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Bright X-ray galaxies in SDSS filaments

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Eighteen bright X-ray emitting galaxies were found in nearby filaments within the SDSS region. Basic X-ray spectral parameters were estimated for these galaxies using a power law model with photoelectric absorption. A close pair of X-ray galaxies was found.

Key words: X-rays: galaxies, large-scale structure of Universe

INTRODUCTION

The large-scale structure (LSS) of the observable Universe contains clusters and groups of galaxies combined into filaments. The problem of (galaxy) filament detection in redshift space is complex, so its solution methods are usually tested on a modelled LSS obtained using N-body simulations. Smith et al. [7] found 53 real filaments for the Sloan Digital Sky Survey (SDSS) galaxies at redshift $z < 0.13$. In this paper, the filaments were considered as elongated structures that contain sufficient groups and clusters for building a minimal spanning tree in redshift space. However, such filaments cover only a relatively small part of SDSS redshift-space volume available for LSS studying. Therefore, new methods must be developed to search the filaments using all SDSS redshifts, and on smaller scales. An attempt to develop and apply such a new method to SDSS volume, will be the subject of our future work (where we intend to use single galaxies instead of groups or clusters). In this paper, however, we confined ourselves to the consideration of 53 filaments from [7].

The goal of this work was to describe X-ray emission of galaxies in filaments, which can in the future be compared with other high-energy sources in the large-scale structures of the Universe (isolated galaxies, clusters, walls). In [9] it was shown that outside of the Local Supercluster it is only possible to detect galaxies with active galactic nuclei (AGN) in the X-ray band, therefore the filaments must contain bright X-ray emitting AGN's. X-ray galaxies in the filaments are established in [7] and their spectra are considered here.

SAMPLES

A sample of 5021 X-ray galaxies from [8] was used for the search of filament galaxies. These galaxies were selected from the Incremental Second XMM-Newton Serendipitous Source Catalogue (2XMMi) [13] of X-ray sources detected by the XMM-Newton observatory. 2092 of them lie in the main SDSS region of sky ($110° < \alpha < 250°$, $-10° < \delta < 70°$). Only the brightest X-ray sources are appropriate for spectral fitting. After the inspection of preliminary spectra of 2XMMi sources in Vizier database, the minimal limiting value of X-ray flux $F_{X,min} = 3.7 \cdot 10^{-13}\,\mathrm{erg/cm^2}$ was picked. It is assumed here that X-ray spectra can be built only for galaxies with $F_X > F_{X,min}$. 978 of the 5021 X-ray galaxies satisfy this condition.

The second condition for galaxy selection was that the galaxy should be inside one of 53 SDSS filaments, established in [7]. These filaments were found with multiscale probability methods in which the size of structures in redshift space is assumed to be $\Delta z = 0.005$. In the present work, filaments from [7] were visually inspected on the sky distribution of galaxies in slices with $\Delta z = 0.023$, which corresponds to the size of void (100 Mpc). 53 filaments from [7] occupy only five slices of 100 Mpc. An example of a slice is shown in Fig. 1. Numbers of galaxies in slices are presented in Table 1. Among 335 bright X-ray galaxies in the SDSS region, only 18 were found in the mentioned filaments. During the selection, several galaxies located inside or very close to the X-ray clusters, were detected. Although these clusters can be considered to be part of a filament, such galaxies were excluded to avoid the problem of distinction of radiation from galaxy, from that of the intergalactic hot gas. To estimate the upper bound of a possible number of X-ray galaxies in filaments, an assumption was made that all galaxies outside clusters are located in filaments. General characteristics of the obtained galaxies are presented in Table 2.

SPECTRAL FITTING

Cross-correlation of XMM and SDSS sources was performed in [6], however there was no detailed study of single galaxies. Basic spectral characteristics of bright filament galaxies are presented in Table 3. A power law model of the X-ray spectrum with photoelectric absorption was used in this analysis. Galactic absorption was taken from [14]. Spectral param-

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Table 1: Number of X-ray galaxies in the SDSS by distances.

Radial velocity, km/s	Filaments in [7]	X-ray galaxies	Notable Objects	Bright X-ray galaxies
0-4000		207	Local Supercluster	79
4000-11000	5	214	Coma Supercluster	60
11000-18000	12	196		31
18000-25000	21	212	Sloan Great Wall	37
25000-32000	10	148		29
32000-39000	5	113		12
39000-46000		109		10
46000-53000		70		11
53000-60000		73		7
Distant		555		59
Total	53	2092		335

eters for some galaxies, when possible, were taken from literature. Nine galaxies had no spectral analysis in previous works, thus it was conducted in the present work. These galaxies were mentioned previously only in AGN catalogues such as [12], and their cross-correlation with XMM sources was mentioned in [6]. There are several notes for the few selected galaxies.

2MASX J12034921+0205575. This Seyfert 1 galaxy has five references in the SIMBAD database, including [6, 12] and 3 older optical surveys. 2XMMi database contains a preliminary spectrum for this galaxy, however the full archive of observation data files is not available for downloading.

2MASX J09590662+1301351 and 2MASX J09591475+1259161. This pair of bright X-ray galaxies has angular distance of 3 arcmin, which corresponds to a spatial distance of 140 kpc. They can interact or be physically bound.

CONCLUSIONS

Eighteen bright X-ray galaxies in SDSS filaments were found. The most common type of such galaxies is Seyfert 1. Spectral parameters for nine galaxies were estimated. Since the number of X-ray sources in filaments is very small, X-ray observations cannot be used for the detection of new filaments. Therefore, the procedure of describing LSS in the high-energy band should include a detailed description of the filaments, on the basis of optical galaxy surveys, statistical studies of X-ray sources in a large homogeneous volume, and comparison of parameters of X-ray extragalactic sources inside and outside filaments. Such a study is going to be performed in our future works.

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Table 2: General properties of bright X-ray galaxies.

Object name	Coordinate code	SIMBAD Type	V_{3K}, km/s	X-ray flux, 10^{-12} erg/cm^2
2XMMi J082912.8+500652	0829+5007	Seyfert 1	13141	1.91±0.11
2MASX J08413787+5455069	0842+5455	Seyfert 1	13512	3.83±0.14
2MASX J09590662+1301351	0959+1301	Galaxy	11296	1.25±0.03
2MASX J09591475+1259161	0959+1259	Galaxy	10619	1.39±0.03
2MASS J10003549+0524285	1001+0524	QSO	23905	0.99±0.04
Mrk 176	1133+5257	Seyfert 1	8325	0.62±0.02
NGC 3921	1151+5505	Interacting Galaxies	6017	0.42±0.01
2MASX J12034921+0205575	1204+0206	Seyfert 1	24714	1.09±0.11
2E 2620	1214+1403	Seyfert 1	24581	10.97±0.02
NGC 4686	1247+5432	Galaxy in Group	5181	1.13±0.03
MCG+07-28-006	1324+4318	Seyfert 2	8374	1.12±0.04
2XMM J134245.8+403913	1343+4039	X-ray source	26889	0.59±0.03
2MASS J14134834+4400141	1414+4400	Seyfert 1	26842	0.74±0.02
NGC 5548	1418+2508	Seyfert 1	5358	74.44±0.13
Mrk 684	1431+2817	Seyfert 1	13949	7.54±0.06
87GB 150115.3+102756	1501+1028	AGN	28668	0.55±0.05
Mrk 841	1504+1026	Seyfert 1	11126	35.02±0.15
2MASX J15113367+0545479	1512+0546	AGN	25065	0.43±0.01

Table 3: Spectral properties of bright X-ray galaxies.

Target	Galactic N_H, 10^{22} cm^{-2}	N_H, 10^{22} cm^{-2}	Photon index	χ^2/d.o.f.	Source
0829+5007	0.046	0.05	2.64±0.08	102.4/101	[2]
0842+5455	0.038	0.31±0.02	1.56±0.06	109/135	This work
0959+1301	0.032	12.7±2.5	1.34±0.29	15.8/16	This work
0959+1259	0.032	0.77 ± 0.05	1.88 ± 0.08	206/267	[4]
1001+0524	0.027	<0.01	2.26±0.11	35/28	This work
1133+5257	0.011	12.7±2.5	1.34±0.29	11.4/11	This work
1151+5505	0.010	1.93±0.20	1.55±0.10	93/86	[5]
1214+1403	0.030	0.043±0.006	2.07±0.01	896/746	This work
1247+5432	0.015	0.024±0.001	2.00±0.05	119/61	[10]
1324+4318	0.015	$0.06^{+0.34}_{-0.04}$	$2.74^{+2.40}_{-0.67}$	141/68	[4]
1343+4039	0.008	3.8±1.2	1.25±0.37	10.6/11	This work
1414+4400	0.009	$16.7^{+4.5}_{-5.6}$	$1.55^{+0.24}_{-0.23}$	63/75	[3]
1418+2508	0.017	0.02	1.65		[11]
1431+2817	0.016	<0.01	2.45±0.02	400/286	This work
1501+1028	0.024	<0.01	1.48±0.01	1022/770	This work
1504+1026	0.024	0.02	1.75±0.05		[1]
1512+0546	0.036	0.08±0.02	2.22±0.19	62/58	This work

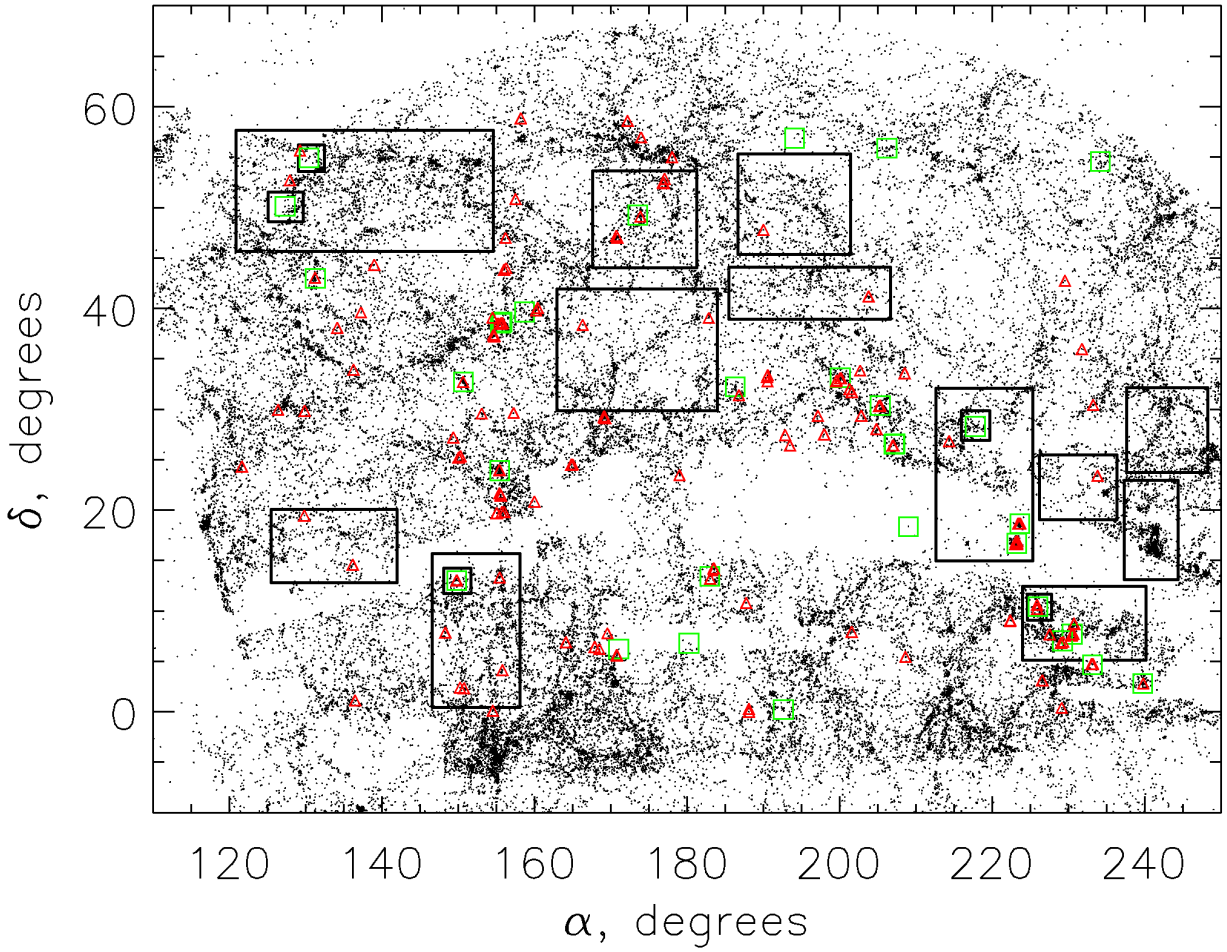

Fig. 1: Sky distribution of SDSS galaxies with radial velocities between 11000 and 18000 km/s. Triangles are X-ray galaxies with $F_X < F_{X,min}$, squares – bright X-ray galaxies with $F_X > F_{X,min}$, large rectangles – filaments from [7], double squares – galaxies in filaments which are considered in this work.