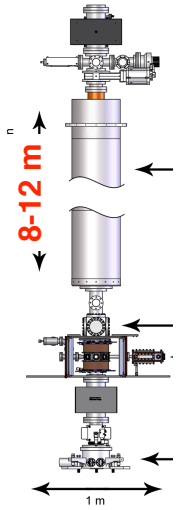
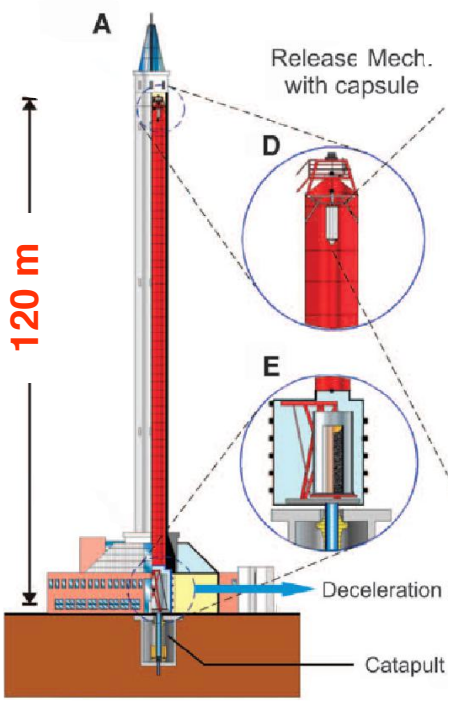
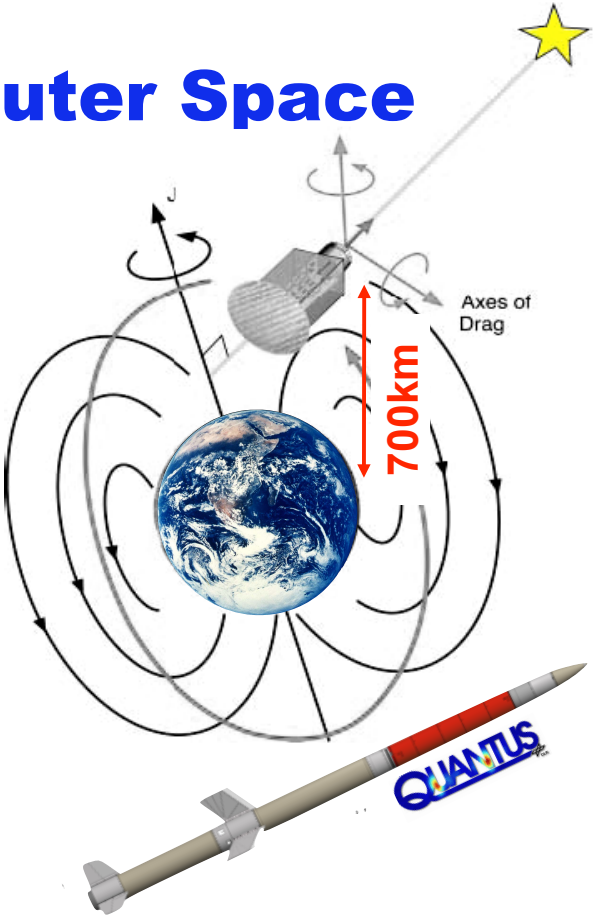
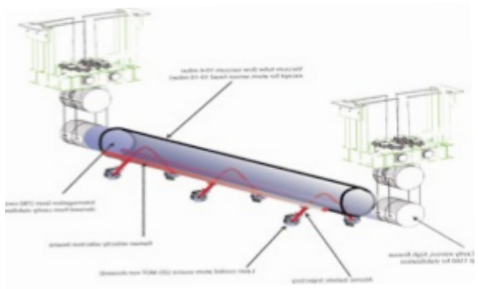
Free Space





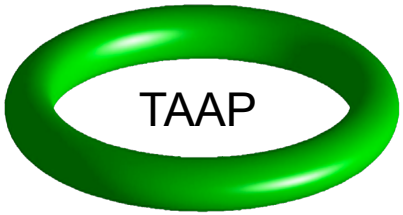
Outer Space



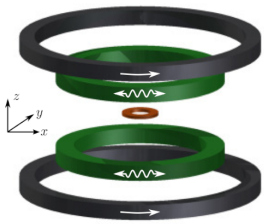


Atomtronics !

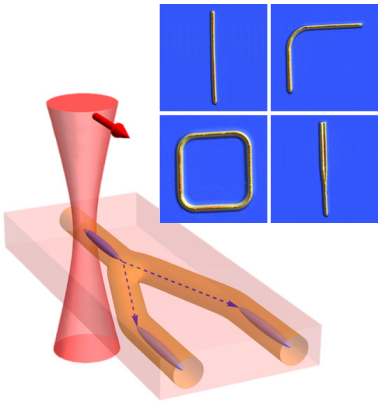
← 2cm →



← 5 µm - 2 cm →



← cm →



Phase-Coherent Atomtronics

- **Small Size**
- **Long Time**
- **Real-World Appl.**
- **New Physics**

- **Interactions**
  - With the environment
  - With other atoms
  - With the guide

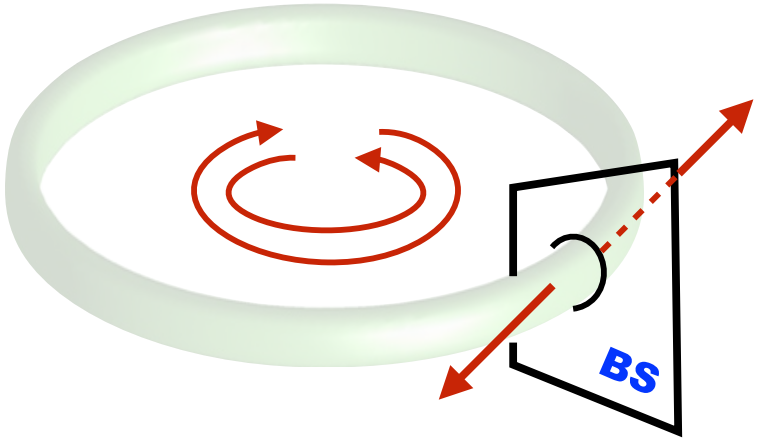
CRETANMATTERWAVES

Matter-Wave Interferometry, an example

A Sagnac Gyroscope:

$$\Delta\phi = \frac{4\pi}{\lambda v}\Omega A$$

$$\frac{\Delta\phi_{\text{atom}}}{\Delta\phi_{\text{light}}} = \frac{\lambda_{\text{light}}\, c_0}{h/m} = \textbf{5x10}^{\textbf{10}}$$



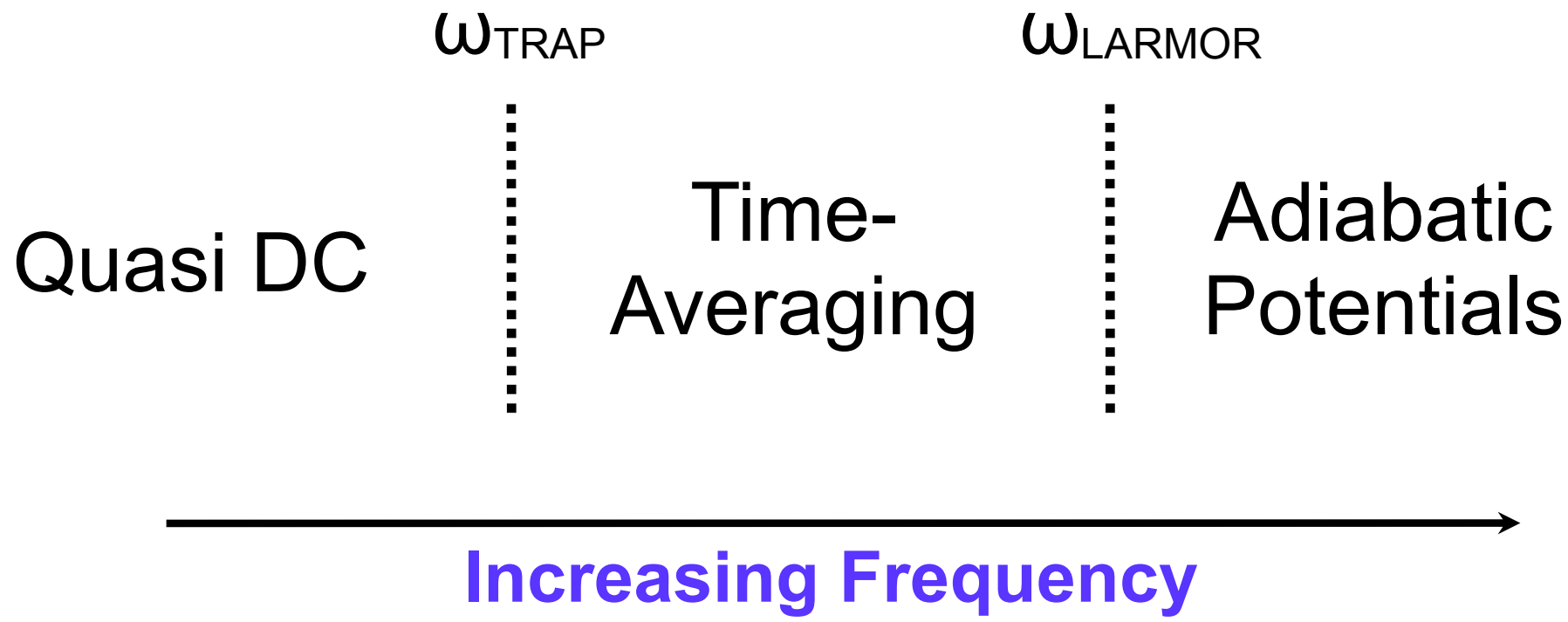
Plus

+ Internal States
+ Gravitation (waves)
+ Atom-Atom Interaction
    => Heisenberg Limited Detection

Savas Dimopoulos et al. *Physics Letters B* **678:1** 37--40 (2009)

Cretan Matter Waves

Time-Scales of Magnetically Trapped Atoms



Cretan Matter Waves

Time-Scales of Magnetically Trapped Atoms

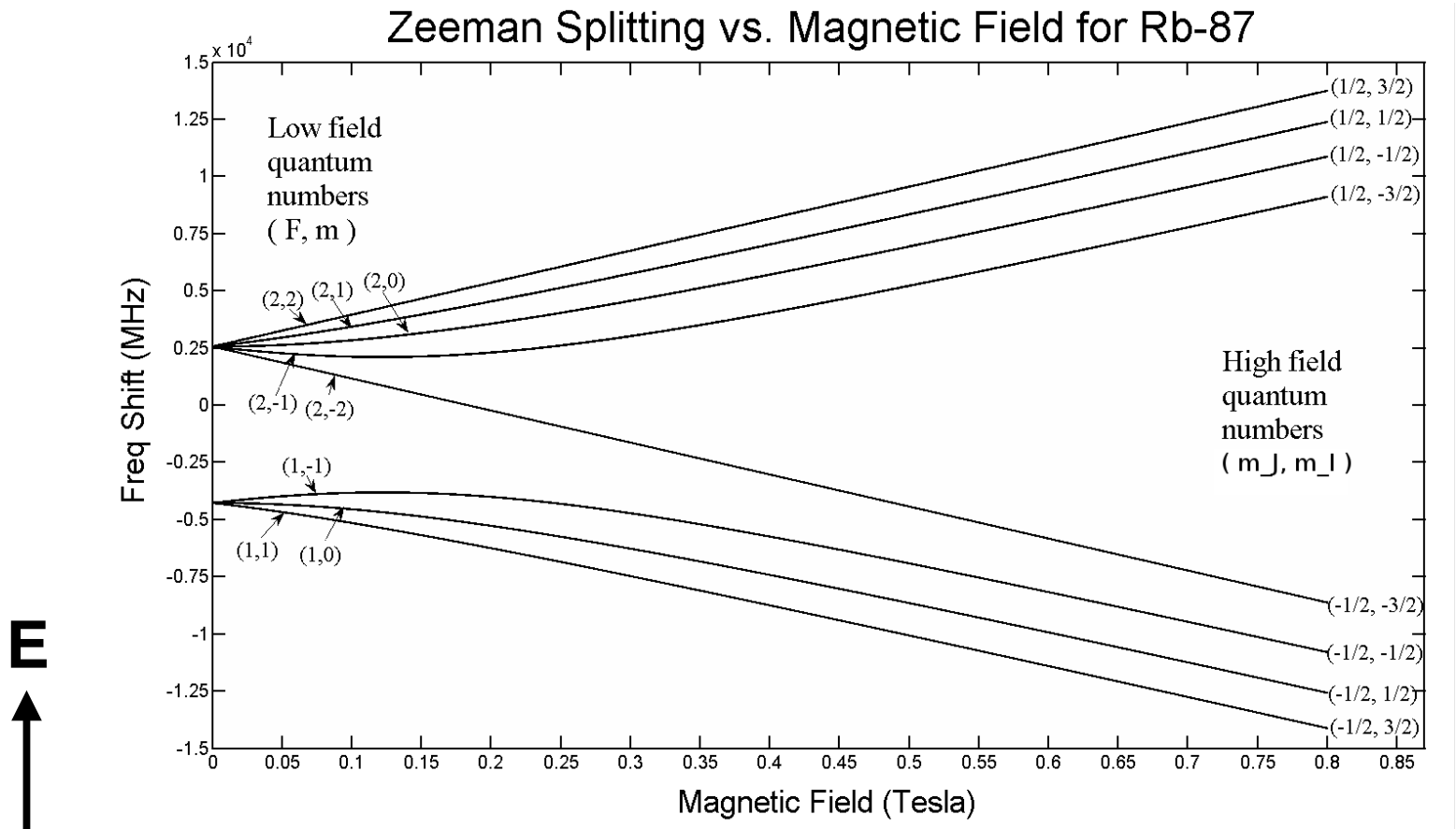
ω_{TRAP} ω_{LARMOR}

Quasi DC | Time-Averaging | Adiabatic Potentials

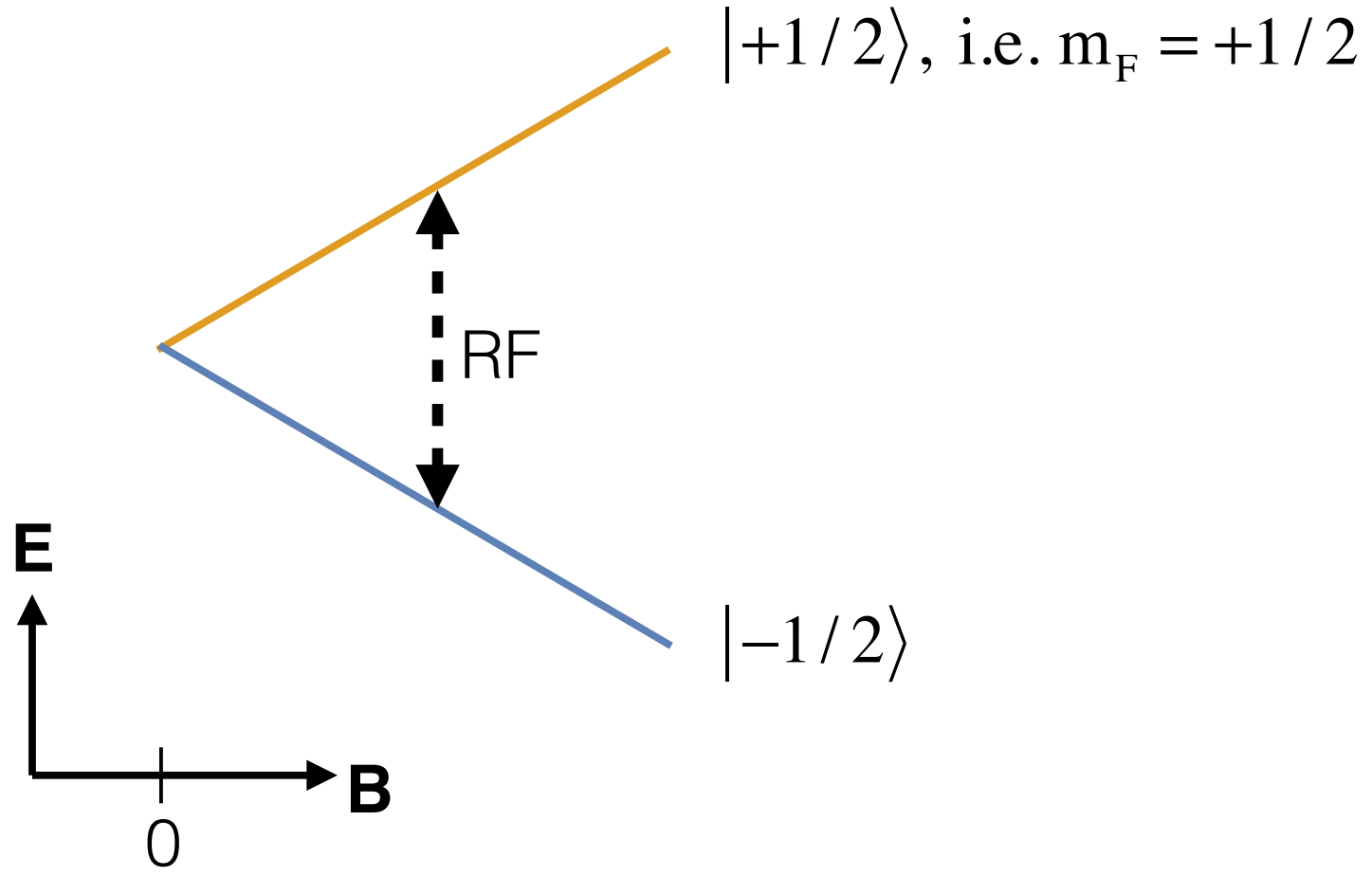
Increasing Frequency

$$V_{\pm}^{eff}(\mathbf{r}) = \frac{\omega_m}{2\pi}\int_0^{2\pi/\omega_m} dt\, V_{\pm}(\mathbf{r},t) = \frac{\omega_m}{2\pi}\int_0^{2\pi/\omega_m} dt\, \hbar\sqrt{\left(\Omega_L(\mathbf{r},t)-\omega(t)\right)^2+\Omega_{\pm}^2(\mathbf{r},t)}$$

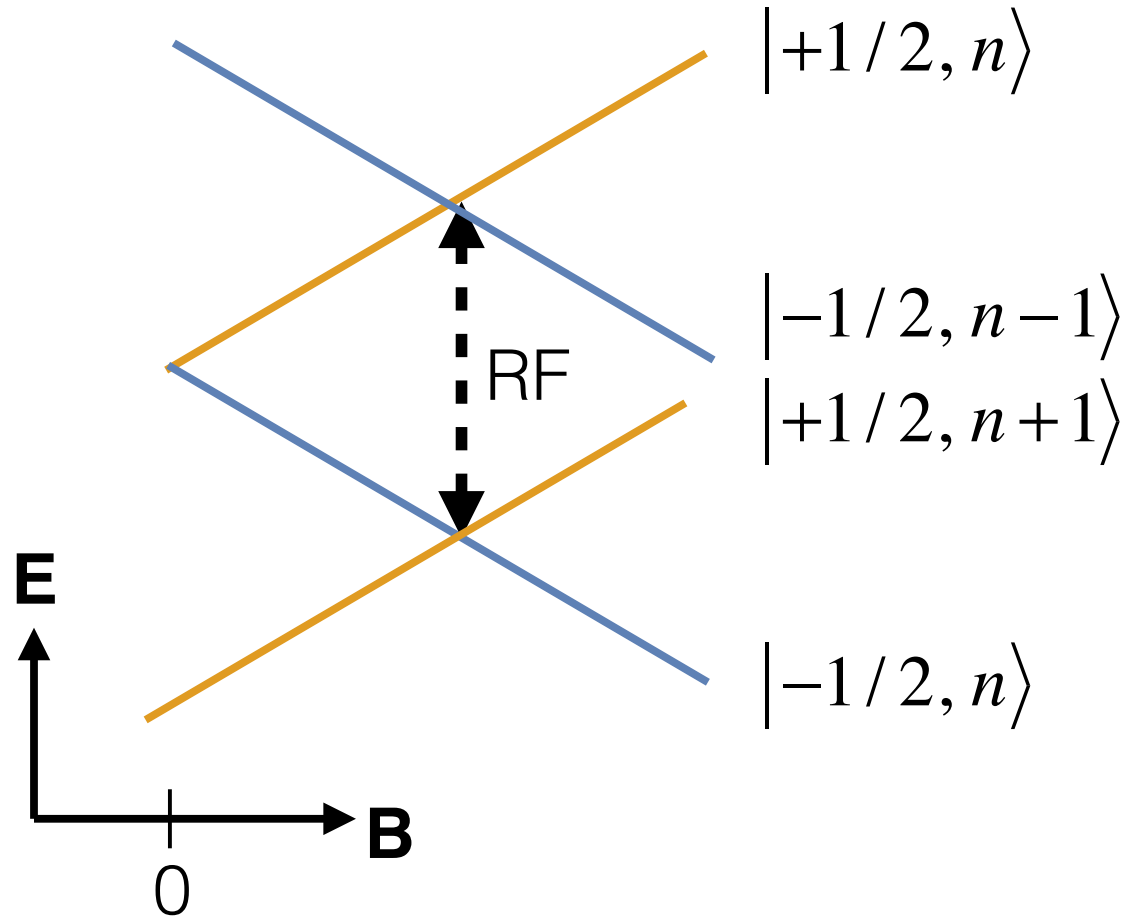
Dressed Potentials



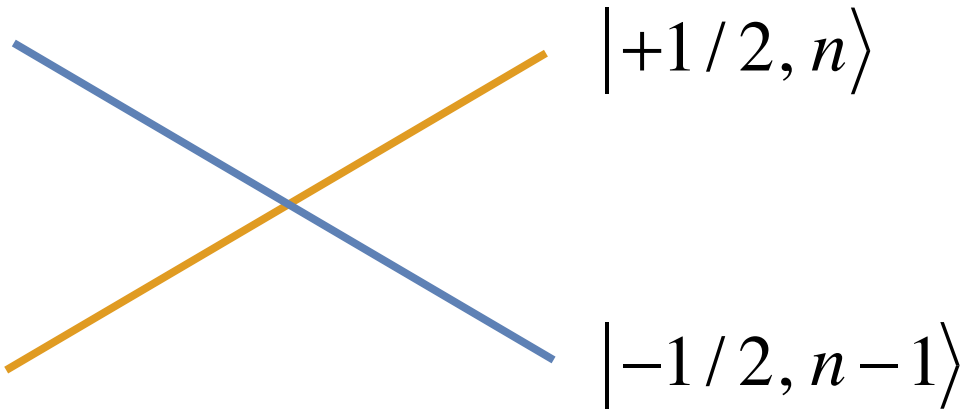
Dressed Potentials

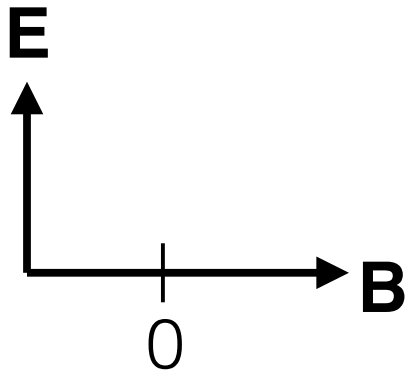


Dressed Potentials

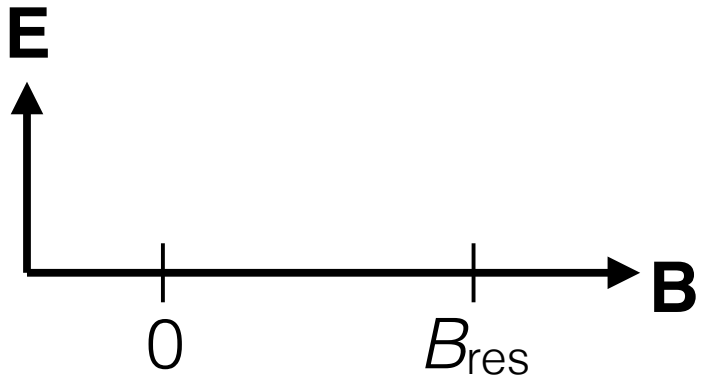


Dressed Potentials





Dressed Potentials



$$B_{\mathrm{res}} = \frac{\hbar\omega_{\mathrm{rf}}}{g_{\mathrm{f}}\mu_{\mathrm{B}}}$$

Cretan Matter-Waves Group

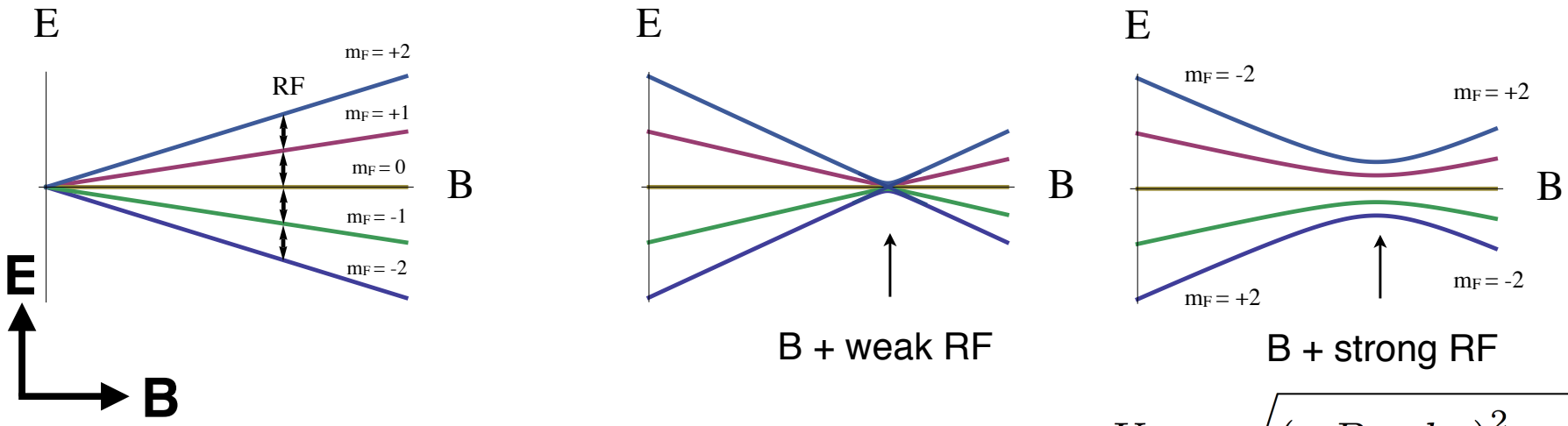
Magnetic Trapping + RF

FORTH
IESL

$E(B)$

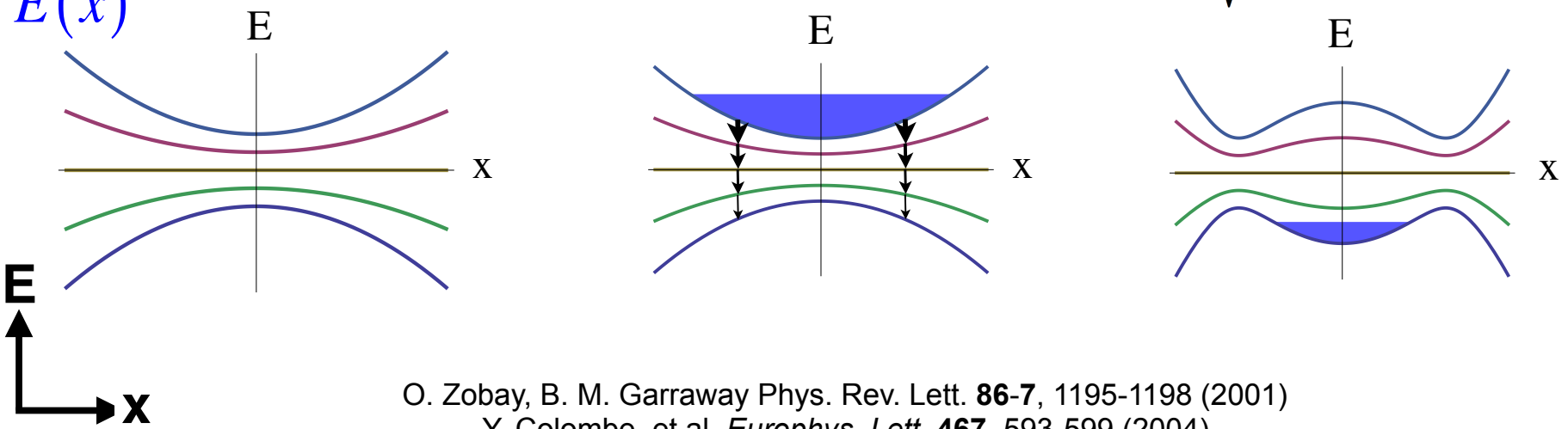
Weak Coupling
(Spin flips)

Strong Coupling
(Adiabatic Potentials)



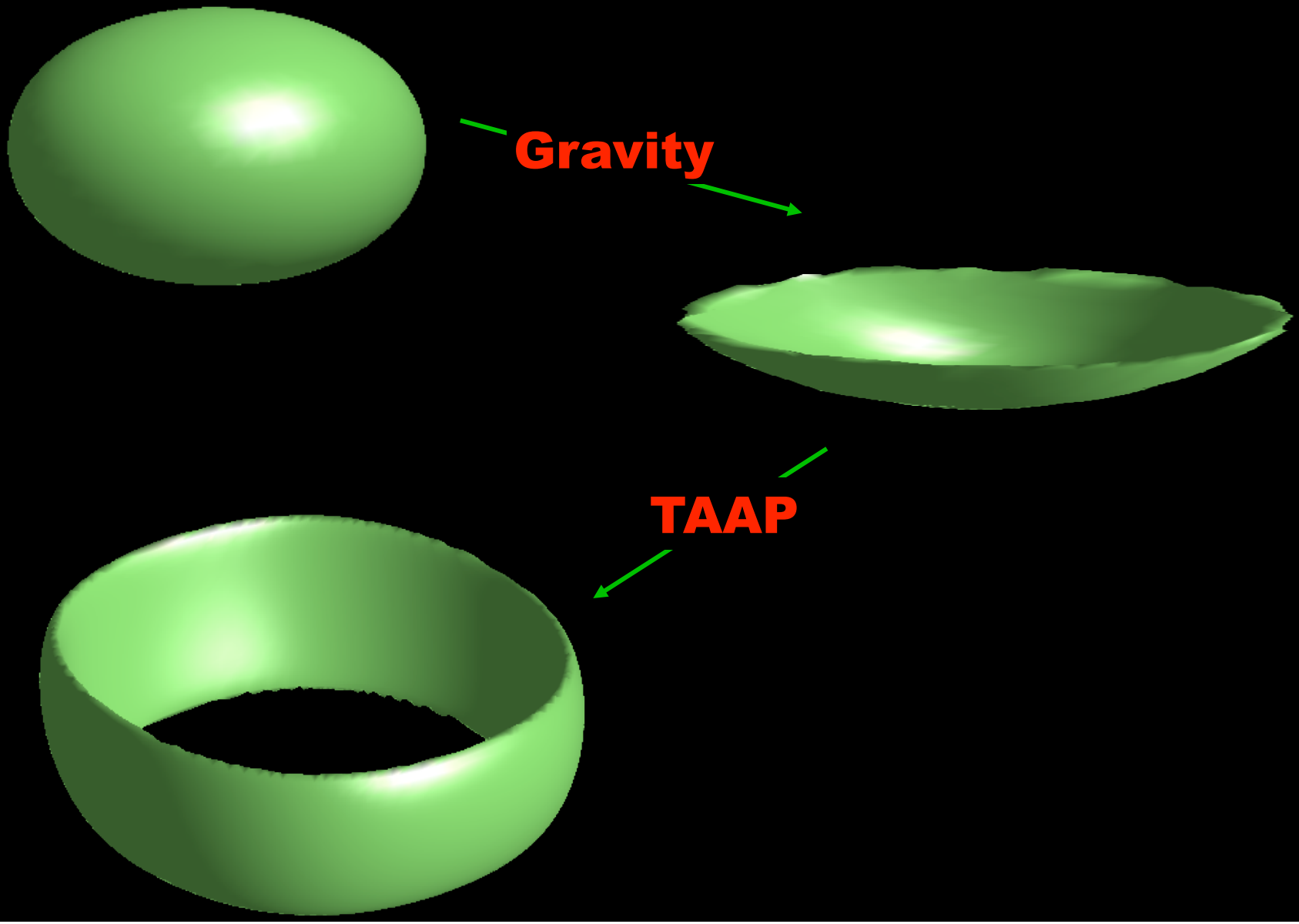
$$U_{\mathrm{rf}} = \sqrt{(\mu B - h\nu)^2 + (h\Omega)^2}$$

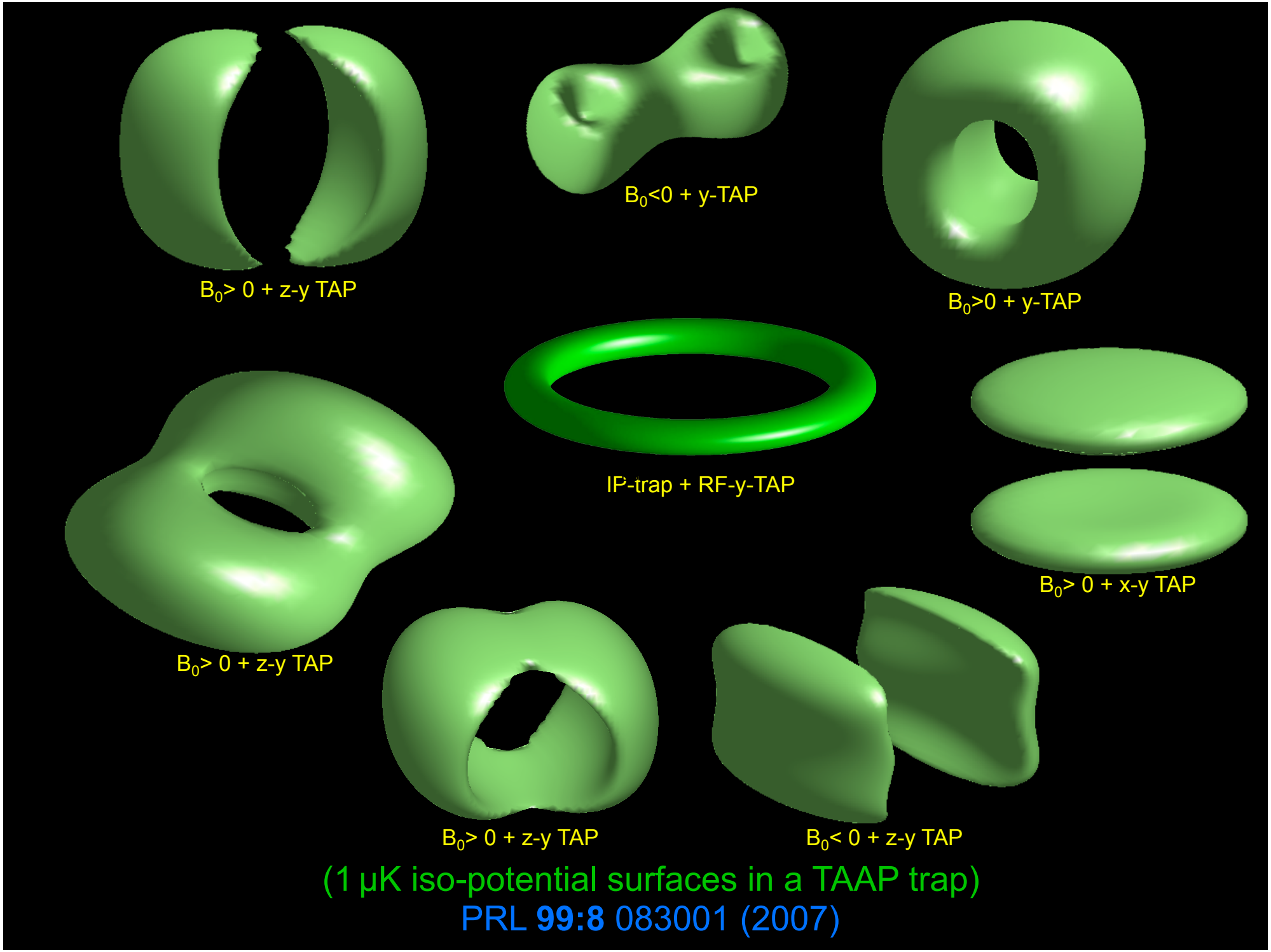
$E(x)$



O. Zobay, B. M. Garraway Phys. Rev. Lett. **86-7**, 1195-1198 (2001)
Y. Colombe, et al. *Europhys. Lett.* **467**, 593-599 (2004)

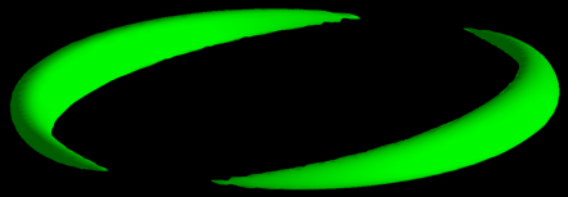
Time-Averaged Adiabatic Potentials (TAAP)





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

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

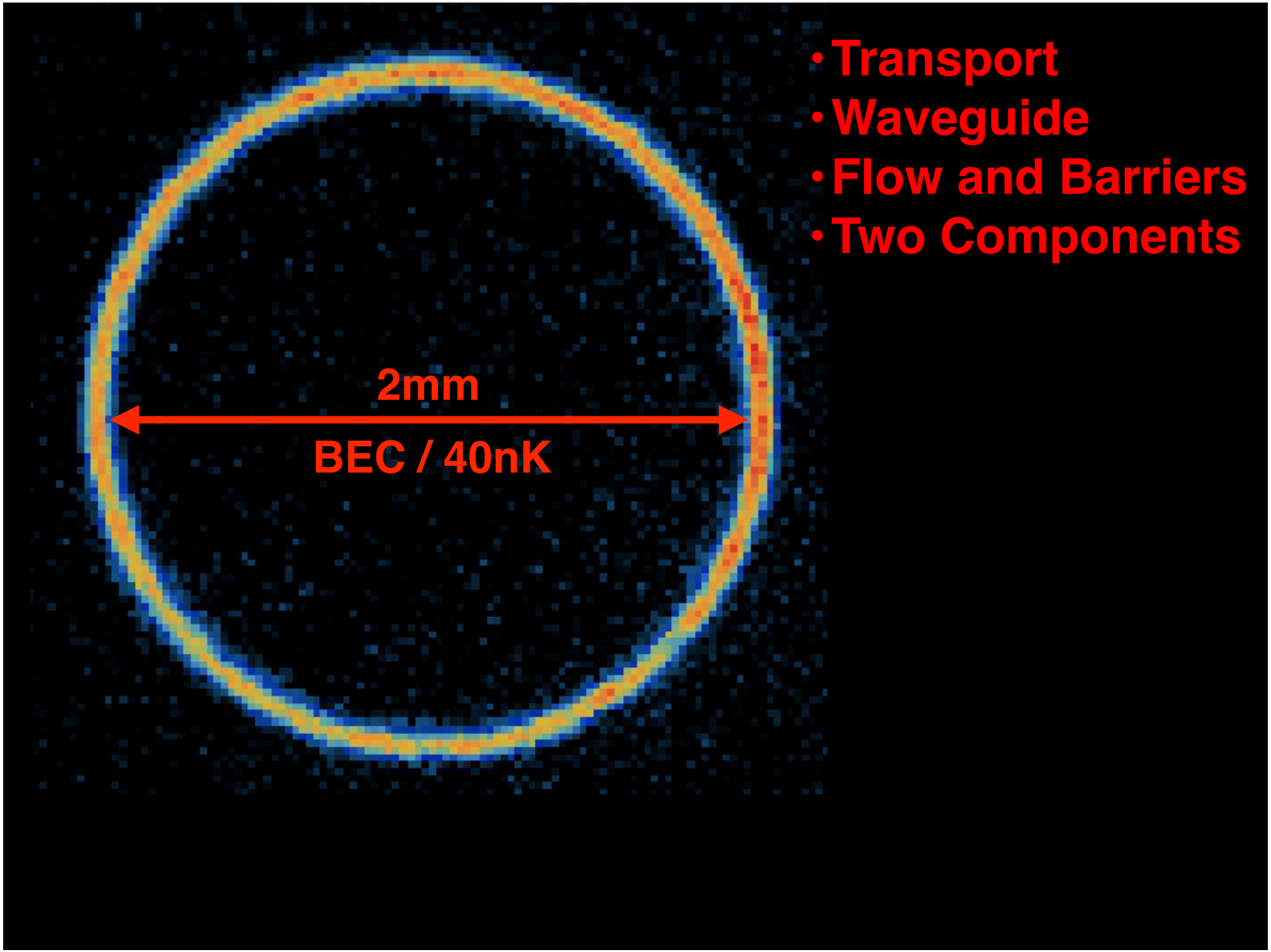


IP-trap + RF-y-TAP

Smooth

Radius 10 µm - 2 cm

Transverse confinement > 1000 Hz



- Transport
- Waveguide
- Flow and Barriers
- Two Components

Atomtronic Transport

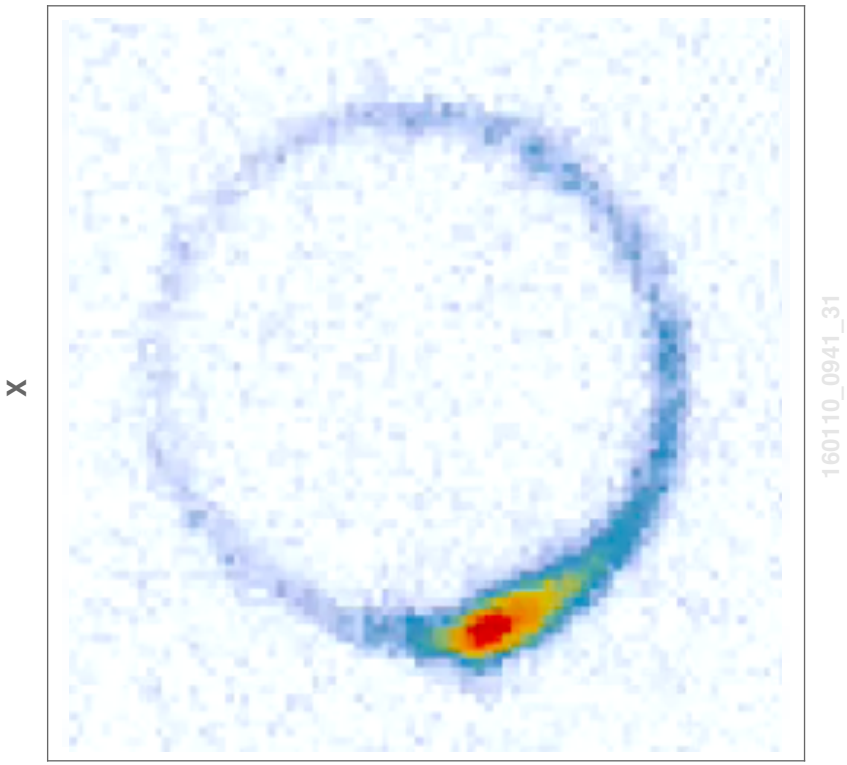
CRETANMATTERWAVES

Cretan Matter-Waves Group

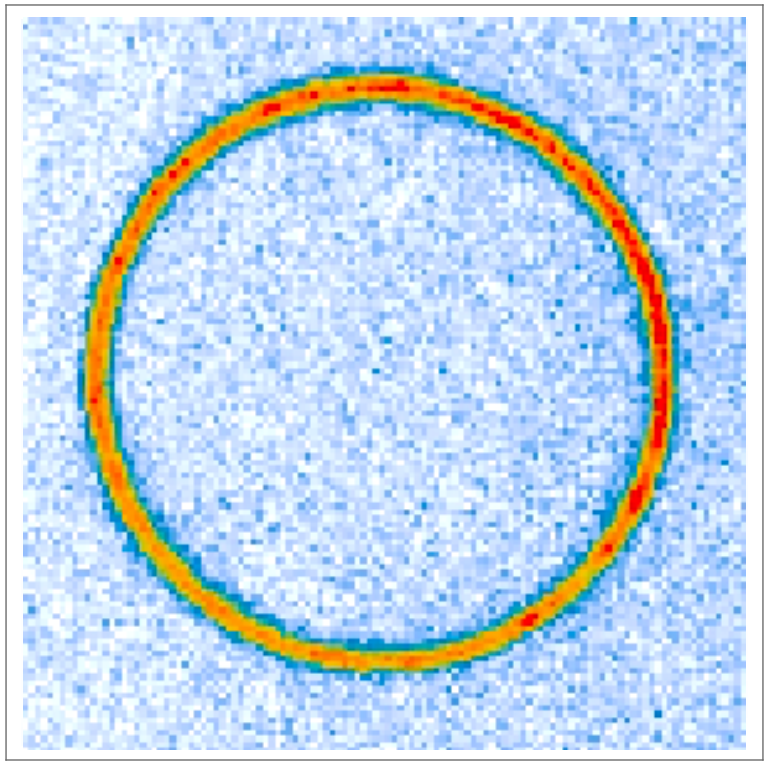
Real Rings and …

FORTH—IESL

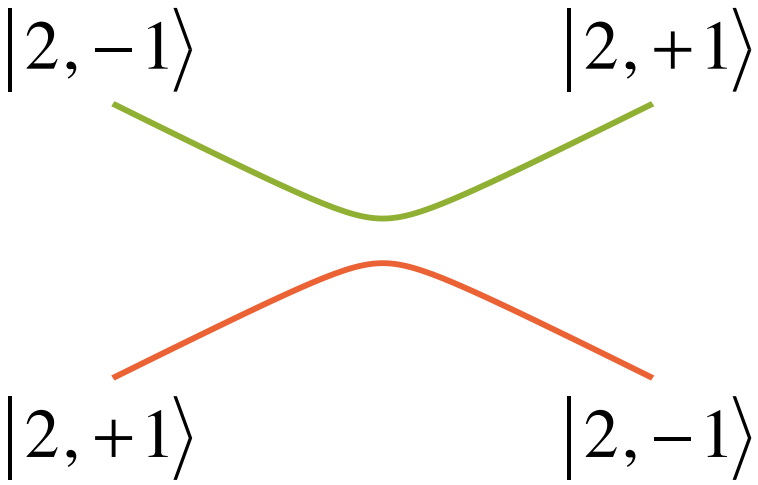
Waveguide

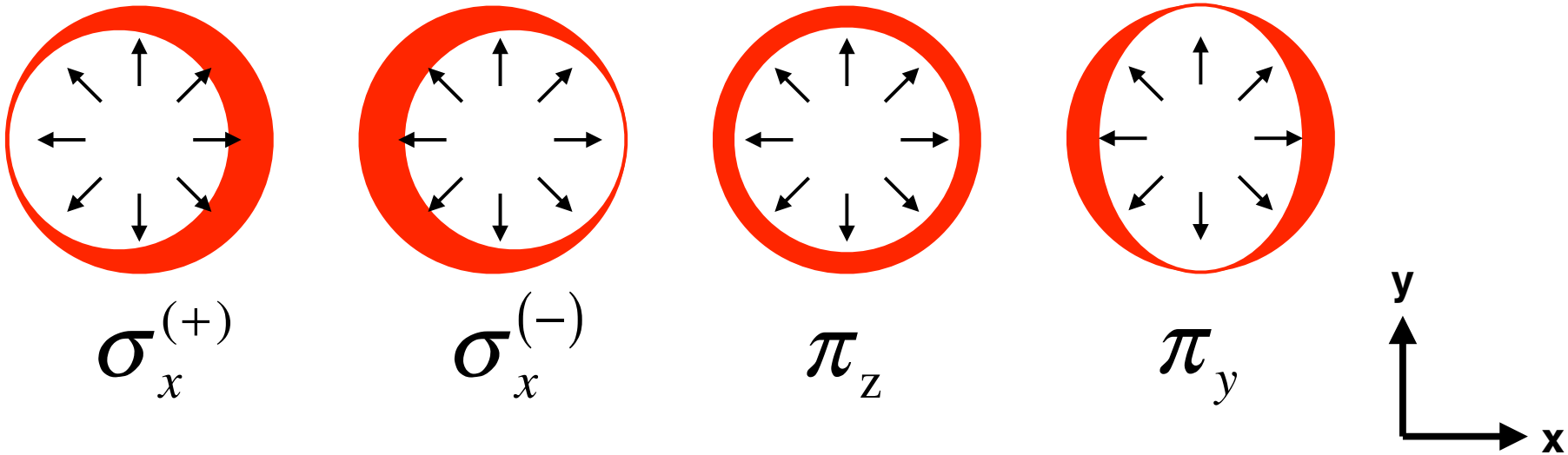


Flat Ring



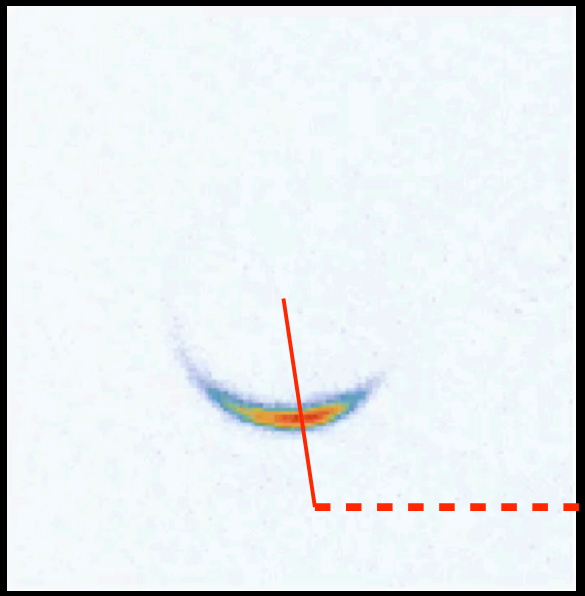
Dressed Potentials and Polarization and Tilt

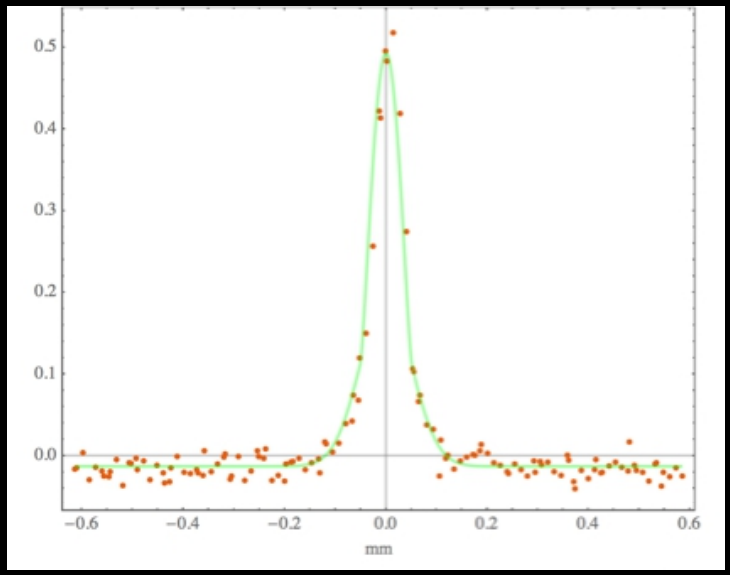




BEC in a Ring

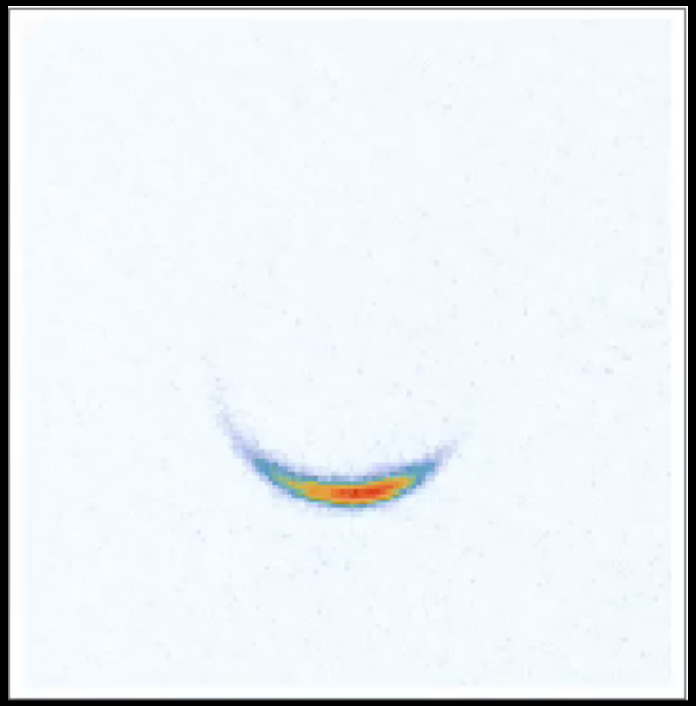
BEC in a Ring

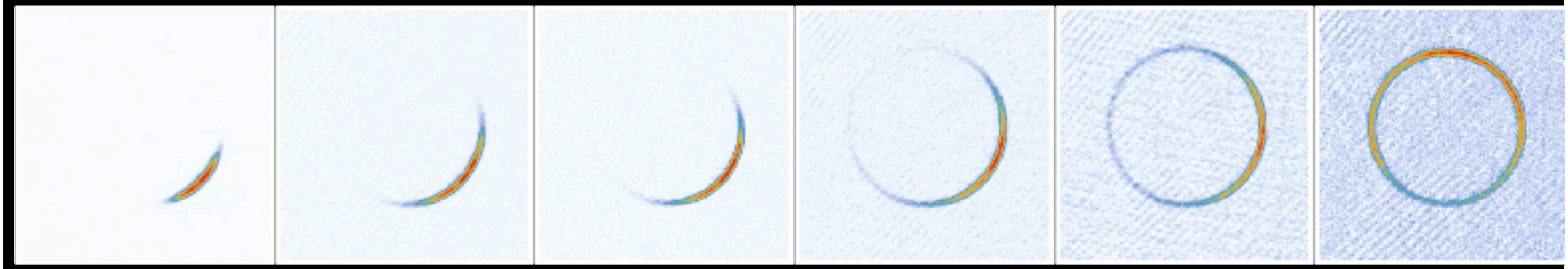




Slow Release

(mechanical + polarization tilt)



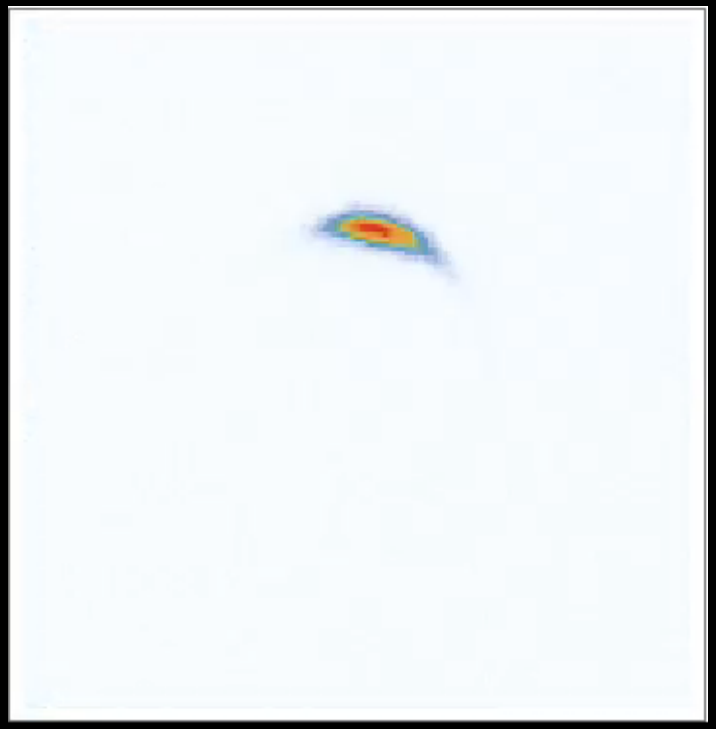


0.1s

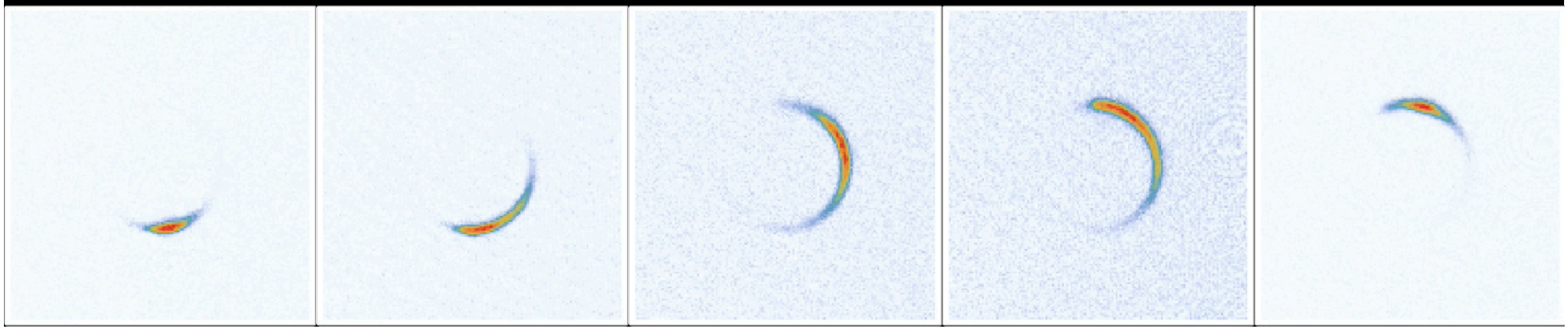
0.5s

Condensate Oscillations

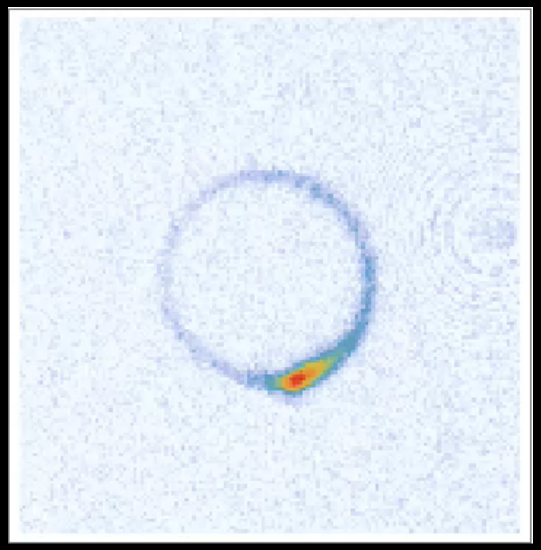
(f = ~ 8 Hz)

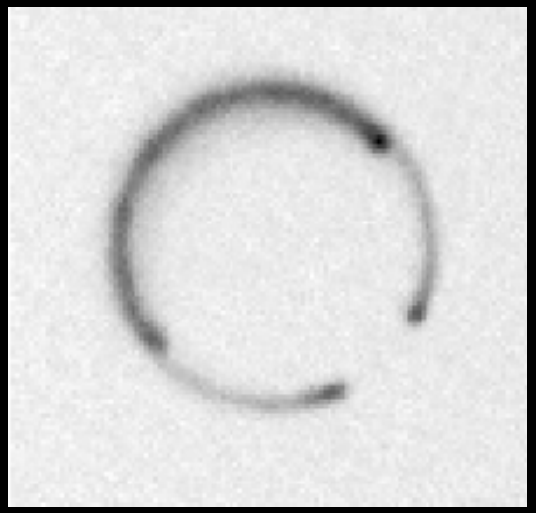


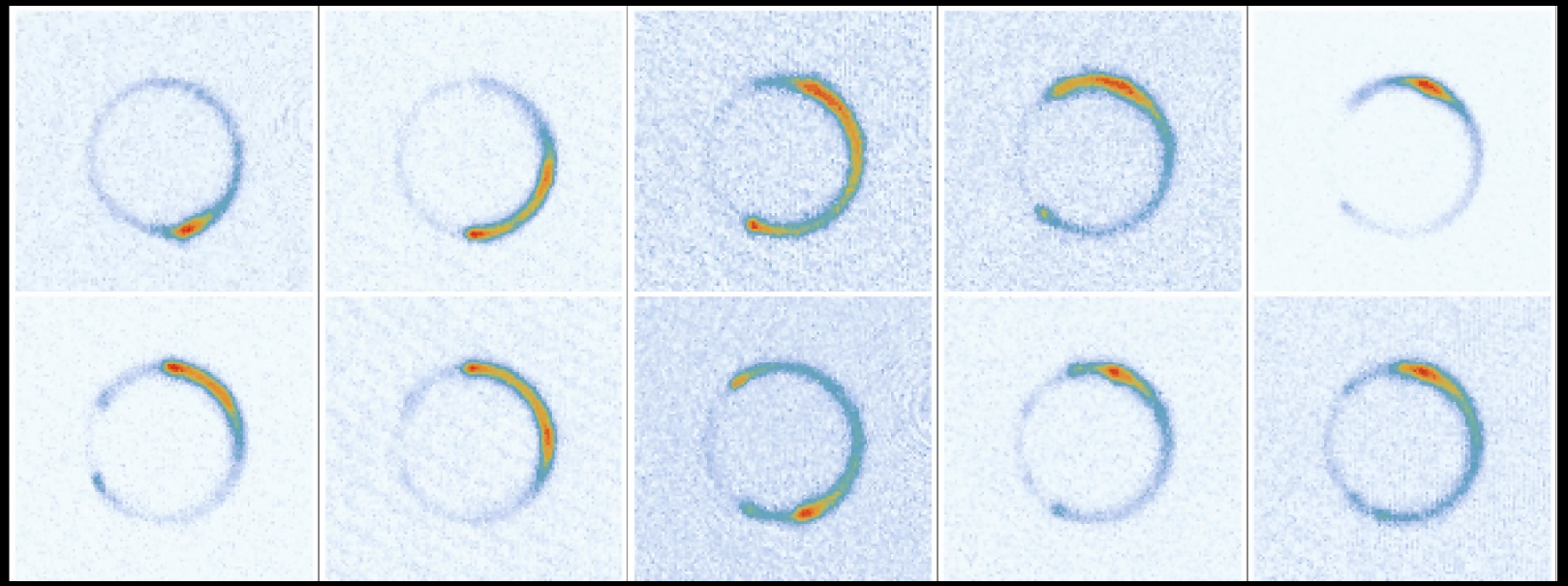
wave-guiding over 2 mm



BEC Waveguide with two barriers





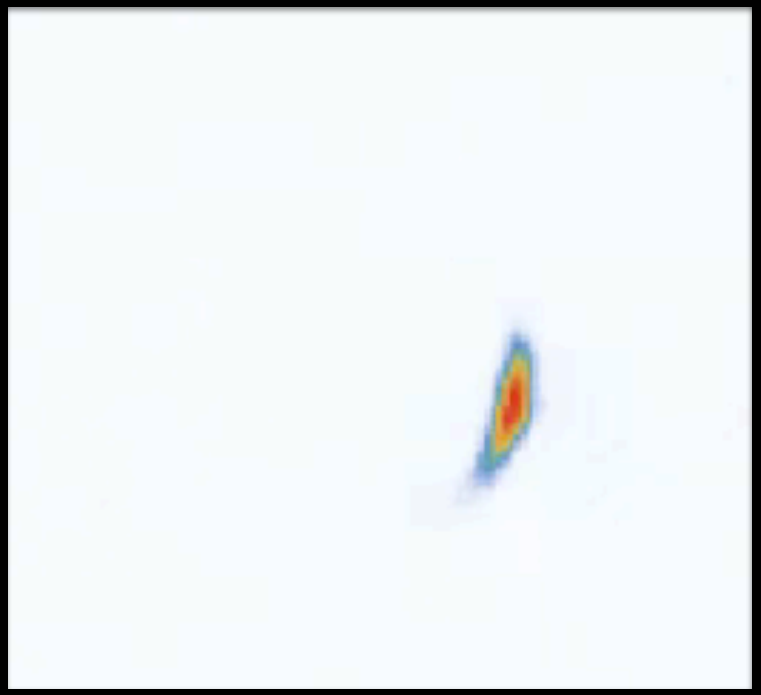


Ring Accelerator

Ring Accelerator

(polarization tilt)

Transport over
28 turns
= 9 cm
Rotation @ 15Hz

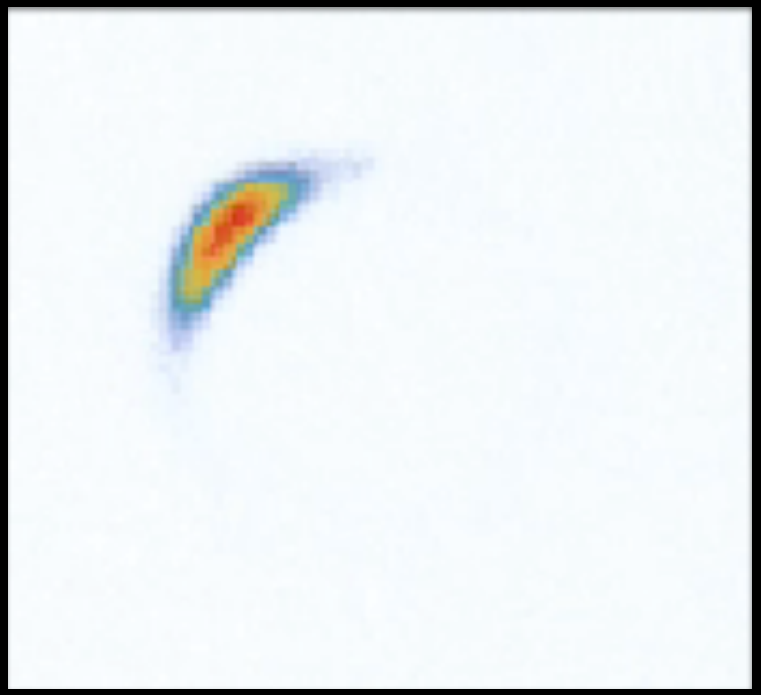


Enclosed
Area
21 mm^2

And it is still a BEC

Ring Accelerator

(polarization tilt)

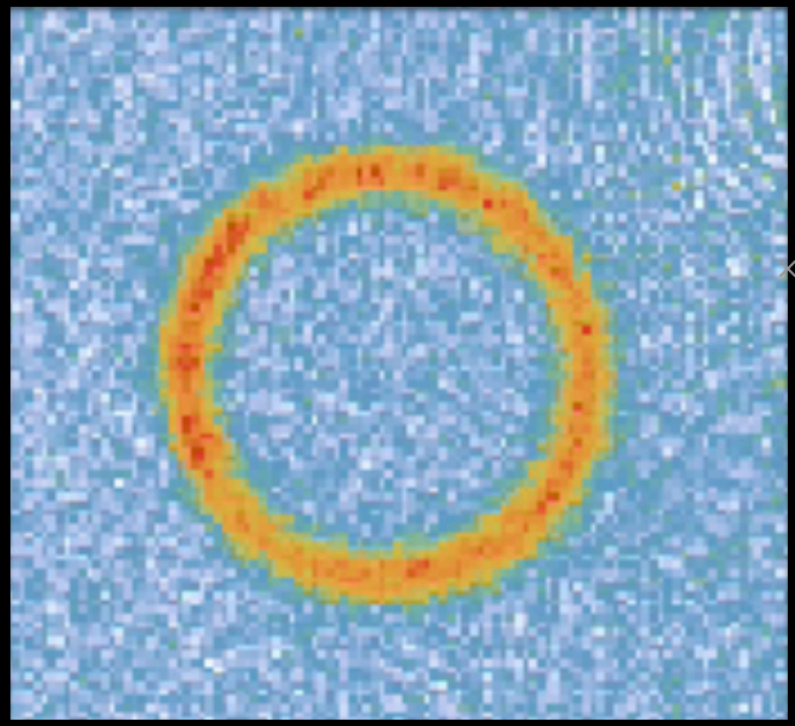


Expansion of a rotating BEC in the ring

Ring Accelerator

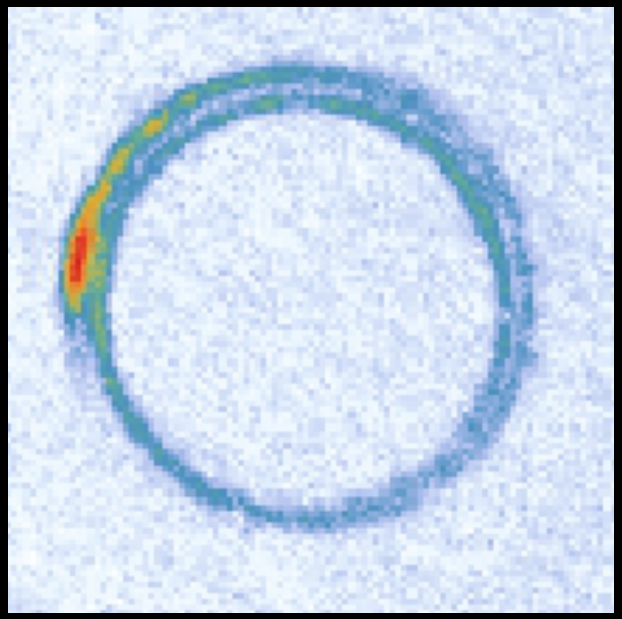
(polarization tilt)

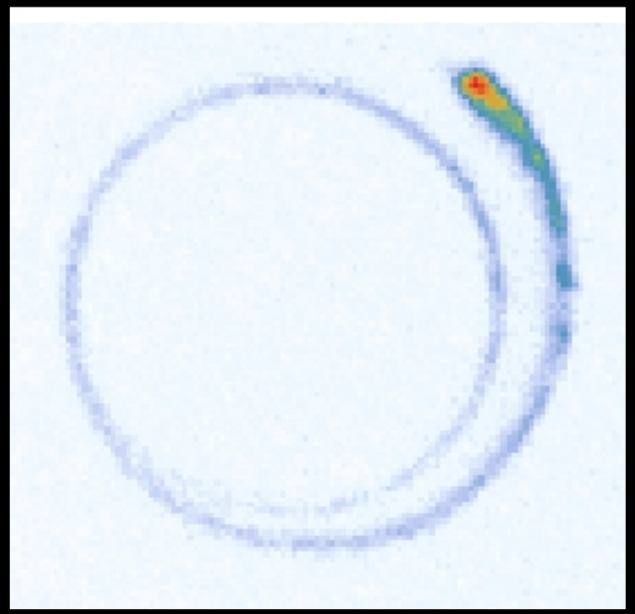
80 000 atoms with 30 000 $\hbar$ / atom

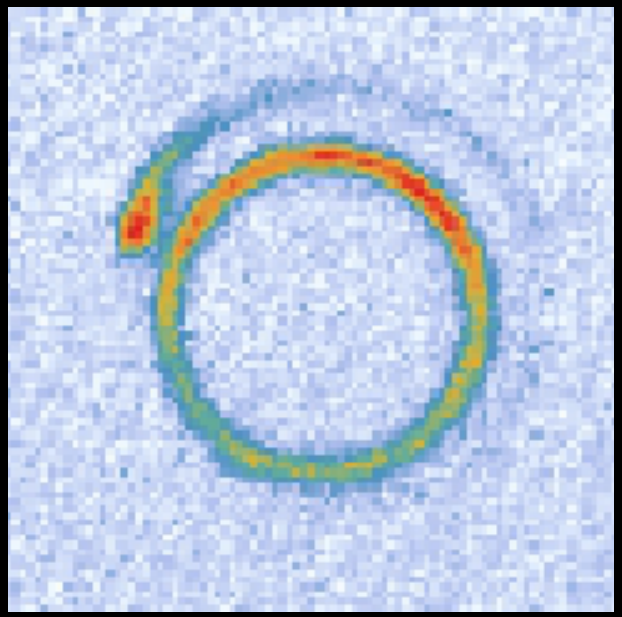


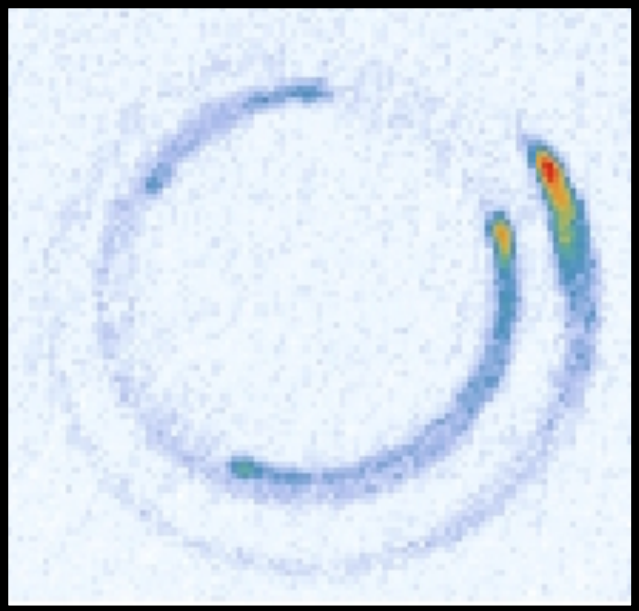
$$n = \frac{r^2}{\hbar/m}\Omega$$

Atomtronic Ring-Accelerator



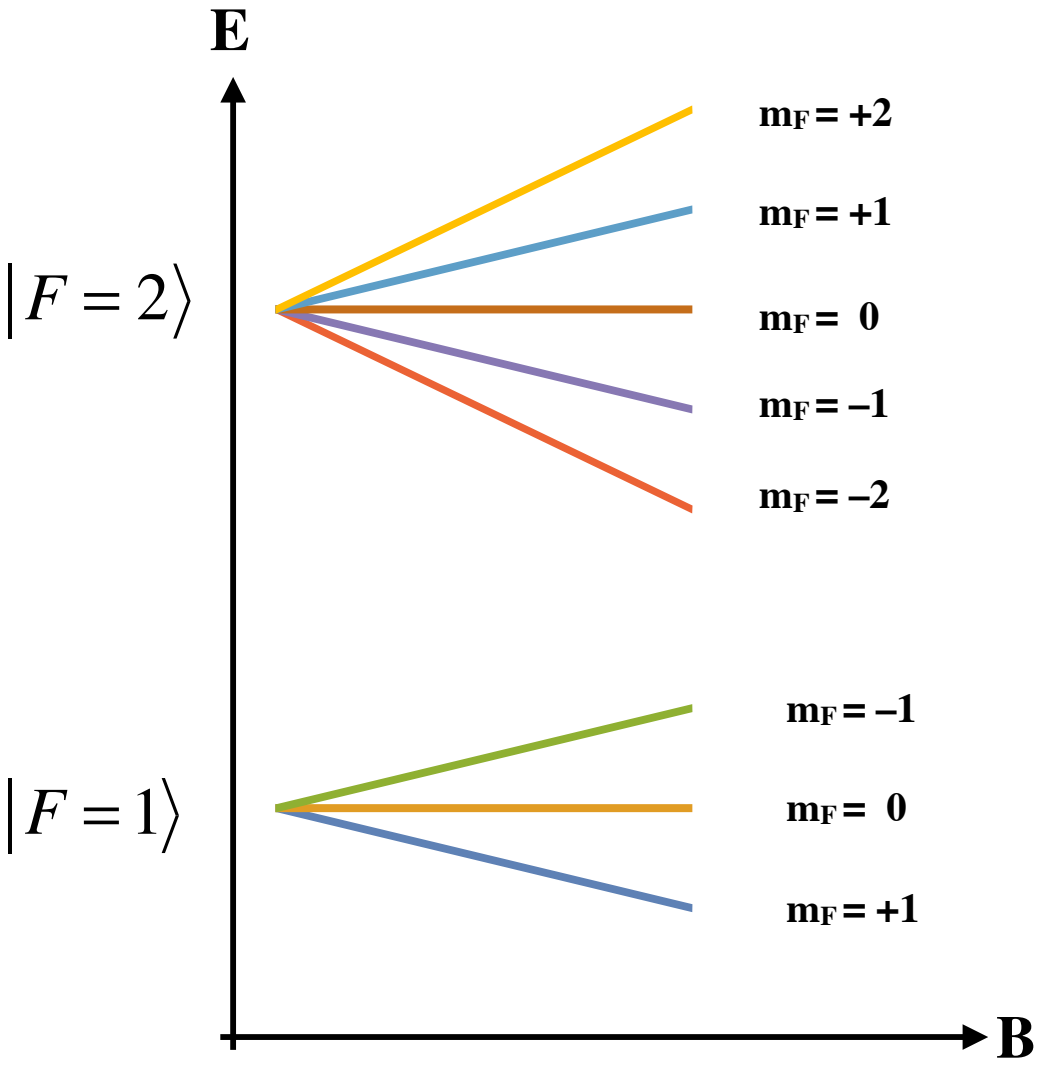






Atomtronics: State Dependent Transport

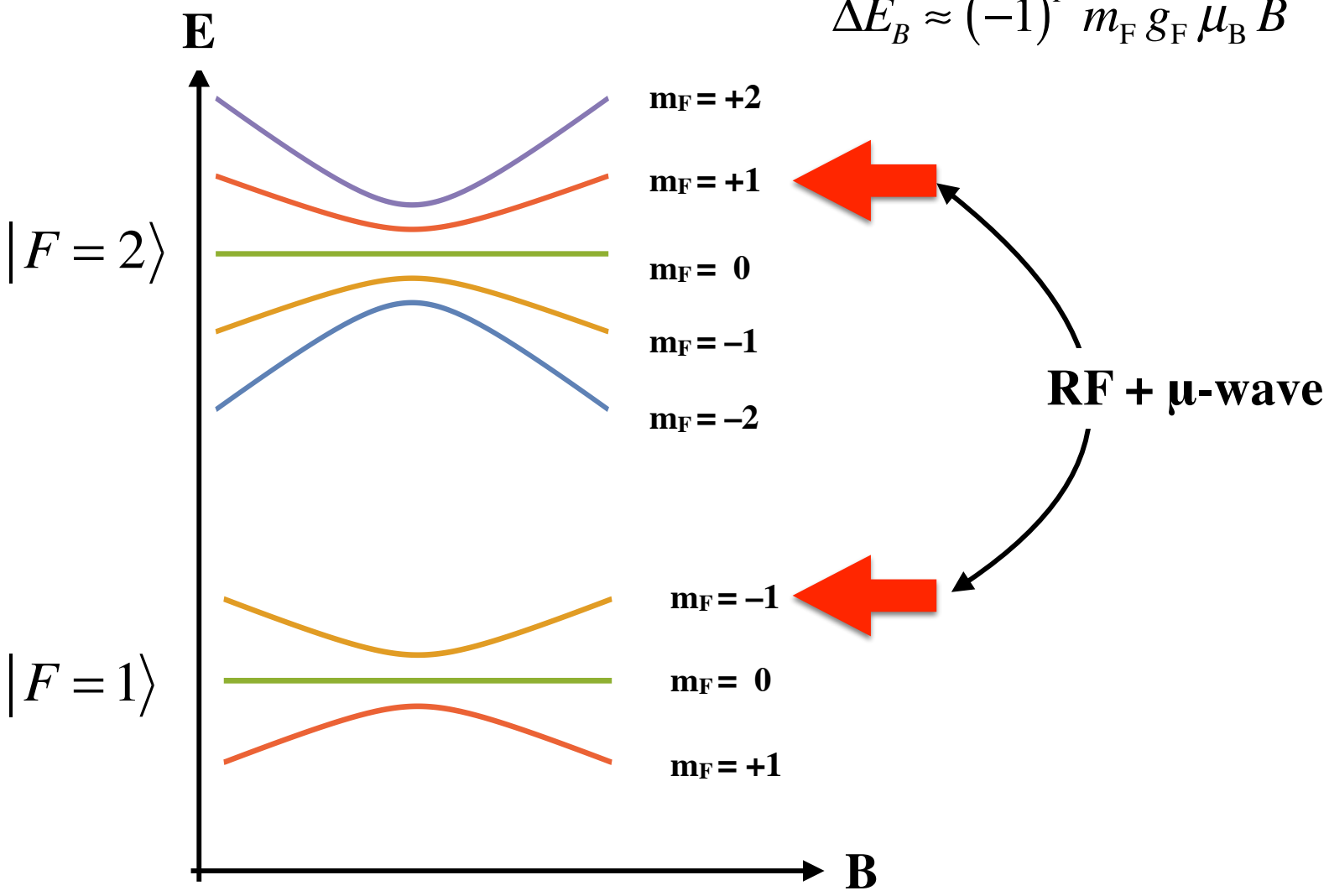
Microwave Coupling



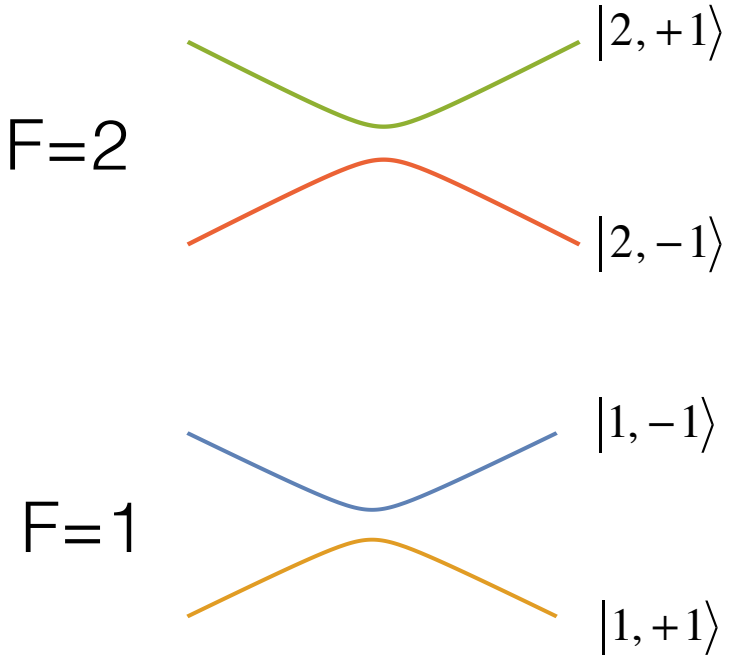
$$\Delta E_B \approx (-1)^F \, m_F g_F \mu_B B$$

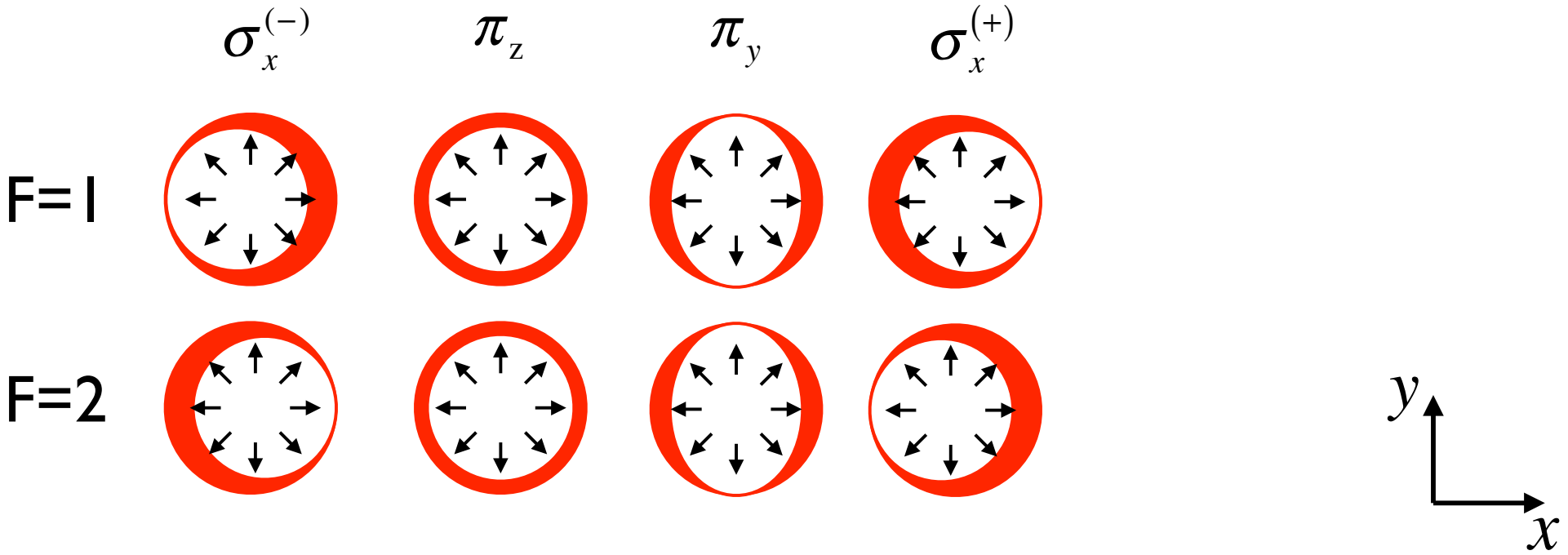
Microwave Coupling

$$\Delta E_B \approx (-1)^F m_F g_F \mu_B B$$



Dressed Potentials and Polarization and Tilt





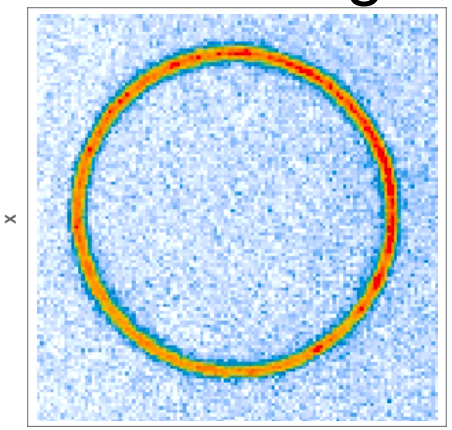
CRETANMATTERWAVES

Cretan Matter-Waves Group

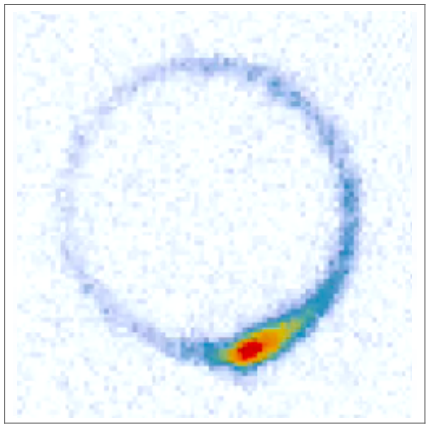
FORTH—IESL

State-Dependent Buckets

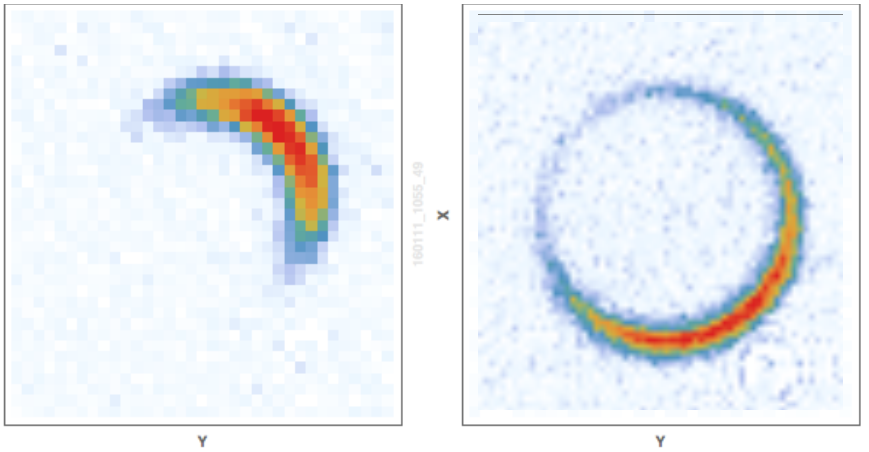
Flat Ring



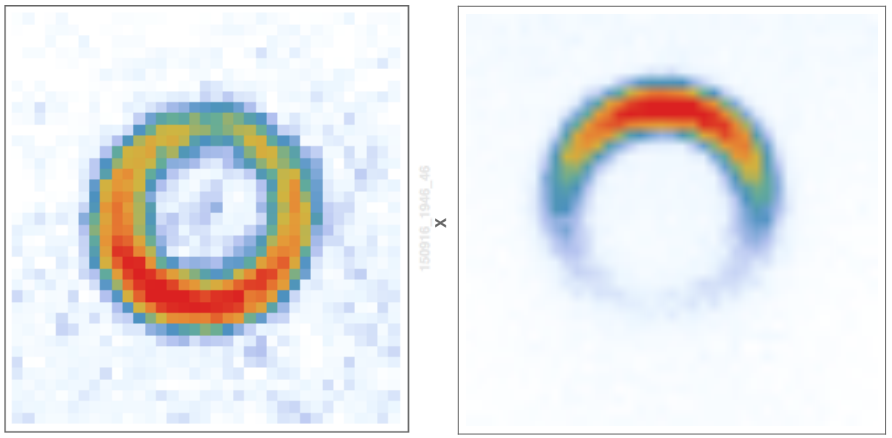
Waveguide



Gravity Tilt

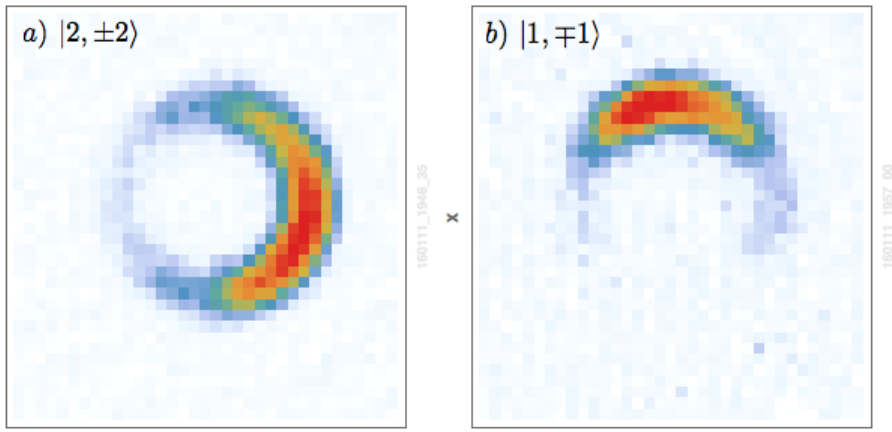


Polarization



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

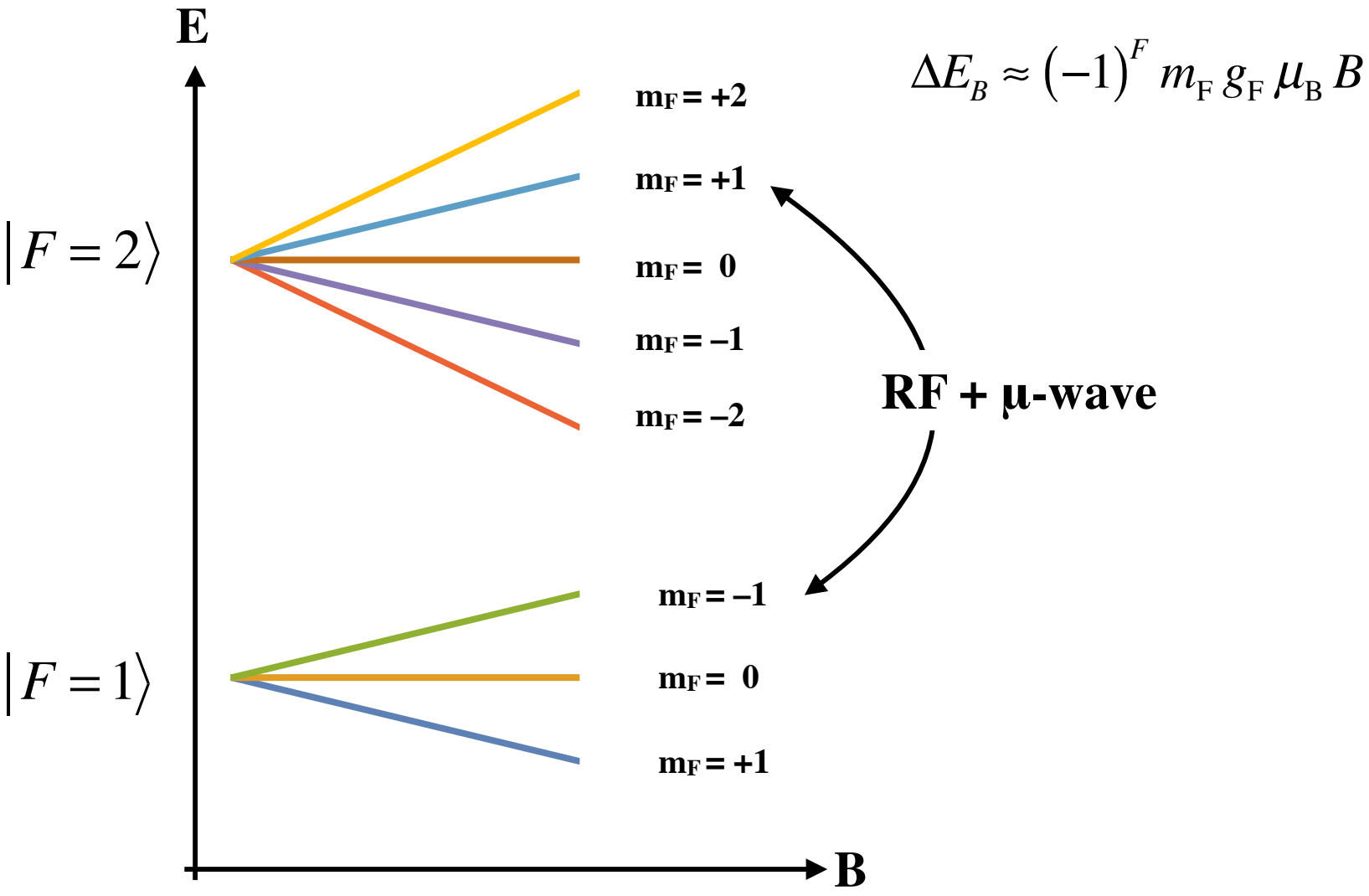
Gravity Tilt + Polarization



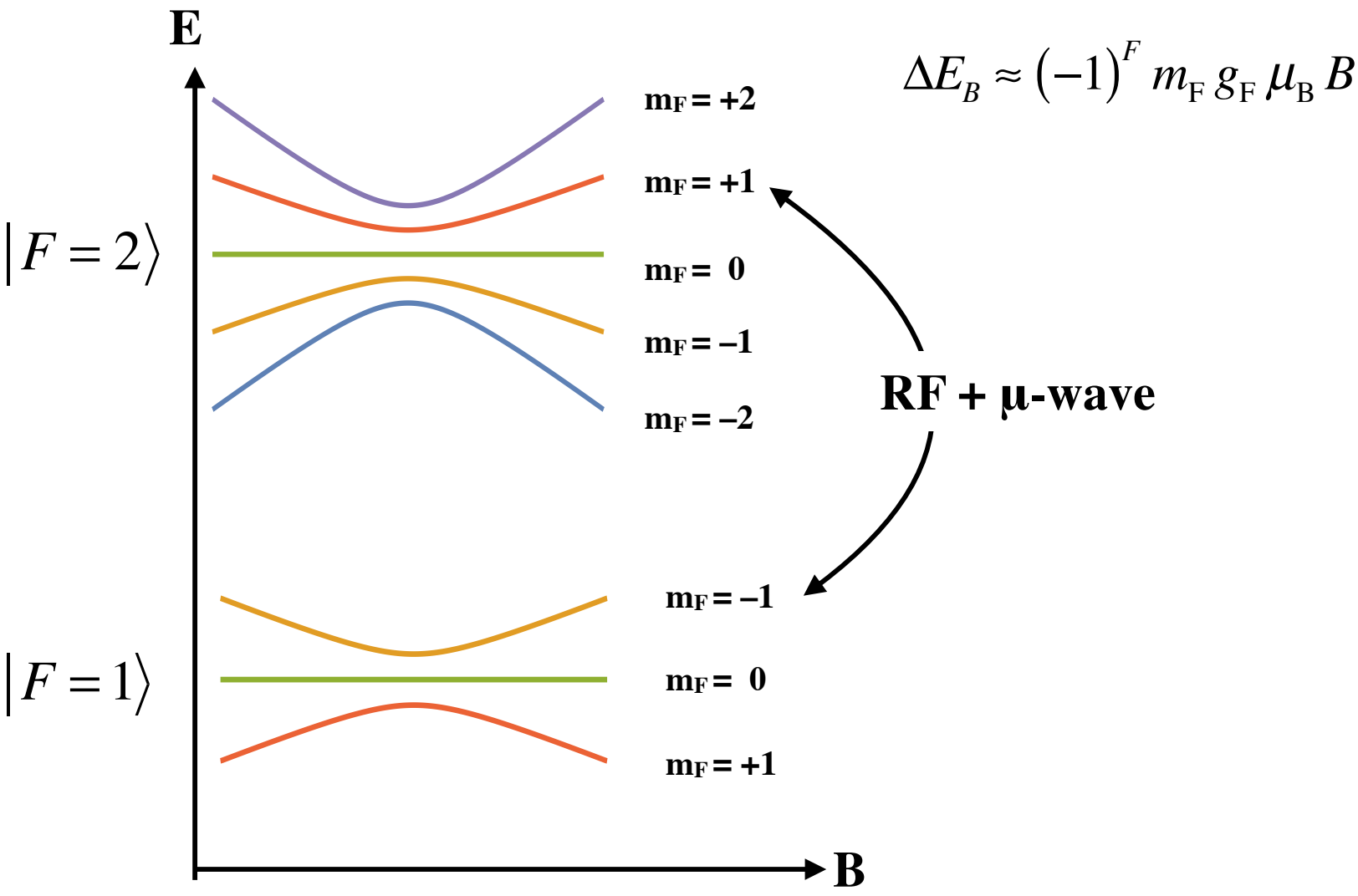
$$\left|F=1,m_F=-1\right\rangle \quad \left|F=2,m_F=+1\right\rangle$$

A Shell Clock

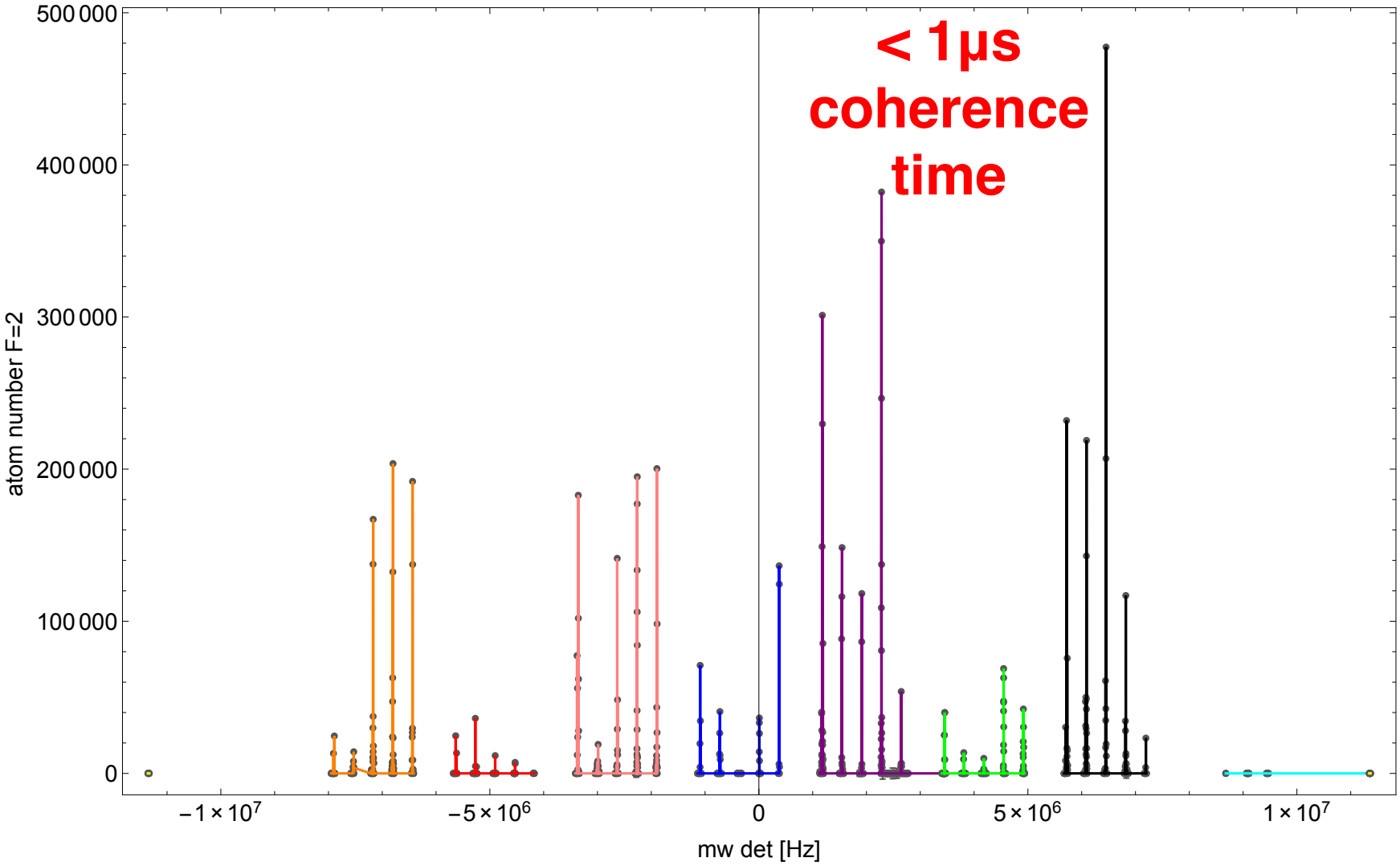
Microwave Coupling



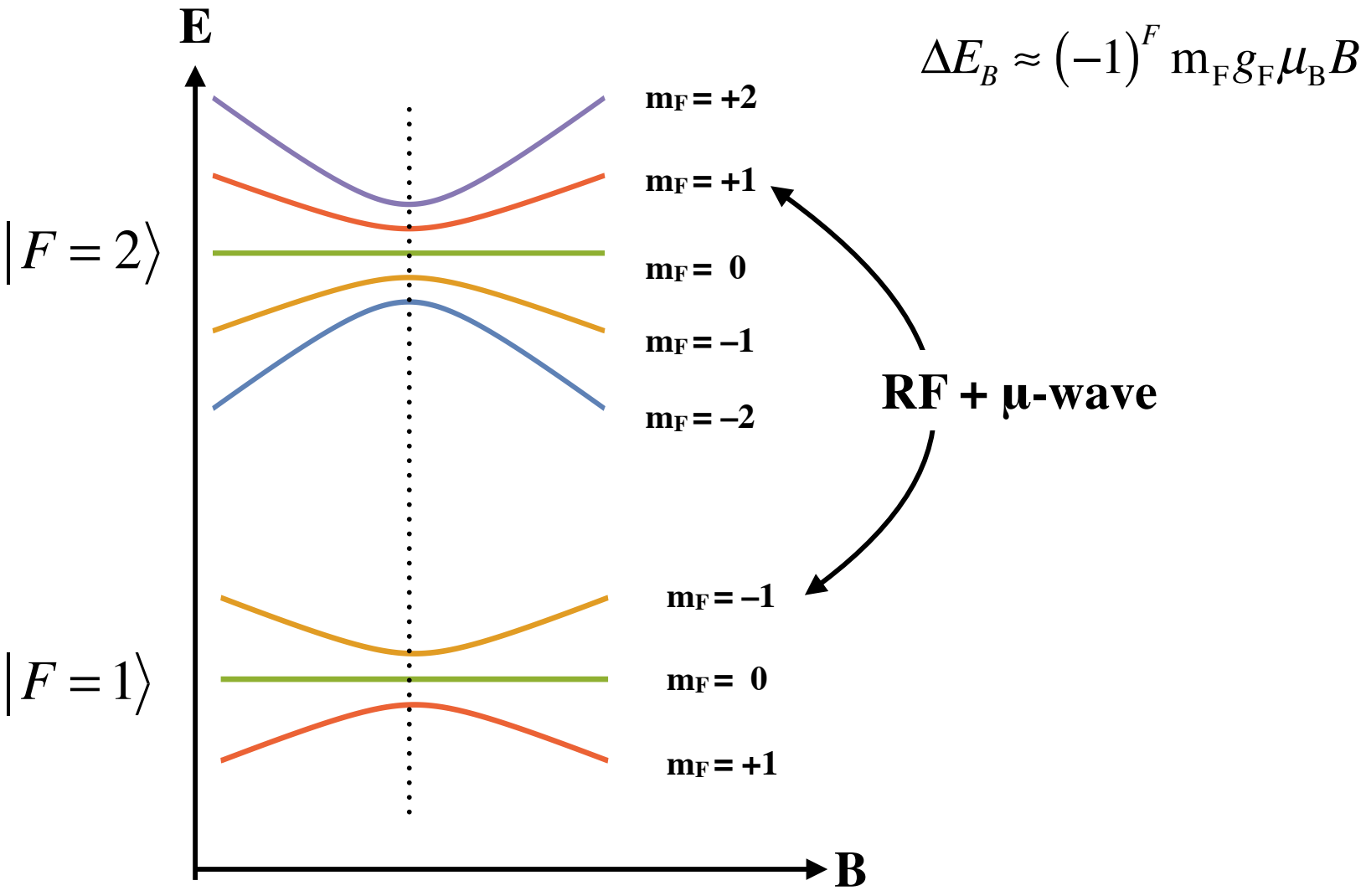
Microwave Coupling



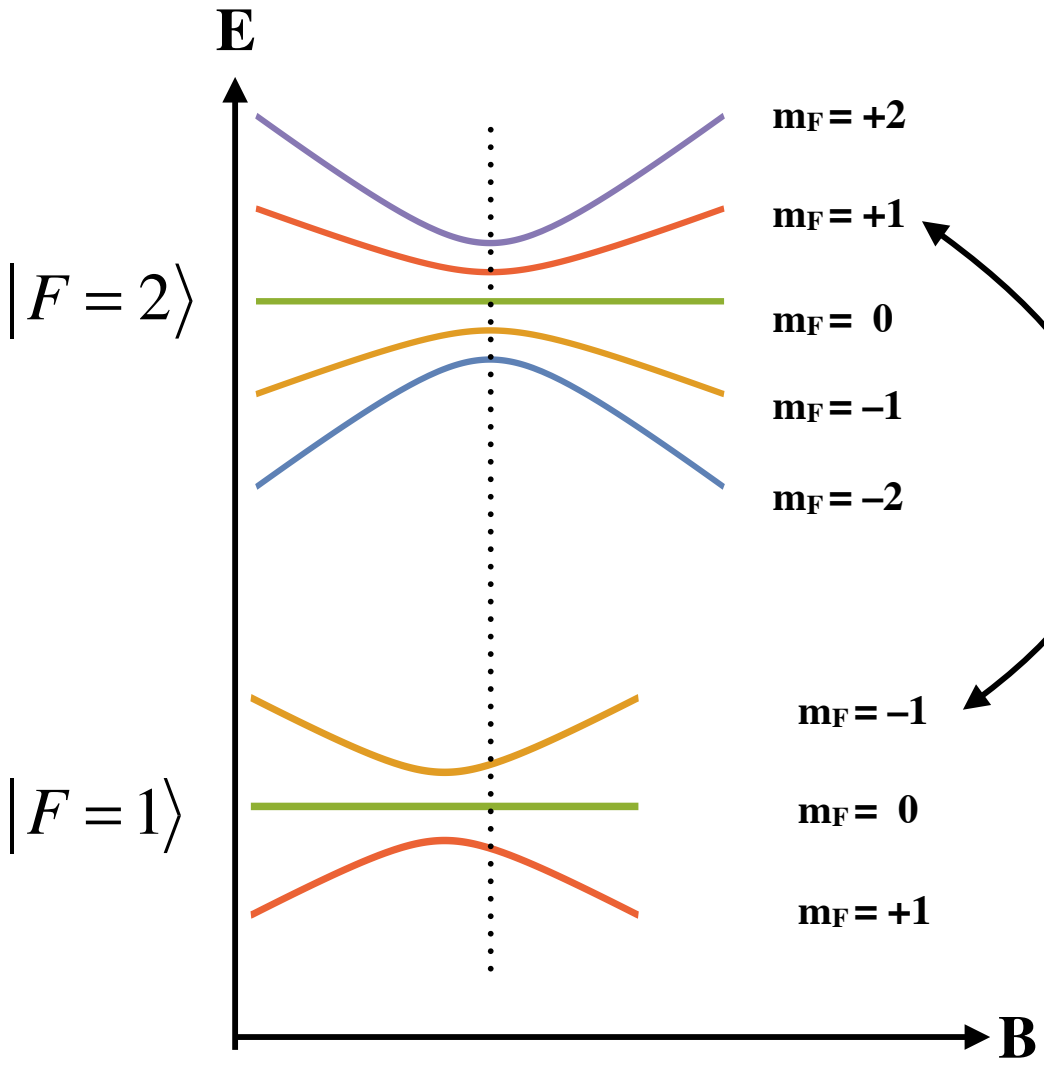
In-Trap Microwave Spectrum



Microwave Coupling



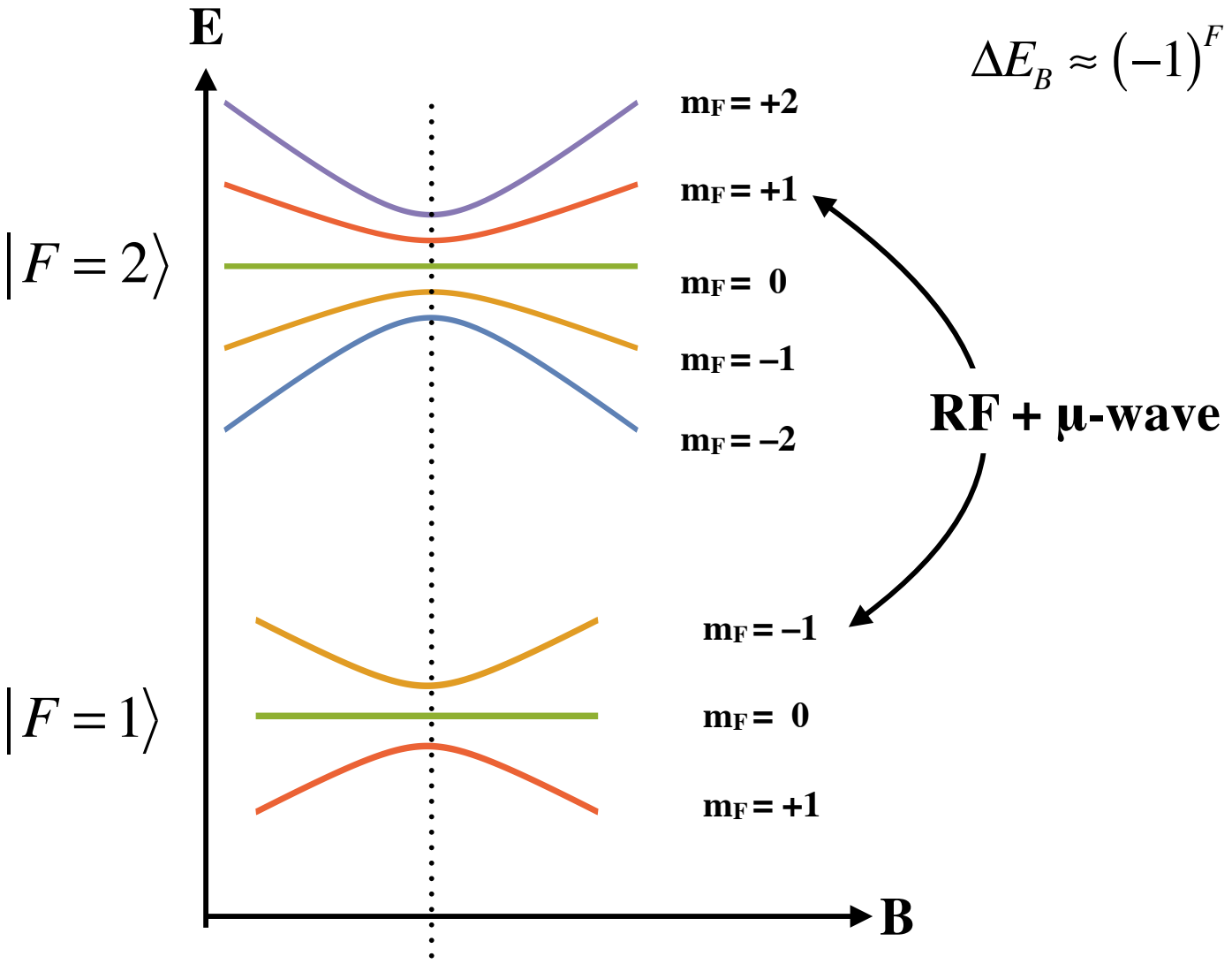
Microwave Coupling



$$\Delta E_B \approx (-1)^F \, m_F g_F \mu_B B$$

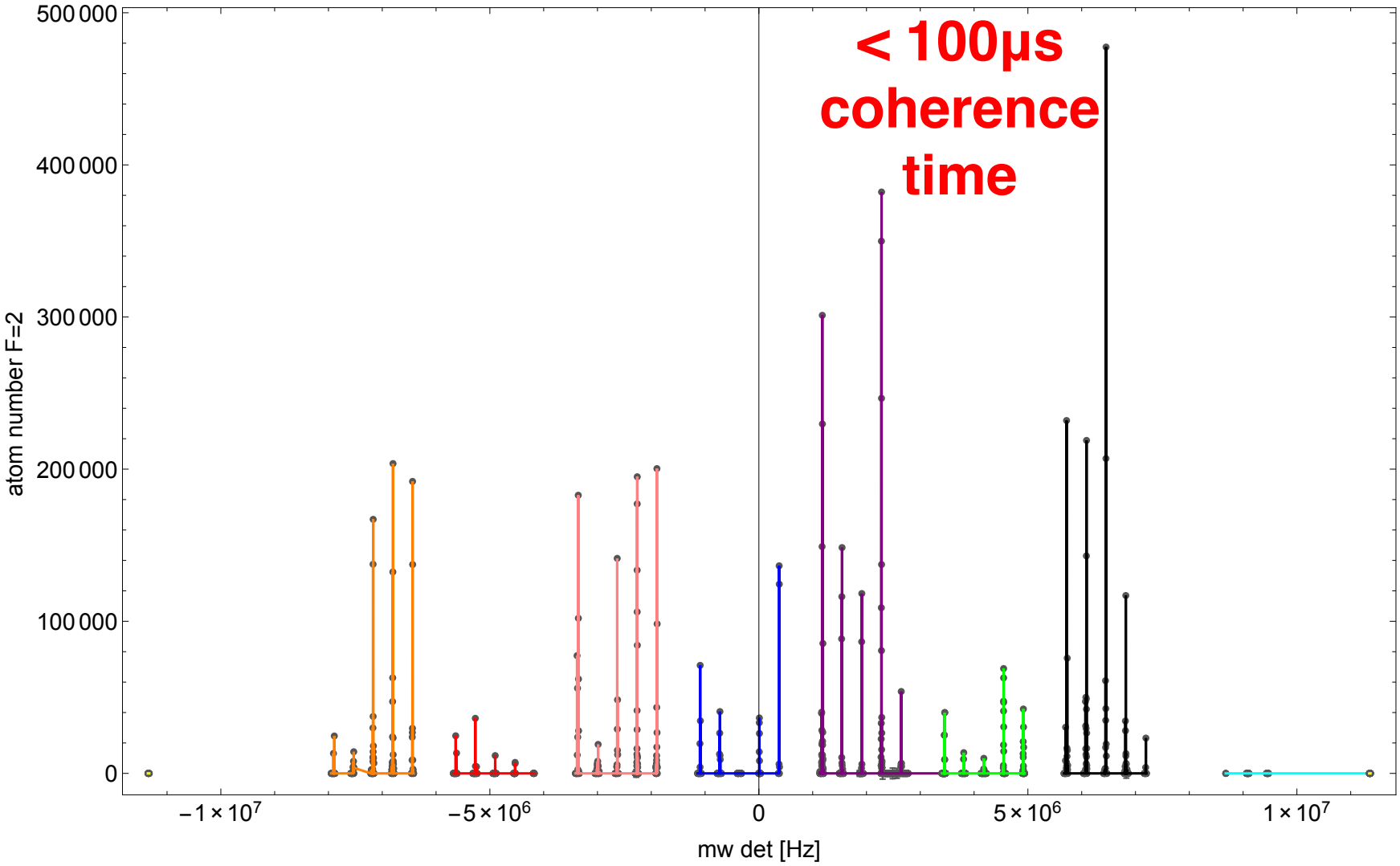
$$g_{F=1} > g_{F=2}$$

Microwave Coupling

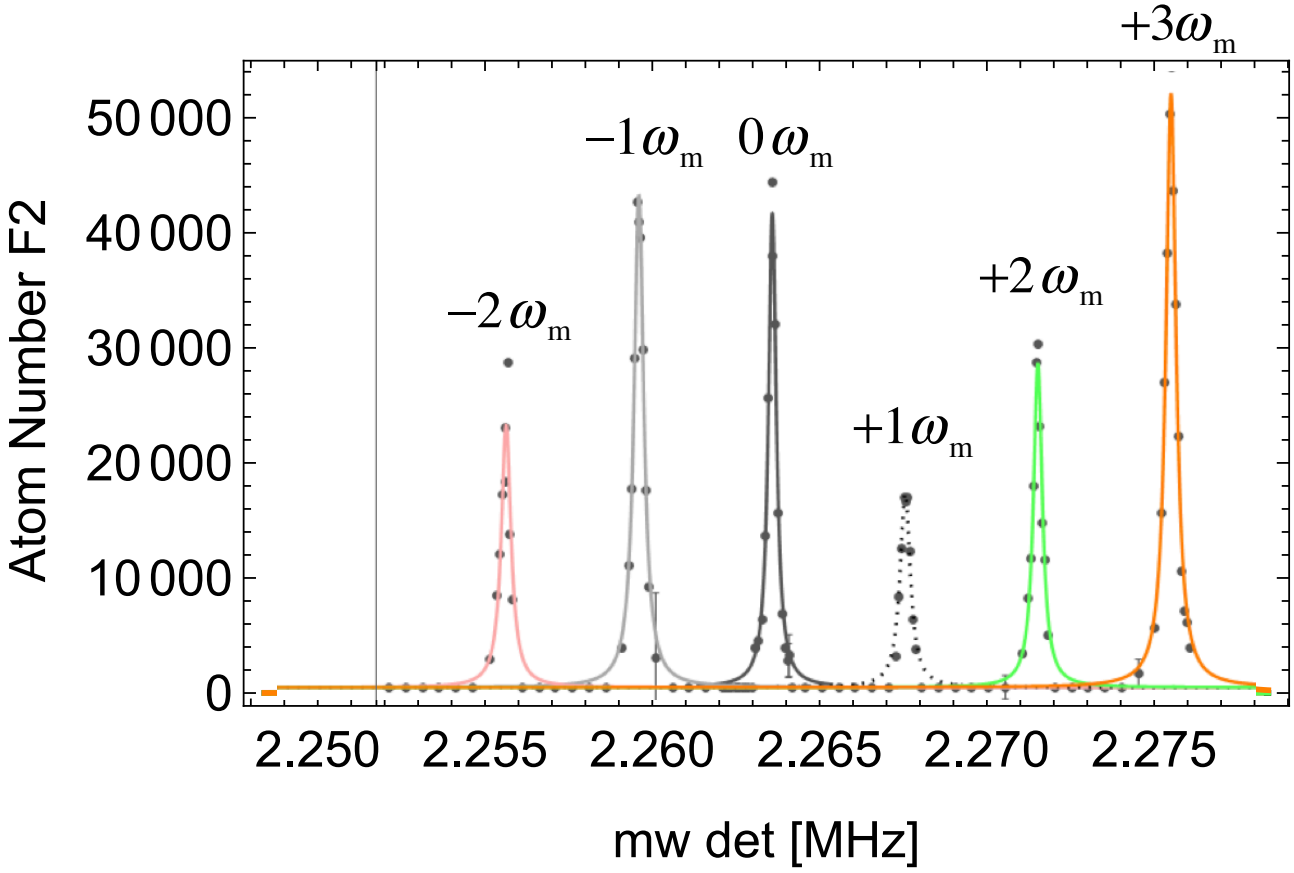


shift RF of F=1 by +8 kHz

Microwave Spectrum



Another Spectrum



Coherence time
> 10 ms

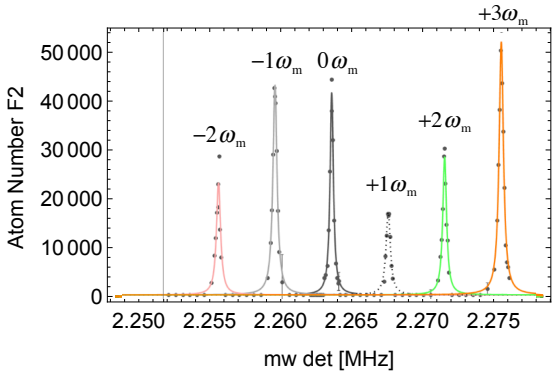
CRETANMATTERWAVES

Cretan Matter-Waves Group

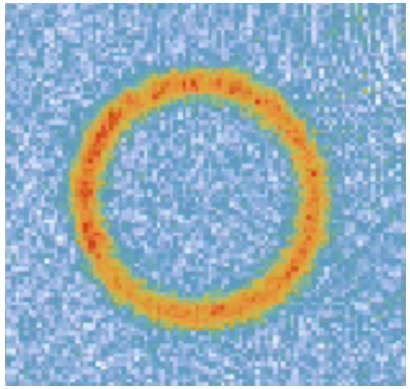
FORTH—IESL

Atomtronic Conclusions

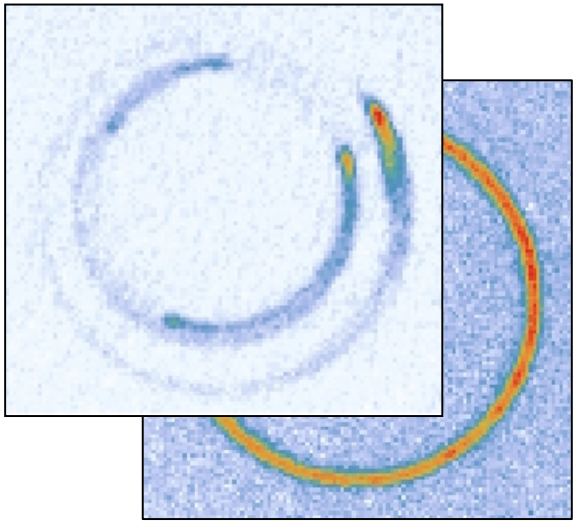
Coherence time 0.1s

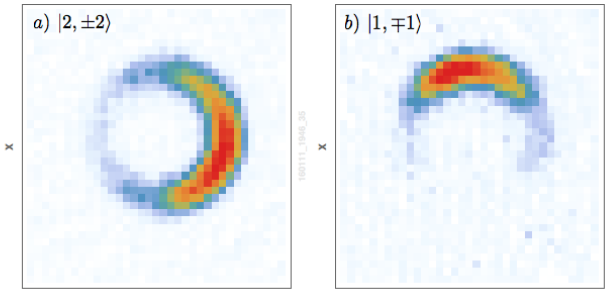


30 000 $\hbar$ / atom

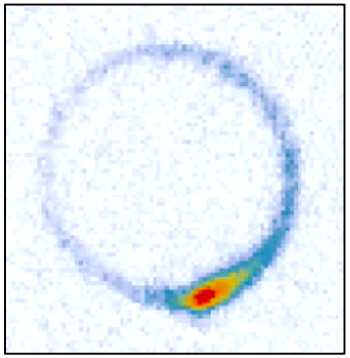


Large Rings

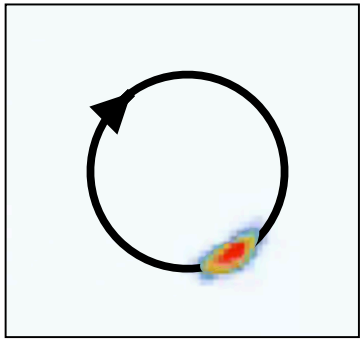




Transport Buckets



Coherent Waveguides



Neutral atom Accelerator

G. Vasilakis
M. Mikis

S. Pandey, G. Drougakis, K. Mavrakis, P. Christodoulou, K. Poulios, I. Alonso-Miguel
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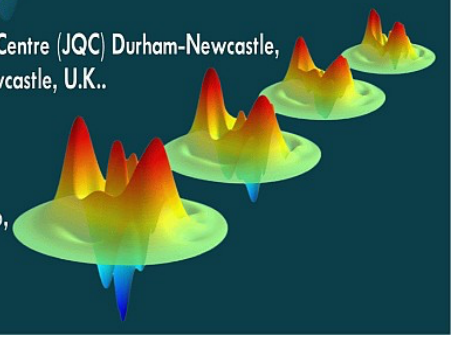

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FORTH—IESL

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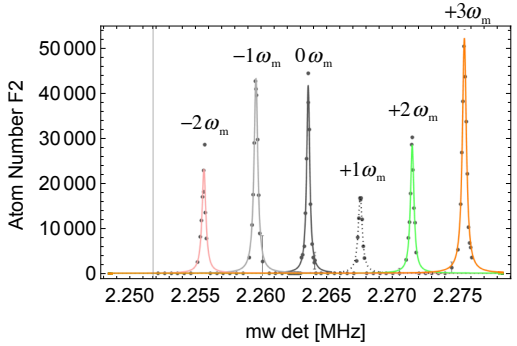
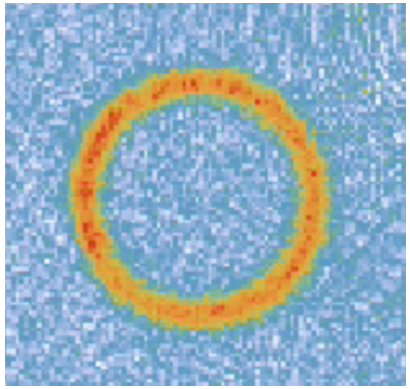


30 000 $\hbar$ / atom



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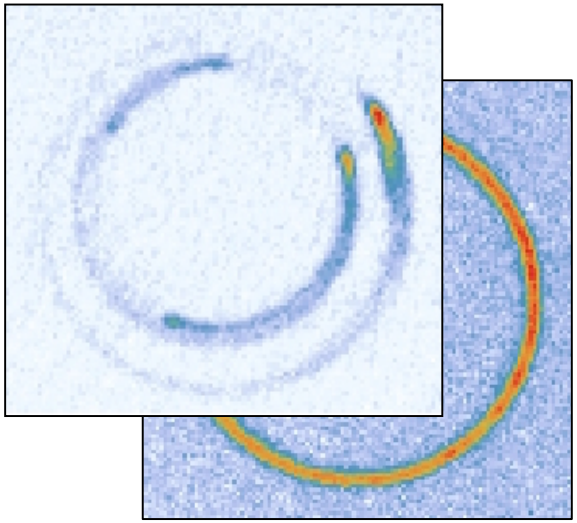

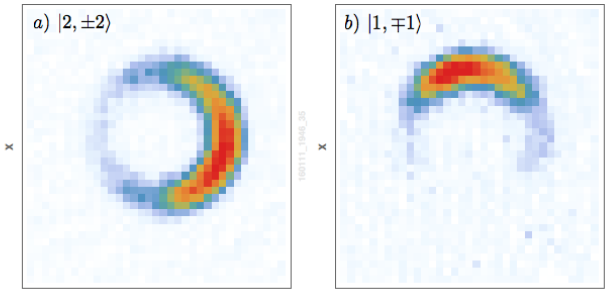

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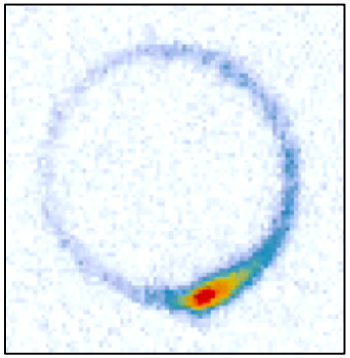

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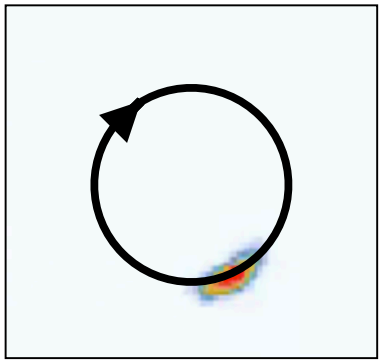

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