Black Hole Thermodynamics in de Sitter Spacetimes

F. Simovic[a], R. B. Mann[b]

[a]*School of Mathematical & Physical Sciences, Macquarie University, Sydney, NSW 2109, Australia.*

[b]*Department of Physics and Astronomy, University of Waterloo, Waterloo, Ontario, Canada.*

The subject of black hole thermodynamics lies at the center of numerous fields of study, many of which appear disparate yet have proven to be deeply entwined. One such example is the connection between the thermodynamic phase structure of black holes in asymptotically anti-de Sitter ($\Lambda < 0$) spacetimes and strongly coupled boundary systems through the anti-de Sitter/conformal field theory (AdS/CFT) correspondence. Over the years, the thermodynamics of asymptotically AdS black holes have been extensively studied in this regard, while significantly less attention has been given to asymptotically *de Sitter* ($\Lambda > 0$) black holes—the type believed to be of astrophysical relevance. This is owing to the presence of the cosmological horizon, which in general radiates at a different temeprature than the black hole and renders the system manifestly out of equilibrium.

In this work we investigate thermodynamic aspects of these de Sitter black holes, adopting a Euclidean path integral approach where thermodynamic data is fixed at a finite radius 'cavity' outside the black hole, allowing the system to achieve equilibrium in the presence of the cosmological horizon. Working in the extended phase space where the cosmological constant is treated as a thermodynamic pressure, we study the phase structure of both uncharged and charged black holes, uncovering a wealth of phenomena. We also examine black hole solutions in various extensions of Einstein-Maxwell theory, including non-linear electromagnetism and Lovelock theory, and uncover a unique an rich phase structure in these solutions [1]. We close by commenting on applications to conformal field theory and de Sitter space holography, as well as motivating future directions of research.

[1] F. Simovic and R. B. Mann, *Critical Phenomena of Charged de Sitter Black Holes in Cavities*, Classical and Quantum Gravity 36, 014002 (2019) DOI: 10.1088/1361-6382/aaf445, arXiv:1807.11875