Possibilities and Surprises of Vacuum Dark Energy

Astronomical data provide convincing evidence that the Universe is dominated in 70% of its density by a dark energy, with negative pressure $p = w\rho$; $w < -1/3$. Current observations constrain the parameter w to $w < -0.7$ with the best fit $w = -1$ corresponding to cosmological constant Λ related to a vacuum density $\Lambda = 8\pi G\rho_{vac}$ which must be constant by the Einstein equations. The quintessence Q was introduced as a negative-pressure time-evolving non-vacuum alternative to Λ. Future observations are aimed to study evolution of the dark energy with time to distinguish between Λ and Q. This suggests a need in a time-dependent space-inhomogeneous version of a cosmological vacuum energy. The Einstein cosmological term $\Lambda g_{\mu\nu}$ is associated with a vacuum stress-energy tensor of maximal symmetry, Lorentz group for stress-energy tensor, 10-parametric de Sitter group for space-time. Our mathematical instrument is the variable cosmological term $\Lambda_{\mu\nu} = 8\pi G T^{vac}_{\mu\nu}$ based on the Petrov classification scheme. It describes a cosmological vacuum defined by symmetry of its stress-energy tensor and evolving from $\Lambda g_{\mu\nu}$ to $\lambda g_{\mu\nu}$ with $\lambda < \Lambda$. The full symmetry remains asymptotically, in between it is reduced to the Lorentz boosts in a certain space direction. Existence of such geometries follows from imposing requirements of regularity of density, finiteness of the mass, and certain energy conditions on a stress-energy tensor. In the spherically symmetric case $T^{vac}_{\mu\nu}$ generates regular spherically symmetric space-time with the de Sitter center. Dependently on parameters and choice of a coordinate frame, geometry describes cosmological models with variable vacuum density, and localized objects with de Sitter vacuum core: nonsingular black holes and self-gravitating particle-like structures. Mass of the objects with the de Sitter center is related to both smooth breaking of space-time symmetry and de Sitter vacuum trapped in the origin. This has been tested by evaluating the gravito-electroweak unification scale from the measured mass-squared differences for solar and atmospheric neutrinos.