Enabling precise X-ray polarimetry for the IXPE space explorer

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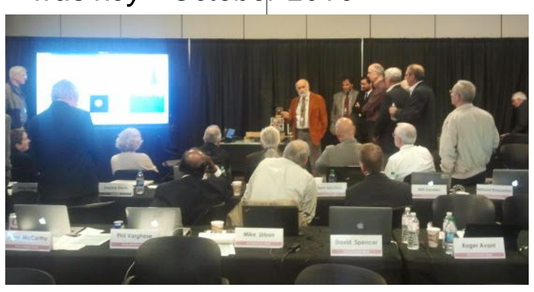
on behalf of the IXPE Collaboration

Successfully launched in December 2021, after only five years from the adoption, IXPE belongs to the NASA Explorers program, which offers frequent flight opportunities for world-class scientific investigations from space. IXPE will accomplish the first-ever survey of the polarization properties of tens of celestial X-ray sources, with percent accuracy, and within the boundaries of a small explorer program. This goal can be achieved with the use of Gas Pixel Detectors, which precisely reconstruct the sub-mm long tracks of single electrons generated by the photo-electric interactions of incoming soft X-rays. This poster summarises the most important design elements of the GPDs and of the Detector Unit housing them, the qualifications obtained for operating them onboard IXPE, and the fast-paced integration and verification cycle entirely developed in Italy to make the IXPE mission a reality.

The Mission

IXPE is a NASA Small Explorer, cost-capped at ~200M$ with a timeline of 5 years to launch and a 2-year baseline operations

Mission adoption after competitive site visit - live demonstration of X-ray polarization sensitive prototype was key - October 2016



2017 PhaseB
- Contracts
- Hardware Prototypes
- Requirements definition

2018 Phase C-D1
- Design reviews
- Prototype completion
  - Eng. Mod.
  - Qual. Mod.

2019 Phase C-D1
- Flight units integration & test
- Mission Critical Design Review

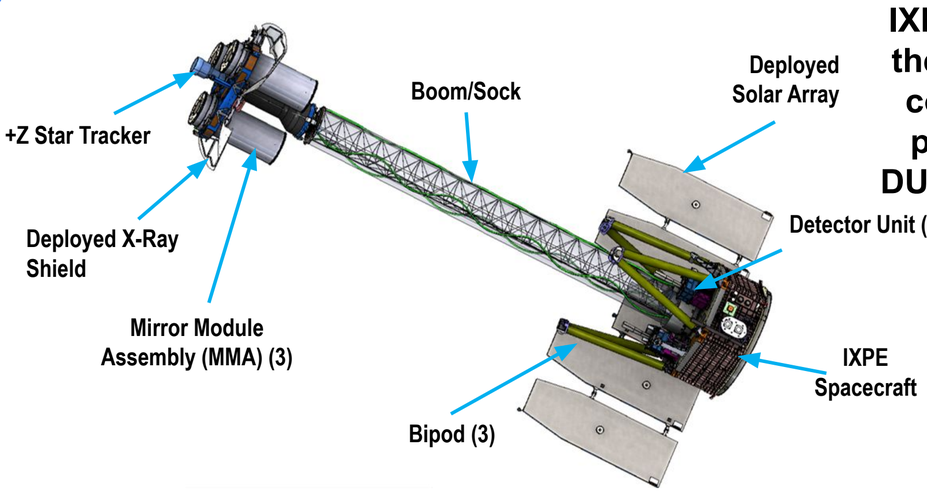
2020 Phase D2
- Instrument handoff to NASA
- Telescope calibration

2021 Phase D2
- Observatory AIVT
- Launch Preparation
- Launch
- Commissioning

> 2022 Phase E Operations

IXPE deployed into space in a 0° equatorial orbit at 600 km altitude - December 2021

The Telescope

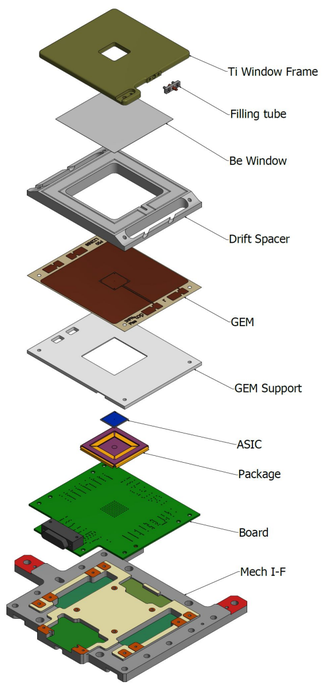


IXPE images X-rays in the 2-8 KeV range and measures their polarization using three identical telescopes each comprised of a Mirror Module Assembly (MMA) and a polarization sensitive Detector Unit (DU) at its focus. DU Data are handled by the Detector Service Unit (DSU).

The mission is managed by Marshall Space Flight Center (MSFC), which was also responsible for the MMA fabrication, testing, and calibration.
The Italian Space Agency (ASI) delivered the Instrument, which comprises the DUs, which were designed, assembled and qualified by INFN and calibrated at INAF-IAPS, and the DSU, designed and fabricated by OHB.
Ball Aerospace integrated the Observatory.
Space-X launched IXPE into space and placed it on its orbit

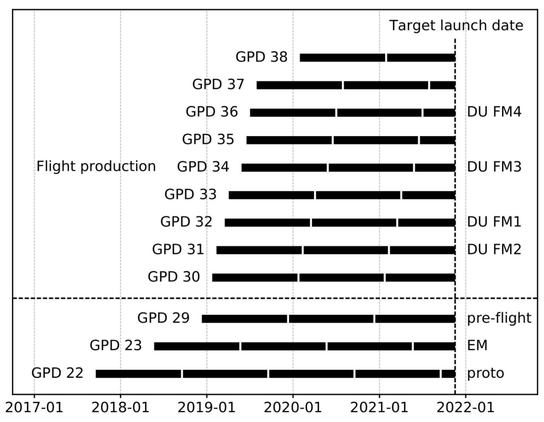
The Detector

The IXPE Gas Pixel Detectors (GPD) can reconstruct single photo-electron tracks with ~µm resolution, thus mapping the polarization of the incident beam, with better than 20% resolution at 5.9KeV and ~1 msec typical deadtime between photons.
These GPDs are truly enabling a new observational window in X-ray astrophysics, as demonstrated by the first results (see A. Manfreda's talk).

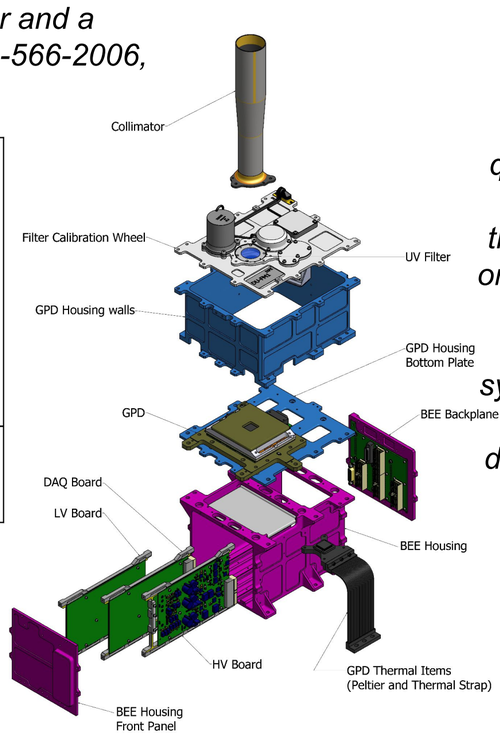


The concept of the GPD as a sealed gas cell with a Gas Electron Multiplier and a finely pixelated custom ASIC readout was conceived 15 years ago (NIM-A-566-2006, 552-562) and its maturity was key in the adoption by NASA for IXPE.

However, mass and power constraints imposed by the SMEX program, the breakout of the Covid pandemic during the I&T phase, as well as unexpected behaviors of the GPDs required extraordinary efforts on the DU integration and qualification and on the GPD calibration programs to deliver the detectors in time with the mission schedule and in line with its scientific requirements (Astropart.Phys. 133,102628)



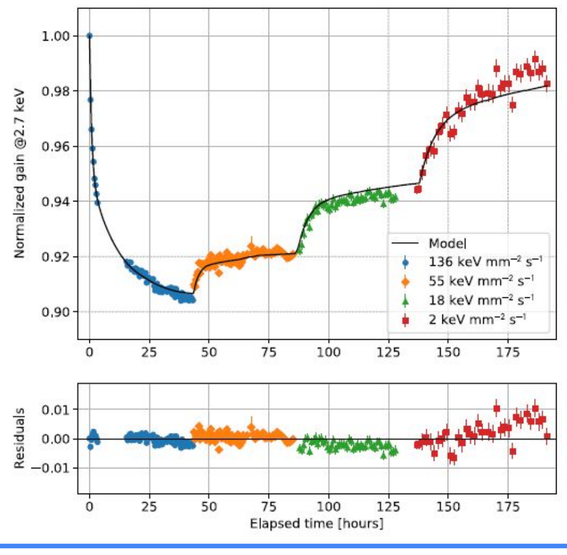
12 GPDs were built and calibrated equivalent to a 25 GPD-year operation



Each DU hosts the GPD with its electronics and services.
DUs were designed, assembled and qualified by INFN under the requirement to minimize their footprint and allocate three DUs on the spacecraft top deck, in order to maximize the telescope effective area and reduce systematics effects by operating three independent detectors symmetrically oriented around the target.
Tight constraints on the DU mass, dimensions and mechanical rigidity were applied in the design to match the capabilities of the Pegasus launcher originally foreseen in the proposal.

When Space-X won the tender, suddenly a ~10x mass and dimension margin appeared at less than one year into launch.
The additional power offered by the Falcon-9 rocket was then used to place the original IXPE design into a real equatorial orbit with minimum background and satellite drag, potentially extending the mission lifetime to more than a decade

Gain variation of the GPD with irradiation - a residual maximum charging of ~10% was recorded despite the GEM design based on laser drilling and LCP dielectric.
This effect is easily calibrated using ground data or the ^{55}Fe signal peak from the onboard sources



A structured ~% level modulation from unpolarized X-rays was recorded through calibrations. This effect is kept under control by dithering the satellite, effectively averaging the response across the active surface. The IXPE sensitivity to polarization is so restored to typical Minimum Detectable Polarizations of few %, opening the way to the first-ever polarization census of 10s of X-ray sources