# Minimum *e* Lorentz factor and matter content of jet in blazars


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# 1. Why

**minimum electron Lorentz factor ?**

**Crucial for jet power estimation and constraint on jet matter content!**

$$P_{\rm jet} \propto \gamma_{\rm min}^{1-p}$$

$$N_e \propto \gamma_e^{-p}$$

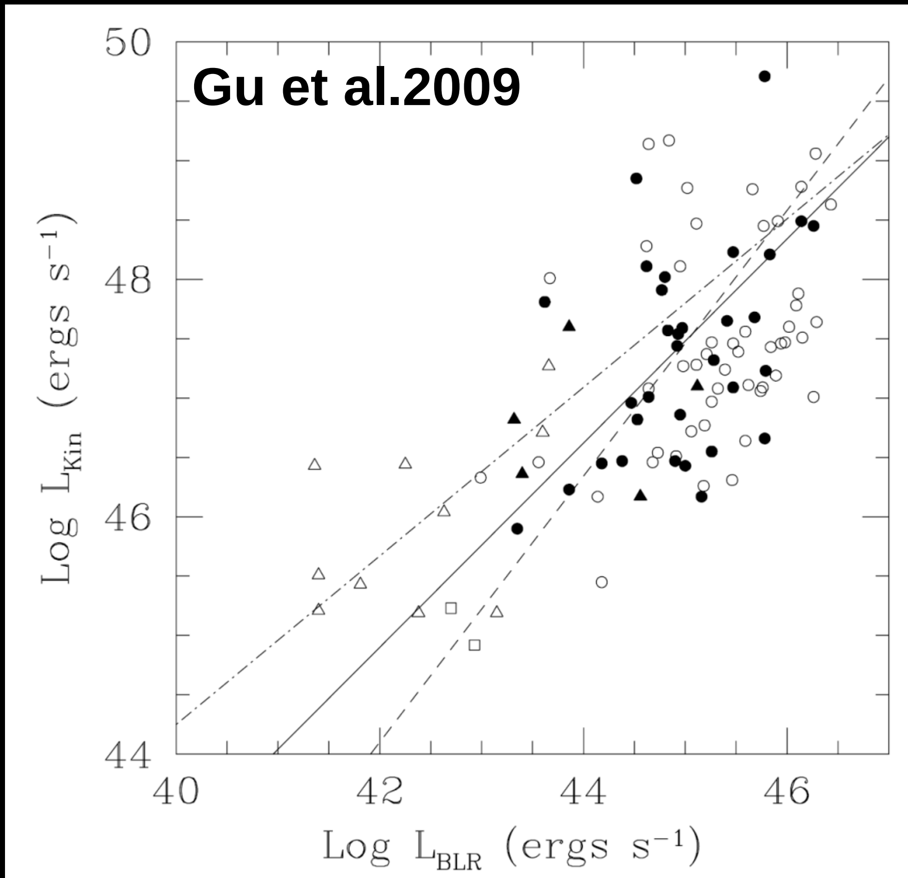
# Jet kinetic power

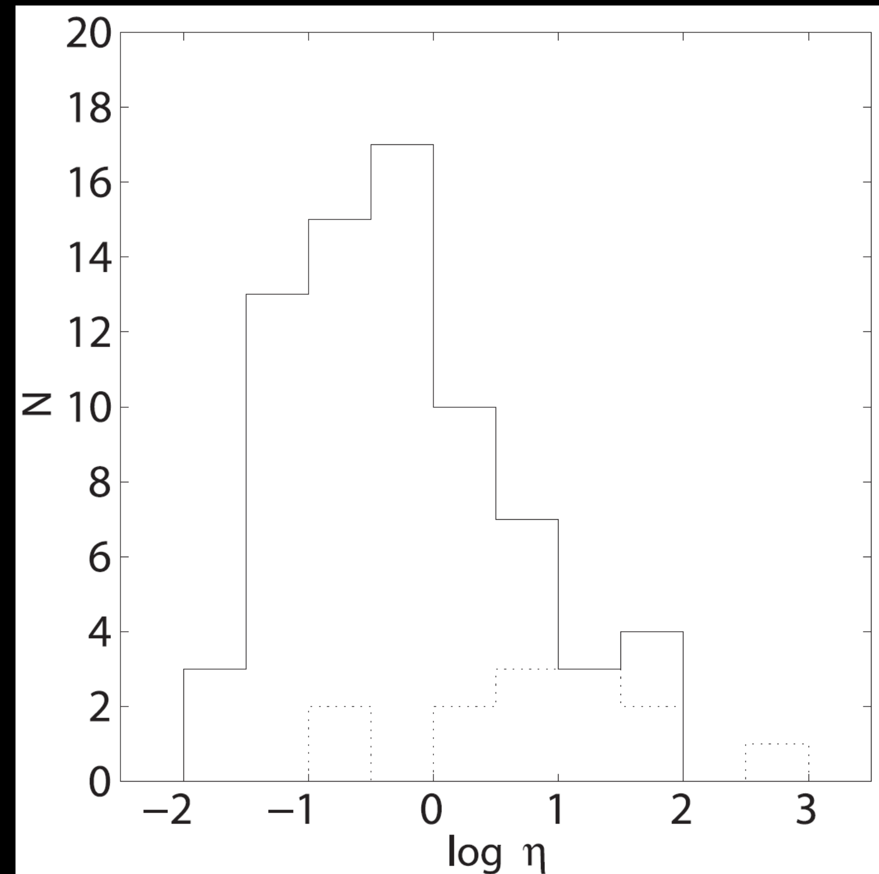
## Inhomogeneous jet model:

$$L_{\mathrm{kin}} = \frac{4}{3}\pi r_1^2 n_1 \underline{\gamma_{\mathrm{e,min}}^{-\frac{3}{2}}}[1 - \cos(1/\Gamma)](m_{\mathrm{e}}\langle\gamma_{\mathrm{e}}\rangle + m_{\mathrm{p}}\langle\gamma_{\mathrm{p}}\rangle)\Gamma(\Gamma - 1)\beta c^3$$

$$\theta_{\mathrm{d}} = \frac{r(\tau_{\nu_{\mathrm{s}}} = 1)\sin\theta}{D_{\mathrm{a}}}$$

**VLBI core size, proper motion, X-ray (SSC) and** with a assumed minimum electron Lorentz factor



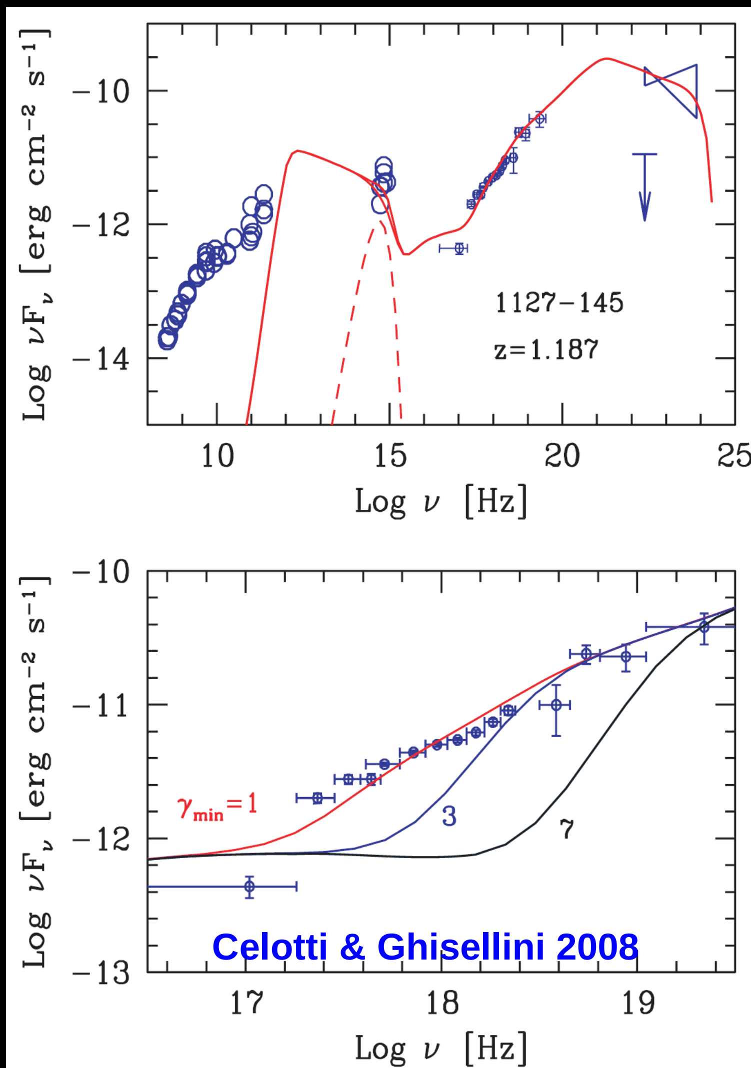



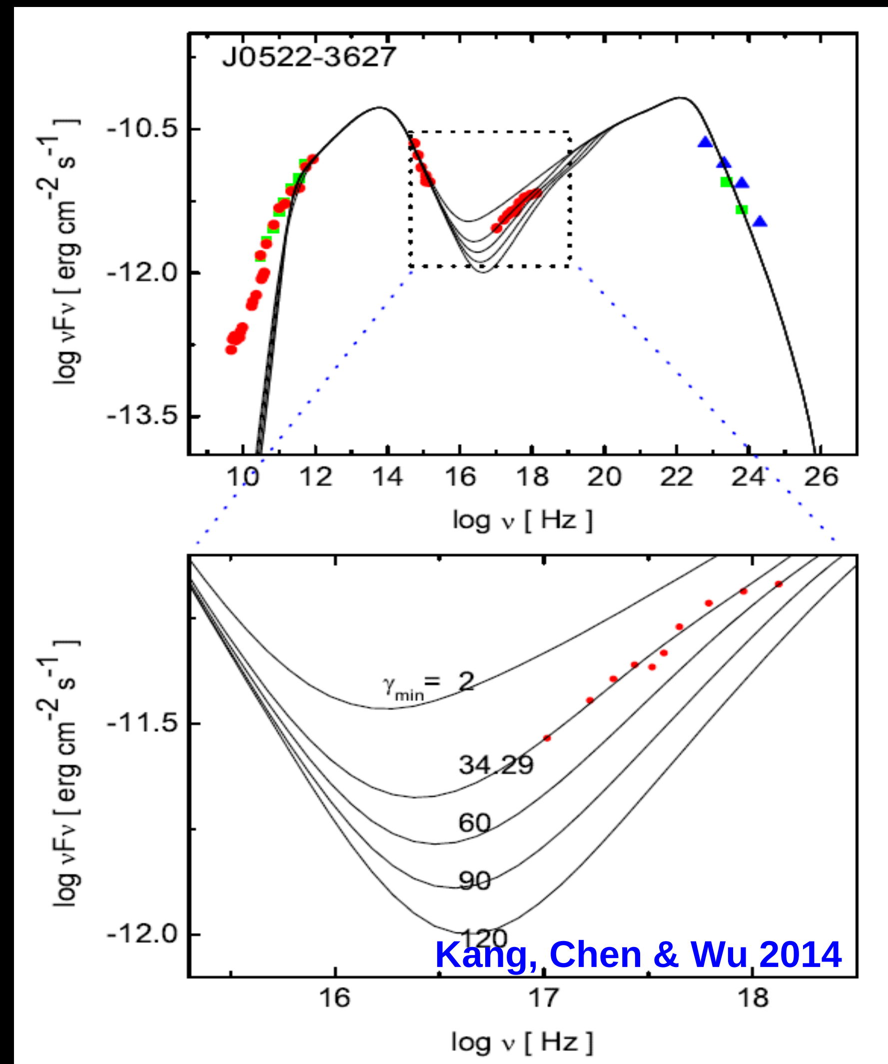

$$\gamma_{\rm min} = 1$$

$$\eta_{\rm jet} = \frac{0.1 L_{\rm kin}}{L_{\rm bol}}$$

MHD simulations on jet efficiency, e.g., Tchekhovskoy, Narayan … (2012)

- **Constrain minimum electron Lorentz factor from**



# 2) Sample & Model

- **Sample: 30 Low-Synchrotron-Peaked(LSP) blazars (FSRQs) with (quasi-)simultaneous observations (Fermi, Swift, Plank & ground based radio, optical, infrared telescopes).**

**X-rays of LSP blazars are mainly dominated by SSC**

# 2) Sample & Model

- **Model:** **one-zone leptonic model**

$$N(\gamma) = \begin{cases} N_0 \gamma^{-p_1} & \gamma_{\rm min} \leqslant \gamma \leqslant \gamma_{\rm b} \\ N_0 \gamma_{\rm b}^{p_2 - p_1} \gamma^{-p_2} & \gamma_{\rm b} < \gamma \leqslant \gamma_{\rm max} \end{cases}$$

**IC: SSC + EC**

**Seed photons for EC?**

# 2) Sample & Model

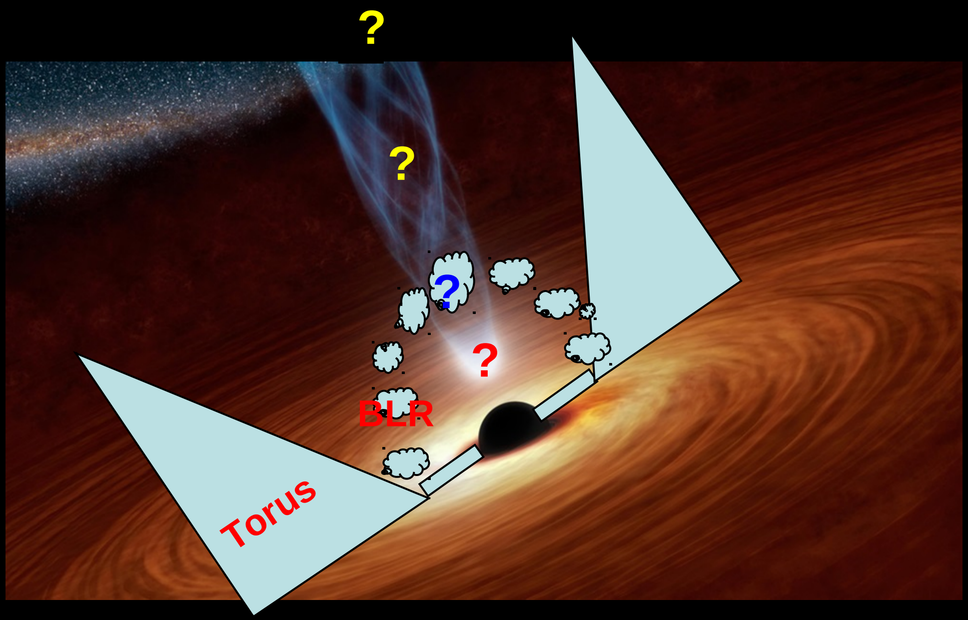
- **Jet dissipation region & seed photon field**

**Possibilities:**

(1) $R < R_{BLR}$

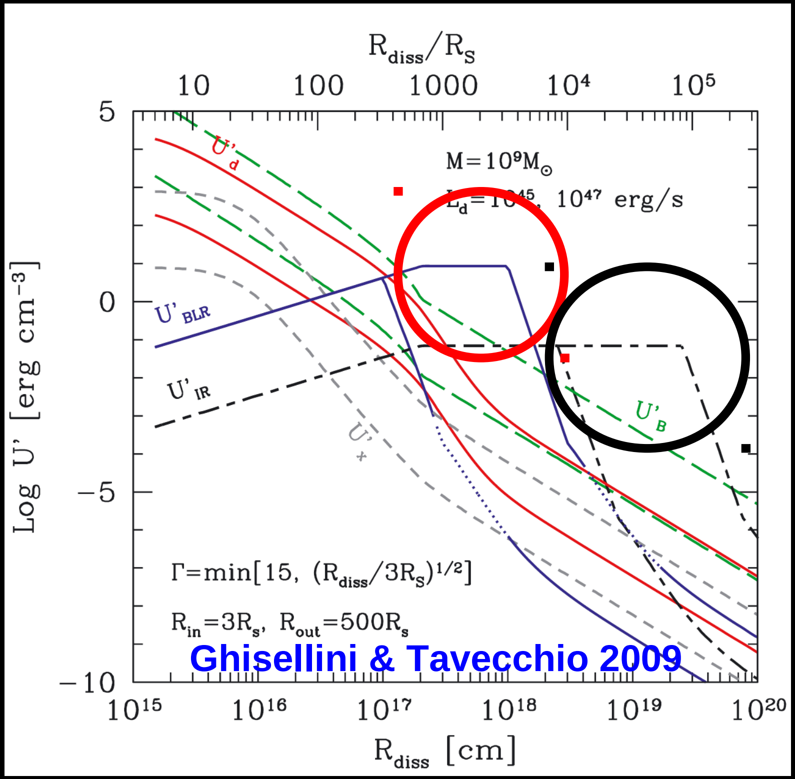
(2) $R_{BLR} < R < R_{torus}$

(3) $R > R_{torus}$



# 2) Sample & Model

- **Jet dissipation region & seed photon field**




## Indirect test?

**Origin of seed photon field may provide a test on the gamma-ray location**

# 2) Sample & Model

- **Model:** **one-zone leptonic model**

**BLR and torus seed photons are considered in IC respectively.**

$$u_{\rm BLR} \sim f_{\rm BLR} L_{\rm d}/(4\pi c R_{\rm BLR}^2)$$

$$u_{\rm IR} \sim f_{\rm IR} L_{\rm d}/(4\pi c R_{\rm IR}^2)$$

# 2) Sample & Model

- **Model:** **one-zone leptonic model**

**Model parameters:**

$R$, $B$, $\delta$, $p_1$, $p_2$, $\gamma_{\rm min}$, $\gamma_{\rm max}$, $\gamma_{\rm b}$, and $N_0$

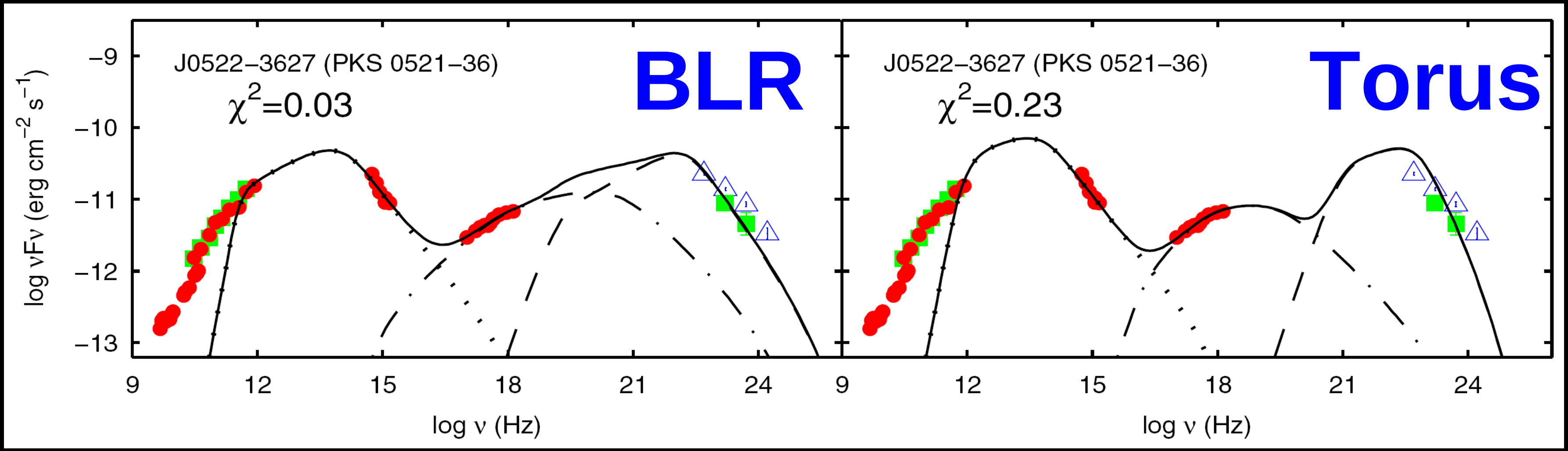
$R = c\delta\Delta t_{\rm var}/(1+z)$ $\gamma_{\rm max} = 100\gamma_{\rm b}$

**7 free parameters**

**Fitting method:** $\chi^2$-minimization procedure

# 3) Results

- **Fitting results**

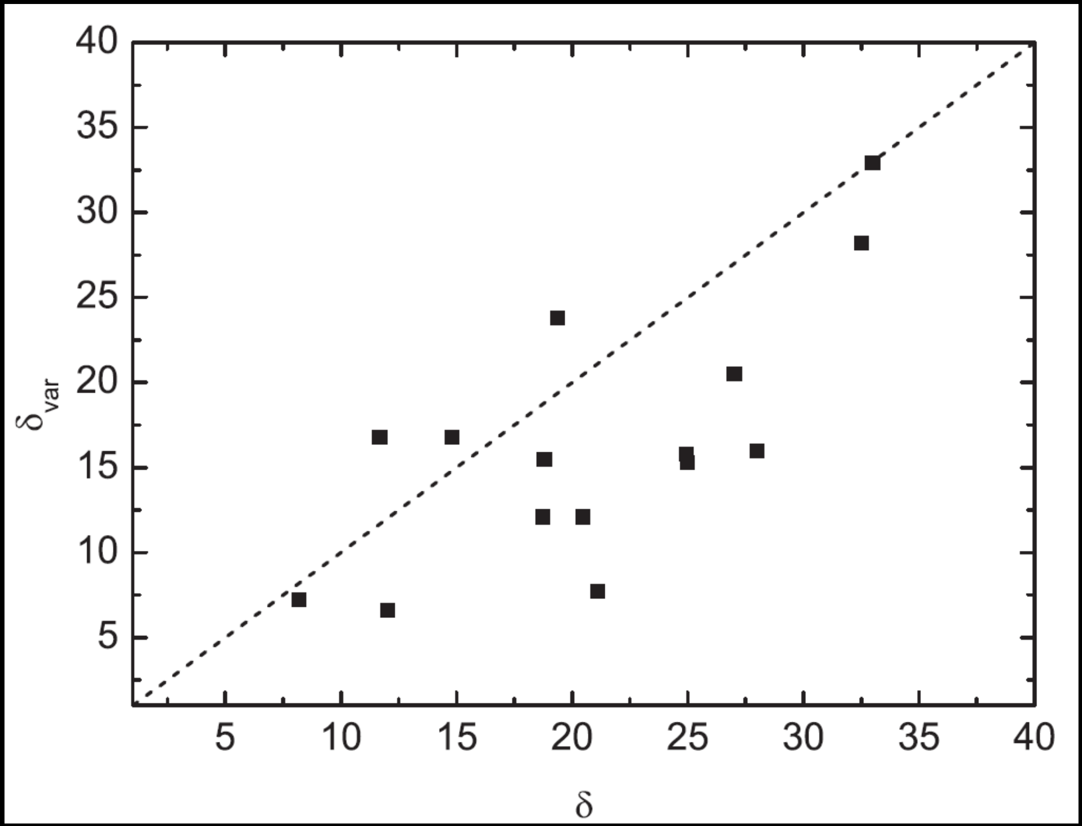



**Fit the data from submm to Gamma-ray (e.g., > 300GHz)**

**Giroletti's talk: optically thin at >~86 GHz**

# 3) Results

- Doppler factor & Doppler factor

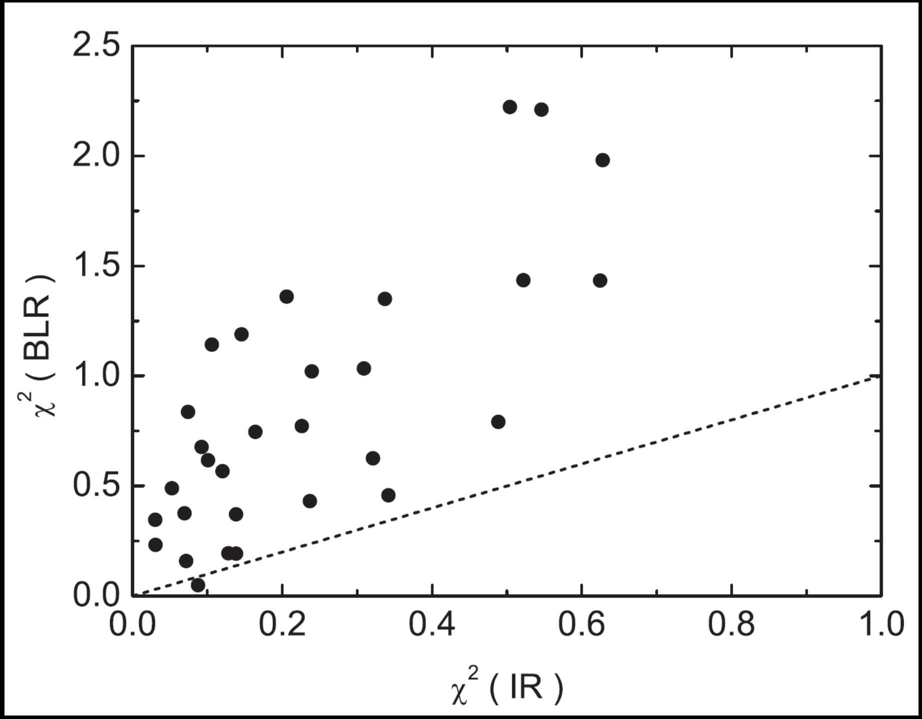



$$\delta_{\rm var} = \left(1.47 \times 10^{13} \frac{\Delta S_{\max} d_{\rm L}^2}{\nu^2 \Delta t^2 (1+z) T_{\rm b,\,int}}\right)^{1/3}$$

Hovatta's talk & works

# 3) Results

- **Seed photon field**




$$\chi^2_{IR} < \chi^2_{BLR}$$

**Klein-Nishina effect?**

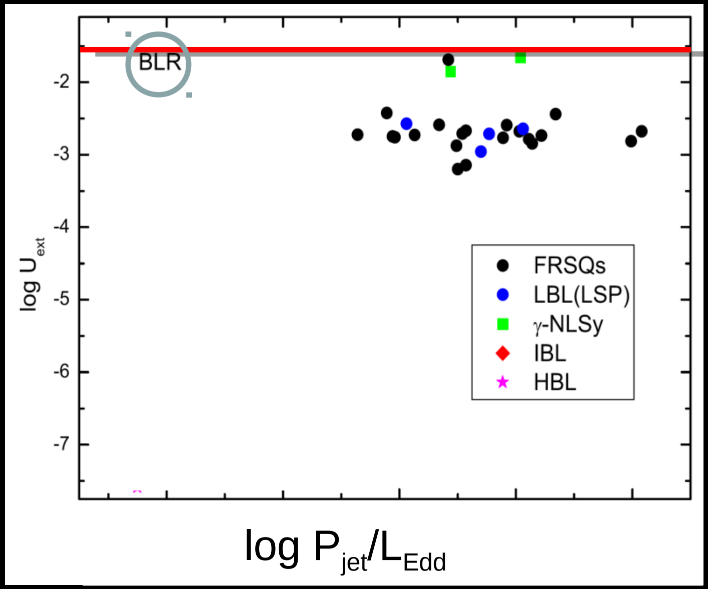
$$\nu^{T}_{\mathrm{EC,BLR}} \lesssim 6 \times 10^{23}\ \mathrm{Hz}$$

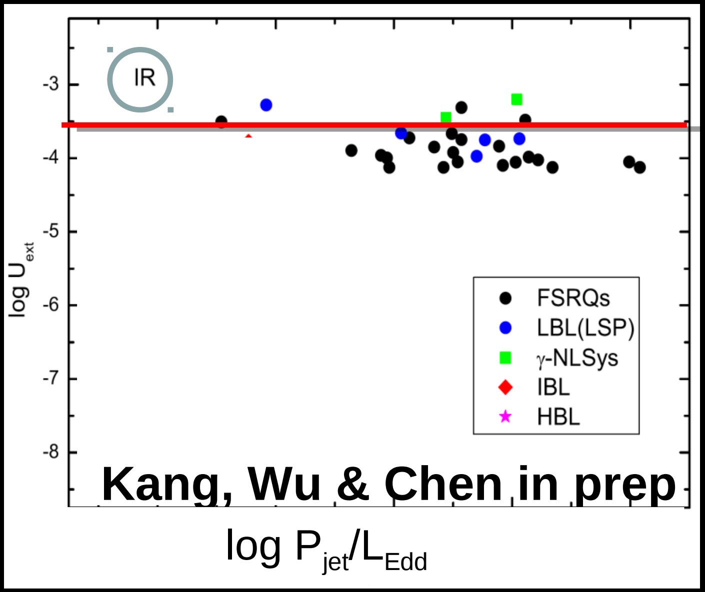
$$\nu^{T}_{\mathrm{EC,torus}} \lesssim 4 \times 10^{25}\ \mathrm{Hz}$$

**It suggests that IR seed photons are preferred and $R_{BLR} < R_{dissi} < R_{torus}$.**

# 3) Results

- $u_{BLR}$, $u_{IR}$ as a free parameter (but $p_1$ or $p_2$ fixed)



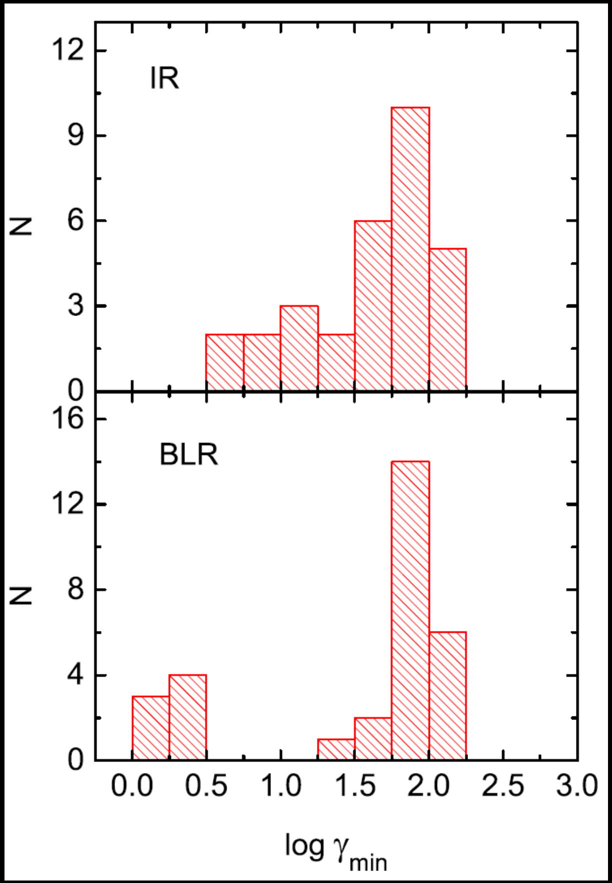



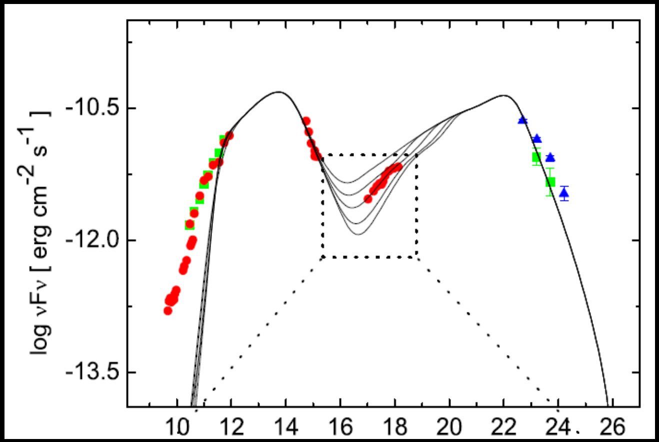

IR seed photons are preferred?

$R_{BLR} < R_{dissi} < R_{torus}$?

# 3) Results

- **Minimum electron Lorentz factor**



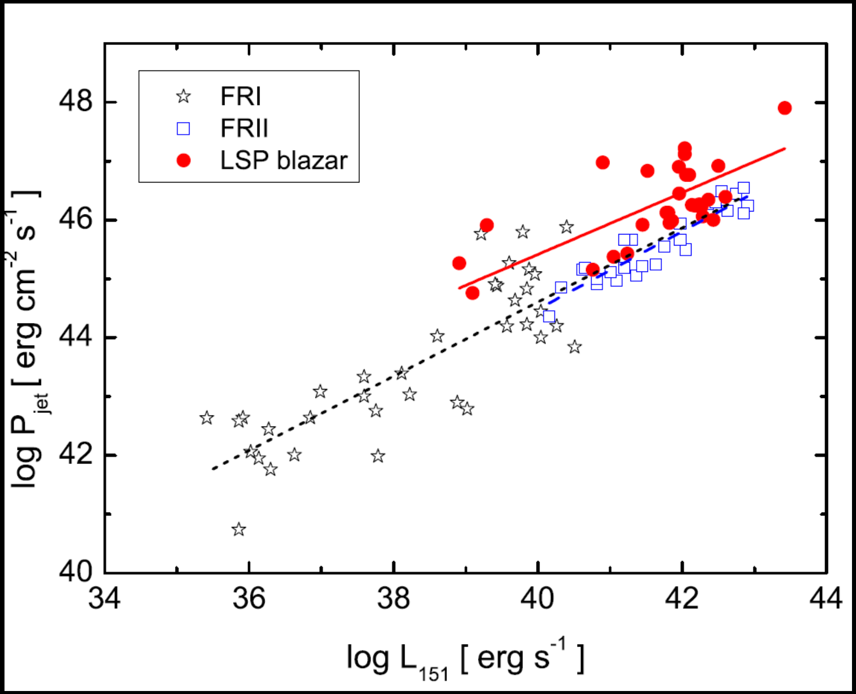

$\gamma_{\rm min}$ ~ several tens, which is not sensitive to seed photon field (SSC!).

$$\gamma_{\rm min} = [(p-2)/(p-1)](m_p/m_e)\varepsilon_e\Delta\Gamma$$

$\sim 40$ Sari et al. 1998

# 3) Results

- **Jet power & matter content**




$$P_i = \pi R^2 \Gamma^2 c U_i'$$

One electron one proton, jet power of blazars is systematically larger than

that of FR IIs at given 151 MHz radio luminosity.

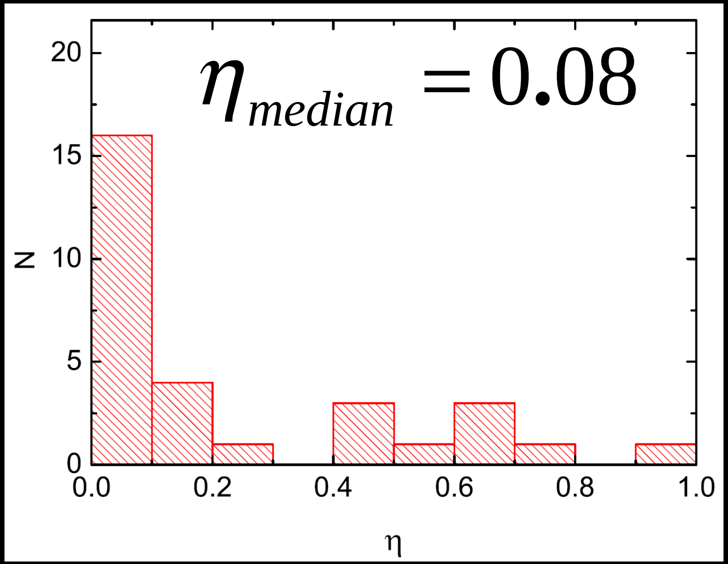
**The jet power will decrease if positrons exist!**

# 3) Results

- **Jet power & matter content**

Assume $n_p = \eta n_{e^-}$ , $n_{e^+} = (1-\eta) n_{e^-}$ **and**

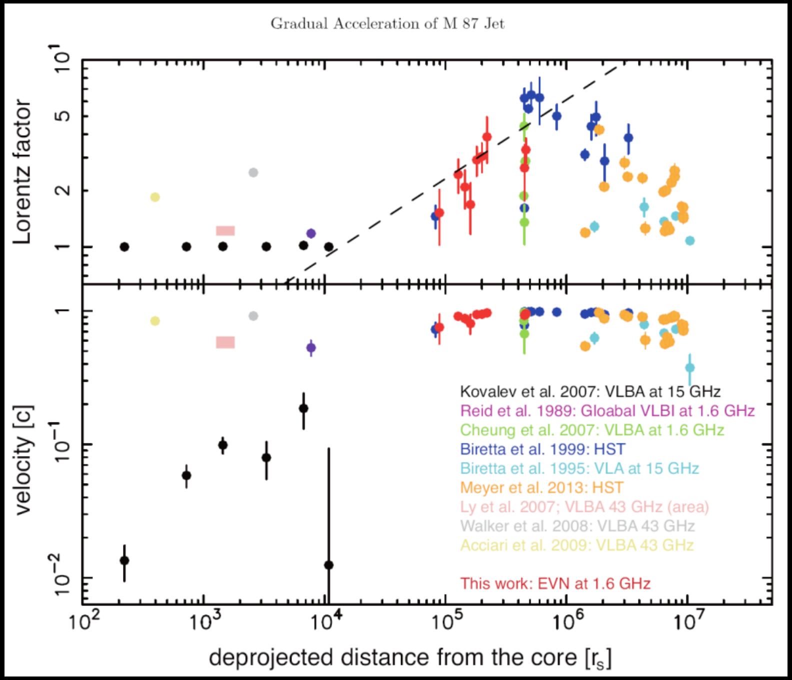
**set $P_{jet} = P_{jet}^{151}$, we get**




**$n_{e^+}/n_p \sim 10$**

# 4) Conclusion

- SED modeling with IR seed photon is better than that of BLR, which suggest that gamma-ray emitting region may locate outside of BLR.




Most of jet energy is dissipated at $10^5$Rg?

**M87**

**Asada et al. 2014**
**& Nakamura’s talk**

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- Mixed composition of $e^{+}$-$e^{-}$-p in FSRQs.

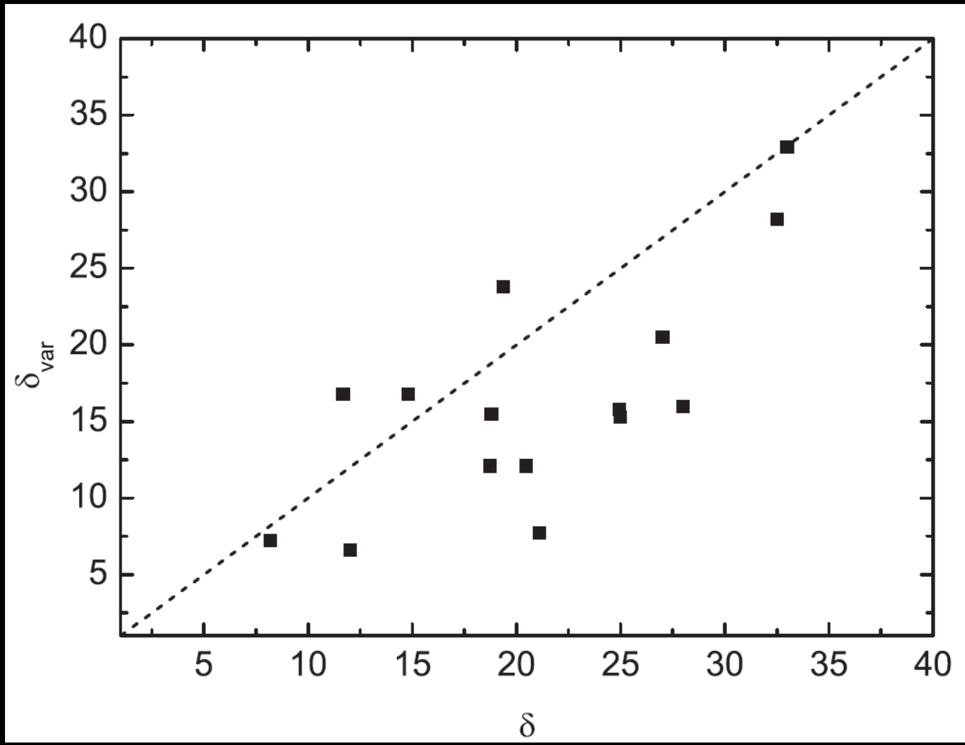
# 4) Conclusion

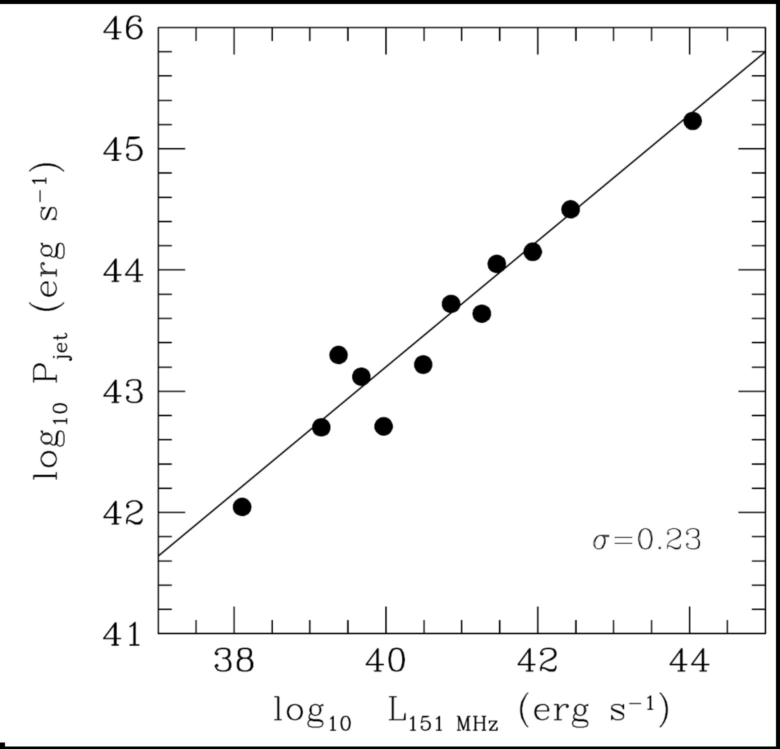
- ◆ SED modeling with IR seed photon is better than that of BLR, which suggest that gamma-ray emitting region may locate outside of BLR.

- ◆ Minimum electron Lorentz factors are ~ several tens in FSRQs.

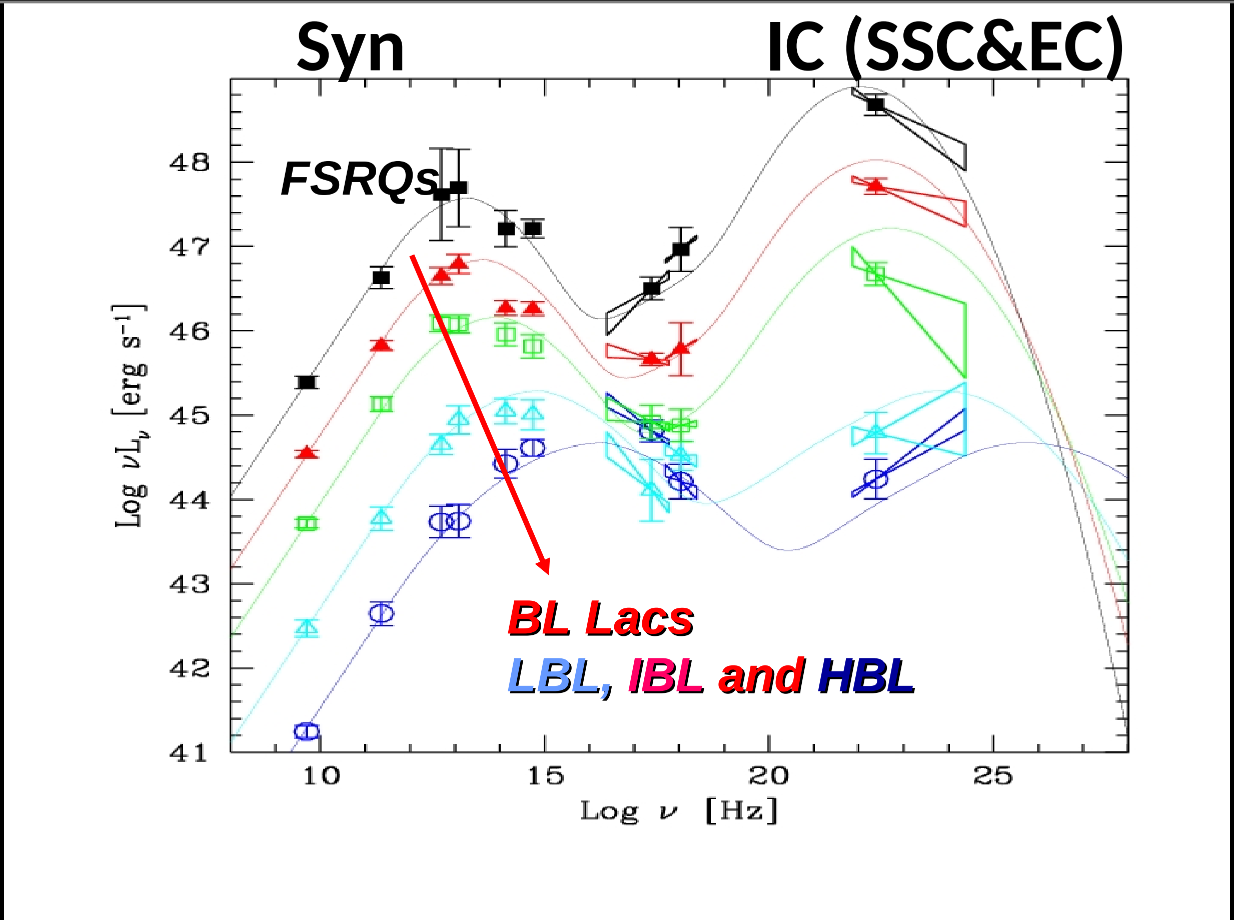
- ◆Mixed composition of $e^+$-$e^-$-p in FSRQs.

**Thanks for your**


δvar
δ
5
10
15
20
25
30
35
40

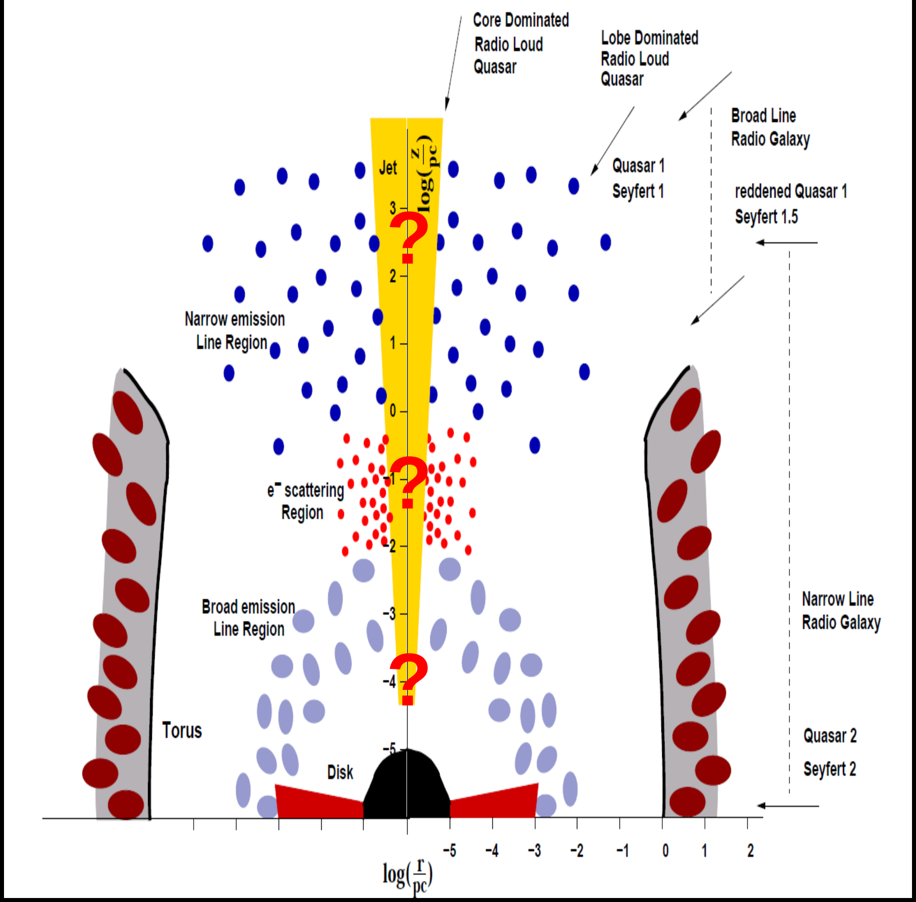

log10 Pjet (erg s⁻¹)
log10 L151 MHz (erg s⁻¹)
σ=0.23
41
42
43
44
45
46
38
40
42
44

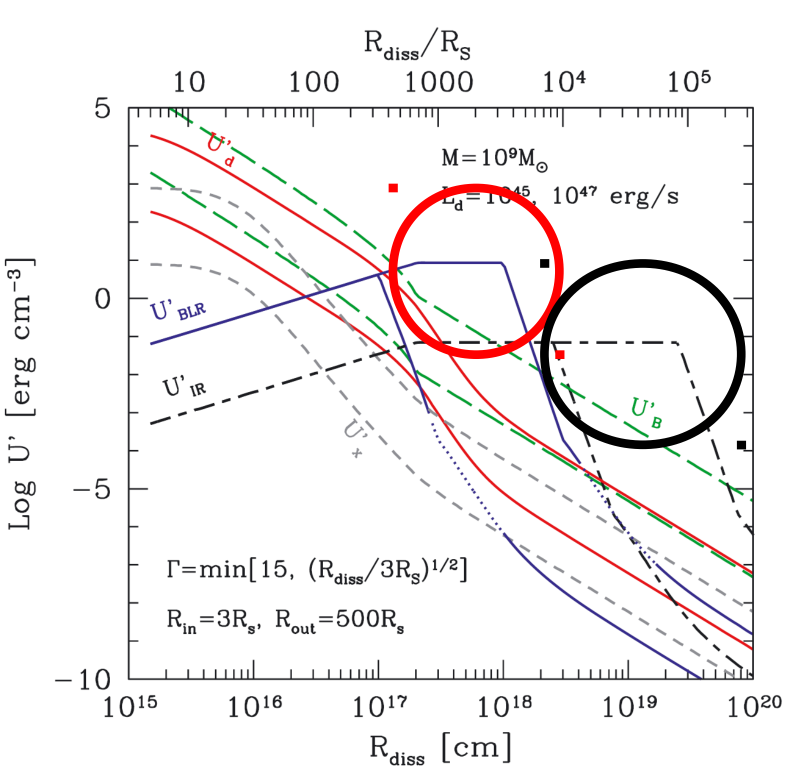
# 2.5 Gamma-ray emitting region and jet composition in blazars




Multi-band SED normally can be modeled by one-zone model (size $R \sim D^*c^*t_{min}$, $t_{min} \sim 1$ day).

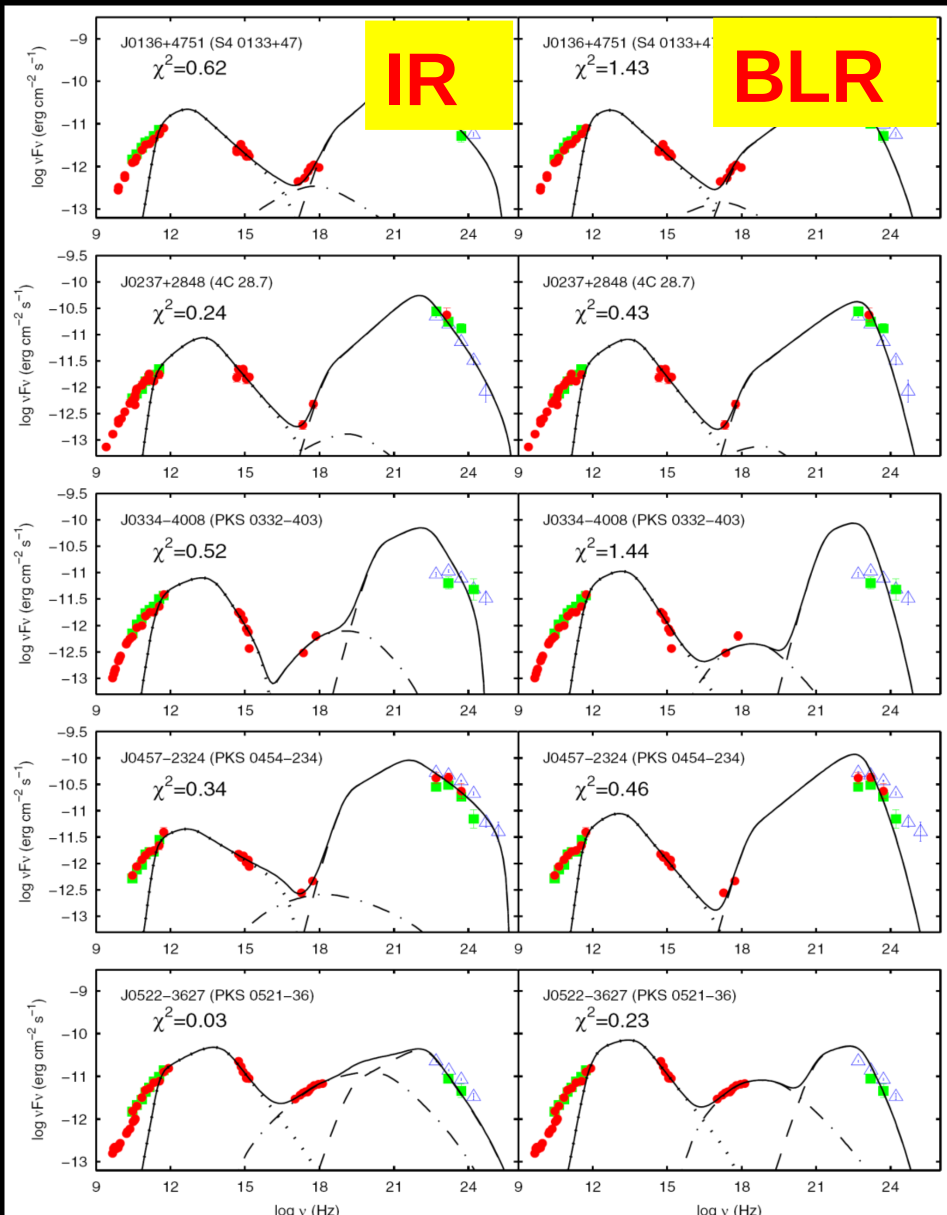
- **Possibilities:**
  **(1)** $R < R_{BLR}$
  **(2)** $R_{BLR} < R < R_{torus}$
  (3) $R > R_{torus}$




**Different locations will lead to different IC seed photons.**

# SED modeling results



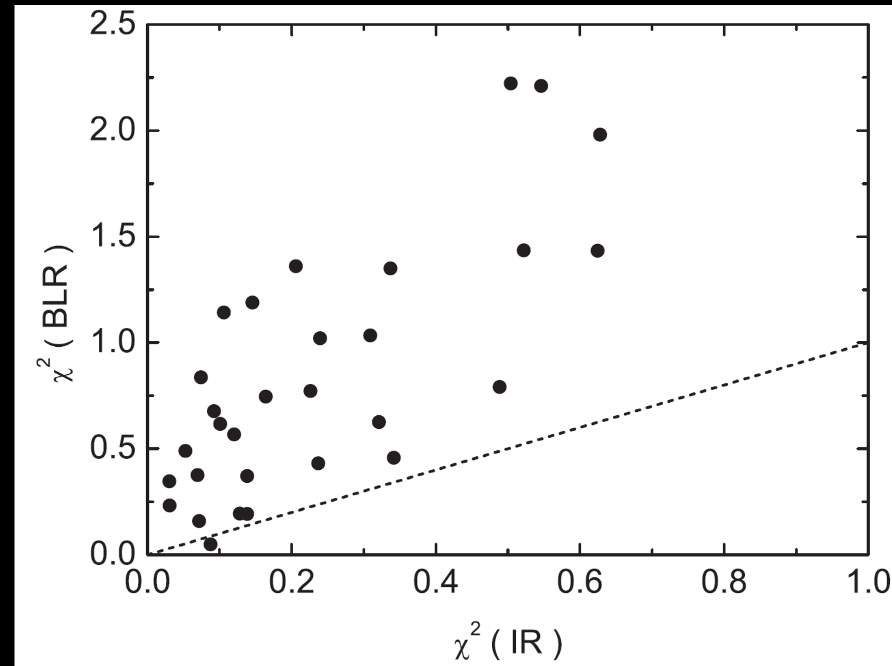
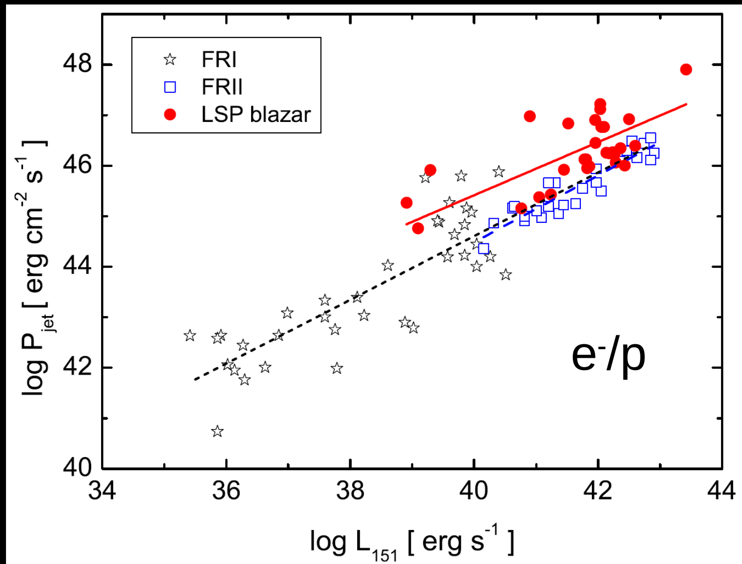



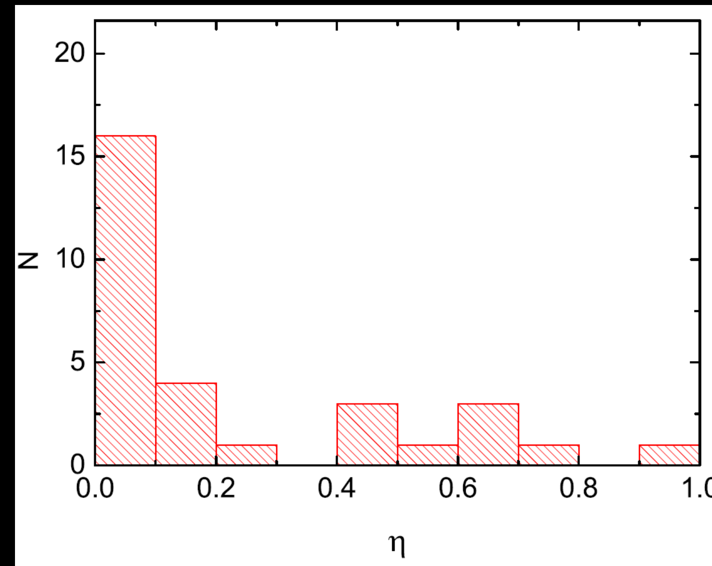

**Figure 1.** $\chi^2$ values derived from multiwavelength SED fittings with the IR seed photons of the torus are plotted against the fittings with BLR seed photons. The dashed line represents $y = x$.

$$\chi^2_{IR} < \chi^2_{BLR}$$

**Support the IR soft photons**
**-> located at $R > \sim R_{BLR}$**

# Blazar jet include positrons?




$$n_p = \eta n_{e^-} \text{ and } n_{e^+} = (1-\eta) n_{e^-}$$

**Median value is 0.08, average value is 0.22**

**$n_{e+}/n_p$ ~10 electron-positron dominated!**

**Kang, Chen & Wu* 2014,**

# MHD Jet efficiency

Energy Flux

| Model | $a/M$ | $E^m_{\rm hole}$ | $E^{\rm em}_{\rm hole}$ | $E^m_{\rm jet}$ | $\eta_m$ | $E^{\rm em}_{\rm jet}$ | $\eta_{\rm em}$ | $\eta_{\rm NT}$ |
|---|---|---|---|---|---|---|---|---|
| KDR | −0.90 | −20.8 | 0.41 | 2.71 | 0.088 | 0.509 | 0.023 | 0.039 |
| KD0c | 0.00 | −20.6 | −0.02 | 0.16 | 0.0022 | 0.007 | $3.1 \times 10^{-4}$ | 0.057 |
| KDIb | 0.50 | −21.7 | 0.10 | 2.06 | 0.063 | 0.129 | 0.0063 | 0.081 |
| KDPg | 0.90 | −21.8 | 0.88 | 5.89 | 0.22 | 0.892 | 0.046 | 0.155 |
| KDG | 0.93 | −19.8 | 1.37 | 3.13 | 0.065 | 0.824 | 0.038 | 0.173 |
| KDH | 0.95 | −16.9 | 2.79 | 4.26 | 0.13 | 1.46 | 0.072 | 0.190 |
| KDJ | 0.99 | −9.9 | 6.86 | 9.94 | 0.41 | 3.28 | 0.21 | 0.264 |

**Hawley & Krolik 2006**

**Minimum electron Lorentz factor >> 1 ?**

But see Tchekhovskoy, Narayan …

$\eta \approx 140$ per cent

for a*~0.99