Hawking radiation from sonic black holes in flowing atom condensates

Fernando Sols
Universidad Complutense de Madrid

In collaboration with:

M. Albert (LPTMS Orsay - Univ. Geneve)
J. R. M. de Nova (UCM)
D. Guéry-Odelin (Toulouse)
R. Parentani (LPT Orsay)
I. Zapata (UCM – UAM)

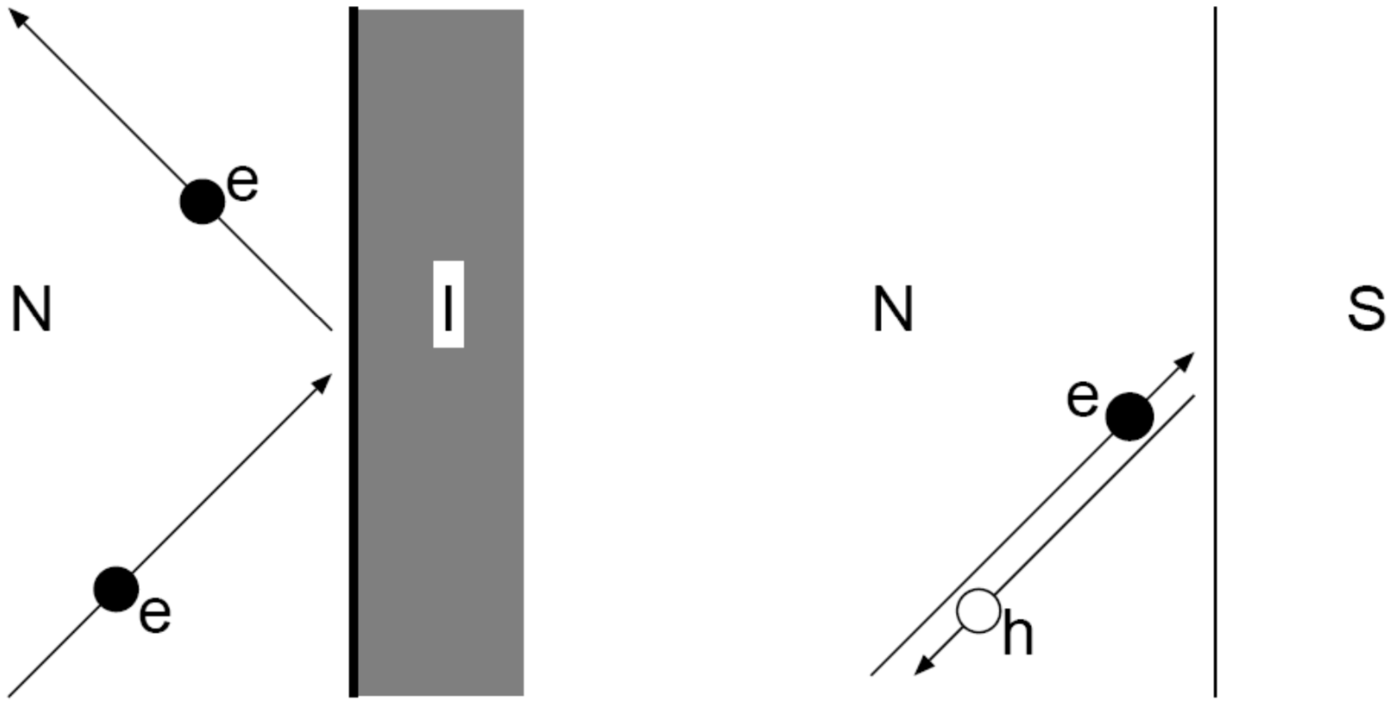
OUTLINE

- Resonant Hawking radiation
- Violation of Cauchy-Schwarz inequalities by HR
- Birth of quasi-stationary sonic black hole in an outcoupled BEC

Hawking radiation from sonic black holes in flowing atom condensates

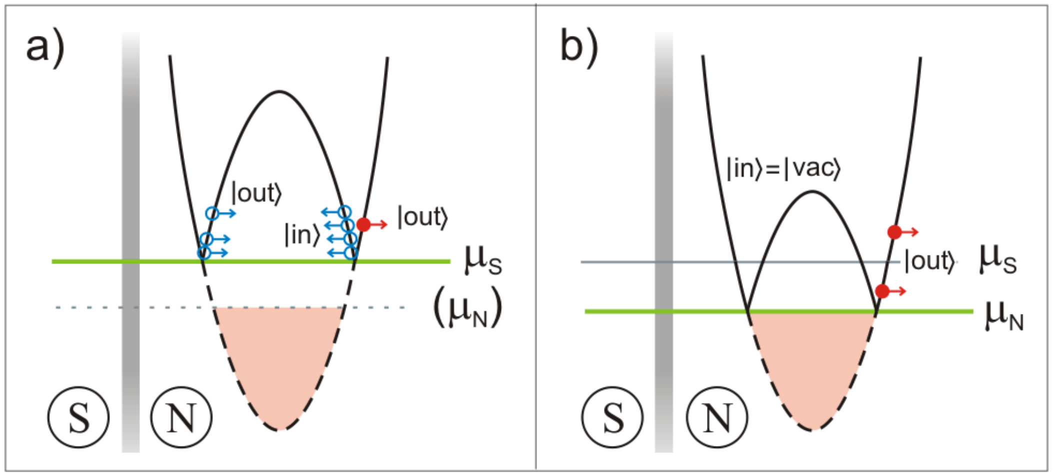
Zapata, Albert, Parentani, FS	New J. Phys (2011)
de Nova, FS, Zapata	Phys. Rev. A (2014)
de Nova, Guéry-Odelin, FS, Zapata	New J. Phys. (2014)
de Nova, FS, Zapata	New J. Phys. (2015)

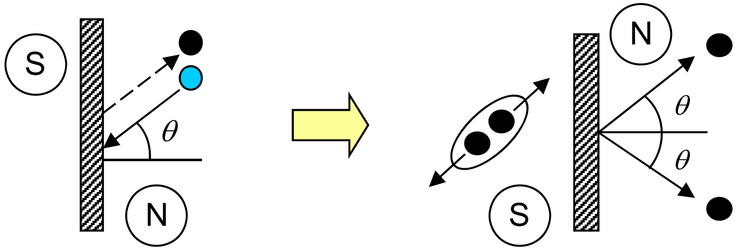
Andreev reflection in superconductors



from C. Beenakker (Les Houches, 1994)

hole Andreev reflection vs. two-electron emission





E. Prada, FS, EPJB (2004)
also Samuelsson, Sukhorukov, Büttiker, PRL (2003)

BE Condensate: Gross–Pitaevskii and Bogoliubov – de Gennes equations

$$\hat{\Psi}(x,t) = e^{-i\mu t/\hbar}\left[\Psi_0(x) + \delta\hat{\Psi}(x,t)\right]$$

$$\left[-\frac{\hbar^2}{2m}\frac{\partial}{\partial x^2} - \mu + V_{\text{ext}}(x) + g_{1D}|\Psi_0(x)|^2\right]\Psi_0(x) = 0$$

Gross-Pitaevskii (GP) equation

mean field

$$\delta\hat{\Psi}(x,t) = \sum_{\omega_i>0}\begin{cases}\sum_{\nu_i>0}\left[u_i(x)e^{-i\omega_i t}\hat{\gamma}_i + v_i^*(x)e^{i\omega_i t}\hat{\gamma}_i^\dagger\right] \\ +\sum_{\nu_i<0}\left[u_i(x)e^{-i\omega_i t}\hat{\gamma}_i^\dagger + v_i^*(x)e^{i\omega_i t}\hat{\gamma}_i\right]\end{cases}$$

Bogoliubov expansion

$$\begin{bmatrix}\hat{H} & g_{1D}\Psi_0(x)^2 \\ -g_{1D}\Psi_0^*(x)^2 & -\hat{H}\end{bmatrix}\begin{bmatrix}u_i(x) \\ v_i(x)\end{bmatrix} = \hbar\omega_i\begin{bmatrix}u_i(x) \\ v_i(x)\end{bmatrix}$$

Bogoliubov-deGennes (BdG) equations

non-Hermitian!

$$\hat{H} := -\frac{\hbar^2}{2m}\frac{\partial}{\partial x^2} - \mu + V_{\text{ext}}(x) + 2g_{1D}|\Psi_0(x)|^2$$

$$\nu_i := \int dx\left[|u_i(x)|^2 - |v_i(x)|^2\right] = \pm 1 \quad \text{normalization}$$

$$\left[\hat{\gamma}_i, \hat{\gamma}_j^\dagger\right] = \delta_{ij}$$

Bogoliubov approximation
= independent quasiparticles

BE Condensate: Gross–Pitaevskii - two speeds

$$\hat{H} := -\frac{\hbar^2}{2m}\frac{\partial}{\partial x^2} - \mu + V_{ext}(x) + 2g_{1D}\,|\Psi_0(x)|^2$$

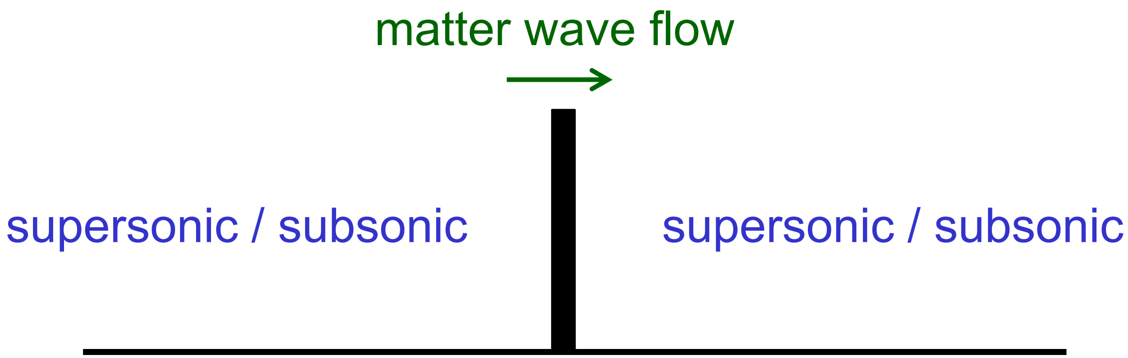
$$c(x) = |\Psi_0(x)|\sqrt{\frac{g_{1D}}{m}}$$ sound speed

$$v(x) = \frac{j}{|\Psi_0(x)|^2}$$ flow speed

$v(x) < c(x)$ subsonic

$v(x) > c(x)$ supersonic

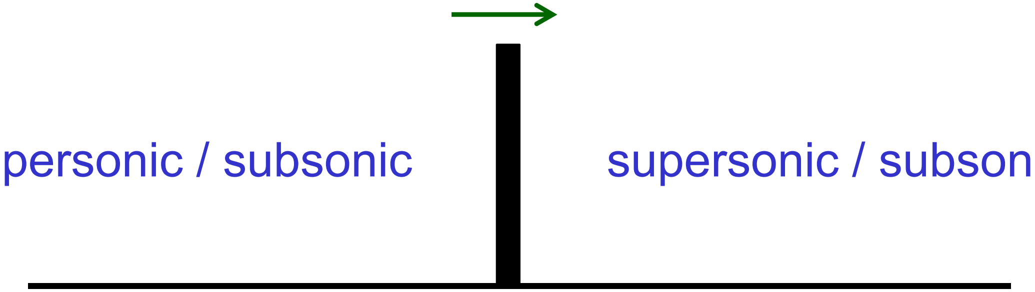
Three paradigms of quantum transport through a barrier



Three paradigms of quantum transport through a barrier

matter wave flow

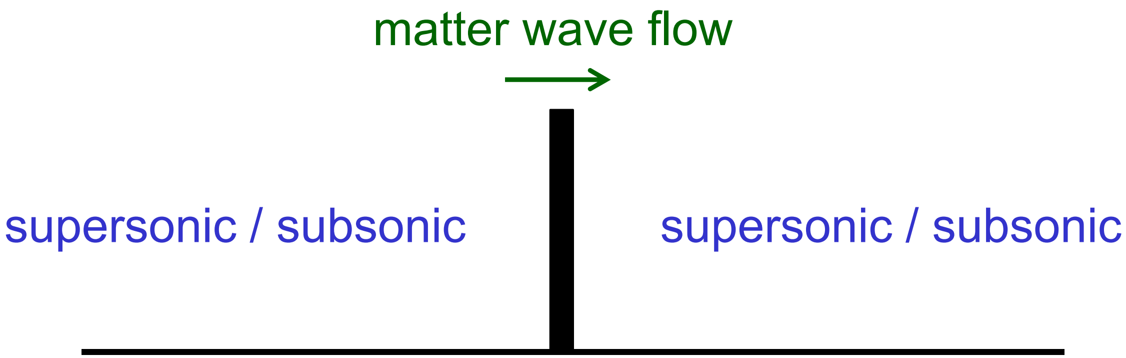
supersonic / subsonic



supersonic / subsonic

supersonic || supersonic → ~ noninteracting Schrödinger-like

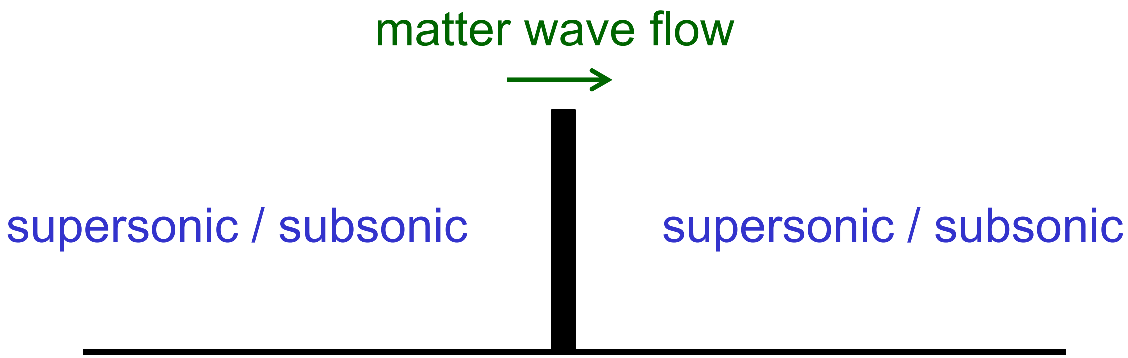
Three paradigms of quantum transport through a barrier



supersonic || supersonic → ~ noninteracting Schrödinger-like

subsonic || subsonic → ~ superfluid Josephson link

Three paradigms of quantum transport through a barrier



supersonic || supersonic → ~ noninteracting Schrödinger-like

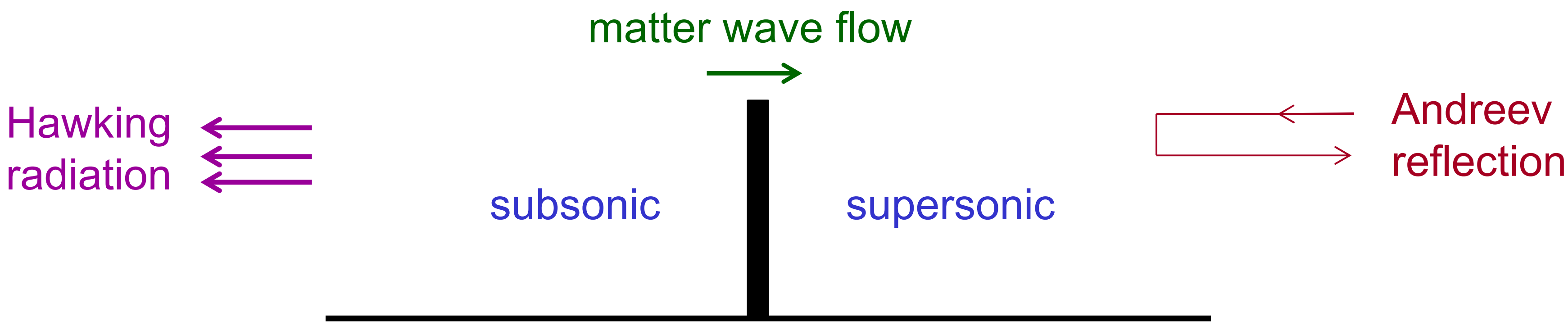
subsonic || subsonic → ~ superfluid Josephson link

subsonic || supersonic → leaking (outcoupled) condensate sonic black-hole

P. Leboeuf, N. Pavloff, PRA (2001)

or sonic white-hole (unstable)

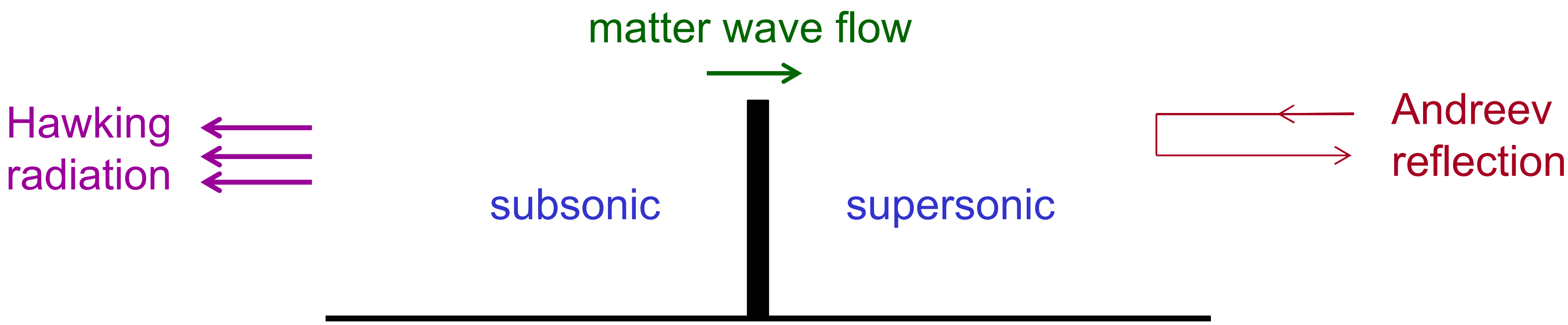
Hawking vs Andreev



S. W. Hawking, Nature (1974); Commun. Math. Phys. (1975)

A.F. Andreev, JETP (1964)

Hawking-Unruh vs Andreev



S. W. Hawking,
Nature (1974);
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W. G. Unruh
PRL (1981)

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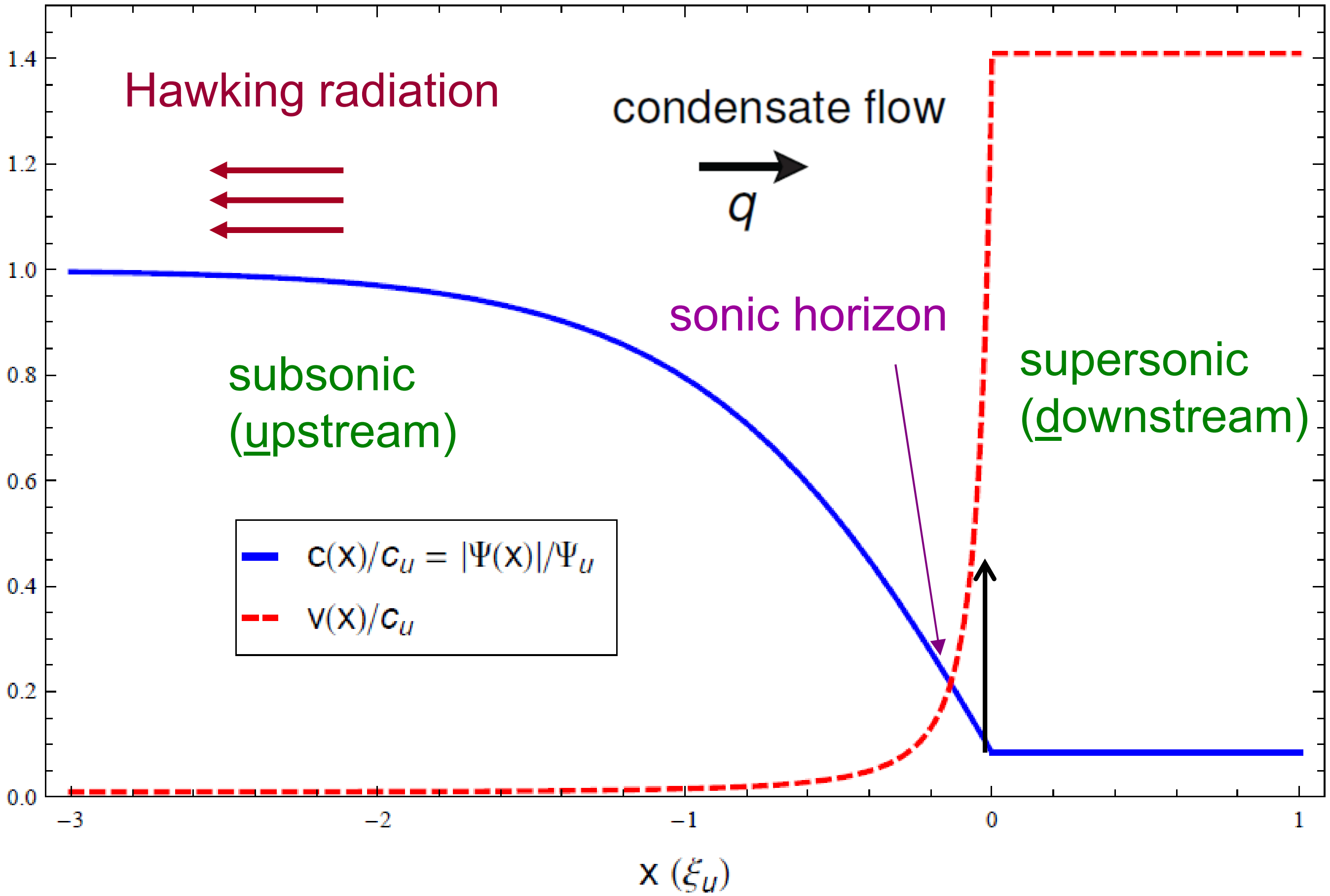
Hawking radiation in BECs



$$V(x) = Z\hbar c_u \delta(x)$$

- one (or two) delta barriers
- u: upstream (left, subsonic, "superfluid")
- d: downstream (right, supersonic, "normal")
- one black-hole, and several white-hole/black-hole pairs

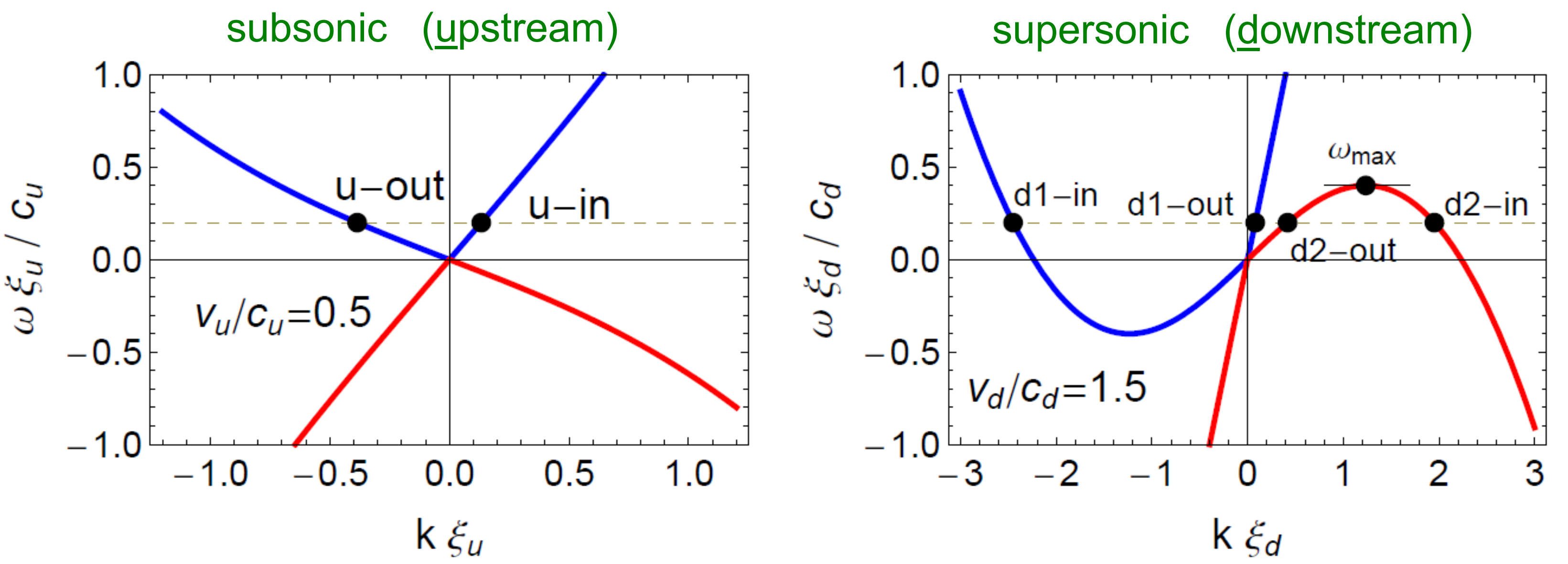
Hawking radiation in BECs

$$\omega(k) = vk \pm \underbrace{c|k|\sqrt{1+\frac{(k\xi)^2}{4}}}_{\Omega(k)}$$

Dispersion relation in laboratory frame for a (comoving frame) Bogoliubov dispersion relation (normal/anomalous normalization)

$\nu > 0$

$\nu < 0$



- u=upstream
- d1=downstream normal
- d2=downstream anomalous → gives rise to Hawking radiation at T=0
- ω_{max} is maximum possible frequency for Hawking radiation

Symmetry property of BdG wave functions

For each solution with frequency ω and wave function (u, v), there exists another (physically identical) solution with frequency −ω*, wave function (v*, u*), and opposite normalization. And γ → γ+

$$\delta\hat{\Psi}(x,t) = \sum_{\omega_i>0} \begin{cases} \sum_{\nu_i>0} \left\{ u_i(x) e^{-i\omega_i t} \hat{\gamma}_i + v_i^*(x) e^{i\omega_i t} \hat{\gamma}_i^\dagger \right\} + \\ \sum_{\nu_i<0} \left\{ u_i(x) e^{-i\omega_i t} \hat{\gamma}_i^\dagger + v_i^*(x) e^{i\omega_i t} \hat{\gamma}_i \right\} \end{cases}$$

Symmetry property of BdG wave functions

For each solution with frequency ω and wave function (u, v), there exists another (physically identical) solution with frequency −ω*, wave function (v*, u*), and opposite normalization. And γ → γ+

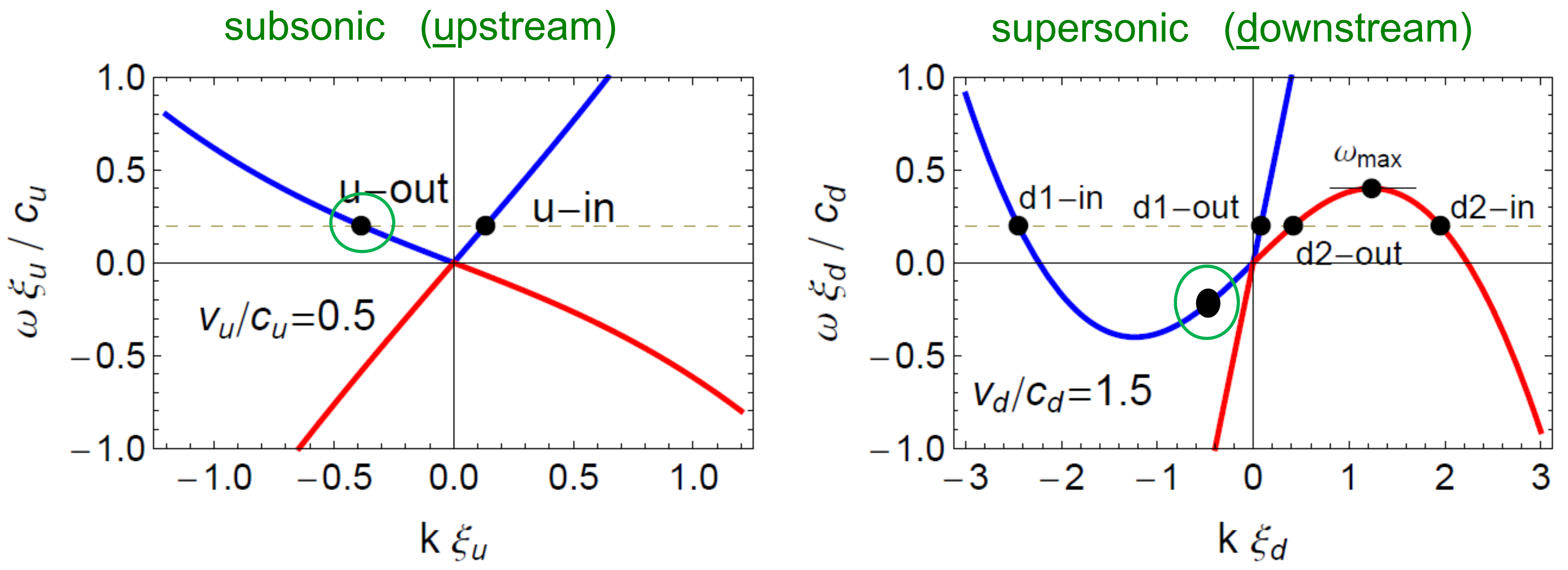
$$\delta\hat{\Psi}(x,t) = \sum_{\omega_i > 0} \begin{cases} \sum_{\nu_i > 0} \left\{ u_i(x) e^{-i\omega_i t} \hat{\gamma}_i + v_i^*(x) e^{i\omega_i t} \hat{\gamma}_i^\dagger \right\} + \\ \sum_{\nu_i < 0} \left\{ u_i(x) e^{-i\omega_i t} \hat{\gamma}_i^\dagger + v_i^*(x) e^{i\omega_i t} \hat{\gamma}_i \right\} \end{cases}$$

We can choose:

all frequencies > 0, normalizations = ± 1

frequencies >< 0, all normalizations = +1,

Hawking radiation (with positive normalization)

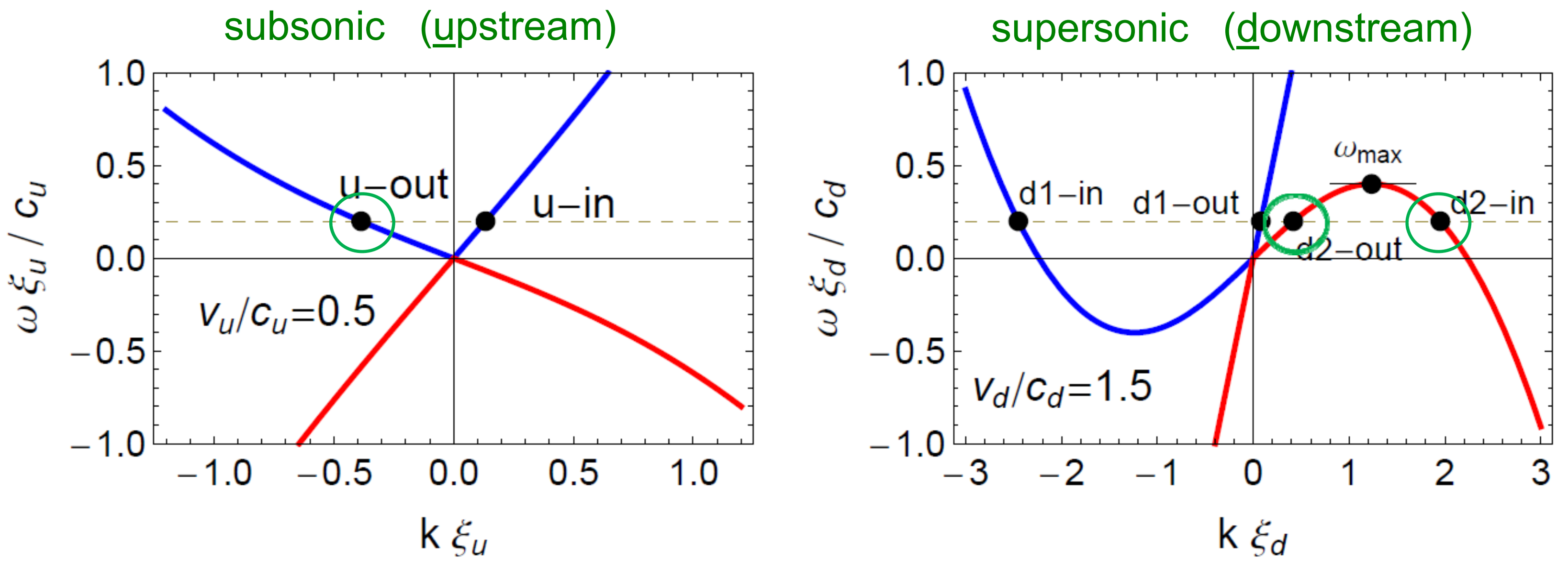


spontaneous particle-antiparticle pair production

condensate flow

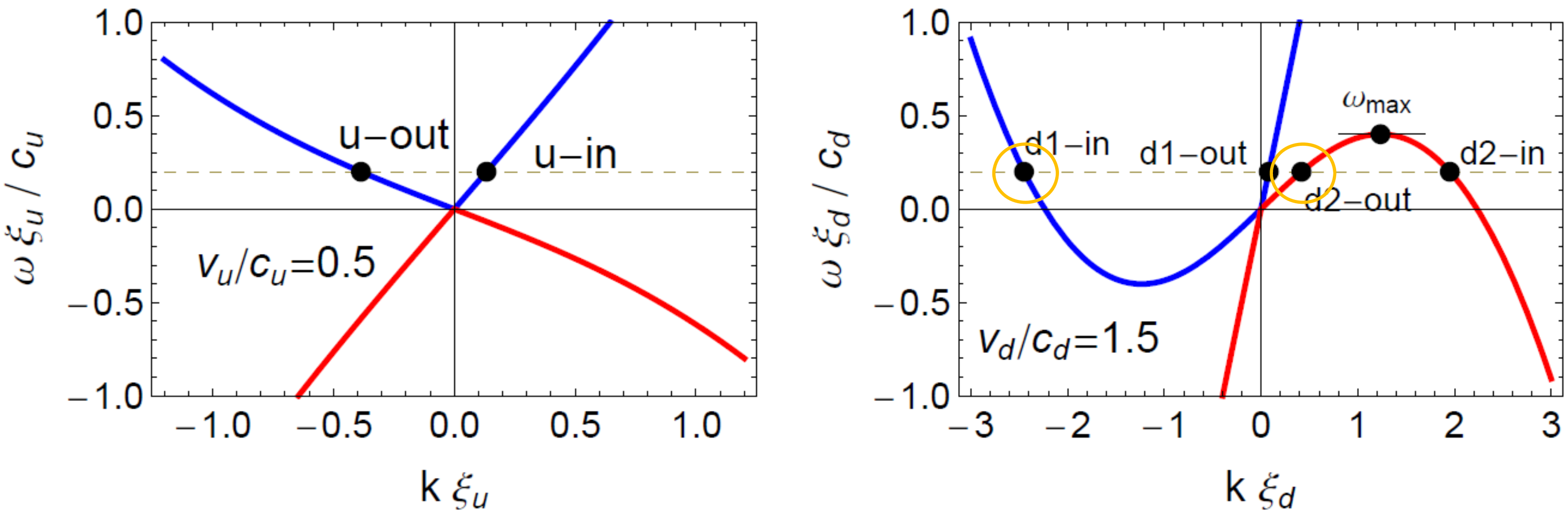
q

Hawking radiation (with positive frequency)



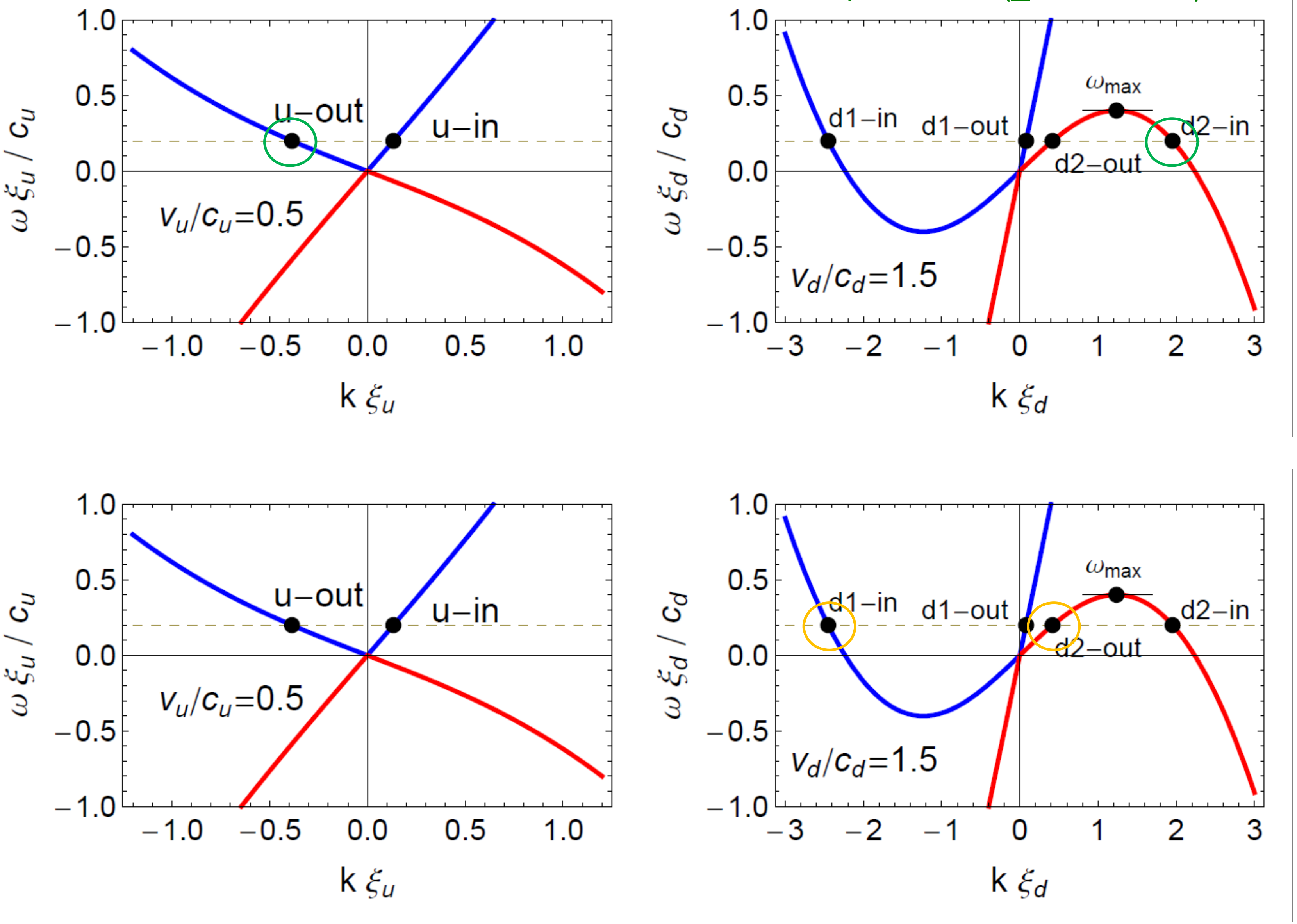
Andreev reflection

I. Zapata, FS – PRL (2009)



Andreev-Hawking (anomalous) processes

subsonic (upstream) supersonic (downstream)



Hawking radiation in BEC

$$\text{if} \quad \omega < \omega_H \to \begin{bmatrix} \hat{a}_u^{\text{out}} \\ \hat{a}_{d1}^{\text{out}} \\ \hat{a}_{d2}^{\dagger\text{out}} \end{bmatrix} = S(\omega) \begin{bmatrix} \hat{a}_u^{\text{in}} \\ \hat{a}_{d1}^{\text{in}} \\ \hat{a}_{d2}^{\dagger\text{in}} \end{bmatrix}, \qquad S^\dagger \eta S = \eta, \;\; \eta := \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

$$\Rightarrow |S_{d2d2}|^2 - |S_{ud2}|^2 - |S_{d1d2}|^2 = 1, \quad \text{etc...}$$ (non-Hermitian)

$$\Rightarrow \frac{dI_u^{\text{out}}}{d\omega} = |S_{uu}|^2 \frac{dI_u^{\text{in}}}{d\omega} + |S_{ud1}|^2 \frac{dI_{d1}^{\text{in}}}{d\omega} + |S_{ud2}|^2 \left(\frac{dI_{d2}^{\text{in}}}{d\omega} + 1 \right),$$

$$\frac{dI_j^{\text{in}}}{d\omega} = \frac{1}{e^{\hbar\Omega_j / k_B T} - 1}, \qquad \Omega_j = \text{comoving frequency of mode } j$$

in-vacuum ≠ out-vacuum

Stationary transport:

A. Recatti, N. Pavloff and I. Carusotto, Phys. Rev. A **80**, 043603 (2009)

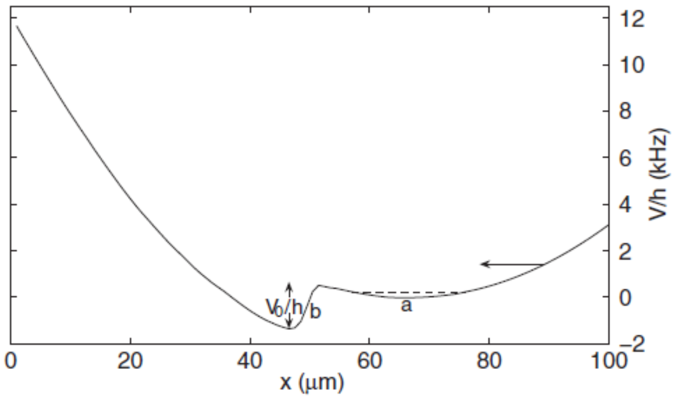
J. Macher and R. Parentani, Phys. Rev. A **80**, 043601 (2009)

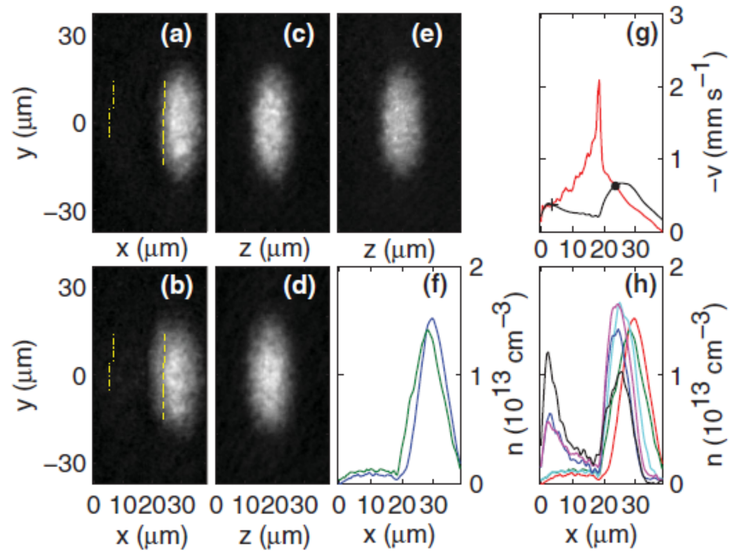
X.-J. CHen, Z.-D. CHen and N.-N. Huang, J. Phys. A: Math. Gen. **31**, 6929 (1998)

…

Realization of a Sonic Black Hole Analog in a Bose-Einstein Condensate

Oren Lahav, Amir Itah, Alex Blumkin, Carmit Gordon, Shahar Rinott, Alona Zayats, and Jeff Steinhauer
Technion—Israel Institute of Technology, Haifa, Israel

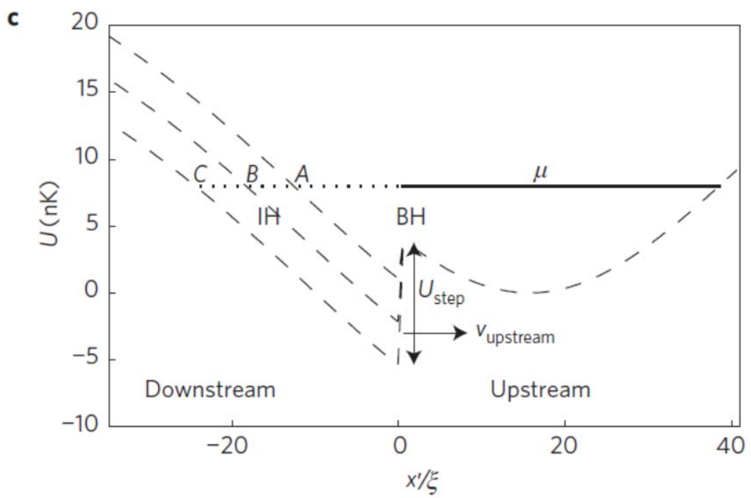


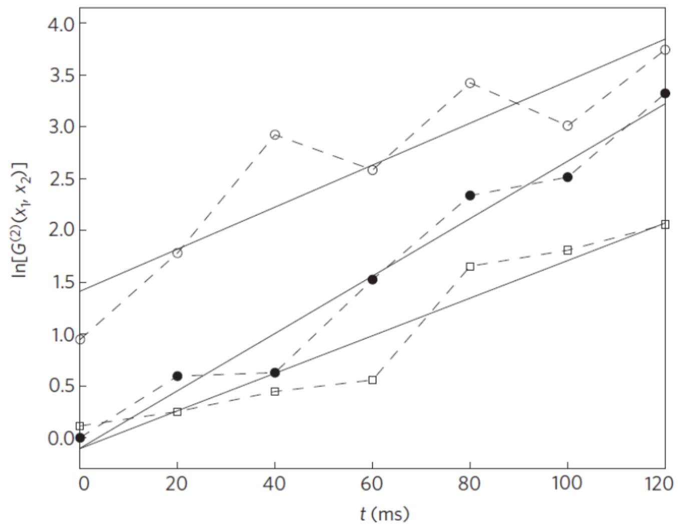


nature physics
ARTICLES
PUBLISHED ONLINE: 12 OCTOBER 2014 | DOI: 10.1038/NPHYS3104

Observation of self-amplifying Hawking radiation in an analogue black-hole laser

Jeff Steinhauer



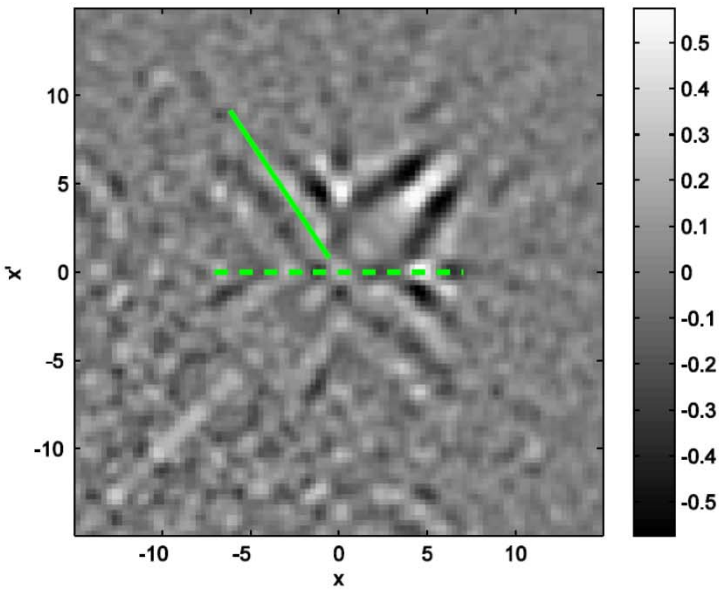


The exponential growth of the lasing mode.

Observation of thermal Hawking radiation and its entanglement in an analogue black hole

Jeff Steinhauer

Department of Physics, Technion—Israel Institute of Technology, Technion City, Haifa 32000, Israel



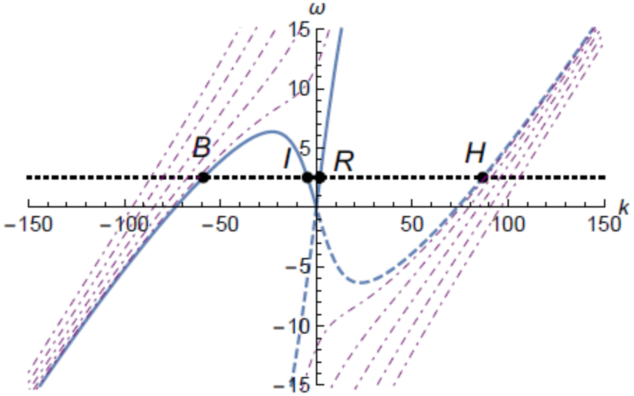
arXiv:1510.00621

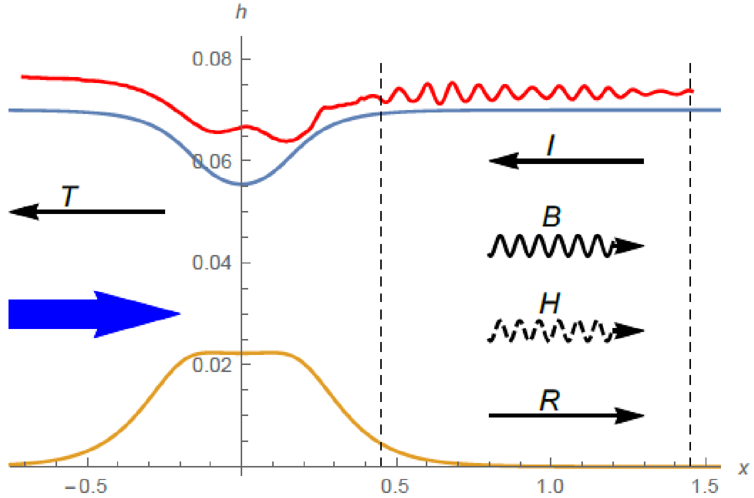
Fig. 5. Wave motion near the horizon. A preliminary experiment is shown in which the step potential at the horizon is caused to oscillate at 50 Hz with an amplitude of 1 μm. The solid line is drawn parallel to the feature marking equal times on opposite sides of the horizon.

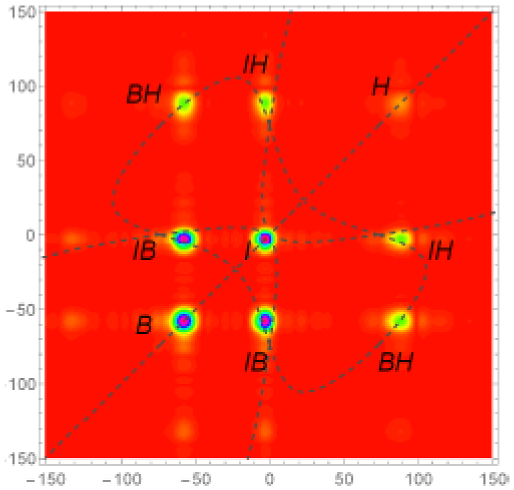
Observation of noise correlated by the Hawking effect in a water tank

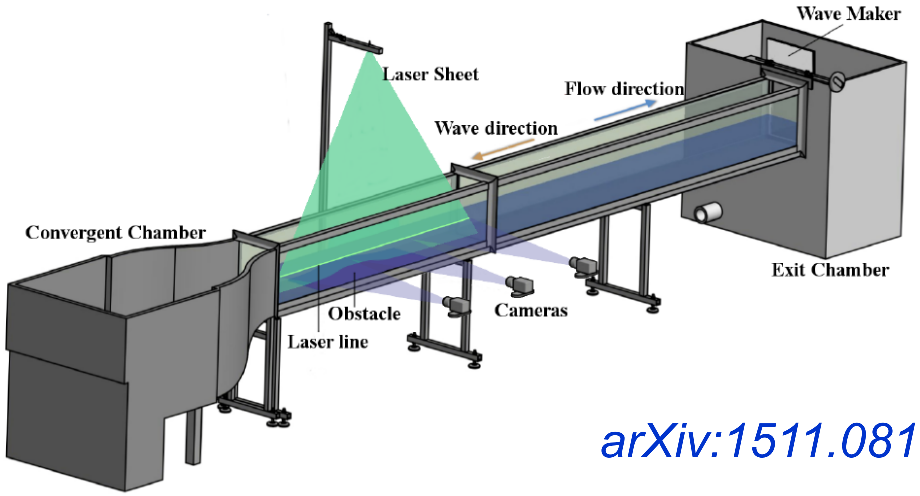
L.-P. Euvé,[1] F. Michel,[2] R. Parentani,[2] T. G. Philbin,[3] and G. Rousseaux[1]

[1]*Institut Pprime, UPR 3346, CNRS-Université de Poitiers-ISAE ENSMA 11 Boulevard Marie et Pierre Curie-Téléport 2, BP 30179, 86962 Futuroscope Cedex, France*
[2]*Laboratoire de Physique Théorique, CNRS, Univ. Paris-Sud, Université Paris-Saclay, 91405 Orsay, France*
[3]*Physics and Astronomy Department, University of Exeter, Stocker Road, Exeter EX4 4QL, UK*



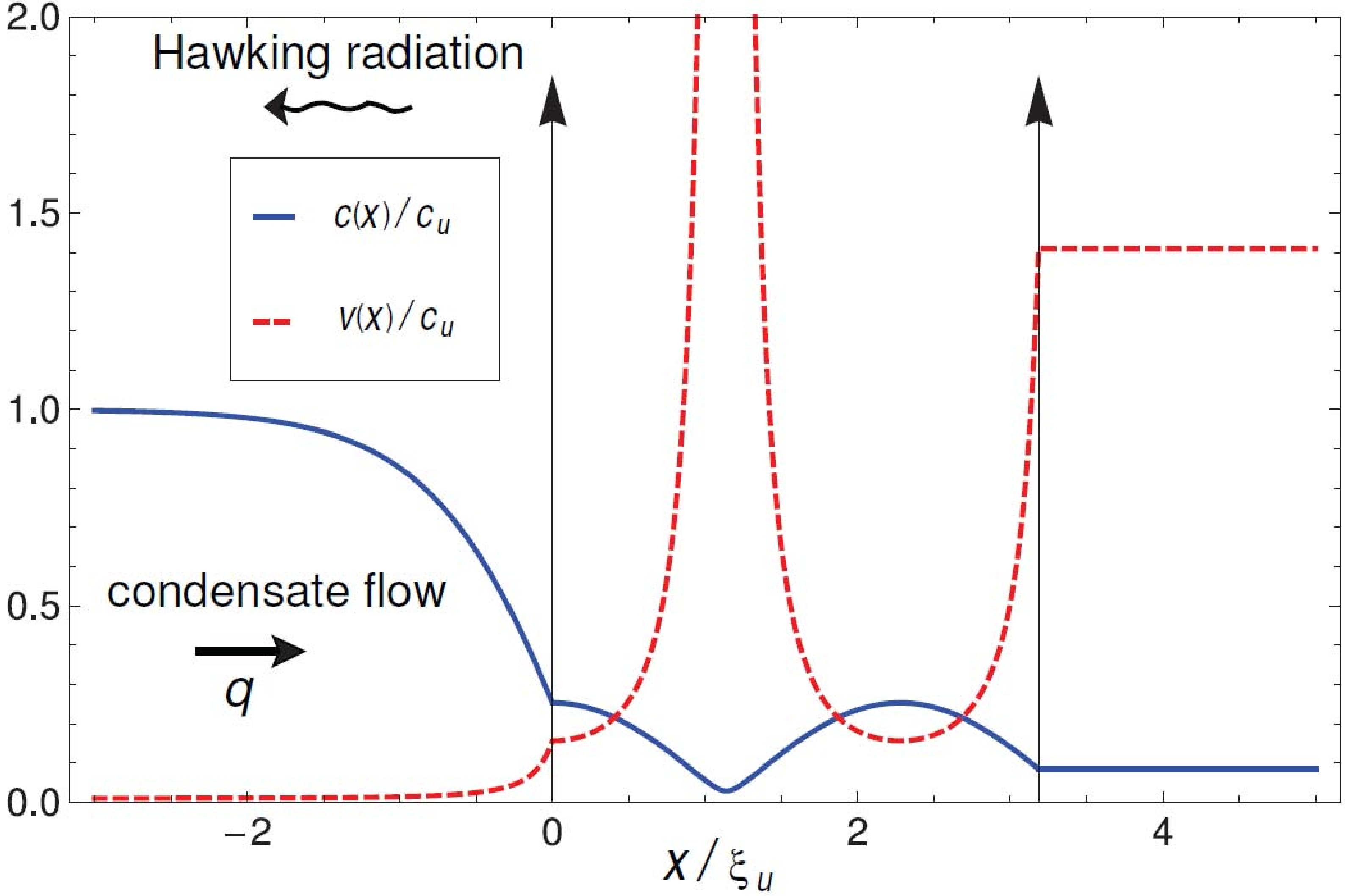






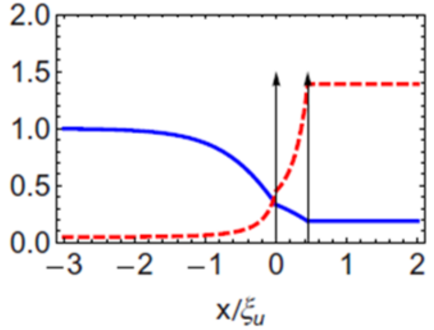
arXiv:1511.08145

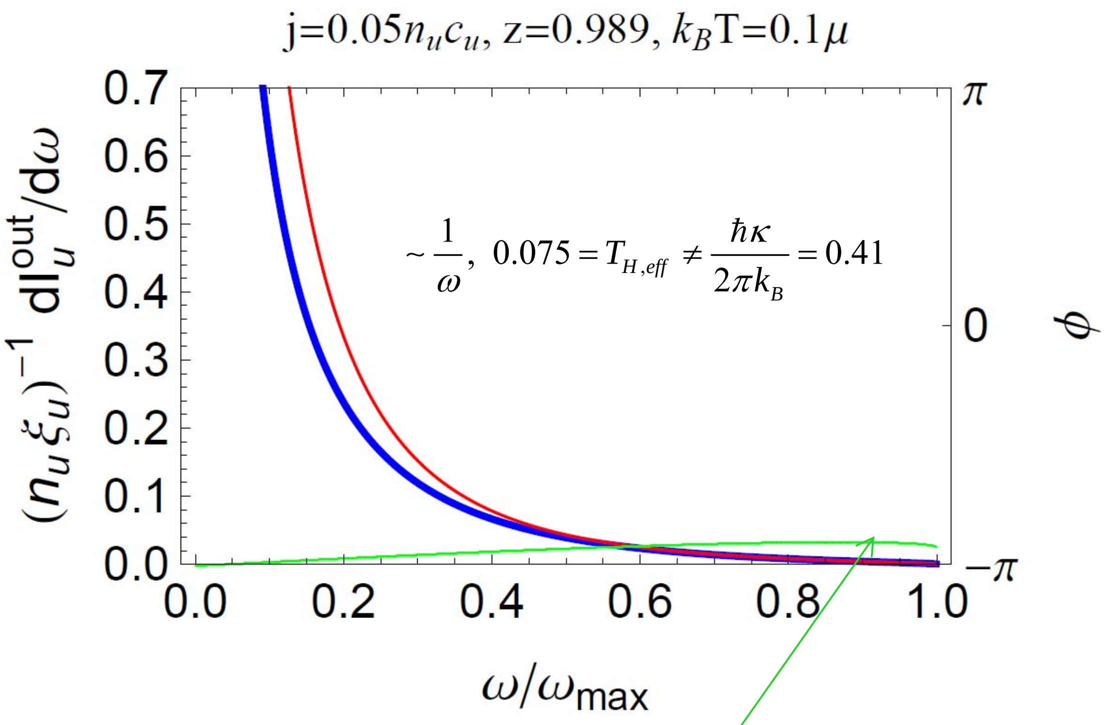
Resonant Hawking radiation



$$V(x) = z\hbar c_u \left[\delta(x) + \delta(x-d) \right]$$

Resonant Hawking radiation: Hawking spectrum

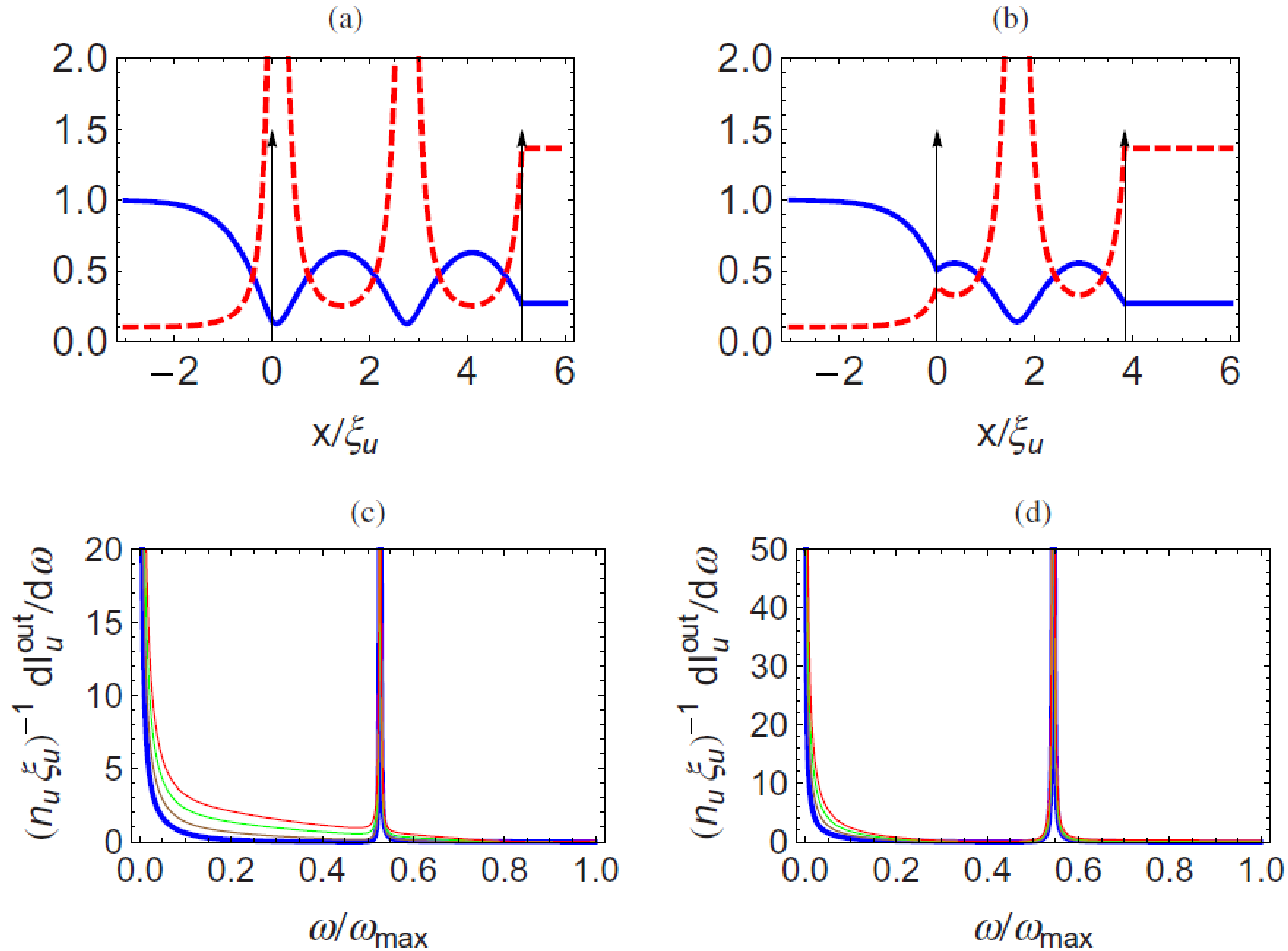




Upstream current:
Zero temperature (Hawking radiation)
Finite temperature

Phase shift of determinant of S-matrix

Resonant Hawking radiation: Spectrum



$k_B T / \mu = 0, 0.3, 0.6, 0.9$

Bogoliubov vacuum: depletion cloud

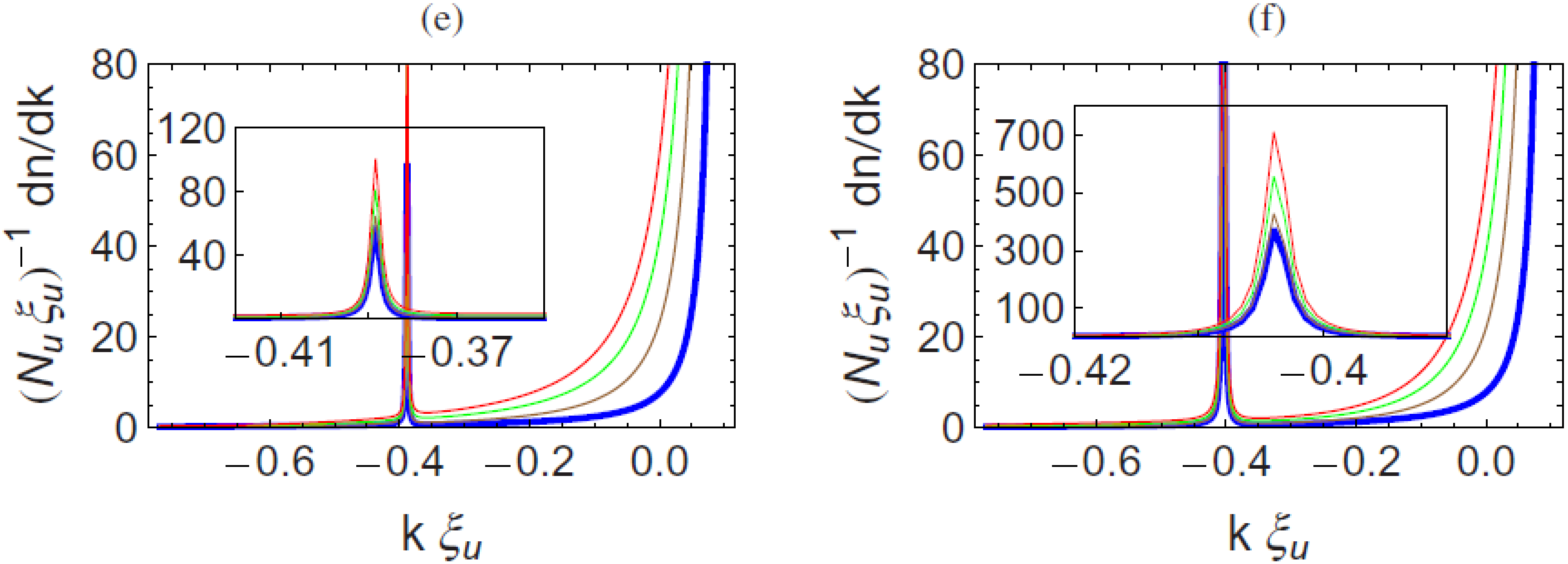
mean field $\left(c_0^\dagger\right)^N |\mathrm{vac}\rangle$

Bogoliubov vacuum $\left(c_0^\dagger c_0^\dagger + \sum_k \lambda_k c_k^\dagger c_{-k}^\dagger\right)^{N/2} |\mathrm{vac}\rangle$

due to interactions

e.g. A J Leggett – RMP (2001)

Resonant Hawking radiation: Time of flight



$k_B T / \mu = 0, 0.3, 0.6, 0.9$

I. Zapata, M. Albert, R. Parentani, FS
New J. Phys. (2011)

Classical vs Quantum coherence (I)

$$g^{(2)}(\tau) := \frac{\left\langle E^*(t)E^*(t+\tau)E(t+\tau)E(t)\right\rangle}{\left\langle E^*(t)E(t)\right\rangle^2};$$

$$g_{a,b}{}^{(2)}(\tau) := \frac{\left\langle E_a{}^*(t)E_b{}^*(t+\tau)E_b(t+\tau)E_a(t)\right\rangle}{\left\langle E_a{}^*(t)E_a(t)\right\rangle\left\langle E_b{}^*(t+\tau)E_b(t+\tau)\right\rangle};$$

Classical inequalities:

$$g^{(2)}(\tau) \le g^{(2)}(0);$$

$$1 \le g^{(2)}(0);$$

$$\left[g_{a,b}{}^{(2)}(\tau)\right]^2 \le g_{a,a}{}^{(2)}(0)g_{b,b}{}^{(2)}(0)$$

Quantum violations:

$g^{(2)}(\tau) > g^{(2)}(0)$ $\Rightarrow$ Anti-bunching

$1 > g^{(2)}(0)$ $\Rightarrow$ Sub-Poissonian statistics

$\left[g_{a,b}{}^{(2)}(\tau)\right]^2 > g_{a,a}{}^{(2)}(0)g_{b,b}{}^{(2)}(0)$ $\Rightarrow$ Cauchy-Schwarz inequality violation

$\left\langle a^\dagger b^\dagger ba\right\rangle^2 > \left\langle a^\dagger a^\dagger aa\right\rangle\left\langle b^\dagger b^\dagger bb\right\rangle$ (two-mode squeezed light)

Classical *vs* Quantum coherence (II)

$$\text{if}\quad \omega<\omega_{\max}\rightarrow\begin{pmatrix}\hat{\gamma}_u^{\text{out}}\\ \hat{\gamma}_{d1}^{\text{out}}\\ \hat{\gamma}_{d2}^{\dagger\text{out}}\end{pmatrix}=S(\omega)\begin{pmatrix}\hat{\gamma}_u^{\text{in}}\\ \hat{\gamma}_{d1}^{\text{in}}\\ \hat{\gamma}_{d2}^{\dagger\text{in}}\end{pmatrix},\; S(\omega)^\dagger\eta S(\omega)=\eta,\; \eta:=\begin{pmatrix}1&0&0\\0&1&0\\0&0&-1\end{pmatrix}$$

$$\left\langle\hat{\gamma}_u^{\dagger\text{out}}\hat{\gamma}_{d2}^{\dagger\text{out}}\hat{\gamma}_{d2}^{\text{out}}\hat{\gamma}_u^{\text{out}}\right\rangle^2\le\left\langle\hat{\gamma}_u^{\dagger\text{out}}\hat{\gamma}_u^{\dagger\text{out}}\hat{\gamma}_u^{\text{out}}\hat{\gamma}_u^{\text{out}}\right\rangle\left\langle\hat{\gamma}_{d2}^{\dagger\text{out}}\hat{\gamma}_{d2}^{\dagger\text{out}}\hat{\gamma}_{d2}^{\text{out}}\hat{\gamma}_{d2}^{\text{out}}\right\rangle$$

$$T=0\Rightarrow 4\left|S_{ud2}\right|^4\left\{\left|S_{d2d2}\right|^2-\tfrac{1}{2}\right\}^2\le 4\left|S_{ud2}\right|^4\left\{\left|S_{d2d2}\right|^2-1\right\}^2$$

CS inequality

Always violated because $\left|S_{d2d2}\right|^2\ge 1$ (unless $\left|S_{ud2}\right|=0$)

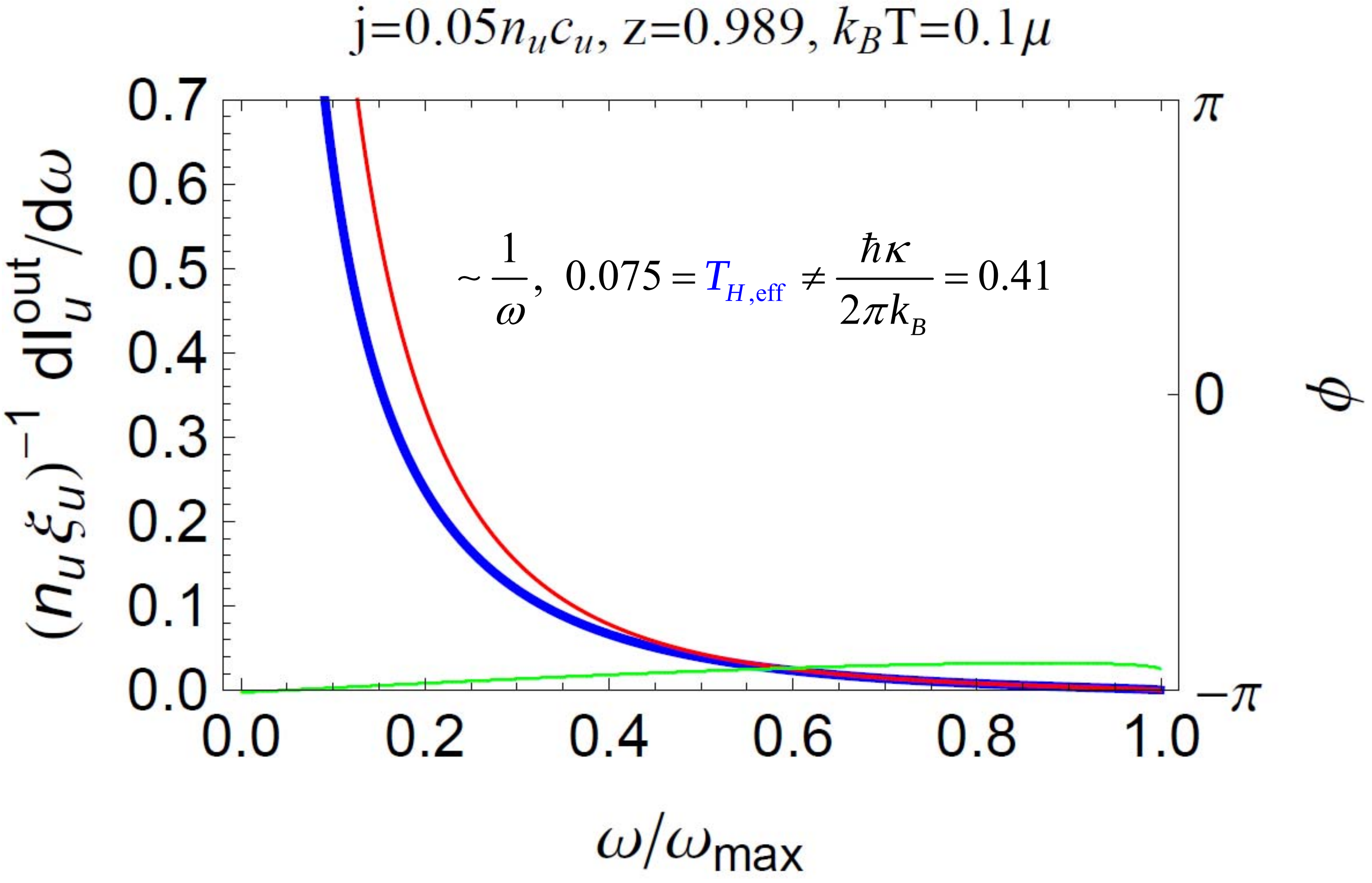
$T>0$ & general case

$$\Rightarrow\left|S_{ud2}\right|^2\left(1+n_u+n_{d1}+n_{d2}\right)\le\left|S_{d1u}\right|^2 n_{d1}n_{d2}+\left|S_{d1d1}\right|^2 n_u n_{d2}+\left|S_{d1d2}\right|^2 n_u n_{d1}$$
$$+\left|S_{d2d1}\right|^2 n_u+\left|S_{d2u}\right|^2 n_{d1}$$

$$n_j:=\left\langle\hat{\gamma}_j^{\dagger in}\hat{\gamma}_j^{in}\right\rangle=\frac{1}{e^{\hbar\Omega_j/k_BT}-1}$$

CS never violated at ω=0

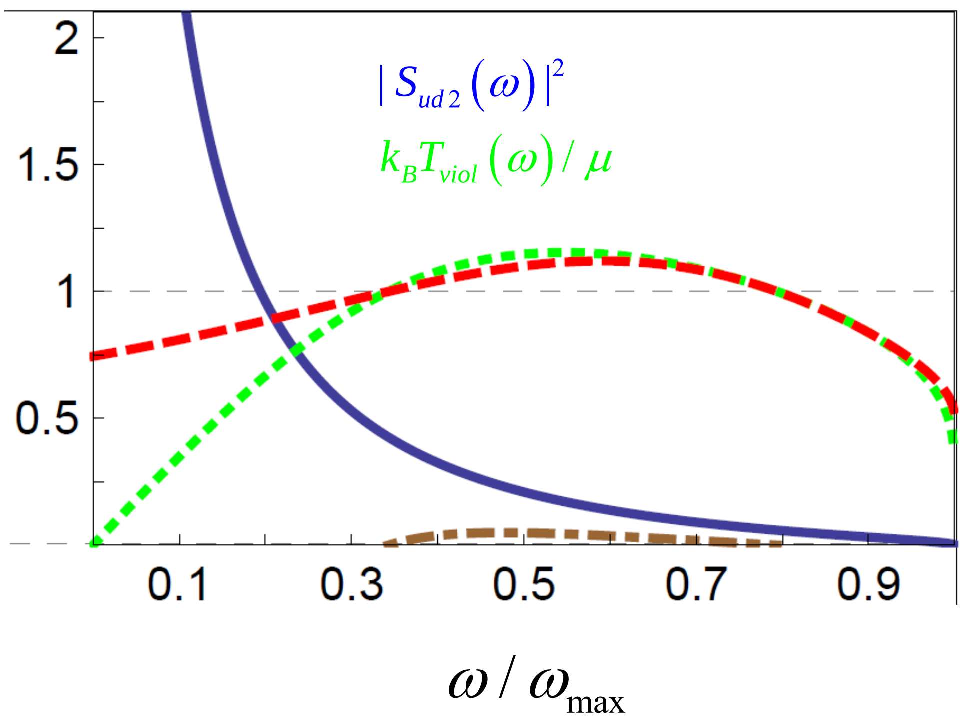
One barrier - Hawking spectrum (non-resonant)



Upstream current:
Zero temperature (Hawking radiation, $T_{H,eff}$)
Finite temperature

Phase shift of the determinant of the S-matrix

One barrier - CS violation (non-resonant)



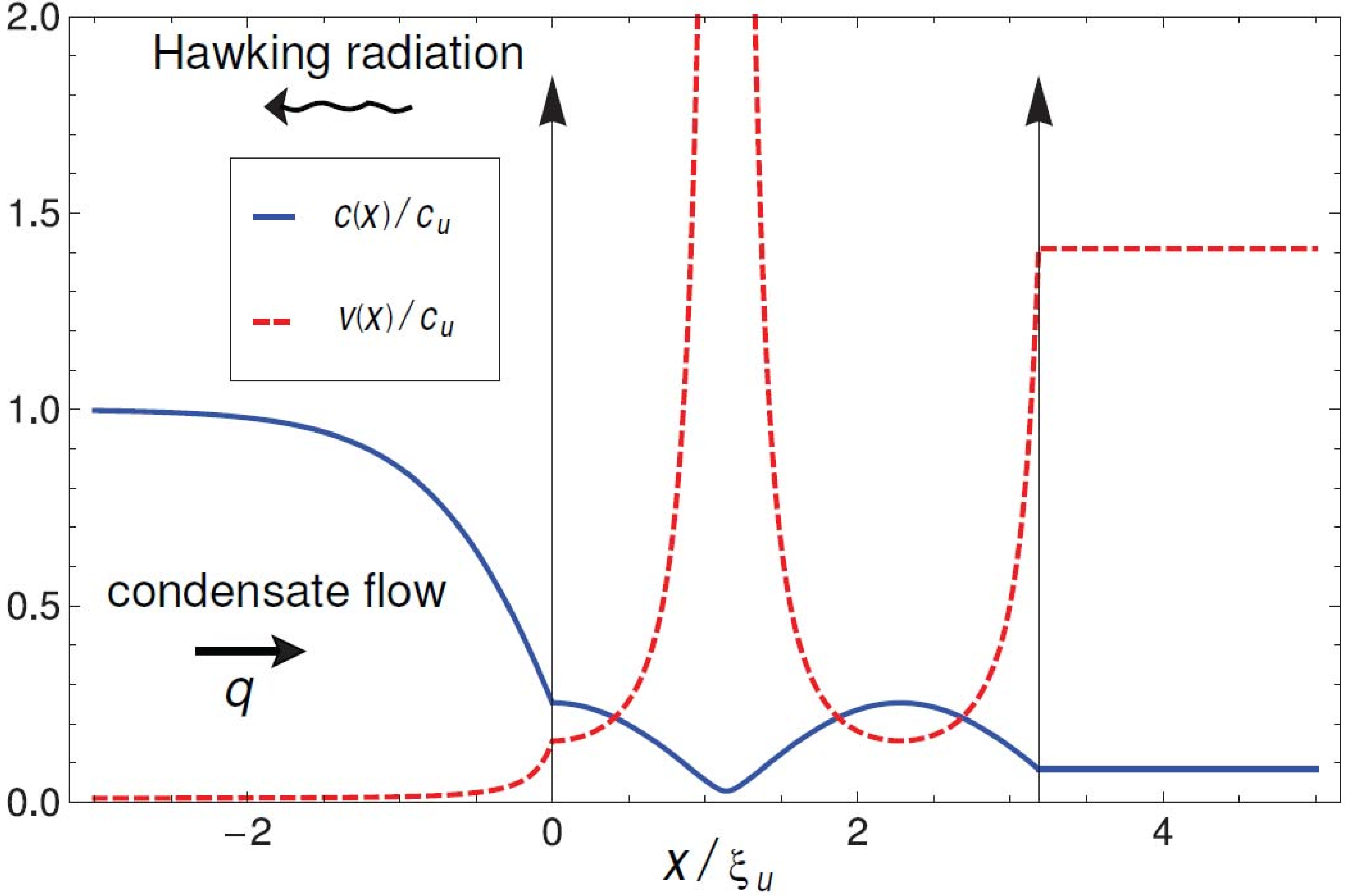
small absolute violation

$$\left\langle \gamma^\dagger_{d2,out}\gamma^\dagger_{u,out}\gamma_{u,out}\gamma_{d2,out}\right\rangle_{k_BT=\mu} / \sqrt{\left\langle \gamma^\dagger_{u,out}\gamma^\dagger_{u,out}\gamma_{u,out}\gamma_{u,out}\right\rangle_{k_BT=\mu}\left\langle \gamma^\dagger_{d2,out}\gamma^\dagger_{d2,out}\gamma_{d2,out}\gamma_{d2,out}\right\rangle_{k_BT=\mu}}$$

$$\left\langle \gamma^\dagger_{d2,out}\gamma^\dagger_{u,out}\gamma_{u,out}\gamma_{d2,out}\right\rangle_{k_BT=\mu} - \sqrt{\left\langle \gamma^\dagger_{u,out}\gamma^\dagger_{u,out}\gamma_{u,out}\gamma_{u,out}\right\rangle_{k_BT=\mu}\left\langle \gamma^\dagger_{d2,out}\gamma^\dagger_{d2,out}\gamma_{d2,out}\gamma_{d2,out}\right\rangle_{k_BT=\mu}}$$

No CS violation near the conventional $\omega \to 0$ peak

Two barriers - Hawking spectrum (resonant)

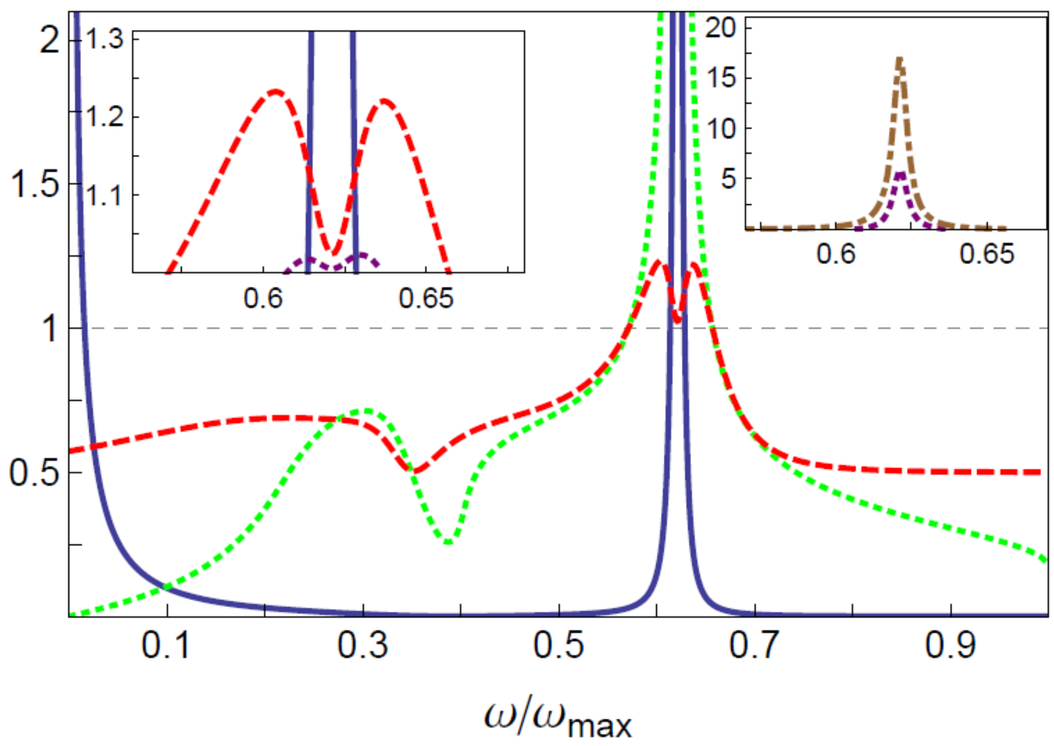


double barrier: $V(x) = z\hbar c_u \left[\delta(x) + \delta(x-d) \right]$

Two barriers - CS violation (resonant)

$|S_{ud2}(\omega)|^2$

$k_B T_{viol}(\omega)/\mu$



total violation

direct atom signal

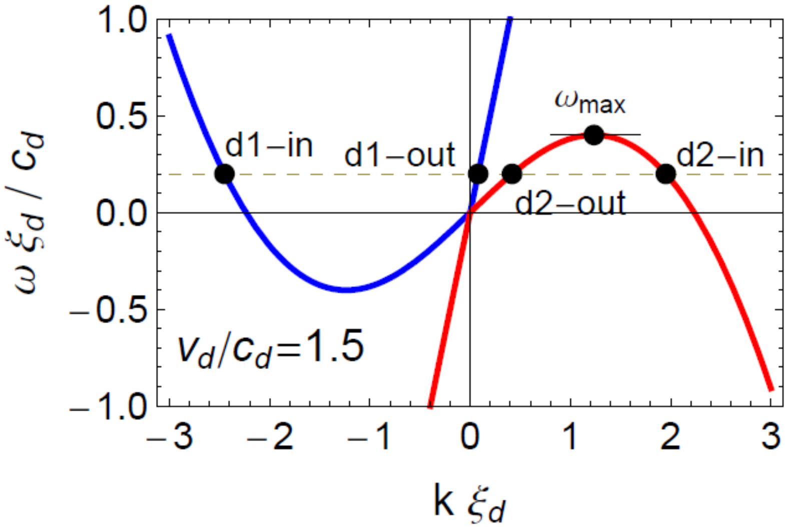
$$\left\langle \gamma^{\dagger}_{d2,out}\gamma^{\dagger}_{u,out}\gamma_{u,out}\gamma_{d2,out}\right\rangle_{k_BT=\mu} / \sqrt{\left\langle \gamma^{\dagger}_{u,out}\gamma^{\dagger}_{u,out}\gamma_{u,out}\gamma_{u,out}\right\rangle_{k_BT=\mu}\left\langle \gamma^{\dagger}_{d2,out}\gamma^{\dagger}_{d2,out}\gamma_{d2,out}\gamma_{d2,out}\right\rangle_{k_BT=\mu}}$$

$$\left\langle \gamma^{\dagger}_{d2,out}\gamma^{\dagger}_{u,out}\gamma_{u,out}\gamma_{d2,out}\right\rangle_{k_BT=\mu} - \sqrt{\left\langle \gamma^{\dagger}_{u,out}\gamma^{\dagger}_{u,out}\gamma_{u,out}\gamma_{u,out}\right\rangle_{k_BT=\mu}\left\langle \gamma^{\dagger}_{d2,out}\gamma^{\dagger}_{d2,out}\gamma_{d2,out}\gamma_{d2,out}\right\rangle_{k_BT=\mu}}$$

Large CS violation near resonant peaks

Resonant Hawking radiation

Time-of-flight CS violation by atoms



$$\hat{c}_{k_{d1}(\omega_{\text{peak}})} \sim \hat{\gamma}_{d1}^{\text{out}}(\omega_{\text{peak}})$$

$$\hat{c}_{k_{d2}(\omega_{\text{peak}})} \sim \hat{\gamma}_{d2}^{\text{out}}(\omega_{\text{peak}})$$

$$\hat{c}_{k_{u}(\omega_{\text{peak}})} \sim \hat{\gamma}_{u}^{\text{out}}(\omega_{\text{peak}})$$

ω-peak high

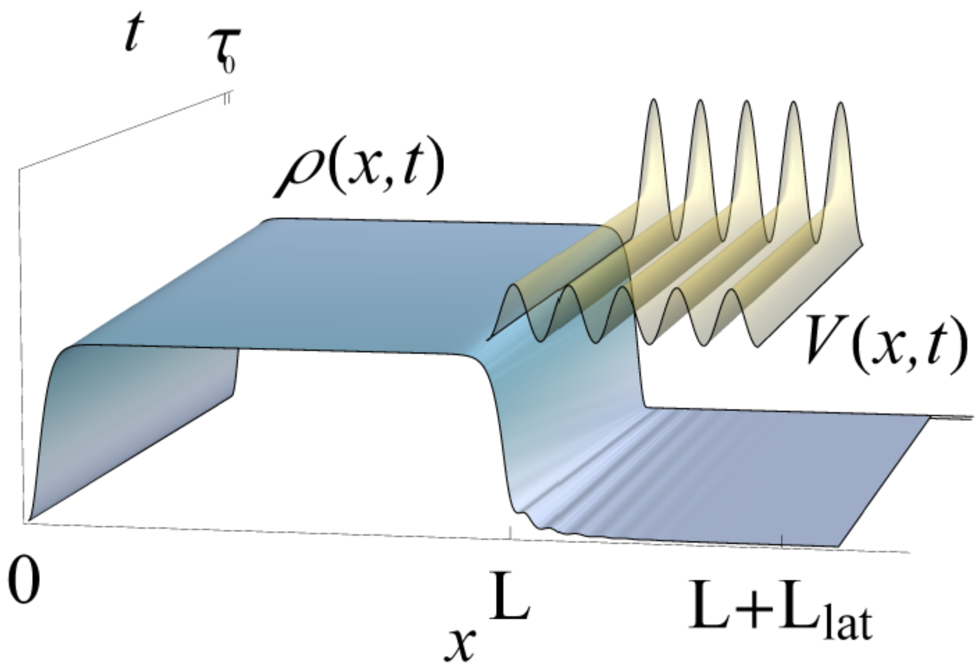
particle-like

Gradual outcoupling of a BEC

$$i\hbar\frac{\partial\Psi(x,t)}{\partial t} = \left[-\frac{\hbar^2}{2m}\partial_x^2 + V(x,t) + g|\Psi(x,t)|^2\right]\Psi(x,t)$$

$$V(x,t) = V(t)\cos^2\left[k_L(x-L)\right]$$
$$V(t) = V_\infty + (V_0 - V_\infty)e^{-t/\tau}$$

Gradual lowering of the (initially) confining optical lattice

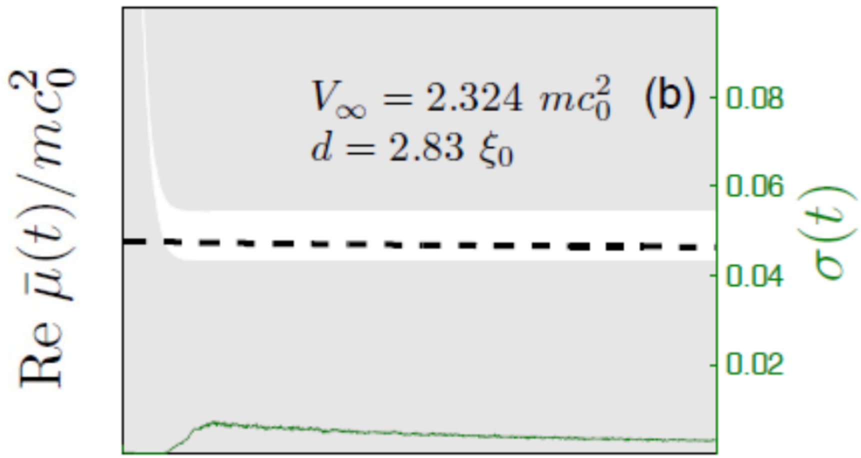


measure of flatness σ(t)

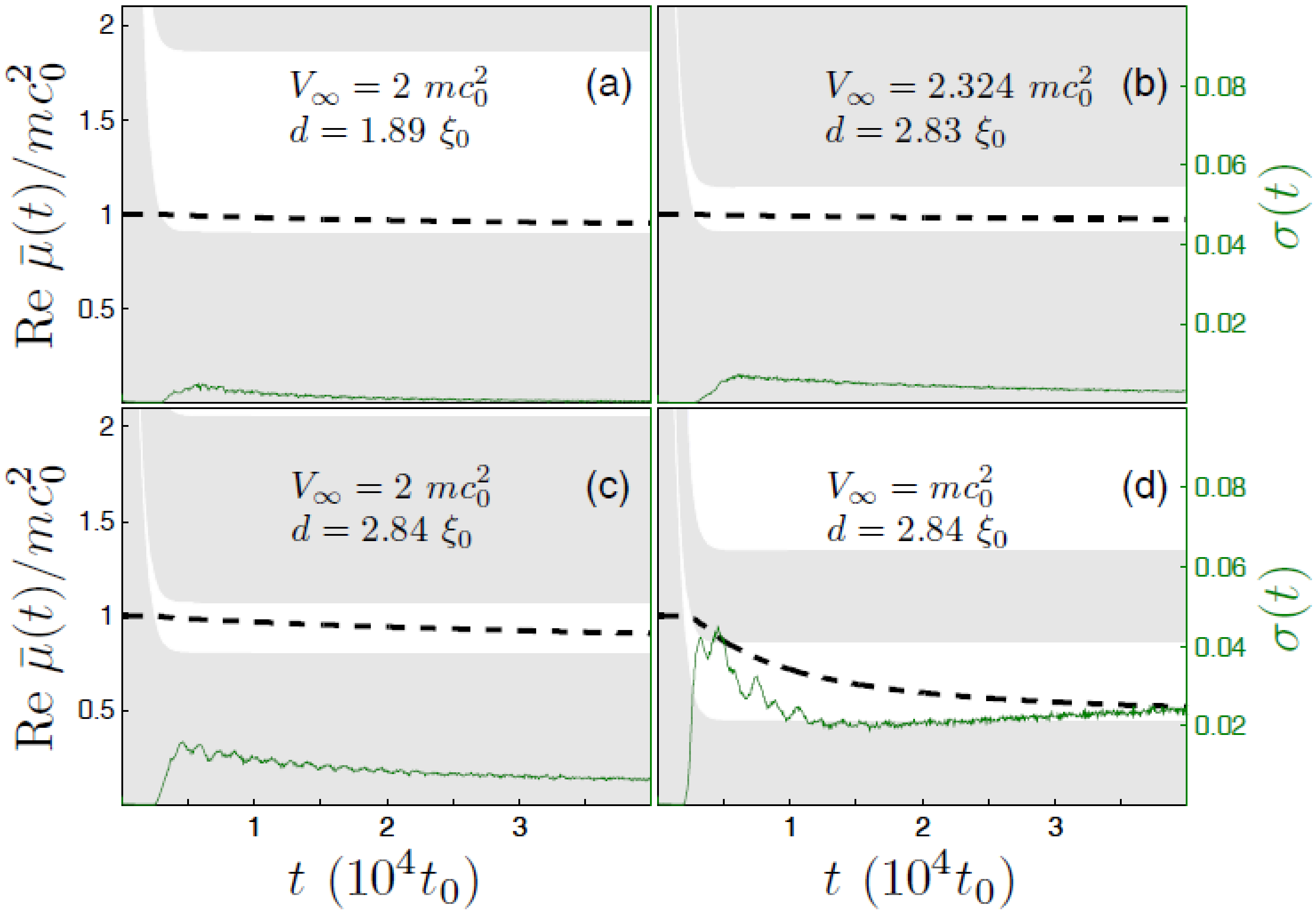
$$\mu(x,t) \equiv -\frac{\hbar^2}{2m}\frac{\partial^2\Psi(x,t)/\partial x^2}{\Psi(x,t)} + V(x,t) + g|\Psi(x,t)|^2$$

$$\bar{\mu}(t) \equiv \frac{\int_0^{L_t} \mathrm{d}x\, \rho(x,t)\mu(x,t)}{\int_0^{L_t} \mathrm{d}x\, \rho(x,t)}$$

$$\sigma(t) \equiv \frac{1}{\bar{\mu}(t)}\left[\frac{\int_0^{L_t} \mathrm{d}x\, \rho(x,t)|\mu(x,t)-\bar{\mu}(t)|^2}{\int_0^{L_t} \mathrm{d}x\, \rho(x,t)}\right]^{\frac{1}{2}}$$



Evolution of the condensate

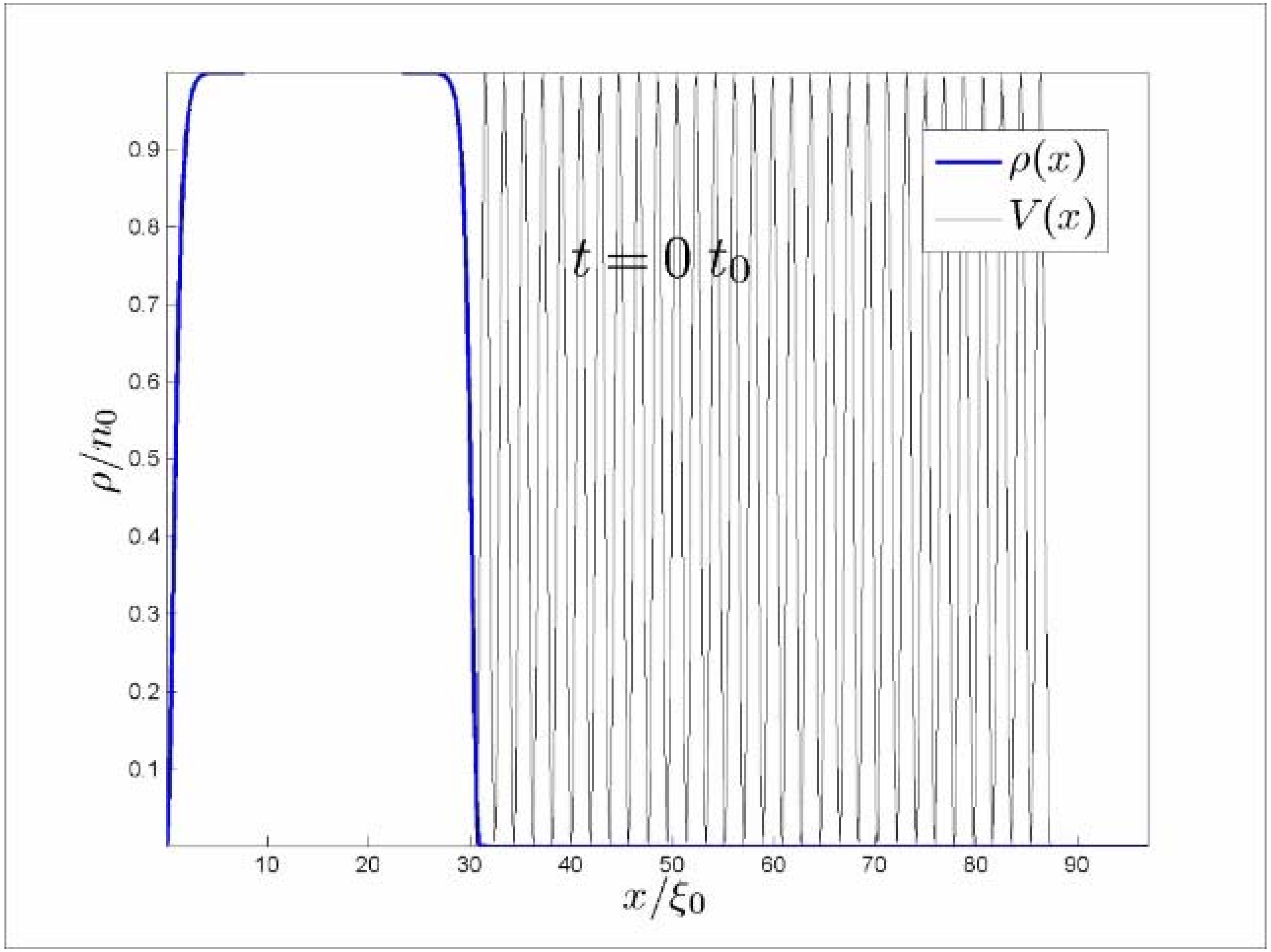


initial chemical potential

vs

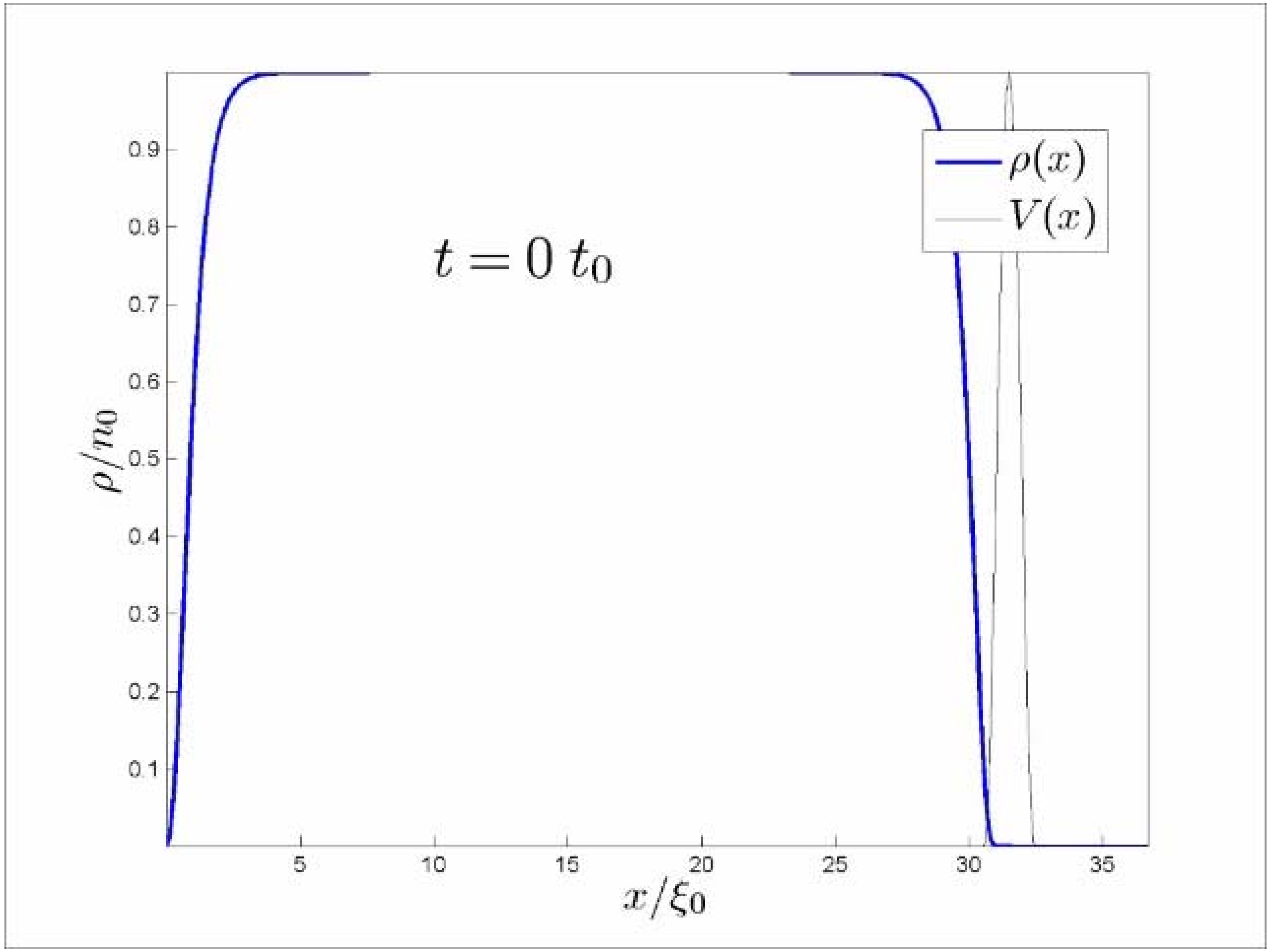
final conduction band

Time for a movie!



flat optical lattice - 30 barriers

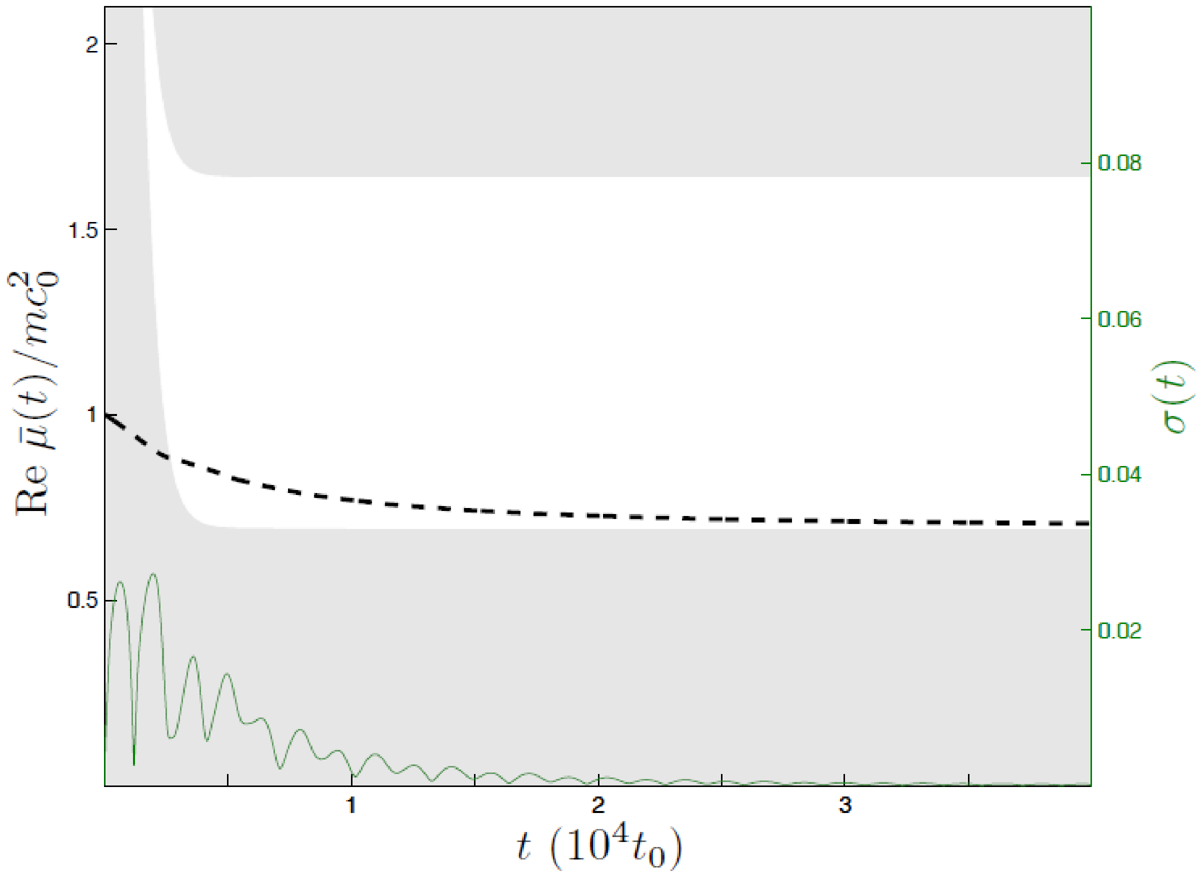
one more movie…



single barrier

Gaussian-shaped (realistic) optical lattice

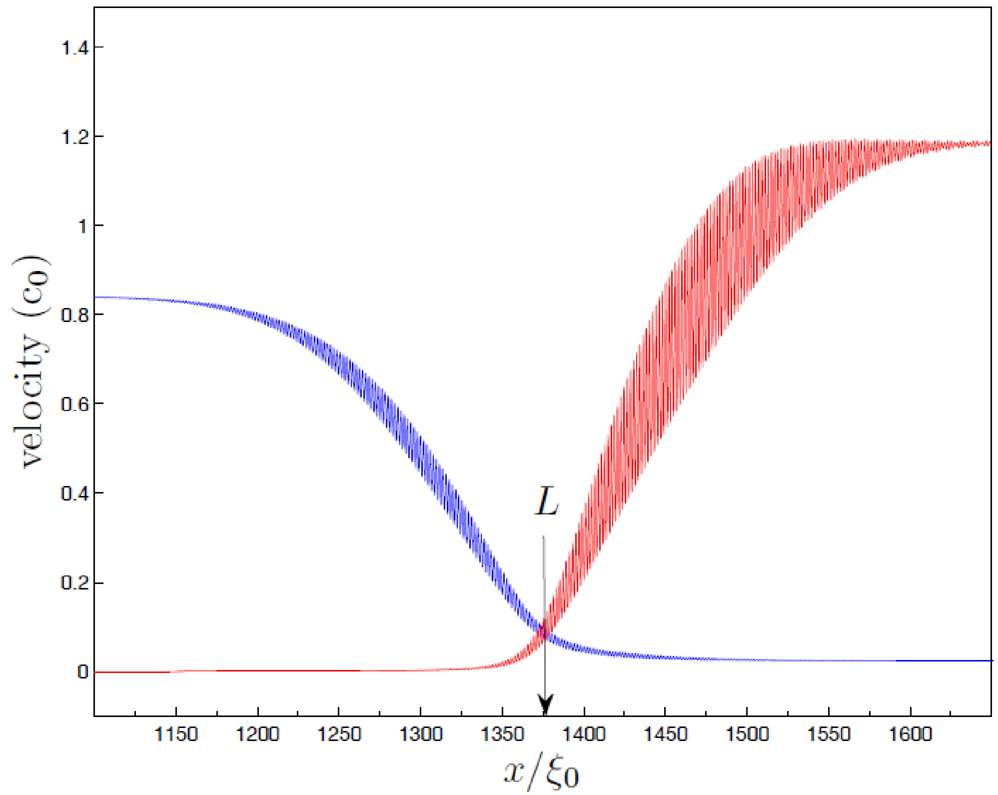
$$V(x,t) = V(t)\cos^2\left[k_L(x-L)\right]\exp\left[-2\left(\frac{x-L}{\tilde{w}}\right)^2\right]$$



similar
behavior
as for
flat lattice

Gaussian – local velocities

$$V(x,t) = V(t)\cos^2\left[k_L(x-L)\right]\exp\left[-2\left(\frac{x-L}{\tilde{w}}\right)^2\right]$$



Event horizon at the center of the Gaussian envelope
(simplified proof, *m* cnst.)

$$\mu \simeq \bar{V}(x) + \frac{1}{2} m \bar{v}^2(x) + m \bar{c}^2(x)$$

potential + *kinetic* + *interaction* = constant

$\bar{c}^2(x)\bar{v}(x)$ constant because of uniform current (stationary regime)

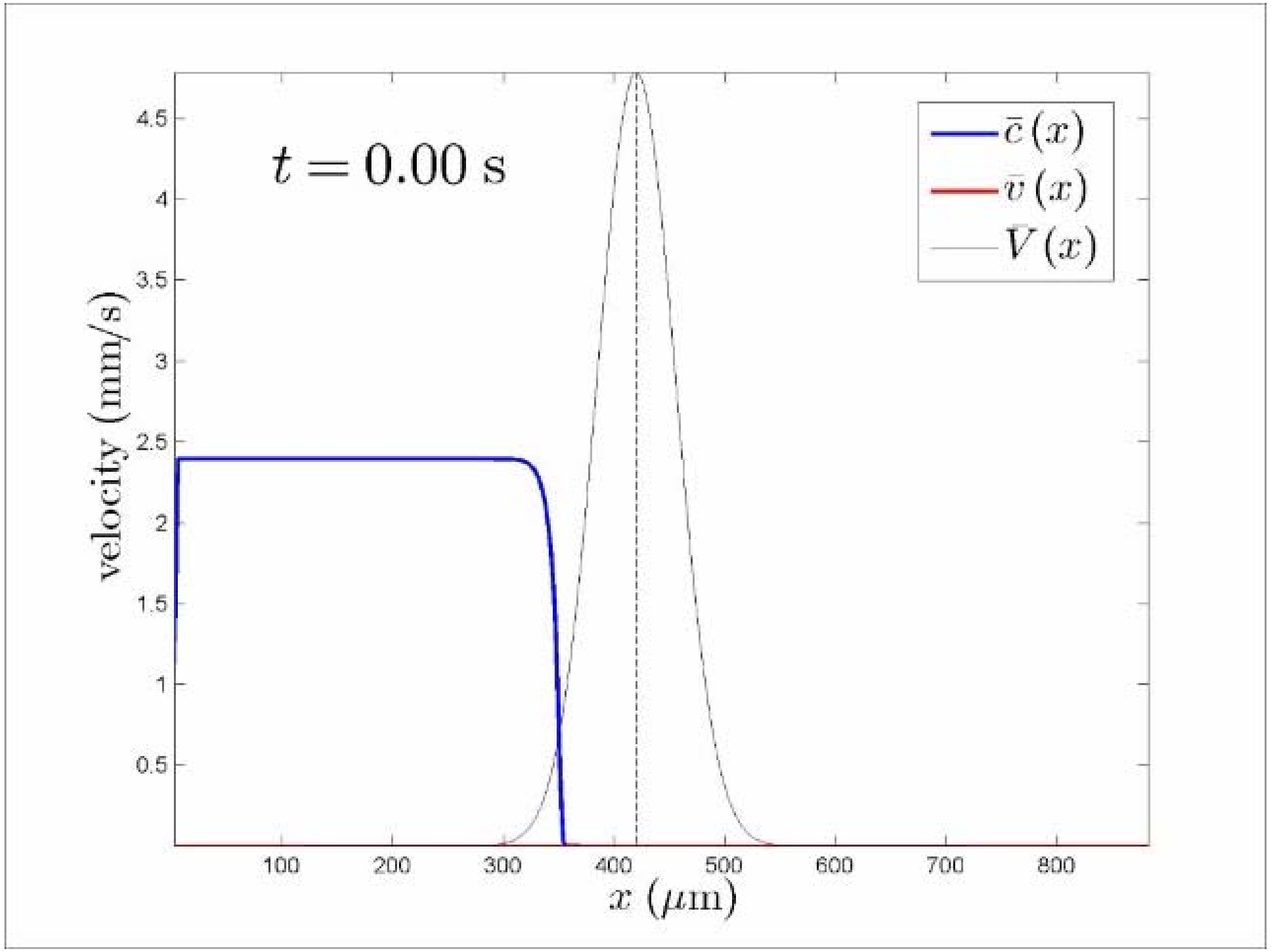
$\frac{1}{2} m \bar{v}^2(x) + m \bar{c}^2(x)$ constant at V maximum (x=L)

$$\bar{v}'\bar{c} + 2\bar{c}'\bar{v} = 0$$
$$\bar{v}\bar{v}' + 2\bar{c}\bar{c}' = 0$$

⇒

$$\boxed{\bar{c}(L) = \bar{v}(L)}$$

The movie



Gaussian-shaped (realistic) optical lattice

sonic horizon right at the center of the Gaussian lattice!

(can be explained theoretically)

CONCLUSIONS – Hawking radiation

- Highly non-thermal Hawking (zero-point) radiation is generated on the subsonic (superfluid) side of a condensate leaking through a double barrier interface

- Many of the interesting solutions are stable, i.e. true resonances

- Cauchy-Schwarz violation in the u-d2 channel occurs if and only if spontaneous (zero-point) Hawking radiation is present.

- It can be observed near the peak in the Hawking spectrum of a resonant double-barrier structure.

- In some setups, CS violation can be directly observed in the atom signal of a time-of-flight experiment.

- The decisive CS violation cannot occur near the conventional, zero-frequency peak universally shown by one-dimensional sonic black-hole structures.

CONCLUSIONS – birth of a sonic black hole

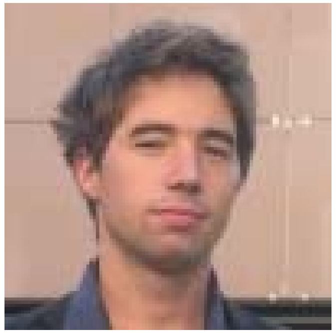
- Lowering of an extended optical lattice favors the emergence of well controlled quasi-stationary subsonic -> supersonic condensate flow.

- Lowering of a Gaussian-envelope (realistic) optical lattice is likely to give birth to a robust quasi-stationary sonic black hole.

- This scenario offers hopes for the observation of spontaneous Hawkling radiation.

J. R. Muñoz de Nova
UCM - Haifa

Ivar Zapata
UCM



Mathias Albert
Univ. Geneva - Nice

David Guery-Odelin
Univ. Toulouse

Renaud Parentani
Univ. Paris-Sud, Orsay

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