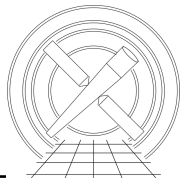
CHANDRA
X-ray Center 60 Garden St., Cambridge Massachusetts 02138 USA



MEMORANDUM

Date: September 28, 2016
From: **Ping Zhao**
To: **CXC**
Subject: **Close Pair Sources and Extended Sources in the Chandra Source Catalog 2.0**
File: `close_pair_memo.tex`
Version: `1.0`

The Chandra Source Catalog (CSC) is a comprehensive list of X-ray sources detected by the Chandra X-ray Observatory (CXO). Ultimately it is intended to be the definitive X-ray source catalog of the CXO. To achieve that goal, the catalog will be released to the user community in a series of increments with increasing capability.

CSC release 1.1 (CSC1.1)[1] became available in August 2010. CSC Preliminary Release 2.0 (CSC2.0)[2] became available in August 2015.

This memorandum reports a study of close pair sources and extended sources in the CSC2.0, and intends to answer the following two questions:

- Are there actually single point sources listed as two or more separate sources in CSC2.0?
- Are there actually two or more separate point sources listed as a single source in CSC2.0?

1 The Chandra Source Catalog Release 2.0 (CSC2.0)

The Chandra Source Catalog Release 2.0 (CSC2.0) includes data from Chandra observations released publicly through the end of 2014. The images were reorganized. For multiple observations of the same target region, if the aimpoints are within one arcminute, the images were stacked. The newly organized images are called evt3 files. All the sources in the CSC2.0 were extracted from the evt3 images. There are 5327 evt3 files for the CSC2.0. Sources from the same evt3 files are also called from the same *cohort*. As of today (September 2016), CSC2.0 only includes sources with RA in the range of 0–18 hrs.

The CSC2.0 contains 244382 entries[3], with 166225 (68.02%) labeled as SRC_QUALITY = TRUE and 78157 (31.98%) as SRC_QUALITY = MARGINAL. When split by EXTSRC_CLASS, there are 241036 (98.63%) detections with value of POINT, 2856 (1.17%) with EXTENDED, and 490 (0.20%) with POSSIBLE. The breakdown by EBAND - the energy band corresponding to the measured values - there are 188493 (77.13%) broad band (b), 19135 (7.83%) hard (h), 17243 (7.06%) medium (m), 17591 (7.20%) soft (s), 250 (0.10%) ultra-soft (u), and 1670 (0.68%) wide (HRC) band (w) rows. There are 212 detections with STREAK_SRC_FLAG = TRUE. Tables 1 and 2 give the detailed classifications of the CSC2.0 catalog

[1] `http://cxc.harvard.edu/csc`

[2] `http://cxc.harvard.edu/csc2`

[3] The file `preliminary_detlist.fits.gz` posted on `http://cxc.cfa.harvard.edu/csc2/preliminary` actually only has 241074 entries. The list used for this study is provided by Frank Primini. It has 3308 more entries.

Table 1: CSC2.0 Source Classification

Source	Point	Extended	Possible	Total
True	163459	2405	361	166225
Marginal	77577	451	129	78157
All	241036	2856	490	244382

Table 2: CSC2.0 Source Eband Classification

Source	True				Marginal				
Eband	Point	Extended	Possible	Sum	Point	Extended	Possible	Sum	Total
b	130401	1932	300	132633	55503	295	62	55860	188493
h	10613	87	26	10726	8352	37	20	8409	19135
m	10282	50	14	10346	6823	51	23	6897	17243
s	10997	226	21	11244	6268	57	22	6347	17591
u	187	4	0	191	51	6	2	59	250
w	979	106	0	1085	580	5	0	585	1670
All	163459	2405	361	166225	77577	451	129	78157	244382

2 Close Point Source Pairs

To answer the first question: "Are there actually single point sources listed as two or more separate sources in CSC2.0?", we search for the close point source (*EXTSRC_CLASS = "POINT"*) pairs in the same cohort.[4] We also consider additional criteria of *SRC_QUALITY = "TRUE"* and *EBAND = "b"*, which are the most abundant and secure sources. Also, we select sources with off-axis (from the Chandra optical axis) angles $\theta \leq 2'$, to ensure the best PSF for point source detections. Table 3 shows the number of close pairs (separation $d \leq 2''$) found under different criteria: 1) Point: both sources of the pair are of the type *EXTSRC_CLASS = "POINT"*; 2) Point & True: in addition to criterion 1, both sources are also of the type *SRC_QUALITY = "TRUE"*; 3) Point & True & Eband=b: in addition to criteria 1&2, both sources are also of the type *EBAND = "b"*.

Table 3: Close Point Source Pairs in CSC2.0

Source	$\theta \leq 1'$		$1' < \theta \leq 2'$	
Criteria	$d \leq 1''$	$1'' < d \leq 2''$	$d \leq 1''$	$1'' < d \leq 2''$
Point	0	64	4	64
Point & True	0	54	0	55
Point & True & Eband=b	0	38	0	38

θ is the source off-axis angle; d is the separation between the pair.

As seen in Table 3, for off-axis angle $\theta \leq 1'$, there are no close pairs with separation $d \leq 1''$; for $1' < \theta \leq 2'$, there are only 4 close pairs with $d \leq 1''$, but in each pair, at least one of the sources is of the type *SRC_QUALITY = "MARGINAL"*. For off-axis angle $\theta \leq 1'$, there are 64, 54 and 38 pairs with separations in the range of $1'' < d \leq 2''$ under the three criteria, respectively; for

[4]The same source detected in different cohorts (most likely due to different off-axis angles) almost certainly have slightly different coordinates, since the RA and Dec in CSC2 are given in more than 14 significant digits.

$1' < \theta \leq 2'$, the numbers are 64, 55 and 38, almost exactly the same as for $\theta \leq 1'$. Figure 1 shows all of the CSC2.0 sources (blue dots) with close point pairs marked by red diamonds, for sources with criterion 3, separation $1'' < d \leq 2''$ and off-axis angle $\theta \leq 2'$. There are 76 close point source pairs from 49 cohorts, of which, 32 cohorts are from single obsids; 17 cohorts are stacked from two or more obsids.

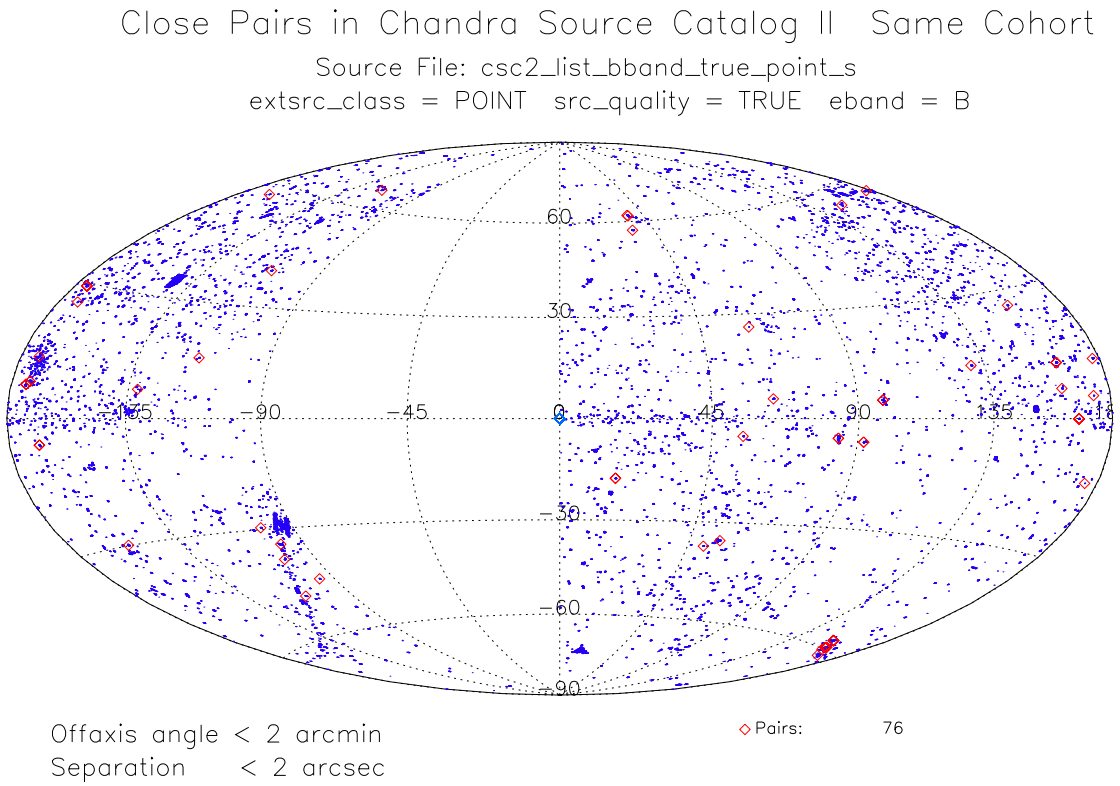


Figure 1: Chandra Source Catalog 2.0: Blue dots are the sources listed in the catalog (so far only released sources with RA between 0 and 270 degrees); red diamonds indicate the locations of the close point source pairs found. For sources in the same cohort, with *EXTSRC_CLASS = "POINT"*, *SRC_QUALITY = "TRUE"*, *EBAND = "b"* and off-axis angle less than 2 arcminute. There are 76 pairs of point sources from 49 cohorts with separation less then 2 arcseconds.

Tables 4 and 5 list these 76 close pairs. Tables 4 lists 38 pairs with $\theta \leq 1'$; Tables 5 lists 38 pairs with $1' < \theta \leq 2'$. Figures 2 – 7 show 6 selected pairs with the highest counts. Obviously, each close pair consists of two distinct point sources. Examining the rest of the pairs, we also arrive at the same conclusion. So the answer to the first question is "NO". There is NO single point source listed as two or more separate sources in CSC2.0. In the same cohort, every point source has one and only one entry in the catalog.

Table 4: Close Pairs of "True", "Point" and EBAND = "b" sources with $1 < d \leq 2''$ and $\theta \leq 1'$.

Cohort	ID1	ID2	LH1	LH2	Sb1	Sb2	θ_1	θ_2	d	RA1	Dec1	RA2	Dec2
acisfJ0107473m173032	145	146	15.44	22.10	64	67	0.253	0.232	1.966	16.94322	−17.50767	16.94346	−17.50817
acisfJ0107473m173032	149	150	123.58	132.49	161	143	0.160	0.146	1.332	16.94528	−17.50721	16.94567	−17.50715
acisfJ0218593p570702	206	204	41.60	29.88	16	14	0.806	0.834	1.740	34.74003	57.10388	34.74008	57.10339
acisfJ0225395p620537	116	118	58.11	27.46	23	11	0.034	0.021	1.881	36.41493	62.09328	36.41528	62.09378
acisfJ0322360m371302	28	26	30.67	23.73	13	11	0.373	0.382	1.940	50.65702	−37.21422	50.65749	−37.21461
acisfJ0342165m352340	32	34	49.65	50.42	25	34	0.552	0.584	1.899	55.58022	−35.39265	55.58087	−35.39260
acisfJ0403487p261048	1	2	1280.58	1351.74	192	227	0.110	0.134	1.568	60.95525	26.18079	60.95560	26.18109
acisfJ0414376p053407	32	30	7561.33	27117.19	1445	5039	0.587	0.556	1.893	63.65716	5.57896	63.65734	5.57847
acisfJ0535165m052323	2085	2082	862.95	3579.21	204	1531	0.247	0.263	1.603	83.82403	−5.39512	83.82410	−5.39556
acisfJ0631564p045625	250	249	970.80	459.17	191	89	0.974	0.965	1.925	97.97908	4.95541	97.97961	4.95546
acisfJ0631564p045625	249	552	459.17	75.37	89	23	0.965	0.947	1.698	97.97961	4.95546	97.98006	4.95530
acisfJ0840490p131255	12	11	167.95	40.42	117	33	0.599	0.583	1.935	130.19959	13.20645	130.20014	13.20649
acisfJ1001536p554041	22	23	135.16	144.49	35	37	0.388	0.387	1.606	150.48430	55.67563	150.48456	55.67605
acisfJ1023578m574530	275	272	25.44	123.50	21	62	0.137	0.168	1.951	155.99371	−57.76009	155.99468	−57.76025
acisfJ1023578m574530	285	274	35.05	105.37	35	54	0.215	0.243	1.982	155.99662	−57.75964	155.99732	−57.76004
acisfJ1023578m574530	392	389	18.01	23.33	10	21	0.517	0.510	1.742	155.99855	−57.75165	155.99917	−57.75200
acisfJ1023578m574530	283	293	47.48	24.86	23	15	0.964	0.973	1.757	156.02009	−57.75966	156.02040	−57.75920
acisfJ1043559m593241	489	499	107.62	84.77	40	34	0.359	0.337	1.744	160.98375	−59.55082	160.98432	−59.55044
acisfJ1043559m593241	458	452	522.15	247.42	131	69	0.490	0.515	1.901	160.98612	−59.55286	160.98693	−59.55320
acisfJ1043559m593241	1666	1657	31.82	20.99	53	47	0.201	0.227	1.577	160.98667	−59.54762	160.98728	−59.54793
acisfJ1043559m593241	672	674	58.59	43.77	14	12	0.567	0.586	1.873	160.99010	−59.53613	160.99110	−59.53601
acisfJ1043559m593241	549	540	63.75	25.11	21	9	0.620	0.642	1.801	161.00283	−59.54708	161.00337	−59.54750
acisfJ1044141p064551	20	22	114.69	171.06	29	42	0.616	0.599	1.657	161.05413	6.75530	161.05458	6.75540
acisfJ1044406m592139	252	253	30.87	26.18	11	11	0.645	0.652	1.822	161.18998	−59.36295	161.19034	−59.36248
acisfJ1105499m000241	15	12	35.11	41.92	17	22	0.671	0.640	1.874	166.45189	−0.03543	166.45206	−0.03592
acisfJ1105493m000137	40	41	45.49	37.51	23	25	0.639	0.609	1.794	166.45262	−0.03732	166.45270	−0.03683
acisfJ1105493m000137	49	46	26.94	44.71	22	30	0.501	0.524	1.753	166.45280	−0.03499	166.45297	−0.03544
acisfJ1105493m000137	46	45	44.71	146.59	30	58	0.524	0.531	1.912	166.45297	−0.03544	166.45345	−0.03568
acisfJ1131578p045618	4	5	195.63	94.75	38	23	0.615	0.587	1.887	172.98486	4.93019	172.98533	4.93043
acisfJ1139104m135118	19	5	500.88	132.28	274	130	0.629	0.614	1.987	174.79288	−13.84471	174.79339	−13.84494
acisfJ1149127p560532	29	30	19.85	15.66	16	12	0.637	0.647	1.680	177.31686	56.08491	177.31760	56.08513
acisfJ1220110p291719	51	48	70.02	92.85	27	29	0.915	0.933	1.906	185.04714	29.27351	185.04767	29.27325
acisfJ1229467p080030	1048	968	83.69	174.05	207	229	0.804	0.812	1.340	187.44267	7.99806	187.44297	7.99783
acisfJ1513119p071335	8	9	22.62	15.79	9	6	0.286	0.294	1.899	228.30443	7.22519	228.30469	7.22565
acisfJ1639586m485154	124	118	56.71	71.77	13	17	0.836	0.827	1.566	249.97371	−48.86247	249.97384	−48.86290
acisfJ1712213m382926	70	69	28.12	68.47	22	34	0.121	0.095	1.997	258.08787	−38.49280	258.08856	−38.49292
acisfJ1714326m292751	55	58	71.39	18.27	15	9	0.676	0.680	1.842	258.63264	−29.46116	258.63306	−29.46080
acisfJ1736184m444353	165	157	233.16	199.04	110	100	0.506	0.475	1.968	264.07093	−44.73416	264.07151	−44.73380

Note: Cohort – evt3 image name; id – source ID; 1&2 – Source 1&2 of the pair; LH – likelihood; Sb – SRC_RDATA_B (Raw counts in b band); θ – off-axis angle in arcmin; d – separation of the pair in arcsec.

Table 5: Close Pairs of "True", "Point" and EBAND = "b" sources with $1 < d \leq 2''$ and $1' < \theta \leq 2'$.

Cohort	ID1	ID2	LH1	LH2	Sb1	Sb2	θ_1	θ_2	d	RA1	Dec1	RA2	Dec2
acisfJ0227061p615213	69	70	28.12	38.55	8	11	1.013	1.020	1.834	36.77534	61.88731	36.77640	61.88742
acisfJ0337443m050222	33	35	142.92	366.68	34	76	1.518	1.489	1.766	54.40984	−5.04377	54.41031	−5.04360
acisfJ0535165m052323	2683	3417	13010.91	1813.33	2659	553	1.798	1.786	1.642	83.79369	−5.37933	83.79406	−5.37907
acisfJ0607506m062250	178	176	68.94	30.74	22	10	1.230	1.215	1.964	91.94169	−6.37335	91.94175	−6.37389
acisfJ0607506m062250	210	208	262.81	257.10	54	56	1.593	1.592	1.653	91.96747	−6.35493	91.96791	−6.35506
acisfJ1023578m574530	194	190	48.15	48.36	23	21	1.018	1.050	1.943	156.01788	−57.76713	156.01883	−57.76731
acisfJ1023578m574530	343	337	52.07	20.37	21	11	1.295	1.304	1.961	156.03017	−57.75631	156.03054	−57.75682
acisfJ1023578m574530	189	196	80.51	43.65	30	18	1.562	1.559	1.552	156.03621	−57.76735	156.03636	−57.76693
acisfJ1029089p262244	125	126	5602.21	1263.76	1079	295	1.502	1.494	1.859	157.30940	26.39451	157.30963	26.39403
acisfJ1043559m593241	433	432	26.34	32.24	9	12	1.838	1.812	1.658	160.92564	−59.55462	160.92655	−59.55465
acisfJ1043559m593241	324	328	17.49	15.77	8	8	1.696	1.675	1.558	160.94086	−59.56342	160.94102	−59.56299
acisfJ1044406m592139	154	157	19.71	33.59	10	13	1.518	1.518	1.885	161.19663	−59.38208	161.19748	−59.38179
acisfJ1047086m600555	168	167	80.15	44.63	22	16	1.642	1.652	1.590	161.79738	−60.07203	161.79825	−60.07196
acisfJ1047473p123348	79	81	139.39	718.30	71	243	1.280	1.301	1.959	161.95572	12.58315	161.95626	12.58331
acisfJ1047513p123606	311	65	135.17	174.57	93	131	1.312	1.293	1.944	161.95686	12.58092	161.95739	12.58108
acisfJ1047473p123348	60	62	40.85	28.59	22	18	1.130	1.159	1.714	161.95806	12.57908	161.95831	12.57949
acisfJ1047473p123348	78	202	119.90	116.21	41	39	1.484	1.504	1.400	161.96302	12.58282	161.96340	12.58296
acisfJ1111516m611830	460	126	42.70	53.12	13	16	1.247	1.264	1.388	168.00778	−61.30510	168.00843	−61.30532
acisfJ1148233p124147	14	16	20.11	25.92	9	11	1.426	1.443	1.438	177.08366	12.71618	177.08373	12.71657
acisfJ1220110p291719	80	76	62.78	105.93	39	58	1.211	1.204	1.654	185.02471	29.28107	185.02503	29.28070
acisfJ1220110p291719	76	74	105.93	805.97	58	253	1.204	1.213	1.960	185.02503	29.28070	185.02512	29.28016
acisfJ1220110p291719	107	104	35.37	34.59	17	15	1.049	1.029	1.824	185.02629	29.28613	185.02674	29.28581
acisfJ1220011p291610	56	58	42.41	68.86	19	26	1.273	1.288	1.526	185.03349	29.27840	185.03366	29.27880
acisfJ1220059p291548	55	56	47.02	87.06	17	26	1.000	1.025	1.597	185.03355	29.27840	185.03360	29.27884
acisfJ1224254p071801	117	120	54.44	77.44	25	32	1.080	1.101	1.406	186.11993	7.31225	186.12032	7.31234
acisfJ1224310p072006	37	39	25.09	31.43	10	10	1.486	1.467	1.643	186.11996	7.31217	186.12039	7.31234
acisfJ1224254p071801	221	219	69.40	58.25	34	33	1.998	1.980	1.494	186.12102	7.33032	186.12114	7.32992
acisfJ1229490p132618	17	18	25.57	25.92	8	10	1.406	1.405	1.818	187.46792	13.41931	187.46833	13.41962
acisfJ1229467p080030	303	302	43.50	83.60	37	55	1.539	1.554	1.627	187.47212	8.01517	187.47242	8.01483
acisfJ1231229p254432	25	23	23.18	29.37	14	15	1.961	1.932	1.830	187.85236	25.77444	187.85241	25.77393
acisfJ1248335m054908	45	46	60.16	59.00	26	28	1.196	1.219	1.524	192.14876	−5.80108	192.14907	−5.80080
acisfJ1248335m054908	46	47	59.00	241.61	28	86	1.219	1.239	1.766	192.14907	−5.80080	192.14955	−5.80068
acisfJ1256128p565257	23	22	76.91	30.94	23	13	1.937	1.947	1.966	194.11060	56.87430	194.11064	56.87375
acisfJ1336552m295344	430	429	66.07	54.44	159	169	1.932	1.958	1.772	204.25086	−29.86847	204.25136	−29.86824
acisfJ1609179p653118	14	13	163.17	101.82	40	25	1.243	1.212	1.868	242.30837	65.54134	242.30862	65.54083
acisfJ1625124p154632	97	18	29.32	17.35	22	14	1.270	1.295	1.568	246.31034	15.75613	246.31061	15.75577
acisfJ1641547p395915	22	21	14.86	14.48	10	10	1.529	1.498	1.859	250.44539	39.98427	250.44607	39.98426
acisfJ1726017m341446	125	126	34.54	37.45	14	13	1.753	1.740	1.627	261.50734	−34.27541	261.50781	−34.27519

Note: Cohort – evt3 image name; id – source ID; 1&2 – Source 1&2 of the pair; LH – likelihood; Sb – SRC_RDATA_B (Raw counts in b band); θ – off-axis angle in arcmin; d – separation of the pair in arcsec.

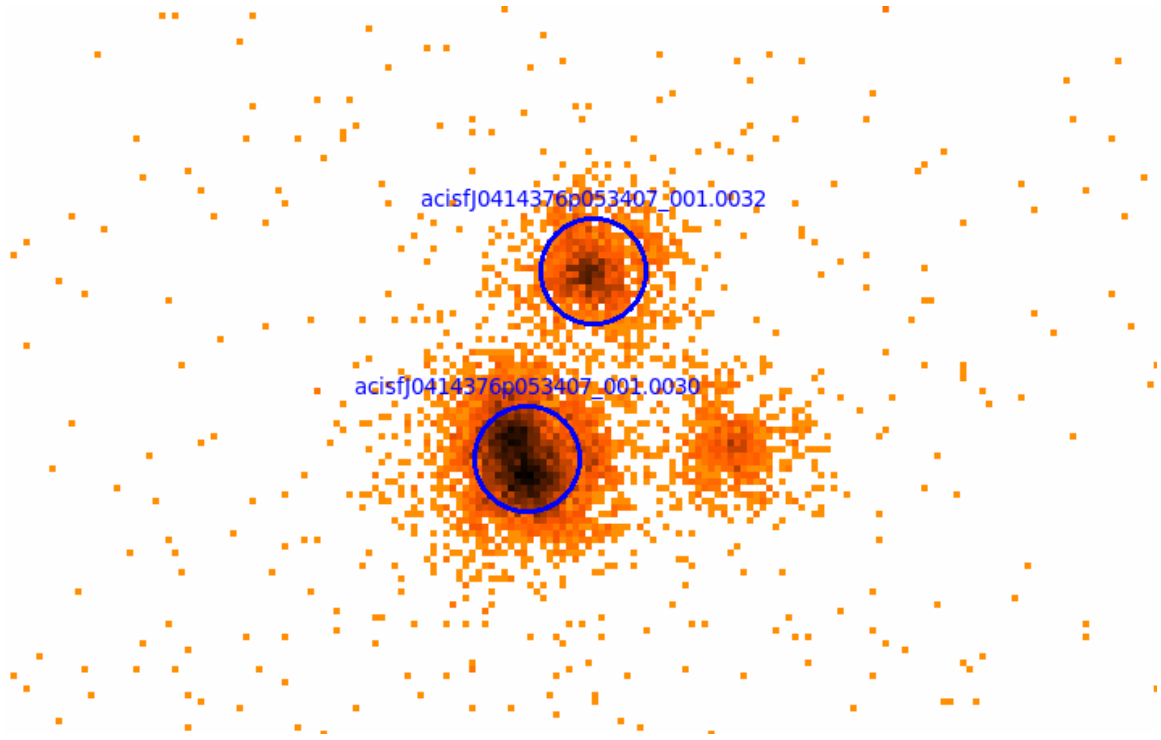


Figure 2: Close pair: Cohort: acisfJ0414376p053407, ID1: 32, ID2: 30. Blue circles are 1″ in diameter.

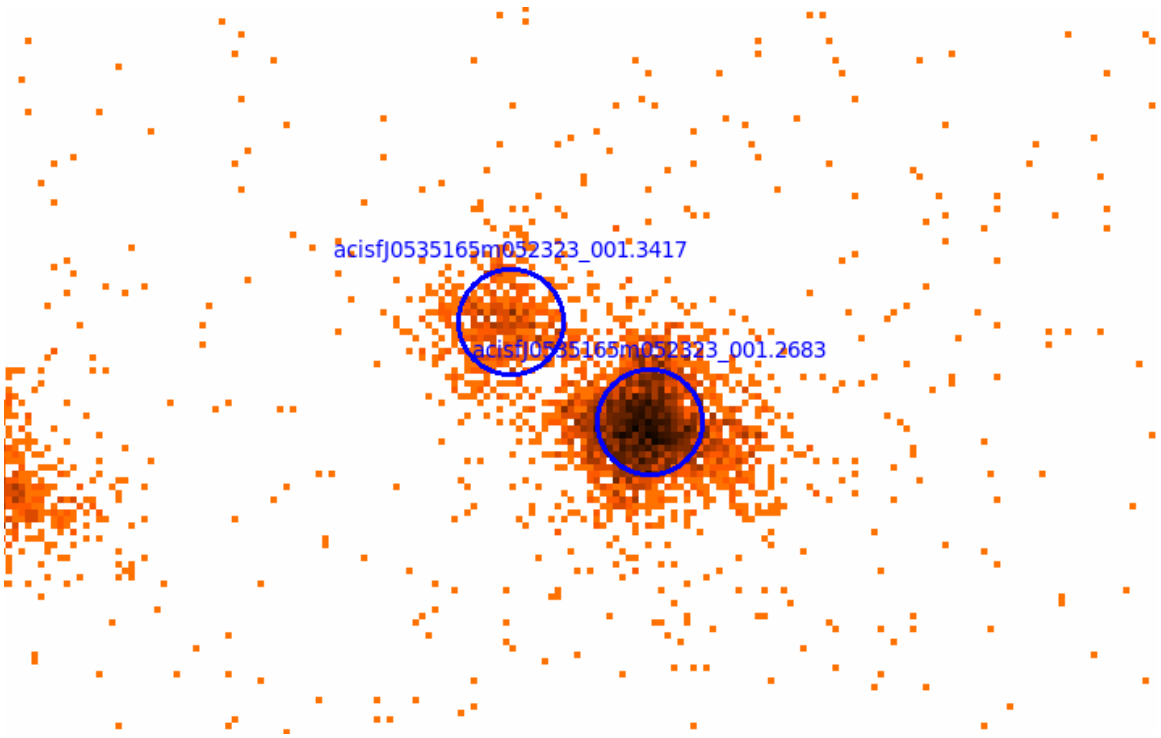


Figure 3: Close pair: Cohort: acisfJ0535165m052323, ID1: 2683, ID2: 3417. Blue circles are 1″ in diameter.

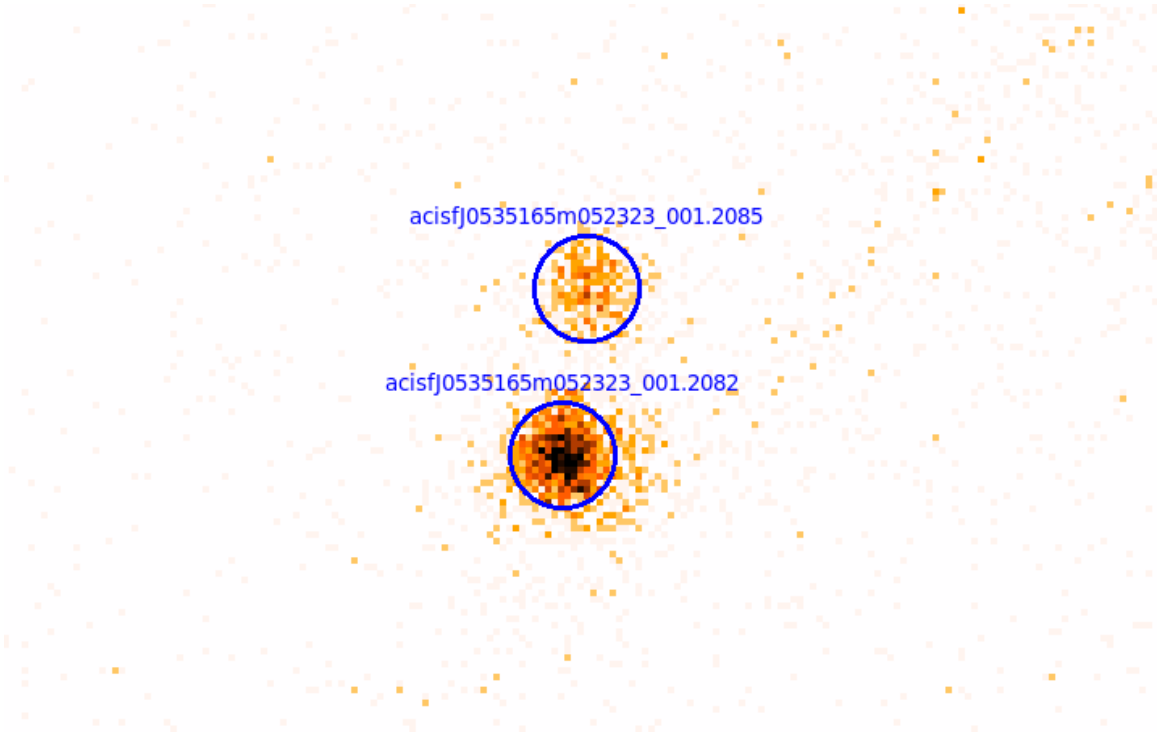


Figure 4: Close pair: Cohort: acisfJ0535165m052323, ID1: 2085, ID2: 2082. Blue circles are 1″ in diameter.

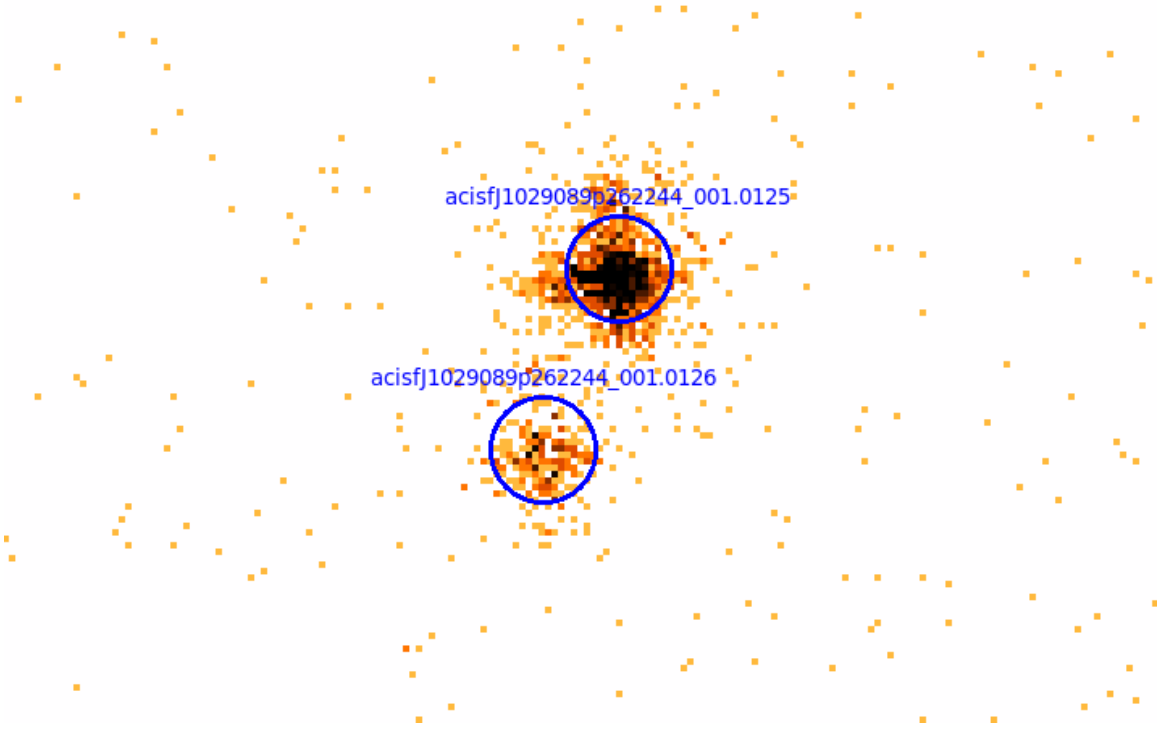


Figure 5: Close pair: Cohort: acisfJ1029089p262244, ID1: 125, ID2: 126. Blue circles are 1″ in diameter.

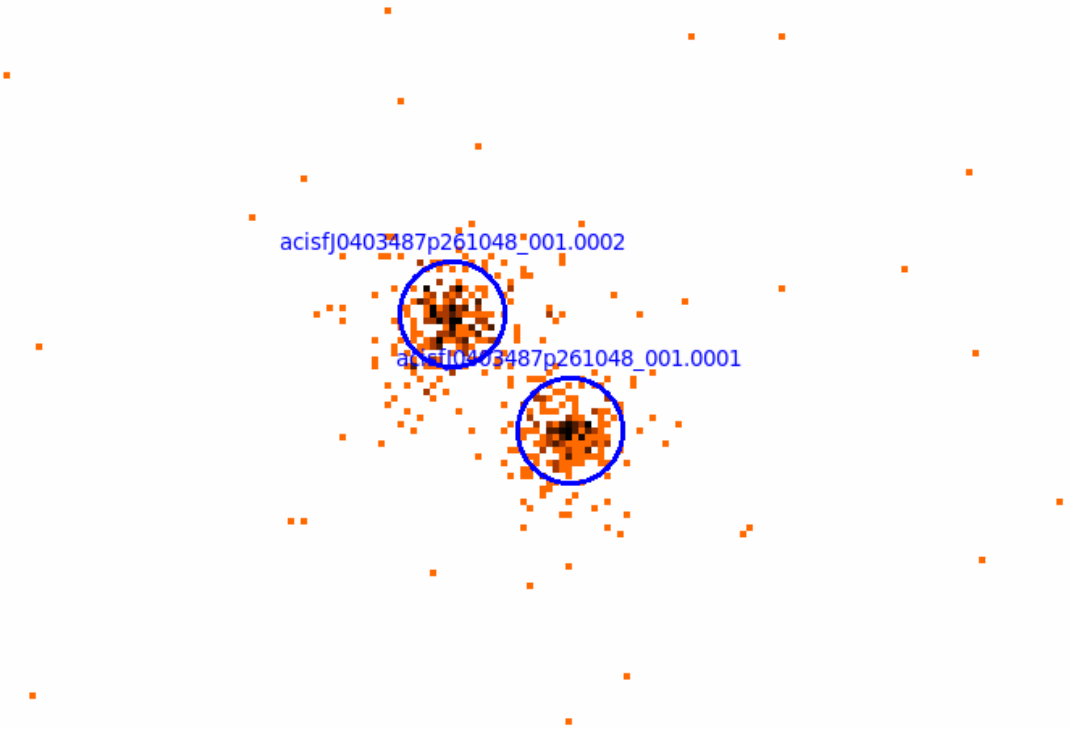


Figure 6: Close pair: Cohort: acisfJ0403487p261048, ID1: 1, ID2: 2. Blue circles are 1″ in diameter.

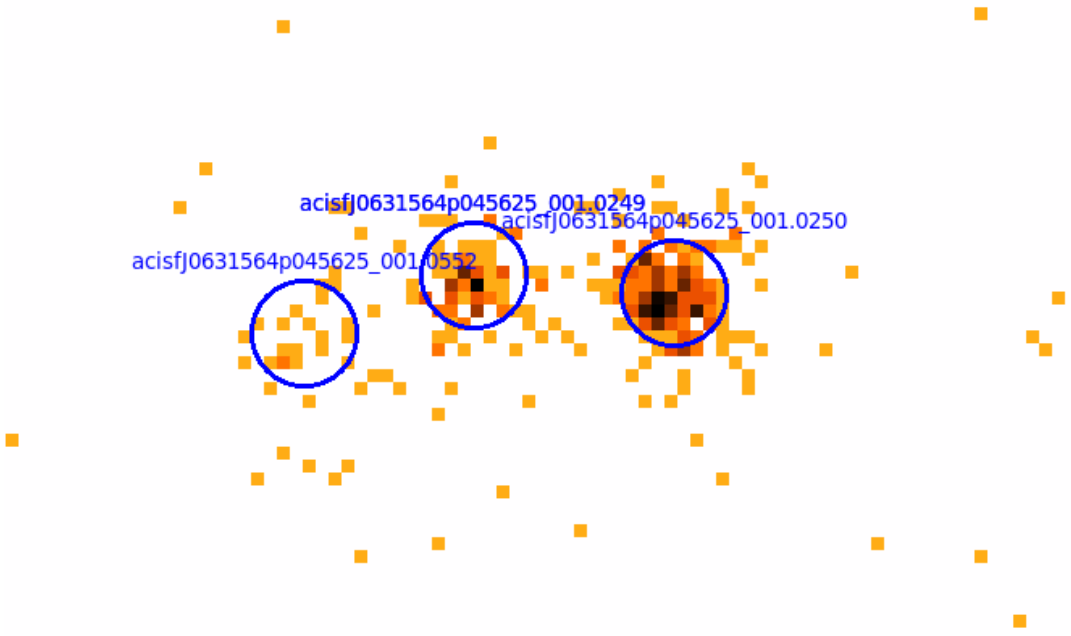


Figure 7: Close pair: Cohort: acisfJ0631564p045625, ID1: 250, ID2: 249. Blue circles are 1″ in diameter.

3 Extended Sources

To answer the second question: "Are there actually two or more separate point sources listed as a single source in CSC2.0?", we search for extended sources (*EXTSRC_CLASS = "EXTENDED"*) in the same cohort, with additional criteria of *SRC_QUALITY = "TRUE"* and *EBAND = "b"*. There are 638 sources satisfying the above criteria. Table 6 lists the number of sources under these criteria found in the regions of off-axis angle $\theta \leq 1'$ and $1' < \theta \leq 2'$ with different eccentricity[5]

Table 6: Extended Sources in CSC2.0

e	$\theta \leq 1'$	$1' < \theta \leq 2'$	Sum
0.9−1.0	163	58	221
0.8−0.9	104	45	149
0.7−0.8	79	38	117
0.6−0.7	56	23	79
0.5−0.6	22	15	37
0.4−0.5	19	10	29
0.3−0.4	2	1	3
0.2−0.3	1	0	1
0.1−0.2	2	0	2
0.0−0.1	0	0	0
Total	448	190	638

$e = \sqrt{1 - (\frac{ext\_smin}{ext\_smaj})^2}$ is the eccentricity;
θ is the source off-axis angle.

There are different issues for the extended sources, most of them occur among the high eccentricity sources. We discuss them separately below.

3.1 Double or Triple Sources Detected as Single Extended Sources, $e > 0.9$

Many extended sources with eccentricity $e > 0.9$ listed in CSC2 actually consist of double or triple (mostly point) sources. For example, Figure 8 shows an extended source – acisfJ0913015p525934_001.0007, which was observed only once with OBSID 8176. Both of its evt2 image and evt3 image, which was used to detect the sources in the CSC2, show the source is actually made up from two point-like sources. But CSC2 lists them as one extended source with $e = 0.997$. In the figure, The green circle has an $1''$ diameter and centered at the source position given in CSC2. The blue ellipse, also centered at the source position, has semi-major and semi-minor axes equal to 5 times of the "EXT_SMAJ" and "EXT_SMIN" given in the CSC2, for clarity. All the extended sources in the rest of the figures will have the same region reference.

Figure 9 is another extended source – acisfJ0042460p411550_001.0455. This source was observed 24 times. The figure shows one of the observations (OBSID 14196) and the stacked image of all 24 observations. Both of its evt2 and evt3 images show the source actually also consists of two point-like sources. But CSC2 again lists them as one extended source with $e = 0.954$.

[5]For an ellipse with semi-major axis "a" and semi-minor axis "b", its eccentricity is defined as $e = \sqrt{1 - (\frac{b}{a})^2}$. In CSC2.0, "a" and "b" are called "EXT_SMAJ" and "EXT_SMIN".

Figure 10 is another extended source – acisfJ1424365p225555_001.0024. This source was observed three times. The figure shows all three observations (OBSIDs 367, 1631 and 12801) and the stacked image. All the images show the source is probably made up from three point-like sources. But CSC2 again lists them as one extended source with $e = 0.974$.

Figure 11 shows another extended source – acisfJ1229467p080030_011.0976 at the lower left. This source was also observed three times (OBSIDs 322, 11274 and 12888). The figure shows that the source maybe made up from two or three distinct sources. But CSC2 lists them as one extended source with $e = 0.986$.

So the answer to the second question is "YES". There are actually two or more separate point sources listed as a single extended source in CSC2.0.

3.2 Single Moving Point Source Detected as Extended Sources, $e > 0.9$

Sometimes a single moving point source can be detected as an extended source as a result of stacking the image. For example, Figure 12 shows the images of a fast moving point source – pulsar PSR J1308+2127, with high proper motion of 223 mas/y. This pulsar was observed twice, 5 years apart. So the coordinates of the pulsar in the two observations was about 1.1 arcsec apart. But the stacked image put the two observed positions on the same image and CSC2 detected them as a single extended source with $e = 0.979$, and the average position of the two observations as its coordinate.

3.3 Image Process Changes Image Quality and Resolution, $e > 0.9$

Sometimes the process from evt2 to evt3 files changed the image quality and resolution. For example, Figure 13 shows a source that was only observed once. But its images in the evt2 and evt3 files are very different. The evt2 image show an extended source; the evt3 image show two distinct point sources.

3.4 Extended Sources with Lower Eccentricity, $e < 0.9$

Most of the extended sources with lower eccentricity are true extended sources under the Chandra resolution. Figure 14 shows one high eccentricity source (acisfJ0535165m052323_001.2698, $e = 0.960$) and many lower eccentricity ($e < 0.9$) sources. Only the high eccentricity source looks like it is made up from two distinct sources. All the lower eccentricity sources look like true extended sources.

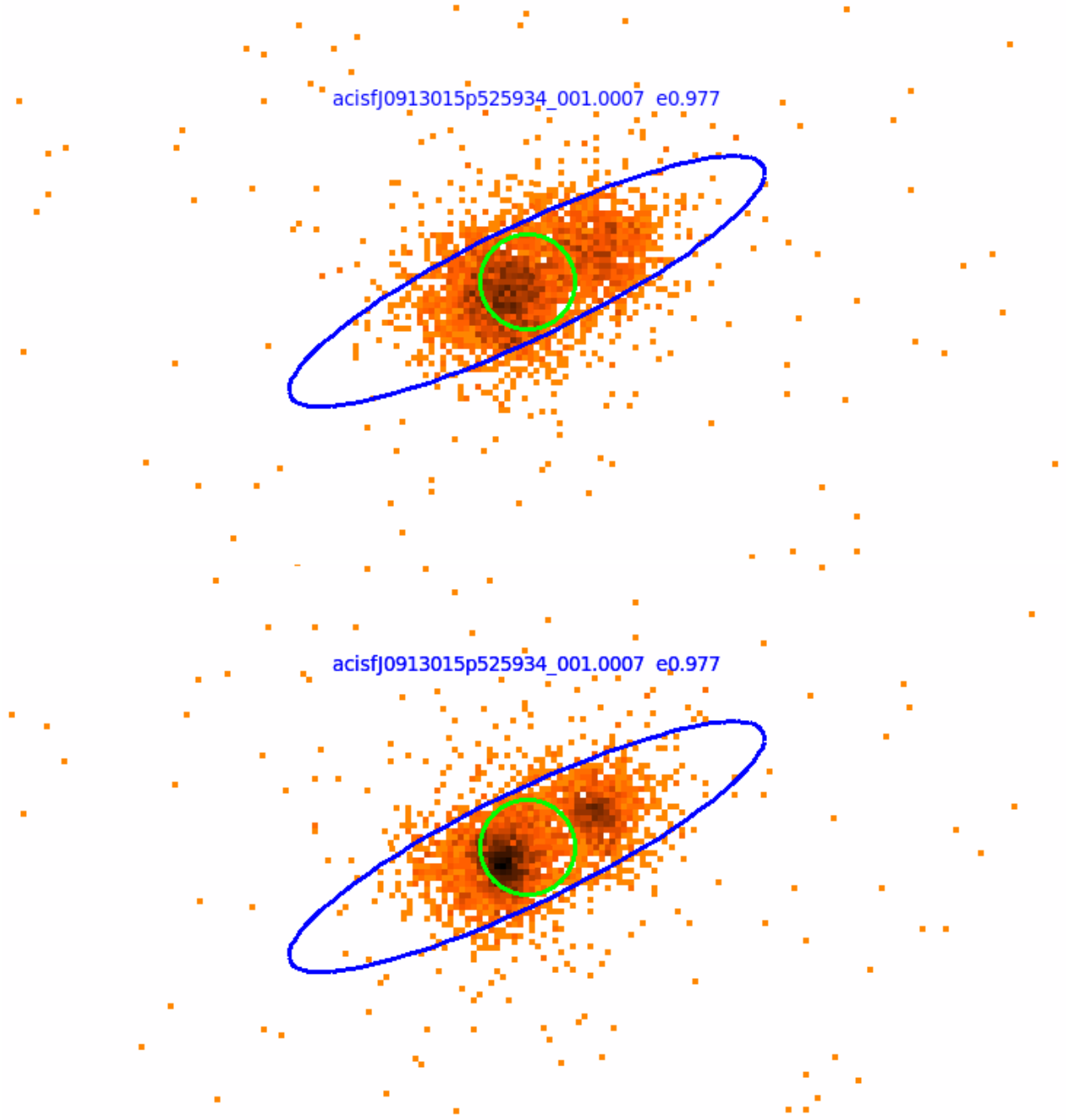


Figure 8: Extended source acisfJ0913015p525934_001.0007. This source was observed only once. The top image is from the evt2 file of OBSID 8176. The bottom image is from the evt3 file used by CSC2. The green circle has an 1″ diameter and centered at the source position given in CSC2. The blue ellipse, also centered at the source position, has semi-major and semi-minor axes equal to 5 times of the "EXT_SMAJ" and "EXT_SMIN" given in the CSC2, for clarity. Both images show two distinct sources. But CSC2 listed them as one extended source with $e = 0.997$.

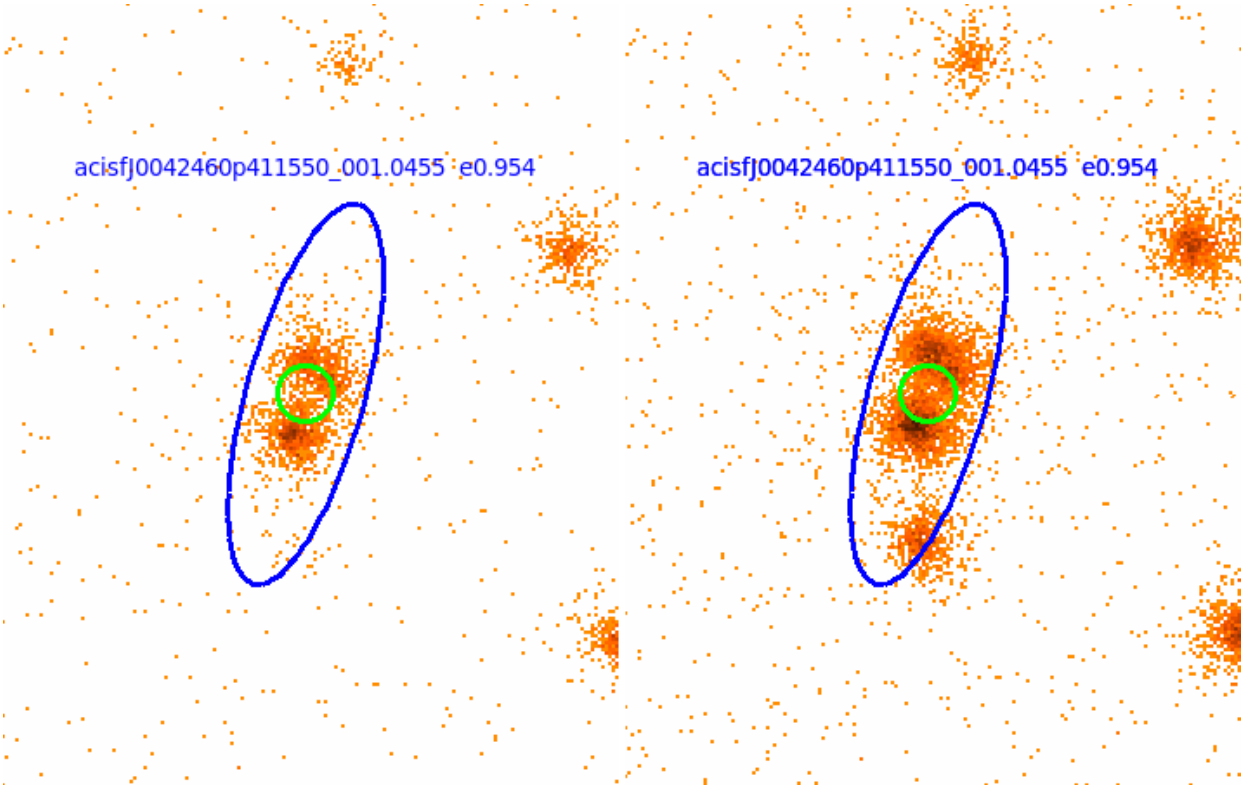


Figure 9: Extended source acisfJ0042460p411550_001.0455. This source was observed 24 times. The left image is from one of the observations (OBSID 14196). The right image is the stacked image of all 24 observations. Both images show at least two distinct sources. But CSC2 listed them as one extended source with $e = 0.954$.

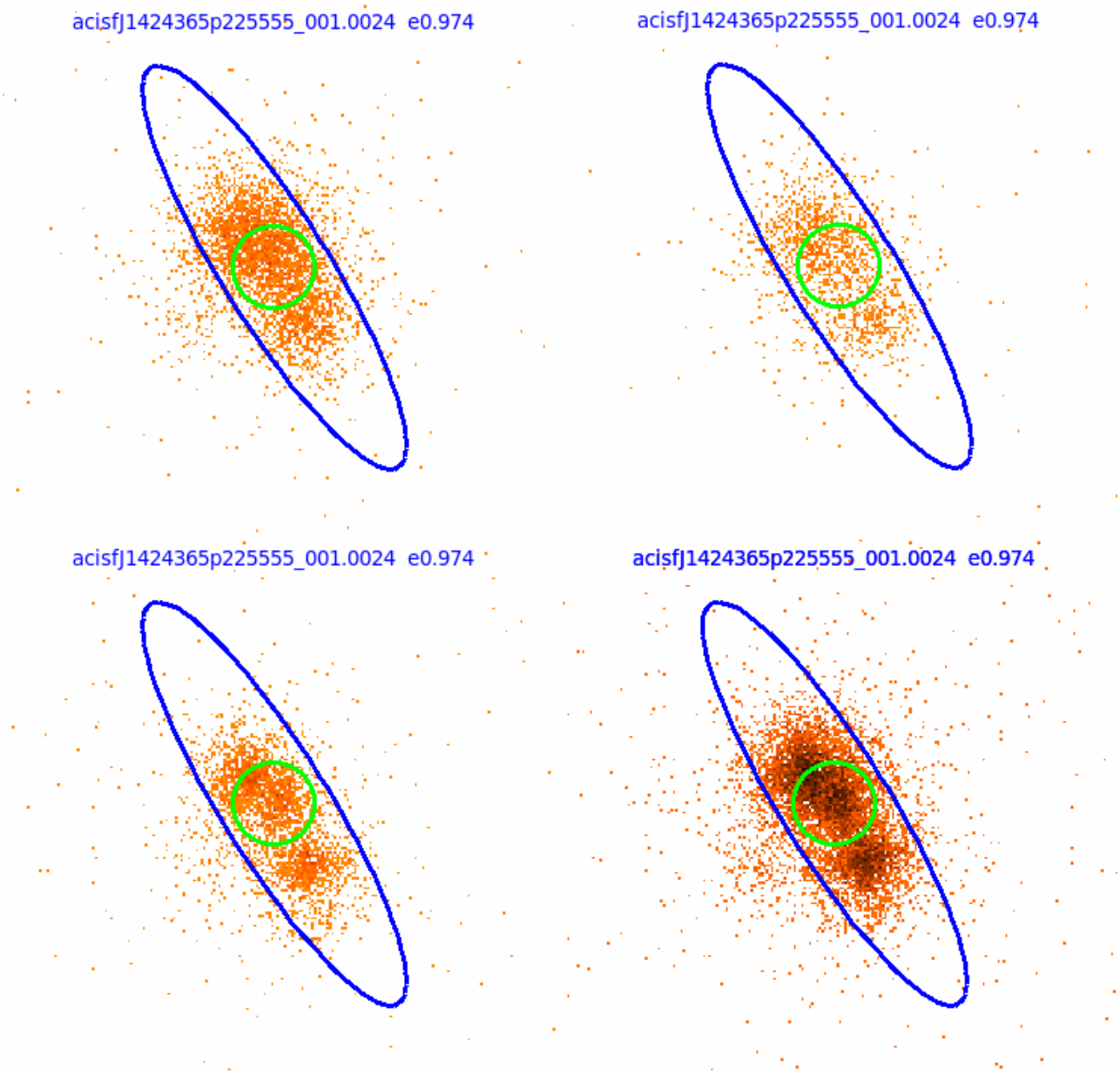


Figure 10: Extended source acisfJ1424365p225555_001.0024. This source was observed three times. The top left, top right left and bottom left images are from the evt2 file of OBSIDs 367, 1631 and 12801, respectively. The bottom right image is from the stacked evt3 file used by CSC2. The images show possibly three distinct sources. But CSC2 listed them as one extended source with $e = 0.974$.

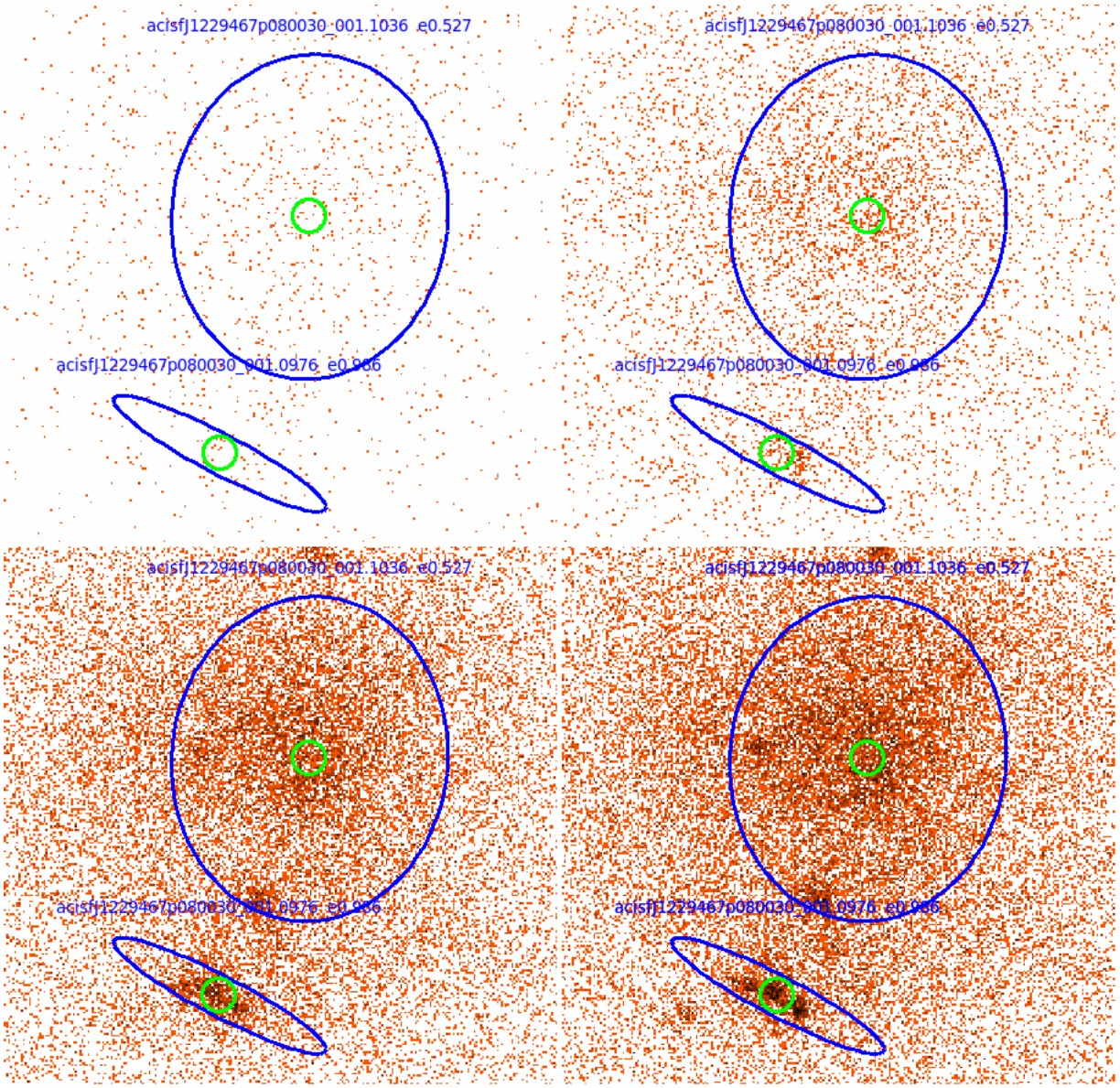


Figure 11: Extended source acisfJ1229467p080030_011.0976 (lower left). This source was observed three times. The top left, top right left and bottom left images are from the evt2 file of OBSIDs 322, 11274 and 12888, respectively. The bottom right image is from the stacked evt3 file used by CSC2. The images show possibly two or three distinct sources. But CSC2 listed them as one extended source with $e = 0.986$.

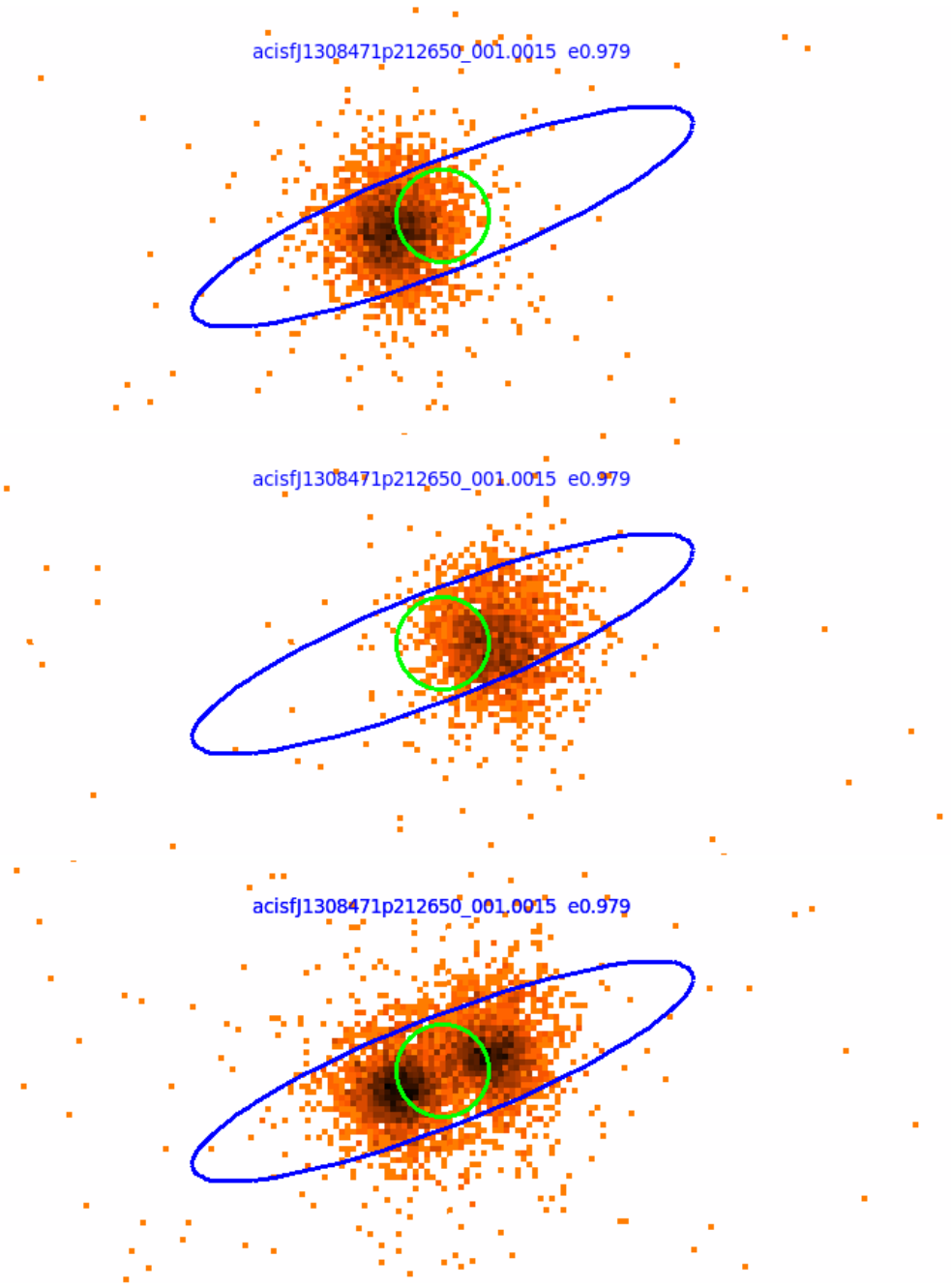


Figure 12: Extended source acisfJ1308471p212650_001.0015. This is a fast moving point source – pulsar PSR J1308+2127, with high proper motion of 223 mas/y. It was observed twice. The top image (OBSID 2790) was observed in 2002; the middle image (OBSID 7610) was observed in 2007. The displacement between the two observations is 1.1 arcsec. The bottom image is the stacked image of OBSID 2790 and 7610, used to produce CSC2. CSC2 listed this high proper motion pulsar as an extended source with $e = 0.979$, and the average position of the two observations as its coordinate.

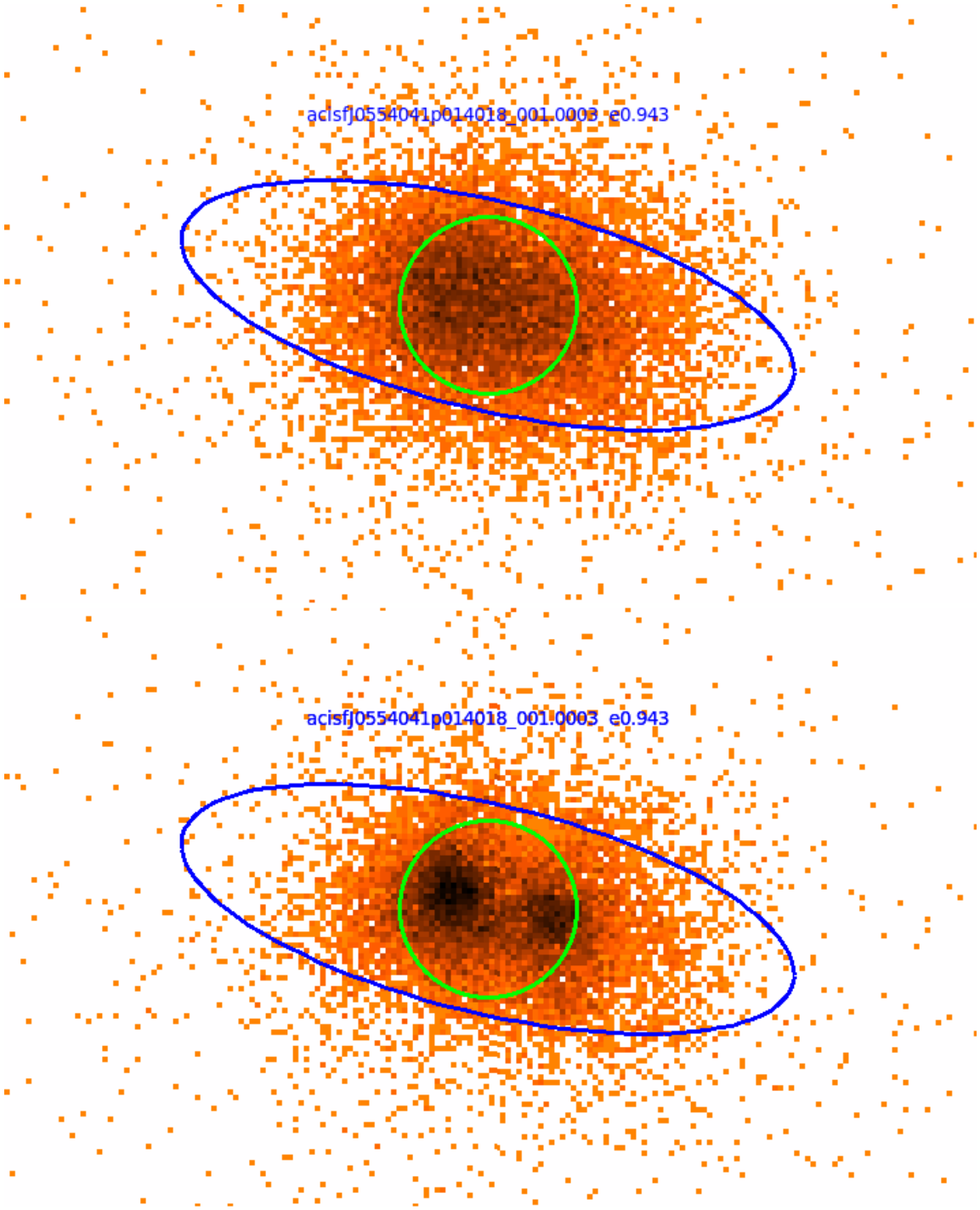


Figure 13: Extended source acisfJ0554041p014018_001.0003. This source was observed only once. The top image is from evt2 file of OBSID 12383. The bottom image is from the evt3 file used by CSC2. The top images shows an extended source. But the bottom image show two distinct sources. Yet CSC2 still listed them as one extended source with $e = 0.943$.

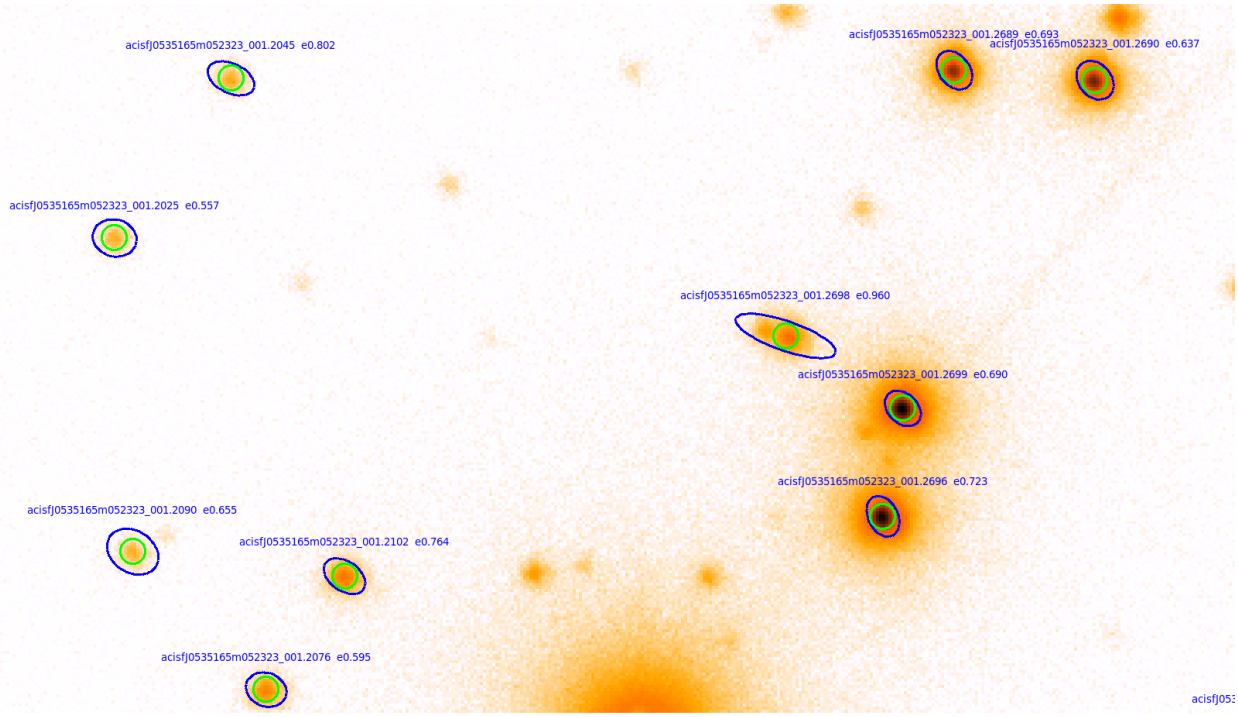


Figure 14: This image is part of the evt3 file acisfJ0535165m052323_001N020_evt3.fits. It includes many extended sources. It shows that the high eccentricity sources ($e > 0.9$, e.g. acisfJ0535165m052323_001.2698) are more likely consisted of more than one source, while lower eccentricity sources ($e < 0.9$) are more likely true extended sources.

4 Conclusion

A study of close pair and extended sources in the CSC2.0 was conducted, aiming to answer two questions:

- Are there actually single point sources listed as two or more separate sources in CSC2.0?
- Are there actually two or more separate point sources listed as a single source in CSC2.0?

The answer to the first question is "NO". There is NO single point source listed as two or more separate sources in CSC2.0. In the same cohort, every point source has one and only one entry in the catalog.

The answer to the second question is "YES". There are actually two or more separate point sources listed as a single extended source in CSC2.0. Most of these scenarios happen in the high eccentricity sources with $e > 0.9$. Sometimes a high proper motion point source was also listed as an extended source due to image stacking.

Sometimes the image process from evt2 to evt3 changed image quality and resolution and hence made an extended source looks like two or more separate sources.

Most of the lower eccentricity ($e < 0.9$) extended sources are true extended sources under the Chandra resolution.