

Executive Summary

Pulsar winds interacting with sources of external pressure are well-established as efficient and prolific TeV accelerators in our Galaxy. Yet, enabled by observations from Fermi-LAT, a growing class of non-accreting pulsars in binaries has emerged and these are likely to become apparent as TeV emitters in the CTA era. This class consists of the black widows and redbacks, binaries in which a millisecond pulsar interacts with its low-mass companion. In such systems, an intrabinary shock can form as a site of particle acceleration and associated nonthermal emission. We have developed a new multizone code which models the X-ray and gamma-ray synchrotron and inverse Compton spectral components for select spider binaries, including diffusion, convection, and radiative energy losses in an axially symmetric, steady-state approach. This new multizone code simultaneously yields energy-dependent light curves and orbital-phase-resolved spectra. It also better constrains the multiplicity of electron/positron pairs that have been accelerated up to TeV energies and are necessary to power orbitally-modulated synchrotron emission components between the X-rays and MeV/GeV bands potentially observed in some systems. This affords a more robust prediction of the expected high-energy and VHE gamma-ray flux.

The code takes as input known binary and pulsar parameters (including orbital inclination, orbital period, spin-down power, mass ratio), distance constraints, optical characterization of the system (radius, effective temperature), and particle spectral index (which may be readily chosen to be consistent with X-ray spectral index). Free parameters are those associated with the particle injection and shock, such as bulk motion, magnetic field at the shock, shock radius and geometry, acceleration efficiency, and pulsar pair multiplicity in terms of the Goldreich-Julian rate. More specifically, we assume a hemispherical intrabinary shock that is subdivided into multiple spatial zones. For simplicity, the shock is assumed to possess azimuthal symmetry. In each zone, a parameterized fraction of the pulsar wind's power is injected as a power-law accelerated leptonic particle population. The contribution of particles advected from upstream zones along the shock are taken into account with additional injection terms. Energy losses are treated in each individual spatial zone for different effects (radiative losses, convection/adiabatic losses and diffusion), and a particular zone's proximity to the photon bath from the companion is treated appropriately. Note that synchrotron self-Compton radiation is generally negligible because the magnetic field is sufficiently low, and synchrotron and (external) inverse Compton losses dominate radiative losses. We find that adiabatic losses generally dominate radiative ones, so the injected particle spectral shape does not change significantly across most zones. At the conclusion of the transport calculation, steady-state particle distributions in each zone are obtained, as well as the accelerated electron/positron population which escapes the system. Emission from synchrotron and inverse Compton channels and Doppler boosting from the shock bulk flow are then computed for each zone, and summed to arrive at a total flux for a given orbital phase and observer viewing angle.

In van der Merwe et al 2020, we presented case studies of select spiders (those accessible to H.E.S.S.-II, but by no means a comprehensive study of all sources) with extant nonthermal X-ray shock emission. Assuming the particle acceleration in the intrabinary shock in spiders is not substantially less efficient than known pulsar wind nebulae (i.e., particles may radiate at up to the synchrotron radiation reaction limit), the spectral energy distributions of these systems is predicted to be double-humped, with the synchrotron component peaking at several hundred MeV and the (external) inverse Compton component at several TeV. Two-photon absorption of TeV photons by the companion photons is found to be generally negligible.

The predicted spectra and light curves are currently somewhat unconstrained solely by available X-ray and optical data -- more broadband detections are needed, especially by IACTs and MeV instruments (e.g., e-ASTROGAM or AMEGO), in order to better constrain the model parameter space. Nevertheless, for nearby systems we considered, the expected MeV flux is readily characterizable by next-generation MeV concepts such as AMEGO, and TeV flux may reach H.E.S.S.-II sensitivity for 60 hours (and would be likely detectable by CTA in only a few hours). Fermi-LAT detections of orbitally-modulated multi-MeV emission, whose phasing is consistent with that for the shock, also constrain the models (such as in black widow J1311--3430). Moreover, we find that J1311--3430 may be observable by H.E.S.S.-II if the companion is in a high optical flaring state owing to the target photon number density scaling as T^3 . IACTs are particularly suited for such short-timescale variability and orbitally phase-resolved observations of these binaries are highly encouraged by current IACTs and CTA.