Experimental Report

18/03/2014

Proposal:	**6-01-327**	**Council:**	10/2012	
Title:	Quantum dynamics in Fermi and Bosecommensurate Helium bilayers			

This proposal is a new proposal

Research Area: Physics

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Samples: 4He
graphite
3He

Instrument	Req. Days	All. Days	From	To
IN5	6	6	09/05/2013	15/05/2013

Abstract:

The strongly correlated commensurate phases of helium adsorbed on graphite offer the opportunity to investigate the dynamics of almost-localized quantum many-body systems. In particular, the 4/7 phase of the 3He helium bilayer displays remarkable properties: a quantum frustrated spin-liquid ground state has been observed in fermionic 3He, where detailed heat capacity and NMR investigations have been performed. In addition, a supersolid ground state has been predicted for bosonic 4He. However, the actual structure and the excitation spectrum of these systems are still unknown.
Here we propose to measure the dispersion relation of the elementary lattice excitations of the pure 4He and 3He 4/7 phases as well as the neighbouring vacancy-doped coverages. The results on these systems is of current theoretical interest in the field of quantum fluids and solids, correlated fermions and high Tc superconductors and ultra-cold atoms.

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Graphite sample**:** The sample consists of a stack of very high quality ZYX exfoliated graphite substrate. Using accurate gas handling techniques, helium films of selected densities are adsorbed at low temperatures.

Two-dimensional helium samples**:** A dense (solid) monolayer of ^{4}He is first deposited in order to create a homogeneous new substrate (preplating technique). Several submonolayer coverages are deposited (forming the "second layer"). Depending on the selected coverage (adsorbed amount), the second layer is fluid (at low densities), a commensurate solid phase (4/7 phase), or an intermediate phase (possibly coexistence, or most likely a new type of phase, as discussed below). Measurements have been performed using ^{4}He or ^{3}He in the second layer.

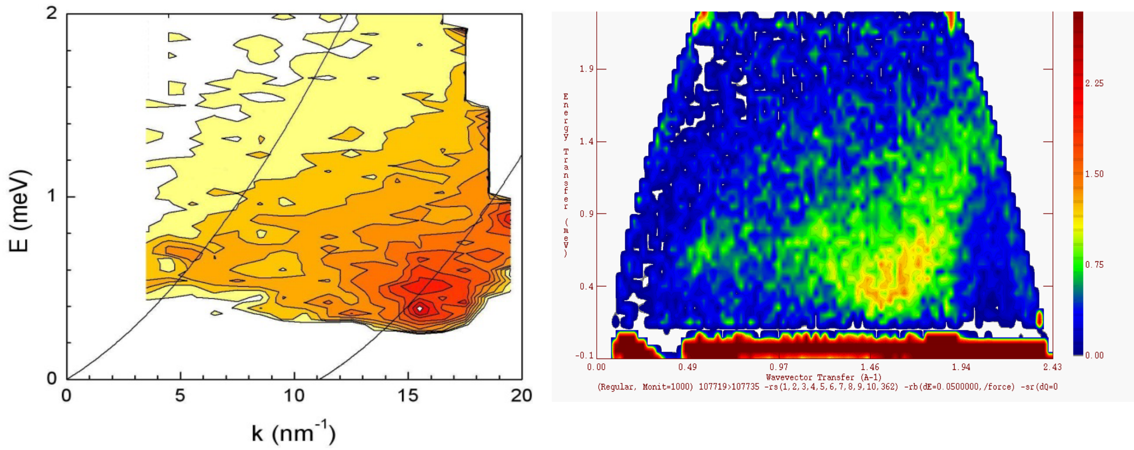
Preliminary work carried out**:** During the week prior to the experiment reported here, we performed a complete set of helium adsorption isotherms at the ILL cryogenics workshop, with the sample cell mounted in the ILL dilution refrigerator. Excellent agreement has been obtained with previous surface area determination, yielding a commensurate area of 60.52 m^2. This verification was essential, in order to be able to compare the present data to previous neutron [1] and NMR [2, 3] results at the same helium coverage.

Measurements: the choice of the wave-length was made after short tests, selecting the most convenient ones in terms of resolution and background (spurions…)

Vanadium: was measured at 4.8 and 6.0 Å.
Background: the background (bare graphite sample) was measured at 4.8 and 6.0 Å.
The ^{4}He monolayer spectrum was measured at 4.8 and 6.0 Å.
The ^{4}He 4/7 phase spectrum was measured at 4.8 and 6.0 Å.
Spectra were measured at 4.8 Å for 6 coverages of ^{3}He adsorbed on ^{4}He preplated graphite, exploring the fluid phase, the commensurate 4/7 phase, and neighbouring coverages.
Finally, a measurement at the solid incommensurate phase coverage, was performed at 4.8 Å.

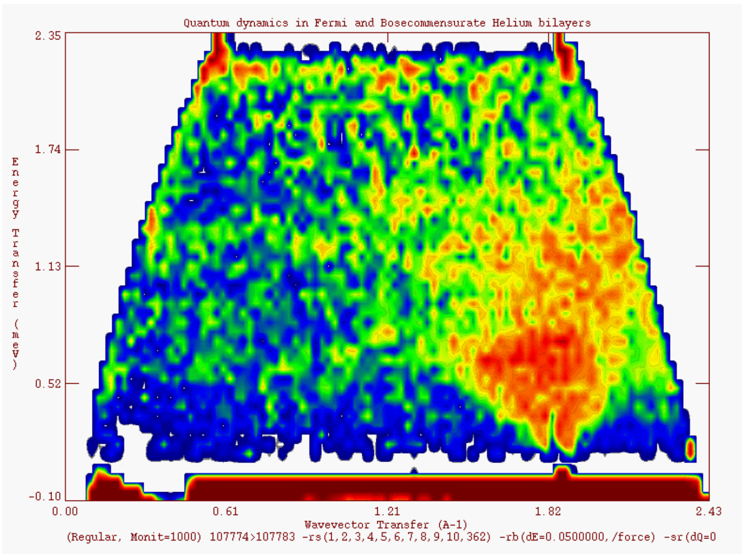
Results: Data of high quality were obtained during these measurements:
1) Bilayer ^{4}He
Given the limited available experimental time, only few scans were made.
The spectrum obtained for the bilayer for ^{4}He is in line with the expected solid-like phonon spectrum of a commensurate phase.

2) Bilayer ^{3}He
a) Fermi liquid regime
The measurements performed for ^{3}He second layer coverages at low densities provides us with much better results that those we obtained earlier using IN6 [1].
As seen in the figures, the IN5 data display directly the main features claimed in the Nature paper [1]. The high quality if the spectrum allows us to perform a deconvolution using the Warren line-shape, an asymmetric curve characteristic of two-dimensional samples. This work, presently in progress, should provide us with a quantitative knowledge of the elementary excitations of a two-dimensional Fermi liquid.



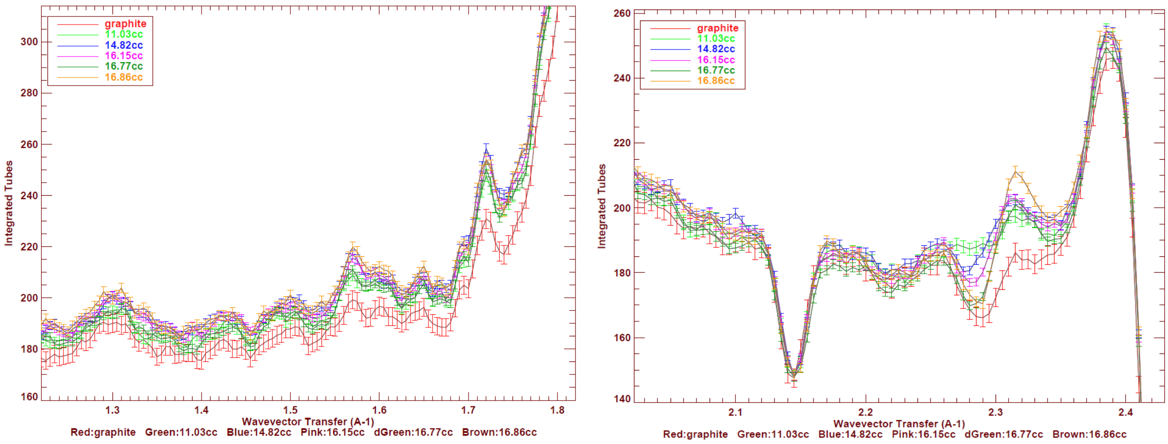
Left: *IN6 results for second layer ^{3}He Fermi liquid, after background subtraction and extensive data treatment [1].*
Right: *IN5* ***raw data*** *at the same density (highly correlated 2D Fermi liquid)*

b) Commensurate 4/7 phase regime
A major surprise is the observation of several branches in the spectra of what is presently thought to be a simple commensurate solid. In addition, the evolution as a function of density is rather progressive, another unexpected feature.



S(Q,w) determined for the 4/7 phase (^{3}He/^{4}He/graphite).
Note the presence of several branches, not expected theoretically.

The subtraction of background is not trivial, due to interference effects among the first and second helium layers (see ref. [1]), and to the very small inelastic signal, compared to the substrate background. In the figure below we show the spectra integrated over energy, clearly displaying the evolution of the signal with density, at Q-values on the order of 1.7 Å for the ^{3}He second layer, and about 2.3 Å for the first layer (^{4}He).
In order to go beyond our first simple analysis, substantial work has to be done to obtain fully corrected inelastic spectra.



Left: S(Q) for second layer ^{3}He for different densities (the data were integrated over the energy). Note the presence of peaks at Q =1.6 and 1.75 Å^{-1}. Also note the importance of the background in these surface measurements.

Right: S(Q) for first layer ^{3}He for the same densities. The evolution indicates a possible reconstruction of the first layer, which has to be taken into account in the analysis.

In parallel with the analysis of the data, we are collaborating with theorists (E. Krotscheck (Linz) and J. Boronat (Barcelona) in order to find an explanation of the results. Presently, we believe that our data can be understood only if one assumes that the very weakly bound commensurate phase displays density excitations that, at high energy, retain a liquid-like character. According to our preliminary analysis, the system is evolving, as density is increased, from a Fermi liquid, undergoing an instability probably linked to the formation of flat band ("Fermi condensate), to a doped Mott-Hubbard insulator.
If our final data analysis confirms this interpretation, it would be an important contribution to the field of correlated Fermions.

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References

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