IXPE Users Committee Report

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Table of Contents:

I. Overview

The IXPE mission: A joint collaboration between NASA and the Italian Space Agency, IXPE is an explorer-class mission (total cost < $200M) currently operating in a low-Earth orbit. It uses a three-telescope design with a gas pixel detector to measure linear polarization of incoming X-rays over the energy range of 2-8 keV, reaching a sensitivity 2 orders of magnitude deeper than predecessor OSO-8, which was operational in the

1970s. IXPE was launched in December 2021 and began its 2-year prime mission phase the following February. In February 2024 the mission entered its extended mission phase and is now carrying out observations of general observer (GO) programs accepted during the first general call for proposals in late 2023. IXPE operations are funded through FY25 (30 September 2025) and will undergo a senior review in early 2025, where the team intends to request a 3-year mission extension through FY28.

This Report: The IXPE Users Committee (IUC) was formed in January 2024 and currently consists of the members listed on the title page of this report. The IUC charter is available at the IXPE webpage hosted at MSFC.[1] In preparation for this report, the IUC collected information and presentations from the IXPE team and conducted a community survey prior to the formal semi-annual IUC meeting on 10 May 2024. Information about the meeting, survey, and modes of sending both anonymous and non-anonymous feedback to the IUC were advertised to the community via the HEAD listserv and other venues several weeks prior to the meeting. A contact form is also available at the IXPE UC page linked in the above footnote. This report reflects the information gathered before and during the May 2024 meeting.

II. Prime Mission Science Outcomes

The convening of the IUC is one of several activities marking the transition of IXPE to a general observer (GO) facility. For this initial report, we provide here a brief summary of the prime mission phase science outcomes. The IXPE team, consisting of over 150 members in 15 countries, carried out 115 pointings on 64 science targets during the 2-year mission, resulting in over 65 papers by collaboration authors as well as ~10 by non-team members (enabled by the lack of a traditional proprietary period). As a benchmark, the much larger, probe-class Fermi gamma-ray observatory (specifically the LAT collaboration) resulted in approximately similar numbers of collaboration papers in its first two years.[2] Despite the impressive rapidity with which IXPE collaboration papers have appeared in the literature, some of the papers by non-team author groups preceded the IXPE collaboration publications, and several members of the IXPE user community reported that the lack of a proprietary period caused a high pressure to publish as soon as possible. The committee has concerns about the impact of this no-proprietary-period policy (e.g., on early career researchers and scientific return); see further comments in section III regarding the GO program.

The major results from the first two years of IXPE operations include the first X-ray polarization imaging and the first-ever detection of X-ray polarization from many source classes including blazars, active galactic nuclei, pulsars and pulsar wind nebulae, neutron star and black hole X-ray binaries, magnetars, and supernova remnants, increasing the number of known sources of polarized X-rays from one to several dozen.

[1] https://ixpe.msfc.nasa.gov/for_scientists/users_comm.html
[2] https://www-glast.stanford.edu/cgi-bin/pubpub

Many IXPE publications have appeared in high-profile journals, including 2 in *Science*, 3 in *Nature*, and 3 in *Nature Astronomy*, speaking to the very high impact of the discoveries. In addition to the observational results mentioned above, IXPE has also spurred the development in polarimetric data analysis, theory, and complimentary multi-wavelength and multi-messenger investigations, as evidenced by the 197 papers on NASA/ADS mentioning IXPE in the abstract as of May 2024 (with 86 in the last year alone).

III. General Observer Program and Growth of the IXPE Community

The first cycle of the IXPE General Observer program was announced via the NASA Research Opportunities in Space and Earth Science (ROSES) 2023 solicitation. The call opened in June 2023, with optional notices of intent (NOI) due 18 September 2023 and full phase I (science) proposals due 18 October 2023. One hundred and thirty-five (135) proposals were submitted requesting over 100 megaseconds (Ms) of time on 99 distinct targets, compared to the approximately 15 Ms available, an over-subscription rate of 6.9. This is even higher than the typical over-subscription of 5-6 for highly in-demand time on flagship missions like Hubble and Chandra.[3,4] It also strongly suggests that several more years of IXPE operations will be scientifically productive.

The in-person science review of phase I proposals took place in November 2023. Ultimately 2 Ms of time was awarded to one large program, while the remaining time was apportioned to 21 A-ranked and 10 C-ranked programs, where the latter are observed as essentially filler targets with no guarantees of observation. With 7 theory proposals also being accepted, this gave an overall program acceptance rate of 39/135 or 29%. Over 1400 scientists participated as co-Is on IXPE proposals and approximately ⅓ of programs involved a PhD student thesis, showing the role of IXPE in sustaining community growth in high-energy astrophysics.

The IUC requested the IXPE team to present a breakdown of the proposal topics as well as the PI location and gender for all programs vs phase-I selected programs, to examine possible trends. In terms of topics, the proposals showed roughly similar acceptance rates across categories, which were: neutron stars and white dwarfs (33% of submitted, 28% of selected), black holes (25% / 25%), blazars (13% / 22%), AGN (11% / 3%), pulsar wind nebulae (6% / 13%), and other topics (11%/ 9%).[5] Similarly, the breakdown by geographical location appeared consistent, comparing US-based PIs (49% of submitted / 54% of accepted) to those in Italy (25% / 21%), and other international PIs (26% / 26%). Finally, while information about PI gender was not collected during the

[3] https://www.stsci.edu/contents/annual-reports/2022/by-the-numbers
[4] https://cxc.harvard.edu/newsletters/news_28/article4.html
[5] The committee found it difficult to compare the GO proposal topical balance to the prime mission phase program due to very significant errors and incompleteness in the current IXPE Browse archive table. Rectifying this (including consistent target categories and clarification of non-observed class C targets) would allow the IUC to better understand the growth of IXPE science breadth during the GO phase in future reports.

proposal submission, the gender.api website was used to infer it from PI first names as a rough check for gender bias. Here again the numbers appear within expectations given small number statistics, with 31/132 (23%) likely female PIs in the submitted proposal pool and 7/39 (18%) in the accepted pool. (The IUC notes the limitations of a necessarily binary and post-hoc analysis.) The IXPE review was conducted in dual-anonymous format in keeping with NASA's commitment to reducing bias in proposal reviews. Outreach and workshops to encourage submissions from early-career researchers may be one way to improve the gender imbalance in submitted proposals.

The IUC conducted a survey of the high-energy community to gather feedback on a number of matters, including the GO program and proposal submission process. While the number of respondents was not large (26) the trend of comments showed that the GO proposal submission and program selection processes are satisfactory. Importantly, more than 40% of the people who filled out the survey have no experience in IXPE and are interested in using IXPE in the future, meaning that the pool of IXPE users will likely continue to grow.

The committee finds the $3M in funding for GO programs in cycle 1 a necessary amount given the more time-consuming and challenging nature of opening a new field and developing analysis methods for a new observing mode. The experience of the committee is that these challenges dissipate slowly (over a few years) rather than rapidly, and that continued high levels of funding are critical to maintaining scientific output and to grow the community of users.

In a similar vein, the committee notes that a consistent level of funding for IXPE operations outside of the GO program (i.e., instrument support staff), sustained over several years at least, is critical to the ultimate success of the mission, which is now spending 100% of its time as a guest observer facility supported by the IXPE team. Currently, important instrument support work, including the reprocessing of IXPE data with new and better calibrations, derivation of correction factors for bright sources, and the implementation of new X-ray image analysis tools leveraging neural networks, have all been deferred due to insufficient personnel support.

Returning to the GO program, in addition to adequate funding, it is also critical for proposal teams to have adequate time to fully exploit the data and yield the highest scientific return. As previously noted, the lack of a proprietary period, especially for a brand-new observing capability, leads to a high pressure to publish very rapidly, for fear of being 'scooped'. The side effect of this pressure is that complex and deeper analyses, requiring unavoidably more time, are often postponed to subsequent papers which may not always appear due to the arrival of new/additional data which competes for the finite time of researchers. The final effect is likely the publication of more papers, but with average lower quality, which is particularly upsetting for the novelty of the data provided by IXPE. The committee feels this pressure to publish will be even higher for new IXPE users, who will need to invest not only the work to prepare a successful proposal, but

also to learn how to analyze IXPE data. The IXPE GO program does allow for early career researchers and programs which are part of student theses to request proprietary periods, but the move away from default proprietary periods (previously the standard practice in astronomy) to the requirement of an exception statement may discourage those that would benefit from the proprietary time from requesting it, as evidenced by the several cycle 1 IXPE programs which involve a PhD thesis but which did not request the exception. The committee notes that PIs/teams from under-resourced institutions, such as those with high teaching loads during the academic year, would also likely benefit from proprietary time; we believe further study is urgently needed to understand the potential impacts of this policy on new and early-career IXPE users in particular.

In IXPE GO cycle 1, funding was available to both US PIs and co-Is (for non-US PI programs), as well as theory proposals. While any cuts to GO program funding will necessarily reduce the science output of the mission, these impacts can be minimized (which is not to say that they will be minimal) by prioritizing US PI-lead observing programs, at the expense of theory proposals (for which other NASA programs exist, though highly over-subscribed and non-IXPE-specific), followed by US co-I support under non-US PI programs. The IUC notes that many observatories and organizations (such as the NRAO[6]) dedicate some funds to publication support for accepted papers which heavily feature data from that observatory/telescope and lack a supporting research grant. As the IXPE archive grows and under the possibility of future GO program funding reduction, such a program for funding IXPE-related publication costs would be one way to preserve some of the scientific output from IXPE observations.

IV. Data Archive and Data Reduction Software

The IUC is appreciative of the efforts of the IXPE team in providing a data archive and disseminating analysis software to the wider astrophysical community, especially as the mission moves into a General Observer phase. The IUC recognizes the challenges of preparing and vetting these tools while data very rapidly became public during the Prime Mission phase. The committee notes that in order to best aid the GO community, and grow it beyond those already associated with the mission team, significant consideration of the experience of new users is critical. This means making sure that installation of the software is made as straightforward as possible, and that clear documentation for software installation and testing is provided with an eye toward these novice users.

Two sets of software exist for IXPE analysis: ftools based software provided through HEASARC, and ixpeobssim, provided through github. Although the latter is not "official" instrument team software, it is frequently and extensively used in papers that have significant contributions from instrument team members. As such, there is a certain

[6] https://library.nrao.edu/pubdetails.shtml

obligation for the IXPE team to make sure that the procedures for installation of these tools are also straightforward and adequately described for users.

The IUC appreciates the early availability of an analysis quickstart guide posted in February 2023 to the HEASARC hosted IXPE web site, and recently updated with additional material. The IUC finds these materials to be an important step towards more fully fleshed-out tutorials. Indeed, standard practice for high-energy missions is to provide highly commented guided analysis tutorials that include actual archival data. The IUC noted with approval that plans for such tutorials are already underway. We note again the importance of supporting users that utilize the ftools-based as well as those using ixpeobssim-based tools.

Given that IXPE analyses specifically, and X-ray polarization analyses in general, are relatively new to the high energy astrophysics community, it might be expected that data analysis software and procedures could undergo significant changes over the course of the IXPE mission. To aid with the learning curve of the community, and to provide them with the greatest chance of providing feedback to the instrument teams, the IUC finds that major new releases of software, calibration updates, and/or analysis guide additions and revisions will most benefit the community if timed to be released prior to or early in the summer season, when research activity is typically at a peak, and conveniently a few months before the (current) typical GO proposal deadline for IXPE in late summer.

V. Outreach and Community Training

The IUC is highly supportive of community outreach and training sessions, such as the Joint NICER/IXPE Workshop to be held in Washington, D.C. Jul. 29-Aug. 1, 2024. The IUC is pleased to see that this meeting will be a hybrid virtual/in person meeting, increasing the number of IXPE users who will be able to attend relevant sessions. The committee notes that continuing to offer all or portions of workshops in virtual format (e.g., by advertising the first hour or two of each workshop day as new user “training sessions") is very important to attract and grow the IXPE user community. This is supported by the feedback received in our May IUC survey, which specifically asked about past and future workshop attendance, and where a virtual format was preferred by likely future attendees by a wide margin. Several survey respondents and committee members noted that they would greatly benefit from the recording and posting of the most useful training talks and sessions, along with their accompanying materials.

The Guest Observer phase promises to bring in a significant number of new IXPE users. To help understand the experience of these users and determine the success of outreach and training efforts, the IUC intends to perform a survey of phase 1 GO teams. Possible areas of inquiry could include determining the amount of time and support new users required to obtain useful results, determining whether proprietary time or the lack thereof was important to the team, etc. Details of the survey, including its timing, will be considered at the September 2024 IUC meeting.

VI. Multiwavelength Synergies & Future Plans

The scientific value of X-ray polarization is greatly enhanced by images, light curves, polarimetry, and spectra of IXPE targets at wavelengths from radio to gamma-ray. Recognizing this, the IXPE mission team has included during the Prime Mission a wide range of correlative multi-wavelength data to help in the interpretation of the IXPE data and to place it into the broader context of the physics of high-energy cosmic phenomena. In many of the published papers based on IXPE results, IXPE X-ray polarization maps superposed on radio, optical, X-ray, and gamma-ray images of supernova remnants and pulsar wind nebulae have determined the level of order and direction of the magnetic field in regions where high-energy particles are accelerated. This reveals the presence of shocks and turbulence in the X-ray emission regions. In blazars, the degree and position angle of X-ray polarization measured by IXPE have been compared with the optical, IR, and radio polarization, X-ray spectrum, overall spectral energy distribution, and light curves from radio to gamma-ray wavelengths. This has led to confirmation of the energy-stratified shock scenario as the likely model for particle acceleration and emission in the relativistic jets. The study of X-ray polarization of X-ray binaries also benefits greatly from multi-wavelength observations.

Recognizing the importance of contemporaneous multi-wavelength data combined with IXPE polarization measurements, the IXPE Cycle 2 GO program includes the possibility for proposers to request coordinated joint observing time with NICER, NuSTAR, and Swift (expanding from the 300 ks of NICER time available in cycle 1). This will allow accurate X-ray spectra to be determined simultaneously with IXPE polarization measurements. There is a plan to add NRAO instruments in Cycle 3, and the possibility of adding a joint program to obtain optical polarimetry has been discussed. Such joint programs will facilitate the multi-wavelength synergies by requiring a single proposal to request observations by multiple telescopes.