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The BMW-Chandra Serendipitous Source Catalogue⋆

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Abstract. We present the BMW-*Chandra* Source Catalogue drawn from all *Chandra* ACIS-I pointed observations with an exposure time in excess of 10 ks public as of March 2003 (136 observations). Using the wavelet detection algorithm developed by (Lazzati et al., 1999) and (Campana et al., 1999), which can characterize point-like as well as extended sources, we identified 21325 sources which were visually inspected and verified. Among them, 16758 are not associated with the targets of the pointings and are considered certain; they have a 0.5–10 keV absorption corrected flux distribution median of $\sim 7 \times 10^{-15}$ erg cm^{-2} s^{-1}. The catalogue consists of source positions, count rates, extensions and relative errors in three energy bands (total, 0.5–7 keV; soft, 0.5–2 keV; and hard band, 2–7 keV), as well as the additional information drawn from the headers of the original files. We also extracted source counts in four additional energy bands, (0.5–1.0 keV, 1.0–2.0 keV, 2.0–4.0 keV and 4.0–7.0 keV). We compute the sky coverage in the soft and hard bands. The complete catalogue provides a sky coverage in the soft band (0.5–2 keV, S/N =3) of ~ 8 deg^2 at a limiting flux of $\sim 10^{-13}$ erg cm^{-2} s^{-1}, and ~ 2 deg^2 at a limiting flux of $\sim 10^{-15}$ erg cm^{-2} s^{-1}.

Key words. catalogs – X-rays: general

1. Introduction

The Brera Multi-scale Wavelet (BMW, (Lazzati et al., 1999; Campana et al., 1999)) algorithm, which was developed to analyse *ROSAT* High Resolution Imager (HRI) images ((Panzera et al., 2003)), was recently modified to support the analysis of *Chandra* Advanced CCD Imaging Spectrometer (ACIS) images ((Moretti et al., 2002)), and led to interesting results on the nature of the cosmic X-ray background ((Campana et al., 2001)). Given the reliability and versatility of the BMW, we decided to apply it to a large sample of *Chandra* ACIS-I images, to take full advantage of

the superb spatial resolution of *Chandra* while being able to automatically analyse crowded fields and/or with very low background. We thus produced the Brera Multi-scale Wavelet

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Chandra Source Catalogue ((Romano et al., 2004)).

2. Data Sample and Processing

Our choice of the *Chandra* fields favored the ones that would maximise the sky area not occupied by pointed objects. We considered data from all four front-illuminated CCDs in the ACIS-I imaging fields with exposure time in excess of 10 ks available in 2003 March. We excluded fields dominated by extended sources, planetary and supernova remnant observations, bright point-like or high-surface brightness extended sources. We put no limit on Galactic latitude, but we selected subsamples based on latitude at a later time. As a result, 136 fields reported successful completion of the pipeline. Our pipeline is a combination of `Ciao 2.2` tasks (data screening, image reduction, exposure map creation), IDL programs (additional data screening, wavelet detection), tasks in the `HEAsoft` package and UNIX shell scripts (drivers and house-keeping) that reduces and analyses the Level 2 data generated by the *Chandra* X-ray Center standard data processing in a uniform fashion. The data were filtered to only include the standard event grades (*ASCA* grades 0, 2, 3, 4, 6) and corrected for aspect offset. We then applied energy filters and created soft (SB, 0.5–2.0 keV), hard (HB, 2.0–7.0 keV) and total (FB, 0.5–7.0 keV) band event files (see Table **??**). Our results in the 0.5–10 keV band are extrapolations from our findings in the 0.5-7 keV range. We also removed background flares, hot/flickering pixels and bad columns (see (Moretti et al., 2002)). The effective exposure times given in the catalogue reflect these corrections that amount on average to a reduction by 4%.

3. Source Detection and Catalogue Construction

We ran the detection algorithm on the source images rebinned by a factor of 2 (1 pixel $\sim 0\farcs98$), and then in their inner 512×512 part at the full resolution, using 7 scales = $[1, 2, 4, 8, 16, 32, 64]$ pixels to cover a wide range of source sizes, with a single significance threshold for the sources that corresponds to ~ 0.7 spurious detections per field. Given our 136 fields, we expect a total of $\sim$ 95 spurious sources in the catalogue. We applied corrections to the source counts for vignetting and PSF modelling (i.e. for using a Gaussian to approximate the PSF function to fit the sources in wavelet space). We excluded the 480×480 pixel central part in the analysis at rebin 2, then cross-correlated the positions of the sources found at rebin 1 and 2 to exclude common double entries. We repeated this procedure for each of the three energy bands, and cross-correlated the resulting source coordinates to form the definitive list (for coincident sources, the coordinates of the highest S/N one were kept). An example of the results of the detection is shown in Fig. 1.

The wavelet detection produced a catalogue of source positions, count rates, counts, extensions, and relative errors in three bands, as well as the additional information drawn from the headers of the original files for a total of 21325 sources. Approximate fluxes in the three bands were calculated using a count rate to flux conversion factor CF0 = 1×10^{-11} erg cm^{-2} cts^{-1}. We also extracted source counts within a box centered around the positions determined with the detection algorithm, with a side which is the 90% encircled energy diameter at 1.50 keV. For the SB, HB and FB bands the background counts were extracted from the same box from the background image. We extracted source counts in the four additional bands (see Table **??**): SB1 (0.5–1.0 keV), SB2 (1.0–2.0 keV), HB1 (2.0–4.0 keV) and HB2 (4.0–7.0 keV). We converted the count rates in fluxes assuming a Crab spectrum, i.e. a power law with photon index 2.0, modified with the absorption by Galactic $N_{\rm H}$ relative to each field, and with a simple Crab spectrum ($N_{\rm H} = 0$). The catalogue lists the 0.5–10 keV observed flux, the absorption corrected one and the corresponding conversion factors. Problematic portions (such as extended pointed objects) and pointed objects (within a radius of $30''$ from the target position) were flagged.

The full catalogue contains 21325 sources, 16834 of which are not associated with

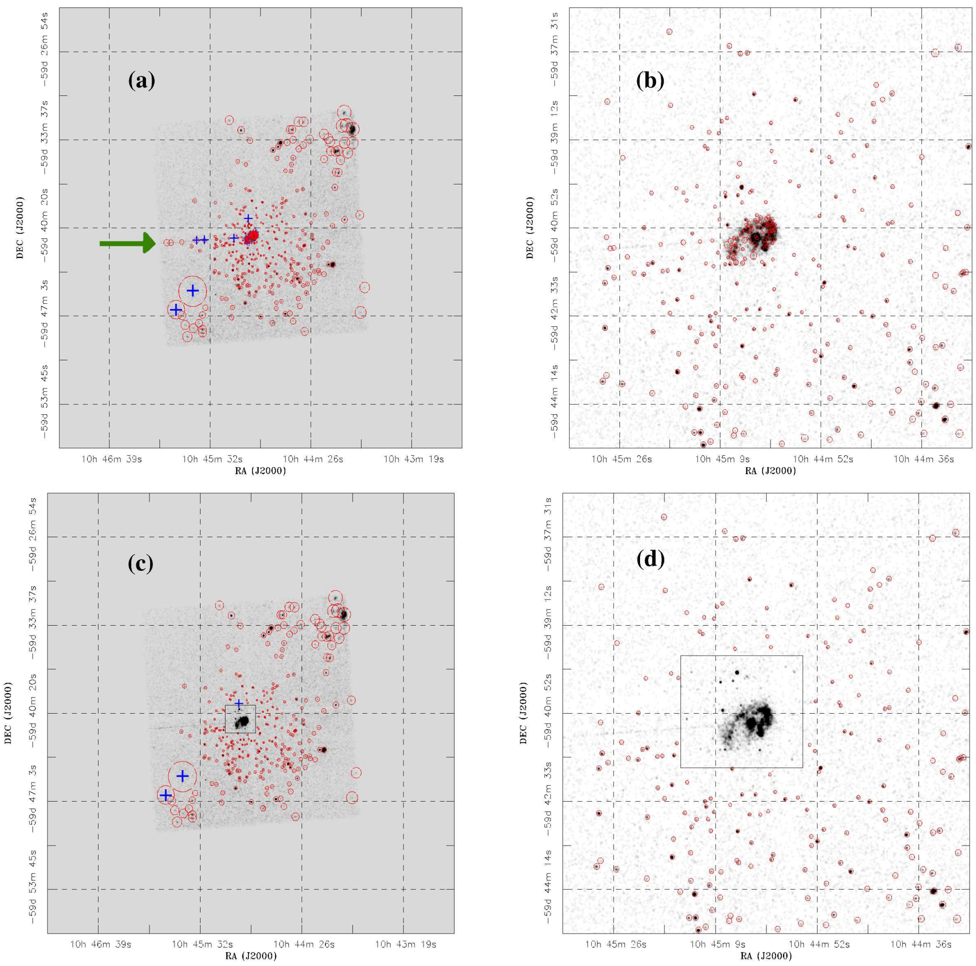

Fig. 1. Example of detection. **(a)** The η Carinae full field at half resolution. Note the complicated extended structure at the centre and the spurious detections along a readout streak (green arrow). Crosses mark sources that the detection algorithm classifies as extended (e.g. left-bottom corner and along readout streak). **(b)** Central portion of the field at full resolution. **(c)** Example of manual cleaning. The spurious sources along the readout streak were eliminated and **(d)** the sources in the central portion of the image (contained within the box and not shown) were flagged for later inspection.

bright and/or extended sources, including the pointed ones. It is particularly important for cosmological studies to have a sample which is not biased toward bright objects. To this end, we constructed the **BMW-*Chandra* Serendipitous Source Catalogue that contains 16758 sources not associated with pointed objects**, by excluding sources within a radius of 30″ from the target position. Their sky coverage is shown in Fig. 2.

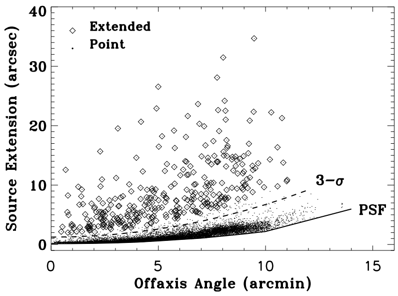

Fig. 3. Extension of the BMW-*Chandra* sources as a function of the off-axis angle. The dashed line is the 3-σ limit for point sources. Diamonds are the truly extended sources ($\sim 4.5\sigma$, 316 points).

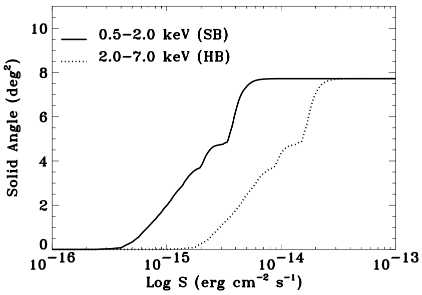

Fig. 2. Solid angle versus flux limit for S/N = 3 for the soft (solid line) and hard (dotted line) bands. This sky coverage was constructed using 94 independent fields (no fields covered the same sky area).

4. Catalogue Exploitation

Among the avenues of scientific exploitation are: 1) search for periodic and non-periodic variability using both light curves and spectra extracted for bright sources; 2) the optical/IR follow-up of a list of galaxy cluster candidates drawn from our sub-sample of ~ 300 extended sources [shown in Fig. 3 and obtained with the σ-clipping algorithm described in (Campana et al., 1999); 3) analysis of blank fields, i.e. X-ray detected sources without counterparts at other wavelengths; 4) optical/IR follow-up of peculiar sources, such as isolated neutron stars candidates (ultra-soft sources) and heavily absorbed sources (ultra-hard sources, not observed in the soft bands).

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