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Optical properties of variable radio sources from NVSS and FIRST

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Abstract

We have carried out a number of studies to reveal radio properties of active galaxies, namely AGN and Starbursts. A major work was related to the cross-correlation of NVSS and FIRST radio catalogues and revelation of variable radio sources. Most probably, most of them are extragalactic ones; AGN and Starbursts. We have carried out spectroscopic classification of 6301 of these objects and revealed many Seyferts, LINERs and Starbursts. We have also studied radio properties of VCV-13 AGN, Markarian galaxies and Blazars. One of the aims of our studies is to establish the radio/opt flux ratio limit between normal galaxies detected in radio and radio loud active galaxies. The ultimate goal of these studies is to combine results obtained from radio studies and derived radio properties of active galaxies with gamma-ray, X-ray, UV, optical, IR and submm/mm to have the overall multiwavelength understanding on these objects.

Keywords: *radio sources, radio flux, optical flux, absolute magnitudes.*

Radio and optical variability of radio variables sources

NVSS and FIRST radio catalogues have been cross-matched. Our principle is to take into account positional errors for individual sources, and we have applied similar to our previous research method. In the FIRST catalogue there is no information on positional errors for each source, that is why 5 arcsecond as errors for all sources is adopted. In NVSS catalogue, each source is given with its individual positional error. We have created a software through which cross-correlations are done. This software allows considering positional errors for each source individually and we have taken associations having coordinate differences between counterparts not exceeding 3σ (calculated using both σ-s from NVSS and FIRST). As a result, we have obtained 556,282 associations between NVSS and FIRST.

Our main task is the revelation of the variability of radio sources in radio wavelengths. For variability criteria, we will take into account those radio sources which have associations within less than 3σ of the positional errors and for which the second association is 2 times farther than the first one. The systematic shift (SS) between fluxes of NVSS and FIRST catalogues was considered. We counted SS between these catalogues to get rid of systematic errors that could appear due to different flux calibration. As FIRST accuracy is higher, we have shifted NVSS using SS. The first step that was accomplished is computing systematic shift (SS) for fluxes between NVSS and FIRST (SS = 0.765 mJy).

Having 6301 radio sources that have radio variability, we try to check how many of these sources are optically variable. To understand how radio variability correlates with optical one, these radio variable sources with POSS1 and POSS2 based optical catalogues are cross correlated: APM, USNO A2.0, USNO B2.0, and GSC 2.3.2. To get rid of photometric measurements systematic effects, the systematic shifts between these catalogues were counted. In the next step, the average magnitudes in POSS1 and POSS2 both for red and blue were counted. Having this result, then we have counted the shift of each magnitude from the average for each source and averaged for each catalogue.

These two methods complement each other, as in general small magnitude differences may be a reason for doubtful variability, but relative σ numbers are important to check it additionally. Having ΔB, ΔR, B_r and R_r, all sources in variability categories have been divided. For each formula, we have one category. In We build the distribution of ΔB and ΔR to have an understanding of possible breaks for ΔB and ΔR.

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Two fractures are seen (at 1.5 and at 2.5 for ΔR, at 1.45 and at 2.51 for ΔB). Using these breaks, the categories by ΔB and ΔR are limited. Thus, there are 2425 radio sources which have both radio and optical variability. For each source, we have four means for understanding their variability and for each source, based on this we give variability category flags from 1 to 3. For a detailed picture of variability of these sources, 4 category flags are counted together. We give in the list of 2425 NVSS/ FIRST radio sources showing optical variability based on POSS1 and POSS2 epoch measurements.

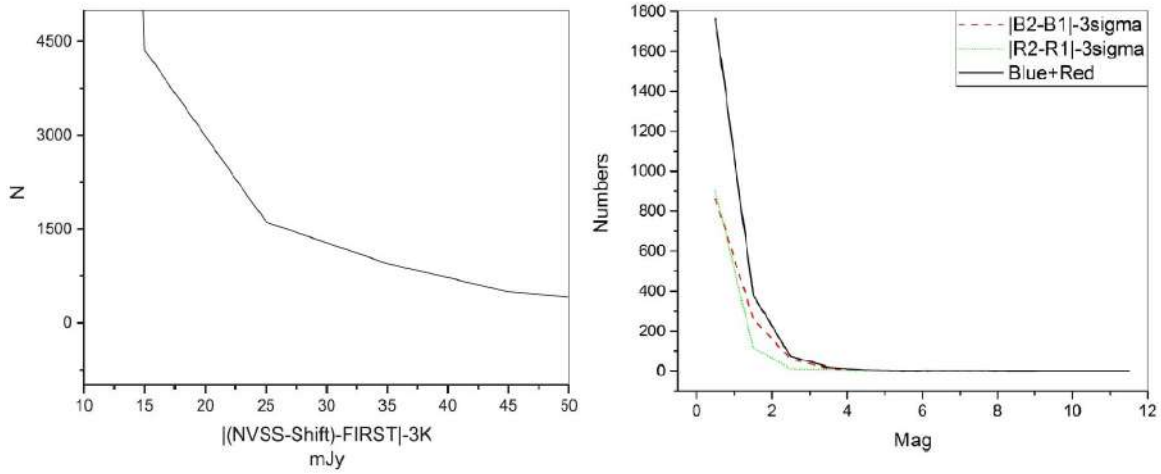

Figure 1. a)ΔF distribution, b)Distribution of ΔB and ΔR.

Optical classification

In a number of our papers, we have used the same approach to classify thousands of spectra for active galaxies from various sample. Our approach is based on BPT diagrams, however we use most recent options of such diagrams. To guarantee the best accuracy and consider all possible details, we classify the objects in several ways and then consider all obtained types and subtypes:

- By the **1st diagnostic diagram** (DD1) using line intensity ratios [OIII]/H$_\beta$ vs. [OI]/H$_\alpha$,
- By the **2nd diagnostic diagram** (DD2) using line intensity ratios [OIII]/H$_\beta$ vs. [NII]/H$_\alpha$,
- By the **3rd diagnostic diagram** (DD3) using line intensity ratios [OIII]/H$_\beta$ vs. [SII]/H$_\alpha$,
- By comparison and using the **1st, 2nd and 3rd diagnostic diagrams** simultaneously,
- **By eye** (considering all features and effects). Very often, the diagnostic diagrams do not give full understanding for all objects and only eye can reveal some details.

As it is known, the diagnostic diagrams are for classification of narrow line ratios, i. e. objects having Sy1 features (broad lines), QSOs, etc. cannot be classified by them. In addition, the classification by eye has been done in comparison with the classification by diagnostic diagrams because not all objects appear on them due to lack of line measurements data. The eye examination of spectra allows revealing broad lines (for Seyfert subtypes Sy1.0-Sy1.9), estimate (and later measure) the width of broad lines and reveal FeII lines on both sides of H$_\beta$ to identify Narrow Line Seyfert 1s, etc., as well as classifying absorption line objects. On diagnostic diagrams, for Sy/LINER separation, we have used the criteria: [OIII]/H$_\beta$ > 4, and to distinguish AGN from HII, we have used the criteria: [SII]/H$_\alpha$ > 2/3 and [OI]/H$_\alpha$ > 0.1. For all classifications, we have used the following lines:

- **Absorption lines**: NaI 5890/5896 doublet, MgI 5175, Hydrogen Balmer lines (mostly H$_\alpha$ and H$_\beta$), etc.
- **Emission lines**: most prominent are Hydrogen Balmer series lines (H$_\alpha$ 6363, H$_\beta$ 4861, H$_\gamma$ 4340, etc.), Oxygen lines ([OIII] 4959 and 5007, [OII] 3727 and [OI] 6300), Nitrogen lines ([NII] 6548 and 6484), Sulfur doublet ([SII] 6716/6731), Helium lines HeI 5876 and HeII 4686, etc.

Summary and conclusions

We have carried out a cross-correlation of NVSS and FIRST catalogues to distinguish sources which have large differences of fluxes at 1400 MHz. We have selected 6301 radio sources with flux difference at least 15 mJy. Further investigation of these radio sources led to a new sample of radio sources, which have high optical variability. The main results of our study are the cross-correlation of NVSS and FIRST radio catalogues at 1.4 GHz and construction of a large sample of 79,382 radio variable sources, including 6301 with radio variability >15 mJy flux differences between NVSS and FIRST, 1699 with flux differences >50 mJy and 260 with flux differences >200 mJy, revelation of 2425 optically variable objects out of 6301 radio sources, revelation of 1206 (19%) active galaxies out of 6301 radio sources, and compilation of a list of 619 (25.5%) out of 2425 radio sources with at the same time having optical variability (including many AGN among them).

So, we have developed a fine classification scheme for active galaxies and accordingly carried out classification of the SDSS spectra for 1864 radio variable sources.

The most important results related to the classification of active galaxies and other results are:

1) Introducing the fine classification scheme for active galaxies using SDSS spectroscopy. This became possible for the first time, as SDSS quality spectra were not available before. Detailed description of the types and subtypes of active galaxies is given, including many of them **introduced for the first time**;

2) Optical spectroscopic classification of the SDSS spectra for 1864 radio variable sources, out of which 1746 appeared to be genuine extragalactic objects. Revealing many new QSOs, Seyferts, LINERs and other active galaxies;

3) Calculating absolute magnitudes and luminosities for the sample objects. Estimation of average M and L and ranges of their values for various types of active galaxies;

4) Building colour-magnitude and colour-colour diagrams in both optical wavelengths (using SDSS photometry) and IR (using AllWISE photometry) to follow the location of different types of active galaxies on these diagrams.

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