# Self-cavity electrodynamics of van der Waals heterostructures

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Van der Waals (vdW) heterostructures exhibit tunable many-body quantum phenomena that can be controlled *in-situ* using electrostatic gates. The two-dimensional materials and gates within these structures naturally form plasmonic self-cavities, confining light in standing waves of current density due to finite-size effects (see Figure 1a). The plasmonic resonances of typical graphite gates fall within the GHz-THz range, aligning with the µeV-meV energy scale of the phenomena they electrically control in vdW heterostructures. This suggests that the built-in cavity modes of graphite gates may play a significant role in shaping the low-energy physics of vdW heterostructures. However, probing these cavity-coupled electrodynamics is challenging due to the sub-wavelength scale of the devices relative to the diffraction limit. In this study, we leverage advances in on-chip THz spectroscopy to investigate the intrinsic cavity conductivity of gate-tunable graphene heterostructures. As the carrier density was tuned, we observed spectral weight transfer and hybridization between graphene and graphite plasmonic cavity modes in the ultrastrong coupling regime (see Figure 1b). We introduce an analytical model to describe these results and propose cavity design principles. Our findings demonstrate that intrinsic cavity effects are essential for understanding the low-energy electrodynamics of vdW heterostructures and offer new opportunities for functionality through cavity control [1].

## References

[1] Gunda Kipp*, Hope M Bretscher*, Benedikt Schulte, Dorothee Herrmann, Kateryna Kusyak, Matthew W. Day, Sivasruthi Kesavan, Toru Matsuyama, Xinyu Li, Sara Maria Langner, Jesse Hagelstein, Felix Sturm, Alexander M Potts, Christian J Eckhardt, Yunfei Huang, Kenji Watanabe, Takashi Taniguchi, Angel Rubio, Dante M Kennes, Michael A Sentef, Emmanuel Baudin, Guido Meier, Marios H Michael, James W McIver†, arXiv:2403.19745, (2024).

## Figures

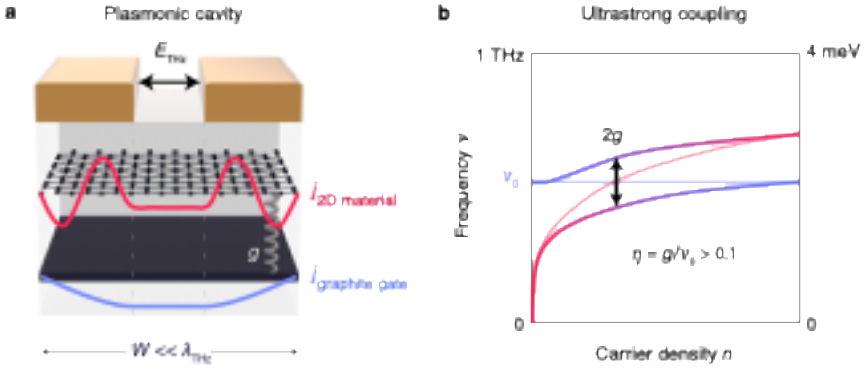


**Figure 1:** Self-cavity formation and ultrastrong coupling between a 2D material and its graphite gate