Title: Exciton Condensates are Super!

Date: Apr 29, 2015 03:00 PM

URL: http://pirsa.org/15040089

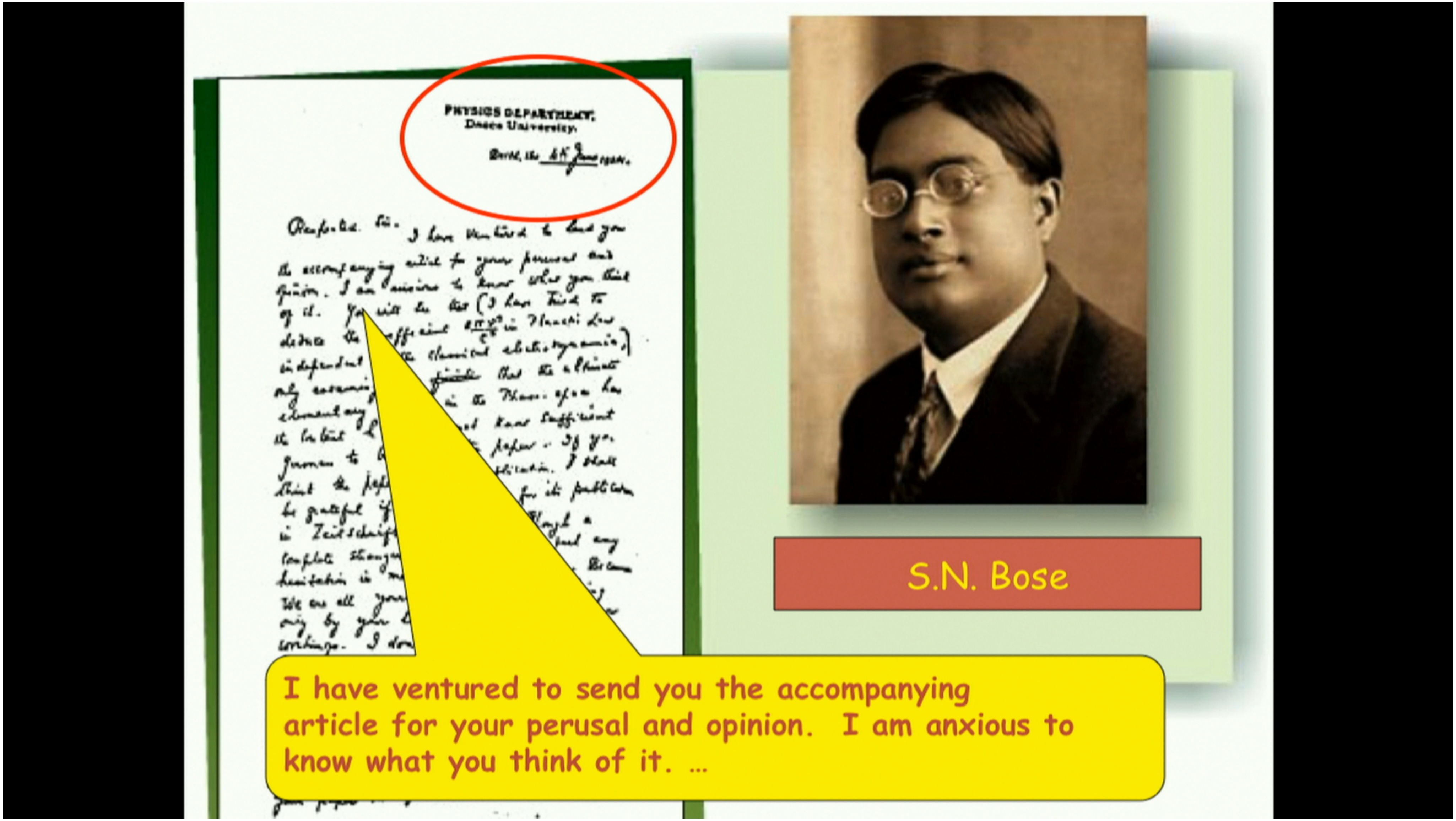
Abstract: <p>The spatially-indirect exciton condensates (SIXC) is an interesting ordered electronic state in which coherence is spontaneously established between particles localized in separate two-dimensional layers. I will discuss some of the properties SIXCs, commenting on their counterflow superfluidity, their collective excitations, and on similarities and differences relative to superconductors, easy-plane ferromagnets and anti-ferromagnets, and the standard model of particle physics. Finally I will discuss the prospects of achieving SIXC states at elevated temperatures in multi-layer 2D material systems. </p>

<p> </p>

Excitons are Super!

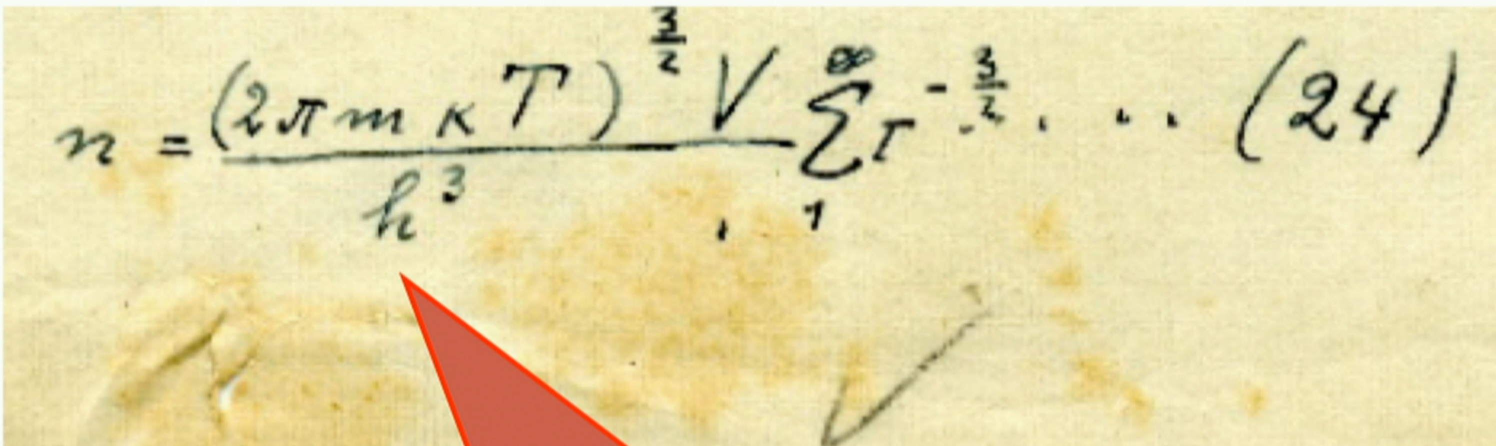
JPE and AHM - Nature (2004)
JPE - Annual Review of CMP (2014)
Fengcheng Wu and Fei Xue - UT Austin

Bose Condensates


PHYSICS DEPARTMENT,
Dacca University.
4th June 1924.
I have ventured to send you the accompanying article for your perusal and opinion. I am anxious to know what you think of it. …
S.N. Bose

Bose-Einstein Condensation

Einstein 1925



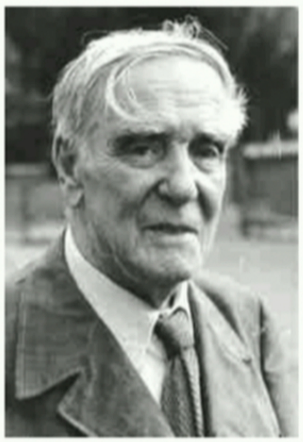
$$n = \frac{(2\pi m \kappa T)^{\frac{3}{2}} V}{h^3} \sum_{1}^{\infty} \tau^{-\frac{3}{2}} \quad \ldots \ldots (24)$$

University of Leiden
Einstein Archive

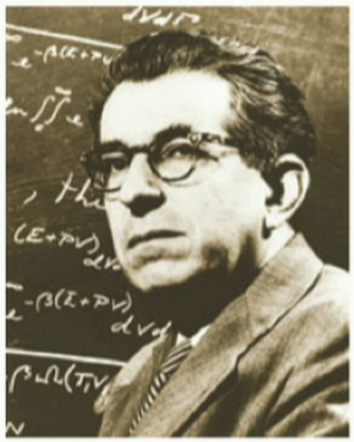
Bose-Einstein Condensation

$$\langle \hat{\Psi}(\vec{r}) \rangle \neq 0$$

- Finite Fraction of all Particles in Same State
- Broken Symmetry
- Matter-Wave Interference Phenomena
- Superfluidity



Kapitza



London

Pair Condensation

$$\langle \hat{\Psi}_{\uparrow}(\vec{r})\hat{\Psi}_{\downarrow}(\vec{r})\rangle \neq 0$$

Cooper Pairs

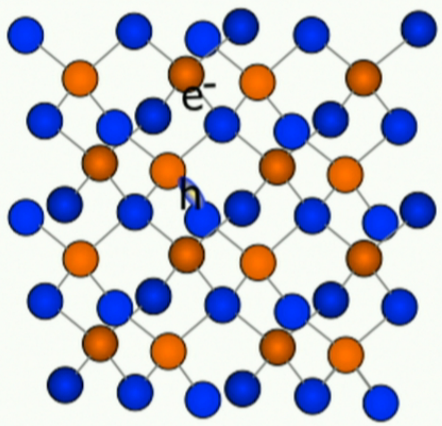
$$\langle \hat{\Psi}^{\dagger}_{c}(\vec{r})\hat{\Psi}_{v}(\vec{r})\rangle \neq 0$$

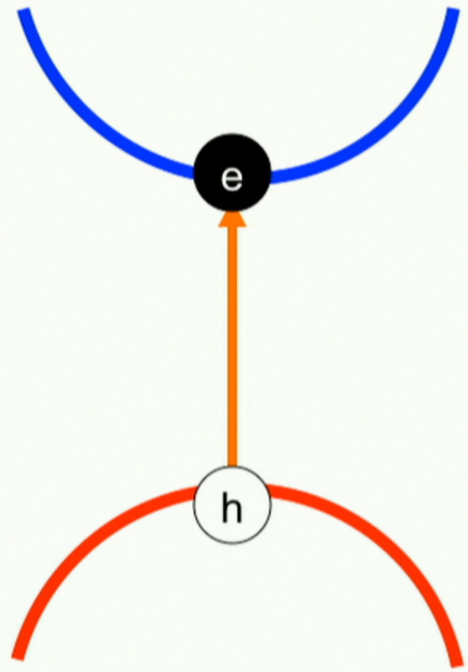
Excitons

CDW, SDW
Ferromagnetism

Some History of Exciton Condensates

Excitons – Elementary Excitations of Intrinsic Semiconductors





Bose-Einstein Condensation of Excitons

JOHN M. BLATT
Courant Institute of Mathematical Sciences, New York University, New York, New York and Applied Mathematics Department, University of New South Wales, New South Wales, Australia

AND

K. W. BÖER AND WERNER BRANDT
Department of Physics, Radiation and Solid-State Laboratory, New York University, New York, New York

(Received January 8, 1962)

Since excitons are electrically neutral, we cannot expect to detect such condensation by spectacular electrical effects.

3:12 PM

6. NECESSARY AND SUFFICIENT CONDITION FOR SUPERFLUIDITY

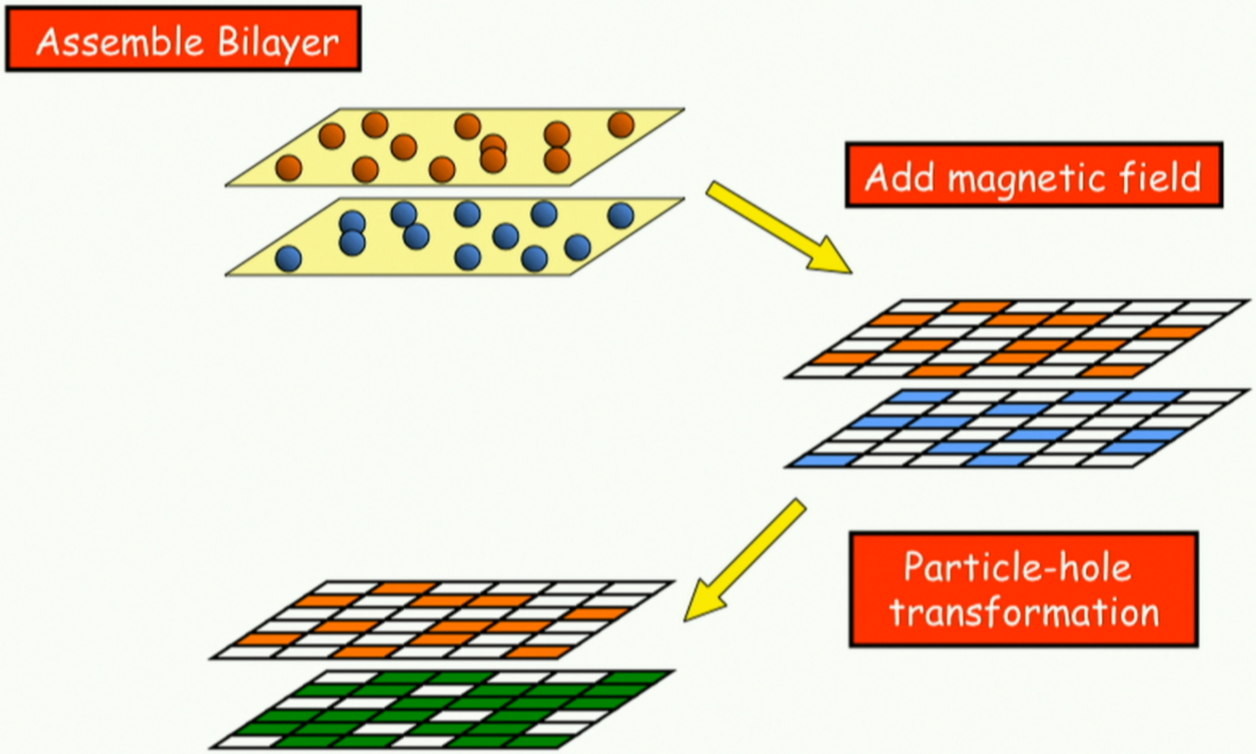
On the other hand, a boson of type II is an elementary excitation of a many-body system which is essentially a bound complex of equal numbers of fermions and their holes. An exciton is an example of this type.

When they condense, the resultant state is not superfluid.

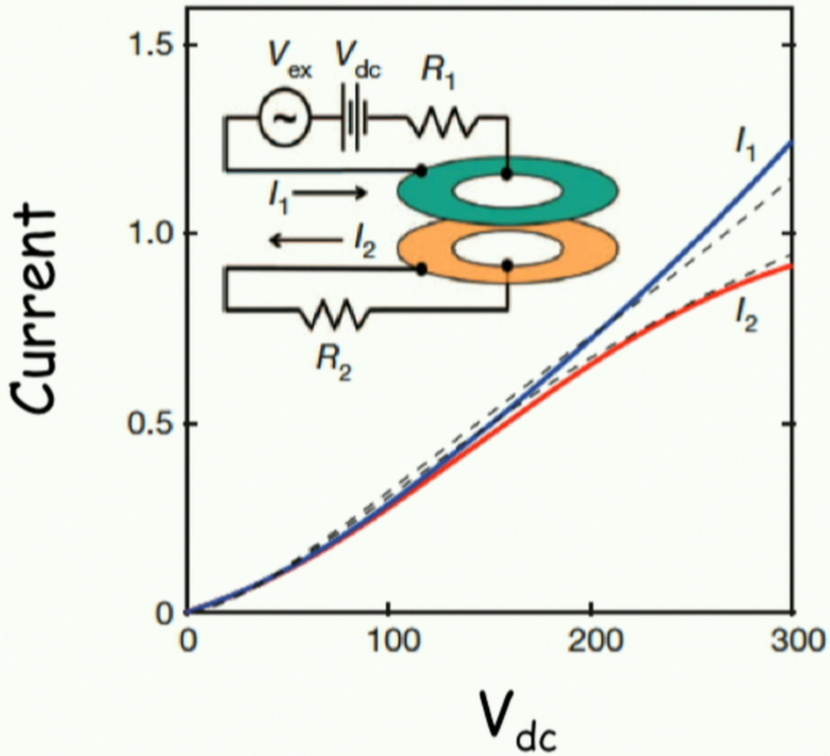
Walter Kohn & David Sherrington RMP (1970)

Transport Properties of Equilibrium Exciton Condensates

Electrons and Holes in the QH Regime



Transport Properties of Bilayer Exciton Condensates



Nandi et al.
Nature
(2012)

Scattering off the Condensate

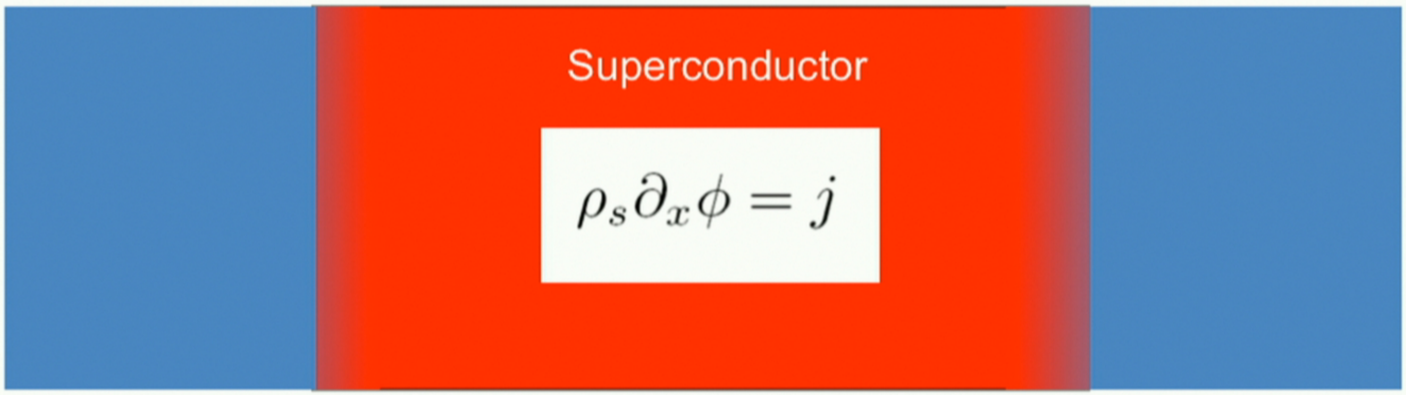
$$U\ \Psi_T^* \Psi_T \Psi_B^* \Psi_B$$

$$\approx$$

$$U\ \Psi_T^* \Psi_B \langle \Psi_T \Psi_B^* \rangle + \text{h.c.}$$

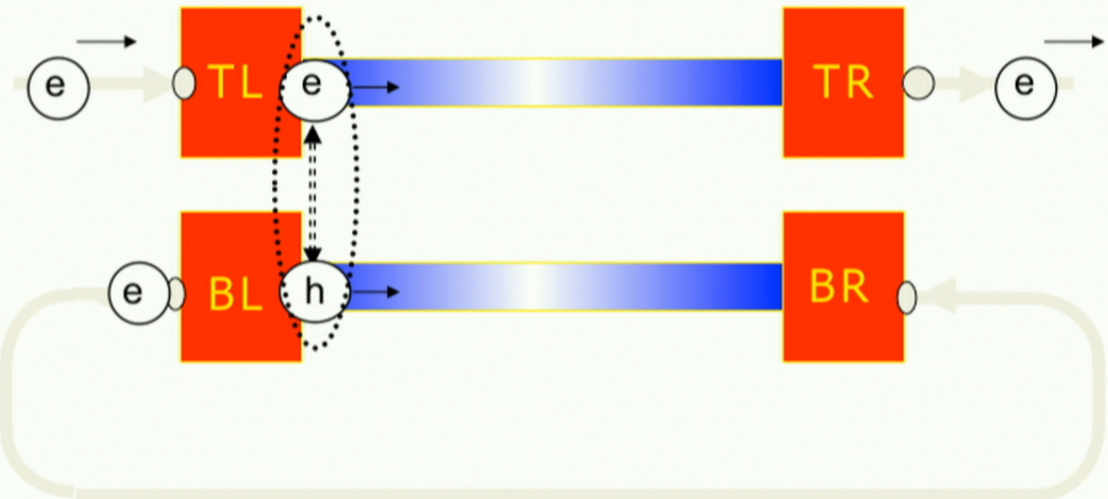
Interlayer Tunneling Mean-Field

Andreev Scattering



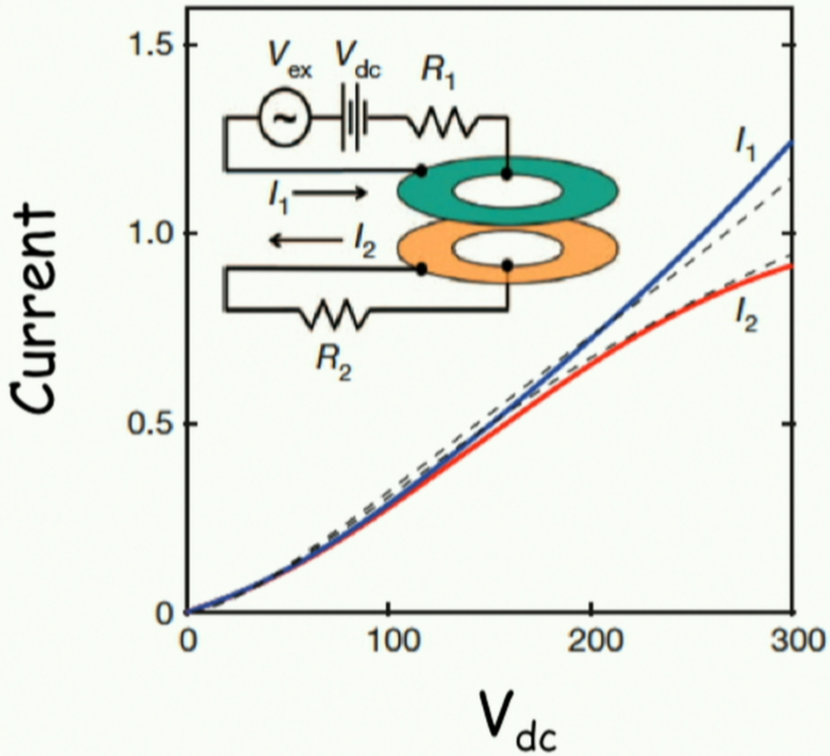
Charge Conservation

Exciton Superflow – in pictures



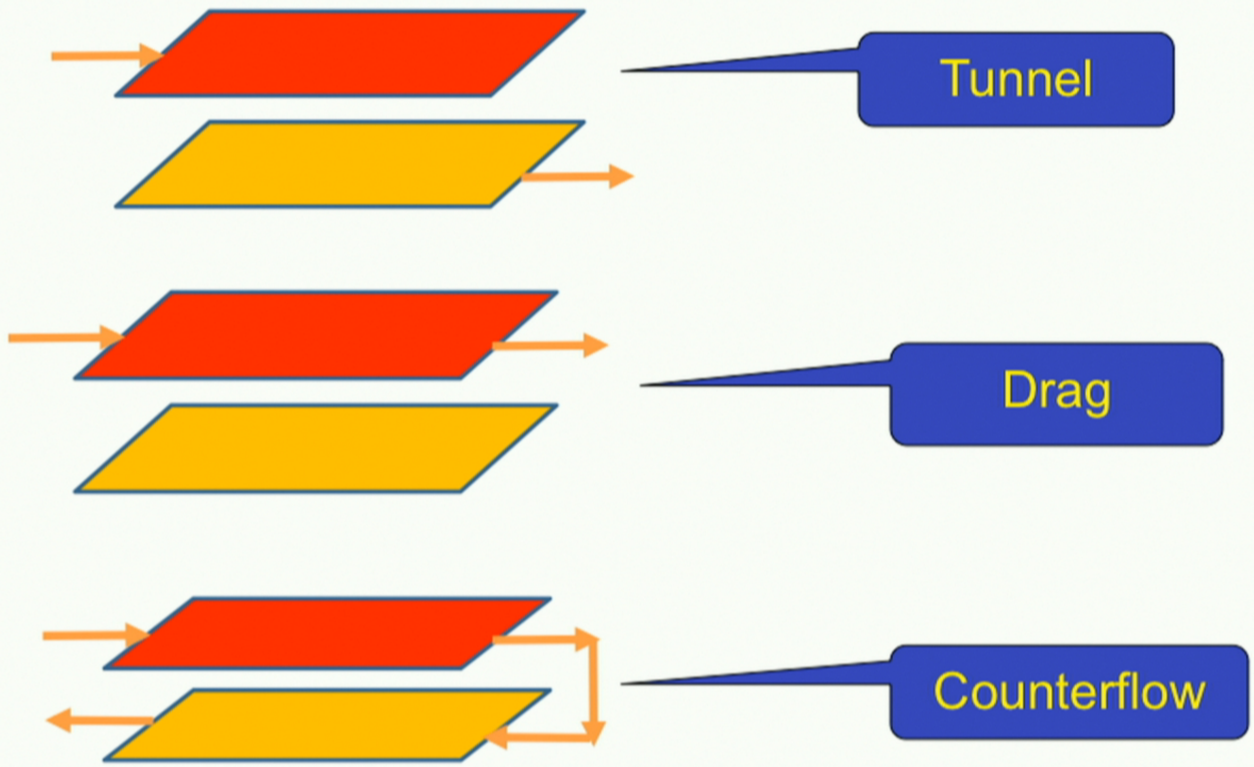
Drag Counterflow
Su & AHM
Nature Phys. (2008)

Transport Properties of Bilayer Exciton Condensates



Nandi et al.
Nature
(2012)

Three Transport Experiments



Interlayer Tunneling

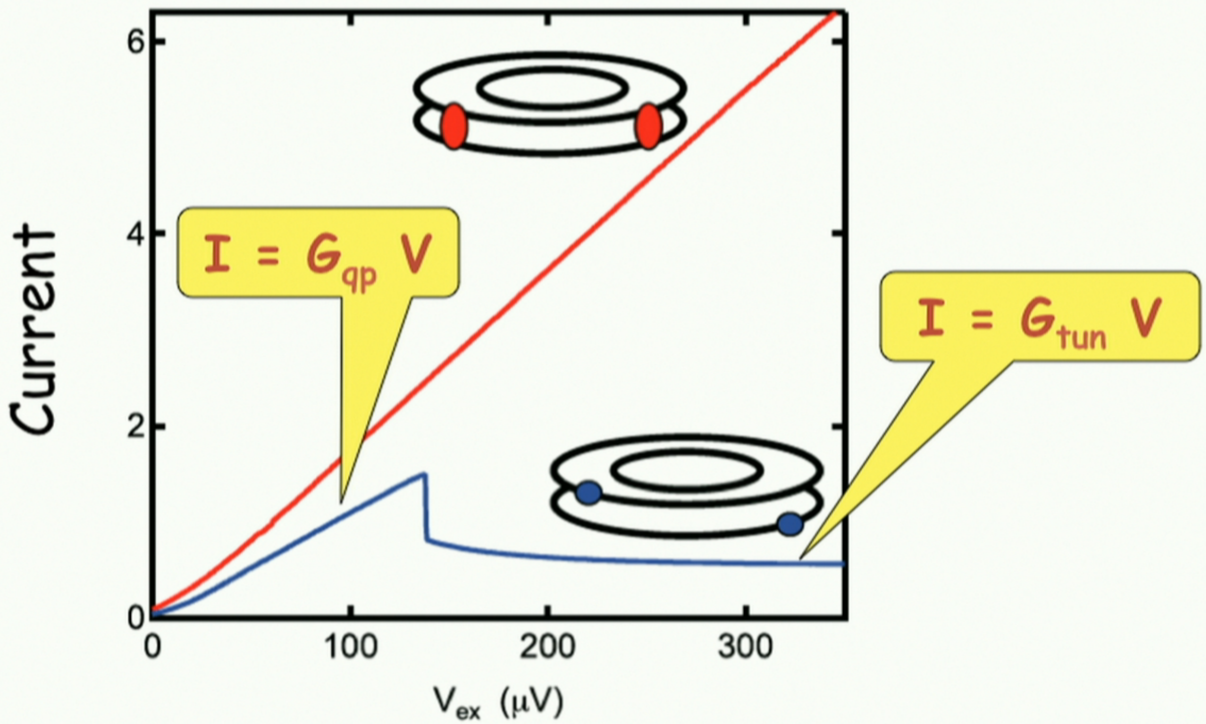
Dipolar Exciton Density

$$\mathcal{E}[\phi, M_z] = -\Delta \cos\phi + \rho|\nabla\phi|^2 + \frac{e^2}{2c}M_z^2$$

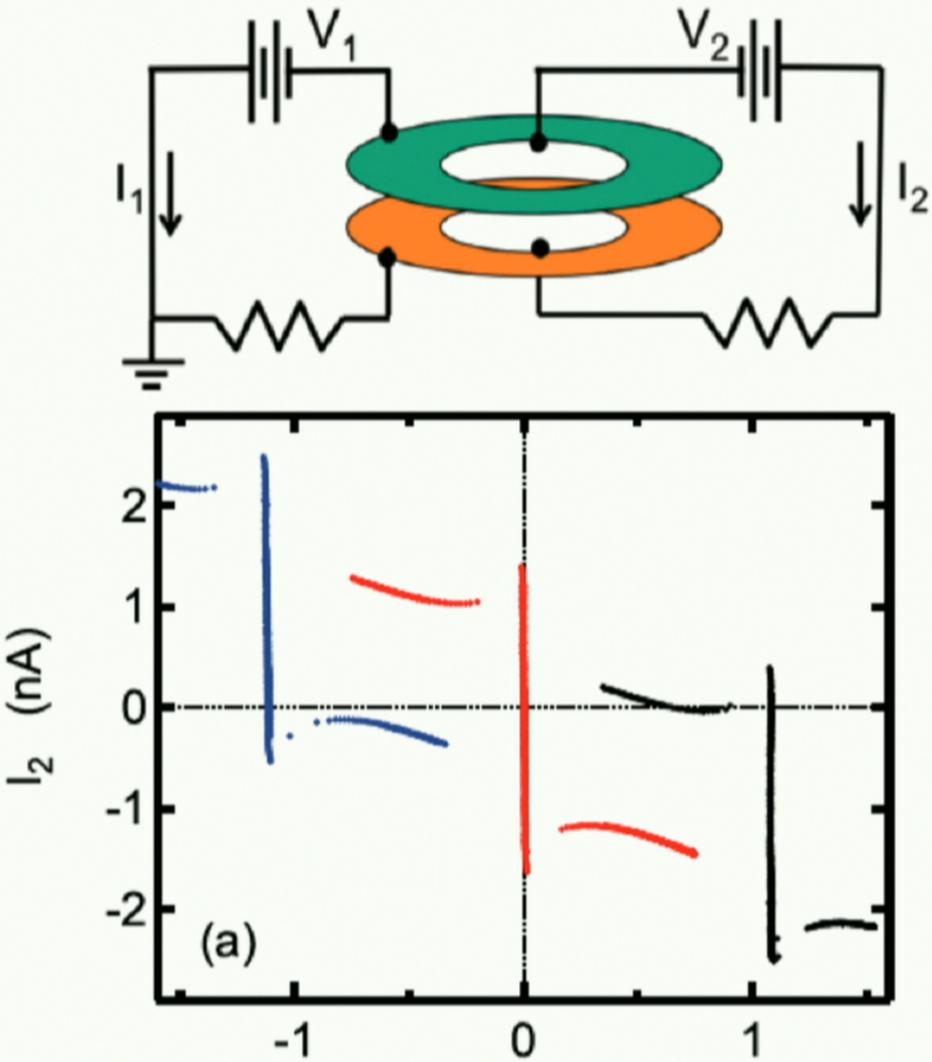
Exciton Andreev Scattering

$$\hbar\dot{M}_z = -\Delta\sin\phi + 2\rho\nabla^2\phi - \frac{g_{qp}}{A}\hbar\dot{\phi} + \sum_k \frac{\hbar I_k}{2} l_k \delta(\vec{r} - \vec{R}_k)$$

Transport Properties of Bilayer Exciton Condensates



Nandi et al. PRB (2013)



BISFET

Nandi et al.
PRB (2013)

BISFET DEVICE

Sanjay Banerjee Frank Register Emanuel Tutuc
Allan MacDonald

SWAN NRI Project
The University of Texas at Austin

TACC
TEXAS ADVANCED COMPUTING CENTER

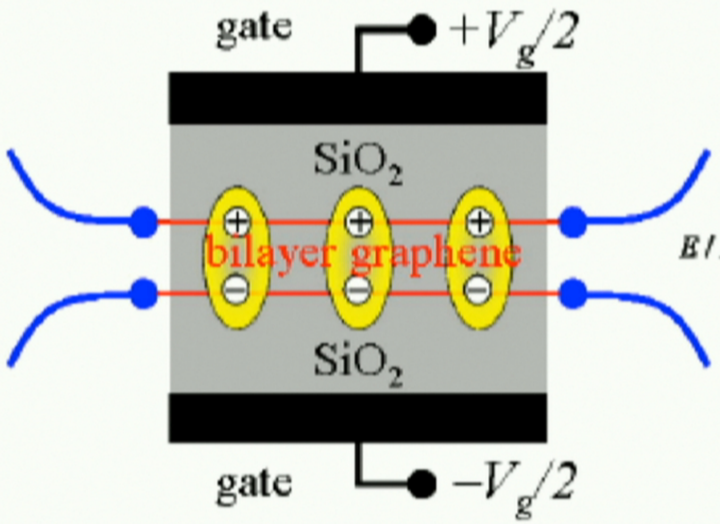
SRC Semiconductor Research Corporation

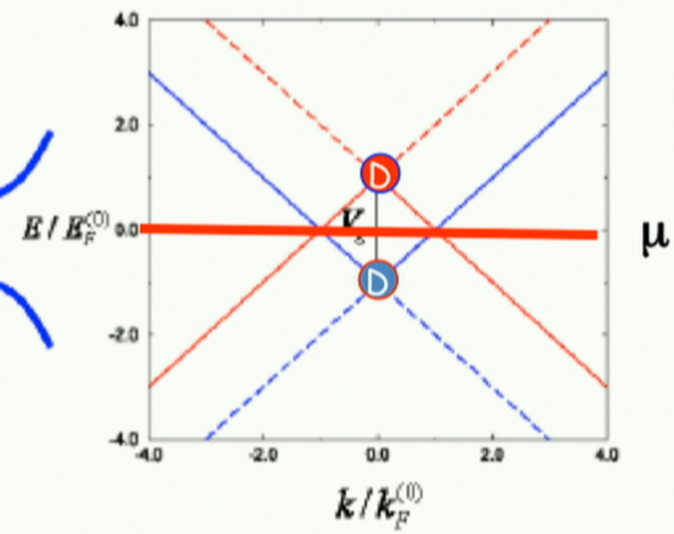
NRI nanoelectronics RESEARCH INITIATIVE

NIST National Institute of Standards and Technology U.S. Department of Commerce

Desperately Seeking Room Temperature

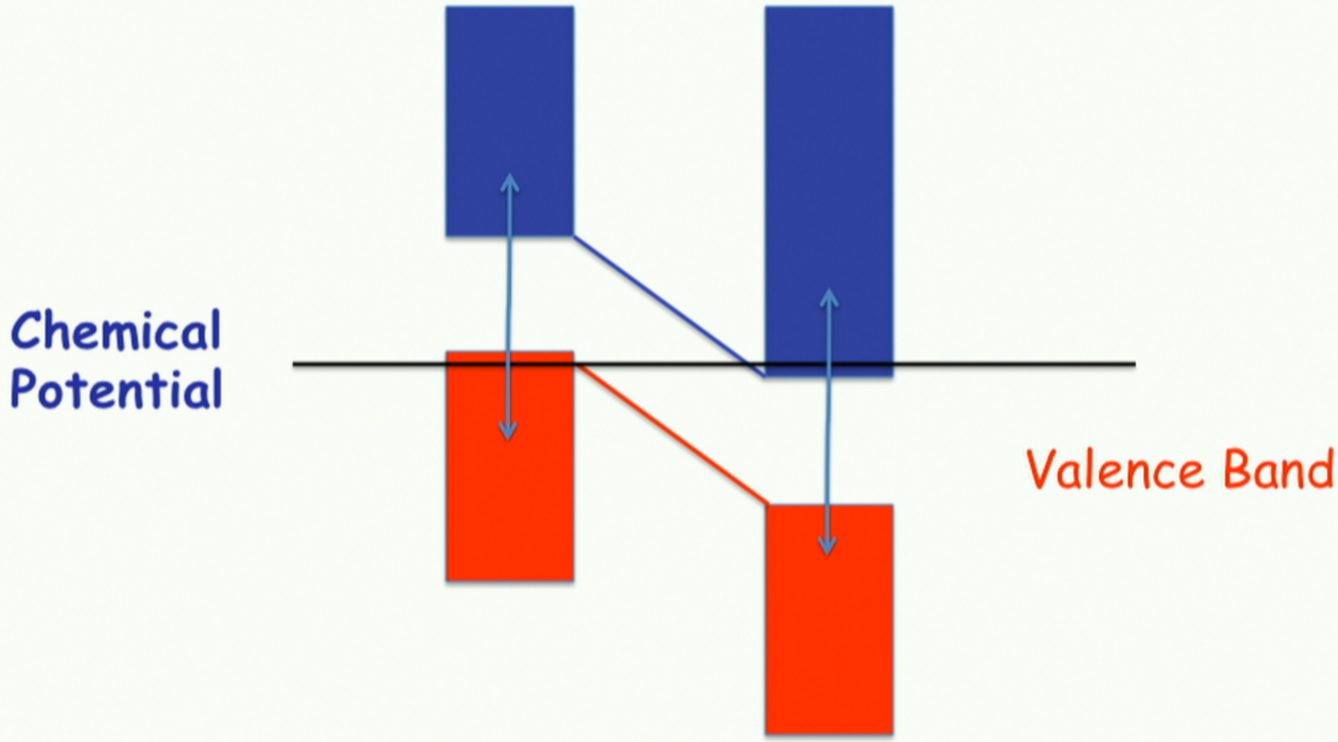
Neutral Graphene Bilayer



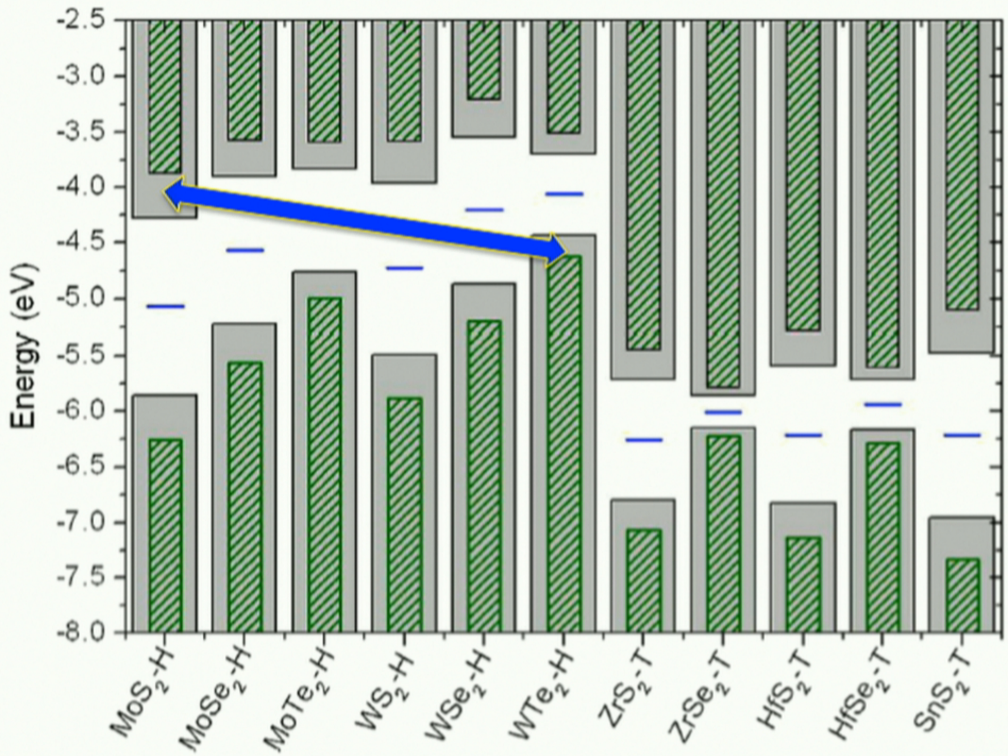


Min et al. , Joglekar, Aleiner PRB (2008)

Gapped 2D Materials are Simpler

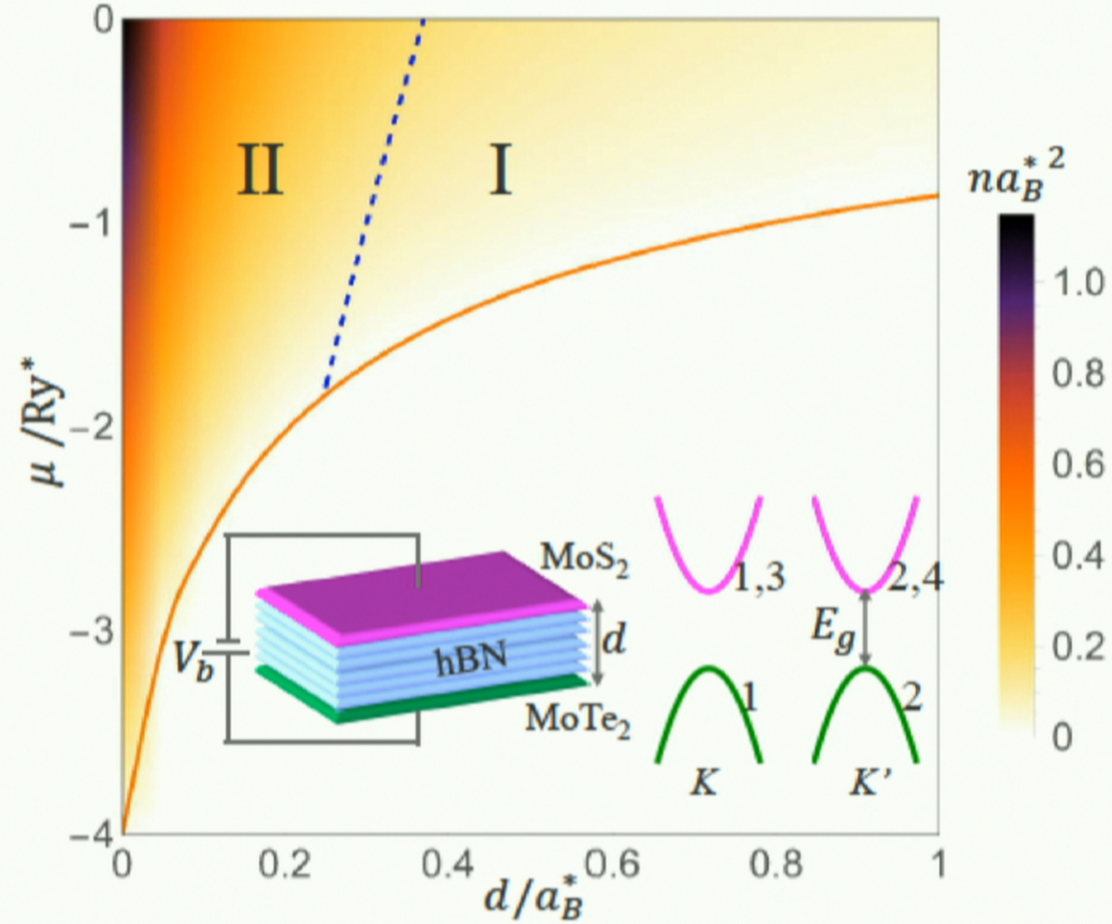


TMD Band Alignments

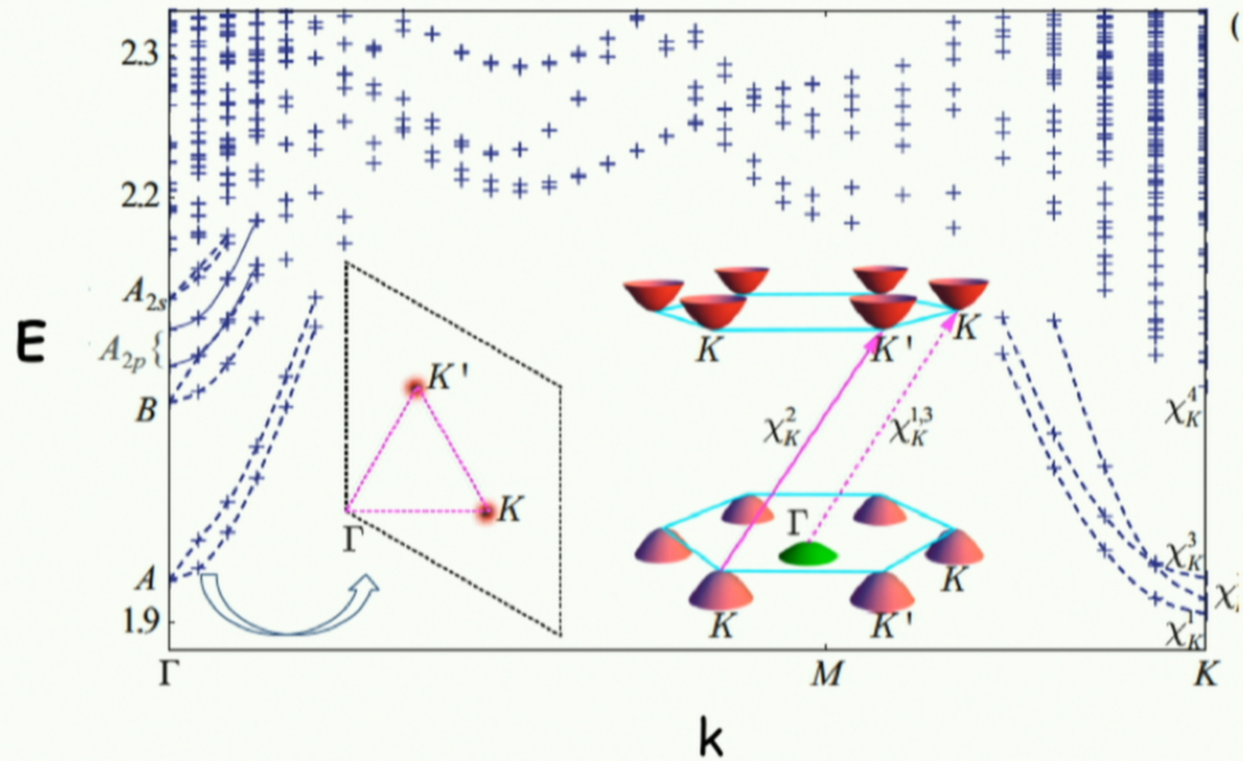


Cho et al. - UTD - APL (2013)

TMD Bilayer XC Phase Diagram

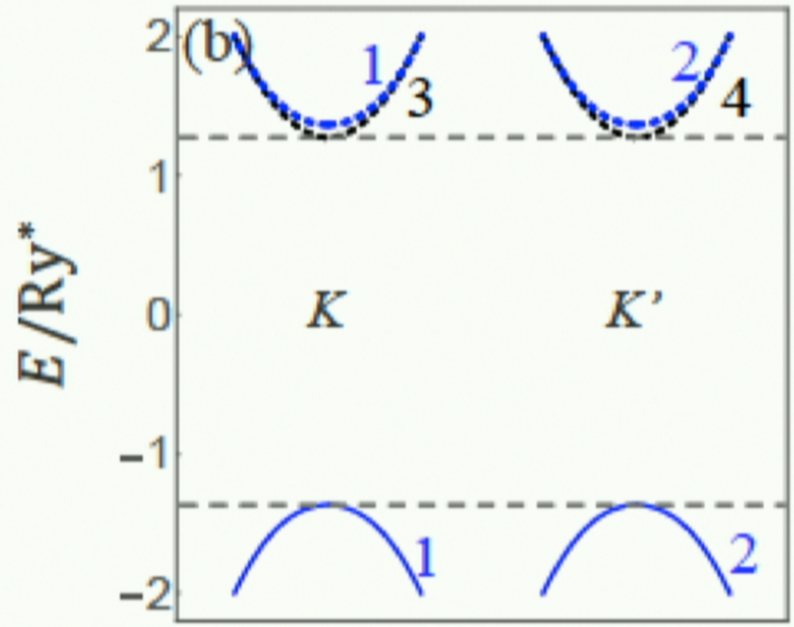


TMD Exciton Band Structure



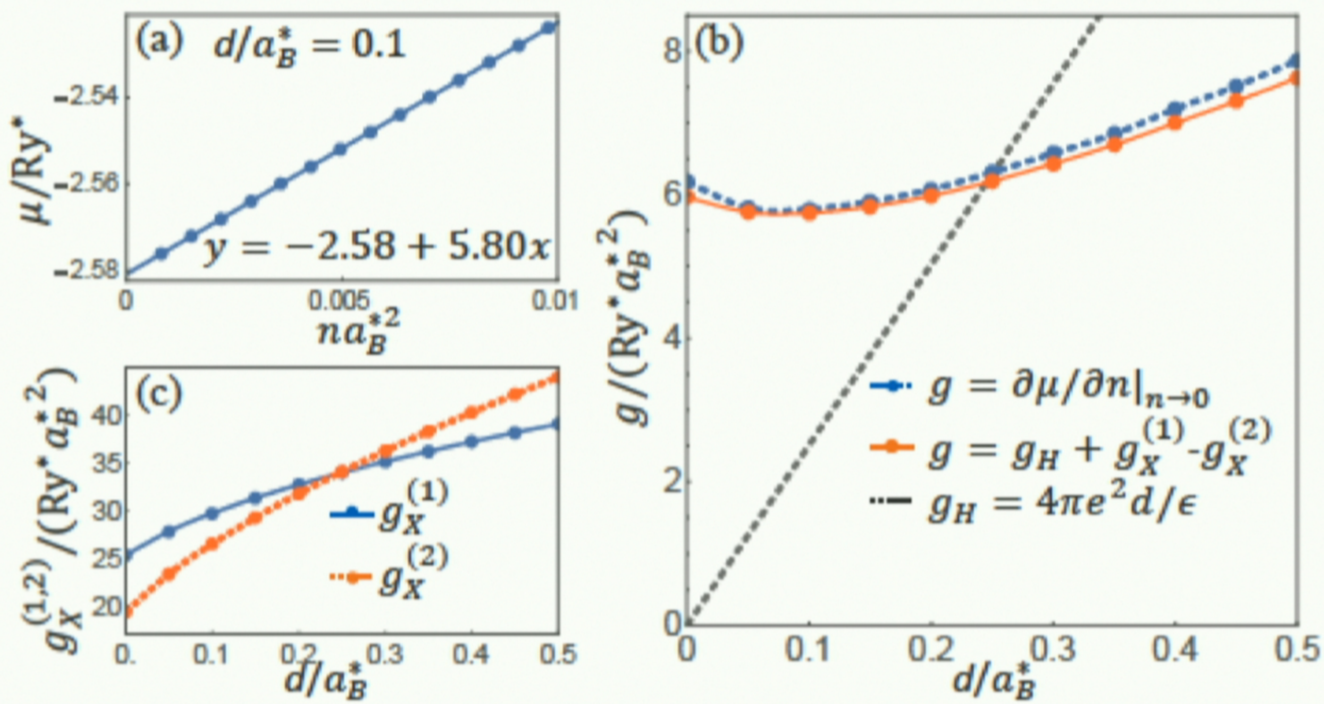
Wu and AHM - PRB (2015)

Many Exciton States



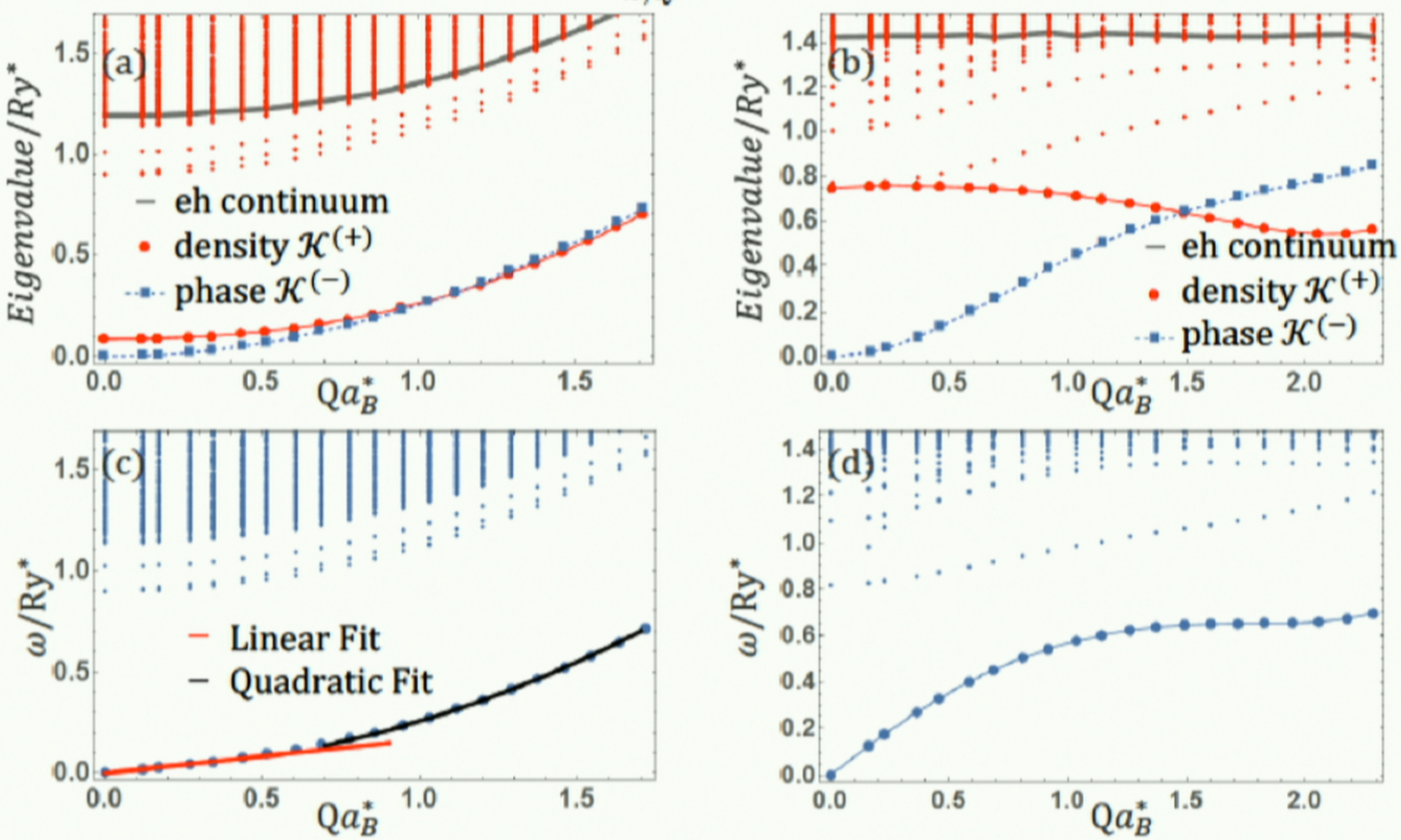
$$|XC\rangle = \Pi_k \; (u_k \,|vk\rangle + v_k|ck\rangle)$$

Exciton-Exciton Interactions



Fluctuation Lagrangian

$$|\Phi\rangle = \left[\mathcal{Z} + \sum_{\vec{k},\vec{Q}} z_{\vec{k}}(\vec{Q})\gamma^{\dagger}_{(\vec{k}+\vec{Q}),1}\gamma_{\vec{k},0}\right]|XC\rangle$$



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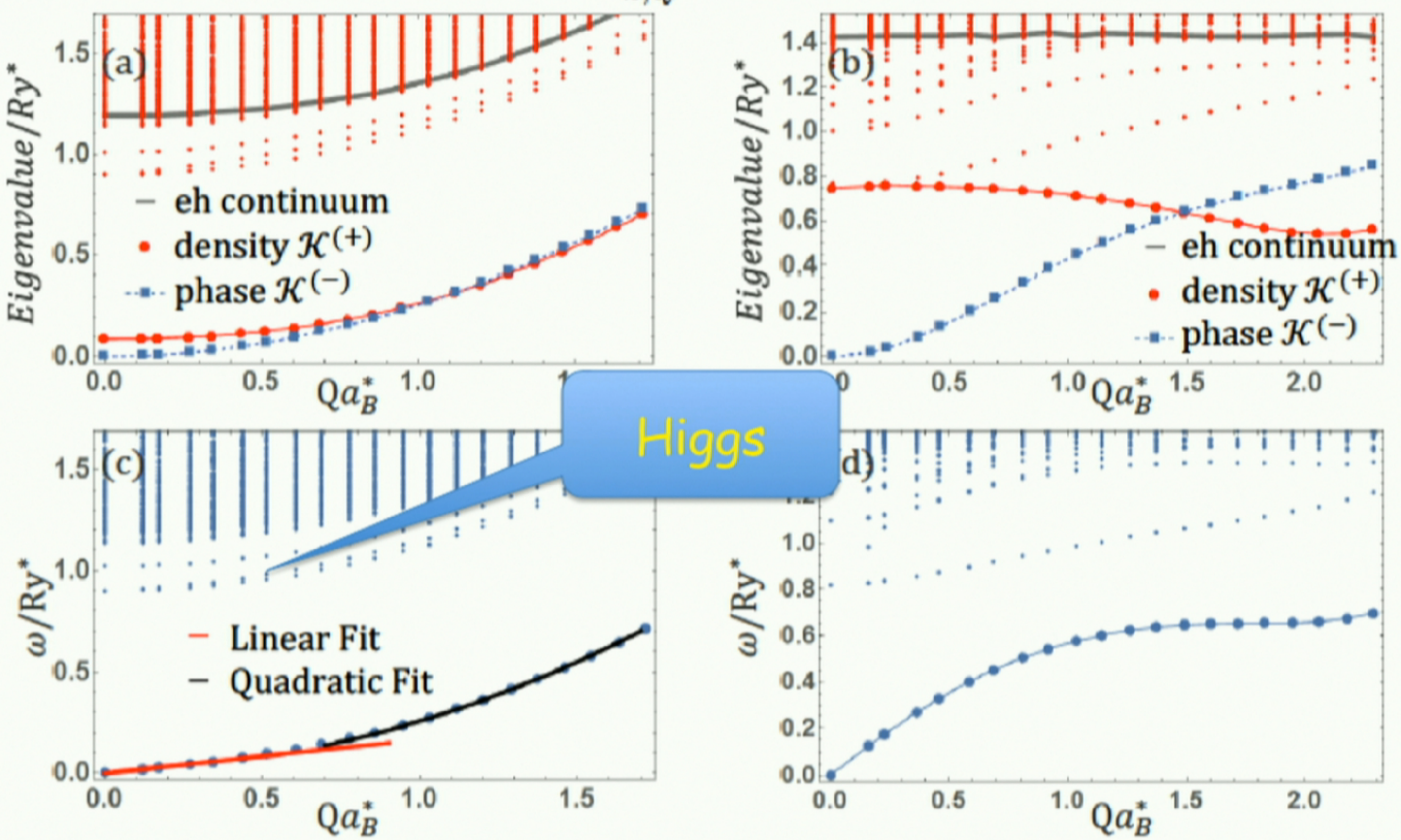
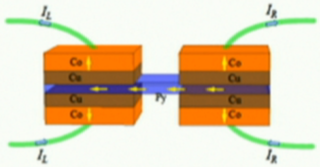
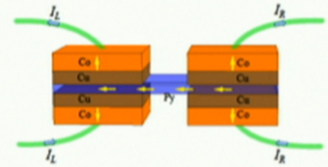




BISMAT



Magnetic Correspondence

Top Layer Electrode = Spin-Up Electrode

Bottom Layer Electrode = Spin-Down Electrode

$(\text{Capacitance})^{-1}$ = Easy-Plane Anistropy

Tunneling = In-Plane Anisotropy

Chen, Kent, AHM PRB (2014)