Neutron Star Astrophysics at the Crossroads: Magnetars and the Multimessenger Revolution
Proceedings IAU Symposium No. 363, 2023
E. Troja & M. G. Baring, eds.
doi:10.1017/S1743921322000874

NS parameters from IXPE data of AMPs

Alessandro Di Marco[1], **Alessandro Papitto**[2], **Maura Pilia**[3], **Juri Poutanen**[4] and **Tuomo Salmi**[5]

[1]INAF/IAPS, via Fosso del Cavaliere 100, I-0133, Rome, Italy

[2]INAF/OAR, via Frascati 33, I-00078 Monteporzio Catone (RM), Italy

[3]INAF/OAC, via della Scienza 5, I-09047 Selargius (CA), Italy

[4]Tuorla Observatory, Dept. of Physics and Astronomy, 20014 University of Turku, Finland

[5]Anton Pannekoek Inst. Astronomy, Univ. Amsterdam, Science Park 904, 1090GE, NL

Abstract. IXPE is a NASA/ASI Small Explorer Mission. It will probe the X-ray polarization properties of celestial sources. In particular, for Accretion-powered Millisecond Pulsars (AMPs), IXPE can provide us with unique information on their geometry. These information together with pulse shape modelling will strongly boost the achievable sensitivity on measuring the AMPs mass and the radius. As a case-study, we simulated an observation of SAXJ1808.4-3658 and studied the accuracy that can be achieved in the measured time-dependent Stokes profiles. From these data we estimated how well IXPE will be able to constraint NS geometrical parameters, such as the inclination and hot-spot co-latitude angles.

Keywords. X-ray, polarimetry, pulsar, IXPE

1. Introduction

The determination of the equation of state (EoS) of neutron stars (NSs) is one of the long-standing promises of high energy astrophysics. However, the quest for such measurements revealed troublesome. In this scenario the study of accretion-powered millisecond pulsars (AMPs) can help to better determine the EoS. In particular, modelling the X-ray pulse profiles produced from the surface of AMPs is less affected by systmatic errors (1) and allows to extract the desired information on the mass and radius of the NSs (2). A further problem is that we need to now geometrical parameters of the AMPs under study, these informations can be obtained using X-ray polarimetric data of the Imaging X-ray Polarimetry Explorer (3). Thus, combining polarization data from IXPE with phase-resolved pulse profiles obtained from other observatories, e.g. XMM-Newton will allow to obtain strong constraints on the EoS.

2. Simulations

As a case-study we simulated IXPE observations of SAX J1808.4-3658 using IXPEOBSSIM (5), a tool developed by IXPE collaboration to simulate and analyze IXPE observations, it includes the detectors responses, the Mirro effective areas and so on. In these simulations we fixed the model as in (6) (the geometrical parameters are reported in Figure 1-*Left*) setting the following parameters: (i) flux $\simeq$130 mCrab (2.8×10^{-9} erg/cm^2/s) in 2-8 keV band, corresponding to the expected mean flux during the outburst; (ii) Position 272.11° ra -36.98° dec; (iii) Spin frequency 400.975 Hz with first and second derivative equal to zero; (iv) Equatorial radius 12 km; (v) mass 1.4 $M_\odot$; (vi) $i = 60°$; (vii) $\theta = 20°$; (viii) spot angualar radius 1°; (ix) Pulsar rot. axis

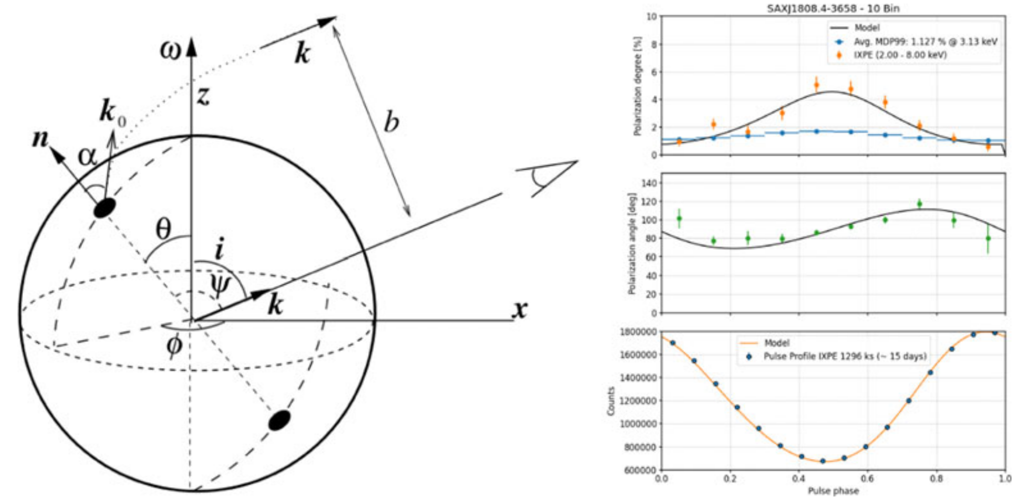

Figure 1. Left: Geometry of an AMP. θ is the spot colatitude, the second spot is situated at the opposite side. The inclination of the spin axis and the unit vector in the direction to the observer are i and k, respectively. The unit vector of the spot normal is n. The angle between the direction to the spot and the line of sight is given by $\cos\psi = k \cdot n$. In Schwarzschild metric the photon orbits are planar and the original direction of the photon is k_0 and α is the angle between k_0 and n (4). Right: top) Polarization degree as a function of the phase, in blue MDP (Minimum Detectable Polarization at 99% C.L.) shows that such an observing time allows us to obtain a significant result; (center) Polarization angle as a function of the phase; (bottom) Pulse as a function of the phase.

position angle, χ, and phase shift $\Delta\phi$ equal to 0°. The observing time has been fixed at 15 days (accounting for occulation and SAA passages, it corresponds to ∼8 effective days), corresponding to the typical duration of the brightest part of the source outburst. The observed pulse profile, and the estimated polarization degree and angle are shown in Figure 1-*Right*.

3. Results

From the simulated data we have obtained a good estimate of the spin frequency and its derivatives using HENDRICS (7), results were in agreement with simulated and literature values. The polarization degree and angle resolved in phase have been fitted with expectations from model of (6) applying a χ^2 test. The best-fit values for geometrical parameters from 10 simulations are: $i = (64.6 \pm 2.3)°$ and $\theta = (21 \pm 1)°$, compatible with expectations. Stokes profiles have been analyzed also with a Bayesian approach using MultiNest (8) obtaining: $i = (57.5 \pm 1.2)°$ and $\theta = (17.8 \pm 1.4)°$. Both results are in agreement with simulated geometrical parameters. This study shows that IXPE will allow to obtain important results in the constraint of NS geometrical parameters. In the next years combining IXPE observations with ones from other observatories (authors are part of an accepted observation proposal with XMM-Newton) will help to better understand the nature of AMPs.

Acknowledgments

The Italian contribution to the IXPE mission is supported by the Italian Space Agency (ASI) through the contract/agreements ASI-OHBI-2017-12-I.0, ASI-INAF-2017-12-H0 and ASI-INFN-2017.13-H0 and its SSDC, and by the INAF and INFN. IXPE is a NASA Astrophysics Small Explorers (SMEX) mission, managed by MSFC and overseen by the

https://doi.org/10.1017/S1743921322000874 Published online by Cambridge University Press

Explorers Program Office at GSFC. The computer resources of the Finnish IT Center for Science (CSC) and the FGCI project (Finland) are acknowledged.

References

1. Miller and Lamb EPJ A 52, 63 (2016);
2. Watts et al., RvMP, 88, 2 (2016);
3. P. Soffitta et al., AJ 162, 208 (2021).
4. K. Viironen and J. Poutanen, A&A 426, 985 (2004).
5. M. Pesce-Rollins et al., NIMA 936, 224 (2019).
6. T. Salmi et al., A&A 646, A23 (2021).
7. M. Bachetti, ASCL1805.019 (2018).
8. F. Feroz, et al., MNRAS 398, 1601-1614 (2009)