Counting All the SHEEP:

A summary of the past and present work associated with ASCA's The Search for the High-Energy Extragalactic Population (SHEEP) survey

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Abstract

SHEEP is the Search for the High-Energy Extragalactic Population, a survey of X-rays sources found in 5-10 keV band images from the ASCA satellite. Because hard X-rays are difficult to obscure, SHEEP provides a largely unbiased accounting of the AGN population. We have been identifying SHEEP using new high-resolution Chandra images, and following up with deep optical imaging from Greece and near-infrared imaging from Wyoming. Spectral classifications are obtained at NOAO 4-meter telescopes. Our initial work shows a wide variety of optical classes, ranging from QSOs to optically normal galaxies (despite their high X-ray luminosities). We have also identified several high-redshift quasar pairs, which is intriguing given the size of the sample. Completion of identifications and classifications will permit us to finally "count the SHEEP" and provide a better picture of the AGN population and the sources contributing to the X-ray background.

Introduction

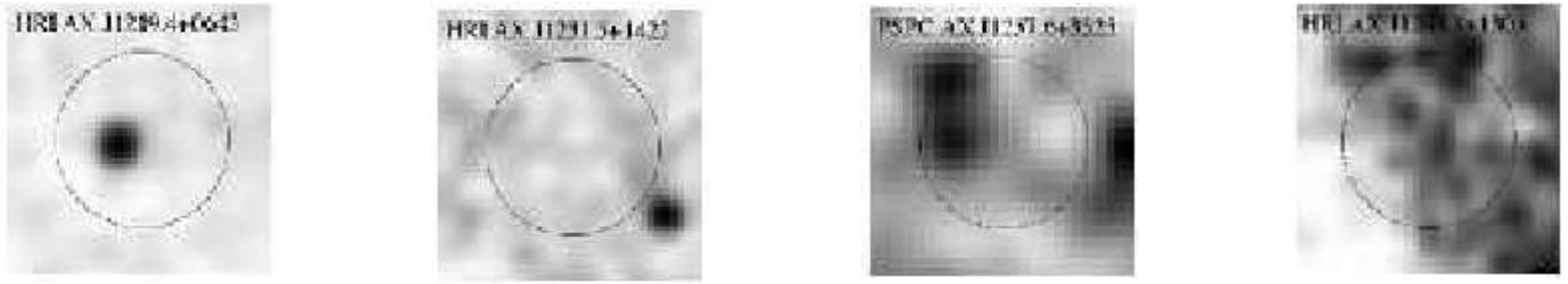
- It has been hypothesized that large numbers of AGNs are heavily absorbed in the X-ray band. Optical and soft-X-ray surveys are insensitive to such AGNs. Hard X-ray surveys, however, are not biased toward obscured sources.
- Chandra has been particularly valuable in conducting hard X-ray surveys. It has uncovered a population of hard X-ray sources in the 2-8 keV band that are likely to be obscured AGNs; they outnumber classical QSOs and appear rather different than local Seyfert 2s.
- A problem with these objects is that they are extremely faint in the optical band. This makes spectroscopic identification and detailed astrophysics very difficult.
- One way around this is to undertake large-area hard X-ray surveys to locate bright examples of the Chandra population for easy study. The 5-10keV BeppoSAX HELLAS survey is one example of such an effort (Fiore et al. 1999). The 5-10keV SHEEP survey with the ASCA satellite is an alternative equivalent approach.

Overview of the SHEEP Survey

- The SHEEP survey utilized the Tartarus database of ASCA observations with the GIS detectors. From 149 fields altogether spanning 38.9 deg^2, 69 serendipitous sources were detected. The limiting flux was ~10^{-13} ergs cm^{-2} s^{-1}.
- Compared to the Chandra deep surveys, the SHEEP survey covers a larger area but has a lower sensitivity. Determining whether the SHEEP are part of the predicted obscured AGN population or an entirely new population is now the subject of inquiry.
- The size of the SHEEP survey is advantageous. Identification and characterization of the 69 sources will provide statistically meaningful results. Furthermore, the sample is small enough be observed and classified in a modest timeframe.
- Thirty four of the SHEEP sources were detected previously by ROSAT, although 53 of them were observed by the satellite. ROSAT data is valuable because it provides constraints on the spectral properties and an improvement to the ASCA positional accuracies of the SHEEP.

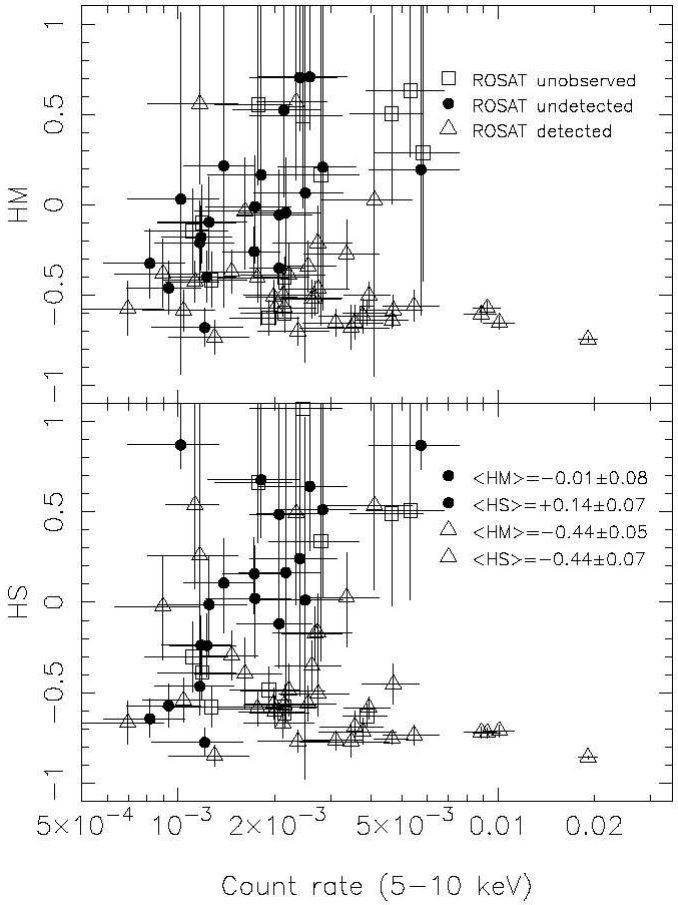
Overview of the SHEEP Survey Continued

- Spectral analysis reveals that these objects comprise a relatively soft sub-sample of the 69 SHEEP. The remaining 35 SHEEP are extremely hard objects in comparison.
- A wide variety of spectral properties are evident within the SHEEP sample. The softest objects have unabsorbed power-law spectra. The harder SHEEP are not well represented by simple absorbed spectra. Rather, they appear to be complex, having both an absorbed component and a softer component.
- The hardness of the average spectrum suggests that many of the SHEEP are obscured.



Above: A quartet of ROSAT images of some SHEEP. The circles are 2' in radius and are centered on the ASCA positions.

Overview of the SHEEP Survey Diagrams



Count rates in the “hard”=H (5-10keV), “medium”=M (2-5keV), and “soft”=S (0.7-2keV) bands were extracted from the ASCA images. Hardness ratios defined as HM=(H-M)/(H+M), HS=(H-S)/(H+S), and HR1=(H+M-S)/(H+M+S) were calculated. These diagrams illustrate how the ratios were applied in analyzing the ASCA data.

Sample (1)	N_{obj} (2)	Method (3)	Ratio (4)	Value (5)	Γ (6)
Full	69	Unweighted	HM	-0.23 ± 0.05	$\Gamma = 0.7 \pm 0.2$
Full	69	Unweighted	HS	-0.14 ± 0.08	$\Gamma = 0.9 \pm 0.2$
Full	69	Unweighted	HR1	0.28 ± 0.05	$\Gamma = 1.1 \pm 0.1$

Above: Graphs comparing the count rate versus the HM and HS ratios. In both cases, the ROSAT-detected SHEEP represent a systematically softer sub-sample.

Above: The mean hardness ratios and equivalent spectral indices of the full SHEEP sample. The mean spectrum depends on the method of calculation and is subject to statistical bias. The HR1 value is likely to be the least subject to bias and is harder than the XRB.

Optical Follow-Up

- Being bright examples of the Chandra deep sources, the SHEEP ought to be amenable to follow-up observations in the optical.

SHEEP/ROSAT Sub-Sample:

- The 2' error boxes associated with the ASCA positions of the SHEEP are inconvenient. However, the coordinates of the 34 ROSAT-detected SHEEP, denoted SHEEP/ROSAT, are known to within 15''.

- Excluding 13 objects that already have secure optical counterparts in archival catalogs, imaging and spectroscopic identities have been obtained from ROSAT coordinates for the majority of the remaining SHEEP/ROSAT with ground-based telescopes.

- Most of the identified SHEEP/ROSAT are type-1 AGNs, i.e. QSOs and Seyfert 1s. Also present at a 4:1 ratio are type-2 AGNs.

- In 11 cases, an unambiguous optical counterpart could not be found within the error circle of the ROSAT coordinates .

Optical Follow-Up Continued

SHEEP/Chandra Sub-Sample:

- Unambiguous optical counterparts of the SHEEP ROSAT failed to detect are not so easily found with only the ASCA positions. These 35 SHEEP, denoted SHEEP/Chandra, were observed by Chandra to improve positional accuracy to less than one arcsecond. Exposures 5ks in duration were obtained with the ACIS-S3 chip.

- NOAO 4m-spectroscopy at CTIO and KPNO has been successful in identifying optical counterparts of 26 of the SHEEP/Chandra. Only nine out of 35 sources have yet to be identified with spectroscopy.

Future Work:

- The optical follow-up program is almost complete. Twenty SHEEP have yet to be assigned optical classifications.

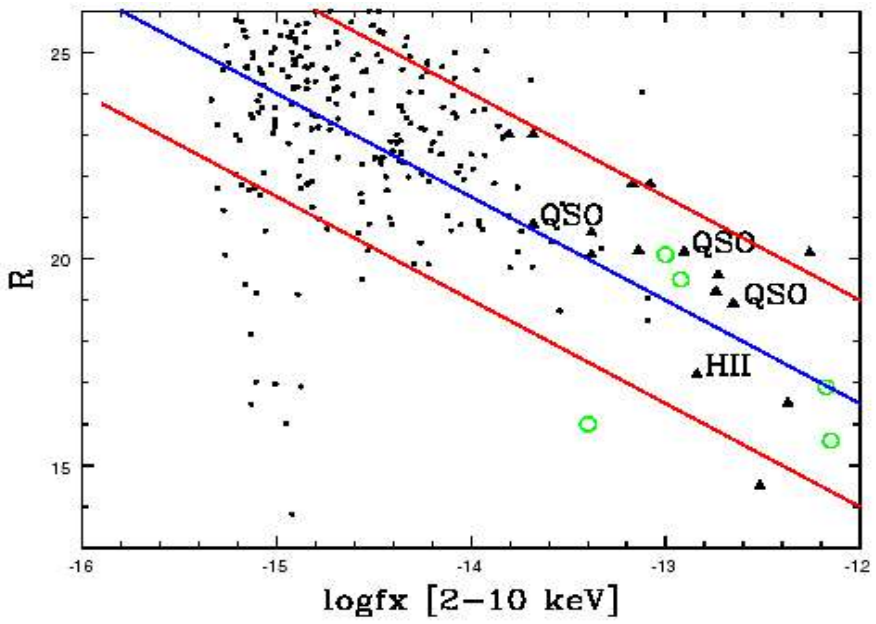
- The remaining objectives are to observe the 11 SHEEP/ROSAT with Chandra to obtain improved coordinates and conduct 4m-spectroscopy of the 20 SHEEP.

Optical Follow-Up Continued

Preliminary Results:

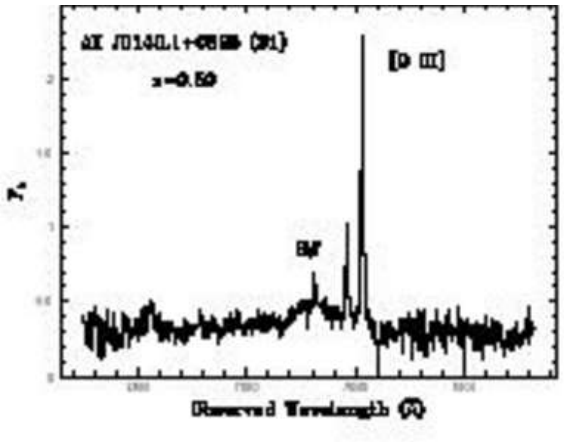
- Small number statistics of 17 SHEEP/Chandra reveal that the sample is roughly divided into two groups: QSOs at high redshift ($z>0.5$) and Low Luminosity AGNs in the local Universe ($z<0.1$).
- An emerging trend is that optical and X-ray spectra have little correspondence. For some objects, optical emission is prominent while the X-ray spectrum is hard due to obscuration, a property not found in classical AGNs.
- The implication is that obscured AGNs may evolve differently than X-ray unobscured AGNs. If so, current models may not be particularly useful for phenomena such as black hole accretion at high redshifts. Then, AGN classification schemes founded on low-redshift Seyferts may need to be revised.
- A particularly unexpected result is the identification of two sets of quasar pairs. This implies a surprisingly large number of double quasars.

Optical Follow-Up Diagrams



Above: The lines from bottom to top represent f_X/f_{opt} of -1,1, and 0. The triangles are 17 SHEEP/Chandra, and the open circles are AMSS sources, three of which are associated with low- redshift NELG. The position of the SHEEP implies they can be broken into two classes: QSOs and local AGNs.

Below: An optical spectrum of a type-1 QSO with strong emission and a broad Hβ line. The object's X-ray spectrum is hard and shows heavy obscuration, implying that the obscuring material is dust free or very close to the nucleus. This particular property is common among the SHEEP.



Near-Infrared Follow-Up

- Probing the SHEEP in the near-IR is complementary to doing so in the hard X-ray band. Both near-IR light, which passes through dust, and hard X-rays, which pass through gas, penetrate obscuring material.
- Two and three-meter ground-based telescopes are adequate for determining the near-IR magnitudes of the SHEEP.

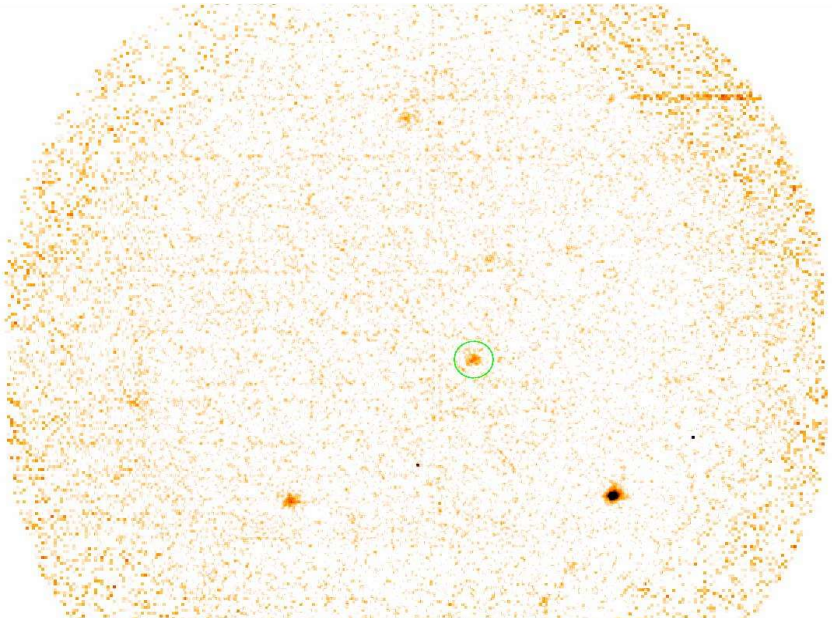
WIRO Observations:

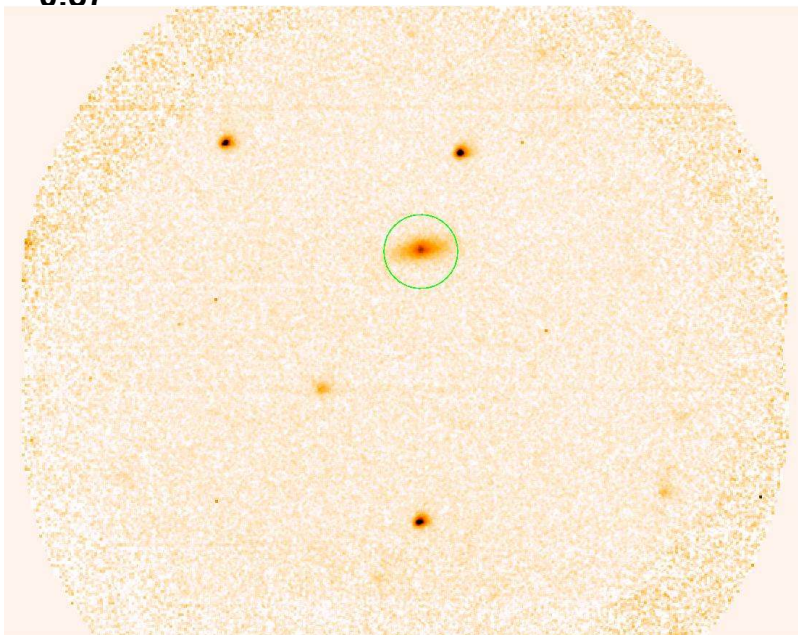
- A small sample of SHEEP was observed during June 2004 at Wyoming Infrared Observatory (WIRO). Images were gathered with the WIRO's 2.3m telescope and Goddard IR camera.
- The WIRO images were dithered. A series of 15 45-second exposures, making for an effective observation time of 675 seconds, was obtained for each SHEEP. Exposures were taken under photometric conditions.
- The K' magnitudes of seven SHEEP were then calibrated from observations of standard stars acquired during the observing run.

Near-Infrared Follow-Up Diagrams

Object	K' Mag	R Mag	(R-K')	Redshift
AXJ1354.0+3346	18.00	20.2	2.20	. . . .
AXJ1406.1+2233	14.76	. . . .	. . . .	0.17
AXJ1511.7+5702	16.75	21.8	5.05	. . . .
AXJ1512.0+5708	17.90	19.5	1.60	0.37
AXJ1531.8+2414	13.66	16.9	3.24	0.10
AXJ1531.9+2420	14.82	17.2	2.38	0.63
AXJ1532.3+2401	16.56	19.3	2.74	0.57

Left: A table containing the k' (1.95-2.35 μm) magnitudes of the SHEEP observed at WIRO during June 2004.





Above: Two composite images made from WIRO observations. Circled on the left is AXJ1531.9+2420. No SHEEP detected in the image on the right; a galaxy is circled instead. The field of view is approximately 2.25 arcmin^2.

Summary

- The 69 sources from the 5-10keV ASCA SHEEP survey define a new, flux-limited sample of hard X-ray selected AGNs that are amenable to follow-up work in multiple band passes.
- Bright examples of the Chandra deep sources, the SHEEP could very well be representative of the dominant universal AGN population.
- The optical program of determining spectroscopic identifications of all the SHEEP is nearly complete. A modest investment from and Chandra and NOAO telescopes is required to classify the remainder of the SHEEP.
- The purpose of the IR component is to measure the near-IR magnitudes of the SHEEP. Doing so complements the hard X-ray observations made with ASCA and Chandra.
- The SHEEP are turning out to be unlike familiar AGN classes. This implies that standard AGN classifications schemes will be of little use at high redshifts and will need to be revised in the future.
- Completion of identifications and classifications will permit us to finally "count the SHEEP“ and better understand the nature of the XRB.

References:

Fiore, F., et al. 1999, MNRAS, 306, L55

Georgantopoulos, I. et al. 2003, AN, 324, 32

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