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In-situ Magnetometry for Experiments with Atomic Quantum Gases

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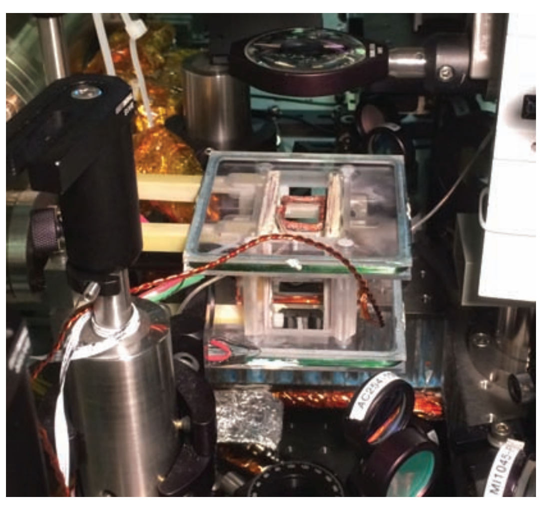
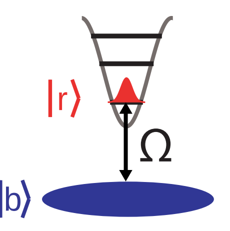
Motivation

Improved control of differential Zeeman energies of ultracold atoms in (our) quantum-gas apparatus



Example: Rabi-coupled system



Zeeman shifts ~ 1 kHz/mG

typ. energy scale in BEC μ ~1kHz

require <100 μG stablility to study mean-field effects and dynamics on few-ms scales

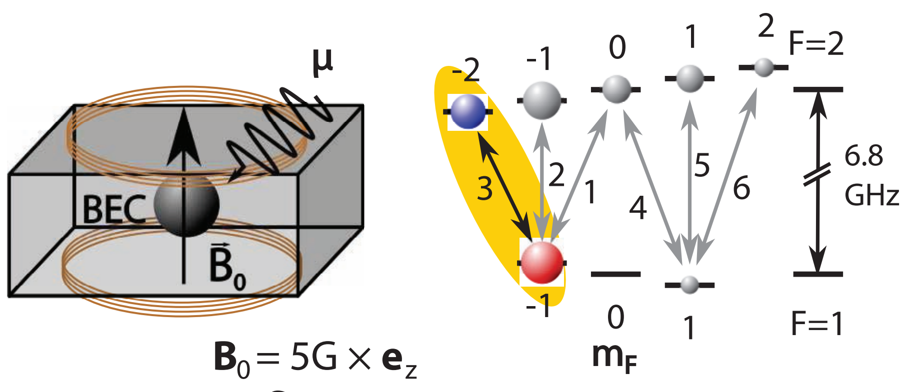
Ambient field fluctuations:

- AC line ~ 1mG
- Earth mag. field ~ 0.1mG
- other sources ~ 10mG/d (nearby steel posts etc.)

- limited access for magnetic field sensors
- shielding not possible (optical access)

Principle of Operation

Idea: use of atomic cloud as *in-situ field probe*



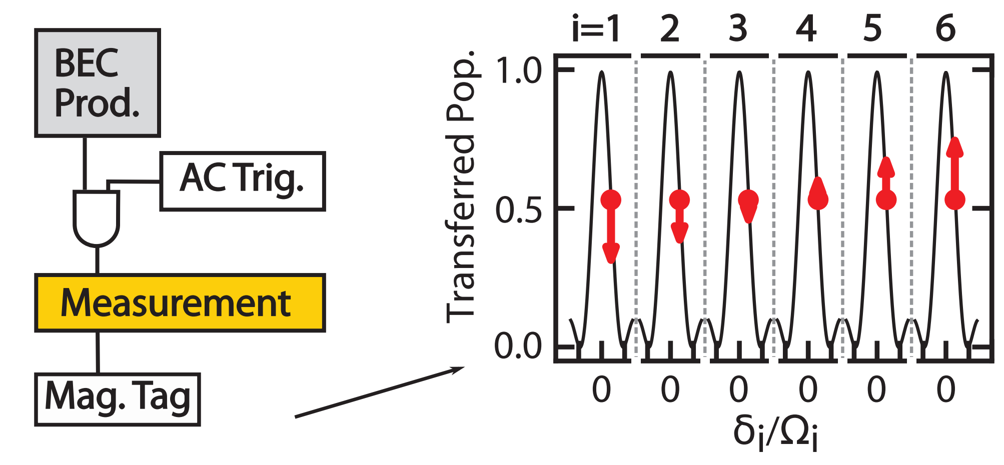
$\mathbf{B} = \mathbf{B}_0 + \delta\mathbf{B}_{fluct}$

$B \approx B_0 + \delta B_{fluct,z}$

(scalar magnetometer)

"free" HF states allow for rapid sampling of Rabi resonances to determine field at the end of a run ("tagging")

Magnetic-field tag ***Rabi pulse sequence***



$\Omega_i \tau_i = 0.94\pi$
$\delta_i = 0.82\Omega_i$

max. sensitivity to δB and min. sensitivity to fluct. in Ω

Magnetic-Field Reconstruction

Reconstruction method

$P_{F,m_F} = N(F,m_F)/N$ post-sequence populations

$p_1 = P_{1,1} + P_{2,0} + P_{2,1} + P_{2,2}$
$p_2 = P_{2,-1}/(P_{1,-1} + P_{2,-1} + P_{2,-2})$
$p_3 = P_{2,-2}/(P_{1,-1} + P_{2,-2})$ transfer prob.
$p_4 = (P_{1,1} + P_{2,1} + P_{2,2})/(P_{1,1} + P_{2,0} + P_{2,1} + P_{2,2})$
$p_5 = P_{2,1}/(P_{1,1} + P_{2,1} + P_{2,2})$
$p_6 = P_{2,2}/(P_{1,1} + P_{2,2})$

fitting

$p_i = (\Omega_i/\tilde{\Omega}_i)^2 \sin^2(\tilde{\Omega}_i \tau_i/2)$ Rabi osc.

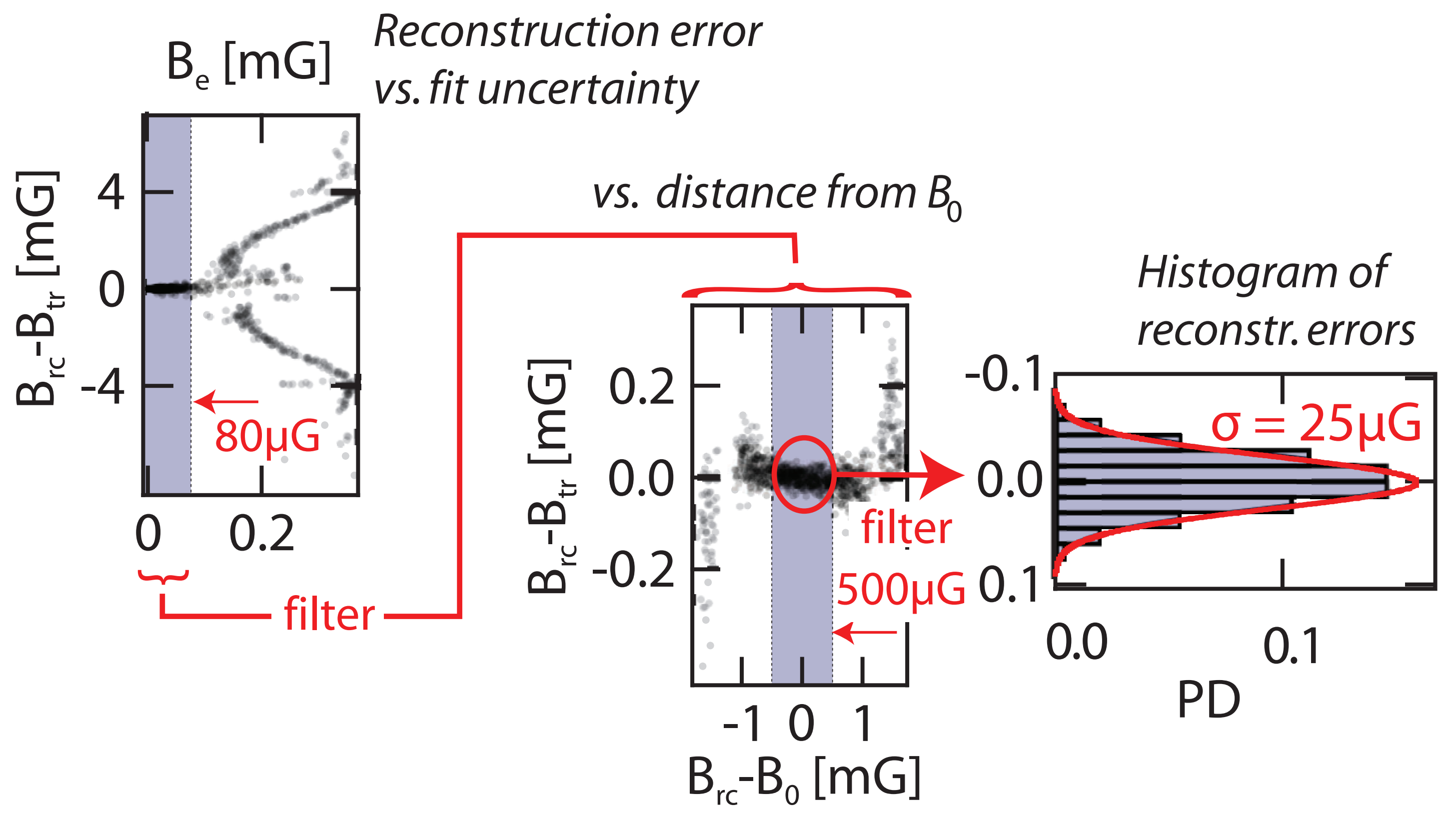
$\tilde{\Omega}_i = (\Omega_i^2 + \delta_i^2)^{1/2}$

$h(\delta_i + \omega_i) = E(F_i, m_{F_i}; B) - E(F_i', m_{F_i'}; B)$ Breit-Rabi

scalar magnetic field B

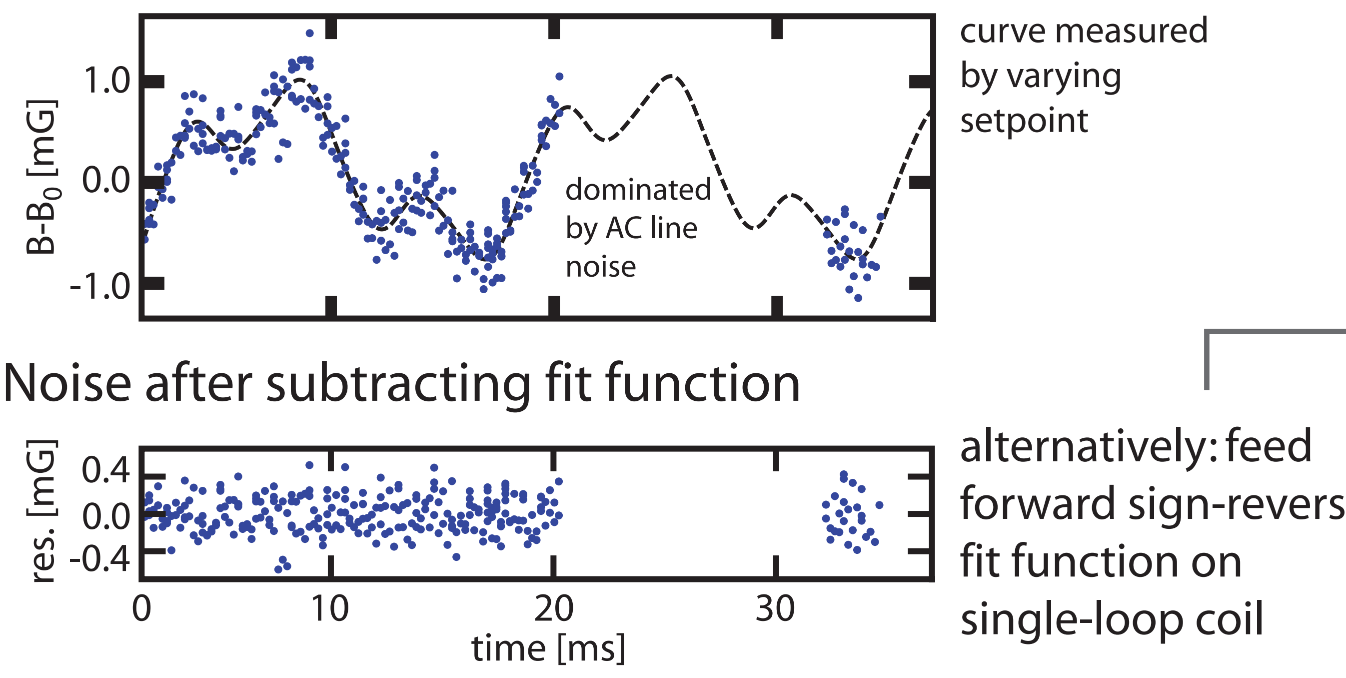
Monte-Carlo performance estimate

- "true field" B_{tr} drawn from Gaussian distrib. around B_0
- 10000 runs with $\Omega_i/2\pi = (0.9, 1.9, 3.1, 1.2, 1.9, 3.1)$ kHz
- assumed fluctuations:
  pulse parameters $\tau_i\,(\pm 2\mu s)$ $\Omega_i\,(\pm 1\text{dB})$ $\delta_i\,(\pm 2\pi \times 7\text{Hz})$
  instantaneous field $(\pm 100\mu G)$

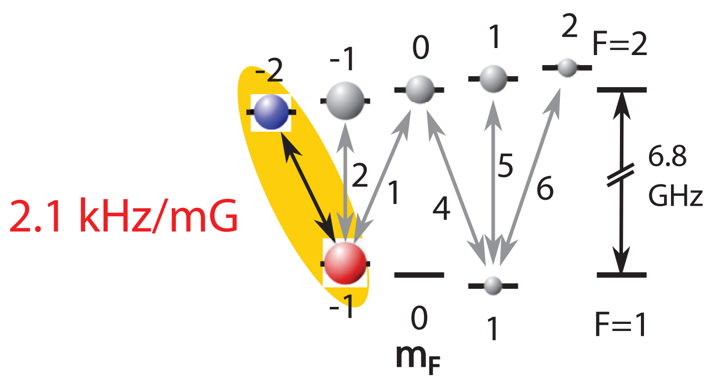


Experimental Characterization

Ambient field fluctuations

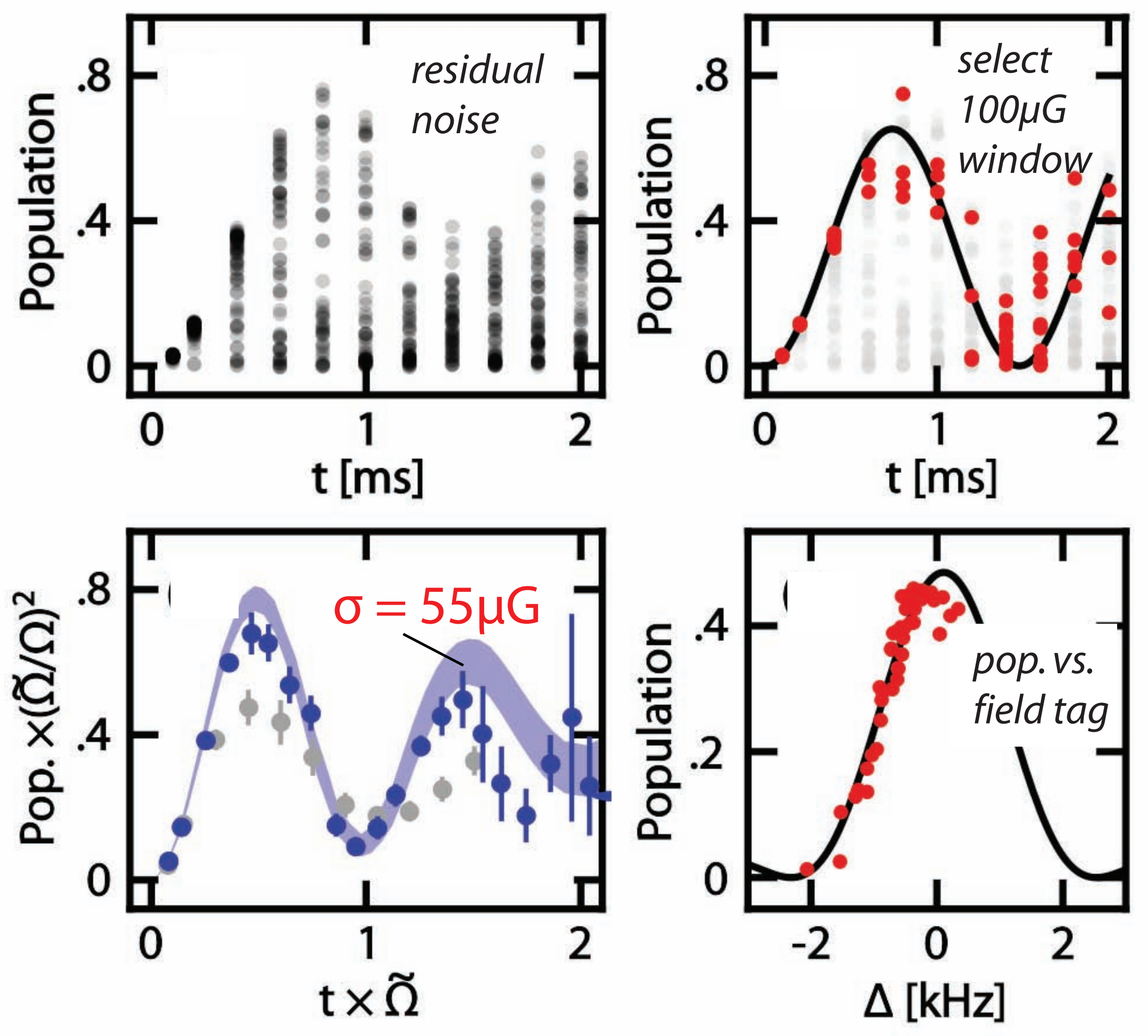


alternatively: feed forward sign-reversed fit function on single-loop coil



$\Omega_i/2\pi$ ~ 2kHz
τ_i ~ 150μs
i.e. sequence duration < 1ms

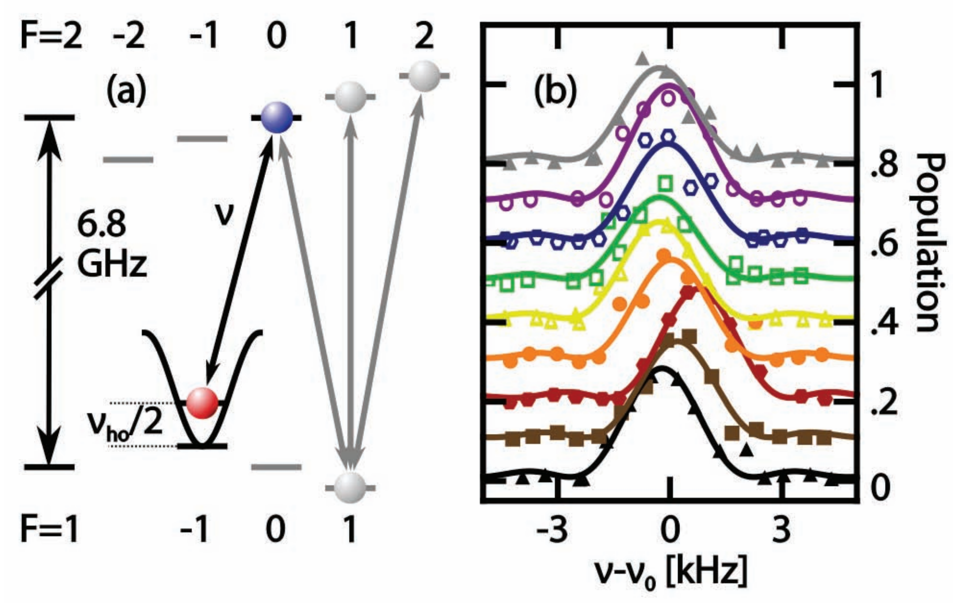
Test: slow Rabi cycling $\Omega = 2\pi \times 0.61(3)$kHz, $\delta = 2\pi \times 0.44(3)$kHz.



Note: *5-pulse sequence; pulse parameters chosen did not fulfil optimum condition*

Application

Spectroscopy of state-selective optical lattices



filter down to 100Hz level to identify drifts of optical potential

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