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Probing an Ultracold-Atom Crystal with Matter Waves

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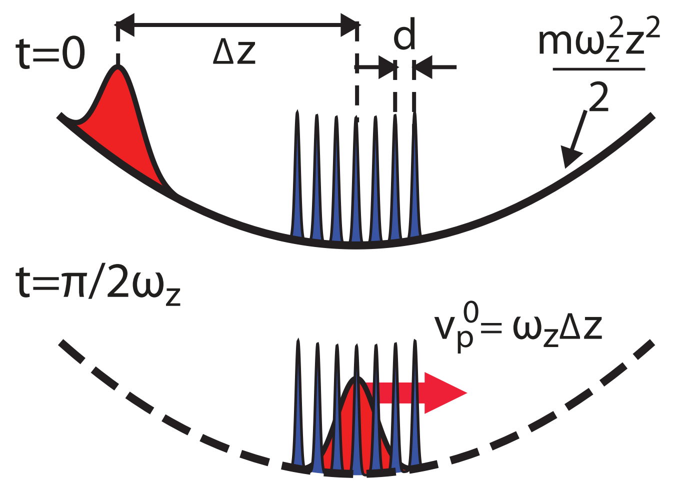
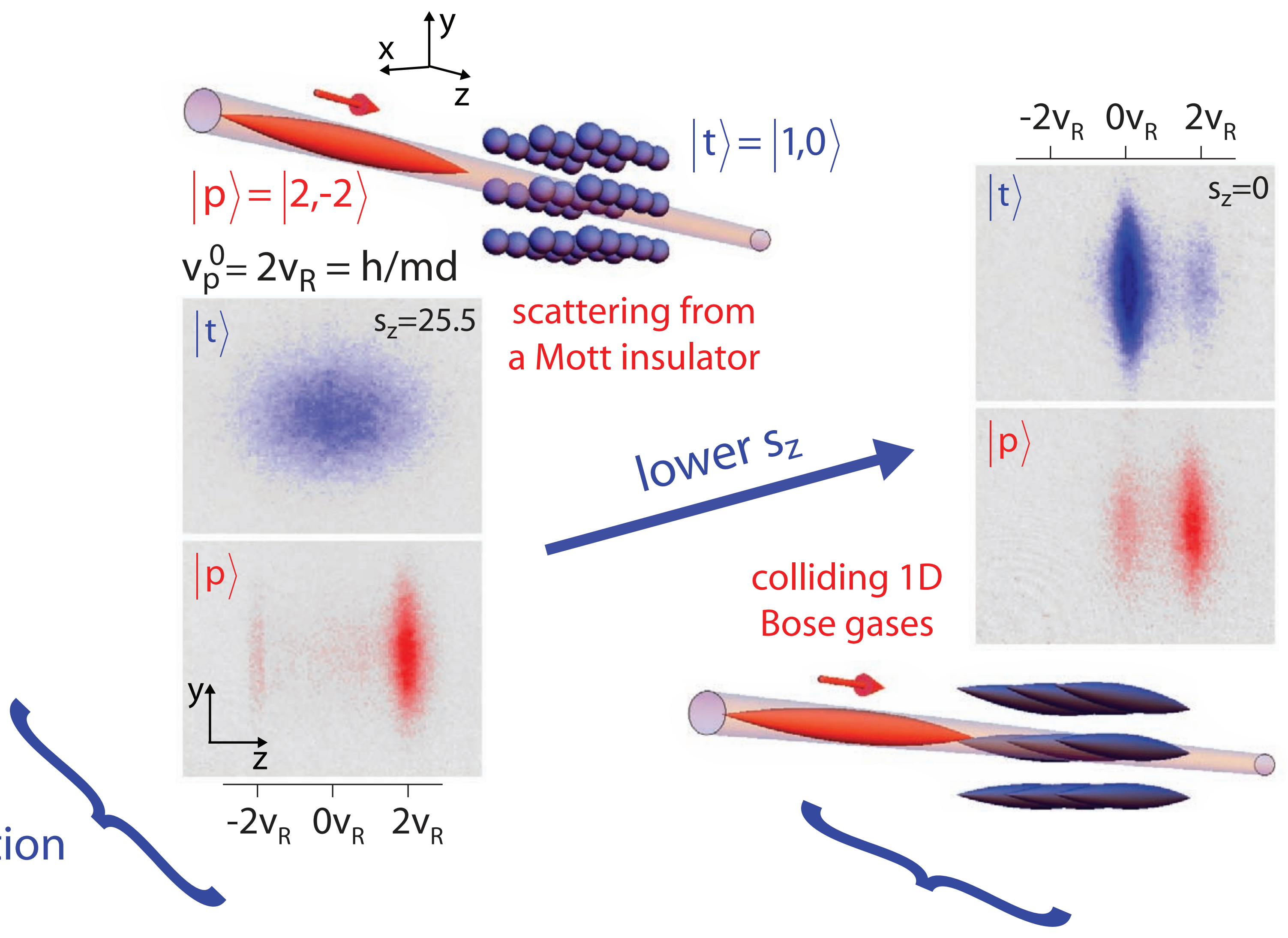
Motivation

- tunable de Broglie wavelength: no resol. limit
- non-destructive interrogation
- inelastic scattering for study of excitations
- spin-dependent coupling for the study of magnetic ordering in quantum gas mixtures
  Sanders et al., PRL 2010



simplest implementation: use of a magetic field gradient for relative displacement; release probe atoms into weakly confining ODT

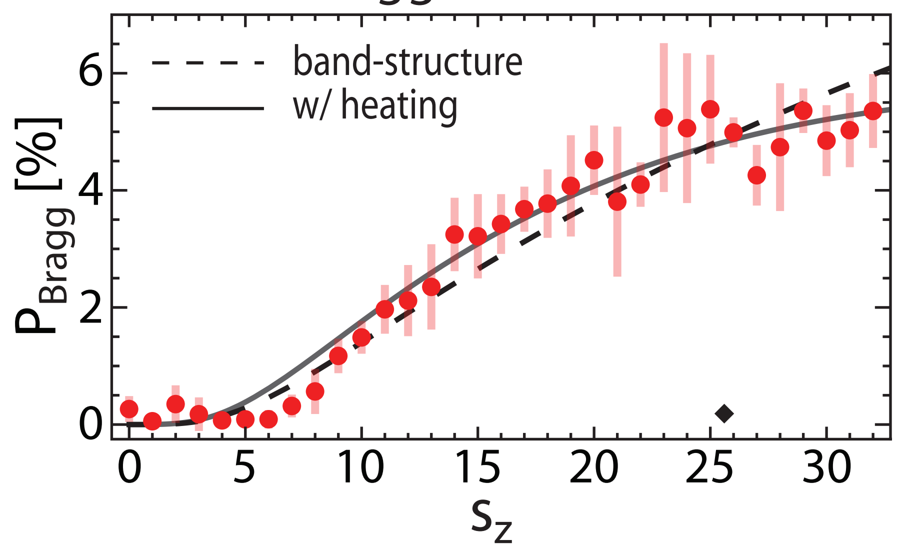
Elastic vs. Inelastic Scattering



Binary 1D collisions (quantum "Newton's cradle") with a spin mixture

Probing Localization in the Target

2nd order Bragg diffraction



Structure factor of the target

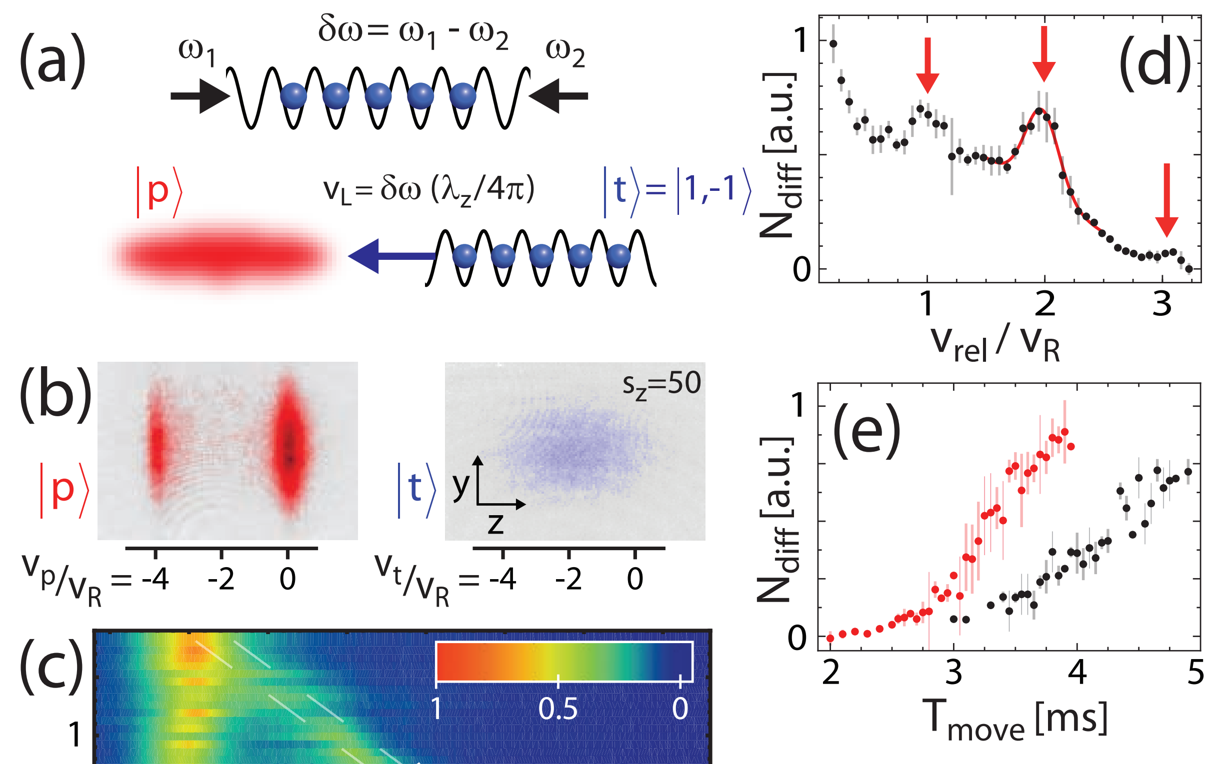
$$|f(q)|^2 = |\langle \varphi_0 | e^{iqz} | \varphi_0 \rangle|^2$$

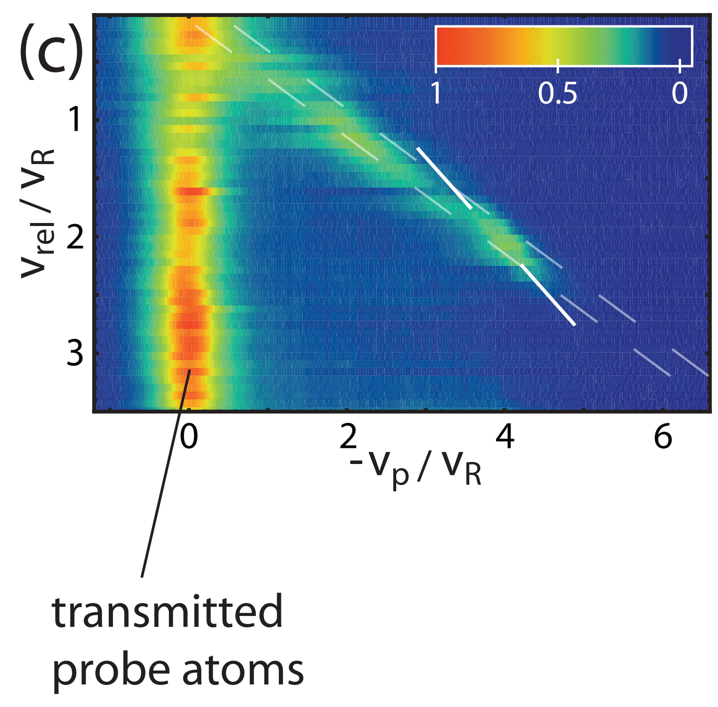
= square of Fourier transform of target's single-site density

analogous to thermal Debye-Waller (DW) factor ($e^{-q^2 \langle u^2 \rangle /2}$)
but here due to spread of target wavefunction φ_0
i.e. zero-point, rather than thermal, motion

Identifying Bragg Resonances

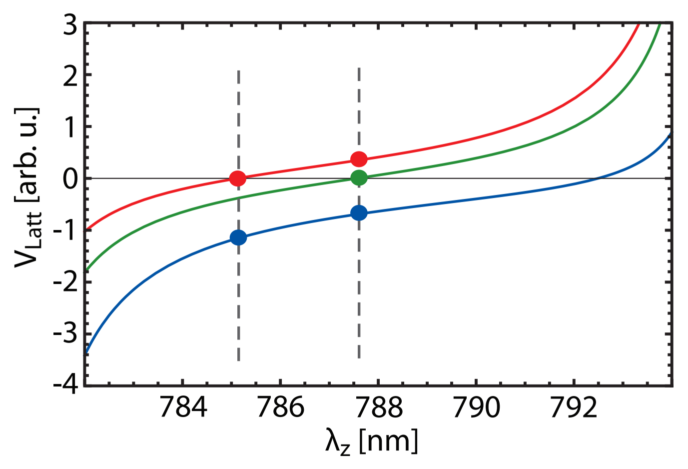
The de-Broglie wavelength associated with the relative motion is scanned precisely using a moving optical lattice for the target atoms





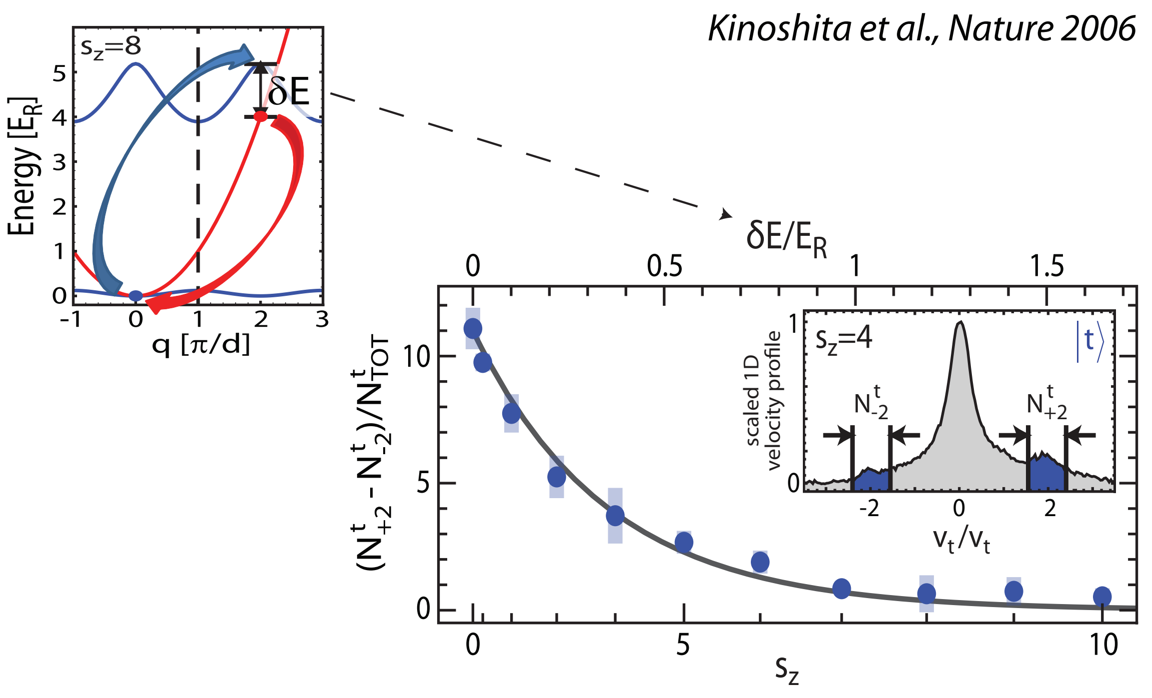
(a) experimental method
(b) TOF spectrum for 2nd order Bragg diffraction
(c) velocity scan: integrated TOF spectra of the probe
(d) Specular reflection and Bragg resonances
(e) Growth of population in diffracted peaks

Optical potentials (σ^- polarization)



Collisions in the Presence of Lattice Band Structure

Olshanii, PRL 1998
Kinoshita et al., Nature 2006

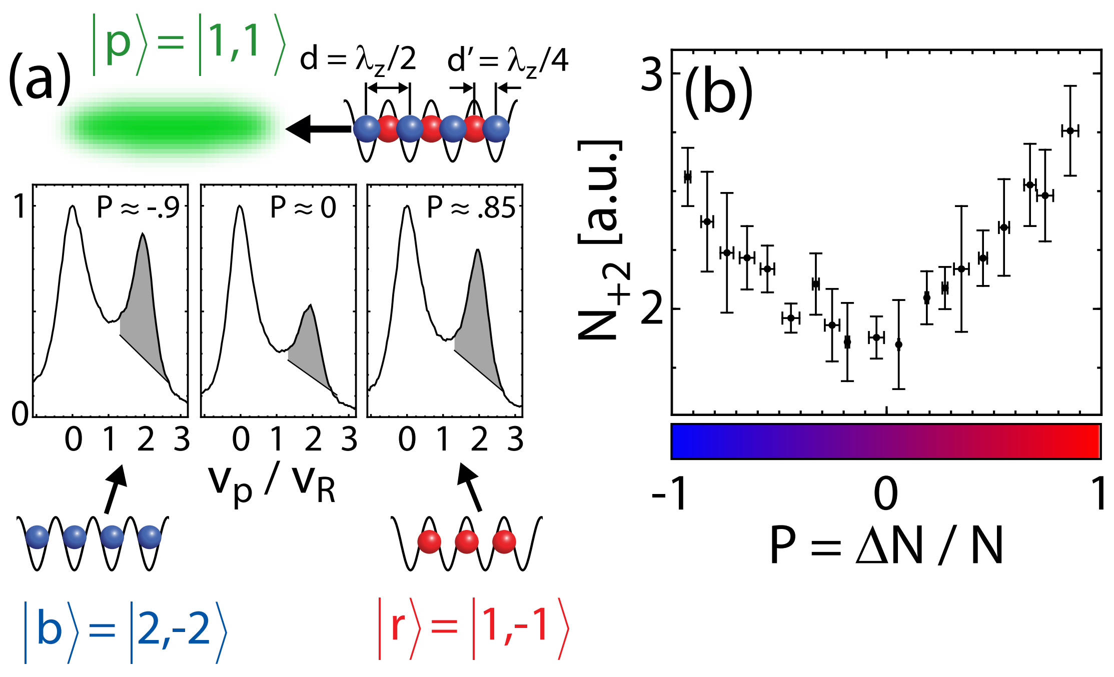


- decay is nearly exponential with band-structure mismatch δE
- short interaction time → Fourier spread

inhibition is of consequence for thermalization & thermometry schemes in quantum gas mixtures

Detecting Forced-AFM Order

we create a short-perdiod crystal of two atomic species that are pinned to the intensity maxima/minima of a state-dependent optical lattice at 788 nm, moving at v= - v$_R$



(a) Velocity spectrum of the probe (atoms in state $|1,1\rangle$) after interacting with the crystal. The first-order Bragg resonance of the half-period crystal is at v= -2v$_R$, leading to a suppression of the signal at v= - v$_R$.

(b) Number of Bragg-diffrated atoms as a function of the spin population imbalance in the crystal.