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The Chandra Source Catalog 2.0: Definitive Cross-matches

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Cross-matching the Chandra Source Catalog (CSC) with other catalogs presents considerable challenges, since the Point Spread Function (PSF) of the Chandra X-ray Observatory varies significantly over the field of view. For the second release of the CSC (CSC2) we have been developing a cross-match tool that is based on the Bayesian algorithms by Budavari, Heinis, and Szalay (ApJ 679, 301 and 705, 739), making use of the error ellipses for the derived positions of the sources.

However, calculating match probabilities only on the basis of error ellipses breaks down when the PSFs of the catalogs involved are significantly different. Not only can bonafide matches easily be missed, but the scene is also muddied by ambiguous multiple matches. These are issues that are not commonly addressed in cross-match tools. We have applied a satisfactory modification to the algorithm that, although not perfect, ameliorates the problems for the vast majority of such cases.

Here we present our definitive cross-matches of the CSC2 catalog with two obvious candidate catalogs: SDSS (DR15) and AllWISE.

Cross-matching CSC2: what is the problem?

. Cross-matching historically started out as a visual exercise
. Subsequently, cross-matching catalogs was based on a fixed radial proximity match (say, within 1")
. This becomes problematic, as it does not work well for catalogs that are:
  . taken from very different parts of the electromagnetic spectrum—
    detected sources may represent physically different objects which may or may not be visible at other frequencies/energies/wavelengths
  . derived from observations with significantly different PSFs—
    a source in a lower-resolution catalog may represent a blend of multiple sources from a higher-resolution one
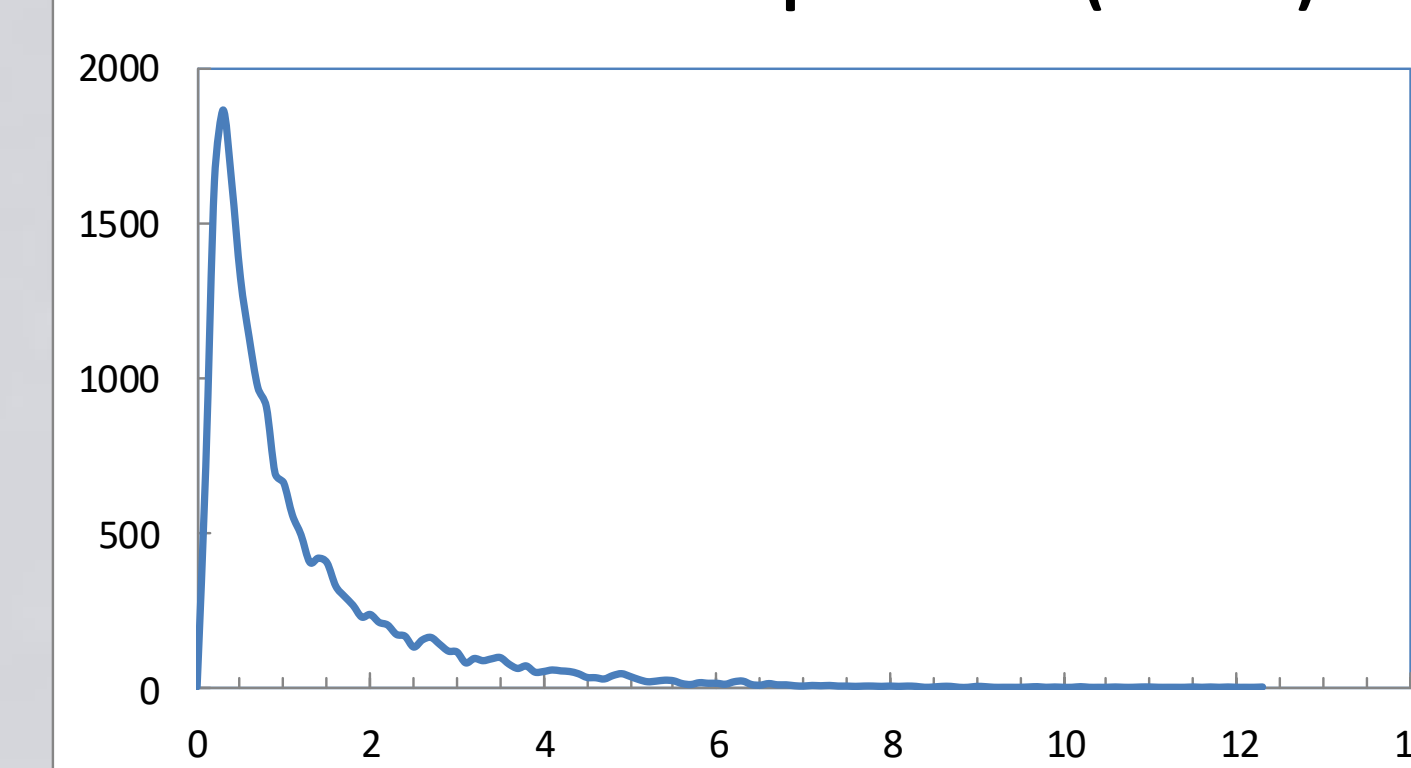
What is required to solve this?

. A rigorous calculation of match probabilities:
  . Based on detected positions and their error ellipses
  . A robust method to set the acceptance probability threshold
. Reliable PSF information and a way to apply it

How did we solve it?

. A rigorous calculation of match probabilities:
  . The Bayesian algorithms developed by Budavári & Szalay
  . A self-consistency argument sets the acceptance threshold based on the sum of probabilities
. PSF information is folded into the probability calculation
. Ambiguous matches are identified on the basis of the accepted matches
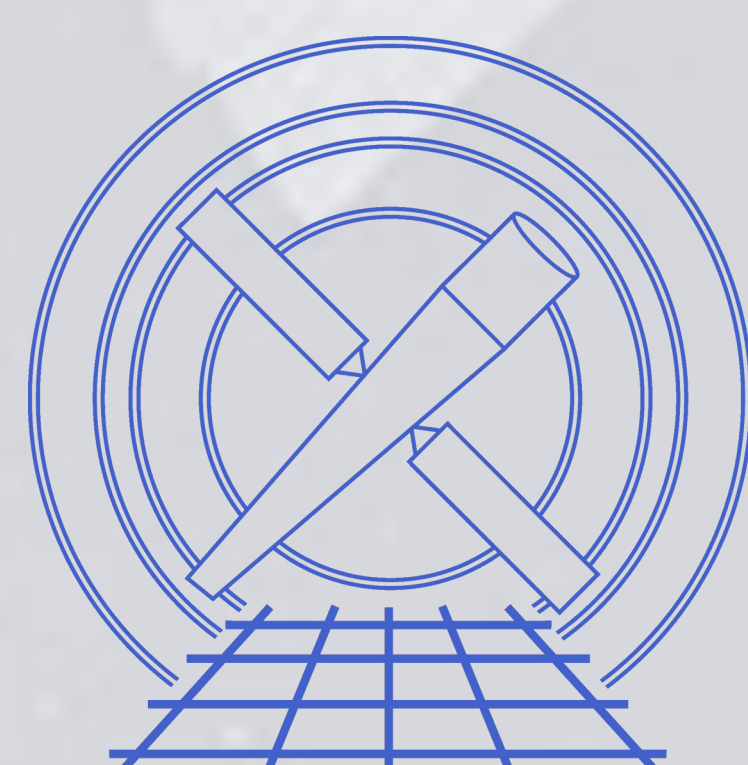
Ambiguous Matches

The problem of significantly different PSFs raises an important issue that has not been commonly recognized in cross-match operations: with widely varying PSF sizes from different catalogs, matches — even those with a high probability — are not necessarily 1-to-1 anymore; they may be one-to-one, one-to-many, or many-to-one.
. As long as a source has a match probability above the acceptance threshold with no more than one source per (other) catalog, and the reverse is true as well, it can be unambiguously identified as representing the same physical object
. As soon as there are matches with more than one source in a single catalog, the source becomes ambiguously identified
  . In such a case either a high resolution source may be matched with multiple low resolution sources, or a low resolution source may "cover" multiple high resolution sources
  . To disentangle this, we keep track of pairwise potentially ambiguous matches
  . Ambiguous matches are included in the crossmatch catalogs

CSC2 and SDSS DR15

This cross-match involved 1573 distinct contiguous areas covered by the CSC2, matching with all SDSS "good stars" within the bounding box of each CSC2 area

	CSC2	SDSS DR13
Sample coverage area (sq deg)	199	405
Total number of sources/stars	87,276	2,600,034
Unambiguous matches	18,209	18,209
Ambiguous matches	376	11

CSC-SDSS match separations (arcsec)

CSC2 and AllWISE

This cross-match involved 4380 distinct contiguous areas covered by the CSC2, matching with all sources from the AllWISE catalog that are within the bounding box of each CSC2 area

	CSC2	WISE
Sample coverage area (sq deg)	596	1204
Total number of sources/stars	321547	22,701,205
Unambiguous matches	152,615	152,615
Ambiguous matches	799	2,205

CHANDRA
SOURCE CATALOG