Flaring X-ray Sources in the *Chandra* Archive

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Introduction

After 20 years, the *Chandra* archive contains several tens of thousands data sets harboring hundred of thousands X-ray point sources across every active chip, nearly all of which were not the intended target of the original observer. We are in the midst of a comprehensive search of the archive for any astrophysical objects that vary by a factor of >10 over short time scales to reveal unusual objects previously un/under-appreciated in X-ray timing studies. Here, we present some of our most spectacular X-ray flaring objects – three factor of ~100 flares in nearby galaxies, and a violent X-ray outburst from a Milky Way brown dwarf or M star.

The Plan

For each ACIS-S or ACIS-I observation in the archive, we ran *wavdetect* on all chips, and extracted the time-ordered events for each source detected. Starting with the first photon detected for each source, we searched for bursts of four photons by comparing the count rate within each 4-photon grouping to the global count rate for that source and determined if a statistically significant increase of at least 10 occurred during a 4-photon group. We then repeated this for 5-photon, 6-photon, up to 20-photon groupings to search for flares on a variety of photon grouping scales. This list was then culled of flare masqueraders, such as cosmic ray afterglows (CRAs), bad column glitches, and sources that were periodically dithered into a chip gap. For the remaining bona fide sources, we used *Vizier* to attempt to find counterparts at other wavelengths.

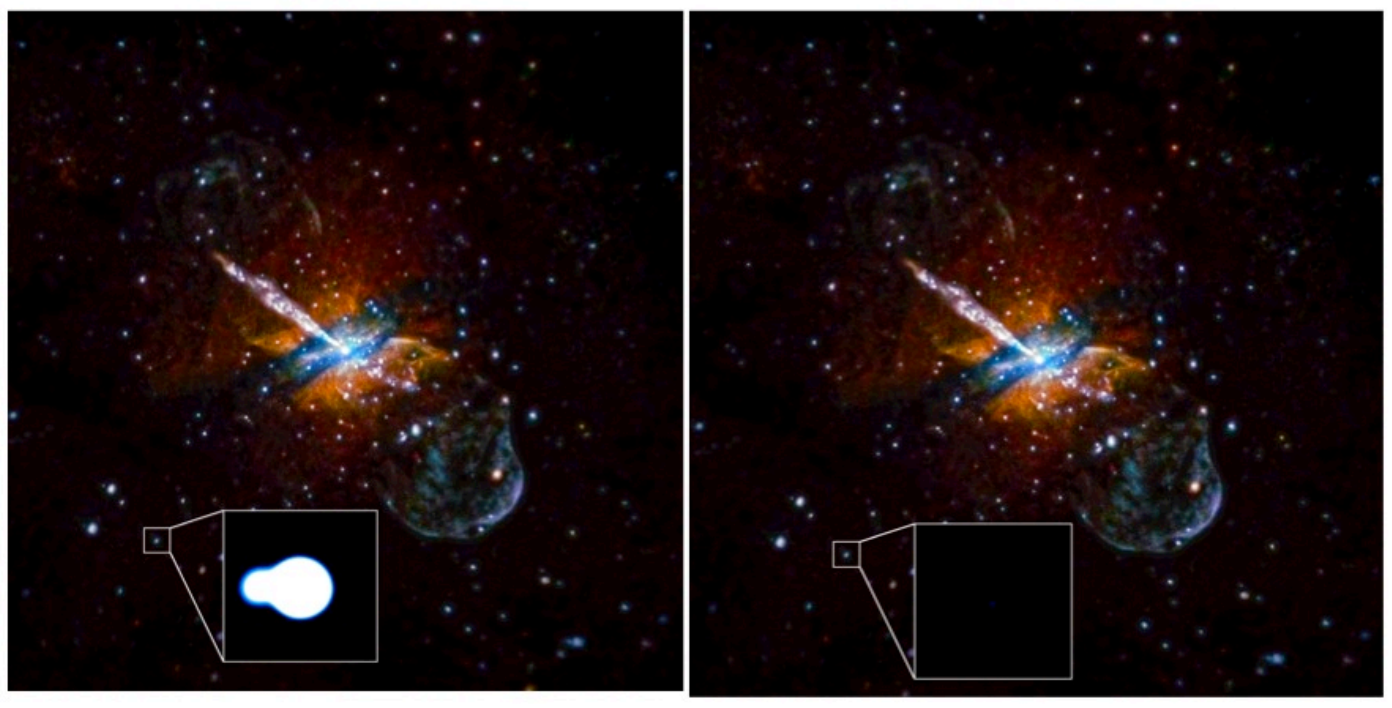


Figure 1: Chandra images of CXO J132552.7-430546 in NGC 5128 during a flare (*left*) and at its baseline value (*right*). Image courtesy NASA/CXC/UA/J. Irwin.

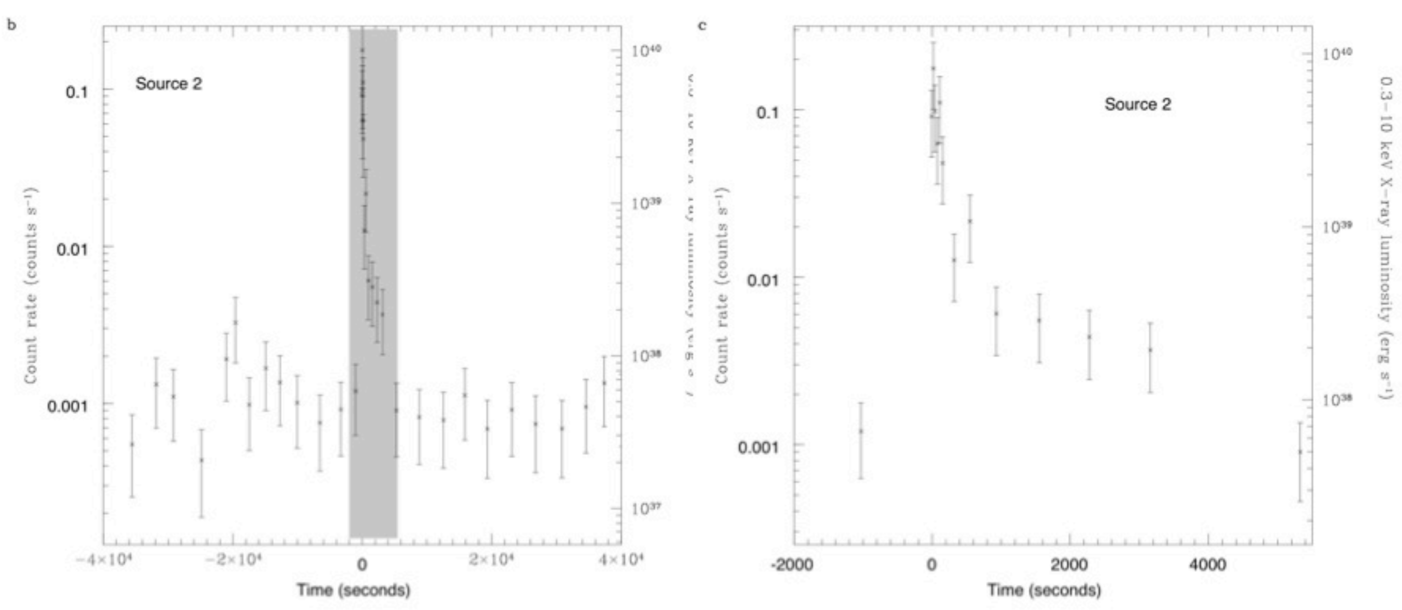


Figure 2: (*left panel*) Summed light curves of four flares observed in CXO J132552.7-430546, with the flare happening at time zero. A steep rise of >200 is seen in the first minute (*right panel*) of the flare before it decays back to the baseline value over the course of an hour (figures from Irwin et al. 2016, *Nature*, 538, 356).

Multiple Violent X-ray Flares in an Extragalactic Star Cluster

The X-ray source CXO J132552.7-430546 in NGC 5128 was observed to flare four times with *Chandra* (Figure 1), and once with *XMM-Newton* and *Swift* (not shown). The X-ray light curve of the four combined *Chandra* flares (Figure 2) reveals that the source increases its luminosity by over a factor of 200 to 10^{40} ergs s^{-1} in less than a minute before decaying back to its baseline value over the course of the next hour. The host of the X-ray flaring source is a globular cluster or ultracompact dwarf galaxy (UCD) orbiting NGC 5128 (Figure 3). On average, the source flares every ~1.7 days.

How Unique are These Flares?

The only previously-known astrophysical objects that (1) flare above the Eddington limit of a stellar-mass black hole (>10^{39} ergs s^{-1}) by (2) at least a factor 100 in (3) less than a minute (4) without destroying themselves are soft-gamma repeaters/anomalous X-ray pulsars (SGRs/AXPs). However the timing properties and total energy fluence of CXO J132552.7-430546 is quite different from SGRs/AXPs, and we conclude that CXO J132552.7-430546 is a new type of repeating, high-amplitude, energetic flare that is too rare to have a counterpart within the Milky Way.

What Are These Flares?

Possible explanations for the flares include (1) Eddington flares from intermediate mass black holes (IMBHs), (2) neutron star or stellar-mass black holes that periodically beam their emission toward us, and (3) neutron star/small black holes that somehow beat their Eddington limits by large amounts for very short periods of time. In addition, Shen (2019, *ApJ*, 871, L17) has suggested they are caused of the tidal stripping of a white dwarf by an IMBH.

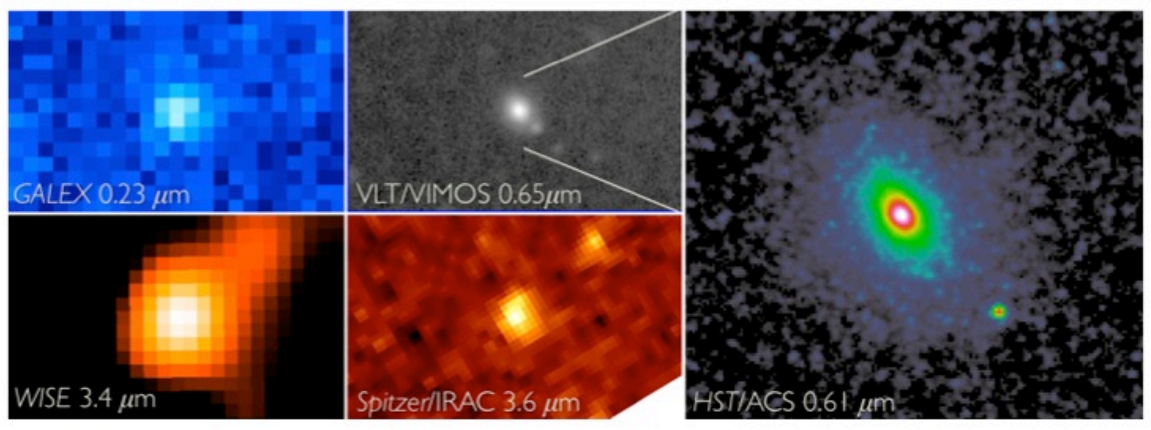


Figure 3: Montage of the star cluster in NGC 5128 harboring the flaring CXO J132552.7-430546 at various wavelengths. It is unclear if the star cluster is a globular cluster or an ultracompact galaxy. Our recent on-axis *Chandra* observation of the source indicates that the X-ray source is consistent with being in the center of the cluster.

Additional Violent X-ray Flares in Nearby Galaxies

We have also discovered two additional X-ray flaring objects in nearby galaxies: CXOU J124251.4+023835 in NGC 4636 (Irwin et al. 2016, *Nature*, 538, 356) and CXO J095524.2+690957 in M81 (Irwin et al., *in prep.*). CXOU J124251.4+023835 resides within a globular cluster of NGC 4636, and flared by a factor of >100 to almost 10^{41} ergs s^{-1} in less than a minute before decaying back to its baseline value, making it the most luminous event ever recorded in a globular cluster (Figure 4).

CXO J095524.2+690957 in M81 has been observed to flare over 10 times to ~70 times its baseline value before decaying quickly. Unlike the other two flaring sources in galaxies, it is not located in a globular cluster, but instead coincident with a bluish counterpart with M_V = –3.1 (southern object in magenta error circle in Figure 5).

Both sources appear to be very similar to CXO J132552.7-430546 in NGC 5128, indicating a small class of rare, violent, but non-destructive outbursts from compact objects in the local Universe.

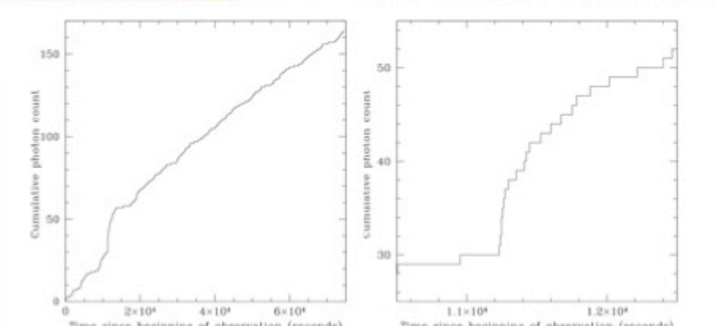
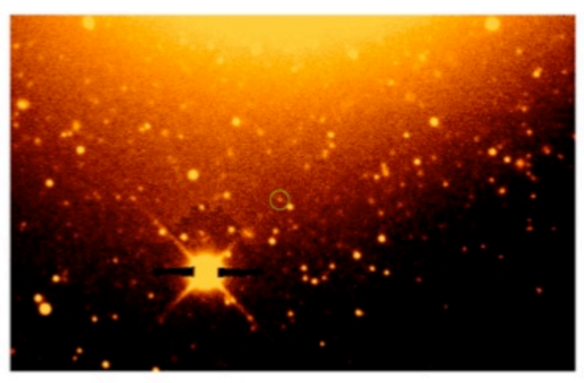


Figure 4: Cumulative X-ray photon arrival time plot for CXOU J124251.4+023835 in NGC 4636 showing the flare at the 11,000 sec mark (*above left*) and zooming in on the beginning of the flare where 6 photons were recorded in just 22 seconds (*above right*), a factor of 100 increase. (*below*) Globular cluster of NGC 4636 which harbors CXOU J124251.4+023835 (green circle).



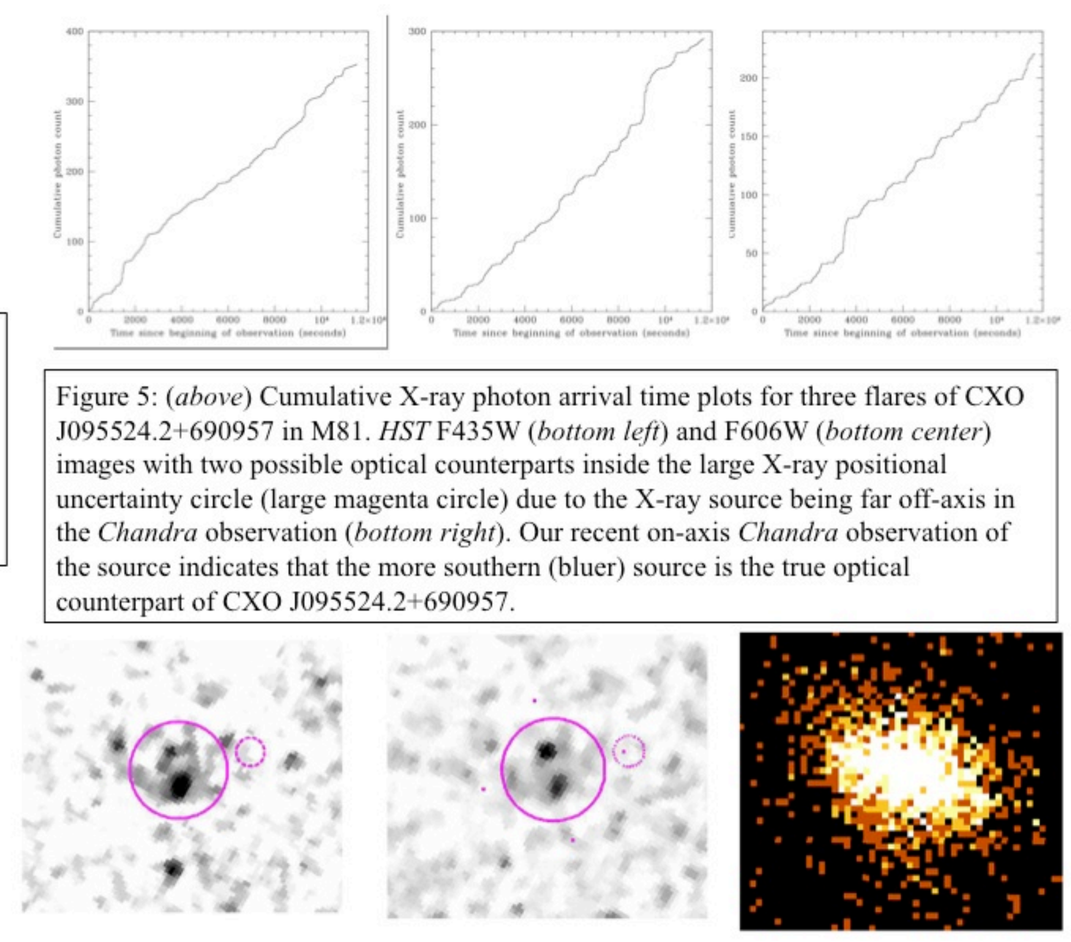
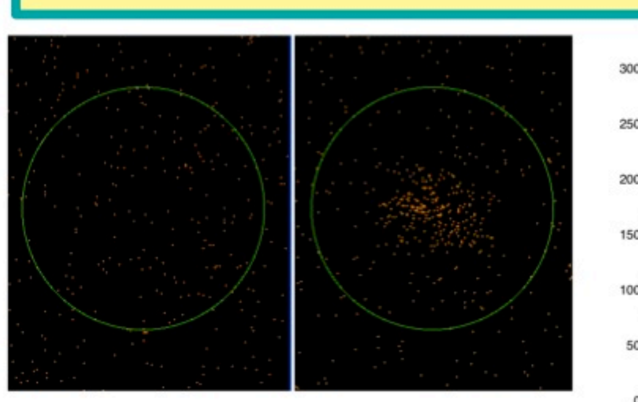


Figure 5: (*above*) Cumulative X-ray photon arrival time plots for three flares of CXO J095524.2+690957 in M81. *HST* F435W (*bottom left*) and F606W (*bottom center*) images with two possible optical counterparts inside the large X-ray positional uncertainty circle (large magenta circle) due to the X-ray source being far off-axis in the *Chandra* observation (*bottom right*). Our recent on-axis *Chandra* observation of the source indicates that the more southern (bluer) source is the true optical counterpart of CXO J095524.2+690957.



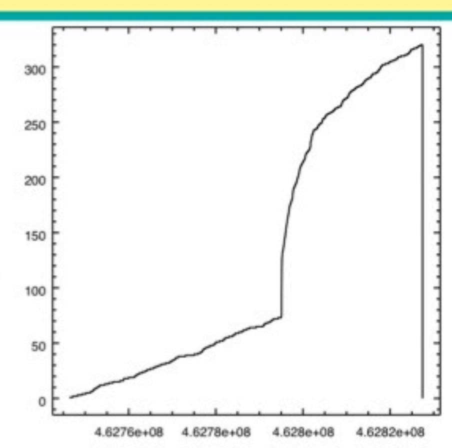


Figure 6: First 50 ksec of the *Chandra* observation (*left*) of XRT120830, for which only background photons were detected, followed by the turn on of the source (*center*). Then, in a 3.2 sec time frame, 3 photons were detected followed by 20 photons in the next 3.2 sec time frame. The source then declined in flux for the rest of the observation (*right*).

The Milky Way Brown Dwarf or M dwarf star XRT120830

Originally identified by Glennie et al. 2015 (*MNRAS*, 450, 3765) additional optical data on this source collected after 2015 indicates that the spectral type of the optical counterpart of XRT120830 is ambiguous – while it was detected at R=18.9 mag in Gaia DR1, it was undetected down to POSS R band (limiting magnitude = 20.9 mag). Given its 2MASS J = 18.6 mag, its J – R colors indicates it is either a M2.5V or an L1V brown dwarf. Either way, the source exhibited a phenomenal flare (Figure 6). If a brown dwarf at ~80 pc, the peak of the flare was L_X= 7 x 10^{31} ergs s^{-1}, by far the strongest flare seen in a brown dwarf. If it is an M2.5V star at ~900 pc, its proper motion of 74 mas yr^{-1} implies that it is moving at 330 km s^{-1}, suggesting it is a halo star. The inferred peak luminosity of 9 x 10^{33} ergs s^{-1} would be quite unexpected from an old star in the halo.

Summary and Future Work

So far, our X-ray timing survey has uncovered scores of previously-unknown flaring objects, primarily Milky Way stars, but also sources in nearby galaxies and sources of unknown distance and origin. Some of the sources remained undiscovered in the archive for over a decade before our survey. We will continue our search for more unique flaring examples as more data arrives in the archive and extend our survey to include other forms of extreme variability (eclipses, short-term periodic, etc.).