M. Cranney, F. Vonau, D. Aubel, E. Denys, L. Simon

Institut de Sciences des Matériaux de Mulhouse, France

C. Bena

LPS, Orsay and IPT, CEA-Saclay, France

P.B. Pillai, M.M. De Souza

Dpt of Electronic and Electrical Engineering, Sheffield, UK

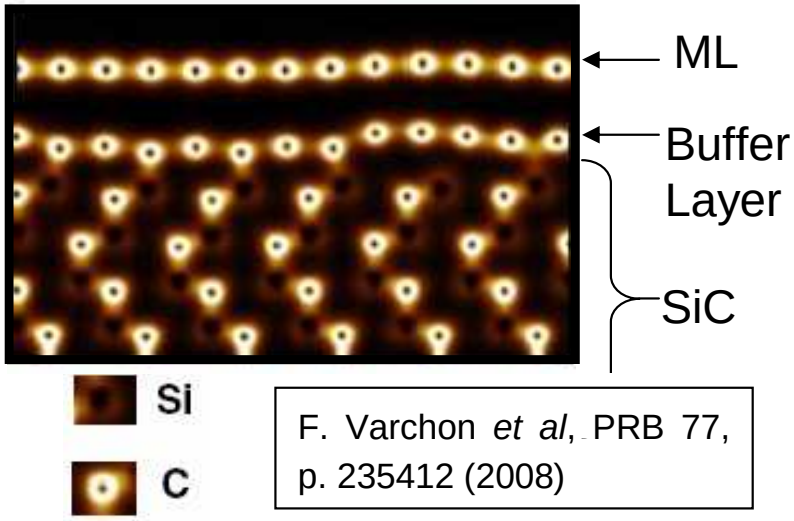
Resonators created by intercalated gold nanoclusters under monolayer graphene on SiC

Epitaxial Graphene on SiC(0001)

- SiC(0001), n doped, annealing above 1500 K

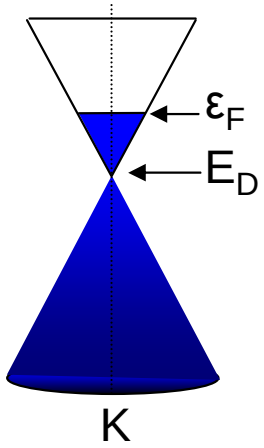
⇒ formation of a Buffer Layer (BuL)

⇒ mostly monolayer graphene (ML)



F. Varchon *et al*, PRB 77, p. 235412 (2008)

(1 x 1 µm², -0.3 V)



- EG intrinsically n-doped : charge transfer from SiC(0001) to graphene

$E_D - \varepsilon_F \approx -0.45$ eV

- A. Bostwick *et al*, Nat Phys 3, p. 36 (2007)
- L. Vitali *et al*, Surf Sci 602, p. L127 (2008)
- F. Varchon *et al*, PRL 99, p. 126805 (2007)

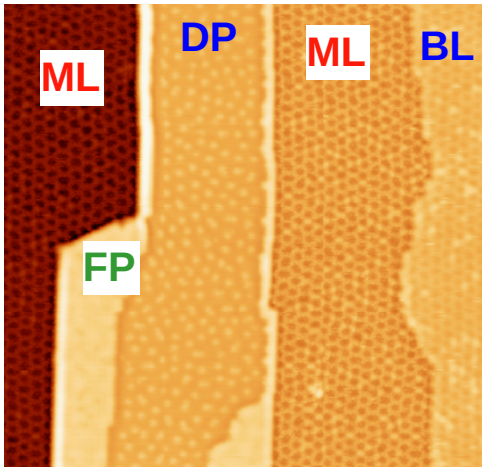
Motivation: p-doping of epitaxial graphene by depositing Au

- T. Ohta *et al*, Science 313, p. 951 (2006)
- I. Gierz *et al*, Nanolett 8, p. 4603 (2008)

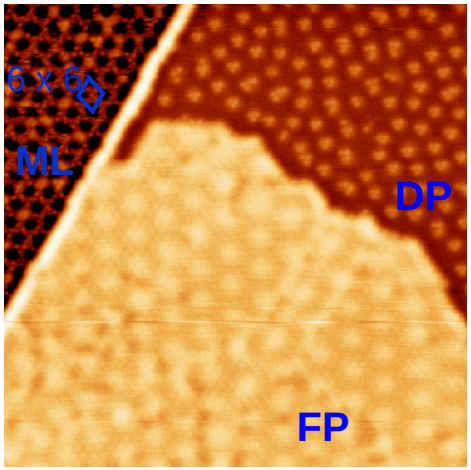
IS2M

Deposition of Au on Epitaxial Graphene

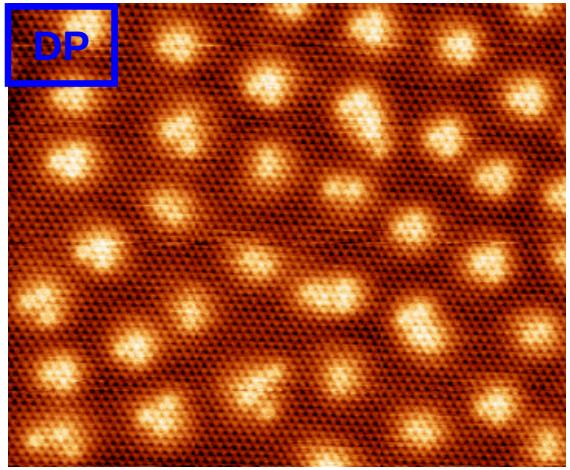
- Deposition of several ML Au at RT, followed by short annealing cycles at 1000K
- Omicron LT-STM working at 77K (10^{-11} mbar range)



(67 x 65 nm², -1.5 V)

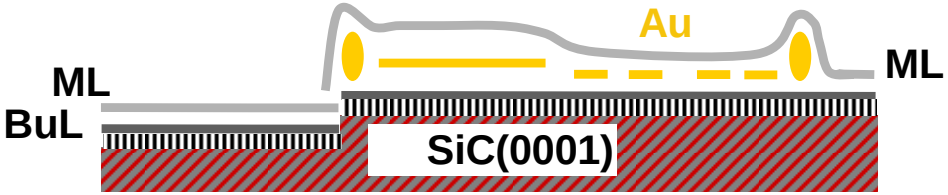


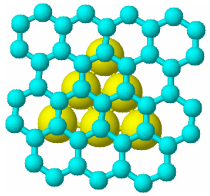
(40 x 40 nm², -1.0 V)

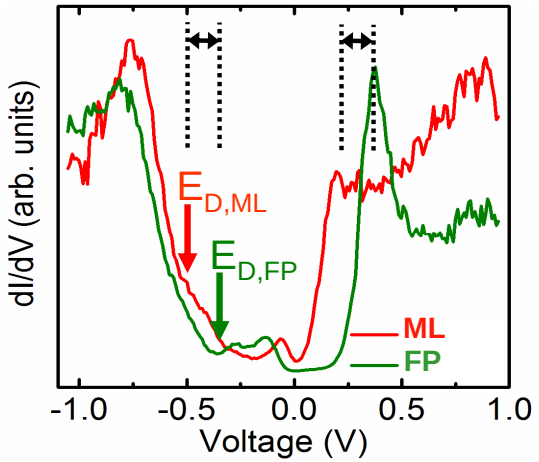


(14 x 12 nm², -1.6 V)

- **Intercalated** Gold structures between Buffer Layer and Monolayer Graphene :
  - Film Phase (FP): intercalated **monolayer of Au**, free-standing ⇒ **p doping**
  - Diluted Phase (DP): intercalated **Au_6 clusters**, with an irregular distribution (2.2 ±0.1 nm between clusters), free-standing ⇒ **no p doping**







IS2M

B. Premlal *et al*, APL 94, p. 263115 (2009)

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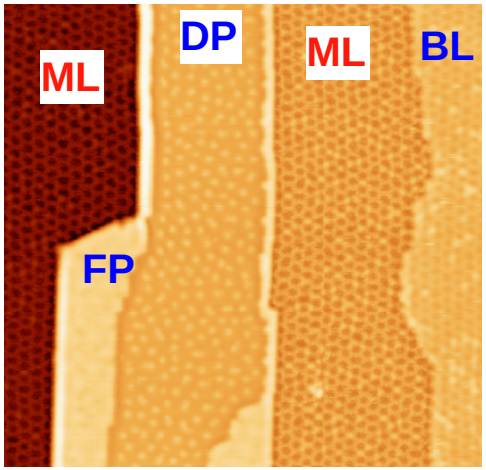

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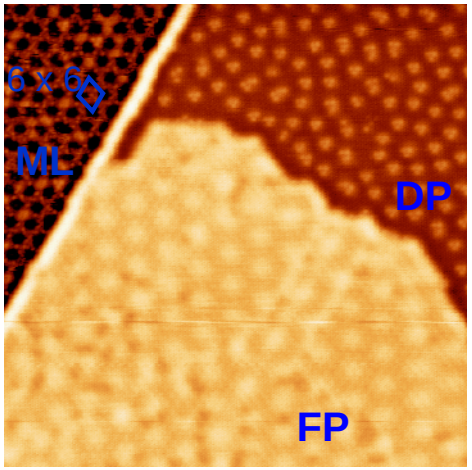

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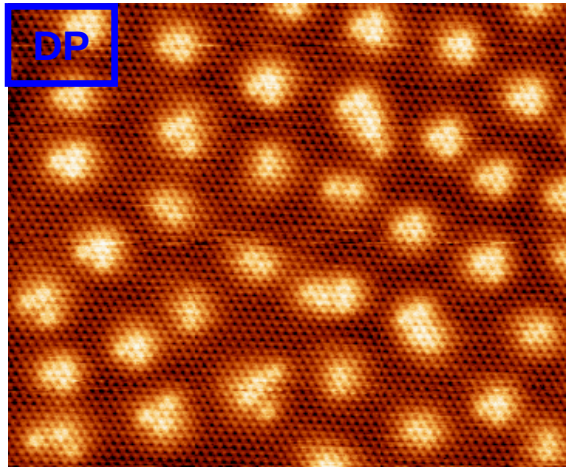

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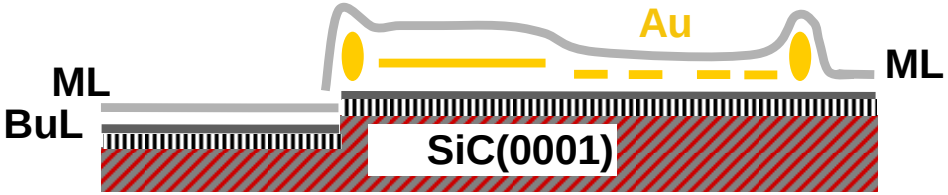
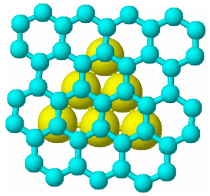
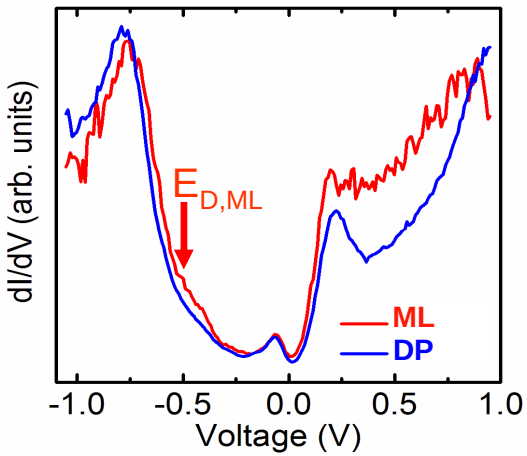






IS2M

B. Premlal *et al*, APL 94, p. 263115 (2009)

Diluted Phase

topography

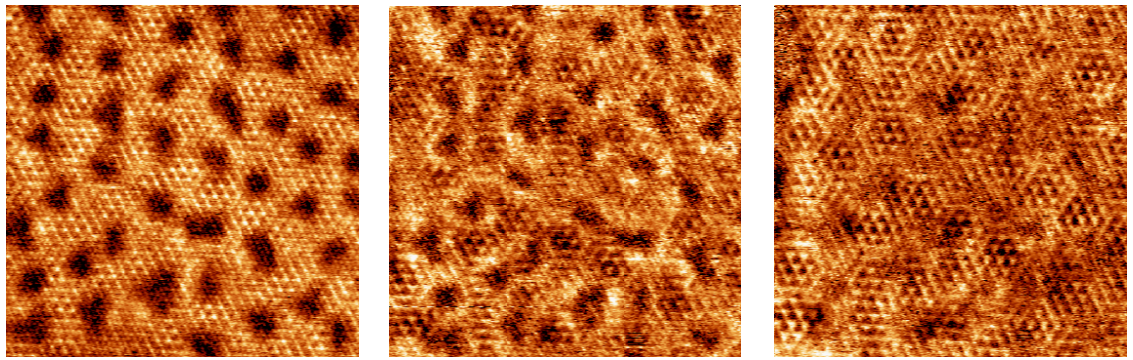
+0.8 V

+0.9 V

+1.0 V

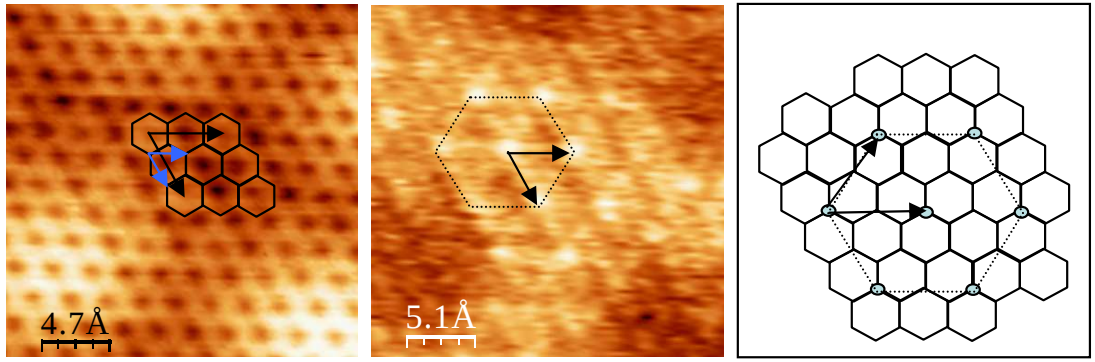
(13x13nm²)

dI/dV map



- Standing wave patterns at positive energies

- (2x2) bright protrusions



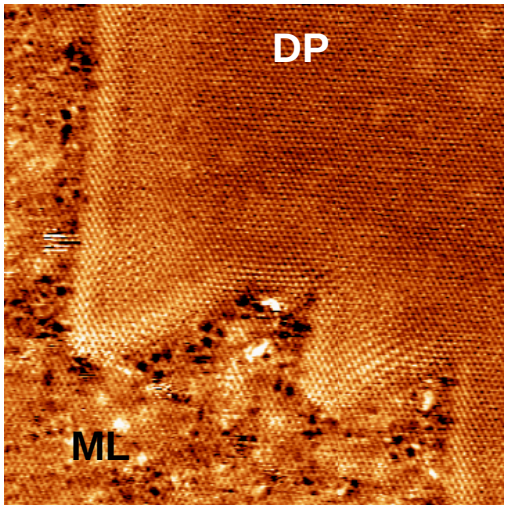
topography
(2.5 x 3.2 nm², +0.8 V)

dI/dV map

Au clusters act as scatterers, perturbing the quasiparticles on the top graphene layer

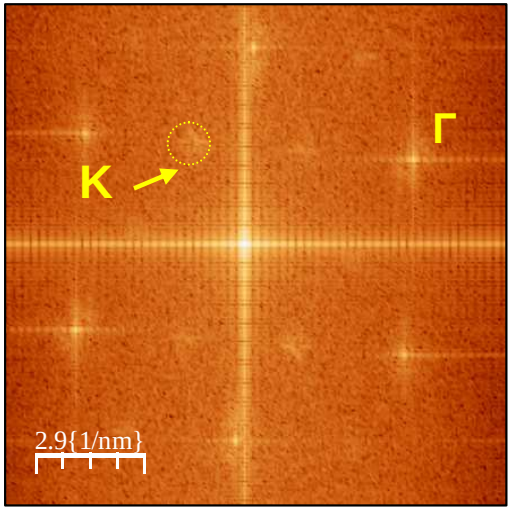
From STS to CEC

No wave pattern
in DP at -0.7 V



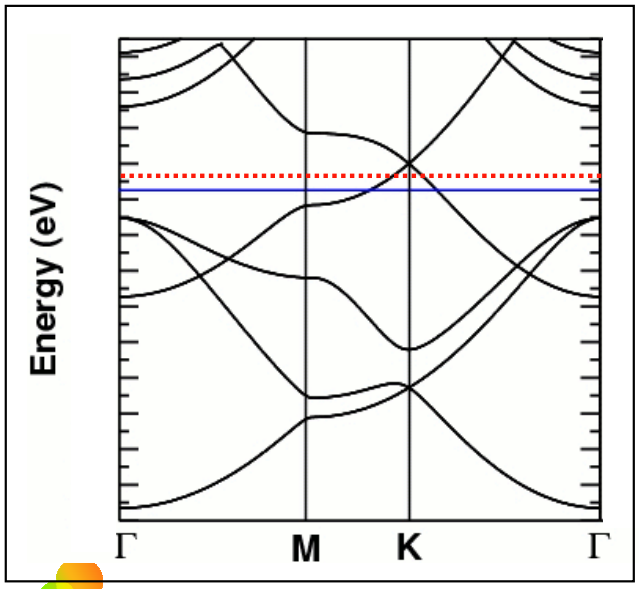
(**dI/dV map**, 19 x 19 nm², -0.7 V)

Fourier Transform

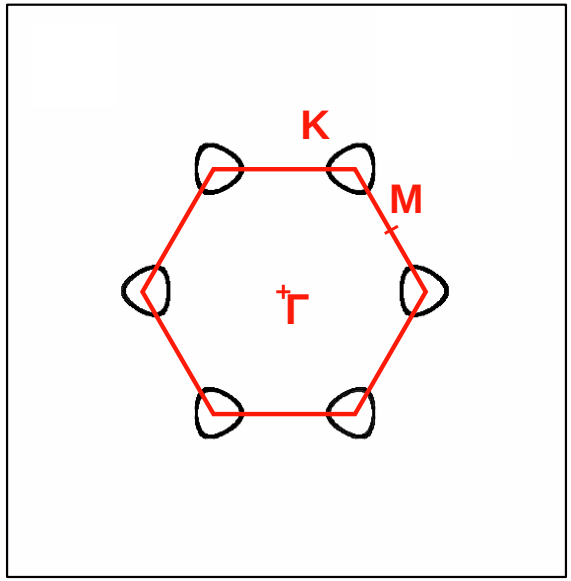


FT-conductance image

TB Band structure of graphene



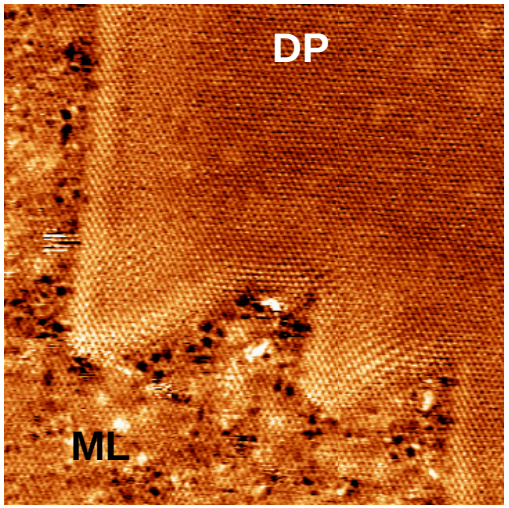
Constant Energy Contour



IS2M

From STS to CEC

No wave pattern
in DP at -0.7 V



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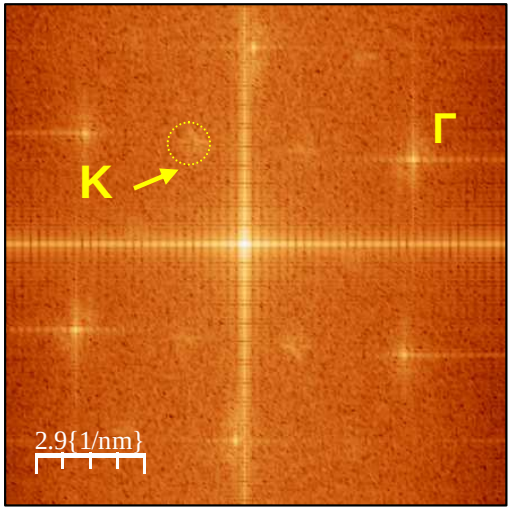
Fourier Transform

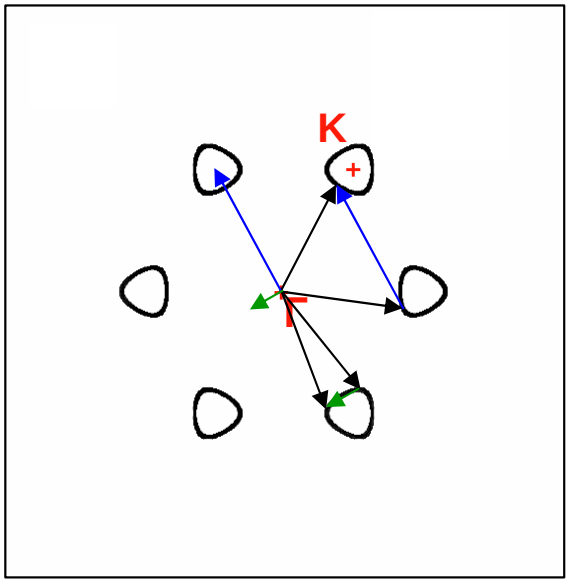


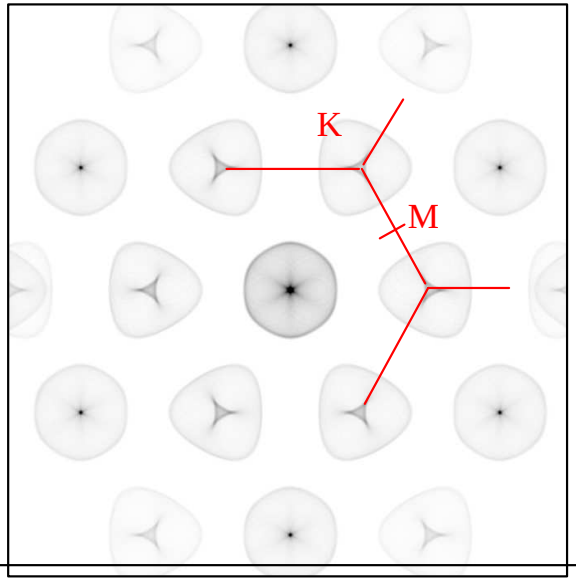
FT-conductance image

Joint Density of states

JDOS calculation
with CECs :

all scattering
wave vectors
q = k – k′ + G

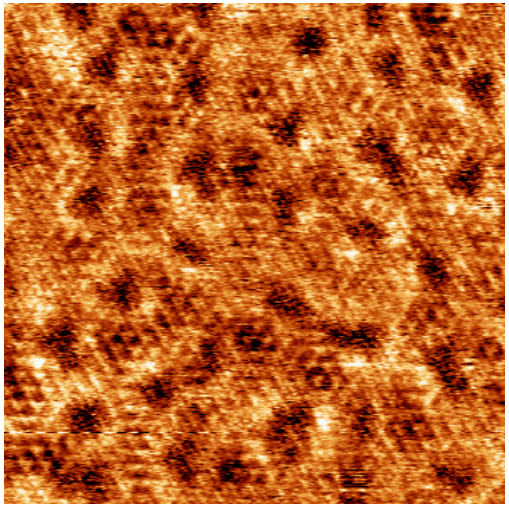




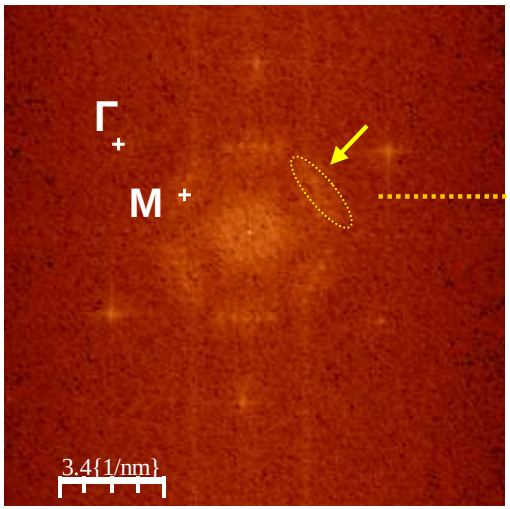
intervalley scattering
intravalley scattering

•F. Vonau *et al*, PRL 95, p. 176803 (2005)
•K. Mc Elroy et al PRL 96, p. 067005 (2006)
•L.Simon *et al*, J Cond Mat 19, p. 351009 (2007)
•L.Simon et al, EPJB 69, p. 351 (2009)

Standing waves on Diluted Phase

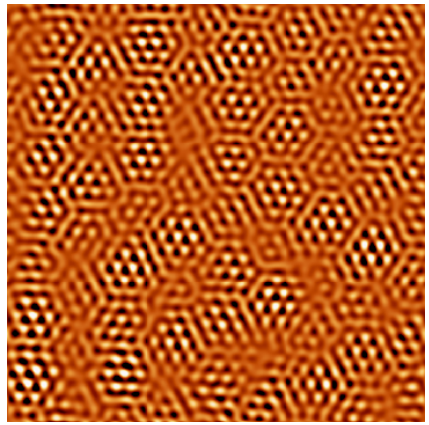


(dI/dV map, 13 x 13 nm², +0.9 V)



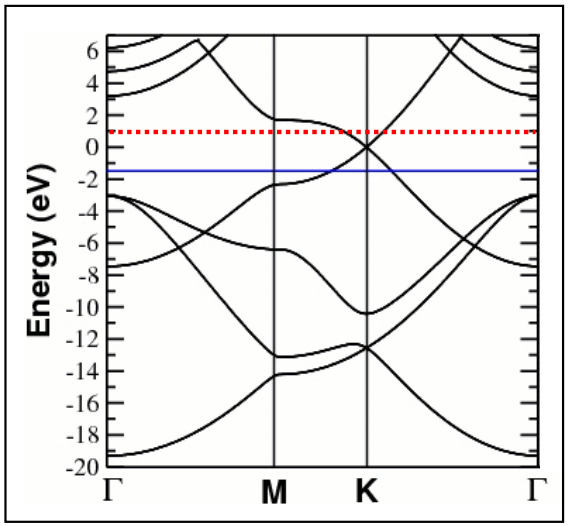
FT-conductance image

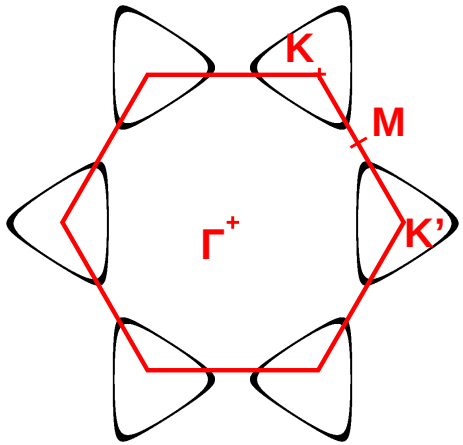
filtering



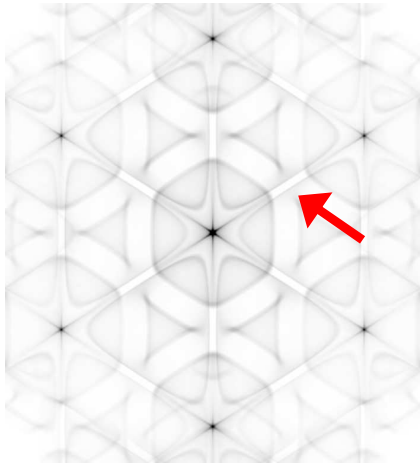
Standing wave pattern related to elliptical features observed in M

CEC with trigonal warping at high energies





CEC

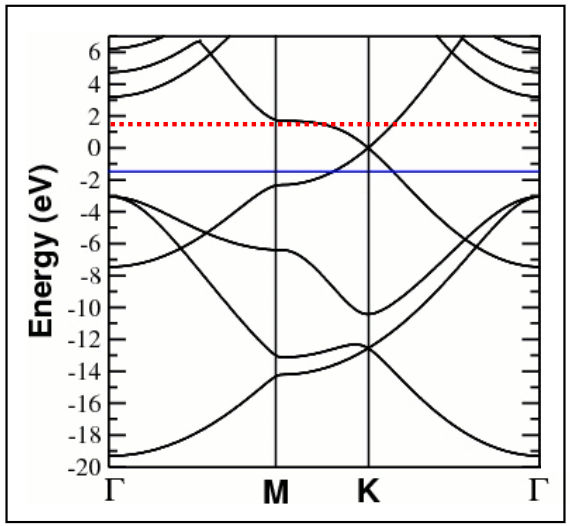


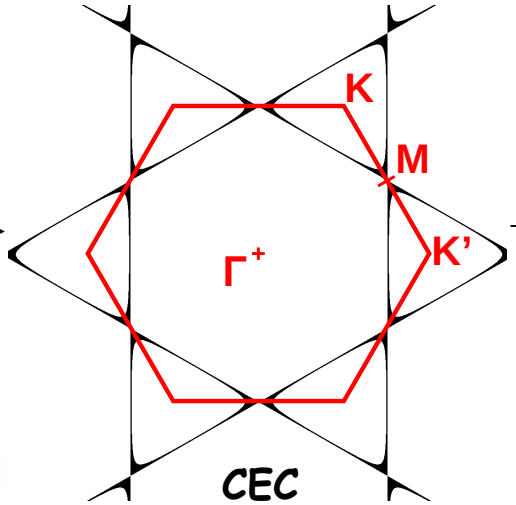
JDOS

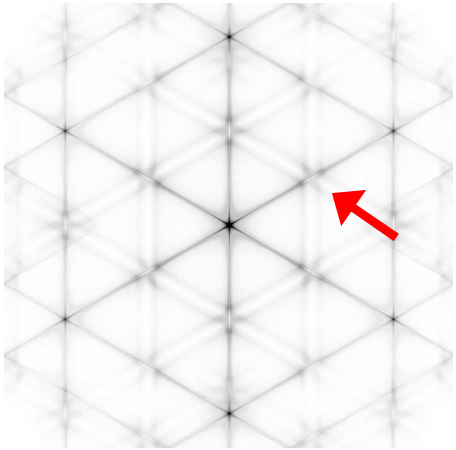
No feature in M in the JDOS

IS2M

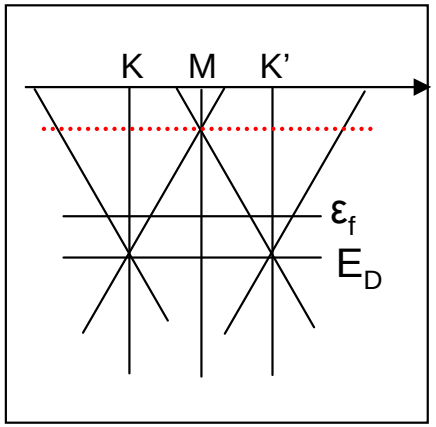
Standing waves on Diluted Phase





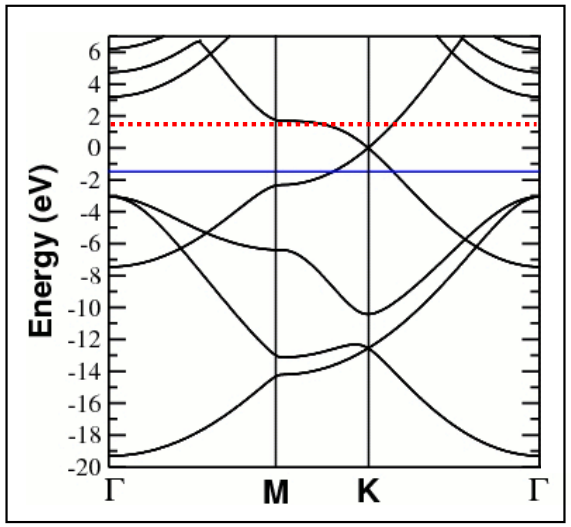


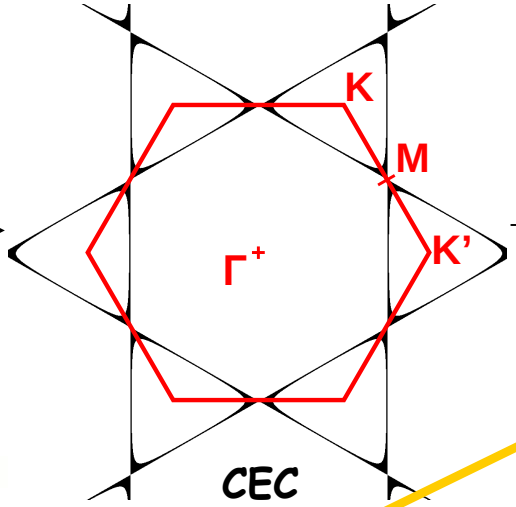
CECs must be in contact to see elliptical features in M
⇒ band-crossover begins at +0.7 eV

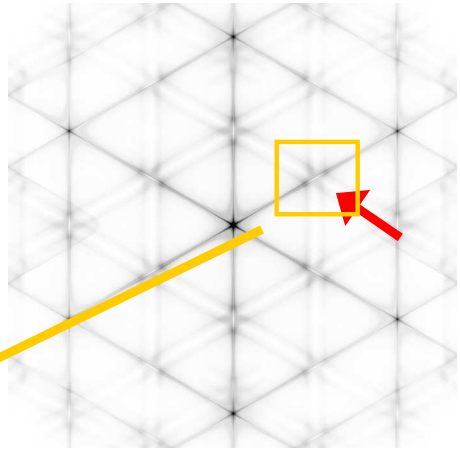


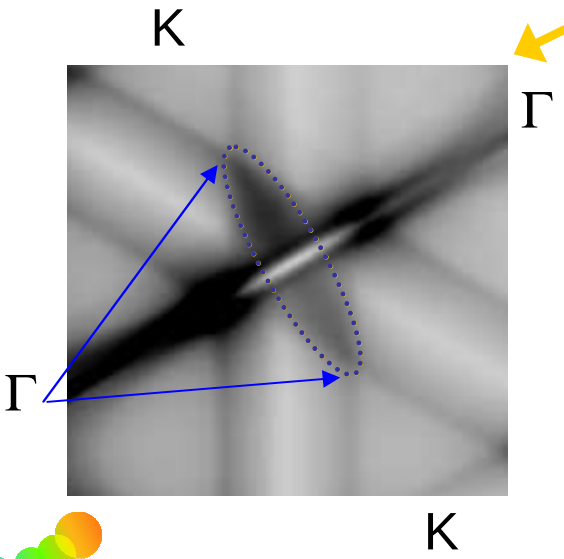
IS2M

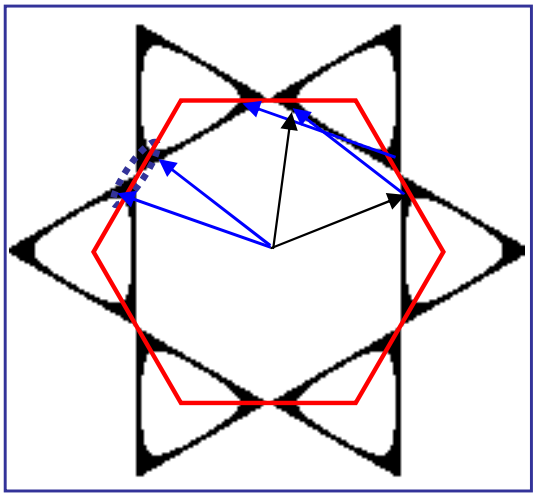
Standing waves on Diluted Phase







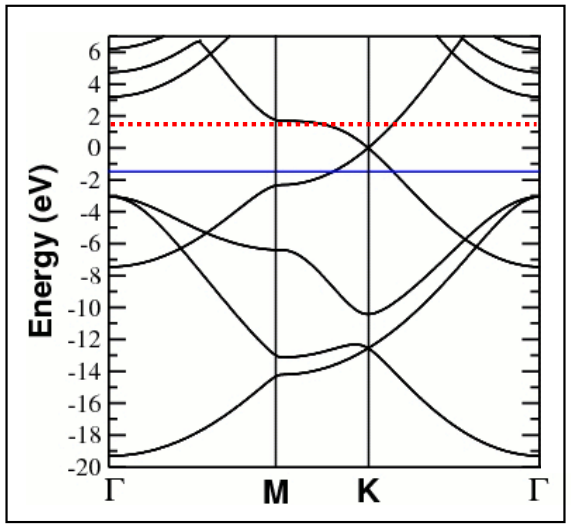


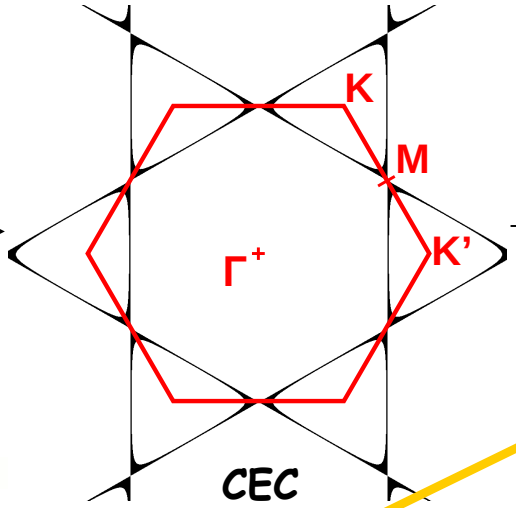


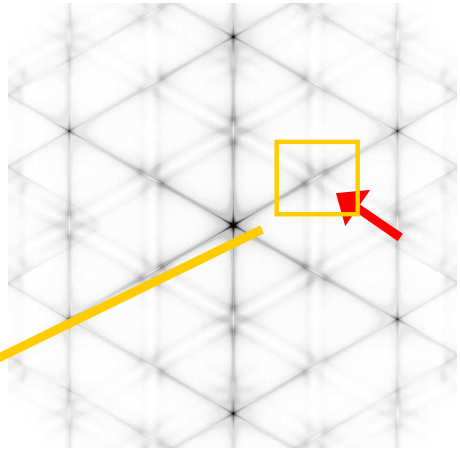
intervalley scattering

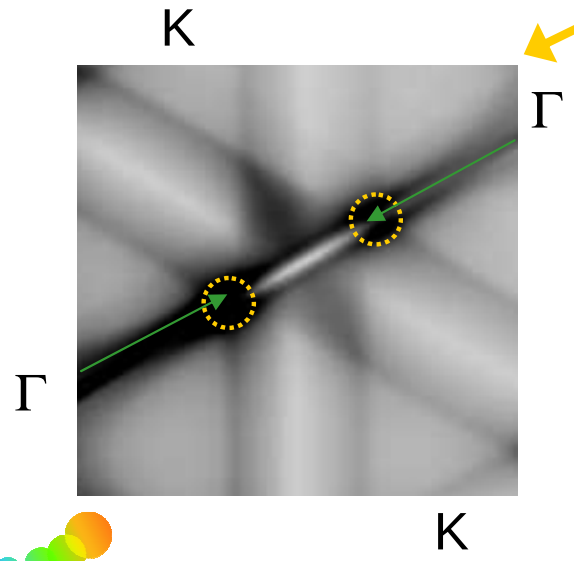
IS2M

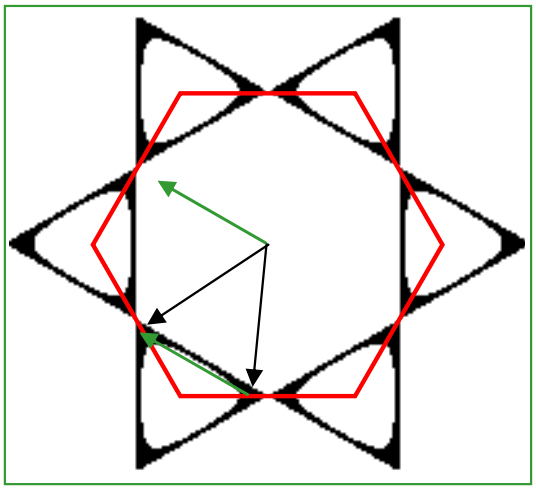
Standing waves on Diluted Phase







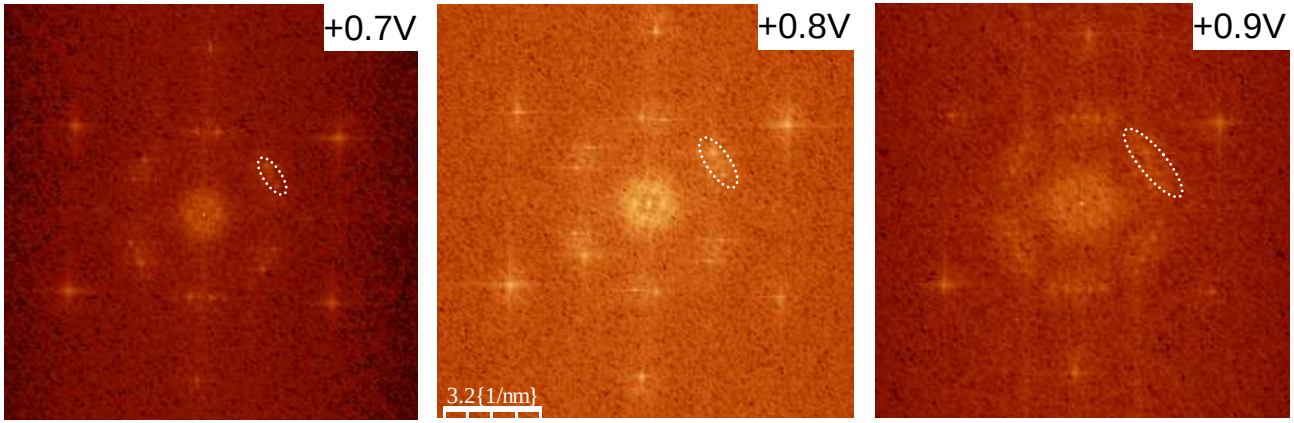




- elliptical features observed in M are due to intervalley scattering at the band-crossover
- Why no structure related to intravalley scattering?

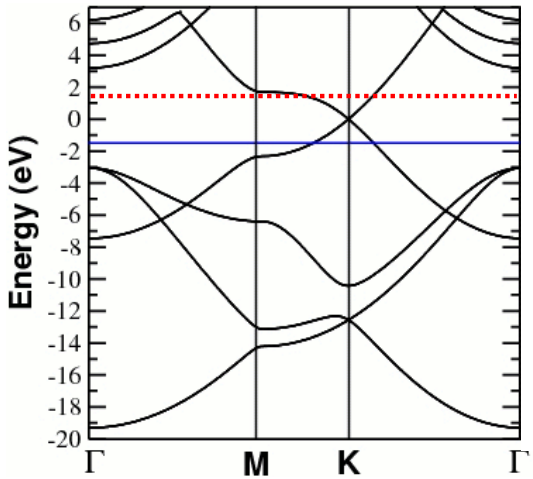
IS2M

Standing waves on Diluted Phase



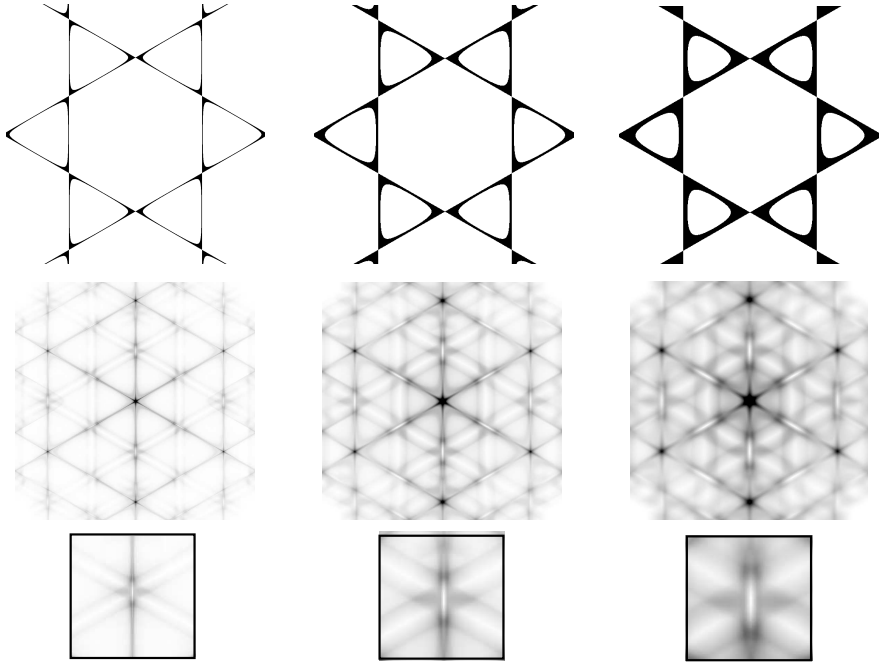
Size of the ellipse is increasing with V

Van Hove Singularities at high energies



→ Increase of the density of states at E ←

By using JDOS calculations



- Standing wave pattern due to the extension of Van Hove Singularities
- From +0.7 eV to +1.0 eV, band structure no more dispersive

M. Cranney *et al*, accepted in EPL

Summary about Au/Epitaxial Graphene

- Au atoms intercalate between Buffer Layer and Monolayer Graphene

- Diluted phase ⇒ flat Au_6 clusters, with no p-type doping of ML graphene

- Standing wave patterns are observed on the Diluted Phase for unoccupied states ⇒ Au clusters are acting as scatterers, perturbing the QP on the graphene

- Standing waves due to intervalley scattering at the band-crossover

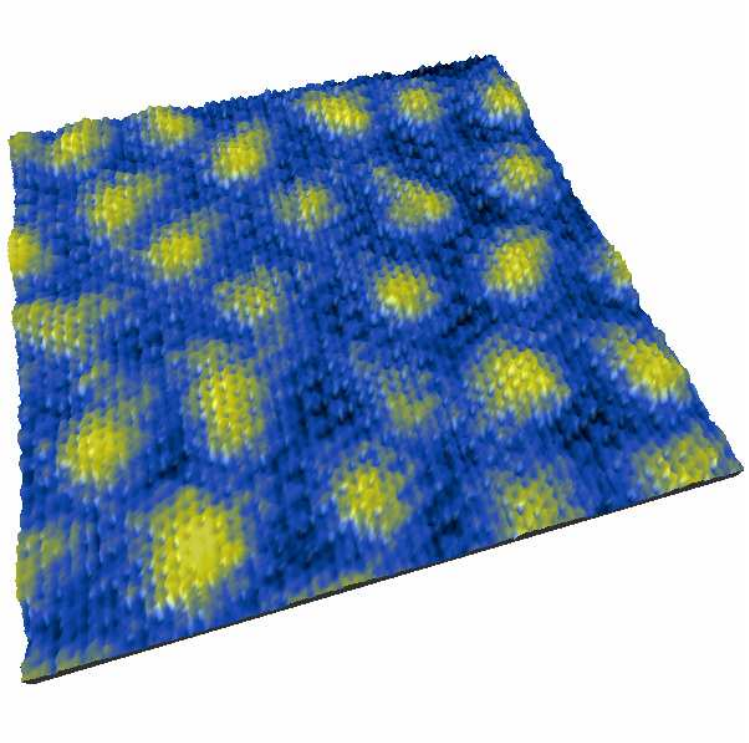
- Possible effects of Au clusters on the band structure of graphene :
  - Dispersion is lost from +0.7 eV to +1.0 eV
  - Extension of the Van Hove Singularities

- There are still questions:
  - Why no intravalley scattering? **Absence not related to the pseudospin**
  - Why is the band structure modified like this by Au clusters?

- B. Premlal *et al*, APL 94, p. 263115 (2009)
- M. Cranney *et al*, accepted in EPL

IS2M

Thank you !



Thanks to my co-workers:

F. Vonau
D. Aubel
L. Simon

IS2M - Mulhouse, France

C. Bena

LPS – Orsay, France

P.B. Pillai
M.M. De Souza

DEEE - Sheffield, UK

Financial support:

FoNE
Fundamentals of NanoElectronics

cnrs
dépasser les frontières

Région Alsace

IS2M