UNIVERSITY OF CAMBRIDGE
150 YEARS
Cavendish Laboratory
Department of Physics

Microscopic Quantum Simulation of an Optical Quasicrystal

Yong-Guang Zheng (郑永光)

EMMI workshop, Benasque, Sept. ~~1~~ 5, 2025

EPSRC Engineering and Physical Sciences Research Council
DesOEQ
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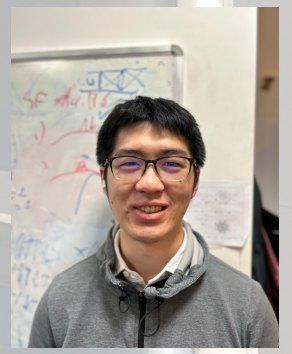
AQ$\hat{\psi}$S ANALOG QUANTUM SIMULATORS FOR MANY-BODY DYNAMICS
QCi3 HUB

The quasicrystal team at Cambridge

YGZ

Zhuoxian (Chelsea) Ou

Leanne Reeve



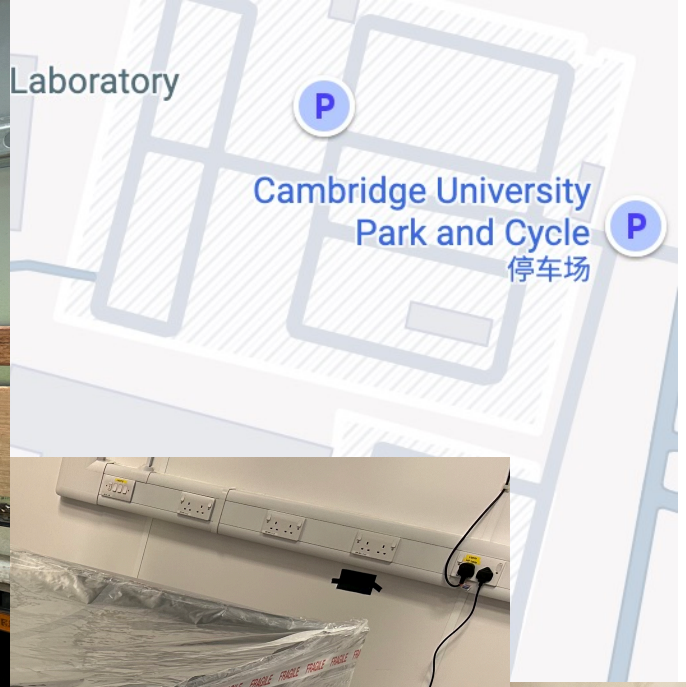
Qijun Wu

Baptiste Lerat

Ulrich Schneider

RAY DOLBY CENTRE CAVENDISH LABORATORY

Millennia eV
Newport


Laboratory
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Cambridge University
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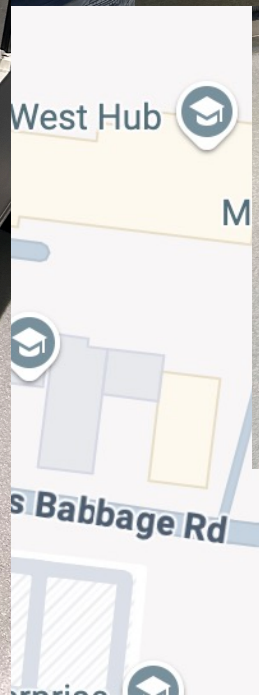
West Hub
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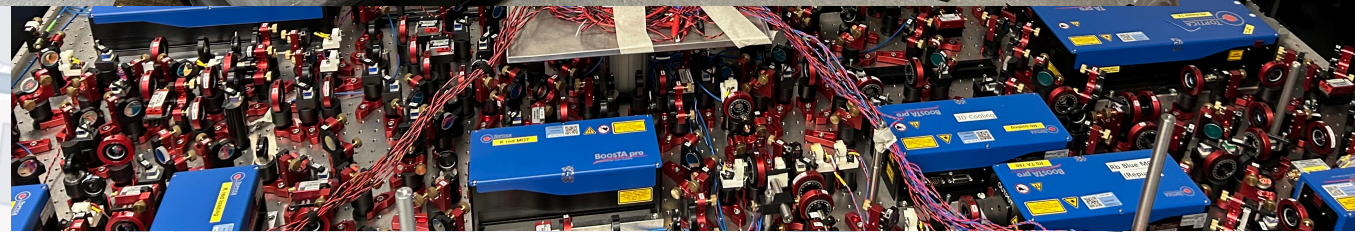
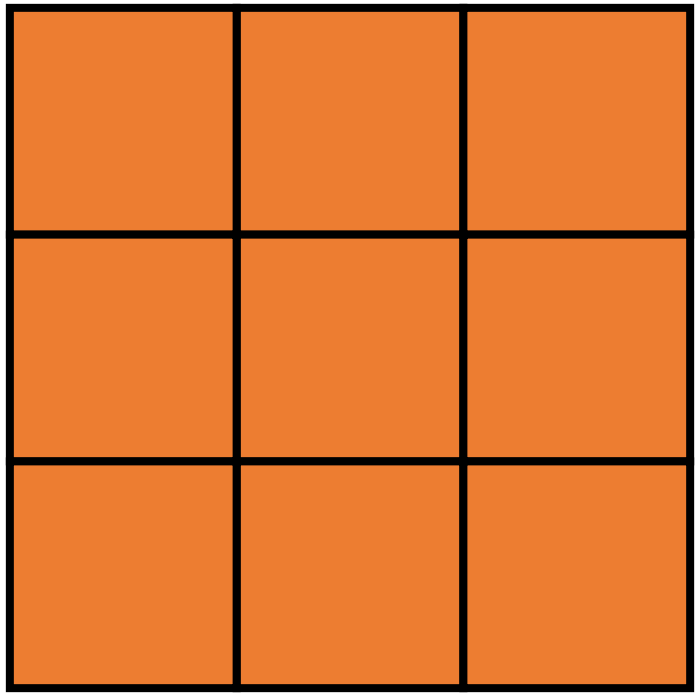
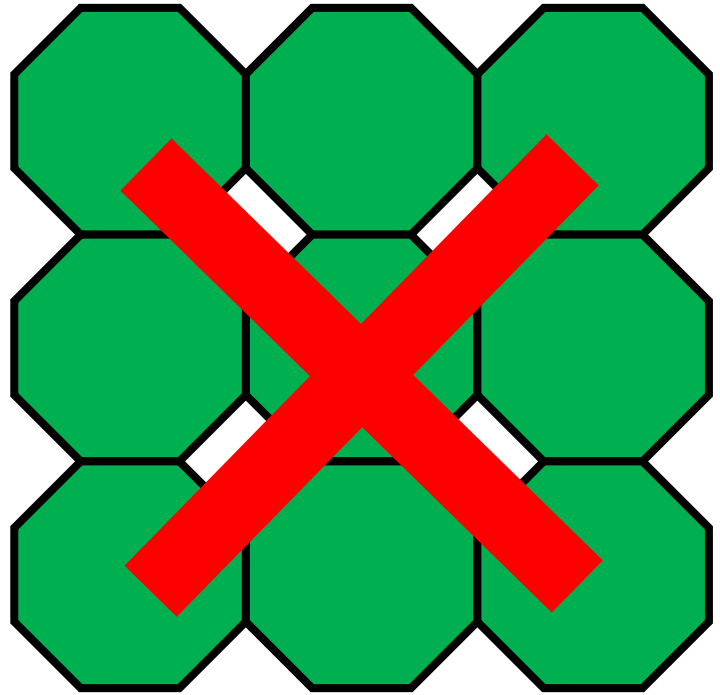
FRAGILE


BOOSTA pro

What/Why is quasicrystal?

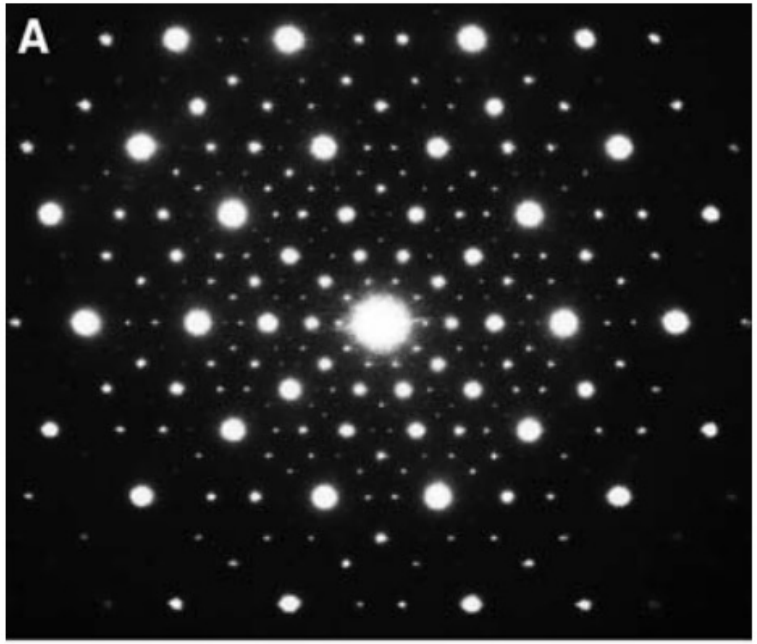


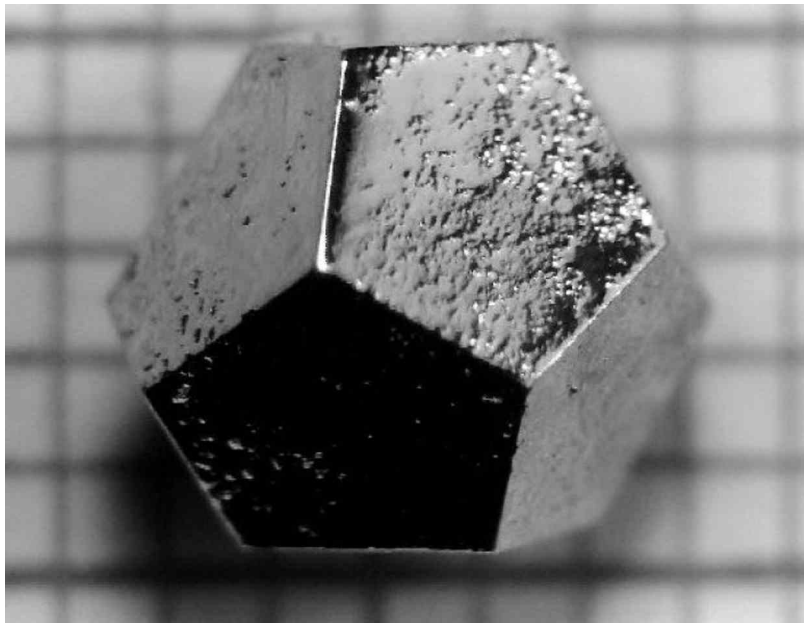
Crystal: translation symmetry and rotational symmetry (three-fold, four-fold, six-fold,⋯)



Forbbiden rotational symmetries for a crystal: five-fold, eight-fold,⋯

Quasicrystals in condensed matter physics

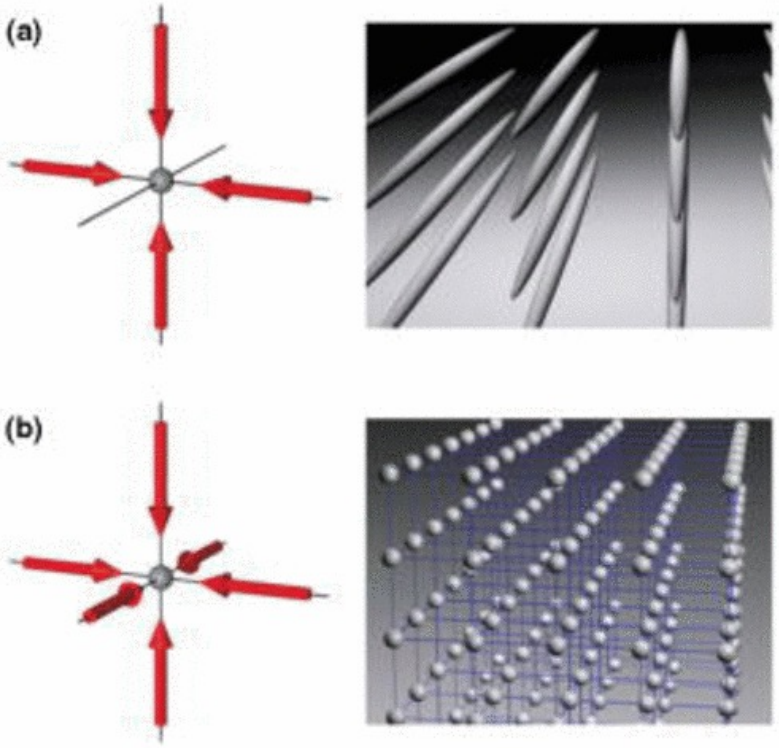




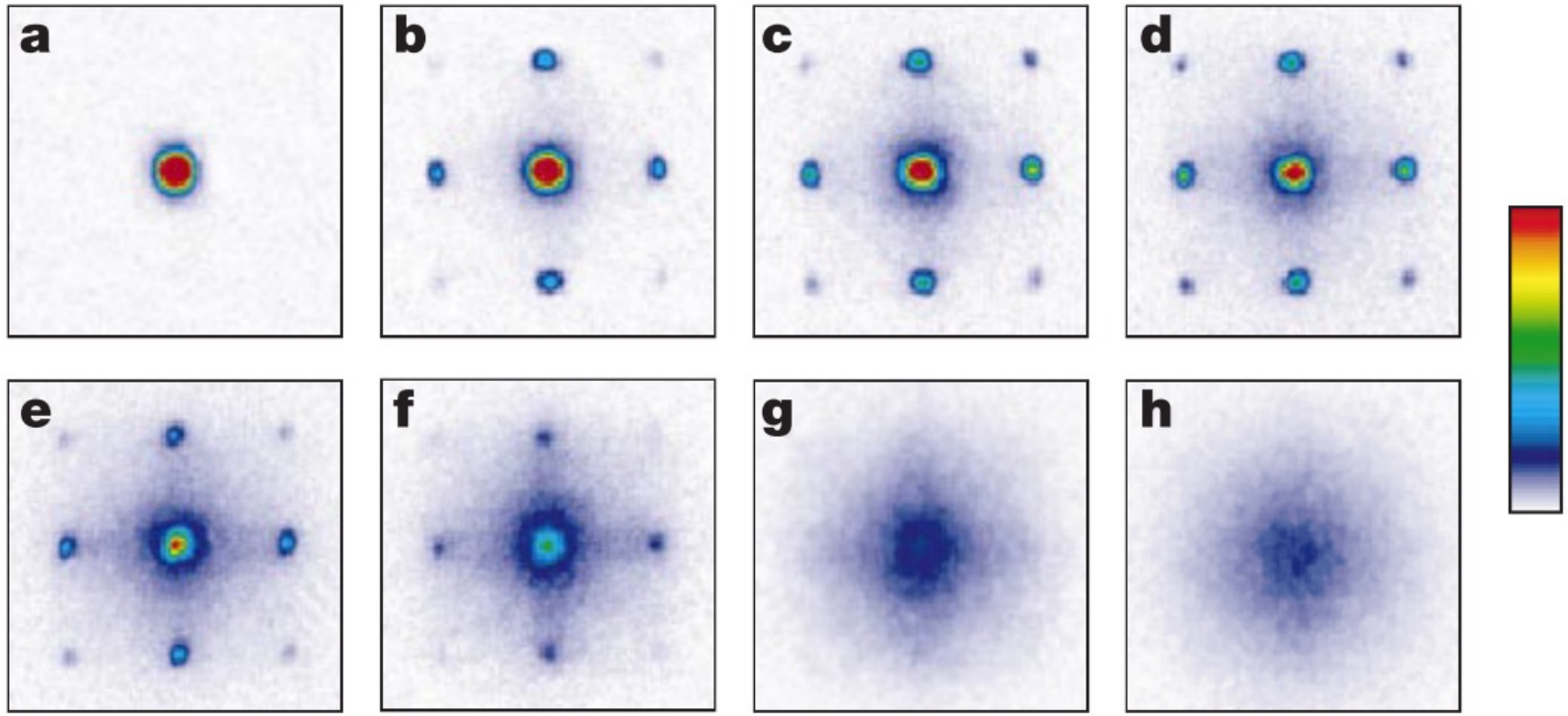
-Ho-Mg-Zn icosahedral quasicrystal

Bindi B. et al.,Science 324,1306-1309(2009)

Quantum simulation using ultracold atoms



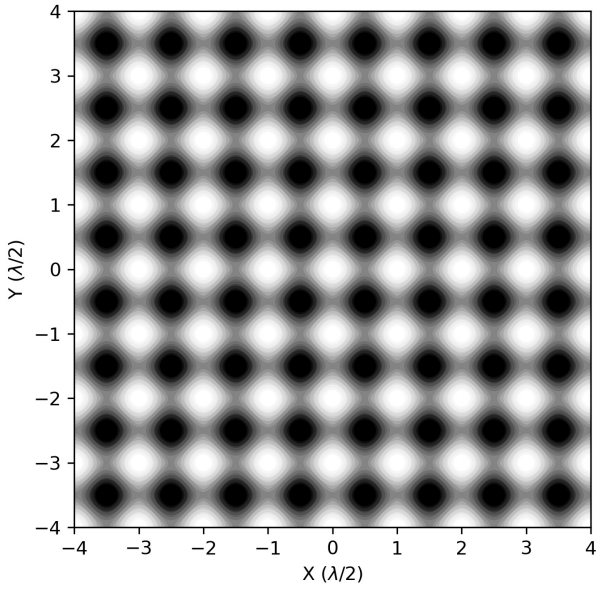
Optical lattices



Superfluid to Mott insulator transition

Greiner, M., et al. (2002). Nature, 415(6867), 39–44.
Bloch, I., et al. 2008, Rev. Mod. Phys. 80, 885-964

Eight-fold optical quasicrystals



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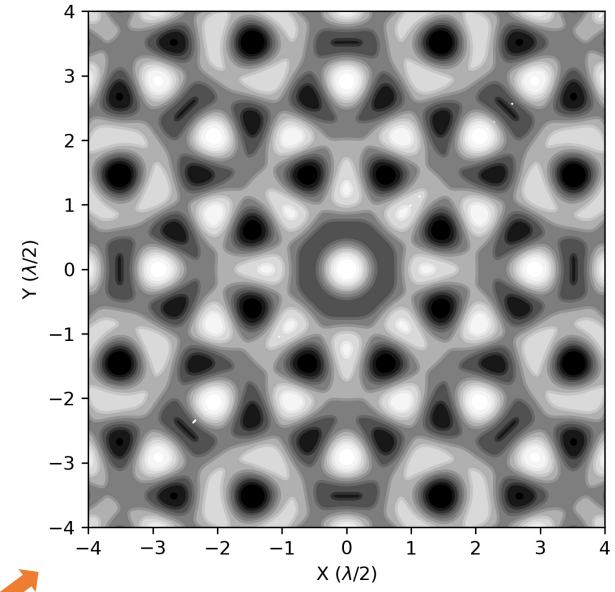

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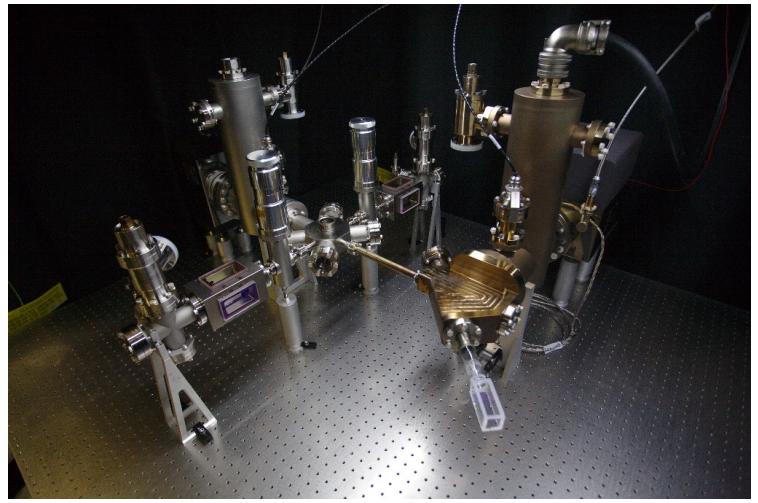
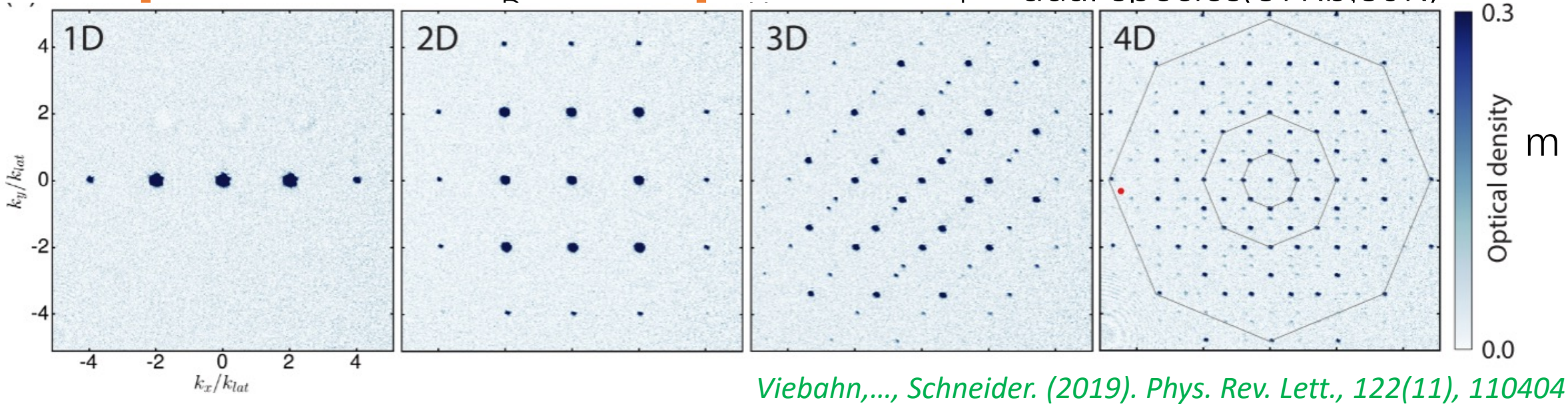


T -dual species(87Rb,39K)



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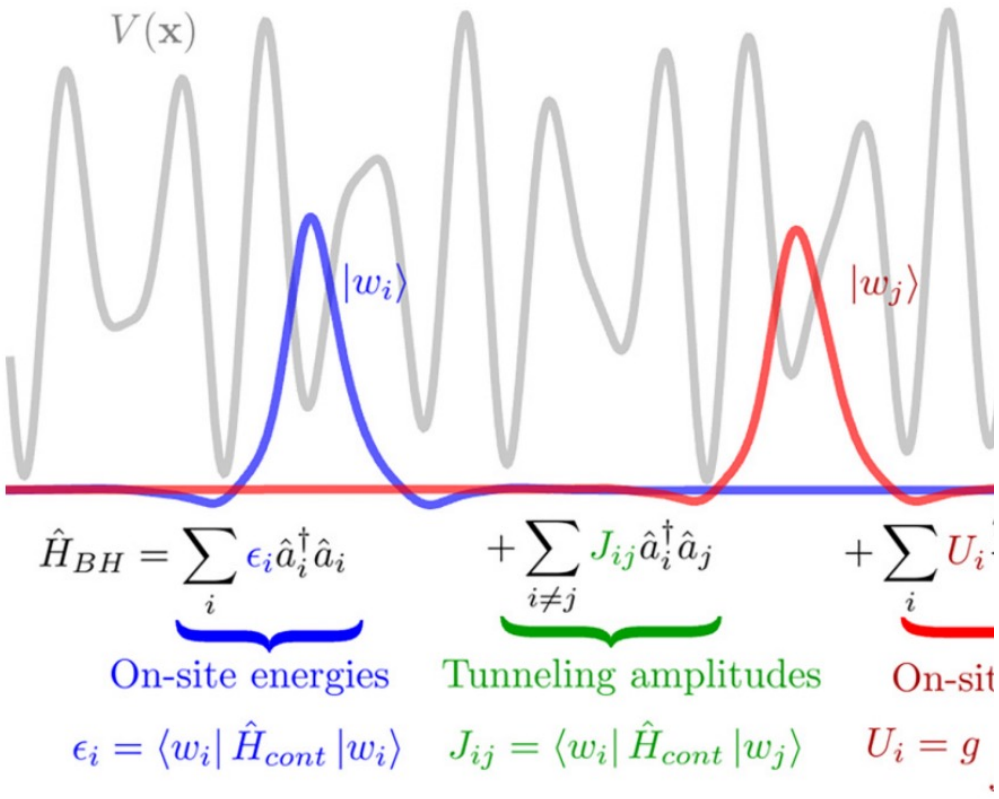
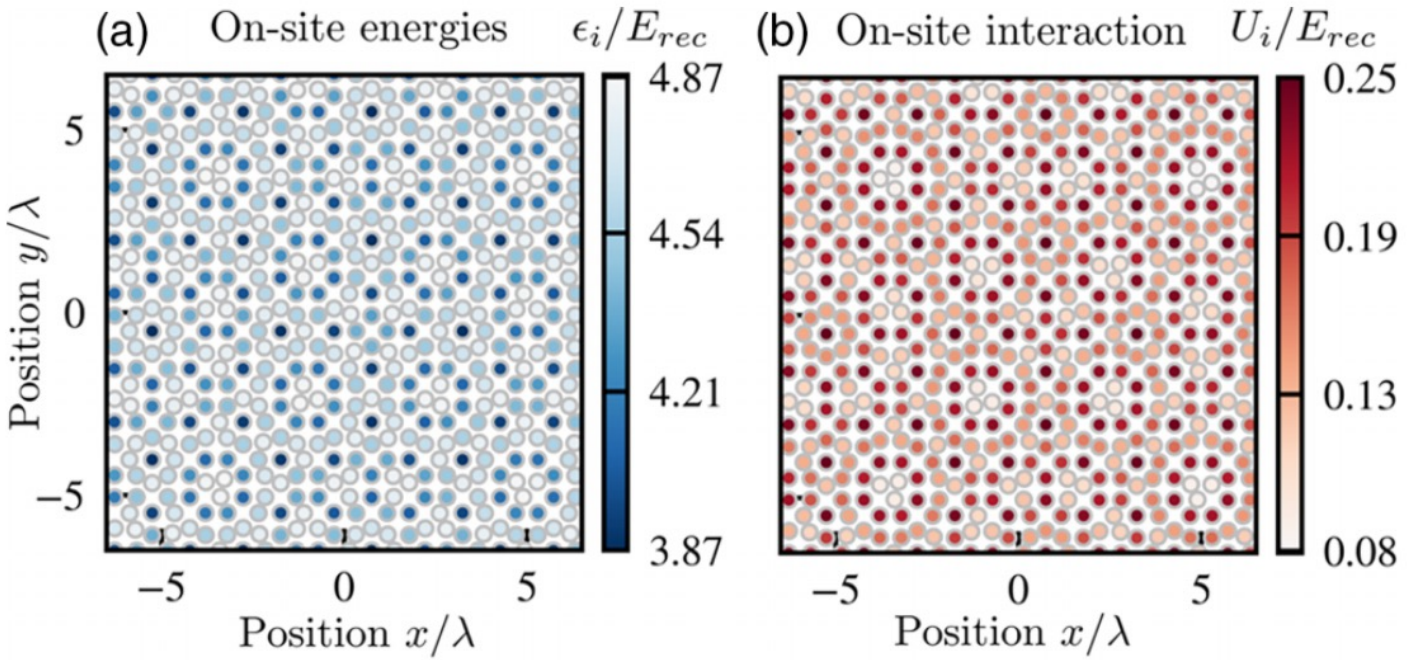
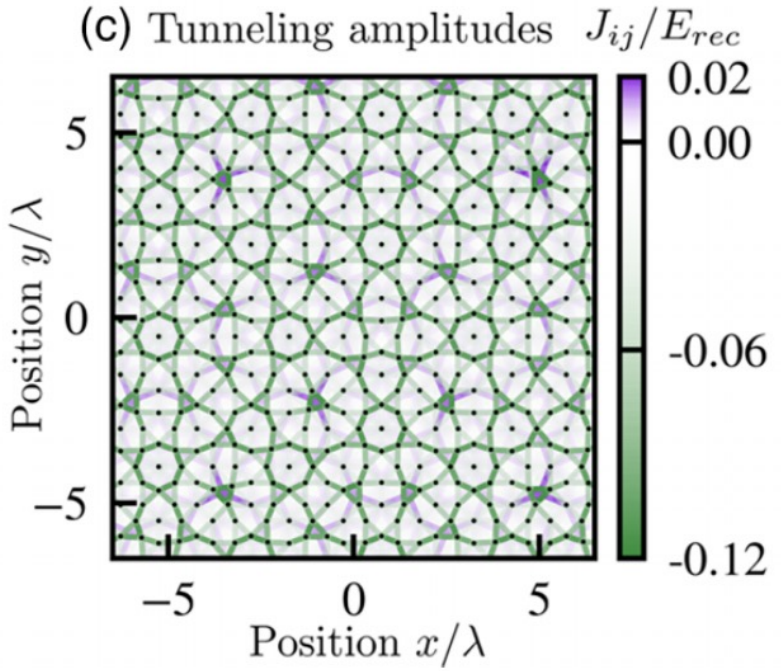
Viebahn,..., Schneider. (2019). Phys. Rev. Lett., 122(11), 110404

Eight-fold optical quasicryst

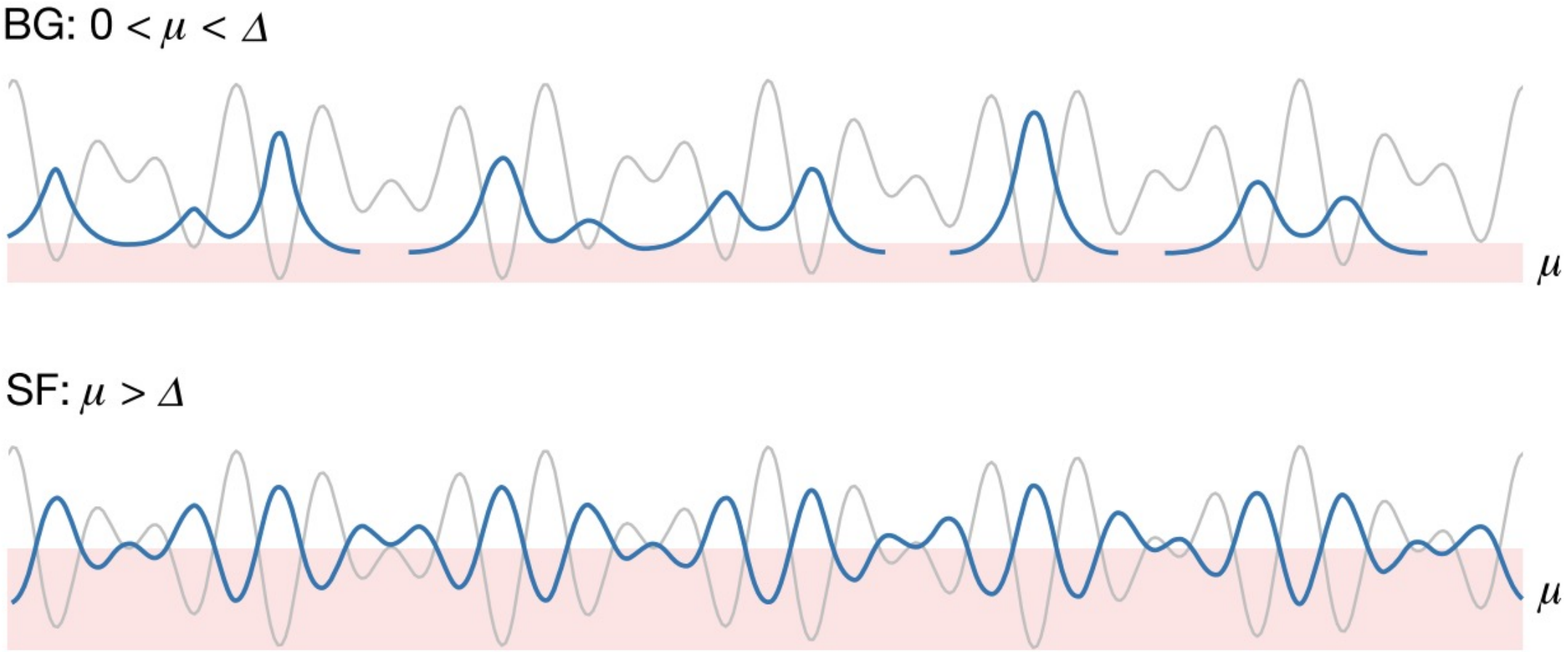






Gottlob & Schneider (2023). PRB

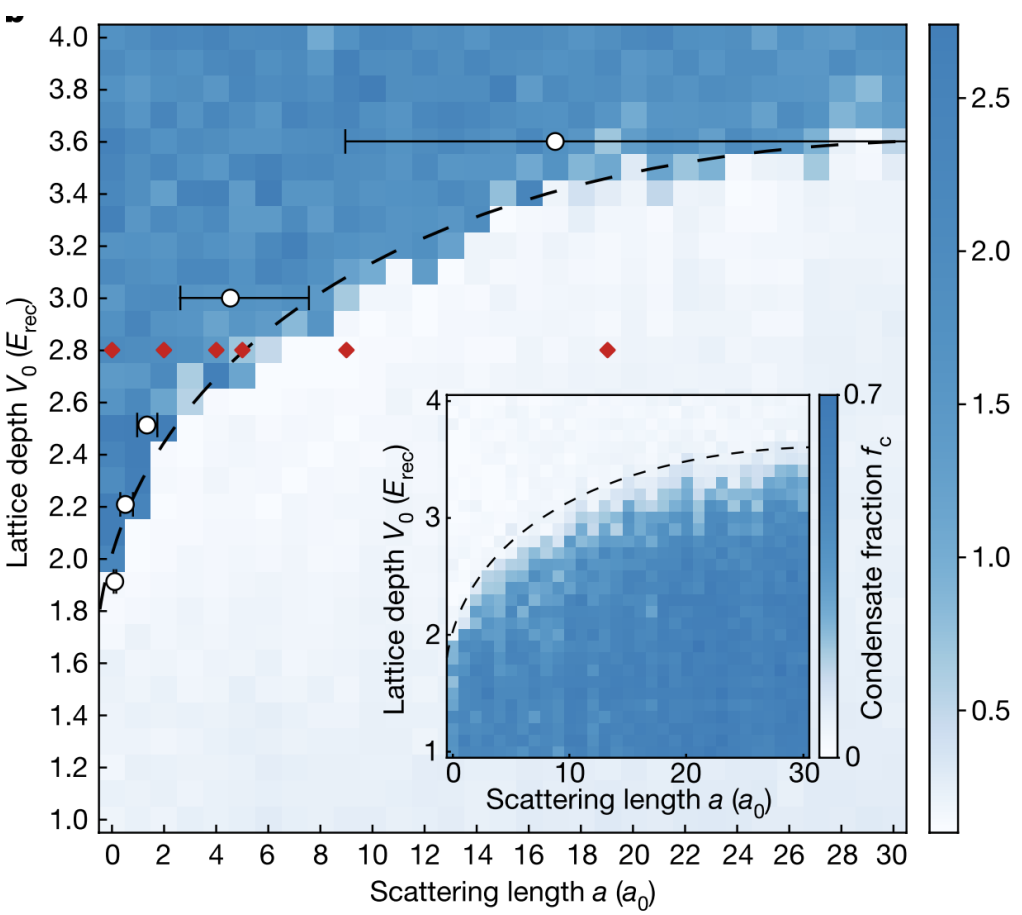
Superfluid to Bose glass transition in a quasicrystal

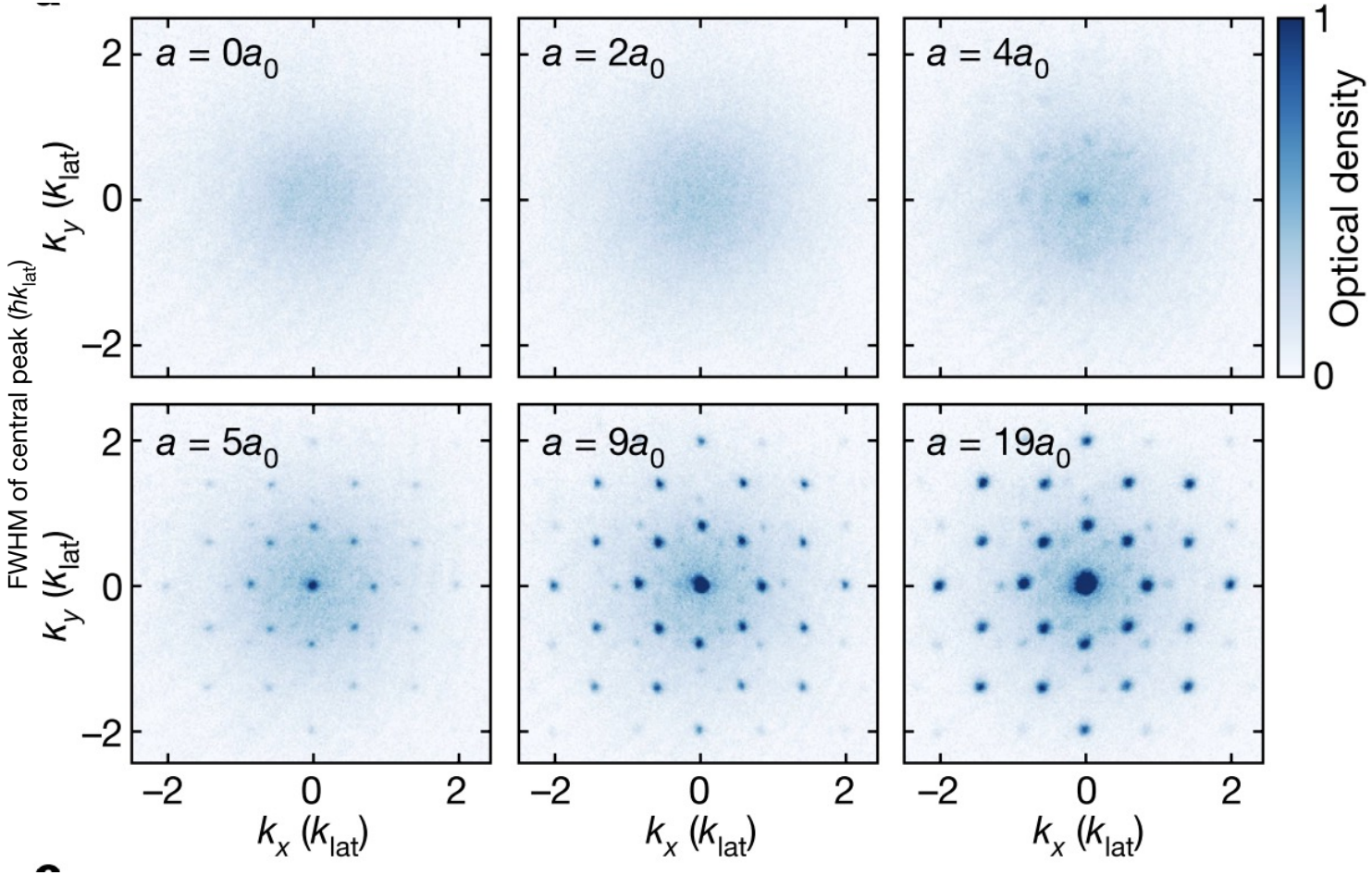


-Superfluid to Bose glass transition observed in the optical quasicrystal

Yu, …, Schneider (2024) Nature, 633(8029), 338–343.

Superfluid to Bose glass transition

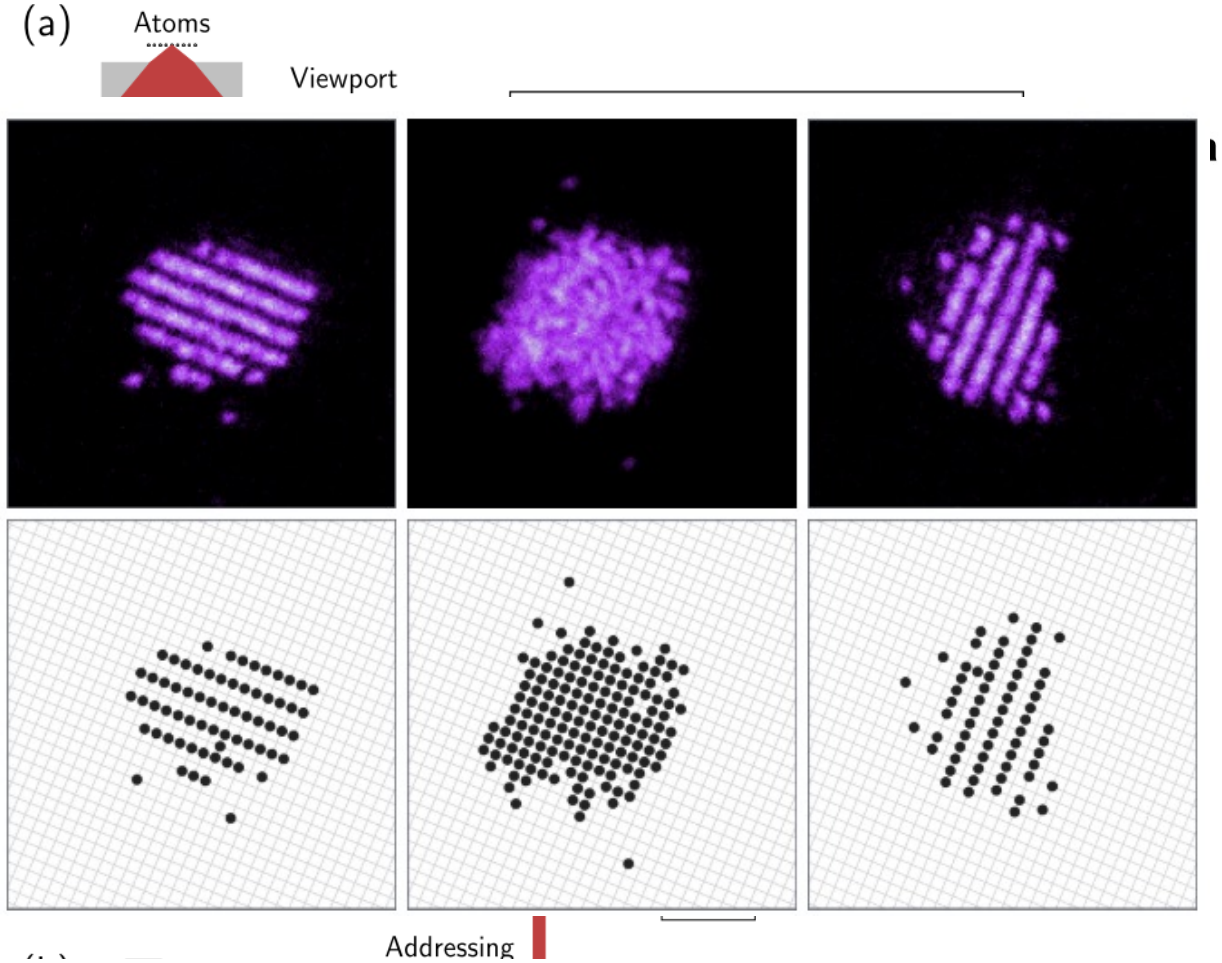


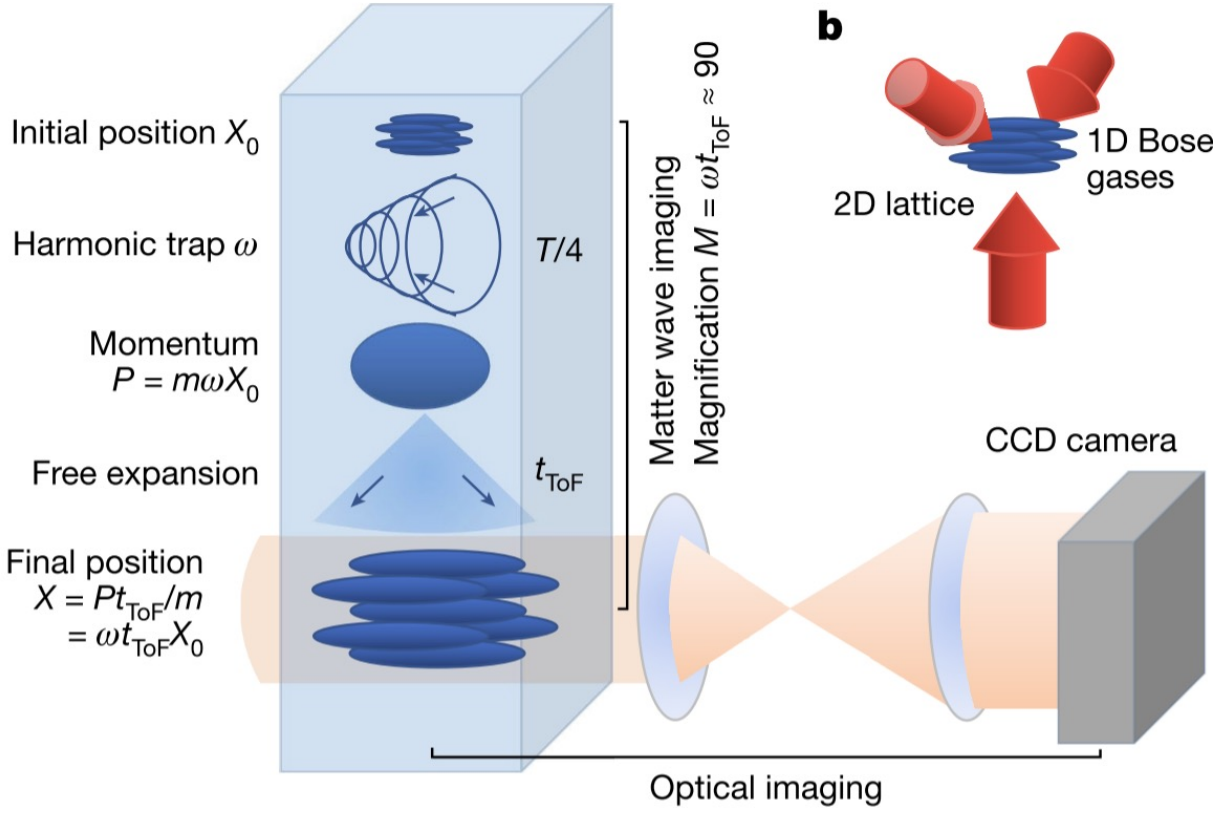


-Superfluid to Bose glass transition observed in the optical quasicrystal

Yu,…, Schneider. (2024) Nature, 633(8029), 338–343.

To resolve atoms at the single site level





Asteria, …, Weitenberg, (2021). Nature, 599(7886), 571–575.

Quantum gas **microscopes**

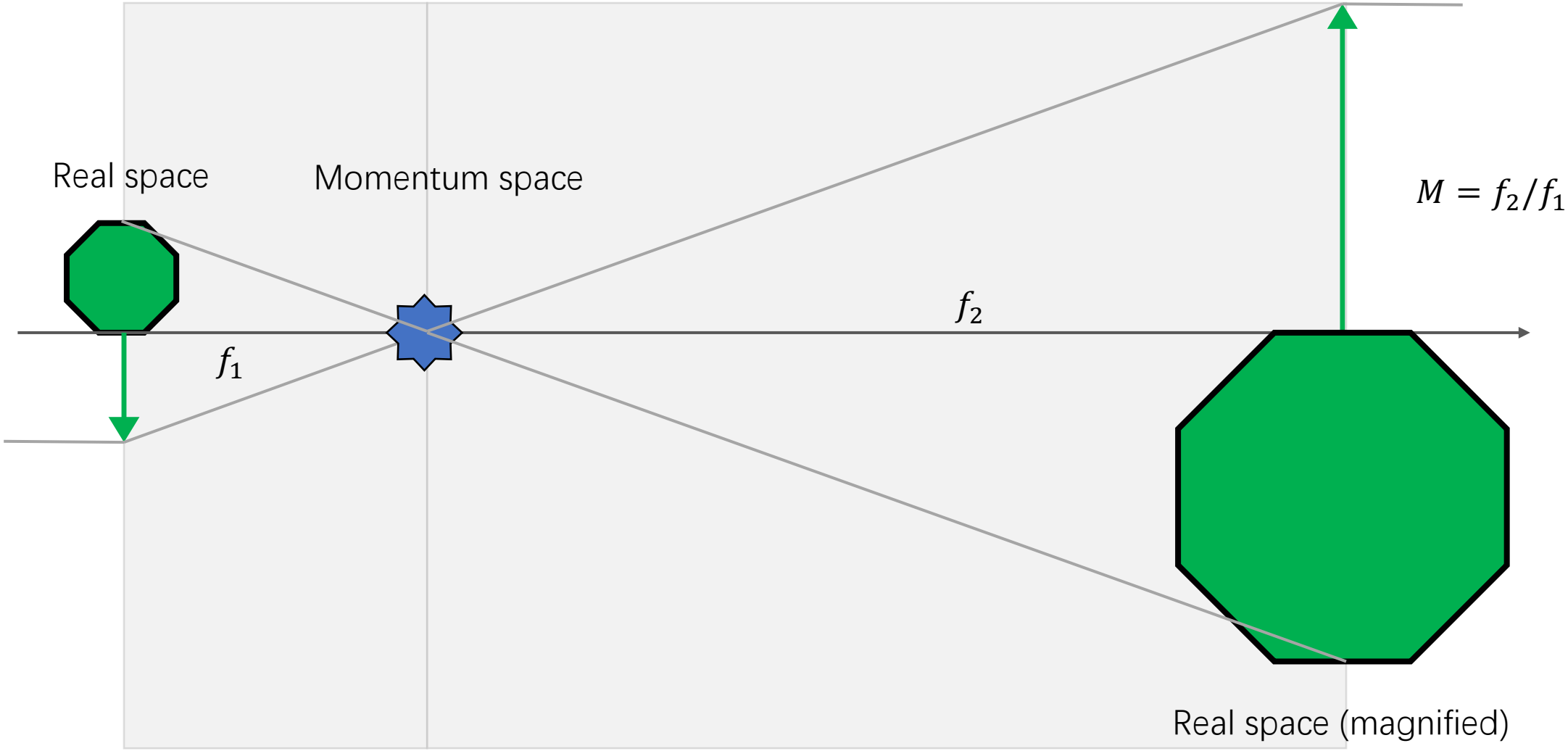
YGZ,…, Yuan, Pan (2022). Opt. Lett., 47, 4239.

also: Harvard, MPQ, Princeton, MIT, Strathclyde, Kyoto, Tokyo, KAIST, Barcelona, ⋯

Quantum gas magnifiers

Hamburg, Heidelberg,⋯

Quantum gas magnifier -- how it works

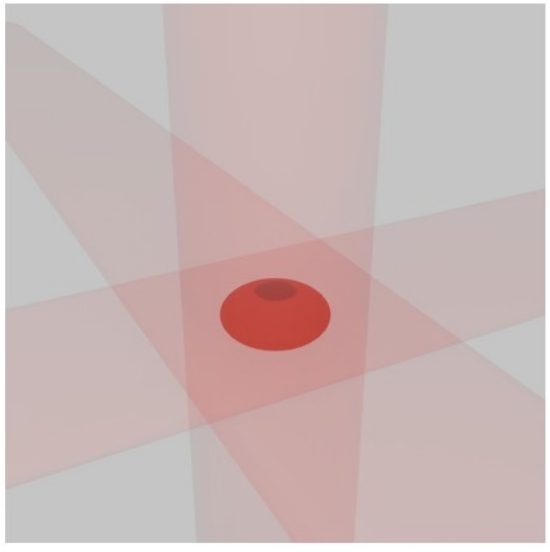


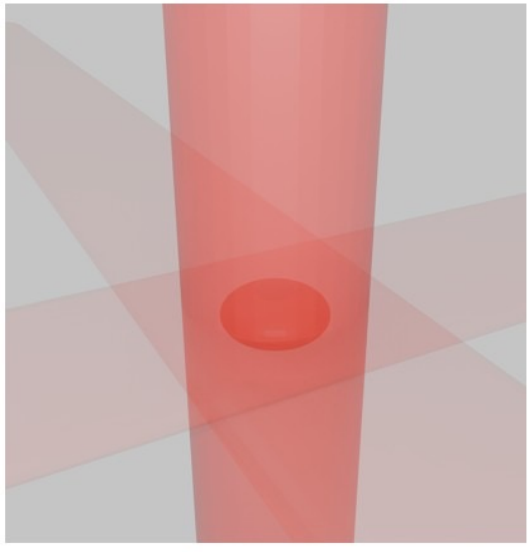
TOF in a harmonic trap for $T/4$

TOF in free space for τ

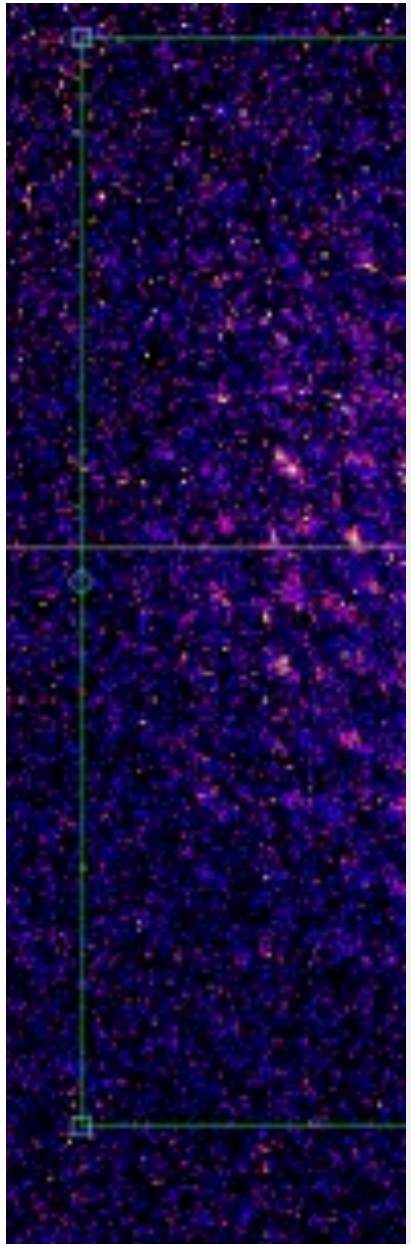
$M = 8\pi\tau/T$

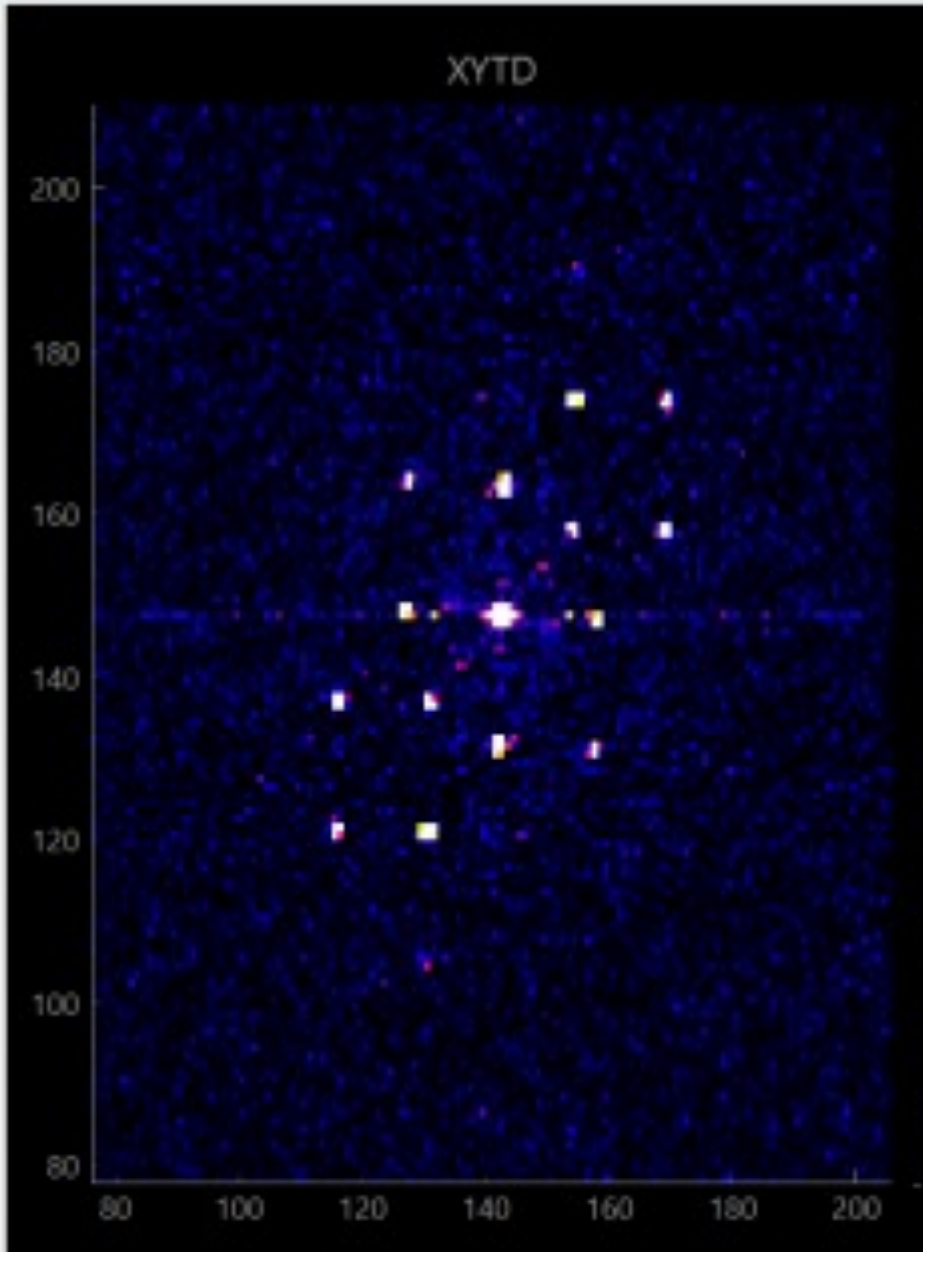
Quantum gas magnifier at Cambridge



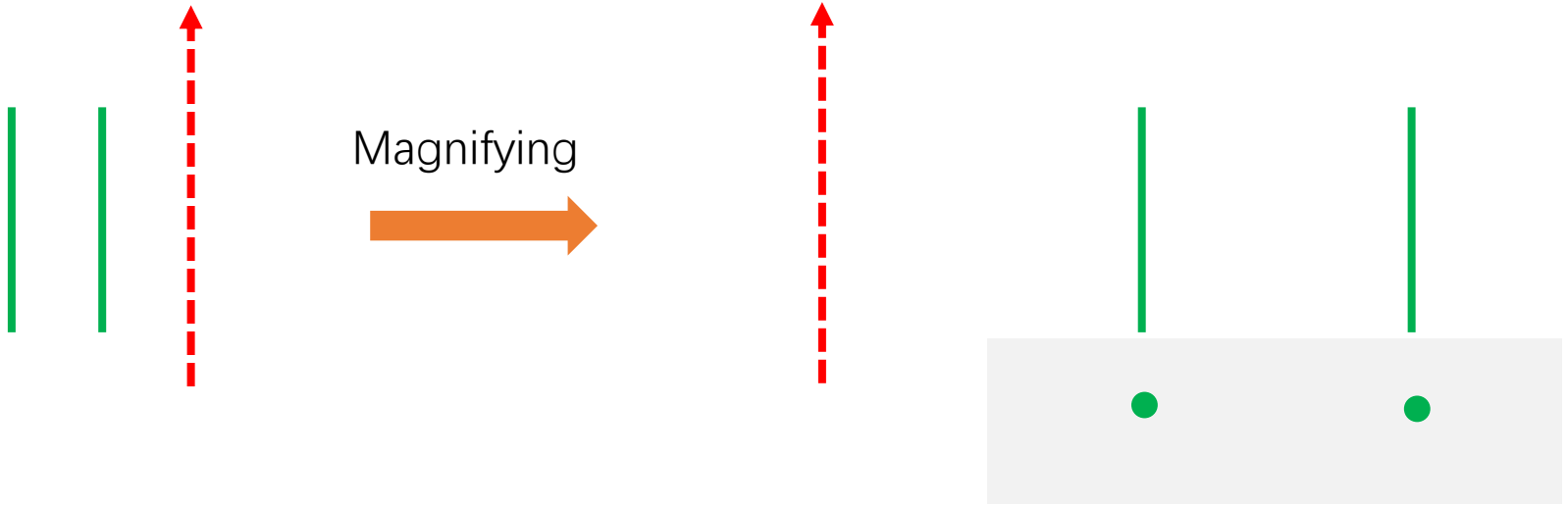


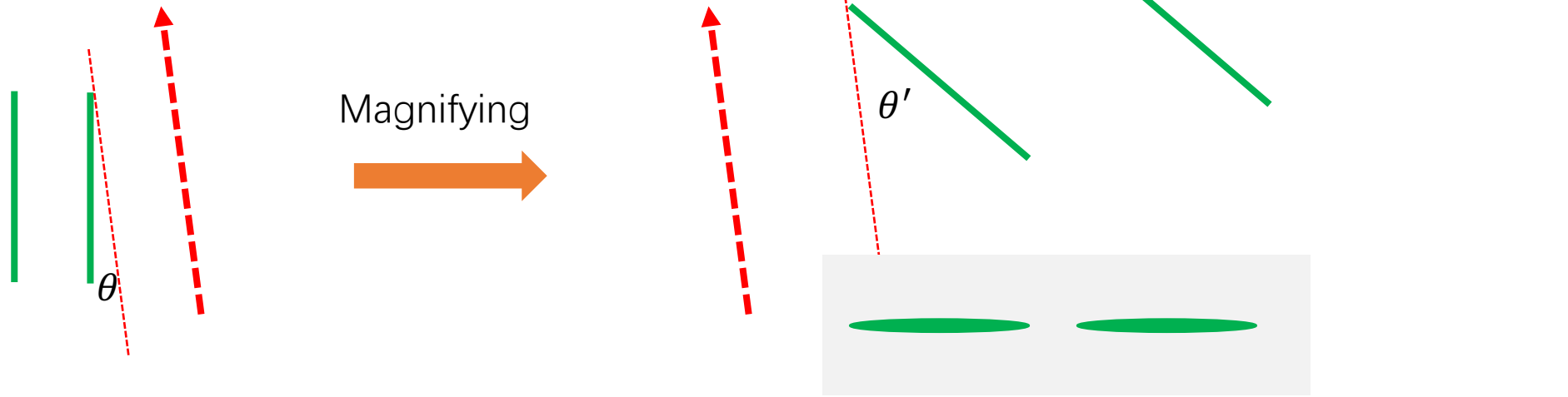
Specifications
-1065 nm dipole trap
-90 um waist, 5W
-890 Hz
-M~50





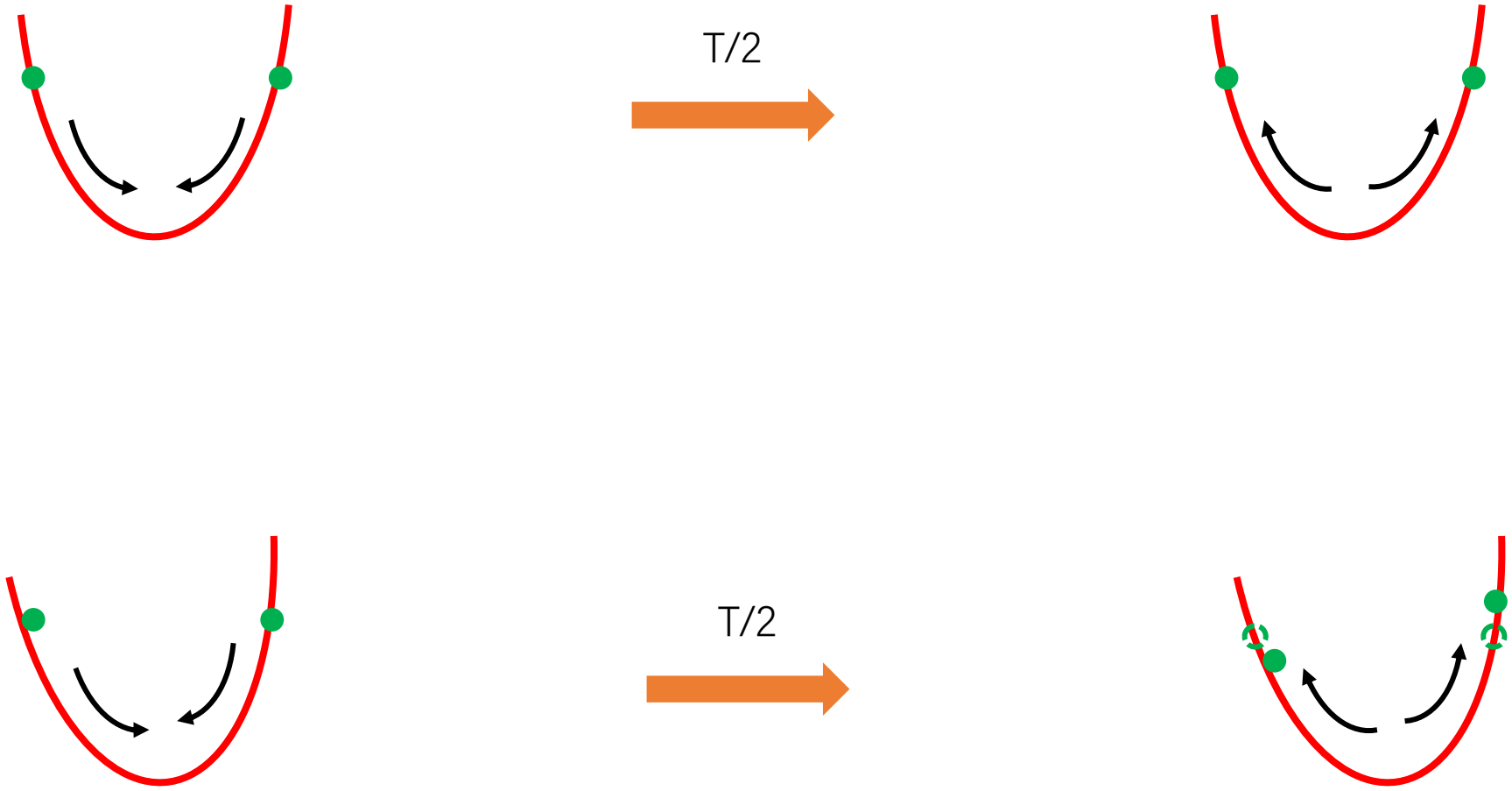
Quantum gas magnifier at Cambridge



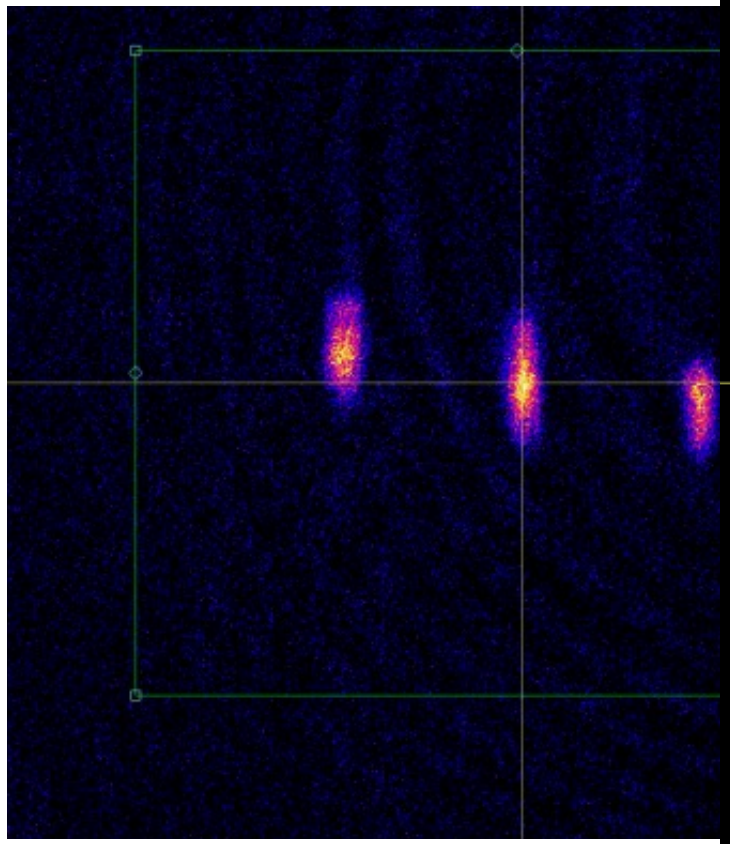


$$\tan\theta' = M\ \tan\theta$$

Quantum gas magnifier at Cambridge

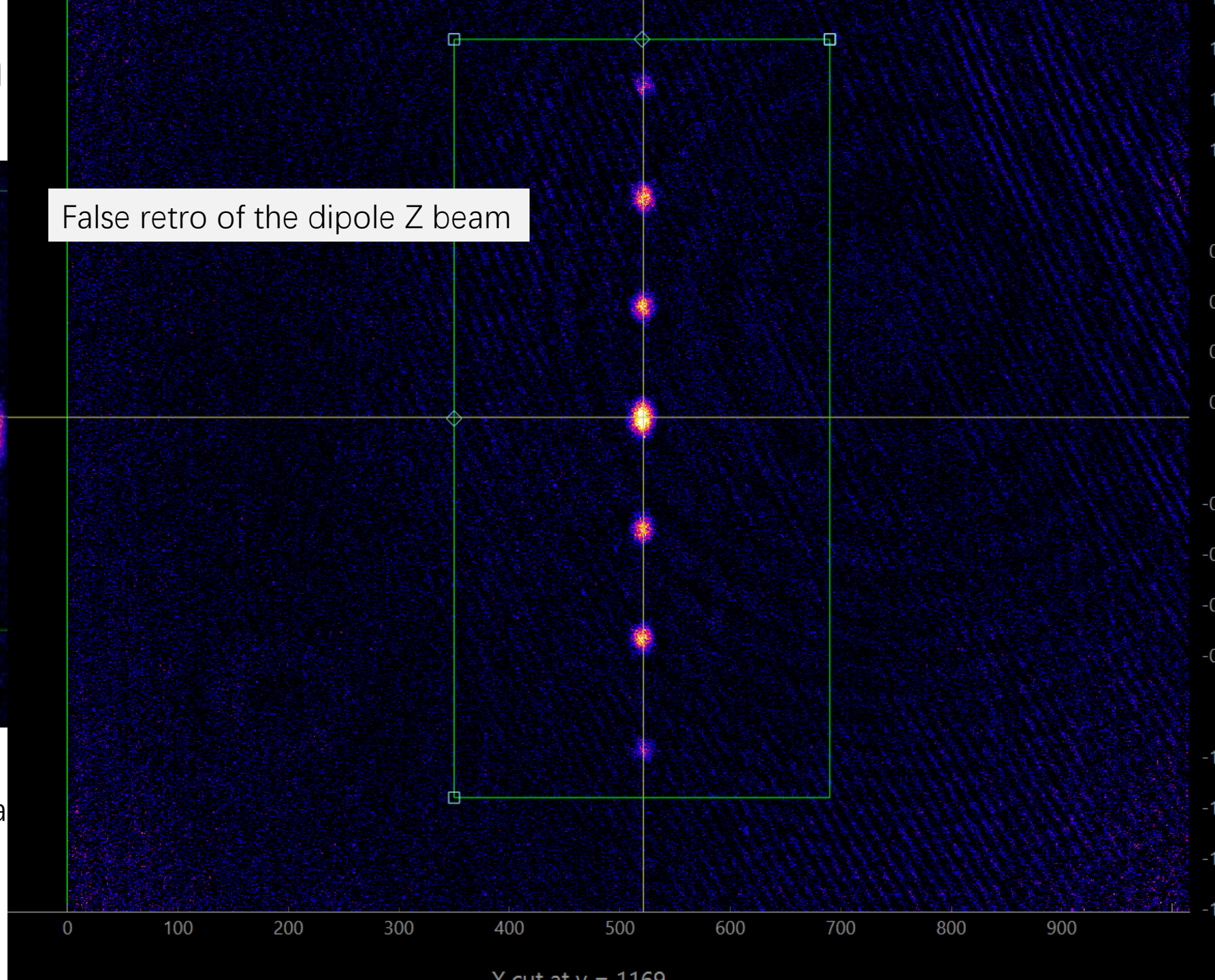


Quantum gas magn

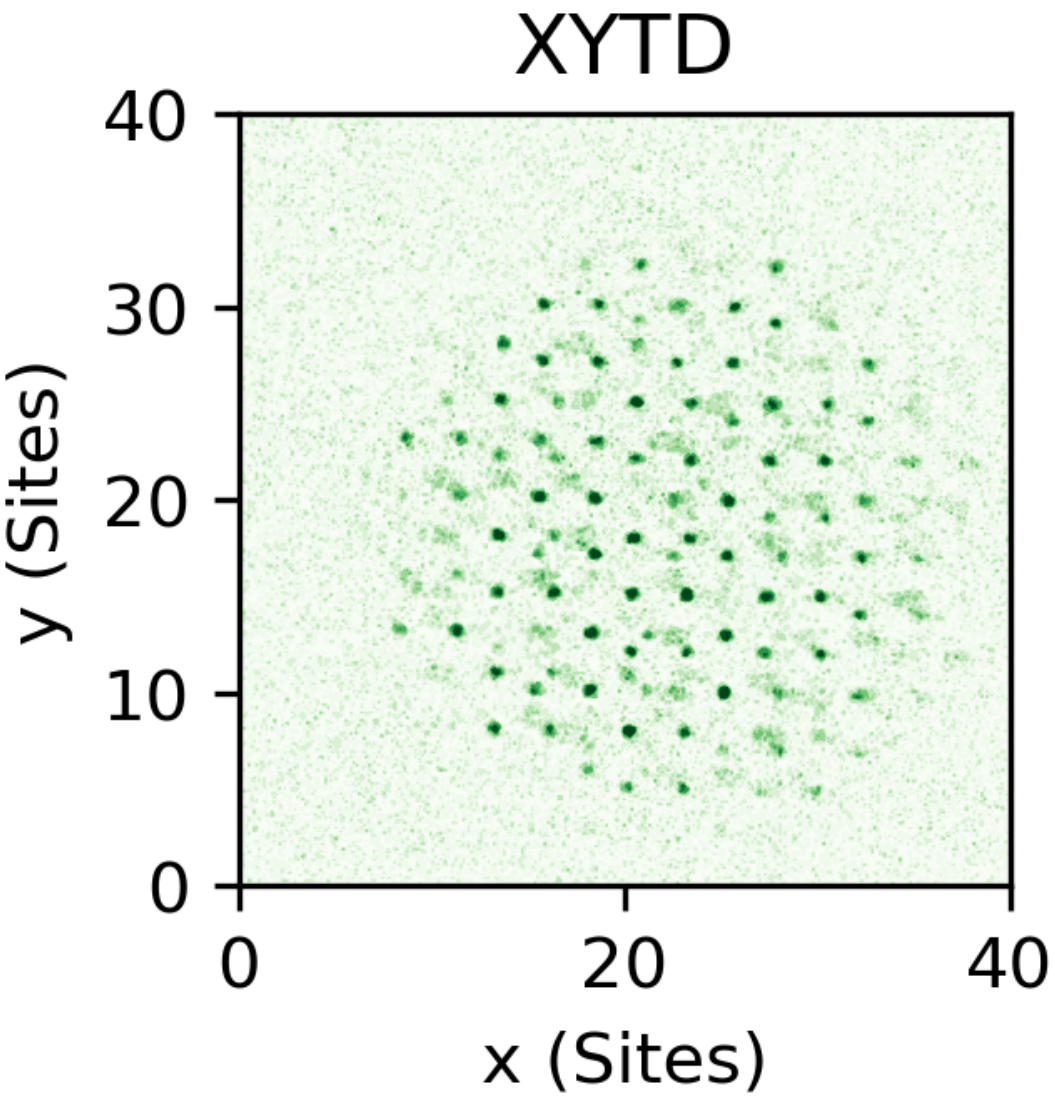


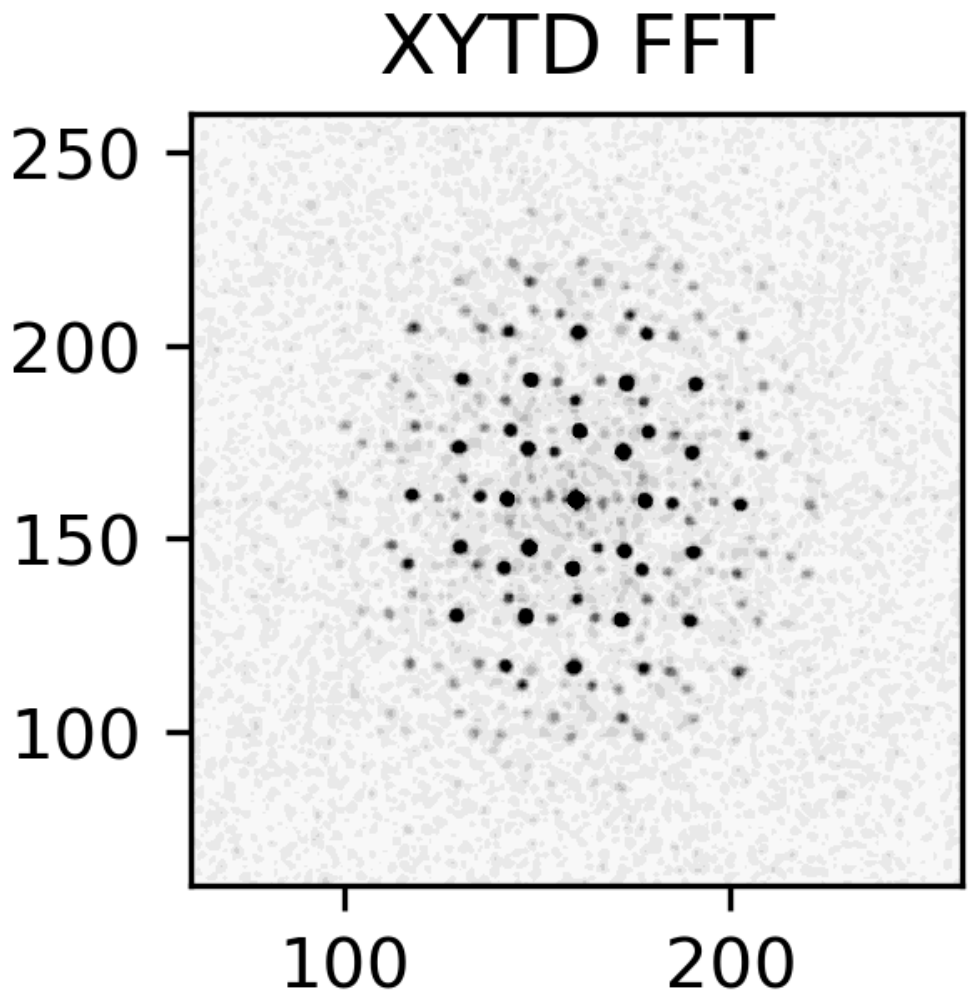
False retro of the dipole Z beam

T/2, before tilting ma

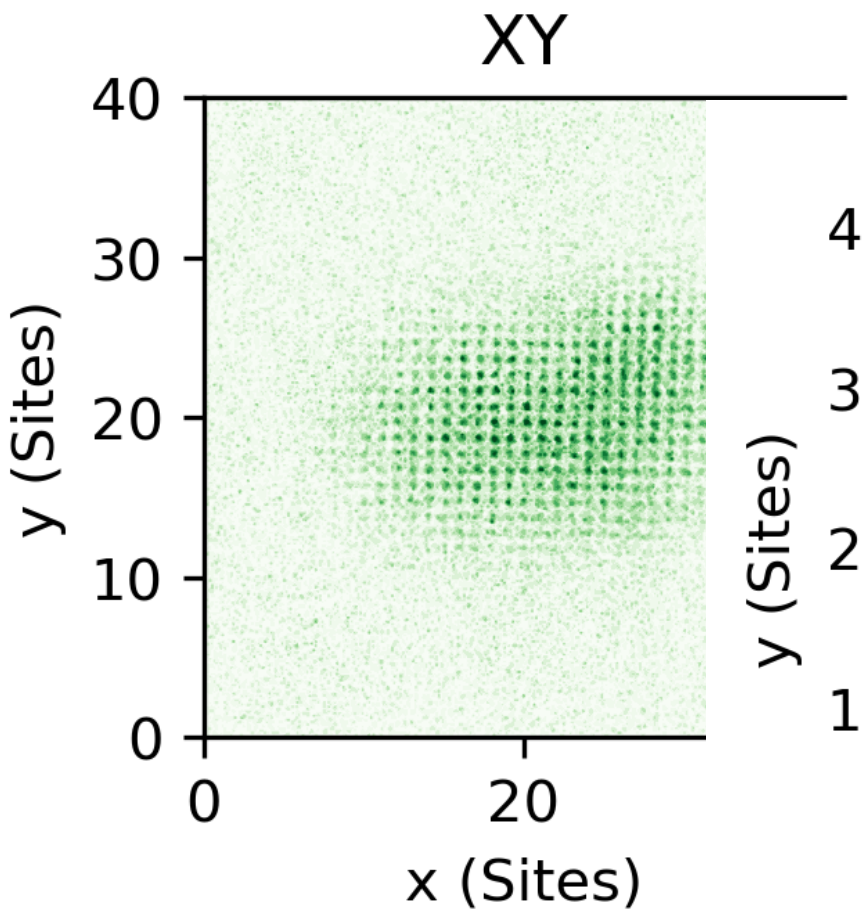


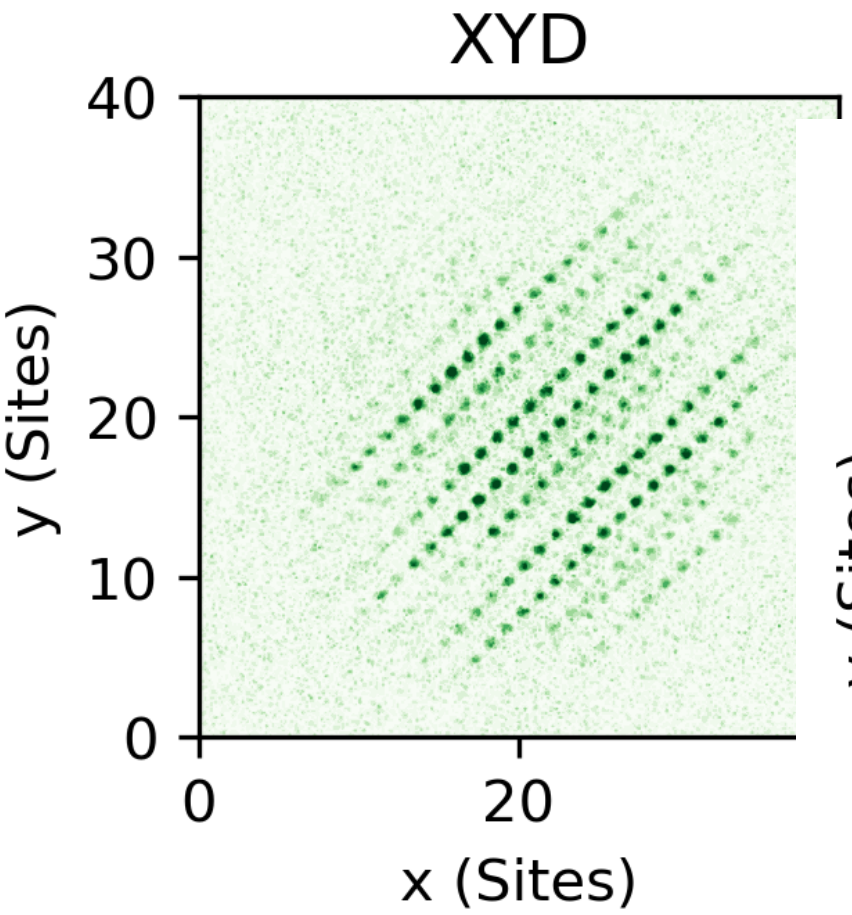
Quantum gas magnifier at Cambridge

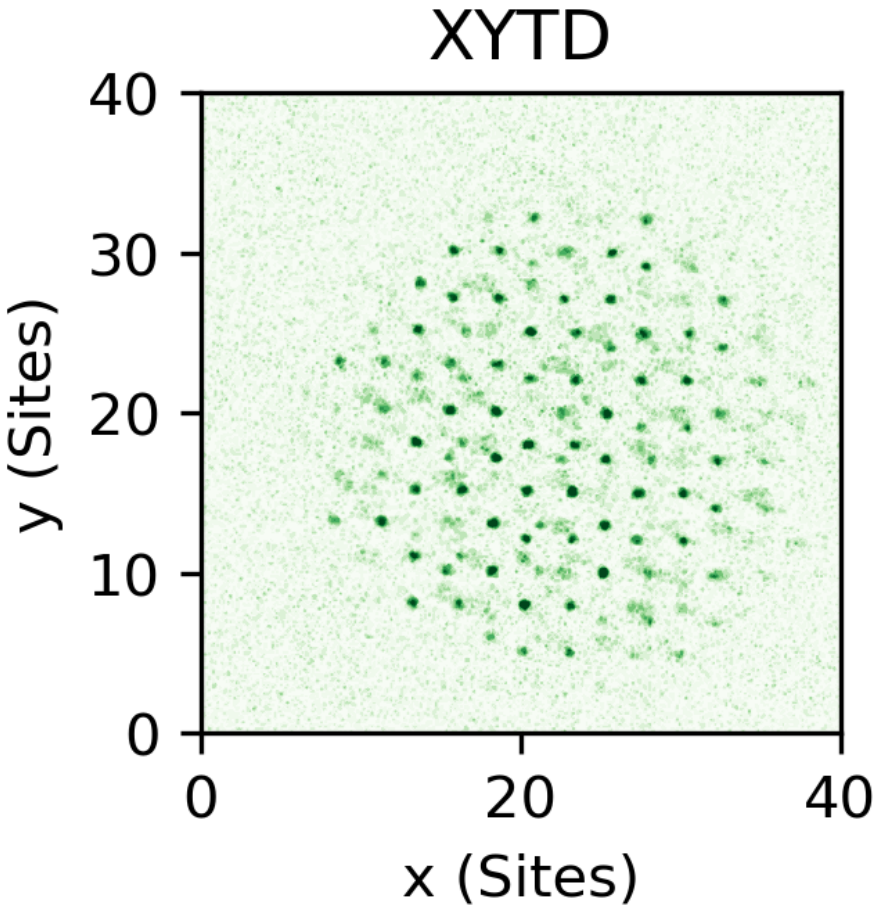




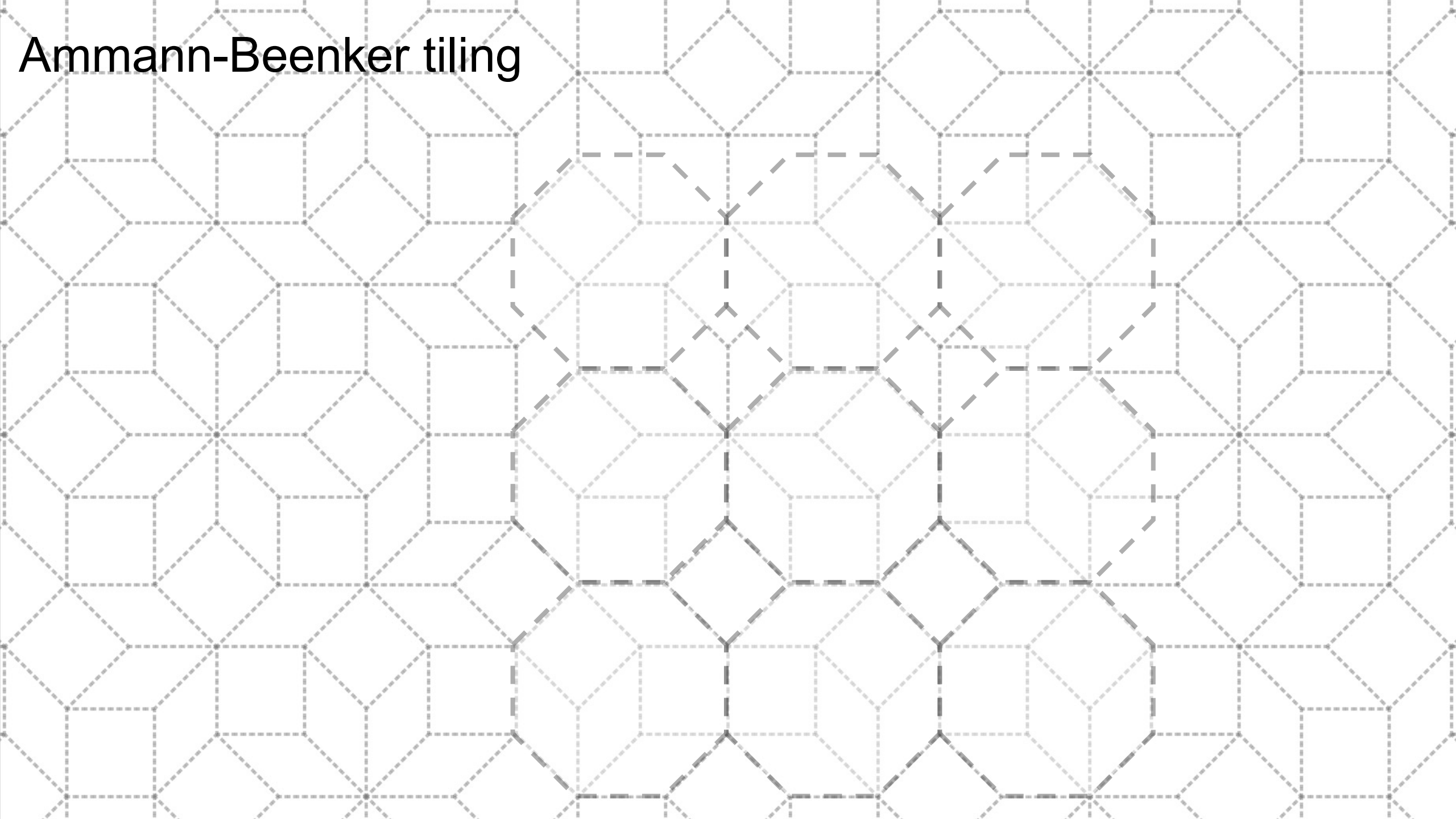
Quantum gas magnification of the quasicrystal



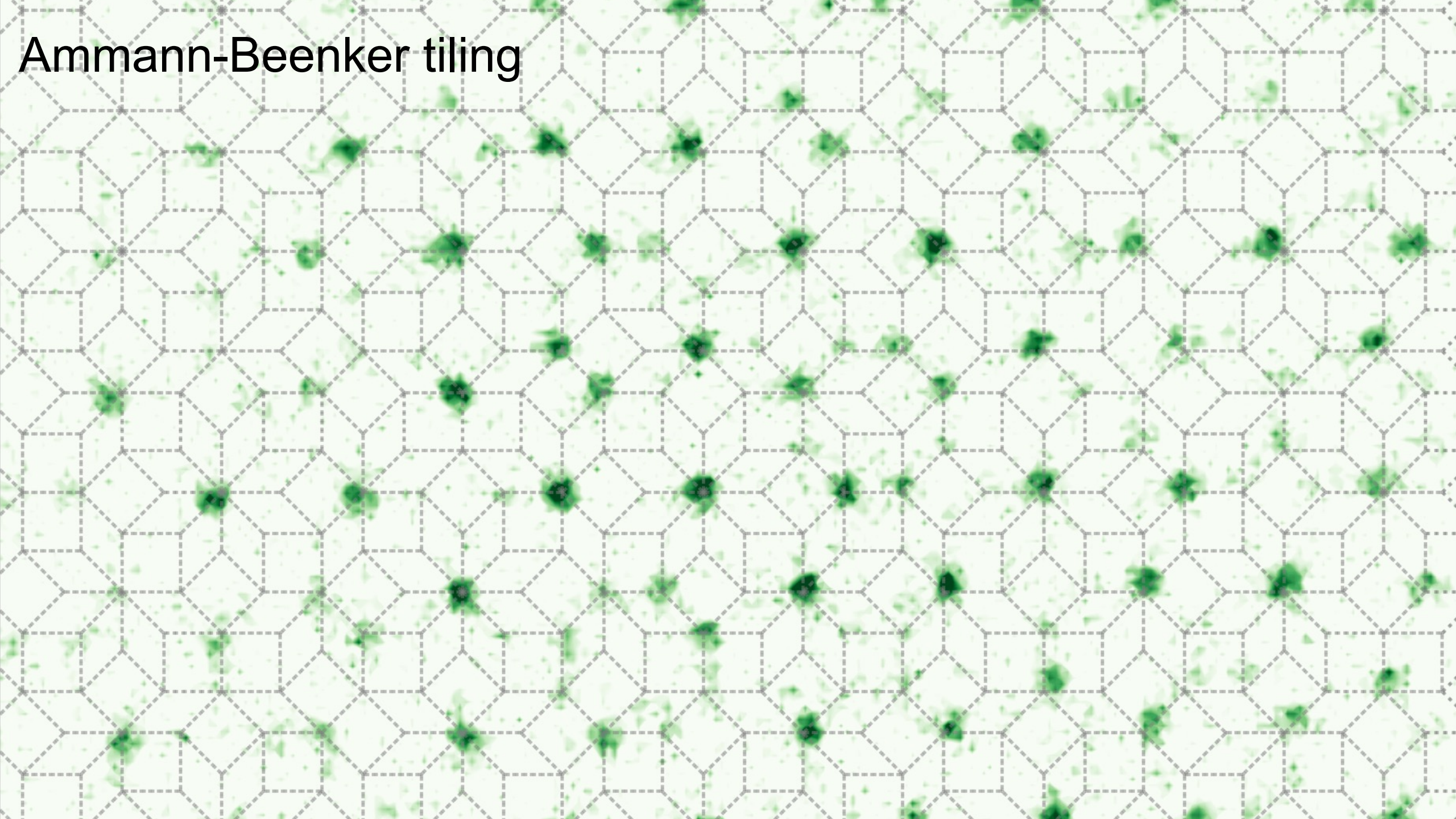




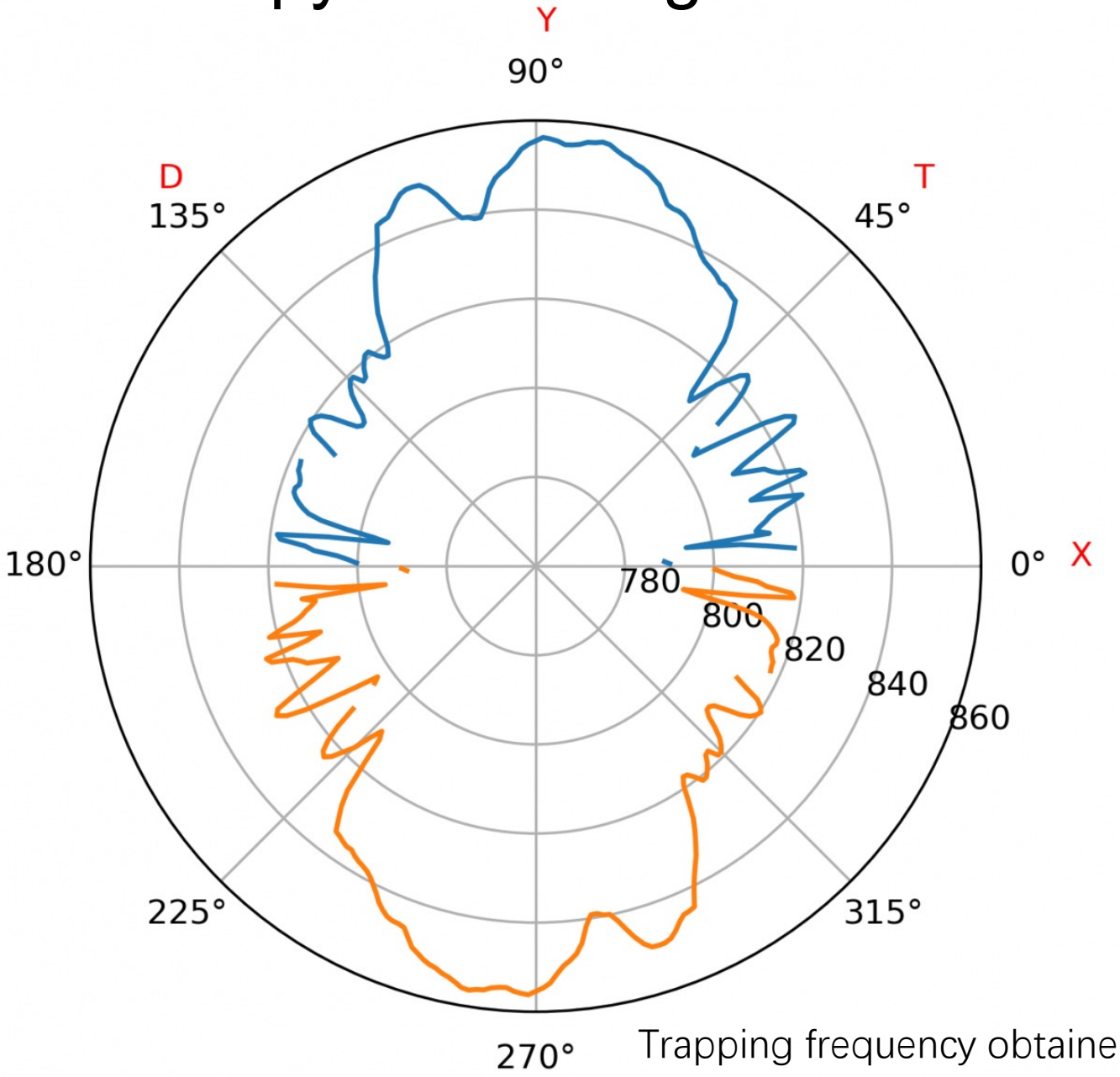
Ammann-Beenker tiling

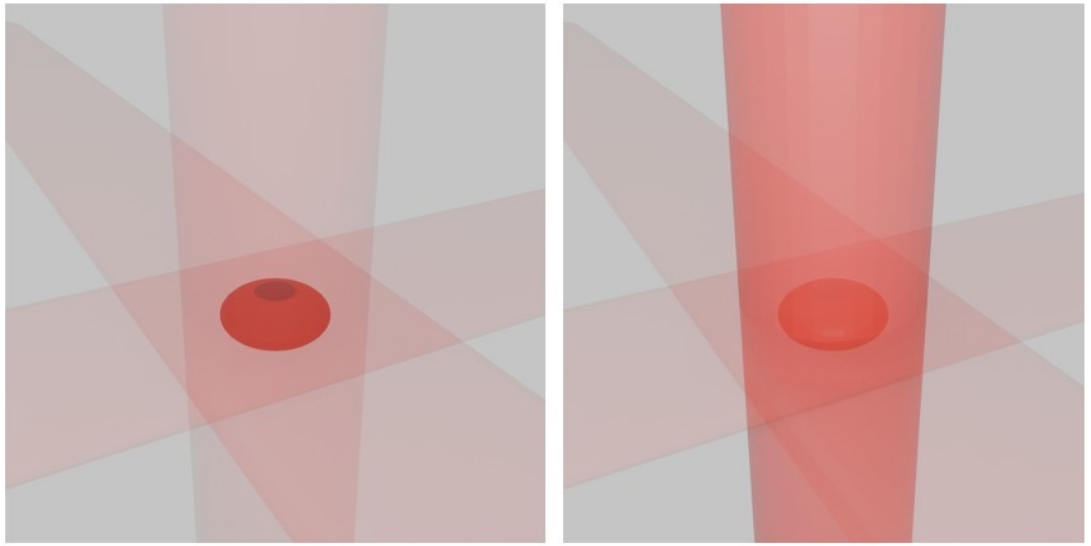


Ammann-Beenker tiling



Anisotropy of the magnifier

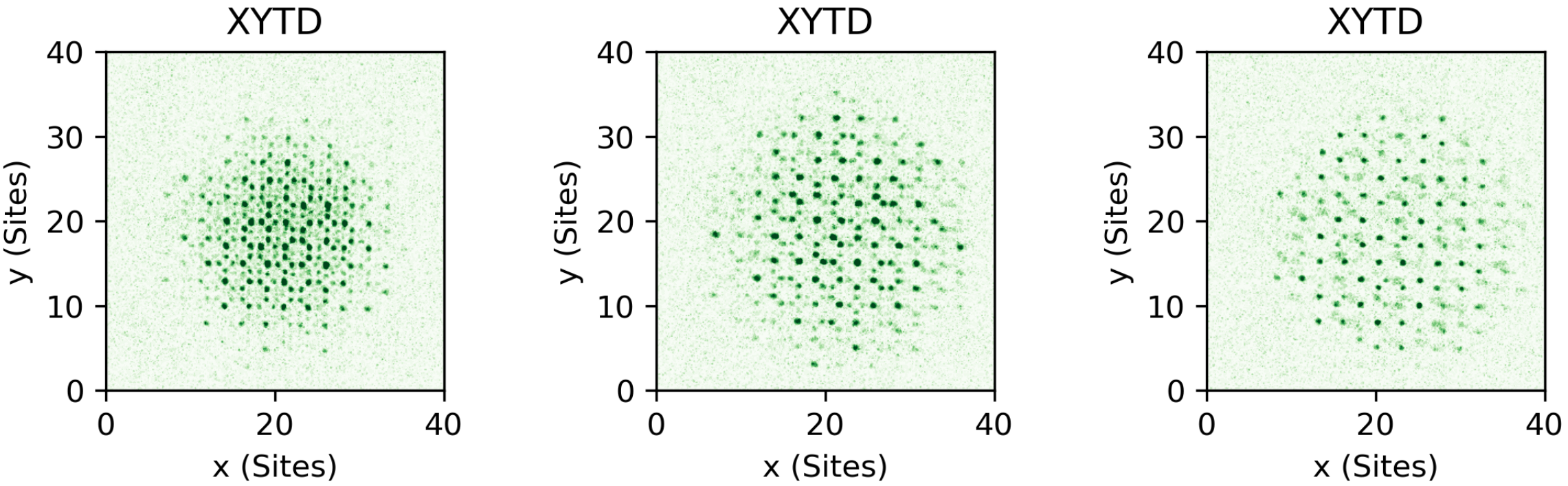




Compensation by cross dipole beams

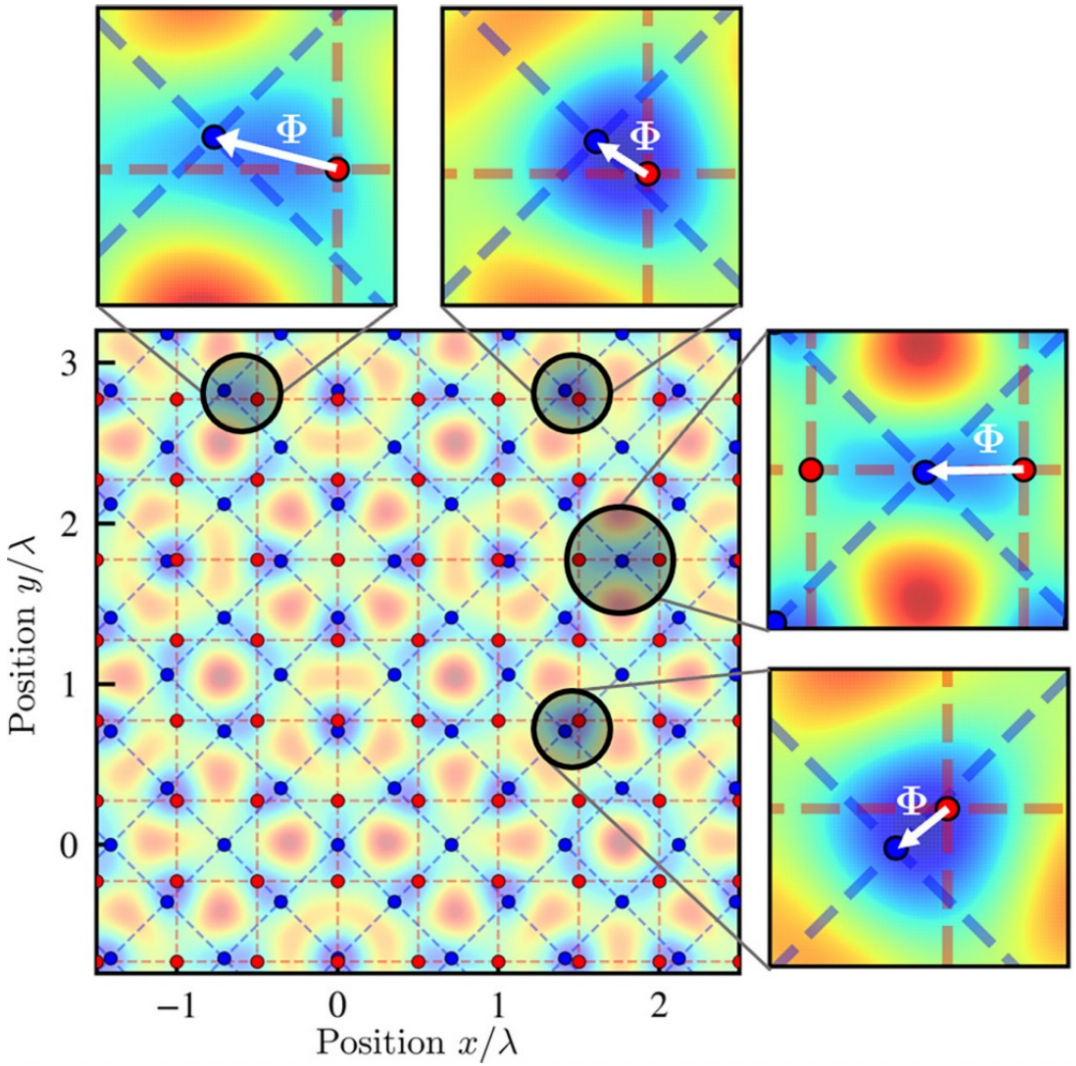
Trapping frequency obtained by breathing/sloshing mode

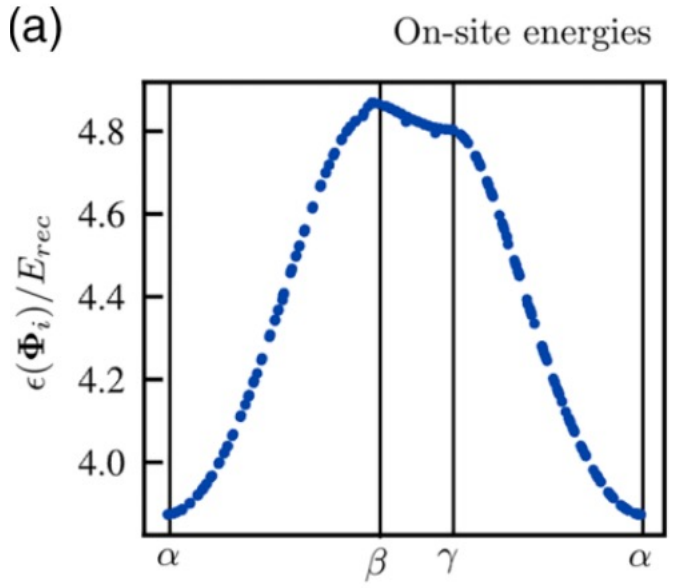
Quantum gas magnification of the quasicrystal

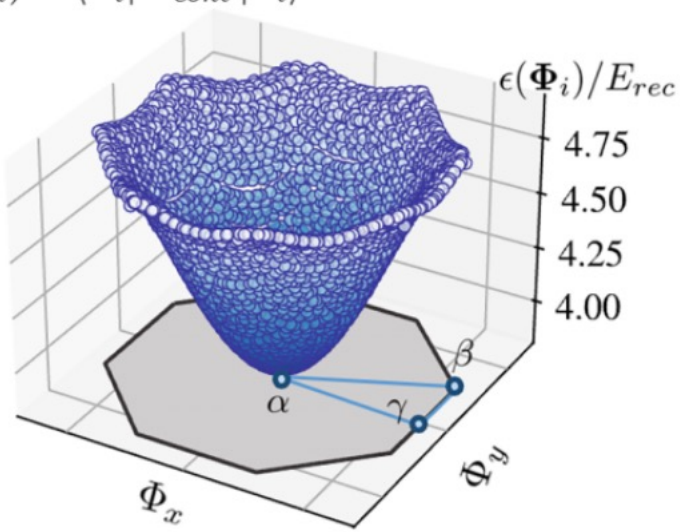


Lattice depth (Er)

Configuration space

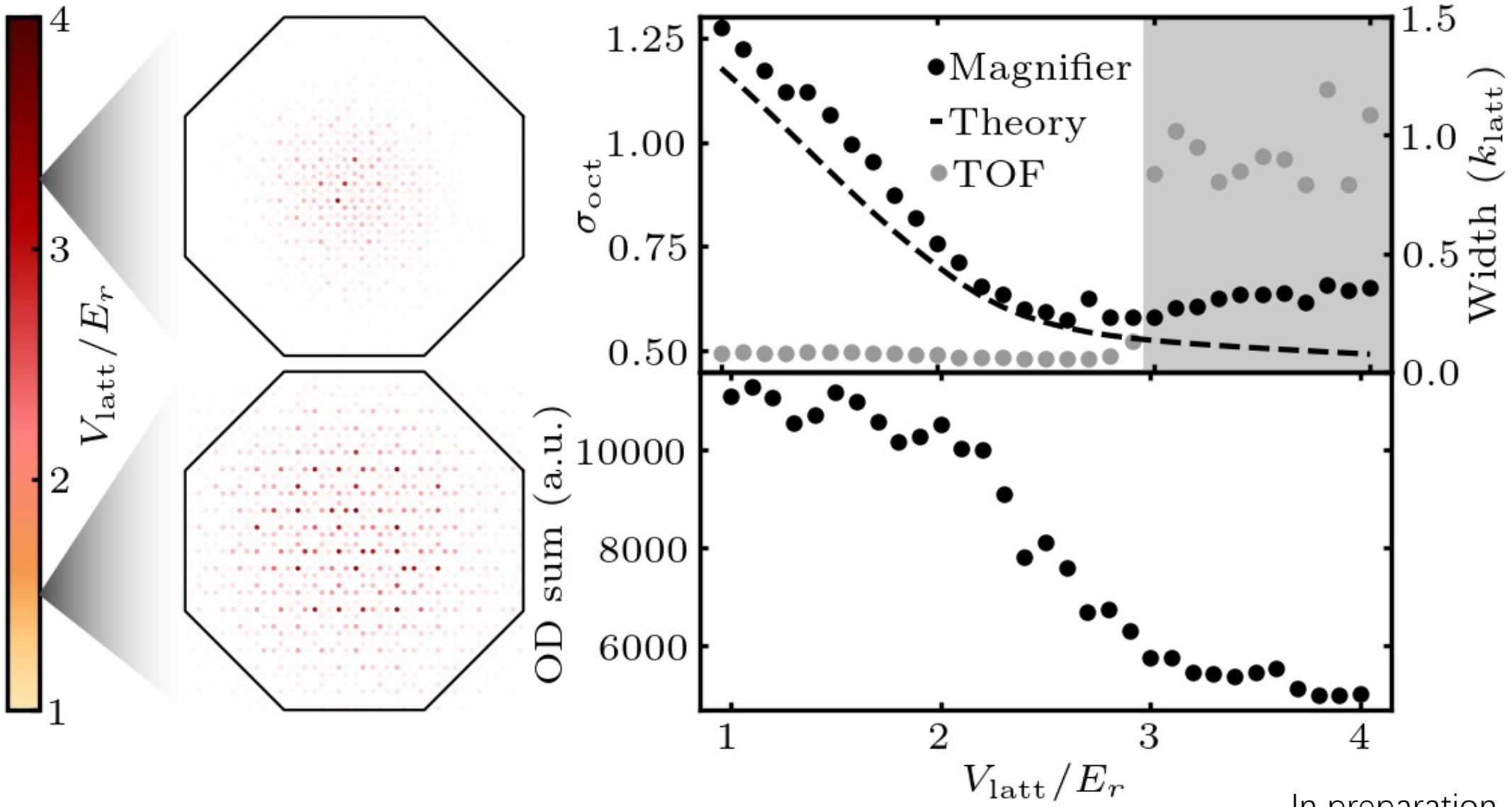






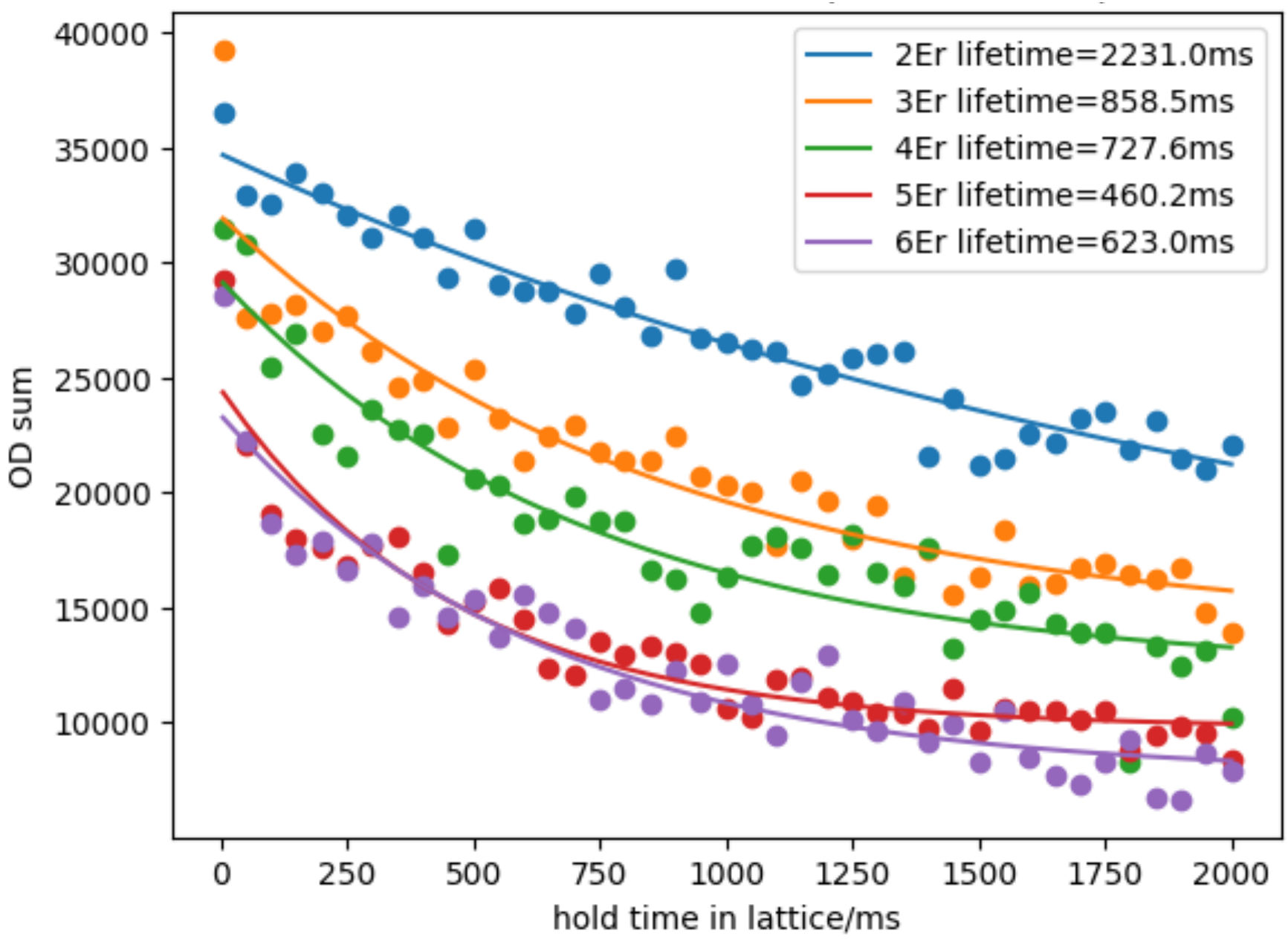
Gottlob & Schneider (2023). Physical Review B, 107(14), 144202.

Microscopy of the SF to BG transition

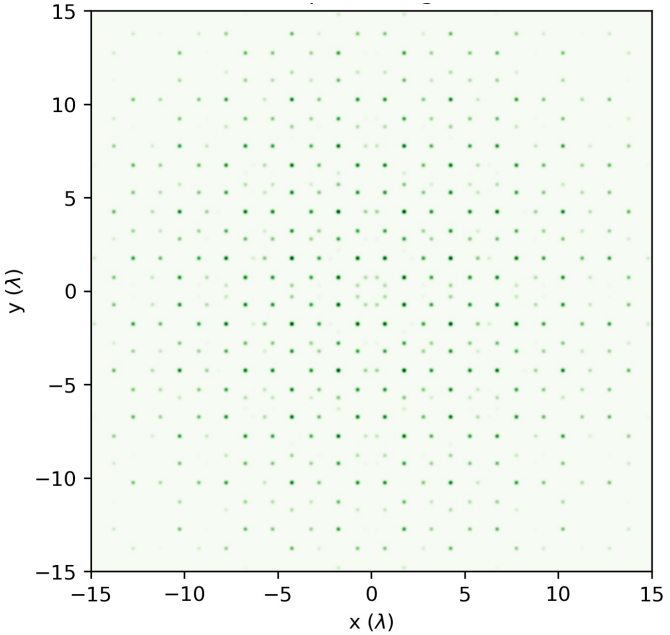


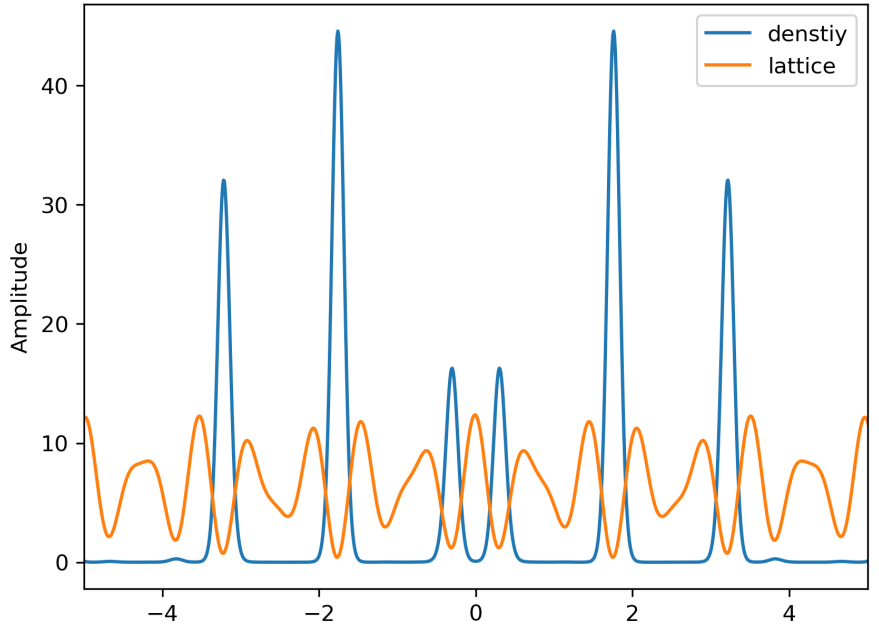
In preparation

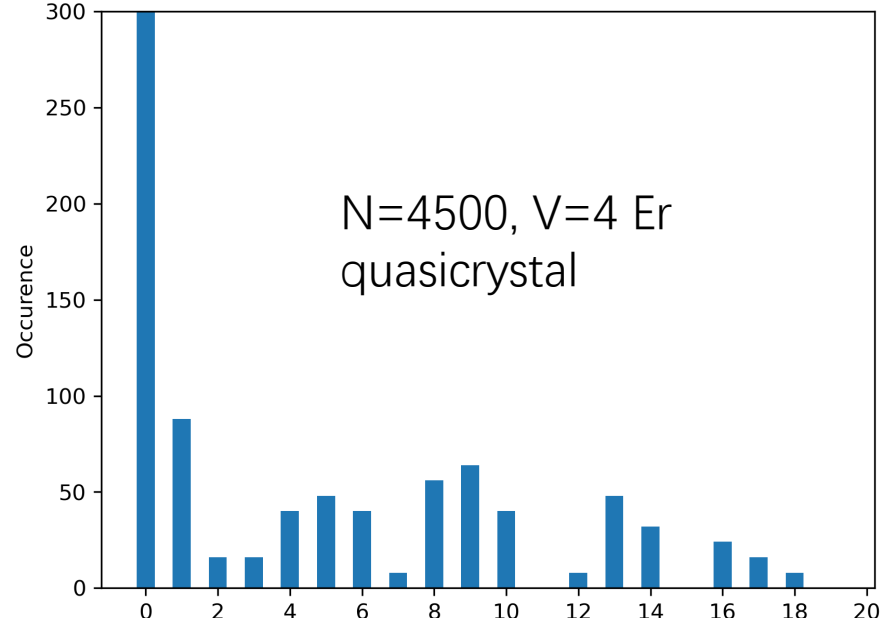
Atom loss holding in the quasicrystal

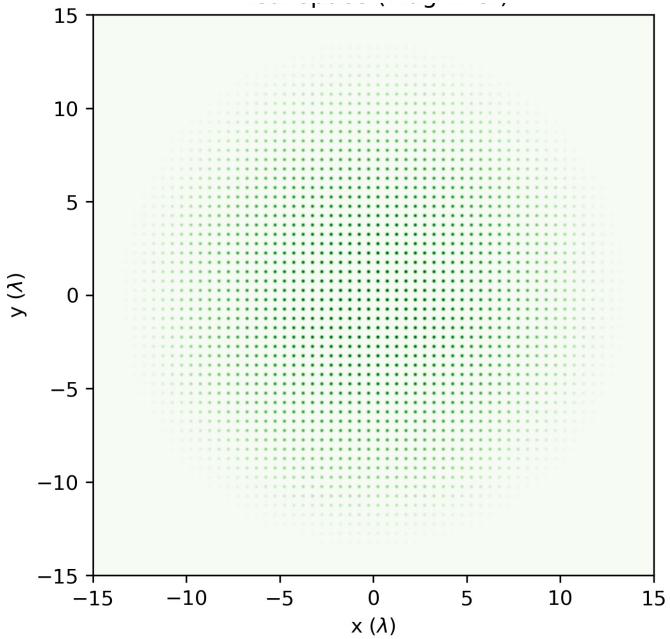


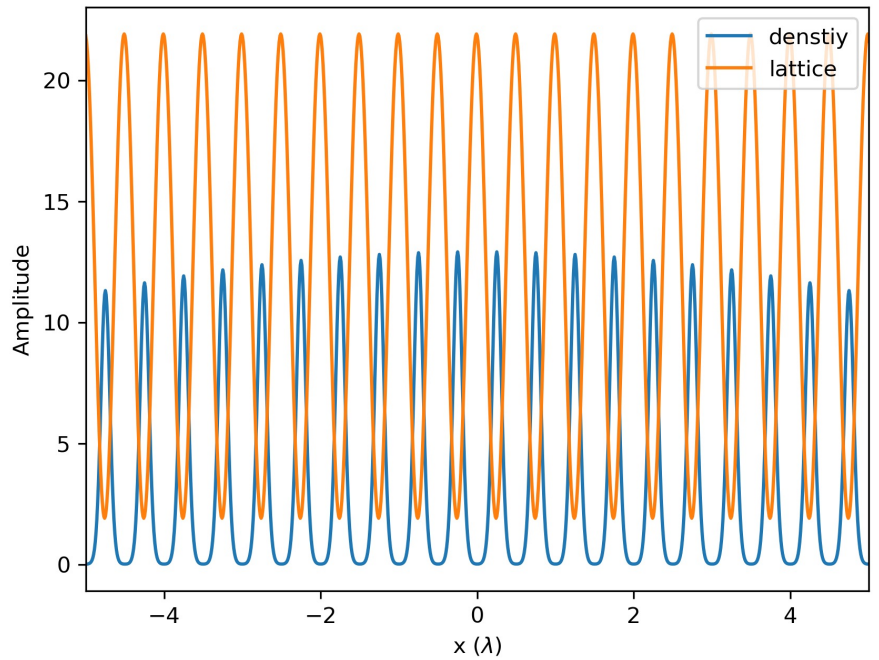
Local density in quasicrystals/square lattices

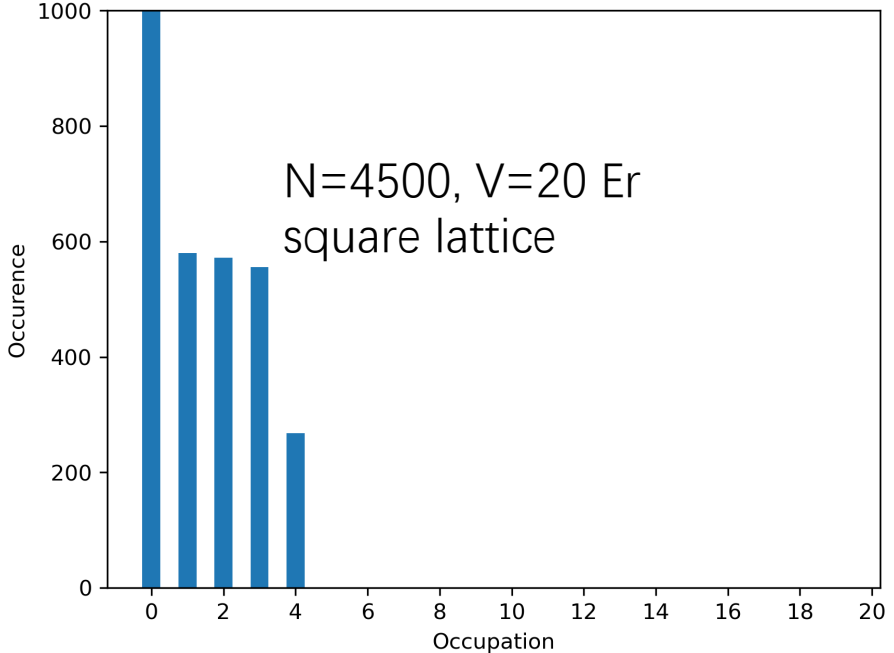












Conclusion and Outlook

- ❑Site-resolved detection of the SF-BG transition in optical quasicrystals

What's next?

- ❖Understanding atom loss mechanism in quasicrystals
- ❖Accessing 4D topological matter with 2D quasicrystals?
- ❖Quasiperiodicity protecting quantized transport…

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