A guided matter-wave interferometer

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[1]CNR-IOM SISSA - MatterWave EU STReP Project

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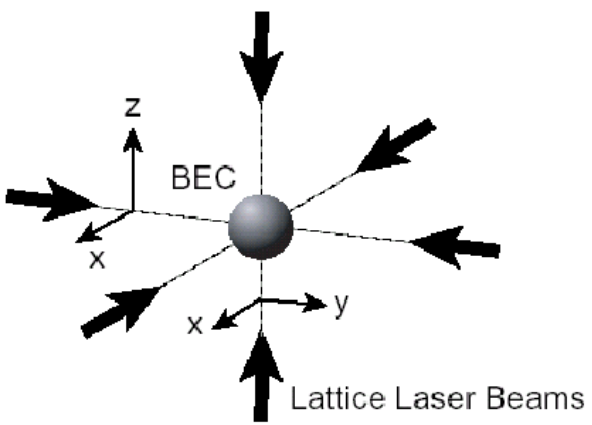
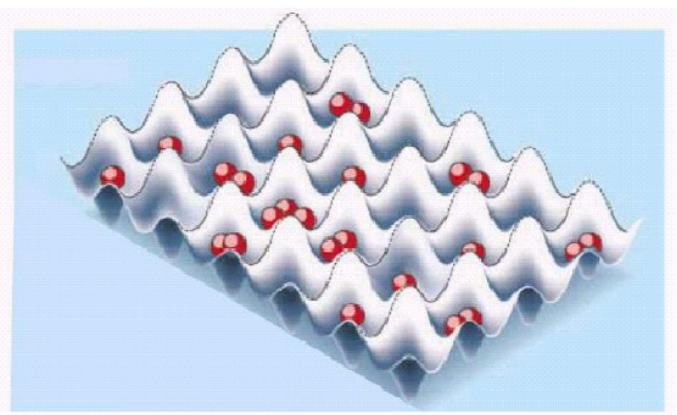
The MatterWave STReP (Specific Targeted Research Projects):

- Institute of Electronic Structure and Lasers, Greece (experiment)
- University of Nottingham, UK (theory/experiment)
- Ben Gurion University, Israel (experiment)
- CRN-IOM Trieste, Italy (theory)
- University of Birmingham, UK (experiment)

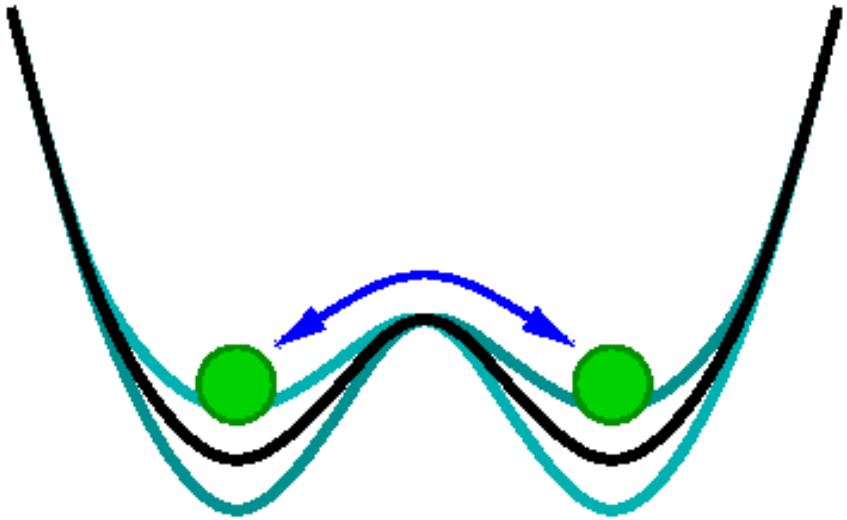
Cold atomic system: some features

- coldness & isolation
- tunability of interaction parameters
  - periodic potentials for lattice systems
  - Feshbach resonances
  - long-range interaction: (di)polar, Rydberg
- Ease of measurement (TOF+imaging)





BEC in a two well system

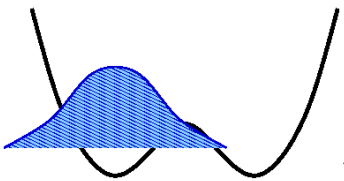
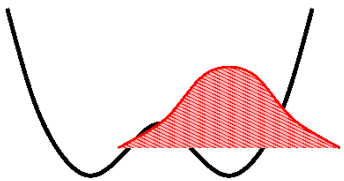


In a mean-field description the condensate wavefunction obeys the GPE equation:

$$i\hbar\frac{\partial\psi}{\partial t} = (-\frac{\partial^2}{\partial x^2} + V(x))\psi + g|\psi|^2\psi \qquad (1)$$

- Basic model for the description of two quantum coherent interacting coupled systems.
- Two mode Ansatz

$$\psi(x,t) = \phi_L(t)\psi_L(x) + \phi_R(t)\psi_R(x) \tag{2}$$

$\psi(x,t) = \phi_L(t)$  $+\phi_R(t)$ 

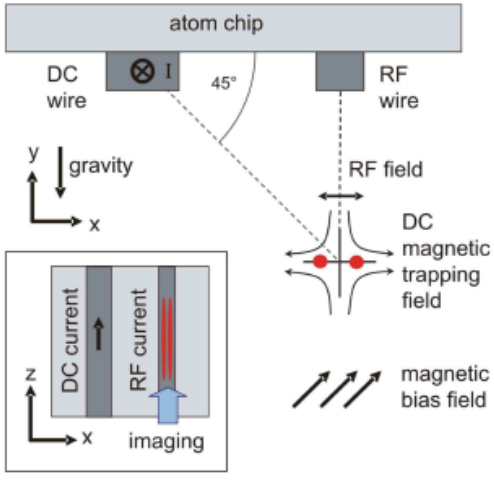
- Number phase representation: $\phi_i(t) = \sqrt{N_i(t)}e^{i\varphi_i(t)}$
- Population unbalance: $z = (N_L - N_R)/(N_L + N_R)$,
- Phase difference: $\varphi = \varphi_L - \varphi_R$
- Current-phase equations

$$\begin{cases} \hbar\dot{z} &= -2K\sqrt{1-z^2}\sin\varphi + C(1-z^2)\sin 2\varphi \\ \hbar\dot{\varphi} &= Uz + \frac{2Kz}{\sqrt{1-z^2}}\cos\varphi - Cz\cos 2\varphi \end{cases} \tag{3}$$

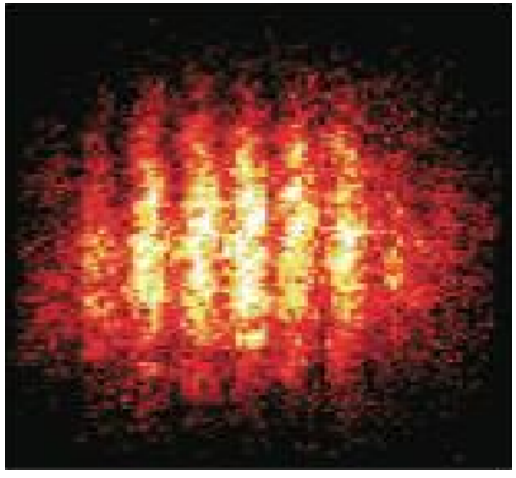
[Smerzi et al., 2001], [Ananikian, Bergeman, 2006]
...bears resemblace to the equation governing counterpropagating fields in a ring laser...

A BJJ interferometer [Schumm et al.]

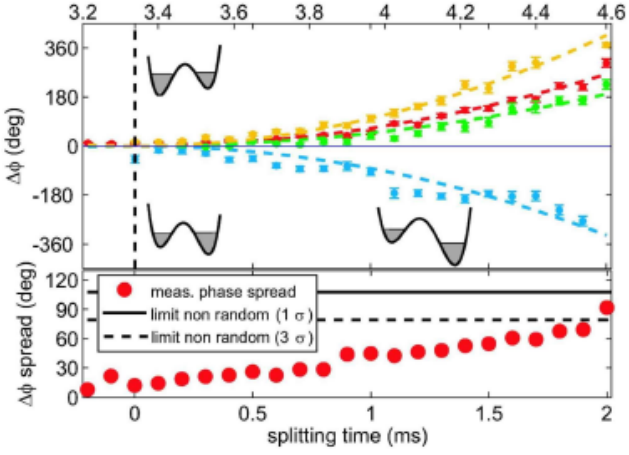
- experimental setup



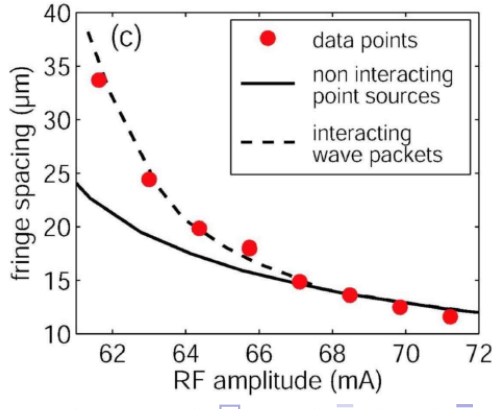
- interference fringes



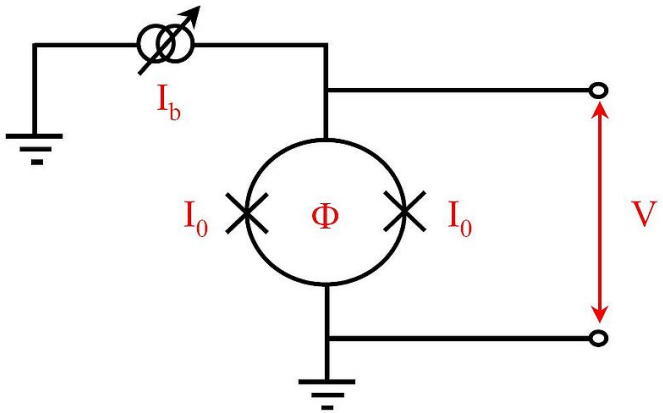
- coherence preservation



- role of interaction



The dc-SQUID

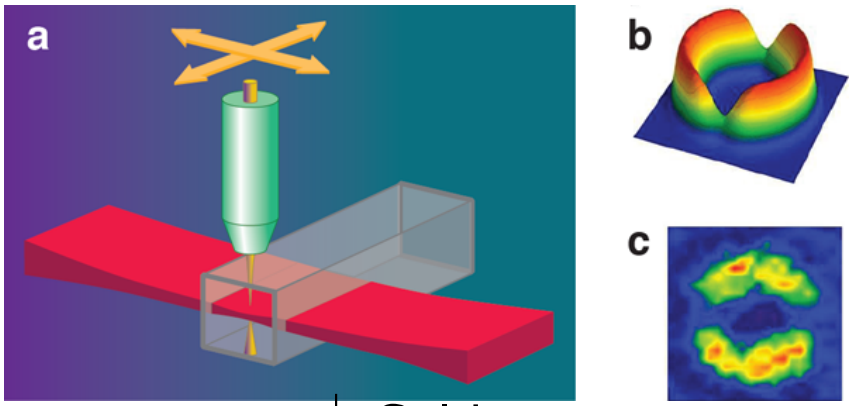


- Two Josephson junctions (aka weak links)

Critical current shift vs. critical mass current shift.

Moving weak-link experimental sequence [Giovanazzi et al. 2000].

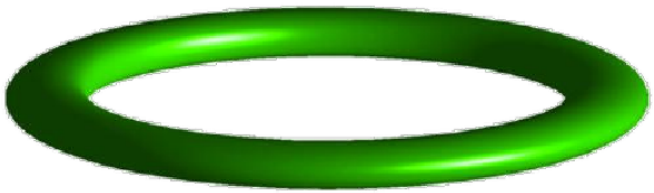
- Superfluid ^{3}He dc-SQUID [Packard group @Berkley, 2001].
- cold atomic [Ryu et al. @LANL, 2013]

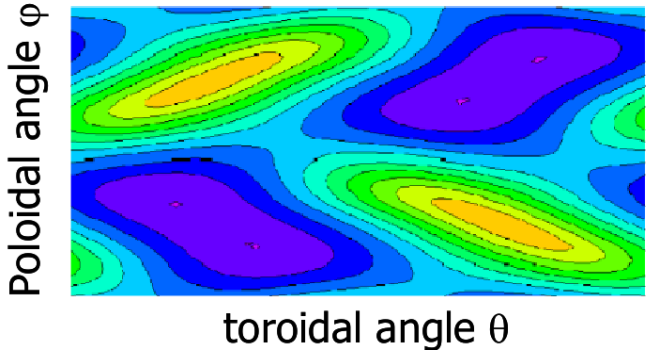


^{3}He	Cold atoms
no tunable interaction	full tunability
quantum coherence through multiple holes??	full control of dynamics around a barrier

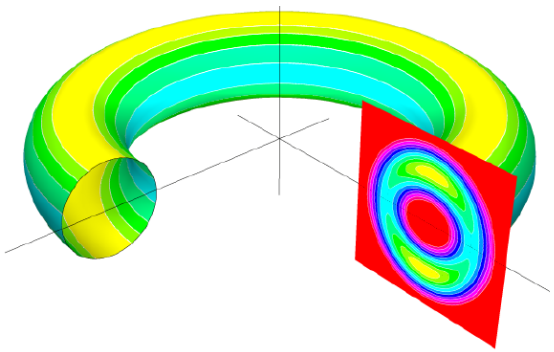
Guiding potentials

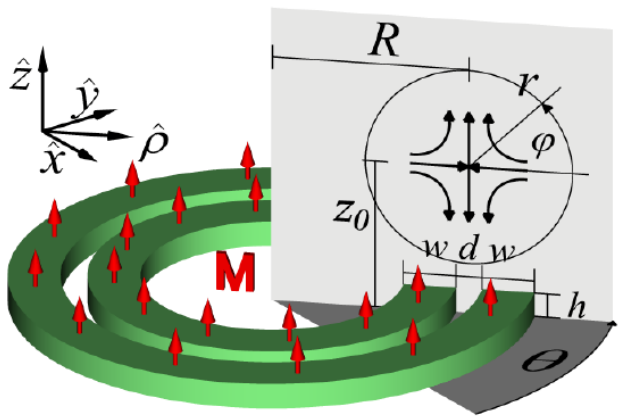
- Time-averaged adiabatic potentials (TAAP available at IESL) [Lesanovsky and Von Klitzing, 2007]





- Dressed state potentials





Current work:

- Assesment of the two mode model
  with full 3D GPE simulation on parallelized HPC facilities
- "nonlinear" tight-binding model: i.e. number dependent localized wafefunctions [Smerzi & Trombettoni, 2003]

Next steps:

- Inclusion of finite temperature effects
- Entangled initial state ($\rightarrow$ Heisenberg limit?)
- $\Rightarrow$ full quantum description