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Study of the X-ray properties of radio sources, based on NVSS catalogue

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Abstract

An identification of radio sources from the NVSS list with ROSAT X-ray sources was made as well as also with optical objects from SDSS DR 16. We have tried to find the connection between the fluxes of different wave ranges, for different types of objects. We also have tried to find the relationship between the sizes and polarization angles of sources with the types of objects and recurrence. The fluxes detected from X-ray, optical, and radio bands for them are compiled. This database allows an investigation on broad band energy distribution and other possible correlations among spectral indices and luminosities for various types of extragalactic objects.

Keywords: *active galactic nuclei - radio source - NVSS - quasar - X-ray*

1. Introduction

In this work an attempt was made to create an X-ray selected radio source catalogue and make its multiwavelength (MW) studies, in order to find connections between the fluxes in different ranges of electromagnetic waves.

To ensure the homogeneity and completeness of the sample, only data from ROSAT catalogues have been taken for X-ray sources. The ROSAT satellite was endowed with an X-ray detector having sensitivity between 0.1–2.4 keV and with a mirror of 84 cm diameter. With this satellite a whole sky survey was accomplished in X-ray.

ROSAT data are mainly listed in three catalogs: ROSAT Bright Source Catalogue (BSC) (Voges et al., 1999a), ROSAT Faint Source Catalogue (FSC) (Voges et al., 2000b) and Second ROSAT all-sky survey (2RXS) source catalog (Boller et al., 2016a). They are clearly distinguished from each other by X-ray flux expressed in count-rate (CR) (the number of particles registered by the receiver per unit time). ROSAT-BSC contains 18,811 sources with CR > 0.05 ct/s, while ROSAT-FSC, 105,924 sources with CR < 0.05ct/s with a sensitivity limit CR < 0.0005 ct/s. Thus ROSAT all-sky survey (2RXS) source catalog contain 135,118 X-ray sources (Boller et al., 2016a). There are thousands of interesting objects among them, and even though a number of recent X-ray missions have been conducted, ROSAT so far remains the only all-sky enough deep survey, particularly containing some 60,000–70,000 X-ray AGN.

In both catalogues, the selection of radio sources was made due to the following advantages of NVSS (Condon et al., 1998).

The NRAO VLA Sky Survey (NVSS) covers the sky north of -40 deg (82% of the celestial sphere) at 1.4 GHz. The principal data products are: (1) a set of 2326 4deg x 4deg continuum "cubes" with three planes containing Stokes I, Q, and U images plus,

(2) a catalog of almost 2x10^6 discrete sources stronger than S $\sim$ 2.5 mJy. The images all have theta = 45 arcsec FWHM resolution and nearly uniform sensitivity.

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We combined these two Catalogues and created a new homogeneous and complete catalogue of X-ray selected radio source, which covers all sky limited by north of -40 deg.

Thus we have obtained the X-ray large-area homogeneous complete radio sources sample and made possible detailed studies of their MW properties.

2. Combination of ROSAT and NVSS and collection of accurate photometric data

In order to avoid further mistakes and errors, before starting the main work, we studied in details the catalogue.

For detection of AGN's these two catalogues were cross-matched with the Catalogue of QSOs and Active Nuclei, Version 13 (Véron-Cetty & Véron, 2010, , hereafter VCV-13). VCV-13 includes only those objects, which have optical spectra and their spectroscopic studies confirmed their AGN nature. It contains 168,940 AGN. To complement VCV-13, we also used BZCAT (Massaro et al., 2015) due to its better completeness for blazars (high probability X-ray sources).

We have carried out homogeneous search for all available data in various databases, including non-optical ranges. In order to make final identifications we used all the listed catalogues, which more or less guarantee the completeness condition (we have used all-sky or large-area surveys) and provide many flux measurements at different bands:

- γ-ray: FERMI (Nolan et al., 2012), INTEGRAL (Bird et al., 2010);
- X-ray: ROSAT (Boller et al., 2016a), XMM-Newton DR12 (Webb et al., 2023); Chandra Source Catalog V2.0 (Evans et al., 2019);
- UV: GALEX (**?**);
- Optical: APM (McMahon et al., 2000), USNO-B1.0 (Monet et al., 2003), GSC 2.3.2 (Lasker et al., 2021), SDSS DR16 (Ahumada et al., 2020);
- IR: 2MASS Point Source Catalogue (PSC, Cutri et al., 2003), 2MASS Extended Source Catalogue (ESC, Skrutskie et al., 2006), WISE (Cutri & IPAC/WISE Science Data Center Team, 2012), IRAS Point Source Catalogue (PSC, Beichman et al., 1988), IRAS Faint Source Catalogue (FSC, Moshir et al., 1992), IRAS PSC/FSC Combined Catalogue (Abrahamyan et al., 2015); IRAS Combined Catalogue contains all sources from PSC and FSC;
- Radio: NVSS (Condon et al., 1998), FIRST (White et al., 1997).

Out of the 9193 objects (from cross-correlation between ROSAT and NVSS), 3259 sources were confirmed as AGN by means of optical spectral classifications, the main criteria in VCV-13 and BZCAT.

Graphs and histograms of the distribution of sources at different ranges, stellar magnitudes and the data dependence on each other were built in order

We have carried out cross-correlations of our sample with the recent all-sky and large-area catalogues from γ-ray to radio. To determine the correct search radius for all cross-correlations and avoid misidentifications, a preliminary identification was made with a large radius, and then the distribution of distances of identifications was constructed for all sources. This allowed determine the correct search radius. Figure 1 gives an example of such computation for NVSS catalogue.

We conclude that objects with distances from the input positions up to 20 arcsec should be considered as genuine associations, though the real search radius were taken larger not to miss some genuine associations having larger positional errors.

Table 1 provides the numbers of 8037 identified ROSAT sources in various catalogues.

For 2372 objects in our sample there are spectra from SDSS DR16, we are do a detailed spectral classification thus.

In order to distinguish AGN among all X-ray sources, we need to identify which are the flux ratio limits that give us opportunity to do this. Graphs and histograms based on the collected data were constructed for this purpose. This will allow finding all observed QSOs and other AGN in the nearby Universe having detected X-ray radiation and the exact number of existing X-ray AGN as a fraction of all AGN.

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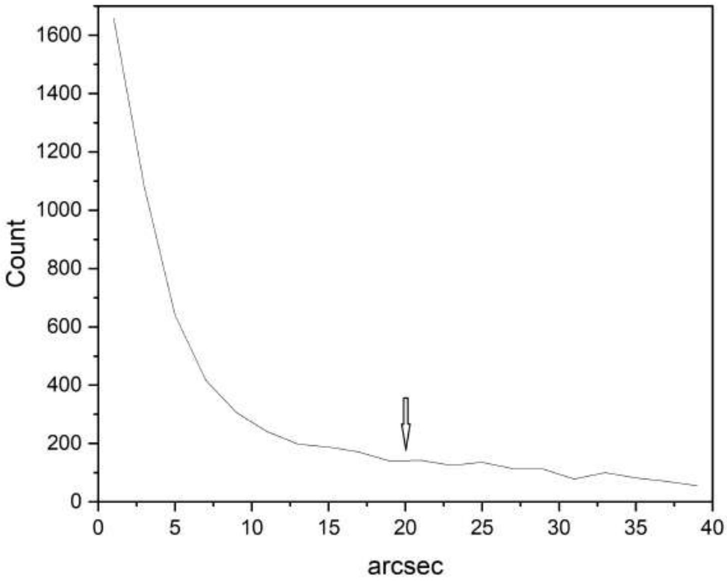

Figure 1. Example of computation of the correct radius of identifications for NVSS catalogue.

Table 1. Results of cross-correlations of ROSA/NVSS sources with MW catalogues.

Catalogs	Search (arcsec)	N	Catalogs	Search (arcsec)	N
FERMI	250	1129	INTEGRAL	250	104
XMM-Newton DR12	20	815	Chandra V2.0	20	611
ROSAT	–	9193	GALEX	40	6056
APM	10	4222	USNO-B1.0	10	7721
GSC 2.4.2	10	6067	SDSS DR16	40	2372
2MASS	5	3825	WISE	10	7870
IRAS	60	409	NVSS	30	9193
FIRST	20	3512	VCV-13	30	3094
BZCAT	15	1318			

3. Physical and statistical properties of identified X-ray sources

The Catalogue consists of 9193 X-ray selected sources, including 3993 confirmed AGN, QSO or BL Lac and 5200 their candidates. In order to check these objects as AGN, QSO or BL Lac and to find new ones, we have built diagrams of the dependence between various data for these sources, as well as normal galaxies and stars have been used for comparisons.

In Figure 2 the hardness ratio HR2 is plotted *vs*. Count for different classes of objects. There is a slight difference in the distribution of HR2 showing a separation between QSO, AGN and BL Lac. To remind, hardness ratios are defined as:

$$HR2 = \frac{[D] - [C]}{[D] + [C]}, \tag{1}$$

where [D] and [C] are the count rates in the corresponding energy bands: C = 0.52–0.90 keV, and D = 0.91–2.01 keV.

An interesting feature is seen in AGN. Their distribution has a double peak, this may be due to the fact that two types of objects are possibly hidden under this definition. This issue will be carefully studied by us in the future.

Having X-ray and Radio fluxes, we have built the dependence of luminosity on redshift graph (see Figure 3).

Active galaxies and Blazars are very interesting objects in the Universe. In order to understand some physical properties, we must identify which properties our objects have in X-ray and radio range. We have 3993 active galaxies with X-ray/radio fluxes at different wavelengths. A very important X-ray/radio

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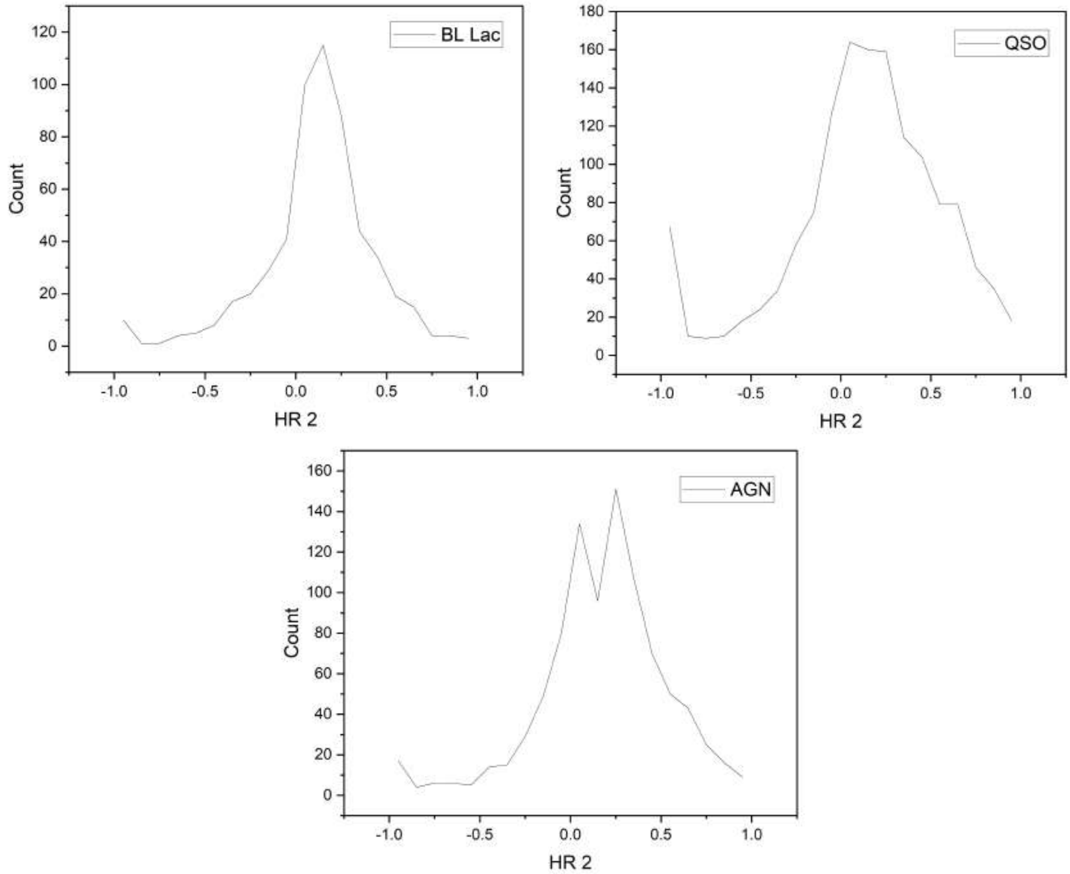

Figure 2. The distribution of HR2 for various types of object: BL Lac, QSO and AGN.

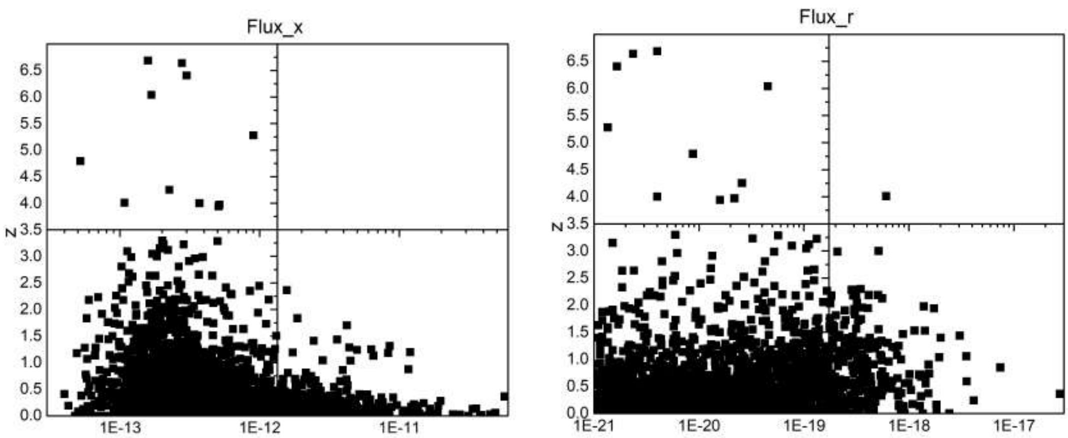

Figure 3. Distribution of redshift to X-ray and Radio flux.

property for objects is the spectral index. Using more bands, we have developed a graph for all sources (lg[flux] vs. lg[frequencies]). Using an lg[flux] versus lg[frequencies] graph for each source, we have made linear fitting. The software "Origin" gives the formula for each linear fit, and using that, we have measured the X-ray/radio spectral index for each source.

The table shows that in the X-ray range, the energy flux decreases from BL Lac to QSO, but but in the radio range, on the conversely, the flux increases from BL Lac to QSO. This is a very interesting effect and will be throughly studied by us in the future.

4. Summary and Conclusion

We have cross-correlated ROSAT PSC and FSC X-ray catalogues with NVSS radio catalogue to reveal objects with both X-ray and radio, very high probability active galaxies (mostly AGN but also Starbursts).

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Table 2. Distribution of X-ray and Radio band fluxes for Blazars, AGN's and QSO's

N	Catalog	BL Lac	AGN	QSO
1	$NVSS_F$	6.24x10^{-}20	1.33x10^{-}19	2.64x10^{-}19
2	$FIRST_F$	3.09x10^{-}20	3.41x10^{-}20	1.17x10^{-}19
3	$ROSAT_F$	3.49x10^{-}12	2.41x10^{-}12	8.44x10^{-}13
4	XMM_{F8}	2.45x10^{-}11	1.64x10^{-}11	6.83x10^{-}12
5	$Chandra_{Fb}$	3.18x10^{-}12	2.41x10^{-}12	1.64x10^{-}12

Moreover, objects having both X-ray and radio must be among the strongest AGN, namely Blazars and powerful QSOs. Therefore, SDSS spectra will be later used for classification for activity types.

Further work will be related to multiwavelength studies of these sources, as well as detailed classification for the activity types (based on our Fine Classification; Mickaelian et al., 2021, https://www.bao.am/activities/projects/21AG-1C053/mickaelian/).

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