Coupling Optical Transitions of Rb Vapor with Plasmonic Excitations

Ahmad Fumani
The Odom Group

MRSEC-IRG3
May 8th, 2017

THE ODOM GROUP

Atom-plasmon systems

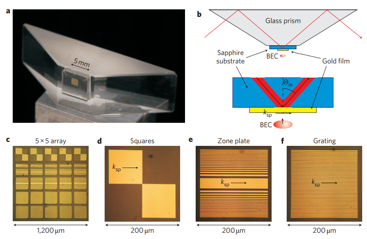
Why atom-plasmon systems are interesting:

Atoms:
- Identical quantum emitters
- Narrow optical transitions

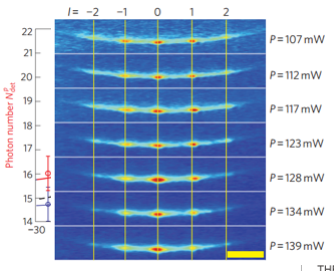
Plasmonic traps:
- Control over atomic motion in subwavelength regime
- Preparing exotic quantum many body states

Direct SPP and cold atom coupling

Plasmonically tailored micro-potentials



Diffraction images of cold atoms from Fano resonance between SPP plasmonic potentials

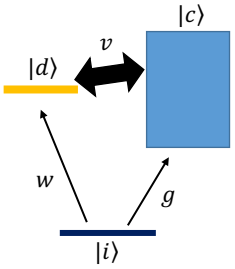


C Stehle, *et al*; Nature Photonics 5, 494 (2011) & Nature Physics 10, 937(2014)

THE ODOM GROUP

Fano resonance

- Coupling between a discrete and a continuum state



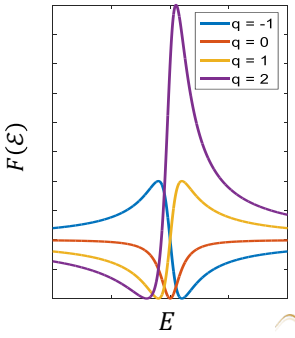
Lorentzian lineshape | Fano lineshape

- Coupling factors determine the shape of the resonance

$$F(\mathcal{E}) = \frac{(\mathcal{E}+q)^2}{\mathcal{E}^2+1}$$ Probability of exciting the mixed state

$$q = \frac{vw/g}{\Gamma_m(E)/2} + \frac{E-E_p}{\Gamma_p/2}$$ Excitation probability ratio

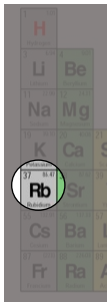
$$\mathcal{E} = \frac{E}{\Gamma_m(E)/2} - \frac{E-E_p}{\Gamma_p/2}$$ Reduced energy



THE ODOM GROUP

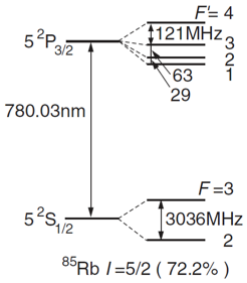
Rubidium vapor, the discrete state

- Alkali metal, Z = 37
- Single electron in 5S orbital



Very reactive metal
Melts at 39.3 C

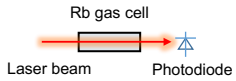
- Two natural isotopes: ^{85}Rb (72%)
  ^{87}Rb (28%)

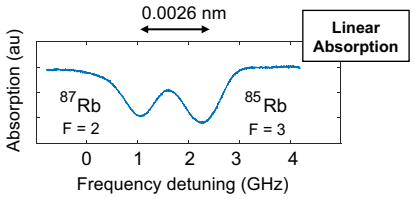


THE ODOM GROUP

Rubidium vapor, the discrete state

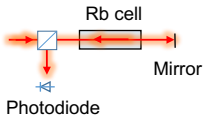
- Linear Absorption measurement

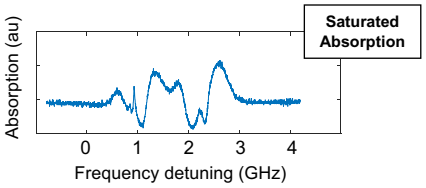




Doppler broadening covers the hyperfine lines

- To observe the hyperfine structure





- Extremely narrow lines provide the discrete state

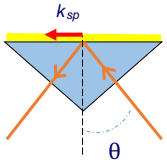
THE ODOM GROUP

Plasmonic excitation, the continuum state

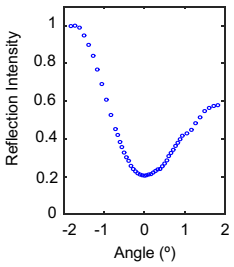
- **SPPs on a gold film**

Coupling photons and plasmons via a prism :

$$\frac{2\pi}{\lambda} n_{prism}\, Sin(\theta) = k_{sp}$$



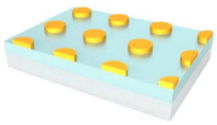
Pumped at 780.02 nm



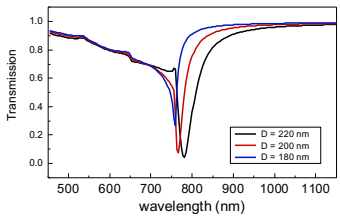
- Evanescent decay length is ~ 500 nm

- **Lattice plasmon resonance**

Localized surface plasmon coupled to Rayleigh anomaly :



Lattice resonance, simulation

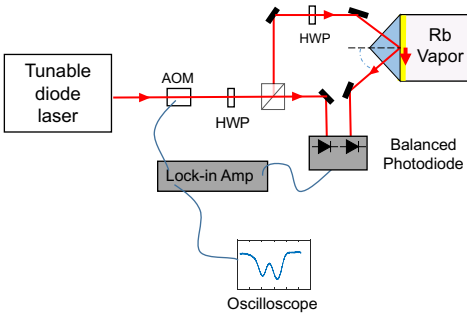


A Yang, …., T Odom; Nature Comm. 6, 6939 (2015)

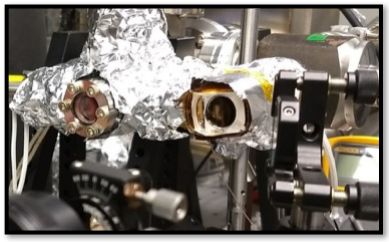
THE ODOM GROUP

Experimental setup

Balanced photodetection method



Prism with gold film on the chamber

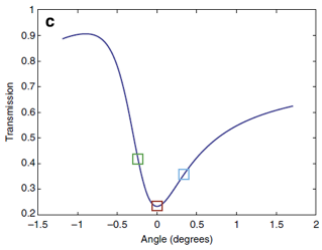


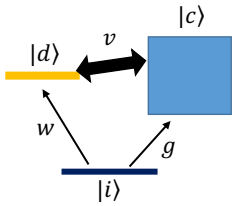
- Rb is released from a filament.
- Laser intensity fluctuates in ~1-2%.
- Signal is ~0.001 change in intensity.

THE ODOM GROUP

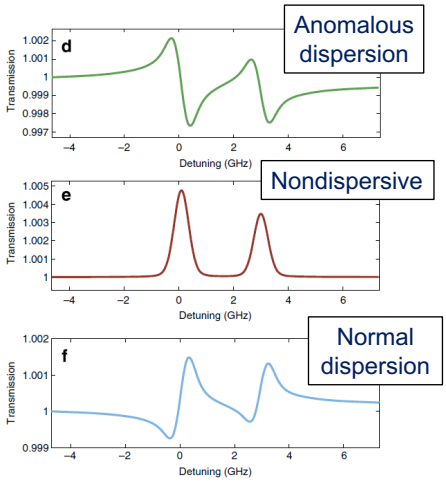
Fano resonance in hybrid atom-plasmon system

Plasmonic resonance on prism





Gas-Plasmon Spectra
Different coupling regimes

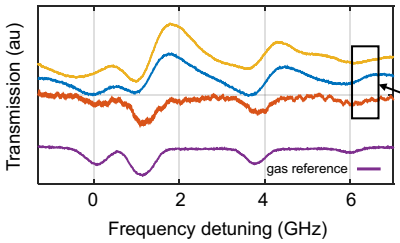


L Stern, et al. Nature Communications 5, 4865 (2014)

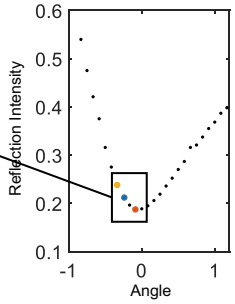
THE ODOM GROUP

Measurement results

- Atom-Plasmon response in three different regimes



Measured plasmonic resonance



- Controlling the Fano resonance between atoms and plasms

THE ODOM GROUP

Preparing lattice resonance for gas

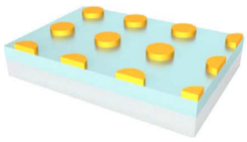
- Plasmonic lattice resonance needs a uniform environment
- Refractive index of Rb gas = 1

Low refractive index nanoporous film with n = 1.16

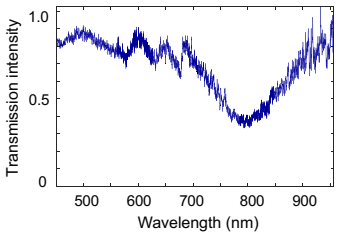
Two components:
1- Poly (methyl silsesquioxane), an organosilicon compound
2- Poly(styrene-block-2-vinylpyridine), block copolymer

Thermolysis at 400 C

Gold particles on a nanoporous film



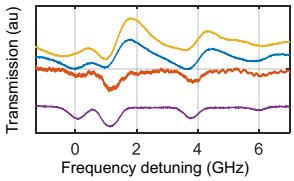
Lattice resonance with air on top

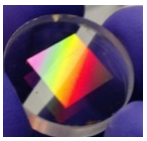


THE ODOM GROUP

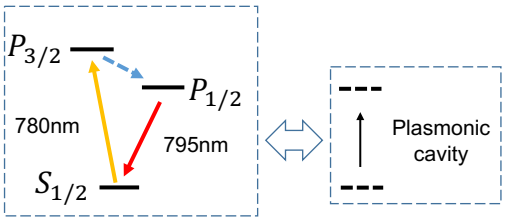
Summary & Conclusions

- Fano resonance between atoms an plasmons:
  Signature of a hybrid atomic-plasmonic state:
- How we implement this state,
  experimental detection method
- Ongoing work on using
  stronger local electric fields





- Lasing Scheme in Rb



Thank you for your attention!

THE ODOM GROUP