# Entropic Force

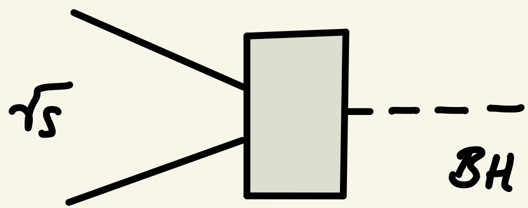
Work with Gia Dvali, Marco Michel, Sebastian Zell

# SUMMARY

Time-evolve quantum system $\hat{H}$:

Does system go to state with maximal degeneracy?

# Motivation: "Classicalization"




$\sqrt{s} \gg M_p$

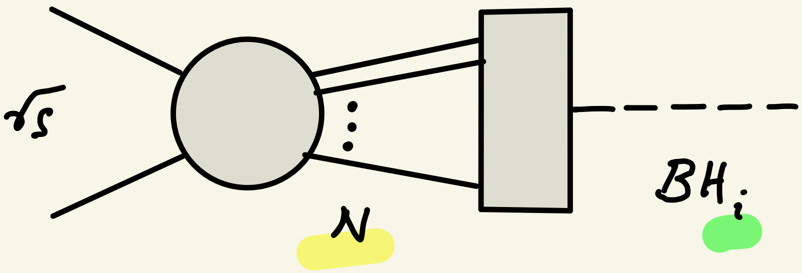
$b \ll r_g(\sqrt{s})$

Classicalization:*

- BHs are N-graviton bound states
- gravity just a special case

*) Review: 1607.07422

# Classicalization & Entropy




$$\sum_{i=1}^{e^S} \underbrace{|\langle 2|S|N\rangle|^2}_{\sim e^{-N}} \underbrace{|\langle N|BH_i\rangle|^2}_{\sim 1} \sim$$

$$\sim e^{-N+S}$$

$$N \sim S \sim 1/\alpha \sim \frac{\sqrt{s}^{\,2}}{M_p^2}$$

Entropy Enhancement

| | | |
|---|---|---|
| 2 | hard | $\sqrt{s}/2$ |
| $N$ | soft | $\sqrt{s}/N \sim r_g^{-1}(\sqrt{s})$ |
| $N$ | super-soft | $\sqrt{s}/N^2$ |

# Classicalization at $\Lambda \sim$ TeV ?

- $M_P^{eff} \ll M_P \equiv 10^{19}$ GeV possible
- Classicalizing Higgs: $\frac{1}{\Lambda^4}\left(\partial_\mu H \partial^\mu H^\dagger\right)^2$

signature: tower of resonances

# "Assisted Gaplessness"

$$\underbrace{\varepsilon\left(1-\alpha\hat{n}_0\right)}\sum_{k=1}^{Q}\hat{n}_k$$

$N_0 \equiv \langle \hat{n}_0 \rangle$

$\hat{n}_i \equiv \hat{a}_i^\dagger \hat{a}_i$

$[\hat{a}_i, \hat{a}_j^\dagger] = \hat{1}\,\delta_{ij}$

Bogolyubov-approximation:

$$\mathcal{E}_{\text{eff}} = \varepsilon\left(1-\alpha N_0\right) + \mathcal{O}\left(1/N_0\right)$$

$$\boxed{N_0^{cr} \sim 1/\alpha \quad \Rightarrow \quad S = \log 2^Q}$$

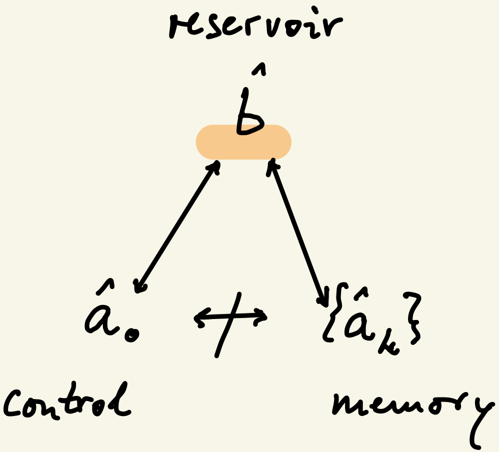
1804.06154

# The Model

$$\hat{n}_b \equiv \hat{b}^\dagger \hat{b}$$
$$\hat{n}_k \equiv \hat{a}_k^\dagger \hat{a}_k$$

$$\hat{H}_{diag} = \varepsilon \hat{n}_b + \varepsilon \hat{n}_0 + \varepsilon \left(2 - \alpha \hat{n}_0\right) \sum_{k=1}^{Q} \hat{n}_k$$

$$N_0^{cr} \sim 1/\alpha$$




$$\hat{H}_{off} = g_0 \hat{b} \hat{a}_0^\dagger + \sum_{k=1}^{Q} g_k \hat{b} \hat{a}_k^\dagger + h.c.$$

$g_0, g_k$ : sufficiently
- small
- different

# Time-Evolution

$$|t_0\rangle = |\underset{\hat{b}}{N};\ \underset{\hat{a}_0}{0};\ \underbrace{0,0,\dots,0}_{\hat{a}_k}\rangle$$

Free parameters:
$Q, \alpha, N$

$$N_0(t) \equiv \langle \hat{a}_0^\dagger \hat{a}_0 \rangle (t)$$

$$N = 15,\ \ 1/\alpha = 6;\ \ Q = 0, 1, 2, \dots$$

# Time-Evolution of Occupations

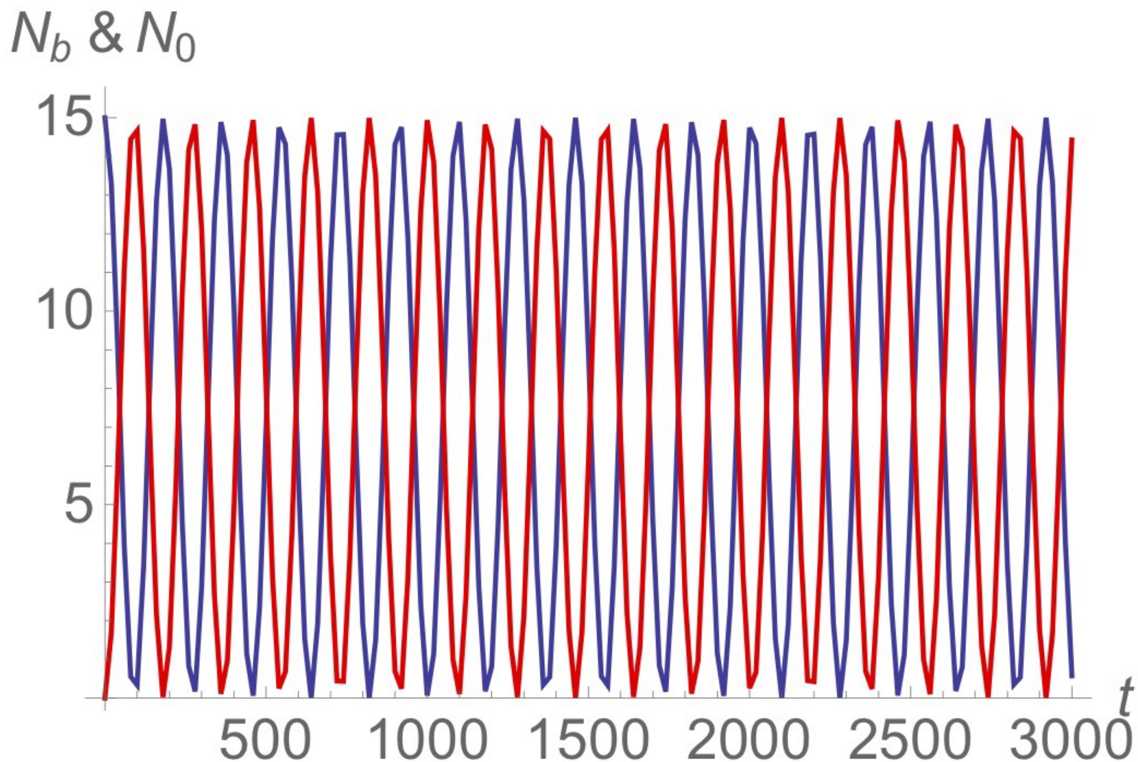



Figure: Q=0 (Red: $N_0$)

# Time-Evolution of Occupations

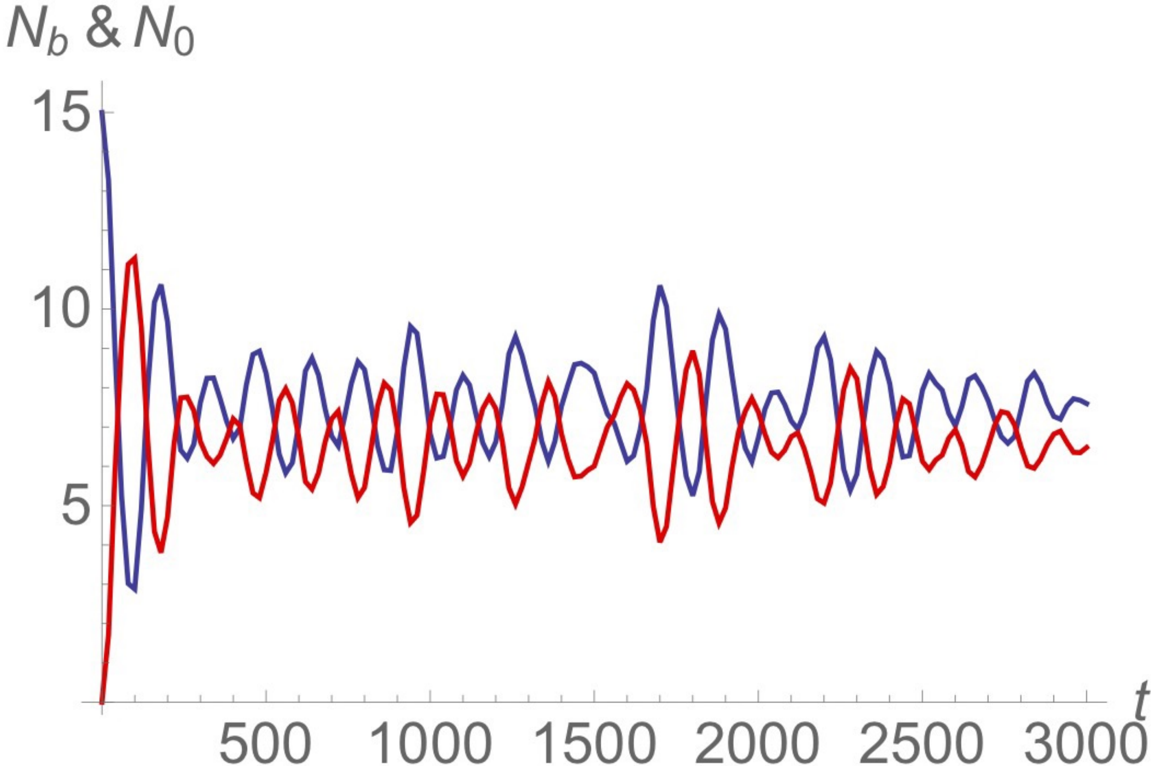



Figure: Q=4 (Red: $N_0$)

# Time-Evolution of Occupations

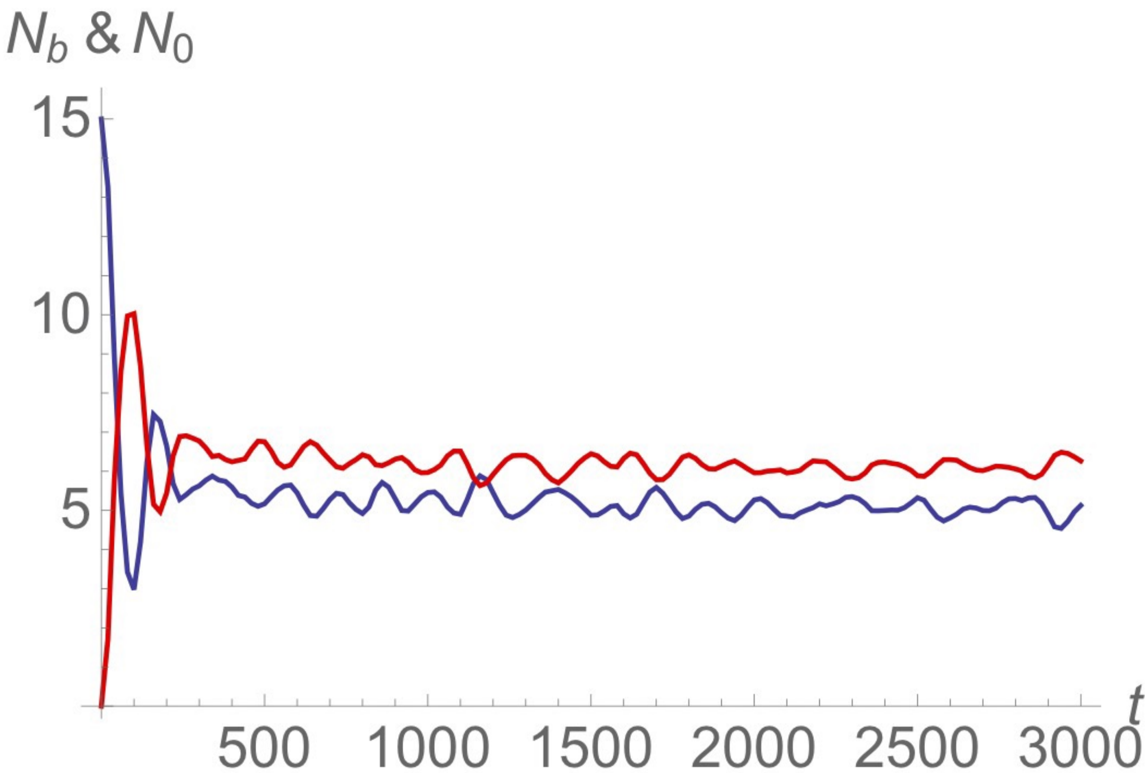



Figure: Q=9 (Red: $N_0$)

# Time-Evolution of Occupations

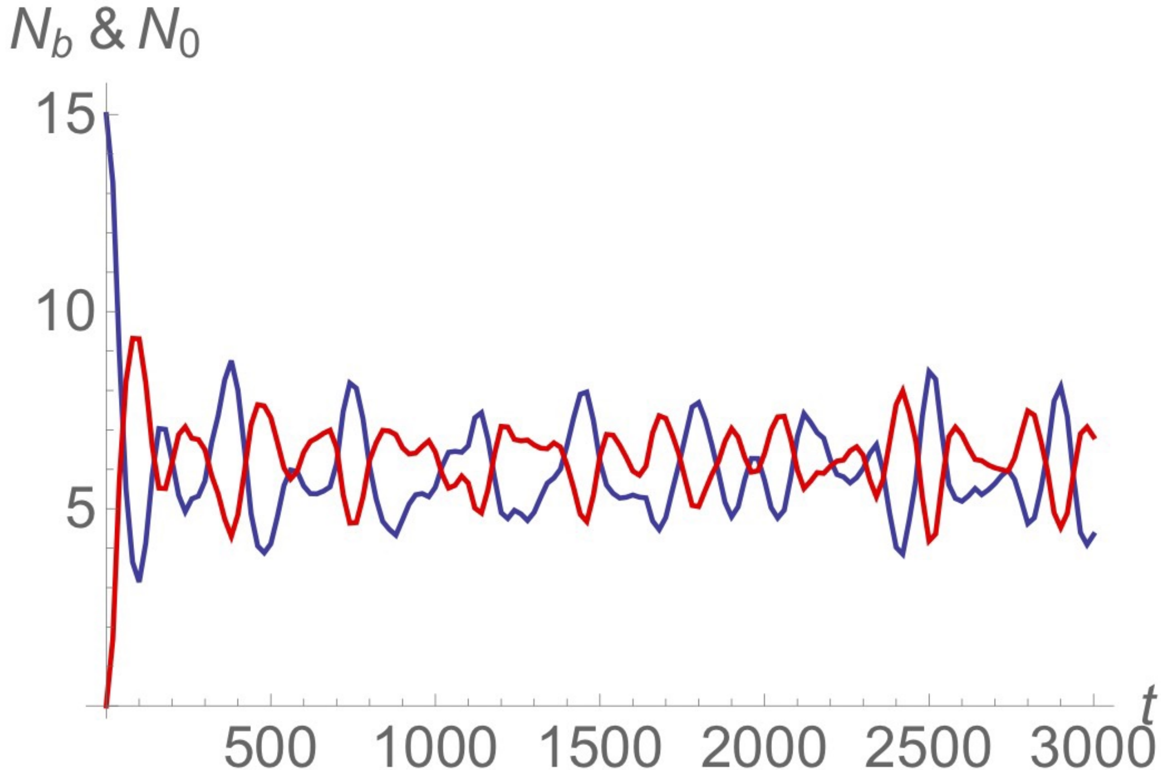



Figure: Q=14 (Red: $N_0$)

# Time-averaged characteristics

$$N_0(t) \equiv \langle \hat{a}_0^\dagger \hat{a}_0 \rangle(t)$$

$\overline{N}_0$ , $\delta N_0^2$ as function of $Q$

$$\overline{N}_0 \equiv \frac{1}{\Delta t} \int_{\Delta t} dt \, N_0(t)$$

$$\delta N_0^2 \equiv \frac{1}{\Delta t} \int_{\Delta t} dt \left( N_0(t) - \overline{N}_0 \right)^2$$

# Q-Scan: Temporal Means and Variances

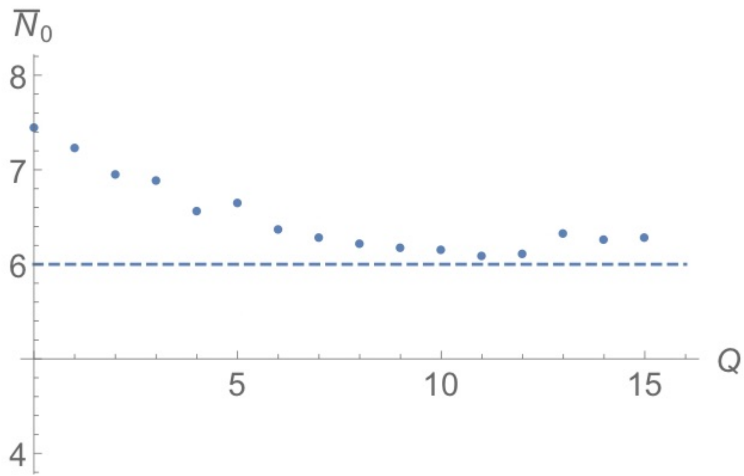



Figure: Means

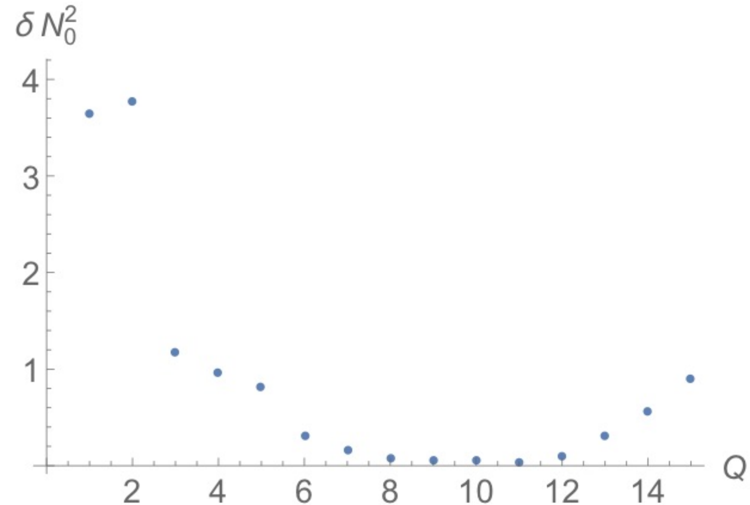



Figure: Variances

# Q-Scan: Temporal Means and Variances

$$N = N_b + N_0 + \underbrace{\sum_{k=1}^{Q} N_k}_{\le N - N_0} \quad \Rightarrow \quad Q_* = N - 1/\alpha = 15 - 6 = 9$$

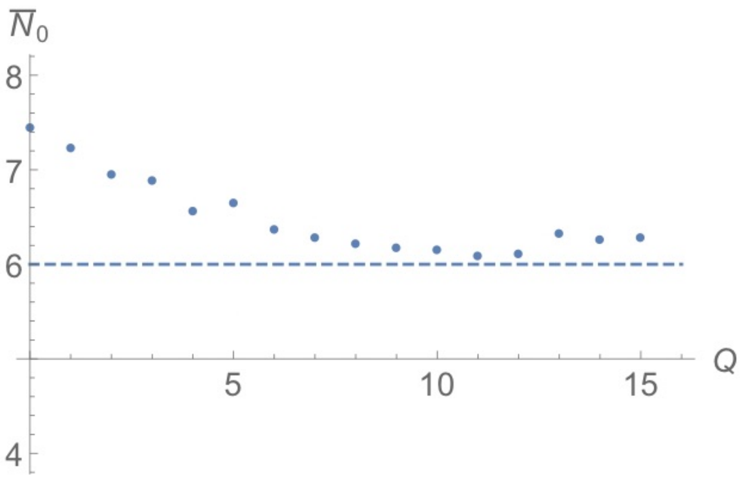



Figure: Means

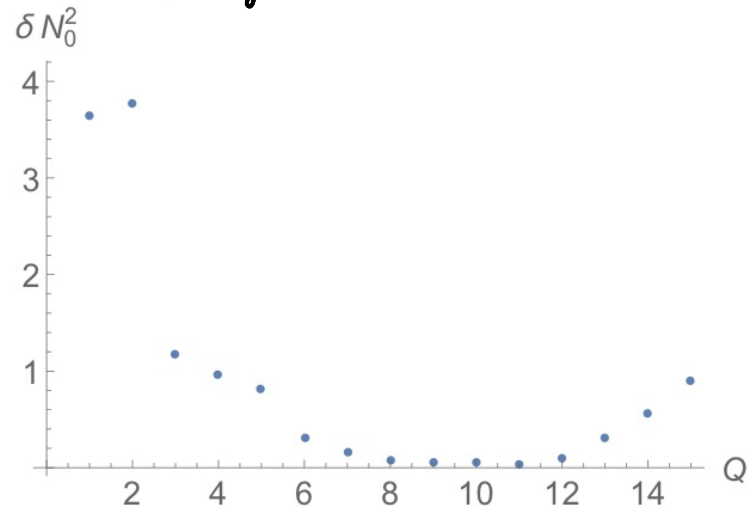



Figure: Variances

# SUMMARY

Time-evolve quantum system $\hat{H}$:

Does system go to state with maximal degeneracy?

# Q-Scan: Temporal Means and Variances

Fitting

$$\delta N_0 = \frac{k_1}{S^{p_1}} + k_2 N_{tot}^{p_2}$$

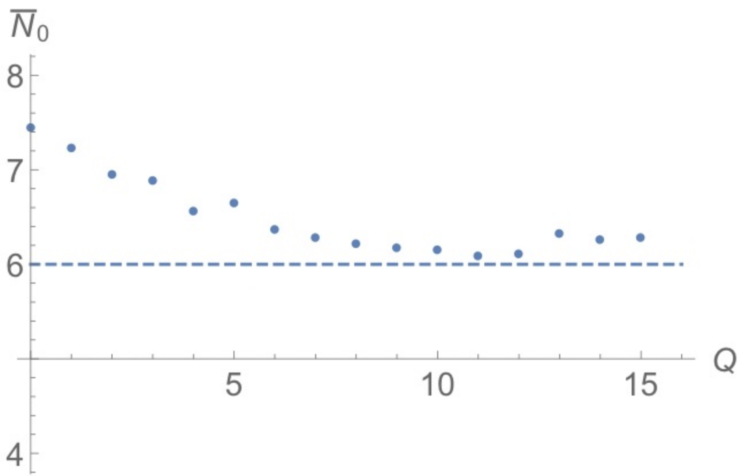



Figure: Means

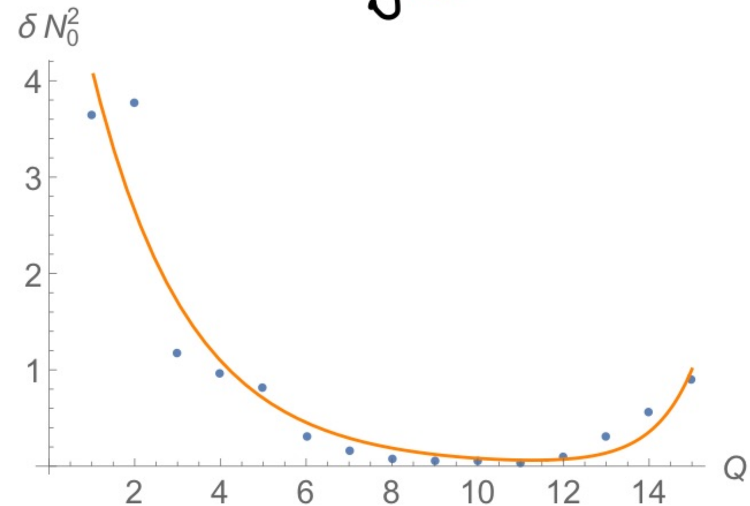



Figure: Variances

# $\alpha$-Scan: $N = 30$, $Q = 10$, $C = 1$

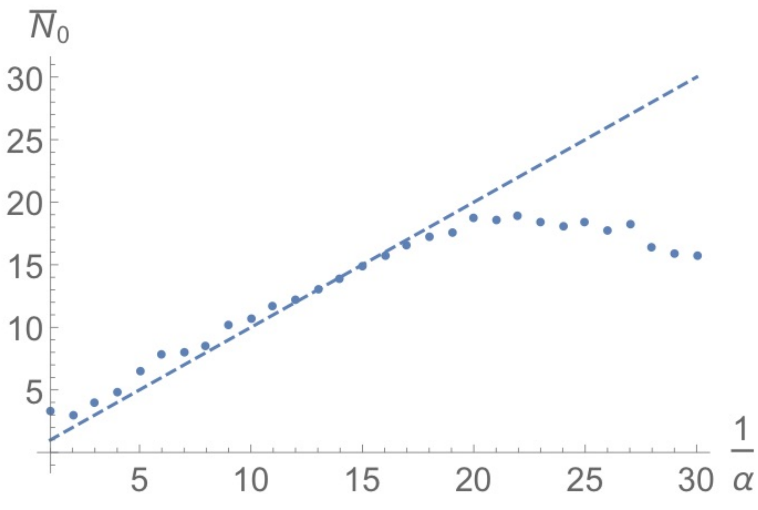



Figure: Means

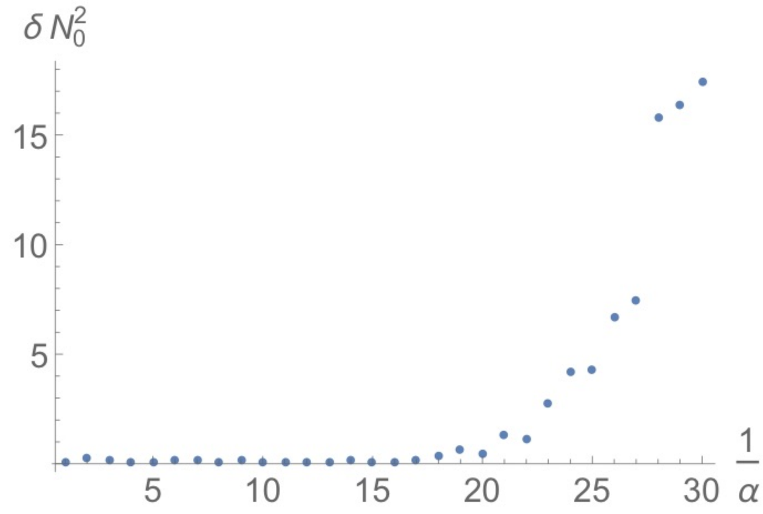



Figure: Variances

# N- and Q-Scan: $Q = N - 1/\alpha$

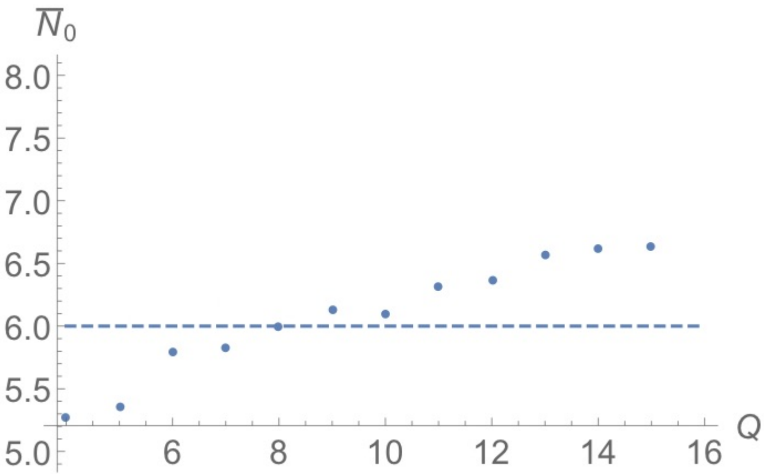



Figure: Means

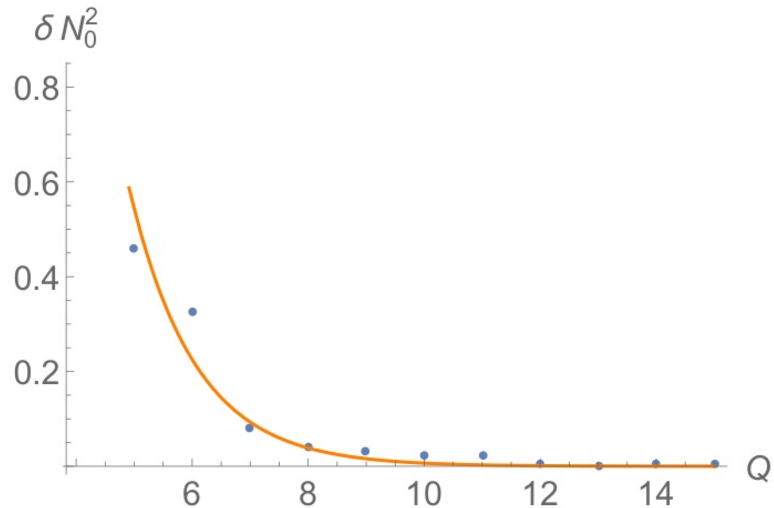



Figure: Variances