



X-Ray Polarimetry with the IXPE observatory

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X-Ray Polarimetry

In the last few decades X-ray spectroscopy and timing have probed compact objects where images cannot

Polarimetry adds two additional observables:

- Polarization degree
- Polarization angle

These give information on:

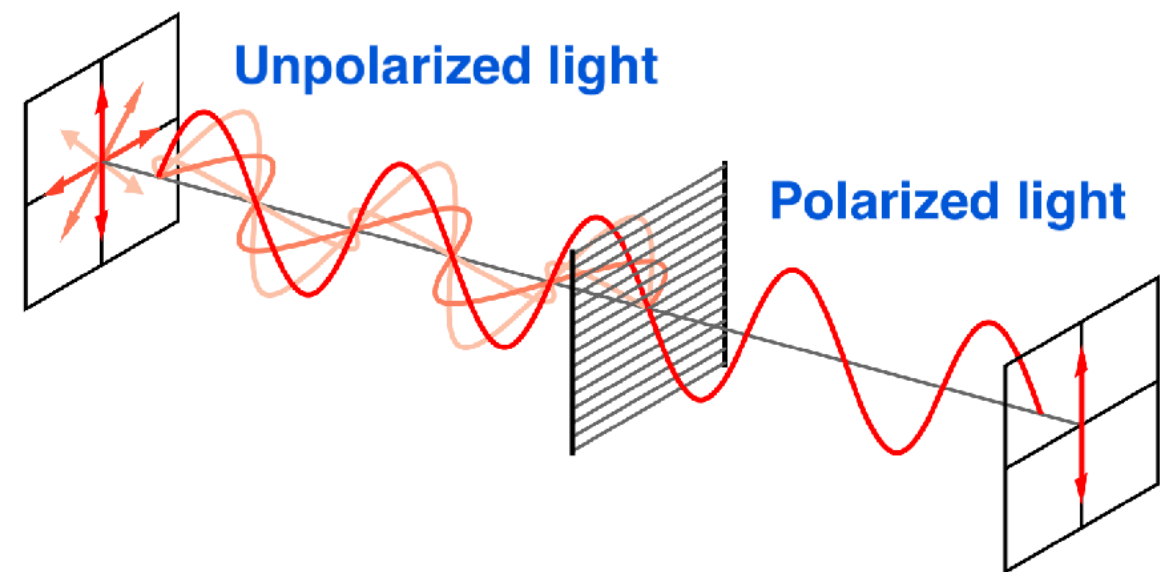


Image credit: Wikimedia Commons

Geometry

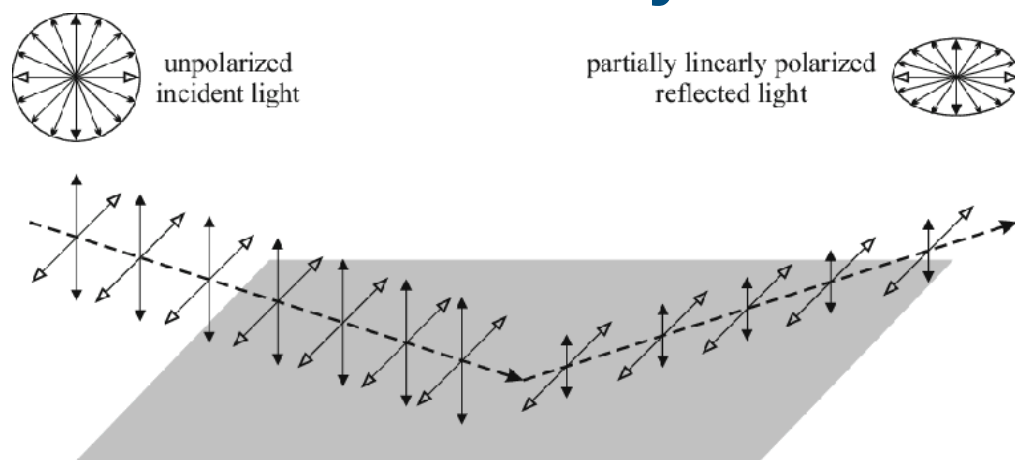
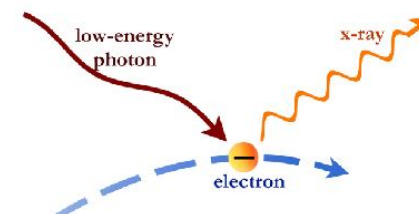


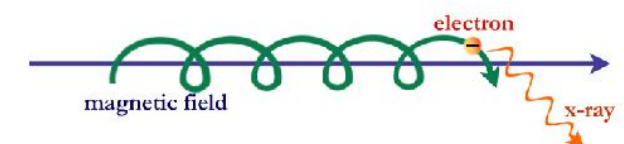
Image credit: Horvát+ 2019

Emission mechanisms

Inverse Compton Scattering



Synchrotron



Images credit: NASA



X-Ray Polarimetry until 2021

- 1971 and 1978: Bragg diffraction detectors on board a rocket and OSO-8
- 2019: Photoelectric detectors on board the PolarLight cubesat

The next step is an observatory with optics:
IXPE mission

IXPE the day before launch:

All of these missions have no optics, and have mostly studied only the Crab Nebula:

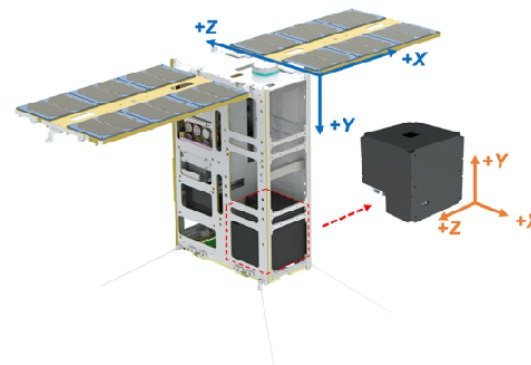
- $P=(19\pm1)\%$ indicated synchrotron origin of the X-rays from the pulsar wind nebula



Image credit: NASA



M. C. Weisskopf 2018



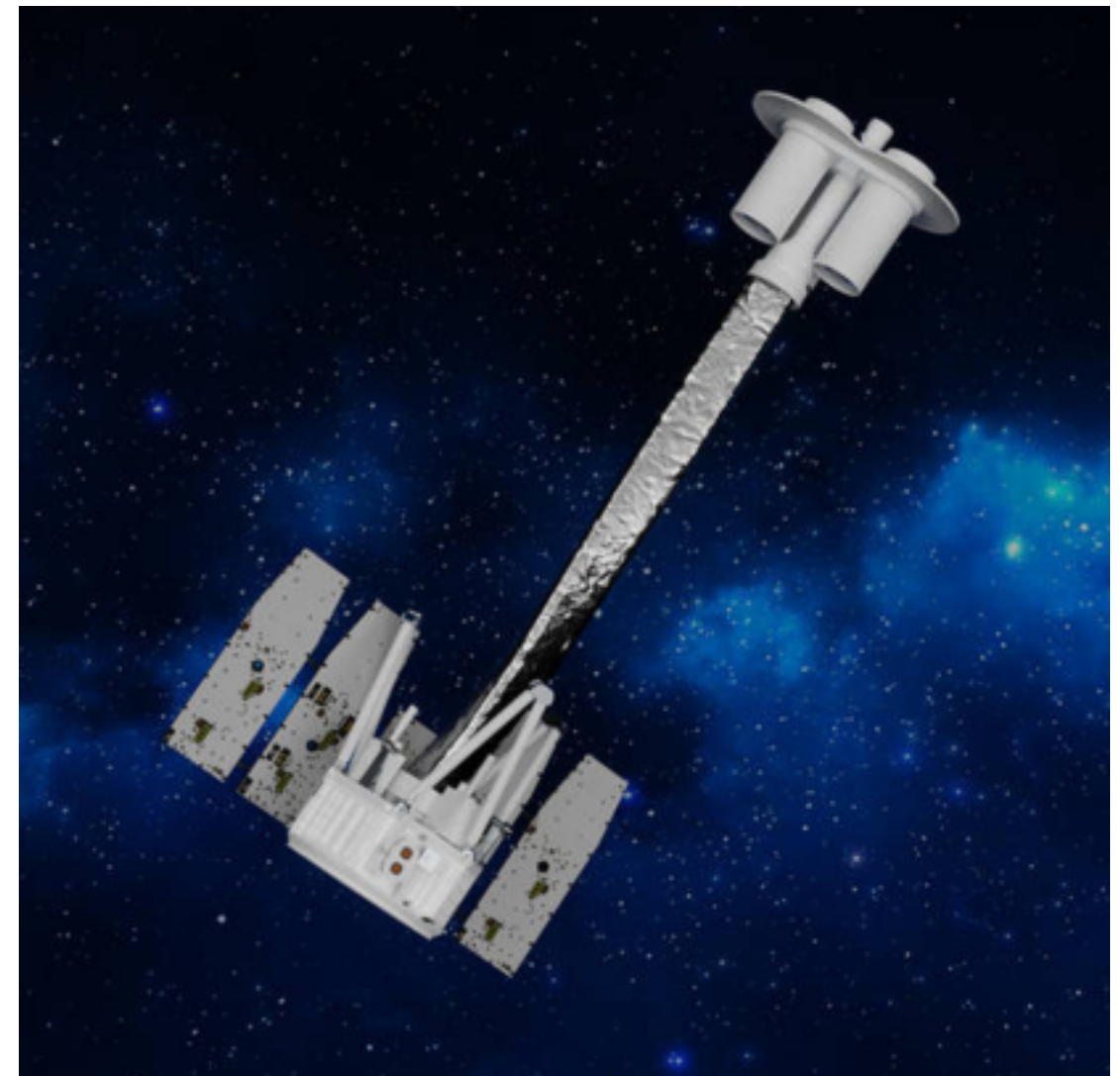
Hua Feng+ 2019
















Imaging X-ray Polarimetry Explorer (IXPE)

- First observatory dedicated to X-ray polarimetry
 - Photoelectric polarimeters + X-ray optics
- Launched December 2021
- Reaches same sensitivity as OSO-8 in 1/100 of the time
- Can study polarimetry of tens of sources



 Marshall Space Flight Center PI team, project management, SE and S&MA oversight, mirror module fabrication, X-ray calibration, science operations, and data analysis and archiving	    Polarization-sensitive imaging detector systems
 ASI Detector system funding, ground station	 LASP Mission operations
 Bell Spacecraft, payload structure, payload, observatory I&T	 ROMA TRE Scientific theory
	 Stanford University Thermal shields
	 NAGOYA UNIVERSITY Co-Investigator



Imaging X-ray Polarimetry Explorer (IXPE)

3 Gas Pixel Detectors (GPD) based on the photoelectric effect (ASI, INAF, INFN)

3 gracing incidence X-ray optics (NASA)



Mirror Module Assembly (3x)

Deployable Boom

Tip/Tilt/Rotate Mechanism

Deployable Shield (3x)

Detector Units (3x)

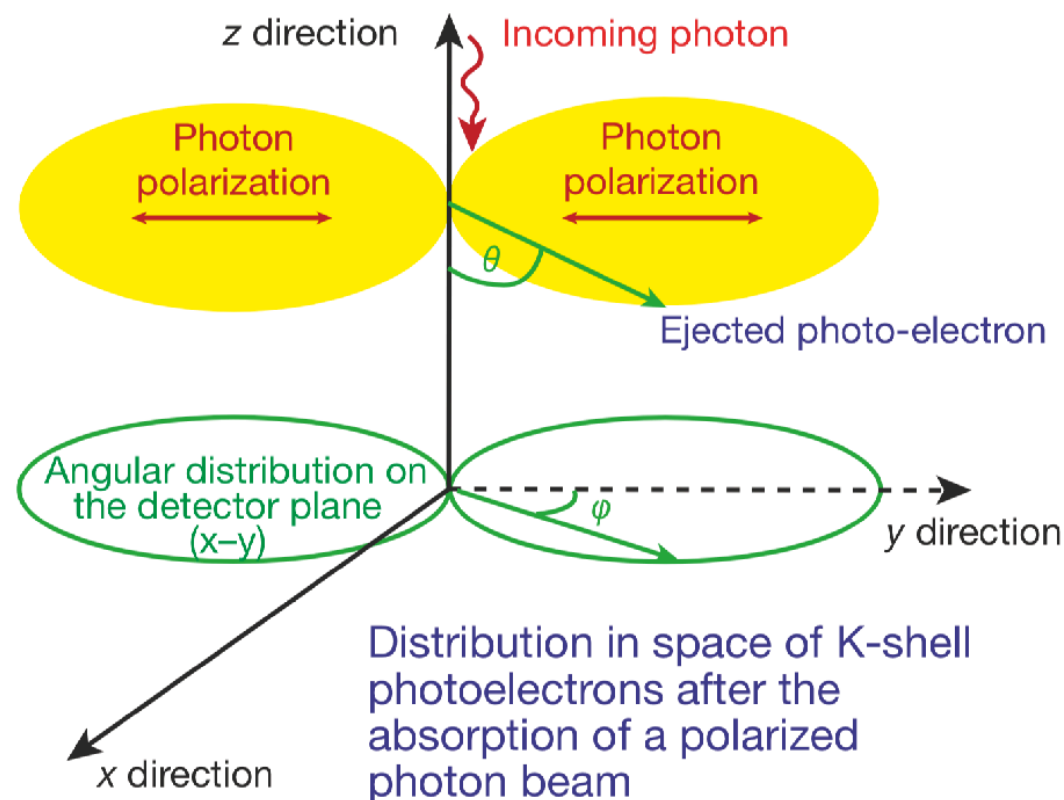
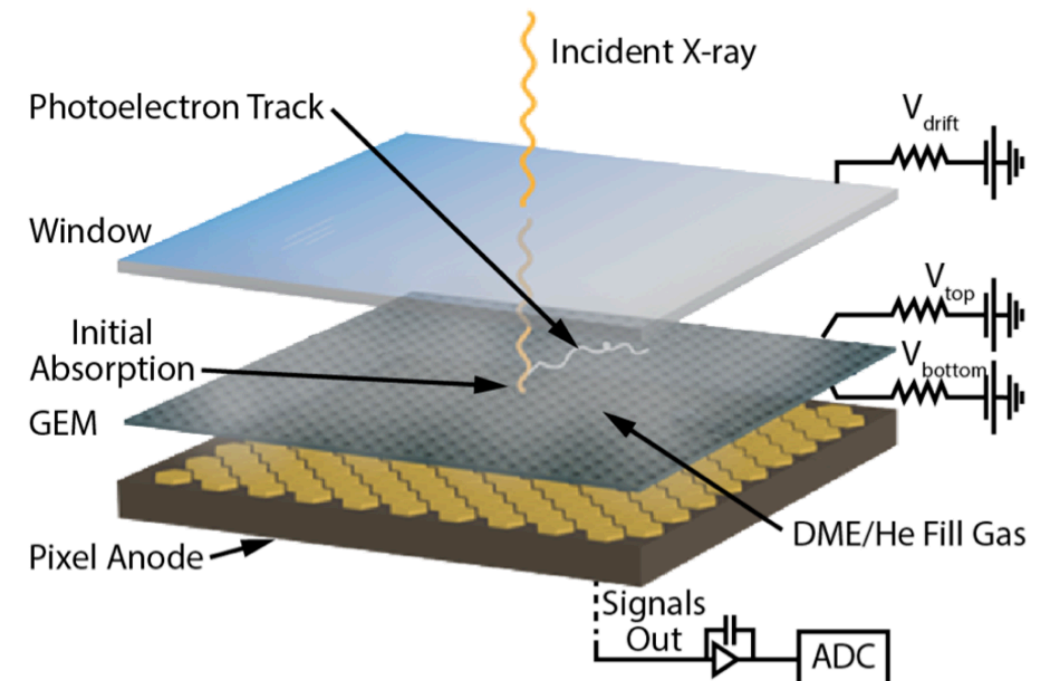
Energy range	2-8 keV
Timing	10 μ s
Energy resolution	<20% at 5.9 keV
Angular resolution	<30 arcsec
Field of view	10 arcmin
Polarization sensitivity	<5.5% (10^{11} erg/s/cm ² , 10 days)



How IXPE measures polarization

Using the Gas Pixel Detectors,
based on the photoelectric effect

- The distribution in angle of ejected photoelectrons is peaked around the polarization's direction

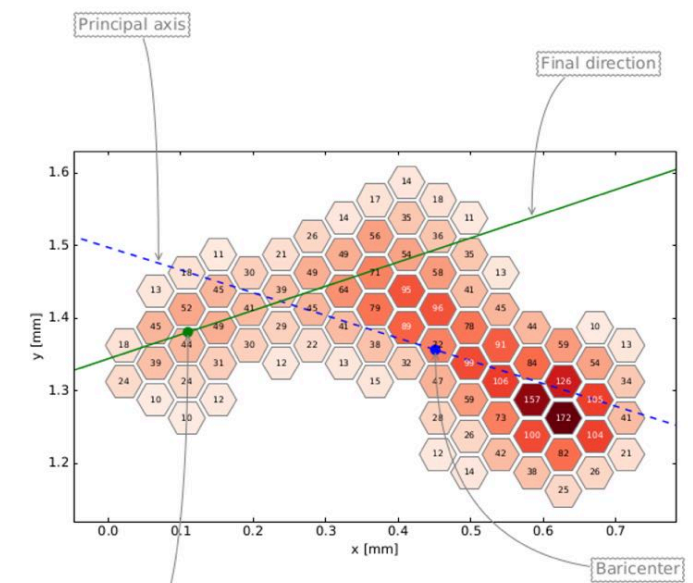
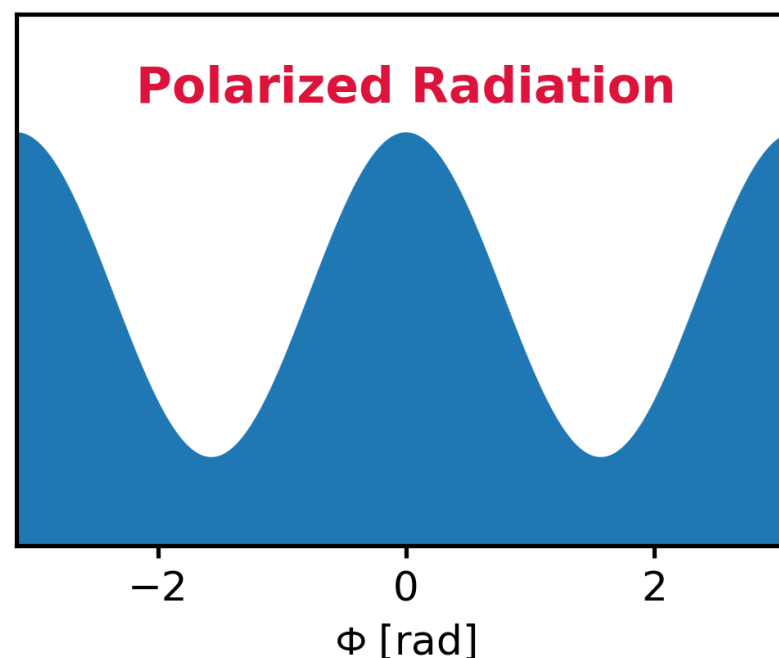
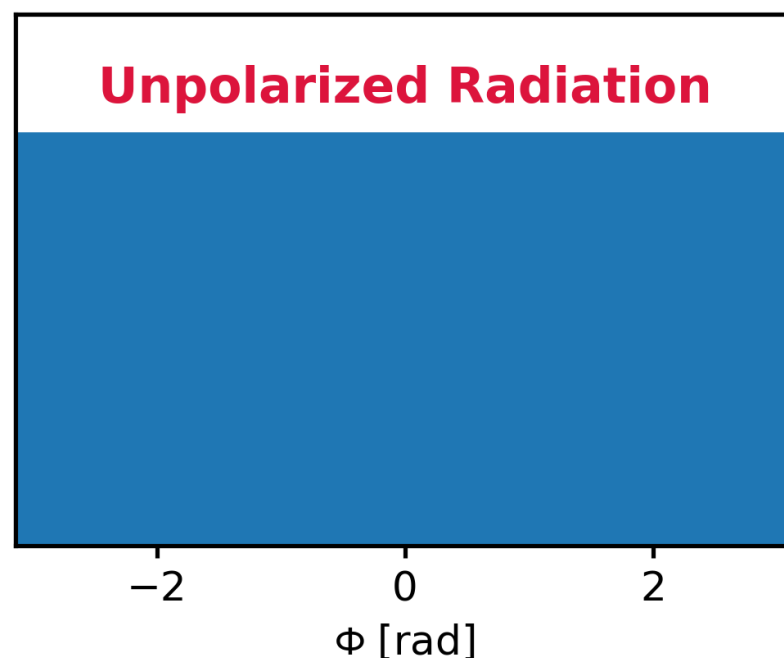
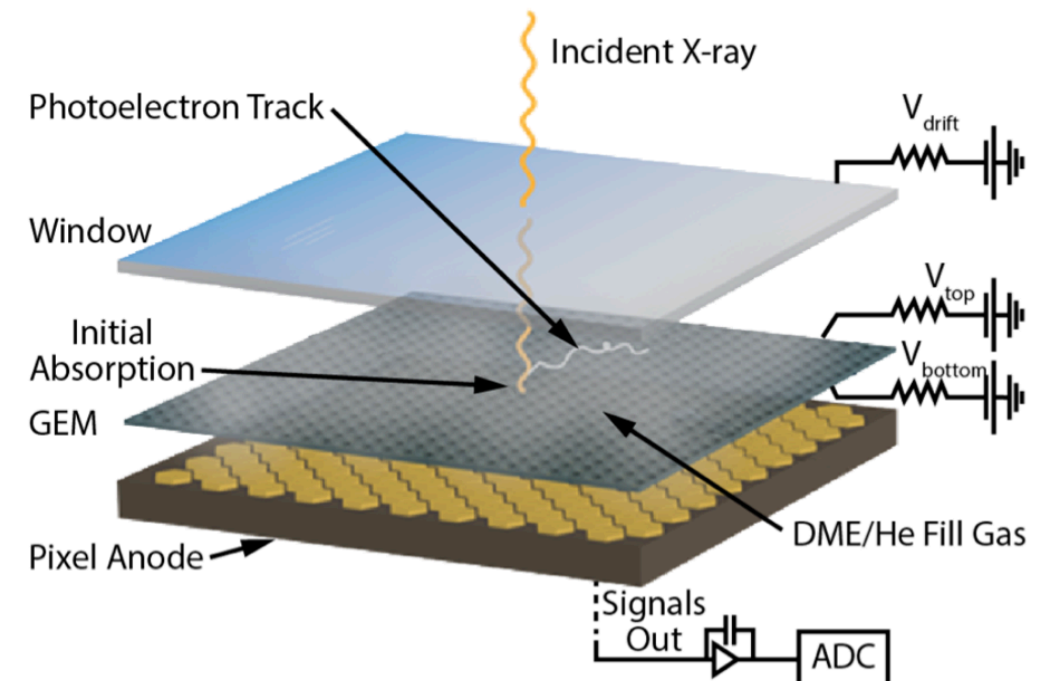




How IXPE measures polarization

Using the Gas Pixel Detectors,
based on the photoelectric effect

- The incident X-ray extracts a photoelectron that produces a ionization track in the gas
- The track is amplified and read
- A histogram of the directions of all tracks is produced

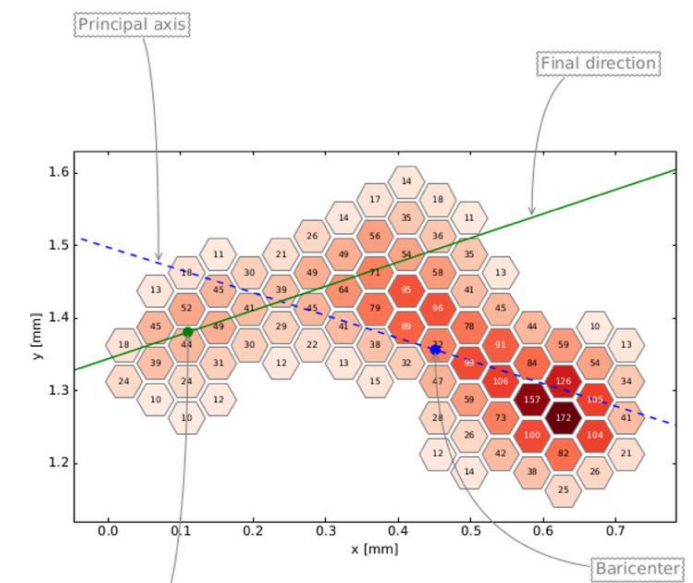
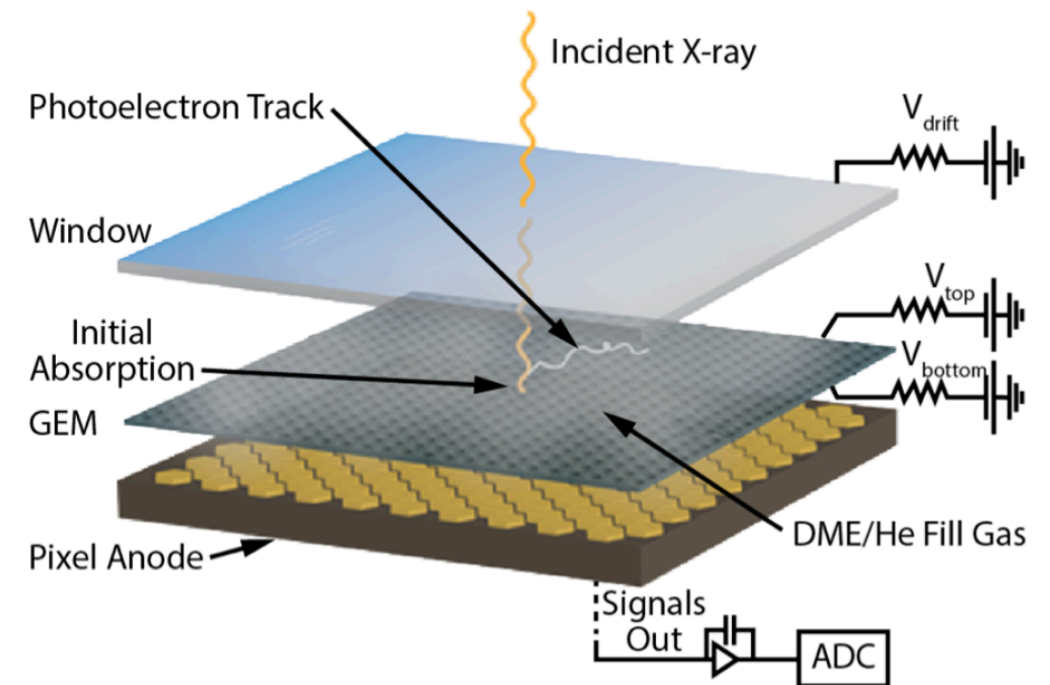




How IXPE measures polarization

Using the Gas Pixel Detectors,
based on the photoelectric effect

- For each X-ray it detects
 - Photoelectric track direction
 - Energy
 - Position
 - Time of arrival





The instrument on-board IXPE

Each detector units contains:

- Gas Pixel Detector
- Back-End Electronics which power and control the detectors
- Filter and calibration wheel
 - 4 calibration sources
 - Gray filter

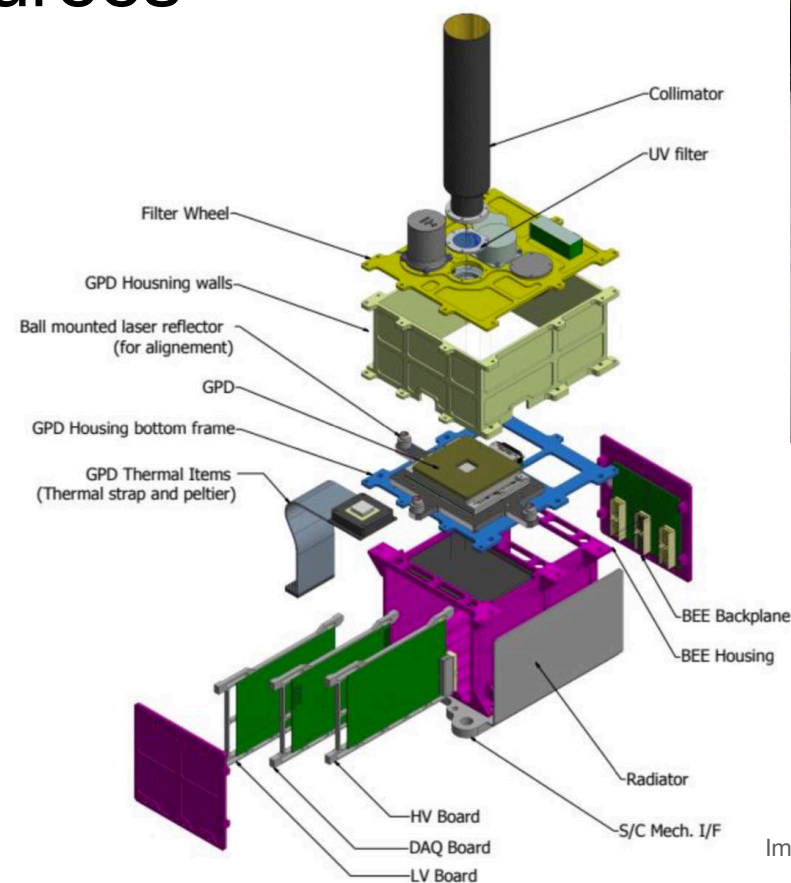


Image credit: INFN



Calibration of IXPE

How do we distinguish if a photon is telling real astrophysical information or something else (instrumental effects)?

- Crab Nebula, only source with previous X-ray polarization measurements

Variable over time: cannot be used



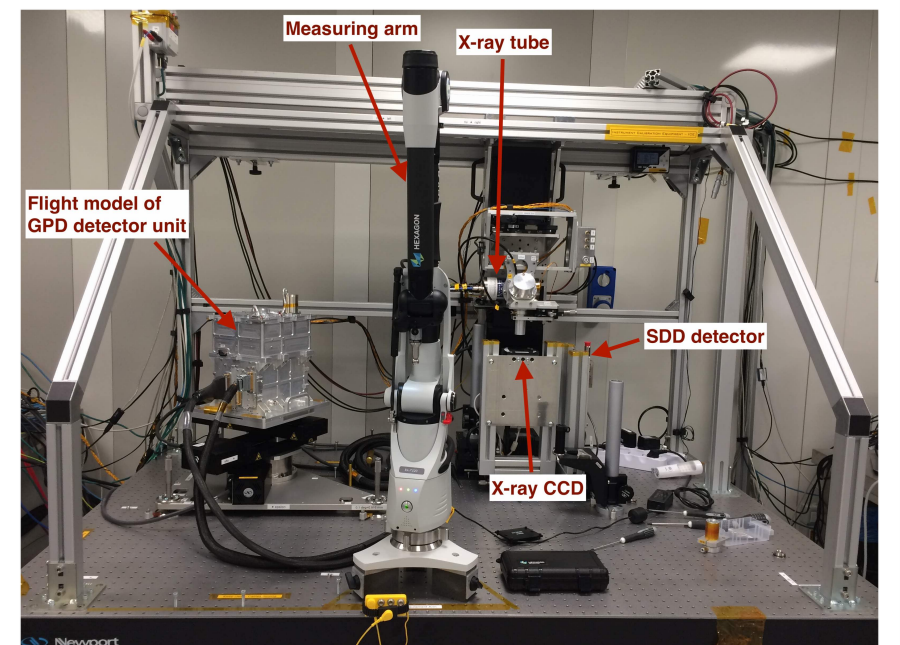
Thorough ground calibration required



In-flight monitoring of this calibration



Image credit: NASA





Ground Calibration of IXPE

Detector Units calibrated
at INAF/IAPS in Italy



Spare detector+ optics
calibrated at NASA/MSFC in
USA



Integration at Ball Aerospace in USA

Optics calibrated at
NASA/MSFC in USA





Flight Calibration of IXPE

Four calibration sources on-board

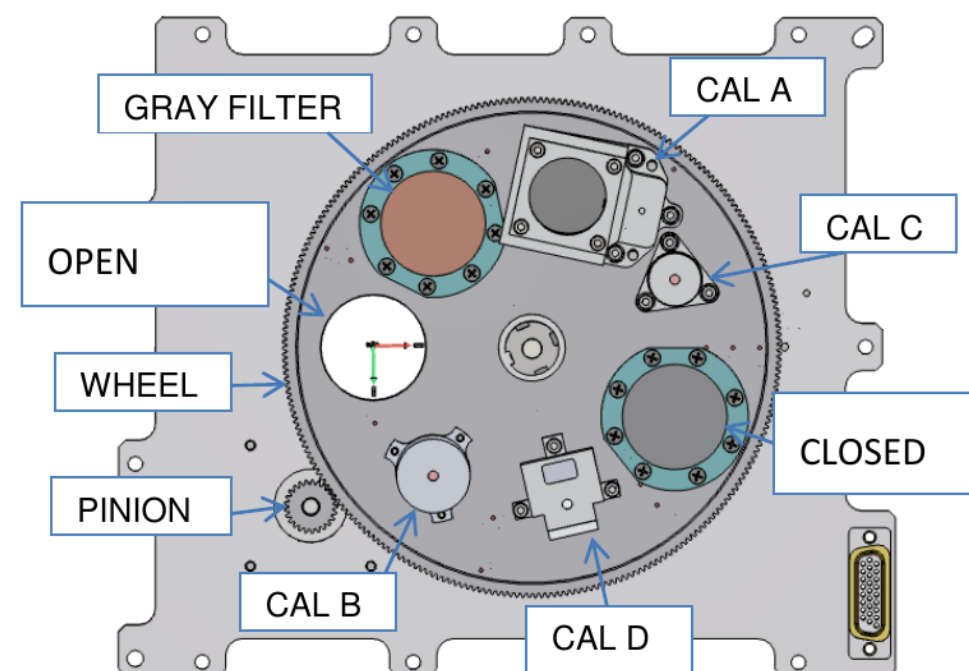
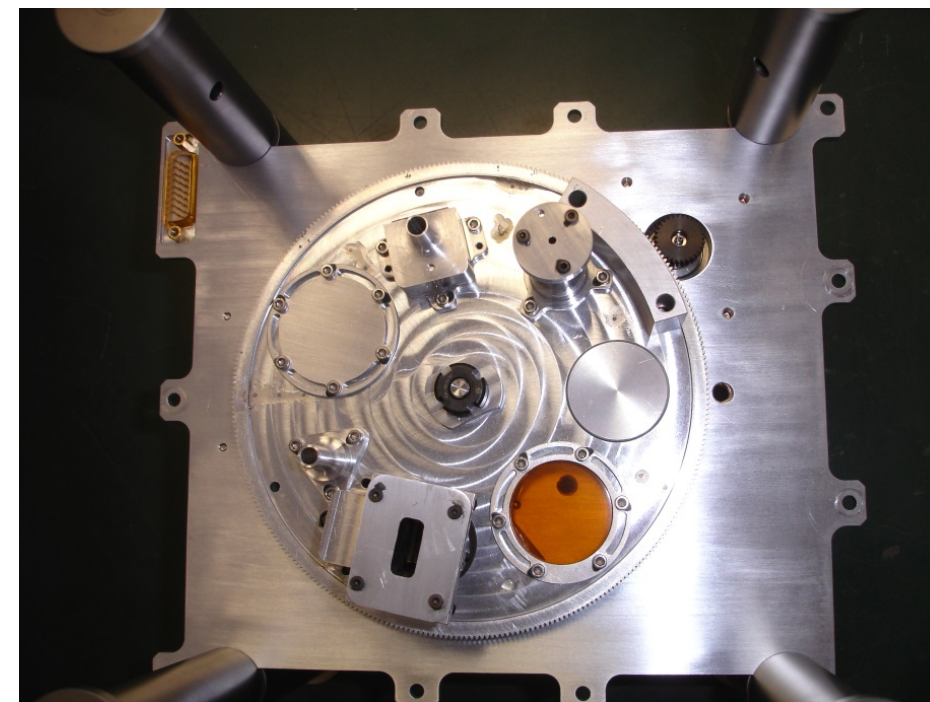
Response to polarization
depends on energy



Accurate polarization calibration
requires accurate energy
calibration



Energy variations calibrated with
on-board sources



Launch of IXPE

IXPE was launched on
December 9, 2021 from
Kennedy Space Center



Image credit: NASA



Jordan Sirokie

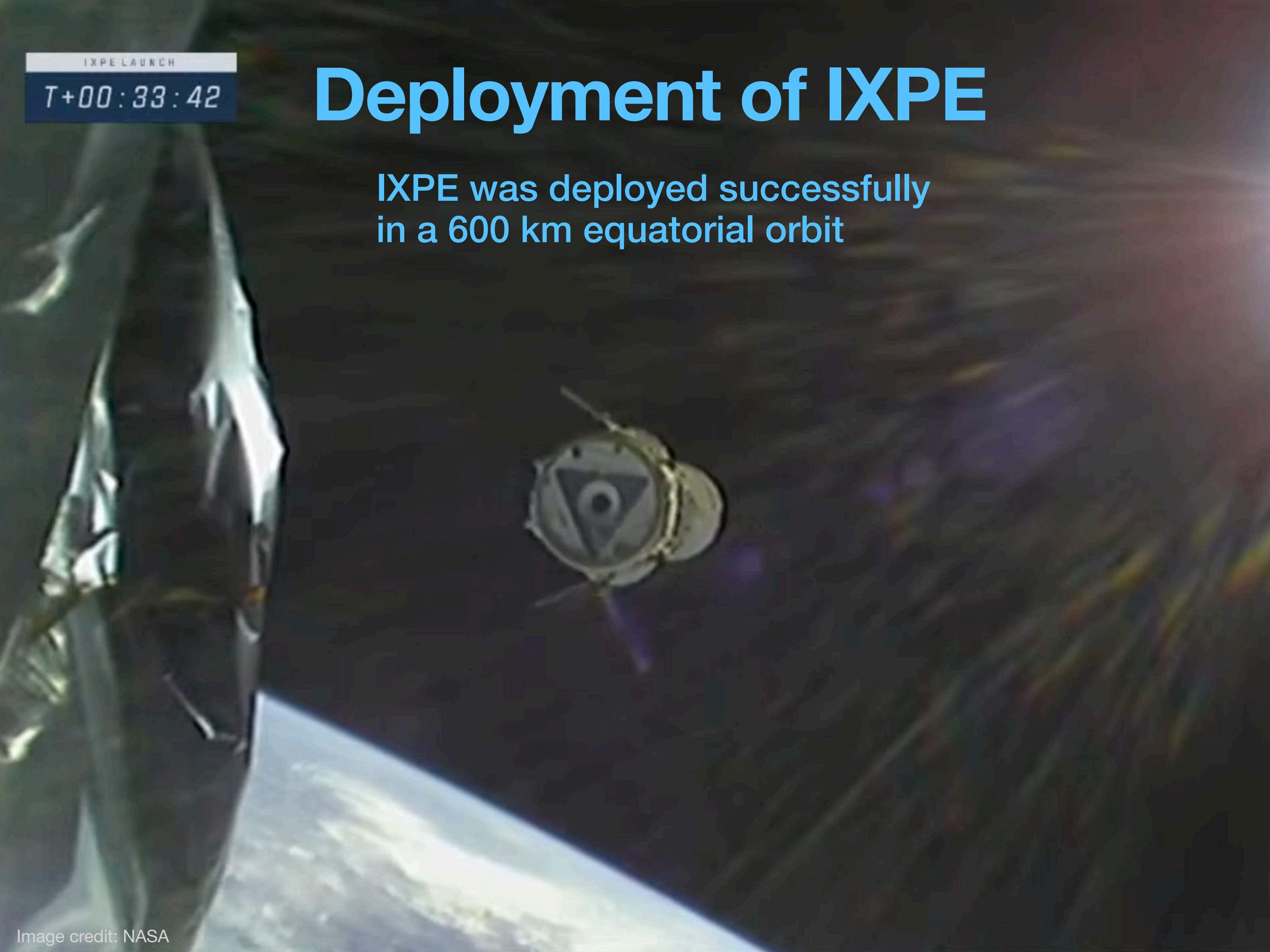
Image credit: Jordan Sirokie

IXPE LAUNCH

T+00:33:42

Deployment of IXPE

IXPE was deployed successfully
in a 600 km equatorial orbit

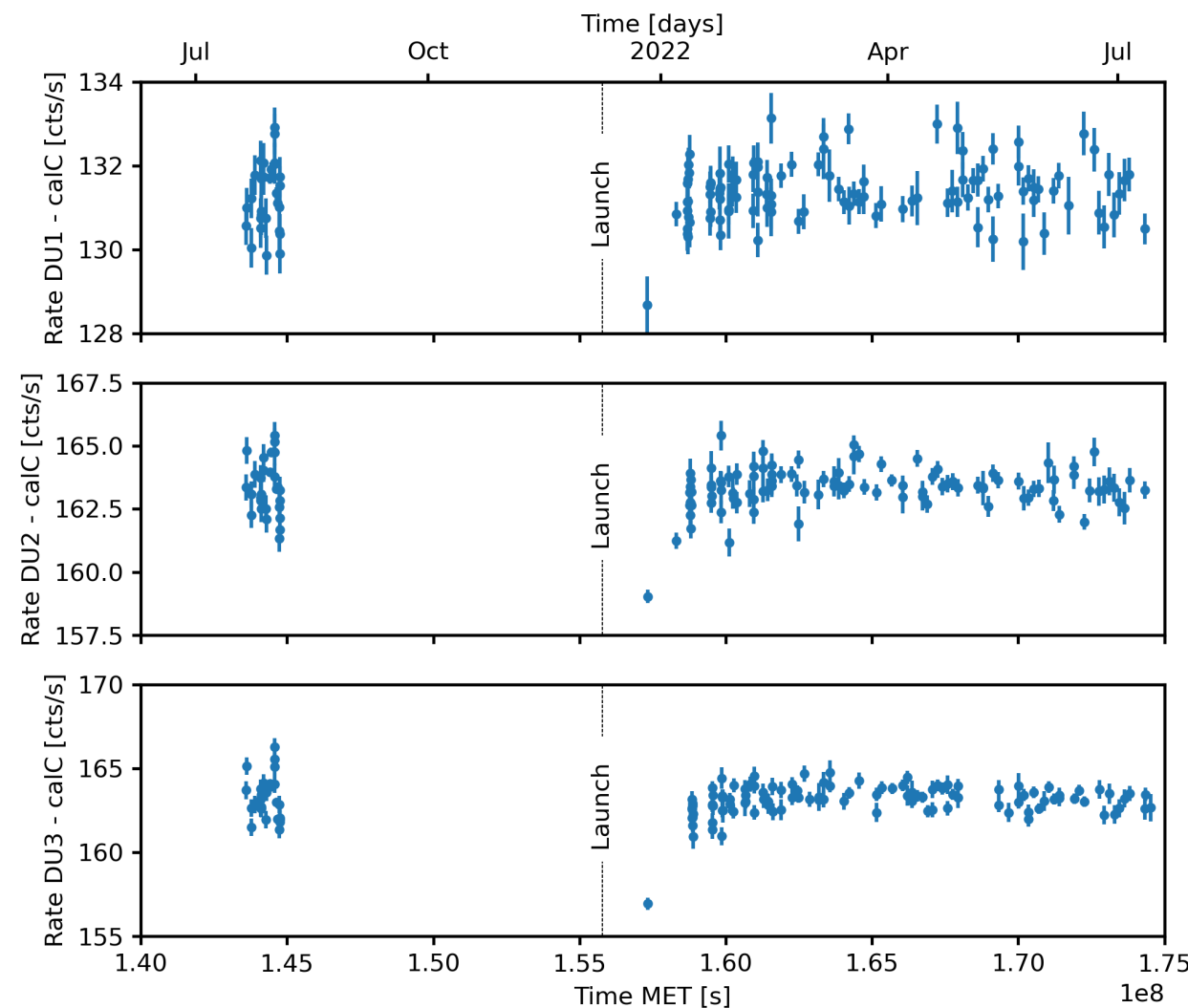




Monitoring of instrument performance

The Health of the IXPE instruments is continuously monitored by the on-board calibration sources

- The detectors are working well, as expected



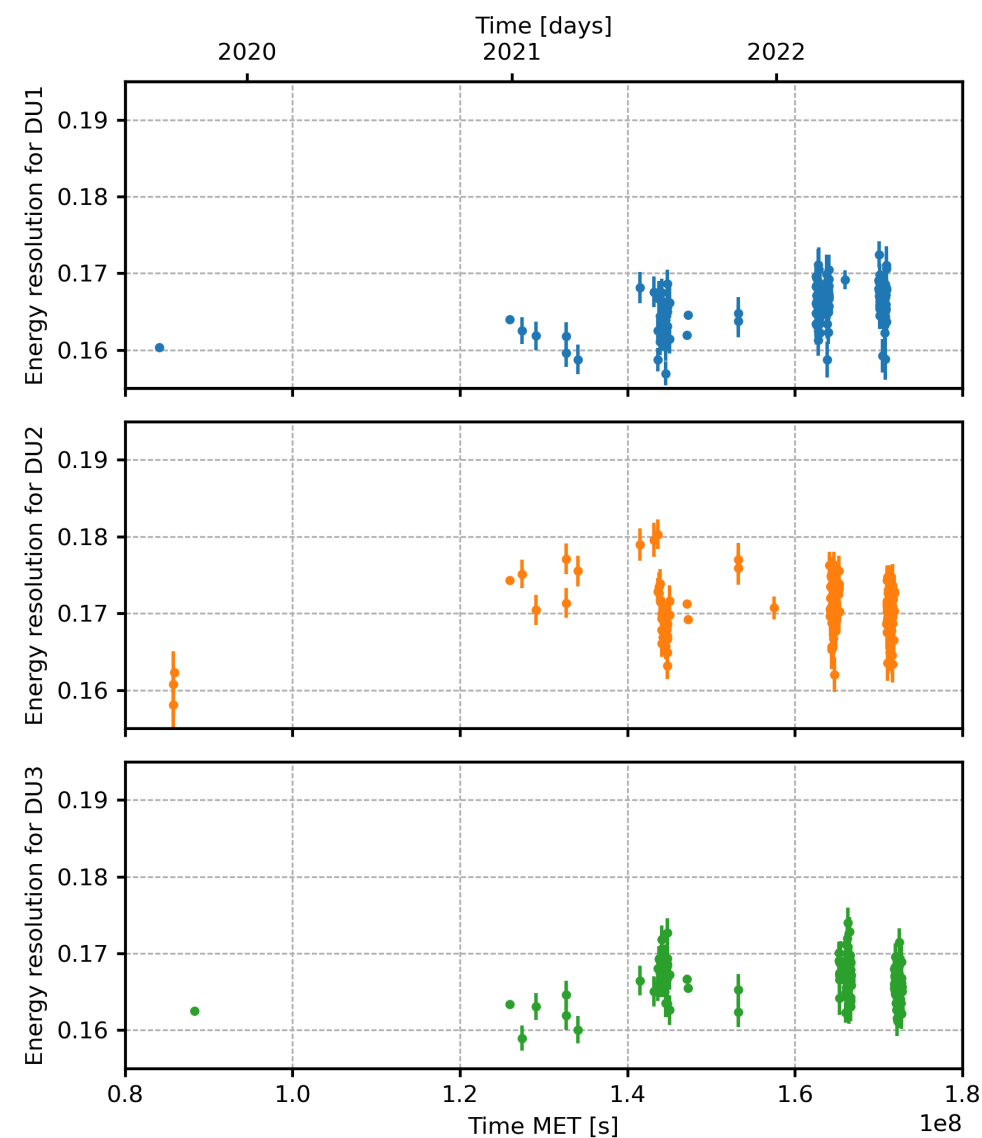
Rate



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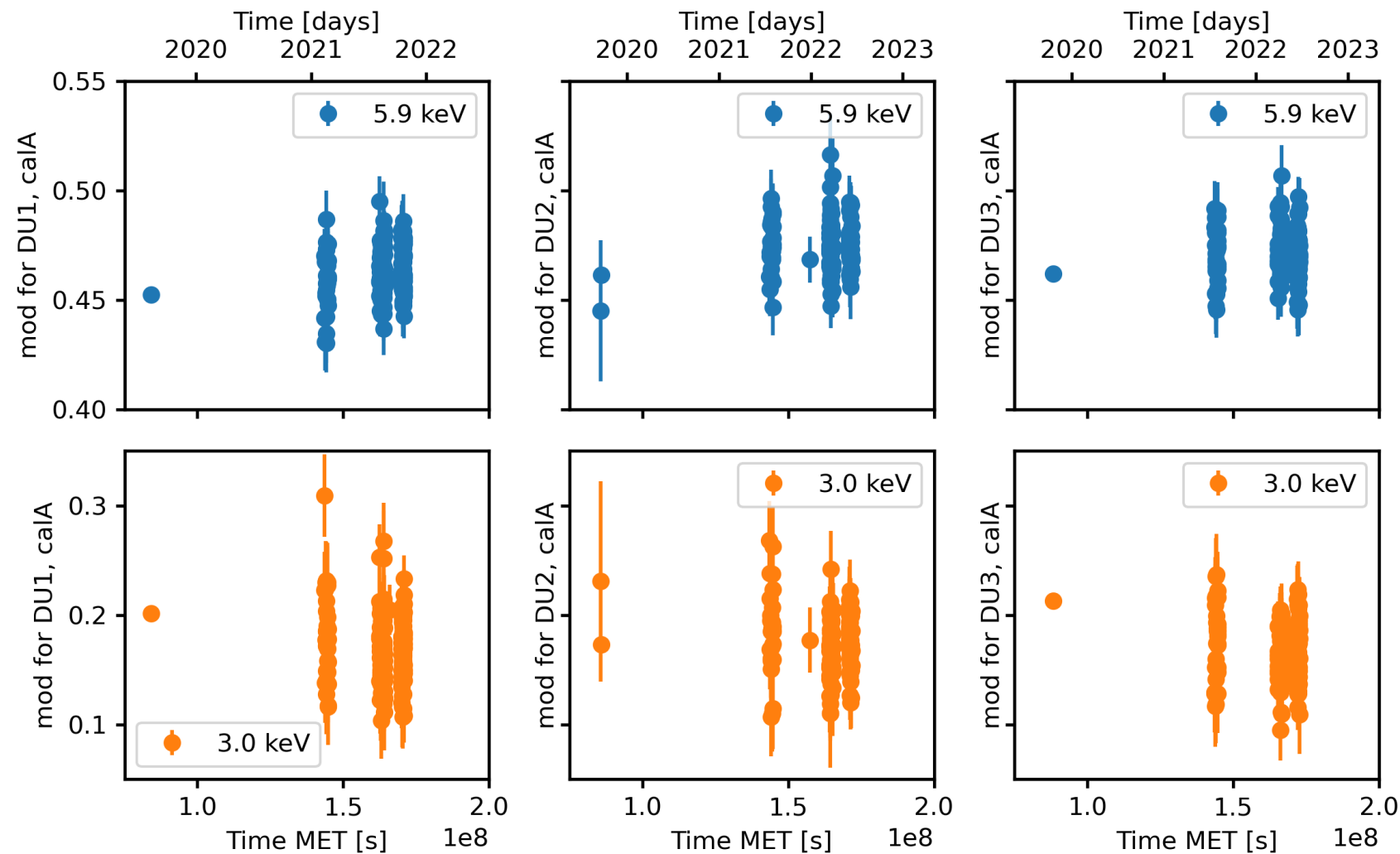
Energy resolution



Monitoring of instrument performance

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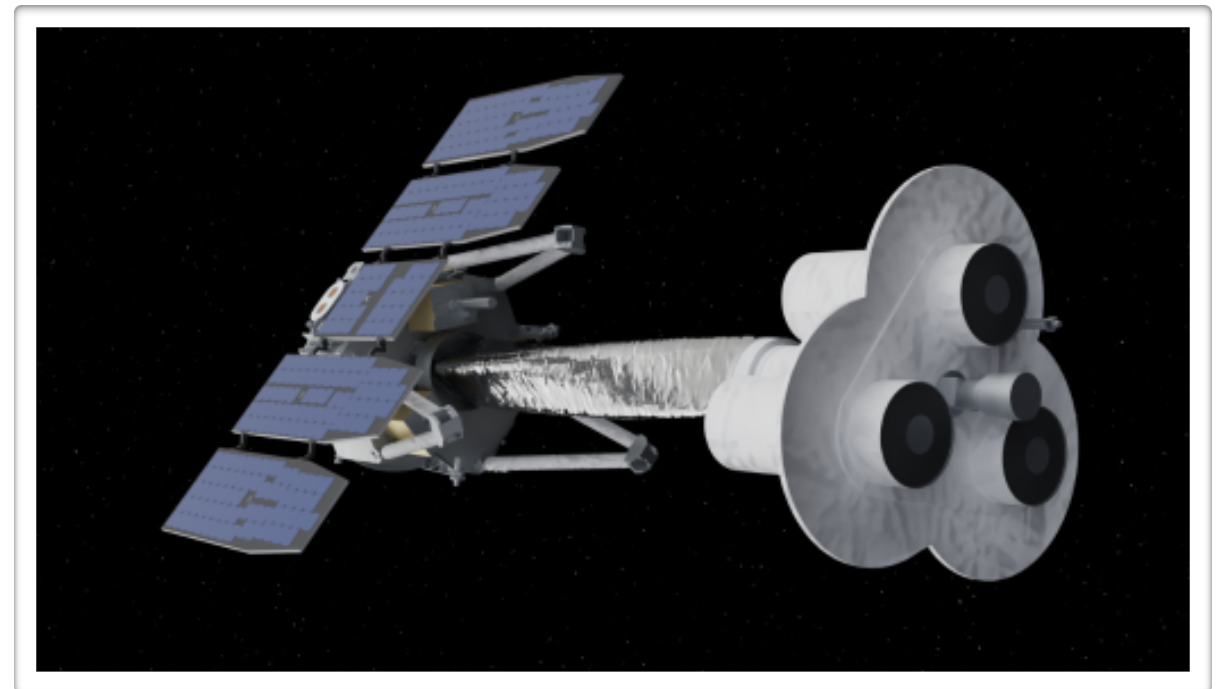


Modulation factor: sensitivity to polarization



Pointing Strategy

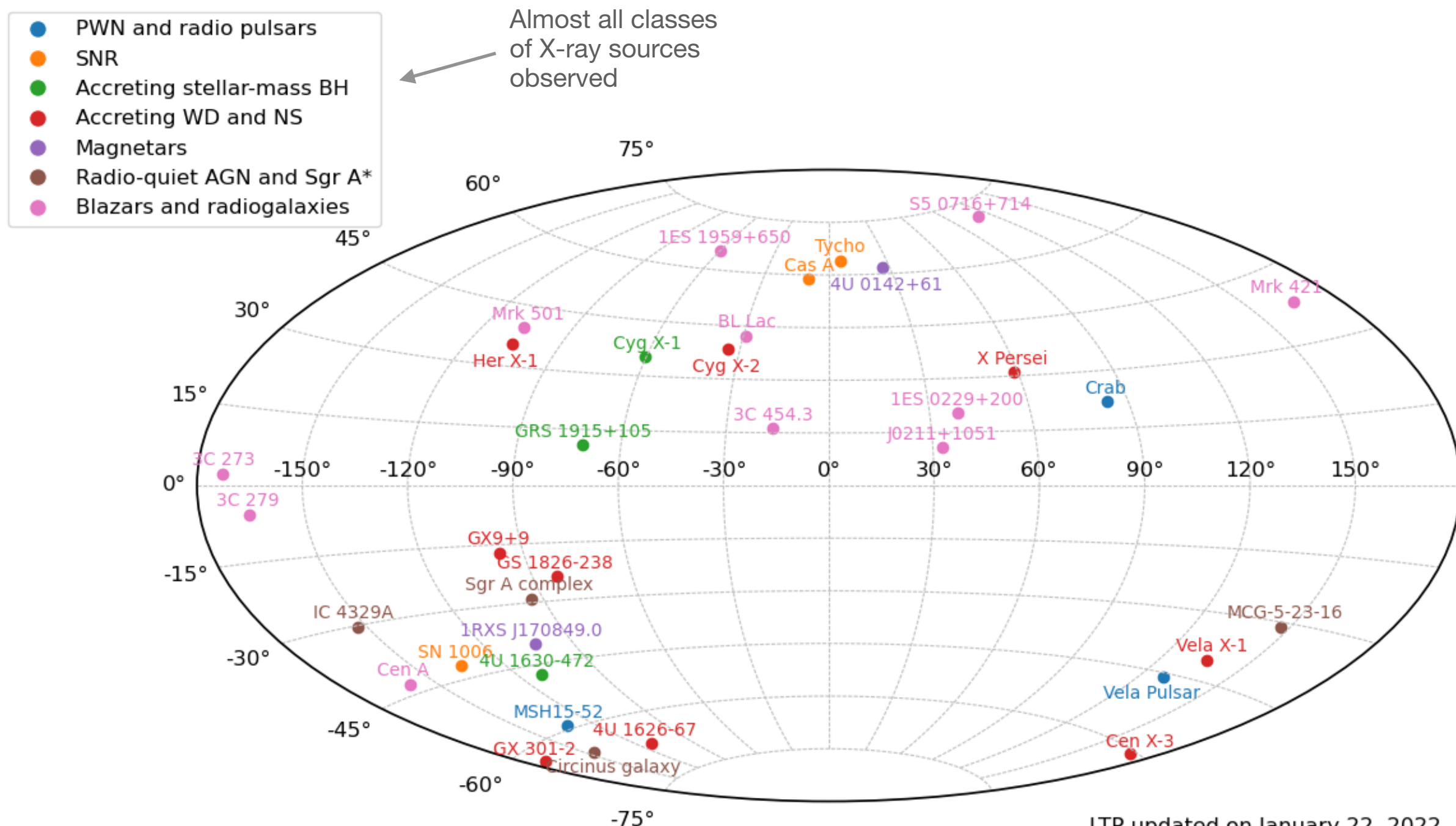
- The observatory is controlled by Mission Operations Center (MOC) in Boulder, Colorado
 - Simultaneously observe target with the 3 detectors while not in occultation
 - Observations are dithered to average systematics
- The Science Operations Center (SOC) is at NASA/MSFC in Huntsville, Alabama
 - Formulates observing plane
 - Processes data in the pipeline
- Data is stored and distributed at the High Energy Astrophysics Science Archive Research Center (HEASARC)





Observations

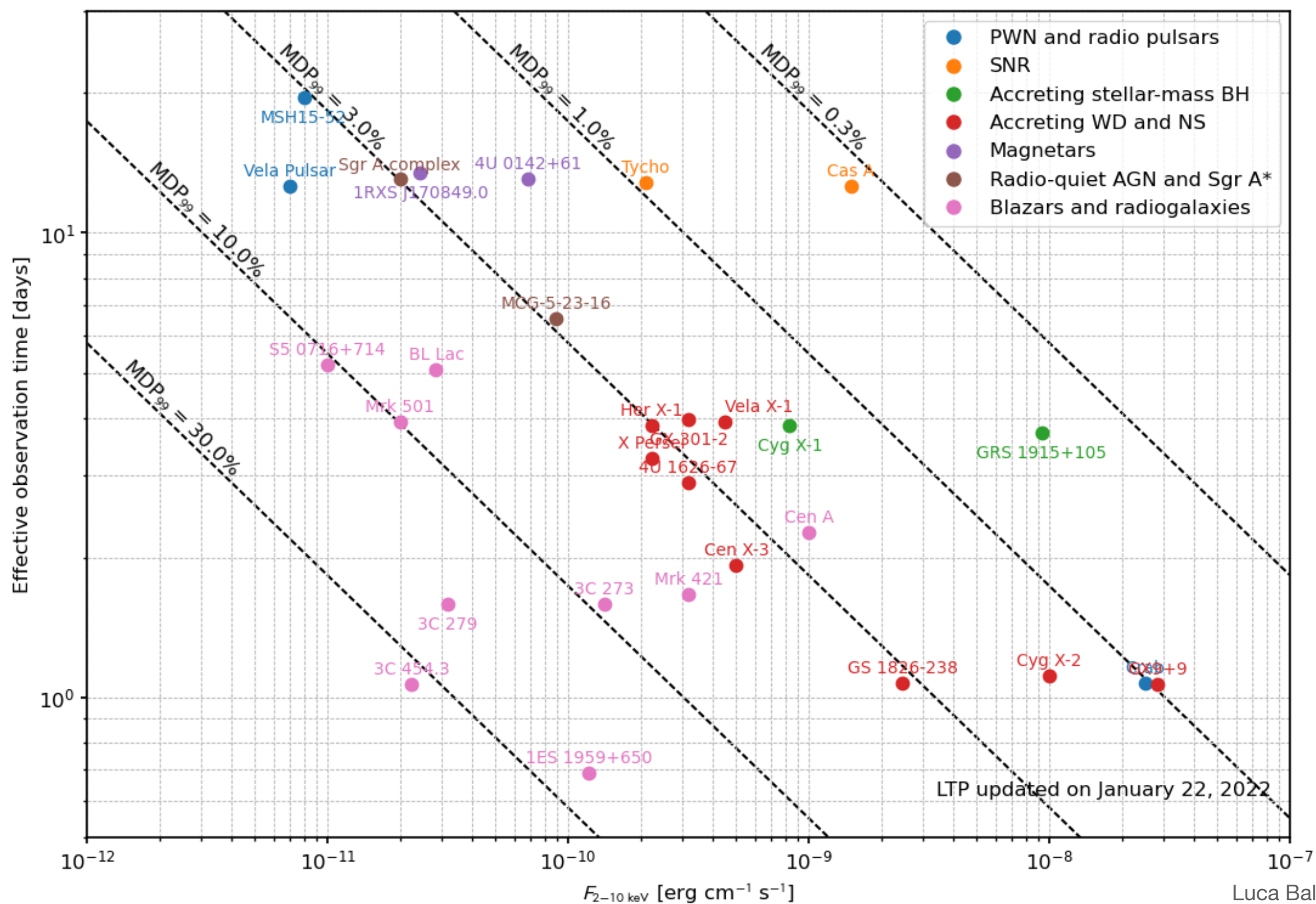
During its first year IXPE has observed tens of sources



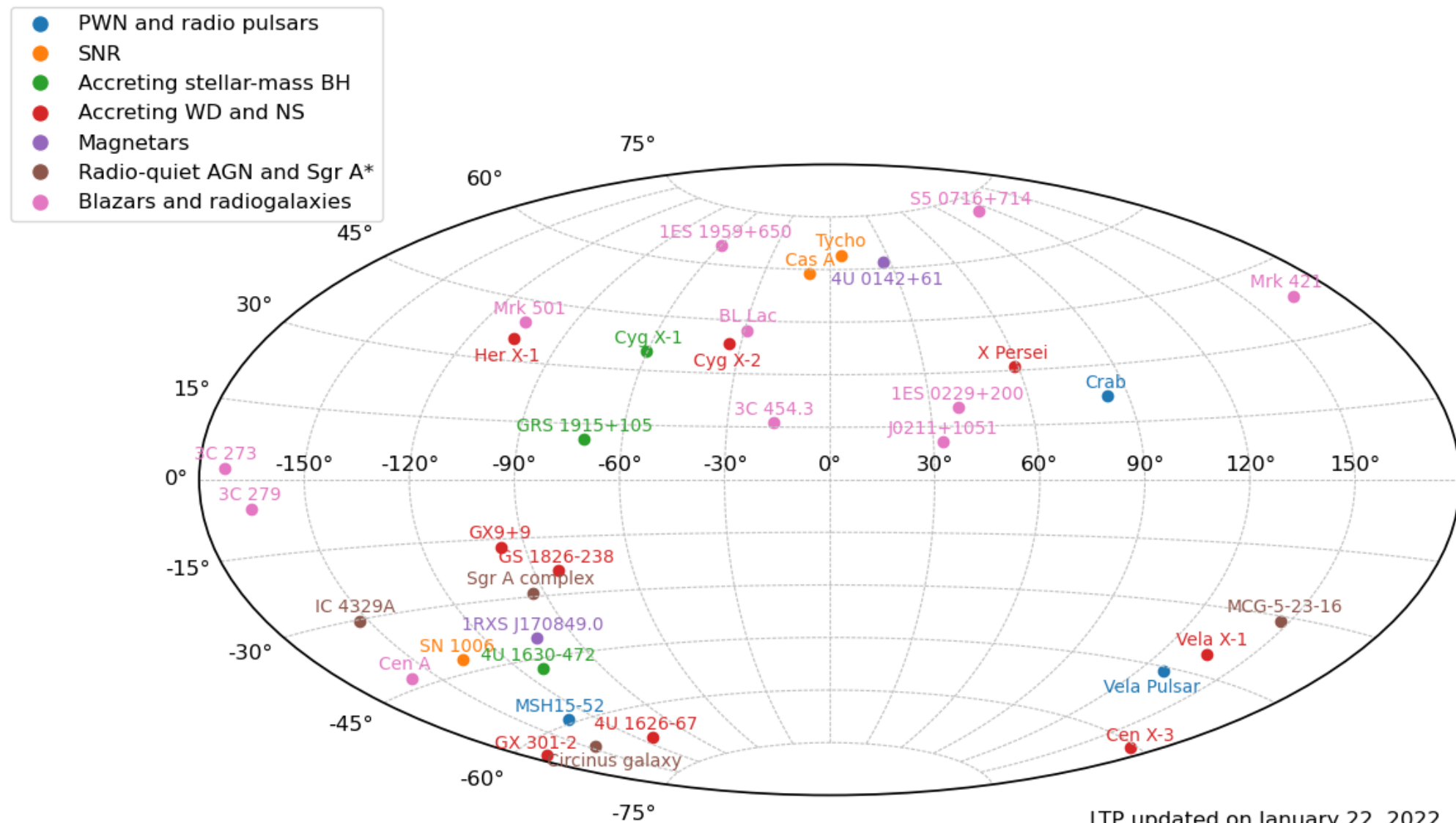


Observations

The detectable polarization depends on observing time and flux



First Scientific Results





First Science Target: Cas A

IXPE observed this supernova remnant in January 2022

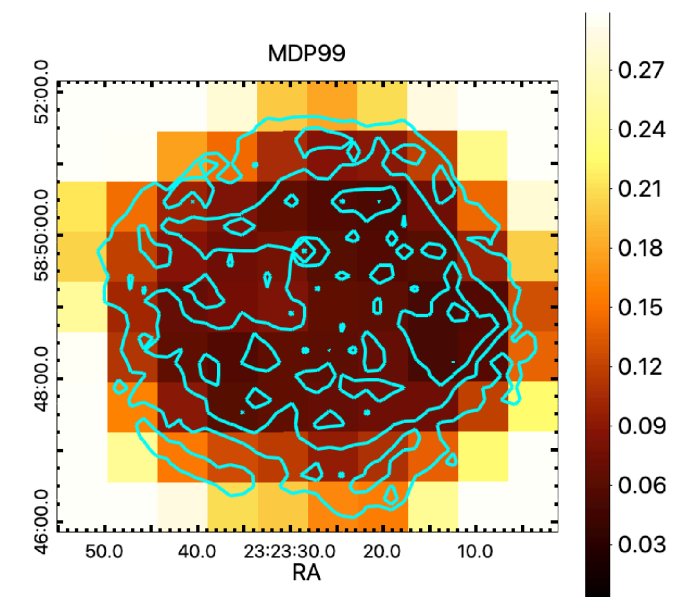
- X-ray polarization shows that the magnetic field is turbulent



Image
credit:
NASA

Combined **IXPE** and **Chandra** image

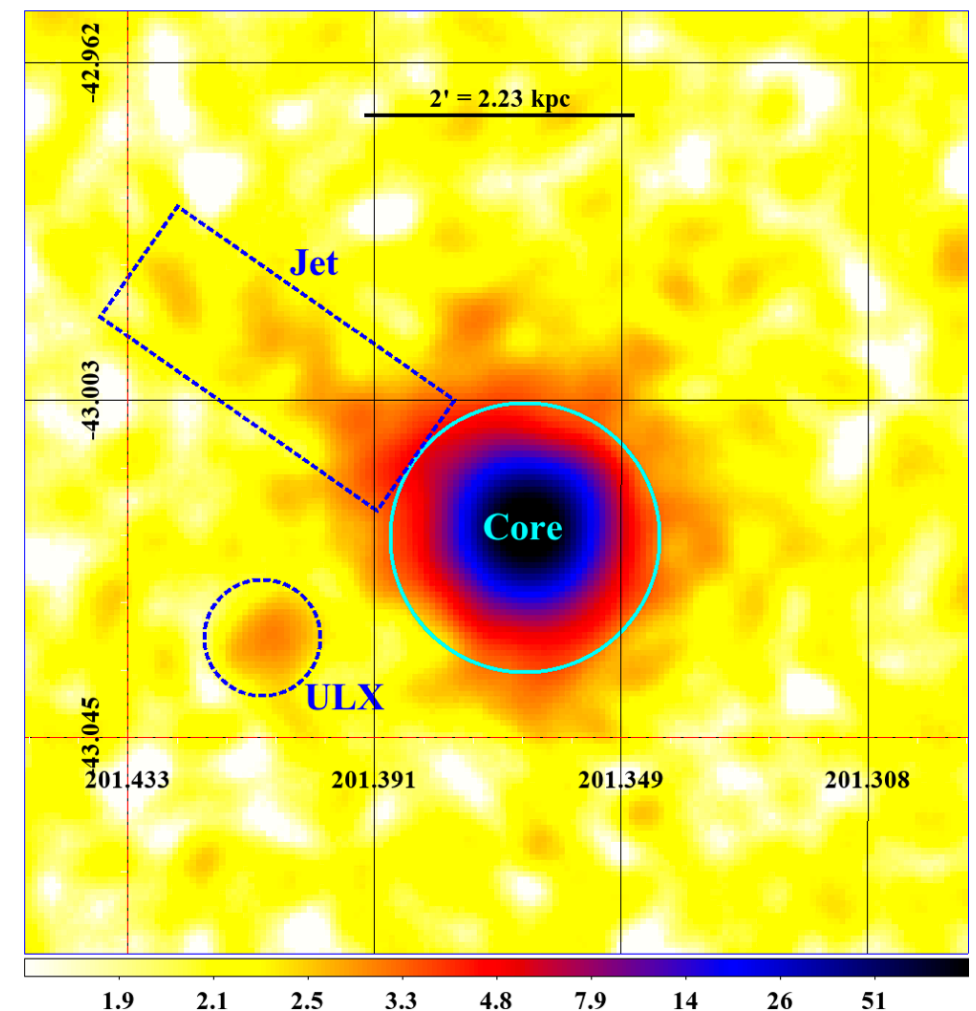
See Riccardo Ferrazzoli's talk!





Cen A Radio Galaxy

- Upper limit on polarization for the inner region — base of the jet — of 6.5% at 99% c.l.
- Compatible with inverse Compton scattering, whose seed photons can be
 - synchrotron (synchrotron self Compton)
 - external





Conclusion

- IXPE was launched in December 2021, opening this X-ray polarimetry window
- Telescopes are perfectly cross-calibrated
- Tens of sources have been observed
 - Magnetic fields are the main players, but scattering is also present
- IXPE is keeping its promises!

See next talks!

