Chandra, Meet Sloan: SDSS Spectroscopy of *Chandra* Source Catalog Counterparts

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Abstract The Chandra Source Catalog version 2.1 (CSC2.1) will be released in mid-2023, and will encompass close to four hundred thousand well-characterized X-ray sources observed by Chandra from launch (1999) through 2021, covering about 800 square degrees. The Sloan Digital Sky Survey V (SDSS-V) will be obtaining new optical and infrared spectroscopy of Chandra source counterparts across the entire sky. SDSS-V is expected to provide new spectra, pipeline classifications and velocities for tens of thousands of CSC source counterparts. These will add to the seventeen thousand such counterparts that have spectra already in the SDSS archive. SDSS-V will newly provide infrared spectra for a fraction of CSC2.1 sources, mostly in the Galactic plane, that have bright infrared but no optical counterparts.

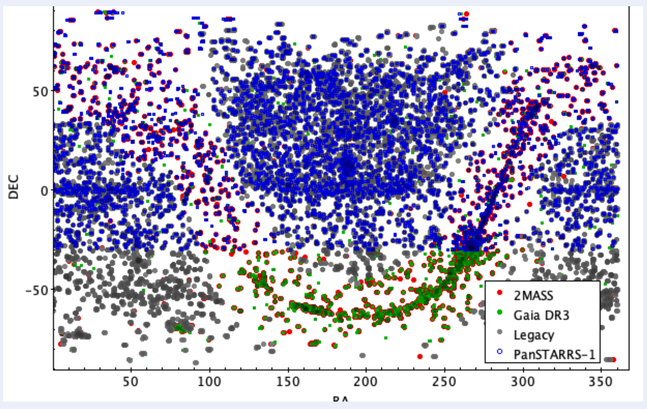
1. The Chandra Source Catalog & Optical/IR Matching

- The ***Chandra* Source Catalog** version 2.1 (CSC 2.1) (Evans et al. 2010, Evans 2020), which covers 800 square degrees of sky and will include about 414,000 individual X-ray sources. detected by Chandra through December 31, 2021.
- Note: *Special Sessions at this HEAD AAS meeting, Thu March 30, 1230PM CSC2.1 hands-on tutorial, 2PM CSC2.1 Science*
- We match 387,442 X-ray sources (available as of this writing) to optical and infrared catalogs, using the programs NWAY (Johannes Buchner; see Salvato et al. 2018) and Xmatch (Arnold Rots 2021). Both are based on the Bayesian spatial cross-matching algorithm developed by Budavari & Szalay 2008), but Xmatch has the added capability of taking X-ray source extent and/or PSF into account.
- For spectroscopic targeting in SDSS-V, we match Chandra X-ray sources to only one optical/IR counterpart, using in priority order Gaia DR3, then Legacy Survey DR10, then PanSTARRS-1, then 2MASS. The percentage of the total 188,647 matched counterparts from each is shown in the table below.

Optical/IR Catalog	Magnitude Range	% Matches
Gaia DR3	$14 < G < 20$	37
Legacy	$14 < (g\|r\|z) < 21.5$	38
PS1	$14 < (g\|r\|i\|z) < 21.5$	16
2MASS	$H <= 14$	8

Optical/IR catalogs, in priority order, used for matching to CSC2.1 X-ray sources. Magnitude rates are selected to match SDSS-V spectroscopy.

2.



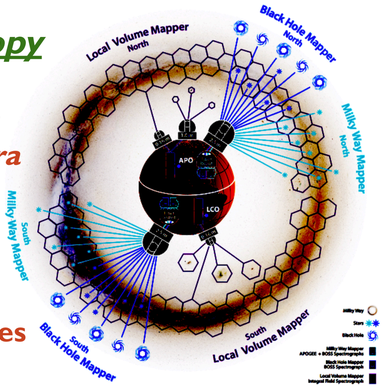
RA, Dec distribution of 188,647 CSC2.1 sources matched to optical/IR catalogs. About 13k already have SDSS spectra, with perhaps another 40k expected by the end of SDSS-V

3. SDSS Spectroscopy

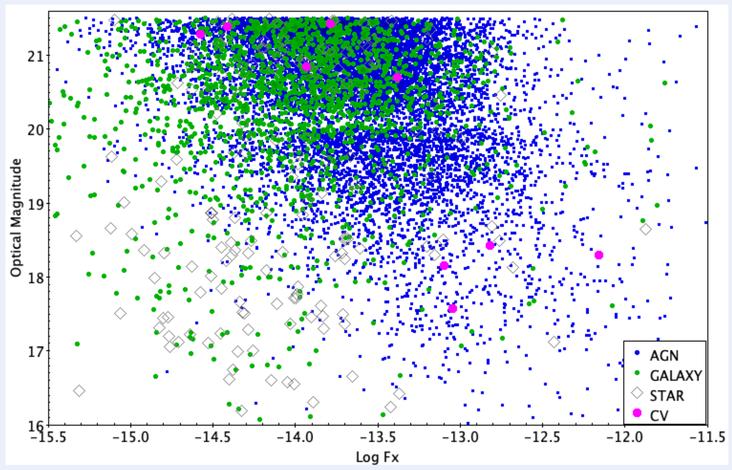
SDSS-V 2020 - 2027 http://www.sdss.org/future

All-Sky Spectroscopy

- ❑ **Black Hole Mapper**
  - *Repeat QSO spectra*
  - *eROSITA followup*
  - *r < 21.5 mag*
- ❑ **Milky Way Mapper**
  - stars in IR at high-res
  - *H* <14 mag

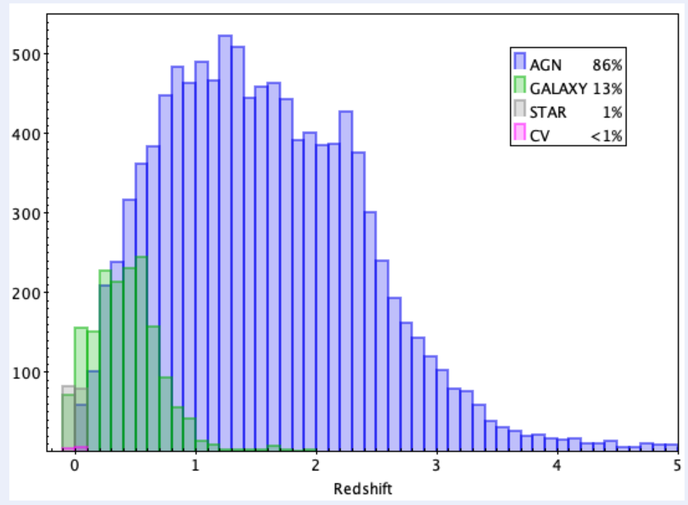


SDSS-V Mapper programs obtain multi-fiber, multi-epoch spectroscopy across the entire sky for selected science programs, including followup fo CSC2.1 sources. Up to 50% of provided targets may be observed during SDSS-V, adding to the 13k CSC2.1 sources that already have SDSS Legacy spectra.



- Best magnitude versus log X-ray flux (0.5-7ke) for 12,862 CSC2.1 X-ray source counterparts with spectra from SDSS I - IV already characterized and published in SDSS Data Release 16 (Ahumada et al. 2020).
- AGN are shown as blue dots, Galaxies as green dots, Stars as open diamonds and 78 CVs as large magenta dots. A huge range of X-ray to optical flux ratio is in evidence for all source types. The "best" magnitude is represented, which may be G, g, r, i, z or H, depending on the catalog chosen according to our prioritized selection. The sparse region near mag 20 is an artifact of prioritizing Legacy Survey DR10 and PanSTARRS-1 catalogs if no Gaia G<20 counterpart is found.

4. Source Populations



Redshift histogram for 12,862 CSC2.1 X-ray source counterparts with spectra already observed, characterized and published in SDSS Data Release 16 (Ahumada et al. 2020). The SDSS pipeline classifies objects and provides radial velocities. The vast majority of matches are classified as quasars, active galactic nuclei, or galaxies with broad emission lines, which are all represented here as "AGN". Note that luminous AGN are detected out to high redshifts, only about a Gyr after the Big Bang.

5. The Promise of CSC+SDSS-V

- SDSS-V is now accruing thousands of optical and IR spectra each night in the North at Apache Point, NM, and is coming online soon in the South at Las Campanas, Chile. About 7k new SDSS-V spectra of CSC2.1 X-ray source counterparts have already been obtained.
- We may expect up to about 40k new spectra of CSC2.1 X-ray source counterparts over the duration of SDSS-V
- Most of the X-ray sources matched only to H<14 2MASS counterparts will be young stellar objects or X-ray binaries buried by dust in the Galactic plane.
- The Chandra X-ray Center will be releasing to the public catalogs of these matches with basic source properties at https://cxc.cfa.harvard.edu/csc/csc_crossmatches.html or pages linked thereto

References

Ahumada, R. et al. 2020, ApJS, 249, 3. **Budavari** 2008, ApJ, 679, 301 **Evans**, I. et al. 2010, ApJS, 189, 37 **Rots**, A. 2021, https://cxc.cfa.harvard.edu/csc/csc_crossmatches.html **Salvato**, M. et al. 2018, MNRAS 473, 4937