THE DEEP X-RAY RADIO BLAZAR SURVEY (DXRBS)

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ABSTRACT. We have undertaken a survey for blazars by correlating the ROSAT WGACAT database with publicly available radio catalogs, restricting our candidate list to serendipitous flat-spectrum sources ($\alpha_{\rm r} \leq 0.7$, $f_\nu \propto \nu^{-\alpha}$). Our survey is found to be $\sim 90 - 95\%$ efficient at finding blazars, a figure which is comparable to or greater than that achieved by other radio and X-ray survey techniques. DXRBS provides a much more uniform coverage of the parameter space occupied by blazars than any previous survey. Particularly important is the identification of a large population of flat-spectrum radio quasars with ratios of X-ray to radio luminosity $\gtrsim 10^{-6}$ ($\alpha_{\rm rx} \lesssim 0.78$) and of many low-luminosity flat-spectrum radio quasars. Moreover, DXRBS fills in the region of parameter space between X-ray selected and radio-selected samples of BL Lacs.

1. Introduction

Blazars are the most extreme variety of Active Galactic Nuclei (AGN) known. Their signal properties include irregular, rapid variability; high optical polarization; core-dominant radio morphology; apparent superluminal motion; flat ($\alpha_{\rm r} \lesssim 0.5$) radio spectra; and a broad continuum extending from the radio through the gamma-rays (e.g., Urry & Padovani 1995). These properties are consistent with relativistic beaming, that is bulk relativistic motion of the emitting plasma at small angles to the line of sight (as originally proposed by Blandford & Rees in 1978). The blazar class includes flat-spectrum radio quasars (FSRQ) and BL Lacertae objects. The main difference between the two classes lies in their emission lines, which are strong and quasar-like for FSRQ and weak or in some cases outright absent in BL Lacs. As a consequence of their peculiar orientation with respect to our line of sight, blazars represent a very rare class of objects.

2. Why a Blazar Survey?

A blazar survey is needed essentially for two reasons: number statistics and limiting fluxes. All existing blazar samples, in fact, are relatively small and at relatively high fluxes. The largest radio-selected BL Lac sample, the 1 Jy sample (Stickel et al. 1991), includes 37 objects with $f_{5\mathrm{GHz}} > 1$ Jy. In the X-rays, there are a few available samples, made up of $40-70$ objects (the EMSS sample [Maccacaro et al. 1994], the Slew sample [Perlman et al. 1996], plus various ROSAT-based samples [Laurent-Muehleisen et al. 1998; Bade et al. 1998]) but the deepest sample is still the EMSS one, which reaches $f_{\mathrm{x}} \sim 2 \times 10^{-13}$ erg cm^{-2} s^{-1}. (See however Wolter et al. 1997 for an ongoing deeper survey.)

Moving to FSRQ, until very recently the only sizeable sample with complete redshift information was the one extracted from the 2 Jy sample (Wall & Peacock 1985), which includes 52 sources. (The FSRQ in the 1 Jy and S4 samples reach lower fluxes [1 Jy and 0.5 Jy respectively] and are more numerous but the identification of the two samples is still not complete.) Drinkwater et al. (1997) have recently published the PKS 0.5 Jy sample, which includes 323 flat-spectrum radio sources with $f_{2.7\mathrm{GHz}} > 0.5$ Jy, 86% of which have a measured redshift. Finally, Hook, Shaver, and collaborators have just put together a sample of more than 400 flat-spectrum objects down to $f_{2.7\mathrm{GHz}} = 0.25$ Jy (Hook et al. 1998).

There is then clearly a need for a deeper, larger blazar survey, to address many open questions of blazar research, namely, BL Lac evolution, luminosity functions, and unified schemes; flat-spectrum radio quasar evolution, luminosity functions, and unified schemes; the relationship between BL Lacs selected in the radio and X-ray band; the relationship between flat-spectrum radio quasars and BL Lacs; the relationship between physical parameters (e.g., X-ray and radio spectral indices, equivalent width, line luminosity, continuum luminosity, etc.)

3. The DXRBS

The basic idea behind our Deep X-ray Radio Blazar Survey (DXRBS) is quite simple: blazars are relatively strong X-ray and radio emitters so selecting X-ray and radio sources with flat radio spectrum (one of their defining properties) should be a very efficient way to find these rare sources. We adopt a spectral index cut $\alpha_{\mathrm{r}} \leq 0.7$. This will: 1. select (by definition!) flat-spectrum radio quasars; 2. select basically 100% of BL Lacs; 3. exclude the large majority of radio galaxies.

As a result of the correlations between the X-ray (WGACAT, a catalog of ROSAT PSPC sources; White, Giommi & Angelini 1995) and the radio catalogs (NORTH20CM, GB6, PMN), detailed in Perlman et al. (1998), we have obtained a list of about 200 blazar candidates (with $|b| > 10^{\circ}$), to which we add 88 previously known, serendipitous (i.e., not ROSAT targets) blazars (77 FSRQ and 11 BL Lacs), for a total of about 300 sources.

Accurate positions to pinpoint the optical counterparts were obtained from either the NVSS (Condon et al. 1998) or our ATCA survey. Magnitudes for X-ray/radio sources were obtained from sky survey plates and, for the empty fields, from imaging done at the KPNO 0.9m, the CTIO 0.9m, or ESO 2.2m and 3.6m telescopes. This allowed identification of optical counterparts to $R = 23$. The magnitude distribution of the blazar candidates peaks around 18. Spectroscopic observations were conducted at the KPNO 2.1m, MMT, Lick 3m, ESO 2.2m and 3.6m, and CTIO 1.5m telescopes.

Tab. 1 - DXRBS Identifications

Class	Newly identified	Previously known	Total
Radio Quasars	93	76	169
BL Lacs	28	11	39
Radio Galaxies	8	10	18
Total	129	97	226

The breakdown of the identifications as of May 1998 is given in Table 1. So far we have identified $\sim$ 60% of our candidates and 94% of them are blazars. 90% of the previously known objects are also blazars. Our method is then indeed very efficient (92%) at identifying blazars.

4. First Results

The 169 DXRBS FSRQ we have so far indentified span the redshift range of 0.1 to 3.8, with a mean value of 1.25. Figure 1a shows the greatly improved coverage of the radio/X-ray flux plane for FSRQ provided by DXRBS, as compared to previously available samples (note that both the 1 Jy and S4 samples are not completely identified and X-ray data are available only for $\sim$ 60% of their FSRQ). DXRBS FSRQ go about an order of magnitude deeper in radio flux and a factor of $\sim$ 4 deeper in X-ray flux. Moreover, while very few previously known FSRQ had relatively large X-ray-to-radio flux ratios ($f_{\rm x}/f_{\rm r} > 10^{-11.5}$ in the units of Fig. 1: see the dashed line), many DXRBS FSRQ are quite "X-ray bright." About 25% of DXRBS FSRQ, in fact, have $L_{\rm x}/L_{\rm r} \gtrsim 10^{-6}$ (or, alternatively, $\alpha_{\rm rx} \lesssim 0.78$). Only nine 1 Jy/S4 FSRQ had such luminosity ratios. Due to their lower radio fluxes, DXRBS FSRQ are also reaching relatively low radio luminosities, approaching what should be the lower end of the FSRQ luminosity function according to unified schemes ($L_{\rm r} \approx 10^{24.5}$ W Hz^{-1}: Urry & Padovani 1995). In particular, more than 20% of them have $L_{\rm r} < 10^{26.5}$ W Hz^{-1}, as compared to only 3% for the 1 Jy and S4 samples.

As regards BL Lacs, DXRBS is again exploring uncharted territory, as it is finding BL Lacs which cover a previously unexplored region of the radio/X-ray plane, and go deeper (by almost an order of magnitude) in X-ray flux than currently available samples (see Fig. 1b). Note also how the DXRBS BL Lacs are intermediate in their X-ray-to-radio flux ratios as compared to the "classical" radio and X-ray selected samples.

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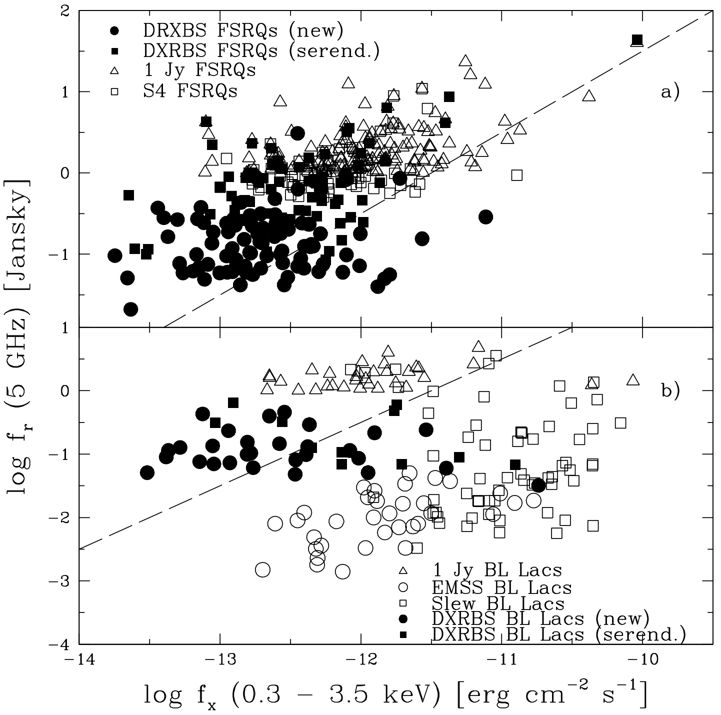

Fig. 1. The radio/X-ray flux plane for FSRQ (a); top) and BL Lac (b); bottom) samples. Note how DXRBS is sampling previously unexplored regions of parameter space. The dashed lines correspond to $\log f_{\rm x}/f_{\rm r} = -11.5$.

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