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Sakurai Thesis Prize Talk: Quantum Gravity Constraints for Effective Field Theories[1]

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A fundamental open question in quantum field theory is related to ultraviolet completion: Which low-energy effective field theories can be consistently combined with quantum gravity? A celebrated example of the swampland program–the investigation of this question–is the weak gravity conjecture, which mandates, for a U(1) gauge field coupled consistently to gravity, the existence of a state with charge-to-mass ratio greater than unity. In this talk, I will discuss the tension between the weak gravity conjecture and the naturalness principle in quantum field theory, generalize the weak gravity conjecture to multiple gauge fields, and exhibit a model in which the weak gravity conjecture solves the standard model hierarchy problem. Further, this thesis demonstrates that gravitational effective field theories can be constrained by infrared physics principles alone, namely, analyticity, unitarity, and causality. I will discuss bounds related to the weak gravity conjecture that can be derived by placing such infrared constraints on higher-dimension operators in a photon-graviton effective theory. In addition, I will explore bounds on higher-curvature corrections to the Einstein equations using analyticity of graviton scattering amplitudes and unitarity of an arbitrary tree-level completion, as well as constraints on the couplings in models of massive gravity. Building on this thesis, the weak gravity conjecture can be proved using ideas in black hole entropy. Finally, I will briefly comment on the other topics of this thesis work, including a reformulation of graviton perturbation theory as well as various other results in emergent gravity, holography, and cosmology.

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