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Modelling the multipolar magnetic field of NICER MSP J0030+0451

Contributed Talk //

Pulsars and Pulsar Wind Nebulae (PWNs)

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Session 4 //
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The Neutron star Interior Composition ExploreR (NICER) has been operating since 2017 to better understand the extreme nature of neutron stars. With its exceptional sensitivity, its ultimate aim is to constrain the equation of state of neutron stars to better precision. Modelling thermal X-ray light curves of pulsars can provide insights into the magnetic field structure of neutron stars and the morphology of the hot spots on their surface, leading to constraining mass and radius due to the gravitational light bending effects.

Recent studies have strongly indicated the presence of a multipolar magnetic field for the millisecond pulsar PSR J0030+0451 (J0030) while also localizing hot spots on the surface. Kalapotharakos et al. (2021) used an offset static dipole plus quadrupole magnetic field description to fit the NICER X-ray light curves of J0030. We are developing a code to implement a generic multipolar magnetic field to constrain the field parameter space for J0030, adopting retarded vacuum field solutions (Pétri 2015), as opposed to previous works based on static fields, since these are closer to the more realistic force-free field configurations required to simultaneously explain and fit the gamma-ray emission light curves seen by Fermi LAT. We consider all m = -l to l field components from l = 1 to l = 3, and employ Markov chain Monte Carlo (MCMC) methods to fit the bolometric X-ray light curves of J0030, and constrain the number of components and orientation of the field required for an adequate fitting.

We aim to eventually expand our parameter space by keeping the stellar mass and radius independent, and hence, putting more robust constraints on the equation of state. In this talk, we will present the methods and techniques of our approach, highlight the field configuration differences between different multipolar components, and show an exploration of the MCMC parameter space for the optimal multipolar field configuration required to fit the thermal X-ray light curve of J0030.

Sponsored by the Department of Science and Innovation (DSI) and the National Research Foundation (NRF) through the South African Gamma-Ray Astronomy Programme (SA-GAMMA)

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Spatio-temporal Modelling of Young Pulsar Wind Nebulae

Poster Presentation //

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Recent observations of a few young, nearby pulsar wind nebulae (PWNe) have revealed their morphologies in some detail across the electromagnetic spectrum. With the availability of spatio-temporal data, we aim to model two young PWNe: Kes 75 (G29.7-0.3) and G21.5-0.9 (G21.5).

Kes 75 is a galactic composite supernova remnant (SNR) with an embedded pulsar, PSR J1846-0258 (J1846), that powers a PWN (~700 years old) which was seen to have expanded rapidly over the past several years. J1846 exhibited magnetar-like outbursts and a glitch in 2006, and then after 14 years of quiescence, again in 2020. The eventful history of this nebula during its short lifetime makes it an interesting target to understand its switching behaviour between a rotation-powered and magnetar-like state.

PWN G21.5 is also known as composite SNR, where the central region is emission-filled and powered by a pulsar (PSR J1833-1034), and it also has an expanding shell of material powered by the supernova blast wave. Furthermore, It has a morphology very similar to that of the Crab PWN. This object has been observed at multiple-wavelengths, from radio to TeV gamma rays. Its X-ray and TeV spectral shapes are harder than those of the Crab, with a spectral index of 2.1 ± 0.2, and it can be a plausible source for TeV-PeV radiation.

Our multi-zone leptonic emission code for young PWNe exploits the combination of spectral and spatial data to constrain certain physical parameters. We will present a detailed parameter study for both these sources, highlighting the importance of fine-tuning parameters for modelling PWNe, while finding reasonable joint fits to the broadband spectrum, X-ray surface brightness profile, expansion rate, flux for a few different epochs, and X-ray photon index vs. central radius.

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