Stable longitudinal spin domains in a nondegenerate ultracold gas

CAP Congress

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Spin diffusion

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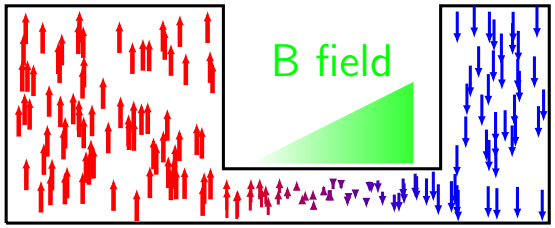
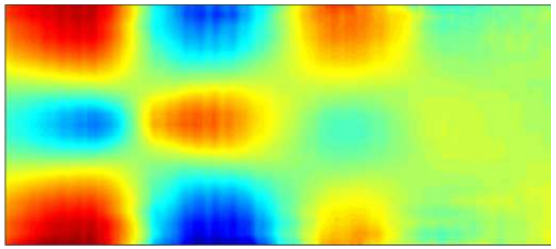
Liquid helium NMR



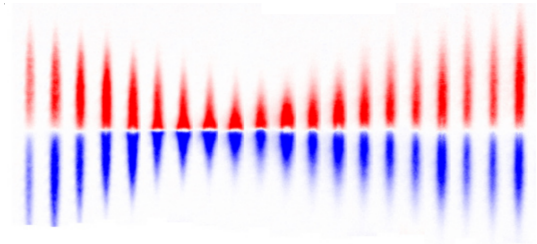
PRB **46**, 9082 (1992)

Spin waves in ultracold atoms



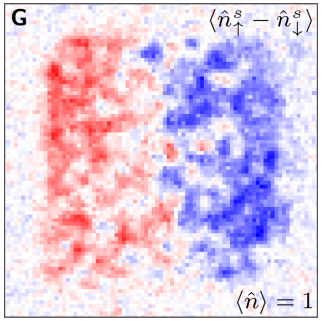
PRL **89**, 090402 (2002)

Modified spin diffusion



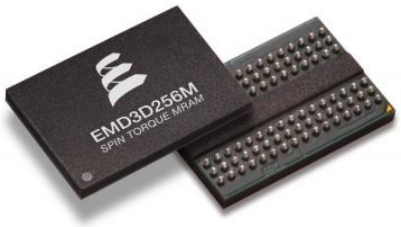
Nature **472**, 201 (2011)

Science **363**, 383 (2019)



Why should we care about spin diffusion?

- Use spin to carry information
- Spintronics: developing devices that use spin instead of charge (MRAM)
- Fundamental knowledge transferable to similar non-equilibrium systems



1D spin diffusion with ultracold gases

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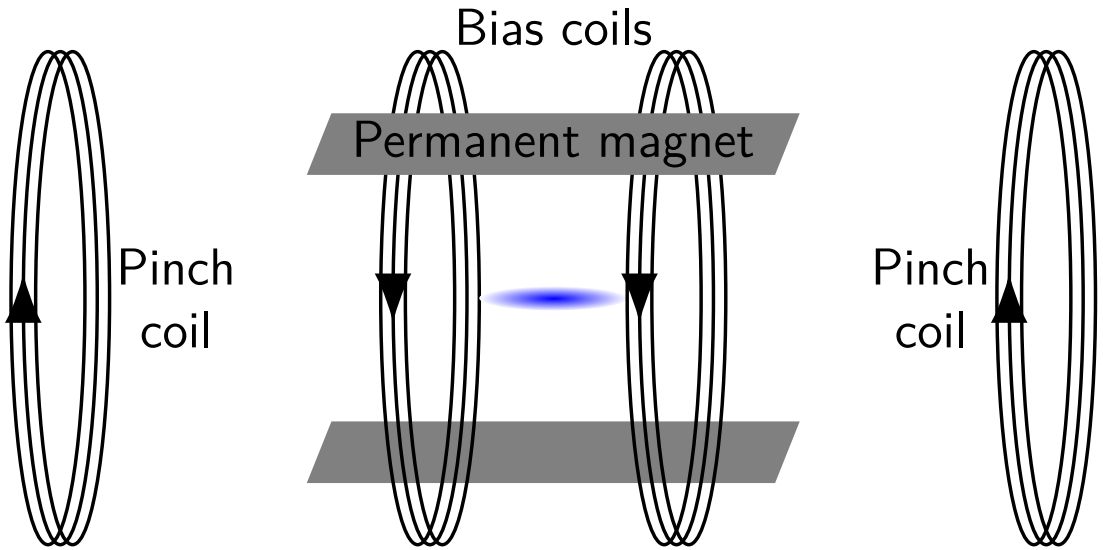
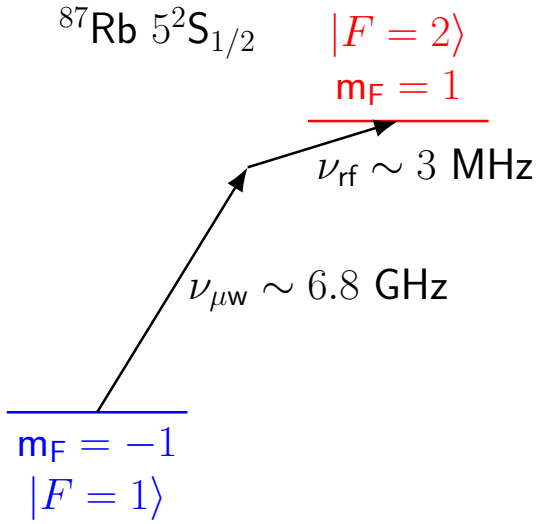
Hybrid Ioffe-Pritchard trap



Level diagram



- Quasi-1D rubidium-87 system (37:1 pencil shaped trap)
- Cloud size is ~ 1 mm in axial direction
- Peak densities of $\sim 1.4 \times 10^{13}$ cm^3
- Nondegenerate clouds $T \sim 650$ nK ($T \sim 2T_C$)
- Spin manipulation performed with two-photon pulses (RF and μW)

Modifying spin diffusion

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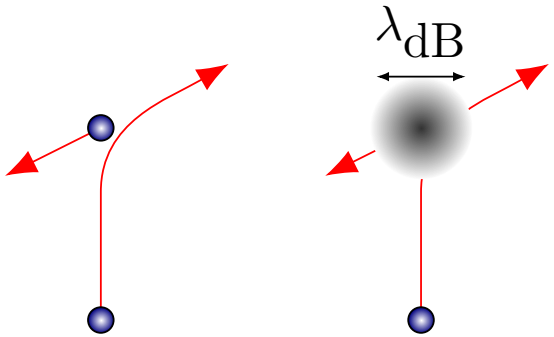
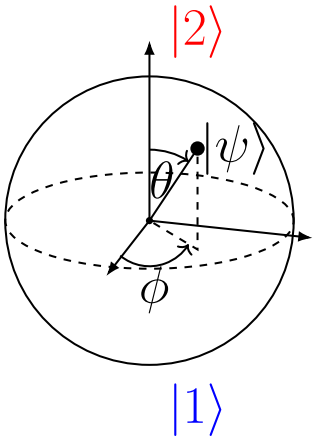
Identical spin rotation effect (ISRE)

Collision between two atoms

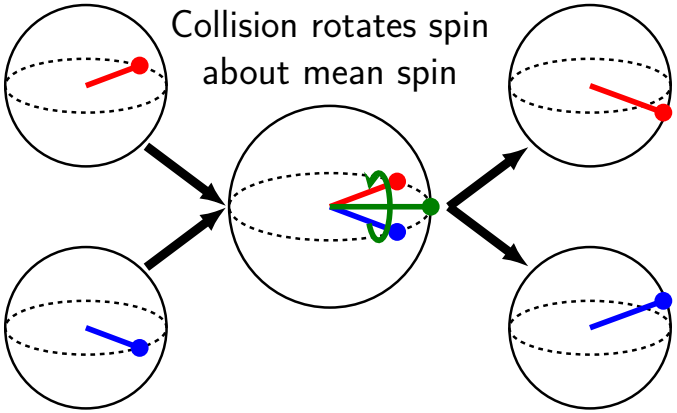


$\lambda_{\mathrm{dB}} >$ scattering length



Phase difference between transverse spin states

Conversion of transverse to longitudinal spin



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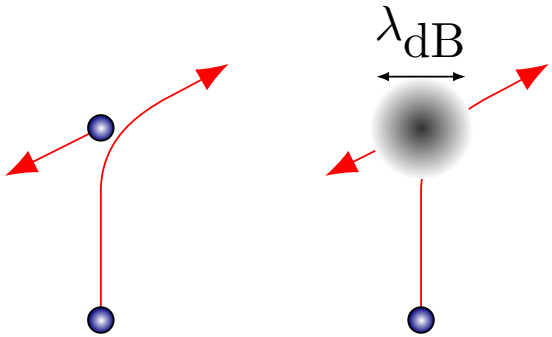

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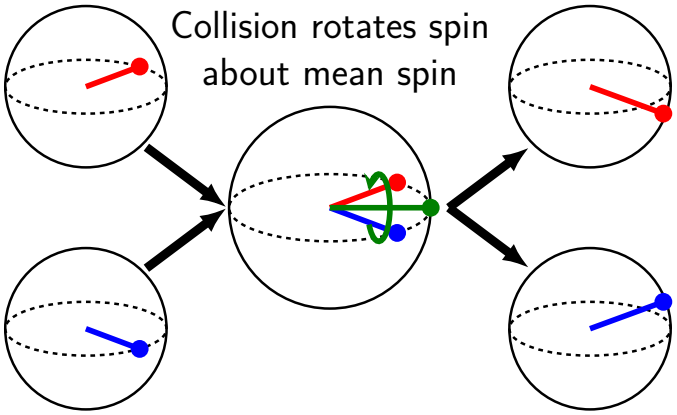
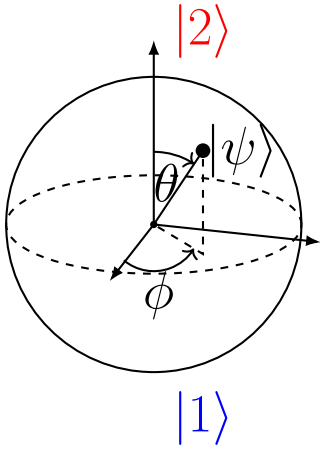
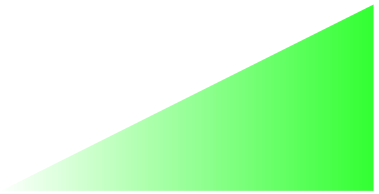


Local Larmor precession



$$B_{\mathrm{eff}} = U_{\mathrm{diff}} = U_{|2\rangle} - U_{|1\rangle}$$



Slow precession

Fast precession

Cloud parameters

- Leggett-Rice parameter (temperature)
- Mean free path (density)

Longitudinal spin domains

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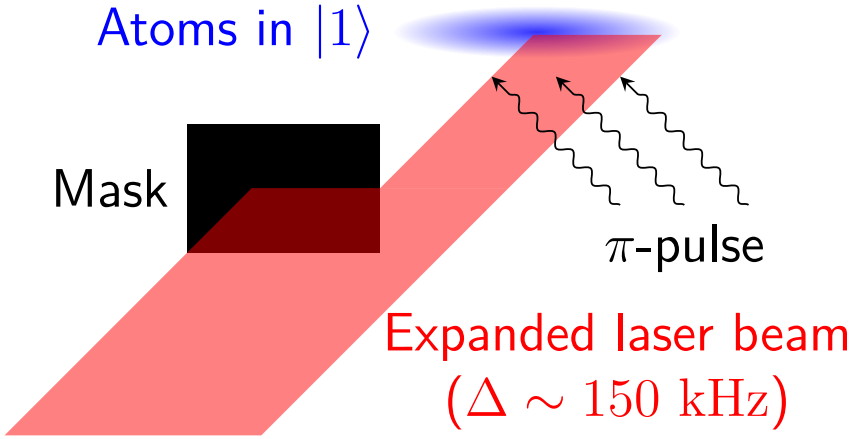
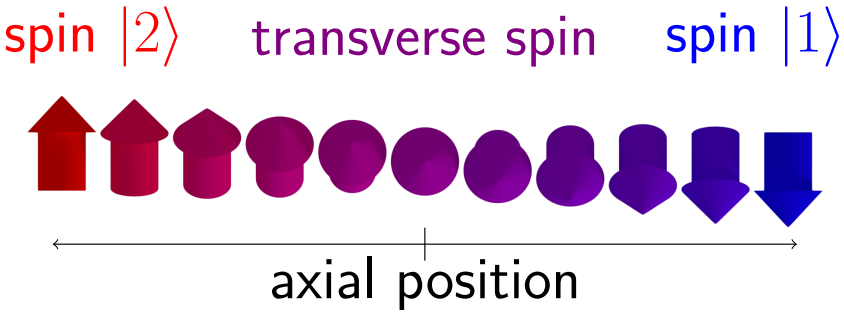
Domain preparation

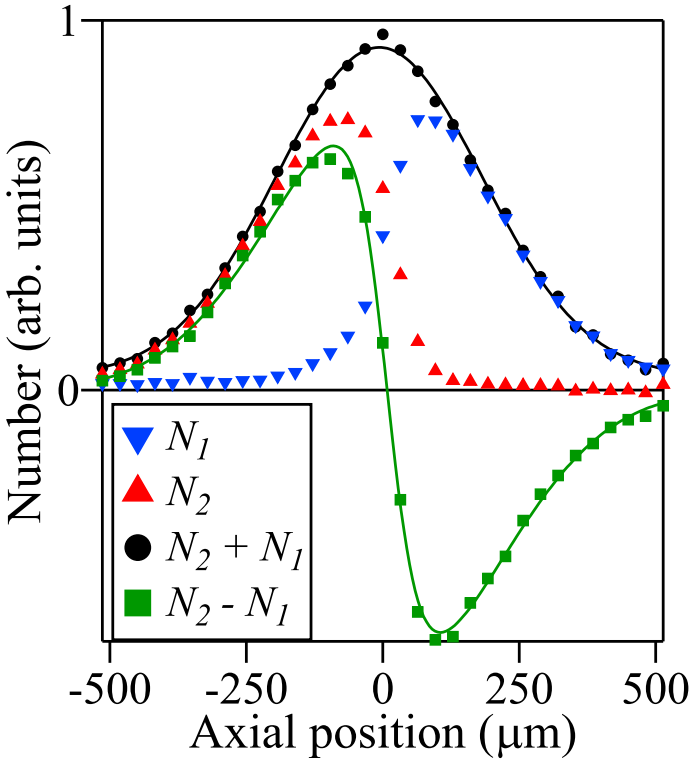


Helical spin domain



Detection: Absorption imaging

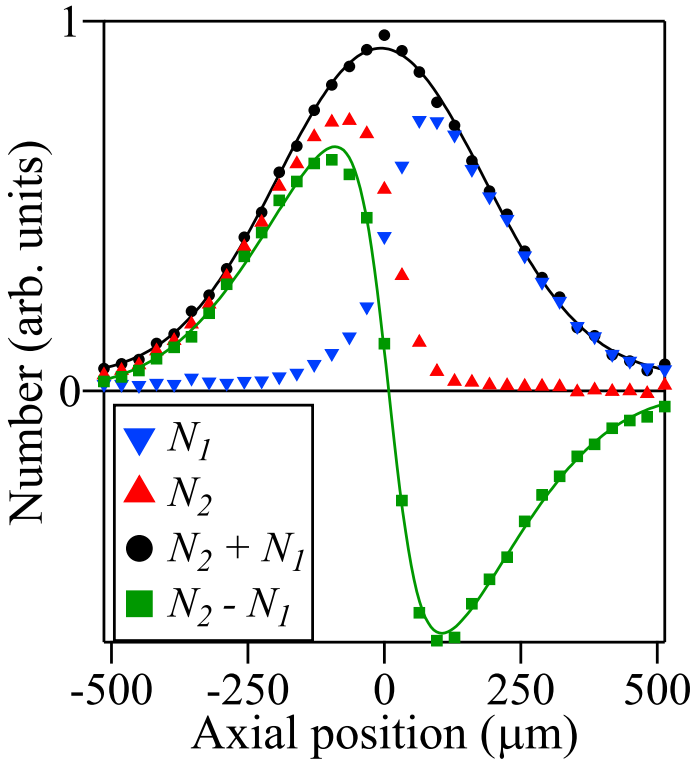
- Destructive $\rightarrow$ 2 images
- Combine images to get spin profile (green) or atomic profile (black)



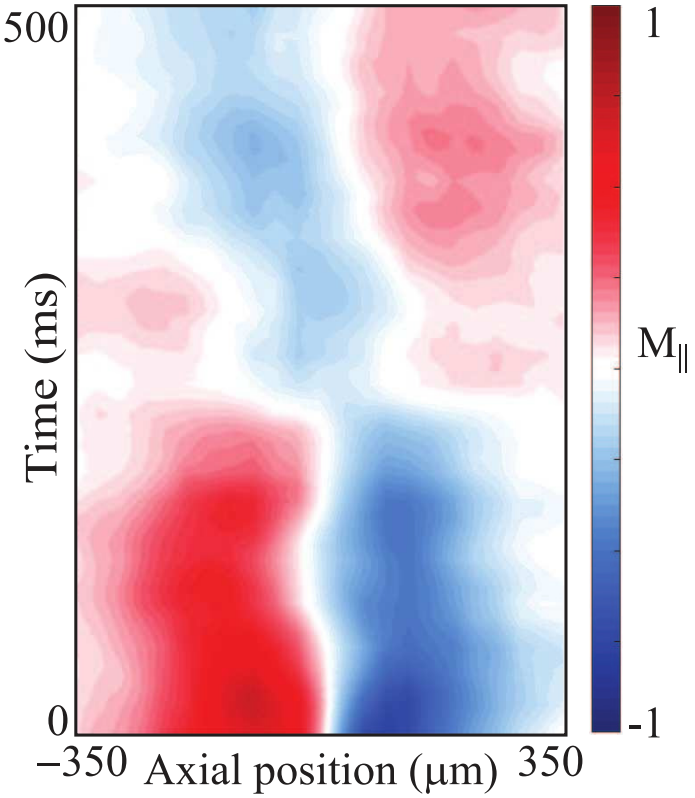
Longitudinal spin diffusion

SFU

- Collect a spin profile (2 images) at various times
- Stitch images together to view diffusion



$T = 650$ nK, $n_0 = 1.4 \times 10^{13}$ cm^{-3}



- $\tau_{\text{classical}} \sim 25$ ms, $\tau_{\text{trap}} \sim 150$ ms
- slowed diffusion due to ISRE

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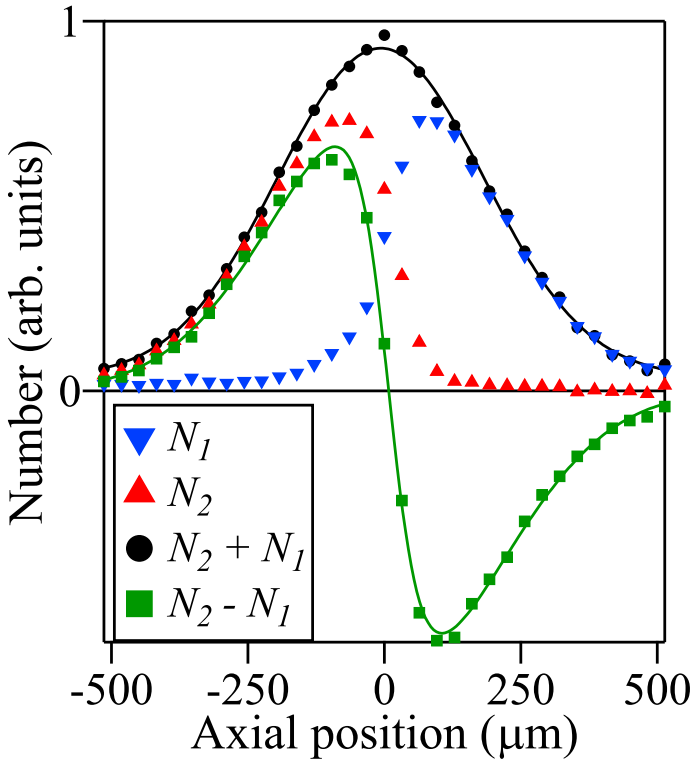

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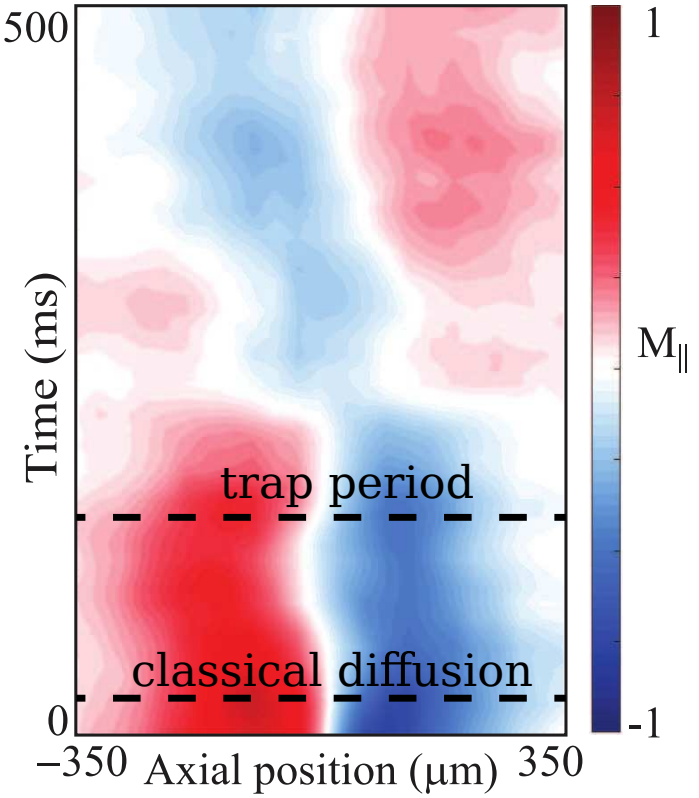

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Effective magnetic field

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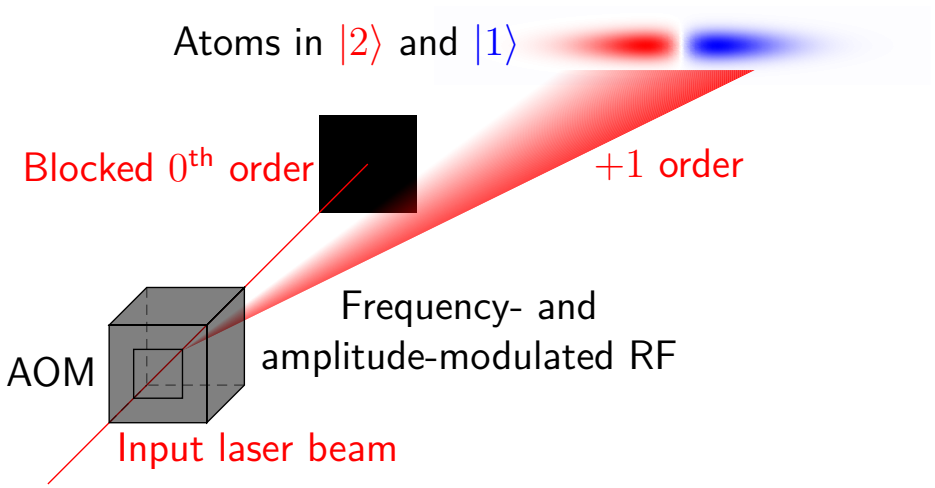
Tuning the local Larmor precession

- Laser AC Stark shifts spin states
- Creates a differential potential U_{diff}
- Draw linear U_{diff} pattern with AOM

Acousto-optical modulator (AOM)



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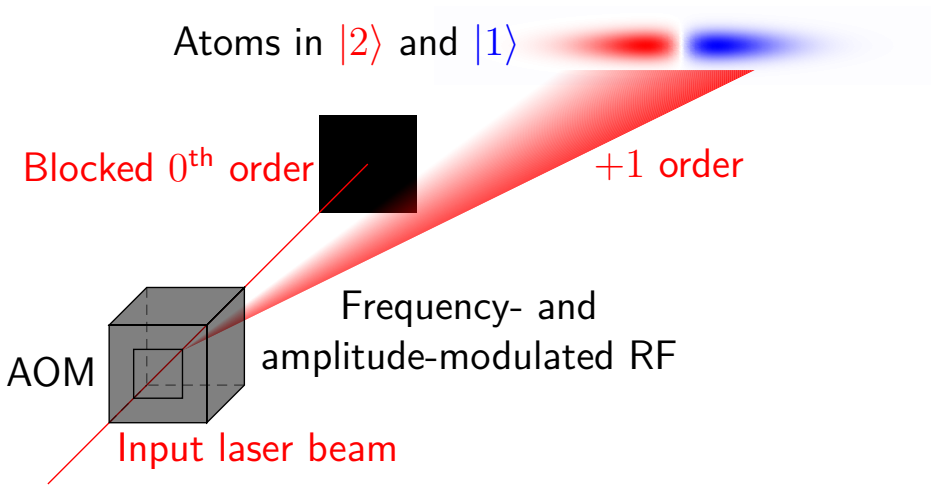
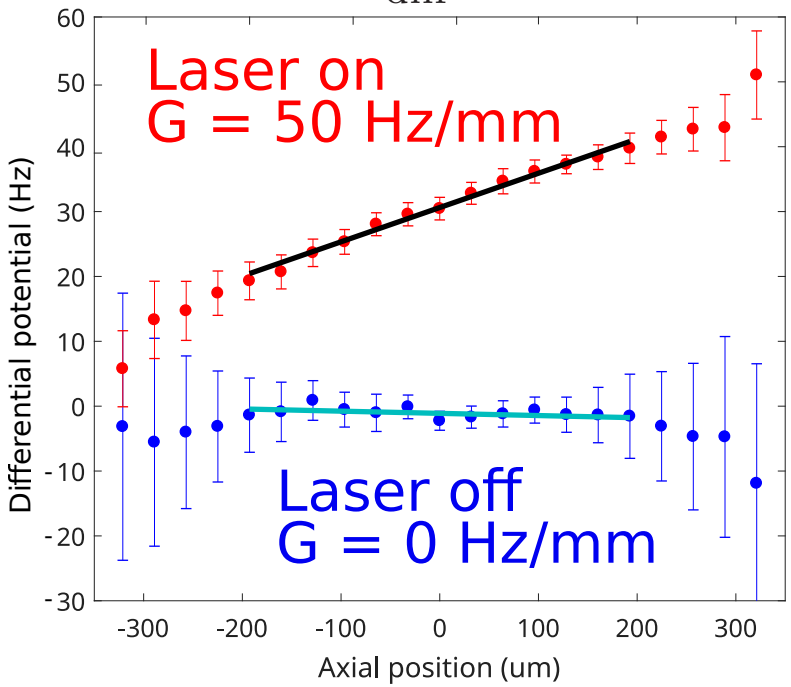


Measuring U_{diff}

Linear $U_{\mathrm{diff}} = G\,z$

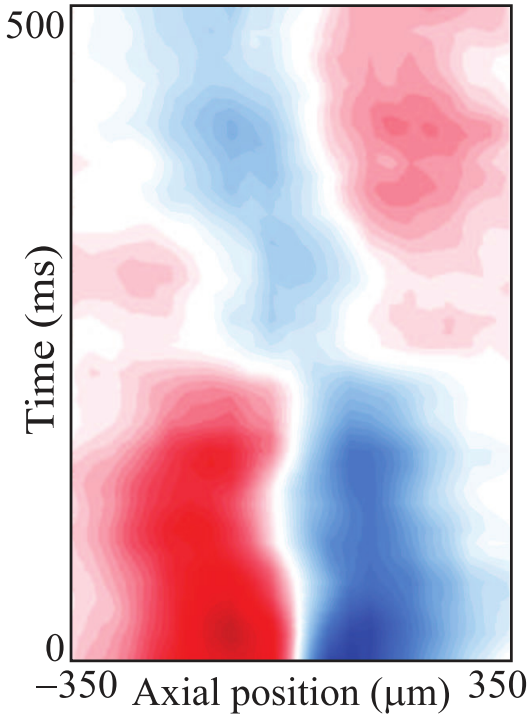


U_{diff} is small relative to thermal energy $k_B T/h \sim 350\,U_{\mathrm{diff}}$

Stabilizing a longitudinal spin domain

SFU

$G = 0$ **Hz/mm**



Stabilizing a longitudinal spin domain

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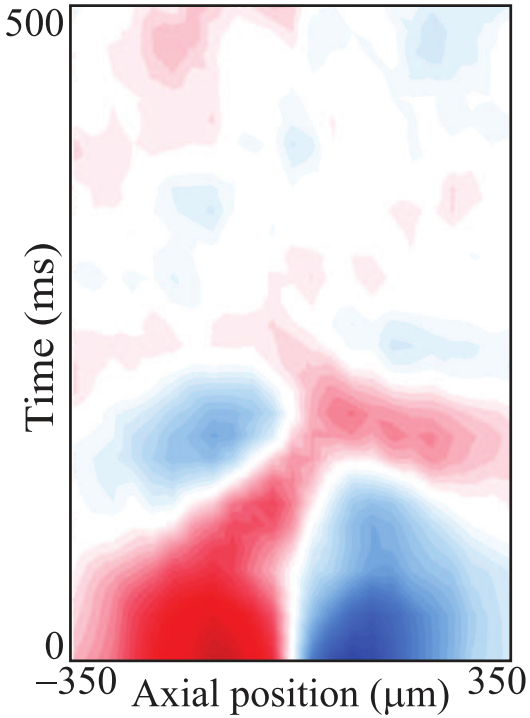
$G = -20$ **Hz/mm**



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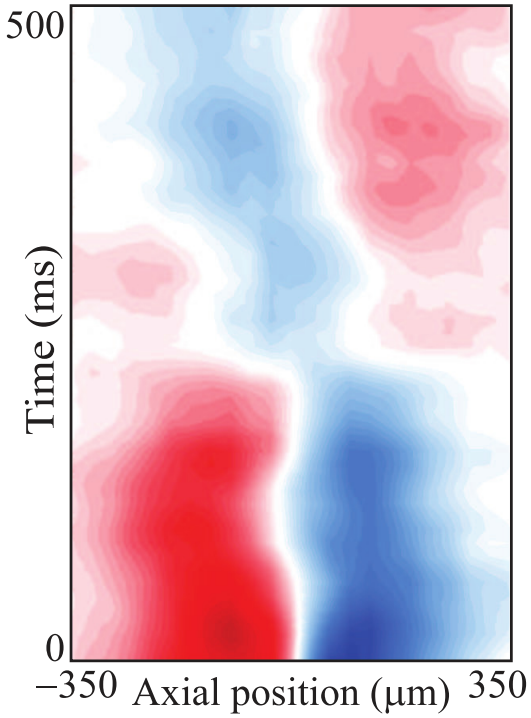

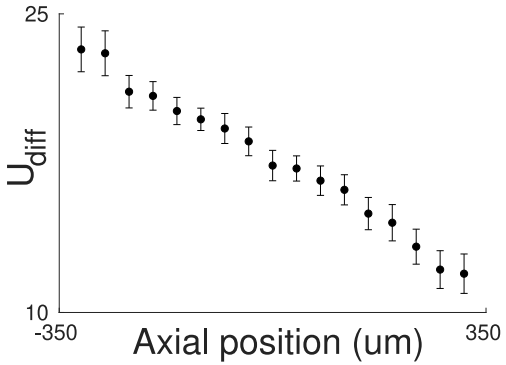

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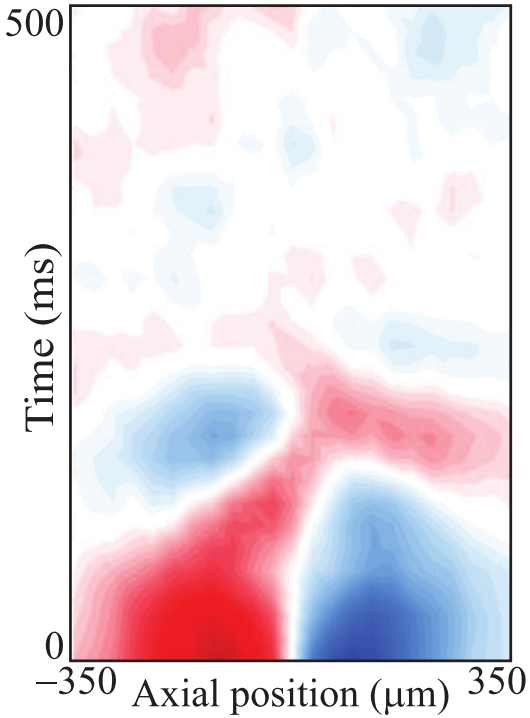

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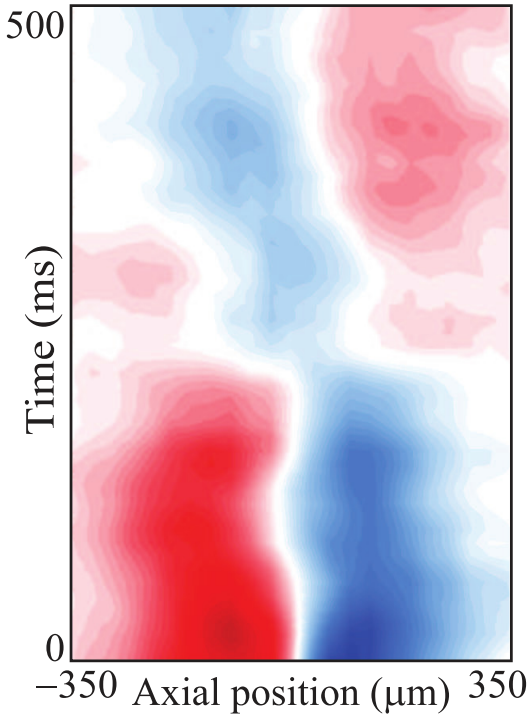
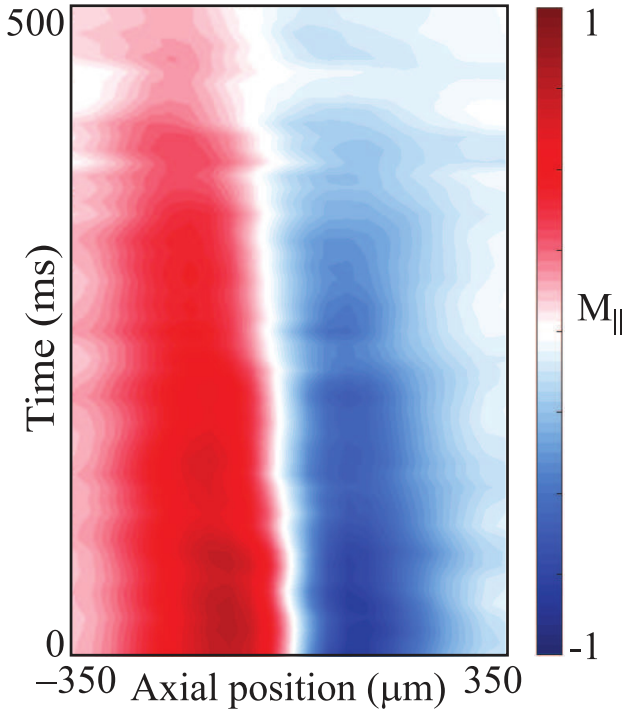
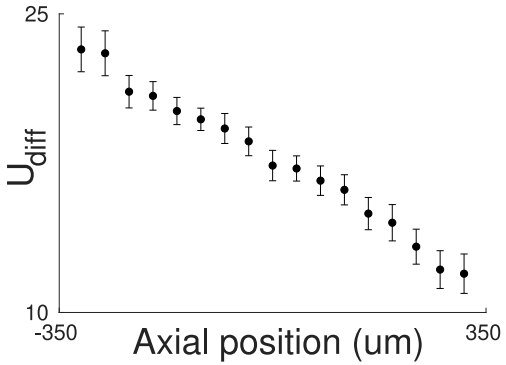
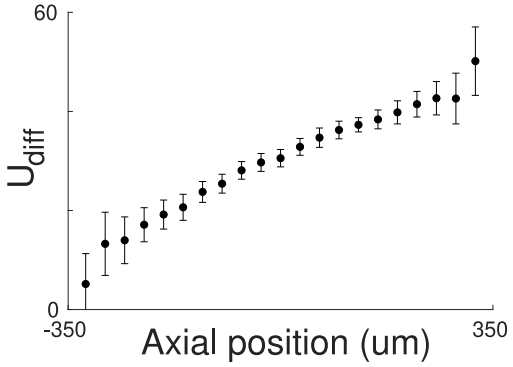


$G = 50$ **Hz/mm**





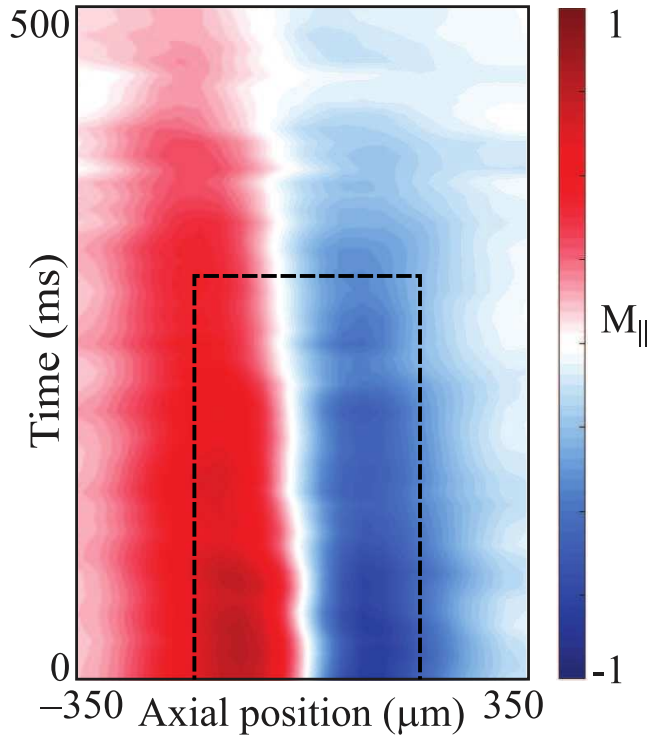
- Diffusion sped up or slowed down
- Stable domain for positive linear U_{diff}



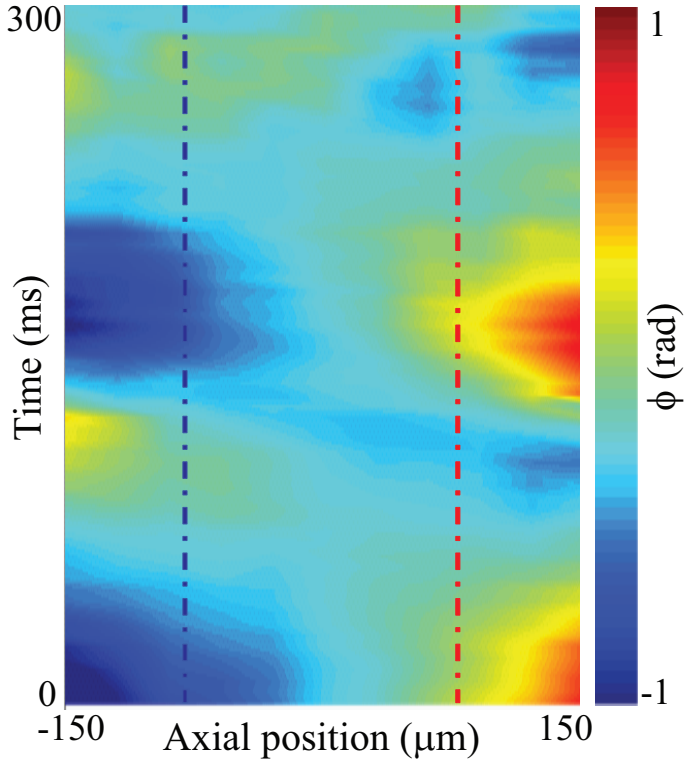
What about the transverse spin?

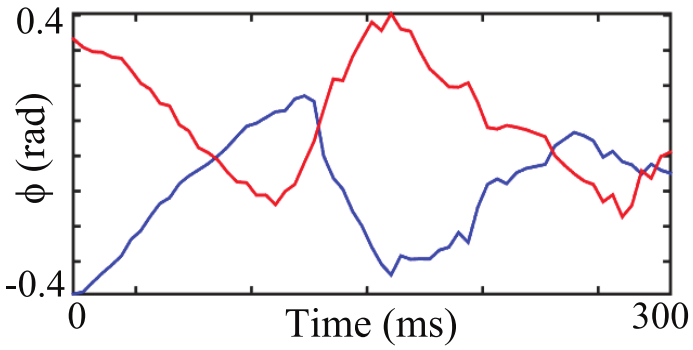
SFU

$G = 50$ **Hz/mm**



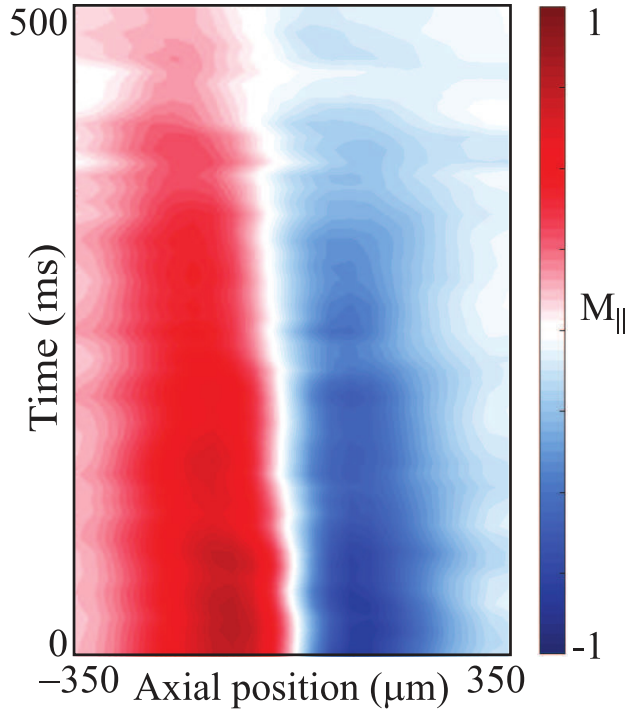
Spin wave within domain wall



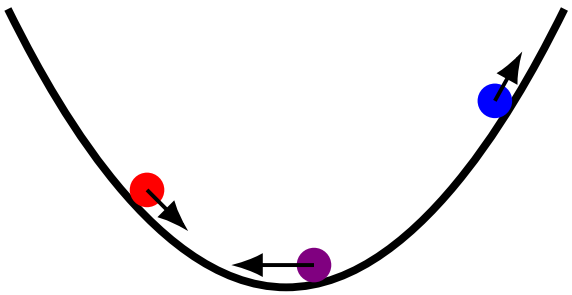


- Transverse spin coherently transfers spin from $|1\rangle$ to $|2\rangle$
- Decoupled macroscopic spin dynamics

Is this spin-charge separation?

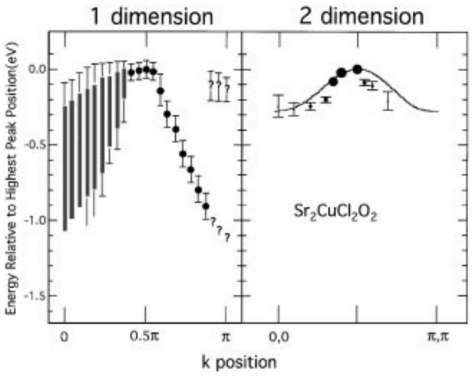


- Neutral atoms, so no charge



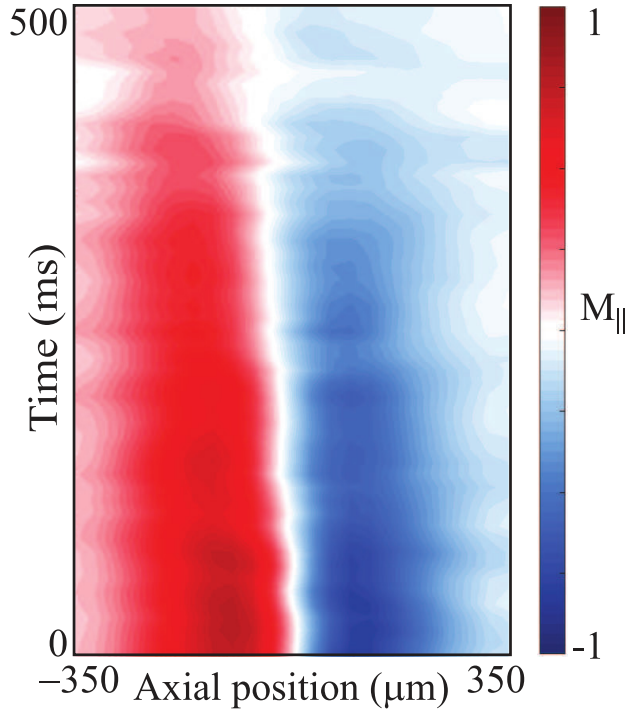
Neutral atoms moving in magnetic trap

Spin-charge separation in $SrCuO_2$

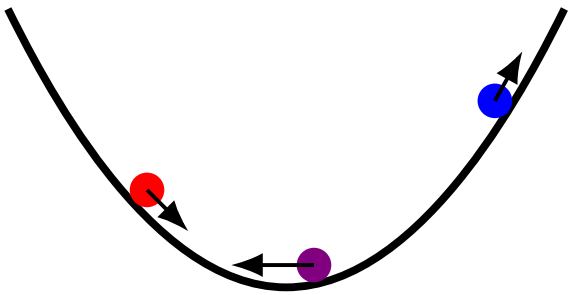


PRL **77**, 4054 (1996)

Is this spin-charge separation?



- Neutral atoms, so no charge
- Spin-density separation: similar to lattice systems, but our density distribution is fixed by initial conditions
- This work is an example of spin-carrier separation



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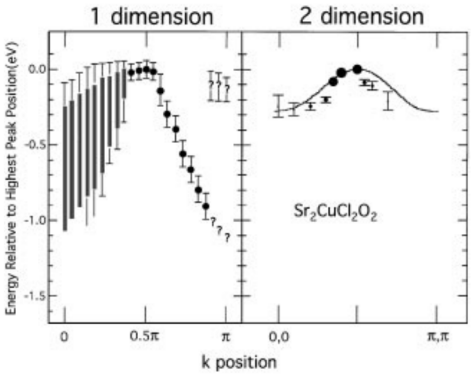
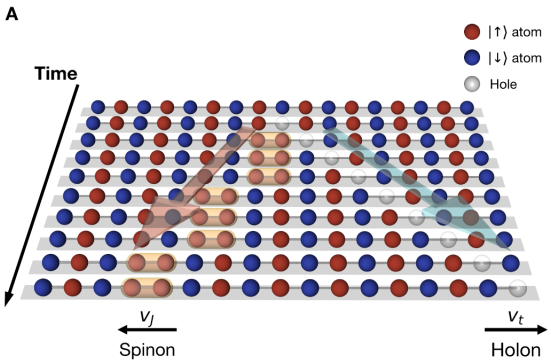


PRL **77**, 4054 (1996)

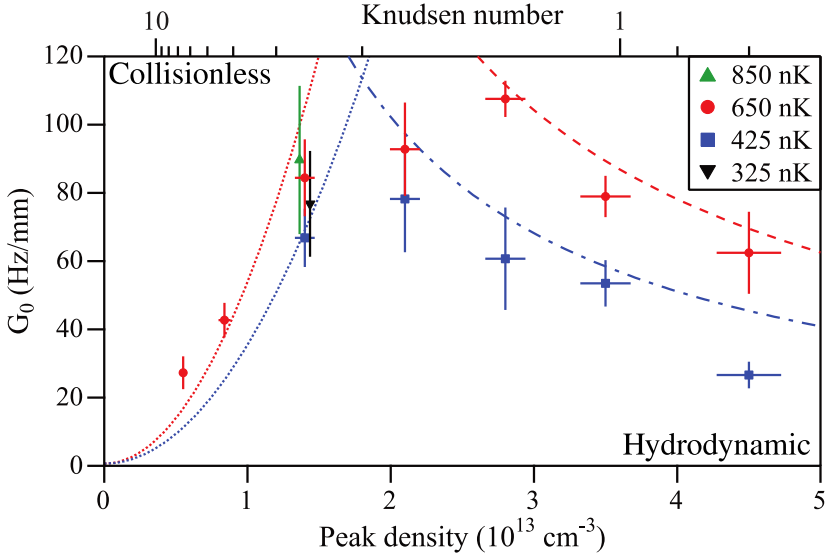


arXiv:1905.13638

Conclusion and Acknowledgements

SFU

Reference:
SDG, Niroomand, Ragan, and McGuirk. Phys. Rev. A **97**, 051603(R) (2018)



- Small effective magnetic fields can lead to large changes in spin diffusion
- Stabilize spin domains with linear effective magnetic fields
- Macroscopically decoupled longitudinal and transverse spin diffusion

Collaborators

Experiment (SFU):
Dorna Niroomand
Jeffrey M. McGuirk

Theory (University of Wisconsin - La Crosse):
Robert J. Ragan