A Sample of X-Ray active extragalactic Sources suitable for NIR Adaptive Optics Observations

Jens Zuther, Andreas Eckart, Christian Straubmeier

1. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany

Wolfgang Voges
Max-Planck Institut für extraterrestrische Physik, 85748 Garching, Germany

Abstract. Recent X-ray surveys have now resolved most of the X-ray background (XRB) into discrete sources. While this represents a breakthrough in the understanding of the XRB, the astrophysical nature of these sources still remains mysterious. In this article we present a sample of X-ray/optically selected extragalactic objects which are suitable for adaptive optics observations in the near infrared (NIR) at highest angular resolution. The sample is based on a cross-correlation of the Sloan Digital Sky Survey and the ROSAT All Sky Survey. The NIR properties can help to disentangle the nature of the X-ray bright, partially absorbed and spectroscopically passive background objects and their hosts.

1. Introduction

1.1. Near Infrared Adaptive Optics

Adaptive Optics (AO) systems on large telescopes like NACO at the VLT (Brandner et al. 2002) overcome the limitations introduced by earth’s turbulent atmosphere in terms of image degradation and allow imaging and spectroscopy at the diffraction limit of these telescopes (see Beckers 1993 for a review). For example an 8m-class telescope offers an angular resolution of ~50 mas at 1.65 μm. AO therefore enables the study of extragalactic targets at highest spatial resolution and e.g. directly allows the comparison of more distant galaxies with nearby ones, observed without AO in the same wavelength domain, at the same spatial resolution.

The near infrared (NIR) is a sensitive tracer of the mass dominating (older) stellar populations in galaxies. At the same time the NIR is less affected by extinction, but still sensitive to the distribution and contribution of (warm) dust. Studying the detailed morphology, dynamics and composition of the sources described below is therefore ideally done in the NIR since especially the circum-nuclear regions of the targets are expected to be extincted.
1.2. The X-Ray Background

The X-ray background (XRB) in the 0.5-10 keV regime has been resolved into discrete sources by recent work on X-ray surveys like ROSAT, Chandra, and XMM (e.g. Hasinger 1998; Miyaji, Hasinger, & Schmidt 2000; Mushotzki et al. 2000; Giacconi et al. 2001; Brandt et al. 2001b). However, the astrophysical nature of these sources still remains unknown. Especially two subjects are of interest in this context. **The hardness of the X-ray spectra:** It is found that the cosmic XRB is much harder than the X-ray emission of unobscured (type I) AGN in the local universe. Therefore the existence of a substantial obscured AGN (type II) population is required. These are found preferentially at lower redshifts (\(z \sim 0.6\)), in contrast to predictions of XRB models (Gilli 2003 and references therein). An important question in understanding the nature of sources with hard X-ray spectra is whether they are hardened due to a large amount of intrinsic (circum-nuclear) absorption or whether the spectrum of the central engine itself is intrinsically hard. It is quite likely that the X-ray spectra are of composite nature, i.e. both the emission and absorption mechanisms are of importance. In this case it has to be determined how the nuclear properties are correlated with the properties of the corresponding hosts. **Evolution of X-ray active AGN:** A recent result (Tacconi et al. 2002) is that the more (spectroscopically) passive X-ray-bright, early-type galaxies may originate from a population of ULIRG galaxies that contain QSO-like active galactic nuclei. Some of the ULIRGs resemble local QSOs in their NIR and bolometric luminosities because they are very efficiently transforming dust and gas into stars and/or feed their central engine. However, ULIRGs have smaller effective radii and velocity dispersions than the local QSO/radio galaxy population. This then implies that their corresponding host and black hole masses must be smaller. Smaller Black holes are found in local Seyfert galaxies. Indeed, based on optical SDSS spectra, the sources in our sample resemble those of LINERs or Seyferts (Fig. 1). It is therefore likely that they do not evolve into optically bright QSOs but rather into quiescent field ellipticals or in a still active state into X-ray-bright, early-type galaxies that can be found in ROSAT and CHANDRA based samples. If this finding is correct then our X-ray based sample should revealhost galaxy properties quite similar to AGN-dominated and star formation dominated ULIRGs. In other words they should fall close to the fundamental plane of early-type galaxies. The question is: How do they compare to \(L_\star\) rotating ellipticals, giant ellipticals, optically/UV-bright, and low-z QSOs/radio galaxies, i.e. what is their parent population?

2. The ROSAT/SDSS based Sample

The Sloan Digital Sky Survey (SDSS, e.g. York et al. 2000) with its multi-color photometric and spectroscopic data presents a rich source to search for astrophysically interesting objects.

To address the above stated questions, using a cross-correlation of SDSS optical and ROSAT X-ray data provided by the Early Data Release (EDR, Stoughton et al. 2002) and the ROSAT All Sky Survey (RASS, Voges et al. 1999), we searched for extragalactic, X-ray active objects brighter than \(r < 20\) with a natural guide star (NGS) brighter than \(r < 15\) in their vicinity. These
Sample of X-Ray active Galaxies suitable for AO Observations

Figure 1. Hubble diagram of the sources of the ‘initial’ sample. Different source types are indicated on the right axis (Hasinger, private communication). Left inset displaying the luminosity function of AGN compared to those of normal galaxies (Hasinger, private communication). Right inset comparing NIR-colors of sources of the sample (stars) with those of Gissel-stellar-evolutionary model colors (Hutchings & Neff 1997).

Magnitude units provide reasonable AO performance on 8m-class telescopes. Recent AO implementations allow NGS/science target angular separations up to 40″. These criteria resulted in a set of 27 galaxy/NGS pairs.

To only select the best optical X-ray counterparts we rejected those objects fulfilling one or more of the following conditions:

1. Angular separation between optical and X-ray position larger than 40″. The SDSS database identifies ROSAT sources with galaxies/AGN if the separation between both positions is less than 60″.
2. Hardness ratio of -1 or a stellar optical color $u-g < 1.3$. These are indicative for X-ray active stars, the former typical for white dwarfs. In this case the X-ray emission might be dominated by the NGS rather than the galaxy.
3. X-ray emission which shows excess extend over the ROSAT psf width. Here the X-ray flux is likely to be dominated by emission from an extended hot gas component at the center of a galaxy cluster (cf. Voges et al. 1999).

The final sample consists of 12 galaxy/NGS pairs in the redshift range $0.06 < z < 0.67$. Their X-ray luminosities (calculated, assuming a power-law index of -2 and an average galactic absorption column density of $3 \times 10^{20} \text{ cm}^{-2}$)
range from $10^{42}$ erg s$^{-1}$ to $10^{43}$ erg s$^{-1}$ (Fig. 1). Of these sources five objects have SDSS spectra, one of which appears as a ‘passive’ elliptical, although its X-ray luminosity indicates nuclear activity (cf. Comastri et al. 2002). For the remaining galaxies we used their photometric redshifts. Another source also shows a red nucleus (source no. 5 in right inset of Fig. 1) contained in the 2Mass survey, indicating the presence of warm dust, heated by star formation and/or the central engine.

3. Conclusions

The SDSS and its cross-correlations with other surveys provide means to find suitable extragalactic sources for follow-up NIR observations at highest angular resolution and sensitivity of 8m-class telescopes. Large telescopes are also necessary, because the optical counterparts of deep X-ray sources become very faint. NIR observations give complementary information to the optical and X-ray data in terms of highest resolution images of the detailed structure of the host galaxies. NIR colors and spectra give information on the stellar content of the host galaxies and the importance of the presence of dust. Furthermore dynamical information from spectra give estimates for host masses and possibly black hole masses, since the NIR emission is a more accurate tracer of the mass in galaxies.

Our sample represents a significant first step to a statistically relevant sample of X-ray active extragalactic sources observable with adaptive optics on large telescopes like the VLT.

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