Stationary, dynamic and thermal properties of quantum droplets

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dr hab. Piotr Deuar

NARODOWE CENTRUM NAUKI

Introduction

- ultracold quantum gas

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$$\tau \sim 2.5 \text{ ms}$$

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Bogoliubov spectrum of uniform density (local density approximation)

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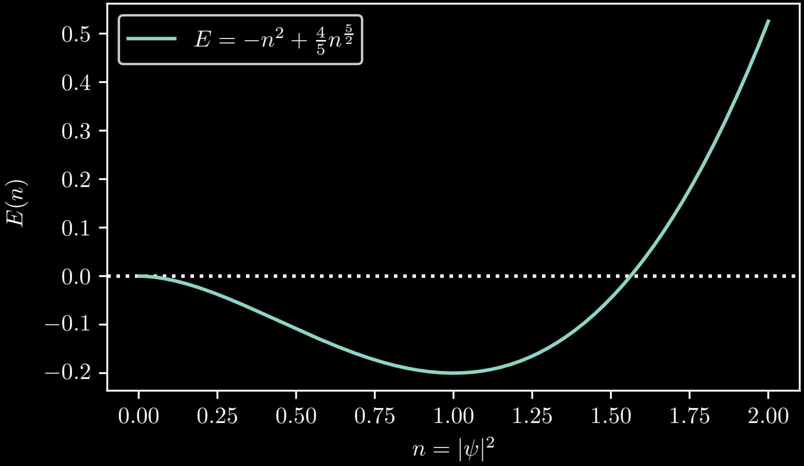

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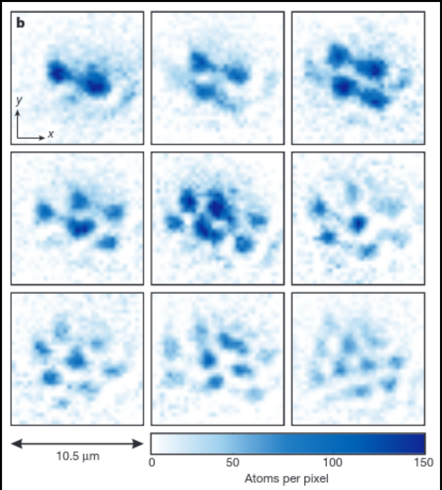
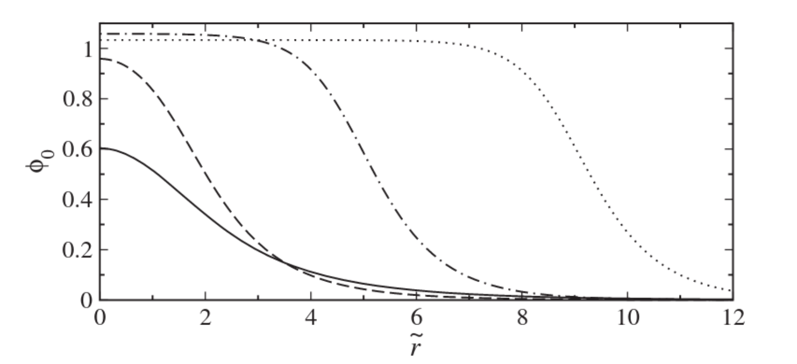
Finite number of particles at preferred density $\implies$ finite volume

Unexpected discovery



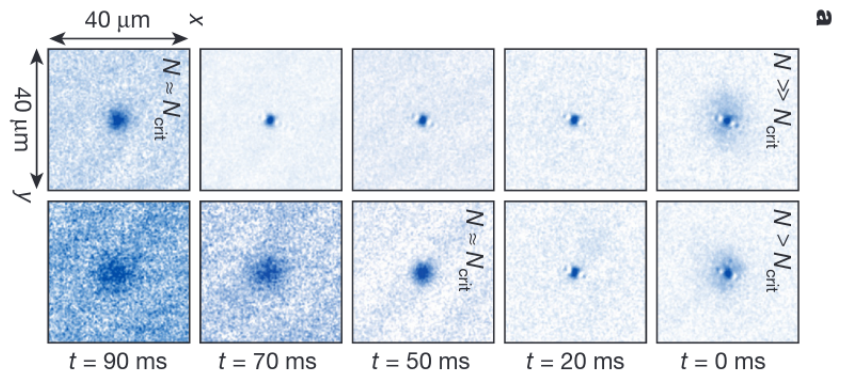
H. Kadau et al., Nature 530, 194 (2016)

Theoretical prediction



D. S. Petrov, Phys. Rev. Lett. 115, 155302 (2015)

Confirmation



M. Schmitt et al., Nature 539, 259 (2016)

Extended Gross–Pitaevskii equation

$$i\partial_t\phi = (-\frac{\nabla^2}{2} - 3|\phi|^2 + \frac{5}{2}|\phi|^3 - \mu)\phi$$

$$\phi = \phi(x/\xi, t/\tau)$$

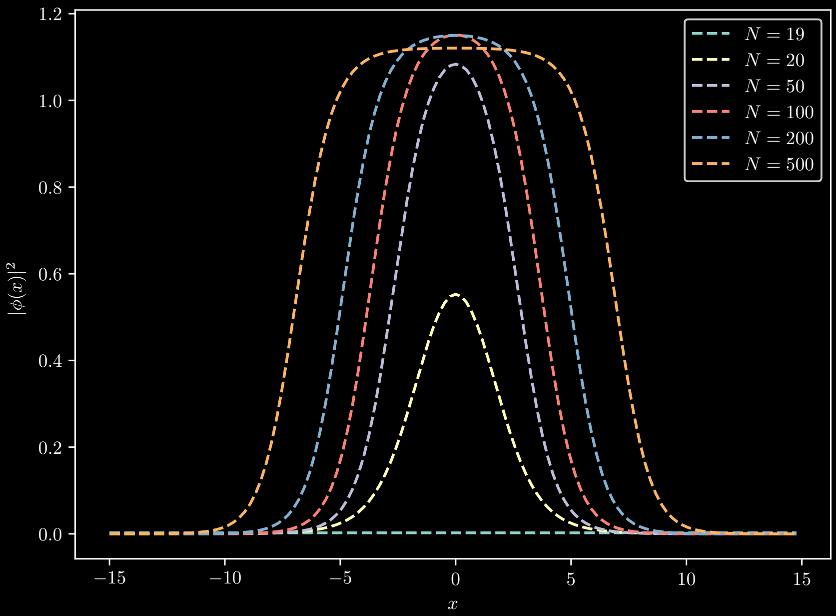
For ^{39}K atoms:
cooritinate units:

$$\xi \approx 2\mu m$$

time units:

$$\tau \approx 2.5ms$$

3D droplets



$N = 19$
$N = 20$
$N = 50$
$N = 100$
$N = 200$
$N = 500$
$|\phi(x)|^2$
x
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−15
−10
−5
0
5
10
15

2 components

2 component Bose-Bose mixture

$$E = E_0 + \frac{1}{2}\sum_{i,j} g_{ij} n_i n_j$$

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$g_{ii} > 0 \wedge g_{12}^2 < g_{11} g_{22} \implies$ stable (gas)

2 components

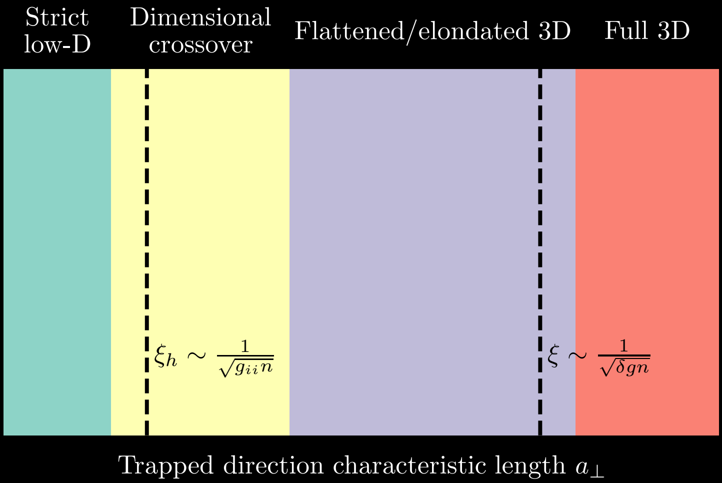
$$\delta g = g_{12} + \sqrt{g_{11} g_{22}}$$

$$\delta g < 0 \wedge g_{ii} > 0 \wedge |\delta g| \ll g_{ii}$$

$$\downarrow$$

Droplets!

Sausages and pancakes: an effective low dimensional description



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Strict 1D, 2D

D. S. Petrov and G. E. Astrakharchik, Phys. Rev. Lett. 117, 100401 (2016)

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P. Zin, M. Pylak, T. Wasak, M. Gajda, and Z. Idziaszek, Phys. Rev. A 98, 051603 (2018)

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Flattened/elongated 3D

this presentation

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D. S. Petrov, Phys. Rev. Lett. 115, 155302 (2015)

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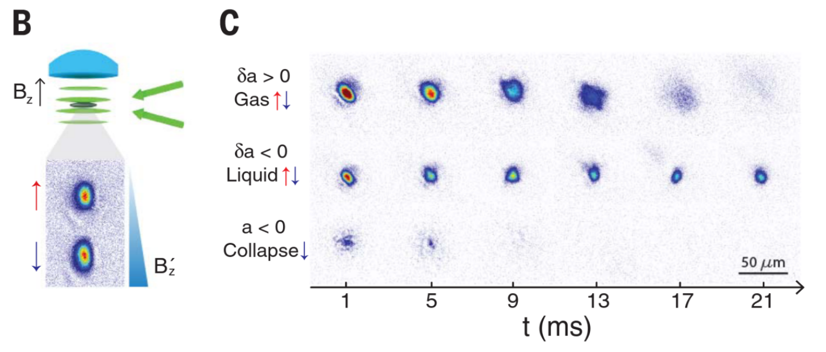

C. R. Cabrera, L. Tanzi, J. Sanz, B. Naylor, P. Thomas, P. Cheiney, and L. Tarruell, Science 359, 301 (2018)

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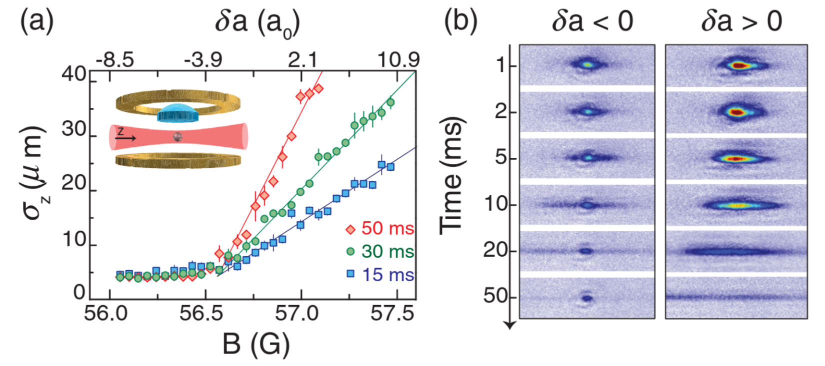

P. Cheiney et al., Phys. Rev. Lett. 120, 135301 (2018)

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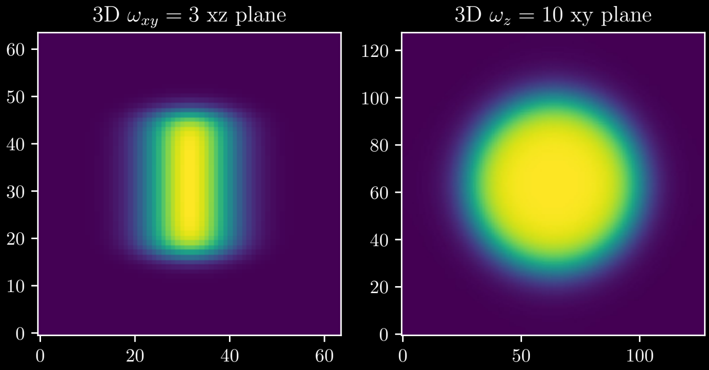

Sausages and pancakes: an effective low dimensional description

2D

$$\phi(x, y, z) = \phi_{\text{2D}}(x, y)\phi_{\text{gaussian}}(z)$$

1D

$$\phi(x, y, z) = \phi_{\text{gaussian}}(x, y)\phi_{\text{1D}}(z)$$

Sausages and pancakes: an effective low dimensional description

$$i\partial_t\phi = (-\frac{\nabla^2}{2} - 3|\phi|^2 + \frac{5}{2}|\phi|^3 - \mu)\phi$$

$$i\partial_t\phi_{2D} = (-\frac{\nabla^2}{2} - g_2(\omega)|\phi_{2D}|^2 + c_2(\omega)|\phi_{2D}|^3 - \mu)\phi_{2D}$$

$$i\partial_t\phi_{1D} = (-\frac{\nabla^2}{2} - g_1(\omega)|\phi_{1D}|^2 + c_1(\omega)|\phi_{1D}|^3 - \mu)\phi_{1D}$$

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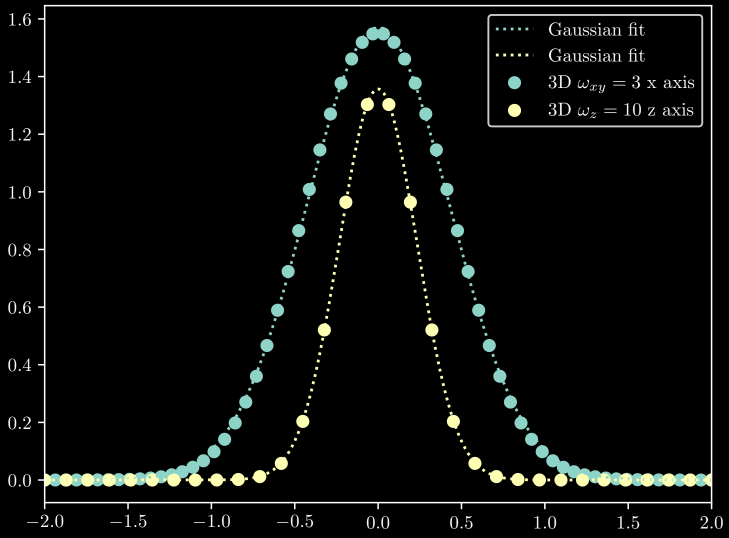
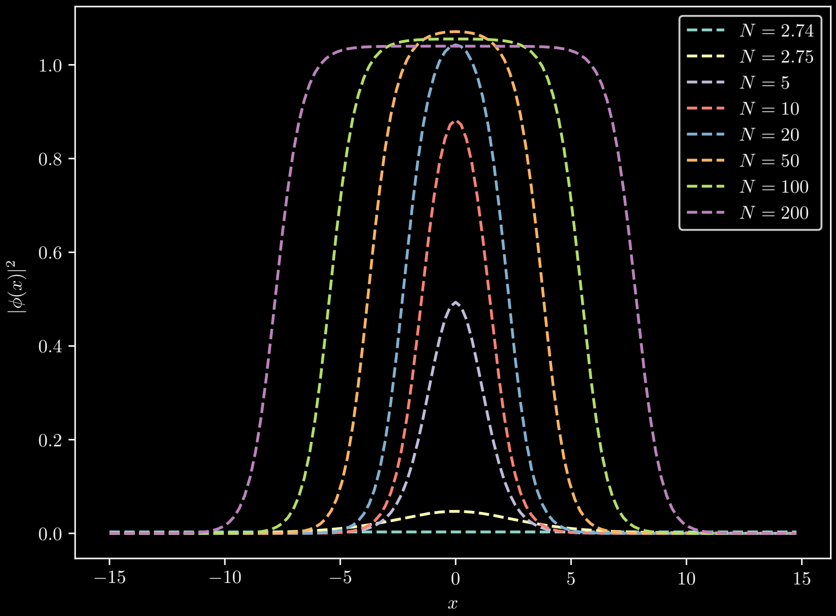


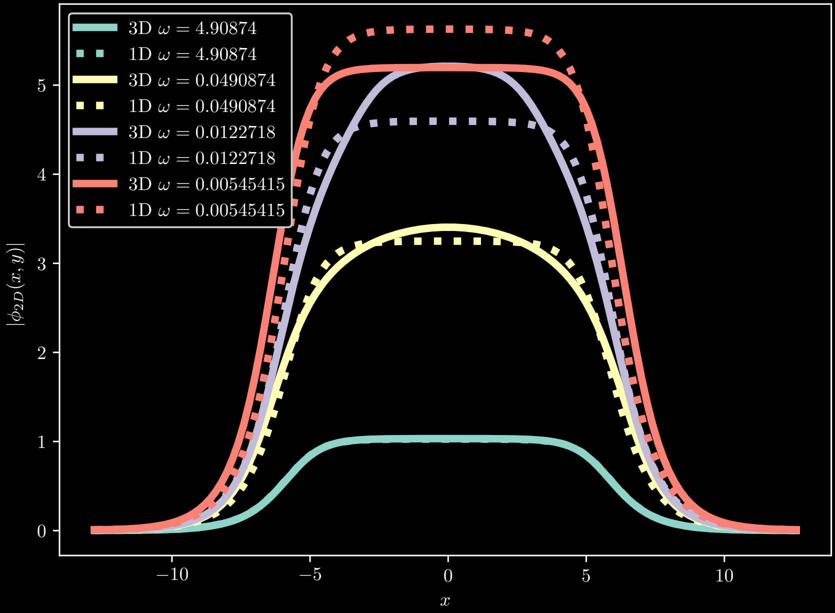
Effective 2D (flattened 3D)



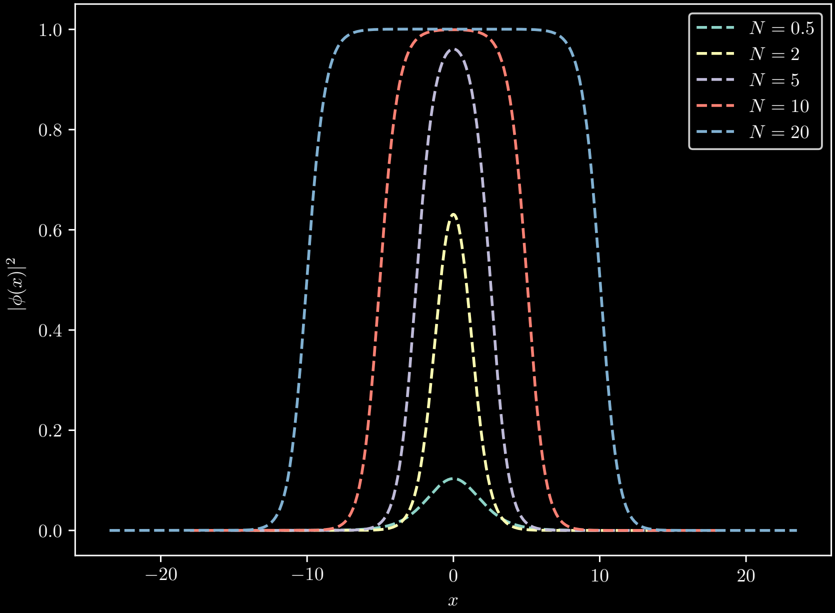
Effective 2D (flattened 3D)

$$2.74 < N_c < 2.75$$

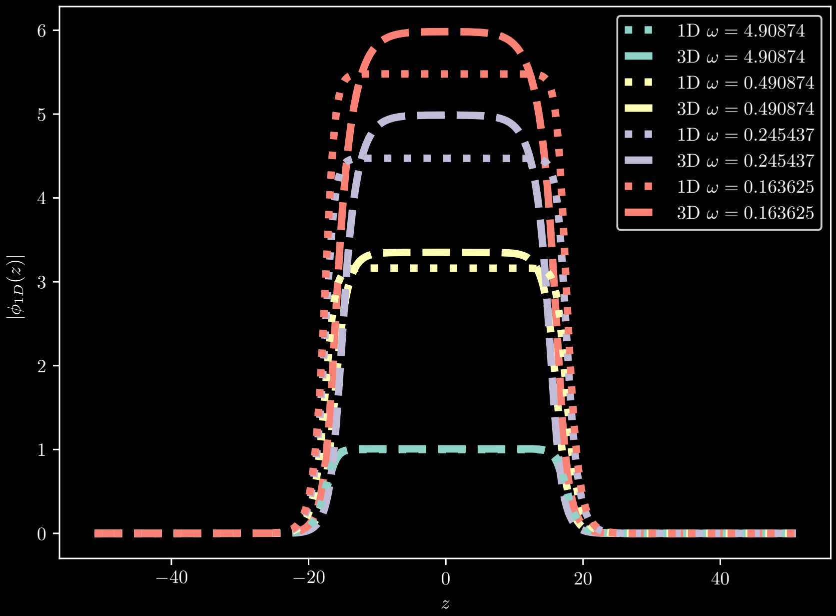
Effective 2D (flattened 3D)



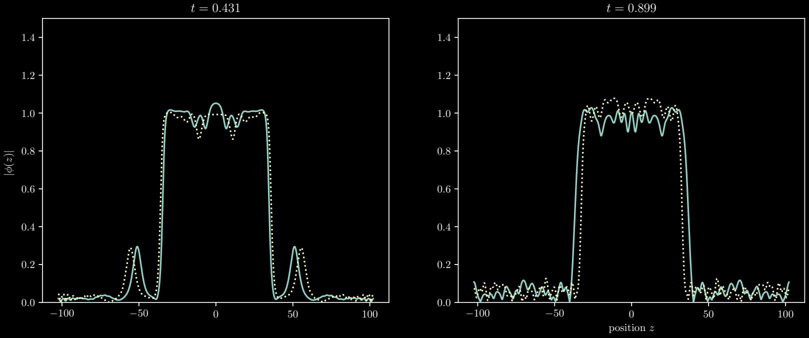
Effective 1D (elongated 3D)



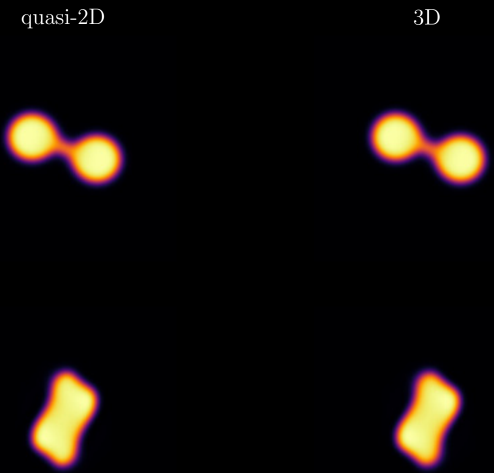
Effective 1D (elongated 3D)



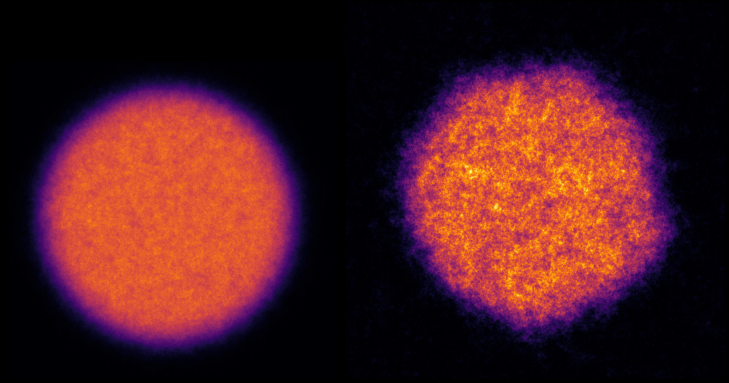
Effective 1D dynamics



Effective 2D dynamics



Thermal properties



Thermal properties

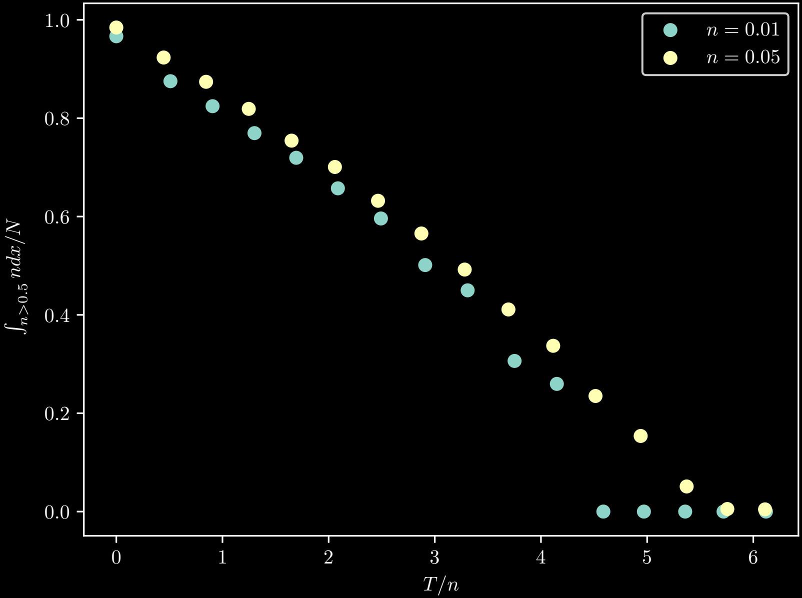
Modified Projected Stochastic GPE:

$$i\partial_t\phi = \mathcal{P}_C((1 - i\gamma)(-\frac{\nabla^2}{2} - 3|\phi|^2 + \frac{5}{2}|\phi|^3 - \mu)\phi$$
$$- \frac{\gamma T}{\sigma^2}(N(\phi) - \bar{N})\phi$$
$$+ \sqrt{2\gamma T}\eta(x,t))$$

$$C = |\mu| + (\log 2)T$$

complex Gaussian noise: $\eta, \langle\eta^*(x,t)\eta(x',t'))\rangle = \delta(x - x')\delta(t - t')$

Thermal properties



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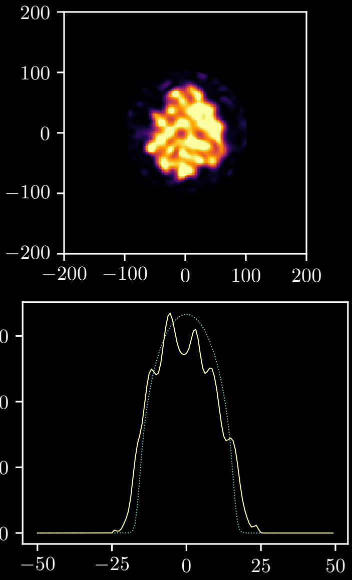

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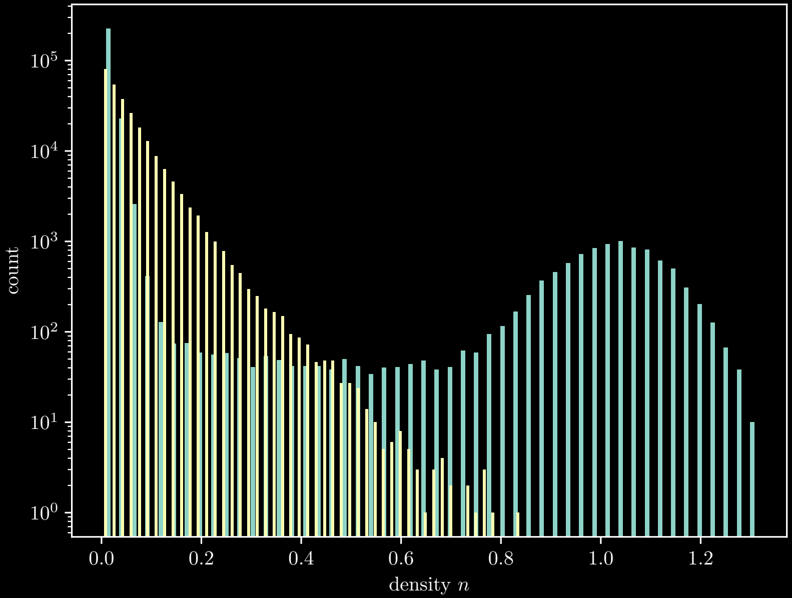

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