Symmetry protected entanglement between gravity and matter

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Local Poincaré symmetry in classical GR

Formalization of the principle of general relativity amounts to the statement that GR should be invariant with respect to local Poincaré transformations.

As a consequence, GR is a theory with constraints, in particular:

- the scalar constraint $\mathcal{C}$,
- 3-diffeomorphism constraints $\mathcal{C}_i$, and
- local Lorentz constraints $\mathcal{C}_{ab}$.

The Hamiltonian then takes the general form [1]:

$$H = \int_{\Sigma_3} d^3\vec{x}[N\mathcal{C} + N^i\mathcal{C}_i + N^{ab}\mathcal{C}_{ab}]$$

Scalar constraint in the canonical quantisation — nonseparability

The Dirac's quantisation programme of constrained systems [2] — local Poincaré gauge invariance conditions (Gupta-Bleuler [3, 4]):

$$\hat{\mathcal{C}}|\Psi\rangle = 0\,, \qquad \hat{\mathcal{C}}_i|\Psi\rangle = 0\,, \qquad \hat{\mathcal{C}}_{ab}|\Psi\rangle = 0\,.$$

The physical gauge-invariant Hilbert space is a proper subset of the total Hilbert space:

$$\mathcal{H}_{\text{phys}} \subset \mathcal{H}_G \otimes \mathcal{H}_M\,.$$

The scalar constraint:

$$\hat{\mathcal{C}} = \mathcal{C}_G(\hat{g},\hat{\pi}_g) + \hat{\pi}_\phi \hat{\nabla}_\perp \hat{\phi} - \frac{1}{N}\mathcal{L}_M(\hat{g},\hat{\pi}_g,\hat{\phi},\hat{\pi}_\phi)\,.$$

The matter Lagrangian $\mathcal{L}_M$ is nonseparable (for the scalar, spinor and vector fields), thus generically:

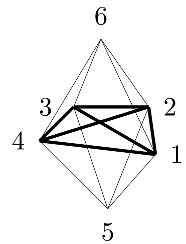
$$|\Psi_G\rangle \otimes |\Psi_M\rangle \notin \mathcal{H}_{\text{phys}}\,.$$

Hartle-Hawking state in the covariant quantisation — entanglement

Feynman's quantisation programme — the path integral of a gravity-matter quantum system:

$$Z = \int \mathcal{D}g \int \mathcal{D}\phi \; e^{iS[g,\phi]} \,.$$

Hartle-Hawking state [5] and the spacetime triangulation:



$$\Psi_{\mathrm{HH}}[g,\phi] = \mathcal{N} \int \mathcal{D}G \int \mathcal{D}\Phi \; e^{iS[g,\phi,G,\Phi]} \,.$$

The density matrix of a partial matter state:

$$\hat{\rho}_M = \mathrm{Tr}_G \, |\Psi\rangle \otimes \langle\Psi| = \int \mathcal{D}\phi \int \mathcal{D}\phi' \; \left[\int \mathcal{D}g \;\; \Psi_{\mathrm{HH}}[g,\phi] \Psi^*_{\mathrm{HH}}[g,\phi] \right] \;\; |\phi\rangle \otimes \langle\phi'| \,.$$

Trace of the square of reduced density matrix operator [6]:

$$\mathrm{Tr}_M \, \hat{\rho}_M^2 = 0.977 \pm 0.002 \,.$$

Consequences

- **Matter does not decohere, it is by default decohered.**
- **The impact to the decoherence programme: allows for an explicit system-apparatus-environment tripartite interaction violating the stability criterion of a faithful measurement.**
- **A confirmation of a "spacetime as an emergent phenomenon".**
- **A possible candidate for a criterion for a plausible theory of quantum gravity.**
- **Introduces an effective "exchange-like" interaction, possibly violating the weak equivalence principle.**

Bibliography

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THANK YOU!