Field theory description for dynamics in non-equilibrium quantum systems

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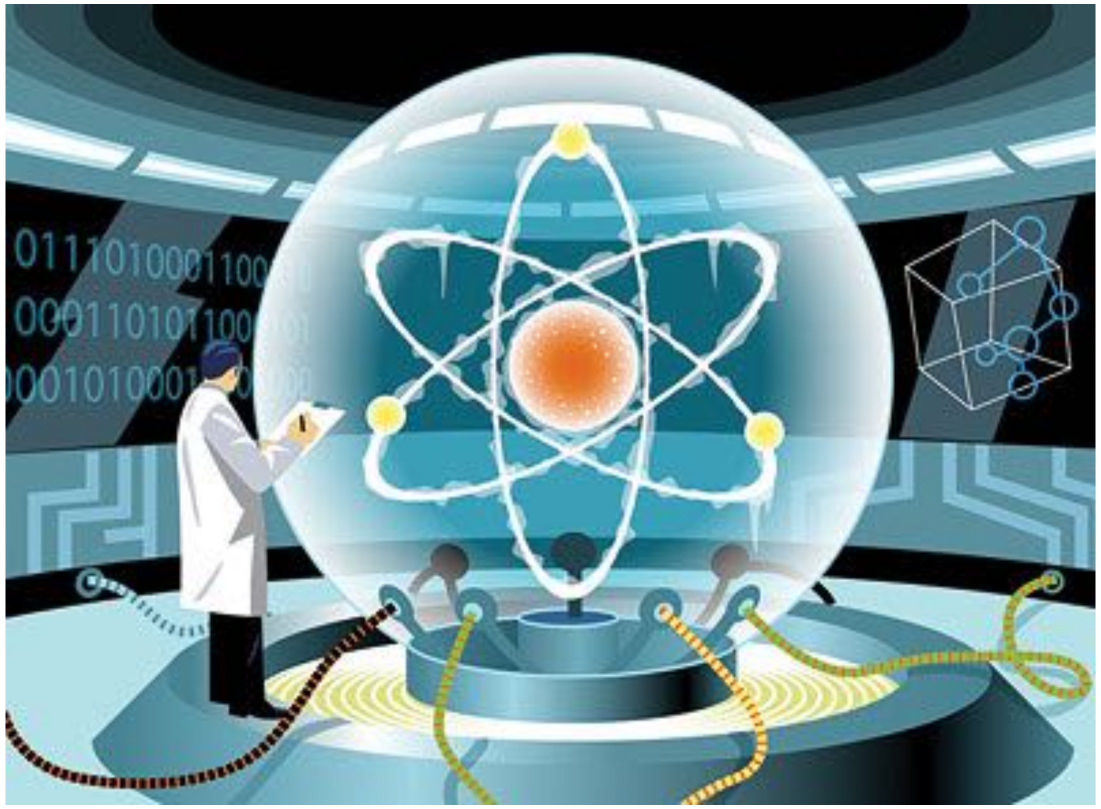
PROJECT
FINANCED FROM
THE NRDI FUND
MOMENTUM OF INNOVATION

Cold atoms as quantum simulators

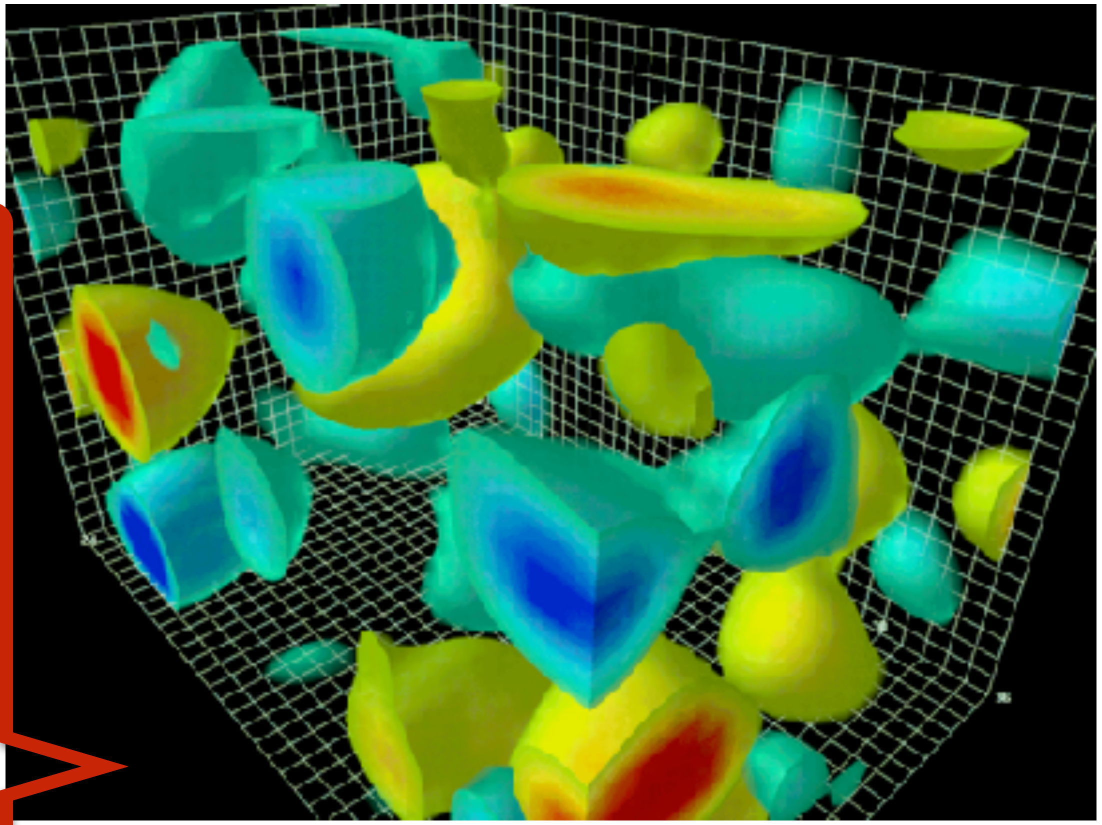


Closed quantum systems can be realised with trapped ultra-cold atoms

An interesting application of quantum computing:

Quantum simulation

Fundamental interactions: described by quantum field theory



Strongly interacting quantum fields: even the vacuum is complicated!

Eg. quantum chromodynamics: theory of how the proton and neutron are made.

Simulating strongly interacting quantum fields

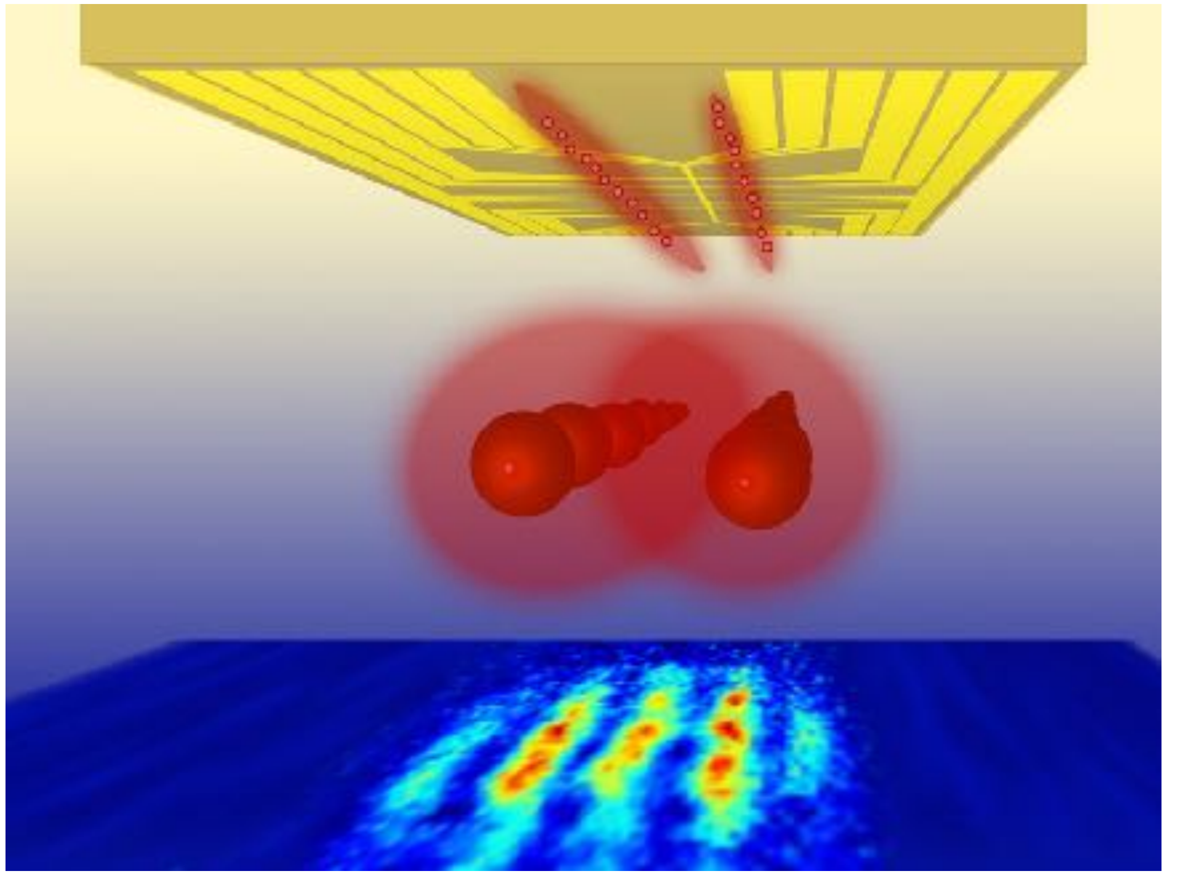
Atoms trapped and manipulated by electric, magnetic and optical fields

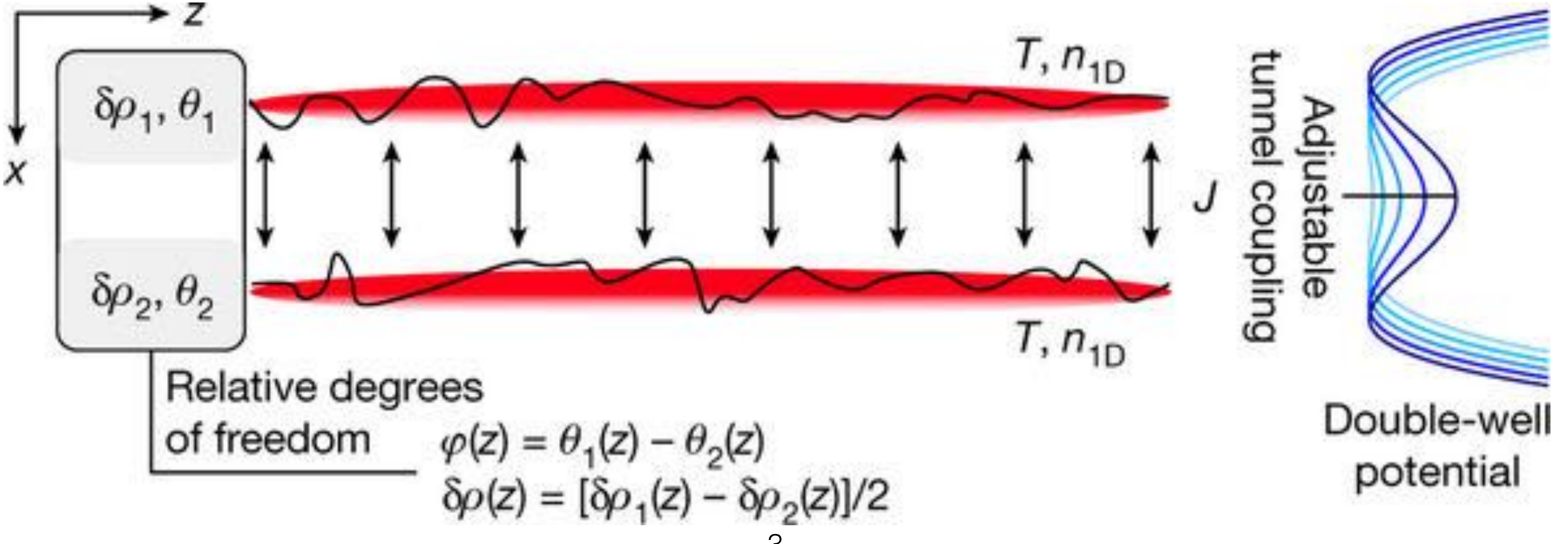
Size of region: $\sim \mu m$

Temperature: $\sim 100\, nK$

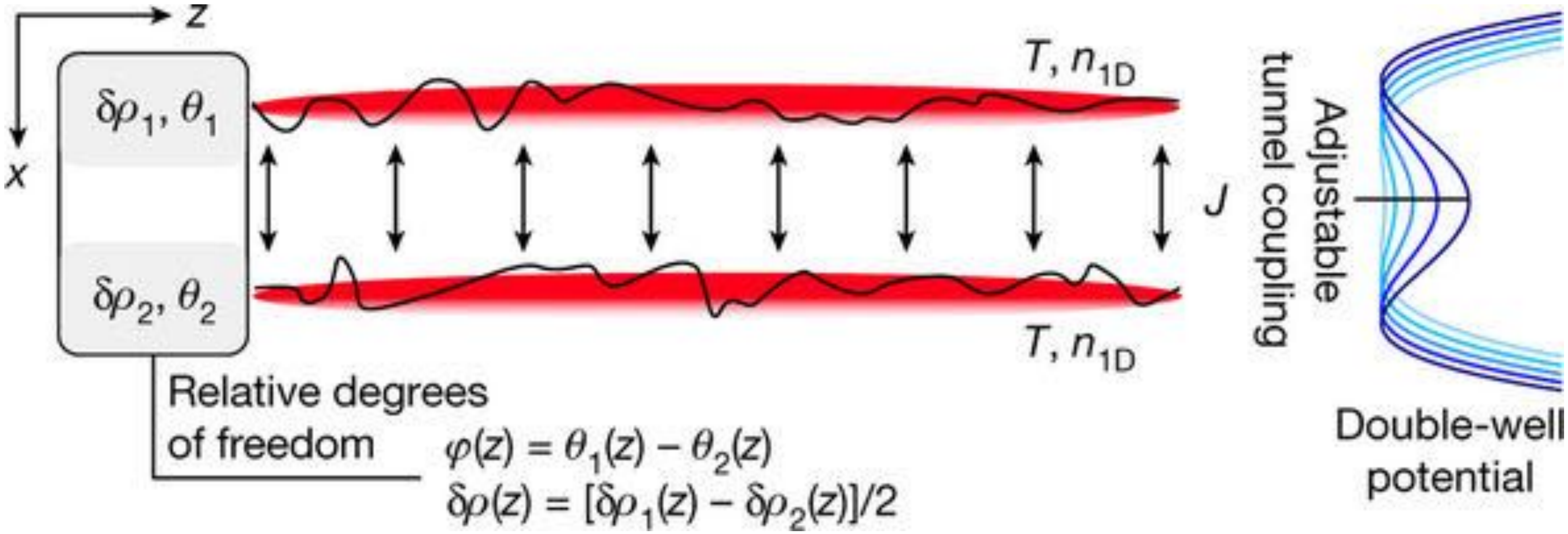
Quasi-1D Bose condensates

T. Schweigler et al., Nature 545 (2017) 323-326.





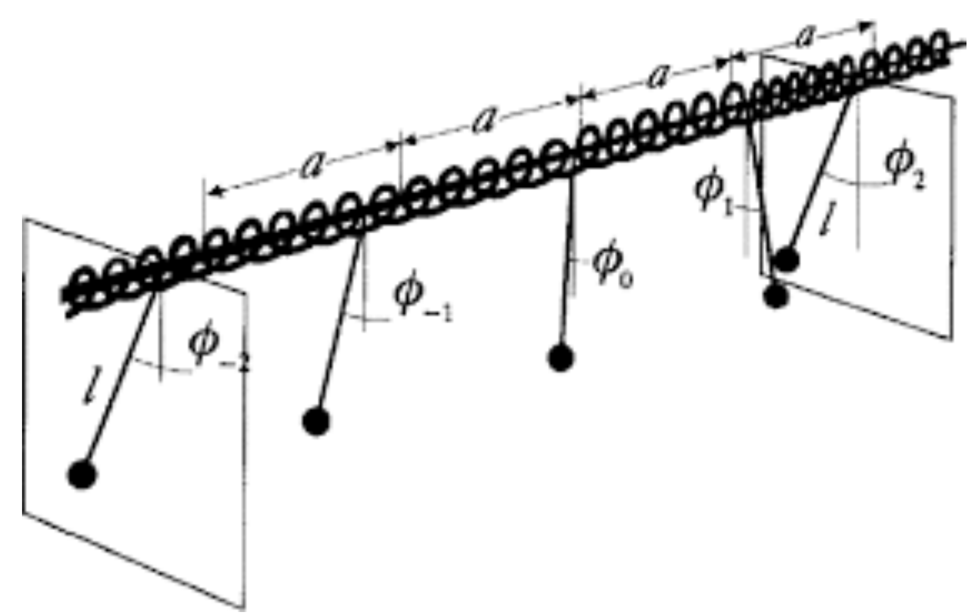
Sine-Gordon model



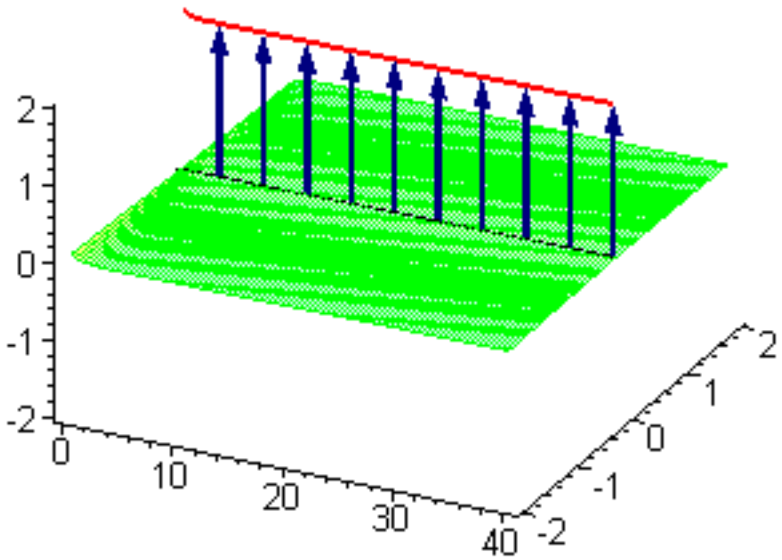
Ultracold gas of ^{87}Rb atoms, confined to 2 x 1D

$$H_{sG} = \int dz \left\{ g\delta\rho(z)^2 + \frac{\hbar^2 n_{1D}}{4m} \left(\partial_z \varphi(z)\right)^2 - 2\hbar J n_{1D} \cos\varphi(z) \right\}$$

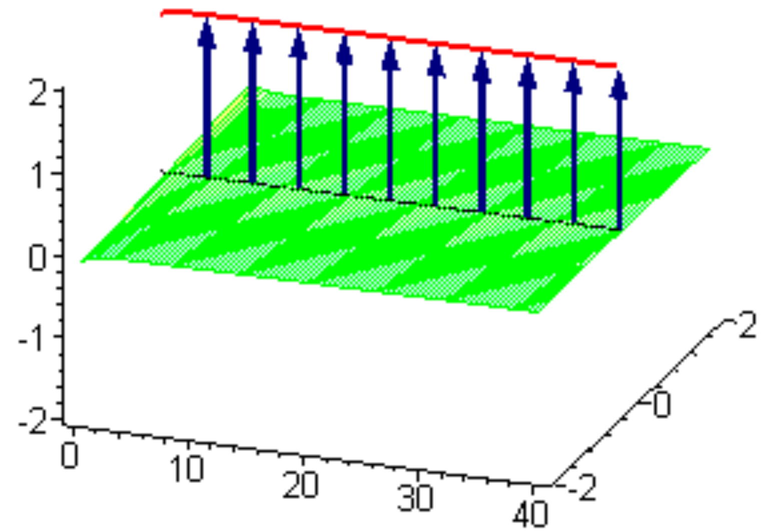
Classical sine-Gordon: continuum version of discrete pendulum chain



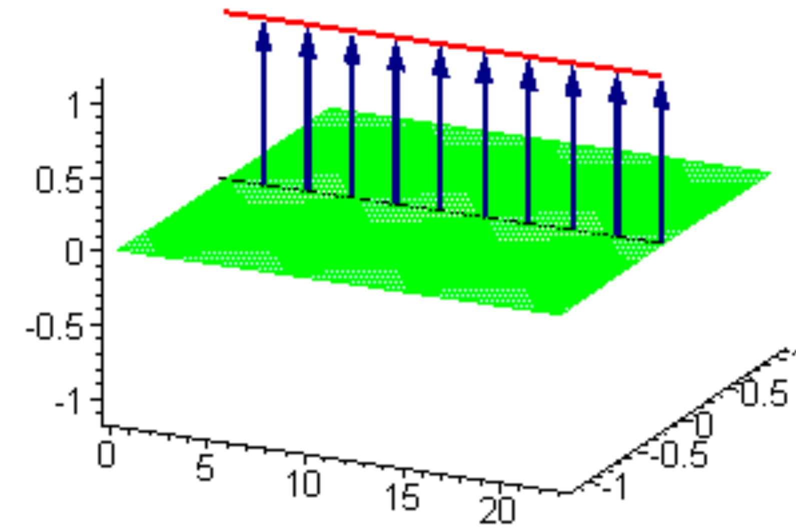
Solitons and breathers



soliton

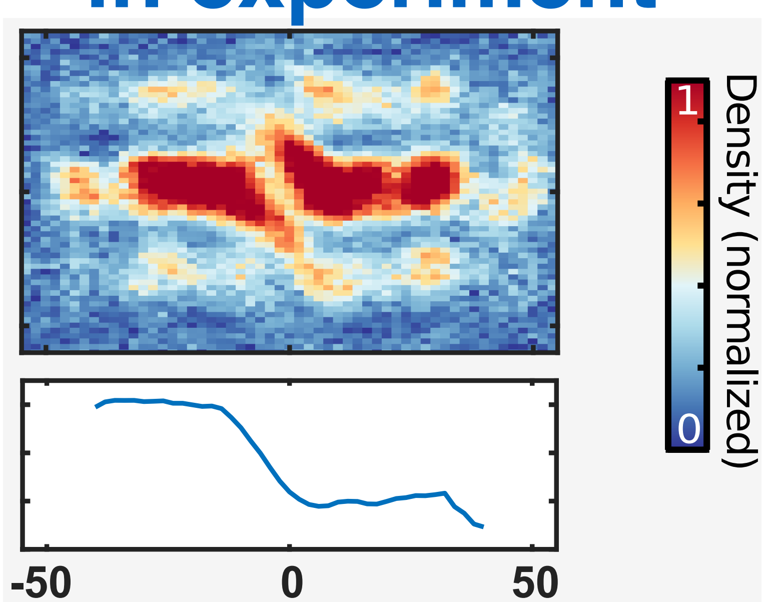


antisoliton



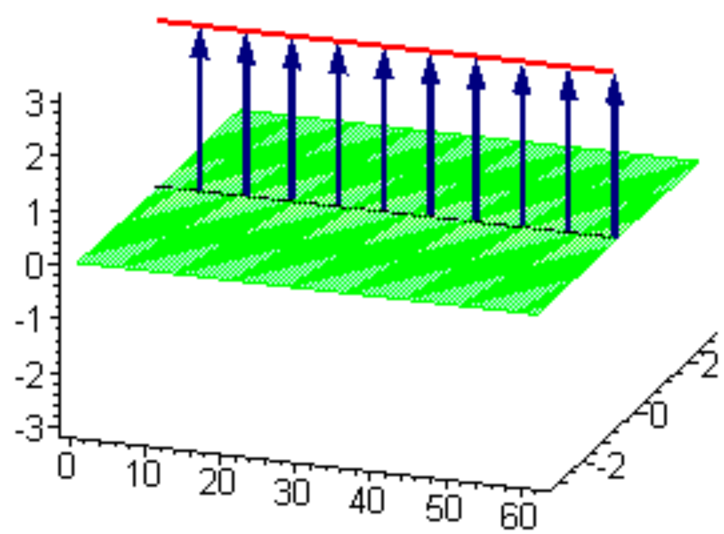
breather

in experiment

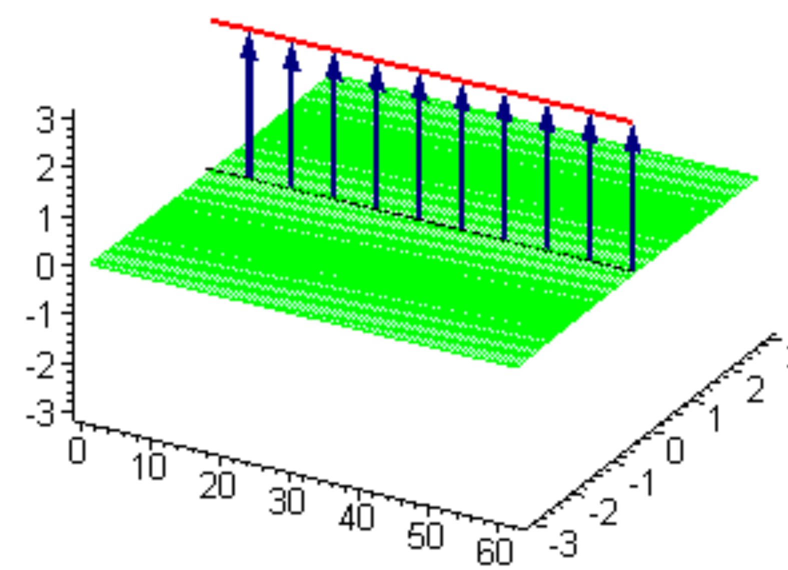


T. Schweigler et al.,
Nature 545 (2017) 323-326.

Collisions



soliton-soliton



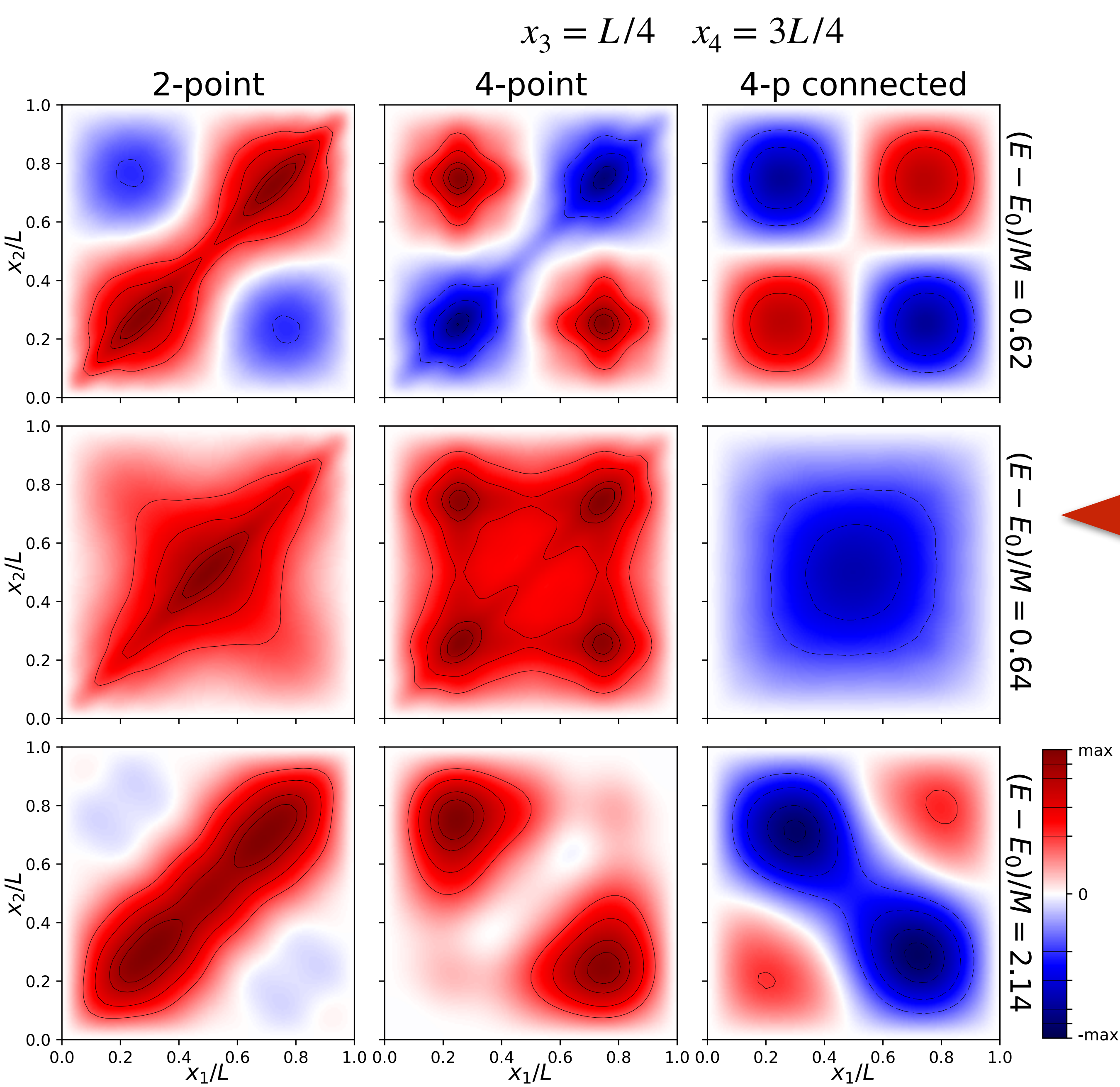
antisoliton-soliton

Quantum sine-Gordon vs. experiment

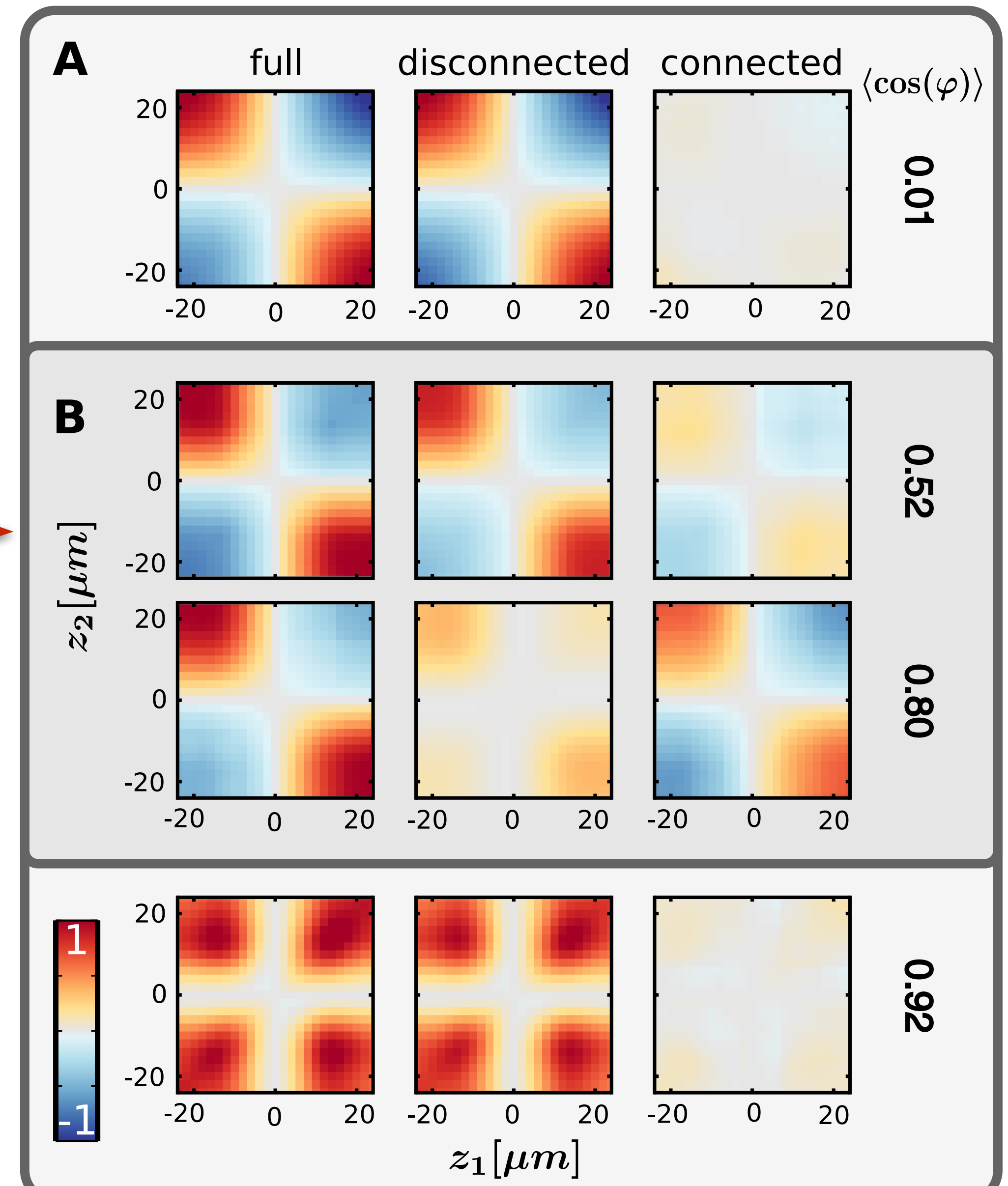
Phase correlations: $G_2(x_1,x_2) = \langle \varphi(x_1)\varphi(x_2)\rangle \quad G_4(x_1,x_2,x_3,x_4) = \langle \varphi(x_1)\varphi(x_2)\varphi(x_3)\varphi(x_4)\rangle$

Connected 4-point correlation: measures non-Gaussianity from interactions

$$G_4^{conn}(x_1,x_2,x_3,x_4) = G_4(x_1,x_2,x_3,x_4) - G_2(x_1,x_2)G_2(x_3,x_4) - G_2(x_1,x_3)G_2(x_2,x_4) - G_2(x_1,x_4)G_2(x_2,x_3)$$



I. Kukuljan, S. Sotiriadis and G. Takács,
Phys. Rev. Lett. 121 (2018) 110402.

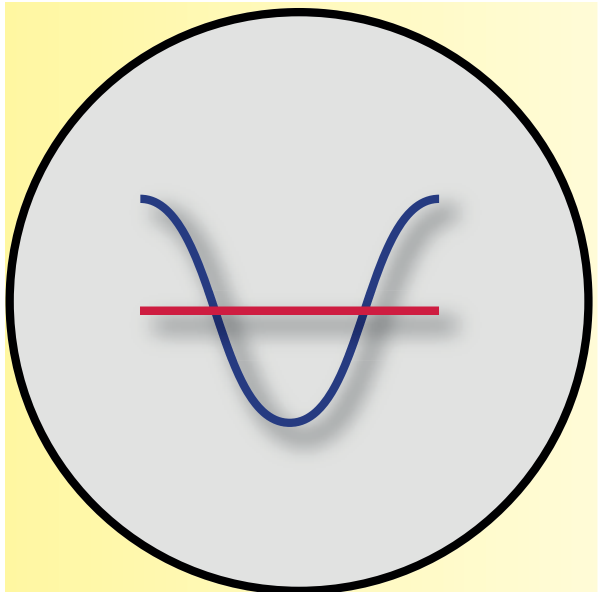


T. Schweigler et al.,
Nature 545 (2017) 323-326.

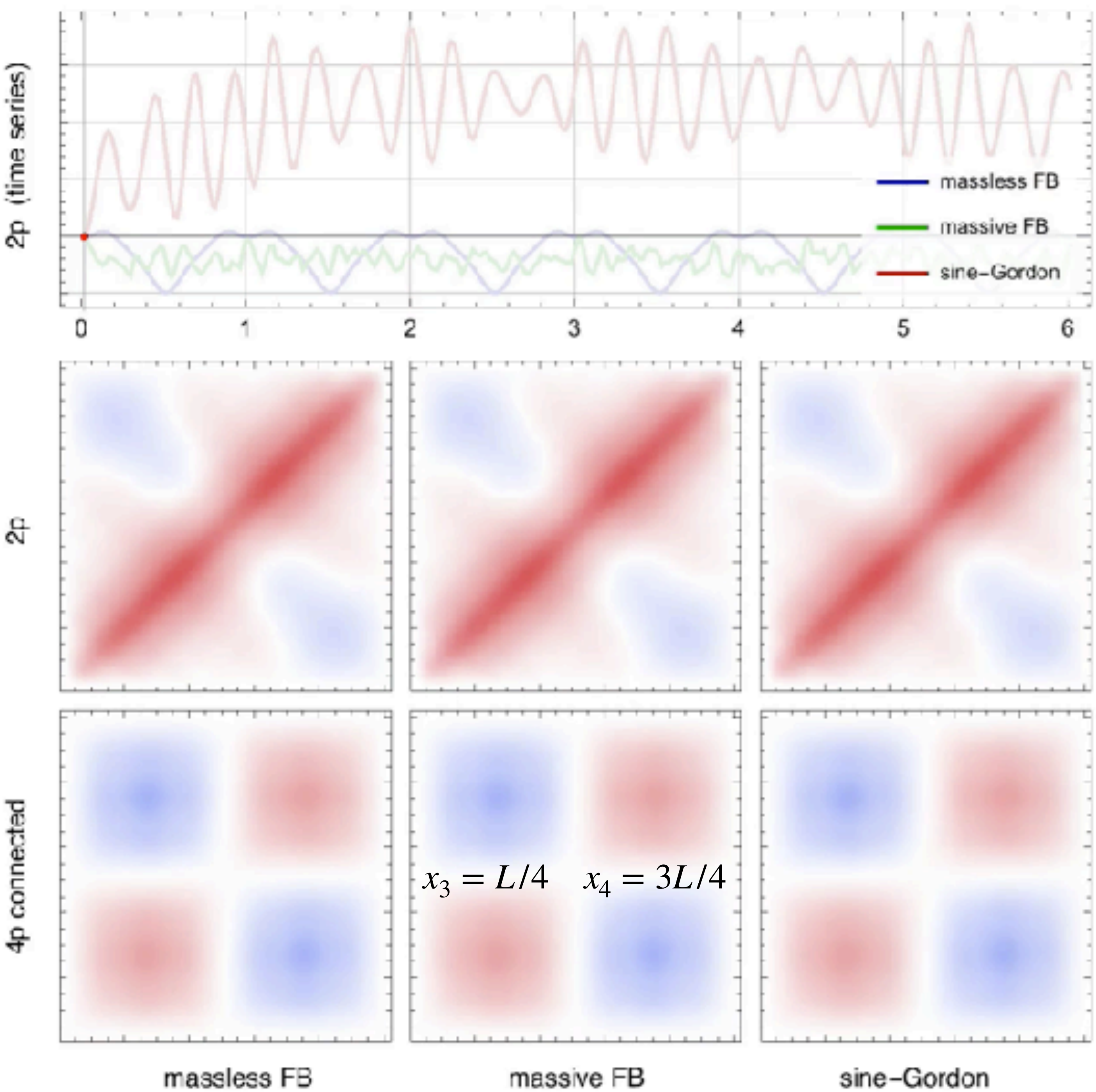
Time evolution out-of-equilibrium

$$G_2(x_1,x_2) = \langle \varphi(x_1)\varphi(x_2)\rangle \quad G_4(x_1,x_2,x_3,x_4) = \langle \varphi(x_1)\varphi(x_2)\varphi(x_3)\varphi(x_4)\rangle$$

$$G_4^{conn}(x_1,x_2,x_3,x_4) = G_4(x_1,x_2,x_3,x_4) - G_2(x_1,x_2)G_2(x_3,x_4) - G_2(x_1,x_3)G_2(x_2,x_4) - G_2(x_1,x_4)G_2(x_2,x_3)$$

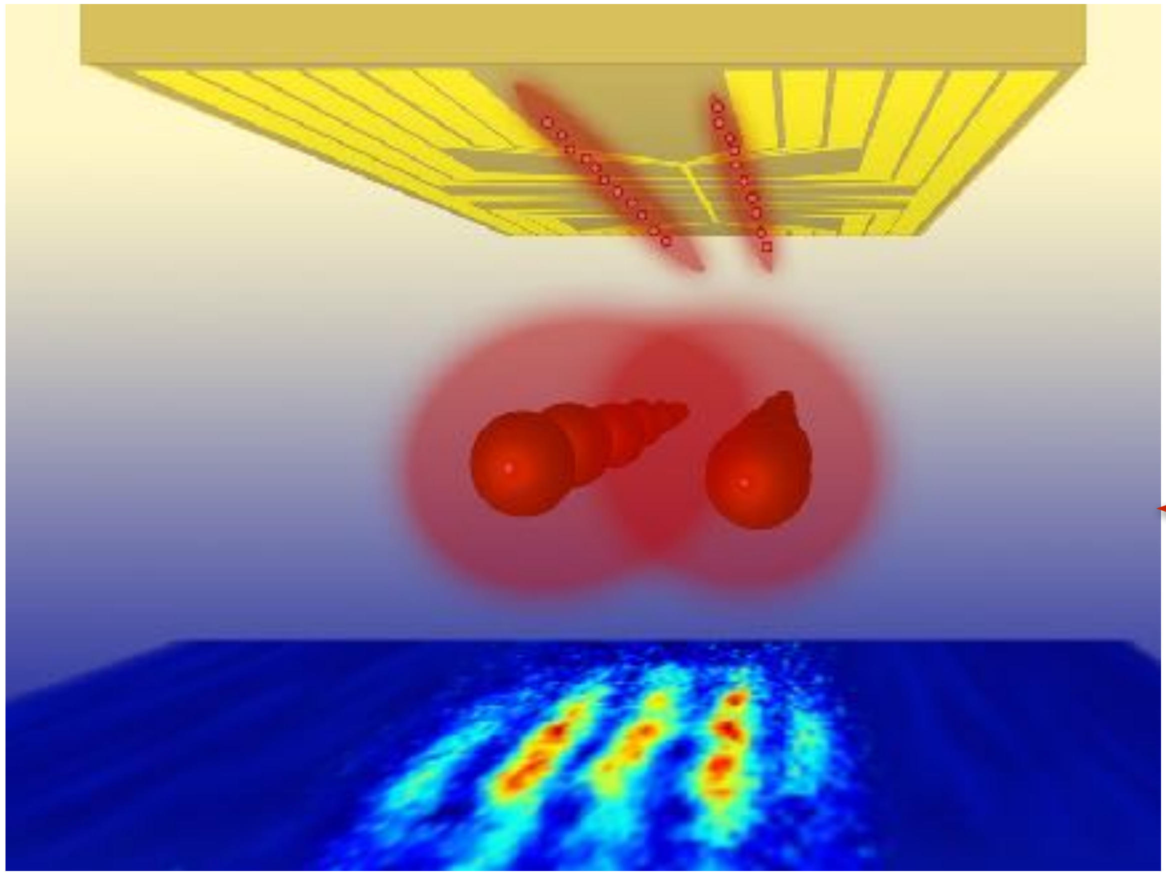


Interaction quench from an excited state midway up the sine-Gordon potential well



I. Kukuljan, S. Sotiriadis and G. Takács, Phys. Rev. Lett. 121 (2018) 110402.

Does the simulator work?



?

$$H_{sG} = \int dz \left\{ g\delta\rho(z)^2 + \frac{\hbar^2 n_{1D}}{4m}\left(\partial_z\varphi(z)\right)^2 - 2\hbar J n_{1D}\cos\varphi(z) \right\}$$

- **Seems to work in equilibrium**
- **Problems in non-equilibrium:**
  - **sine-Gordon predicts dephasing**

    D.X. Horváth, I. Lovas, M. Kormos, G. Takács and G. Zaránd, arXiv: 1809.06789
  - **experiment shows phase-locking**

    M. Pigneur, T. Berrada, M. Bonneau, T. Schumm, E. Demler and J. Schmiedmayer, Phys. Rev. Lett. 120 (2018) 173601.

Thank you for your attention!