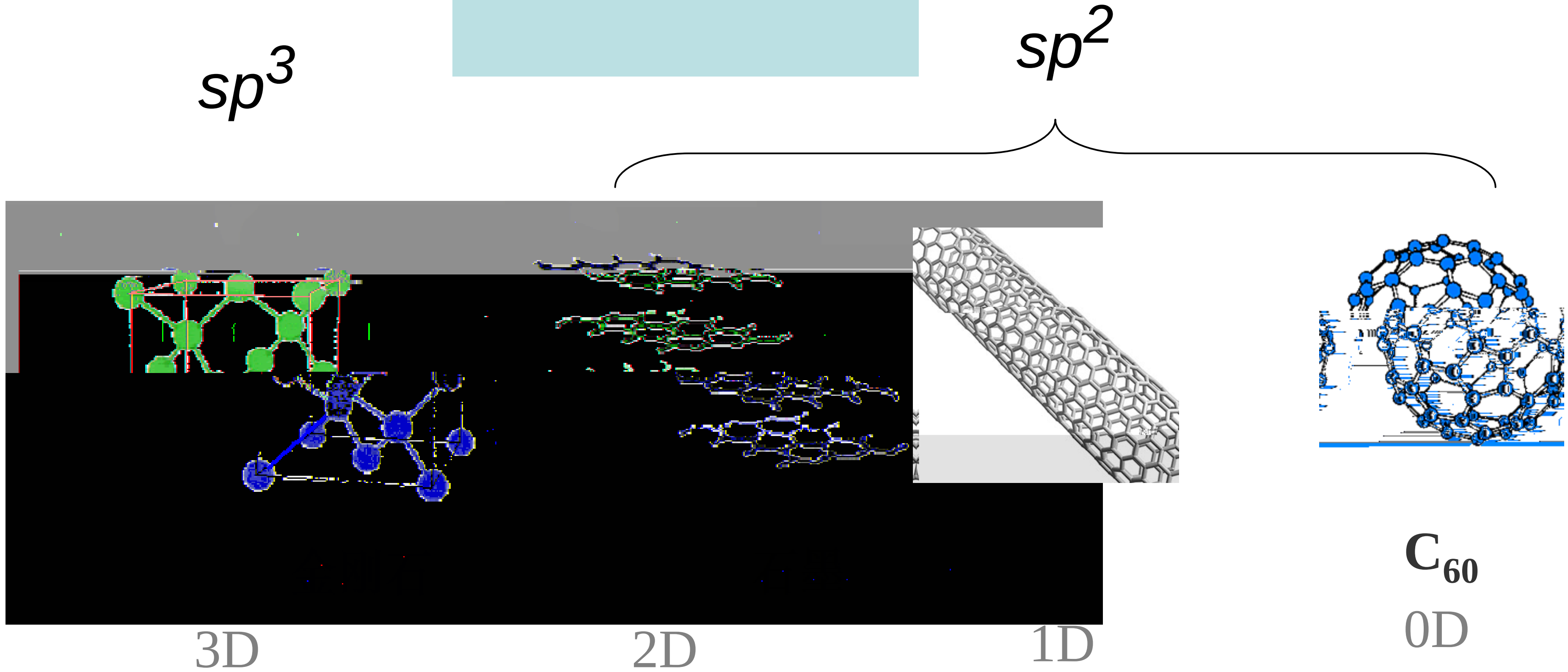
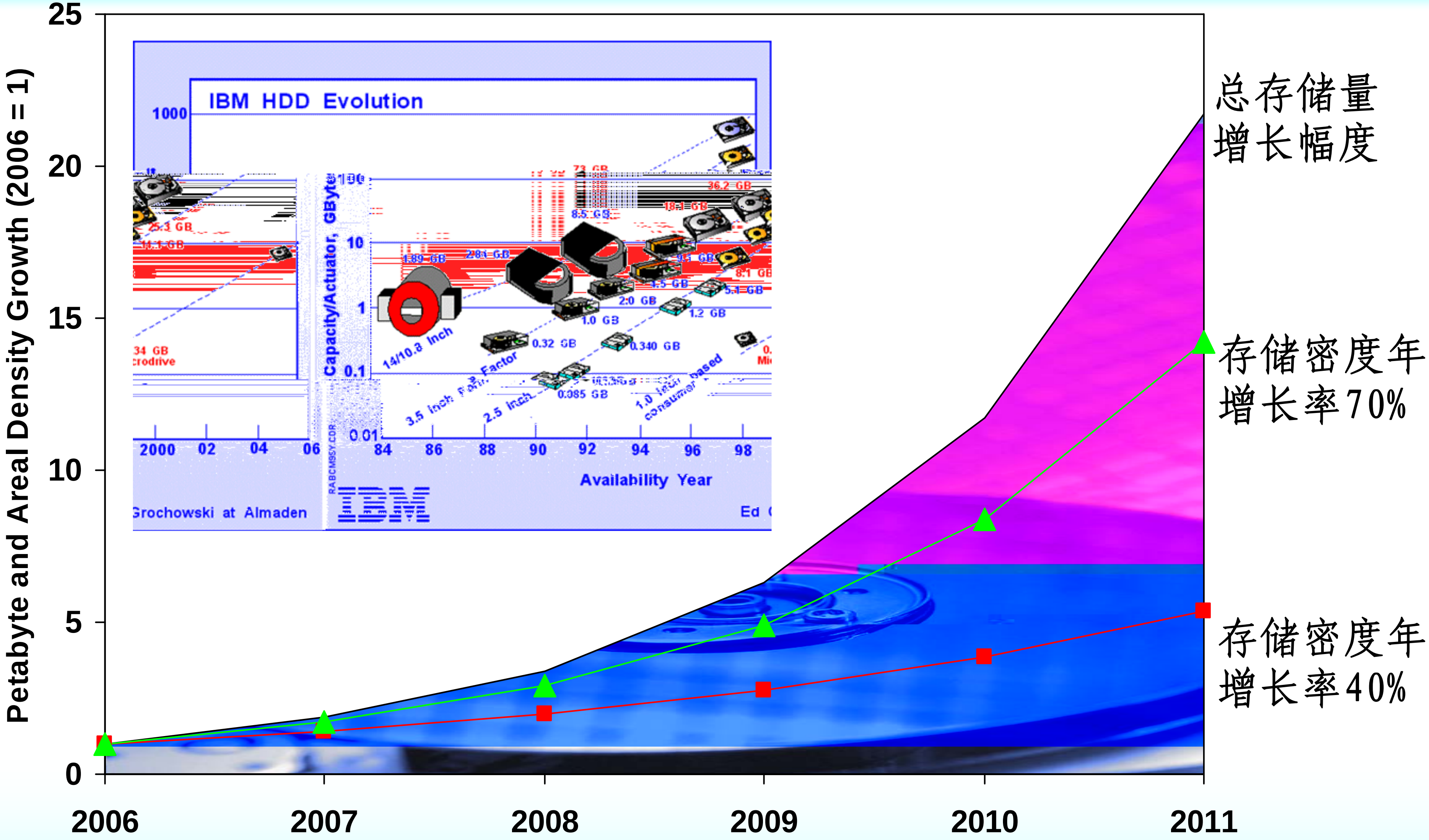
C_{60} ,   ,

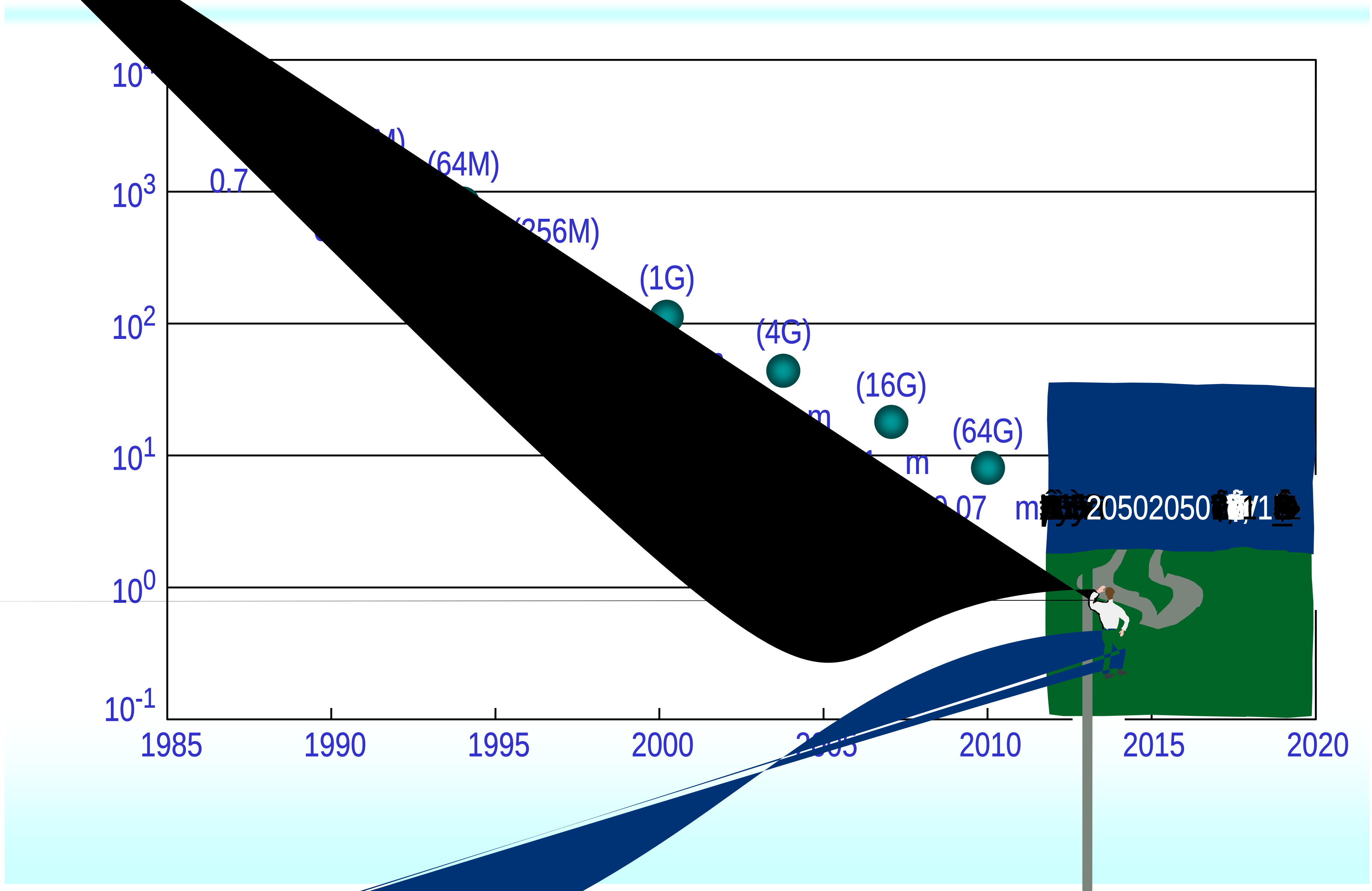
2009 12 17



sp^3
sp^2
C_{60}
3D
2D
1D
0D

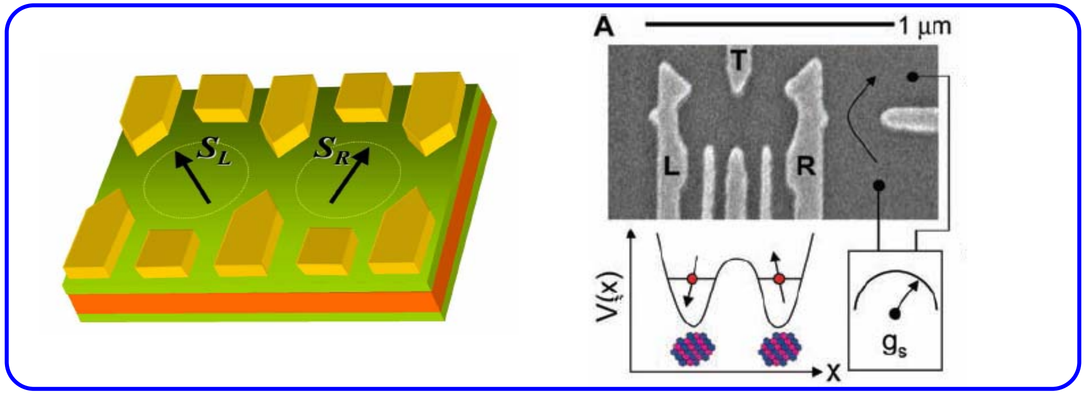


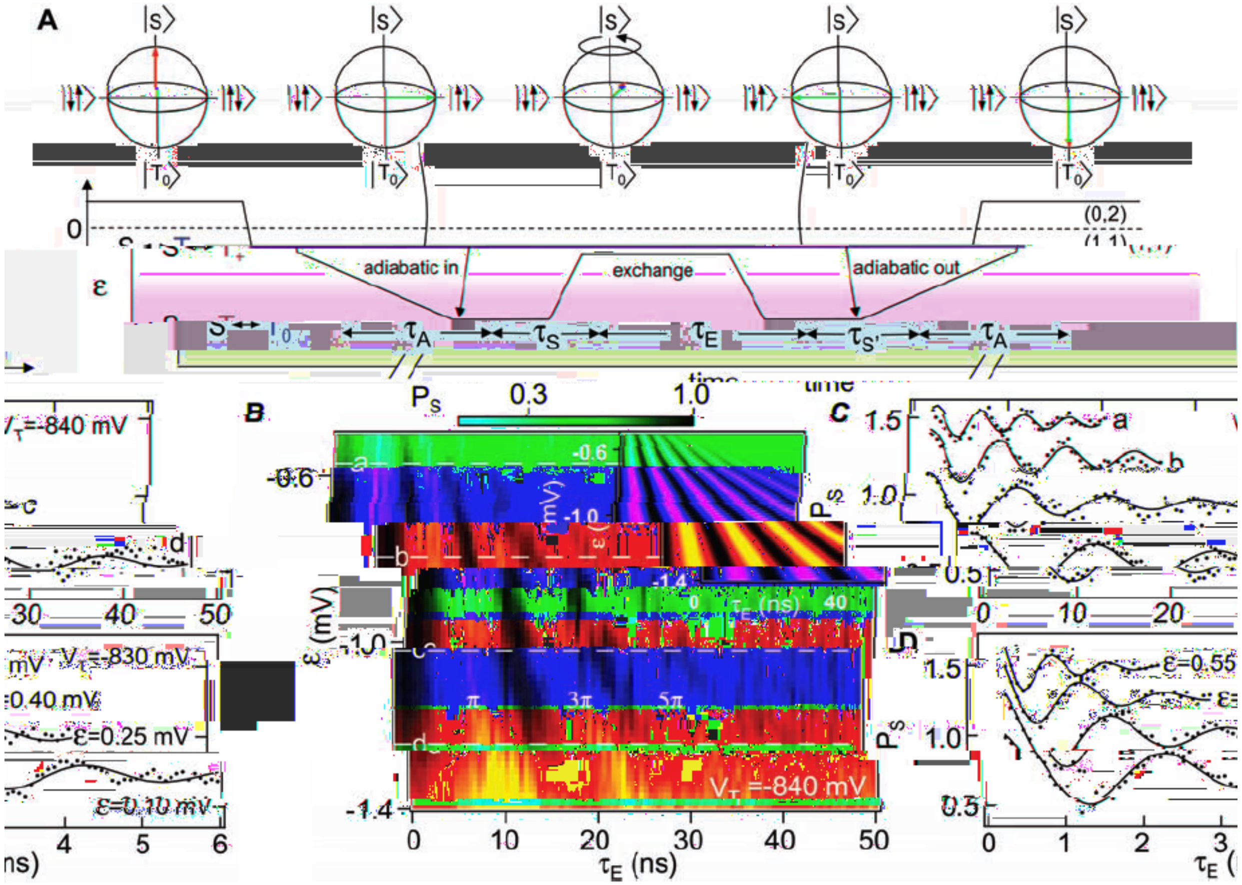
Average Petabyte Growth Year on Year From 1995 to 2005 was > 85%, Seagate Analyst & Investor Meeting June 2006



10^4
10^3
10^2
10^1
10^0
10^-1
1985
1990
1995
2000
2005
2010
2015
2020
0.7
(64M)
(256M)
(1G)
(4G)
(16G)
(64G)
m
m
0.07
m

Spin qubits in semiconducting quantum dots systems





AlGaAs/GaAs:

Very short decoherence time, due to:

- Hyperfine interaction
- Spin-orbital interaction

Other materials ?

- Si or Si/Ge system
- Graphene
- Carbon nanotubes

- Marcus group
- Vandersypen group
- … … …

For Graphene:

- SO coupling is weak :

  $2\ {}_{so} \sim 1$ eV (10 mK) (Y.G. Yao, et al, PRB'06)

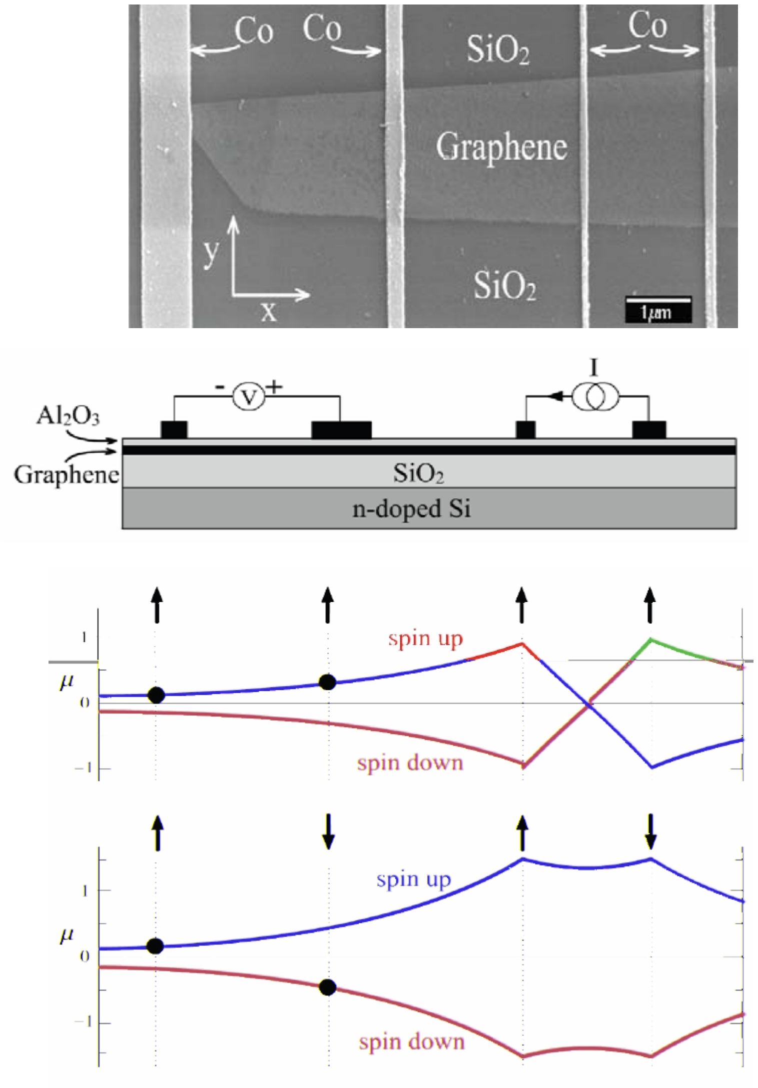
- Hyperfine interaction is weak:

  ^{13}C (spin ½) abundance ~1%

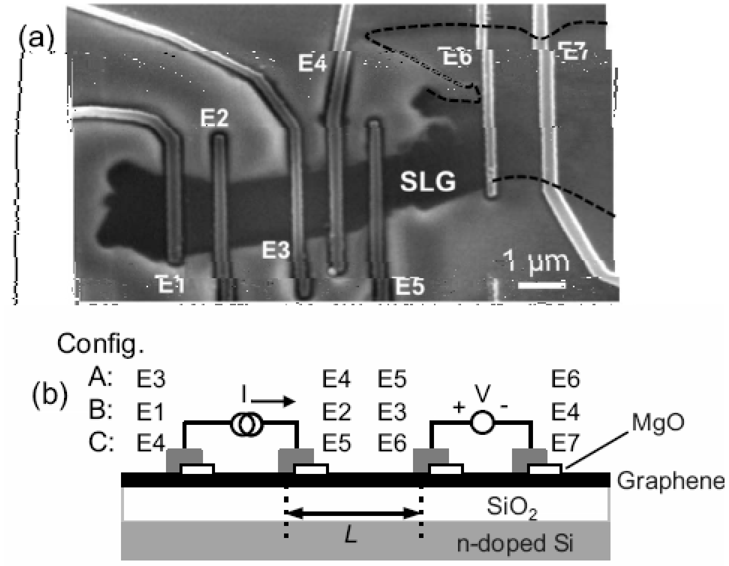
Longer T_1 and T_2 ?

Answer: No.

Spin polarized electron injection and non-local detection



van Wees group



C. N. Lau group

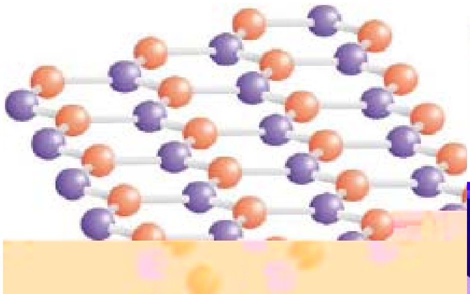
	van Wees	C. N. Lau
so	~ 150 ps	~ 84 ps
l_{SO}	~ 1.6-2.0 m	~ 1.5 m

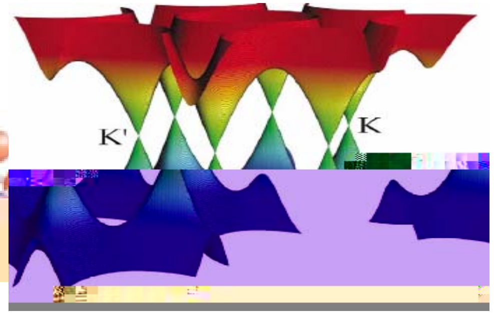
What is the cause of spin decoherence in graphene ?

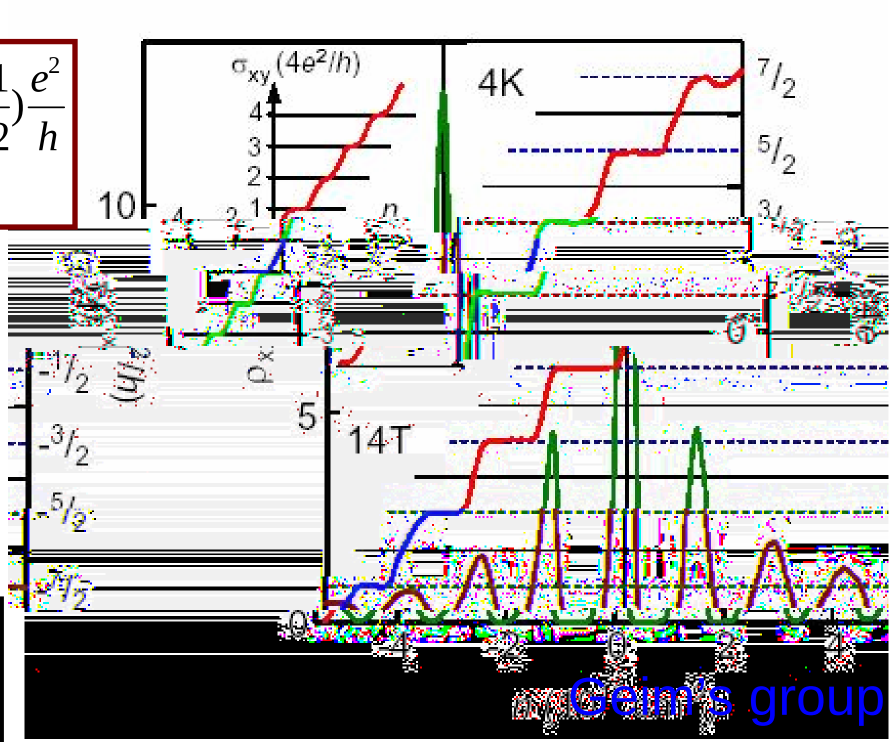
Graphene
Novel Properties:

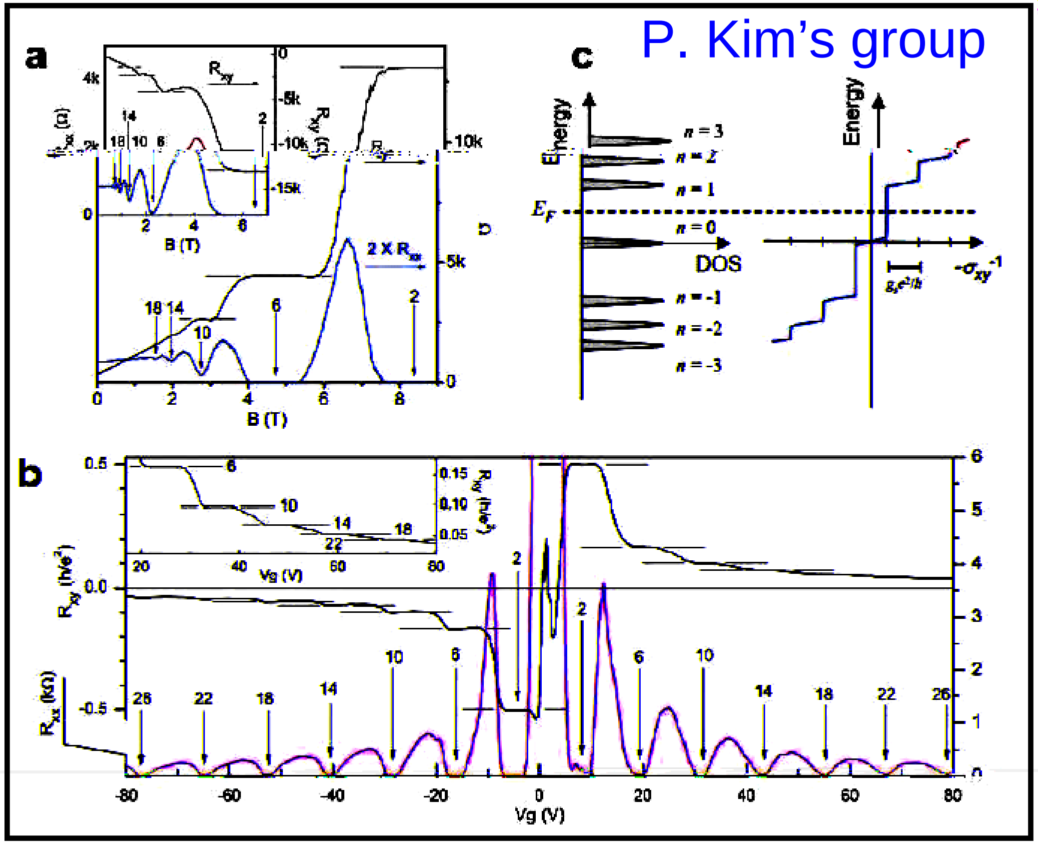
$$R_{xy}^{\ 1} \quad g_s(N \quad \frac{1}{2})\frac{e^2}{h}$$

$$g_s \quad 4$$



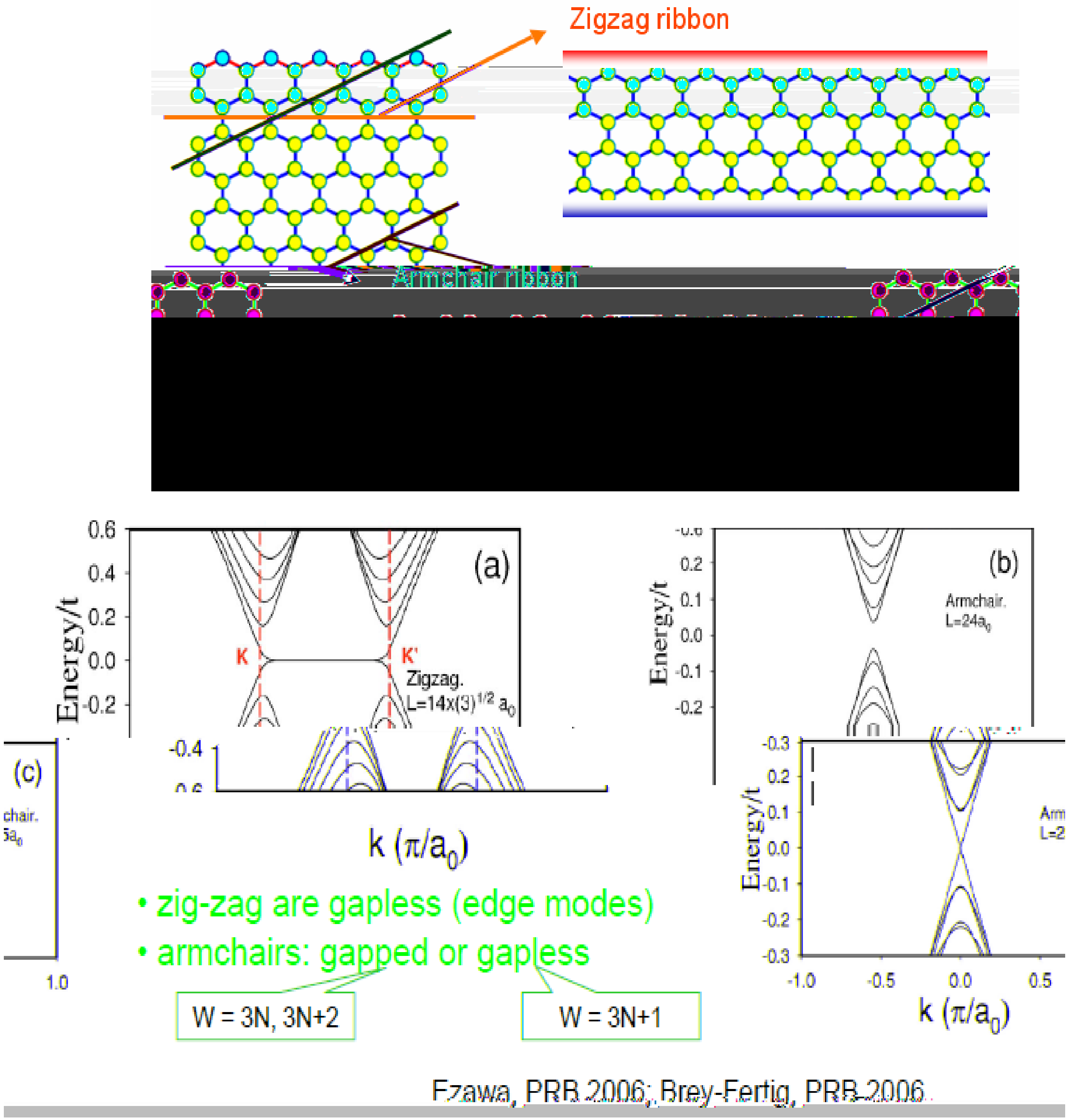


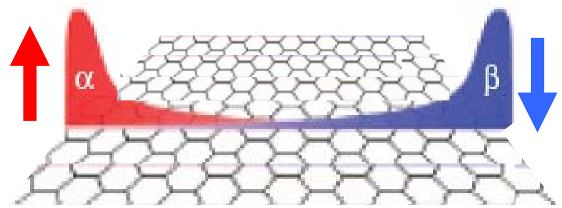




- Two sublattices
- Pseudospin
- Four-fold degeneracy (valley x 2 + spin x 2)
- Berry phase
- Half integer QHE
- Klein Tunneling
- … … …

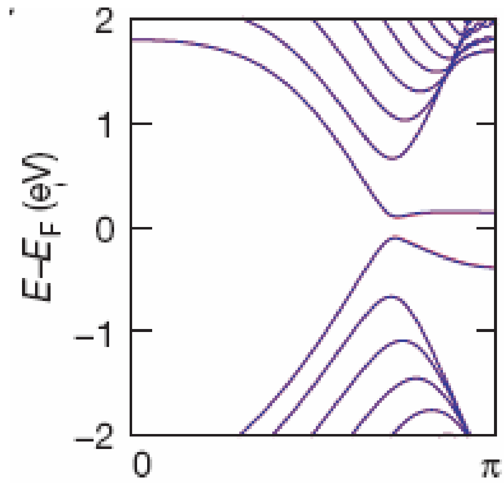
Edges of graphene nanoribbon (GNR)



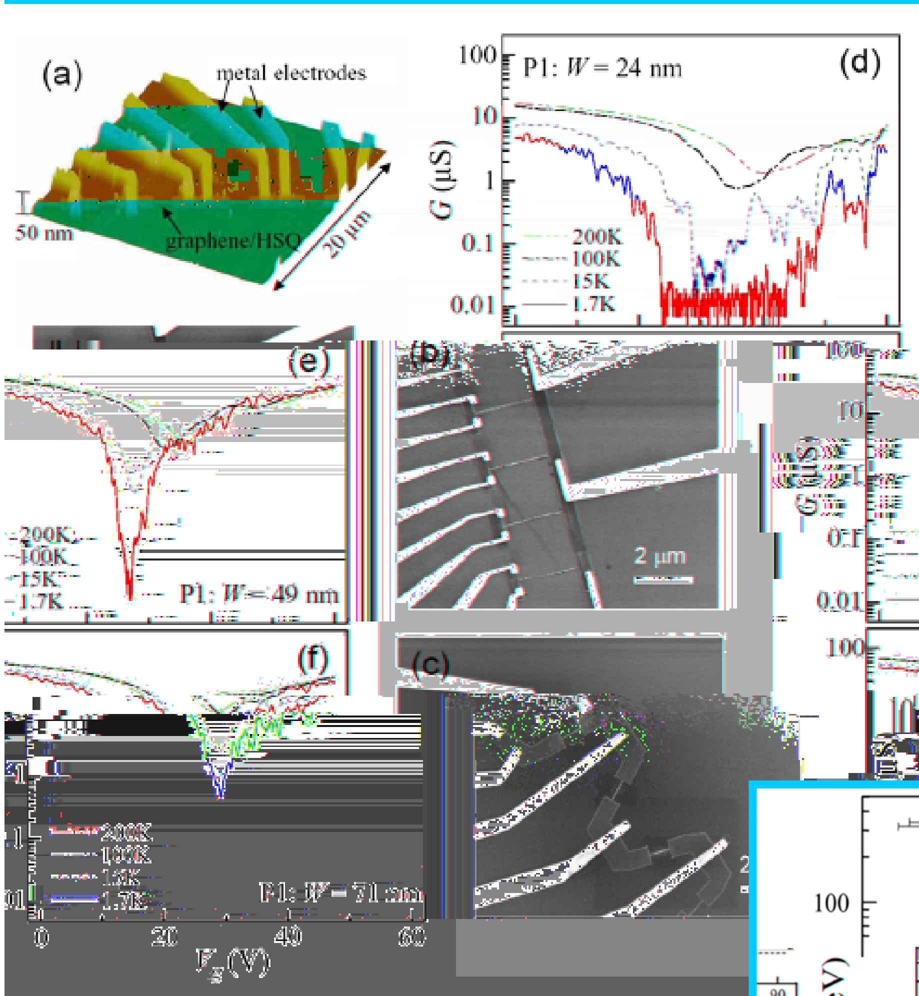


Theoretical prediction:

- Zigzag GNR has spin polarized edge states.
  W.Y. Son et al., Nature'06
  L. Pisani et al., PRB'07
- Same for bilayer GNR.
  E.V. Castro et al., PRL'08



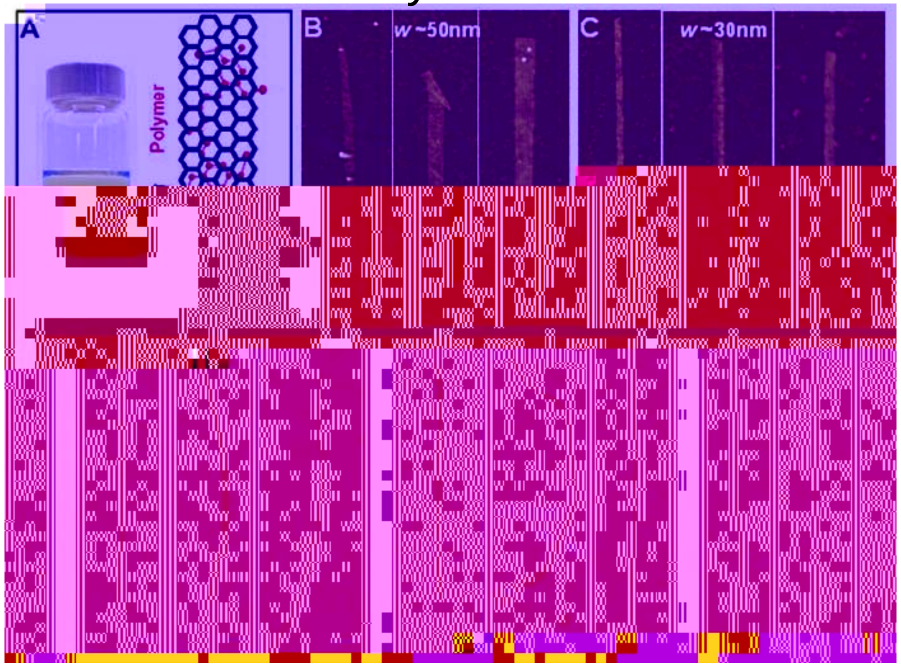
Experiments on GNR



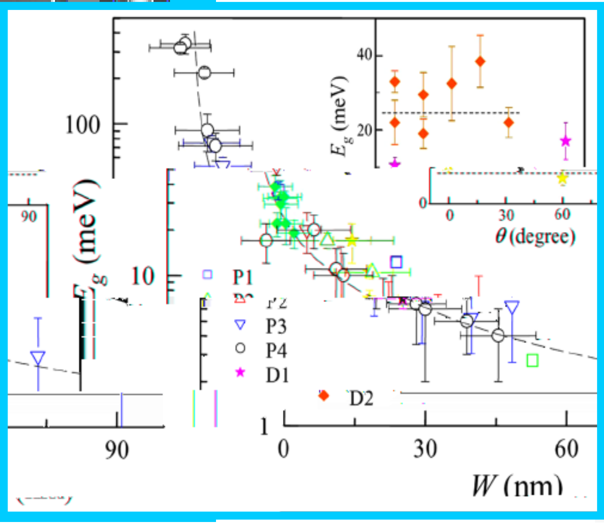
Kim Group, PRL'07

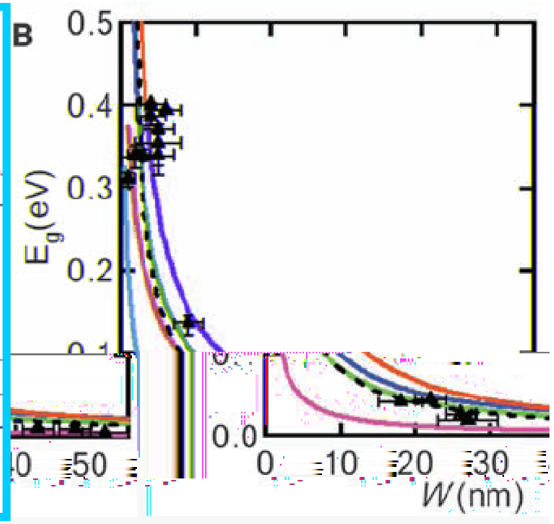
Lithograph-made GNRs

Chemically derived GNRs

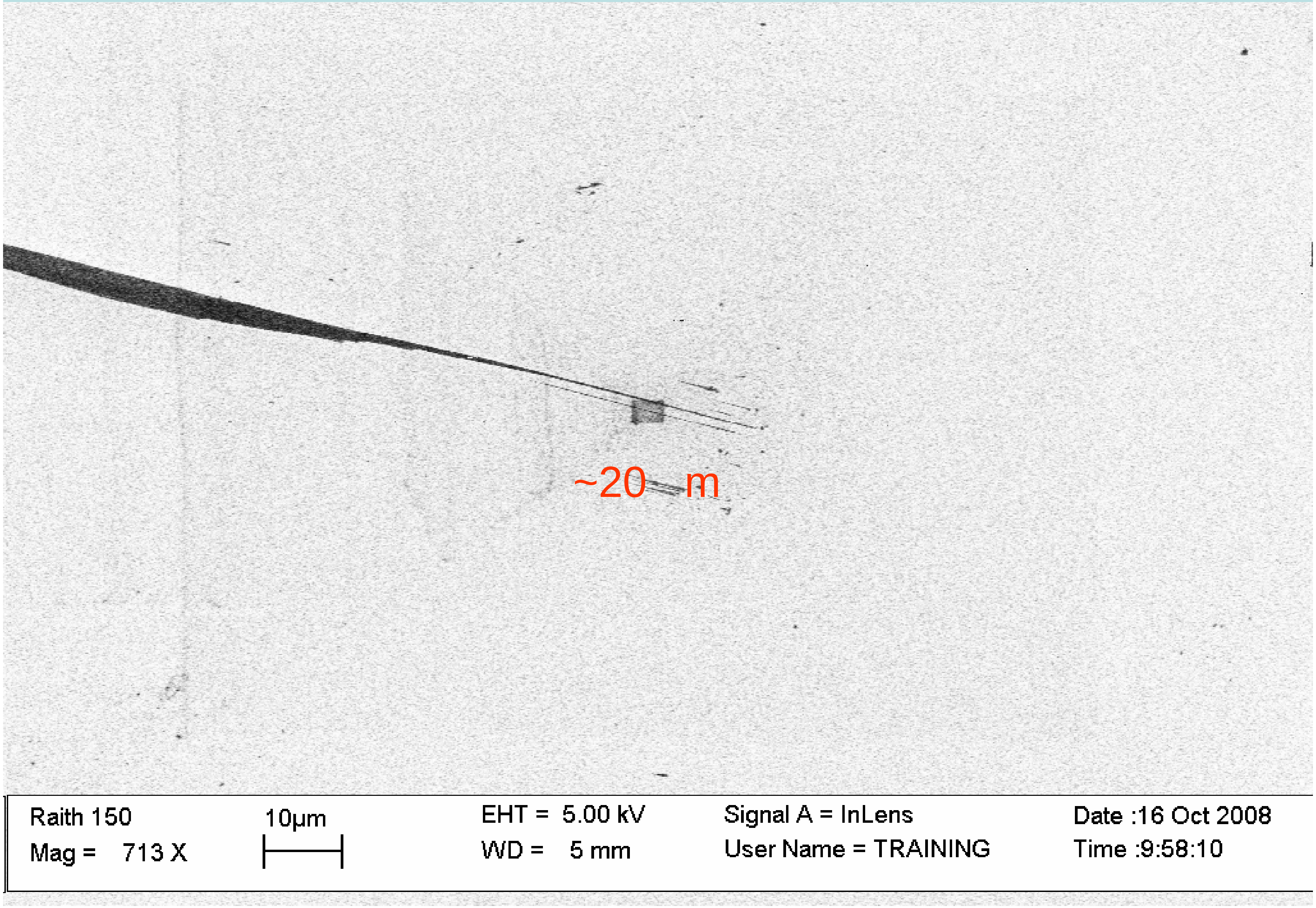


Dai Group, Science'08

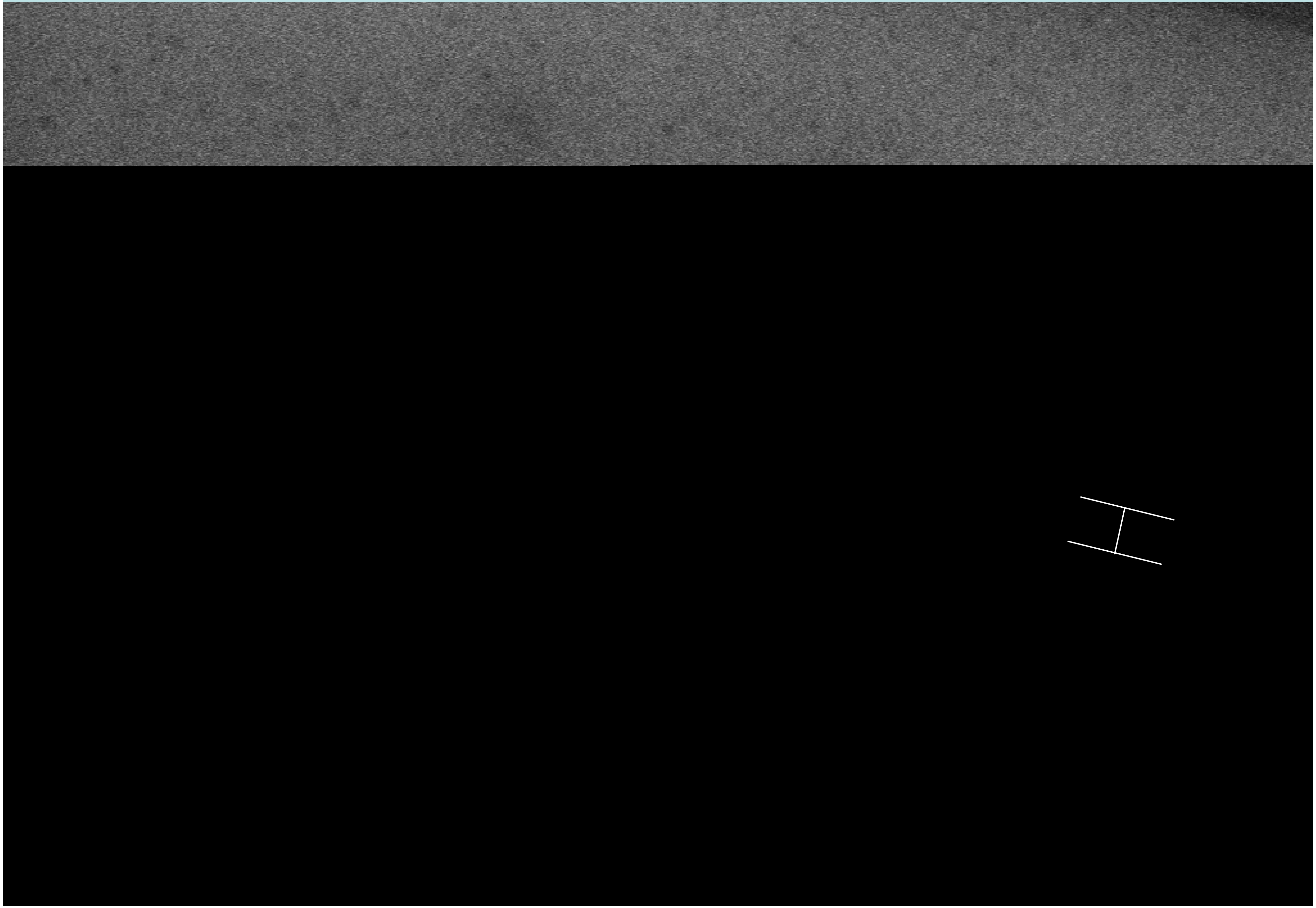




Our samples: mechanically exfoliated GNRs

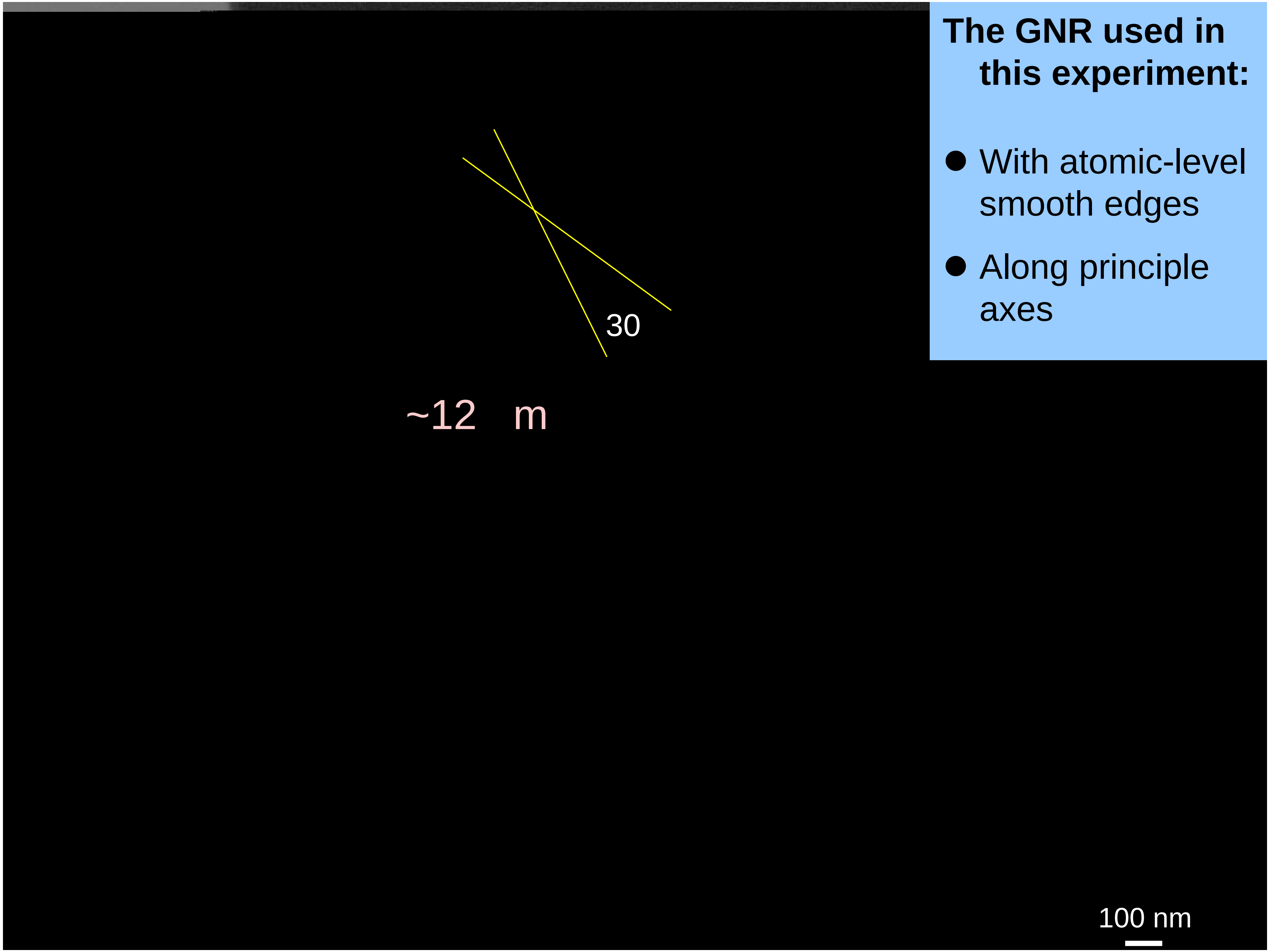


Our samples: mechanically exfoliated GNRs

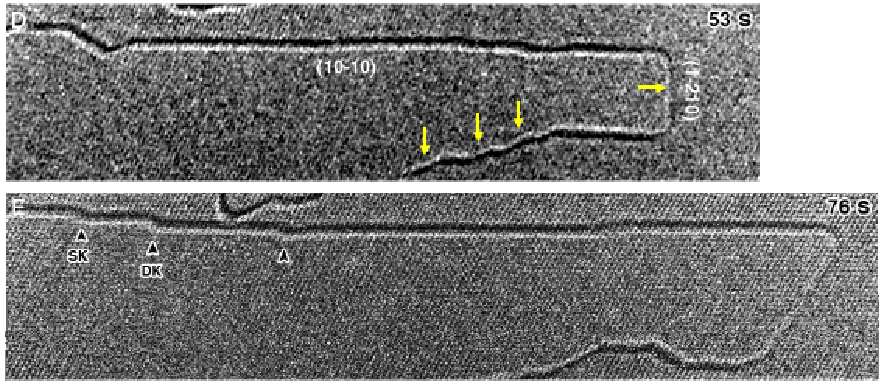


The GNR used in this experiment:

- With atomic-level smooth edges
- Along principle axes



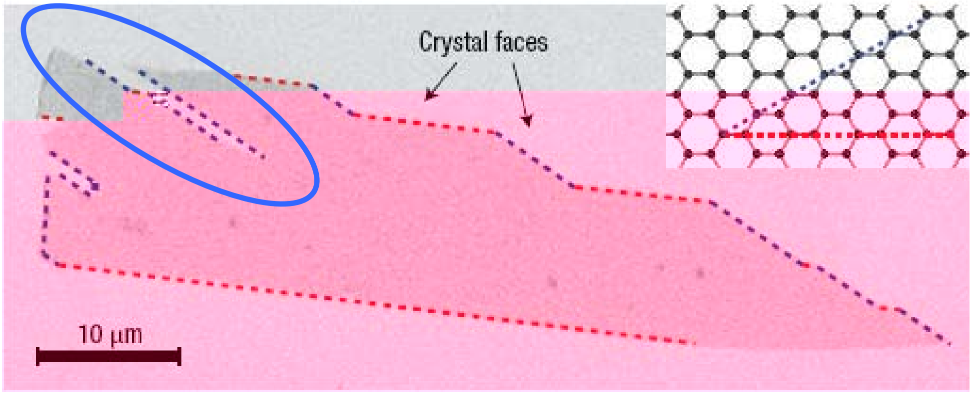
Edges of graphene nanoribbon (GNR)



99% edges are zigzag

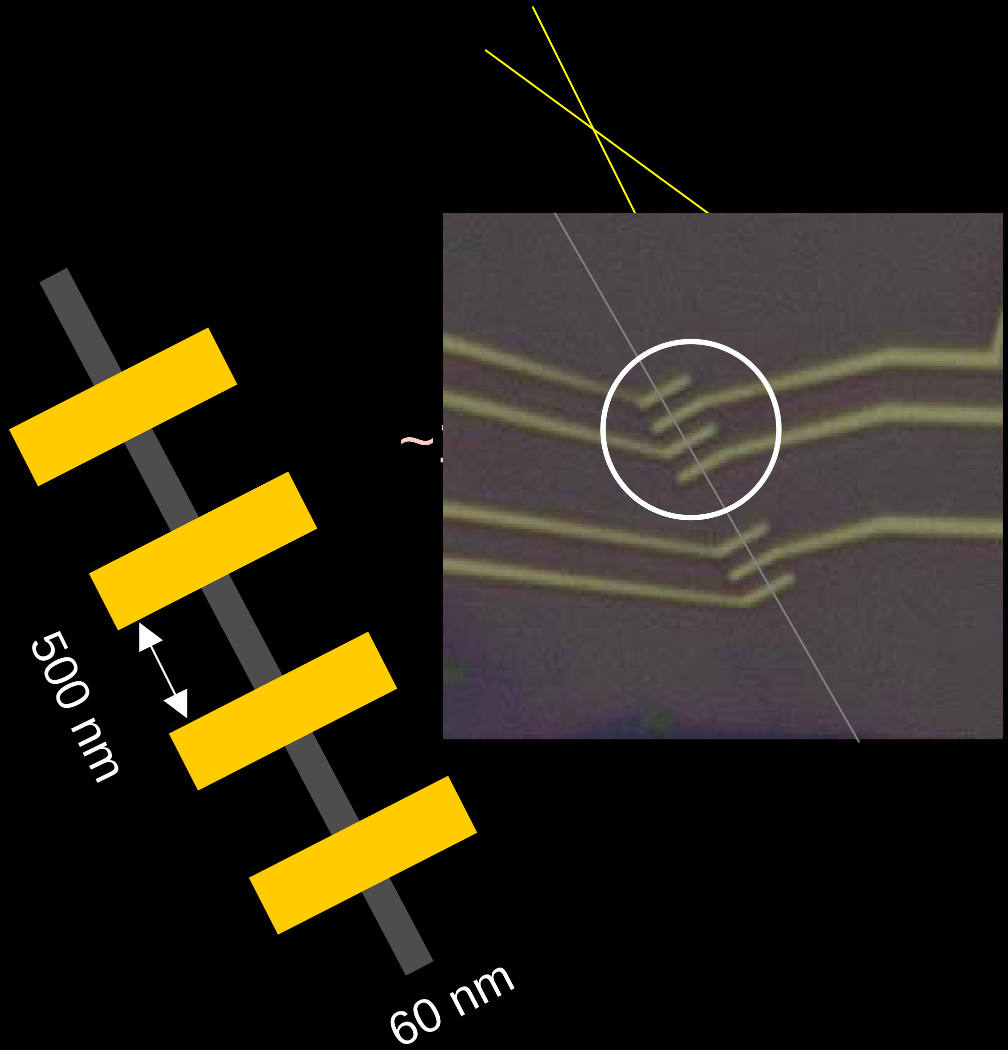
Jian Yu Huang et al., PNAS’09

Zigzag ribbon



Edges are along principle axes.

A. K. Geim, Nature Materials’07



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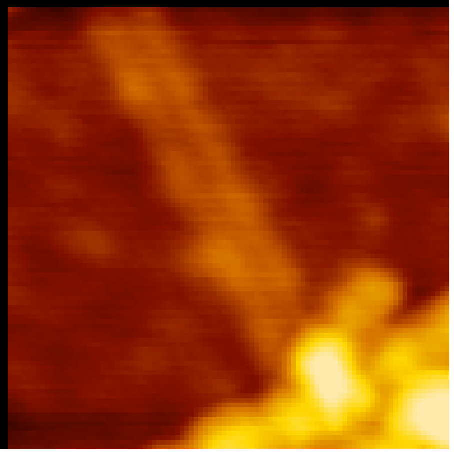
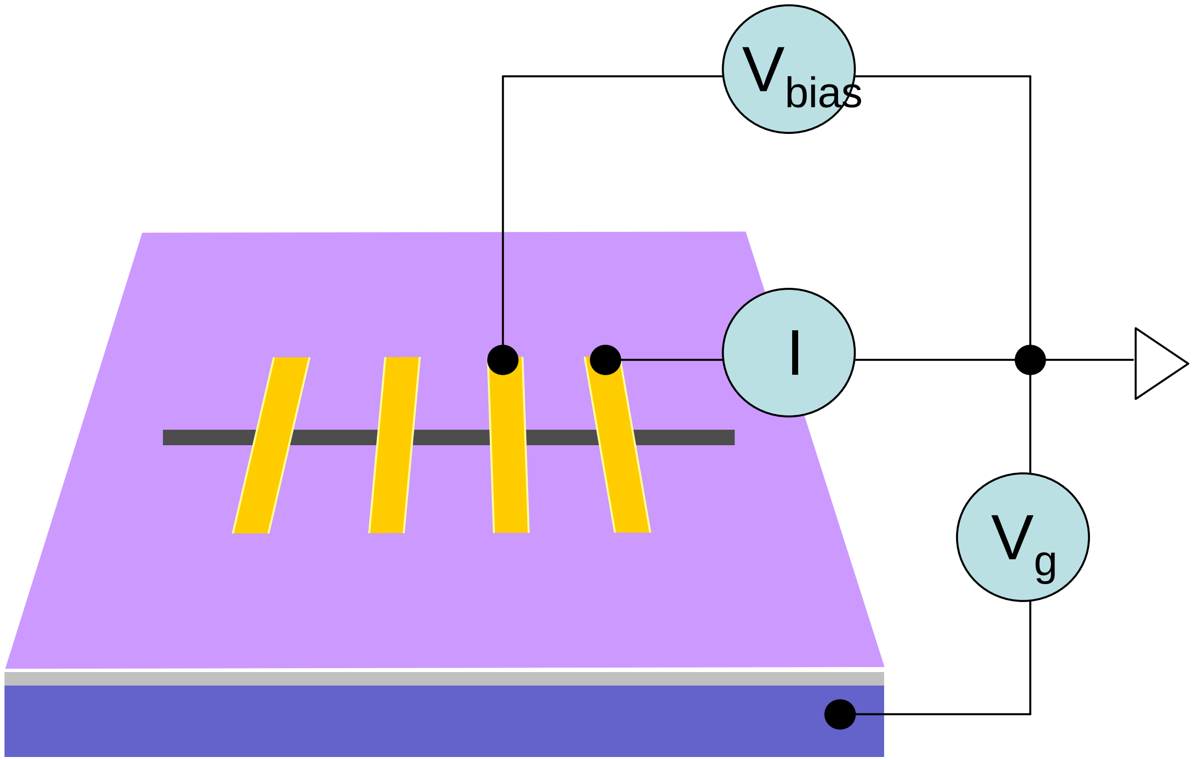
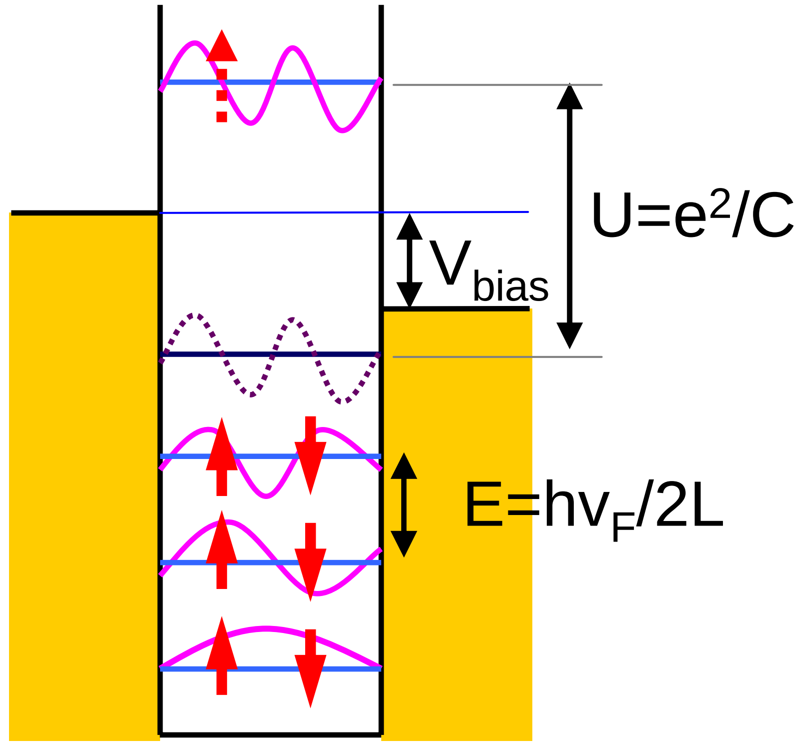
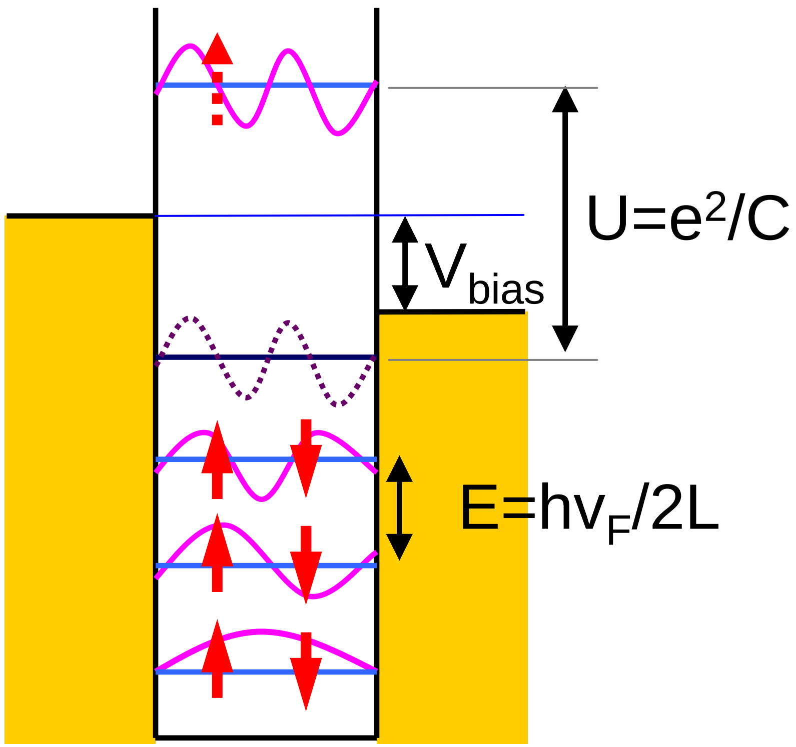




Interplay of different energy scales:

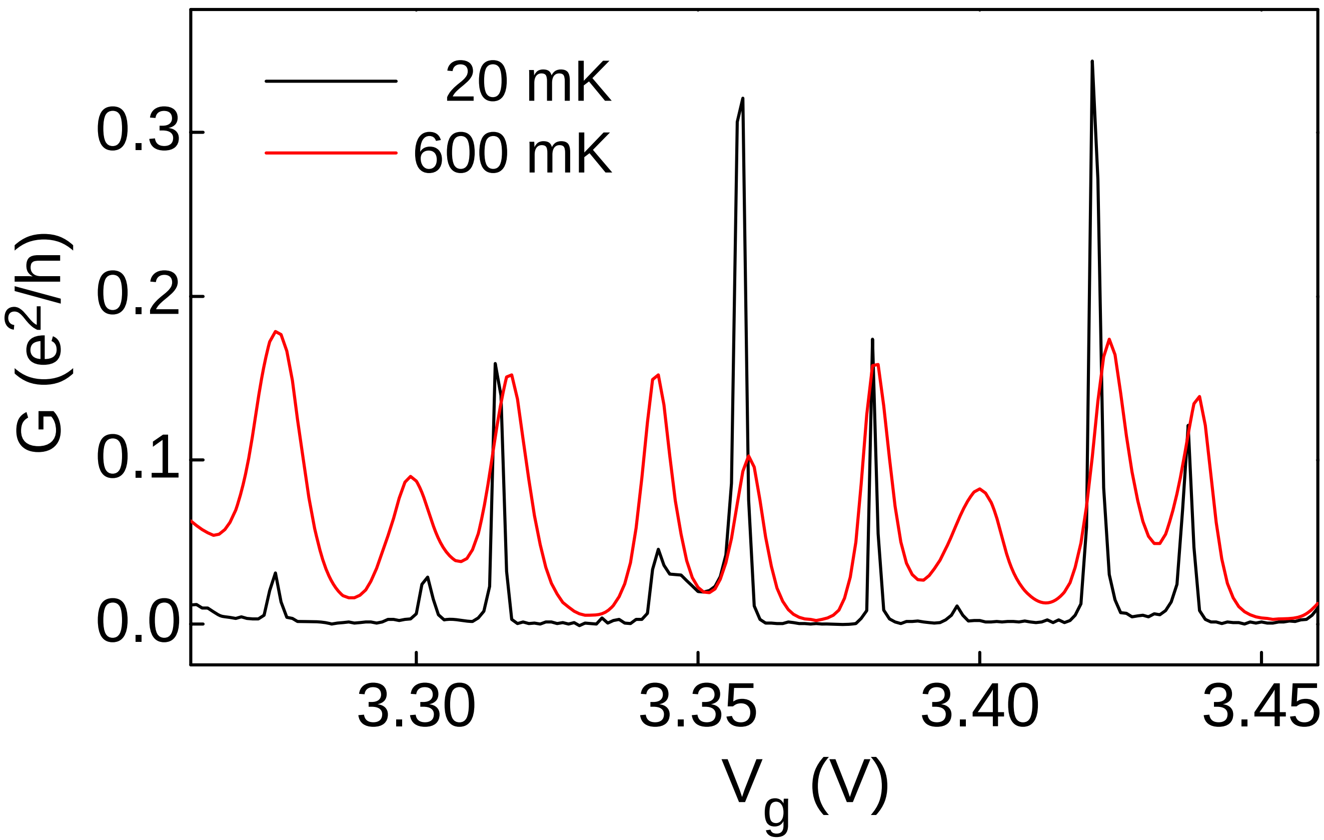
- E, level spacing (excited energy)
- V_g, shifts the levels in the QD
- V_{bias}, the bias window
- U, Coulomb charging energy



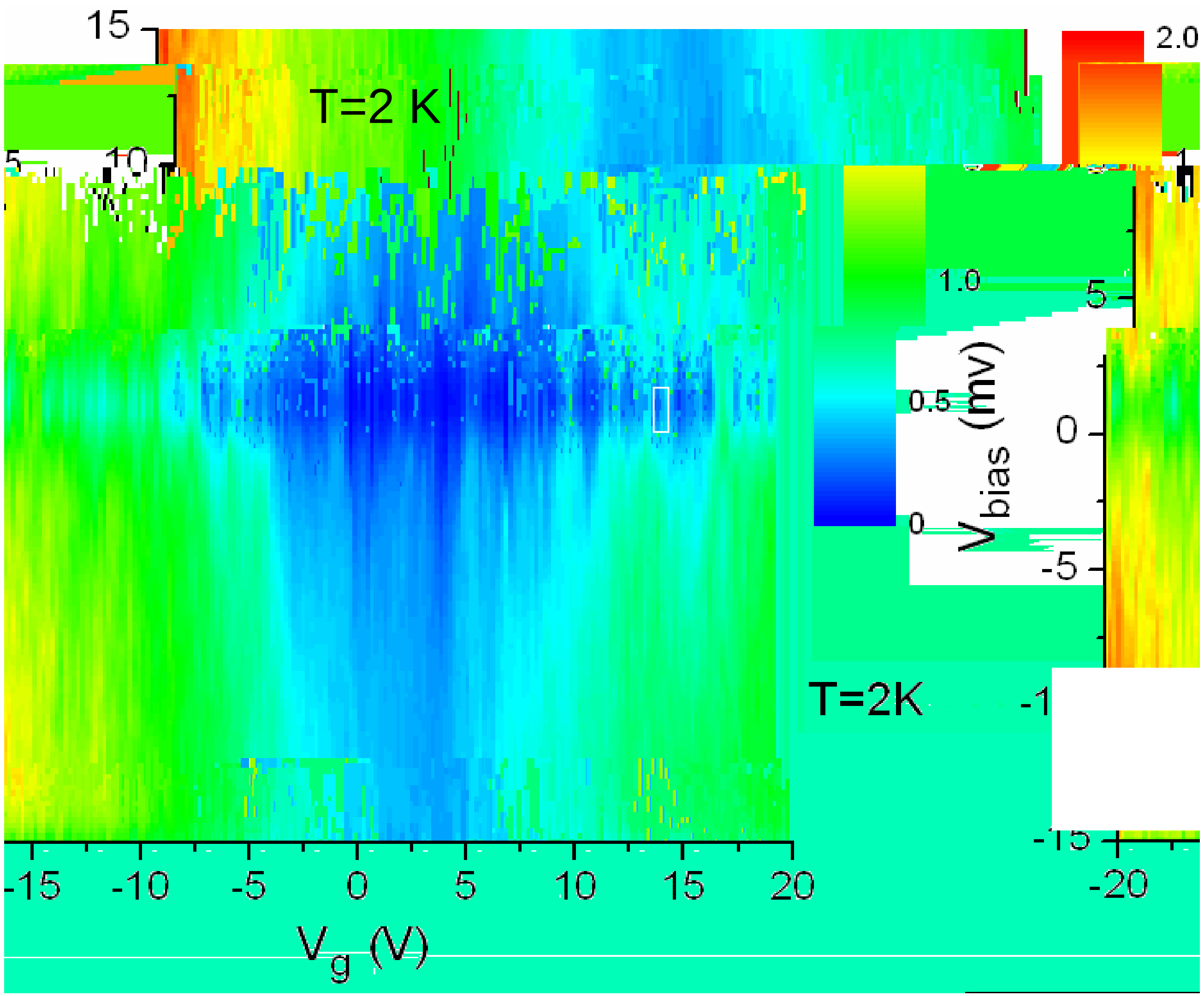


U=e2/C
Vbias
E=hvF/2L

Coulomb oscillation: G peak gets sharper at low T

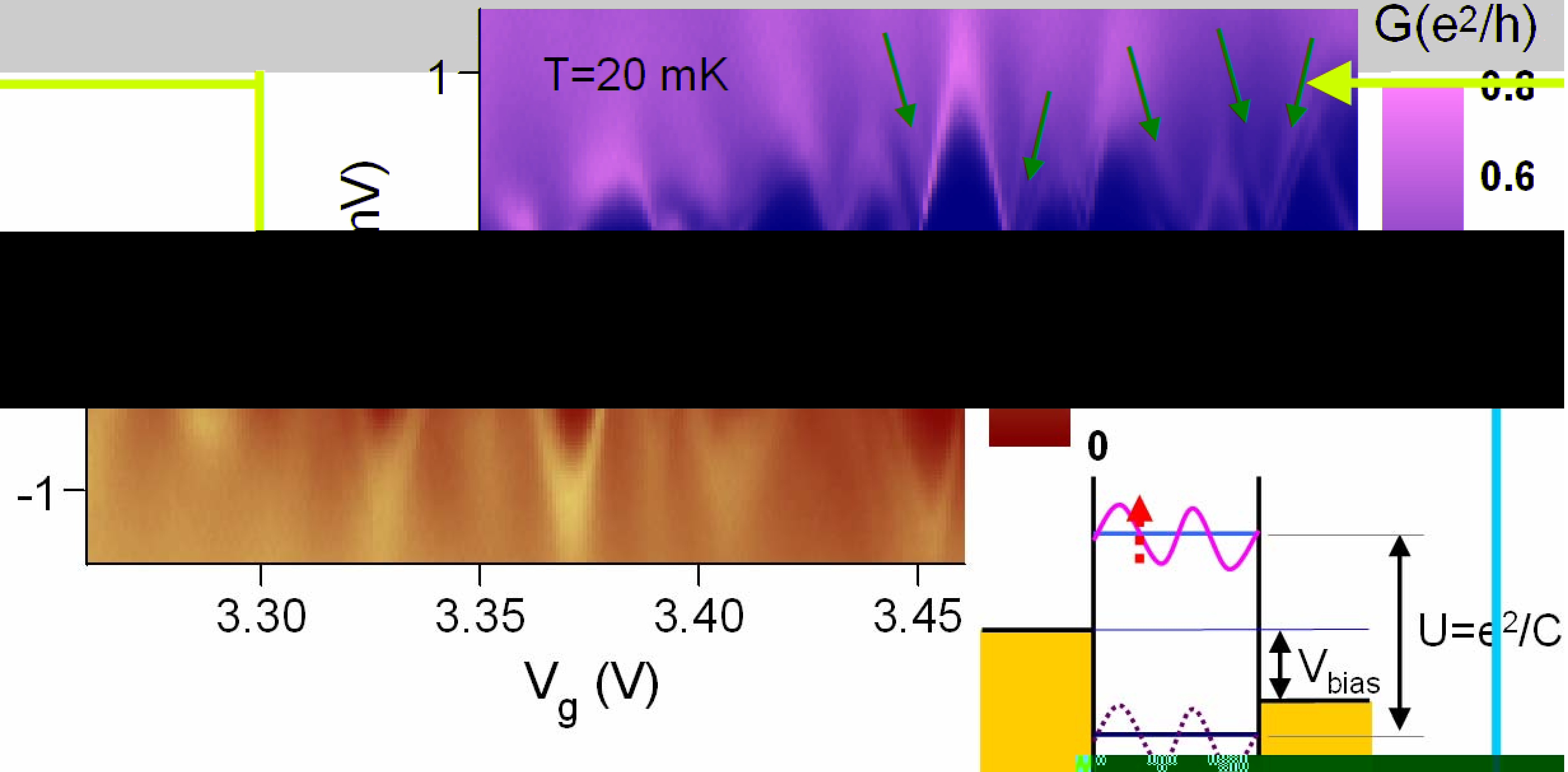


Conductance as a function of V_{bias} and V_g

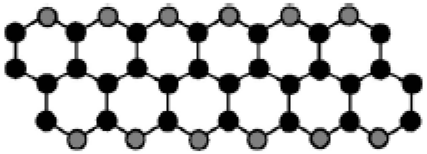


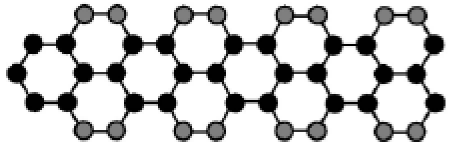
Two-fold spin shell filling in a bar-like QD

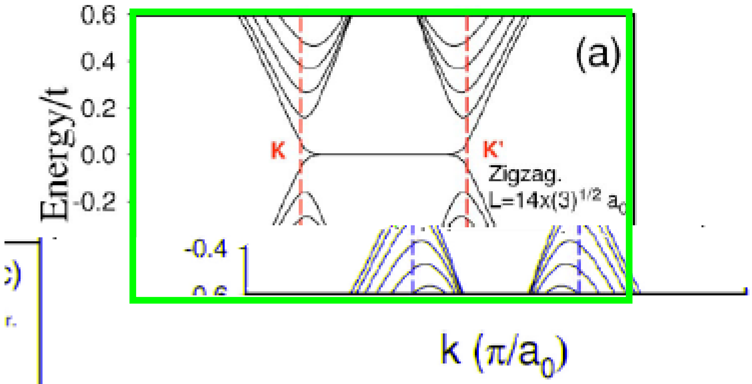
→ Break down of K and K' degeneracy

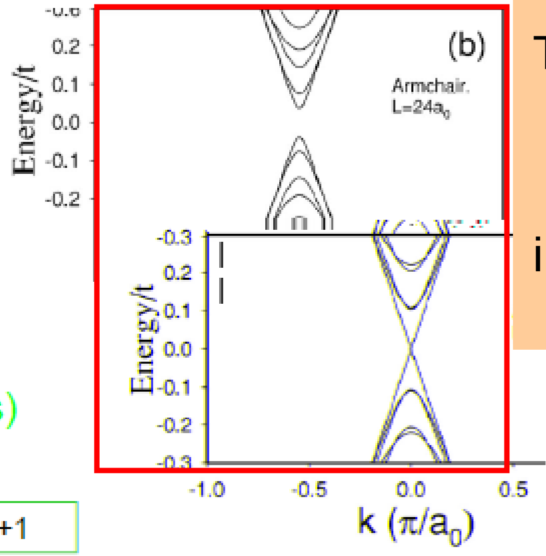


Excited energy → Zigzag ribbon





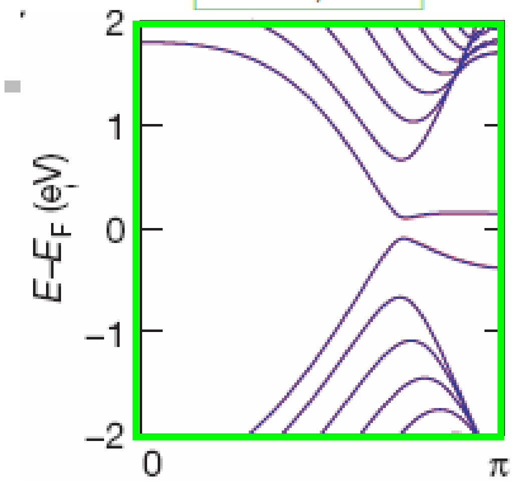




- zig-zag are gapless (edge modes)
- armchairs: gapped or gapless

W = 3N, 3N+2

W = 3N+1



Ezawa, PRB 2006; Brey-Fertig, PRB 2006

If armchair:

V_F=1e6m/s, E 12meV

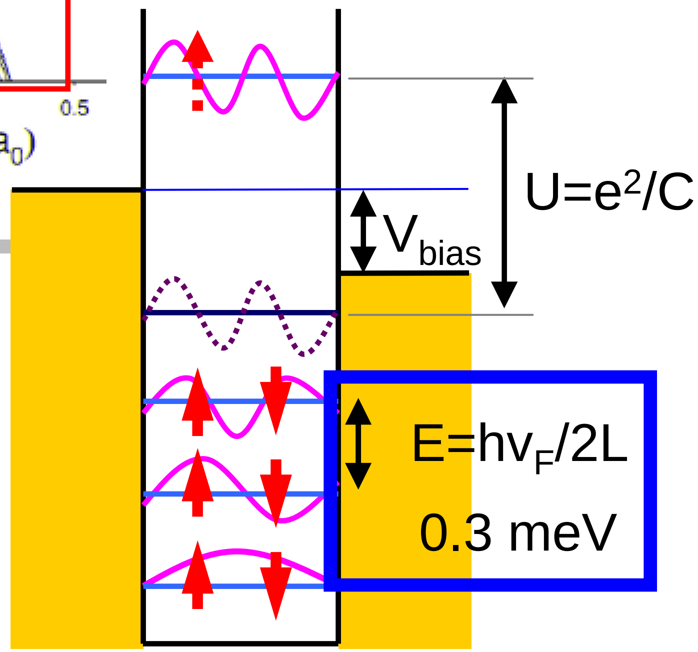
To get E 0.3meV, more than 10 subbands must be filled with ~700 elec.

i.e, Dirac point is 10V away from the V_g window.

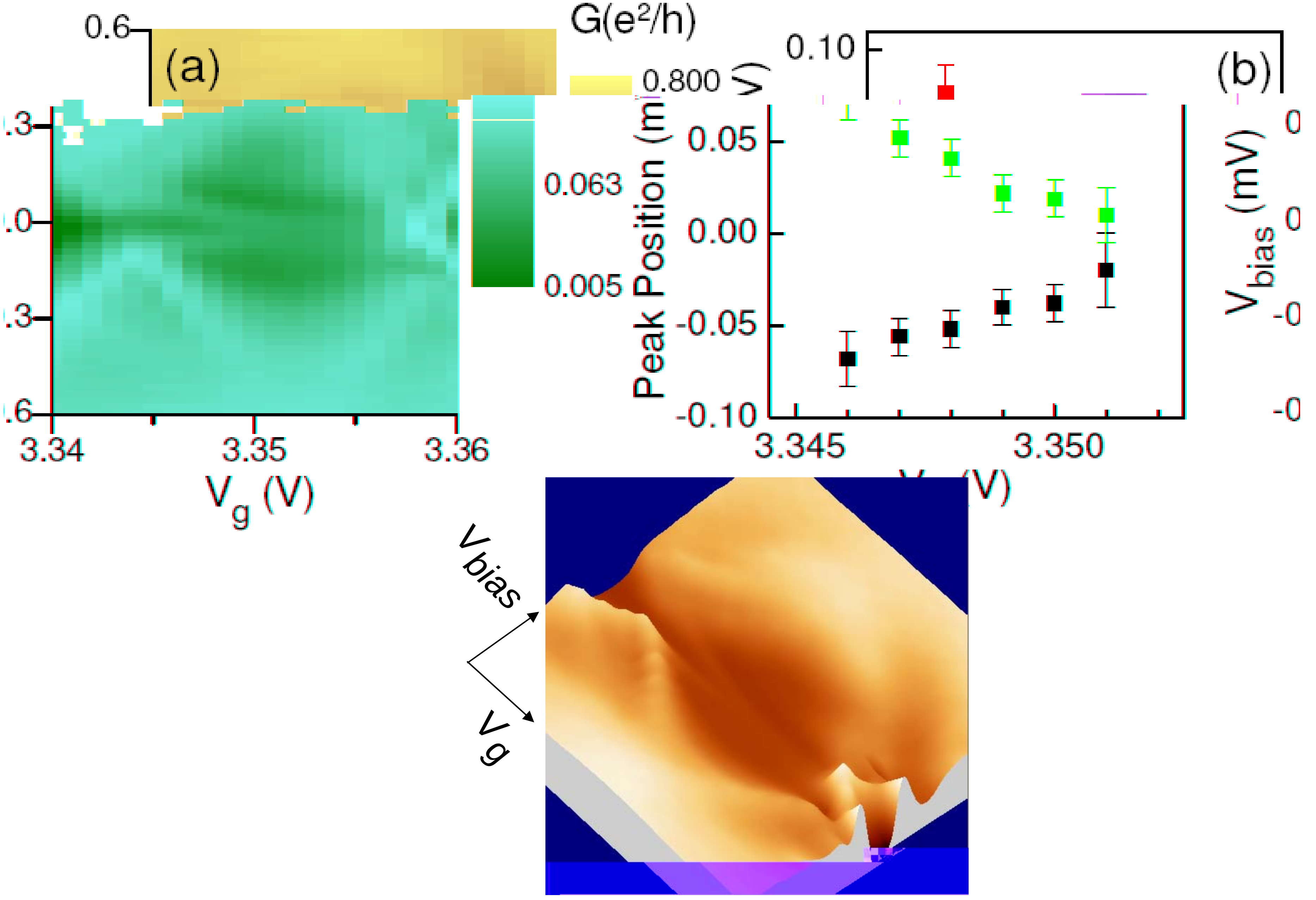
If zigzag:

$V_F'/V_F \sim t'/t$ 1/30

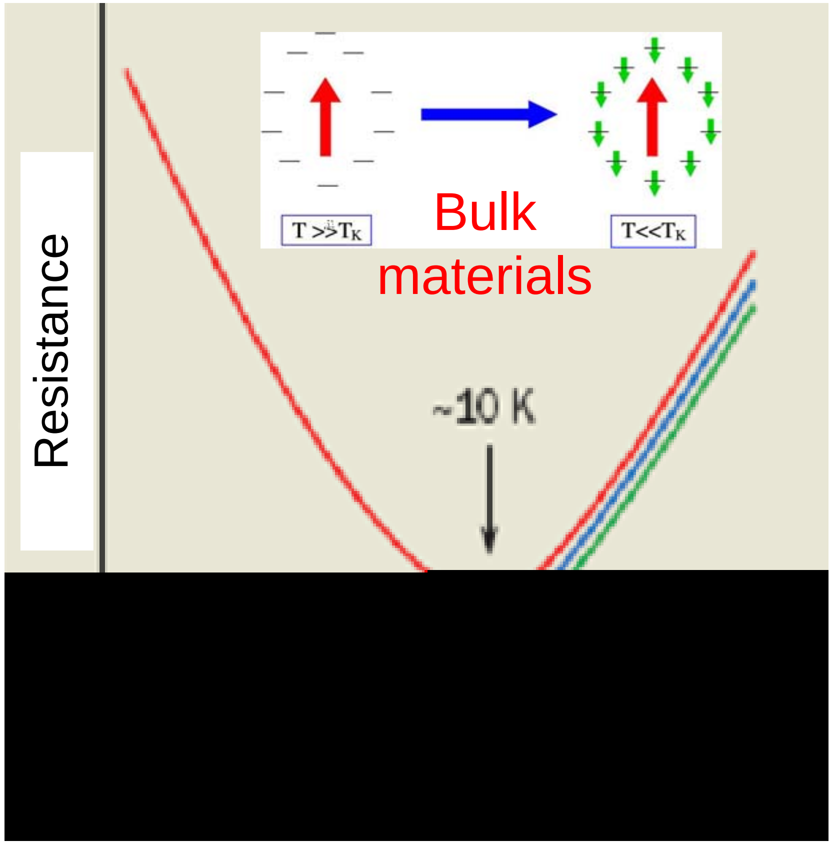
$E=hV_F'/2L^*$ 0.4 meV

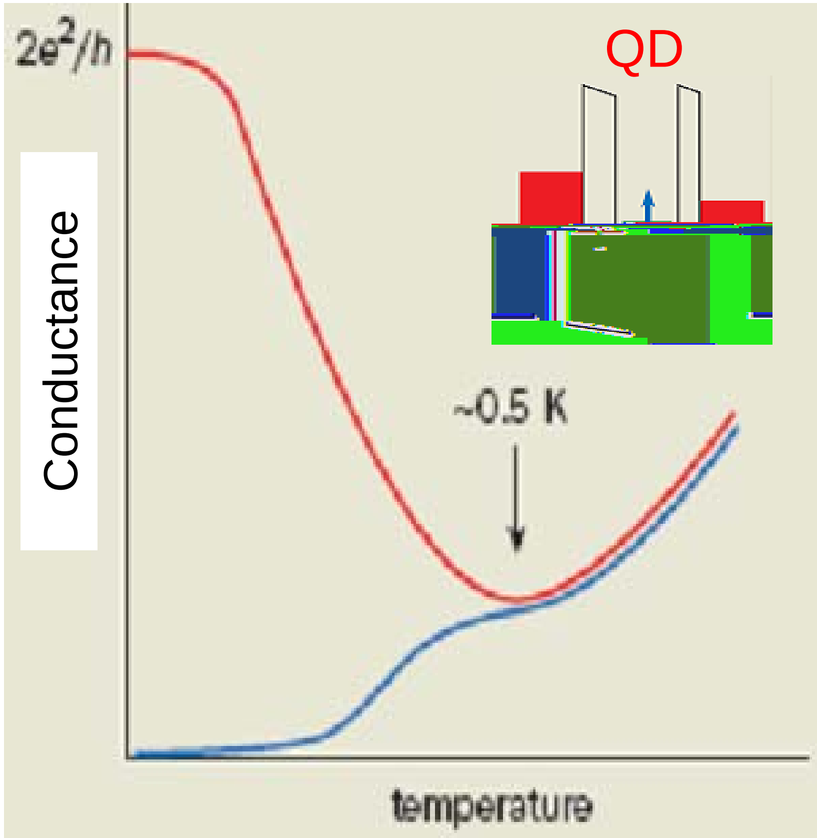


Inelastic Kondo resonance



Kondo problem





Scattering and screening:

R ↑@ low T

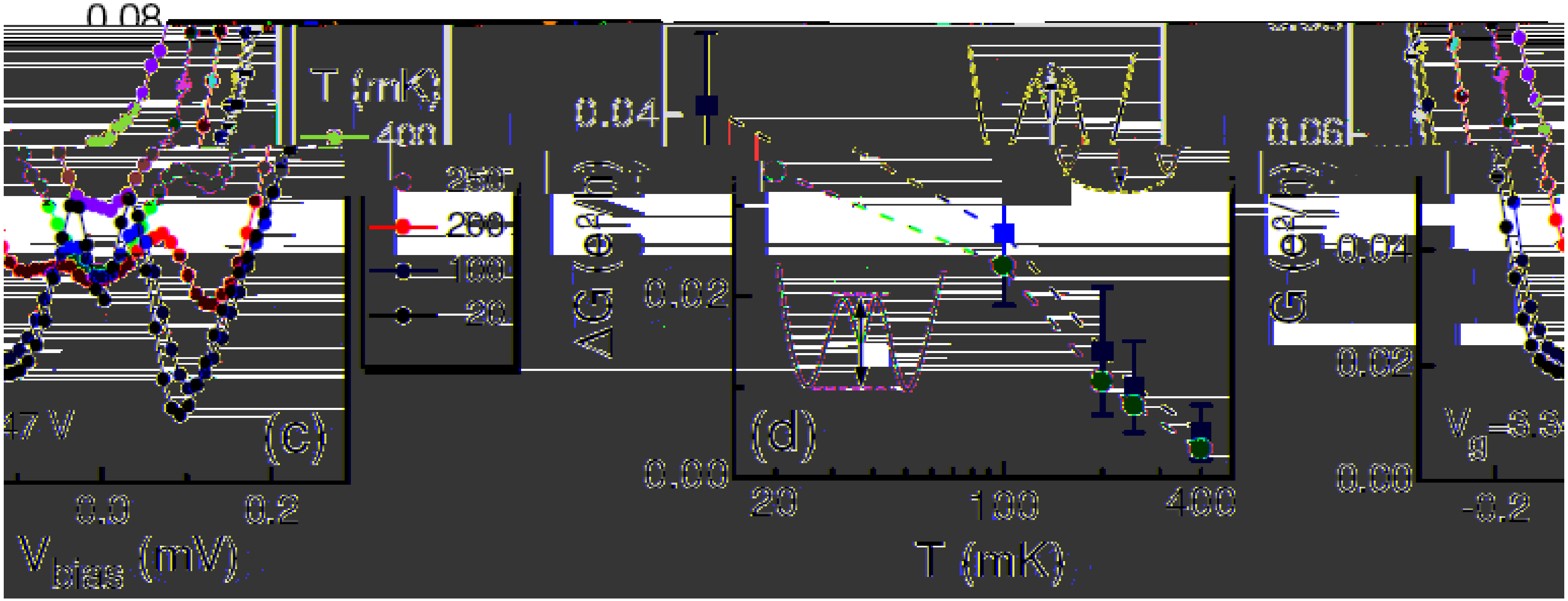
Kondo

Resonant co-tunneling:

Provides a conduction mechanism in the CB regime.

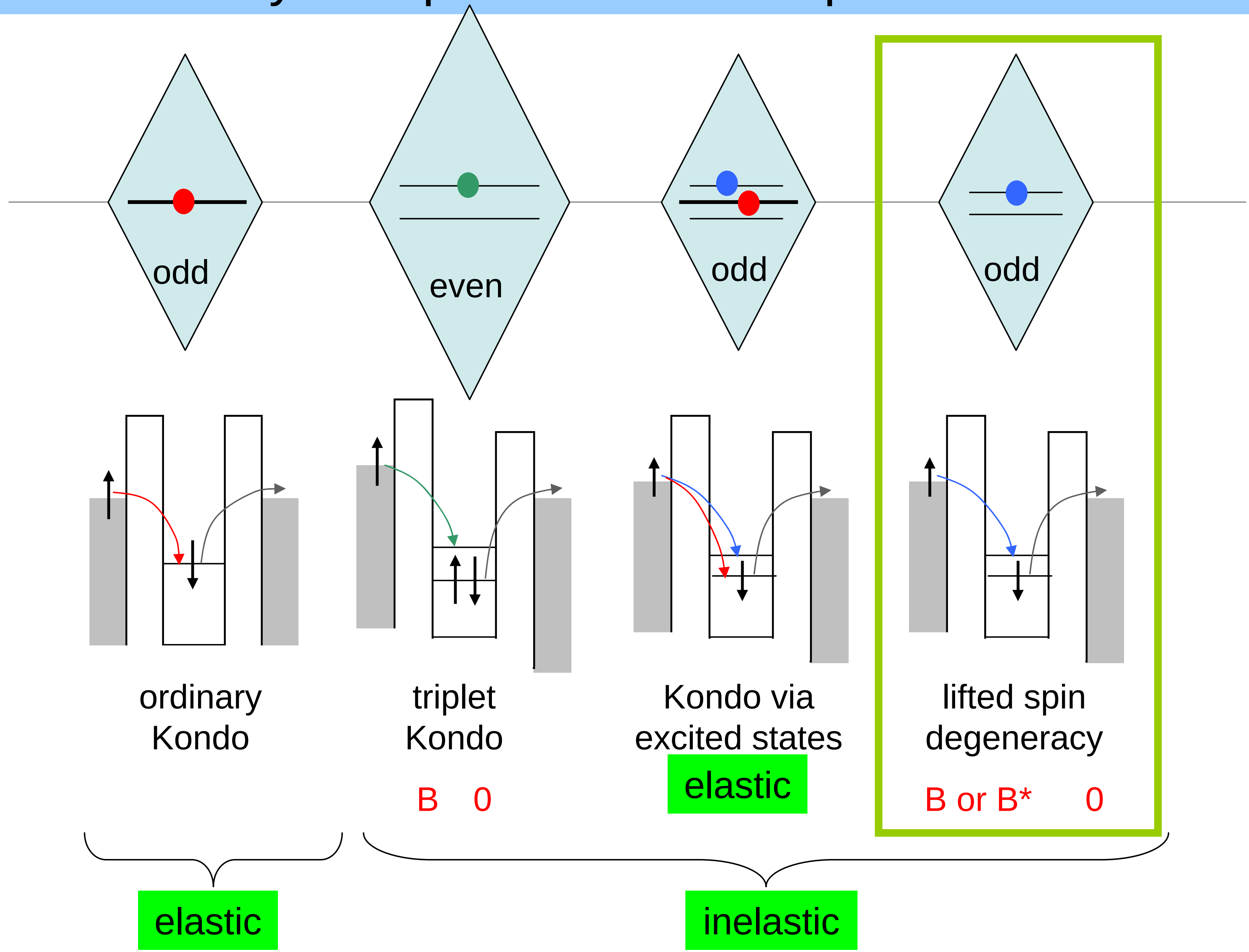
T. K. Ng and P. A. Lee' 1988
L. I. Glazman, et al.'1988

Logarithmic temperature dependence

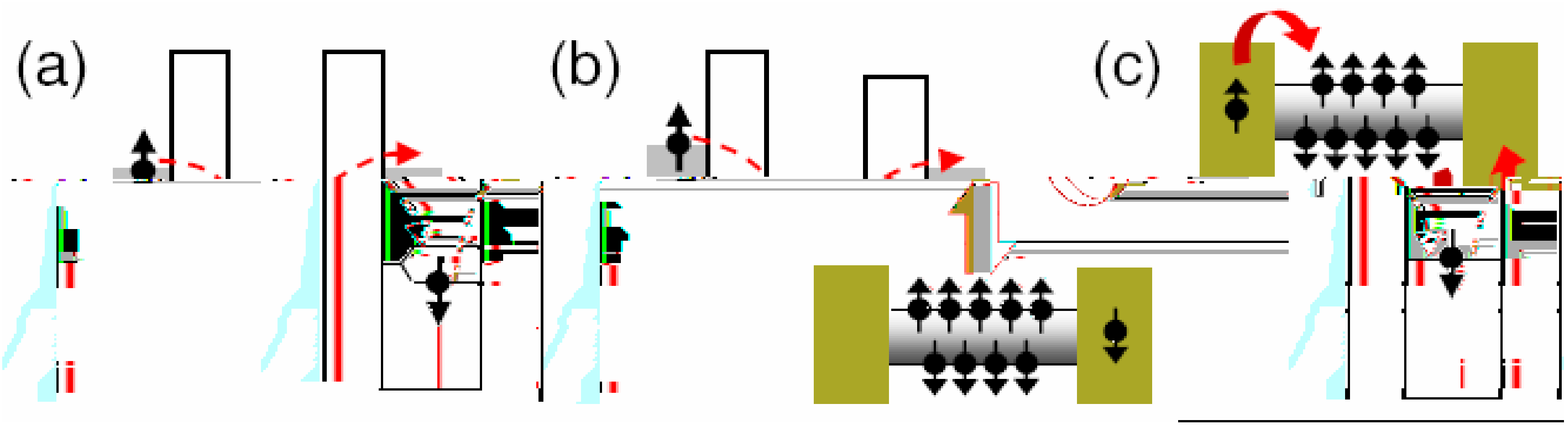


Kondo-like

Why multiple conductance peaks ?

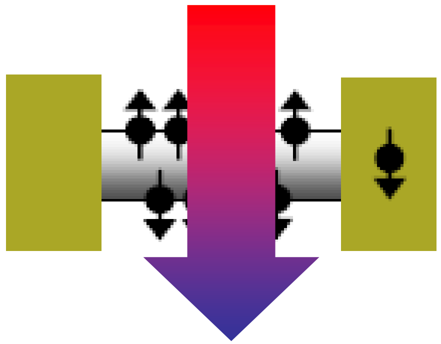


A toy model for inelastice Kondo resonance involving spin-polarized edge states



Elastic Kondo

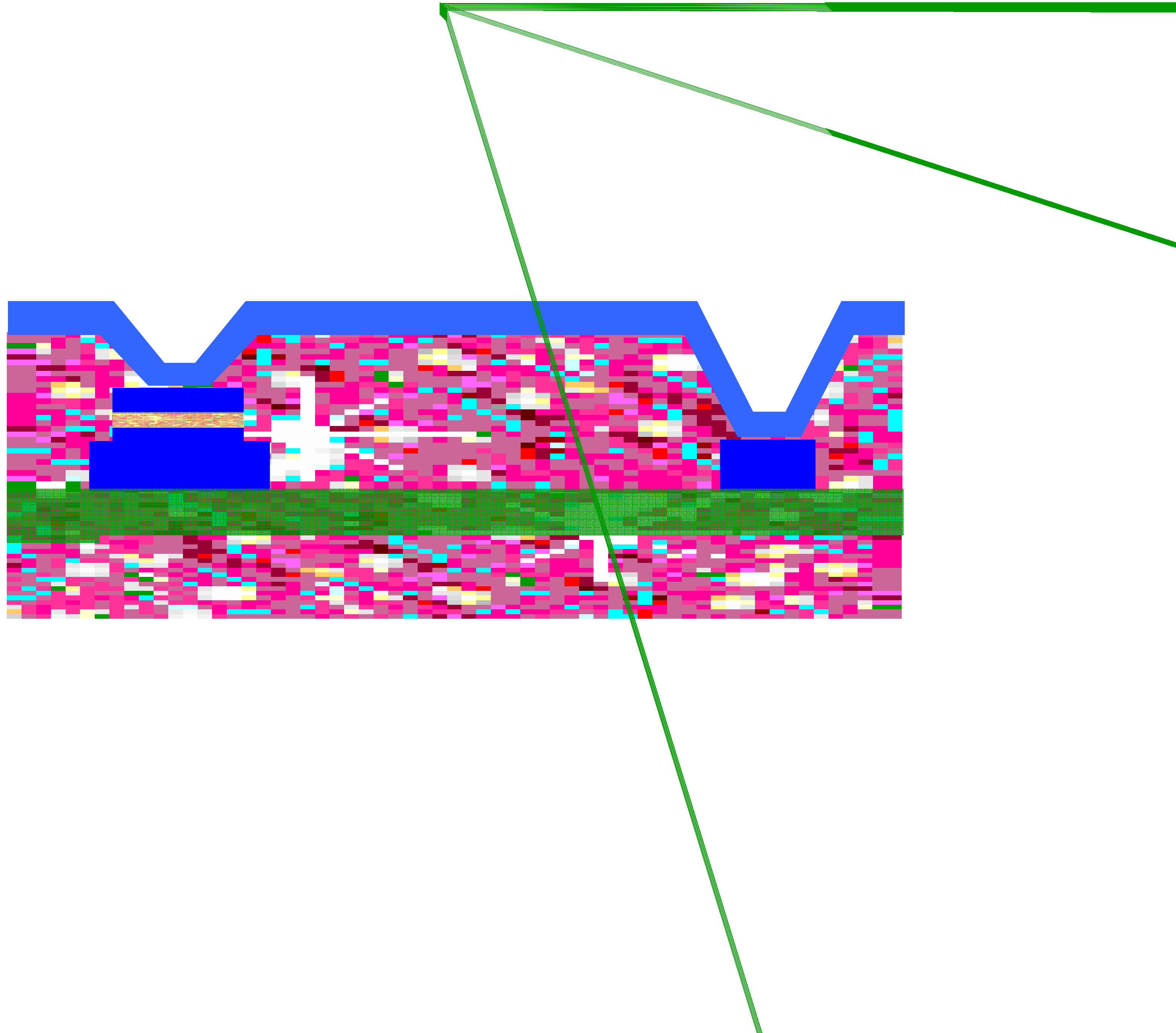
Inelastic Kondo



Inelastic Kondo realized in a zigzag GNR at B=0,

When the electrostatic potential of the two edges are different,

due to applied transverse electric field or trapped charge vacancies.



Summary

- Measured the transport properties of a zigzag GNR.
- Observed two-fold spin shell filling in CB regime.
- Provided transport evidence of spin polarization in the zigzag GNR.

C. L. Tan, et al, submitted

感　谢