On the connection of radio and gamma-ray emission of blazars

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Abstract

Blazars are a sub-category of radio-loud Active Galactic Nuclei which is characterized by non thermal emission coming from highly relativistic particles. These sources exhibit in some cases a correlation between gamma-ray and radio emission, especially during flaring episodes. In this work we construct a one zone leptonic model in order to explain these correlations. Adopting the hypothesis that high energy photons are produced by relativistic electrons close to the central black hole, we study the evolution of this population of particles as it moves down the jet and loses energy by radiation and adiabatic expansion. Utilizing a numerical code we calculate the multiwavelength emission as a function of the radial distance which can be translated into a time coordinate once the velocity of the emission region is known. In this scenario gamma-rays are produced early on, while the electrons are still very energetic, while radio emission at a later time when the electrons have cooled and the emission region becomes optically thin to synchrotron self-absorption due to expansion. We will discuss the parameters entering our calculations (like the magnetic field strength, the density of relativistic electrons, etc) in connection to the observational data.

Adiabatic Expansion

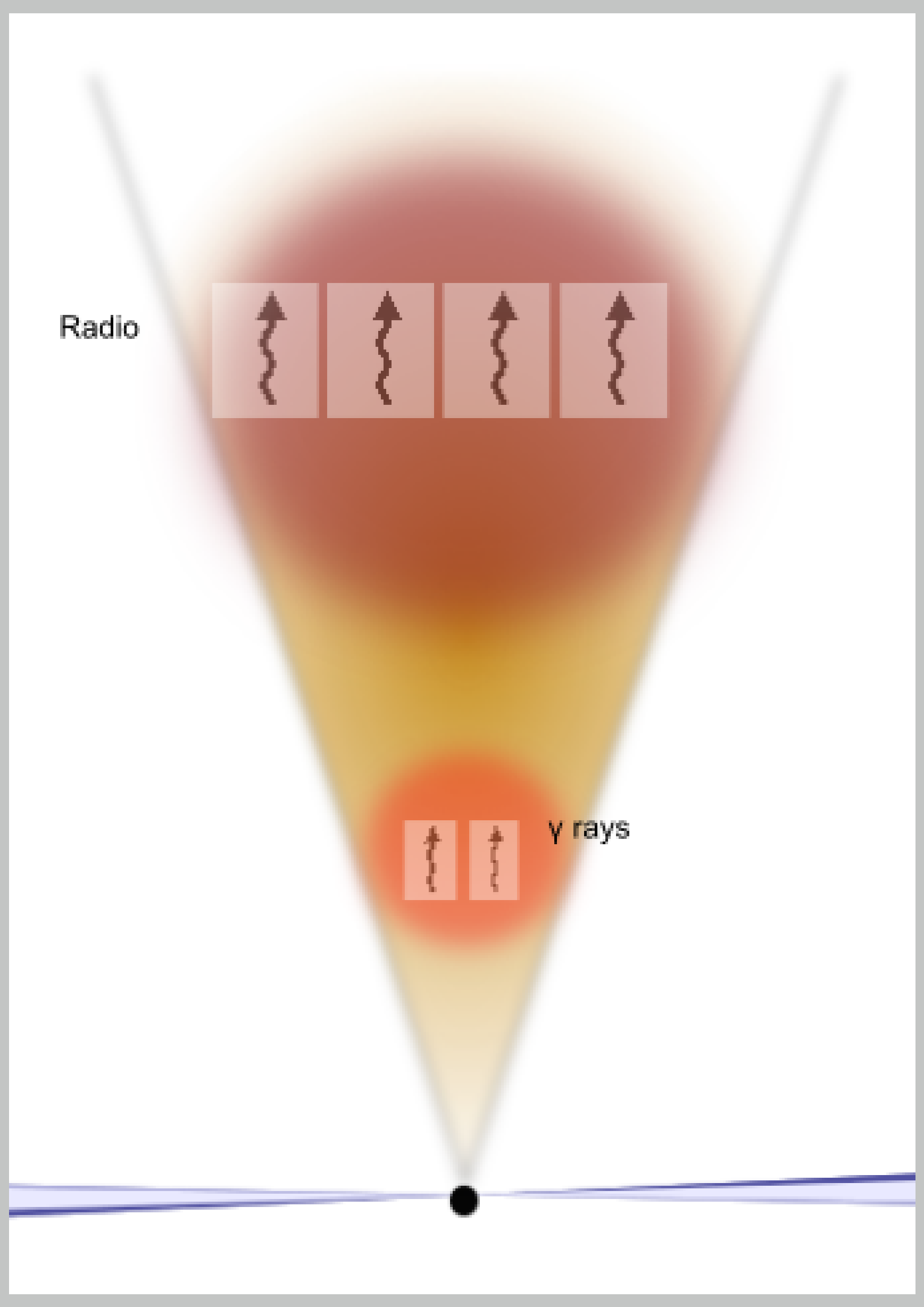

Figure 1: Sketch of the adiabatic expansion of a relativistic radiative blob of plasma. High energy emission is produced close to the central regime; as the source expands it becomes optically thin to synchrotron self absorption and radio photons are emitted.

In this work we construct a simple leptonic model in order to explain the steady state Spectral Energy Distribution (SED) as well as flaring episodes of blazars by taking into account radiative and adiabatic losses [1]. The emitting region is assumed to be spherical with initial radius R_o in its comoving frame, to move with highly relativistic speed βc, giving it a Lorentz factor $\Gamma = (1-\beta^2)^{-1/2}$ and at the same time to expand with a velocity u_{exp}. The jet makes an angle to our line of sight θ, so the Doppler factor is $\delta = [\Gamma(1-\beta\cos\theta)]^{-1}$. The characteristic timescale of the problem is the crossing time of the blob $t_{cross} = R_0/c$ in its initial position. Utilizing the numerical code of [3] we solve the integro-differential equations of electrons and photons and we produce the SED of BL Lac objects. These kinetic equations have the form:

$$\frac{\partial n_i}{\partial t} + \frac{n_i}{t_{esc}} = \mathcal{L}_i + \mathcal{Q}_i \qquad (1)$$

where n_i is ths differential number density of electrons and photons, $\mathcal{L}_i$ the terms of energy losses and $\mathcal{Q}_i$ the injection terms. In the case of electrons:

$$\mathcal{L}_e = \mathcal{L}_{syn} + \mathcal{L}_{ICS} + \mathcal{L}_{ad} \qquad (2)$$

where $\mathcal{L}_{syn}$, $\mathcal{L}_{ICS}$ and $\mathcal{L}_{ad}$ are the losses due to synchrotron radiation, inverse compton scattering and adiabatic expansion, respectively.

We assume that the electron injected rate has the form of a power law:

$$Q_e(\gamma) = k_e \gamma^{-p} \quad \gamma_{min} \le \gamma \le \gamma_{max},$$

where k_e is the normalization factor, p is the slope of the power law, γ_{min} and γ_{max} is the minimum and maximum electrons Lorentz factor, respectively.

Figures (2), (3) show the SED of a specific model, in this case the initial size of the source is $R_0 = 2 \times 10^{15}$ cm, the expansion velocity is $u_{exp} = 0.1$ c, the initial value of the magnetic field is $B_0 = 2.5$ Gauss, the electron luminosity is $L_{e0} = 10^{42}\ \frac{\mathrm{erg}}{\mathrm{sec}}$, $\gamma_{min} = 3 \times 10^2$, $\gamma_{max} = 10^5$, $p = 1.9$ and the Doppler factor has the value $\delta = 5$.

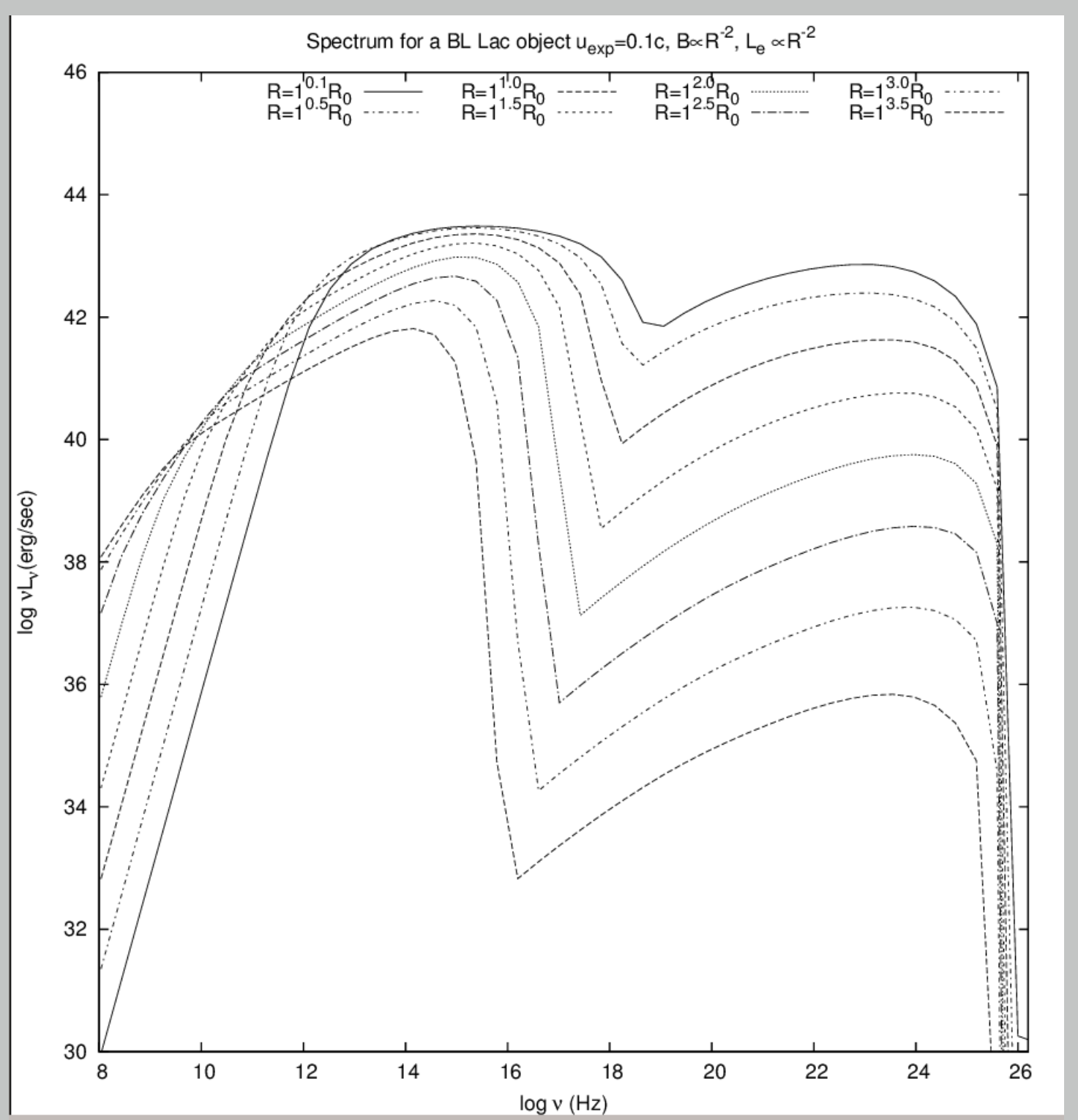

Figure 2: Snapshots of photon spectra at various radii in the case where magnetic field and electron luminosity decrease as R^{-1} as the source expands .

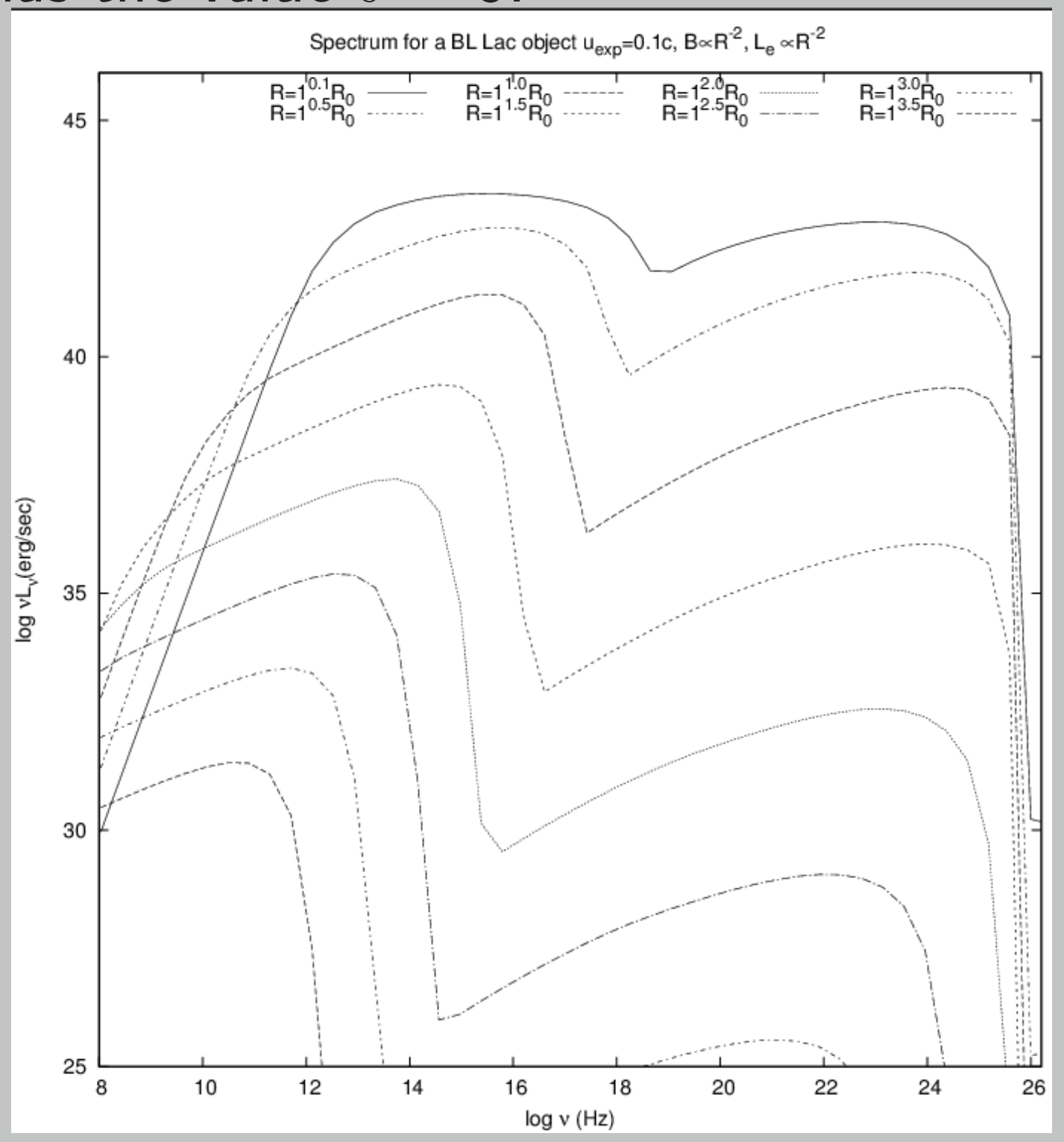

Figure 3: The same as figure 2, but in this case as the source expands the various quantities are assumed to decrease as R^{-2}.

Mrk 421 - Preliminary Results

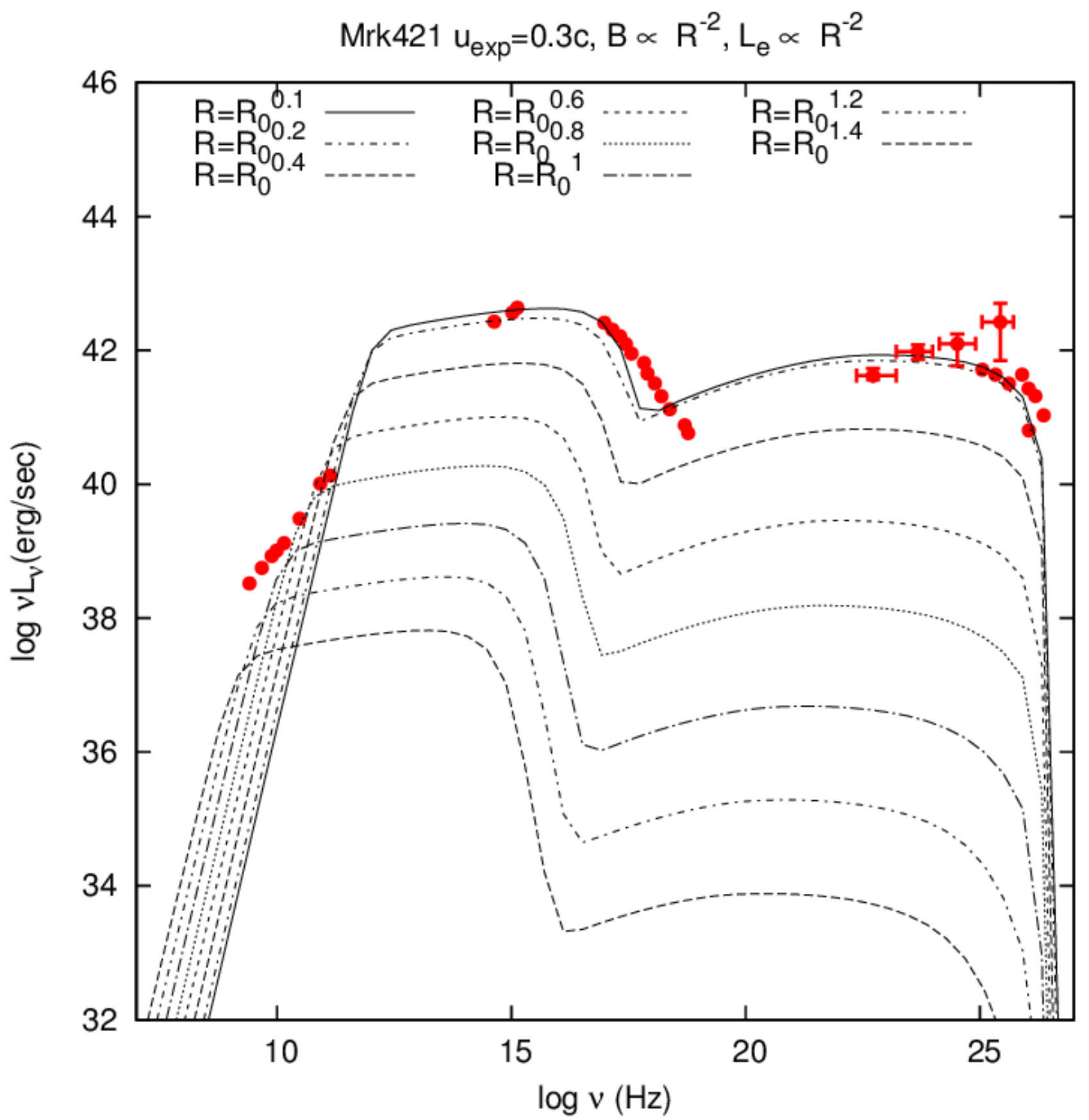

Figure 4: Time dependent SED of Mrk 421.

Figure 4 depicts the evolution of Mrk421 SED in time. The dependence of physical quantities (such as magnetic field and electron luminosity) on R has the functional form $\propto R^{-2}$.

R_0	1.2×10^{15} cm
B_0	0.1 Gauss
L_{e0}	$10^{42}\ \frac{\mathrm{erg}}{\mathrm{sec}}$
u_{exp}	0.3 c
p	2.7
γ_{min}	10^2
γ_{max}	1.2×10^5
δ	30

Table 1: The parameters of Mrk421 fiting model due to expansion.

Flare - Preliminary results

Assuming that the observed radio and gamma-ray flares are physically connected (see for example [2]), we simulate a flare by adopting a lorentzian functional form for the injected electrons:

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

where α gives the value at the maximum, w is a parameter specifying the width of the injection and t_0 is the time when the maximum electron luminosity is injected.

In figure 5 we produce the time dependent SED of a BL Lac object in the case where magnetic field and electron luminosity decreases as R^{-2}, the full set of parameters that we used can be found in table 2. We show in figure 6 the connection between radio and gamma-ray emission. There is a time delay of about 5 hours.

R_0	2×10^{15} cm
B_0	2.5 Gauss
L_{e0}	$10^{42}\ \frac{\mathrm{erg}}{\mathrm{sec}}$
u_{exp}	0.1 c
p	1.9
γ_{min}	3×10^2
γ_{max}	10^5
δ	5
w	10
t_0	30 t_{cross}
α	20

Table 2: The parameters for the flaring episode

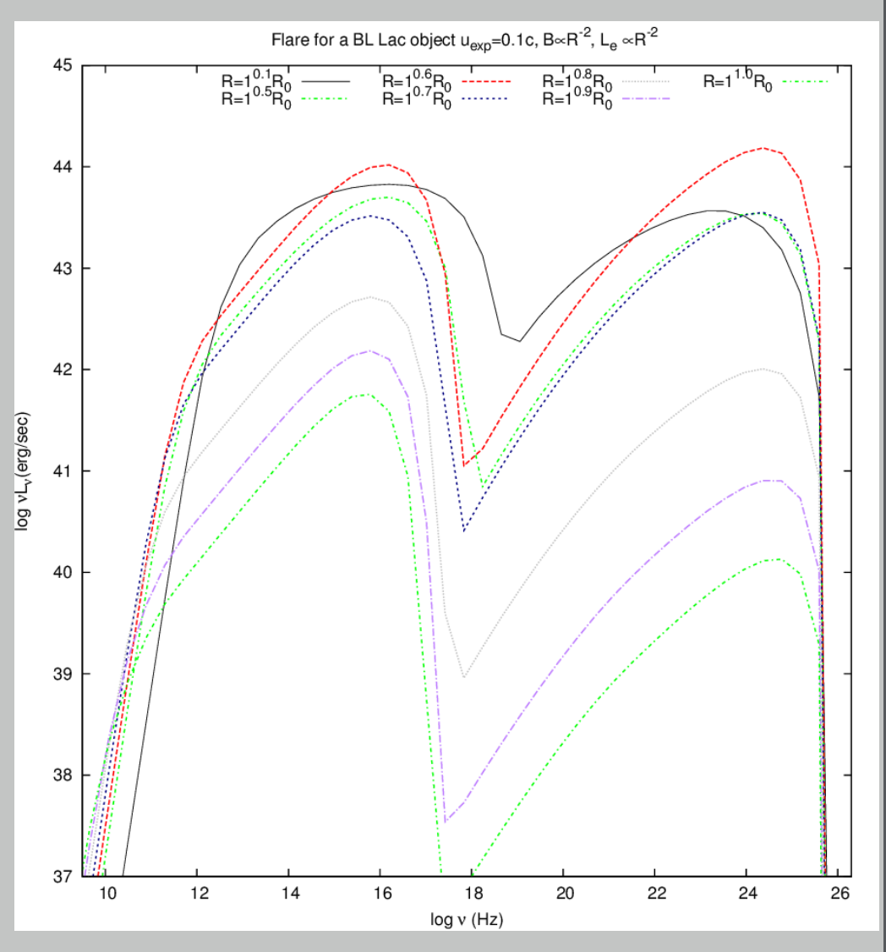

Figure 5: Time evolution of SED in the case of a flaring episode as the source expands.During the flare 100 times more energy is released.

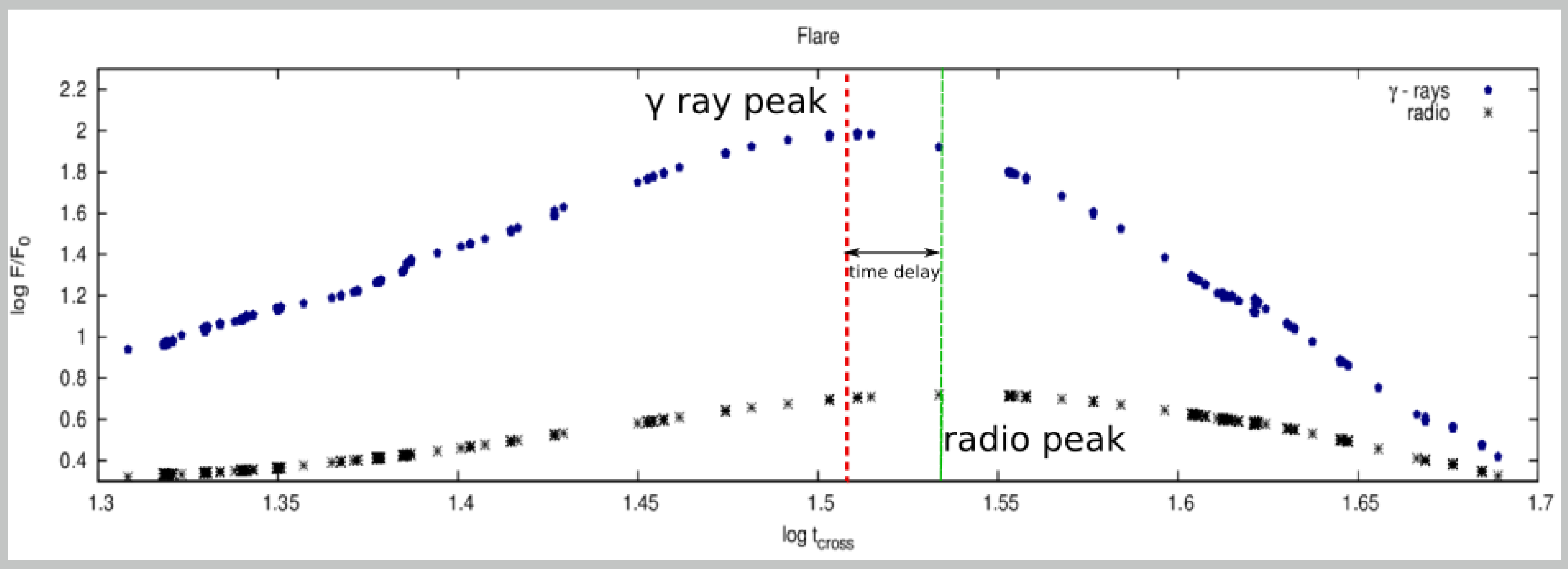

Figure 6: Gamma ray and radio lightcurves for the produced flare in figure 5.

Future Work

Although this work is at a preliminary stage, it shows that radio emission can be produced by the same population of relativistic electrons which produce the gamma ray emission as they travel down the jet losing energy. In principal the parameters of the problem can be related to the blob's distance from the center. We plan to invistigate this possibility and search the parameter space to produce enough SED of BL Lac objects in order to compare with observations during both steady state conditions and flaring episodes.

References

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