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ROSAT's view of the X-ray sky

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All-sky X-ray surveys with satellites started in the early 1970s with relatively crude, non-imaging instrumentation. The resulting survey catalogs, for example those from Uhuru & Ariel 5, contained only a few hundred sources, rising only modestly to ~1000 entries by the end of the decade with the HEAO-1 (A-1) survey.

Since then the most important and influential X-ray sky survey has undoubtedly been that carried out by ROSAT in the early 1990s. The ROSAT Bright Source Catalogue paper by Voges et al., when it was published 10 years ago, thus represented not only the culmination of the ROSAT project's primary aim of surveying the whole sky at X-ray wavelengths with an unprecedented sensitivity, but also a major step forward in our knowledge of the X-ray sky. ROSAT (RÖntgen SATellit; Trümper 1982) was a German national project with an international partnership with the UK and US. From its origins as a mission concept in the middle of the 1970s to its realization as ROSAT, the main aim of the project was to perform the first all-sky survey with an imaging X-ray telescope, but the scope of the project was expanded through the international partnerships to encompass a program of pointed observations (with the provision of an additional focal plane detector by the US) and to include an extreme ultraviolet (EUV) capability with a separate EUV telescope supplied by the UK.

Originally planned as a space shuttle launch, the Challenger tragedy in 1986 delayed the project until an alternative launch – by a Delta II rocket – could be secured. ROSAT was eventually launched on 1990 June 1, just over a month after the Hubble Space Telescope. ROSAT's main X-ray telescope operated in the soft X-ray band (0.1–2.4 keV) with two different, interchangeable, detectors in the focal plane: two Position Sensitive Proportional Counters (PSPCs), used for the all-sky survey, and the High Resolution Imager (HRI), provided by the US and used only for pointed observations. The ROSAT EUV telescope had a separate micro-channel plate detector, the ROSAT Wide Field Camera (WFC).

The ROSAT All-Sky Survey (RASS) took place in late 1990/early 1991[1]. Rather remarkably, in 6 months observing time, ROSAT surveyed essentially the whole sky to a sensitivity a factor 20 better than previous missions, while simultaneously delivering a large improvement in positional accuracy and reduction in source confusion, issues that had plagued earlier X-ray sky surveys. This achievement was, of course, due to the large increase in sensitivity afforded by using imaging X-ray optics and true imaging detectors, contrasting with the non-imaging technology employed for earlier X-ray surveys. Particularly important for ROSAT was the optical design of the X-ray telescope, which gave a wide imaging field of view (≈2 degrees), providing a very large survey grasp.

After the completion of the all-sky survey, ROSAT spent the rest of its operational life (until its demise in early 1999) making over 9000 pointed observations of specific targets.

The Voges et al. paper presents the RASS Bright Source Catalogue (BSC), consisting of some 20 000 X-ray sources, together with a detailed description of the survey itself, the survey data processing, and the overall characteristics of the catalog, such as the source counts, spectral and temporal properties, and identification content. As such, it is primarily an observational and technical paper that does not present many of the scientific results from the RASS itself, but its importance lies, of course, in its being the definitive publication describing the whole ROSAT survey. The final output of the RASS includes the much larger Faint Source Catalogue (FSC), subsequently released in 2000, and containing >100 000 X-ray sources of which the BSC was a subset (Voges et al. 2000).

Much of the impact of the RASS followed directly from the size of the catalog of X-ray sources that it produced. The BSC alone was over 20 times larger than any previous all-sky X-ray catalog, whilst the FSC was over a 100 times bigger than its forerunners. The RASS was of course a sky survey in the soft X-ray band, so RASS results are naturally biased towards object types with soft X-ray spectra, or at least those without substantial low-energy absorption.

The completion of the RASS thus immediately provided access to much larger samples of soft X-ray emitting object types that had already been known before ROSAT flew, such as active galaxies, coronally-active stars, clusters of galaxies, and cataclysmic variables. It also made possible the discovery of X-ray emission from many rare object types, some not even anticipated, such as isolated neutron stars and super-soft stellar objects. Some of these samples could be produced directly from cross-correlation of the RASS with existing catalogs (as described in the Voges et al. paper), but realizing the full potential of the RASS in many areas did not come anywhere nearly as easily. Even with the 10–20 arcsec positional accuracy available for

[1] A small part of the RASS missed in the original observations was subsequently completed in 1997. A parallel EUV sky survey was carried out simultaneously with the ROSAT EUV telescope & WFC (Pounds et al. 1993).

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most of the RASS objects, very substantial follow-up programs were needed to produce the complete samples required for much of the science (see, for example, Schwope et al. 2000).

The impact of the RASS in many areas of astrophysics has been immense, as can be judged, for example, from many of the articles in Trümper & Hasinger (2008). Any list of scientific highlights has necessarily to be rather selective[2], but among the major contributions made by the RASS, the following more than adequately reflect its legacy:

- The compilation of very large samples of clusters of galaxies based on the RASS (see, e.g. Rosati et al. 2002, for a recent review) provided the data to probe the cluster population out to $z \sim 0.2$–0.3, extending even to $z \sim 0.5$. These studies enabled the assessment of the large-scale structure of the Universe (Böhringer et al. 2004) and provided constraints on the matter density of the Universe (Schuecker et al. 2003a) and the equation-of-state parameter of dark energy (Schuecker et al. 2003b).
- A key measurement of the space density of active galactic nuclei (AGN) provided the local and high-luminosity anchor needed to determine their cosmological evolution. Using large optically identified samples from the RASS and ROSAT pointed observations, Miyaji et al. (2000) were able to show that AGN have a complicated, luminosity-dependent, density evolution, later confirmed to be a unique property of AGN in all bands (e.g., Hasinger et al. 2005).
- The RASS made a major contribution to studies of X-ray emission from stars throughout the HR diagram, leading to a mature understanding of stellar X-ray emission processes and their relationship to fundamental stellar properties. RASS-based studies confirmed the universality of X-ray emission among late-type stars with outer convection zones, extending to the lowest mass and latest spectral types (see, e.g., Schmitt & Liefke 2004) and mapped for the first time the large-scale distribution of active stars in the Galaxy (e.g. Guillout et al. 1998). In the field of stellar astronomy, one of the biggest surprises was the number of white dwarfs detected in the RASS, more than a factor 30 times smaller than predicted (Fleming et al. 1996), because of the opacity produced in their atmospheres by trace metals (Barstow et al. 1993).

At the time that ROSAT was operating, there was widespread impatience in the community over the perceived delay in the release of the RASS catalogs, exacerbated by the earlier release of many initial results based on the RASS. Apocryphally at least, the slogan at high-energy astrophysics conferences in the 1990s was "free the ROSAT 100 000" (Trimble & Aschwanden 2001). These sentiments ignored, to a large extent, the scope of the data processing and data analysis challenge faced by the ROSAT team in producing the RASS catalog and the time needed to adequately verify the catalog with both automatic and manual screening procedures. While it is undoubtedly true that a version of the RASS could have been released earlier (and might, of course, have guaranteed an even higher citation count for the Voges et al. paper), it must be equally true that such a catalog would not have reached the standard of reliability of the final RASS that undoubtedly contributed significantly to its legacy.

Since the publication of the RASS in 1999, there has not been a dedicated all-sky survey at X-ray wavelengths, not because this is an uninteresting exercise, but simply because subsequent missions (those that were selected at least) typically emphasized pointed observations.

The exception to this trend was the ABRIXAS mission, designed to carry out an all-sky survey with even higher sensitivity than ROSAT and in a much broader energy band (0.5–10 keV), thus providing a view of the absorbed source population not accessible to ROSAT. Sadly, the ABRIXAS mission failed because of a technical problem that became apparent shortly after launch in 1999, but ABRIXAS lives on in the form of e-ROSITA, the core instrument in the Spectrum Röntgen-Gamma (SRG) mission. It is planned that the e-ROSITA instrument will carry out its all-sky survey in the 0.2–12.0 keV band early in the next decade, providing both a rich survey resource and, equally importantly, acting as a pathfinder for future missions such as the ESA-JAXA-NASA International X-ray Observatory (IXO).

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[2] It is also difficult, in many cases, to disentangle the primary contribution from the RASS itself from subsequent, more detailed pointed ROSAT studies.