Dissipative cooling of spin chains by a bath of dipolar particles

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Spinors quantum gases to explore magnetism

Cold atoms in optical lattices

Much effort into the Heisenberg hamiltonian and t-J model

$$H=-J\sum_{<i,j>}\vec{S}_i\cdot\vec{S}_j$$

Hulet, Greiner, Bloch, Zwierlein, Kohl, Esslinger...

Tunable geometries, large spin systems, diversity in interaction properties (spin-dependence of contact, short- or long-range)

Magnetic Quantum gases group at LPL :

Strongly dipolar Chromium gases

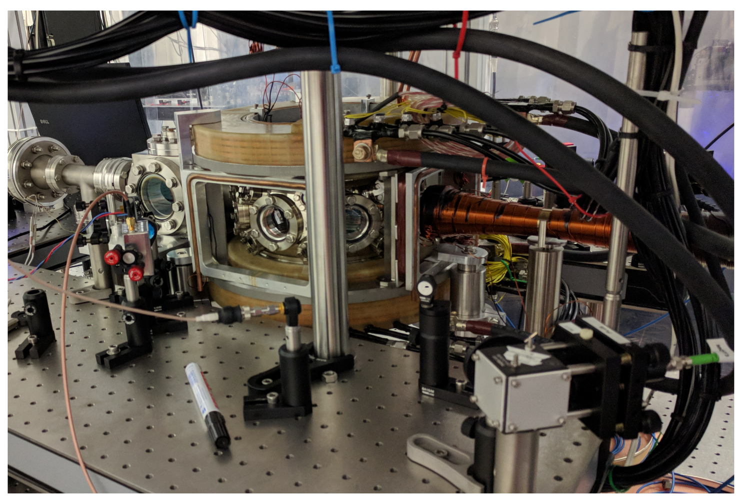
S. Lepoutre, L. Gabardos, E. Maréchal, O. Gorceix, B. Laburthe-Tolra, L. Vernac

SU(N ≤ 10) symmetric Strontium gases (new)

I. Manai, E. Maréchal, O. Gorceix, B. Laburthe-Tolra, M. Robert-de-Saint-Vincent

Theory of large spin quantum gases

K. Kechadi, P. Pedri



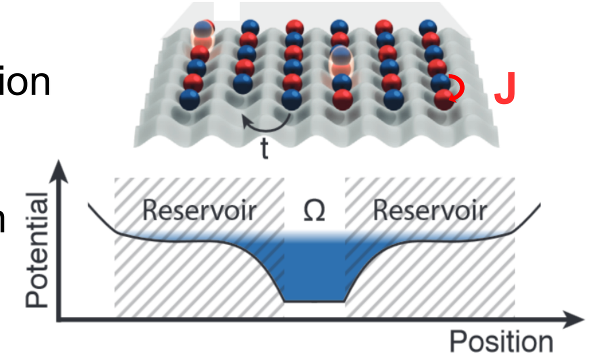
This year for ^{87}Sr : narrow-line laser cooling and degeneracy

Cooling spins on a lattice

Problem

Adiabatic loading of spins in an optical lattice : transport inhibited → spin ordering by reorganisation does not follow easily

State of the art approach: inhomogeneous system for equilibration to ***locally*** low entropy. (Mathy 2012, Hart 2015, Mazurenko 2017)

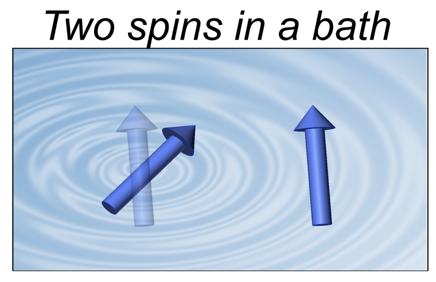


Concept

Ability to flip a spin if it reduces the interaction energy; dissipation of this energy into a bath.

Many present proposals use light as a bath (e.g. Diehl 2010, Kaczmarczyk 2016)

Two spins in a bath



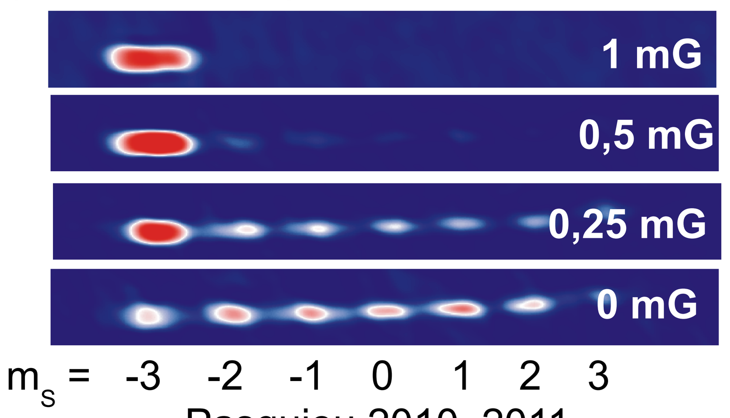
Present proposition :

Via dipole-dipole interactions, **a polarised, strongly dipolar BEC thermalizes with the spin degrees of freedom of fermions in a lattice**

Dipolar interactions with an atomic bath

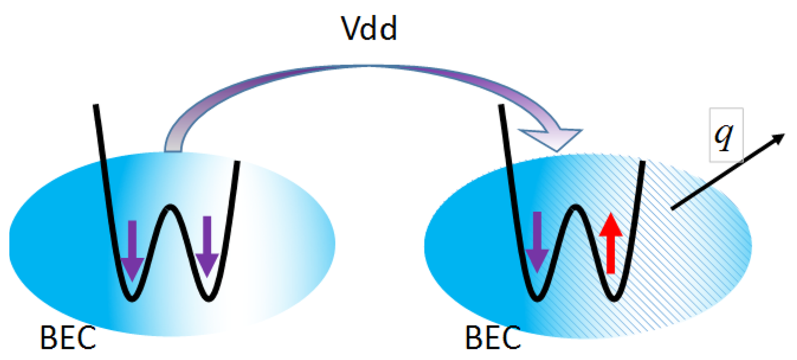
Tool : Dipolar relaxation

Spontaneous depolarization of a Cr BEC



Pasquiou 2010, 2011

Here: spins magnetization freed by interactions with a dipolar BEC



Effective interaction between **spin F fermions** and **spin S *polarised* bosons**

$$V=\frac{\mu_0}{4\pi}g_F g_S \mu_B^2\frac{\int d^3r\,d^3r'}{|\vec{r}-\vec{r}'|^3}\left(F_z(\vec{r})S_z(\vec{r}')-\frac{3\left(\vec{F}(\vec{r})\cdot(\vec{r}-\vec{r}')\right)\left(S_z(\vec{r}')(z-z')\right)}{|\vec{r}-\vec{r}'|^2}\right)$$

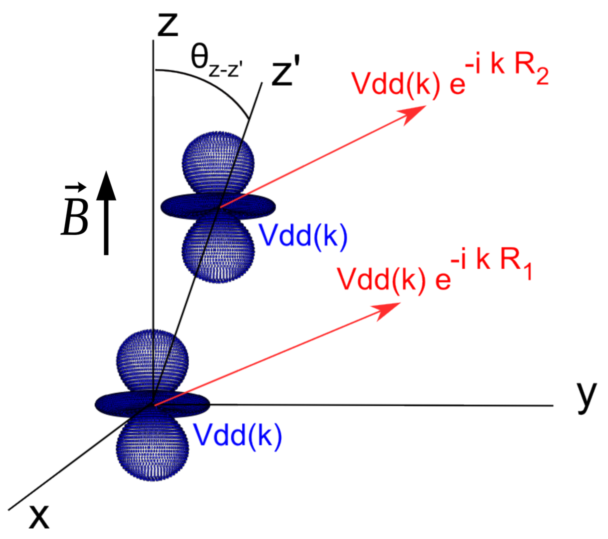
Phonon radiation diagram between two collective spin states |i>, |f>

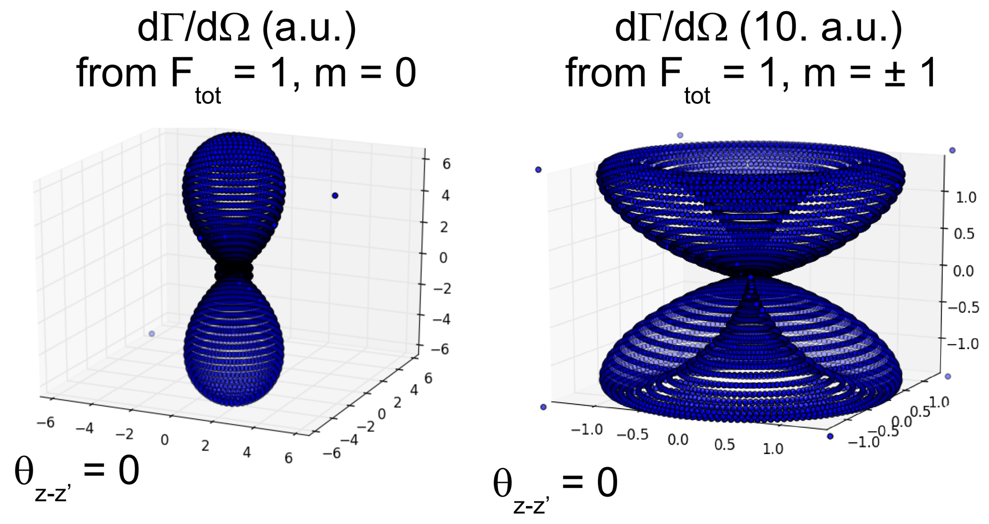
based on the Fermi golden rule and on the dispersion relation of dipolar BEC excitations

$$\Gamma_{i\to f}\sim\frac{1}{h}\int d^3k\left|\tilde{V}(\vec{k})\sum_j <f|e^{j\vec{k}\vec{r}_i}\hat{F}^j_{+,-,z}|i>\right|^2\delta(E_i-E_f-\epsilon(\vec{k}))$$

Collective emission of phonons, affected by propagation phases

Two-spins phonon radiation diagrams dΓ/dΩ – homogeneous BEC

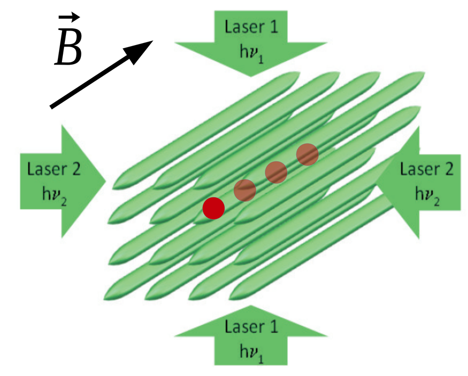




Strong impact of the bath lattice potential

Dispersion relation
Spatial modes of the bath excitations
Stabilisation of the bath dipolar instability

→ **optimum situation for anisotropic bath lattice** with a very different radiation diagram



Straightforward extension to spin chains with N>2 atoms, and finite BEC temperature

- compute dipolar coupling between exact spin chain eigenstates

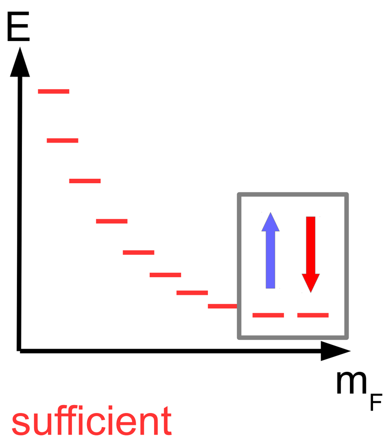
Application example

Pseudo-spin 1/2 with non-zero magnetic dipole moment

Potassium 40, F = 9/2, g_F = 2/9

- Antiferromagnetic effective interactions at low field
- In the magnetic field, a light-induced quadratic shift* maintains two states m_F = 9/2, 7/2 degenerate

(*Gerbier 2006)



Strongly dipolar bath

e.g. Dysprosium 164 (μ = 10 μ_B) , or Erbium 168 (μ = 7 μ_B)

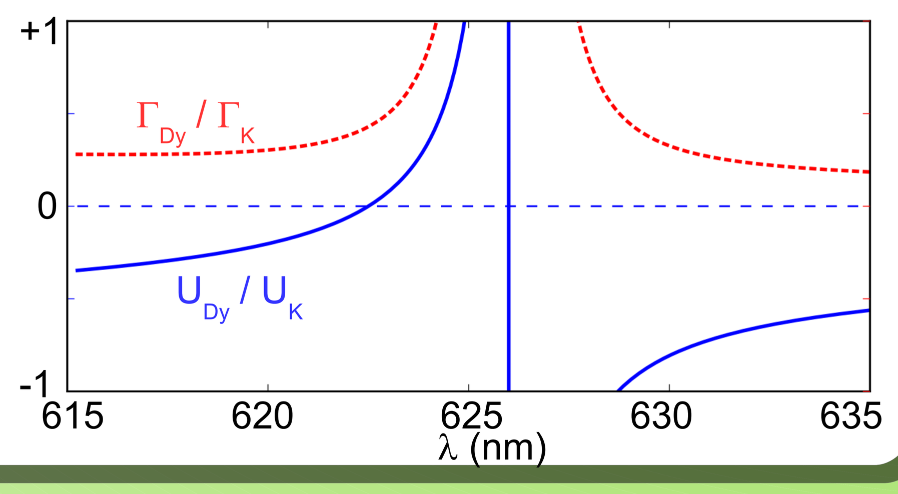
Requirements on the magnetic field : $\mu_{bec}.B > (J, k_B T)$ → B ~ mG sufficient to ensure that the BEC remains polarised

Requirement on BEC : $k_B T_{BEC} < J$

Lattice wavelength

Er, Dy lines : tunable Boson to Fermion depth

- Mott regime for fermions
- 3D coherence for bosons
- Enhanced interaction



Simulation of dynamics

Rate-equation evolution of the chain eigenstate populations

^{40}K -^{164}Dy

U_K = (25x25x3.5) E_r^K – effective 1D chain

U_{int}/t = 7.5, J = h x 630 Hz

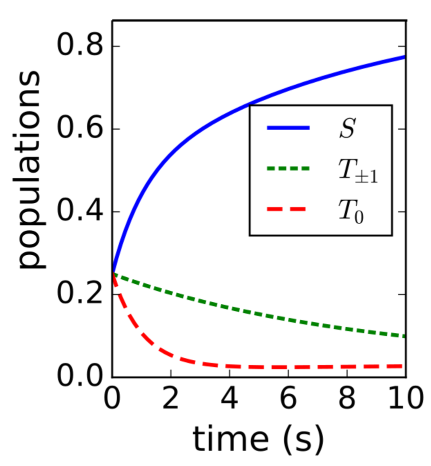
U_{Dy} = (12x12x3.5) E_r^{Dy} – 3D coherent BEC

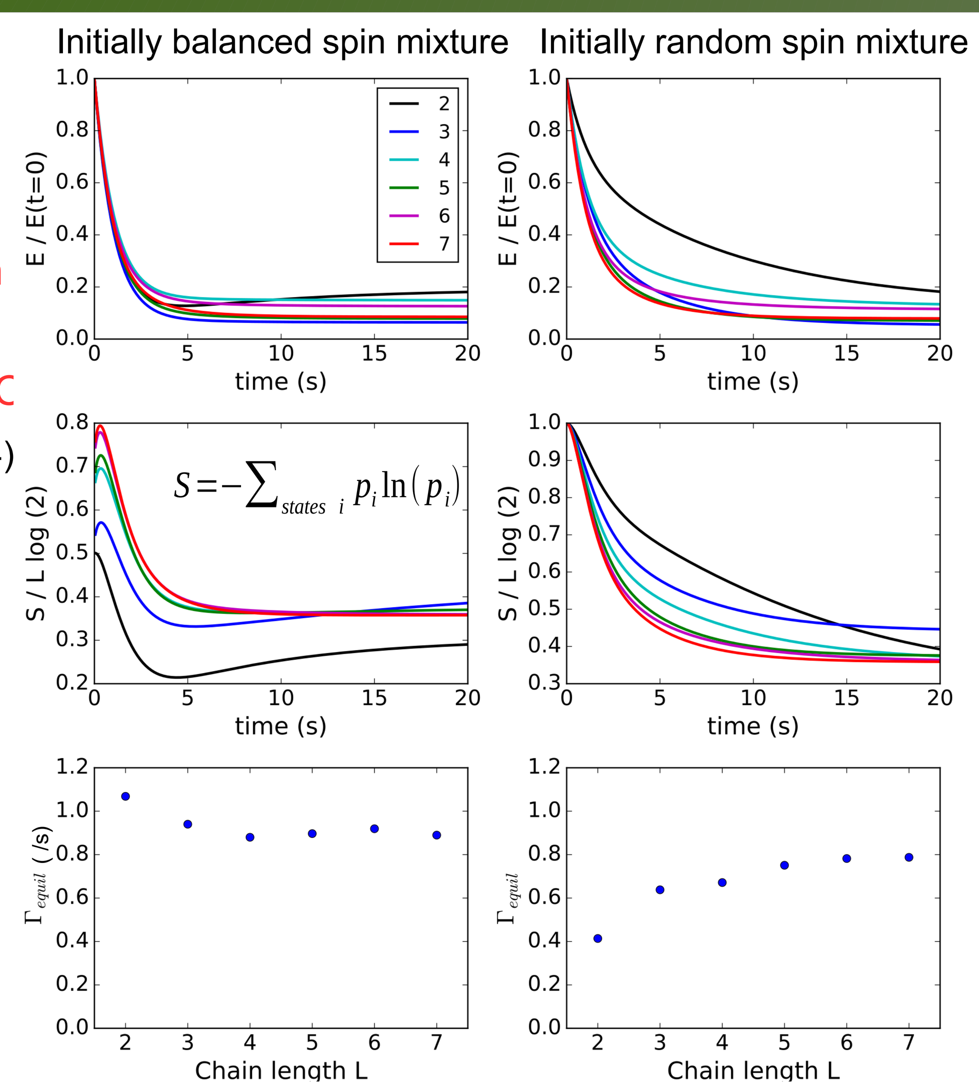
(Cazalilla 2006, Vogler 2014)

$<n_{bec}>$ = 3.10^{13} / cm^3

T_{BEC} = 0,3 J / kB = 9 nK

Evolution for length 2 :





Outlook

Anisotropic cooling of spin excitations

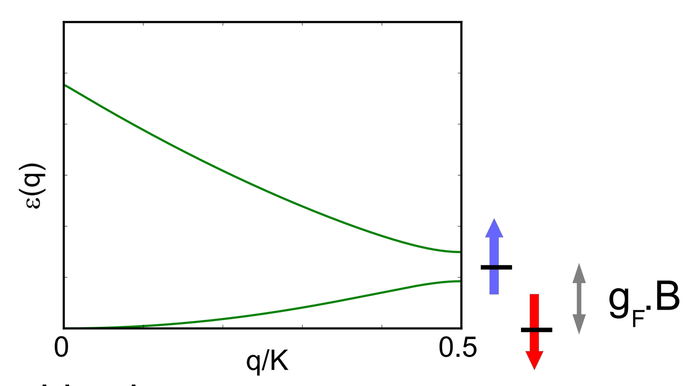
Fixed magnetization evolutions (m_{tot} = cte)

Use gaps in the bath dispersion relations : g_F.B in band gap

→ reduced sensitivity to external magnetic field

→ no need for quadratic shift engineering

Drawback : Slower evolution (less processes available)



Other mixtures of interest

Erbium bath for its low-field Feshbach resonances

Applications to spins with stronger dipoles (e.g., Cr instead of K)

Solutions when spins have no magnetic dipole

Pumping procedures (e.g. Kaczmarczyk 2016) related to dissipative preparation of entangled states

References

- M. Cazalilla, A. Ho, and T. Giamarchi, New J. Phys. **8**, 158 (2006)
- S. Diehl et. al., Phys. Rev. Lett. **105**, 227001 (2010)
- F. Gerbier et. al., Phys. Rev. A. **73**, 041602 (2006)
- Hart et. al., Nature **519**, 211 (2015)
- J. Kaczmarczyk, H. Weimer, and M. Lemeshko, New J. Phys. **18**, 093042 (2016)
- Mazurenko et al., Nature **545**, 462 (2017)
- Mathy et. al., Phys. Rev. A **86**, 023606 (2012).
- B. Pasquiou et. al., Phys. Rev. A **81**, 042716 (2010)
- B. Pasquiou et. al., Phys. Rev. Lett. **106**, 255303 (2011)
- A. Vogler et. al., Phys. Rev. Lett. **113**, 215301 (2014)

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