Chandra Source Catalog CSC2.1 Optical/IR Counterparts Catalog Matched to SDSS DR17 Public Spectra
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We describe below a catalog based on a preliminary version of the Chandra Source Catalog, matched to three optical photometric catalogs and one infrared catalog, and then also to SDSS spectroscopy. This is intended to provide a useful starting point for some scientific projects within the astronomical community, but comes with a number of caveats described in the last section.

1. CSC2.1p

A preliminary version of the Chandra Source Catalog v2.1 as of 2022 Nov contained 387441 unique Chandra X-ray sources. The majority of these sources (~317k or 82%) have completed processing in CSC 2.1. For those that haven't, we provide the CSC 2.0 positions and fluxes, which may change somewhat in a future release after 2.1 processing is complete. The last column ('csc2.1_flag') is set to TRUE if the source had completed CSC 2.1 processing. We include both true and marginal sources. (Candidate detections included in the CSC are classified as either TRUE or MARGINAL in the catalog, by comparing their likelihood estimates with a pair of thresholds that calibrate the permissible false detection rates.) Source extent is detected for 22371 sources.

2. OPTICAL MATCHING

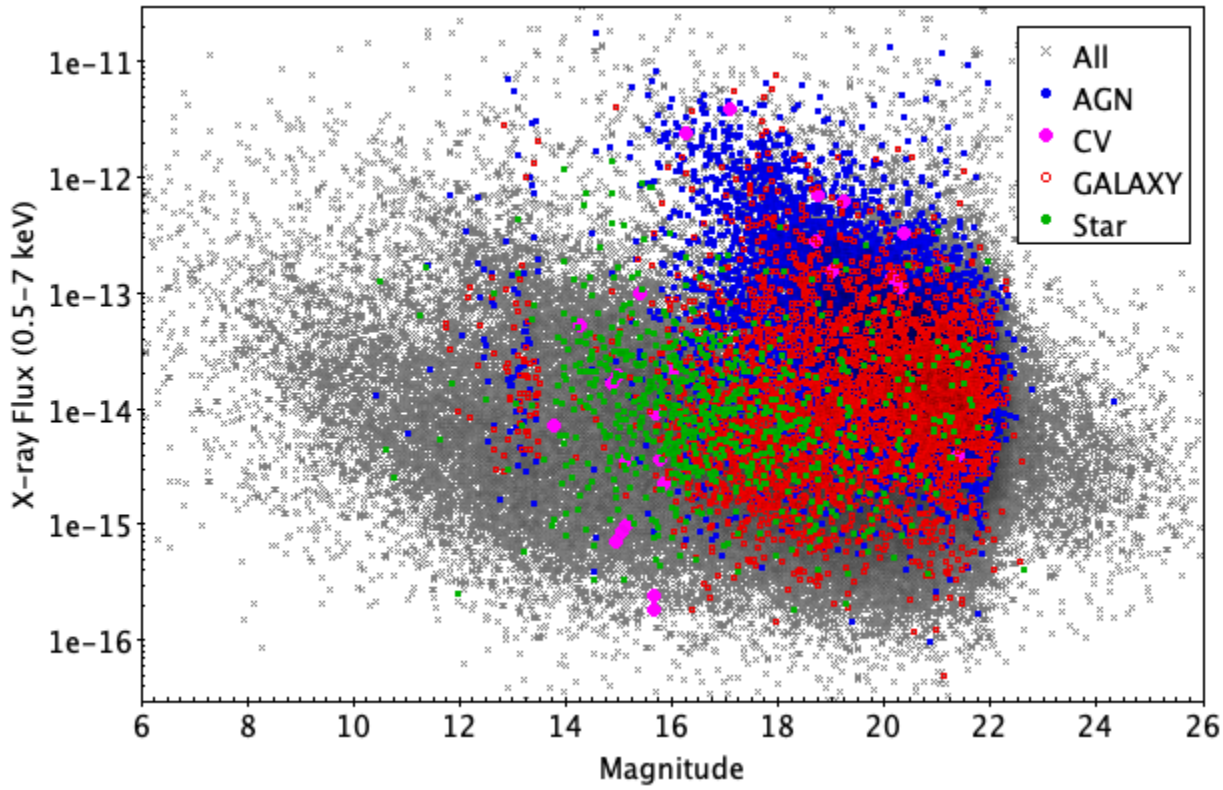
We performed a separate positional match to each of four optical/infrared catalogs - Gaia DR3, PanSTARRS-1 DR2, Legacy DR10, and 2MASS using NWAY (Salvato, M. et al. 2018, MNRAS, 473, 4937). In some cases, NWAY will identify multiple potential matches. For the current catalog, we retain only the best match, and only if the separation is less than 3arcsec, and the probability of a correct association is at least 0.5. Of the 387,441 CSC2.1 X-ray sources, 229,045 thus have an optical or infrared counterpart. Of those, 215,936 also have a non-zero X-ray flux listed.

3. MATCHING to PUBLIC SDSS SPECTRA

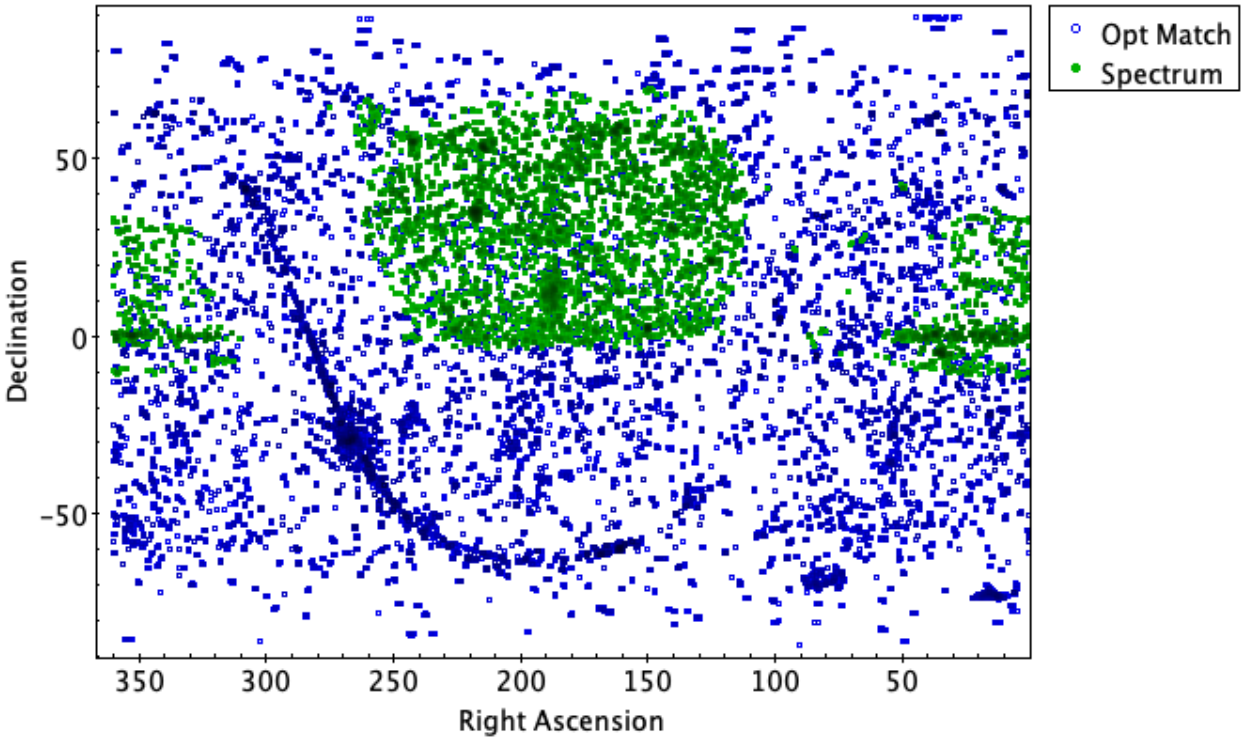
In the SDSS DR17 release, the table specObj-dr17.fits contains redshifts and classifications for 5.8 million optical spectra taken through SDSS-IV. We performed a direct match to all CSC2.1 X-ray source positions, using a 3arcsec radius from SDSS PLUG_RA, PLUG_DEC, including only the best (nearest) spectrum matched. We include only SDSS spectra with pipeline ZWARNING=0, which indicates that the spectrum was of adequate quality for a reliable redshift. 17,666 X-ray sources are thus associated with an SDSS DR17 optical spectrum. Of those, 3,207 have NSPECOBS>1, indicating that multiple spectra for the object are available from SDSS. There are also 132 cases where a spectrum is matched to more than one X-ray source. In some cases, a spectrum is matched to as many as 4 CSC sources. Columns are described below.

CSC2.1p_OIR_SDSSspecmatch.fits (216Mb)
CSC2.1p_OIR_SDSSspecmatch.csv (196Mb)

After a couple of summary plots, catalog columns are described below.



CSC2.1p broadband (0.5 - 7 keV) X-ray flux vs. optical magnitude. The magnitude shown is the closest magnitude available in the r band, which for Gaia we take as the G mag. The SDSS DR17 spectral pipeline object type is shown, where for AGN we also include any CLASS=GALAXY if it has BROADLINE or AGN as SUBCLASS. AGN are shown as blue dots, Galaxies with red dots, Stars with green dots, and CVs with large cyan dots. CSC2.1p sources with any optical match but no SDSS DR17 spectrum are shown in grey. AGN outnumber Galaxies about four to one. The vast majority brighter than 15th magnitude are likely stars, from which reliable classifications can probably be found in Gaia.



Sky distribution of CSC2.1p sources matched to optical catalogs (blue) and also with SDSS DR17 optical spectra (green). The density of spectra near Dec = 0 is largely due to spectroscopy focusing on SDSS Stripe 82. The dense region near RA=180, Dec=13 is near the Virgo Cluster. The Galactic plane and Galactic center are clearly visible, but have virtually no spectral coverage as SDSS I-IV spectra were all obtained in the Northern hemisphere at Apache Point Observatory, NM.

4. CATALOG COLUMNS:

CSC21pFull_PS_GAIA_LEG_2MASS_SDSSdr17CleanSpec.fits

For full definition of columns, see details at the website relevant to each constituent catalog.

NAME	FORMAT	USAGE
CSC21P_name	22A	Chandra Source Catalog source name
ra	D	source position, ICRS right ascension
dec	D	source position, ICRS declination
likelihood_class	8A	highest detection likelihood across all ensembles
extent_flag	L	source is extended in any band
err_ellipse_r0	D	major axis 95% confidence radius
err_ellipse_r1	D	minor axis 95% confidence radius
err_ellipse_ang	D	position angle of ellipse
significance	D	highest flux significance in any band
flux_aper_b	D	0.5-7keV ACIS flux, bkg-subtracted, aperture-corrected
flux_aper_lolim_b	D	68% lower confidence limit on this flux
flux_aper_hilim_b	D	68% upper confidence limit on this flux

flux_aper_h	D	2-7 keV ACIS flux, bkg-subtracted, aperture-corrected
flux_aper_lolim_h	D	68% lower confidence limit on this flux
flux_aper_hilim_h	D	68% upper confidence limit on this flux
flux_aper_m	D	1.2-2 keV ACIS flux, bkg-subtracted, aperture-corrected
flux_aper_lolim_m	D	68% lower confidence limit on this flux
flux_aper_hilim_m	D	68% upper confidence limit on this flux
flux_aper_s	D	0.5-1.2 keV ACIS flux, bkg-subtracted, aperture-corrected
flux_aper_lolim_s	D	68% lower confidence limit on this flux
flux_aper_hilim_s	D	68% upper confidence limit on this flux
flux_aper_w	D	0.1-10 keV HRC flux, bkg-subtracted, aperture-corrected
flux_aper_lolim_w	D	68% lower confidence limit on this flux
flux_aper_hilim_w	D	68% upper confidence limit on this flux
csc2.1_flag	L	flags complete CSC 2.1 processing (otherwise 2.0)
PS21P_objID	18A	PanSTARRS-1 DR2 unique object identifier
PS21P_ippObjID	15A	IPP internal object identifier.
PS21P_ra	D	PanSTARRS-1 Right Ascension
PS21P_dec	D	PanSTARRS-1 Declination
Sep_PS21P_CSC21P	E	arcsec between PanSTARRS-1 DR2 and CSC2.1 position
PS21P_g	D	PS1 g mag
PS21P_r	D	PS1 r mag
PS21P_i	D	PS1 i mag
PS21P_z	D	PS1 z mag
GAIA21P_source_id	20A	Gaia unique object identifier
GAIA21P_ra	D	Gaia Right Ascension
GAIA21P_dec	D	Gaia Declination
Sep_GAIA21P_CSC21P	E	arcsec between Gaia DR3 and CSC2.1 position
GAIA21P_g	D	Gaia G mag
LEG21P_LS_ID	17A	Legacy Survey DR10 ID
LEG21P_OBJID	J	Legacy Survey DR10 ID
LEG21P_RA	D	Legacy Survey Right Ascension
LEG21P_DEC	D	Legacy Survey Declination
Sep_LEG21P_CSC21P	E	arcsec between Legacy DR10 and CSC2.1 position
LEG21P_G	E	Legacy g mag
LEG21P_R	E	Legacy r mag
LEG21P_Z	E	Legacy z mag
2MASS21P_designation	24A	2MASS Name
2MASS21P_ra	D	2MASS Right Ascension
2MASS21P_dec	D	2MASS Declination
Sep_2MASS21P_CSC21P	E	arcsec between 2MASS and CSC2.1 position
2MASS21P_j_m	D	2MASS J mag
2MASS21P_h_m	D	2MASS H mag
2MASS21P_k_m	D	2MASS K mag
PLUG_RA	D	SDSS spectroscopic fiber plug Right Ascension
PLUG_DEC	D	SDSS spectroscopic fiber plug Declination

NSPECOBS	I	Number of spectral observations
SOURCETYPE	25A	Science target selection
PLATE	J	Plate number
MJD	J	MJD of observation
FIBERID	J	Fiber ID
CLASS	6A	Spectroscopic class (GALAXY, QSO, or STAR)
SUBCLASS	21A	Spectroscopic subclass
Z	E	Redshift
Z_ERR	E	Redshift error
RCHI2	E	Reduced Chi squared of best fit
DOF	J	Degrees of Freedom in best fit
WAVEMIN	E	Minimum observed (vacuum) wavelength
WAVEMAX	E	Maximum observed (vacuum) wavelength
ZWARNING	J	Bitmask of redshift warning values; 0 means all is well
SN_MEDIAN_ALL	E	Median signal-to-noise over all good pixels
GroupID	J	Group ID for SDSS spectra with multiple CSC2.1 matches
GroupSize	J	Number spectra matched to CSC2.1 source in this Group
Sep_SPEC_CSC21P	D	arcsec between SDSS spectral and CSC2.1 position

5. Known Caveats

The base catalog, CSC2.1p from Nov 2022, has a number of deficits relative to the anticipated official release of CSC2.1. Not all sources have their fluxes computed using the latest methods and data, but instead list fluxes from CSC2.0. These will be listed with csc2.1_flag=0. These tend to cluster around the deepest fields, where many overlapping observations contribute to the ensemble from which final CSC2.1 fluxes were the last to be calculated e.g., near Sgr A*. Furthermore, while the final X-ray positions and their error ellipses will be determined in one of the final steps of processing CSC2.1, using an all-sky cross-match to Gaia DR3, those corrections are not included here.

Of all X-ray sources, 25131 (6%) are significant in some band/aperture and have non-zero flux_aper_avg but nevertheless have tabulated flux_aper fluxes (in Chandra b, h, m, s, w bands) that are all zero in this subcatalog.

The crossmatching to photometric catalogs was done with NWAY (Salvato, et al. 2018, MNRAS, 473, 4937) for each ensemble. The false match rate is <5% in most cases, where the optical/IR source density is less than 10 per square arcmin. However, it can be higher in crowded fields, like the Galactic Center. For more details, we refer to Kim, D.-W. et al. (2023, ApJS, 268, 17).

We ran NWAY for each optical/IR catalog independently and did not perform simultaneous multi-catalog matches. Reasonably assuming that nearby optical/IR cataloged objects represent the same celestial objects, the separation between counterparts from different optical/IR catalogs should generally be very small, since their positional errors are typically no more than a

few tenths of an arcsecond. However, for a few percent of CSC2.1 counterparts, SDSS-spec and PanSTARRS/Legacy/Gaia positions may differ by 2arcsec or more. The effect appears to be smallest for SDSS-spec, larger for 2M vs. other opt/IR catalogs (likely due to epoch differences), and largest for Legacy/Gaia (likely due to actual object mismatches, given their substantially different magnitude limits).

We did not correct for the proper motion, which is only available in Gaia. Some high PM nearby stars may thus be incorrectly matched.

The matching to the SDSS DR17 spectral pipeline output was performed simply by using the closest match within 3arcsec between the X-ray source position and the optical spectroscopic fiber plug position. The reliability of that method has not been determined. Given that both X-ray sources and SDSS spectroscopic targets are relatively sparse on the sky, and that most of the spectra reveal AGN - known X-ray emitters, we can broadly speculate that this method is reasonable. A more reliable method would be, as for the other imaging catalogs, to match to the SDSS imaging catalog first using NWAY, and then determine directly which SDSS photometric object was targeted spectroscopically.

We urge extreme caution for the 1452 X-ray sources with names ending in “X”, which denote large, extended sources (often more than 60 arcsec in extent). Of these, 800 are matched to an optical/IR source and/or SDSS spectrum. The single optical/IR source matched to the X-ray centroid of these extended sources may be quite misleading. In some cases, it may be e.g., one optical galaxy in a cluster of galaxies, the nucleus or perhaps a star-forming region of a nearby galaxy, or a foreground star along the line of sight to supernova remnant. Such matches should be examined and interpreted carefully.

Note that since we have limited the matching to SDSS spectra with reliable redshifts (requiring ZWARNING=0), this may exclude some interesting counterparts, most notably many BL Lacs, which may not have sufficient spectral signatures for a redshift determination, even at reasonable S/N.