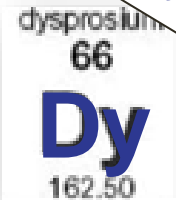
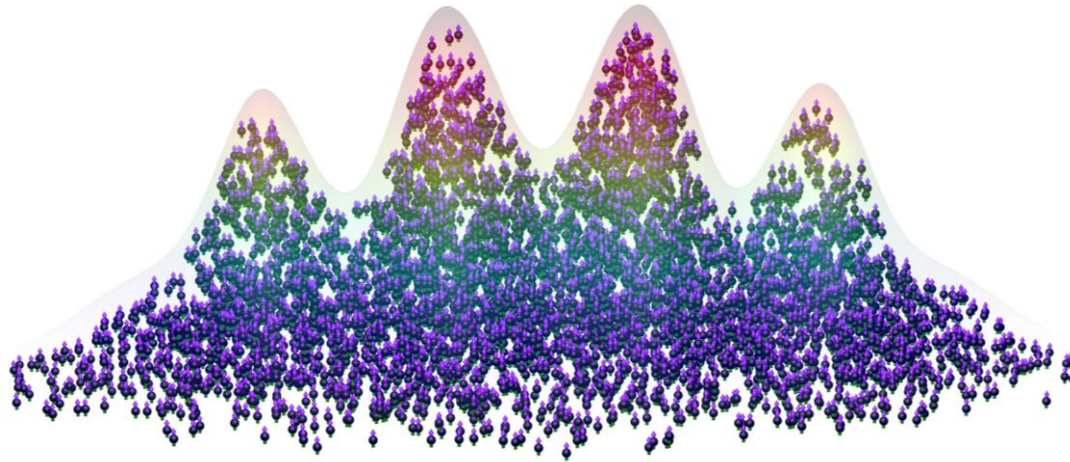
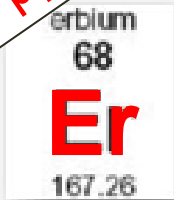


7 μ B



10 μ B

Supersolidity in Erbium and Dysprosium

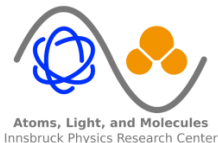
Gianmaria Durastante

Supervised by Univ.-Prof. Francesca Ferlaino



MIP seminar

22.01.2020



Atoms, Light, and Molecules
Innsbruck Physics Research Center

**universität
innsbruck**

HISTORY OF COLD

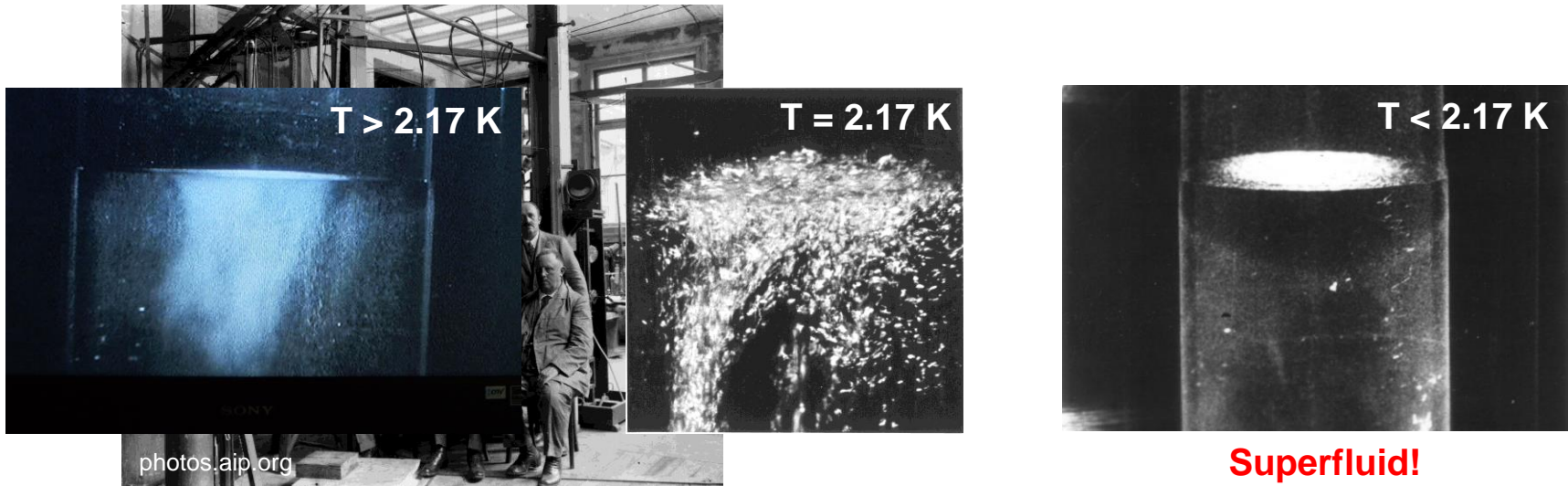
1665 Boyle introduces the concept of an absolute zero*



1908 Kamerlingh Onnes liquifies Helium $\sim 4\text{K}$ (-269°C)



1937 Kapitsa, Allen, Misener discover superfluidity in ^4He $< 2.17\text{ K}$ (-271°C)



WHAT IS A SUPERFLUID?

Fluid without viscosity \rightarrow particles move **without friction!!!**

coffee



superfluid
coffee



NEXT LEVEL OF “SUPER-”

1908 Kamerlingh Onnes liquifies Helium ~4K (-269°C)



1937 Kapitsa, Allen, Misener discover superfluidity in ^4He < 2.19 K (-271°C)



1970 If superfluid exists, is there a **supersolid** too?

Can a Solid Be “Superfluid”?

A. J. Leggett

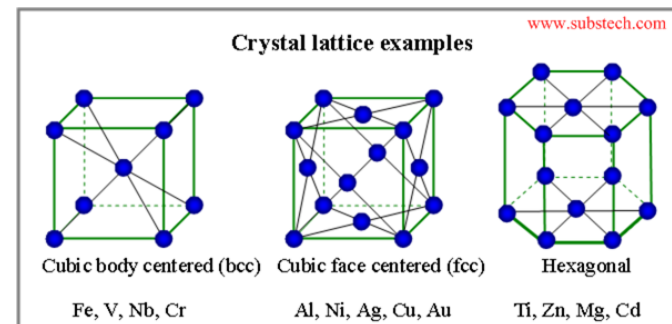
School of Mathematical and Physical Sciences, University of Sussex, Falmer, Brighton, Sussex, England

(Received 15 September 1970)

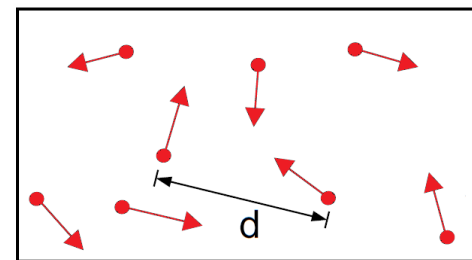
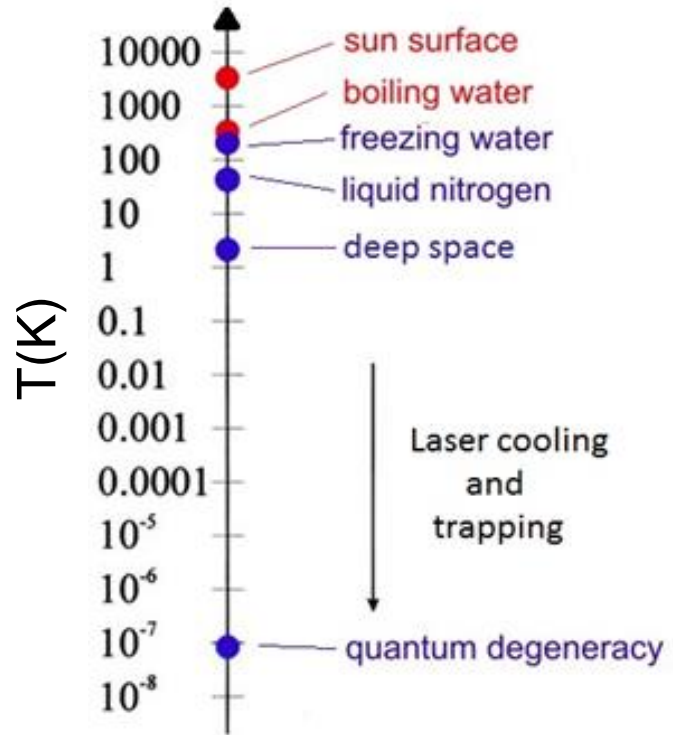
WHAT IS A SUPERSOLID?



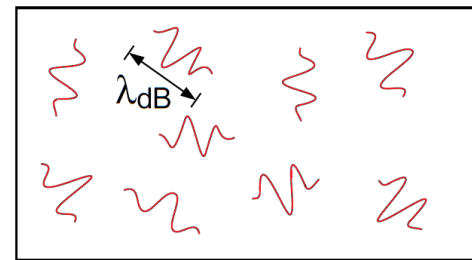
frictionless flow + spatial periodicity



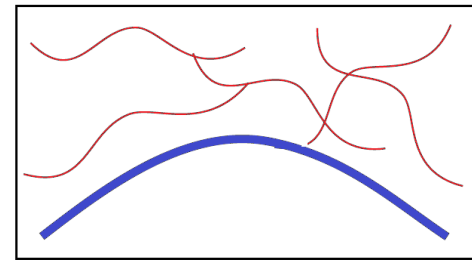
FIRST INGREDIENT: QUANTUM



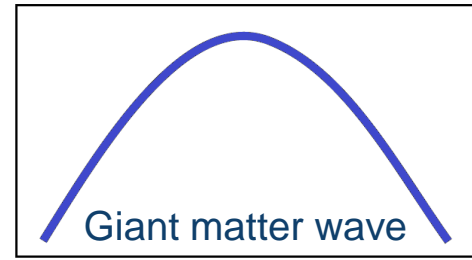
>1mK



<1mK



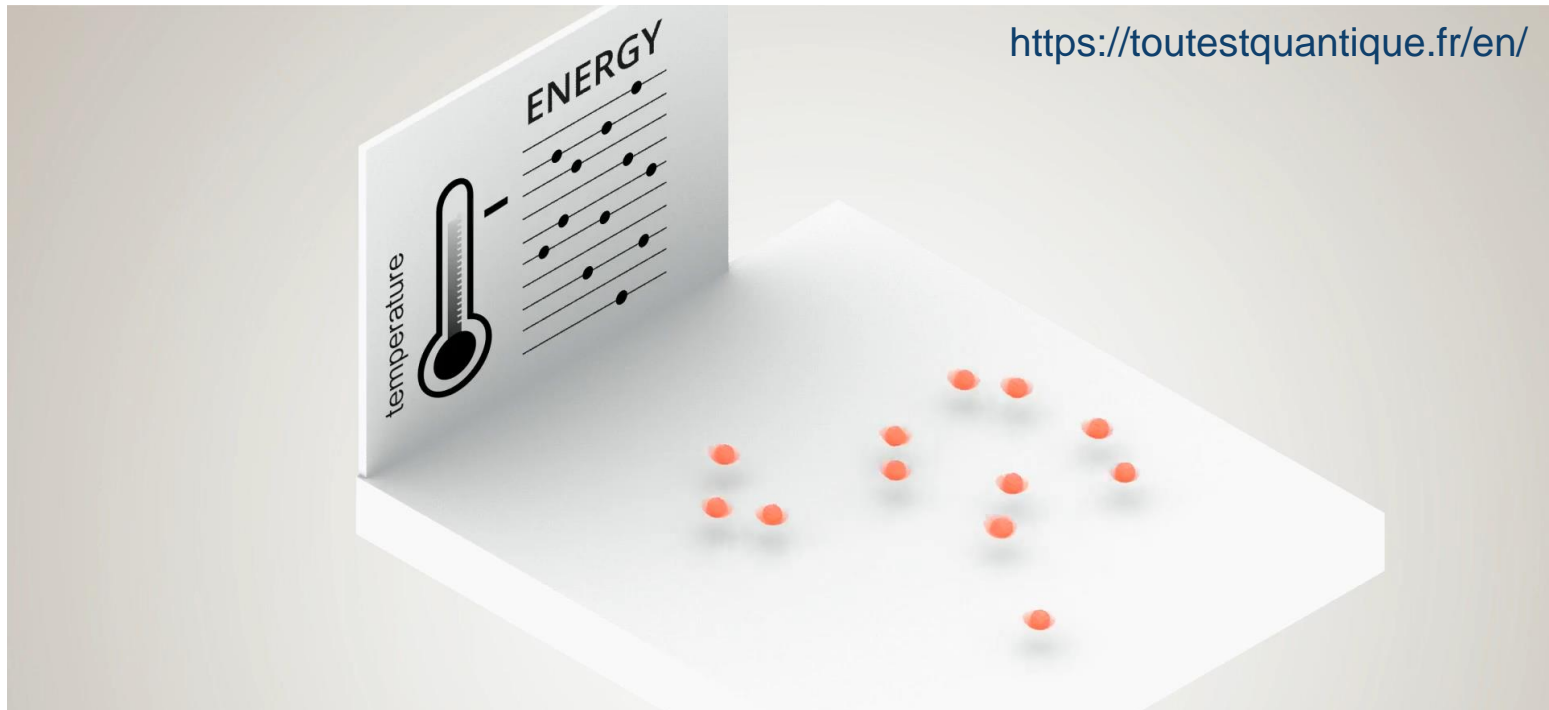
<1μK



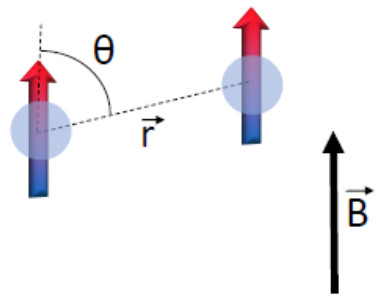
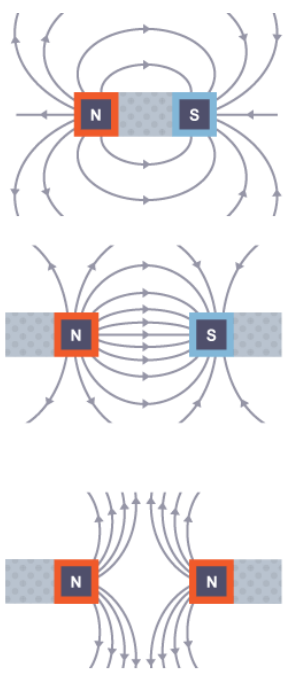
Wave nature $\sim \frac{\text{Veeery small number } h}{mass * temp}$

Ketterle et al., arXiv:cond-mat/9904034

FIRST INGREDIENT: QUANTUM



SECOND INGREDIENT: TENDENCY TO FORM STRUCTURES



en.wikipedia.org

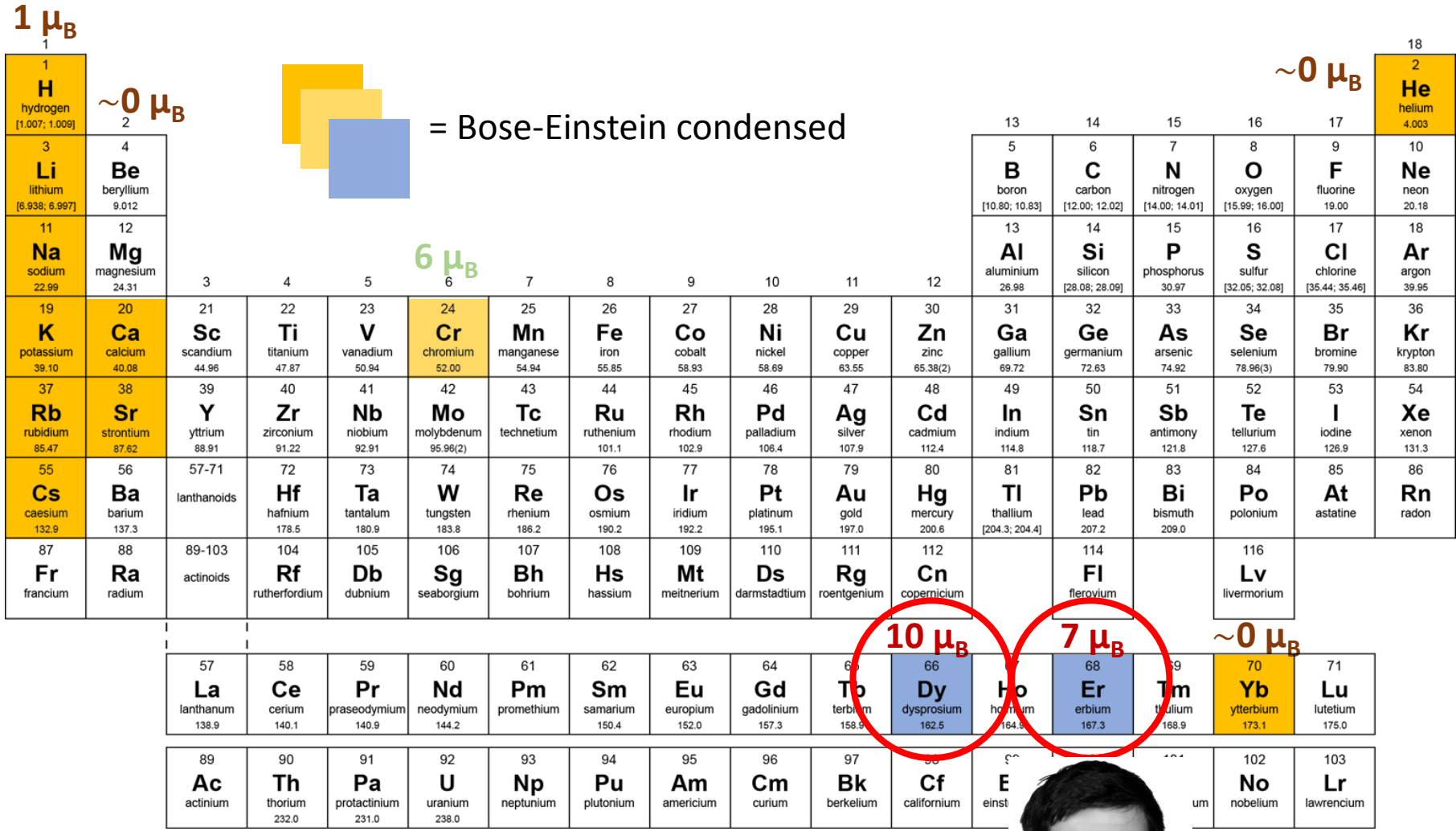
$$\text{Magnetic interaction} \sim \frac{1 - 3(\cos \theta)^2}{r^3}$$

Angle-dependent!
Long-range!



Cowley and Rosensweig, J. Fluid Mech. **30**, 671 (1967)

WHICH QUANTUM GAS DO WE NEED?

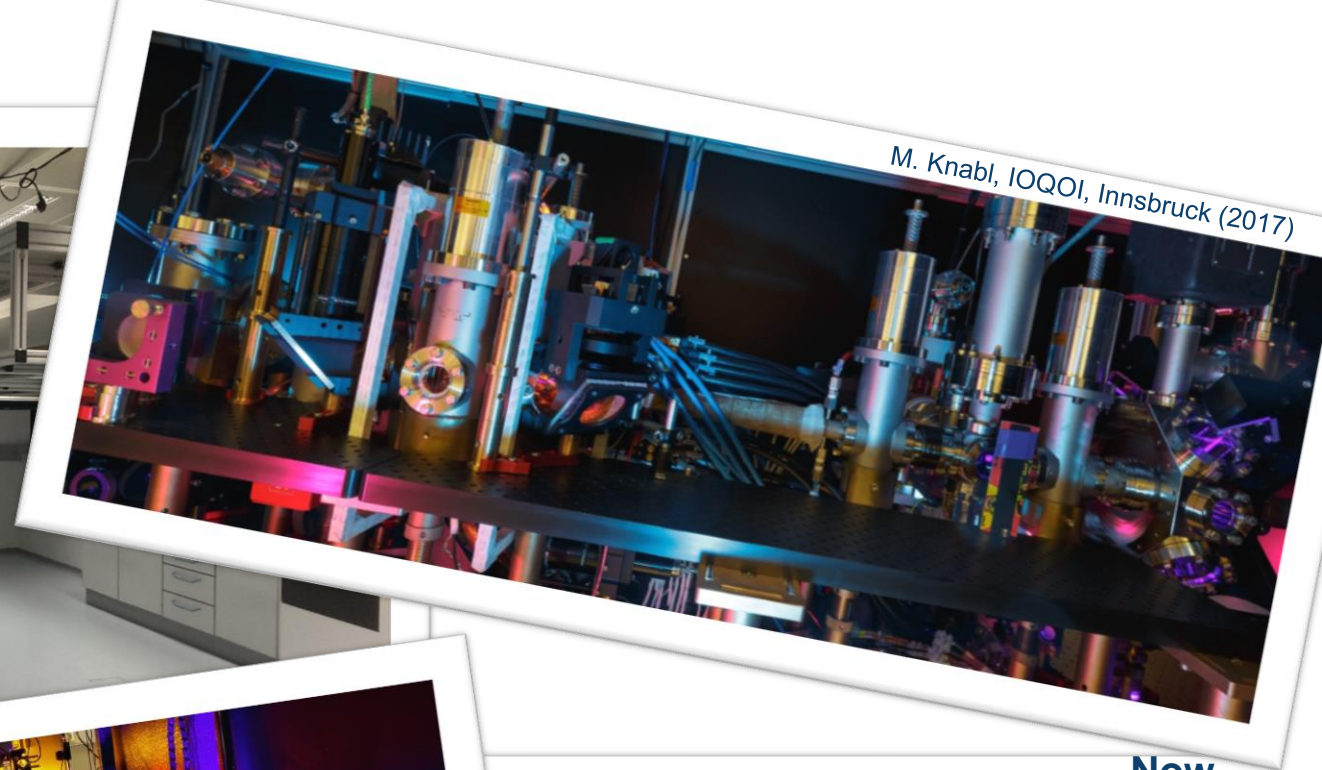


Daniel Petter:
Exploring Collective Phenomena in Ultracold Bose-Einstein
Condensates Made of Magnetic Atoms (08.01.2020)



IN REAL LIFE...

2015

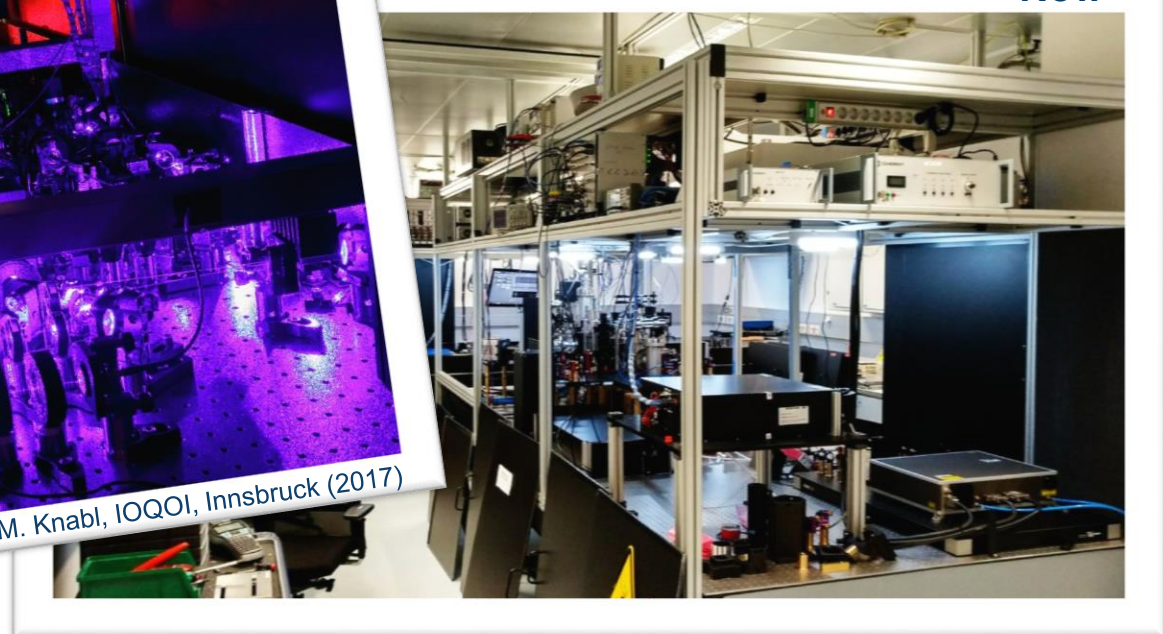


M. Knabl, IOQOI, Innsbruck (2017)

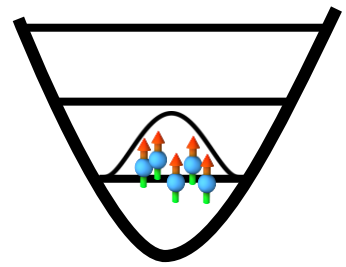
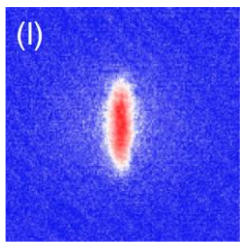
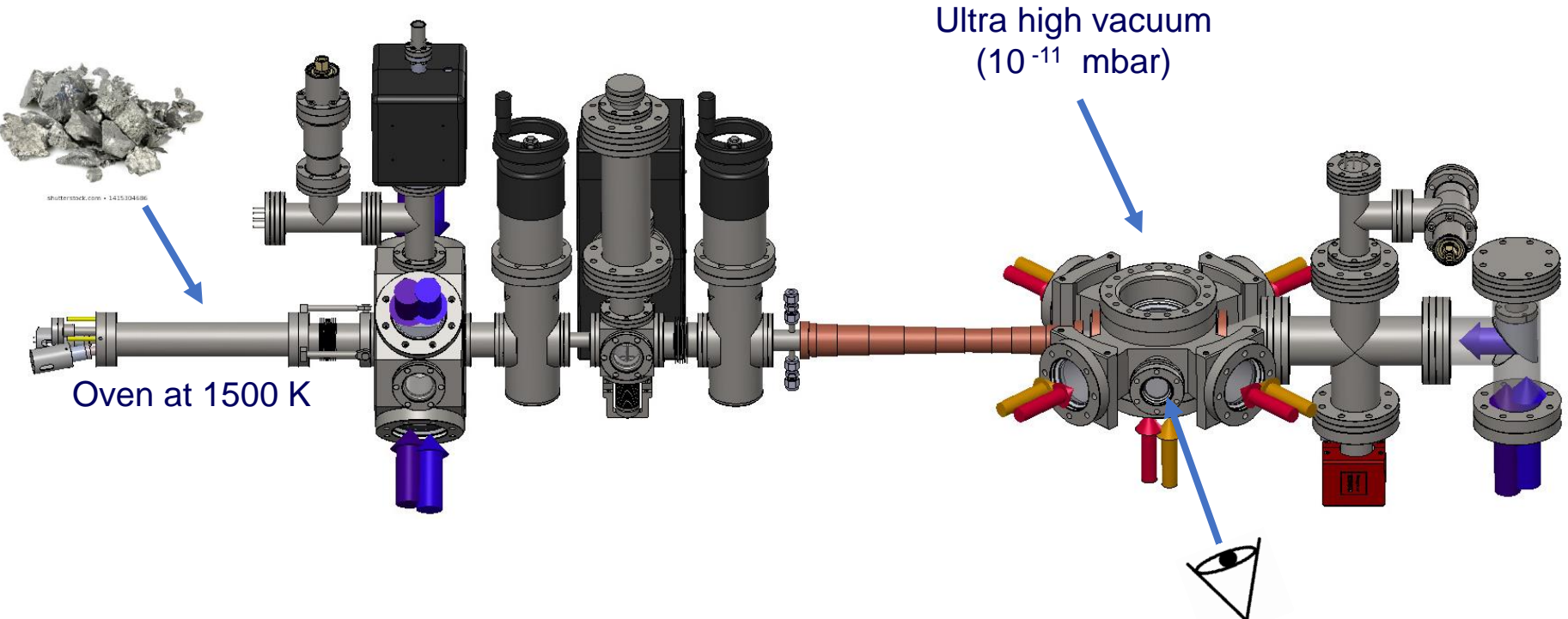


M. Knabl, IOQOI, Innsbruck (2017)

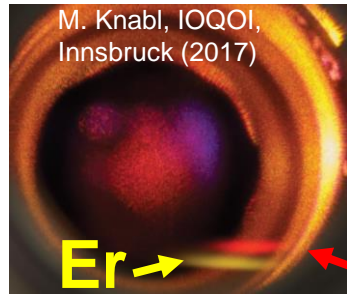
Now



EXPERIMENTAL SEQUENCE



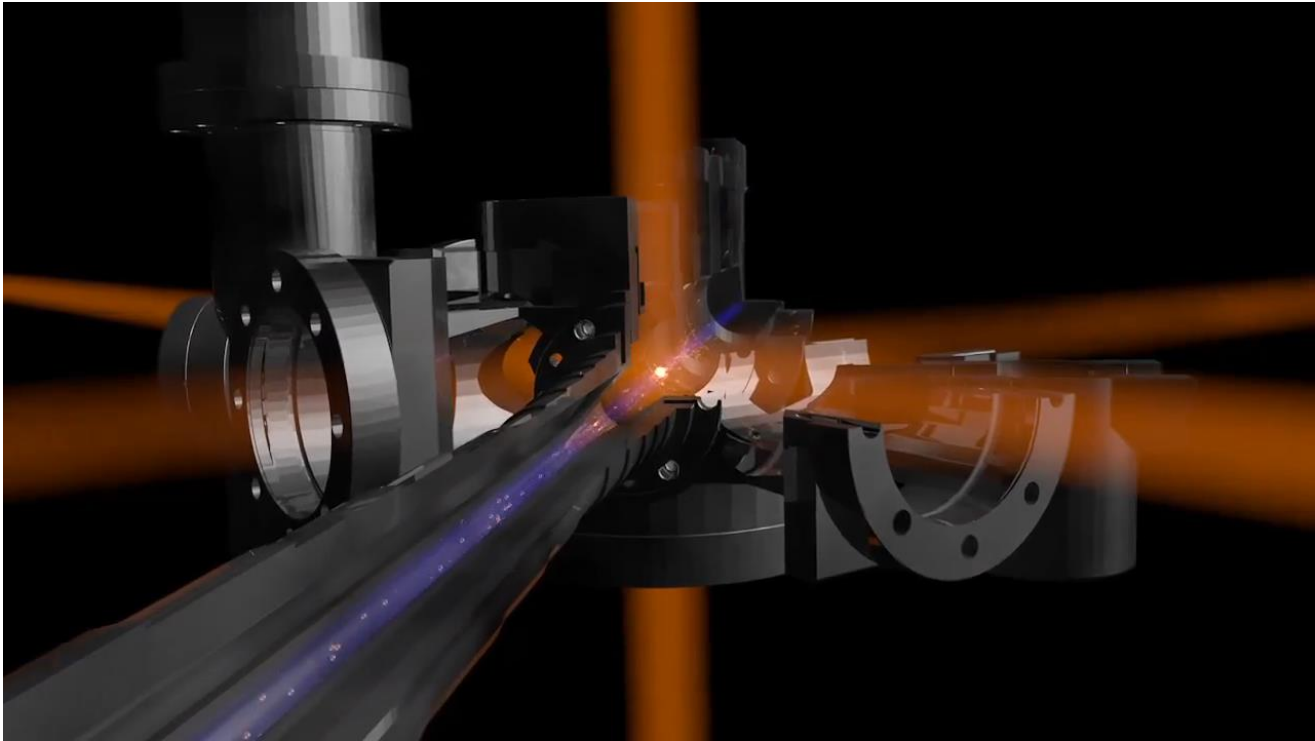
← Further cooling



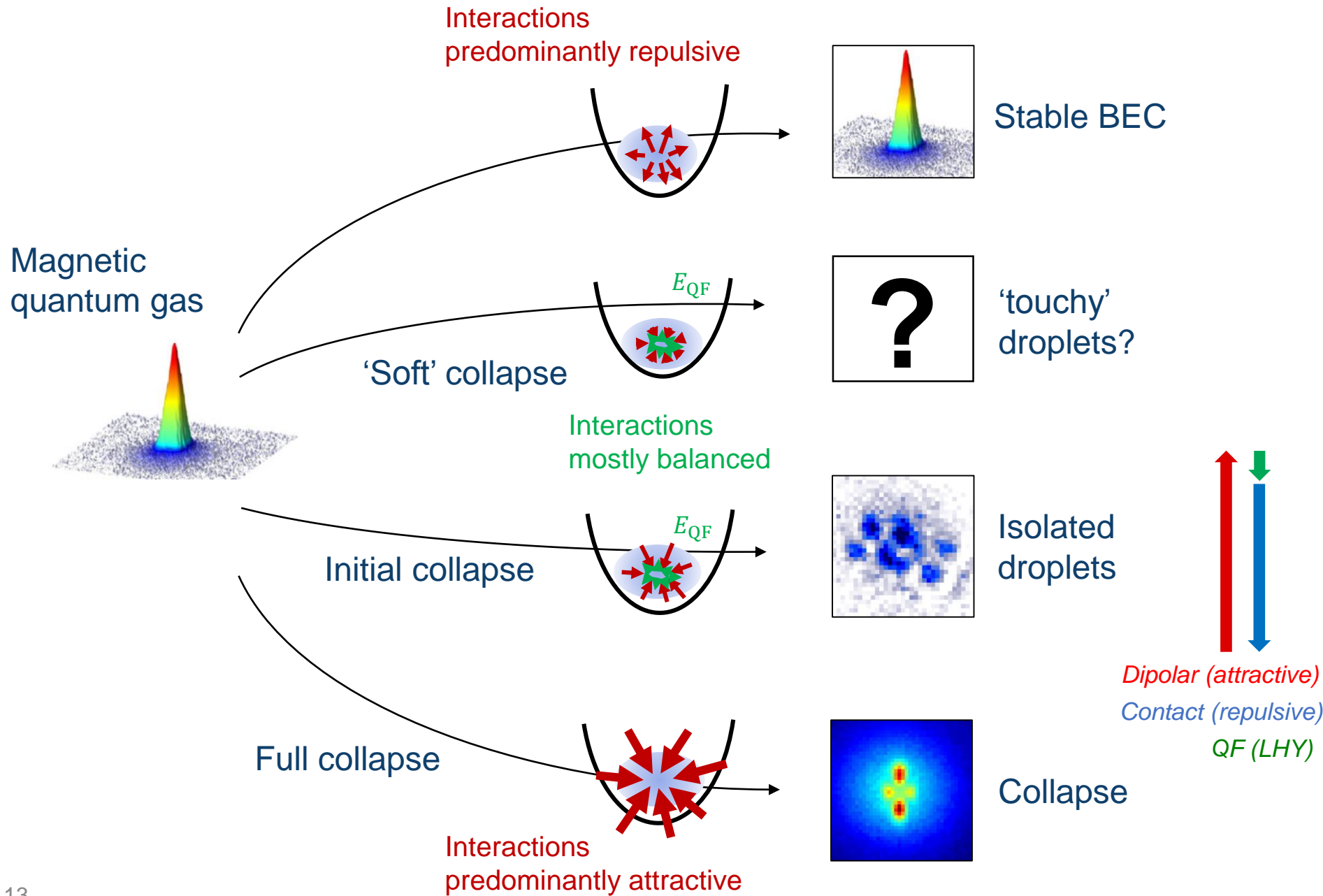
Dy

Cold gas $\sim 10\mu\text{K}$

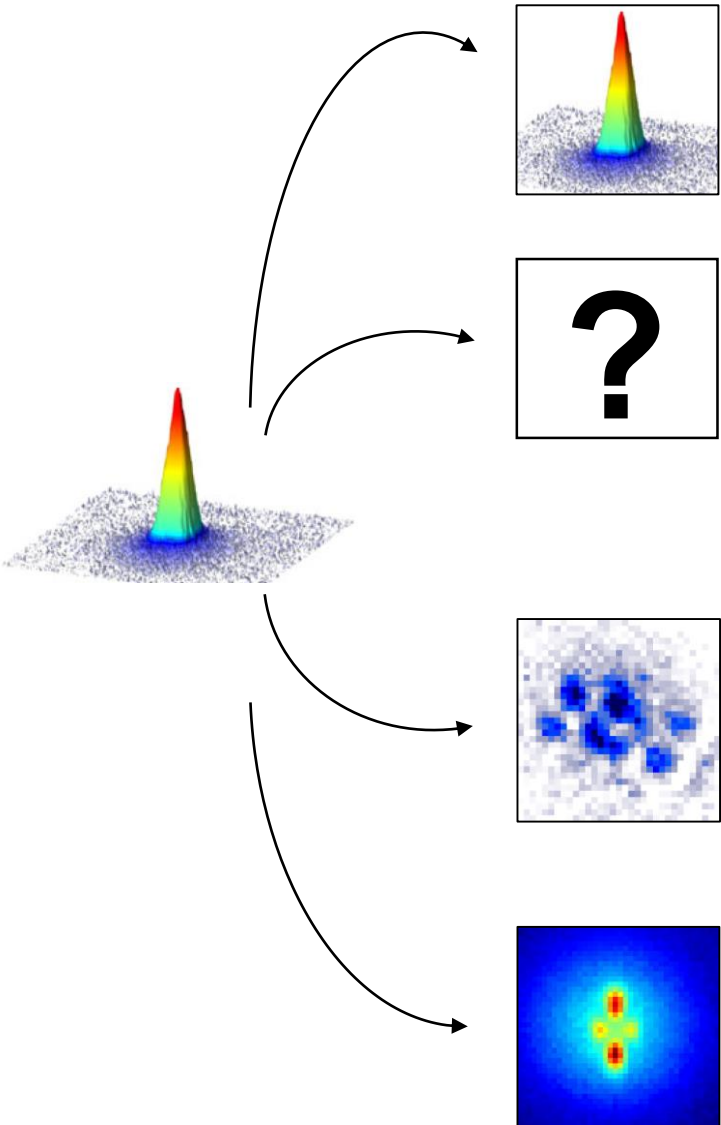
EXPERIMENTAL SEQUENCE



ENERGY OF AN ULTRACOLD DIPOLAR CLOUD



ENERGY OF AN ULTRACOLD DIPOLAR CLOUD

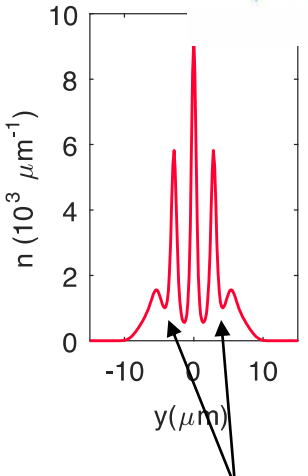
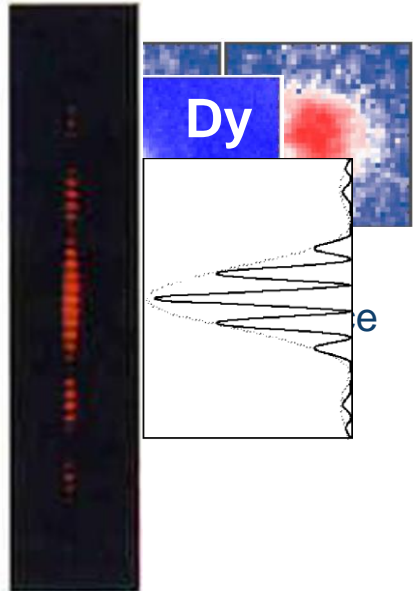
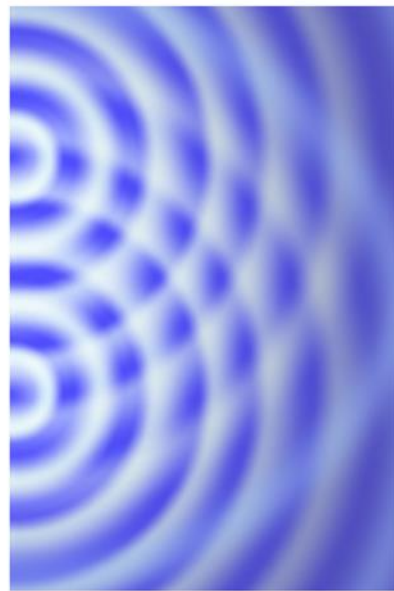
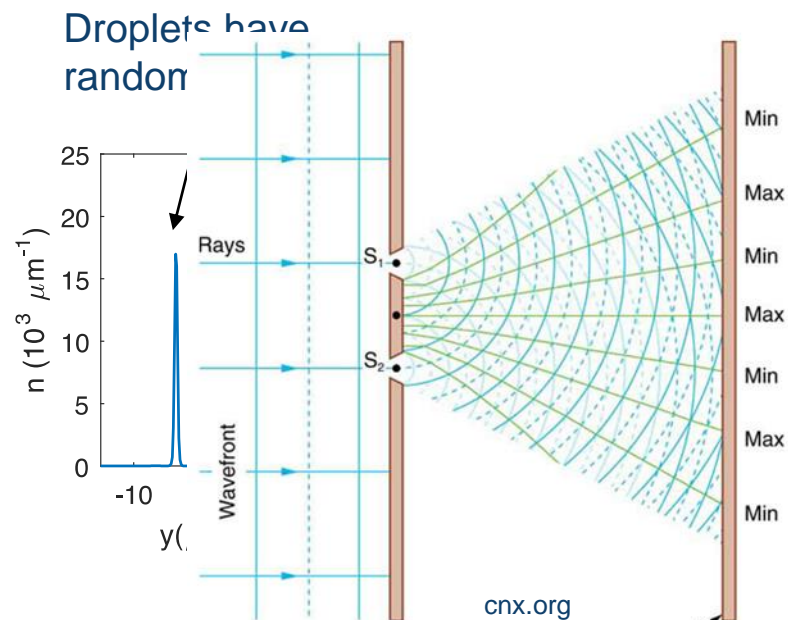


Timonen et al., Science **341**, 253 (2013)

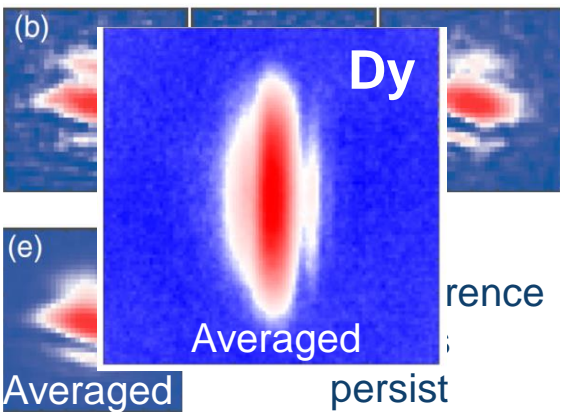
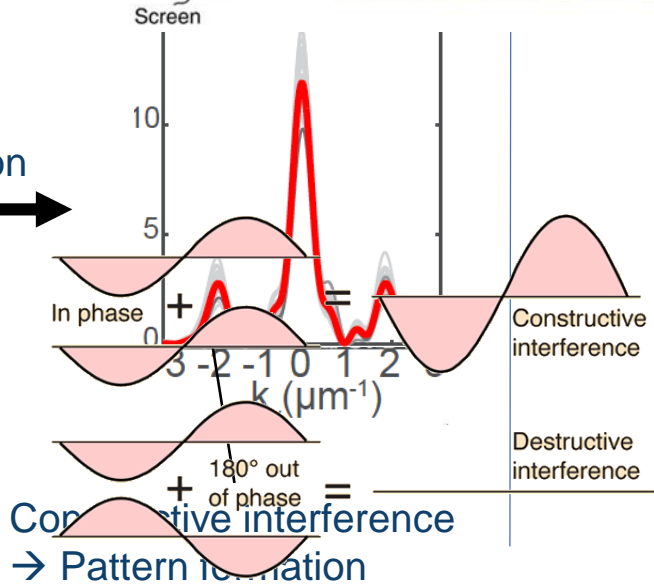
ATOM INTERFEROMETRY

Simulation

Experiment

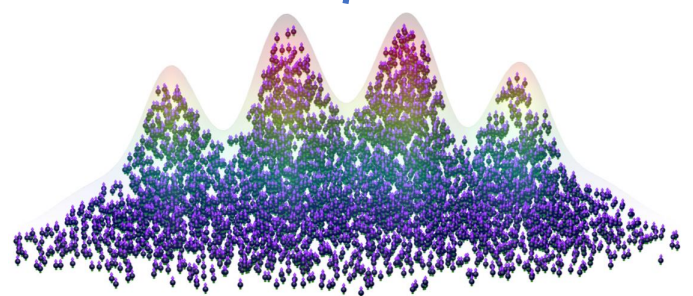
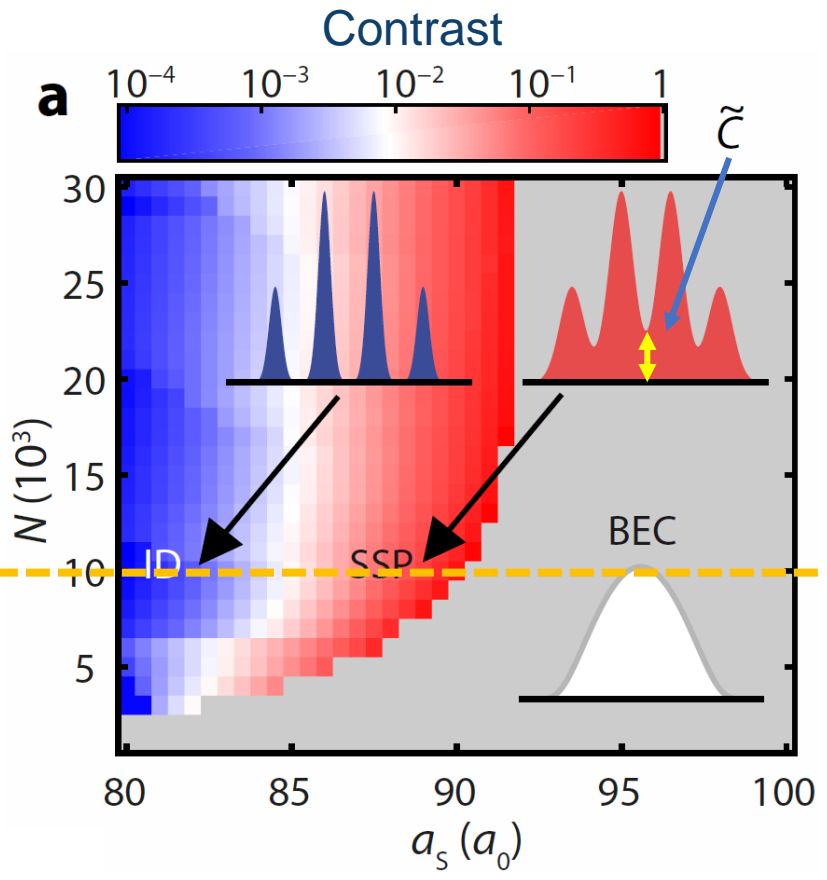
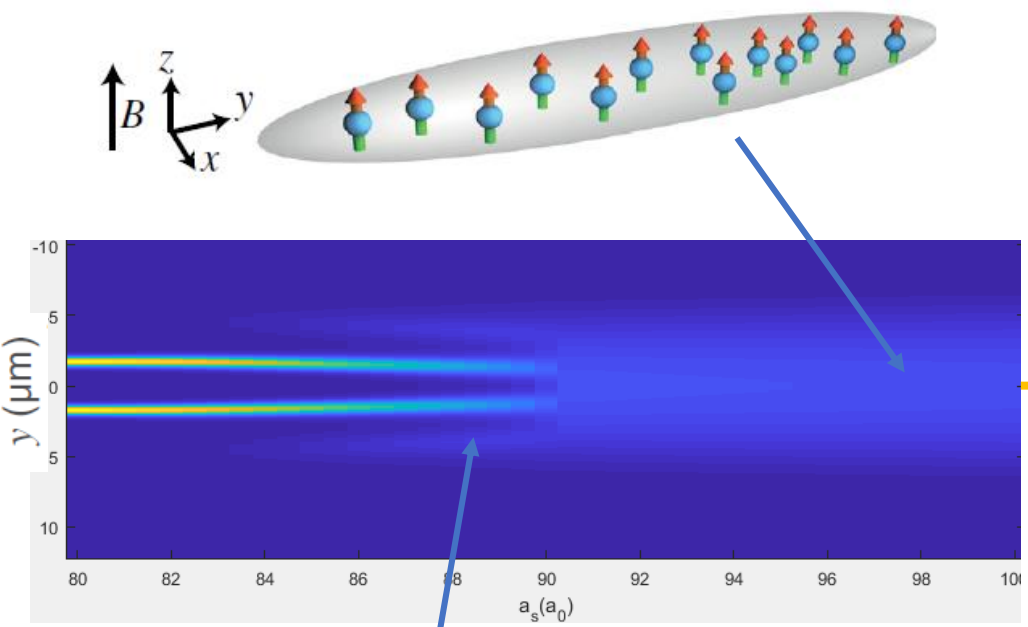


Free evolution

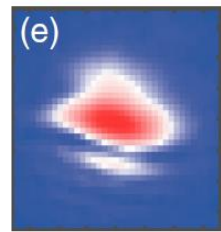
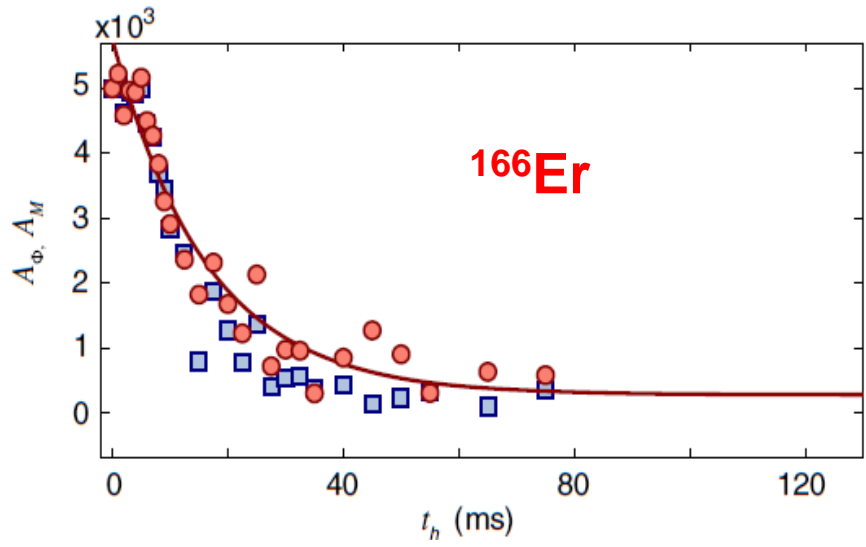


Droplet phases are locked

PHASE DIAGRAM

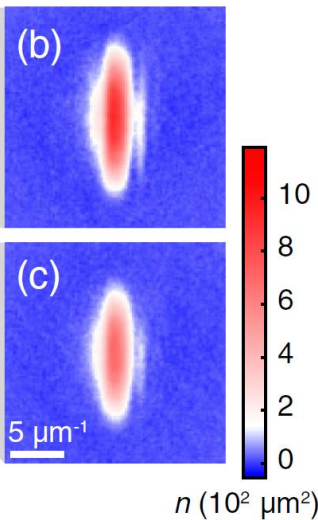
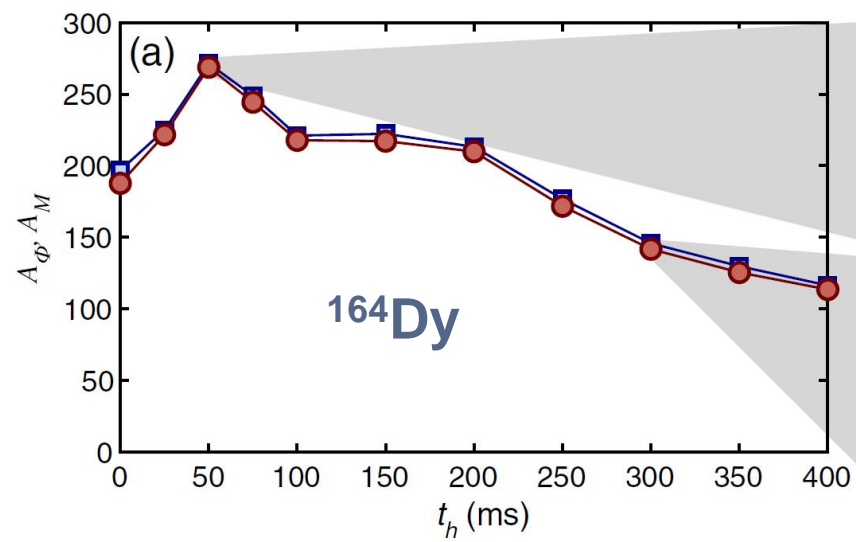


SUPERSOLIDITY IN DIPOLAR BEC



$A_M \sim$ single shot modulation amplitude

$A_\phi \sim$ averaged modulation amplitude

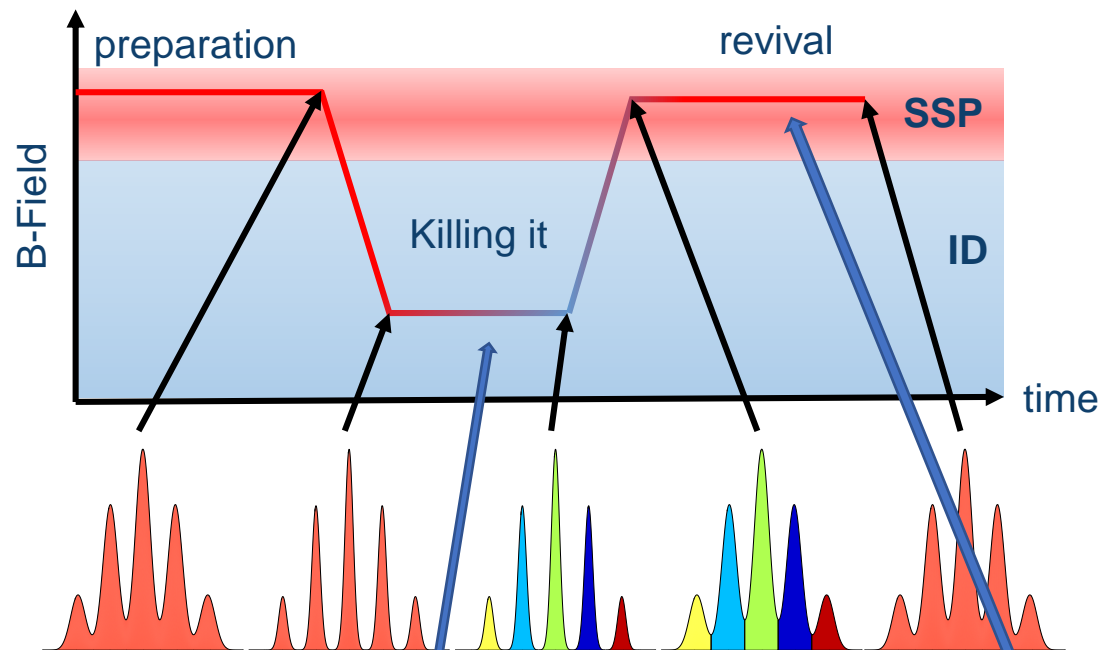
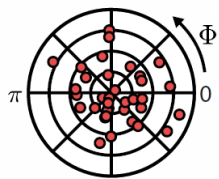
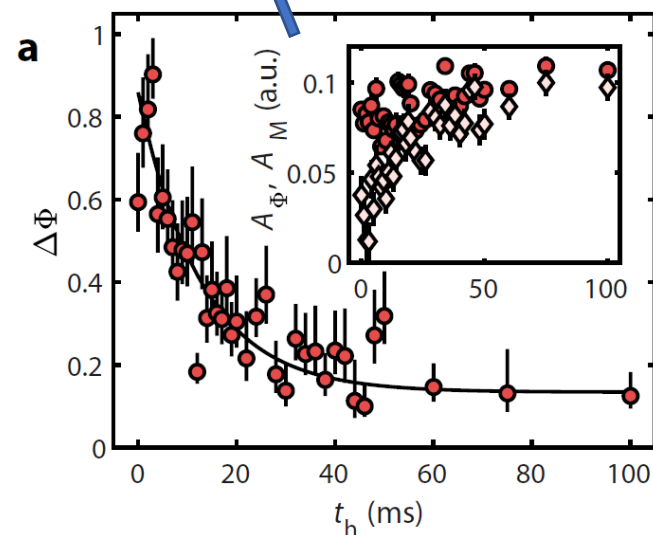
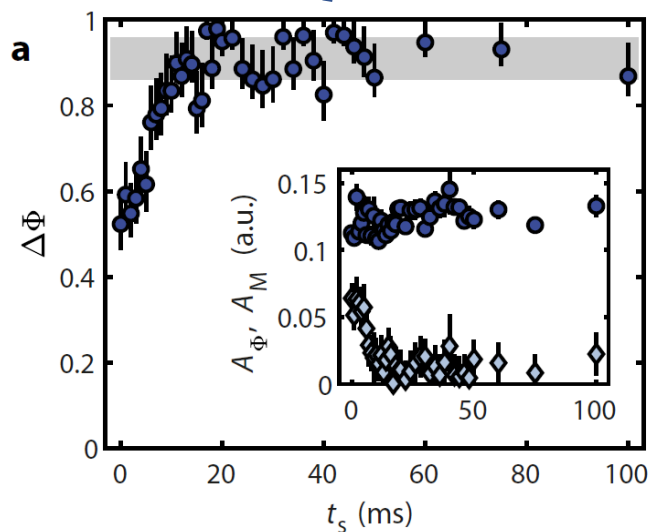
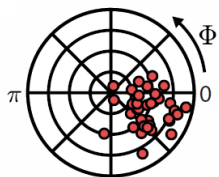


Lifetimes:
 $^{166}\text{Er} \sim$ tens ms
 $^{164}\text{Dy} \sim$ hundreds ms

PRX 9, 021012 (2019)

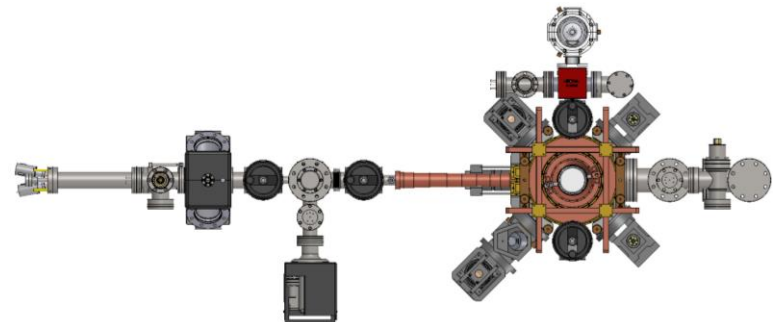
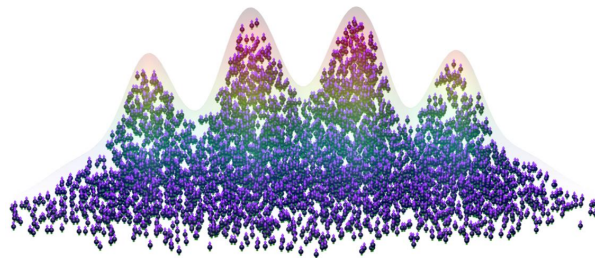
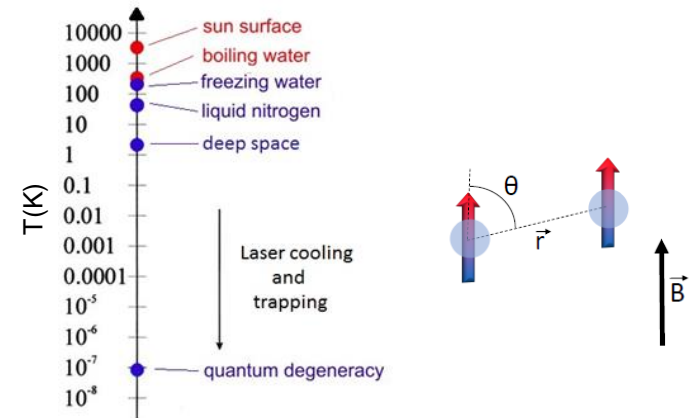
Related work:
 PRX 9, 011051 (2019)
 PRL 122, 130405 (2019)

DEATH AND REVIVAL OF SUPERSOLID!

 $\Delta\Phi \sim 1$  $\Delta\Phi \sim 0$ 

CONCLUSIONS

- QM is mind blowing
- Ultracold magnetic atoms are ideal candidates to investigate it
- First observation of long-lived supersolidity



Thanks!

L→R

P. Ilzhöfer
A. Trautmann
M. Mark
M. Sohmen
G.D.
S. Brandstetter
C. Politi
F. Ferlaino

