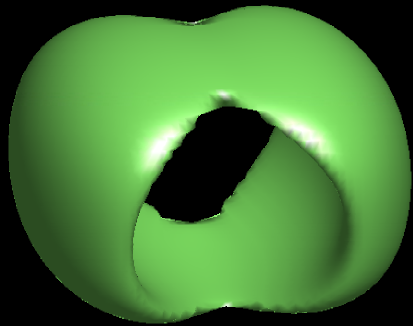
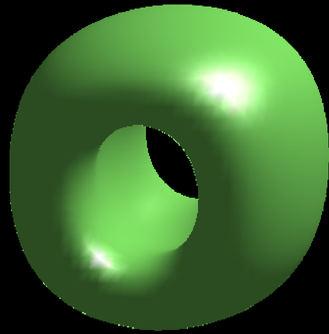
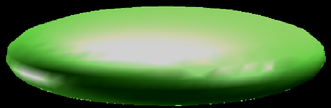
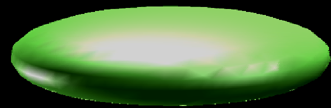
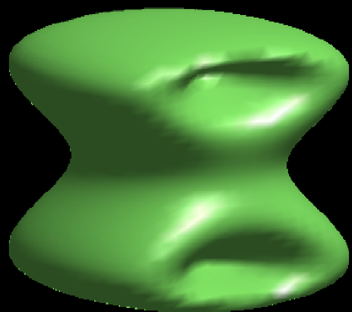
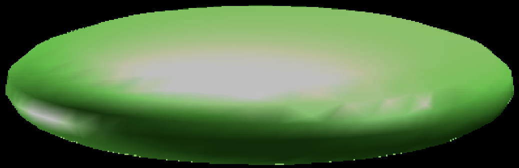





TAPs, TOPs and quantum interference:
physics with novel magnetic traps



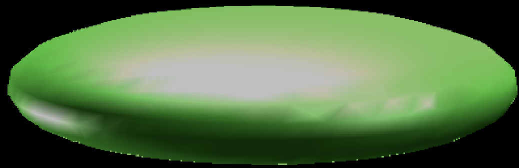



(1μK iso-potential surfaces in dressed TAP traps)

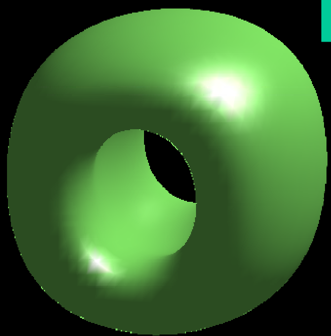


Linear Accelerator

Christian Buggle, Jérémie Léonard
Wolf von Klitzing, Jook Walraven
University of Amsterdam



TAPs, TOPs and quantum interference: physics with novel magnetic traps

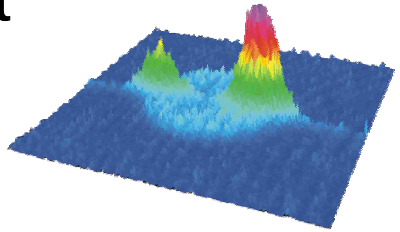


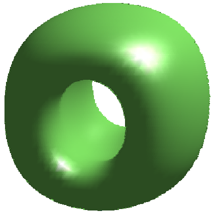
Ring trap

Wolf von Klitzing
IESL-FORTH
Crete (Greece)

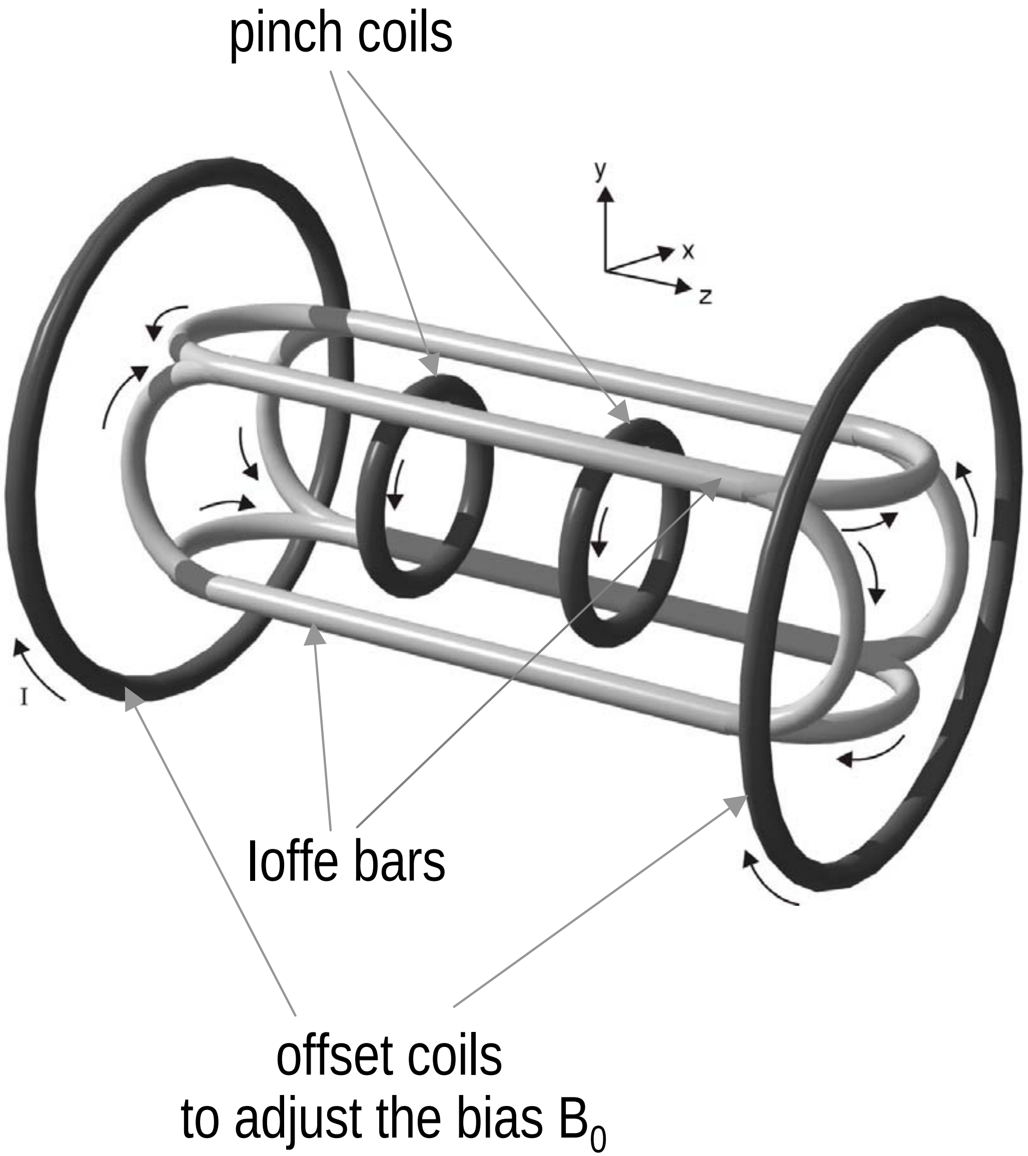
Outline

- The Ioffe-Pritchard trap revisited
  - The double TOP trap
  - Controlled cold collisions in a linear accelerator
- More Ioffe-Pritchard traps
  - Ring trap
  - BEC wave guide
  - Sagnac interferometer
- Conclusions and bonus

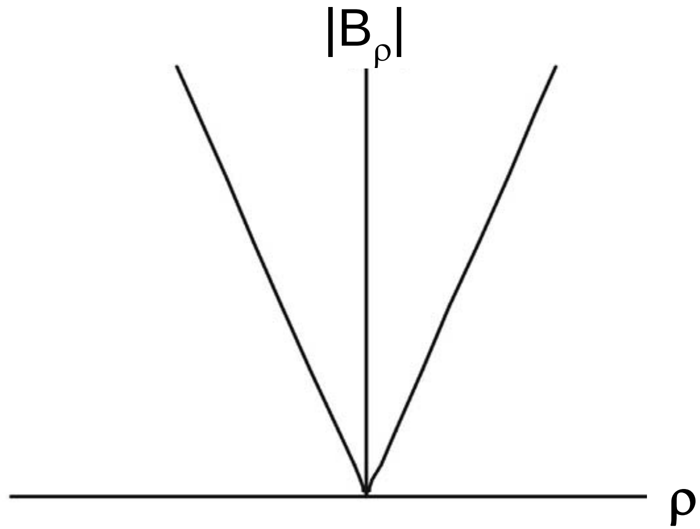




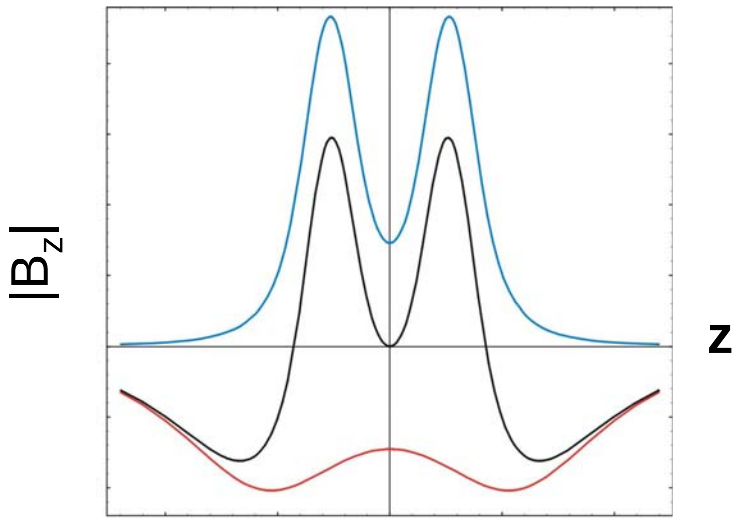
Ioffe-Pritchard Quadrupole Trap



Radial component

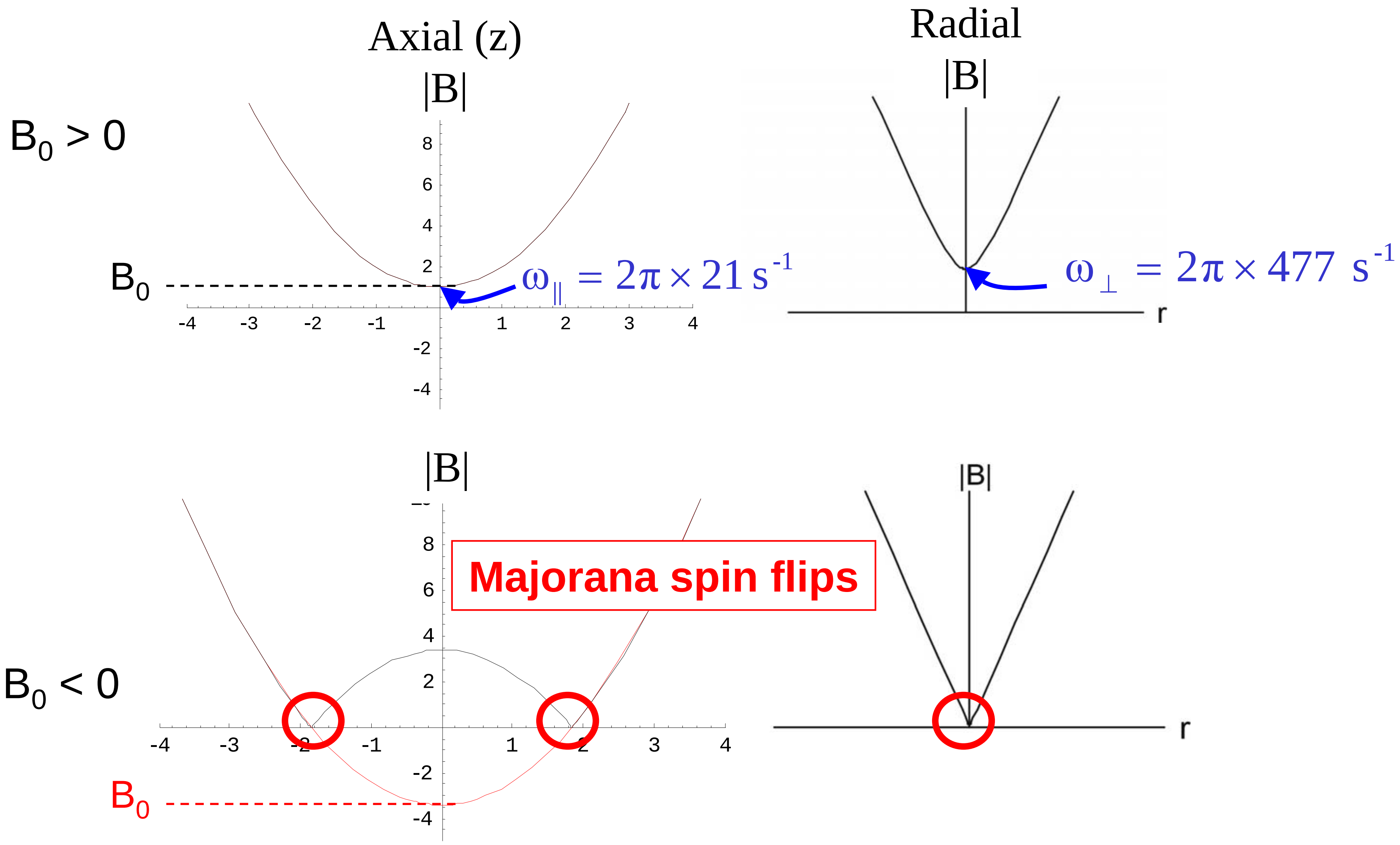


Axial component



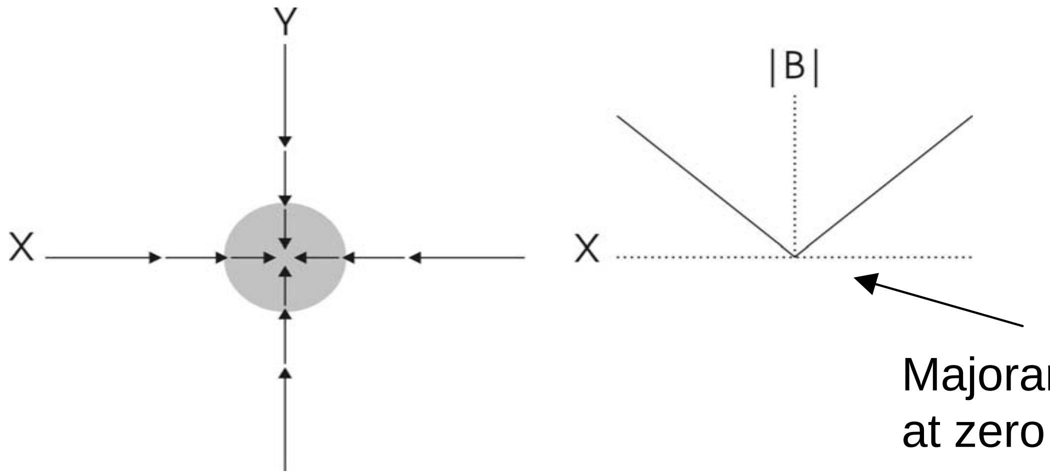
Ioffe-Pritchard Quadrupole Trap

Trapping potential: $E = -\vec{\mu}.\vec{B} \propto |B|$



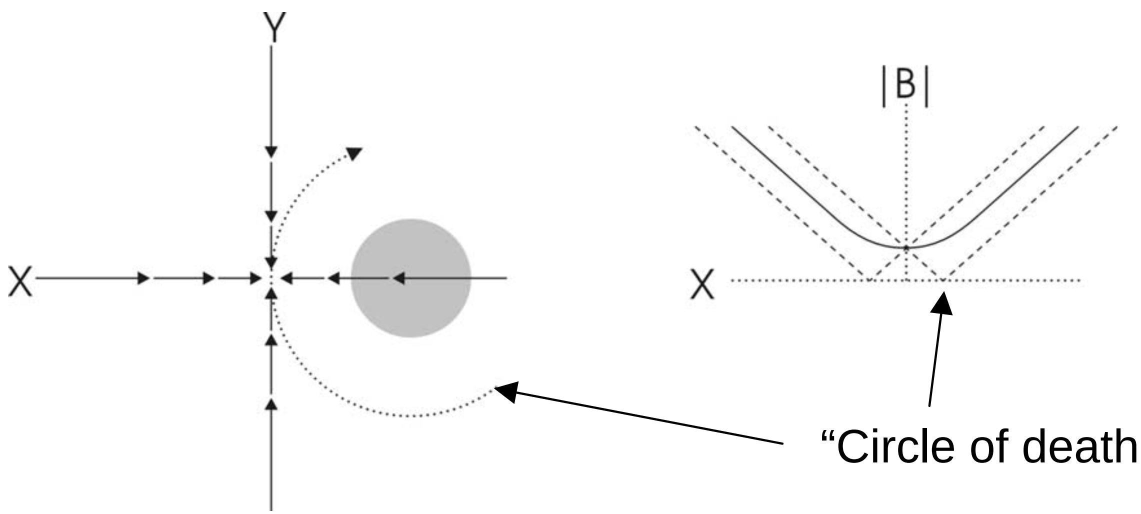
Time orbiting potential (TOP)

Quadrupole
without TOP



Majorana spin flips
at zero B-field

Quadrupole
with TOP



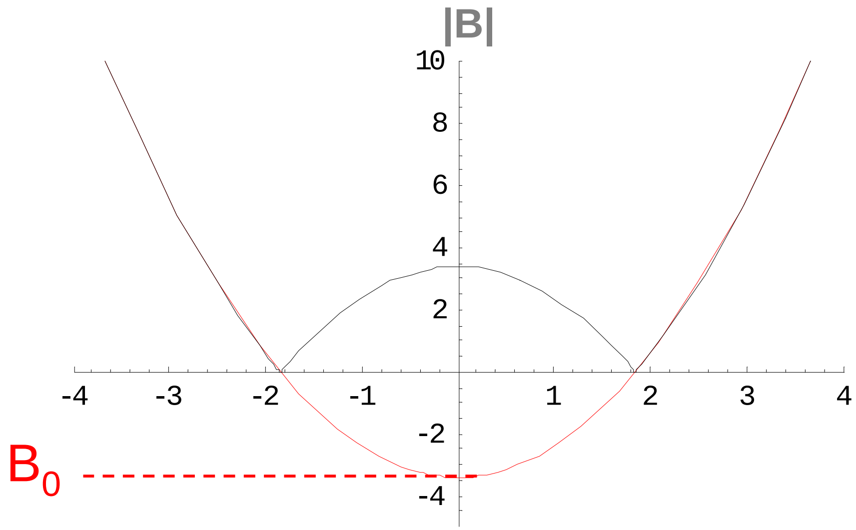
“Circle of death”

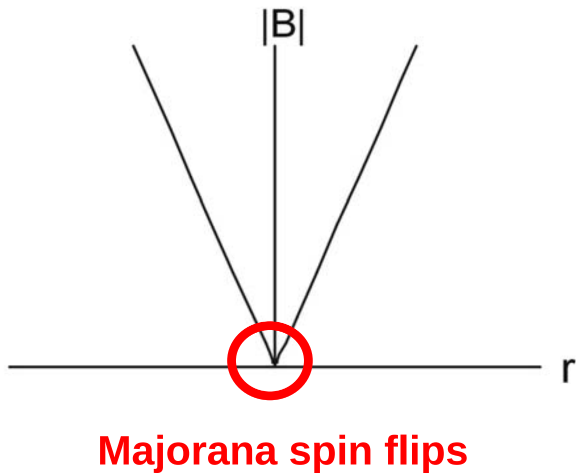
Petrich, et. al PRL 74 (1995) 3352

The double TOP trap

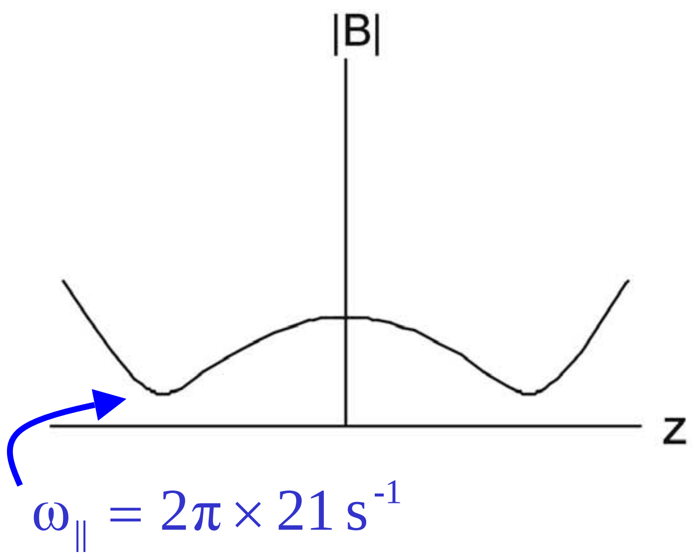
axial radial

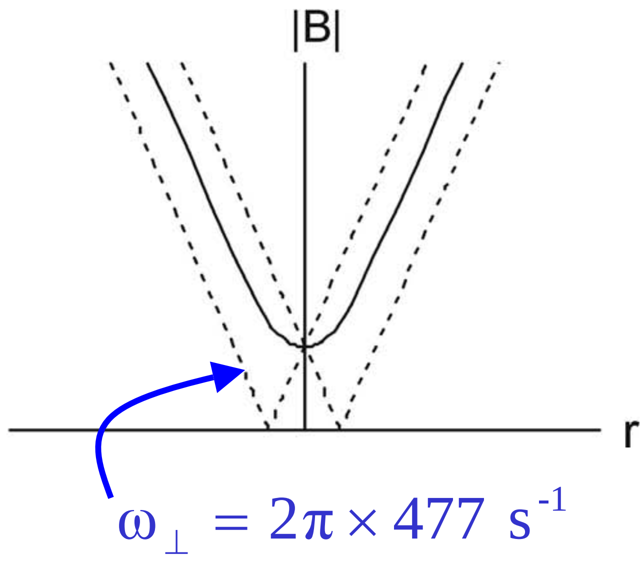
$B_0 < 0$
TOP *off*





$B_0 < 0$
TOP *on*

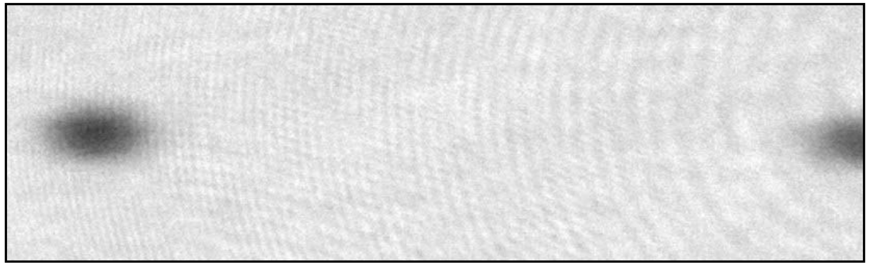


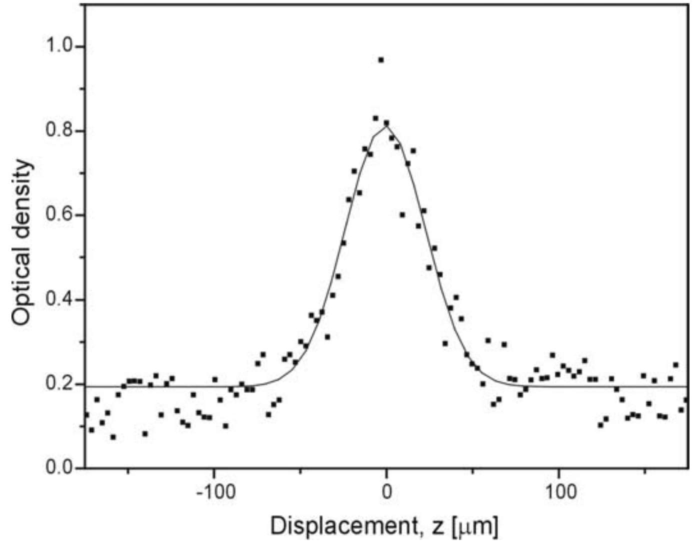


T. G. Tiecke, et al J. Opt. B 5, S119 (2003).

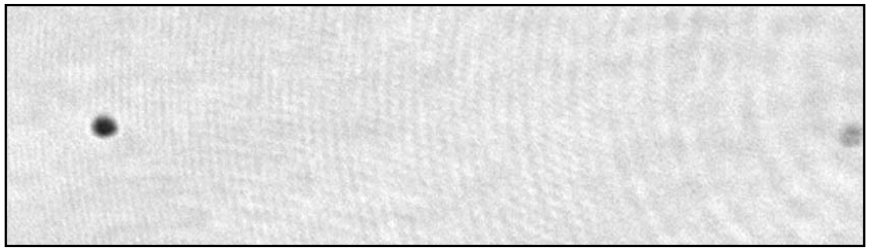
Atoms in the double TOP-trap

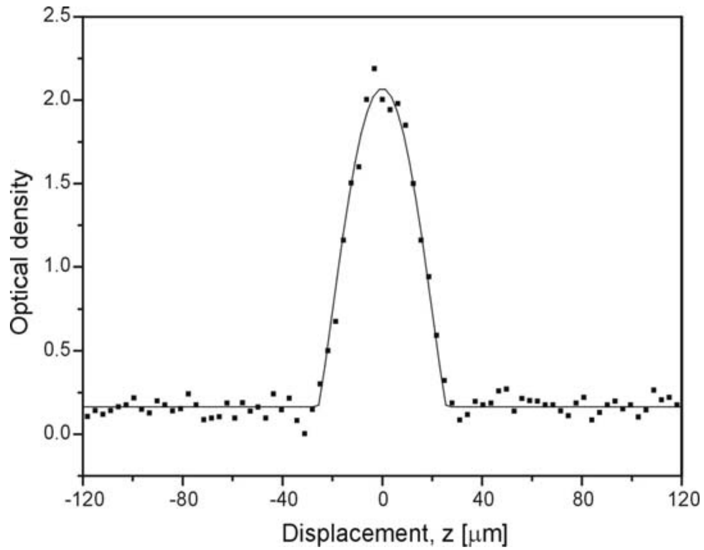
Thermal





Condensate



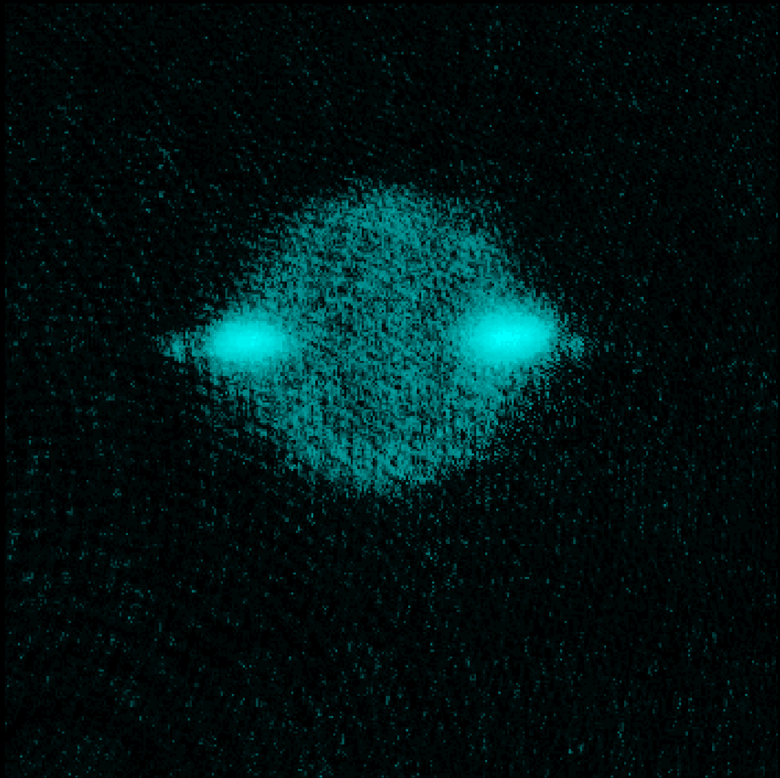


~ 1 mm

Complex scattering amplitudes

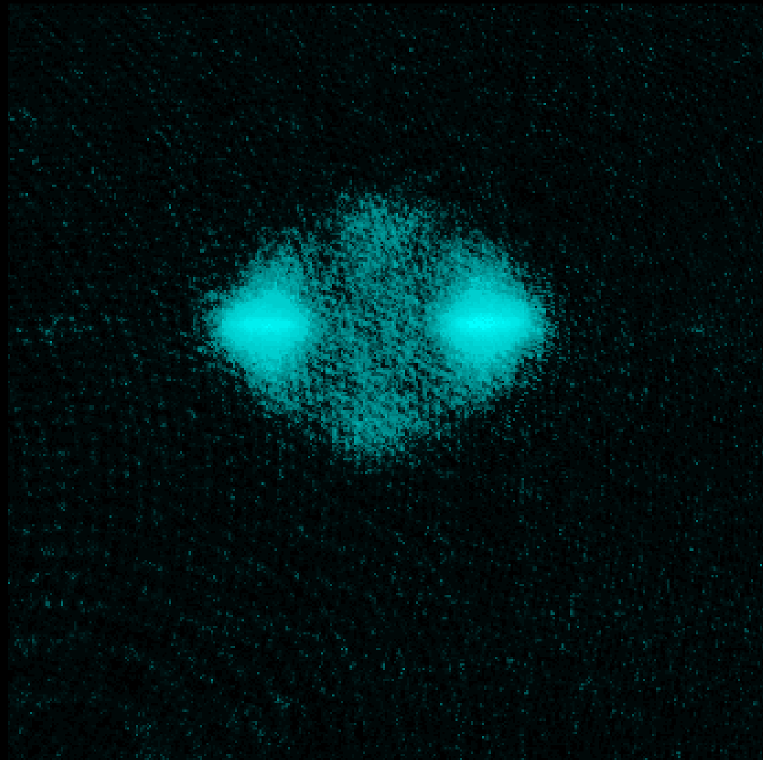
s-wave (l=0) : $f_s(\theta) = \frac{1}{k} e^{i\eta_0} \sin \eta_0$

d-wave (l=2) : $f_d(\theta) = \frac{5}{2k} e^{i\eta_2} \left(3\cos^2\theta - 1\right) \sin \eta_2$.



E_c/k_B=138 μK

$Y_0^0(\theta)$
s-wave



E_c/k_B=1230 μK

$Y_2^0(\theta)$
d-wave

Complex scattering amplitudes

s-wave (l=0) : $f_s(\theta) = \frac{1}{k} e^{i\eta_0} \sin\eta_0$

d-wave (l=2) : $f_d(\theta) = \frac{5}{2k} e^{i\eta_2} \left(3\cos^2\theta - 1\right) \sin\eta_2.$

THEREFORE
we can determine the
absolute phase-shifts and cross sections
for both s- and d-waves
without knowing the atom numbers !

E_c/k_B=138 μK

$Y_0^0(\theta)$

s-wave

E_c/k_B=1230 μK

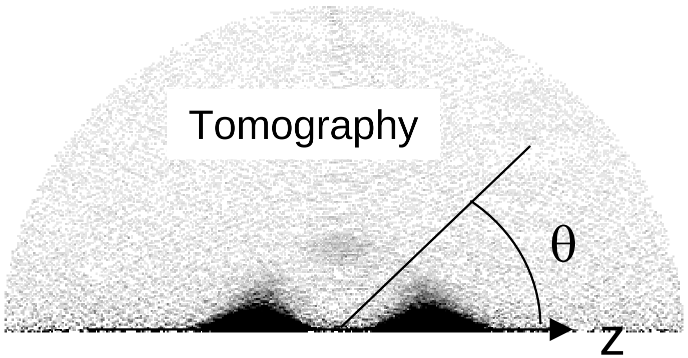
$Y_2^0(\theta)$

d-wave

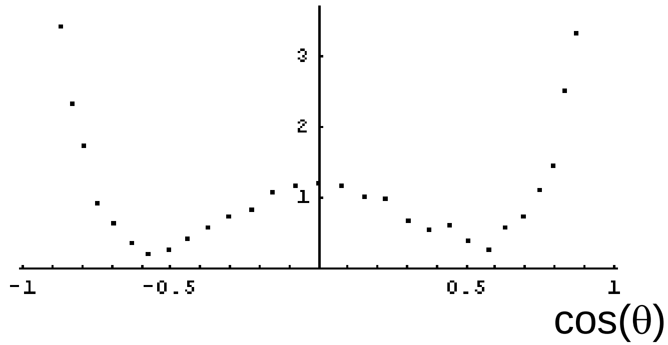
Image processing

Collision energy = 1230 μK (almost) pure d-wave

Optical density

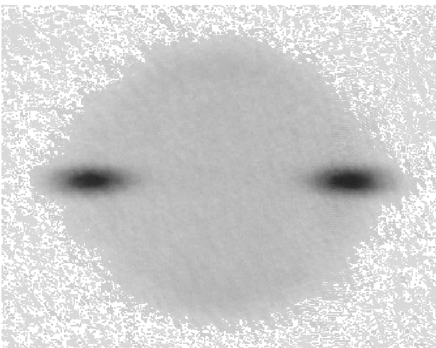


Differential cross section

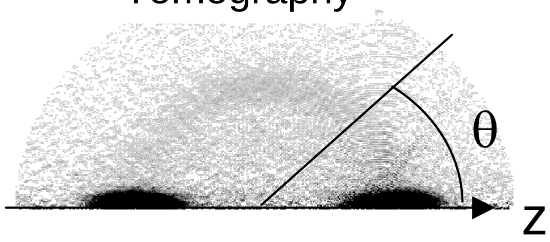


Collision energy = 138 μK (almost) pure s-wave

Optical density



Tomography



Differential cross section

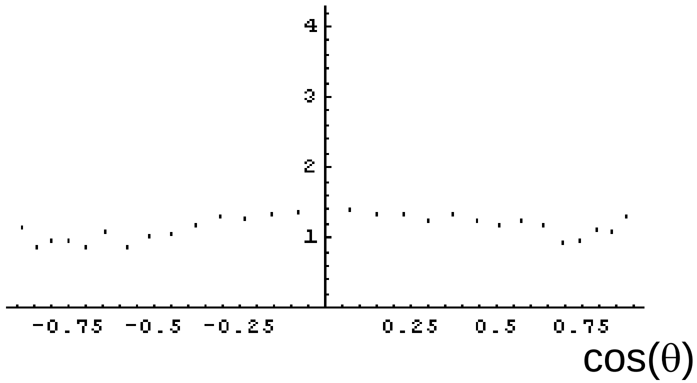
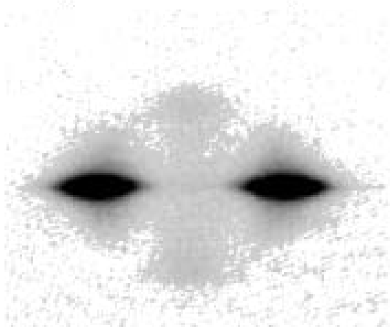


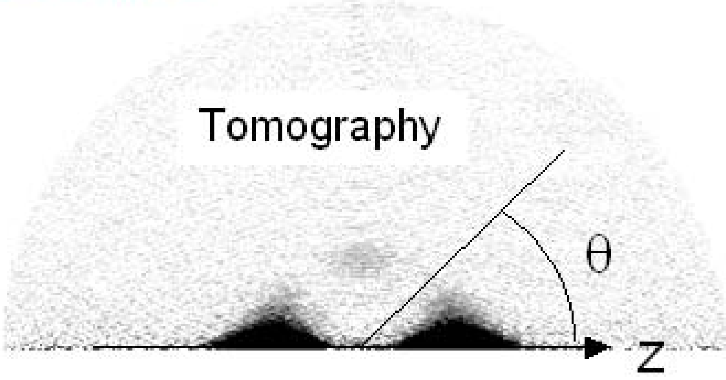
Image processing…

Collision energy = 1230 μK **(almost) pure d-wave**

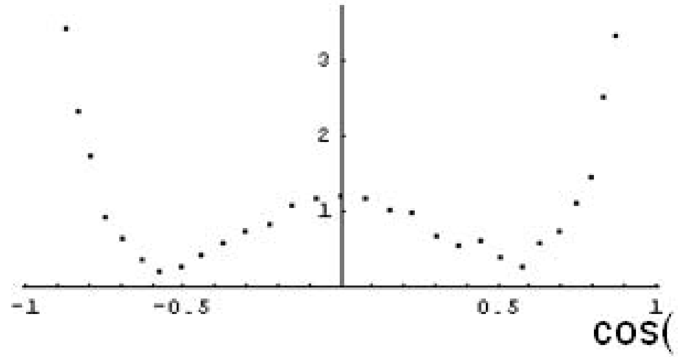
Optical density



Tomography



Differential cross section



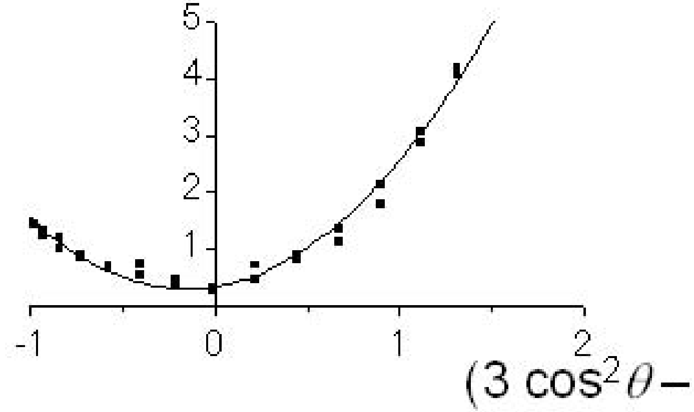
… and fitting the differential cross section:

$$\sigma(\theta) = 2\pi\left|f(\theta) + f(\pi-\theta)\right|^2$$

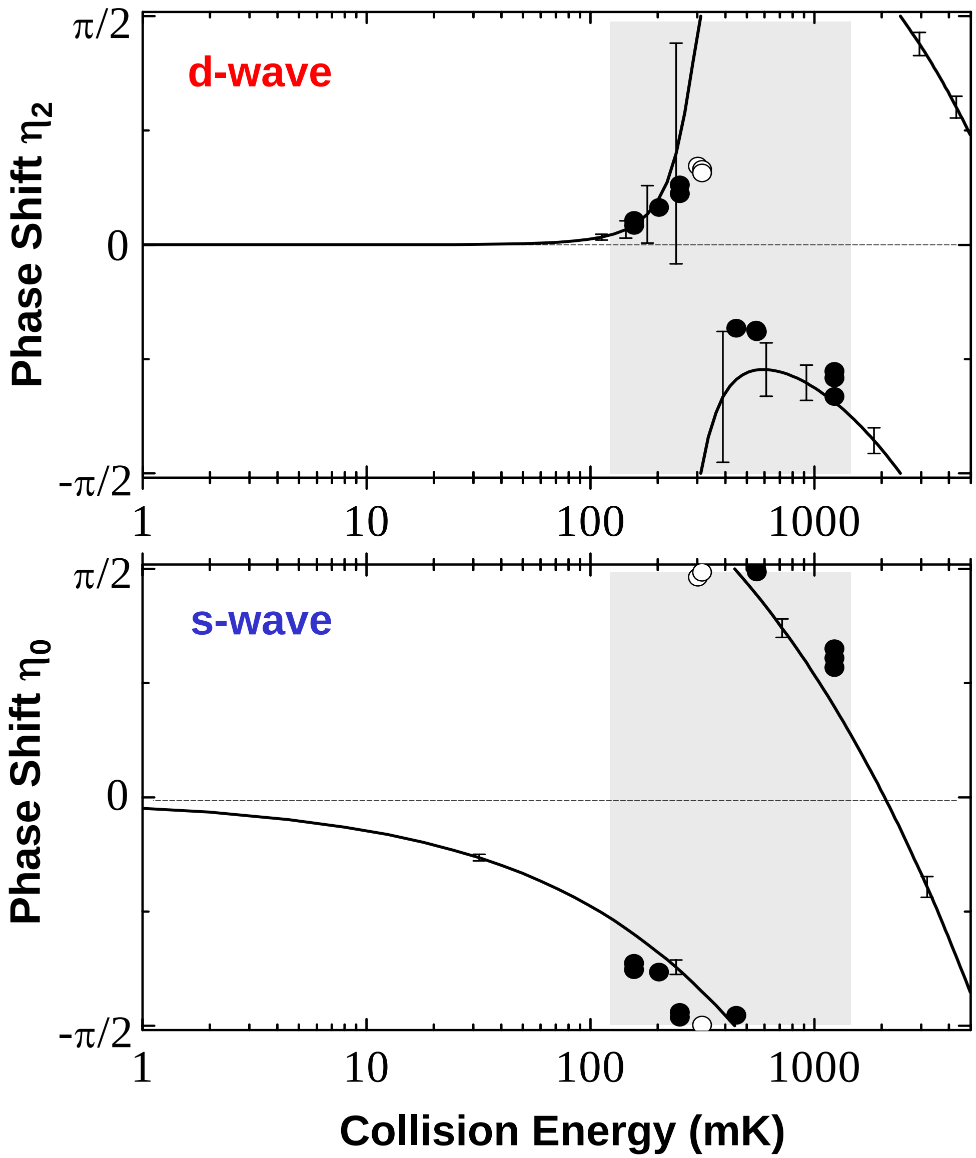
$$= \frac{8\pi}{k^2}\sin^2\eta_0 \times \left[1 + 5\cos(\eta_0 - \eta_2)\, u + \frac{25}{4}u^2\right]$$

With $u \equiv \frac{\sin\ \eta_2}{\sin\ \eta_0}(3\cos^2\theta - 1)$

Differential cross section



C_6+ accumulated phase method



+Theoretical input:
C_6/R^6
(Van der Waals interaction)

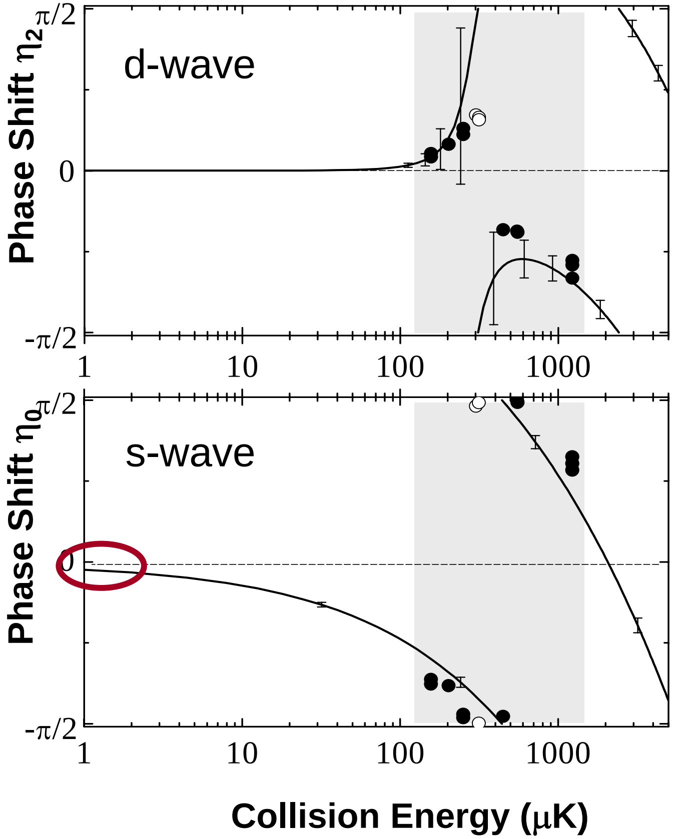
Phase Shifts at ANY (low) energy

Scattering amplitude at ANY (low) energy

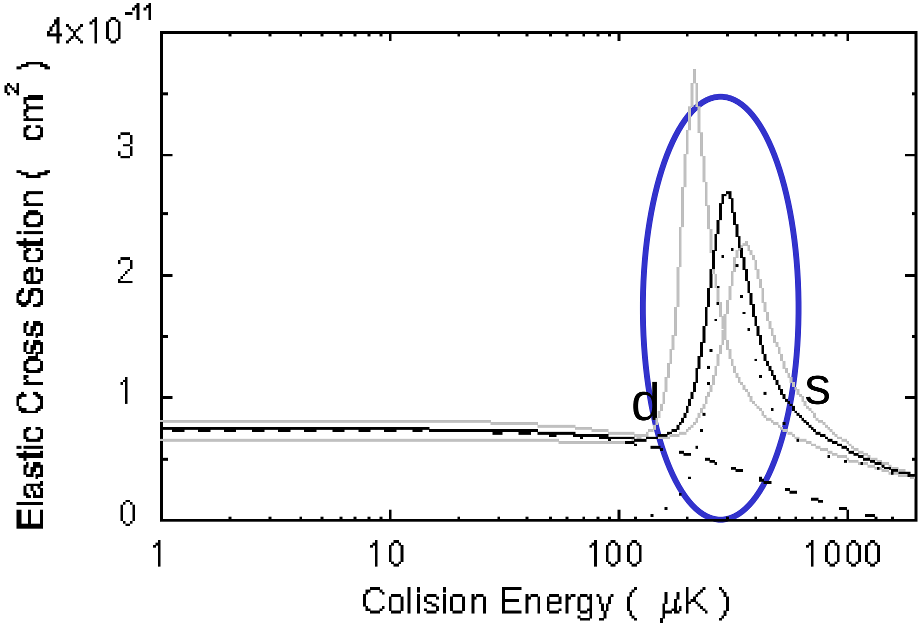
cond-mat/0406093
To appear in Phys.Rev.Lett.

Phase-shifts and elastic cross section

cond-mat/0406093 - to appear in Phys.Rev.Lett.



$$\sigma = \int \sigma(\theta)\sin\theta d\theta = \frac{8\pi}{k^2}\sum_{l=even}\sin^2\eta_l$$



$$\lim_{k\to 0}\eta_0(k) = -ka$$ ⟹ $a_{triplet}$= + 102(6)a_0

$a_{triplet}$ = 98.99(2)a_0 Van Kempen, Kokkelmans, Heinzen, Verhaar PRL **88**, 93201 (2002)
"…Interactions from *three high-precision experiments* "

d-wave resonance found to be at 0.30(7) mK

See also: Thomas, Kjaergaard, Julienne, Wilson, cond-mat/0405544 (2004)

Conclusion

- First application of the ‘new’ Ioffe Pritchard quadrupole trap
- New method to measure accurately the scattering cross section for *any* (low) energy

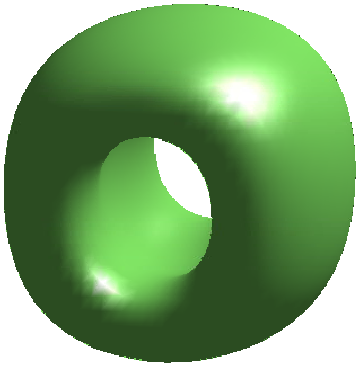
Outlook #1

(Amsterdam)

- Lower densities (no multiple scattering)
- Higher energies (higher order waves)

Outlook #2
(Crete)

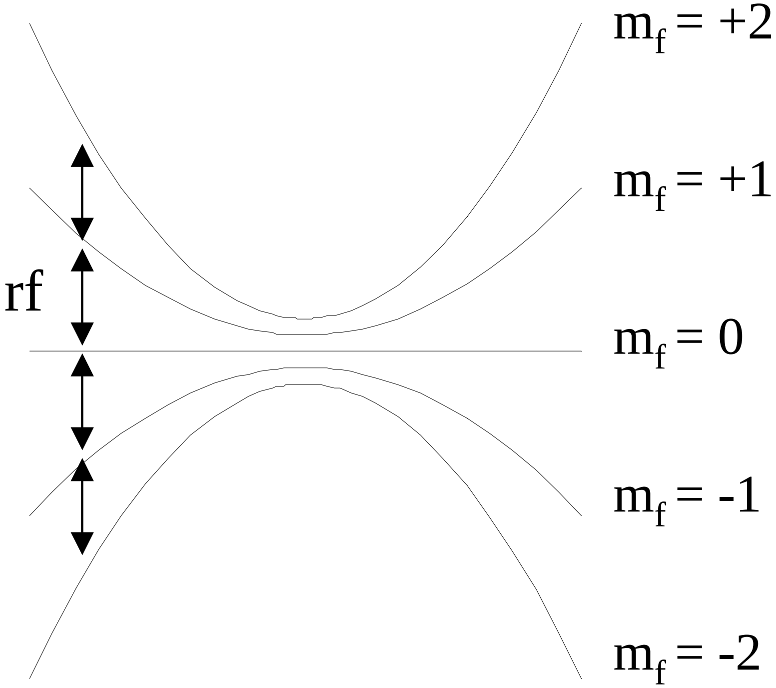
- Novel trapping geometries
- A magnetic ring trap
- BEC Interferometry

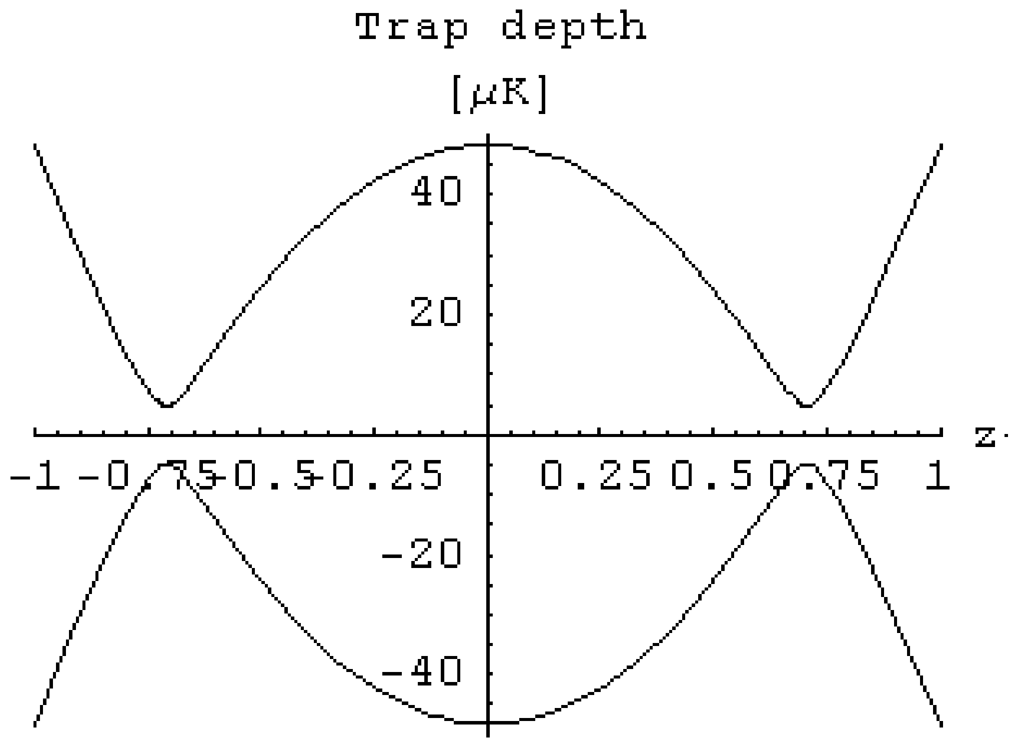


Dressing the Ioffe Quadrupole Trap

$$U_{\mathrm{B}} = \mu_{\mathrm{B}} \sqrt{(\alpha\,\rho)^2 + \left(\tfrac{1}{2}\beta\,\mathbf{z}^2 + \mathbf{B}_0\right)^2}$$

$$U_{\mathrm{rf}} = \sqrt{(U_{\mathrm{B}} - h\,\nu_{\mathrm{rf}})^2 + (h\,\Omega_{\mathrm{rf}})^2}$$



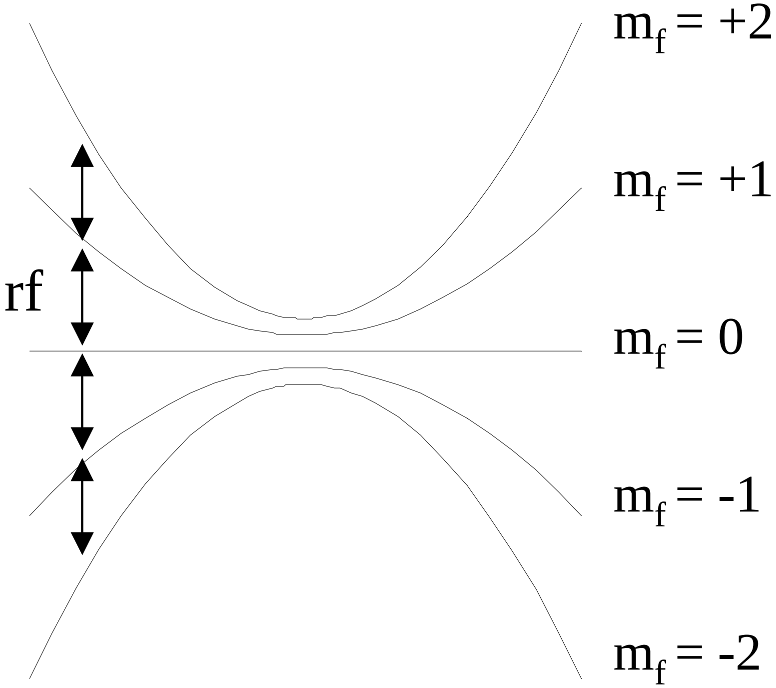


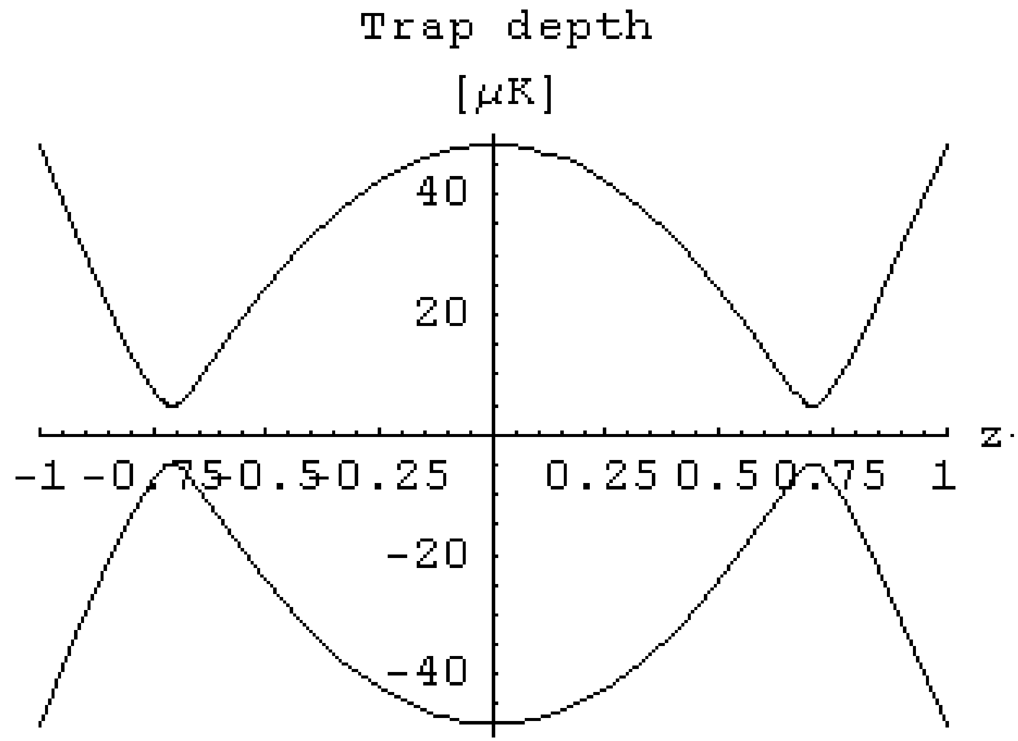
O. Zobay, B. M. Garraway Phys. Rev. Lett. **86-7**, 1195-1198 (2001)

Dressing the Ioffe Quadrupole Trap

$$U_{\mathrm{B}} = \mu_{\mathrm{B}} \sqrt{(\alpha\,\rho)^2 + \left(\tfrac{1}{2}\beta\,\mathbf{z}^2 + \mathbf{B}_0\right)^2}$$

$$U_{\mathrm{rf}} = \sqrt{(U_{\mathrm{B}} - h\,\nu_{\mathrm{rf}})^2 + (h\,\Omega_{\mathrm{rf}})^2}$$



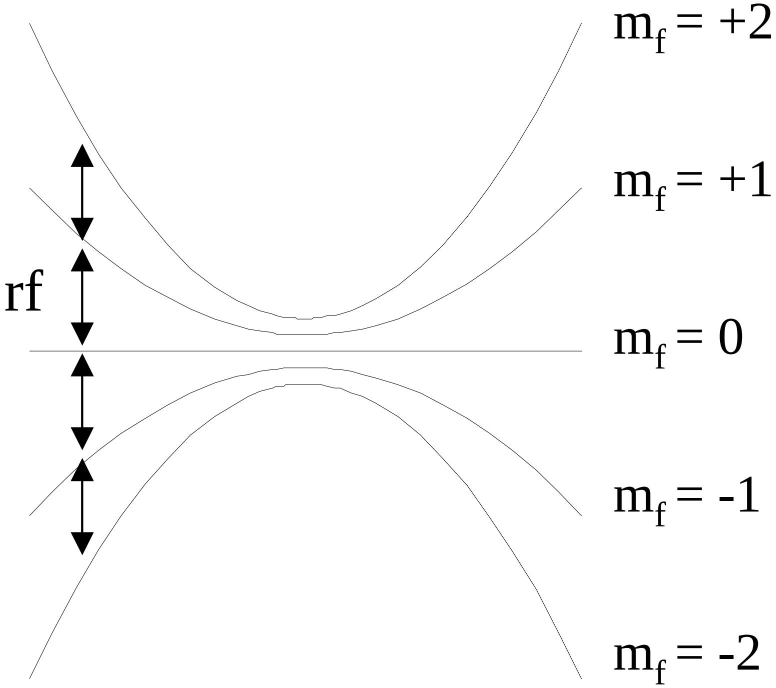


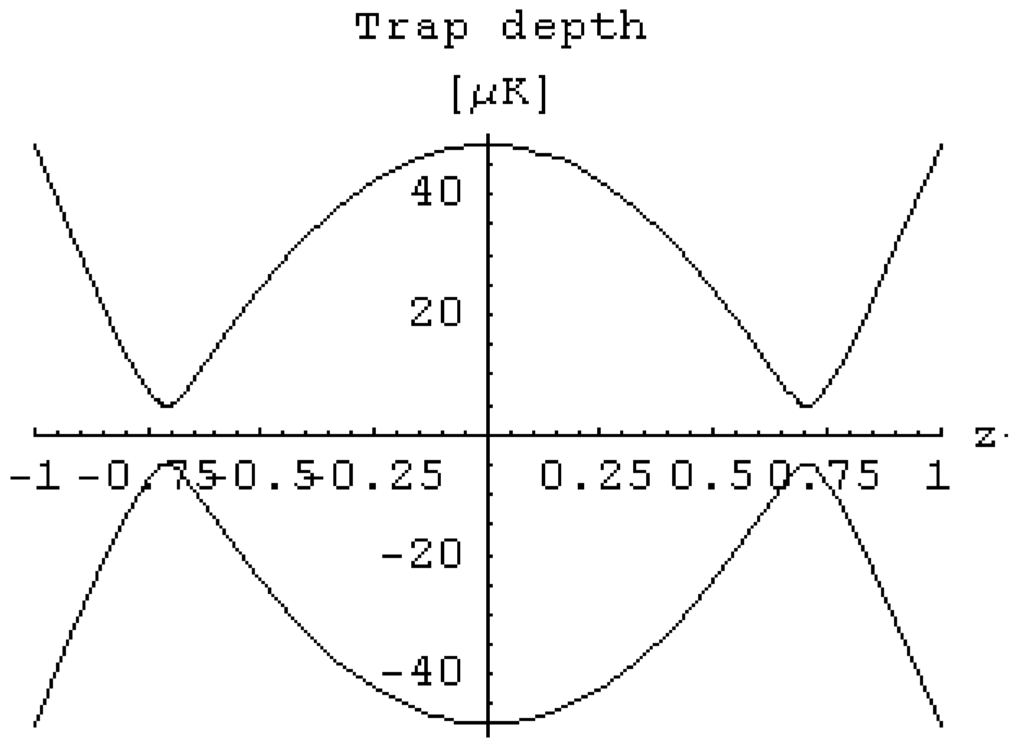
O. Zobay, B. M. Garraway Phys. Rev. Lett. **86-7**, 1195-1198 (2001)

Dressing the Ioffe Quadrupole Trap

$$U_B = \mu_B \sqrt{(\alpha\rho)^2 + \left(\tfrac{1}{2}\beta \mathbf{z}^2 + \mathbf{B}_0\right)^2}$$

$$U_{rf} = \sqrt{(U_B - h\nu_{rf})^2 + (h\Omega_{rf})^2}$$



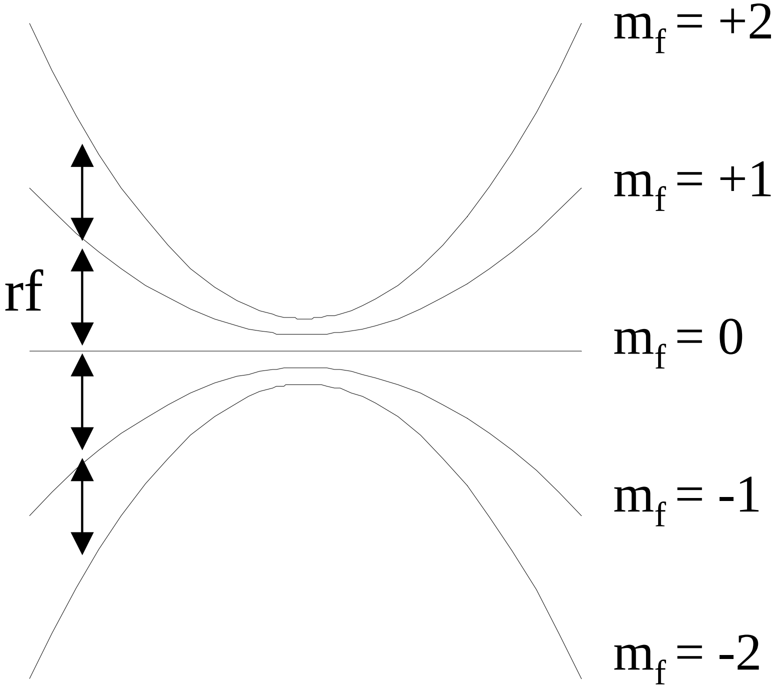


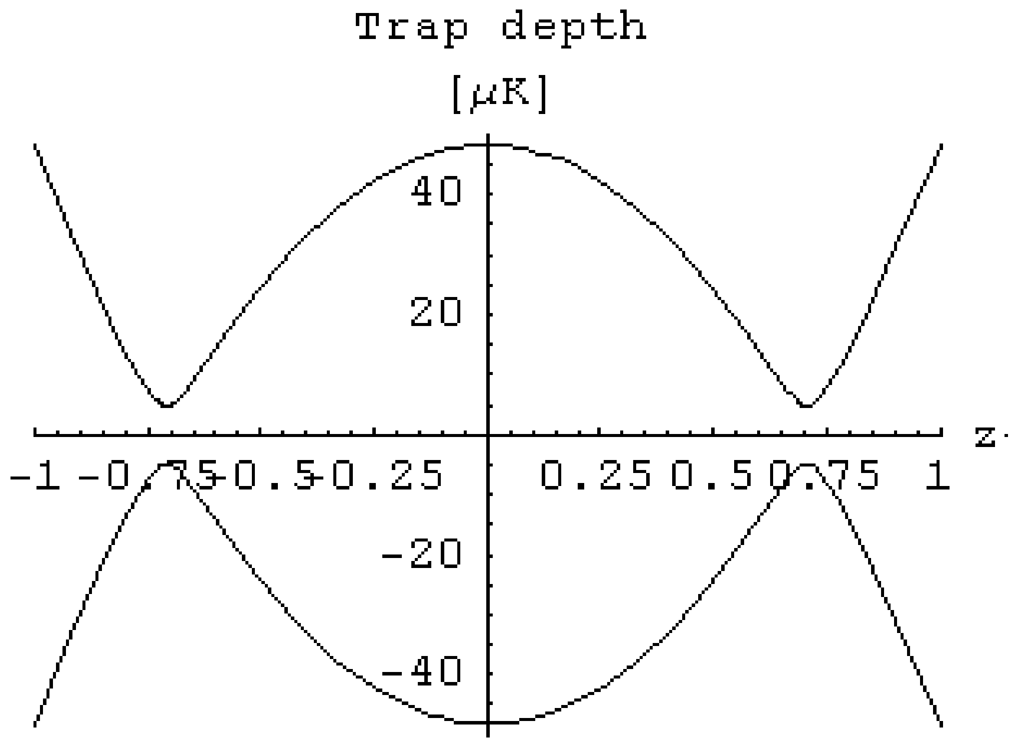
O. Zobay, B. M. Garraway Phys. Rev. Lett. **86-7**, 1195-1198 (2001)

Dressing the Ioffe Quadrupole Trap

$$U_B = \mu_B \sqrt{(\alpha\rho)^2 + \left(\tfrac{1}{2}\beta \mathbf{z}^2 + \mathbf{B}_0\right)^2}$$

$$U_{rf} = \sqrt{(U_B - h\nu_{rf})^2 + (h\Omega_{rf})^2}$$



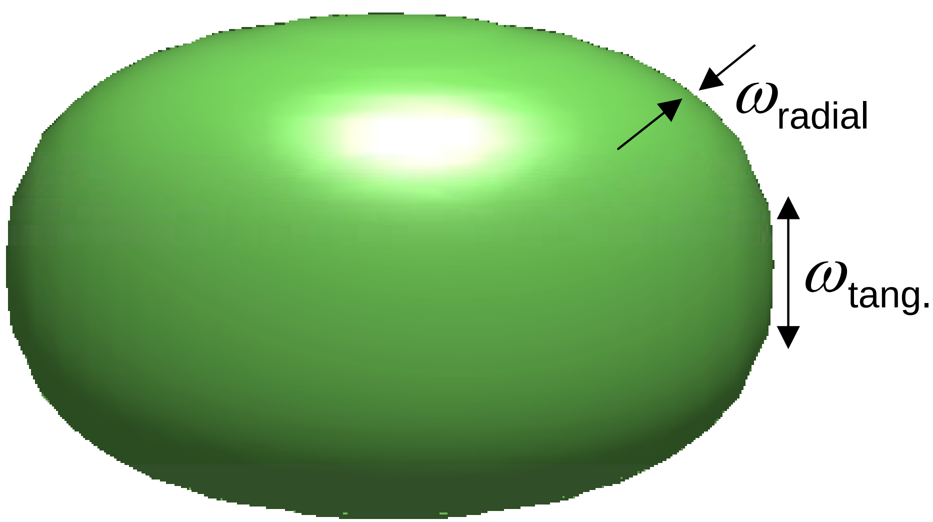


O. Zobay, B. M. Garraway Phys. Rev. Lett. **86-7**, 1195-1198 (2001)

Gravity in the dressed Ioffe Quadrupole Trap

$$U_{\mathrm{rf}} = \sqrt{\left(U_{\mathrm{B}} - h\nu_{\mathrm{rf}}\right)^2 + \left(h\Omega_{\mathrm{rf}}\right)^2}$$

$$U_{\mathbf{B}} = \mu_{\mathbf{B}}\sqrt{(\alpha\,\rho)^2 + \left(\tfrac{1}{2}\beta\,\mathbf{z}^2 + \mathbf{B}_0\right)^2}$$

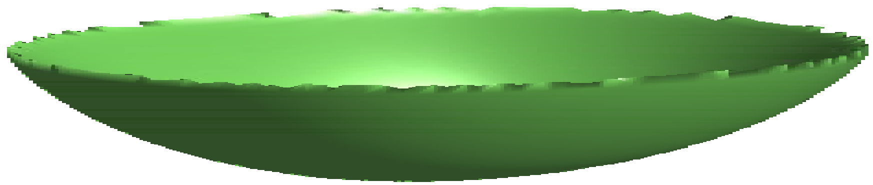


$$\omega_{\mathrm{radial}} = \frac{\alpha\,\mu}{\sqrt{m\,h\,\Omega_{\mathrm{rf}}}}\sqrt{1-\left(\frac{\mu\,B_0}{h\,\nu_{\mathrm{rf}}}\right)^2}$$

$$\omega_{\mathrm{tang.}} \cong 0$$

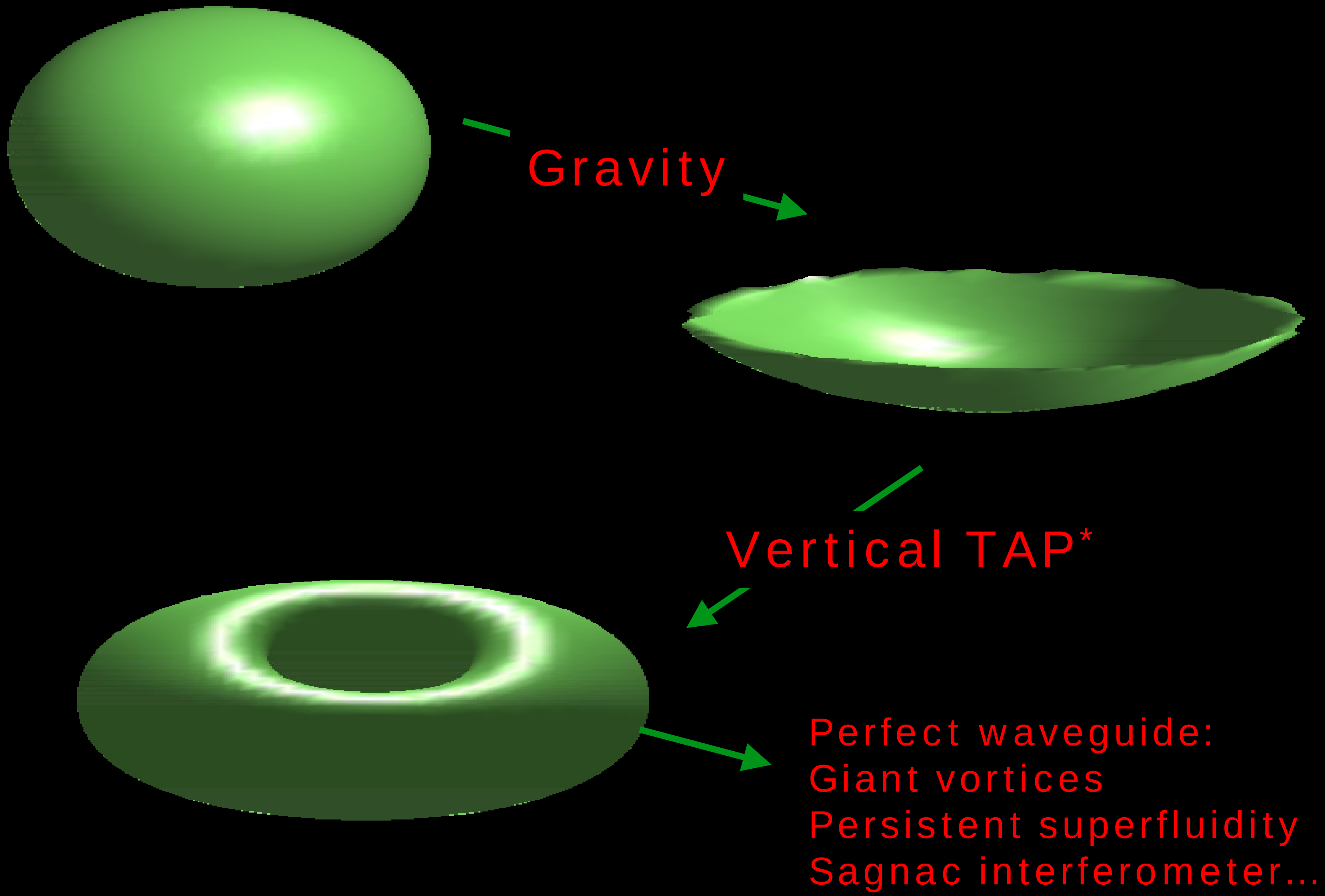
$+\,Gravity$

$\Rightarrow$



O. Zobay, B. M. Garraway Phys. Rev. Lett. **86-7**, 1195-1198 (2001)

The dressed TAP:



(*) An oscillating, homogeneous B-field in vertical direction creates a Time-Averaged Potential TAP


Finishing your PhD? Still interested in BEC?
Contact Wolf !!