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An expanding one-zone model for studying blazars emission

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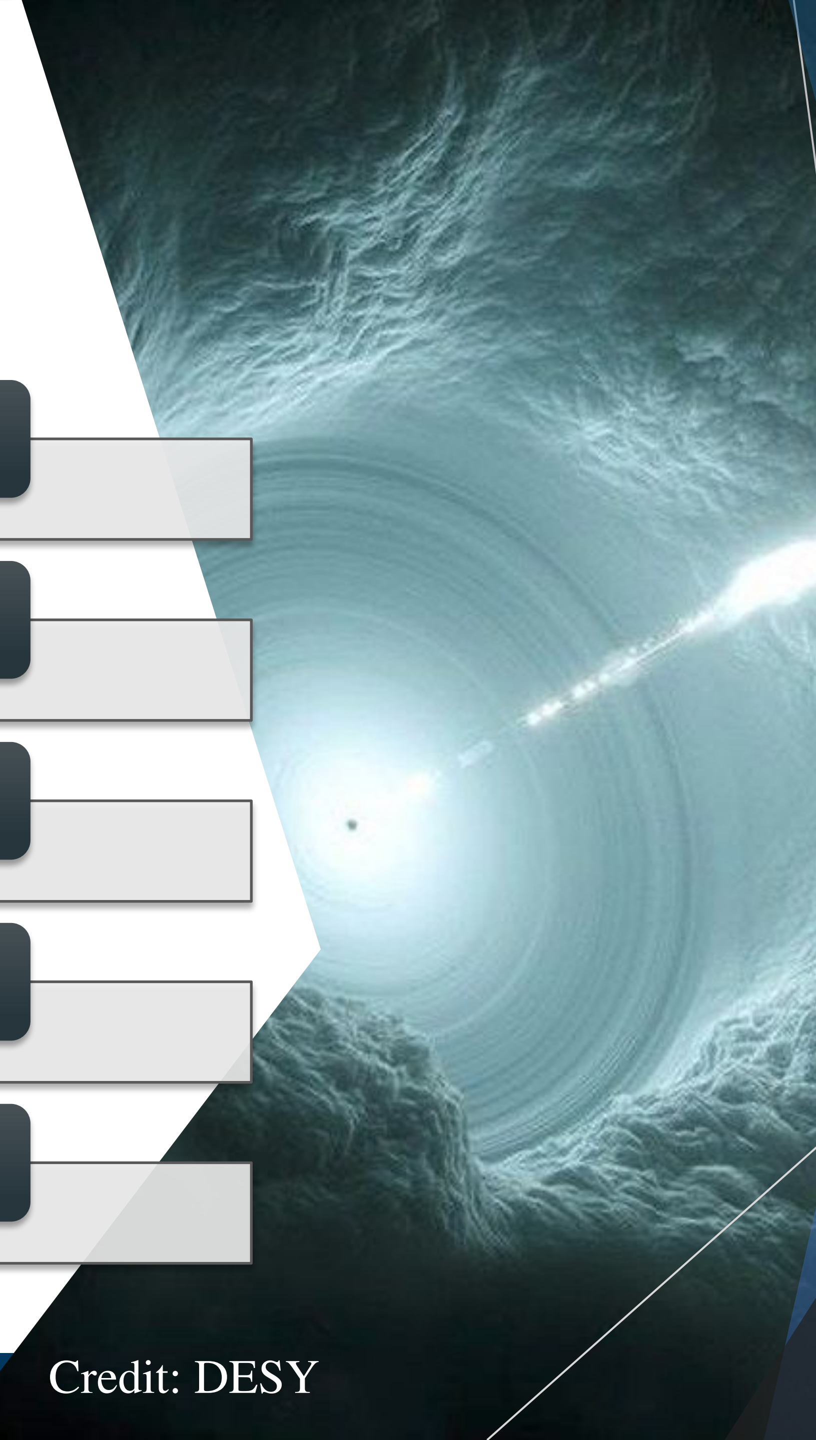
Based on Boula & Mastichiadis, A&A, 2021

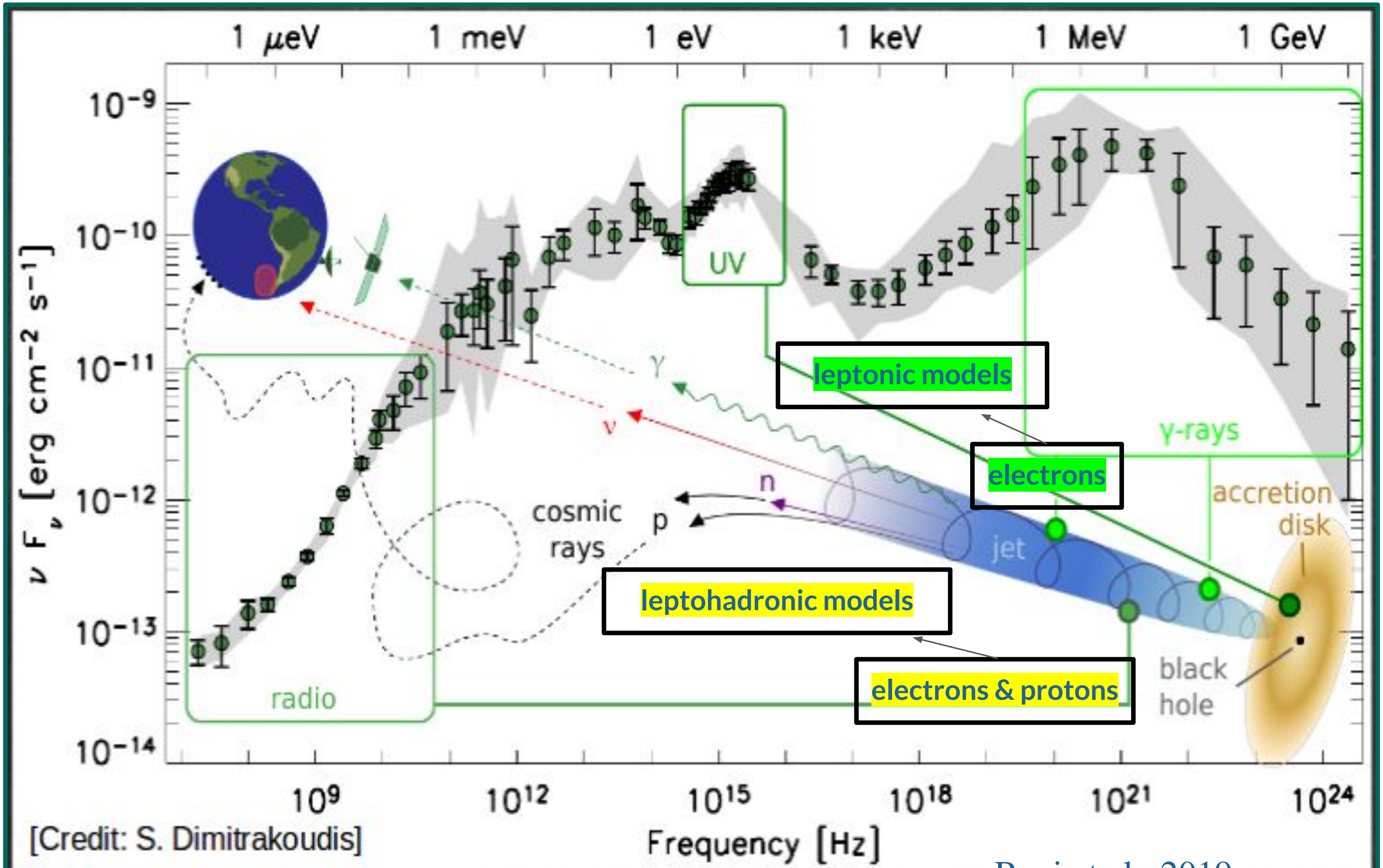
Outline

- Introduction
- Model
- Numerical Approach
- Results
- Summary



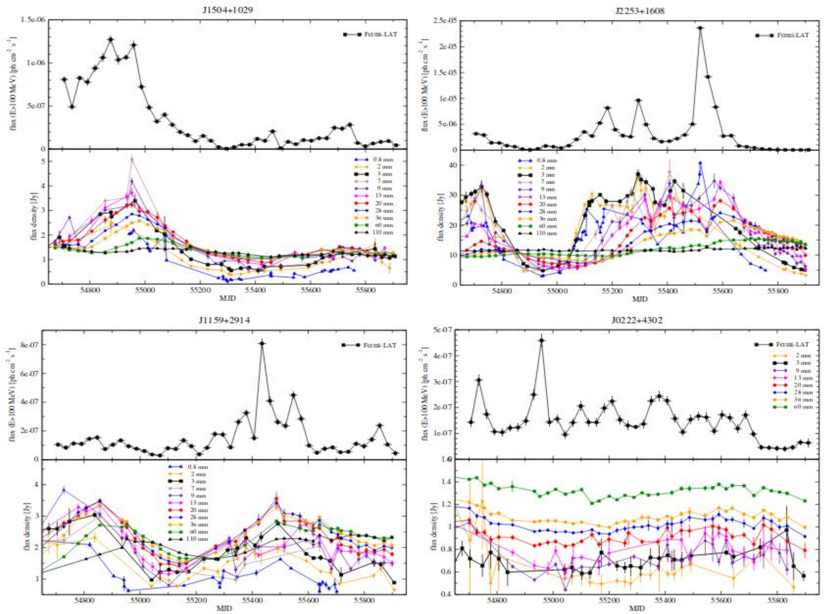
Credit: DESY

Blazars Spectral Energy Distribution (SED)



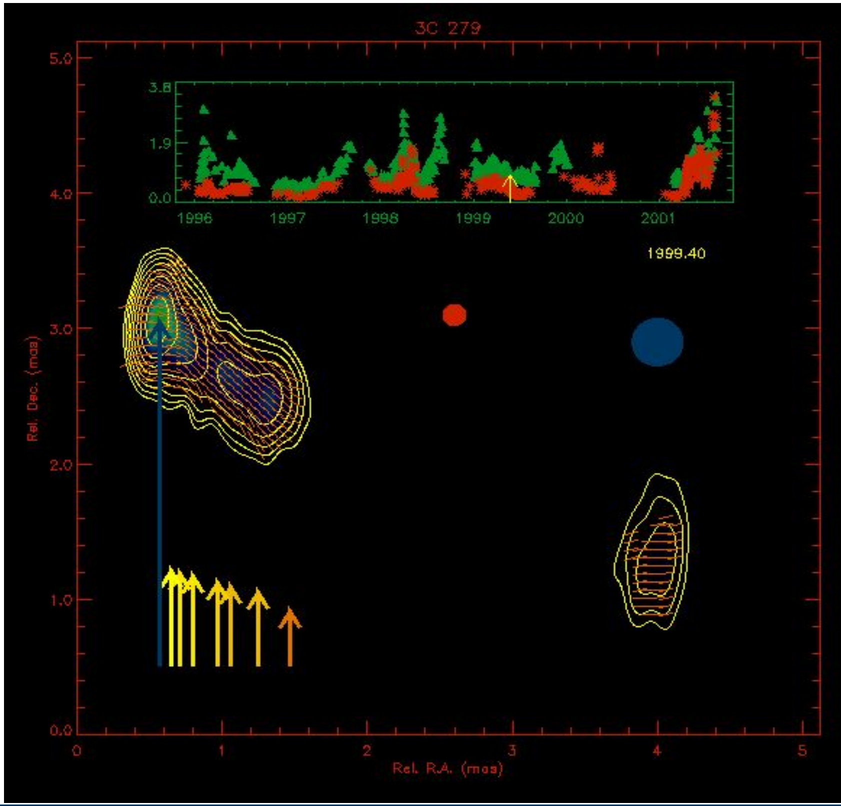
Rani et al., 2019

Blazars Monitoring Programs



F-gamma project

Boston University Blazar Group

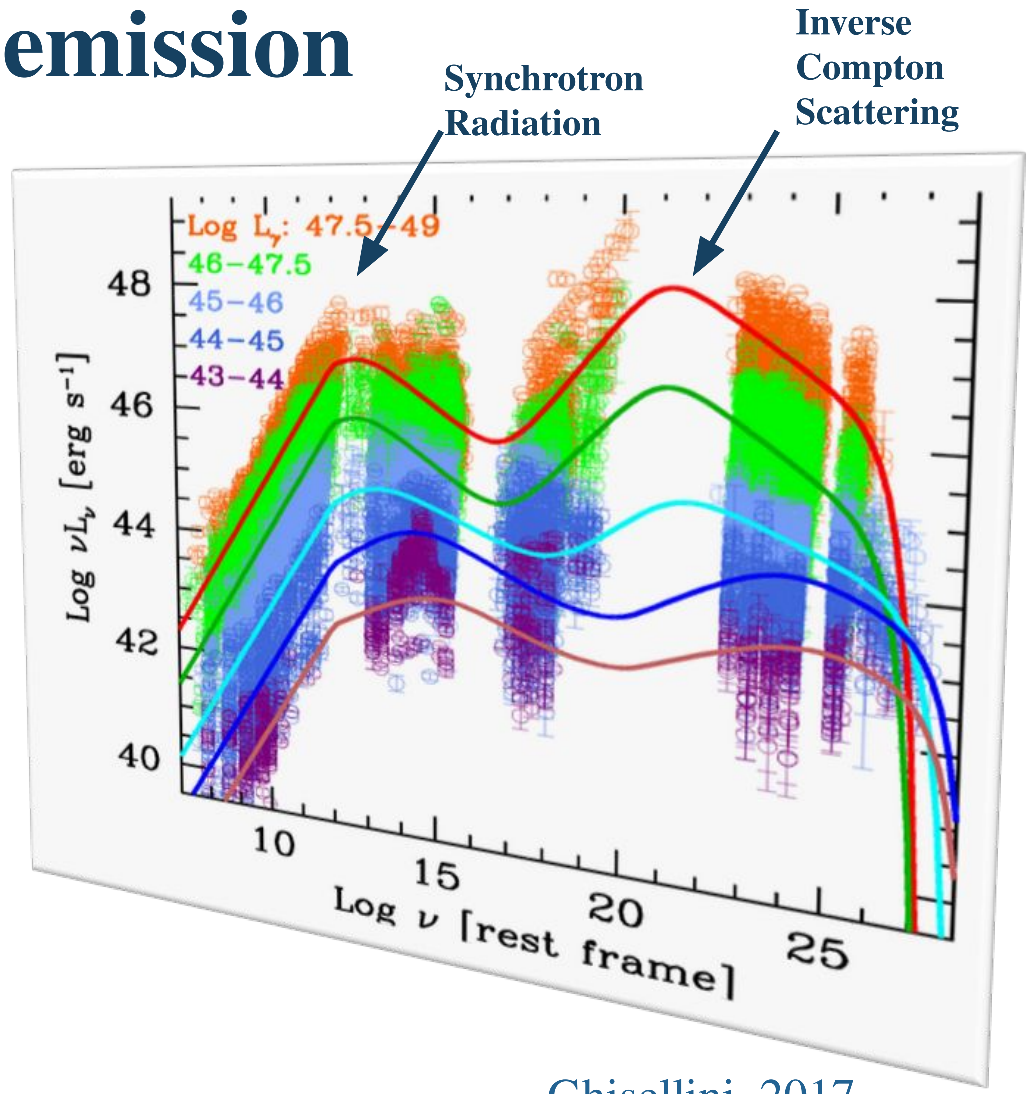


You can find a list of Blazars Monitoring Programs at MOJAVE page: https://www.physics.purdue.edu/MOJAVE/blazarprogramlist.html

Modeling the blazar emission

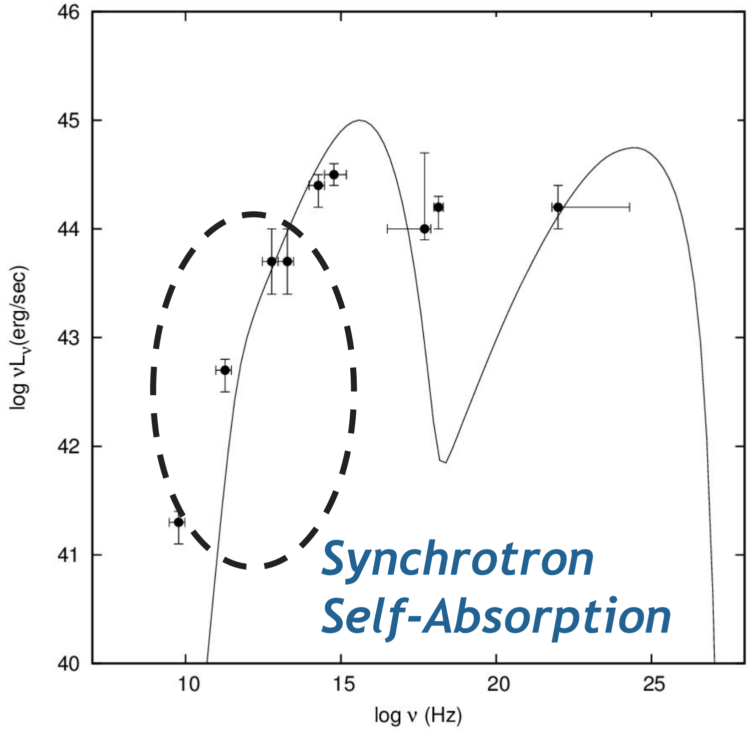
Parameters of the Leptonic Model:

- Radius of the source
- Magnetic field strength
- Electrons energy distribution
- Photon fields
- Bulk Lorentz factor
- Doppler factor



Ghisellini, 2017

Limitations of the one zone leptonic models



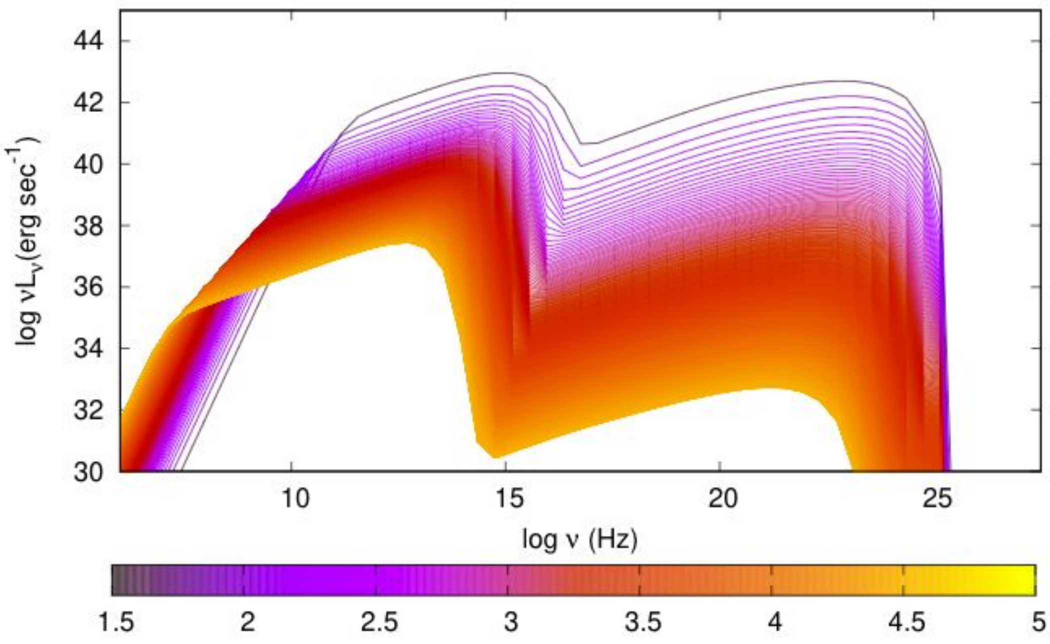
Numerical code:
Mastichiadis & Kirk, 1995, A&A

$$\nu_{ssa} = \left[\frac{\sqrt{3}q^3}{8\pi m}\left(\frac{3q}{2\pi m^3 c^5}\right)^{\frac{p}{2}} C (B \sin\alpha)^{\frac{p+2}{2}} \Gamma\left(\frac{3p+2}{12}\right)\Gamma\left(\frac{3p+22}{12}\right) R\right]^{\frac{2}{p+4}}$$

Rybicki & Lightman, 1974

A new numerical approach:

A one-zone expanding model



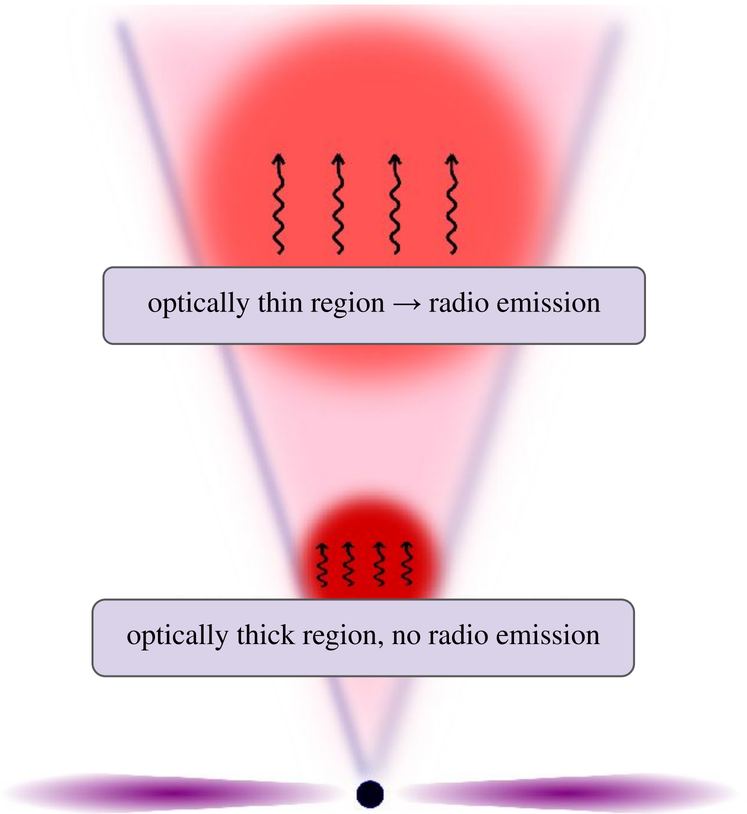
- Synchrotron Radiation
- Inverse Compton Scattering
- Synchrotron Self Absorption
- Photon-Photon Absorption
- Adiabatic Losses

in an **expanding** source

A new numerical code based on Mastichiadis & Kirk, 1995, 1997; see also Boula et al., 2019, Boula & Mastichiadis 2021

Model

- Spherical regions of accelerated particles, that move along the jet and at the same time are expanding.
- Superposition of the emission of these blobs leads to a continuous jet emission.

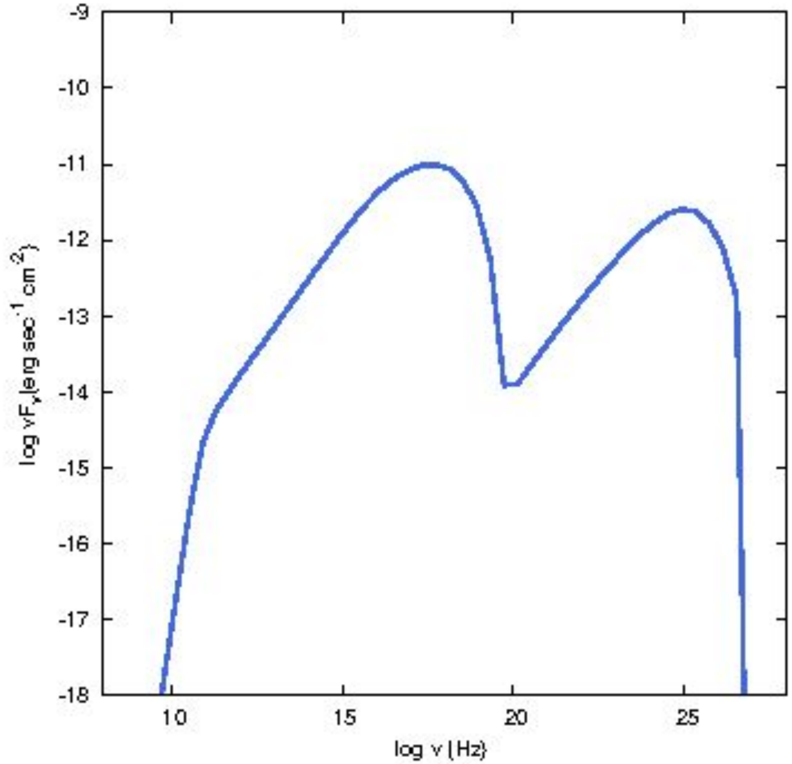


$$R(t) = R_0 + u_{exp} t, \qquad B = B_0 \left(R_0 / R\right)^s$$

$$\frac{\partial N(\gamma, R)}{\partial R} + \frac{\partial}{\partial \gamma}\left[\left(A_{syn}(\gamma, R) + A_{ICS}(\gamma, R) + A_{exp}(\gamma, R)\right) N(\gamma, R)\right] = Q_e(\gamma, R),$$

$$Q_e(\gamma, R) = q_e(R)\gamma^{-p} = q_{e_0}\left(\frac{R_0}{R}\right)^{\chi}\gamma^{-p}, \quad \gamma_{min} \leq \gamma \leq \gamma_{max}.$$

Steady State Emission of Mrk 421



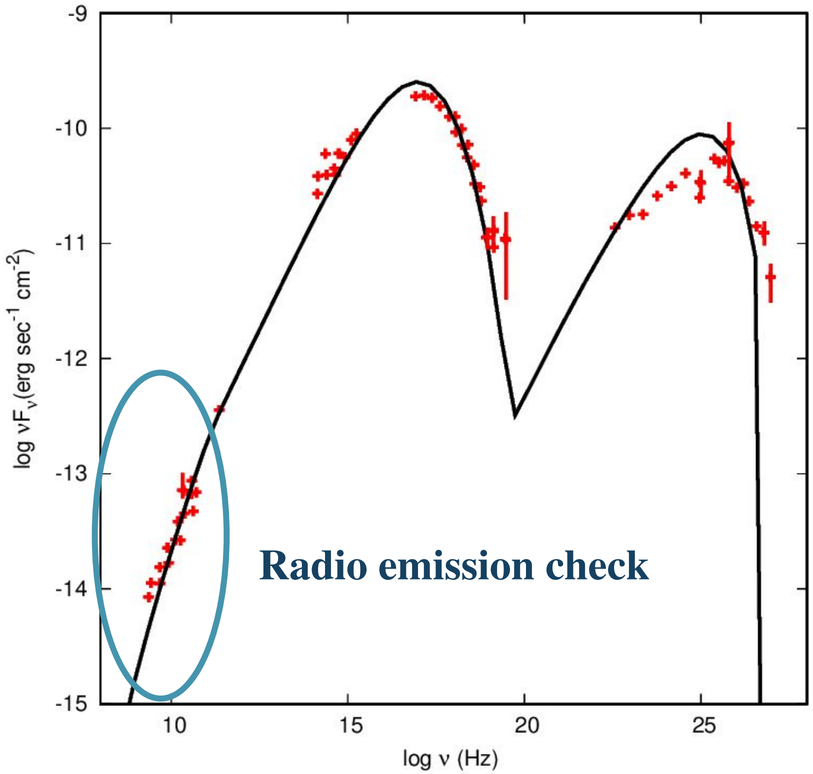
Produced by supeposition of expandinhg blobs injected at z_0 = 0.01 pc with the following properties:

B_0 = 0.3 G, R_0 = 1.e16 cm, $L_{inj\ e0}$ = 3.e41 erg/s, u_{exp} = 0.2c, γ_{min} = 1, γ_{max} = 1.e6,

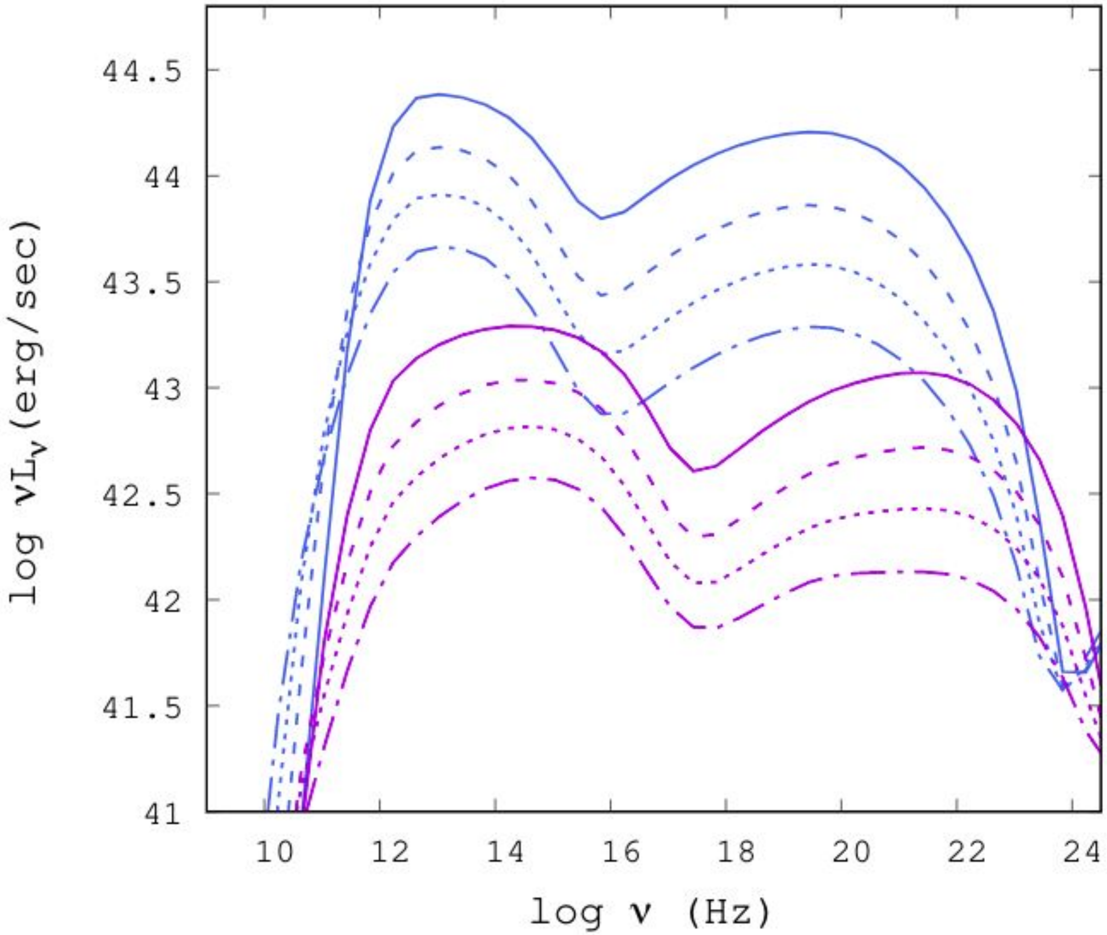
slope index= -2, δ = 10.

The magnetic field and electron injection luminosity decrease linearly with radius

Steady State Emission of Mrk 421

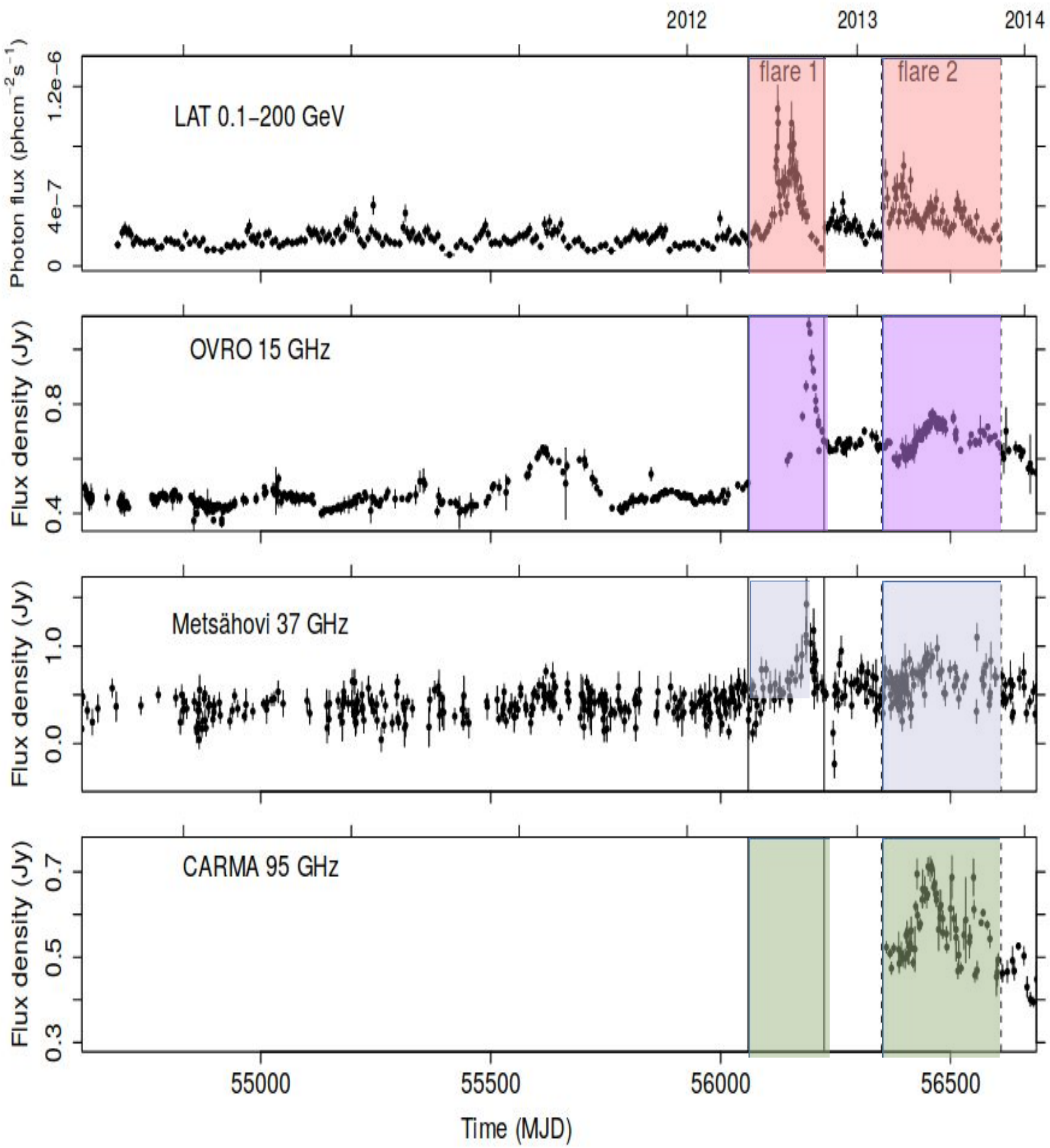


Different mass accretion rates and expansion velocities



B_0(G)	$L_{e_0}^{inj}$ $\left(\frac{erg}{sec}\right)$	γ_{max}	Blazar Class
1.5	43.5	4	LBL
1.0	42.5	5	HBL

u_{exp} = 0.010, 0.025, 0.050, 0.100

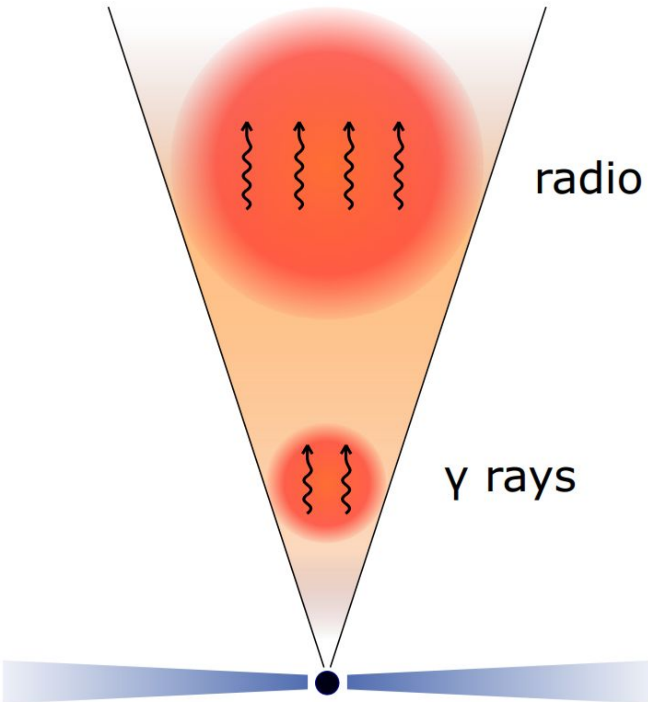


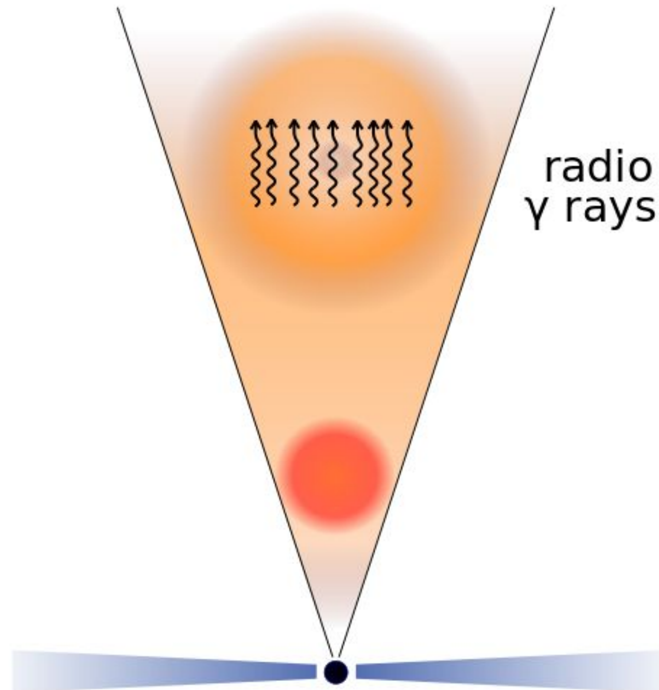
Challenges: The connection of γ-ray and radio flare

- Is there a causal connection between γ-ray and radio flares?
- What drives the time-lag between radio and γ-ray flares?

A combined radio and GeV gamma-ray view of the 2012 and 2013 flares of Mrk 421 (Hovatta et al., 2015)

Flaring Episodes





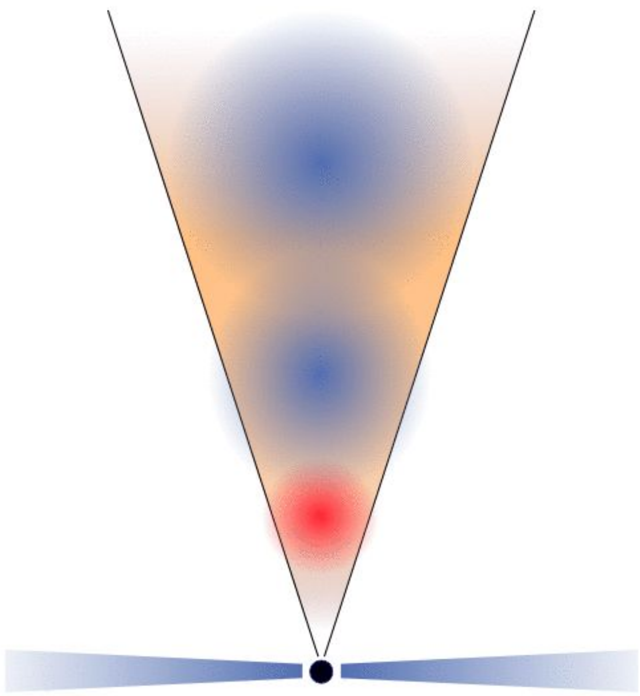
Case 1

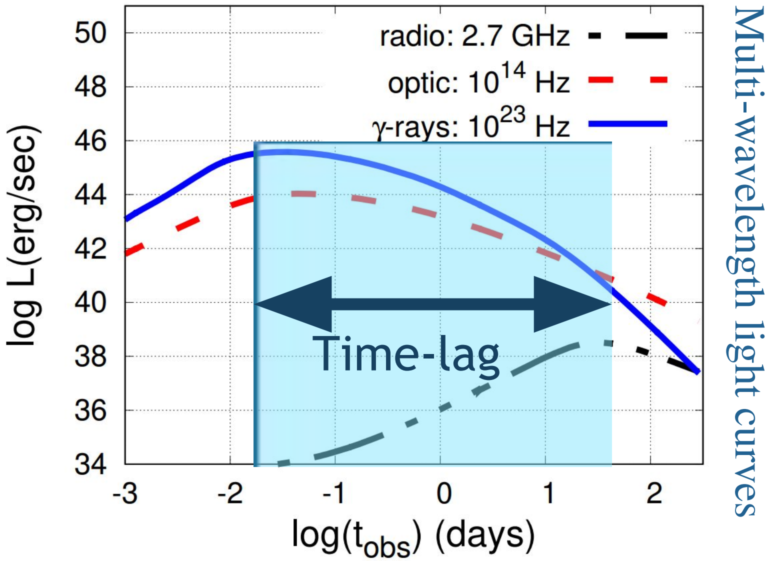
Blob with different initial properties → flare

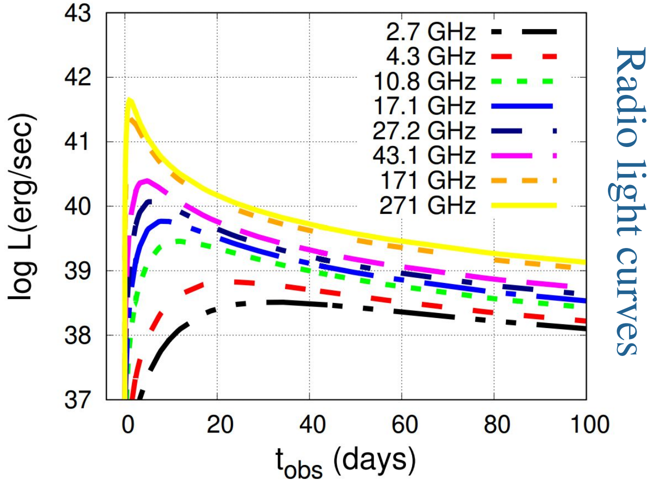
Case 2

Particle re-acceleration at a distance z → flare

Case 1







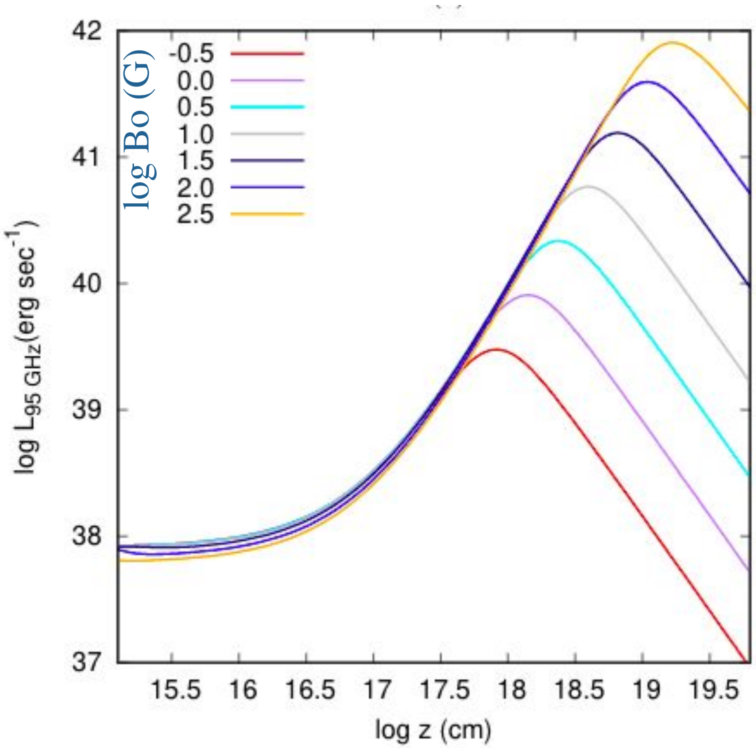
Produced by a single blob injected at $z_0 = 0.001$ pc with the following properties:

$B_0 = 1$ G, $R_0 = 1.e15$ cm, $L_{inj\ e0} = 1.e43$ erg/s, $u_{exp} = 0.4c$, $\gamma_{min} = 1$, $\gamma_{max} = 1.e5$, $p = 2$, $\delta = 10$.

The magnetic field and electron injection luminosity decrease linearly with radius

Boula et al., 2019

The role of the initial Magnetic Field

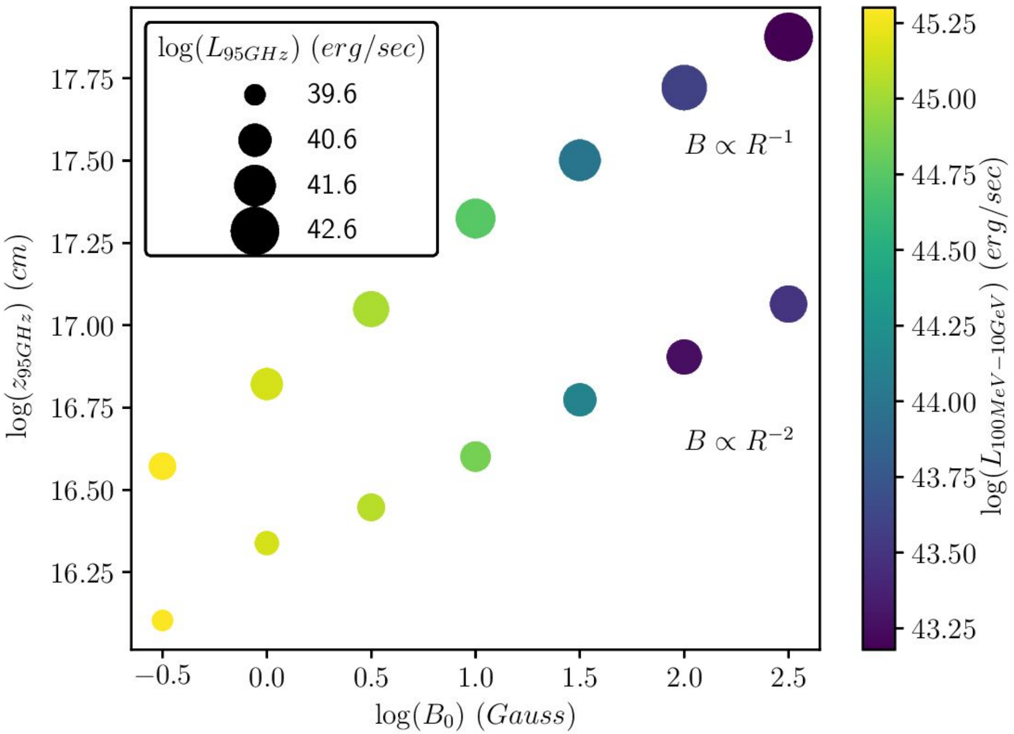


The values of the rest parameters:

R_0 = 1.e15 cm, $L_{inj\ e0}$ = 1.e42 erg/s, u_{exp} = 0.01c,

γ_{min} = 1, γ_{max} = 1.e6, slope index= -2, δ = 10.

The magnetic field strength and electron injection luminosity decrease linearly with radius



The values of the rest parameters:

R_0 = 1.e15 cm, $L_{inj\ e0}$ = 1.e42 erg/s, u_{exp} = 0.1c,

γ_{min} = 1, γ_{max} = 1.e6, slope index= -2, δ = 10.

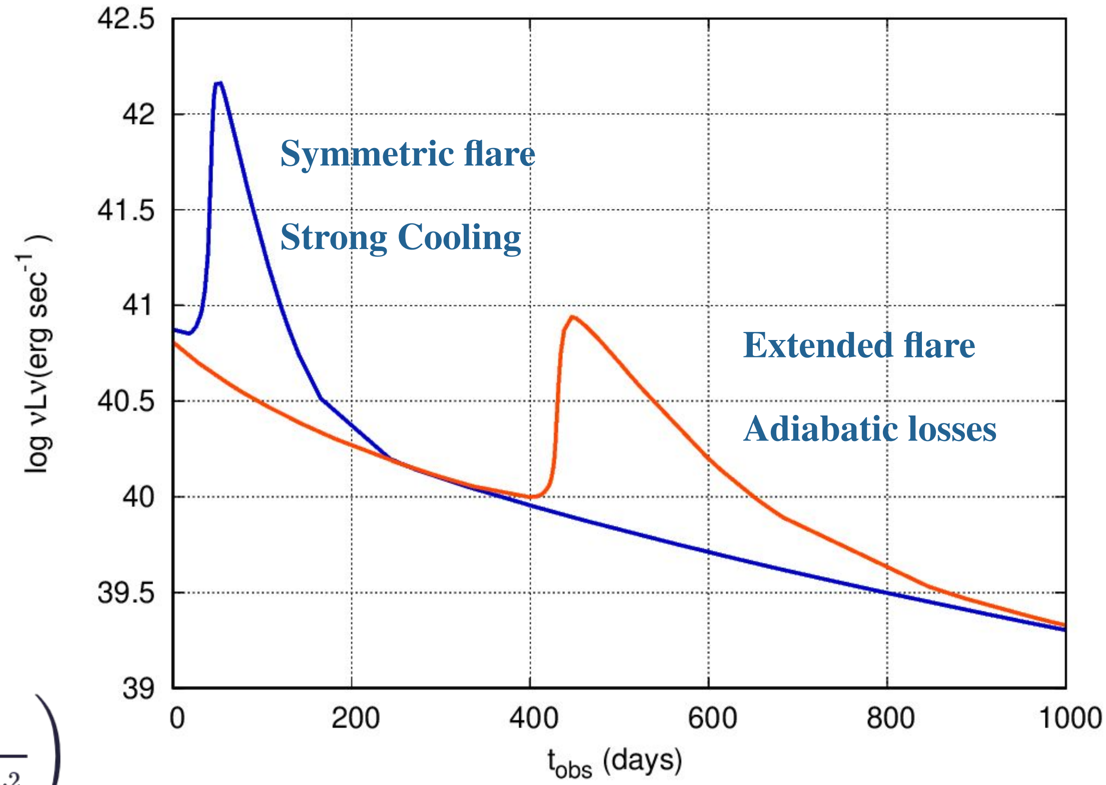
The electron injection luminosity decrease linearly with radius

Case 2

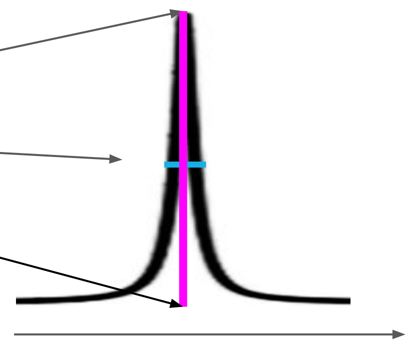
A particle re-acceleration episode "somewhere"into the jet could produce a photon flare.

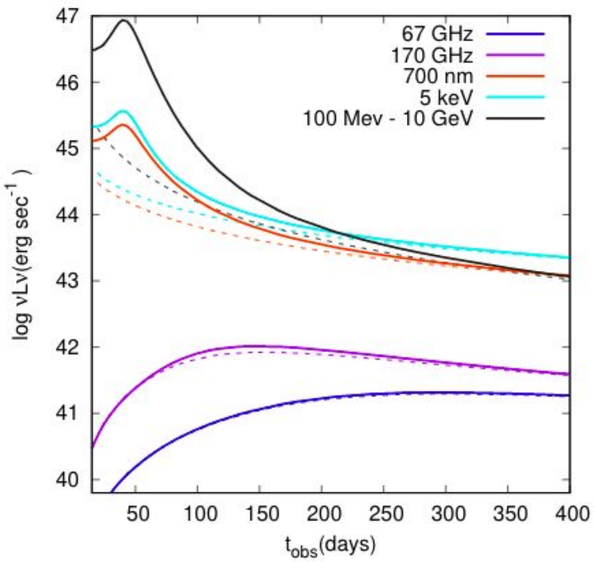
Here we use the assumption that this injection has the form of a lorentzian distribution.

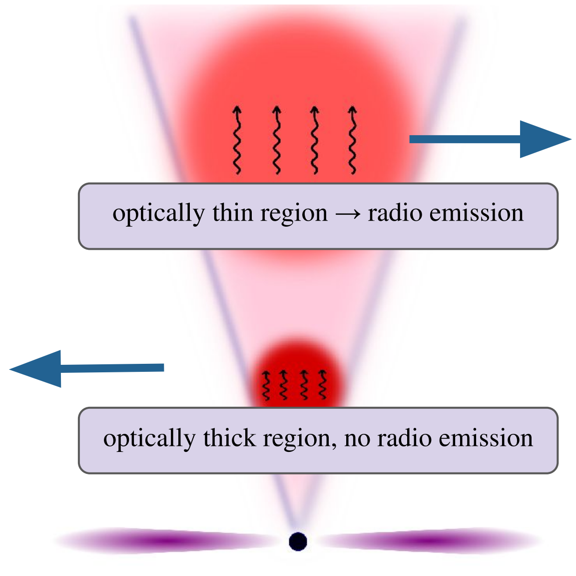
$$Q_e(\gamma,t) = q_e(t)\gamma^{-p}\left(1+\frac{\alpha w^2}{4(t-t_0)^2+w^2}\right)$$

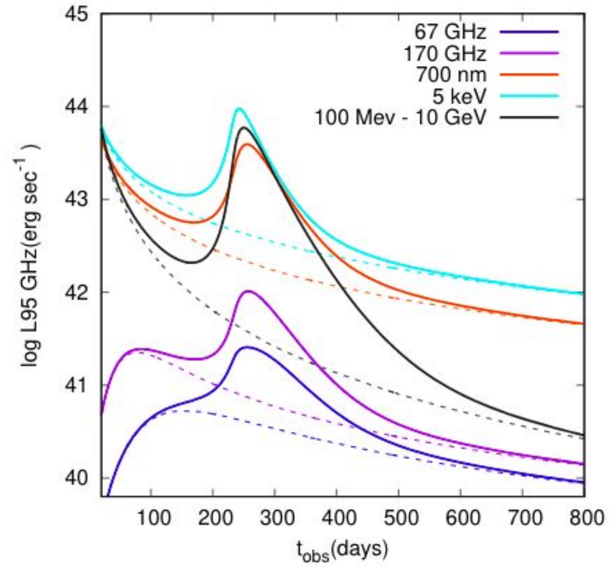


α=the value of the luminosity at the peak
w=the width of the injection
t_0=the time of the injection at the peak







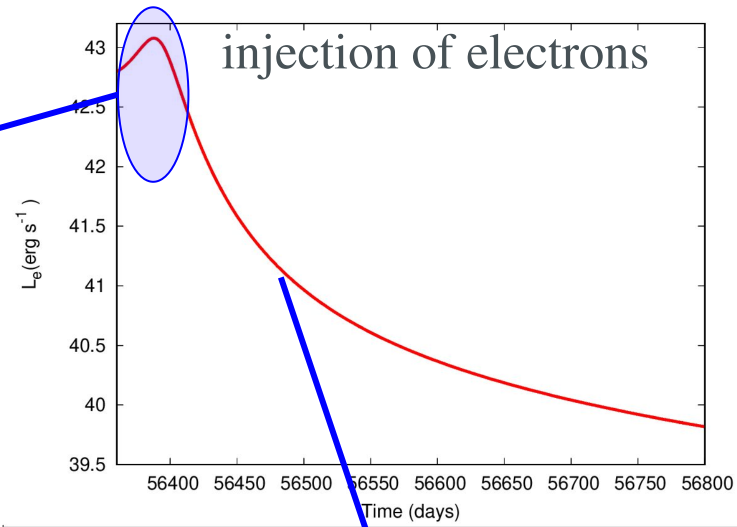


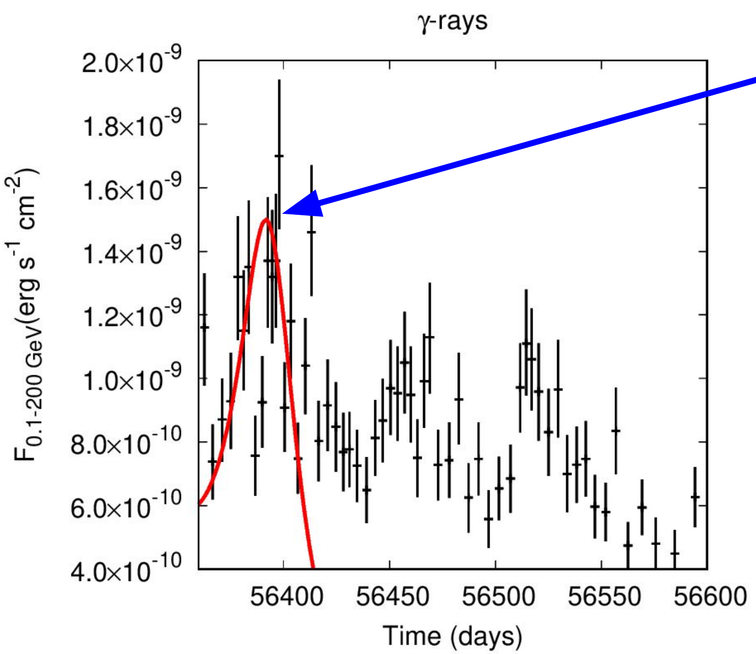
optically thick region

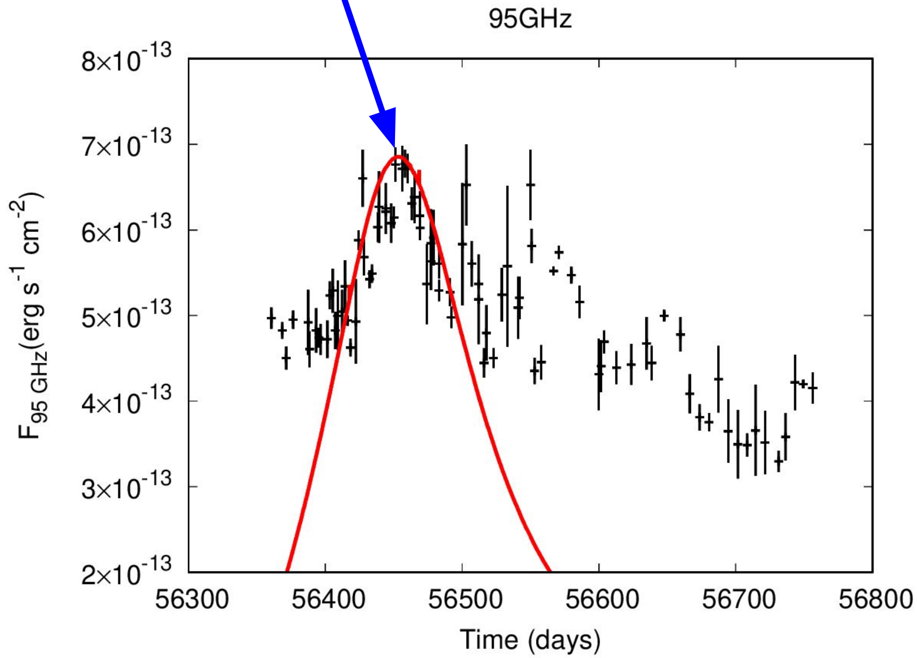
optical thin region

Gamma-ray flare is produced by a re-acceleration episode close to the central engine and radio flare is produced by the transition from the optical thick to the optically thin region

Application to Mrk 421 2013 flaring episode







B_0 = 1,25 G, R_0 = 4.e16 cm, $L_{inj\ e0}$ = 1.58e42 erg/s,

u_{exp} = 0.05c, γ_{min} = 1, γ_{max} = 1.e5, p = 2,

δ = 10.

t_{inj}=40t_{cross}, α = 60, w= 22t_{cross}

$B \propto R^{-1}$

$L_e \propto R^{-2}$

Data by Hovatta et al., 2015

“Keep” home message

- Development of a new one-zone expanding radiation model.
- Study of the steady state emission.
- Prediction of zero or positive time lags, i.e., the γ-rays come first and the radio follow.
- Flares in radio and γ-rays with a wide range of time-lags may be produced by re-acceleration of electrons.
- Correlations between γ-rays and radio flares are studied.

thank you!

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