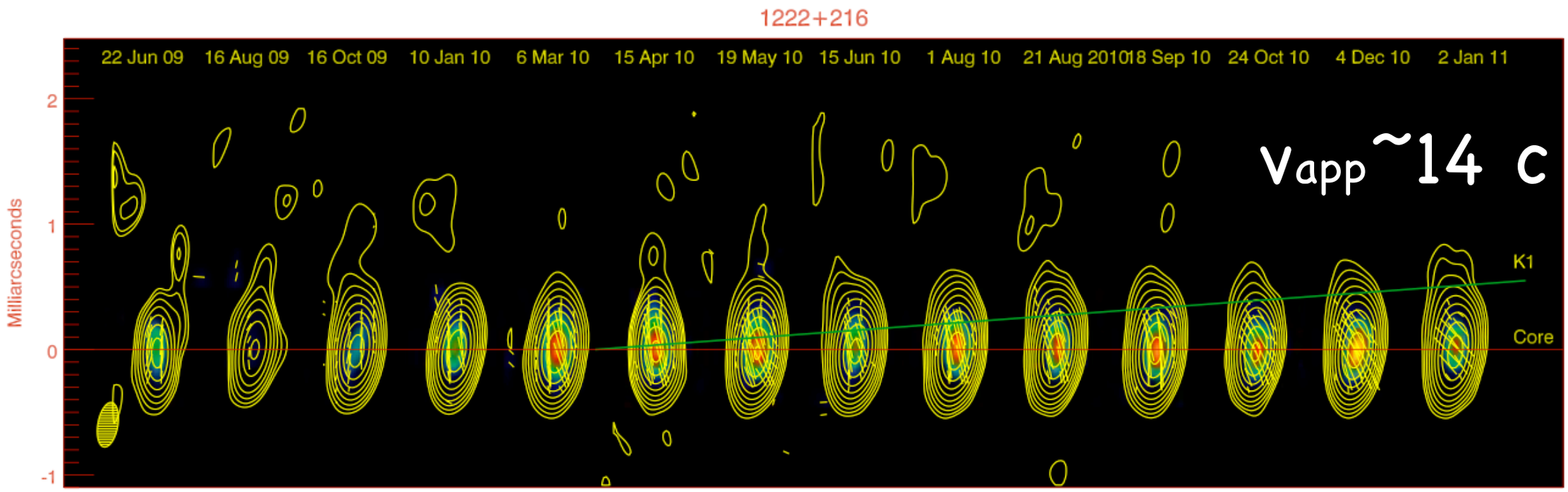
GeV

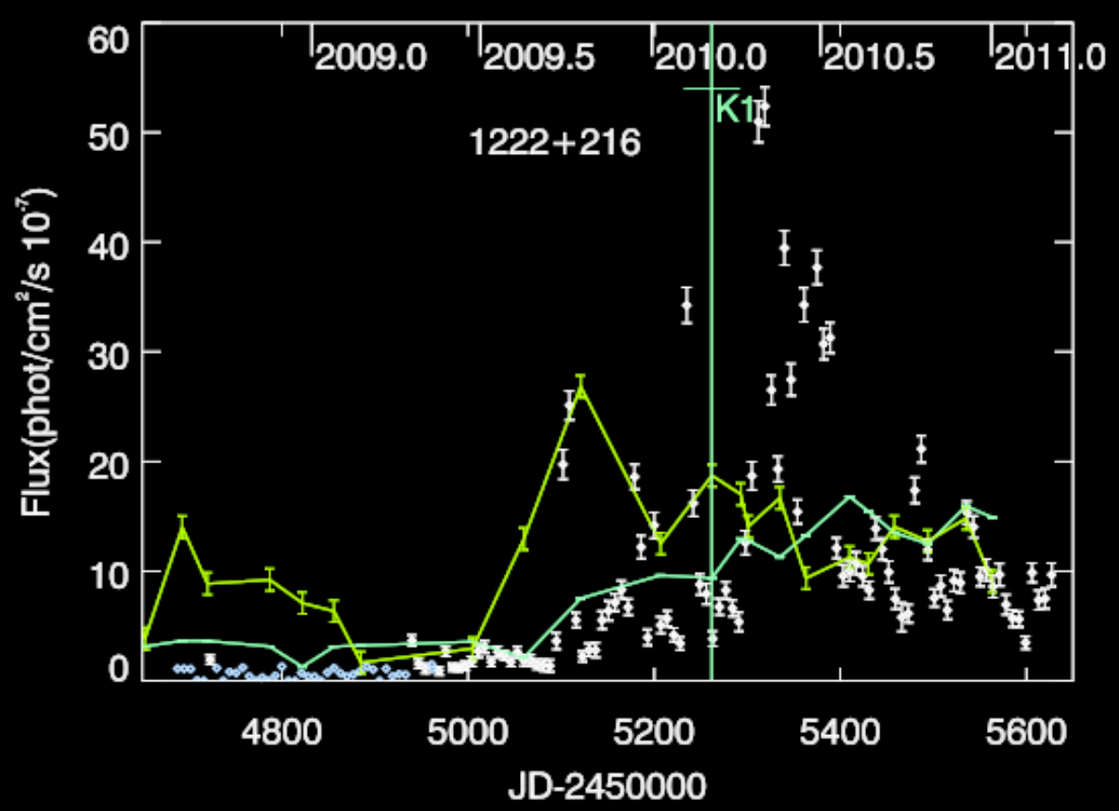
TeV



FT et al. 2012

VLBI



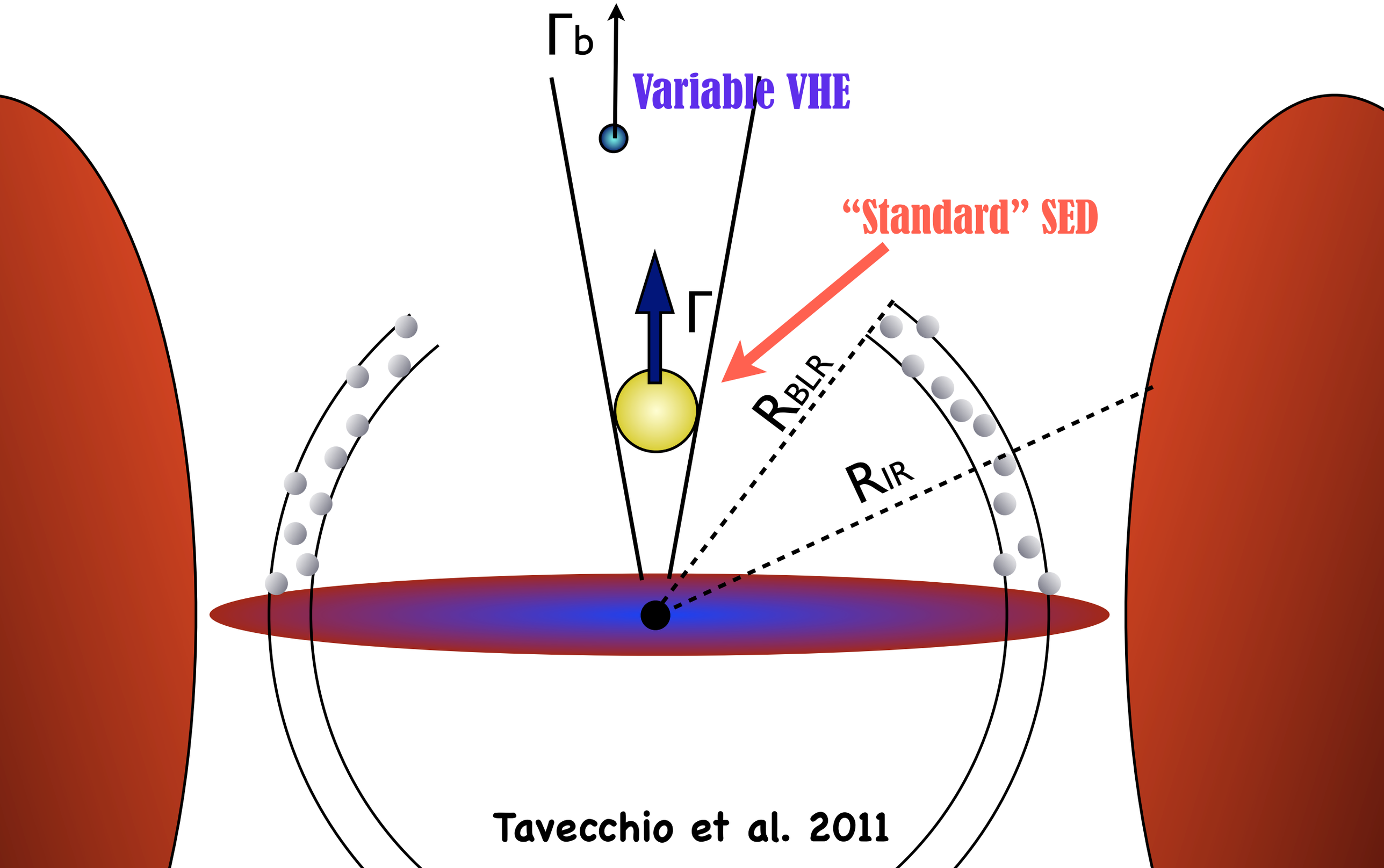


Jorstad et al. 2012

Polarization increased from <1% to 6.5% during the high γ-ray state while the optical EVPA rotated by 200 deg

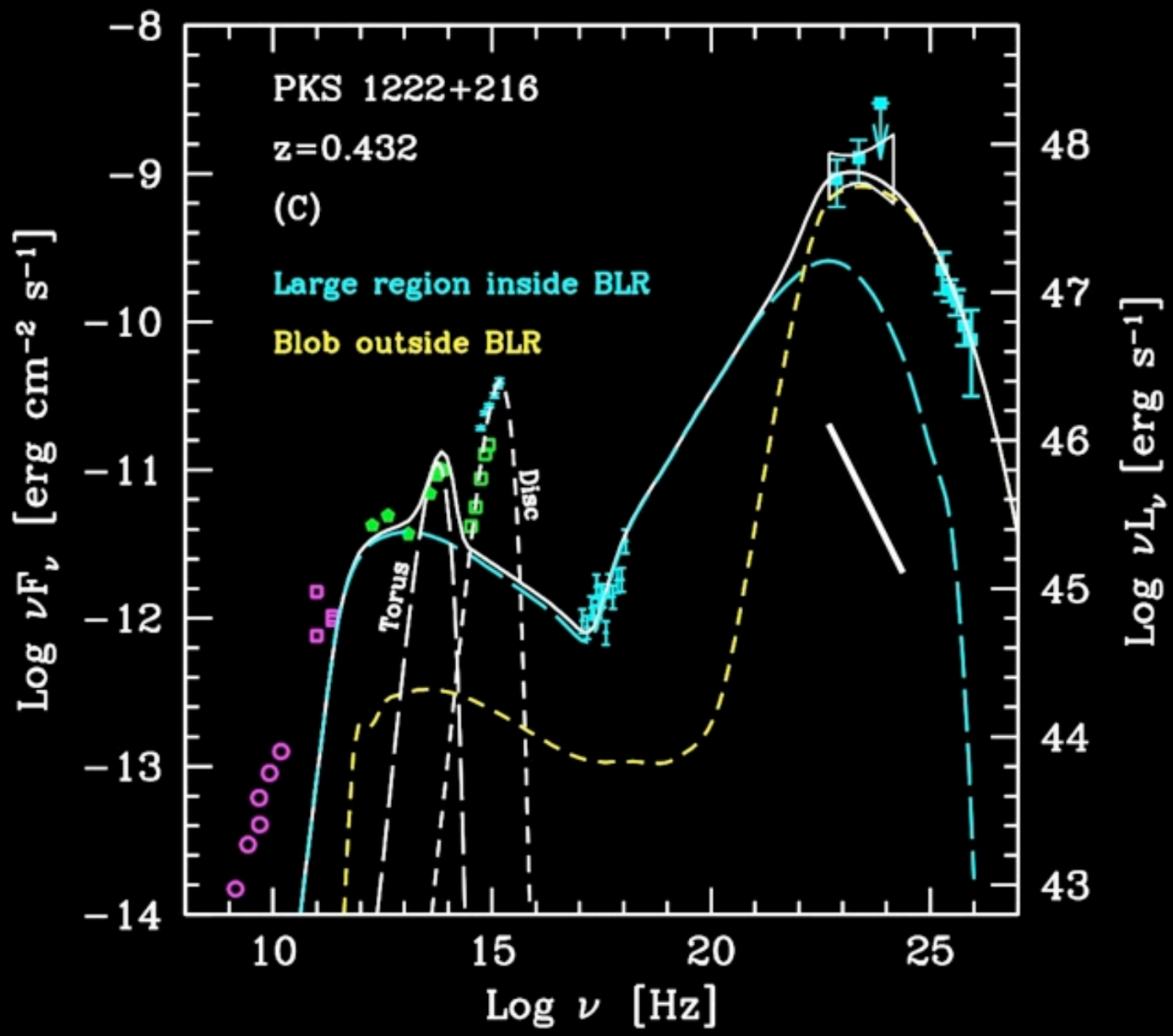
Similar to other blazars

External emission?



Tavecchio et al. 2011

Tavecchio et al. 2011



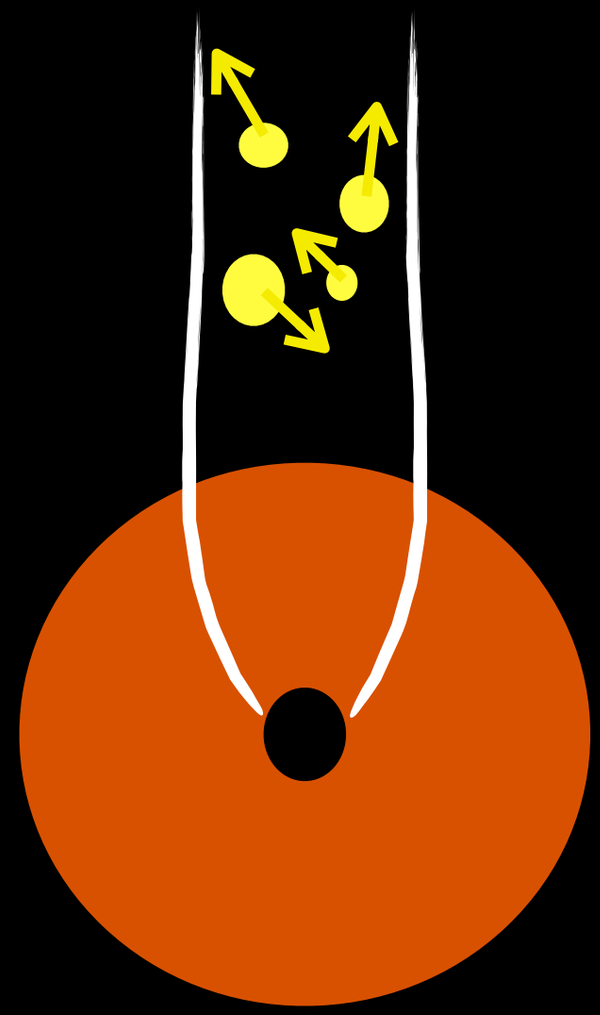
	γ_{min}	γ_p	γ_{max}	n_1	n_2	B [G]	K [cm^{-3}]	R [cm]	δ	Γ	$P_{p,45}$	$P_{e,45}$	$P_{B,45}$
Jet (out)	3	2×10^3	6×10^4	2	4.1	0.09	3×10^2	1.1×10^{17}	19.7	10	17.7	0.3	5×10^{-2}
Blob	100	900	4×10^5	2.2	3.6	0.18	10^7	6.2×10^{14}	75	50	3.9	0.8	1.5×10^{-4}

Possibilities to reconcile large d and rapid variability

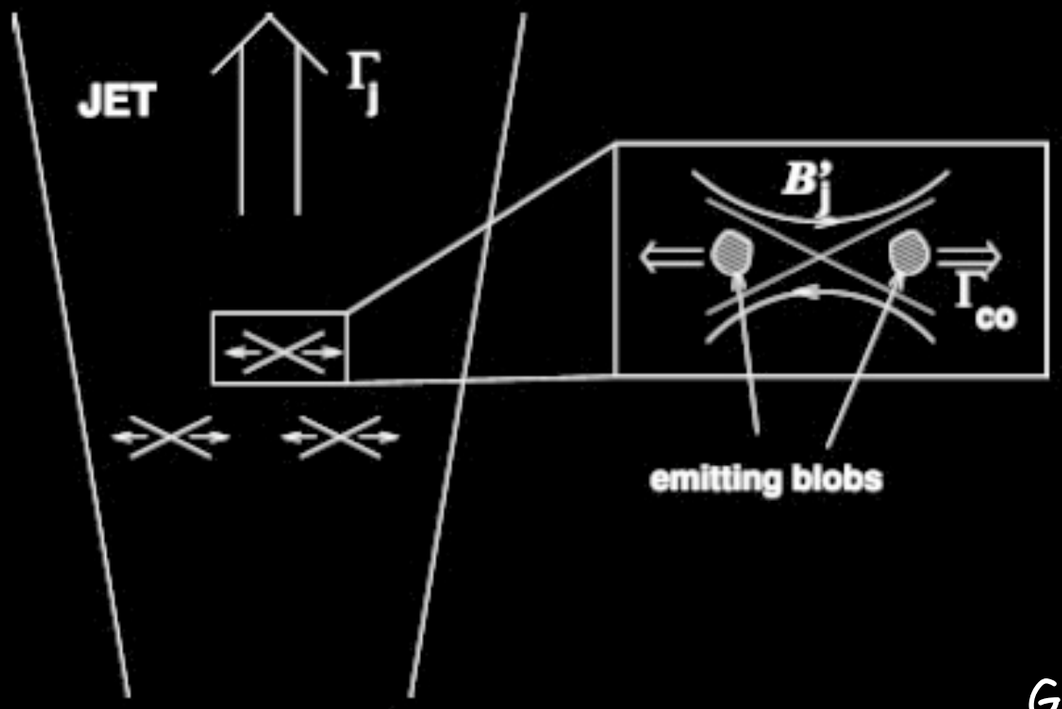
Jet substructure

e.g. Ghisellini & FT 2008
Nalewajko+12

Self collimation through,e.g., pinch



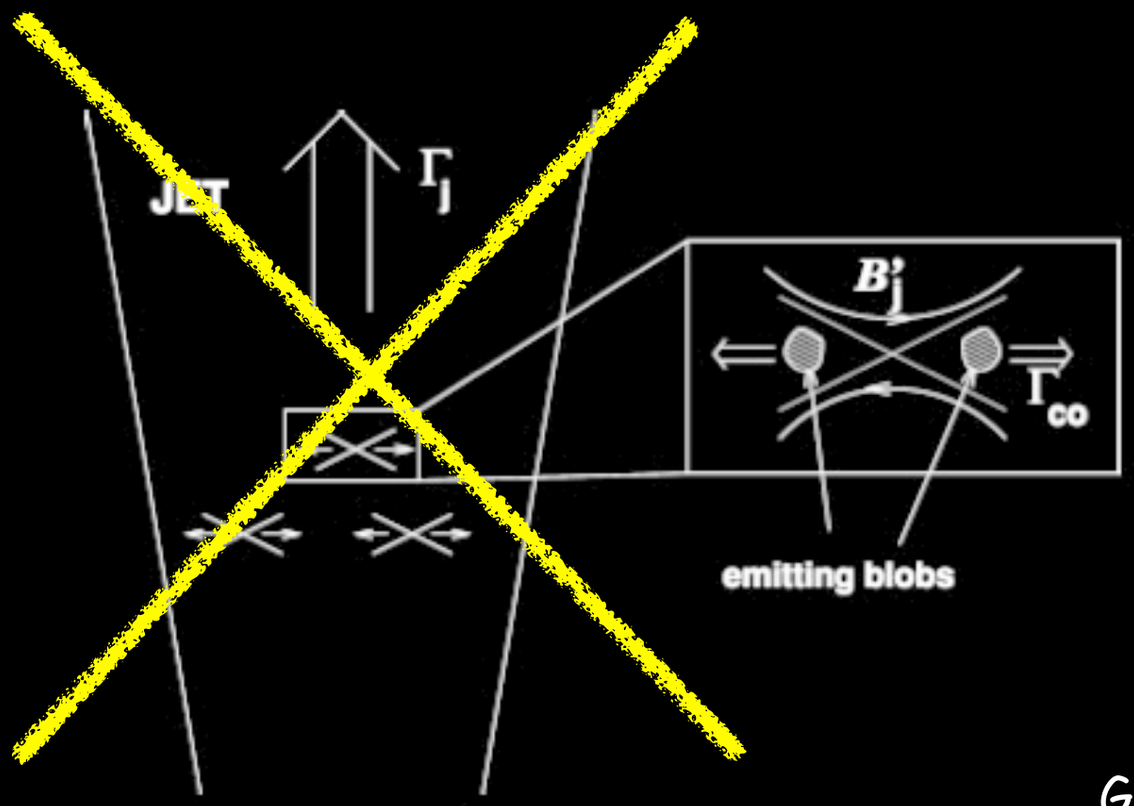
Possibilities to reconcile large d and rapid variability



Giannios et al 2009, 2010

Minijets from fast reconnection in a highly magnetized jet (σ~100)

Possibilities to reconcile large d and rapid variability



Giannios et al 2009, 2010

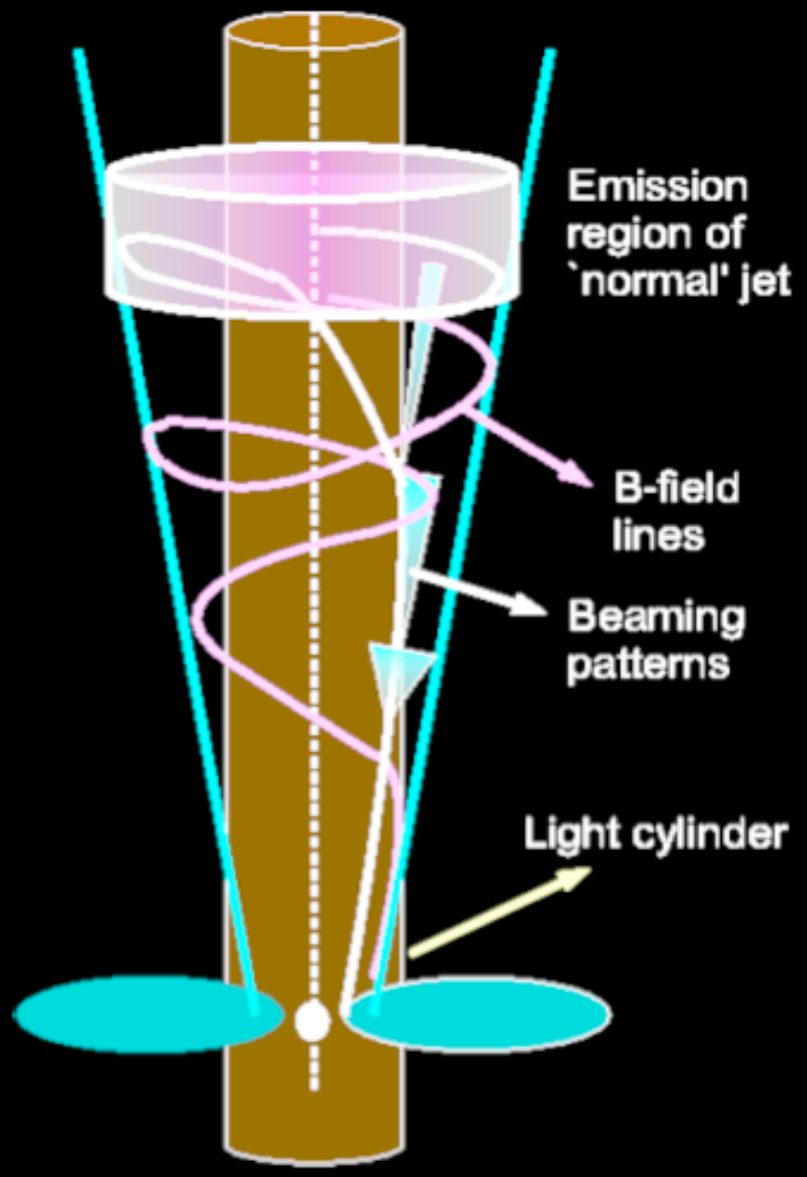
Minijets from fast reconnection in a highly magnetized jet (σ~100)

The jet is likely matter dominated

Too high σ (see also Nalewajko +2012)

Possibilities to reconcile large d and rapid variability

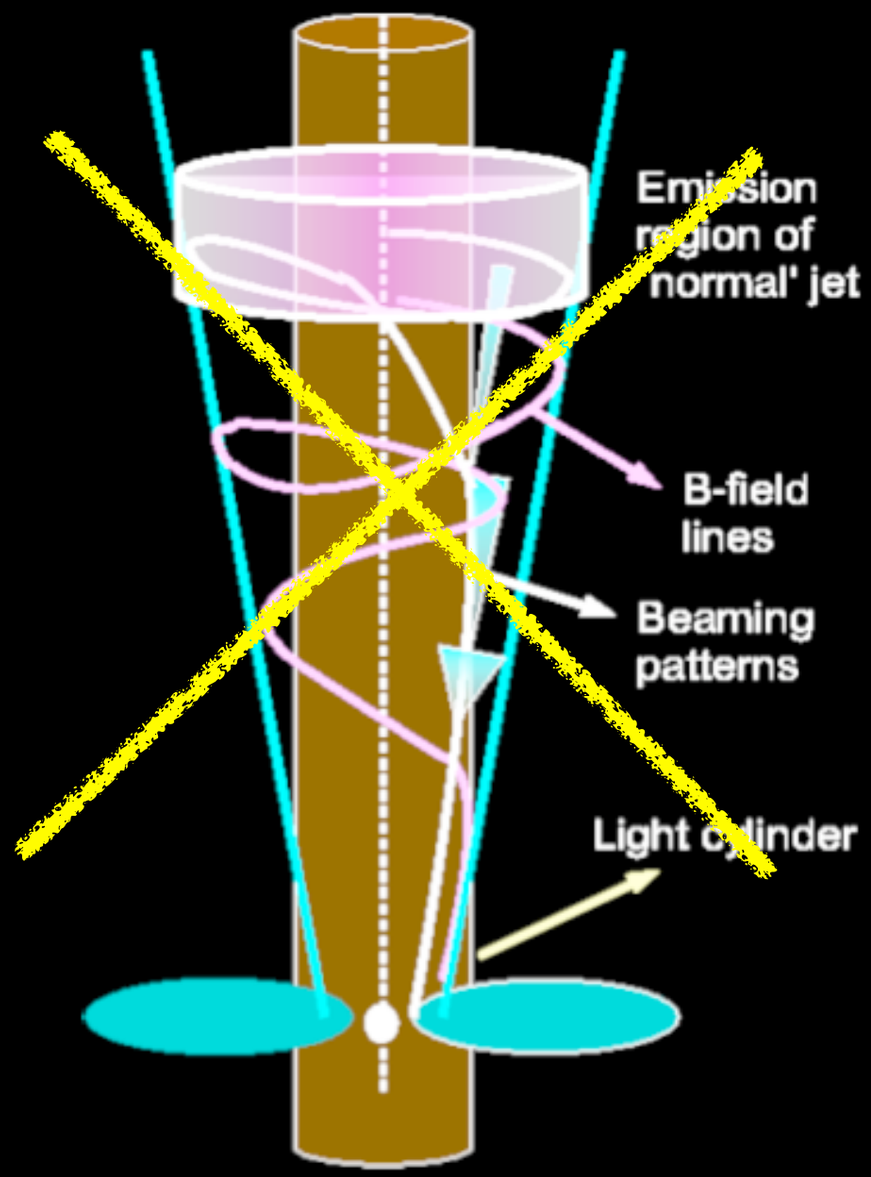
Narrow e beams from magnetocentrifugal acceleration



Ghisellini et al. 2008, 2009

Possibilities to reconcile large d and rapid variability

Large IC cooling!



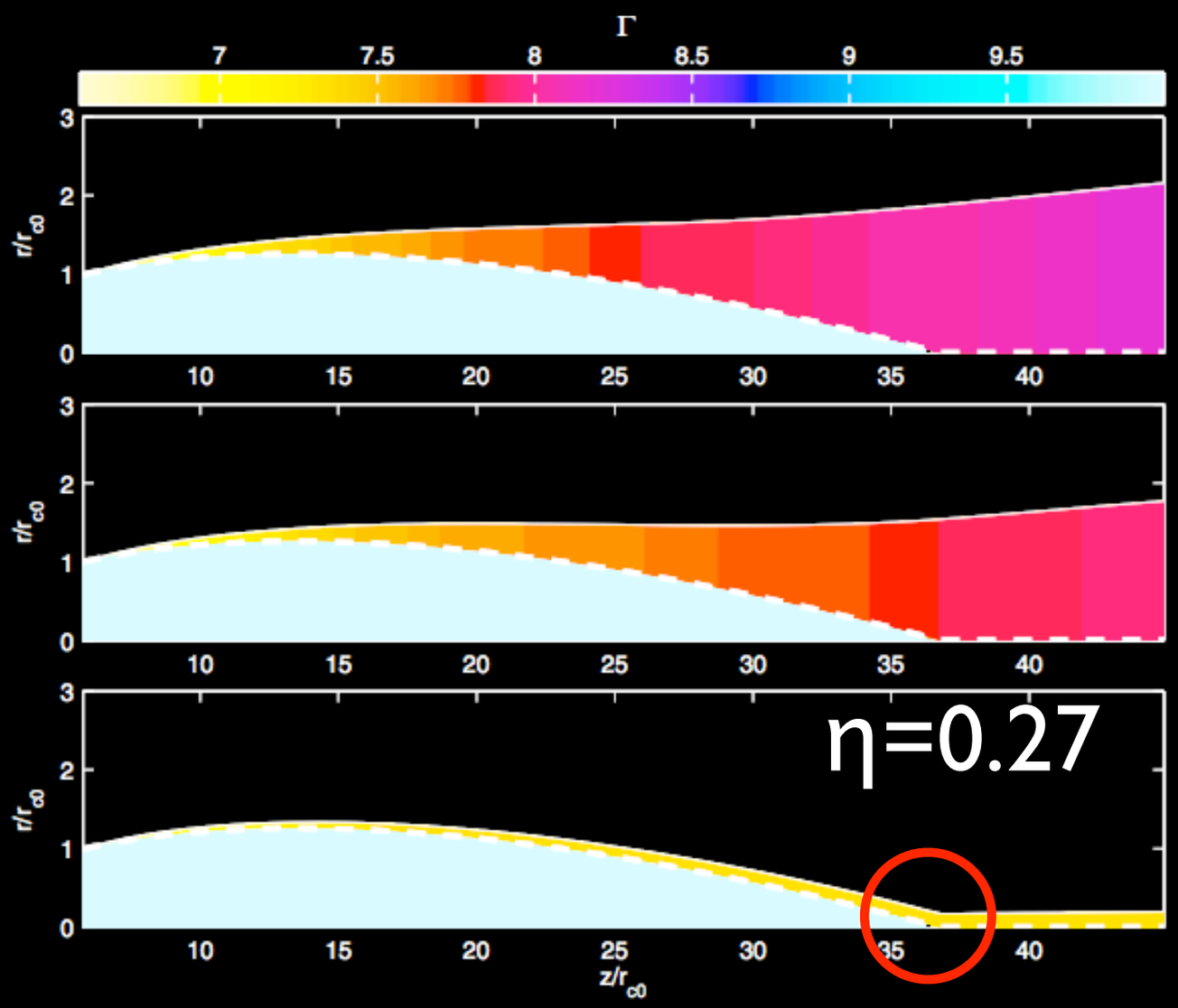
Narrow e beams from magnetocentrifugal acceleration

Ghisellini et al. 2008, 2009

Possibilities to reconcile large d and rapid variability

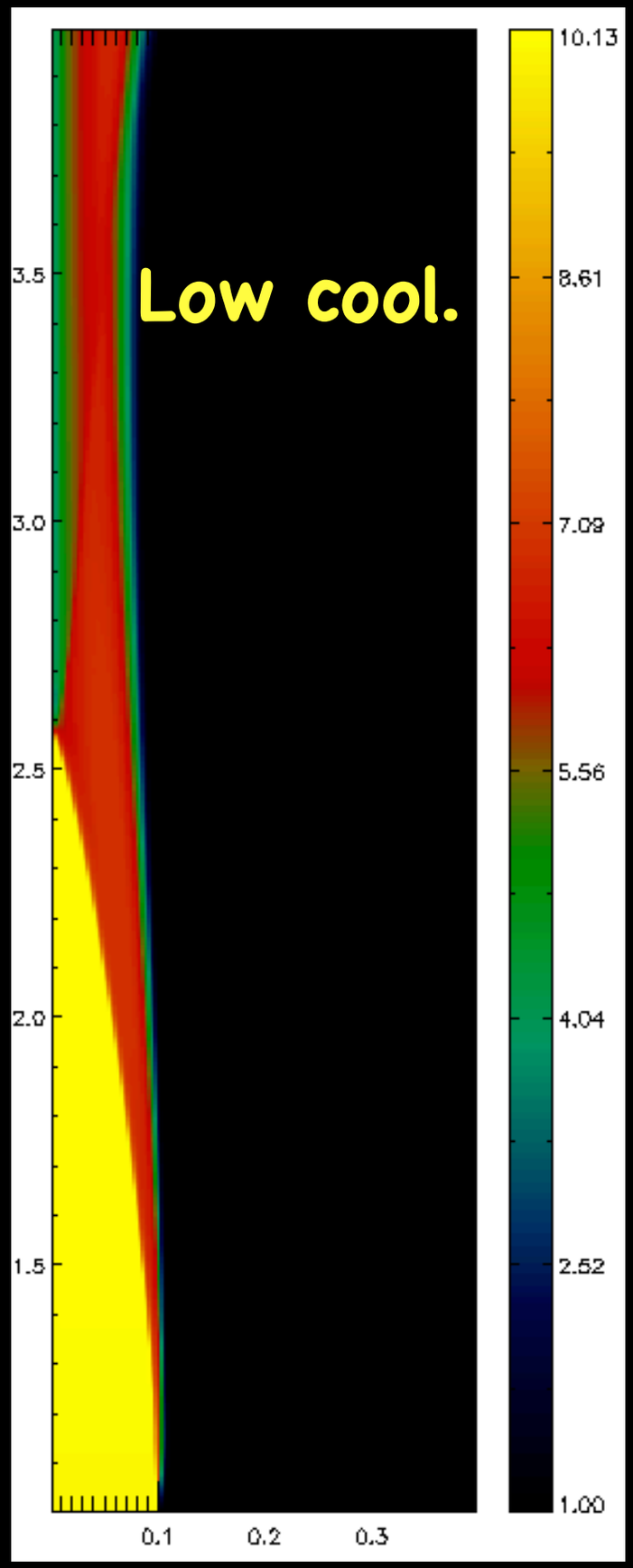
Bromberg & Levinson 2009
2d, semianalitic calculations

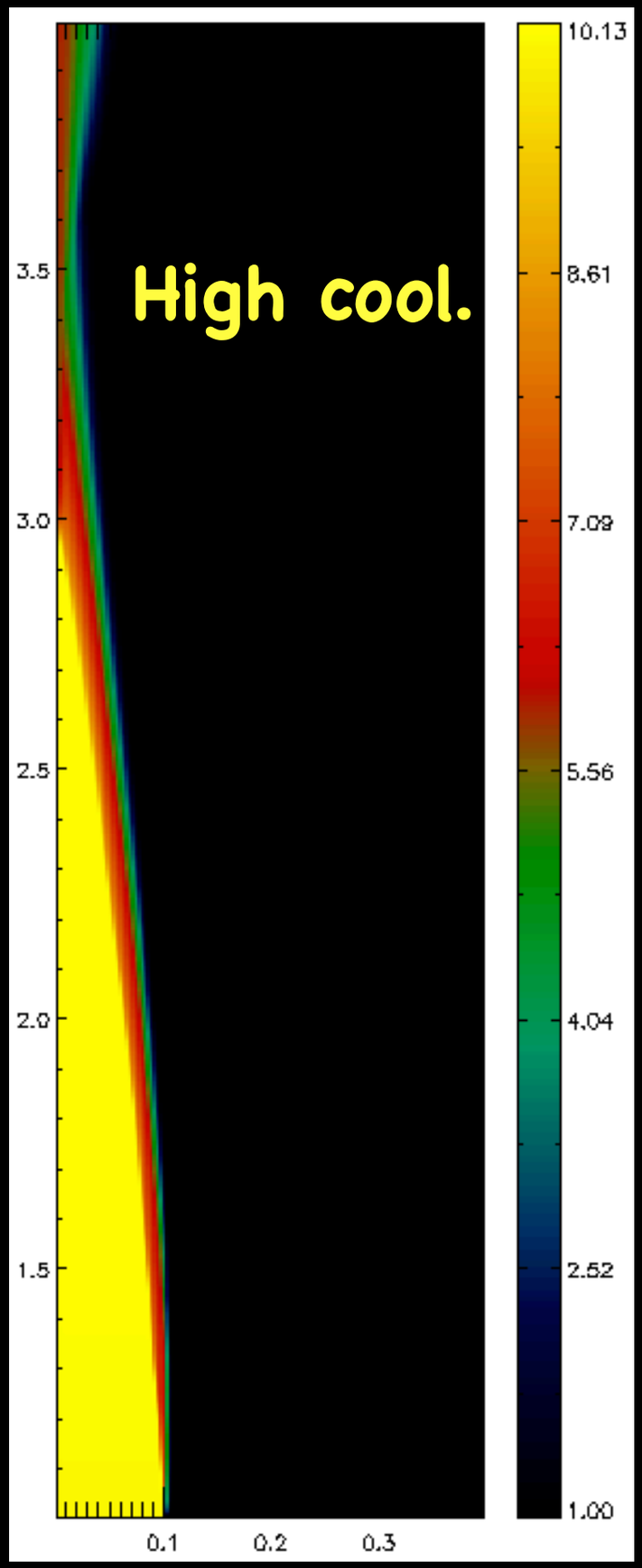
"Focusing"?



Radiative efficiency

Able to reproduce the required radius-to-distance ratio?

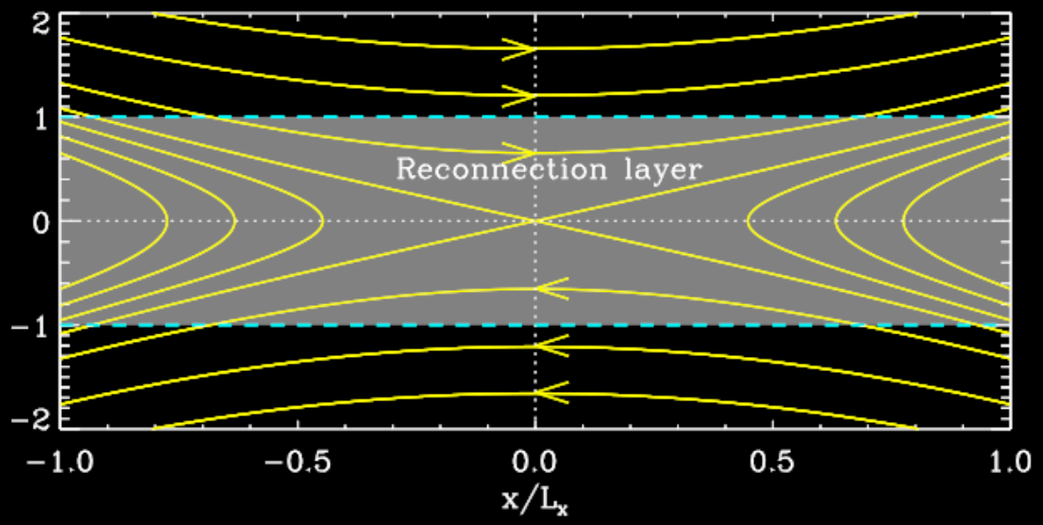




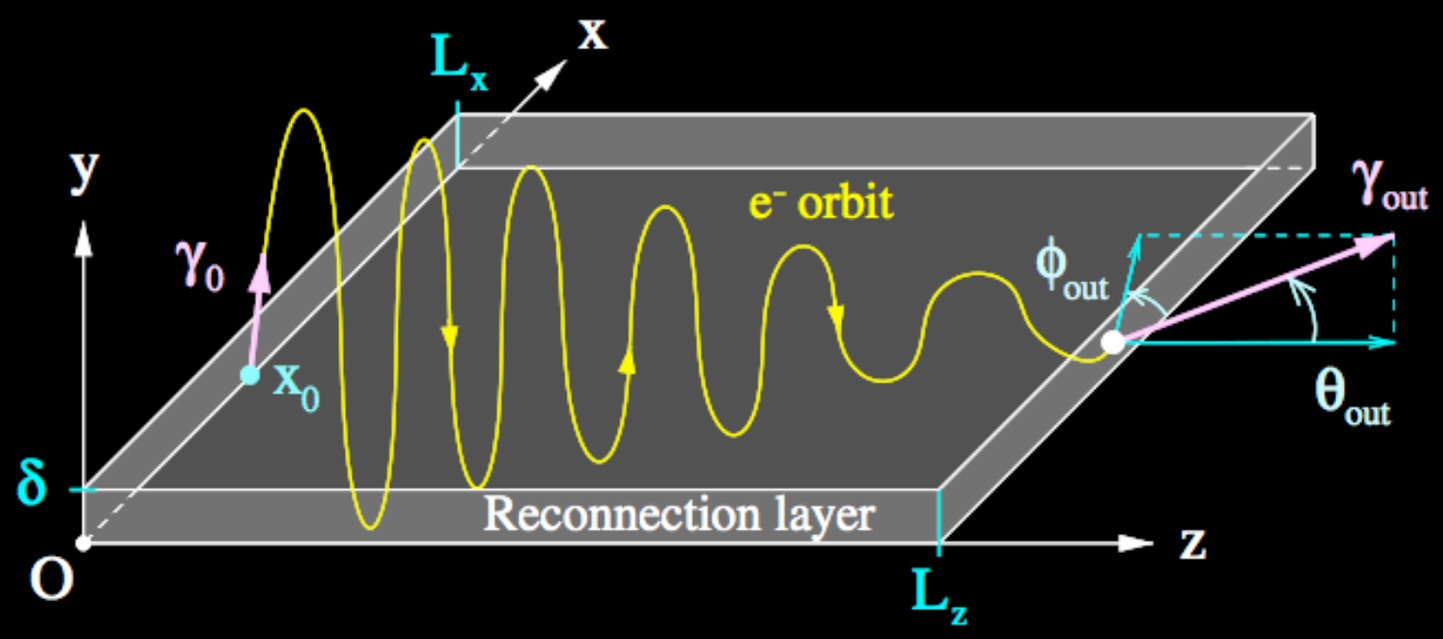
2D RMHD simulations by G. Bodo

Possibilities to reconcile large d and rapid variability

Beams from relativistic reconnection (Cerutti+12a,b, Nalewajko+12)



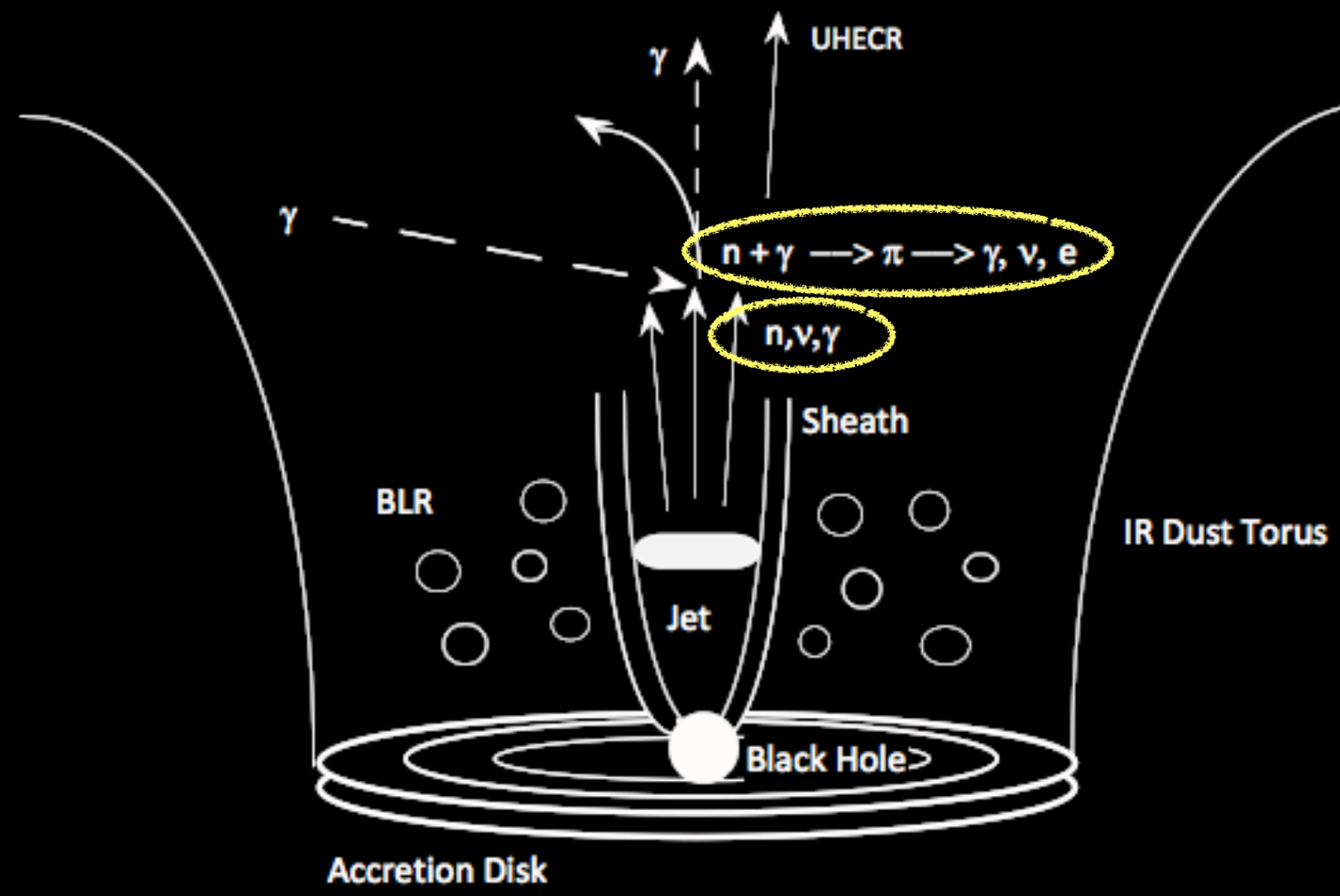
Emission: SSC or EC(IR)



UHE Neutral beams?

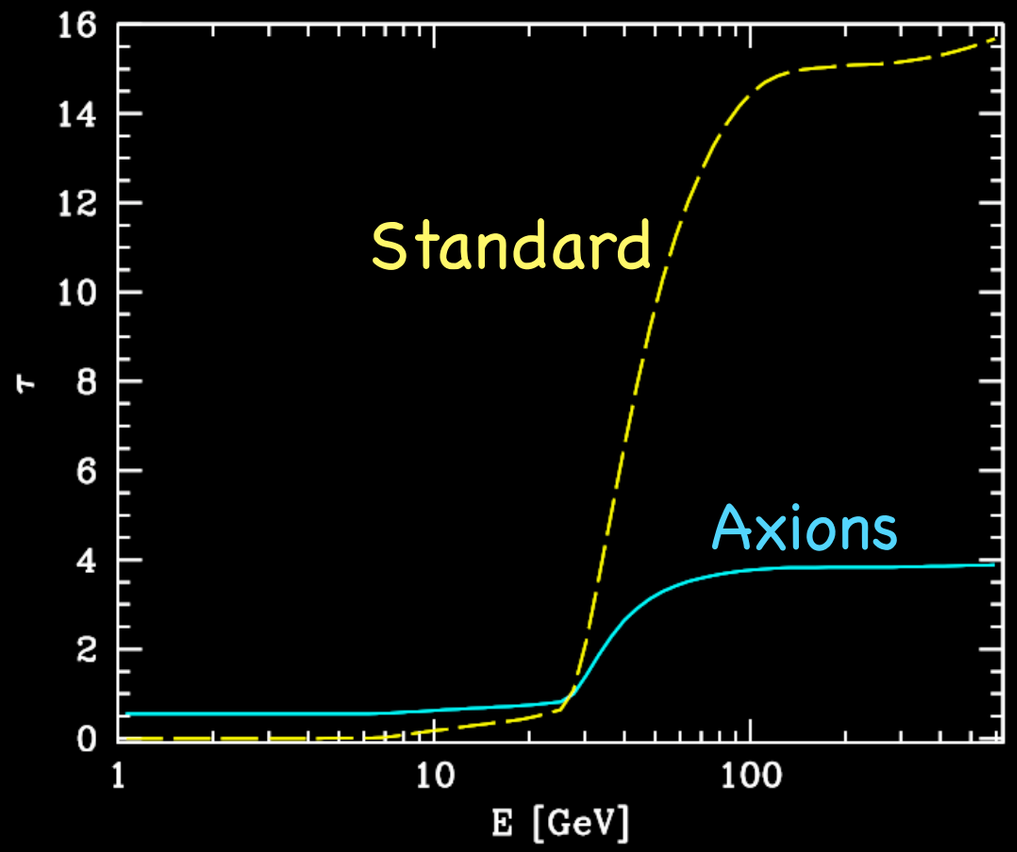
$$p\,\gamma \longrightarrow n\,\pi^{+}$$

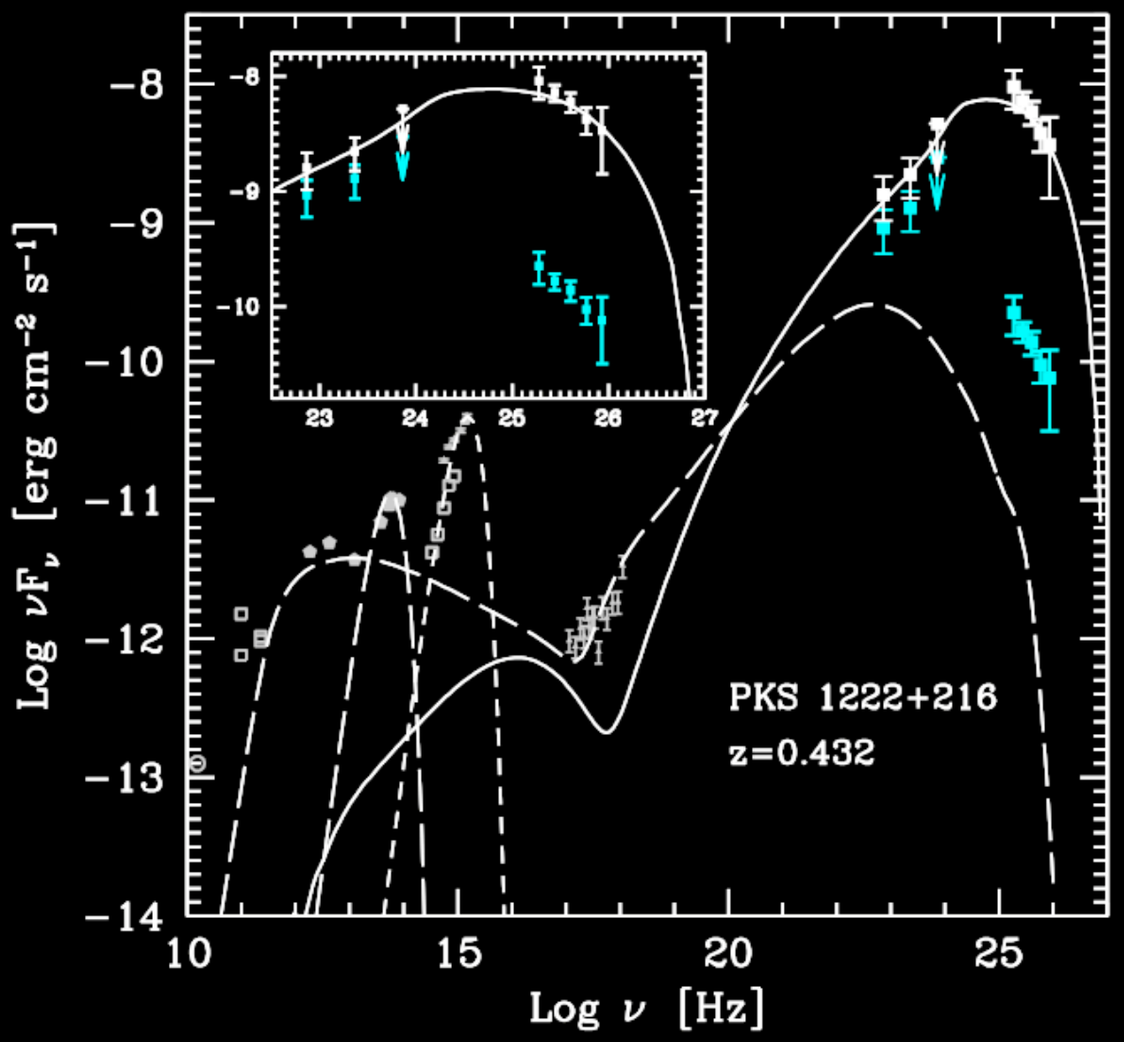
Dermer et al. 2012



A joke (?): Photon-axion oscillation

$$\gamma + \gamma_B \rightarrow a \qquad a + \gamma_B \rightarrow \gamma$$





Tavecchio et al. 2012, submitted

Epilogue

Joint GeV-TeV observations of flaring FSRQs
very constraining for existing models

Observations at radio/optical also crucial

Rapid variability perhaps currently the most compelling
issue in HE astrophysics (also Crab!)

The idea of a unique, large, "relaxed" emission
region is, at least sometimes, inadequate