Fermi-Hubbard physics with a Quantum Gas Microscope

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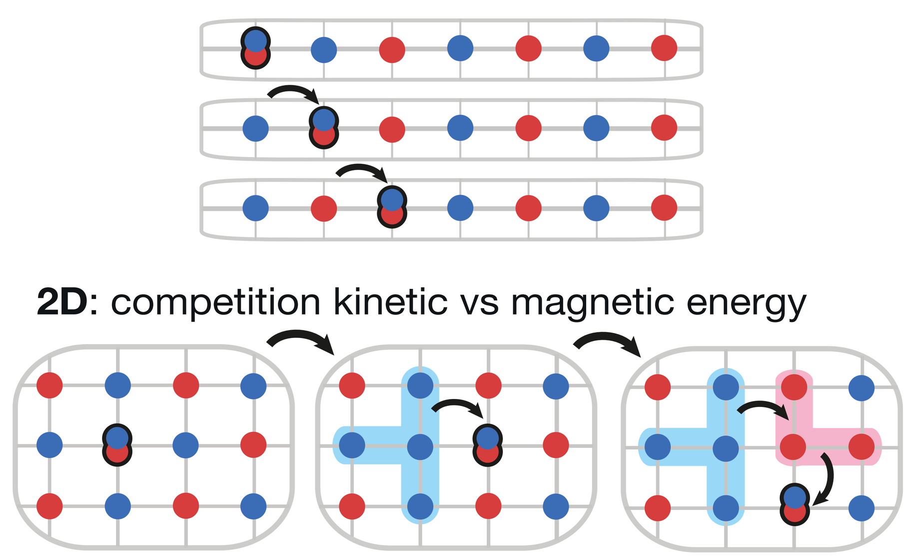
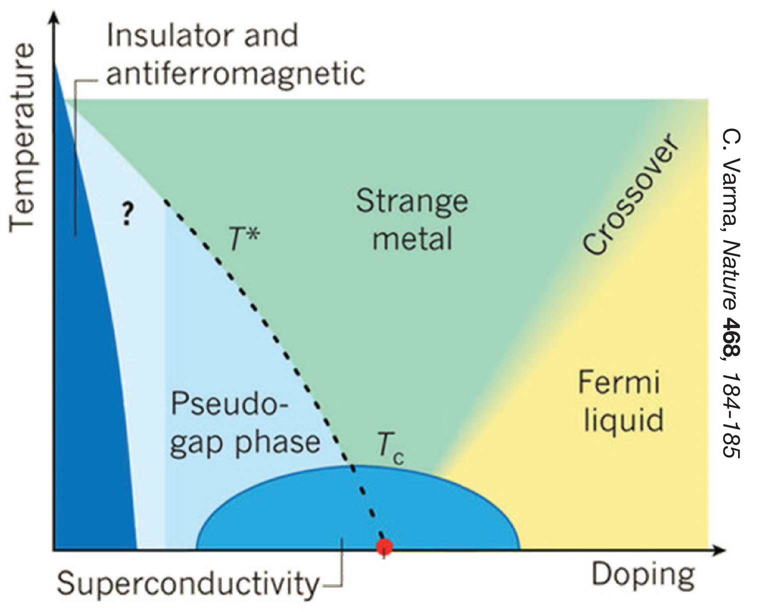
Fermi Hubbard model

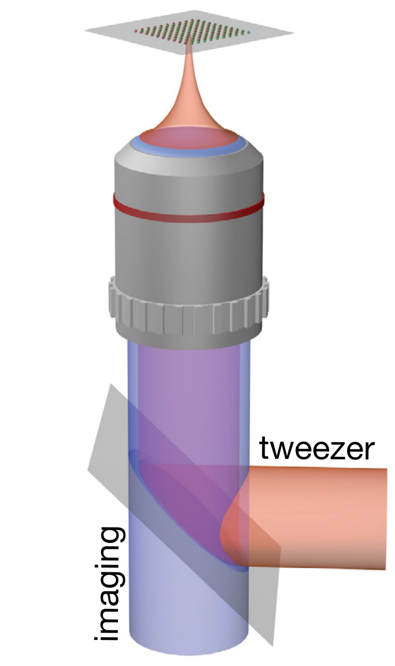
1D: spin-charge separation

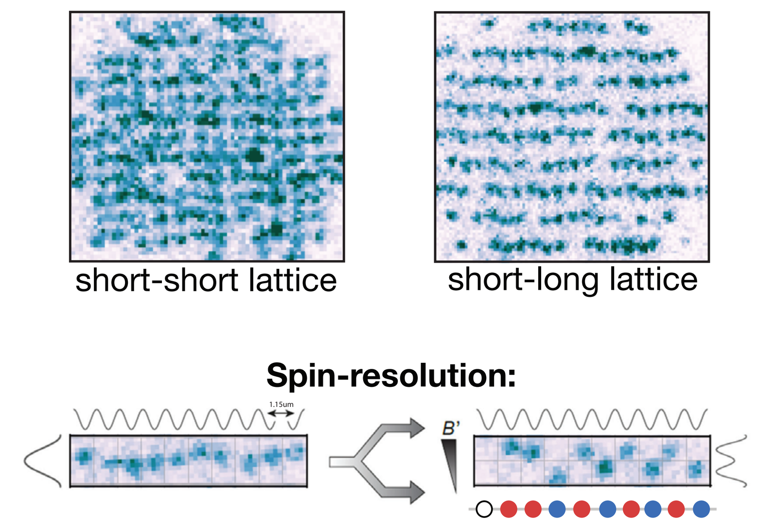
2D: competition kinetic vs magnetic energy

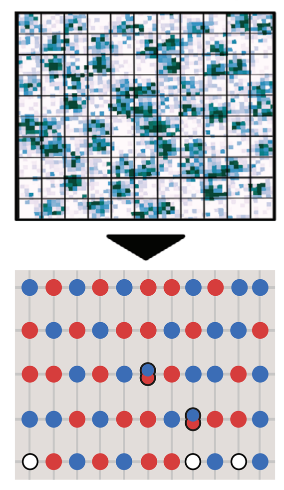




Fermi Gas Microscope



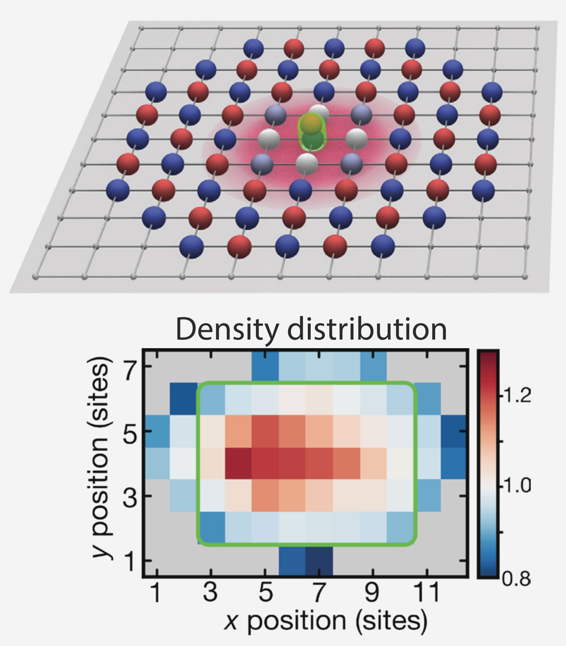




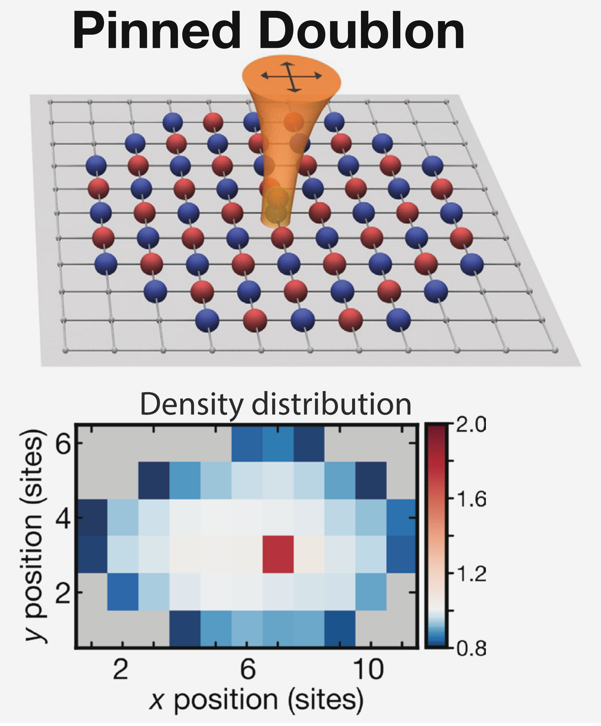
2D Magnetic polaron

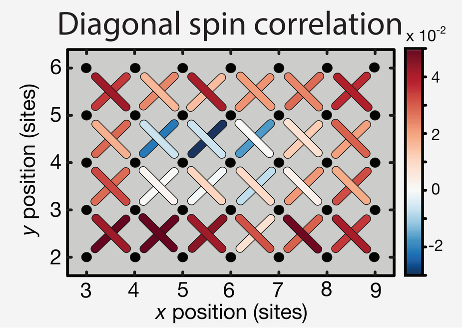
Competition between dopant delocalization and magnetic energy
→Polaron formation

Mobile Doublon

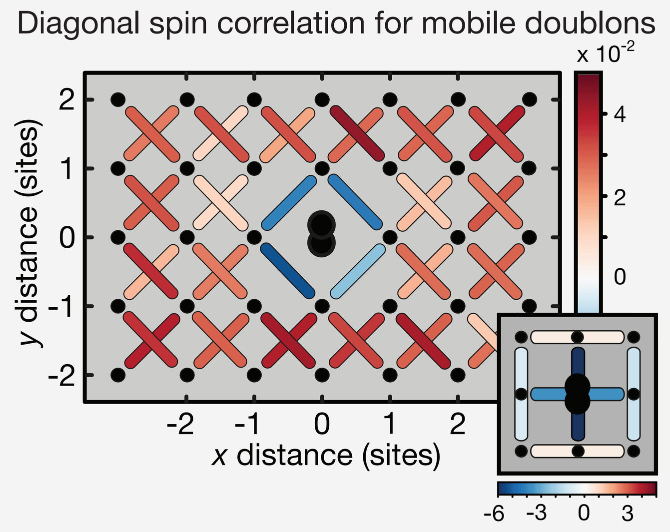


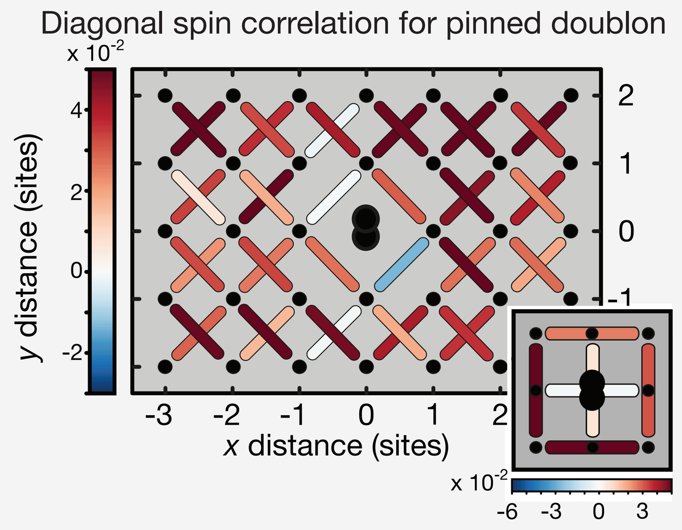
Pinned Doublon



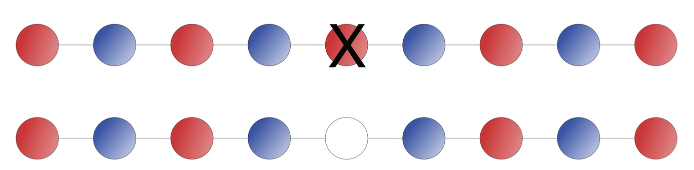


- → Sign reversal of correlations around mobile doublon
- → Small polaron size of around two sites
- → Pinning doublon suppresses polaron formation



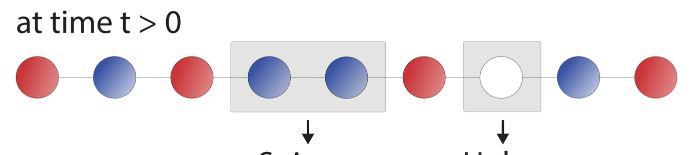


1D Dynamical Spin-Charge Separation



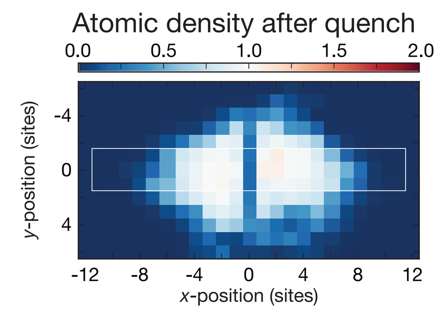
Excitation introduces (**Δcharge**) = *e* and (**Δspin**) = 1/2

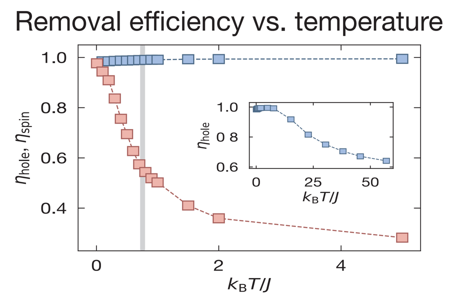
at time t > 0

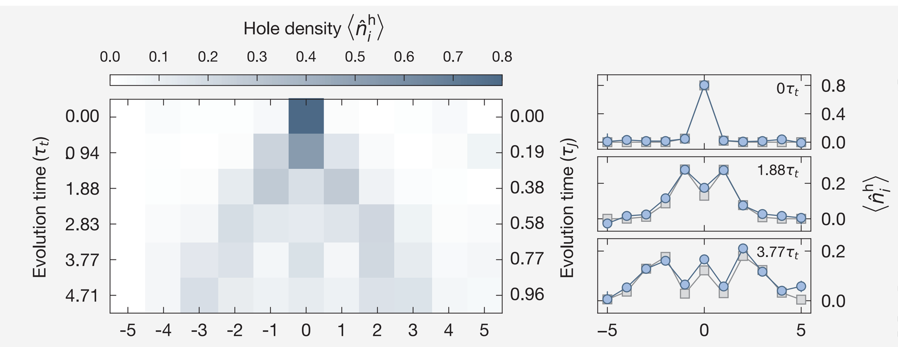


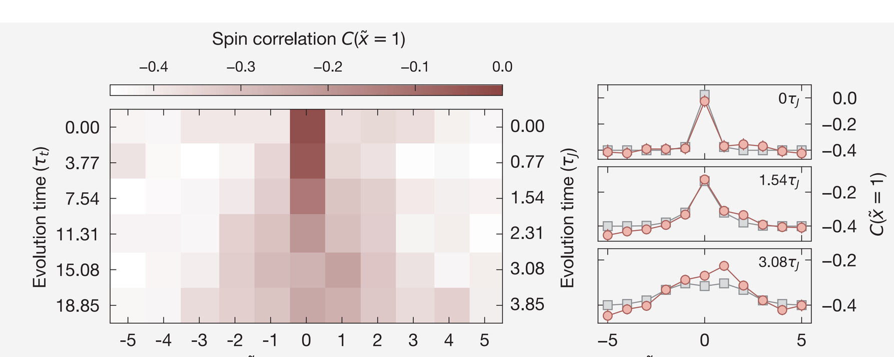
Holon carries (**Δcharge**) = *e* and (**Δspin**) = 0

Spinon carries (**Δcharge**) = 0 and (**Δspin**) = 1/2

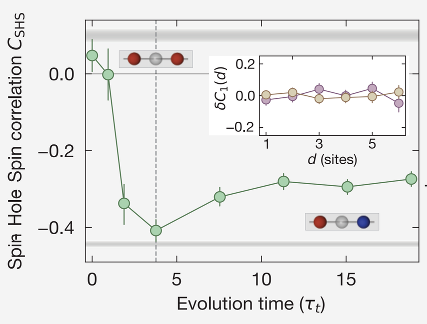




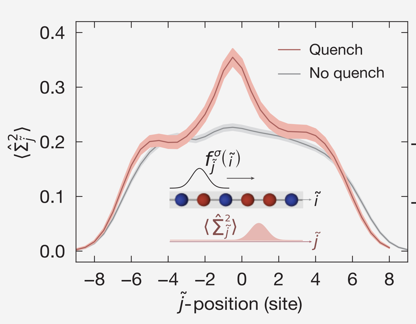




Fractionalization



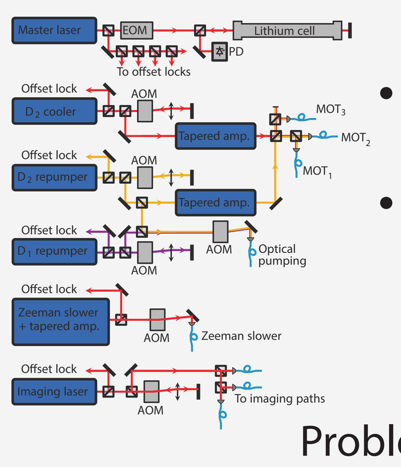
- Spinon and Holon spread linearly in time, but - move on different timescales
- →Spinon and Holon get separated!



- Spin-Hole-Spin correlation drops quickly:
- →Holon separates from Spinon
- →Single excitation became fractionalized

To run this kind of experiment extremely stable lasers are necessary!

Current setup:



- Lithium D_1 and D_2 lines are close to 671nm
- 7 individual ECDLs and 2 TAs are used for cooling, traping and imaging 6Li atoms

Problems:

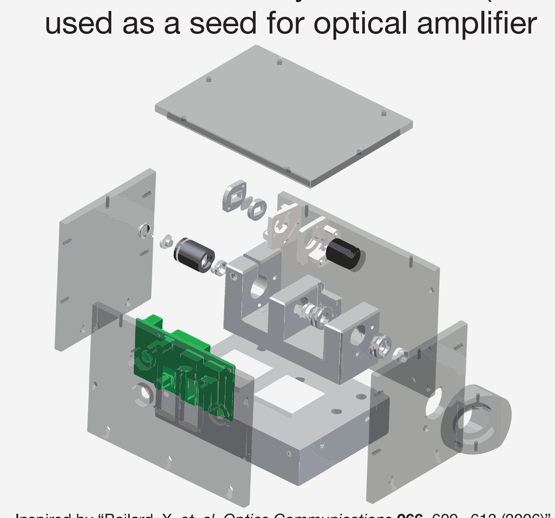
- stability during very long measurements
- ECDLs fall out of lock often
- TAs have limited power output

Planned upgrade:

- Goal: exchange most of the ECDLs with **one stable, narrow linewidth, single mode, single frequency, high power (>1 W)** laser system
- Laser system parts:
  - ▶self-built 1342nm linear laser
  - ▶single pass solid state optical amplifier
  - ▶frequency doubling cavity (1342nm → 671nm)
- To the best of our knowledge, this would be the first 671nm laser system working on a single pass MOPA principle

Linear laser

1342nm external cavity diode laser (ECDL) used as a seed for optical amplifier

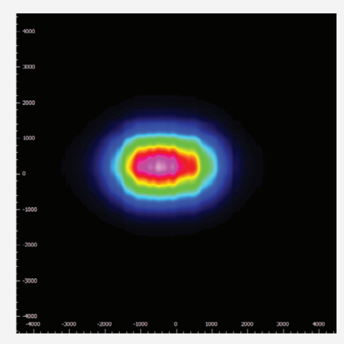


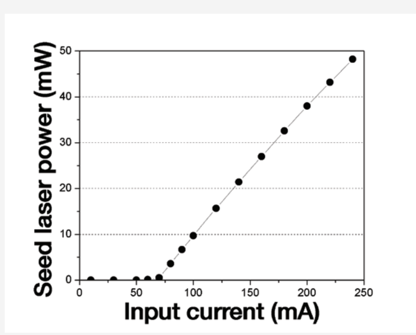
Inspired by "Bailard, X. et. al. Optics Communications 266, 609 –613 (2006)"

Main laser elements:

- AR coated laser diode (Toptica)
- outcoupling mirror (30% reflectivity)
- narrow linewidth interference filter (0.8nm, single mode operation)

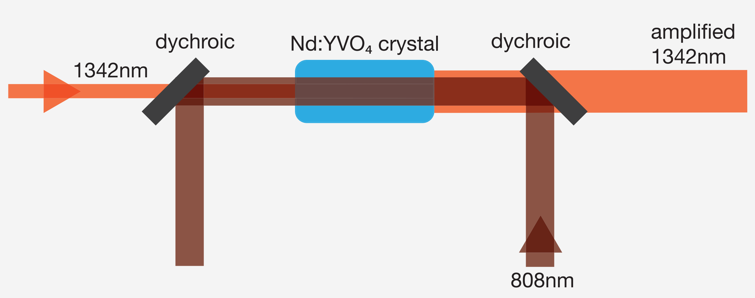
1342nm laser beam profile



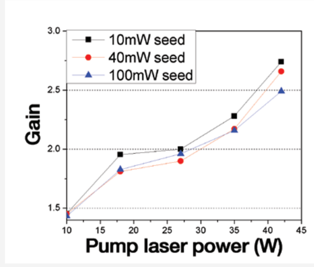


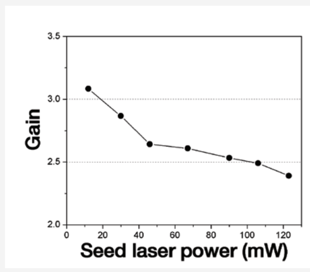
Solid state optical amplifier

Optical amplification is happening in a Nd:YVO_4 crystal through five stages of amplification



Crystal is pumped with 45W of 808nm pump laser. 1342nm seed is amplified after passing through the pumped crystal





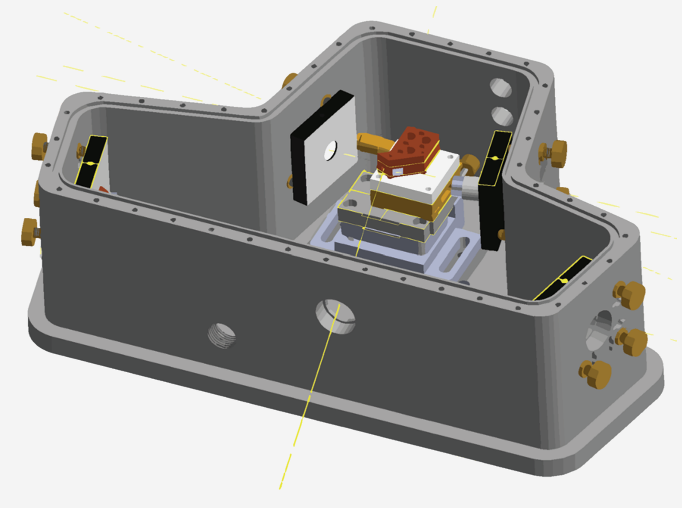
Measured gain:
- **between 2.5 and 3.0**

Expected MOPA output power:
- **>5W of 1342nm**

Nd:YVO_4 crystal properties:

- strong 1064nm and 1342nm emmision cross-section
- strong 808nm absorption cross-section

Frequency doubling cavity



- Second harmonic generation (SHG) in LBO crystal
- Type I critical phasematching, AR coated crystal at 313K
- Expected conversion efficiencies of 40-50%

$$\frac{I(2\omega)}{I(\omega)} = \frac{2\omega^2 |d_{eff}|^2 l^2 I(\omega)}{n^3 c^3 \varepsilon_0} \operatorname{sinc}^2\left(\frac{\Delta k \cdot l}{2}\right)$$

ω – input beam frequency
d_{eff} – nonlinear coefficient
l – length of the crystal
I – beam intensity

References

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J. Koepsell *et al.*, Nature, doi: 10.1038/s41586-019-1463-1 (2019)
J. Vijayan, P. Sompet *et al.*, arXiv:1905.13638 (2018)