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Gamma-ray Emission from Starburst, Main Sequence, and Dead Galaxies: Contributions to Extragalactic Isotropic Backgrounds

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Star-forming galaxies (SFGs) have been considered to be important contributors to the extragalactic gamma-ray background. Their high energy emission is usually considered to be driven predominantly by hadronic processes, and is regulated by the properties of the underlying galaxy populations —in particular their star-formation rates. In these galaxies, cosmic ray protons are accelerated and interact with interstellar gas, producing gamma-rays via the decay of neutral pions. Neutrinos are also generated in this process through charged pion decays, meaning that SFGs can also contribute to the extragalactic neutrino background. However, models that self-consistently predict SFG contributions to extragalactic neutrino and gamma-ray backgrounds tend to under-predict the observed neutrino flux when using the isotropic gamma-ray background as a constraint. This suggests that a large fraction of the neutrino background may not originate from SFGs, and a stronger leptonic component in the gamma-ray background contribution from galaxies is possible. We explore this scenario by considering populations of millisecond pulsars (MSPs) and pulsar halos as potential sources of high-energy gamma-ray emission in galaxies. Our findings suggest that these sources can make a substantial contribution to the gamma-ray emission from evolved massive galaxies and are able to account for a large fraction of the gamma-ray emission detected from nearby main-sequence galaxies. By applying one of the latest semi-analytical galaxy evolution models, UniverseMachine, we demonstrate how galaxies at different evolutionary stages contribute to high-energy multi-messenger backgrounds over cosmic time. We will also discuss how upcoming gamma-ray observations can distinguish between hadronic cosmic ray processes in SFGs and leptonic-driven emission from MSPs and pulsar halos, providing a clearer assessment of the source populations underlying high-energy extragalactic isotropic backgrounds.

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