Modelling the Multi-wavelength Non-thermal Emission of AR Sco.

Louis Du Plessis
louisdp95@gmail.com

Supervisor: C. Venter
Collaborators: A.K. Harding
Z. Wadiasingh

Centre for Space Research, North-West University

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AR Sco Observations

- AR Sco is a binary system containing a white dwarf with a M-dwarf companion.
- The orbital period was inferred as 3.55 hours and a "pulsar" spin period of 1.95 min (Marsh et al., 2016). Observations by Stiller et al. (2018) also inferred a $\dot{P} = 7.18 \times 10^{-13}\ ss^{-1}$.
- The emission lines from the system show no indication of an accretion disc or column.
- The optical and UV are non-thermal emission and pulsed at the WD spin and beat period.
- Buckley et al. (2017) found that the system exhibits strong linear optical polarisation (up to $\sim 40\%$) and estimated the WD B-field to be $\sim 500\mathrm{MG}$

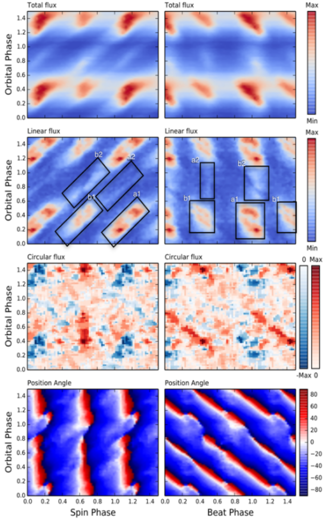


Figure: Optical data from Potter and Buckley (2018)

General Particle Dynamics

- For the particle dynamics we solve the Lorentz force equation given by:

$$\frac{d\mathbf{p}}{dt} = q\left(\mathbf{E} + \frac{c\mathbf{p}\times\mathbf{B}}{\sqrt{m^2c^4+\mathbf{p}^2c^2}}\right). \tag{1}$$

- We implemented an adaptive time step scheme as well as compared various higher order numerical integrators finding the Prince-Dormand 8(7) to be the best choice when balancing numerical runtime and accuracy.
- To test the solvers we set up various test scenarios namely a constant B-field, a changing B-field, a magnetic dipole and a constant B-field with a constant $E_\perp$-field.
- We made sure we had the the correct particle trajectories, Lorentz factors, gyro-radii and drift components.

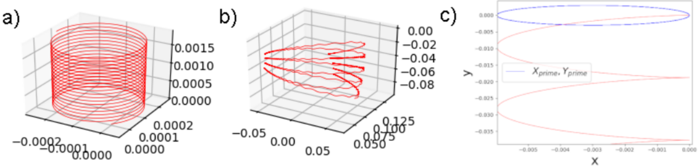


Figure: Particle trajectory for a) constant B-field, b) magnetic dipole and c) constant B-field with constant $E_\perp$.

Radiation-Reaction Force

- For the general radiation-reaction force we used the equation from Landau and Lifshitz neglecting the temporal and spacial change component since its contribution is negligible.
- We also include the super-relativistic form of the equation to probe super-relativistic particle assumptions. The equation is given as:

$$f_x = -\frac{2e^4\gamma^2}{3m^2c^4}\left\{(E_y - H_z)^2 + (E_z + H_y^2)\right\}. \tag{2}$$

- Calculating the particle energy and energy radiated by the particle ($E_{rad} = \int \mathbf{F}_{rad} \cdot \mathbf{v}.dt$), we can self consistently check if the system is losing or gaining energy.

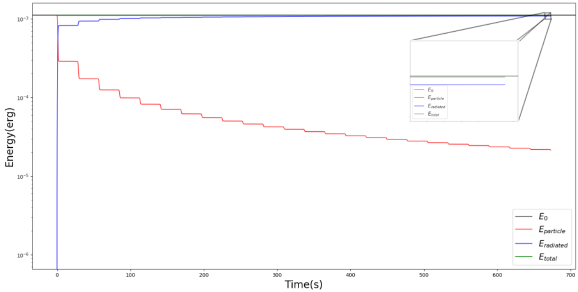


Figure: Comparison plot of particle energy and energy radiated with the initial particle energy in a magnetic mirror scenario.

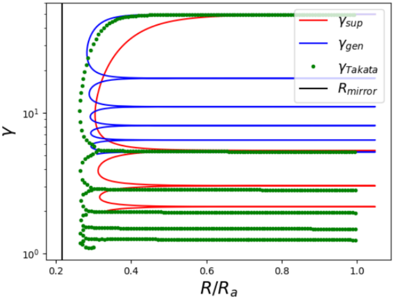
Reproducing Takata et al. (2017)

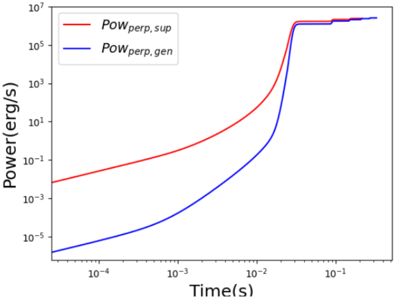
- We reproduce the magnetic mirror scenario from Takata et al. (2017).
- They use rewritten forms of equations from Harding et al. (2005).

$$\frac{d\gamma}{dt} = -\frac{P_\perp^2}{t_s}$$

$$\frac{d}{dt}\left(\frac{P_\perp^2}{B}\right) = -2\frac{B}{t_s\gamma}\left(\frac{P_\perp^2}{B}\right)^2 \tag{3}$$

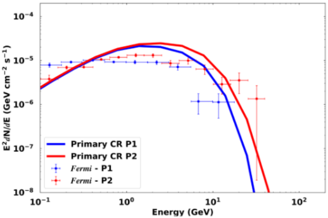
- Where $t_s = 3m_e^3c^5/2e^4B^2$.
- These equations assume super-relativistic particles with small pitch angles.
- Our super-relativistic case agrees with Takata's γ_{loss} but not the mirror point.
- Our general case disagrees largely with Takata's results.





Emission Map Calibration

- We calculate our synchrotron and curvature radiation similar to the model of AK Harding and collaborators.
- Simulating a millisecond pulsar scenario we calibrate our emission maps, light curves and spectra with the results of AK Harding and collaborators.
- To compare we use the same force-free fields and are investigating the correct E-field to compare particle dynamics.
- They include time-of-flight phase correction.



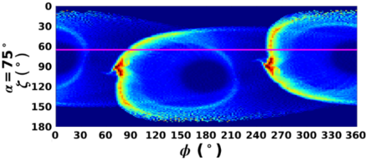


Figure: Example skymap from Barnard et al. (2021)

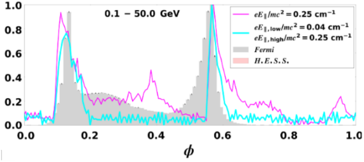


Figure: Example light curve from Barnard et al. (2021)

Future Work

- Calibrate with Harding and collaborators' emission maps and particle trajectories for pulsar scenario.
- Use appropriate E-field (force-free fields) to get $\mathbf{E} \times \mathbf{B}$ drift. Study effect of new WD scenario on model outputs.
- Implement polarisation calculations to produce phase plots.
- Determine how to scale particles' emission to have significant statistics. Invoke magic trickery to get code running in a reasonable time.
- Run code for orbital time scale, investigate different B-fields and E-fields, and investigate different particle pitch-angle distributions.
- Run code for new source similar to AR Sco.