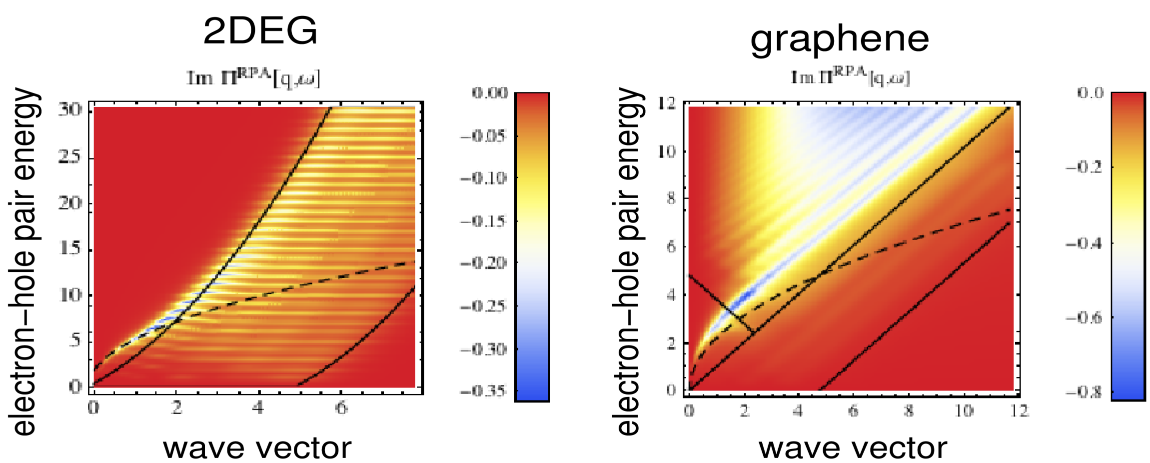
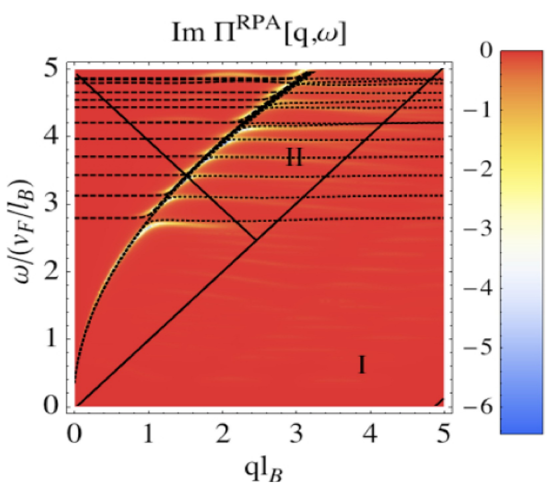
Plasmon-like excitations in graphene in a strong magnetic field

Plasmons, longitudinal charge-density excitations that are generated by the Coulomb interaction between electrons, are a prominent feature of the electron gas and have been studied extensively in metallic systems. In the presence of a magnetic field, these excitations acquire a transverse component as a consequence of the Lorentz force and a finite energy gap that is simply the energy difference between adjacent Landau levels, i.e. the cyclotron frequency. The resulting mode is the upper-hybrid mode, which disperses as the square root of the wave vector. Even though the phenomenology of plasmon excitations is similar in graphene, there are notable differences because of the pseudo-relativistic behaviour of graphene electrons in the vicinity of the Dirac points. First, one needs to underline the non-equidistant separation between the Landau levels in graphene. In contrast to non-relativistic electrons in usual two-dimensional electron systems, the main collective excitations are thus not magneto-excitons (superpositions of inter-Landau-level transitions that acquire a dispersion, see left panel of figure below) but linear magneto-plasmons that disperse roughly linearly and that are clearly visible in the right panel of the figure below (bright lines). The figures have been obtained within the random-phase approximation [1]. Furthermore, one notices the difference in the upper-hybrid mode (dashed lines). In graphene the mode enters the particle-hole continuum associated with interband excitations and is less damped than in the usual two-dimensional electron gas.



The figure on the right-hand side shows a fine structure of the upper-hybrid mode at low energies that consists of avoided level crossings with inter-Landau-level transitions (dashed lines) [2]. These avoided crossings, which are called Bernstein modes, are again a consequence of electron-electron interactions. The theory of Bernstein modes in graphene has been established both within numerical solutions of the polarisability within the random-phase approximation and within a phenomenological model that accounts for the coupling between the upper-hybrid mode and the inter-Landau-level transitions. A possible experimental observation of this effect may be achieved in nano-patterned graphene samples, where a supermodulation imposes a fixed wave vector to the collective excitations, which may then be measured spectroscopically via the Bernstein modes.



[1] R. Roldan, J.-N. Fuchs and M. O. Goerbig., Phys. Rev. B **80**, 085408 (2009).

[2] R. Roldán, M. O. Goerbig and J.-N. Fuchs, Phys. Rev. B **83**, 205406 (2011).,