Black Holes as Bose Einstein Condensates

Tehseen Rug

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Hawking and Black Holes

Hawking: semiclassical treatment of black hole
$M_{BH} \rightarrow \infty$, $L_P \rightarrow 0$, r_g fixed $\Rightarrow$ exact thermal spectrum

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Question: Is the semiclassical treatment appropriate for real black holes?

Black Holes Quantum Picture

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Meaning of N: single characteristic of black hole / measure of classicality

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$$M_{BH} = \sqrt{N}\frac{\hbar}{L_P}, \quad r_g = \sqrt{N}L_P, \quad \alpha = \frac{1}{N} \tag{3}$$

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Black holes are Bose Einstein Condensates at the critical point of a quantum phase transition!

Toy Model

Non-relativistic prototype model: bosons on a ring

$$H = \frac{1}{R}\int_0^{2\pi} d\theta \Big[-\frac{\hbar^2}{2m}\psi^+\partial_\theta^2\psi - \frac{\hbar^2}{2m}\frac{\pi g R}{2}\psi^+\psi^+\psi\psi \Big] \tag{4}$$

Performing Bogoliubov with analysis $\hbar = R = 2m = 1$ gives energy spectrum of Bogoliubov modes:

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$\Rightarrow$ Quantum phase transition: $k = 1$ $gN = 1$.
$\Rightarrow$ **Phase transition is a long wavelength effect.**

Measure of Quantumness

Ground state fidelity: $F(gN, gN+\delta) = |\langle 0_{gN} | 0_{gN+\delta} \rangle|$
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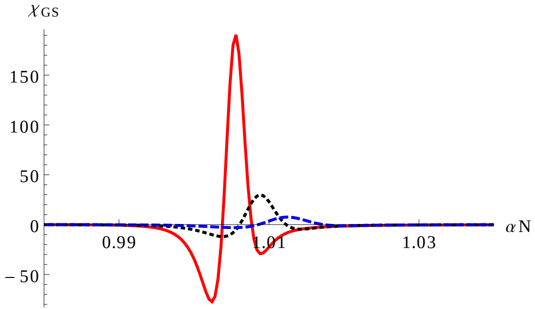

Figure: Numerical ground state fidelity susceptibility

Fluctuation entanglement: Neumann entropy of reduced density matrix:

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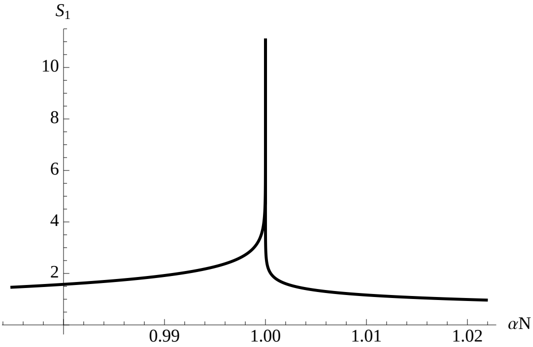

Figure: Analytical fluctuation entanglement

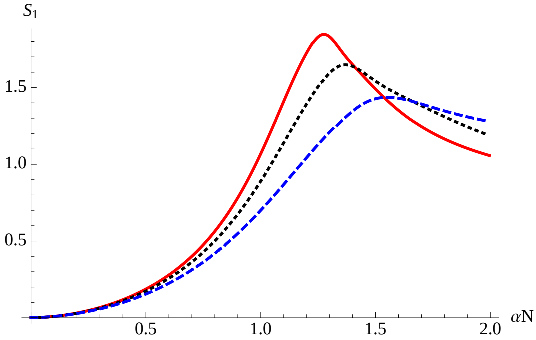

Figure: Numerical fluctuation entanglement

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self-sustainability $\leftrightarrow$ critical point of quantum phase transition
Bekenstein entropy $\leftrightarrow$ quantum degeneracy of the BEC at the critical point
Hawking radiation $\leftrightarrow$ quantum depletion of the BEC.

Peculiarity of Gravity

Black holes: $\alpha N = 1$ fixed $\Rightarrow$ Black holes always at the critical point.

Reason: self-similarity of black hole collapse

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Shrinking of size by one quanta:

$$\Delta E = \frac{\hbar}{\sqrt{N} L_P}. \tag{6}$$

Same energy needed to leak out one quanta.

- Application of the picture to dS/AdS spaces

$$N = \frac{R^{D-2}}{L_D^{D-2}} \tag{7}$$

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- Application to Classicalization

Thank You for Your Attention