

Electron tunneling in graphene-hexagonal boron nitride heterostructures

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Worked done with:

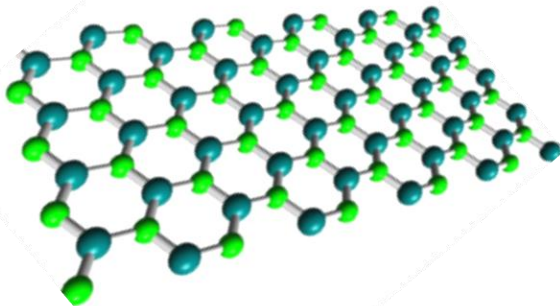
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2D crystalline tunnel barriers

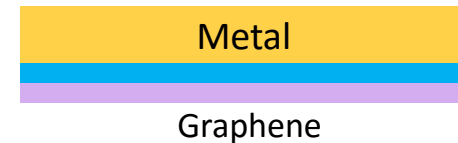
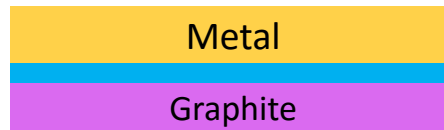
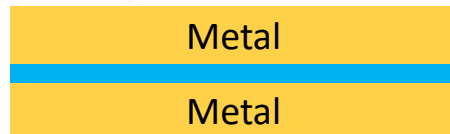
New tunnel barrier : h-BN



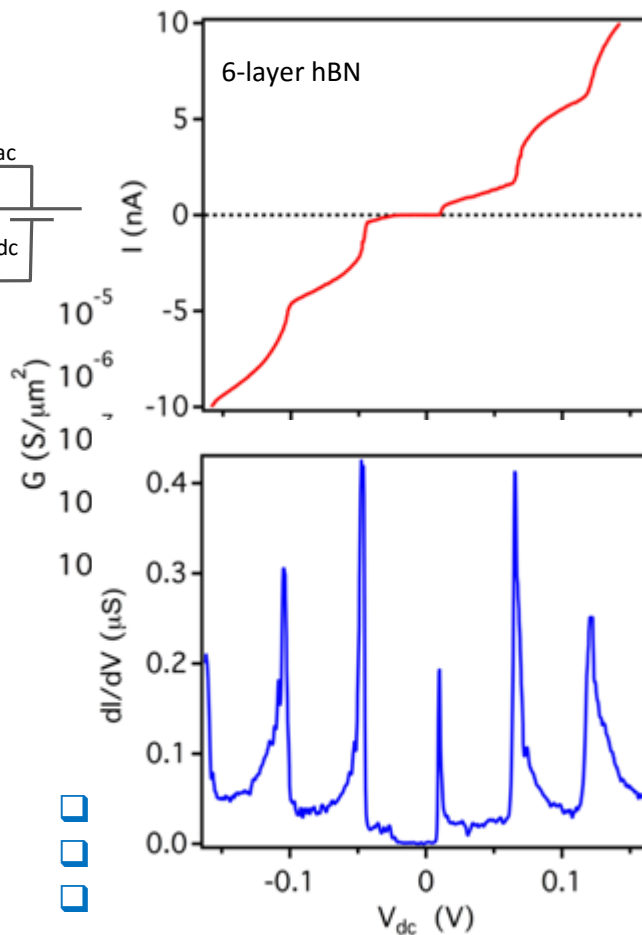
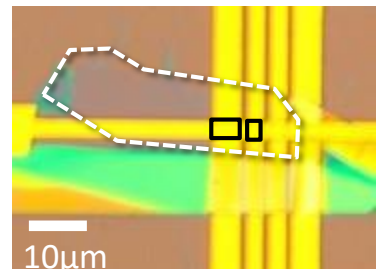
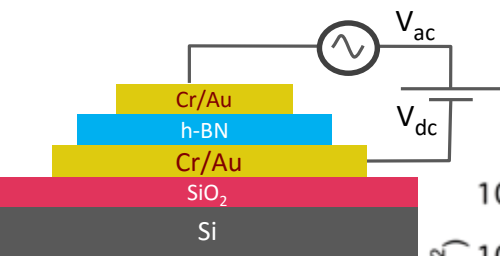
Landau level spectroscopy
Coulomb Drag measurements
and more !

Questions

Is h-BN a good tunnel barrier?
Uniform tunneling
Exponential dependence
Area scaling
Reproducibility
Imperfections

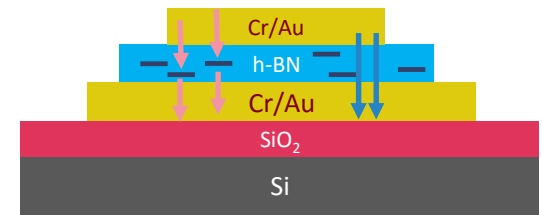


Metal-hBN-Metal junctions



Reminiscent of single electron charging events
Defect-mediated tunneling in hBN-based devices

Defect-assisted tunneling Direct tunneling

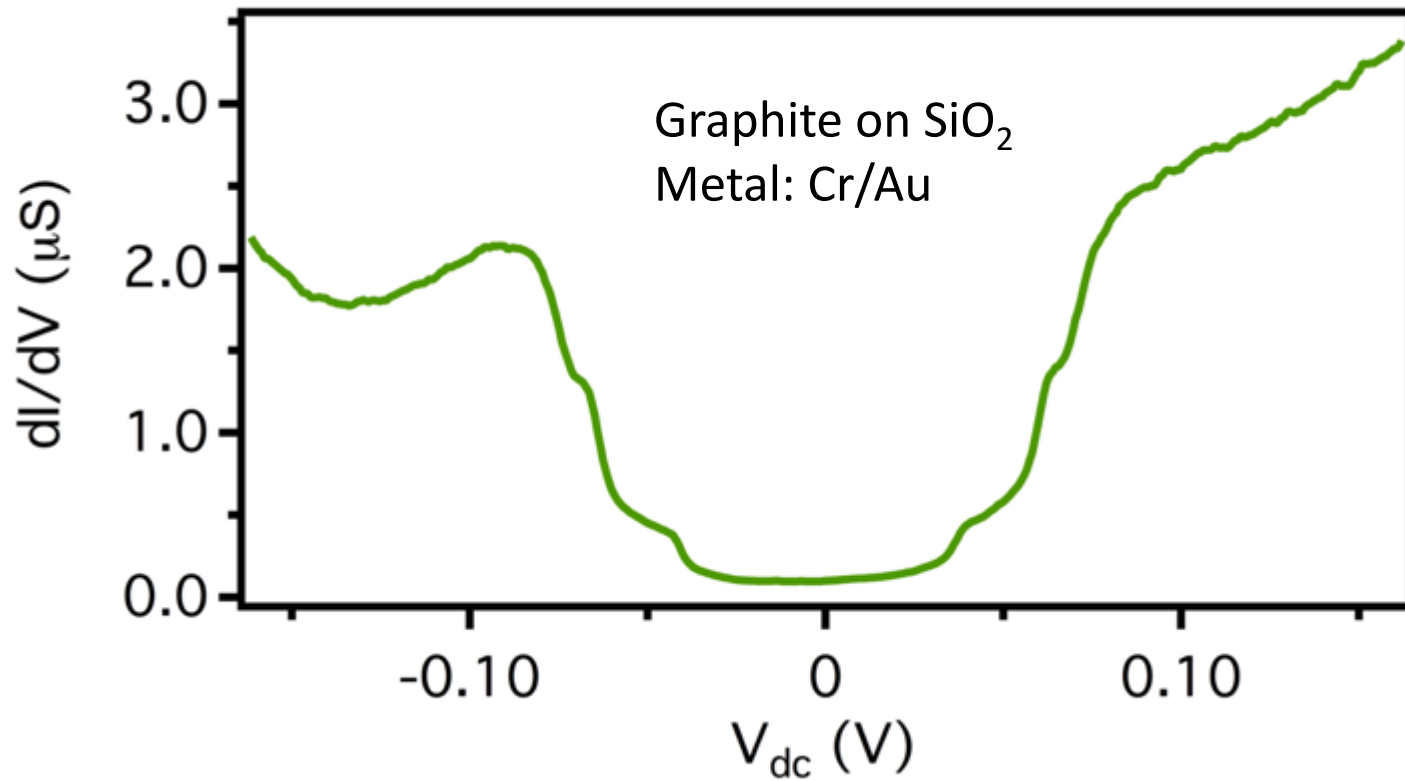


Coulomb diamonds?

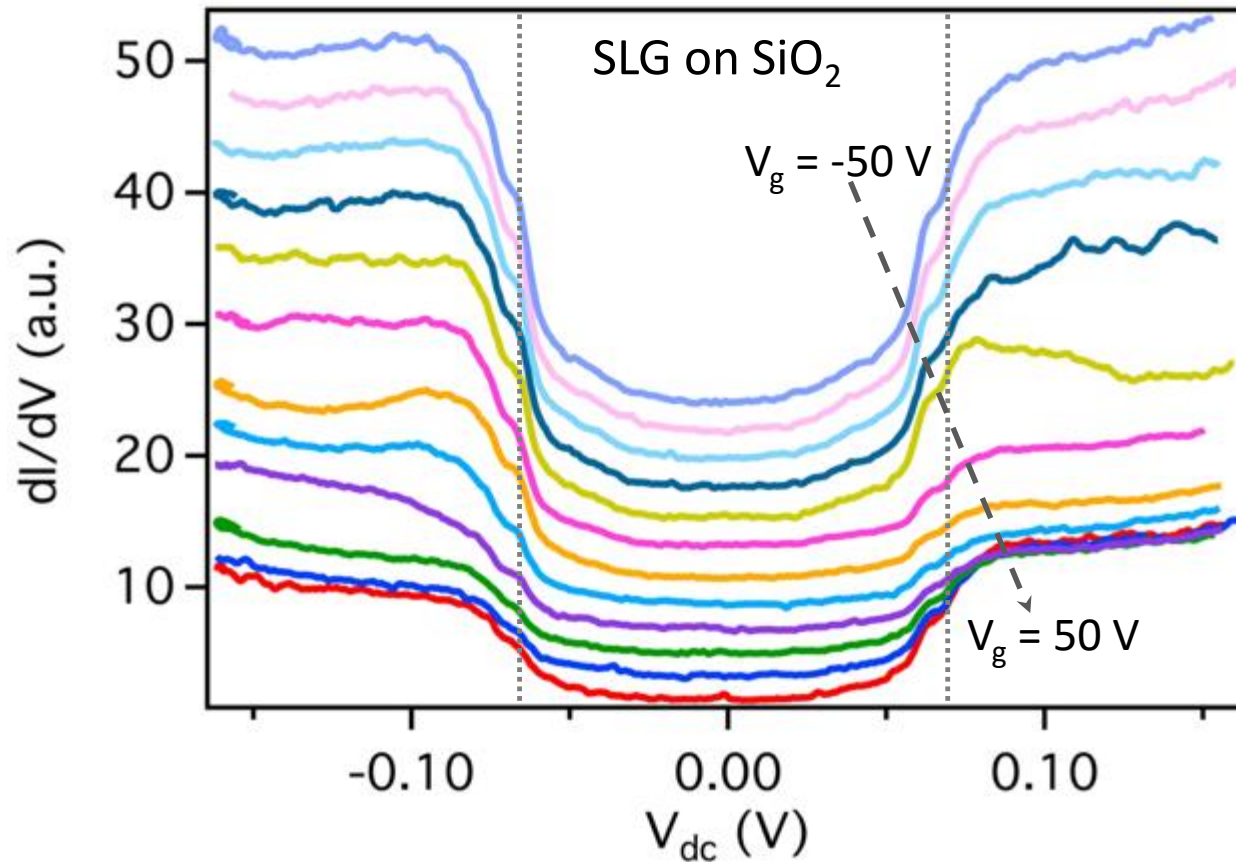
Complete screening of gate field

s of hBN

Metal-hBN-graphene junctions

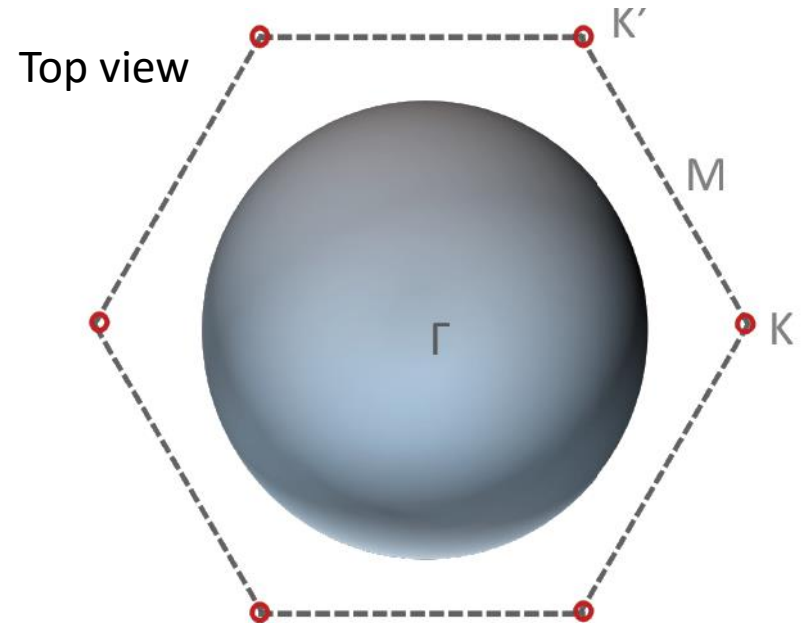
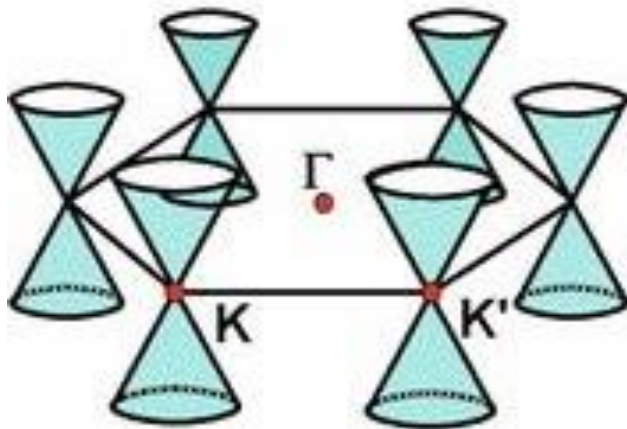


Metal-hBN-graphene junctions



Soft gap independent of metal, substrate and density of carriers in graphene

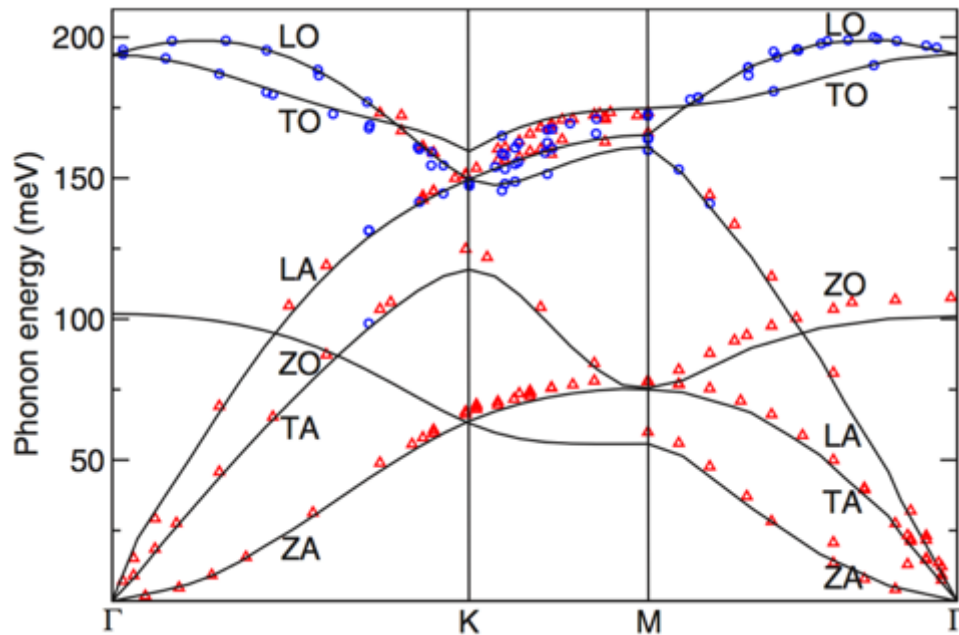
The disjoint Fermi surfaces



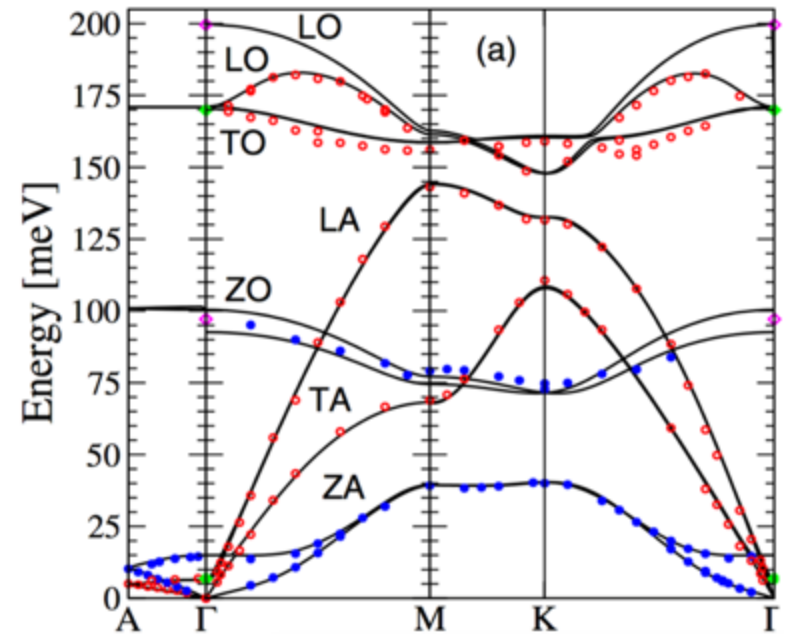
$$I(V) \propto \frac{4\pi e}{\hbar} \int_{-E_F}^{\infty} |M|^2 \underbrace{\delta(\mathbf{k}_T - \mathbf{k}_B)}_{\text{Momentum conservation}} \underbrace{\rho_T(E) \rho_B(E + eV)}_{\text{Density of states}} \underbrace{f(E)[1 - f(E + eV)] dE}_{\text{Availability of states}}$$

Phonon-assisted tunneling

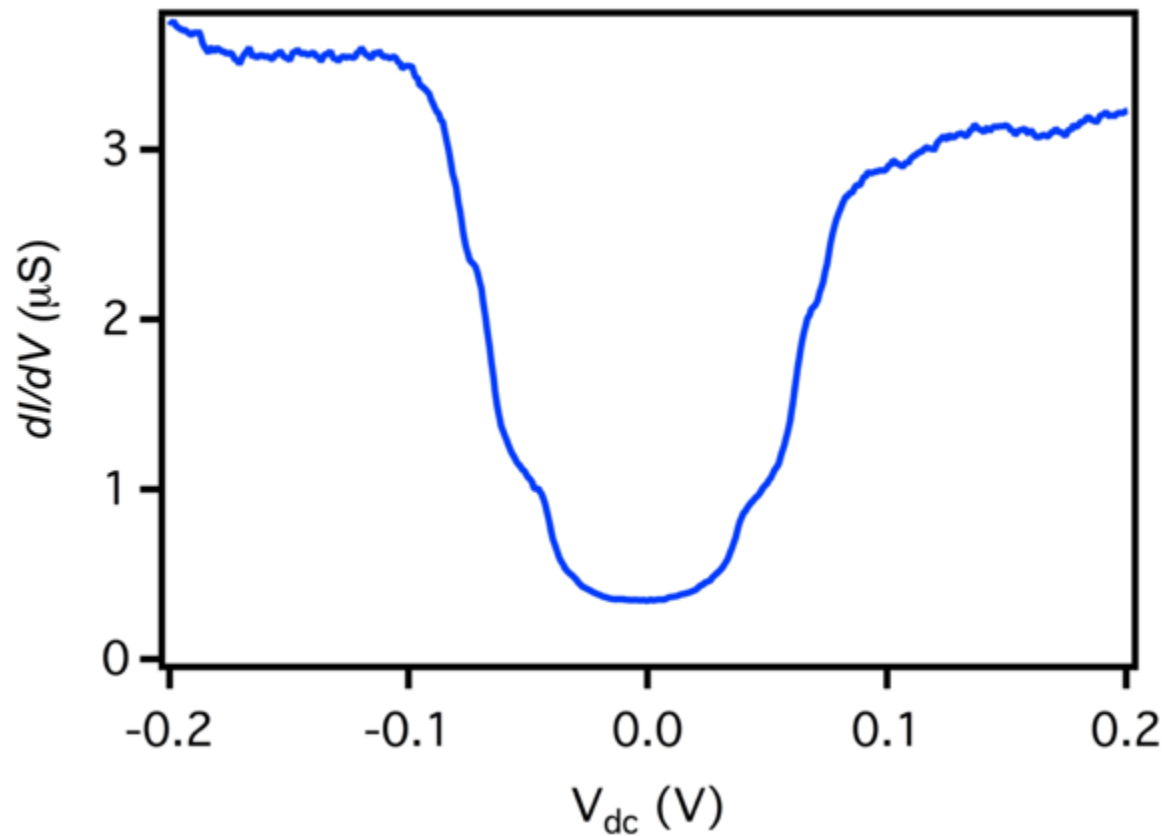
Graphene/Graphite



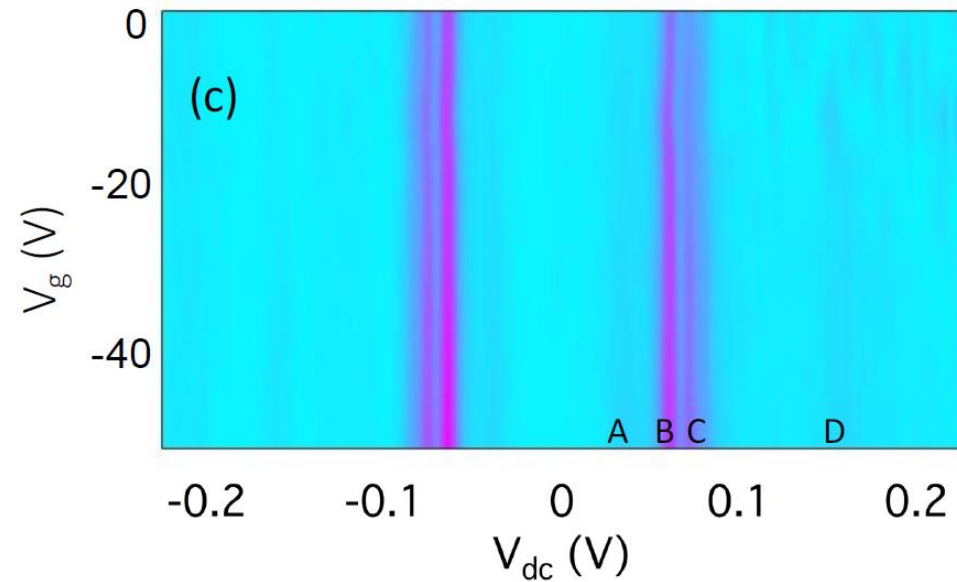
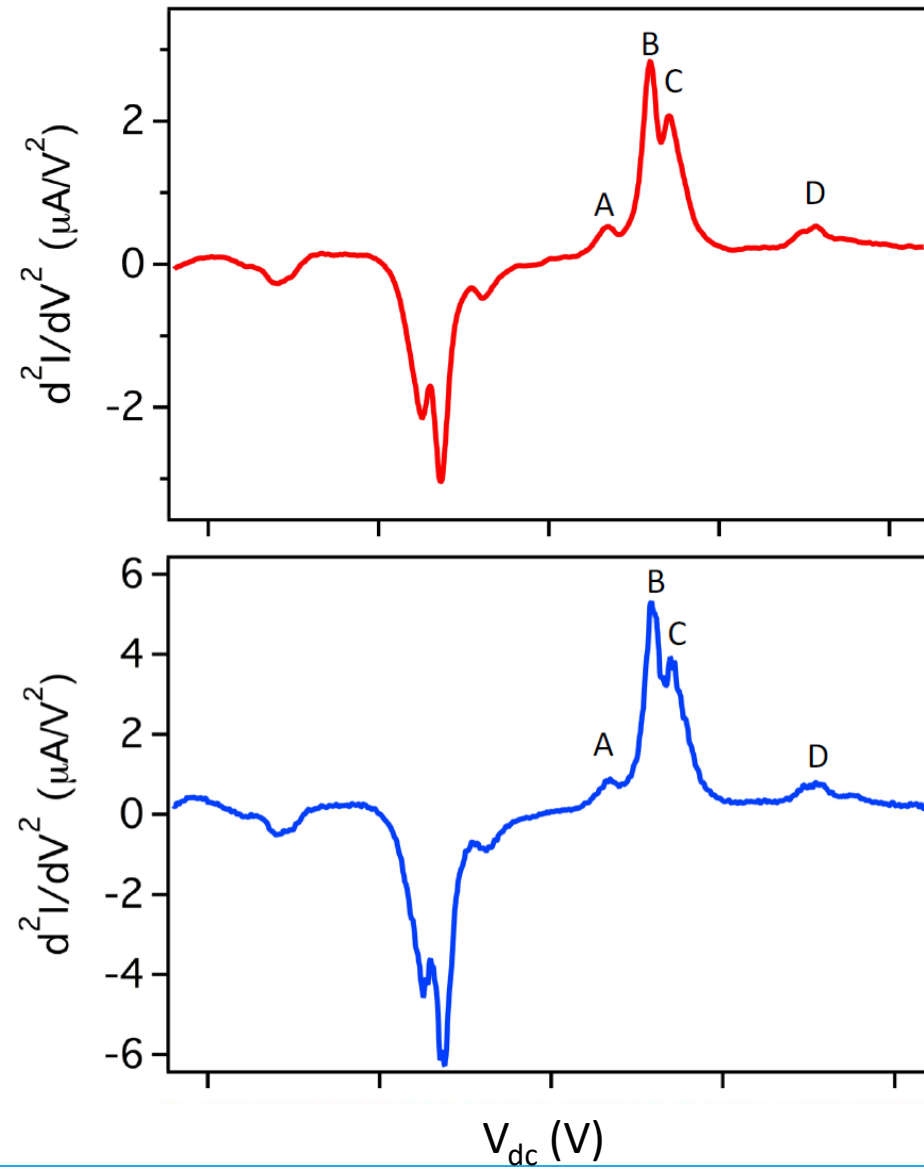
h-BN



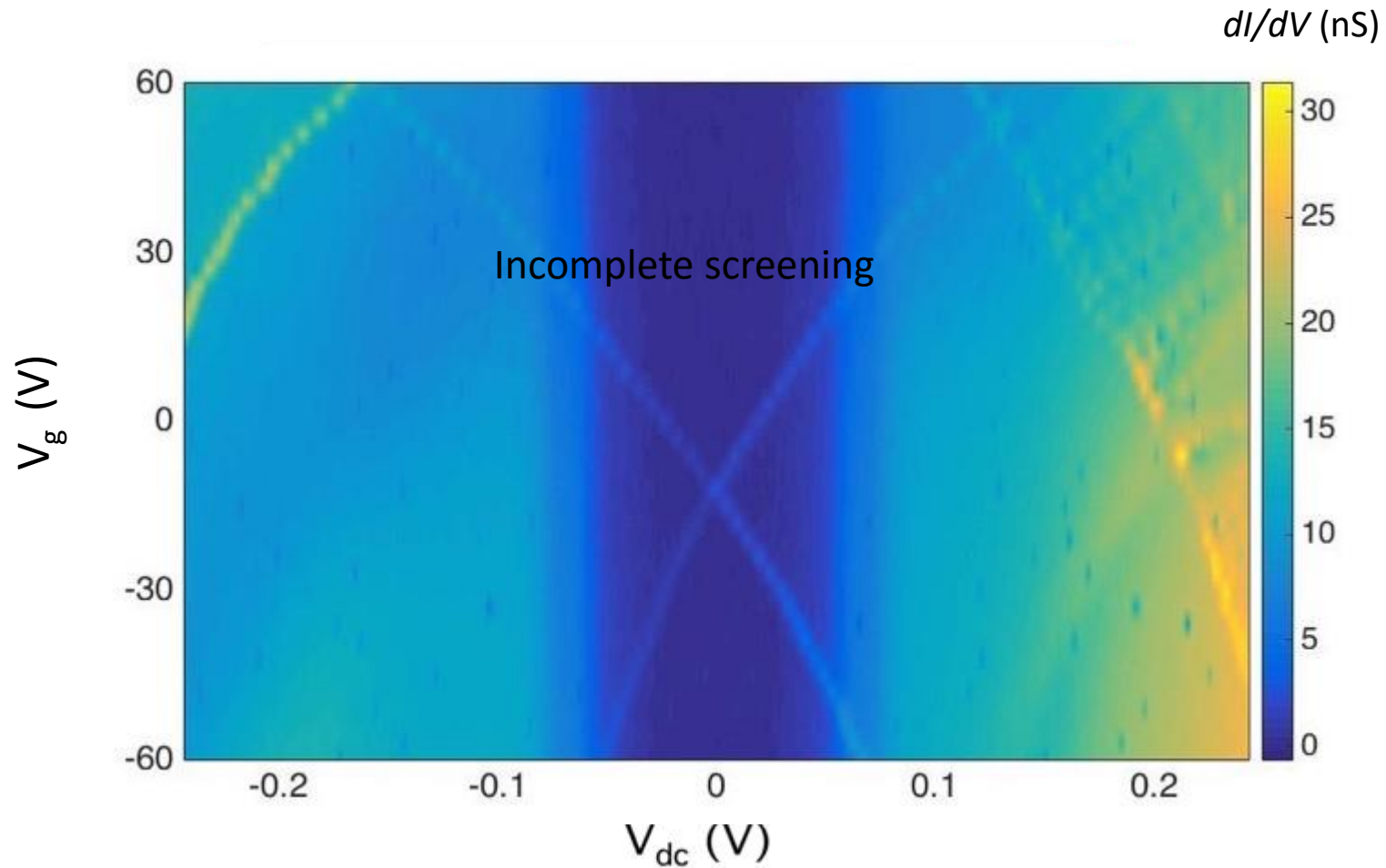
Phonon spectroscopy



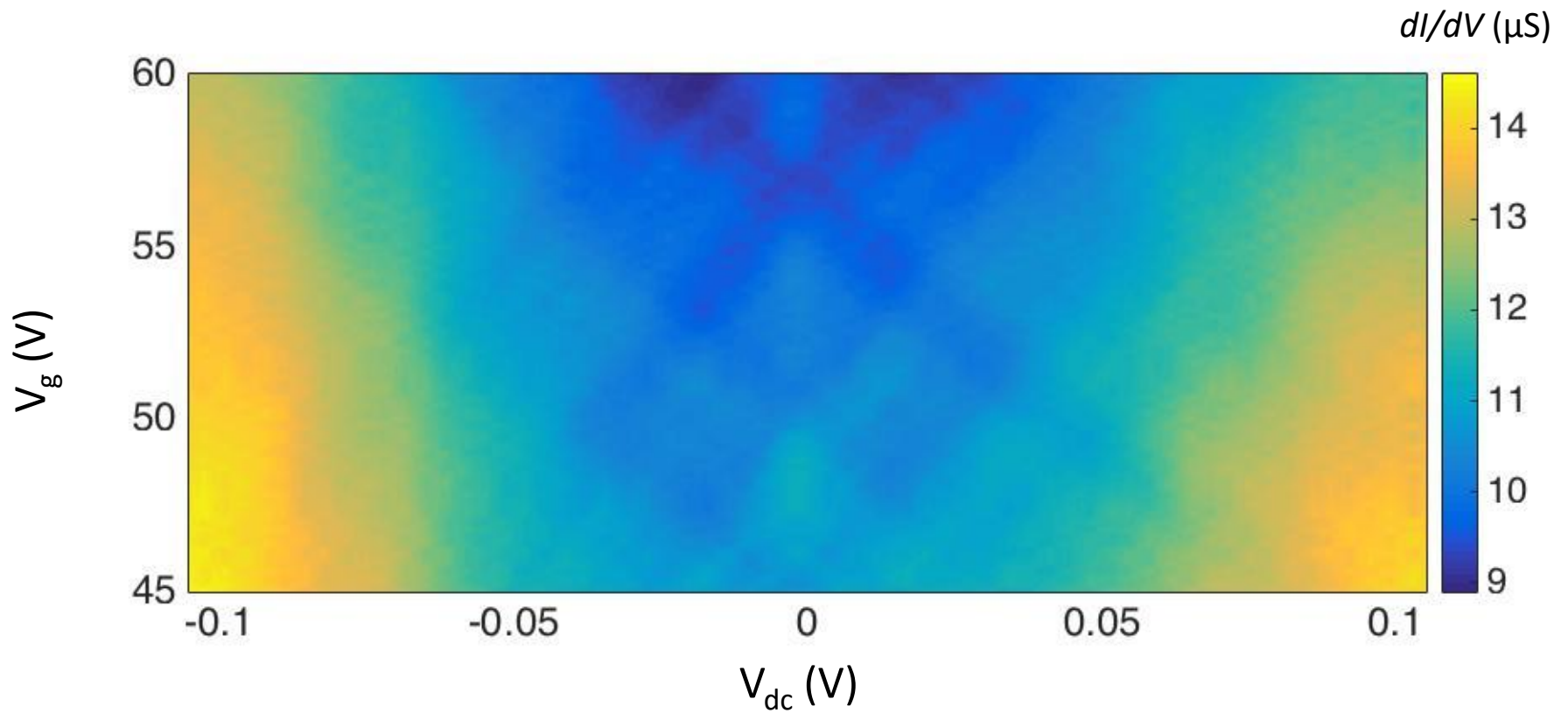
Phonon spectroscopy



Defects Revisited



Defects Revisited



Conclusions

Phonon-assisted tunneling signatures seen.

Coulomb diamonds due to intrinsic nm-scale defects.

References:

U. Chandni, K. Watanabe, T. Taniguchi, J. P. Eisenstein, ***Nano Letters* 15**, 7329 (2015)

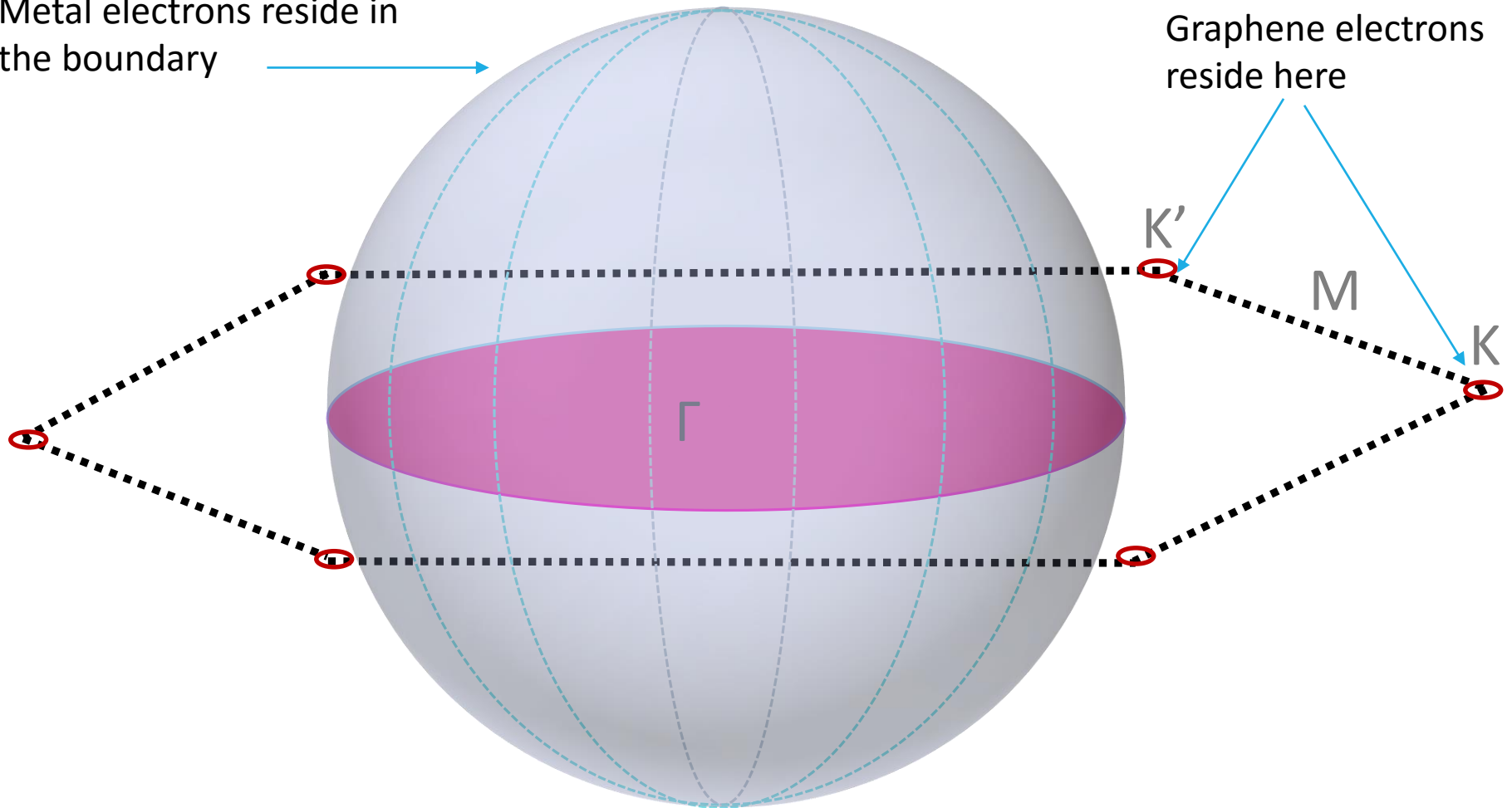
U. Chandni, K. Watanabe, T. Taniguchi, J. P. Eisenstein, ***Nano Letters* 16**, 7982 (2016)

Fermi surfaces and Tunneling + Phonons

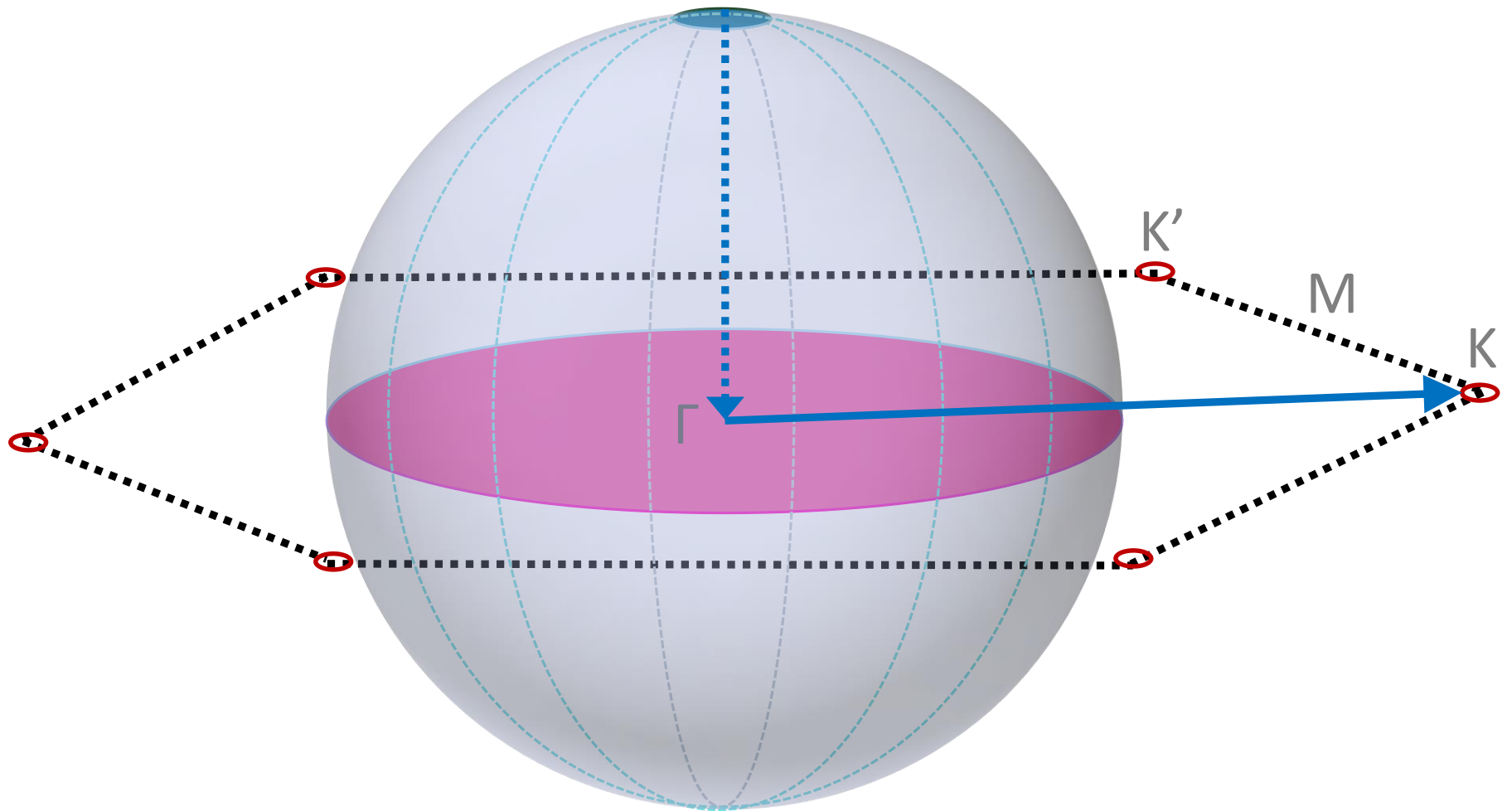
Metal electrons reside in the boundary



Graphene electrons reside here



Fermi surfaces and Tunneling + Phonons



Fermi surfaces and Tunneling + Phonons

