constraining luminous blazars

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Kraków, 24 April 2015

references

1. M. Sikora, Ł. Stawarz, R. Moderski, K. Nalewajko & G. Madejski *„Constraining Emission Models of* ***Luminous Blazar*** *Sources"*, 2009, ApJ, 704, 38

2. M. Janiak, M. Sikora, K. Nalewajko, R. Moderski & G. M. Madejski *„On the origin of the gamma-ray/optical lags in* ***luminous blazars****"*, 2012, ApJ, 760, 129

3. M. Sikora, M. Janiak, K. Nalewajko, G. M. Madejski & R. Moderski *„On the origin of X-ray spectra in* ***luminous blazars****"*, 2013, ApJ, 779, 68

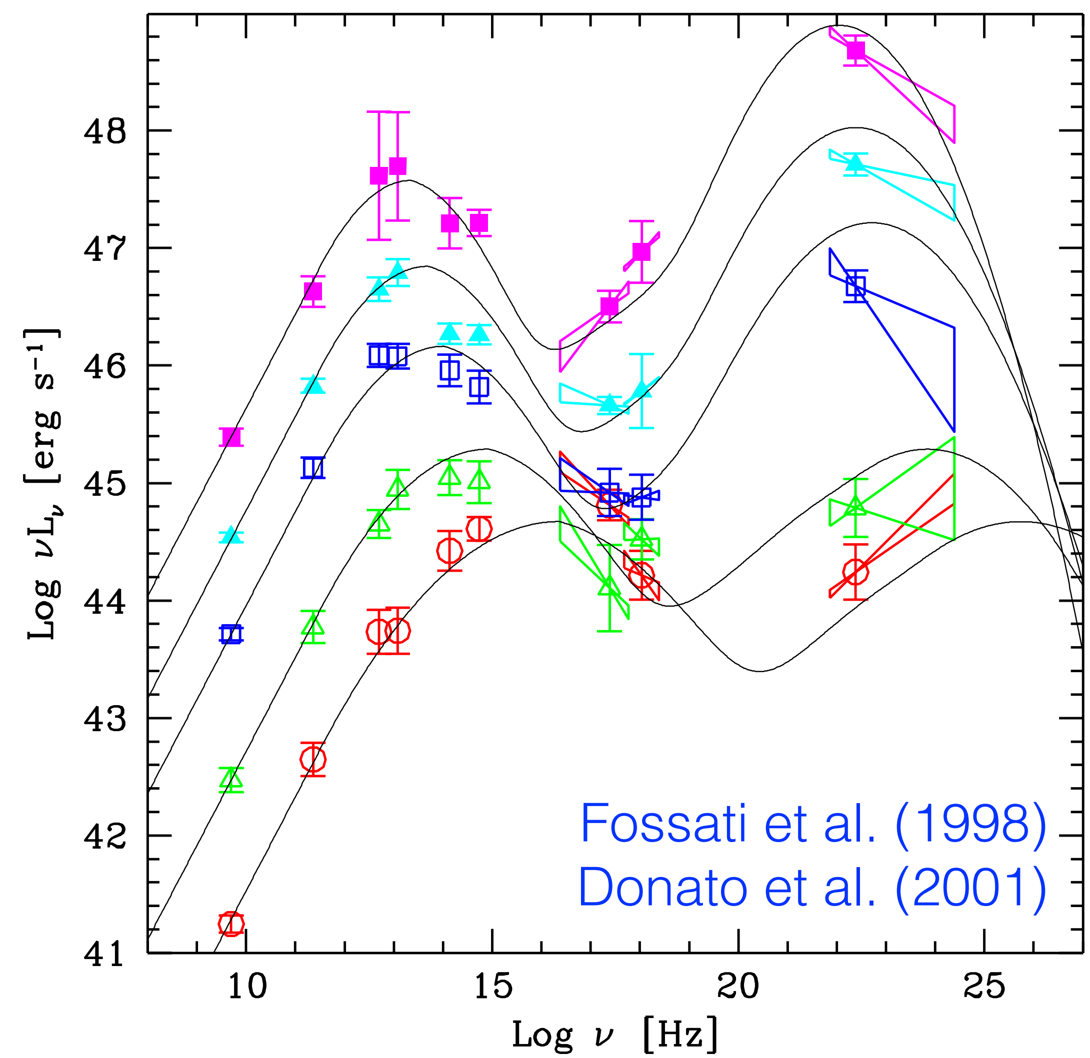
4. K. Nalewajko, M. C. Begelman & M. Sikora *„Constraining the Location of Gamma-Ray Flares in* ***Luminous Blazars****"*, 2014, ApJ, 789, 161

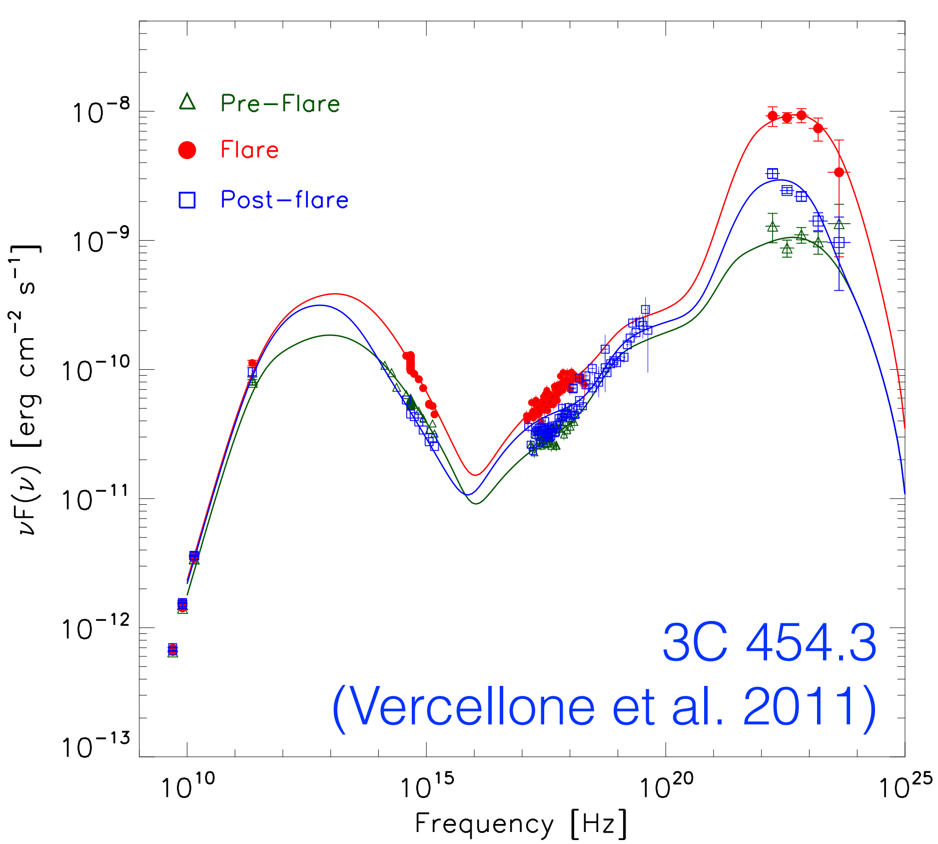
5. K. Nalewajko, M. Sikora & M. C. Begelman *„Reconciling models of* ***luminous blazars*** *with magnetic fluxes determined by radio core shift measurements"*, 2014, ApJ, 796, L5

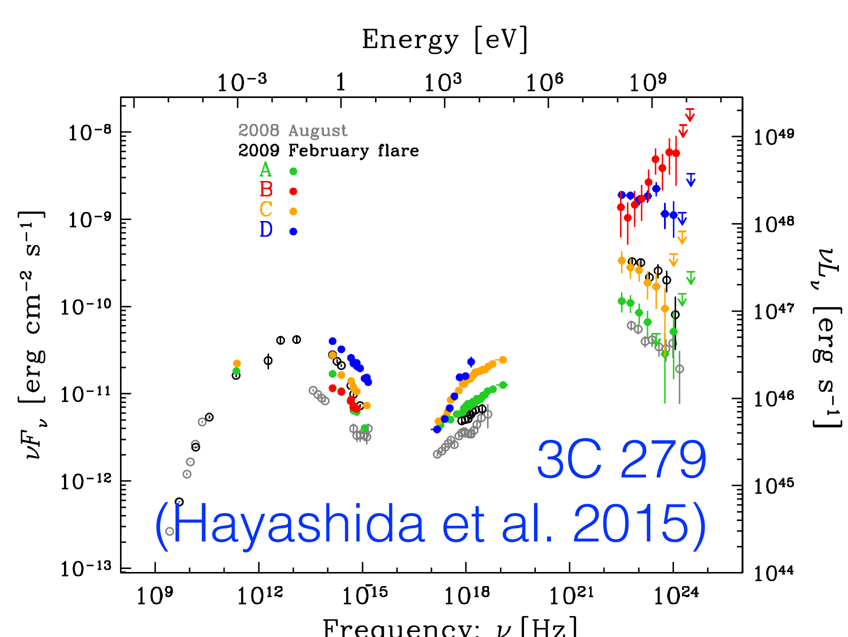
6. M. Janiak, M. Sikora & R. Moderski *"Magnetization of jets in* ***luminous blazars****"*, 2015, MNRAS, 449, 431 **(poster #30)**

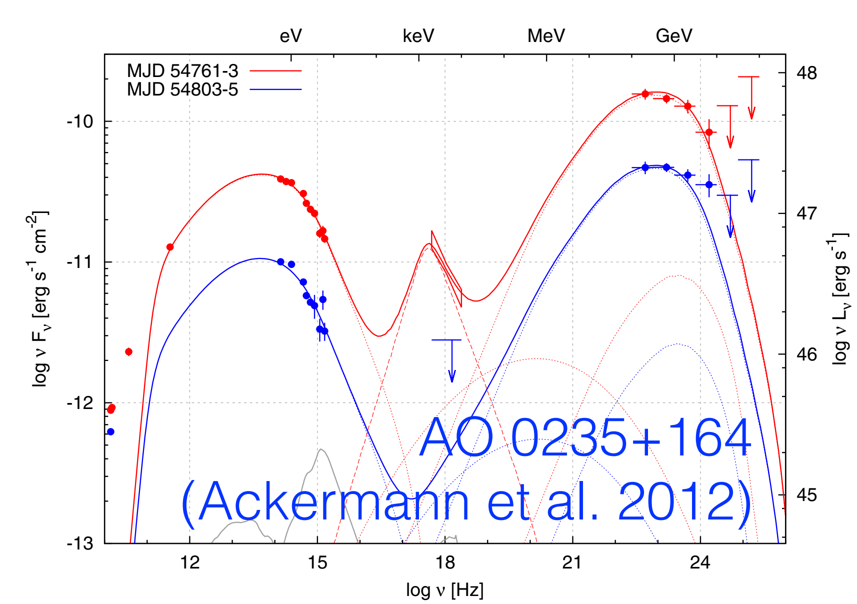
what are luminous blazars?

- flat-spectrum radio quasars (FSRQ)
- low-peaked BL Lac objects (LBLs)
- gamma-ray dominated - observational fact
- external Compton dominated - theoretical paradigm



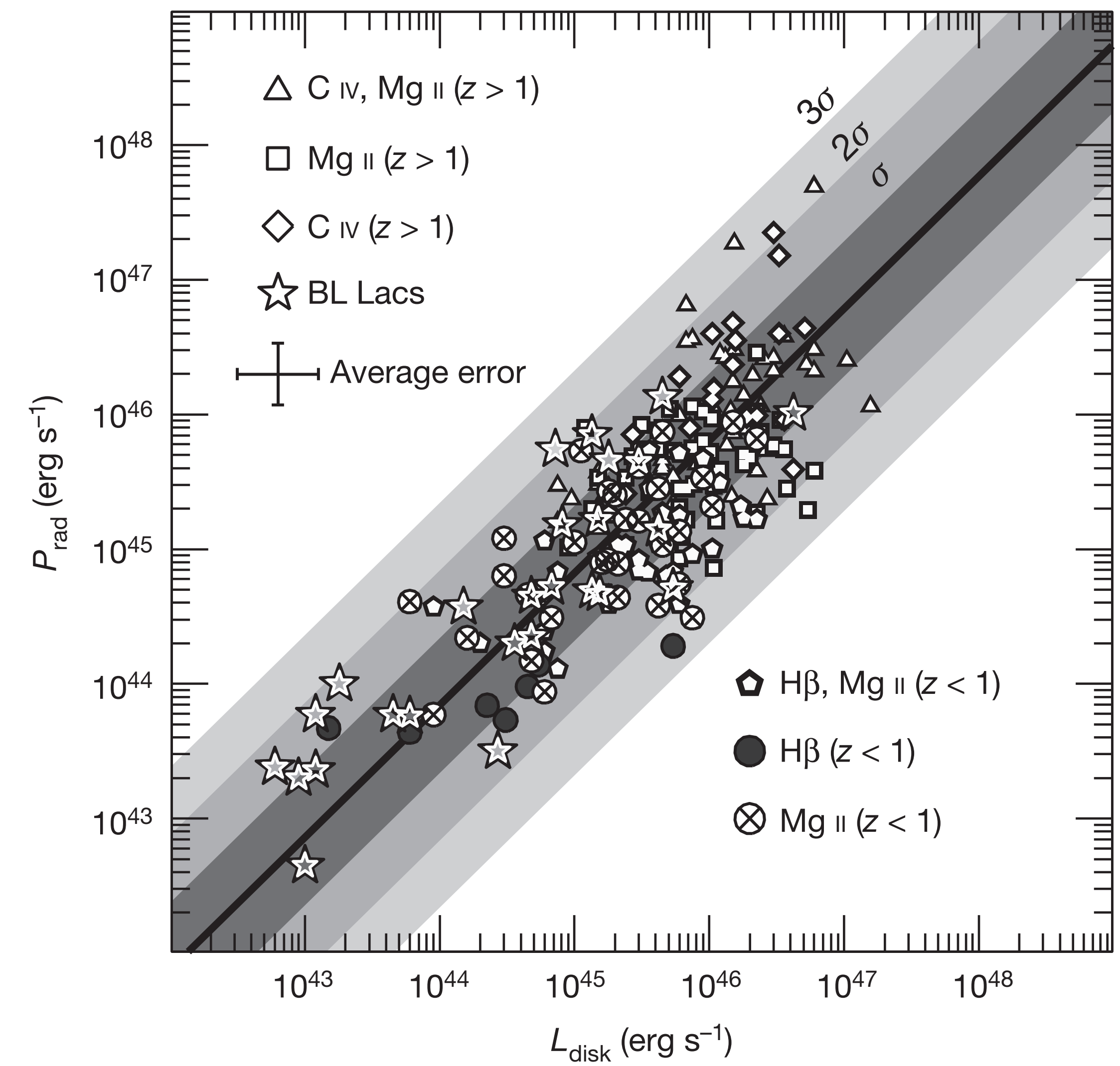






why do we care?

- because they are luminous! (10^{48-50} erg/s)
- very tight energetic requirements
  - ✓ high dissipation efficiency
  - ✓ high radiative efficiency
  - ✓ high fraction of the jet volume
- particularly useful in constraining relativistic particle acceleration



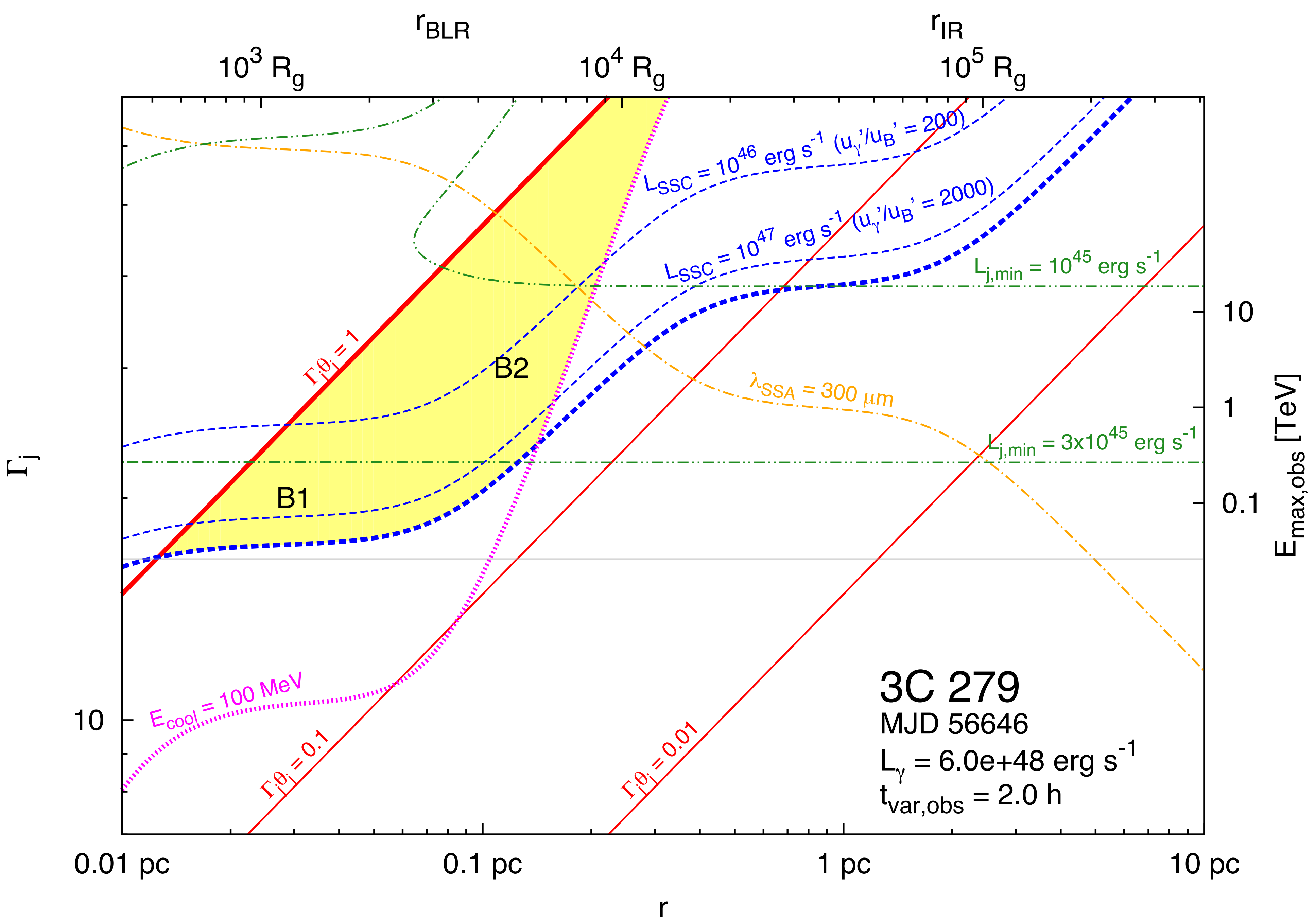
Ghisellini et al. (2014)

current debates

- emission mechanism: leptonic vs. hadronic
  - ✓ leptonic models are 100 times more efficient (Sikora et al. 2009)
  - ✓ hadronic models require accretion paradigm change (Zdziarski & Böttcher 2015), but 1e49 erg/s jet powers may violate observational evidence
  - ✓ TeV blazars may be different (Essey & Kusenko 2013, Cerruti et al. 2014)
- dissipation mechanism: shocks vs. reconnection
  - ✓ shock-in-jet models work well for multifrequency radio flares (F-GAMMA)
  - ✓ reconnection works for a broader range of jet parameters (Sironi, Petropoulou & Giannios 2015)
- location of the blazar zone: < 0.1 pc vs. ~1 pc vs. >10 pc (KN, Begelman & Sikora 2014)
- connection of gamma rays with radio/mm (BU, MOJAVE, F-GAMMA, OVRO, EVN, TANAMI, CARMA et al.)
- origin of (hard) X-rays (Sikora et al. 2013)

parameter space of γ-ray emitting regions

beyond SED modeling to understand parameter degeneracies



collimation

SSC

cooling

SSA

jet power

opacity

$\Gamma\theta < 1$

$L_{SSC} < L_X$

$E_{cool} < 100$ MeV

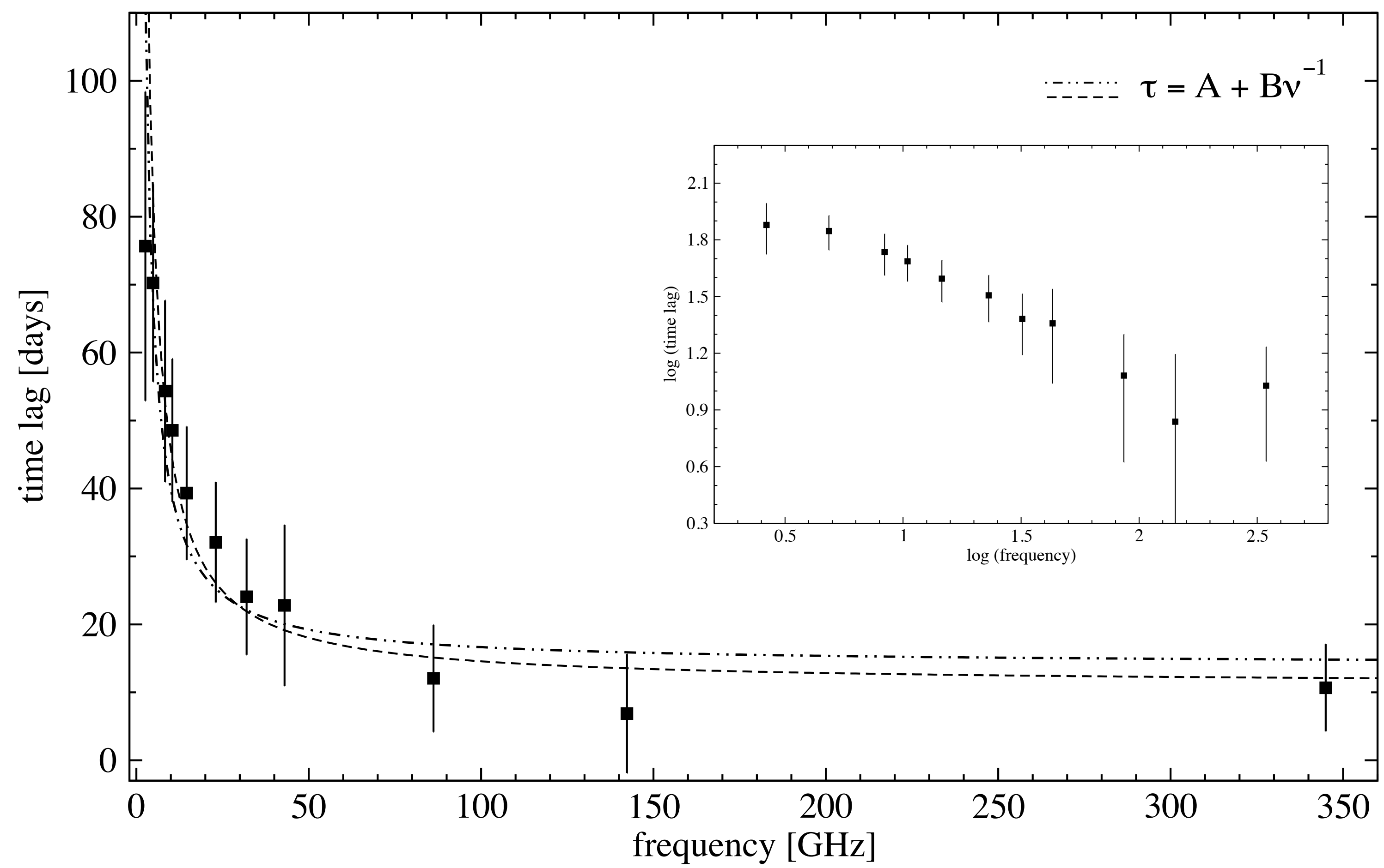
flaring blazars we typically find:

r ~ 0.1-1 pc, $\Gamma > 20$, L_B / L_e ~ 0.01-10, λ_{SSA} ~ 0.2-1 mm

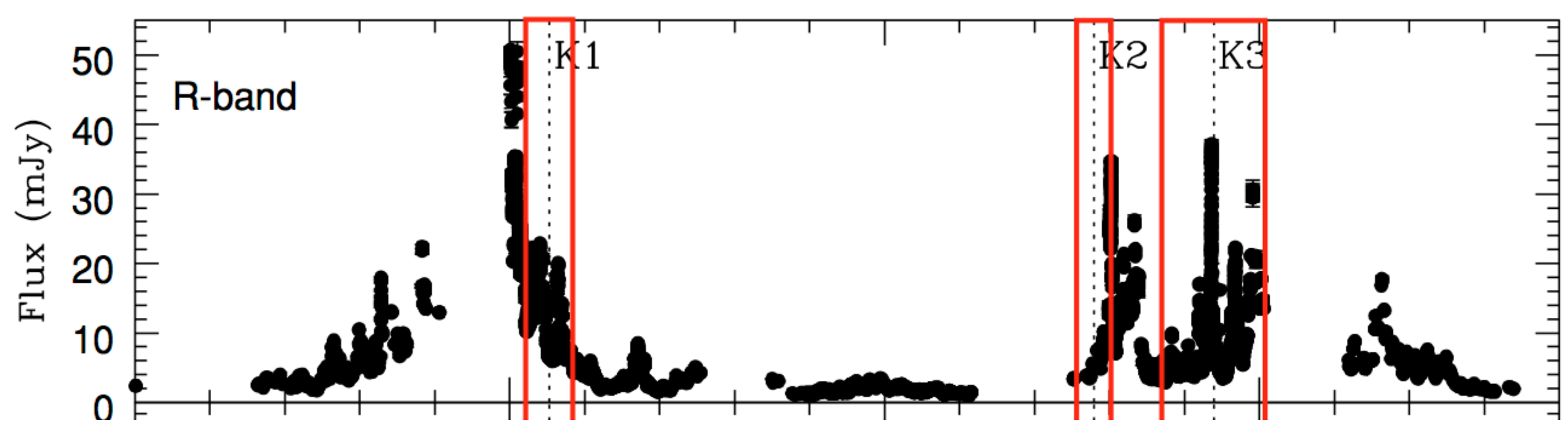
KN, Begelman & Sikora (2014)
Hayashida et al. (2015)

gamma rays vs. radio/mm

- distance scales of order 10 pc often cited from gamma-radio/mm studies
  (but also suggested in Sikora et al. 2008, 2013)
- radio/mm flares are correlated but delayed wrt. gamma-ray flares (Pushkarev et al. 2010, Max-Moerbeck et al. 2014)
  - ✓ ~10 pc at 11 cm
  - ✓ ~5 pc at 2 cm
  - ✓ ~1 pc at 2 mm
    (Fuhrmann et al. 2014)
- connection between gamma-ray flares and superluminal radio knots
  - ✓ 37 +- 21 days at 7 mm
    (S. Jorstad talk yesterday)

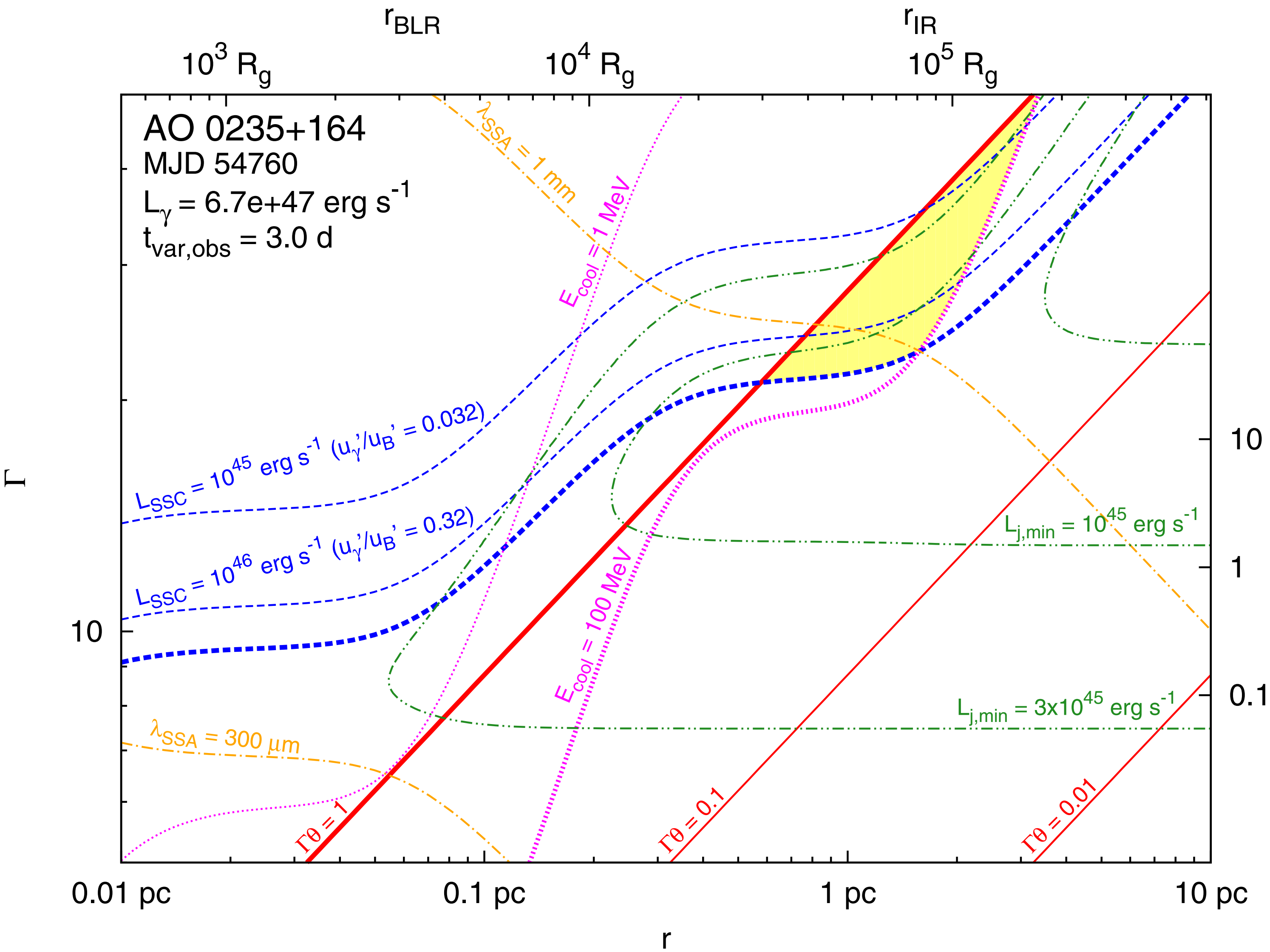


Fuhrmann et al. (2014)

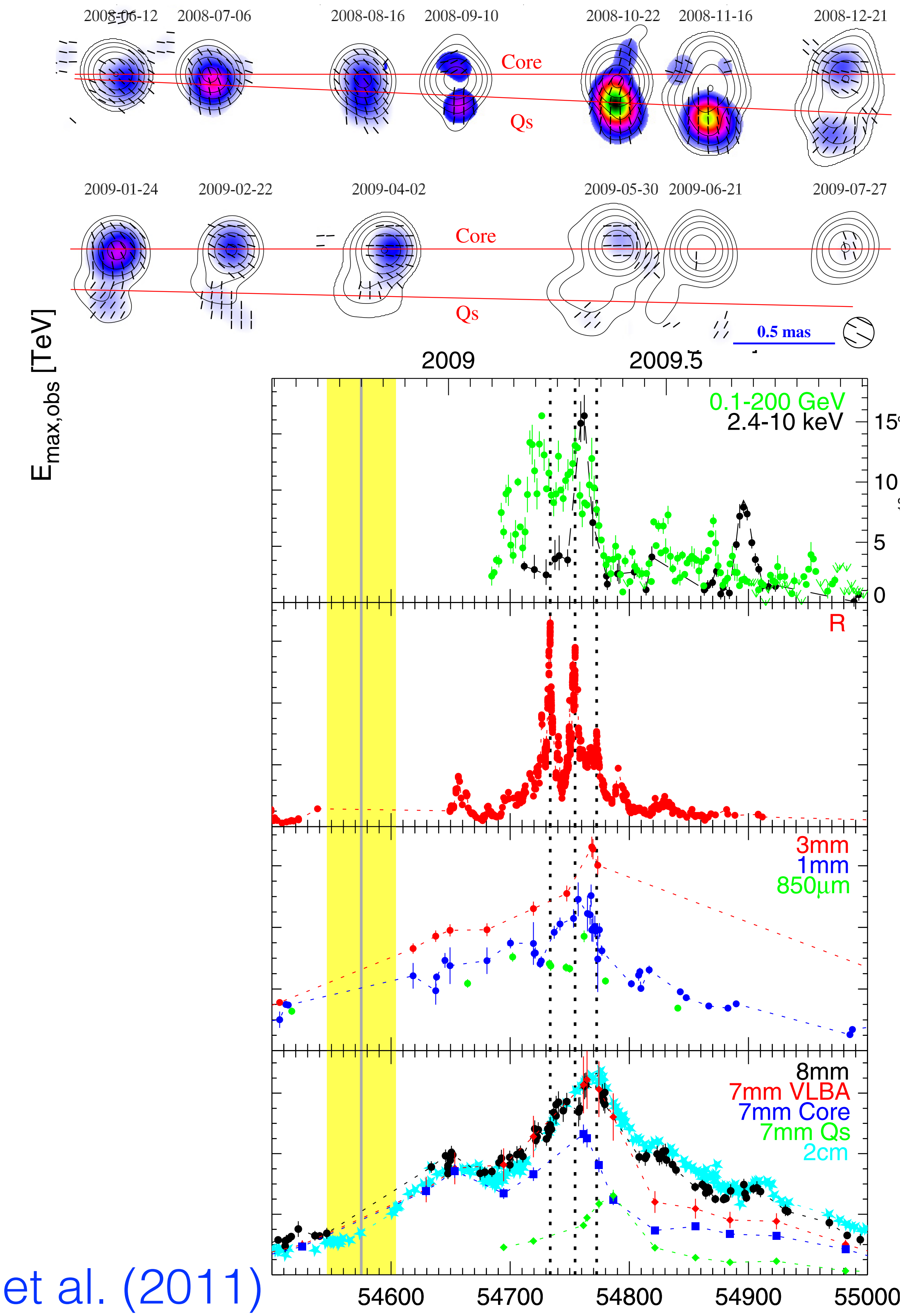


3C 454.3 (Jorstad et al. 2010)

the case of AO 0235+164



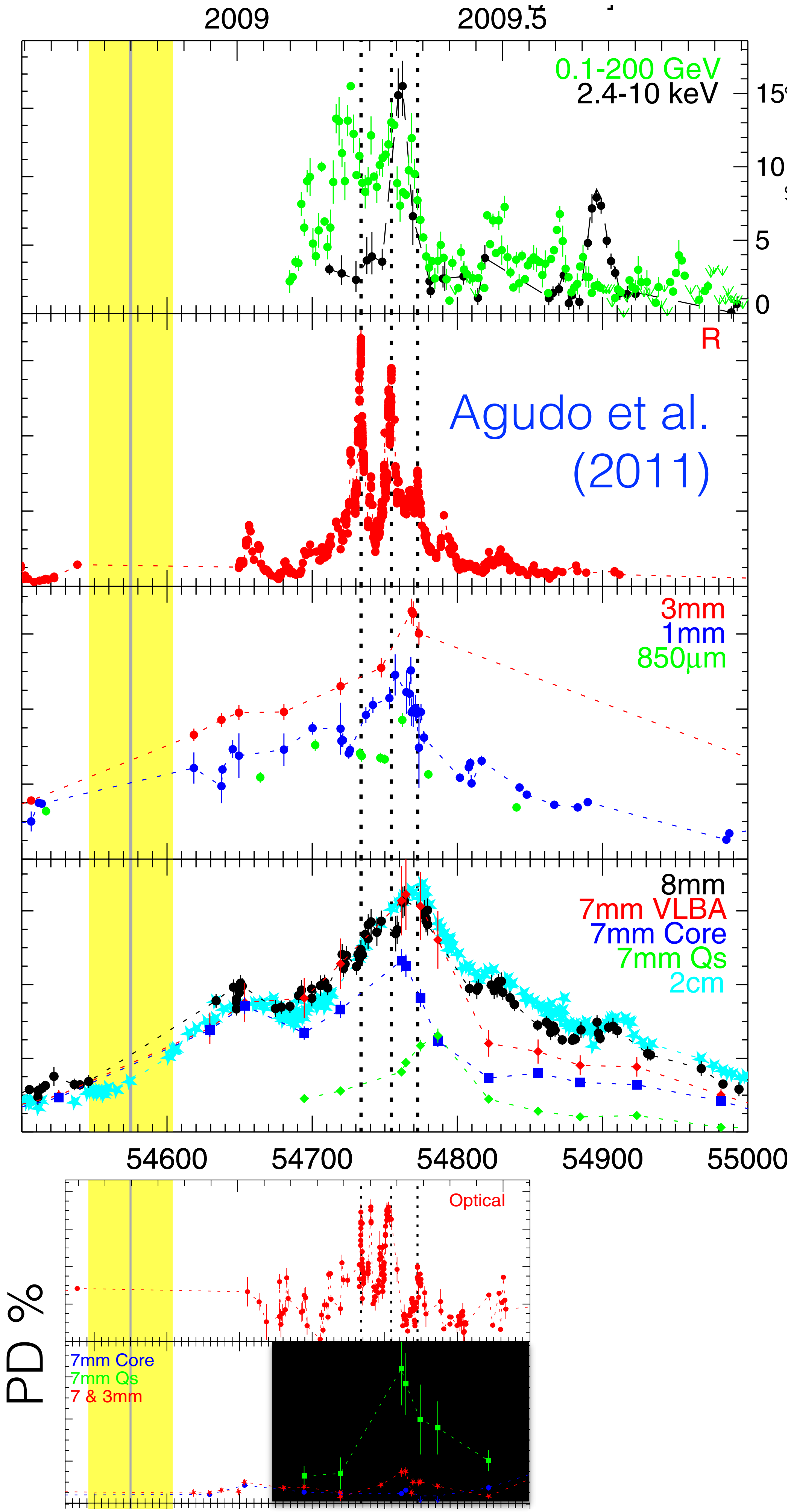
based on Ackermann et al. (2012)
KN, Begelman & Sikora (2014)



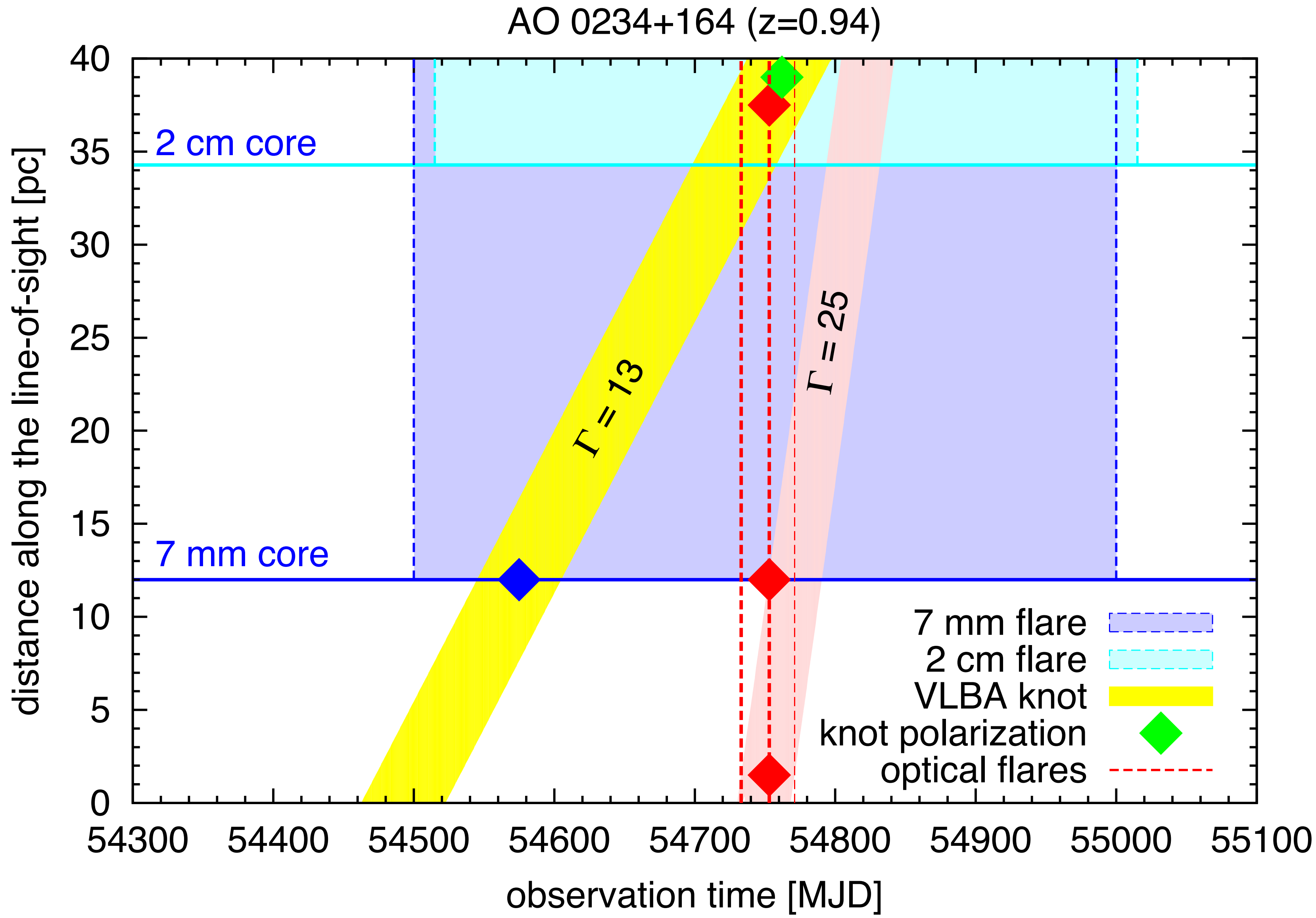
- gamma-ray t_var ~ 3 days
  r ~ 1 pc, Γ > 20, 1 mm photosphere

- 7 mm t_var ~ 80 days
  r ~ 7 pc, β_{app} ~ 13

Agudo et al. (2011)



the case of AO 0235+164



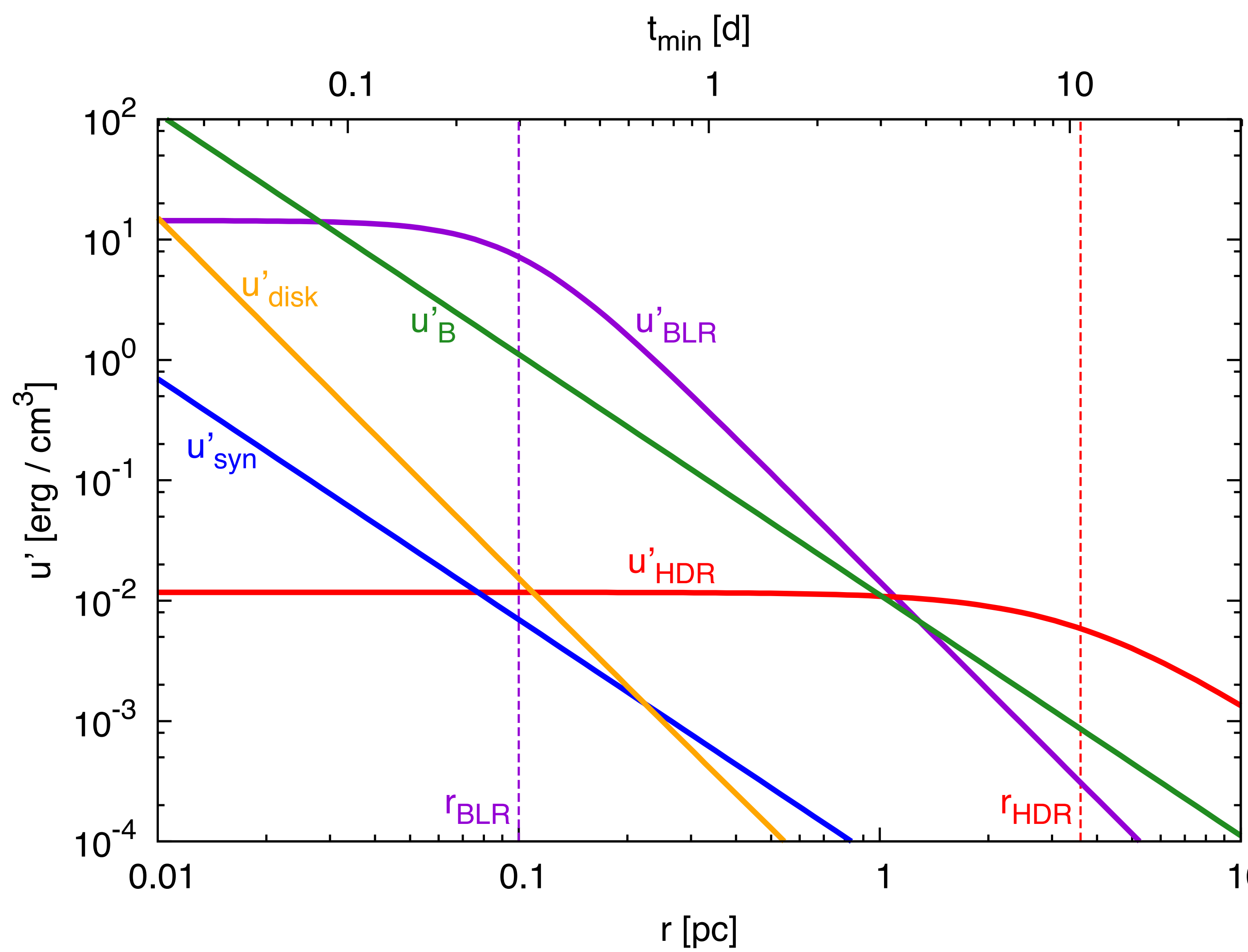
- tiny relative velocity between the jet and the photons: (10 pc) / $c\Gamma^2$ ~ 30 days
- polarization event in 7 mm knot with 1-pc optical/γ-ray flare requires Γ ~ 40
- prolonged cm/mm flare: jet power increase

updated from KN, Begelman & Sikora (2014)

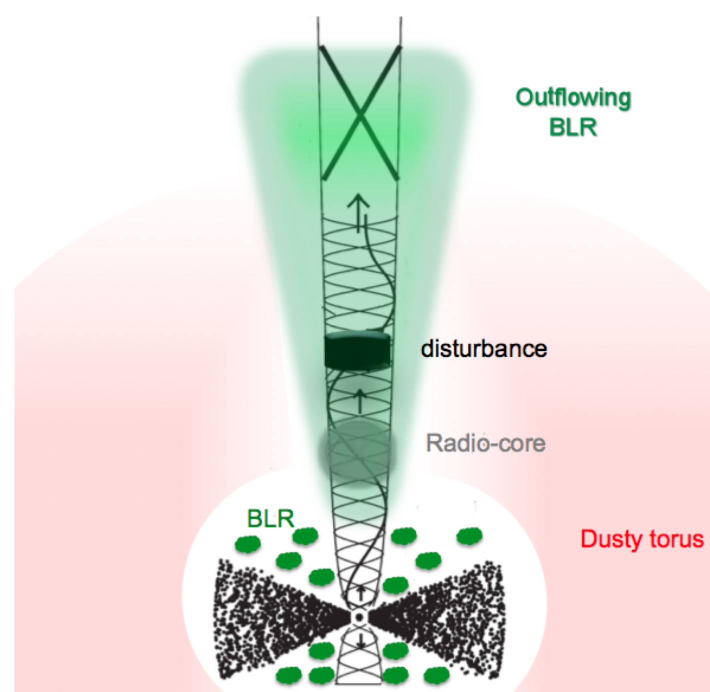
external radiation fields

- energy densities of magnetic field and radiation fields, and hence radiative efficiency decrease with distance

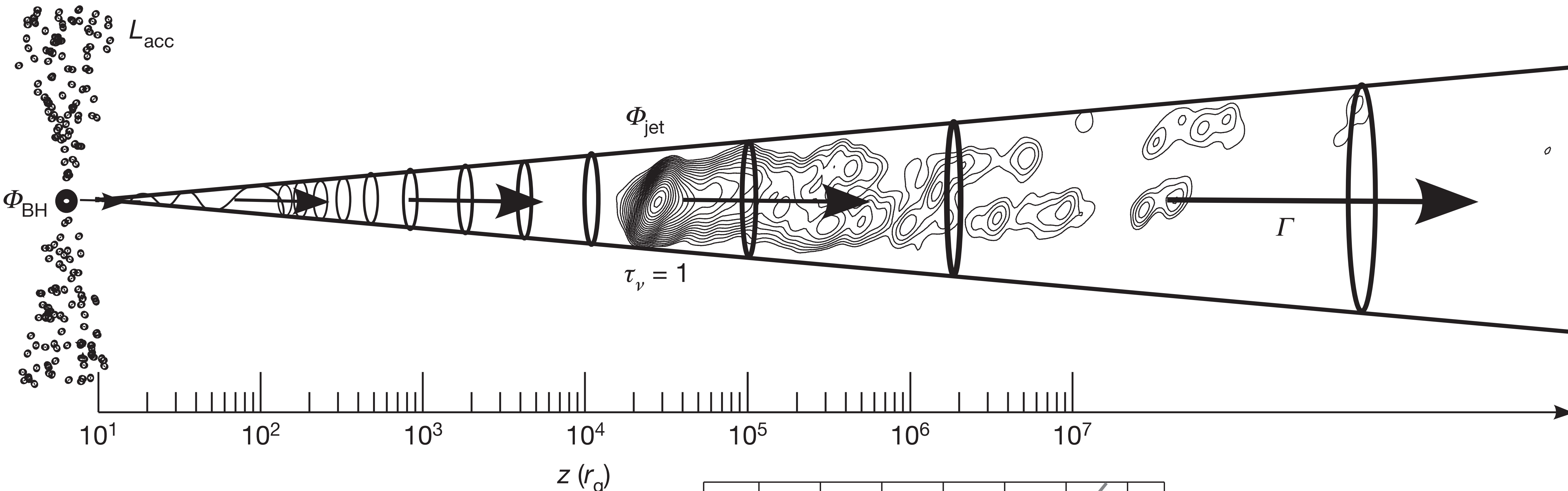
- additional radiation fields at large distances:
  - ✓ Mach disk (A. Marscher)
  - ✓ extended BLR (J. Leon-Tavares)

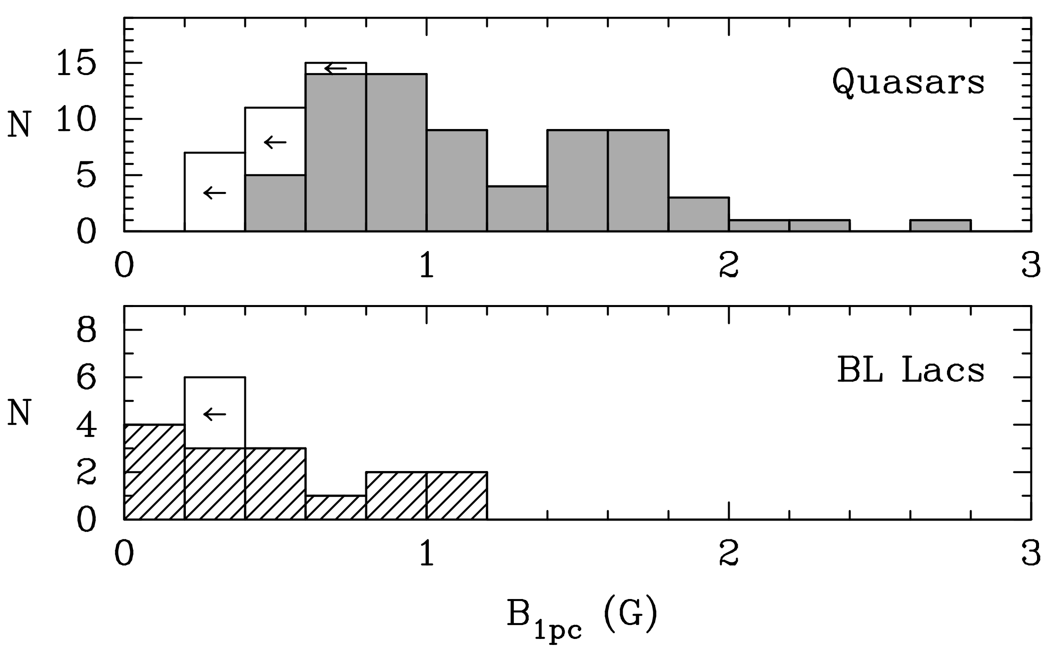


Sikora et al. (2009)

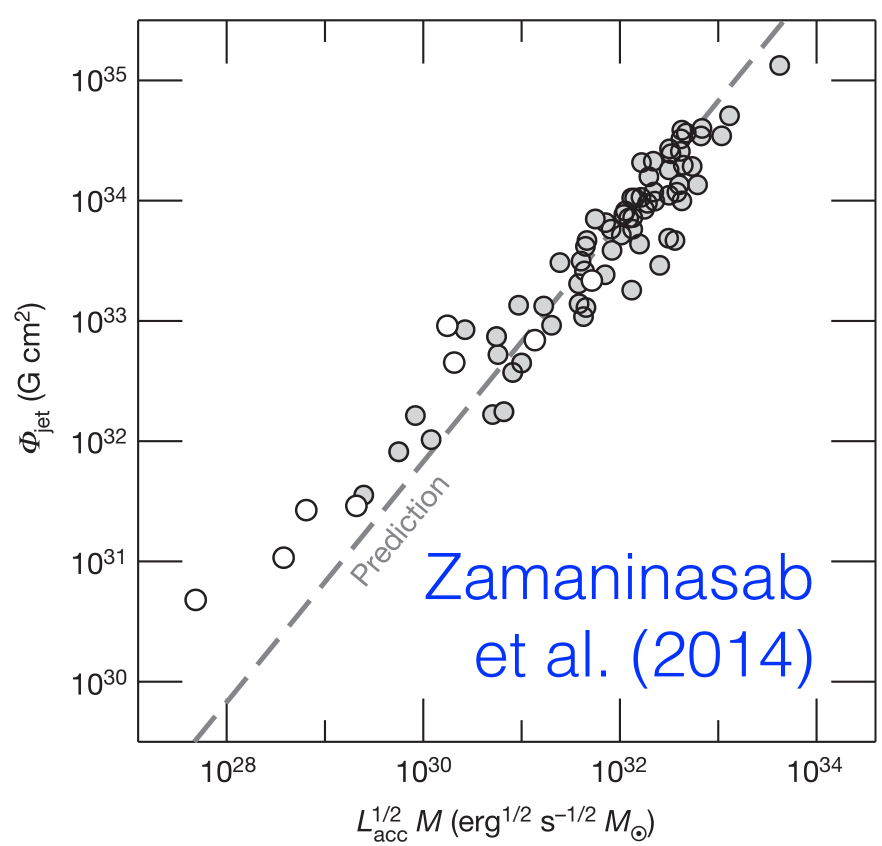


jet magnetic fields from core-shift measurements





Pushkarev et al. (2012)



Zamaninasab et al. (2014)

- consistent with MADs
- consistent with synchrotron luminosities?

Compton dominance

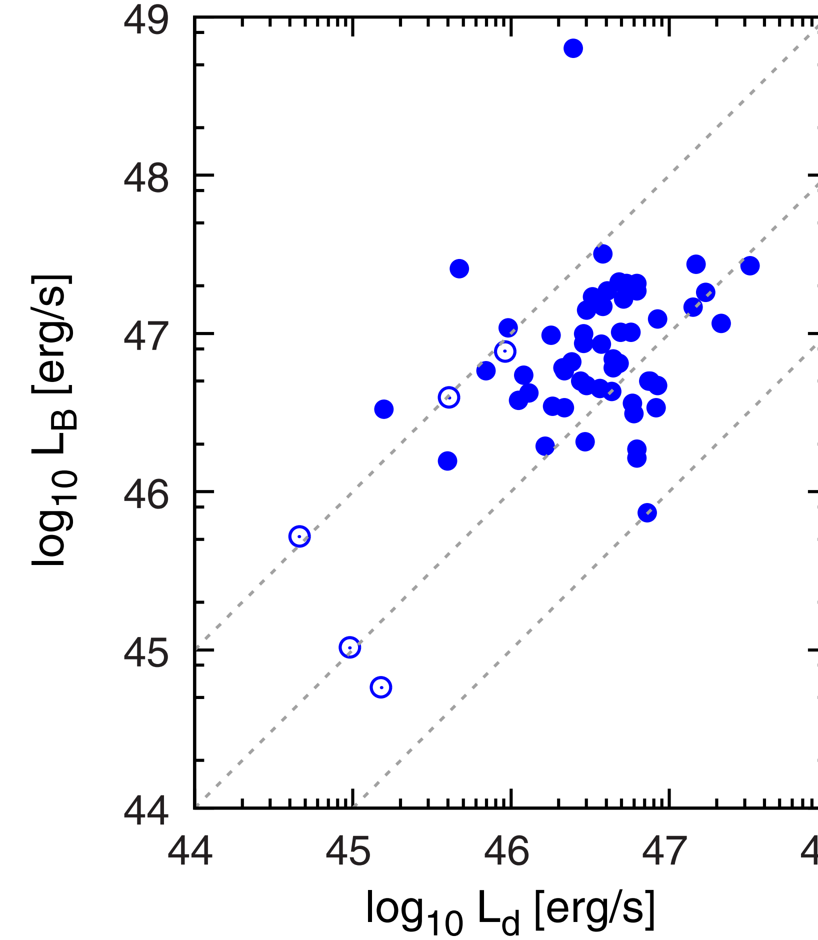
collimation parameter

accretion disk luminosity

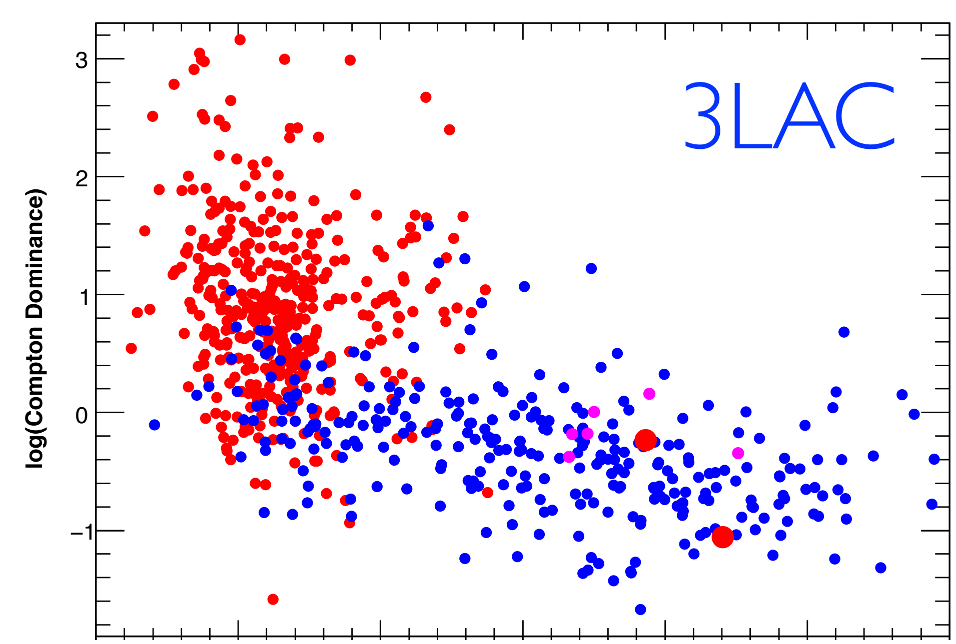
$$L_\gamma / L_{syn} = q = \left(\frac{\zeta}{0.005}\right)\left(\frac{\Gamma}{20}\right)^2 (\Gamma\theta_j)^2 \left(\frac{L_d}{L_B}\right)$$

external radiation scaling factor

magnetic jet power



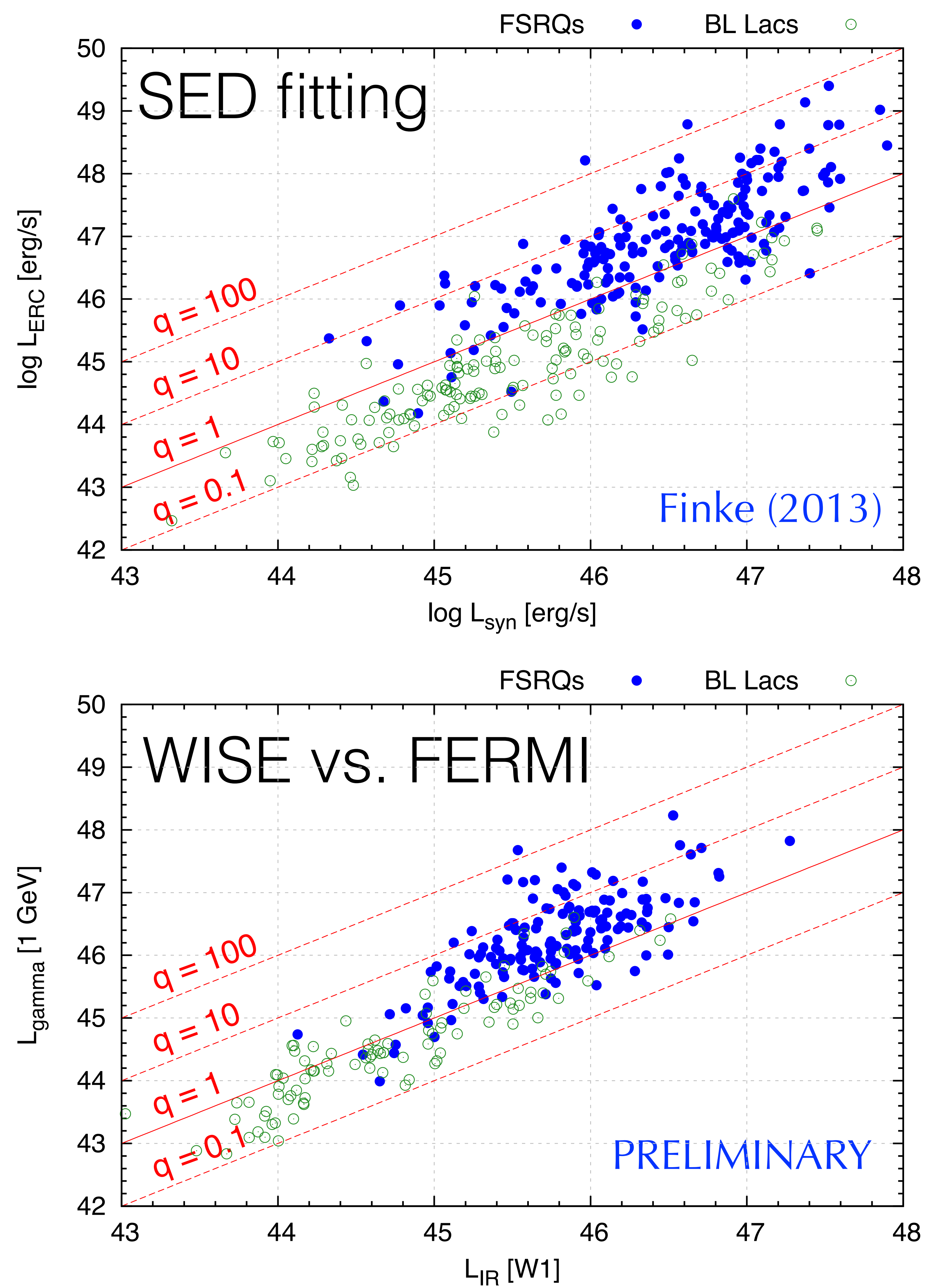
- $L_d \sim L_B$ (Zamaninasab et al. 2014)
- $q > 10$ for flaring FSRQs
- see also Zdziarski et al. (2014)



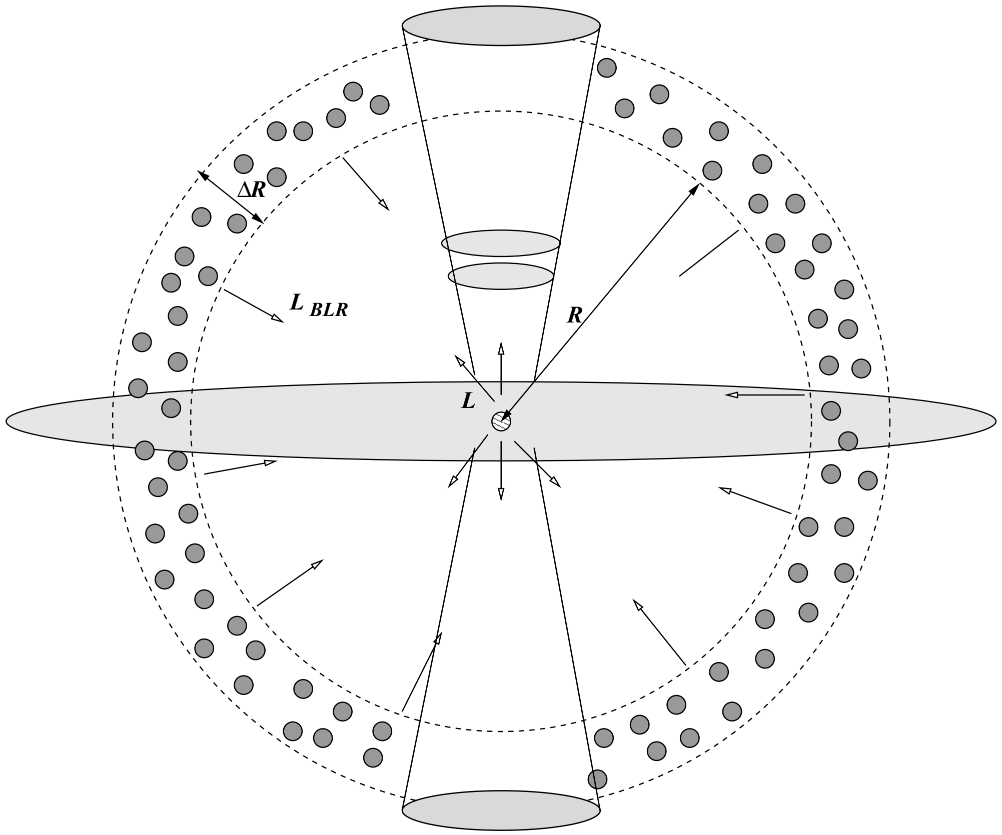
KN, Sikora & Begelman (2014)

L_{syn} vs. L_{ERC}

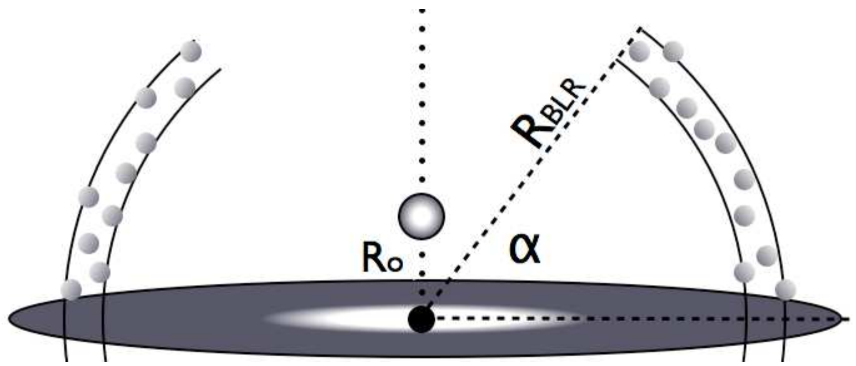
- typical q:
  1-10 for FSRQs
  0.1-1 for BL Lacs
- a few FSRQs with q < 1
- higher L_{syn} from SED fitting
- similar L_γ for BL Lacs with both methods



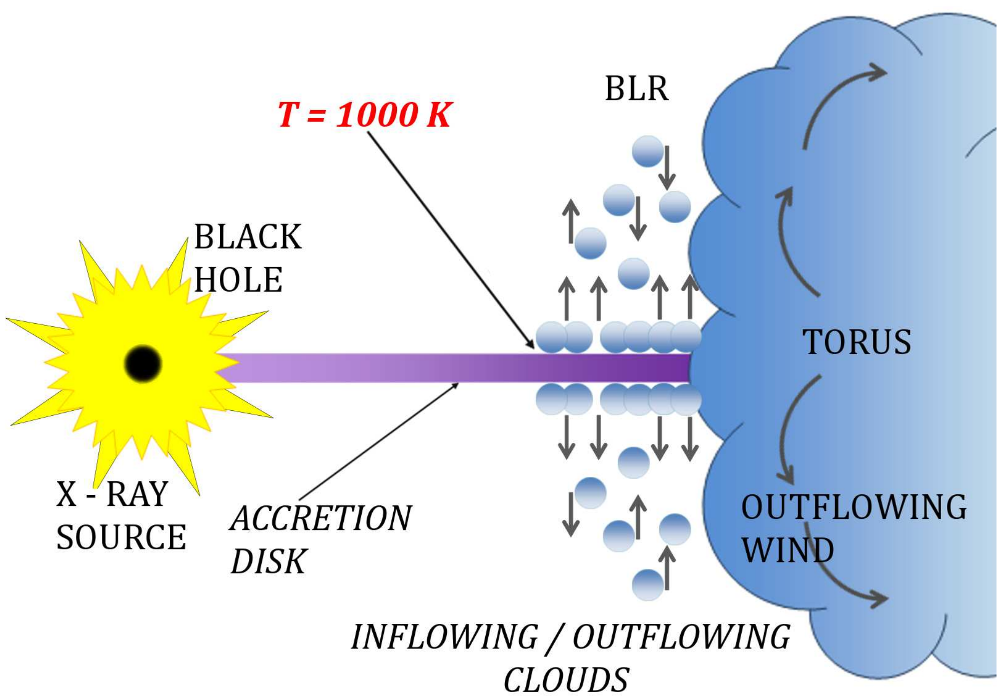
broad line region geometry



Tavecchio & Ghisellini (2009)



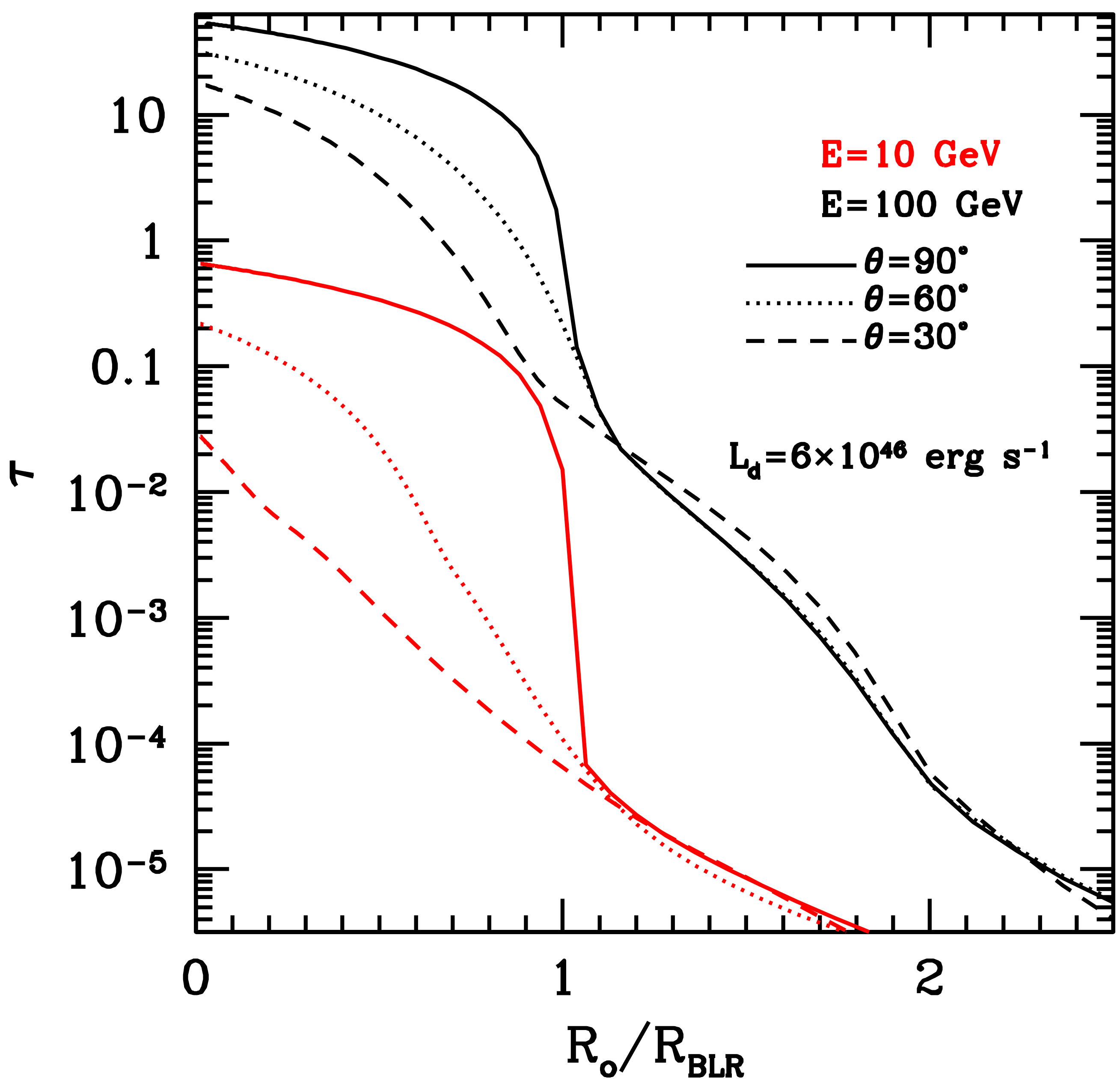
Tavecchio & Ghisellini (2012)



Czerny et al. (2014)

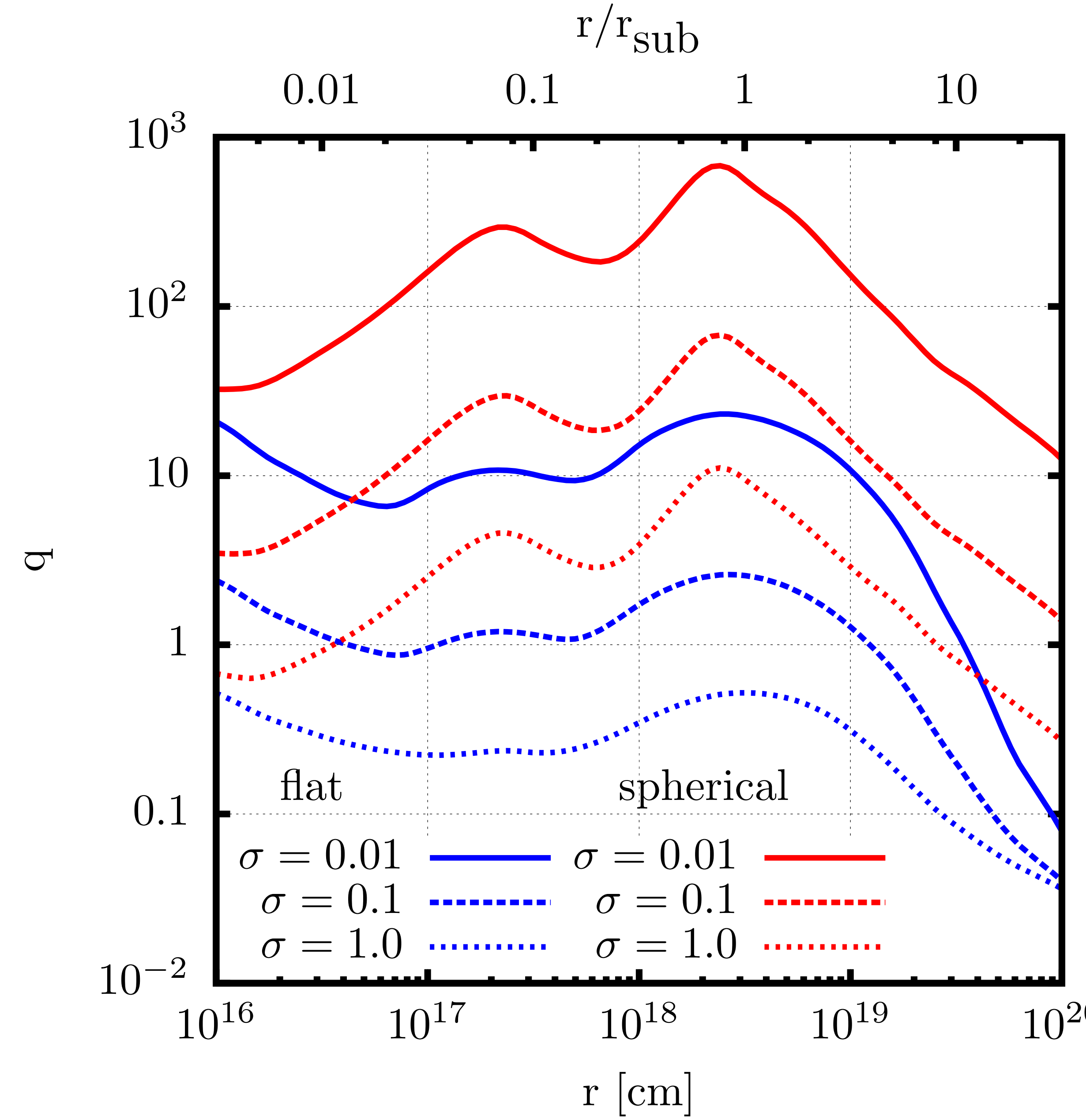
consequences of flat BLR

reduced gamma-ray opacity



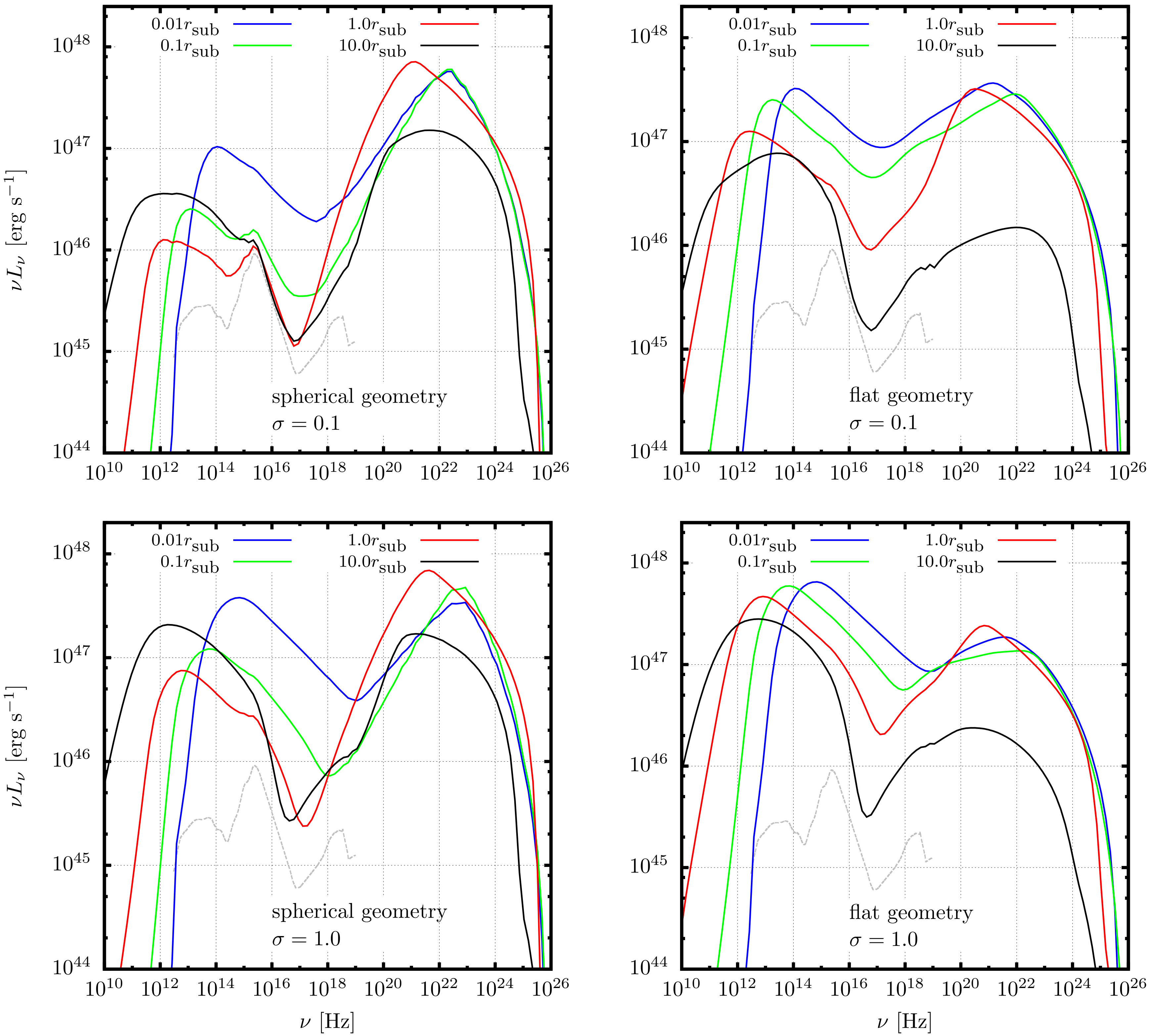
Tavecchio & Ghisellini (2012)

reduced Compton dominance



Janiak, Sikora & Moderski (2015)

constraining jet magnetization

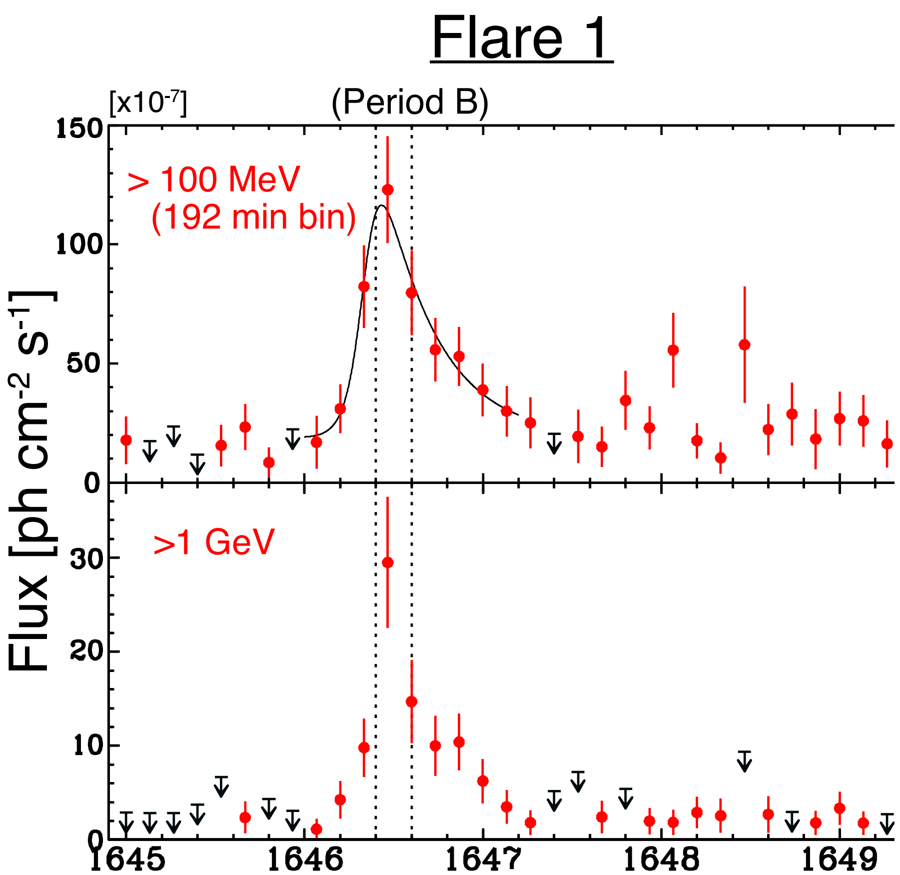


Janiak, Sikora & Moderski (2015)

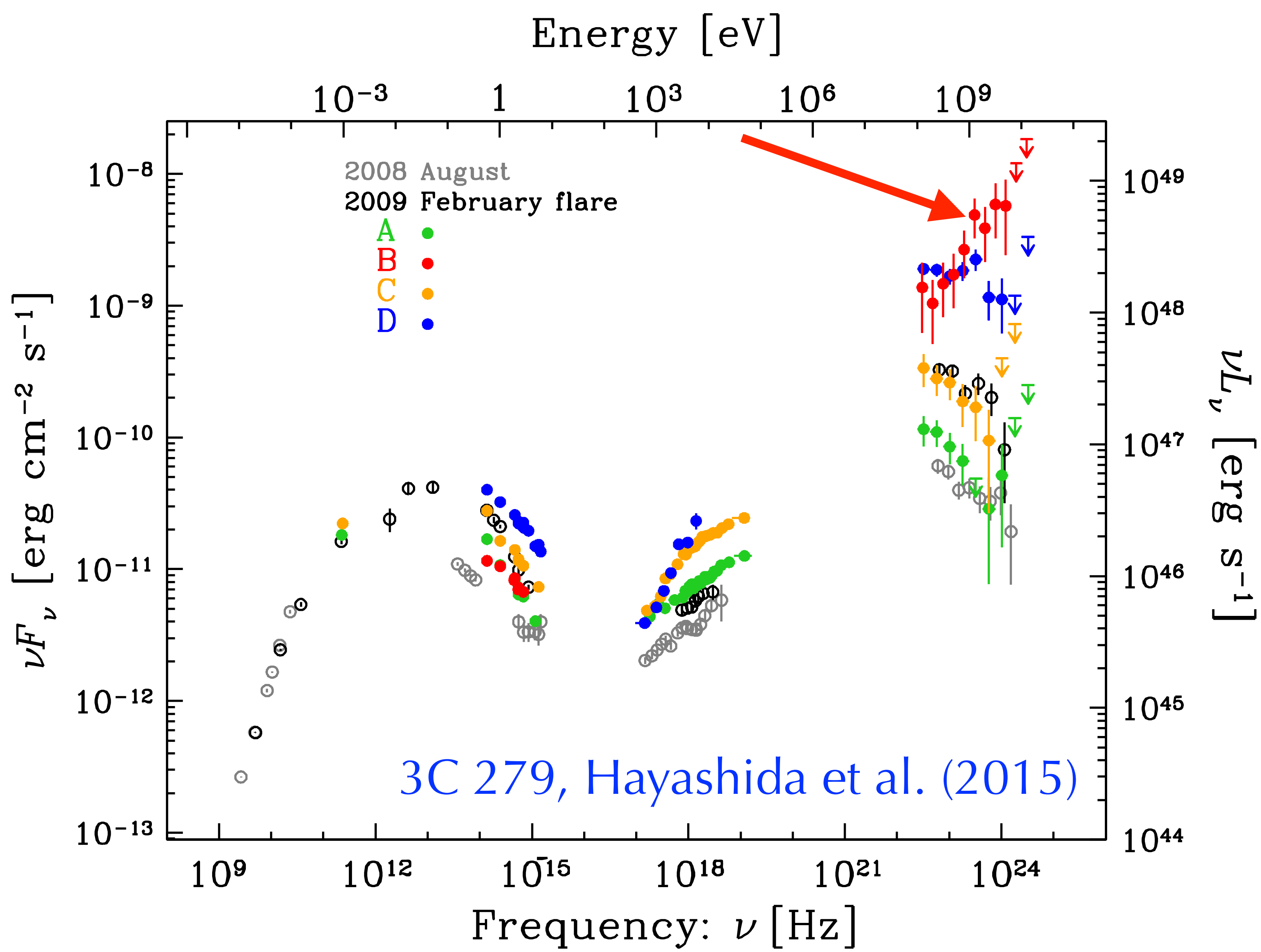
- consider powerful jet in typical radiation environment
- $\sigma = L_B / L_{kin} = 1$ predicts $q < 1$ at $L_{syn} \sim 10^{47}$ erg/s
- if that is not observed, there is no emission from high-σ regions (cf. Sironi et al. 2015)

see poster 30 by M. Janiak

extreme γ-ray flare in 3C 279



severe departure from equipartition (particle-dominated)

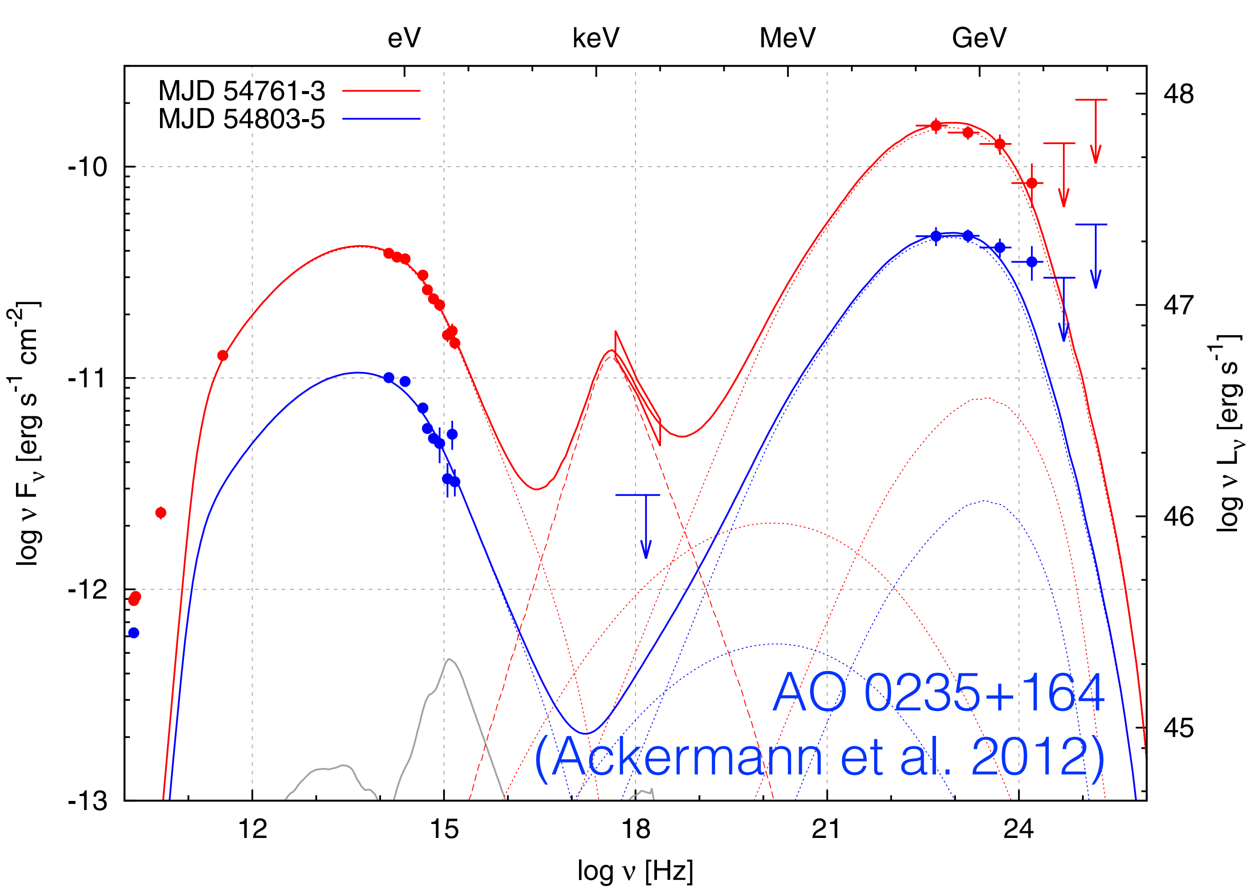


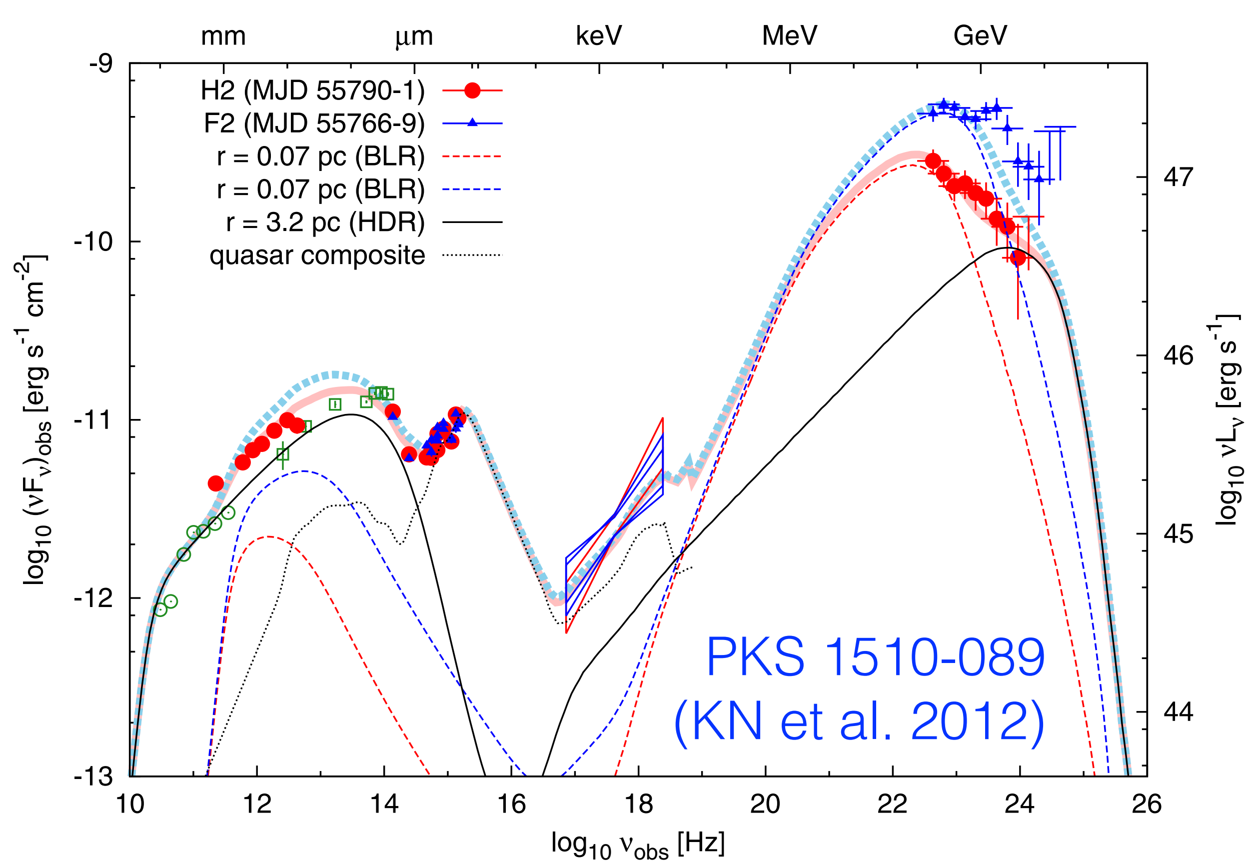
- L_γ = 6e48 erg/s
- t_{var} = 2h
- Γ_{ph} = 1.7
- q > 300
- $L_B / L_j < 10^{-4}$

the origin of X-ray emission

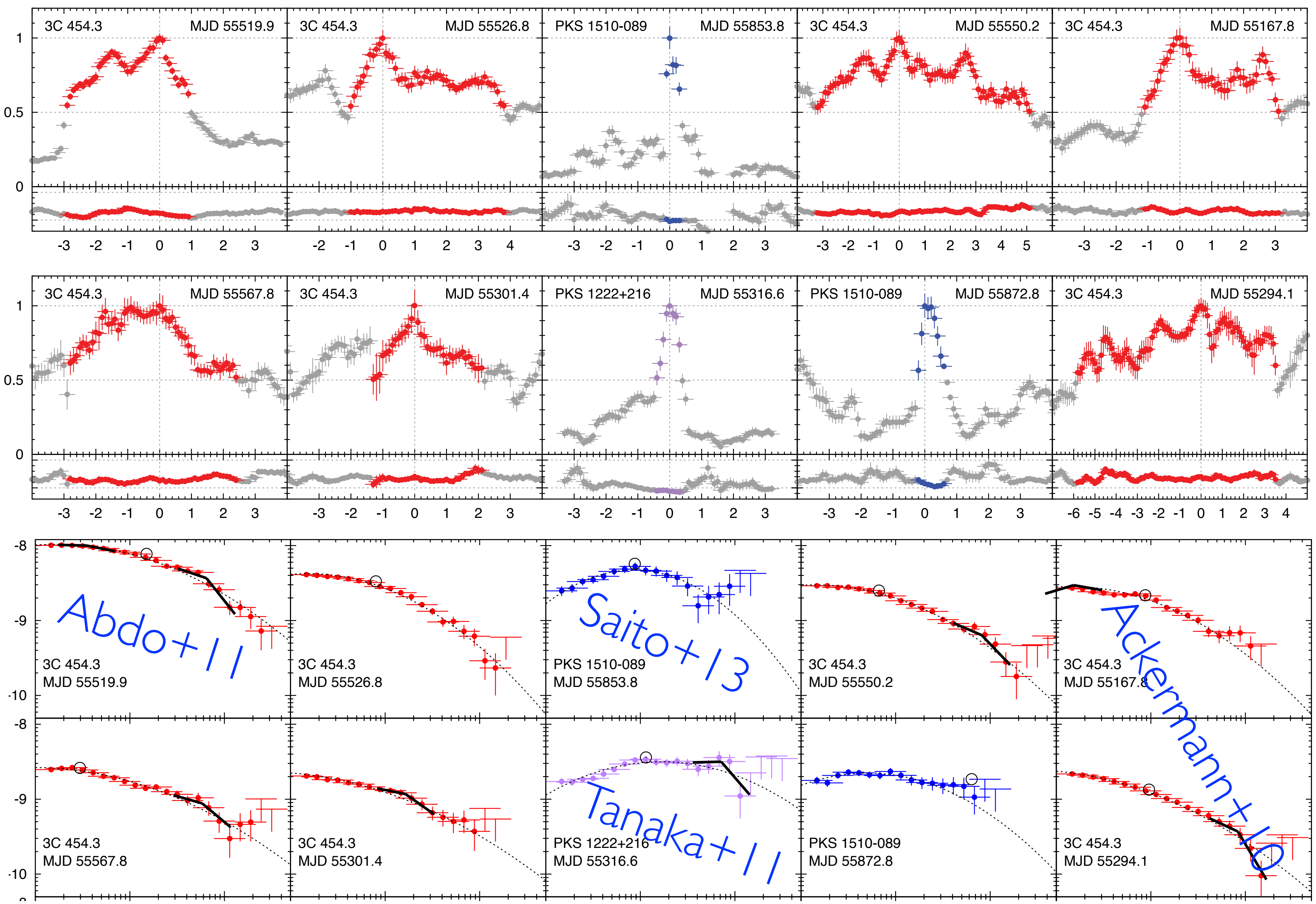
- X-ray emission in FSRQs could be due to:
  - ✓ SSC
  - ✓ ERC (low-E tail)
  - ✓ coronae/jet base

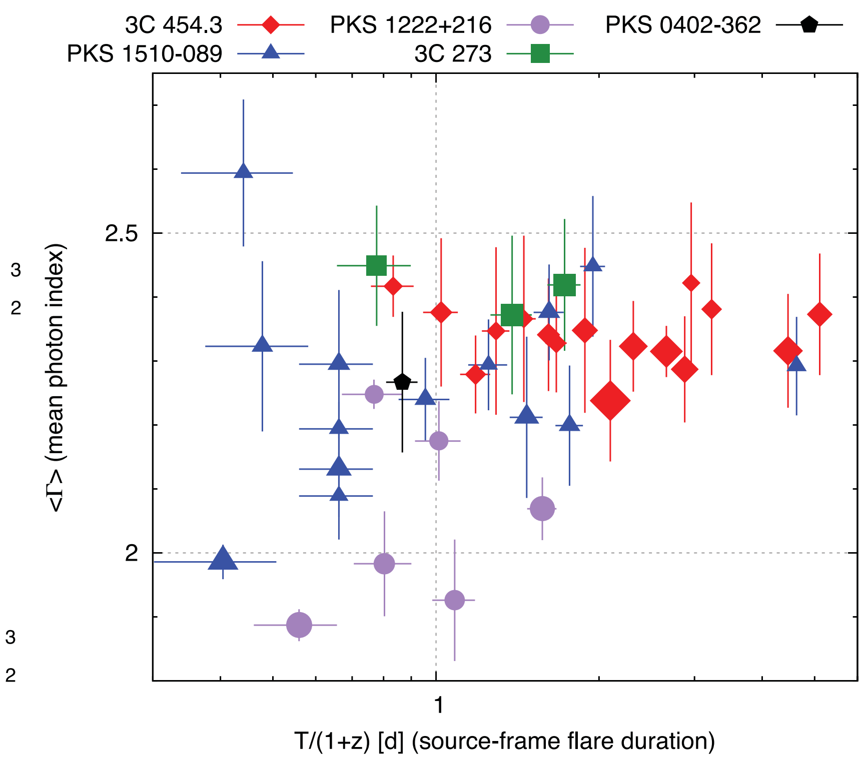
- the hardest X-ray spectra of FSRQs: $\alpha_X \sim 0.2$ (Sikora et al. 2009)
- strong electron-proton coupling can lead to even harder spectra (Sikora et al. 2013)
- need more NuSTAR data on FSRQs

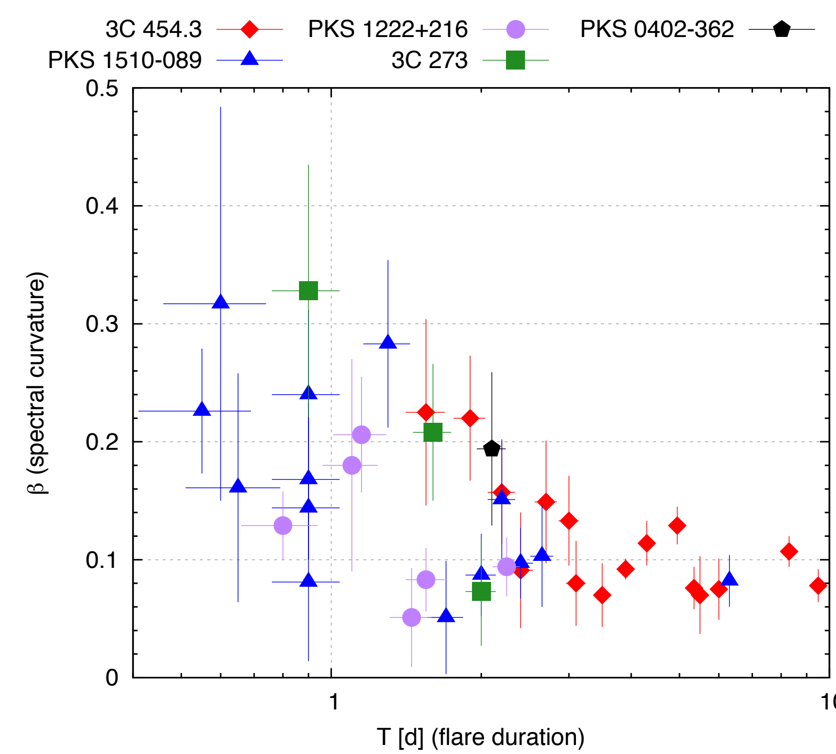




the brightest γ-ray flares of blazars



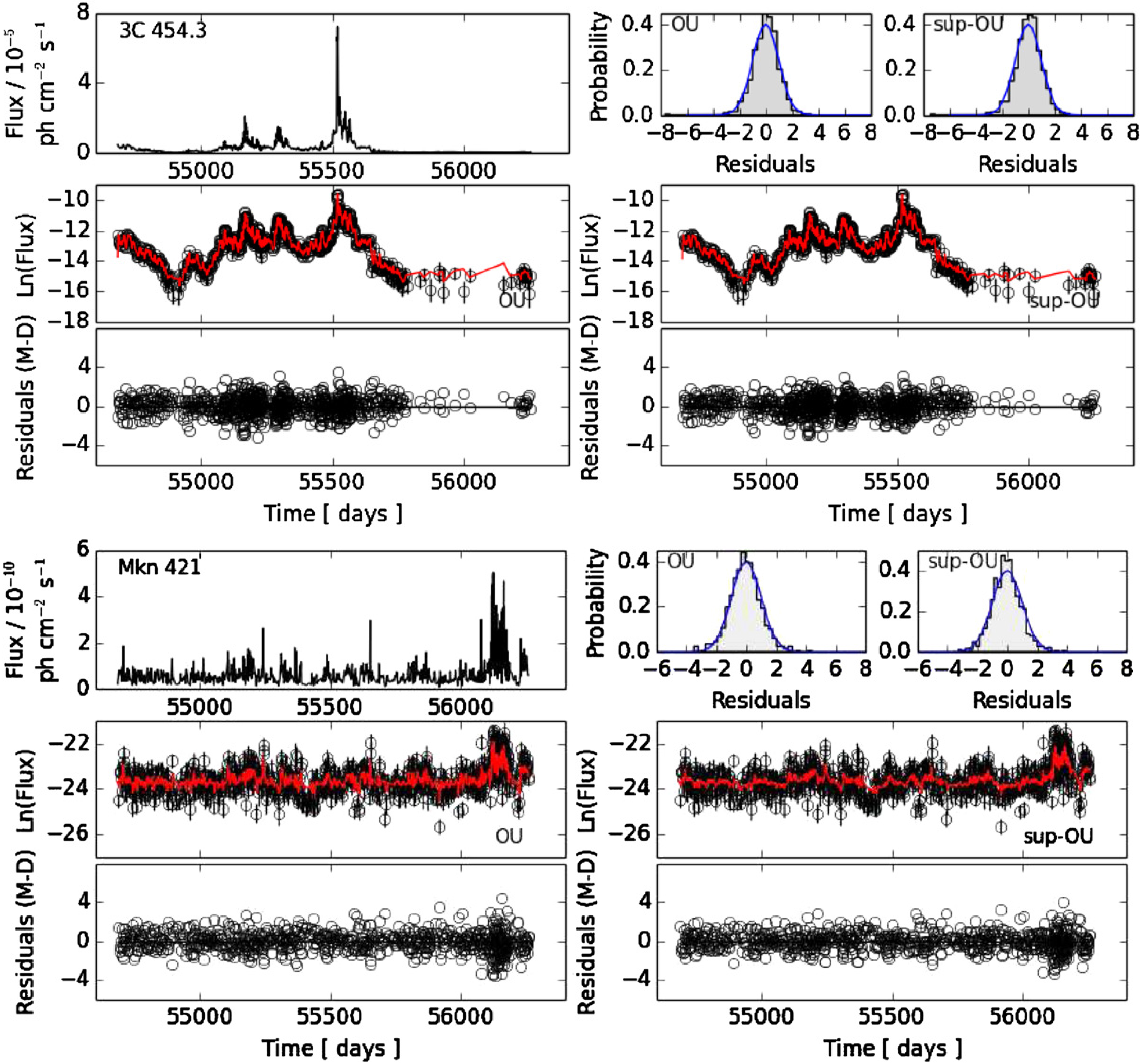




- very short flares (<1 day) have harder and more curved spectra
- systematic difference between 3C 454.3 and PKS 1510-089 (or PKS 1222+216)?
- no systematic spectral breaks

KN (2013), Kohler & KN (2015)

stochastic modeling of blazars variability



- 13 blazars with 4-year adaptive Fermi/LAT light curves
- variability modeling with Ornstein–Uhlenbeck (OU) process, and superpositions (sup-OU)
- good description of 3 sources
- PSD indices cluster around 1

Sobolewska et al. (2014)

see poster 76 by M. Sobolewska

summary

- luminous blazars can be robustly constrained in the leptonic paradigm
- pc-scale location of gamma-ray flares can be reconciled with the radio/mm activity
- low magnetization of gamma-ray emitting regions
- possible tension between core-shift magnetic fields and high Compton dominance
- emerging class of short/hard gamma-ray flares in FSRQs
- more insight possible from NuSTAR, sub-mm variability, polarization (including X-rays), CTA, MeV telescope

thank you for attention