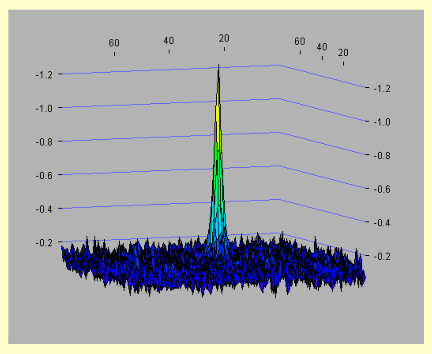

Anisotropy of the excitation spectrum in a dipolar Bose-Einstein Condensate

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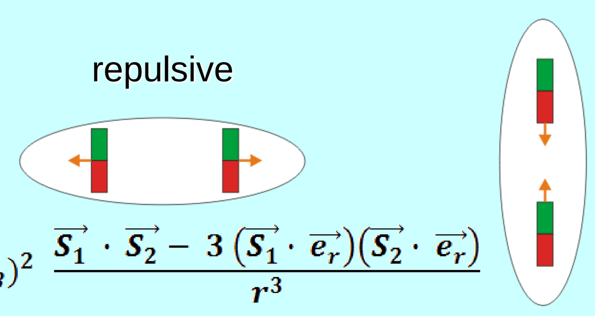
Scientific goals : Production and study of dipolar quantum gases made of chromium atoms (spin S=3 and Landé factor g=2). Generation of strongly correlated systems. Qunatum magnetism

Interactions between particles dictate quantum gas properties. Van der Waals interactions are short-range and isotropic at ultralow temperatures while dipolar interactions are anisotropic and long-range. Many properties of dipolar quantum gases are predicted to differ greatly from those in « ordinary » isotropic quantum gases.



$$V_{dd} = \frac{\mu_0}{4\pi}(g_J\mu_B)^2 \frac{\vec{S_1}\cdot\vec{S_2} - 3(\vec{S_1}\cdot\vec{e_r})(\vec{S_2}\cdot\vec{e_r})}{r^3}$$

In Chromium–BECs, the atom magnetic dipole moment is 6 μ_B
Magnetic Dipole-Dipole Interaction is 36 times bigger than in alkali-BECs.
Cr-BECs are created in m=-3 inside an optical trap

Ratio contact to dipolar interactions

$$\varepsilon_{dd} = \frac{\mu_0 \mu_m^2 m}{12\pi\hbar^2 a}.$$

$\varepsilon_{dd} = 0.16$ for chromium thus ***both*** play a role in the BEC dynamics and there is *no collapse*

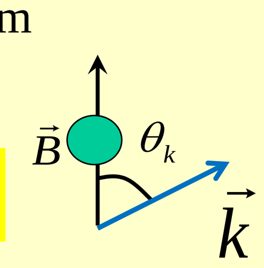
Excitation spectrum of a BEC

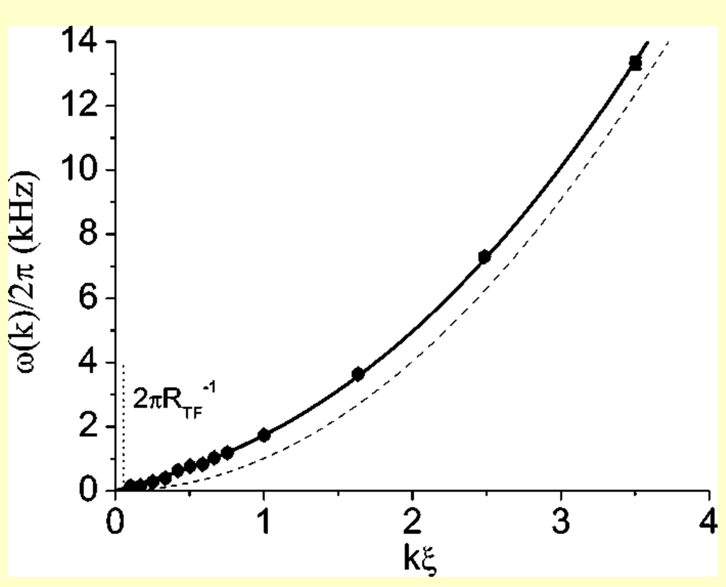
With contact interactions only:

$$\varepsilon_k = \sqrt{E_k(E_k + 2n_0 g_c)}$$ where $g_c = 4\pi\hbar^2 a/m$

With dipolar interactions (DDI) :

$$\varepsilon_k = \sqrt{E_k\left(E_k + 2n_0 g_c\left(1+\varepsilon_{dd}\left(3\cos^2\theta_k - 1\right)\right)\right)}$$

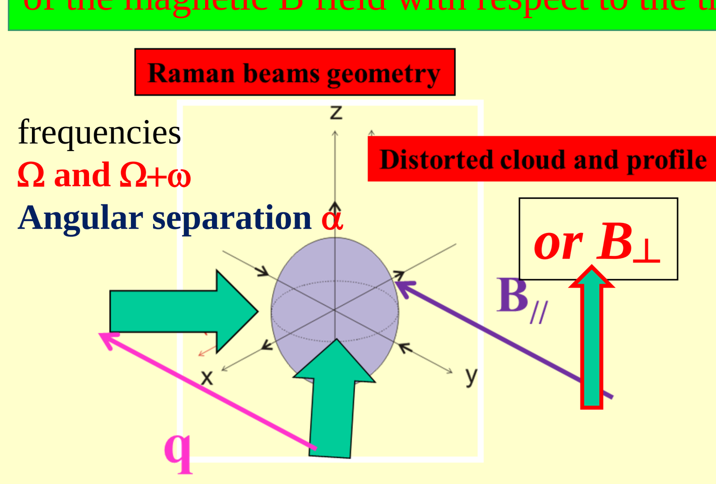


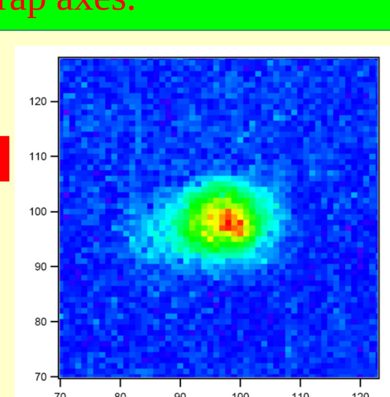


In the phonon range, the spectrum is linear with the sound velocity as slope with DDIs the sound velocity changes by 20% when flipping the direction of B with respect to k

$$c_{//}/c_{\perp} = \sqrt{\frac{1+2\varepsilon_{dd}}{1-\varepsilon_{dd}}} \approx 1.2$$

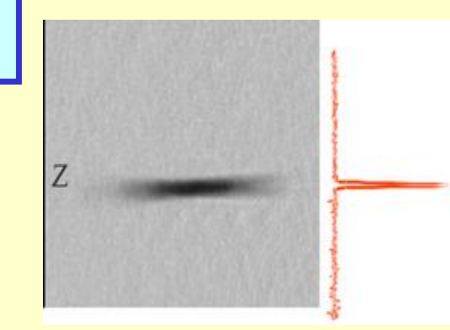
Raman Bragg spectroscopy
We shine to phase-locked detuned laser beams onto the BEC the trap.
The angle between the beams sets the excitation wavevector.
We switch off the trap, let the cloud expand and take an absorption image after TOF.
From the analysis we get the excited fraction as a function of the detuning.
We plot it to get the excitation central frequency and lineshape.
The whole procedure is undertaken for two orthogonal orientations of the magnetic B field with respect to the trap axes.

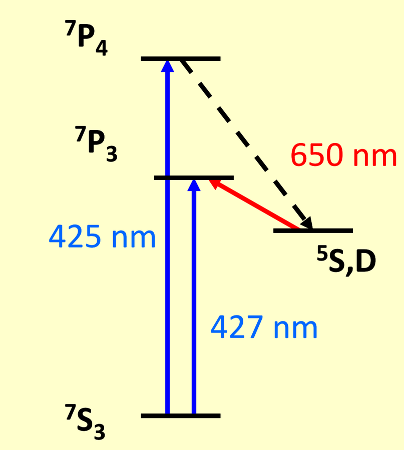


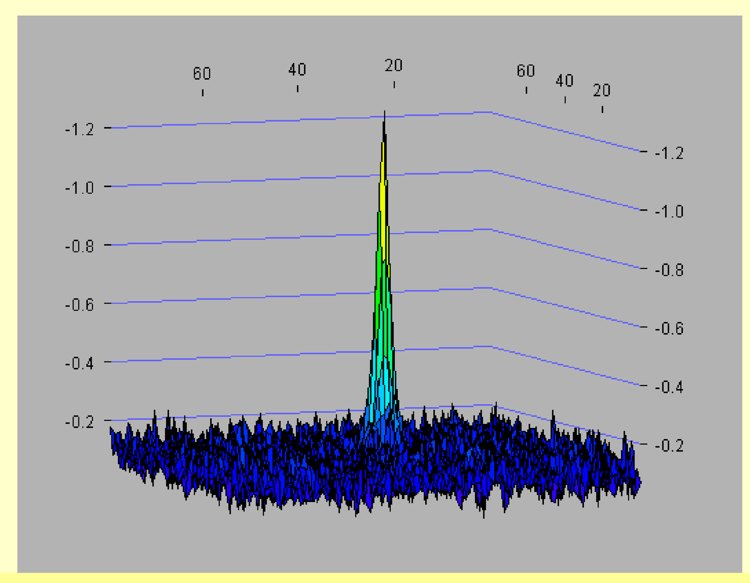


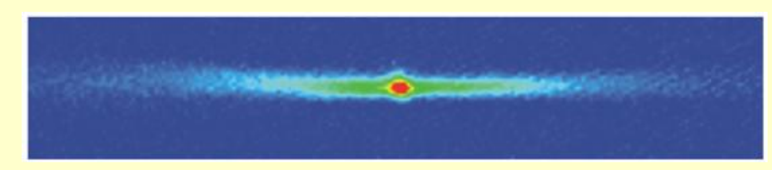
All-optical Bose-Einstein Condensation of Chromium

To produce a Cr-BEC, we use the following cycling procedure.
First, we load a large number of metastable atoms into a linear IR **optical trap** superimposed on the Cr-MOT.
Both MOT and oven are switched off and atoms are pumped back into the ground state.
The atoms are optically pumped into the lowest-energy Zeeman substate.
A further vertical IR trapping beam is superimposed to the linear trap forming a "dimple".
Finally, we lower the trap depth from 35W to 500 mW within 10s (evaporative cooling).









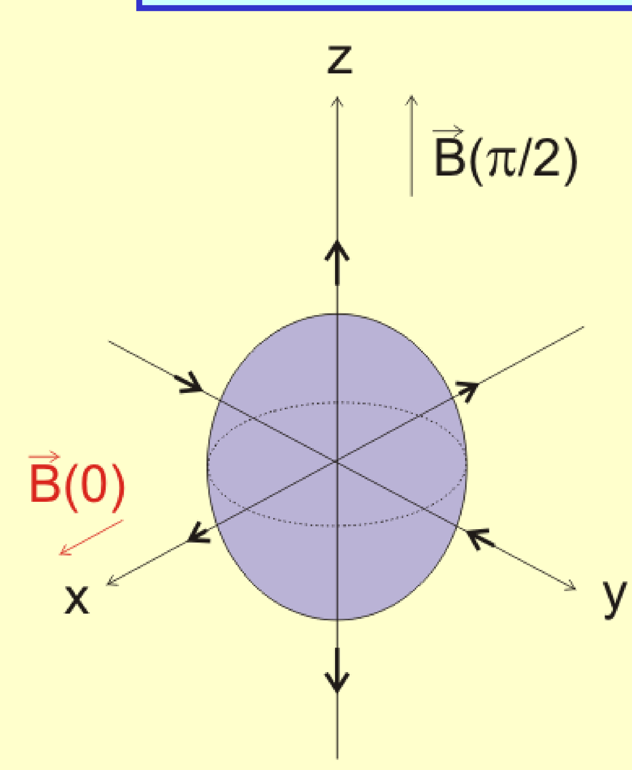
* 5 10^6 atoms fill the optical trap within 100 ms, @ 80 μK, density ~ 3.10[11] at/cm[3].
* Very fast accumulation limited by inelastic collisions
-we use a favorable metastable state $^5S_2$ and
-we use fast rf-sweeps to null the magnetic trap through spin flips, to catch all the m-states and to lower inelastic collisions

BEC transition at ~100 nK

Pure condensate ~30 000 atoms obtained in 10s – Atoms in state M=-3 – chemical potential ~3kHz

see
- Q. Beaufils, et al, Phys. Rev. A, **77**, 053413 (2008)
- **Q. Beaufils, et al, Phys. Rev. A, 77, 061601® (2008)**

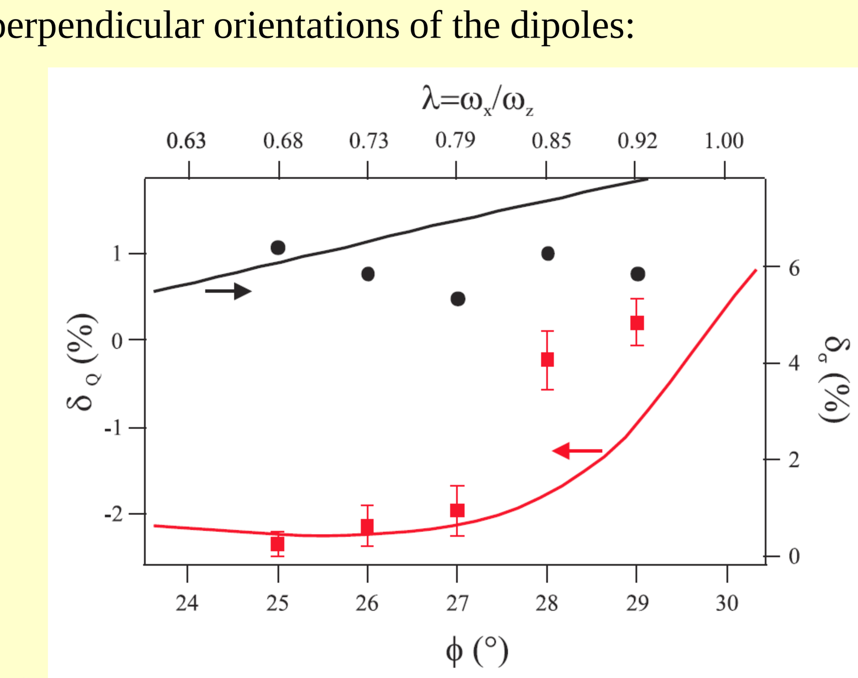
Quadrupolar mode frequencies are shifted by MDDI



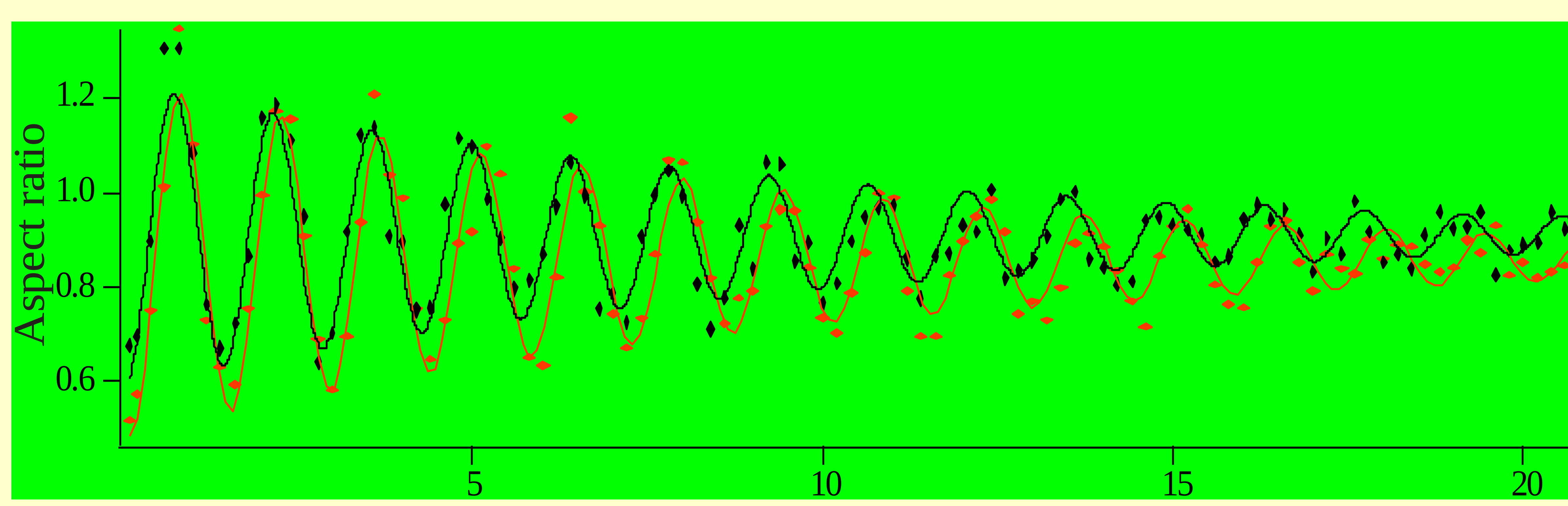
Agreement with theoretical predictions

Greater sensitivity for (δ_Q) than for striction effect (δ_σ)

Relative shifts of the quadrupole mode frequency (δ_Q) and of the released BEC aspect ratio , for two perpendicular orientations of the dipoles:



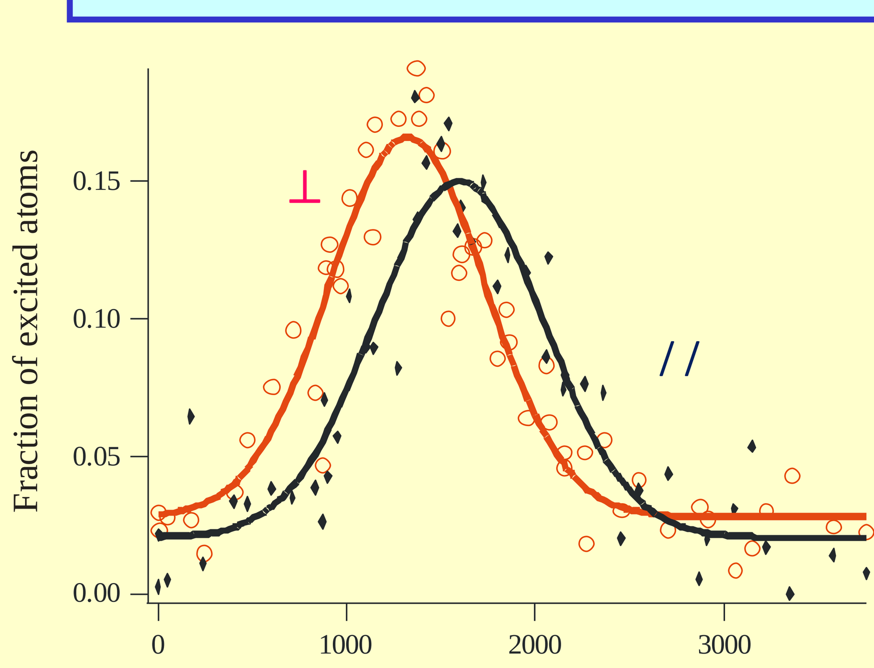
Oscillations of the « intermediate » out-of-phase collective Q-pole mode for two orthogonal orientations of the B field

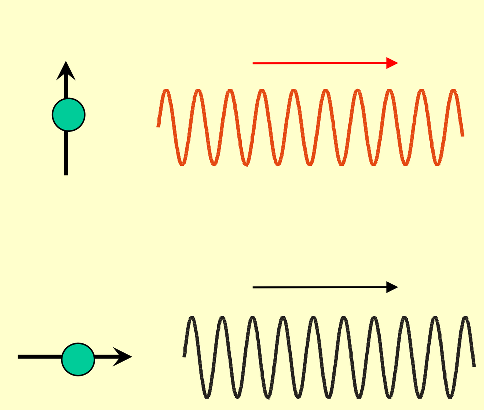


Time in ms

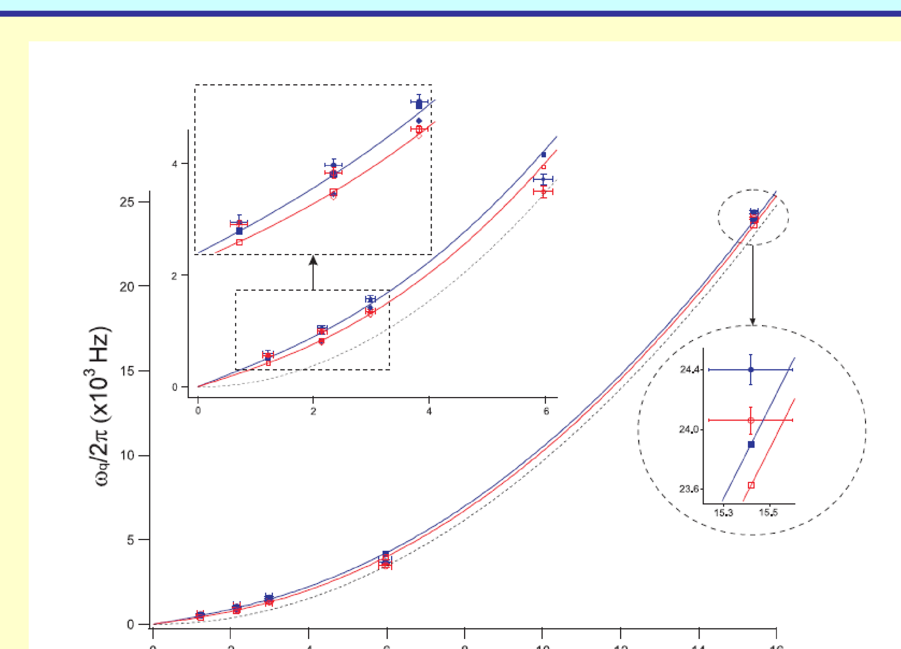
Bismut et al. , Phys. Rev. Lett. , 105, 040404

Anisotropy of the sound velocity induced by MDDI





$c_\perp \neq c_{//}$



Bismut el al, arXiv :1205.6305

Good agreement between theory and experiment:

	Theo	Exp
Parallel	3.6 mm/s	3.4 mm/s
Perpendicular	3 mm/s	2.8 mm/s

Width of resonance curve: finite size effects (inhomogeneous broadening)
Speed of sound depends on the relative angle between spin and excitation wavevector

Other recent works in our group :

Dipolar BEC in optical lattices
Dipolar relaxation control in reduced dimensions
Pasquiou et al. , Phys. Rev. Lett. **106**, 015301 (2011)

Spin 3 spinor physics and quantum magnetism
Spontaneous magnetization

Pasquiou et al, Phys. Rev.. Lett. **106**, 255303 (2011) and Phys. Rev. Lett.**108**, 045307 (2012)

2 other posters at ICAP

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ICAP Palaiseau July 2012