Visualizing and Using the Global *Chandra* Footprint

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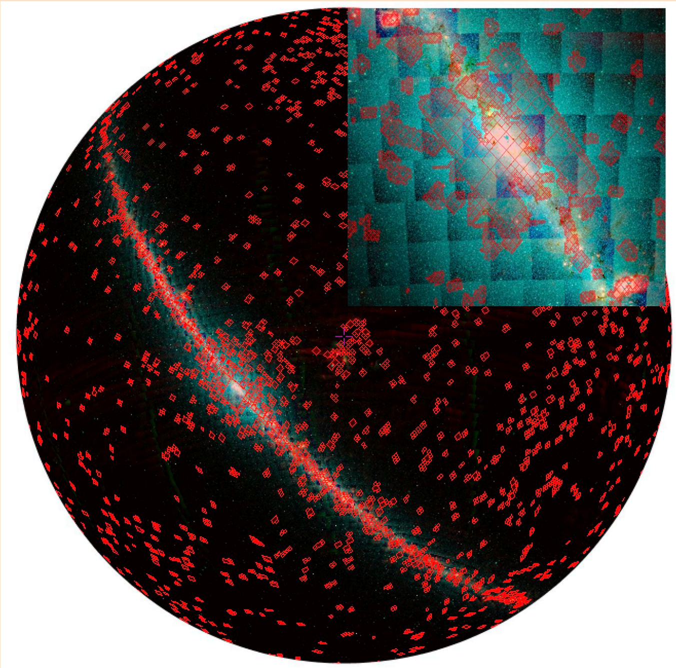

Figure 1: Visualization of the half-sky distribution of the footprints of all public *Chandra* observations (excluding gratings observations) with the CDA-generated MOC data product. The red tiles, which indicate the *Chandra* footprints, are overlaid on the HiPS color image of the WISE all sky survey. The inset in the upper right corner shows a magnified view of the center of the Milky Way.

With *Chandra* approaching its 20th year of operation, the total fraction of sky observed has reached the 1.9% mark. To the untrained eye, a map showing the footprints of all the public observations taken by *Chandra* would resemble a large and sparse collection of isolated rectangular shapes, a few islands of closely and orderly positioned tiles, and a patchwork of large, often connected regions, typically associated with structures in the sky, such as Sgr A* and the Andromeda galaxy.

A common question that astronomers ask is whether *Chandra* has observed a particular point in the sky. Based on the response, new projects involving observing proposals and/or the use of *Chandra* archival data, novel discoveries and innovative astrophysical insights may ensue. So, creating and distributing easy-to-use but powerful tools that answer this question is one of the key goals of the *Chandra* Data Archive (CDA).

Since November 2010, the CDA has offered access to the *Chandra* Footprint Service (FPS) (*http://cxc.harvard.edu/cda/footprint/*), which provides users with information about *Chandra* observations within a given radius of a position in the sky. The FPS provides visual access to chip geometry on the sky and tabulated instrumental and observational parameters of the available *Chandra* observations for the point in the sky. Nonetheless, the increasing interest in all sky population studies that require knowledge of whether very large number of sources are covered by *Chandra* observations, calls for new methods to visualize the *Chandra* footprint at a larger spatial scale and to quickly determine positions that are located within the footprint.

The need for this new visualization and analysis tool is being addressed by the CDA through the production of a new type of data product called Multi-Order Coverage maps (MOCs). MOCs combine the field-of-views of all public *Chandra* observations into a unique and conveniently compressed representation of the entire *Chandra* footprint. MOCs are optimized for interactive exploration at multiple levels of detail, i.e., spatial resolutions. The *Chandra* MOCs, in their FITS serialization, can also be used to filter a theoretically unlimited number of positions based on where they are located relative to the *Chandra* footprint. The MOC representation of astronomical footprints, which is recognized as a standard format by the International Virtual Observatory Alliance (IVOA), is based on the HEALPix tessellation and can encode arbitrarily complex geometrical shapes from the all sky level up to any desired spatial resolution based on the maximum value of the HEALPix level used to generate the MOC.

The MOCs of all *Chandra* observations that have become public by the end of 2017 are available from the CDA webpage (*http://cxc.harvard.edu/cda/cda_moc.html*). We also plan to start updating the *Chandra* MOCs on a weekly basis soon. The MOCs use HEALPix orders from 9 to 13, corresponding to average resolutions for the cells in the highest HEALPix level ranging from ~6.8′ to ~25.7″. The *Chandra* MOCs will also be discoverable across all VO-compatible data portals and interfaces. MOCs can be displayed in both local clients (Aladin; *http://aladin.u-strasbg.fr/*) and web-based applications, like ESAsky (*http://sky.esa.int/*). More importantly, *Chandra* MOCs can be used to select positions within the *Chandra* footprint, estimate global properties of the *Chandra* coverage (such as the total area covered), and compare the intersection of the *Chandra* footprint with footprints of other observations. These operations can be performed either via GUI tools such as TOPCAT and Aladin, or programmatically, using MOC-compatible libraries such as the Starlink Tables Infrastructure Library Tool Set (STILTS) or Python libraries MOCPy and PyMOC.

MOCs will complement the FPS by providing astronomers quick and comprehensive access to the geometric properties of *Chandra* observations, thus making the X-ray Universe seen by *Chandra* more easily discoverable and accessible. ■