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Probing Supermassive Black Hole-Host Galaxy Scaling Relations in Cosmological Simulations with Machine Learning

Observations have established intriguing correlations between supermassive black holes (SMBHs) and their host galaxies. However, state-of-the-art cosmological simulations have revealed discrepancies in the slope, amplitude, and scatter of the scaling relations when compared to both observational data and among different simulations. Understanding the underlying physical mechanisms responsible for these scaling relations remains a challenging task, although it has been demonstrated that SMBH feedback plays a crucial role in shaping them within simulations. In this study, we conduct a comprehensive analysis of SMBH-host scaling relations in three cosmological simulations, namely Illustris, TNG, and EAGLE. Leveraging the power of machine learning techniques, we quantify the tightness of each scaling relation across the different simulations. We find the M-sigma relation to be the tightest scaling relation across simulations except for TNG. EAGLE exhibits more scattered scaling relations overall. Additionally, we explore the dependence of scatter on SMBH mass and investigate SMBH-host "fundamental planes." Our analysis sheds light on the coevolution of SMBHs and galaxies in cosmological simulations with different SMBH feeding and feedback implementations. Our work also paves way for future studies to connect observations and simulations, and provide constraints for theoretical models.

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