Abstract. We examine the X-ray and infrared properties of galaxies and AGNs in the 9 deg$^2$ Boötes field, using data from the Chandra XBoötes and Spitzer IRAC Shallow Surveys, as well as optical spectroscopy from the AGES survey. A sample of $\sim$30,000 objects are detected in all four IRAC bands, of which $\sim$2,000 are associated with X-ray sources. We also study X-ray fainter sources using stacking techniques, and find that X-ray fluxes are highest for objects with IRAC colors that are known to be characteristic of AGNs. Because these are shallow, wide-field surveys, they probe the bright end of the AGN luminosity function out to spectroscopic redshifts as high as $z = 3–4$. We can use this multiwavelength dataset to explore the properties and redshift evolution of a large sample of luminous active galaxies.

1. Overview

Recent deep extragalactic surveys (e.g. GOODS, Lockman Hole, Groth Strip) have provided great insights into distant galaxy populations, in particular AGNs. Deep surveys detect primarily faint, distant objects, but miss many rare, more luminous objects. A complementary approach is to perform shallow, wide-field surveys that obtain large numbers of sources and probe the bright end of the flux distribution.

The Chandra XBoötes (Murray et al. 2005) and Spitzer IRAC Shallow Surveys (Eisenhardt et al. 2004) cover a large area of 9 deg$^2$ that also has deep optical photometry from the NOAO Deep Wide Field Survey (Jannuzi & Dey 1999), and optical spectroscopy from the AGES survey (Kochanek et al. 2004). A total of $\sim$270,000 IRAC sources are detected, of which $\sim$30,000 have detections in all four IRAC bands. Some $\sim$2000 of these have X-ray counterparts, most of which are AGNs. For many X-ray sources that do not have optical spectroscopy, we also have photometric redshifts (Brodwin et al. 2006). Here we provide a description of the datasets and present some preliminary results.

2. Mid-IR selection of AGNs

Using IRAC data and optical spectroscopy, Lacy et al. (2004) and Stern et al. (2005) showed that AGNs can be selected on the basis of their IRAC colors. Fig. 1 shows the Stern et al. (2005) color selection, which was derived using data from
Figure 1. Color-color diagram for all IRAC sources detected at 5σ in all four bands. The Stern et al. (2005) AGN region is shown by the dashed lines. X-ray sources with spectroscopic classifications (broad-line AGNs, narrow-line AGNs, and normal galaxies (with absorption line spectra)), are shown as stars.

Boötes. The IR colors of XBoötes X-ray sources with optical spectroscopy are shown. Optical spectra are classified as broad-line AGNs, narrow-line AGNs, or “normal” galaxies. X-ray sources, particularly those classified as broad-line AGNs, lie preferentially in this region of color-color space.

3. Redshift and luminosity distributions

Fig. 2 shows the redshift and $L_X$ distributions for all the X-ray sources in the XBoötes catalog with redshifts. Note that “normal” galaxies are not seen above $z \sim 1$, however AGNs are detected out to $z \sim 3–4$. Because of the wide field and flux limits of the XBoötes survey, we detect preferentially distant, luminous AGNs with $L_X > 10^{44}$ ergs.

4. X-ray stacking analysis

For objects that do not have detected X-ray counterparts, we can study their average X-ray emission by stacking analyses. Fig. 3 shows the average X-ray flux as a function of IR color. Note that in both soft and hard X-rays, the average photon flux is <1 count per source. However, the emission peaks in the AGN region defined by Stern et al. (2005), indicating a population of X-ray emitting AGNs at below the XBoötes flux limits.
Figure 2. Left: redshift distribution for all the X-ray sources in the XBoötes catalog with spectroscopic or photometric redshifts. The different optical spectroscopic classifications are shown as bold lines, while objects with photo-z's are classified as AGN or normal galaxies by the Stern et al. (2005) color selection (see Fig. 1), and are shown with light dashed lines. Right: 0.5–7 keV X-ray luminosity distribution for X-ray sources with redshifts. A $\Gamma = 1.7$ power law with Galactic absorption is assumed.

Figure 3. Average X-ray emission (in counts/source) for IRAC sources that do not have X-ray matches, binned by their IR colors for (left) 0.5–2 keV and (right) 2–7 keV. The Stern et al. (2005) AGN region is shown as in Fig. 1.

5. Prospects

The Boötes sample of thousands of X-ray, infrared, and optically selected active galaxies will allow us to address a number of questions such as:

1. How do the broad-band spectral properties and number densities of luminous AGNs evolve with redshift? Are these related to changes in the accretion process, particularly for $z < 1$ where luminous AGN activity may decline sharply (e.g. Barger 2005)?

2. Are significant numbers of AGNs obscured in the optical or X-ray bands? What multiwavelength properties of these sources can be used to identify them?

3. How are the properties of active galaxies related to their local environment? For the Boötes field, local galaxy densities can be determined by the 3-D
distributions from the AGES data, and correlated to the luminosities and spectral types of AGNs. Do such correlations change with redshift?

References

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