High Energy Variability Of Synchrotron-Self Compton Emitting Sources: Why One Zone Models Do Not Work, And How We Can Fix It

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With the anticipated launch of GLAST, the existing X-ray telescopes, and the enhanced capabilities of the new generation of TeV telescopes, developing tools for modeling the variability of high energy sources such as blazars and microquasars is becoming a high priority. We point out the serious, innate problems one zone synchrotron-self Compton models have in simulating high energy variability. We then present the first steps toward a multi zone model where non-local, time delayed Synchrotron-self Compton electron energy losses are taken into account. Our code will not only simulate variability properly, but it will be able to treat sources at stages of high Compton dominance, a situation typical of flaring systems.

1. The One Zone Model

When modeling blazar radiation, past models have all incorporated some form of a one zone model. However, these models are limited by the following factors:

•High-energy electrons cool faster than the light crossing time
•Light crossing effects must be considered

When neither of these are accounted for, this produces variability on scales less than the light crossing time, which is incorrect. One must consider the time that it takes for light to be transmitted from different parts of the zone, and as Chiaberge and Ghisellini (1999) showed in their paper, and as shown below in Figure 1, the shortest observable variability that can be trusted is the light crossing time of the zone.

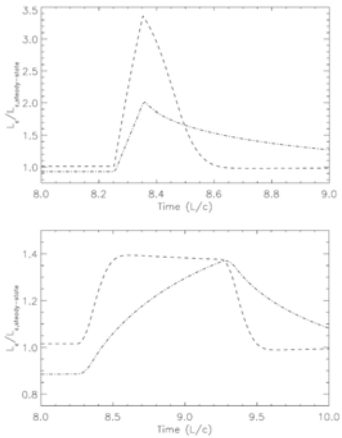

Figure 1. Here the injection is only increased for only one tenth of the light crossing time. The upper graph shows their development over time without delays accounted for. The lower graph accounts for these delays and depicts the minimal observable variation time.

2. The Multi Zone Model

In this model, we couple the equations describing each zone in the following fashion:

Zone 1: $$\frac{\partial n(\gamma,t)}{\partial t}+\frac{\partial}{\partial\gamma}\left[\dot{\gamma}n(\gamma,t)\right]+\frac{n(\gamma,t)}{t_{esc}}=q(\gamma,t)$$

Zone 2: $$\frac{\partial n(\gamma,t)}{\partial t}+\frac{\partial}{\partial\gamma}\left[\dot{\gamma}n(\gamma,t)\right]+\frac{n(\gamma,t)}{t_{esc}}=q(\gamma,t)$$

Zone 3: $$\frac{\partial n(\gamma,t)}{\partial t}+\frac{\partial}{\partial\gamma}\left[\dot{\gamma}n(\gamma,t)\right]+\frac{n(\gamma,t)}{t_{esc}}=q(\gamma,t)$$

$\vdots$ $\vdots$

By doing so, we are able to examine the same spacial region while decreasing the light crossing time for any single zone.

Formulas for the emissions were taken as delta functions as described by Rybicki and Lightman (1979) in order to expedite the simulation.

Time steps in this simulation were used as the escape time of the electrons from one cell to the next. This way, variations in the electron energy distribution would be transmitted at the proper rate and this allows variations to be measured at the smallest interval that can be trusted. Below is a graphical example of the multi zone model, Figure 2.

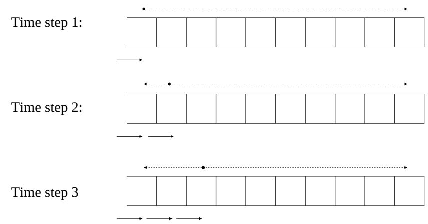

Figure 2. This depicts the energetic electrons (lower arrows) propagating from cell to cell at each time step and the radiated photons (upper dashed arrows) propagating throughout the system at the speed of light.

In the coupling of the equations, the light present in a cell incorporated light from all other cells at proper time delays. This was acheieved by using the following formula:

$$U(x,t,\varepsilon)=\int_{l_{\min}}^{l_{\max}} L\left(l,t=\left|x-l\right|/c,\varepsilon\right)/4\pi c(x-l)^2\,dl$$

In this formula, *l* is the distance along the zones. The time calculation used for *L* finds the retarded time for the light travel. The most important implication of this addition is that it enables the model to be able to properly handle and simulate inverse Compton dominated states in blazars.

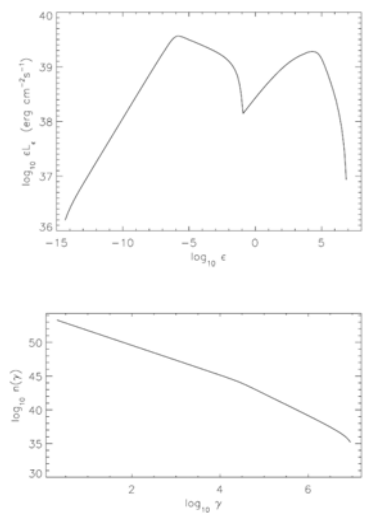

Figure3. The upper graph is the spectral energy distribution from a synchrotron dominated blazar. The injection is a power-law function with an index of 2.2. The first peak is in the X-ray region and is from synchrotron emission. The second peak is just below the TeV region and is from synchrotron-self Compton emission. The lower graph displays the electron energy distribution

4. Orphan Flare Case Studies

Orphan flares have been observed by Krawczynski, et. al. (2004) and Blazejowski, et. al. (2005). They are the appearance of a flare in the gamma ray region of emission without an accompanying flare in the X-ray spectrum. They occur infrequently and we are not sure exactly what causes them. Below are two possible explanations for these flares and simulations in the multi zone model.

EXAMPLE 1: Flare in TeV range with no accompanying X-ray flare.

•Caused by a production of more low-energy electrons
•Provides seed phoons for current high-energy electrons
•Dominance or near-dominance of inverse Compton cooling

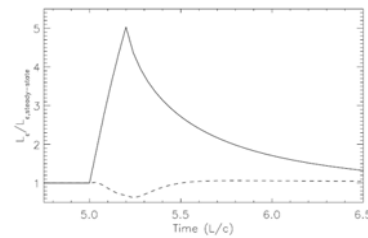

Figure 4. In this figure we show the time development of two frequencies of light. The dashed line is X-ray emission and the solid line is low TeV.

EXAMPLE 2: Delayed flare in TeV range following a regular flare

•Pulse adds more high-energy electrons
•Not able to be simulated with a one zone model
•Requires an "echo" effect from light transmission between zones
•Electrons cool as they travel, and emit radio photons in a later zone
•Photons travel back to the beginning and are Compton scattered

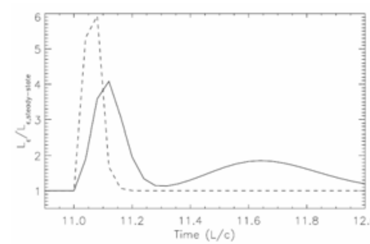

Figure 5. In this figure we show the time development of two frequencies of light. The dashed line is X-ray emission and the solid line is TeV.

5. Citations and Acknowledgements