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Crossover between Strongly-coupled and Weakly-coupled Exciton Superfluid

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Abstract:

In fermionic systems, superconductivity and superfluidity occur through the condensation of fermion pairs. The nature of this condensate can be tuned by varying the pairing strength, which is challenging in electronic systems. We studied graphene double layers separated by an atomically thin insulator. Under applied magnetic field, electrons and holes couple across the barrier to form bound magneto-excitons whose pairing strength can be continuously tuned by varying the effective layer separation. Using temperature-dependent Coulomb drag and counterflow current measurements, we were able to tune the magneto-exciton condensate through the entire phase diagram from weak to strong coupling. Our results establish magneto-exciton condensates in graphene as a model platform to study the crossover between two bosonic quantum condensate phases in a solid-state system.

Device Structure:

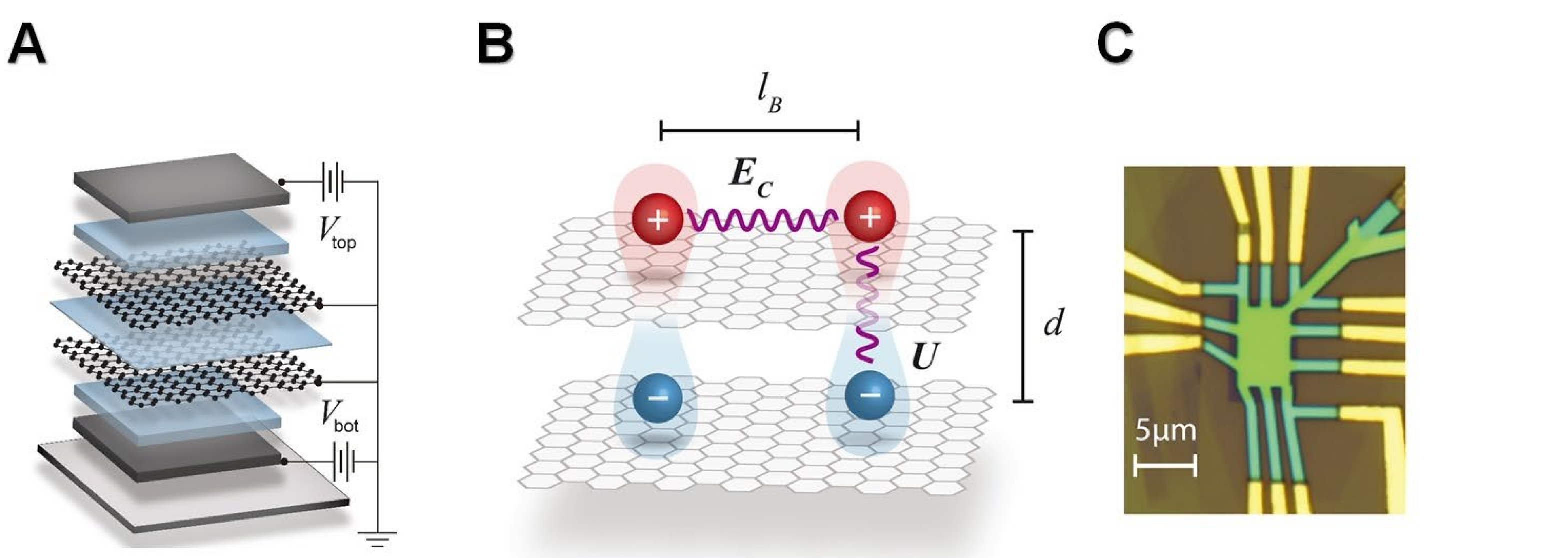

Fig.1 (A) Van de Waals Heterostructure for the device. **(B)** Illustration of the energy and length scales associated with exciton pairing in a graphene double-layer structure under a magnetic field. **(C)** Optical image of a graphene double-layer device used in this study.

BKT Transition in the BCS regime:

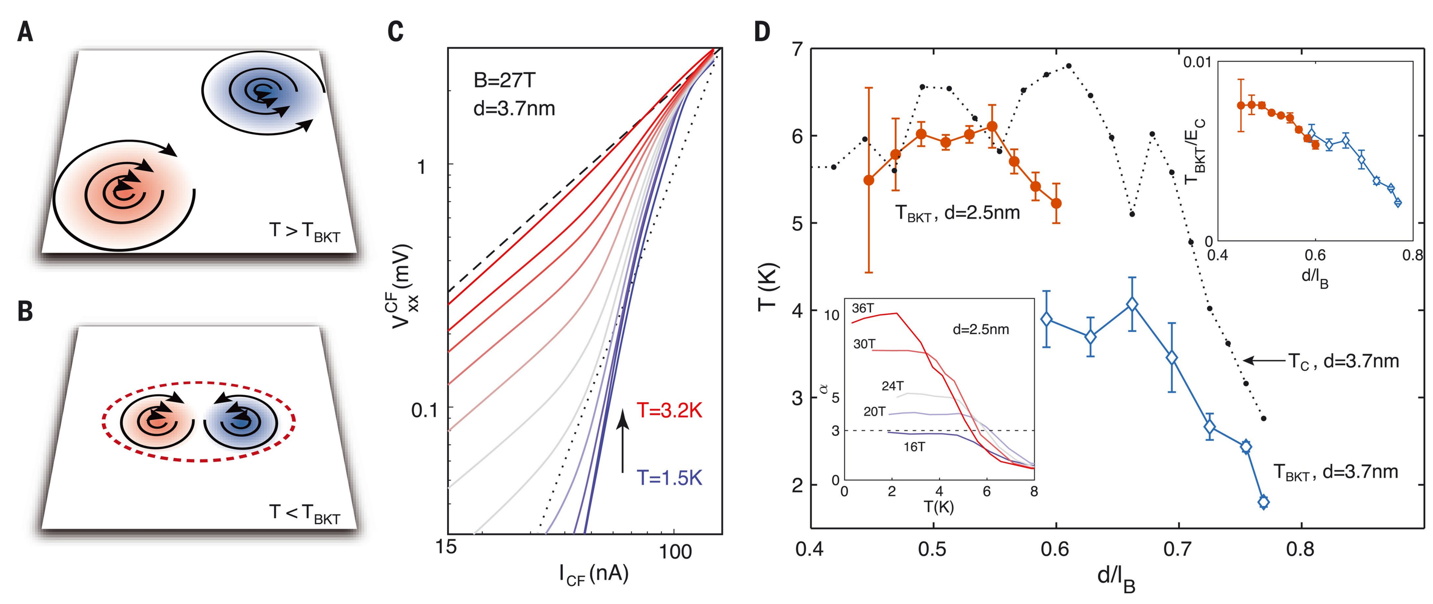

Fig.3 (A, B) Illustration of BKT transition. The circling black lines show the winding of the superfluid phase. **(C)** Counterflow current-voltage relationship at B =27T between T =1.5K and T = 3.2 K The dashed and dotted lines mark power-law exponents a = 1 and 3 **(D)** BKT transition temperature as a function of d/l_B in two samples.

Two Regimes of the Exciton Condensate:

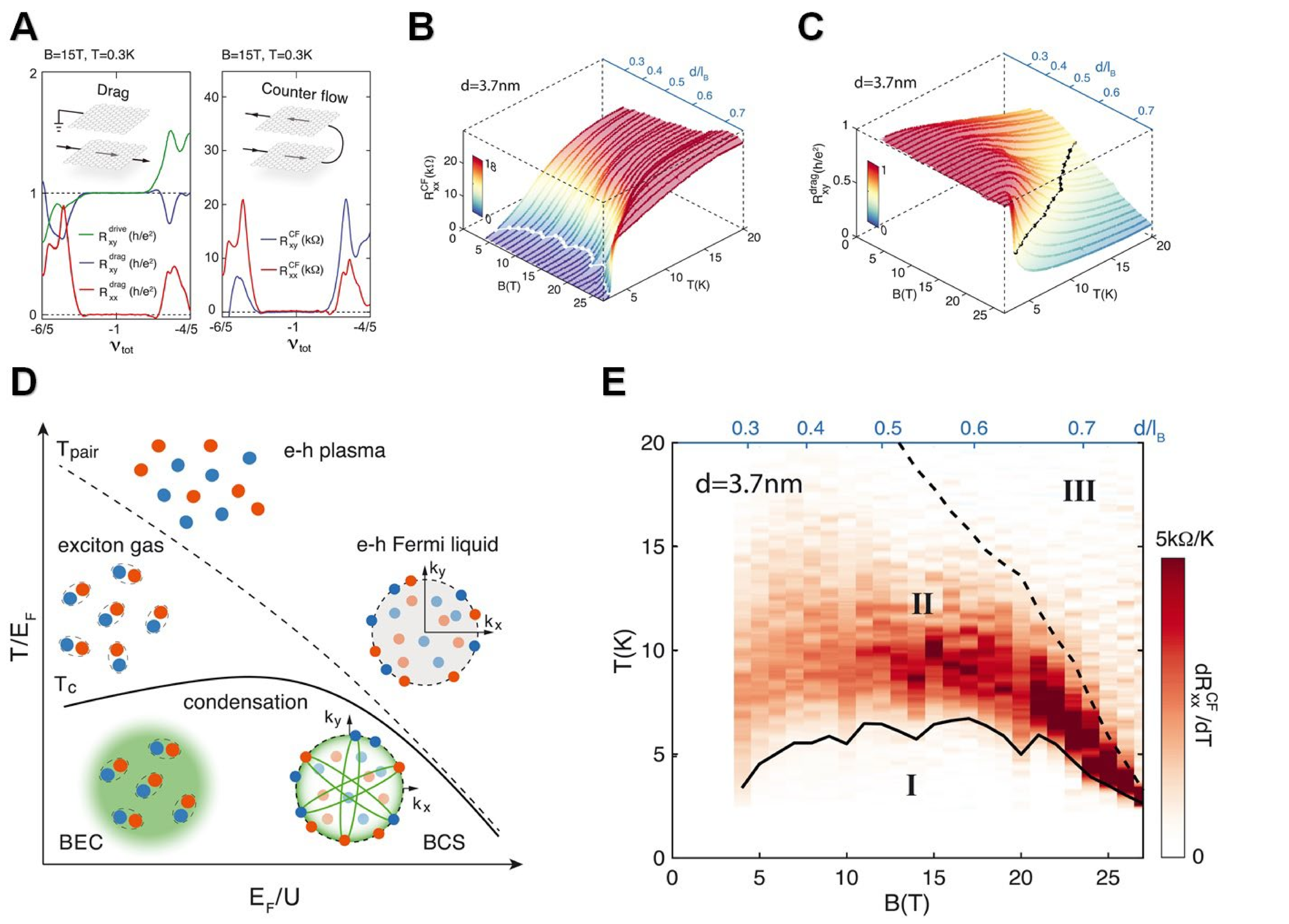

Fig.2 (A) left: Coulomb drag response of exciton condensate at $\nu_{total} = -1$ Right: Longitudinal and Hall resistance in counterflow geometry measured at $\nu_{total} = -1$. Inset: Arrows indicate the direction of current flow in each layer.**(B)** Superfluid transition temperature T_c for a range of $\boldsymbol{B}$ values. **(C)** Pairing temperature T_{pair} for a range of $\boldsymbol{B}$ values. **(D)** Schematic phase diagram for equal densities of electrons and holes with varying temperature and coupling strength. **(E)** Temperature derivative of R_{xx}^{CF} as a function of temperature and magnetic field.

Activation Energy in BEC regime:

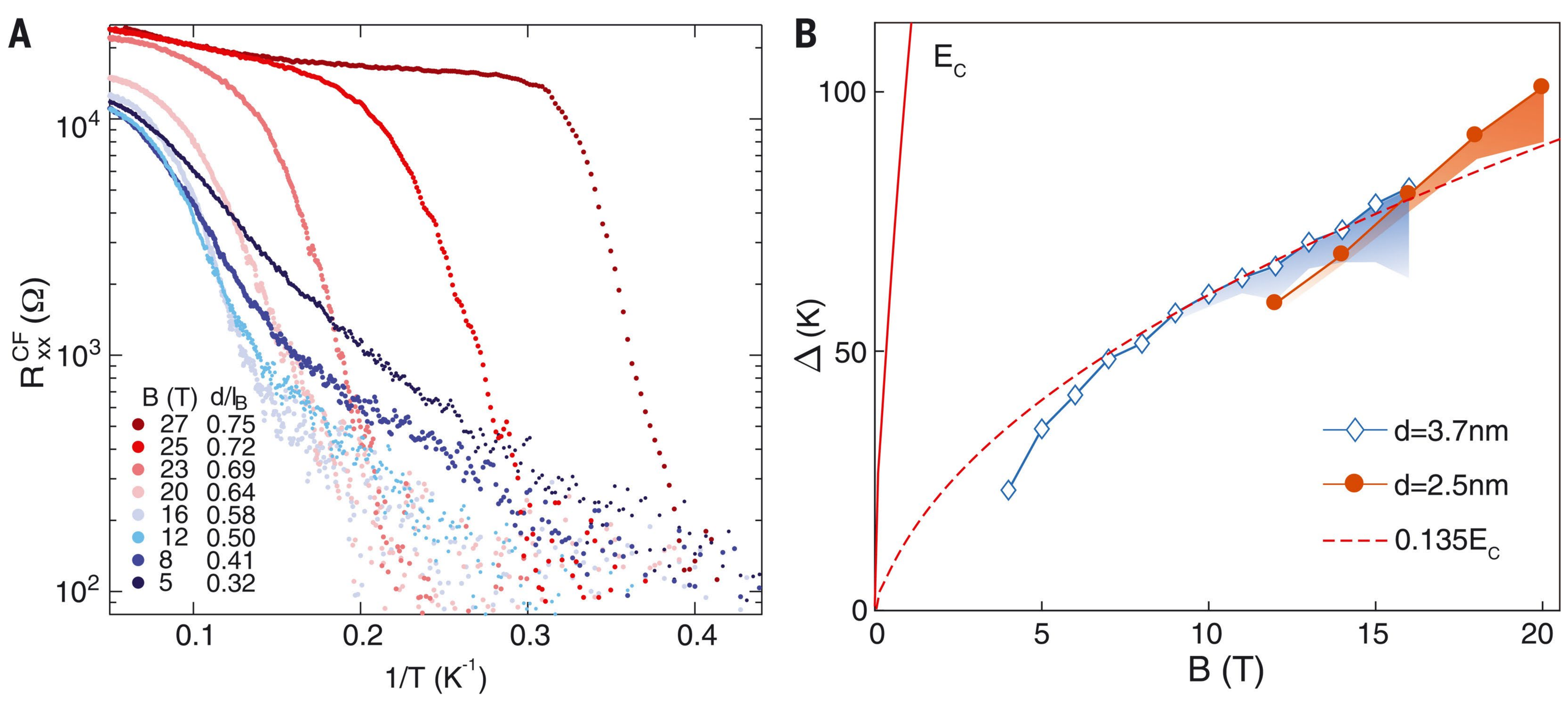

Fig.4 (A) Arrhenius plot of R_{xx}^{CF} measured at different magnetic fields in the d =3.7 nm device. **(B)** Activation gap D as a function of magnetic field for two devices with different interlayer separation d = 3.7 nm and 2.5 nm. The red solid curve corresponds to the Coulomb energy $E_c = e^2/\epsilon l_B$. The red dashed curve shows $0.135E_c$.

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REFERENCES

Xiaomeng Liu, J. I. A. Li, Kenji Watanabe, Takashi Taniguchi, James Hone, Bertrand I. Halperin, Philip Kim, and Cory R. Dean. "Crossover between strongly coupled and weakly coupled exciton superfluid." *Science* 375, no. 6577 (2022): 205-209.

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