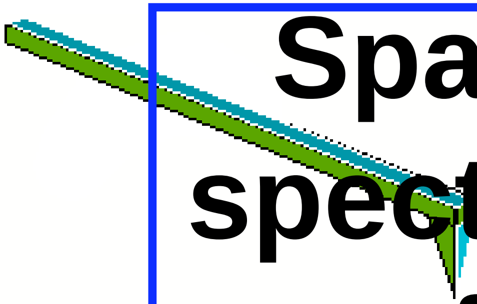
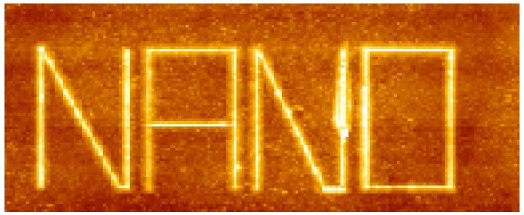


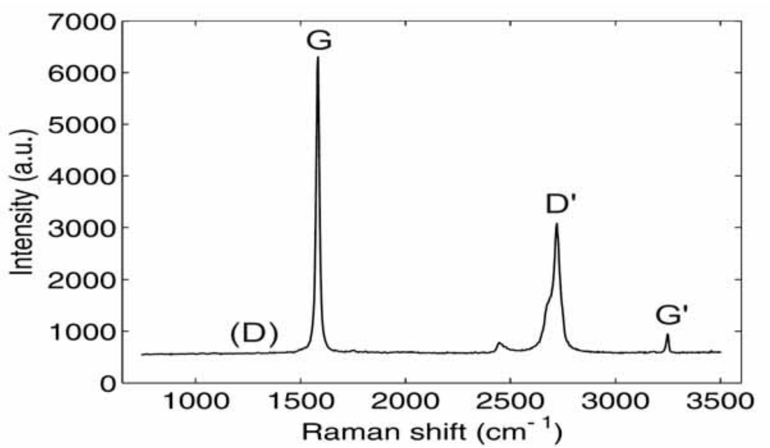
Spatially resolved Raman spectroscopy on single- and few-layer graphene

D. Graf, F. Molitor, and K. Ensslin



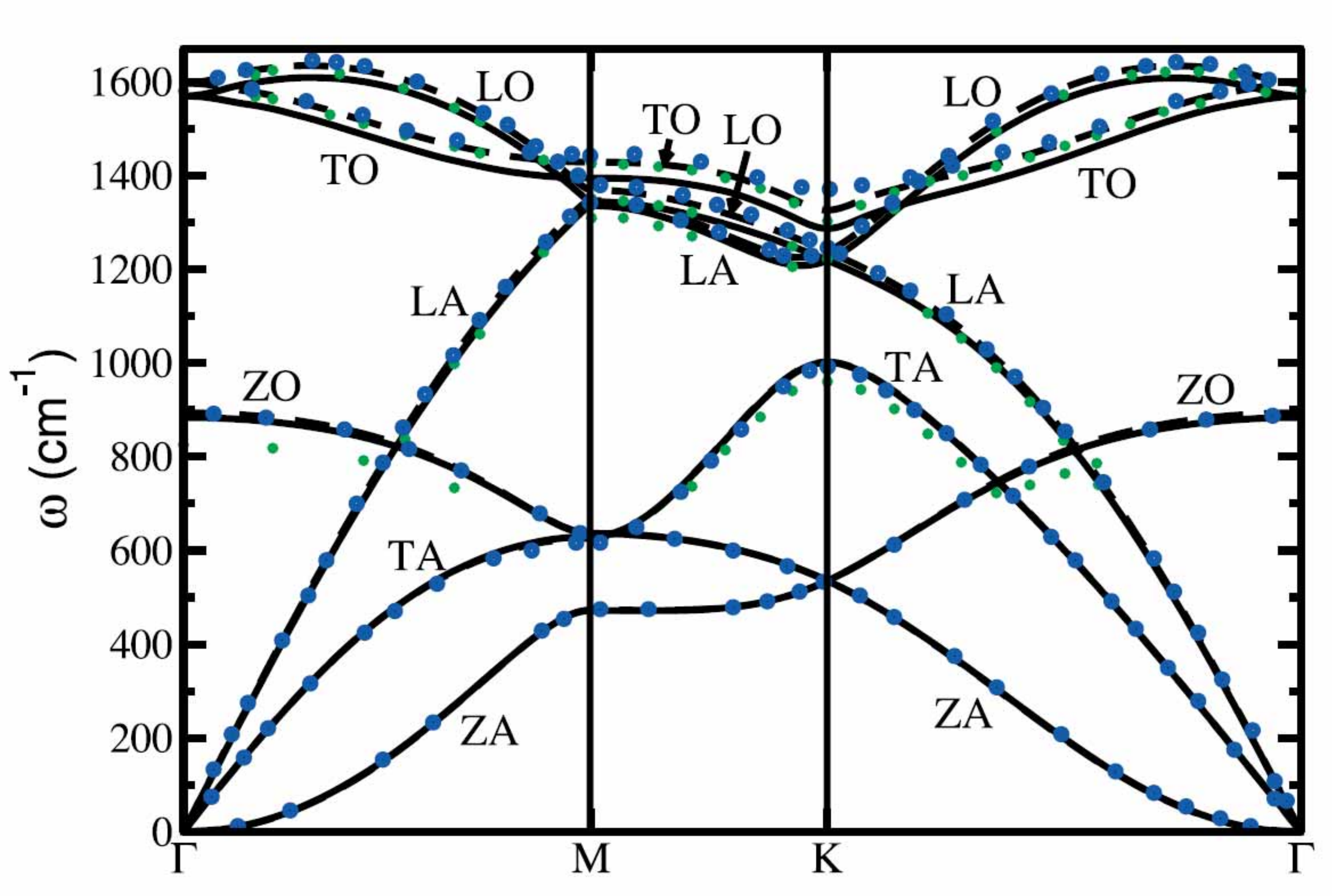
Solid State Physics ETH Zürich

C. Stampfer, A. Jungen, and C. Hierold, Micro and Nanosystems, ETH Zürich
L. Wirtz, Institute for Electronics, Microelectronics, and Nanotechnology, Lille



Raman on graphene
Spectral resolution
Spatial resolution

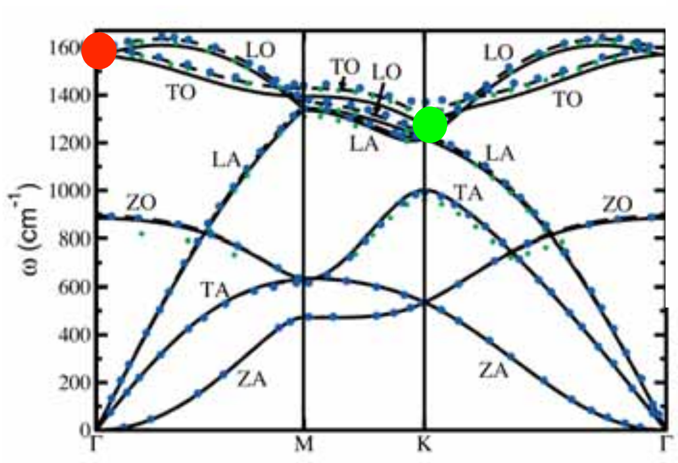
Phonon spectrum of graphite

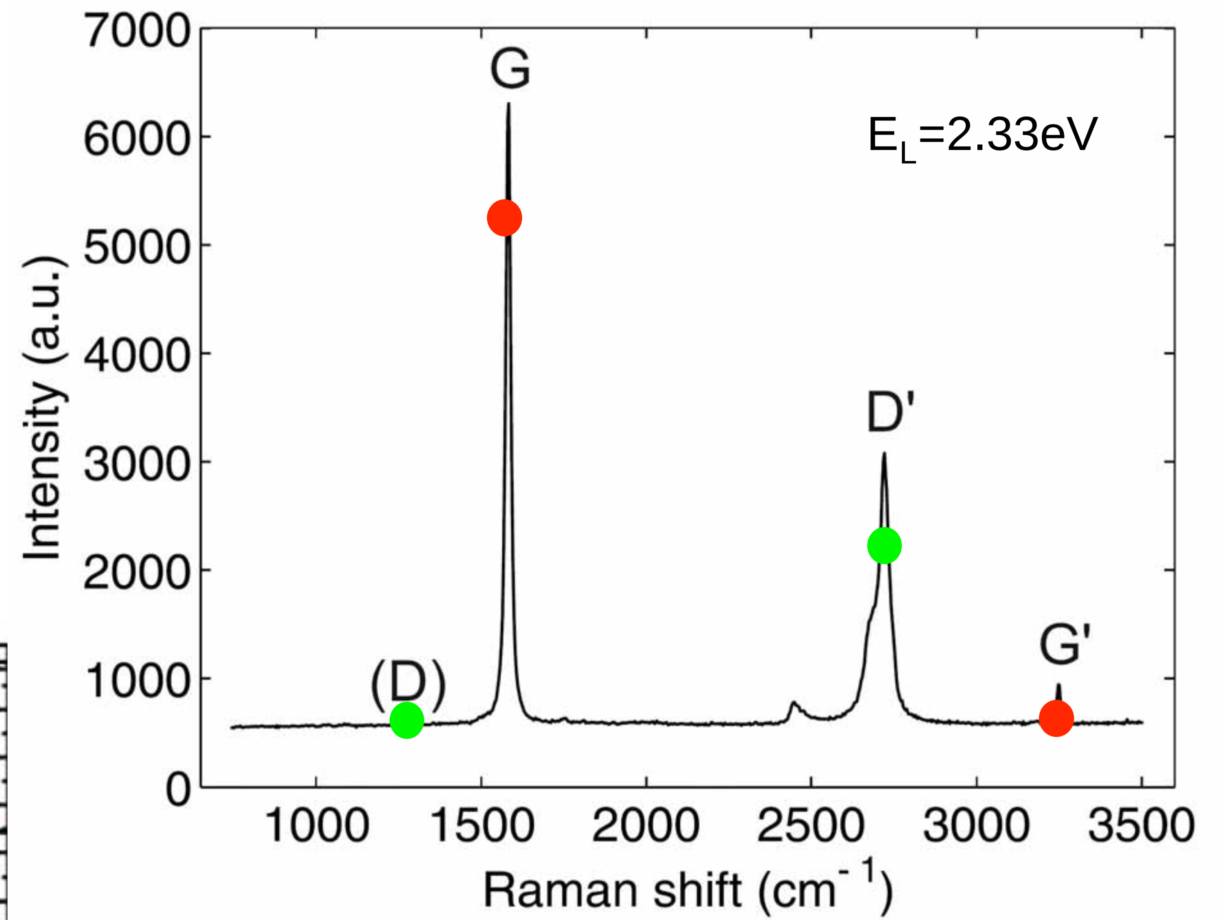


Ref.: Ludger Wirtz and Angel Rubio, Solid State Communications **131**, 141 (2004)

- does the phonon spectrum depend on the number of layers ?

Raman spectrum of graphite

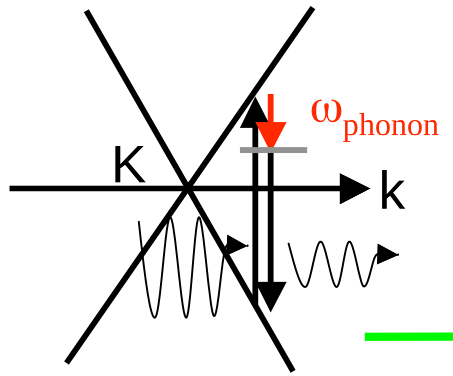




- does the phonon spectrum depend on the number of layers ?

Raman spectrum of graphite

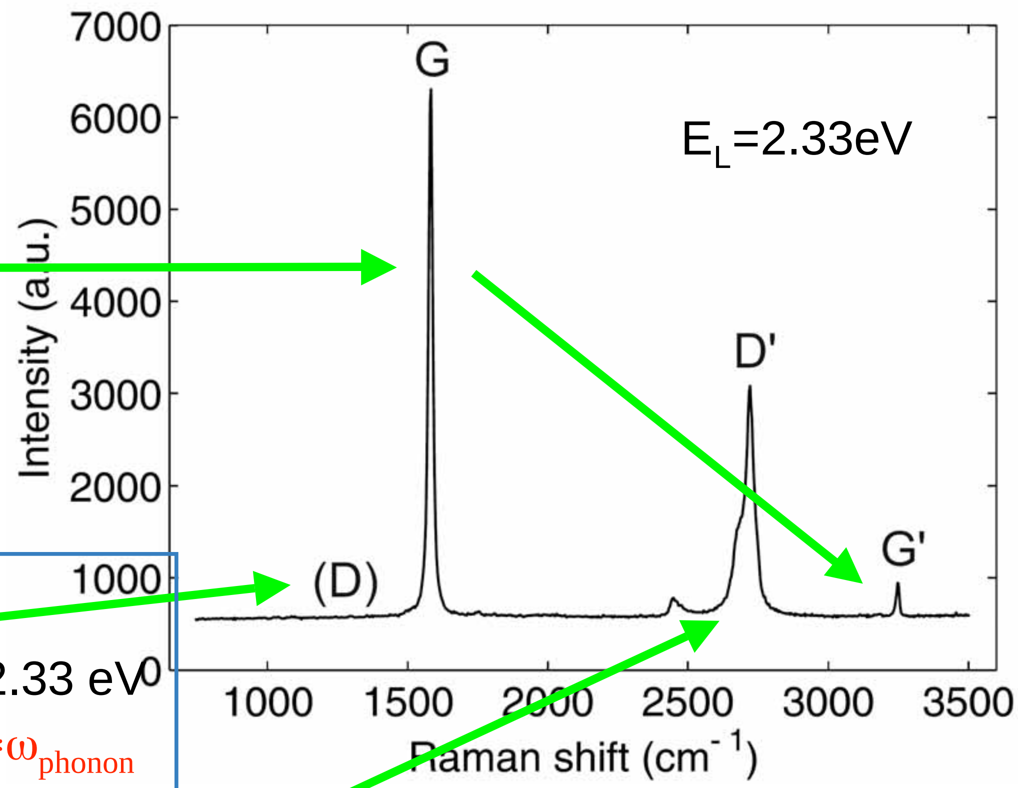
Single-resonant



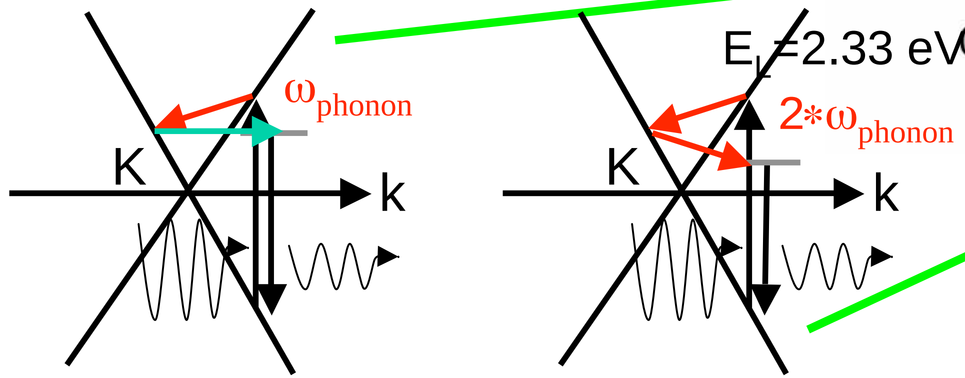
at Γ point, k~0

→ **G, overtone G'**

(1582 cm^{-1})



Double-resonant



close to K point, k>0

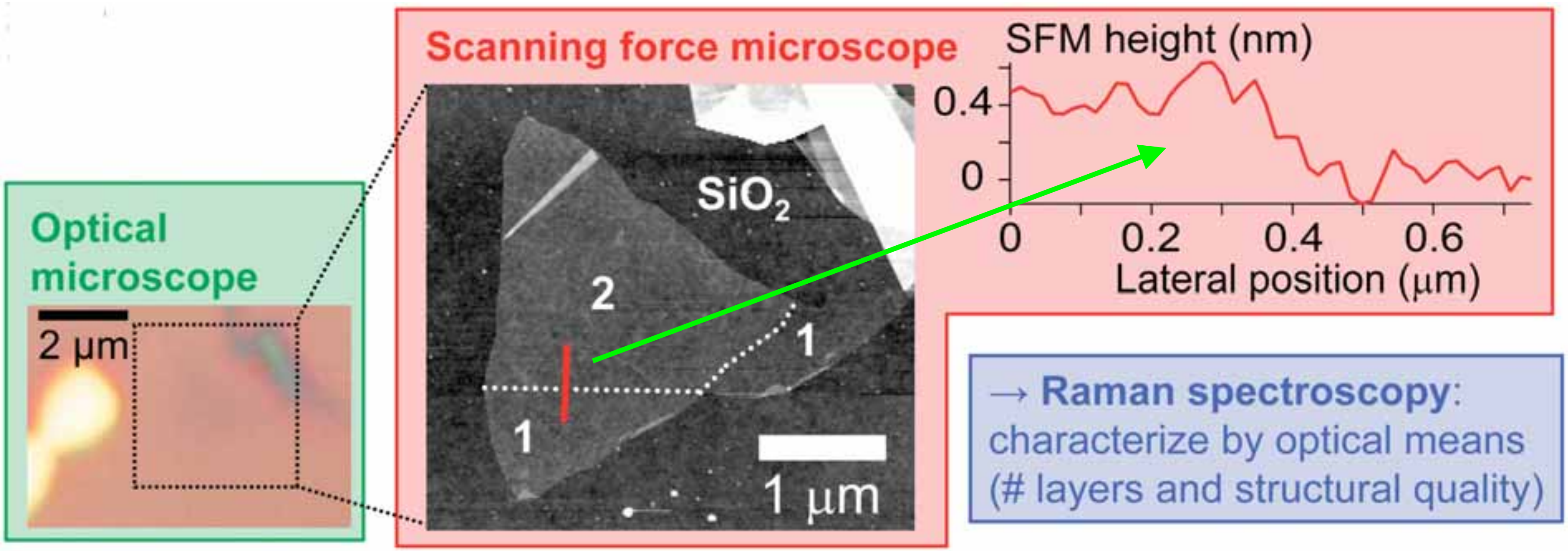
elastic scattering → **D**

(~1350 cm^{-1})

close to K point, k>0

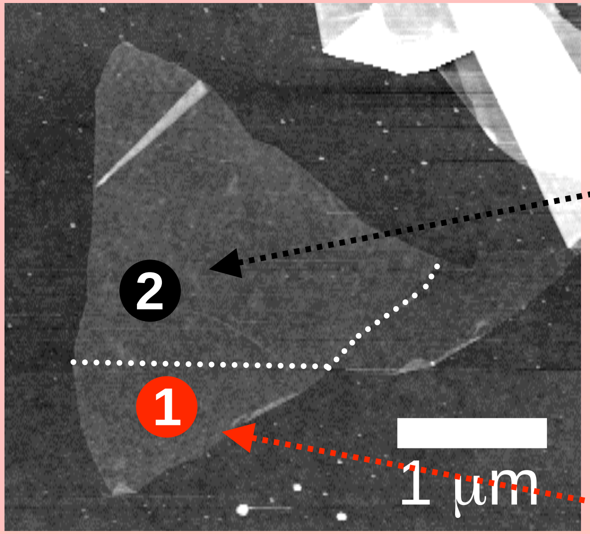
→ **D' (~2700 cm^{-1})**

Spatial resolution: AFM



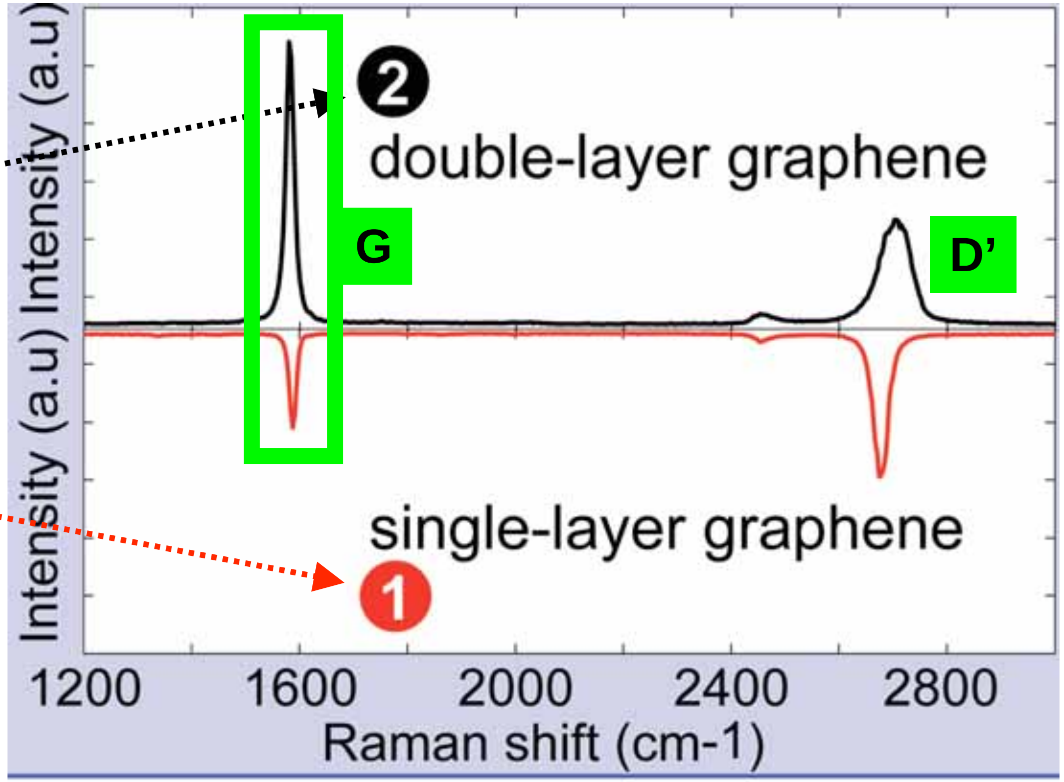
Raman spectra of single- and double layer graphene

Scanning force microscope



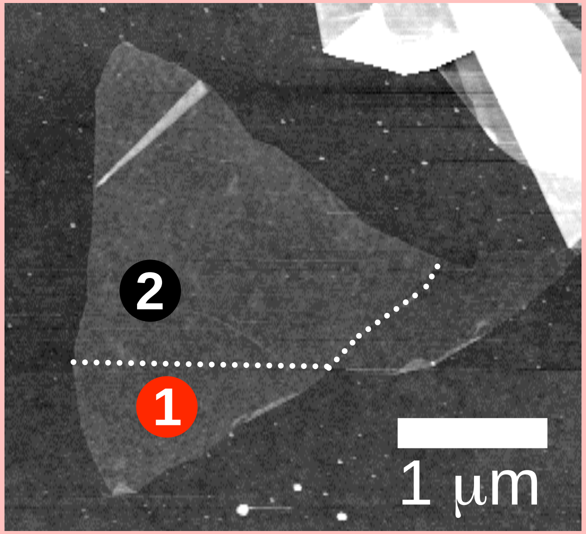
Scanning confocal Raman spectroscopy:

- Laser excitation of 532 nm/ 2.33 eV
- Spot size:



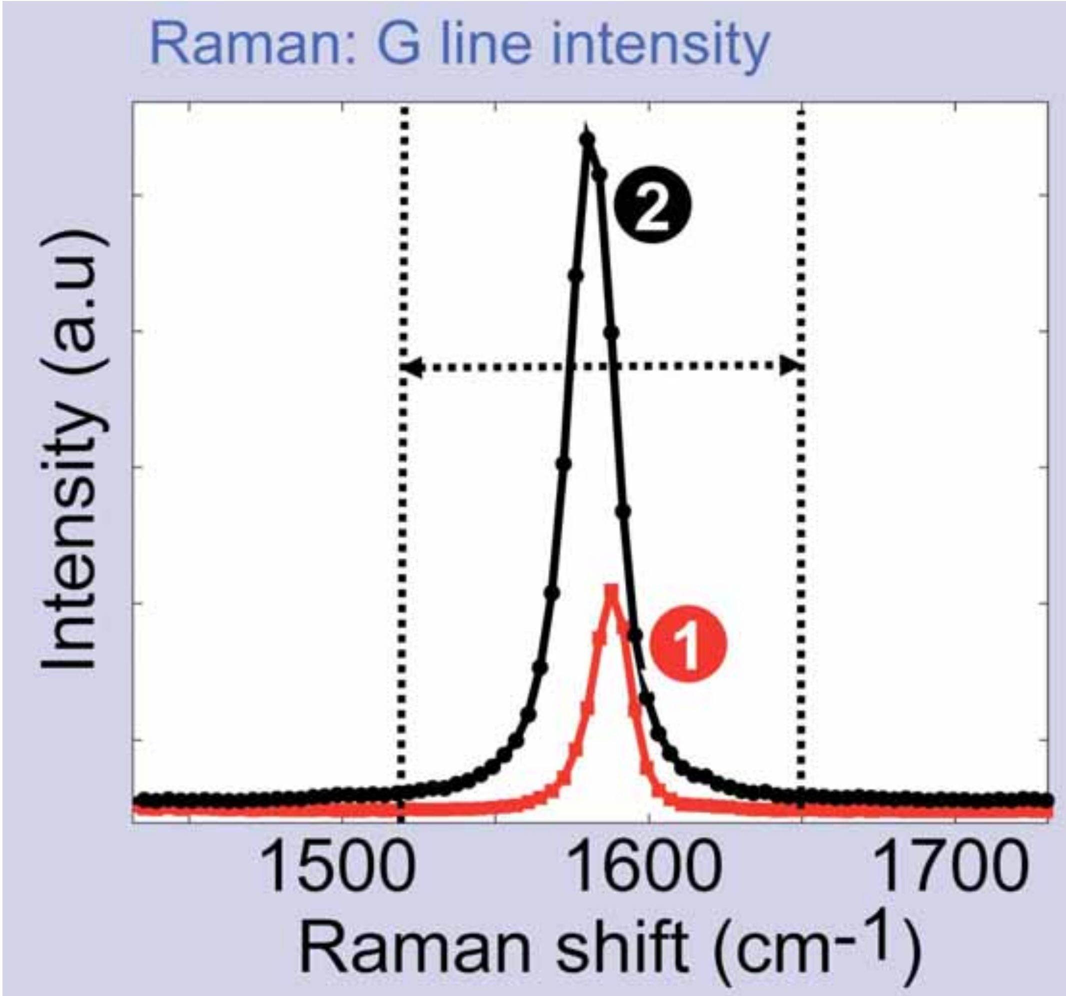
Raman mapping: intensity of G-line

Scanning force microscope



Scanning confocal Raman spectroscopy:

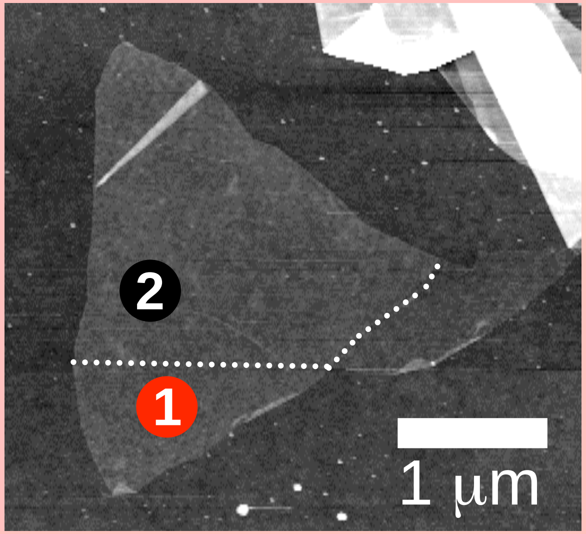
- Laser excitation of 532 nm/ 2.33 eV
- Spot size:



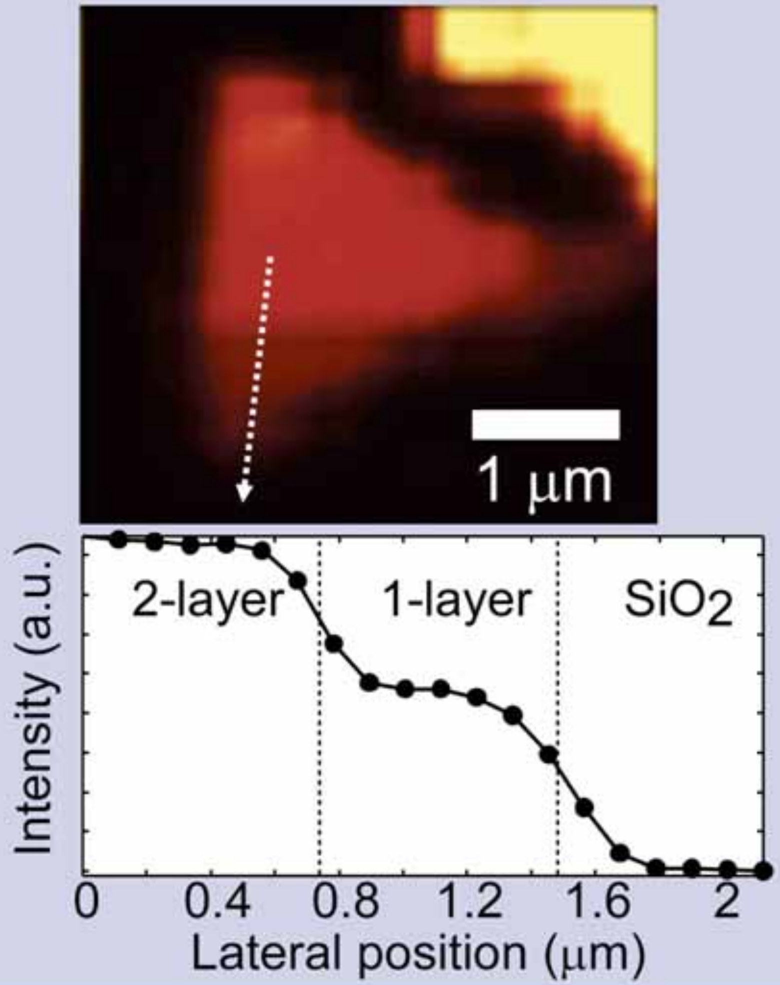
two layers have higher G-line intensity, slightly different peak position

Raman mapping: intensity of G-line

Scanning force microscope



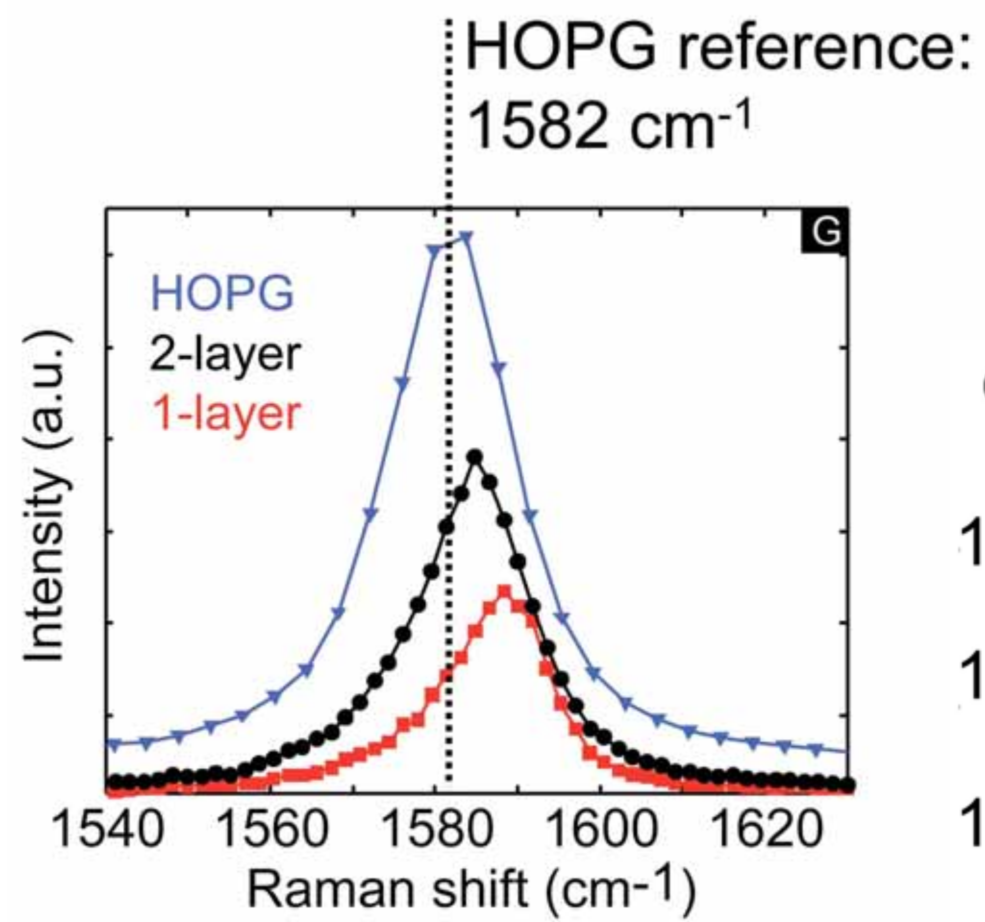
Raman: Integrated G line intensity

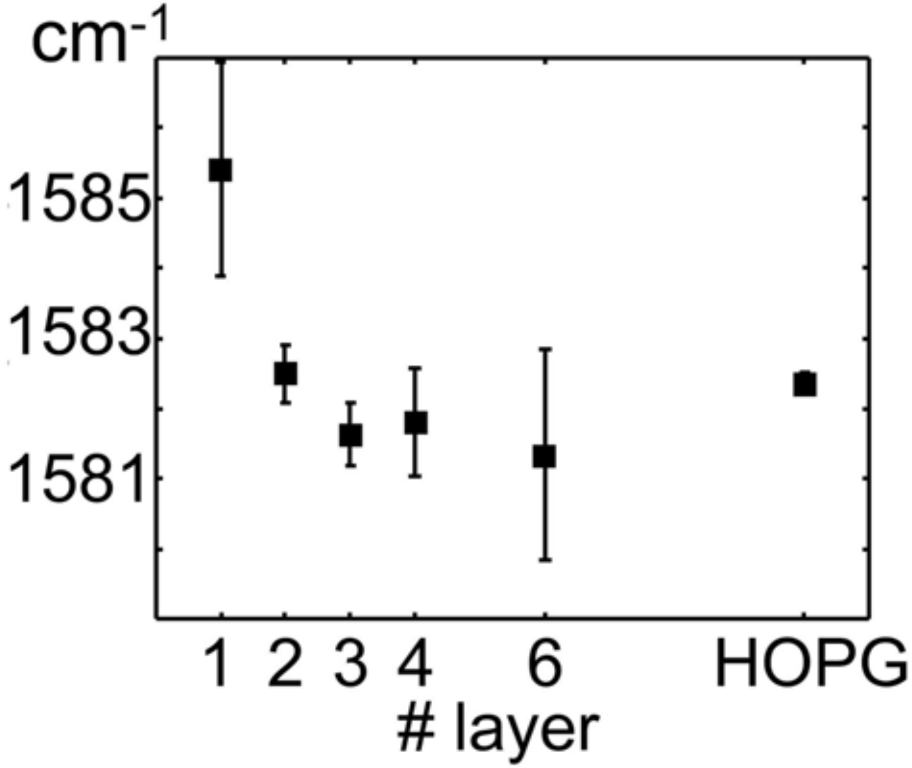


Scanning confocal Raman spectroscopy:

- Laser excitation of 532 nm/ 2.33 eV
- Spot size:

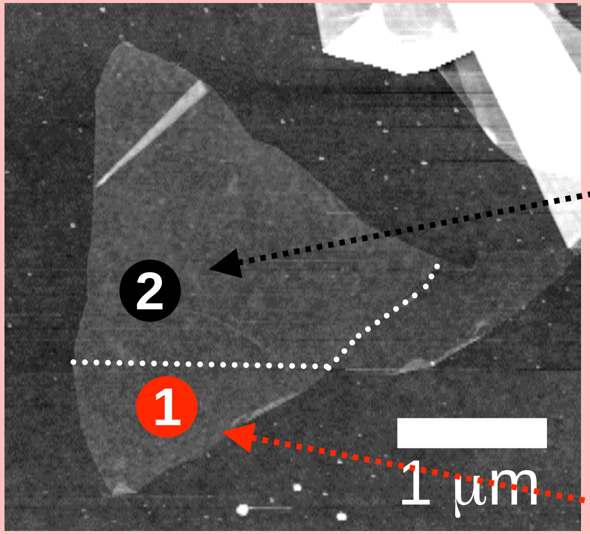
Raman mapping: position of G-line

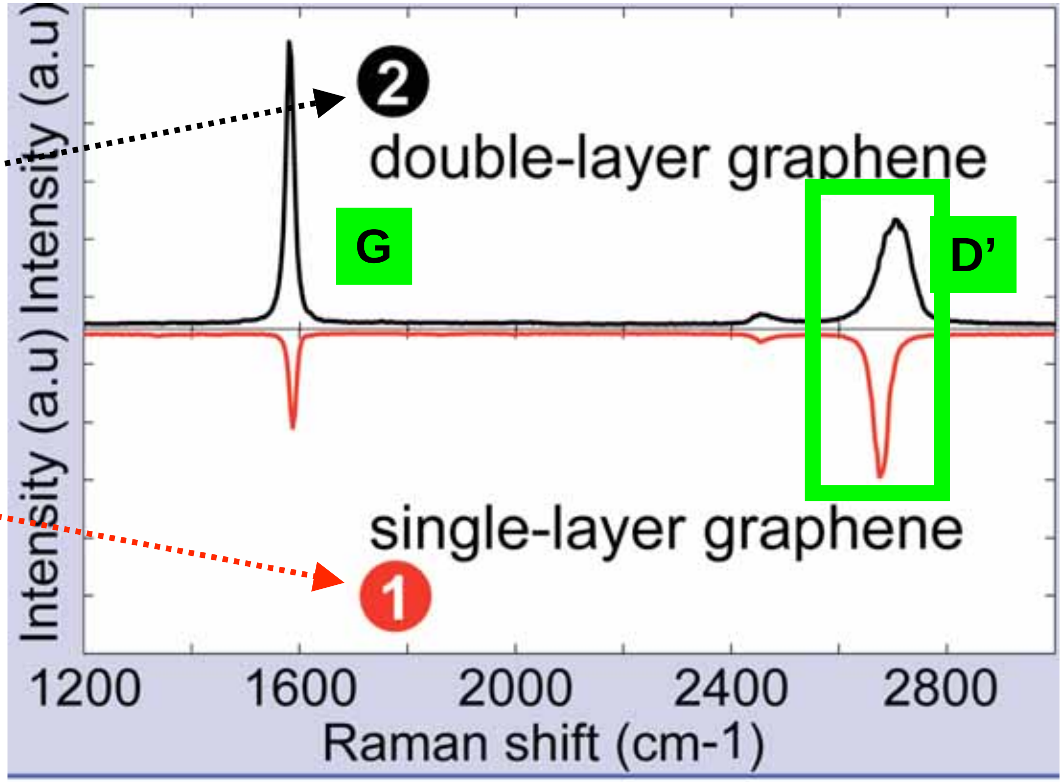




Raman spectra of single- and double layer graphene

Scanning force microscope



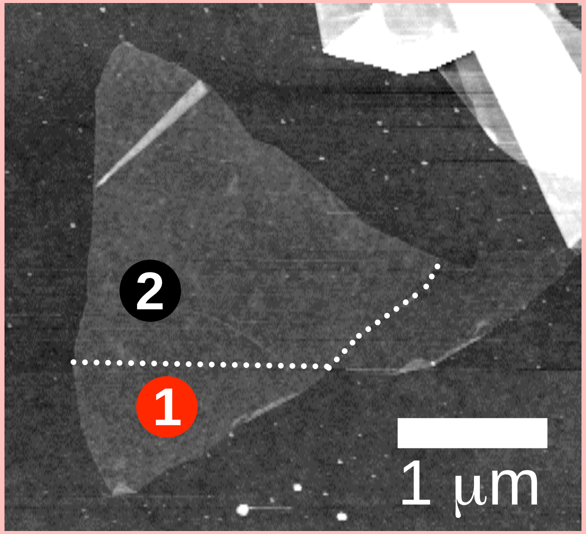


Scanning confocal Raman spectroscopy:

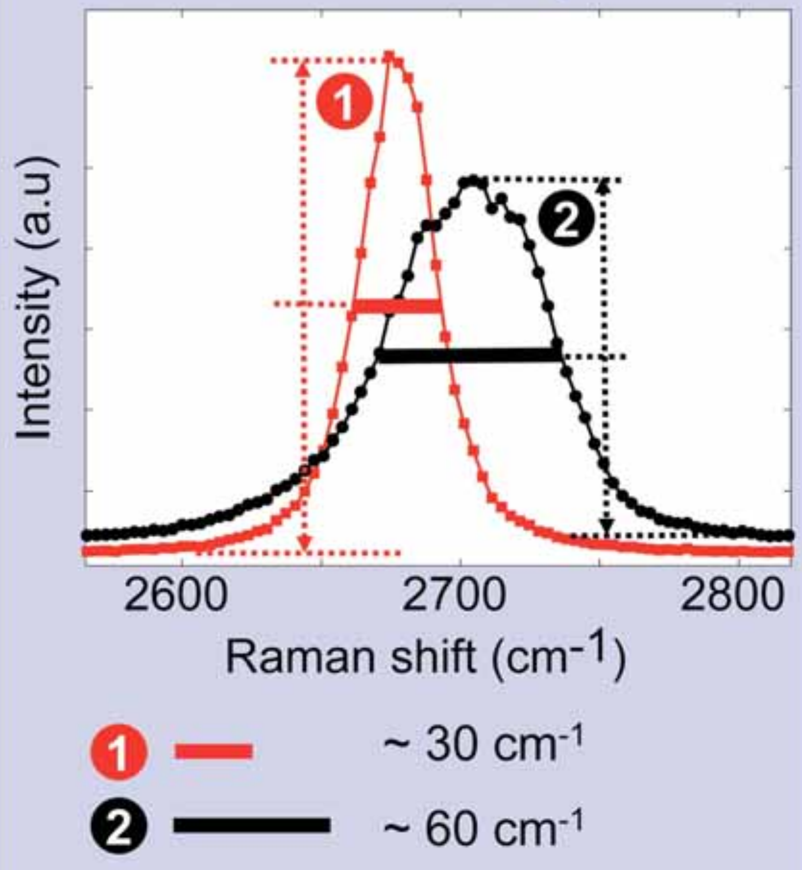
- Laser excitation of 532 nm/ 2.33 eV
- Spot size:

Raman mapping: FWHM of the D‘ line

Scanning force microscope



Raman: D‘ line intensity



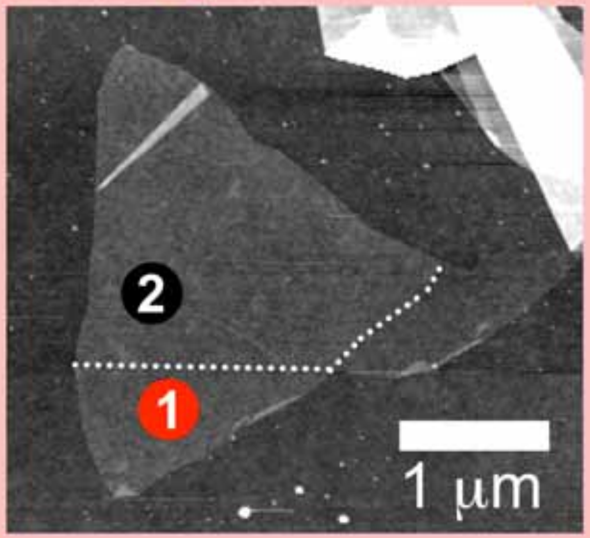
Scanning confocal Raman spectroscopy:

- Laser excitation of 532 nm/ 2.33 eV
- Spot size:

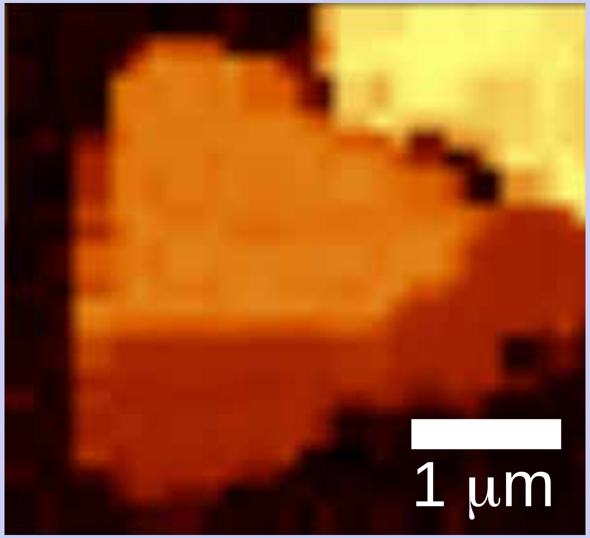
two layers have broader G-line, different peak position

Raman mapping:
FWHM of the D‘ line

Scanning force microscope



Raman: FWHM of D‘ line

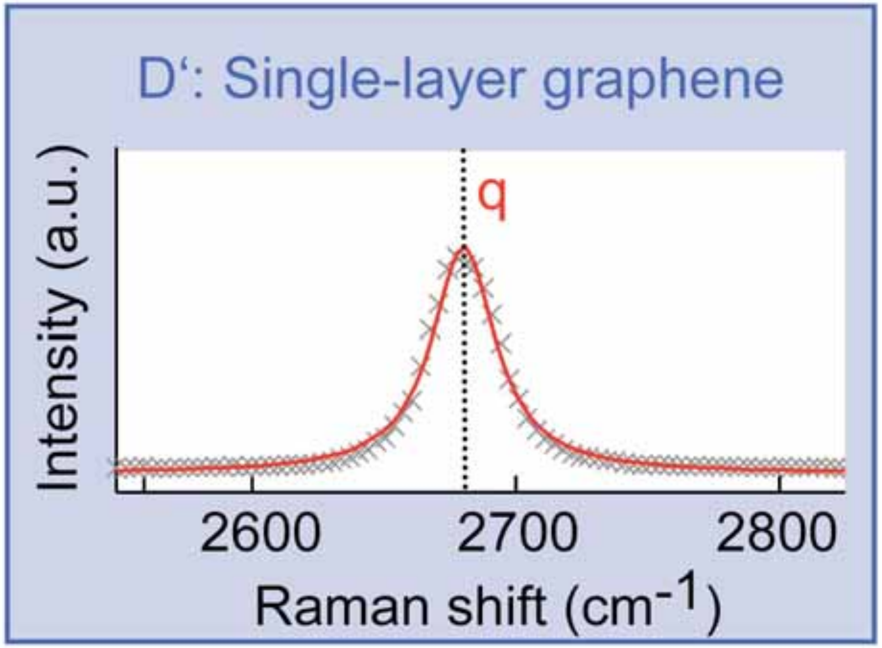


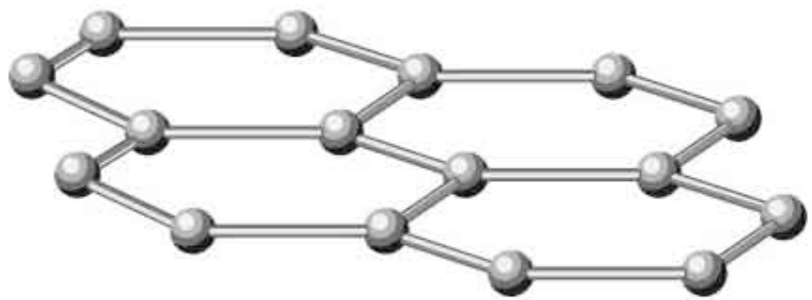
Scanning confocal
Raman spectroscopy:

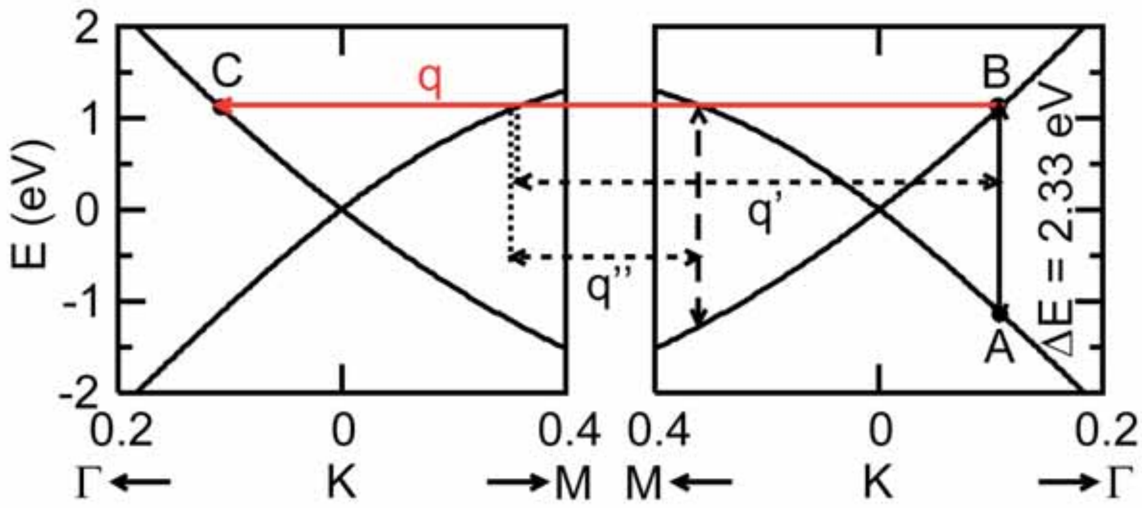
- Laser excitation of 532 nm/
  2.33 eV
- Spot size:

two layers have broader G-line, different peak position

D‘ line for single layer graphene

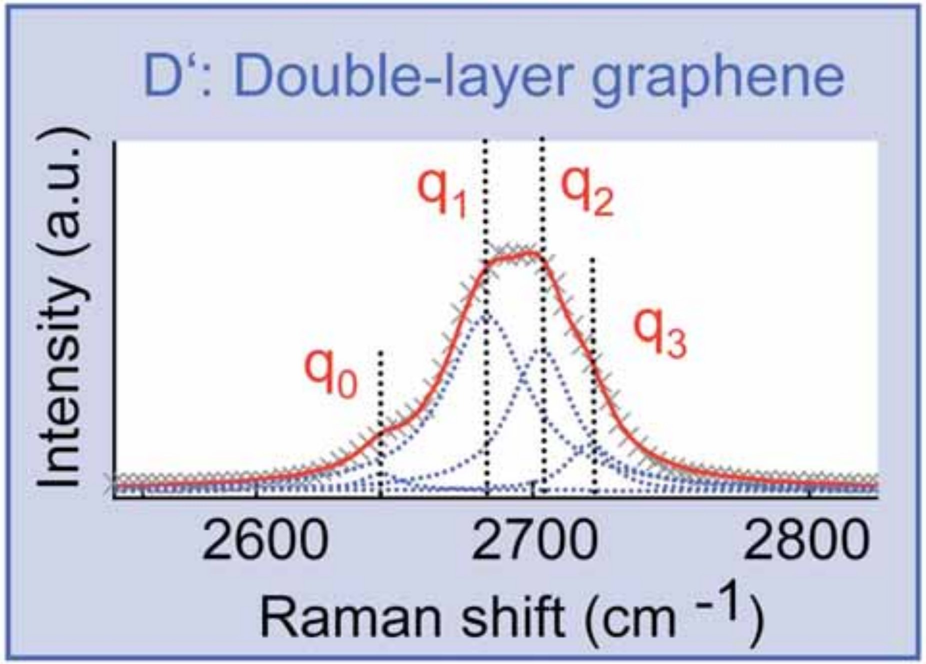


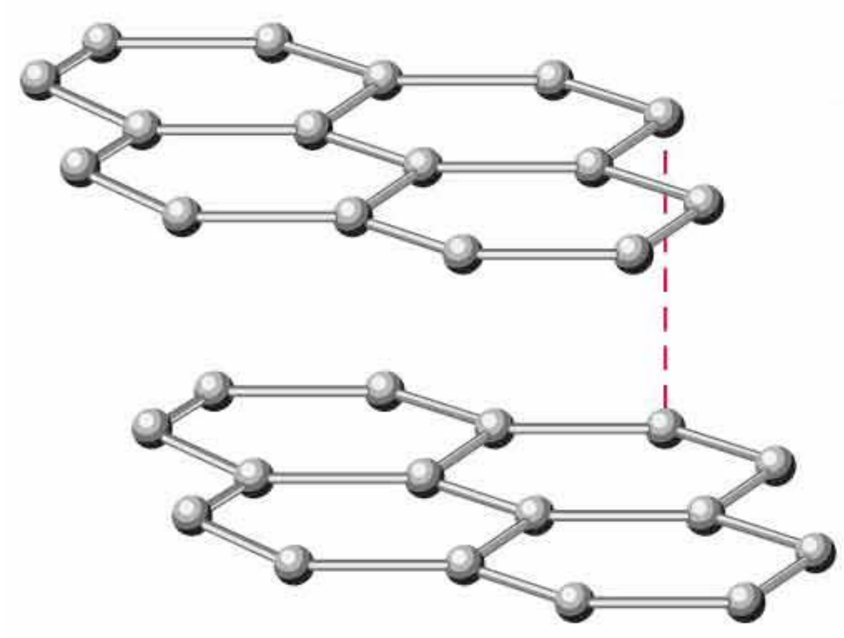


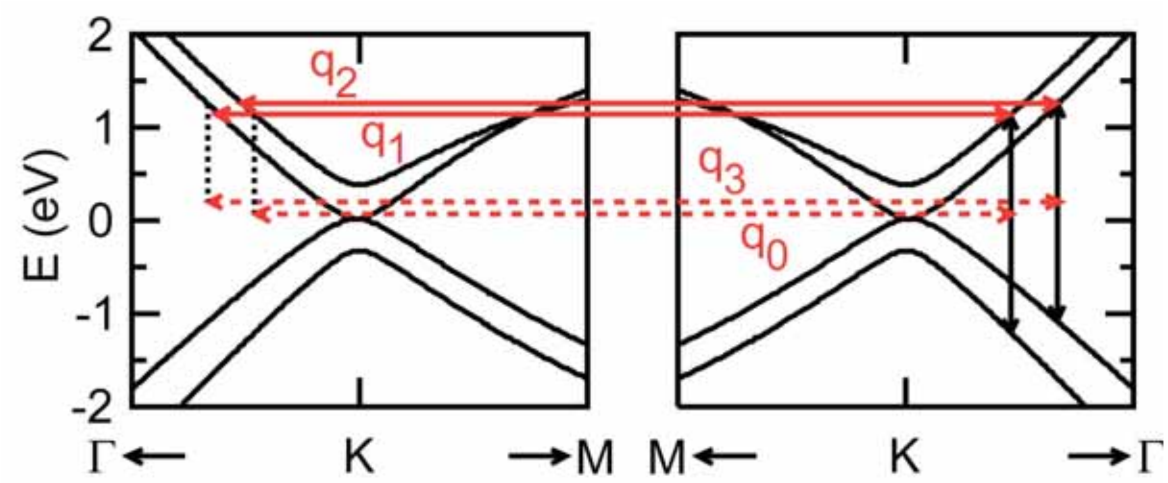


Related work: A.C. Ferrari et al., cond-mat/0606284

D‘ line for double layer graphene

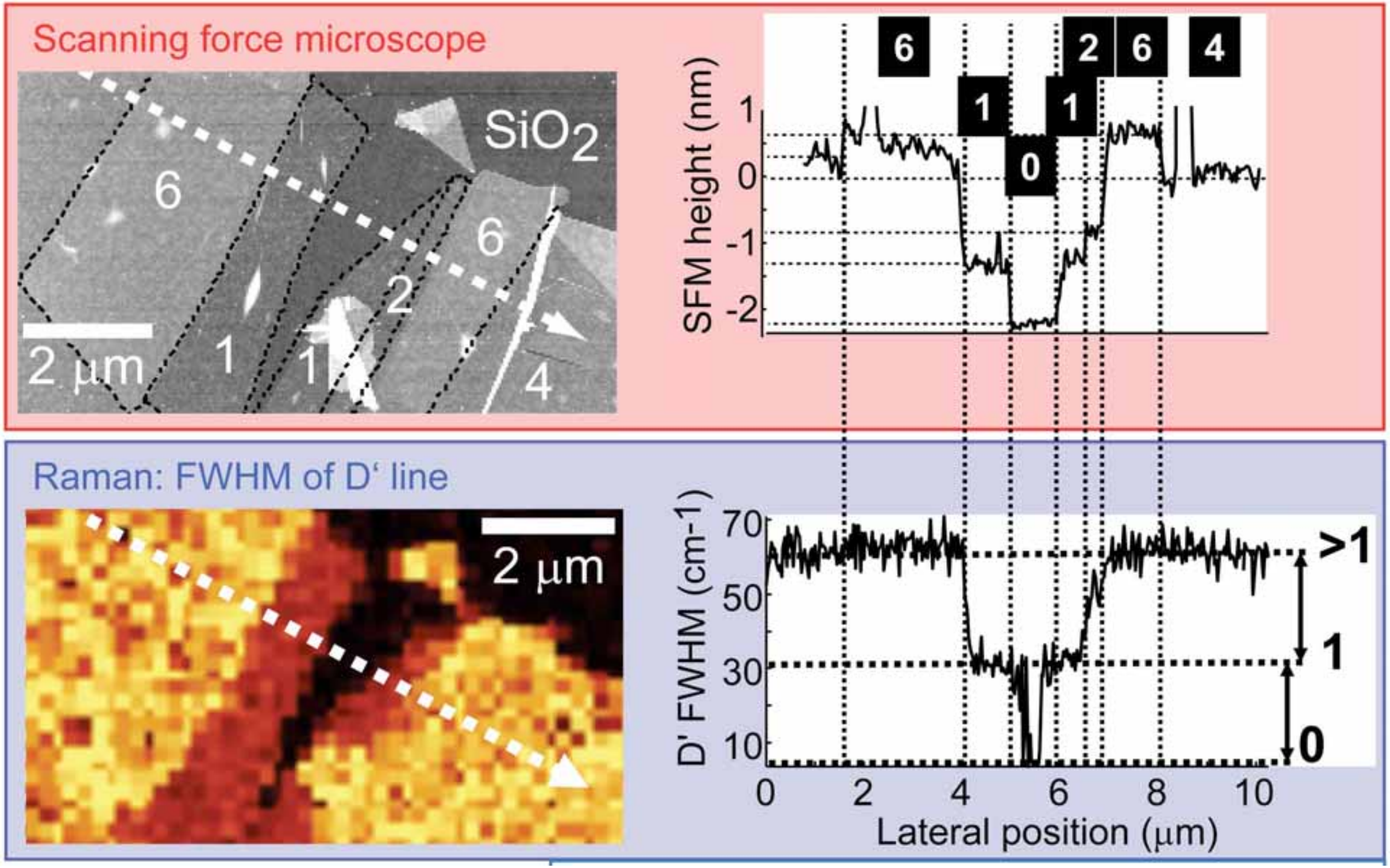






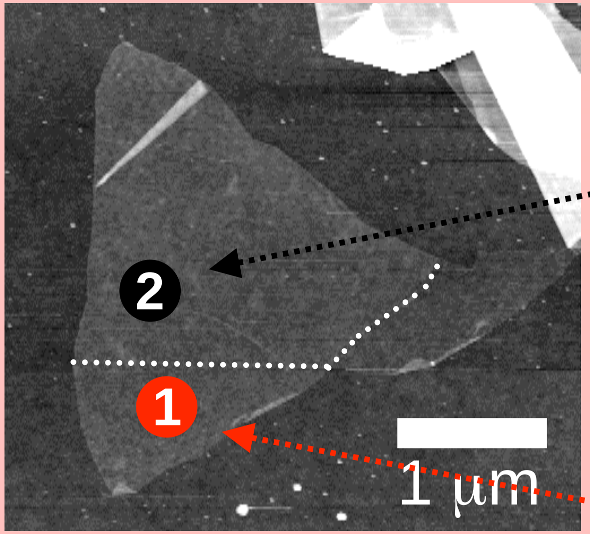
Related work: A.C. Ferrari et al., cond-mat/0606284

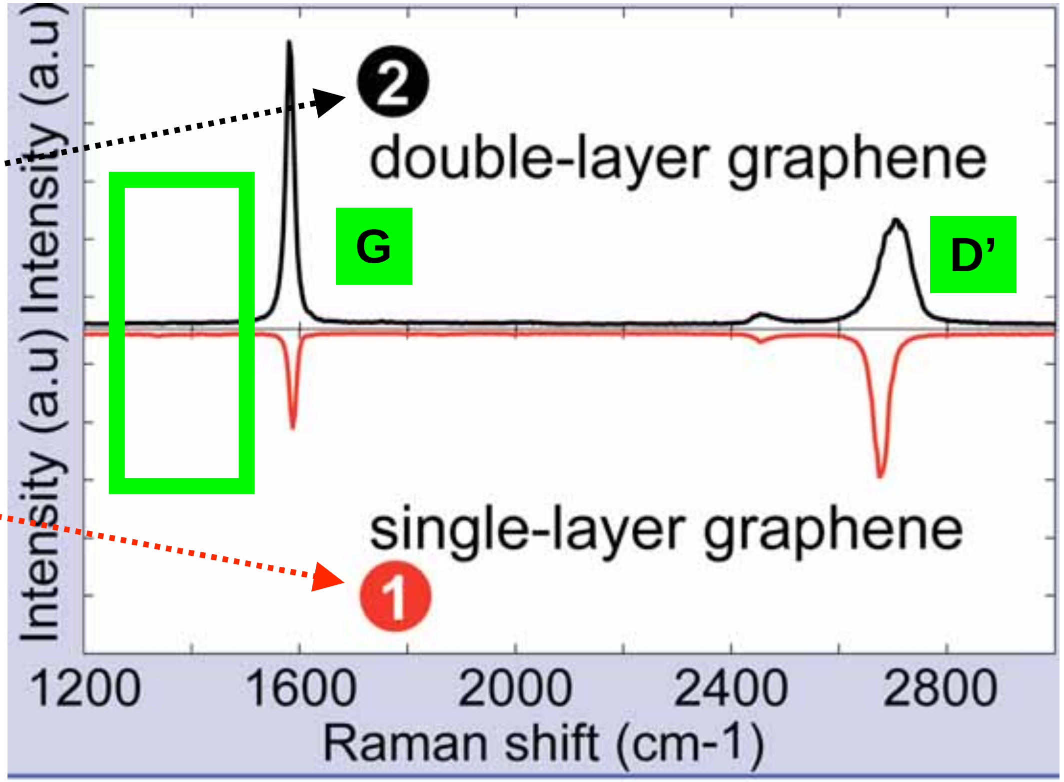
Detecting single layer graphene



What about the D-line?

Scanning force microscope

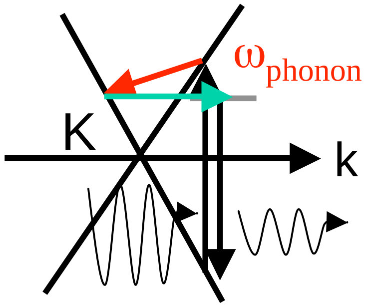




Scanning confocal Raman spectroscopy:

- Laser excitation of 532 nm/ 2.33 eV
- Spot size:

Raman mapping: intensity of the D line



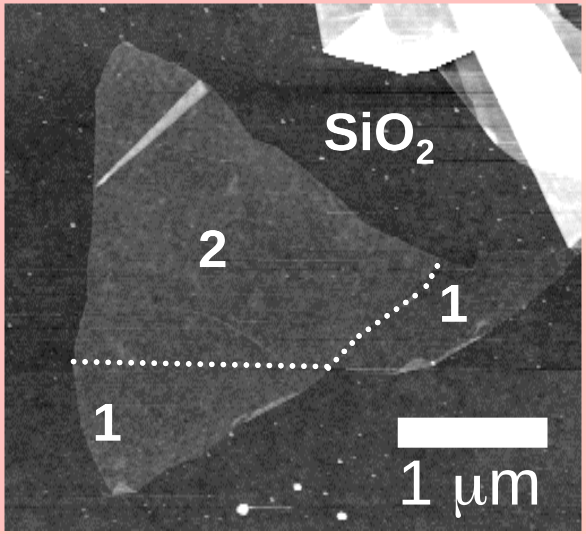
Double-resonant

close to K, M point, k>0
Momentum restoring:
elastic scattering → **D**

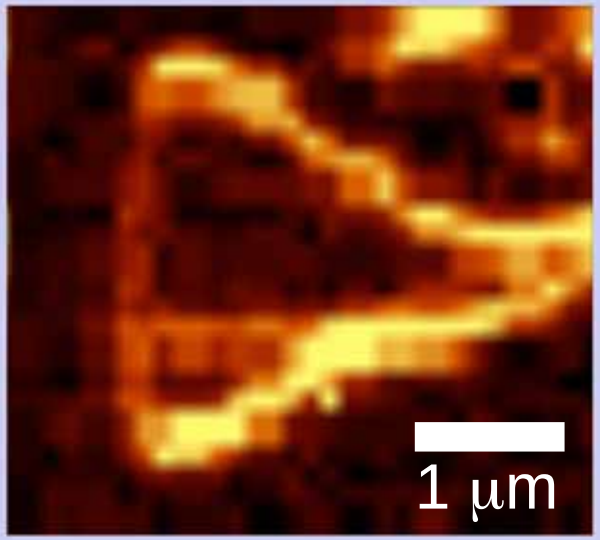
1) **Crystallite grain size, symmetry breaking**
[Tuinstra and Koenig, 1970]

2) **Defects, disorder in general**
[Y. Wang et al, 1990]

Scanning force microscope



Raman: Integrated D line intensity



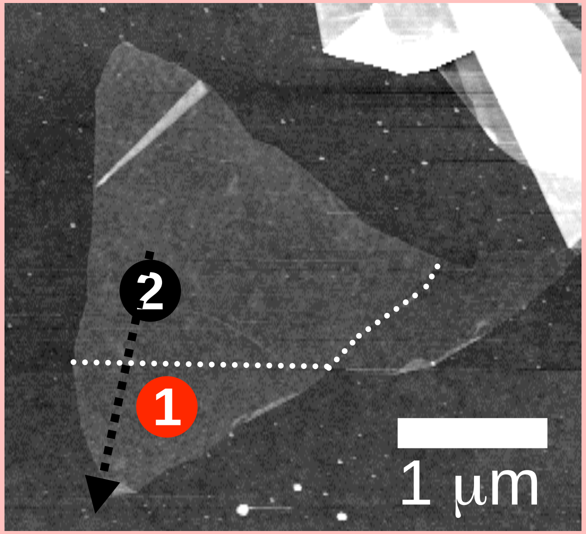
Symmetry breaking and defects

at edges and boundaries,

not within the flake.

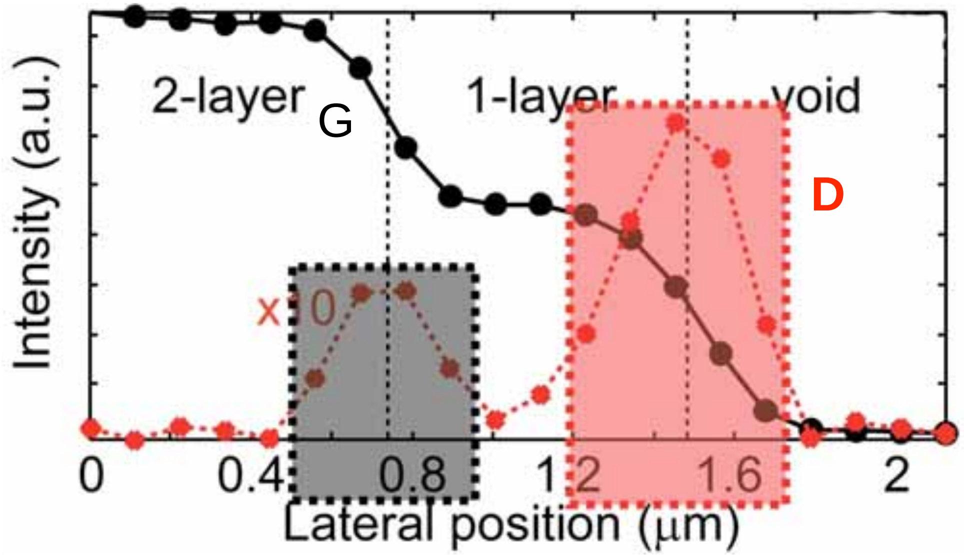
Raman mapping: position of D-line

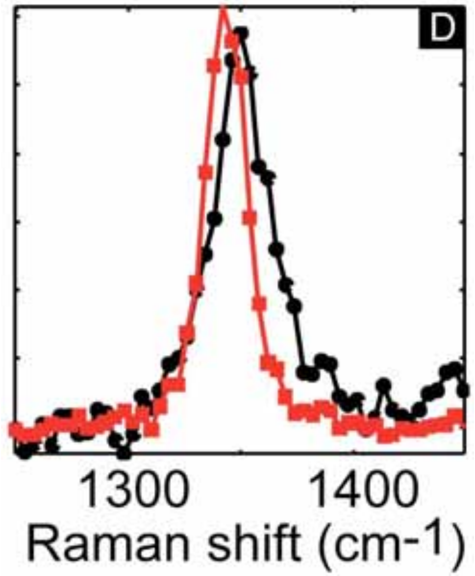
Scanning force microscope



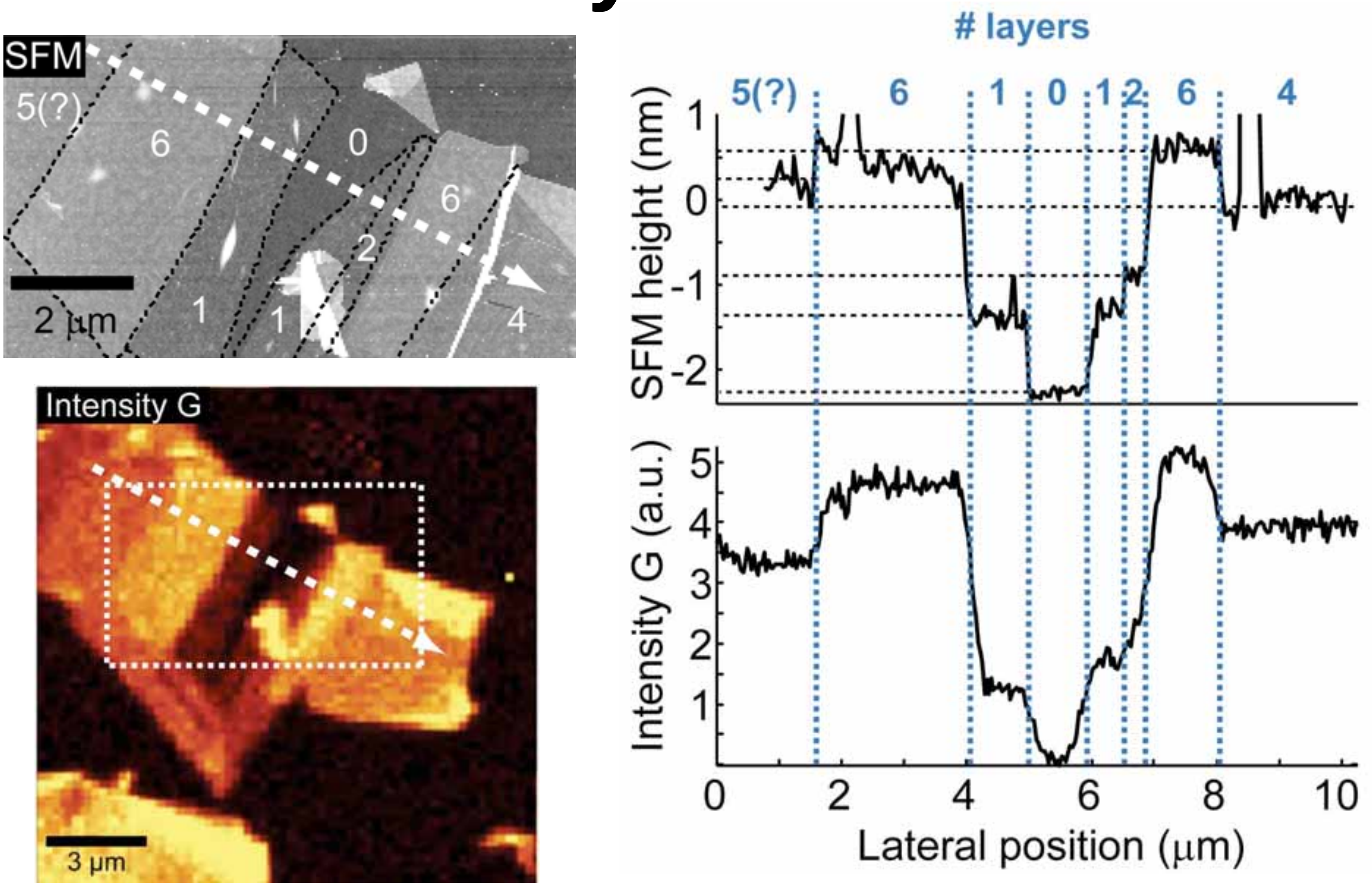
Scanning confocal Raman spectroscopy:

- Laser excitation of 532 nm/ 2.33 eV
- Spot size:

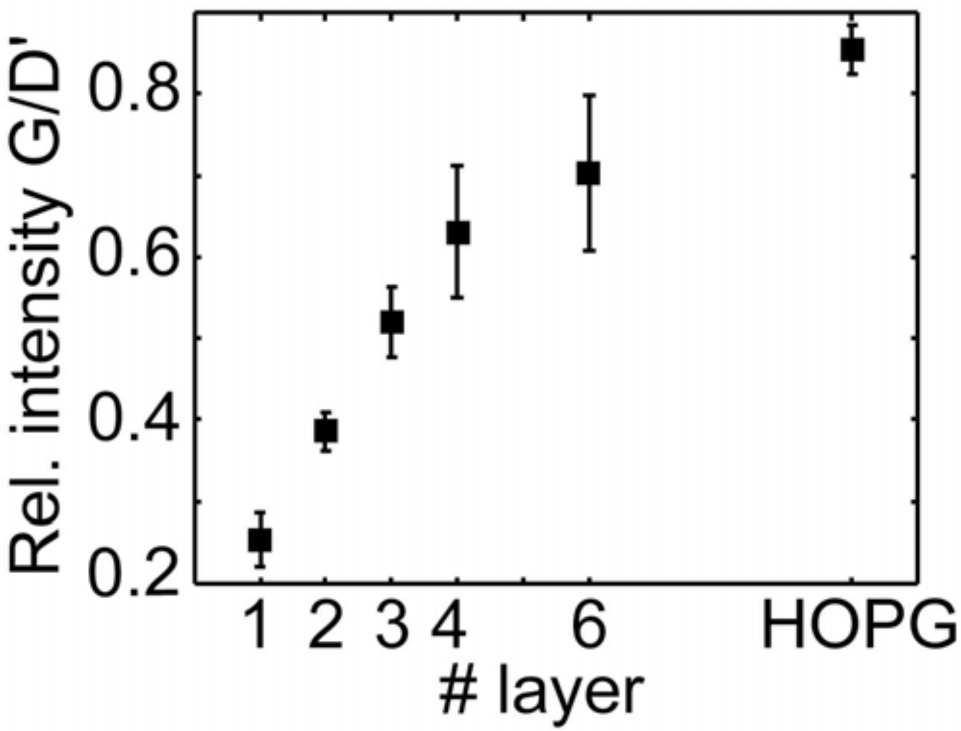


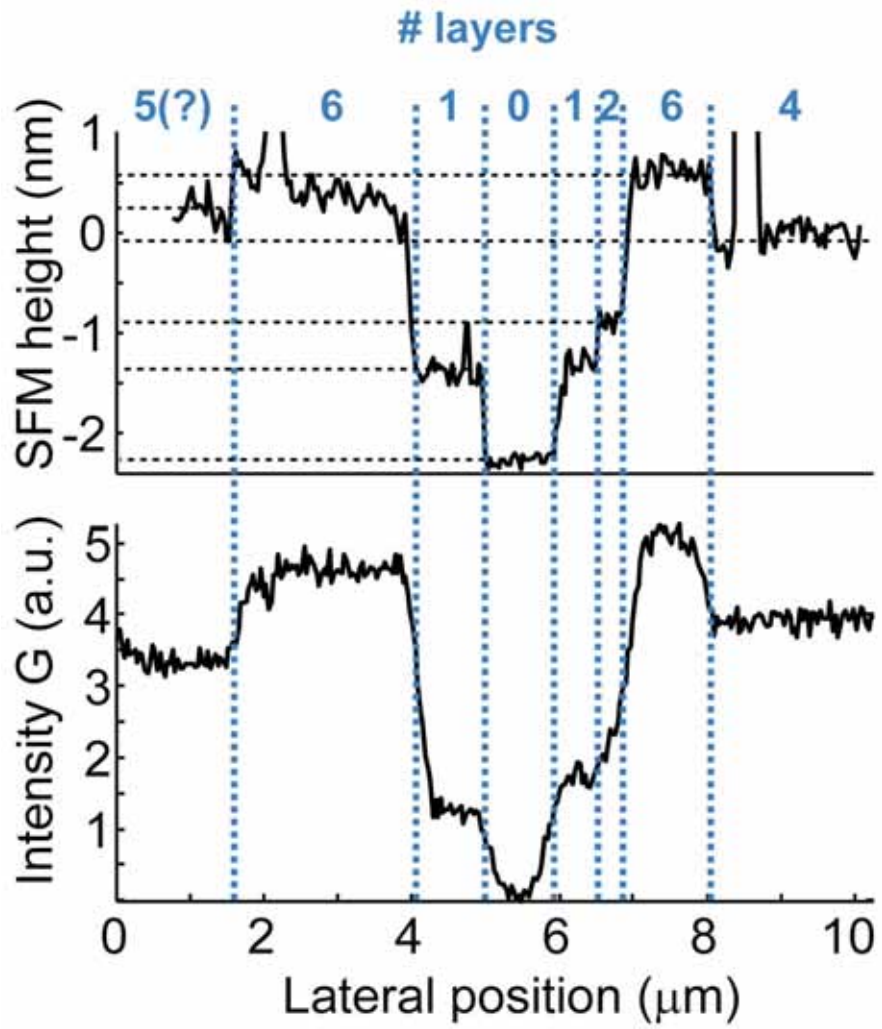


Raman mapping: intensity of G-line



Raman mapping: relative intensity of G/D'-line



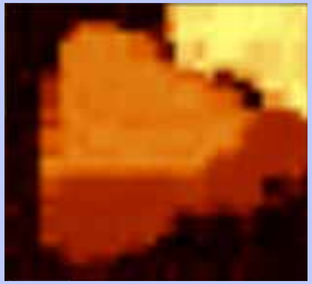


- Height sensitivity for few-layer graphene
- Proportional to # of layers, but saturation above ~ 6 ML

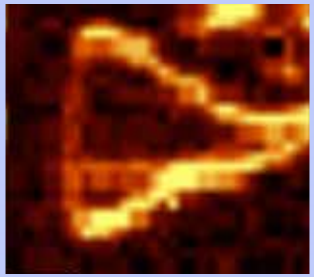
Conclusions

- Raman spectroscopy: an alternative to scanning force microscopy
- Monolayer sensitivity (single to double layer)
- Defects/symmetry breaking at the edge (not within the flakes)

Raman: FWHM D'



Raman: Intensity D



Experiment:
Davy Graf,
Françoise Molitor,
and Klaus Ensslin
Solid State Physics,
ETH Zürich, Switzerland

Christoph Stampfer,
Alain Jungen,
and Christofer Hierold
Micro and Nanosystems,
ETH Zürich, Switzerland

Theory:
Ludger Wirtz
Institute for Electronics, Microelectronics, and Nanotechnology (IEMN),
59652 Villeneuve d'Ascq,
France

D. Graf *et al.*, cond-mat/0607562, submitted
Related work: A.C. Ferrari *et al.*, cond-mat/0606284,
A. Gupta *et al.*, cond-mat/0606593