Locating Gamma-ray Emitting Zone in FSRQ Jets Through Modeling Flaring Light Curves

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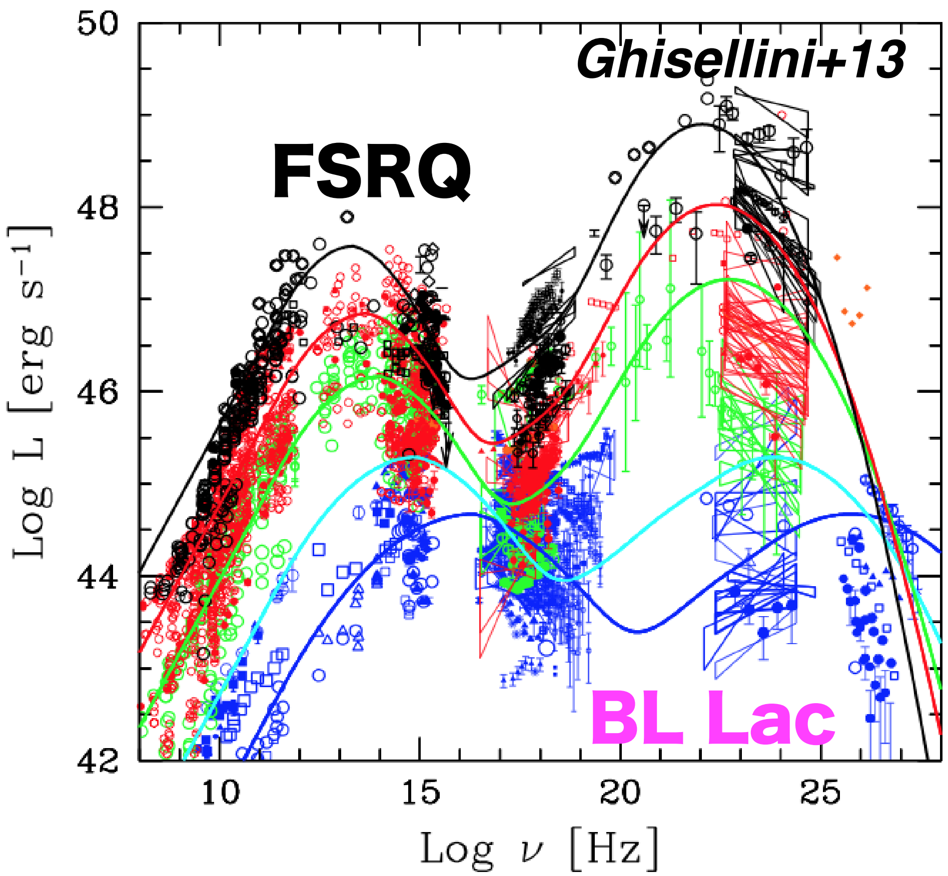
(This talk is based on Saito+15 submitted to ApJ)

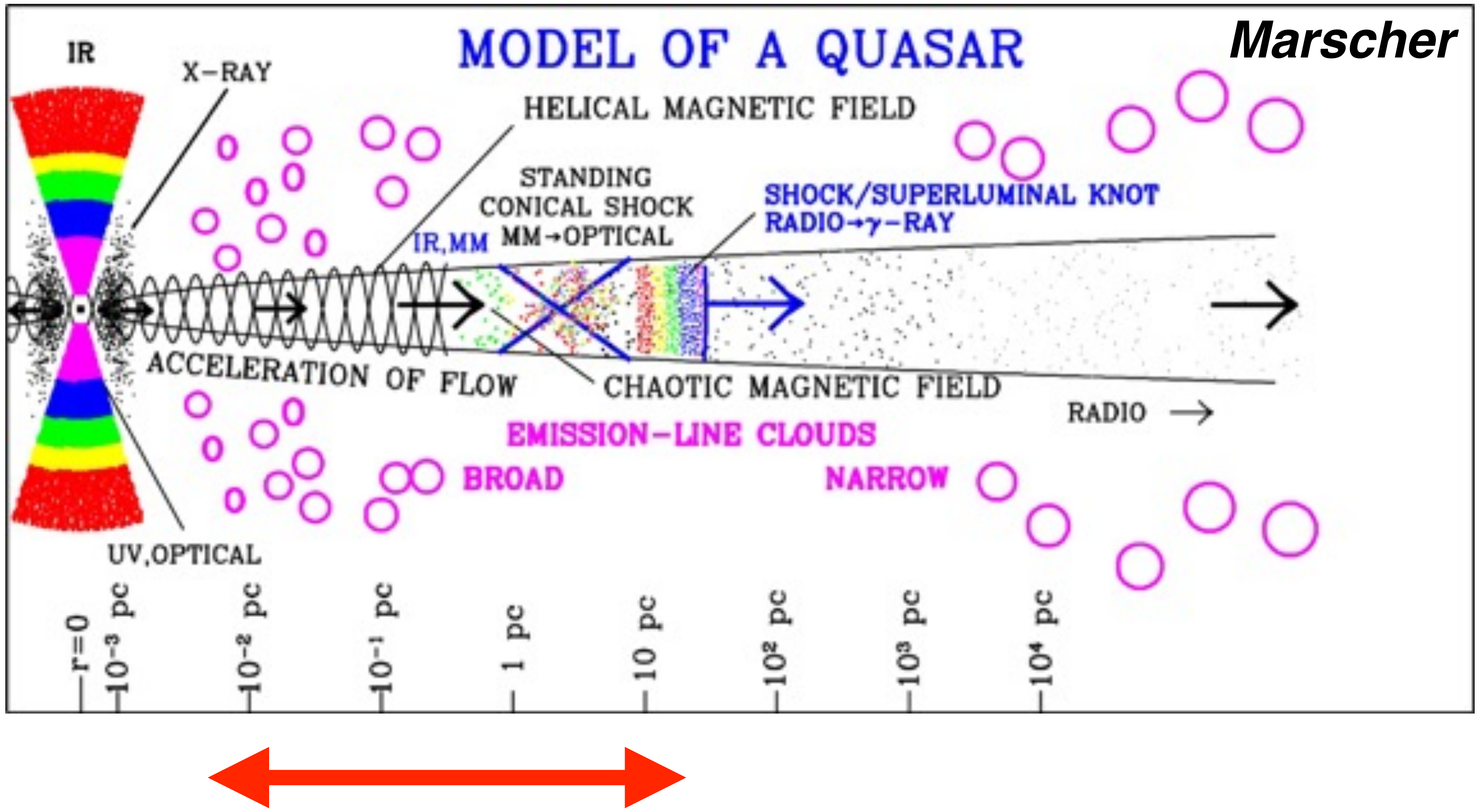
Blazar Emission Zone

The site and structure of the emission region is controversial.

Multiwavelength observations have been extensively performed.

- Broadband sed modeling
- Polarization measurement
- Correlation of broadband variability

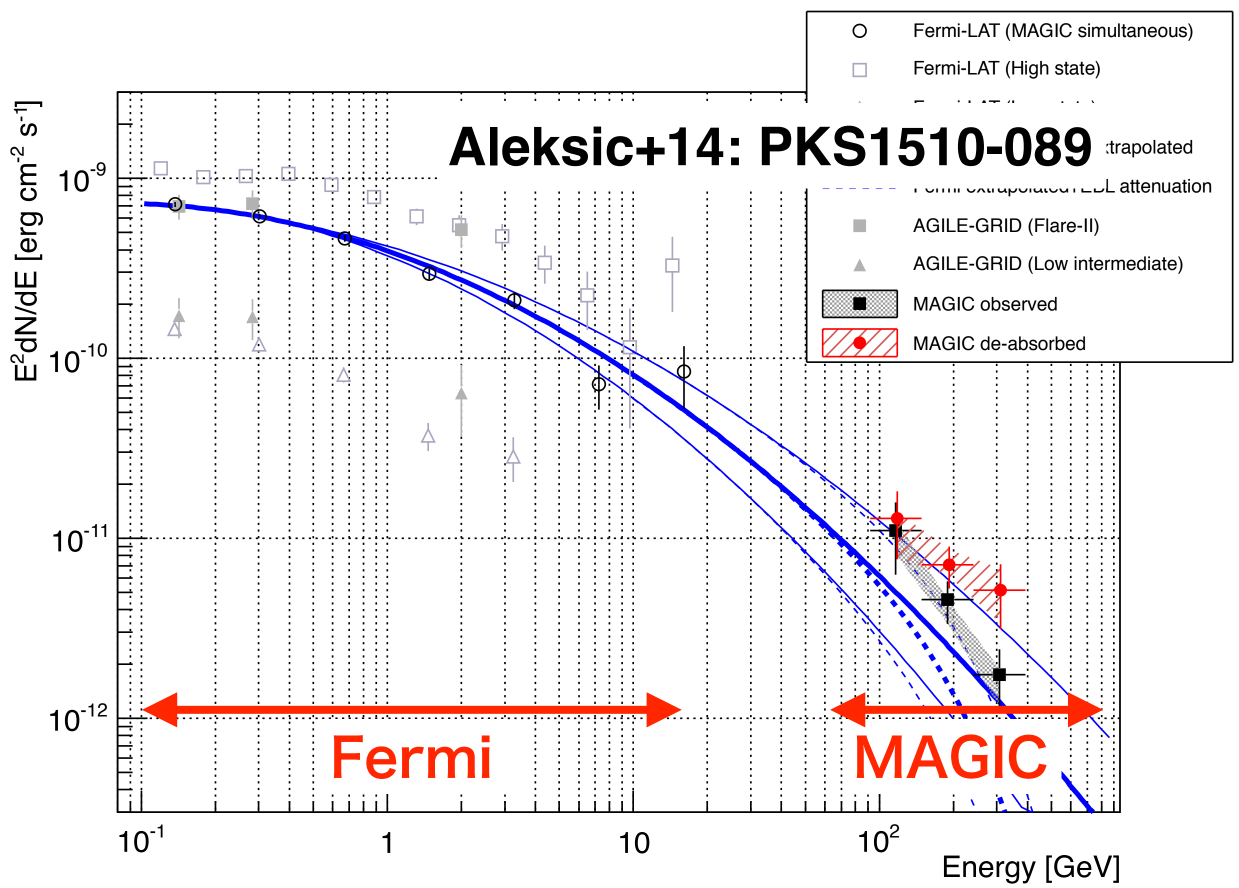


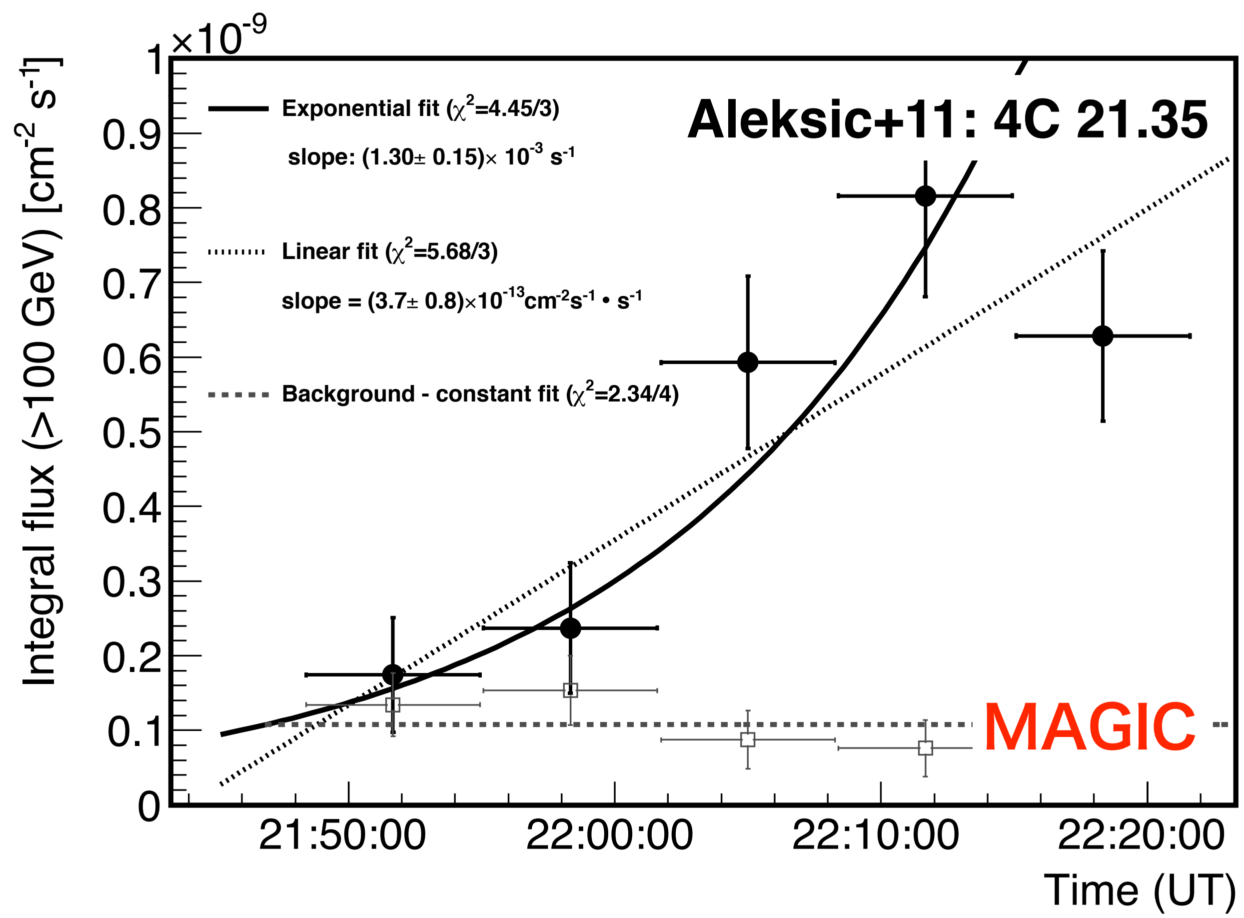


Wide range of estimated position

Rapid gamma-ray variability in FSRQs

- Variability of a few hours is observed with Fermi-LAT (GeV).
  (Foschini+11, Saito+13, Brown +13, Foschini+13, Rani+13, Hayashida+15)
  → Location of emission site: $R < c\delta\Gamma\Delta t/(1+z) \fallingdotseq 10^{16}$ cm (Δt=2hours, Γ=10)





- Smooth connection of GeV and TeV spectra during GeV flare.
  →Suggesting co-spatiality of GeV/TeV emission zone locating outside BLR; $>10^{17}$ cm, since VHE photon is absorbed in BLR due to $\gamma\gamma \rightarrow e^+e^-$.

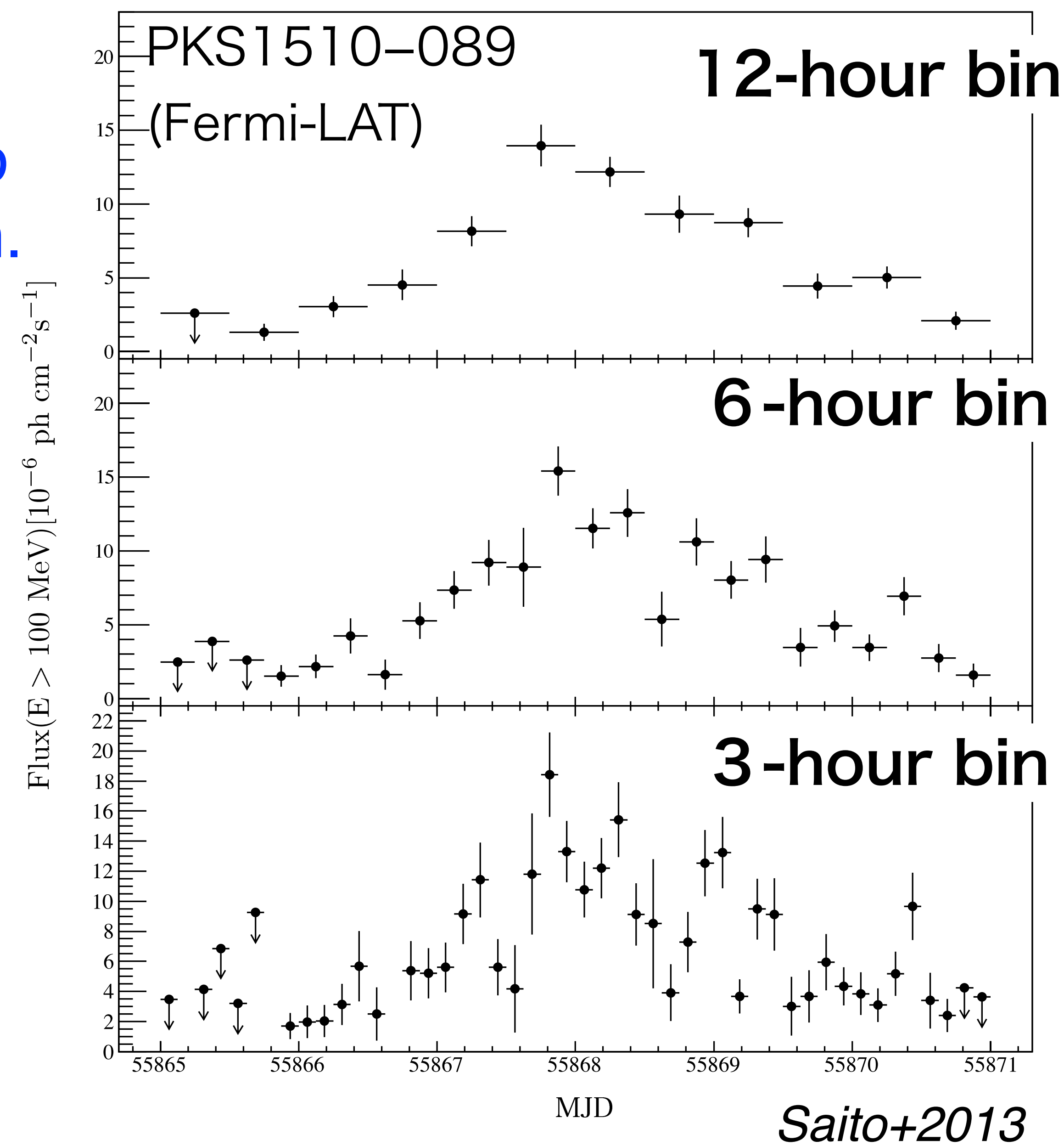
- Variability of several minutes in TeV range
  → Compact emission region at large distance?

Time-dependent modeling of FSRQ flares

- Modeling time evolution of SEDs during flares.
- Fitting simulated GeV gamma-ray light curves to observed ones.

"Finer time resolution" is important since an apparently coherent flare would be resolved into superposition of sub-flares with better resolution.

The brightest gamma-ray flares with excellent photon statistics and apparently coherent time profile in three hour binning were modeled.



Saito+2013

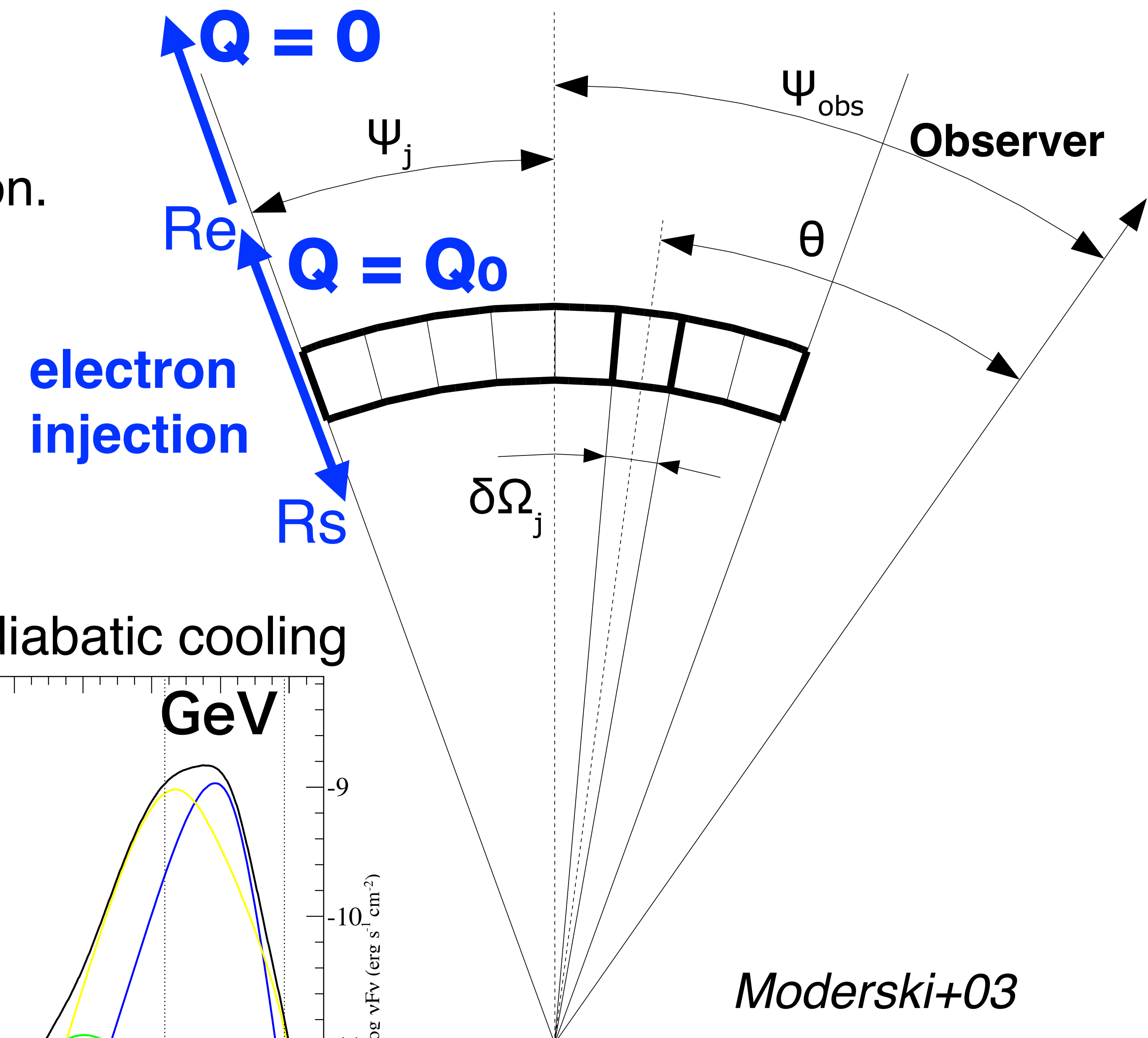
Modeling the Flaring Light Curves

- A single-zone model with underlying assumption of internal shock.
- **"BLAZAR" model (*Moderski+03, 05*)**

0. Assume a thin shell moving along the jet.
1. Electron injection (Q) during a certain section.
2. Calculate time evolution of electron energy distribution (N_γ).

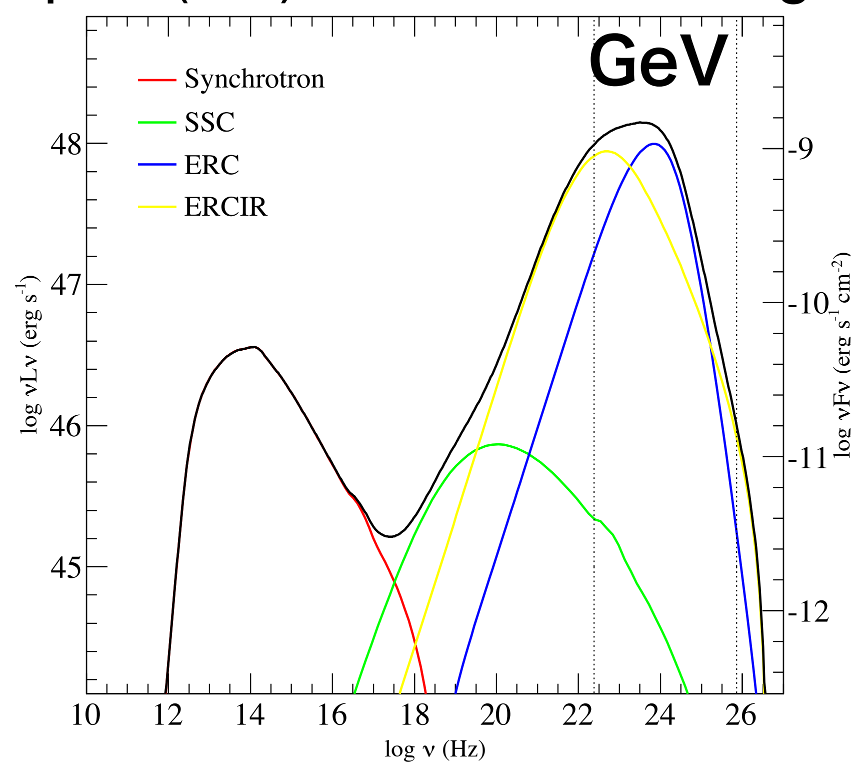
$$\frac{\partial N_\gamma}{\partial t'} = -\frac{\partial}{\partial \gamma}\left(N_\gamma \frac{d\gamma}{dt'}\right) + Q$$

synchrotron /inverse Compton(KN) /adiabatic cooling



Moderski+03

3. Calculate observed spectra at each moment.
4. Extract GeV band and make GeV light curves.

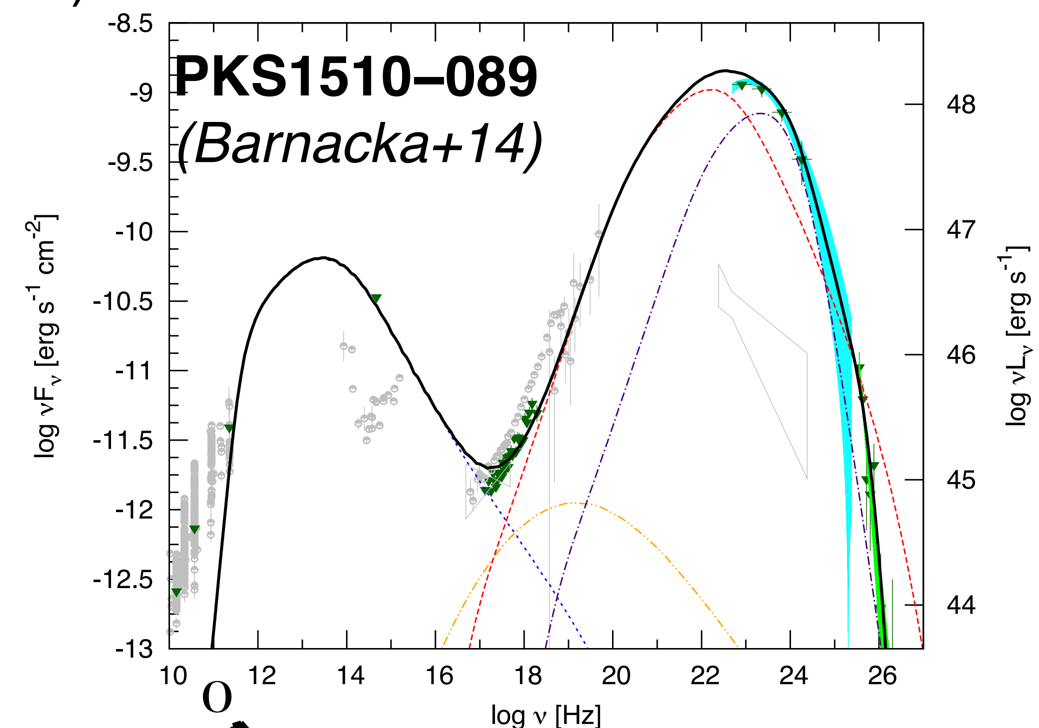


Model Parameters (PKS1510–089)

- **Electron distribution**

$$Q(\gamma) = K_e \gamma^{-p} \left(1 + (\gamma/\gamma_b)^4\right)^{(p-q)/4}$$

Derived from recent broadband SED fitting (*Barnacka+14*).
(p=1.2, q=3.4, γ_b=900, γ_{min}=1, γ_{max}=10^5)



- **Photon fields**

Estimated from accretion disk luminosity.
(*Nalewajko+12, Barnacka+14*)

	Size (10^{18} cm)	Density (erg/cm^3)	Energy (eV)
BLR	0.12	0.055	10
HDT	1.94	5×10^{-3}	0.15

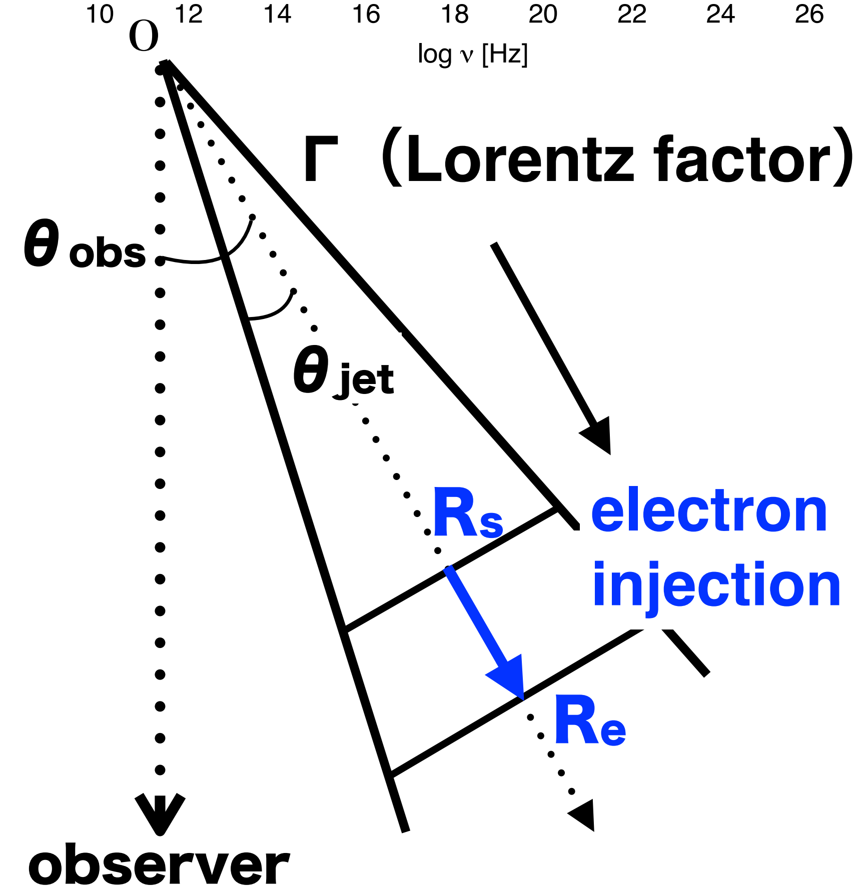
- **B(R) = 0.8G x 10^{18} cm/ R**

- **Geometry**

Γ＝22

θ_{jet} ＝1/Γ= 0.045 = 2.6° down to 0.1/Γ = 0.3°

θ_{obs}＝ θ_{jet}

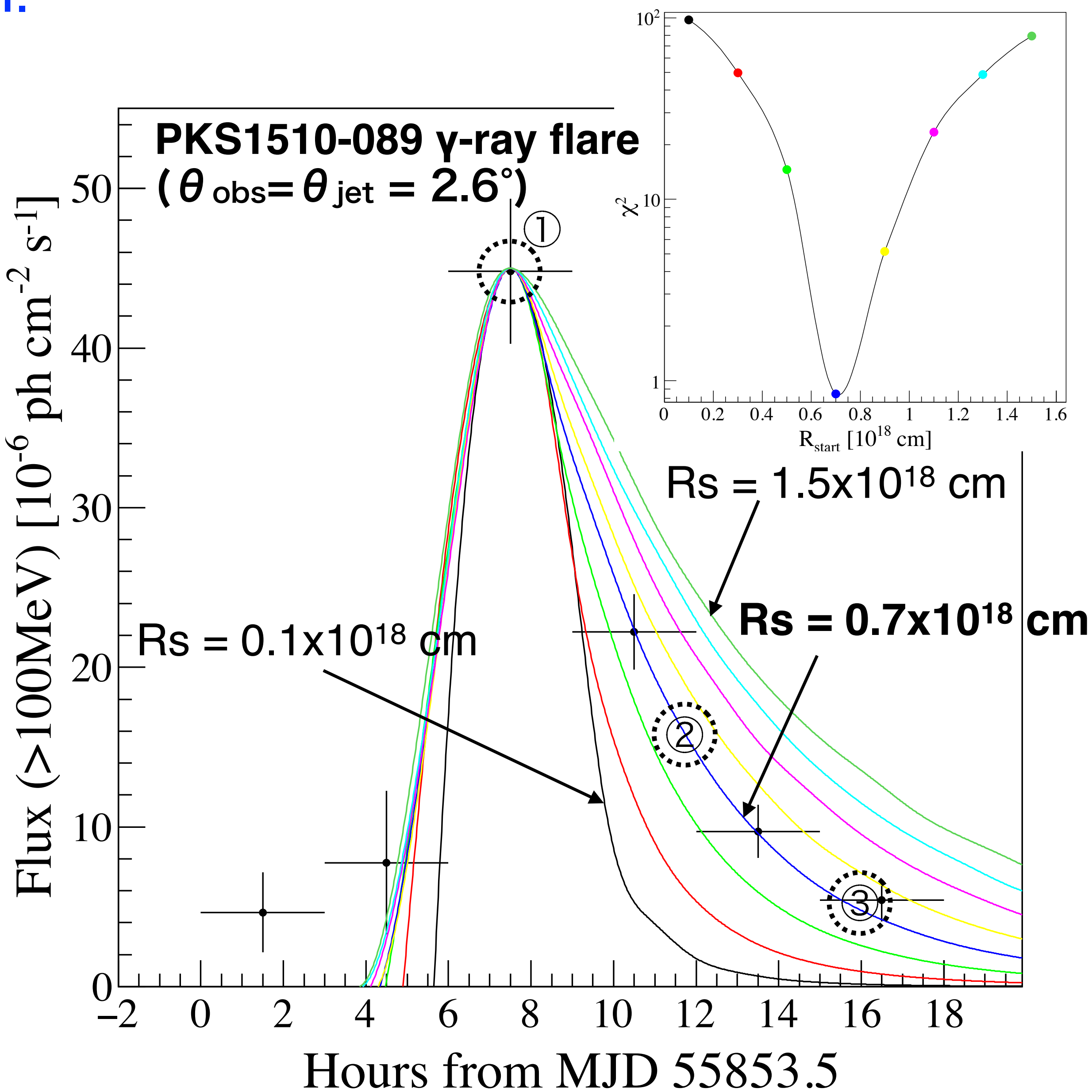


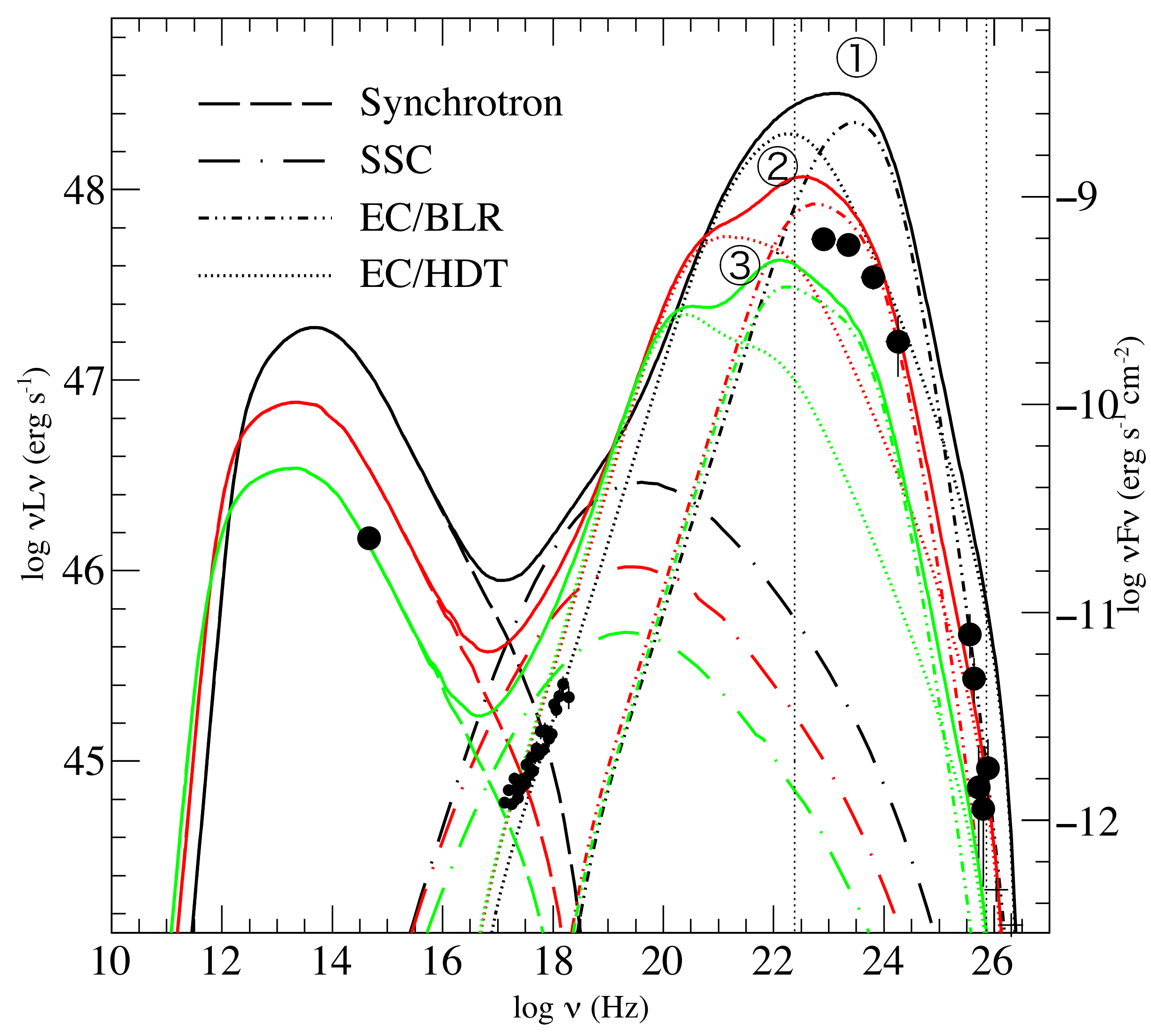
Locations of electron injection (R_s, R_e) are set as free parameters

Constraints on the Location of Emission Zone

- Length of section with electron injection (Re-Rs) was estimated to be 0.2×10^{18} cm.
- Simulations were performed for various locations of emission zone.

→ Location of gamma-ray emission zone was estimated to be $(0.7 \pm 0.2)\times10^{18}$ cm from the SMBH.

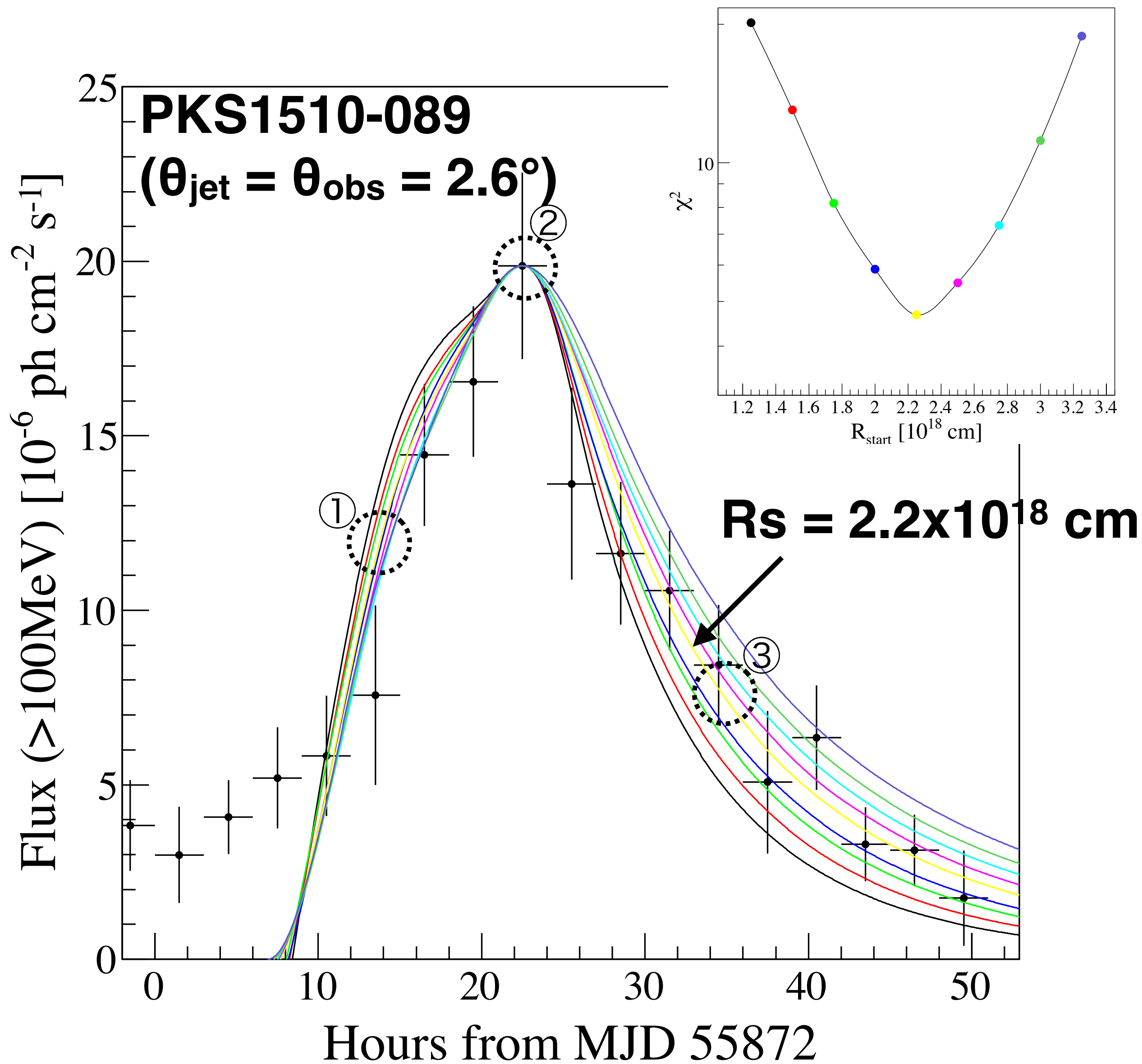


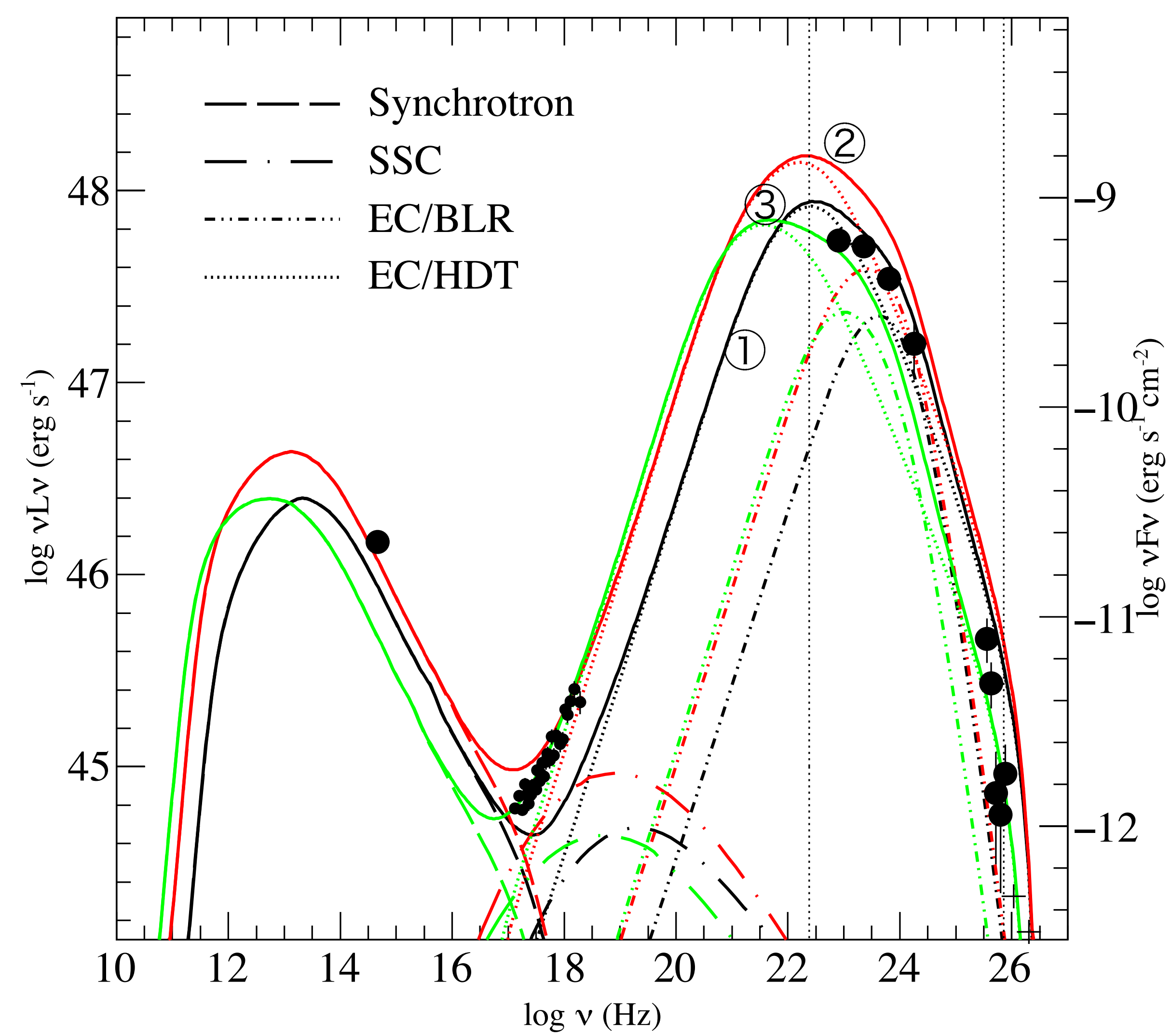


data poiints from Saito+2013

Constraints on the Location of Emission Zone

- Light curve modeling of another flare in PKS 1510-089 also suggests emission zone locating around ~10^{18} cm from the SMBH.





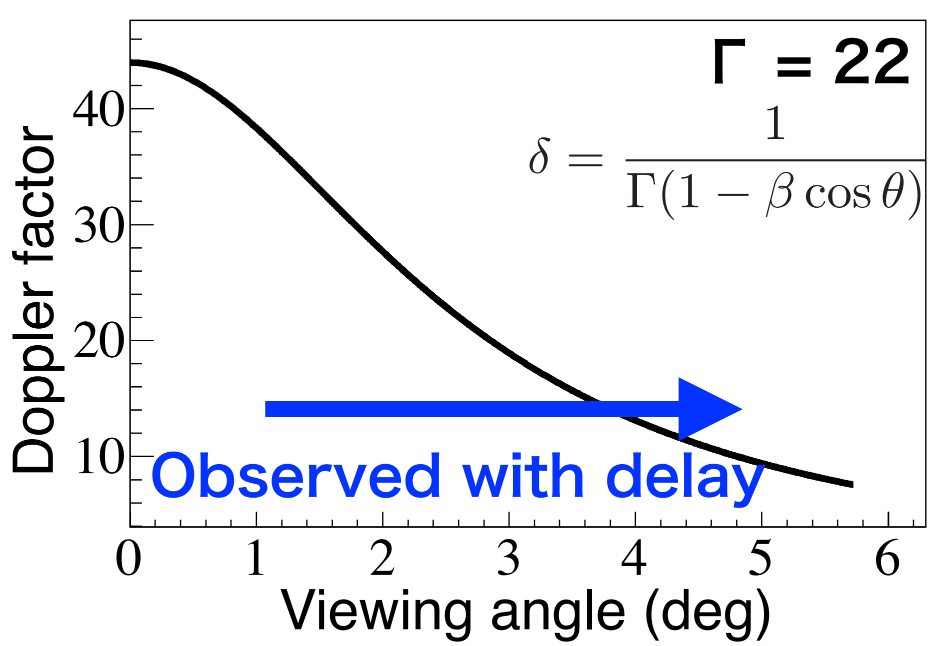
data poiints from Saito+2013

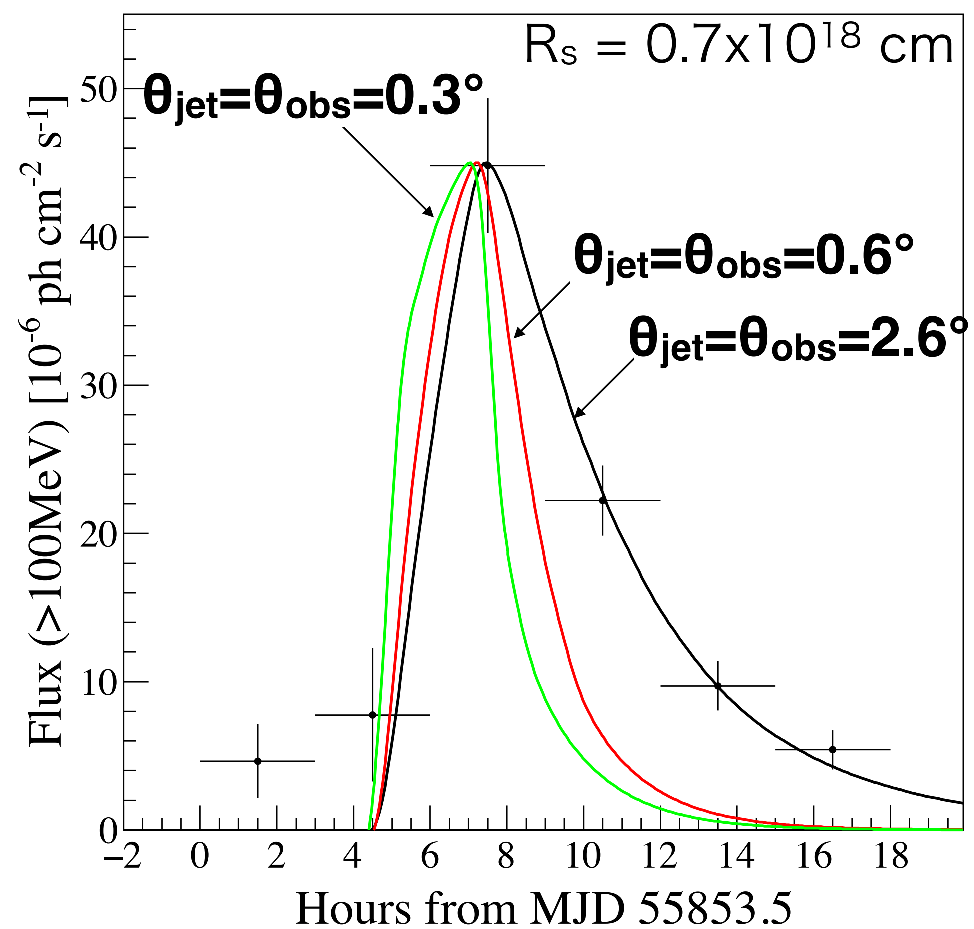
Effect of Non-uniform Doppler Factor on Observed Light Curves

・Gradient in Doppler factor across the jet due to the difference in viewing angle significantly affects the observed flaring timescale.

→Observed flaring light curves are not characterised only by cooling timescale of relativistic electrons.

(Electron cooling time via inverse Compton scattering is only ~30 mins at 10^{18} cm.)

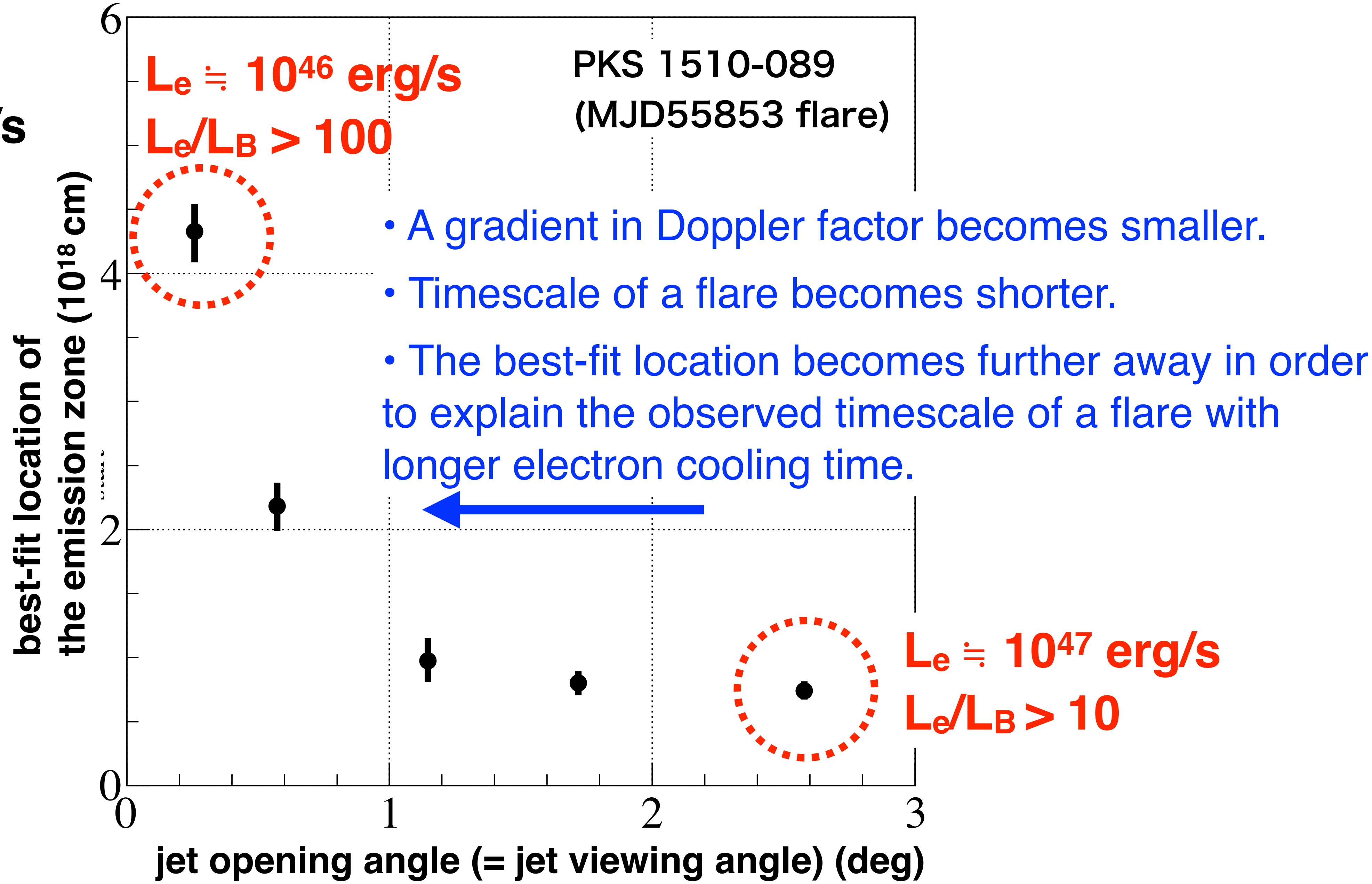




Emission zone for a highly collimated jet

- Gamma-ray flaring light curves were simulated for a well-collimated jet (smaller jet opening angle of down to 0.3°: $\Gamma\theta_{jet} \fallingdotseq 0.1$), which is suggested by radio studies (*e.g. Jorstad+05, Clausen-Brown+13*).

$L_{acc} \fallingdotseq 5\times10^{45}$ erg/s



- Exactly simultaneous MWL observations will remove the degeneracy.

Summary

- We collected the brightest samples of gamma-ray flares, and performed time-dependent modeling of gamma-ray flares in FSRQs with time resolution as good as three hours.
- The estimated location of emission zone during gamma-ray flares in PKS 1510-089 is around $\sim 10^{18}$ cm from the central SMBH, which is reconciled with detection of VHE photons reported during GeV flares.
- Observed time profile a flare was found to be characterised not only by electron cooling timescale, but also geometrical effect.