Searching for short-duration transients in the Chandra archive

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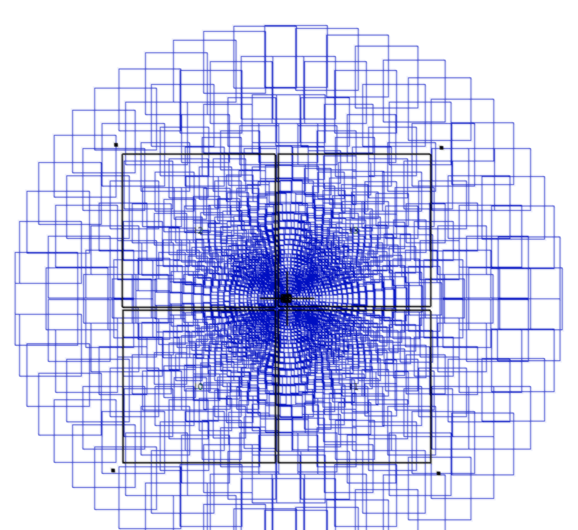
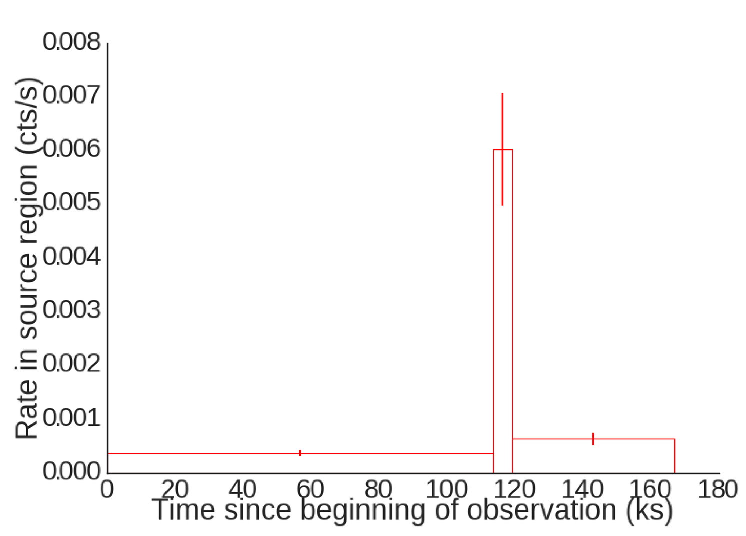
Abstract

The Chandra ACIS X–ray instrument is very well suited to study short transients, and indeed has occasionally detected some in the past (see for example Rutledge et al., 2000). However, no systematic search has been carried out up to now. The official Chandra Source Catalog (CSC, Evans et al., 2010) is optimized for steady and variable sources, but has poor sensitivity for transients of duration $\lesssim 1000s$. We have implemented a blind search for short-duration X-ray transients, and we have applied it to a suitable subsample of Chandra observations. Our pipeline uses both custom-written tools and tools from the official Chandra CIAO package. Based on the Bayesian Block algorithm of Scargle et al. (2013), it is time-scale-agnostic, i.e., can trigger on transients of any duration. We will describe our search and present our preliminary results.

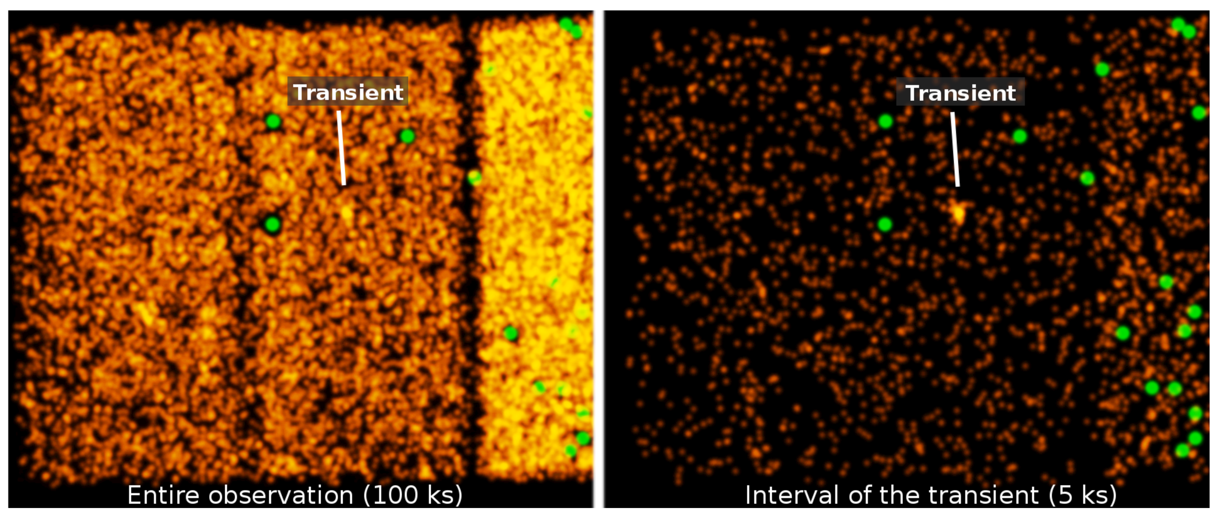
Our search: divide and conquer



We consider one observation at the time. We divide the field of view of Chandra in thousands of square regions, with an area following the variation of the PSF size with the off-axis angle. Here on the left we show an example for an ACIS-I observation, where we have magnified the size of the regions by 10 for visibility. The black rectangles represent the 4 CCDs of ACIS-I, while the cross marks the center of the field of view. The regions overlap significantly with each other, in order to avoid gaps in sensitivity. Each region is processed independently using the Bayesian Block algorithm (Scargle et al., 2013, BB). BB divides the events found within a region in time intervals (blocks) where the event rate is perceptively constant. We have modified BB to account for background variations and trends, so that it will detect count rate variations with respect to the background. For a given region, if no transient is present, BB will find one block covering the entire observation. If instead a transient is present, BB will typically find 3 intervals: before, during and after the transient, as shown here on the right. For all regions where more than one block is found, we then perform a source-detection procedure based on a likelihood analysis ("TS map") during the time interval with the largest rate (the interval of the transient). All candidates having a detection significance larger than 5 σ are then considered transient candidates and are kept for further inspection.



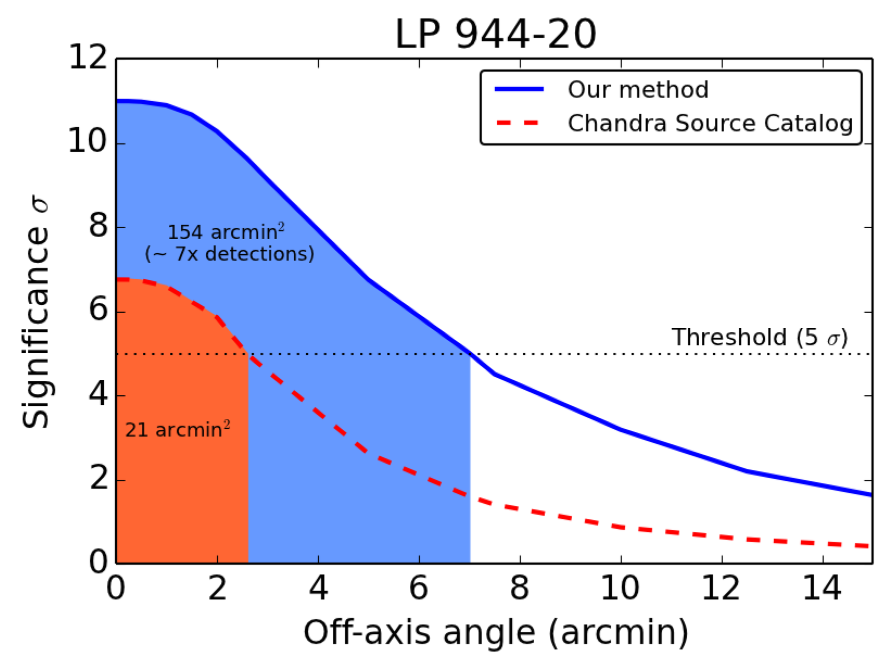
Example of a new Galactic transient



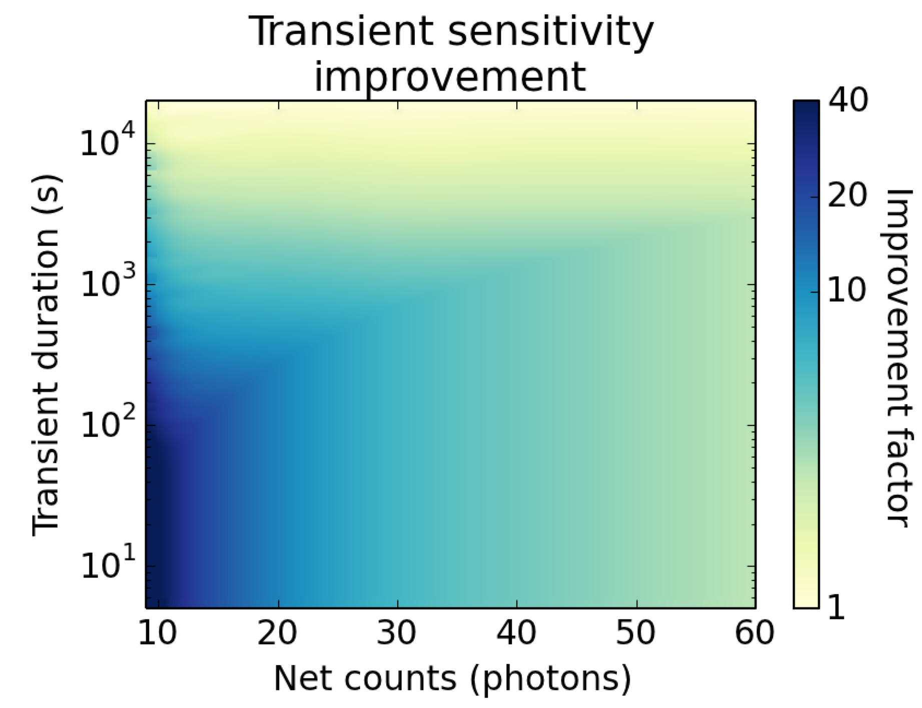
Left panel: image for the entire observation, right panel: image for the optimal interval found with the BB algorithm. The green circles represent known CSC sources. The transient is evident in the right panel, while it is drowned in the background on the left. Its nature is still being investigated, but it is probably a Galactic source given its latitude of $b \sim -4$ deg.

Sensitivity improvement over CSC

During a flare from the Brown Dwarf LP 944-20 Chandra detected 15 counts in $\sim 2760s$, during a 44 ks long observation (Rutledge et al., 2000). The source was detected at $\sim 7\ \sigma$ over the entire observation, and was later recognized as a transient. The source was on-axis, with a 90% containment radius for the PSF of $ECF_{90} \sim 1$ arcsec. **What happens if Chandra detects a similar transient off-axis?**



The PSF gets worse going off axis, hence the size of the source region increases and the signal-to-noise ratio decreases, decreasing the source significance. With an analysis similar to the one used in the CSC (red line), which considers the entire observation at once, we would detect the transient from LP 944-20 above 5 σ up to an off-axis angle of $r_{5\sigma,csc} \sim 2.6$ arcmin. Our analysis instead finds first the time interval in which the transient is active (as explained here on the left). Using such interval we detect LP 944-20 up to an off-axis angle of $r_{5\sigma} \sim 7$ arcmin (blue line).

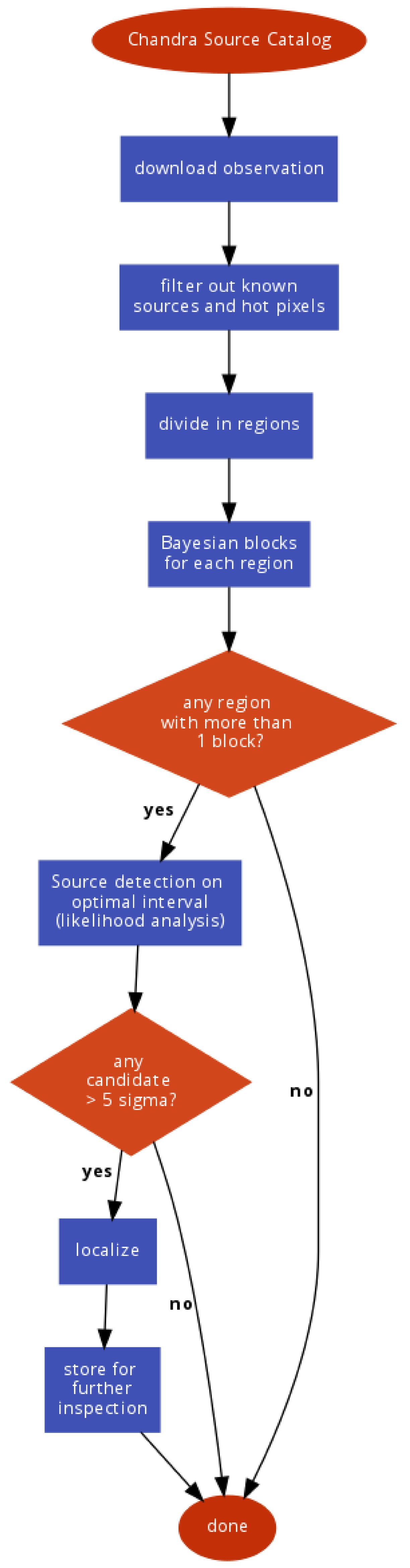


We define the improvement over the CSC analysis as the ratio $I = s(r_{5\sigma})/s(r_{5\sigma,csc})$, where $s(r_{5\sigma})$ is the solid angle corresponding to the largest off-axis angle where the source is detected $> 5\ \sigma$. In the case of LP 944-20 we find $I \simeq 7$. In the right panel we show I for different fluences and durations, considering a typical observation of 20 ks. I is large for durations $< 10^3$ and from moderate to small count fluences ($\sim<$ 40 counts). Therefore, by optimizing the analysis on the appropriate time interval we are able to improve the sensitivity for faint transients with duration $< 10^3$ s by more than one order of magnitude.

Work in progress

We have applied our new search to all $\sim$ 4500 ACIS imaging observations included in the Chandra Source Catalog, finding over 300 transient candidates. The analysis to confirm these candidates is ongoing.

Pipeline



Steps of our search pipeline.

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References

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