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The Multi-Wavelength Quasar Survey IV. Quasars in the Leo Cluster *

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Abstract We aim to provide a quasar sample that is more complete than any previous surveys by using a combined selection technique to reduce the selection effects. Here we present the observational results for the X-ray candidates in the field of the Leo Cluster. We found 33 X-ray AGNs in this field of which 10 are new discoveries. The X-ray data and optical spectra of these AGNs are given. We also study the near-IR properties of the X-ray-selected AGNs by using the data from 2MASS. Most of the AGNs in our sample span the color range $0.0 < B - J < 2.5$, $1.0 < J - K_s < 2.0$ and $0.5 < H - K_s < 1.2$.

Key words: galaxies: active: individual (Leo Cluster) — X-rays: galaxies: quasars

1 INTRODUCTION

This paper is the fourth in a series presenting the results from the Multiwavelength Quasars Survey (MWQS), which is aimed at obtaining a sample of ~ 350 new AGNs brighter than $B = 19.0$. The candidates are selected from the ROSAT All-Sky Survey (RASS) data. The scientific objectives and the detailed candidate selection procedures have been described in the previous three papers in the series (He et al. 2001 (Paper I); Chen et al. 2002 (Paper II); Bai et al. 2007 (Paper III)). This paper reports the observational results for the X-ray candidates in the Leo field. Section 2 describes the observations and the results for the X-ray candidates in the Leo Cluster. Ten new AGNs are discovered. A short discussion is carried out in Section 3. Section 4 gives a prospect of future work.

Throughout this paper, we assume a standard Einstein-de Sitter cosmological model with H_0=50 km s^{-1} Mpc^{-1} and $q_0 = 0.5$.

2 OBSERVATIONS AND RESULTS

The survey region of the X-ray sources in the Leo Cluster covers an area of $6^\circ \times 6^\circ$, centered at R.A.= $11^{\rm h}30^{\rm m}$, decl.=$15^\circ 00'$ (J2000.0). The candidate selection procedures have been described in Papers I and II. After the preselection, we have 75 X-ray candidates. As in Papers I-III, we compared our list with previously published list (Véron-Cetty & Véron 2006) and astronomical databases (the SDSS (Sloan Digital Sky Survey) Data Release 5, NED (NASA/IPAC Extragalactic Database) and SIMBAD), and found 23 known AGNs, including nine quasars, 11 Seyfert galaxies, one BL Lacertae object, and two LINERs.

From 1999 March 10 to March 15, we observed the candidates at Kitt Peak Observatory. We used the GoldCam CCD spectrograph and grating 32. The spectral coverage is 4000−10 000 Å, with a spectral resolution of about 7 Å. In 2002 February and 2006 March, we observed the other candidates on the 2.16 m

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Table 1 The X-ray AGNs Sample

ROSAT Name	R.A. (2000)	DEC (2000)	Count Rate	$\log(f_x/f_o)$	log(ext)	B	z_{em}	M_B	Type
111710.4+143732	11 17 12.1	14 38 17	0.019	−0.74	1.77	16.5	0.121	−22.80	Sey*
111836.9+145651	11 18 36.2	14 57 21	0.014	−0.42	1.77	17.7	0.171	−22.35	Sey
111852.7+172318	11 18 50.9	17 22 28	0.032	0.40	1.77	18.1	0.571	−24.56	QSO*
111854.6+141149	11 18 52.8	14 12 01	0.028	0.33	0.85	18.8	0.143	−20.87	Sey
111857.4+130536	11 18 55.9	13 05 32	0.019	0.37	1.77	19.3	0.003	−11.75	LINER
111857.7+123434	11 18 57.3	12 34 42	0.044	0.17	1.77	17.9	2.129	−27.54	QSO
111956.1+165642	11 19 55.8	16 56 43	0.049	0.30	1.77	18.1	0.198	−22.27	Sey*
112016.7+125917	11 20 15.0	12 59 30	0.118	0.36	1.72	17.3	0.002	−13.49	LINER
112131.3+123614	11 21 29.7	12 36 17	0.039	0.28	1.00	18.3	0.684	−24.75	QSO
112240.5+163512	11 22 40.1	16 35 07	0.047	−0.28	1.77	16.7	0.473	−25.55	QSO*
112255.0+160044	11 22 55.2	16 00 41	0.032	−0.48	1.20	16.6	0.115	−22.59	Sey*
112317.5+165252	11 23 17.9	16 52 55	0.034	0.06	1.77	17.9	0.890	−25.71	QSO*
112400.2+170724	11 23 59.9	17 07 20	0.025	−0.16	1.77	17.7	0.150	−22.07	Sey*
112614.7+120039	11 26 14.1	12 00 27	0.069	0.37	1.04	17.9	0.391	−23.94	QSO
112632.9+120438	11 26 32.9	12 04 37	0.060	0.07	1.77	17.3	0.977	−26.51	QSO
112813.0+134939	11 28 13.7	13 49 25	0.037	−0.23	1.77	17.1	0.285	−24.06	QSO*
112945.9+120054	11 29 45.6	12 00 50	0.015	0.17	1.77	19.1	0.313	−22.27	Sey
113112.8+151953	11 31 11.0	15 20 19	0.022	0.48	1.77	19.4	0.275	−21.68	Sey
113129.2+124344	11 31 29.7	12 43 50	0.058	–1.07	1.11	18.6	0.091	−20.08	Sey
113137.0+144250	11 31 37.3	14 43 05	0.024	0.15	1.77	18.5	0.712	−24.63	QSO
113137.2+155703	11 31 37.2	15 56 45	0.085	0.10	1.04	17.0	0.182	−23.19	QSO*
113209.6+161317	11 32 09.8	16 13 13	0.170	0.20	1.77	16.5	0.117	−22.73	Sey
113210.5+133507	11 32 10.6	13 35 09	0.061	−0.28	1.20	16.4	0.199	−23.98	QSO
113315.6+122114	11 33 15.8	12 21 15	0.031	−0.05	1.77	17.7	0.144	−21.97	Sey
113451.0+134853	11 34 51.2	13 49 05	0.016	−0.31	1.77	17.8	0.231	−22.91	Sey
113534.5+145141	11 35 34.1	14 51 42	0.014	−0.13	1.77	18.4	0.180	−21.77	Sey*
113618.1+160148	11 36 17.5	16 01 53	0.029	0.56	1.77	19.3	0.460	−22.89	BL
113827.7+133233	11 38 28.7	13 32 42	0.018	0.10	1.77	18.7	0.246	−22.14	Sey
113905.4+131031	11 39 04.9	13 10 19	0.052	0.01	1.11	17.3	0.154	−22.52	Sey
113931.7+142354	11 39 32.4	14 23 56	0.019	−0.18	1.77	17.9	0.942	−25.83	QSO
114002.4+152745	11 40 03.3	15 27 21	0.066	0.07	1.77	17.2	0.193	−23.12	QSO
114003.0+124112	11 40 02.4	12 41 02	0.033	0.13	1.77	18.1	0.282	−23.04	QSO
114035.8+153443	11 40 36.8	15 34 37	0.040	0.61	1.77	19.1	0.373	−22.64	Sey

* Newly identified X-ray AGNs.

optical telescope at the Xinglong Station of National Astronomical Observatories, Chinese Academy of Sciences (NAOC). We used a 195 Å mm^{-1} grating and a Tektronix 1024×1024 CCD detector. The spectral coverage was 4000–8000 Å, with a spectral resolution of about 13 Å. All of the spectra were reduced with IRAF.

The spectroscopic results led to the discovery of ten AGNs, two stars, and four unclassified objects. Among the newly discovered AGNs, five have absolute magnitudes $M_B < -23.0$ and are classified as quasars (Paper I), and the other five are classified as Seyferts. The unclassified objects have spectra with signal-to-noise ratios too poor to allow unambiguous classification.

Table 1 gives the observational data for all the 33 AGNs in this field. The first three columns display the ROSAT source designation and optical position, column (4), the ROSAT count rate in counts s $^{-1}$, column (5), the X-ray-to-optical flux ratio, column (6), the likely source extent, and column (7), the B magnitude obtained from USNO−A2.0 (see *http://ftp.nofs.navy.mil/projects/pmm/a2.html*). Column (8) shows the emission-line redshift and column (9) the B absolute magnitude, calculated by using the equations from Weedman (1986), in which we assume an optical spectral index of −0.5 ($F_\nu \propto \nu^\alpha$). Column (10) shows the type abbreviation: Seyfert (Sey), quasar (QSO), BL Lacertae (BL), and LINERs, with asterisks marking the new AGNs found in our MWQS, to distinguish them from the previously known ones. The spectra of the new AGNs are shown in Figure 1. Figure 2 displays the distribution of the sample objects on the sky.

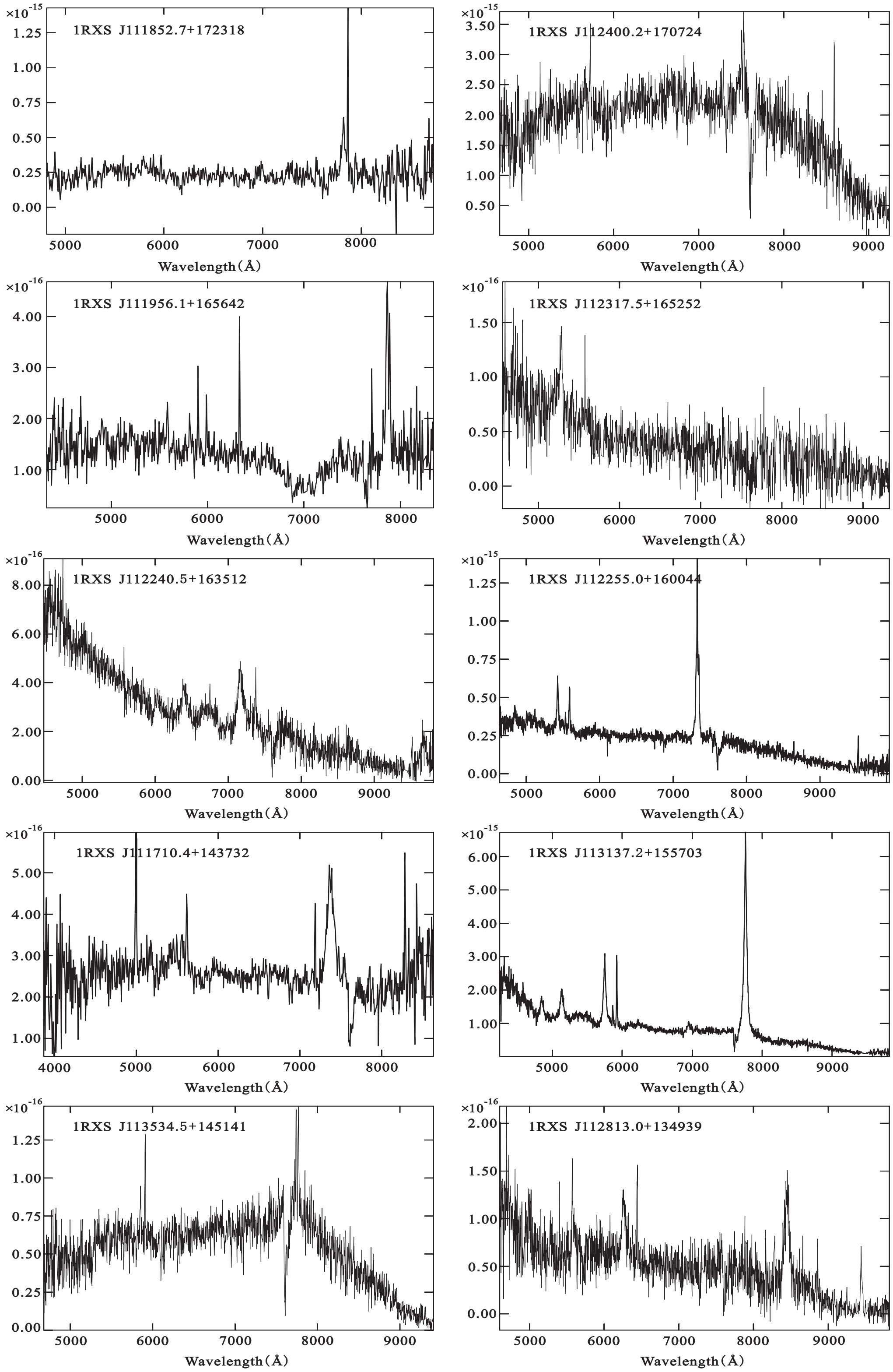

Fig. 1 Spectra of newly identified AGNs in the Leo Cluster. Spectral flux (F_λ) is in units of erg cm^{-2} s^{-1} Å^{-1}.

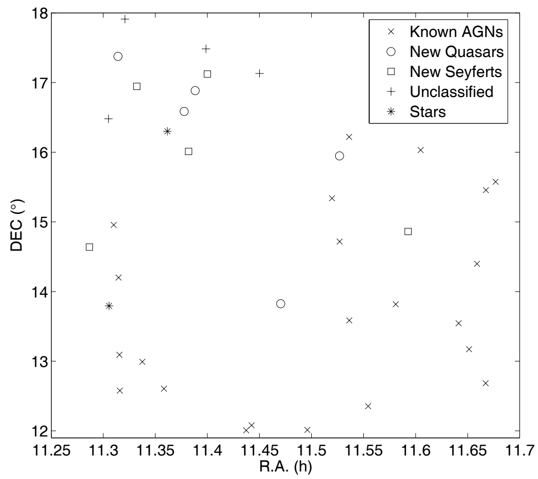

Fig. 2 Distribution of the X-ray sample on the sky.

3 DISCUSSION

This paper has continued the study on a sample of ROSAT sources in the MWQS region. Of the 75 X-ray candidates in the field of the Leo Cluster, 33 are discovered to be AGNs and ten are presented here for the first time. We adopted the same candidate selection criteria as in Papers II and III. Although nine known AGNs with weaker X-ray emission failed to satisfy the criteria, the AGN candidate selection method is effective in practice: it possibly has minimized 'contamination' of the candidate list by successfully excluding stars and clusters of galaxies.

Some of the newly discovered AGNs are very interesting. An example is 1RXS111956.1+165642. It is a strong X-ray source with z=0.198 and M_B=-22.27, its $\log(f_{\rm x}/f_{\rm o})$ and count rate are much higher than most of the newly identified AGNs. Based on the threshold absolute magnitude between quasars and Seyferts, M_B=-23, it could be a bright Seyfert. It has a distinctive spectrum, and according to the flux ratio [OIII]$\lambda5007$/Hβ (Peterson 1997), it would be an HII-region galaxy rather than a Seyfert. There is also a broad absorption region between $H\alpha$ and [OIII]$\lambda5007$. 1RXS111956.1+165642 has a counterpart (2MASS J111956.1+165642) in the 2MASS (Two Micron All Sky Survey) All-Sky Catalog of Point Sources, and another 2MASS source 2MASS J111956.5+165650 is only $7.4''$ away. Based on the spectrum and the position, they could possibly be a pair of interacting galaxies. However, we have not obtain the spectrum of 2MASS J111956.5+165650 yet, for its B magnitude of 20.60 mag, is beyond the limiting magnitude of the 2.16 m optical telescope at the Xinglong Station. A discussion of this object will be presented in detail in another paper of ours.

Like 1RXS111956.1+165642, 27 among the 33 AGNs in the Leo Cluster region have counterparts in the Point Source Catalogue of 2MASS. We use this sample of 27 AGNs to study the near-IR properties of X-ray-selected AGNs. Table 2 gives the 2MASS data for all the 27 AGNs in this field. The first three columns display the ROSAT source designation and near-IR position. Columns (4)–(6) list the J, H and K_s magnitudes taken from 2MASS.

The distribution of the different types of AGNs in the color-color diagrams is shown in Figure 3. It is impossible to distinguish quasars from Seyferts in the color-color diagram while most of the AGNs span a color range $0.0 < B-J < 2.5$, $1.0 < J-K_s < 2.0$ and $0.5 < H-K_s < 1.2$. Leipski et al. (2005) applied a color index $H-K_s > 0.5$ as one of the criteria when searching for AGNs free of dust extinction. Francis et al. (2004) used $J-K_s > 1.2$ to obtain a near-IR-selected AGN sample. Our results are in agreement with their criteria .

The primary target of our MWQS survey is to reduce the selection effects and to produce a highly complete sample. X-rays selection enabled the discoveries of elusive AGN that are completely hidden in starburst nuclei (Maiolino et al. 2003), while IR selection is a good way to identify buried AGNs. The

Table 2 The 2MASS Data of AGNs in Leo Cluster Region

ROSAT Name	R.A. (2000)	DEC (2000)	J(mag)	H(mag)	K_s(mag)
111710.4+143732	11 17 12.06	14 38 17.6	15.344	14.706	14.111
111836.9+145651	11 18 36.17	14 57 21.1	16.684	15.624	14.834
111852.7+172318	11 18 50.94	17 22 28.3	15.945	15.089	14.558
111854.6+141149	11 18 52.83	14 12 01.0	16.472	15.682	14.966
111857.4+130536	11 18 55.90	13 05 32.3	10.850	10.026	9.974
111956.1+165642	11 19 55.81	16 56 41.9	16.143	15.262	14.390
112016.7+125917	11 20 14.99	12 59 29.8	10.983	10.276	9.743
112240.5+163512	11 22 40.08	16 35 07.6	16.418	15.890	14.827
112255.0+160044	11 22 55.20	16 00 40.6	15.147	14.258	13.348
112400.2+170724	11 23 59.93	17 07 19.6	15.764	15.192	14.537
112614.7+120039	11 26 14.06	12 00 27.3	16.876	16.048	14.912
112632.9+120438	11 26 32.91	12 04 37.2	15.598	15.342	14.557
112813.0+134939	11 28 13.71	13 49 24.5	16.413	15.829	14.743
112945.9+120054	11 29 45.63	12 00 50.5	17.060	15.805	15.106
113129.2+124344	11 31 29.78	12 43 48.8	15.043	14.486	14.046
113137.2+155703	11 31 37.18	15 56 45.2	16.132	15.323	14.435
113209.6+161317	11 32 10.03	16 13 14.7	15.293	14.406	13.727
113210.5+133507	11 32 10.56	13 35 09.2	15.569	14.665	13.775
113315.6+122114	11 33 15.77	12 21 14.9	16.227	15.489	14.938
113451.0+134853	11 34 51.18	13 49 04.7	16.557	15.779	15.016
113534.5+145141	11 35 34.13	14 51 41.7	16.384	15.562	14.943
113827.7+133233	11 38 28.65	13 32 42.3	17.221	16.636	15.624
113905.4+131031	11 39 04.96	13 10 19.4	15.976	15.353	14.638
113931.7+142354	11 39 32.39	14 23 55.1	16.802	16.495	15.349
114002.4+152745	11 40 03.26	15 27 21.7	16.890	15.878	15.076
114003.0+124112	11 40 02.41	12 41 01.6	16.785	15.629	15.587
114035.8+153443	11 40 36.80	15 34 36.5	17.101	16.176	15.007

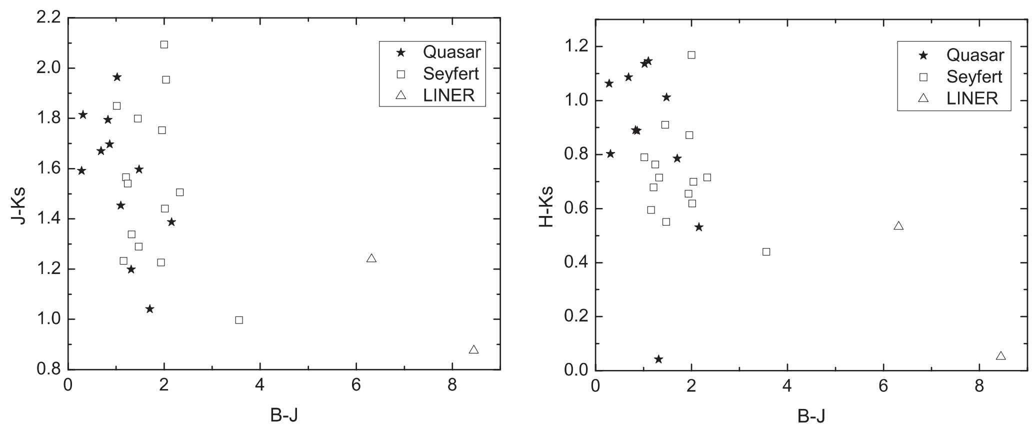

Fig. 3 Color-color diagrams of 27 AGNs in the Leo Cluster.

combination of the IR selection and X-ray selection may provide a new way to identify dusty, red AGNs. We also studied the relationship between the near-IR flux and the X-ray flux, and did not find any connections between them.

4 FUTURE WORK

From the quasars detected so far, about 14 quasars cover a $6^\circ \times 6^\circ$ region of the Leo Cluster. Leo Cluster (Abell 1367) is a young, dynamically unevolved cluster (Forman & Jones 1982), and has a relatively cool gas temperature and a high spiral fraction. The galaxy content is 43% spiral, 40% S0, and 17% elliptical (Oemler 1974). Strom & Strom (1978) found that the elliptical galaxies in Leo Cluster were larger than those of the same absolute magnitude in dense clusters like Coma Cluster. Their interpretation that galaxies in Leo Cluster have undergone fewer collisions and little tidal stripping, agrees with the classification of Leo Cluster as an unevolved cluster.

The SDSS covers this sky field, but the data have not been released to the public completely. Combing the new and published quasars, we could analyze the quasar distribution and luminosity function in the Leo Cluster. Similar studies have been done on the Virgo cluster. It was shown that there was no evidence for an association between the quasars and the Virgo galaxies, and that the distribution of the quasars in the region is weak clustered (Impey & He 1986; Yang et al. 1995). A further investigation on the Leo Cluster may provide more information about the characteristics of quasars in such rich clusters of galaxies.

Furthermore, the properties of galaxy halos and intracluster medium in the cluster of galaxies are highly uncertain. Metal-line absorption systems in quasars may have been caused by material along the line-of-sight. We also plan to obtain high-resolution spectra of the quasars in the Leo Cluster, which may provide a valuable probe of the absorptions due to galaxy halos and intracluster medium.

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