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The Origin of Supermassive Black Holes from Pop III.1 Seeds and Implications for Particle Physics and Cosmology

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The origin of supermassive black holes (SMBHs) is a key open question for contemporary astrophysics and cosmology. Here we discuss the predictions of a model of SMBH formation from Pop III.1 protostars, i.e., metal-free stars forming in locally isolated dark matter minihalos, where dark matter annihilation has a chance to alter the structure of the star allowing growth to supermassive scales (Banik, Tan & Monaco 2019; Singh, Monaco & Tan 2023; Cammelli et al. 2025; Nandal et al. 2025; Sanati et al. 2025a,b; for a review see Tan et al. 2024 and this project page: http://cosmicorigins.space/smbh). The model predicts that all SMBHs form very early in the Universe (i.e., by z ~ 20) with a spatial distribution that is initially relatively unclustered. It also makes predictions for SMBH occupation fractions, host galaxy properties, frequency of binary SMBHs and the gravitational wave background. These predictions are compared to latest results from the Hubble Space Telescope, James Webb Spact Telescope and pulsar timing array observations. Another key prediction of the model is an early phase of "flash"ionization of the universe at z~20, which can help alleviate cosmological tensions (Hubble tension, dynamical dark energy, negative neutrino masses) (Tan 2025; Komatsu & Tan 2025). Finally, since the Pop III.1 mechanism relies on the process of WIMP dark matter self-annihilation, there are implication for the nature of the dark matter particle.

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