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.

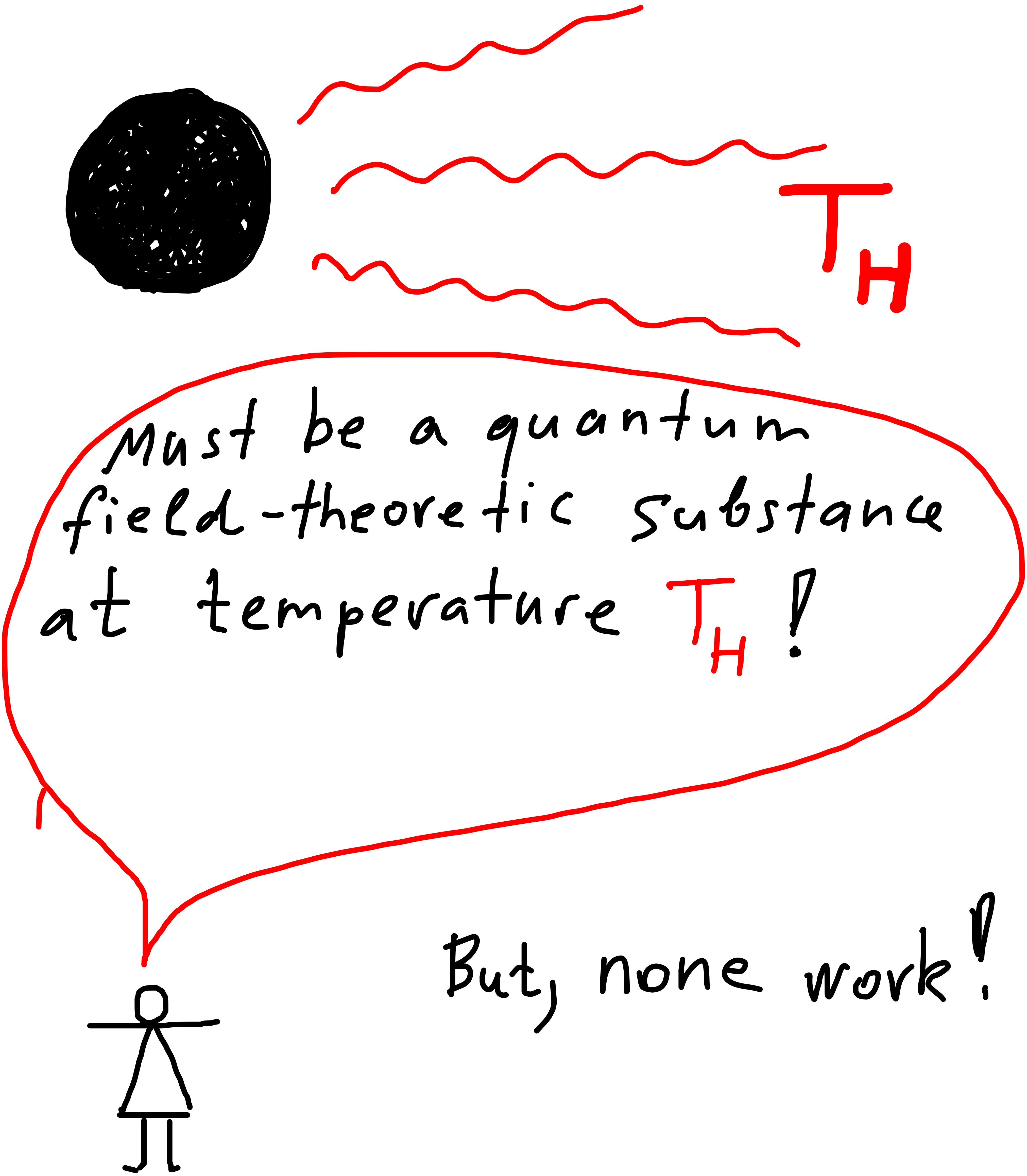
Black Hole Mysteries (semi-classically):

*) Absence of hair;

*) Exact thermality of Hawking radiation and negative heat;

*) Bekenstein entropy;

*) . . . . . .


T_H
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 seemengly-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.

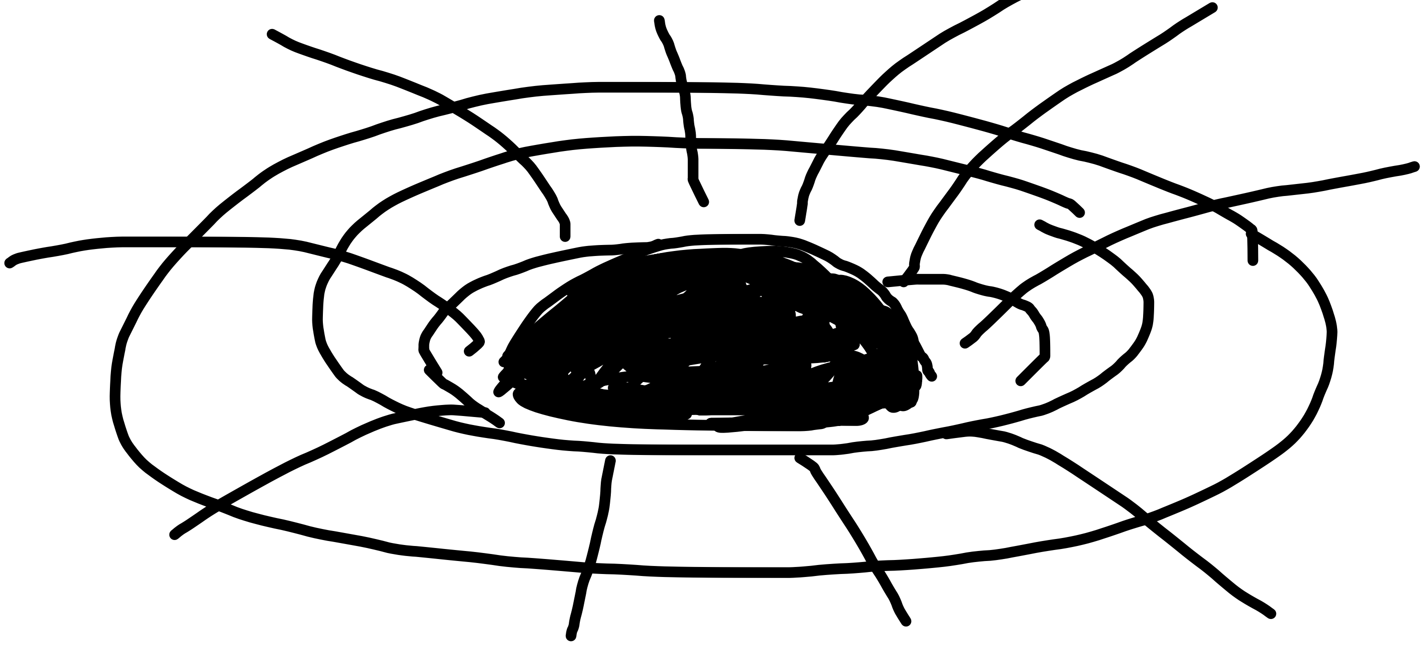
In this talk we shall provide such a theory and show how it demystifies semi-classical black hole properties.

We shall see:

Black holes <u>do carry</u> - hair under global charges (baryonic and leptonic numbers), which can be of 100% astrophysical importance.

Recall:

Schwarzschild black hole is a solution in GR



$g_{\mu\nu}(x)$

Intrinsically-classical concept!

In quantum field-theory the building blocks are particles:

$$a^{\dagger}|0\rangle = |1\rangle$$

There is nothing else.

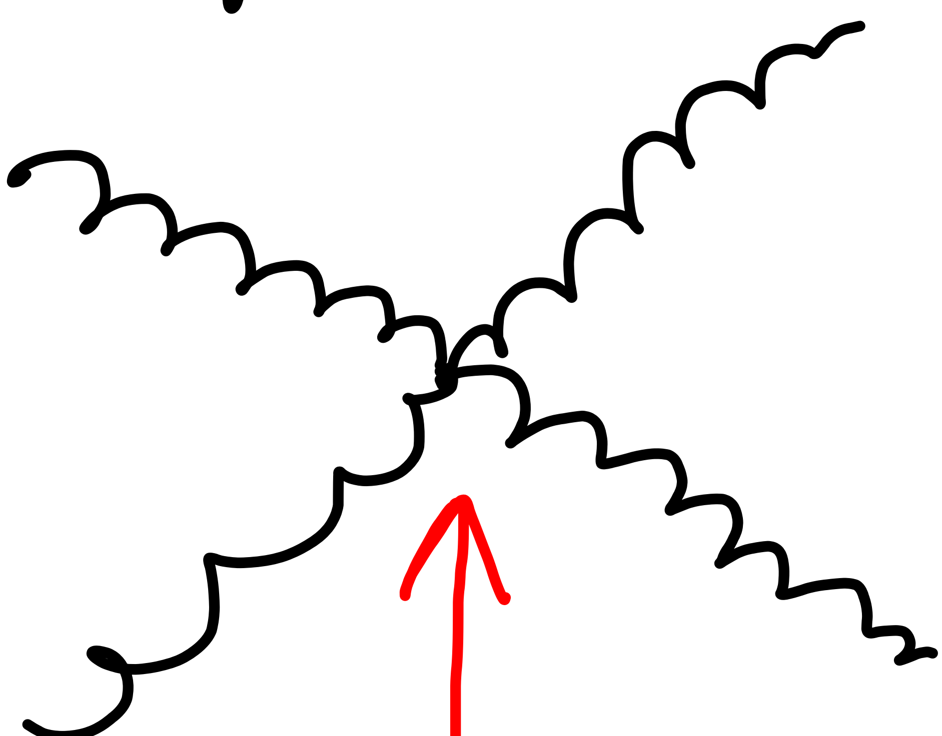
Our main concept:

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 spin $= 2$



$$\alpha_{gr} \equiv \hbar G_N \bar{\lambda}^{-2}$$

Quantum entities:
Planck length and Mass

$$L_p^2 \equiv \hbar G_N, \quad M_p \equiv \frac{\hbar}{L_p}$$

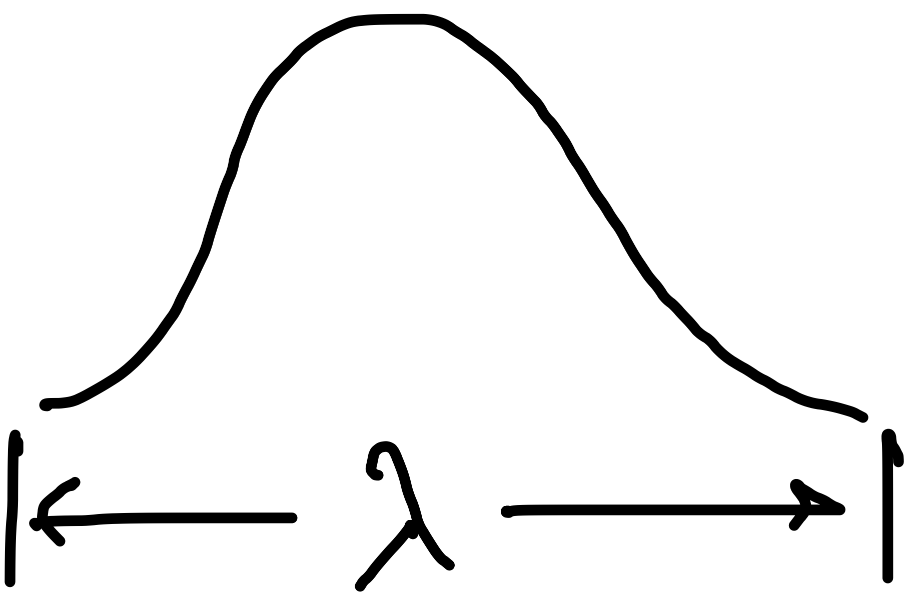
$$\alpha_{gr} = \frac{L_p^2}{\lambda^2}$$

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

$$L_p \to 0$$

$$\alpha_{gr} \longrightarrow 0$$

Now, try to form a graviton wave packet.



For $\lambda \gg L_p$

$\alpha_{gr} \ll 1$

A typical Hartree situation:

Eech graviton sees a collective potential.

Collective binding potential for $r \sim \lambda$

$$V = -N\alpha_{gr}\frac{\hbar}{\lambda}$$

and kinetic energy

$$E_k = \frac{\hbar}{\lambda}$$

The boundstate condition

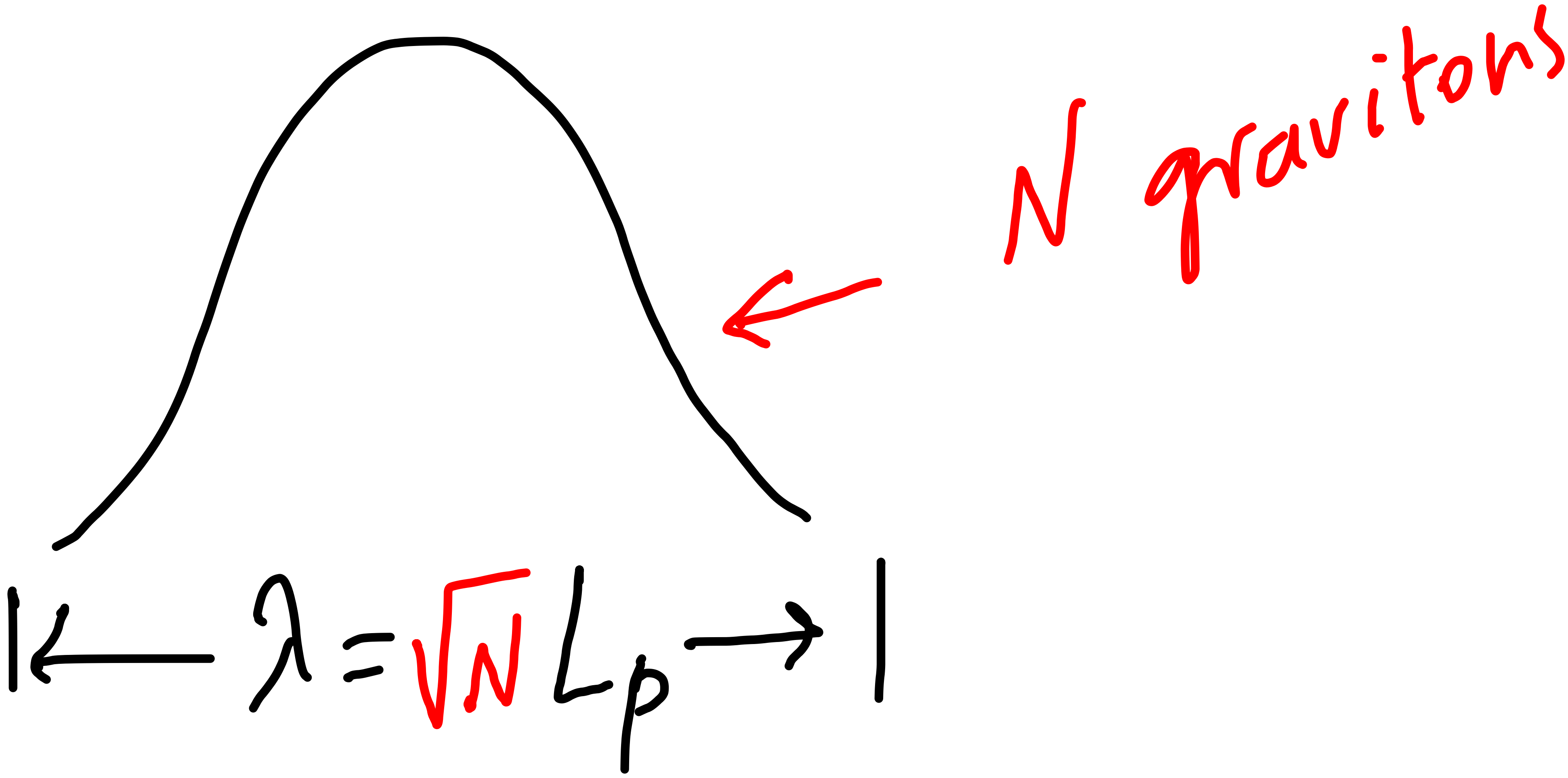
$$E_k + V = 0$$

$$\downarrow$$

$$\left(1 - N\alpha_{gr}\right)\frac{\hbar}{\lambda} = 0$$

A self-sustained boundstate is formed for

$$\alpha_{gr} = 1/N \;!$$



This self-sustained boundstate is a black hole

$$\lambda = \sqrt{N} L_p , \quad \alpha_{gr} = \frac{1}{N}$$

Black hole quantum physics is remarkably simple, with a singe parameter N:

$$M = \sqrt{N}, \quad \lambda = \sqrt{N},$$

$$\alpha_{gr} = \frac{1}{N}$$

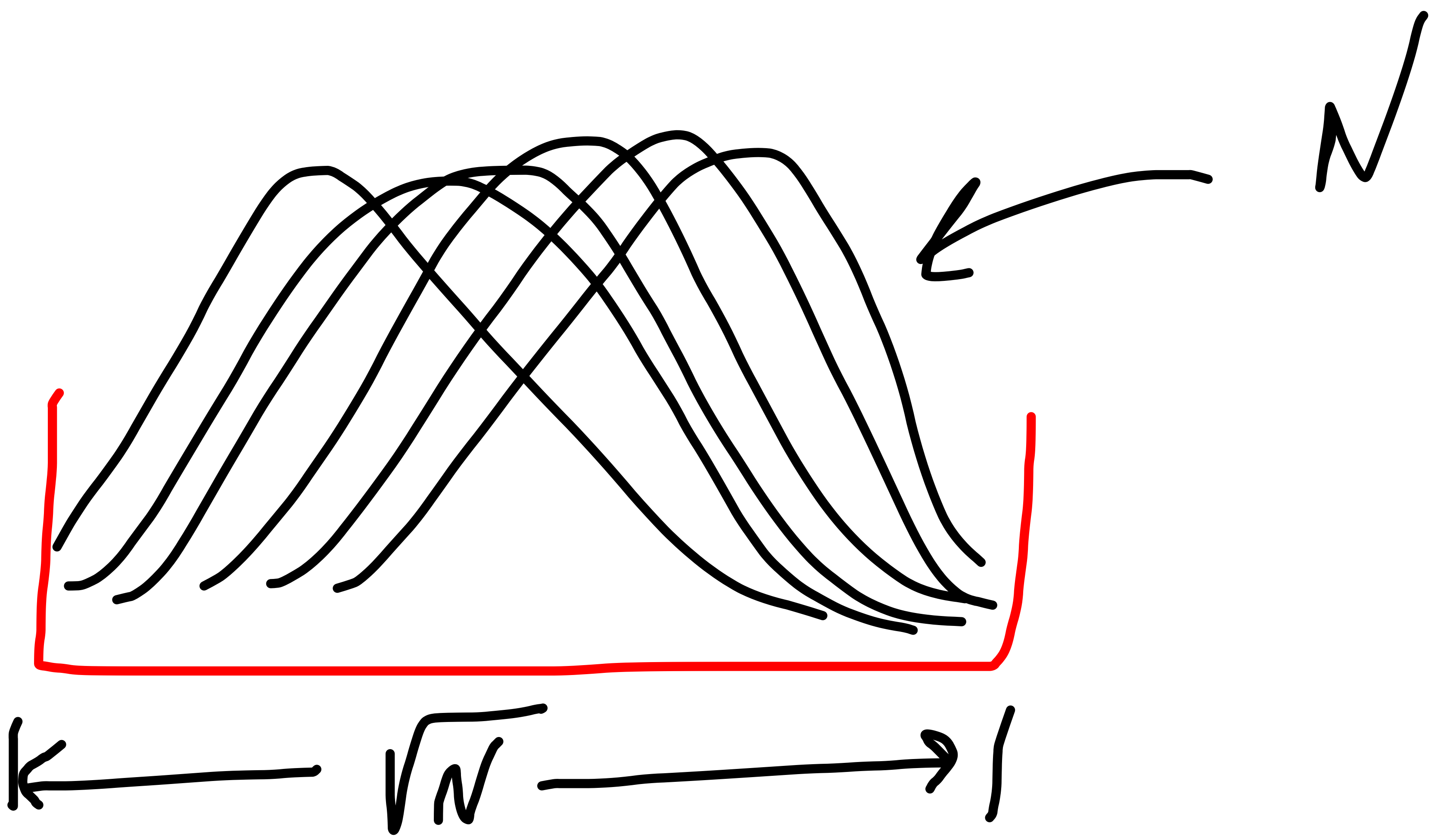
It is a large-N physics (in 't Hooft's sence) and is a result of maximal overpacking.

Black hole is a most overpacket quantum system of nature

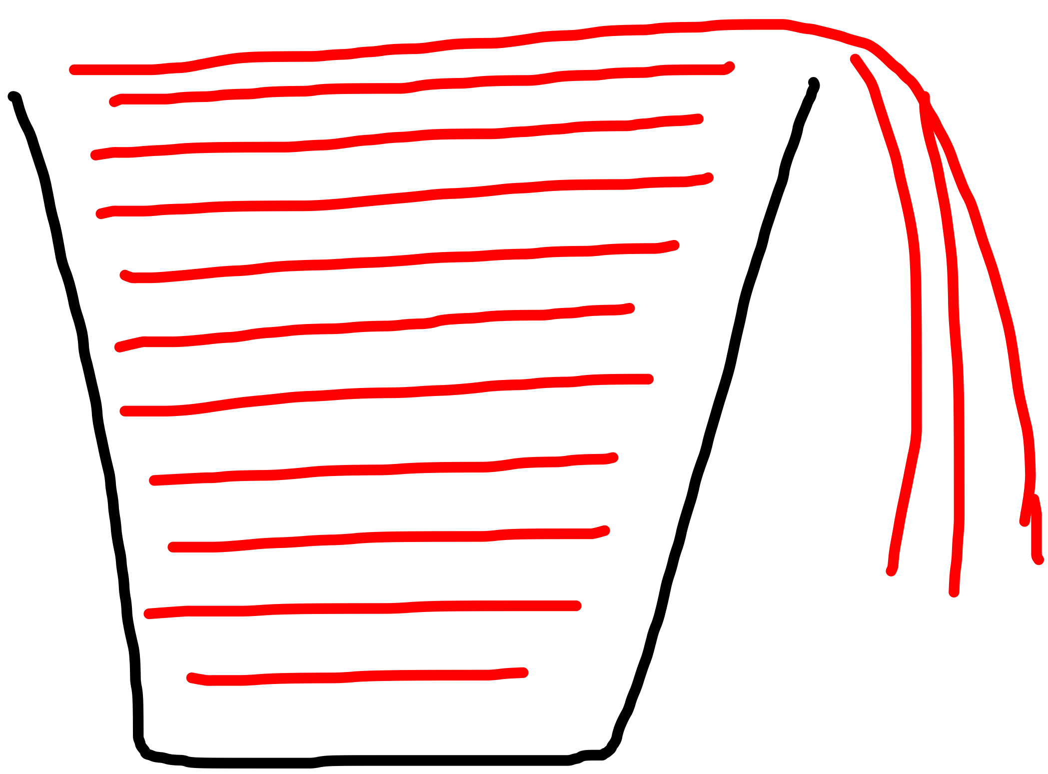
and

because of this it is

maximally simple

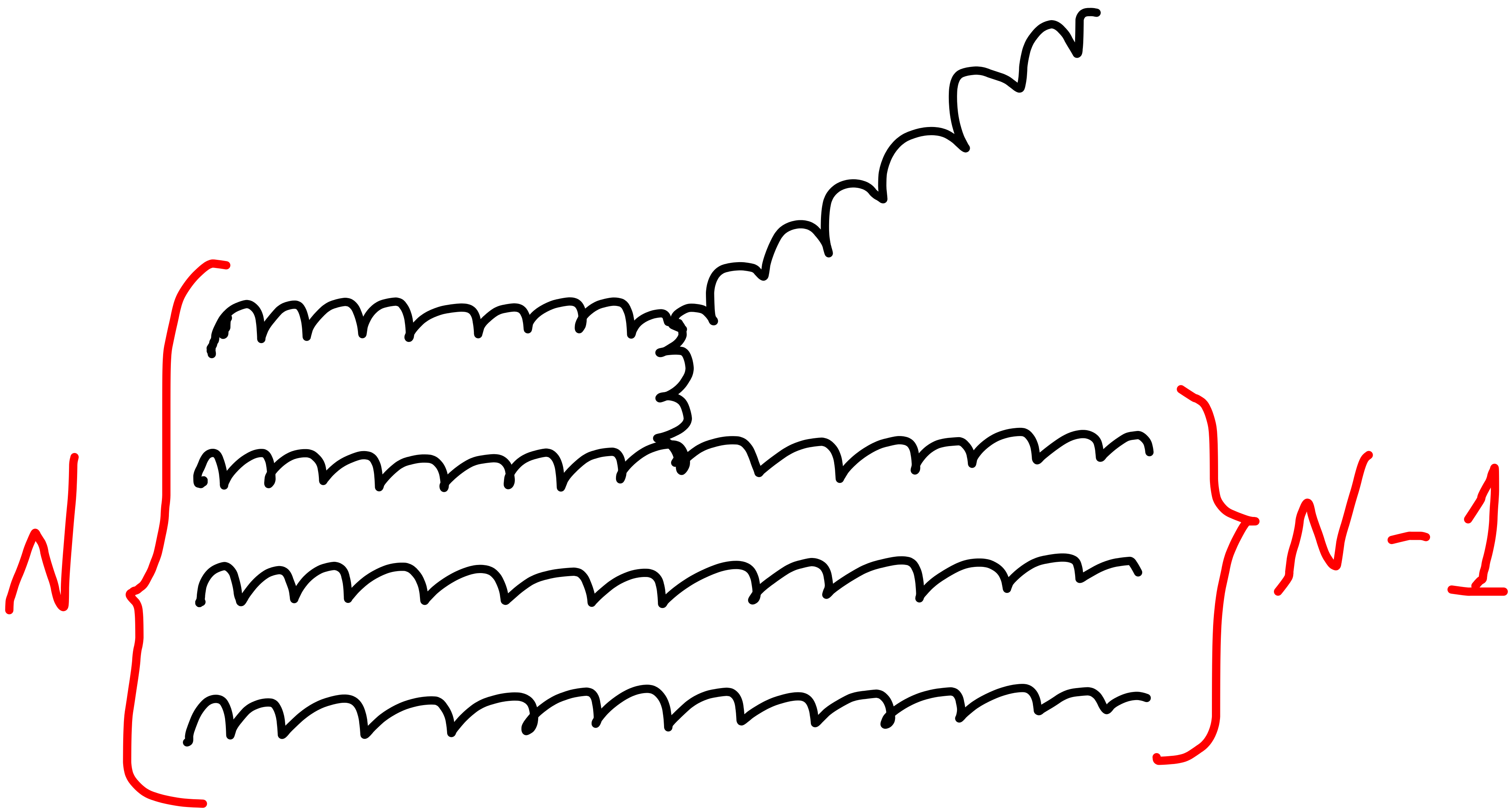


This self-sustained Bose-condensate exists for any N and for any N it is leaky



The condensate depletes self-similarly

$$N \to N-1$$



depletion law

$$\dot{N} = -\frac{1}{\sqrt{N}\, L_P} + O\left(\frac{1}{N^{3/2}}\right)$$

$$\dot{N} = -\frac{1}{\sqrt{N}\,L_p}$$

Defining $T \equiv \frac{\hbar}{\sqrt{N}\,L_p}$,

in the semi-classical limit

$N \to \infty$, $L_p \to 0$, $\sqrt{N}\,L_p = \text{fixed}$

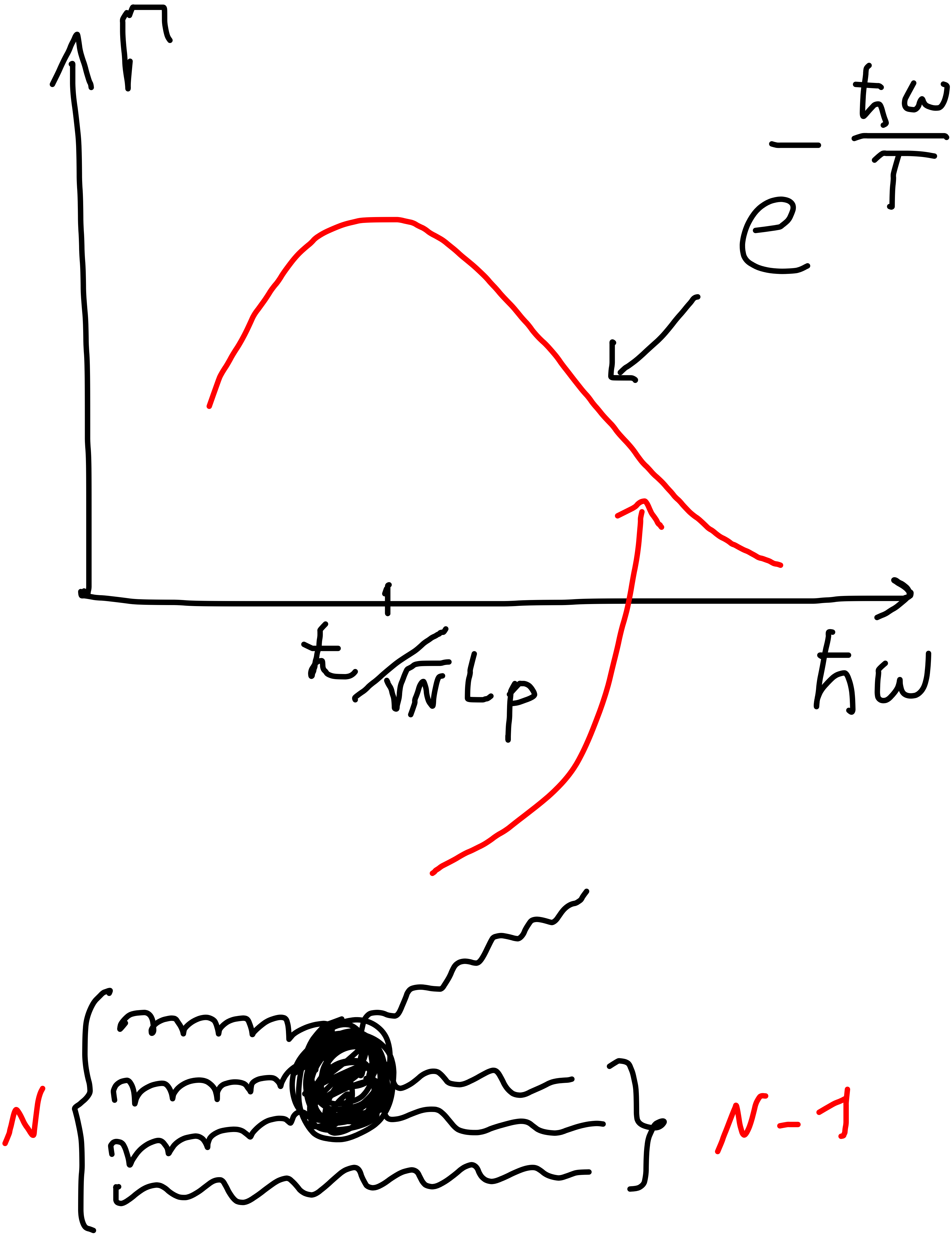
We get Stefan-Boltzmann law for Hawking evaporation

$$\dot{M} = -T^2/\hbar$$

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!



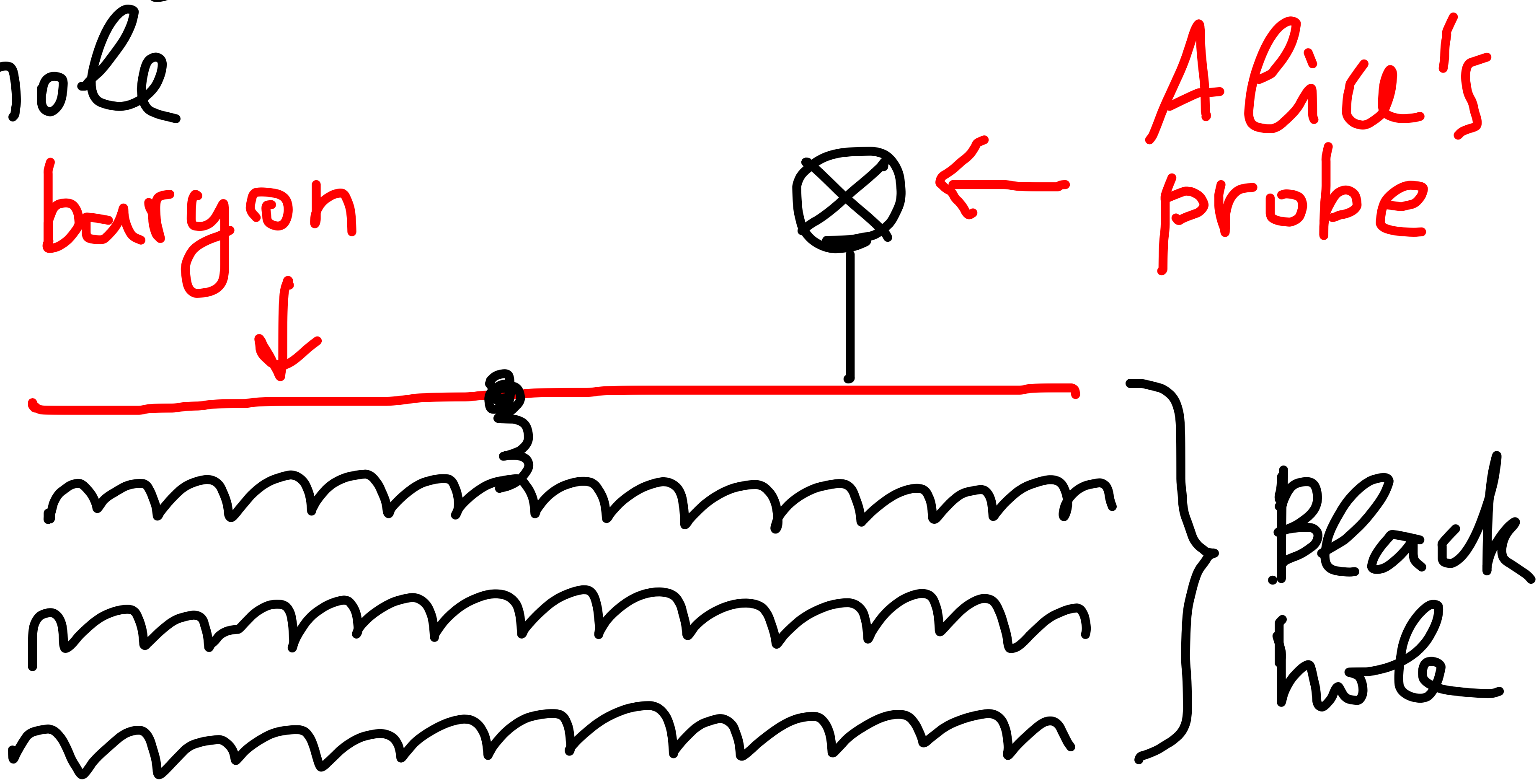
Γ
$e^{-\frac{\hbar\omega}{T}}$
$\hbar/\sqrt{N}L_p$
$\hbar\omega$
N
$N-1$

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



$$\Gamma_{hair} = \frac{1}{\sqrt{N} L_p} \left(\frac{N_B}{N} \right)$$

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.

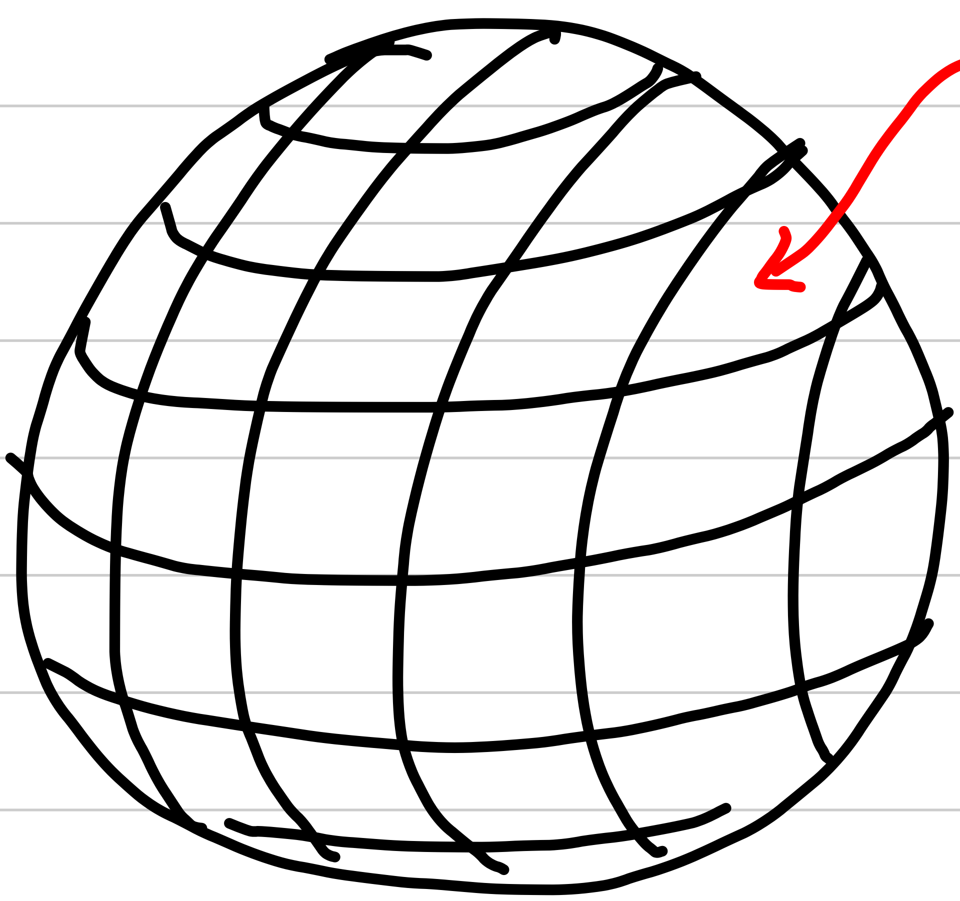
It's a graviton Condensate with

$$N \sim 10^{120}$$

We are learning that overpacked systems get oversimplified.

Origin of holography

L_p^2-pixel



$$N = \frac{r_g^2}{L_p^2}$$