SUZAKU OBSERVATIONS OF γ-RAY BRIGHT BLAZARS BL LACERTAE AND PKS 1510-089

SCIENTIFIC JUSTIFICATION

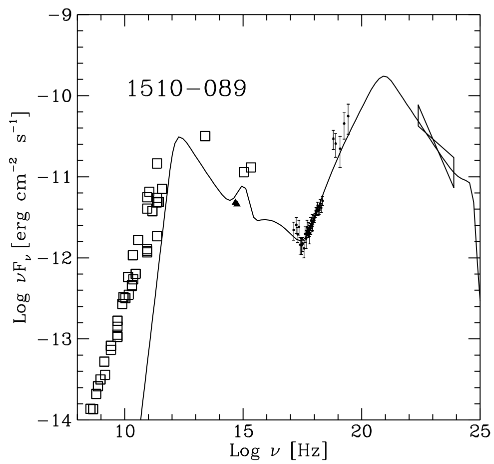
The nature of relativistic jets in AGN (active galactic nuclei) is one of the most important, unsolved problems of contemporary astrophysics. The jet ejection mechanism, their matter content (pair to proton number ratio) and cooling mechanisms are largely uncertain and subject to controversy (see, e.g. Sikora & Madejski 2000; Moderski et al. 2004; Sikora et al. 2005). These problems are best studied via observations and modeling of a particular subclass of AGN that have jets oriented close to the line of sight. In those objects – which are generally detected in all observable bands, up to the high-energy γ-ray regime – the radio spectrum is generally flat. The observed radiation in all bands is variable and highly polarized, and is best explained as dominated by the Doppler-boosted non-thermal radiation produced by parsec/subparsec scale jets. Such objects are classified as blazars, and those with very weak or absent emission lines are called BL Lac objects after their prototype, BL Lacertae. Blazar spectra consist of two humps, a low-energy one, with the luminosity peak in the IR-UV-X-ray range, and a high-energy one, with the luminosity peak in the MeV-GeV range (von Montigny et al. 1995). The production mechanism for the low-energy component is well established to be the synchrotron process, while the high-energy component is very likely produced by inverse Compton scattering (IC) (see review by Sikora & Madejski 2001). The seed photons for the IC process can be provided by: local or rescattered synchrotron radiation of a jet; an accretion disc; BELR (broad emission line region); and/or hot dust.

At least during high states, blazars show strong and fast variability. Their light curves are largely superposed from individual flares. Non-thermal events responsible for the flares can be powered either by the reconnection of magnetic fields that is likely to take place in the Poynting flux dominated flows, or by internal shocks in an unsteady, matter-dominated jet. In the latter case, in luminous blazars associated with quasars, the non-thermal flares are predicted to be preceded by soft X-ray flares produced by the bulk-Compton process, i.e. scattering of externally produced photons by cold electrons in a jet. The study of soft X-ray excesses and of soft X-ray precursors of the non-thermal flares in luminous blazars can provide powerful diagnostics of the structure of quasar jets near their bases. In particular, the absence of such excesses and precursors would indicate that jets are accelerated and collimated on scales $> 10^{17}$cm. This in turn would imply a dominant role of magnetic fields in their formation. Eventually, the lack of soft excesses can jeopardize the internal shock models and favor the external, re-confinement shocks and/or reconnection of magnetic fields as the source of energy for relativistic electrons. If detected, the detailed spectral / temporal analysis can be used to trace the structure of the innermost parts of jets and to constrain the pair content (Sikora & Madejski 2000).

So far, only a few quasar-associated blazars have been found to have a soft X-ray excess (Sambruna, Chou, & Urry 2000; Padovani et al. 2002; Gambill et al. 2003). In some of them, such as 3C 273 or 3C 345 – where jets are very likely seen at much larger angles than the Doppler angle – the soft X-ray excess can belong to the high-energy tail of the UV bump. In some cases, such as RGB J1629+4008 and RGB J1722+2436 the excess is probably, the synchrotron tail, as in many BL Lac objects. In others, the soft excess might be dominated by the bulk-Compton process: these objects potentially put the strongest constraints on models of jets in AGN. The most promising candidate for the latter mechanism is PKS 1510-089, a γ-ray emitting quasar with a head-on view of the jet (Homan et al. 2002) and showing variability on very short time scales in both the soft X-ray excess and the hard X-ray component (Gambill et al. 2003).

A soft X-ray excess has also been detected in BL Lacertae (see, e.g., Tanihata et al. 2000; Ravasio et al. 2003). However, noting that the parent population of the BL Lac objects is represented by FRI radio galaxies that host rather low accretion rate AGN, the radiative environment in BL Lac objects is expected to be too weak for jets to produce soft X-ray excesses via the bulk-Compton process. Hence, the soft X-ray excesses in BL Lacs are presumably not related to that process, and most likely represent the high-energy tails of the synchrotron component. However, the discovery of broad emission lines with equivalent widths larger than the upper limit for the BL Lac subclass (Vermeulen et al. 1995; Corbett et al. 1996) and detection of a prominent MeV-GeV flare (Bloom et al. 1997) may indicate that BL Lacertae behaves occasionally more like quasar-associated blazars and that the soft X-ray excess in BL Lacertae may also result from the bulk-Compton process.

PKS 1510-089 is a nearby ($z = 0.361$), radio-selected, high-polarization blazar with a highly superluminal jet. It has been extensively observed by all recent X-ray satellites: EXOSAT (Singh, Rao, & Vahia 1990; Sambruna et al. 1994), Ginga (Lawson & Turner 1997), ROSAT (Siebert et al. 1996), ASCA (Singh, Shrader, & George 1997), BeppoSAX (Tavecchio et al. 2000) and Chandra (Gambill et al. 2003). Observations by ROSAT, ASCA and BeppoSAX show a large difference between the soft and hard X-ray spectral indices with a break in the underlying continuum above ~ 1 keV. Observations by BeppoSAX indicate a soft excess that can be fitted by a black-body with $kT \approx 0.2$ keV or power law with photon index $\Gamma = 2.65$ (see Figure 1). Chandra observations confirmed the presence of a soft X-ray excess. However the robust analysis was impossible because the detector suffered from the photon pile-up effect. Because of this, the origin of the excess remains uncertain. Chandra and ROSAT found erratic variability on time scales of ~ 1.5 ksec in both the soft and hard X-ray channels (see Figure 2).



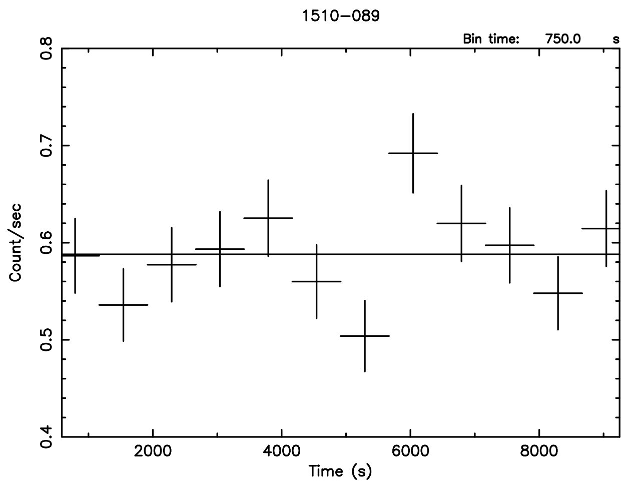


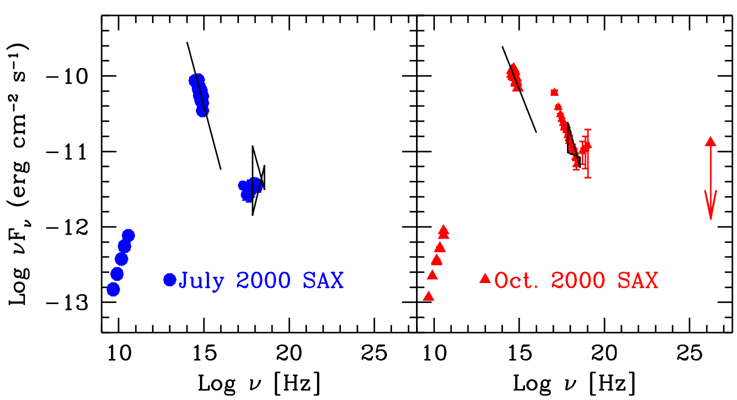
Fig. 1, left: Overall SED of PKS 1510-089 with the spectrum calculated using the homogeneous ERC model (from Tavecchio et al. 2000). **Fig. 2, right:** Chandra light curve of PKS 1510-089 binned at 750 s intervals. Low-amplitude flux changes on a timescale of 25 min are present (from Gambill et al 2003).

The spectrum of PKS 1510-089 in the hard X-ray band is very hard, $\alpha_X \leq 0.5$ (Tavecchio et al. 2000; Cappi et al. 1997; Reevs & Turner 2000; Malizia et al. 2000). In order to produce such a hard spectrum two conditions must be satisfied: radiative cooling of electrons must be inefficient; and the electron injection function must be hard ($p = 2\alpha_X + 1 < 2$, where $Q \propto \gamma^{-p}$ is the injection function). The first condition excludes models where X-rays are produced by synchrotron radiation of secondary electrons. This is because synchrotron radiation in the X-ray band involves extremely relativistic electrons that cool very fast and produce spectra with $\alpha_X > 0.5$. Also, it is very difficult to generate very hard spectra with synchrotron-self-Compton models, because that requires magnetic fields well below equipartition. No such difficulty is faced by the ERC (external-radiation-Compton) model in which the high-energy spectra result from Comptonization of the ambient radiation fields (Sikora, Begelman & Rees 1994). In quasars these fields are provided by the BELR and by hot dust irradiated by an accretion disc. According to the ERC model, the soft and mid-band X-rays are produced by mildly relativistic electrons. Therefore, Suzaku observations in these bands can be used to extract information about distribution of electrons at the lowest energies, and about the total number of electrons (note that as long as $\alpha_X > 0$, the number of electrons is still the largest at the lowest energies). This provides an exceptional opportunity to estimate the electron/positron pair content, the parameter critical for understanding the jet formation conditions (see, e.g., Sikora et al. 2005).

We propose a 50 ksec observation of PKS 1510-089 to obtain a broadband X-ray spectrum between 0.2 and a few hundred keV, aimed to confirm the existence of the soft X-ray, rapidly variable excess suggested by previous X-ray missions and to study nature of the high-energy component. In particular, such an observation will be able to show if this excess is the high-energy tail of the disc's thermal emission (the "blue-bump"), the low-energy end of the jet's synchrotron emission, or the bulk-Compton radiation of cold electrons in the jet. The latter conclusion would justify the ERC scenario for the production of nonthermal radiation in the hard X-ray and γ-ray bands.

BL Lacertae (1ES 2200+420; $z = 0.069$), the prototype of the BL Lac subclass of AGN, is one of the best studied blazars. It was a target of many multi-wavelength campaigns (see Table 5 in Ravasio et al. 2003). They reveal complex spectral variability patterns, particularly in the X-ray band, where at least two radiative components contribute. One, dominating at higher energies, is presumably produced by Comptonization of synchrotron radiation (synchrotron-self-Compton scenario: SSC), another one, forming the soft X-ray excess, may represent a high-energy tail of the synchrotron component. In this respect BL Lacertae itself is not exceptional, as synchrotron spectra extend up to X-ray energies in many BL Lac objects. Also, like several other BL Lac objects, BL Lacertae was detected to be γ-ray emitter (Catanese et al. 1997; Bloom et al. 1997), at least during powerful outbursts.

However, there are some features that seem to challenge the pure synchrotron + SSC interpretation of the broadband spectrum in BL Lacertae. These features are: (i) a spectral 'glitch', observed in October-November 2000 between the UV and soft X-ray portions of the spectrum (see Figure 3; Ravasio et al. 2003); (ii) an exceptionally prominent γ-ray flare, observed in July 1997 (Bloom et al. 1997); (iii) bright broad emission lines detected in 1995 (Vermeulen et al. 1995; Corbett et al. 1996). Possible origins of the glitch have been investigated by Ravasio et al. (2003). They are: the dust-to-gas ratio towards the object is higher than in the interstellar one; the soft X-ray excess results from bulk-Comptonization; UV and soft X-rays represent tails of two separate synchrotron components; the glitch reflects redistribution of the highest energy electrons by electron scatterings in the Klein-Nishina regime. As pointed out by Böttcher & Reimer (2004), the glitch can also be observational artifact of time averaging of the rapid variations of a synchrotron tail.



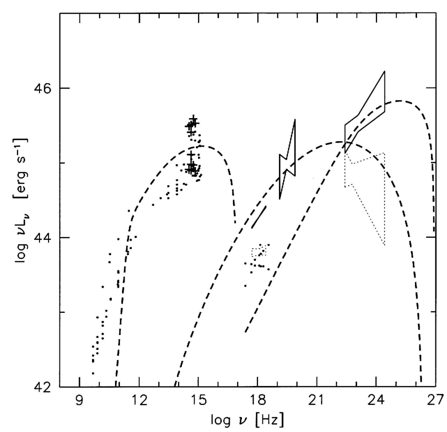


Fig. 3, left: Broadband spectrum of BL Lacertae: left panel: 26-27 July SED; right panel: 31 October-2 November SED (from Ravasio et al. 2003). **Fig. 4, right:** Broadband spectrum of BL Lacertae in 1997 July (from Madejski et al. 1999).

The July-1997 MeV-GeV flare, with a luminosity $\sim 4\times$ larger than the synchrotron component, together with the X-ray spectral data, seems to require a hybrid model in which the SSC process is responsible for the X-rays and the ERC process responsible for γ-rays (Figure 4; Madejski et al. 1999; Böttcher & Bloom 2000). The latter, although successfully applied for γ-ray production in blazars associated with quasars, is disregarded in radiation models of BL Lac objects because of the low density of external radiation fields. However, in several BL Lac objects broad emission lines are occasionally sufficiently bright to make a competitive contribution to the seed photons for the inverse-Compton process. Such lines, with equivalent widths of ~ 7Å, i.e. larger than the upper limit for the BL Lac subclass of blazars, were measured on two occasions in BL Lacertae in 1995 (Vermeulen et al. 1995; Corbett et al. 1996). It is not clear whether these lines are always present, but not detected in brighter states because the continuum level is higher and thus the equivalent widths are lower, or whether the lines are only occasionally strong, reflecting, e.g., some unsteady accretion events.

These open questions make BL Lacertae exceptionally interesting target for Suzaku and accompanied ground-based multi-wavelength observations. At the time of this writing, BL Lacertae is undergoing an optical outburst (which may or may not continue when the proposed observations are conducted). Hence, we propose 50 ksec XIS and HXD observations of BL Lacertae, and plan to organize simultaneous optical/UV observations, including spectroscopy. Such observations would allow to solve some puzzling features of BL

Lacertae, which seems to share some properties with luminous, quasar-associated blazars and some properties with classical, radio-selected BL Lac objects hosted by low accretion rate radio galaxies. In addition, we will try to arrange simultaneous observations of BL Lacertae by the VERITAS imaging atmospheric Cerenkov telescope, which can be critical in discriminating directly between leptonic and hadronic models, since the latter predicts significant TeV fluxes (Böttcher & Reimer 2004).

Feasibility: Both objects were always detected by previous X-ray satellites with similar 2 - 10 keV flux levels, of $\sim 10^{-11}$ erg cm^{-2} s^{-1} or more, so there is no question about a strong detection and measurement of the time-averaged X-ray spectrum. Under an assumption of a broken power law ($\Gamma_{lo} = 2.5, \Gamma_{hi} = 1.5, E_{BR} = 4$ keV) the individual indices can be recovered to ~ 0.01 in 50 ks. The $E > 4$ keV spectra of both objects are very hard, and our simulations indicate that the spectra should be measured up to ~ 150 keV, including the first few channels of the GSO (see Fig. 5). Both objects show rapid variability, on (doubling) time scales less than 1000 s (cf. Fig. 2), and the interesting observational question is: how well can the flux be measured on those time scales? Each XIS should produce ~ 1 ct s^{-1}, so each orbit of data will allow separate determination of the $E < 4$ keV and $E > 4$ keV fluxes to better than 5%, and index measurement better than 0.2, much better than the Chandra measurements (Fig. 2). The detection with the PIN on such short time scales will be more challenging, requiring ~ 7 ks to measure the flux to 10% with a detection up to ~ 30 keV.

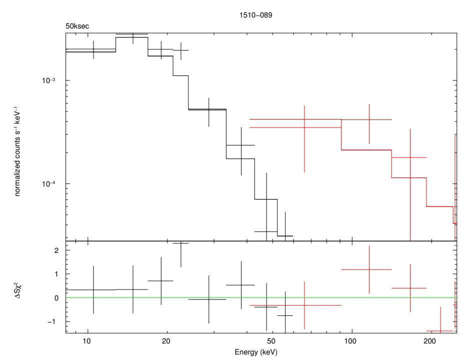


Fig. 5: Simulated 50 ks Suzaku HXD spectrum of PKS 1510-089, with paramaters as given in the text.

As emphasized above, it is important to assure good coverage at other wavebands. The observations requested here will involve multi-wavelength campaigns, with the emphasis on the optical band, where BL Lacertae has shown rapid (sub-hour) variability. We have secured commitments from optical observers (Torino) who are preparing to participate in future observing campaigns simultaneous with GLAST. If successful, the observations requested here will become available to the members of the GLAST AGN Science Analysis Group, to be treated as a "test case" for future campaigns involving GLAST. With this, we do not require any special scheduling (although "dark moon" time is preferred), but we request that once the targets are put into the Suzaku timeline that the schedule is not altered, so observers in other bands can plan accordingly. We note that PKS 1510-089 is our first priority target, and BL Lacertae is our second.

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