SEARCH FOR ULTRALUMINOUS X–RAY SOURCES IN NEARBY GALAXIES

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Little is presently known about the nature of ultraluminous X–ray sources (ULX). Different hypotheses have been proposed to explain their properties: intermediate–mass BHs, Kerr BHs, young SNR, or background AGN. Some of the current problems and open questions in this research field are here reviewed.

1 Introduction

The study of the X–ray emission from discrete sources in nearby galaxies began with the Einstein satellite1. Soon after, ROSAT contributed with other important steps and drew the attention to those pointlike X–ray sources with high luminosities \(10^{39}–10^{40}\) erg/s, while ASCA observations produced the first spectra and lightcurves2, triggering a number of hypotheses about the nature of these ultraluminous X–ray sources (ULX). The most intriguing hypothesis is that these ULX are powered by accretion around a black hole with masses up to \(10^2–10^4\) solar masses. Chandra, with its sub–arcsecond resolution produced a great advancement in this study: in the observation of the Antennae galaxies, 14 ULX were found5. Among these 14 ULX a few could well be background AGN, but certainly not all. One of these ULX has \(L_X \approx 10^{40}\) erg/s, similar to low luminosity AGN. It is however located far from the centre of the host galaxy, posing several problems about the evolution of the off–nuclear black holes in nearby galaxies. During the last few years, with the advent of Chandra and XMM–Newton, a lot of efforts have been done to observe and to understand these sources and how they are linked to the host galaxy. Here we review some of the most important problems in this type of research field.

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2 Optical identification

The search for the optical counterpart of ULX is now one of the most important issues to understand the nature of the ULX and to “clean” the surveys from background objects. One case experienced by our team can be considered paradigmatic. During a survey searching for ULX in nearby galaxies with XMM–Newton, we discovered one ULX in NGC4698 with $L_X = 3 \times 10^{39}$ erg/s. From online archives we found a clear counterpart at radio (VLA 6 and 20 cm) and at optical wavelengths (DSS, HST). Despite the variety of data none was decisive to discriminate between an ULX or a background object. Only after we observed it with ESO–VLT, we were able to measure the redshift of $z = 0.43$ (to be compared with the $z = 0.0033$ of NGC4698) and it became clear that the detected source is a background BL Lac.

For another ULX candidate in our survey (NGC4565–ULX4), we have found two possible counterparts in online archives: a globular cluster and a planetary nebula, located at $8.6''$ and $8.4''$, respectively, from the XMM–Newton position. However, Wu et al.\cite{wu2004}, after a deeper analysis of HST archival data, have found the most probable optical counterpart ($B \approx 25.1$) at less than $0.5''$ from the Chandra position and $1.8''$ from the XMM–Newton position. They suggest that the X–ray source is an accreting black hole located in a globular cluster at the outer edge of NGC4565.

Other possible counterparts have been found for NGC5204–X1 (HMXRB system with O star plus BH or neutron star\cite{fender2000}) and for a few ULX in NGC1399 (black holes in globular clusters\cite{gebhardt2000}). For other ULX the nearby environment has been studied, showing that these objects are often associated with HII regions or planetary nebulae. In conclusion, the search for optical identification of ULX sources is not yet conclusive and it remains the most important question in this field.

3 Criteria for selection and the contamination problem

Given the present scarce knowledge about ULX, the criteria of definition and selection are still an open question as well. Although there is general agreement to search for sources with super–Eddington luminosities (by assuming the same distance of the supposed host galaxy), the threshold value is still matter of debate. The name itself is still matter of discussion: ULX (ultraluminous X–ray sources or ultraluminous compact X–ray sources)\cite{heindl1992}, SLS (superluminous X–ray sources)\cite{kallman1999}, SES (super–Eddington sources)\cite{heindl1992}, IXO (intermediate luminosity X–ray objects)\cite{heindl1992} are all acronyms found in literature, but they refer to slightly different definition criteria. Most authors suggest that the threshold luminosity should be $10^{39}$ erg/s, because it allows to select the most theoret-
ically challenging to explain sources (e.g. Roberts, personal communication). However, it should be noted that there are some known pulsars able to reach luminosities up to $10^{39}$ erg/s, because of accretion via polar cap $^{15}$. In our survey $^6$, we used threshold value of $2 \times 10^{38}$ erg/s, a value that may appear to be too low for “ultraluminous” sources (ultraluminous with respect to what?), but has the advantage of being driven by physical arguments, rather than by observational criteria. Indeed, it is the Eddington limit for a $1.4 M_\odot$ object, corresponding to the limit of Chandrasekhar for a white dwarf. For a neutron star a similar limit can be set to $3 M_\odot$, so that an object with a greater mass/luminosity can be considered a black hole candidate.

It is however known that several factors are important in the calculation of the object mass from its luminosity: the mode of accretion, the presence or not of a strong magnetic field, flare activity, the Eddington ratio, and so on. For example, if one considers an Eddington ratio of $0.01 - 0.1$, that is a typical for black hole candidates in our Galaxy $^{16}$, and that the X–ray luminosity is about 30% of the bolometric luminosity, the inferred mass from the X–ray luminosity of $2 \times 10^{38}$ erg/s could be of the order of $26 - 260 M_\odot$. Therefore, although objects with X–ray luminosity greater than $10^{39}$ erg/s are surely the most intriguing one, we stress that the search for ULX (or any other acronym you prefer) is still at an early phase and it is meaningful to avoid thight boundaries and keep less restrictive selection rules.

If this philosophy can be true for luminosity threshold, it can be misleading in the definition of the research area. This is generally considered to be the $D_{25}$ ellipse of the host galaxy. However, some authors suggested a search radius of $2R_{25}$, because with smaller radii, some famous ULX (e.g. NGC1313–X2) are excluded (e.g. Colbert, personal communication; see also Colbert and Ptak $^{14}$). Whatever the selection area adopted, this has important consequences in the probability of being contaminated by background objects.

The available literature generally provides the $\log N - \log S$ in different wavelengths$^{17,18}$. Therefore, we can calculate the expected background sources at certain fluxes in a certain area. Adopting the $\log N - \log S$ of XMM–Newton studies of the Lockman Hole $^{17}$, one expects 0.06 background objects per arcmin$^2$ with flux $10^{-14}$ erg cm$^{-2}$ s$^{-1}$ in the $2 - 10$ keV energy band, while the number is even lower (0.03) in the $0.5 - 2$ keV energy band (same flux). These flux limits are commonly reached by both Chandra and XMM–Newton with exposures of the order of $10 - 100$ ks.

On the other hand, by adopting the space distribution of quasars in the blue band $^{18}$, one expects 0.02 quasar per arcmin$^2$ with $B > 22$.  

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4 Final remarks

We have exposed here a few important open questions about the search for off-nuclear pointlike luminous X-ray sources. We note that, in addition to the questions on the nature of these sources, the definition of selection rules is still matter of debate. As far as surveys are concerned, we suggest to keep lower thresholds in luminosity to increase the statistics for variability, spectroscopic, and optical identification studies, i.e. to avoid to cut away some interesting sources.

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