Highly variable blazars (FSRQ): theoretical implications

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Gamma-ray rapid (<1 day) variability highly constraining for models of blazar jets

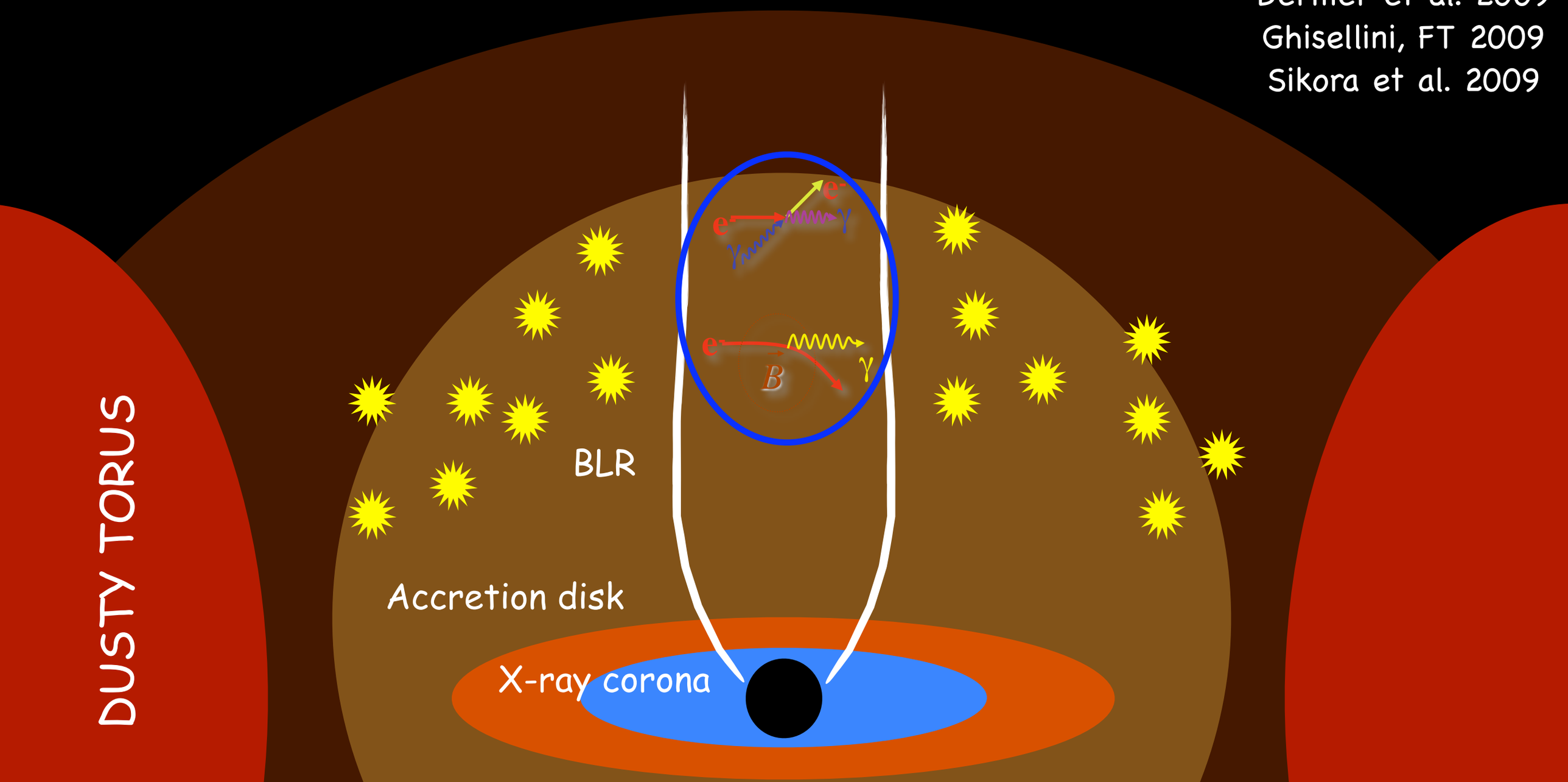
✓Structure and location of the emitting region

✓Lorentz factor

✓Particle acceleration

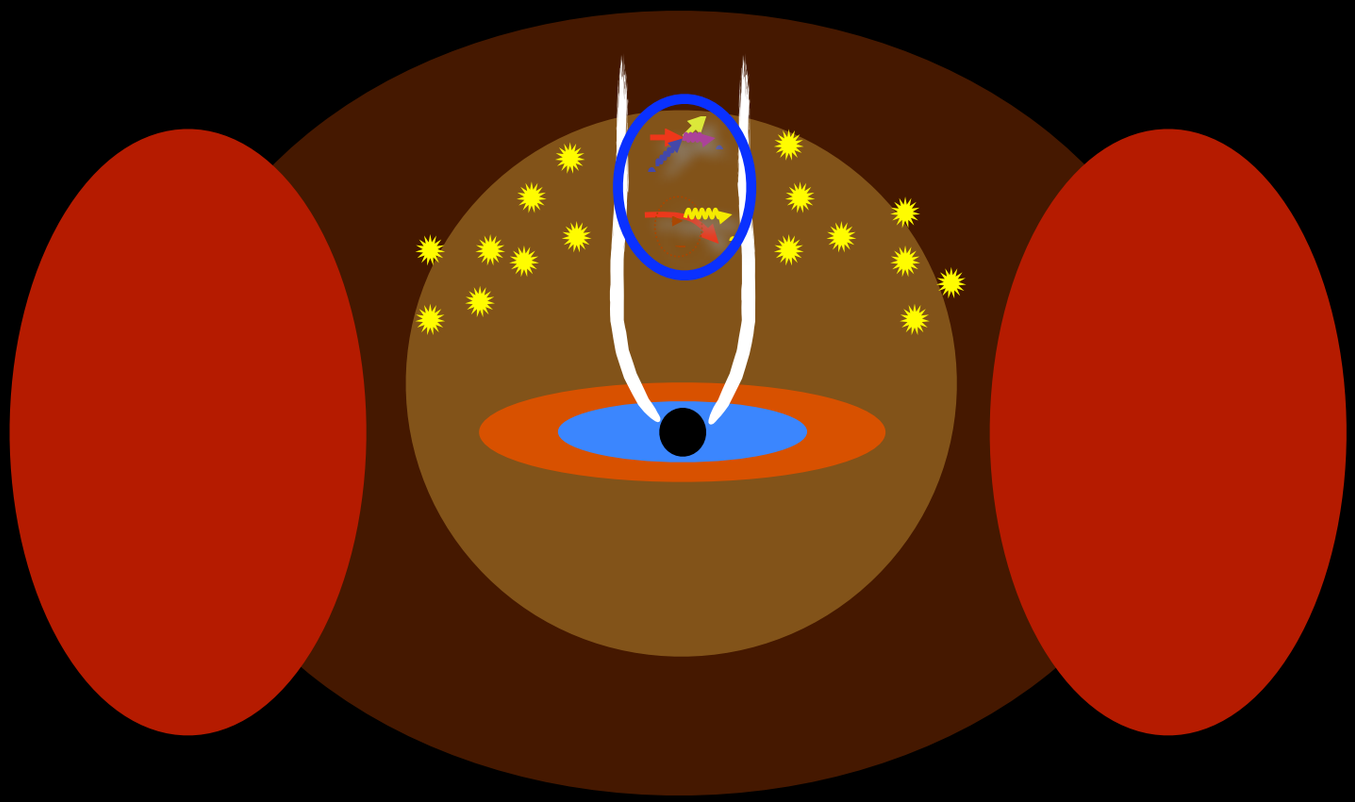
Setting the stage

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



Localizing the emission region

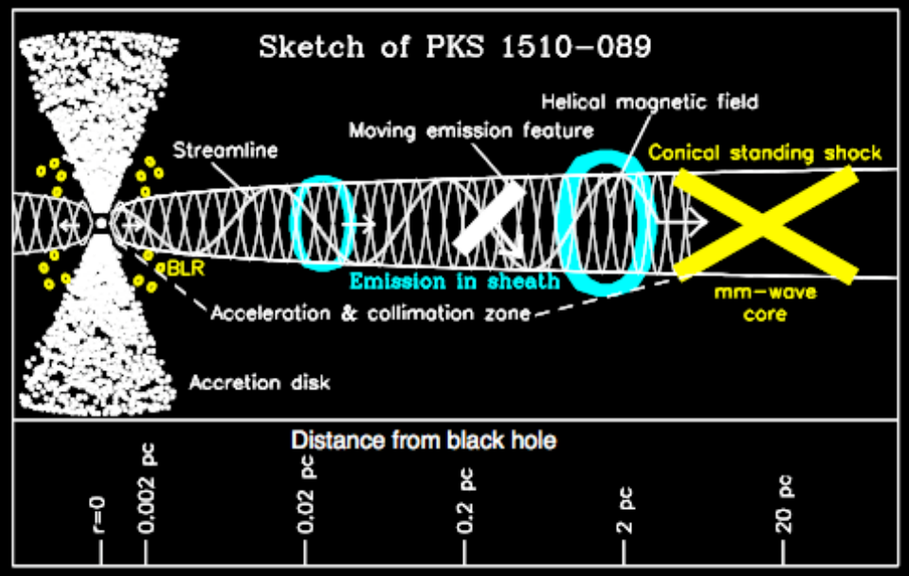
Standard distances < 0.1–0.3 pc < R_{BLR}



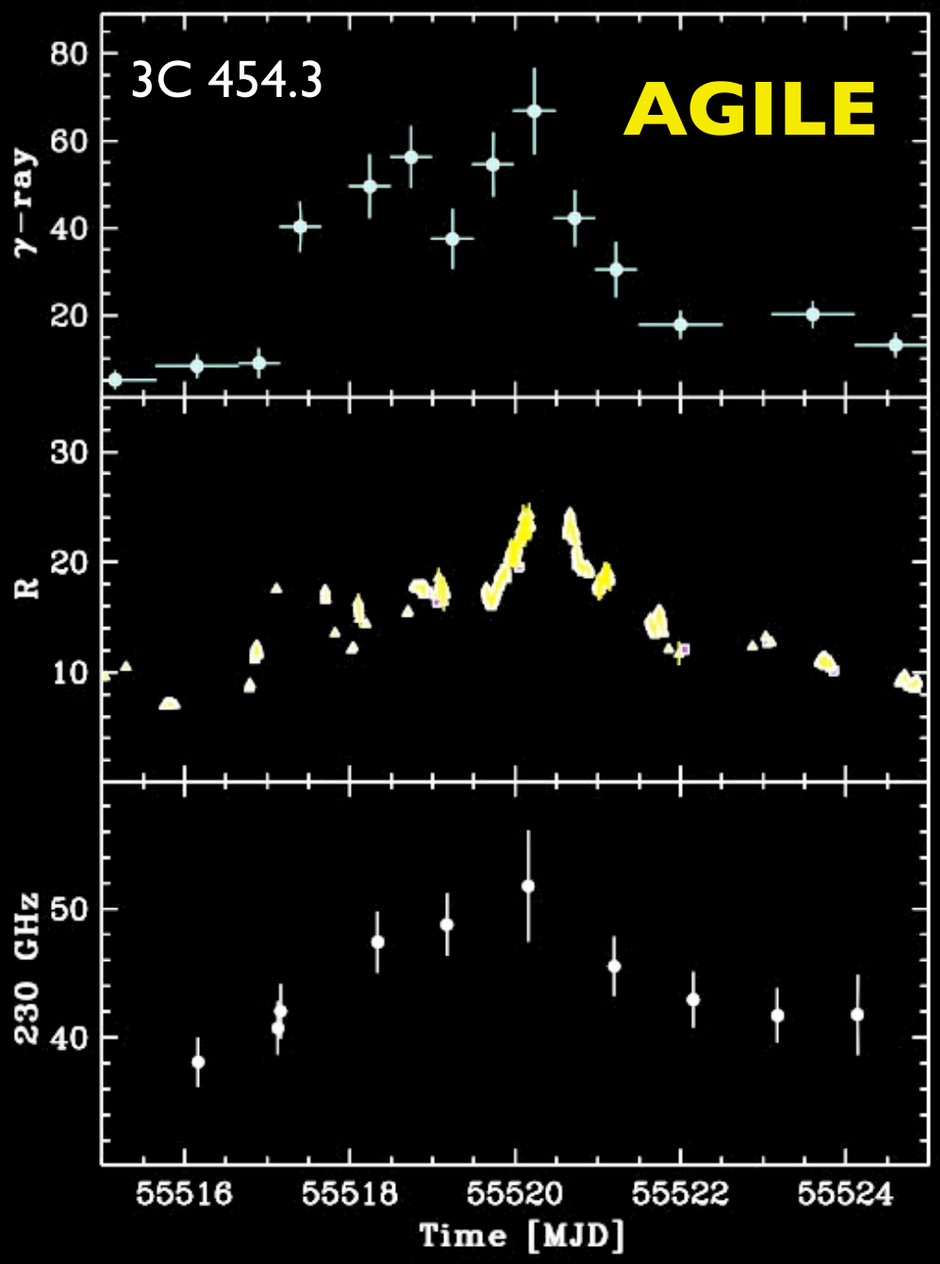
But:
Sikora et al. 2009
Marscher et al. 2009, 2010

~10 pc!

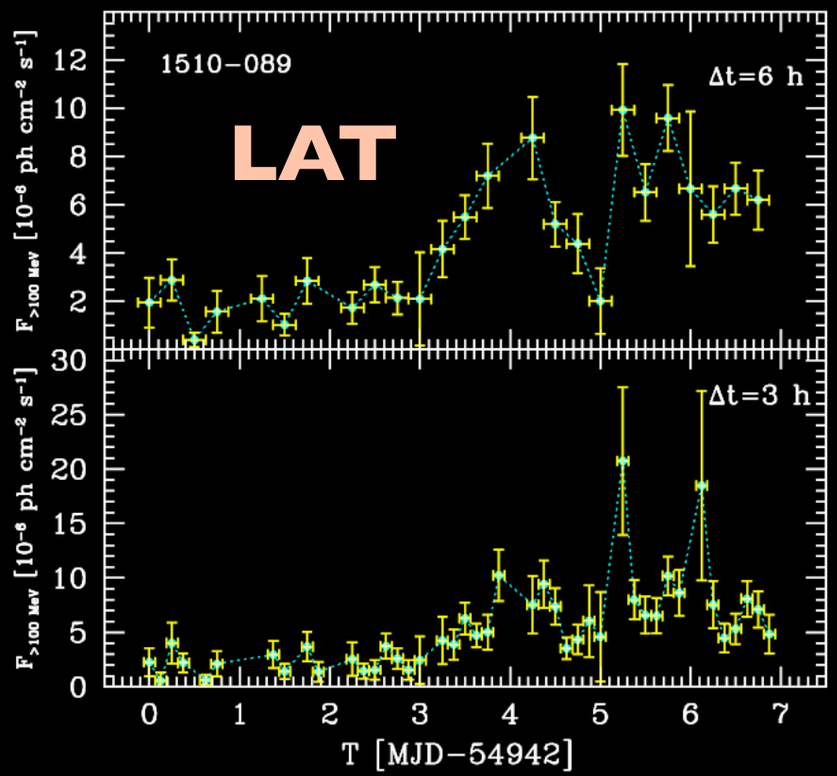
Marscher et al. 2010

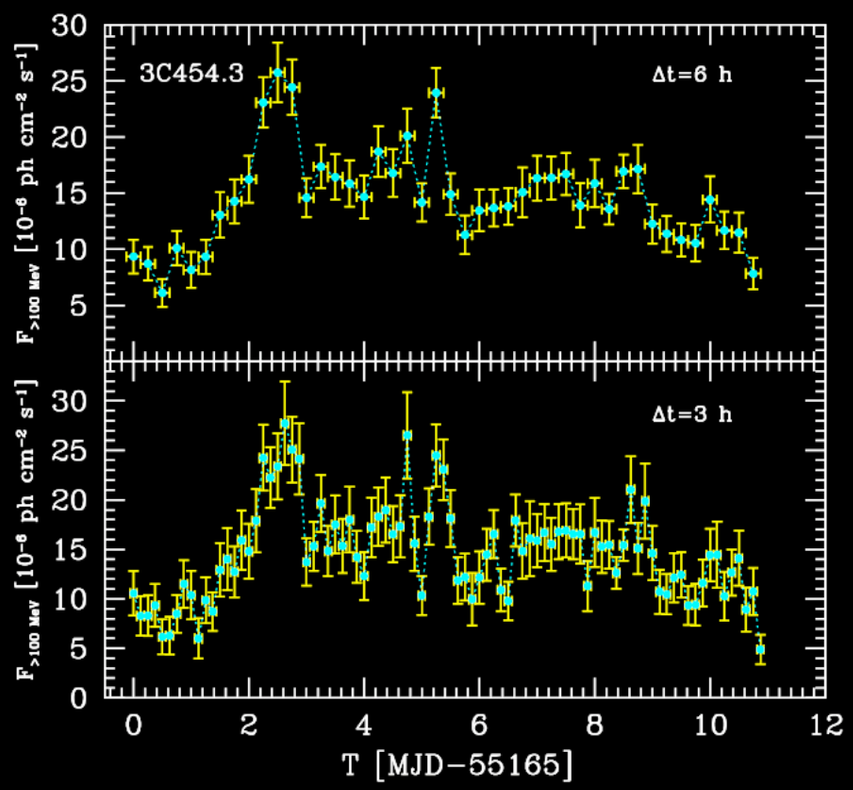


Rapid gamma-ray variability!



Vercellone et al. 2011





FT et al. 2010

Rapid gamma-ray variability

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

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

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

i.e. inside the BLR

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

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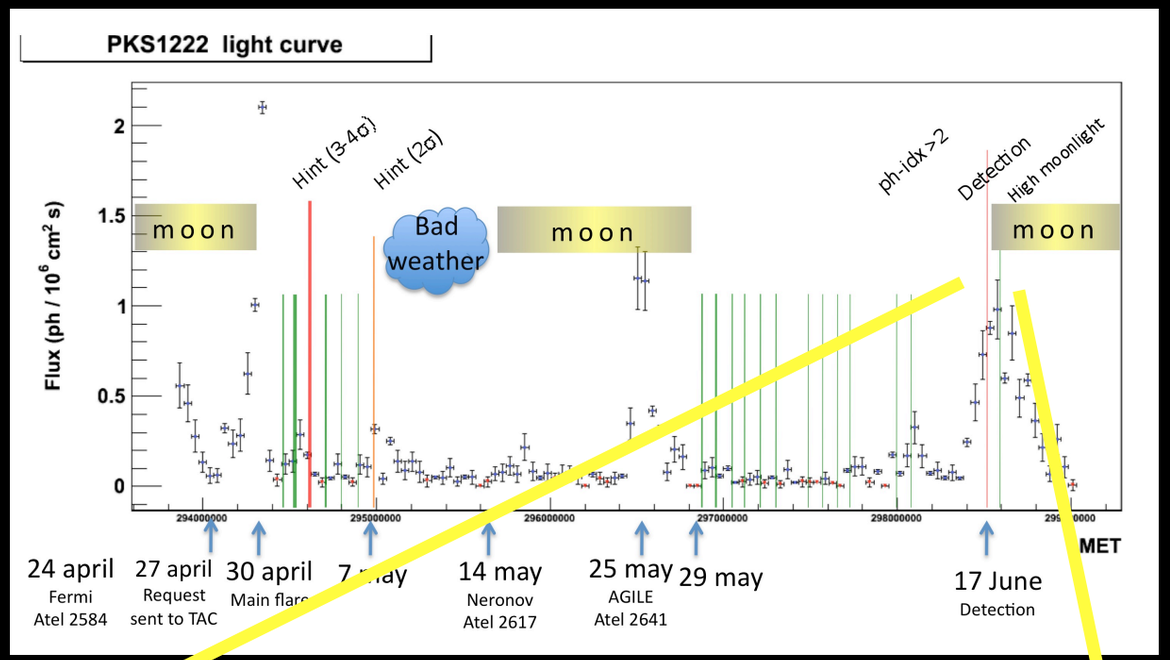
Very small collimation angle? If d=10 pc

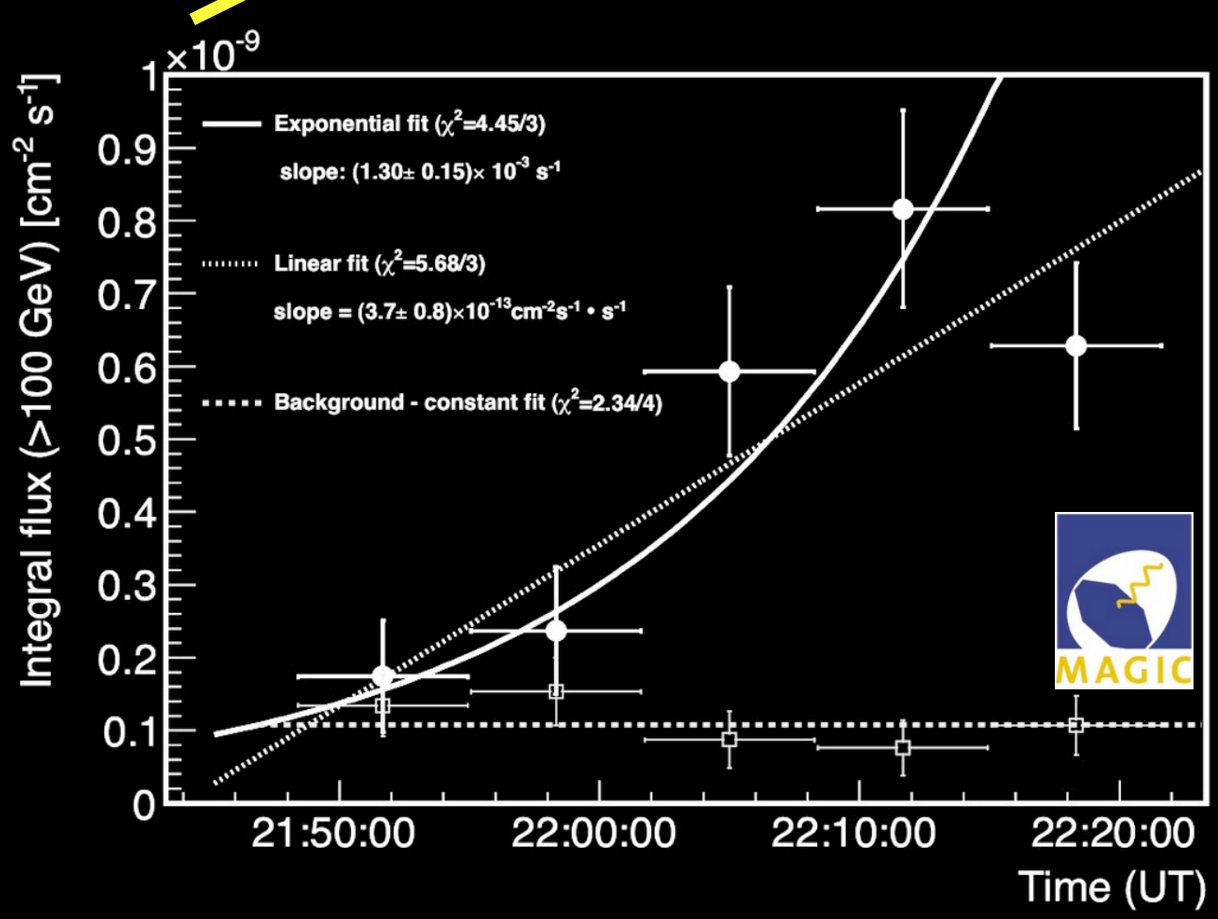
$$\theta_{\rm j} \simeq \frac{10^{-4}}{1+z}\left(\frac{t_{\rm var}}{6\,{\rm h}}\right)\left(\frac{\delta}{10}\right)$$

The breakthrough: the FSRQ 1222+216



$t_{double} \sim 10$ min!

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



Location of VHE emission?
Difficult inside BLR!

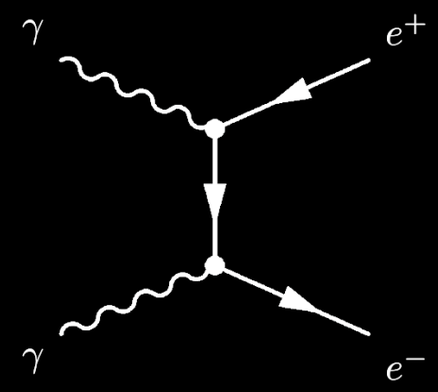
Strong absorption
(E>30 GeV within BLR, E>1 TeV outside)
(e.g. Liu et al. 2008, Reimer 2007, FT & Mazin 2009)

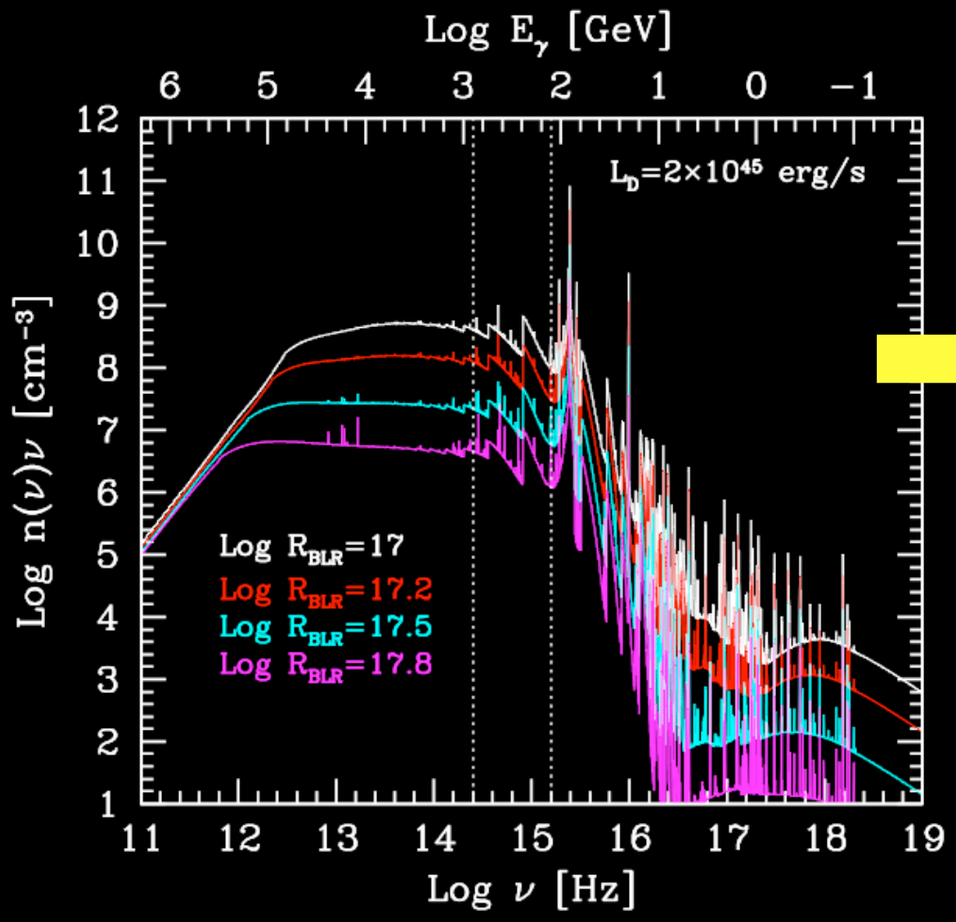
Decline of the IC scattering efficiency
(e.g. Albert et al. 2008, FT & Ghisellini 2008)

General

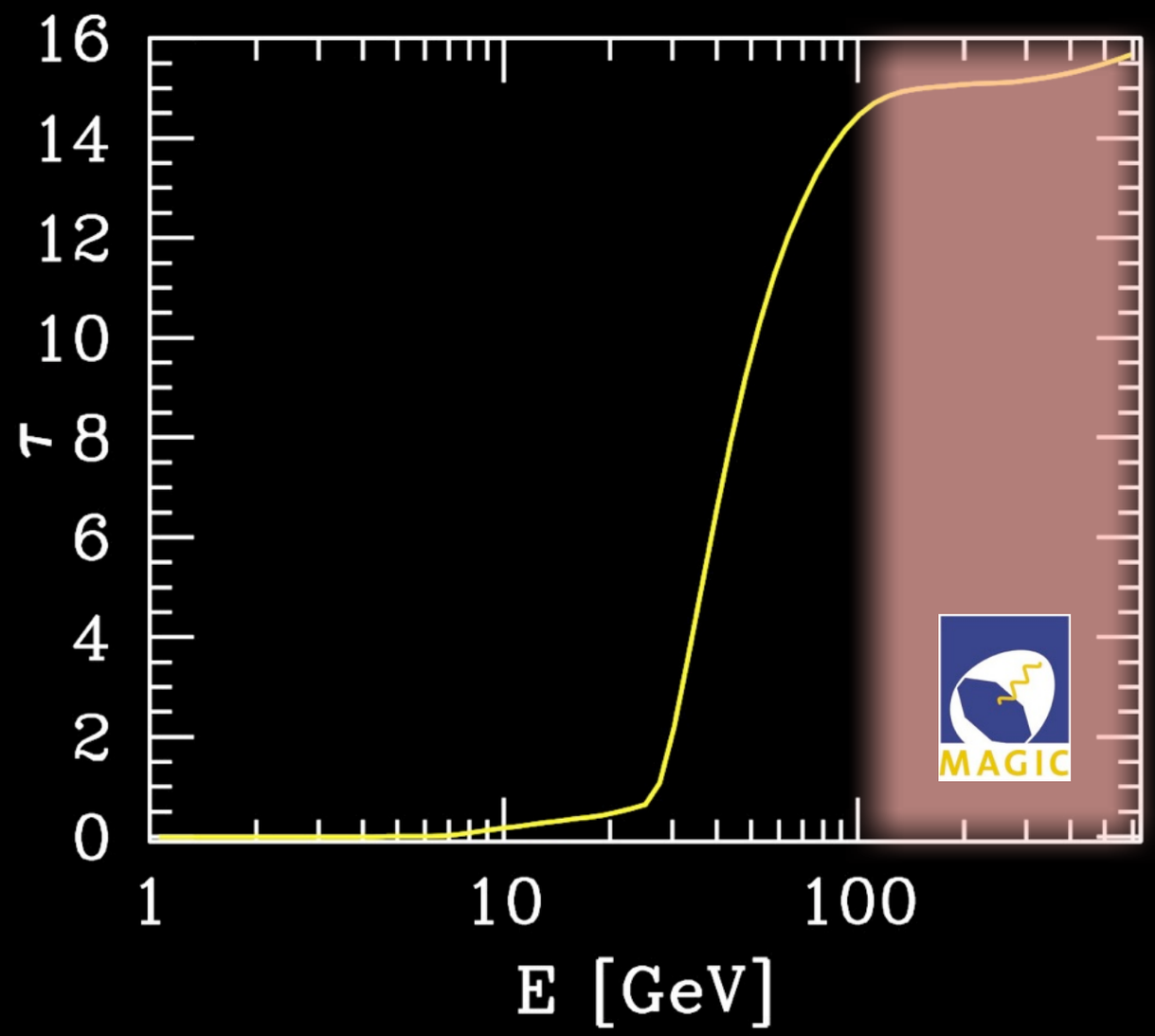
Model dependent
(not applicabile to hadronic)

Huge optical depth of BLR



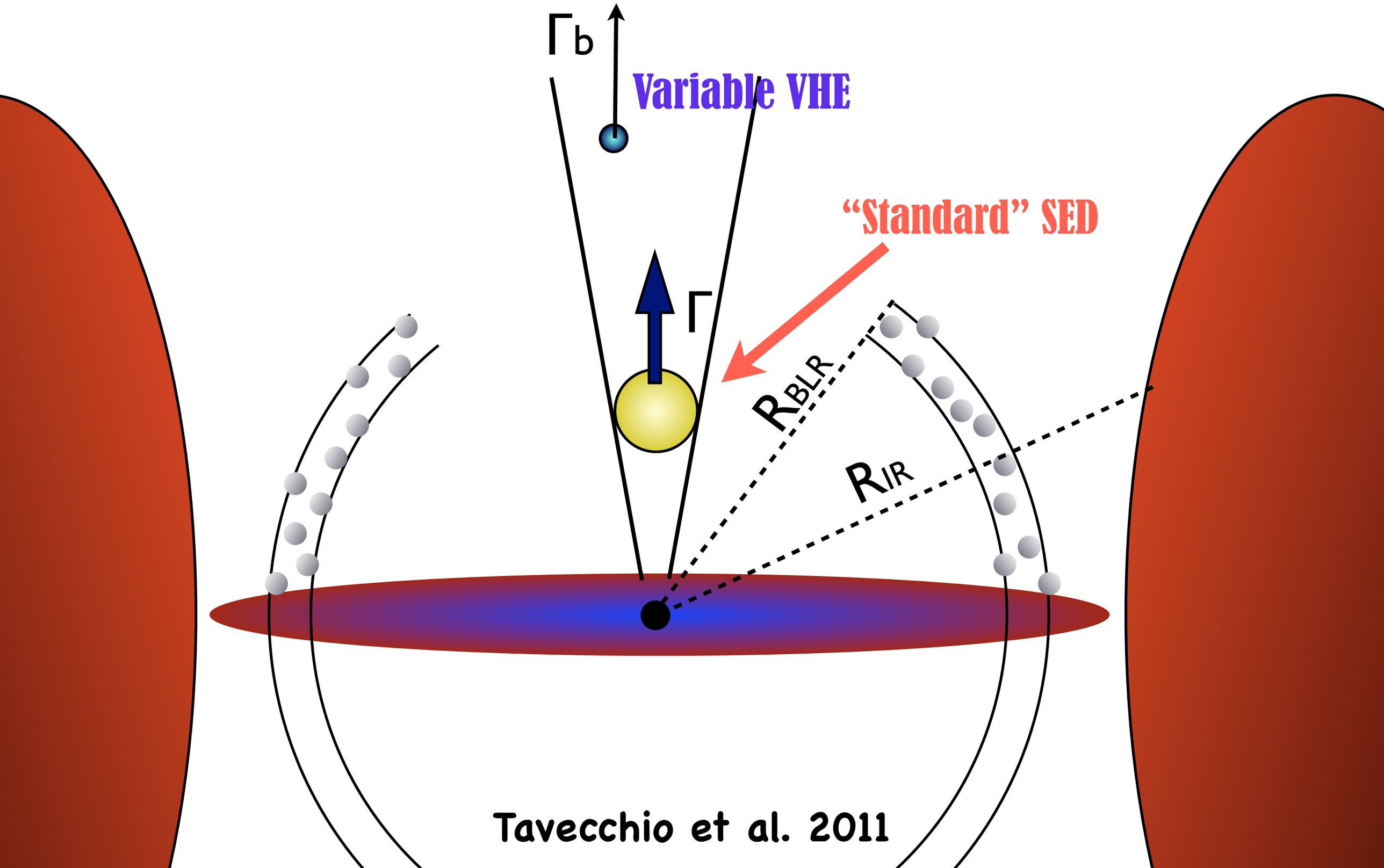


FT & Mazin 2009



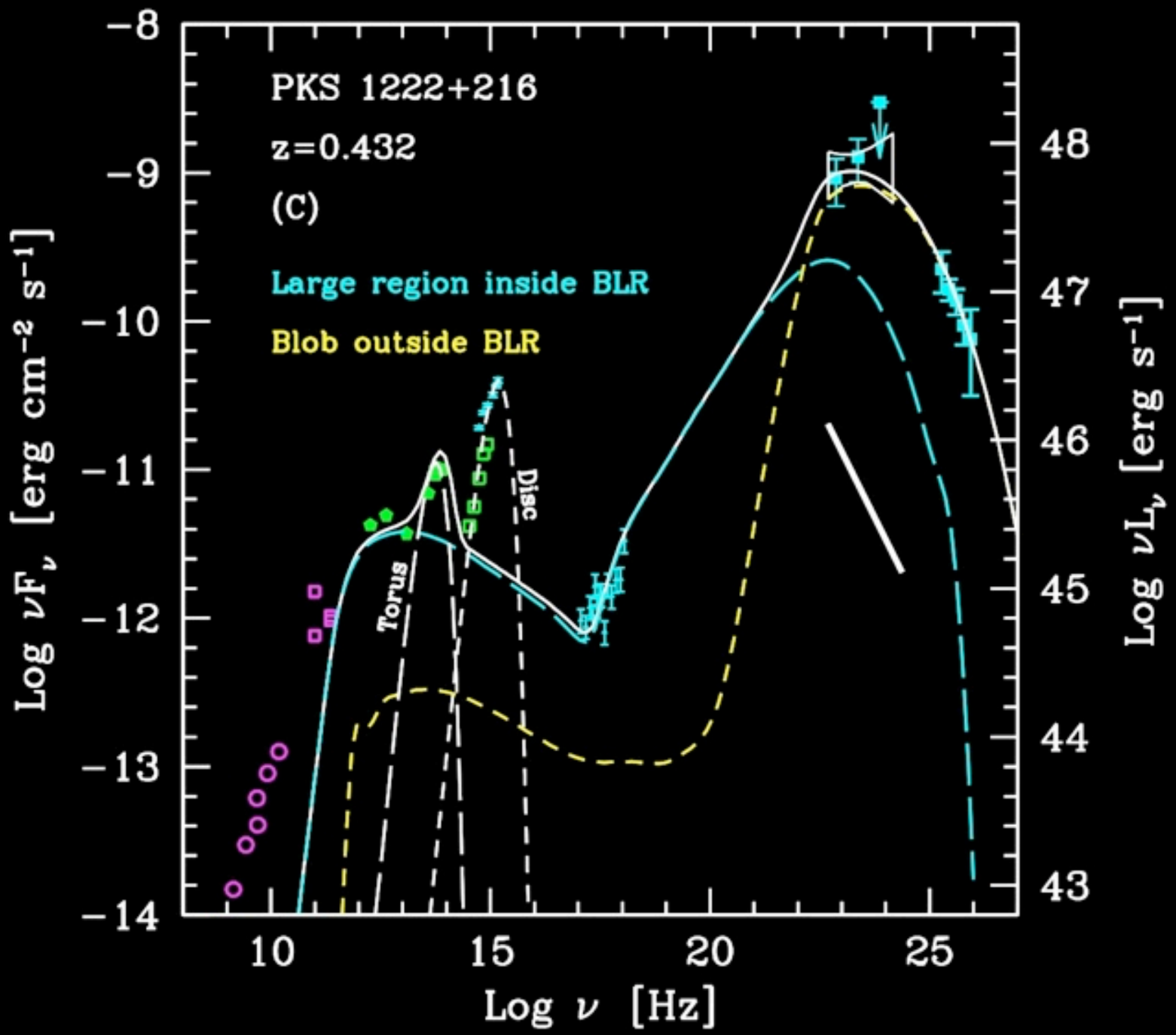
FT et al. 2012

External emission?



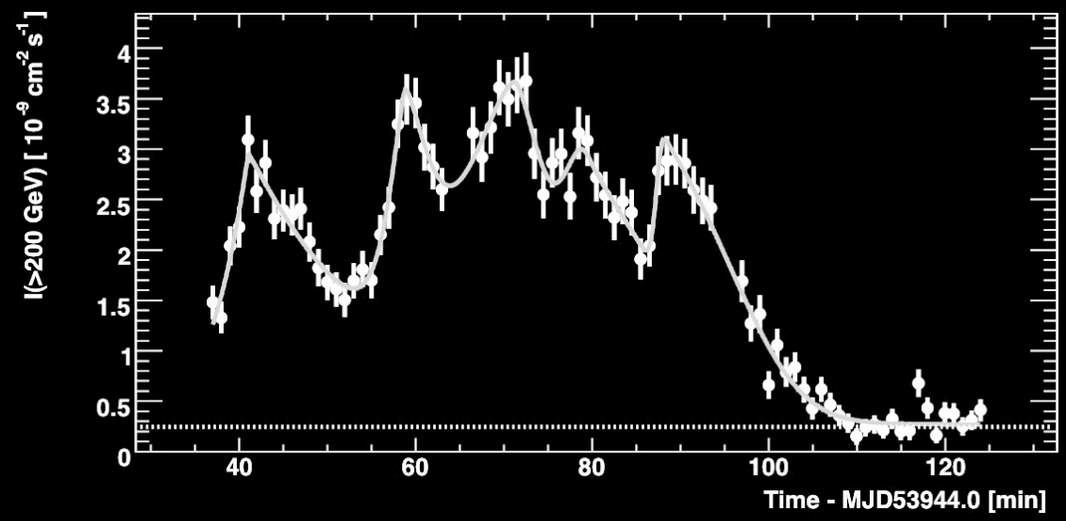
Tavecchio et al. 2011

Tavecchio et al. 2011



A similar problem: rapid TeV variability of BL Lacs

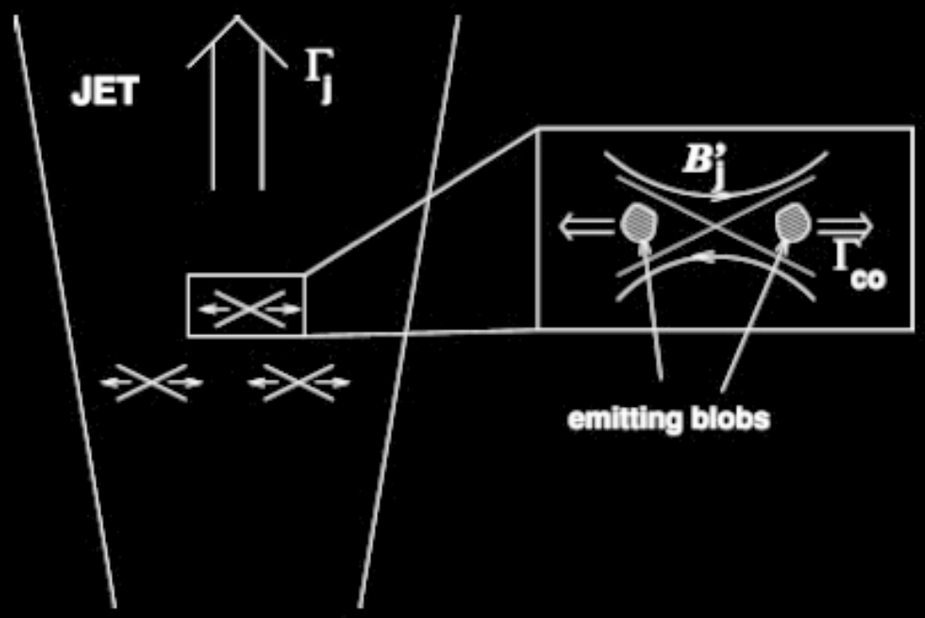
PKS 2155-304 - HESS



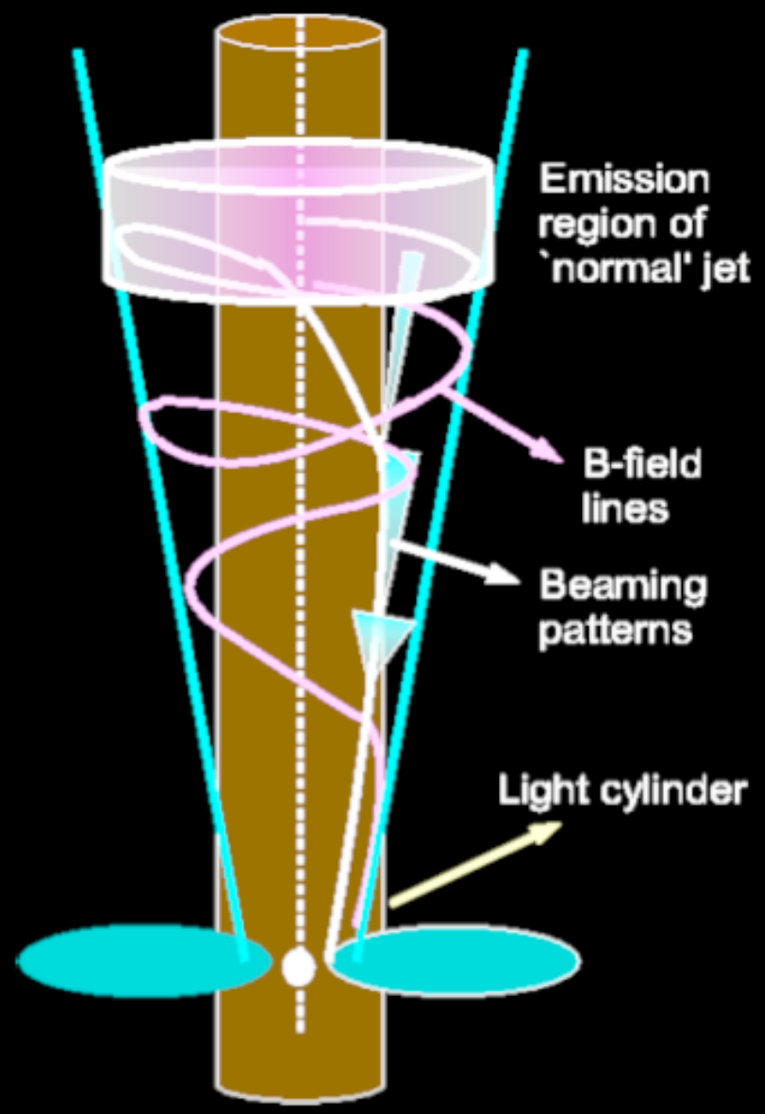
Ultrafast (~200 s) variability (Aharonian et al. 2007, Albert et al. 2007) needs major changes (e.g. Ghisellini et al. 2008, 2009, Giannios et al 2009, Neronov et al. 2008)

Possibilities to reconcile large d and rapid variability

e.g. Ghisellini et al. 2008, 2009
Giannios et al 2009
Marscher & Jorstad 2010



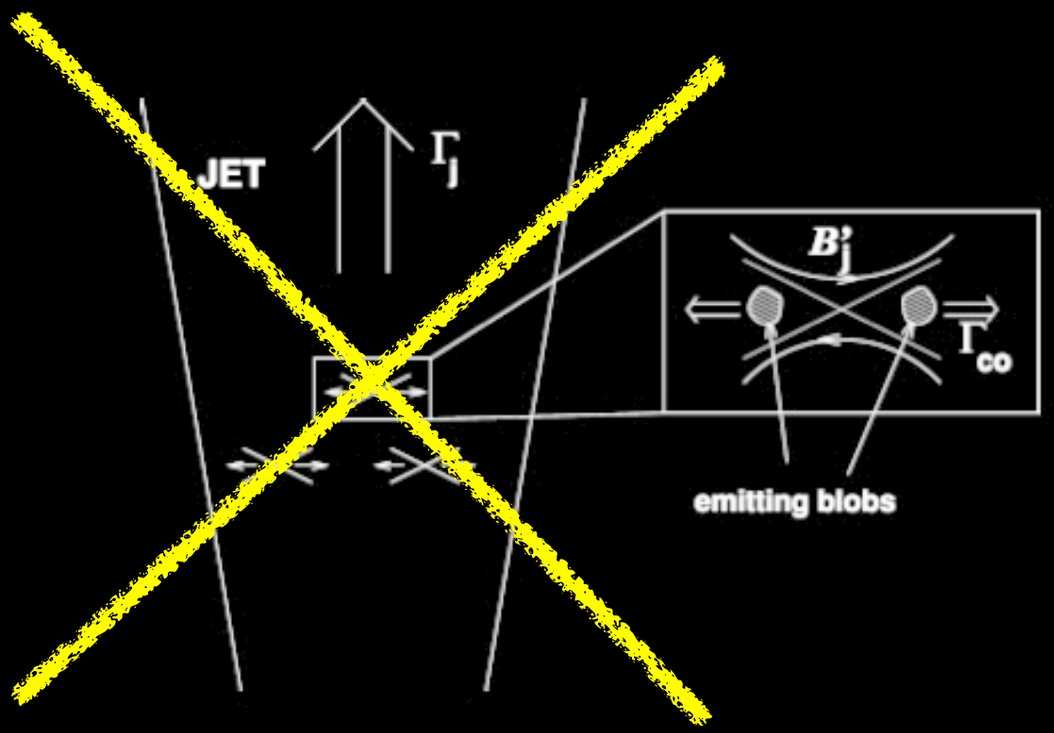
Minijets from fast reconnection



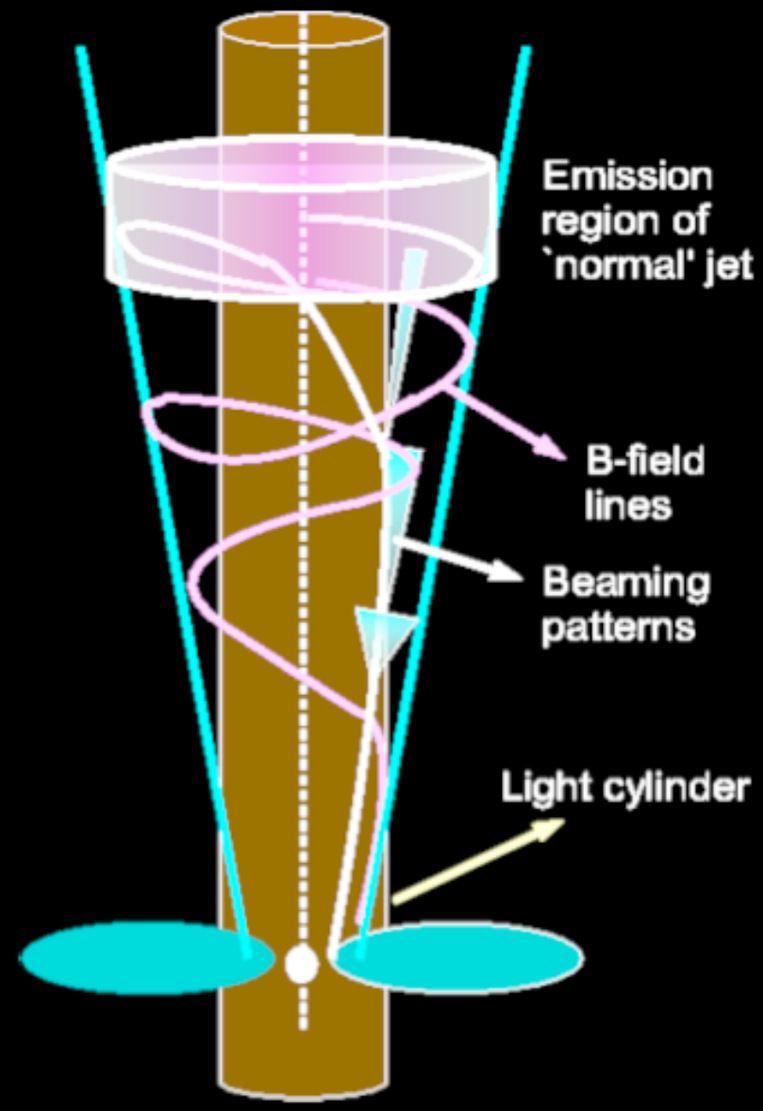
Magnetocentrifugal acceleration

Possibilities to reconcile large d and rapid variability

Too high B? (>100 G, Nalewajko +2012)
E/B~26



Minijets from fast reconnection



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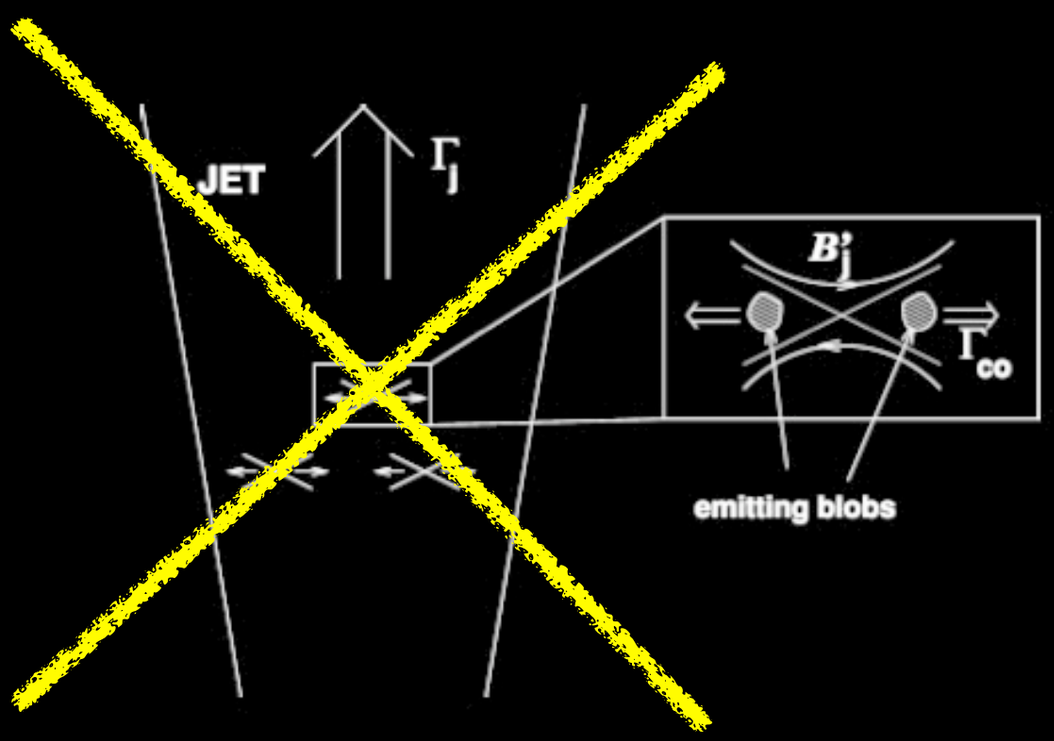
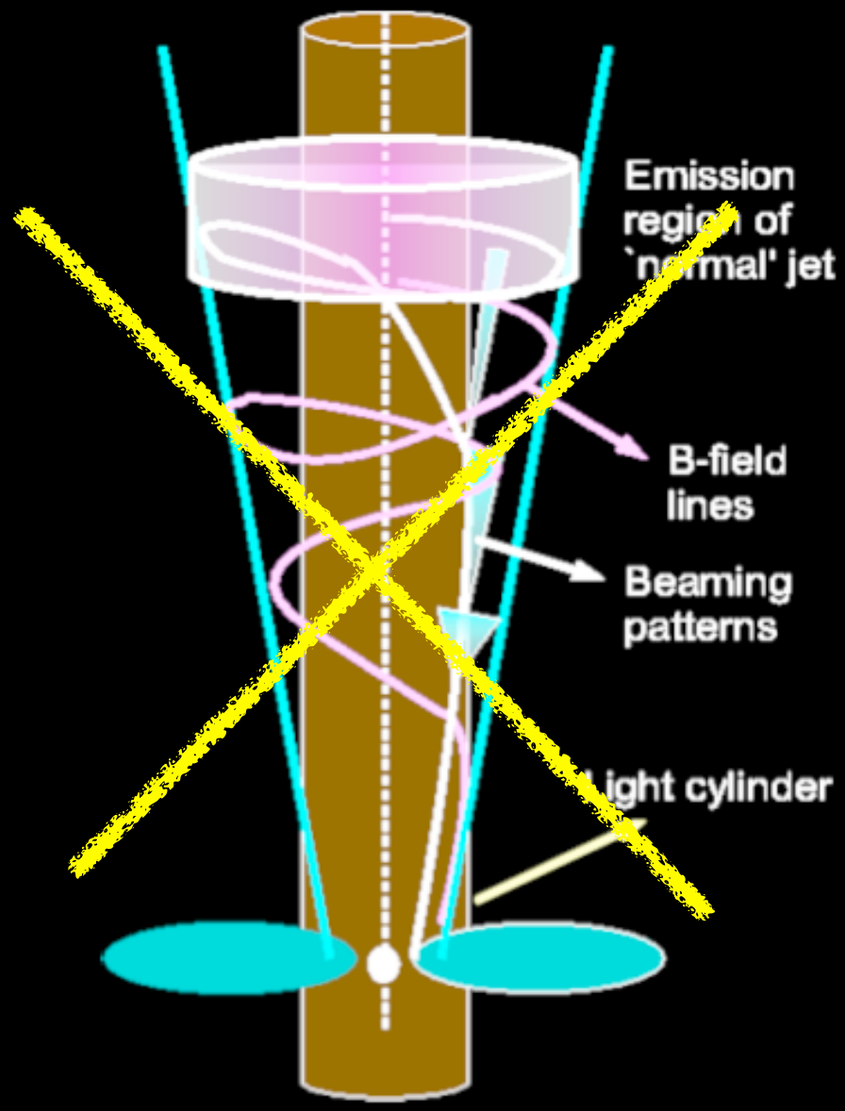


Minijets from fast reconnection

Large IC cooling!

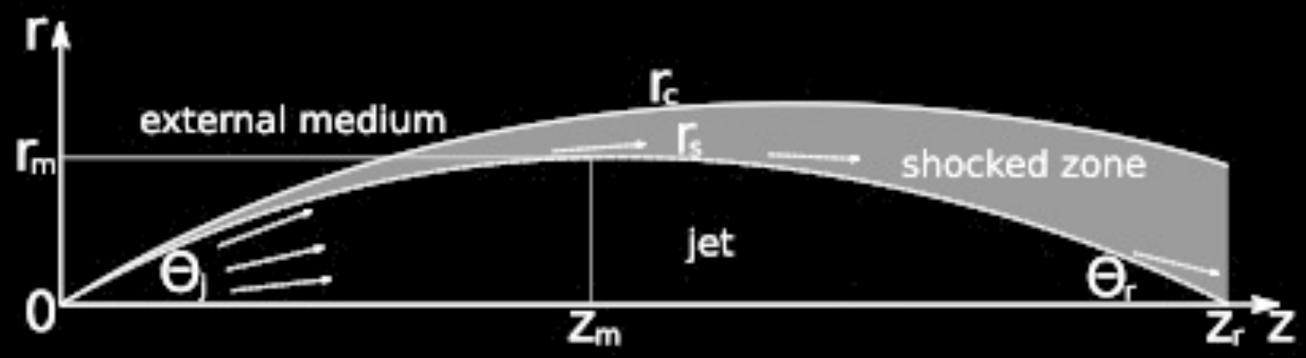


Magnetocentrifugal acceleration

Possibilities to reconcile large d and rapid variability

Strong recollimation

e.g. Nalewajko & Sikora 2009
Bromberg & Levinson 2009

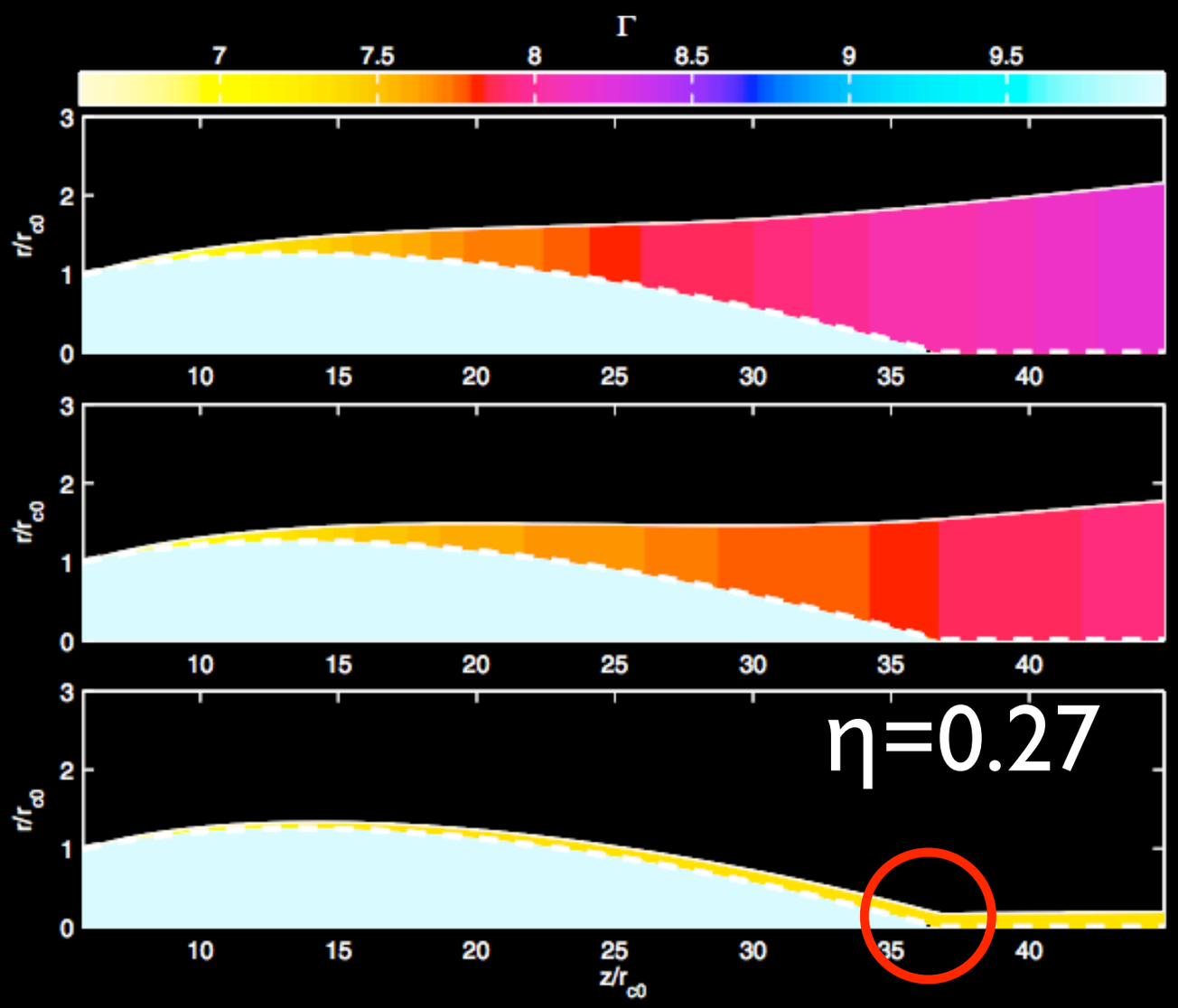


Possibilities to reconcile large d and rapid variability

Bromberg & Levinson 2009

2d, semianalitic calculations

"Focusing"

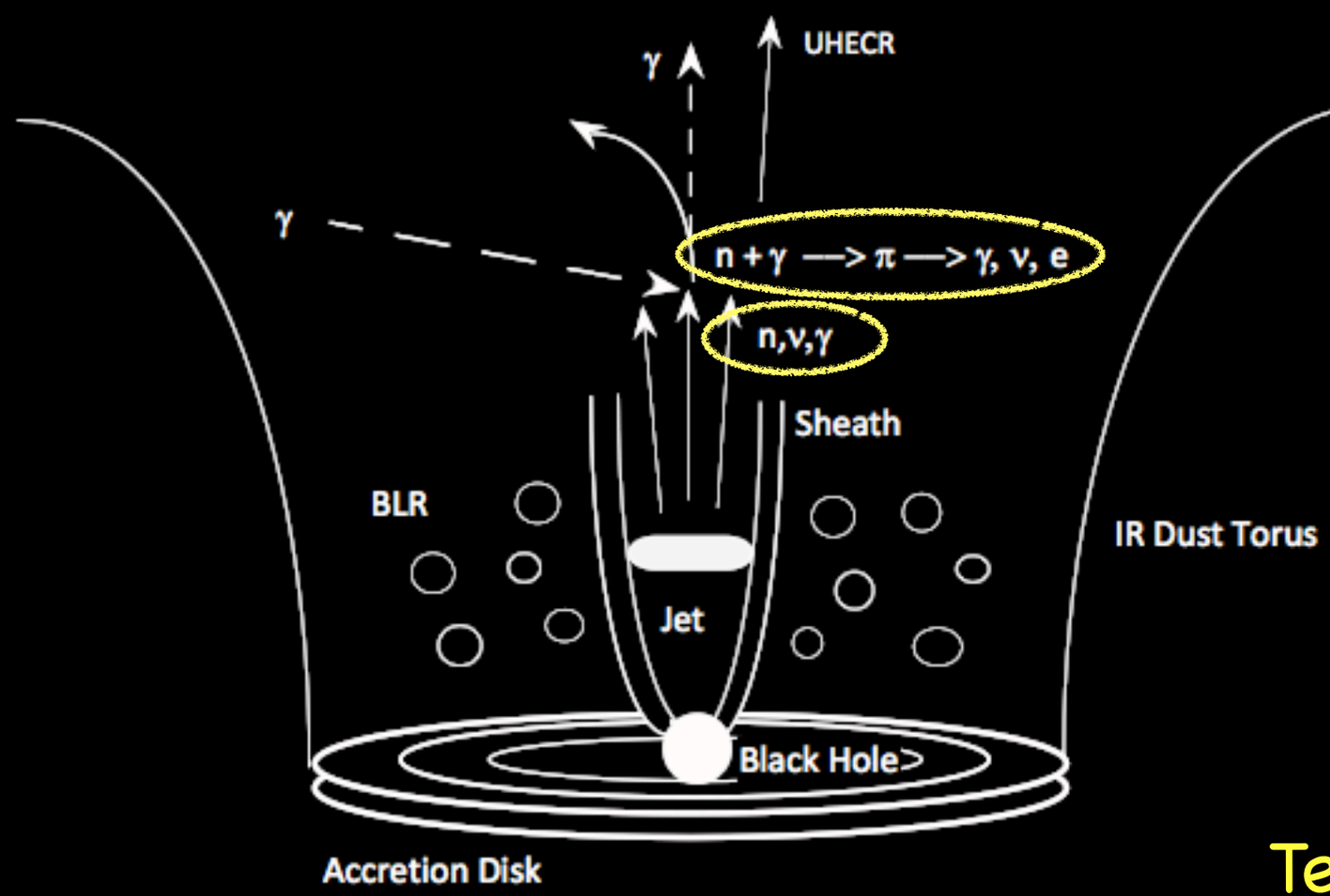


Radiative efficiency

A new proposal: UHE Neutral beams

Dermer et al. 2012

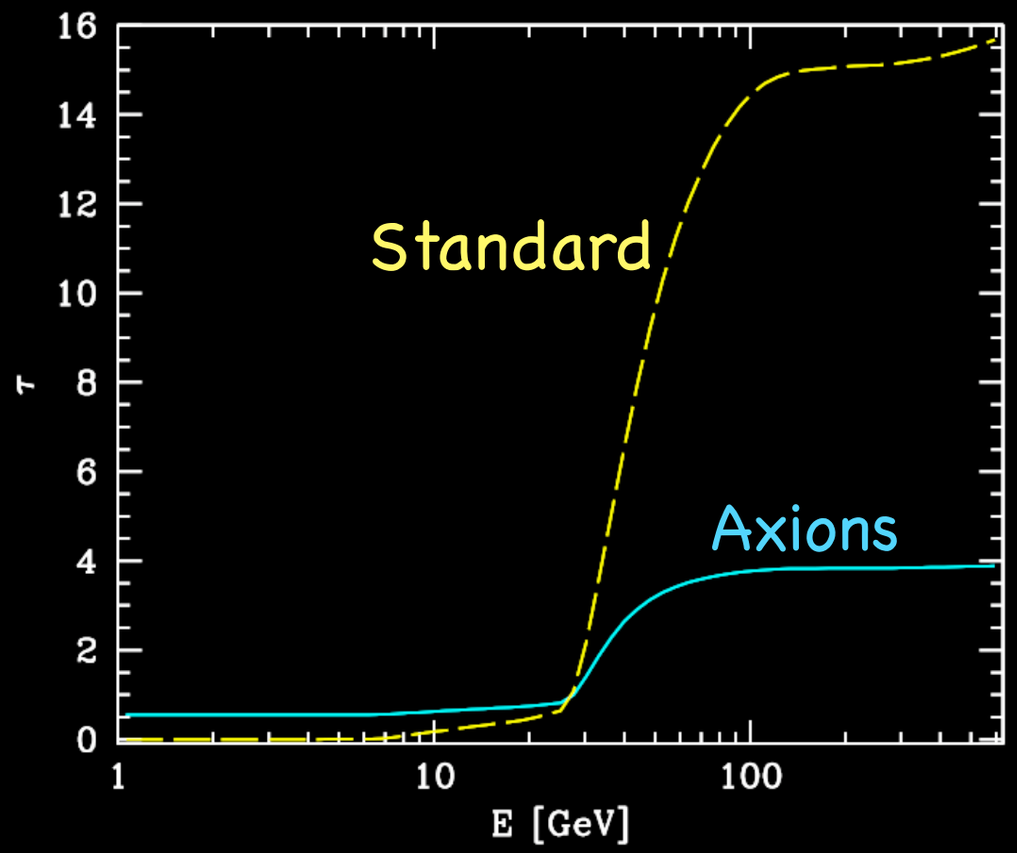
$$p\,\gamma \longrightarrow n\,\pi^{+}$$

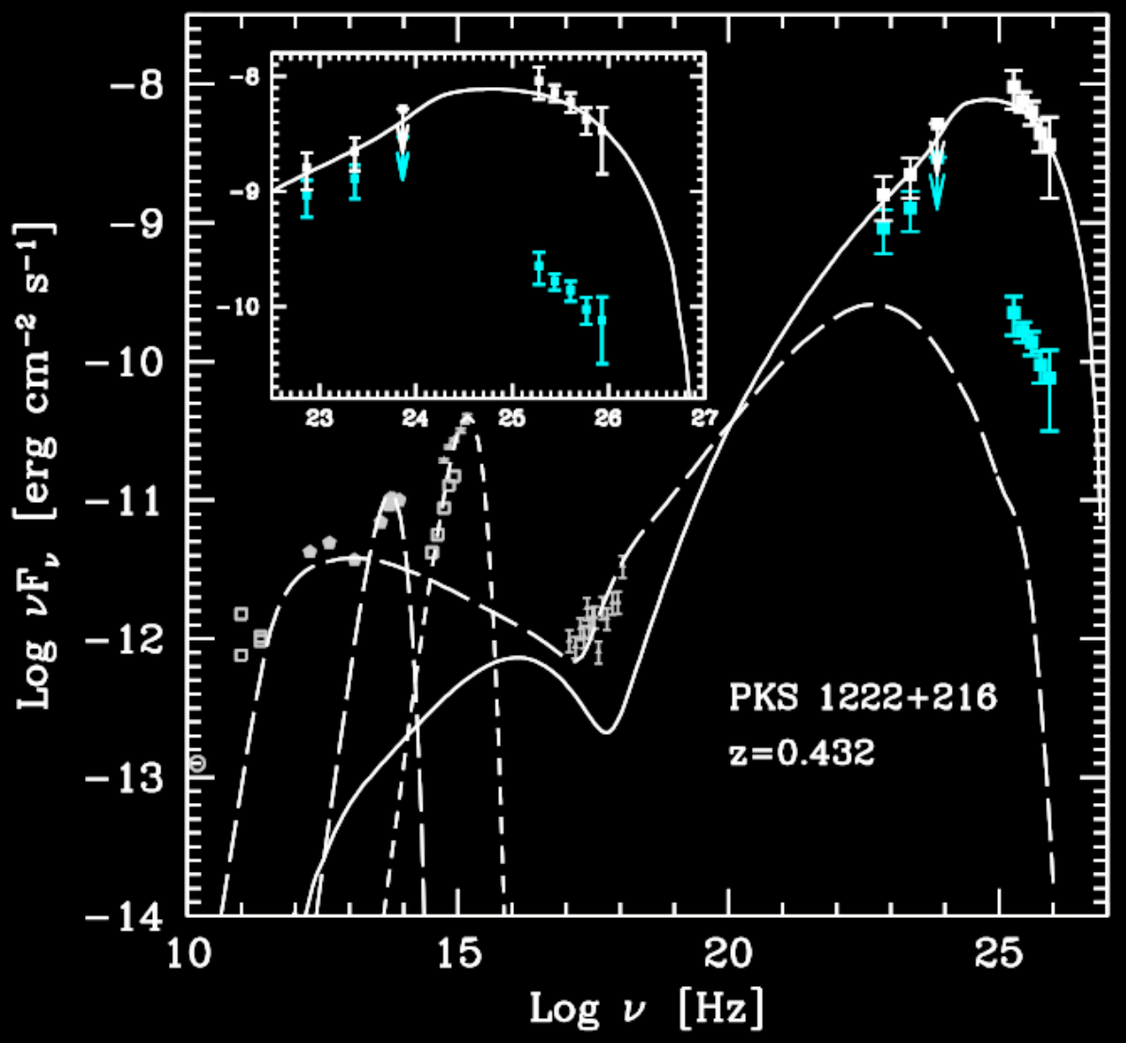


Test: neutrinos

An "exotic" scenario: photon-axion oscillation

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





Tavecchio et al. 2012, submitted

Conclusions

Ultrarapid events among the most challenging phenomena (not only in AGN... Crab!)

PKS 1222+216: beyond BLR (unless exotic physics at work, e.g. axions, Tavecchio et al. 2012)

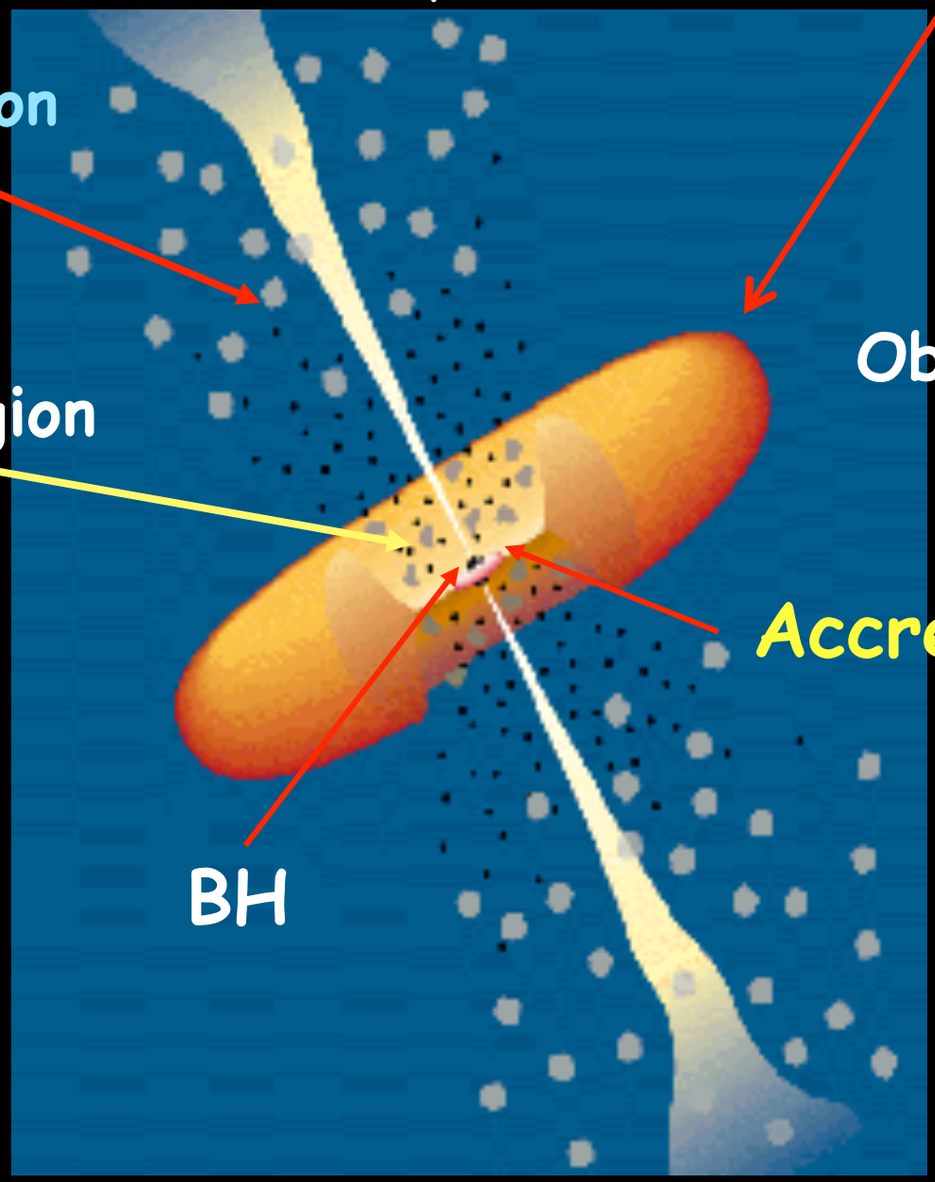
Recollimation/focusing?
Deeper studies required
(3D, RMHD simulations in progress)

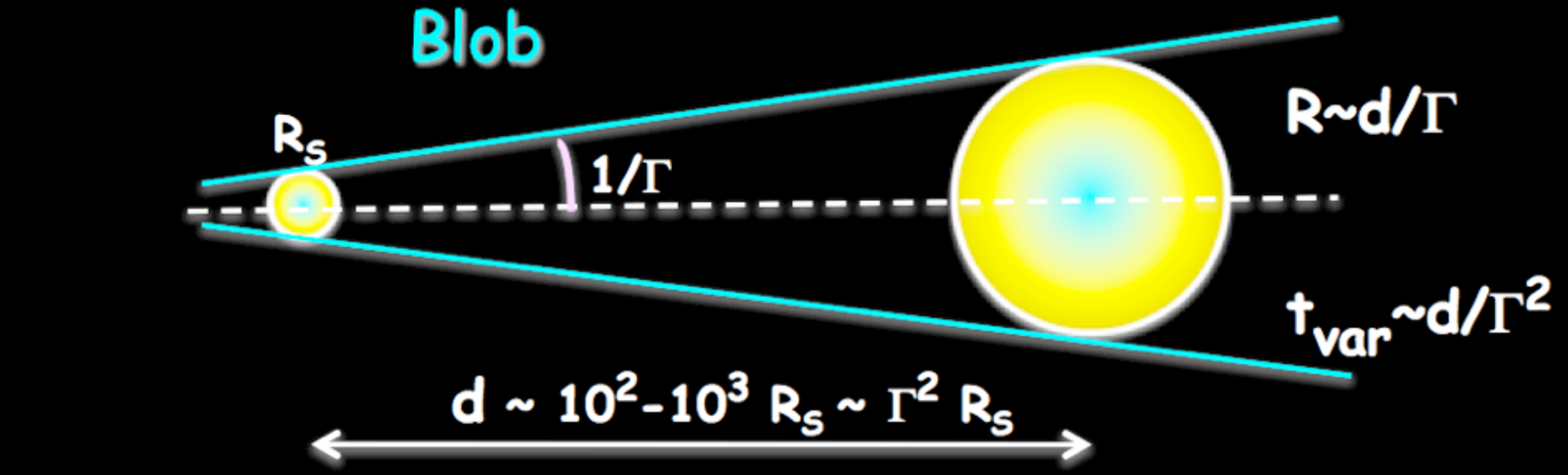
Blazar "unification scheme"

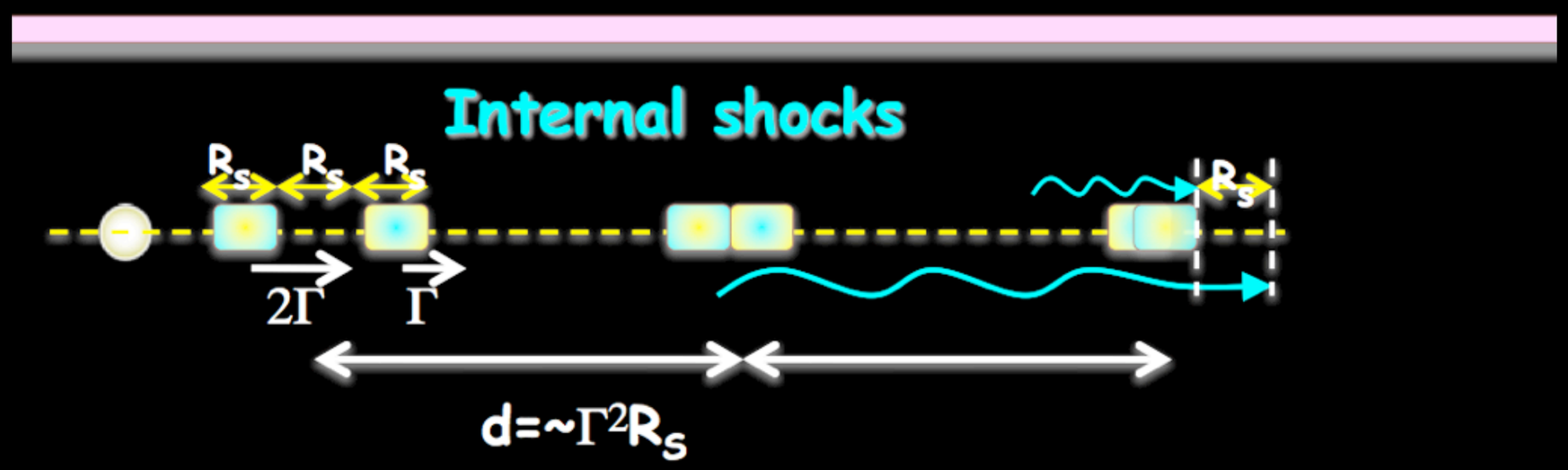
Blazar (BL Lac [no BL], FSRQ [BL])

Radiogalaxy (FRI, FRII), SSRQ

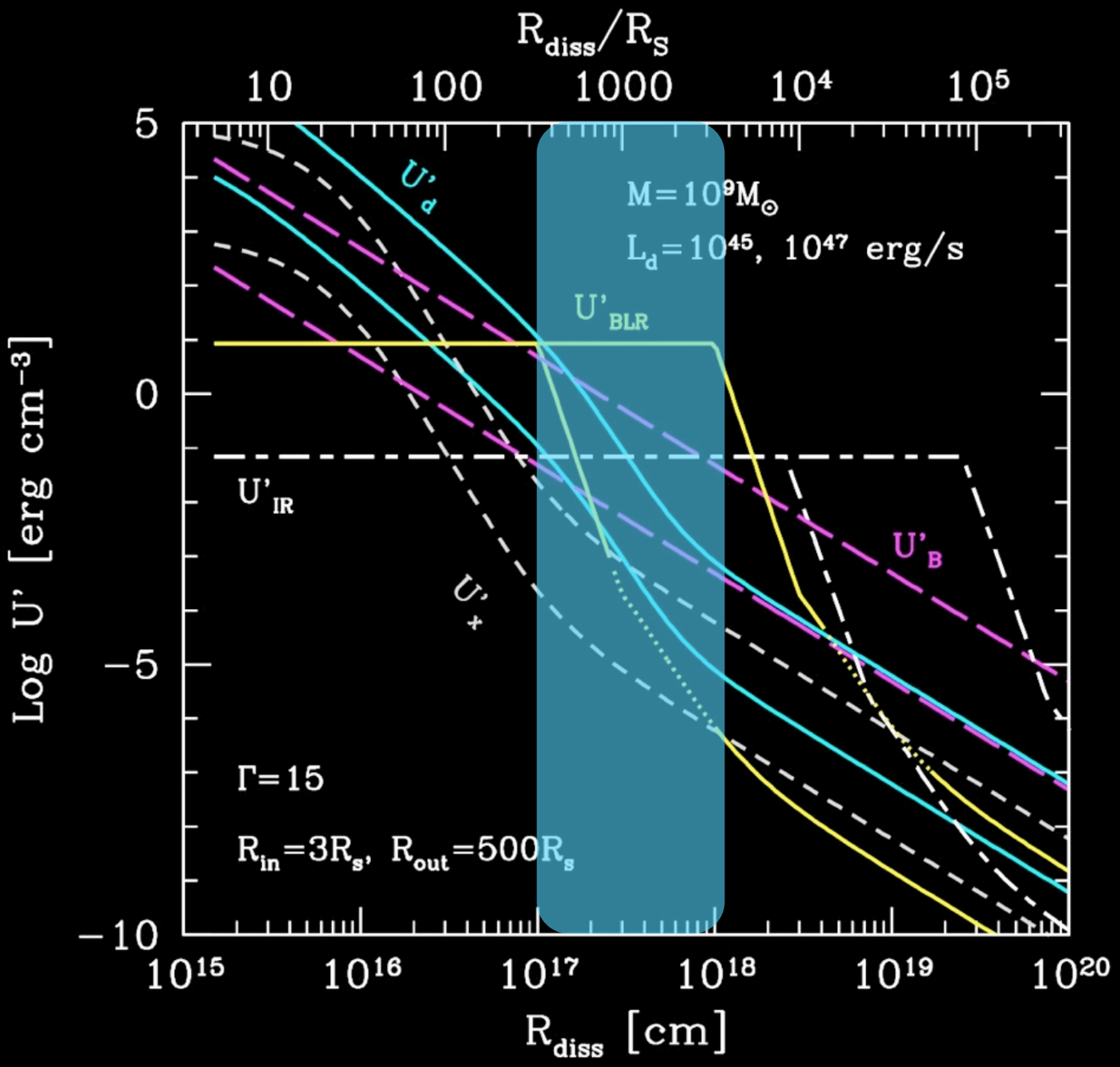
Urry & Padovani 1995







$t_{var} \sim 10^4\ M_9$ seconds (3 h)


R_{diss}/R_S
10
100
1000
10^4
10^5
5
0
−5
−10
Log U' [erg cm^{-3}]
$M=10^9 M_\odot$
$L_d=10^{45}$, 10^{47} erg/s
U'$_d$
U'$_{BLR}$
U'$_{IR}$
U'$_{tot}$
U'$_B$
Γ=15
$R_{in}=3R_s$, $R_{out}=500R_s$
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
R_{diss} [cm]