1. Level of the project, i.e. Honours or Master's
Master's

2. Name of supervisor

Dr. Monica Barnard[1,2]

Name of co-supervisor

Prof. C. Venter[1,2]

Name of co-supervisor

Dr. A. K. Harding[3]

Name of co-supervisor

Dr. C. Kalapotharakos[4]

3. Institution of supervisor and co-supervisor

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7. Project title
Modelling curvature and synchro-curvature gamma-ray emission from the Vela pulsar in a dissipative force-free magnetosphere

8. Description of project, including the aims and anticipated outcomes, what will be expected of the student, and any special qualifications required (maximum 500 words). Please also stipulate if any specific skills are required (eg, computational skills).

Pulsars are rapidly rotating, highly magnetized neutron stars that emit pulsed radiation across the electromagnetic spectrum. Despite major observational advances from instruments such as the Fermi Large Area Telescope (LAT) and H.E.S.S. II, the detailed microphysics and electrodynamics of pulsar magnetospheres remain unresolved, particularly regarding the origin of high-energy gamma-ray emission.

This project investigates the high-energy emission of the Vela pulsar as synchro-curvature (SC) radiation within a non-ideal, dissipative magnetospheric framework. While traditional models assume ideal force-free electrodynamics, recent studies indicate that realistic pulsar magnetospheres contain finite conductivity regions, especially in the current sheet, where particle acceleration and radiation are expected to occur.

To extend beyond idealised descriptions, this study introduces a dissipative electric field component with explicit radial and azimuthal dependence within a global force-free magnetic field configuration. The field is assumed to be force-free in the interior region, where the accelerating electric field is negligible, and becomes dissipative in the exterior region. This formulation allows for spatially varying parallel electric fields associated with resistive plasma effects and current sheet geometry. The inclusion of this non-ideal term enables particle acceleration to be computed self-consistently along open field lines and in dissipative regions, rather than imposed parametrically.

Starting from a single-particle framework, electron trajectories will be calculated in this global magnetospheric field, including the azimuthally varying dissipative E-field component. The resulting particle dynamics will be used to compute energy-dependent SC emission spectra, as well as phase-resolved and phase-averaged gamma-ray light curves.

A key objective is to quantify how the inclusion of a spatially structured dissipative electric field modifies: (1) particle transport between curvature and synchro-curvature regimes, (2) spectral cutoffs, and (3) energy-dependent pulse morphology and relative lag with respect to the radio pulses. The model predictions will be compared with observational data from the Vela pulsar to assess whether non-ideal electrodynamic effects improve agreement with measured gamma-ray spectra and light curves.

The student will be expected to independently conduct a literature review, develop and implement numerical simulations (Python/C/C++), perform data analysis, and produce scientific visualisations and interpretation. Strong programming ability and a solid foundation in classical electrodynamics are recommended, with guidance provided in relativistic magnetospheric modelling and numerical methods.

Timeline for project:
Literature review + write a research proposal + ethics approval: 3 months.
Data / simulation / modelling: 5 months.
Analysis + first results: 4 months.
Writing + revision cycles + submission: 6 months.