Corpuscular description of black hole interiors

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Overview

1. Motivations
2. Classicalization
3. The corpuscular model of BHs
4. Effective theory and study of perturbations

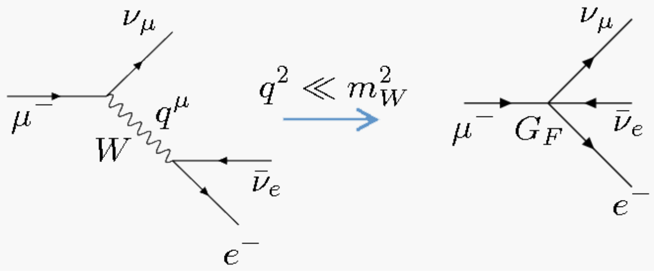
Motivations

Motivations

- Incompleteness of semiclassical paradigm
- Corpuscular model: fully quantum BH description
- No central singularity $\rightarrow$ internal BH structure can be considered

Classicalization

The problem with gravity

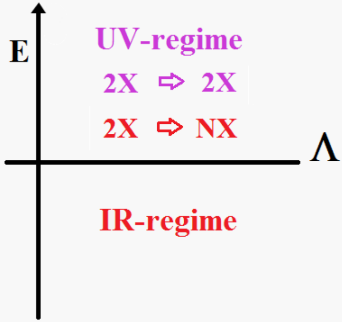


Source: arXiv:1510.07633. Fermi's theory is a low-energy limit of the Electro-Weak theory.

- GR is non-renormalizable, just like Fermi's theory
- Effective theory = low-energy approximation of a more fundamental description
- Non-renormalizable theories break down at energy Λ and need UV-completion

Classicalization

- Classicalization: theories like GR can self-complete in the UV-regime [1]
- One $2X \to 2X$ high-energy process becomes many $2X \to NX$ low-energy ones
- UV physics = IR physics
- Λ is the Planck scale: GUP censorship supports classicalization

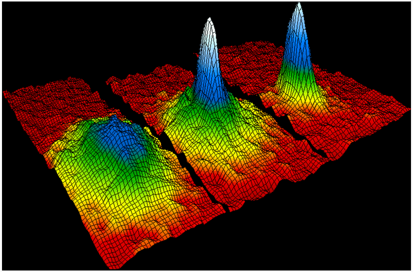


[1] G. Dvali et al., "UV-completion by classicalization", JHEP 108 (2011)

The corpuscular model of BHs

The corpuscular model of black holes

- Black holes are effectively Bose-Einstein condensates of gravitons at the verge of the phase transition [2]
- N tunes all the other parameters
- $\lambda \sim \sqrt{N}\ell_{\mathrm{p}}$
- $\alpha = 1/N$
- $M = \sqrt{N}m_{\mathrm{p}}$



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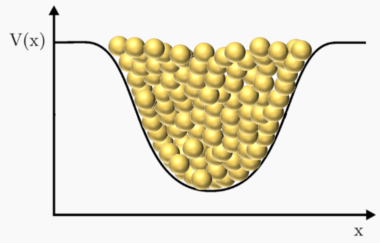
- The condensate is self-sustained $\rightarrow$ self-sourcing of gravity

[2] G. Dvali et al., "Black holes as critical point of quantum phase transition", EPJC 74 (2014)

Black holes as Bose-Einstein condensates

- Very large number N of bound gravitons $\rightarrow$ Extreme gravitational potential
- Maximal packing: increase in $N \rightarrow$ increase in R
- Bekenstein entropy: $S \propto N$
- Hawking radiation, with flux $\Gamma = \frac{1}{N^2} N^2 \frac{\hbar}{\sqrt{N}\ell_{\mathrm{p}}}$

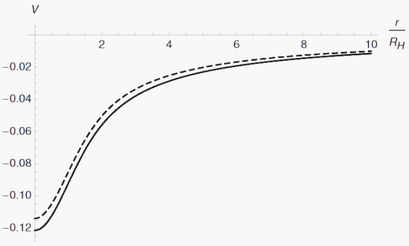


- Spacetime geometry regarded as emergent

Effective theory and study of perturbations

Corpuscular corrections → post-Newtonian contributions

- Effective theory with scalar toy gravitons addresses the role of matter [3]
- Potential for spherical and static sources recovered with coherent states
- Corpuscular corrections → post-Newtonian contribution



Source: [3]. Potential obtained from effective theory (solid line) vs. Newtonian potential (dashed line)

[3] R. Casadio et al., "Quantum corpuscular corrections to the Newtonian potential", PRD 96 (2017)

Effective theory

Lagrangian density for the scalar graviton field up to P-N order in [3]:

$$\mathcal{L}[\Phi] = \left[\frac{1}{2}\Phi\Box\Phi - q_{\mathrm{B}}J_{\mathrm{B}}\Phi\left(1 - 2q_{\Phi}\sqrt{\frac{G_{\mathrm{N}}}{c^3}}\Phi\right). + 2q_{\Phi}\sqrt{\frac{G_{\mathrm{N}}}{c^3}}(\partial_{\mu}\Phi)^2\Phi\right]$$

Corresponding E-L equations:

$$\left(1 - 4q_{\Phi}\sqrt{\frac{G_{\mathrm{N}}}{c^3}}\Phi\right)\Box\Phi \;=\; q_{\mathrm{B}}J_{\mathrm{B}}\left(1 - 4q_{\Phi}\sqrt{\frac{G_{\mathrm{N}}}{c^3}}\Phi\right) + 2q_{\Phi}\sqrt{\frac{G_{\mathrm{N}}}{c^3}}(\partial_{\mu}\Phi)^2$$

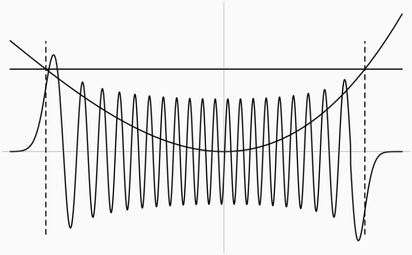
Study of perturbations

- Perturbations of the system studied through linearisation of the equations $\rightarrow \boldsymbol{\Phi} = \phi + \varphi$
- Explicit choice for the background: $\phi = q_{\mathrm{B}} \frac{G_{\mathrm{N}} M_0}{2R^3}(r^2 - 3R^2)$
- Equations for the fluctuations:

$$\Box\varphi\left(1 - 4q_{\boldsymbol{\Phi}}\sqrt{\frac{G_{\mathrm{N}}}{c^3}}(\phi+\varphi)\right) - 4q_{\boldsymbol{\Phi}}\sqrt{\frac{G_{\mathrm{N}}}{c^3}}\left[\frac{1}{2}\left(\partial_\mu\varphi\right)^2 + \partial_\mu\phi\partial^\mu\varphi\right] = 0$$

Dispersion relation

- Ansatz for φ: WKB approximation as in black hole perturbation theory
- Spherical wave:
  $$\varphi = \frac{e^{ikr}}{kr} e^{i\omega t + \sigma t}$$
- After substitution in EOM:
  $$\begin{cases} \omega = ck + q_{\Phi}\omega_1 \\ \sigma = q_{\Phi}\sigma_1 \end{cases}$$



- WKB: wave oscillates on much smaller spatial scale than potential

Discussion of results

$$\sigma = -2q_\Phi \sqrt{\frac{G_\mathrm{N}}{c^3}} c \cdot \left(\frac{q_\mathrm{B} G_\mathrm{N} M_0 r}{R^3} + -\frac{1}{2k^2 r^3} \sin(kr) - \frac{1}{kr^2} \cos(kr) \right)$$

- $\lambda = \frac{1}{k} \ll R$ $\rightarrow \phi$-term dominates.
- $\sigma < 0 \rightarrow$ Decay of perturbations
- $\lambda = \frac{1}{k} \sim R$. If $R \sim M$, the oscillating terms dominate.
- $\sigma > 0 \rightarrow$ Amplification of perturbations. Hawking radiation? [4]

[4] A. Giugno, S. Giardino et al., to appear

Summary

- Classicalization: GR (effective) can self-complete at high energies
- Corpuscular model: black holes are Bose-Einstein condensates of gravitons
- Corpuscular correction $\rightarrow$ Post-Newtonian contribution to gravitational potential
- Study of perturbations $\rightarrow$ Two different limits: Hawking radiation emission or stability

Thank you for your attention!