Time-dependent Modeling of Flares from Blazar Jets

Justin D. Finke (US Naval Research Laboratory)

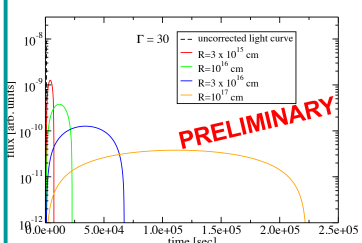
Abstract: I begin with the standard model of a one-zone, relativistically moving, expanding blob in a blazar jet. I describe two features not often taken into account in this type of modeling: light travel time effects and the changing external radiation field, as observed in the frame of the blob. Emission and electron energy loss rates are computed with the full Compton cross-section, taking into account the changing geometry of the external fields. The energy loss rates are used to solve the full continuity equation for the electron distribution, which is used to compute the synchrotron and Compton-scattering emission.

I. Light Travel Time Effect

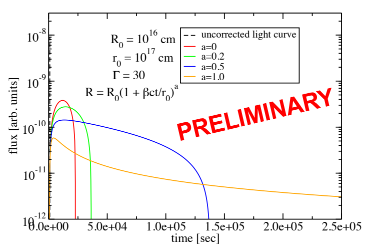
Consider a one-zone jet model for a blazar. Even in this case, photons from the closer part of the blob reach the observer before ones from the farther part of the blob!

For non-expanding blobs, this effect was described by Chiaberge & Ghisellini (1999) and Zacharias & Schlickeiser (2013). I generalize it for ***expanding*** blobs.

Consider a Dirac delta-function flare in a spherical blob of radius R.

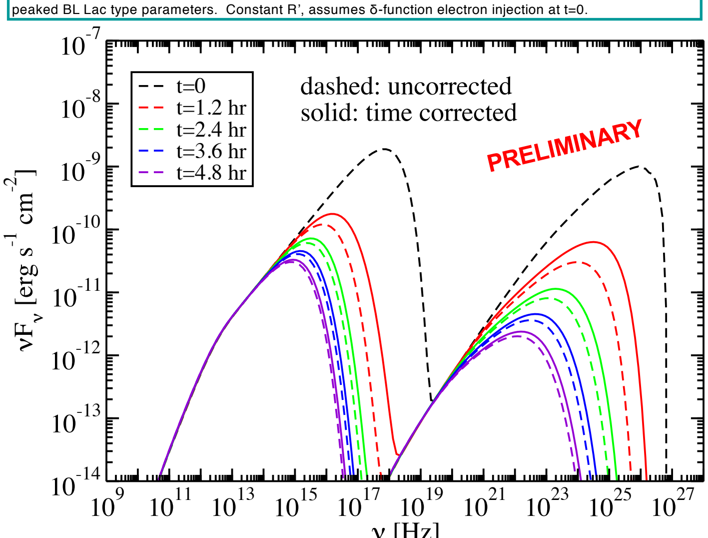


Constant size blob



Expanding blob

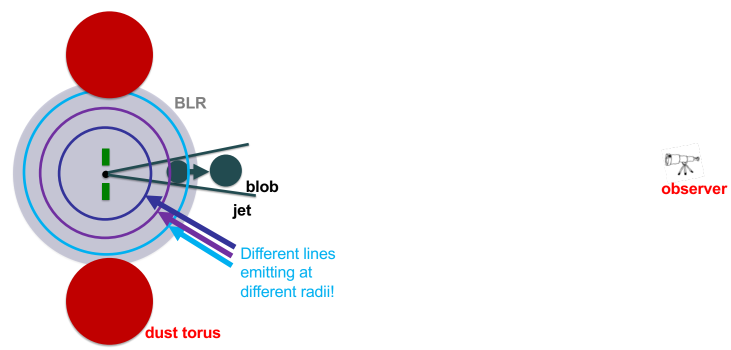
Example of including this effect in a synchrotron/synchrotron self-Compton (SSC) flare model with High-peaked BL Lac type parameters. Constant R', assumes δ-function electron injection at t=0.



Parameters:

z = 0.03	We' = 10^{45} erg
B = 0.52 G	γ1' = 2 x 10^2
Γ = δ = 33	γ2' = 2 x 10^5
R' = 1.3 x 10^{15} cm	p = 1.75

II. Electron energy loss rates



As the blob moves at high relativistic speed, the external radiation field (as seen from the blob) will change. For a 0.1 pc broad-line region (BLR), a blob moving with Γ=30 will move out of the BLR in ***3 hours***. For a 1.0 pc dust torus (DT), the blob will move out of the DT in ***32 hours***.

Gamma-ray flares observed by Fermi often last longer than this!

Detailed emission from Compton scattering of external radiation fields has been computed previously (Dermer et al. 2009; Finke 2016). But one must calculate energy loss rates from Compton scattering to evolve the electron distribution in a self-consistent model!

$$-\langle\dot{\gamma}'(\gamma')\rangle_{\rm rng} = \left(\frac{L_0}{4\pi c x^2}\right)\frac{c\sigma_{\rm T}}{4\pi m_e c^2 \epsilon_0^2}\int_{-1}^{1} d\mu'_e \times \int_0^{2\pi} d\phi'\ S_4(\bar{\epsilon}')\ ,$$

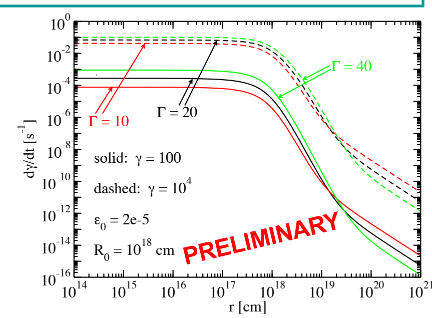
Thomson regime approximations:

r << R_0 reduces to isotropic field:

$$-\langle\dot{\gamma}'(\gamma')\rangle_{\rm rng,in,T} \rightarrow \frac{4}{3}\Gamma^2\left(\frac{L_0}{4\pi c R_0^2}\right)\frac{c\sigma_{\rm T}\gamma'^2}{m_e c^2}$$

r >> R_0 reduces to point source behind jet:

$$-\langle\dot{\gamma}'(\gamma')\rangle_{\rm rng,out,T} \rightarrow \frac{4}{3}\frac{1}{\Gamma^2(1+\beta)^2}\left(\frac{L_0}{4\pi c r^2}\right)\frac{c\sigma_{\rm T}\gamma'^2}{m_e c^2}\ ,$$

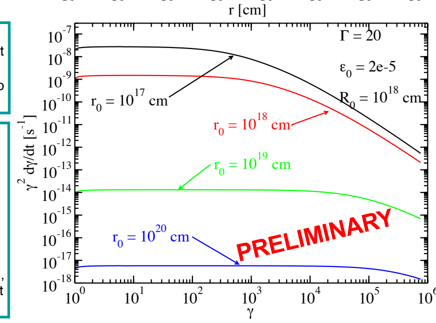


The Klein-Nishina energy depends on blob distance from black hole (r_0)! So one cannot simply scale the energy loss rate with radius! The detailed calculation is needed to accurately include the energy loss rate.

Once dγ/dt is known, one can evolve the electron distribution:

$$\frac{\partial N'_e(\gamma';t')}{\partial t'} + \frac{\partial}{\partial\gamma'}[\langle\dot{\gamma}'(\gamma')\rangle_{\rm tot}N'_e(\gamma';t')] + \frac{N'_e(\gamma';t')}{t'_{\rm esc}} = Q'(\gamma',t')\ ,$$

Then compute the time-dependent emission, taking into account the light travel time effect and changing radiation field!



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