# Hysteresis loops of magnetoconductance in graphene devices

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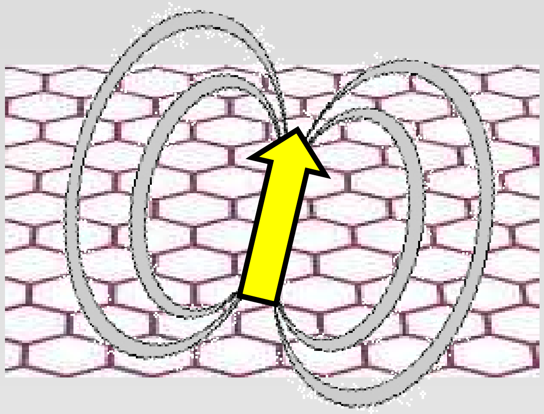
# Introduction

## Magnetism in graphene



## Theory

- Vacancies
- H adatoms
- Metal adatoms
- Edges

## Experiments (see also next talk)

Ferromagnetism in defected HOPG (Esquinazi *et al.* PRL 91, 227201 2003)

Magnetism of single vacancy (Ugeda *et al.* PRL 104, 096804 2010)

Ferromagnetism in graphene (Wang *et al.* Nano Lett. 9, 202 2009)

Paramagnetism in graphene (Sepioni *et al.* PRL 105, 207205 2010)

# Introduction

## …*however*… No evidence from magnetotransport

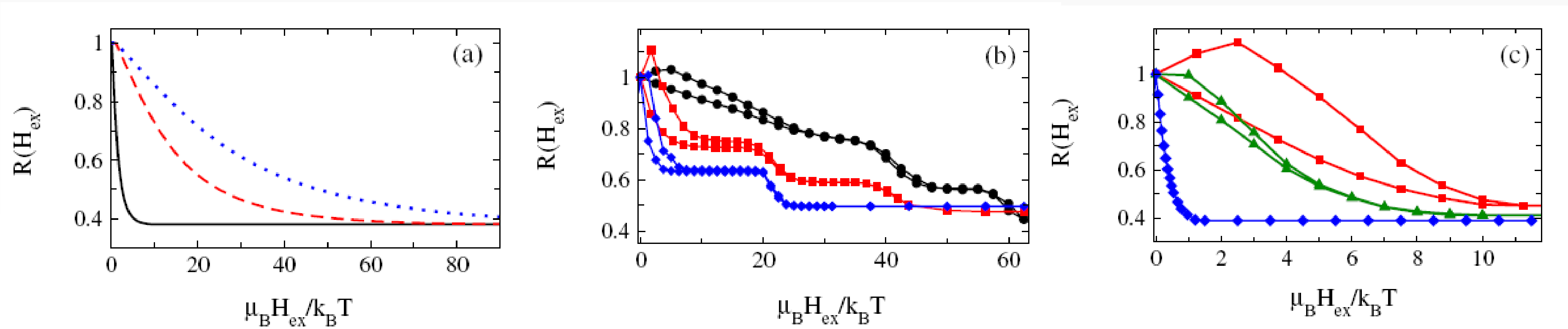
Large number of data available

"Prediction" of visibility

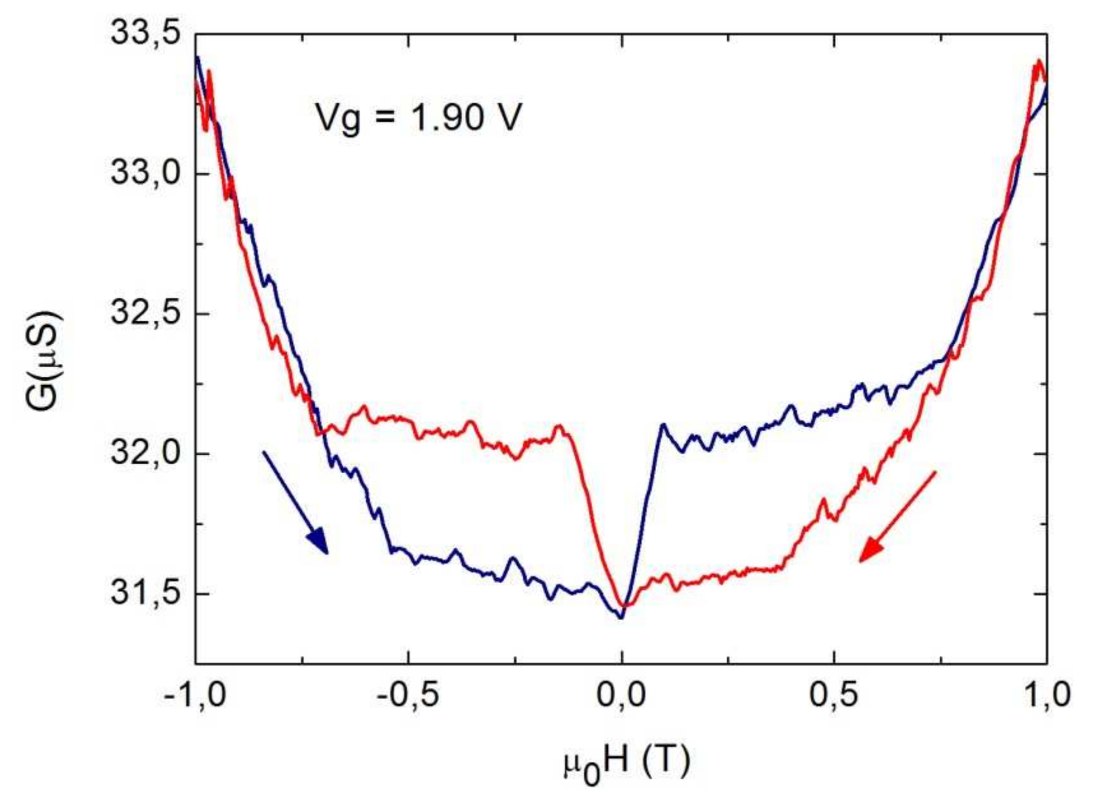
PHYSICAL REVIEW B 80, 245408 (2009)

**Magnetism and magnetotransport in disordered graphene**

T. G. Rappoport,[1] Bruno Uchoa,[2] and A. H. Castro Neto[3]



# Introduction




In-plane field

T = 0.04 K

Sweep rate = 0.05 T/s

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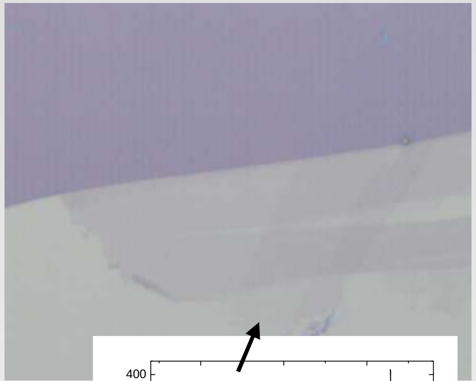
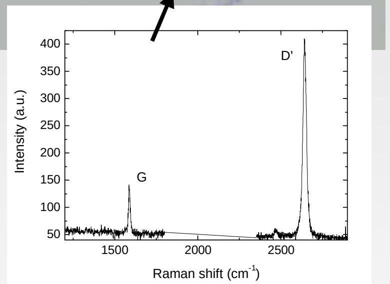
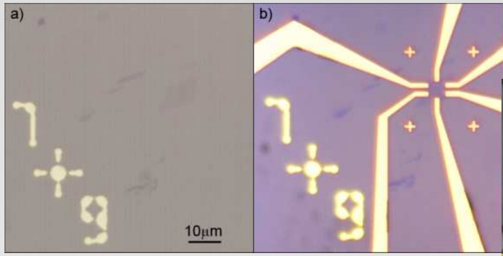
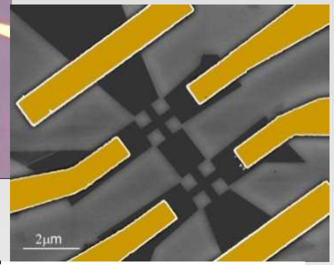
# Fabrication of Graphene Devices

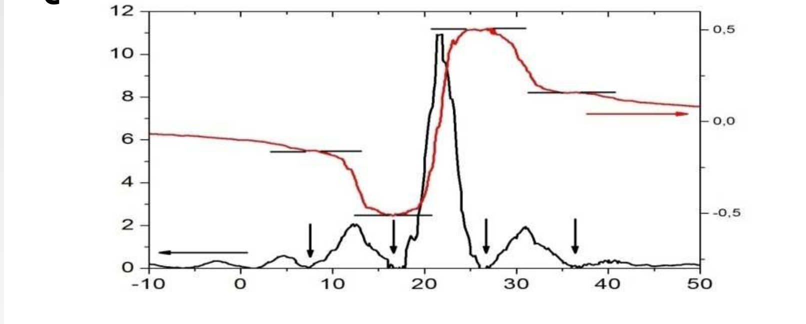





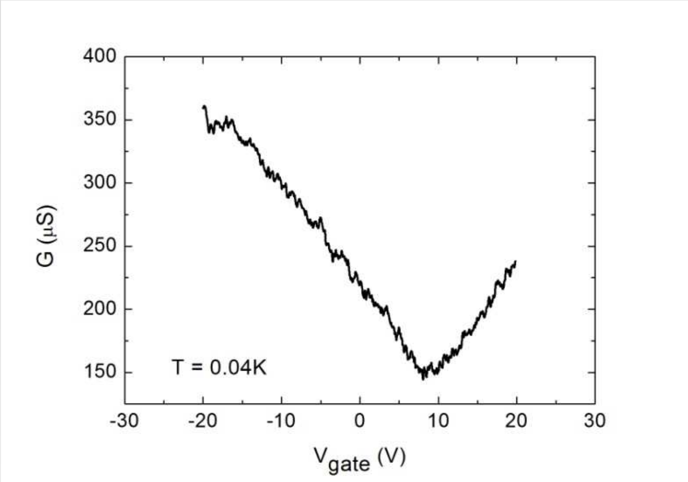




Quantum Hall Effect

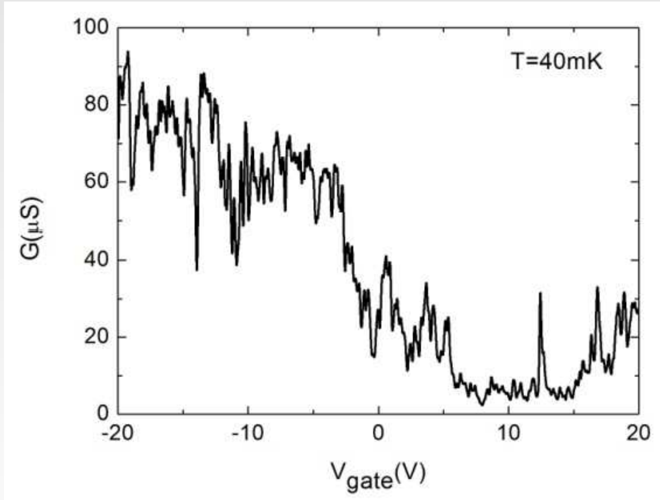



- Graphene obtained by the Scotch-tape method
- Characterization by micro-Raman spectroscopy
- Electron Beam Lithography to define contacts and to etch devices
- Devices of good quality (observation of Quantum Hall effect)

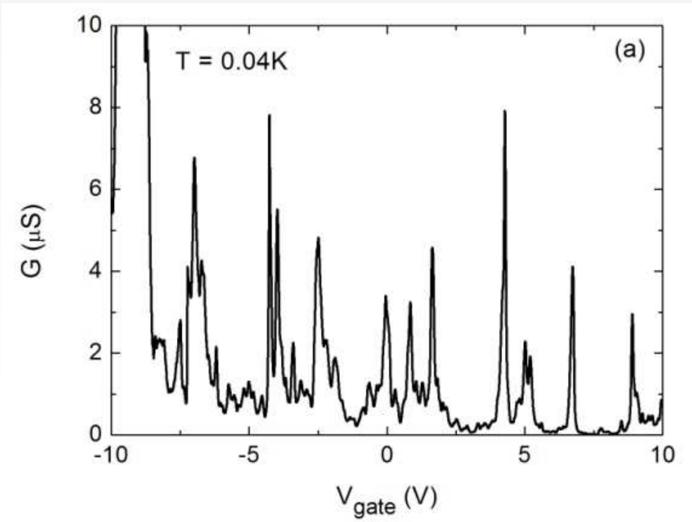
# Device size




Unetched devices
$\mu$ up to 5000 $cm^2/Vs$

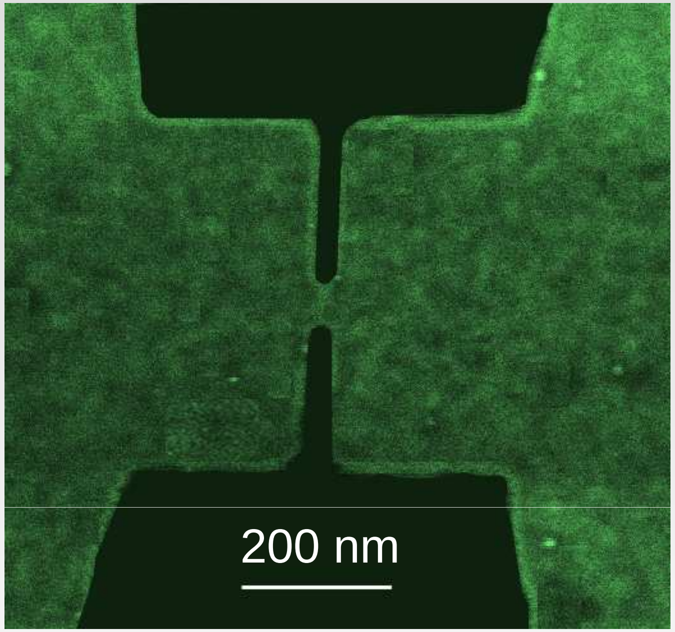


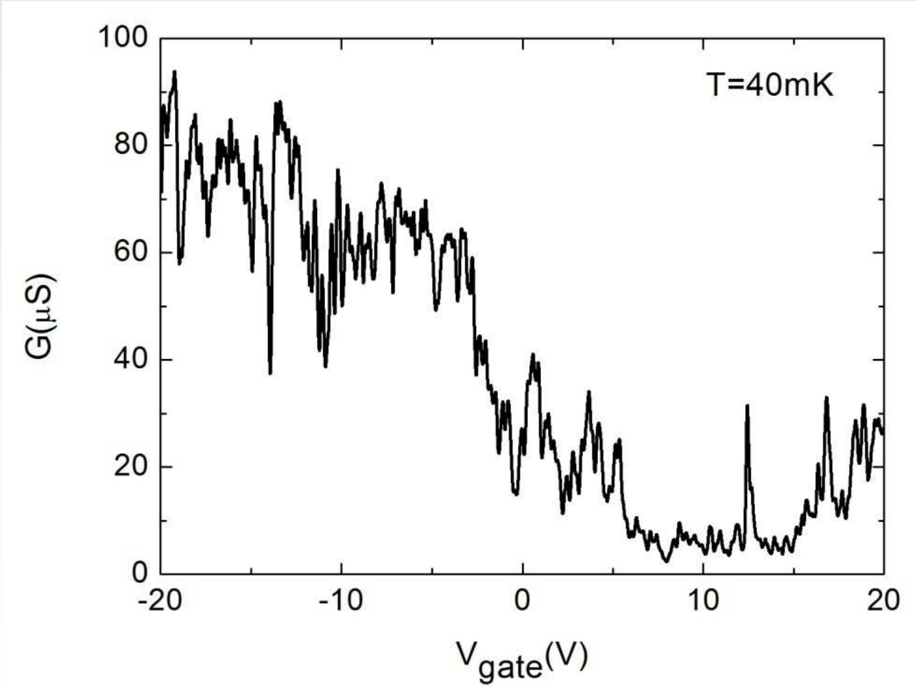

Constriction ~ 60nm




Constriction ~ 30nm

# Sample characterization

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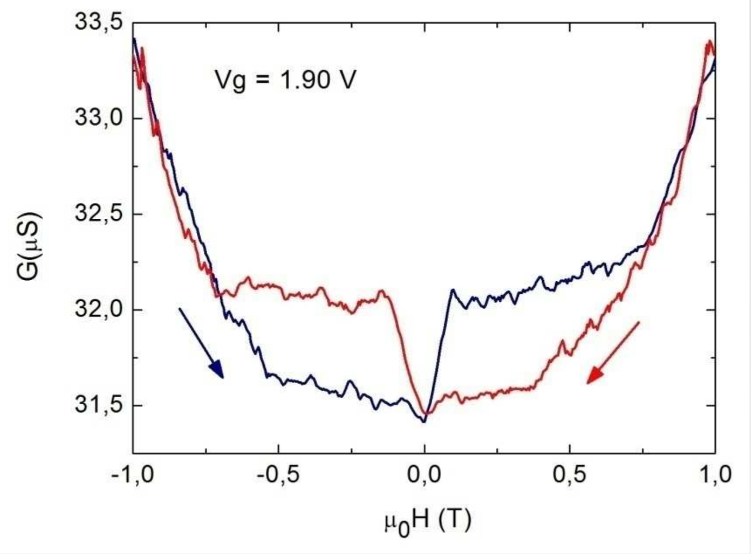
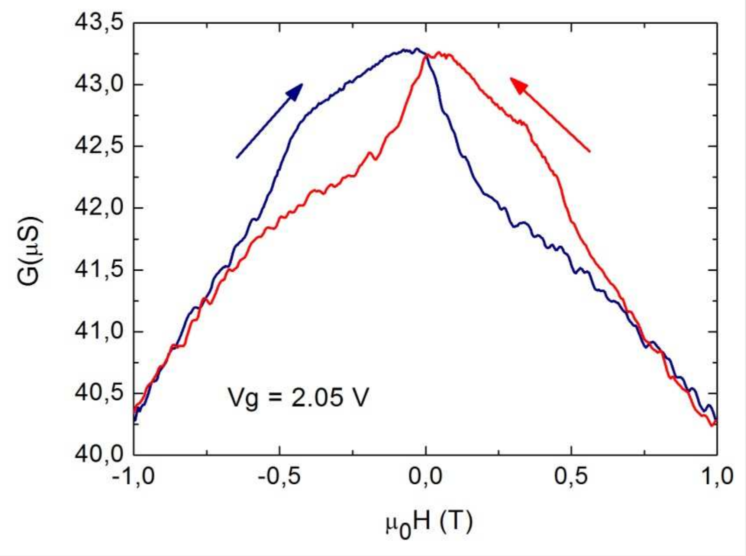
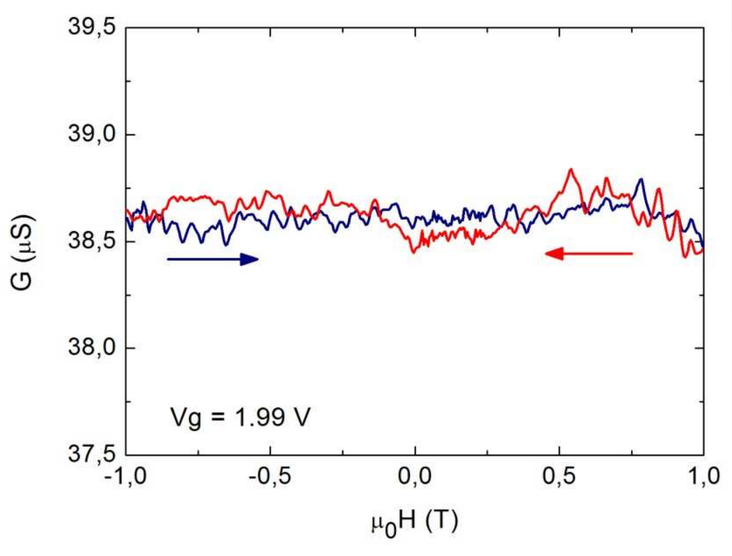
# Magneto-transport




T = 0.04 K

Sweep rate = 0.05 T/s

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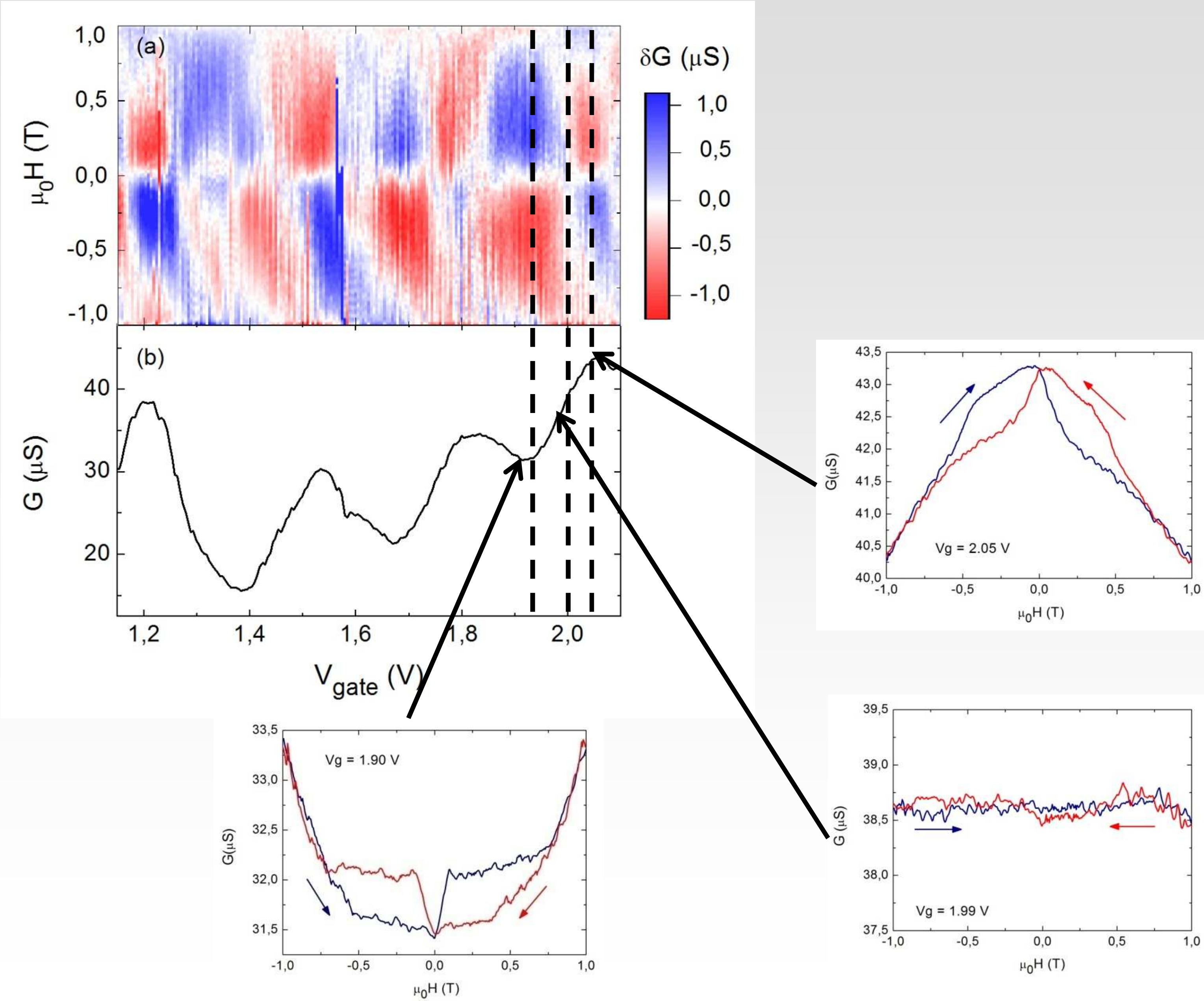
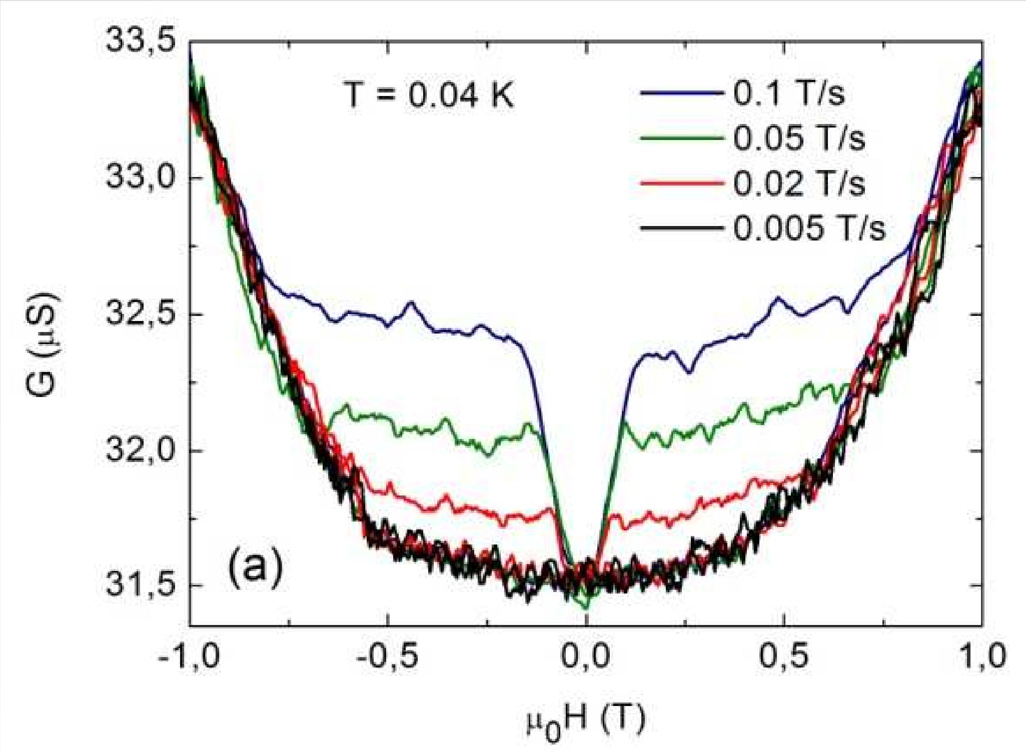
# Gate-dependence



# Field sweep rate dependence




The hysteresis disappears for slow sweep rates

The (non-hysteretic) magnetoconductance is still present

Magnetoconductivity ➡ Non hysteretic part (gate dependent) + Hysteretic part

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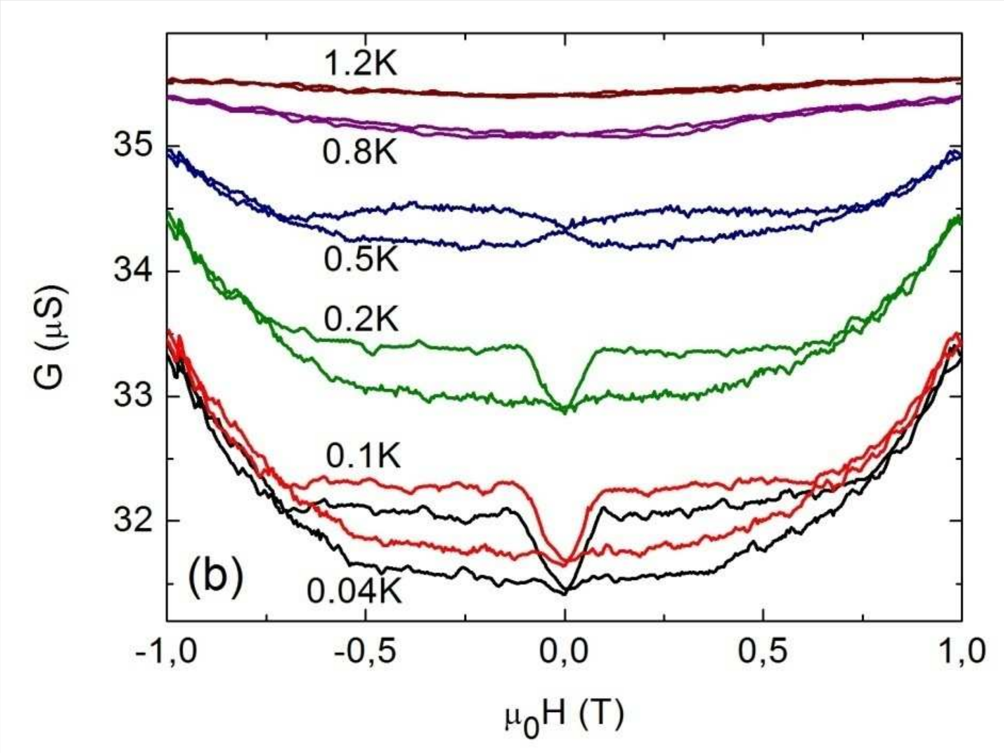
# Temperature dependence




The hysteresis disappears only above ~ 1K

It disappears only when the (non-hysteretic) magnetoconductivity becomes flat

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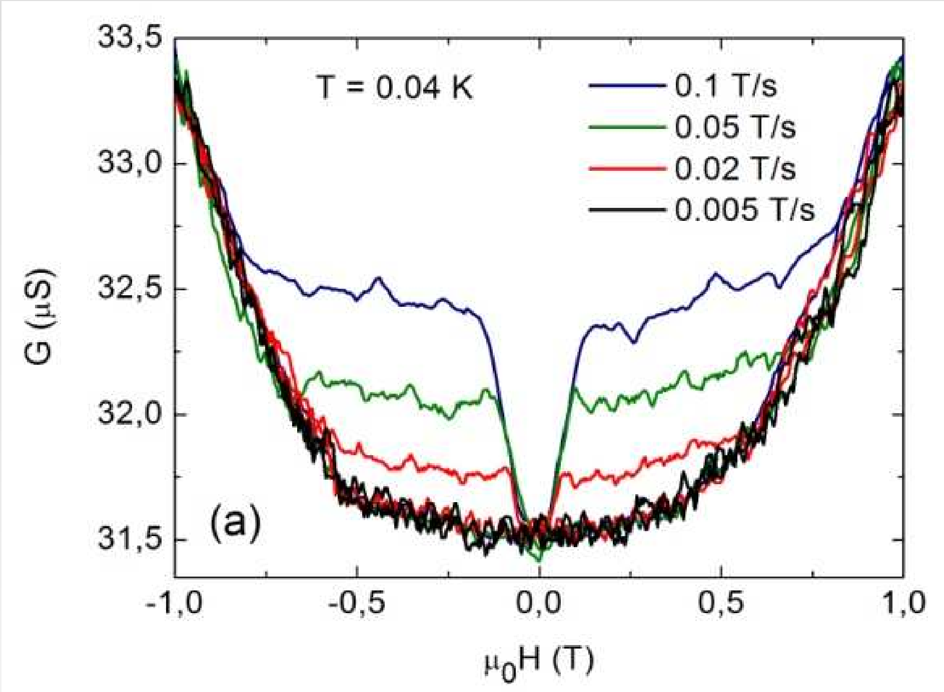
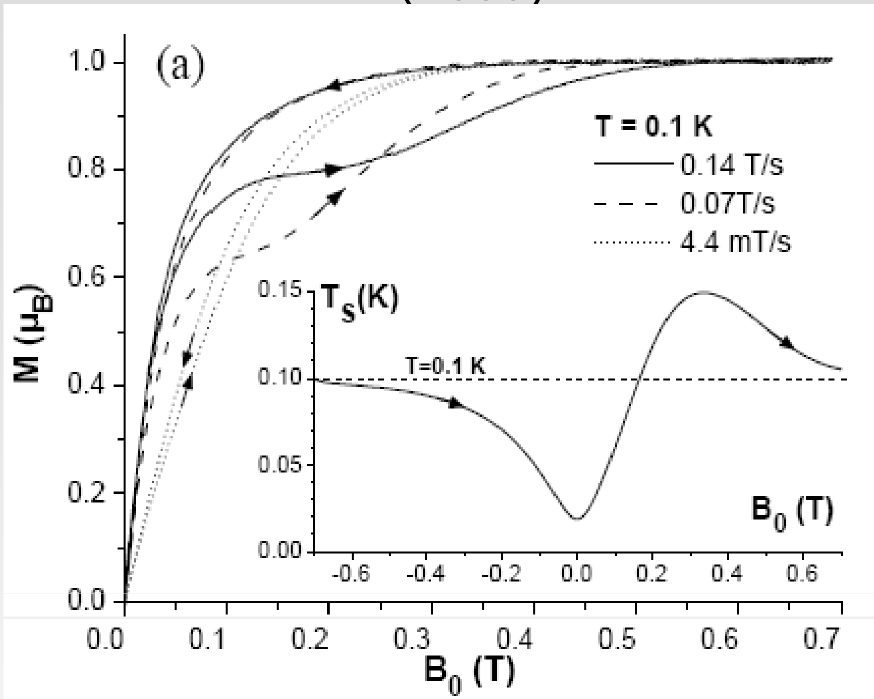
# Explanation

I. Chiorescu *et al* PRL 84, 3454 – 3457 (2000)




Magnetic signal from paramagnetic spin moments

Hysteresis appears in the **phonon-bottleneck** regime (low temperature, fast field sweep rate)

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# Explanation

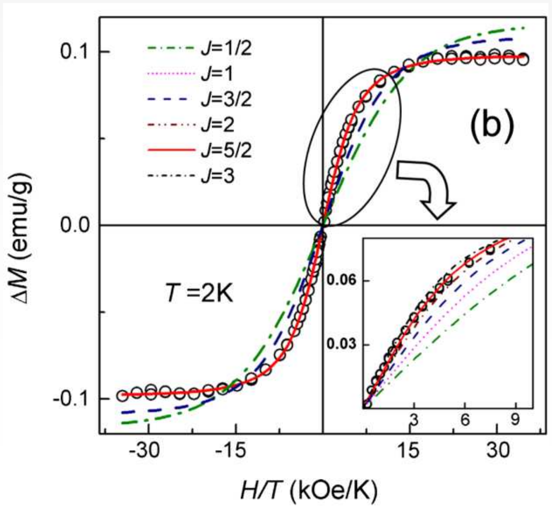
Presence of (para)magnetic impurities

Their magnetization reversal is sensed by the conduction charges

Hysteresis is suppressed for $T > 1K$ and $H_t > 0.5T$

**S > 1/2**

Agreement with
Sepioni et al. PRL 105 207205 2010



# Origin of magnetic impurities

Vacancies / (Passivated) intrinsic defects

Metal adatoms / adsorbates *unwanted*

~~H - adatoms~~ No dependence on annealing

~~Edges~~ No dependence on the size or etching

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# Conclusions

Observation of hysteresis loops of the (in plane) magnetoconductivity in graphene devices at low temperatures and fast field sweep rate

True for different sizes and transport regimes

Magnetization reversal of spin moments in graphene (probably defects) with $S > 1/2$

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# Thanks to

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