The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

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1859-19

Summer School on Novel Quantum Phases and Non-Equilibrium Phenomena in Cold Atomic Gases

27 August - 7 September, 2007

Theory of dipolar gases

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Trieste, September 5, 2007

Dipolar gases: Theory

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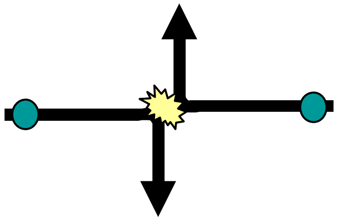
CO.CO.MAT
CONTROL OF QUANTUM CORRELATIONS IN TAILORED MATTER
SFB/TR 21 – STUTTGART, ULM, TÜBINGEN

SFB 407

Overview

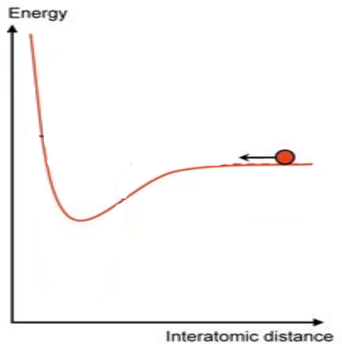
- Introduction to dipolar gases
- Nonlocal NLSE
- Stability
- Multidimensional bright solitons
- Vortex-lines in dipolar BEC
- Stable dark nodal planes

„Usual“ gases : Short-range interactions



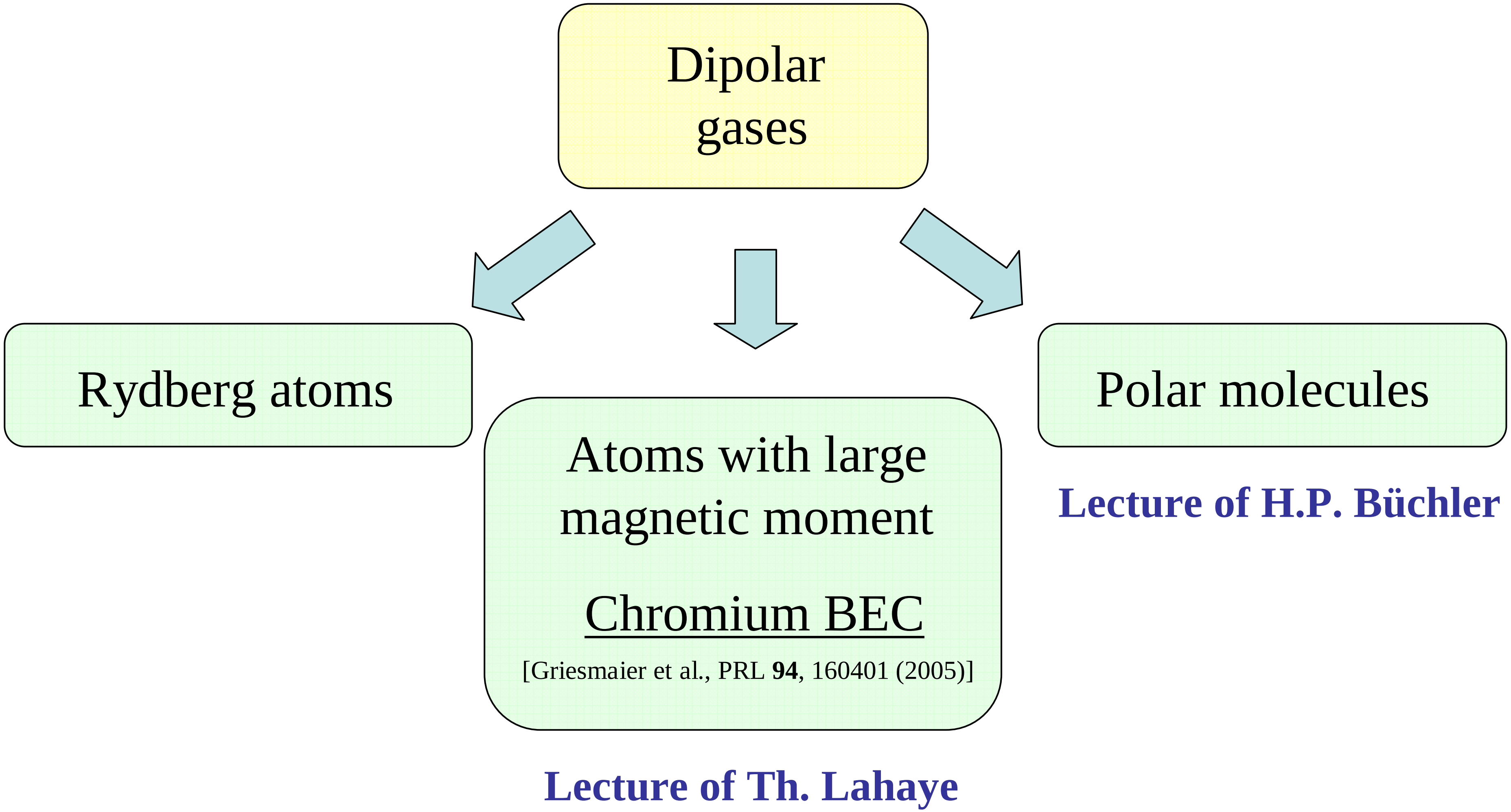
In typical experiments up to now the atoms interact via short-range isotropic interactions

The interaction is given by **the s-wave scattering length “a”**

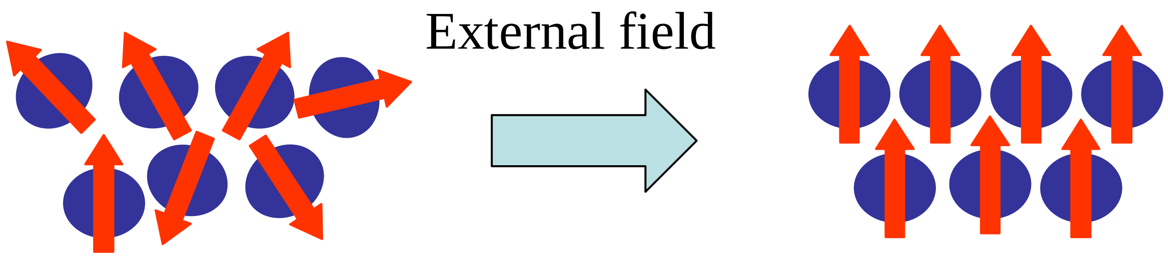


$$V(\vec{r}-\vec{r}\,')\approx\frac{4\pi\hbar^2 a}{m}\delta(\vec{r}-\vec{r}\,')\equiv g\delta(\vec{r}-\vec{r}\,')$$

Dipolar gases



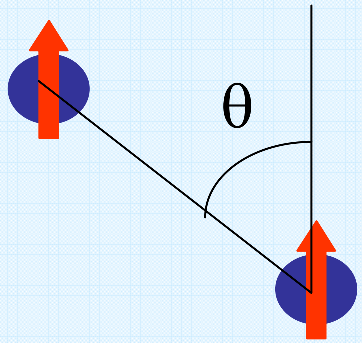
Dipole-dipole interaction



Dipole-Dipole Interaction

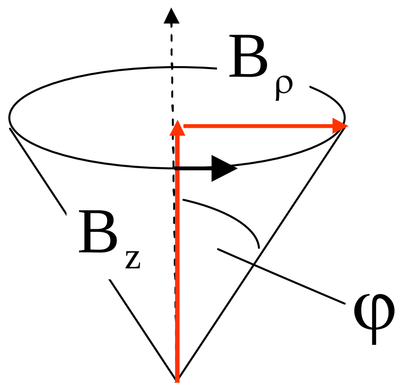
$$V(\vec{r}) = \frac{d^2}{r^3}\left(1 - 3\cos^2\theta\right)$$

Anisotropic
long-range
interaction



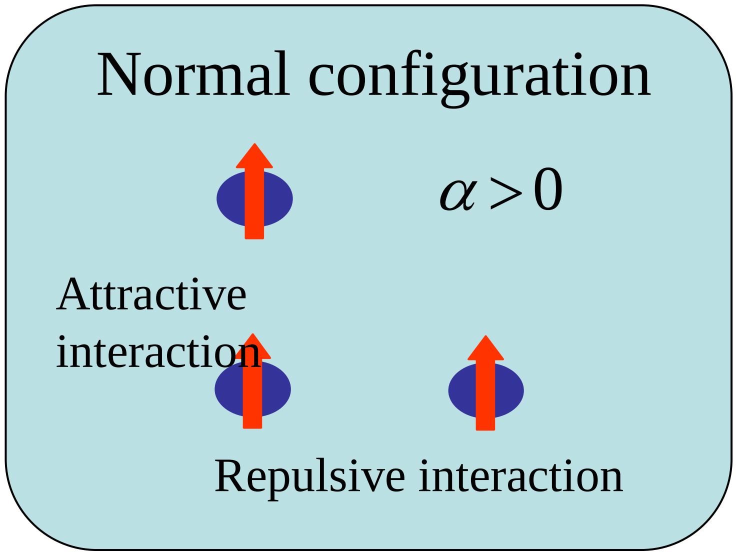
Dipolar gases: Tunability

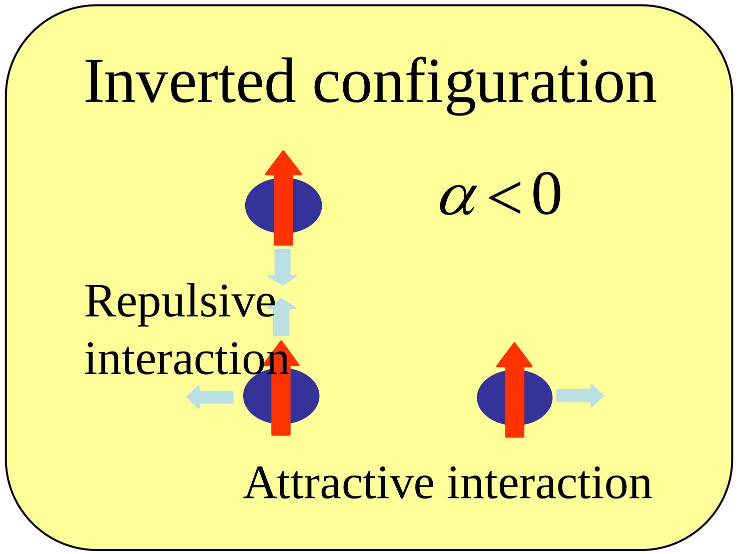
The strength of the dipolar interaction can be tuned [Giovanazzi *et al.*, PRL **89**, 130401 (2002)]



$$V_d(\vec{r}) = \alpha \frac{d^2}{r^3}\left(1 - 3\cos^2\theta\right)$$

$$-\frac{1}{2} \le \alpha = \frac{1}{2}\left(3\cos^2\varphi - 1\right) \le 1$$





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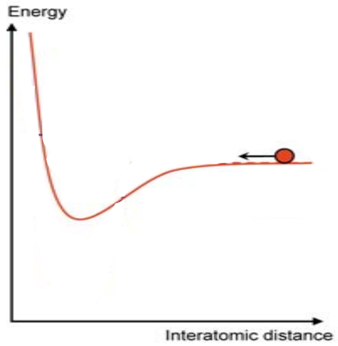
„Usual“ BEC: Gross-Pitaevskii equation



$$\Rightarrow \quad V\left(\vec{r}-\vec{r}'\right) \approx \frac{4\pi\hbar^2 a}{m}\delta(\vec{r}-\vec{r}') \equiv g\delta(\vec{r}-\vec{r}')$$

At low Temperatures the BEC physics is given by a nonlinear Schrödinger equation with local cubic nonlinearity

Gross-Pitaevskii equation

$$i\hbar\frac{\partial\Psi(r,t)}{\partial t} = \left[-\frac{\hbar^2\nabla^2}{2m} + U(r,t) + \frac{4\pi\hbar^2 aN}{m}\left|\Psi(r,t)\right|^2\right]\Psi(r,t)$$

External potential (trap)

Atom-Atom interactions

Dipolar BEC: Nonlocal nonlinearity

At low temperatures the physics of a dipolar BEC is given by a nonlocal nonlinear Schrödinger equation

Nonlocal NLSE

$$i\hbar \frac{\partial}{\partial t}\psi(\vec{r},t) = \left\{ \begin{array}{l} \dfrac{-\hbar^2}{2m}\nabla^2 + V(\vec{r},t) + g\left|\psi(\vec{r},t)\right|^2 + \\ + \int d\vec{r}\,' V_d\left(\vec{r}-\vec{r}\,'\right)\left|\psi(\vec{r}\,',t)\right|^2 \end{array} \right\} \psi(\vec{r},t)$$

Generally g(d)
(shape resonances)
[Yi & You, PRA **61**, 041604 (2000);
Ronen et al., PRA **74**, 033611 (2006)]

Close to the shape resonances the form of the pseudopotential must be in general corrected
[Wang, arXiv:0704.3868]

Dipolar BEC: Nonlocal nonlinearity

At low temperatures the physics of a dipolar BEC is given by a nonlocal nonlinear Schrödinger equation

Nonlocal NLSE

$$i\hbar \frac{\partial}{\partial t}\psi(\vec{r},t) = \left\{ \begin{aligned} &\frac{-\hbar^2}{2m}\nabla^2 + V(\vec{r},t) + g|\psi(\vec{r},t)|^2 + \\ &+ \int d\vec{r}\,' V_d(\vec{r}-\vec{r}\,')|\psi(\vec{r}\,',t)|^2 \end{aligned} \right\} \psi(\vec{r},t)$$

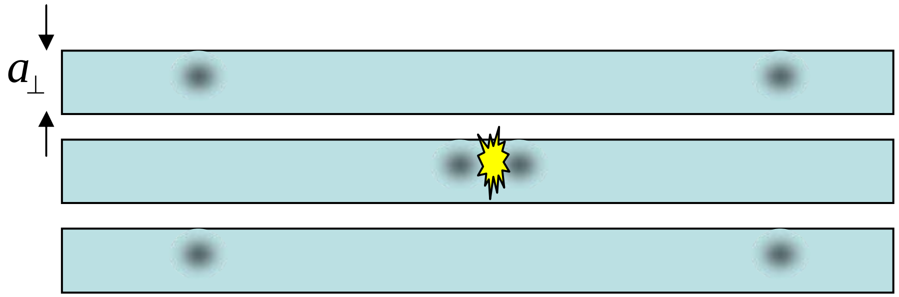
„Usual“ BEC ⟺ Kerr media

Dipolar BEC ⟺ Plasma physics [Litvak et al., Sov. J. Plasma Phys. **1**, 60 (1975)]; Nematic Liquid Crystals [Peccianti et al., Nature **432**, 733 (2004)]

1D gases: Confinement-induced resonances

How atoms interact under constrained geometries?

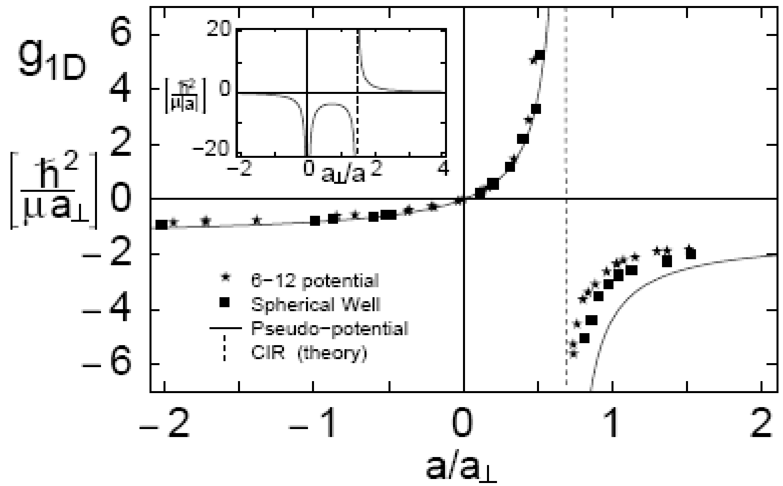
[M. Olshanii, PRL **81**, 938 (1998)]



$$\frac{-\hbar^2}{2m}\nabla^2\psi + \left[V_{trap}(\vec{r}) + V_{s-range}(\vec{r})\right]\psi = 0$$

$$\frac{-\hbar^2}{2m}\frac{d^2}{dx^2}\psi + \left[g_{1D}\delta(x)\right]\psi = 0$$

$$g_{1D} = \frac{2\hbar^2 a_{3D}}{m a_\perp^2\left(1 - \frac{C}{\sqrt{2}}\frac{a_{3D}}{a_\perp}\right)}$$



[Bergeman, Moore and Olshanii, PRL **91**, 163201 (2003)]

Confinement-induced resonances in 1D dipolar gases

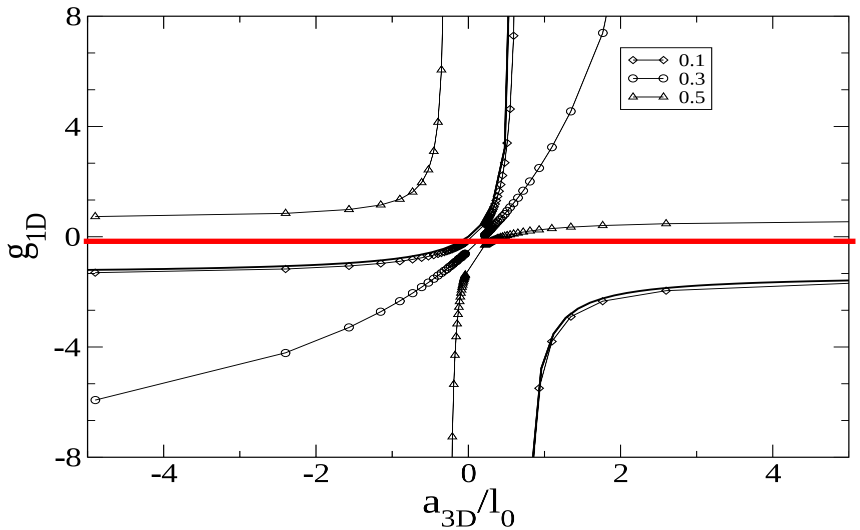
[S. Sinha and L. Santos, PRL 2007; arXiv:0705.1668]

How dipolar particles interact in 1D geometries?

$$\frac{-\hbar^2}{2m}\nabla^2\psi + \left[V_{trap}(\vec{r}) + V_{s-range}(\vec{r}) + V_{dip}(\vec{r})\right]\psi = 0$$

$$\frac{-\hbar^2}{2m}\frac{d^2}{dx^2}\psi + \left[g_{1D}\delta(x) + V_{dip}^{1D}(x)\right]\psi = 0$$

$$V_{1d}(x) = \frac{2\alpha d^2}{a_\perp^3}\left[2\left|\frac{x}{a_\perp}\right| - \sqrt{\pi}\left(1 + 2\frac{x^2}{a_\perp^2}\right)e^{x^2/a_\perp^2}\, erfc\left[\left|\frac{x}{a_\perp}\right|\right]\right]$$



Even if $a_{3D} >> d^2$ the dipole may change completely the properties of the 1D gas, since g_{1D} may change its sign !!

Confinement-induced resonances in 1D dipolar gases

[S. Sinha and L. Santos, PRL 2007; arXiv:0705.1668]

How dipolar particles interact in 1D geometries?

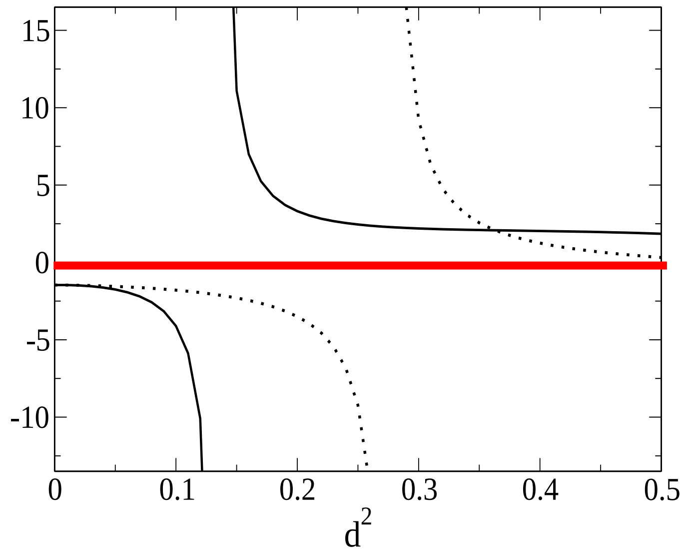
$$\frac{-\hbar^2}{2m}\nabla^2\psi + \left[V_{trap}(\vec{r}) + V_{s-range}(\vec{r}) + V_{dip}(\vec{r})\right]\psi = 0$$

$$\Downarrow$$

$$\frac{-\hbar^2}{2m}\frac{d^2}{dx^2}\psi + \left[g_{1D}\delta(x) + V^{1D}_{dip}(x)\right]\psi = 0$$

$$V_{1d}(x) = \frac{2\alpha d^2}{a_\perp^3}\left[2\left|\frac{x}{a_\perp}\right| - \sqrt{\pi}\left(1 + 2\frac{x^2}{a_\perp^2}\right)e^{x^2/a_\perp^2}erfc\left[\left|\frac{x}{a_\perp}\right|\right]\right]$$

Asymptotic value of g_{1D}



Even if $a_{3D} >> d^2$ the dipole may change completely the properties of the 1D gas, since g_{1D} may change its sign !!

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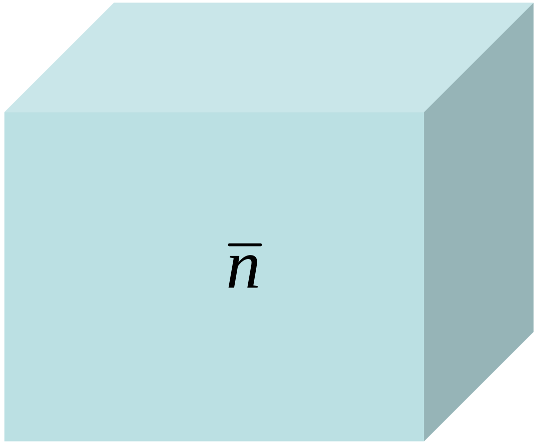
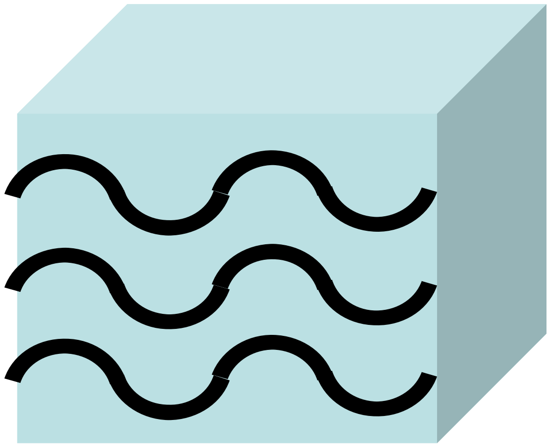
Dipolar gases. Homogeneous solution. Phonon instability

Homogeneous BEC

$$\Psi_0(\vec{r}) = \sqrt{\bar{n}}\, e^{i\mu t}$$





Homogeneous BEC + Excitations

Linearization : Bogoliubov analysis

$$\Psi(\vec{r}) = \left(\sqrt{\bar{n}} + \sum_{\vec{k}} \begin{pmatrix} u_{\vec{k}}(\vec{r})\, e^{i\vec{k}\cdot\vec{r} - i\varepsilon(\vec{k})t} \\ -v_{\vec{k}}(\vec{r})^{*}\, e^{-i\vec{k}\cdot\vec{r} + i\varepsilon(\vec{k})t} \end{pmatrix} \right) e^{i\mu t}$$

Dipolar gases. Homogeneous solution. Phonon instability

$$\varepsilon(\vec{k})^2 = E_{kin}(\vec{k})\left[E_{kin}(\vec{k}) + E_{\text{int}}(\vec{k})\right]$$

$$E_{kin}(\vec{k}) = \hbar^2 k^2 / 2m$$

$$E_{\text{int}}(\vec{k}) = 2g\left(1 + \beta\left(3\cos^2\theta_{\vec{k}} - 1\right)/2\right)$$

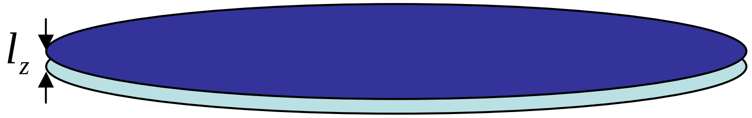
$$\beta \equiv \frac{8\pi\alpha\, d^2/3}{g} \approx \frac{\text{dipole}}{\text{short-range}}$$

If $\varepsilon(\vec{k} \to 0)^2 < 0$ ⇨ phonon instability

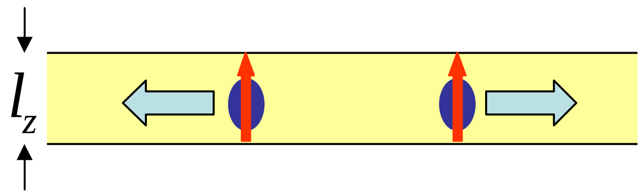
Stable phonons only if $E_{\text{int}}(\vec{k}) > 0$ ⇨ $-1 \leq \beta \leq 2$

Dipolar gases: phonon-roton spectrum

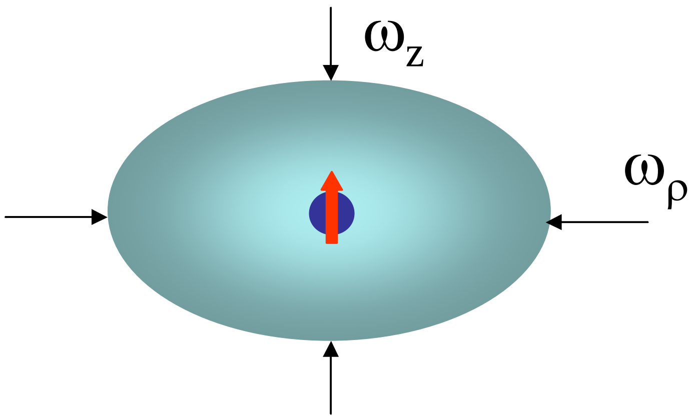
Dipoles (with β>0)
in a pancake trap



Average repulsive
dipolar interaction



Phonon-instability is geometrically avoided



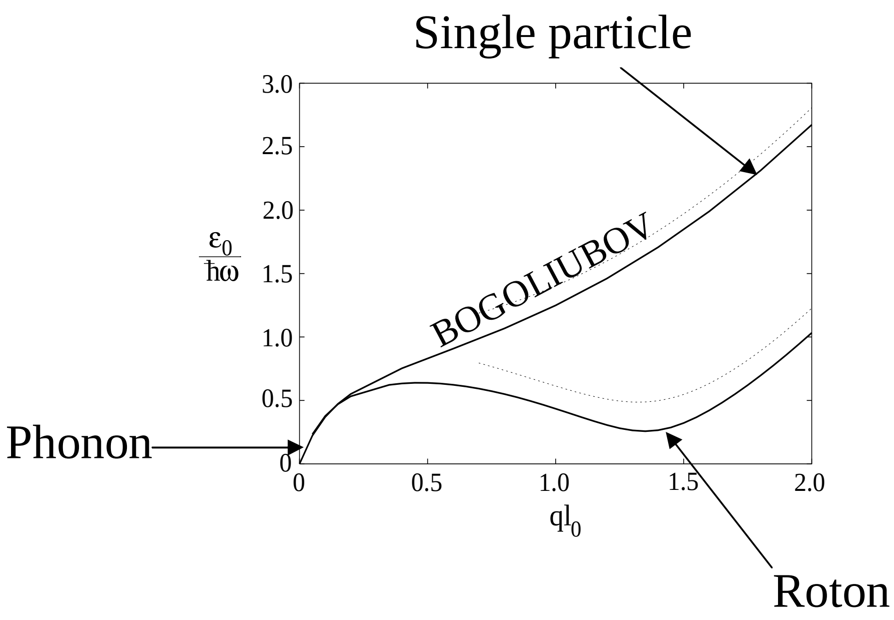
$$\sqrt{\omega_\rho / \omega_z} < 0.41$$

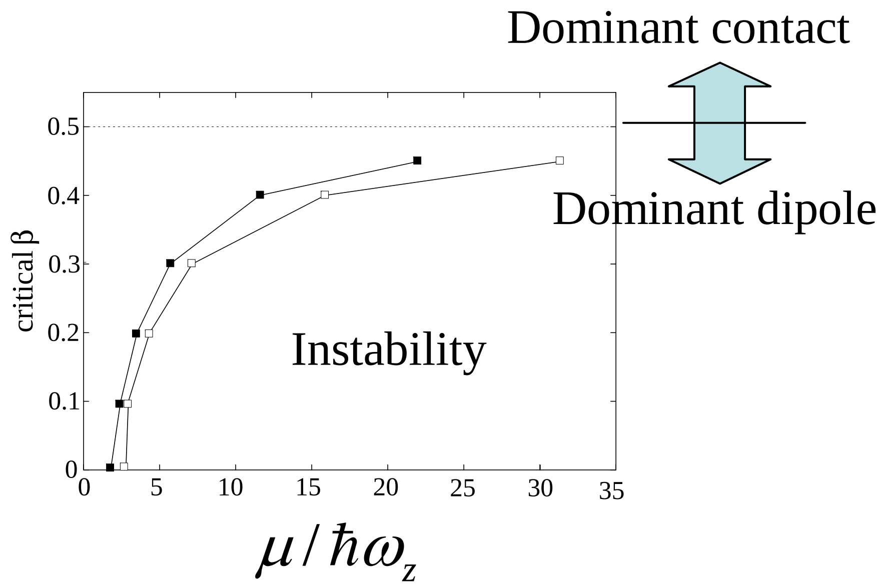
[Santos et al., PRL **85**, 1791 (2000)]

Dipolar gases: Phonon-Roton spectrum

What happens if $\sqrt{\omega_\rho / \omega_z} < 0.41$?

The dispersion law shows a roton for sufficiently large dipole-dipole interactions





The gas becomes eventually unstable when the roton touches zero

[O'Dell et al., PRL **90**, 110402 (2003); Santos et al., PRL **90**, 250403 (2003);
Ronen et al., Phys. Rev. Lett. **98**, 030406 (2007); Komineas and Cooper, Phys. Rev. A **75**, 023623 (2007)]

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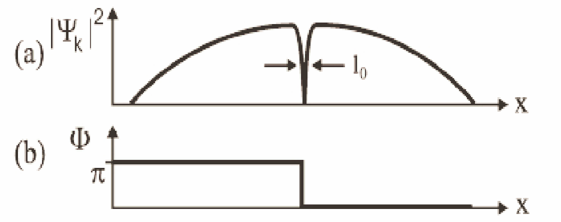
Nonlinear BEC Physics. Solitons

Gross-Pitaevskii equation

$$i\hbar \frac{\partial}{\partial t}\psi(\vec{r},t) = \left\{ \frac{-\hbar^2}{2m}\nabla^2 + V(\vec{r},t) + \frac{4\pi\hbar^2 a}{m} N\left|\psi(\vec{r},t)\right|^2 \right\}\psi(\vec{r},t)$$

Dark Solitons (a>0)

[Burger et al, PRL **83**, 5198 (1999)]
[Denschlag et al., Science **287**, 97 (2000)]

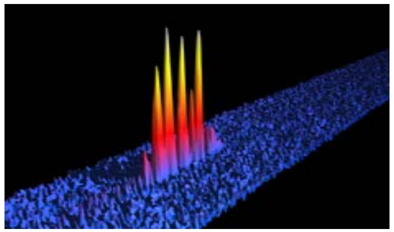


1D NLSE

[Zakharov & Shabat., JETP **34**, 62 (1972)]

Bright solitons (a<0)

[Strecker et al., Nature **417**, 150 (2002)]
[Khaykovich et al., Science **296**, 1290 (2002)]

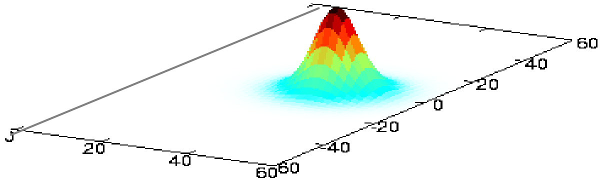


Continuous solitons become unstable in 2D and 3D

Nonlocal nonlinearity. Multidimensional solitons

[P. Pedri and L. Santos, PRL **95**, 150406 (2005)]

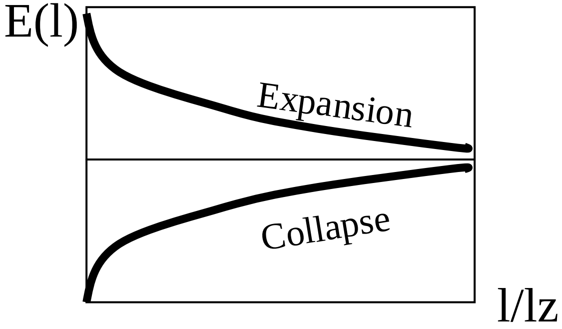
$$\psi(\vec{r}) \propto e^{-\rho^2/2l^2} e^{-z^2/2l_z^2}$$



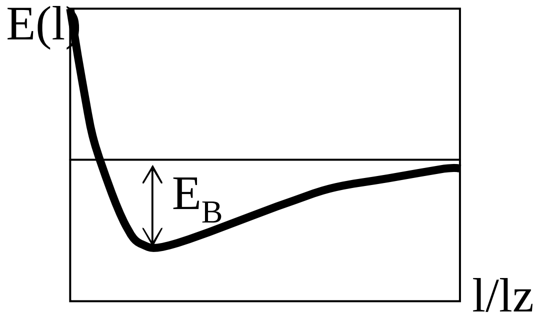
$$E(l) \propto \frac{1}{(l/l_z)^2}\left(1+\frac{g}{2(2\pi)^{3/2}}+\frac{\alpha d^2}{3\sqrt{2\pi}}\, f\left(\frac{l}{l_z}\right)\right)$$

$$f(x)=\frac{1}{x^2-1}\left[2x^2+1-\frac{3x^2\arctan\left[\sqrt{x^2-1}\right]}{\sqrt{x^2-1}}\right]$$

No dipole



Dipolar gas

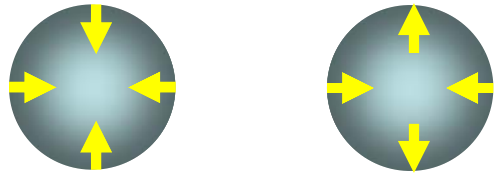


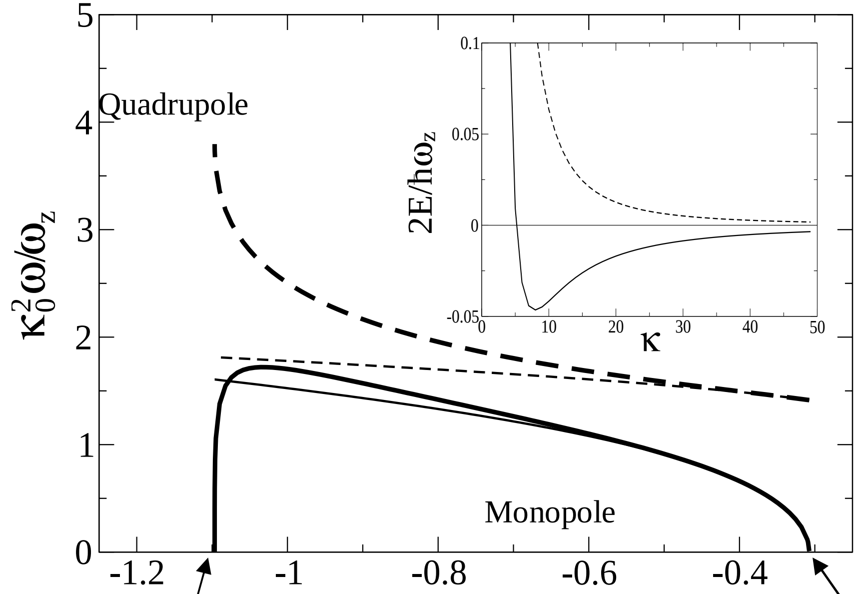
Stability condition

$$\frac{\alpha d^2}{3\sqrt{2\pi}} < 1+\frac{g}{2(2\pi)^{3/2}} < \frac{-2\alpha d^2}{3\sqrt{2\pi}}$$

Nonlocal nonlinearity. Multidimensional solitons

3D Analysis of the lowest-lying excitations





$$\gamma = \alpha d^2 / g$$

3D instability

2D instability

Crucial role of the anisotropy

Stability Window

$$|\gamma| > |\gamma_1|$$

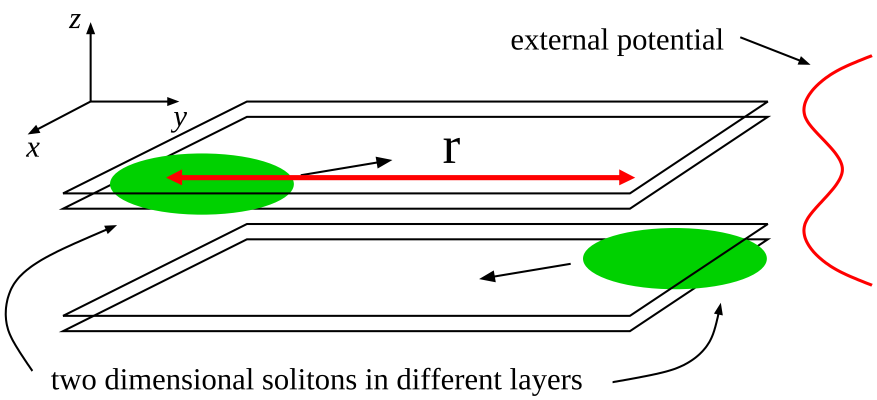
2D instability against expansion for small dipoles

$$|\gamma| < |\gamma_2|$$

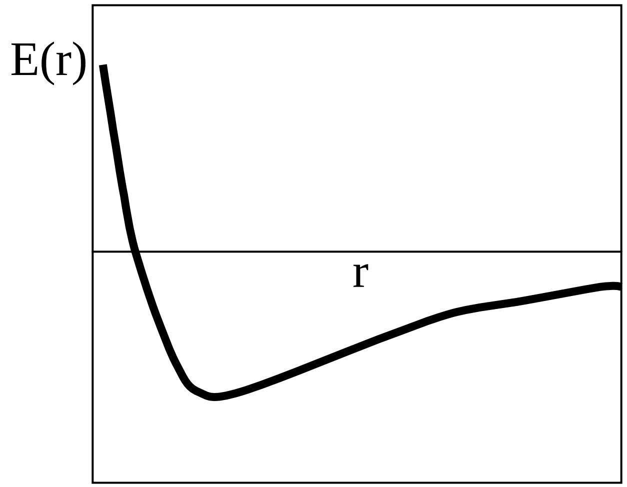
3D instability against collapse for large dipoles

Nonlocal nonlinearity. Inelastic soliton scattering

[R. Nath, P. Pedri and L. Santos, PRA **76**, 013606 (2007)]



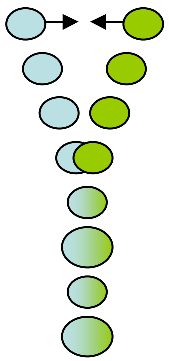
The dipole-dipole interaction induces interlayer effects between fully disconnected layers

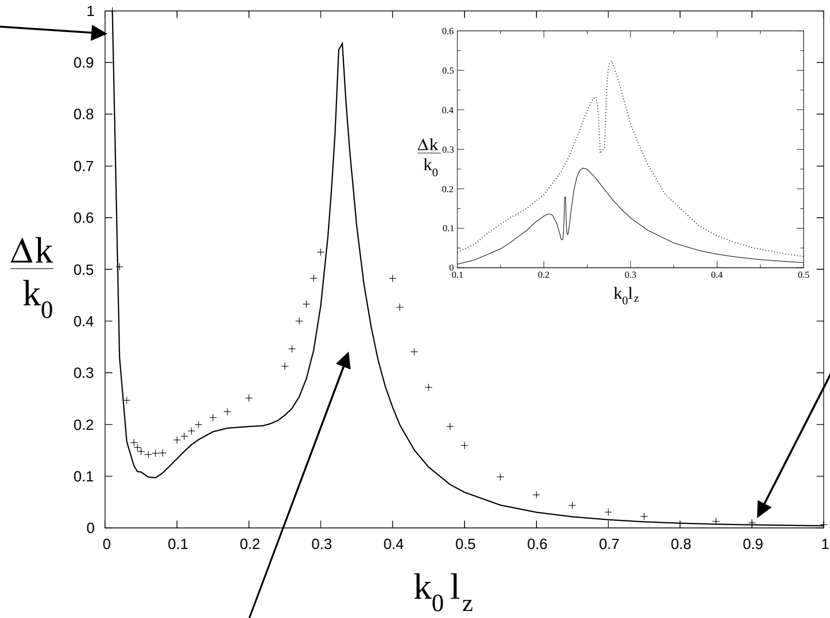


Purely dipolar soliton-soliton interlayer molecular potential

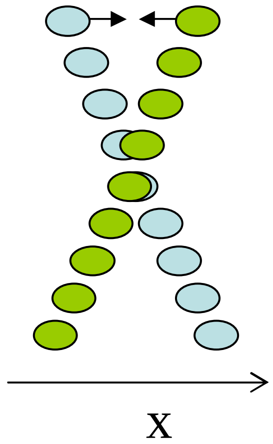
Nonlocal nonlinearity. 1D scattering

Fusion

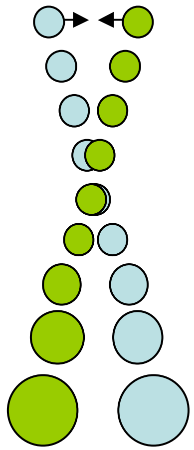




Ellastic



Inelastic resonance

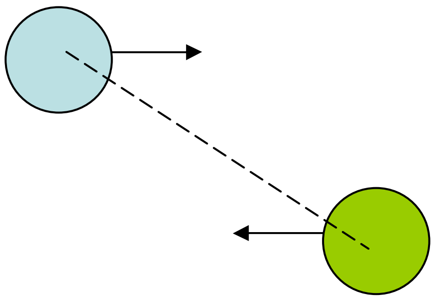


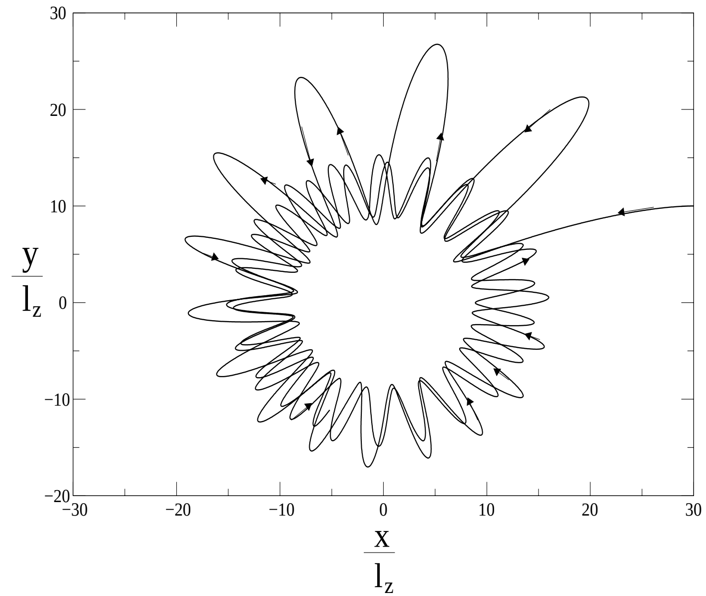
★ Also for 1D dipolar solitons

Nonlocal nonlinearity. 2D scattering

2D Scattering: Spiraling solitons

[Mitchell et al., Opt. Comm. **85**, 59 (1991);
Shih et al., PRL **78**, 2551 (2000)]





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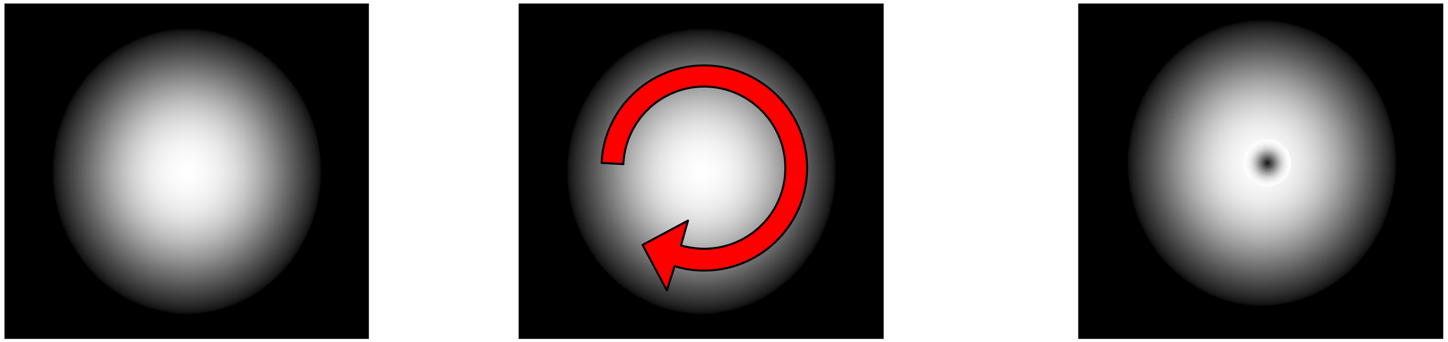
Vortices and vortex lines

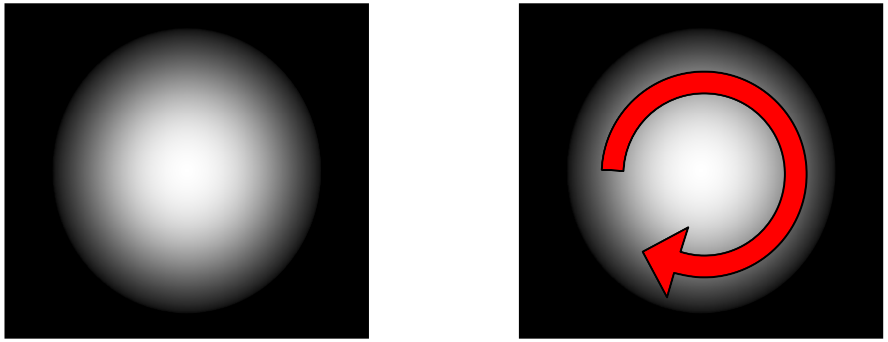
Quantized vortices

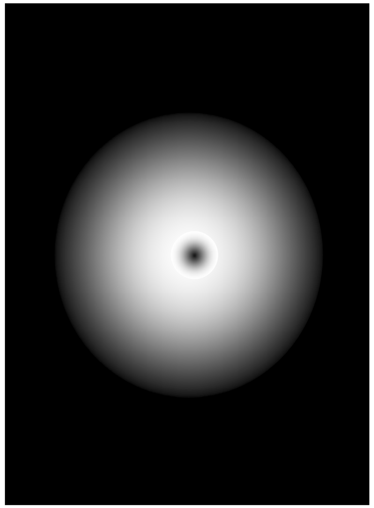
[Onsager 1949; Feynman 1955]



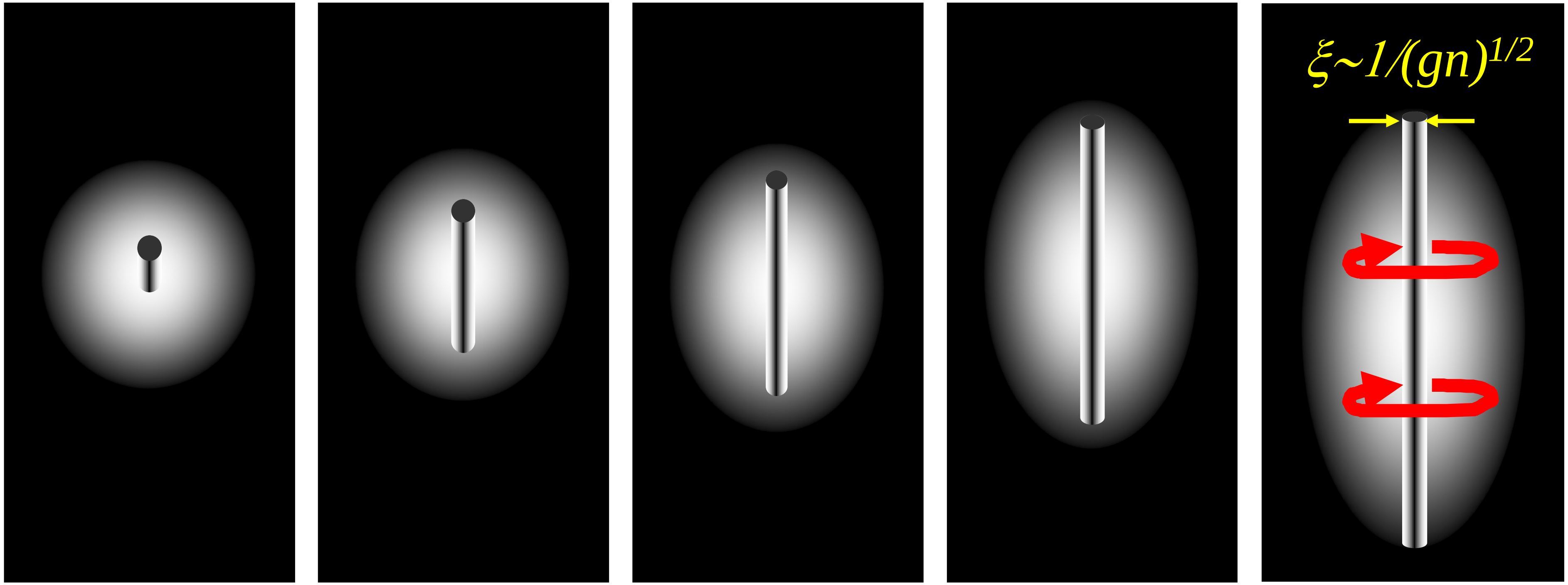
[Matthews et al, PRL **83**, 2498 (1999);
Madison et al., PRL **84**, 806 (2000);
Raman et al., PRL **87**, 210402 (2001)]

Vortices and vortex lines





Vortex lines



Vortices and vortex lines

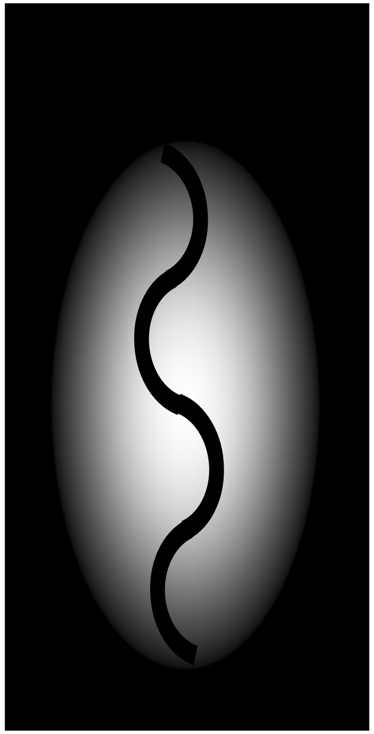
Vortex lines can have transverse vibration modes like a string

Kelvin modes

[Pitaevskii, JETP **13**, 451 (1961)]

$$E(k) = -k^2 \ln k\xi$$

[V. Bretin et al, PRL **90**, 100403 (2003)]



Vortices in dipolar gases

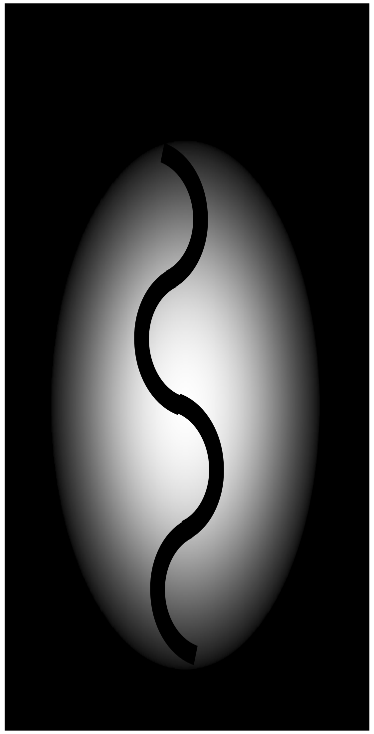
[M. Klawunn, R. Nath, P. Pedri and L. Santos, arXiv:0707.0441]

Vortices and vortex lattices in dipolar gases:

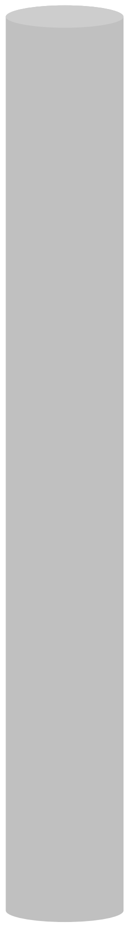
[N.R. Cooper, E.H. Rezayi, and S.H. Simon, PRL **95**, 200402 (2005); Zhang and Zhai, Phys. Rev. Lett. 95,200403 (2005); Yi and Pu, PRA 73, 061602 (2006); O'Dell and Eberlein, PRA **75**, 013604 (2007); Komineas and Cooper, Phys. Rev. A **75**, 023623 (2007)]

What is special with vortex lines in dipolar condensates ??

How are the Kelvin modes in dipolar BEC ??

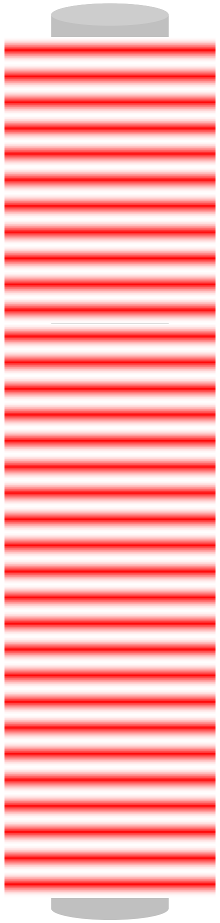


Vortex lines in dipolar gases: additional optical lattice



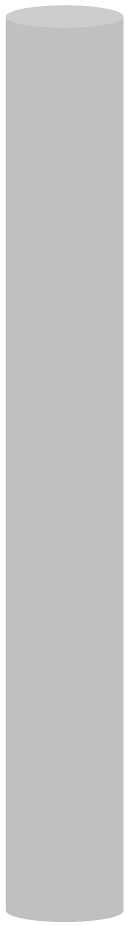
$$i\hbar \frac{\partial}{\partial t}\Psi = \left\{ \begin{aligned} & -\frac{\hbar^2 \nabla^2}{2m} + g\left|\Psi(\vec{r})\right|^2 \\ & + \int d\vec{r}\,'\left|\Psi(\vec{r}\,')\right|^2 V_d\left(\vec{r} - \vec{r}\,'\right) \end{aligned} \right\} \Psi(\vec{r})$$

Vortex lines in dipolar gases: additional optical lattice



$$i\hbar\frac{\partial}{\partial t}\Psi=\left\{\begin{array}{l}-\dfrac{\hbar^2\nabla^2}{2m}+V_{lat}(z)+g\left|\Psi(\vec{r})\right|^2\\+\int d\vec{r}'\left|\Psi(\vec{r}')\right|^2 V_d\left(\vec{r}-\vec{r}'\right)\end{array}\right\}\Psi(\vec{r})$$

Vortex lines in dipolar gases: additional optical lattice

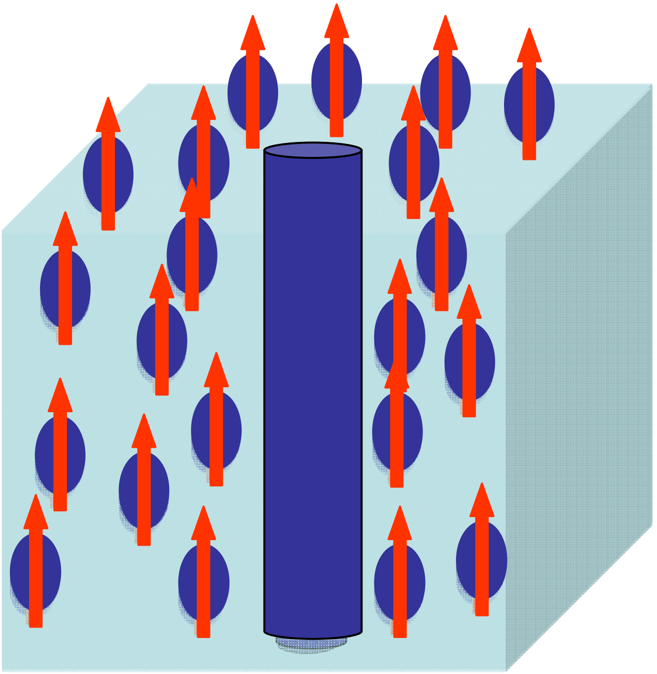


$$i\hbar \frac{\partial}{\partial t}\Psi = \left\{ \begin{array}{l} -\frac{\hbar^2\nabla_\perp^2}{2m} - \frac{\hbar^2\nabla_z^2}{2m^*} + g\left|\Psi(\vec{r})\right|^2 \\ + \int d\vec{r}' \left|\Psi(\vec{r}')\right|^2 V_d\left(\vec{r} - \vec{r}'\right) \end{array} \right\} \Psi(\vec{r})$$

Vortex cores in dipolar BEC: 3D vs. 2D

$$\Psi_0(\vec{r},t) = \psi_0(\rho) e^{i\phi} e^{-i\mu t/\hbar}$$

$$\mu\psi_0(\rho) = \left\{ \frac{-\hbar^2}{2m}\nabla_\rho{}^2 + \frac{\hbar^2}{2m\rho^2} + g\left(1-\frac{\beta}{2}\right)|\psi_0(\rho)|^2 \right\}\psi_0(\rho)$$



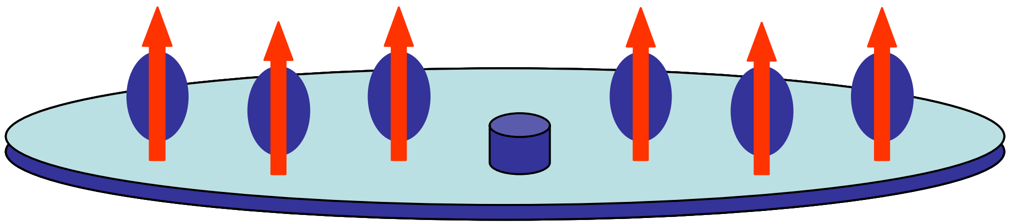
$$g_{eff} = g\left(1-\frac{\beta}{2}\right)$$

$$\xi_{eff} \propto \frac{1}{\sqrt{g_{eff}\, n}}$$

Vortex cores in dipolar BEC: 3D vs. 2D

$$\Psi_0(\vec{r},t) = \psi_0(\rho) e^{i\phi} e^{-i\mu t/\hbar} \Phi(z)$$

$$\mu\psi_0(\rho) = \left\{ \frac{-\hbar^2}{2m} \nabla_\rho^2 + \frac{\hbar^2}{2m\rho^2} + g(1+\beta)|\psi_0(\rho)|^2 \right\} \psi_0(\rho)$$



$$g_{eff} = g(1+\beta)$$

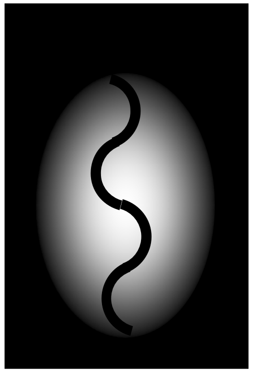
$$\xi_{eff} \propto 1/\sqrt{g_{eff} n}$$

The dependence of the vortex core on the dipole strength depends on the dimensionality

→

The vortex core depends on the trap geometry

Kelvin modes: Bogoliubov analysis



$$\Psi_0(\vec{r},t) = \left[\psi_0(\rho) + \sum_k \left(u_k(\rho)e^{-iE_k t/\hbar}e^{iqz}e^{i\phi} - v_k^*(\rho)e^{iE_k t/\hbar}e^{-iqz}e^{-i\phi}\right)\right]e^{i\phi}e^{-i\mu t/\hbar}$$

Bogoliubov-de Gennes equations

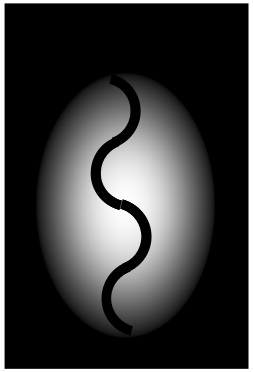
$$E_q u_q(\rho) = \left[-\frac{\hbar^2}{2m}\nabla_\rho^2 + \frac{2\hbar^2}{m\rho^2} + \frac{\hbar^2 q^2}{2m^*} + g_{eff}\psi_0(\rho)^2 - \mu\right]u_q(\rho)$$

$$- g_{eff}\psi_0(\rho)^2 v_q(\rho)$$

$$+ 4\pi q^2 g_d \int_0^\infty d\rho' \rho' \psi_0(\rho')\psi_0(\rho)\left[u_q(\rho') - v_q(\rho')\right]F(q,\rho,\rho')$$

$$F(q,\rho,\rho') = \begin{cases} I_1(q\rho')K_1(q\rho) & \rho' < \rho \\ I_1(q\rho)K_1(q\rho') & \rho' > \rho \end{cases}$$

Kelvin modes: Bogoliubov analysis



$$\Psi_0(\vec{r},t) = \left[\psi_0(\rho) + \sum_k \left(u_k(\rho)e^{-iE_k t/\hbar}e^{iqz}e^{i\phi} - v_k^*(\rho)e^{iE_k t/\hbar}e^{-iqz}e^{-i\phi}\right)\right]e^{i\phi}e^{-i\mu t/\hbar}$$

Bogoliubov-de Gennes equations

$$E_q u_q(\rho) = \left[-\frac{\hbar^2}{2m}\nabla_\rho^2 + \frac{2\hbar^2}{m\rho^2} + \frac{\hbar^2 q^2}{2m^*} + 2g_{eff}\psi_0(\rho)^2 - \mu\right]u_q(\rho)$$
$$- g_{eff}\psi_0(\rho)^2 v_q(\rho)$$

Usual BdG Eqs. for Kelvin modes

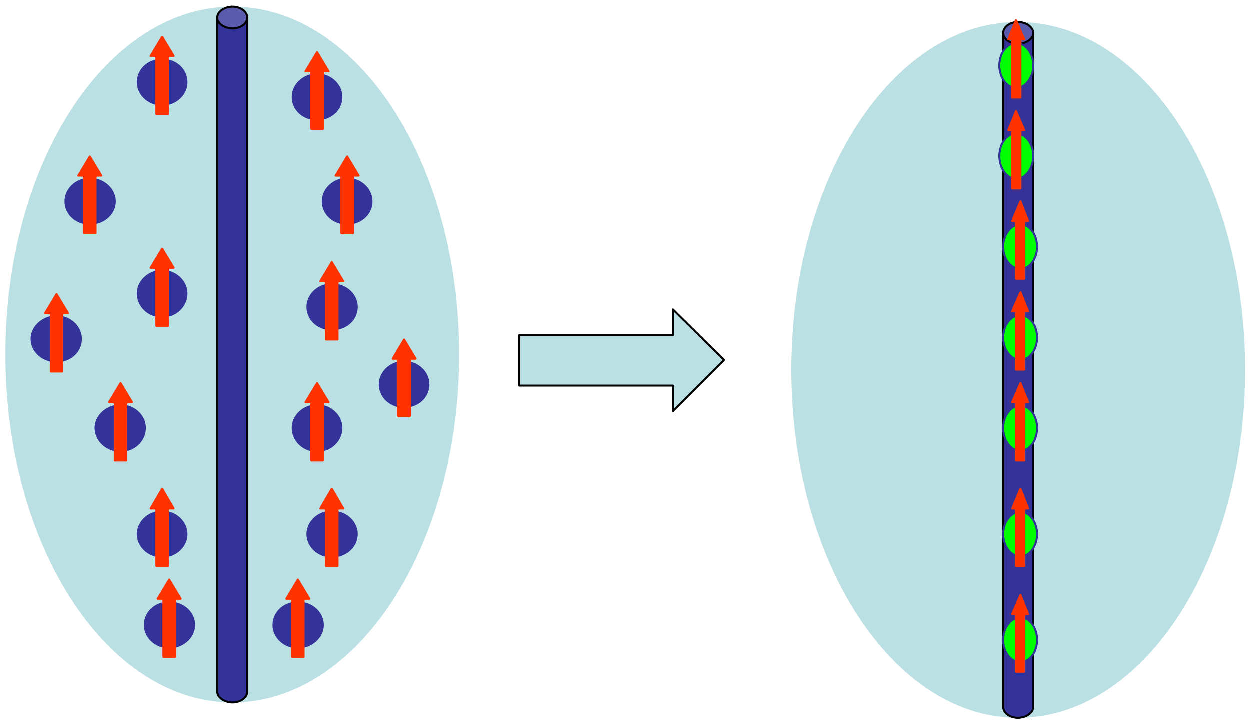
[Pitaevskii, JETP **13**, 451 (1961)]

$$+ 4\pi q^2 g_d \int_0^\infty d\rho'\rho'\psi_0(\rho')\psi_0(\rho)\left[u_q(\rho') - v_q(\rho')\right]F(q,\rho,\rho')$$

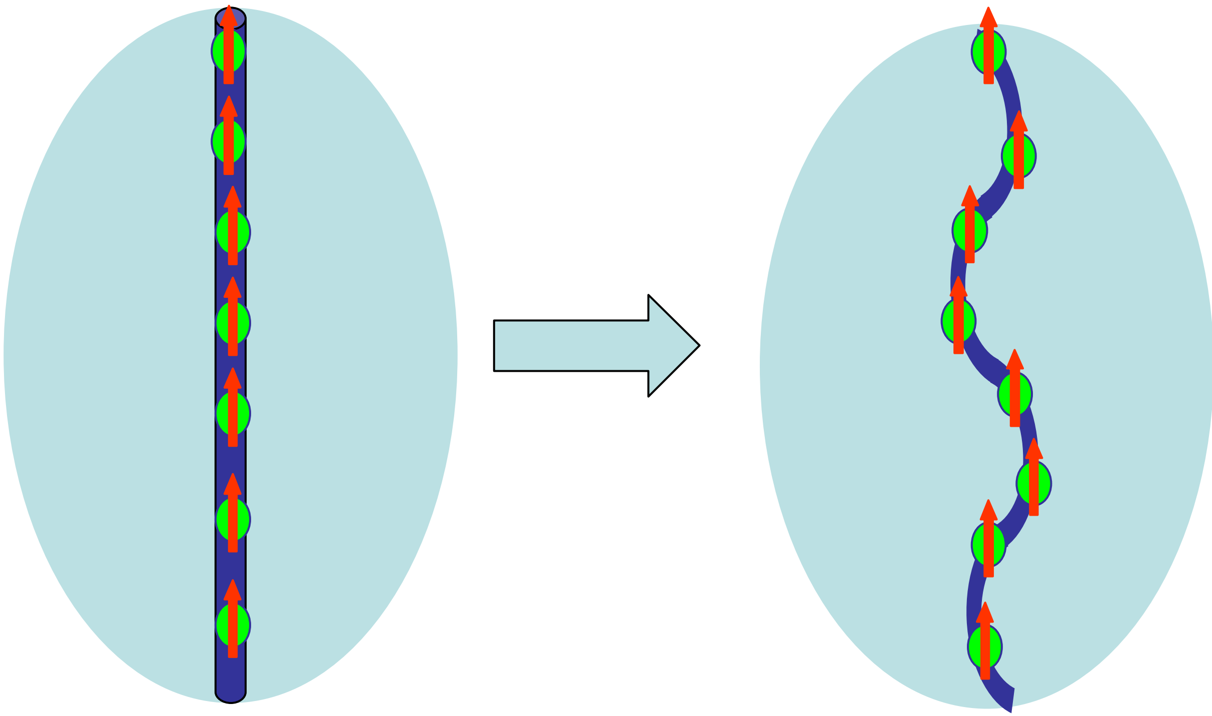
Extra DDI-induced effect

$$F(q,\rho,\rho') = \begin{cases} I_1(q\rho')K_1(q\rho) & \rho' < \rho \\ I_1(q\rho)K_1(q\rho') & \rho' > \rho \end{cases}$$

Kelvin modes in dipolar gases

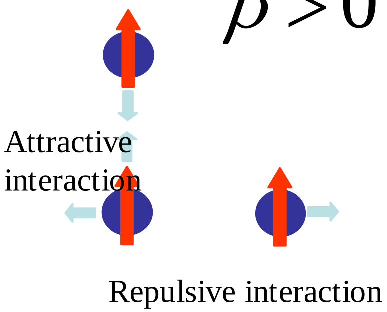


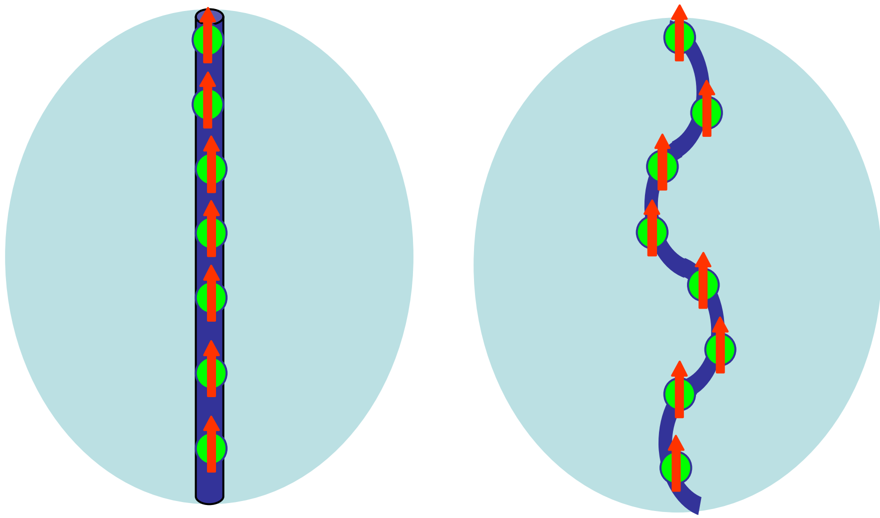
Kelvin modes in dipolar gases



Vortex lines: Dipole-induced „rigidity“

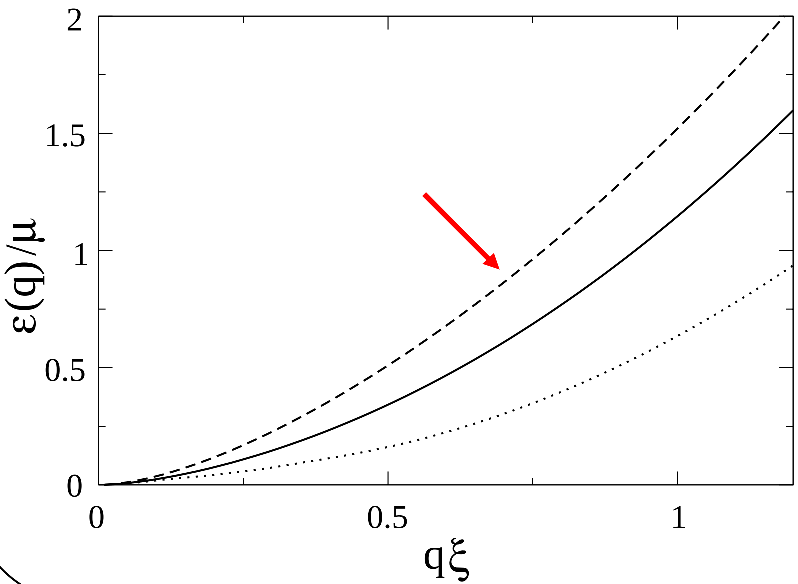
$\beta > 0$





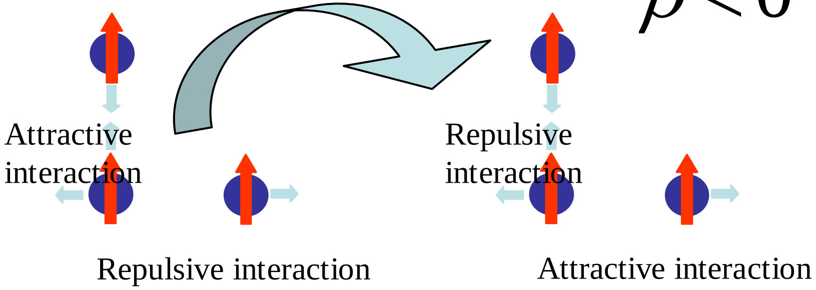
The bending increases the DDI

V_d ↑

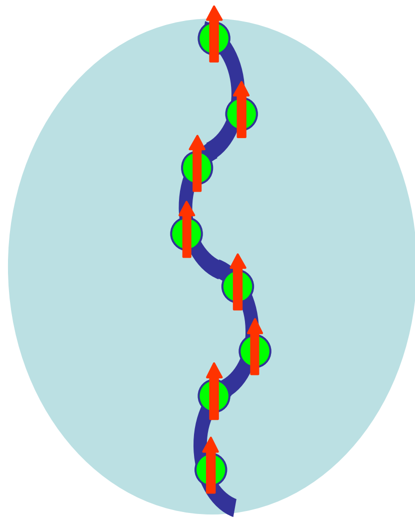


The dipole-dipole interaction makes the vortex line more rigid

Vortex lines: Dipole-induced „softness“

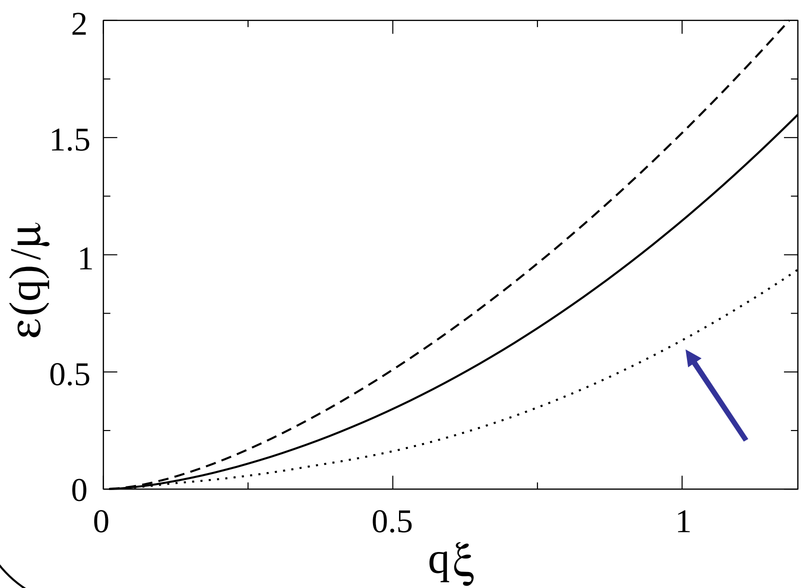


$\beta < 0$



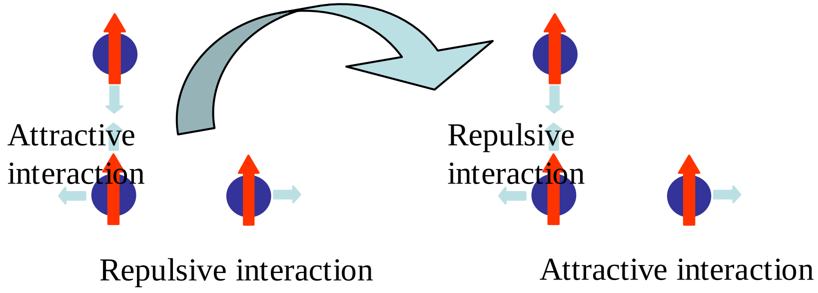
The bending decreases the DDI

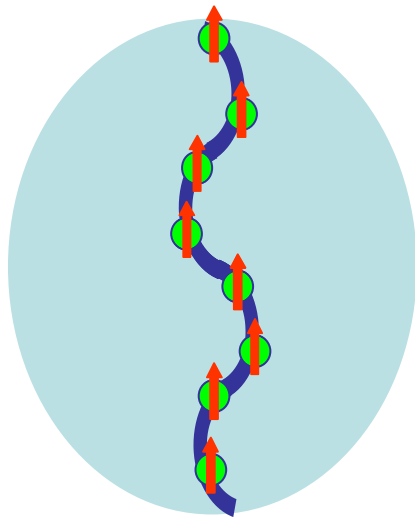
$V_d \downarrow$



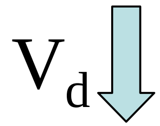
The dipole-dipole interaction makes the vortex line less rigid

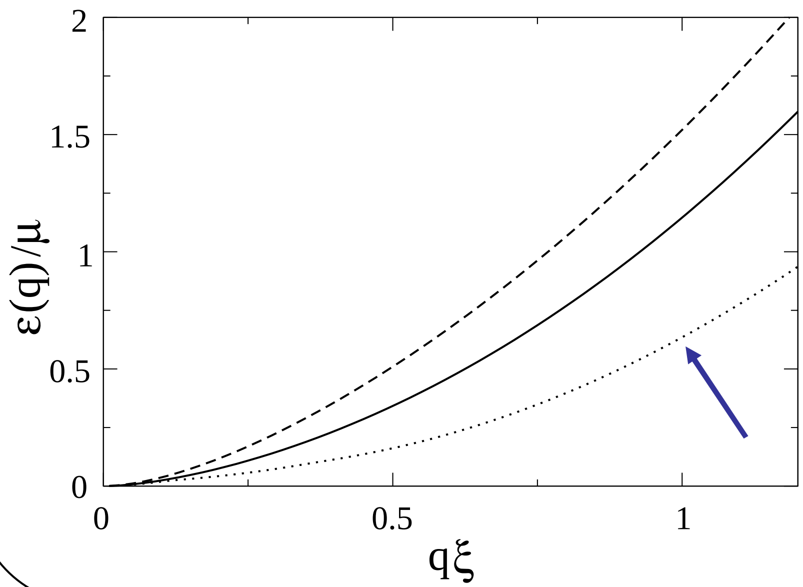
Vortex lines: Dipole-induced „softness“





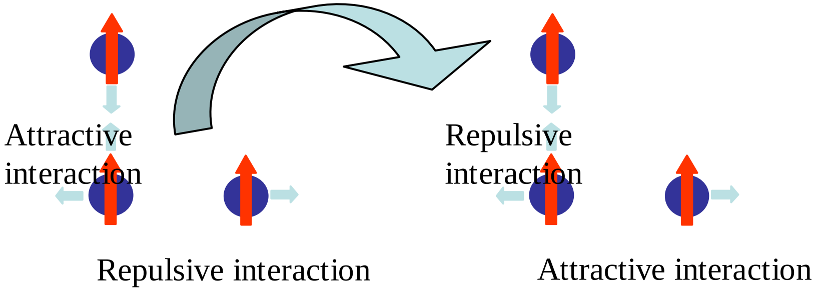
The bending decreases the DDI

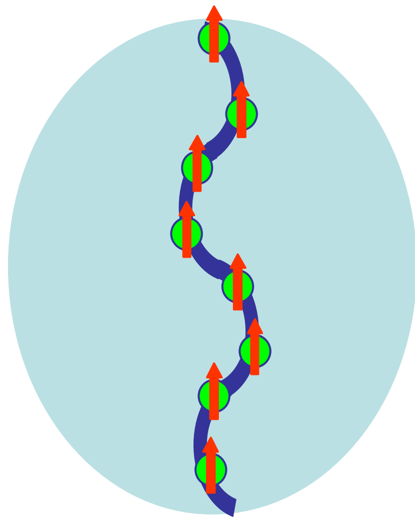




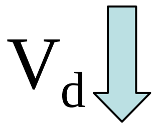
Eventually a sufficiently large dipole could destabilize the straight vortex line but without an additional lattice this only occurs for $\beta<-1$ (phonon instability)

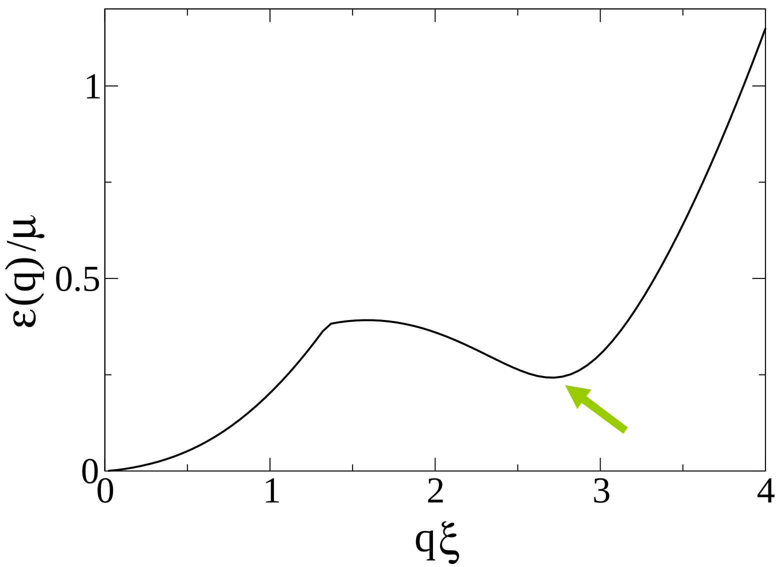
Vortex lines: Kelvon-roton spectrum





The bending decreases the DDI

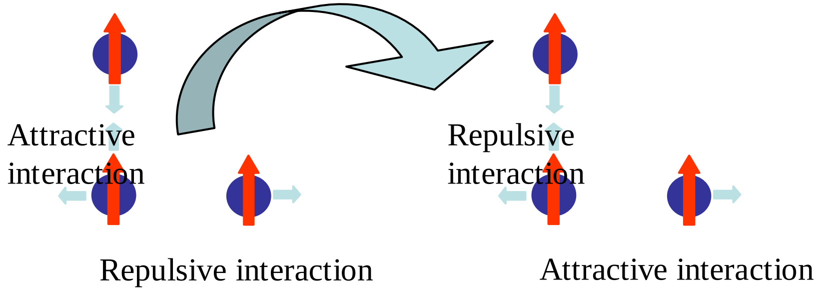


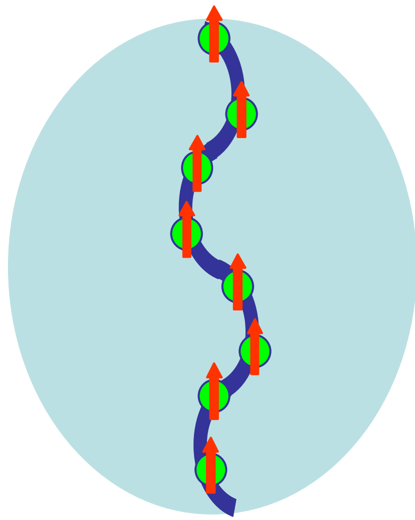


For sufficiently large m*>m one obtains a kelvon-roton spectrum

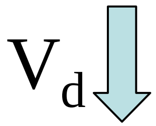
The roton can eventually become unstable

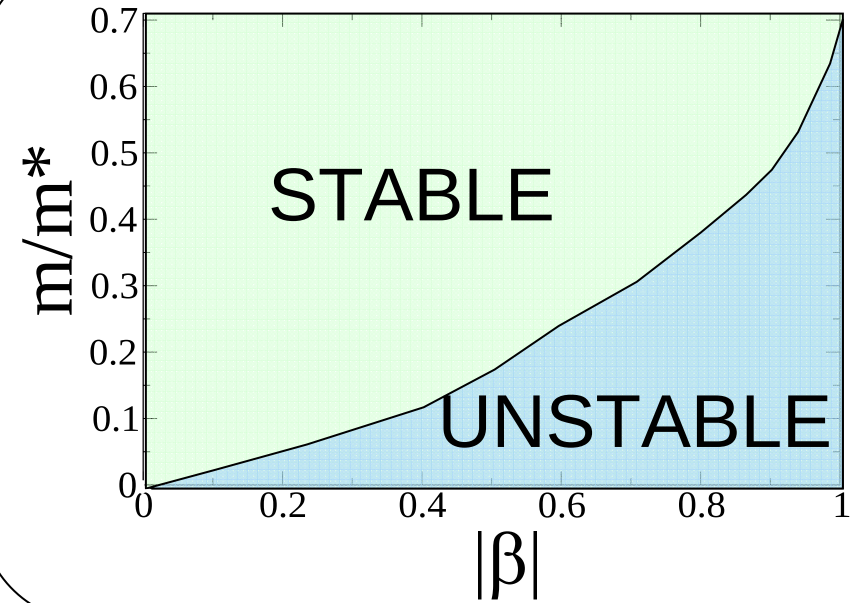
Vortex lines: Kelvon-roton instability





The bending decreases the DDI





For sufficiently large m*>m one obtains a kelvon-roton spectrum

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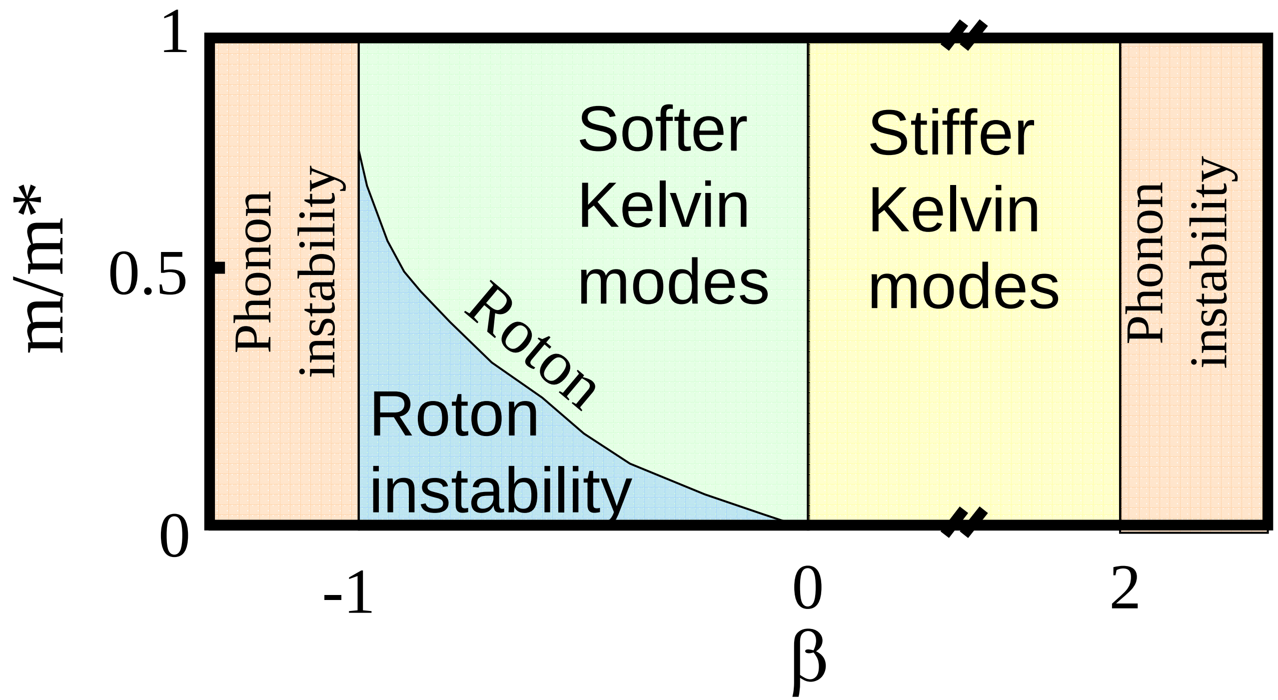
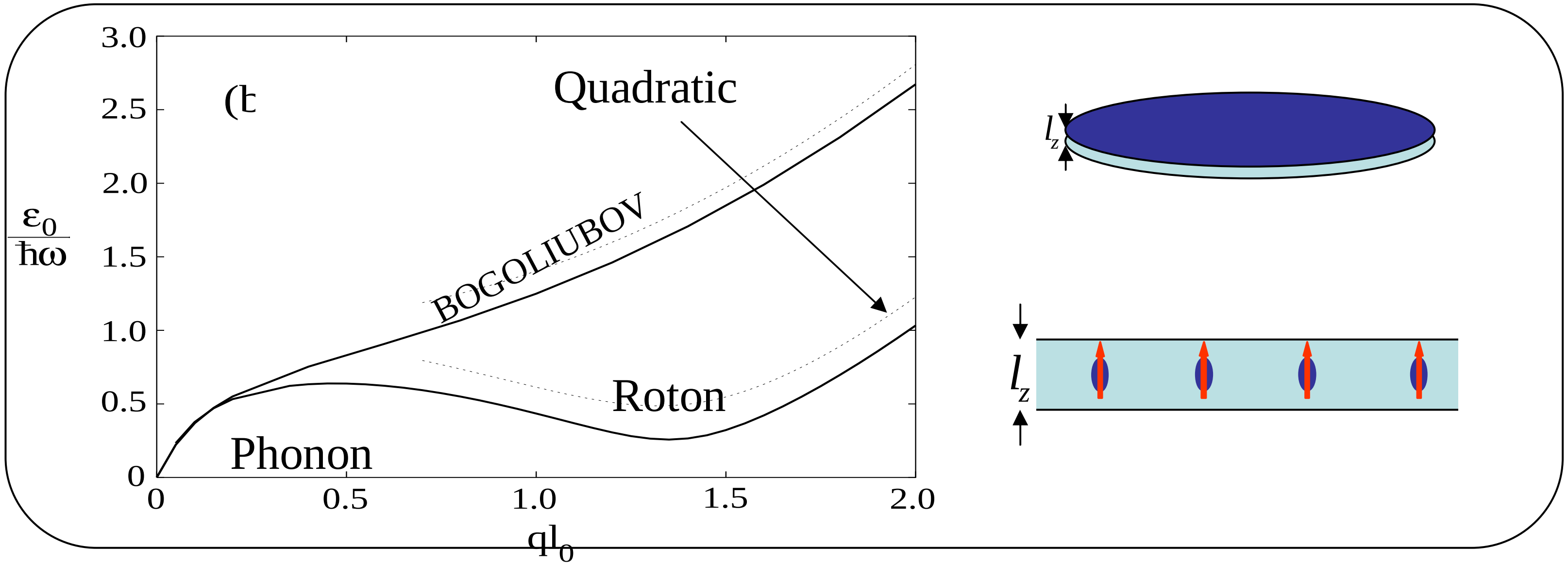
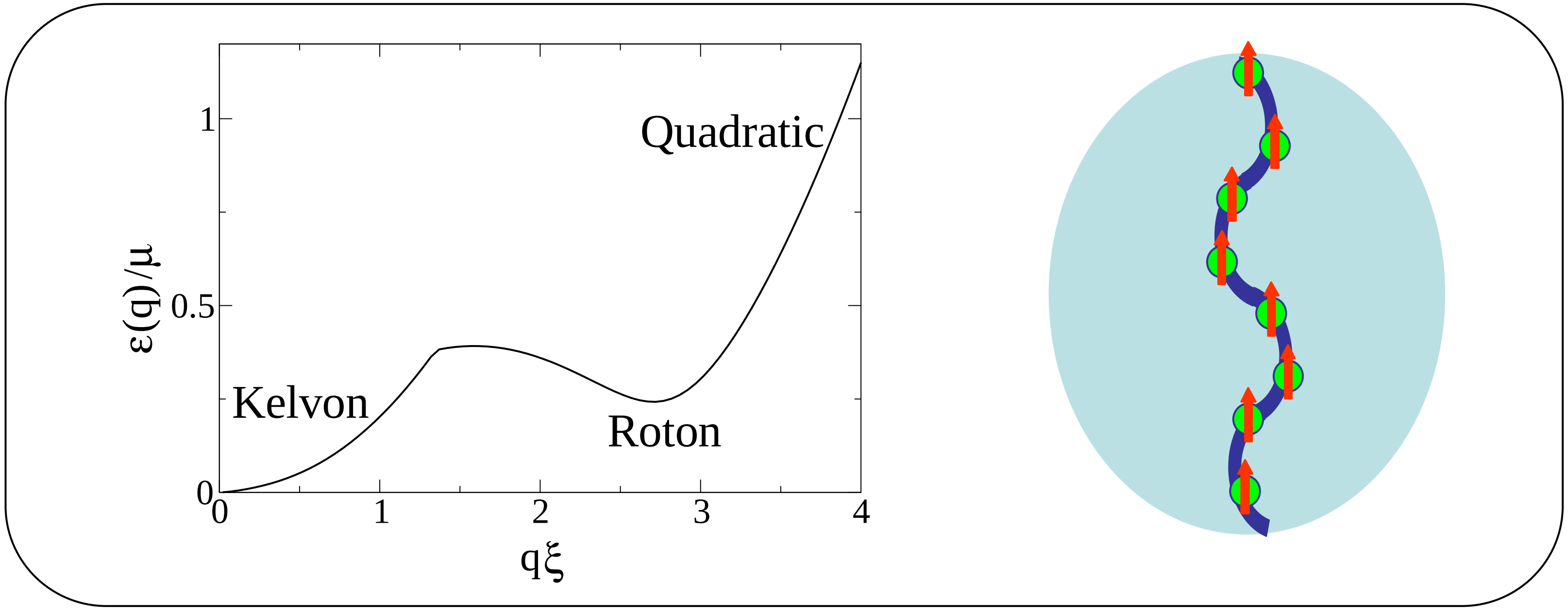
Vortex lines: Kelvon-roton instability



Phonon-Roton vs Kelvon-Roton





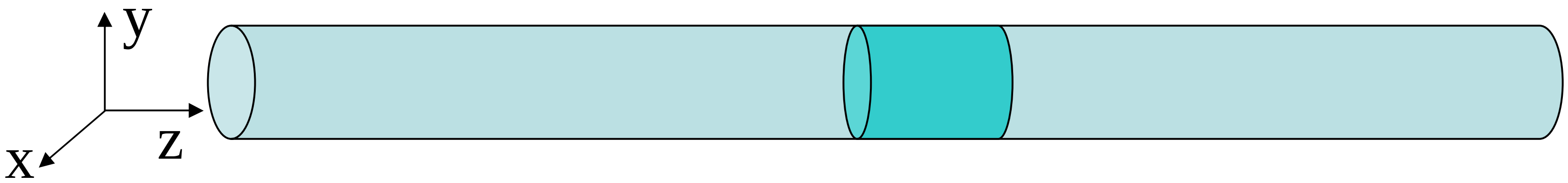
Overview

- Introduction to dipolar gases
- Nonlocal NLSE
- Stability
- Multidimensional bright solitons
- Vortex-lines in dipolar BEC
- Stable dark nodal planes

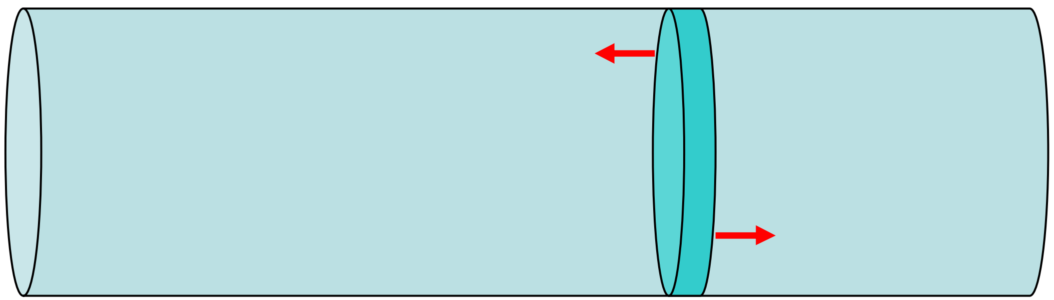
3D Dark solitons

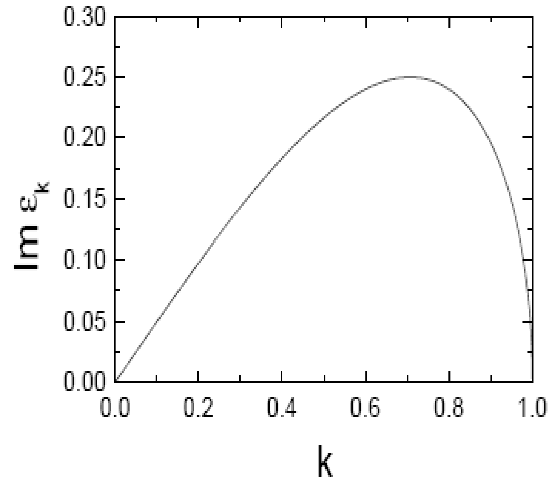
Stable dark solitons : transversal length < healing length

[Muryshev et al. , Phys.Rev. A **60**, R2665 (1999)]



Instability against long-wavelength transversal excitations

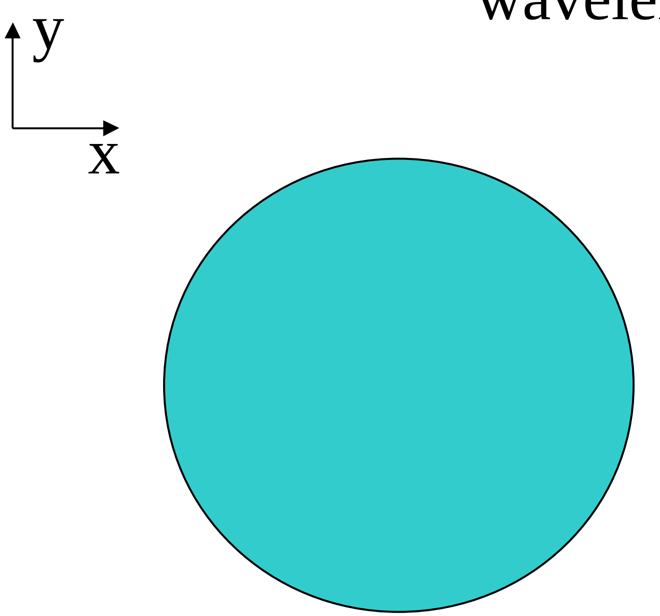




3D Dark solitons in dipolar gases

[R. Nath, P.Pedri and L. Santos, in preparation]

Dipolar interactions can prevent the long-wavelength instability of nodal planes



$$i\hbar\frac{\partial}{\partial t}\Psi = \left\{ \begin{array}{l} -\dfrac{\hbar^2\nabla_z^2}{2m} - \dfrac{\hbar^2\nabla_\perp^2}{2m} + g\left|\Psi(\vec{r})\right|^2 \\ + \int d\vec{r}' \left|\Psi(\vec{r}')\right|^2 V_d\left(\vec{r}-\vec{r}'\right) \end{array} \right\} \Psi(\vec{r})$$

3D Dark solitons in dipolar gases

[R. Nath, P.Pedri and L. Santos, in preparation]

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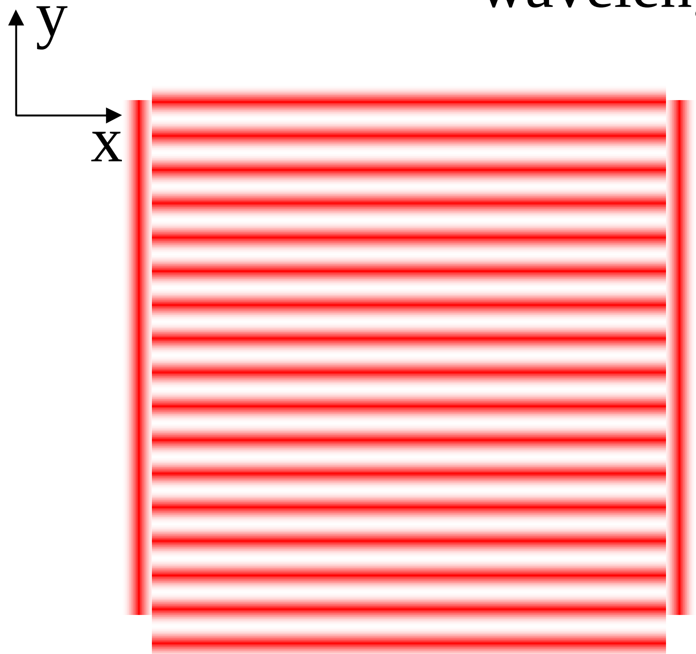
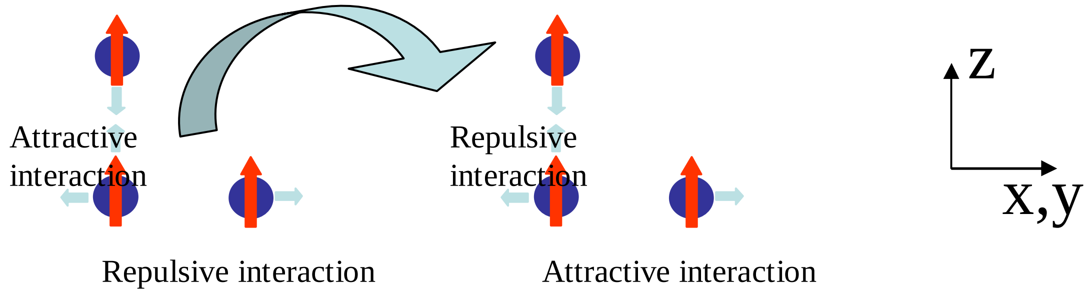


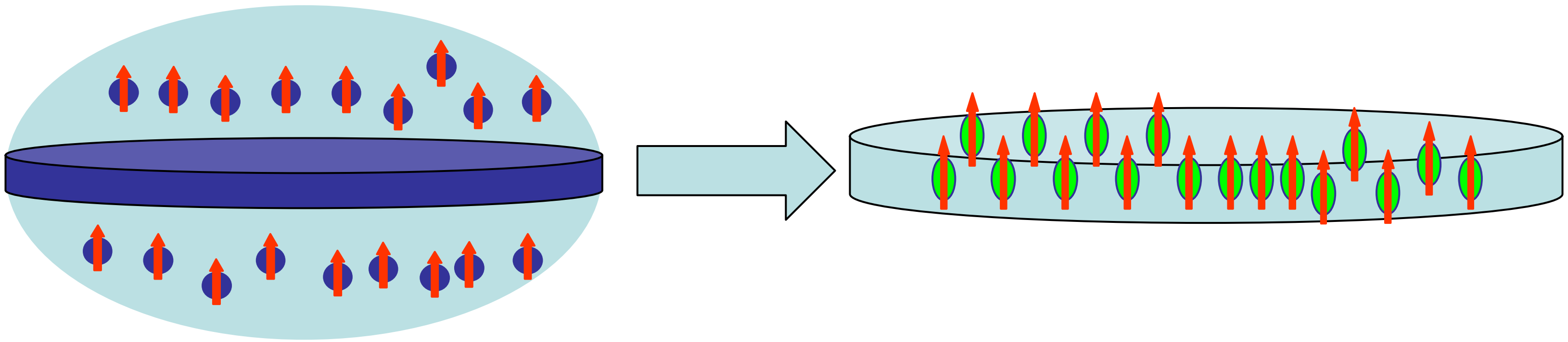
$$i\hbar\frac{\partial}{\partial t}\Psi = \left\{ -\frac{\hbar^2\nabla_z^2}{2m} - \frac{\hbar^2\nabla_\perp^2}{2m^*} + g\left|\Psi(\vec{r})\right|^2 + \int d\vec{r}\,'\left|\Psi(\vec{r}\,')\right|^2 V_d\left(\vec{r}-\vec{r}\,'\right) \right\}\Psi(\vec{r})$$

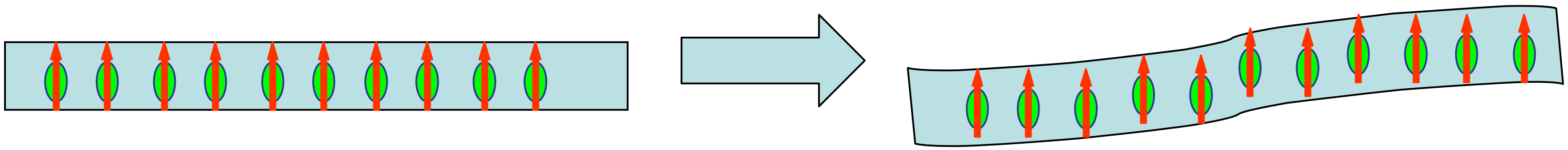


3D Dark solitons in dipolar gases

[R. Nath, P.Pedri and L. Santos, in preparation]

Dipolar interactions can prevent the long-wavelength instability of nodal planes



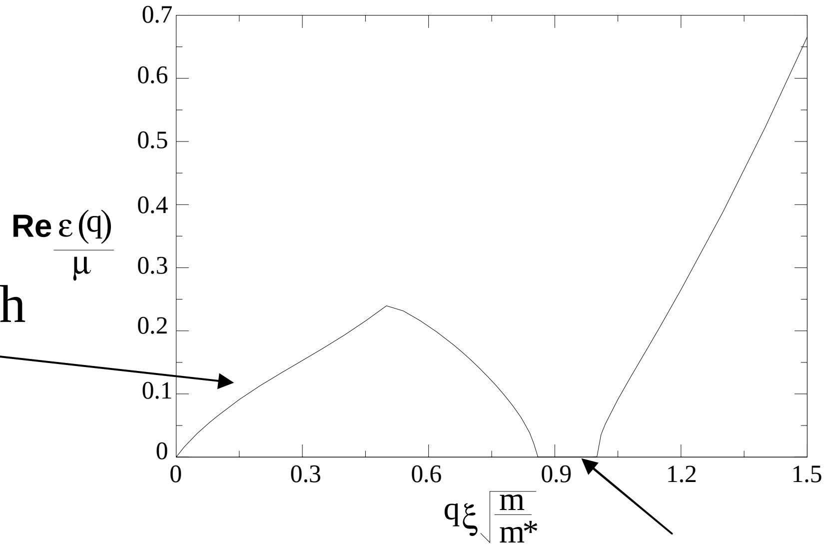


Transversal excitations of the nodal plane increase the dipolar energy

3D Dark solitons in dipolar gases

[R. Nath, P.Pedri and L. Santos, in preparation]

Dipolar interactions can prevent the long-wavelength instability of nodal planes



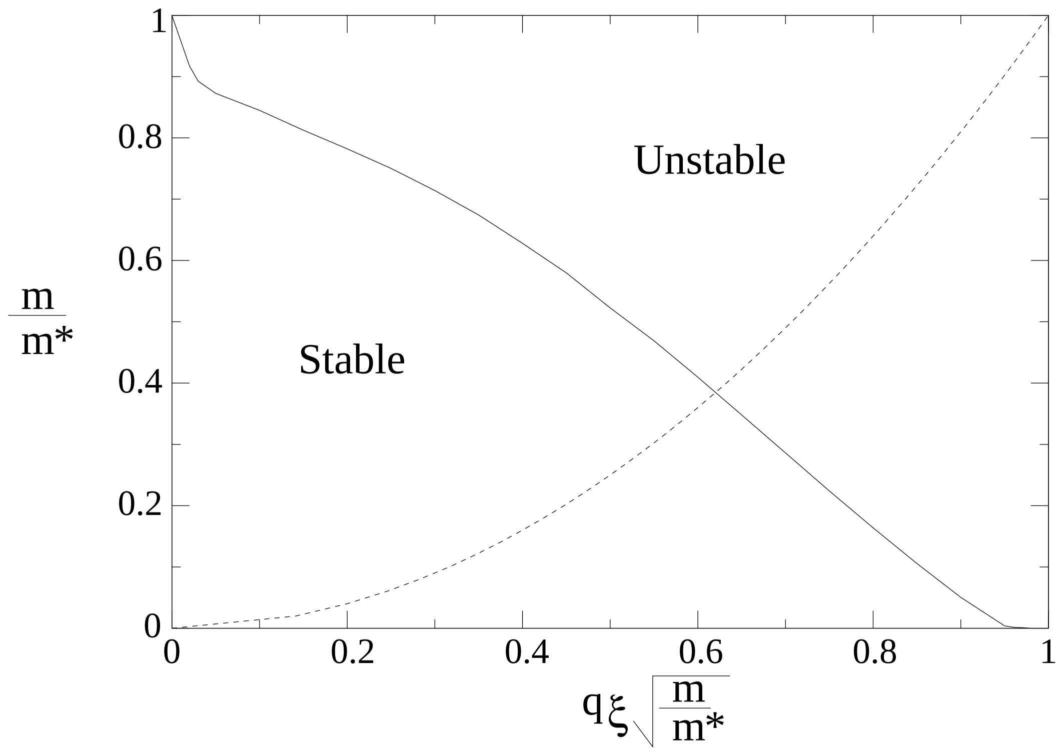
Long-wavelength stability

Instability for large momenta (actually prevented by the optical lattice itself)

3D Dark solitons in dipolar gases

[R. Nath, P.Pedri and L. Santos, in preparation]

Dipolar interactions can prevent the long-wavelength instability of nodal planes



3D Dark solitons in dipolar gases

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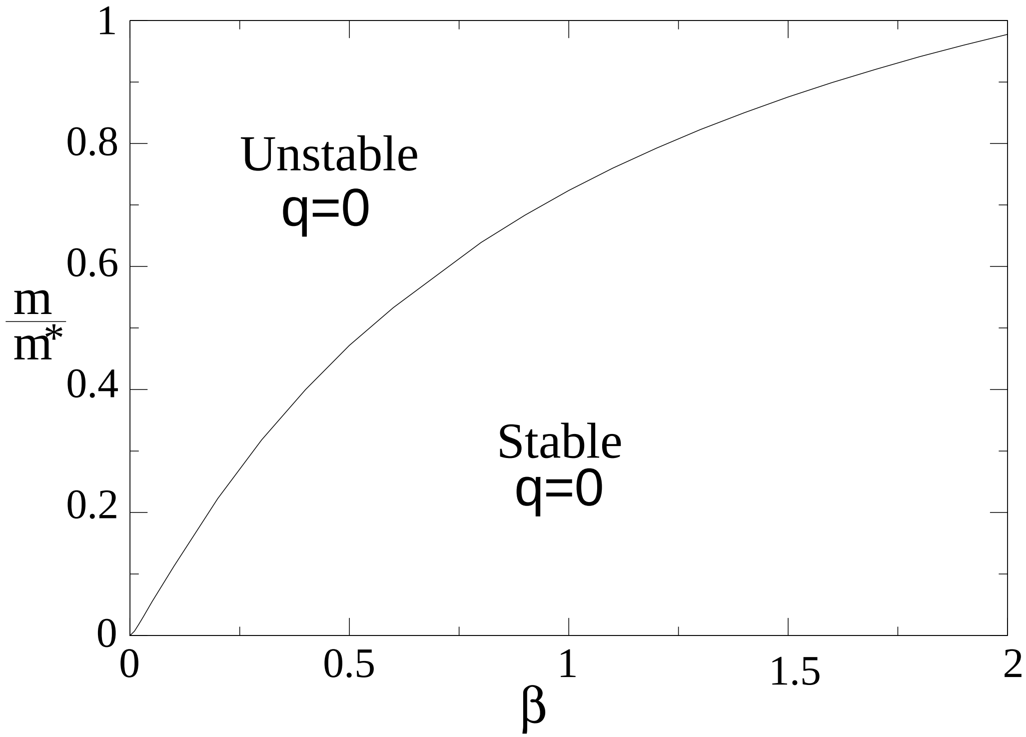
Dipolar interactions can prevent the long-wavelength instability of nodal planes



Overview

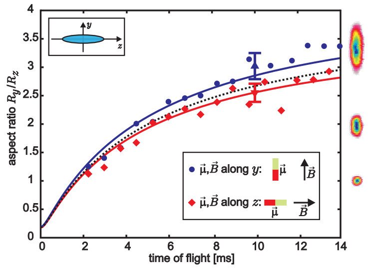
- 1D Dipolar gases: modified CIR
- Stable inelastic 2D bright solitons
- Unstable transverse excitations of straight vortex-lines
- Stable dark nodal planes

Dipolar gases: Rich new physics

Expansion dynamics

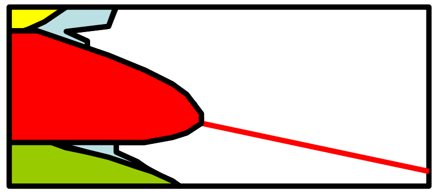
[Stühler et al., PRL **95**, 150406 (2005);
Giovanazzi et al., PRA **74**, 013621 (2006);
T. Lahaye et al., Nature 448, 672 (2007).]

See lecture of Th. Lahaye



Quantum phases in lattices

[Góral et al., PRL **88**, 170406 (2002); Wang et al, PRL **97**, 180413 (2006); Wang, cond-mat/0611394; Dalla Torre et al, PRL **97**, 260401 (2006); Argüelles and Santos, PRA **75**, 053606 (2007); S. Yi et al., PRL **98**, 260405 (2007); Menotti et al., Phys. Rev. Lett. **98**, 235301 (2007)]



Einstein-de Haas effect

[Kawaguchi et al., PRL **96**, 080405 (2006);
Santos and Pfau, PRL **96**, 190404 (2006) ;
Gawryluk et al., cond-mat/0609061;
Santos et al., PRA **75**, 053606 (2007)]

See lecture of Y. Kawaguchi

Fermionic dipolar gases

[Baranov et al., PRA **66**, 013606 (2002);
Baranov et al., PRL **92**, 250403 (2004)]

Strongly-correlated systems

[Baranov et al., PRL **94**, 070404 (2005); Rezayi et al., PRL **95**, 160404 (2005);]

Quantum information

[Brennen et al., PRL **82**, 1060 (1999); Jaksch et al., PRL **85**, 2208 (2000); DeMille., PRL **88**, 067901 (2002)]

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