FORTH

Hypersonic matterwave guiding for atom-interferometry

CRETANMATTERWAVES

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Atomtronics @ Benasque
08/08/2019

FET FUTURE & EMERGING TECHNOLOGIES scheme
MatterWave
Marie Curie-Excellence MatterWaves

MARIE CURIE ACTIONS
QUESCA
Marie Curie-Excellence Fellowship

esa
ESA-OBST1
ESA-OBST2

AtomQT
cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

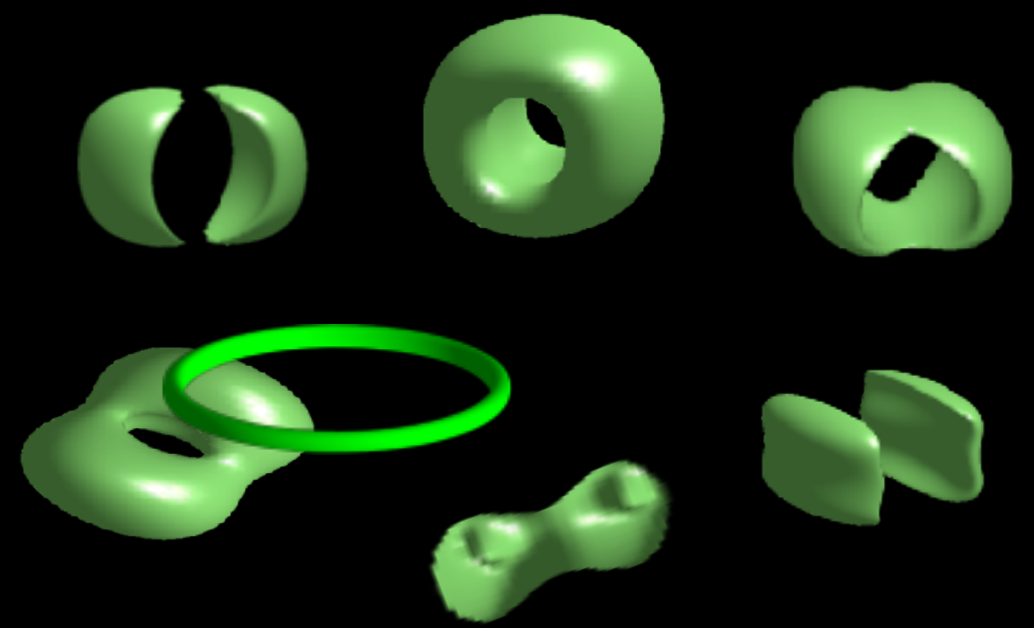
BEC and MatterWaves at IESL-FORTH

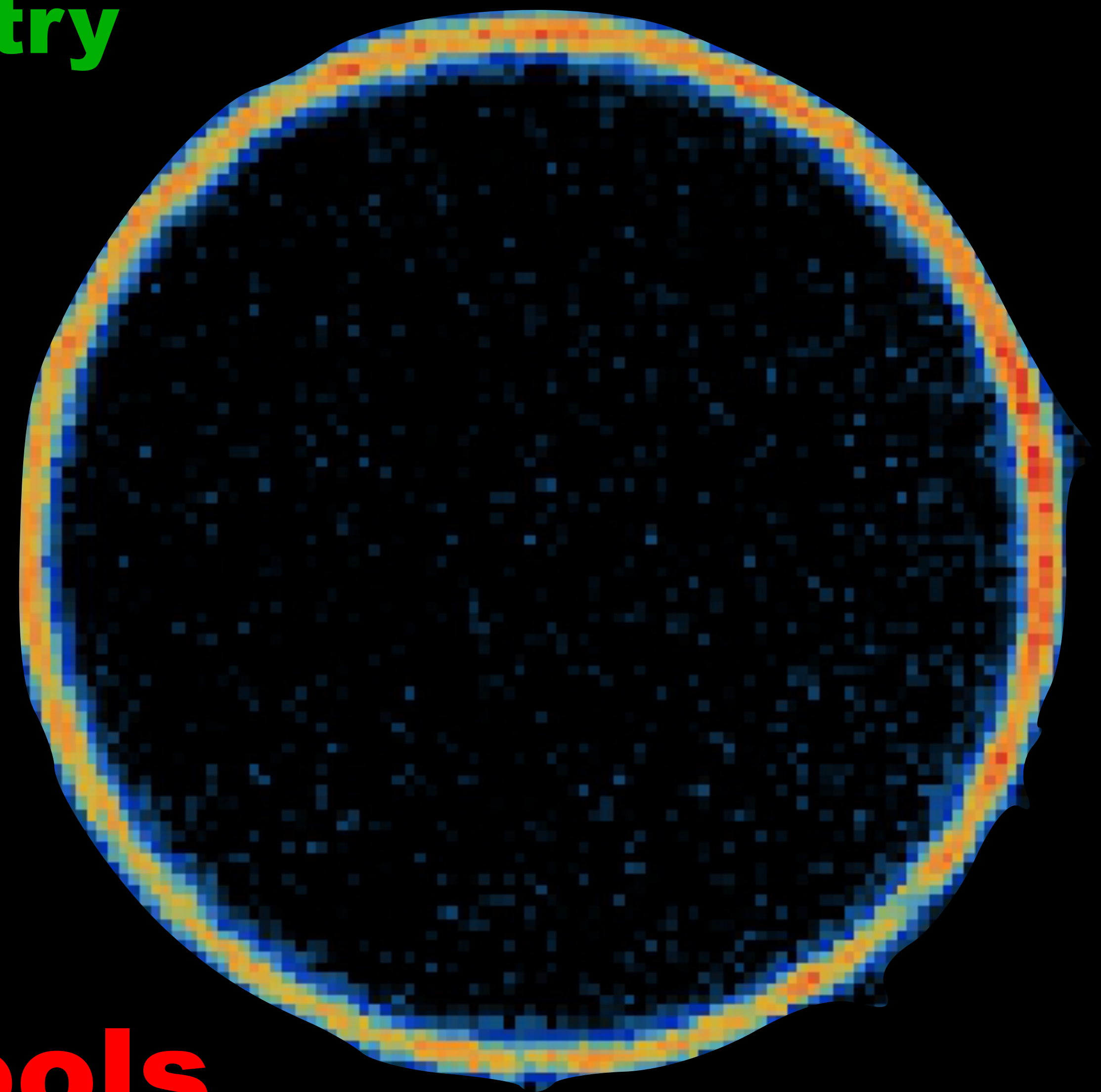
CRETANMATTERWAVES

FORTH
INSTITUTE OF ELECTRONIC STRUCTURE AND LASER

Matter-Wave Interferometry

Guided for Matter-Wave Interferometry for inertial navigation



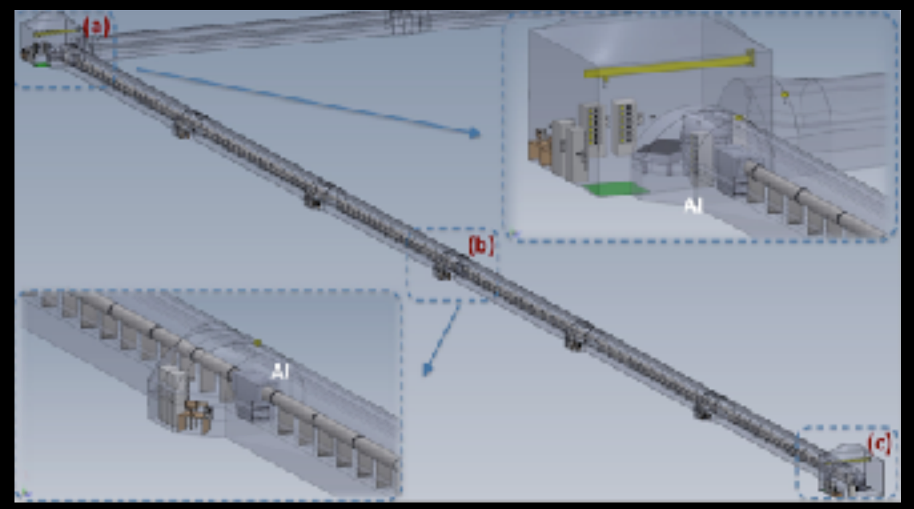


Large Interferometers

BEC in Space: Testing Einstein's Weak equivalence principle

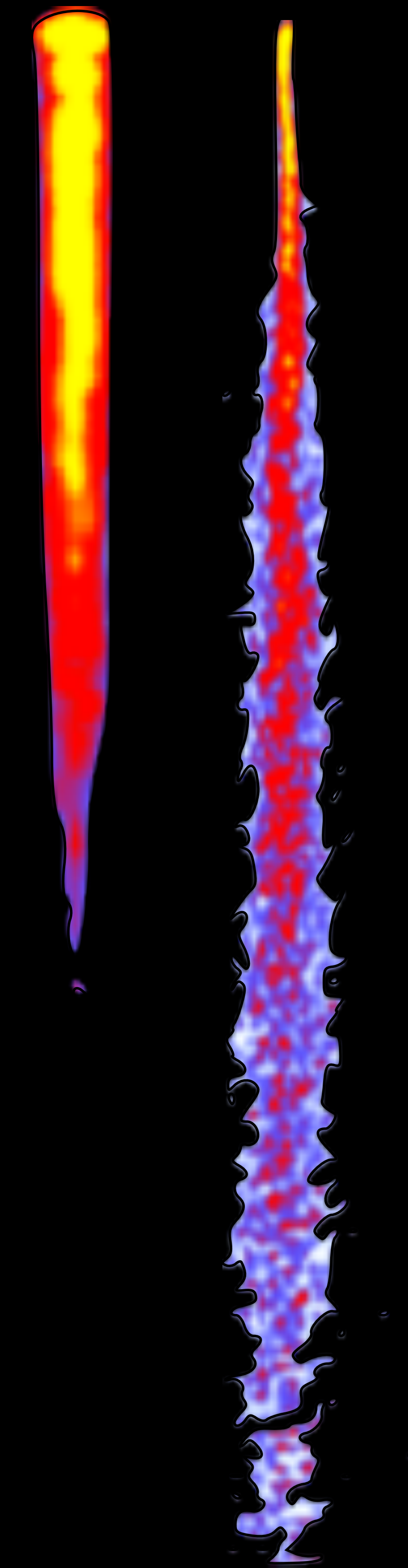
STE-QUEST

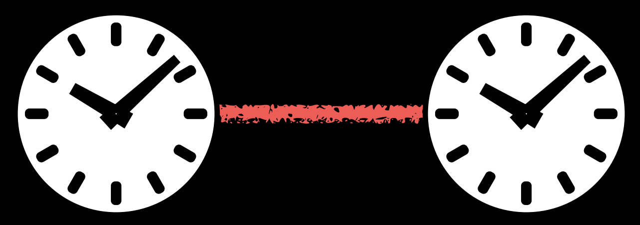
Very long Baseline Matterwave interferometry



ELGAR

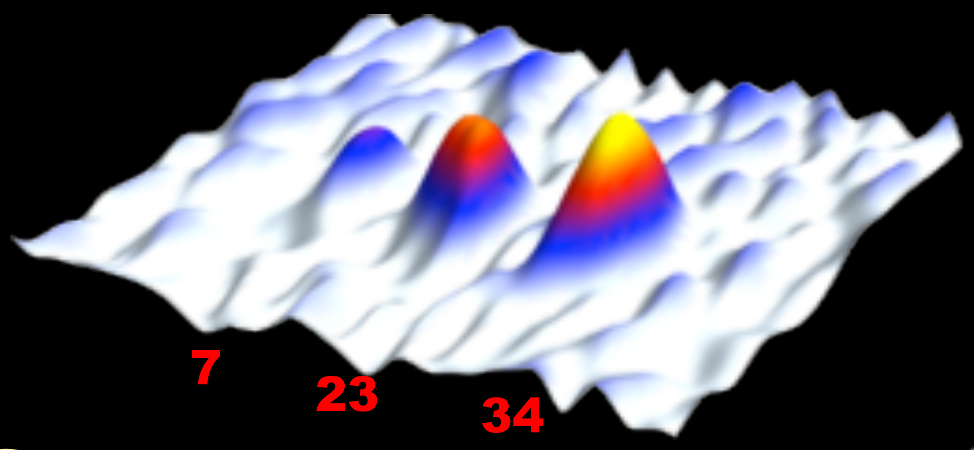
Ultra-Bright Atom Lasers

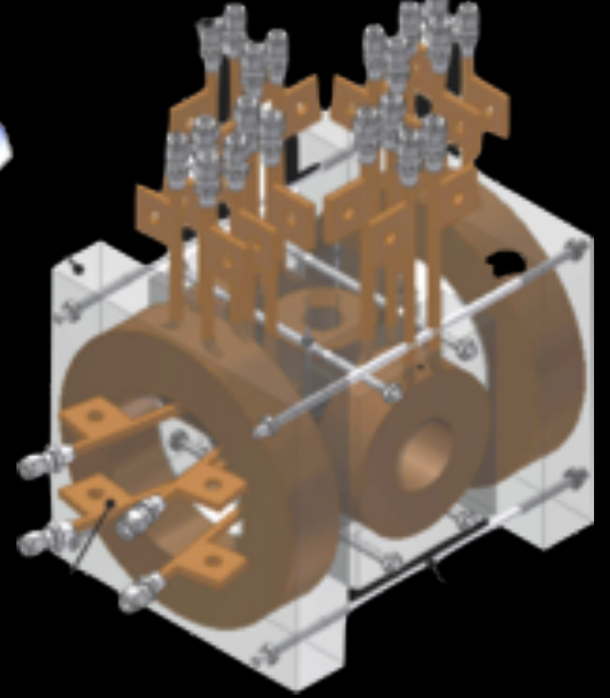


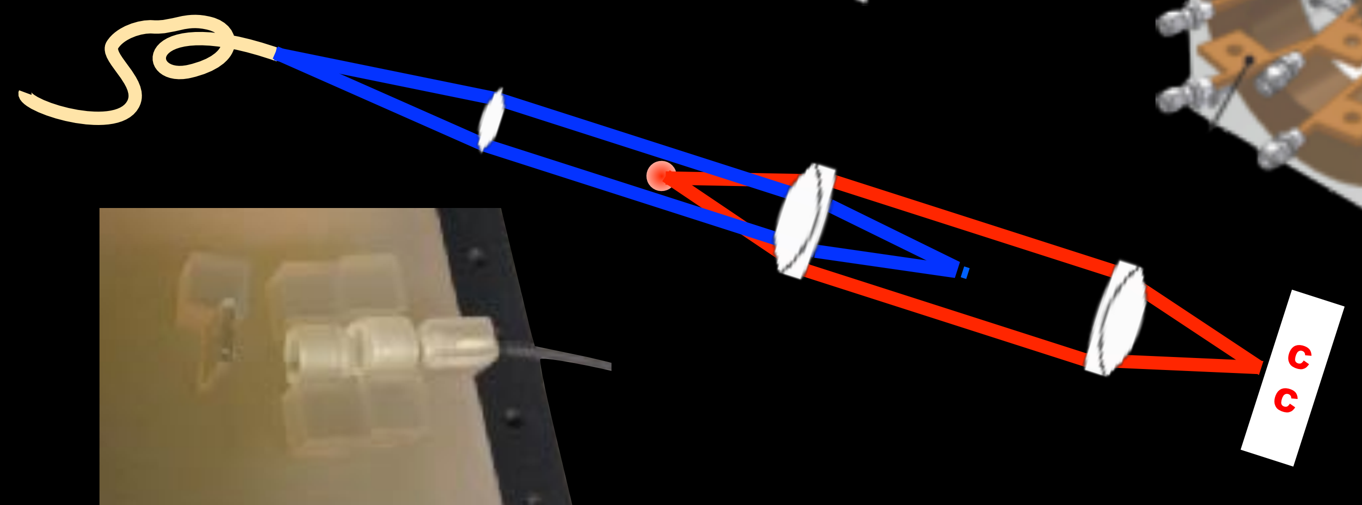


SAGE

Matter-Wave&Quantum Tools







Experiment | **Theory** | **Partners**

Laserlab Europe

Short-term visits…
1 week - 2 months
for experimentalists
and theorists

AtomQT


To the lab

For open PhD and Postdoc Positions see BEC.gr

For open PhD and Postdoc Positions see BEC.gr

Matterwave Interferometry

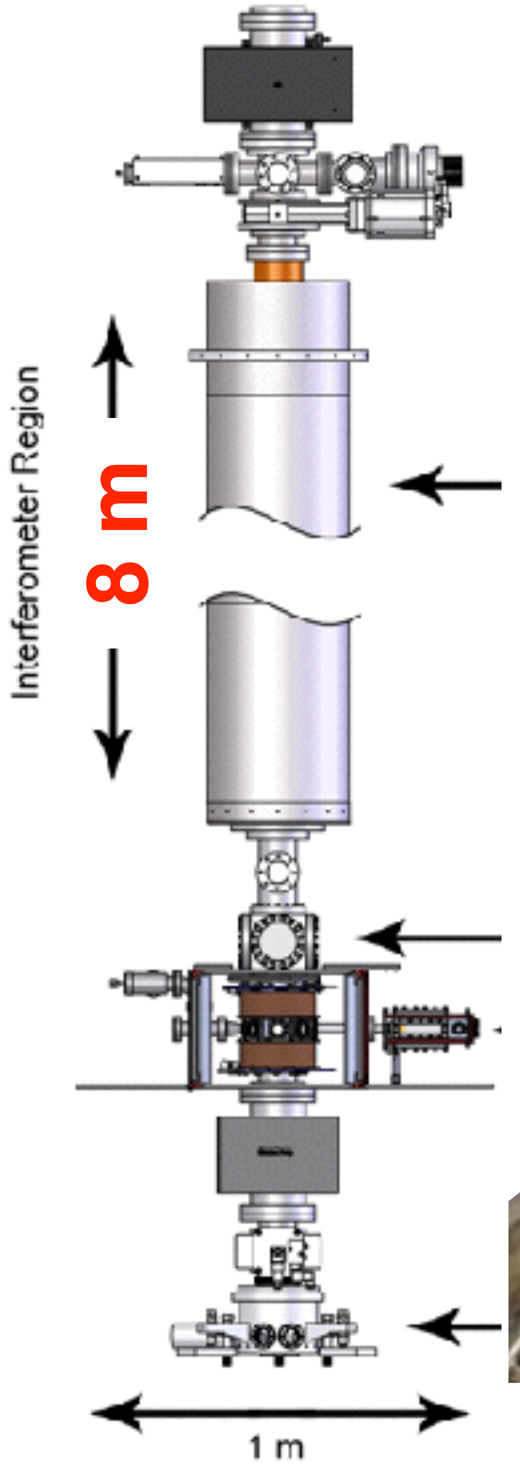
$$\phi = \frac{1}{\hbar}\int\Big(U_2(t) - U_1(t)\Big)\,dt$$

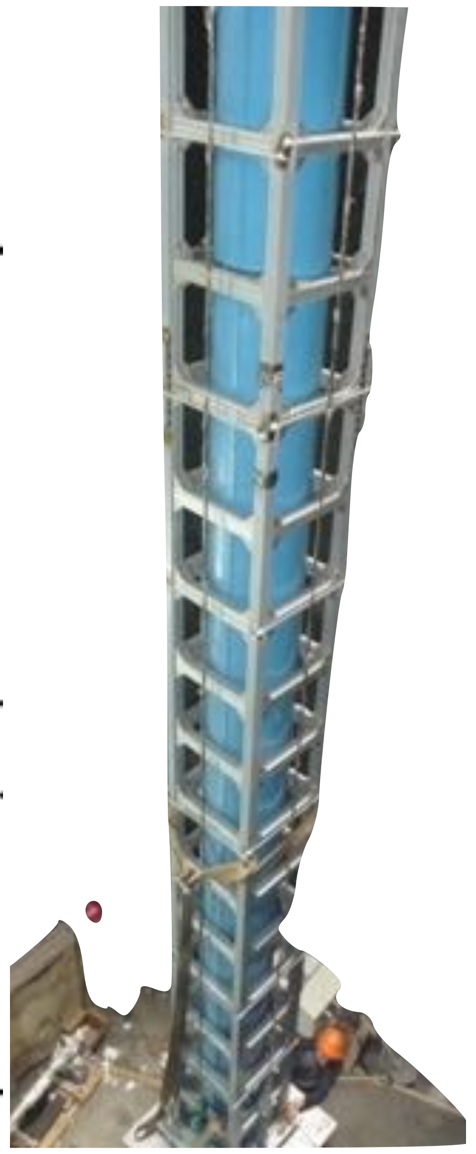
$= 1.5$ rad/feV in 1s

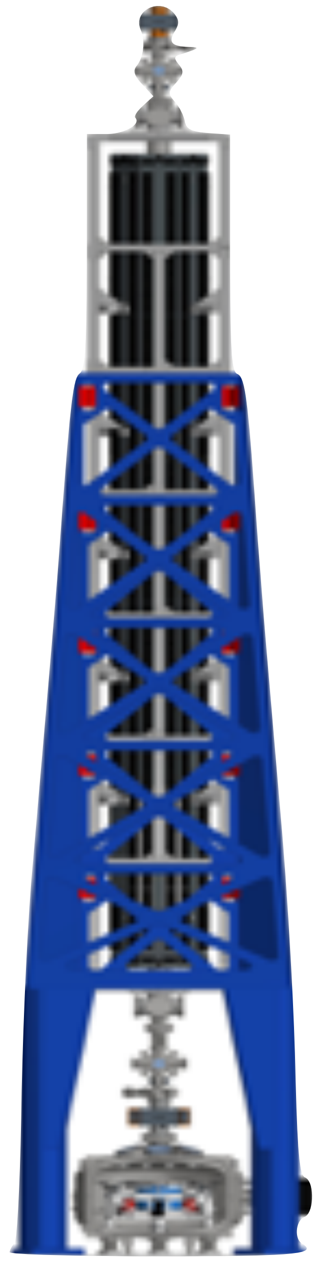
Bloch Lab

Matter-Wave Interferometers

Free Space

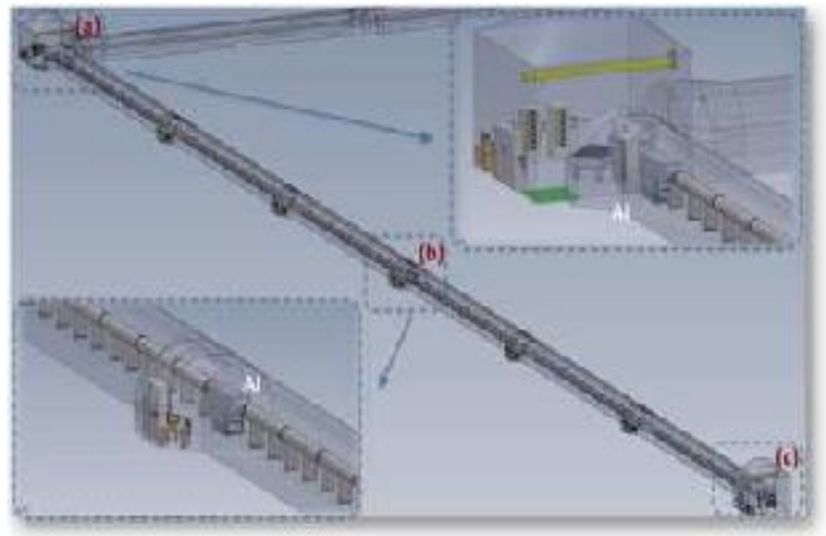






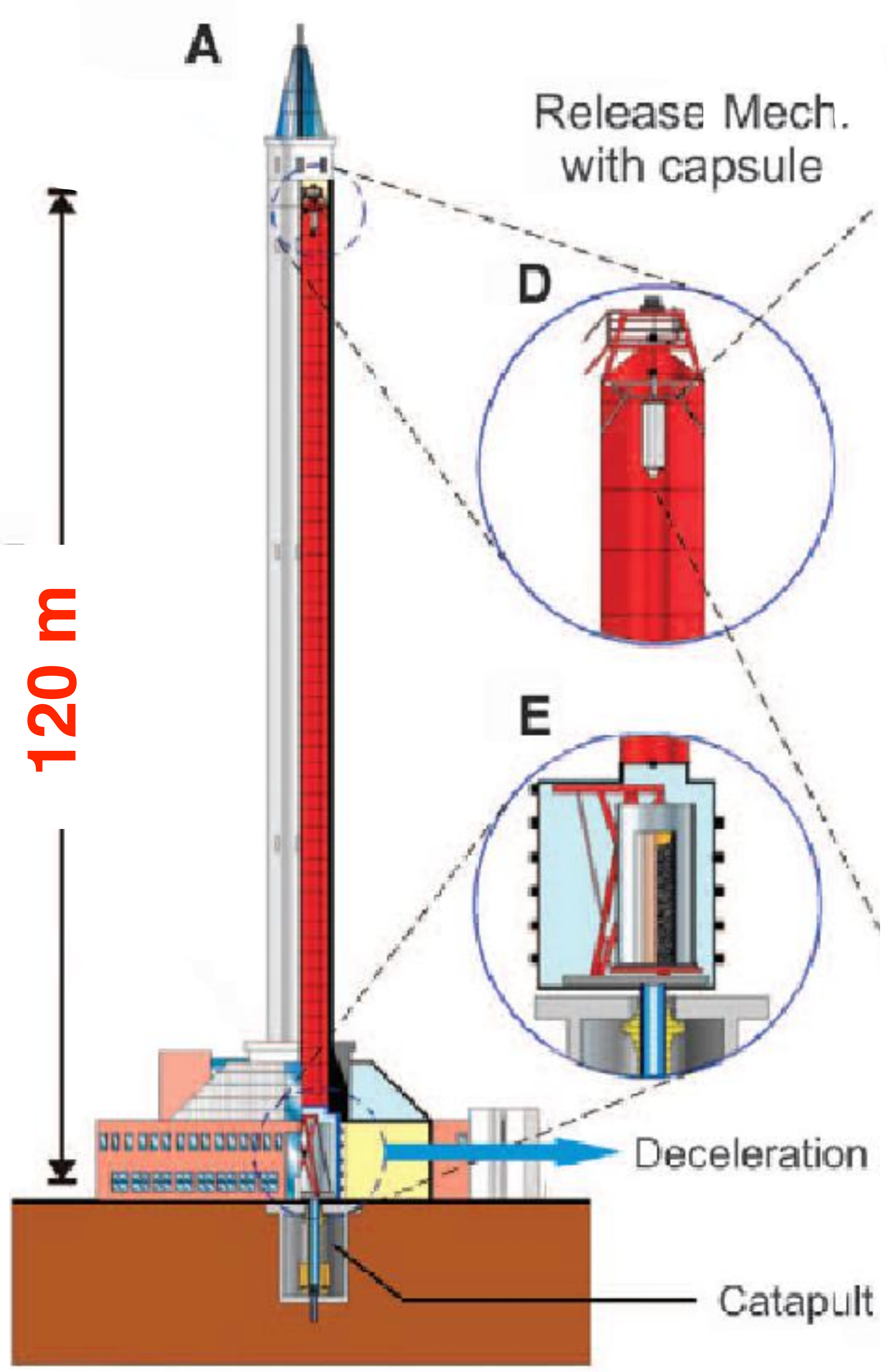
Stanford / Wuhan / Hannover

ELGAR



Free Fall

ZARM drop Tower

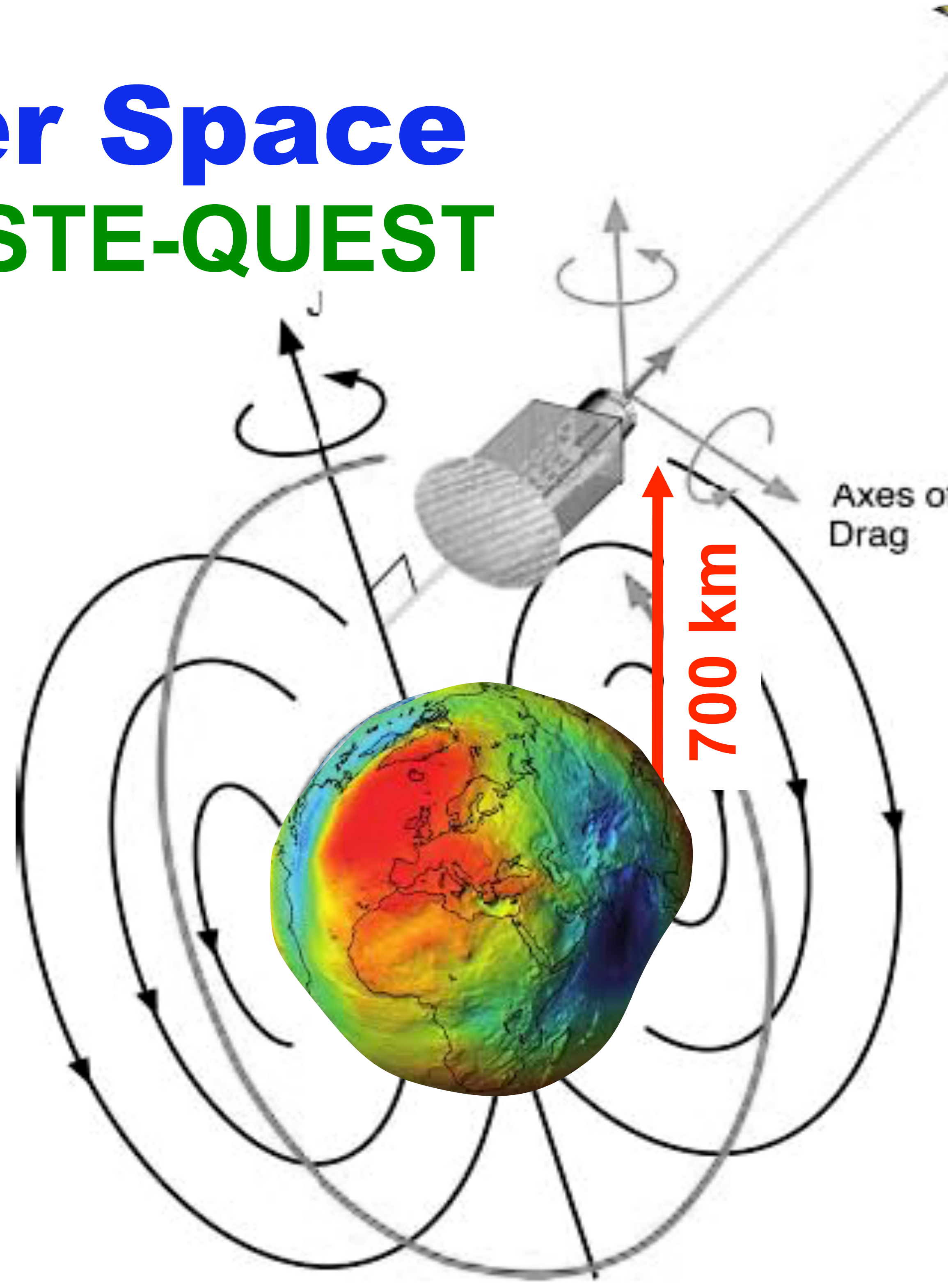


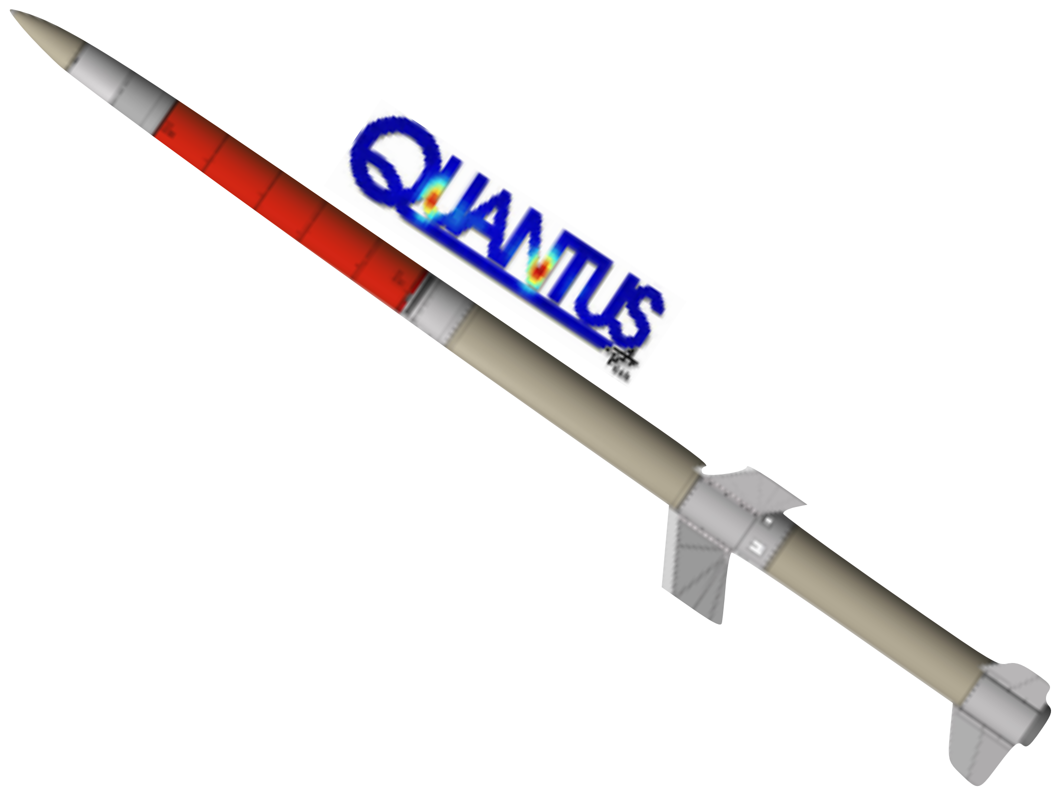
Outer Space

NASA CAL

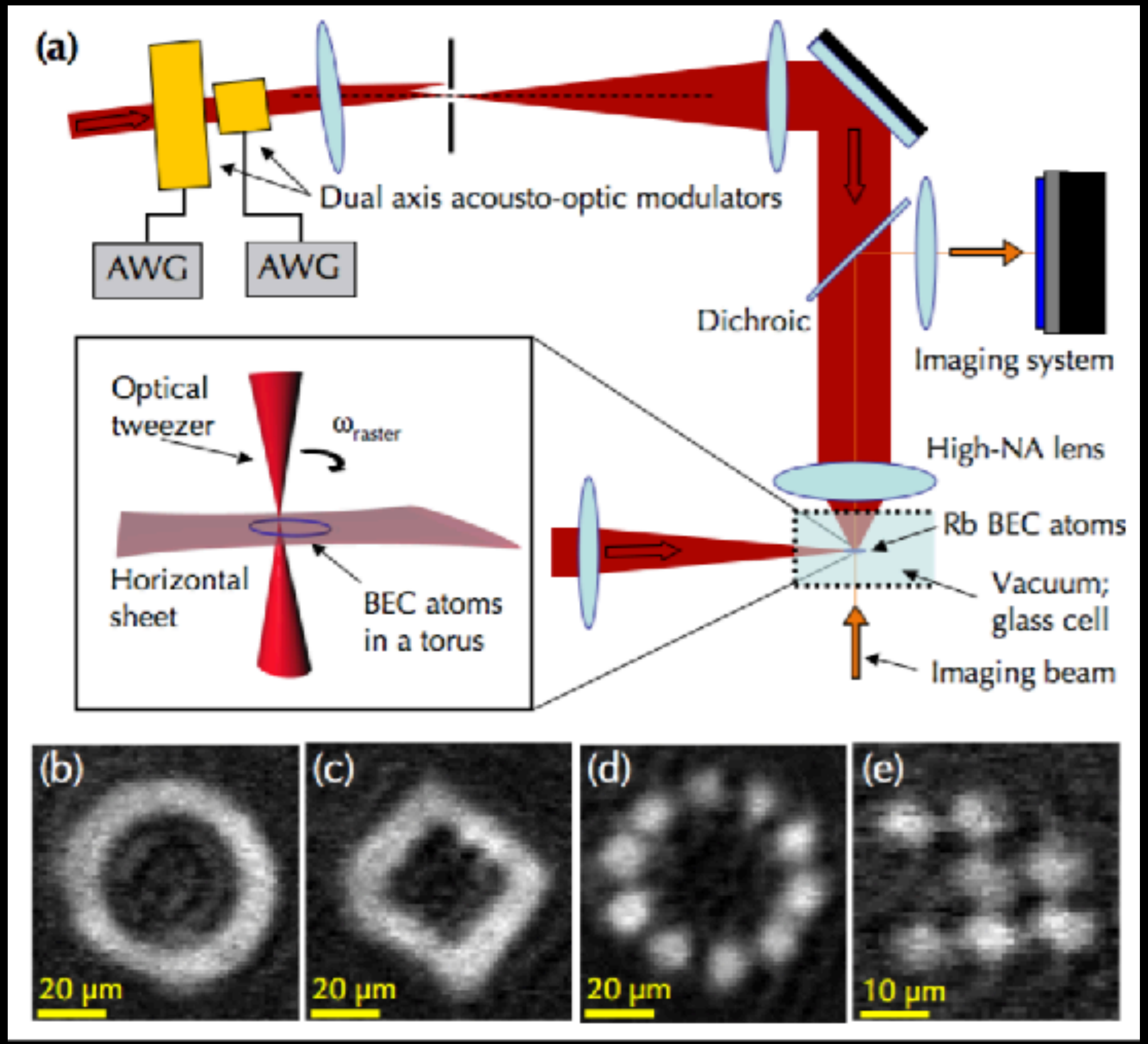
ESA C-COOL

STE-QUEST





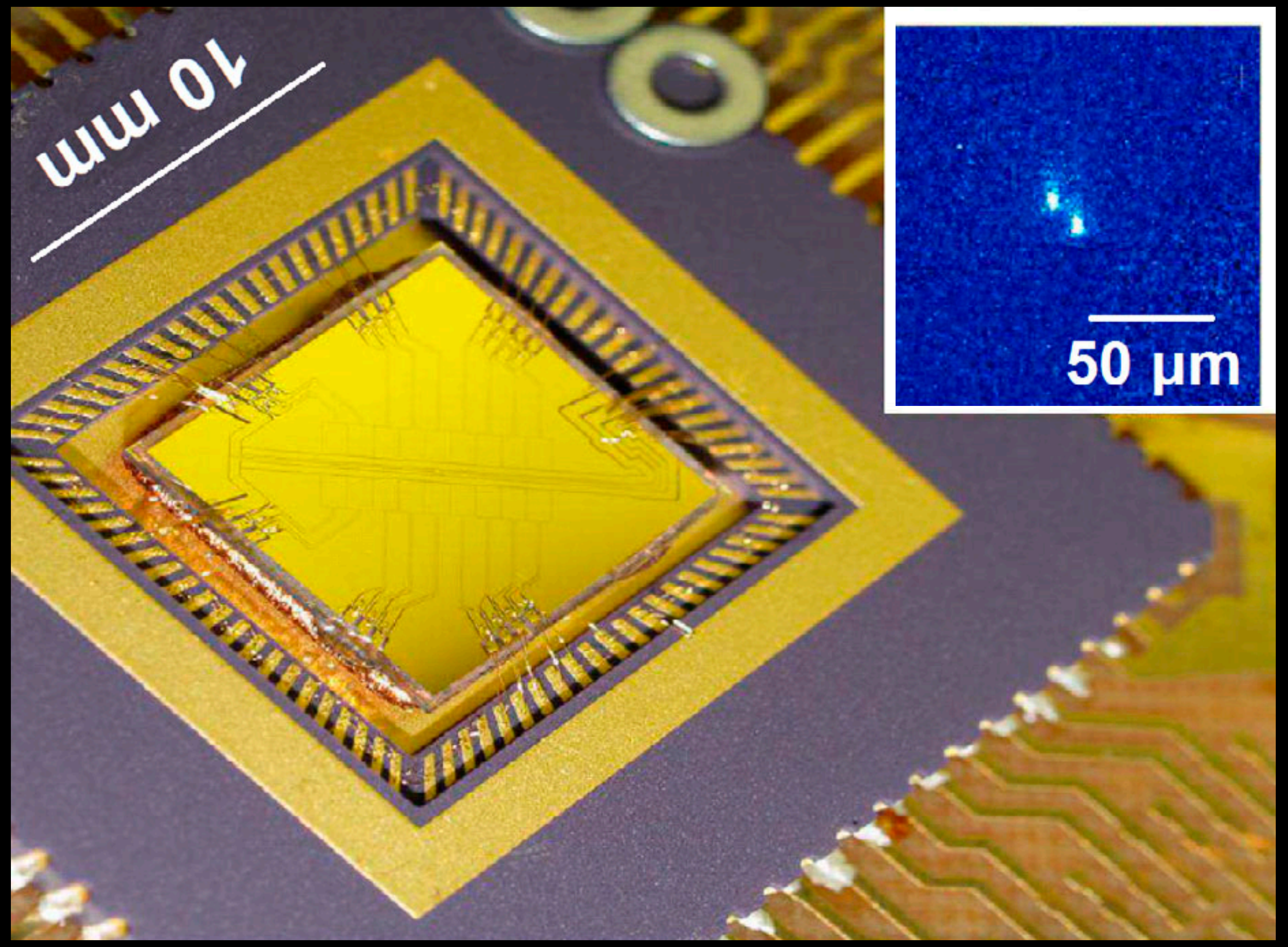
Atomtronics



K. Henderson et al. N. J. Phys. 11: 043030 (2009)

G. Gauthier et al. Optica 3:10 1136 (2016)

Y. J. Wang et al. Phys.Rev.Lett 94: 090405 (2005)



Mark Keil et al. Journal of Modern Optics : 1-46 (2016)

Atomtronics
Wave Guides

- **Magnetic Fields**

LSD - IP-Trap

LSD - Atomic chips

LSD - Mini-traps

LSD - Adiabatic (**LSD**)

LSD - TAAPs

Time-Averaged Adiabatic Potentials

Benasque 2015 ?

Boshier Criteria of Atomtronics
- **Loop**
- **Smooth**
- **Dynamic**

- **Dipole Traps**

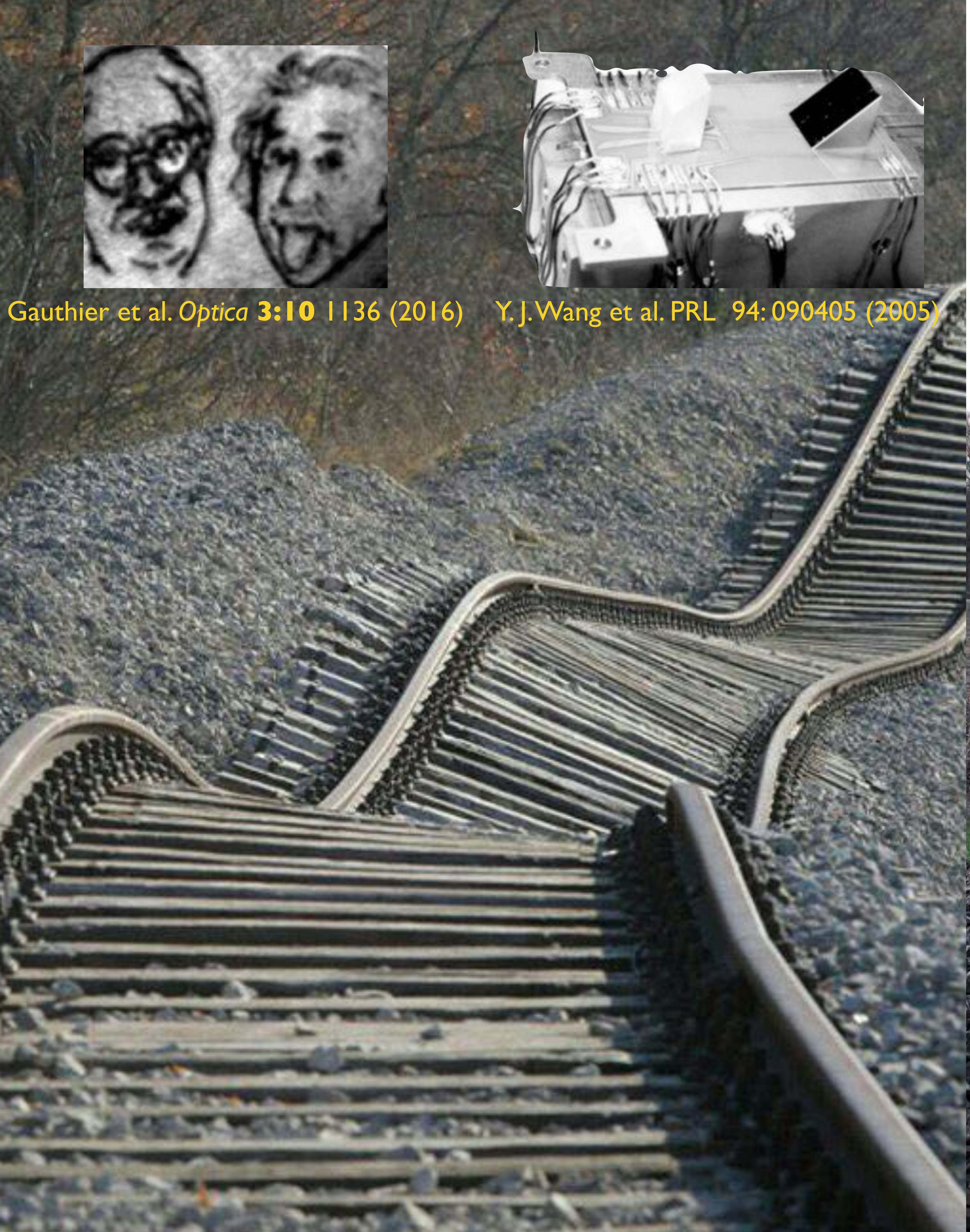
LSD - Guides

LSD - Lattices

LSD - Paintings

LSD - Fibres


Kufstein
MERIDIAN
109

Gauthier et al. *Optica* **3:10** 1136 (2016)   Y. J. Wang et al. PRL 94: 090405 (2005)

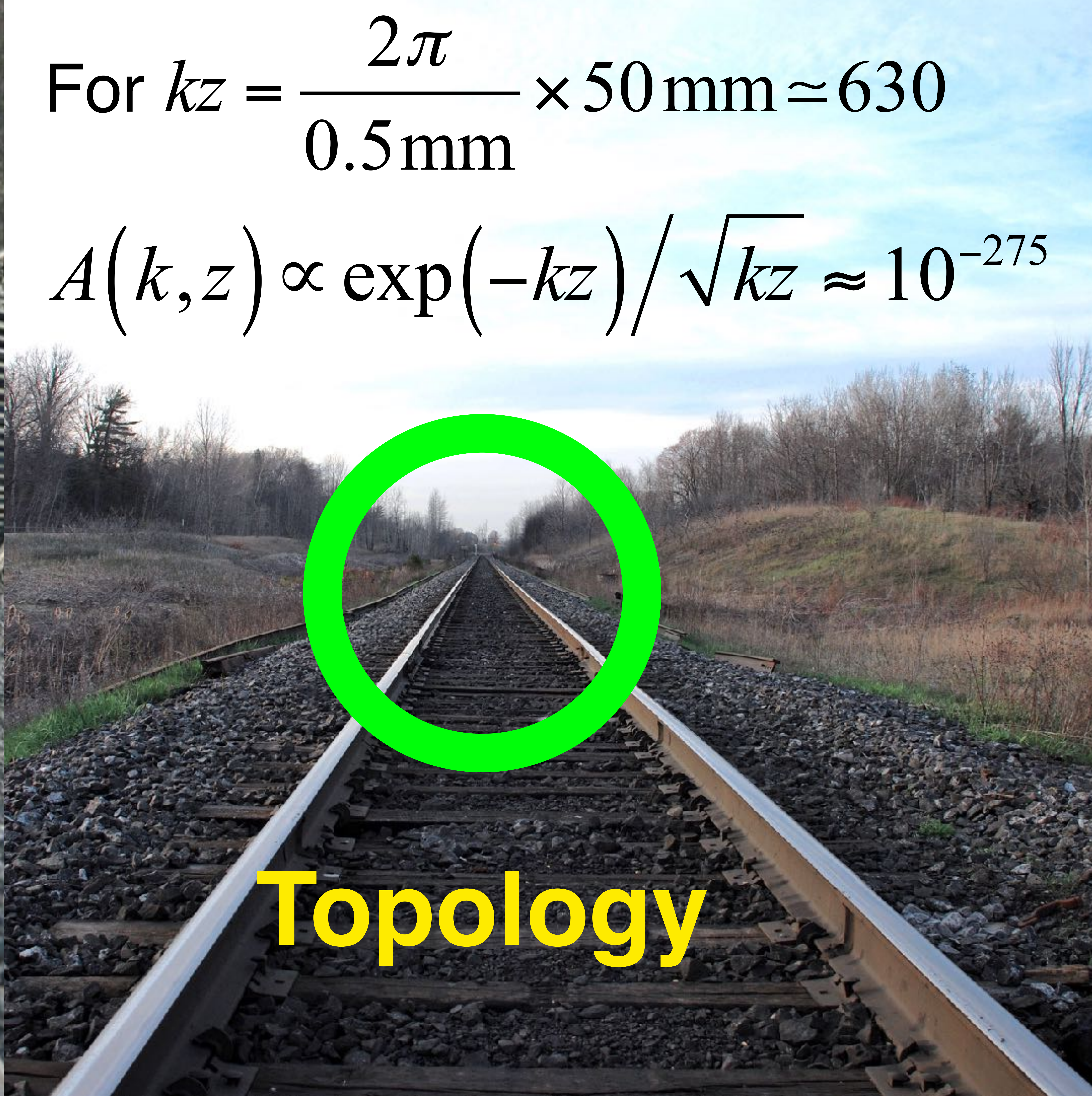
For $kz \gg 1$

$$A(k,z) \propto \exp(-kz)/\sqrt{kz}$$

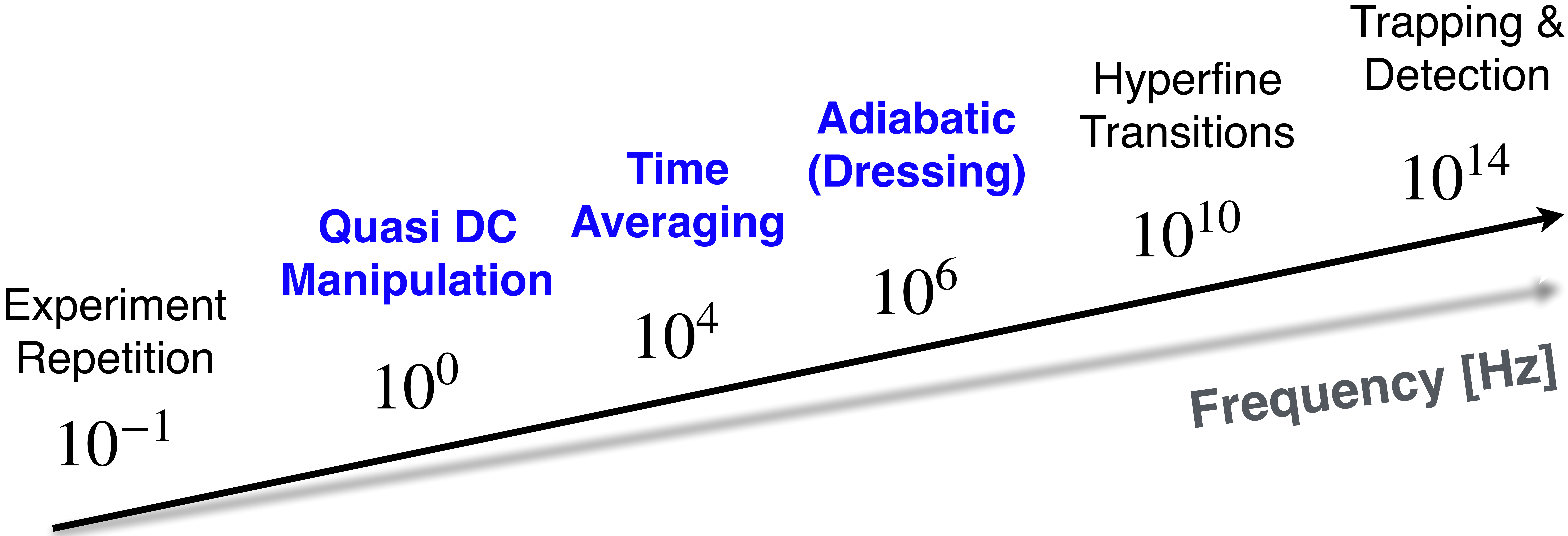
Jones, *et al. J. Phys. B* 37, L15 (2004)

$$\text{For } kz = \frac{2\pi}{0.5\,\text{mm}} \times 50\,\text{mm} \simeq 630$$

$$A(k,z) \propto \exp(-kz)/\sqrt{kz} \approx 10^{-275}$$



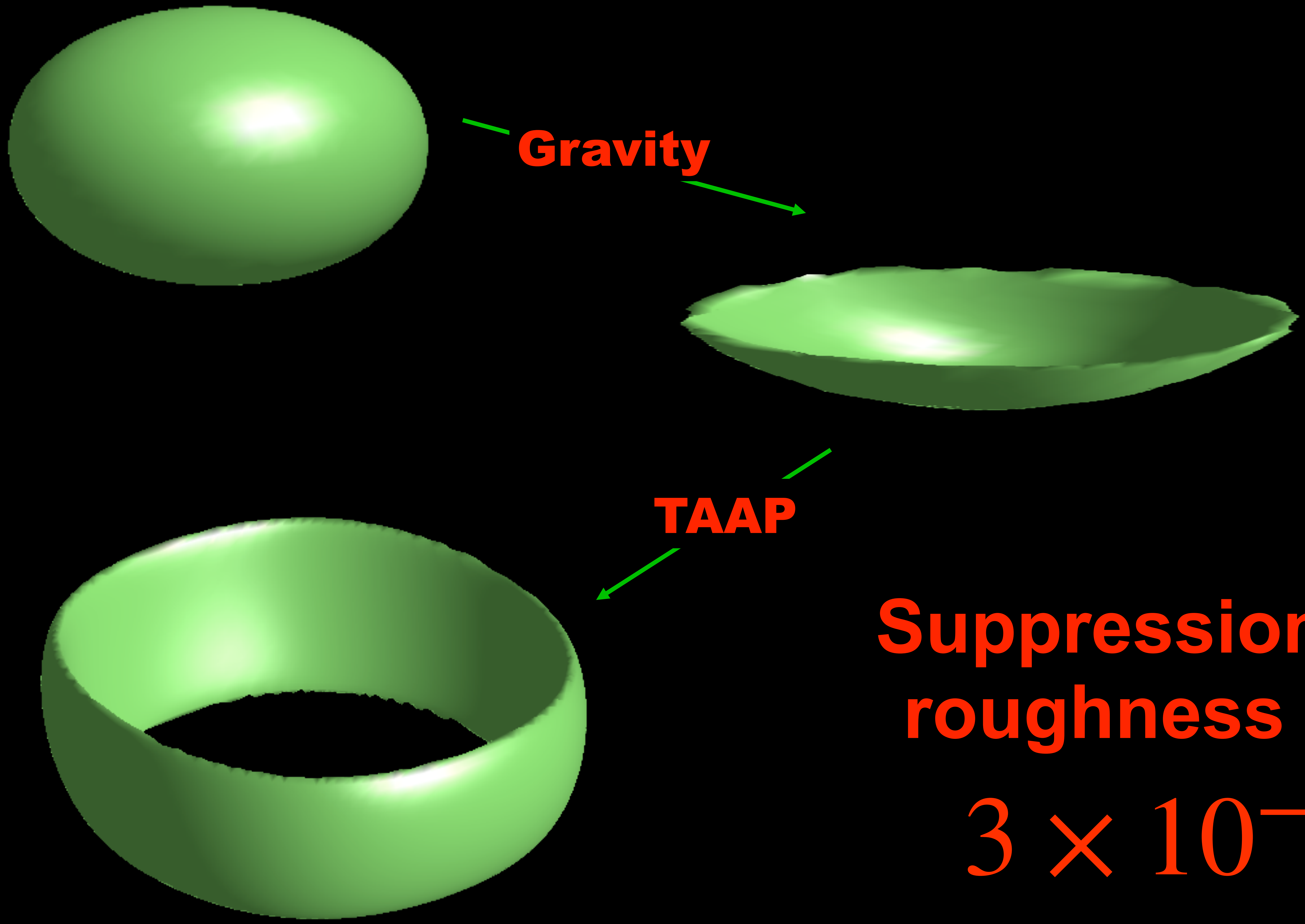
Atomtronic Time Scales @ Crete



Time averaged Adiabatic Averaged Potentials
(TAAP)

ω_{Trap}		ω_{Larmor}	
Quasi Static	**Time-Averaging**	**Adiabatic Potentials**	
~ DC	Audio	RF	

Time-Averaged Adiabatic Potentials (TAAP)



Suppression of roughness by

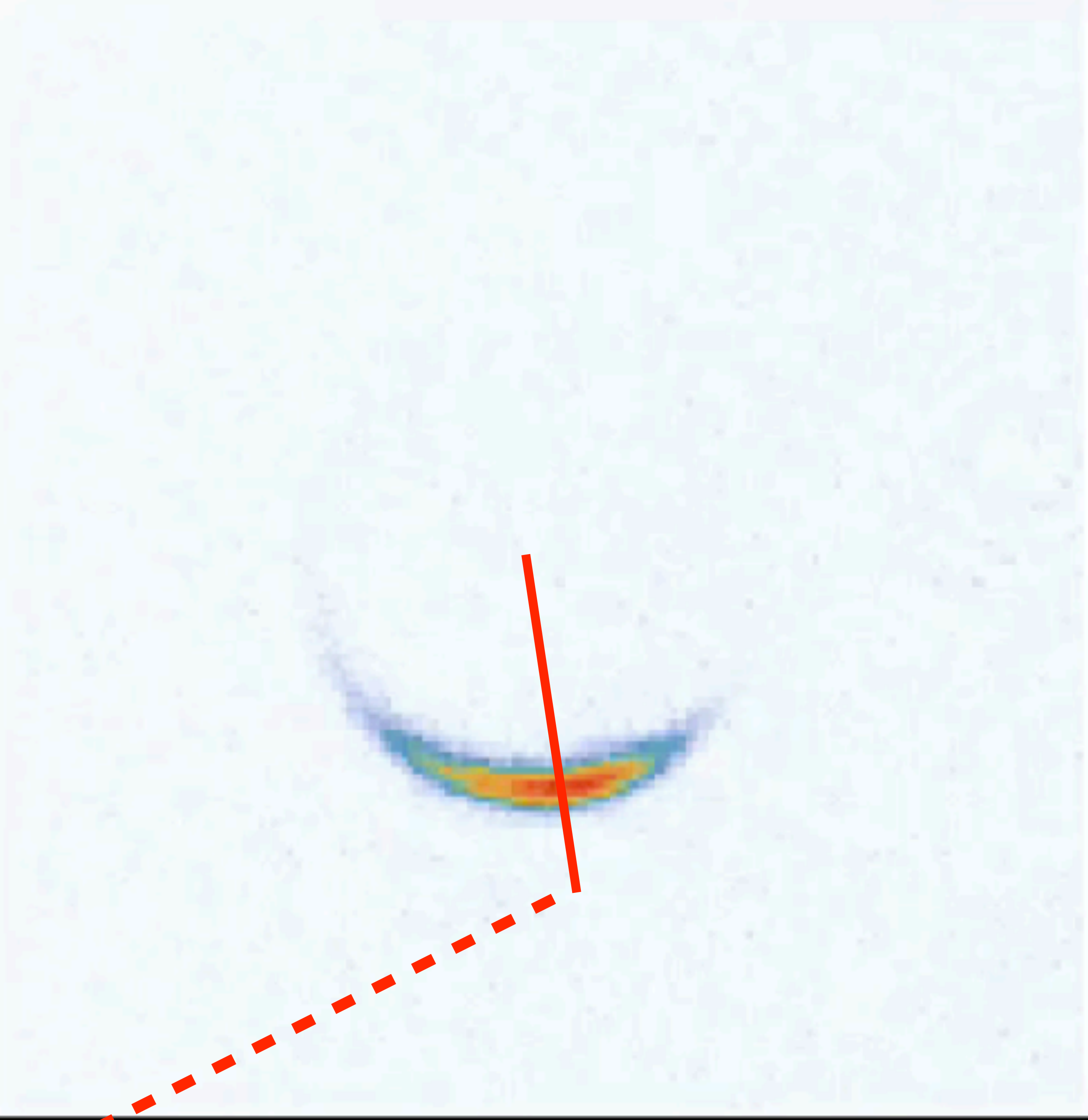
$$3 \times 10^{-275}$$

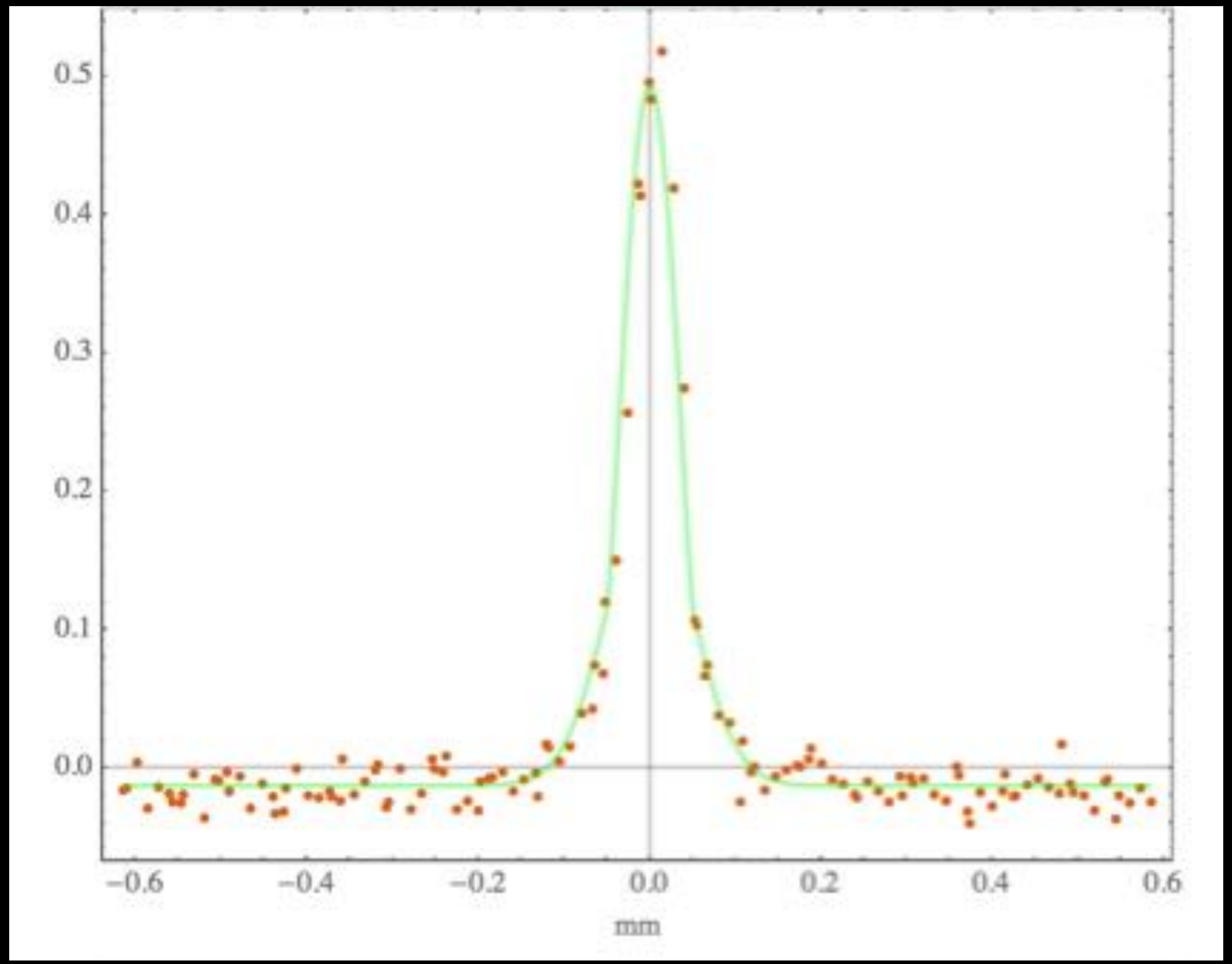
BEC in a Ring

1) MOT
2) Quadrupole-Trap
3) BEC in Dipole Trap
4) BEC in Ring

BEC in a Ring

1) MOT
2) Quadrupole-Trap
3) BEC in Dipole Trap
4) BEC in Ring
5) **Accelerate**





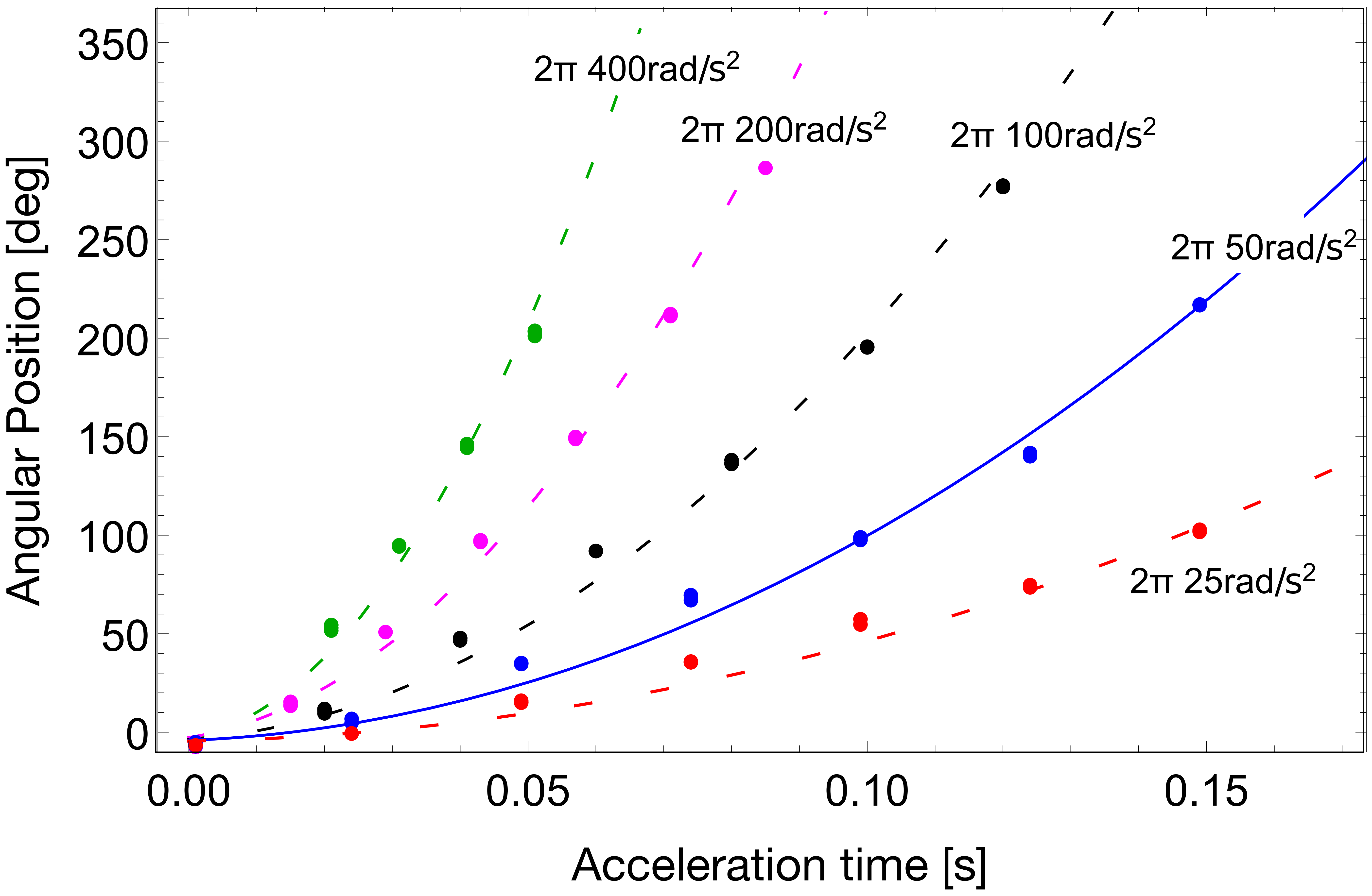
Bang-Bang Scheme of Optimal Control Theory

Chen et al. Phys. Rev. A **84,** 43415 (2011).

Acceleration of BECs in TAAP rings

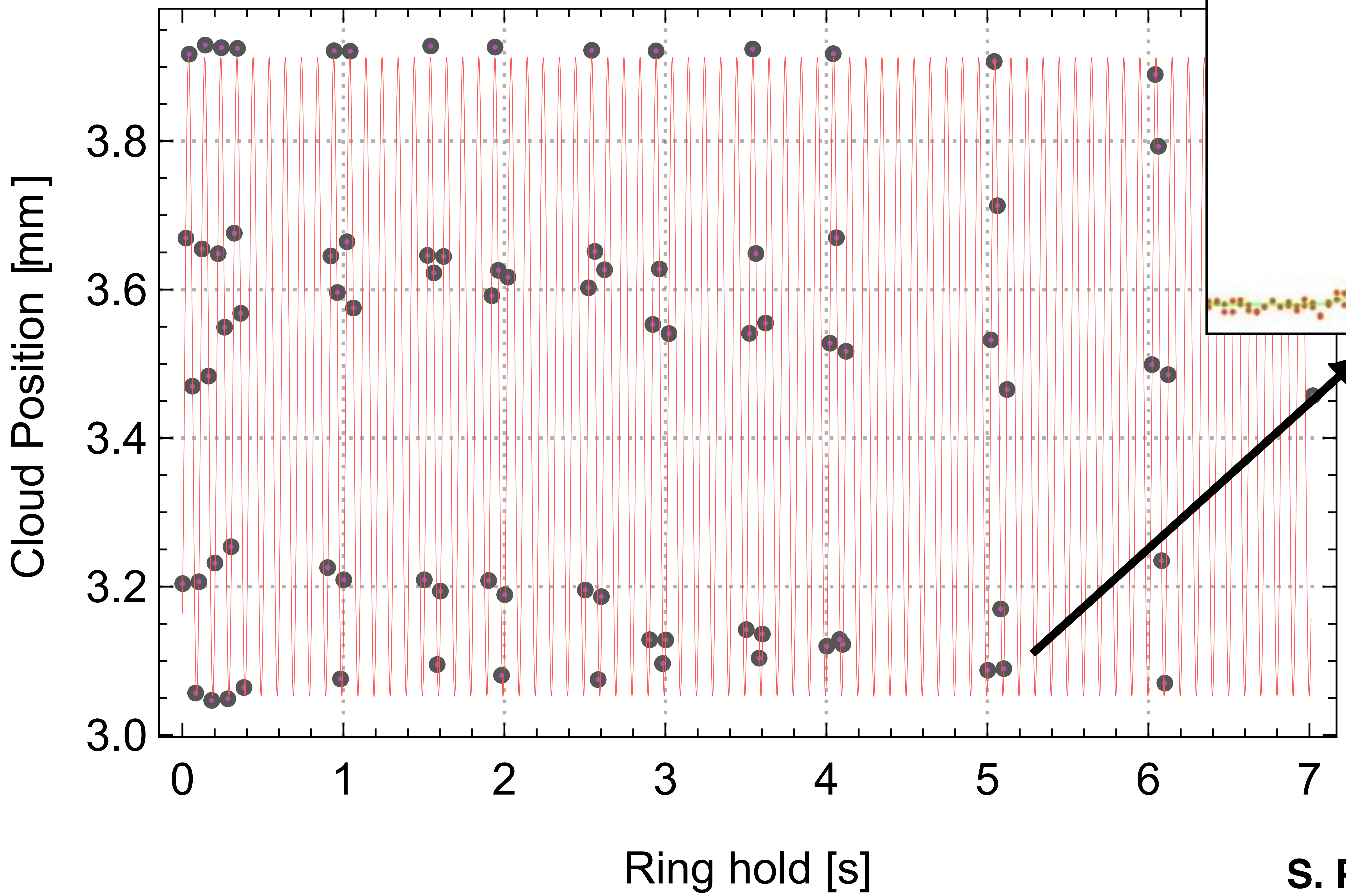
using the bang-bang scheme of optimal control theory

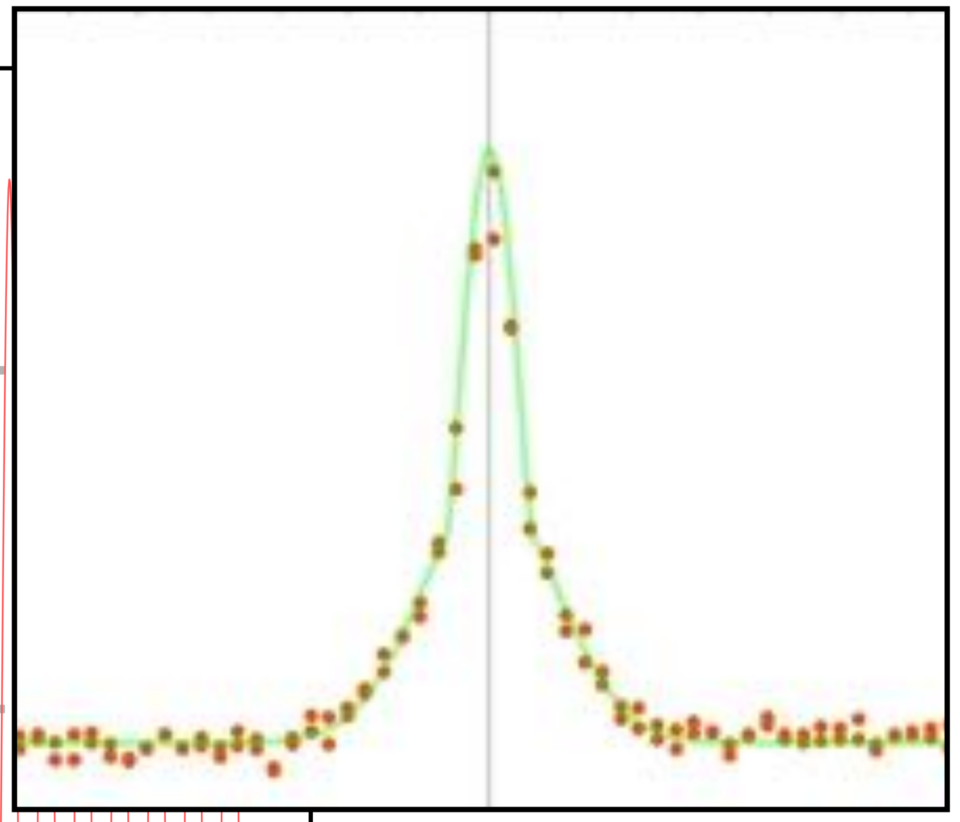
Chen et al. Phys. Rev. A **84,** 43415 (2011).



Hypersonic BEC in an accelerator ring

No extra heating !





$$v_c = \sqrt{\mu/m}$$

$$v = 30\,\text{mm/s}$$

v = Mach 16

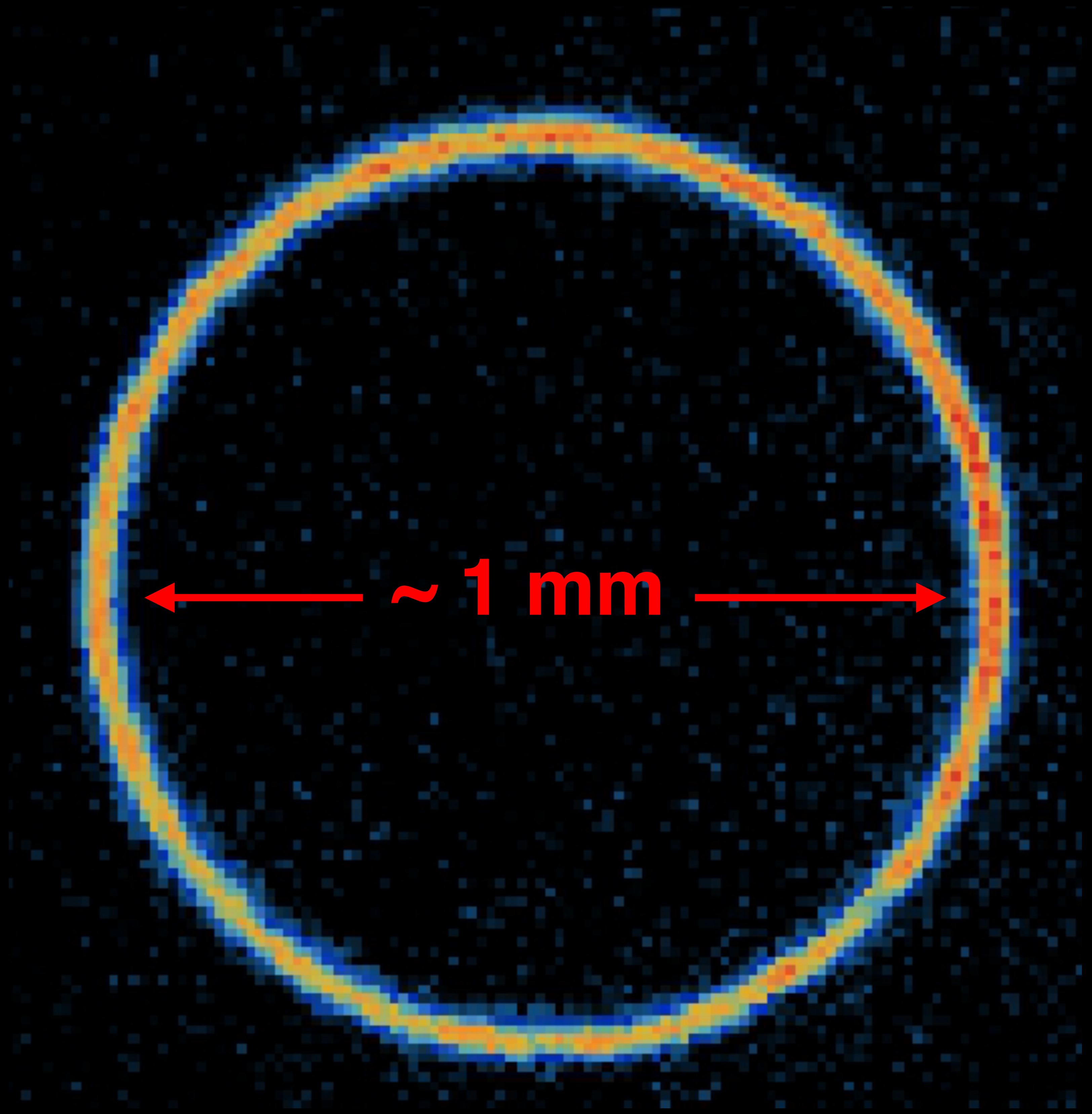
S. Pandey et al. *Nature*, in press

Ring Accelerator

Expansion of a rotating BEC in the ring

Ring Accelerator

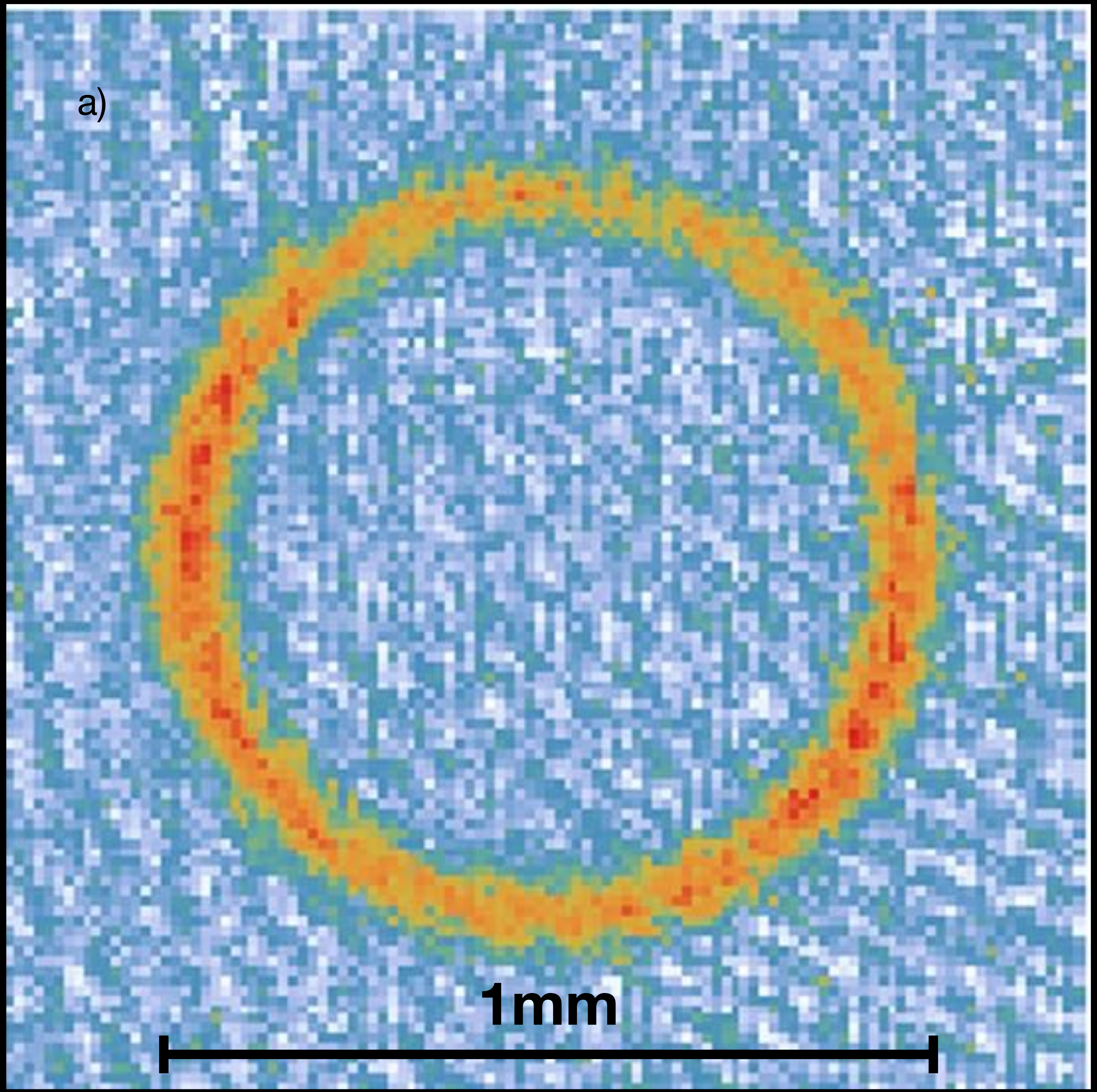
80 000 atoms with 40 000 $\hbar$ / atom



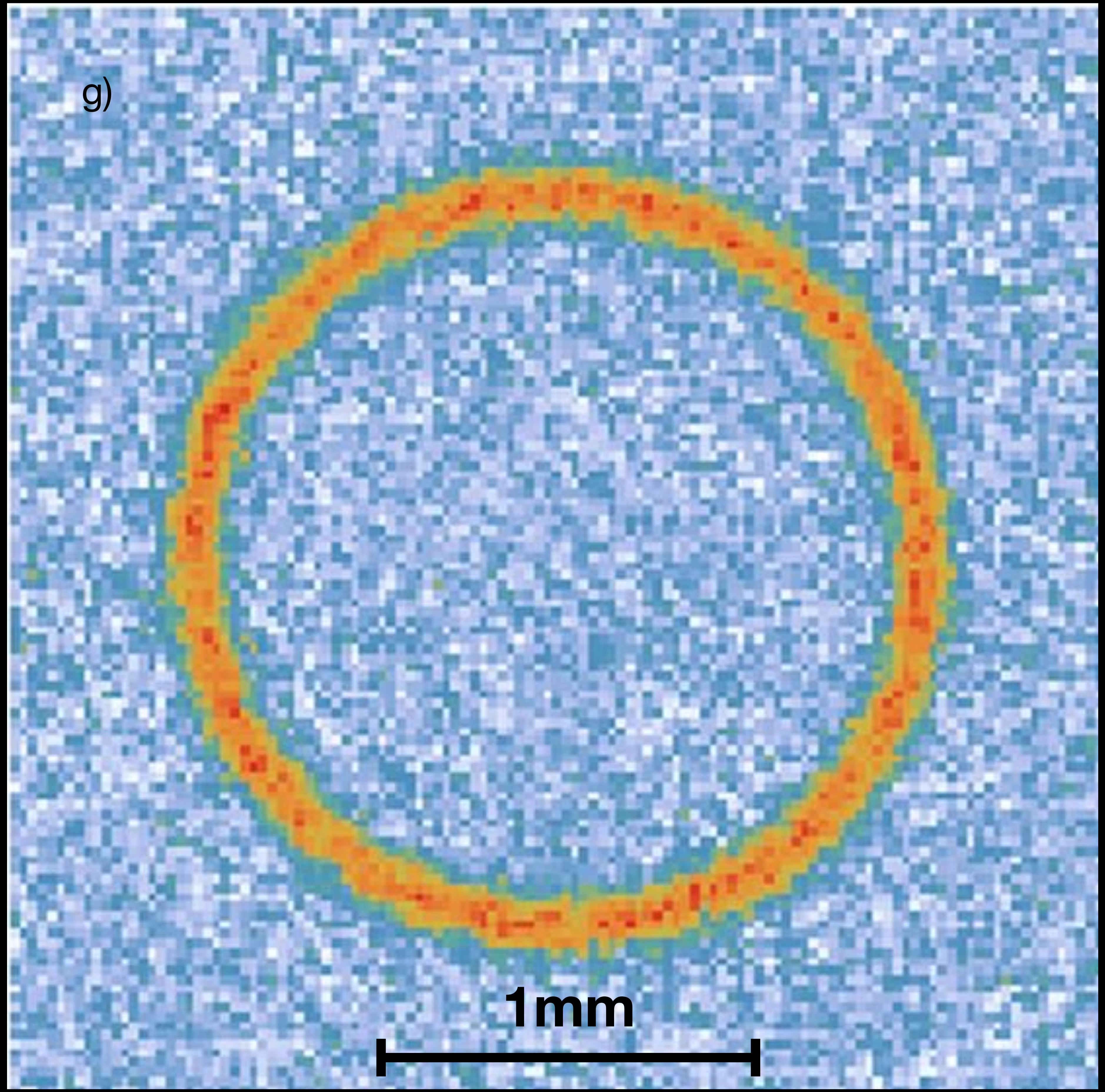
Effective Flatness of the waveguide:

189 pK = 2 nm

Static vs Supersonic atoms

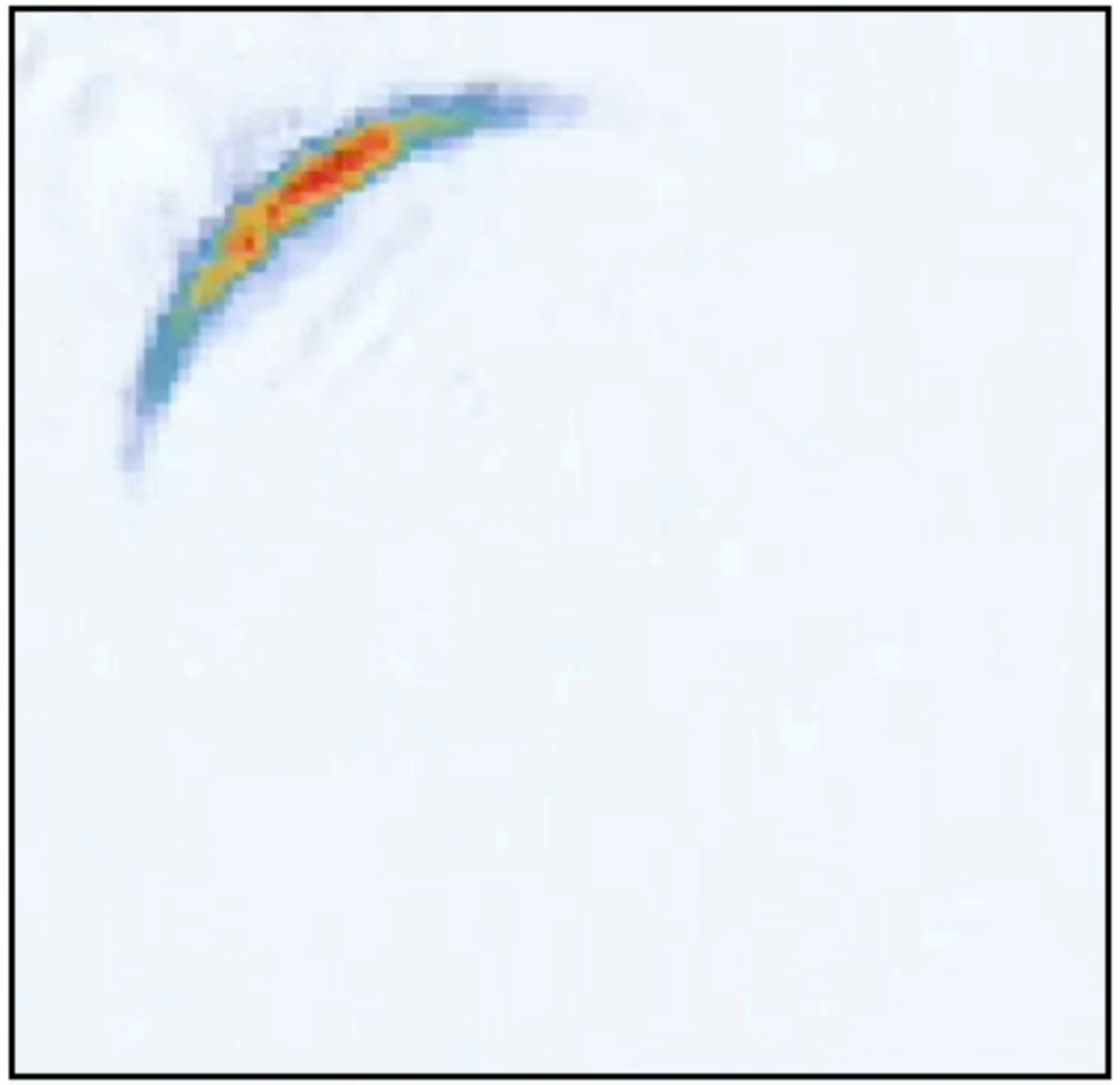


Flatness < 250 nK

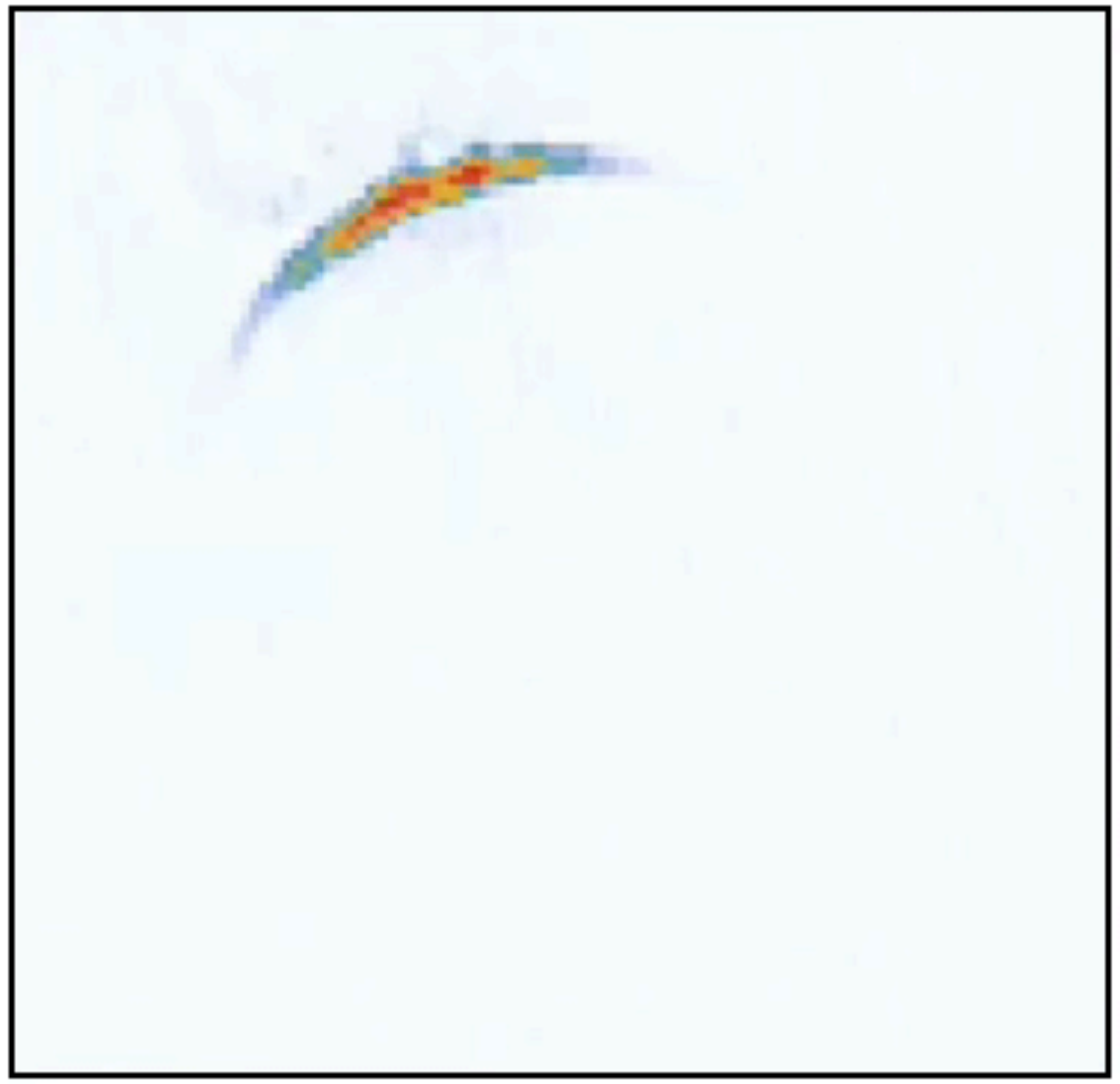


Flatness < 189 pK

Optimal Control
Atom-Optics

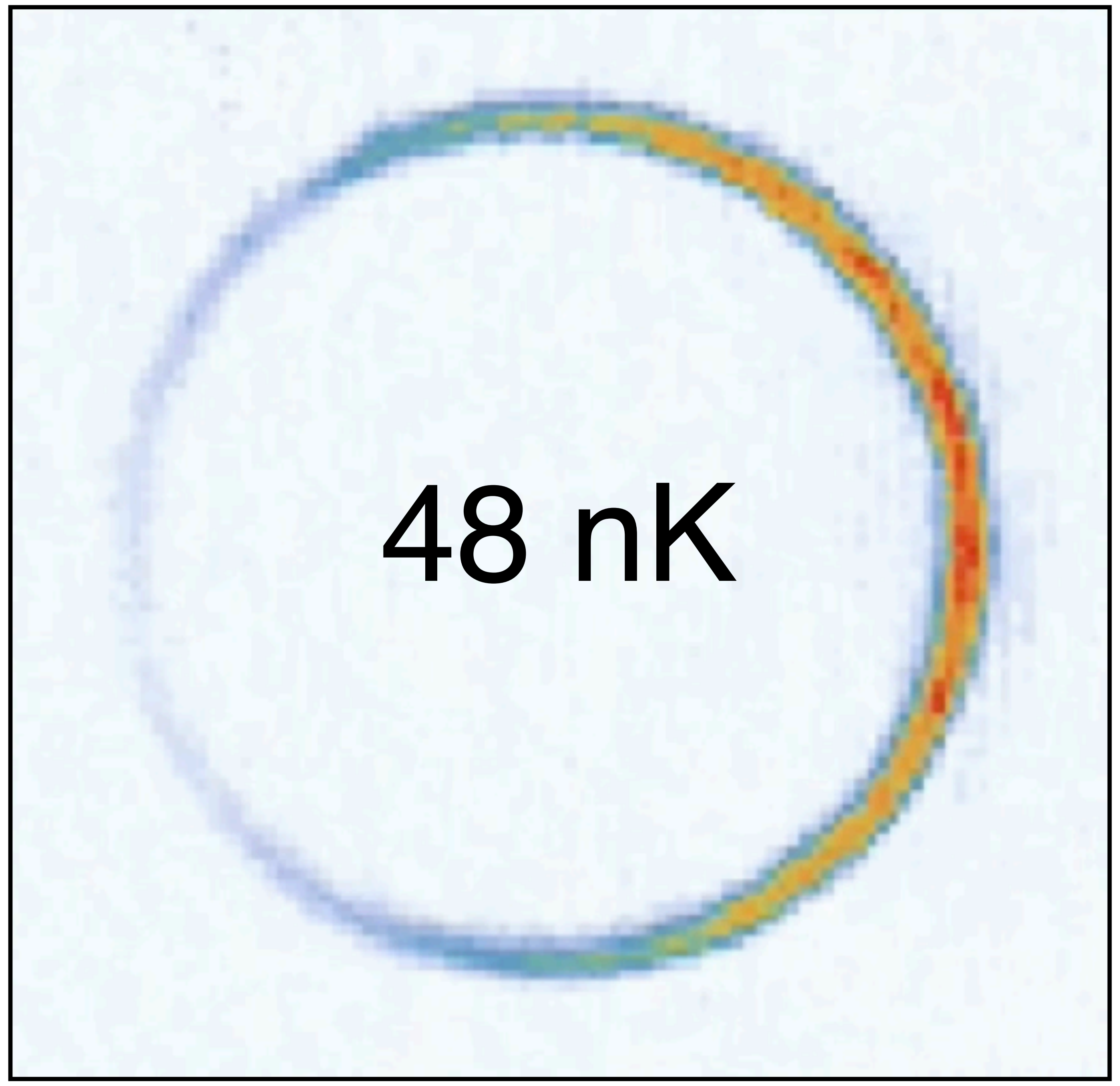


Free expansion

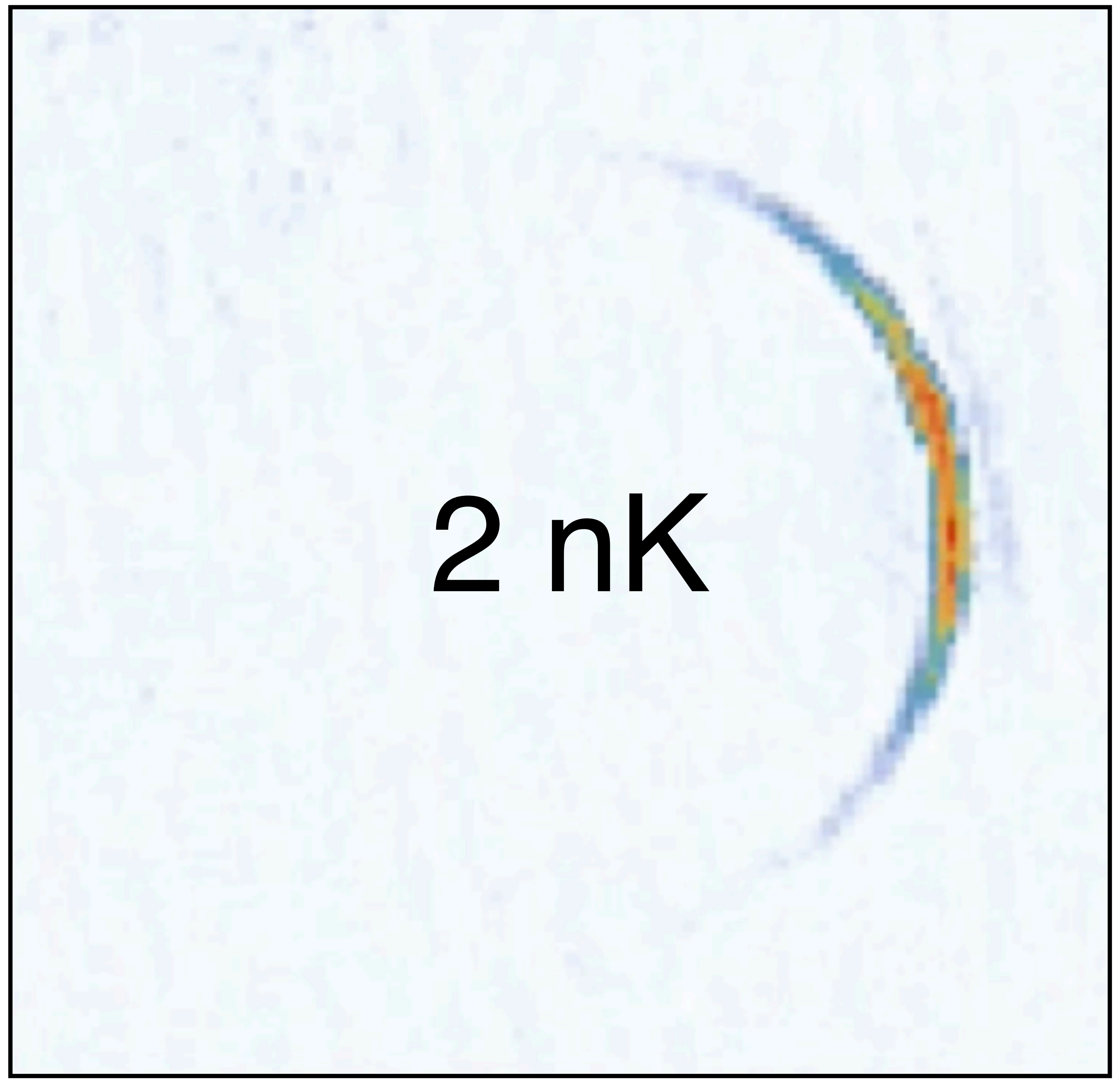


Delta Kick

Optimal Control Atom-Optics

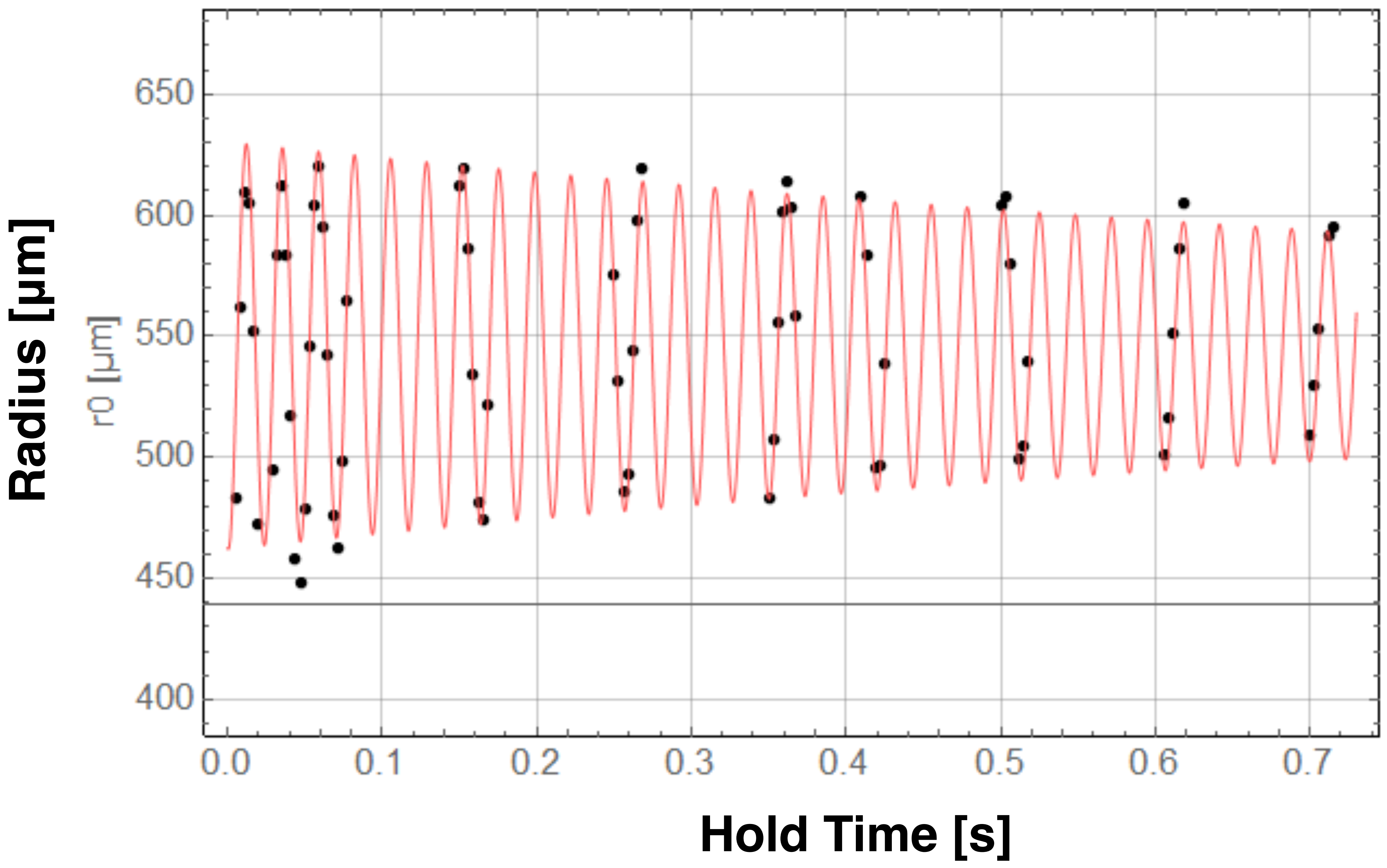


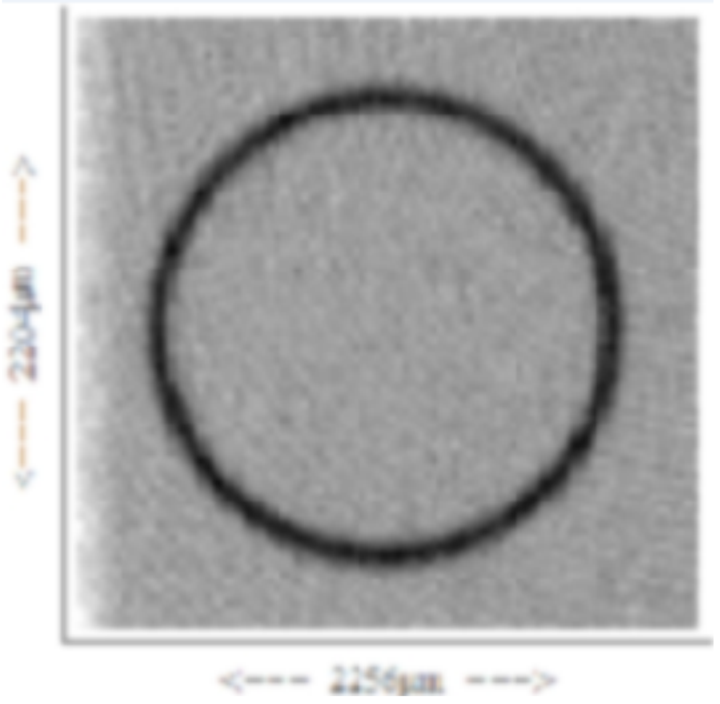
Free expansion



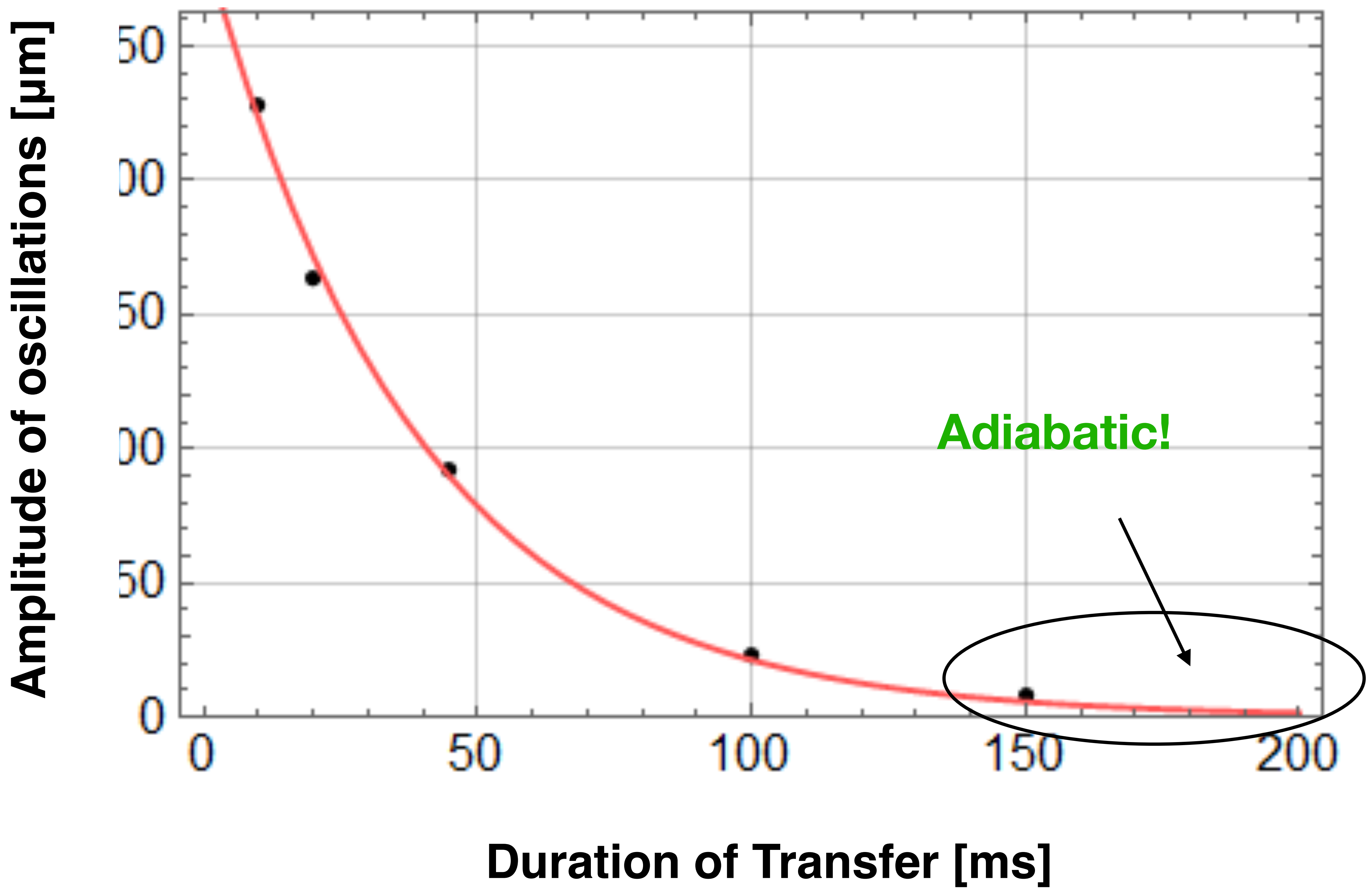
Delta Kick

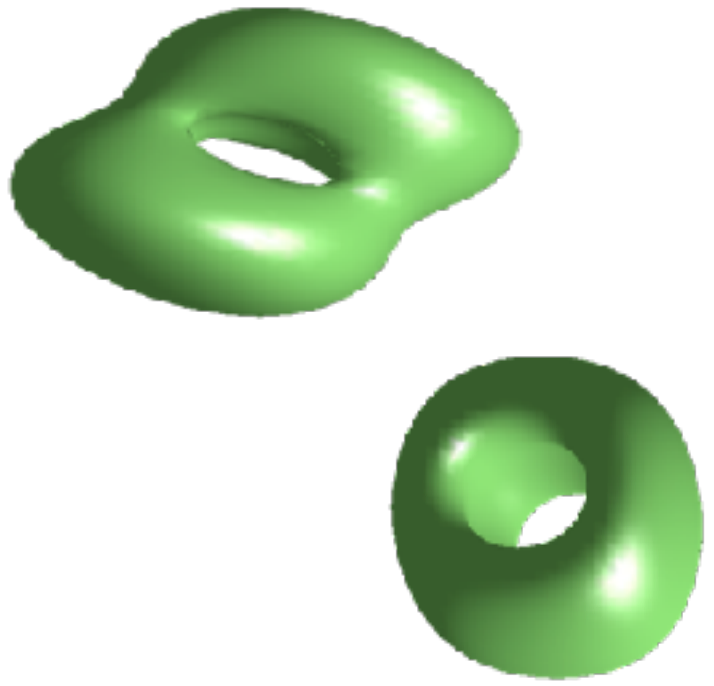
Loading Rotating BECs in to a Shell



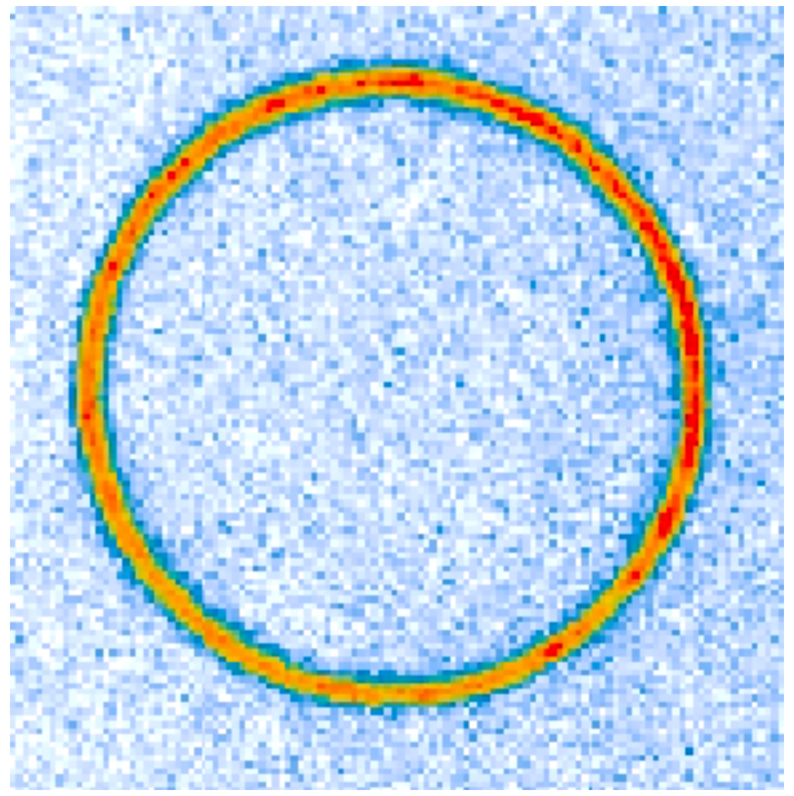


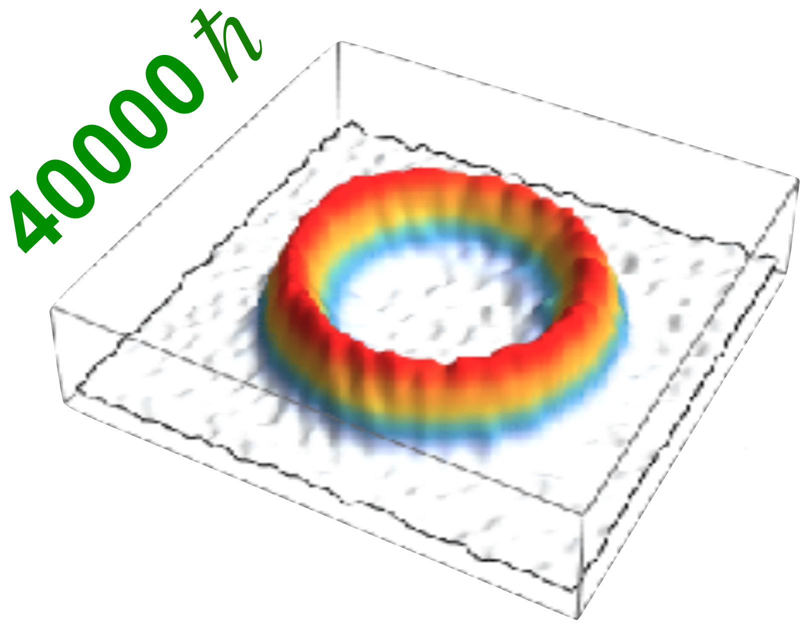
BECs in a shell
at 50nK



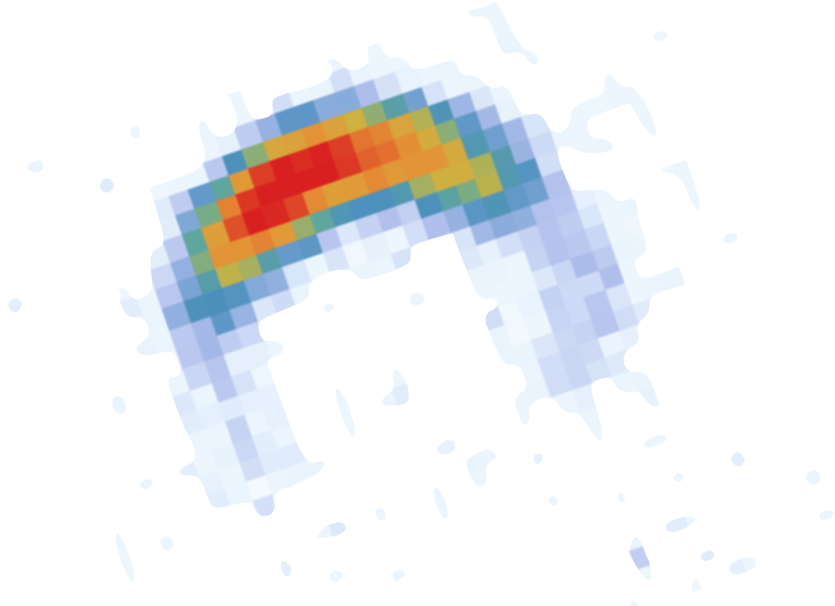


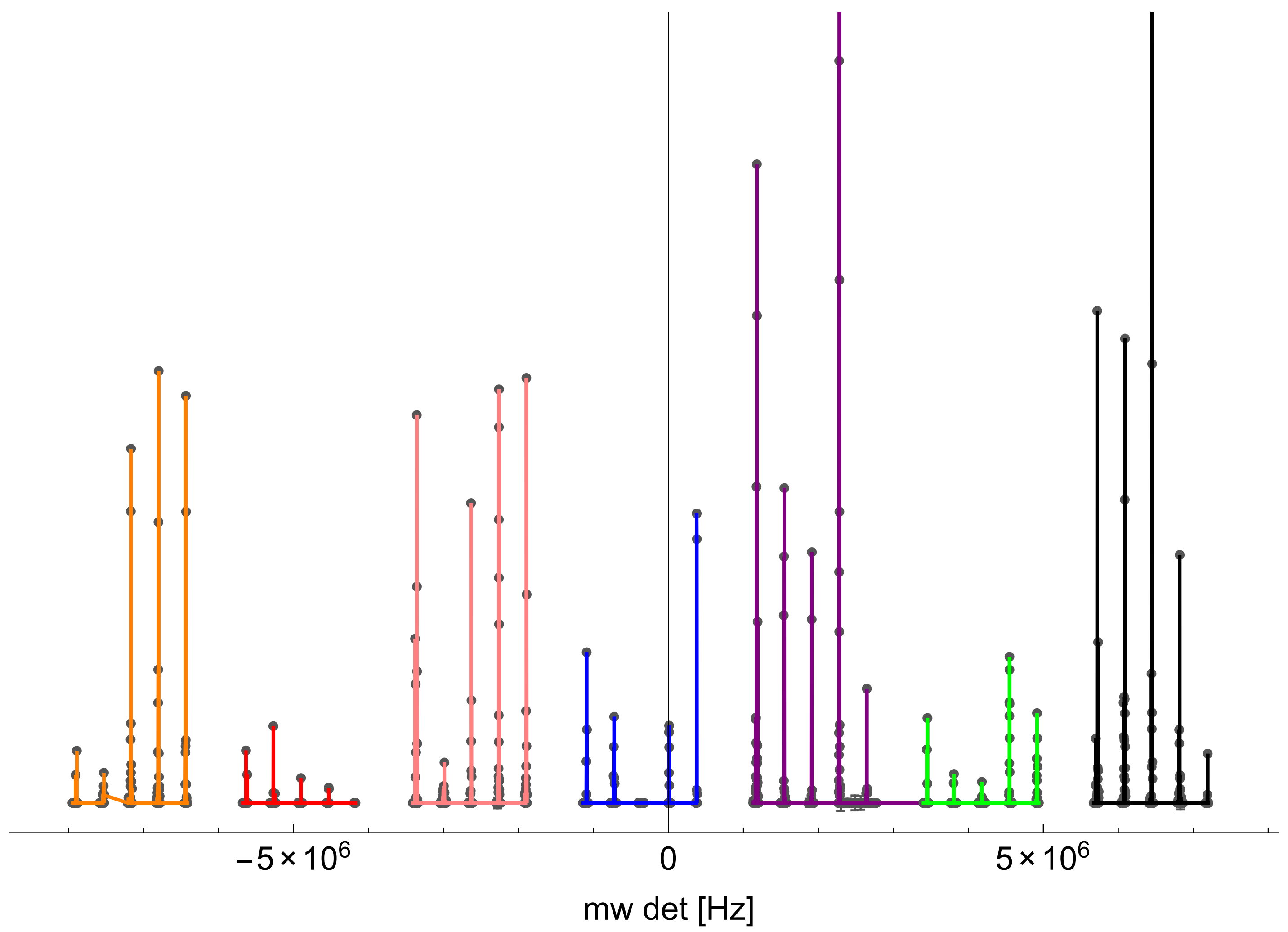
Summary



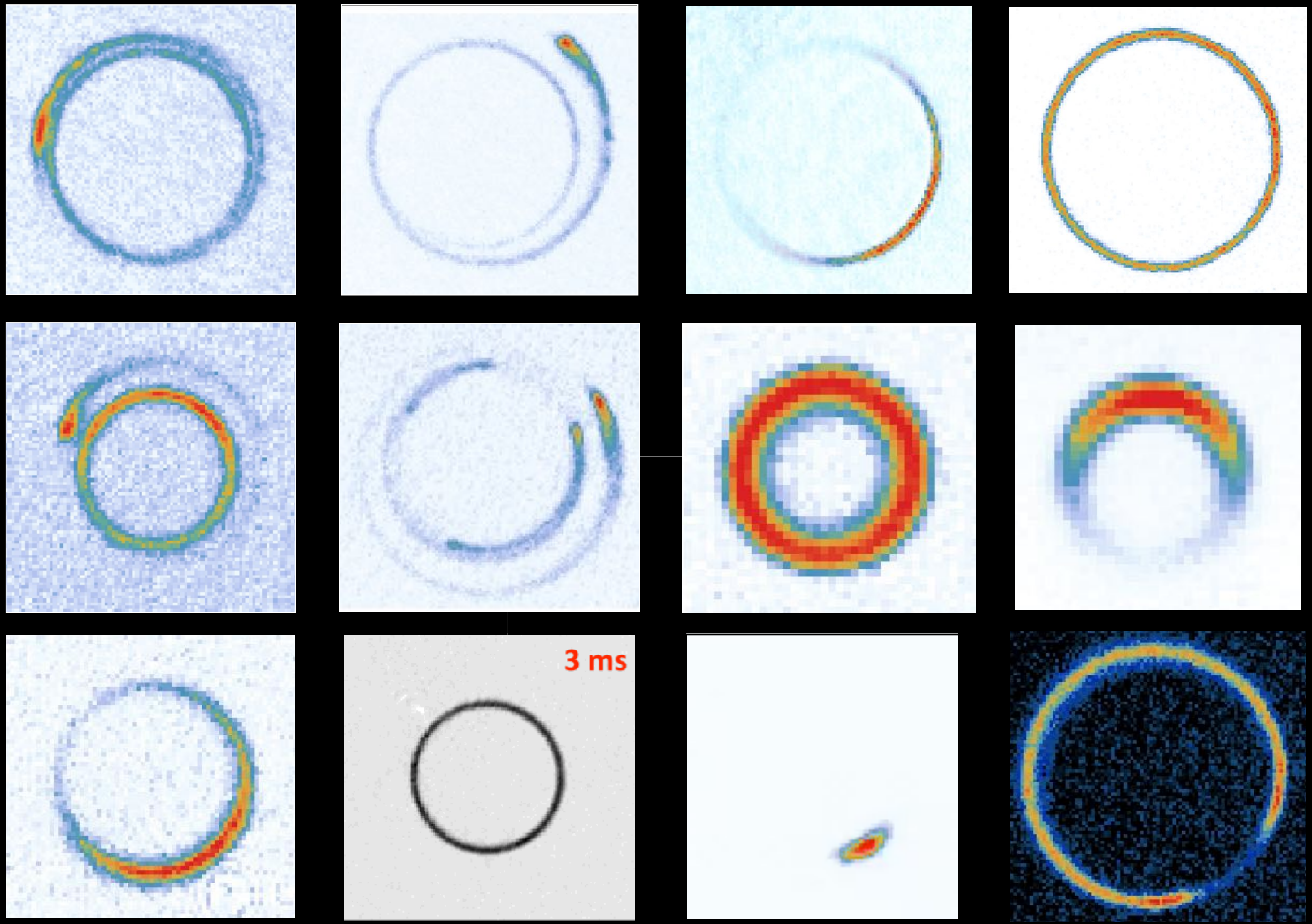


- Matterwave accelerator ring
- Lossless Hypersonic flow of BECs
- Optimal Control
- Ultra-high angular Momentum
- Atomtronics (Delta-Kick)
- State dependent control of multi-component BECs





Atomtronic Ring Physics



Pandey et al @ Nature 2019