FORTH

CRETANMATTERWAVES

Bubble Rings

Wolf von Klitzing

06/05/2022

FET

FUTURE & EMERGING TECHNOLOGIES scheme

NanoLace

Marie Curie-Excellence MatterWaves

FET

FUTURE & EMERGING TECHNOLOGIES scheme

MatterWave

Marie Curie-Excellence MatterWaves

ΕΣΠΑ 2014-2020

ανάπτυξη - εργασία - αλληλεγγύη

esa

3 ESA-OBST

AtomQT

cost

EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Bubble Rings

FORTH

CRETANMATTERWAVES

PostDoc

Giannis Drougakis

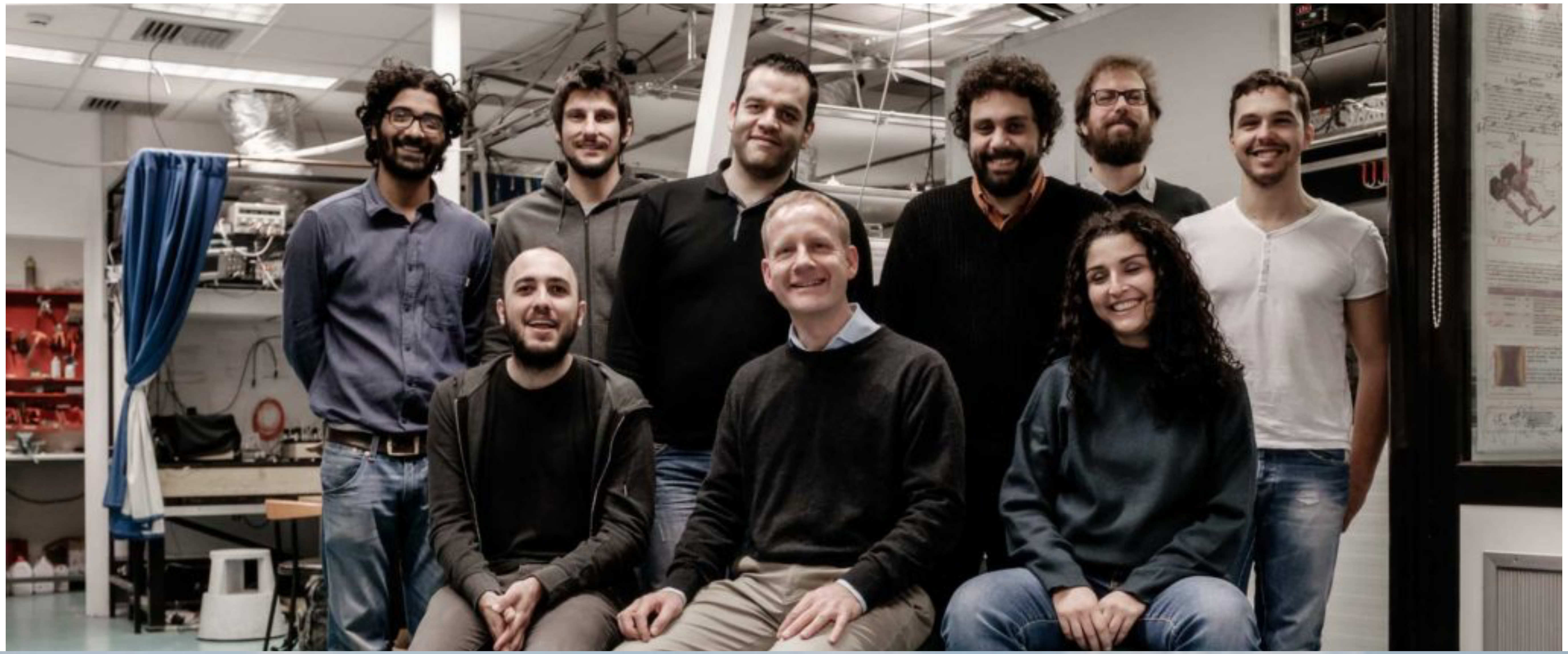
Faculty

Georgios Vasilakis

Konstantinos Makris

Dimitris Papazoglou

Wolf von Klitzing



PhD Students

Vishnupriya Veettil

Vidhu Catherine Antony

Apostolos Brimis

Pandora Examilioti

Vinay Pareek

(Saurabh Pandey)

(Hector Mas)

FET

FUTURE & EMERGING TECHNOLOGIES scheme

NanoLace

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EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

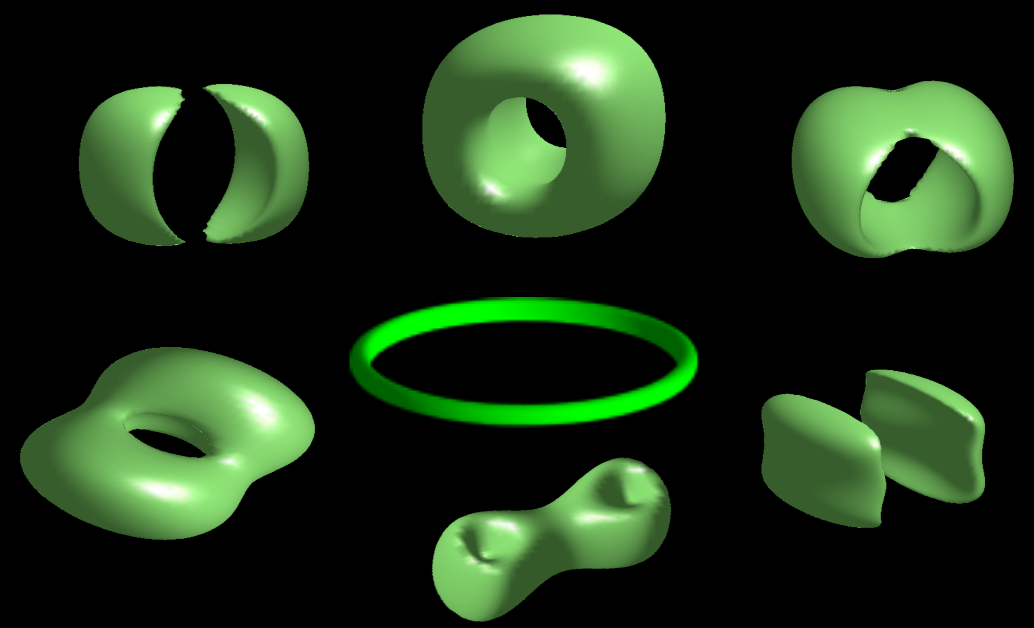
CRETANMATTERWAVES

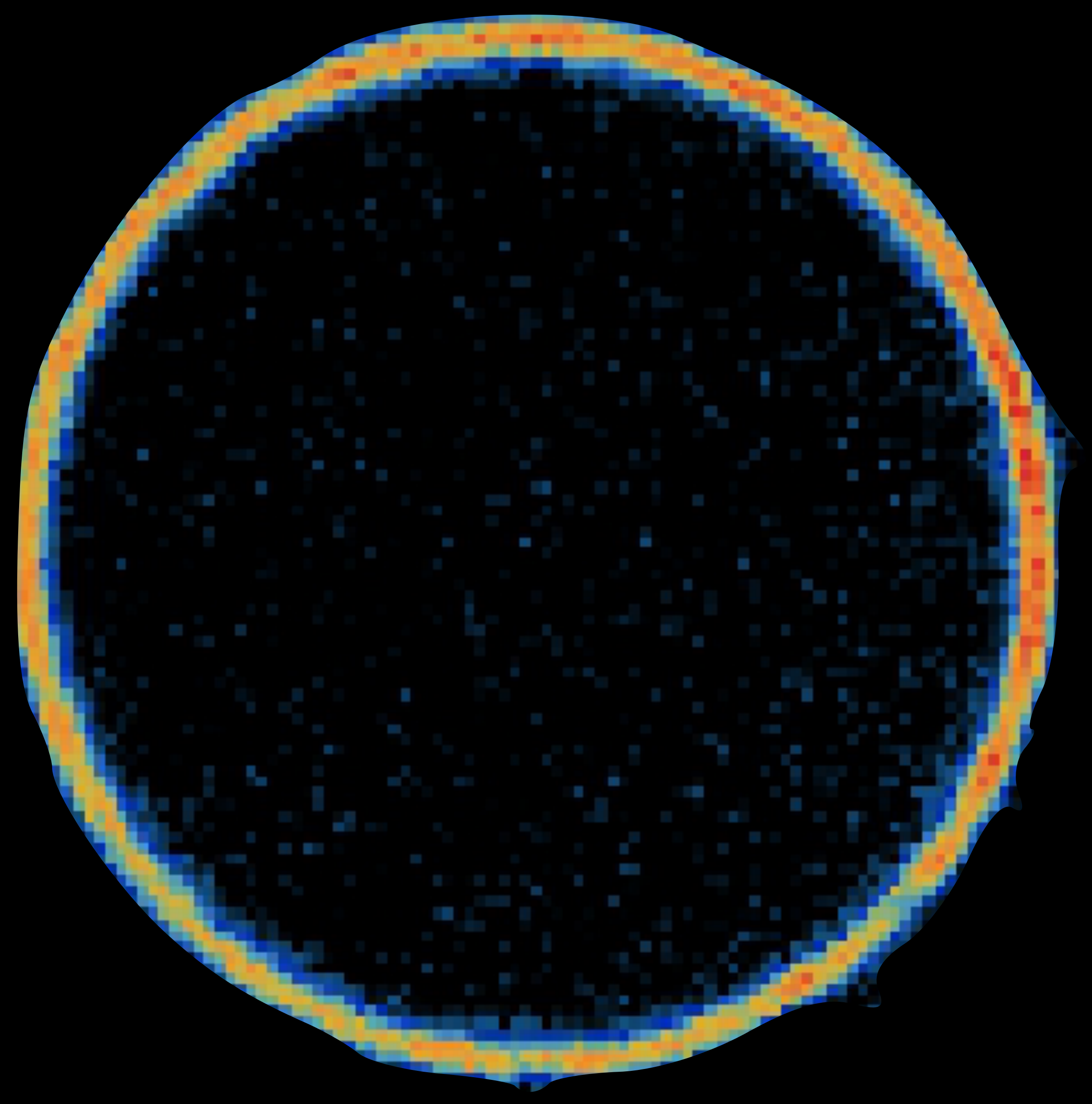
FORTH
INSTITUTE OF ELECTRONIC STRUCTURE AND LASER

BEC and MatterWaves at IESL-FORTH

Guided Matter-Wave Interferometry

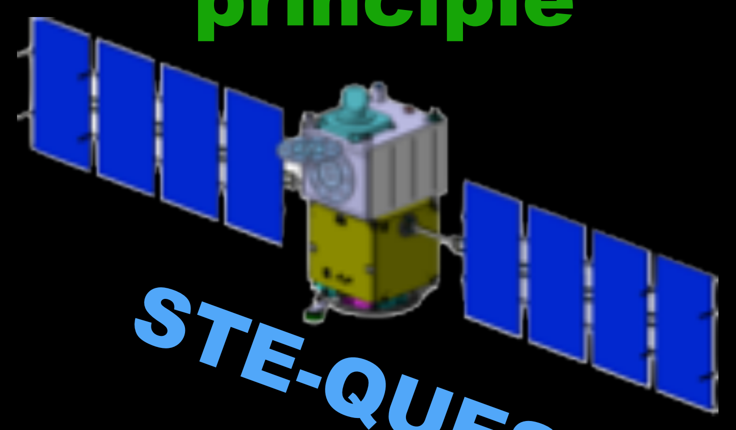
Guided for Matter-Wave Interferometry for inertial navigation





Large Interferometers

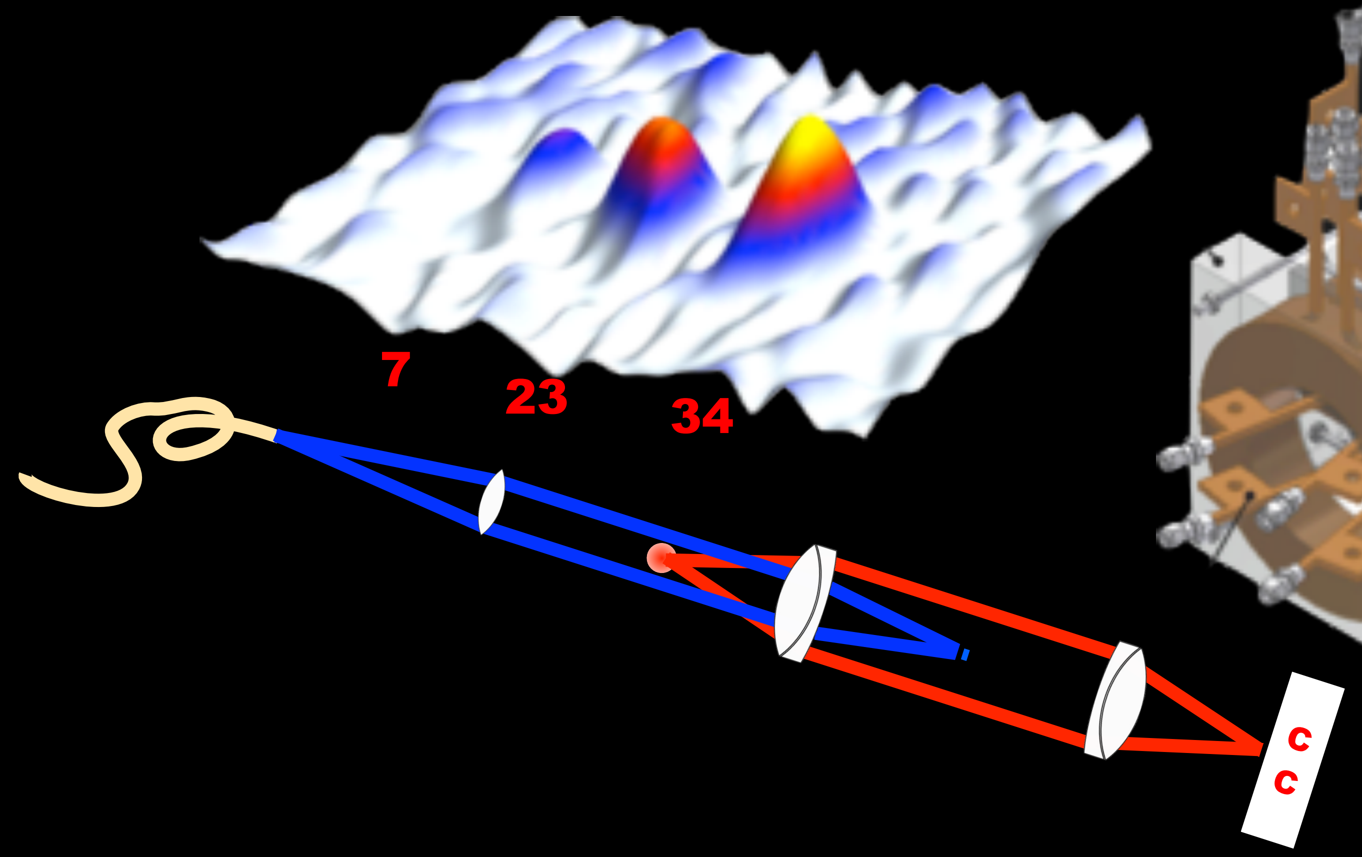
BEC in Space: Testing Einstein's Weak equivalence principle

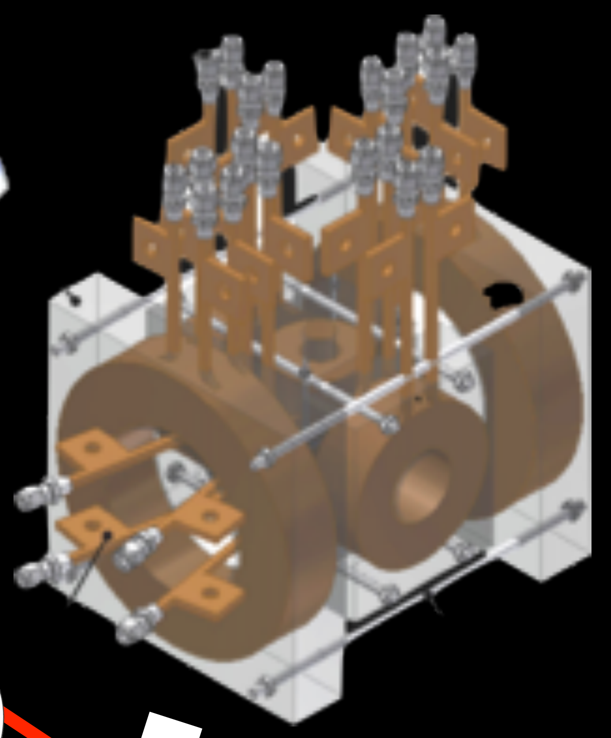


STE-QUEST

Space Clocks:
SAGE

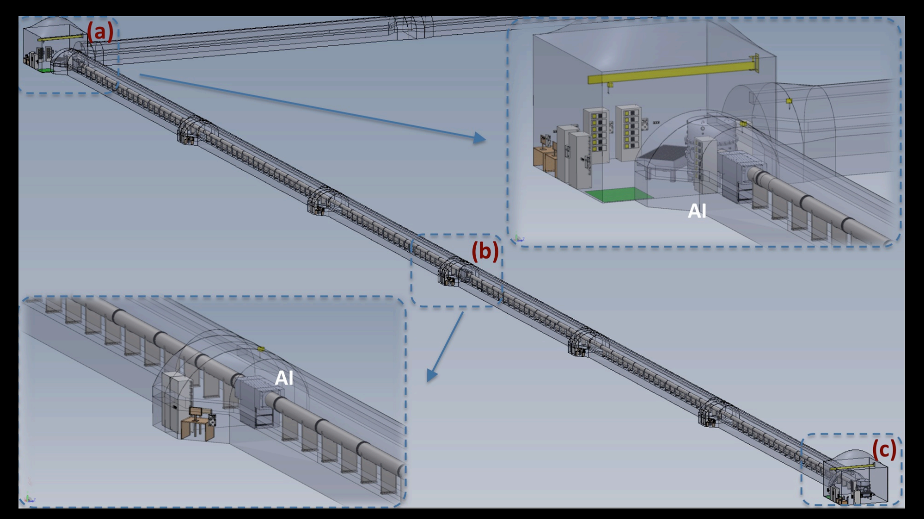
Matter-Wave & Quantum Tools





Atom Space Technologies:
OBST 1 & 2

Very long Baseline Matterwave interferometry



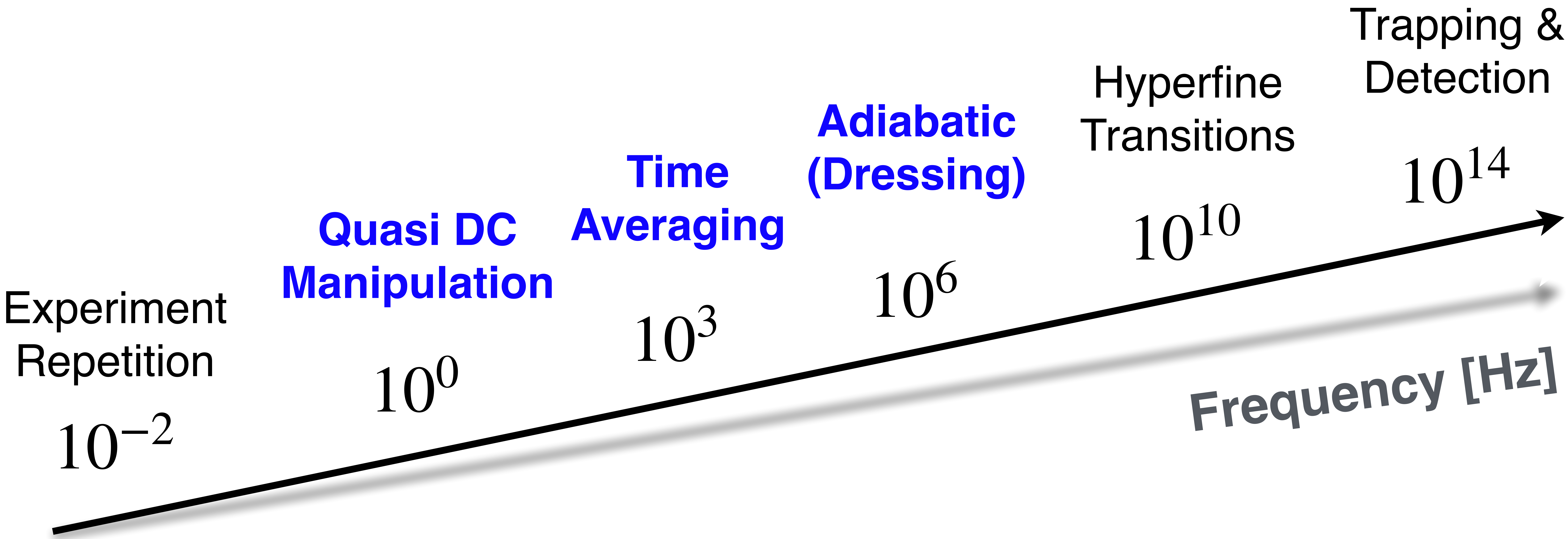
ELGAR

Time averaged Adiabatic Averaged Potentials (TAAP)

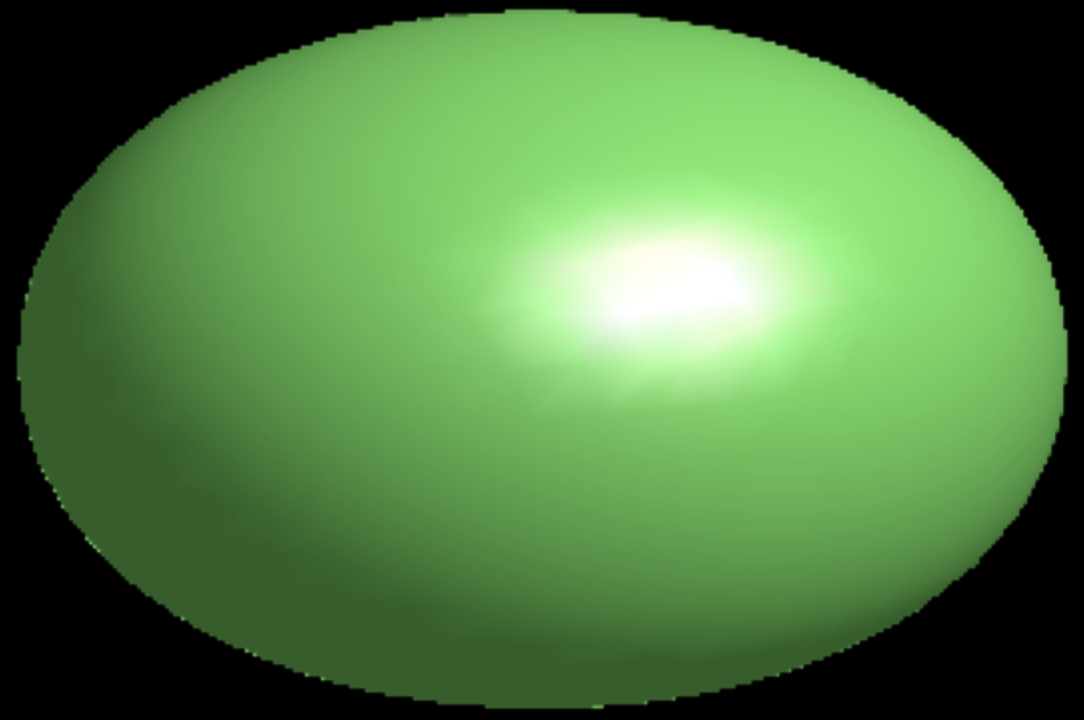
ω_{Trap} ω_{Larmor}

Quasi Static	**Time-Averaging**	**Adiabatic Potentials**
~ DC	Audio	RF
		Bubble Traps :-)

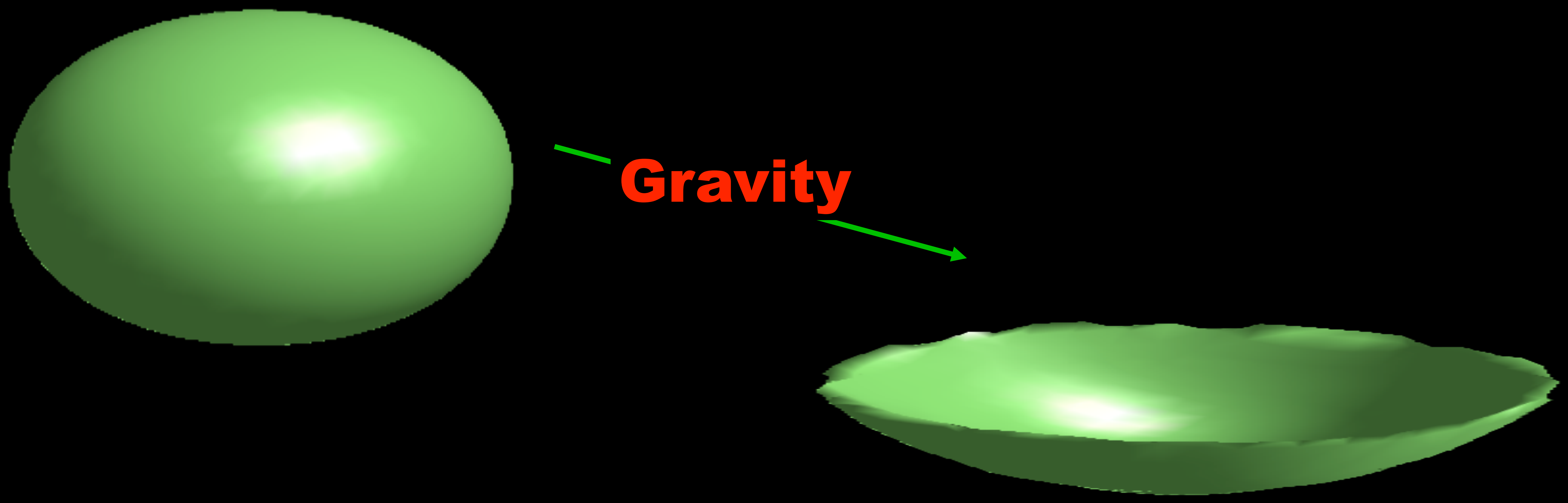
Atomtronic Time Scales



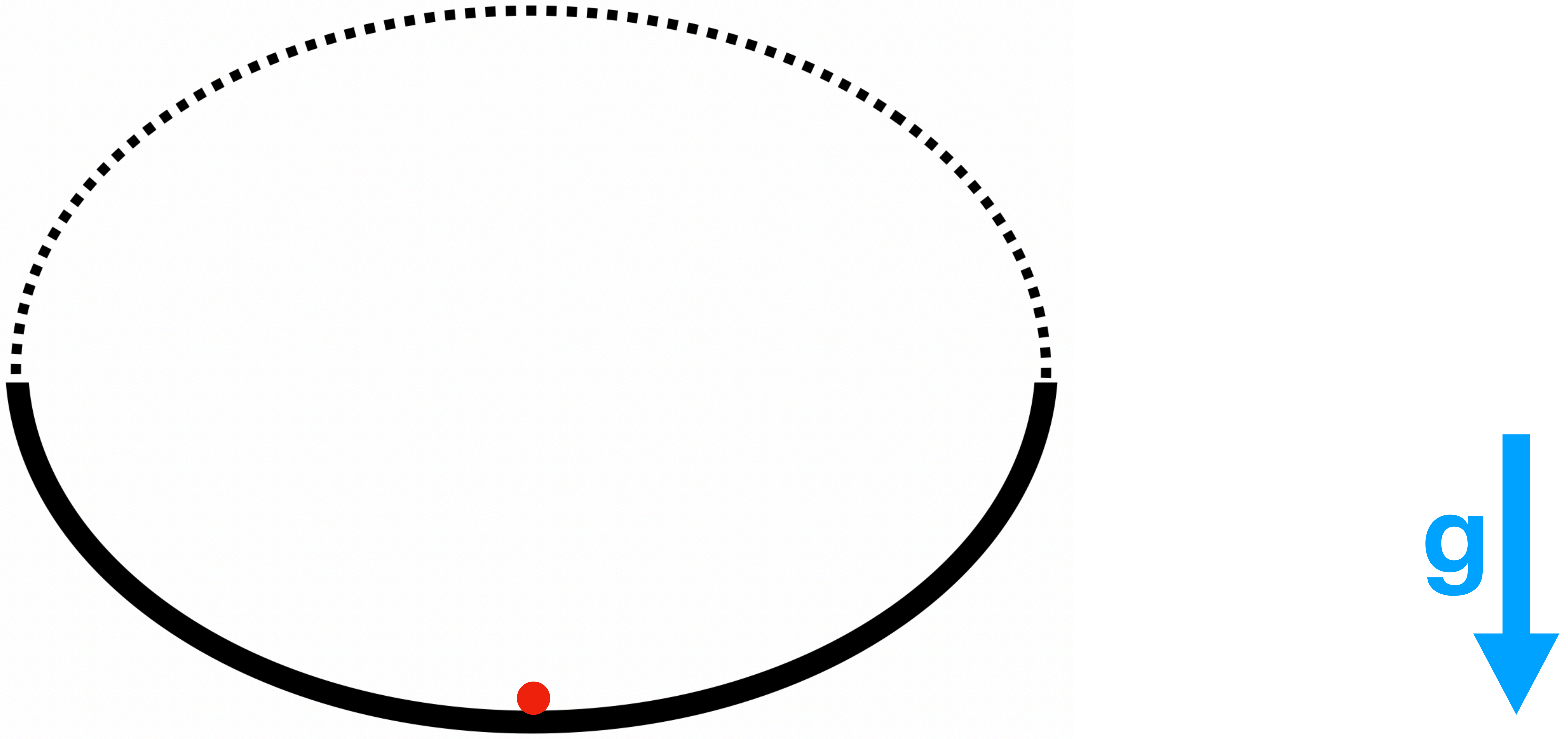
Adiabatic Potentials



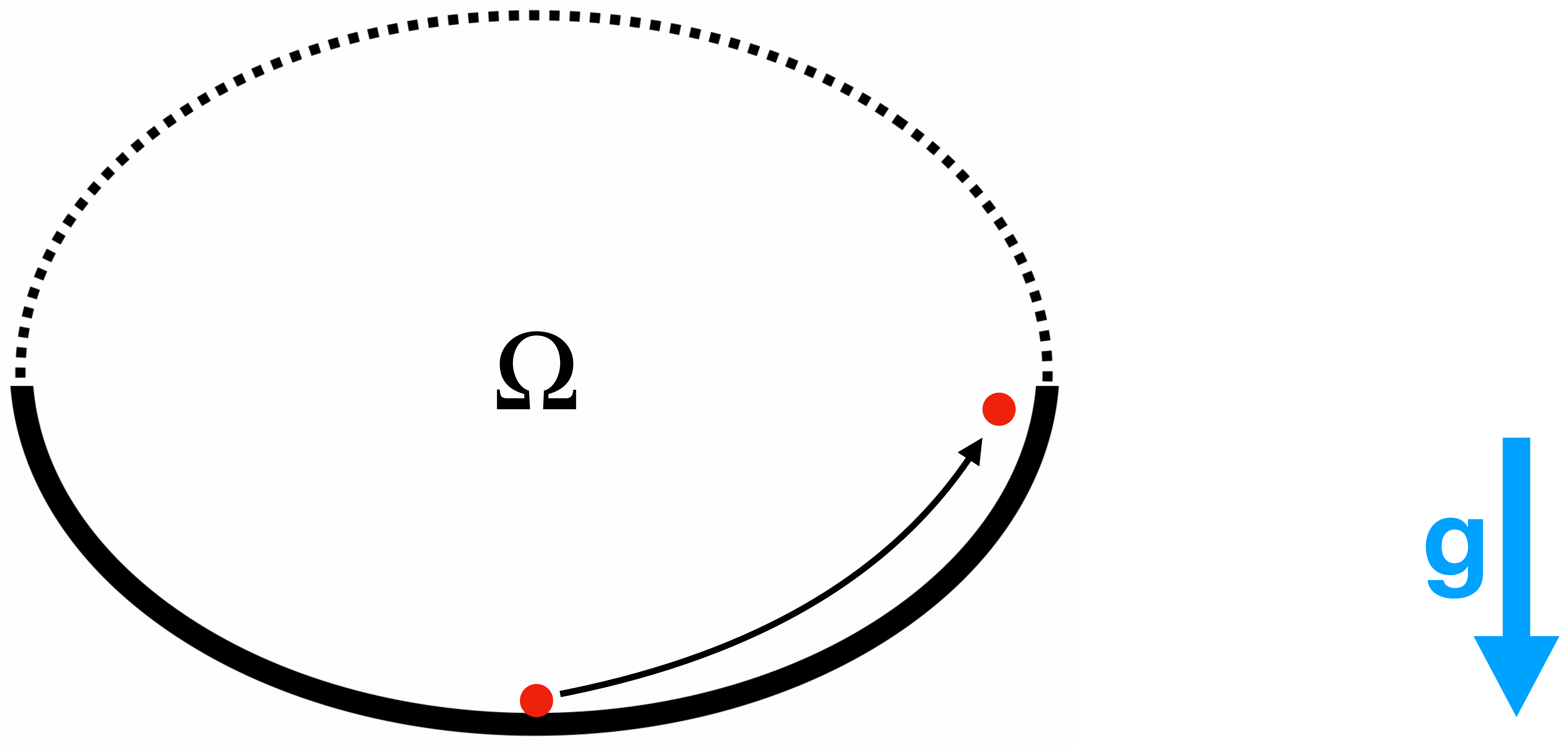
Adiabatic Potentials



Bubble in Gravity

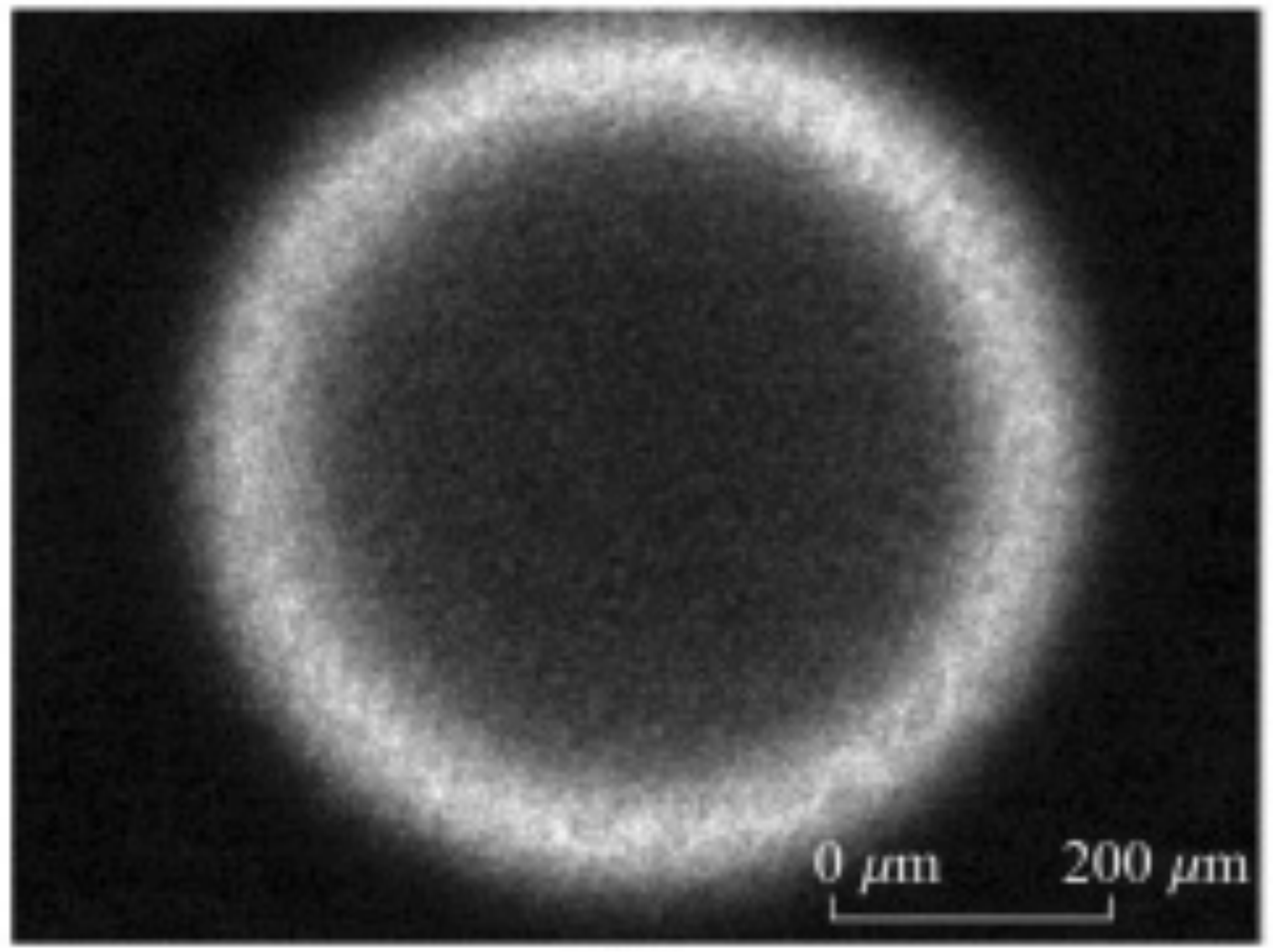


Bubble in Gravity

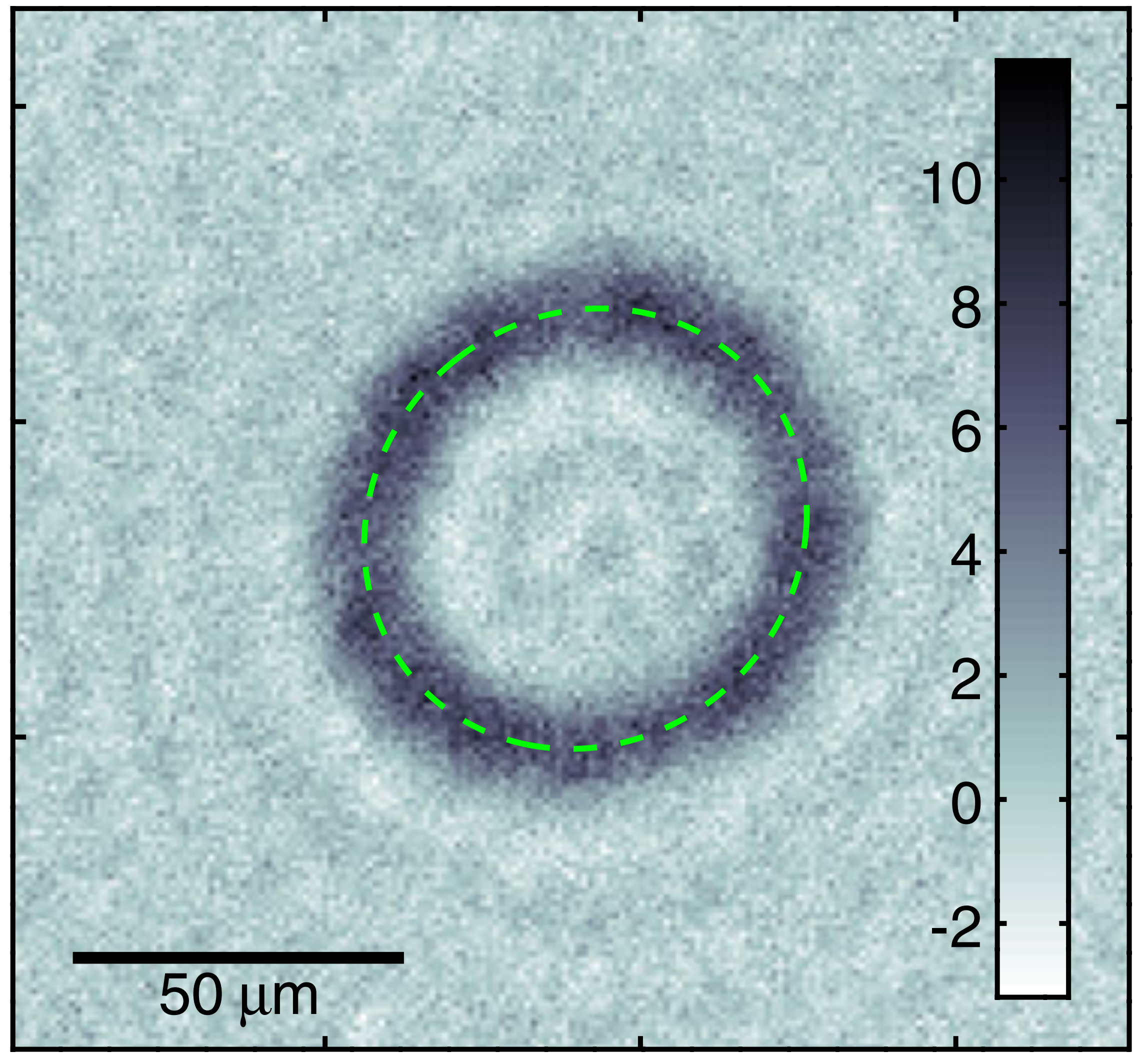


Bubble Rings

Self-supporting ring in bubble traps



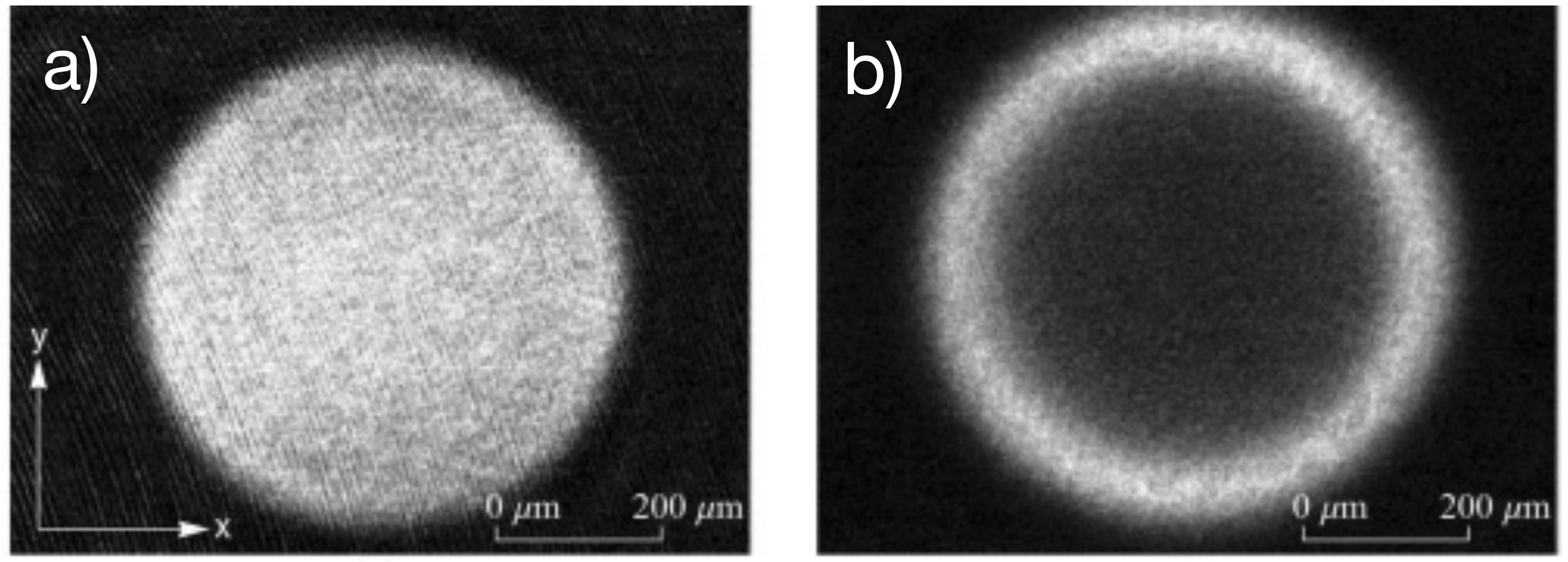
B. E. Sherlock et al.
Phys. Rev. A **83:4** 043408 (2011)



Yuanyuan Guo et al.
Phys. Rev. Lett. 124:2 (2020)

Computed TAAP with rotating polarization

Absorption Images
a) with and without b) angular momentum



B. E. Sherlock et al.
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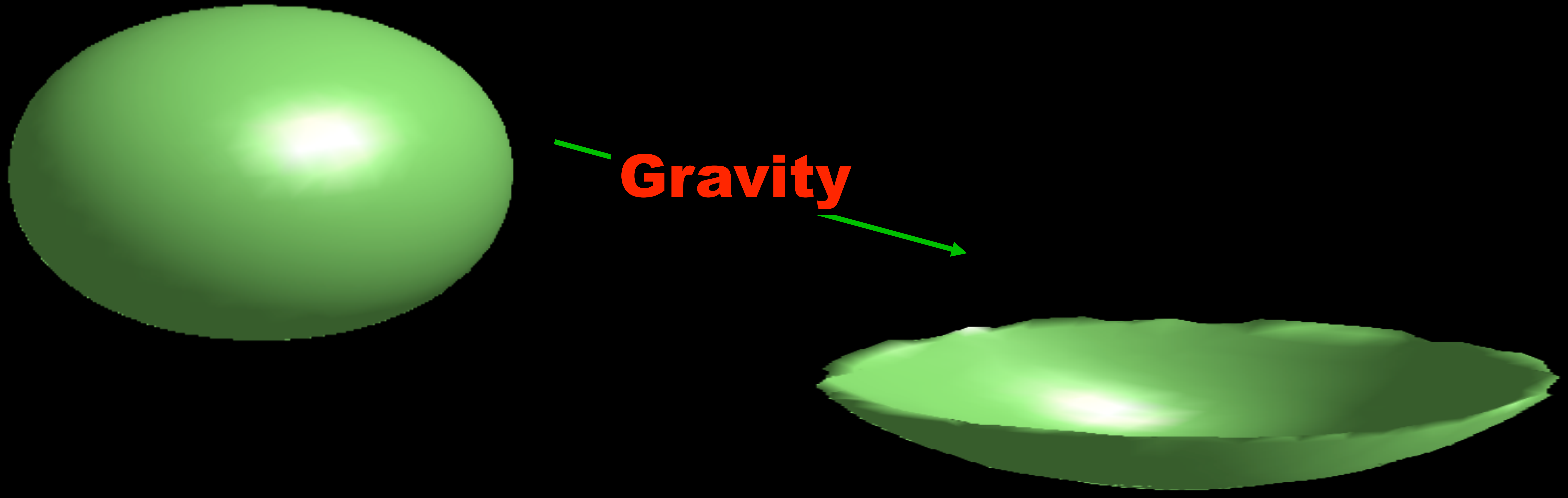
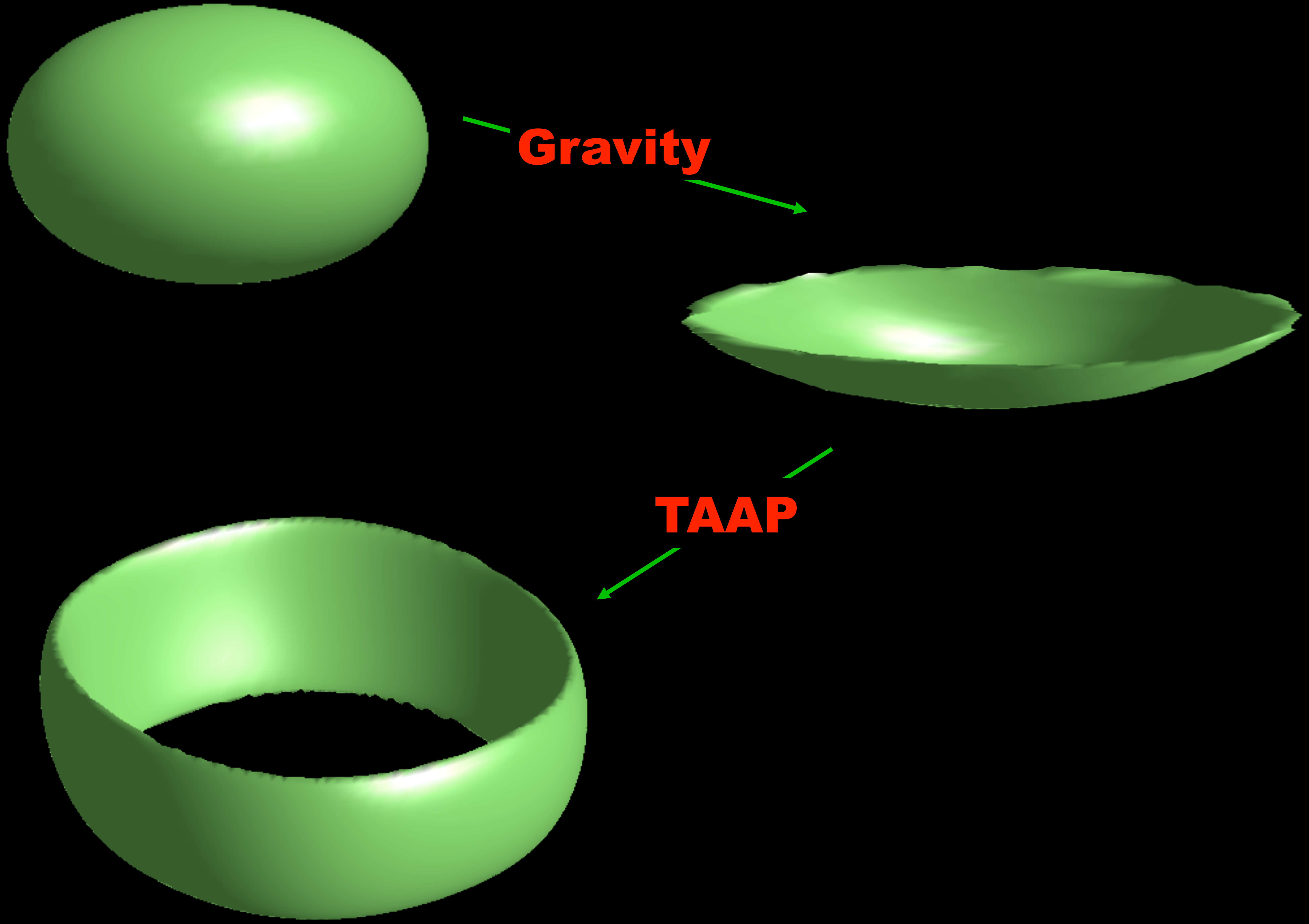
Time averaged Adiabatic Averaged Potentials
(TAAP)

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

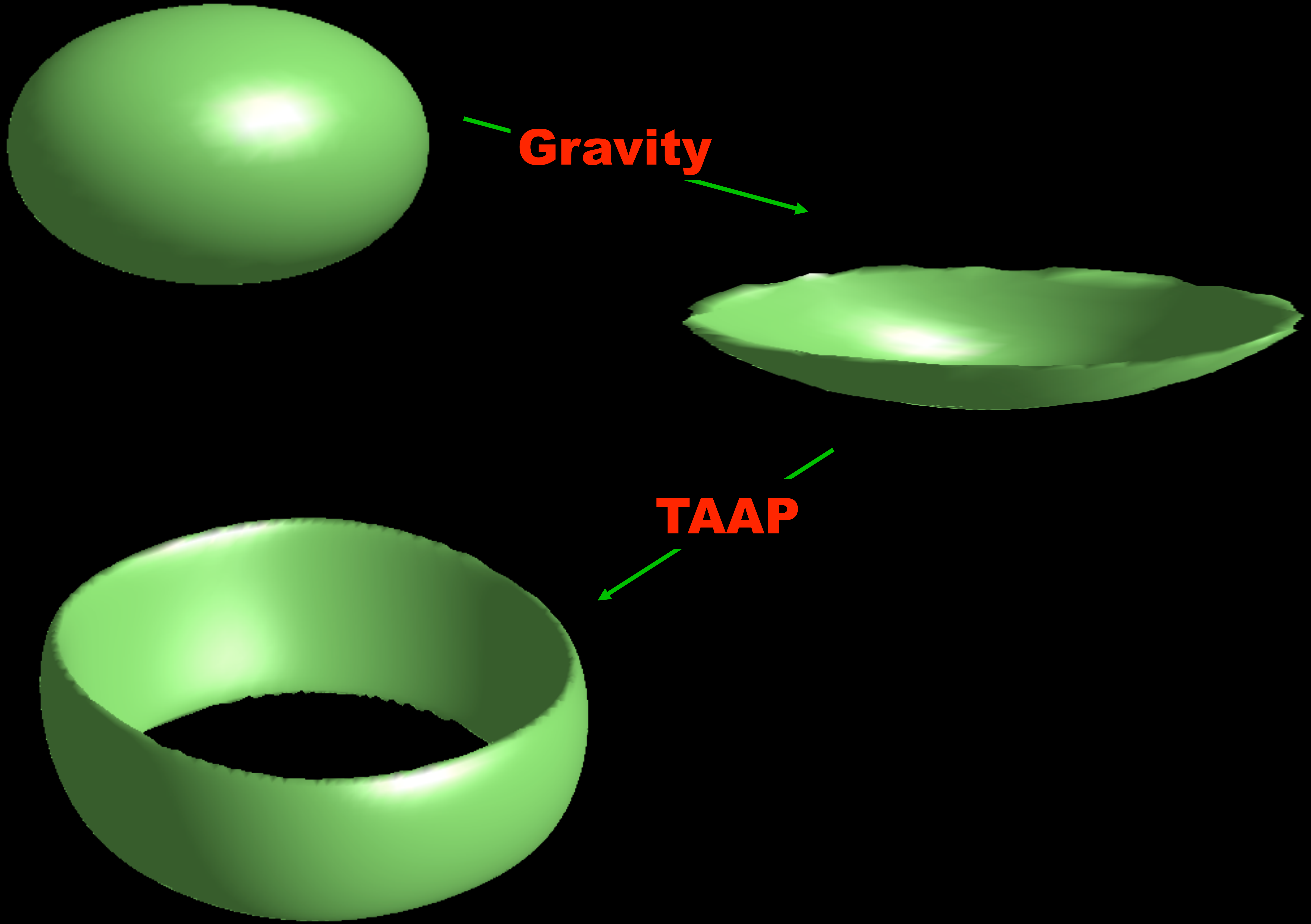
Adiabatic Potentials

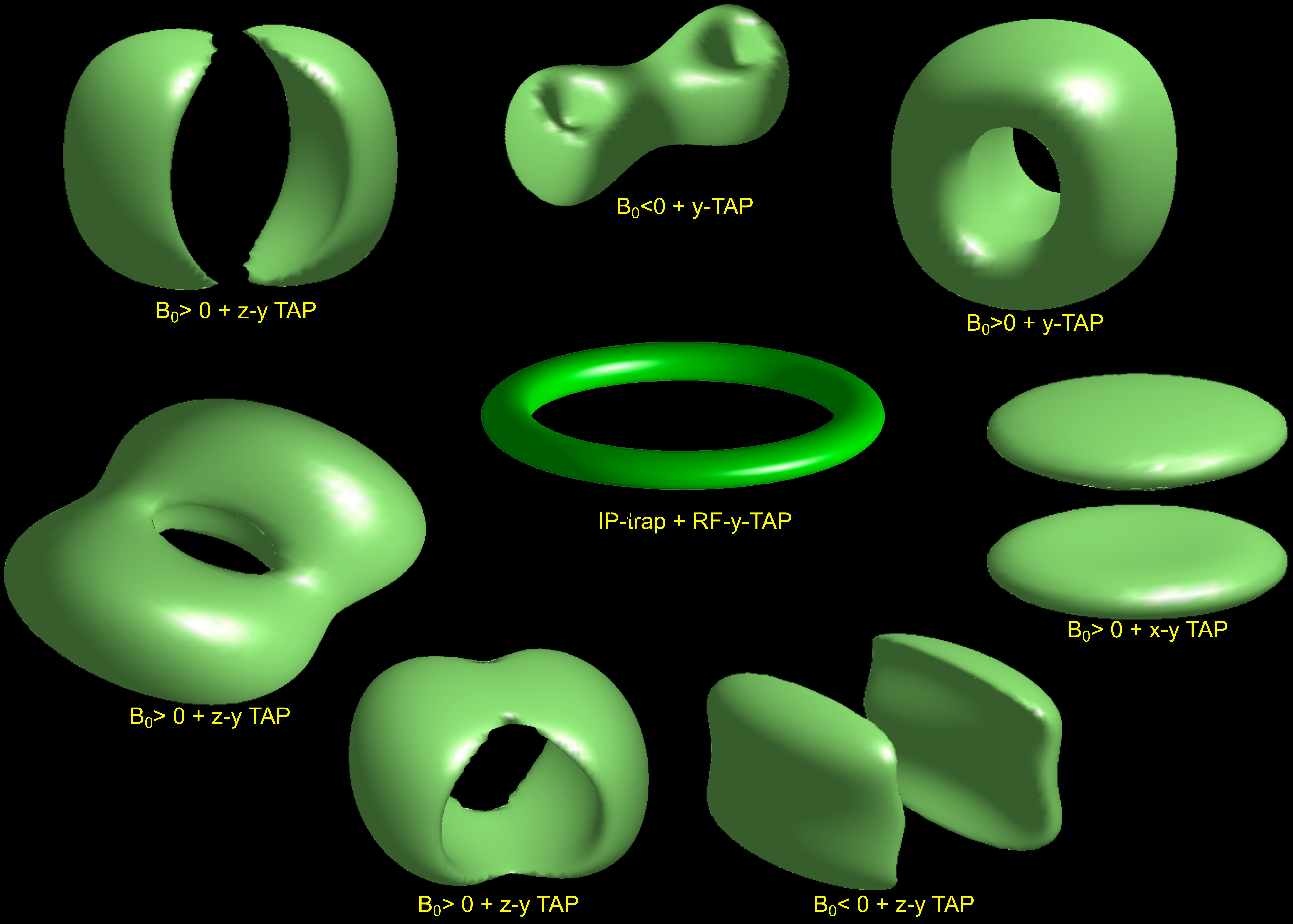


Time-Averaged Adiabatic Potentials (TAAP)



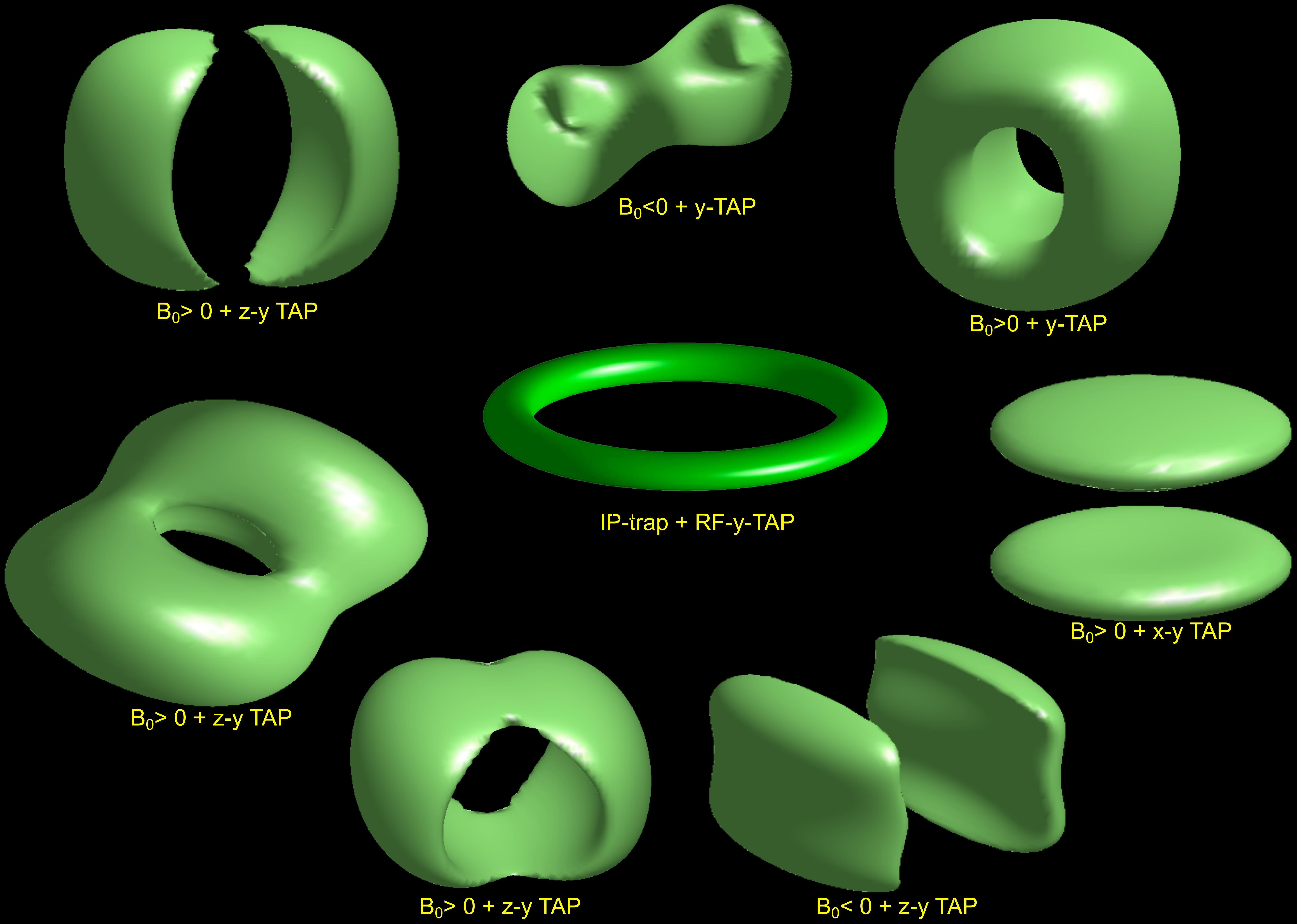
Time-Averaged Adiabatic Potentials (TAAP)





(1 µK iso-potential surfaces in a TAAP trap)

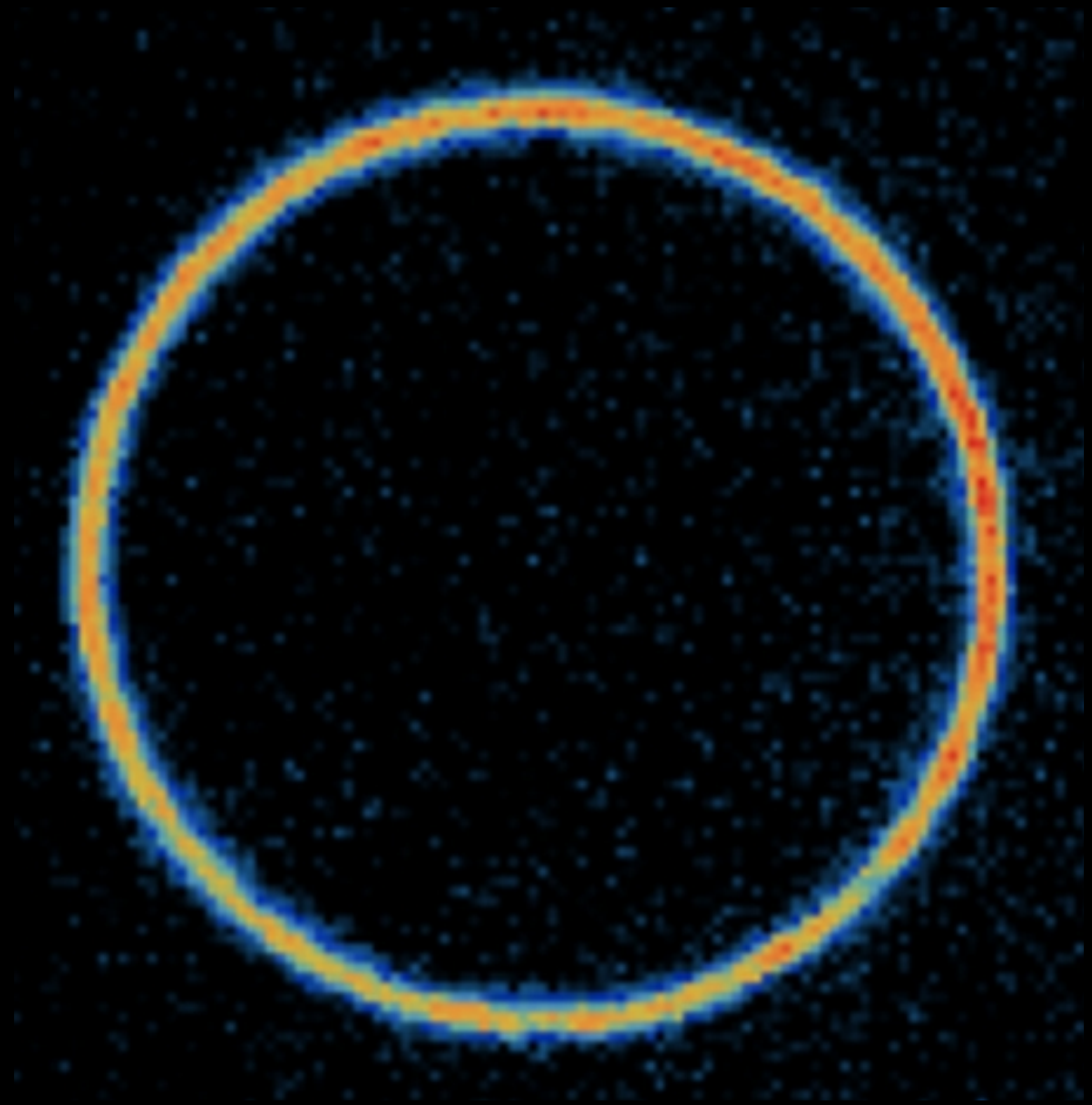
PRL **99:8** 083001 (2007)



(1 μK iso-potential surfaces in a TAAP trap)

PRL **99:8** 083001 (2007)

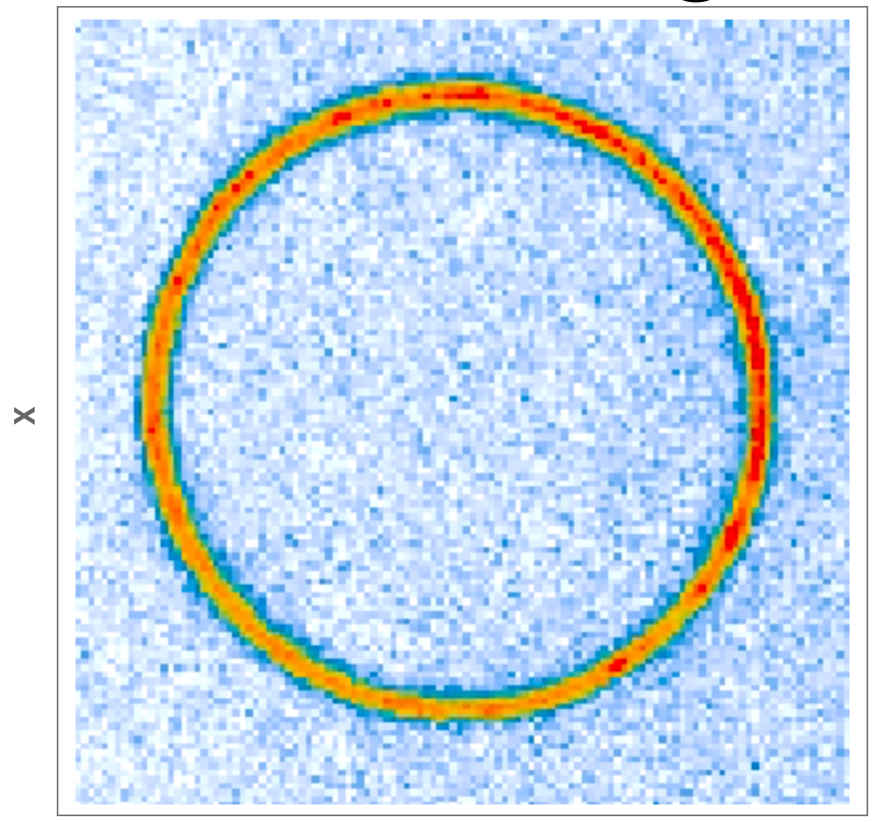
BEC in a Ring



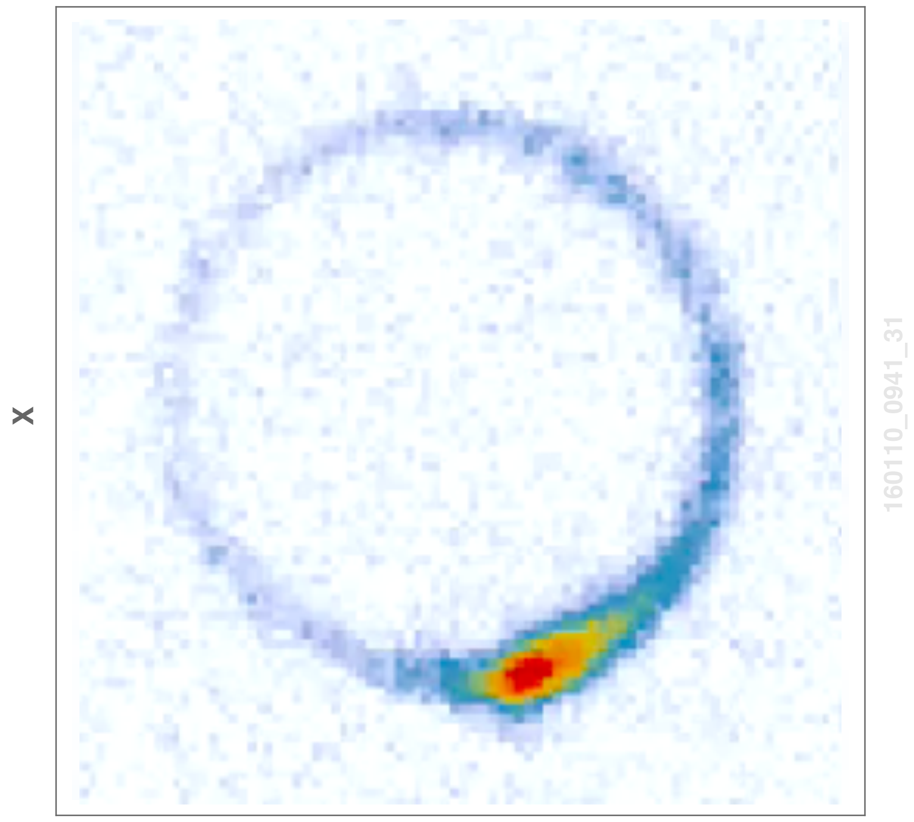
N=300k, T=3-30 nK Ø=1-2 mm

Independent State-Dependent Buckets

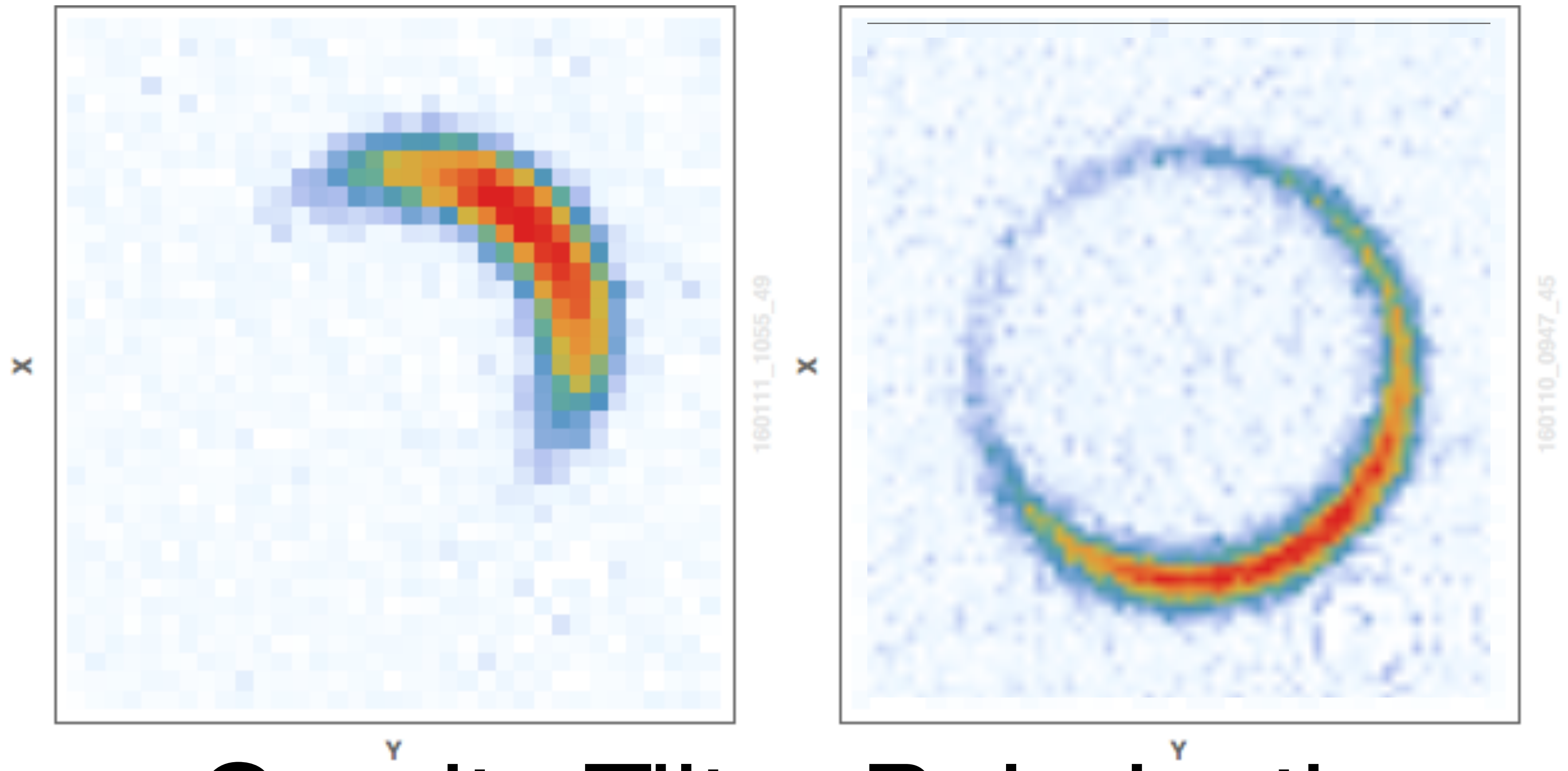
Flat Ring



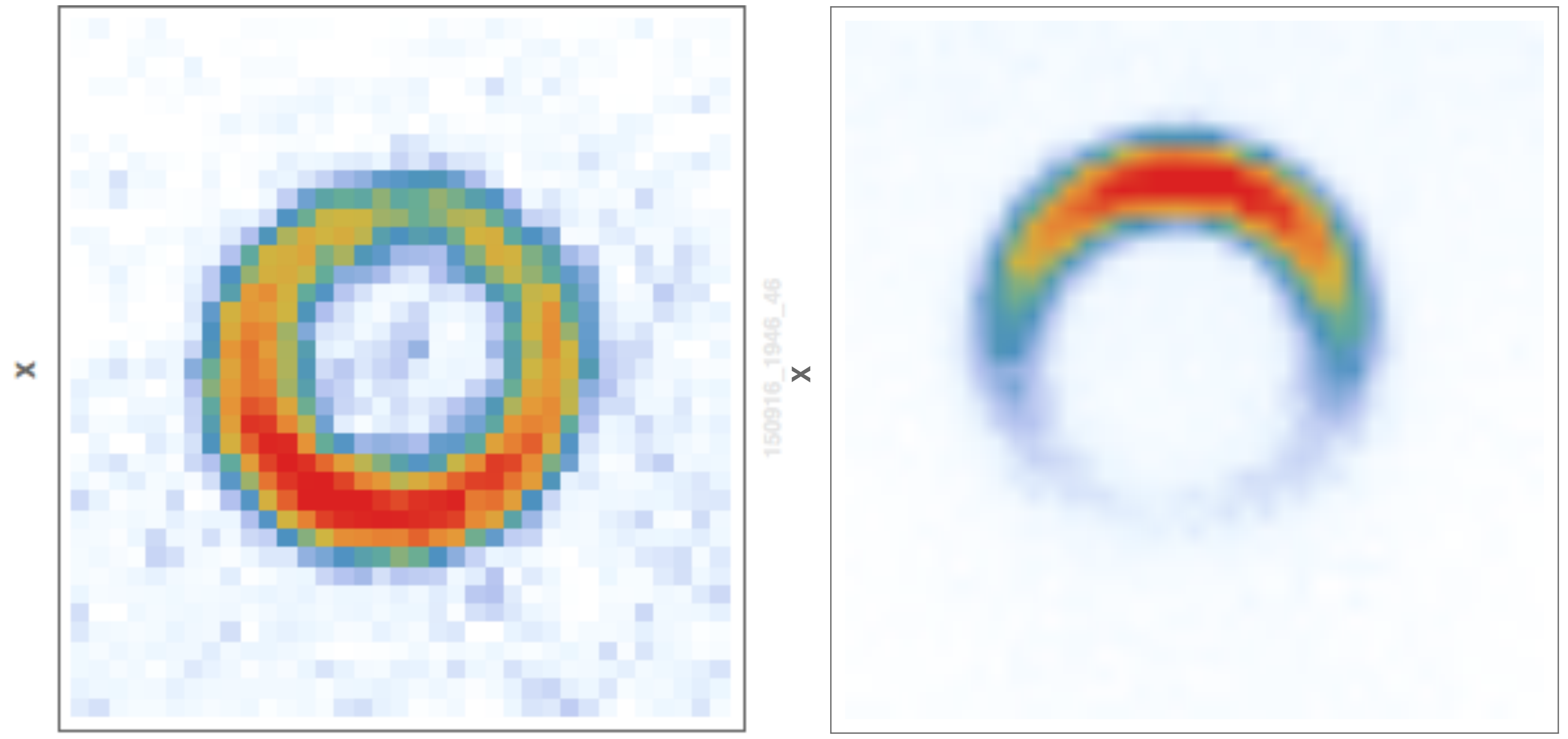
Waveguide



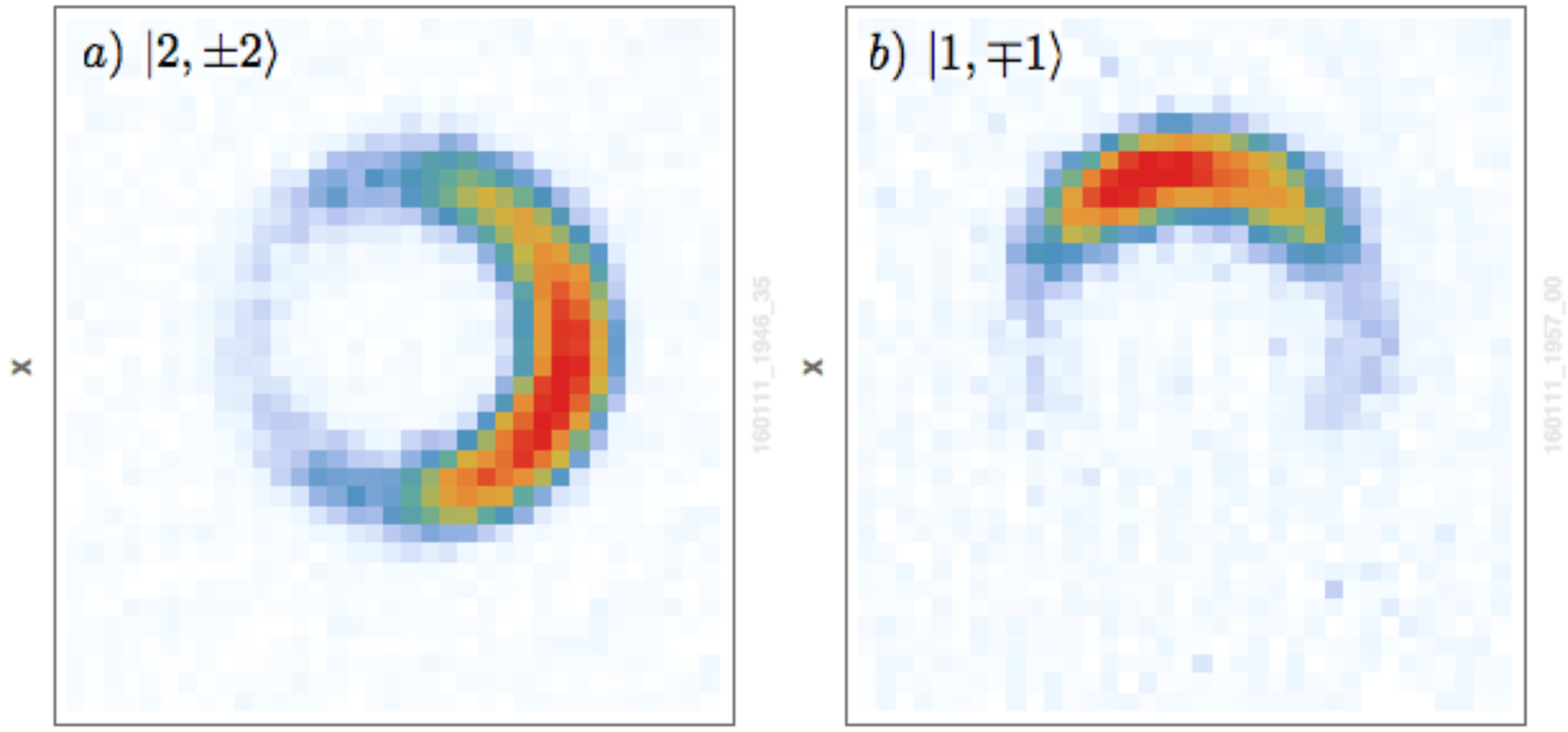
Gravity Tilt



Polarization



Gravity Tilt + Polarization

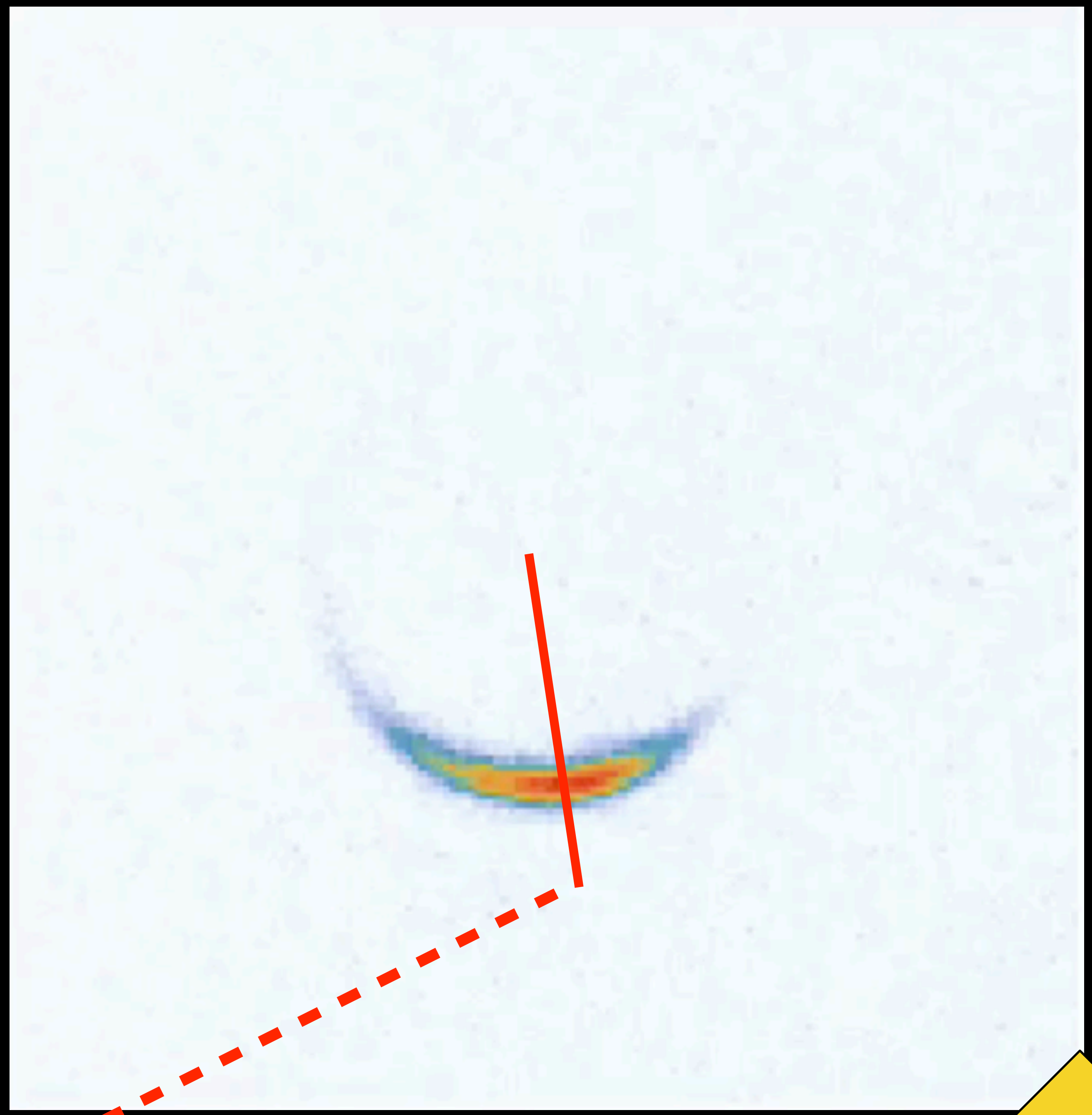


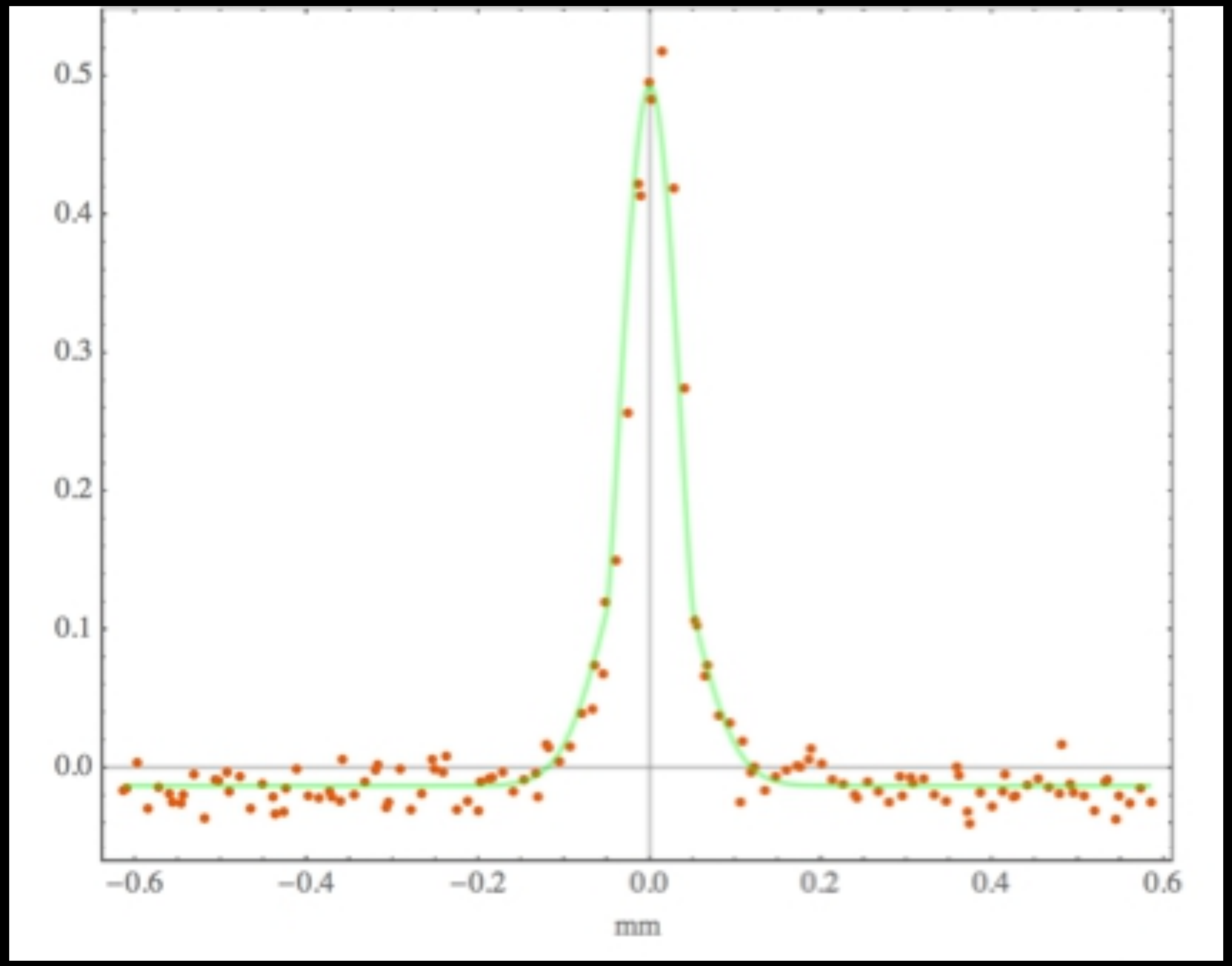
$|F=1, m_F=-1\rangle$ $|F=2, m_F=+1\rangle$ $|F=1, m_F=-1\rangle$ $|F=2, m_F=+1\rangle$

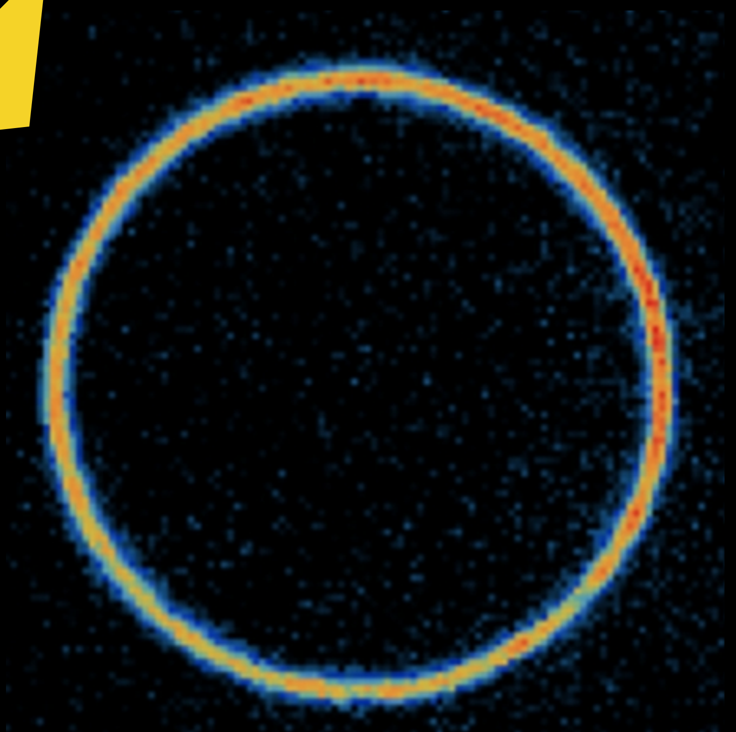
P Navez et al. *New Journal of Physics* **18:7** 075014 (2016)

BEC in a Ring

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







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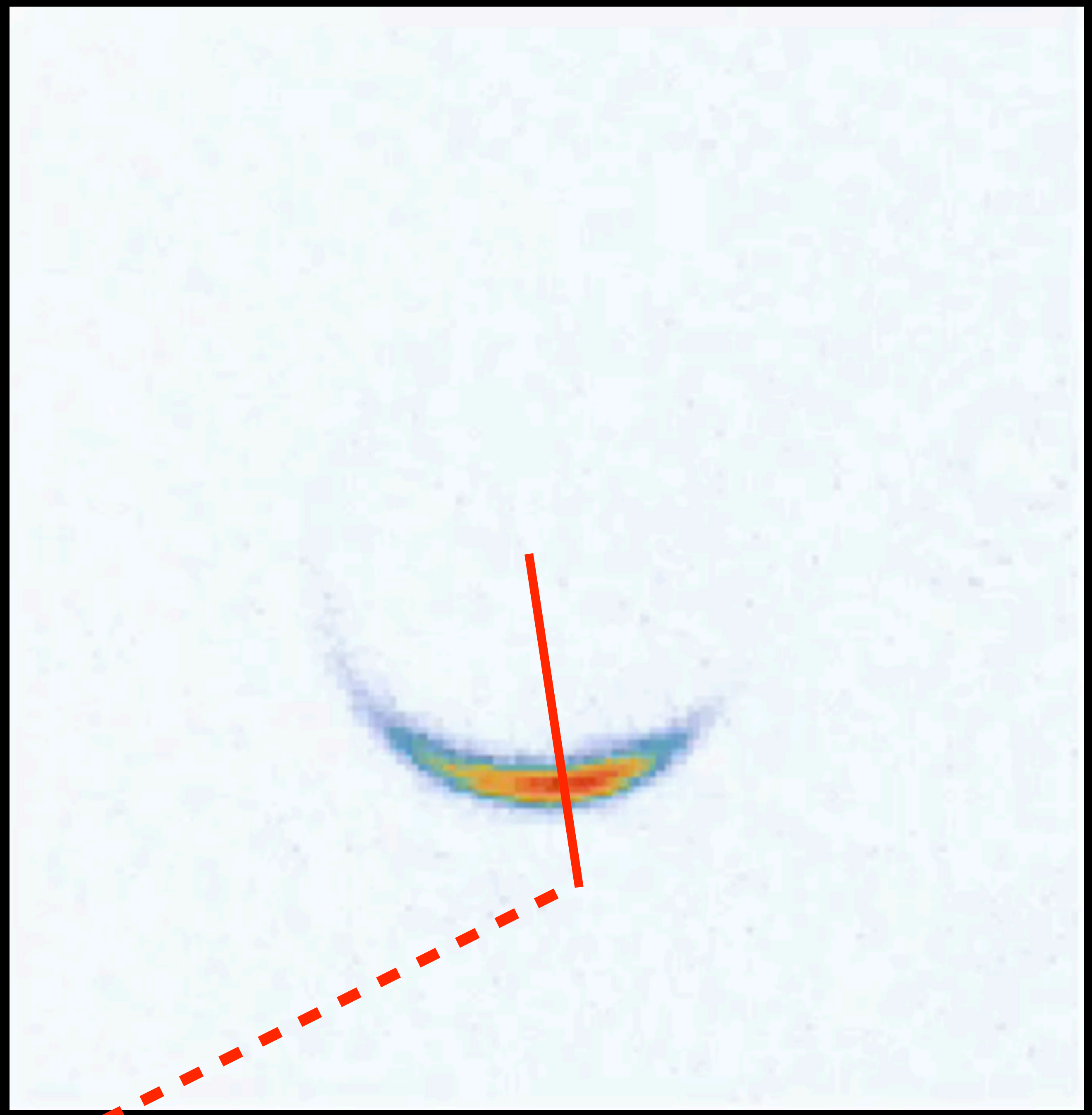
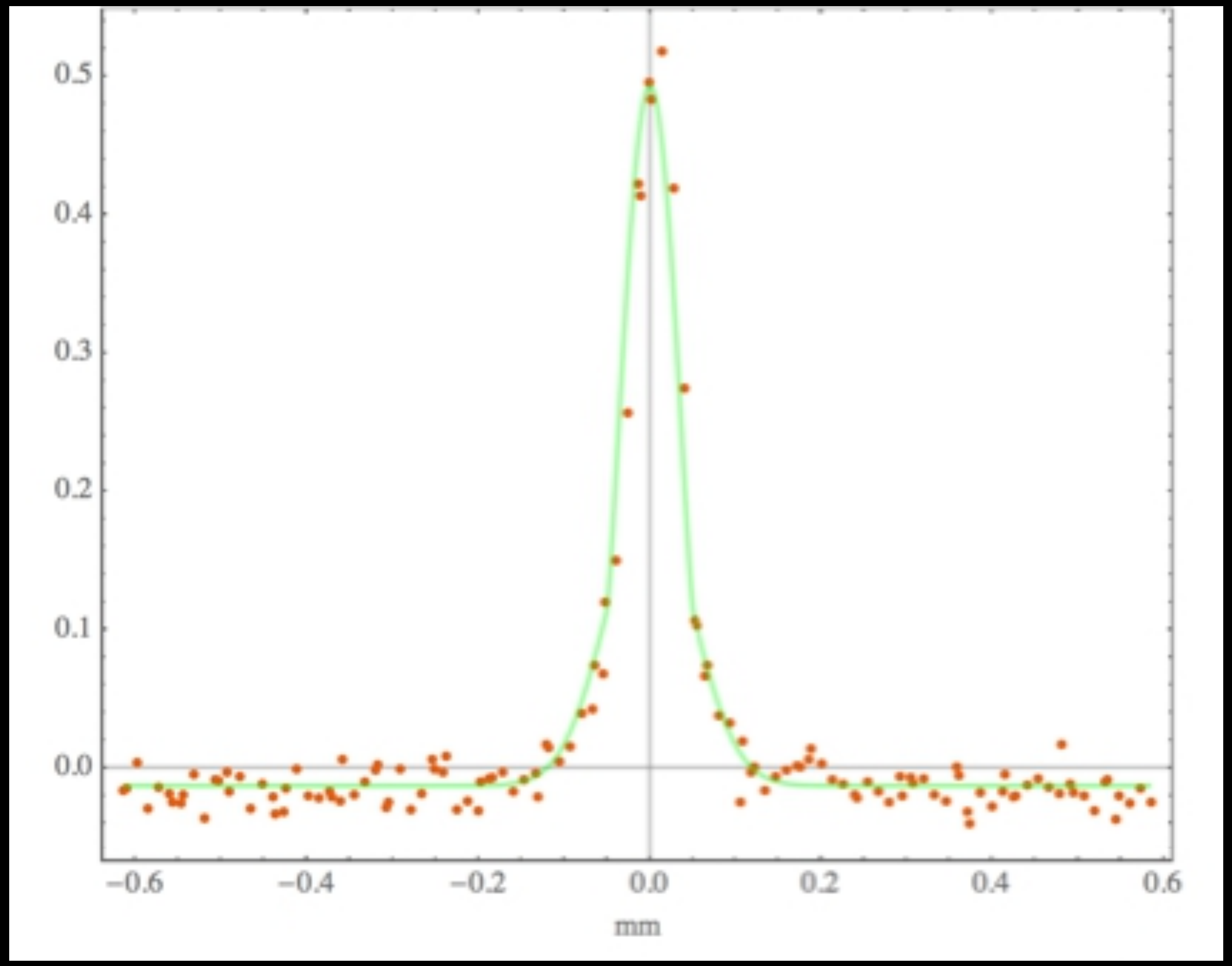
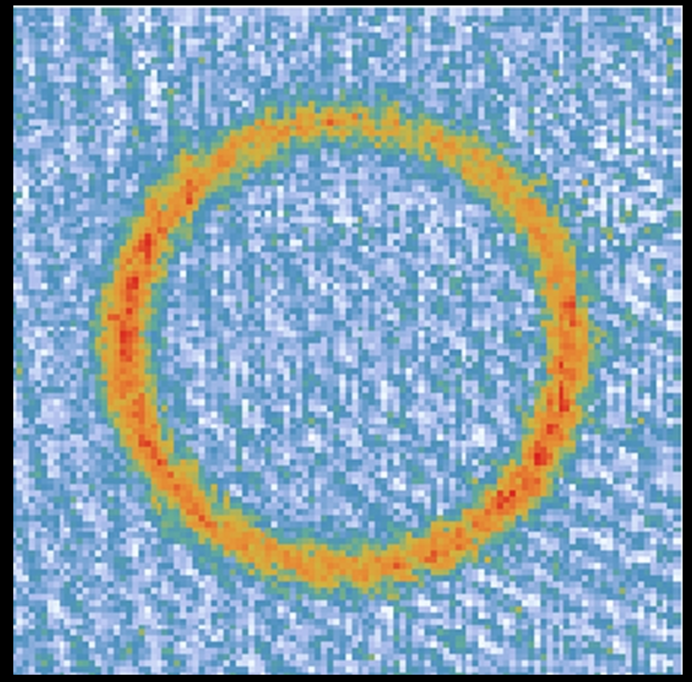
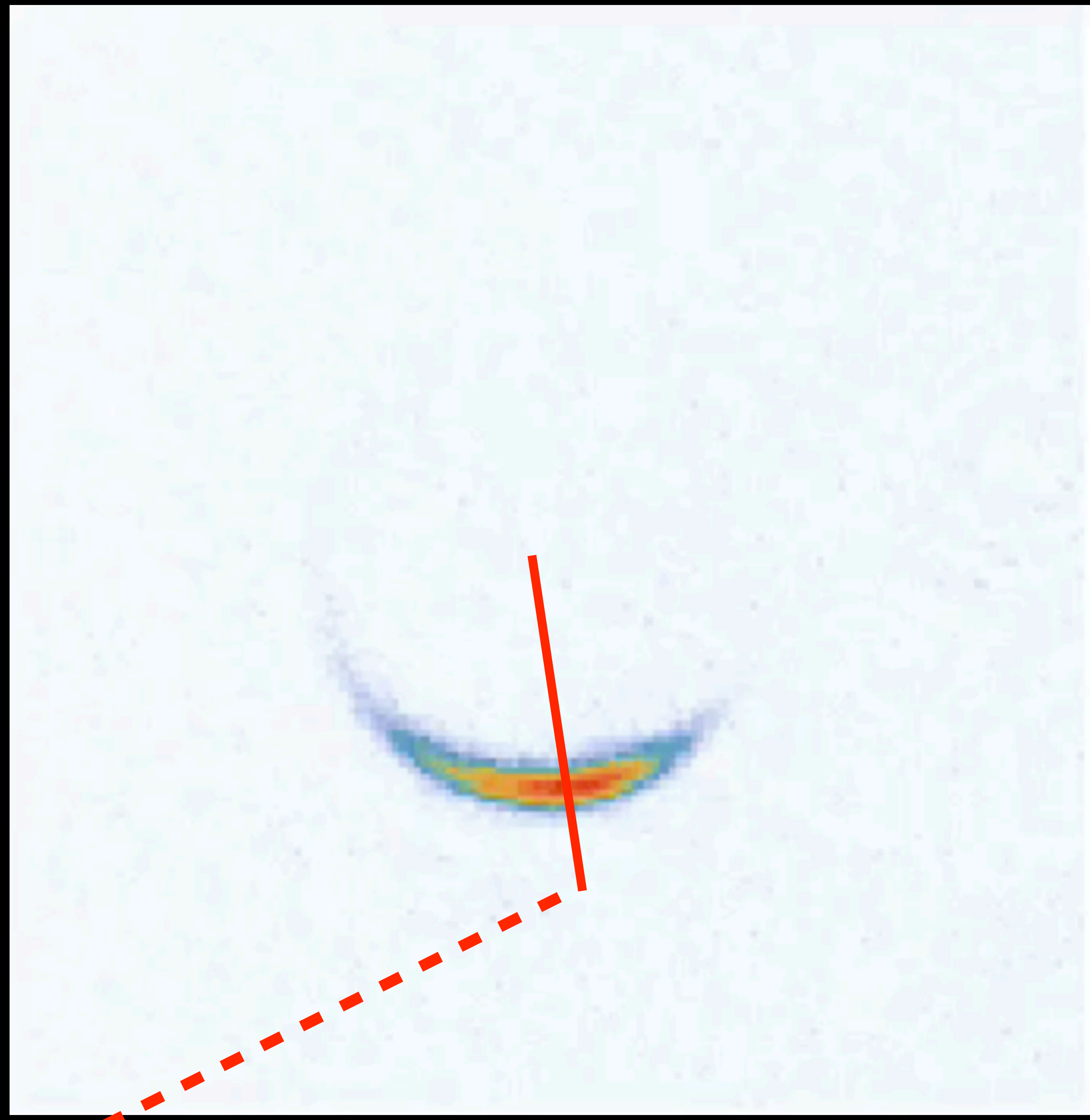


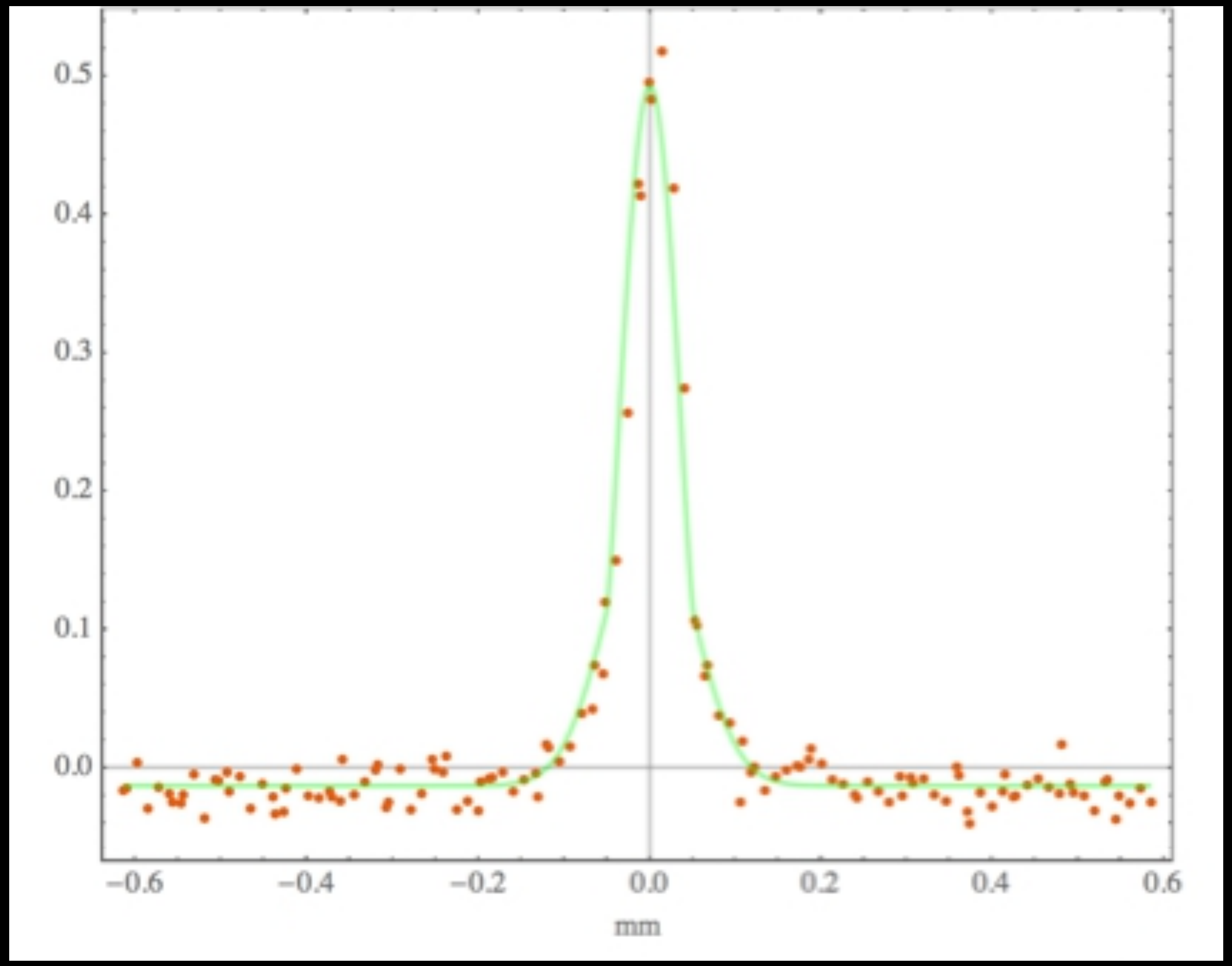




BEC in a Ring

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





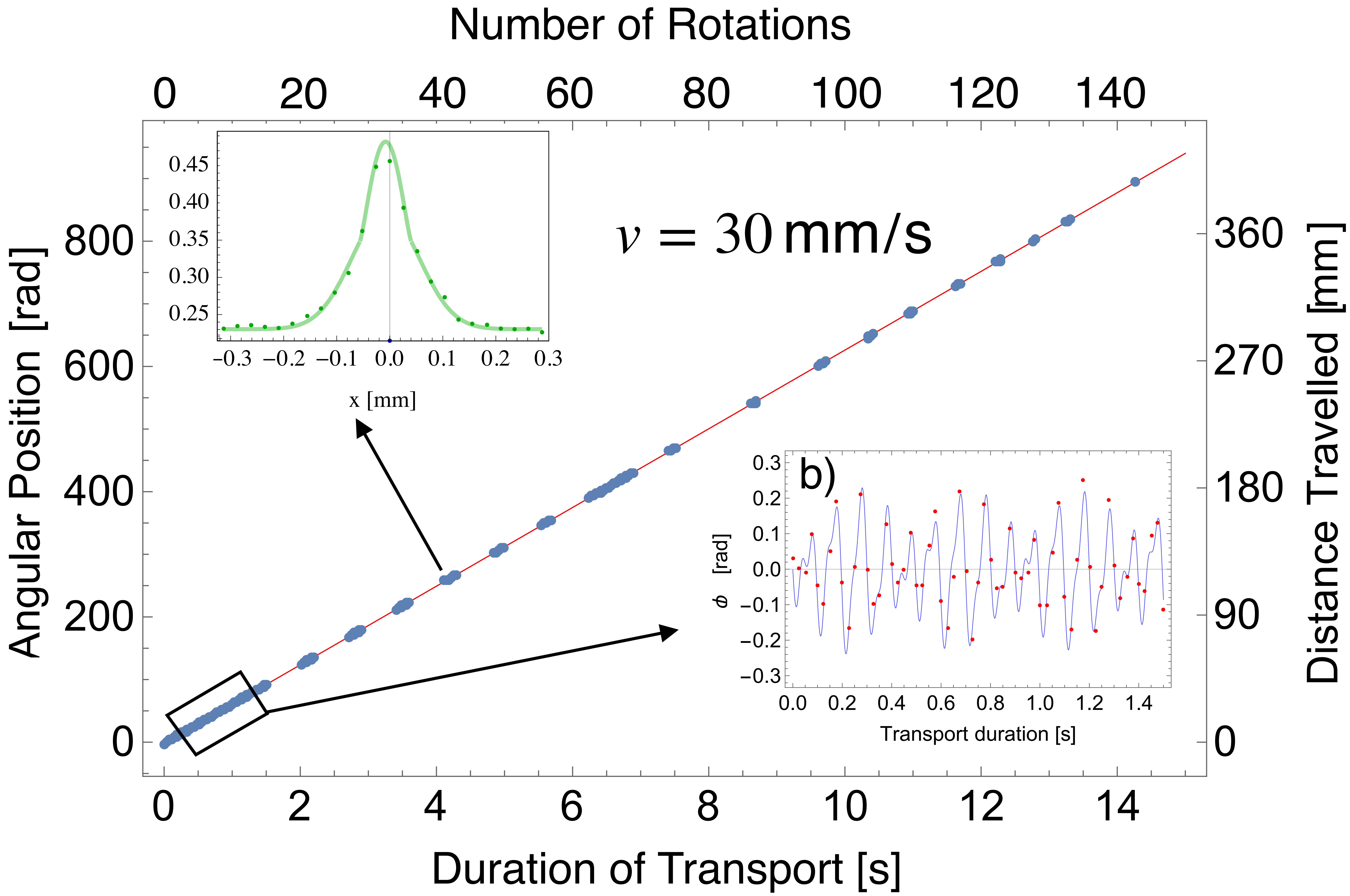
Bang-Bang Scheme of Optimal Control Theory

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

Ring Accelerator

Ring Accelerator

BEC in a waveguide @ 30 mm/s



Superfluid critical velocity:

$$v_c = \sqrt{\mu/m}$$
$$= 1.8\,\mathrm{mm/s}$$

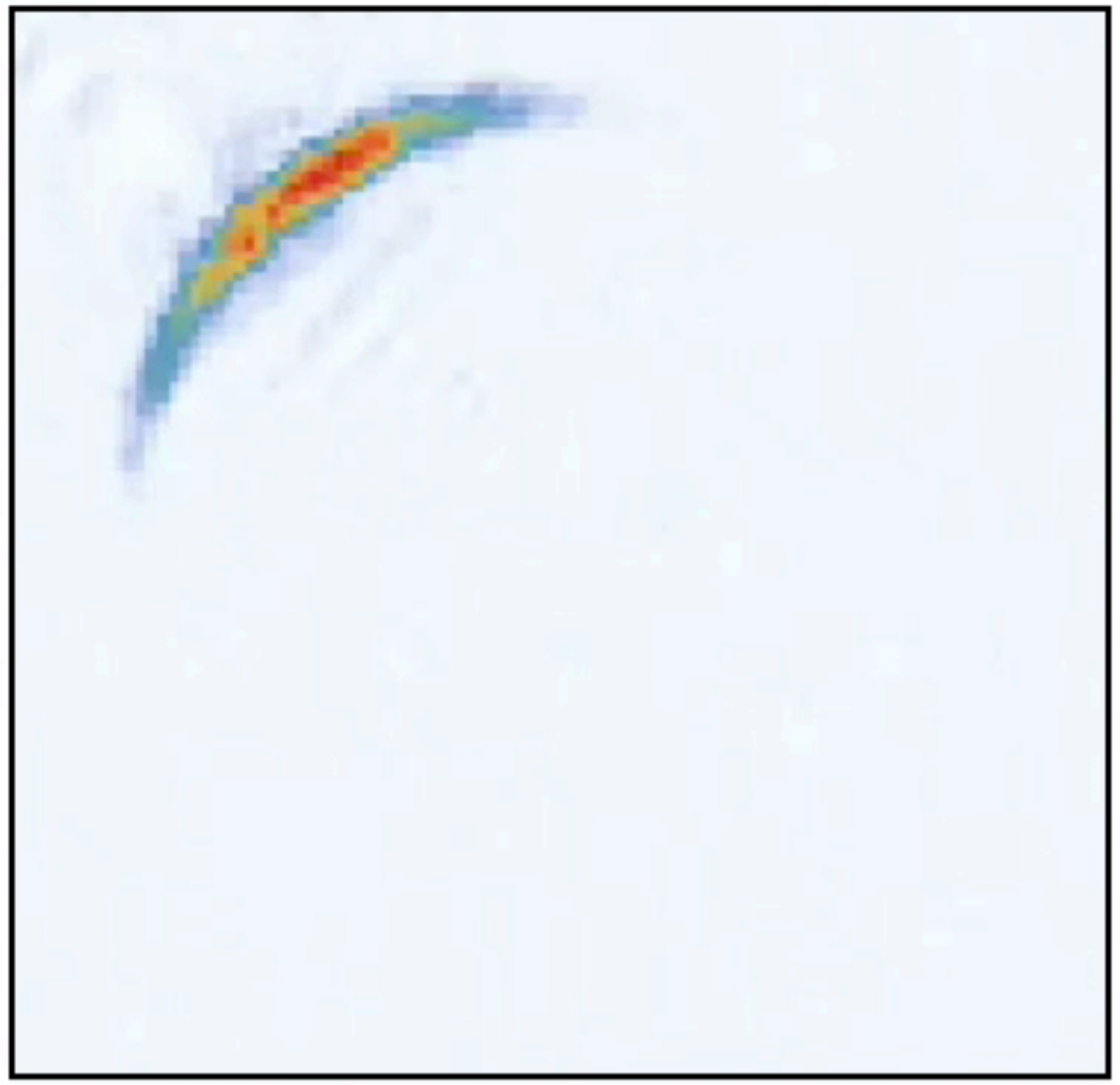
$$\boxed{v = \text{Mach } 17}$$

=> perfectly smooth wave guides

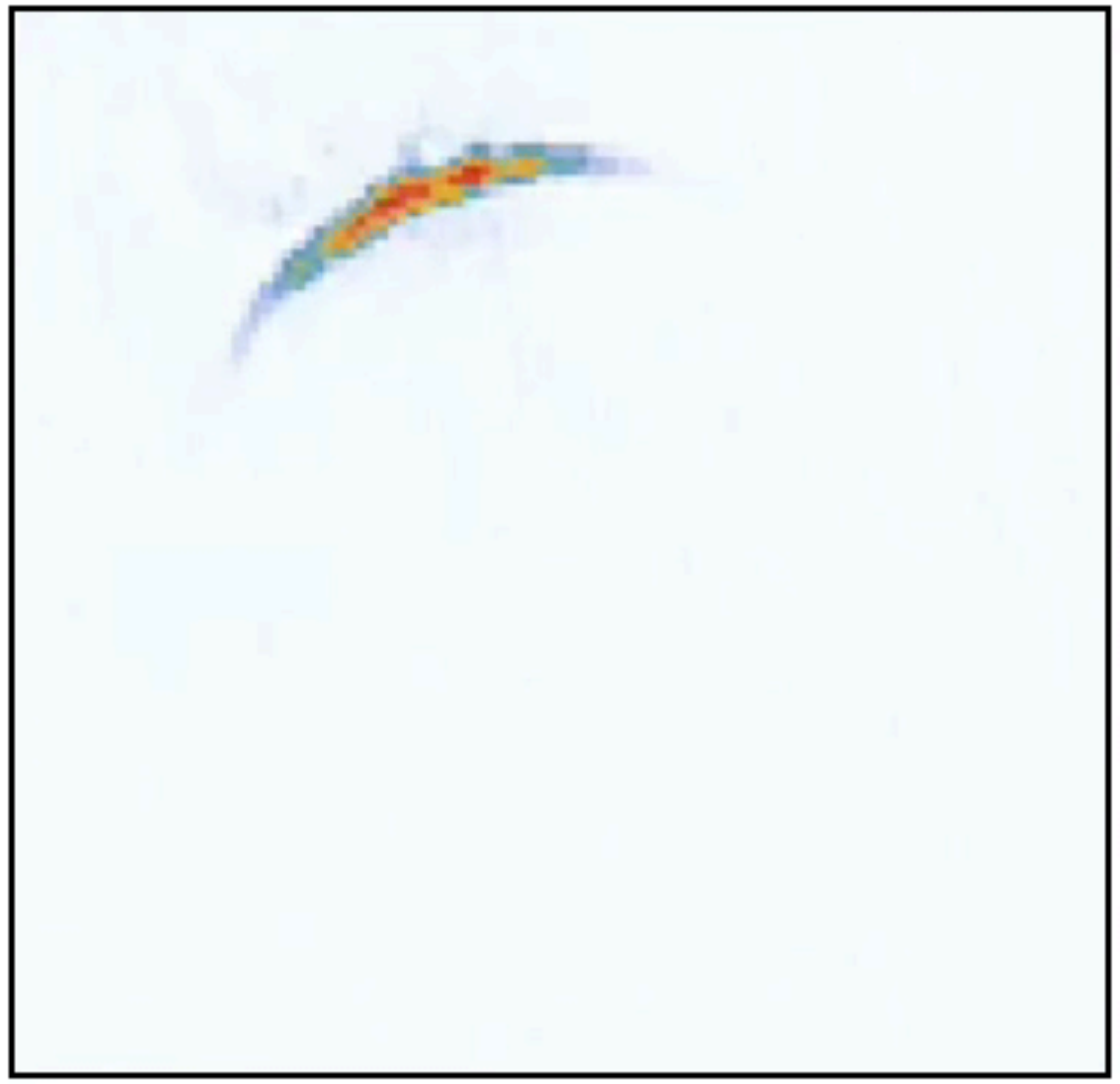
Saurabh Pandey et al.
***Nature* 570:7760** 205--209 (2019)

Expansion of a rotating BEC in the ring

Optimal Control Atom-Optics

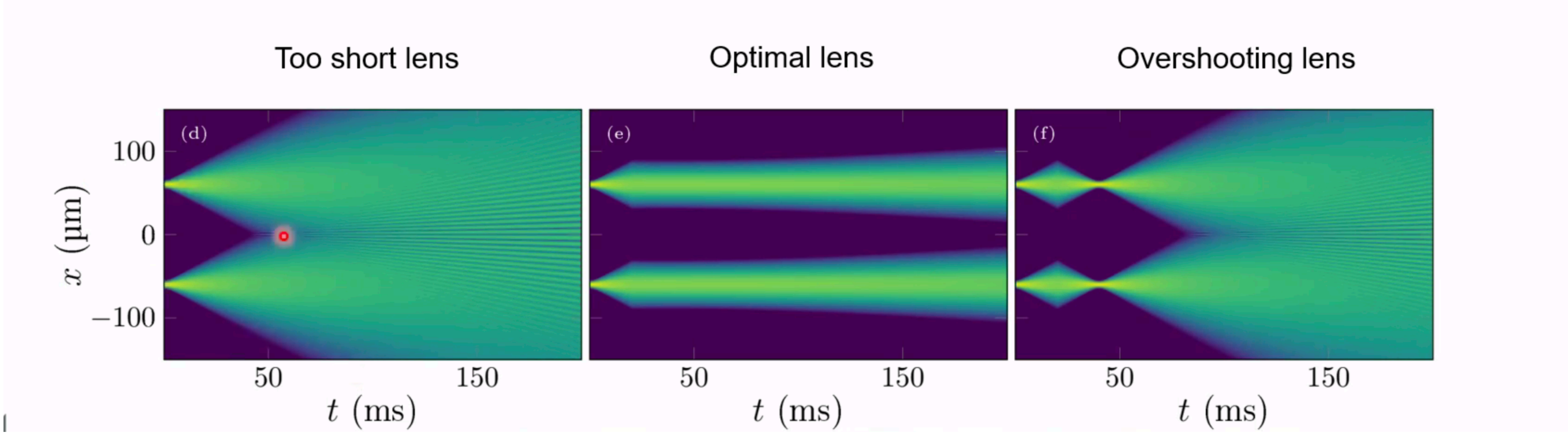


Free expansion



Matterwave Lensing

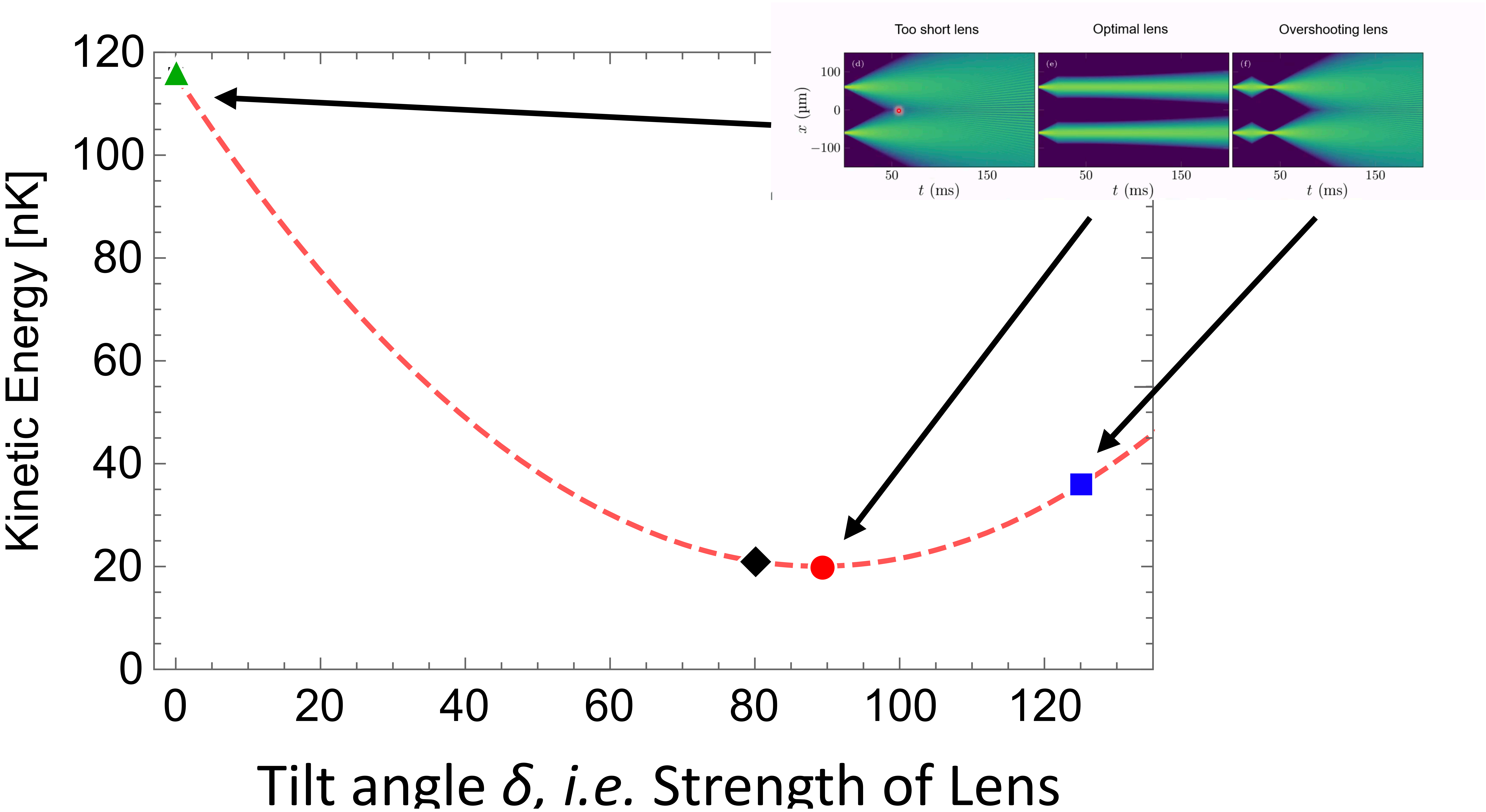
Focusing the MW-Lens



Matthias Meister

Saurabh Pandey et al.
Atomtronic Matter-Wave Lensing
Physical Review Letters **126 17** (2021)

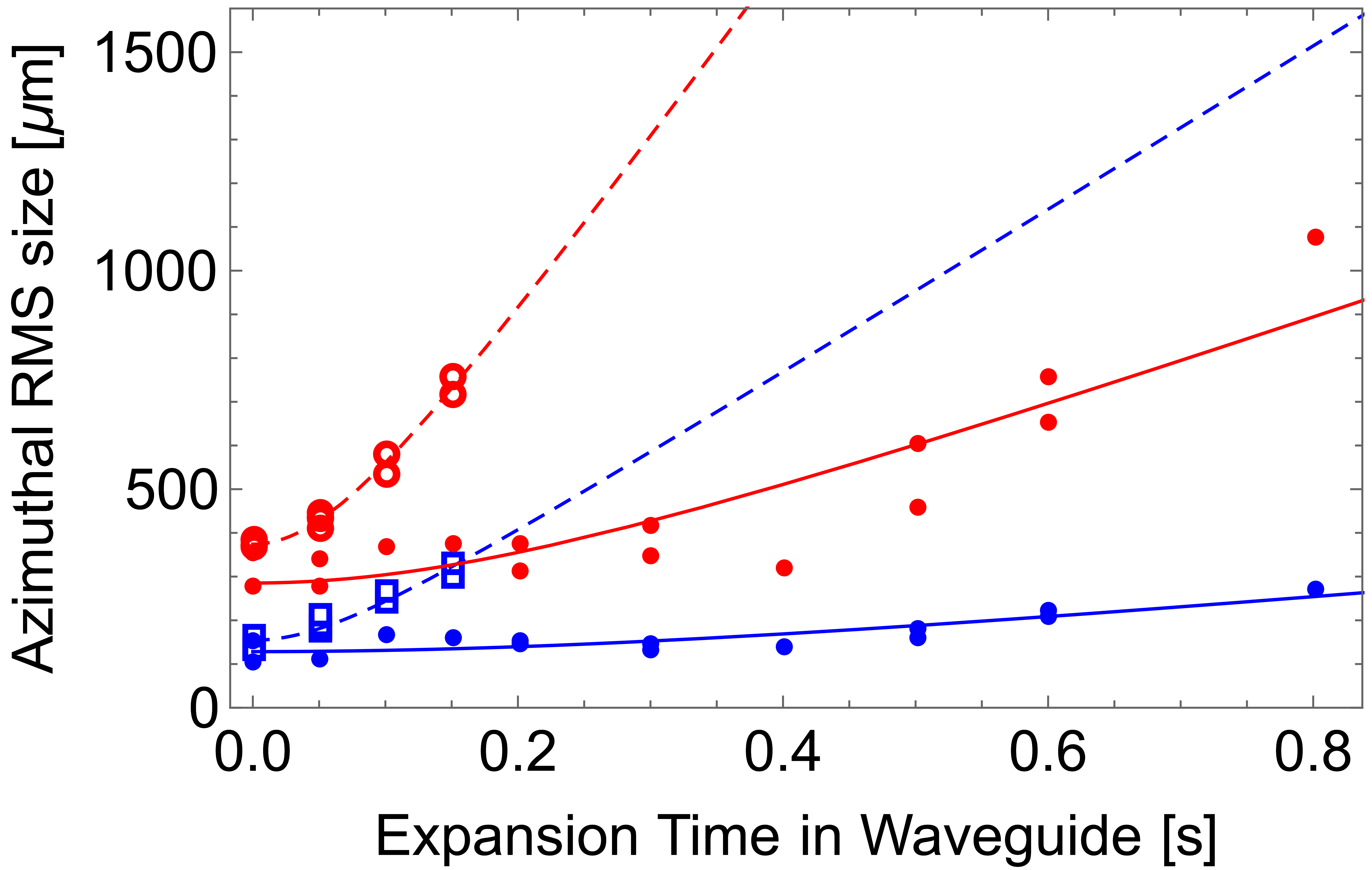
Focusing the MW-Lens



Expansion in the Ring

Thermal (Free expansion)
$T_{kin} = 183^{+21}_{-20}\ nK_{rms}$

BEC (Free expansion)
$T_{kin} = 37^{+10}_{-9}\ nK_{rms}$



Thermal (Delta–Kick Cooled)
$T_{kin} = 12^{+4}_{-4}\ nK_{rms}$

BEC (Delta–Kick Cooled)
$T_{kin} = 0.8^{+0.3}_{-0.3}\ nK_{rms}$

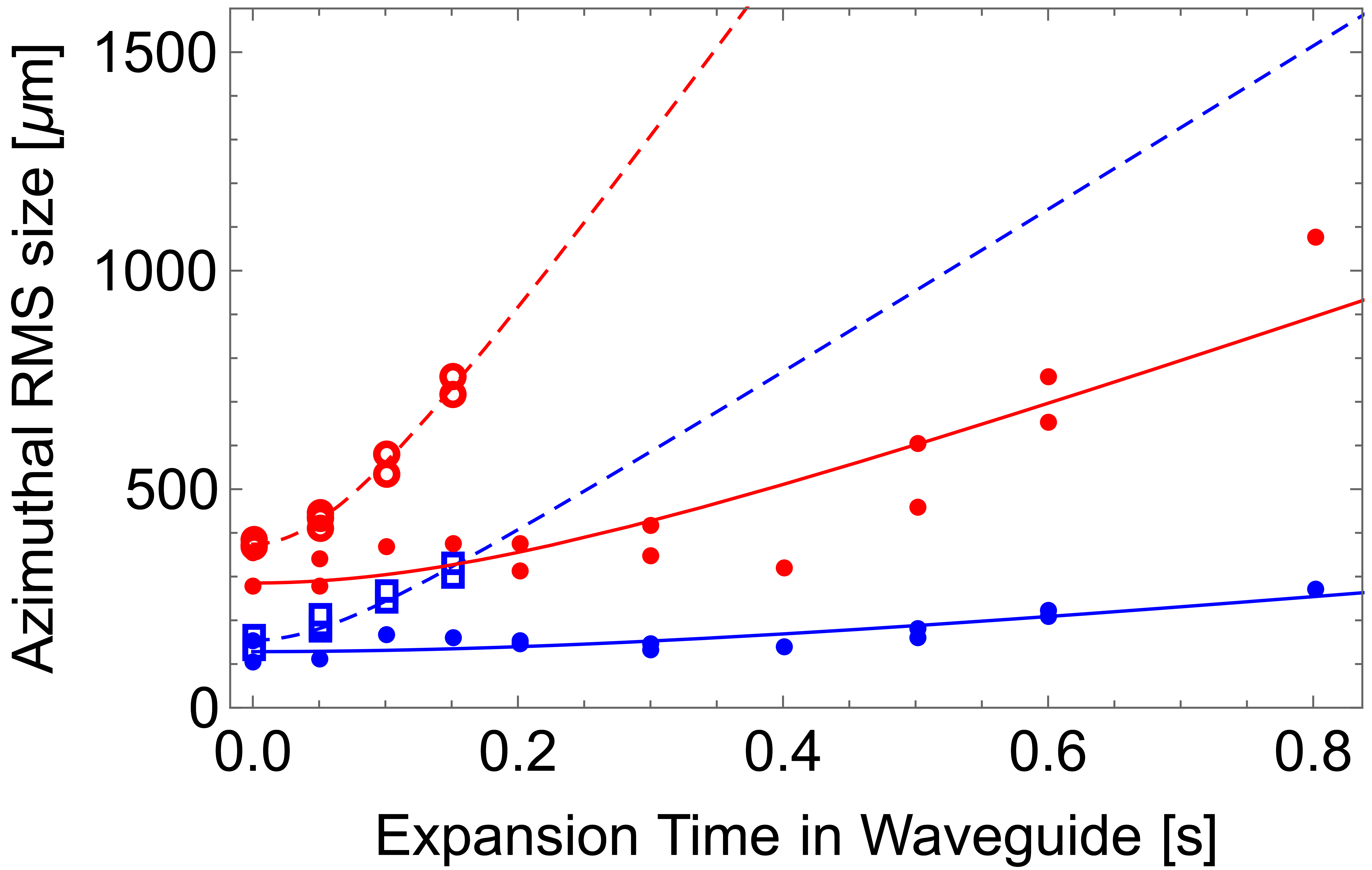
46 x decrease in Energy

Saurabh Pandey et al. *Physical Review Letters* **126:17** (2021)

Future: Expansion in the Bubble

Thermal (Free expansion)
$T_{kin} = 183^{+21}_{-20}\ nK_{rms}$

BEC (Free expansion)
$T_{kin} = 37^{+10}_{-9}\ nK_{rms}$



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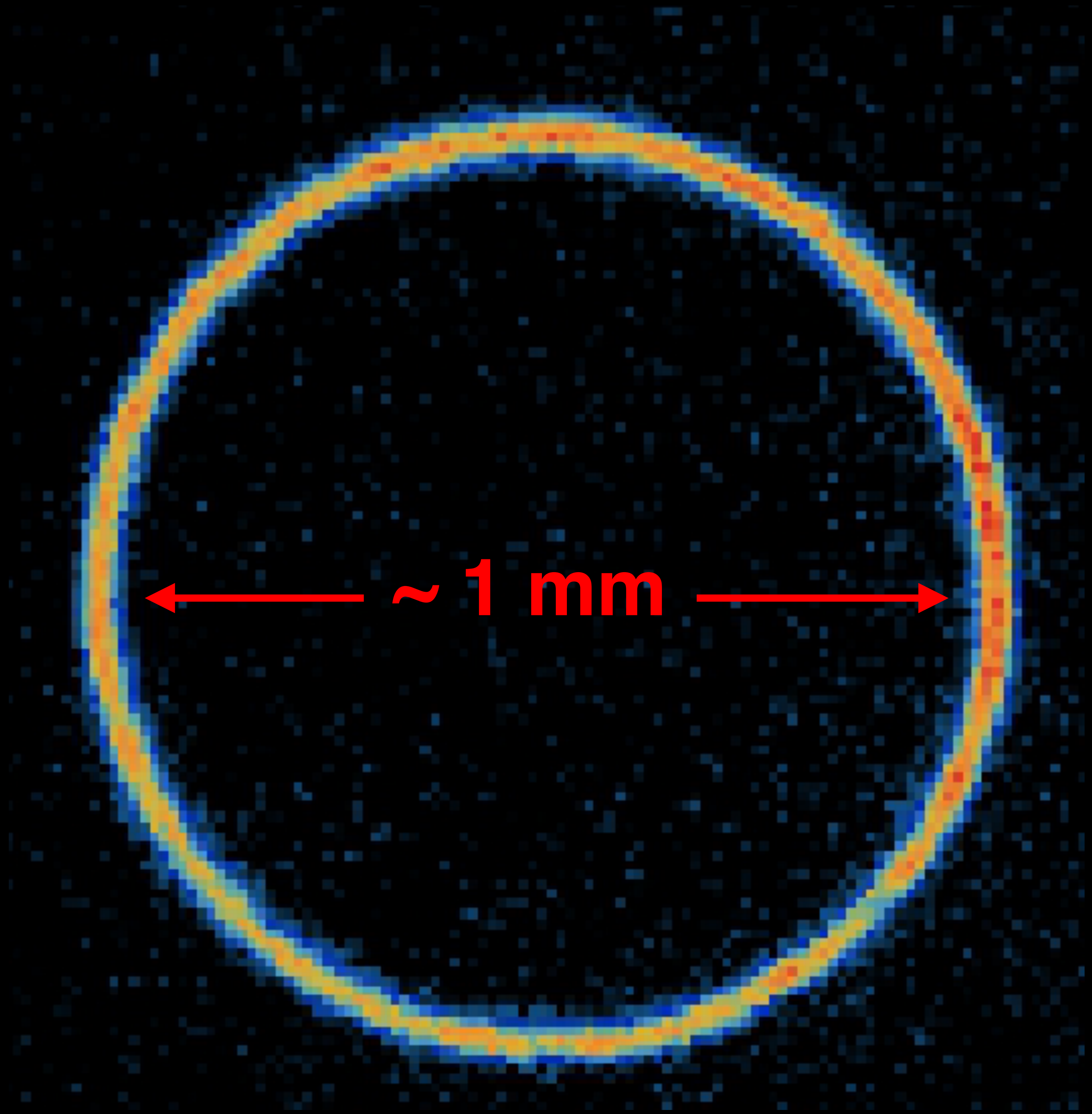
Matterwave Guide/Ring

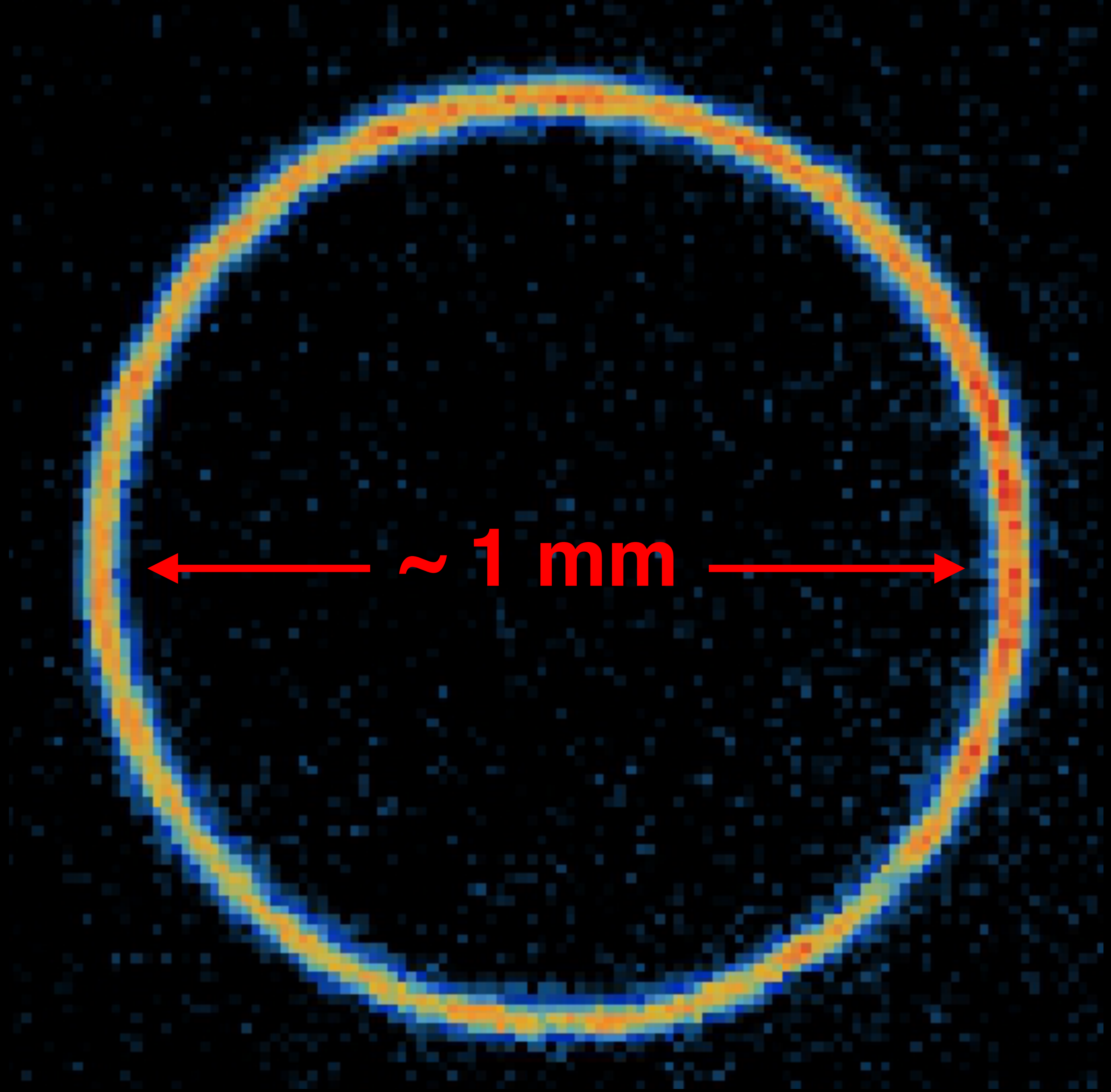


Effective Flatness of the waveguide:

189 pK = 2 nm height difference

Matterwave Guide/Ring

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



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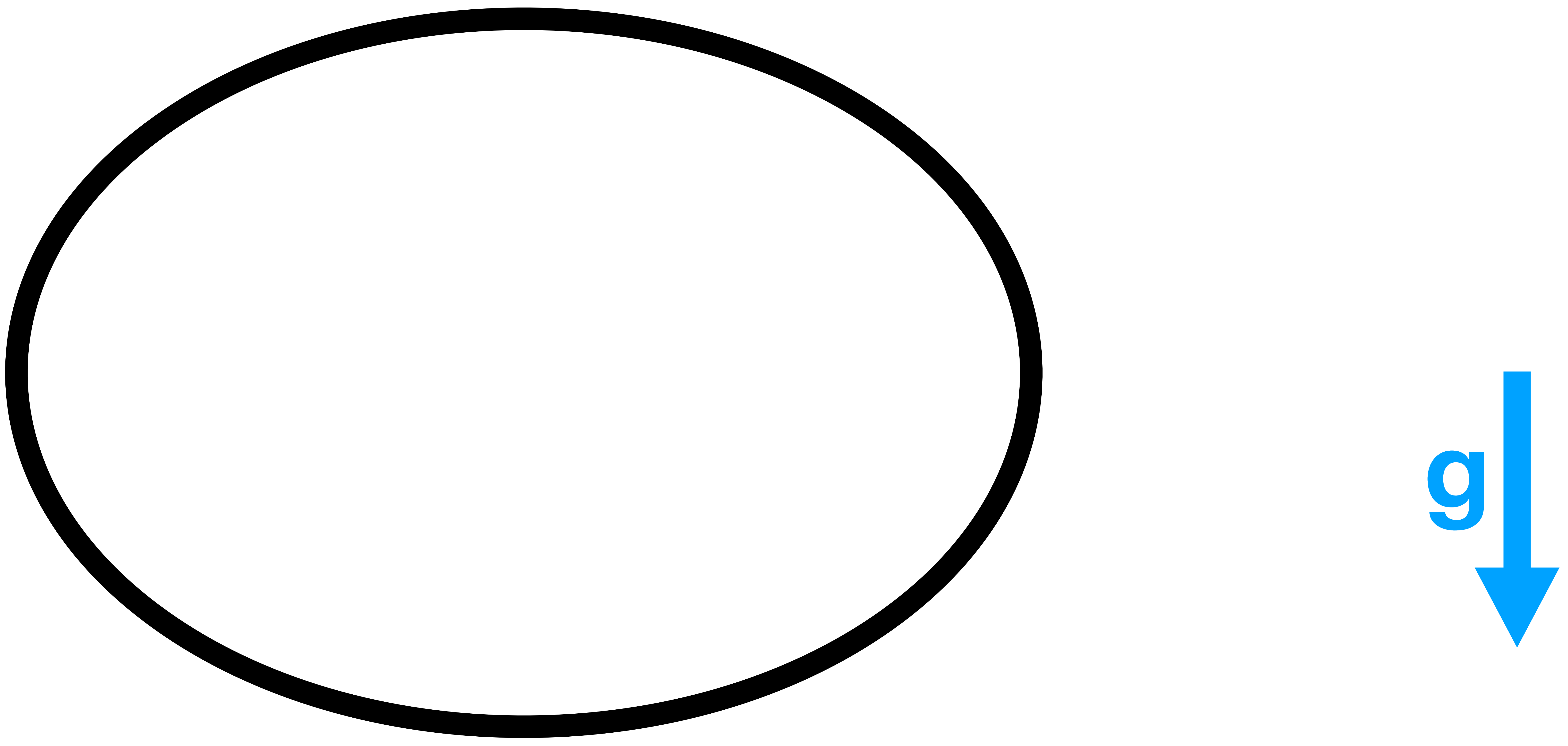
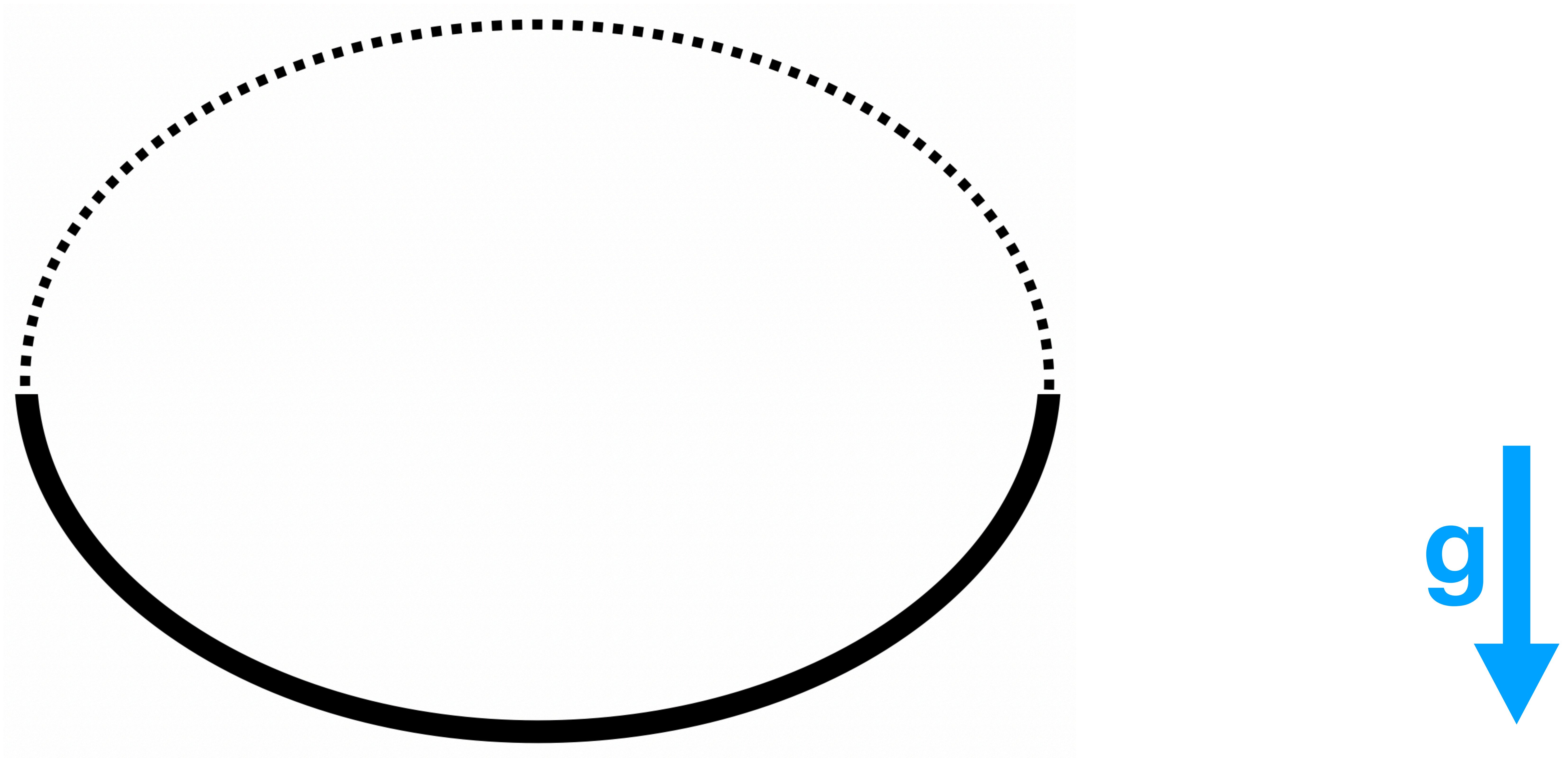
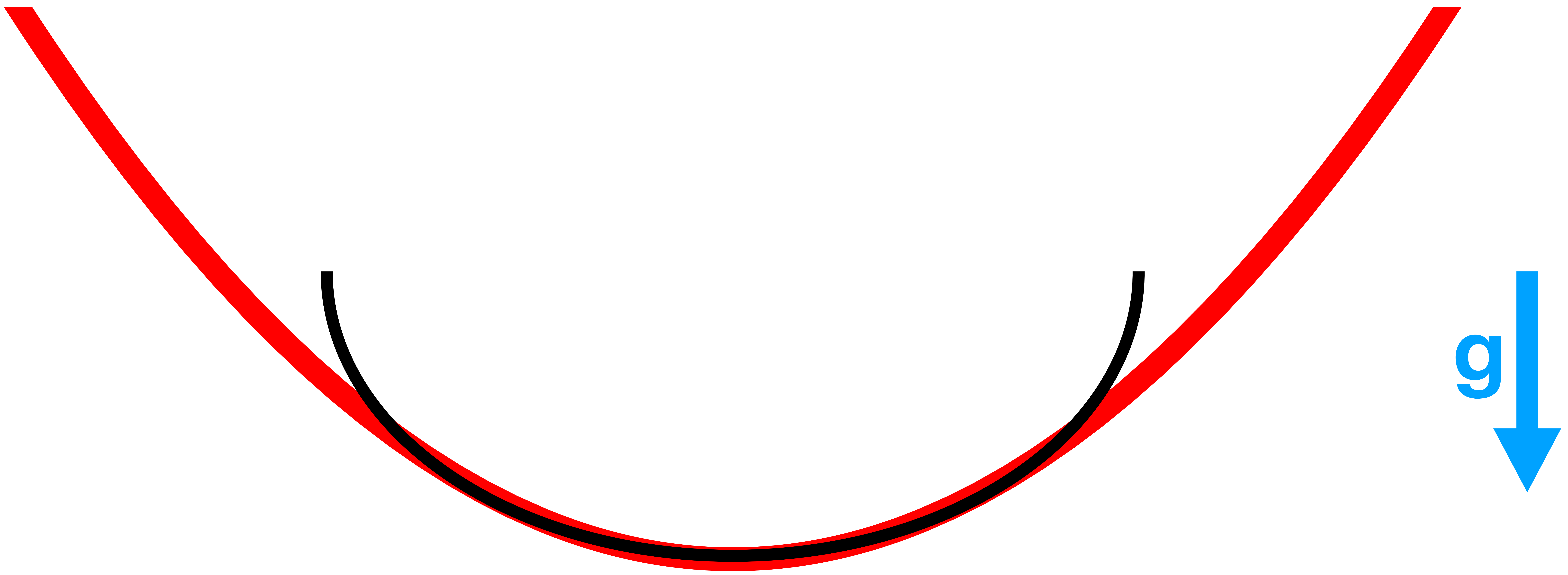
Bubble in Gravity



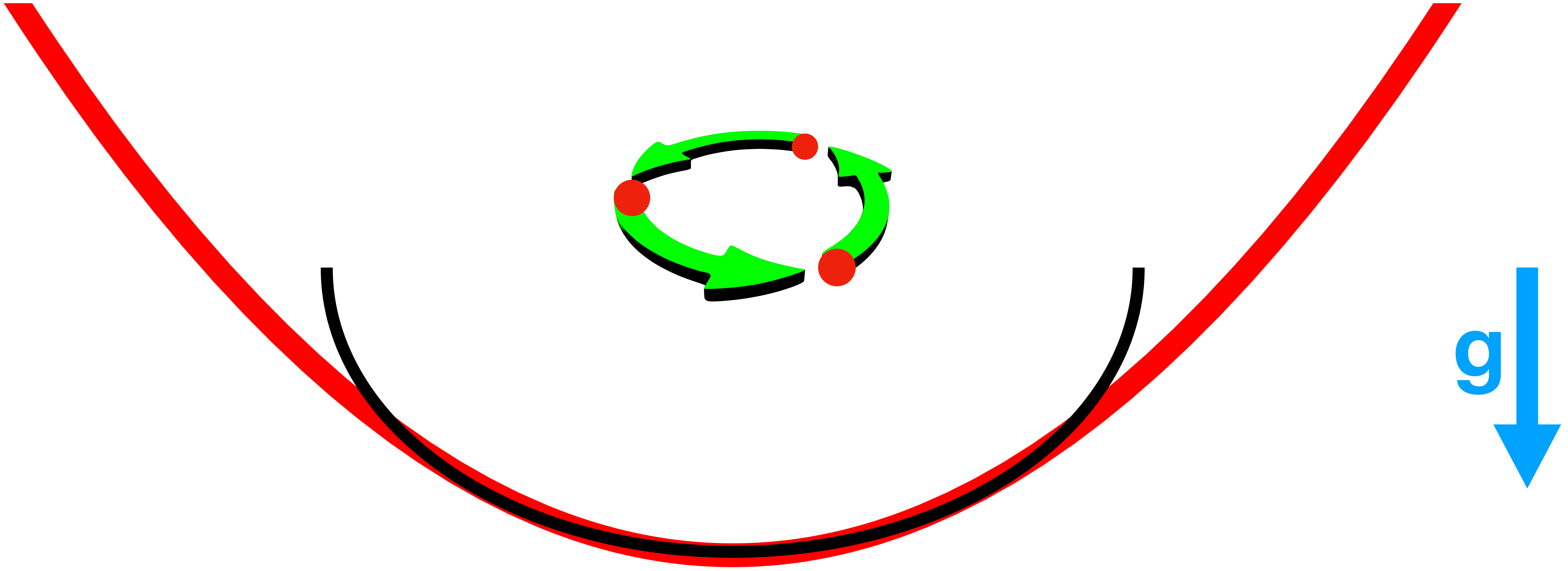
Bubble in Gravity



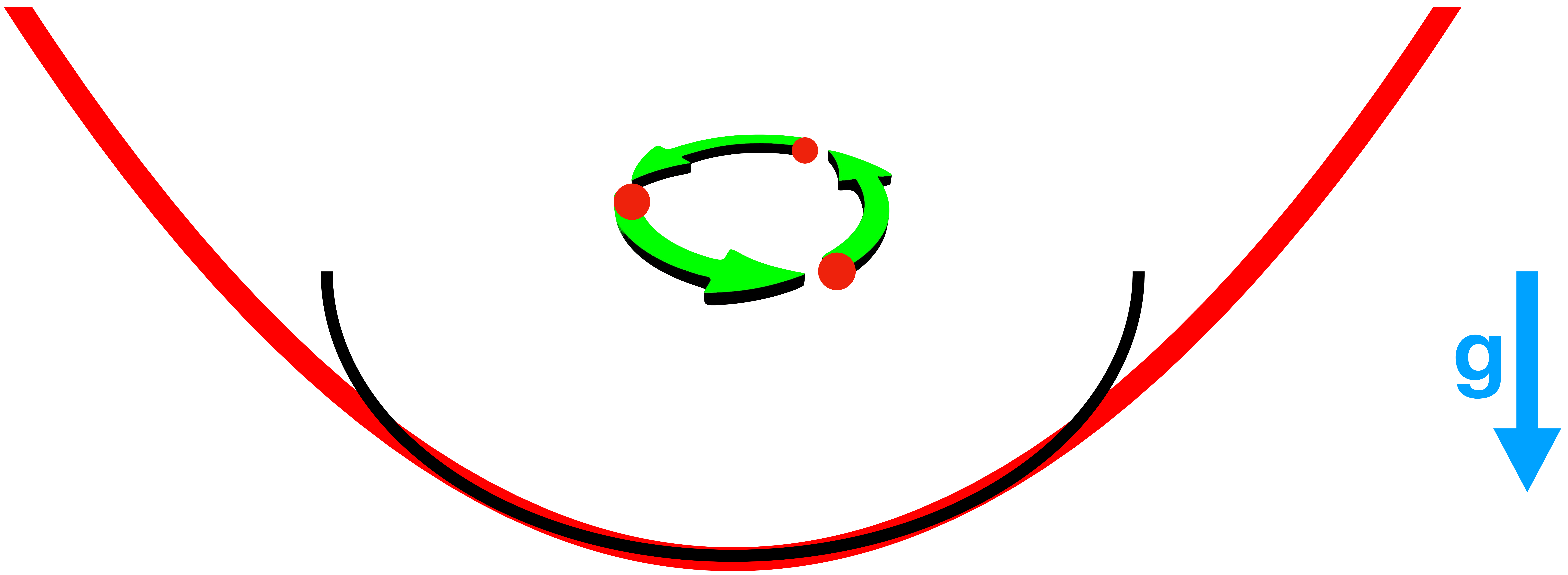
Bubble in Gravity



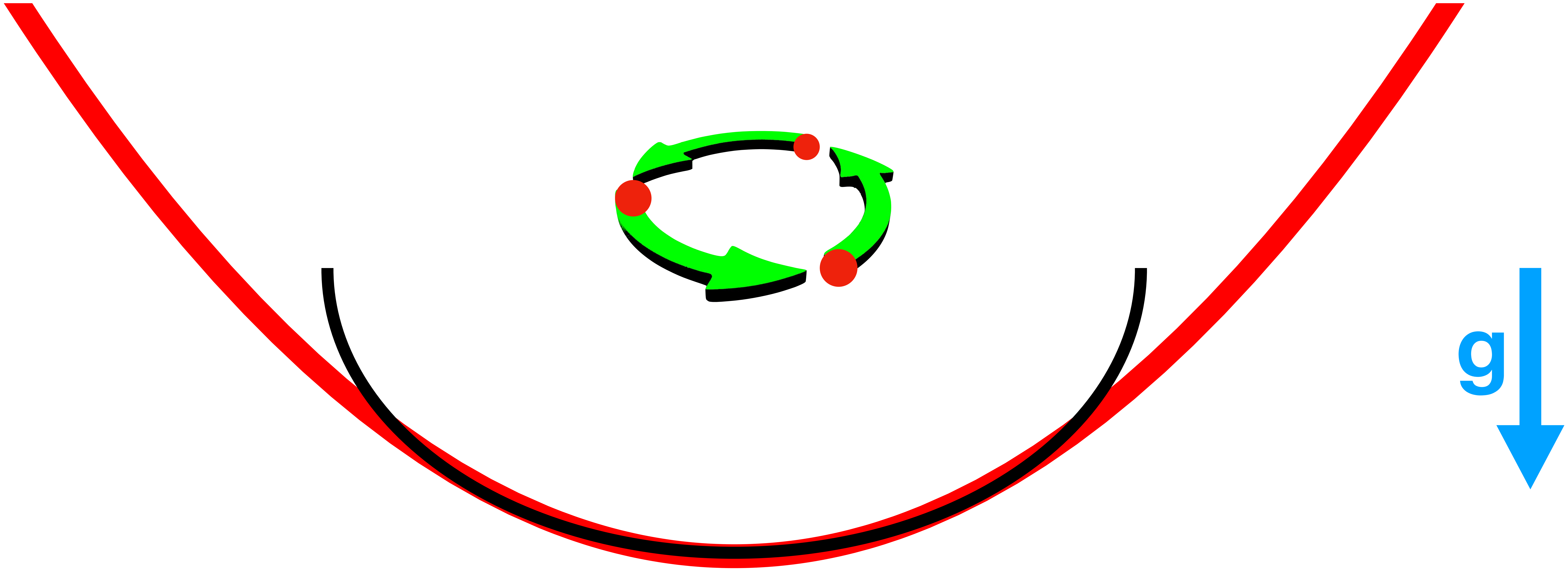
Bubble in Gravity



Laughlin vs Giant Vortex

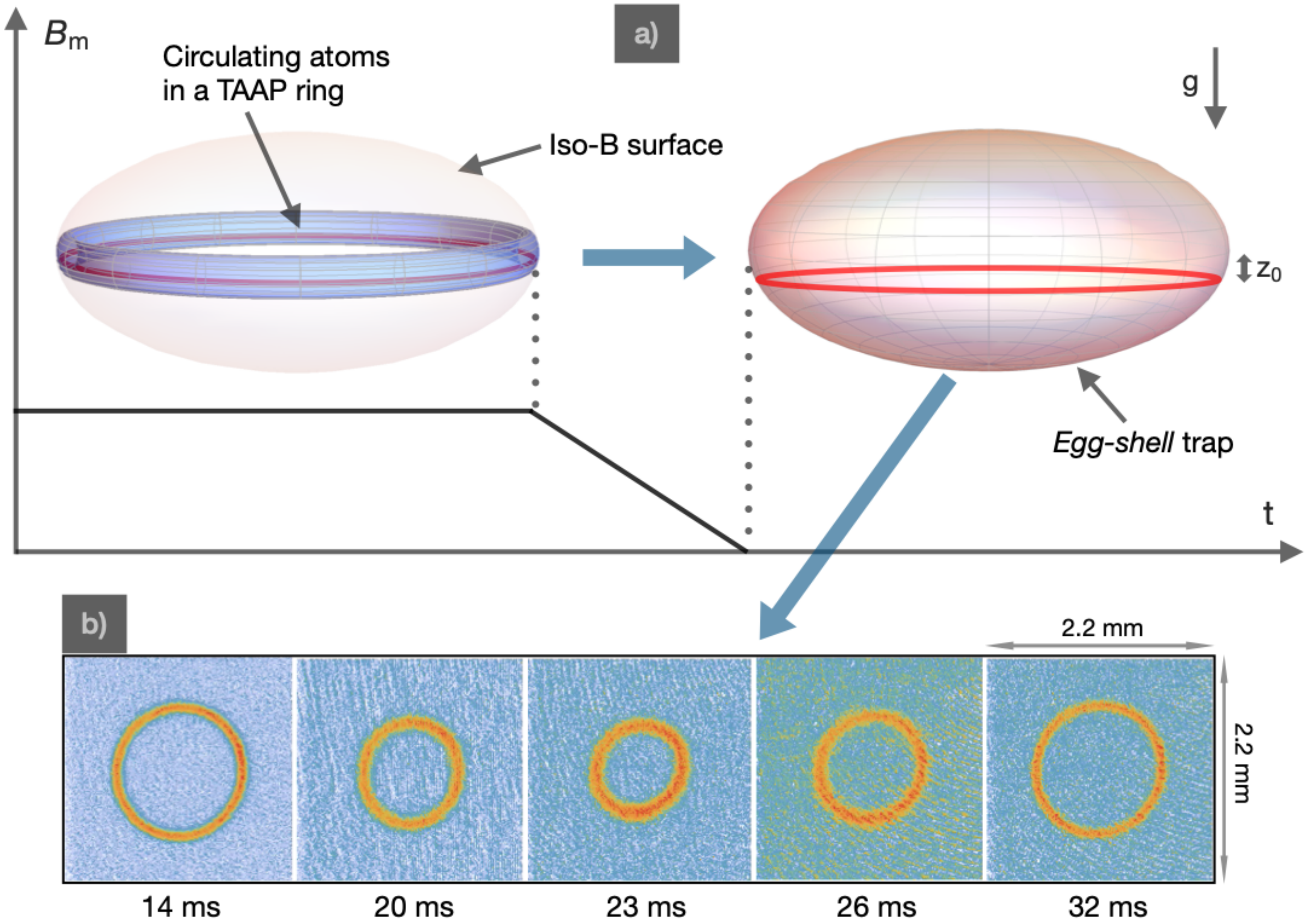


~~Laughlin vs~~ Giant Vortex



Transition from the mean-field to the bosonic Laughlin state in a rotating Bose-Einstein condensate (**O**)
G. Vasilakis, A. Roussou, J. Smyrnakis, M. Magiropoulos, W. von Klitzing, and G. M. Kavoulakis
Physical Review A ***100*** *(2019)*

Loading the Bubble



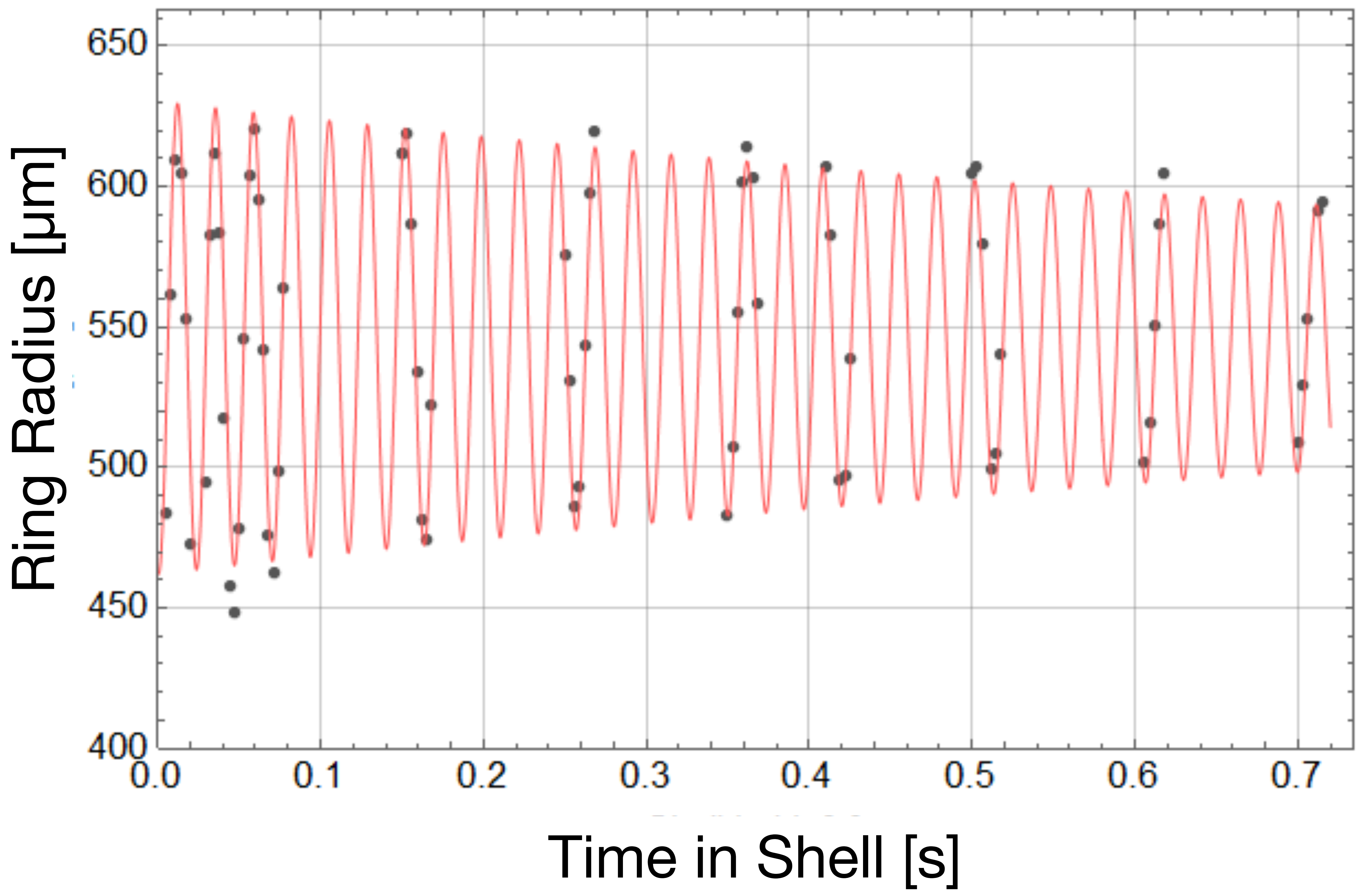
Giant Vortex ?

$\Omega/\omega_\rho > 1.7$

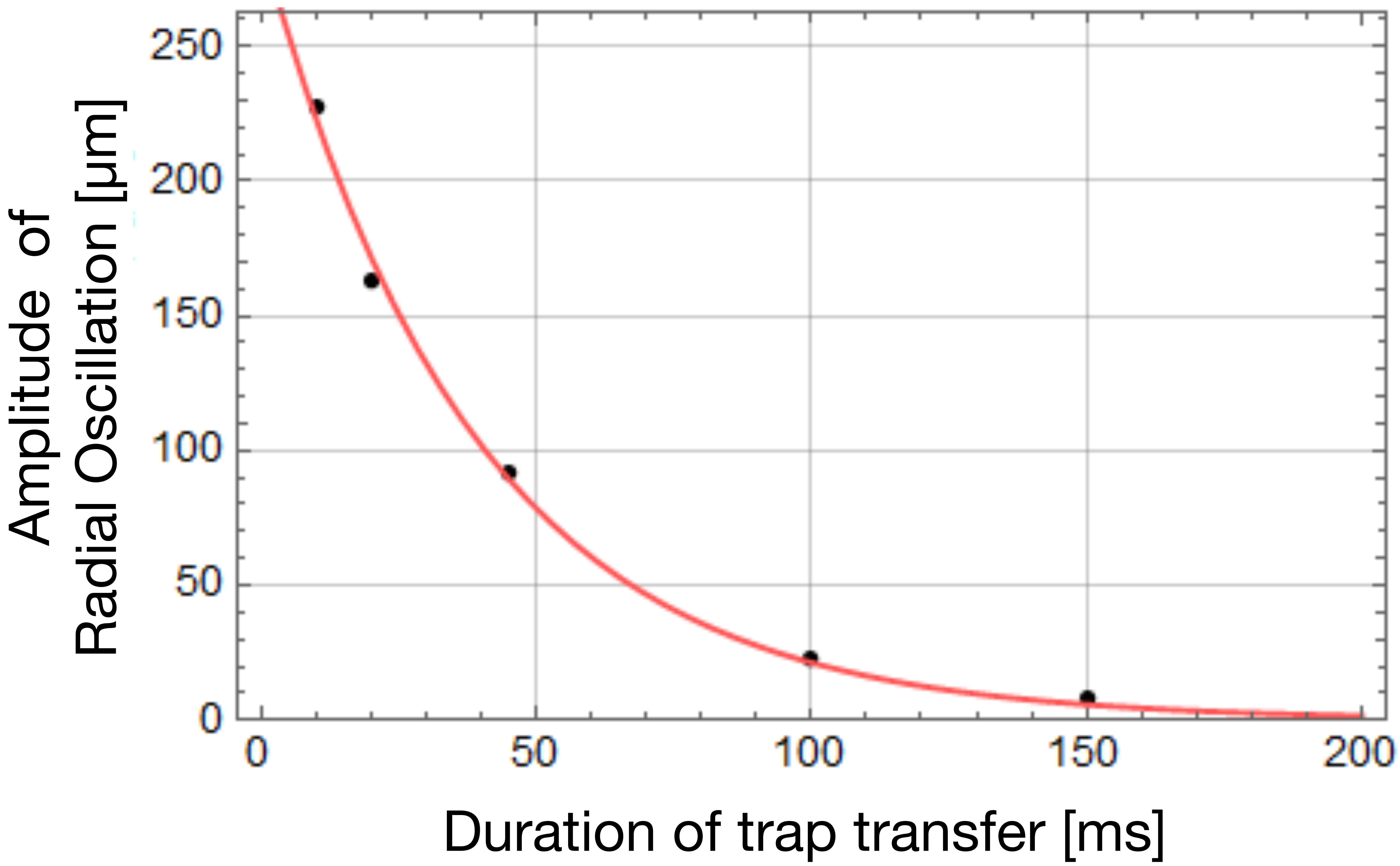
B. E. Sherlock et al.
Phys. Rev. A **83:4** 043408 (2011)

Fast Loading ➜ Oscillations

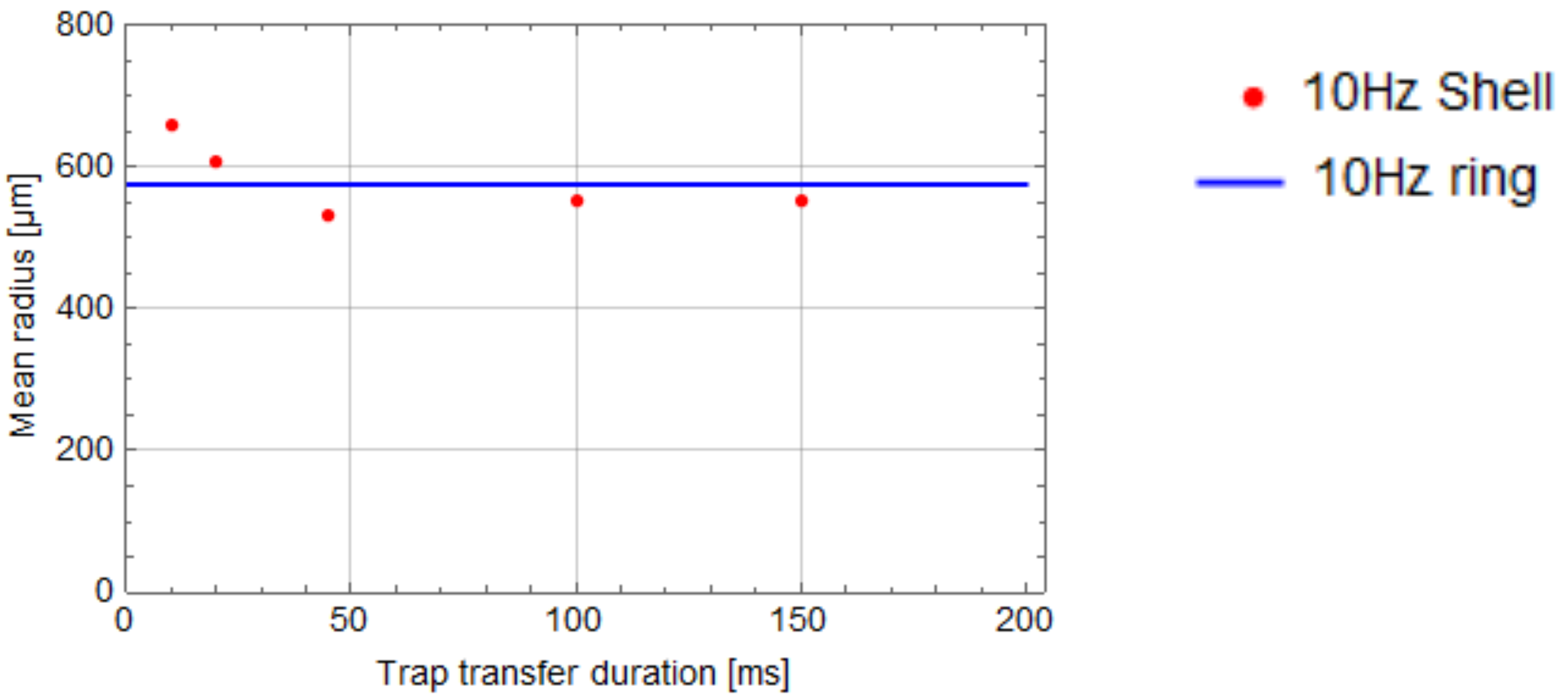
(45 ms transfer)



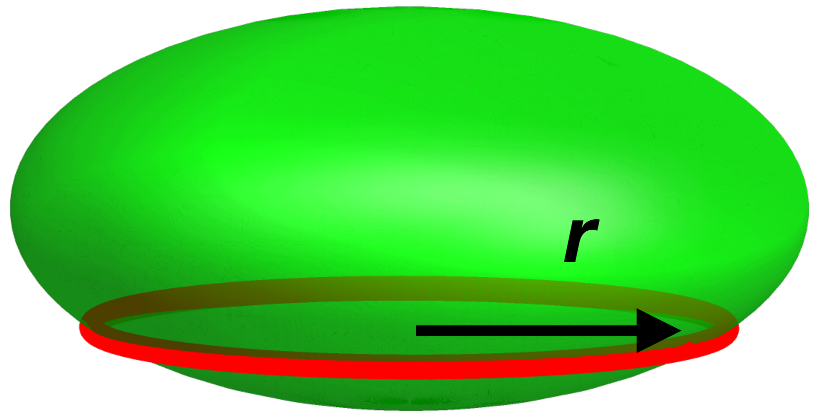
Adiabtic Loading:
(non) oscillating bubble ring

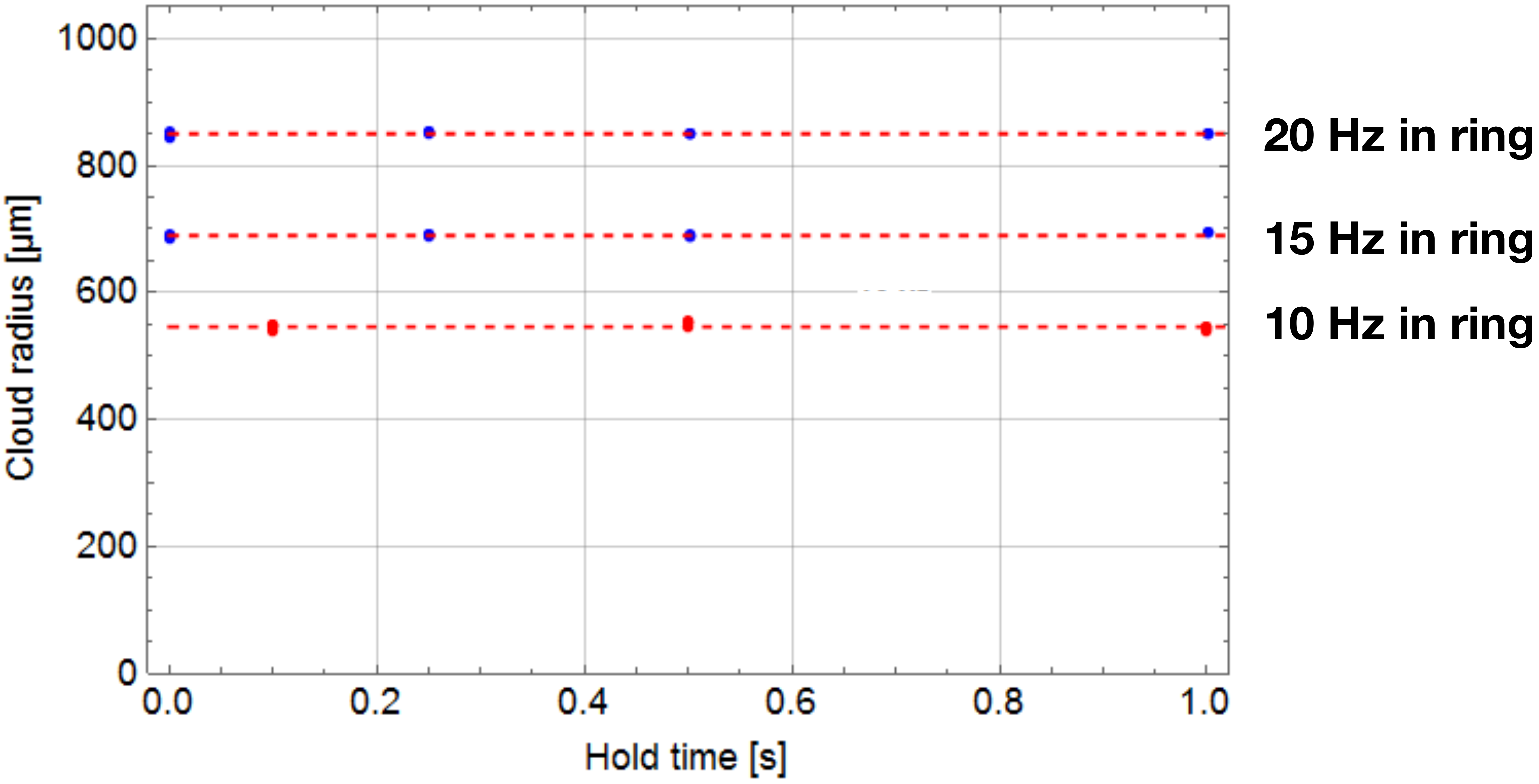


Adiabatic loading: Radius of Ring vs Bubble

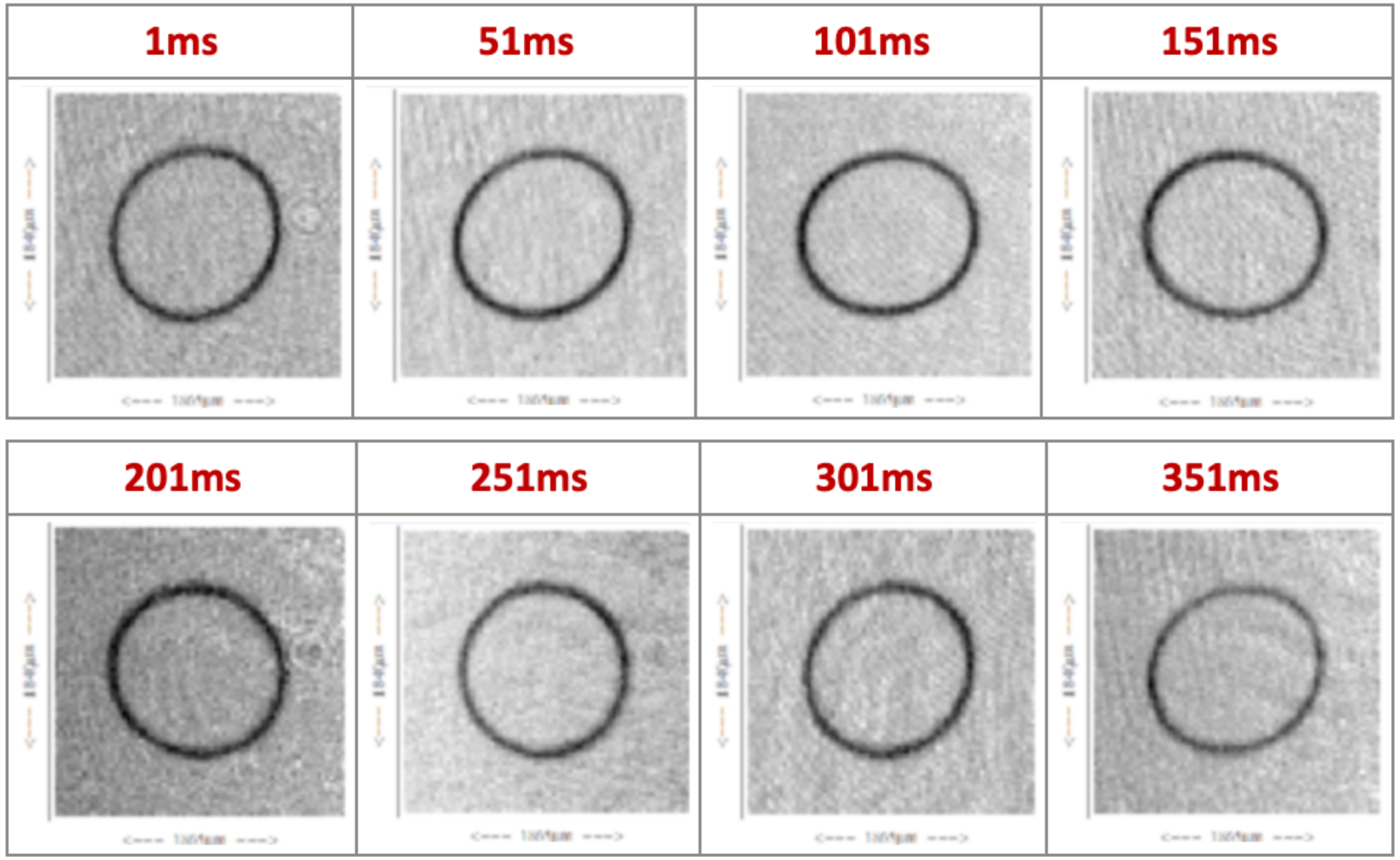


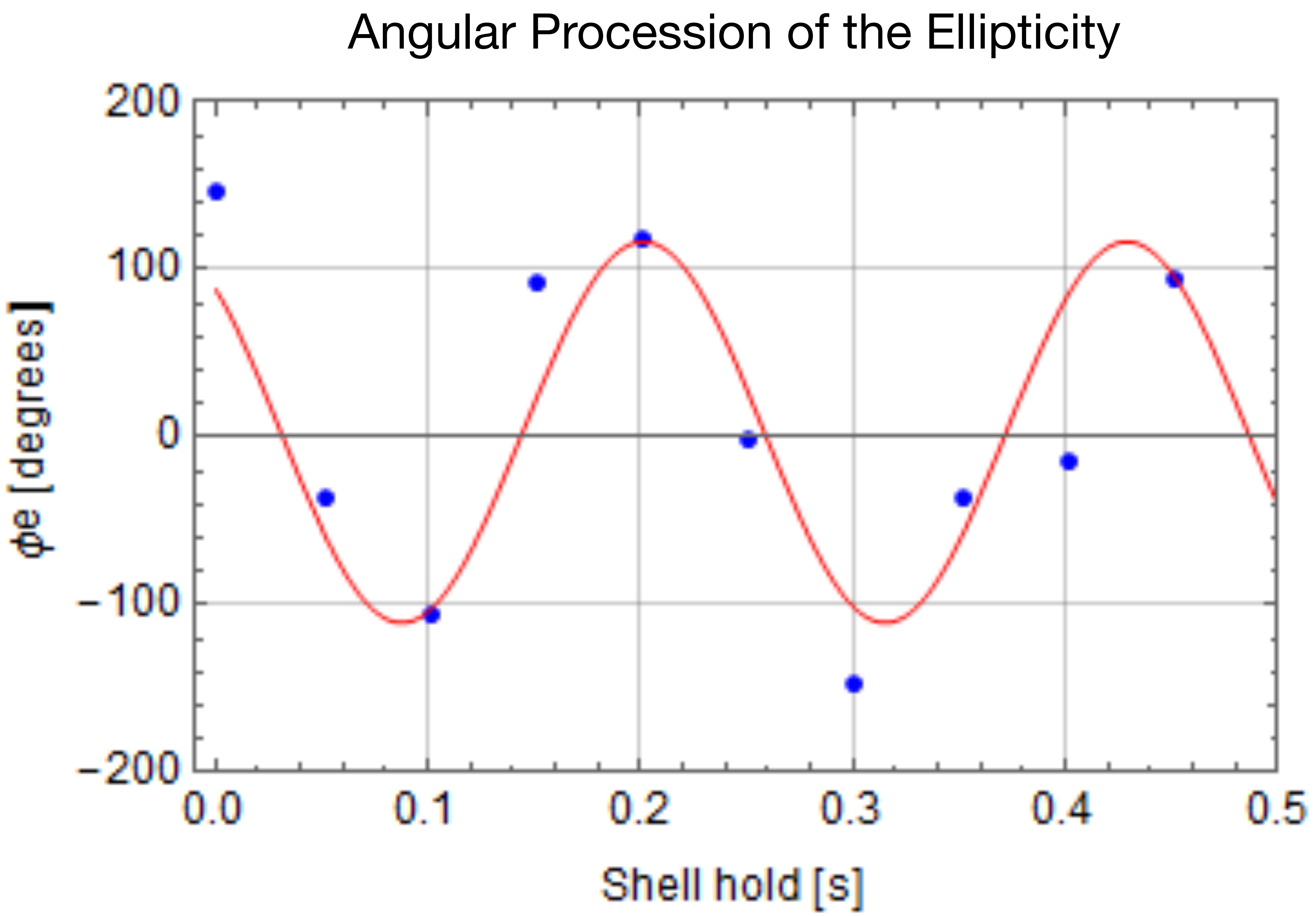
Adiabatic loading:
Radius of Ring vs Bubble





Ellipticity



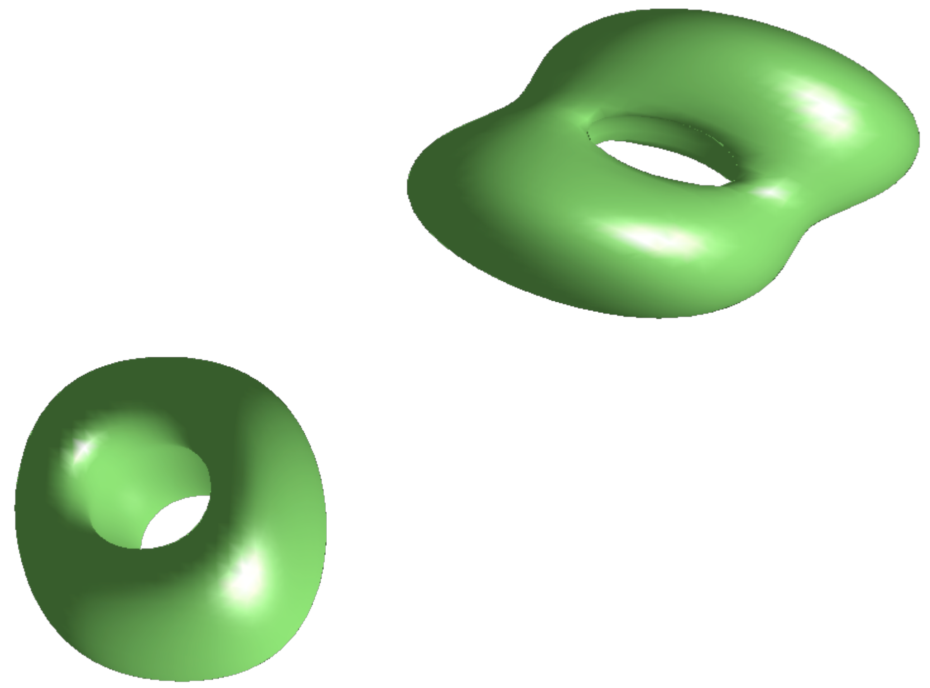


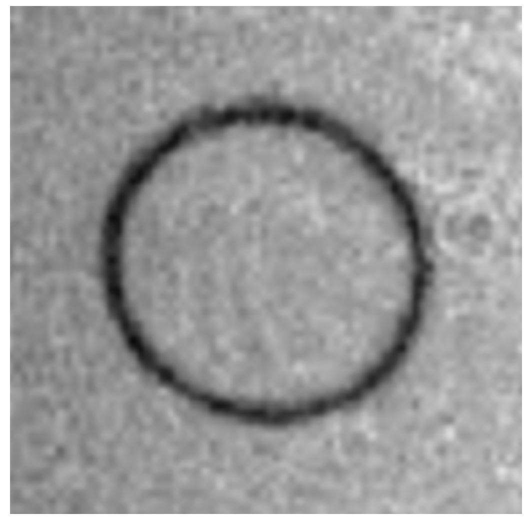
Giant Vortex ?

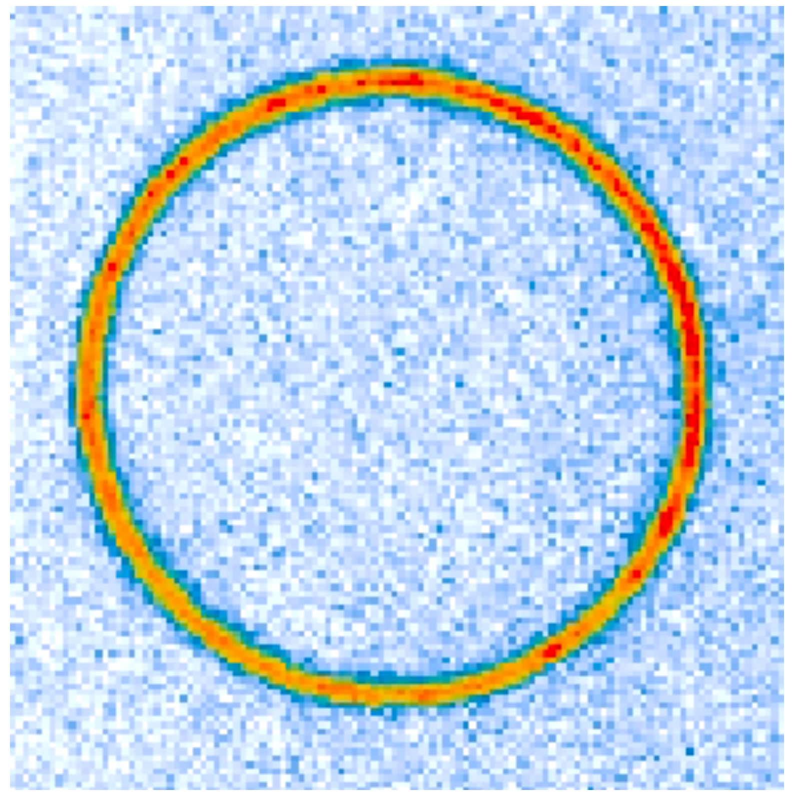
$\Omega/\omega_\rho > 1.7$

(Observed with condensed *and* thermal atoms)

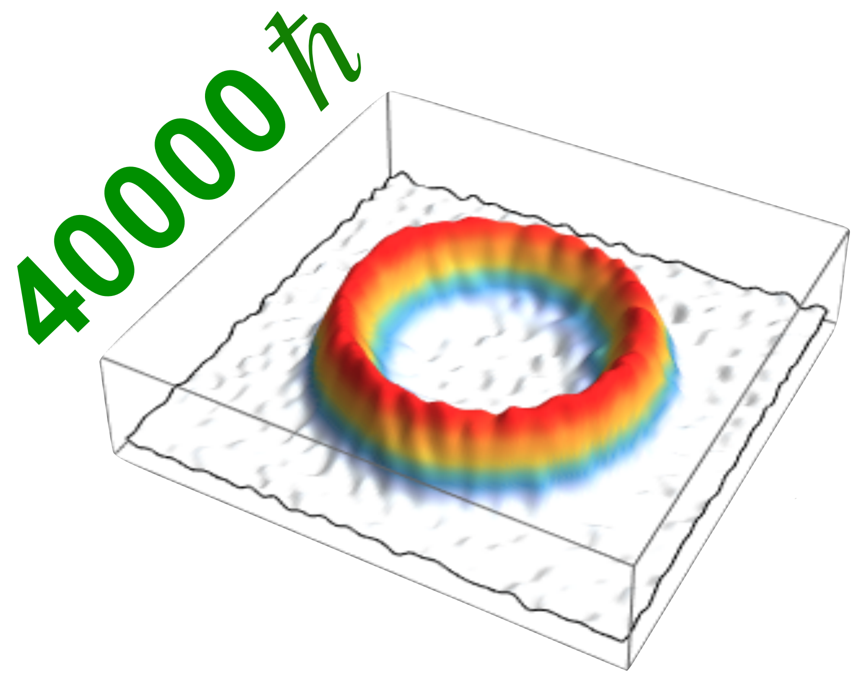
Summary



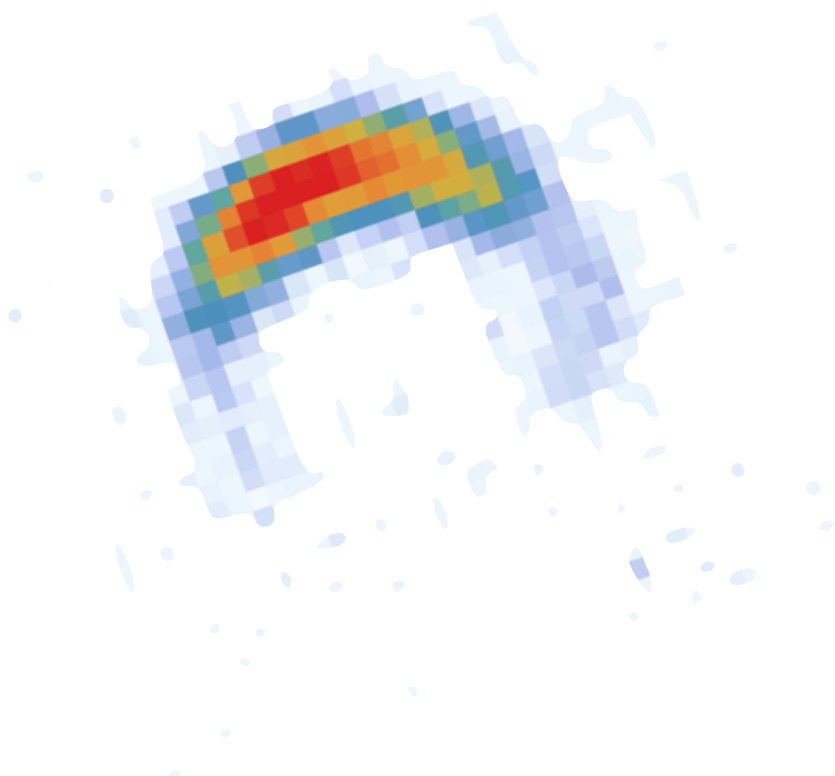




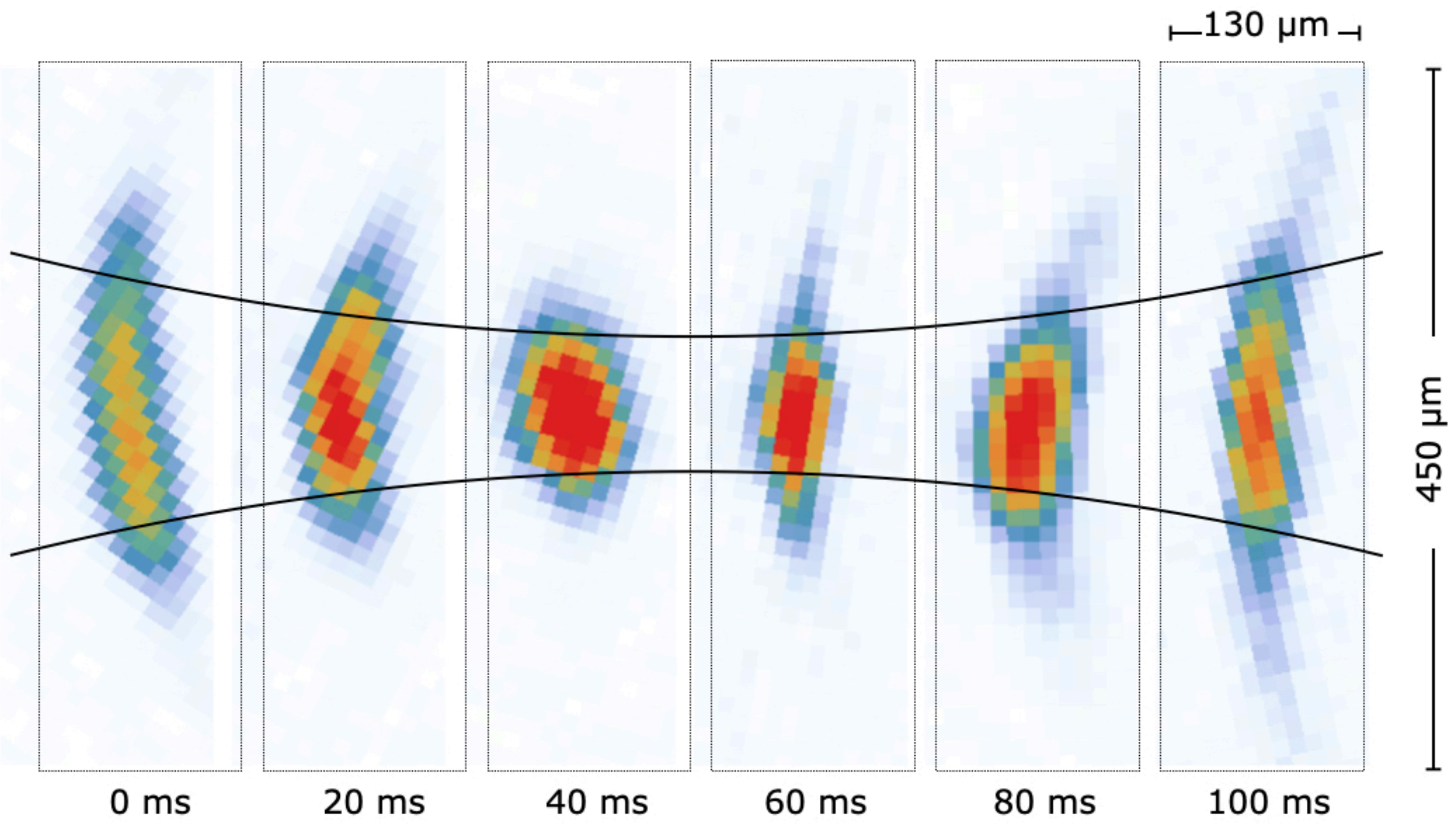
BEC rings



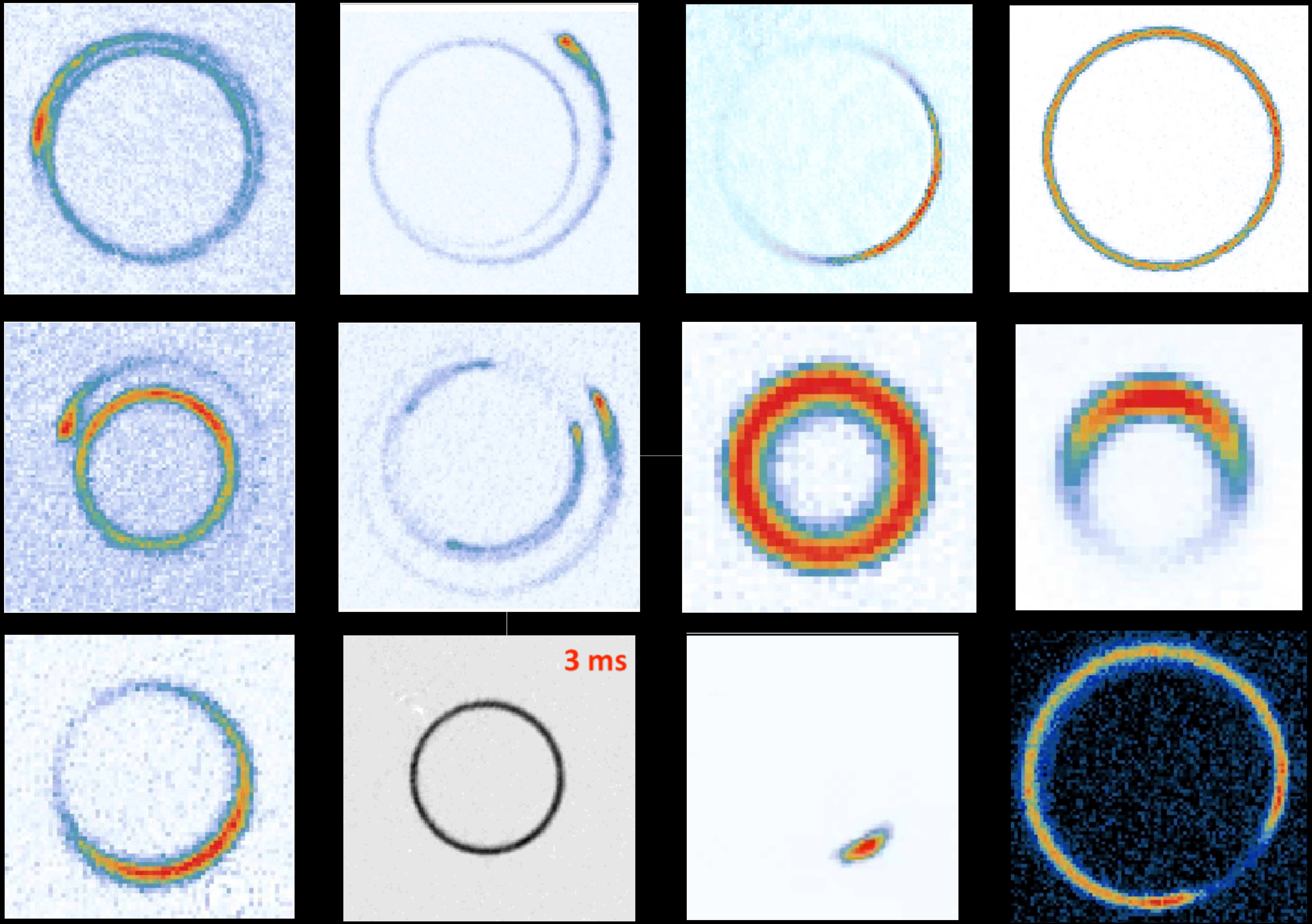
- Matterwave Waveguide
  - Lossless, Hypersonic flow of BECs
  - Ultra-high angular Momentum
  - Super Flat and Controllable



- Giant Vortices
- Bubble - Rings
- Ellipticity / Oscillations



Atomtronic Ring Physics



Pandey et al @ Nature 2019