Composite picosecond control of atomic state through a nanofiber interface

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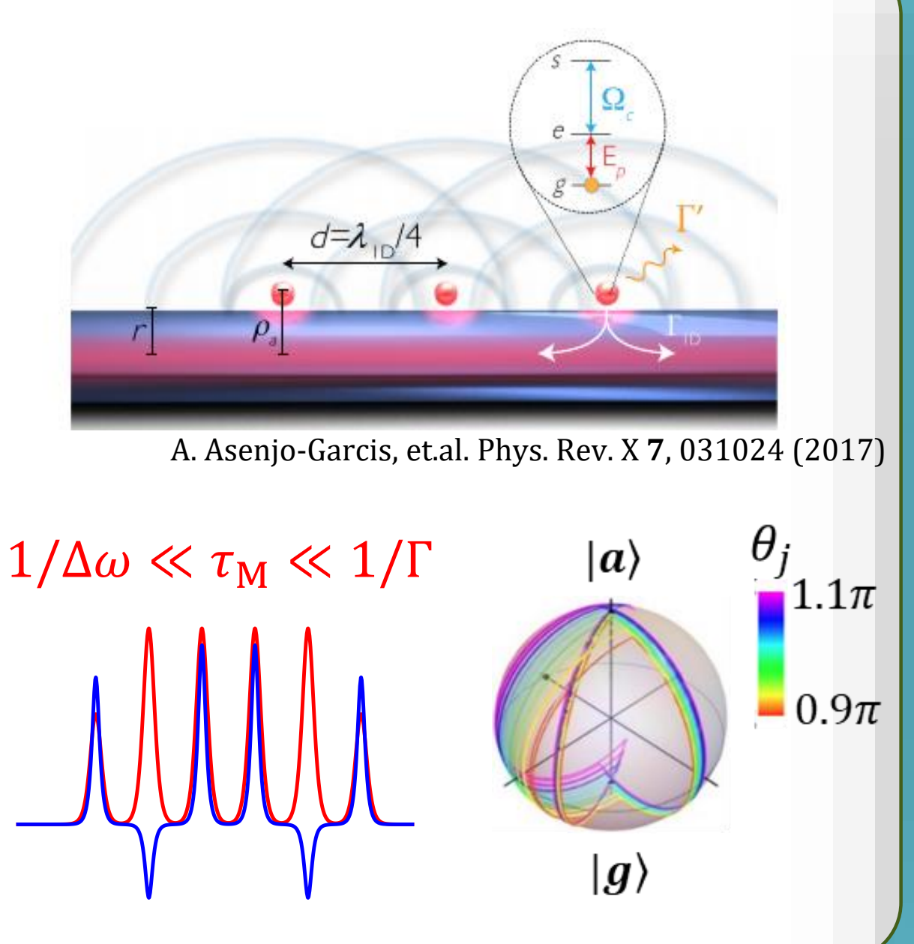
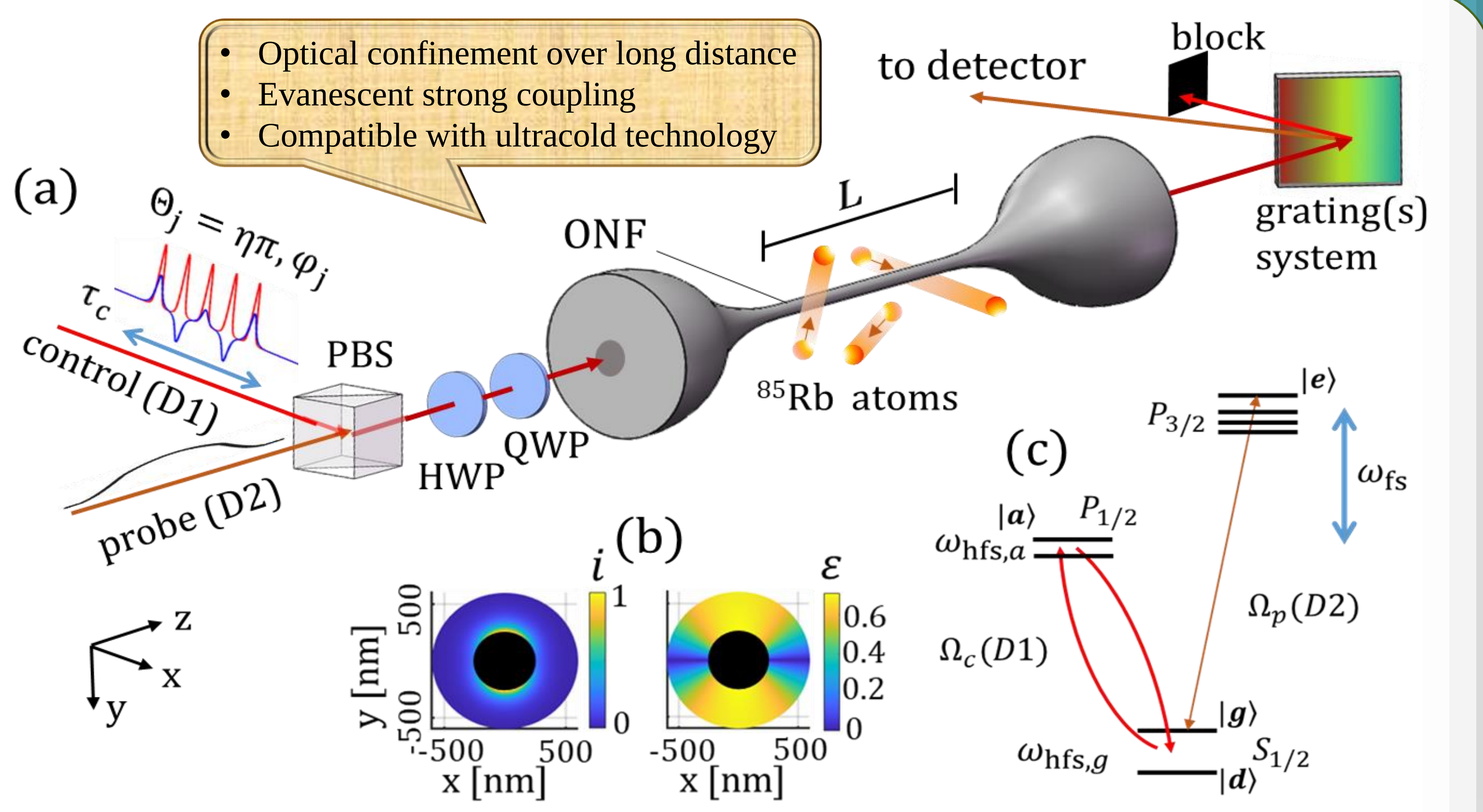
Introduction

- Nanophotonic interfaces: strong interaction between confined photons and nearby atoms.
- We propose to achieve high precision nanophotonic control of atomic states by composite excitation with coherent arrays of picosecond pulses.
- This work: A proof-of-concept by controlling atomic states of mesoscopic vapor at a nanofiber interface.

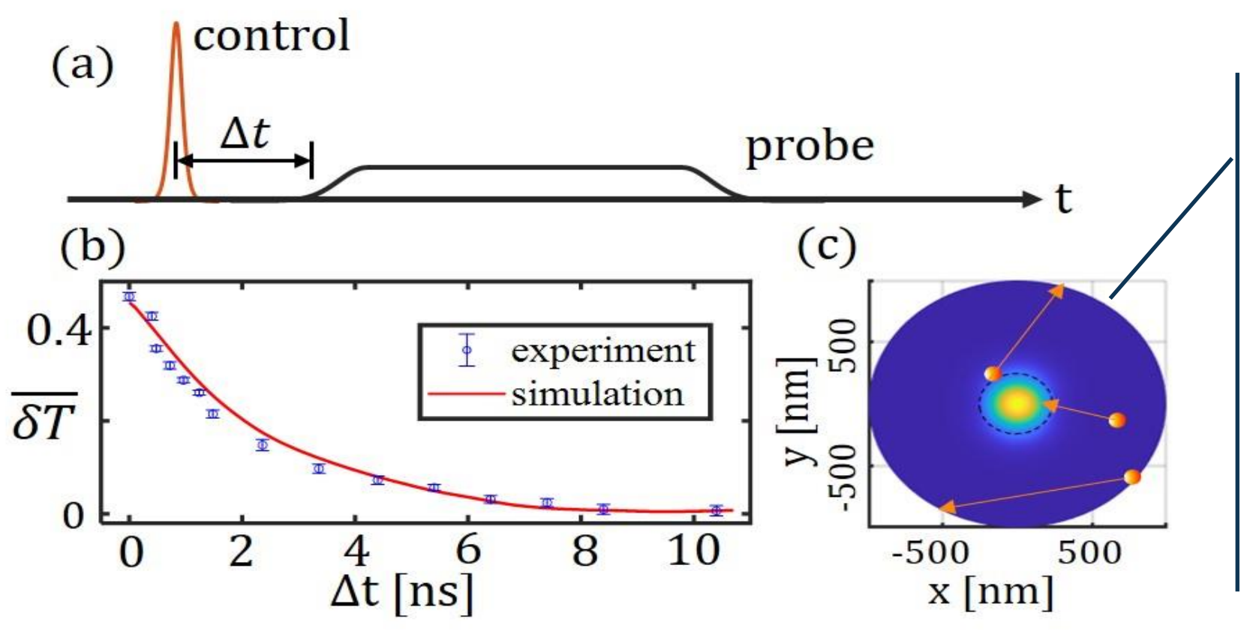

A. Asenjo-Garcis, et.al. Phys. Rev. X **7**, 031024 (2017)

Experimental Setup



- State-of-art atom-nanofiber interface.
  (L.Tong, Opt. Express,**12**, 1025(2004), D.Su, New J. Phys. **21**, 043053(2019)).
- Novel picosecond pulse shaping scheme for strong transition control [1].
- Composite picosecond D1 pulses to control transmission at D2.
- Controlling atoms at 300 m/s across the sub-micron evanescent field.
- Adjustable ellipticity distribution ε(r) through incident polarization control.

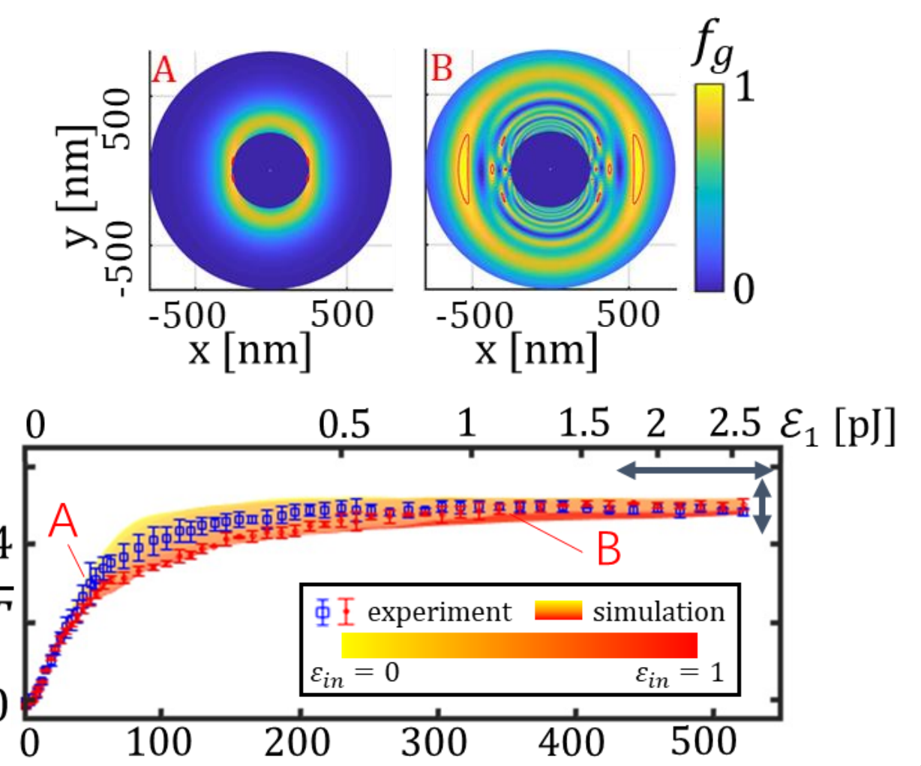
One pulse benchmark



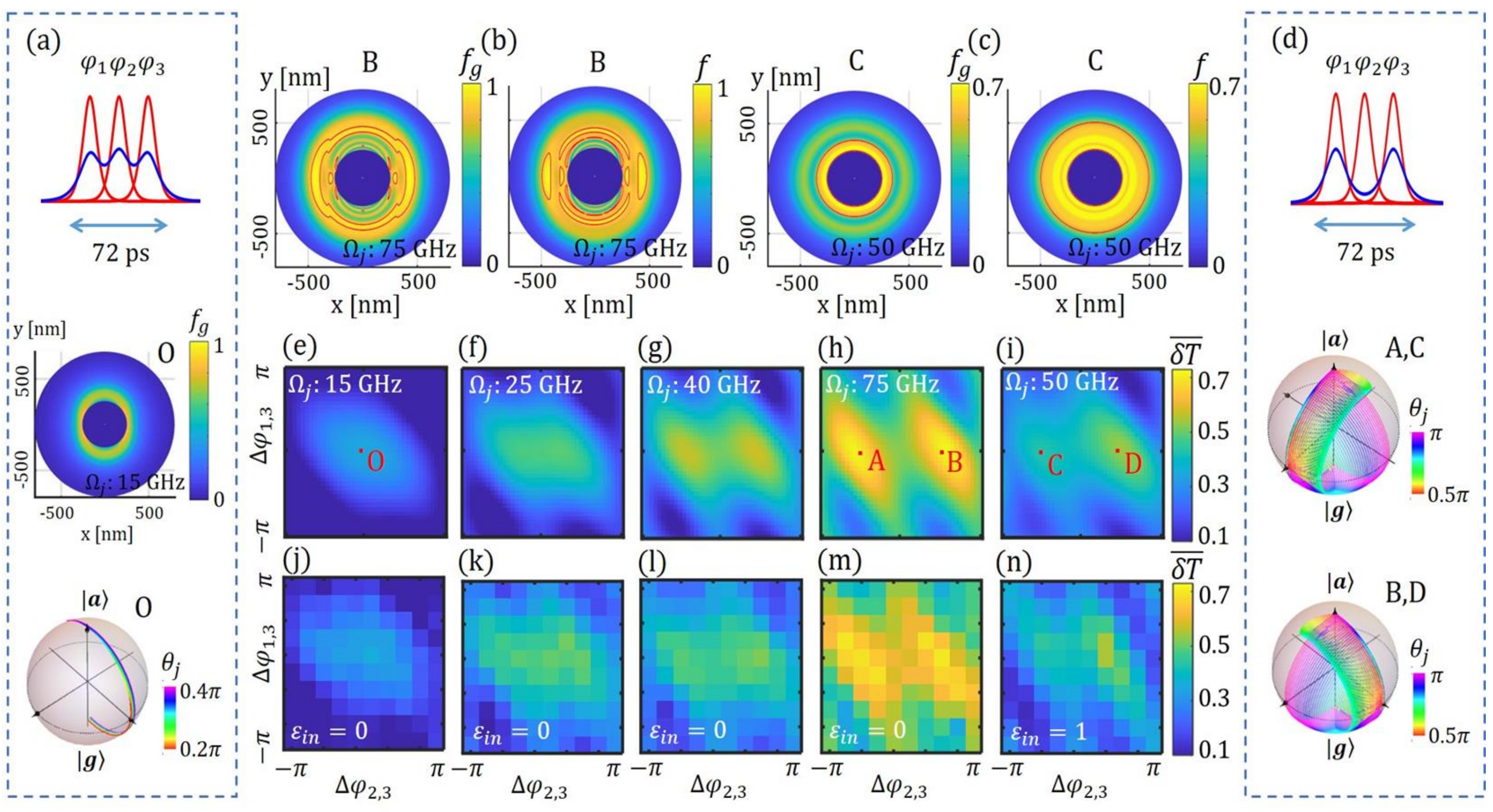
- We develop a full-level Monte Carlo simulation to recover the optical response of the mesoscopic vapor .
- Subtle features may unveil surface interaction dynamics.

· For N=1 picosecond control pulse, we delay the probe Δt to study the transient optical response of the thermal atoms (Fig. (a)). The result is shown in Fig. (b) with scatter plots. Here $\overline{\delta T}$ represents the control induced transient change of probe transmission, which reflects the D1 population inversion efficiency.

- We scan the control pulse energy $\mathcal{E}_1$ with linear or circular incident polarization at Δt=0 delay.
- Transient change of absorption $\overline{\delta T}$ up to ~45% is observed merely @ 1pJ.
- Incident helicities of control-probe matters.

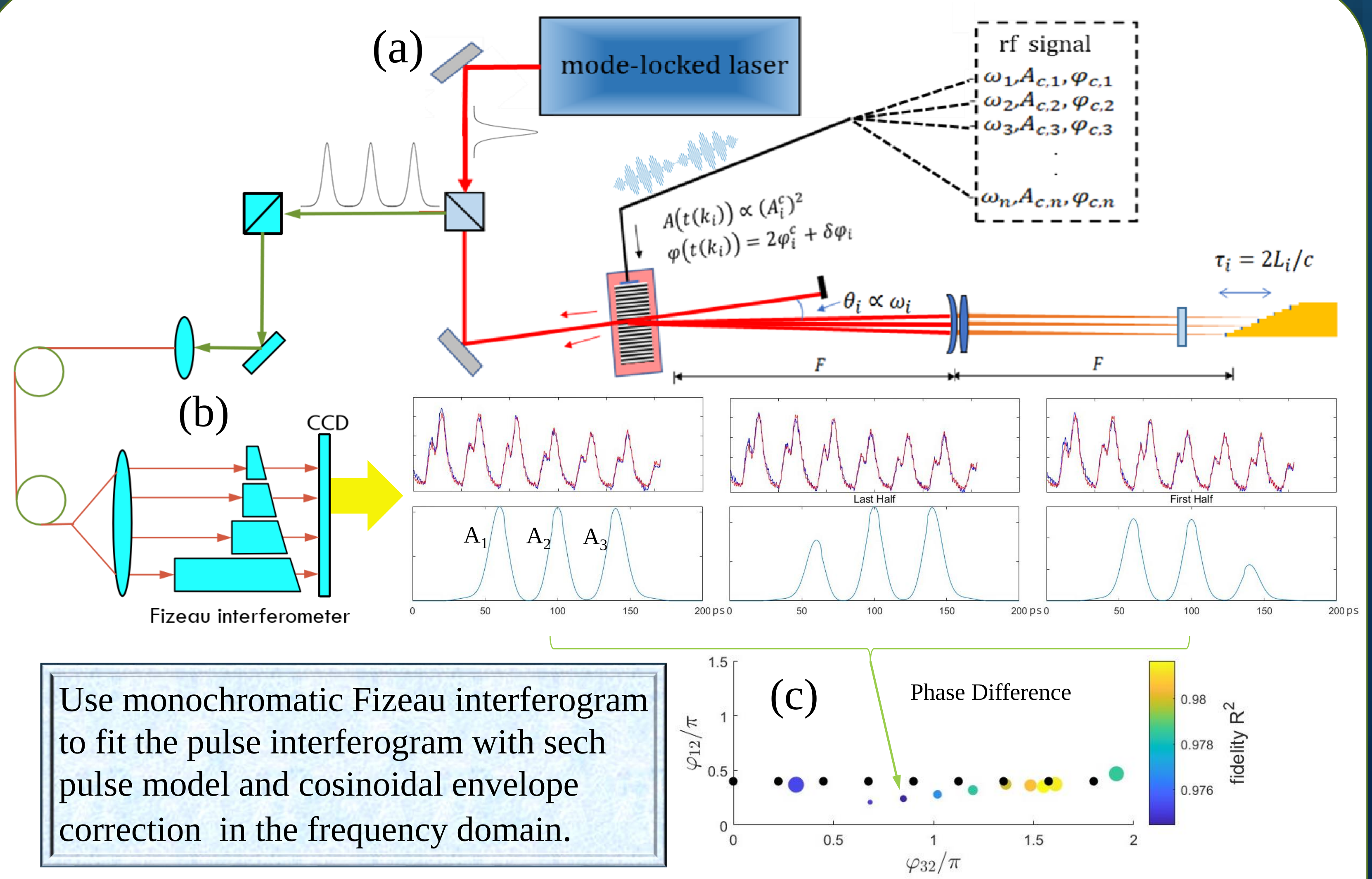


Composite control with three-pulse seq.



- We apply a phase-coherent N=3 pulse sequence to control the atoms in the evanescent field. Figs. (j-n) show the experimental measured $\overline{\delta T}$ at different incident polarization and power (associated with Ω_j).
- The experimental observations are corroborated with a full-level simulation (Figs. (e-i)).
- The broken sign symmetry in Fig.(i)(n) is associated with substantial |g) ↔ |d) Raman transfer, as unveiled by comparing the ρ_{gg}- depletion efficiency f_g(r) with the expected inversion efficiency f(r) in Fig. (c) according to the simulations.
- Behind the ~70% enhancement to the probe transmission is local population inversion efficiency of >90% (red curve in Fig.(b)) over a 100 nm-sized area. The control efficiency is improvable with larger N-sequences for high-fidelity manipulation of confined electric dipoles.

Pico-array generation and measurement



Use monochromatic Fizeau interferogram to fit the pulse interferogram with sech pulse model and cosinoidal envelope correction in the frequency domain.

(a) Picosecond pulse array is generated with a direct time-domain pulse shaping method [1].
(b) The array is too fast to be detected in the time domain directly. Instead, we develop a model-based method to infer the array waveform through spectrum measurement, using a commercial Fizeau interferometer (Moglabs FZW600).
(c) The Fizeau-inferred φ_j agrees quite well with rf-controlled φ_j^c. The deviations are likely due to nonlinear AOM transduction [1].

Acknowledgement & Reference

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Summary and outlook

- We demonstrate a composite picosecond scheme to achieve error-resilient control of a strong transition within the proximity of an optical nanofiber. A phase-coherent 3-pulse excitation efficiently invert the D1 transition of a ^{85}Rb vapor across the evanescent field, leading to an enhancement of fiber transmission of a nanosecond D2 probe by up to ~70%.
- Full-level numerical simulation suggests the composite scheme supports high fidelity control of alkaline atoms (f~99% level) through the ONF interface, robust against the near-field inhomogeneity associated with the rapidly varying intensity and polarization distributions. In future work, cyclic inversions driven by oppositely propagating guided pulses can shift the dipole spinors in k-space to control the collective interaction [4], thereby support efficient access to many-body physics in the subradiant manifold of the ONF-atom system featuring infinite-range 1D interaction [5,6].

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