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# The Challenge of Identifying Optical Counterparts to Ultraluminous X-ray Sources ⋆,⋆⋆

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**Abstract.** We report on the identification of the optical counterpart of the ultraluminous X–ray (ULX) source XMMU J121214.5+131248 (NGC4168-ULX1). The optical spectrum yields a redshift of $z = 0.217$, which implies that the ULX is not associated with the nearby galaxy NGC4168, but rather it is a background object. Optical spectral line ratios and the spectral energy distribution constructed from the available data indicate that the source is likely a bulge-dominated galaxy with a starburst component.

**Key words.** Galaxies: distances and redshifts — Galaxies: photometry — Galaxies: starburst

## 1. Introduction

Ultraluminous X–ray sources (ULXs), i.e. off-nuclear sources with luminosities well above the Eddington limit for a typical neutron star, are now known to populate about 30% of the nearby galaxies; e.g., van der Marel (2003). Despite much effort, little is presently known about the nature of these sources, particularly since the counterparts at other wavelengths are difficult to find. Indeed, often these sources are superposed against regions of high surface brightness in their host galaxy.

To date, only two ULXs appear to have a clear optical identification (Roberts et al. 2001; Wu et al. 2002), while for others it has been possible to study the nearby environment only (Pakull & Mirioni 2002; Wang 2002; Roberts et al. 2003). One ULX (NGC4698-ULX1) has been identified with a background BL Lac (Foschini et al. 2002a).

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⋆ Based on observations collected at the Bologna Astronomical Observatory in Loiano, Italy, and at the Astronomical Observatory of Asiago, Italy

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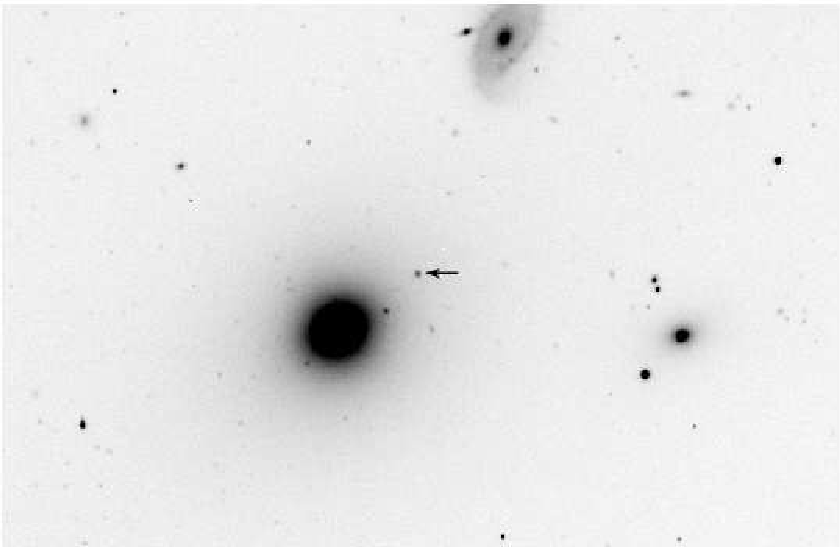

**Fig. 1.** $R$-band image (exposure time: 10 minutes) of NGC4168-ULX1 acquired in Loiano starting at 23:52 UT of 4 March 2003. North is up and East to the left. The field size is $8' \times 5'$. The arrow indicates the position of the source.

Here we report the identification of the nature of another ULX, NGC4168-ULX1. The derived optical redshift of $z = 0.217$ indicates a background galaxy in this case also. A thorough presentation of these results is reported in (Masetti et al. 2003).

## 2. The X–ray source: NGC4168-ULX1

NGC 4168 is an E2 elliptical galaxy located in the Virgo cluster ($d = 16.8$ Mpc). It hosts an active galactic nucleus, classified as a Seyfert 1.9 by Ho et al. (1997). The galaxy was observed on 4 December 2001 using the European Photon Imaging Camera (EPIC) on board the *XMM-Newton* satellite; see Foschini et al. (2002b).

One ULX (NGC4168-ULX1) was found apparently associated with NGC 4168, being inside the galaxy's $D_{25}$ ellipse, at $45''$ from the optical centre of the galaxy. The source has coordinates (J2000) $\alpha = 12^{\rm h}12^{\rm m}14\overset{\rm s}{.}5$ and $\delta = +13°12'48''$, with an uncertainty radius of $4''$. The flux emitted from the ULX in the 0.5–10 keV band is $(1.8 \pm 0.3) \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$. At the distance of NGC 4168 the resulting 0.5–10 keV luminosity is $6 \times 10^{38}$ erg s$^{-1}$.

## 3. Optical Observations

Medium-resolution optical spectroscopy of the ULX was acquired on March 4, 2003 in Loiano (Italy) with the Bologna Astronomical Observatory 1.5m "G.D. Cassini" telescope plus BFOSC, for a total exposure time of 3 hours. One single 1-hour medium-resolution spectrum was also obtained at the "L. Rosino" Astronomical Observatory of Asiago (Italy), on February 26, 2003, with the 1.8m "Copernicus" telescope plus AFOSC.

On March 4, 2003, $UBVRI$ optical photometry was also acquired in Loiano with BFOSC. The source (Fig. 1) was well detected in all bands.

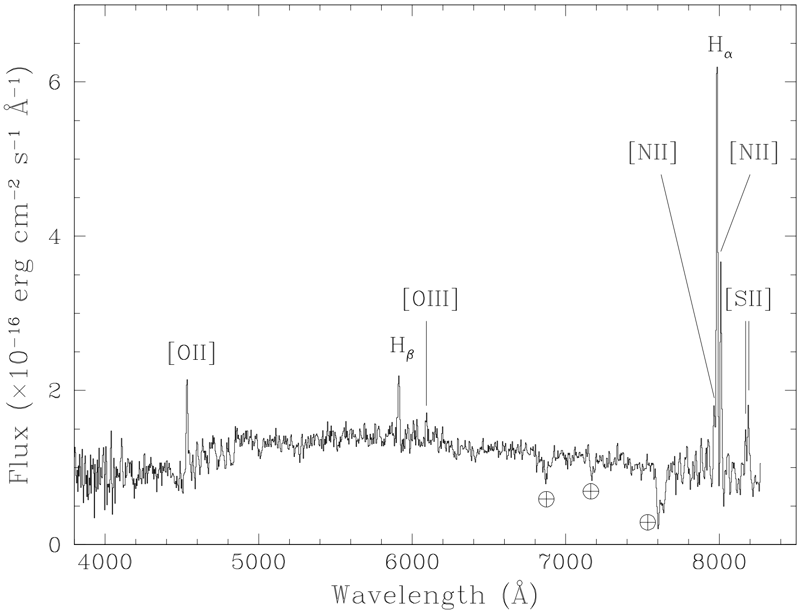


**Fig. 2.** Average optical spectrum of NGC4168-ULX1 taken with the Cassini telescope at Loiano. The main spectral features are labeled. These allowed us to determine the redshift of the source as $z = 0.217$. The symbol $\oplus$ indicates atmospheric telluric features.

## 4. Results

### 4.1. Spectral analysis

The 3-hour spectrum taken at Loiano on 4 March 2003 (Fig. 2) shows an evident emission line at 7980 Å which we identified as $H_\alpha$. In the same spectral region we identified emissions at 7967, 8011, 8172 and 8191 Å as [N II] $\lambda$6548, [N II] $\lambda$6583, [S II] $\lambda$6716 and [S II] $\lambda$6731. Other clear emissions at 6090, 5910 and 4530 Å were identified with [O III] $\lambda$5007, $H_\beta$ and [O II] $\lambda$3727, respectively. The identified emission lines yield a redshift $z = 0.217$. This result is, in hindsight, not surprising, as the images acquired in Loiano show that the field is eminently populated by galaxies of various sizes and brightnesses, with very few foreground stars.

The 1-hour Asiago spectrum obtained on 26 February 2003, albeit having lower S/N due to shorter exposure and smaller spectral coverage (4200-7800 Å), shows the presence of H$\beta$ and [O II] $\lambda$3727 at the same redshift, thus confirming the result of the Loiano observations. Table 1 reports the emission line fluxes as determined from the Loiano spectrum, dereddened for the Galactic absorption.

**Table 1.** Fluxes (in units of $10^{-15}$ erg s$^{-1}$ cm$^{-2}$) of the emission lines detected in the spectrum acquired in Loiano. Values are corrected for Galactic absorption

| Line | Flux |
|---|---|
| [O II] $\lambda$3727 | 1.51±0.15 |
| H$\beta$ | 1.1±0.2 |
| [O III] $\lambda$5007 | 0.35±0.09 |
| [N II] $\lambda$6548 | 0.90±0.18 |
| H$\alpha$ | 6.4±0.3 |
| [N II] $\lambda$6583 | 2.90±0.15 |
| [S II] $\lambda$6716 | 0.63±0.13 |
| [S II] $\lambda$6731 | 0.86±0.17 |

### 4.2. Photometry

Magnitudes of the source in the Loiano images were measured through aperture photometry, since its profile is significantly larger than the image PSF ($2''.6$ versus $1''.5$) and, as measured on the $U$-band frame, is possibly elongated in the NW-SE direction. Using an aperture radius of $2''.6$, we found the following optical magnitudes: $U$ = 19.49±0.08, $B$ = 19.78±0.04, $V$ = 18.69±0.03, $R$ = 18.33±0.03, and $I$ = 17.68±0.05.

## 5. Discussion

So, yet another putative ULX is found to be a background source. Assuming a cosmology with $H_0 = 65$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_\Lambda = 0.7$ and $\Omega_{\rm m} = 0.3$, we find that the luminosity distance to this source is 1.16 Gpc, and that its X–ray luminosity is $2.9\times10^{42}$ erg s$^{-1}$ in the 0.6–12 keV restframe range. The angular size of the source translates into a linear diameter of about 30 kpc at $z = 0.217$.

The [N II]/$H_\alpha$ and [S II]/$H_\alpha$ ratios measured from the optical spectrum place this source in the regime of metal-rich giant extragalactic H II regions or starburst nuclei (Ho et al. 1993, 1997).

The inspection of the optical colours of this source shows that the object is quite red. Given the dominance of the stellar continuum in the spectrum (Fig. 2), most of the optical light comes from the integrated stellar emission from the galaxy. These colours are typical of an evolved stellar population. The X–ray emission, by contrast, is likely to be associated with the star-forming regions that give rise to the optical line emission. This may consist of a single starburst nucleus or multiple off-nuclear sources. An X–ray luminosity of $\approx10^{42}$ erg s$^{-1}$ is high, but not unusual, for a starburst (David et al. 1992). All these characteristics point to the fact that this object is likely a bulge-dominated galaxy with a starburst component.

In conclusion, we wish to remark that this case, as that of the ULX in NGC 4698 reported by Foschini et al. (2002a), has been instructive: despite the availability of broad-band multiwavelength data, they have proven insufficient to disclose the true nature of the source. The most crucial piece of information is optical spectroscopy of sufficient quality to reveal clear spectral features, which simultaneously provide redshift information and spectral diagnostics.

Besides, we stress the fact that high-quality science results on up-to-date astrophysical topics, such as the hunt for the nature of ULXs, can be achieved with the use of small- and medium-sized Italian telescopes.

## References


David, L.P., Jones, C., & Forman, W., 1992, ApJ, 388, 82

Foschini, L., Ho L.C., Masetti N., et al., 2002a, A&A, 396, 787

Foschini, L., Di Cocco, G., Ho, L.C., et al., 2002b, A&A, 392, 817

Ho, L.C., Filippenko, A.V., & Sargent, W.L.W., 1993, ApJ, 417, 63

Ho L.C., Filippenko A.V. & Sargent, W.L.W., 1997, ApJS 112, 315

Pakull, M.W., & Mirioni, L., 2002. In: Jansen, F. (ed.) New Visions of the X–ray Universe in the *XMM-Newton* and *Chandra* Era, ESA-SP 488 [astro-ph/0202488]

Masetti, N., Foschini, L., Ho, L.C., et al., 2003, A&A, in press [astro-ph/0305452]

Roberts, T.P., Goad, M.R., Ward, M.J., et al., 2001, MNRAS 325, L7

Roberts, T.P., Goad, M.R., Ward, M.J., & Warwick, R.S., 2003, MNRAS, in press [astro-ph/0303110]

van der Marel, R.P., 2003, Coevolution of Black Holes and Galaxies. Ed. L.C. Ho, Carnegie Observatories Astrophysics Series, Vol. 1. Cambridge University Press, Cambridge, in press [astro-ph/0302101]

Wang, Q.D., 2002, MNRAS, 332, 764

Wu H., Xue S.J., Xia X.Y., et al., 2002, ApJ 577, 738