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Probing relativistic particles in jets with SIMBOL-X

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Abstract. I review some of the properties of blazars, Active Galactic Nuclei whose emission is dominated by the relativistically-boosted, non-thermal continuum produced close to the base of a jet aligned with the line of sight. I will briefly discuss the advances in the understanding of the physical processes acting in these sources promised by the planned mission *SIMBOL-X*.

Key words. Galaxies: active – Galaxies: jets – Radiation mechanisms: non-thermal – X-rays: galaxies

1. Introduction

Despite decades of intense investigation, the physical processes acting in extragalactic relativistic jets are still poorly constrained (e.g. de Young 2002). Basic questions concern the processes able to accelerate and collimate such powerful outflows in the vicinity of supermassive black holes and the mechanisms involved in the interaction between jets and their environment. One of the major difficulties derives from the fact that even the basic physical quantities characterizing the flow (speed, density, composition, geometry and intensity of magnetic fields) are unaccessible to a direct measure. The observation provides direct access only to relativistic electrons, emitting through synchrotron and inverse Compton processes (e.g. Ghisellini et al. 1998).

Blazars provide the best laboratory to address several issues related to the physics of relativistic jets. The broad-band emission of these sources, extending from the radio to γ-rays, is dominated by the boosted non-thermal continuum produced close to the base of a relativistic jet pointing toward us (e.g. Tavecchio 2007). Hence blazars offer the unique possibility to probe the jet close to the black hole: in particular, precious information on the mechanisms acting on the relativistic particles (acceleration, cooling) can be in principle derived from the observations. In this respect, the X-ray band lies in a critical place, allowing to probe the particles with the highest energies (in low power blazars) and at the low energy end of the energy distribution (in powerful sources). In the following I review some of the main topics related to the X-ray emission from blazars, focussing in particular on the contribution expected from *SIMBOL-X* (Ferrando 2008).

2. Relativistic particles in blazars

An example of the spectral energy distribution (SED) of blazars is reported in Fig.1,

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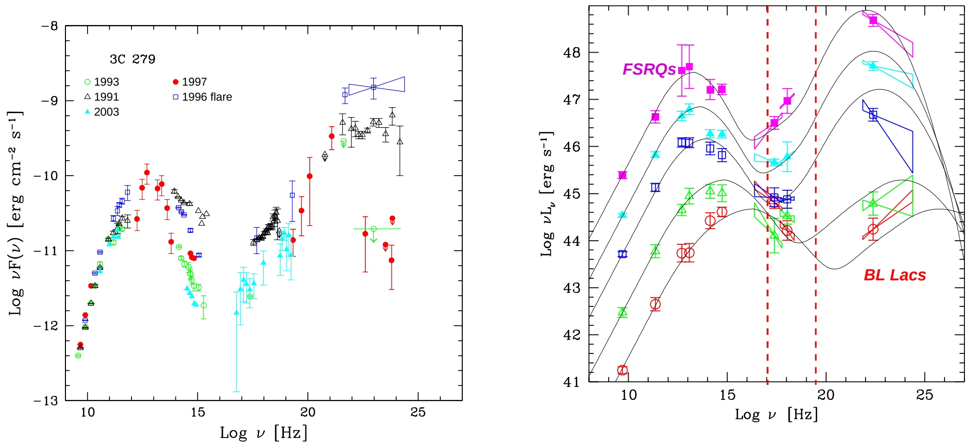

Fig. 1. *Left:* Spectral Energy Distribution of the blazar 3C279 at different epochs assembled with quasi simultaneous data obtained during multiwavelength campaigns (adapted from Ballo et al. 2002). Two broad bumps are clearly present. *Right:* The "spectral sequence" (from Donato et al. 2001). A trend of the position of the peaks with the radiative output is clearly visible, with the most powerful sources (belonging to the FSRQs class) having both peaks located at low frequency and *vice-versa*. The two vertical red lines mark the band that will be accessible with *SIMBOL-X*. This energy range lies in a crucial region: in FSRQ one can study the low energy tail of the high-energy component, while in the low-power BL Lac object it is possible to probe the peak of synchrotron emission.

showing the data for 3C279, one of the best studied sources, collected thanks to several multifrequency campaigns (for references see Ballo et al. 2002). Two bumps characterize the SED: the first one (peaking in the IR band) is due to synchrotron emission from relativistic electrons, while the second bump (with the maximum around 1 GeV) is likely due to inverse Compton scattering by the same electrons, although other possibilities (in particular involving hadronic reactions) have been proposed (e.g. Mannheim 1993). The existence of featureless, power-law spectra extending over decades in frequencies is a convincing evidence that particles are accelerated in power-law distributions, as expected from shock acceleration.

The shape of the SED follows a trend with the energetic output of the sources (the so-called "blazar sequence", Fossati et al.1998; see Padovani 2007 for criticisms). In powerful sources, belonging to the class of Flat Spectrum Radio Quasars, both peaks are located at low energy, the first one in the sub-mm–IR band, the high-energy one in the MeV band. With the decrease of power both peaks progressively shift toward higher frequencies, reaching the X-ray and the TeV band in the case of the low power BL Lac objects. The existence of such a trend could be related to the acceleration/cooling of particles (Ghisellini et al. 1998). Following this view, in powerful sources, characterized by huge cooling, electrons cannot reach high-energies, while in low power BL Lacs the limited energy losses allow the electrons to be accelerated up to multi-TeV energies.

Observations in the X-ray band offer the opportunity to probe the SEDs at different positions, depending on the class of source under study (Fig.1). In powerful sources the X-ray emission is dominated by the low energy tail of the inverse Compton component (External Compton emission, produced through the scattering of photons of the quasar environment: disk, Broad Line Region). X-rays in low power

BL Lacs, instead, track the peak of the synchrotron emission. Consequently, in FSRQ one can investigate the low energy end of the electron energy distribution, while in BL Lacs we observe the emission from the electrons with the highest energies. In intermediate sources both component can be investigated. In the following I limit the discussion on few points related to the sources at the extreme ends of the blazar sequence, namely the low power TeV BL Lacs and the powerful, high-redshift FSRQ.

2.1. Low power sources: probing the high-energy tail

BL Lac objects are extreme sources, showing variability at all frequencies, often characterized by extreme amplitude and short timescales. Their emission extends up to the TeV band, as revealed by the increasing number of BL Lacs detected by ground-based Cherenkov telescopes (an updated list can be found at `http://www.mppmu.mpg.de/ rwagner/sources`).

X-rays are produced by particles with extreme energy, with typical Lorentz factors $\gamma \sim 10^{5-7}$, the same responsible for the emission in the TeV band through synchrotron self-Compton emission. The simultaneous knowledge of TeV and X-rays spectrum is essential to disentangle the main physical parameters (Tavecchio et al. 1998), higlighting the importance of a good description of the X-ray continuum. An example is reported on Fig.2 (Hayashida et al. 2007), in which we report the simultaneous SED assembled with optical, X-ray (*Suzaku* and *Swift*) and TeV (*MAGIC*) data. The high flux of the source, together with the broad band accessible with *Suzaku*, assures a good description of the synchrotron peak. In particular, the high-energy instruments HXD/PIN allows to follow the steeply declining continuum up to 50 keV. The rapid decrease of the curved synchrotron component, incompatible with a single power law, suggests that the emission is produced by the electrons at the high-energy end of the distribution. This, in turn, provides a limit to the maximum energy of the TeV emission, that should die off at

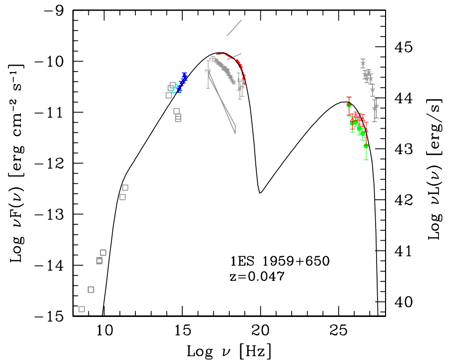

Fig. 2. SED of the BL Lac object 1ES1959+650 assembled with simultaneous optical-UV, X-rays (*Suzaku*) and TeV (green: observed, red: corrected for the intergalactic absorption) data taken in May 2006 (*MAGIC*). Grey points show historical data. The solid line shows the one-zone synchrotron-inverse Compton model reproducing the data (Hayashida et al. 2007).

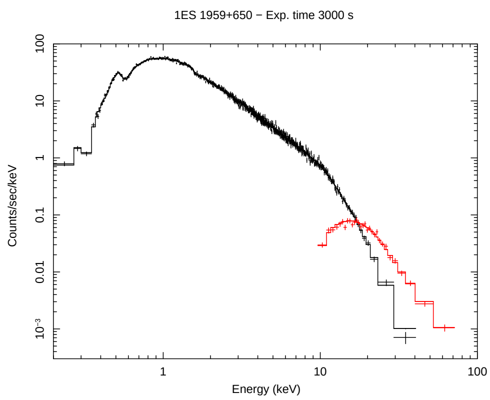

Fig. 3. Simulated *SIMBOL-X* spectrum (black: low energy instrument, MPD; red: high-energy instrument, CZT) of 1ES 1959+650 assuming the parameters of the best fit model reproducing the *Suzaku* observation reported in Fig.2 and with an exposure time of 3000 s (to be compared with the exposure of 10^5 s of *Suzaku*). The source is clearly detected up to 80 keV and the spectral parameters can be derived with an uncertainty below 10%.

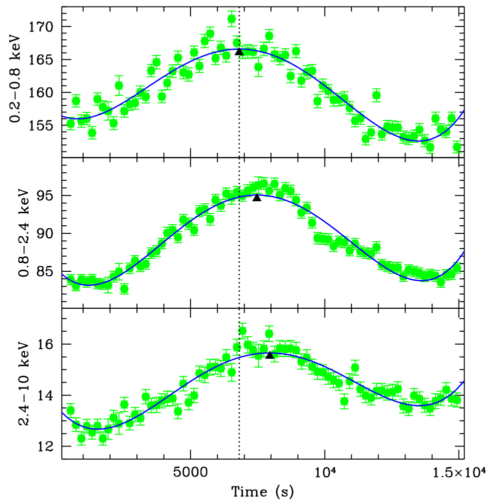

Fig. 4. Light curves in the soft (0.2-0.8 keV), medium (0.8-2.4) and hard (2.4-10) bands for Mkn 421 obtained with *XMM-Newton* in December 2002 (black lines show a fit of the data). The maximum of the flare (marked by black triangles) appears to progressively move to later times with increasing energy (from Ravasio et al. 2004).

few TeV. Note that, due to the limited sensitivity of the HXD, it is not possible to study possible spectral variations during the relatively long ($\sim 10^5$ s) observation. As an example of the improvement expected by *SIMBOL-X* we report in Fig.3 a simulated spectrum assuming the spectral parameters derived for the *Suzaku* observation, but with an exposure time of just 3000 s. The source is clearly detected up to 80 keV and the spectral parameters can be well constrained, allowing to trace spectral variations on short timescales. This example highlights the importance, for this kind of studies, of an instruments, like *SIMBOL-X*, able to study the hard X-ray band with good sensitivity.

TeV BL Lacs often exhibit a rich phenomenology in the X-ray band, with rapid spectral variability and temporal delays between different energy bands. An example of the latter is reported in Fig.4 (Ravasio et al. 2004), showing the light-curve of a flare observed with *XMM-Newton* in the BL Lac Mkn 421 in three different energy bands, 0.2-0.8 keV, 0.8-2.4 keV and 2.4-10 keV band. Clearly, with increasing energy, the maximum of the emission shifts at later times, with a delay between the two extreme band of about 1000 s. Quite interestingly, a similar behaviour has been recently observed in the TeV band in the BL Lac Mkn 501 (Albert et al. 2007). Such delays are commonly interpreted as the signature of acceleration acting on the electrons, progressively increasing their energy and thus causing their emission to move to higher frequencies (e.g. Kirk et al. 1998). Other examples include cases in which variations in the hard band lead those in the soft band. In this case it is believed that the delay tracks the cooling of the electrons. The measure of the delay allows one, in principle, to derive some of the physical parameters of the source, such as the magnetic field. However with a limited energy band, the study of this interesting phenomenology is rather difficult. *SIMBOL-X* allowing to significantly enlarge the bandpass and increase the sensitivity will assure an important improvement of these studies.

2.2. Powerful sources: the low-energy end

X-ray observations of FSRQs probe the low energy tail of the high-energy peak of the SED. While in intermediate-power sources both SSC and EC can contribute, in the most powerful ones the extreme hard continuum is probably dominated by the low-energy tail of the EC component (Fig.5). This offers the opportunity to study the low-energy part of the electron distribution, unaccessible by other means (the corresponding synchrotron emission is self-absorbed inside the source). Several important issues can be effectively investigated with X-ray observations:

• Absorption vs intrinsic curvature. It is known since a long time that several FSRQ located at medium-high redshift ($z > 2$) show a deficit of soft X-rays. If interpreted as absorption, the required amount of absorbing material seems to grow with the redshift, supporting theoretical suggestions on the evolution of quasars (Fabian 1999). However, the observational situation is not clear (e.g. Page et al. 2005). Moreover,

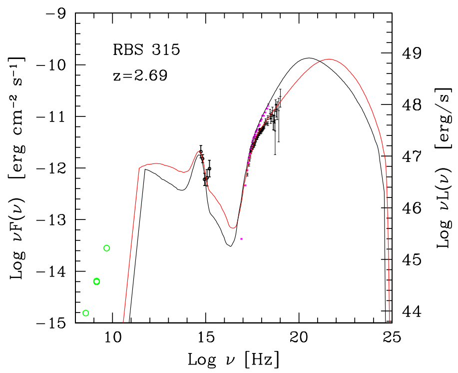

Fig. 5. SED of the FSRQ RBS 315 (z = 2.69) comprising simultaneous *UVOT/Swift* and *Suzaku* data (black) obtained in july 2006. The hard X-ray instrument HXD/PIN allows us to detect the source up to 50 keV. Red points report the data obtained with an earlier *XMM-Newton* pointing. The red and the black lines show the synchrotron-inverse Compton model used to reproduce the data. The hardening of the spectrum below 1 keV is interpreted as due to the intrinsic curvature of the EC component (Tavecchio et al. 2007).

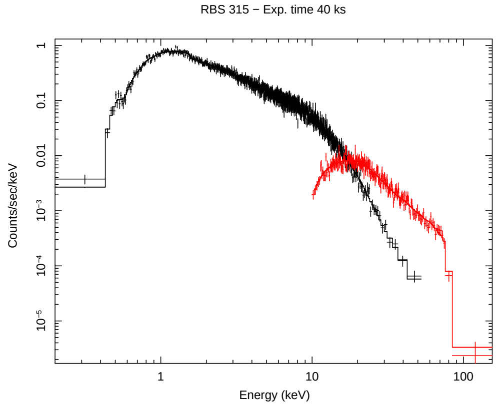

Fig. 6. Simulated *SIMBOL-X* spectrum (black: low energy instrument, MPD; red: high-energy instrument, CZT) of RBS 315 assuming the parameters of the best fit model reproducing the *Suzaku* observation reported in Fig.5 and with an exposure time of 40 ksec s. The source is clearly detected up to 100 keV and the spectral parameters can be derived with an uncertainty below 10%.

there is an alternative explanation for the lack of soft photons, based on the expected *intrinsic* curvature of the low energy tail of the EC continuum (see Fig.5). The conclusive evidence for the presence of absorption would be the direct detection of absorption features imprinted on the soft X-ray continuum. In any case, these studies could be greatly improved by the possibility to investigate the emission over a wider energy range, such as that possible with *SIMBOL-X*.

• Particularly intriguing is the possibility to detect the signature of cold (i.e. non relativistic) particles in the jet, expected to produce a bump in the soft-medium X-ray band through the comptonization of external radiation (Begelman & Sikora 1987). However, the presence of the strong non-thermal continuum from the relativistic electrons can easily outshine the (probably weak) bump (Celotti et al. 2007). To effectively disentangle the different components one would require broad-band X-ray spectra and good sensitivity, as those assured by *SIMBOL-X*.

• Extremely hard X-ray continua. Many powerful FSRQ display hard X-ray continua above 1 keV (with spectral indices $\alpha = 0.4 - 0.3$), difficult to be reconciled with the standard acceleration scenarios (Ghisellini 1996, Sikora et al. 2002). This evidence could suggest either that shocks can produce relativistic electrons with a distribution much harder than predicted by the standard models or that another mechanism energizes the electrons, at least those with Lorentz factors below $\gamma \sim 10$ (which typically emits through EC at energies below 100 keV). The small number of sources with good spectra measured above 10 keV limits present studies on this topic.

• Variability in the hard X-ray band. If the variability of FSRQs at soft-medium energies is still not completely characterized, very sparse are the information on the changes of the emission from these sources above 10 keV (e.g. Foschini et al. 2006). I refer to Foschini (2008) for a more complete discussion.

To illustrate the potentiality of *SIMBOL-X* I present in Fig.6 a simulation of the spectrum of the FSRQ RBS 315 performed using the parameters derived from a recent observation with *Suzaku*. With an exposure time of 40 ksec, the source is easily detected up to 100 keV. The excellent statistics of this spectrum would allow one to address the points discussed above. In particular the slope of the hard spectrum (> 10 keV) would be strongly constrained, as well as the presence of spectral features like the Compton bump would be easily detected. Spectral variability on relatively short timescale ($\sim 10^4$ s) could also be detected.

3. Conclusions

As shown by the examples discussed above, the study of blazars will surely receive great impulse by an instrument as the planned *SIMBOL-X*. Finally, it is worth noting that, being blazars intrinsically "multifrequency sources", to fully exploit the X-ray observations one requires to couple them with observations at other frequencies. In the period when *SIMBOL-X* will hopefully operate, other observational facilities should be available, especially for high-energy, either on ground (CTA) or in space (GLAST) (Lebrun 2008). The synergy between instruments operating at different energies will assure a broad coverage of the SED and thus the possibility to extract the maximum of the information from the data.

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