Modelling the June 2015 rapid flare of 3C279

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Abstract

Flat Spectrum Radio Quasars (FSRQs), a sub class of Blazars, are strong emitters of electromagnetic radiation, with jets pointing close to our line of sight, strong broad emission lines and a rapid variability ranging from minutes to several hours. Quasar 3C279 is one of the most extensively studied FSRQs. In June 2015 the source underwent a giant outburst with a minute scale variability that was observed by Fermi Large Area Telescope. In this project we investigate whether a one-zone proton synchrotron model could describe the origin of the observed GeV flare. Specifically we examine whether a log-parabolic distribution of relativistic electrons and protons could provide a better fit to the observational data of this flare and also minimize the total power of the jet.

Model Assumptions

- We adopt the standard picture of the one zone hadronic radiation model, according to which a spherical emitting region of radius R_b containing a randomly orientated magnetic field of strength B, is moving with Lorentz factor Γ. We assume that in this region relativistic protons & electrons are injected with a log-parabolic energy distribution

$$Q_{inj} = Q_{inj,0} \, (\frac{\gamma}{\gamma_{peak}})^{-b \; log10(\frac{\gamma}{\gamma_{peak}})} \tag{1}$$

  instead of the usual power-law.

- The radius of the source is inferred from the light crossing time t_{var}

$$R_b = \frac{\delta \; c \; t_{var}}{(1+z)} \tag{2}$$

  where δ is the Doppler factor of the source

$$\delta = [\Gamma(1-\beta \; cos\vartheta)]^{-1} \tag{3}$$

  ϑ the angle with our line of sight and z the redshift of the extragalactic object. The observed minute-scale variability suggests a very compact emitting source.

- Gamma rays are produced via proton synchrotron as well as via radiation of secondaries resulting from photohadronic (pγ) collisions. Target photons for photopion and photopair interactions are those produced from synchrotron emission of co-accelerated relativistic electrons.

- A flare is simulated from some low flux steady-state through a variation of the proton and electron injection function in the form of a lorentzian profile.

$$Q'_{inj}(t) = Q_{inj} \; (1 + (n-1) \; \frac{w^2}{4 \; (t-t_0)^2 + w^2}) \tag{4}$$

Parameters	Value
γ^p_{peak}	10^6
γ^e_{peak}	$10^{1.25}$
b_p	0.3
b_e	1.4
n	2.0
w_p	$9 \; t_{cross}$
w_e	$9 \; t_{cross}$
t_0	$100 \; t_{cross}$

Table 1: Particle injection parameters derived from the numerical modelling, (see equations 1, 4).

- Motivated by the idea of [5], we try fits with values of B and δ that minimize the total jet power

$$P_j = 2\pi \; R_b^2 \; \Gamma^2 \; c \; (U'_p + U'_B) \tag{5}$$

  where U'_p is the proton energy density and U'_B is the magnetic energy density in the fluid frame.

- We take into account absorption of gamma-rays both on soft synchrotron photons inside the emitting region and on photons outside of it coming from the Broad Line Region. For the latter we assume that the Broad Line Region is spherical with radius $R_{blr} = 2.7 \; 10^{17} \; cm$ [3] and luminosity $L_{blr} = 6 \; 10^{44} \; \frac{erg}{sec}$ [2].

Numerical Results

We calculate the time dependent spectra by using the numerical code of Mastichiadis & Kirk [4]. The results, using the parameters from Tables 1 and 2, are shown in Figures 1, 2.

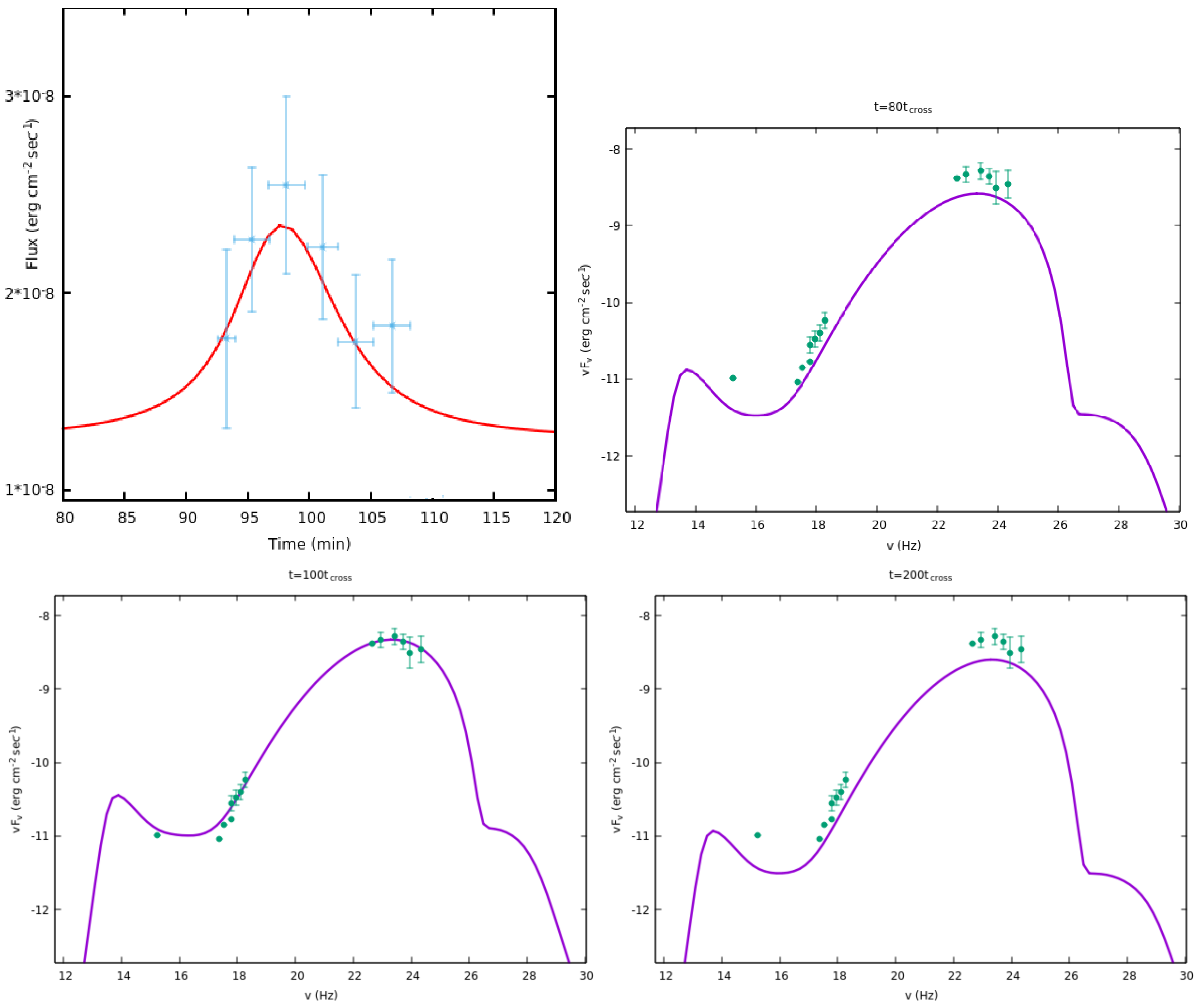

Figure 1: The top left panel shows the $t_{var} < 5 \; min$ lightcurve calculated from our model (red line). The blue points are observational data from Fermi LAT [1]. The other three panels show different snapshots at various crossing times of the source, $t_{cross} = \frac{R}{c}$. Internal photon photon absorption is taken into account. We find that a fit is achieved at snapshot $t = 100t_{cr}$.

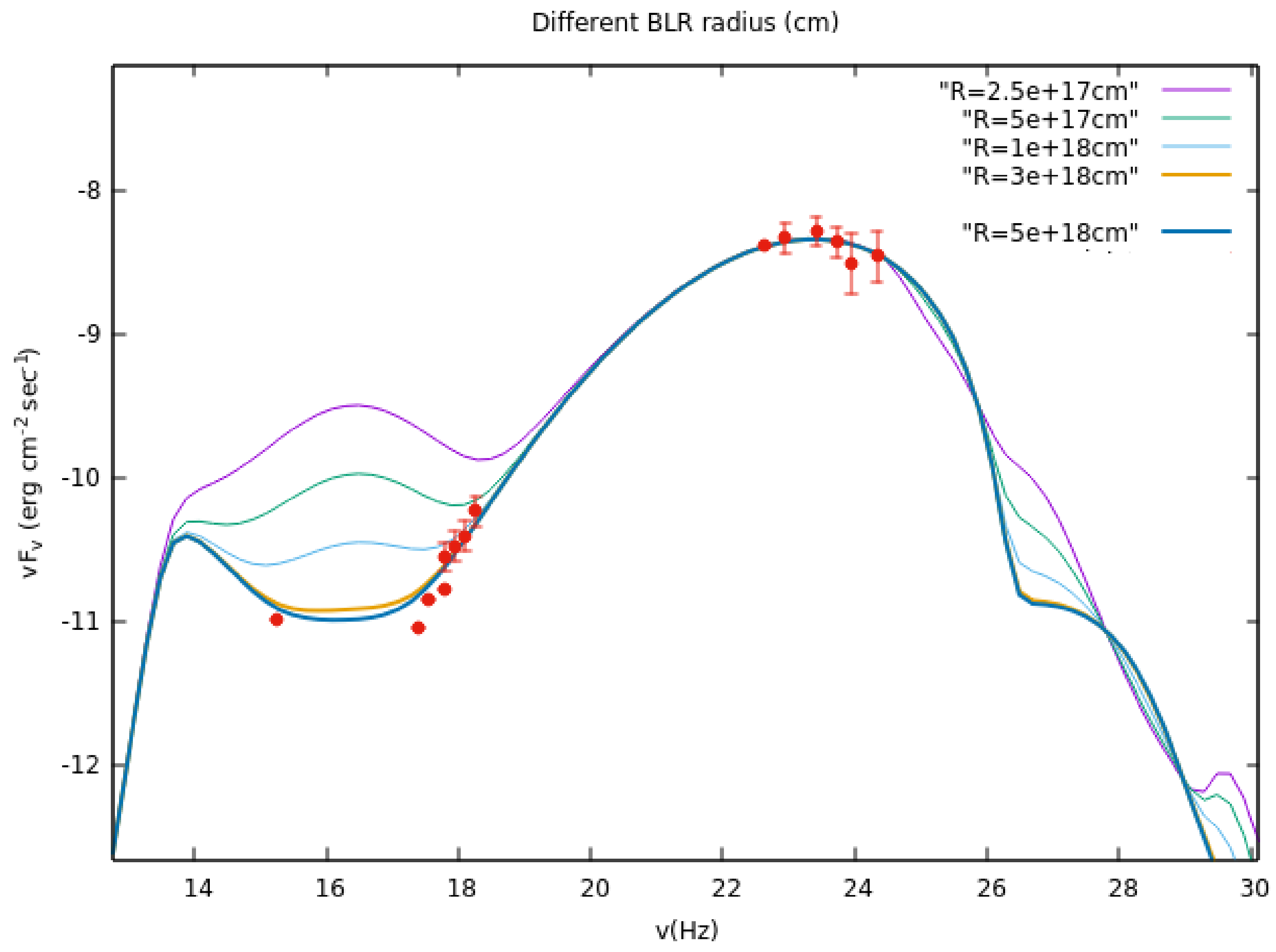

Figure 2: The model light curve (purple curve) if external $\gamma\gamma$ absorption is taken into account. In order to produce a better fit we try to get lower opacity of the Broad Line region by increasing its radius. The different lightcurves produced are depicted. We find that the absorption on soft photons is suppressed and an acceptable fit is achieved only when the emitting source is outside the the Broad Line Region $(R = 5 \; 10^{18} \; cm)$.

Parameters	Value
Doppler factor δ	56
Magnetic Field $B \; (G)$	500
Source Radius $R_b \; (cm)$	$4.4 \; 10^{14}$
Magnetic energy density $U_b \; (\frac{erg}{cm^3})$	$9 \; 10^3$
Proton energy density $U_p \; (\frac{erg}{cm^3})$	$3.5 \; 10^3$
Total jet power $P_j \; (\frac{erg}{sec})$	$3.8 \; 10^{47}$

Table 2: Spectral fiting parameters that produce a fit after the injection of a Log Parabolic particle distribution into the source. The value of total jet power is calculated greater than the Eddington Luminosity of the SBH $L_{edd} = 5 \; 10^{46} \; \frac{erg}{sec}$.

Conclusions

We find that a log-parabolic distribution is preferred in this case over a power law as produces a better fit to the observational data and it minimizes the total jet power. In our scenarios the gamma rays should be produced at the outer edge of the Broad Line Region in order to prevent their absorption on soft photons. Finally, the total jet power is calculated to be about one order of magnitute greater than the Eddington Luminosity of the source while the particles and magnetic fields are found to be in rough equipartition.

References

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