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Optical Identifications of Companion Soft X-ray Sources of Mrk 231

Hong Wu[1], Zu-Gan Deng[1,2] and Xiao-Yang Xia[1,3]

[1] National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012
[2] Graduate School, Chinese Academy of Sciences, Beijing 100080
[3] Department of Physics, Tianjin Normal University, 300074 Tianjin

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Abstract We present optical identification results for four ROSAT PSPC soft X-ray companions of Mrk 231 based on the deep BATC 6660 Å-band image and the optical spectra obtained by the 60/90 cm Schmidt telescope and the 2.16 m telescope at the Xinglong Station, NAOC. Three optical counterparts are quasars with redshifts $z > 1$ and the remaining X-ray source is probably a background galaxy cluster. Therefore, none of these soft X-ray companions are physically connected with the central X-ray source Mrk 231. Incorporating the previous results of Arp 220 and Mrk 273 (Xia et al. 1998, 1999), we suggest that the apparent soft X-ray associations with ULIRGs are chance coincidence in most cases.

Key words: galaxies: individual (Mrk 231) — X-rays: galaxies — quasars

1 INTRODUCTION

Turner, Urry & Mushotzky (1993) pointed out that some of the Seyfert 2 galaxies have soft X-ray companions within a few arc-minutes based on ROSAT PSPC (Position Sensitive Proportional Counter) observations of six Seyfert 2 galaxies. Similar associations have been found for ULIRGs (Ultra Luminous IRAS Galaxies), such as Arp 220, Mrk 231 and Mrk 273. To investigate the possible connection of ULIRGs and their soft X-ray companions, an optical identification program was carried out for the above three ULIRGs. The spectrum for the optical counterpart (Mrk 273x) of soft X-ray companion of Mrk 273 was obtained by both WHT and the 2.16 m telescope of National Astronomical Observatories, Chinese Academy of Sciences (NAOC) (Xia et al. 1999). It shows that Mrk 273x is a background Seyfert 2 galaxy with a redshift of 0.458. It also shows that the soft X-ray companion of Arp 220 is a background cluster of galaxies with a redshift of about 0.1 (Xia et al. 1998). In this paper, we present the results of the optical identifications (images and spectra) for the soft X-ray companions of Mrk 231 using the 60/90 cm Schmidt telescope and the 2.16 m telescope at NAOC.

⋆ E-mail: wu@vega.bac.pku.edu.cn

2 OBSERVATIONS AND DATA REDUCTION

2.1 ROSAT PSPC Data

Mrk 231 was observed by ROSAT PSPC on 1991 June 7 and the data were processed by EXSAS software at MPE. Figure 1 is the ROSAT PSPC image contour overlaid on the deep 6660 Å-band optical image of Mrk 231 obtained by BATC (Beijing-Arizona-Taipei-Connecticut Multi-Color Survey). In the figure it is obvious that there are several soft X-ray companions surrounding the central source Mrk 231 within $15' \times 15'$ of Mrk 231. Also there appears to be a bridge between Mrk 231 and the east X-ray source. To explore the possible relation between Mrk 231 and its surrounding X-ray sources, four strong soft X-ray sources, with broad band (0.1–2.4 keV) count rate above 3×10^{-3} counts per second, were selected. Three of them are point X-ray sources, and the fourth presents diffuse X-ray emission extending toward the north-west. The selected X-ray sources are numbered in Figure 1.

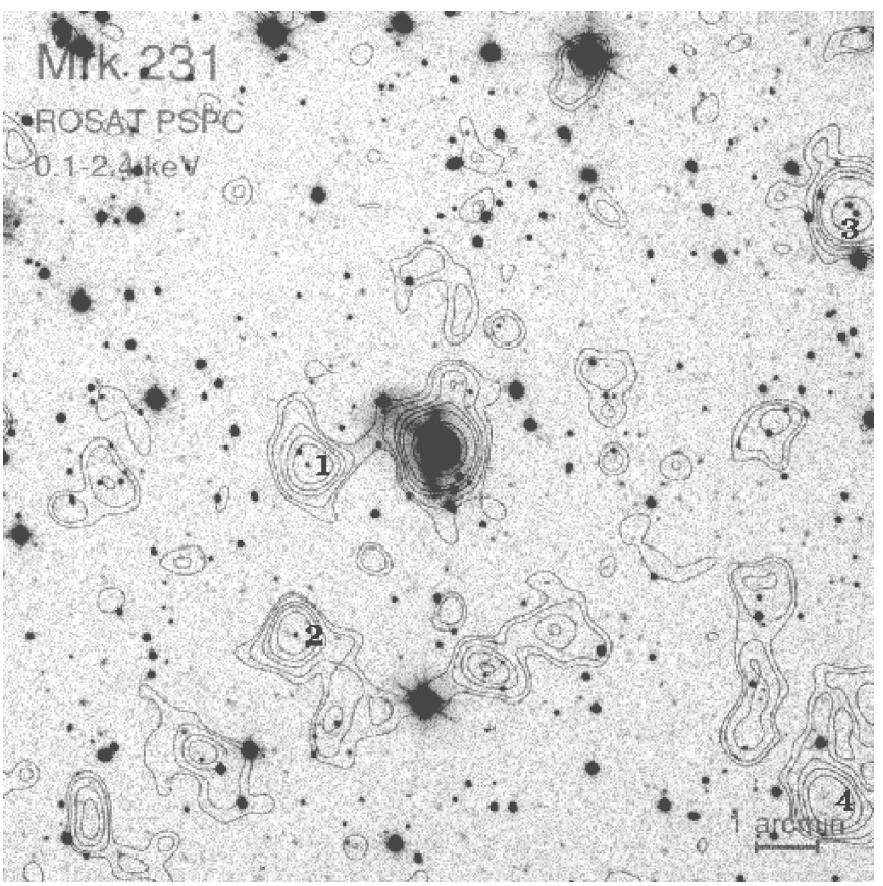

Fig. 1 Overlay of the soft X-ray contour on the optical image centered on Mrk 231. The optical image is a BATC 6660 Å-band image, limiting magnitude about 22.5 mag. The X-ray contours are from ROSAT broad band (0.1–2.4 keV). Four selected X-ray sources are numbered 1, 2, 3, 4. Most of the surrounding strong X-ray sources are associated with faint optical counterparts.

2.2 Optical Image

With a limiting magnitude of about 20.5, the DSS (Digital Sky Survey) image is not deep enough to reveal the faint optical counterparts of most of X-ray companions of Mrk 231. The 60/90 cm Schmidt telescope at the Xinglong Station of NAOC was used for deeper image (about 22.5 mag). A thick Ford 2048×2048 CCD was employed (scale $1.7''$/pixel). The filter used for the observations reported here is the BATC i-band filter with central wavelength of 6660 Å and bandwidth of 480 Å (Fan et al. 1996; Yan et al. 2000).

A total of 20 frames of Mrk 231 were obtained with a field of view $58' \times 58'$ during May, 1996 with a total exposure time about 6.67 h. Oke and Gunn (1983) standards were observed for flux calibration on three photometric nights.

The general CCD reduction was performed using the BATC routine PIPELINE I. The images were combined in IRAF. Figure 1 shows the central field of view of about $15' \times 15'$ of the final combined image.

2.3 Spectroscopy

Because there is no optical counterpart near the X-ray position of RXP J125528.2+564640 within the confidence circle (see Section 3.1), we only observed the spectra of the optical candidates of three soft X-ray companions of Mrk 231 on Jan. 21, Apr. 8, and Apr. 11, 1997 with the 2.16 m telescope at the Xinglong Station of NAOC. A Zeiss universal spectrograph was used with a Tektronix 1024×1024 CCD and a 200 Å mm^{-1} grating. An Fe-He-Ar lamp was used for wavelength calibration and KPNO standards were used for flux calibration. The exposure time ranged between one and three hours. IRAF packages were used for the spectral data reduction.

3 OPTICAL IDENTIFICATION

3.1 BATC i-Band Image

Figure 1 shows the BATC 6660 Å-band image of the region around Mrk 231, overlaying the contour map of the ROSAT soft X-ray. The central galaxy Mrk 231 is surrounded by the X-ray companions. Our deep image shows that except for the lower-right X-ray companion, we can find faint optical counterparts centered on the others. Figure 2 presents the zoomed optical images for four X-ray companions, centered on each. The central circles are the 90% confidence positional range for the X-ray sources. For RXP J125528.2+564640, there is no optical counterpart within the 90% confidence circle, while there seems to exist more than three fainter optical objects nearby. We assume that the X-ray emission could come from a background galaxy cluster.

The BATC 6660 Å magnitudes are measured using aperture photometry with the package DAOPHOT. It can be transformed to broad band R magnitude with the formula (Zhou et al. 2001)

$$R = i(\mathrm{BATC}) + 0.1048. \quad (1)$$

The optical coordinates and the photometry results are given in Table 1. For RXP J125528.2+564640, we only give the apparent magnitude of the brightest optical member of the possible galaxy cluster.

3.2 Spectroscopy

For the three X-ray sources RXP J125629.6 + 565208, RXP J125631.3 + 564925 and RXP J125525.3+ 565615 (Figure 2), within the 90% confidence positional circle, the corresponding optical counterpart is unique. We give three optical spectra in Figure 3. For purpose of display, all the three spectra are binned. RXP J125629.6+565208 presents very broad CIVλ1549 and CIII]λ1909 emission lines with redshift 2.26. The X-ray Source RXP J125631.3+564925 presents MgIIλ2798 and CIII]λ1909 emission lines with redshift 1.182.

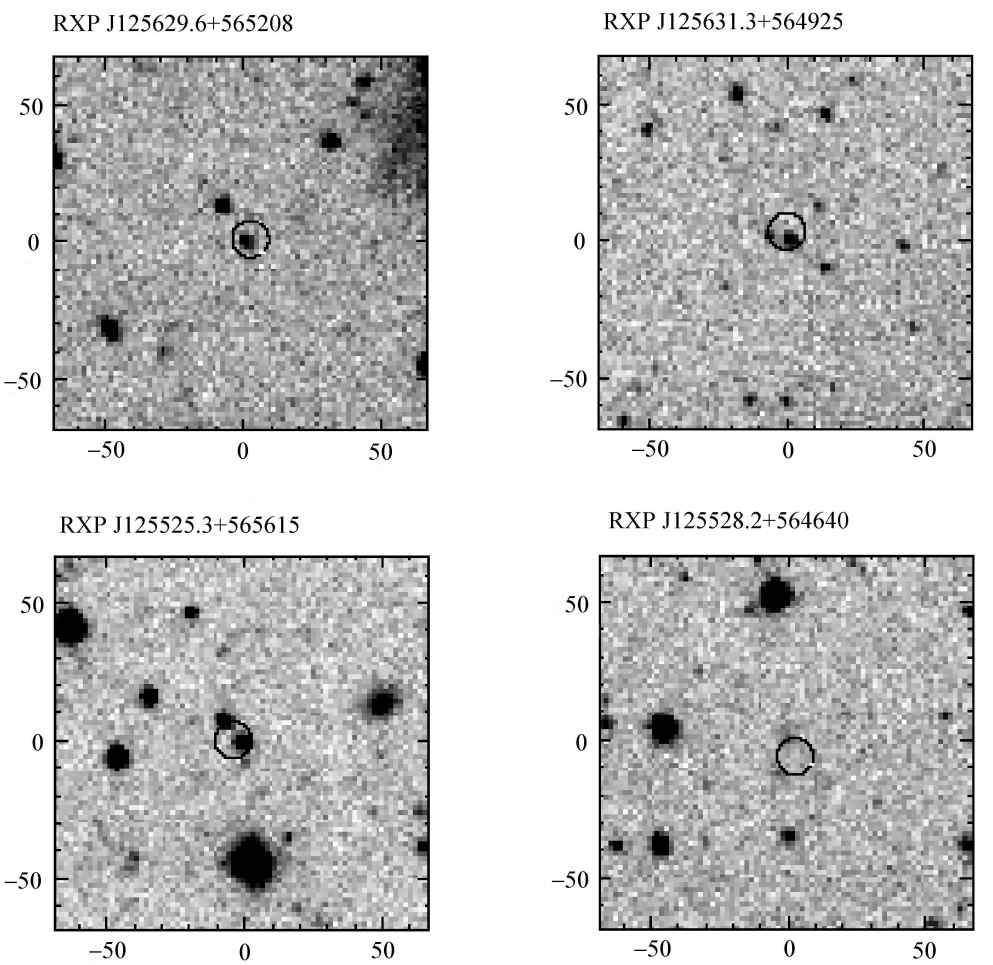

Fig. 2 Optical finding charts with fields of view $2' \times 2'$ for four soft X-ray sources from the BATC 6660 Å-band image. The central circle in each image marks the 90% confidence limit.

Because the obtained spectrum is redder than 4500 Å, the optical counterpart of RXP J125525.3 + 565615 only shows one strong emission line. As we know, at redshift of around 1.0, the only strong line that falls within the observed optical range is MgIIλ2798 (Puchnarewicz et al. 1997). So, we presume it to be the MgII emission, and so obtain a redshift of 1.191, and the CIII]λ1909 emission just falls outside the spectrum. The redshift agrees with the result of ROSAT International X-ray/Optical Survey (RIXOS) (Mason et al. 2000). In the finding chart, another optical

object is found near the confidence circle, we tried hard to obtain its spectrum, but failed to identify any emission lines, because of its low S/N. So we regard the object with redshift 1.191 as the X-ray emitter of RXP J125525.3+565615.

Table 1 Optical Identification of ROSAT PSPC Sources around Mrk 231

No.	Name	RA (2000)	Dec.	R	err	z	M_R	$\log(L_x)$	ID
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	RXP J125629.6+565208	12:56:29.79	56:52:07.1	20.66	0.07	2.265	–24.8	45.27	quasar
2	RXP J125631.3+564925	12:56:31.15	56:49:21.3	20.41	0.07	1.185	–23.4	44.57	quasar
3	RXP J125525.3+565615	12:55:24.93	56:56:13.9	19.21	0.02	1.193	–24.7	44.95	quasar
4	RXP J125528.2+564640	12:55:28.54	56:46:46.1	21.43	0.21	–	–	–	Cluster?

Column 1: Numbers. **Column 2:** ROSAT PSPC source designations, derived from the J2000 coordinates. **Column 3, 4:** J2000 coordinates of the optical counterparts. **Column 5, 6:** Broad R-band magnitudes and error bars of the optical counterparts, transformed from BATC 6660 Å-band magnitudes. **Column 7:** measured redshifts. **Column 8:** Absolute R magnitudes, using $H_0 = 72$ km s^{-1} Mpc^{-1}. **Column 9:** Soft X-ray broad band (0.1–2.4 keV) luminosities in unit of erg cm^{-2} s^{-1}, adopting the spectral slope of 1.9 and the galactic column density of 1.29×10^{20} in the direction of Mrk 231. **Column 10:** Object classifications.

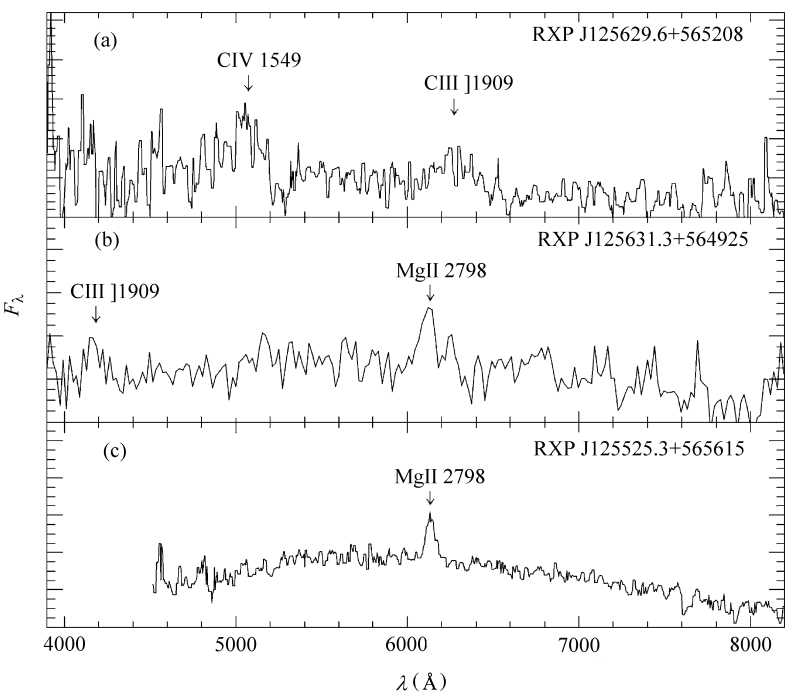

Fig. 3 Optical spectra of the optical counterparts of three X-ray sources. All the spectra are binned for displaying purpose.

4 RESULTS

Based on the BATC 6660 Å-band deep image and the long-slit spectra of 2.16 m telescope, we identified the optical counterparts of four soft X-ray companions of Mrk 231. Three of them show emission lines with redshifts greater than 1 and absolute R-band magnitudes brighter than –23 mag. Their optical luminosities are in the range of quasars. Two of them (RXP J125629.6+565208 and RXP J125631.3+564925) are newly discovered quasars. All the three sources have soft X-ray (0.1–2.4 keV) luminosities higher than 10^{44} erg s^{-1} cm^{-2} (Table 1), which also fall in the range of X-ray luminosities of quasars. Though no optical counterpart is found for the X-ray source RXP J125528.2+564640, the presence of a few faint diffuse objects nearby in our deep BATC image indicates that the counterpart could be a background galaxy cluster.

Through optical identifications of the X-ray companions of Mrk 231, we found three background quasars with redshifts much larger than that of Mrk 231 ($z = 0.0422$) and one background galaxy cluster. This rules out the possibility that the X-ray companions are physically associated with Mrk 231. This result agrees with our previous observations for both Mrk 273 and Arp 220. For Mrk 273($z = 0.0376$), the nearby X-ray bright companion is a background AGN with a redshift of 0.458 (Xia et al. 1999). For Arp 220 ($z = 0.018$), the counterpart of the X-ray companion is likely a background group or cluster with a redshift about 0.1 (Xia et al. 1998). Therefore, we suggest that most X-ray companions around ULIRGs are not physically associated with the ULIRGs, but are chance coincidences.

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