

A detailed illustration of the Imaging X-ray Polarimetry Explorer (IXPE) satellite in space. The satellite is shown from a perspective that highlights its large, circular, segmented X-ray telescope at the front and its long boom extending towards the rear, which carries four large, rectangular solar panel arrays. The background is a vibrant, colorful nebula with shades of red, purple, and blue, set against a starry space. The Earth's horizon is visible in the lower-left corner. In the bottom-left corner, there is a circular logo for IXPE, featuring the satellite and the text 'Imaging X-ray Polarimetry Explorer' and 'IXPE' with the NASA and Italian flags.

IXPE: data analysis using
ixpeobssim

Niccolò Di Lalla
niccolo.dilalla@stanford.edu

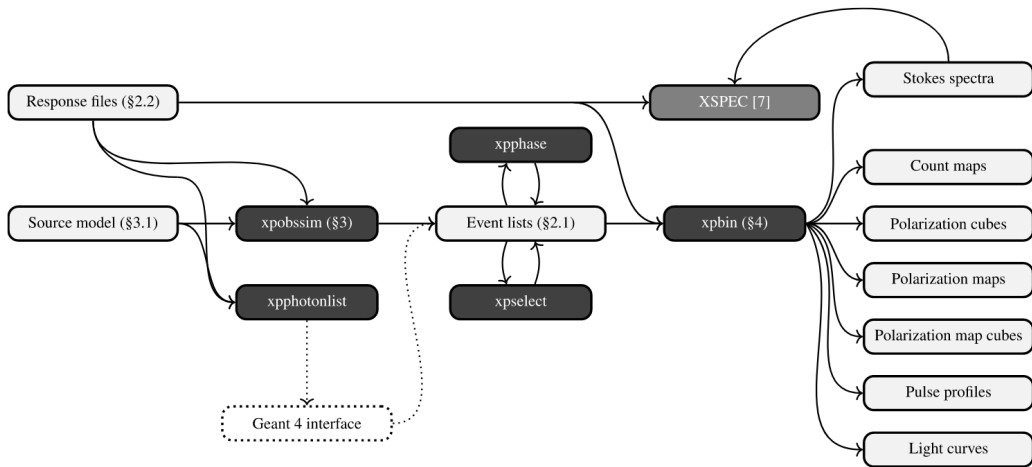
Stanford University

Friends of IXPE Forum



Friends of IXPE Forum

- ▷ Project started in 2015 under the name of XIMPOL:
 - ▷ Initially not tied to any specific mission or instrument design
 - ▷ After IXPE selection in 2017, it was renamed and progressively tailored in preparation for the new mission
 - ▷ Publicly released in 2022 to support the analysis of public IXPE data and engage the broader community in anticipation of the General Observer program
- ▷ Simulation and analysis framework:
 - ▷ Based on `python` programming language and the associated scientific ecosystem
 - ▷ Designed to produce fast and realistic simulated IXPE observations
 - ▷ Complemented by a suite of post-processing applications to select, bin and analyze simulated and real IXPE data
 - ▷ Modular nature allows for the implementation of complex, polarization-aware analysis pipelines
- ▷ Output data are:
 - ▷ Event lists in FITS format, containing a strict superset of the information included in the publicly released IXPE data products
 - ▷ Fully compliant with the visualization and analysis tools commonly used by the X-ray community (XSPEC, Sherpa, 3ML, DS9, HENDRICS).



▷ Each of the three DUs has its own set of IRFs:

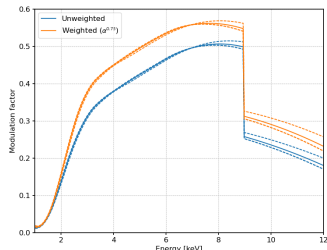
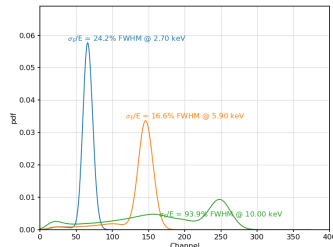
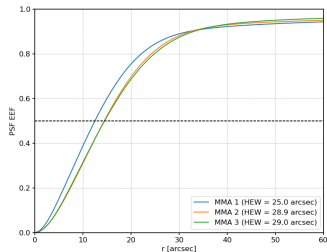
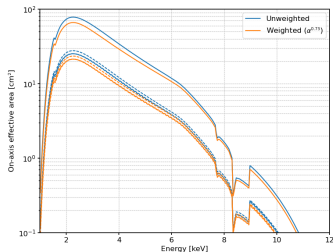
- ▷ FITS files compliant with the OGIP format
- ▷ Weighted and un-weighted flavors

▷ Generated and stored in a local CALDB:

- ▷ Kept in sync with the official IXPE CALDB

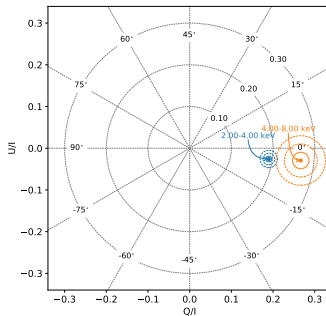
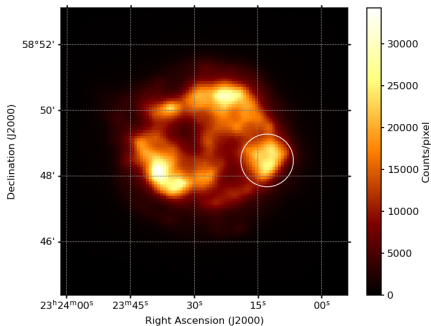
▷ Latest IRF version released in May 2026:

- ▷ Time-dependent, validity time binned in 6-month interval
- ▷ User has to select the appropriate set of IRFs (e.g. `irfname=ixpe:obssim20260701:v13`)

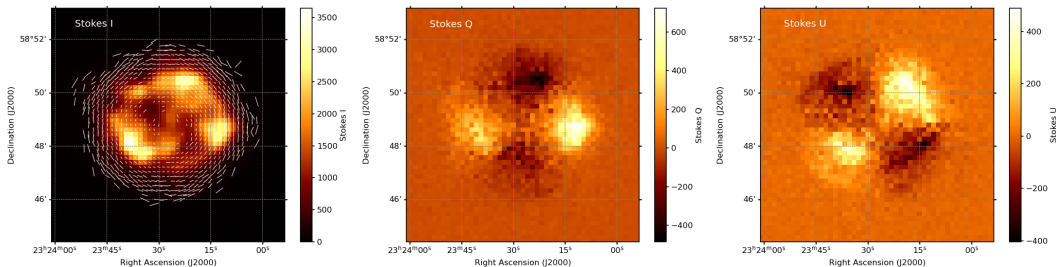


- ▷ *ixpeobssim* is distributed with its own set of analysis tools:
 - ▷ Provide an easy-to-use interface to manipulate **simulated and real IXPE data**
 - ▷ Full support for weighted and un-weighted types of analysis
- ▷ *xpphase*:
 - ▷ Calculate the phase of a periodic source based on its ephemeris
- ▷ *xpselect*:
 - ▷ Filter event lists based on energy, direction, time or phase
- ▷ *xpbin*:
 - ▷ Bin the data using several different algorithms, producing binned events lists
- ▷ *xpbinview*:
 - ▷ Visualize the binned data products
- ▷ *xpsun*
 - ▷ Create in-sun and in-eclipse level2 files for solar flare subtraction (deflaring)
- ▷ *xpstokesalign*:
 - ▷ Align the Stokes parameters to a given polarization model on an event-by-event basis
- ▷ *xpxspec*:
 - ▷ Perform a spectro-polarimetric fit in XSPEC

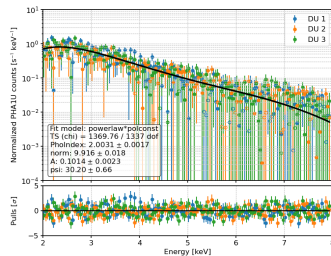
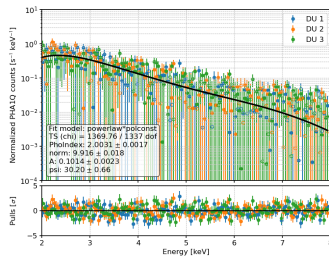
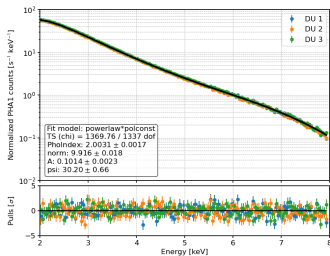
- ▷ The simplest possible data structure holding polarization information
 - ▷ PCUBE algorithm of *xpbin*
- ▷ Table listing spatially-integrated I, Q, U, polarization degree and angle with the associated uncertainties in **multiple energy bins**:
 - ▷ Provided with methods to rescale and subtract the background contribution



- ▷ Hold the exact same information as polarization cubes, but **binned in sky-coordinates**
 - ▷ PMAP or PMAPCUBE algorithms of *xpbin*
- ▷ Maps of I, Q, U, polarization degree and angle in multiple energy layers:
 - ▷ Provided with methods to convolve the map with a generic binned kernel and overlay the arrows of polarization information

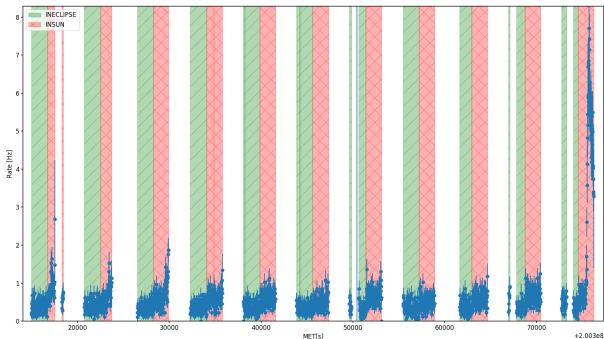


- ▷ Generalization of the standard PHA spectra:
 - ▷ PHA1, PHA1Q and PHA1U algorithm of *xpbin*
- ▷ Main interface to **spectro-polarimetric fitting** in XSPEC, Sherpa and 3ML
- ▷ Lightweight python wrapper dubbed *xpyspec* shipped with *ixpeobssim*:
 - ▷ Together with a few simple, multiplicative polarimetric models provided by HEASARC through the page hosting XSPEC additional models



```
1 def simulate(duration=100000, irf='ixpe:obssim20260701:v13'):  
2     """Run the simulation.  
3     """  
4     pipeline.xpobssim(duration=duration, configfile='toy_point_source_bkg.py', irfname=irf)  
5  
6 def select(src_rad=0.75, bkg_inner_rad=1.5, bkg_outer_rad=3.):  
7     """Select the photon lists.  
8     """  
9     file_list = pipeline.file_list()  
10    pipeline.xpselect(*file_list, rad=src_rad, suffix='src')  
11    pipeline.xpselect(*file_list, innerrad=bkg_inner_rad, rad=bkg_outer_rad, suffix='bkg')  
12  
13 def bin_(ebinning=[2, 4, 8], irf='ixpe:obssim20260701:v13'):  
14     """Create the necessary binned files.  
15     """  
16    pipeline.xpbin(*pipeline.file_list(), algorithm='CMAP', irfname=irf)  
17    kwargs = dict(algorithm='PCUBE', ebinalg='LIST', ebinning=ebinning, irfname=irf)  
18    pipeline.xpbin(*pipeline.file_list('src'), **kwargs)  
19    for algorithm in ['PHA1', 'PHA1Q', 'PHA1U']:  
20        pipeline.xpbin(*pipeline.file_list('src'), algorithm=algorithm, irfname=irf)  
21        pipeline.xpbin(*pipeline.file_list('bkg'), algorithm=algorithm, irfname=irf)
```

- ▷ IXPE observations are affected by **solar flares** when the Sun is not occulted
 - ▷ Time scales of minutes–hours
- ▷ Effect can be estimated by the difference in spectrum between in-sun and in-eclipse and subtracted to the data
 - ▷ Lvl2 data are split between in-sun and in-eclipse with *xpsun* (need also lvl1 and hk data)
 - ▷ The split dataset is passed to *xpbin* to deflare the data while binning
- ▷ Feature added in version 32.0.0 released on April 10, 2026
 - ▷ Works with flight data only (not simulation)
 - ▷ Background contribution important for **extended sources with increased solar activity**



```
# Run xpsun to create the insun and ineclipse fits file
xpsun.py /path/to/your/folder/where/lvl1&2/files/are

# Run xpbin on the whole region with the CMAP algorithm to create the count map
xpbin.py /path/to/your/lvl2/files/ixpe_det*_v01.fits --algorithm CMAP --irfname "ixpe:obssim20260701:v13" --
insun /path/to/your/lvl2/files/ixpe_det*_v01_insun.fits --ineclipse /path/to/your/lvl2/files/ixpe_det*_
_v01_inecl.fits

# Run xpbin on the whole region with the PMAPCUBE algorithm to create the polarization map cube
xpbin.py /path/to/your/lvl2/files/ixpe_det*_v01.fits --algorithm PMAPCUBE --irfname "ixpe:obssim20260701:v13"
--ebins 2 --insun /path/to/your/lvl2/files/ixpe_det*_v01_insun.fits --ineclipse /path/to/your/lvl2/files/
ixpe_det*_v01_inecl.fits

# Run xpbinview to show the PMAPCUBE results
xpbinview.py /path/to/your/lvl2/files/ixpe_det*_v01_pmapcube_deflared.fits

# Run xpselect to select a subregion of the extended source
xselect.py /path/to/your/lvl2/files/ixpe_det*_v01.fits --ra RA --dec DEC --rad RAD

# Run xpbin on this subregion with the PCUBE algorithm to create the polarization cube
xpbin.py /path/to/your/lvl2/files/ixpe_det*_v01_select.fits --algorithm PCUBE --ebins 2 --irfname "ixpe:
obssim20260701:v13" --insun /path/to/your/lvl2/files/ixpe_det*_v01_insun.fits --ineclipse /path/to/your/
lvl2/files/ixpe_det*_v01_inecl.fits

# Run xpbinview to show the PCUBE results
xpbinview.py /path/to/your/lvl2/files/ixpe_det*_v01_select_pcube_deflared.fits
```

- ▷ Github webpage:
<https://github.com/lucabaldini/ixpeobssim>
- ▷ Software documentation: <https://ixpeobssim.readthedocs.io/en/latest/index.html>
- ▷ Paper: <https://www.sciencedirect.com/science/article/pii/S2352711022001169>
- ▷ Pip: <https://pypi.org/project/ixpeobssim/>
 - ▷ `pip install ixpeobssim`
 - ▷ Latest version: 33.0.0 released on May 29, 2026
- ▷ Tutorials @ NICER/IXPE workshop 2024: <https://github.com/nmik/nicer-ixpe/tree/main>

SoftwareX 19 (2022) 101194

Contents lists available at ScienceDirect

SoftwareX

journal homepage: www.elsevier.com/locate/softx

Original software publication

ixpeobssim: A simulation and analysis framework for the imaging X-ray polarimetry explorer

Luca Baldini^{a,b,*}, Niccolò Bucciantini^{c,d,e}, Niccolò Di Lalla^f, Steven Ehler^g, Alberto Manfreda^h, Michela Negro^{i,j,k}, Nicola Omodei^l, Melissa Pesce-Rollins^h, Carmelo Sgrò^h, Stefano Silvestri^h

^a Università di Pisa, Dipartimento di Fisica Enrico Fermi, Largo E. Fermi 2, I-56127 Pisa, Italy
^b Istituto Nazionale di Fisica Nucleare, Sezione di Pisa, Largo B. Pontecorvo 3, I-56127 Pisa, Italy
^c Istituto Nazionale di Astrofisica, Osservatorio Astronomico di Arcetri, Largo E. Fermi 2, I-50125 Firenze, Italy
^d Dipartimento di Fisica e Astronomia, Università degli Studi di Firenze, Via G. Galilei 2, I-50125 Firenze, Italy
^e Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, Via G. Galilei 2, I-50125 Firenze, Italy
^f NASA Marshall Space Flight Center, Huntsville, AL 35812, USA
^g University of Maryland, Baltimore County, Baltimore, MD 21250, USA
^h NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
ⁱ Center for Research and Exploration in Space Science and Technology, NASA/GSFC, Greenbelt, MD 20771, USA

ARTICLE INFO

Article history:
 Received 12 March 2022
 Received in revised form 21 July 2022
 Accepted 19 August 2022

Keywords:
 X-ray polarimetry

ABSTRACT

ixpeobssim is a simulation and analysis framework specifically developed for the Imaging X-ray Polarimetry Explorer (IXPE). Given a source model and the response functions of the telescopes, it is designed to produce realistic simulated observations, in the form of event lists in FITS format, containing a strict support of the information included in the publicly released IXPE data products. The core simulation capabilities are complemented by a full suite of post-processing applications which support the spatial, spectral, and temporal analysis needed for the analysis of typical polarized X-ray sources, allowing for the implementation of complex, polarization-aware analysis pipelines, and facilitating the integration with the standard visualization and analysis tools traditionally in use by the X-ray community. Although much of the framework is specific to IXPE, the modular nature of the underlying implementation makes it generally straightforward to adapt it to different missions with polarization capabilities.

© 2022 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

Code metadata

Current code version	33.0.0
Permanent link to code/repository used for this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-22-00065
Permanent link to Reproducible Capabilities	
Legal Code License	
Code versioning system used	Git
Software code languages, tools, and services used	Cython, NumPy, SciPy, Matplotlib, Astropy, Regions, Skyfield
Compilation requirements, operating environments & dependencies	https://github.com/luca-baldini/ixpeobssim
Full available link to developer documentation/manual	https://ixpeobssim.readthedocs.io
Support email for questions	luca.baldini@pi.infn.it

1. Introduction

Launched on December 9, 2021, the Imaging X-ray Polarimetry Explorer (IXPE) is a NASA Small Explorer Mission developed in collaboration with the Italian Space Agency [1–3], and the first

* Corresponding author at: Università di Pisa, Dipartimento di Fisica Enrico Fermi, Largo E. Fermi 2, I-56127 Pisa, Italy.
 E-mail address: luca.baldini@pi.infn.it (Luca Baldini).

- ▷ *ixpeobssim* was developed to support the IXPE mission by providing advanced simulation and analysis facilities
- ▷ With the official public release of IXPE data, we decided to release the codebase under an OSI-approved license:
 - ▷ Support the community engaged in the analysis of IXPE data
 - ▷ Support the simulation effort required for the General Observer program
 - ▷ Encourage reuse for future X-ray polarimetry missions
- ▷ *ixpeobssim* is stable but still under an active development phase:
 - ▷ A few releases per year (check the release notes)
 - ▷ Please open a new issue on github if you find a bug or have something to propose/discuss
 - ▷ **Everyone is very welcome to participate and help us with the development!**