IXPE
Proposal Preparation Tools

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Purpose

The goal of this presentation is to help the User Community assess the Technical Feasibility of potential IXPE observations using basic tools for the purpose of responding to the IXPE Cycle 4 Call for Proposals

Top-level reference URLs:

- IXPE WebPIMMS https://ixpe.msfc.nasa.gov/for_scientists/pimms/
- HEASARC's Viewing Tool https://heasarc.gsfc.nasa.gov/cgi-bin/Tools/viewing/viewing.pl
- IXPE-specific FTOOLS https://heasarc.gsfc.nasa.gov/docs/software/lheasoft/help/ixpe.html
- IXPE Data Analysis & Documentation https://heasarc.gsfc.nasa.gov/docs/ixpe/analysis/
- IXPE Helpdesk https://heasarc.gsfc.nasa.gov/cgi-bin/Feedback?selected=ixpe

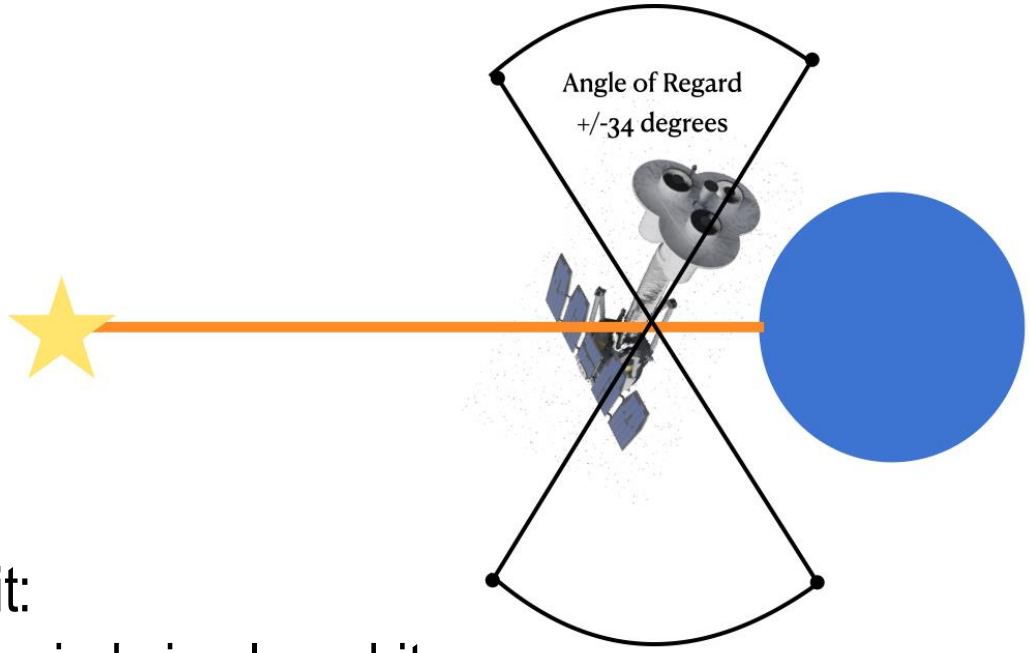
Mission Parameters

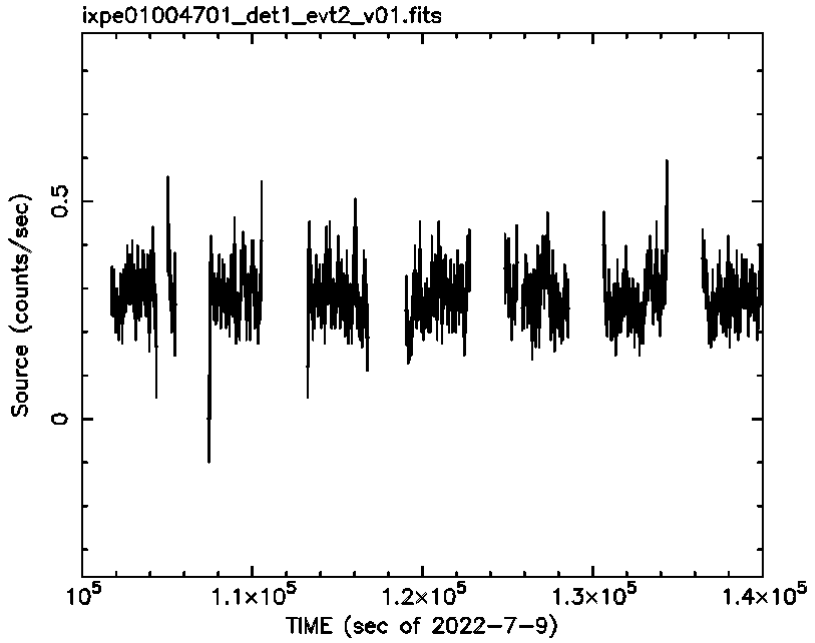
Three co-aligned telescopes:
Fit data from all three telescopes simultaneously

- FOV ~10’ diameter (+dither); HPD = 30”
- 1 Crab ~ 100 c/s per telescope (0.5-10 keV)

Photon counting: E, t, x, y plus Stokes I, Q, U

- Spectral, timing, imaging, plus polarization





Low Earth Orbit:

- 97-minute-period circular orbit
- ~0^O inclination; Solar panels +/-34^O w.r.t. Sun
- Targets are observable for ~70 days 2x per year

Continuous point-and-stare until exposure complete

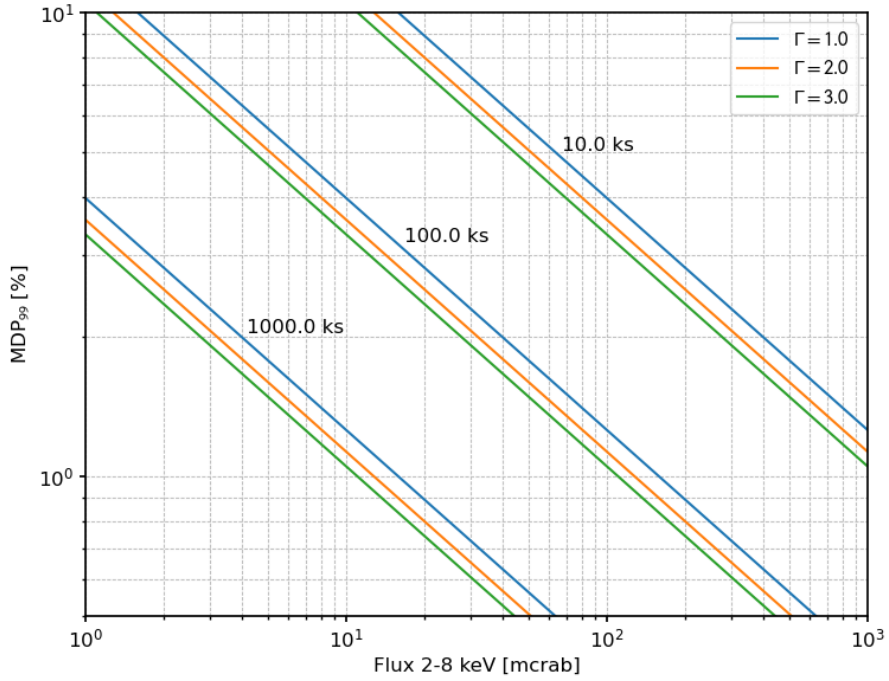
- Interrupted by Earth-occultations (and SAA passages) that limits average observing efficiency to ~50-60%

IXPE Proposal Tools

Summary of Observations

From Primary Mission start, 2022-01-11, through 2026-06-22 (4.4 years):

- 250 Observations (including 59 targets segmented into typically 2 or 3 segments; max 8)
- 271,779 sec average exposure time @ 49% efficiency (6.5-day average real elapsed time)
- 5,768 s minimum exposure time
- 2,186,674 s maximum exposure time



Why are such long exposures needed?

Minimum Detectable Polarization at 99% C.L. (MDP99):

$$\mathrm{MDP}_{99} = \frac{4.29}{\langle\mu\rangle C_S}\left[\frac{C_S + C_B}{T}\right]^{1/2} \approx \frac{4.29}{\langle\mu\rangle\sqrt{N}}$$

where C_S & C_B are Source and Background count rates, T is the exposure time, μ is the modulation factor, and $N = C_S T$ is the total number of counts when $C_S >> C_B$

IXPE Proposal Tools

On-Line Tools: WebPIMMS

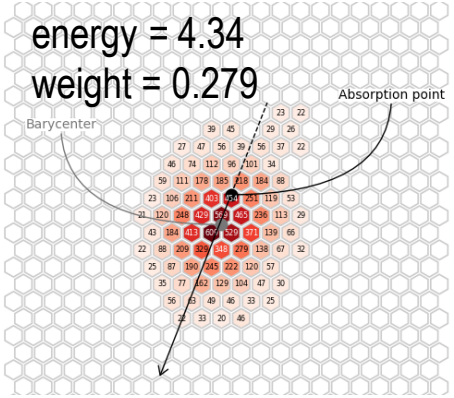
https://ixpe.msfc.nasa.gov/for_scientists/pimms/

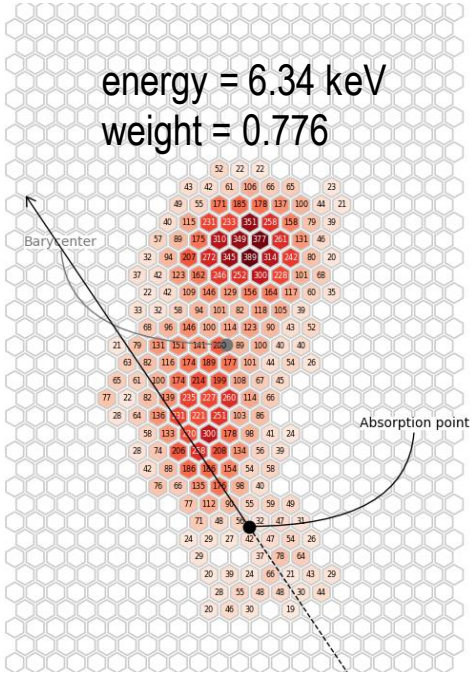
Recommend reading the introduction to PIMMS at the MSFC IXPE url above

Standard PIMMS interface for selecting:

- Convert From/To (e.g., Flux to IXPE count rate)
- Input (required for Flux) and Output Energy Range
- Source Model parameters (Power Law, APEC, etc.)
- Estimate Count Rate

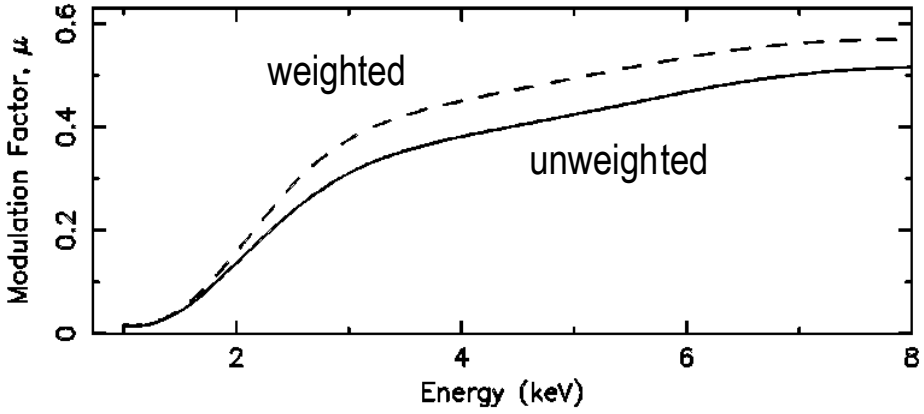
On-Line Tools: WebPIMMS





Event weights are a power of the ellipticity of the ionization track:

$$(TL - TW) / (TL + TW)^{0.75}$$



https://ixpe.msfc.nasa.gov/for_scientists/pimms/

Recommend reading the introduction to PIMMS at the MSFC IXPE url above

For IXPE, PIMMS returns:

- MDP99, or the time needed to reach a given MDP99
- Total Count Rate (3 telescopes), C_T
- Effective Count Rate (weights applied; use for polarization sensitivity calculations), C_E
- Modulated Count Rate, $C_M = \langle\mu\rangle C_E$

On-Line Tools: WebPIMMS

Example output for a 1 mCrab source
(results are for 3 telescopes combined):

PIMMS predicts 1.767E-01 cps with IXPE OPEN (2.000- 8.000keV)
The above is the total count rate.
The effective count rate for polarization is 0.1498
and the modulated count rate is 0.0488
for a modulation factor of 0.3257
Now estimating 99% confindence level minimum detectable polarization
(MDP_99) as a function of exposure time
In 10000.0 s, MDP_99 = 34.06%
In 100000.0 s, MDP_99 = 10.77%
% MDP_99 scales as the inverse of the square root of the integration time

PIMMS predicts 4.263E-02 cps with IXPE GRAY (2.000- 8.000keV)
The above is the total count rate.
The effective count rate for polarization is 0.0365
and the modulated count rate is 0.0152
for a modulation factor of 0.4181
Now estimating 99% confindence level minimum detectable polarization
(MDP_99) as a function of exposure time
In 10000.0 s, MDP_99 = 53.76%
In 100000.0 s, MDP_99 = 17.00%
% MDP_99 scales as the inverse of the square root of the integration time

https://ixpe.msfc.nasa.gov/for_scientists/pimms/

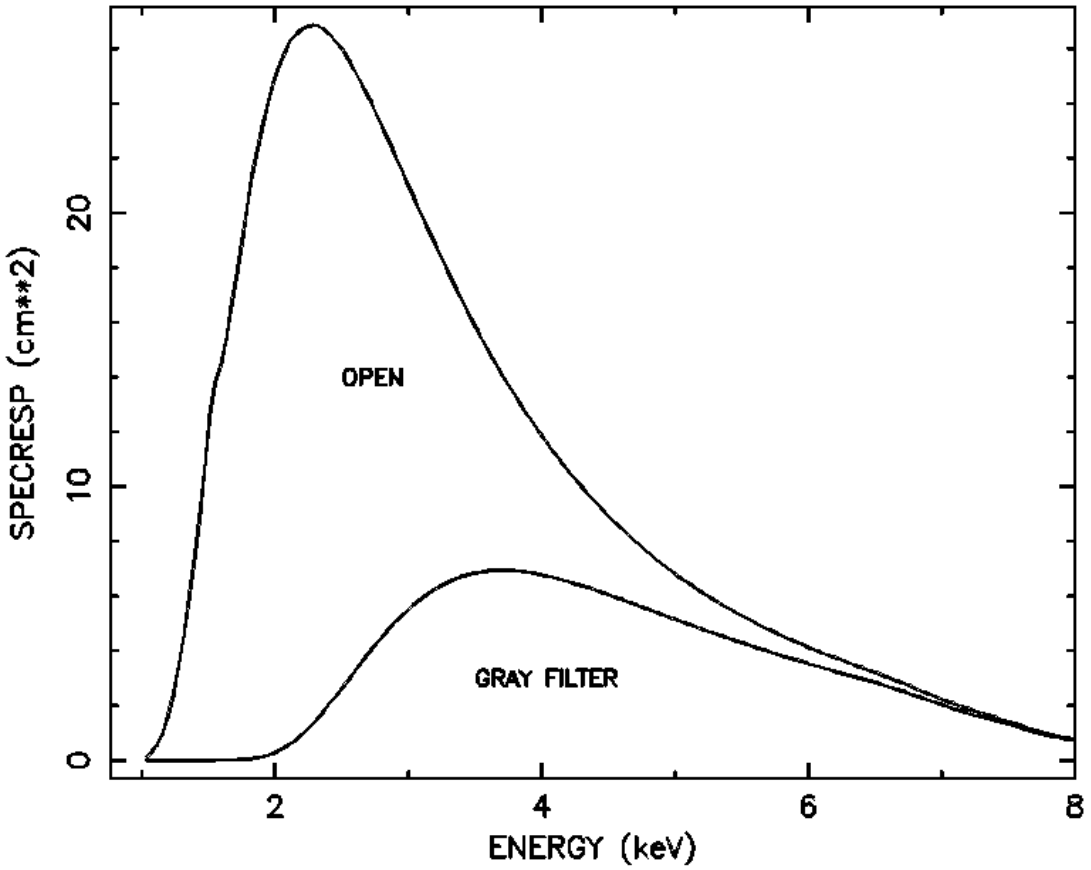
Converting from Flux to IXPE count rate returns the Total, Effective, and Modulated count rates.

Also returns the Modulation Factor and MDP99 for a 10 ks and for a 100 ks exposure (or, the Exposure Time needed to reach a given MDP99)

- MDP99 scales as (Exposure Time)$^{-1/2}$
- Use a 2-8 keV energy range for MDP99 sensitivity
- Use 0.5-10 keV for Total count rate estimates
- Provides results for both Open and for Gray Filter (use the gray filter for sources brighter than ~2 Crab in 0.5-10 keV)

On-Line Tools: WebPIMMS

Example output for a 1 mCrab source (results are for 3 telescopes combined):



https://ixpe.msfc.nasa.gov/for_scientists/pimms/

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Also returns the Modulation Factor and MDP99 for a 10 ks and for a 100 ks exposure (or, the Exposure Time needed to reach a given MDP99)

- MDP99 scales as (Exposure Time)$^{-1/2}$
- Use a 2-8 keV energy range for MDP99 sensitivity
- Use 0.5-10 keV for Total count rate estimates
- Provides results for both Open and for Gray Filter (use the gray filter for sources brighter than ~2 Crab in 0.5-10 keV)

On-Line Tools: WebPIMMS

Example 1: Bright point source with negligible background
Gamma=2.05, N_H=2x10^{21} cm^{-2}, F_{2-8}=2.1x10^{-11} erg/s/cm^2
On the 2-8 keV range (input and output)

https://ixpe.msfc.nasa.gov/for_scientists/pimms/

PIMMS predicts 1.767E-01 cps with IXPE OPEN (2.000- 8.000keV)
The above is the total count rate.
The effective count rate for polarization is 0.1498
and the modulated count rate is 0.0488
for a modulation factor of 0.3257
Now estimating 99% confindence level minimum detectable polarization (MDP_99) as a function of exposure time
In 10000.0 s, MDP_99 = 34.06%
In 100000.0 s, MDP_99 = 10.77%
% MDP_99 scales as the inverse of the square root of the integration time

This is the simplest and most common case. The reported MDP99 can be used straight away. To get a better estimate of the total count rate, change the output energy range to 0.5-10 keV.

On-Line Tools: WebPIMMS

Example 1: Bright point source with negligible background
Gamma=2.05, N_H=2x10^{21} cm^{-2}, F_{2-8}=2.1x10^{-11} erg/s/cm^2
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The above is the total count rate.
The effective count rate for polarization is 0.1498
and the modulated count rate is 0.0488
for a modulation factor of 0.3257
Now estimating 99% confindence level minimum detectable polarization (MDP_99) as a function of exposure time
% It takes 1288625.1s to achieve an MDP_99 of 3.00%

This is the output when PIMMS is given an input MDP99 (here, 3%). If you predict your source will deliver somewhat more than 3% polarization degree, then you should propose for at least this 1.3 Ms exposure time.

On-Line Tools: WebPIMMS

Example 2: Extended source with measurable background (same absorbed power law model as example 1)

PIMMS predicts 1.767E-01 cps with IXPE OPEN (2.000- 8.000keV)
The above is the total count rate.
The effective count rate for polarization is 0.1498
and the modulated count rate is 0.0488
for a modulation factor of 0.3257
Now estimating 99% confindence level minimum detectable polarization (MDP_99) as a function of exposure time
In 10000.0 s, MDP_99 = 34.06%
In 100000.0 s, MDP_99 = 10.77%
% MDP_99 scales as the inverse of the square root of the integration time

https://ixpe.msfc.nasa.gov/for_scientists/pimms/

Perform the following steps:

1. Estimate area of source region of interest, ***A*** (should be limited to w/in an ~5' radius)
2. Estimate 2-8 keV flux in ***A*** and select a spectral model
3. Use PIMMS to determine source Effective count rate, C_S, and modulation factor, μ, (ignore MDP99 values)
4. Estimate background rate, C_B, in ***A***: (***A***)(0.0012 cts/s/arcmin^2)(Di Marco et al. 2023)
5. Compute MDP99 from:

$$\mathrm{MDP}_{99} = \frac{4.29}{\langle\mu\rangle C_S}\left[\frac{C_S + C_B}{T}\right]^{1/2}$$

On-Line Tools: WebPIMMS

Example 3: Two-component point source; one component polarized

https://ixpe.msfc.nasa.gov/for_scientists/pimms/

Polarized Power Law component (see Example 1):

PIMMS predicts 1.767E-01 cps with IXPE OPEN (2.000- 8.000keV)
The above is the total count rate.
The effective count rate for polarization is 0.1498
and the modulated count rate is 0.0488
for a modulation factor of 0.3257

Unpolarized APEC component (0.61 keV, solar Z, N_H=2x10^{21} cm^{-2}, F_{2-8}=2.1x10^{-11} erg/s/cm^2):

PIMMS predicts 3.819E-01 cps with IXPE OPEN (2.000- 8.000keV)
The above is the total count rate.

Perform the following steps:

1. Estimate 2-8 keV flux and a spectral model for both components
2. Use PIMMS to determine source Effective count rate and modulation factor (ignore MDP99 values) for the polarized component
3. Use PIMMS to determine Total count rate in unpolarized component
4. Treat unpolarized component as a background and compute MDP99 as before from:

$$\mathrm{MDP}_{99} = \frac{4.29}{\langle\mu\rangle C_S}\left[\frac{C_S + C_B}{T}\right]^{1/2}$$

On-Line Tools: Viewing

https://heasarc.gsfc.nasa.gov/cgi-bin/Tools/viewing/viewing.pl

Viewing Results

Input equatorial coordinates:
Cyg X-2, resolved by SIMBAD (local cache) to
[326.1715°, 38.3214°], equinox J2000.0

```
                              IXPE

        *** VIEWING Version 3.4      run on 2025 Jul  1 ***
              for the period 2025 Jul 01 to 2027 Jul 02

               With IXPE (Sun angle range =  56-124):
        Observable between 2025 Jul 01 or before and 2025 Aug 05
        Observable between 2025 Oct 13           and 2026 Feb 02
        Observable between 2026 Apr 10           and 2026 Aug 06
        Observable between 2026 Oct 13           and 2027 Feb 02
    Observable between 2027 Apr 10          and 2027 Jul 02 or later
```

Simple Input:

1. Select Mission (IXPE)
2. Select Object Name or Coordinates

Output:

1. Returns list of all observable windows start/end dates (year, month, day)
2. Returns results for a 2 year period beginning on day of query

If planning Joint proposal, can repeat for XRISM, XMM-Newton, …

On-Line Tools: Viewing

https://heasarc.gsfc.nasa.gov/cgi-bin/Tools/viewing/viewing.pl

Viewing Results

Input equatorial coordinates:
Cyg X-2, resolved by SIMBAD (local cache) to
[326.1715°, 38.3214°], equinox J2000.0

```
*** VIEWING Version
        for the perio

        With IXPE (Su
Observable between 20
Observable between 20
Observable between 20
Observable between 2026 Oct 13          and 2027 Feb 02
Observable between 2027 Apr 10          and 2027 Jul 02 or later
```

Simple Input:

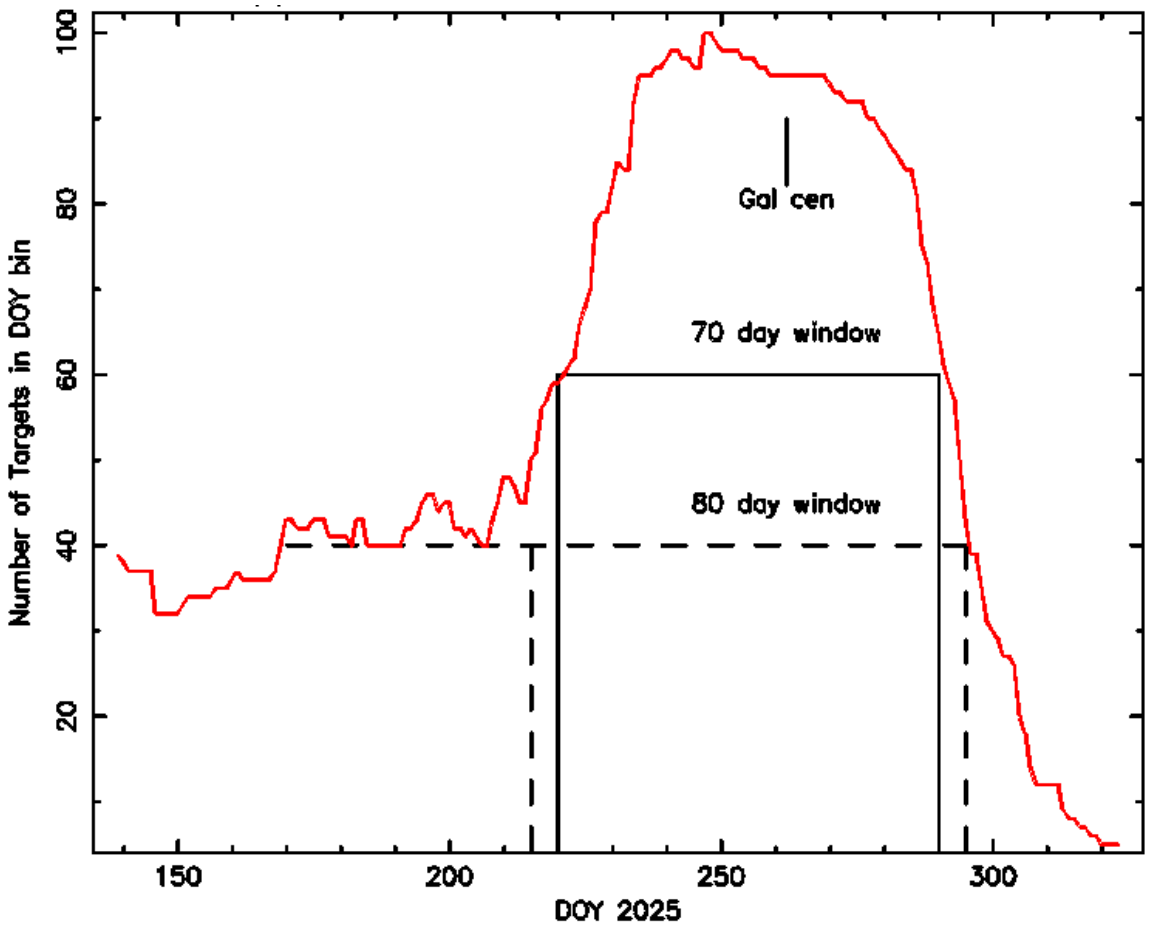
1. Select Mission (IXPE)
2. Select Object Name or Coordinates

windows start/end

eriod beginning on

If you plan to **monitor** a target, take the simple step to ensure you can observe your target at the cadence you need.

On-Line Tools: Viewing



'/heasarc.gsfc.nasa.gov/cgi-bin/Tools/viewing/viewing.pl

The Galactic Center region is oversubscribed !
If your target is only viewable at dates within the following Cycle 4 date ranges, then it is in the oversubscribed Galactic Center window and subject to a restricted time allocation.

- 12 Feb 2027 --- 25 Apr 2027
- 18 Aug 2027 --- 25 Oct 2027

The figure at left is from Cycle 3 and shows only days-of-year around the 2nd window

As-Run Target List & Long Term Plan

https://ixpe.msfc.nasa.gov/for_scientists/asrun.html

https://ixpe.msfc.nasa.gov/for_scientists/ltp.html

OBSID	Start Time	Stop Time	Name
01001301	2022-01-11T11:23	2022-01-29T12:39	Cas A
01006501	2022-01-29T12:39	2022-01-31T06:58	Cen X-3
01003299	2022-01-31T07:23	2022-02-27T19:14	4U 0142+61
01004301	2022-02-15T00:13	2022-02-17T13:52	Cen A
01001899	2022-02-17T13:52	2022-02-24T19:36	Her X-1
01001099	2022-02-21T16:12	2022-03-08T02:38	Crab
01003499	2022-02-27T19:14	2022-03-24T01:51	Sgr A comple:
01004501	2022-03-08T02:38	2022-03-10T08:19	Mrk 501
01002701	2022-03-24T01:51	2022-03-27T05:39	4U 1626-67
01004601	2022-03-27T05:39	2022-03-29T07:14	Mrk 501
01002801	2022-03-29T07:14	2022-03-31T09:20	GS 1826-238
01005301	2022-03-31T09:20	2022-04-05T19:50	S5 0716+714
01001299	2022-04-05T19:50	2022-04-30T10:33	Vela Pulsar

P	S	Pnum	Name	RA	Dec	Start	buffer
A	0	2103	KES 75	281.604	-2.975	2025-04-08T06	0.0
A	0	2022	SS 433 WEST	287.672	5.032	2025-04-19T00	0.0
A	0	2003	MCG-5-23-16	146.917	-30.949	2025-04-24T12	0.0
A	0	2184	GRS 1915+105	288.798	10.946	2025-05-10T12	0.0
C	0	2152	NGC 3227	155.877	19.865	2025-05-13T18	0.0
D	0	0000	Cyg X-2	326.171	38.321	2025-05-28T12	1669.8
A	0	2014	LIGHTHOUSE N	165.359	-61.015	2025-05-30T12	0.0
C	0	2095	1ES 1927+654	291.831	65.565	2025-06-17T12	0.0
D	0	0000	H 1417-624	215.300	-62.699	2025-06-27T18	0.0
D	0	0000	Cyg X-2	326.171	38.321	2025-07-03T12	2337.7
A	0	2067	PG 1553+113	238.929	11.190	2025-07-06T06	1636.4
C	0	2093	UW CRB	241.441	25.863	2025-07-09T00	167.6

As-Run Target List & Long Term Plan

https://ixpe.msfc.nasa.gov/for_scientists/asrun.html https://ixpe.msfc.nasa.gov/for_scientists/ltp.html

OBSID	Start Time	Stop T		buffer
01001301	2022-01-11T11:23	2022-0	T06	0.0
01006501	2022-01-29T12:39	2022-0	T00	0.0
01003299	2022-01-31T07:23	2022-0	T12	0.0
01004301	2022-02-15T00:13	2022-0	T12	0.0
01001899	2022-02-17T13:52	2022-0	T18	0.0
01001099	2022-02-21T16:12	2022-0	T12	1669.8
01003499	2022-02-27T19:14	2022-0	T12	0.0
01004501	2022-03-08T02:38	2022-0	T12	0.0
01002701	2022-03-24T01:51	2022-0	T18	0.0
01004601	2022-03-27T05:39	2022-0	T12	2337.7
01002801	2022-03-29T07:14	2022-0	T06	1636.4
01005301	2022-03-31T09:20	2022-0	T00	167.6
01001299	2022-04-05T19:50	2022-0		

Purpose of target lists is two-fold:

- Ensure your favorite source hasn't already been observed
- Find a source similar to yours and see what was observed

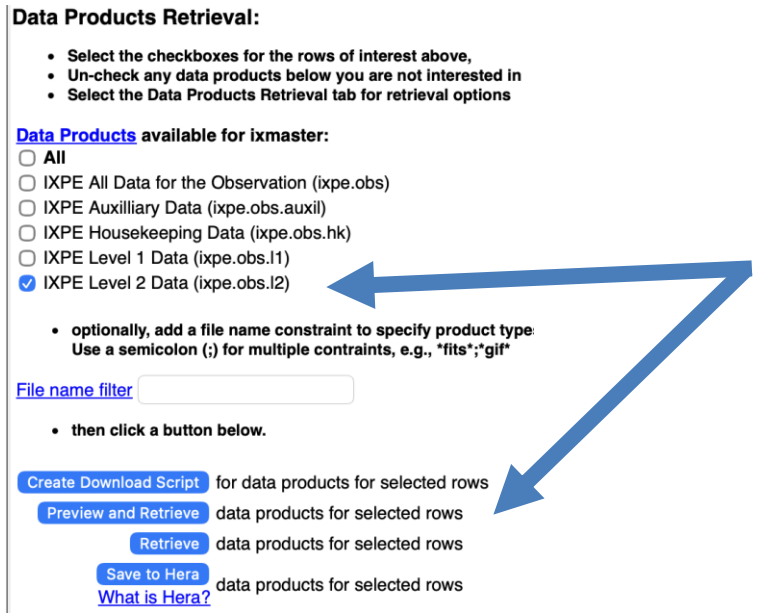
See also:

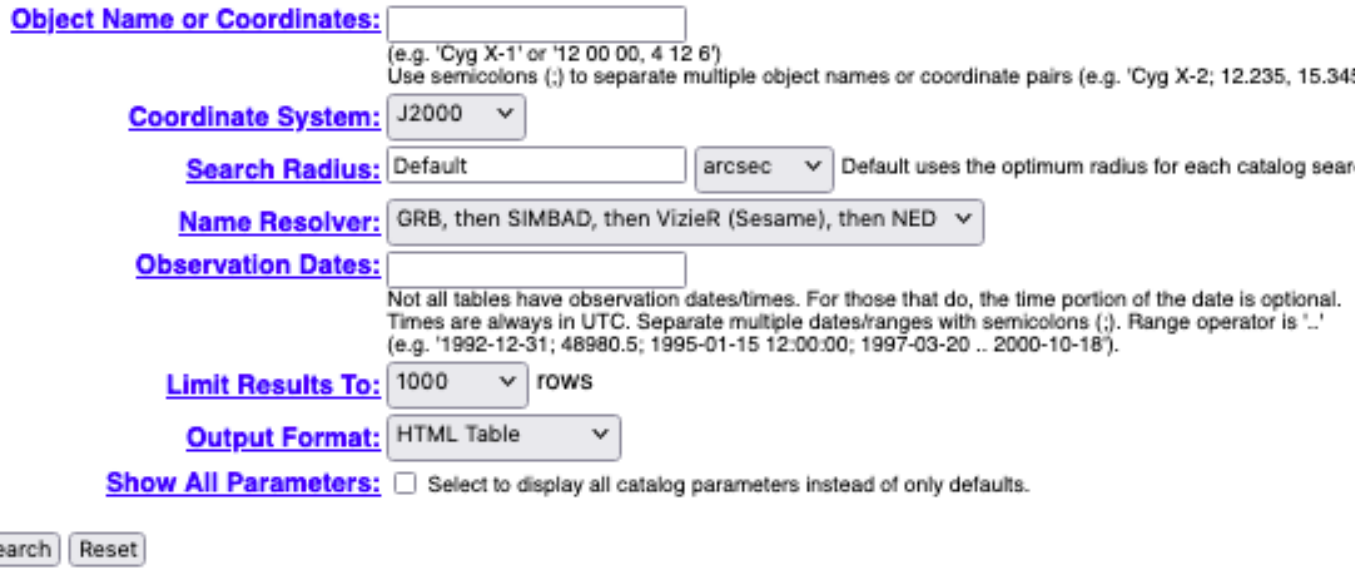
- HEASARC's IXPE Master List
https://heasarc.gsfc.nasa.gov/db-perl/W3Browse/w3table.pl?tablehead=name=ixmaster&Action=More+Options
- HEASARC's IXPE-related publications list
https://heasarc.gsfc.nasa.gov/docs/heasarc/biblio/pubs/ixpe.html

IXPE Data Archive

Public access is through HEASARC https://heasarc.gsfc.nasa.gov/docs/ixpe/archive/

- Browse interface
- Xamin interface (+ command-line batch)
- FTP via HTTPS
- Python





Example using w3browse…only need the Level 2 event lists (3 telescopes = 3 data files)

IXPE Documentation

- Available at the IXPE Analysis page, includes “official” documentation on the observatory, software, data formats, and other useful information that is updated occasionally

  https://heasarc.gsfc.nasa.gov/docs/ixpe/analysis/

Documents	Release Date	Description
Quick Start Guide	June 2025	Information to enable basic scientific analysis of IXPE data. Release Notes
IXPE Observatory	June 2022	The IXPE Team description of the observatory and guide for users.
IXPE Data Formats	June 2022	The IXPE Team description of the data formats for level 1, level 2, and calibration data products.
IXPE Software User Guide	March 2022	Software analysis guide including a description of the pipeline as well as help for each tool (pdf)
IXPE Instrument	June 2022	The IXPE Team description of the instrument.
Statistics Guide	September 2022	Recommended practices for statistical treatment of IXPE results.