X-RAY POLARISATION STUDIES OF TRANSITIONAL BINARY SYSTEMS

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The Imaging X-ray Polarimetry Explorer (IXPE) is a Small Experiment (SMEX) mission observing from 2 to 10 keV [1], financed by NASA with a close Italian partnership (ASI, INAF, INFN). IXPE will launch in 2021 and will be the first detector to perform imaging polarimetry in X-rays after a void of 40 years. Its capabilities are based on the Gas Pixel Detector (GPD) developed by Italian groups [2] which allows detection of the energy and direction of the incident photon, but also of polarisation angle and degree of the radiation thanks to a cos^2 modulation arising from a preferential direction of the photons in case of linearly polarised emission. The Minimum Detectable Polarisation (MDP) quantifies the expected performance of the instrument for each observation.

IXPE key science objectives will initially be the brightest extended X-ray sources: AGN jets, Pulsar Wind Nebulae and Supernova Remnants. Its imaging capabilities enable more sensitive measurements of the polarisation properties of point sources embedded in nebular emission or adjacent to other sources, i.e. pulsars within nebulae or in binary systems. The IXPE collaboration has developed IXPEOBSSIM [3], a software which allows simulations of astrophysical targets for future observations with IXPE. Within this framework, our group developed a task for the simulation of pulsars in binary systems which was used to predict the outcome of IXPE studies of Accreting Millisecond X-ray Pulsars.

Low-Mass X-ray Binaries (LMXBs) and Millisecond pulsars are thought to be evolutionary related: a "dead" pulsar can be spun-up to millisecond periods if it belongs to a binary system where the companion star accretes mass (and therefore angular momentum) on it. A first compelling evidence for this "recycling" scenario came from the detection of SAX J1808.4-3658 which was the first LMXB for which pulsation was detected in X-rays [4]. This source undergoes bright outbursts roughly every 2.5-3 years, the last of which started last August. The smoking gun to the recycling scenario was only found when the canonical radio pulsar J1023+0038 disappeared as a radio source to later reappear as an X-ray accreting pulsar [4]. The source is now in a steady-disk state where X-ray pulsations are observed in a high state for ~70% of the time. The latest X-ray + optical observations have shown that the two seem to be related, thus challenging the standard model, and leading to the hypothesis that a sort of pulsar wind shock is actually what is powering the X-ray emission [5,6].
Polarisation studies of these systems, which are believed to be at least a few percent polarised, are going to be fundamental to better understand their geometry and, eventually, to discriminate among emission models.

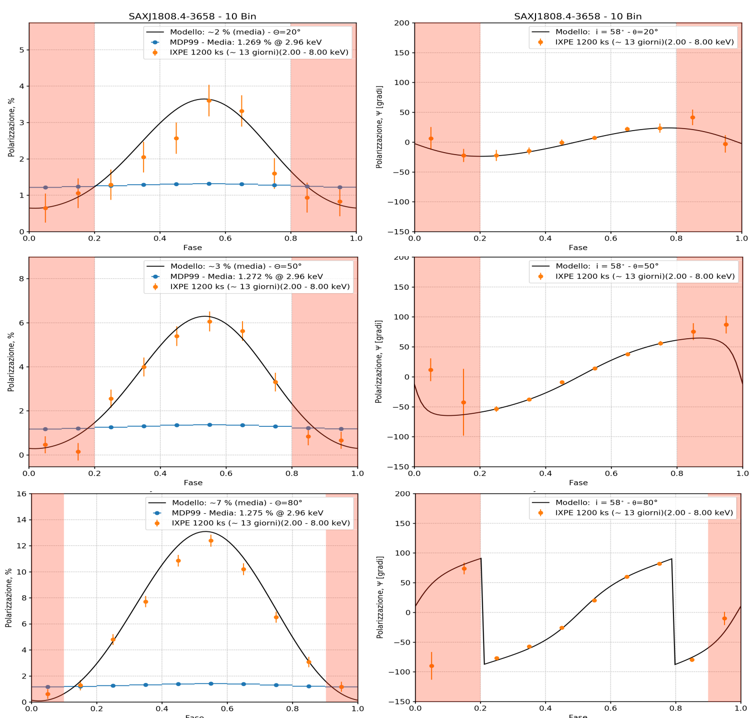

Fig. 1: Simulations results obtained for ~ 2 weeks of observations of SAX J1808.4-3658 at peak flux. Modelling of the outbursts has shown that the source remains in a $F_{(2-10)\mathrm{keV}} \simeq 2\times10^{-9}\mathrm{erg\,cm^{-2}s^{-1}}$ state for ~ 14 days before a slow decay lasting ~ 40 days. We performed simulations of IXPE observations of the outburst, as one can be expected during its lifetime.
The three horizontal panels show the trend of polarisation degree (left) and angle (right) for different geometries of the system (viewing angle and magnetic inclination). We use a modulated model for the emission (black line) following [7]. We input a mean intrinsic polarisation of the source of ~ 5%. Except for the shaded area, IXPE simulated observations (orange dots) are all well above the 1% MDP for this observation (blue dots) and therefore we show that IXPE will be able to detect phase-resolved polarisation and discriminate between different geometries of the system.

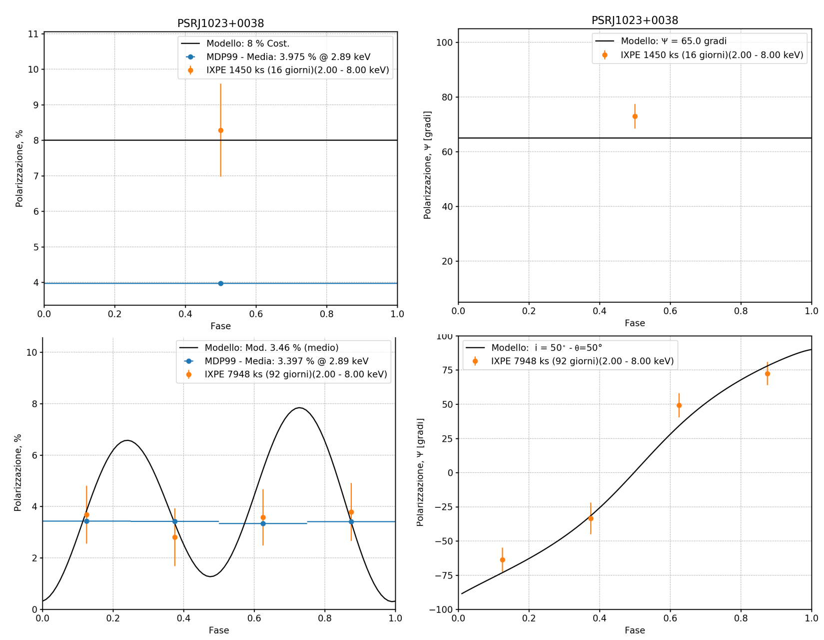

Fig. 2: Simulations results for a ~ 2 week observation of J1023+0038 in high state ($F_{(2-10)\mathrm{keV}} \simeq 1\times10^{-11}\mathrm{erg\,cm^{-2}s^{-1}}$). The input polarisation was taken as a best case scenario (following indications from the optical and extrapolating flux ratios) is a polarisation fraction of 8%.
The top panel shows that no phase resolved studies can be attempted with such a short observation, though integrated polarisation should be detected. We then integrated for ~ 90 days of exposure, in the hypothesis that IXPE might observe the source along the timespan of more years (as its ephemeris is quite stable). Because MDP behaves asymptotically, even in this case we do not reach 1%. We conclude that it will be difficult to observe phase-resolved polarisation for J1023+0038 unless an outburst is observed.

References:

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