The Las Campanas Redshift Survey, an optically selected survey which contains 26 418 galaxy redshifts, has been correlated with “The First ROSAT Source Catalogue of Pointed Observations with the PSPC,” which contains 50 408 sources from 2876 ROSAT pointed observations. Ten matches were found. The optical spectra of most of the ten matches show weak narrow emission lines. Due to their high x-ray luminosities, their high x-ray–to–optical flux ratios, and the evidence of rapid x-ray variability in the two brightest matches, we interpret the majority of these objects to be narrow-line Seyfert galaxies or “hidden” active galactic nuclei. Of the ten matches, only one galaxy shows the characteristics of a bona fide starburst.

Key words: catalogs – surveys – galaxies: active – galaxies: starburst – x-rays: galaxies

1. Introduction

Great strides have been made in recent years in resolving the soft (0.5 – 2 keV) extragalactic x-ray background (XRB) into discrete sources (for a review, see Hasinger 1996). These sources include stars, galaxies, quasars and other active galactic nuclei (AGNs), and groups and clusters of galaxies. Most recent surveys of the soft XRB have focused on finding the optical counterparts of x-ray sources from flux-limited x-ray catalogues. In this paper, however, we reverse the process: we take an optically selected galaxy redshift survey – the Las Campanas Redshift Survey (LCRS; Shectman et al. 1996) – and search for x-ray sources within it, taking for our x-ray sample “The First ROSAT Source Catalogue of Pointed Observations with the PSPC” (ROSATSRC; Zimmermann 1994). That our approach is complementary to the standard strategy is evident, since it is based upon a magnitude-limited optical galaxy survey which therefore contains much fainter x-ray sources (down to $\sim 3 \times 10^{-15}$ erg s$^{-1}$ cm$^{-2}$) than most present-day x-ray surveys. With such an approach, we can learn about the x-ray properties of a typical, optically selected catalogue of galaxies.

2. The LCRS and the ROSATSRC

The LCRS is an optically selected galaxy redshift survey which extends to a redshift of 0.2 and which is composed of a total of 6 alternating $1.5^\circ \times 80^\circ$ slices in the North and South Galactic Caps. Accurate $R$-band photometry and sky positions for program objects have been extracted from CCD drift scans obtained on the Las Campanas Swope 1-m telescope; spectroscopy has been performed at the Las Campanas Du Pont 2.5-m telescope, originally via a 50-fiber Multi-Object Spectrograph (MOS), and later via a 112-fiber MOS. For observing efficiency, all the fibers are used, but each MOS field is observed only once. Hence, the LCRS is a collection of 50-fiber fields (with nominal apparent magnitude limits of $16 < m_R < 17.3$) and 112-fiber fields (with nominal apparent magnitude limits of $15 < m_R < 17.7$). Recently completed, the LCRS contains 26 418 galaxy redshifts; in this
paper, we consider only those 25,327 LCRS galaxy redshifts which lie in the 6 published slices (Shectman et al. 1996).

Our x-ray sample, ROSATSRC, contains 50,408 x-ray sources in 2872° fields of the ROSAT Position Sensitive Proportional Counter (PSPC; Pfeffermann et al. 1986). This catalogue is composed of PSPC fields in the public ROSAT Data Archive observed before June 1993. The sources in the catalogue were extracted at a detection threshold of log P ≥ 10, which corresponds to a rate of accidental detections of about 1%.

3. Correlation of LCRS Galaxies with ROSATSRC Sources

The typical errors in the sky positions for LCRS galaxies and ROSATSRC sources are, respectively, ∼ 1 arcsec and ∼ 10–20 arcsec. Hence, to match LCRS galaxies with ROSATSRC sources, we follow a three-step procedure:

1. Within a search radius of 30 arcsec, match an LCRS galaxy with the closest ROSATSRC source (if any). At this stage, we had 19 potential LCRS-ROSATSRC matches.
2. Cull matches which lie outside a 2-sigma positional error box. This step removed 3 “matches” from the sample, leaving 16.
3. By visual inspection of the Palomar Digitized Sky Survey, remove ambiguous identifications and sources which appear to be groups or clusters. This final step left a cleaned sample of 10 LCRS-ROSATSRC matches.

Such a small number of matches is perhaps not too surprising: although the LCRS covers 700 sq deg of sky, the public ROSATSRC pointings only overlap ≈ 9% of this area (≈ 60 sq deg) non-redundantly; if one considers only the more sensitive inner 20 arcmin radius of the ROSATSRC fields, this fraction drops to ≈ 0.7% (≈ 5 sq deg). The sky and (redshift) space distributions of the LCRS galaxies and of the 10 LCRS-ROSATSRC matches are presented in Figs. 1 & 2. The optical spectra of the LCRS-ROSATSRC matches can be found in Fig. 3.

4. LCRS-ROSATSRC Sample Characteristics

Since the LCRS is a galaxy survey (and thus selects against objects which appear stellar), none of the LCRS-ROSATSRC matches were quasars (which, nevertheless, are relatively common in typical, x-ray selected surveys). Indeed, we find instead the following general characteristics for the LCRS-ROSATSRC matches (see Table 1):

1. Most have relatively narrow [OII] 3727, Hβ, and [OIII] 5007 emission lines (FWHM < 1000 km s⁻¹).
2. In general, their soft (0.5 – 2 keV) x-ray flux f_X lies in the range f_X ∼ 0.1 – 1 f_R, where f_R is the R-band (“optical”) flux. [The x-ray fluxes f_X were estimated from the count rates assuming Galactic values of N_H and a power law spectrum with energy index 1; the flux ratios were calculated according to the formula
   \[ \log(f_X/f_R) = \log(f_X(0.5 – 2 \text{ keV})) + 0.4m_R + 5.7, \]
   which is appropriate for the LCRS R-filter.]
3. They generally have soft (0.5 – 2 keV) x-ray luminosities in the range L_X ∼ 10^{42} – 10^{44} erg s⁻¹ (H_0 = 50 km s⁻¹ Mpc⁻¹, q_0 = 0.5).
4. Their x-ray spectra are of moderate “hardness,” ranging typically between values of -0.5 and +0.5 for both the H R 1 and H R 2 hardness ratios.

As such, their general properties closely resemble those of other samples of x-ray luminous, narrow-emission-line galaxies (e.g., Boyle et al. 1995a,b; Carballo et al. 1995; Griffiths et al. 1996; Romero-Colmenero et al. 1996).

Furthermore, we have produced x-ray light curves for two of the brightest and longest exposed LCRS-ROSATSRC galaxies, one of which shows a factor of two increase in brightness on a timescale on the order of a few hours and the other of which shows a less-significant-but-suggestive variation on a similar timescale (Fig. 4).

In summary, due to their relatively high luminosities and f_X/f_R ratios and due to the evidence for rapid x-ray variability, we interpret the majority of these objects as narrow-line Seyfert galaxies or “hidden” AGN; of these galaxies, only one (LCRS B120117.2-032552) shows definite characteristics of a starburst.
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References
Boyle, B.J., McMahon, R.G., Wilkes, B.J., Elvis, M.: 1995a, MNRAS 272, 462
Boyle, B.J., McMahon, R.G., Wilkes, B.J., Elvis, M.: 1995b, MNRAS 276, 315
Carballo, R., Warwick, R.S., Barcons, X., et al.: 1995, MNRAS 277, 1312
Griffiths, R.E., Della Ceca, R., Georgantopoulos, I., et al.: 1996, MNRAS 281, 71
Hasinger, G. 1996: in "Röntgenstrahlung in the Universe", eds. H.-U. Zimmermann, J.E. Trümper, H. Yorke, MPE Report 263, p. 291
Pfeffermann, E., et al.: 1986, Proc. SPIE 733, 519
Romero-Colmenero, E., Branduardi-Raymont, G., Carrera, F.J., et al.: 1996, MNRAS 282, 94
Shectman, S.A., Landy, S.D., Oemler, A., et al.: 1996, ApJ 470, 172
Zimmermann, H.-U.: 1994, IAU Circ. #6102

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Table 1
Observed characteristics of the LCRS-ROSATSRC sample.

| Name          | cz⊙ | mₚ | Mₚ | W₁ | count rate | fₓ | log Lₓ | HR¹ | HR² |
|---------------|-----|----|----|----|------------|----|-------|-----|-----|
| LCRS B        |     |    |    |    |            |    |       |     |     |
| 002810.0-422515 | 54034 | 17.06 | -23.38 | 5.63 | 2.56 | < 2. | 82.7 ± 7.5 | 60.8 | 43.963 | −0.31 ± 0.07 −0.44 ± 0.11 |
| 020707.7-392308 | 29491 | 17.51 | -21.50 | 3.38 | < 2. | 8.14 | 8.72 | 5.12 | 42.347 | 0.00 ± 0.00 0.00 ± 0.00 |
| 033922.7-442138 | 22883 | 16.62 | -21.80 | 16.72 | 3.99 | 2.83 | 5.20 ± 0.55 | 3.14 | 41.910 | 0.13 ± 0.14 −0.27 ± 0.12 |
| 102524.8-022953 | 53070 | 17.48 | -22.91 | < 2. | < 2. | 10.8 | 10.6 | 43.190 | 0.00 ± 0.00 0.00 ± 0.00 |
| 120011.5-033039 | 19341 | 15.71 | -18.77 | 89.02 | 41.60 | 123.72 | 0.45 ± 0.15 | 0.35 | 39.42 | 0.94 ± 0.82 0.28 ± 0.34 |
| 120117.2-032552 | 3925 | 15.73 | -18.77 | 89.02 | 41.60 | 123.72 | 0.45 ± 0.15 | 0.35 | 39.42 | 0.94 ± 0.82 0.28 ± 0.34 |
| 120154.1-030604 | 47819 | 17.81 | -22.33 | 10.84 | < 2. | 4.56 | 1.27 ± 0.36 | 0.90 | 42.02 | 0.12 ± 0.25 −0.05 ± 0.24 |
| 124520.5-060334 | 29190 | 17.25 | -21.73 | 8.68 | 3.60 | 4.81 | 28.5 ± 4.7 | 19.7 | 42.922 | −0.25 ± 0.16 −0.25 ± 0.48 |
| 125310.5-051811 | 25960 | 17.07 | -21.64 | 2.18 | < 2. | 3.68 | 3.58 ± 0.45 | 2.55 | 41.932 | 0.43 ± 0.15 0.12 ± 0.13 |
| 215759.7-413356 | 41143 | 17.28 | -22.50 | 3.83 | < 2. | 3.35 | 3.10 | 19.8 | 43.231 | −0.01 ± 0.09 −0.22 ± 0.11 |

a A description of the IAU-registered naming convention for individual LCRS galaxies, LCRS BHHMMSS.s-DDMMSS, can be found in the online "Dictionary of Nomenclature of Celestial Objects," at [http://astro.u-strasbg.fr/cgi-bin/Dic](http://astro.u-strasbg.fr/cgi-bin/Dic).
b Heliocentric recessional velocity in km s⁻¹.
c LCRS R-band apparent magnitude.
d LCRS R-band absolute magnitude (H₀ = 50 km s⁻¹ Mpc⁻¹, q₀ = 0.5).
e Rest-frame equivalent width (estimated by a Gaussian fit to the line profile) in Å; the detection limit is ≈ 2.0 Å.
f Source counts per 10⁴ seconds (vignetting corrected).
g X-ray flux (0.5 – 2.0 keV) in units of 10⁻¹⁴ erg s⁻¹ cm⁻²; assumes Galactic values of N_H and a power law spectrum with energy index 1.
h Log of the x-ray luminosity (0.5 – 2.0 keV) in units of erg s⁻¹ (H₀ = 50 km s⁻¹ Mpc⁻¹, q₀ = 0.5).
i HR¹ ≡ (H – S)/(H + S), where H is the flux in the 0.4 – 2.4 KeV band and S is the flux in the 0.1 – 0.4 KeV band.
j HR² ≡ (H₁2 – H₁)/H₂ + H₁, where H₁ is the flux in the 0.5 – 0.9 KeV band and H₂ is the flux in the 0.9 – 2.0 KeV band.

### Notes:
- **cz⊙**: Heliocentric recessional velocity in km s⁻¹.
- **mₚ**: LCRS R-band apparent magnitude.
- **Mₚ**: LCRS R-band absolute magnitude (H₀ = 50 km s⁻¹ Mpc⁻¹, q₀ = 0.5).
- **W₁**: Rest-frame equivalent width (estimated by a Gaussian fit to the line profile) in Å; the detection limit is ≈ 2.0 Å.
- **count rate**: Source counts per 10⁴ seconds (vignetting corrected).
- **fₓ**: X-ray flux (0.5 – 2.0 keV) in units of 10⁻¹⁴ erg s⁻¹ cm⁻²; assumes Galactic values of N_H and a power law spectrum with energy index 1.
- **log Lₓ**: Log of the x-ray luminosity (0.5 – 2.0 keV) in units of erg s⁻¹ (H₀ = 50 km s⁻¹ Mpc⁻¹, q₀ = 0.5).
- **HR¹**: Ratio of the flux in the 0.4 – 2.4 KeV band to the flux in the 0.1 – 0.4 KeV band.
- **HR²**: Ratio of the flux in the 0.5 – 0.9 KeV band to the flux in the 0.9 – 2.0 KeV band.
Fig. 1. RA-velocity “wedge” map (top) and RA-DEC sky map (bottom) for the three slices of the LCRS Northern Galactic Cap sample. In both maps, points denote LCRS galaxies and asterisks the LCRS-ROSATSRC galaxy matches. In the sky map, lightly shaded circles represent the 2°-diameter public PSPC fields near the region surveyed by the LCRS. Sky coordinates are Epoch 1950.0; radial velocities are heliocentric.
Las Campanas Redshift Survey: Southern Galactic Cap

$N_{\text{LAEs}} = 12564$

$N_{\text{PSPC}} = 4$

Fig. 2. RA-velocity “wedge” map (top) and RA-DEC sky map (bottom) for the three slices of the LCRS Southern Galactic Cap sample; symbols are as in Fig. 1.
Fig. 3. Spectra of the matched LCRS-ROSATSRC galaxies (NOT flux calibrated).
Fig. 4. X-ray light curves for (a) LCRS B002810.0-422515 and (b) LCRS B215759.7-413356.