

<b>IXPE Science Operations Center ST-12</b>		
<b>Title: User Guide — Software</b>	<b>Document No.: IXPE-SOC-DOC-009</b>	<b>Revision: C</b>
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National Aeronautics and  
Space Administration

**IXPE-SOC-DOC-009**  
Revision C  
EFFECTIVE DATE: 2022-03-28

**George C. Marshall Space Flight Center**  
Marshall Space Flight Center, Alabama 35812

ST-12

**IMAGING X-RAY POLARIMETRY EXPLORER  
(IXPE)  
SCIENCE OPERATIONS CENTER (SOC)**

User Guide — Software

IXPE Science Operations Center  
User Guide to Software

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## Revision Log

Date	Rev	Notes
2022-02-28	A	Added “Flow of analysis...” section, and corrected parameter lists and descriptions to match latest software.
2022-03-10	B	Added more description to ixpeevtrecn, and additional step required for ixpedet2j2000 to run correctly.
2022-03-25	C	Added Introduction, section structure, and table of contents; made several clarifications or corrections to text

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## 1 Introduction

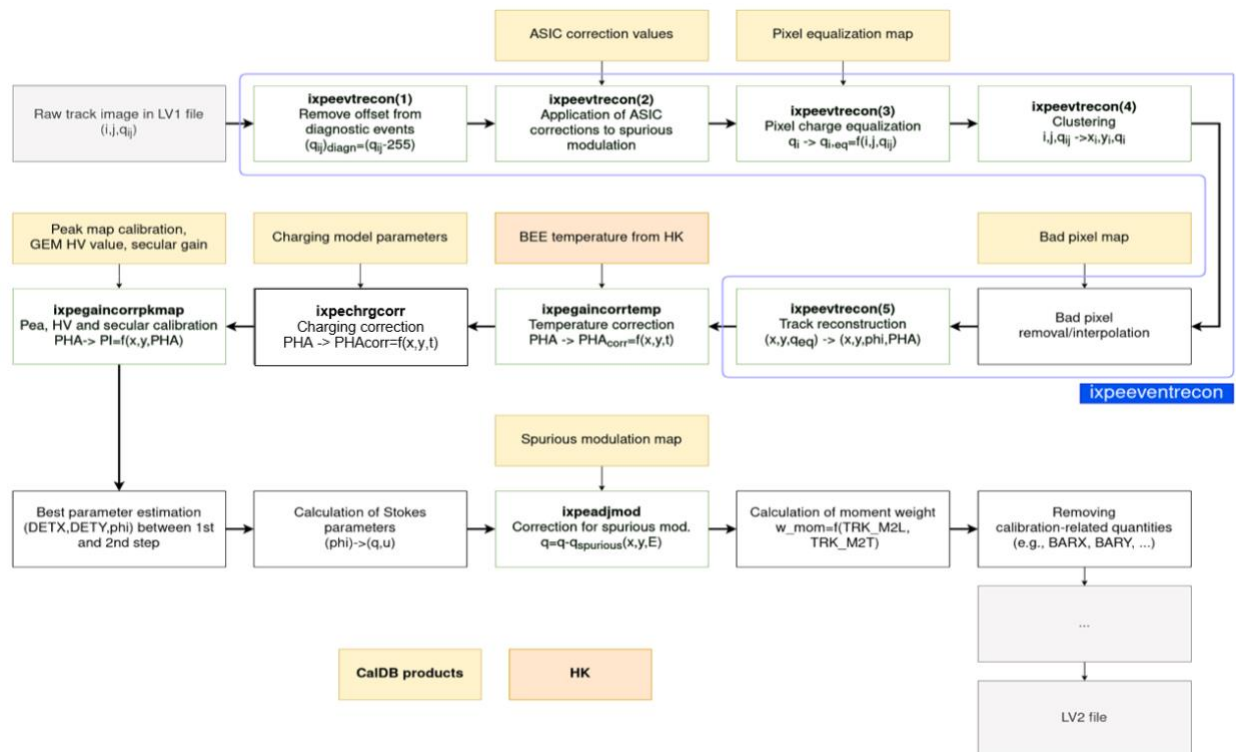
This document serves as a User Guide to software provided by the IXPE Science Operations Center, at NASA Marshall Space Flight Center (MSFC). Much of the Instrument-related software and calibration database (CALDB) were produced by the Space Science Data Center (SSDC) of the Agenzia Spaziale Italiana (ASI), with substantial contributions by the IXPE Instrument Team at Istituto Nazionale di Astrofisica (INAF) and at Istituto Nazionale di Fisica Nucleare (INFN).

## 2 Overview

### 2.1 Instrument pipeline

The following figure shows the data flow through the Instrument pipeline. The main tool is *ixpeevtrecn*, which makes several corrections to the ionization track and then uses the standard moments method to reconstruct the event. Other tools apply various gain corrections (*ixpegaincorrpkmap*, *ixpechrgcorr*, *ixpegaincorrtemp*), calculate a modulation Stokes parameter for the event (*ixpecalcstokes*), and remove detector-induced spurious modulation (*ixpeadjmod*). In addition, module *ixpeweights* calculates additional values required for computing a weighted polarization based upon the moments analysis.

For users who want to reconstruct events using a method other than the moments analysis, it is important first to run *ixpeevtrecn* with the writeTracks option. This will remove all pixel-to-pixel gain variations that could bias the track analysis.



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## 2.2 Other tools

This User Guide also describes other user-visible FTOOLS. These tools map events onto the sky (*ixpedet2j2000*), correct residual aspect errors (*ixpeaspcorr*), produce an exposure map (*ixpeexpmap*), and map the instrument field of view onto the sky for planning purposes (*ixpecalfov*). The final tool, *ixpepolarization*, is designed to run in conjunction with the image display tool ds9 to allow the user to select regions interactively and to estimate the polarization in those regions. As the detector can produce a radial polarized signal in the wings of the PSF, some care should be exercised to ensure that regions are centered on bright point sources.

## 2.3 Version numbers

For each observation, the SOC runs the pipeline to produce standard data products. Every time a given file (same object ID, same detector or "all", same file type) is generated, the SOC archives that file with an incremented version number, to maintain a complete record of the processing. Occasionally, the SOC may need to re-run a tool for a single file of a given type but not for all files of that type (e.g., for one detector but not for the other two). In such cases, the version numbers of files of the same type will not be the same.

## 3 Flow of analysis from Level 1 to Level 2

IXPE data sets contain both Level-1 and Level-2 event data, as well as Level-1 housekeeping data. Level-1 event and housekeeping data contain all the necessary information for processing into Level-2 data with the tools mentioned above. This section describes this processing flow.

*ixpeevtrecn*: This module is run as the starting point for the instrument pipeline, which generates Level-1 data. Re-running *ixpeevtrecn* is not required to analyze the Level-1 data unless the user wants to generate corrected ionization tracks to analyze using an event reconstruction algorithm other than the standard moments method. In this case, *ixpeevtrecn* module should be run with the writeTracks option.

To process the output file through the remaining tools, the output file will need to have some keyword values replaced that are removed by *ixpeevtrecn*. For a Level-1 file named `$FILE` in directory LV1, and the resulting output file from *ixpeevtrecn* named `recon_file`, the following commands need to be executed:

```
fdump LV1/$FILE[0] tmp.lis - 1 prdata=yes showcol=no
grep -i S_VDRIFT tmp.lis >> fix.lis
grep -i S_VBOT tmp.lis >> fix.lis
grep -I S_VGEM tmp.lis >> fix.lis
echo "FILE_LVL = '1'" >> fix.lis
```

```
fmodhead recon_file fix.lis
rm tmp.lis fix.lis
```

*ixpegaincorrtemp*: This module corrects for gain variations due to changes in the detector temperature. The output from previous step is used as input, as well as the appropriate temperature file for the given detector analyzed.

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*ixpechrgcorr*: This module corrects for gain variations due to charging and discharging of the Gas Electron Multiplier material. It uses the previous output event file and an initial charging map (or an uncharged map from the CALDB) to track the charging and correct the gain.

*ixpegaincorrpkmap*: This module corrects for large scale variations across a detector and changes with pressure and time. It uses the previous output event file as input and uses CALDB maps of the gain variations to correct the gain.

*ixpecalcstokes*: This module uses the output from *ixpeevt recon* to calculate the modulation Stokes q and u parameters for each event.

*ixpeadjmod*: This module uses the output from the previous module and CALDB maps of the spurious modulation to correct the modulation Stokes parameters for each event.

*ixpeweights*: This module uses the output from *ixpeevt recon* to calculate the moments-method weights used for computing the weighted modulation Stokes parameters over an ensemble of events.

*ixpedet2j2000*: This module uses positions, as well as the star tracker attitude (“\_att\_”) housekeeping file for the given detector, and the CALDB alignment and telescope definition files to correct each event for the spacecraft attitude.

#### Caveats

1. At this time, the generation of Q and U columns rotated onto the sky is disabled. These values require some precautions to produce and to use. The feature will be enabled in future releases of the software.
2. Some of the keyword values in the Level-1 file are removed during processing by other modules. These keyword values can be replaced with the following script lines:
  - `yes | fdump ixpe01006501_det1_evt1_v02.fits["EVENTS"] outfile=STDOUT ROWS=0 | grep TC > wcs.lis`
  - `sed -i 's/36 /44 /;s/37 /45 /' wcs.lis`
  - `echo -e "TLMIN44 = 0\nTLMAX44 = 600\nTLMIN45 = 0\nTLMAX45 = 600" >> wcs.lis`
  - `fmodhead ixpe01006501_det1_evt1_v02_det2j2000.fits["EVENTS"] wcs.lis`
3. The STATUS2 keyword values in the Level-1 file are also altered during processing by other modules. This column must be replaced before processing with *ixpedet2j2000* using the following script lines (assuming the Level 1 file is named “level\_1\_file” and the pre-*ixpedet2j2000* file is named “det2j2000\_file”):
  - `fdelcol (delete STATUS2 column from det2j2000_file)`
  - `faddcol (copy STATUS2 from level_1_file to det2j2000_file)`

*ixpeaspcorr*: This module uses the event sky positions from the previous module to find and correct longer-period changes in the aspect that are not captured by the star tracker. It also adds a column of corrected pointing information to the given attitude (“\_att\_”) housekeeping file.

*ixpeexpmap*: This module uses the Level-2 GTI (Good Time Interval) file and the additional information in the attitude (“\_att\_”) file produced by the previous module to calculate the exposure map for the given object.

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## 4 Description of tools

The remainder of this user guide describes the individual tools and their functional interfaces in greater detail. The notation [...] indicates a ‘hidden’ parameter in FTOOLS parlance. Tools are referenced in *italic* and parameters in Courier fonts.

### 4.1 *ixpeevtrecn*

#### 4.1.1 Synopsis

Extracts time, position, PHA, and electron ejection direction from raw event image data.

#### 4.1.2 Syntax

```
ixpeevtrecn infile outfile [pixeqfile] [xpolpedestalfile]
[xpolnoisefile] [outsuffix] [logTermLvl] [logFileLvl] [logFile]
[minTrackHits] [minDensityPoints] [threshold] [moma1Threshold]
[moma2Threshold] [dmin] [dmax] [weightScale] [writeTracks]
[CoherentNoiseOffset] [TriggerMiniclusterOffset]
[ignoreErrorFlag] [firstEvent] [clobber]
```

#### 4.1.3 Description

*ixpeevtrecn* extracts, from raw data contained in an IXPE Event FITS file (*infile*), the physical information of interest for polarimetry, imaging and spectroscopy on an event-by-event basis and places the results in an output event FITS file (*outfile*, or overwrites *infile* if *outfile=NONE*). This is a complex, multi-step, process that is described here only in so far as is needed to understand the various parameters associated with the *ixpeevtrecn* tool. Please refer to the above figure and to the GPD Workbook for additional information.

The IXPE back-end electronics is designed in ‘windowed’ readout mode in which the chip is configured for self-triggering and automatic definition of a region of interest (ROI) for the serial readout. In this mode, the event is localized upon trigger in a rectangle containing all triggered mini-clusters plus a pre-defined padding for successive serial readouts.

During flight the pixels are read out twice and the second readout, which is dominated by the pedestal, is automatically subtracted. (The pedestal is like a dark current in a CCD.) The software allows for the alternate method where the pedestals are not subtracted in the instrument, but on the ground using external files specified by *xpolpedestalfile* and *xpolnoisefile*. These parameters should not be used for normal operations.

To save telemetry the instrument does not transmit any pixels with pedestal subtracted values below some threshold. This value corresponds to a threshold value of 18. A higher threshold can be set using the *threshold* parameter. All the ground calibration products were created using a threshold value of 20. This allows some room to raise the threshold if needed (i.e., background being higher than expected). Use the default value. There is no advantage to using a value below the hardware setting.

This is followed by grouping together all the contiguous pixels above threshold into ‘clusters’. Briefly, clusters are characterized by core pixels with at least a certain density of other pixels in



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its neighborhood (`minDensityPoints`; up to 6 in the IXPE hexagonal grid) above threshold so that a cluster is a complete set of mutually density-connected pixels. Here ‘complete’ means that every pixel which is reachable from a pixel belonging to the cluster must be part of the cluster as well. Non-core pixels form the edge of the cluster; they still have to be above threshold but, differently from core pixels, do not have to satisfy the density requirement. To prevent random noise fluctuations being identified as clusters, clusters must include a minimum of `n` pixels.

By design, clusters define the track of charge deposited by the primary photoelectron cloud and thus are the basis for determining the event location, energy, and the initial direction of the photoelectron, which is correlated with the polarization position angle of the incident photon. Thus, ‘track’ and ‘cluster’ refer to the same set of pixels. However, tracks are defined in the physical space (IXPE coordinates system), while clusters are defined in the logical space (XPOL coordinates system). While the clustering happens in logical space, all the reconstruction downstream happens in physical space, with no further reference to the pixel address (i.e., column and row) within the readout window.

The unique feature of *ixpeevtrecn* is the determination of the photon interaction location and the initial direction of the photoelectron using moments analysis. First, an un-weighted moments analysis is performed using the barycenter of the cluster as the pivot point that provides the angle of the principal axis of the cluster, the longitudinal and transverse moments of the charge distribution, and the skewness. Since the longitudinal development of the ionization is on average asymmetric, with the largest signal residing in the Bragg peak at the end of the track, the sign of the skewness is a solid indicator of the direction in which the original photon conversion point is lying, relative to the barycenter of the charge distribution. This knowledge is used to define a search region for finding the photon conversion point. The search region is defined by selecting all those pixels whose centers are located a distance within the range (`dmin`) to (`dmax`) of the barycenter and on the side indicated by the skewness. The barycenter of this region is then calculated and a set of exponentially decreasing weights for all pixels in the cluster, based on their distance from the new barycenter and with e-folding weight (`weightScale`) to be used in the second step of the reconstruction. The weight function is calculated for each pixel, and a new barycenter is estimated which is used as the best estimate for the photon conversion point. The conversion point is used as the pivot for a second iteration of the moments analysis, this time weighted with the above defined weights. The direction of the principal axis in this second moments-analysis pass is the final photoelectron direction.

In addition, the optional `logFile` name (default=`recon.log`) records debugging (`logFileLvl=0`), general information (`logFileLvl=1`), warnings (`logFileLvl=2`), errors (`logFileLvl=3`), or only critical (`logFileLvl=4`) problems. Similar verbosity is written to the terminal by selecting the `logTermLvl` values from 0 through 4.

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#### 4.1.4 Parameters

Name	Type	I/O	default	min	max	units	required?
Infile	file	input					yes
Outfile	file	output					yes
Pixeqfile	file	input	CALDB				
Xpolpedestalfile	file	input	NONE				
Xpolnoisefile	file	input	NONE				
Outsuffix	string		recon				
logTermLvl	integer		1	0	4		
logFileLvl	integer		1	0	4		
Logfile	file	output	recon.log				
minTrackHits	integer		6	1	100		
minDensityPoints	integer		4	0	6		
Threshold	integer		20	0	3000	PHA	
moma1Threshold	real		36.0	0.0	3000		
moma2Threshold	real		36.0	0.0	3000		
Dmin	real		1.5	0.0	100.0		
Dmax	real		3.5	0.0	100.0		
weightScale	real		0.05	0.01	1.0	mm	
writeTracks	boolean		no				
CoherentNoiseOffset	string		CALDB				
TriggerMinicluster Offset	string		CALDB				
ignoreErrorFlag	boolean		no				
firstEvent	integer		0	0	1e7		
Clobber	boolean		no				

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## 4.2 *ixpegaincorrtemp*

### 4.2.1 Synopsis

Corrects detector gain for temperature effects

### 4.2.2 Syntax

```
ixpegaincorrtemp infile outfile hkfile [tempgainfile]
[logTermLvl] [logFileLvl] [logfile] [clobber]
```

### 4.2.3 Description

*ixpegaincorrtemp* is part of the event reconstruction pipeline tool set.

*ixpegaincorrtemp* requires an input IXPE event FITS file (*infile*) and the name of an output event FITS file (*outfile*) and the name of a housekeeping FITS file (*hkfile*). The housekeeping files to use depend on the detector ID of the data being processed. Event files which contain “det1” in the filename use housekeeping files that contain “pay\_1321” in the filename, “det2” event files use “pay\_1322”, and “det3” event files use “pay\_1323” files. The module also utilizes a temperature gain correction file (*tempgainfile*; default= CALDB). The optional *logfile* name (default=recon.log) records debugging (*logFileLvl*=0), general information (*logFileLvl*=1), warnings (*logFileLvl*=2), errors (*logFileLvl*=3), or only critical (*logFileLvl*=4) problems. Similar verbosity is written to the terminal by selecting the *logTermLvl* values from 0 through 4.

### 4.2.4 Parameters

Name	Type	I/O	default	min	max	units	required?
<i>infile</i>	file	input					yes
<i>outfile</i>	file	output					yes
<i>hkfile</i>	file	input					yes
<i>tempgainfile</i>	file	input	CALDB				
<i>logTermLvl</i>	integer		1	0	4		
<i>logFileLvl</i>	integer		1	0	4		
<i>logfile</i>	file	output	<i>ixpegaincorrtemp.log</i>				
<i>clobber</i>	boolean		no				

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### 4.3 *ixpehrgcorr*

#### 4.3.1 Synopsis

Corrects gain for the effects of charging and discharging of the Gas Electron Multiplier (GEM) material.

#### 4.3.2 Syntax

```
ixpehrgcorr infile outfile [paramsfile] [initmapfile]
[outmapfile] [timebinsize] [phamin] [phamax] [phacol] [poscol]
[clobber]
```

#### 4.3.3 Description

*ixpehrgcorr* is part of the event reconstruction pipeline tool set. *ixpehrgcorr* corrects for known effects on the gain caused by the build-up of charge within the GEM from incoming x-ray events and its slow discharge over time. The GEM provides the gas multiplication of the primary ionization, which is necessary to generate an electrical signal detectable by the readout ASIC. However, some of the charge deposits in the dielectric material of the GEM during times of high event rate and is dissipated during time of low event rate.

*ixpehrgcorr* requires an input IXPE event FITS file (*infile*) and the name of an output event FITS file (*outfile*). It utilizes an optional calibration file (*paramsfile*; default=CALDB), an initial map of the charging state (*initmapfile*), a name for the post-processing output map of the charging state (*outmapfile*), a time-bin size for integrating the charging (*timebinsize*), a maximum and minimum PHA for the flux cube (*phamin*, *phamax*), the name of the input PHA column (*phacol*), and the base name of the input position columns (*poscol*).

#### 4.3.4 Parameters

Name	Type	I/O	default	min	max	units	required?
<i>infile</i>	file	input					yes
<i>outfile</i>	file	output					yes
<i>paramsfile</i>	file	input	CALDB				
<i>outmapfile</i>	file	output	ql				
<i>timebinsize</i>	float		30.0			sec	
<i>phamin</i>	float		0.				
<i>phamax</i>	float		30000.0				
<i>phacol</i>	str		“PHA_T”				
<i>poscol</i>	str		“ABS”				
<i>clobber</i>	boolean		no				

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## 4.4 *ixpegaincorrpkmap*

### 4.4.1 Synopsis

Corrects gain for pressure change, high voltage adjustments, and large-scale spatial variations

### 4.4.2 Syntax

```
ixpegaincorrpkmap infile outfile [pkgainfile] [hvgainfile]
[secvarfile] [logTermLvl] [logFileLvl] [logfile] [clobber]
```

### 4.4.3 Description

*ixpegaincorrpkmap* is part of the event reconstruction pipeline tool set. *ixpegaincorrpkmap* corrects for known effects on the gain caused by changes in the operating voltage across the top and bottom faces of the GEM, changes in the GEM gas pressure over time, and large-scale special variations over the detector.

*ixpegaincorrpkmap* requires an input IXPE event FITS file (*infile*) and the name of an output event FITS file (*outfile*). It utilizes a peak gain calibration file (*pkgainfile*; default=CALDB), a high voltage calibration file (*hvgainfile*; default=CALDB), and a pressure secular variation calibration file (*secvarfile*; default=CALDB). The optional *logfile* name (default=recon.log) records debugging (*logFileLvl*=0), general information (*logFileLvl*=1), warnings (*logFileLvl*=2), errors (*logFileLvl*=3), or only critical (*logFileLvl*=4) problems. Similar verbosity is written to the terminal by selecting the *logTermLvl* values from 0 through 4.

### 4.4.4 Parameters

Name	Type	I/O	default	min	max	units	required?
<i>infile</i>	file	input					yes
<i>outfile</i>	file	output					yes
<i>pkgainfile</i>	file	input	CALDB				
<i>hvgainfile</i>	file	input	CALDB				
<i>secvarfile</i>	file	input	CALDB				
<i>logTermLvl</i>	integer		1	0	4		
<i>logFileLvl</i>	integer		1	0	4		
<i>logfile</i>	file	output	<i>ixpegaincorrpkmap.log</i>				
<i>clobber</i>	boolean		no				

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## 4.5 *ixpecalcstokes*

### 4.5.1 Synopsis

Calculates modulation Stokes parameters

### 4.5.2 Syntax

```
ixpecalcstokes infile outfile [logTermLvl] [logFileLvl]
[logfile] [applycut] [clobber]
```

### 4.5.3 Description

*ixpecalcstokes* is part of the event reconstruction pipeline tool set.

*ixpecalcstokes* requires an input IXPE event FITS file (*infile*) and the name of an output event FITS file (*outfile*) as a minimum. The parameter `applycut=no` is the default. This parameter should be changed ONLY for debugging. The optional `logFile` name (default=`recon.log`) records debugging (`logFileLvl=0`), general information (`logFileLvl=1`), warnings (`logFileLvl=2`), errors (`logFileLvl=3`), or only critical (`logFileLvl=4`) problems. Similar verbosity is written to the terminal by selecting the `logTermLvl` values from 0 through 4.

### 4.5.4 Parameters

Name	Type	I/O	default	min	max	units	required?
<i>infile</i>	File	input					yes
<i>outfile</i>	File	output					yes
<code>logTermLvl</code>	integer		1	0	4		
<code>logFileLvl</code>	integer		1	0	4		
<code>logfile</code>	File	output	<code>ixpecalcstokes.log</code>				
<code>applycut</code>	boolean		no				
<code>clobber</code>	boolean		no				

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## 4.6 *ixpeadjmod*

### 4.6.1 Synopsis

Removes spurious modulation

### 4.6.2 Syntax

```
ixpeadjmod infile outfile [logTermLvl] [logFileLvl] [logfile]
[applycut] [clobber]
```

### 4.6.3 Description

*ixpeadjmod* is part of the event reconstruction pipeline tool set.

*ixpeadjmod* requires an input IXPE event FITS file (*infile*) and the name of an output event FITS file (*outfile*) as a minimum along with a spurious modulation calibration file (*smodfile*; default=CALDB) that provides, for each pixel of the detector, the spurious modulation coefficients as a function of energy. If the parameter *writedetqucols=yes*, then the original DETQ and DETU columns are included in the outfile with column names DETQ\_ORIG and DETU\_ORIG, respectively. The optional *logfile* name (default=recon.log) records debugging (*logFileLvl=0*), general information (*logFileLvl=1*), warnings (*logFileLvl=2*), errors (*logFileLvl=3*), or only critical (*logFileLvl=4*) problems. Similar verbosity is written to the terminal by selecting the *logTermLvl* values from 0 through 4.

### 4.6.4 Parameters

Name	Type	I/O	default	min	max	units	required?
<i>infile</i>	File	input					yes
<i>outfile</i>	File	output					yes
<i>logTermLvl</i>	integer		1	0	4		
<i>logFileLvl</i>	integer		1	0	4		
<i>logfile</i>	File	output	<i>ixpeadjmod.log</i>				
<i>smodfile</i>	File	input	CALDB				
<i>writedetqucols</i>	boolean		no				
<i>clobber</i>	boolean		no				

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## 4.7 *ixpeweights*

### 4.7.1 Synopsis

Calculates weighting factors used in the moments analysis

### 4.7.2 Syntax

```
ixpeweights infile outfile [logTermLvl] [logFileLvl] [logfile]
[clobber]
```

### 4.7.3 Description

*ixpeweights* is part of the event reconstruction pipeline tool set.<sup>1</sup> In brief, circular tracks provide no information about the direction of the initial electron, whereas highly elliptical tracks can provide a very accurate track direction. This tool calculates the ellipticity.

$$\alpha = (TL - TW) / (TL + TW)$$

of the track where  $TL$  is the track length and  $TW$  the track width. The weight is then  $1/\alpha^{\lambda}$  where the value of  $\lambda$  was optimized using the detector Monte Carlo to be 0.75. The output is `W_MOM`. When computing average values of  $Q, U$  one should always weight by this value.

*ixpeweights* requires an input IXPE event FITS file (`infile`) and the name of an output event FITS file (`outfile`) as a minimum. The optional `logfile` name (default=`recon.log`) records debugging (`logFileLvl=0`), general information (`logFileLvl=1`), warnings (`logFileLvl=2`), errors (`logFileLvl=3`), or only critical (`logFileLvl=4`) problems. Similar verbosity is written to the terminal by selecting the `logTermLvl` values from 0 through 4.

### 4.7.4 Parameters

Name	Type	I/O	default	min	max	units	required?
<code>infile</code>	file	input					yes
<code>outfile</code>	file	output					yes
<code>logTermLvl</code>	integer		1	0	4		
<code>logFileLvl</code>	integer		1	0	4		
<code>logfile</code>	file	output	<code>ixpeweights.log</code>				
<code>clobber</code>	boolean		no				

<sup>1</sup> For more details on the weighed moments analysis, see Di Marco et al. (2022) AJ 163, 170. DOI: [10.3847/1538-3881/ac51c9](https://doi.org/10.3847/1538-3881/ac51c9)



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## 4.8 *ixpedet2j2000*

### 4.8.1 Synopsis

Transforms IXPE event positions and modulation Stokes parameters from detector to sky coordinates

### 4.8.2 Syntax

```
ixpedet2j2000 infile outfile attitude [teldef] [sc] [clobber]
```

### 4.8.3 Description

*ixpedet2j2000* converts DETX,DETY detector coordinates and modulation Stokes parameters DETQ and DETU of events contained in an existing Level-1 IXPE event FITS file (*infile*) to X,Y sky coordinates and Q,U oriented along declination (+Q) and position angle (+U along position angle +45 degrees) and adds these new columns, along with all original Level-1 event file columns, to a new FITS file (*outfile*). Optionally, event positions in spacecraft coordinates can also be added to the output event FITS file (*sc=true*).

*ixpedet2j2000* uses the event time stamp from the Level-1 event list and the rotation quaternions from a Level-1 attitude file (*attitude*) to perform this transformation. The quaternions are calculated by combining time-independent quaternions representing detector frame to the focal plane frame, focal plane frame to the spacecraft frame, and spacecraft frame to star tracker optical head with the time-varying quaternions produced by the star tracker, which rotate from the star tracker optical head frame to the J2000 sky frame. The latter quaternions are generated at a rate of 10 Hz. The transformation quaternion is found by linearly interpolating between the two attitude solutions which bracket the event time component-by-component.

### 4.8.4 Parameters

Name	Type	I/O	default	min	max	units	required?
infile	File	input					yes
outfile	File	output					yes
attitude	File	input					yes
teldef	File	input	CALDB				
sc	boolean		False				
clobber	boolean						

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## 4.9 *ixpeaspcorr*

### 4.9.1 Synopsis

Corrects for residual aspect errors using interpolated event position averages over a user-specified time interval width.

### 4.9.2 Syntax

```
ixpeaspcorr infile n [statout] [uncorr] [att_path]
[x_pix_mean] [y_pix_mean]
```

### 4.9.3 Description

*ixpeaspcorr* uses event time stamps and sky X,Y values from an IXPE Level-1 event FITS file (*infile*) to compute average position over a time width of (*n*) seconds. A corrected position is then given for each event by subtracting the difference between the interpolated means of the *n* events and the mean of all events from the uncorrected position. If *x\_pix\_mean* and/or *y\_pix\_mean* are set to values other than “-“, these values will be used instead of the mean of all events.

If *statout*=True, then the running mean and standard deviation for each axis position is added as columns X\_AVG, X\_STD, and Y\_AVG, Y\_STD. If *uncorr*=True, the original, uncorrected position columns are retained as X\_UNCORR, Y\_UNCORR and, if *statout*=True also, then the uncorrected statistics columns X\_AVG\_UNCORR, X\_STD\_UNCORR, Y\_AVG\_UNCORR, and Y\_STD\_UNCORR are also added. The input file is overwritten with these new columns added as well as a new keyword, XPASPCOR, to prevent unintentional multiple running of *ixpeaspcorr*.

In addition, *ixpeaspcorr* will optionally calculate the interpolated position of the spacecraft pointing direction on the sky plane and add these values as a new column (TXYDZ\_CORR) to an attitude file if *att\_path*=True.

### 4.9.4 Parameters

Name	Type	I/O	default	min	max	units	required?
infile	File	input					yes
n	integer		300			seconds	
statout	boolean						
uncorr	boolean						
att_path	String						
x_pix_mean	Float			0.	599.9	pixels	
y_pix_mean	Float			0.	599.9	pixels	

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## 4.10 *ixpeexpmap*

### 4.10.1 Synopsis

Creates an exposure map in J2000 tangent-plane coordinates from the aspect solution data in the Level-1 housekeeping data.

### 4.10.2 Syntax

```
ixpeexpmap infile gti outfile [graypix] [teldef] [badpix]
[pntmap] [pntname] [clobber]
```

### 4.10.3 Description

*ixpeexpmap* selects the J2000 tangent-plane positions of the pointing direction from a Level-1 Attitude file (*infile*) for all the valid rows within Good Time Intervals read from a GTI file (*gti*) to create a pointing map (*pntmap*; default=false, if *pntmap*=true then the pointing map will be placed in an output file given by the parameter *pntname*). The pointing map contains standard sky tangent-plane X, Y coordinates with the value at each coordinate given by the exposure time in seconds. *ixpeexpmap* then calculates a valid pixel map to be convolved with the pointing map to create the final exposure map. The valid pixel map flags bad pixels and ‘gray’ pixels (if *graypix*=true) from a bad pixel map (*badpix*). *ixpeexpmap* then convolves these two maps to build the final exposure map (*outfile*) using the appropriate rotations, offsets, and pixel-to-sky scalings (as given in the file *teldef*) necessary to convert raw pixels to sky coordinates. Exposure maps for multiple detectors can be co-added as differences in orientation and offset due to relative telescope pointing have already been accounted for.

### 4.10.4 Parameters

Name	Type	I/O	default	min	max	units	required?
<i>infile</i>	File	input					yes
<i>gti</i>	File	input					yes
<i>outfile</i>	File	output					yes
<i>graypix</i>	boolean		False				
<i>teldef</i>	File	input	CALDB				
<i>badpix</i>	Integer		CALDB				
<i>pntmap</i>	boolean		False				
<i>pntname</i>	String	output					
<i>clobber</i>	boolean						

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## 4.11 *ixpecalcfov*

### 4.11.1 Synopsis

Calculates a map of the nominal sky field of view of each detector on the sky.

### 4.11.2 Syntax

```
ixpecalcfov time ra dec outfile [roll] [refframe] [align]
[teldef] [badpix1] [badpix2] [badpix3] [exc_graypix] [use_d1]
[use_d2] [use_d3] [clobber]
```

### 4.11.3 Description

*ixpecalcfov* is a stand-alone mission planning tool that computes the nominal (non-dithered) field of view for a user-selectable sub-set of the three detectors, sky position (*ra*, *dec*) and observing time (*time*). The output is a FITS image file (user selectable with *outfile*) with 1's indicating sky pixels within the field of view and 0's indicating sky pixels outside the field of view. The user can customize the result by specifying a custom roll angle (*roll*) or position angle of the spacecraft Y-axis, the celestial reference frame (*refframe*), and the detectors included in the field of view image (selected by setting *use\_d1*, *use\_d2*, and *use\_d3*, where setting the value to True will include the given detector in the field of view calculation).

By default, the alignment quaternions, telescope definition data, and bad pixel lists are obtained from the IXPE CALDB. *align* is used to designate the name of a custom file of alignment quaternions; *teldef* is used to designate the name of a custom file of telescope definition data; and *badpix1*, *badpix2*, and *badpix3* are used to designate the names of custom files for defining pixels of each corresponding detector to exclude from the field of view. The bad pixel files use flags that designate various types of bad pixels as well as “gray” pixels that may be optionally selected for exclusion by setting *exc\_graypix*=True.

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#### 4.11.4 Parameters

Name	Type	I/O	default	min	max	units	required?
time	String		2021-01-01t00:00:00				yes
ra	Float		15.0	-360.	360.	deg.	yes
dec	Float		25.714	-90.	90.	deg	yes
outfile	File	output					yes
roll	Float		No				
refframe	string		icrs				
align	string						
teldef	String						
badpix1	String						
badpix2	String						
badpix3	String						
exc_graypix	boolean		no				
use_d1	boolean		yes				
use_d2	boolean		yes				
use_d3	boolean		yes				
clobber	boolean		no				

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## 4.12 *ixpepolarization*

### 4.12.1 Synopsis

Calculates overall modulation Stokes parameters for a user-defined region

### 4.12.2 Syntax

```
ixpepolarization infile regfile t_lo t_up pi_lo pi_up color
scale
```

### 4.12.3 Description

*ixpepolarization* computes the overall modulation Stokes parameters Q and U for a sky region defined by the user (e.g., using the display program ds9) over a user-defined time interval and a user-defined PI energy range. The program also outputs a display region file with the modulation fraction and orientation on the sky computed from the Q and U, as well as the standard error of the resulting Q and U values for the region. The polarization may be estimated by dividing the modulation by the average modulation factor.

The tool requires an input IXPE event FITS file (*infile*) and optional sky region (*regfile*), time interval (*t\_lo*, *t\_up*), and energy bounds (*pi\_lo*, *pi\_up*). The default is to compute the modulation Stokes parameters from all events in the file. Clearly, as IXPE is an imaging polarimeter, only Stokes parameters for a region of the sky will be scientifically interesting. It is therefore highly recommended that a region file be provided to *ixpepolarization*. From the modulation Stokes parameters Q and U, the modulation fraction and the position angle of the polarization are also computed with the length scaled by the parameter (*scale*). A modified region file is output which, when displayed in ds9, includes a line in each of the original regions denoting the modulation fraction and orientation on the sky, as well as the standard error of the resulting Q and U values for the region, along with a scale in the top right corner.

### 4.12.4 Parameters

Name	Type	I/O	default	min	max	units	required?
infile	file	input					yes
regfile	file	input	none				
t_lo	string		unbound				
t_up	string		unbound				
pi_lo	integer		unbound				
pi_up	integer		unbound				
color	string		green				
scale	real		0.1				