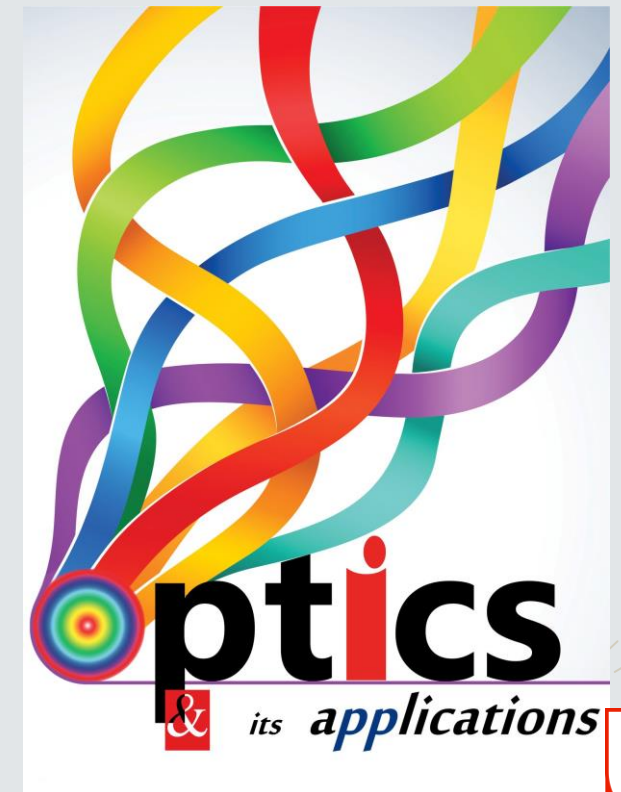


Topological and superconducting phases in the critical behavior of a one-dimensional Fermi gas with spin-orbit and Zeeman couplings

**Diego Alejandro Bedoya M. and
Karem Cecilia Rodriguez R.**

December 5, 2022



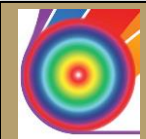
Condensed matter and optics
make possible to produce **exotic
quantum phenomena** in our world

Improve

- **Calculation technology**
- **Medicine**
- **Climate predictions**

Such as

**Topology
and
Superconductivity**



The topological states

Display

Appear as

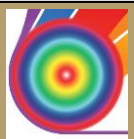
Naturally protected states from decoherence

Zero energy modes at the edges of the system

Kitaev chain [1]

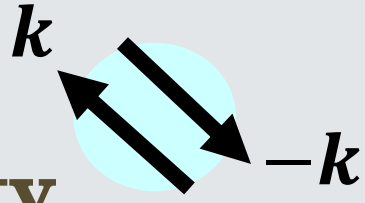


Majorana fermions



Non-conventional superconductivity

Conventional superconductivity



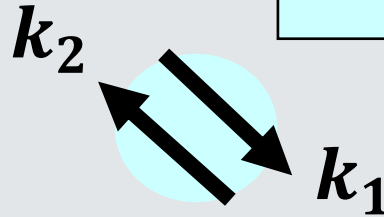
- BCS theory
- **Low temperatures**

Non-conventional superconductivity

In particular

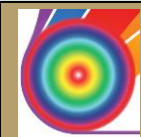
FFLO phase

Start with



Make desirable

High temperature superconductivity



Proposed system

[2] Zhang, J., et al. Annual Review of Cold Atoms and Molecules, 81-143. 2014.

4

$$\hat{H} = \int dx \left[\hat{\Psi}_{\uparrow\downarrow}^\dagger \left(-\frac{\partial_x^2}{2m} - \mu(x) + \left(-i\alpha\partial_x + \frac{\hbar}{2} \right) \sigma^x - \frac{B}{2} \sigma^z \right) \hat{\Psi}_{\uparrow\downarrow} - U \hat{\psi}_\uparrow^\dagger \hat{\psi}_\downarrow^\dagger \hat{\psi}_\downarrow \hat{\psi}_\uparrow \right]$$

Kinetic energy

Chemical potential

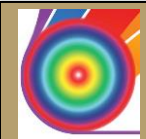
$$\mu(x) = \mu - V(x)$$

Potential trap

Spin-orbit coupling

[2]

Attractive interaction term between opposite spins

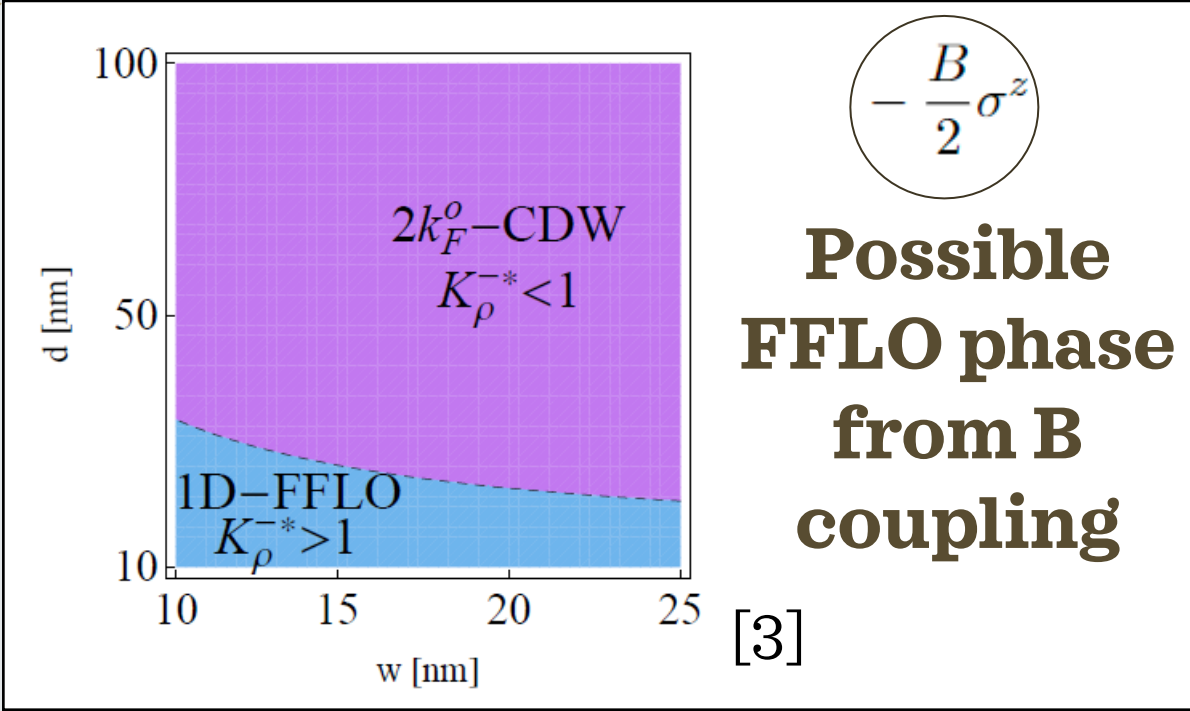


The phases

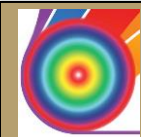
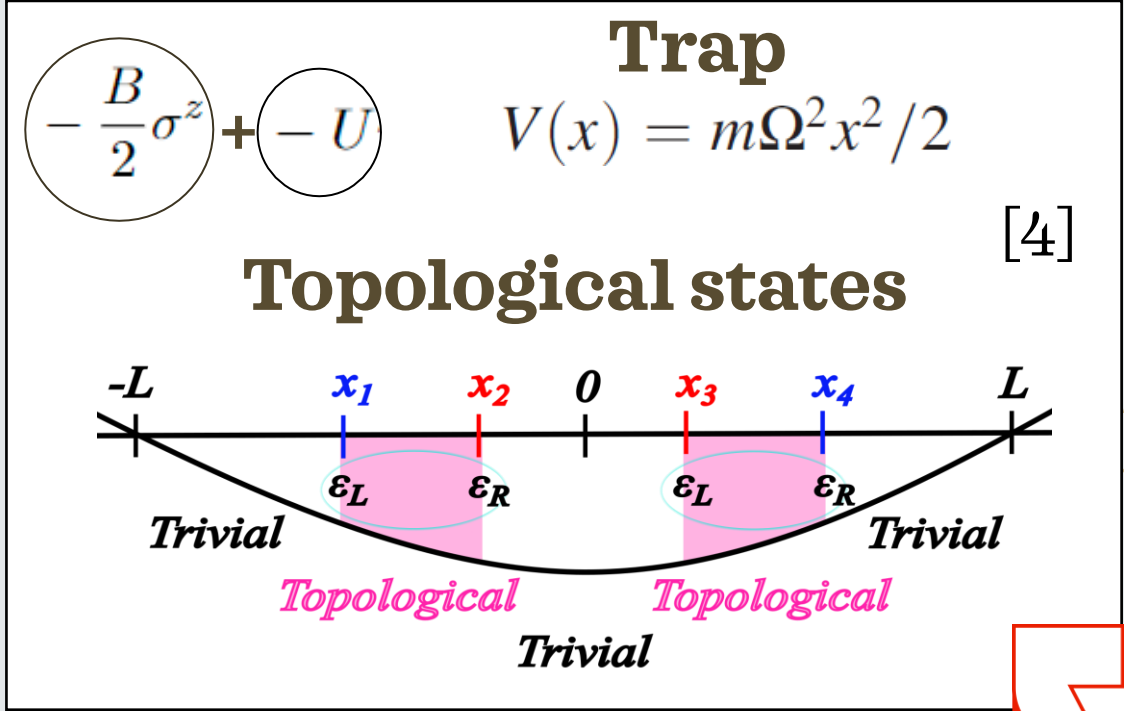
[3] Datta, T. The European Physical Journal B, 67(2), 197-208. 2009.

[4] Ruhman, J., et al. Physical Review Letters, 114(10), 100401. 2015.

If $\mu < \frac{1}{2}m\alpha^2$ and $h = \pm 2\alpha\sqrt{2m\mu}$

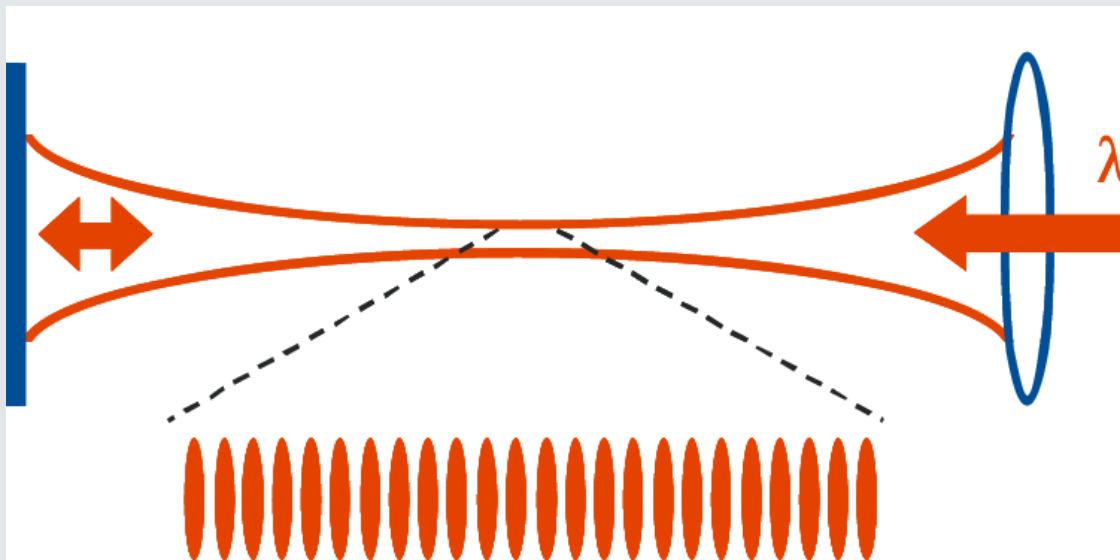


If $\mu = h = 0$

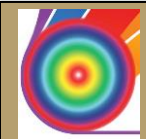
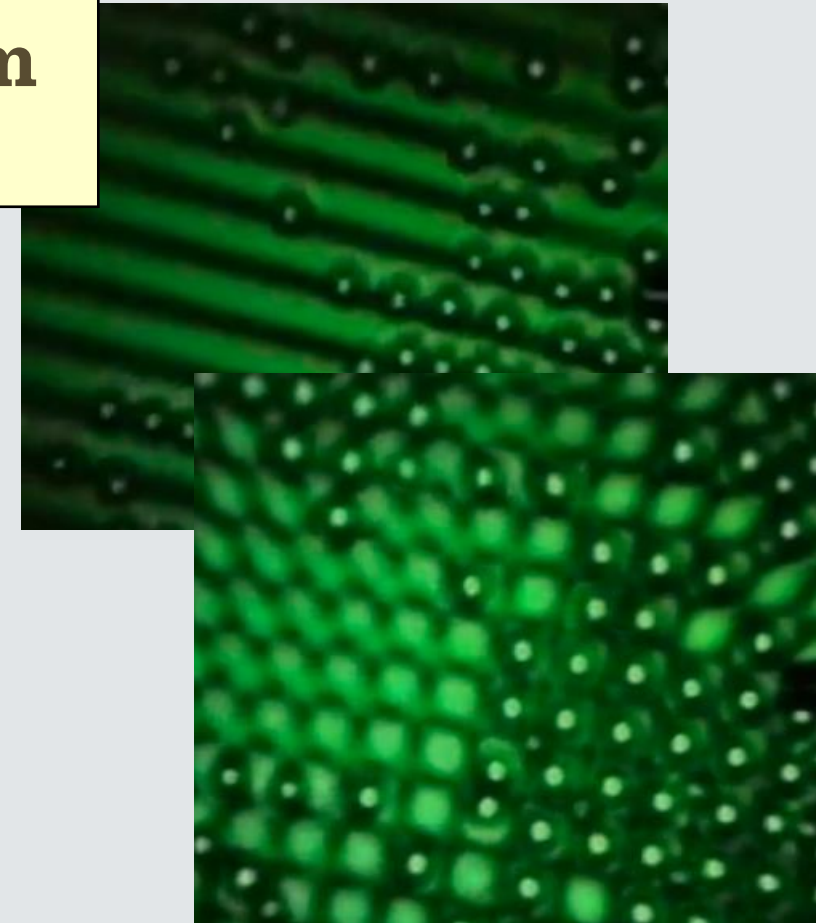


Fermi gases are confined in optical lattices and cooled down to trap them in **potential minima**

1D



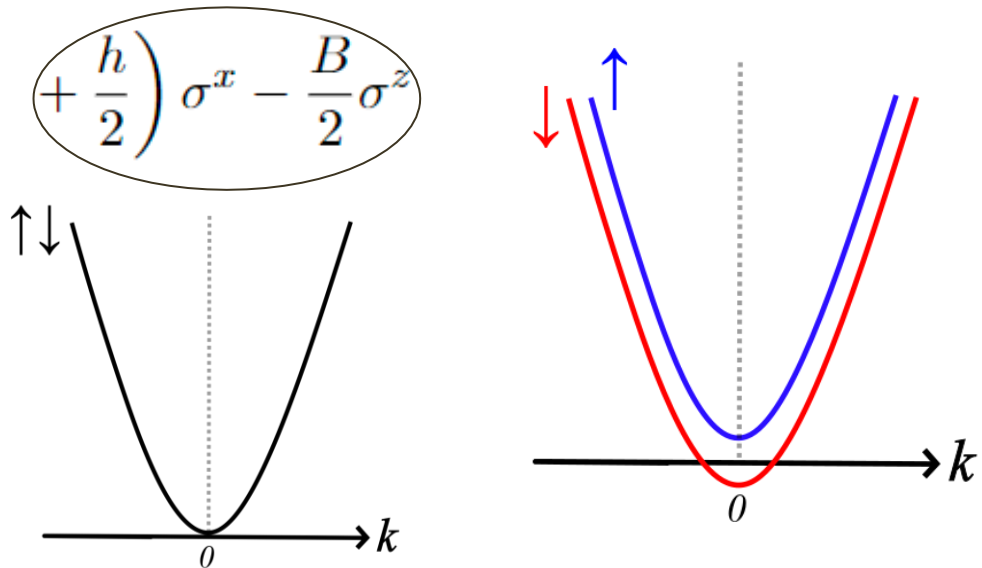
[5]



External coupling which breaks inversion symmetries

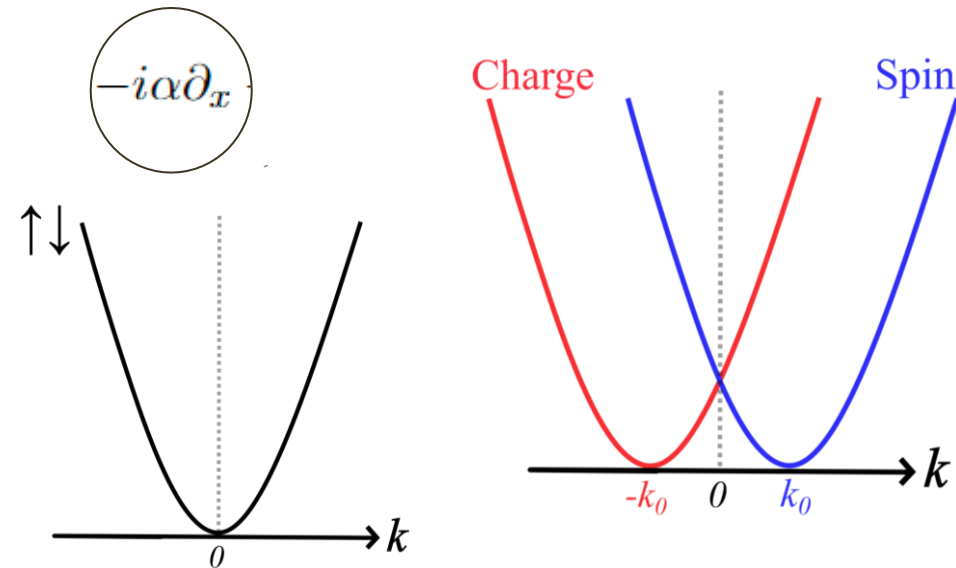
Time reversal symmetry

$$\varepsilon_{\uparrow}(k) = \varepsilon_{\downarrow}(-k)$$



Space reversal symmetry

$$\varepsilon_{\sigma}(k) = \varepsilon_{\sigma}(-k)$$



[6]

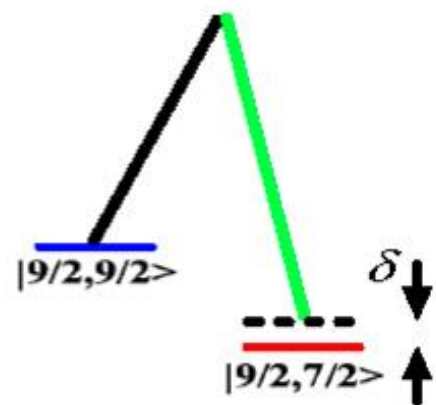
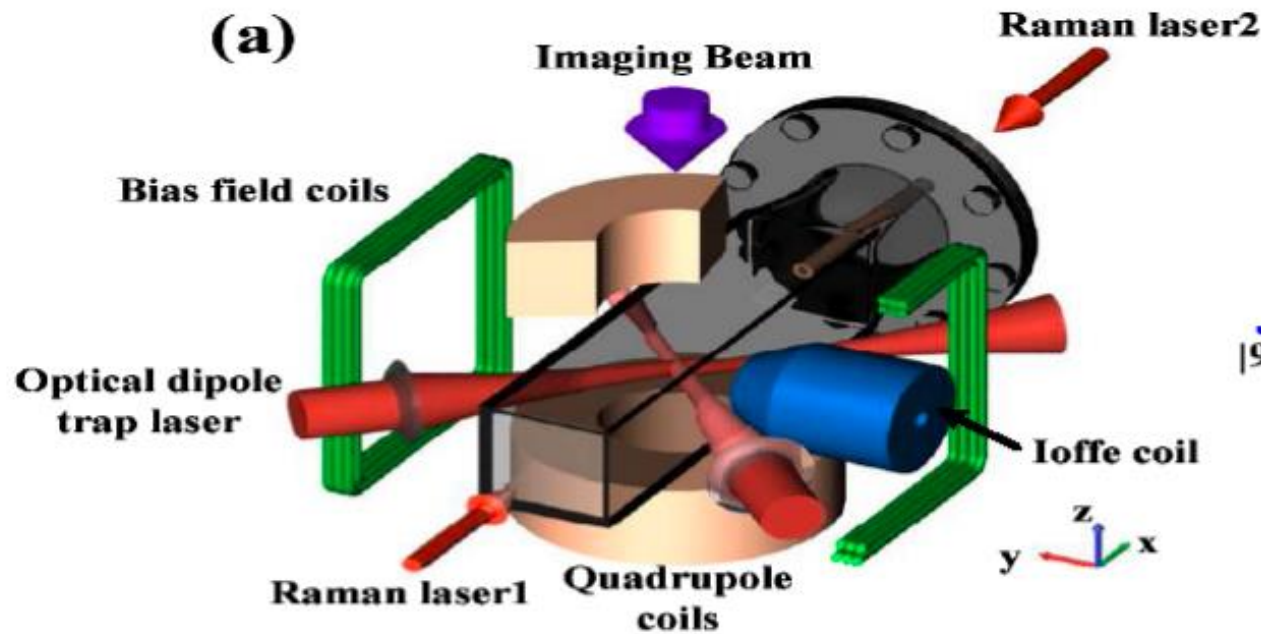


[7] Wang, P., et al. Physical review letters, 109(9), 095301. 2012.

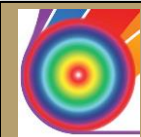
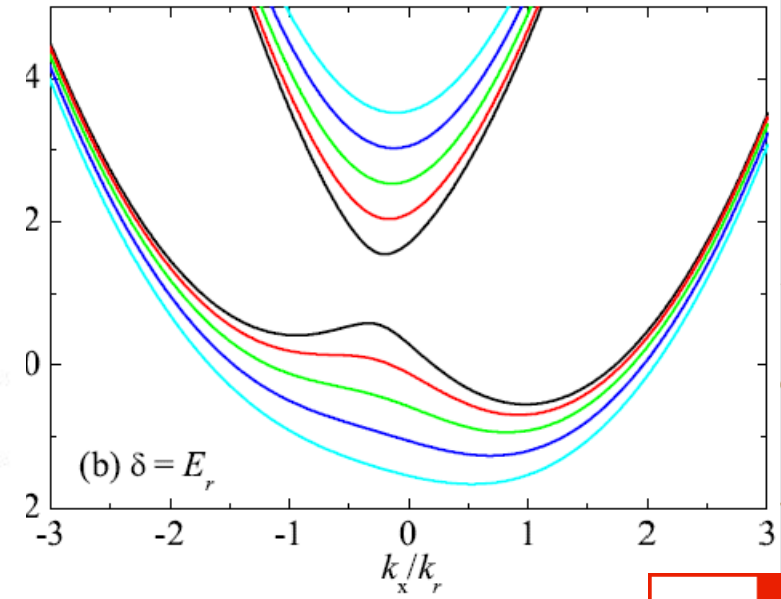
[2] Zhang, J., et al. Annual Review of Cold Atoms and Molecules, 81-143. 2014.

Raman lasers introduce non-elastic scattering with photons

[2]



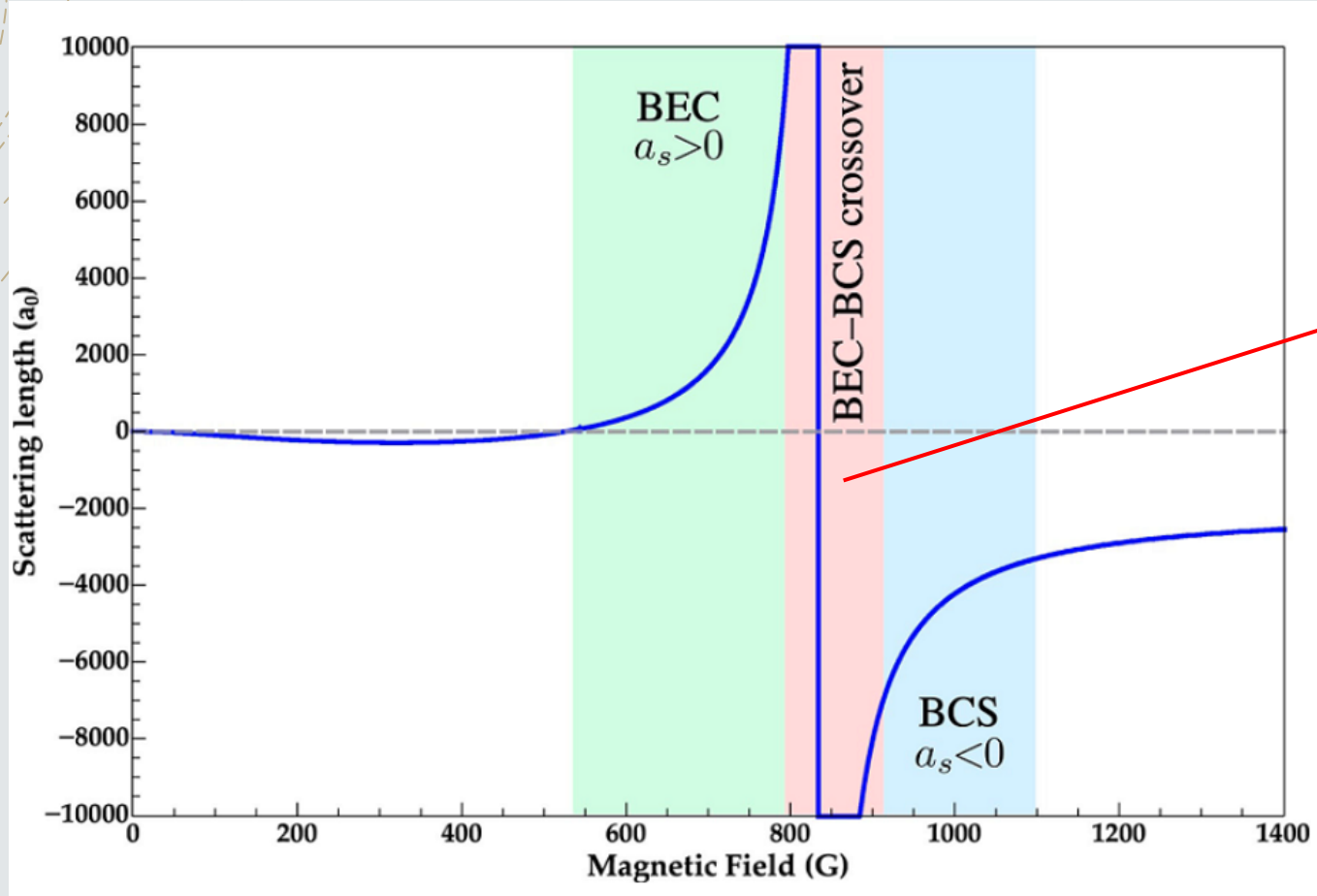
[7]



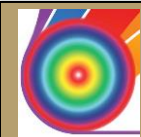
Attractive interactions

[8] Hernández-Rajkov, D., et al. Revista mexicana de física, 66(4), 388-403. 2020.
[9] Chin, C., et al. Reviews of Modern Physics, 82(2), 1225. 2010.

[8]



Attractive interactions are induced under Feshbach resonance. Varying an external magnetic field varies the scattering length a_s to a negative and, if needed, high value. [9]

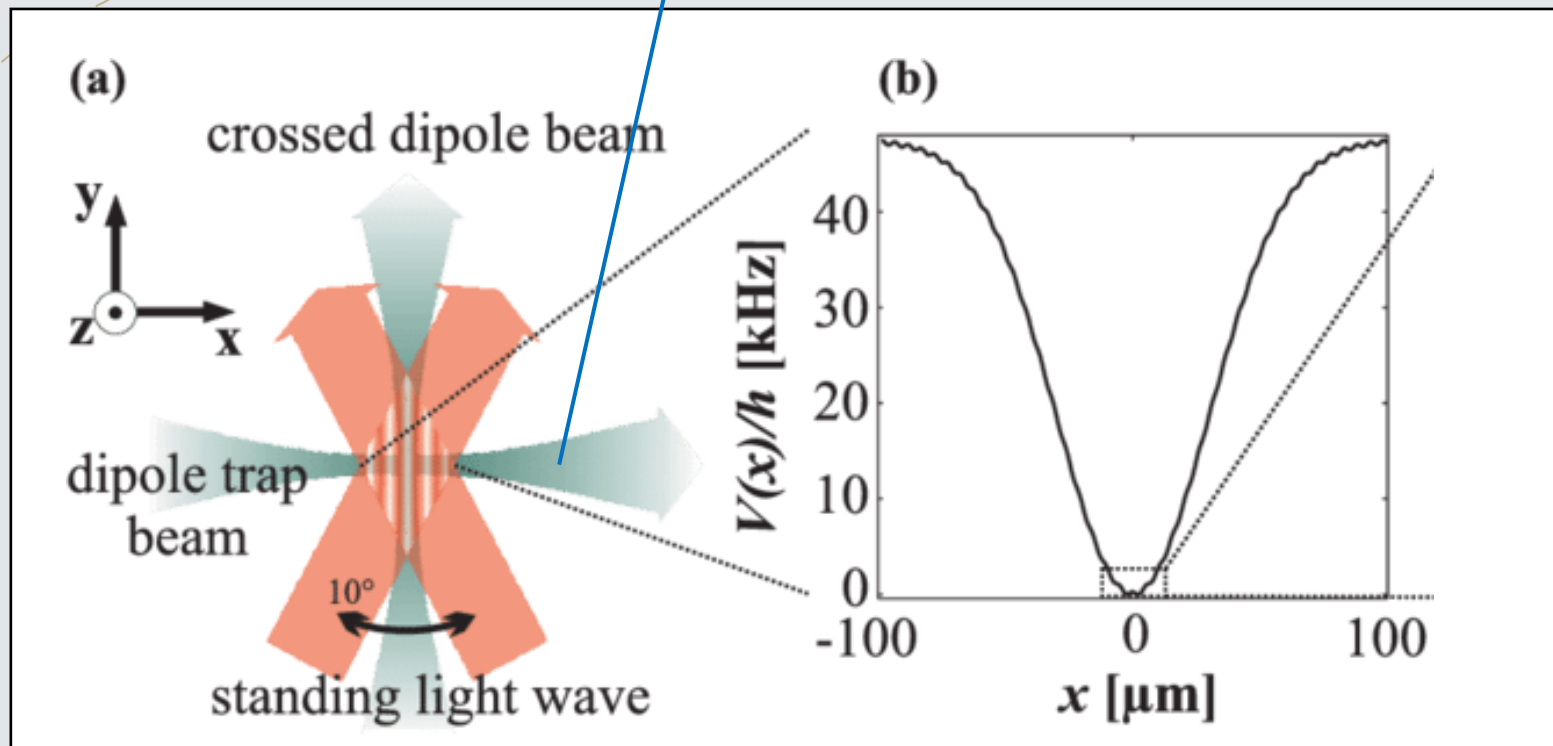


Harmonic trap

[10] Gati, R., et al. New Journal of Physics, 8(9), 189. 2006.

10

Just the Gaussian dipole trap produces the harmonic trap



Optics can give shape to all these exotic phenomena!

[10]

