# Chandra Source Catalog Review

Science Overview and Big Picture

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# Overview

- Introduction to the Chandra Source Catalog
- X-ray Source Populations
- Scope  of the catalog
- Use Cases

# Introduction to the Chandra Source Catalog

## Why a Catalog?

- Uniform reduction of archive (to extent possible)
- For science requiring analysis of many sources, remove need for users to do detailed reduction of each source.
- Useful for science project preparation: identification of samples
- A standard way to access data – SIMBAD, NED, SDSS
- Entering era of big sky surveys and VO; Critical for easy cross-match with other catalogs e.g. 2MASS, Sloan

# Past Catalogs

- Hipparcos, Ptolemy: visible star catalogs
- Messier, NGC, Abell, PG... and famously HD and SAO from here
- Catalogs a primary product for all-sky surveys
- Also productive for pointed missions
- X-ray tradition for pointed mission catalogs: Einstein (2E, Slew), Rosat (WGACAT, MPE) plus specialized-subset catalogs (Einstein galaxy catalog, Fabbiano et al)
- Contemporary X-ray catalogs: CHAMP, XMM
- XMM effort endorsed by its science reviewers

# A catalog for Chandra

- Chandra breaks the resolution barrier (cf. transition from 3C to VLA, IRAS to 2MASS/Spitzer)
- Many sources, low confusion, low background, good astrometry
- Field of view is decent (64 to 256 sq. arcmin)
  - 5-23 x HST ACS (11 sq arcmin)
- Background sources are interesting - mostly AGN, other exotic objects (contrast to optical, most background objects ordinary stars, or – for deepest exposures - galaxies)

## Enabling Chandra Science

- Intended for multiple science use cases
- A science facility
  - A virtual X-ray observatory for data mining
- A science enabler
  - Sample selection, science project feasibility studies, proposal preparation
- Not optimized as a single-science-project catalog
  - e.g. establish LF via complete sample; better done with deep surveys
  - not all-sky, not uniform depth; diverse source types

## Chandra Source Catalog: why now?

- In early years of mission, steadily improved "Level 1" and "Level 2" calibrated products (event lists)
- We ran detect and made source lists, but these products were provided as a guide only.
- Our understanding of the instruments is now at the point where automatic processing can go further along the analysis chain – this was always part of our plan.

# Catalog goals 1: source detection

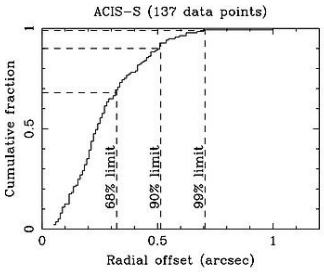
- Provide catalog of point and extended sources for all imaging fields in the Chandra archive
- Target is local threshold of 95% detection efficiency
  - Roughly, this includes all 30-count sources in the field and all 10-count sources within 2' of aimpoint using local background
  - Could go deeper with better model of background
- Target statistical false source rate of less than 2 %
- Distinguish pairs of point sources where flux ratio is less than 2 and separation is more than 0.5 times the PSF FWHM

# Catalog goals 2: source properties

- ENERGY: Measure X-ray colors and statistical uncertainties for all sources, Also fit power-law spectrum for approximate fluxes.
- IMAGING: Fit extent of source: sensitive to extent on 1” to 1' scales.
- TIME: Calculate the likelihood of source variability during the observation.
- AND... Provide sensitivity information to allow upper limit estimates at a given position where no sources are found.

# X-ray astrometry

- An X-ray astrometric catalog: <1" positions across whole sky (1XMM, around 2" with tail to 6", is the only other usable X-ray astrometric catalog)
- Frame error: 99% sources <0.8"




- Count error: significant for weak far-off-axis sources, needs eval.
- Total error: will be evaluated for each source
- Future missions will have inferior resolution - important resource to identify and improve pointing solutions, evaluate confusion
- The only X-ray data comparable with opt/radio/IR sky catalogs

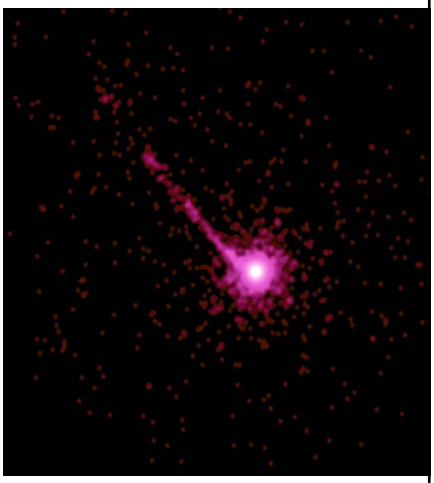
# Limitations and future goals

- Our plan (and direction from the users committee) is to release a basic version of the catalog as soon as possible and solve the hard problems later for subsequent releases
- The biggest limitation in the first release is for sources which are extended on scales beyond 1 arcminute
  - Need better local background model (in work)
  - For very large extent, need global background model (research project - current blank sky files of limited applicability in energy, |b|)
- We will also evaluate use of vtpdetect to identify extended sources; currently compute-limited, plus unclear how to characterize results as source properties
- We would like to go deeper - needs better background and qualifying detect algorithms on merged observations
- Want to run source detect on zero-order grating image
- Pileup flagging and (later) mitigation for bright sources

# X-ray Source Populations

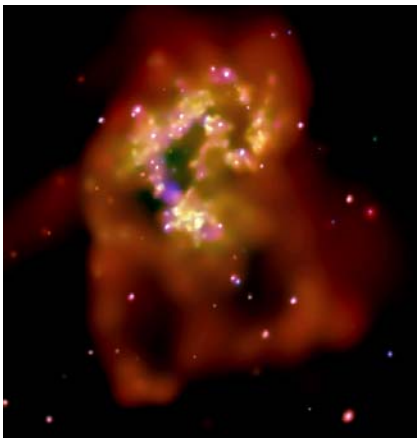
## Extragalactic X-ray Populations: AGN

- Active nuclei:
  - point sources (but may have jets, ionization cones)
  - hard spectrum
  - dominate in all long-exposure fields
  - Supermassive black hole accretion; relativistic lines, extreme physics; X-ray jets



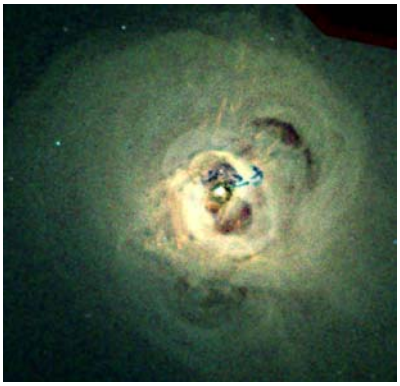
## Extragalactic X-ray Populations: Galaxies

- Galaxies:
  - Ellipticals, spirals, starbursts, mergers
  - Extended (at low z)
  - Mixture of soft diffuse emission (ISM) and hard point sources (binaries). LMXBs probe old population, HMXBs probe star formation
  - ULX sources
  - Role of hot ISM, galactic ecology, mergers and starbursts



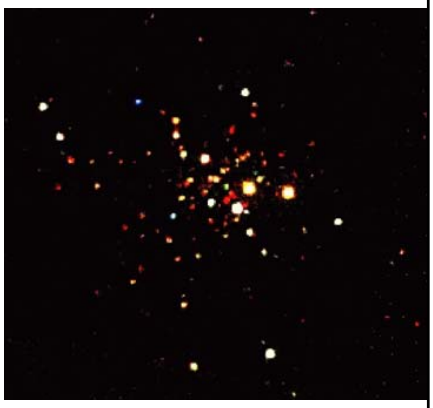
## Extragalactic X-ray Populations - Clusters

- Clusters and groups of Galaxies
  - Extended on > 100 kpc scales
  - Hard spectrum, kT=2-10 keV
  - X-ray selection (cluster gas only detected in X-ray)
  - Get masses, temperatures,
  - S-Z candidates



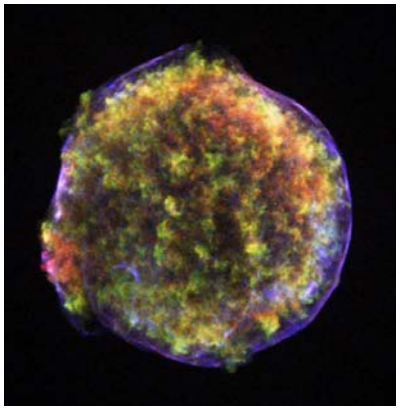
## Galactic X-ray Populations - XRBs

- X-ray Binaries
  - Point sources, highly variable
  - Mostly hard spectrum (changing spectral states)
  - BH and NS binaries: bright, variable; BH and Be binaries in quiescence
  - WD binaries (CVs, symbiotics): fainter, cooler
  - Exotics: microquasars, supersofts, magnetars



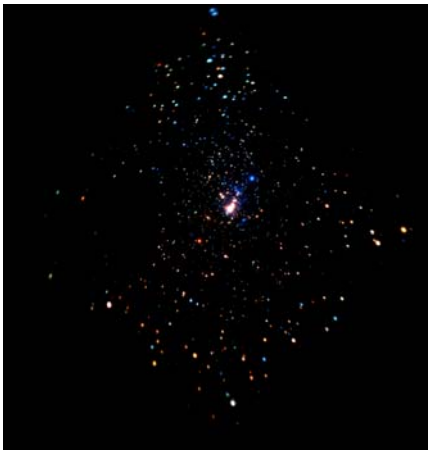
## Galactic X-ray Populations: SNR

- Supernova remnants; pulsar wind nebulae
  - Highly extended, may have (off-)central point source
  - Line dominated ejecta emission
  - Shocked ISM continuum
  - Direct probe of newly created elements, cosmic ray acceleration



## Galactic X-ray Populations: Stars

- Active coronae, flare and normal stars
  - O,B,F coronae; G,K,M flares
  - Soft, variable, several mechanisms
  - Map out coronal and magnetic activity in HR diagram



## Galactic X-ray Populations: other

- Other galactic sources:
  - Extragalactic contamination (AGN as ISM probe)
  - Diffuse hot ISM
  - Exotic sources: isolated neutron stars, galactic center features, surprises
  - Galactic center features

# Scope of the Catalog

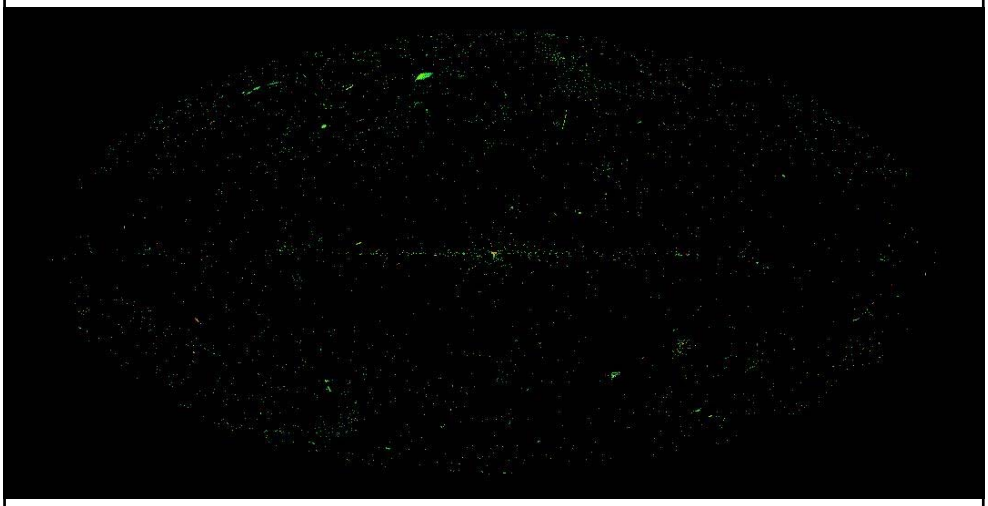
# Chandra Source Catalog

- All imaging data (ACIS, HRC)
- All modes except CC and gratings (maybe later)
- “Blind”, automatic processing: the Chandra Level 3 Pipeline. Handles different instrument configurations and different kinds of field (crowded, extended, etc.)
- Runs over full field (handle large off-axis PSFs)

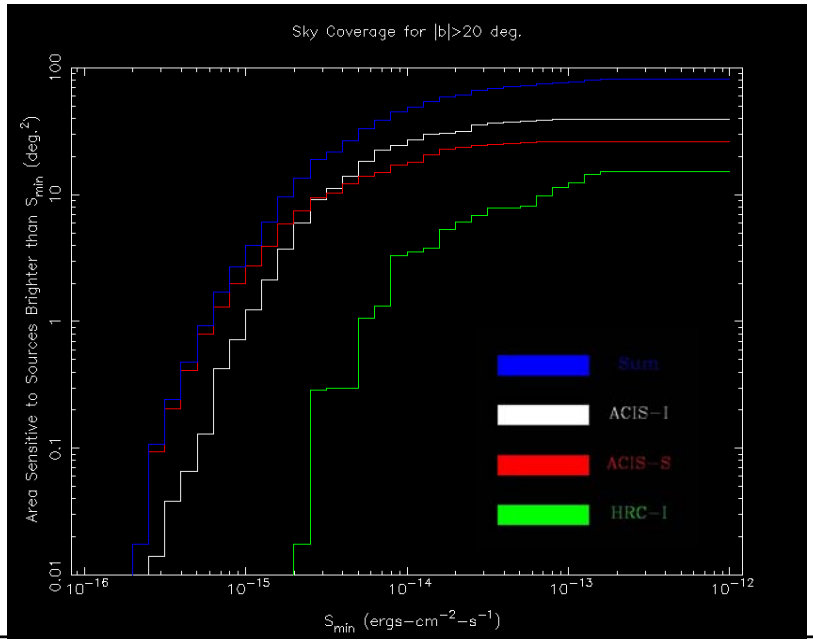
# Chandra Source Catalog: Scope

- No restriction on |b|
- No restriction on extended emission or special fields
- PI survey fields (e.g. galactic plane survey) included once public
- 3200 observations in AO1 to AO6
- Expect mission to last to 2015: about 10000 observations by end of mission

Chandra fields 1999-2005 (galactic coordinates)



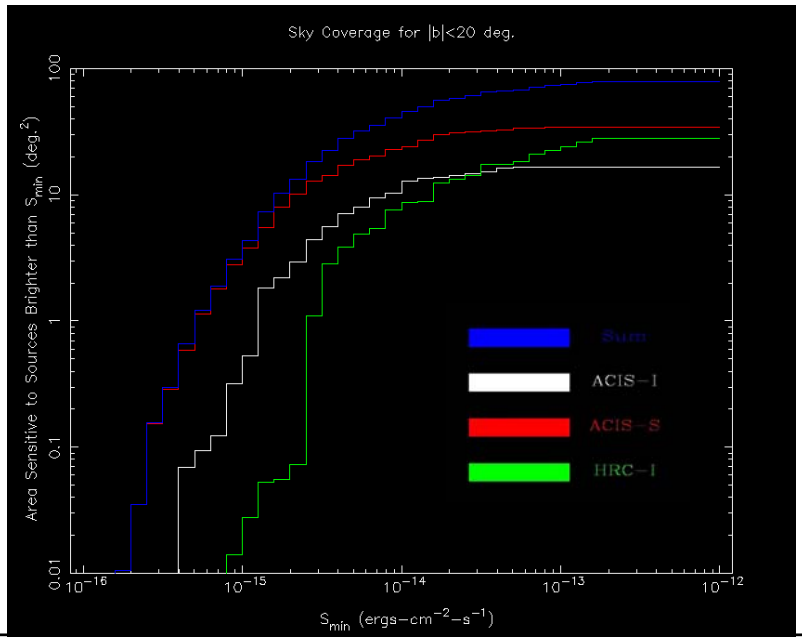
# Sky Coverage: |b| > 20




# Sky Coverage: |b| > 20

- ~80 square degrees in 2444 fields (290 sq deg by end of mission)
- 34 sq deg down to 1.E-14 erg cm-2 s-1
- 7 sq deg down to 2.E-15 erg cm-2 s-1,
- Predict 20000 background sources above 10 counts (30 counts outside 2') , assuming Giacconi et al (2001)
  - N > S = 370 ( S/2E-15)**(-0.85)
- We will go fainter when background characterized
- Hard to predict number of target-related sources
  - Celldetect in archive found 30000 believable sources in 662 ACIS-I fields (after omitting edge sources), cf ~15000 estimated in background.

# Sky coverage |b|<20




# Sky Coverage: |b| < 20

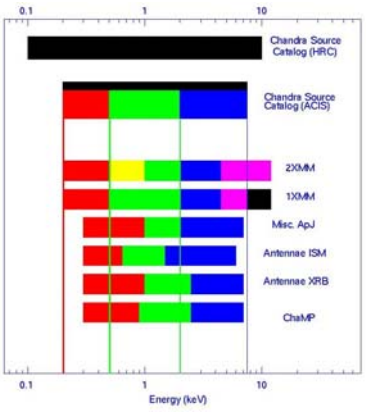
- 766 fields covering ~80 square deg
- 45 Msec exposure
- Galactic N(>S) not well characterized as function of (l,b,NH) below 1E35 erg/s
- Chandra samples galactic plane (slight bias due to targeted pointing); will provide new model baseline of galactic X-ray sky supplementing ChaMPlane with 10x more area.

# Sky Coverage: whole sky

- 3200 fields now in 160 sq deg
- Expect 10000 fields and 400-500 sq deg by 2015
- 75 Msec exposure now
- Scaling from cleaned celldetect results on ACIS-I we estimate 400000 sources by 2015
  - depends if TAC approves lots of revisits to old fields
- Coverage will be 1 percent of sky

# Energy bands

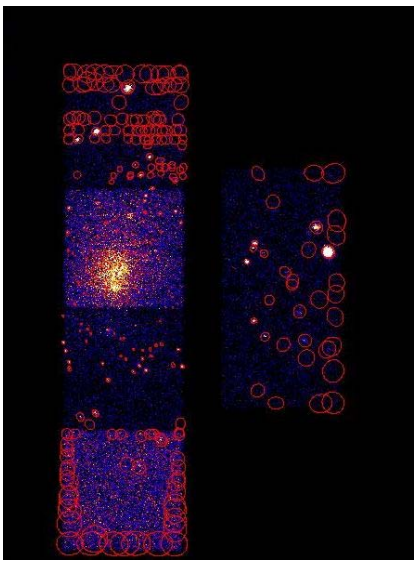
- Energy bands for ACIS: Soft, Medium, Hard, Broad
  - Soft lower bound:
    - 0.2 keV, CCD cutoff
  - Soft upper bound (= medium lower bound):
    - 0.5 keV, below oxygen K, match XMM
  - Hard lower bound (= medium upper bound):
    - 2.0 keV, match XMM
  - Hard upper bound:
    - 7.5 keV, match XMM, include Fe K, S/N cutoff
- Only one broad band for HRC 0.1 - 10 keV

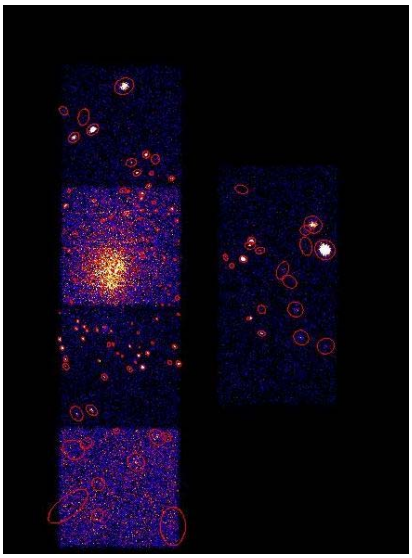


# Data processing pipeline

- CCD reduction (done in existing processing)
- Astrometry (done in existing processing)
- Recalibrate event lists with latest cal files, and perform high background (flare) cleaning
- Source detection (including extent fitting)
- Background estimation
- Absolute photometry by model fitting
- DETAILS IN LATER PRESENTATIONS

Detect comparison: L2 celldetect (left) and L3 wavdetect (right).





## New standard data products

- Extracted events, spectra, ARF, RMF plus cutout images and exposure maps for each source in each band.
- High quality per-observation source list
- Source properties table for each source, with accurate positions and fluxes from 2D fitting as well as colors, extent and variability information
  - 30 photons enough for a color
  - 100 photons enough for a simple spectral index fit
- Web access to data products for VO workflows

## Chandra Source Catalog: a dynamic resource

- Not just a static table:
- Continuous updating as mission continues and data becomes public via Level 3 pipeline
- Access to extracted data products for each source via the catalog and via VO access protocols
- Dynamic interaction to produce user-configured views with on-the-fly analysis workflows

# Use Cases

- Each of the use cases highlighted here is a starting point for multiple science papers
- Three main classes of use case:
  - X-ray classification
  - Crossmatch
  - Detailed sample studies

# Use Cases - X-ray Classification

- Search for outliers
  - Sources with hardness ratio changing from hard-low to soft-high state (X-ray binaries)
  - Asymmetric sources: select sources with off-axis angle less than 5 arcmin and extent flag set; calculate skew on image cutouts
  - Extended sources with companions
  - Supersoft sources (colors)
  - Flaring sources (light curve)

## Use Cases - Crossmatch

- Crossmatch and return fluxes/limits or spectral fits
  - Catalog covers 1/2% of sky fairly evenly distributed ( more than 1% by end of mission)- significant overlap with large catalogs like Sloan; also get upper limits
  - Not so useful for crossmatch with small (1000 source or less) object catalogs, unless targeted - but we cover many interesting targets

## Use Cases - Crossmatch

- crossmatch with recent supernovae
- crossmatch with Simbad AGN with $z > 2$, select X-ray absorbed sources and do spectral fits
- crossmatch and find multiple sources at position, e.g.
  - sources near galaxies with $d < 10$ Mpc
  - radial distribution of soft sources around centers of galaxies

## Use Cases - Detailed studies

- Take advantage of L3 data reduction
- Spectral analysis of user sample
  - trends with redshift
  - look for spectral outliers
  - generate stacked spectrum for object class
  - e.g. fit Fe-K and reflection model for AGN, test for correlation between parameters
  - select sample using results of workflow

## Use Cases - Detailed studies

- Extended sources (on less than 1' scale for first release)
  - Workflow for user sample
  - Radial profile, ellipticity, subtract point sources.
  - Correlate half-light radius with Lx in E's

## Use Case – SED Crossmatch

- Example: combine HST, Spitzer and CXO data on starbursts to get SEDs of star formation knots
- Need to locate catalog data
- Need to locate image data, extract fluxes of knots
- Identify sample using XR/UV ratio
- Need to combine in SED, fit models, etc.

## Use Case - ULX catalog

- Swartz et al 2004 ApJS 154, 519: luminous sources in galaxies
  - Data transfer volume was challenging
  - Making source response files slow
  - Source list from user detect contaminated by streak, edge effects – required extensive manual editing
  - 1.5 years of analysis

# Use Case – X-ray jets

- Dan Schwartz (2002, ApJL569,23) results on brightness of jets vs z
- Theory: IC of jet electrons on CMB makes X-rays
- CMB energy density increase compensates distance, surface brightness constant with z
- 2000 AGN per square deg above 1E-15 erg/cm2/s
- Dan estimates 0.2-20 X-ray jets per square deg.