10th Hel.A.S Conference
Ioannina, 5-8 September, 2011
CONTRIBUTED POSTER

Blazar variability patterns

K. Moraitis and A. Mastichiadis
Department of Physics, University of Athens

Abstract: We study the expected variability patterns of blazars within a two-zone acceleration model, focusing on flare shapes and spectral lags. The kinetic equations describing particle evolution in the acceleration and radiation zone are semi-analytically solved. We then perturb the solutions by introducing variations in its key parameters and examine the flaring behaviour of the system. We apply the above to the X-ray observations of blazar 1ES 1218+304, which exhibited a hard-lag behaviour during a flaring episode and discuss possibilities of producing it within the context of our model. Finally, we examine the capabilities of the model for producing high-energy gamma-ray flares.

1 The model

We employ a two-zone acceleration model as developed by [1, 2]. According to this, electrons are accelerated by a non-relativistic shock propagating along a cylindrical jet, and then they escape in a wider region behind the shock where they radiate the bulk of their energy. In order to compute the time-dependent photon spectrum one needs to:
1) Solve the continuity equation

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial \gamma}\left[N\left(\frac{\gamma}{t_{\rm acc}} - \alpha\gamma^2\right)\right] + \frac{N}{t_{\rm esc}} = Q\delta(\gamma - \gamma_{\rm inj}) \tag{1}$$

for the electron distribution function (EDF) in the acceleration zone (AZ), $N(\gamma, t)$, with $\alpha = \sigma_{\rm T}B^2/(6\pi m_{\rm e}c)$.
2) Solve the corresponding equation in the radiation zone (RZ)

$$\frac{\partial n}{\partial t} - \frac{\partial}{\partial \gamma}\left(\alpha\gamma^2 n\right) = \frac{N(\gamma, t)}{t_{\rm esc}}\delta(x - u_{\rm sh}t) \tag{2}$$

for the differential density, $n(\gamma, x, t)$.
3) Convolve with the single particle emissivity, $I_\gamma(\nu)$, according to

$$I_\nu(t) = I_\nu^{\rm AZ}(t) + I_\nu^{\rm RZ}(t) = \int_1^\infty d\gamma N(\gamma, t) I_\gamma(\nu) + \int_1^\infty d\gamma I_\gamma(\nu) \int_0^\infty dx n(\gamma, x, t)\vartheta[x - u_{\rm sh}(t - t_{\rm b})]. \tag{3}$$

The step function ϑ ensures that only radiation from particles inside the 'blob' of size $L = u_{\rm sh}t_{\rm b}$ is considered, where $u_{\rm sh}$ is the shock speed.

Steady-state synchrotron spectra depend on six parameters, namely the acceleration timescale $t_{\rm acc}$, escape timescale $t_{\rm esc}$, magnetic field B, Lorentz factor of injection $\gamma_{\rm inj}$, rate of injection Q and time the shock needs to travel the blob $t_{\rm b}$.

The steady-state EDF in the acceleration zone is a power law with index $s = 1 + t_{\rm acc}/t_{\rm esc}$ up to the maximum Lorentz factor $\gamma_{\rm max} = (\alpha t_{\rm acc})^{-1}$. The resulting EDF in RZ is a broken power-law with the same energy limits as the EDF in the AZ. The power law has an index s for energies less than the breaking energy $\gamma_{\rm br} \simeq \gamma_{\rm max}t_{\rm acc}/t_{\rm b}$ and $(s + 1)$ otherwise.

Variability in our model is produced by letting the system reach its steady state and then varying one or more of the parameters $t_{\rm acc}$, $t_{\rm esc}$, B and Q in the AZ. We adopt the Lorentz profile for the changes and produce a wide variety of flaring behaviours that can be found in [3]. The form of the

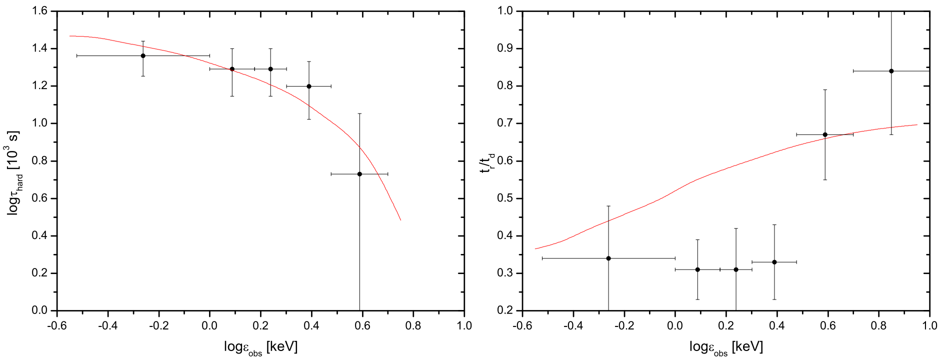

Figure 1: Observed amount of hard lag, $\tau_{\rm hard}(\varepsilon) = t_{\rm pk}(7.1{\rm keV}) - t_{\rm pk}(\varepsilon)$, and ratio $t_{\rm r}/t_{\rm d}$ for the flares of 1ES 1218+304 in the various X-ray energy bands, together with the corresponding theoretical curves. Apart from the overestimation of the ratio $t_{\rm r}/t_{\rm d}$ in the energy interval $1-3$ keV, we reproduce the shape of the flares quite well.

flares is a function of frequency. To quantify this, we define the following parameters for each flare. The time at which the flare peaks, $t_{\rm pk}$, the amplitude of the flare, $y_{\rm pk} = I_\nu(t_{\rm pk})/I_\nu(0)$, the flux doubling time during the rise of the flare, $t_{\rm r}$, and the flux halving time during the decay, $t_{\rm d}$. The ratio $t_{\rm r}/t_{\rm d}$ is then a measure of the time symmetry of the flare, and $w_{\rm fl} = t_{\rm r} + t_{\rm d}$ is the width of the flare.

2 Application to 1ES 1218+304

1ES 1218+304 is a high-frequency peaked BL Lac object at a redshift $z = 0.182$. It was observed in May 2006 with *Suzaku* [4] showing hard-lag flares with asymmetric time profiles. From the photon index in radio frequencies, maximum and breaking frequencies of the radio to X-rays spectrum of 1ES 1218+304 we deduce the parameters s, $t_{\rm b}$ and the relation $\delta B \gamma_{\rm max}^2 \simeq 10^{12}$G, with δ the Doppler factor. The shape of the observed flares is best fit with a Lorentzian change of the injection rate of width $w = 1.7 t_{\rm acc}$ and amplitude $n = 1.4$, as shown in Fig. 1. From the fit we estimate the acceleration timescale $t_{\rm acc} = 1.9\ 10^5\ \delta_{10}$ s, where $\delta_{10} = \delta/10$. This relation enables us to express the magnetic field and maximum electron energy of 1ES 1218+304 as $B = 0.06\ \delta_{10}^{-1/3}$ G and $\gamma_{\rm max} = 1.3\ 10^6\ \delta_{10}^{-1/3}$.

Since the Doppler factor cannot be determined independently, we choose $\delta_{10} = 1$, and deduce the unperturbed value of the injection rate Q. Having estimated all the parameters of the model, we predict the size of the source as $L \simeq 10^{16}$ cm and the energy content of the source in electrons as $\mathcal{E}_{\rm e} = 3\ 10^{48}$ erg.

The method described above can be applied to γ-ray flares as well, but then one needs to include the additional radiation/energy loss mechanisms (i.e. inverse Compton scattering) in the kinetic equations. In the case of scattering in the Thomson limit, this is rather straightforward.

References

[1] Kirk, J.G., Rieger, F.M., and Mastichiadis, A.: 1998, A&A, 333, 452

[2] Kirk, J.G., and Mastichiadis, A.: 1999, APh, 11, 45

[3] Moraitis, K., and Mastichiadis, A.: 2011, A&A, 525, A40

[4] Sato, R., Kataoka, J., Takahashi, T. et al.: 2008, ApJ, 680, L9