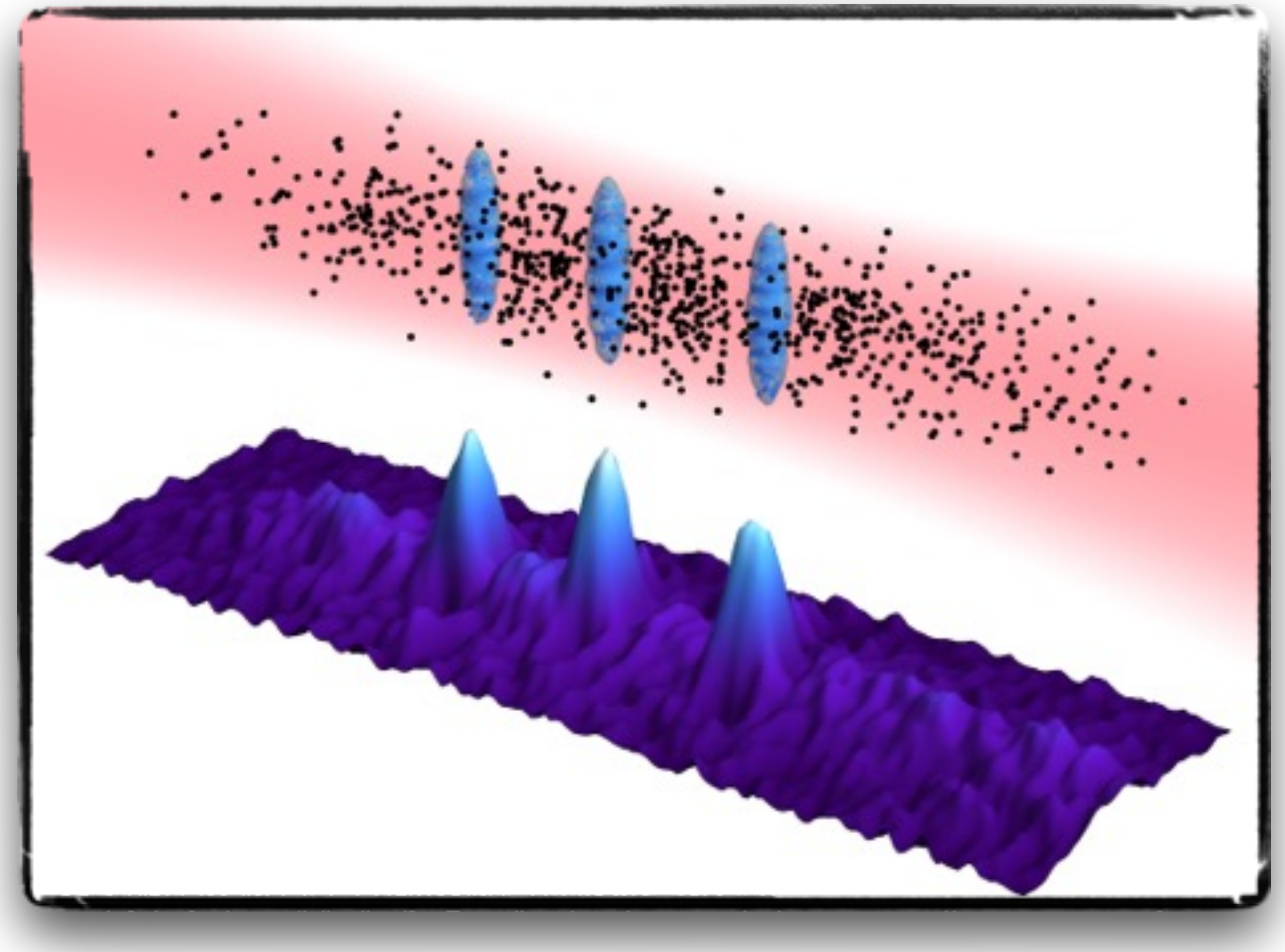
Quantum droplets of a dysprosium BEC



Igor Ferrier-Barbut

Holger Kadau, Matthias Schmitt,
Matthias Wenzel, Tilman Pfau

5. Physikalisches Institut,Stuttgart University

SFB/TRR 21

Can one form a liquid of dilute ultracold bosons?

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Beyond mean-field energy of the weakly-interacting Bose gas

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LHY, quantum fluctuations *Phys. Rev* **106**, 1135 (1957)

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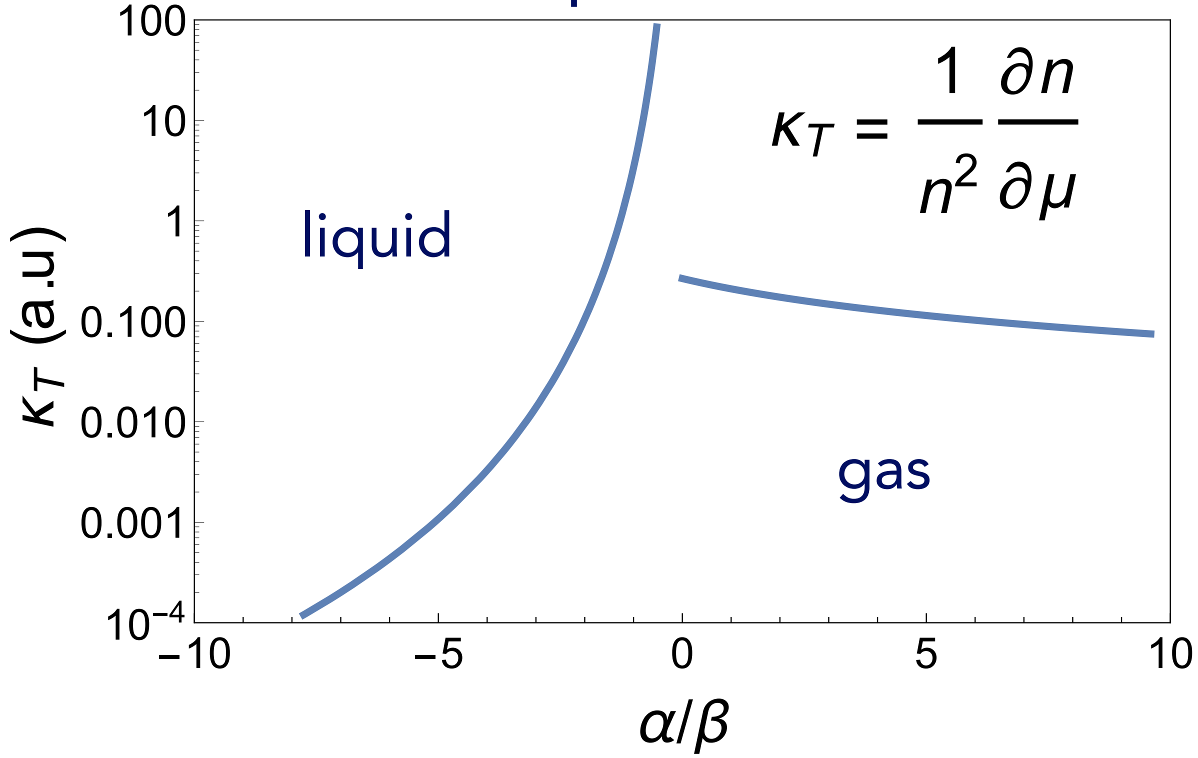

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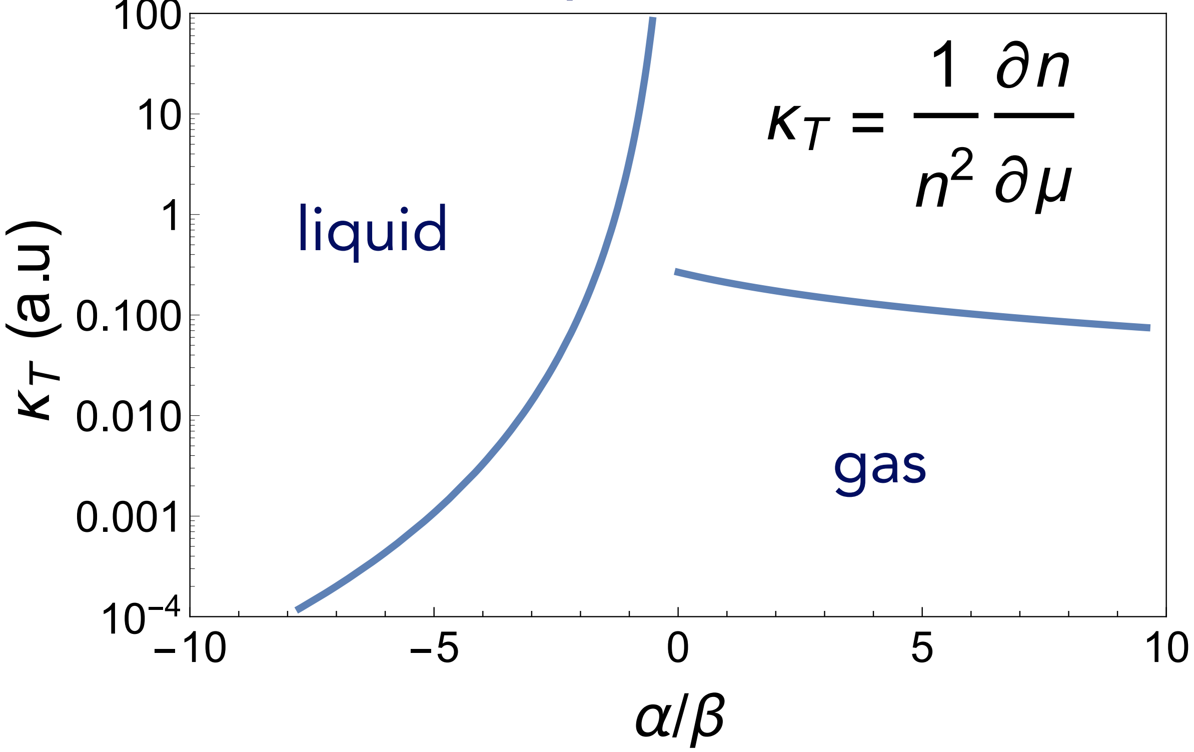

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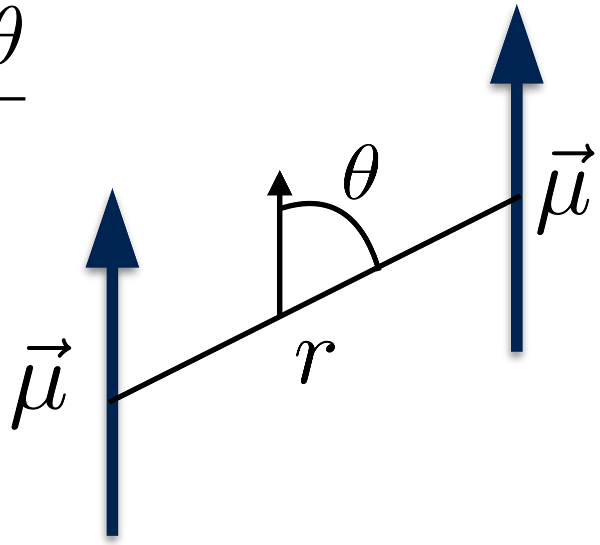

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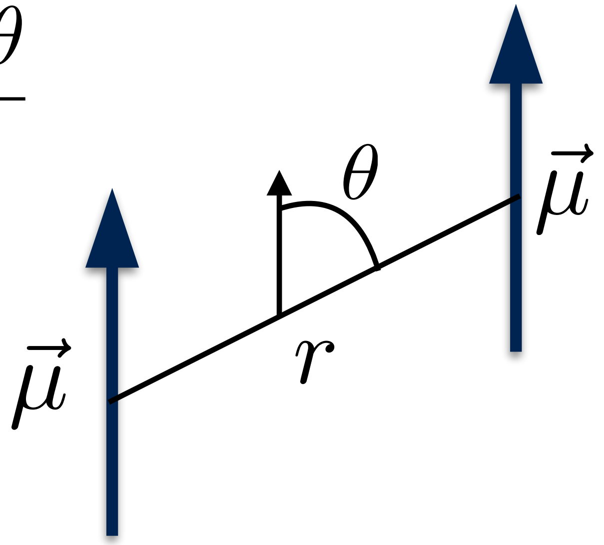

Characteristic length scales:

Scattering length a

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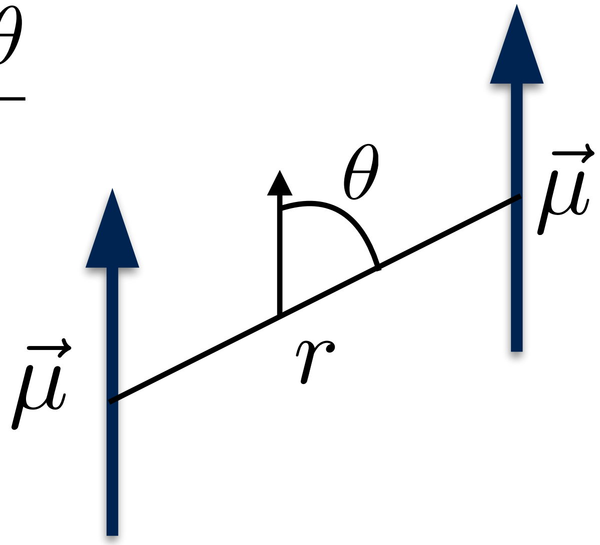

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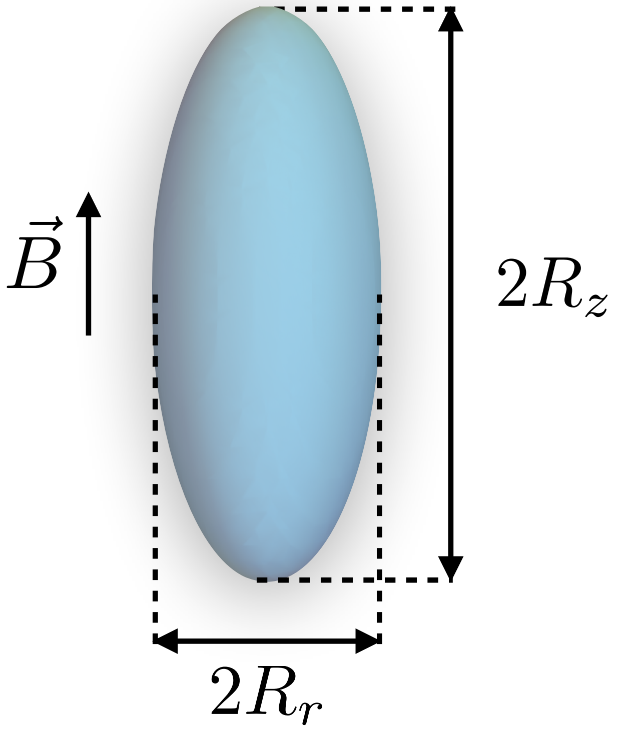
Relative dipolar strength: $$\varepsilon_{\rm dd} = \frac{a_{\rm dd}}{a}$$

Dipolar Bose-Einstein condensates

Mean-field $e(\vec{r}) = \dfrac{g\, n(\vec{r})^2}{2} + \dfrac{n(\vec{r})}{2} \displaystyle\int d\vec{r}\, V_{\mathrm{dd}}(\vec{r}\,' - \vec{r}\,)\, n(\vec{r}\,')$



$$\kappa = \frac{R_r}{R_z}$$

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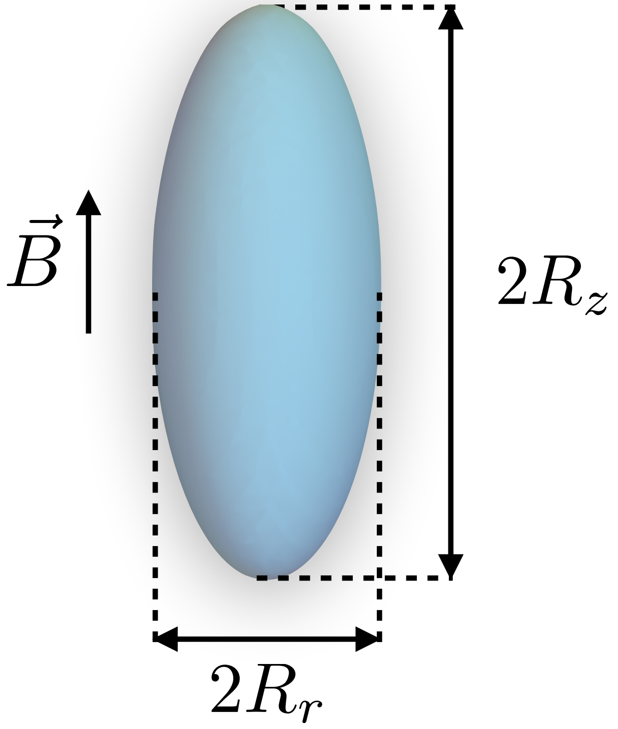

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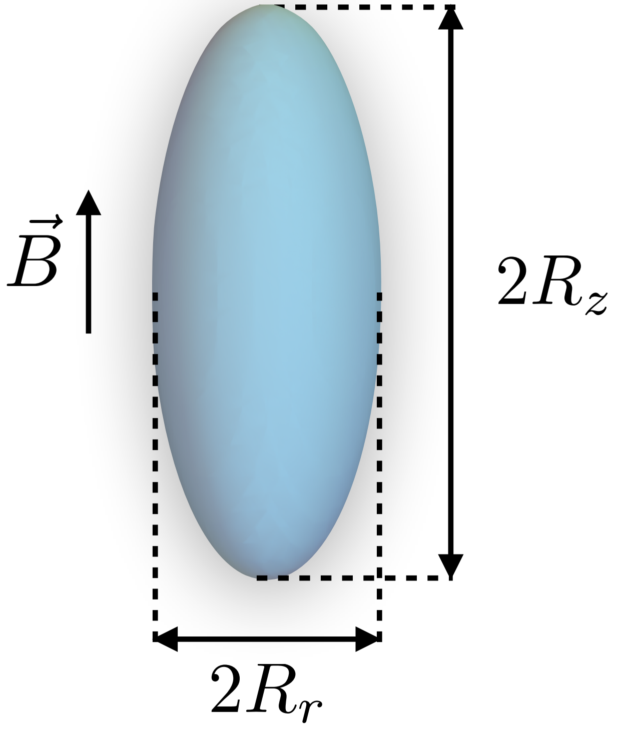

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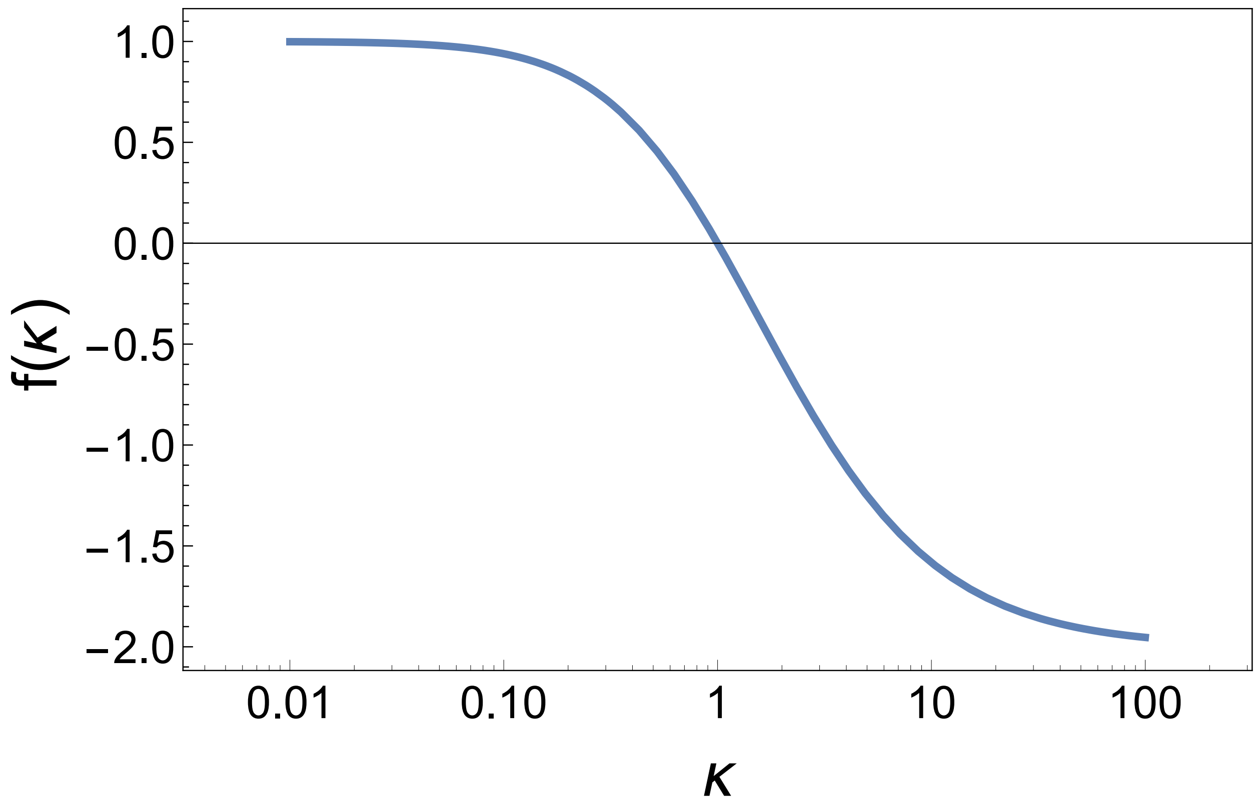

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Dipolar Bose-Einstein condensates

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See poster by R. Bisset and arXiv:1601.04501 (2016) by F. Wächtler and L. Santos

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Scattering length a $a_{\mathrm{bg}} = 92(8)\,a_0$

Tang *et al.*, *PRA* **92**, 022703 (2015)
Maier *et al.*, *PRA* **92**, 060702(R) (2015)

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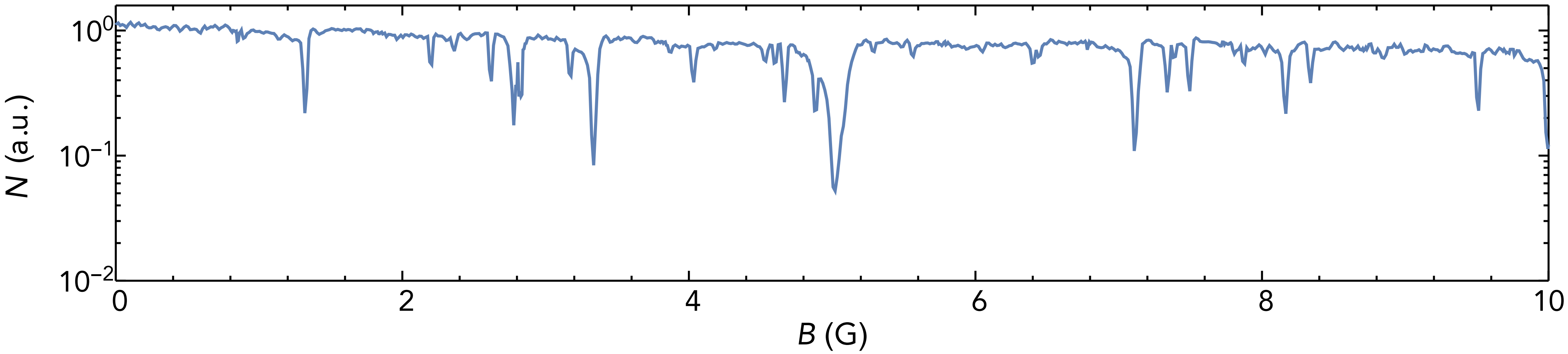
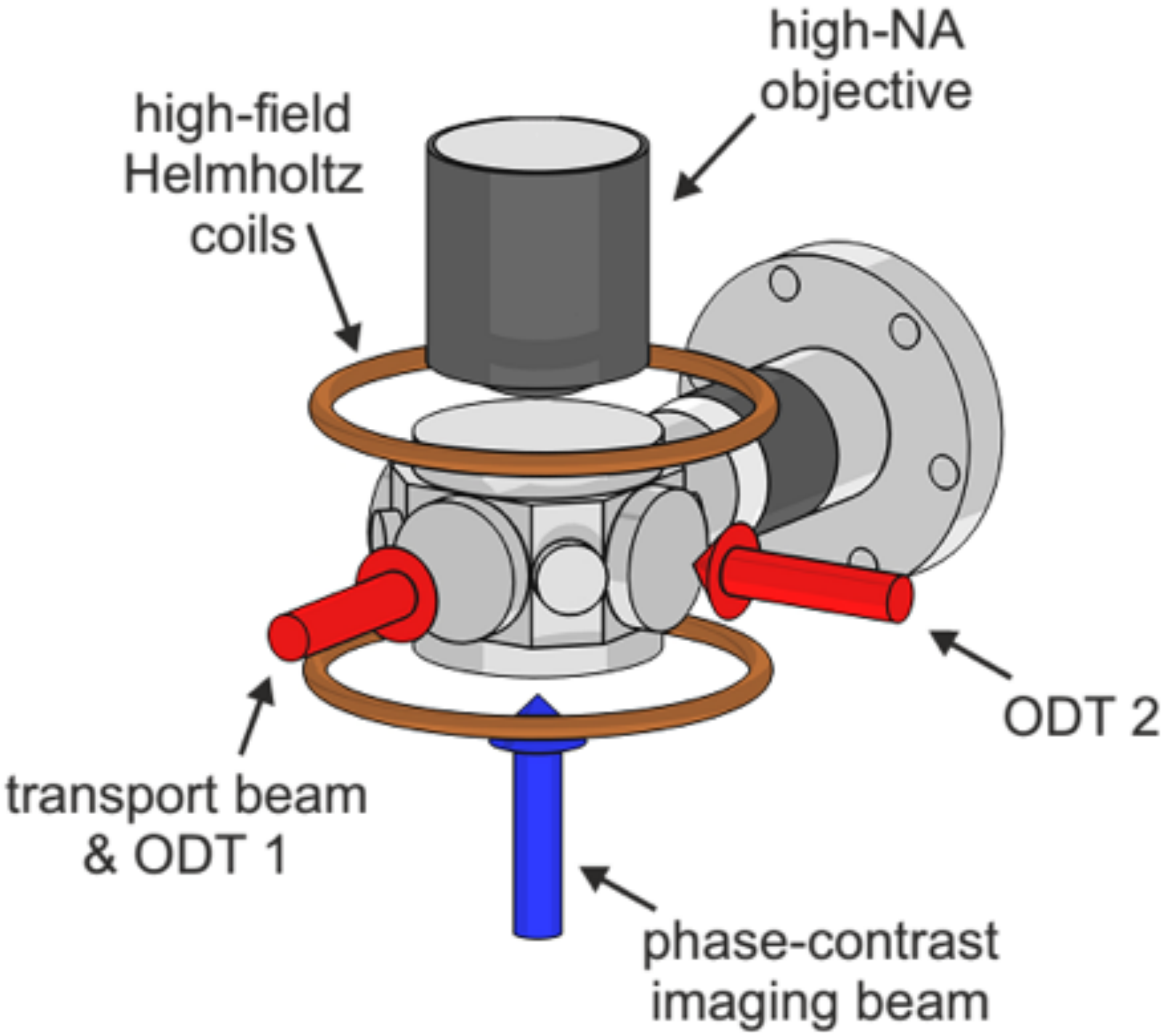
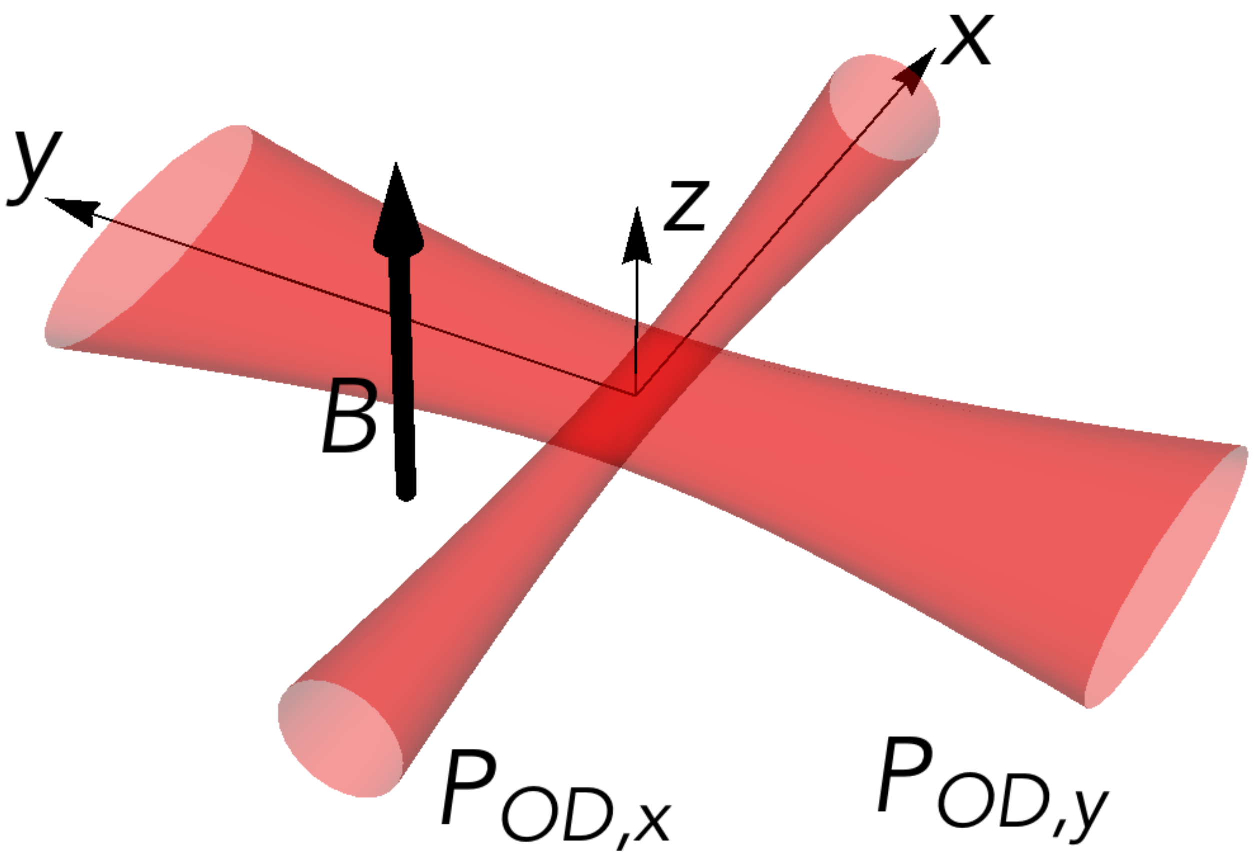
Many Feshbach resonances



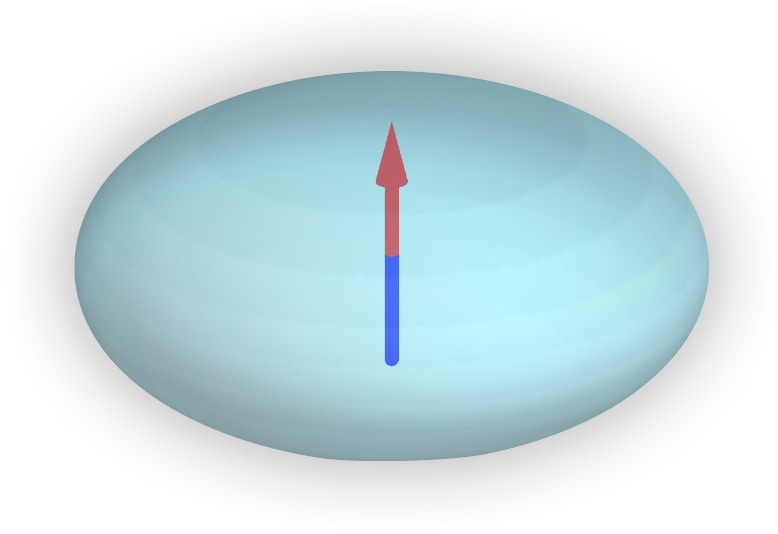
Our experiment





High resolution phase-contrast imaging, 1 μm resolution at 421 nm (32.5 MHz broad), single shot

Oblate dipolar BECs



Trap aspect ratio $\lambda = \omega_z/\omega_r = 2.9(1)$

$$\kappa > 1$$

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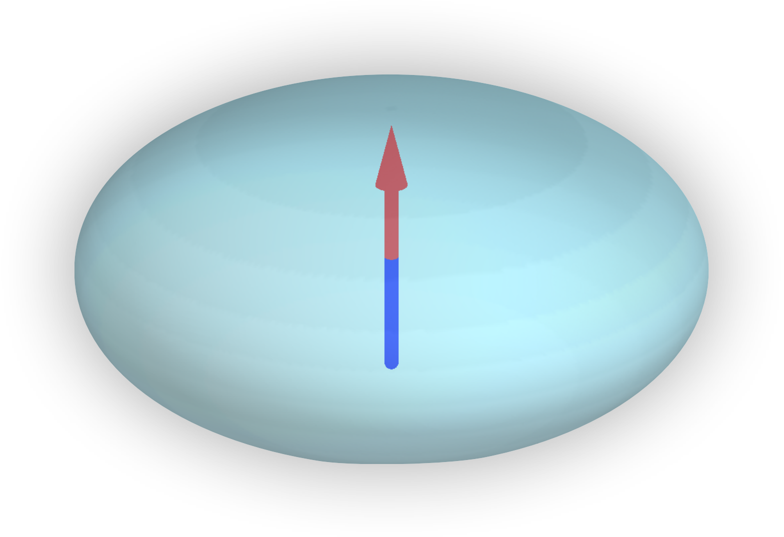

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$\kappa > 1$

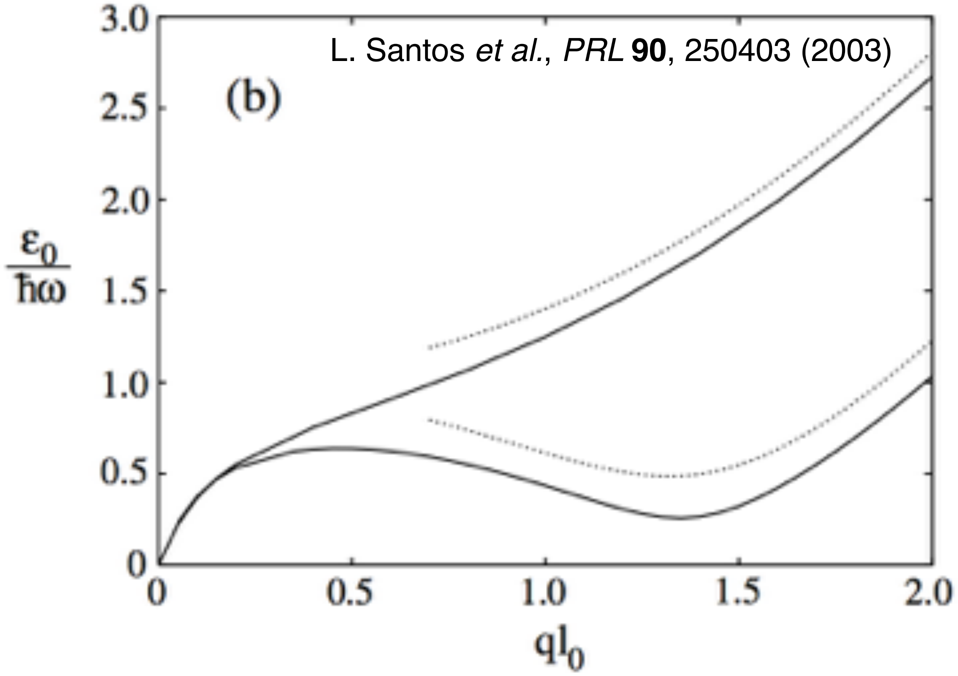
- Uniform case ($\kappa \rightarrow \infty$):

Roton-Maxon dispersion relation

Varies with axial trapping and

short-range interactions

Softening → "roton instability"



L. Santos *et al.*, *PRL* **90**, 250403 (2003)

Rosensweig / normal field instability of classical ferrofluids

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Incompressible, variable magnetization

Competition between:

Surface tension, gravity vs. dipole-dipole interaction

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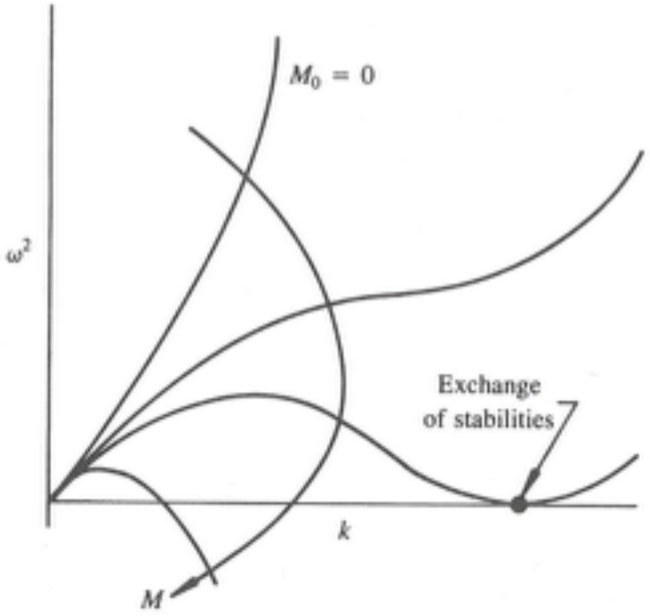
Incompressible, variable magnetization
Competition between:
Surface tension, gravity vs. dipole-dipole interaction

Dispersion relation of surface waves:
Softening of a minimum at the instability



7.4 Dispersion in the $\omega^2 - k$ plane. The upper quadrant corresponds to $\nu = 0$ and $\pm\gamma$ real; in the lower quadrant $\gamma = 0$ and $\pm\nu$ real.

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Sequence

$$\lambda = \omega_z / \omega_r = 2.9(1)$$

- Form BEC close to a Feshbach resonance

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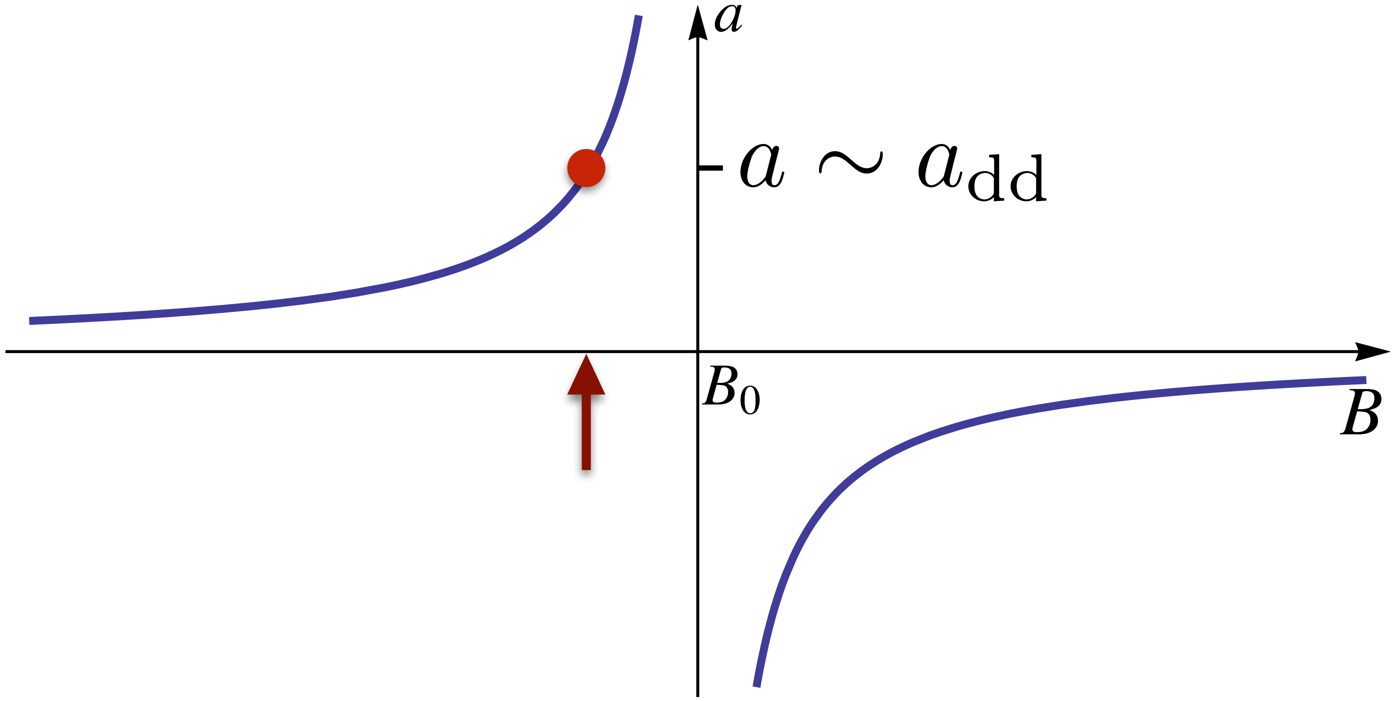

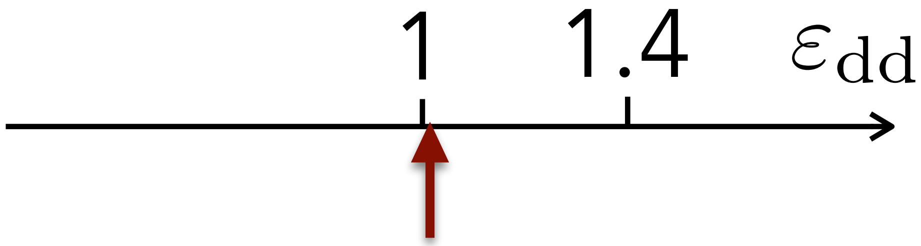

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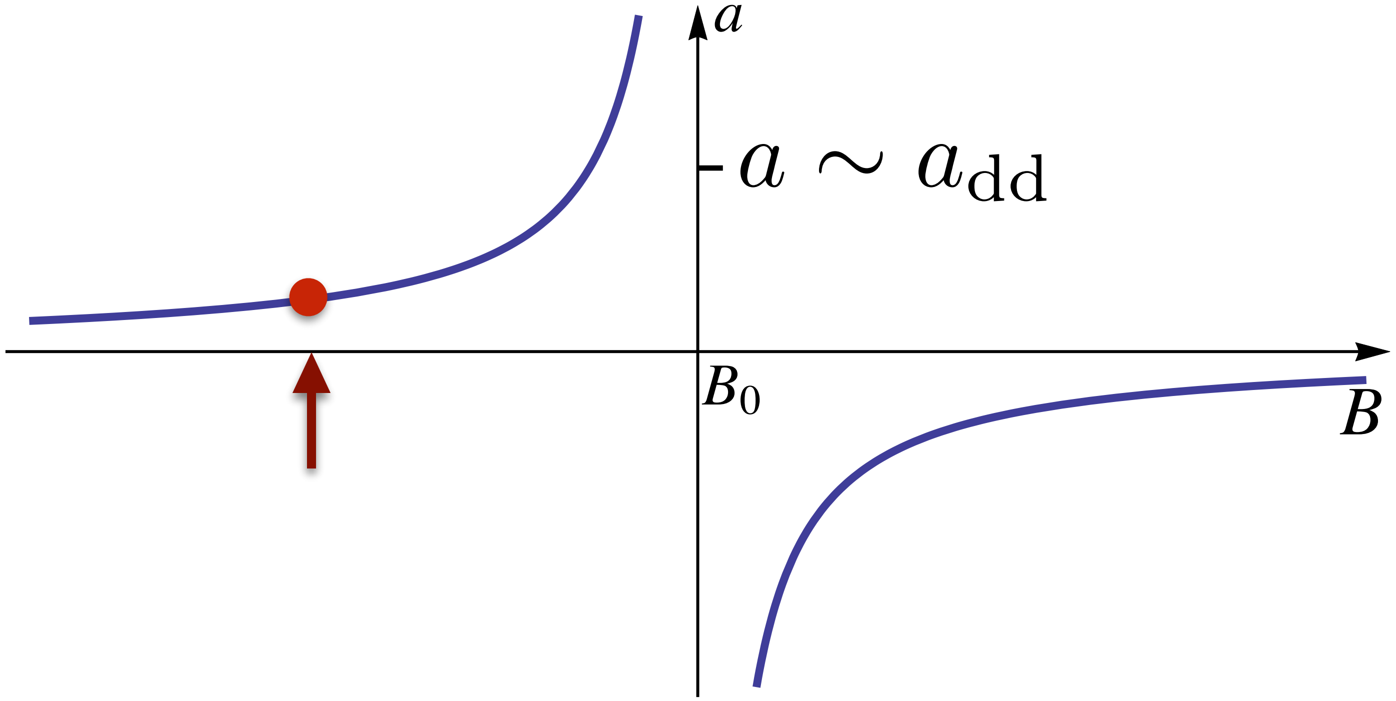
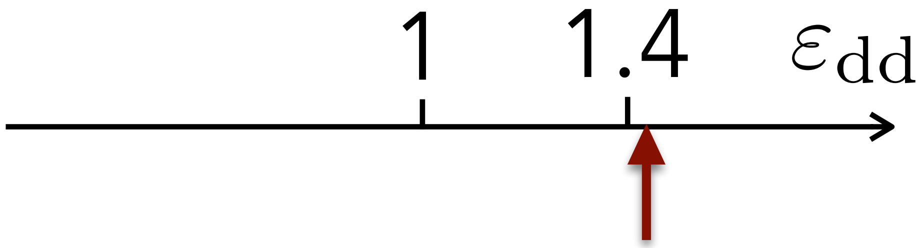


- lower a down to a_{bg}



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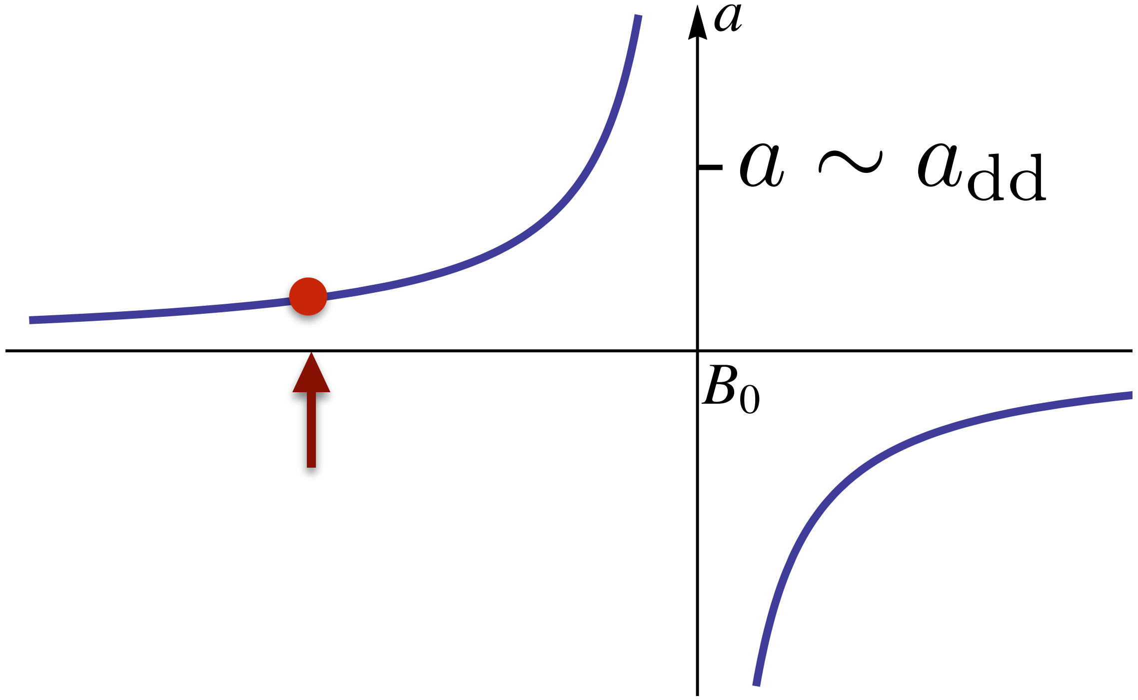

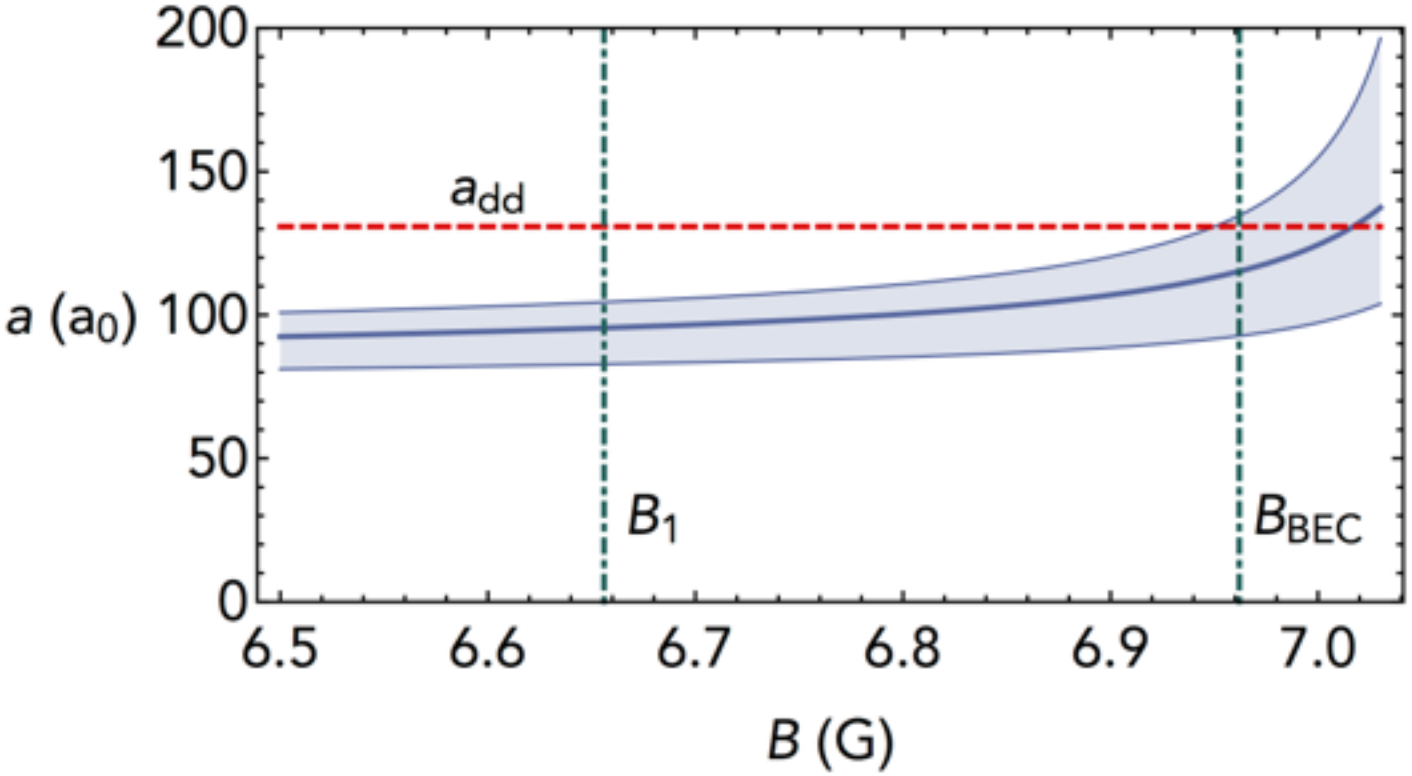

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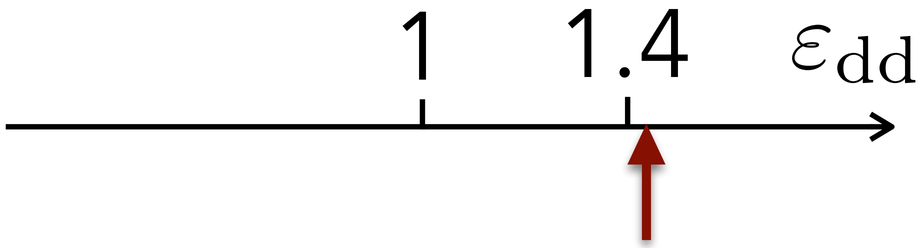
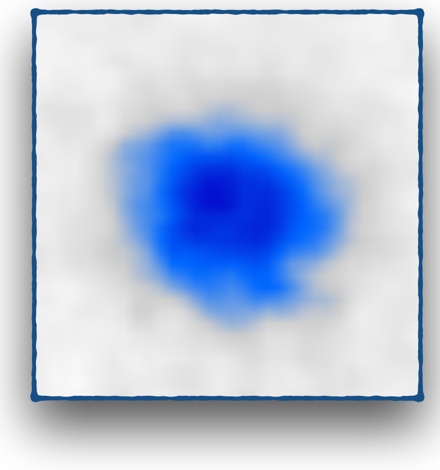


$$\varepsilon_{\mathrm{dd}} = \frac{a_{\mathrm{dd}}}{a}$$

Results

$B=B_{BEC}$



Uniform BEC

H. Kadau, M. Schmitt, M.Wenzel, C. Wink, T. Maier, I. F-B, T. Pfau , *Nature* **530,** 194 (2016)

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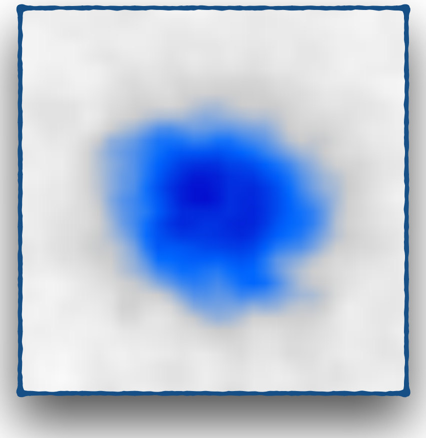
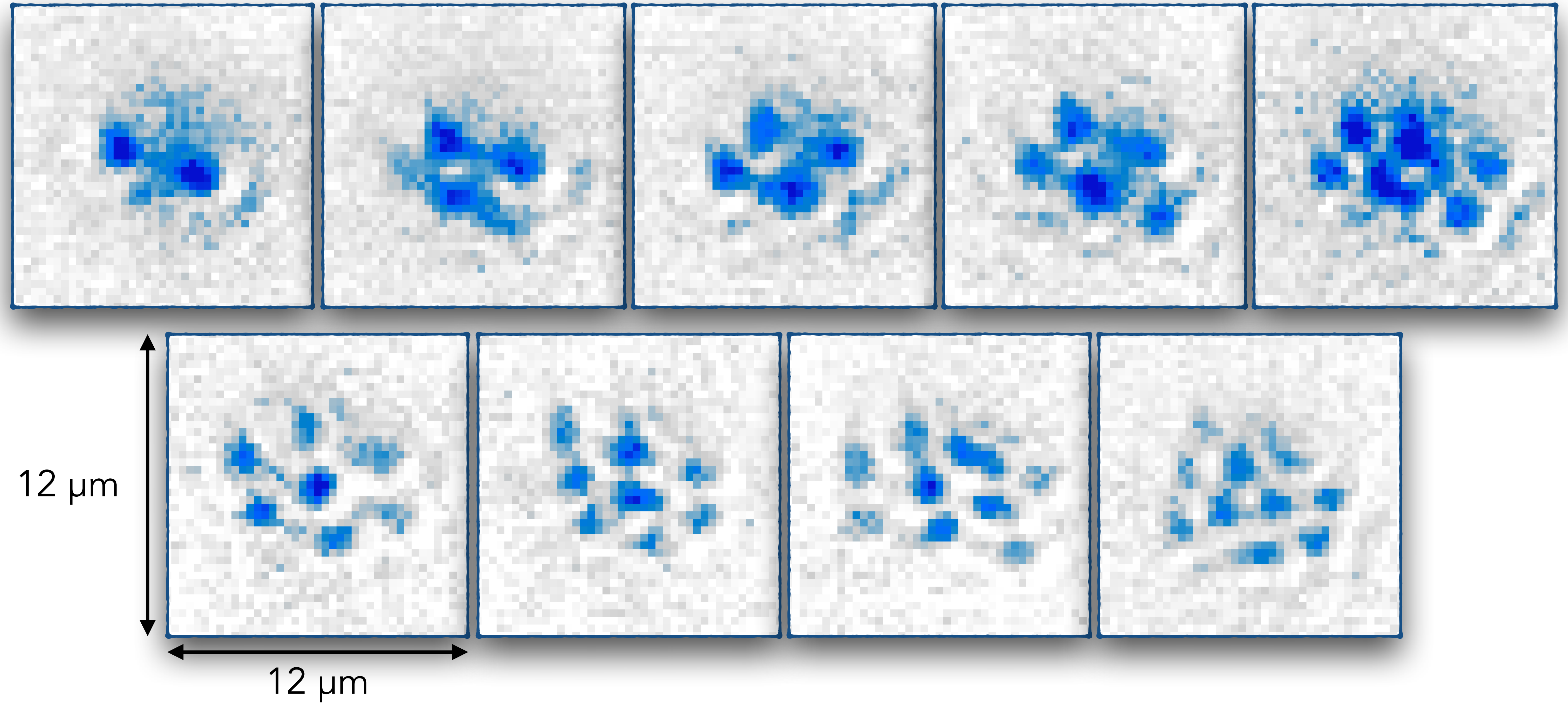


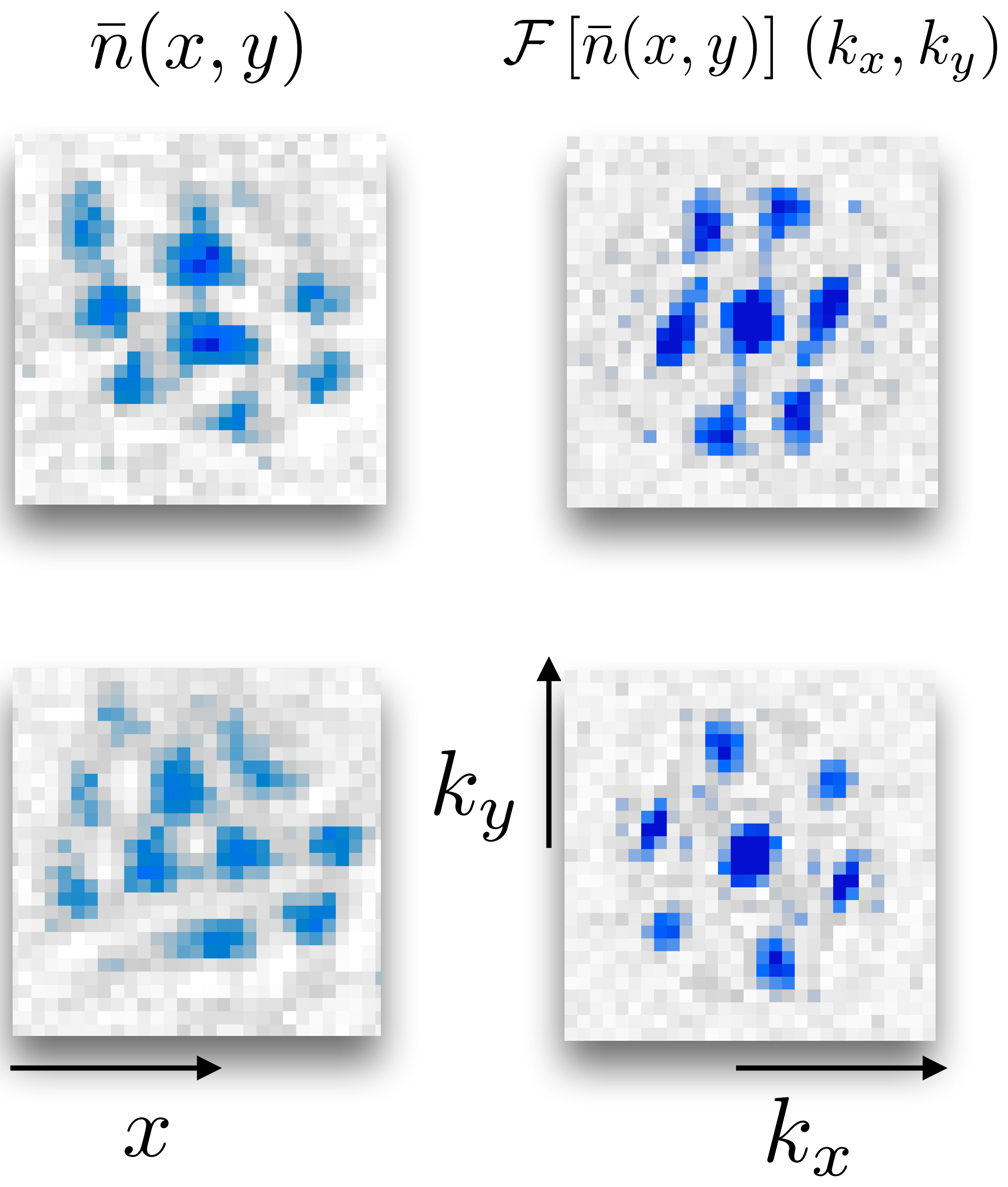
Uniform BEC

B=B_1 $\varepsilon_{\mathrm{dd}} = 1.4$



H. Kadau, M. Schmitt, M.Wenzel, C. Wink, T. Maier, I. F-B, T. Pfau , *Nature* **530,** 194 (2016)

In Fourier space



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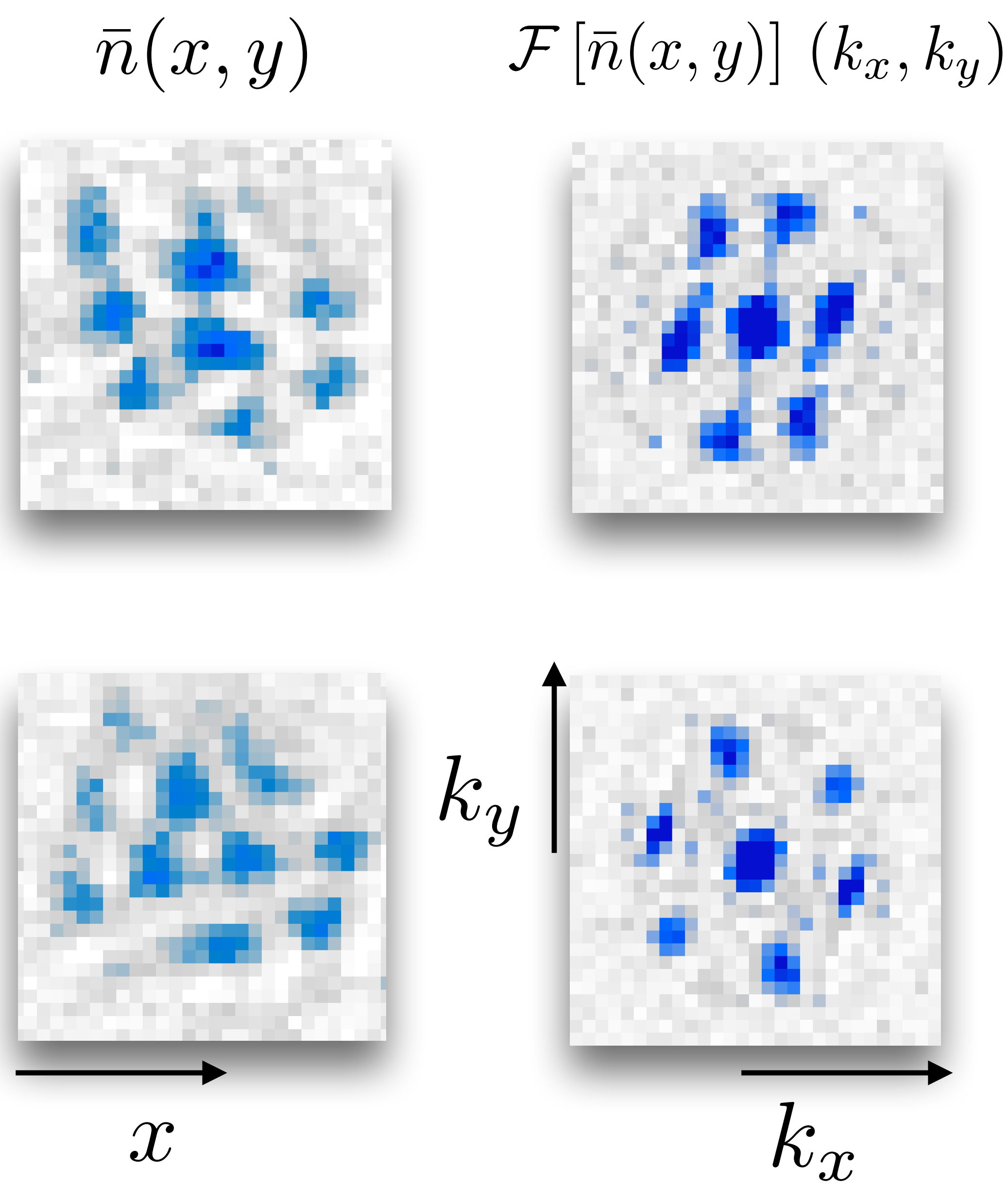
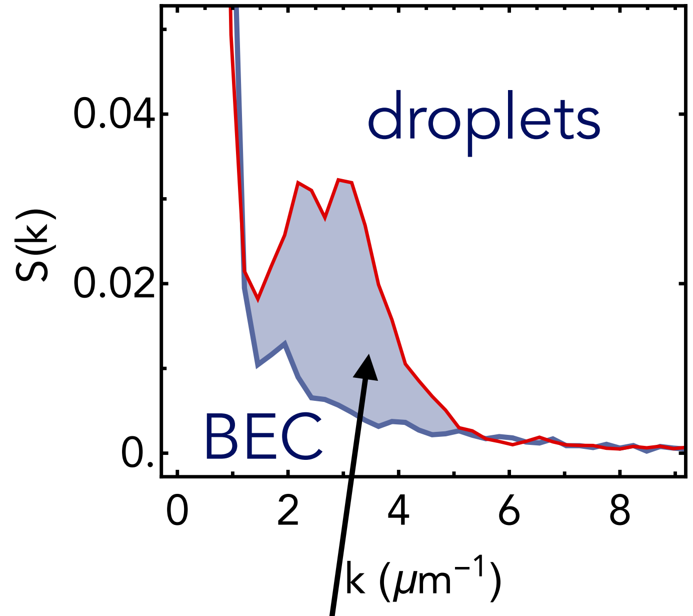


Angular averaging



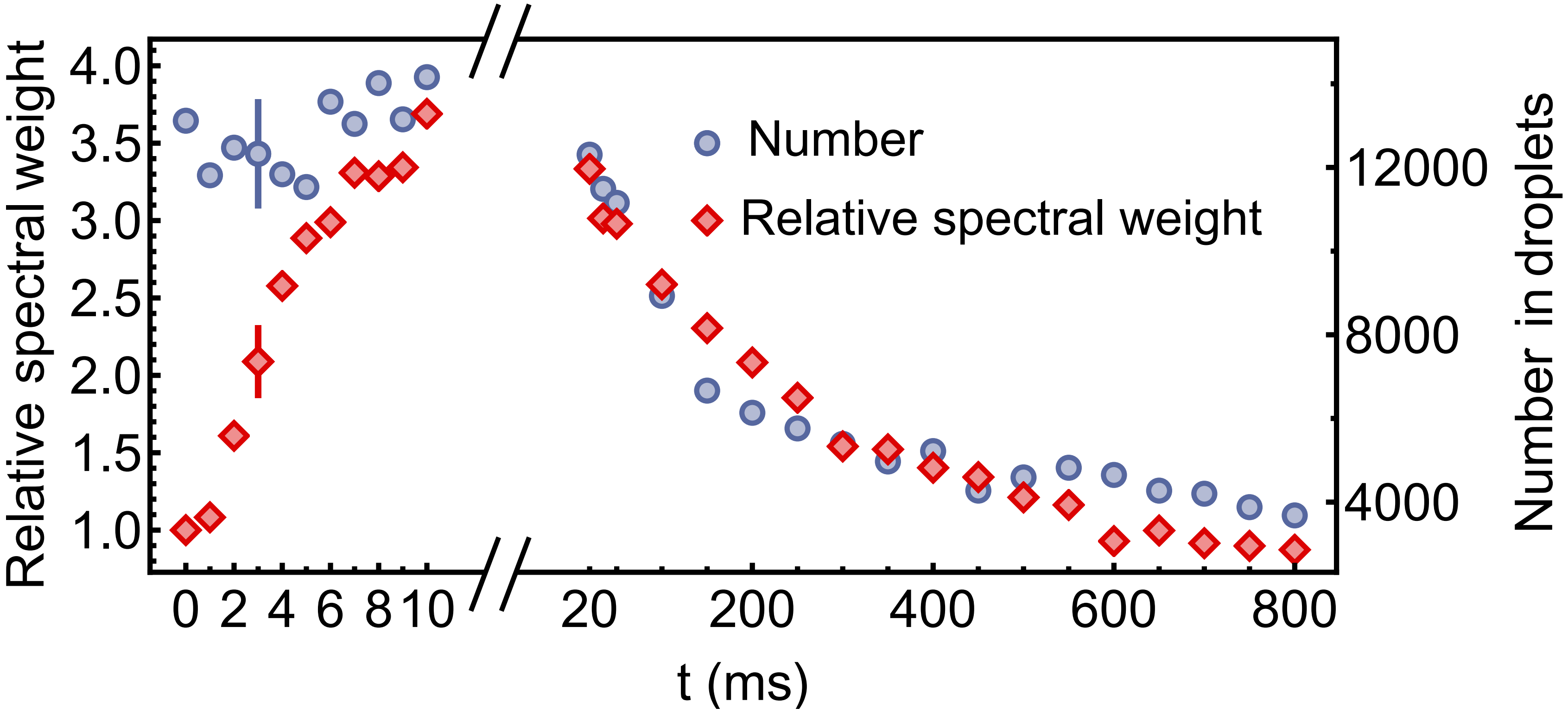
Extra spectral weight between $1.5\ \mu m^{-1}$ and $5\ \mu m^{-1}$

Quantitative marker of the transition

H. Kadau, M. Schmitt, M.Wenzel, C. Wink, T. Maier, I. F-B, T. Pfau , *Nature* **530**, 194 (2016)

Dynamics and lifetime

Droplet formation dynamics



Long lived, several hundred ms

H. Kadau, M. Schmitt, M.Wenzel, C. Wink, T. Maier, I. F-B, T. Pfau , *Nature* **530,** 194 (2016)

Simulations

Elongated droplets, experimentally: $\kappa \leqslant 0.2$

Presence of a dilute "halo"

Wächtler and Santos, arXiv:1601.04501 (2016)

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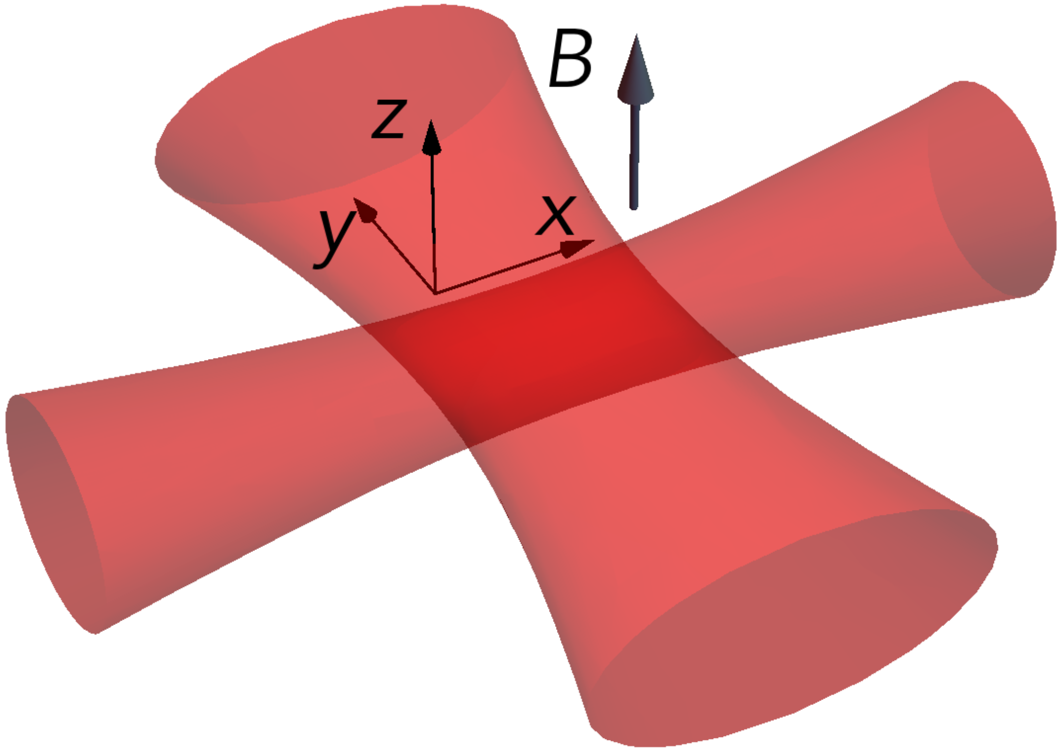
Elongated droplets, experimentally: $\kappa \leqslant 0.2$

Presence of a dilute "halo"

Wächtler and Santos, arXiv:1601.04501 (2016)

Probing droplets in a waveguide



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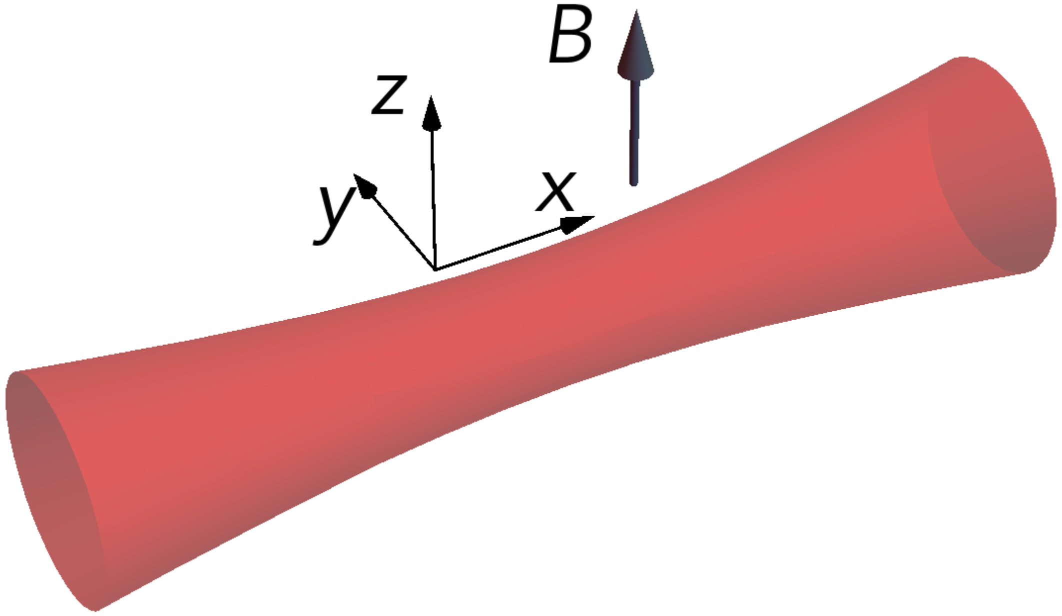

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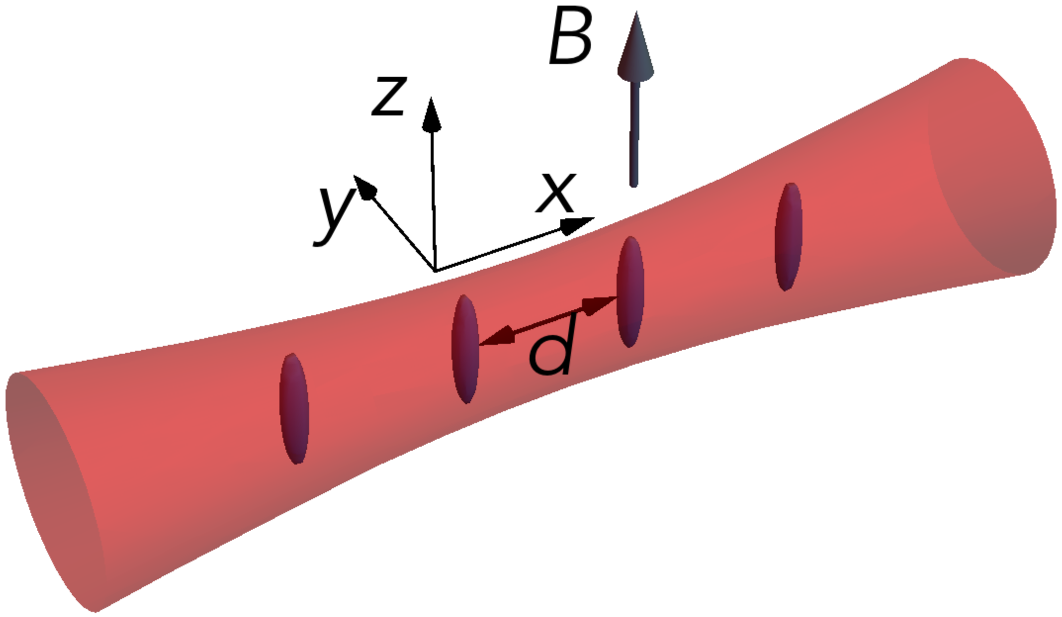

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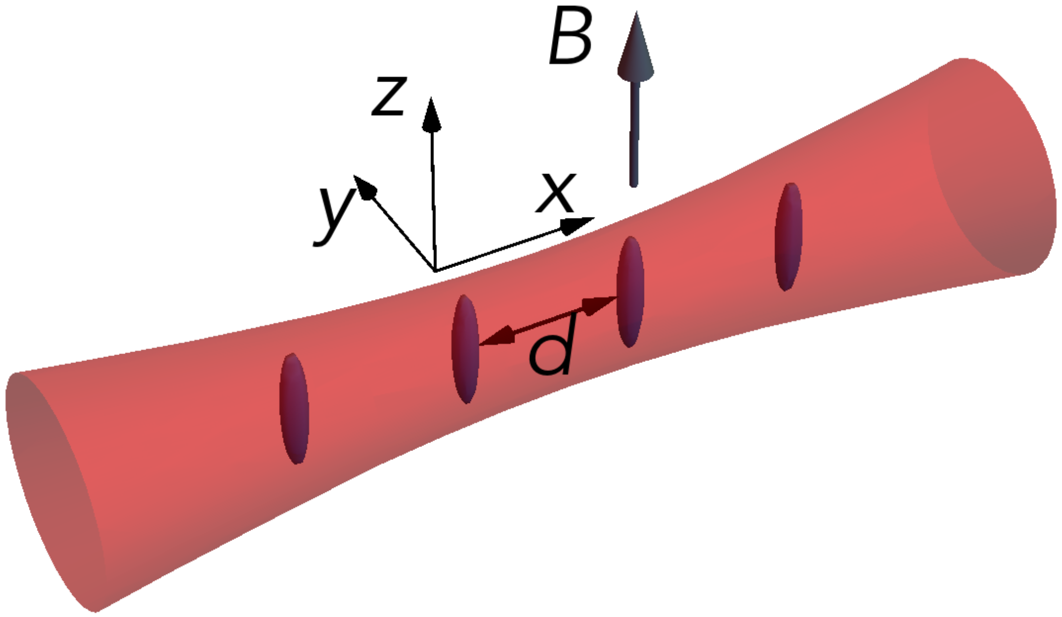

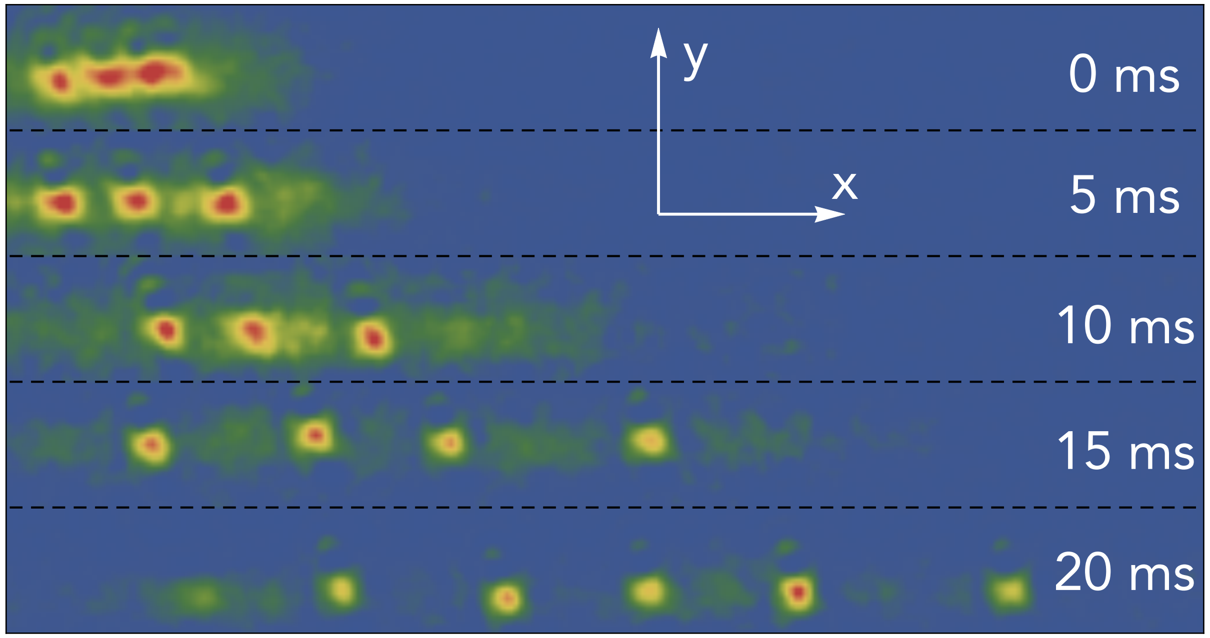

I. F-B, H. Kadau, M. Schmitt, M.Wenzel, T. Pfau, *arXiv:*1601.03318 ***PRL*** (2016)

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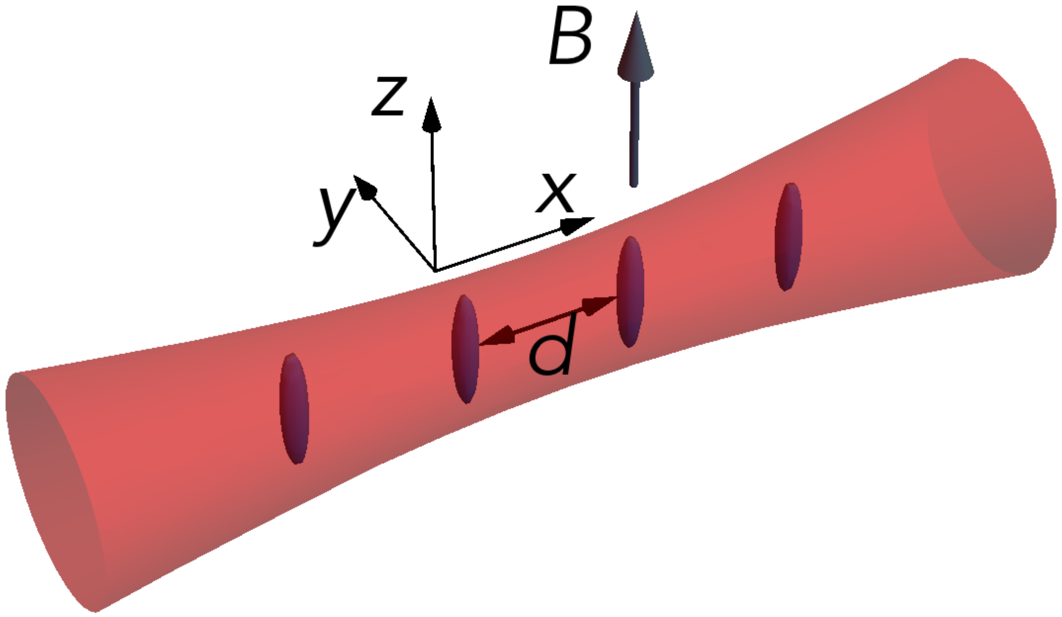

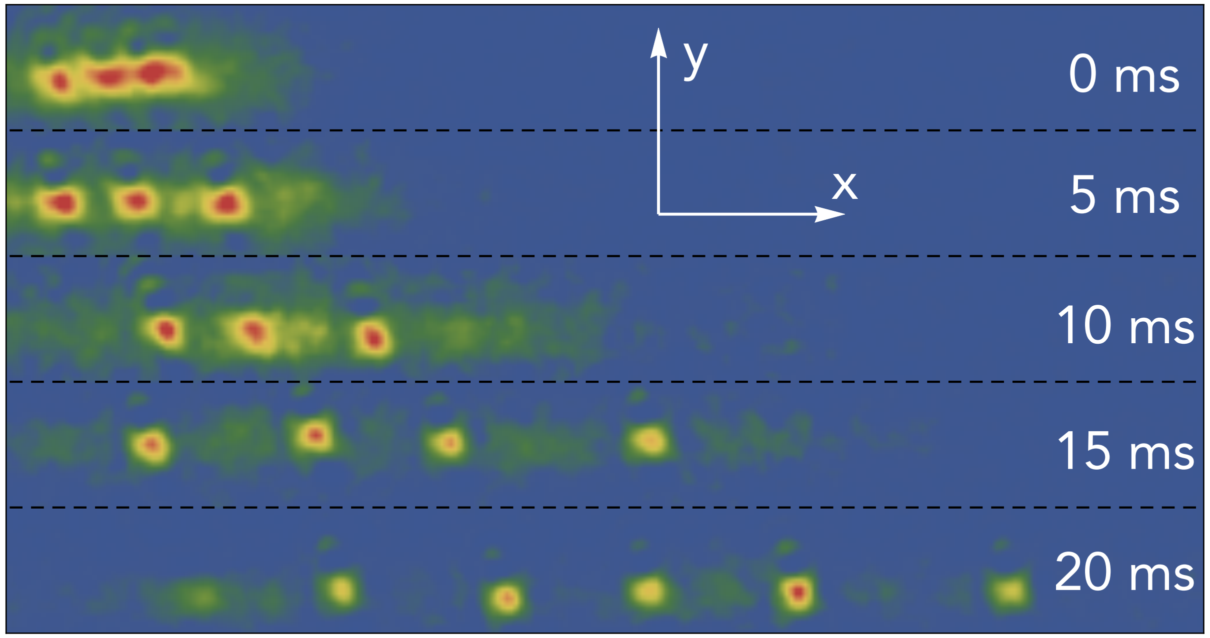

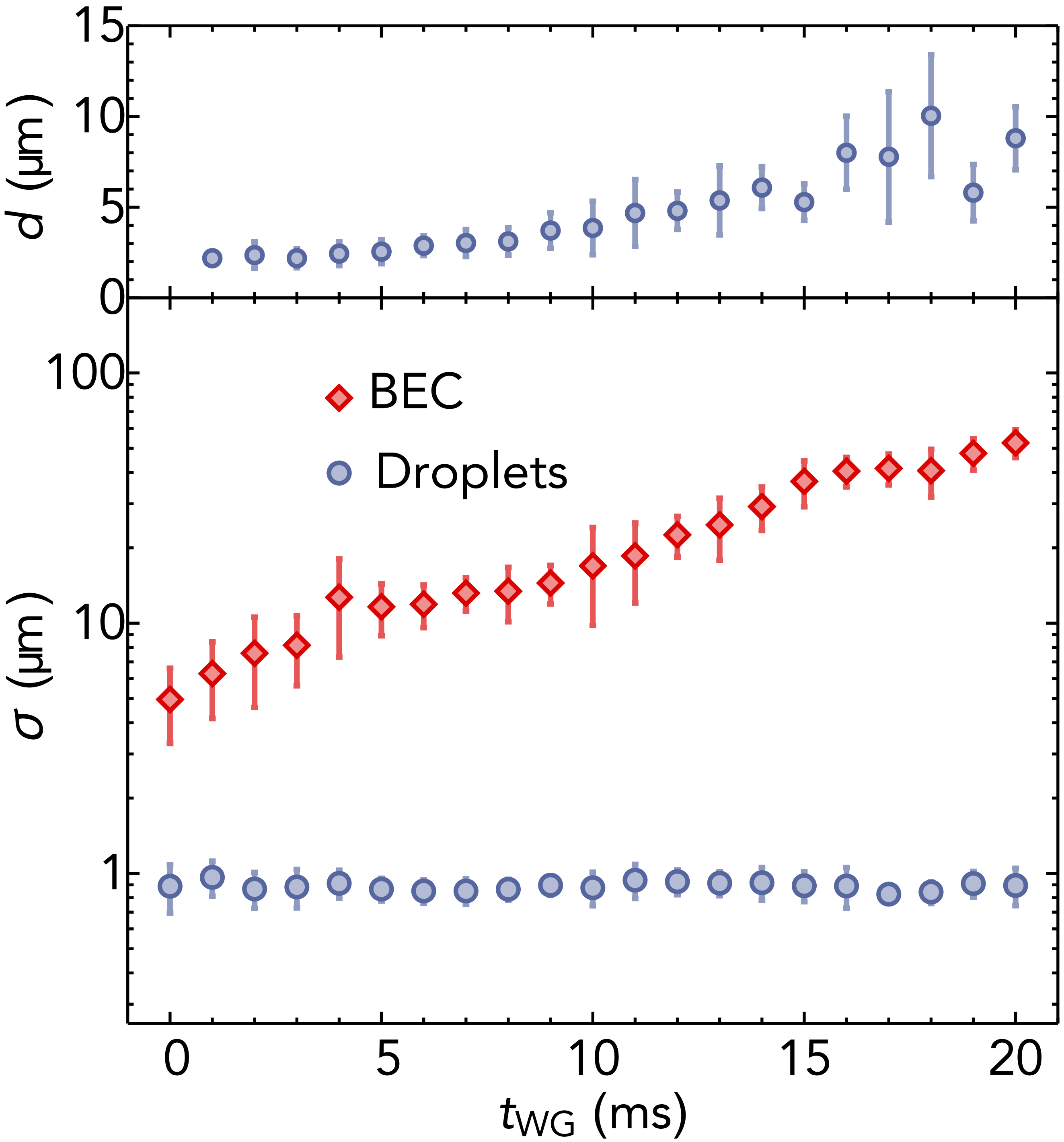

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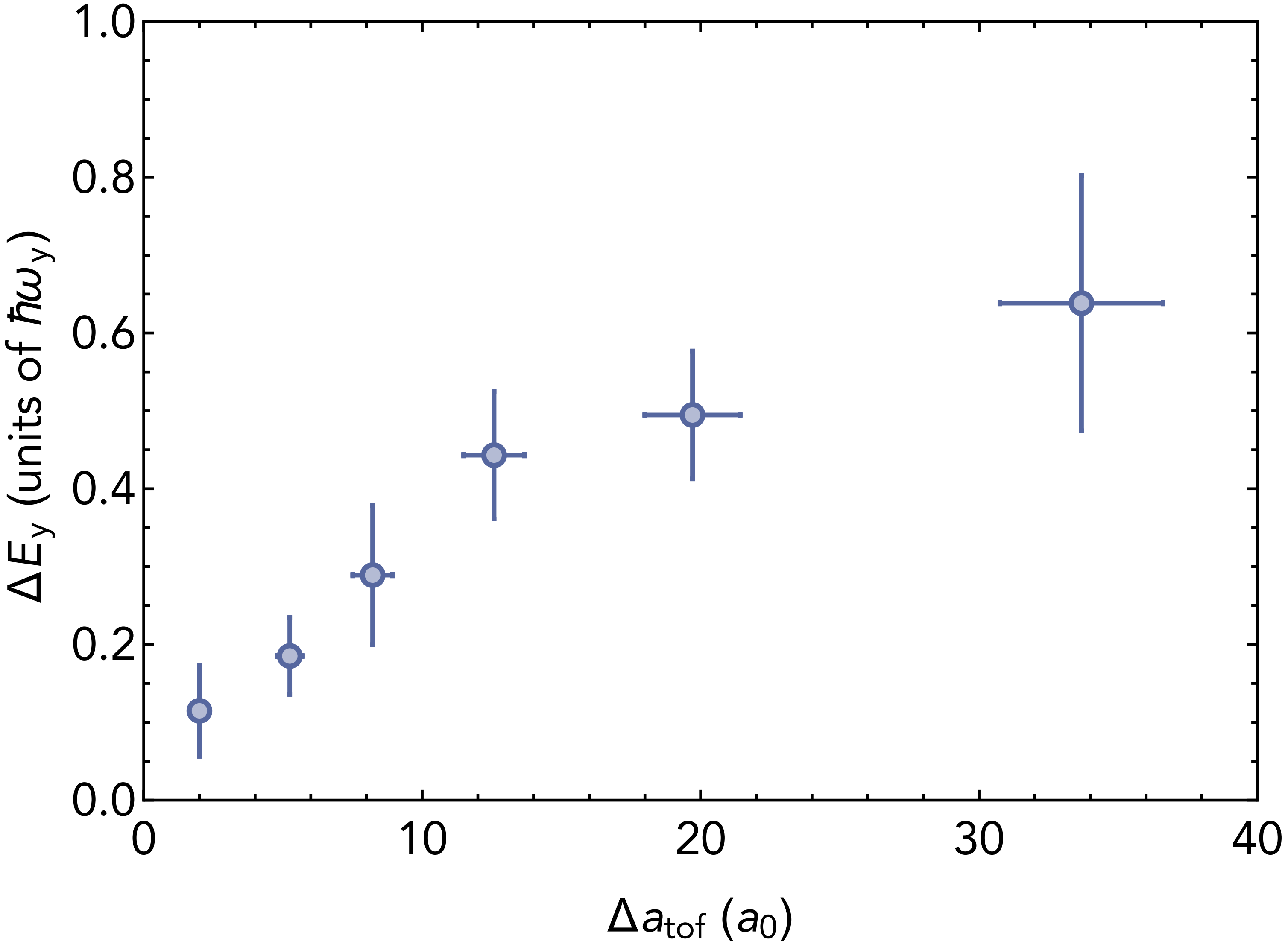
Measuring density



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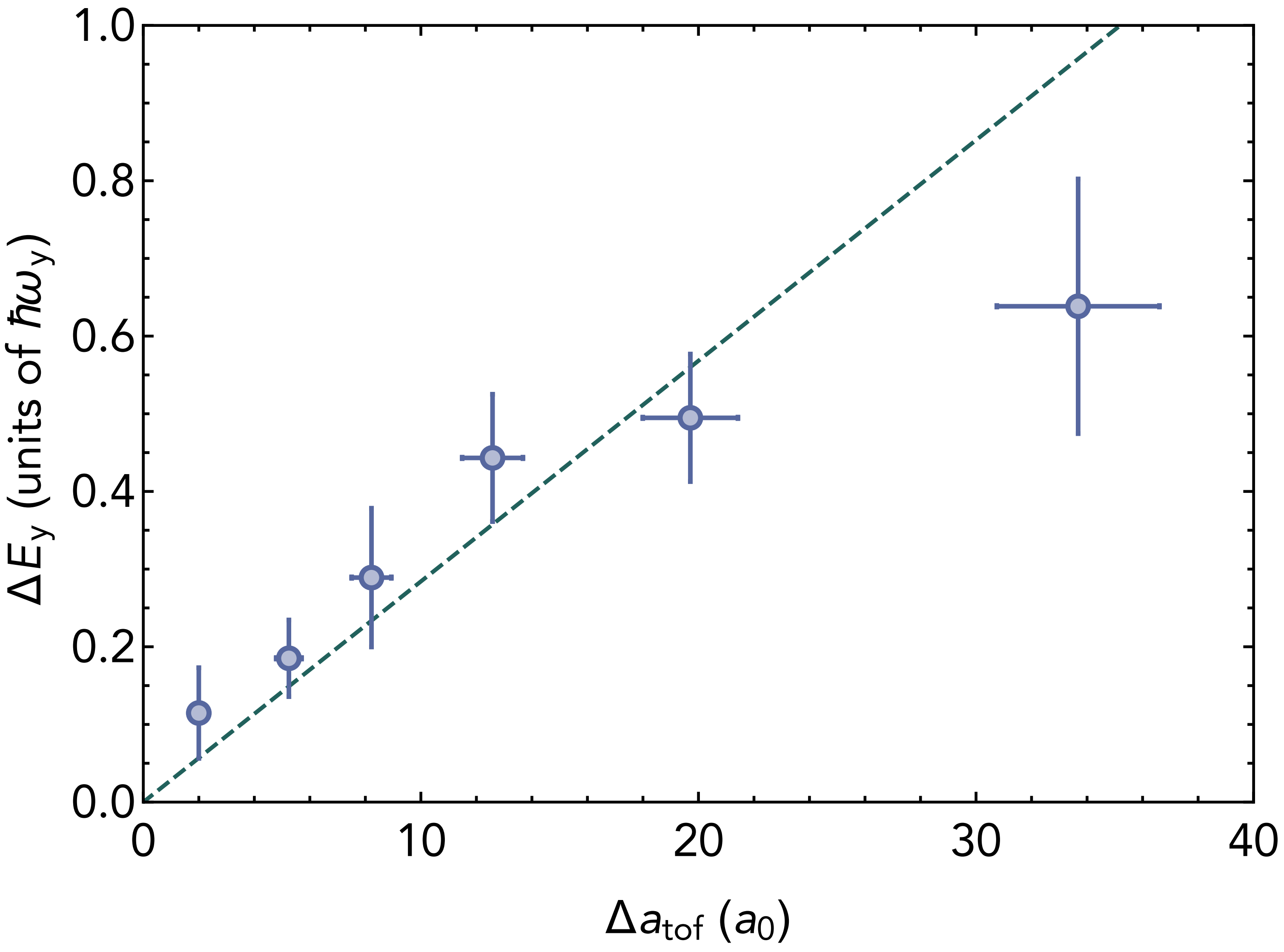

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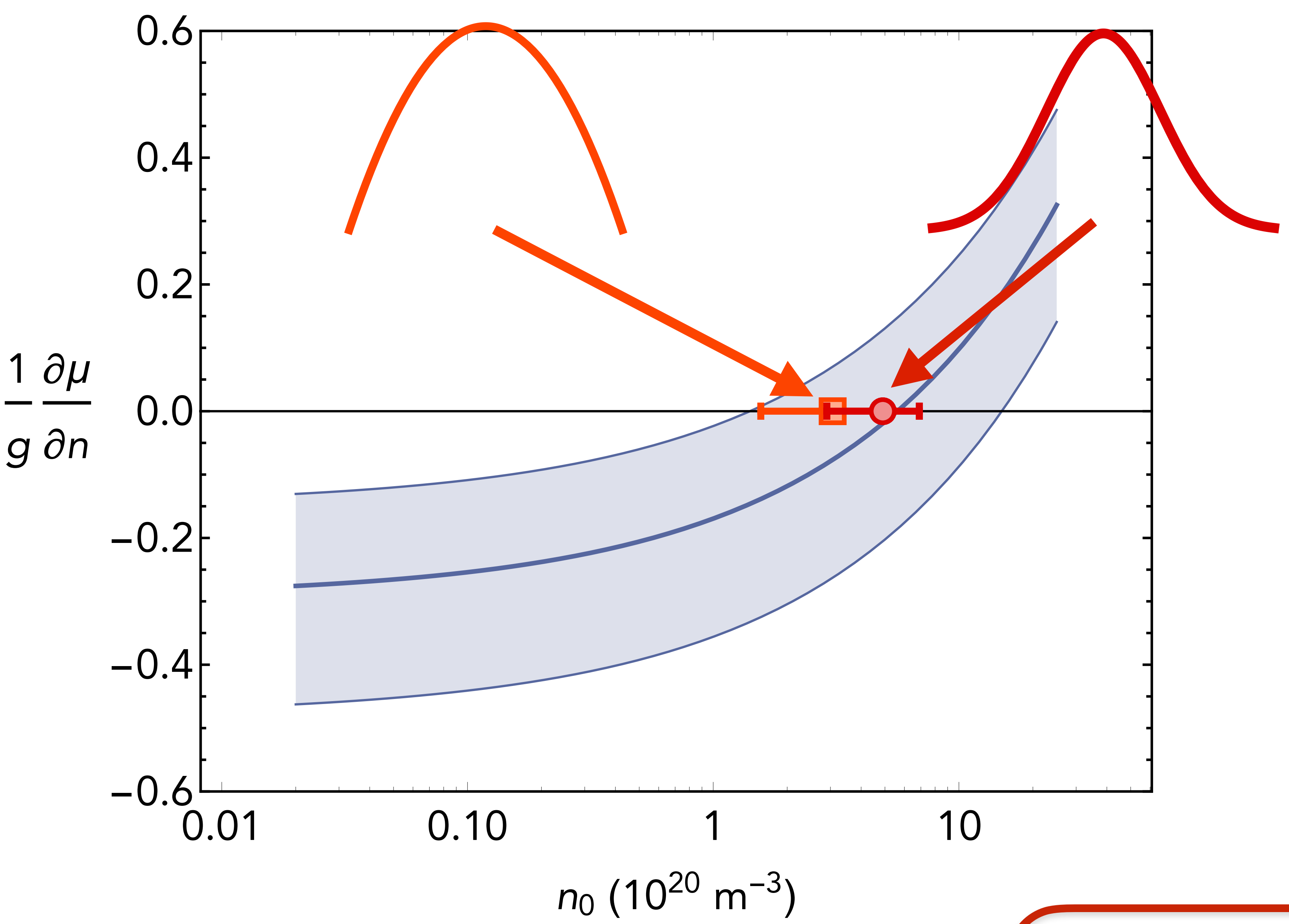

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$$e = \frac{g_3}{6} n^2$$

Xi and Saito *PRA*, **93**, 011604

Bisset and Blakie, *PRA* **92**, 061603

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The lifetime increases with a!

I. F-B, H. Kadau, M. Schmitt, M.Wenzel, T. Pfau, *arXiv:*1601.03318 ***PRL*** (2016)

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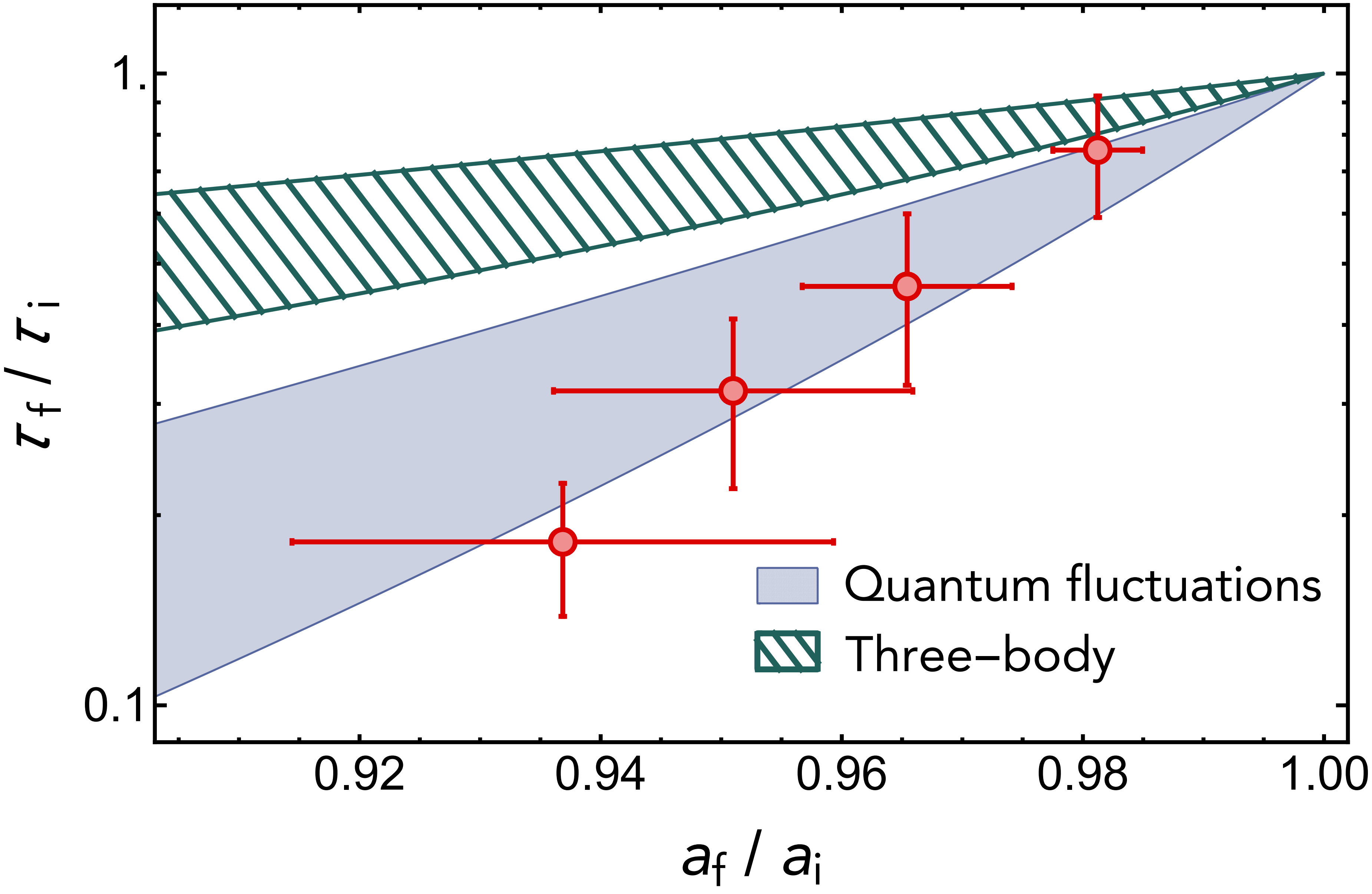

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Summary

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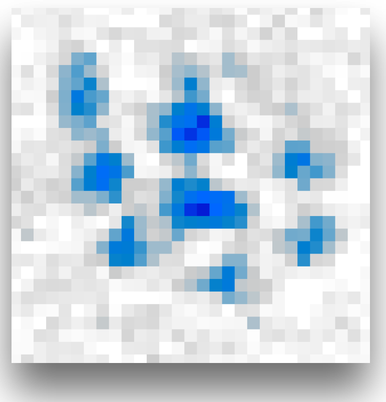
- Observation of a finite-wavelength instability (related to the roton instability)



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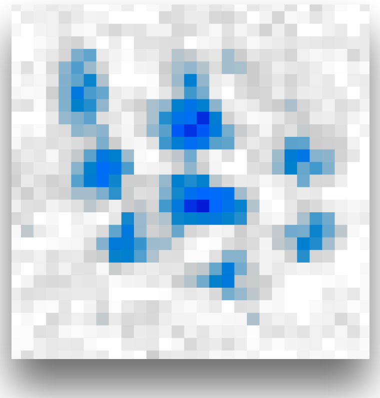

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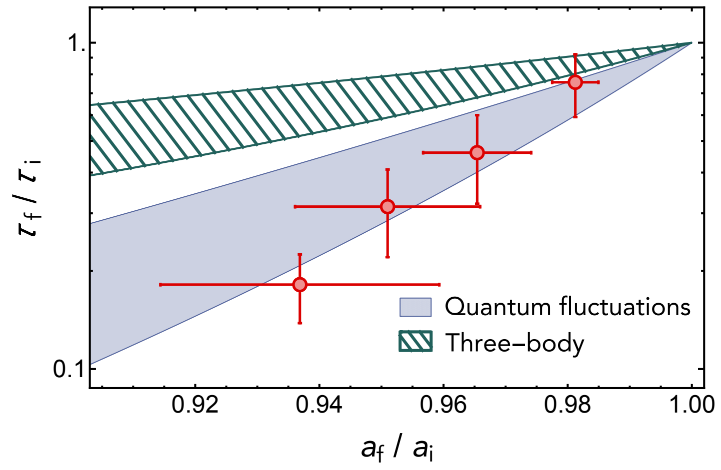

Thanks for your time!