Atomic collapse in graphene

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The chiral nature of charge carriers in graphene prohibits backscattering and prevents confinement by electrostatic potentials, resulting in high electronic mobility and unusual phenomena such as Klein tunneling. This picture breaks down in the presence of charge impurities exceeding a critical value Z_c, where a qualitative change in behavior leads to the capture of electrons akin to atomic collapse in 3D atoms. Although in graphene Z_c is substantially lower than in 3D atoms, attaining the supercritical regime is difficult because screening can significantly reduce the effective charge of the impurity.
The transition from sub-critical to the supercritical regime is accompanied by trapping of electrons in quasi-bound states which are the condensed matter analogue of the long sought after phenomenon of atomic collapse in super-heavy nuclei. The quasi-bound electron-states show up as a strong enhancement of the density of states within a disc centered on the vacancy site. We find that these states are surrounded by a circular halo of hole states which are interpreted as the analogue of positron production in atomic collapse. We further show that the quasi-bound states at the vacancy site are gate tunable and that the trapping mechanism can be turned on and off, providing a new paradigm to confine, control and guide electrons in graphene.