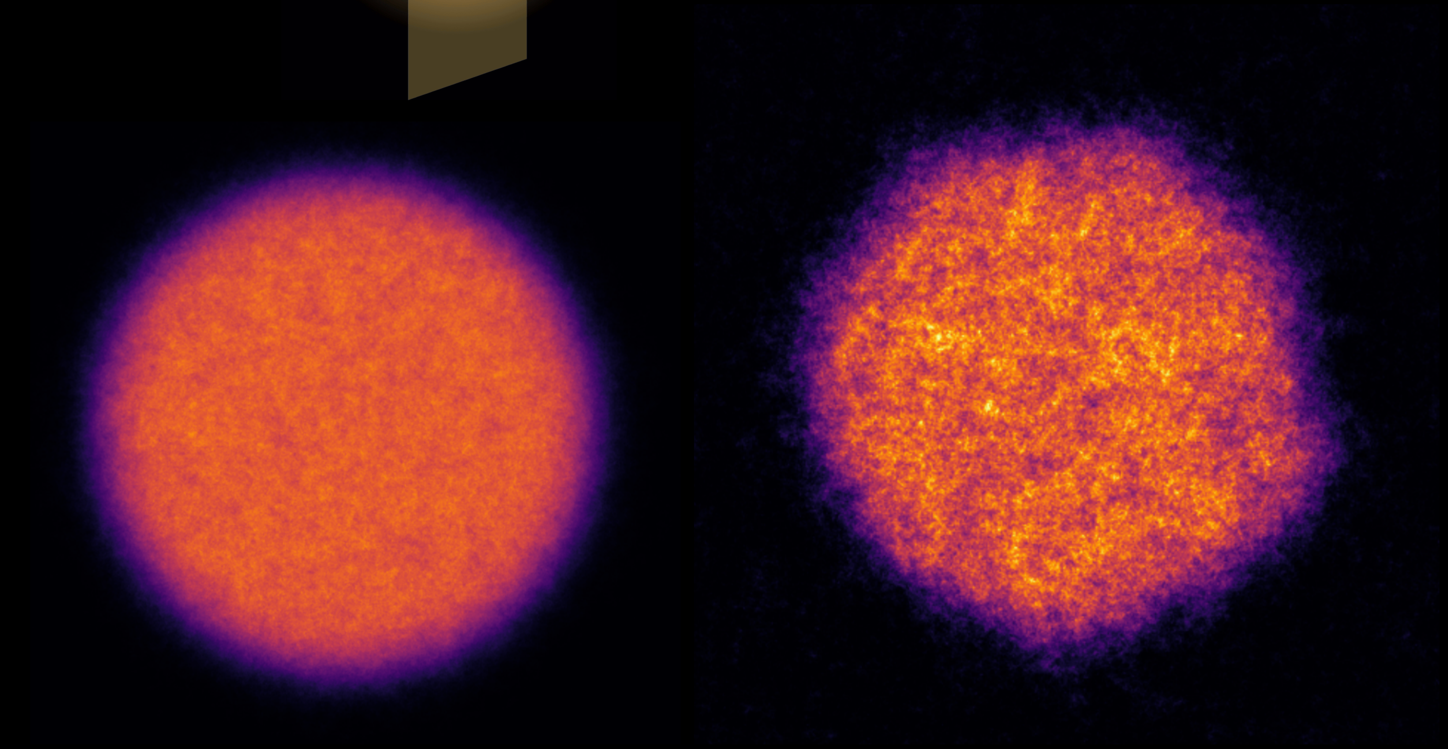
Stationary and thermal properties of flattened and elongated quantum droplets

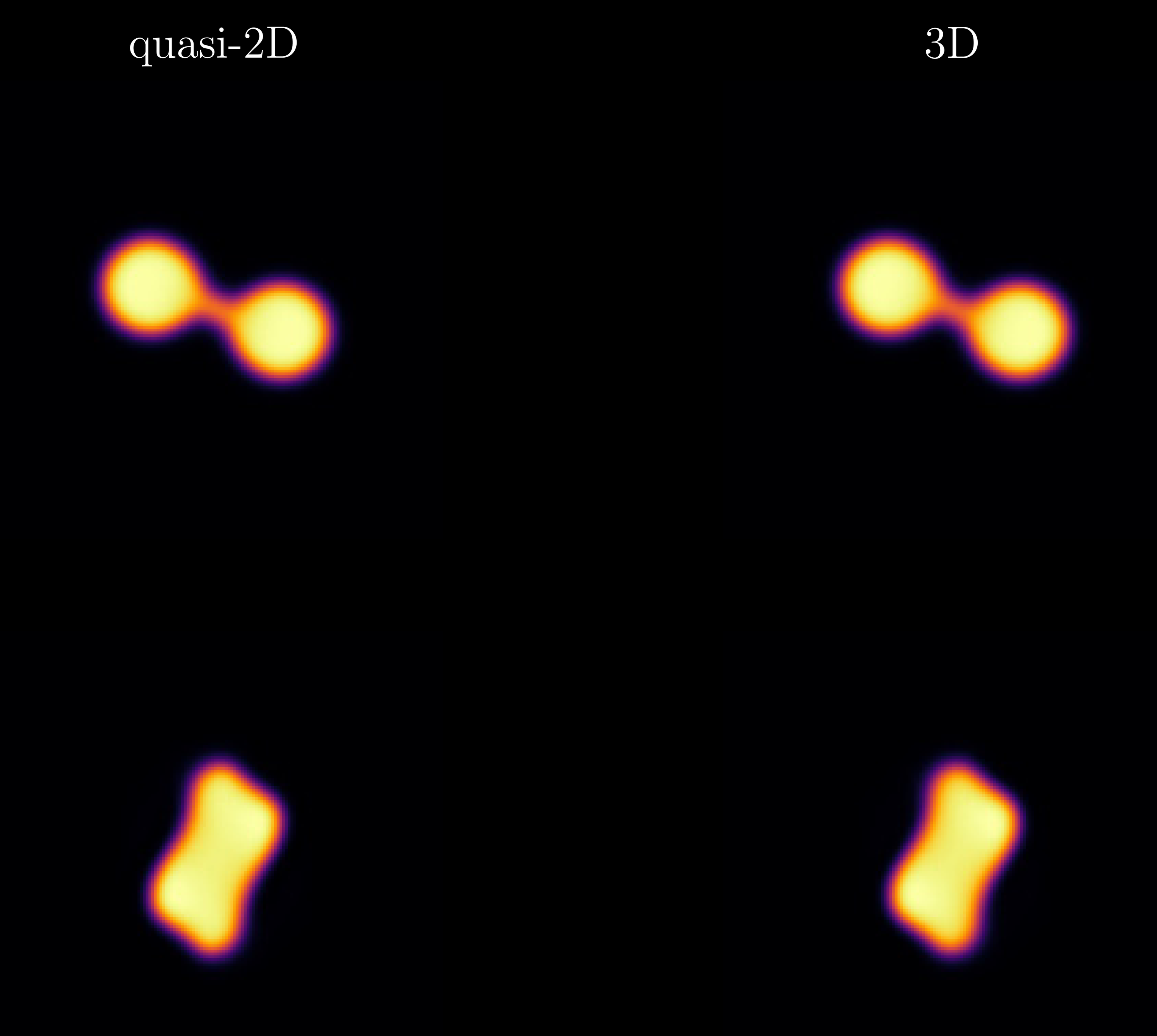
M. B. Kruk[1,*], P. Deuar[1]

[1] *Institute of Physics, Polish Academy of Sciences, Aleja Lotników 32/46, 02-668 Warsaw, Poland*

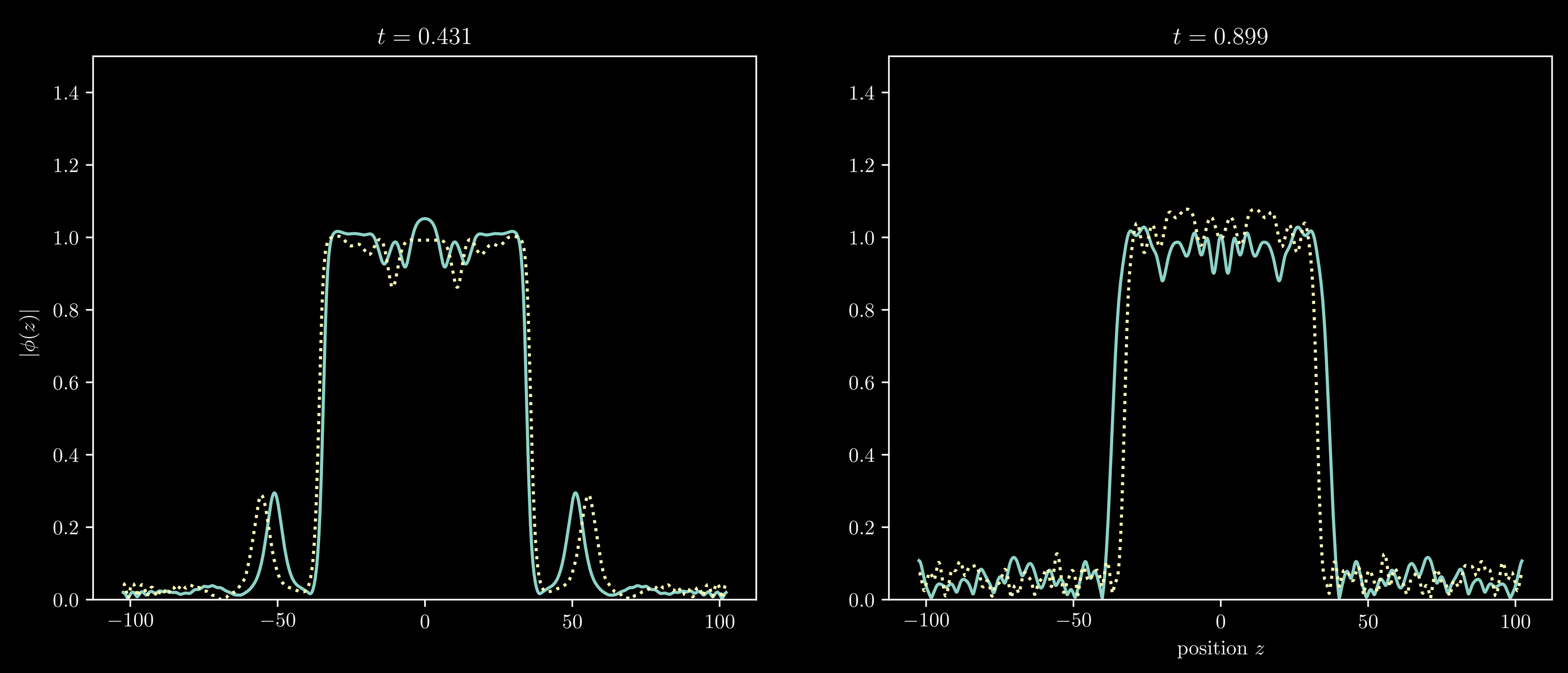
[*] *mbkruk@ifpan.edu.pl*



Effective 2D droplets in contact with thermal reservoir: low temperature (left) and high temperature (right).



Two colliding quantum droplets at two times: effective 2D simulation (left) vs full 3D simulation (right), first contact (top), merged droplets wobbling after a long time (bottom). Note the perfect agreement between effective 2D and full 3D simulations.



Comparison of effective 1D (dotted yellow lines) and full 3D (solid green lines) collision of two droplets at two times. Emission of two "satellite" droplets can be seen (left), droplet ends up in a bath of smaller droplets after a long time (right).

1 Our objective

We study contact-interacting two-component quantum droplets in the regime in which harmonic confinement in one or two directions is sufficient to constrain the droplet wavefunction to the transverse motional ground state, but not yet strong enough to modify the high energy Bogoliubov spectrum or the LHY correction from its 3D form. Examples of this regime include the experiments of Cabrera et al. Science 359, 301 (2018). We develop effective low-dimensional extended Gross-Pitaevskii equations with modified coefficients and dependence on transverse confinement.

Strict 1D, 2D

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

↓

Dimensional crossover

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

↓

Flattened/elongated 3D

this presentation

↓

Full 3D

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

2 Elongated and flattened 3D

We use extended Gross–Pitaevskii equation to numerically calculate droplet ground states of flattened and elongated 3D Bose gases and compare it with our effective low-D theory. We find the regime of applicability for both effective dimensions and study the dynamics and thermal properties of these systems.

3 Full 3D

Single component approximation:

$$\int |\phi|^2 d^3x = N$$

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

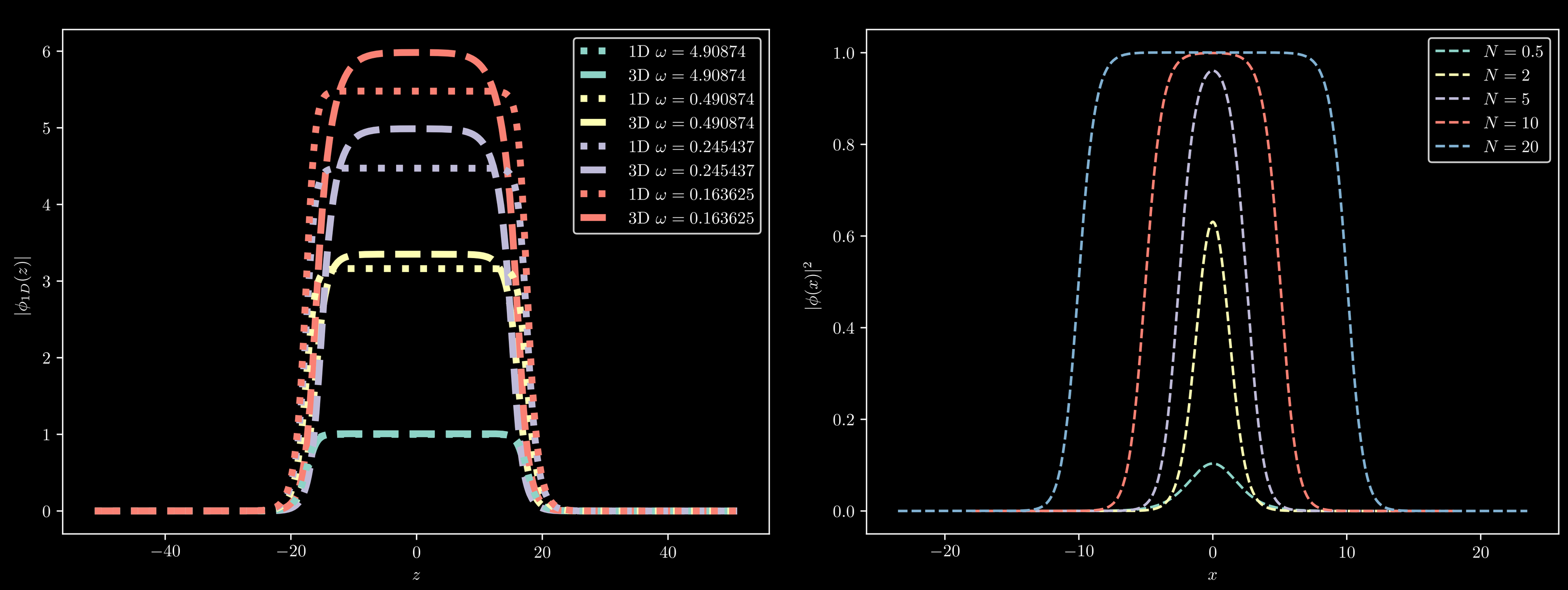
$$E = \int \left(\frac{1}{2}|\nabla\phi|^2 - \frac{3}{2}|\phi|^4 + |\phi|^5\right) d^3x$$

4 Effective 1D (elongated 3D)

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

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

Effective 1D droplet density profiles: as a function of trapping frequency (left), as a function of total number of particles (right).



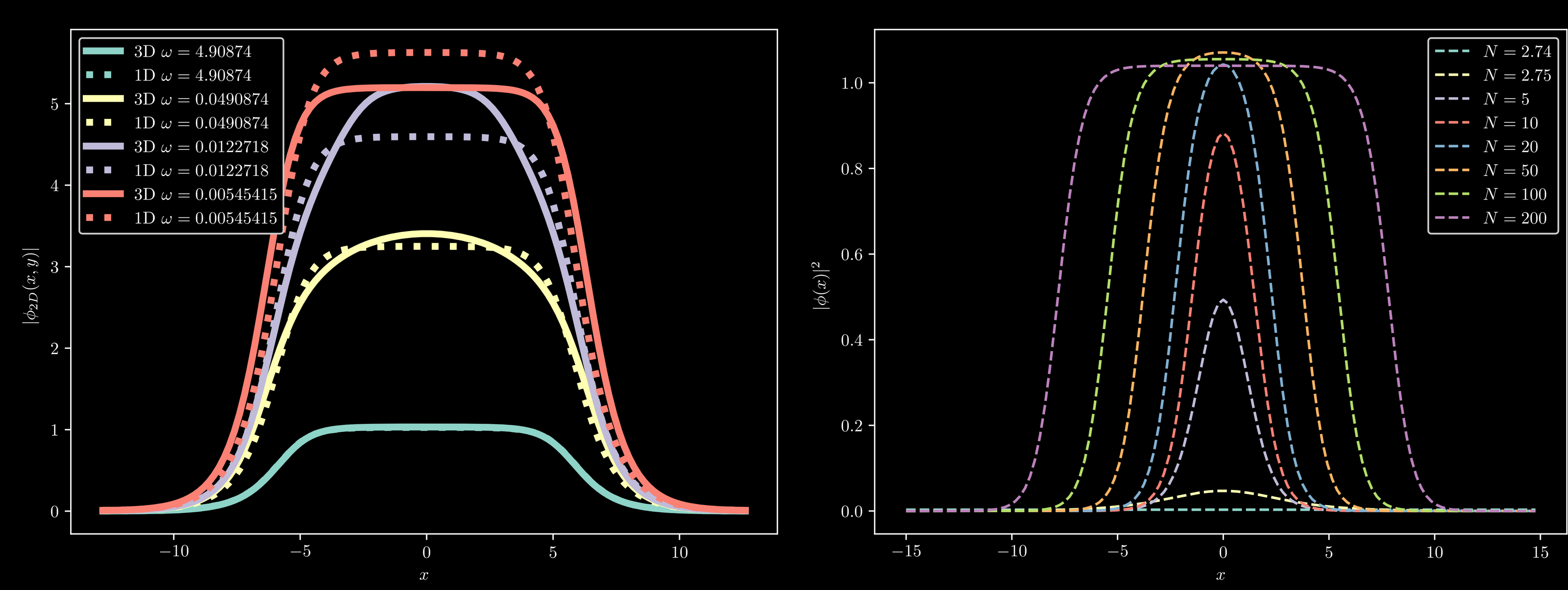
no critical number of particles

5 Effective 2D (flattened 3D)

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

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

Effective 2D droplet density profiles: as a function of trapping frequency (left), as a function of total number of particles (right).



critical number of particles: $2.74 < N_c < 2.75$

In both effective 1D and effective 2D stronger trapping frequency provides better agreement between our effective low-D theory and full 3D.

We acknowledge the support of the National Science Centre, Poland NARODOWE CENTRUM NAUKI