Black Hole's Quantum Portrait

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The Big Goal is to understand UV-completion of gravity.

This is impossible without understanding quantum portrait of Black Holes.

In this talk we shall introduce such a portrait.
Black Hole Mysteries (semi-classically):

*) Absence of hair;

*) Exact thermality of Hawking radiation and negative heat;

*) Bekenstein entropy;

*)
Must be a quantum field-theoretic substance at temperature $T_H$!

But, none work!
Absence of hair and exact thermality

+ 

A small logical gap filled with a seemingly logical assumption

= "Folk theorems" about no global charges (e.g., baryon and lepton numbers).

* "Information Paradox".
To resolve these "paradoxes," and to close the logical gap, we need a microscopic quantum theory.

In this talk we shall provide such a theory and show how it demystifies semi-classical black hole properties.
We shall see:
Black holes do carry hair under global charges (baryonic and leptonic numbers), which can be of 100% astrophysical importance.
Recall: Schwarzschild black hole is a solution in GR.

Intrinsically - classical concept!
In quantum field-theory the building blocks are particles:

\[ a^+ |0\rangle = |1\rangle \]

There is nothing else.
Our main concept:

geometry = many quanta

\[ g_{\mu \nu} = \sum N_\lambda a_\lambda^+ |0\rangle \]

Geometry is a quantum Bose-condensate of gravitons!
Gravity is a quantum theory of a particle (graviton) of $m = 0$ and $\text{Spin} = 2$

$\alpha_{qr} \equiv \hbar G_N \tilde{\lambda}^{-2}$
Quantum entities: Planck length and Mass

\[ L_p = \hbar \frac{G}{N}, \quad M_p = \frac{\hbar}{L_p} \]

\[ \alpha_{gr} = \frac{L_p^2}{\lambda^2} \]

In classical limit (\( \hbar \to 0 \))

\[ L_p \to 0 \quad \alpha_{gr} \to 0 \]
Now, try to form a graviton wave packet.

For $\lambda \gg L_p$

$\lambda_{gr} \ll 1$

A typical Hartree situation:

Each graviton sees a collective potential.
Collective binding potential for $r \sim \lambda$

$$V = -N \chi \frac{\hbar}{\lambda}$$

and kinetic energy

$$E_k = \frac{\hbar}{\lambda}$$
The boundstate condition

$$E_k + V = 0$$

$$\Rightarrow (1 - N \lambda_{gr}) \frac{\hbar}{\lambda} = 0$$

A self-sustained boundstate is formed for

$$\lambda_{gr} = \frac{1}{N}$$
This self-sustained bound state is a black hole.

\[ \lambda = \sqrt{N} L_p, \quad \chi_{gr} = \frac{1}{N} \]
Black hole quantum physics is remarkably simple, with a single parameter \( N \):

\[
M = \sqrt{N}, \quad \lambda = \sqrt{N},
\]

\[
\alpha_{\text{gs}} = \frac{1}{N}
\]

It is a large-\( N \) physics (in 't Hooft's sense) and is a result of maximal overpacking.
Black hole is a most over packet quantum system of nature and because of this it is maximally simple.
This self-sustained Bose-condensate exists for any \( N \) and for any \( N \) it is leaky.
The condensate depletes self-similarly

\[ N \to N-1 \]

\[ N \left\{ \tilde{\text{\ldots}} \right\} N-1 \]

depletion law

\[ \dot{N} = -\frac{1}{\sqrt{N} L_p} + \mathcal{O}\left(\frac{1}{N^{3/2}}\right) \]
\[ \dot{N} = -\frac{1}{\sqrt{N} L_p} \]

Defining \( T = \frac{\hbar}{\sqrt{N} L_p} \), in the semi-classical limit \( N \to \infty, L_p \to 0, \sqrt{N} L_p = \text{fixed} \), we get the Stefan-Boltzmann law for Hawking evaporation:

\[ \dot{M} = -T^2 \frac{\hbar}{\kappa} \]
We discover that thermality is an "optical illusion".

Spectrum is thermal because of the self-similarity of depletion, not because the source is hot.

The graviton condensate is cold!
Another (false) artifact of semi-classical limit is the absence of hair.

In reality black holes carry a detectable hair as

\[
\frac{N_B}{N} - \text{effect}
\]
How Alice detect a baryonic hair of a black hole

baryon

Alice's probe

black hole

\[
\text{hair} = \frac{1}{\sqrt{N L_p}} \left( \frac{N B}{N} \right)
\]
For Astrophysical black holes (that carry large baryonic or leptonic charges), the hair can be an observable effect.
Outlook

Black hole’s quantum portrait is a microscopic framework which allows to address questions that in the conventional treatment cannot even be formulated. It demystifies the known semi-classical puzzles in black hole physics.
Among many potential applications is cosmology:

The Universe is the largest black hole we know.

It's a graviton condensate with

\[ N \sim 10^{120} \]
We are learning that overpacked systems get oversimplified.

Origin of holography

\[ L^2_p \text{-pixel} \]

\[ N = \frac{\sqrt{g}}{L^2_p} \]