Exchange Visit Grants: Scientific Report

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I. PURPOSE OF THE VISIT

I visited the Theory of Condensed Matter group in the Cavendish Laboratory, at the University of Cambridge from the 10^{th} of June 2010 t0 the 11^{th} of August 2010 (8 weeks and 6 days). The aim of the visit was to carry work on electron-hole bilayers in collaboration with M. Parish, an EPSRC Career Acceleration Fellow working in the Theory of Condensed Matter group and Prof. P. Littlewood, the head of the Department. As explained in this report the objectives originally proposed in the project have been succesfully met and have led to one publication (submitted to *Phys. Rev. Lett.*) on this topic. My visit has strongly benefit from the environment provided by the host institution, the Cavendish Laboratory, Cambridge. In particular this project has benefit tremendously from the interaction with the members of the Prof. M. Pepper at the Cavendish Laboratory, such Dr K. Das Gupta. This is one of the leading experimental groups working on the subject of electron-hole bilayers.

In addition to completing the proposed project, I have also coordinated my visit with the visit to Cambridge of Dr Marzena Szymanska (University of Warwick), with whom I am developing several projects on superfluidity in microcavity polariton systems. As explained in Sec. IV, I have already two publications partially supported by Intelbiomat on microcavity polaritons. Moreover I have been interacting with Dr Jonathan Keeling and Dr. C. Creatore, also at the Cavendish, with whom I have set up new projects on pattern formation in polaritonic systems.

II. DESCRIPTION OF THE WORK CARRIED OUT DURING THE VISIT AND MAIN RESULTS OBTAINED

A. Supersolidity in electron-hole bilayers with a large density imbalance

Most of my 9 week visit to the Cavendish Laboratory in Cambridge have been devoted in collaborating with M. Parish and P. Littlewood on the originally proposed project on imbalanced electron-hole bilayers. We have considered an electron-hole bilayer in the limit of extreme density imbalance, where we have a single particle layer interacting attractively with a Fermi liquid in the other parallel layer.

Pairing phenomena in two-component Fermi systems in the case where the densities of the two fermionic species are *imbalanced* are of particular interest because the interspecies pairing is then frustrated. Here, one expects more exotic pairing scenarios such as the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) spatially-modulated phase (Fulde and Ferrell, 1964; Larkin and Ovchinnikov, 1965), where fermions pair at finite center-of-mass momentum, and both gauge invariance and translational invariance are spontaneously broken. However, an unambiguous observation of the FFLO phase has remained elusive, despite being predicted more than four decades ago. Electron-hole bilayers, where electrons and holes in a semiconductor are spatially separated into two closely-spaced quantum wells, may provide an ideal route to achieving the FFLO state. Recently, they have been fabricated with independently contacted layers (Croxall *et al.*, 2008; Seamons *et al.*, 2009), thus allowing the densities in each layer to be controlled individually and providing a means for generating a density imbalance.

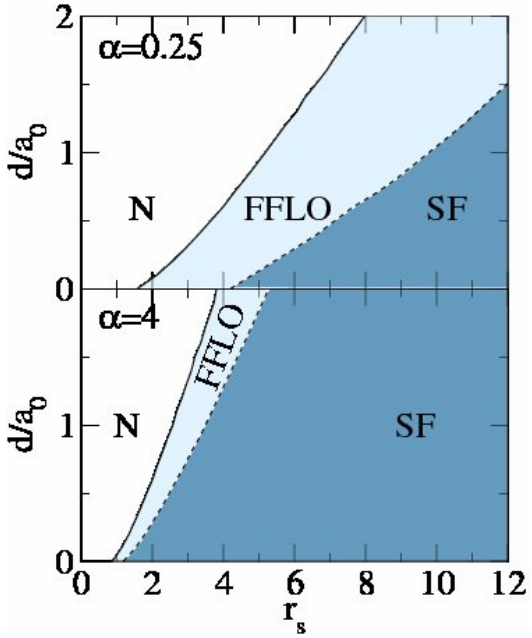

FIG. 1 Single-minority-particle phase diagrams as a function of bilayer distance d/a_0 (in units of the exciton Bohr radius a_0) and interaction parameter $r_s \equiv 1/\sqrt{\pi n_1} a_0$ (n_1 is the density of the filled 1st layer) for fixed mass ratio $\alpha = m_2/m_1$, where the inter- and intralayer interactions have been screened using RPA. The superfluid (SF) region corresponds to excitons with center-of-mass momentum $Q = 0$, while the"FFLO" excitons have their lowest energy when $Q \neq 0$. The normal (N) region is where there are no bound excitons.

In the work carried on in the Cavendish, we have provided strong evidence for the existence of the FFLO

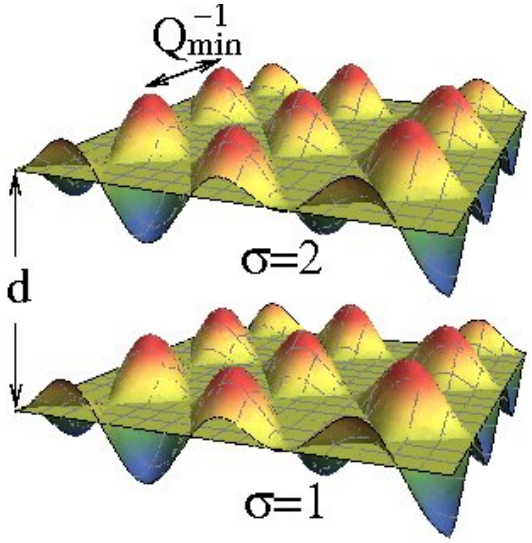

FIG. 2 Density space modulation of a dilute gas of excitons in the FFLO phase.

phase in an electron-hole bilayer with a large density imbalance (see Fig. 1). To address the problem in a controlled manner, we have considered the limit of extreme imbalance where we essentially have a single particle in one layer interacting attractively with a Fermi liquid in the other parallel layer. This allows us to rule out CDW or Wigner crystal phases induced by the presence of the other layer. It also enables us to include interactions beyond mean-field theory. From this analysis, we expose an unusual bosonic limit of FFLO, where a dilute gas of excitons forms a condensate with a 2D spatial modulation (see Fig. 2), a phase otherwise known as a supersolid.

III. FUTURE COLLABORATION WITH HOST INSTITUTION

The completion of this projects opens a wealth of new directions to explore.

1. The possibility of trion formation in both the three-body limit (two electrons in one layer and one hole in the other or the other way around), as well as in prensence of a Fermi sea of majority particles. This part of the project will be developed also in collaboration with Prof. R. Needs (TCM group).

2. The evaluation of the full phase diagram as a function of the density imbalance.

3. Applications to related systems: atomic gases in optical lattices and graphene bilayers.

I am planning to visit the Cavendish Laboratory again during the next academic year.

IV. SUBMITTED AND PROJECTED PUBLICATIONS

We have just submitted a publication to *Phys. Rev. Lett.* as an outcome of this project:

1. M. M. Parish, F.M. Marchetti, and P. B. Littlewood, "Supersolidity in electron-hole bilayers with a large density imbalance", cond-mat/1009.1420 (http://arxiv.org/abs/1009.1420).

In addition, the following publications have been the result of the work carried on last year under the Intelbiomat Grant 2315 *Superfluidity and lasing at room temperature*:

2. F.M. Marchetti, M.H. Szymanska, C. Tejedor, D.M. Whittaker, "Spontaneous and triggered vortices in polariton OPO superfluids", *Phys. Rev. Lett.* **105**, 063902 (2010)

3. M.H. Szymanska, F.M. Marchetti, and D. Sanvitto "Propagating wave-packets and quantised currents in coherently driven polariton superfluids", cond-mat/1005.4625 (http://arxiv.org/abs/1005.4625).

I have acknowledged the support received from the European Science Foundation (ESF) in all the publication mentioned above and from future ones resulting from this grant, as I will also forward reprints to the ESF Secretariat as soon as available.

References

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