Session 9

Posters:

A High-Q Micro-Resonator for Trapping and Detecting a Single Atom on a Chip

Michael Rosenblit[1], Yonathan Japha[1], Peter Horak[2], and Ron Folman[1]

[1]Department of Physics and Ilze Katz Center for Meso- and Nanoscale Sciense and Technology, Ben-Gurion University of the Negev, Beer-Sheva, Israel
[2]Optoelectronic Research Centre, University of Southampton, Southampton, UK

The recent progress in the manufacturing of high Q dielectric microresonant structures may enable their use as photonic devices that can manipulate and/or detect external particles, i.e. single atoms on a nanometer scale. Of specific interest is the wafer-based manufacturing of resonators where a good control of the physical characteristics can be achieved during fabrication and during operation, when they are integrated with other functions on the chip.
We investigate the possibility of simultaneously trapping and detecting single atoms near the surface of a substrate using the external field of optical whispering gallery modes (WGMs) which are supported by a toroid microcavity. The advantages are the small electromagnetic mode volume and the high Q value that can be achieved in a microdisk resonator [1,2].
We have calculated the evanescent fields of some optical WGMs and found that for efficient atom-mode coupling the atom should be placed within 80 – 180 nm from the disk. Such close proximity should be feasible by balancing the attractive van-der-Waals/Casimir forces, the repelling blue detuned resonator light which is used for atom detection, and red detuned light used to create a trap. We show that the latter "all-optical" trapping should be possible and stable [2].
We discuss atom detection efficiencies and the feasibility of non-destructive measurements in such systems depending on key parameters such as atom distance from the surface, intensity of a red- and blue-detuned laser pump fields and disk size.

References

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2. Phys. Rev., A73, 063805 (2006)

DICKE NARROWING IN ELECTROMAGNETICALLY INDUCED TRANSPARENCY

O. Firstenberg, M. Shuker, A. Ben-Kish, A. Ron
Physics Department, Technion
oferfir@tx.technion.ac.il

N. Davidson
Physics of Complex Systems, Weizmann Institute

Electromagnetically induced transparency (EIT) occurs when two radiation fields excite two atomic levels to a common upper level, creating a coherent superposition that reduces the absorption of the medium. This phenomena depends strongly on the Raman (two photon) detuning, showing a sharp resonance around zero Raman detuning (EIT resonance). When a hot atomic vapor is sampled and the two lower levels are non-degenerate, one would naively expect the EIT resonance to be Doppler broadened. However, experimentally measured EIT resonances do not exhibit such broadening. For one photon absorption resonances it is well known that frequent velocity-changing collisions can reduce the Doppler broadening, a phenomena known as Dicke narrowing. The narrowing factor depends on the ratio between the collisions mean free path and the radiation wavelength.

Here we show theoretically and experimentally that the same narrowing effect occurs for EIT resonances. This narrowing enables the high accuracy of almost all EIT applications in vapor medium (e.g. atomic clocks). We present, for the first time, an analytic expression for the Dicke-narrowed EIT line-shape. The narrowing factor depends on the ratio between the mean free path and the wavelength associated with the frequency difference of the two radiation fields. An experimental verification of the theory is attained by introducing an angular deviation between the pump and the probe and measuring the resulting line-shape.

LOSCHMIDT ECHO AS A PROBE TO ATOM OPTICS BILLIARD DYNAMICS

T. Grunzweig, Y. Sagi, Y. Wang, Y. Hertzberg, A. Ridinger and N. Davidson

Dept. of Physics of Complex Systems, Weizmann Institute of Science, Rehovot, Israel
Email: tzahi.grunzweig@weizmann.ac.il, Webpage:
http://www.weizmann.ac.il/~davidson

The possibility to control and manipulate cold atoms has holds promise of applying cold atoms to quantum information processing as well as for precision measurements. Once the atoms are cooled and trapped their internal states can be probed. The difficulty then lies in the coupling between their internal and external degrees of freedom.

In our experiment ultra cold Rubidium 85 atoms were trapped in a wedge shaped optical dipole trap with vertex angle of 30 degrees. This configuration was shown to have mixed dynamics with a large island of stability surrounded by a chaotic "sea". The trapping potential of the atom center of mass (external) state depends on its hyperfine split (internal) state occupation. The optically trapped atoms are initially prepared in their lower hyperfine state. The atoms were then subjected to a microwave Ramsey sequence: First a microwave pulse forms a superposition of both hyperfine states, then the atoms evolve a time T and finally after a second pulse the resulting transfer of population to the excited state is measured by selective fluorescence detection.

The coupling between internal and external degrees of freedom results an envelope to the expected Ramsey cosine, even for a single atom. We show that this envelope function is the Loschmidt echo (also known as the "fidelity"). The Loschmidt echo has been proposed as a measure of sensitivity of mixed phase space systems to perturbations. Ensemble average over all atoms in the trap results in a further decay of fringe contrast due to inhomogeneous effects. It is possible to eliminate the inhomogeneous broadening by use of coherence echo, however this comes at the price of reducing the coherence through trap level mixing due to the larger microwave irradiation required.

As we vary the perturbation strength, the decay envelope structure changes as the dominant mechanism of decay changes from trap level mixing (strong perturbations) to Loschmidt dynamics (intermediate perturbations) and eventually to inhomogeneous broadening (weak perturbations). In the Loschmidt regime, we observe revivals of the fringe contrast at the Thoules time, reflecting the non-generic nature of the perturbation applied here, and the existence of low order periodic orbits motion of atoms in the trap.

CHANGES IN EXCITATION LINE SHAPES DUE TO BELIAEV DAMPING IN A BEC

E. E. Rowen, N. Bar-Gill, R, Pugatch and N. Davidson
Weizmann Institute of Science, Rehovot, Israel
eitan.rowen@weizmann.ac.il

The decoherence of a quantum system typically involves the coupling of an excitation to a continuous bath of modes, leading to an effective irreversibility on time scales longer than the correlation time of the reservoir. In our experiment, the cause for decoherence is the Beliaev decay of Bogoliubov quasi-particles. We can observe both the coherent excitation and the decay products of the collision processes. This is to be contrasted with the photon emitted by an atom in a spontaneous emission process, which is typically untraceable.

The unique structure of the BEC reservoir, which is composed of a continuum of initially unoccupied quasi-particle modes, results from the quantum interference between the hole and particle amplitudes of these modes. The continuum is further modified by inhomogeneity. The cigar shape of the condensate leads to a discrete spectrum in the radial direction, and a quasi continuous density of states in the axial direction. We quantitatively study the Beliaev decay of Bogoliubov quasi-particles of different energies and momenta.

We observe a momentum dependent collisional shift of the excitation spectrum, as can be seen in Fig. (1). We have derived a local density theory to describes this shift, and have verified it against a rigorous calculation of the decay of each radial mode of the condensate.

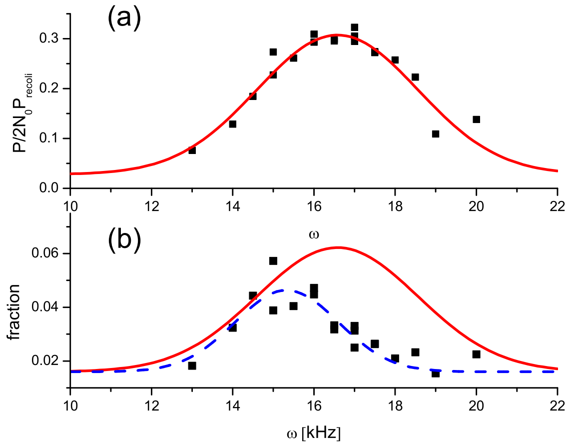

Figure 1: The number of excitations as a function of the exciting frequency for Bogoliubov quasi particles with momentum 4π/(780nm). (a) All excitations (b) Noncollided excitations. There is a clear shift down in the resonance frequency of the non-collided excitations.

SPATIAL SELECTION OF ATOMS IN OPTICAL BILLIARD

<u>Y. Hertzberg</u>, T. Grünzweig, A. Ridinger, Y. Sagi and N. Davidson
Department of Physics of Complex Systems, Weizmann Institute of Science, Rehovot 76100, Israel
Email: Yehonatan.Hertzberg@weizmann.ac.il

By releasing ultra-cold atoms from a small red detuned Gaussian trap to an optical wedge billiard we reduce the energy broadening of the atoms and perform spatial selection on the initial occupied phase space.

Quantum and classical Hamiltonian dynamics has been the subject of active research in physics and mathematics for many years. In particular, two-dimensional billiards [1] in which particles are confined to a closed region, undergoing elastic collision with the walls and free motion in between.

Experimental realization of the theoretical billiard, which is known as “atom-optics-billiard”, is made of blue detuned light sheets that confine cold atoms mostly in the dark. Due to the coupling between the atom's internal state and its dynamics [2] the coherence properties of atoms in an optical dipole trap are affected by their dynamics in the trap. Using echo microwave spectroscopy ($\pi/2$- π- $\pi/2$ short on-resonance microwave pulses) of ultra cold atoms trapped in a wedge billiard, it was recently shown [3] that the revivals in the echo signal are sensitive to the regularity of the time intervals between the interactions of an atom with the billiards walls. Here, we use a mixed dynamics wedge billiard with a 30^o vertex angle, as in [3]. The atoms are loaded to the billiard trap in two different techniques: from a magneto optical trap (MOT) and from a point source. Loading the billiard from a MOT, which is much bigger than the size of the billiard results in uniform occupation of a large area of the trapping phase space by the atoms. In the point source scheme, we load the wedge billiard from a small (20 microns) red-detuned Gaussian beam (Fig. 1) such that the initial conditions of the atoms in space reduce to the spot size of the Gaussian beam. By changing the relative position of the Gaussian beam and the wedge, we select the atomic spatial initial conditions.

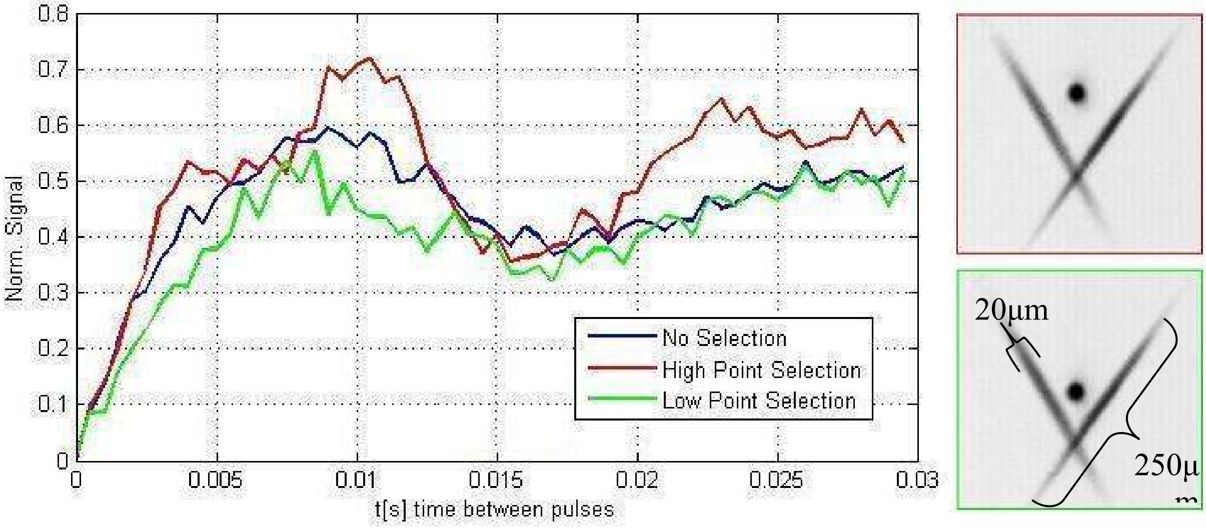

Fig. 1: Echo signals for atoms with no-selection (blue), high point selection (red) and low point selection (green) in a classically mixed phase space wedge billiard. The wedge (right) light sheets are 4nm blue detuned from the D_2 line of ^{85}Rb and the small Gaussian beam, seen at two positions, high (right up) and low (right down) is ~250nm red detuned. The revival and height of the echo signal of the high and low point selections are higher and lower than the no-selection case respectively.

In summary, we have demonstrated a new tool that reduces the energy broadening of the atoms and the optical billiard's initial occupied phase space by loading the atoms into the trapping area of the optical billiard from a smaller trap. Using echo microwave spectroscopy we showed that the type of loading has a strong effect on the regularity of atomic trajectories in the billiard.

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EFFECT OF SUPERRADIANCE ON TRANSPORT OF DIFFUSING PHOTONS IN COLD ATOMIC GASES

A. Gero* and E. Akkermans

Department of Physics, Technion - Israel Institute of Technology, Haifa 32000, Israel
gero@tx.technion.ac.il

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We study the influence of cooperative effects such as superradiance and subradiance on the scattering properties of dilute atomic gases. We show that cooperative effects lead to a potential between two atoms that decays like the inverse of the distance between them. In the case of superradiance, this potential is attractive for close enough atoms and can be interpreted as a coherent mesoscopic effect. The contribution of superradiant pairs to multiple scattering properties of a dilute gas, such as photon elastic mean free path and group velocity, is significantly different from that of independent atoms. Near resonance, it leads to a finite and positive group velocity, unlike the one obtained for light interaction with independent atoms.

* email address: gero@tx.technion.ac.il

MESOSCOPIC FLUCTUATIONS OF DIFFUSING PHOTONS IN COLD ATOMIC GASES

O. Assaf* and E. Akkermans
.ohadasaf@tx.technion.ac.il

Department of physics, Technion – Israel institute of technology, Haifa, 32000, Israel

We study the intensity correlation function of speckle patterns that result from coherent multiple scattering of photons by cold atomic clouds. We show that this correlation function becomes larger than the value given by Rayleigh law for classical scatterers. The enhanced correlation is very sensitive to an applied magnetic field, and is sharply peaked around the level-crossing point, suggesting that it might be used for a new, highly accurate, level-crossing spectroscopy.

*email address: ohadasaf@tx.technion.ac.il.

Sub-Doppler and sub-natural narrowing of an absorption line

N. Gavra [a], M. Rosenbluh [a], T. Zigdon [b], A. D. Wilson-Gordon [b]

[a] *Resnick Institute for Advanced Technology and Department of Physics, Bar-Ilan University, Ramat-Gan, Israel, 52900*

[b] *Department of Chemistry, Bar-Ilan University, Ramat-Gan, Israel, 52900*

E-mail: gavran@mail.biu.ac.il

The phenomenon of "electromagnetically induced transparency" (EIT) has been much explored since its first observation, and has became an important and efficient tool in the non-linear optics and laser spectroscopy. The essential feature of EIT is the existence of quantum superposition states in the atom, also called a "dark state". In atomic systems, this state is established when the frequency difference between a pump and probe laser equals exactly to the difference between two levels of the atom from which normal absorption to upper levels can generally be observed. A typical example is the hyperfine ground state levels of an alkali atom forming a Λ system with an upper state.

Here we present the experimental observation of multiple quantum superposition states that are coupled and interact simultaneously and are thus characterized by a "double-dark" resonance. The probe absorption spectrum of a four-level system, shown schematically in Fig. 1, driven by two pumps, is shown to possess two frequency displaced EIT windows separated by a narrow absorptive frequency range, as shown in Fig 2. The position of the two EIT windows can be tuned by a magnetic field thus making the central absorptive feature very sharp. When the two EIT windows are sufficiently close to each other, the absorptive region between them iss shown to have sub-Doppler and subnatural linewidth.

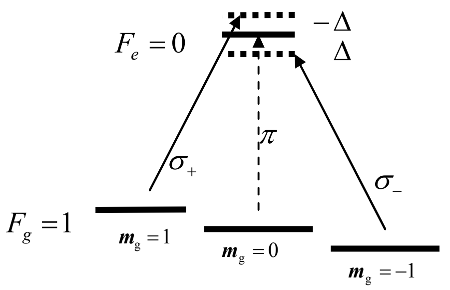

Fig. 1. Fg=1→Fe=0 transition when the degeneracy is lifted by a magnetic field.

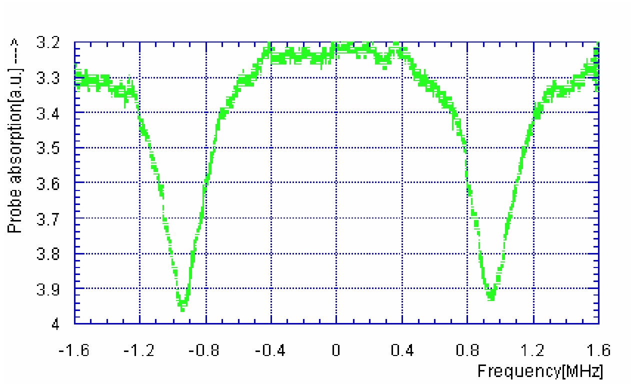

Fig 2. Probe absorption versus Probe detuning for the ground of Rb_{87}. The Pump and $F = 1 \rightarrow F = 0$ state hyperfine level Probe is σ and π polarized respectively. Pump intensity