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Dataset of Classified CXO Sources in Globular Clusters

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1. DETAILED NOTES ON PUBLICATIONS USED

This document contains notes on the processing of sources in certain clusters, including details on astrometric correction of CXO or HST coordinates. Some sources resolved in publications are not resolved in CSC2.1: in these cases, only one published source is kept, and are flagged in the "Unresolved" column in the full dataset. Additionally, we provide notes on cross-referencing MSPs to the ATNF pulsar catalog (Manchester et al. 2005).

1.1. *47 Tuc*

As mentioned in the research note, for 47 Tuc we applied our own astrometric corrections for HST counterparts taken from Edmonds et al. (2003); Albrow et al. (2001). As these works and HUGS both include F336W and F814W magnitudes, we searched within 1.5″of the published HST positions for the HUGS source with the smallest magnitude difference from published values from Albrow et al. (2001). The offsets between these matches clearly show the systematic offset mentioned in the online Catalogue of Variable Stars in Galactic Globular Clusters (Clement et al. 2001), with the median separation being 1.36″. We then corrected the published coordinates by this value, with the residual separation being $\sim 0.1''$. We also compared the nearest HUGS counterpart using separation and magnitude information to verify that it is the same source. After this procedure, 43 high-confidence (with small separations and magnitude differences) HUGS matches to 60 published HST counterparts of X-ray sources were identified. The systematic offset between coordinates in Albrow et al. (2001) and HUGS is shown in Figure 1.

A similar procedure was performed for 43 counterparts taken from the more recent Rivera Sandoval et al. (2018), which corrects the astrometry by aligning the HST source coordinates to their counterparts in UCAC2, which is itself aligned to ground-based images. The systematic offset between these sources and HUGS is much smaller than in previous works, at 0.1″. Correcting for this offset gives 30 confident, very close ($\sim 0.01''$) HUGS counterparts to the 43 literature.

Bhattacharya et al. (2017) added many new CXO sources using the same W-numbering scheme as in previous publications, and also resolved some previous sources into multiple sources. However, some of these sources were not

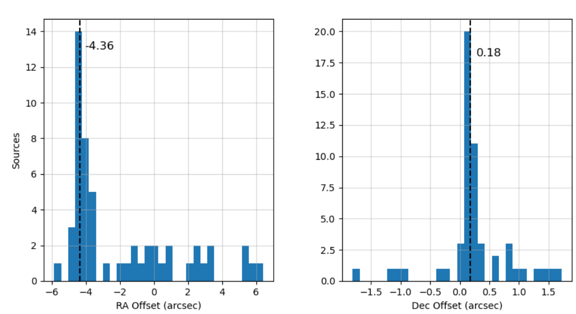

Figure 1. Histogram of offsets in RA and DEC between HST coordinates in Albrow et al. (2001) and HUGS for 47 Tuc. The median offsets used as the astrometric correction are labeled.

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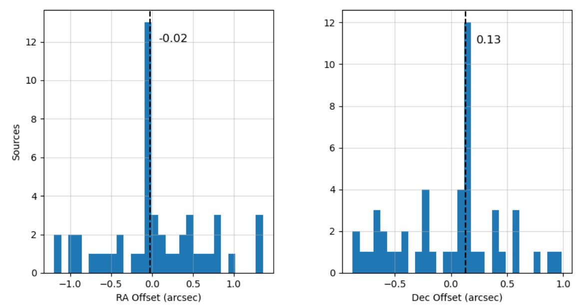

Figure 2. Same as Figure 1, but for Omega Centauri between Cool et al. (2013) and HSC.

resolved in CSC 2.1, and were not added to the final dataset. Additionally, many of these sources were not classified in any works. We provide notes on the crossmatching results of these individual sources:

- W29 = MSP W matching to 1 point and 1 extended CSC source, we took the point source as the counterpart.
- W71 resolved into W360 and W378, but not resolved in CSC. W71 was a candidate CV, but the resolved sources were unclassified.
- W77 = MSP S + MSP F resolved into W352 and W353, but not resolved in CSC.
- W83 not listed in Bhattacharya et al. (2017), but nearby new source W354 added, unclassified.
- W199 not listed in Bhattacharya et al. (2017), but nearby new source W359 added, unclassified.
- W279 not listed in Bhattacharya et al. (2017), but nearby new source W377 added, unclassified.
- W263 resolved into W364 and W374, but not resolved in CSC, unclassified.
- W348 and W384 resolved in Bhattacharya et al. (2017) but not resolved in CSC, unclassified.
- W395 and W404 detected and resolved in Bhattacharya et al. (2017) but not resolved in CSC, unclassified.

1.2. *Omega Centauri*

Omega Centauri is not included in HUGS. The authors conducted a similar study in (Bellini et al. 2010) with all bands used in HUGS, but this study only covers the central $\sim 5'$ of the cluster, leaving out many CXO sources. We therefore cross-match to the Hubble Source Catalog v3 (HSC, Lubow (2017)), using a similar procedure as we use to cross-match to HUGS. We matched HST coordinates in Cool et al. (2013) to HSC sources with the smallest magnitude difference in comparable bands: F435W and F625W in Cool et al. (2013) to F438W and F606W in HSC. For HSC data, we used observations conducted with any instrument (WFPC2, WFC3, ACS / WFC), and we also used F435W magnitudes when F438W magnitudes were not available. The systematic offset between coordinates in Cool et al. (2013) and HSC is shown in Figure 2.

1.3. *NGC 6121 / M4*

Lugger et al. (2023) also used HUGS photometry for their analysis. They found that CX13's photometry in the bluer bands was significantly affected by presumably its large proper motion, therefore they performed their own photometry for this source. We do not correct the HUGS magnitudes, and thus this source is an outlier in several CMDs.

1.4. *NGC 6205 / M13*

The qLMXB X7 was discovered in 2003 with XMM-Newton (Gendre et al. 2003), and the corresponding CXO source is named as X7 in Servillat et al. (2011). However, Servillat 2011 does not explicitly state X7 to be the discovered qLMXB, as they focus on the dwarf-nova X6. In Shaw et al. (2018), which focuses on this qLMXB, the explicit identification with X7 is also not made.

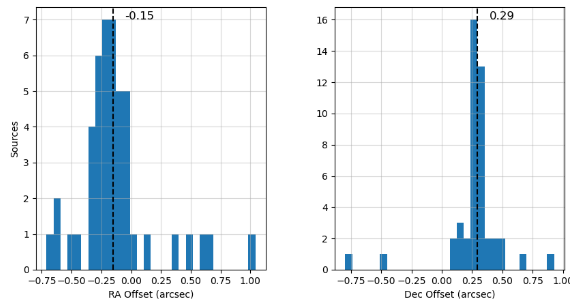

Figure 3. Same as 1, but for NGC 6395 between Dieball et al. (2017) and HUGS.

Similarly, the MSPs M13A to M13E were discovered at the time of Servillat 2011, but precise radio positions were only determined by FAST in 2020 (Wang et al. 2020), enabling the discovery of X-ray counterparts by Zhao et al. (2021). As Zhao et al. (2021) does not use the source names in Servillat 2011, we manually identify MSPs M13D and M13E with the coincident X-ray sources X4 and X1, respectively. MSP M13F, discovered by Wang et al. (2020), is similarly identified with source X11. However, only MSPs E and F are detected in CSC.

1.5. *NGC 6304*

In Guillot et al. (2009), source C12 is reported as CXOU J171432.48-393735.3. There appears to be a typo in the first digit of the declination, and the actual source name should be CXOU J171432.48-292735.3.

1.6. *NGC 6397*

The systematic offset between coordinates in Dieball et al. (2017) and HUGS is shown in Figure 3.

1.7. *NGC 6626 / M28*

In Vurgun et al. (2022), the coordinates of the X-ray counterpart to PSR J1824-2452A are offset from the radio coordinates by 1.25″, and the radio coordinates is much closer to the CSC source, even though this pulsar was used to correct the astrometry of CXO sources. We thus used the radio coordinates to crossmatch to CSC.

1.8. *NGC 6752*

MSP CX14 and candidate CV CX41 were resolved in Cohn et al. (2021), but not resolved in CSC as 2CXO J191052.0-595909.

1.9. *NGC 288*

For NGC 288, there is a large astrometric offset between published CXO coordinates in Kong et al. (2006) and those in CSC. Based on cross-matching to CSC, a manual correction of -1.982″in the RA direction and -0.039″in the DEC direction was applied.

1.10. *Published MSPs that are missing in ATNF*

Some MSPs found in publications had outdated or incorrect coordinates in ATNF; these sources were manually matched using their names, and are listed below.

NGC 6838: 2CXO J195346.4+184704 = PSR J1953+1846A: Coordinates in ATNF are significantly different from published and CSC coordinates.

NGC 6626 MSPs K, H, L have zero positional uncertainties and the same coordinates in ATNF, indicating uncertain positions. ATNF is not using the updated radio coordinates from Vurgun et al. (2022) yet. These MSPs were manually identified between ATNF and Vurgun et al. (2022) based on name.

Terzan 5: MSPs PSR J1748-2446ad and PSR J1748-2446P have zero PU and the same coordinates in ATNF, indicating updated coordinates from Bogdanov et al. (2021) are not used. These MSPs were manually identified based on name.

NGC 6121: 2CXO J162334.1-263134 = CX1 in Lugger et al. (2023) identified as strong MSP candidate, too recent to be added to ATNF.

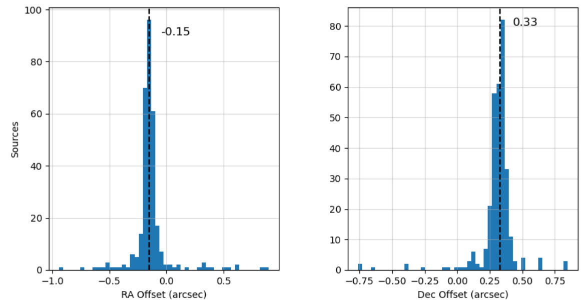

Figure 4. Same as 1, but for CDFS between Skelton et al. (2014) and HSC.

47 Tuc: 2CXO J002407.3-720519 = PSR J0024-7204aa: Coordinates in ATNF point to cluster center only, precise coordinates from Bhattacharya et al. (2017) not used.

1.11. *MSPs in ATNF that are missing in literature*

NGC 104: PSR J0024-7204X far from cluster center, not covered by selected literature

NGC 1851: 13 pulsars recently found with TRAPUM in radio, no precise positions to crossmatch yet (Ridolfi et al. 2022).

NGC 6440: PSR J1748-2021B was blended source CX9 in Pooley et al. (2002), which is now resolved in CSC, matching to 2CXO J174852.9-202138.

NGC 6626: PSR J1824-2452A CXO coordinates in Vurgun et al. (2022) have large offset from radio coordinates, even though radio coordinates are much closer to CSC source. We thus used the radio coordinates to crossmatch.

NGC 6752: PSR J1910-5959C and PSR J1910-5959A discussed in Cohn et al. (2021), but coordinates not given. Matched using coordinates from SIMBAD.

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