Photoionization of Bose-Einstein condensates

D. Ciampini, M. Anderlini, J. H. Müller, F. Fuso, O. Morsch and E. Arimondo

Dipartimento di Fisica Università di Pisa e Istituto Nazionale per la Fisica della Materia, Via F. Buonarroti 2, I-56127 Pisa, Italy

E-mail: anderlin@df.unipi.it, Website: www.df.unipi.it/gruppi/struttura/index.htm

The recent development of laser cooling and magnetic trapping techniques has allowed the realization of always denser and colder atomic samples at the point that the achievement of Bose-Einstein condensation has eventually been reached with several alkali species.
This, in turn, has furnished new powerful means for investigations in the low and ultra-low temperature regimes, not accessible with conventional techniques.
The study of ultra-cold plasmas [1] and of photoionization processes of cold atoms, providing the opportunity to perform accurate measurements of the photoionization cross section [2] have also lately attracted a great interest.
As a matter of fact photoionization of Bose-Einstein condensates with laser light is a process which allows at the same time the investigation of many fascinating properties of cold systems, thanks to the quantum degeneracy of the initial neutral bosonic sample and to the fermionic nature of the produced cold charged particles (electrons and ions) [3]. Due to the coherent nature of the initial ensemble and the narrow spectral width of the light source, the occupation numbers of the final states can become close to unity, especially for excitation close to threshold. The Fermi-Dirac statistics governing the photoionization products then could even slow down the process decreasing the rate of ionization to the value of the rate at which the products escape from the system. In that case a reduction of the photoionization cross section would be observed with the increase of the initial sample's phase space density, that is, when one passes from ionizing a thermal cloud to a BEC.
Moreover the ionization of atoms within a BEC allows the study of interactions between charged and neutral particles of the condensate, and between the charged particles themselves, in conditions very far from thermodynamical equilibrium and with significant overlap of the wavefunctions of the fermions. This means that the standard techniques for the treatment of plasma deviating slightly from the equilibrium state or the standard binary-collision approach cannot be used to describe properly the system, but more refined models have to be used.
In our lab an apparatus for laser cooling and Bose-Einstein condensation of rubidium atoms is in operation, allowing to produces neutral samples with temperatures ranging from a few hundreds of mK down to tens of nK. The typical densities of the clouds ($10^{10} - 10^{12}$ atoms/cm^3) are large enough to perform reliable investigations by absorption or emission techniques. Thus we can study photoionization on atomic samples with different phase space densities, which reach the maximum values for the condensates. Actually BECs are produced with numbers of atoms ($\sim 10^4$) which allow their thermodynamical analysis (temperature, density distribution).
The photoionization of the atomic sample has been achieved by driving a two photon nonresonant transition from the ground state. The radiation was provided by an excimer-pumped

dye laser used at a wavelength close to 594 nm, the two photon ionization threshold, with intensities in the tens of MW/cm^2 range and a pulse duration of 16 ns. To extract the photoionization cross-section we experimentally measured the losses produced by the laser pulses on the trapped cloud, since a charge detector was not present in the vacuum cell. In a first series of experiments we irradiated the cold atoms within the Magneto Optical Trap (MOT) with the ionizing laser, studying the induced additional losses. During the decay time of the MOT, of the order of 60 s, the atoms were subjected to ionizing pulses applied with rates of up to 11 Hz. The effect on the decay rate was of the order of 20% (fig.1).

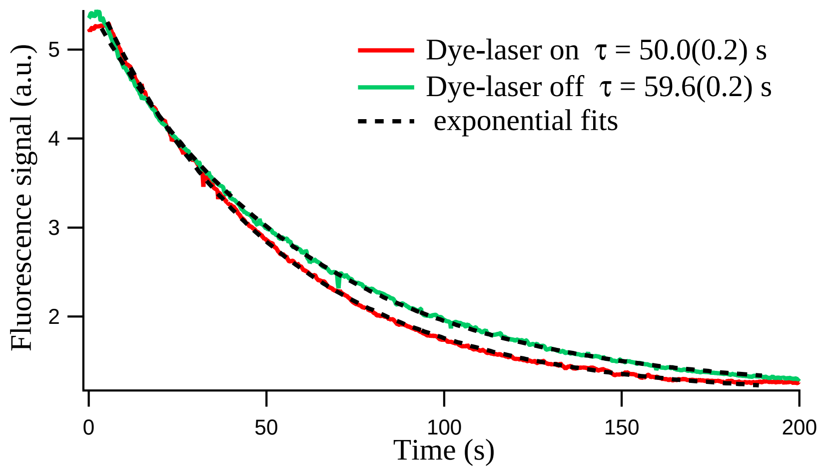

Figure 1: Fluorescence signal emitted by the atoms during the MOT decay with and without ionizing pulses. Ionization increases the decay rate allowing a measure of two photon photoionization cross section

In a second experiment we studied the effect of a single ionizing pulse on the BEC sample, measuring the loss of atoms from the magnetic trap and the density profile modifications of the condensed clouds. The interpretation of these preliminary results suggests the occurrence of different processes involving not only multi-photon ionization, but also dipole forces, Raman scattering (fig. 2), and possibly interaction between neutral and charged particles.
At the present stage, in order to overcome the limited energy resolution of the pulsed radiation, we are setting up experiments with narrowband cw sources. A two-color system involving a frequency doubled diode laser at 421 nm - nearly resonant with the 6P1/2 level of Rb - and a second infrared laser diode operating around 1010 nm has been tested, even if preliminary investigations using the 421nm source have been limited by the shortened condensate lifetime due to spontaneous emission.
The use of stimulated rapid adiabatic passage excitation (STIRAP) techniques [4] to the continuum are expected to overcome such problems and to allow precise measurements of photoionization cross sections.

[1] T.C. Killian et al., *Creation of an Ultracold Neutral Plasma*, Phys. Rev. Lett. **83** 4776 (1999);

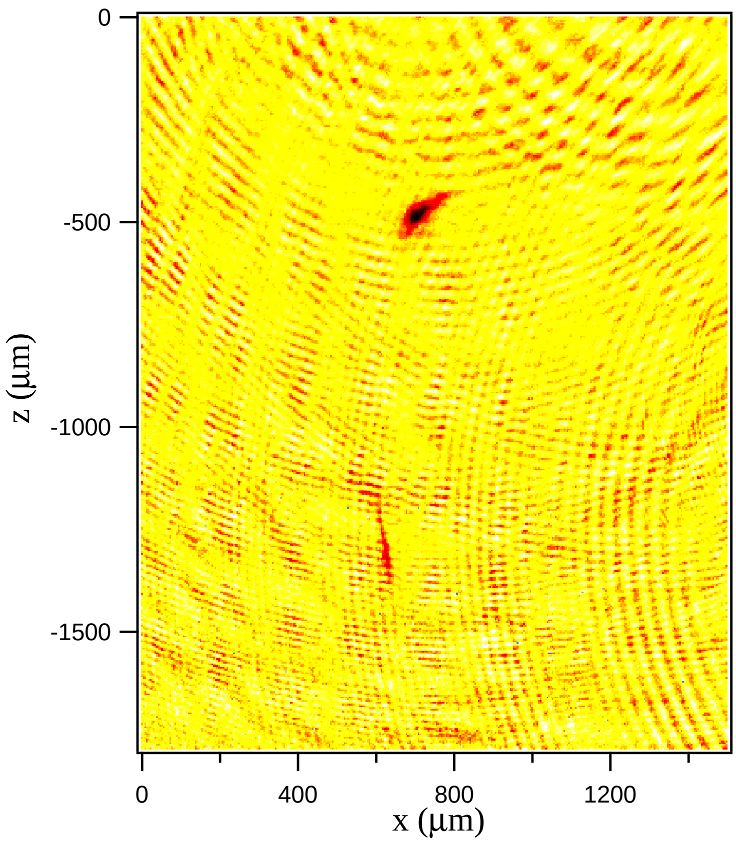

Figure 2: Shadow image of a condensate exposed to a single dye laser pulse. The BEC is evidently deformed and a secondary cloud is present, probably due to the occurrence of magnetic sublevel changing Raman transitions.

S. Kulin et al., *Plasma Oscillations and Expansion of an Ultracold Neutral Plasma*, Phys. Rev. Lett. **85** 318 (2000).

[2] Previous experiments in our lab.: O. Maragò et al., *Photoionization cross sections for excited laser-cooled cesium atoms*, Phys. Rev. A **57** R4110 (1998); E. Arimondo et al., *Laser Cooling and Photoionization of Alkali Atoms*, Appl. Surf. Sci. **154-155** 527 (2000); F. Fuso et al., *Ion processes in the photoionization of laser cooled alkali atoms*, Opt. Commun. **173** 223 (2000).

[3] I.E. Mazets, *Photoionization of neutral atoms in a Bose-Einstein condensate*, Quantum Semiclass. Opt. **10**, 675-681 (1998).

[4] K. Bergmann, H. Theuer, and B.W. Shore *Coherent population transfer among quantum states of atoms and moecules* Rev. Mod. Phys. **70** 1003 (1998).