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High energy emission from flat-spectrum radio sources with ∼ kpc-scale structure

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Abstract. Active Galactic Nuclei emit a substantial portion of their bolometric luminosities in X-rays. For example, the knots in radio jets are prominent sources of synchrotron X-rays while the hotspots of the brightest FRIIs emit self-synchrotron or Inverse Compton radiation. Most high-energy studies on flat-spectrum radio sources have been conducted for blazars which are dominant at γ-rays.

Augusto *et al.* (1998) have built a sample of 55 flat-spectrum radio sources dominated by structures (knots, hotspots, etc.) ∼0.1–2 kpc away from the nucleus. Seventeen (31%) of these are detected in X-rays (they tend to be the radio strongest) evenly splitting, morphologically, *both* at optical (radio) bands: nine QSO/BLLac (core-jets) on one-side; eight Galaxy/Sy2 (CSO/MSO/FRII) on the other. We have identified five confirmed compact/medium symmetric objects (CSO/MSOs) as X-ray emitters. A comparable type of source to CSO/MSOs is the physically similar (1–15 kpc) compact steep spectrum source (CSS), 28/129 (22%) of which are detected in X-rays, from a literature-selected sample (the percentage is smaller than for the 55-source sample due to a lower $<S_{4.85}>$). A 95% conf. level relation is found for CSSs: $S_X \propto (S_{4.85})^{0.6}$ and we found undistinguishable radio/X-ray properties for both the 55-source and CSS samples: clearly, their similar morphologies (e.g. knots in jets) stand up stronger than their radical radio spectrum differences.

Only two sources among the 55 (4%) have γ-ray detections and they seem quite abnormal (in $\alpha_{x\gamma}$ values, at least) – one of them is in a Sy2, not in a blazar.

Keywords. galaxies: active, (galaxies:) BL Lacertae objects: general, galaxies: jets, (galaxies:) quasars: general, galaxies: Seyfert, radio continuum: general, X-rays: galaxies, X-rays: general.

Augusto *et al.* (1998) have selected a sample of 55 flat-spectrum ($S_{8.4\ \mathrm{GHz}} > 100$ mJy; $\alpha_{1.40}^{4.85} < 0.50$) radio sources dominated by structures (knots, hotspots, etc.) typically 0.1–2 kpc away from the nucleus. Using the NASA Extragalactic Database (NED) and the High Energy Missions Catalogue we have looked for any high-energy information (X-ray and γ-ray) for each of the 55 sources: 17 sources (31%) have it in X-rays while 38 are X-ray and γ-ray "quiet". Why? The hypothesis of similarity of the 4.85 GHz distributions is rejected at the 98% confidence level (χ^2-test), implying that the 17 sources tend to be the radio strongest in the 55-source sample.

There are 13 sources (75%) of the X-ray loud sub-sample that are bright enough to have X-ray spectral information, although for four of these we are limited to ROSAT hardness ratios (e.g. Voges *et al.* (1999)). About one-third of AGN in surveys shows a soft X-ray excess (Mushotzky *et al.* 1993, Gambill *et al.* 2003) which seems to be of thermal origin – e.g. Colbert *et al.* (1998). Soft excesses are seen in only two of our 17 (12%) X-ray loud sources (in a BLLac and in a QSO).

Out of the 23 compact/medium symmetric object (CSO/MSO) candidates of Augusto *et al.* (1998), seven (30%) are X-ray loud. Of these, five are already confirmed as CSO/MSOs (Augusto *et al.* 2006). Since the 55 sources were radio-morphologically selected, the only comparable type of source is the physically similar (1–15 kpc) compact steep spectrum source (CSS; $\alpha_{1.40}^{4.85} > 0.50$). We combined the O'Dea (1998) and Fanti *et al.* (2001) samples getting a total of 129 CSSs of which only 28 (22%) have X-ray information available. We compared the radio and X-ray properties ($S_{4.85}$, S_X, α_r and α_{rx}) between our 17 X-ray loud flat-spectrum sources and the morphologically similar 28 X-ray loud CSSs: χ^2 tests cannot rule out similarity for any of the parameters. Thus, the homogeneous population of CSSs and the heterogeneous population of flat-spectrum radio sources have similar radio/X-ray properties. Clearly, their similar morphologies (e.g. knots in jets) stand up stronger than the radical radio spectrum differences. As regards the samples individually, we reject "no correlation" at the $> 95\%$ level and derive approximate regression line fits for the following parameters: $\alpha_{rx} = 0.4\alpha_r + 0.7$ (55-source sample); $\log S_X = 0.6 \log S_{4.85} - 6.8$ (CSS sample).

The 30 core-jets (CJs) identified in Augusto *et al.* (1998) split into 14 bent-jet and 16 straight-jet sources, the same splitting remaining for the X-ray loud subsample: three bent-jets vs. six straight ones. So, there is no apparent preference for selecting CJs in the X-ray loud subsample (possibly because the hot spots in CSO/MSOs are strong competitors for the knots in jets, or simply due to our poor statistics).

Flat-spectrum jets with pc-scale bends, are not likely to have γ-ray emission (von Montigny *et al.* 1995, Tingay *et al.* 1998); this is confirmed by the only bent-jet of the 55-source sample, X-ray and γ-ray quiet, which has VLBI data showing bending from pc- to kpc-scales – Augusto *et al.* (1998). Virtually all γ-ray emitting AGN are blazars (Sowards-Emmerd *et al.* 2005). However, there are two γ-ray detected sources in the 55-source sample (one BLLac) one of which is a Sy2, *not* a blazar! They both have abnormal $\alpha_{x\gamma}$ values: the BLLac value is too flat (0.42 vs. 0.83 ± 0.18 – Comastri *et al.* (1997)) while the one for the Sy2 is steeper than any known AGN value ($\alpha_{x\gamma} = 1.87$), although the soft γ-ray (100 keV) energy used in the calculation differs a lot from the usual mid γ-rays (100 MeV).

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