PROCEEDINGS OF SCIENCE

The X-ray Imaging Polarimetry Explorer mission

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The X-ray Imaging Polarimetry Explorer (XIPE) is a mission proposed to ESA Small Mission Call 2012. Its main objective is to open the polarimetric window also in the X-rays with a set of two imaging focal plane polarimeters sensitive in the 2-10 keV energy range. Additional instruments are dedicated to solar flares polarimetry and Sun spectrophotometry. XIPE is largely based on existent items and mature technologies, nonetheless, it will give the chance to European community to perform a break-through mission, in practice to open a new window in the sky.

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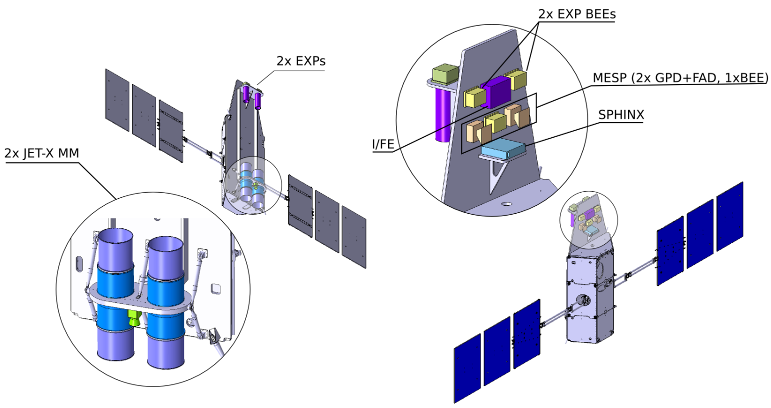

Figure 1: Sketch of the XIPE payload.

1. Why X-ray polarimetry

X-ray polarimetry is expected to produce a significant step forward in the comprehension of what happens in the sites of acceleration of particles such as pulsar wind nebulae [1], supernova remnants [2], jets in microquasars and blazars [3, 4], solar flares [5]. It is also expected to give important results in the study of matter in extreme conditions, providing a measurement of the spin of black holes [6, 7], the orientation of magnetic field versus rotation axis in magnetized neutron stars and an indication of its strength [8]. Polarimetry can also be a powerful tool to test theories of fundamental Physics by using cosmic scenarios as a laboratory. Beside testing General Relativity and Quantum Electrodynamics in extreme gravitational and magnetic fields [9, 10], can provide a tool to test phenomenologies foreseen by some theories of Quantum Gravity [11] and of axion-photon coupling [12]. For a review of science topics accessible with X-ray polarimetry, see [13].

2. The XIPE mission

The scientific instrumentation of XIPE is largely based on that already considered for POLARIX, a small mission concept dedicated to X-ray polarimetry which underwent a Phase A study in 2008 as a part of the Small Mission program of the Italian Space Agency (ASI) [14]. The XIPE payload comprises of four instruments, two Efficient X-ray Polarimeters (EXPs), a Medium Energy Solar Polarimeter (MESP) and a solar photometer (SphinX). A sketch of the XIPE payload is shown in Figure 1.

The two identical **Efficient X-ray Polarimeter**s are composed of two Gas Pixel Detector (GPD) photoelectric polarimeters placed in the foci of two existing mirror modules (MMs) of the Joint European X-ray Telescope (JET-X). The GPD is able to measure the linear polarization of absorbed photons by reconstructing the emission direction of photoelectrons emitted in a gas mixture [15, 16]. Filled with Helium-DME mixtures, the GPD is sensitive in the 2-10 keV energy range where the telescope effective area is larger and it has a Technology Readiness Level of 5 as an heritage of the deep studies carried out for the XEUS/IXO mission under ESA supervision and for POLARIX. JET-X telescope was developed, tested and calibrated for the original SPECTRUM-

	2×EXPs	MESP
Polarization sensitivity	MDP = 14% in 100ks for 1 mCrab	MDP = 5% for X1.2 flare
Imaging capability	Ang. resol. ∼24 arcsec 15×15 arcmin FoV	±30° FoV
Spectral resolution	20% at 5.9 keV	<20% at 5.9 keV
Timing	Res. 8 μs, 10 μs dead time negligible for all observations	Res. 8 μs, 30 μs deadtime, 5% for X10 flare
Mixture	He-DME, 1 atm 1 cm	Ar-DME, 3 atm 3 cm
Energy range	2-10 keV	15-35 keV
Background	1.3 10^{-7} c/s or 1 nCrab	Negligible

Table 1: Main characteristics of EXPs and MESP polarimeters on-board XIPE.

X-Gamma mission which unfortunately never flown [17]. Four mirror modules were developed for that mission, 3 flight modules (FM) and an Engineering Qualification Model (EQM), used for the qualification test campaign but with the same characteristics of the FM unit. One of the flight modules, FM3, is now on-board the Swift satellite. The collecting area of a single unit is ∼159 cm^{a}2 at 1.5 keV and ∼70 cm^2 at 8 keV and the point spread function (PSF) is of ∼15 arcsec at 1.5 keV and ∼19 arcsec at 8 keV (Half Energy Width)[1]. The characteristics of the two EXP instruments are summarized in the Table 1.

In addition to the two EXPs which are devoted to the observation of cosmic sources, XIPE hosts also a small payload dedicated to the study of the Sun. The **Medium Energy Solar Polarimeter** will measure the polarization of bright solar flares thanks to a pair of two GPDs, which will differ from that used in the EXPs only because of the different mixture and gas cell thickness (Fabiani, Mem. S.A.It. proc., in press). To provide a response up to 35 keV, MESP GPDs will be filled with Argon-DME mixtures at high pressure, as a baseline 3 atm, with a cell thickness of 3 cm (see Table 1). A prototype with 80%Ar-20%DME at 2 atm with 2 cm thick gas cells has been already built [18]. Such a configuration would provide a certain polarization sensitivity starting from 6 keV, but a filter is envisaged to remove the photons below about 15 keV. This will prevent the soft component to completely overwhelm the hard X-ray one which should be that highly polarized. Since the MESP is dedicated to quite strong solar flares, it will operate without an X-ray optics, because both the collecting area of two GPDs is sufficient to achieve the scientific objectives and the background is negligible with respect to the observed sources. We envisage the use of only a field of view angular delimiter (FAD) to prevent the large part of the cosmic background to imping on the detectors. The FAD will have a 30 degrees flat top so that the Sun is always in the field of view of the instrument for any pointing of the spacecraft. Eventually, the **SphinX photometer** will use a silicon PIN detector for high time resolution (0.01 s) measurements of the solar spectra of quiet and active corona in the range 1.2-15 keV, allowing for fast photometry of the solar X-ray flux variations in selected and well defined narrow spectral bands including the Fe XXVI and Fe

[1]In November 2012, after the selection of the ESA SMALL mission proposals, a calibration campaign at the PANTER facility demonstrated that the JET-X optics at the focus of a GPD are still effective and suitable for X-ray imaging polarimetry.

	2×EXPs	MESP	SphinX	Other	TOT payload
Mass + margin (kg)	203.6	16.0	3.7	10.7	240.0
Power + margin (W)	168.0	28.8	15.8	29.5	242.1
Telemetry	29 kbit/s (typical)	<2.5 GB (1/month)	8 kbit/s	4 kbit/s HKs	∼41 kbit/s (typical)

Table 2: XIPE payload resources including margins.

XXV iron line groups. SphinX instruments is a heritage of CORONAS-Photon payload.

The low resources required to operate the XIPE payload (see Table 2) allows to envisage the use of standard low-cost three-axis stabilized platforms. A promising possibility is the use of the Iridium Next platform, developed by Thales Alenia Space firm on behalf of Iridium Communications Inc. The advantages in its use is the relatively low cost resulting from the large mass production of satellites (81). The mission profile is rather standard. XIPE should be launched in a Low Equatorial Orbit (600 km altitude, $5^\circ \pm 1^\circ$ inclination, accessible sky $90^\circ \pm 30$ from the Sun direction) and the data downlink can be managed once per orbit with a single Ground Station, e.g. the ASI Malindi Ground Station. XIPE easily fits in the Vega fairing and this is the baseline launcher, notwithstanding the Iridium Next platform and the XIPE payload are also compatible with the cheaper DNEPR launcher. The accomplishment of the science goals is possible with two years of science operation but XIPE does not have any particular consumable which limits the mission lifetime.

3. XIPE science objectives

Acceleration phenomena and jets: XIPE can measure a Minimum Detectable Polarization at 99% confidence level of 2% in 5×5 angular resolved regions of the Crab Nebula in one day of observation (100ks). Also a few other young PWNe will be accessible, exploring similarities and differences with respect to Crab. μQSO, like Cyg X-1, Cyg X-3, XTEJ1550-564, etc., have a flux between a hundred mCrab and a few Crabs and MDP<1% can be reached in 100ks. XIPE can reach an MDP of a few percent in a few days of observations for some of the brightest blazars. For example, an MDP of 3% can be reached for Mrk421 in 4×10^5 s. About 23 solar flares (between X10 and M5 classes) are expected to be observed with the MESP. The detection of a significant polarization would directly reveal the direction of the accelerated electrons.

Emission in strong magnetic field: X-ray polarimetry is essential to test the Comptonization model for the hard component in millisecond pulsars (msPSR) as well as to determine geometrical parameters such as the inclination and the magnetic inclination angles, which are important for improving constraints on the neutron star mass and radius. msPSR are usually transient objects and 14 sources are currently known. In 100 ks observation of SAX J1808.43658 in outburst, a MDP of 1.3% can be reached. Polarimetry of X-ray pulsar can distinguish between "pencil" and "fan" radiation patterns, a long standing problem still awaiting a firm solution. The swing of polarization angle, moreover, is a direct measure of the angle between the rotation axis and the magnetic dipole axis which usually is a free parameter in the models. Many X-ray pulsars are within reach of XIPE: for example, an MDP of 3.5% is achieved in 10 independent phase bins with a 300ks observation

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of Her X-1. Several bright intermediate polars, and certainly the brightest polar, AM Her, when in high state, can be searched for phase-dependent polarization. In the latter case, an MDP of 6% can be reached in 10 phase bins with 1 Ms observation.

Scattering in aspherical situations: X-ray polarization can give unique information on the hot corona and on the reflection component in binary systems and Active Galactic Nuclei. In the case of NGC1068, an MDP of 4.2% can be reached with an observation lasting 500 ks. The detection of polarized emission from molecular clouds in the center of our Galaxy may reveal the past activity of the supermassive black hole hosted in Sgr A*. Although it is not possible to estimate the flux of Sgr B2 when XIPE will be in orbit, assuming the flux measured by BeppoSAX and a polarization of 40%, the precision with which the polarization angle can be measured in 2Ms is 3.5° (1-σ), good enough to set tight constraints on the origin of the illuminating radiation.

Matter in extreme conditions & fundamental Physics: A few pulsars other than the Crab and a few Magnetars, like the Anomalous X-ray Pulsars (AXP) 4U 0142+614 (MDP of 6% in 5 phase bins and 2 energies with 1 Ms observation) and the Soft Gamma Repeaters SGR1900+14 (MDP of 10% in 5 phase bins 2 energies in 1 Ms when in quiescence), can be looked at to start searching for QED effects. The best but not the only source to search for Strong Gravity effect on X-ray polarization is GRS1915+105 because the high inclination suggests an higher degree of polarization. Other less inclined sources may show lower polarization levels, which however could still be easily detected in several other bright objects. In addition, about 4 transient BH binaries are expected during XIPE 2 years operation which may be other good sources to search for GR effects. Polarimetry of distant sources, like known blazars with clear synchrotron spectrum and high optical polarization, can be used to search for quantum gravity effects which increase strongly with the energy. The capability to observe several sources would allow to search for a correlation between the possible swing of the angle of polarization expected because of the birefringence of the vacuum and the distance. An upper limit as low as 3×10^{-10} on the effect [11] can be put with a 1 Ms observation of the Blazar 1ES1101+232 at z=0.186 assuming a conservative polarization of 10%.

4. Conclusion

XIPE will be able to achieve breakthrough in three themes of Cosmic Vision: 2.1 From the Sun to the edge of the Solar System; 3.1 Explore the limits of contemporary physics; 3.3 Matter under extreme conditions and 4.3 The evolving violent Universe. Nonetheless, this mission is designed as and fit a small mission profile thanks to the use of instrumentation with demonstrated maturity and high performance which, in large part, already exists.

The XIPE proposal can be downloaded from ftp://ftp.iasf-roma.inaf.it/polar/XIPE/XIPE.pdf.

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