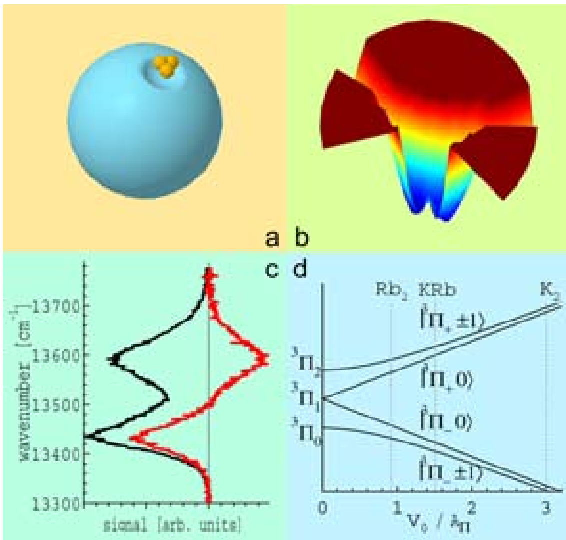
Dr. Carlo Callegari, PhD
Institut für Experimentalphysik
E-Mail: carlo.callegari@tugraz.at
Tel.: 0316 873 8161

Superfluid Helium Nanodroplets: A Miniature Factory of Cold Atoms and Molecules

One of the pillars of modern science is reductionism: to understand a complex system by reducing it to the interaction of its parts. I use spectroscopy to look at atoms and molecules as they are brought together to form complex structures. Even classically, colder is better for the trivial reason that temperature, T, is a measure of statistical disorder. Quantum-mechanically, effects related to indistinguishability of identical particles may become evident. Superconductivity (flow of current without resistance) and superfluidity (flow of a liquid without friction) are prime examples; research in the field is 100 years old, but was limited to the few systems provided by nature. The atom-cooling revolution of the last ten years (Physics Nobel Prizes in 1997 and 2001) has brought us new states of matter, mostly based on spin-polarized alkali-metal atoms; these exhibit collective properties which can be tuned via external parameters. The field has close connections to quantum entanglement and quantum computing, and there is great interest to move on from cold atoms to cold molecules ($T < 1$ K).
Helium droplets, formed in vacuum in a supersonic beam, can be easily doped with atoms and molecules, thus becoming a cryostat to cool and assemble them. He droplets have a typical diameter of ~10 nm, and consist of ~10^4 He atoms. They self-stabilize through evaporation to T=0.37 K, and are superfluid. The dopant can also be a spectroscopic probe of the droplet. Alkali-metal atoms and molecules reside in a dimple on the surface of the droplet, due to their weak interaction with helium. They can be an excellent probe to study the static and dynamic properties of the droplet surface; the latter shares many aspects of more conventional Bose-Einstein condensates, but, although very interesting, has not been studied much yet. All other atoms and molecules reside inside the droplet and are normally used to study liquid He on the atomic scale.
Our group [1] studies the formation of high-spin alkali molecules on He droplets. Besides the themes already mentioned, these exotic molecules are interesting in relation to molecule formation by photoassociation or magnetic tuning, to many-body forces, to the reactivity and magnetism of small metal clusters, and to the Jahn-Teller effect. By means of Magnetic Circular Dichroism, and Optically Detected Magnetic Resonance, we target with particular interest spins in strong magnetic fields, especially as related to spin relaxation in liquid helium. The interpretation of our experimental data depends critically on proper assignment of the spectra and prior knowledge of the electronic structure of the molecules formed. As many of these molecules had never been observed before, we devote part of our effort to running high-level ab initio Quantum Chemistry calculations.

I was born and went to school in Montebelluna, a small town 50 km north of Venice. With a scholarship from the Scuola Normale Superiore, I went to Pisa to study physics. I was interested in new materials; the recently discovered fullerene (C_{60}, the soccerball molecule) had become easily available, so in my thesis work I studied its laser ablation. I then pursued a doctorate at Princeton University (USA); my PhD thesis dealt with the dynamics of molecules embedded in superfluid helium droplets. At the time, this was a new field: spectroscopy had just delivered the droplets' temperature, and evidence of superfluidity, showing how the latter allows dopant molecules to rotate freely. It was not known, however, how to relate the inertial properties of the helium to the observed spectra, nor had rotational thermalization in helium been looked at. I did a systematic spectroscopic study of these topics, developed a hydrodynamic model to rationalize the observations, and also determined that the typical timescale for rotational relaxation is a few nanoseconds. Thereafter I worked at Caltech (California Institute of Technology) on NEMS (nanoelectromechanical systems) development, and application as sensitive mass detectors down to few zeptograms (10^{-21} g). In April 2003 I became Universitäts-Assistent at the Institute of Experimental Physics, TU Graz.

[1] http://iep.tugraz.at/content/research/superfluidheliumdroplets



(a) Renditon of an alkali-metal trimer molecule on the surface of a He droplet.
(b) Calculated ab initio potential energy surface of bare K3
(c) Measured excitation (black) and MCD (red) spectra of an alkali-metal dimer molecule on a He droplet.
(d) The level structure deduced from (c), plotted as a function of the relative strength of dimer-droplet interaction to spin-orbit coupling.

Suprafüssige Helium-Nano-Tröpfchen: Miniaturkryostate zur Erzeugung kalter Atome und Moleküle

Für spektroskopische Untersuchungen einzelner Atome und Moleküle, insbesondere im wohldefinierten Zustand unter einem Kelvin, benutzen wir Helium-Nano-Tröpfchen. Erzeugt in einer Überschallexpansion in Vakuum, bestehen diese aus etwa 10^4 He Atomen und sind mit einem Durchmesser von 10 nm und einer Temperatur von 0,37 K supraflüssig. Dotiert mit Atomen oder Molekülen kann nun einerseits das Tröpfchen, andererseits aber auch der Dopant auf diesem Nanokryostaten untersucht werden. Alkalimetall-Atome stehen momentan im Mittelpunkt unseres Interesses [1]. Sie zeichnen sich durch ihr Verweilen auf der Tröpfchenoberfläche aus und stellen eine vorzügliche Sonde für statische und dynamische Studien dieses Quantensystems dar. Umgekehrt werden Alkalidimere und -trimere hoher Spinmultiplizität überhaupt erst bei tiefsten Temperaturen gebildet und können in magnetischen Feldern mit Laserlicht und Mikrowellen untersucht werden.
Nach meinem Physikstudium in Pisa kam ich bei meiner Dissertation in Princeton erstmals in Kontakt mit supraflüssigen Tröpfchen, wo ich dynamische Eigenschaften von Molekülen, eingebettet im Zentrum derselben, studierte. Nach einem Aufenthalt am California Institute of Technology kam ich im April 2003 als Universitätsassistent an das Institut für Experimentalphysik der TU Graz.