Title: Estimating Quantum Gravity Corrections Near Black Holes

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Collection/Series: Quantum Gravity

Subject: Quantum Gravity

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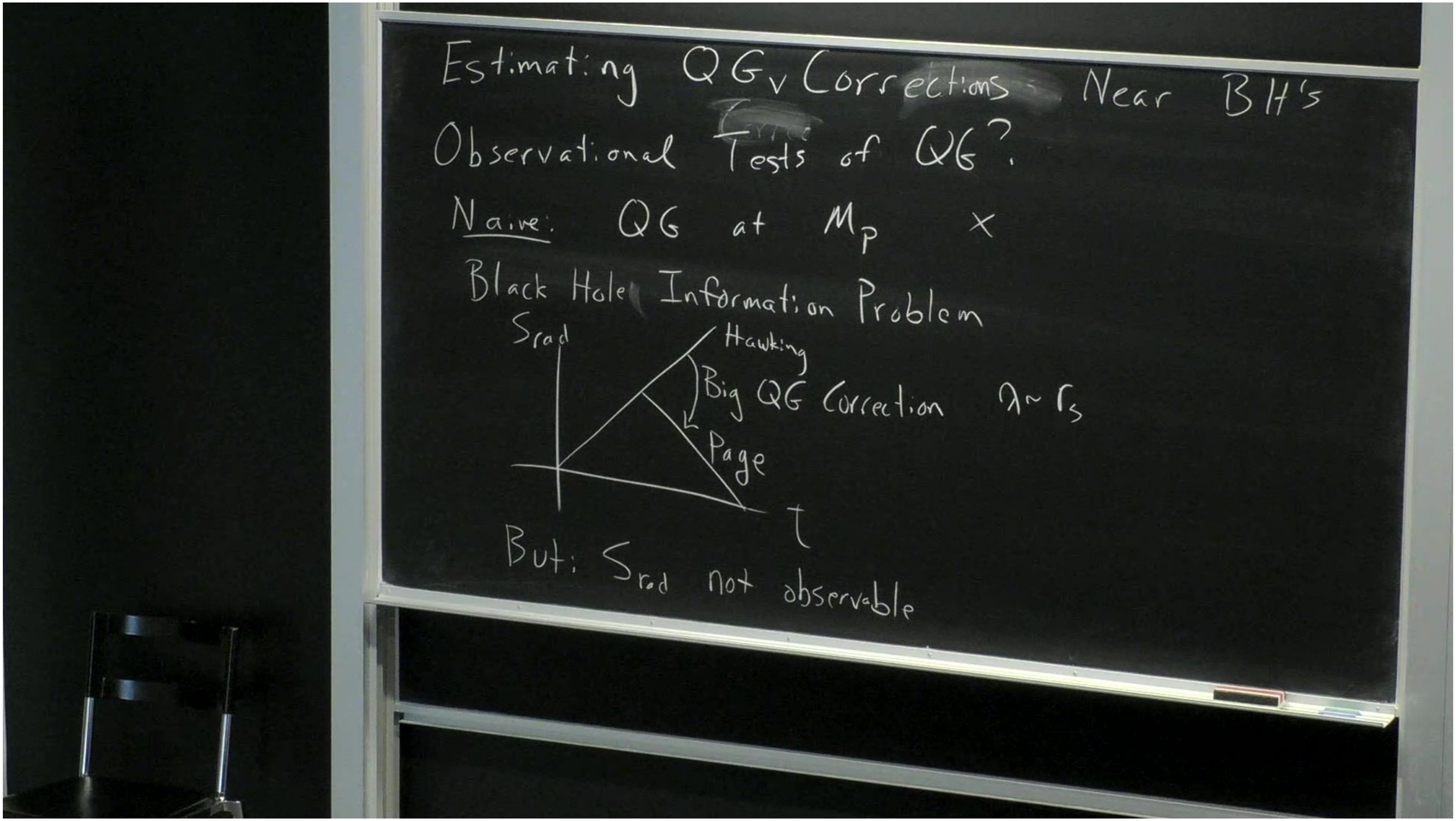
Abstract:

We analyze the size of quantum gravity effects near black hole horizons. By considering black holes in asymptotically AdS spacetime, we can make use of the "quantum deviation" to estimate the size of quantum gravity corrections to the semiclassical analysis. We find that, in a typical pure state, corrections to correlation functions are typically of order exp(-S/2). Both the magnitude and time dependence of the correlator differ from previous results related to the spectral form factor, which estimated the correlator in a thermal state. Our results severely constrain proposals, such as non-violent unitarization and some versions of fuzzballs, that predict significant corrections to the semiclassical computation of correlation functions near black holes. We point out one possible loophole: our results rely on the standard result that bulk reconstruction is state independent for small perturbations outside the black hole.


Estimating QG Corrections Near BH's
Observational Tests of QG?
Naive: QG at M_p ×
Black Hole Information Problem
S_{rad}
Hawking
Big QG Correction $\lambda \sim r_s$
Page
t
But: S_{rad} not observable

$$\Delta \langle \delta g_{\mu\nu} \, \delta g_{\rho\sigma} \rangle \sim \, ?$$

Non-Violent Unitarization (Giddings)

Simplest $\Delta \langle \delta g \, \delta g \rangle \sim \mathcal{O}(1)$

Conservative: $\Delta \langle \delta g \, \delta g \rangle \sim e^{-S_{BH}}$

Fuzzballs: Depends

Calculate this in AdS/CFT

$$\Delta \langle \delta g(x_1) \ldots \delta g(x_n) \rangle \sim e^{-S/2} \, e^{\# n}$$

Tool for calculating QG effects

Side Result

Long-Time Correlator

$\langle A(t)\, A(0) \rangle$ qualitatively different in typical

pure state vs. mixed state.

Other ways to test QG?

I. Rules of Semi-classical Gravity?

$$G_{\mu\nu} = 8\pi G_N \langle T_{\mu\nu} \rangle$$

<u>Classically</u>: Penrose $\Longrightarrow$ No exotics

↑

Null Energy Condition

Semi-Classical: $\langle T_{++} \rangle$ can be negative.

→ Traversable Wormholes (Maldacena Milekhin Popov SM+GR)

Basic QFT Question

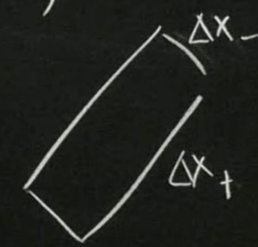
Minkowski space

ANEC ✓

(Semi-) Local Bound, state-independent

DSNEC (Fliss, BF, Kontou)

$$\langle T_{++}^{\text{smear}} \rangle \gtrsim -\frac{N}{(\Delta x_+)^3 (\Delta x_-)}$$



Energy-space time uncertainty principle

'21 [BF Nikolakopoulou Rotondo]

'24 [BF Tianyi Li]

$\langle\psi|O|\psi\rangle - \overline{\langle O\rangle}$ hard

"Quantum Deviation" Ensemble of $|\psi\rangle$ $f(\psi)$

$$\Delta_O^2 = \int d\psi\, f(\psi) \left| \langle\psi|O|\psi\rangle - \overline{\langle O\rangle} \right|^2$$

$$= \overline{\left| \langle\psi|O|\psi\rangle - \overline{\langle O\rangle} \right|^2}$$

Variance in Expectation Value.

$$\neq \langle\psi|O^2|\psi\rangle - |\langle\psi|O|\psi\rangle|^2$$

Weird Quantity, but

- Calculable
- Constrains proposals

[Raju, Shrivastava]

Certain ensembles of $|\psi\rangle$

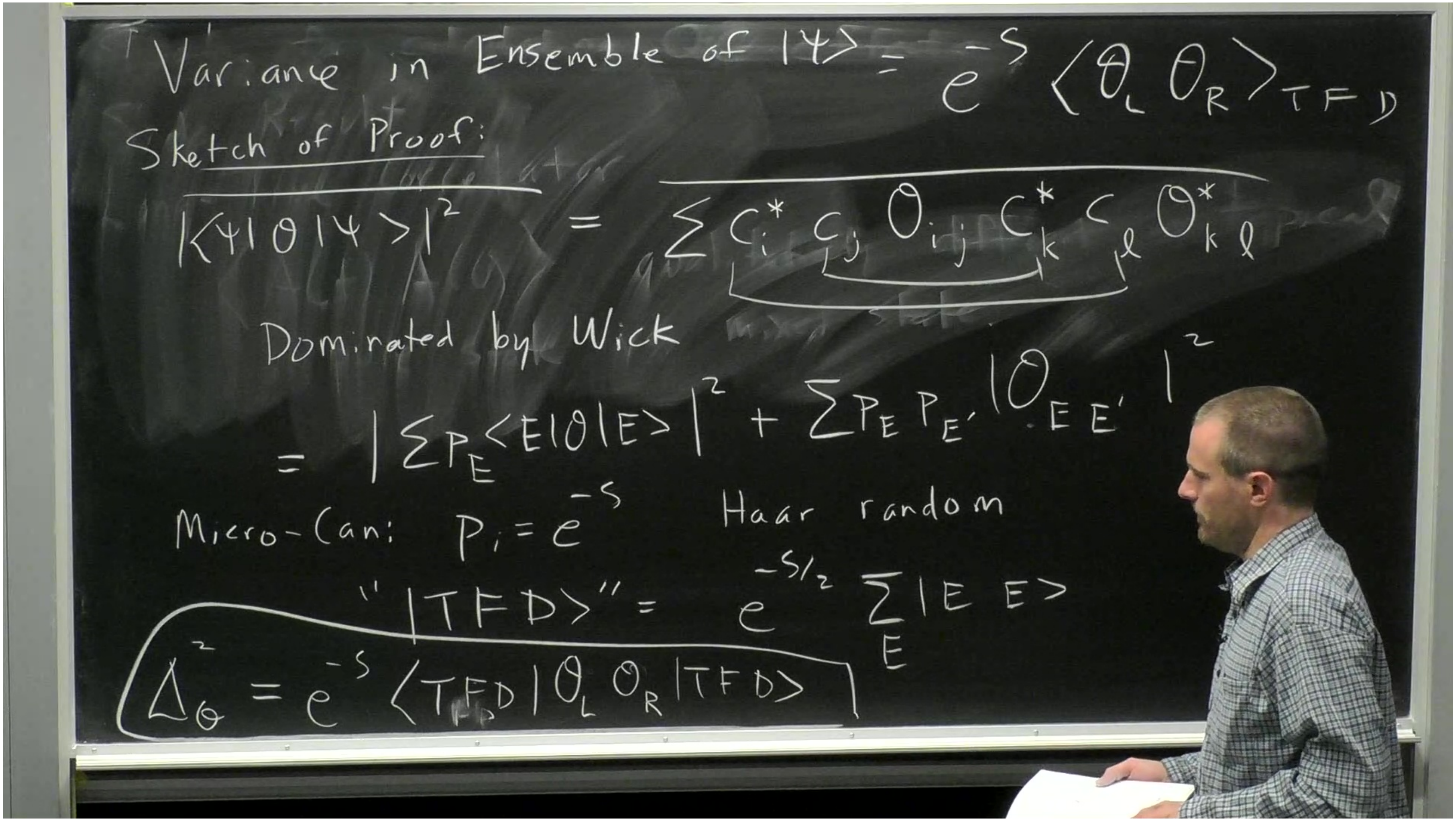
$$|\psi\rangle = \sum_E C_E |E\rangle$$

$$\overline{C_E^* C_{E'}} = \delta_{EE'}\, p(E)$$

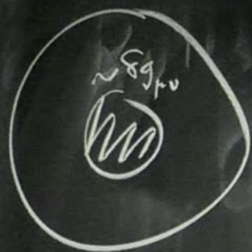
e.g. - Microcanonical
- canonical

QM Result:

$$\Delta_O^2 = e^{-S} \langle O_L O_R \rangle_{TFD} + O(e^{-2S})$$


Variance in Ensemble of $|\psi\rangle = e^{-S} \langle O_L O_R \rangle_{TFD}$
Sketch of Proof:
$\overline{|\langle\psi|O|\psi\rangle|^2} = \overline{\sum c_i^* c_j O_{ij} c_k^* c_\ell O^*_{k\ell}}$
Dominated by Wick
$= |\sum p_E \langle E|O|E\rangle|^2 + \sum p_E p_{E'} |O_{EE'}|^2$
Micro-Can: $p_i = e^{-S}$
Haar random
$\text{"}|TFD\rangle\text{"} = e^{-S/2} \sum_E |E\,E\rangle$
$\boxed{\Delta_O^2 = e^{-S} \langle TFD| O_L O_R |TFD\rangle}$

Convert to Bulk using AdS/CFT



$$\delta g_{\mu\nu} \longleftrightarrow \delta T_{\mu\nu}$$

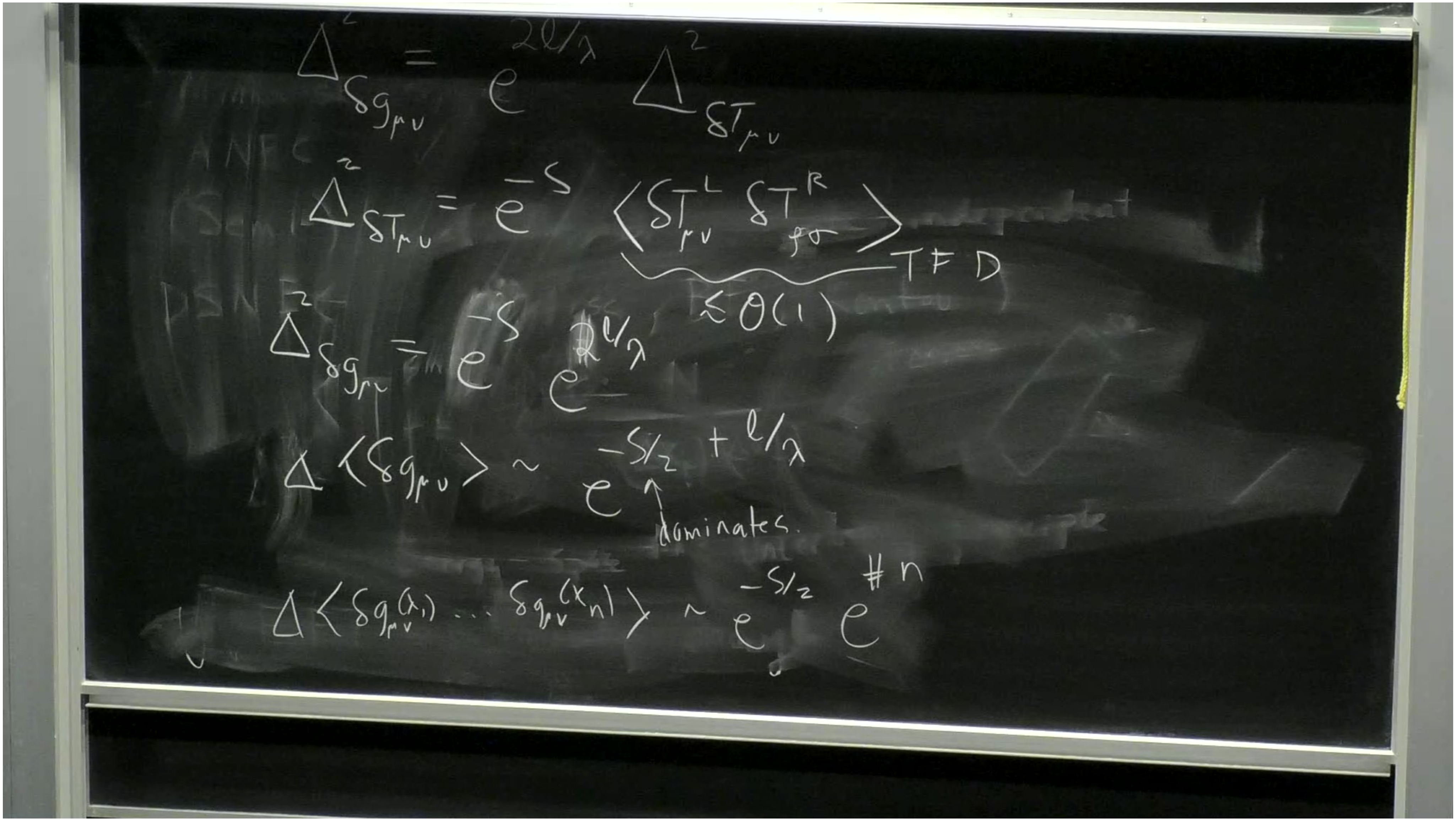
$$\hat{\delta g}_{\mu\nu}(\omega, \vec{k}, r) = f_{\omega k}(r)\, \hat{\delta T}_{\mu\nu}$$

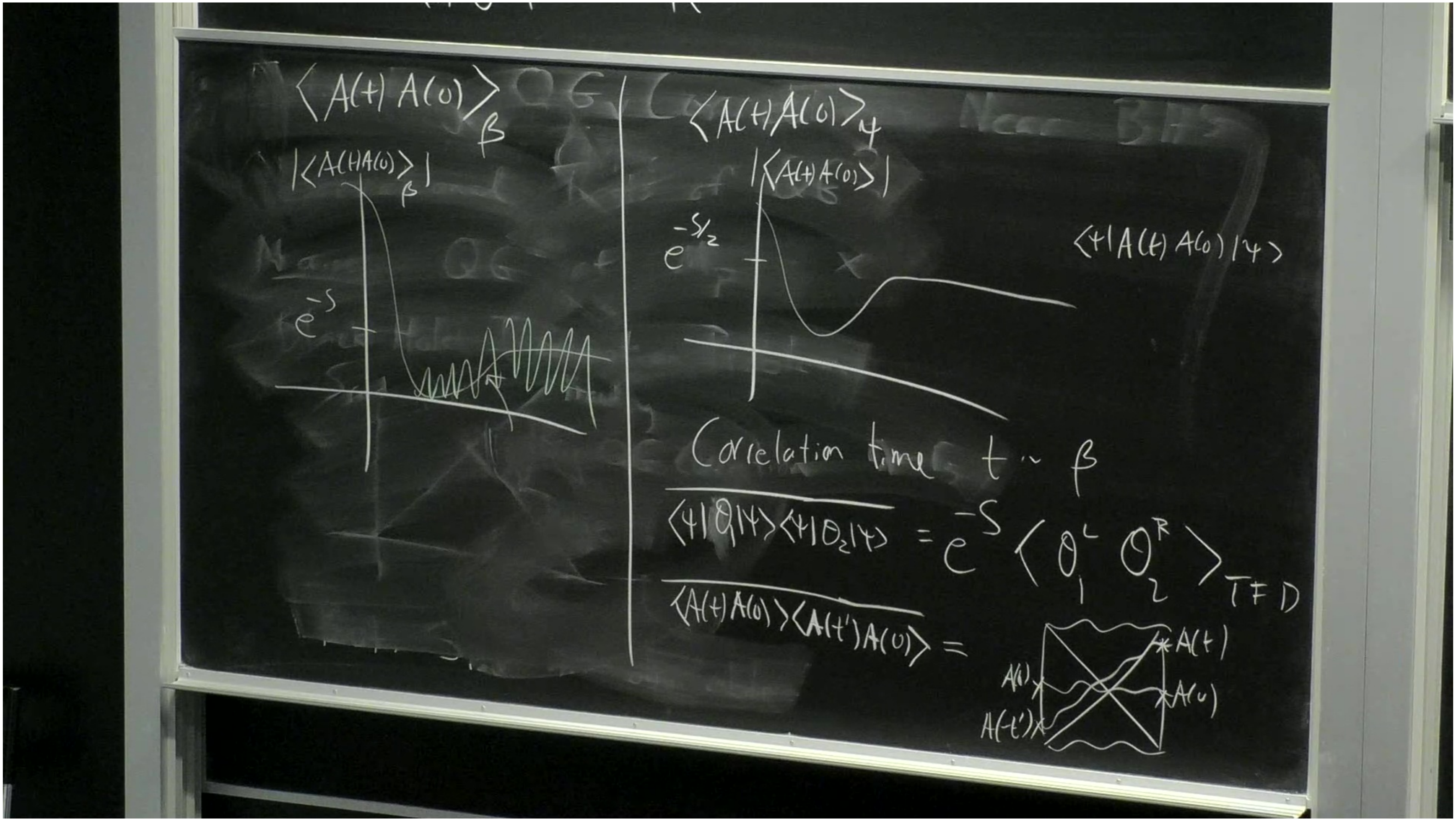
HKLL dictionary.

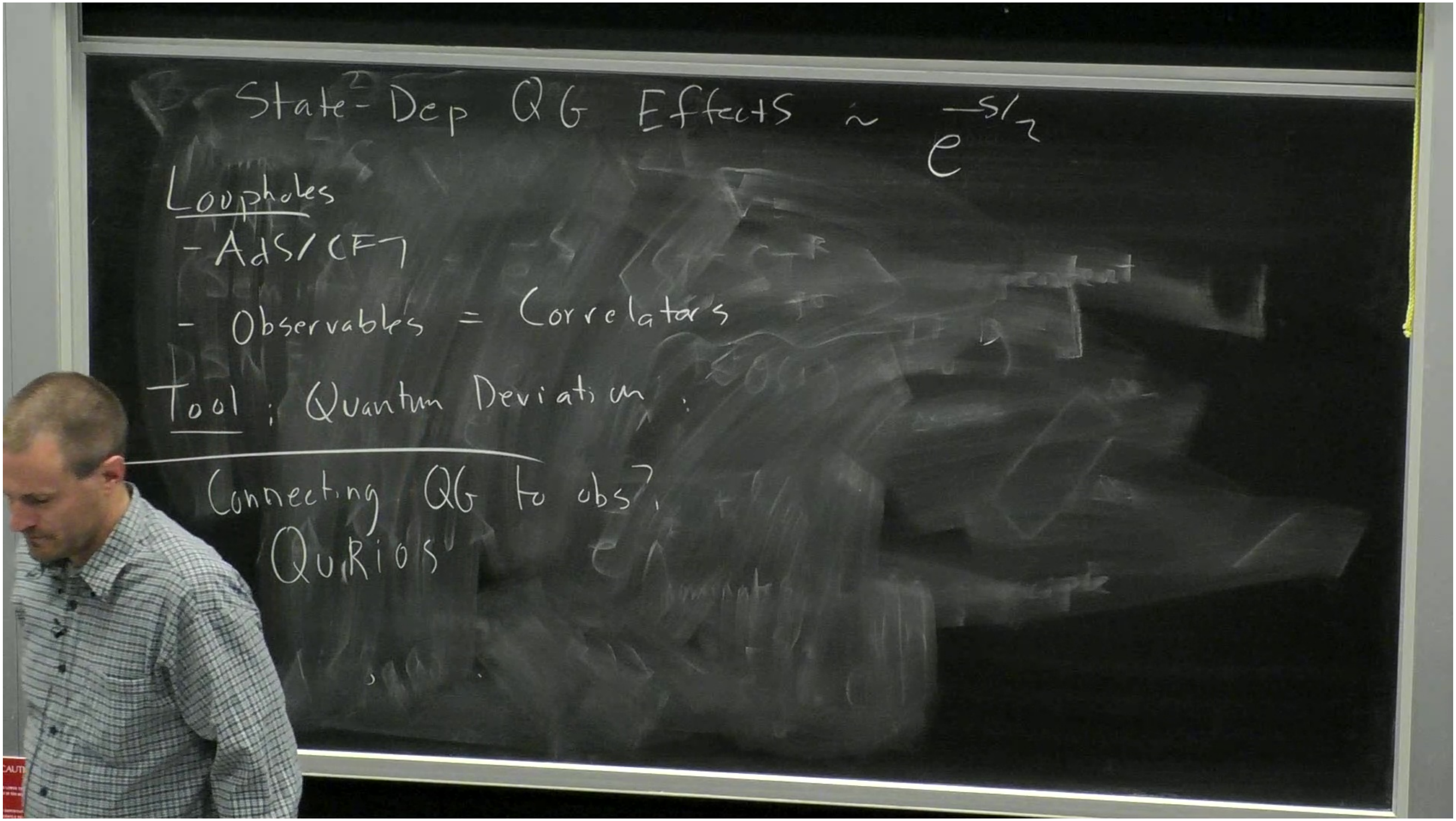
→ State-independent reconstruction outside horizon

$\omega \sim T \qquad k \gg T \qquad r - r_s \ll r_s$

$$f_{\omega k} \sim e^{k/T} \sim e^{\ell_A/\lambda_{phys}}$$


$\Delta^2_{\delta g_{\mu\nu}} = e^{2\ell/\lambda} \Delta^2_{\delta T_{\mu\nu}}$
$\Delta^2_{\delta T_{\mu\nu}} = e^{-S} \underbrace{\langle \delta T^L_{\mu\nu}\, \delta T^R_{\rho\sigma} \rangle_{TFD}}_{\lesssim O(1)}$
$\Delta^2_{\delta g_{\mu\nu}} = e^{-S} e^{2\ell/\lambda}$
$\Delta \langle \delta g_{\mu\nu} \rangle \sim e^{-S/2 + \ell/\lambda}$
dominates.
$\Delta \langle \delta g_{\mu\nu}(x_1) \ldots \delta g_{\mu\nu}(x_n) \rangle \sim e^{-S/2} e^{\# n}$


⟨A(t) A(0)⟩_β
|⟨A(t)A(0)⟩_β|
e^{-S}
⟨A(t)A(0)⟩_ψ
|⟨A(t)A(0)⟩|
e^{-S/2}
⟨ψ|A(t) A(0)|ψ⟩
Correlation time t ~ β
⟨ψ|O_1|ψ⟩⟨ψ|O_2|ψ⟩ = e^{-S} ⟨O_1^L O_2^R⟩_TFD
⟨A(t)A(0)⟩⟨A(t')A(0)⟩ =
A(t)
A(0)
A(-t')


State-Dep QG Effects ~ e^{-S/2}
Loopholes
- AdS/CFT
- Observables = Correlators
Tool: Quantum Deviation:
Connecting QG to obs?
QuRios