Low-dimensional quantum gases: correlations, excitations, and emergent statistics

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quantummatter.at

ICAP2026 in Wuhan, June 12th 2026

Warning: this will be a flash talk

2012-2016
2019-2023
2025-2030

The team(s)

for today`s talk


Milena Horvath
PhD student


Sudipta Dhar
PhD student


Yanliang Guo
Postdoc


Manuele Landini
Senior scientist


Krzysztof Zamarski
PhD student


Charlie Beulenkamp
PhD student

New PhD students:

Emilio Aguilera
Louisa Krbashian
Igor Zhuravlev
Evgenyi Gadylshin


Yi Zeng
Postdoc

now Rochester


Zekai Chen
Postdoc


Karthick Ramanathan
PhD student


Camilo Cantillano
PhD student


Xudong Yu
Postdoc


Reza Nejad
PhD student

Students:

Yijing Zhang
Mingrui Yang
Shien Wan
Wenhan Chen

Collaborations with: **H.Yao** (Beijing), **L.Ying** (Hangzhou), **A.Bastianello** (CNRS), **J.S.Caux** (Amsterdam), **M.Knap** (Munich), **N.Goldman + B.Wang** (Bruxelles), **M.Zvonarev** (Paris), **G.Astrakharchik** (Barcelona), **L.Sanchez-Palencia** (Paris), **T.Giamarchi** (Geneva),...

My Chinese friends

From left to right:

Zekui Wang, PhD student, visiting from Shanxi University

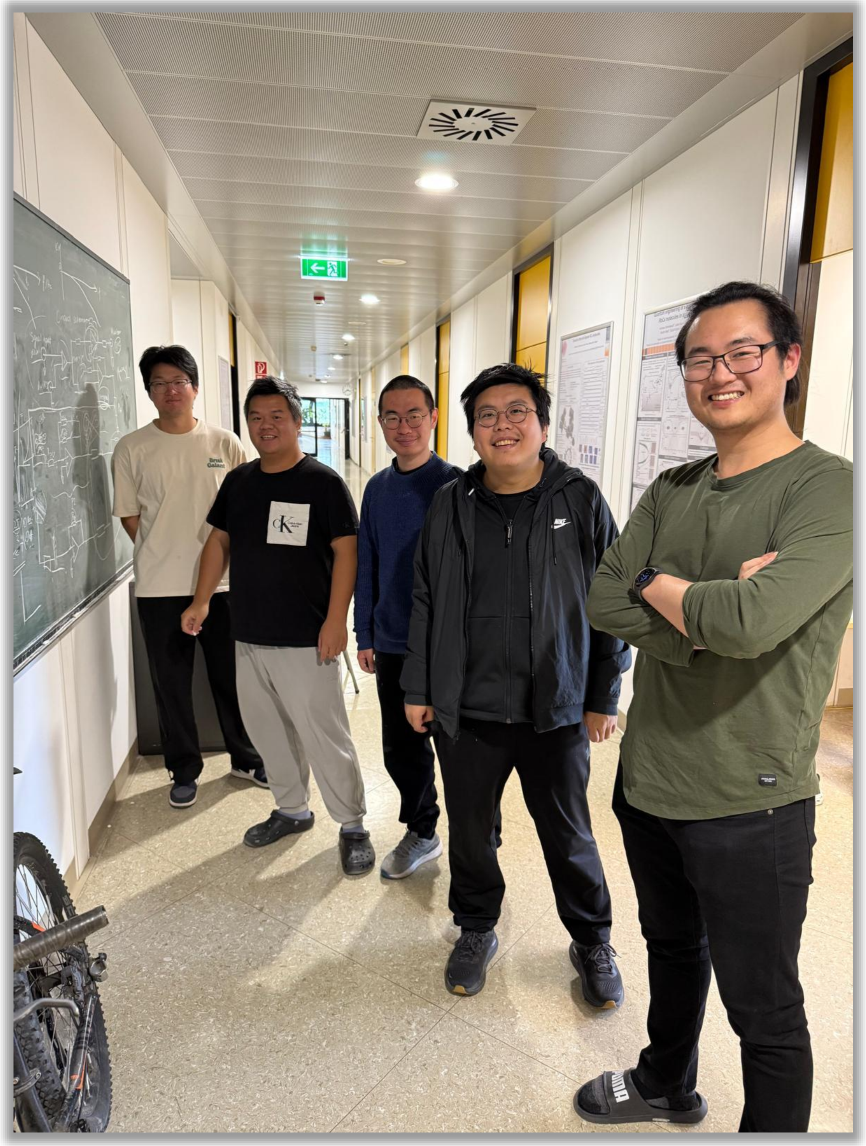
Yanliang Guo, postdoc, here in the audience)

Yijing Zhang, student, visiting from Xi'an Jiaotong University

Xudong Yu, postdoc, arrived from the group of Alain Aspect, Paris, in Feb.2025

Yi Zeng, postdoc, arrived fall 2024 from Caltech

Join us!!!



Not shown: Mingrui Yang, Shien Wan, Wenhan Chen

Botao Wang (Brussels)

Hepeng Yao (Beijing)

Lei Ying (Hangzhou)

Former group members:

to the USA

Dechao Zhang
Postdoc

now Munich

Dizhou Xie
Postdoc

now Rochester

Zekai Chen
Postdoc

The quantum challenge: dynamics

Celebrating 101 years of **quantum mechanics** this year

(note: Schrödinger‘s equation and Born‘s interpretation are from 1926!)

A. Zeilinger: „At least 40% of the world‘s GP is generated on the basis of the **Schrödinger equation**“

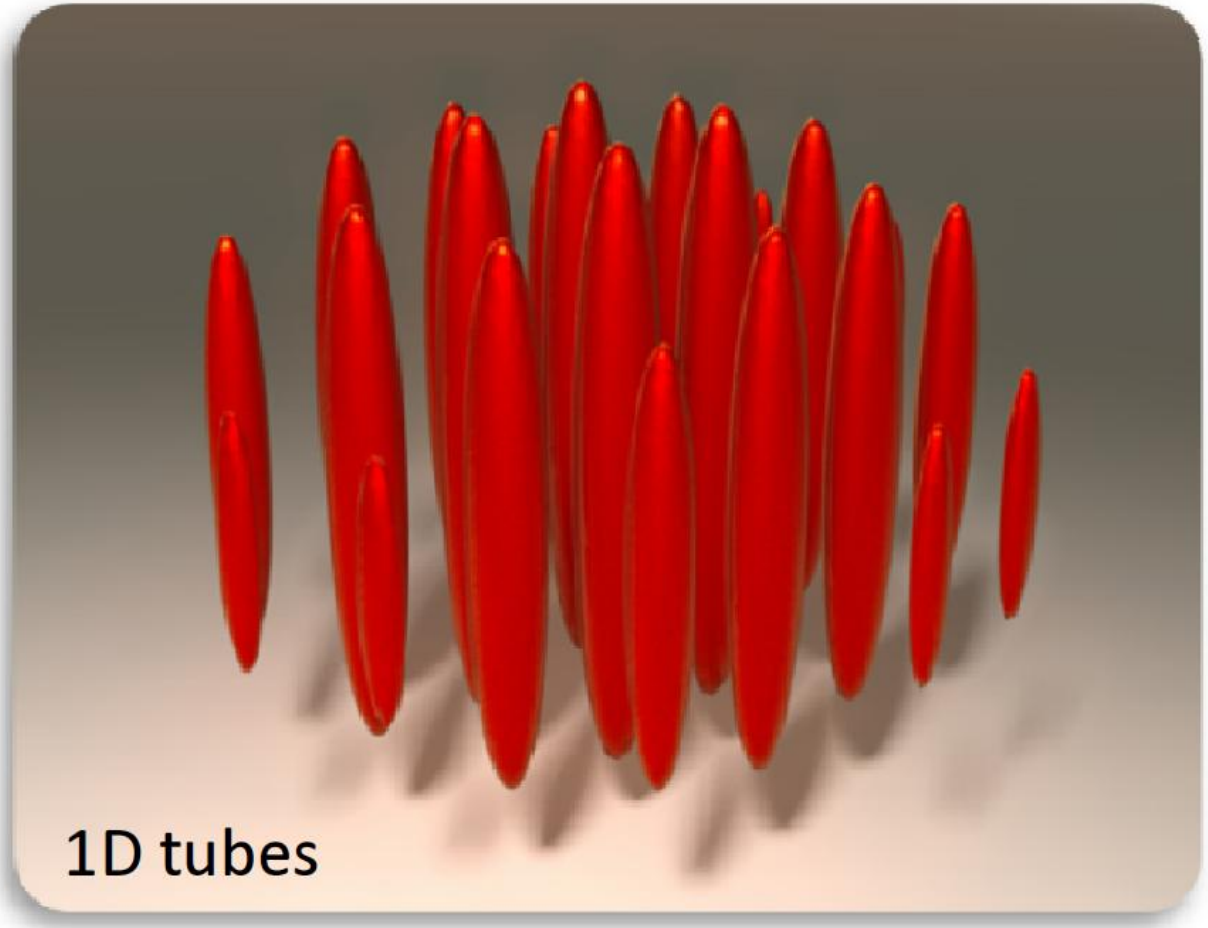
(Nobel laureate 2022)

But: Surprisingly little understood

Almost all problems are **exponentially hard…**

…and dynamical systems even more so

1D: a great platform!



One-dimensional systems are special!

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One-dimensional systems are special!

1D systems exhibit a rich portolio of quantum effects:

- Fermionization Science, 305, 1125 (2004) (Weiss group), Science 325, 1224 (2009)
- Immediate pinning Nature 466, 597 (2010) arXiv:2605.12322 (2026)
- Anyonization Nature 642, 53 (2025)
- Super-fermionization arXiv:2602.17657 (2026)
- Many-body dynamical localization Science 389, 716 (2025)
- Cooling upon confinement Science Advances 10, 6 (2024)
- Anomalous superfluidity arXiv:2602.12320 (2026)
- Exotic bound states arXiv:2505.10550 (2025)
- …

E. Haller *et al.*,

Background on 1D: Lieb-Liniger model

$$\boxed{\hat{H} = -\frac{\hbar^2}{2m}\sum_{i=1}^{N}\frac{\partial^2}{\partial z_i^2} + g_{1D}\sum_{i<j=1}^{N}\delta(z_i - z_j)}$$

1D coupling constant:

$$g_{1\mathrm{D}} \approx 2\hbar\omega_{\perp}a_{\mathrm{s}}$$

transversal trapping frequency

scattering length

Lieb-Liniger parameter:

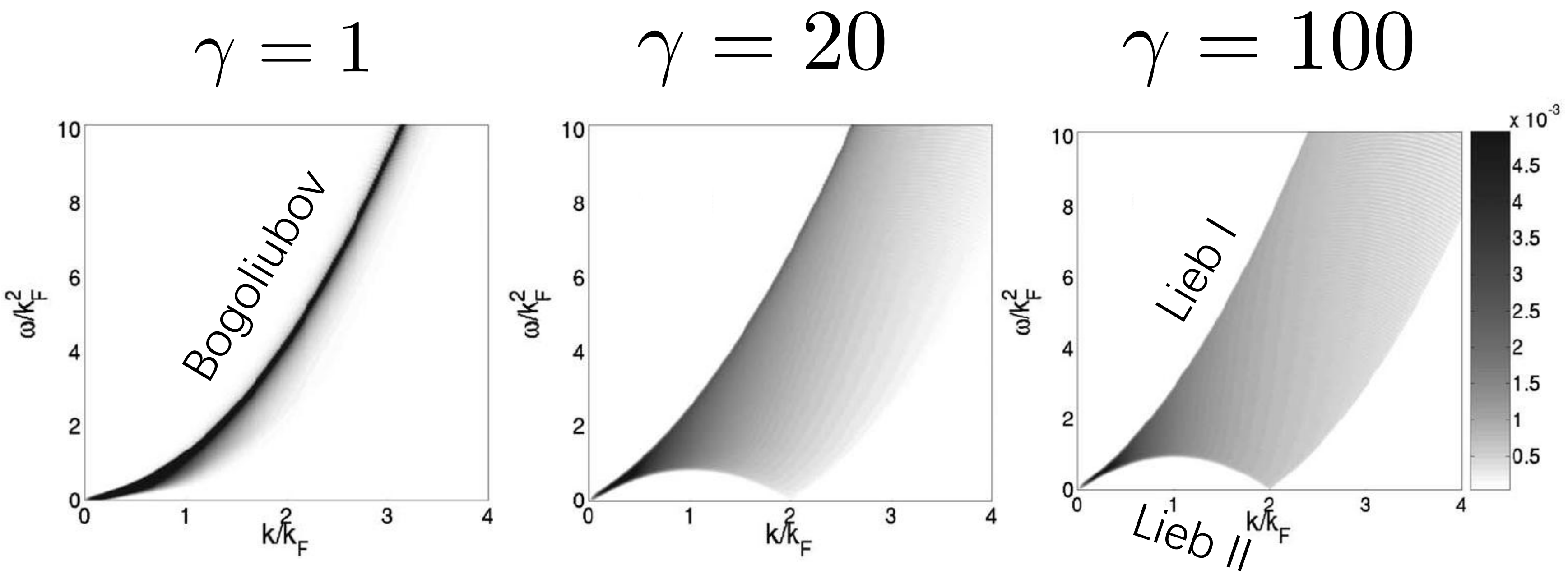
$$\gamma = \frac{m\, g_{1\mathrm{D}}}{\hbar^2 n}$$

1D density

Example: Excitations in the D=1 Bose gas

Dynamic structure factor $$S(k,\omega) = \int_0^L dx \int dt e^{-ikx+i\omega t} \langle \rho(x,t)\rho(0,0) \rangle$$

J.-S. Caux and P. Calabrese,
Phys. Rev. A **74**, 031605(R) (2006)



$\gamma = 1$
Wealy-interacting bosons

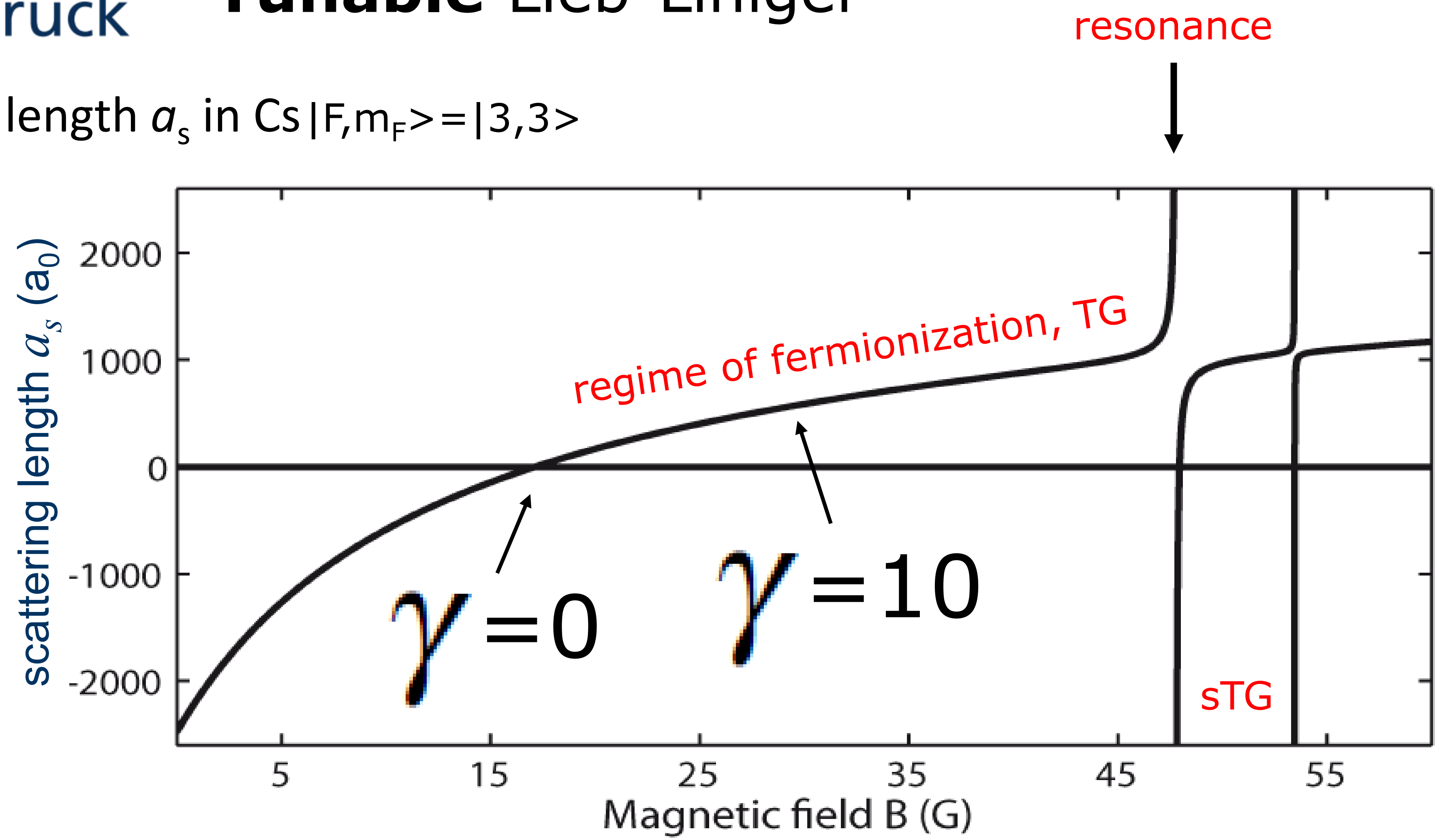
increase interactions

$\gamma \to \infty$
free fermions

systems develops *collective* branches

Tunable Lieb-Liniger

Scattering length a_s in Cs $|F,m_F\rangle=|3,3\rangle$



fermionization in the so-called Tonks-Girardeau (TG, γ>0) and super Tonks-Girardeau (sTG, γ<0) states

Theory: M. Girardeau, J. Math. Phys. 1, 516 (1960);
Experiment: Bloch group, Nature 429, 277 (2004); Weiss group, Science, 305, 1125 (2004); Nägerl group, Science 325, 1224 (2009)

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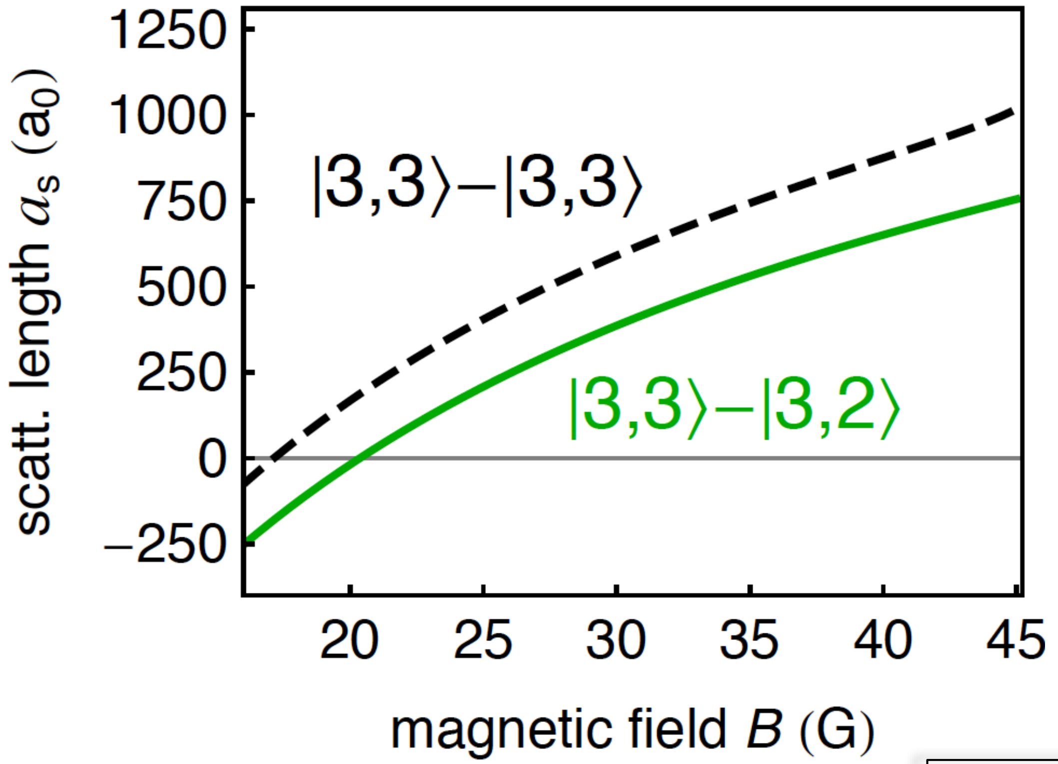
Strongly interacting one-dimensional bosonic quantum gas with an impurity

Tuning interactions: host gas: F=3, m_F=3 impurity: F=3, m_F=2

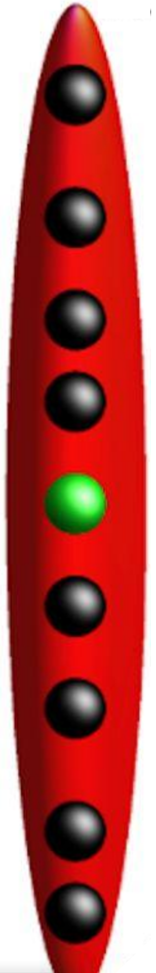


1D coupling constant:

$$g_{1\mathrm{D}} \approx 2\hbar\omega_\perp a_\mathrm{s}$$

Lieb-Liniger parameter:

$$\gamma = \frac{m\, g_{1\mathrm{D}}}{\hbar^2 n}$$



scatterering length data by P. Julienne, NIST, and the Hutson group, Durham

Notation: γ = for the bath-bath interaction

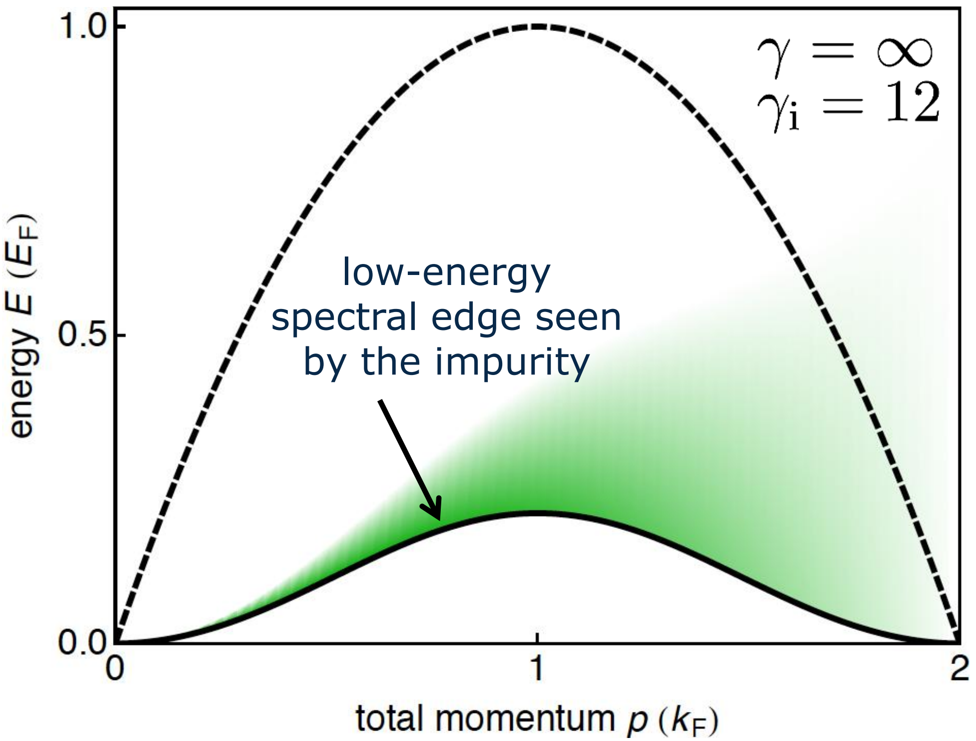
γ_i = for the impurity-bath interaction

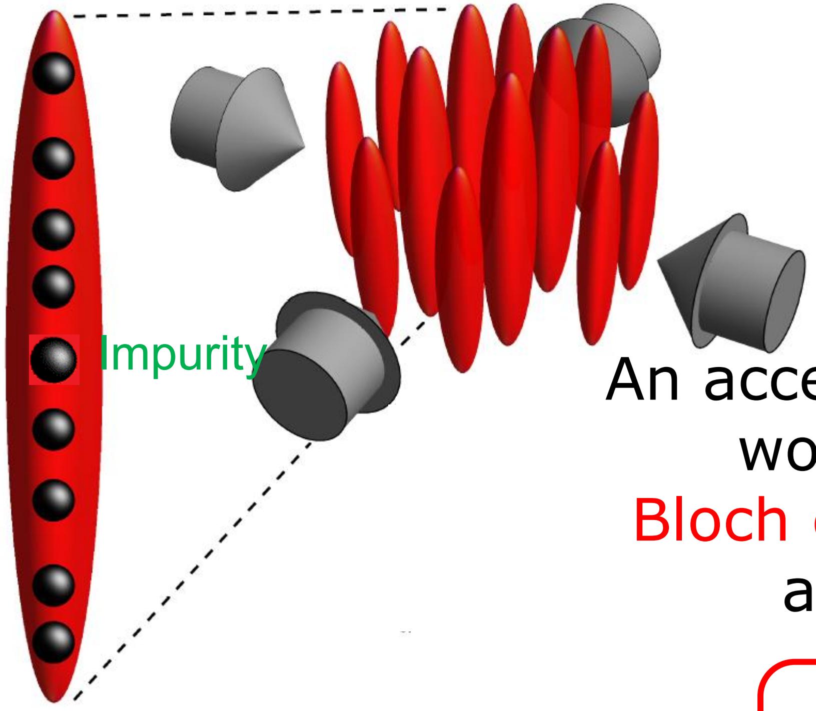
Impurities: dispersion relation

short-ranged crystal-like
properties via strong repulsion

Tonks-Girardeau gas (TG)

$$\boxed{\gamma = \frac{m g_{1\mathrm{D}}}{\hbar^2 n} \rightarrow \infty}$$





An accelerated impurity would undergo Bloch oscillations with a frequency

$$\boxed{f_\mathrm{B} = \frac{F}{2\hbar k_\mathrm{F}}}$$

set by the Fermi momentum

$$k_\mathrm{F} = \pi n_{1\mathrm{D}}$$

However: Damping due to phonons

D. M. Gangardt et al., Phys. Rev. Lett. **102**, 070402 (2009)
M. Knap et al., Phys. Rev. Lett. **112**, 015302 (2014)

Recent Innsbruck results (1)

Observation of many-body dynamical localization (MBDL)

MANY-BODY DYNAMICS

Observation of many-body dynamical localization

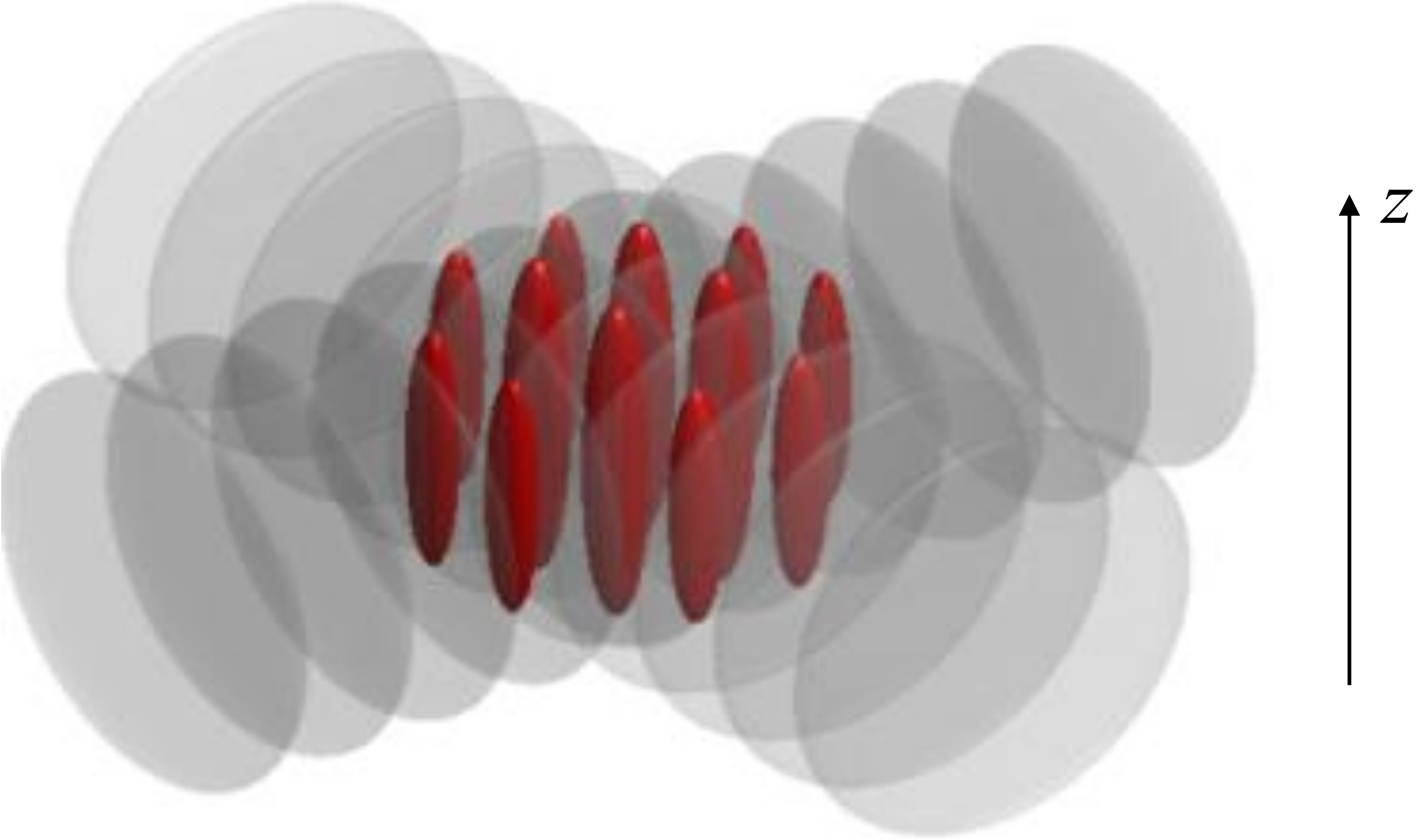
Yanliang Guo[1]†, Sudipta Dhar[1]†, Ang Yang[2]†, Zekai Chen[1], Hepeng Yao[3], Milena Horvath[1], Lei Ying[2]*, Manuele Landini[1], Hanns-Christoph Nägerl[1]*

Y. Guo et al., Science 389, 716 (2025)

see also: *Origin and emergent features of many-body dynamical localization*
A.Yang, Z. Chen, Y. Guo, M. Landini, H.-C. Nägerl, L. Ying,
PRL 136, 123402 (2026)

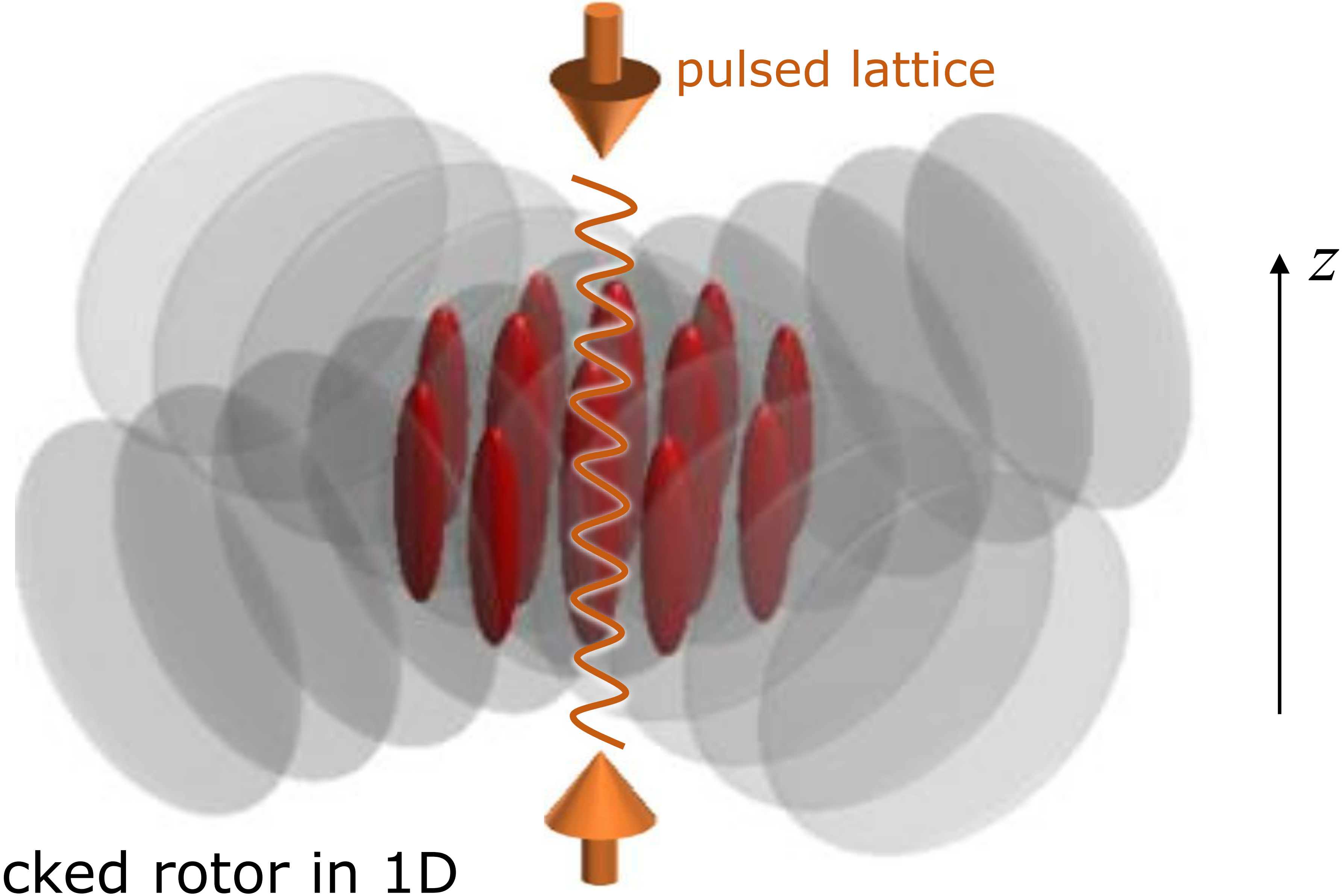
Dynamics in 1D tubes

Array of 1D tubes



Dynamics in 1D tubes

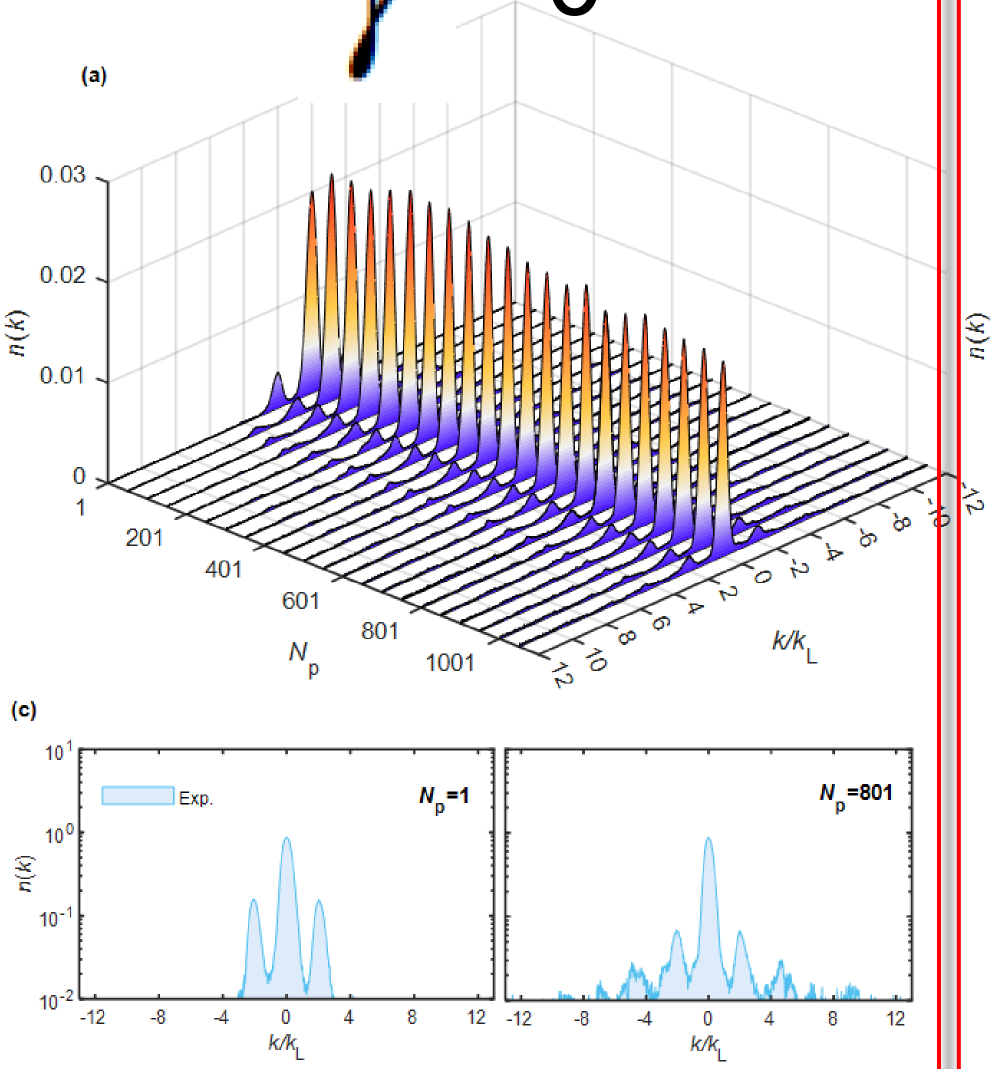
Array of 1D tubes



Quantum kicked rotor in 1D

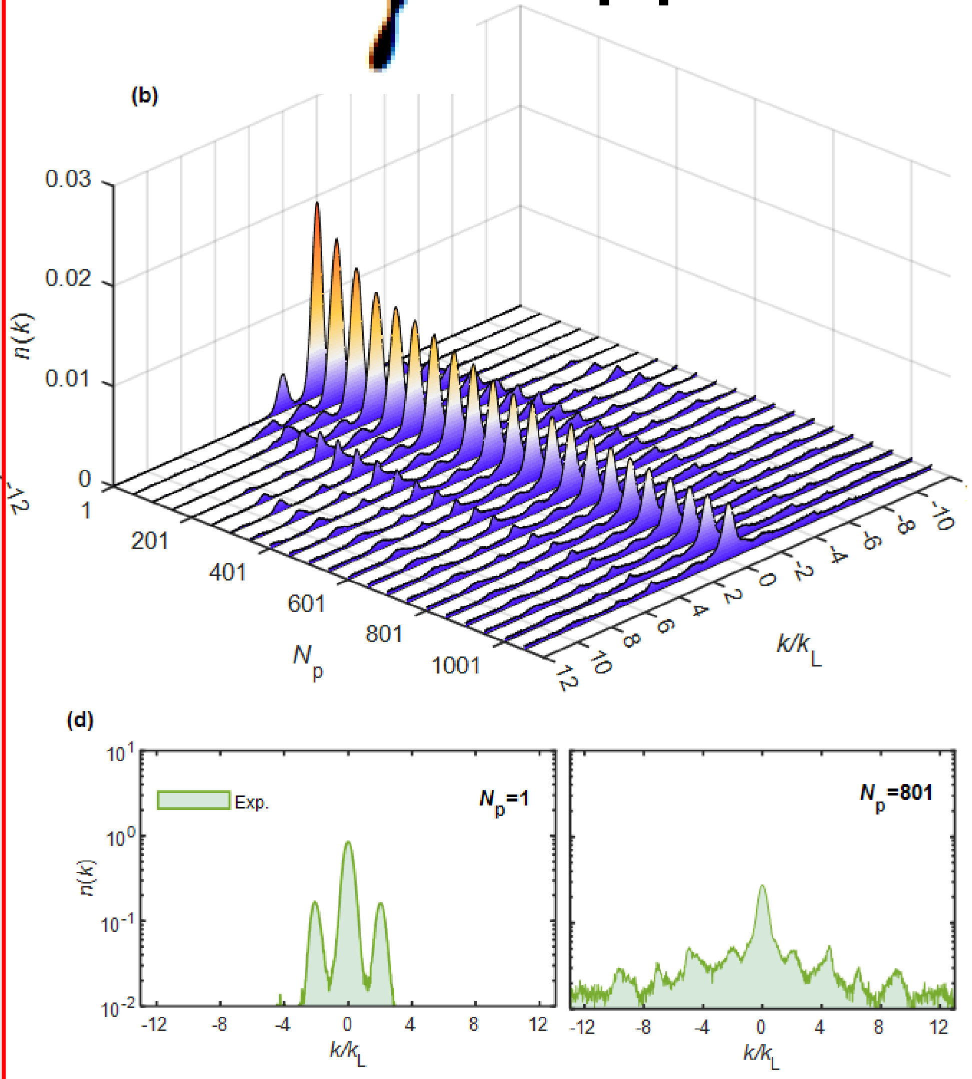
Time evolution: momentum distribution

$\gamma = 0$



Single-particle regime

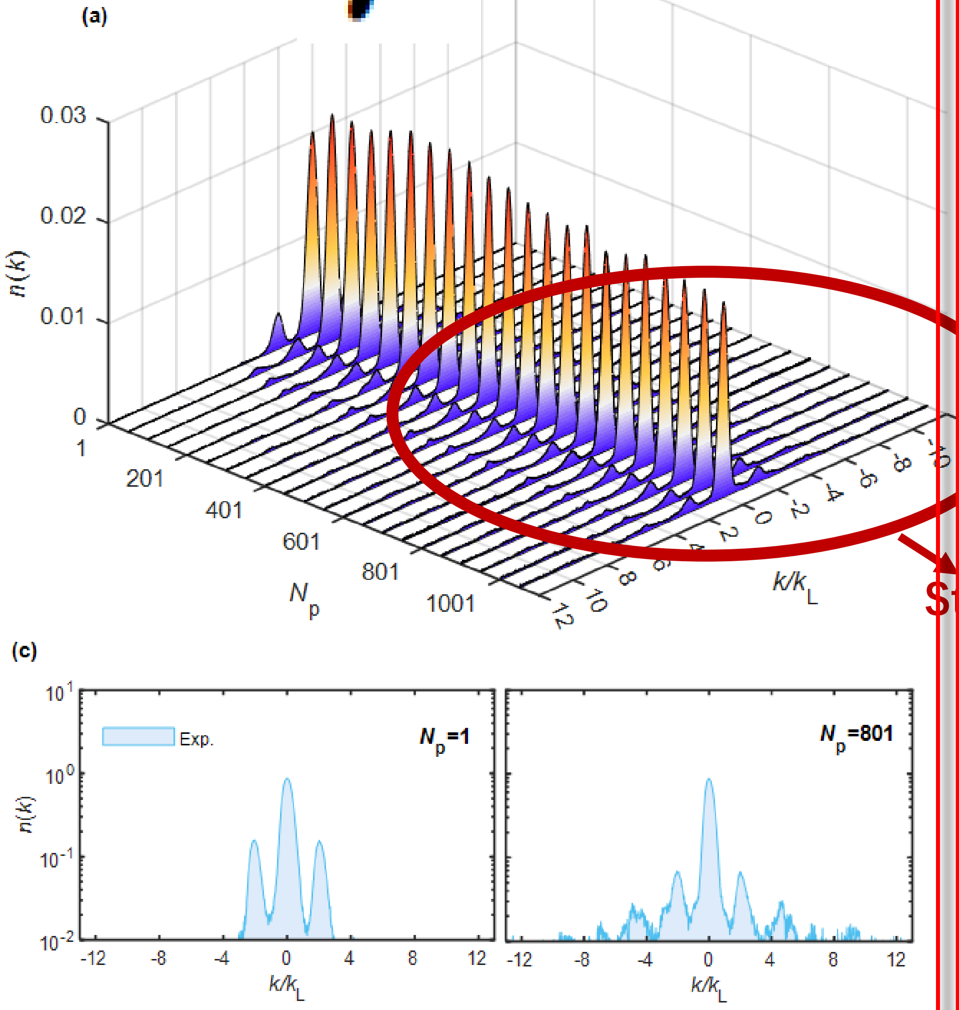
$\gamma = 11$



TG regime

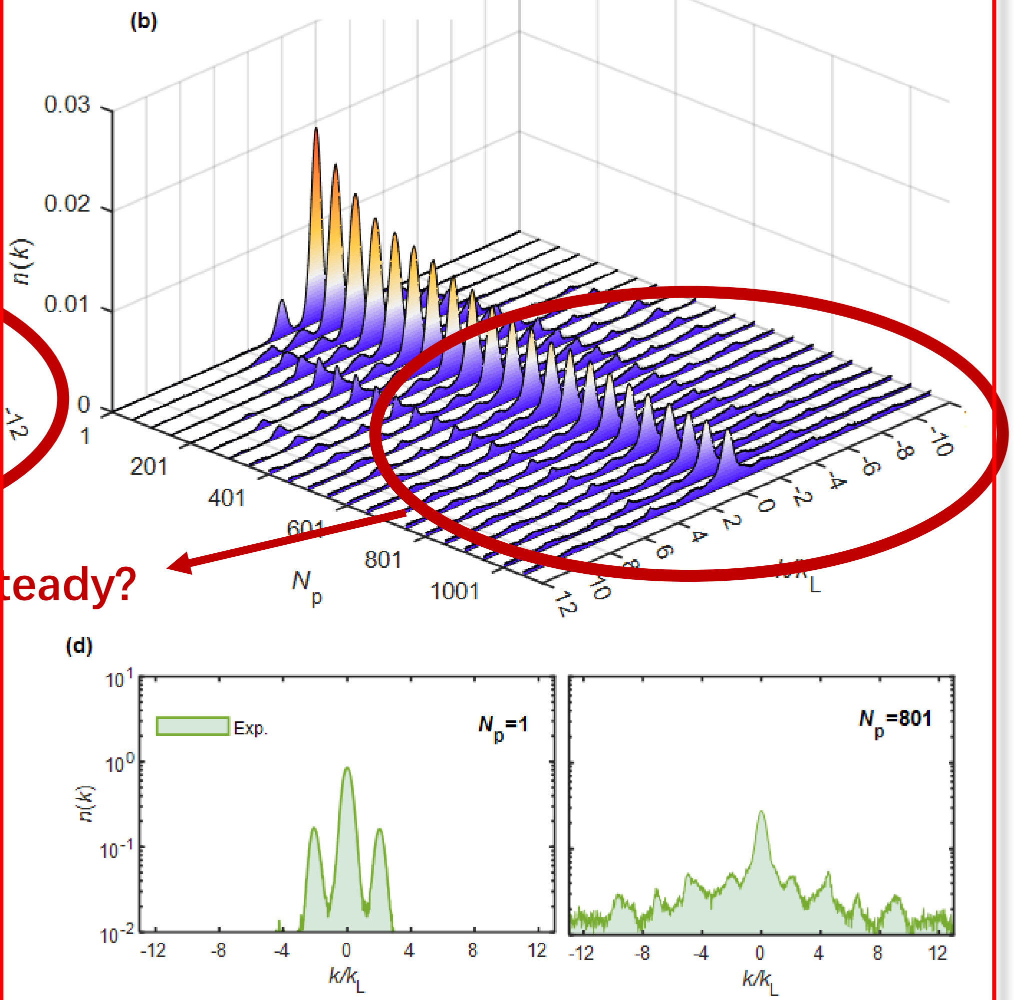
Time evolution: momentum distribution

$\gamma = 0$



Single-particle regime

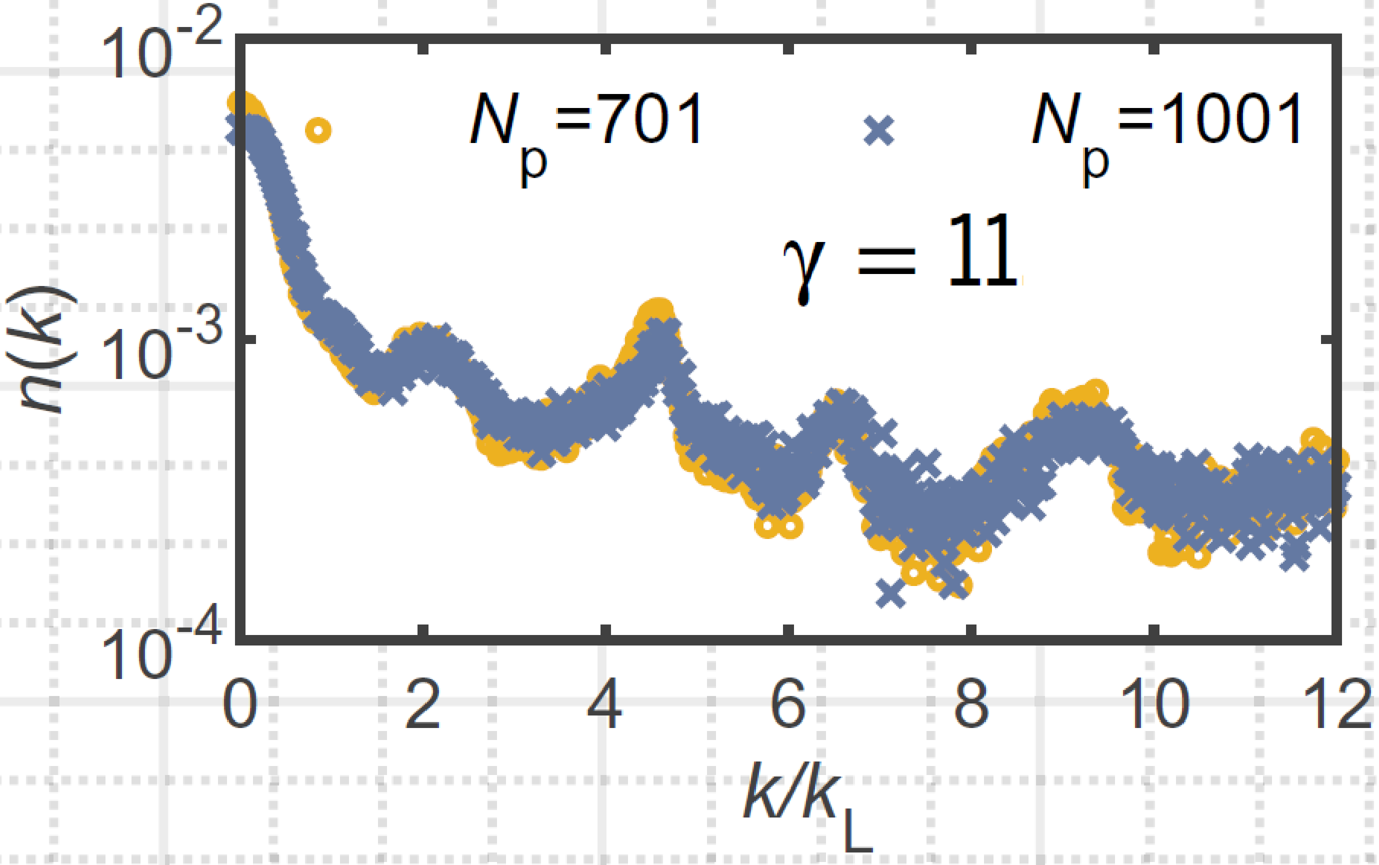
$\gamma = 11$



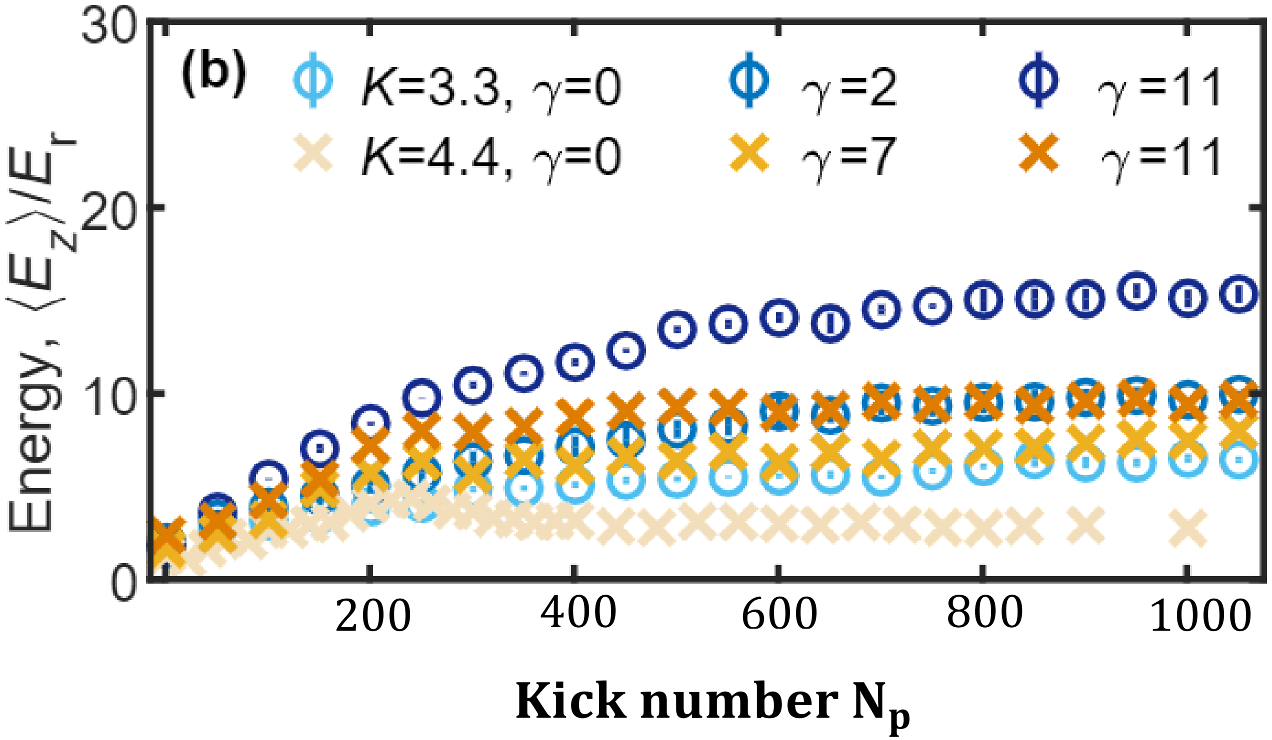
TG regime

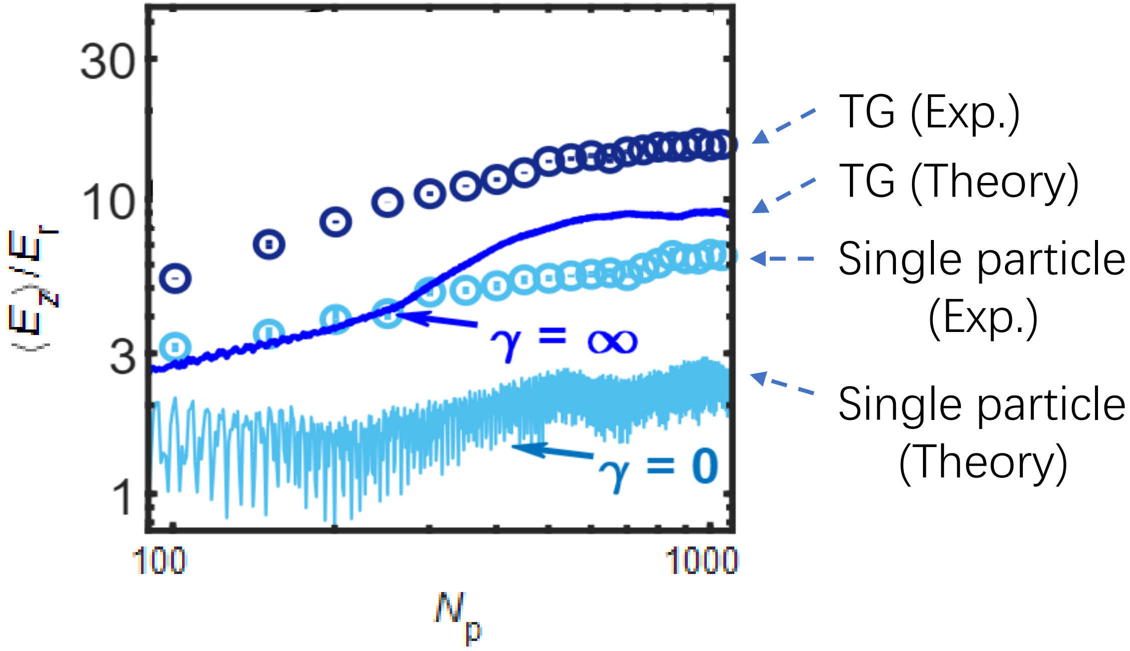
Steady?

Localized!



QKR: Kinetic energy





- Kinetic energy per particle extracted from $n(k)$.
- $\gamma = 0 - 11$

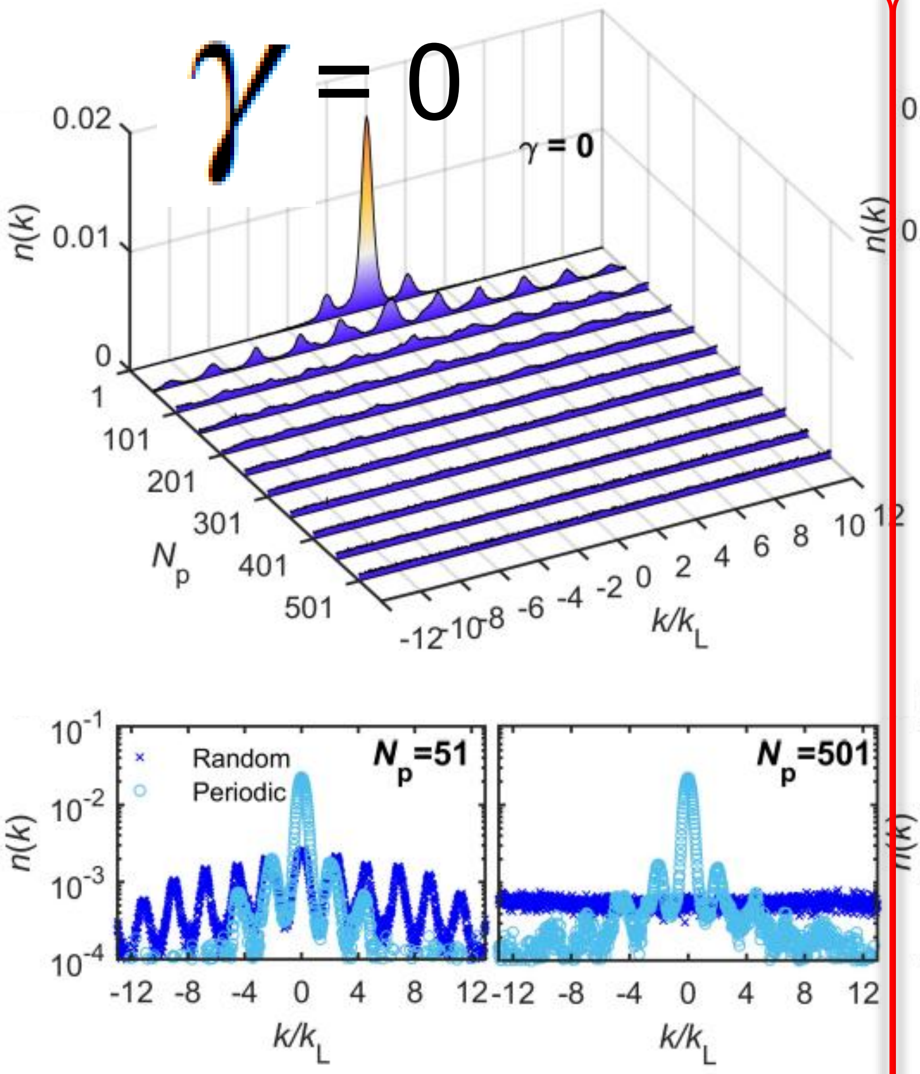
- Energy undergoes sub-diffusion at first.
- Energy saturates at long times.

Breaking localization: randomized pulses

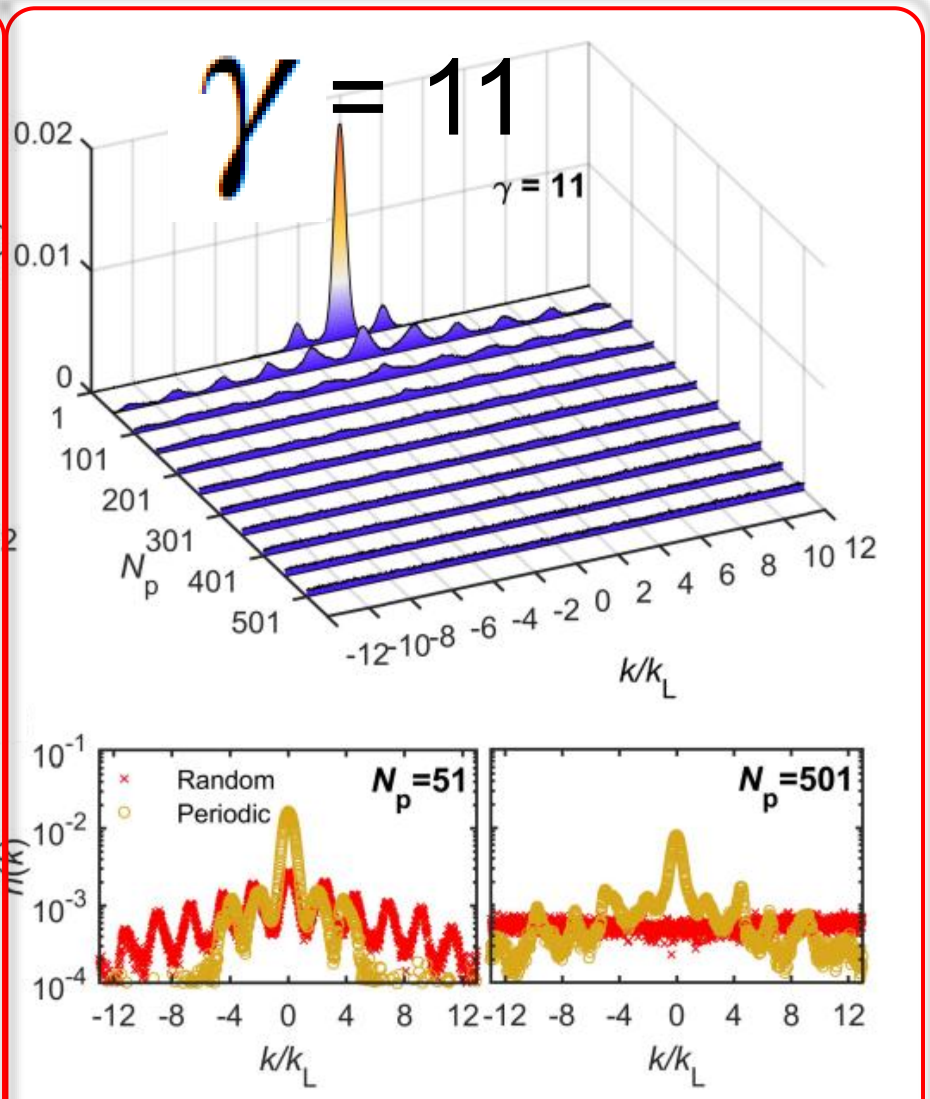
Experiment results:
Momentum distribution

Momentum distributions smear out for random kicks and finally become uniform distributions

$\gamma = 0$



$\gamma = 11$



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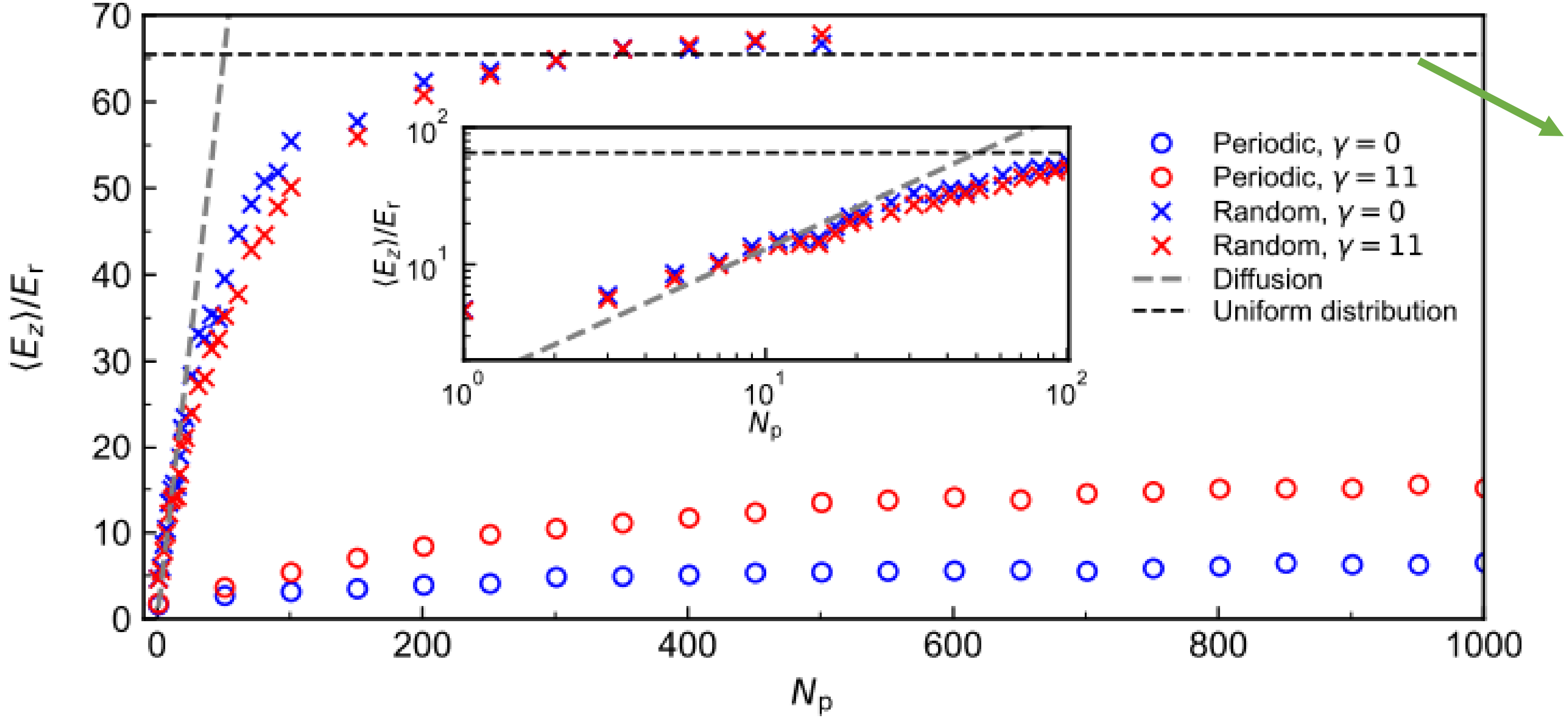
Chaotic dynamics and thermalization

Experiment results: kinetic energy growth



Maximum value set by a uniform n(k) in the limited momentum window

MBDL and DL phases are evidently caused by quantum coherence

Recent Innsbruck results (2)

Experimental results on the *interacting* kicked rotor in 3D

arXiv > cond-mat > arXiv:2605.22449

Condensed Matter > Quantum Gases

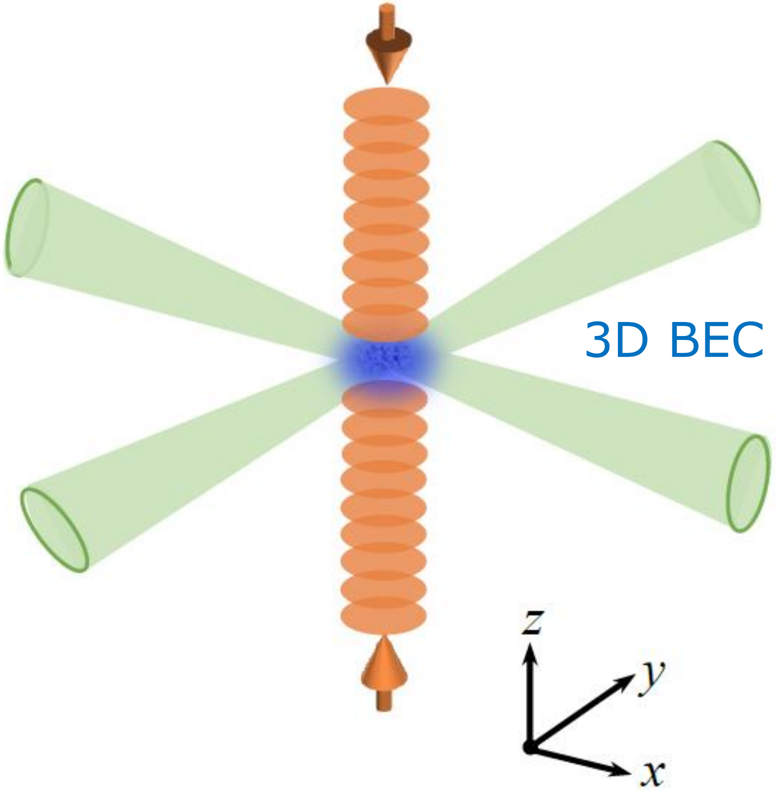
[Submitted on 21 May 2026]

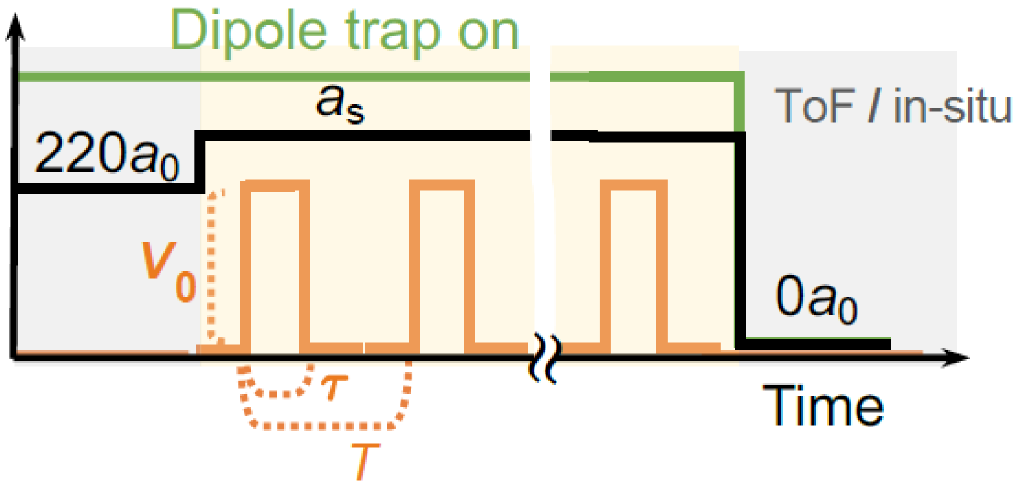
Interaction-enabled metal-insulator phase transition in a driven quantum gas

Camilo Cantillano, Karthick Ramanathan, Zekai Chen, Ang Yang, Emilio Aguilera-Valdes, Lei Ying, Manuele Landini, Hanns-Christoph Nägerl, Yanliang Guo

Re-titled: MBDL and its breakdown in a 3D interacting quantum gas

The (interacting) kicked rotor in 3D

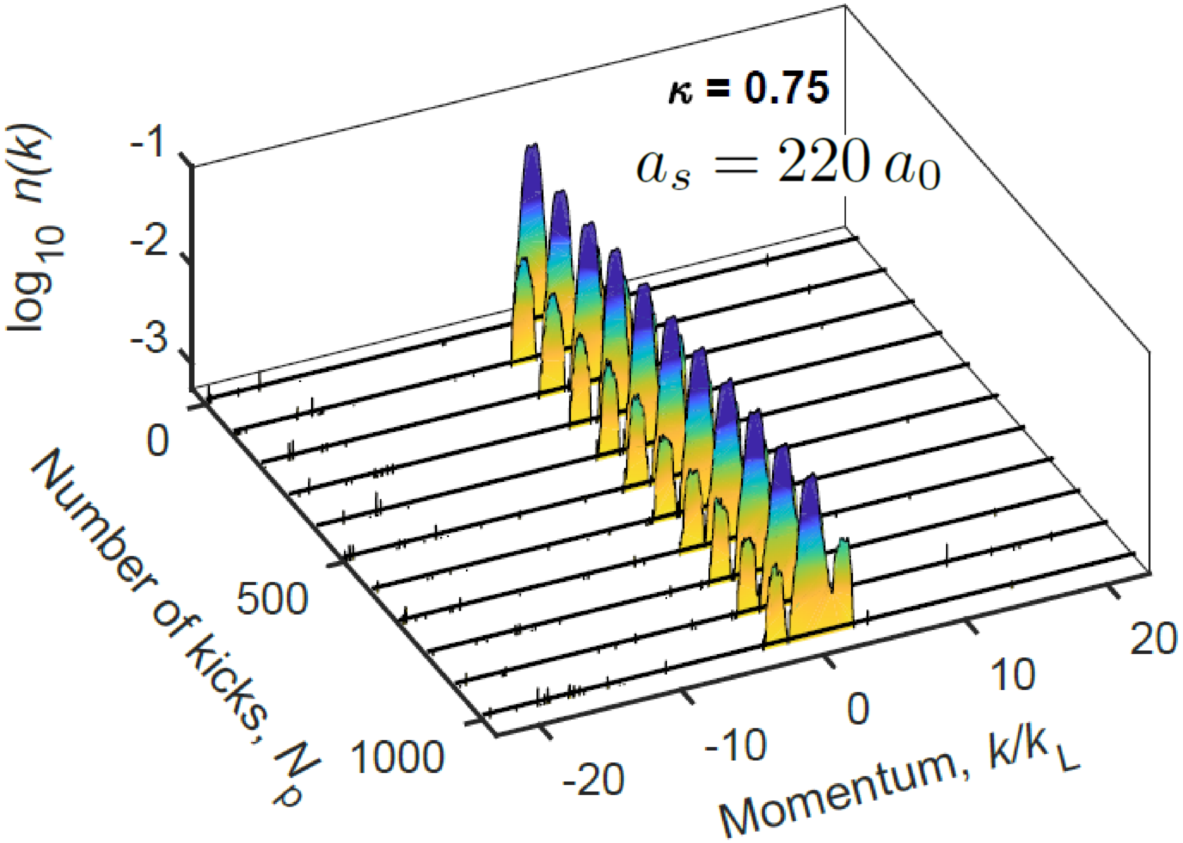




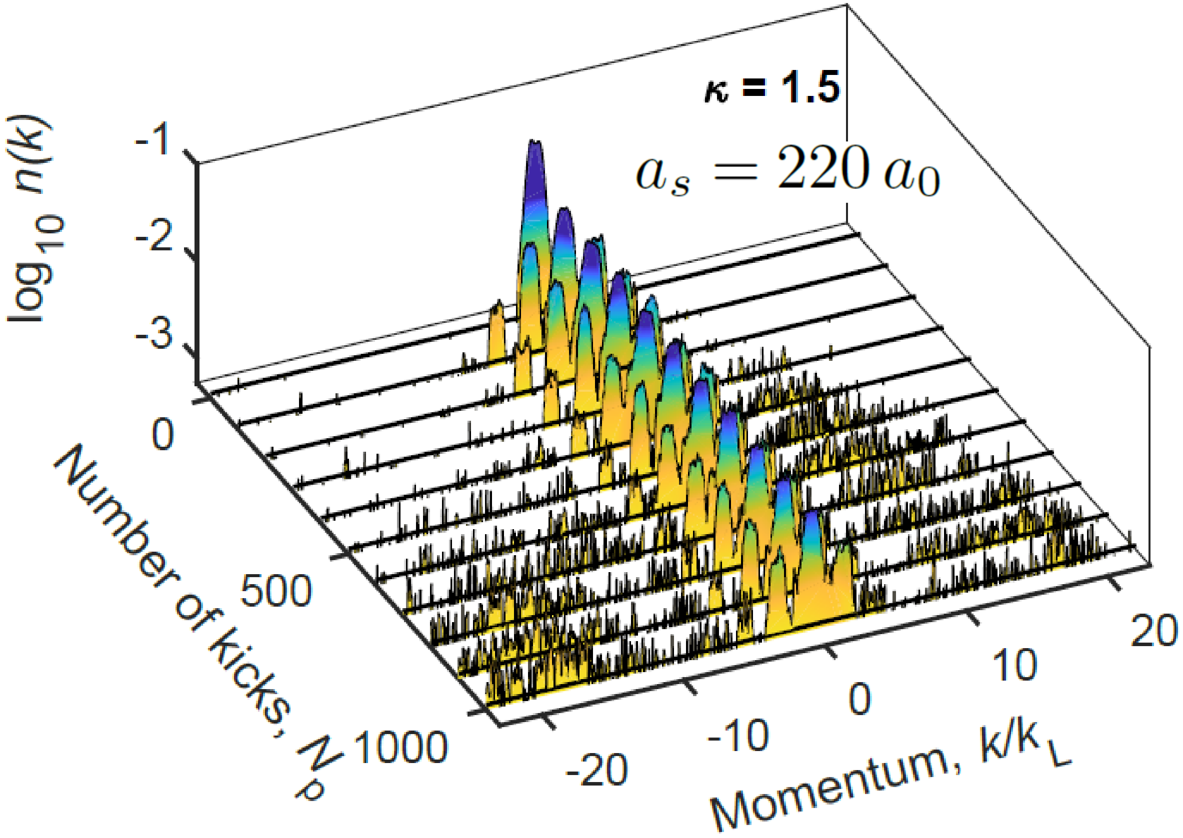
quantum kick strength $\kappa = V_0\tau/2\hbar$

The (interacting) kicked rotor in 3D

Evolution of the momentum distribution *n(k)*



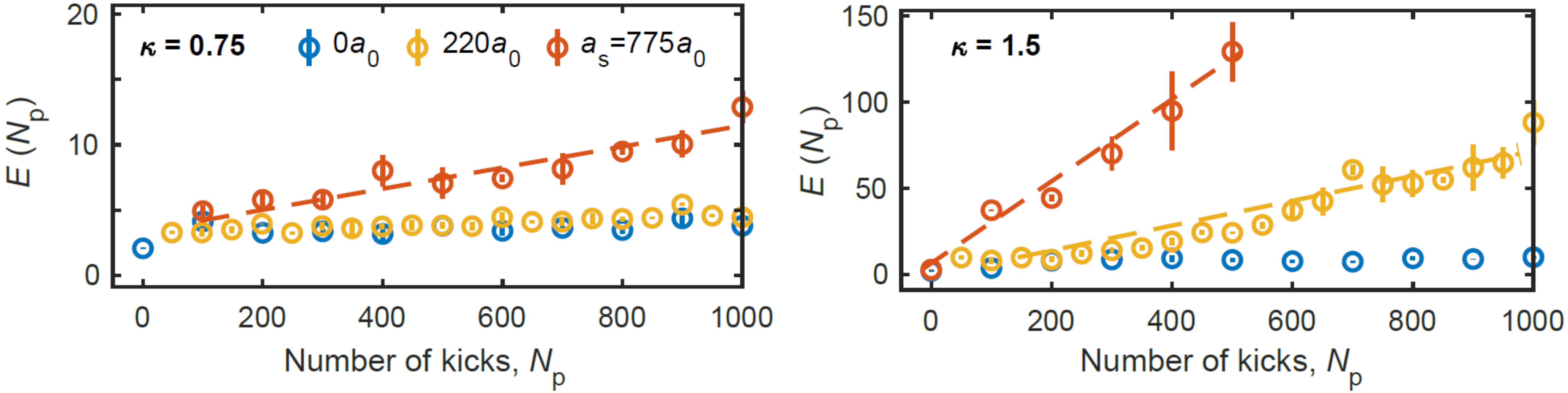
localized



delocalized

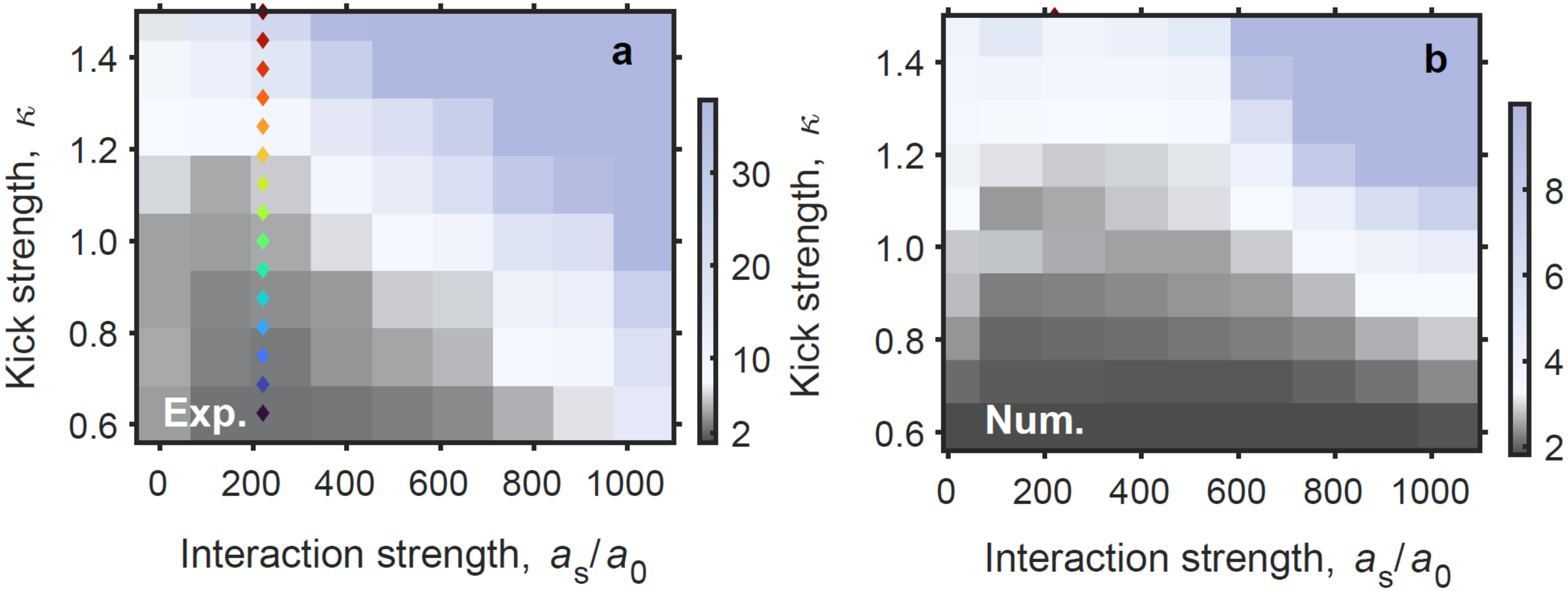
The (interacting) kicked rotor in 3D

Energy proxy $$E(N_\mathrm{p}) = \left| \int_{-0.5k_\mathrm{L}}^{0.5k_\mathrm{L}} n(k)dk \right|^{-2}$$



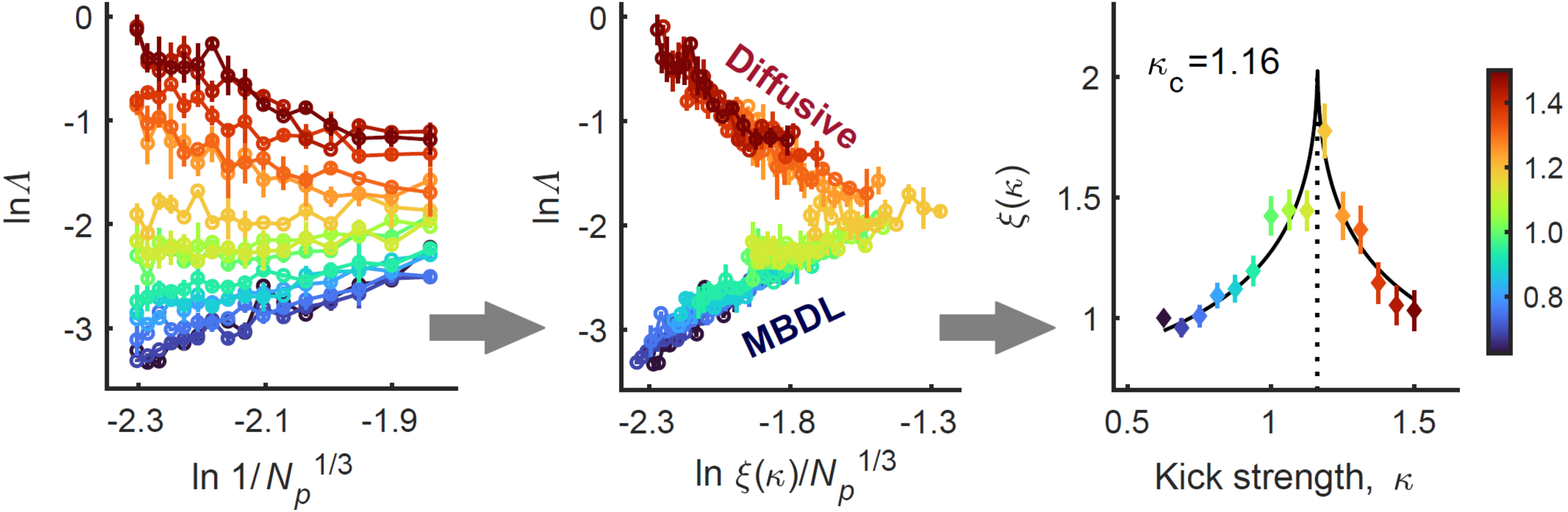
Phase diagram

$$E(N_\mathrm{p}) = \left| \int_{-0.5k_\mathrm{L}}^{0.5k_\mathrm{L}} n(k)dk \right|^{-2}$$



Finite-time scaling analysis

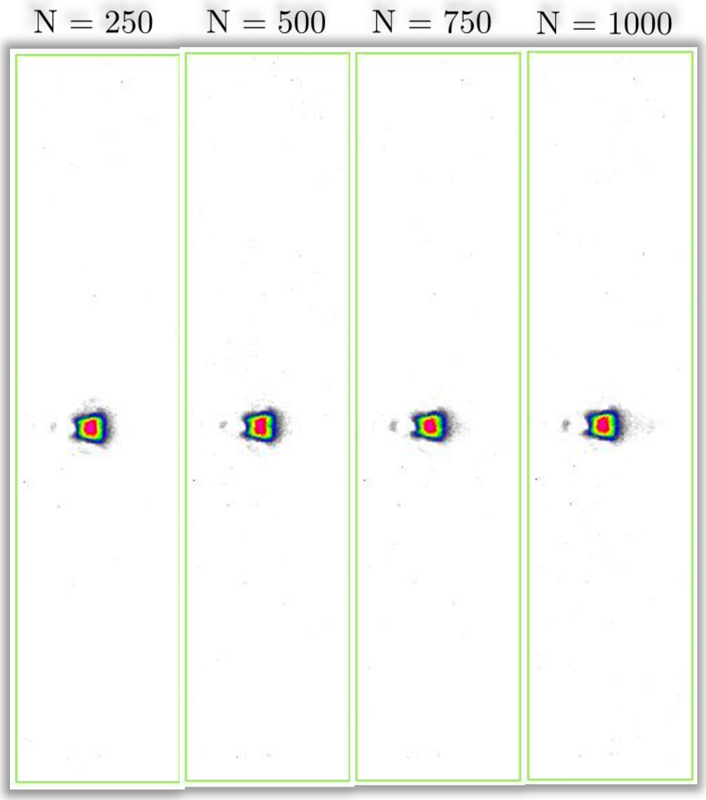
$$\Lambda(\kappa, N_\mathrm{p}) = E(N_\mathrm{p}) \cdot N_\mathrm{p}^{-\beta} = f\left[\xi(\kappa)/N_\mathrm{p}^{1/d}\right]$$



Lemarié et al., PRA 80. 043626 (2009)
Olsen et al., PRL 135, 173403 (2025)

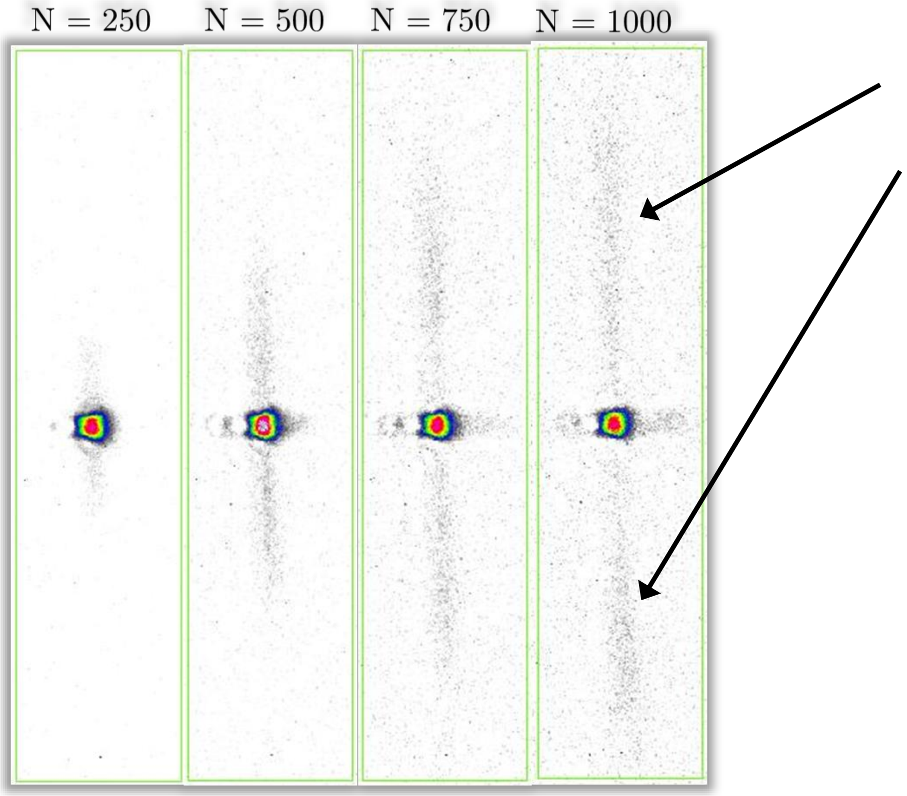
Real-space dynamics

MBDL



$a_s = 220\, a_0 \quad \kappa = 0.75$

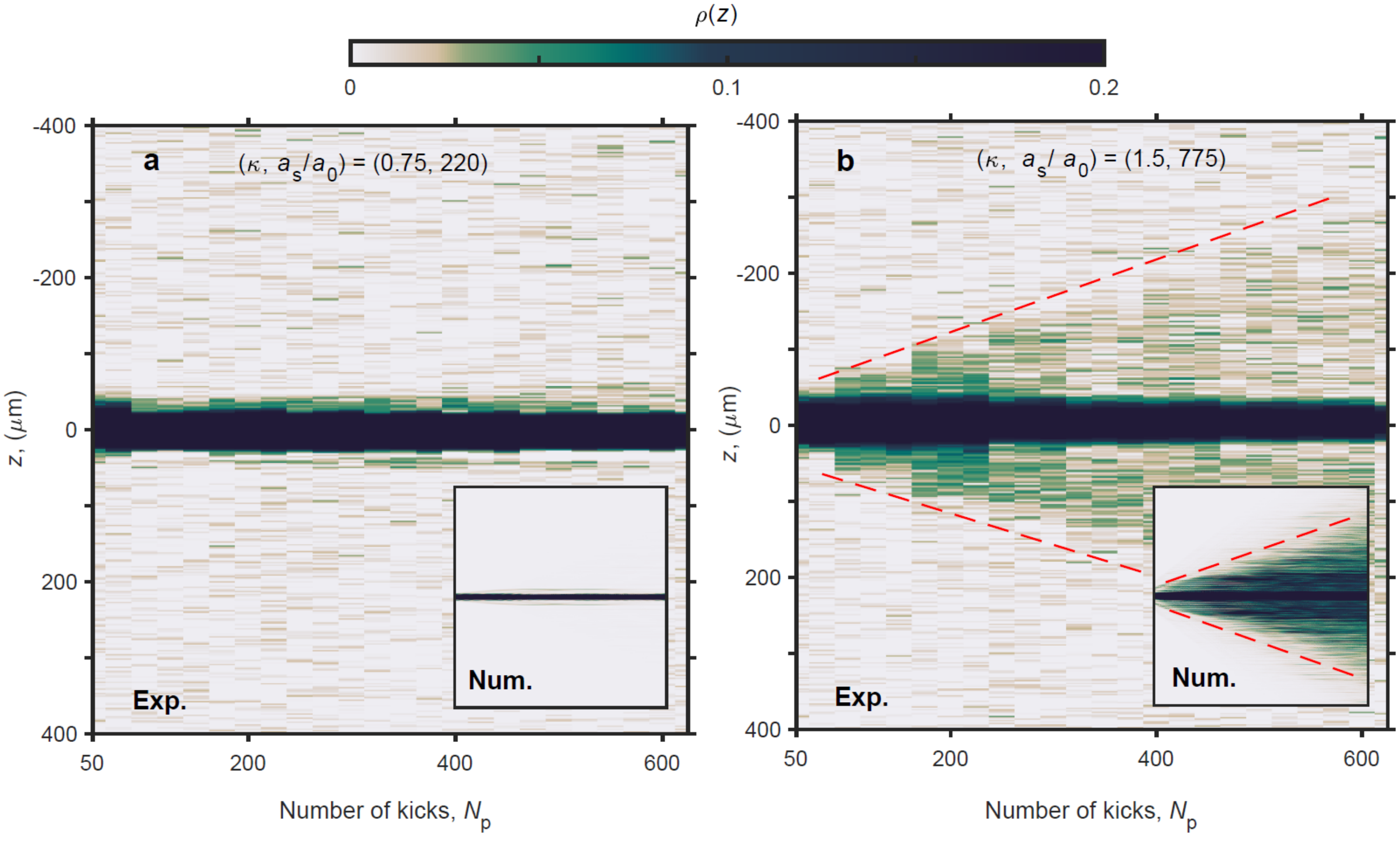
Delocalized



atoms leaving

$a_s = 220\, a_0 \quad \kappa = 1.5$

Real-space localization vs. delocalization



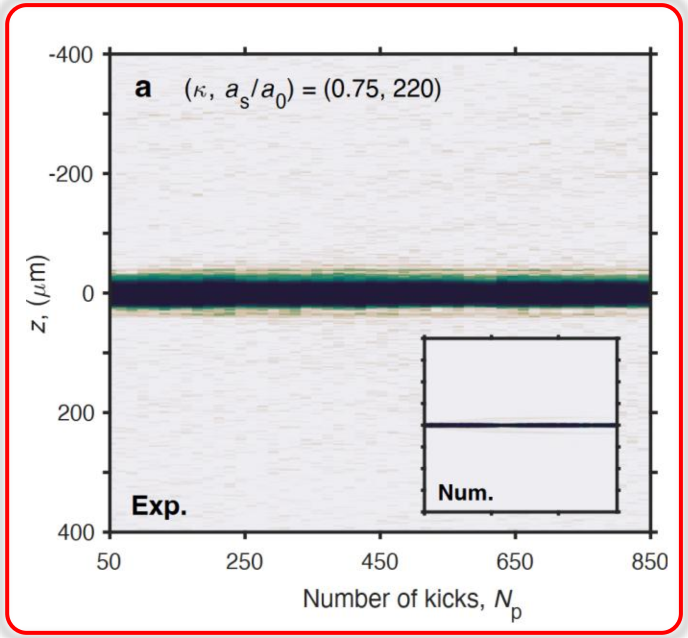
localized

delocalized

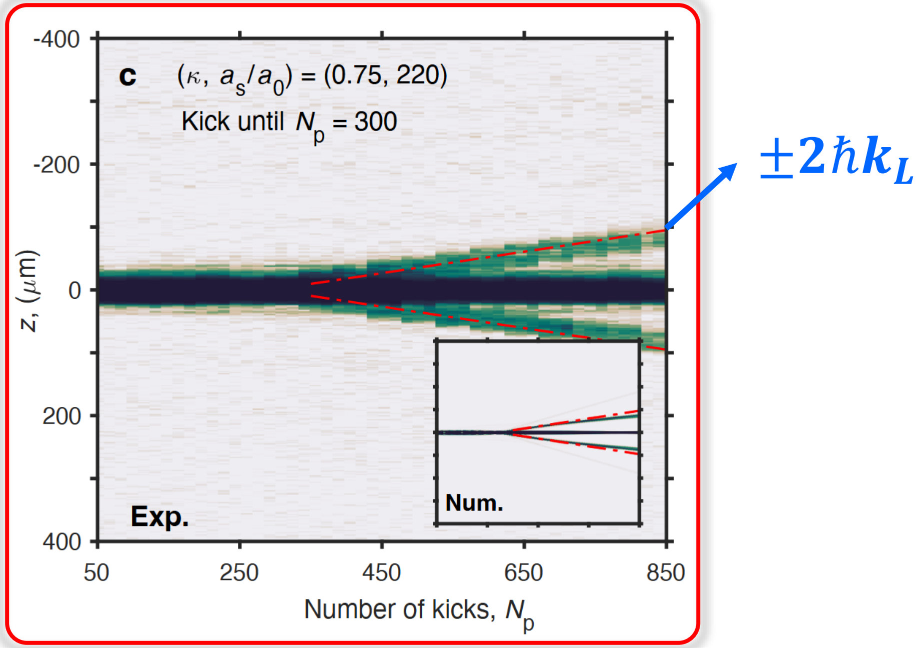
Hilbert-space localization?

Frozen evolution in real-space

MBDL



Stop kicking at $\mathbf{N_p = 300}$



Evidently, the Floquet-type evolution repeatedly re-mixes the populated momentum components and inhibits the coherent accumulation of displacement from period to period

The quantum challenge: dynamics

Observing the emergence of a velocity hierarchy in strongly interacting bosons

Xudong Yu,[1,*] Wenhan Chen,[1,2,*] Igor Zhuravlev,[1] Yi Zeng,[1] Sudipta Dhar,[1] Milena Horvath,[1] Thierry Giamarchi,[3] Laurent Sanchez-Palencia,[4] Manuele Landini,[1] Hanns-Christoph Nägerl,[1,†] and Yanliang Guo[2,1,‡]

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Universität Innsbruck, Technikerstraße 25, Innsbruck, 6020, Austria
[2] *Key Laboratory of Quantum State Construction and Manipulation (Ministry of Education),*
School of Physics, Renmin University of China, Beijing 100872, China
[3] *DQMP, University of Geneva, 24 Quai Ernest-Ansermet, Geneva, CH-1211, Switzerland*
[4] *CPHT, CNRS, École Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*

...almost on the arXiv

The quantum challenge: dynamics

Letter | Published: 25 January 2012

Light-cone-like spreading of correlations in a quantum many-body system

Marc Cheneau ✉, Peter Barmettler, Dario Poletti, Manuel Endres, Peter Schauß, Takeshi Fukuhara, Christian Gross, Immanuel Bloch, Corinna Kollath & Stefan Kuhr

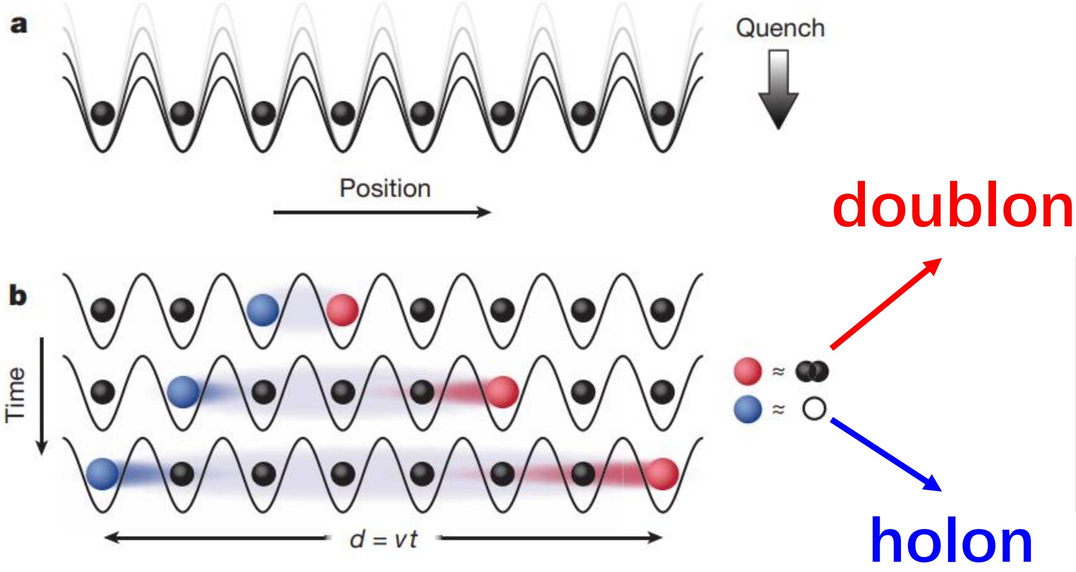
Nature **481**, 484–487 (2012)

$$H = -J \sum_{<i,j>} b_i^\dagger b_j + \frac{U}{2} \sum_i n_i(n_i - 1)$$

Microscopic observation of magnon bound states and their dynamics

Takeshi Fukuhara ✉, Peter Schauß, Manuel Endres, Sebastian Hild, Marc Cheneau, Immanuel Bloch & Christian Gross

Nature **502**, 76–79 (2013)



Quasiparticle engineering and entanglement propagation in a quantum many-body system

P. Jurcevic, B. P. Lanyon, P. Hauke, C. Hempel, P. Zoller, R. Blatt & C. F. Roos ✉

Nature **511**, 202–205 (2014)

Matter-wave dynamics

Mass bends the dispersion relation and splits the velocities

Dispersion in relativistic $E(k) = \sqrt{(m_0c^2)^2 + (\hbar ck)^2}$

group velocity $v_g = \frac{1}{\hbar}\frac{dE}{dk}$

phase velocity $v_p = \frac{E}{\hbar k}$

massless: linear dispersion: $v_p = v_g$

massive: curved dispersion: $v_p \neq v_g$

Relativistic invariance $v_p v_g = c^2$

Gap opening in the Bose-Hubbard system = effective mass generation.

Matter-wave dynamics

In strongly interacting quantum matter, excitations are matter waves carried by interacting particles. Can propagation of such excitations evolve from nearly degenerate velocities into a hierarchy?

Low-energy quasiparticle dispersion

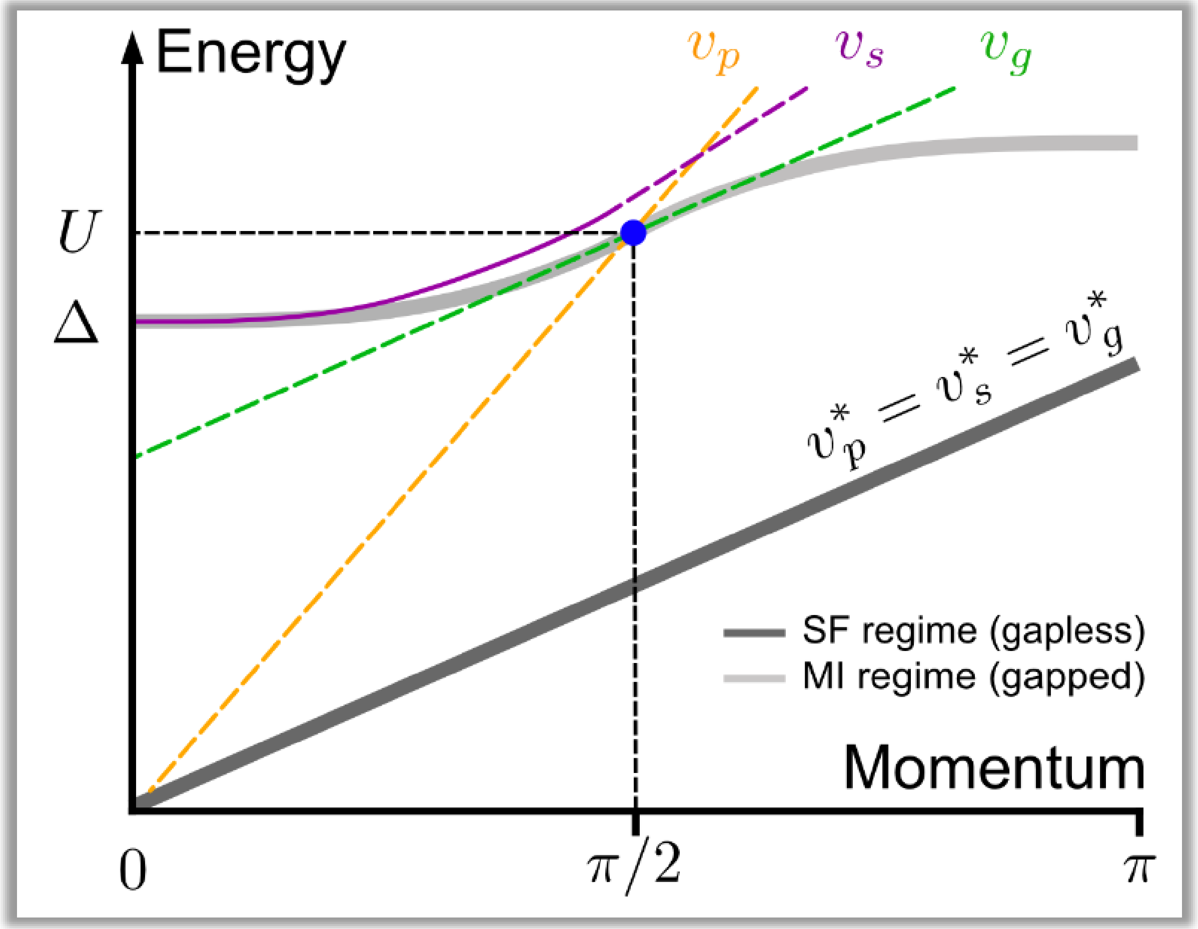
$$E(k) \simeq \sqrt{\Delta^2 + (\hbar v_s k)^2}$$

Relativistic dispersion

$$E(k) = \sqrt{(m_0 c^2)^2 + (\hbar c k)^2}$$

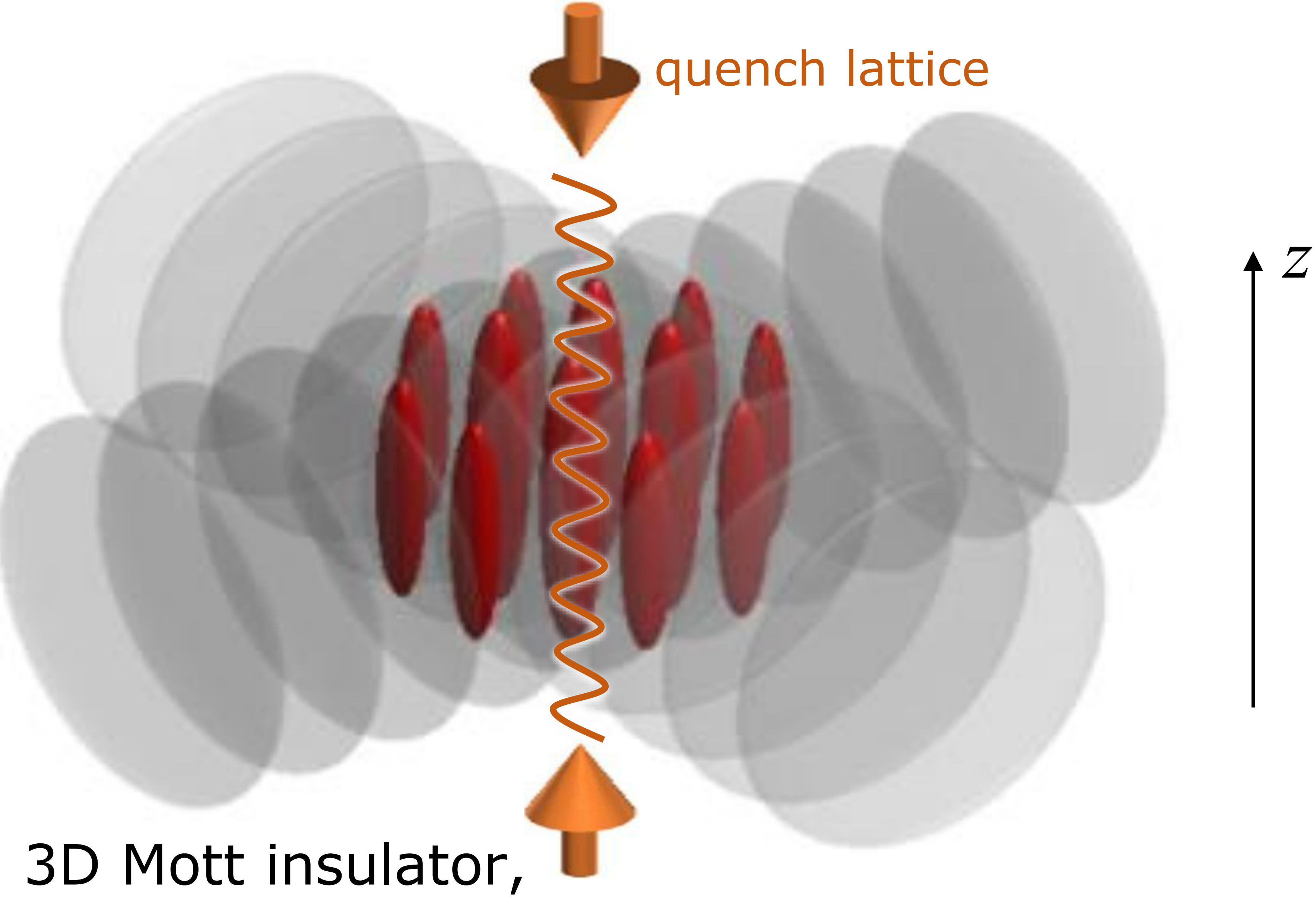
Analogues

$$\boxed{\begin{array}{ccc} \Delta & \longleftrightarrow & m_0 c^2 \\ v_s & \longleftrightarrow & c \end{array}}$$



Dynamics in 1D tubes

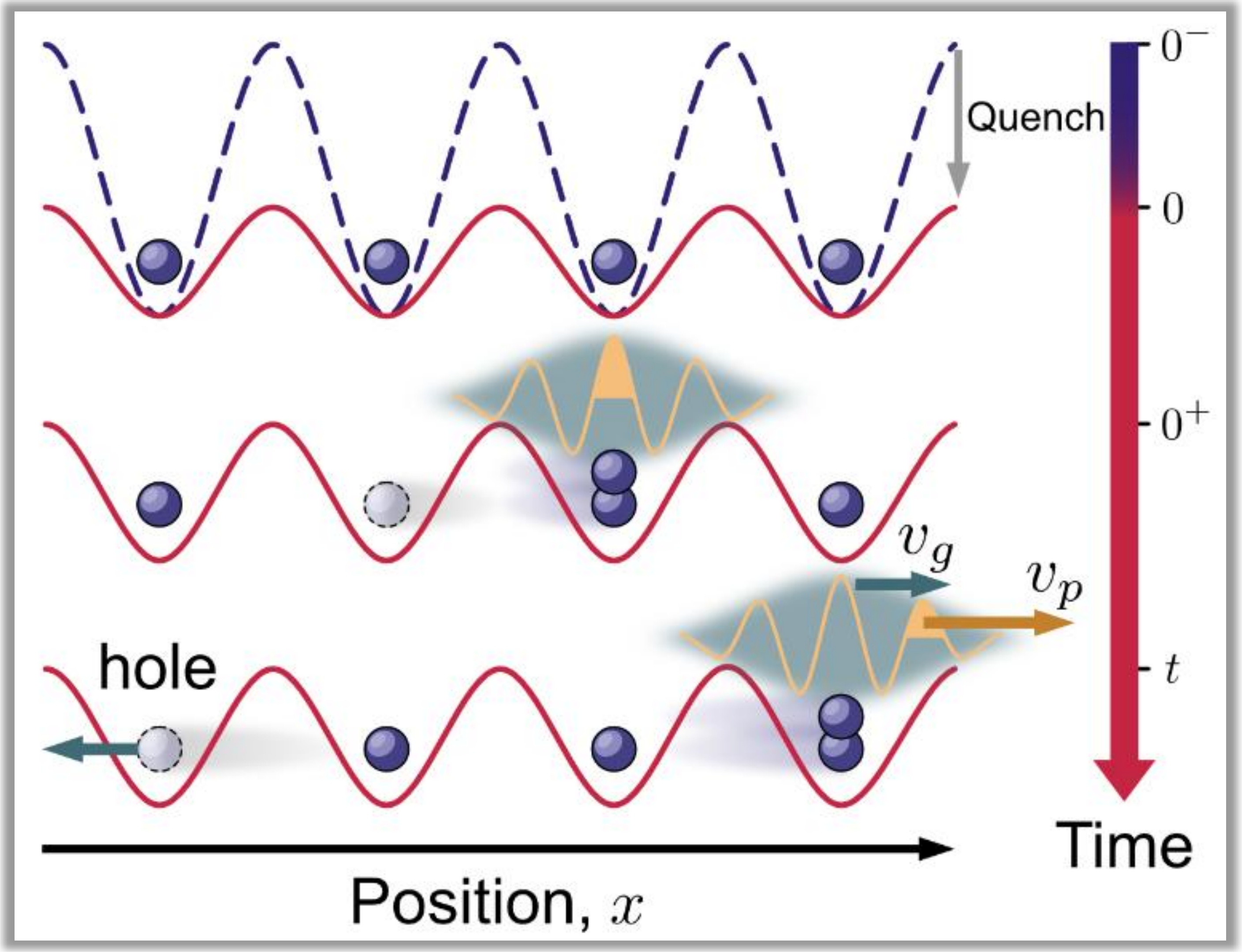
Array of 1D tubes



Initial state: 3D Mott insulator,

unity filling

Dynamics after a quench

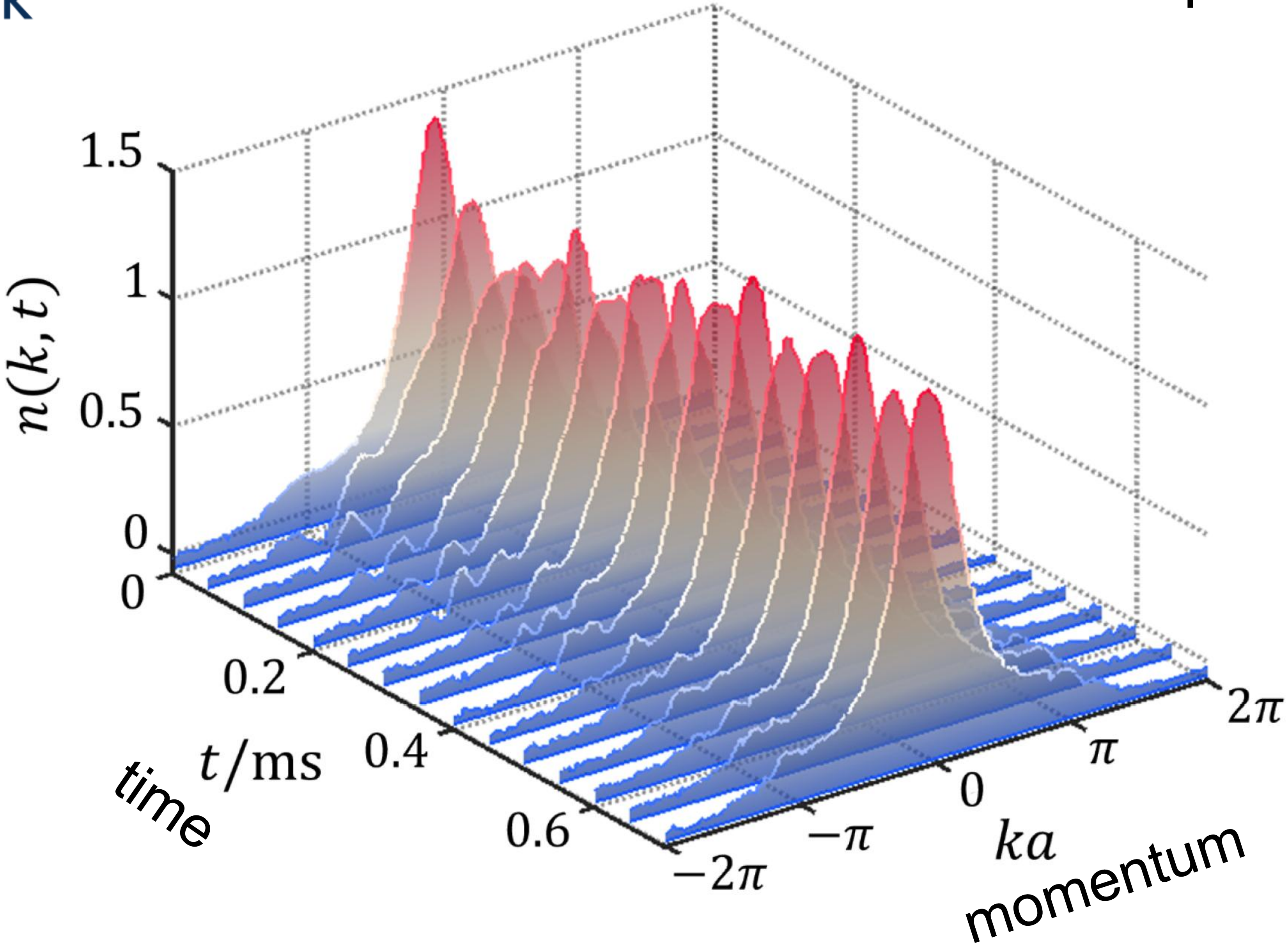


$$V_x = 15\ \mathrm{E_r}$$

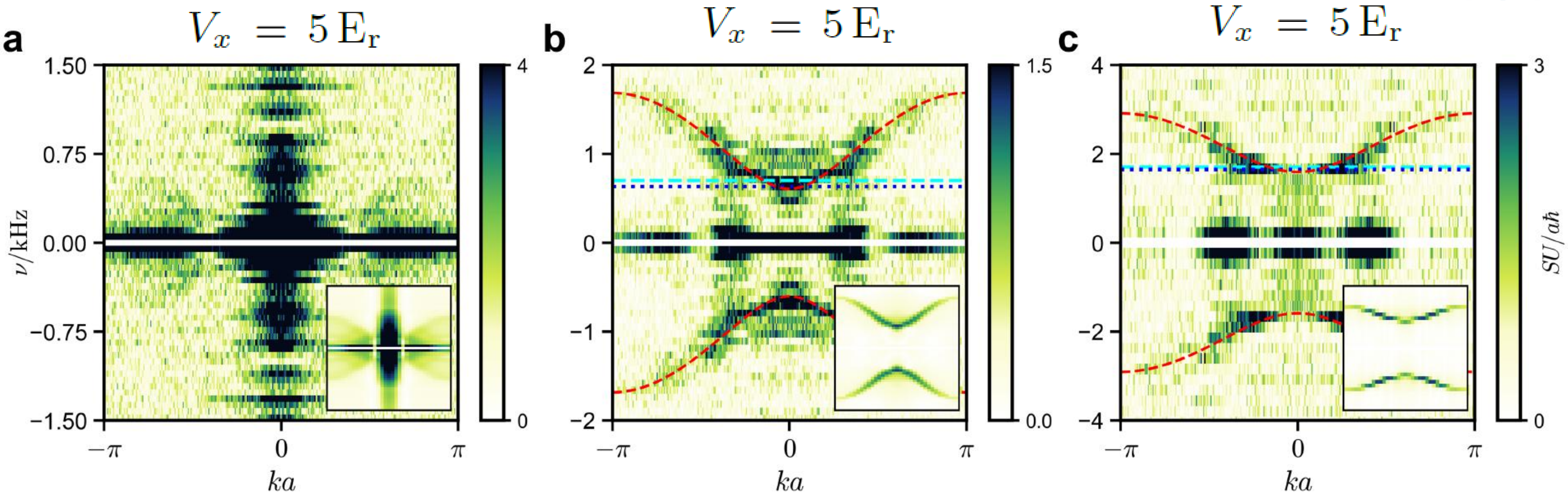
$$V_x = 5\ \mathrm{E_r}$$

starting from
unity occupation

Momentum distributions after the quench



After FT in time: Excitation spectra



$\gamma \approx 0.3$ | $\gamma \approx 4.2$ | $\gamma \approx 11.8$

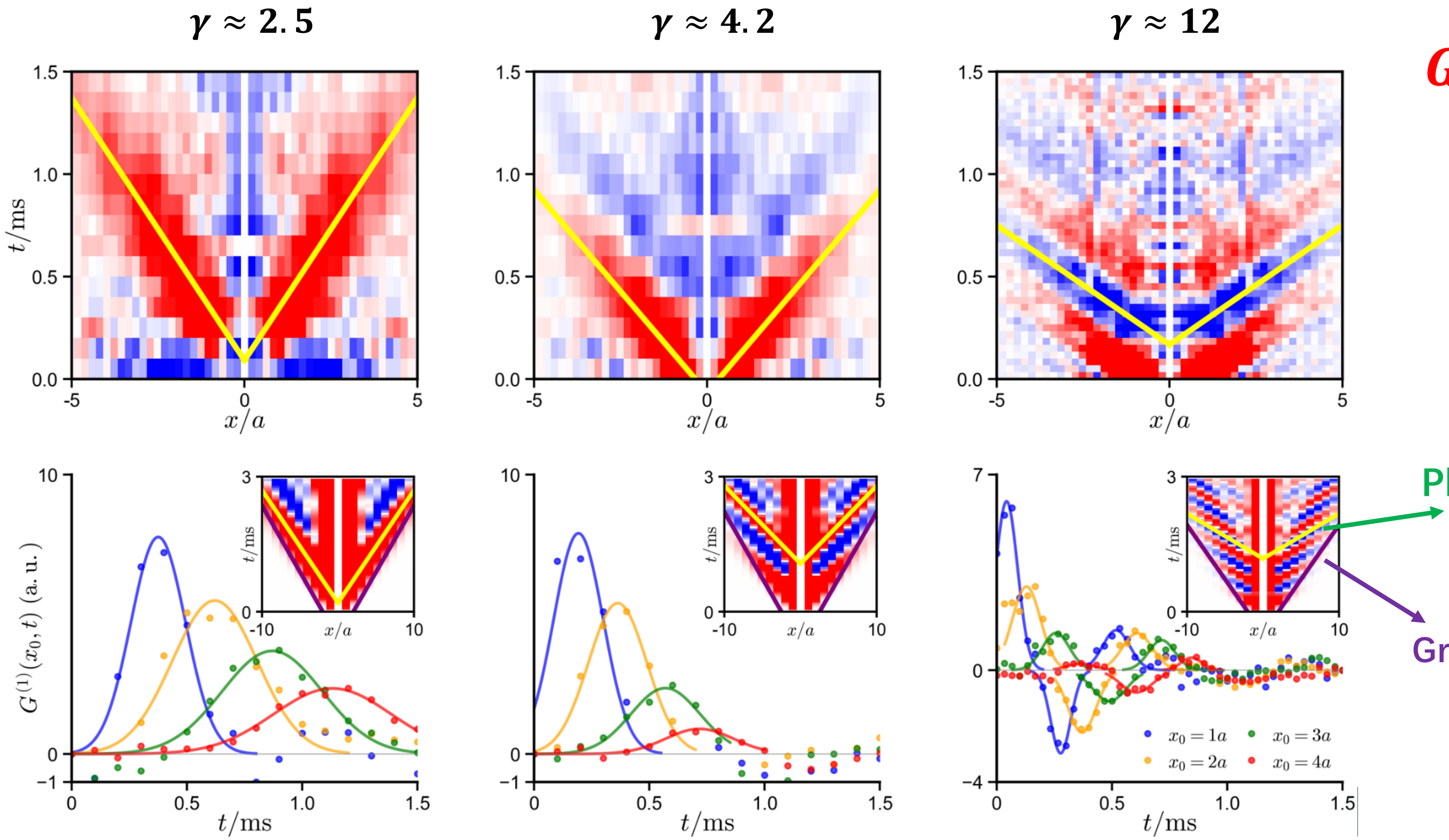
superfluid | insulator | insulator

red lines: Fits to obtain (effective) U and J

insets: DMRG results, T=0

$$E_{\mathrm{ex}}(k) \simeq U - 6J\cos ka$$

After FT in space: Correlation spreading

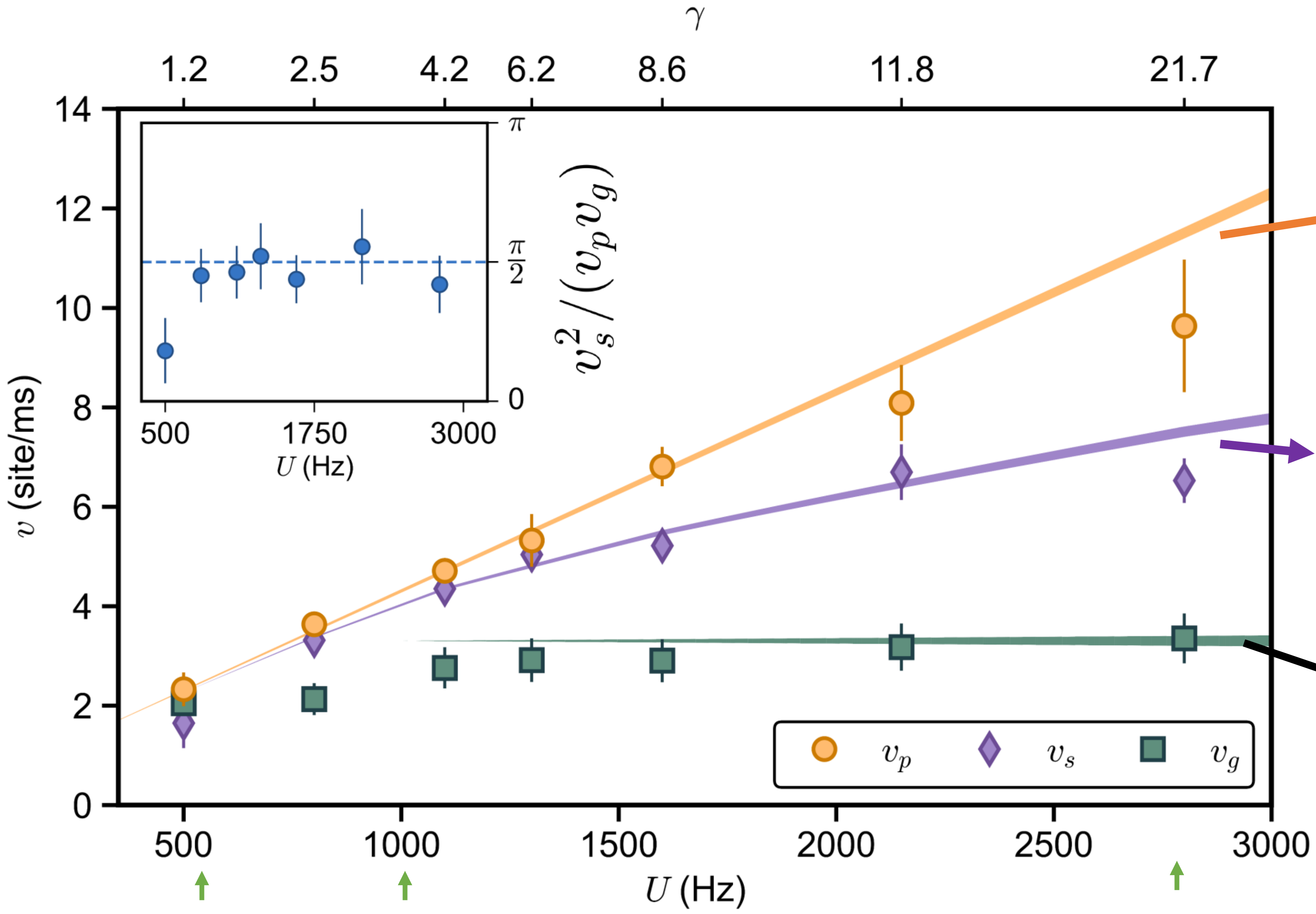


$G^{(1)}(x, t)$

Phase velocity

Group velocity

Velocity hierarchy



Phase velocity $2v_p = 2U/\pi$

Sound velocity $2v_s = \sqrt{6JU}$

Group velocity $2v_g = 6J$

Lieb-Robinson bound for infinite U

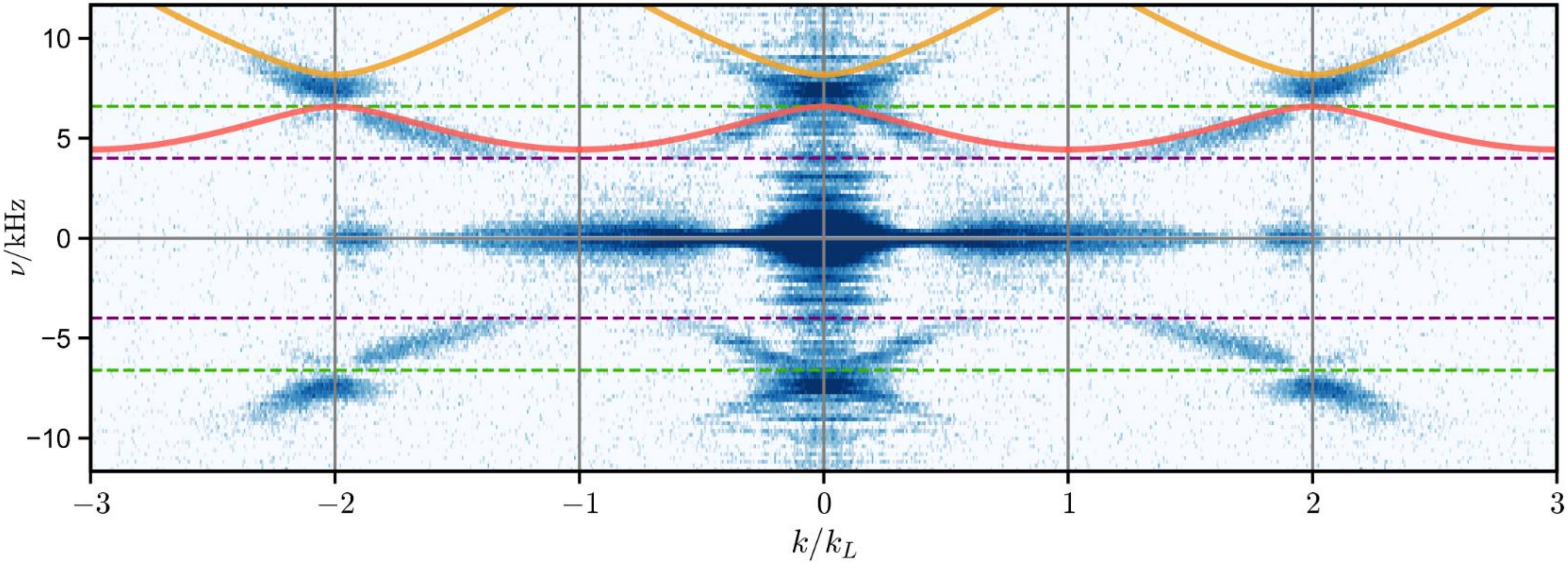
$$\boxed{\pi v_p v_g = 2v_s^2}$$

U/J ~ 9 **U/J ~ 14** **U/J ~ 30**

Quench spectroscopy: Outlook 1

Higher bands: P and D

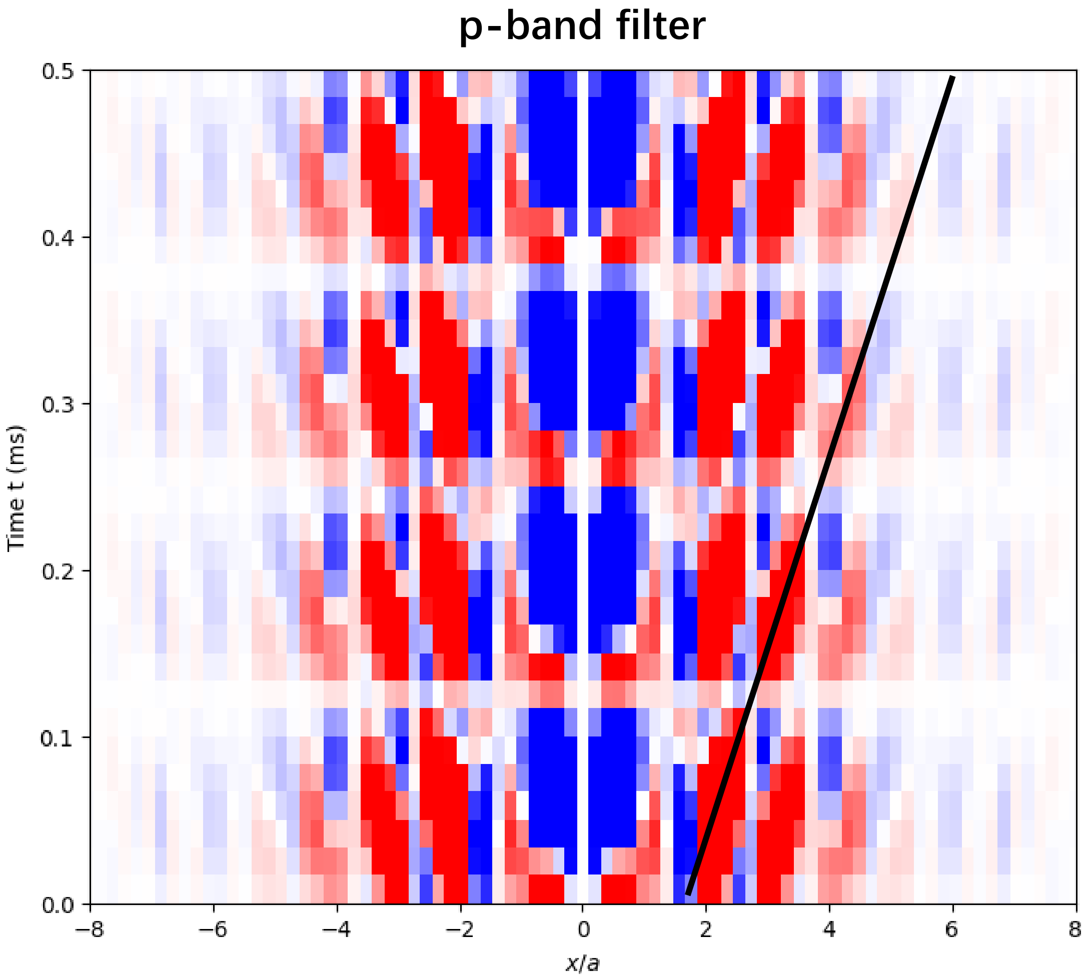
$\boldsymbol{\gamma} \approx \mathbf{0.3}$, superfluid



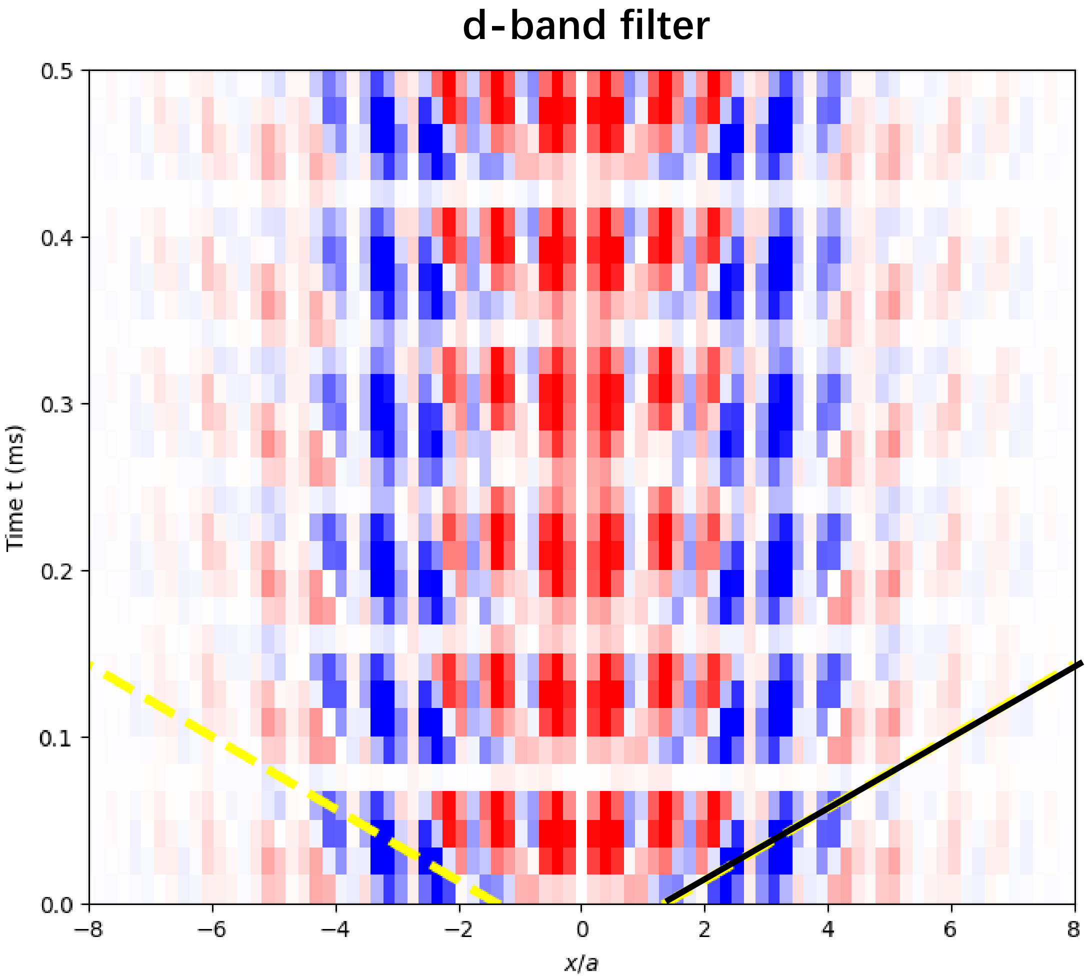
Quench spectroscopy: Outlook 2

Higher bands: P and D

phase velocity in higher bands



p-band filter



d-band filter

$$(V_x, V_y, V_z) = (9{,}25{,}25)E_r;\ a_{3D} = 300a_0$$

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Recent Innsbruck results (3)

arXiv > cond-mat > arXiv:2602.12320

Condensed Matter > Quantum Gases

[Submitted on 12 Feb 2026]

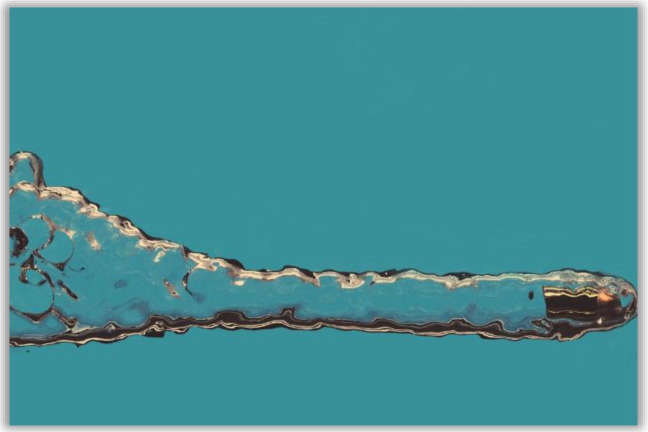
Observing dissipationless flow of an impurity in a strongly repulsive quantum fluid

Milena Horvath, Sudipta Dhar, Elisabeth Wybo, Dimitrios Trypogeorgos, Yanliang Guo, Mikhail Zvonarev, Michael Knap, Manuele Landini, Hanns-Christoph Nägerl

Finite-speed impurity

Classically

Impurity will come to a **stop** due to **friction**

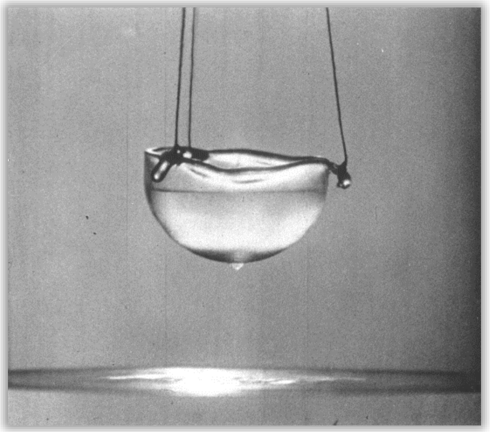


bullet

$$m\frac{\partial v}{\partial t} = -Fv^2, \quad v(t) = \frac{v_0}{1 + (Fv_0/m)t}$$

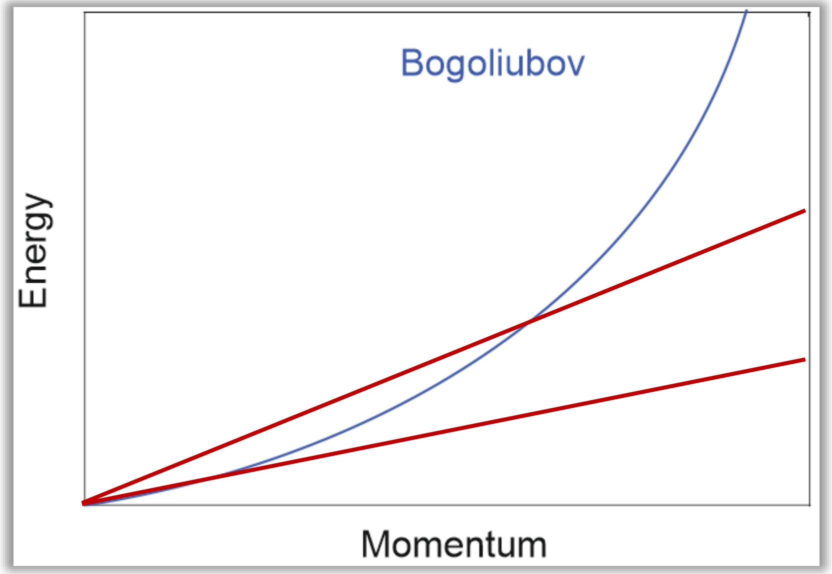
Quantum

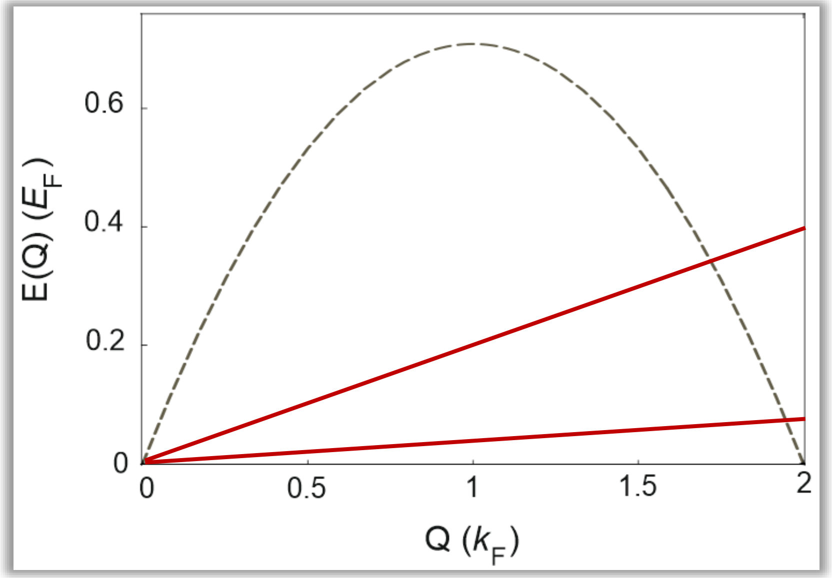
Superfluidity can give rise to **frictionless motion**



$$v(t) = v_0 \text{ for } \quad v_0 < v_c$$

Landau's criterion of superfluidity





Landau criterion: $\boxed{v_c = \min \frac{E(p)}{p}}$

- Dissipationless motion below v_c

Excitations in a 3D BEC (or superfluid):

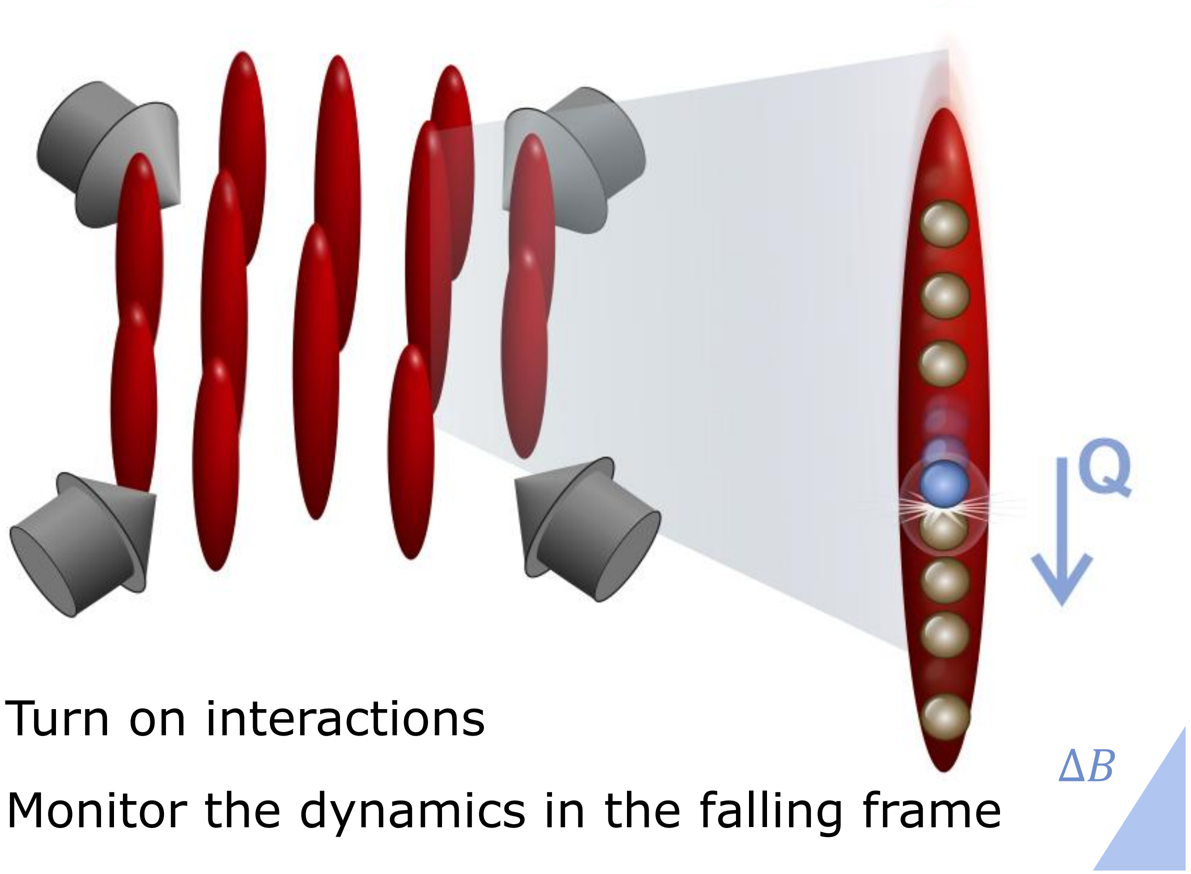
- Linear for low momentum (phonons)
- Quadratic for high momentum

- **In a 1D system**: $v_c = 0$. The system can always be excited
- **However**: Landau assumes classical object (infinite mass)

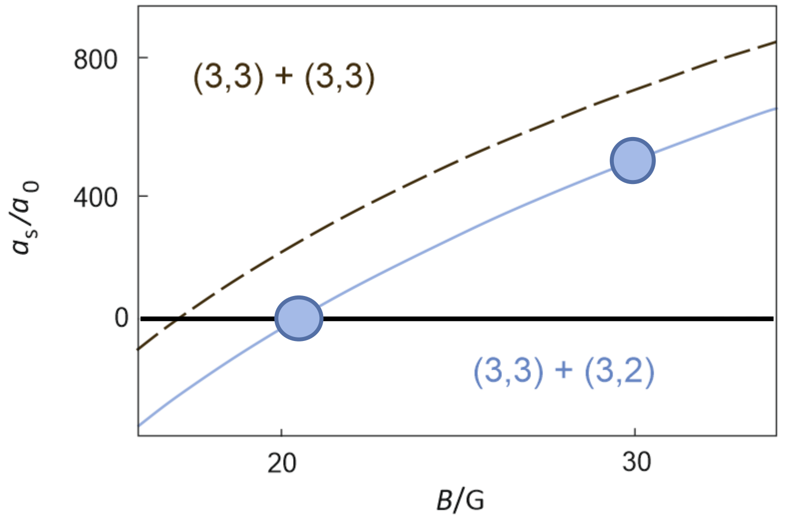
What happens when the object is quantum?

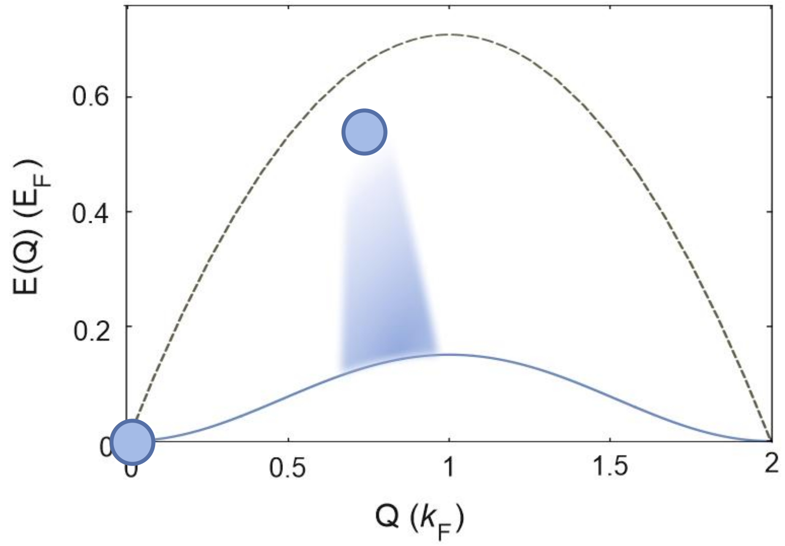
Experimental procedure

1. Create impurity out of the host, noninteracting
2. Accelerate it with no interactions to momentum Q

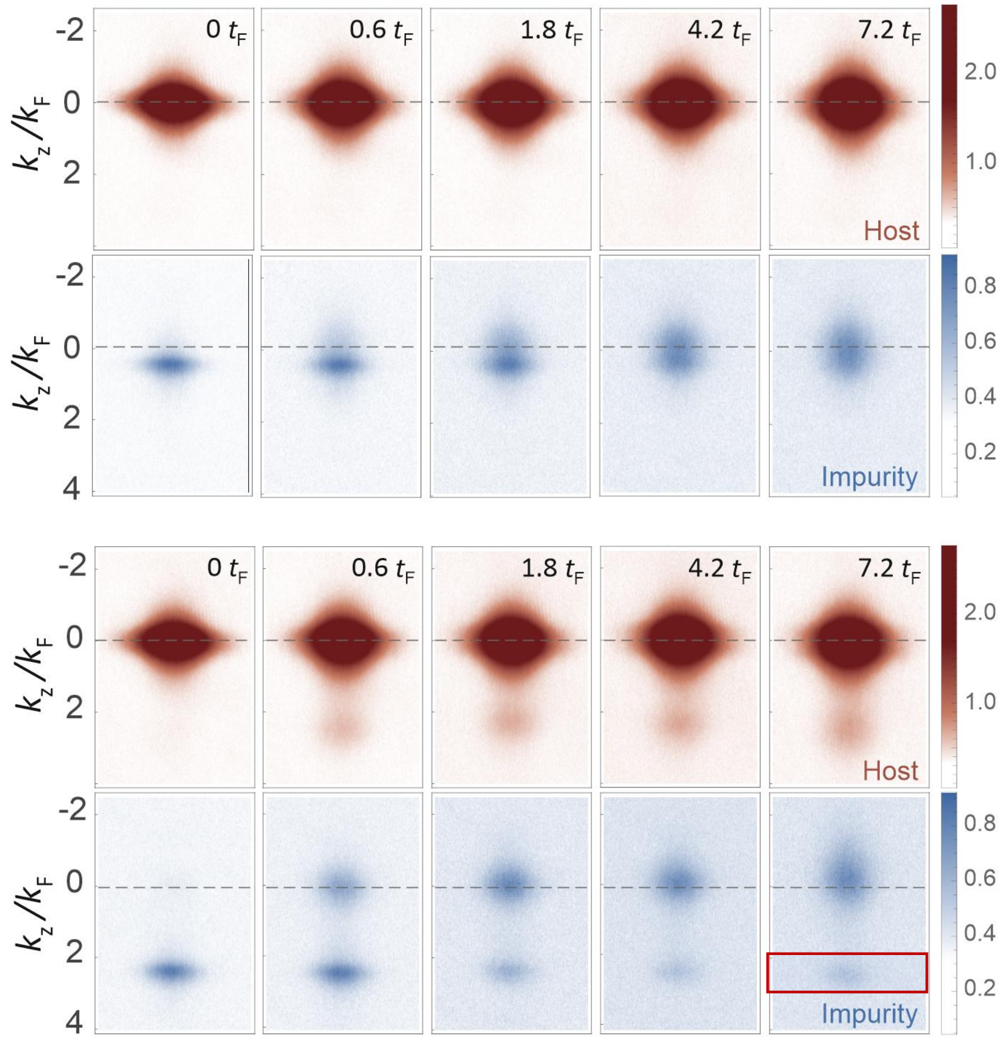


3. Turn on interactions
4. Monitor the dynamics in the falling frame





Subsonic vs. supersonic



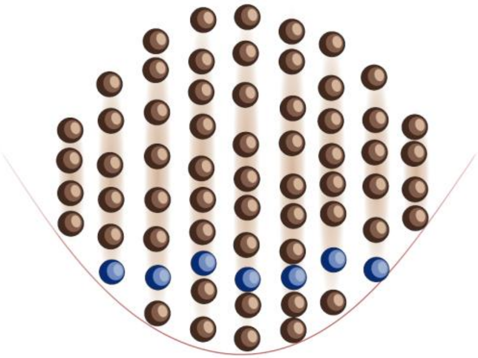
Subsonic ($Q < k_F$):

- Impurity slows down

Supersonic ($Q > k_F$):

- Impurity stops
- Ejected particle from host cloud

Inhomogeneity of the tubes leaves some impurities at the initial momentum



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Subsonic vs. supersonic

Evolution of the momentum distributions

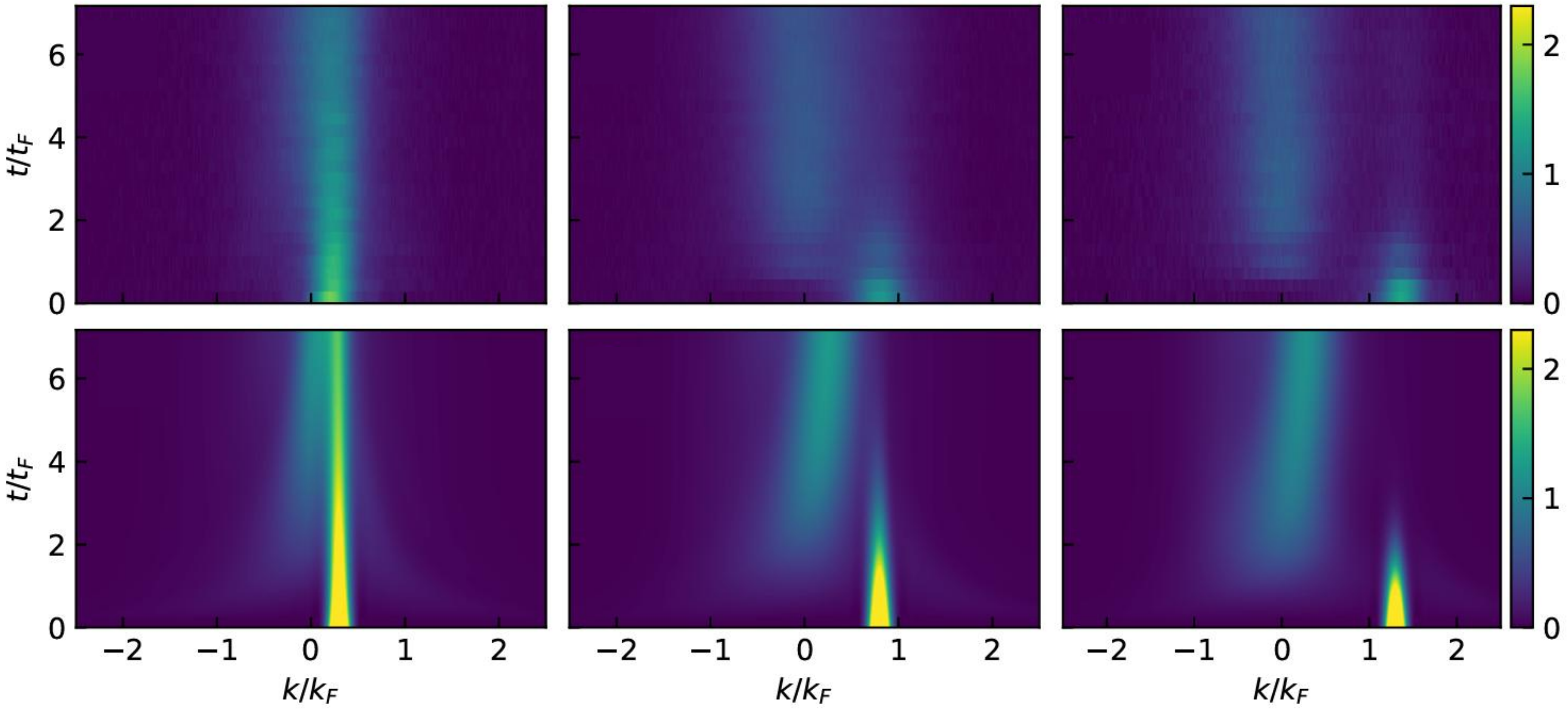
Subsonic
$Q \approx 0.2\,k_F$

$Q \approx 0.9\,k_F$

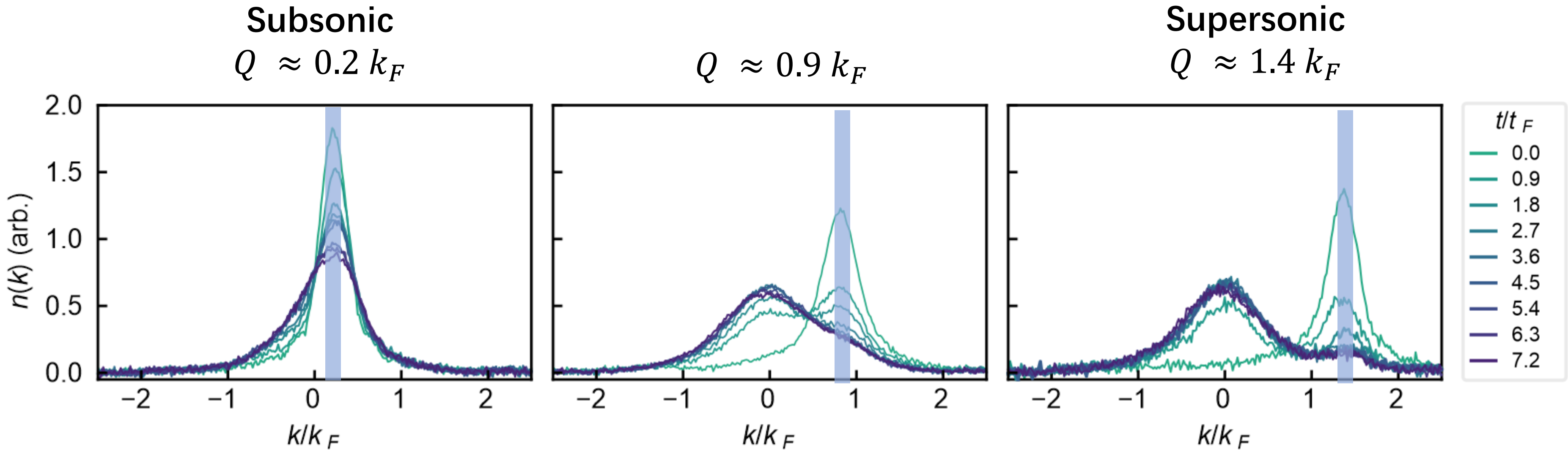
Supersonic
$Q \approx 1.4\,k_F$

Experiment

Theory



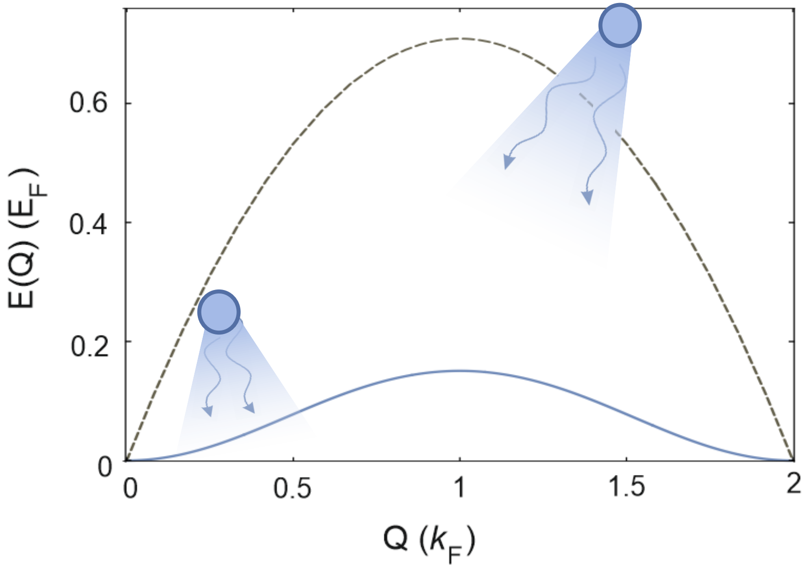
Subsonic vs. supersonic



Subsonic
$Q \approx 0.2\, k_F$

$Q \approx 0.9\, k_F$

Supersonic
$Q \approx 1.4\, k_F$

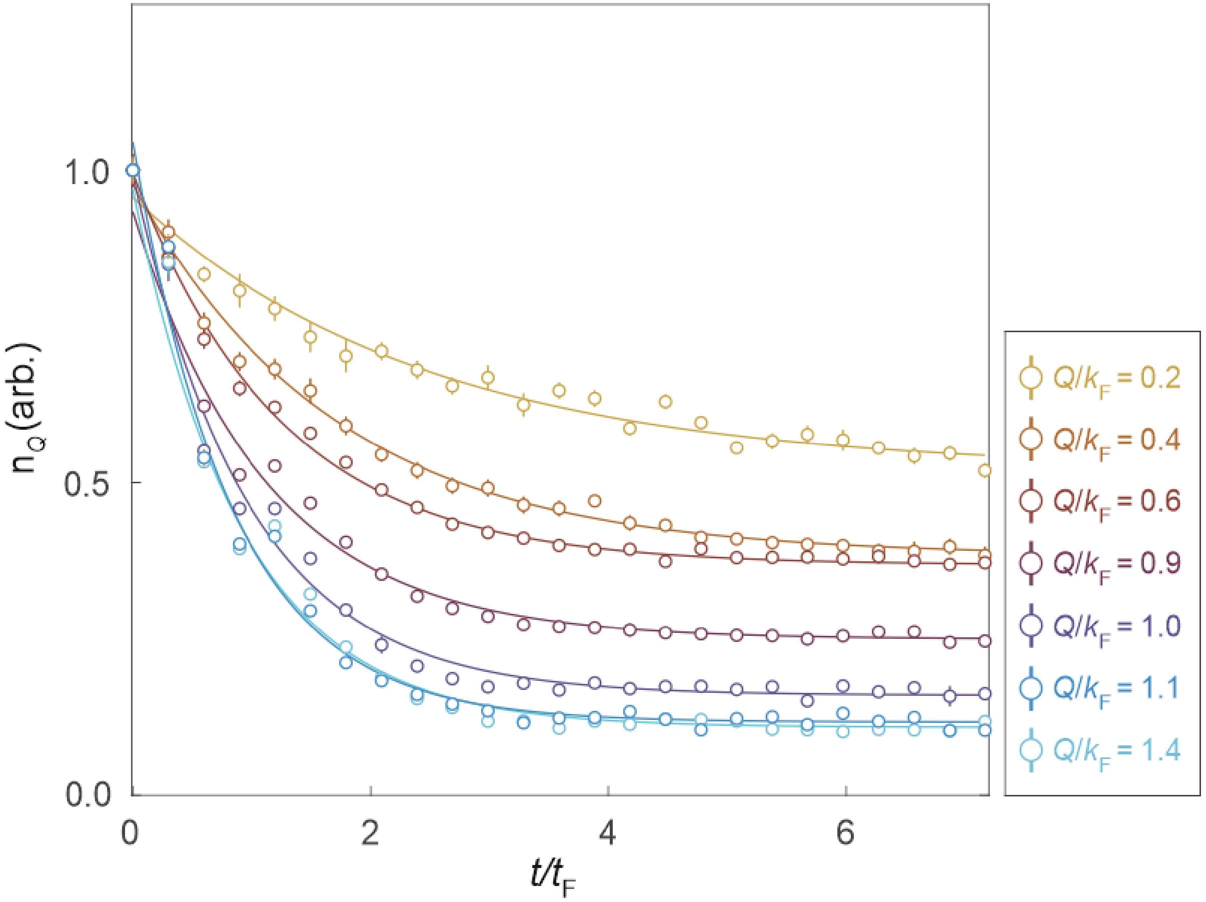


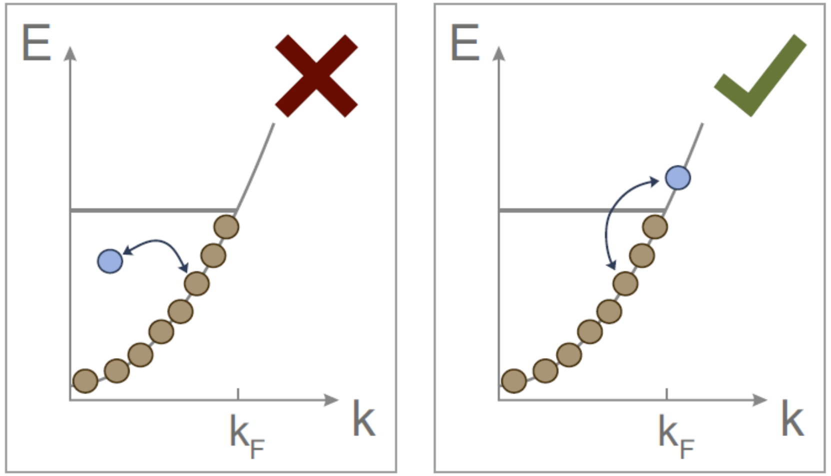
- Inject impurity at momentum Q

- For $Q < k_F,\ n(k)$ is asymmetric
– resembles anyonic distribution around Q
(see below)

- For $Q > k_F,\ \ n(k)$ more symmetric
- resembles momentum distribution at k_F

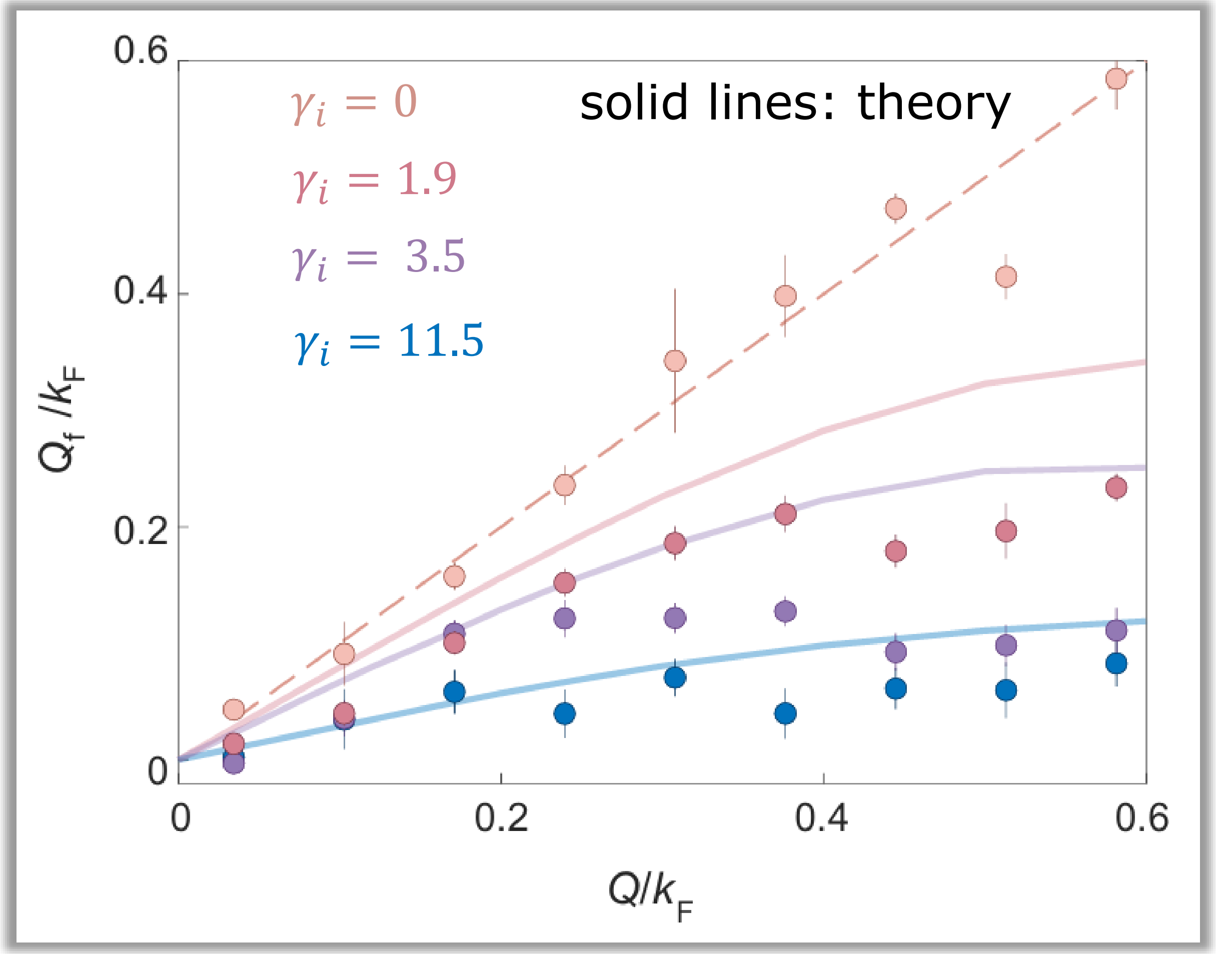
Ultrafast relaxation




Subsonic **Supersonic**

- Relaxation on the timescale of Fermi time
- Slower relaxation for lower momenta: Emergent Pauli blocking in a Bose gas

Dissipationless flow



- Impurity never comes to a full stop! Even for strong interactions

- Dressed impurity evidently experiences frictionless motion

Microscopic impurity results in novel physics beyond the Landau paradigm

Recent Innsbruck results (4)

Observation of Bethe strings

arXiv > cond-mat > arXiv:2505.10550

Condensed Matter > Quantum Gases

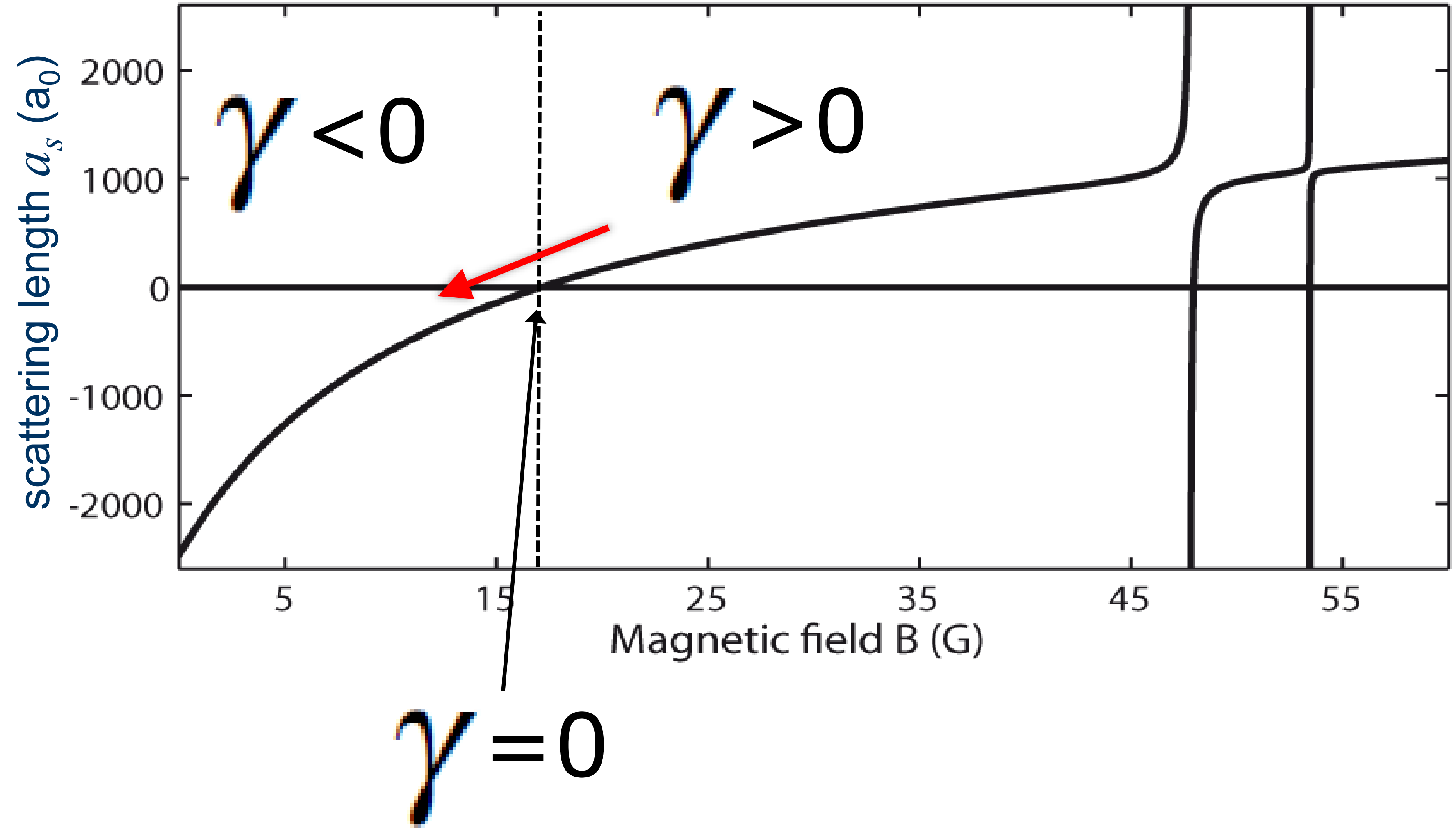
[Submitted on 15 May 2025]

Observing Bethe strings in an attractive Bose gas far from equilibrium

Milena Horvath, Alvise Bastianello, Sudipta Dhar, Rebekka Koch, Yanliang Guo, Jean-Sébastien Caux, Manuele Landini, Hanns-Christoph Nägerl

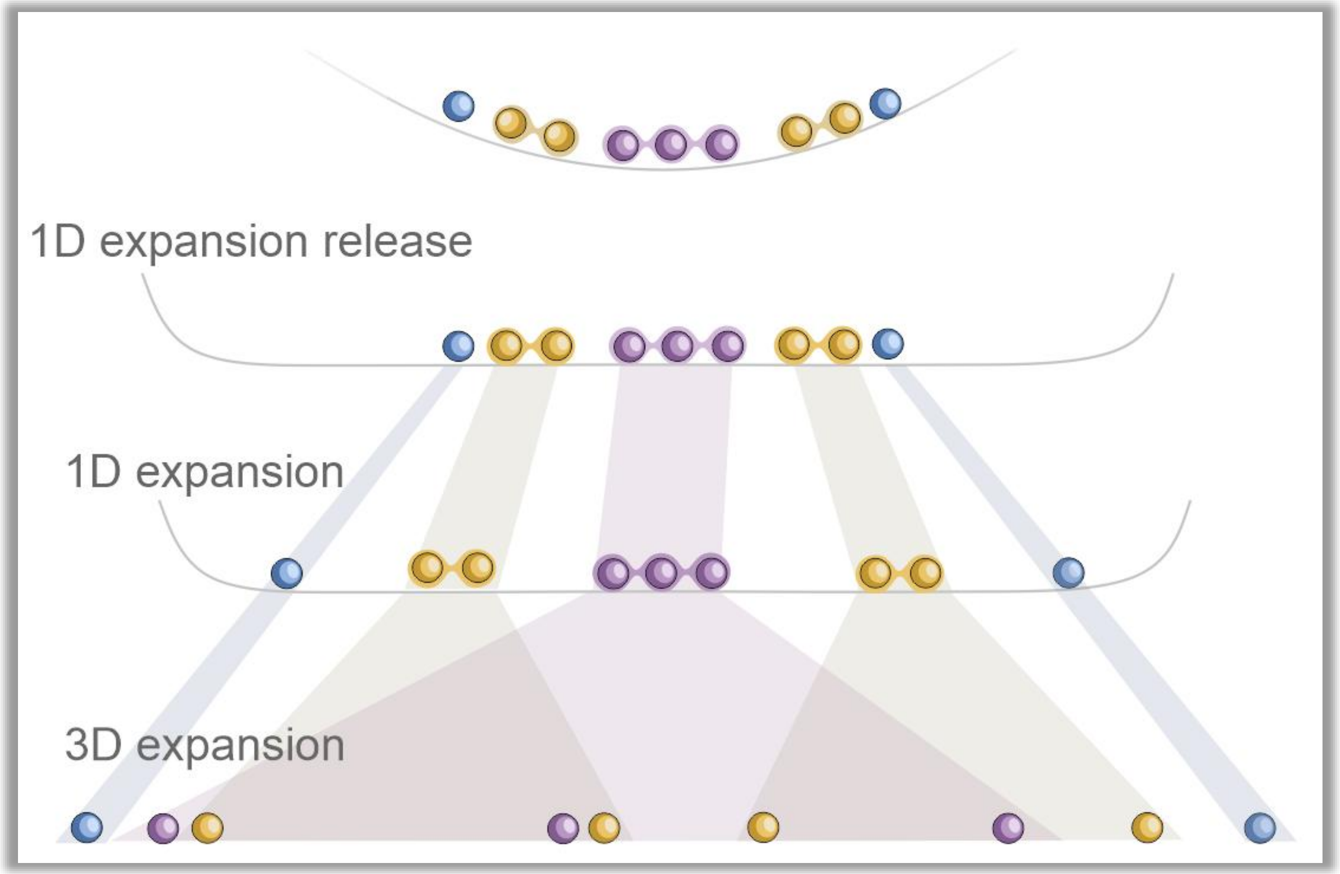
Back to no impurities for Lieb-Liniger

Scattering length a_s in Cs $|F,m_F\rangle=|3,3\rangle$



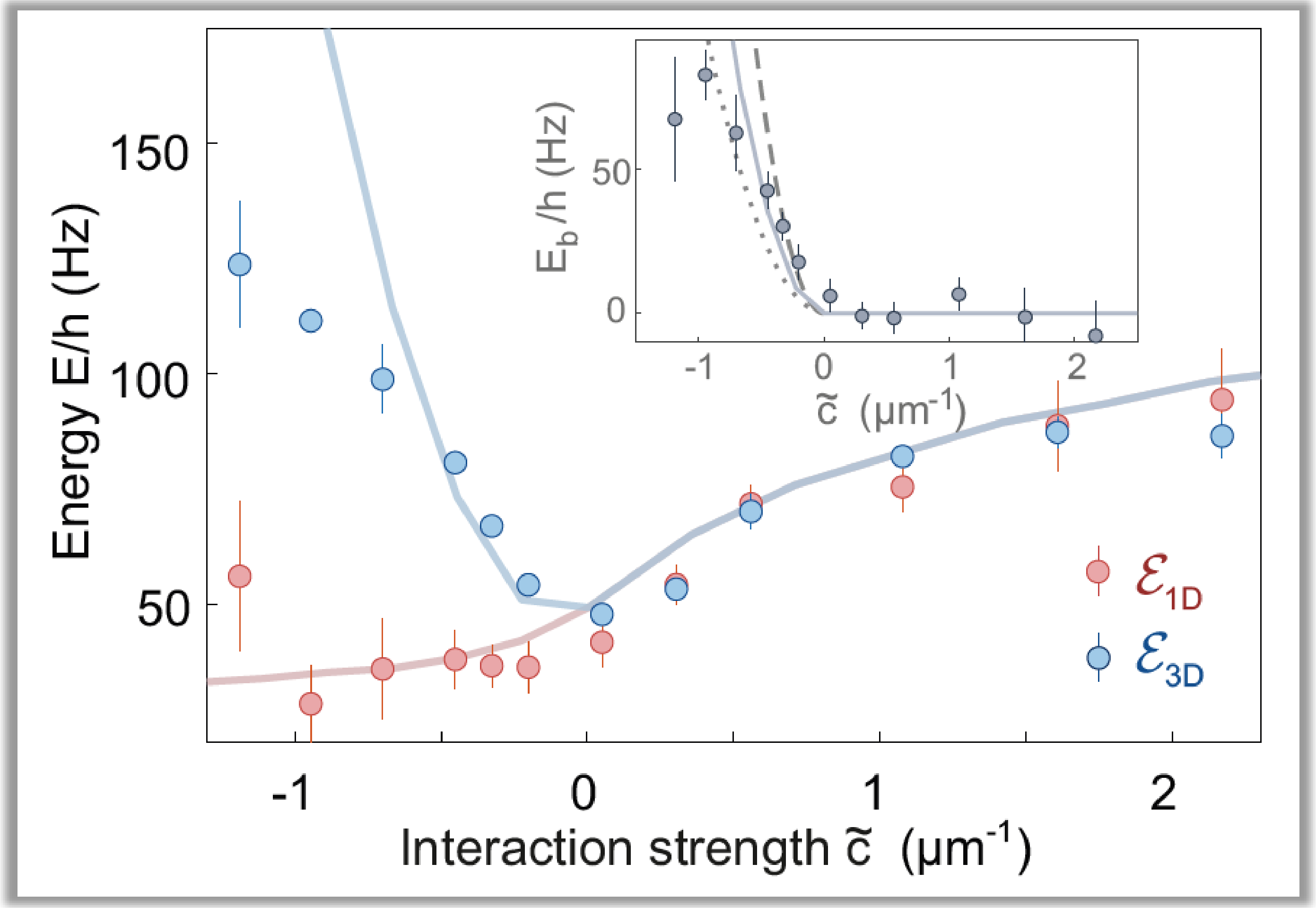
Detecting Bethe strings via release energies

- For repulsive interactions:
  - $\mathcal{E}_{1\text{D}} = \mathcal{E}_{3\text{D}} = U$, where $U = \langle \hat{H}_{\text{LL}} \rangle$
- During the 1D release the bound states remain intact:
  - $\mathcal{E}_{1\text{D}} = \langle E_{\text{com};n} \rangle$
- During 3D release bound states break:
  - $\mathcal{E}_{3\text{D}} = \langle E_{\text{com};n} \rangle + |\langle E_{\text{bind};n} \rangle|$



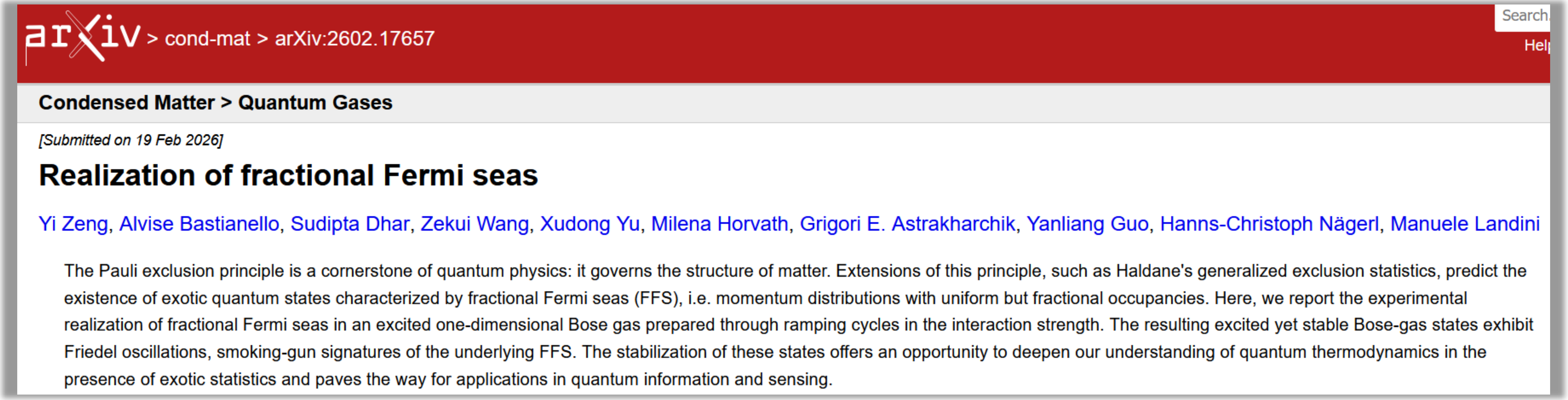
Binding energy

Evidence for **Bethe strings** in 1D vs. 3D release



Recent Innsbruck results (5)

Realization of fractional Fermi seas (FFS)



Condensed Matter > Quantum Gases

[Submitted on 19 Feb 2026]

Realization of fractional Fermi seas

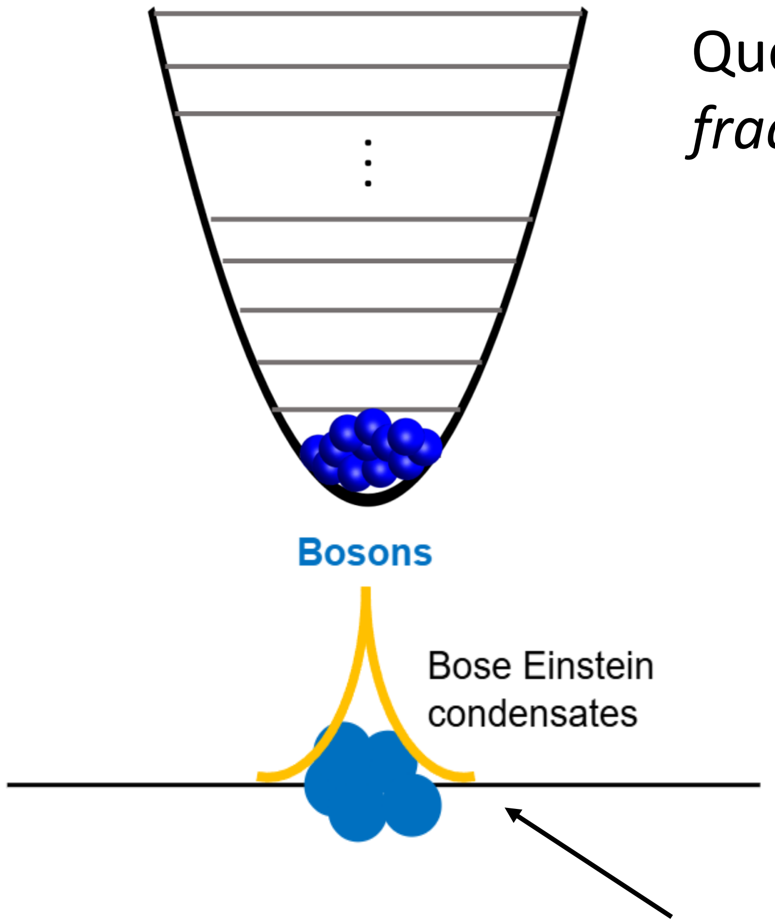
Yi Zeng, Alvise Bastianello, Sudipta Dhar, Zekui Wang, Xudong Yu, Milena Horvath, Grigori E. Astrakharchik, Yanliang Guo, Hanns-Christoph Nägerl, Manuele Landini

The Pauli exclusion principle is a cornerstone of quantum physics: it governs the structure of matter. Extensions of this principle, such as Haldane's generalized exclusion statistics, predict the existence of exotic quantum states characterized by fractional Fermi seas (FFS), i.e. momentum distributions with uniform but fractional occupancies. Here, we report the experimental realization of fractional Fermi seas in an excited one-dimensional Bose gas prepared through ramping cycles in the interaction strength. The resulting excited yet stable Bose-gas states exhibit Friedel oscillations, smoking-gun signatures of the underlying FFS. The stabilization of these states offers an opportunity to deepen our understanding of quantum thermodynamics in the presence of exotic statistics and paves the way for applications in quantum information and sensing.

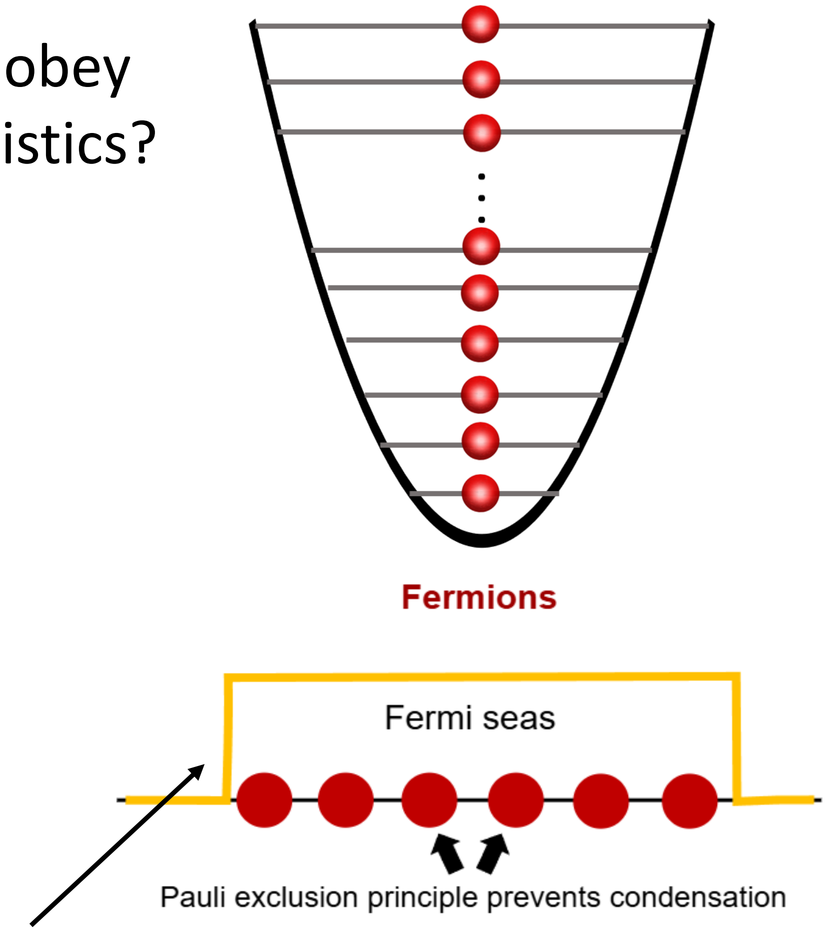
arXiv:2602.17657

See also for the modeling via GHD: *Exotic critical states as fractional Fermi seas in the one-dimensional Bose gas*, A.Bastianello, Y.Zeng et al., arXiv:2602.17656

Quantum statistics: bosons vs. fermions

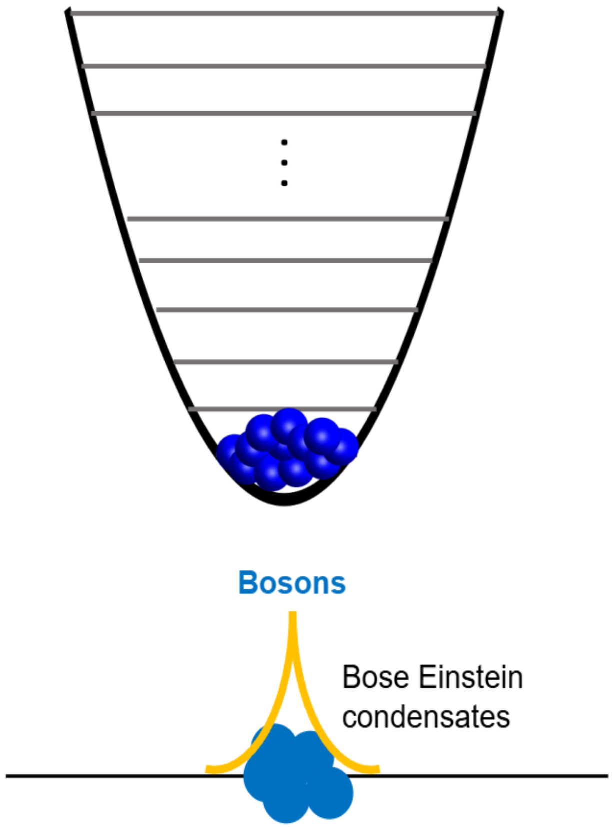


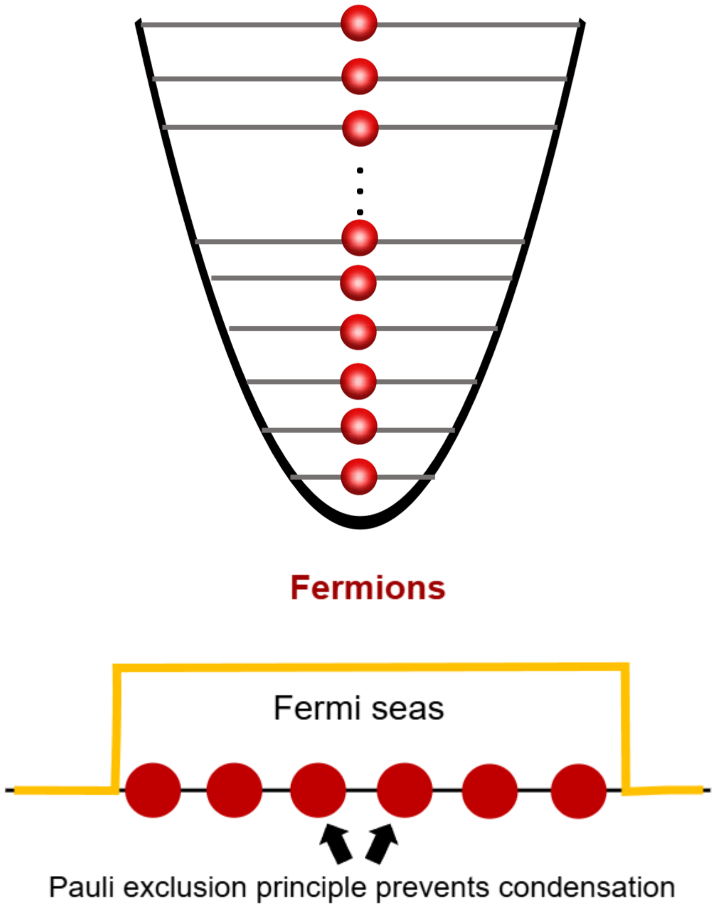
Question: Can particles obey *fractional* quantum statistics?



Momentum distributions

Quantum statistics generalized





Haldane's Generalized Exclusion Statistics (GES)

Based on state counting and works in any dimension

Definition of α:

α new states are needed for adding 1 particle (or quasi-particle) to the system

Bosons: α=0

Fermions: α=1

0<α<1: Anyons

1<α: Super-Fermions

Haldane, F. D. M., Phys. Rev. Lett. 67, 937 (1991).
Wu, Y.-S., Phys. Rev. Lett. 73, 922 (1994).

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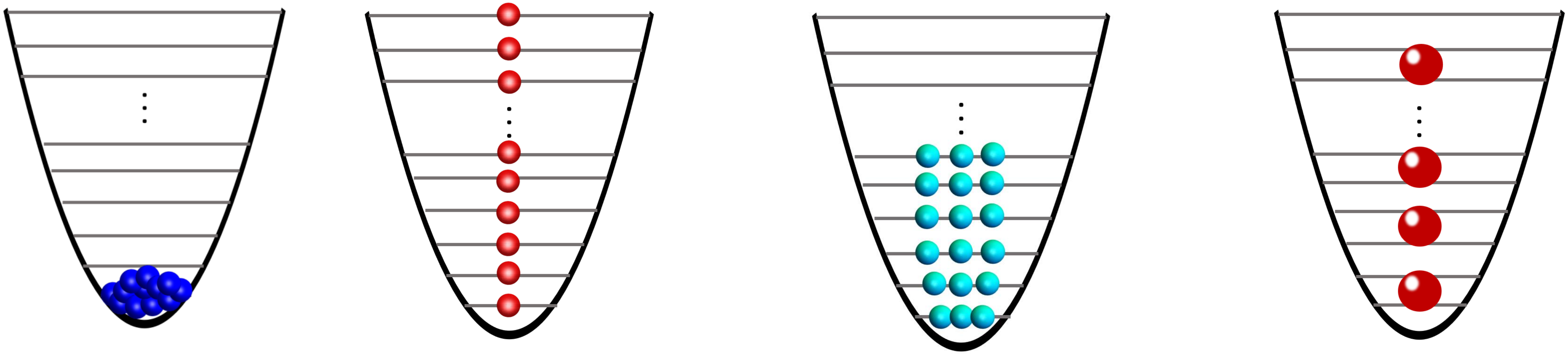
Quantum statistics generalized

Haldane’s Generalized Exclusion Statistics (GES)

Only exist in low-dimension

α new states are needed for adding 1 particle to the system



Bosons: α=0

Fermions: α=1

Anyons: 0<α<1

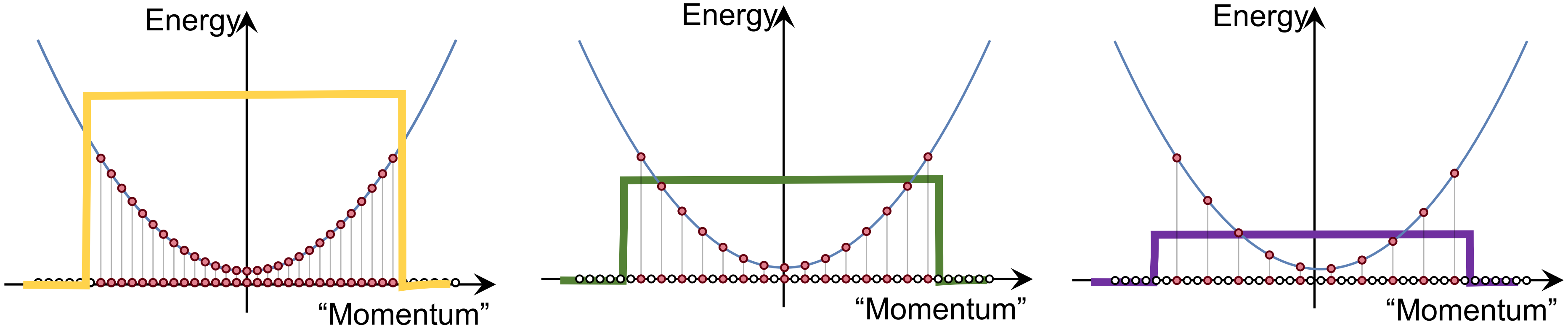
α=1/3

“Super-fermions”: α>1

α=2

Generalizations of the exclusion principle

Can we engineer “fractional” Fermi seas?



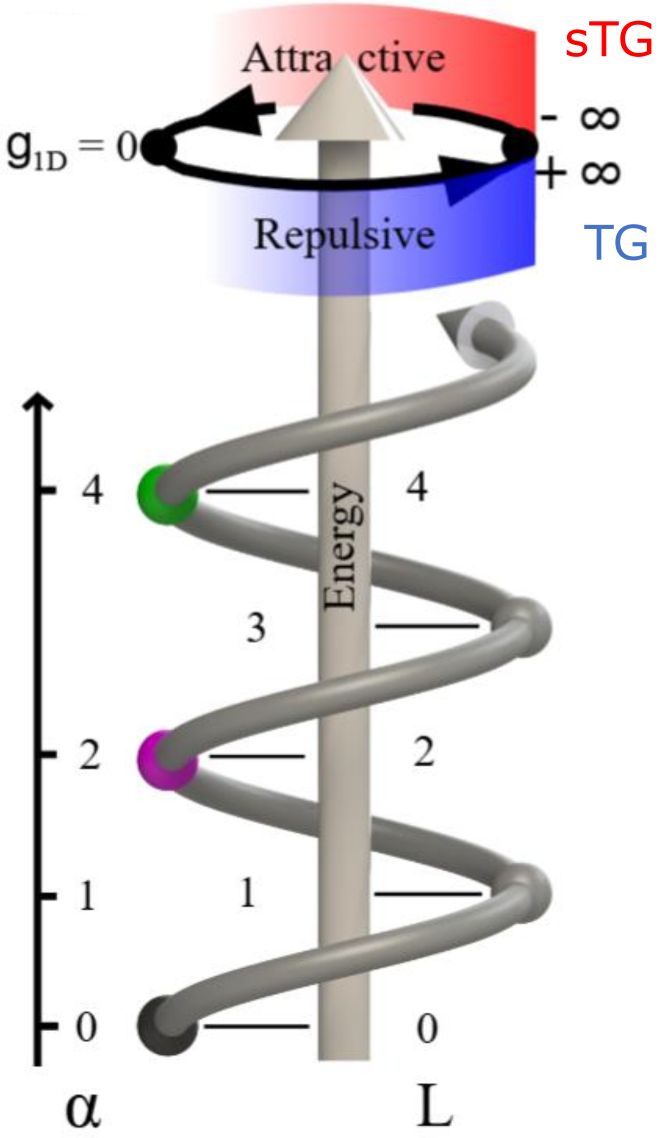
α=1 α=2 α=3

How to excite fractional Fermi seas?

How to prevent their relaxation to thermal states?

Fermionizing the ideal Bose gas via topological pumping,
M. Marciniak, G. E. Astrakharchik, K. Pawłowski, B. Juliá-Díaz;
arXiv:2504.19569 (2025)

Cycling precedure



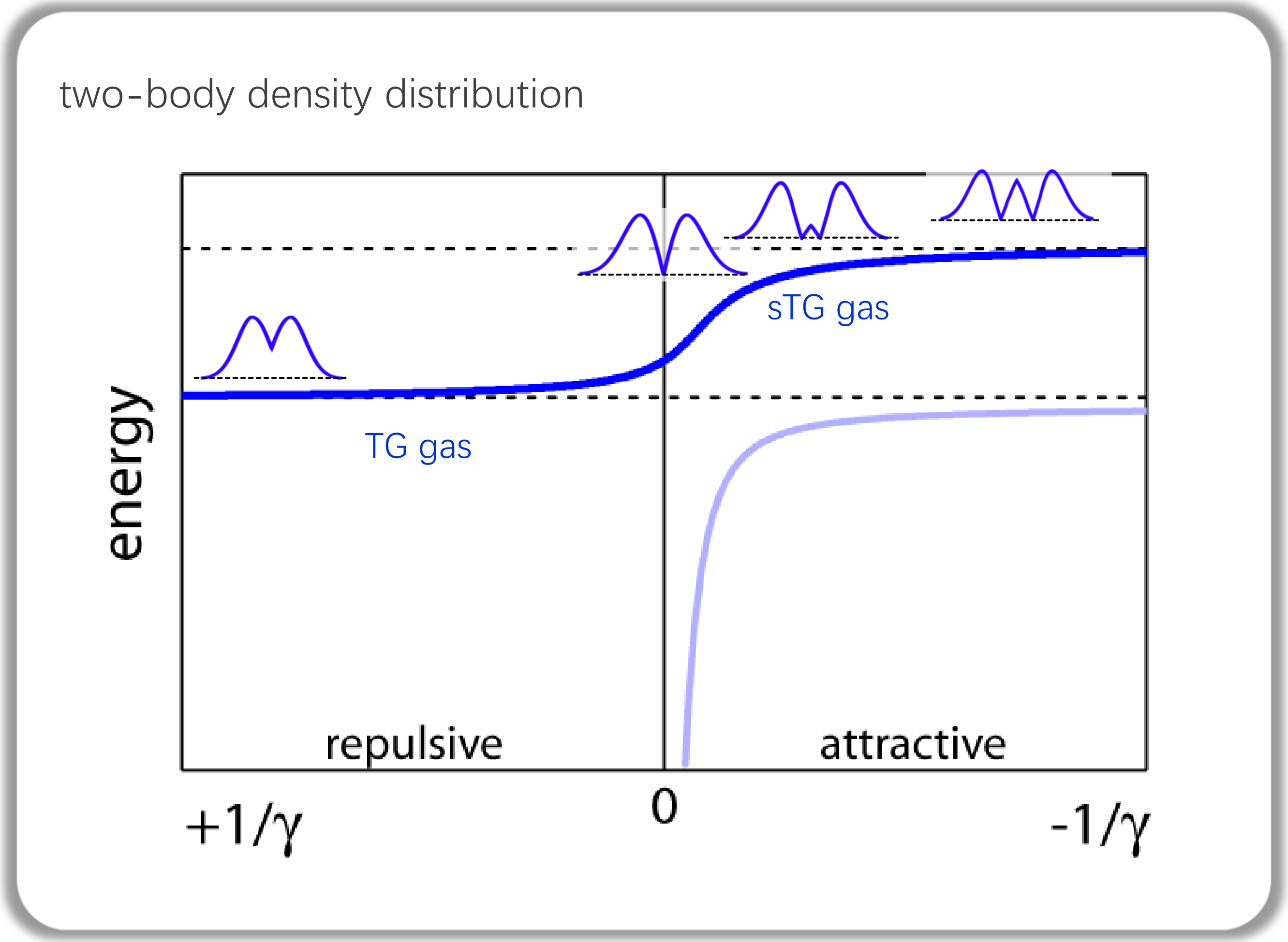
cycle g_{1D} over a CIR

$$\hat{H} = -\frac{\hbar^2}{2m}\sum_{i=1}^{N}\frac{\partial^2}{\partial x_i^2} + g_{1D}\sum_{i<j=1}^{N}\delta(x_i - x_j)$$

„pumping" parameter L

$$\alpha = L$$

Tunable Lieb-Liniger: sTG regime



G. Astrakharchik et al.,
PRL **95,** 190407 (2005)

Realized on a confinement-induced resonance (CIR)

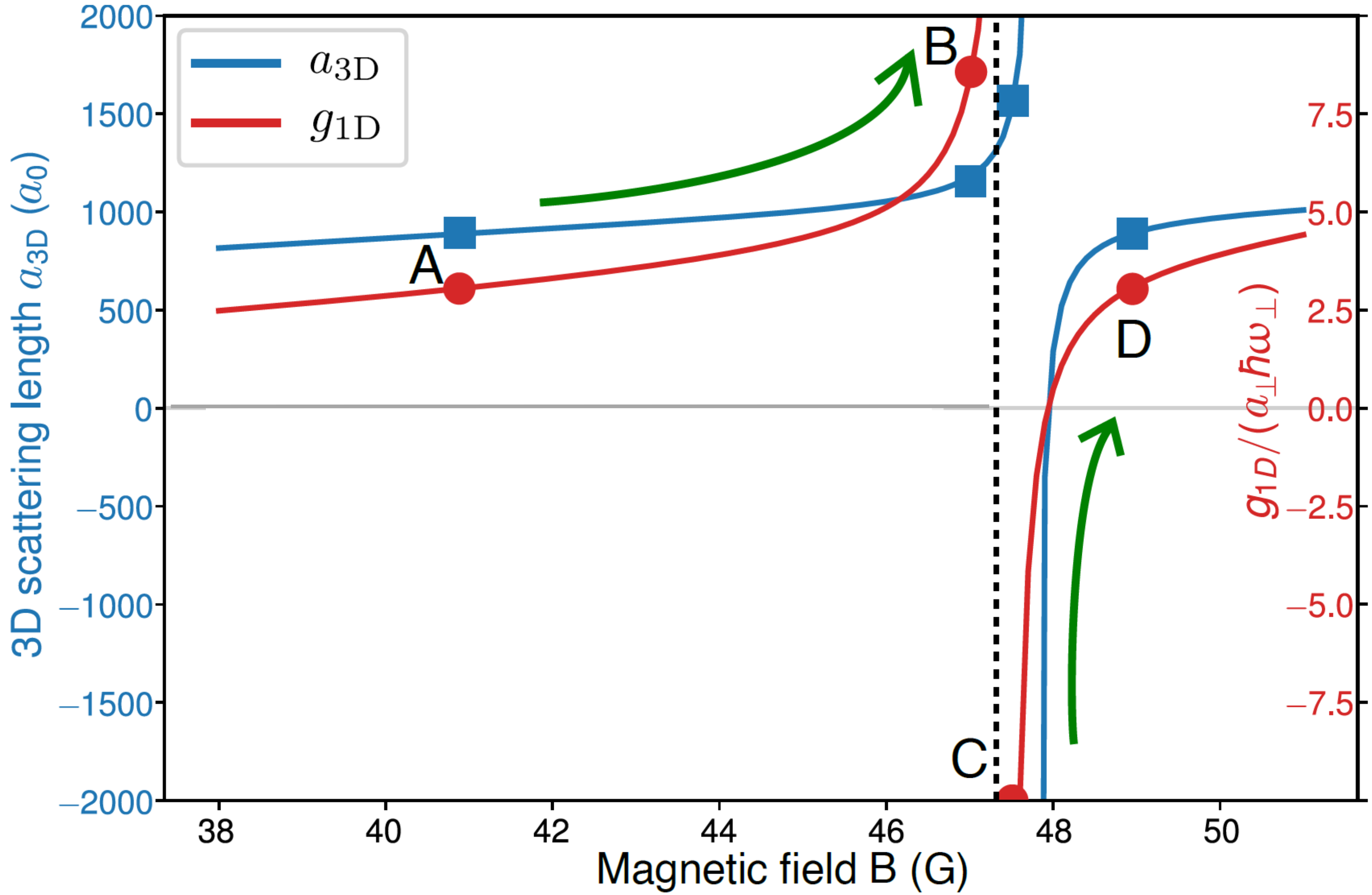
$$g_{1D} = 2\hbar\omega_\perp a_{3D}\left(1 - C\frac{a_{3D}}{a_\perp}\right)^{-1}$$

M. Olshanii,
Phys. Rev. Lett. **81**, 938 (1998)

fermionization in the so-called Tonks-Girardeau (TG, γ>0) and super Tonks-Girardeau (sTG, γ<0) states

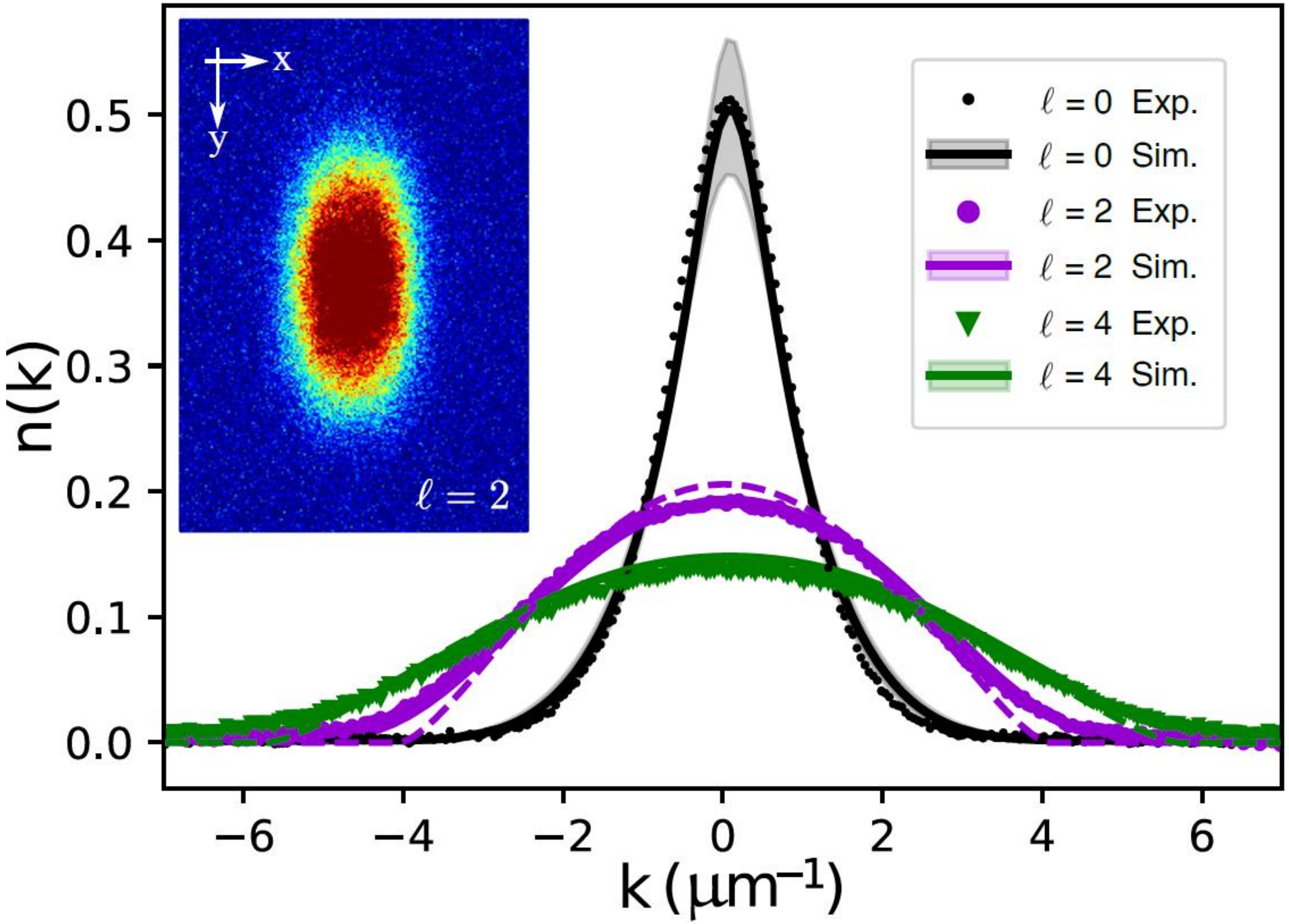
Theory: M. Girardeau, J. Math. Phys. 1, 516 (1960);
Experiment: Weiss group, Science, 305, 1125 (2004); Nägerl group, Science 325, 1224 (2009) and Nature 466, 597 (2010)

Implementation: Confinement-induced resonance (CIR)



On CIR's: E. Haller, M. Gustavsson, M. J. Mark, J. G. Danzl, R. Hart, G. Pupillo, H.-C. Nägerl, **Science 325, 1224 (2009)**

Momentum distribution



Dots: Data

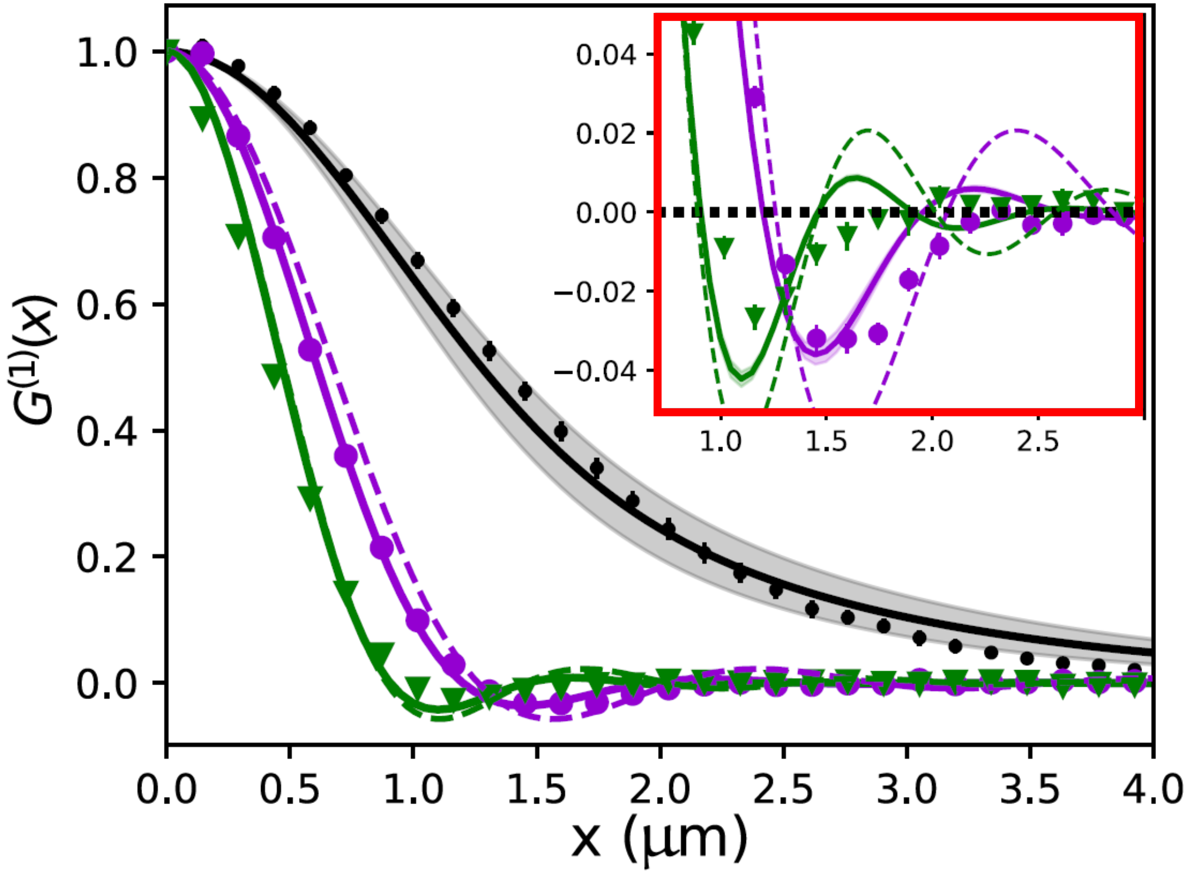
GHD modeling, solid lines: only a fit for l=0

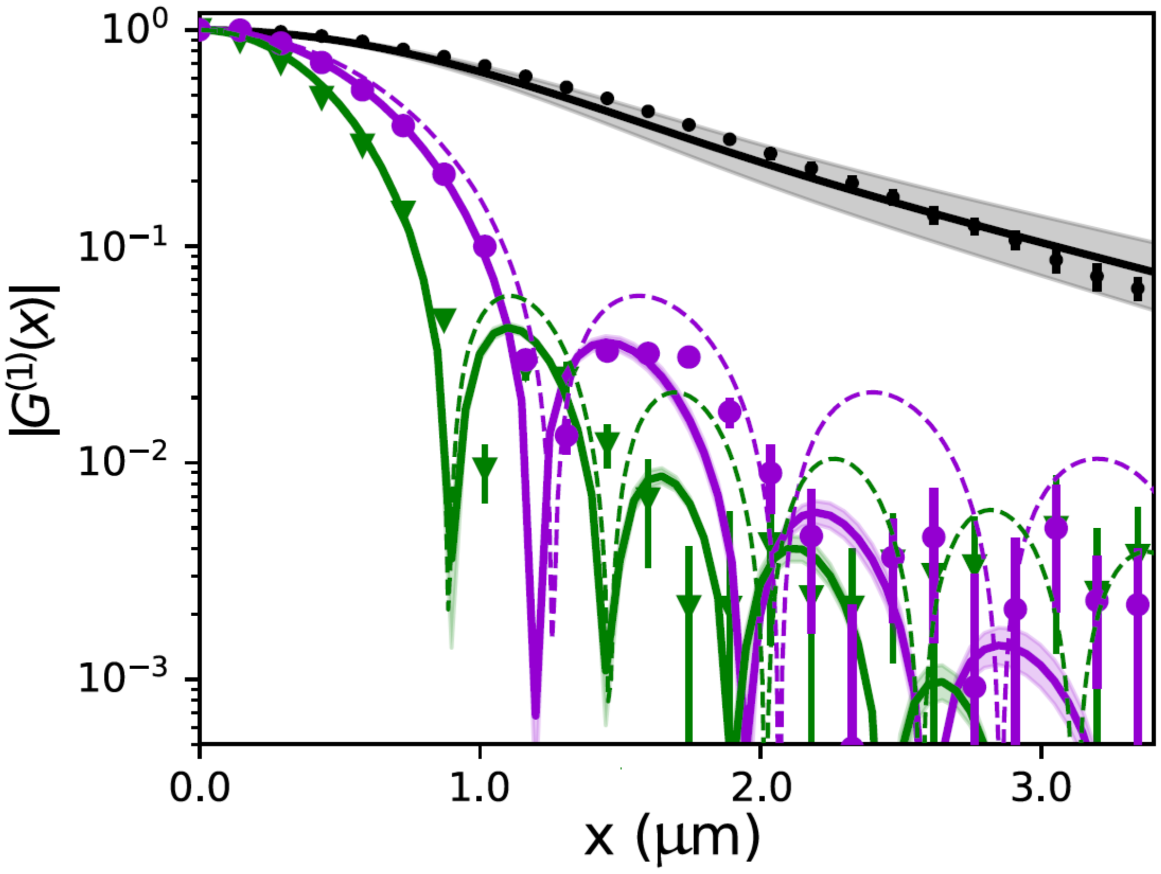
Dashed: Thomas-Fermi approximation (zero temperature)

$G^{(1)}$ function

onset of Friedel oscillations

Dots: Data
solid lines: GHD-theory
Dashed: TF-approx.



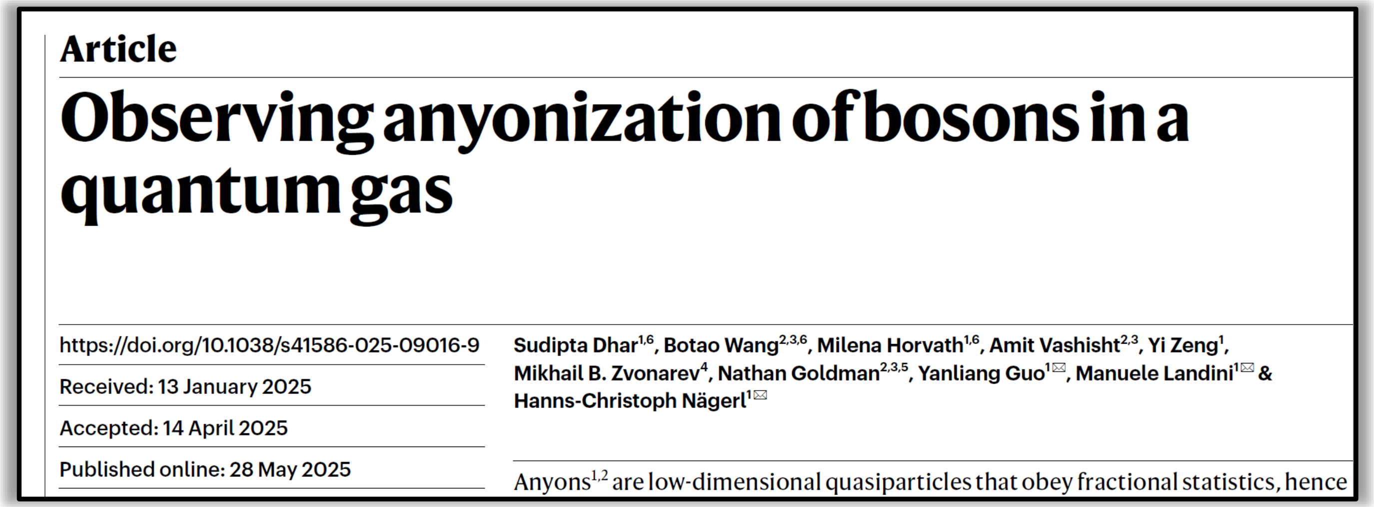


linear

logarithmic

Recent Innsbruck results (6)

Anyonization of bosons



Article

Observing anyonization of bosons in a quantum gas

https://doi.org/10.1038/s41586-025-09016-9

Received: 13 January 2025

Accepted: 14 April 2025

Sudipta Dhar[1,6], Botao Wang[2,3,6], Milena Horvath[1,6], Amit Vashisht[2,3], Yi Zeng[1], Mikhail B. Zvonarev[4], Nathan Goldman[2,3,5], Yanliang Guo[1]✉, Manuele Landini[1]✉ & Hanns-Christoph Nägerl[1]✉

Anyons[1,2] are low-dimensional quasiparticles that obey fractional statistics, hence

Nature 642, 53 (2025)

See also: *Anyonization of bosons in one dimension: an effective swap model*
B. Wang, A. Vashisht, Y. Guo, S. Dhar, M. Landini, H.-C. Nägerl, N. Goldman
Physical Review Letters 135, 253403 (2025), arXiv:2504.21208