ABRIXAS, an Imaging Telescope for a 0.5–10 keV Survey

P. Friedrich[1], G. Hasinger[1], G. Richter[1], K. Fritze[1], J. Trümper[2], H. Bräuninger[2], P. Predehl[2], R. Staubert[3], and E. Kendziorra[3]

[1] Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany
[2] Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstrasse, D-85740 Garching, Germany
[3] Institut für Astronomie und Astrophysik der Universität Tübingen, Waldhäuser Straße 64, D-72076 Tübingen, Germany

Abstract. In cooperation with DARA we are planning the small X-ray satellite mission ABRIXAS (**A Broad**-band **I**maging **X**-ray **A**ll-sky **S**urvey), extending the ROSAT survey to the harder X-ray band (0.5–10 keV) with an angular resolution better than 1′. As a pathfinder mission, ideally before XMM and AXAF, it can pinpoint objects obscured for soft X-rays by absorbing gas and dust. Its main goal is to study the absorbed AGN population and its contribution to the X-ray background. We expect to detect 10000–20000 new AGN. However, ABRIXAS will also obtain high-quality spectra of diffuse emission objects like clusters and supernova remnants. Additionally, the three-year survey will provide monitoring of bright X-ray sources on time scales as yet unexplored.

The optical system consists of 7 identical Wolter-I telescopes of 1600 mm focal length, each with 27 nested mirrors of lengths 300 mm and diameters ranging from 163 mm to 76 mm. The 7 focal planes share one 6 cm × 6 cm XMM pn-CCD array. Thus the 7 fields of view, each about 40′ in diameter, are 7° apart of each other on the sky which is scanned along great circles. The shift of 4′ in ecliptic longitude between successive orbits provides a contiguous coverage of the sky.

The sensitivity calculations are based on a survey duration of 3 years with a minimum requirement of 1.5 years. The projected launch date should therefore be in 1998 to be able to provide an input for XMM and AXAF.

1. Scientific goals

1.1. Absorbed AGN

It became apparent in the last years that different types of active galactic nuclei (AGN), in particular the Seyfert-1 and Seyfert-2 galaxies, can be simply understood in terms of orientation effects: while in Seyfert-1 galaxies we can look straight into the core region of the AGN, where the energy production occurs, the central engine of Seyfert-2 galaxies is obscured by gas and dust clouds of a thick molecular torus (see eg. Antonucci 1993 for a recent review). This hypothesis – sometimes called the unified AGN model – has very recently been confirmed in the most dramatic way by direct observations of Seyfert galaxies with the Hubble Space Telescope, which indeed could resolve a dusty torus in the center of an AGN.

The X-ray appearance of an AGN is therefore expected to be strongly dependent on the viewing angle: in Seyfert-2 galaxies, where the direct view is blocked by the thick torus, all soft X-rays are expected to be absorbed by the gas and dust clouds, which can only be penetrated by X-rays with energies above several keV ($N_H > 10^{24}$ cm^{-2}).

In recent years, through the ROSAT and *Ginga* observations it also became apparent that there is a whole continuum of different X-ray absorption values, probably governed by the shape of the molecular tori in connection with different orientations. There is also unsurmountable evidence that some of the X-ray absorbing gas is partially ionized (e. g. Nandra and Pounds 1992), so that even soft X-rays can "eat their way" through the torus. This offers the exciting possibility to observe a variety of spectral features with a high energy resolution X-ray instrument, like absorption edges and fluorescence lines in the absorber. In addition the ionization state of the matter should depend on the luminosity of the central machine, so that e. g. quasars should on average be less absorbed than Seyfert galaxies.

1.2. X-ray background

The extragalactic X-ray background (XRB), discovered about 30 years ago, has been studied extensively with many X-ray experiments, in particular with the satellites HEAO I and II (see e. g. Boldt 1987) and with ROSAT (e. g. Hasinger et al. 1993). Over the energy range from 3 to about 100 keV its spectrum can be well approximated by an optically thin thermal bremsstrahlung model with $kT \approx 40$ keV, while at lower X-ray energies a steepening into a new component has been observed.

Studies of the isotropy of the X-ray background give strong support for its extragalactic nature. The XRB is isotropic down to a few percent on practically all observable scales.

1.3. Galactic X–ray sources

Soft X–ray emission from galactic sources in the direction of the galactic plane is strongly absorbed by dense clouds of neutral gas which can be seen in the ROSAT all–sky survey. Many X–ray sources which are obscured in the soft band are expected to be unveiled in a 0.5–10 keV survey. Additional goals are therefore the detection of extended sources with low surface brightness, such as SNR or other hot gas bubbles, as well as the long–term monitoring of bright X–ray sources, e. g. cataclysmic variables and X–ray binaries, with a wide spectrum of time scales (10 s, 90 min, 2 d, 14 d, 0.5 yr, 3 yr).

2. The need for a new hard X–ray all–sky survey

By the year 2000, X–ray observatories with good imaging capabilities and extremely wide bandpass up to 10 keV will be available (e. g. XMM and AXAF) and in principle will be able to measure directly a broad distribution of AGN source spectra and absorption at all redshifts. However, in order to study the evolution of the AGN luminosity function as well as a possible evolution of the source spectra and the intrinsic absorption, large statistically complete and unbiased source samples are necessary.

The ROSAT all–sky Survey with about 60000 new X–ray sources over the whole sky could in principle serve as a pathfinder for the future higher–energy observations. However, the soft X–ray sky, because of its sensitivity to absorption, provides only a very biased view of the universe. An all–sky survey in a wide and harder X–ray energy band, ideally before AXAF and XMM fly, would therefore be most desired and scientifically very valuable for analyses much less dependent on selection effects.

3. The X–ray telescope

3.1. pn–CCD detector

The technologically most challenging part, the development of a 6 cm × 6 cm X–ray detector with a spatial resolution of roughly 0.15 mm, a good energy resolution and a high background rejection efficiency for ABRIXAS, is already taken care of by MPE for the ESA project XMM. X–ray CCD detectors are now almost state of the art and the first CCD is already flying on the Japanese ASCA satellite. Others are in preparation for Jet–X, AXAF and XMM. However, the current detector formats, which are mainly conventional optical CCDs adapted for X–ray illumination, are not sufficient for the requirements of the ABRIXAS project. In particular their readout time would not permit a scanning X–ray mission. At MPE a new pn–CCD technology is developed for XMM which provides an unprecedented quantum efficiency in the range 0.1–15 keV. Much larger and deeper pixels and larger wafer formats can be chosen and a faster readout speed achieved.

3.2. Optical system

The optical design has been optimized by Monte Carlo simulations based on a ray tracing method. It consists of seven 27–fold nested gold–coated Wolter–I mirror systems with a focal length of 160 cm, and with outer and inner diameters of roughly 16 cm and 7 cm, respectively. This design achieves a FOV–averaged resolution of better than 30". The company Carl Zeiss has already constructed a single galvanoplastic verification shell for ABRIXAS.

The seven mirror systems share one 6 cm × 6 cm pn–CCD detector in their focal plane, a copy of the XMM MAXI camera. Because of the distribution of the seven field–of–views across the CCD chip and because of the limited opening angle of the MAXI camera the beams of the different mirror systems are crossing each other in front of the detector. At the location of the beam intersection a circular field stop is removing straylight.

4. Sensitivity calculations

In the ROSAT energy range (0.1–2 keV) the celestial X–ray background given by Hasinger (1992) was assumed. For higher energies it was taken from the analytical expression given by Gruber (1992). The expected count rate from the cosmic background, folded through the mirror and CCD efficiency, is about 1.6 cts/s. The residual particle background was assumed to be $2 \cdot 10^{-3}$ cts cm^{-2} s^{-1} keV^{-1}, i. e., the value achieved by the CCD detectors on board of ASCA multiplied by a factor 3.5 to account for the higher–inclination orbit.

A minimum number of 15 photons has been required for the "5–sigma" detection of a point source. The calculated sensitivity for the detection of a point source in a three–year survey corresponds to 6.5 μCrab or a flux of $1.5 \cdot 10^{-13}$ erg cm^{-2} s^{-1} in the 0.5–2 keV band and to 41 μCrab or a flux of $9 \cdot 10^{-13}$ erg cm^{-2} s^{-1} in the 2–12 keV band. Assuming the $\log N$–$\log S$ function given by Hasinger et al. (1993) for the 0.5–2 keV band and a factor of 3 more sources in the 2–12 keV band, the total number of extragalactic sources expected is about 63000 sources in the soft and about 14000 sources in the hard band. A good fraction of these will be new detections.

References

Antonucci, R., 1993, Ann. Rev. Astron. Astrophys., **31**, 473

Boldt, E., 1987, Phys. Rept., **146**, No. 4, 215

Comastri, A., Setti, G.–C., Zamorani, G., Hasinger, G., 1995, Astron. Astrophys., **296**, 1

Gruber, D., 1992, in: The X–Ray Background, X. Barcons and A. C. Fabian eds., Cambridge University Press, p. 44

Hasinger, G., 1992, in: The X–Ray Background, X. Barcons and A. C. Fabian eds., Cambridge University Press, p. 229

Hasinger, G., Burg, R., Giacconi, R., Hartner, G., Schmidt, M., Trümper, J., Zamorani, G., 1993, Astron. Astrophys., **275**, 1

Nandra, K., Pounds, K. A., 1992, Nature, **359**, 215