Dissipative phase transition and thermal radiation in a BEC

Dries Sels & Eugene Demler
Harvard University
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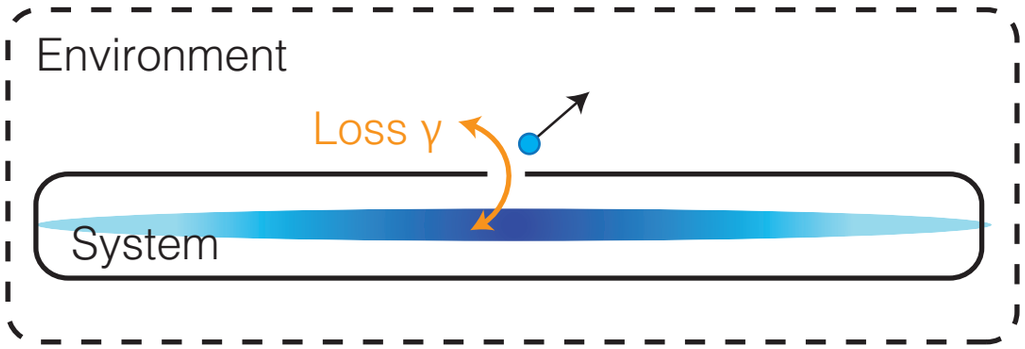
The setup



- Effective 1D system of (weakly) interacting bosons

$$H = \int \mathrm{d}x \left[\frac{\hbar^2}{2m} \partial_x \psi^\dagger(x) \partial_x \psi(x) + \frac{g}{2} \psi^\dagger(x) \psi^\dagger(x) \psi(x) \psi(x) \right]$$

- Loss of atoms in one point along the tube

$$\dot{\rho} = -\frac{i}{\hbar} [H, \rho] + \mathcal{D}(\rho) \qquad \text{with} \qquad \mathcal{D}(\rho) = \int \mathrm{d}x \gamma(x) \left(2\psi(x) \rho \psi^\dagger(x) - \left\{ \psi^\dagger(x) \psi(x), \rho \right\} \right)$$

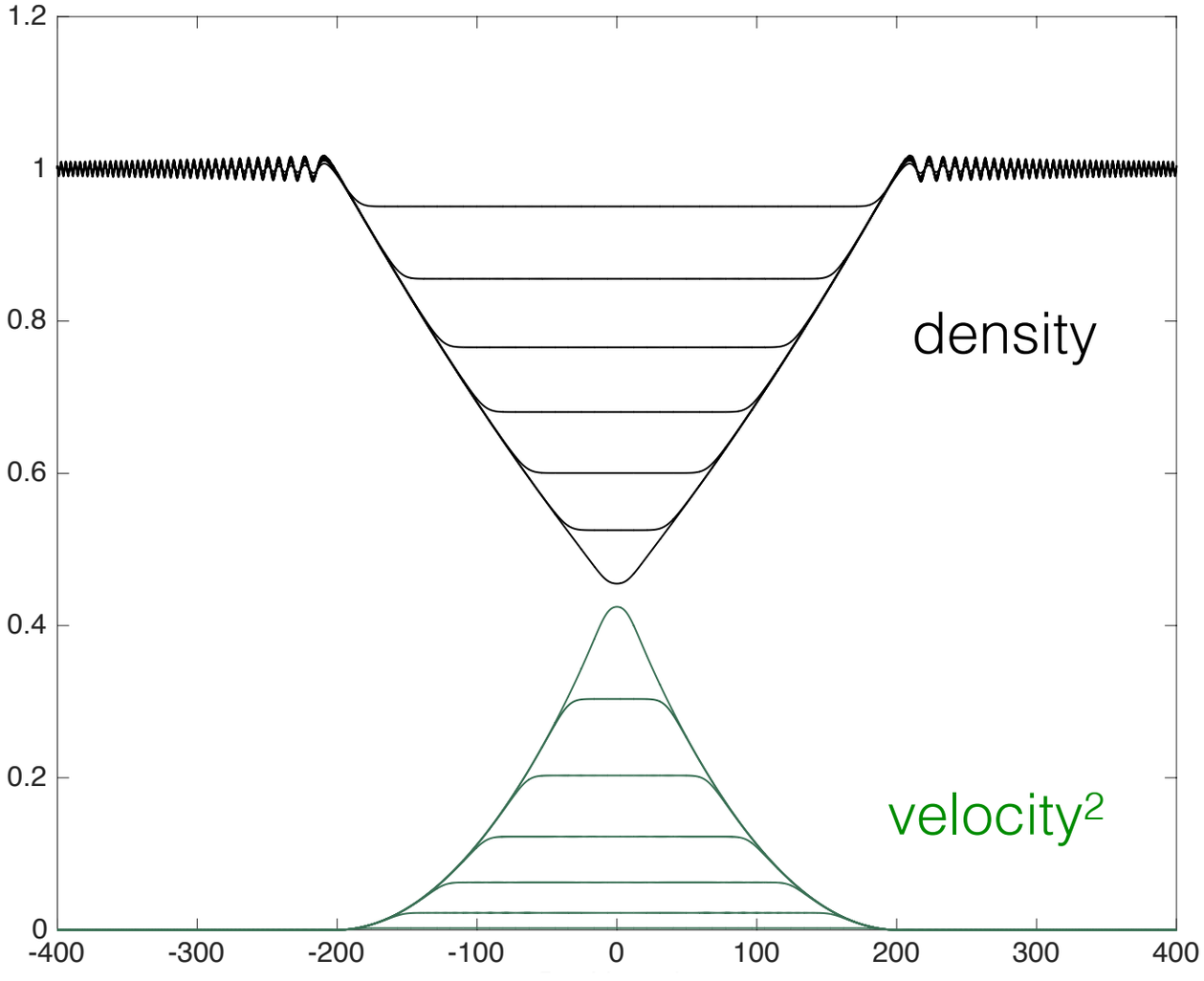
- Use Wigner-Weyl representation + truncate

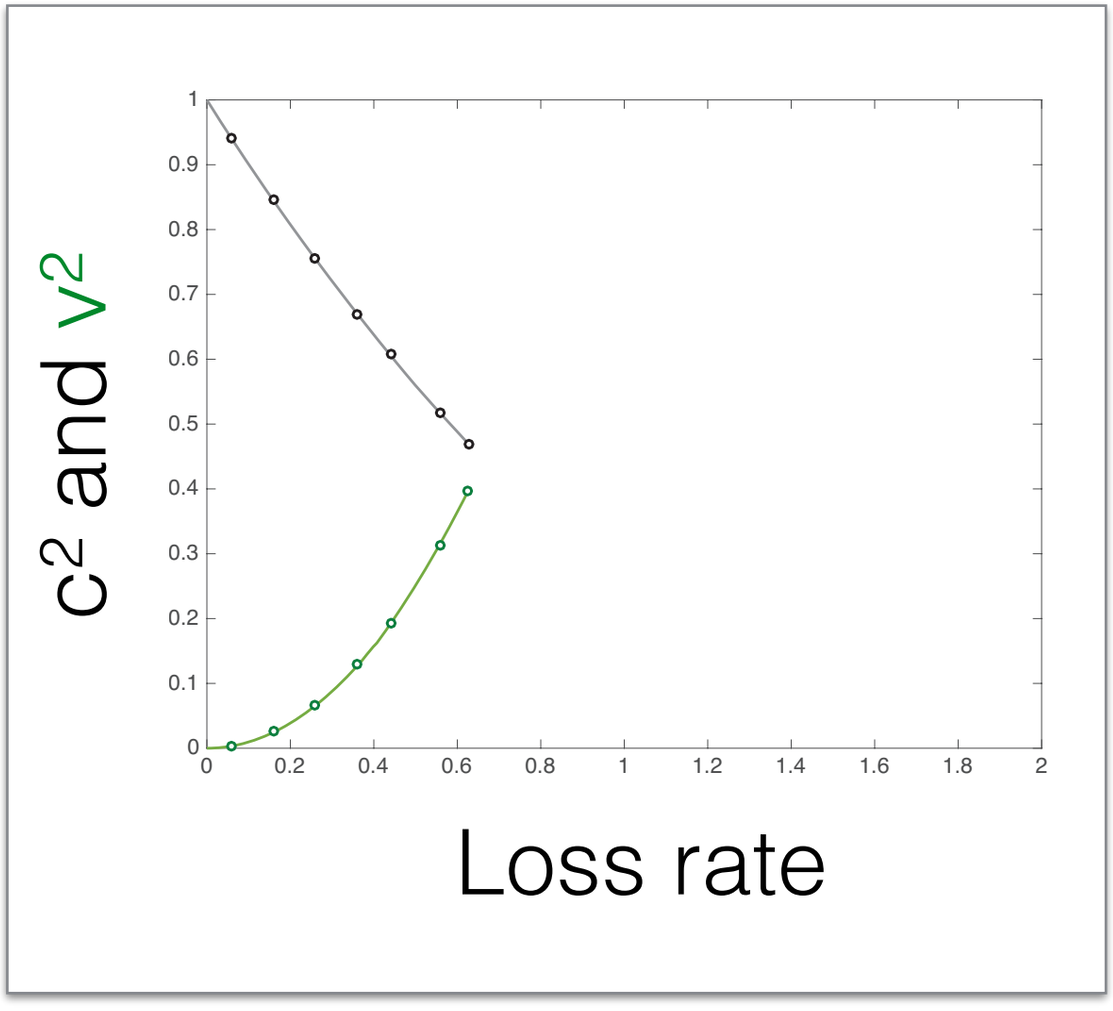
$$i\hbar \partial_t \psi = \left(-\frac{\hbar^2}{2m} \partial_x^2 \psi + g|\psi|^2 - i\hbar\gamma\delta(x) \right) \psi + \eta(t)\delta(x)$$

loss

quantum noise

Condensate dynamics

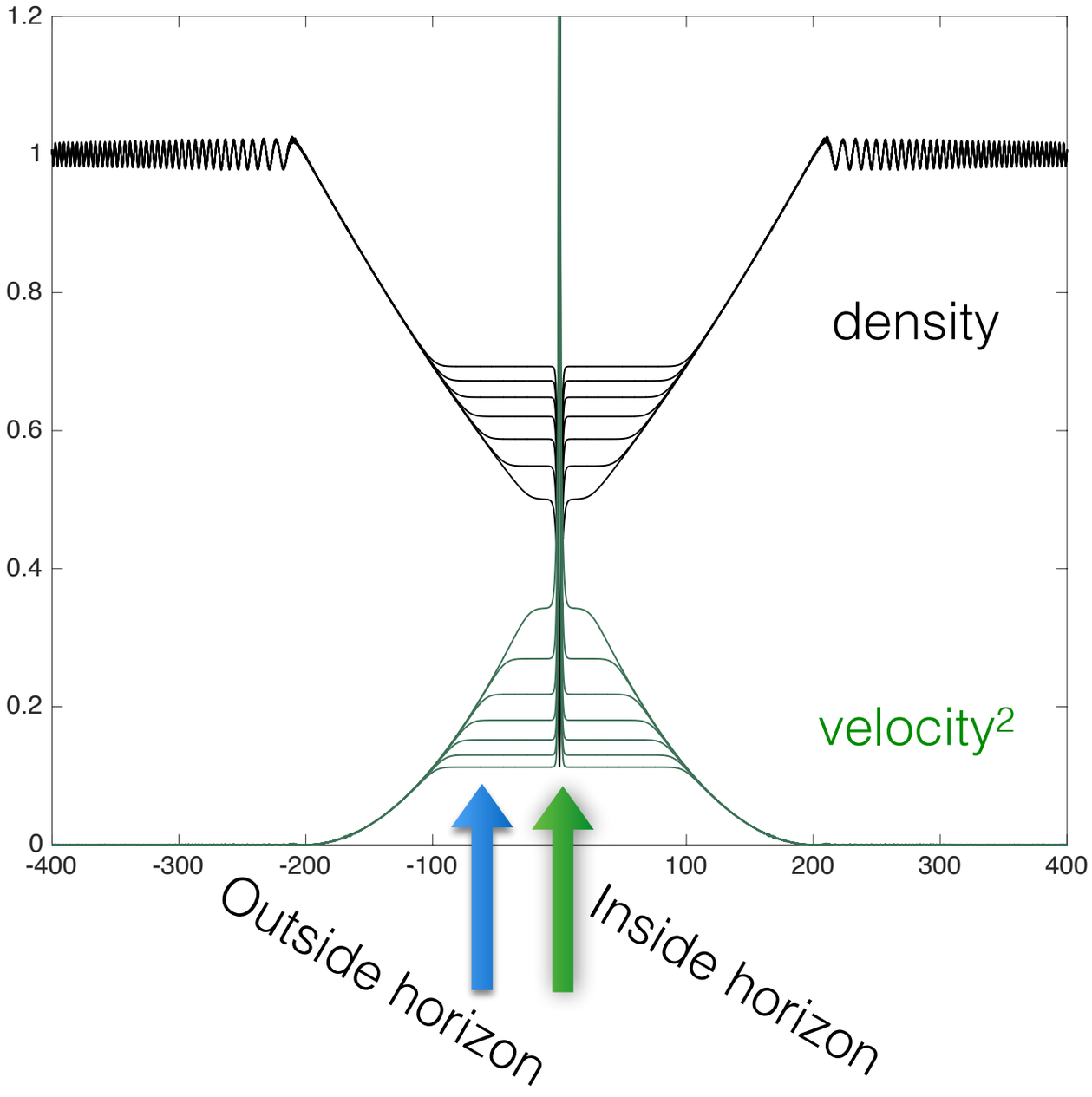


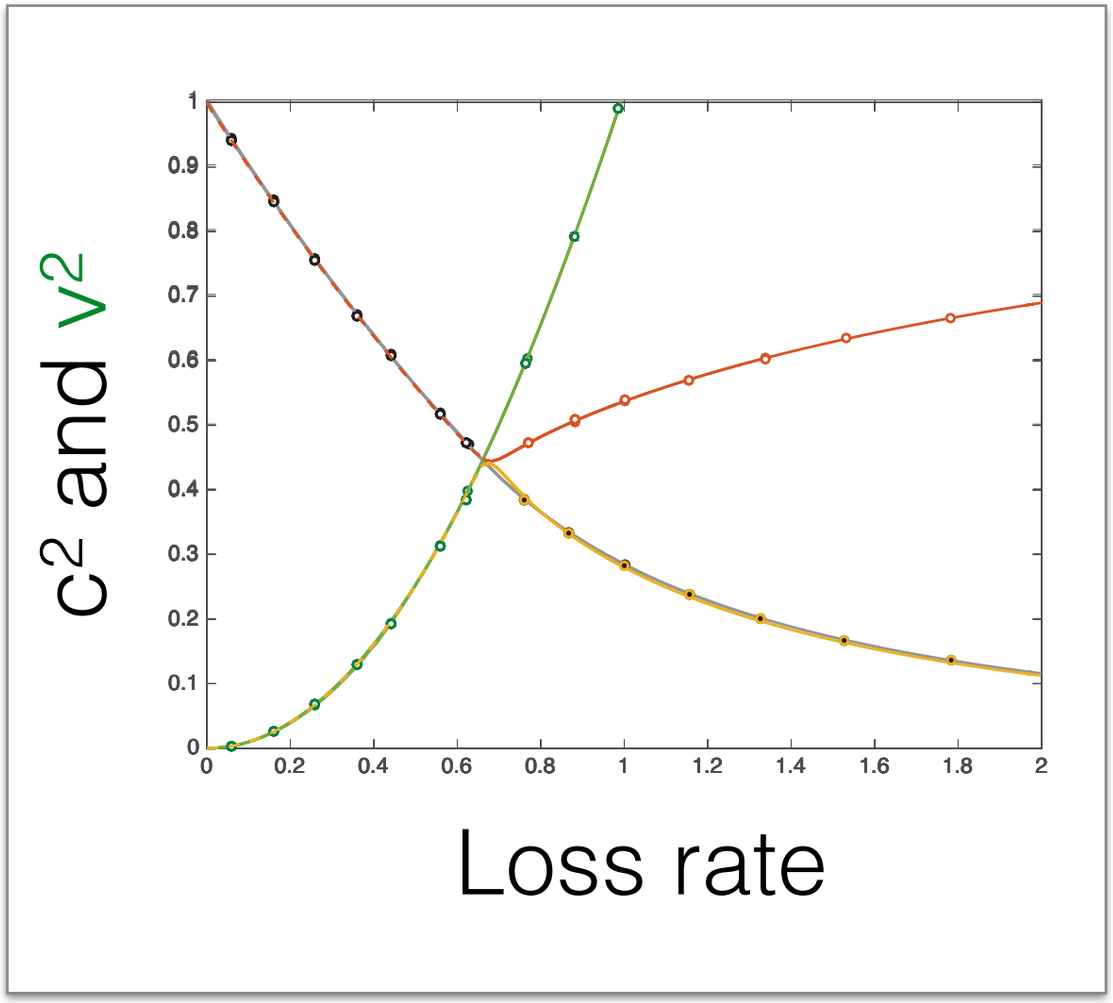


✦ Homogeneous NESS is formed

$$\psi = \sqrt{n} e^{-i(v|x| - \mu t)}$$

Horizon formation





c² outside v² outside

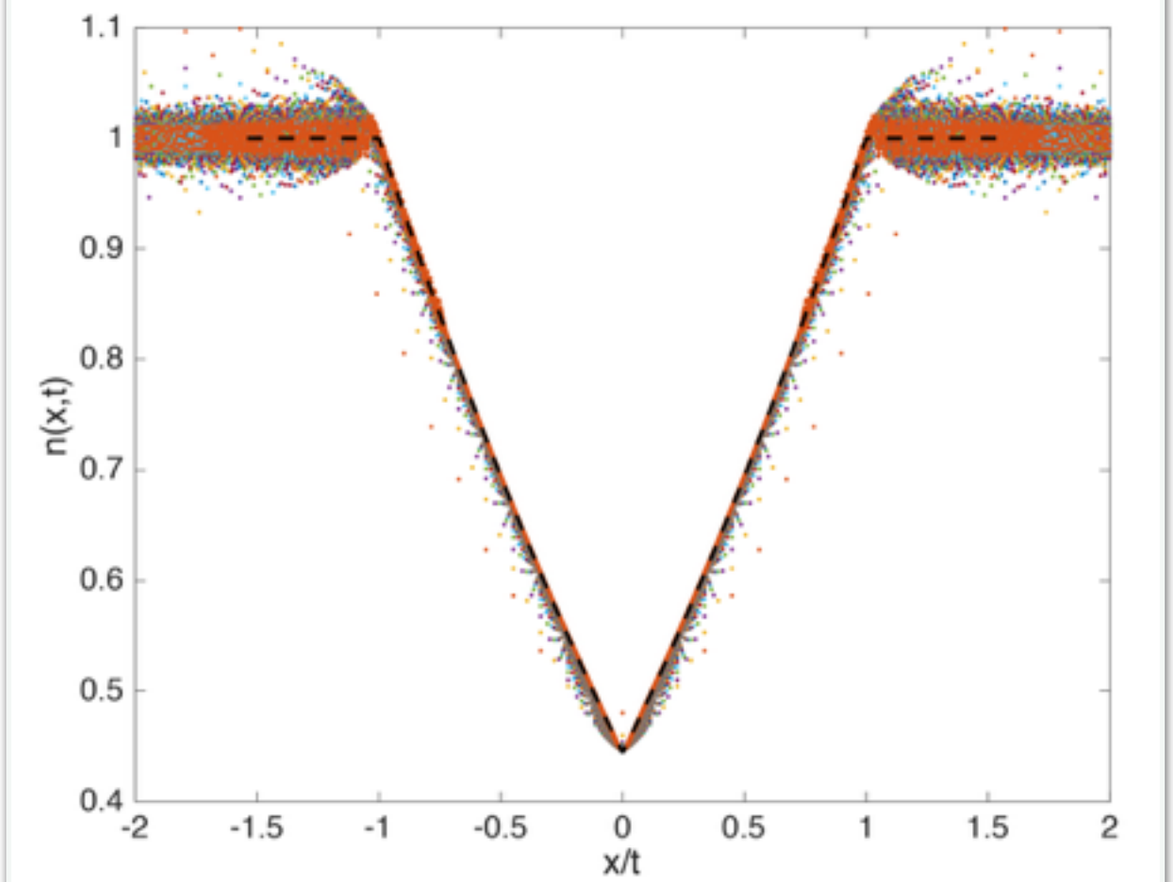
c² inside v² inside

✦ Inhomogeneous NESS is formed

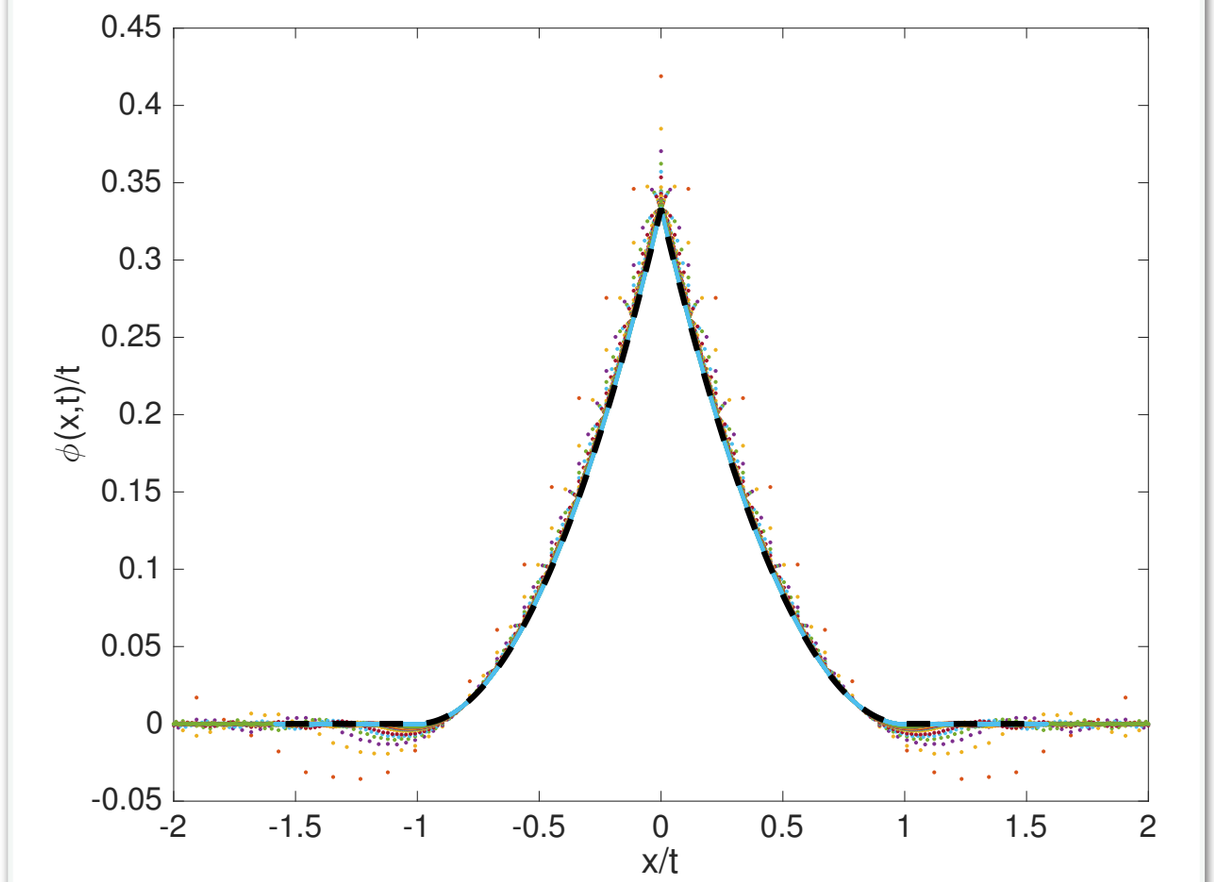
$$\psi = \sqrt{n}\,(iv + \alpha \tanh(\alpha|x|))\, e^{-i(v|x|+\mu t)}$$

Critical state

Rescaled density



Rescaled phase



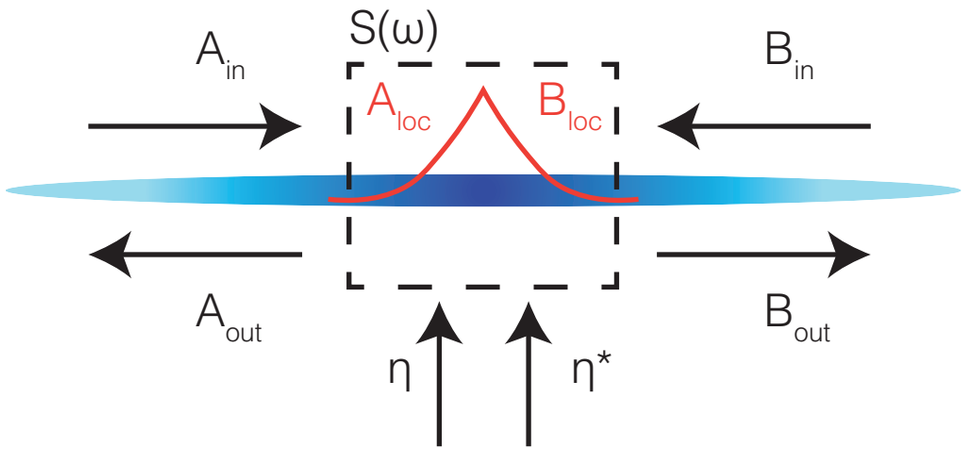
✦ System remains in transient state forever

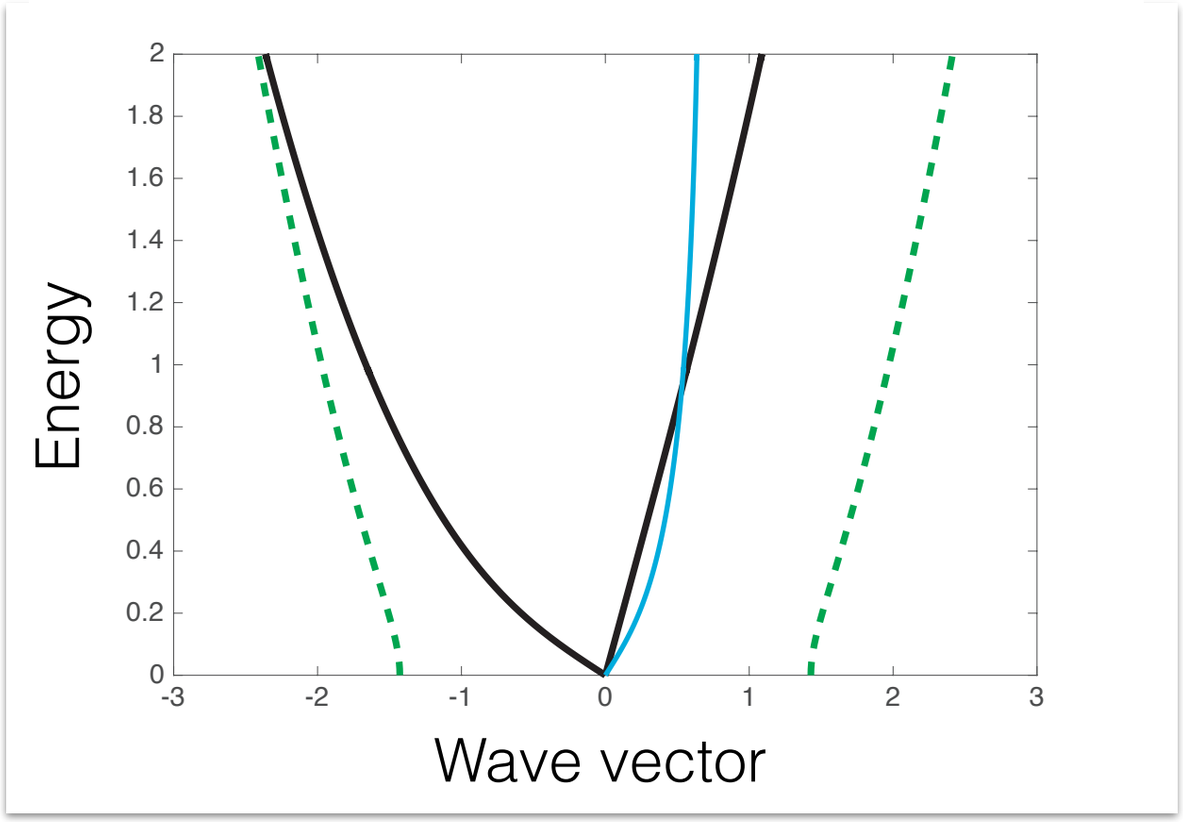
$$n = \frac{4}{9}\left(\frac{x}{2t} + 1\right)^2$$

$$\gamma_c = \frac{2}{3}$$

$$\phi = \frac{t}{3}\left(\frac{x}{t} - 1\right)^2 - t$$

Fluctuations





Set up scattering problem:

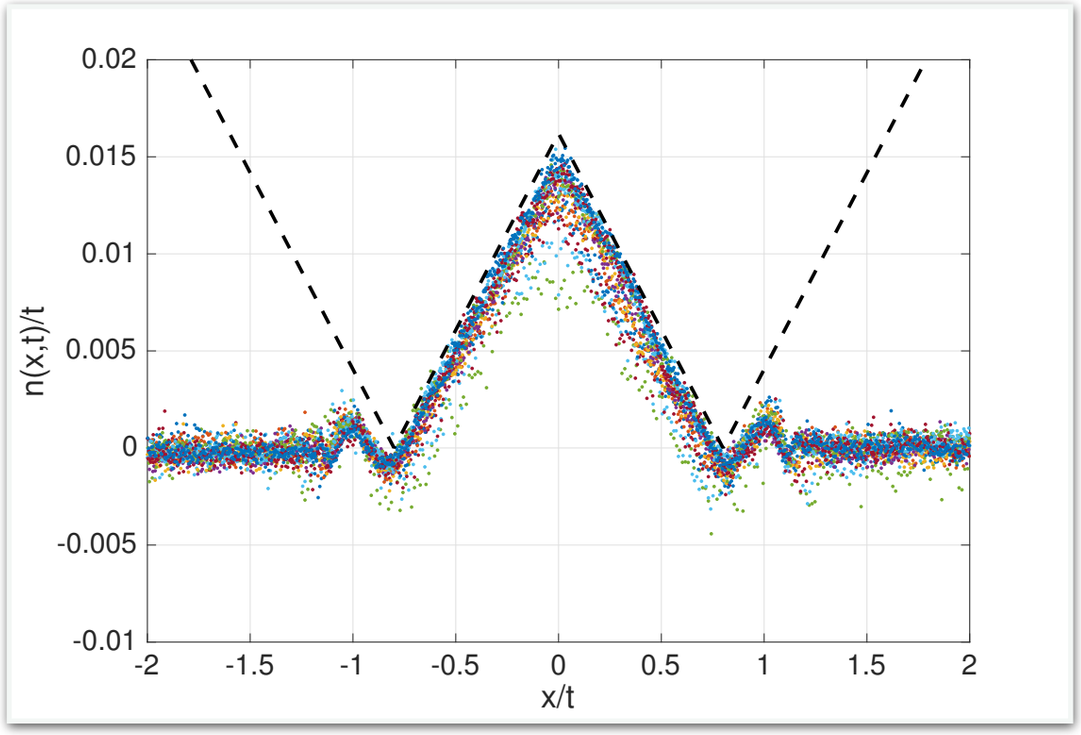
$$i\partial_t \begin{pmatrix} \chi \\ \chi^* \end{pmatrix} = \begin{pmatrix} H_0 & (\psi_0)^2 \\ -(\psi_0^*)^2 & -H_0^\dagger \end{pmatrix} \begin{pmatrix} \chi \\ \chi^* \end{pmatrix} + \delta(x) \begin{pmatrix} \eta(t) \\ \eta^*(t) \end{pmatrix}$$

with $H_0 = -\frac{1}{2}\partial_x^2 + 2|\psi_0|^2 - \mu - i\gamma\delta(x)$

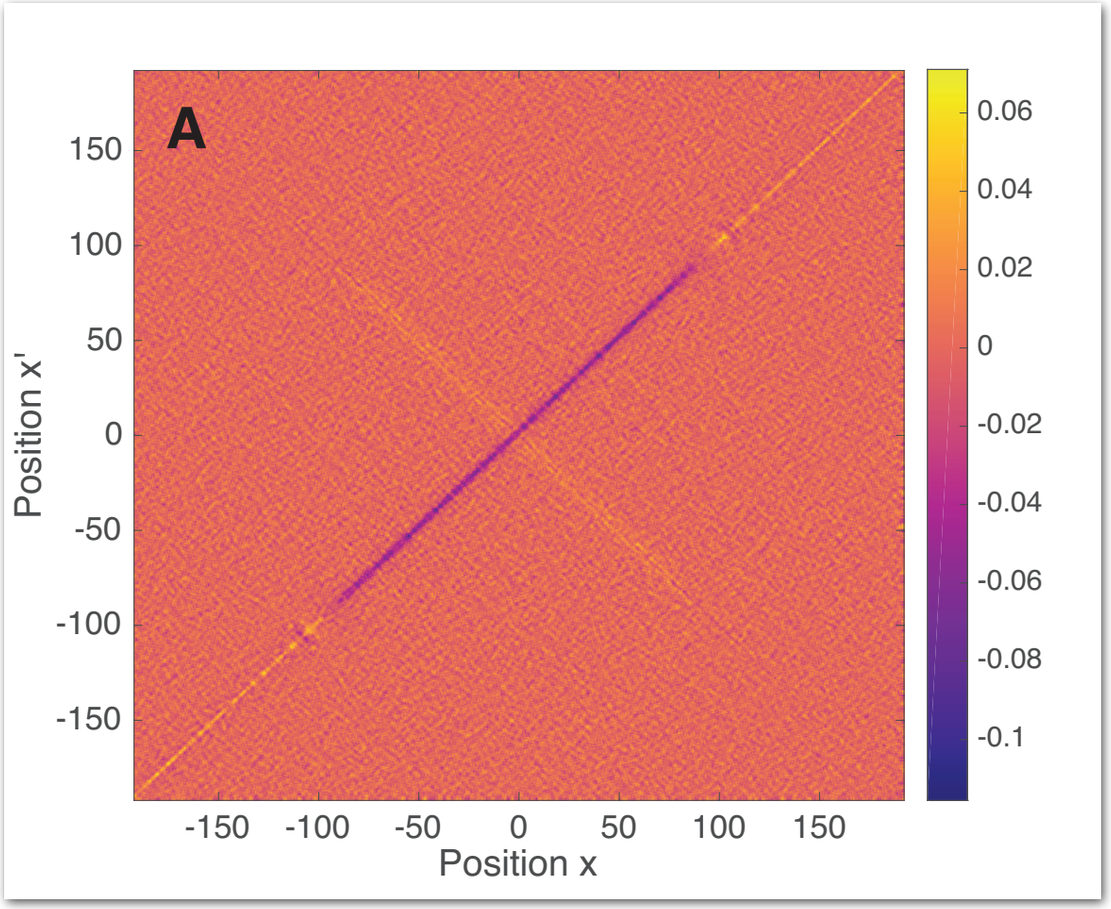
- ✦Evanescent negative norm modes
- ✦Injection of quantum noise

Weak loss fluctuations

Single particle



Two particle



Spontaneous phonon emission

$$k_b T = \frac{v}{v+c}\mu$$

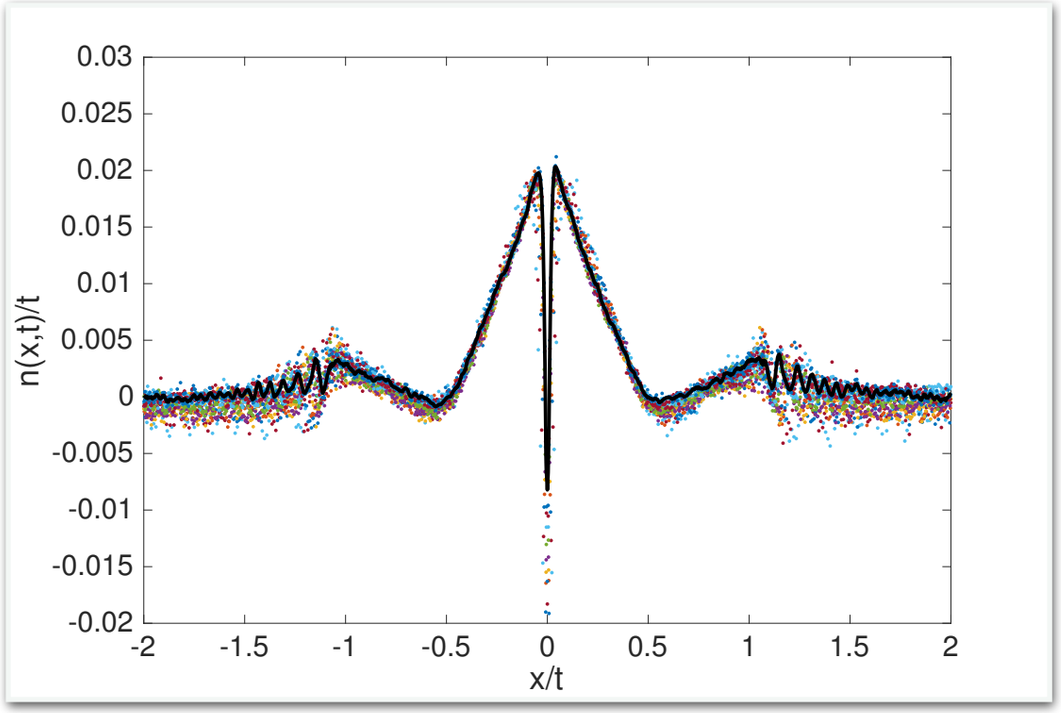
Coherent scattering of drain

$$r = -\frac{v}{\sqrt{c^2 - v^2}}$$

$$t = \frac{c}{\sqrt{c^2 - v^2}}$$

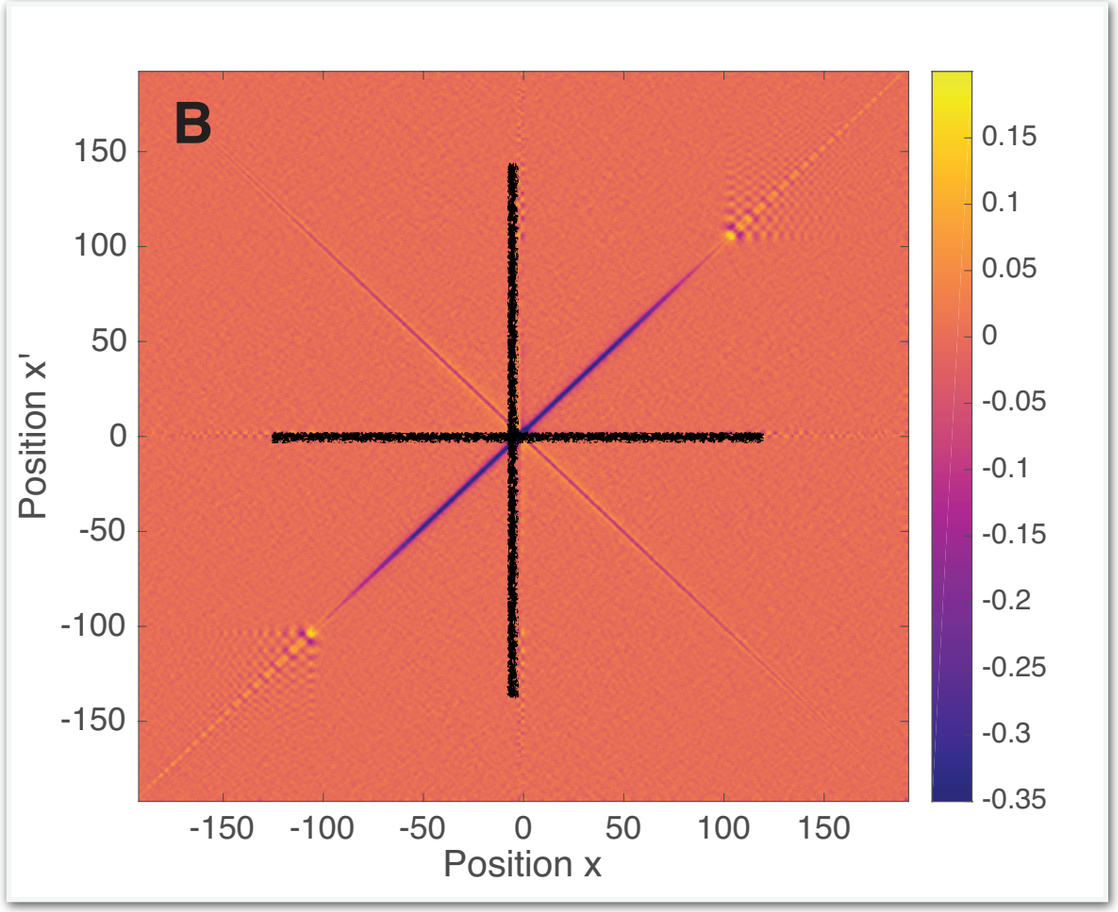
Black hole fluctuations

Single particle



Spontaneous emission
+
scattering in localized mode

Two particle



Hawking process
with negative norm localized mode

Take home

- Dissipative phase transition into Planck size acoustic black hole state

- Vacuum noise from dissipation yields thermal radiation of phonons in both phases

- UV violation of Lorentz invariance is manifested in localized modes

- $g^{(2)}$ reveals correlations between emitted and localized Hawking partners

Black hole laser