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Cylindrical Renormalization and Brown–York Mass in Melvin and Schwarzschild–Melvin Spacetimes

We study the Euclidean action and Brown–York quasilocal mass of the Melvin and Schwarzschild–Melvin geometries in four-dimensional Einstein–Maxwell theory. Since these spacetimes do not exhibit the usual spherically asymptotically flat behavior, we introduce a cylindrical regularization scheme adapted to the magnetic axis. The boundary is placed at a fixed cylindrical radius, while the longitudinal interval is scaled with the radial cutoff. A sequential limiting procedure is then employed to preserve the cylindrical structure of the asymptotic region.
Within this framework, we show that the standard Mann–Marolf-type counterterm does not remove the relevant divergences. We instead propose a local boundary counterterm constructed from the norm of the axial Killing vector, which captures the asymptotic behavior of the azimuthal circumference. This prescription cancels the leading divergences without requiring background subtraction.
The renormalized Euclidean action and Brown–York mass both vanish for the pure Melvin universe. For the Schwarzschild–Melvin geometry, the Euclidean action is one half of the product of the inverse temperature and the black-hole mass parameter, while the Brown–York mass equals the mass parameter. These results identify the Melvin universe as a zero-mass magnetic reference and show that the finite black-hole mass is preserved after cylindrical renormalization.

Primary author(s) : Dr CHOQUE, david (Universidad Adolfo Ibañez)

Co-author(s) : Mr HUAMAN, Alessandro (PUCP)

Presenter(s) : Mr HUAMAN, Alessandro (PUCP)

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