Topologically protected states at domain walls in bilayer graphene

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What are the domain walls in bilayer graphene?

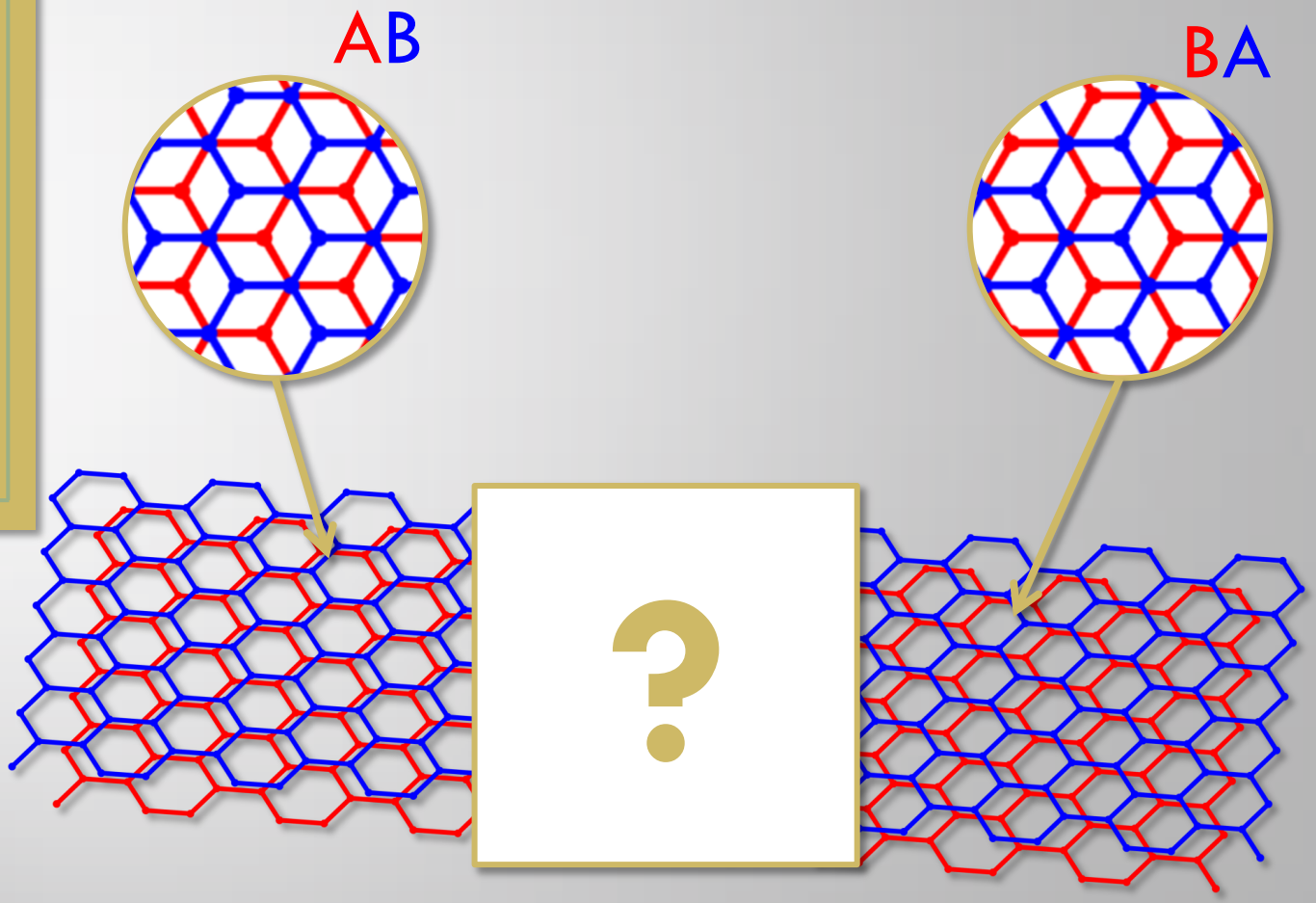
Boundaries between regions with different properties

Magnetic moments

Gate voltage sign

★ Stacking

etc.



Why do we investigate domain walls in graphene?

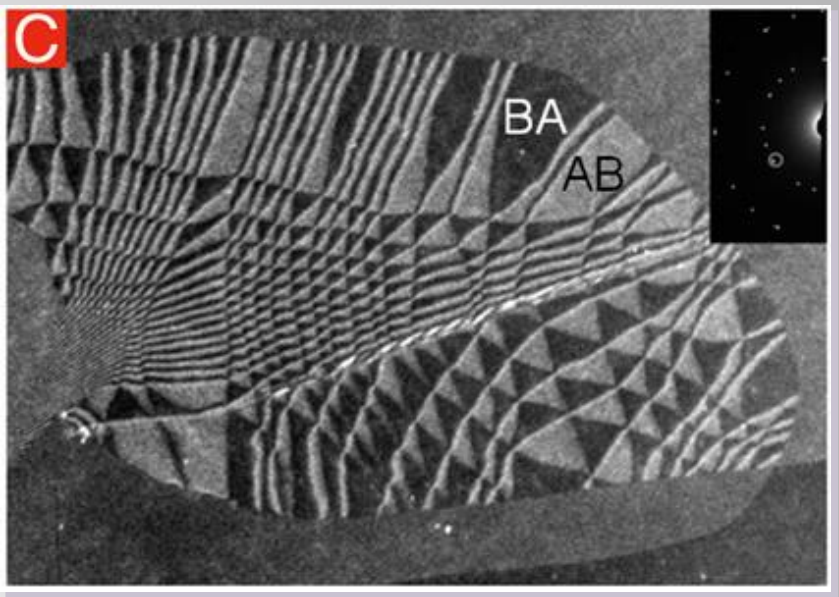
- occur

spontaneously
intentionally

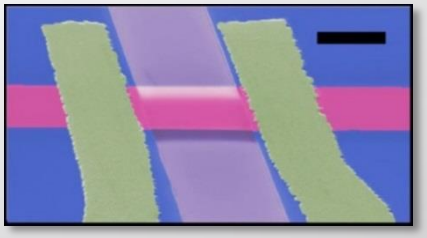
- affect transport

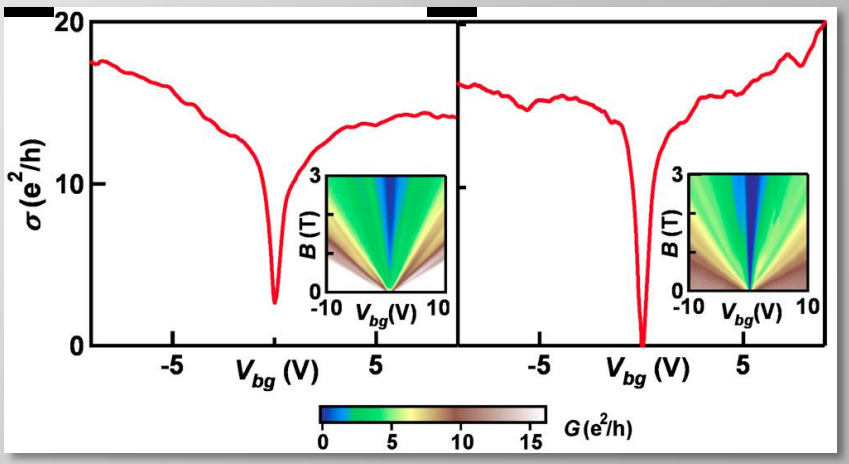
no conductance between the domains
domain wall – conducting channel

Aberration-corrected annular dark-field STEM



Suspended double-gated BL graphene





Two terminal differential conductivity vs. back-gate voltage

Alden – PNAS (2013)
Bao – PNAS (2012)

Why do we investigate domain walls in graphene?

- occur

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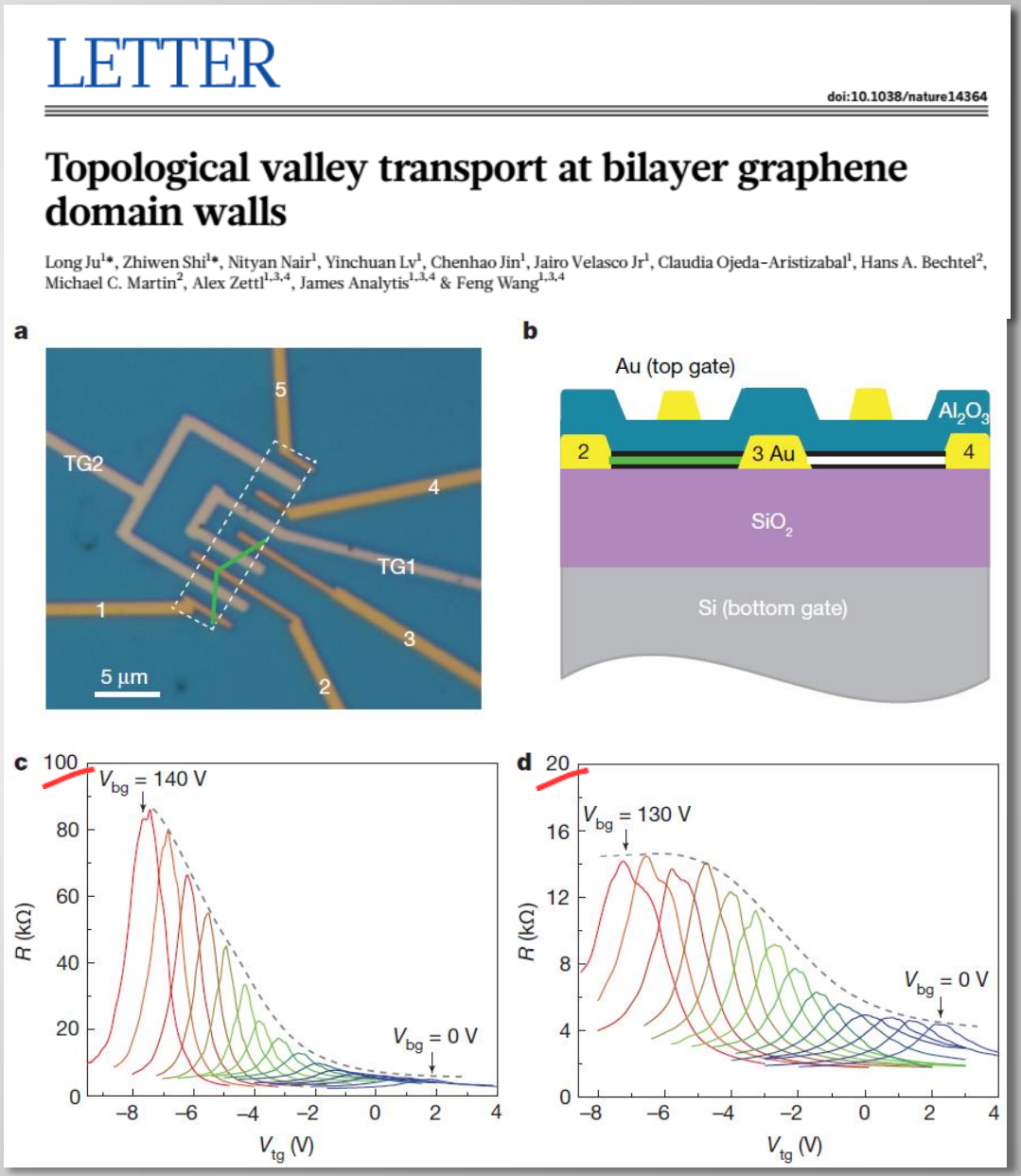
intentionally

- affect transport

no conductance between the domains
domain wall – conducting channel

Dual-gated field effect transistor devices on BLG with AB-BA domain walls (green line)

Ju – Nature (2015)



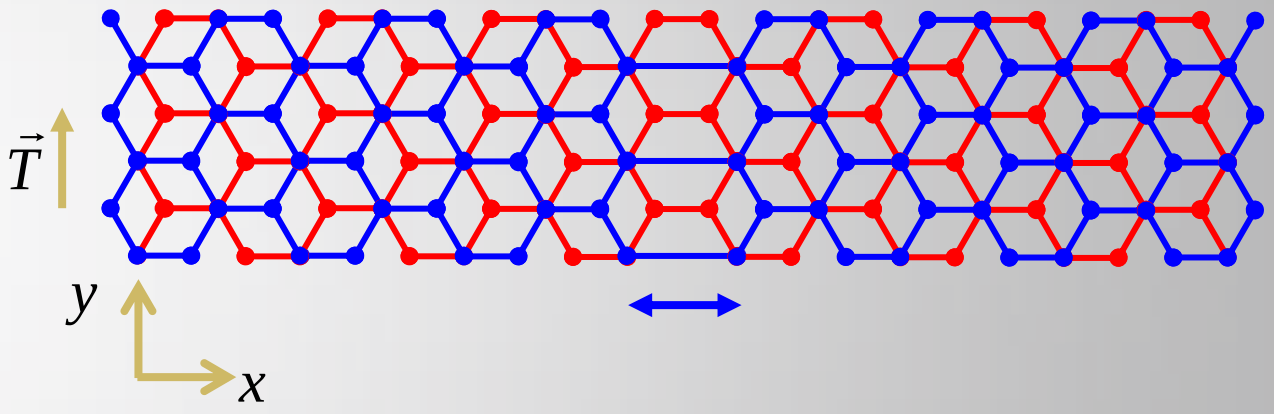
LETTER

doi:10.1038/nature14364

Topological valley transport at bilayer graphene domain walls

Long Ju[1]*, Zhiwen Shi[1]*, Nityan Nair[1], Yinchuan Lv[1], Chenhao Jin[1], Jairo Velasco Jr[1], Claudia Ojeda-Aristizabal[1], Hans A. Bechtel[2], Michael C. Martin[2], Alex Zettl[1,3,4], James Analytis[1,3,4] & Feng Wang[1,3,4]

Abrupt connection



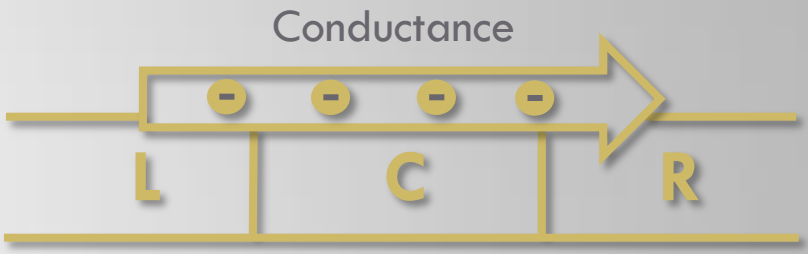
Martin – PRL (2008), Zhang – Nano Lett. (2012)

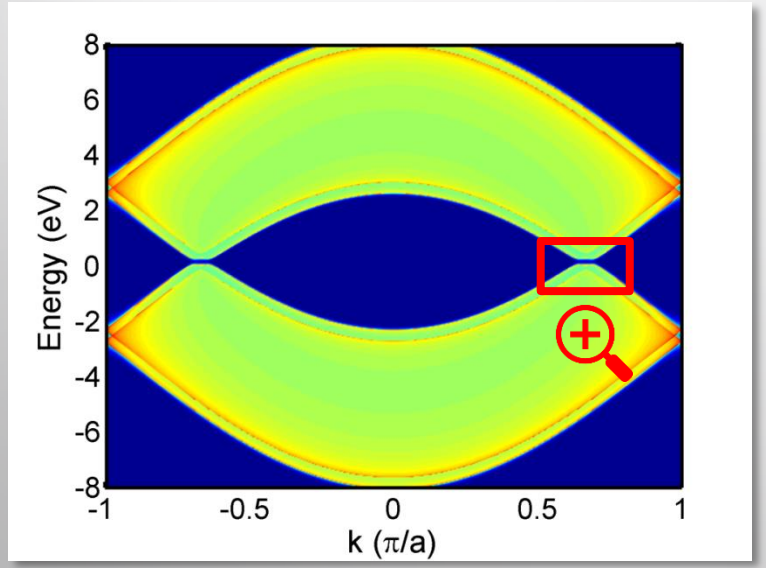
π-electron TB + Green functions

in-plane: nearest neighbor approx.

interplane: hopping for overlapping atoms

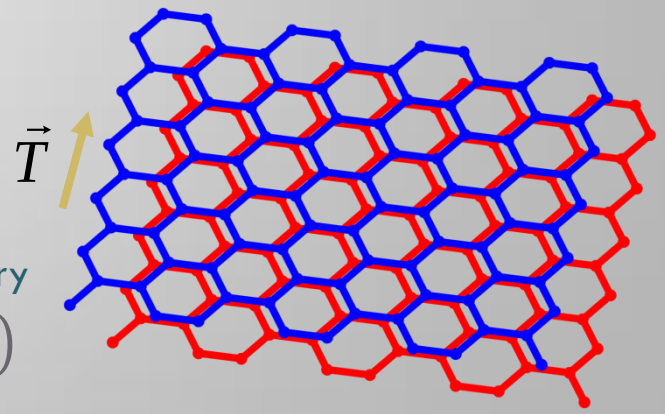
GFMT: Landauer-Büttiker formalism





Time-reversal symmetry

$$\Psi(\vec{k}) = \Psi(-\vec{k})$$

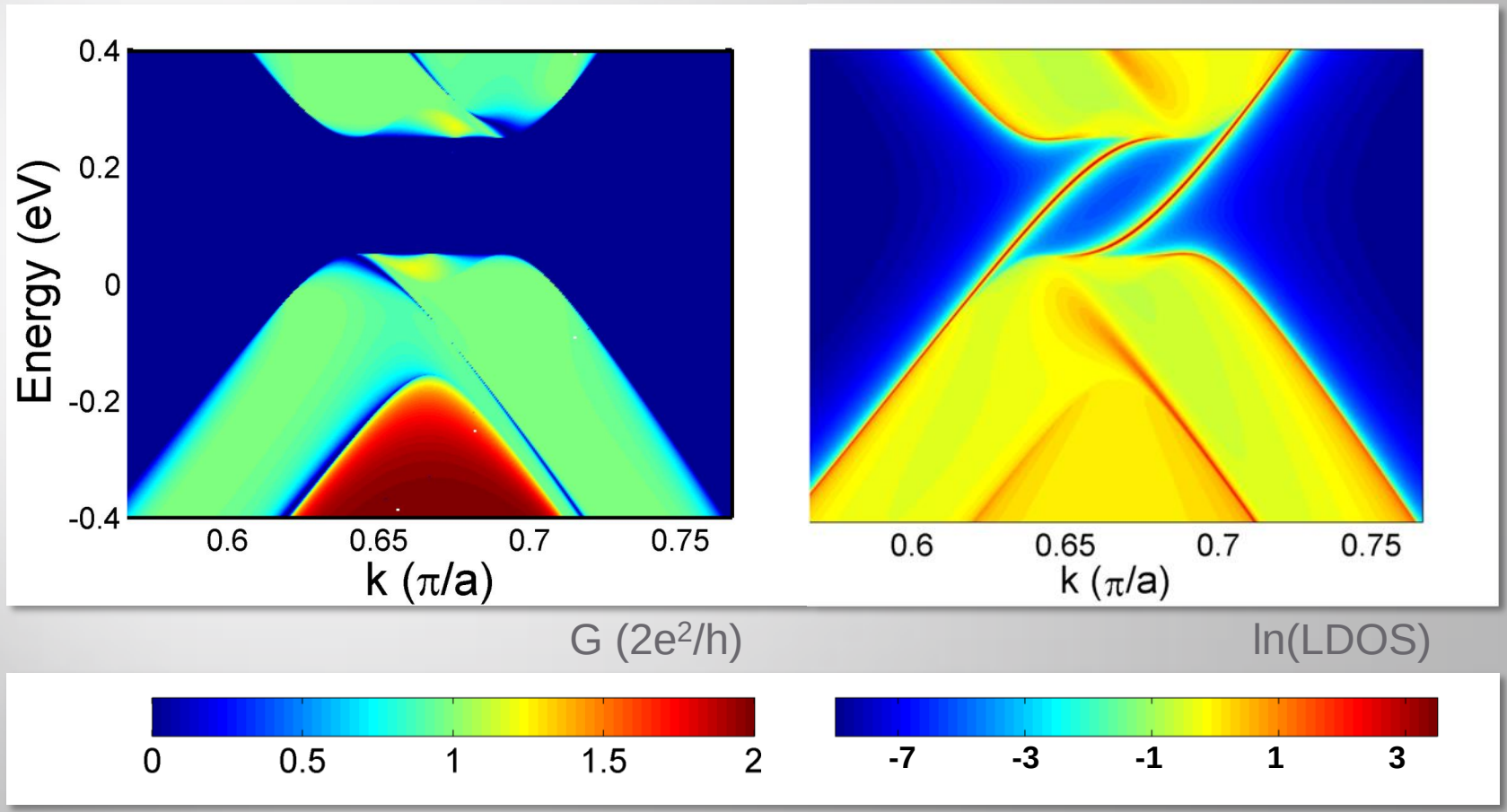


Abrupt connection

$V = 0.3$ eV

Conductance between domains

Local Density of States at the boundary



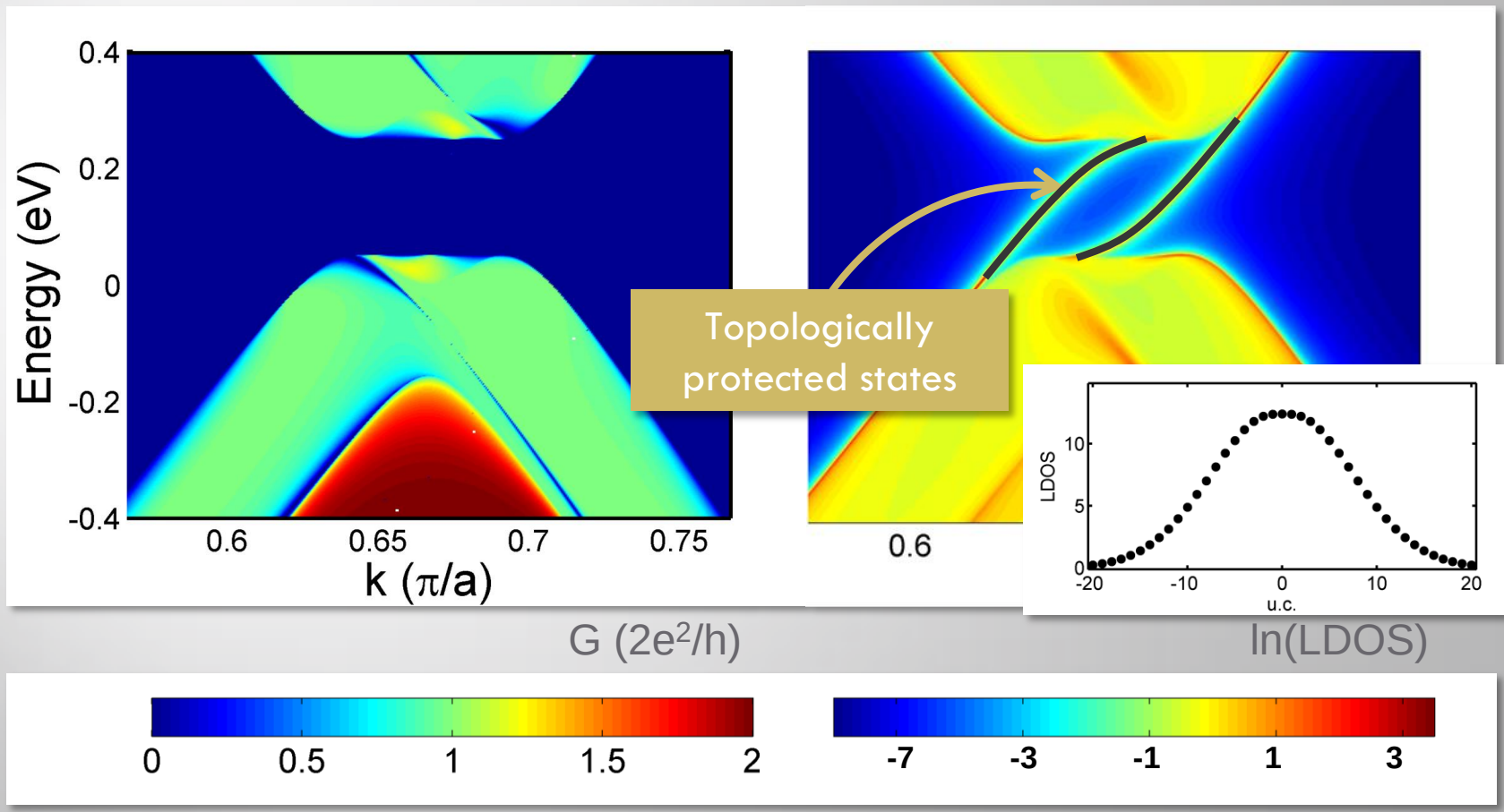
Phys. Rev. B **92,** 085433 (2015)

Abrupt connection

$V = 0.3$ eV

Conductance between domains

Local Density of States at the boundary



Topologically protected states

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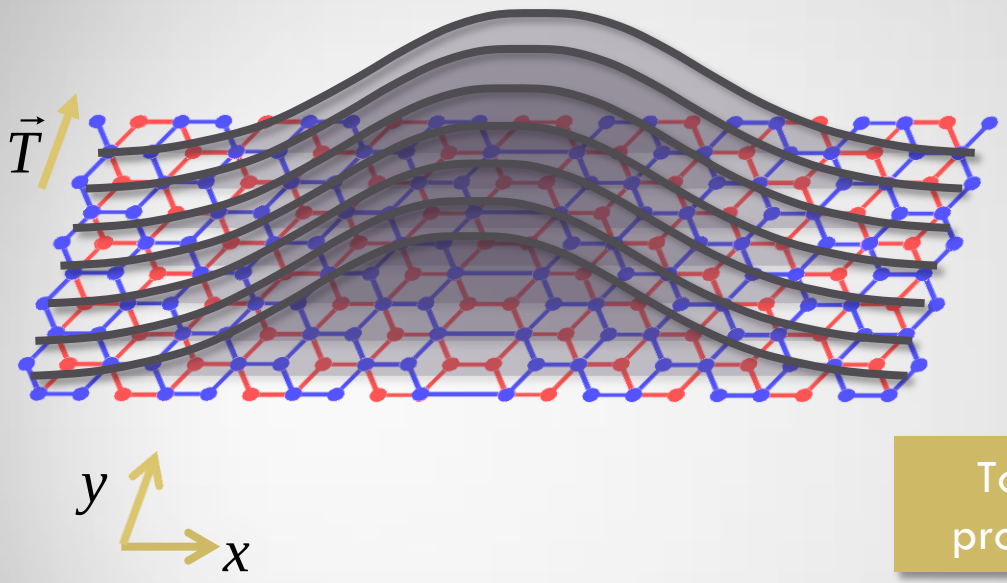
Abrupt connection

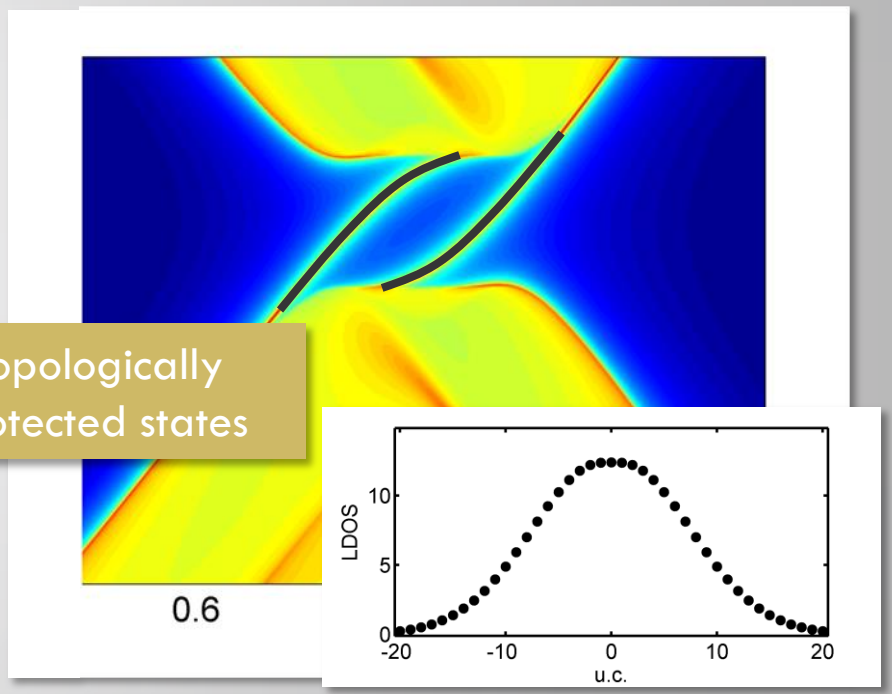


$$G_x(E_F) = 0$$

$$G_y(E_F) \neq 0$$

Local Density of States at the boundary

Topologically protected states



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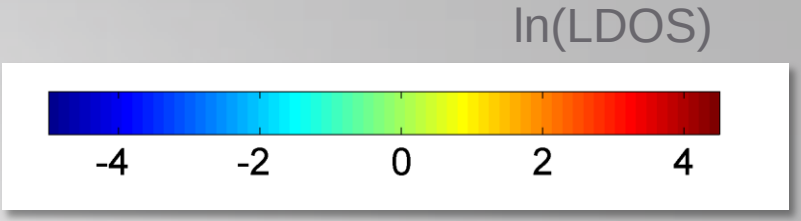
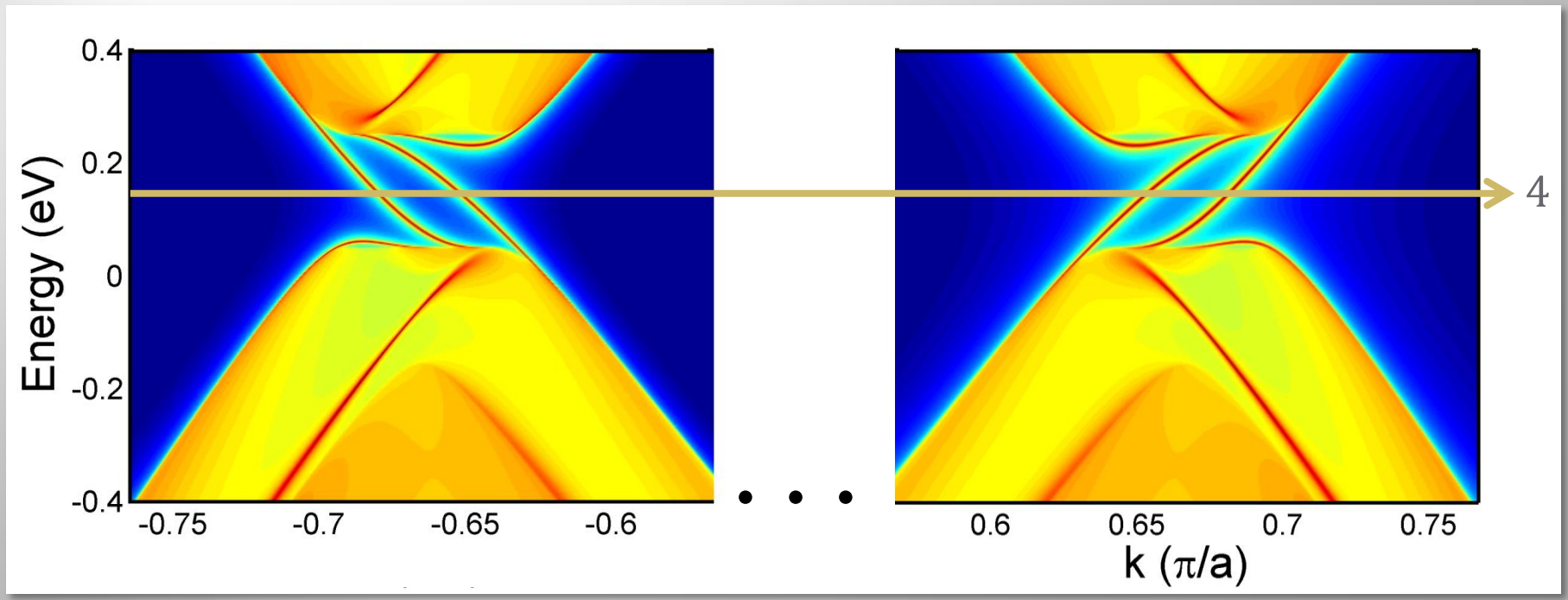
Topology

symmetry-protected topological state
differece of „valley” Chern numbers $= 2$
robust (insensitive to local impurities)

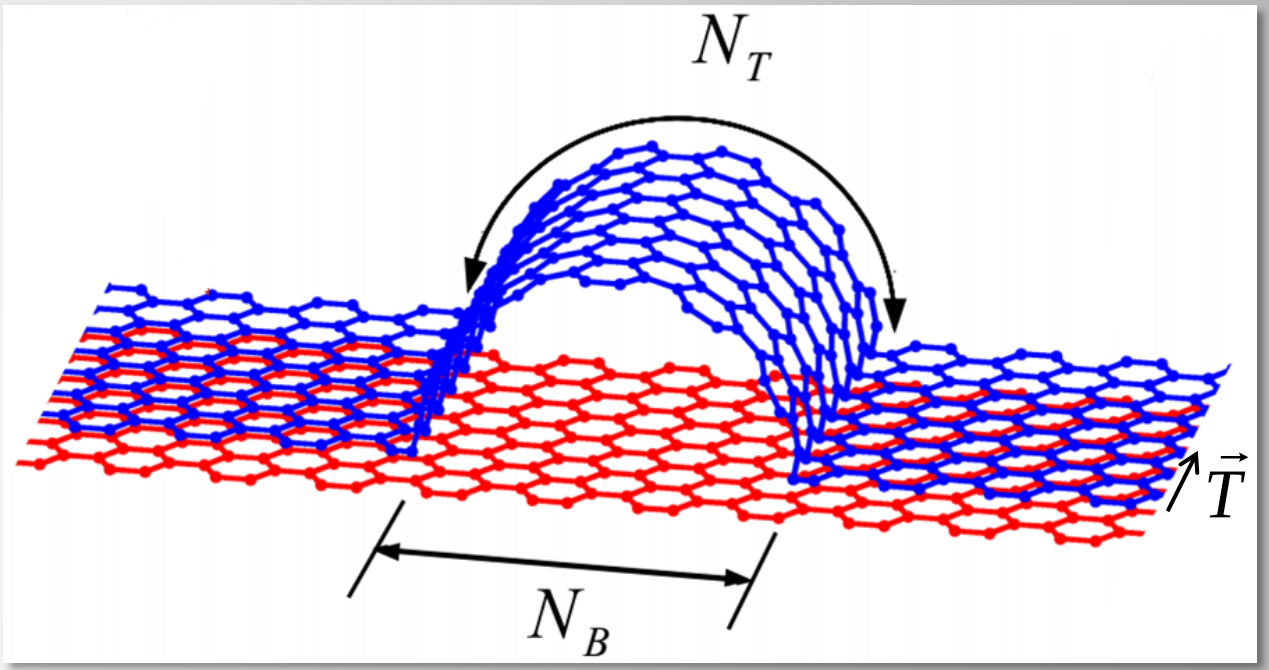


$\circlearrowleft K'$ $n_{AB} = -1$, $n_{BA} = +1$

$\circlearrowleft K$ $n_{AB} = +1$, $n_{BA} = -1$



Corrugation



$$N_T \approx \pi \cdot N_B$$

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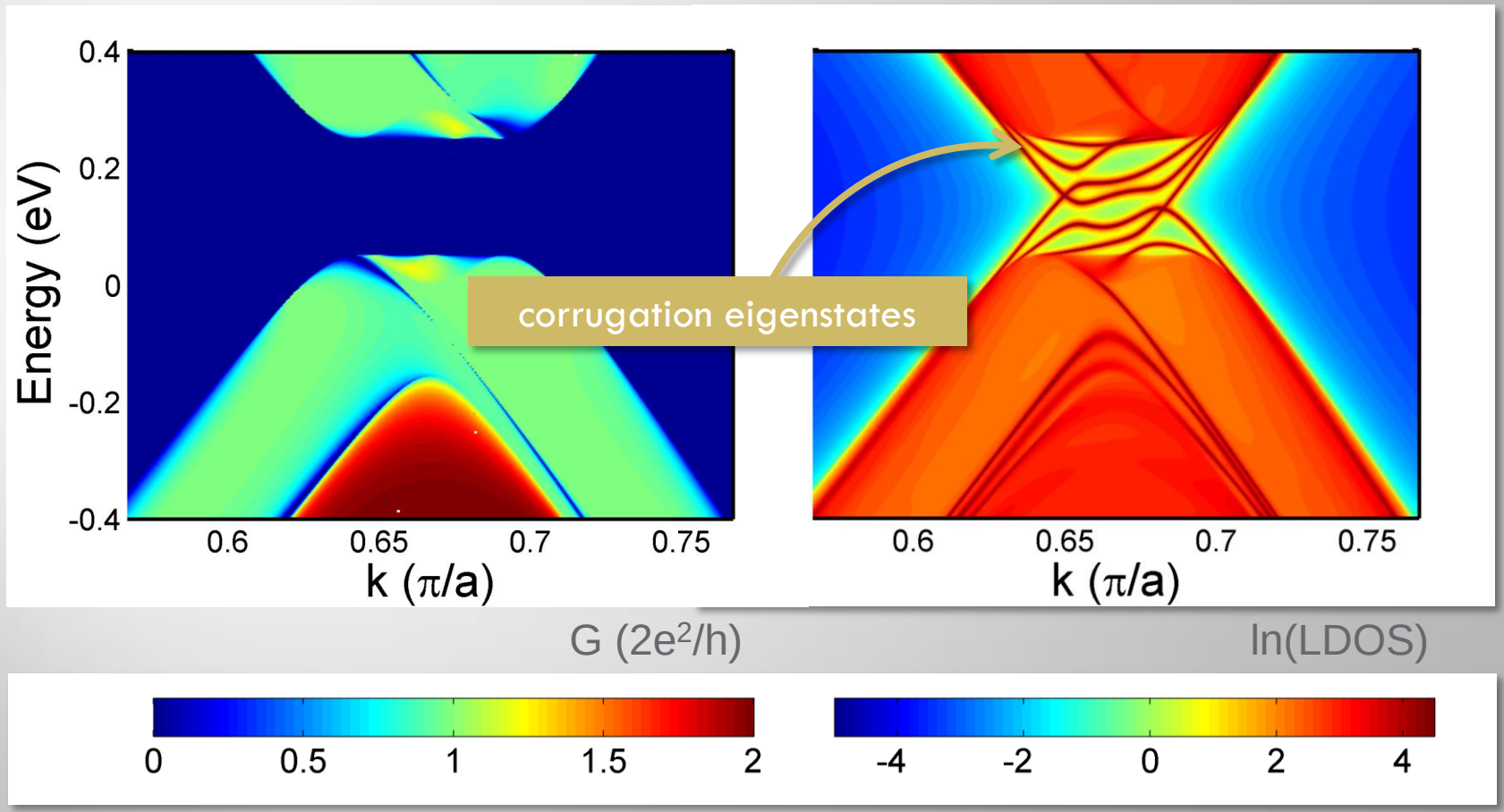
Corrugation

$N_B = 30$ $V = 0.3$ eV
$N_T = 48$

Conductance between domains

Local Density of States at the boundary



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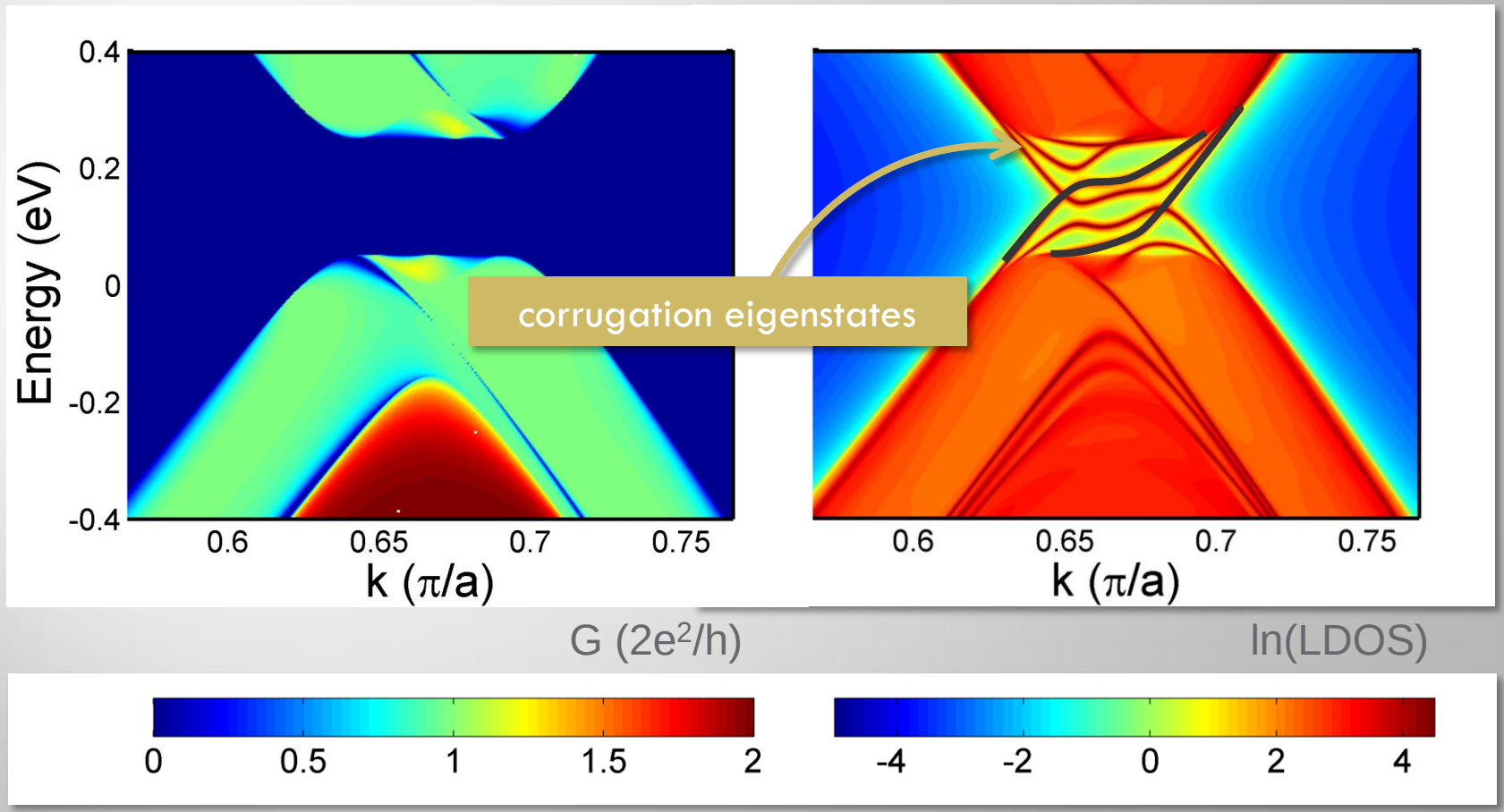


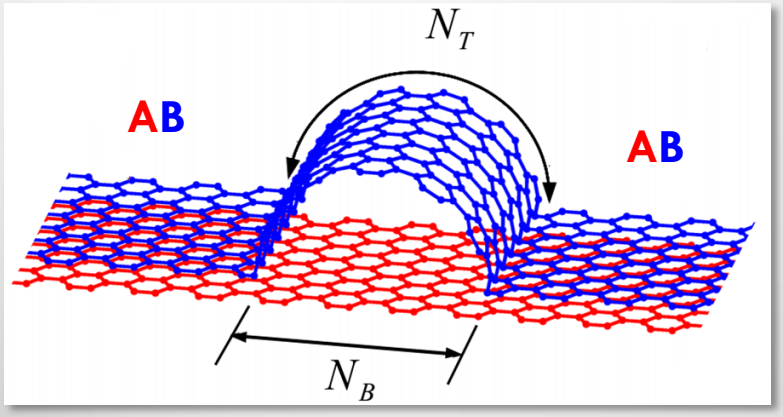
Phys. Rev. B **92,** 085433 (2015)

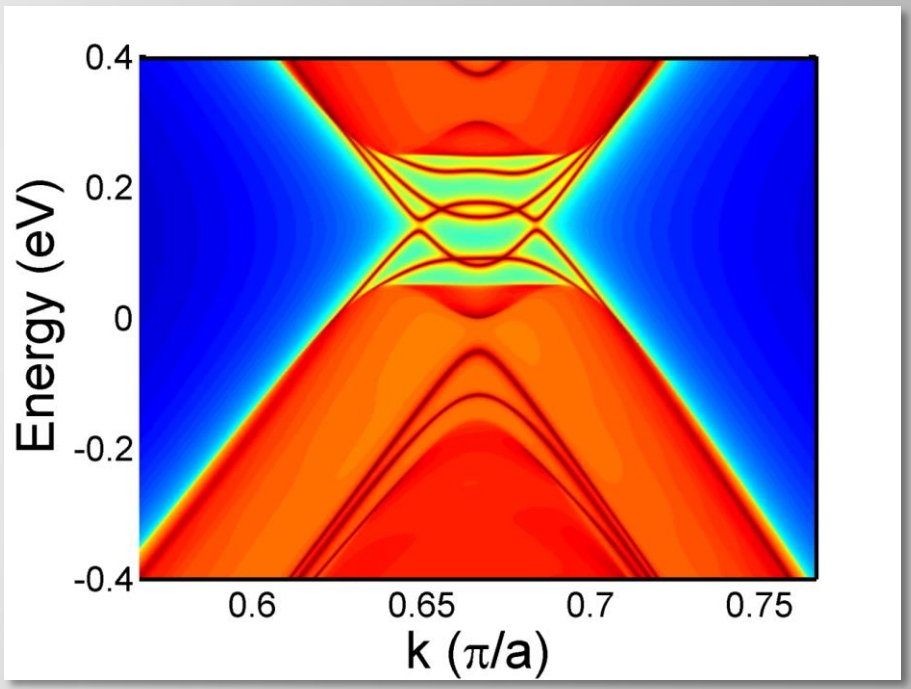
Corrugation

$N_B = 30$ $V = 0.3$ eV
$N_T = 48$

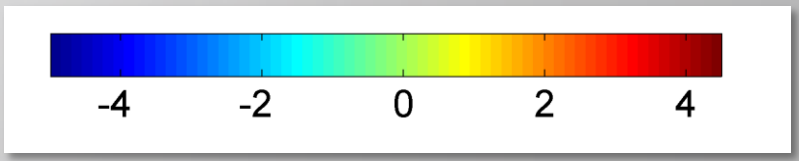
Local Density of States
at the boundary

no stacking change





ln(LDOS)



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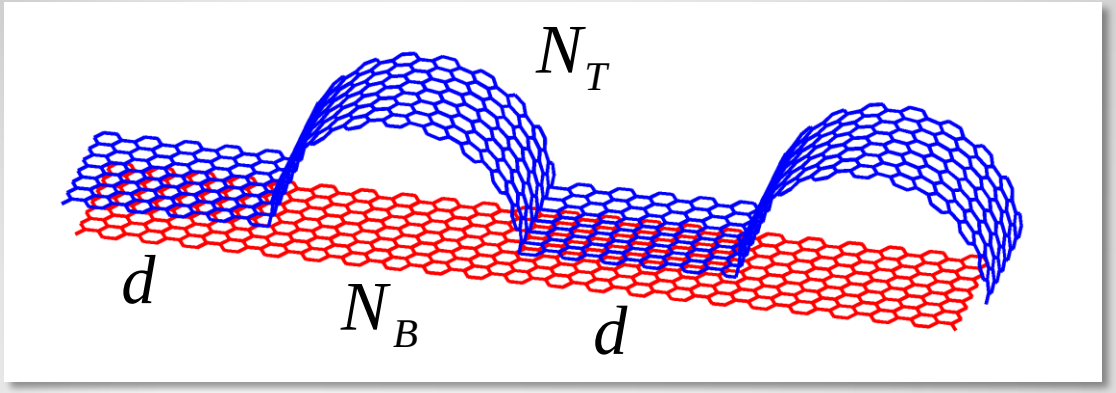
Conductance along the fold

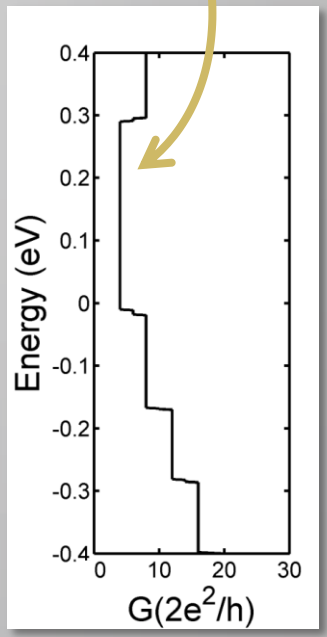
$N_B = 6$
$N_T = 10$
$d = 10$

$V = 0.3$ eV

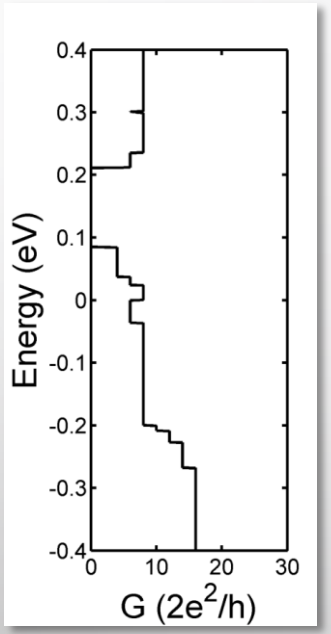


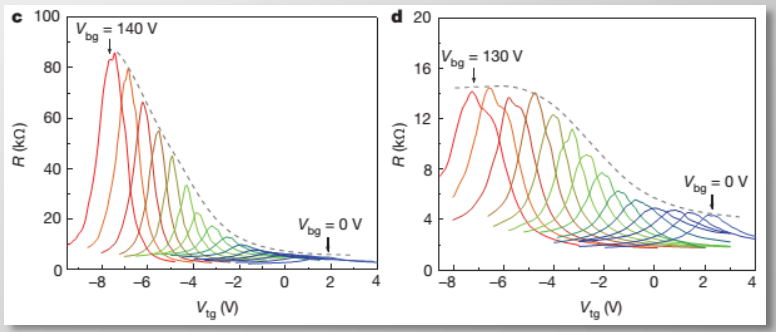
$G(E_F) = 4$

with stacking change



no stacking change





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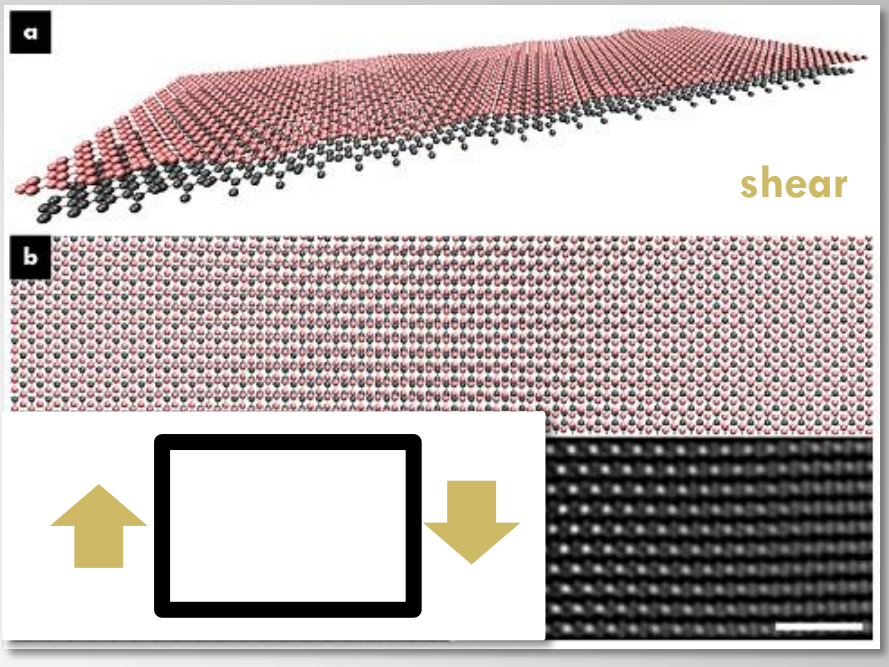
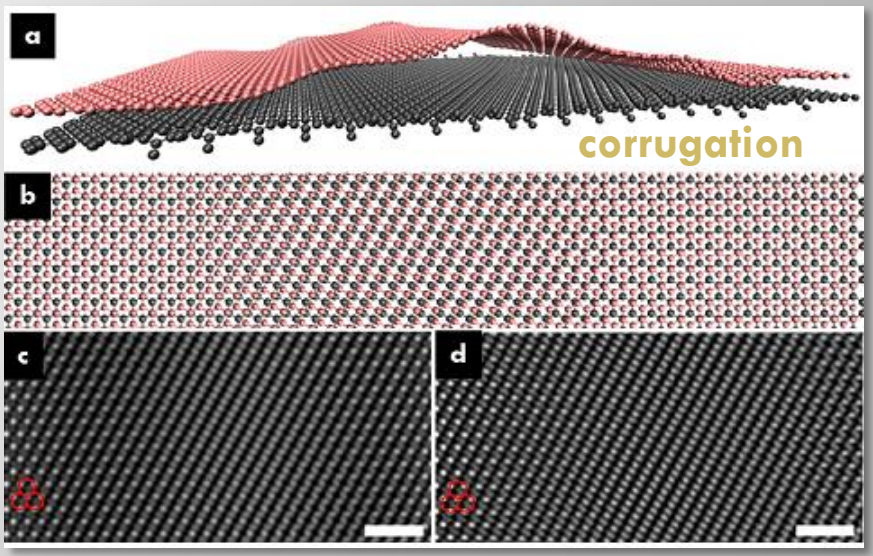
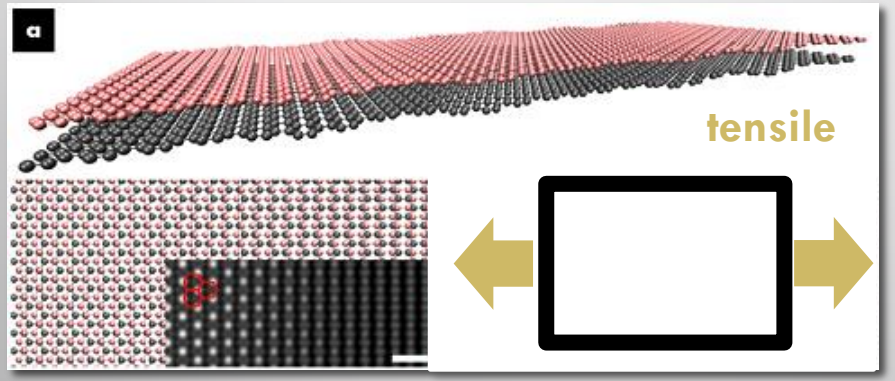
Defectless boundaries

„as long as we do not mix the sublattices"

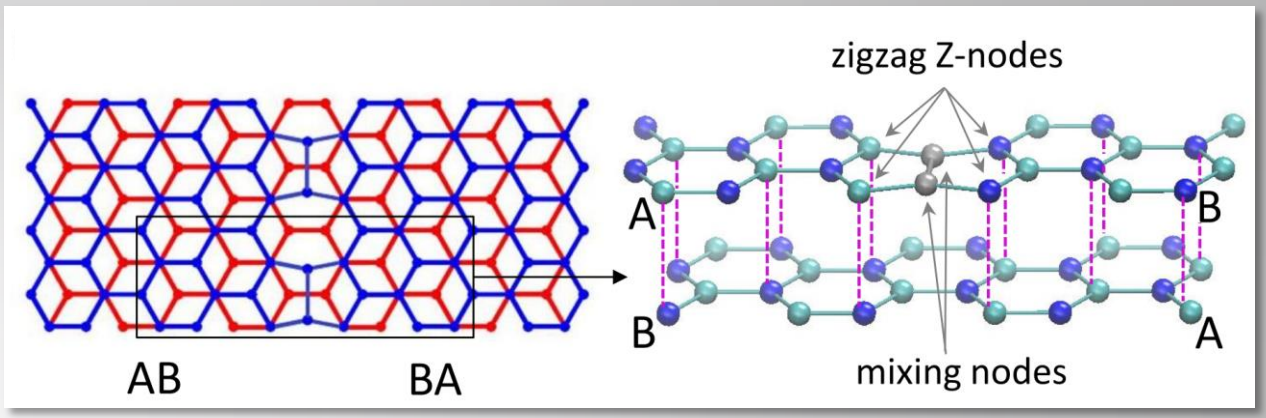


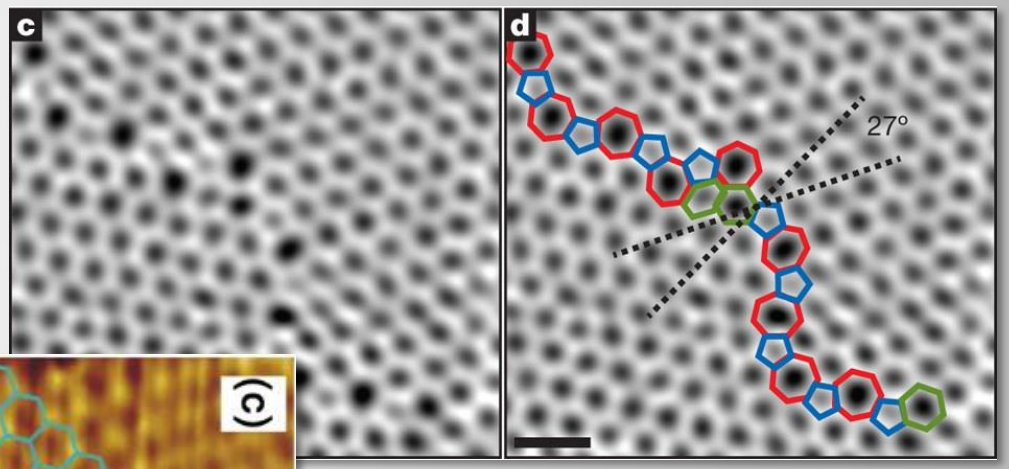


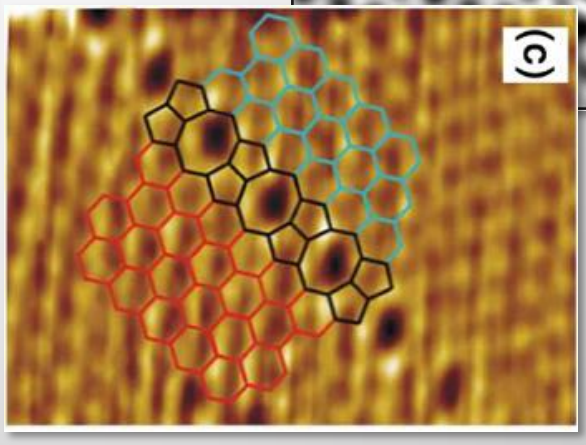


San-Jose – PNAS (2014), Vaezi – PRX (2013)
Katsnelson – PRB (2008)

Grain boundaries



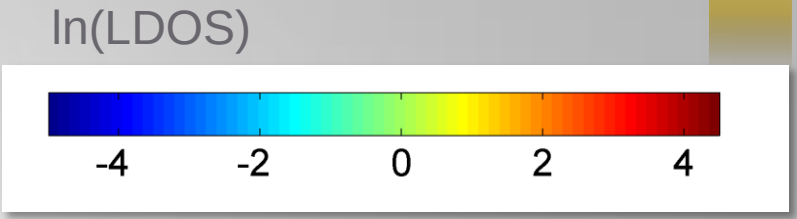


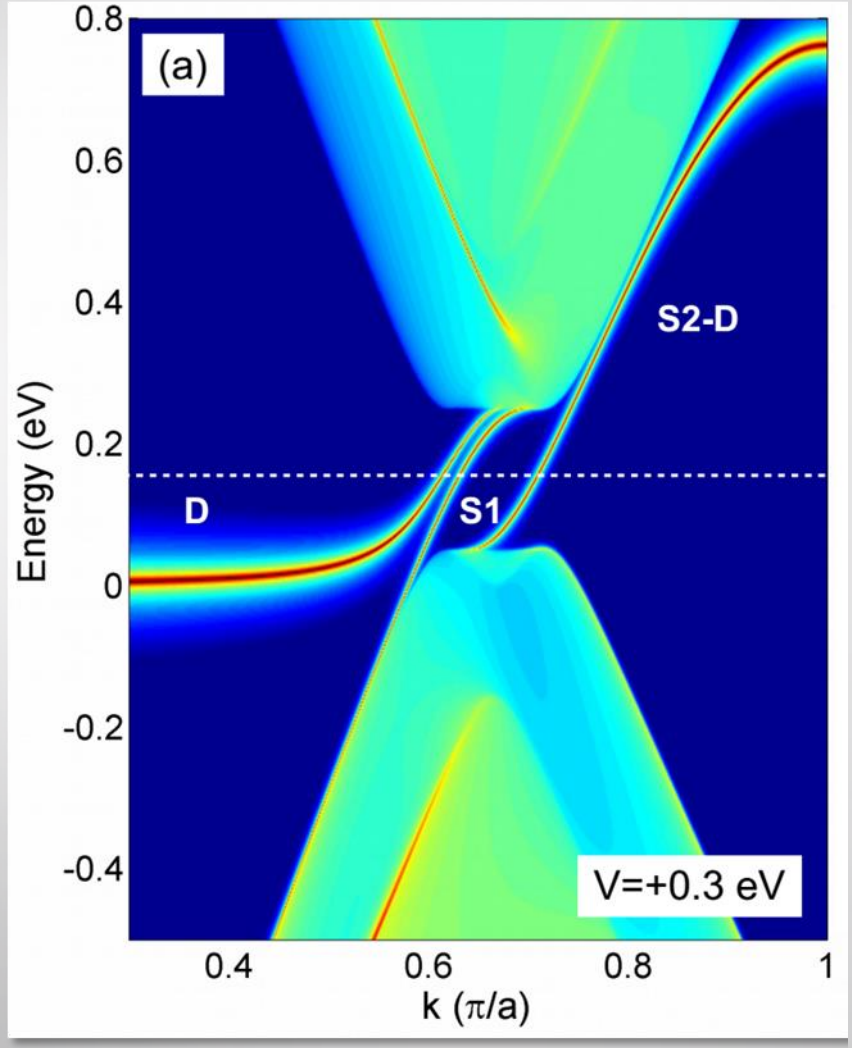


Huang – Nature (2011), Yu – Nat Mater. (2011), Pelc – PRB (2013)

Grain stacking boundary

$V = +0.3$ eV

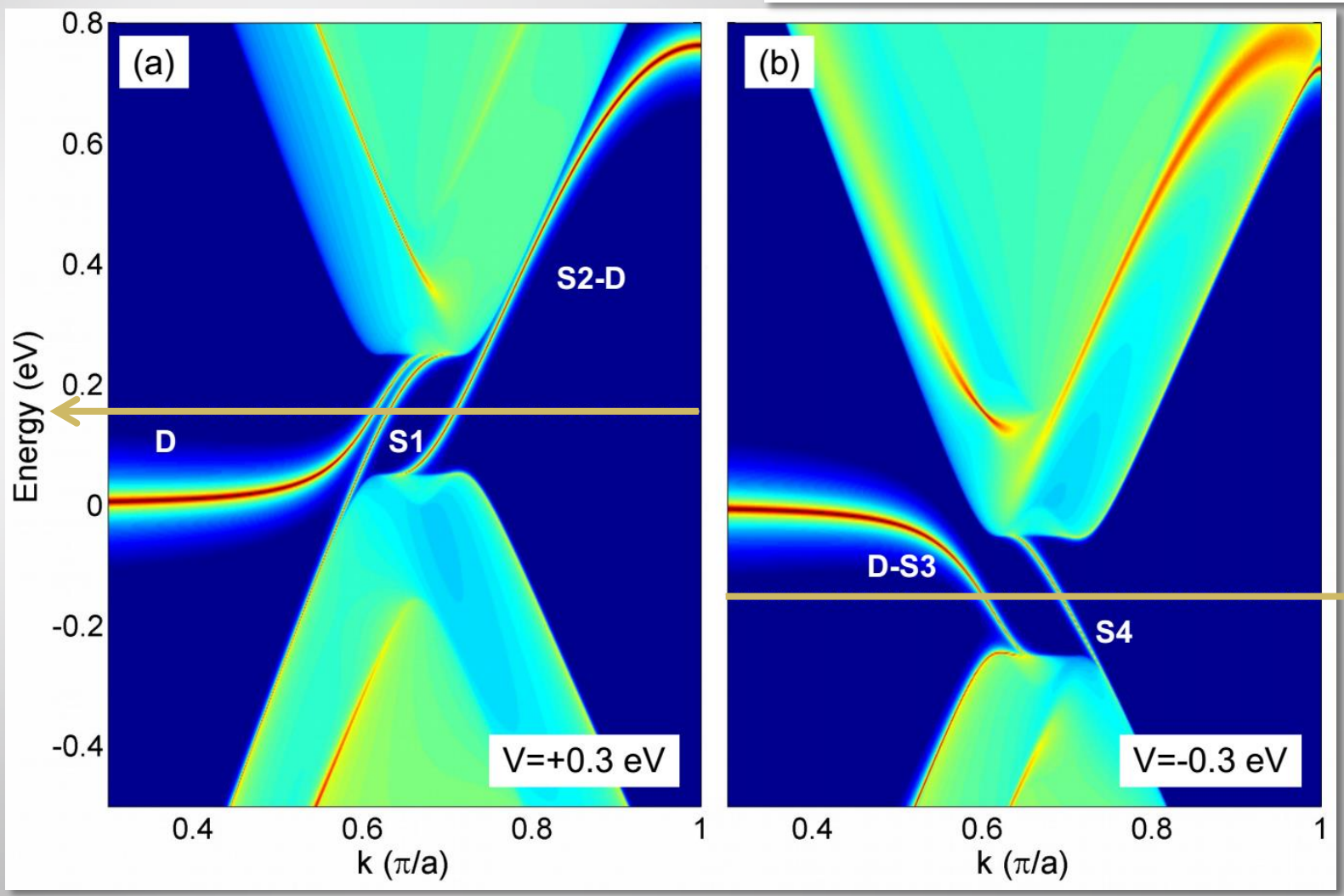




Nanoscale **8,** 6079 (2016)

Grain stacking boundary

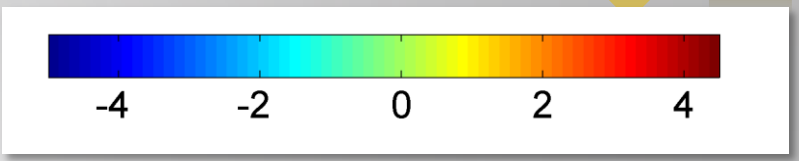
$V = \pm 0.3$ eV



Nanoscale **8,** 6079 (2016)

Ingredients

$V = \pm 0.3$ eV



SL with grain boudary 8/55

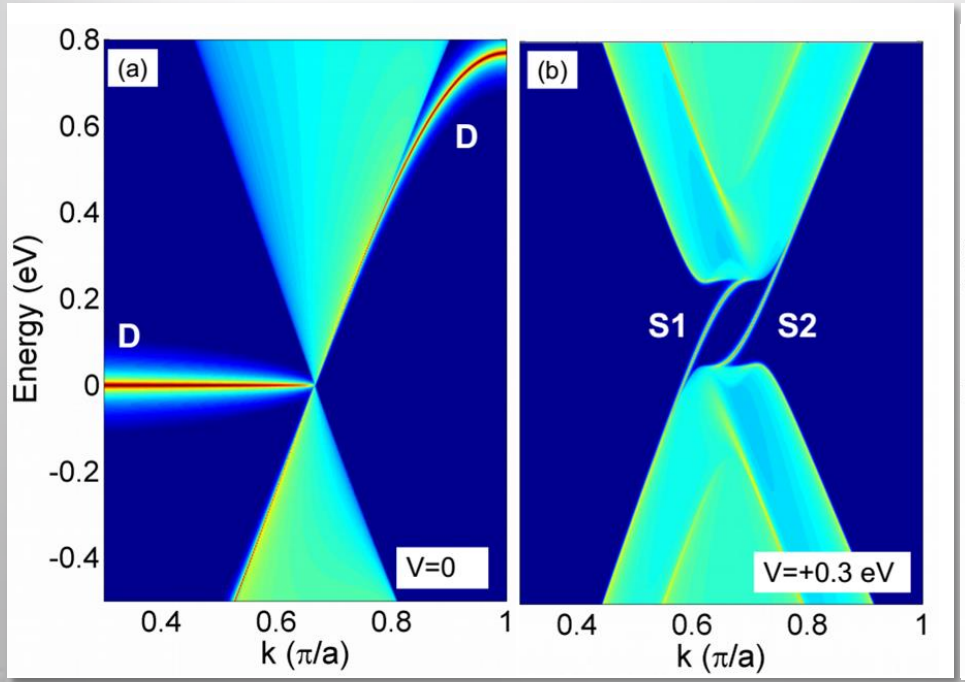
+

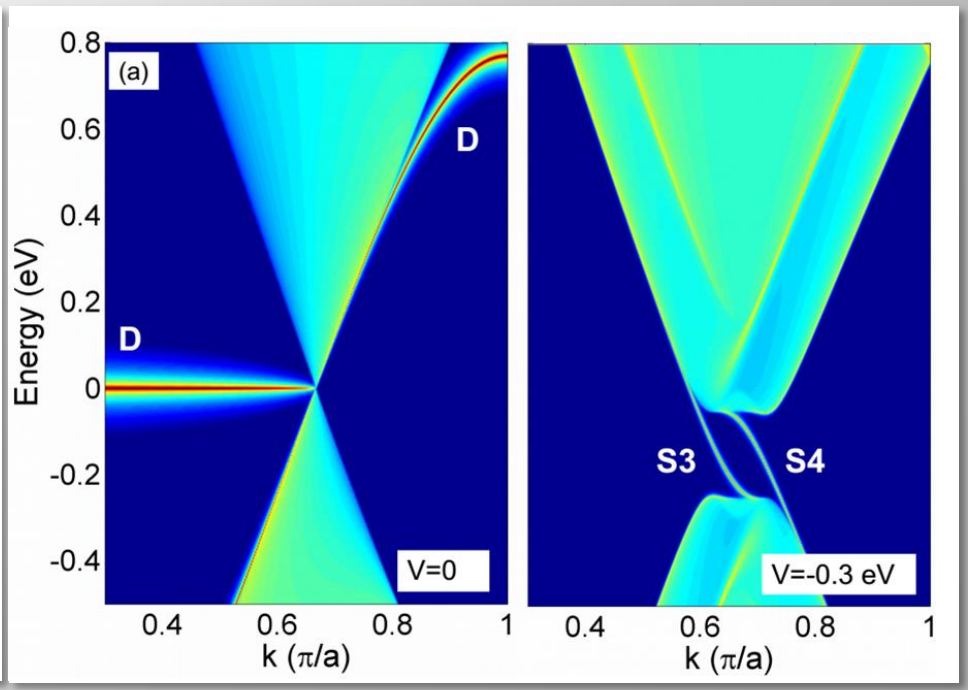
BL with stacking boudary, V>0

SL with grain boudary 8/55

+

BL with stacking boudary, V<0





Localization

$V = \pm 0.3$ eV

different layers

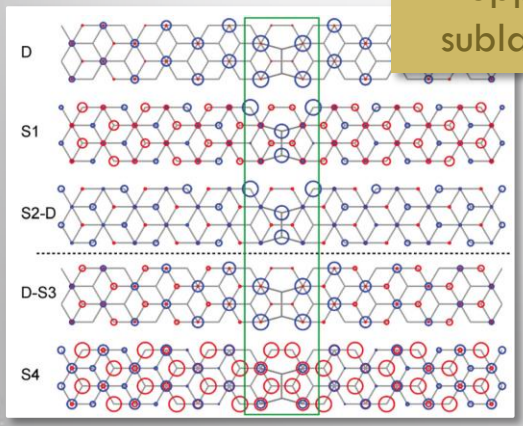
Defect (D) and TPS (S1) coexist when they are localized on different nodes

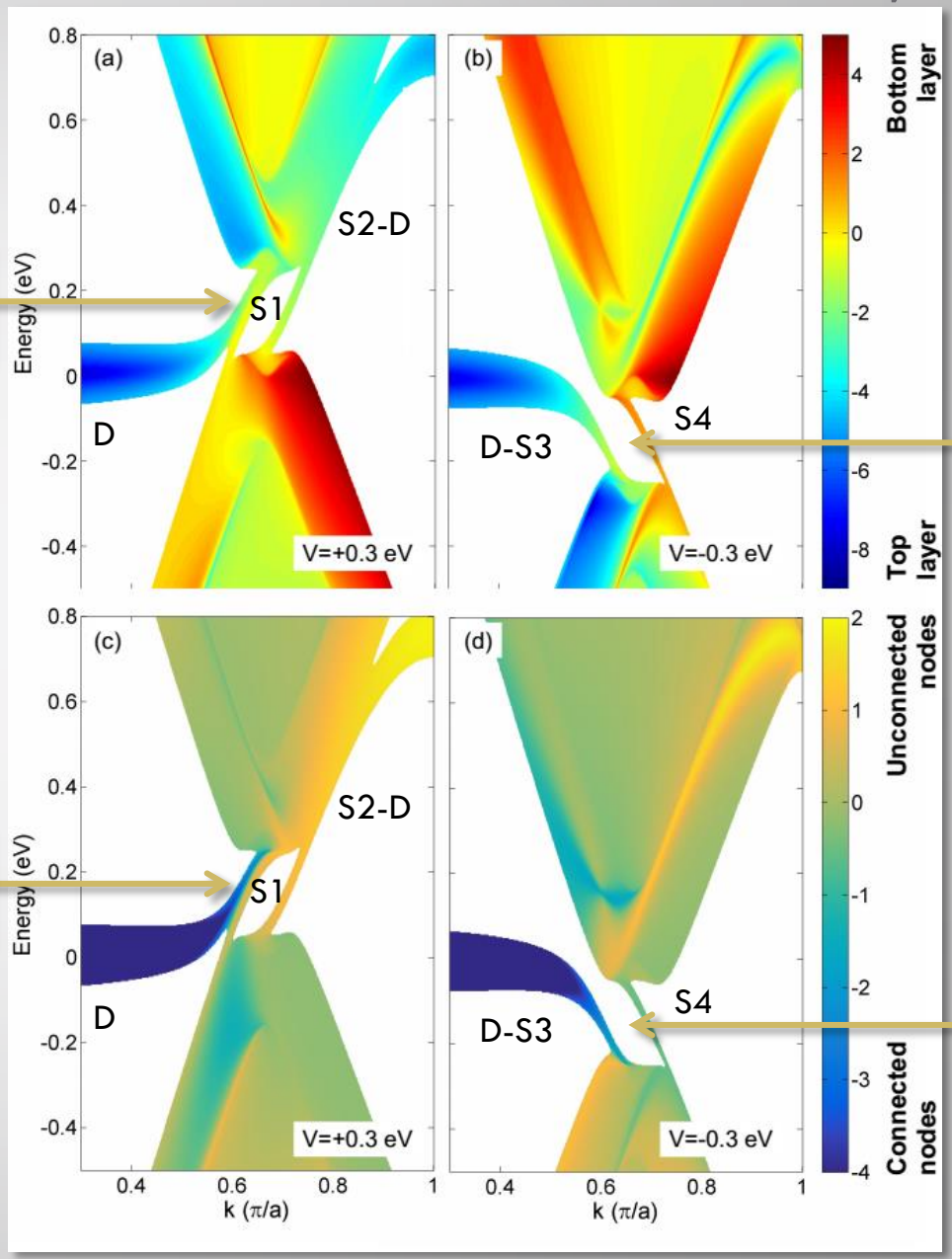
Defect (D) and TPS (S3) hybridize when they are localized on same nodes

opposite sublattices

same layers

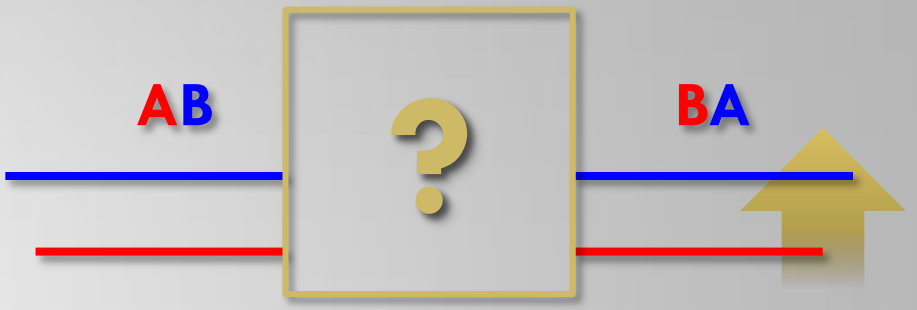
same sublattices



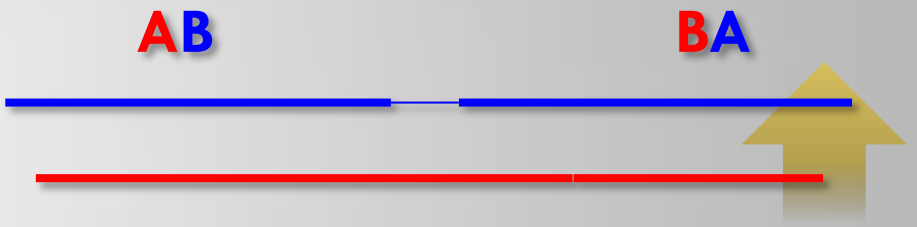


Summary

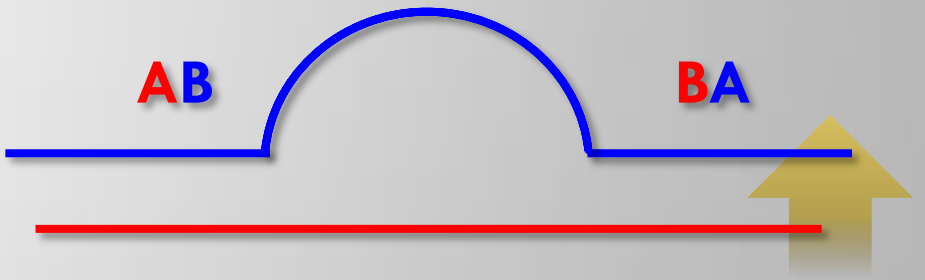
Bilayer graphene with stacking boundary



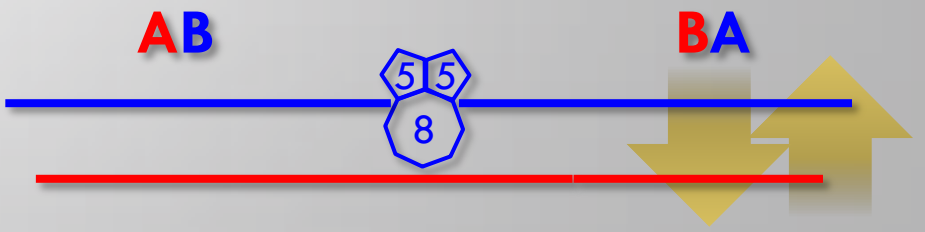
Abrubt connection
The appearance of 2 TPS
(Chern numbers)



Defectless, smooth transitions
More gap states (anticrossings)
2 TPS not affected (Chern numbers)



Grain boundaries with defects
Interaction between TPS and defect state
Asymetry in number gap states for different polarization – potential electrical switches



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Nanoscale **8**, 6079 (2016)

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