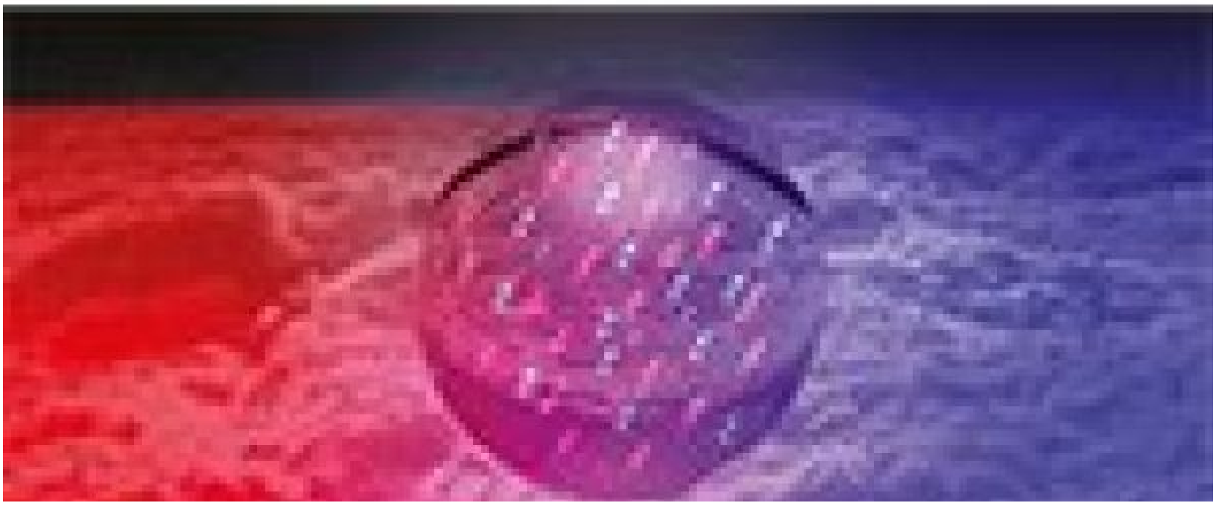

PhD Thesis Defense CESAR CABRERA 'Quantum Liquid Droplets in a mixture of Bose-Einstein Condensates'

CESAR CABRERA

October 10, 2018

Wednesday, October 10, 11:00. ICFO Auditorium

CESAR CABRERA

Ultracold Quantum Gases

ICFO-The Institute of Photonic Sciences

In this thesis, we report on the design and construction of a quantum simulator experiment using quantum gases in Spain. This experiment exploits mixtures of the three isotopes of potassium, which give access in an original approach to the study of Bose-Bose or Bose-Fermi mixtures using the same experimental setup.
We validate our experimental setup with the observation of a Bose-Einstein condensate (BEC)

of 41K and 39K. Moreover we observe the dual Bose-Einstein condensation of 39K-41K. These results represents the first observation of BECs in Spain and give access to a novel quantum degenerate mixture in the field. Since the control of interactions in our experiment are crucial, we characterize the scattering properties of the 39K-41K mixture, and spin mixtures of 39K and 41K.

In addition, using a spin mixture of 39K BEC, we report on the observation of a novel state of matter: a composite quantum liquid droplet. This dilute quantum droplet is a liquid-like cluster of ultra-cold atoms self-trapped by attractive mean-field forces and stabilized against collapse by repulsive beyond mean-field many-body effects. This system follows the original proposal where D. Petrov predicted the formation of self-bound liquid droplets in mixtures of Bose-Einstein condensates.

In the first series of experiments, we have observed the formation of quantum droplets in a regime where the Bose-Bose mixture should collapse from the mean-field perspective.We directly measure the droplet size and ultra-low density via high-resolution in situ imaging, and experimentally confirm their self-bound nature.We demonstrate that the existence of these droplets is a striking manifestation of quantum fluctuations. These droplets do not exist in single-component condensates

with described with contact interactions. Finally, we observe that for small atom numbers, quantum pressure dissociates the droplets and drives a liquid-to-gas transition, which we map out as a function of interaction strength.

These measurements open an intriguing point of investigation: the difference existing between droplets and bright solitons. In the second series of experiments, we address it by placing the mixture in an optical waveguide, realizing a system that contains both composite bright solitons and quantum liquid droplets. In analogy to non-linear optics, the former can be seen as one-dimensional matter-wave solitons stabilized by dispersion, whereas the latter corresponds to highdimensional

solitons stabilized by a higher order non-linearity. We find that depending on atom number, interaction strength and confinement, solitons and droplets can be smoothly connected or remain distinct states coexisting only in a bi-stable region. We measure their spin composition, extract their density for a broad range of parameters, and map out the boundary of the region separating solitons from droplets.

Our experiments demonstrate a novel type of ultra-dilute quantum liquid, stabilized only by contact interactions. They provide an ideal

platform for benchmarking complex quantum many-body theories beyond the mean-field approximation in a quantum simulation approach. Furthermore, they constitute a novel playground to explore experimentally self-bound states stabilized by unconventional higher order nonlinearities, relevant in non-linear optics.

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Thesis Advisor: Prof Dr Leticia Tarruell