Detecting sources in Chandra X-ray images using PWDetect V 1.3.2

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1 Introduction

PWDetect is the wavelet-based source detection code for Chandra X-ray data developed at the Osservatorio Astronomico di Palermo (OAPA). It performs a multiscale analysis of the data, allowing detection of both pointlike and moderately extended sources in the entire field of view. Various Chandra detectors are supported: HRC-I, ACIS-I, and individual ACIS chips (from both ACIS-I and ACIS-S); analysis of HRC-S images is not supported. This document describes briefly how to use PWDetect, and the meaning of its inputs and outputs.

PWDetect needs as input a valid Chandra FITS event file, and its associate FITS exposure map (mandatory), the latter binned to 2 arcsec pixels. The exposure map is strictly needed since it contains important information used throughout the analysis. It should be computed using the CIAO task mkexpmap.

For seasoned CIAO users only (others may skip this single paragraph safely): The input event list is not read using the DataModel interface, and therefore filtering "on the fly" is not possible. Any time or energy filtering must be applied before calling PWDetect (and coherently to both event file and exposure map). We however discourage the use of spatial filters (sub-images), that may cause PWDetect to misidentify the image border and produce a large number of spurious detections.

PWDetect uses the parameter file pwdetect.par to read/save its parameters. This file must reside in the current directory, and its name must not be changed. Command-line parameters will not work, but if you don't like interactive parameter setting you may use the CIAO 'pset' command, as with any other CIAO parameter file (see Sect.4 for examples).

Beside input/output file names, PWDetect requires two most important input parameters to be set, namely the detection threshold and the maximum scale to be used in the analysis. The number of expected spurious detections depends sensitively on the choice of these parameters, and on the image integrated background. Plots describing this dependence are available for both the HRC-I (Figure 1) and ACIS-I (Figure 2) Chandra instruments.

2 Input parameters

This section describes all parameters needed by PWDetect (stored in parameter file "pwdetect.par"):

- Input file name (parameter *inpfile*): a standard Chandra FITS event list

- Exposure map file name (parameter *expfile*): an exposure map for the given observation, created with mkexpmap, of size 2048x2048 and with 2-arcsec pixels. To make it, use

```
pset mkexpmap xygrid="0.5:32768.5:#2048,0.5:32768.5:#2048"
```
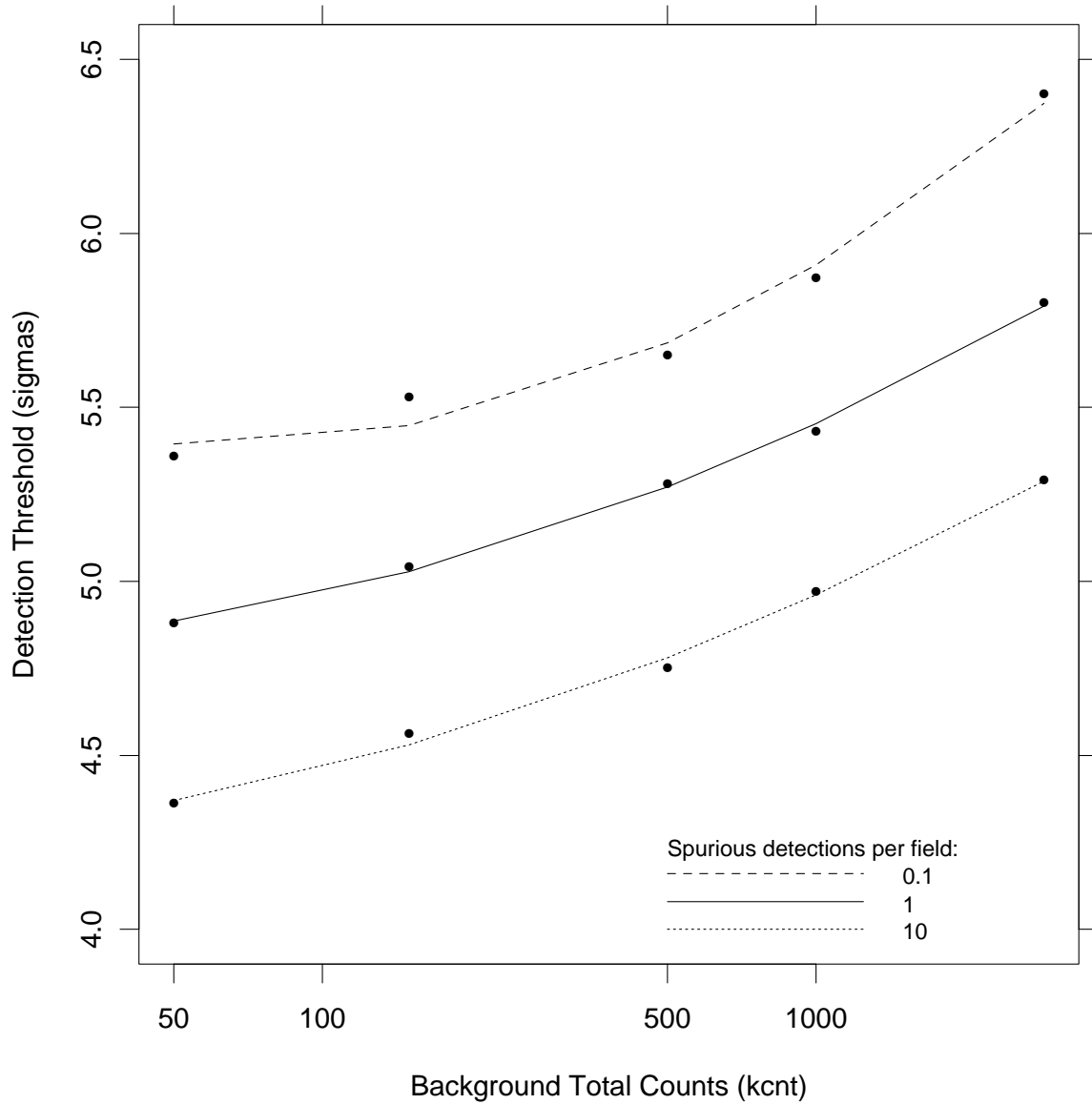
HRC-I -- Simulation results

Figure 1: PWDetect detection thresholds, for Chandra HRC-I data, as a function of total number of background counts, and corresponding to 0.1, 1, and 10 spurious detections per field.
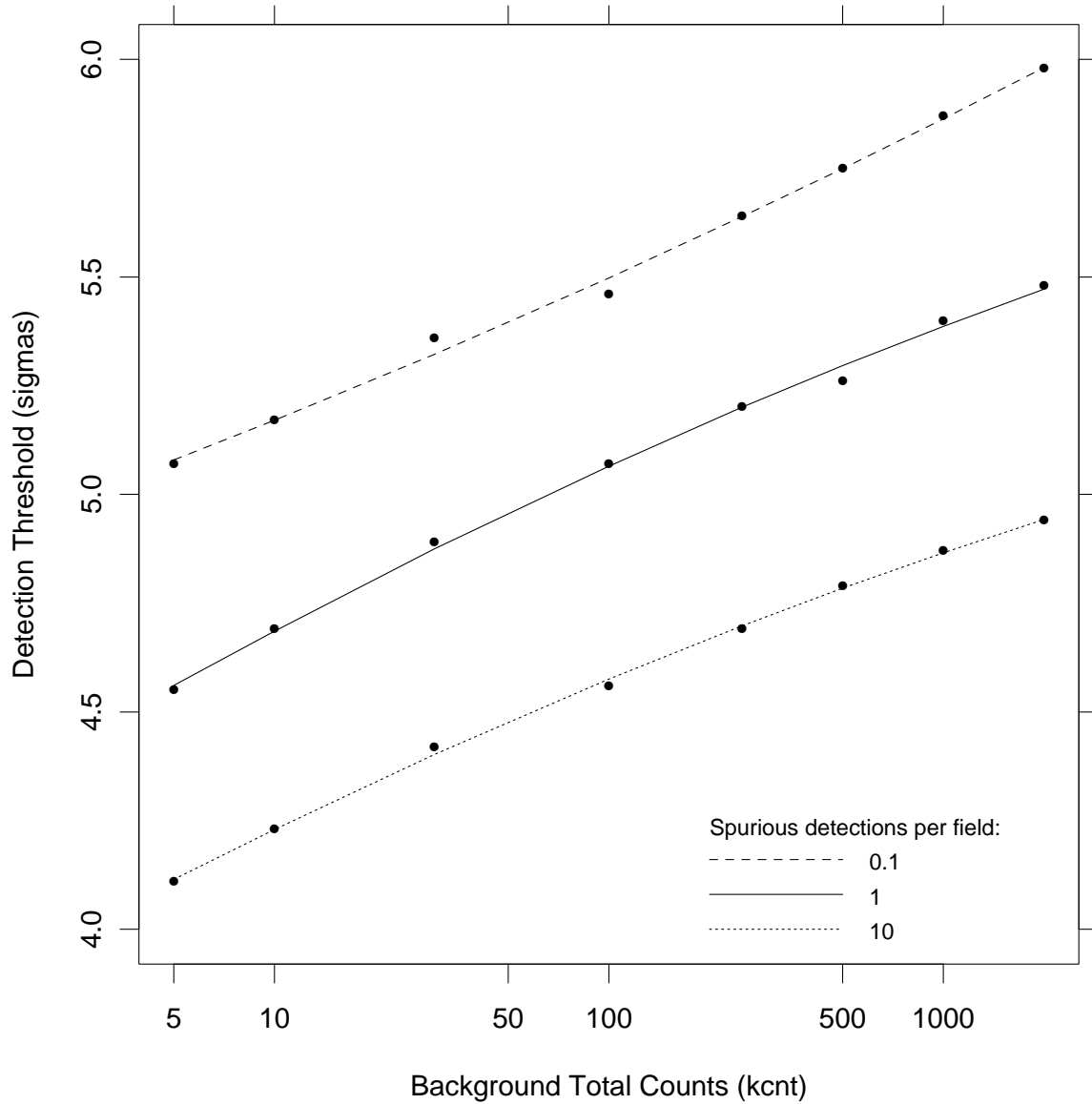
Figure 2: PWDetect detection thresholds, for Chandra ACIS-I data, as a function of total number of background counts, and corresponding to 0.1, 1, and 10 spurious detections per field.

for HRC-I, and

```
pset mkexpmap xygrid="0.5:8192.5:#2048,0.5:8192.5:#2048"
```

for ACIS-I. The same exposure map can be used when analyzing different ACIS chips in single-chip mode (see below).

- First threshold significance for detection (parameter *sigthresh1*): the initial detection threshold, used in the first search for candidate sources. Units are equivalent gaussian sigmas. Its recommended value should be at least 1.0 lower than the final threshold.

- Final threshold significance for detection (parameter *sigthresh2*): the final detection threshold, in equivalent gaussian sigmas. Its recommended value depends sensitively on the desired number of spurious detections per field, the background level, and detector. See Figures 1-2.

- Maximum wavelet scale (parameter *maxscale*): the event list dataset is searched for sources at various spatial scales. The smallest scale is set to 0.25 arcsec for HRC, and to 0.5 arcsec for ACIS, to adequately sample the Chandra PSF. The largest scale can be chosen by the user, up to a value of 181 arcsec. Note that the scales actually used by PWDetect are all powers of sqrt(2), and other values will be rounded to the nearest power of sqrt(2). The recommended (best tested) value of the maximum wavelet scale is 16 arcsec. This value was also used to produce the plots of detection threshold vs. background mentioned above.

- Detection at a single scale (parameter *onescale*): whether or not the detection procedure must be run at a single wavelet scale (the maximum scale), or over a range of scales (default). Mostly used to handle very difficult cases (very crowded fields, mixing of pointlike and extended sources, etc.).

- Additional edge margin (parameter *edgemargin*): correction to the automatically-determined position of the image border (positive outwards, negative inwards), if for some reason the automatic border is found to be unsatisfactory (e.g., a very bright source along the border may mislead the automatic procedure; can be checked using the ds9 region file "bounds.ds9"). Values exceeding few arcsec might lead to improper edge correction, however, with many spurious detections.

- Relative exposure threshold (parameter *relthr*): minimum (relative) exposure-map value for inclusion in background computation. Used to interpolate over CCD gaps. To analyze normal datasets, leave it to its recommended default of 0.9.

- ACIS single chip mode flag (parameter *Single_chip_mode*): while ACIS-I, with its four adjacent front-illuminated chips can be analyzed with PWDetect as a single detector (Single_chip_mode = 0), this is not the case for the alternating front- and back-illuminated chips of ACIS-S. In this case, the individual chips need to be analyzed separately (Single_chip_mode = 1). If the user needs, also individual ACIS-I chips may be analyzed using this option.

- ACIS single chip identifier (parameter *nchip*): if the single-chip mode is set, this is the number of the ACIS chip to analyze.

- Output source list filename root (parameter *srcfile*): the root file name for detected source lists (and overlay).

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- Output background filename root (parameter *bkgfile*): the root file name for output background maps.

- Output log file name (parameter *logfile*): file name for a short log of PWDetect run.

- Live show (parameter *liveshow*): instructs PWDetect to show visually (using the "ds9" display with "xpa" commands) its intermediate products. Its functionality depends on the availability of the ds9 program, external to PWDetect. Setting liveshow=1 will impact somewhat on PWDetect performance.

- Energy band (parameter *eband*): energy used to compute the instrument PSF. Not currently used.

- Functioning mode (parameter *mode*): either "ql" (i.e., query and learn), or "h" (hidden). Whether or not input parameters must be queried interactively, and saven in the pwdetect.par file, or go ahead with parameter values found in the pwdetect.par file (batch mode).

3 PWDetect products

PWDetect produces a number of files as output in the working directory, as described below (the first 3-4 items include fundamental products, which must be checked in all cases; the latter two need only to be examined in problematic cases).

1. a list of detected sources (root_src, root_src.fits), in both ASCII and FITS format, including various computed source properties (position, counts, count rate, size, exposure time, background value, etc.).

2. a DS9-style region file (root_overlay.ds9), for ready visualization of detected sources using the DS9 display. Also, two overlay files (bounds.ds9, bgbounds.ds9) are created to show the region being analyzed by PWDetect. The latter file pertains to the background map.

3. a short log file.

4. two FITS background maps: a zero-order map (bkgroot0.fits), and a second map (bkgroot.fits) with bright sources removed. Units are counts/square arcsec.

5. an ASCII list describing at which individual scales was a source detected (root_signif), and at which significance level.

6. a few ASCII files listing results from intermediate detection steps, mostly for handling of difficult cases where the final products are unsatisfactory (det_merged, det_matched, det_matches, det_best), and their equivalents for display purposes (det_merged0.ds9, det_matched0.ds9, det_best0.ds9). Also, a file listing calibrated PSF non-gaussianity count and flux corrections, instrument dependent, already applied to the final detections (psf_corrections).

The content of the detected source file (root_src[.fits]) is as follows:

```
Column # 1: RA          (deg)          Right Ascension (decimal degrees)
Column # 2: RA_err      (deg)          Error on RA (decimal degrees)
Column # 3: Dec         (deg)          Declination (decimal degrees)
Column # 4: Dec_err     (deg)          Error on Dec (decimal degrees)
```

```
Column # 5: X              (pix)            Position X (physical pixels)
Column # 6: X_err          (pix)            Error on X (physical pixels)
Column # 7: Y              (pix)            Position Y (physical pixels)
Column # 8: Y_err          (pix)            Error on Y (physical pixels)
Column # 9: Offax          (arcmin)         Off-axis angle
Column #10: Det_scale      (arcsec)         Highest-significance detection scale
Column #11: Src_area       (arcsec^2)       Approximate source (core) area
Column #12: Signif                          Detection significance (sigmas)
Column #13: Src_cnt                         Total source counts
Column #14: Cnt_err                         Error on source counts
Column #15: Bkg_cnt                         Background counts in source core area
Column #16: Src_ct_rate    (cts/sec)        Source count rate
Column #17: Src_rate_err   (cts/sec)        Error on source count rate
Column #18: Src_flux       (cts/sec/cm^2)   Source flux
Column #19: Src_flux_err   (cts/sec/cm^2)   Error on source flux
Column #20: Bkg_rate    (cts/sec/arcsec^2)  Background count rate
Column #21: Exp_time       (sec)            Source weighted exposure time
Column #22: Size           (arcsec)         Source size
Column #23: Siz_err        (arcsec)         Error on source size
Column #24: Extent                          Source extent (relative to PSF)
Column #25: Ext_err                         Error on source extent
Column #26: Src_num                         PWDetect source number
```

4   Sample session

First, PWDetect parameters must be set. This may be done interactively (if parameter "mode" is set to "ql"), or not (parameter "mode" set to "h"). To set PWDetect parameters non-interactively, one may issue the commands:

```
pset pwdetect inpfile=event_list.fits
pset pwdetect expfile=exposure_map_1.0keV.fits
pset pwdetect sigthresh1=4.2
pset pwdetect sigthresh2=5.2
pset pwdetect maxscale=16
pset pwdetect onescale="n"
pset pwdetect edgemargin=7
pset pwdetect relthr=0.9
pset pwdetect Single_chip_mode=0
pset pwdetect srcfile="det"
pset pwdetect bkgfile="bkgmap"
pset pwdetect logfile="det_log"
pset pwdetect liveshow=0
pset pwdetect mode="h"
```

In most instances, only the first four-five parameters above need to be set, while all others may be safely kept at their default values. To choose an appropriate detection threshold, the number of total image counts (good approximation for all background counts) must be known. This can be

done using e.g. the CIAO commands (in the case of an ACIS-I dataset named "event_list.fits"):

```
dmstat "event_list.fits[ccd_id=0,1,2,3][cols x]"
pget dmstat out_good
```

The number of counts obtained has to be used with the calibrations shown in Figures 1 or 2 to determine the (final) detection threshold for the desired number of spurious detections.

A sample PWDetect session will look like this:

```
prompt> ./pwdetect_1.3.2.lnx
 Thu Jul 26 19:03:22 2001


                    Welcome to PWDETECT V1.2
              Palermo Wavelet Detect for CHANDRA data


Input file name (event_list.fits):
Final threshold significance for detection (5.2):
Maximum wavelet scale (arcsec) [powers of sqrt(2)] (16):
Detection at Maximum Scale only (y/n) (n):
Additional edge margin (arcsec) (7):
Relative exposure threshold (0-1, recommended: 0.9) (0.9):
ACIS single chip mode flag (0=Full ACIS-I, 1=Single Chip) (0):
ACIS single chip Identifier (0 to 9) (0):
Output source list filename root (det):
Output background filename root (bkgmap):
Output Log file name (det_log):
Live show (1=yes, 0=no) ? (0):
Exposure map file name (exposure_map_1.0keV.fits):

 Reading exposure map:  exposure_map_1.0keV.fits ...done

 initial threshold =  4.00 sigmas
 final threshold   =  5.20 sigmas
 Detector is ACIS-I
   ... reading data
   ... successfully read       20295 events
 performing detection at 11 scales,
 from 0.50 to  16.00 arcsec, in logarithmic steps by a factor sqrt(2)

 computing background image... done
     51   sources at scale =   0.50 arcsec
     69   sources at scale =   0.71 arcsec
     69   sources at scale =   1.00 arcsec
     98   sources at scale =   1.41 arcsec
    113   sources at scale =   2.00 arcsec
    143   sources at scale =   2.83 arcsec
    143   sources at scale =   4.00 arcsec
    118   sources at scale =   5.66 arcsec
```

```
    105   sources at scale =   8.00 arcsec
     86   sources at scale = 11.31 arcsec
     63   sources at scale = 16.00 arcsec
 computing best source properties... done
 computing background image update... done
     51   sources at scale =   0.50 arcsec
     69   sources at scale =   0.71 arcsec
     69   sources at scale =   1.00 arcsec
    100   sources at scale =   1.41 arcsec
    113   sources at scale =   2.00 arcsec
    146   sources at scale =   2.83 arcsec
    148   sources at scale =   4.00 arcsec
    121   sources at scale =   5.66 arcsec
    106   sources at scale =   8.00 arcsec
     91   sources at scale = 11.31 arcsec
     66   sources at scale = 16.00 arcsec
 computing best source properties... done

  Total number of detected sources =           105

  Nominal effective area (cm^2) =    286.6157

 Thu Jul 26 19:10:46 2001
 total elapsed time:           444 sec
prompt>
```

The same output is saved in the log file, named "det_log" in this case.

5   Limitations

There is a limit of 7 million photons maximum that can be handled by the standard PWDetect.

6   Further info

PWDetect for Chandra is largely based on its predecessor for ROSAT/PSPC data (*wdetect*). You may find information about the theory behind it in Damiani et al. 1997 (ApJ, 483, 350), and tests on PSPC data in Damiani et al. 1997 (ApJ, 483, 370).