**MIT Kavli Institute** **Chandra X-Ray Center**

**MEMORANDUM**
February 13, 2008

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| **To:** | Jonathan McDowell, SDS Group Leader |
| **From:** | Glenn E. Allen, SDS |
| **Subject:** | acis_find_afterglow |
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# 1 acis_find_afterglow

## 1.1 Description

A cosmic-ray "afterglow" is produced when a large amount of charge is deposited on a CCD by a cosmic ray. Most of the charge is clocked off of the CCD in a single frame. However, a small amount can be captured in charge traps, which release the charge relatively slowly. As a result, a sequence of events can appear in a single detector pixel over a few frames as the trapped charge is released.

To date, two algorithms have been used by the CXC to identify cosmic-ray afterglows. The first algorithm was implemented in the CIAO tool acis_detect_afterglow and used for pipeline processing from the summer of 2000 to the fall of 2004. This algorithm searches for occasions when events are detected in two or more consecutive frames on the same CCD pixel. While the events are flagged as potential cosmic-ray afterglows and excluded from Level 2 event-data files, the corresponding pixels are not included in the observation-specific bad-pixel file. This algorithm finds many afterglow events, but at the expense of discarding X-ray events associated with real astrophysical sources. The fraction of the source events that are discarded depends on the brightness and variability of the source.

In an attempt to minimize the loss of source events, another algorithm was developed and implemented in the CIAO tool acis_run_hotpix, which is a wrapper around the tools acis_find_hotpix, acis_classify_hotpix and acis_build_badpix. The second algorithm searches for detector pixels that have an unusually large number of events. Suspicious pixels are added to the observation-specific bad-pixel file only if the neighboring pixels do not have a significant excess of events. This condition helps insure that events associated with dithered sources are not discarded. Events associated with afterglows are flagged and excluded from Level 2 event-data files. The newer algorithm has been used for pipeline processing (and reprocessing) since the fall of 2004. While it is relatively gentle on astrophysical sources, it does let some afterglows "slip through the cracks." The afterglow detection efficiency depends on the number of events in the afterglow. The efficiency declines quickly as the number of events in an afterglow drops below about eight.

This spec describes a third afterglow-detection algorithm that is designed to enhance the detection efficiency for afterglows that have as few as four events to remain gentle for real astrophysical sources. The principal change between the second and third afterglow-detection algorithms is that the third algorithm searches for afterglows using the events in a short, sliding time window instead of the entire duration of an observation.

## 1.2 Input

1. Level 0 or 1 event-data files (acis*evt0.fits, acis*evt1.fits)
2. A Level 1 observation-specific bad-pixel file (acis*bpix1.fits)
3. A Level 1 exposure statistics file (acis*stat1.fits)

## 1.3 Output

1. An updated observation-specific bad-pixel file

## 1.4 Parameters

1. infile,s,a,“”,,,“Name of input event-data file(s)”
2. outfile,s,a“”,,,“Name of output bad-pixel file”
3. badpixfile,s,a,“”,,,“Name of input bad-pixel file”
4. maskfile,s,a,“”,,,“Name of input mask file”
5. statfile,s,a,“”,,,“Name of input exposure-statistics file”
6. expnowindow,i,h,10,1,100,“Number of frames in the sliding time window”
7. probthresh,r,h,0.001,1.0e-10,0.1,“Minimum post-trials significance of potential afterglows (1 sigma = 0.159, 2 sigma = 0.0228, and 3 sigma = 0.00135)”
8. cntthresh,i,h,2,4,10,“Minimum number of events in an afterglow”
9. clobber,b,h,“no”,,,“Overwrite output file if it exists?”
10. verbose,i,h,0,0,5,“Amount of messages produced (0=none, 5=a lot)”
11. mode,s,h,“ql”,,,

## 1.5 Processing

1. Verify that the input files exist.
2. If clobber=“no”, then verify that the output files do not exist.
3. Verify that the input event-data file has READMODE=“TIMED”. If READMODE is not equal to “TIMED”, then exit with an error message.
4. Verify that the values of the parameters expnowindow, probthresh and cntthresh are in the valid ranges for these parameters.
5. Create an array $A$ with dimensions $10 \times 1024 \times 1024$ to be used to mark suspicious pixels. Each element of $A$ is preset to zero.
6. Identify which CCDs are “valid.” A CCD is defined to be valid if there is at least one event on the CCD in the input event-data file(s).
7. Loop over a sliding EXPNO window. The first window includes the frames $\mathrm{EXPNO}_{\mathrm{min}} \le \mathrm{EXPNO} \le \mathrm{EXPNO}_{\mathrm{min}} + \mathrm{expnowindow}$. The second window includes $\mathrm{EXPNO}_{\mathrm{min}} + 1 \le \mathrm{EXPNO} \le \mathrm{EXPNO}_{\mathrm{min}} + \mathrm{expnowindow} + 1$. The last window includes $\mathrm{EXPNO}_{\mathrm{max}} - \mathrm{expnowindow} \le \mathrm{EXPNO} \le \mathrm{EXPNO}_{\mathrm{max}}$.
8. For each sliding window, mark suspicious pixels. A suspicious pixel is one on which two or more events occur in the same sliding window. That is, if the pixel at $(\mathrm{CCD\_ID}, \mathrm{CHIPX}, \mathrm{CHIPY}) = (c, x, y)$, contains two or more events in a window, then set $A[c, x, y] = 1$.

9. After every sliding window has been used to mark suspicious pixels, loop over the suspicious pixels. For each suspicious pixel

   i. Determine $\mathrm{EXPNO}_{\mathrm{start}}$, the first frame of the potential afterglow. Loop through the events on the suspicious pixel. If the difference between two consecutive events on the pixel

   $$\mathrm{EXPNO}_{i+1} - \mathrm{EXPNO}_i \leq \mathrm{expnowindow}, \tag{1}$$

   then $\mathrm{EXPNO}_{\mathrm{start}} = \mathrm{EXPNO}_i$. Once $\mathrm{EXPNO}_{\mathrm{start}}$ has been found, stop looping over the events on the pixel.

   ii. Determine $\mathrm{EXPNO}_{\mathrm{stop}}$, the last frame of the potential afterglow. Loop through the events on the suspicious pixel that have EXPNO greater than $\mathrm{EXPNO}_{\mathrm{start}}$. If the difference between two consecutive events on the pixel

   $$\mathrm{EXPNO}_{i+1} - \mathrm{EXPNO}_i > \mathrm{expnowindow}, \tag{2}$$

   then $\mathrm{EXPNO}_{\mathrm{stop}} = \mathrm{EXPNO}_i$. Once $\mathrm{EXPNO}_{\mathrm{stop}}$ has been found, stop looping over the events on the pixel. If the last event on the pixel is processed before equation **??** is satisfied, then $\mathrm{EXPNO}_{\mathrm{stop}}$ is equal to the largest value of EXPNO for the pixel.

   iii. Calculate $N_{\mathrm{evt}}$, the number of events in the potential afterglow. If the suspicious pixel has $(\mathrm{CCD\_ID}, \mathrm{CHIPX}, \mathrm{CHIPY}) = (c, x, y)$, then $N_{\mathrm{evt}}$ is equal to the number of events that satisfy the conditions

   $$\mathrm{CCD\_ID} = c, \tag{3}$$
   $$\mathrm{CHIPX} = x, \tag{4}$$
   $$\mathrm{CHIPY} = y \text{ and} \tag{5}$$
   $$\mathrm{EXPNO}_{\mathrm{start}} \leq \mathrm{EXPNO} \leq \mathrm{EXPNO}_{\mathrm{stop}}. \tag{6}$$

   iv. Calculate $N_{\mathrm{node}}$, the number of events on the same node as the suspicious pixel. If the suspicious pixel has $(\mathrm{CCD\_ID}, \mathrm{NODE\_ID}) = (c, n)$, then $N_{\mathrm{node}}$ is equal to the number of events that satisfy the conditions

   $$\mathrm{CCD\_ID} = c \text{ and} \tag{7}$$
   $$\mathrm{NODE\_ID} = n. \tag{8}$$

   v. Determine $N_{\mathrm{pix}}$, the total number of valid pixels on the same node as the suspicious pixel. A valid pixel is one for which the $\mathrm{SAMP\_CYC} \geq 1$ in the input mask file. Known bad pixels and columns are not excluded (unless they have $\mathrm{SAMP\_CYC} = 0$) because these pixels and columns are searched for afterglows.

   vi. Calculate $N_{\mathrm{frame}}^{\mathrm{aft}}$, the number of valid frames in the potential afterglow. If the suspicious pixel has $\mathrm{CCD\_ID} = c$, then $N_{\mathrm{frame}}^{\mathrm{aft}}$ is equal to the number of rows in the input exposure statistics file that satisfy the conditions

   $$\mathrm{CCD\_ID} = c, \tag{9}$$
   $$\mathrm{EXPNO} \geq \mathrm{EXPNO}_{\mathrm{start}} \text{ and} \tag{10}$$
   $$\mathrm{EXPNO} \leq \mathrm{EXPNO}_{\mathrm{stop}}. \tag{11}$$

   If no frames are missing, then $N_{\mathrm{frame}}^{\mathrm{aft}} = \mathrm{EXPNO}_{\mathrm{stop}} - \mathrm{EXPNO}_{\mathrm{start}} + 1$. Otherwise, the value of $N_{\mathrm{frame}}^{\mathrm{aft}}$ is smaller.

   vii. Calculate $N_{\mathrm{frame}}^{\mathrm{tot}}$, the total number of valid frames. If the suspicious pixel has $\mathrm{CCD\_ID} = c$, then $N_{\mathrm{frame}}^{\mathrm{tot}}$ is equal to the number of rows in the input file that satisfy the conditions

   $$\mathrm{CCD\_ID} = c \text{ and} \tag{12}$$
   $$\mathrm{EXPNO} \geq 3. \tag{13}$$

viii. Calculate $N_{\rm exp}$, the expected number of events on the pixel during the potential afterglow.

$$N_{\rm exp} = \left(\frac{N_{\rm node}}{N_{\rm pix}}\right)\left(\frac{N_{\rm frame}^{\rm aft}}{N_{\rm frame}^{\rm tot}}\right). \tag{14}$$

ix. Calculate $P_{\rm pre}$, the pre-trials probability of obtaining $N_{\rm evt}$ events in the potential afterglow when the expected number of events is $N_{\rm exp}$.

$$P_{\rm pre} = 1 - \left[\left(\sum_{i=0}^{N_{\rm evt}-1} \frac{N_{\rm exp}^i}{i!}\right) + \frac{1}{2}\frac{N_{\rm exp}^{N_{\rm evt}}}{N_{\rm evt}!}\right] e^{-N_{\rm exp}}. \tag{15}$$

x. Calculate $N_{\rm trial}$, the number of trials performed. Here

$$N_{\rm trial} = (4N_{\rm pix}N_{\rm ccd})\left(N_{\rm frame}^{\rm tot} - {\rm expnowindow} + 1\right), \tag{16}$$

where $N_{\rm ccd}$ is the number of valid CCDs. This estimate of $N_{\rm trial}$ is really an upper limit on the number of trials. The actual number of trials includes only the of "independent" searches. Adjacent windows in the sliding EXPNO window are not independent because they overlap. Therefore, a lower limit on $N_{\rm trial}$ can be computed by considering only those windows that do not overlap (i.e. $N_{\rm trial} = (4N_{\rm pix}N_{\rm ccd})\left(N_{\rm frame}^{\rm tot} - {\rm expnowindow} + 1\right)/({\rm expnowindow} + 1)$). Since the actual value of $N_{\rm trial}$ can be difficult to determine, equation 16 is used here since it is the most conservative (i.e. the largest) value.

xi. Calculate $P_{\rm post}$, the post-trials probability of obtaining a value $P$ at least as small as $P_{\rm pre}$ after performing $N_{\rm trial}$ searches.

$$P_{\rm post} = 1 - (1 - P_{\rm pre})^{\rm N_{trial}}. \tag{17}$$

xii. If $P_{\rm post} <$ probthresh and $N_{\rm evt} \geq$ cntthresh, then write the information about the afterglow to the output observation-specific bad-pixel file. The output values of SHAPE, COMPONENT, CHIPX and CHIPY are consistent with their usual definitions. The output value of TIME is given by

$$\rm TIME = TIME_{start} - TIMEPIXR \times TIMEDEL - FLSHTIME \tag{18}$$

(i.e. the time at the beginning of the $\rm EXPNO_{start}$ frame), where TIMEPIXR, TIMEDEL and FLSHTIME are keywords in the exposure statistics file and $\rm TIME_{start}$ is the TIME in the input exposure-statistics file that is associated with EXPNO = $\rm EXPNO_{start}$ and CCD_ID = $c$. The output value of TIME_STOP is given by

$$\rm TIME\_STOP = TIME_{stop} + (1 - TIMEPIXR) \times TIMEDEL \tag{19}$$

(i.e. the time at the end of the $\rm EXPNO_{stop}$ frame), where $\rm TIME_{stop}$ is the TIME in the input exposure-statistics file that is associated with EXPNO = $\rm EXPNO_{stop}$ and CCD_ID = $c$. The output value of STATUS has bit 15 (of 0–31) set for afterglows. Other STATUS bits may be set to one as well if the pixel is bad for other reasons.

xiii. Repeat steps 9 through 9, as necessary, for the same suspicious pixel. That is, if there are additional events on the pixel that have exposure numbers EXPNO > $\rm EXPNO_{stop}$, then steps 9 through 9 are repeated as many times as necessary until all of the events on the pixel have been processed. It is necessary to do so because one pixel may have more than one potential afterglow.

In the standard data-processing pipeline, the tool acis_find_afterglow is run after the observation-specific bad-pixel file (acis*bpix1.fits) has been created because acis_find_afterglow updates this file. After the file has been updated, the tool acis_build_badpix is rerun to insure, if necessary, that pixels adjacent to afterglow events are marked as "bad." The tool acis_process_events is run after the bad-pixel file has been updated since this file is used as input.

At least for the time being, the primary and secondary sets of data for interleaved mode observations are processed separately.

### 1.6 TBD

1. Modify the spec, if necessary, to insure that the algorithm does not discard real x-ray events.
2. Optimize the default values of expnowindow and cntthresh.