X-RAY AND GAMMA-RAY EMISSION IN BLAZARS

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1. Introduction

More than 50 sources have been detected by EGRET in 4 years of operations (e.g. von Montigny et al. 1995). Almost all of them show the violent characteristics typical of blazars, such as superluminal motions, strong radio emission mainly produced in a flat spectrum core and large amplitude variability at all frequencies. Interestingly, optical polarization does not seem to be required, since more than 1/3 of the detected sources are less than 3% polarized.

Theoretical activity is obviously hectic in this new field, and I will concentrate in the following only on those models which base the high energy emission on the inverse Compton process.

The overall spectral energy distribution (SED) of γ–loud blazars in a $\nu F(\nu)$ plot shows two broad peaks, the first in the IR–optical–UV band, and the second in the γ–ray band. We can interpret the first as due to synchrotron emission, and the second to the inverse Compton process, which can operate on synchrotron photons or on photons produced outside the γ–ray emitting region and seen amplified (by relativistic effects) in the frame comoving with the blob or jet.

2. Location of the γ–ray emitting region

In the model of Blandford & Levinson (1995) the high energy radiation is produced in a inhomogeneous jet, immersed in a bath of photons produced outside the jet. The jet plasma, flowing relativistically, sees this radiation amplified, and Compton scatters it to high energies. The γ–rays produced in the inner regions of the jet do not survive collisions with the externally produced X–rays, and create $e^{\pm}$ pairs. These pairs, born relativistic, radiatively cool by scattering UV–soft X–ray photons to higher energies. Only

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further out along the jet, where the X–ray density is lower, the γ–rays of larger energies can escape without being absorbed. The resulting γ–ray spectrum is a superposition of the locally emitted spectra, each with a different high energy cut off due to γ–γ absorption, much like the partially opaque flat radio spectrum of compact radio sources.

The main criticism that can be moved to this model is about the amount of the predicted X–rays. In fact, if the inner regions of the jet produce a γ–ray luminosity L_γ, which is absorbed, one inevitably predicts that this power re–emerges in the X–ray band. This leads to the simple conclusion that the luminosity in the observed 10–100 MeV band should be equal to the X–ray luminosity L_X, contrary to observations (L_X is a factor 10–100 smaller than L_γ, e.g. Dondi & Ghisellini, 1995). Invoking the non–simultaneity of X–ray and EGRET observations does not help, because even if not simultaneously observed in the γ–rays, a γ–loud source should have X–ray flares reaching as much power as seen (at other times) above 100 MeV.

Reversing the argument, we conclude that if dissipation of the primary power occurs too close to the putative black hole and accretion disk, and therefore in a dense environment of X–ray and UV photons, the resulting high energy emission is absorbed, and is reprocessed into too many X–rays. Since this is not observed, the γ–ray emitting region must be thin to γ–γ collisions, and therefore located at some distance R_γ from the black hole, of the same order of the 'γ–ray photosphere': $R_\gamma \geq 10^{16.5}$–10^{17} cm (see Ghisellini & Madau 1995). *Then the dissipation of the primary power into radiation must occur at some distance from the central power–house.*

3. SSC Models

For simplicity, consider a homogenous, one–zone model (which can be a portion of an inhomogeneous jet, as in Maraschi, Ghisellini & Celotti 1992).

In this case the peaks in the SED reflect a break in the electron spectrum $N(\gamma) \propto \gamma^{-n_{1,2}}$ at some energy γ_b, with $n_1 < 3$ below γ_b and $n_2 > 3$ above. Electrons at γ_b produce the first synchrotron peak of luminosity L_S and also scatter this radiation into the self Compton peak (Ghisellini, Maraschi & Dondi 1995).

A change in the normalization of $N(\gamma)$ produces a linear change in the IR–opt–UV, and a quadratic change in the γ–ray band. Other behaviours can exist, especially if γ_b is extremely large, as suggested by the TeV detection of Mkn 421 and Mkn 501. In this case Klein–Nishina effects inhibit the self Compton cooling of the highest energy electrons, which preferentially scatter synchrotron photons of frequencies smaller than the synchrotron peak frequency. *Varying only n_2 results in a change of the synchrotron X–*

rays and the self Compton TeV emission of the same amplitude, while the optical and the GeV emission stays constant.

4. Inverse Compton on external photons

Dermer, Schlickeiser & Mastichiadis (1992) and Sikora, Begelman & Rees (1994) pointed out that if the blob moves relativistically in a photon bath produced outside the blob, then the radiation energy density as seen in the comoving frame is strongly amplified and can overtake the radiation energy density produced by the blob itself.

In these models the Compton peak is produced by scattering off photons produced externally, and the ratio of L_γ to the synchrotron luminosity L_s reflects the ratio of the radiation energy density as seen by the blob and the magnetic energy density U'_{ext}/U_B.

In the model of Sikora et al. (1994), the two peaks in the SED are due to a particle spectrum derived self–consistently, assuming continuous injection and (incomplete) cooling. Since the injected particle spectrum is assumed to be a single power law in the entire energy range, the break in $N(\gamma)$ is due to the particles with $\gamma < \gamma_b$ preferentially escaping instead of cooling. The model is then strongly constrained, because the requirement that the cooling timescale equals the escape time at γ_b fixes the radiation energy density in the comoving frame. This assumption can however be relaxed, if one assumes that the break in $N(\gamma)$ is not due to incomplete cooling, but to the injection mode.

In this model a change in the normalization of $N(\gamma)$ produces a corresponding change of equal amplitude both at synchrotron and inverse Compton energies: the optical and the GeV emissions should therefore vary with similar amplitudes. Variations of different amplitudes occurs if what varies is the bulk Lorentz factor Γ, because the amount of radiation energy density seen in the comoving frame is proportional to Γ^2. For viewing angles $\sim 1/\Gamma$, the observed synchrotron luminosity $L_s \propto \Gamma^4$, while the inverse Compton luminosity $L_C \propto U'_{ext}\Gamma^4 \propto \Gamma^6$. This yields $L_\gamma \propto L_{opt}^{3/2}$.

These considerations have been applied to the simultaneous SED of 3C 279 of June 1991 and beginning of 1993, corresponding to two very different states of the source (Maraschi et al. 1994), and with the γ–rays indeed varying more than the optical–UV emission. Since the two states correspond to two separate events in the life of 3C 279, both the alternatives [change in $N(\gamma)$ or change in Γ] can explain the observations. More secure conclusions could be reached by monitoring simultaneously a γ–loud source in the optical and the γ–rays during a single event, because in that case a change in Γ is unlikely.

5. The 'mirror' model

In the model of Sikora et al. (1994) the BLR and, possibly, some scattering material surrounding the jet are illuminated by the accretion disk. To simplify, assume that the external radiation comes from the reprocessing of the BLR only, located in a spherical shell at distance R_{BLR} from the black hole. As long as the active blob is inside R_{BLR}, it sees a constant U'_{ext}. But the active blob produces some amount of photoinizing radiation (by synchrotron emission) which contributes to the illumination of the BLR clouds. This radiation will be seen greatly amplified by clouds within and in the vicinity of the $1/\Gamma$ emission cone of the blob, and can dominate over the illumination of the accretion disk (Ghisellini & Madau 1995). *In this model the largest γ-ray production occurs when the blob is very close to BLR shell or when it crosses it.*

The crossing time is seen contracted by a factor Γ^2 by the Doppler effect, and therefore a width $\Delta R_{BLR} \sim 3\times 10^{17}$ cm corresponds, for viewing angles $1/\Gamma$, to a time $t_{var} \sim (10/\Gamma)^2$ days.

The distinguishing feature of the model is, once again, the variability pattern it predicts. In fact assume that the blob becomes active at some time. Optical–UV synchrotron photons will partly ($\sim$90%) cross the BLR without being intercepted by the BLR clouds, and reach the observer together with some amount of γ–rays produced at the same time by SSC or by inverse Compton scattering off the line photons produced by the BLR illuminated by the disk. The remaining 10% of the photoionizing photons are immediately converted into (isotropic) line emission, and part of them will reach the blob after some time. At this point the blob increases its γ–ray production, because of the enhanced radiation field, producing a γ–ray flare. *There is a delay between the optical and γ-ray flares, which should again be of the order of $t_{delay} \sim \Delta R_{BLR}/(c\Gamma^2) \sim t_{var}$.*

Furthermore, for small viewing angles, the observer sees an enhancement of the line emission, due to that part of the BLR illuminated by the blob, simultaneous with the optical flare.

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