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Modeling Particle Acceleration and Multi-Wavelength Emission of a PeVatron microquasar V4641 Sgr

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The Large High Altitude Air Shower Observatory (LHAASO) has recently reported five Galactic microquasars as Ultra-High-Energy (UHE) gamma-ray emitters (>100 TeV), an unexpected result that challenges conventional models of Galactic particle acceleration. Among these sources, the microquasar V4641 Sgr exhibits gamma-ray emission up to ˜0.8 PeV, as well as the hardest UHE spectrum. The mechanisms behind particle acceleration to such energies are not well understood. Furthermore, the limited multi-wavelength (MWL) information on this source appears contradictory, further complicating interpretation and suggesting that V4641 Sgr may represent a particularly unusual case. In this work, we present a detailed physical model of V4641 Sgr that combines first-principles simulations of stochastic particle acceleration with MWL emission modeling. We adopt a leptonic scenario in which electrons are accelerated via second-order Fermi process driven by relativistic strong turbulence in the jet. The particle energization is simulated using a dedicated Monte Carlo framework that incorporates the effects of intermittent energy gains and radiative losses. The resulting high-energy electrons produce UHE gamma-rays through inverse Compton scattering on both the cosmic microwave background (CMB) and the interstellar radiation field (ISRF). Our model is capable of reproducing key observational characteristics of the system, including the PeV-scale gamma-ray emission. Nonetheless, several aspects remain unresolved, highlighting the need for deeper observational coverage and further theoretical refinement.

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