SAPIENZA
UNIVERSITÀ DI ROMA

PTOLEMY Project

# Anisotropic and channeling effects in ion-bombarded highly aligned carbon nanotubes


**Maria Grazia Betti, Giulio D'Acunto, Carlo Mariani***

**Dipartimento di Fisica, Università di Roma "La Sapienza"**
***carlo.mariani@uniroma1.it**


(collaboration Università di Roma "La Sapienza", Université Mons, Belgium)


*Kick-off meeting of the PTOLEMY Project*, Laboratori Nazionali del Gran Sasso, Italy, December 11th-12th 2017

## *outline*

- Carbon Nano Tubes (CNTs)

- Why CNTs

- Do they present anisotropic channeling?

- A Microscopy, Optical and Electronic Spectroscopy study

- Prototype Experiment: controlled Ion-Bombardment as probe at exemplary CNTs

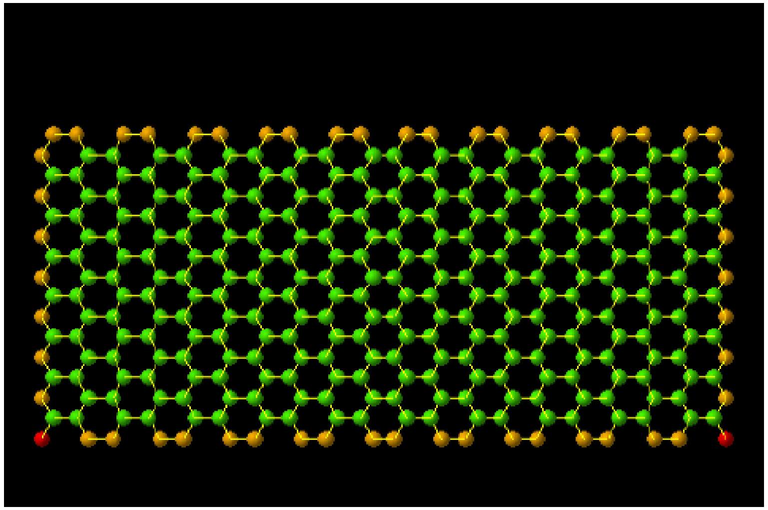
- First conclusions, and perspectives

***outline***

**- Carbon Nano Tubes (CNTs)**

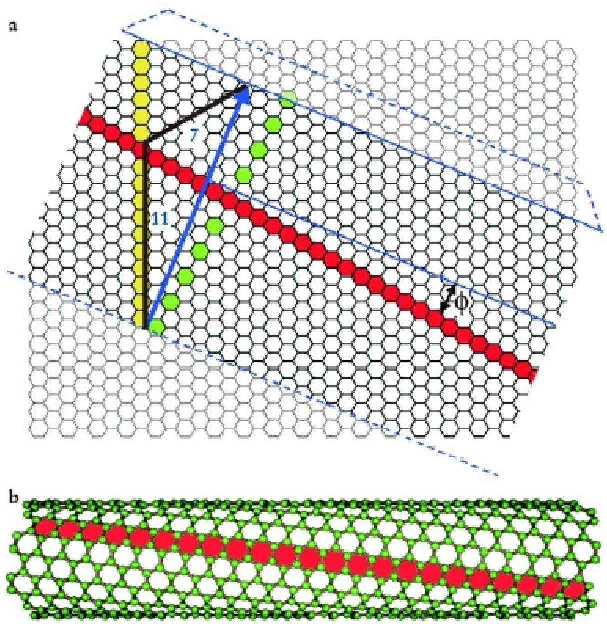
# carbon nanotubes

**Structure:** Imagine wrapping a sheet of graphene into a nanotube

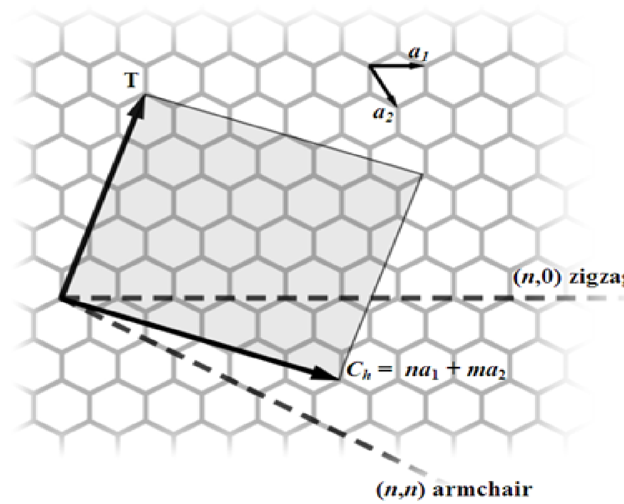


Shigeo MARUYAMA, Univ. Tokyo

Wrapping can be done along many directions in the sheet




=> chiral nanotubes




diameter = a/Ⓟsqrt($n^2 + nm + m^2$) = 0.78 sqrt($n^2 + nm + m^2$) [in Å]

because of the specific symmetry, strong effect on the electronic properties;

**given (n,m)**:

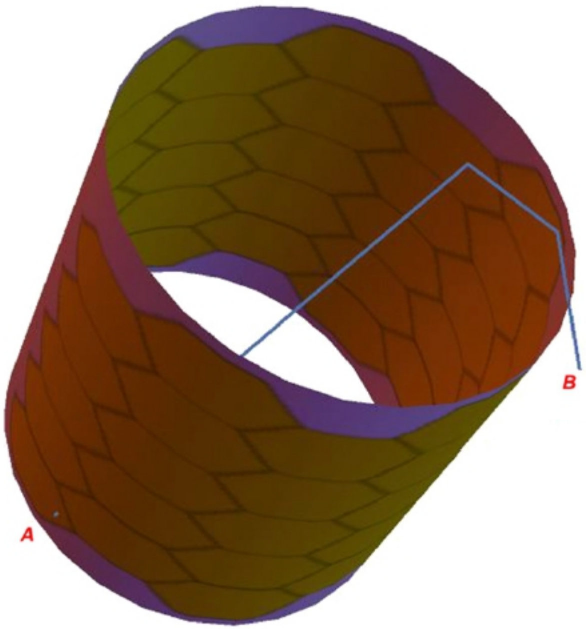
**n=m → metallic**

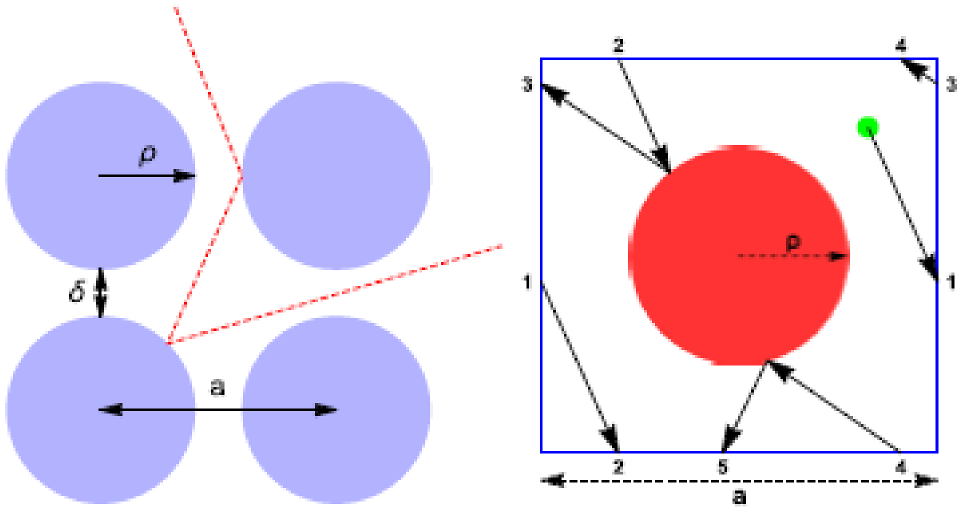
**n – m**= multiple of **3 → semiconducting**

## *outline*

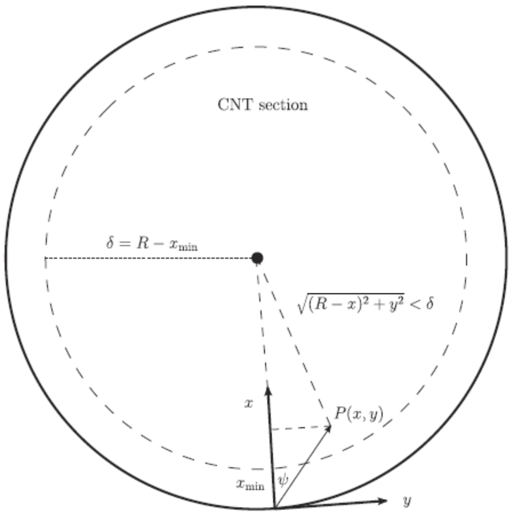
- Why CNTs

# why CNTs



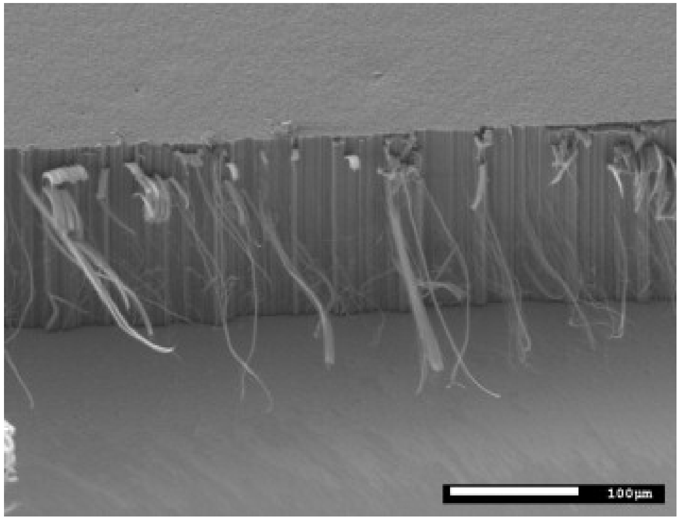

G. Cavoto et alii, Eur. Phys. J. C **76**, 349 (2016)



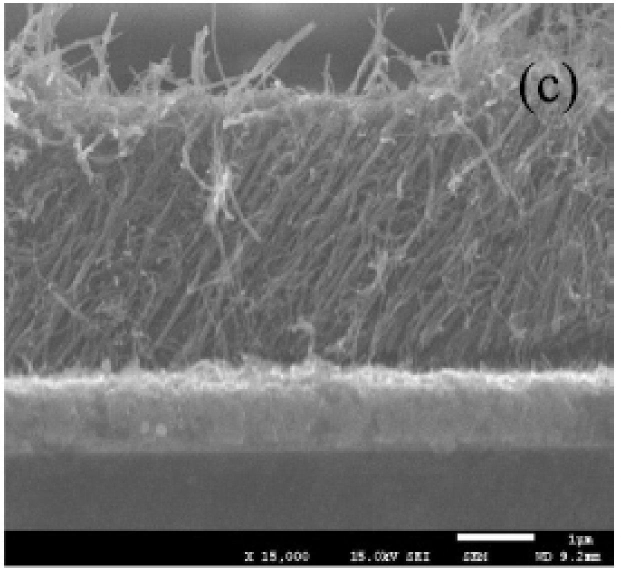

**G. Cavoto**: "Sub-GeV Dark Matter Detection with Electron Recoils in Carbon Nanotubes", talk this morning

L.M. Capparelli et alii, Phys. Dark Univ. **9-10**, 24 (2015); and **11**, 79 (2016)

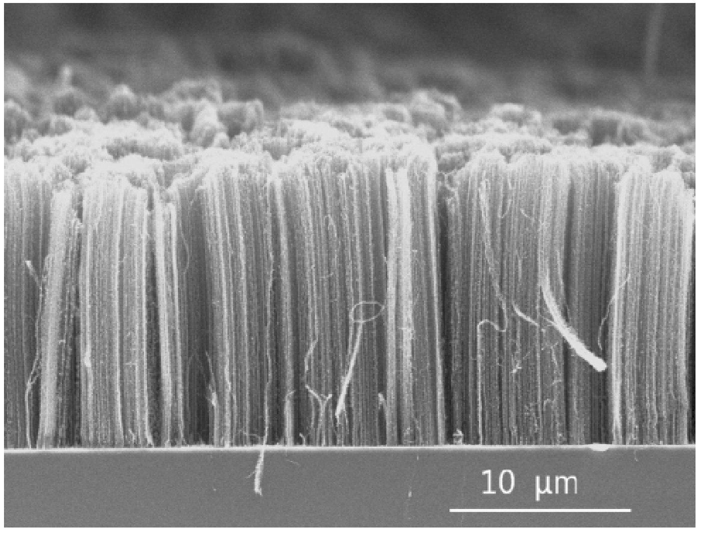
# *a challenge to obtain and high aspect-ratio highly aligned CNTs*



Scardamaglia et alii, Carbon **83**, 118 (2015)




Wenwen Yi et alii, J. Nanotechn. **26**, 125301 (2015)

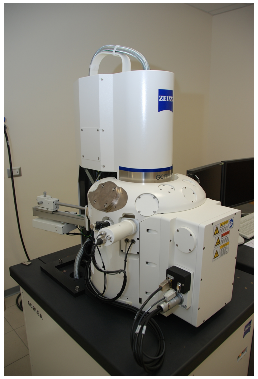



O. Dyatlova et alii, Phys. Rev. B **85**, 245449 (2012)

***outline***

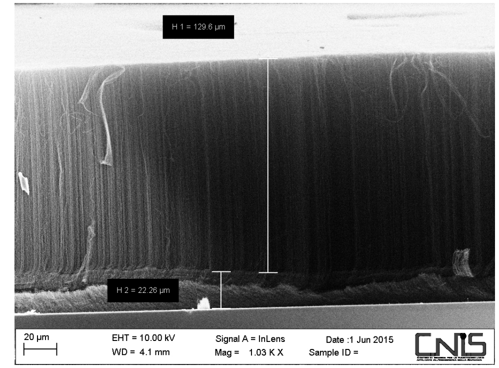
**- A Microscopy, Optical and Electronic Spectroscopy study**

# *microscopy and spectroscopy techniques*



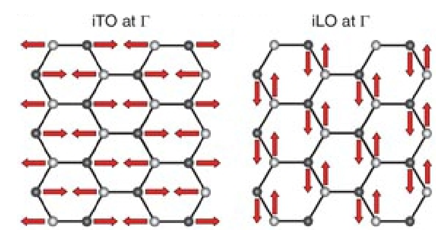
**Scanning Electron Microscopy (SEM) at sub-$\mu$m scale**

CNIS lab. @ Sapienza

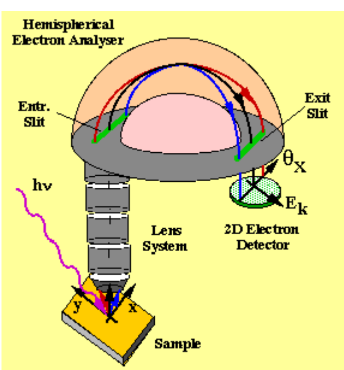



**Raman spectroscopy at sub-$\mu$m scale**

Phys. Dept. @ Sapienza

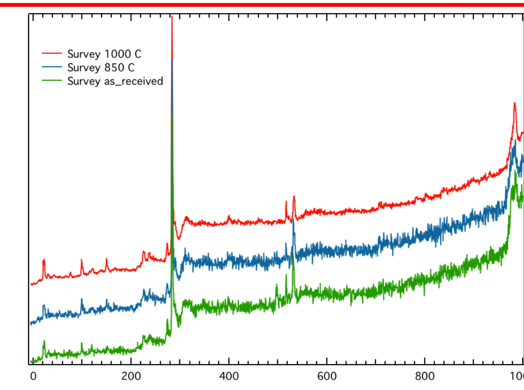



IR inelastic scattering: vibrational structure of the carbon lattice, defects, ...




**X-ray Photoelectron Spectroscopy (XPS)**

Phys. Dept. @ Sapienza and @ Univ. Mons



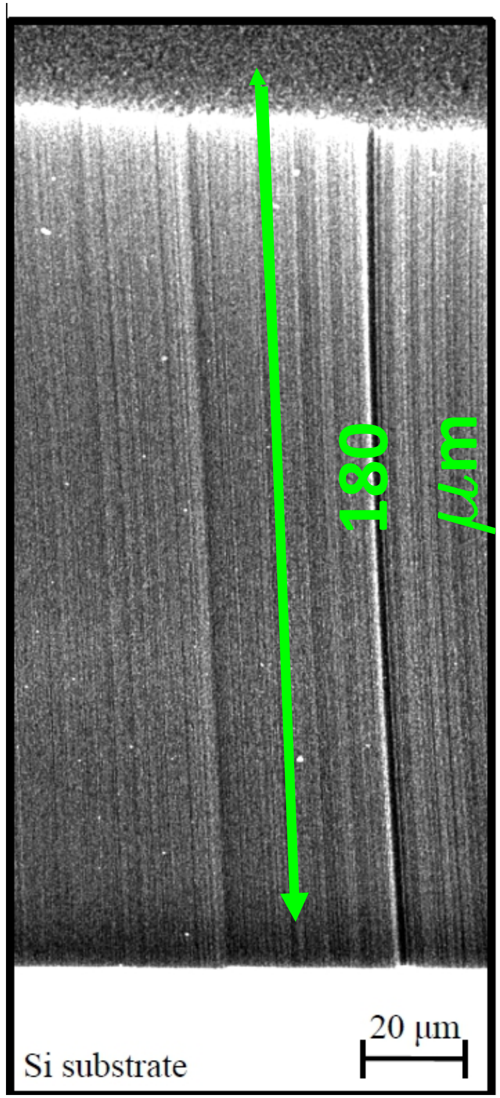

spectral density of electronic states: C chemical state, bonding, defects, ...

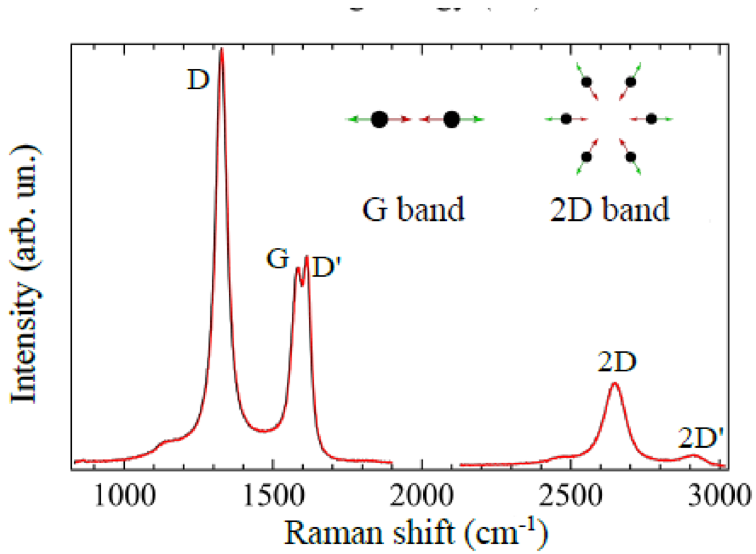
# clean pristine multi-wall CNT (MW-CNT)

| | |
|---|---|
| HEIGHT | $180 \pm 8\ \mu m$ |
| DIAMETER | $20 \pm 1\ nm$ |

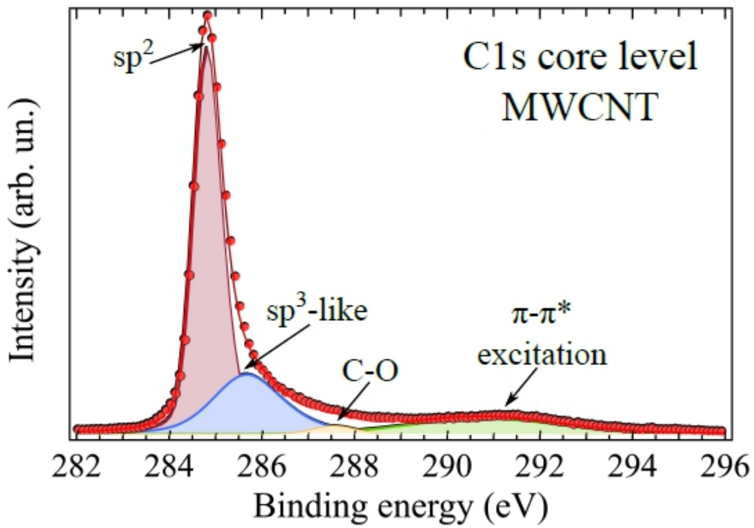
**~$10^4$ aspect ratio**

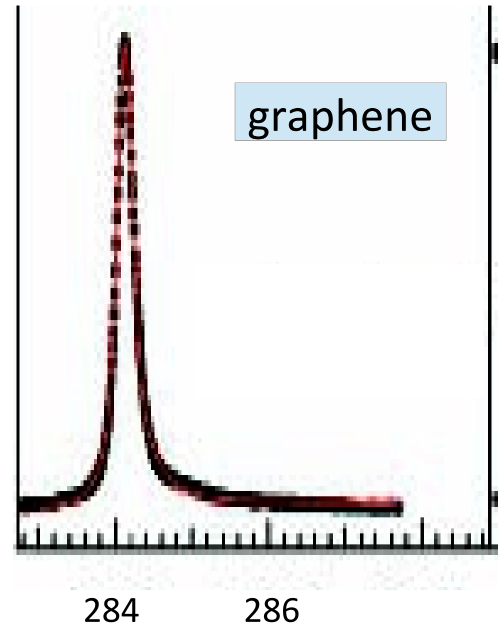
$$\mathcal{N} = 9\ x\ 10^8\ \frac{MWCNTs}{cm^2}$$



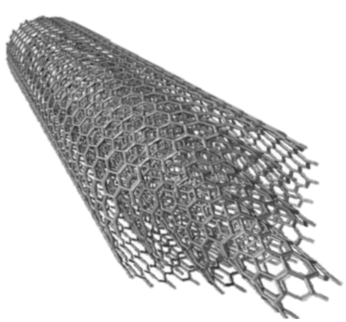



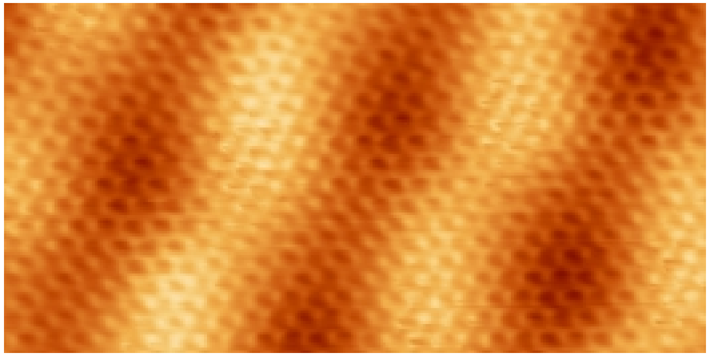
# clean pristine multi-wall CNT (MW-CNT)



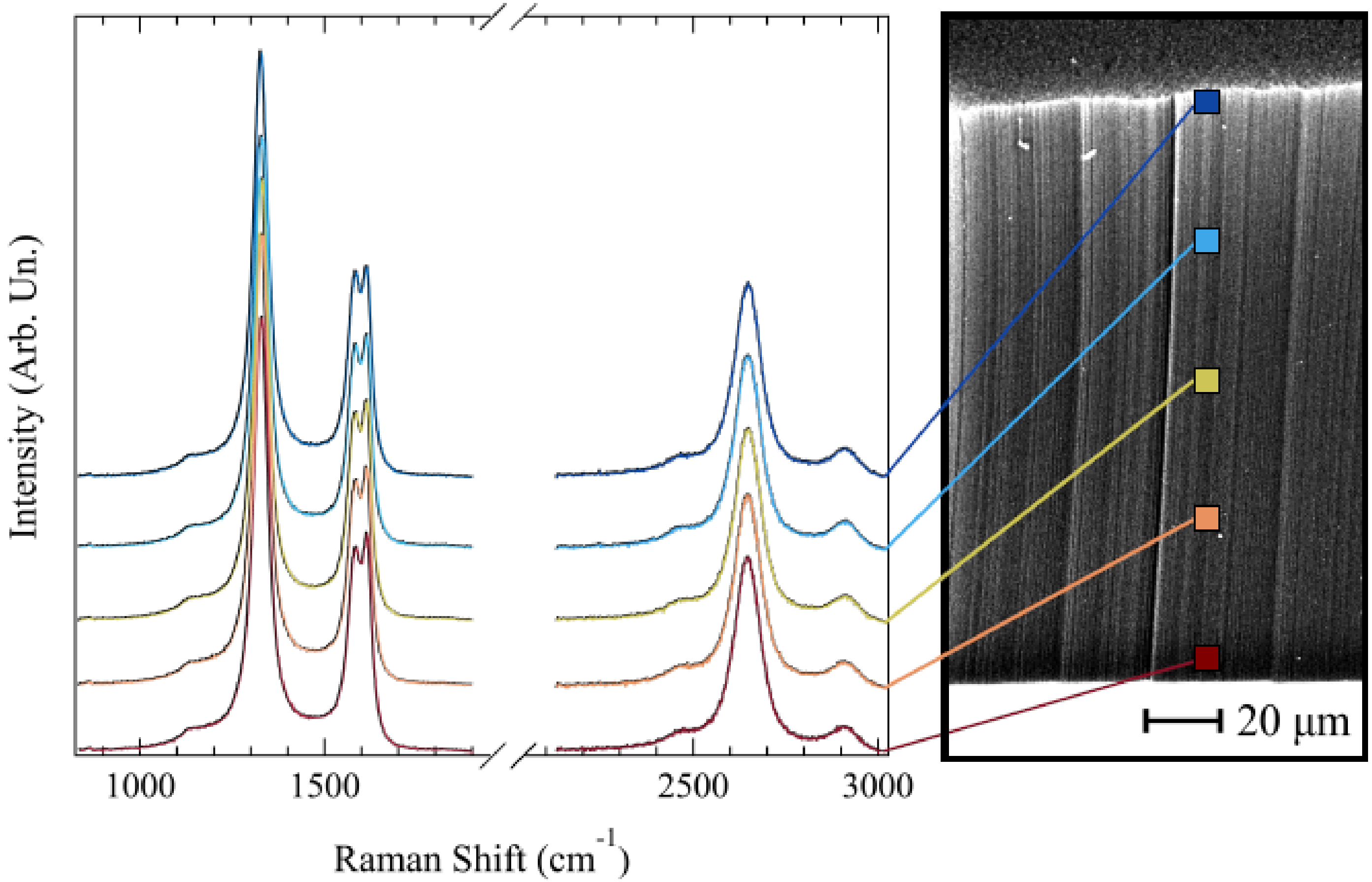

from Scardamaglia et alii, J. Phys. Chem. C **117**, 3019 (2013)





highly uniform quality along the whole MW-CNT length

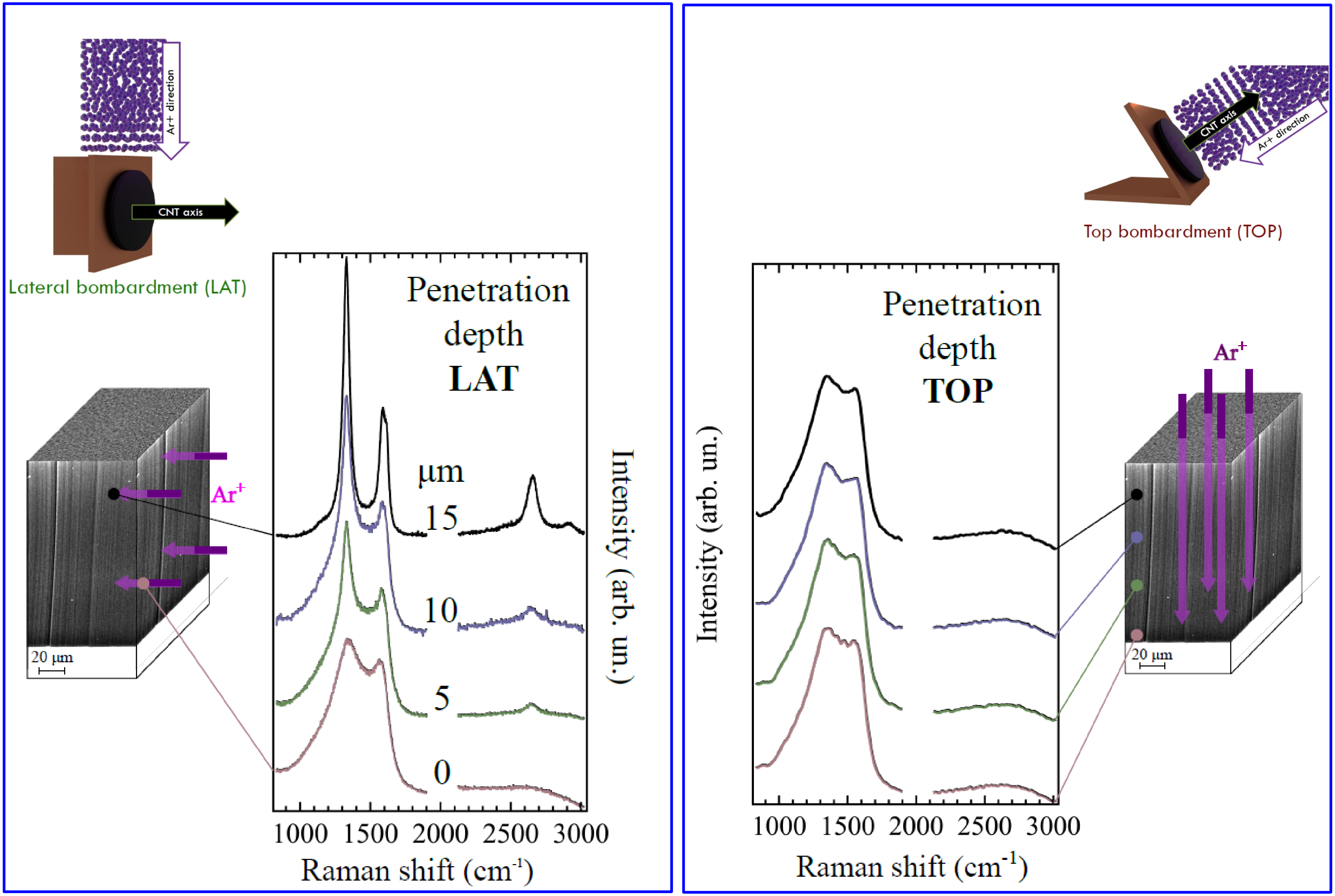
# CNT CHARACTERIZATION: RAMAN SPECTROSCOPY



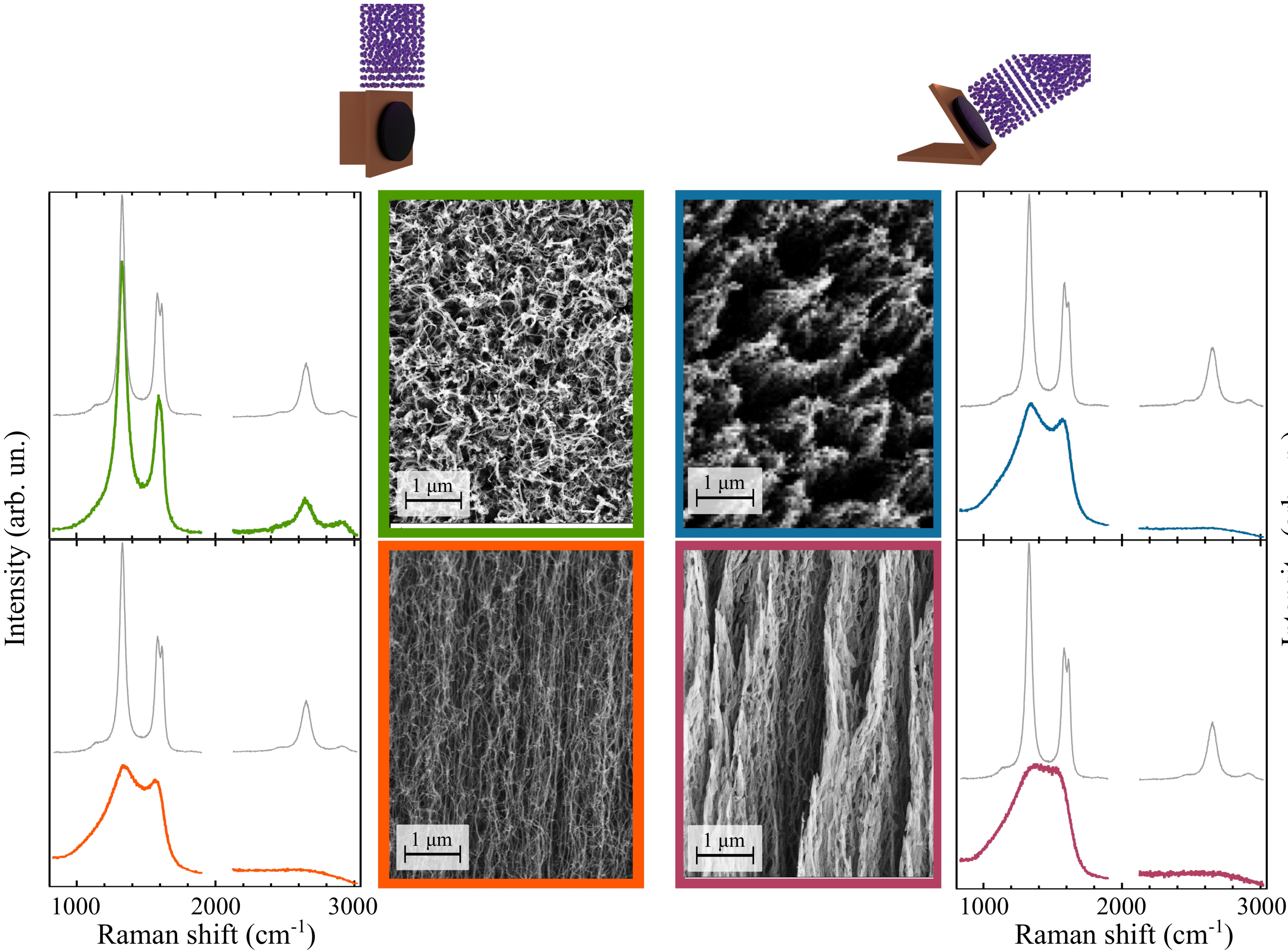
***outline***

**- Prototype Experiment: controlled Ion-Bombardment as probe at exemplary CNTs**

# 5 keV A⁺-ions



Ar+ direction
CNT axis
Lateral bombardment (LAT)
Ar+
20 µm
Penetration depth LAT
µm
15
10
5
0
Intensity (arb. un.)
1000 1500 2000 2500 3000
Raman shift (cm-1)
CNT axis
Ar+ direction
Top bombardment (TOP)
Penetration depth TOP
Intensity (arb. un.)
Ar+
20 µm
1000 1500 2000 2500 3000
Raman shift (cm-1)

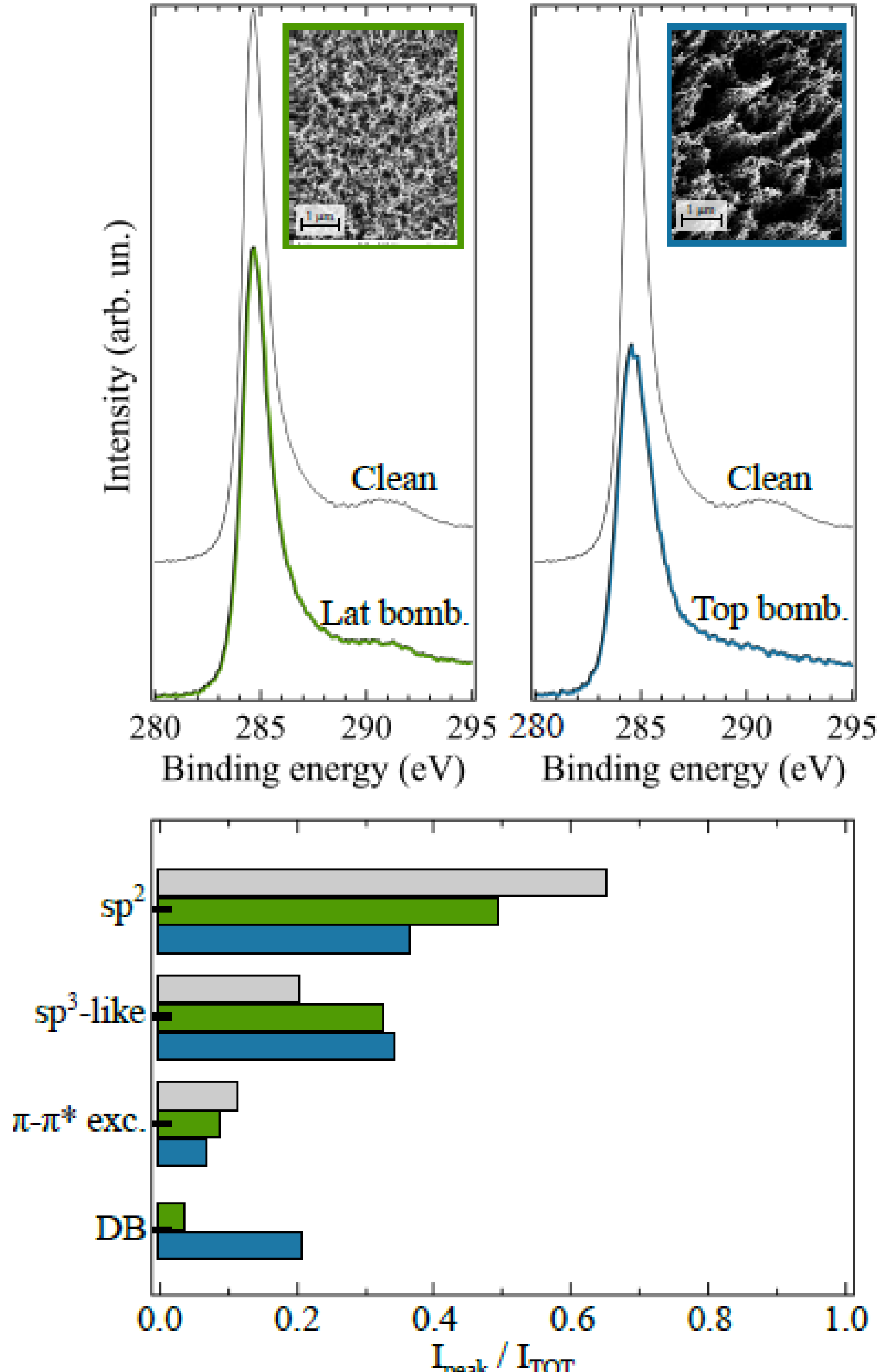


Intensity (arb. un.)
1 µm
1 µm
1 µm
1 µm
Intensity (arb. un.)
1000
2000
3000
Raman shift (cm-1)
1000
2000
3000
Raman shift (cm-1)

Bonding and chemical state effects on the C atoms, by C1 s core-level XPS photoemission

* 5 keV Ar+  ion bombardment

* high ion flux (3.0 x $10^{18}$ ions/$cm^2$)



Bonding and chemical state effects on the C atoms, by C1 s core-level XPS photoemission

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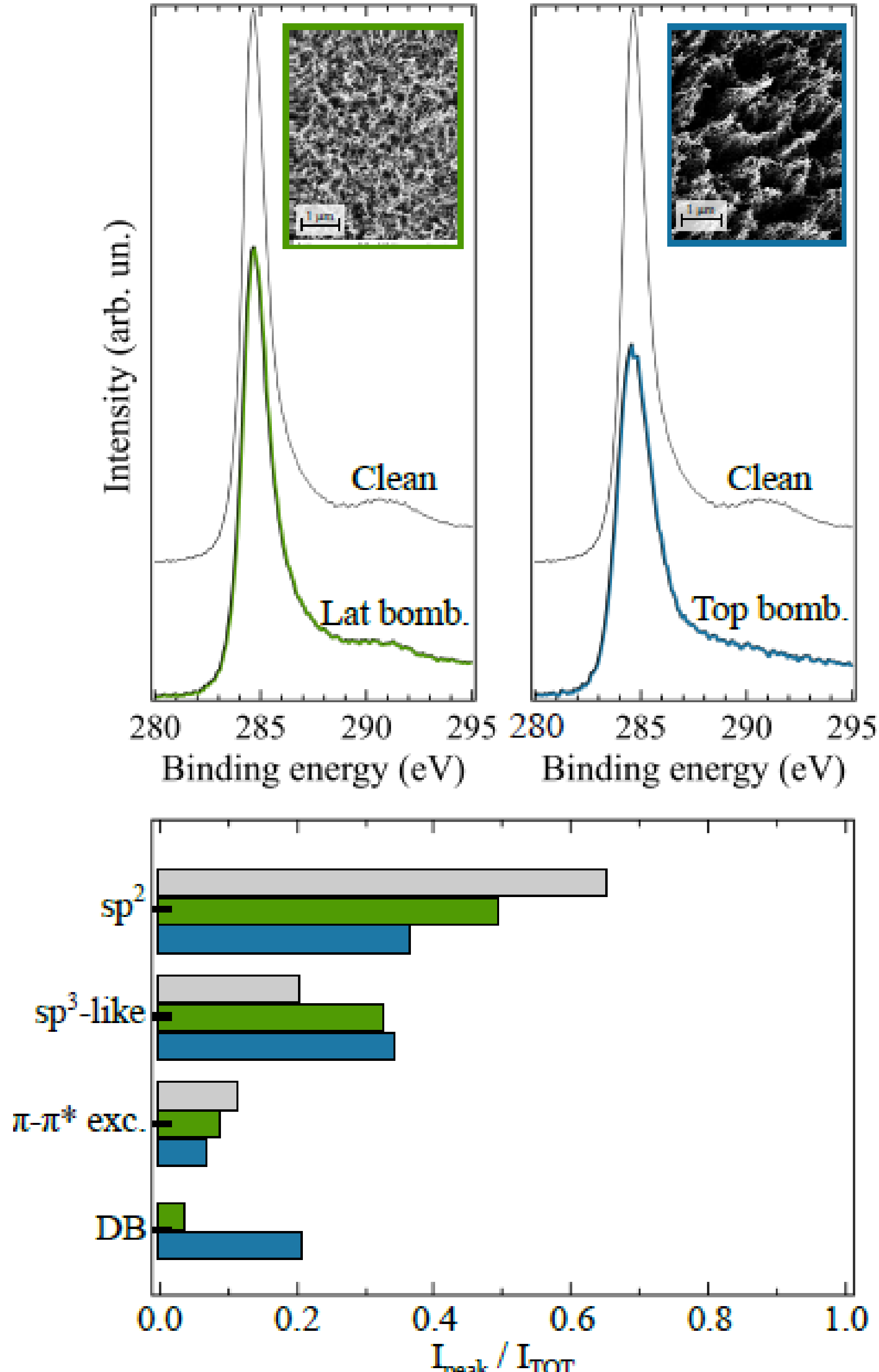
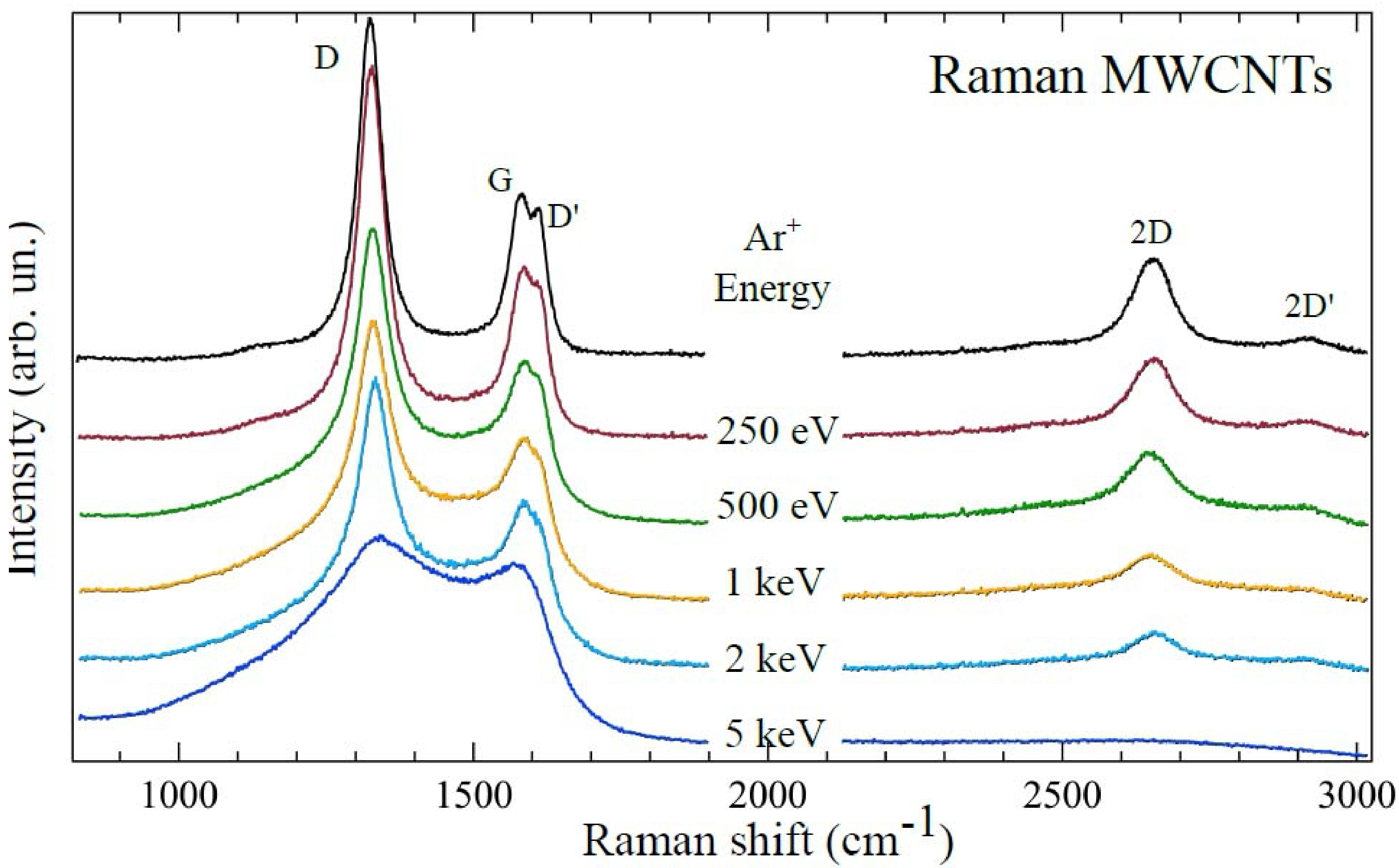
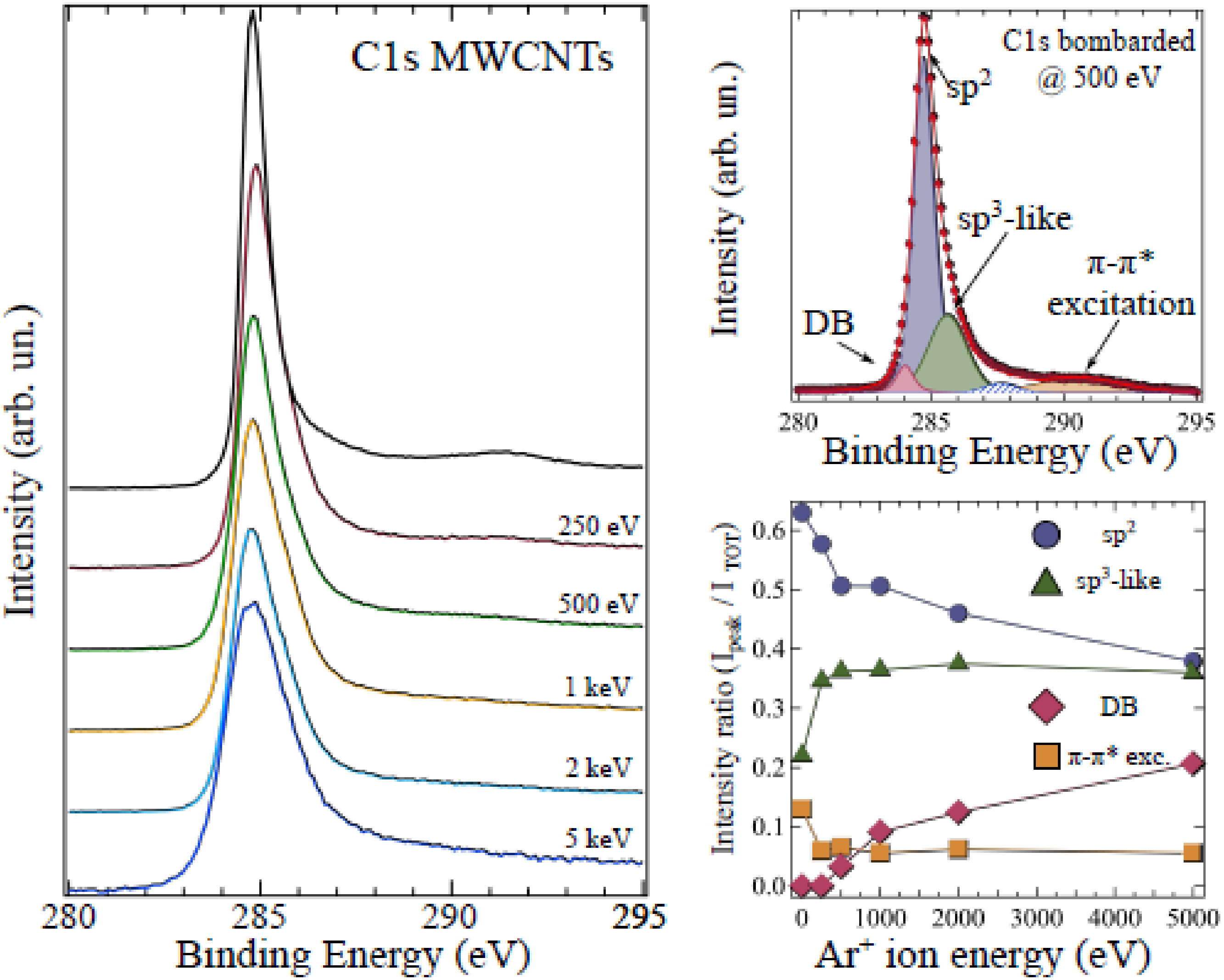
**Which effect at lower $Ar^+$ energy?**



**RAMAN: structural evolution of the C lattice vs. Ar ion energy (at saturation damage)**



# XPS: bonding evolution of the C atoms vs. Ar ion energy (at saturation damage)

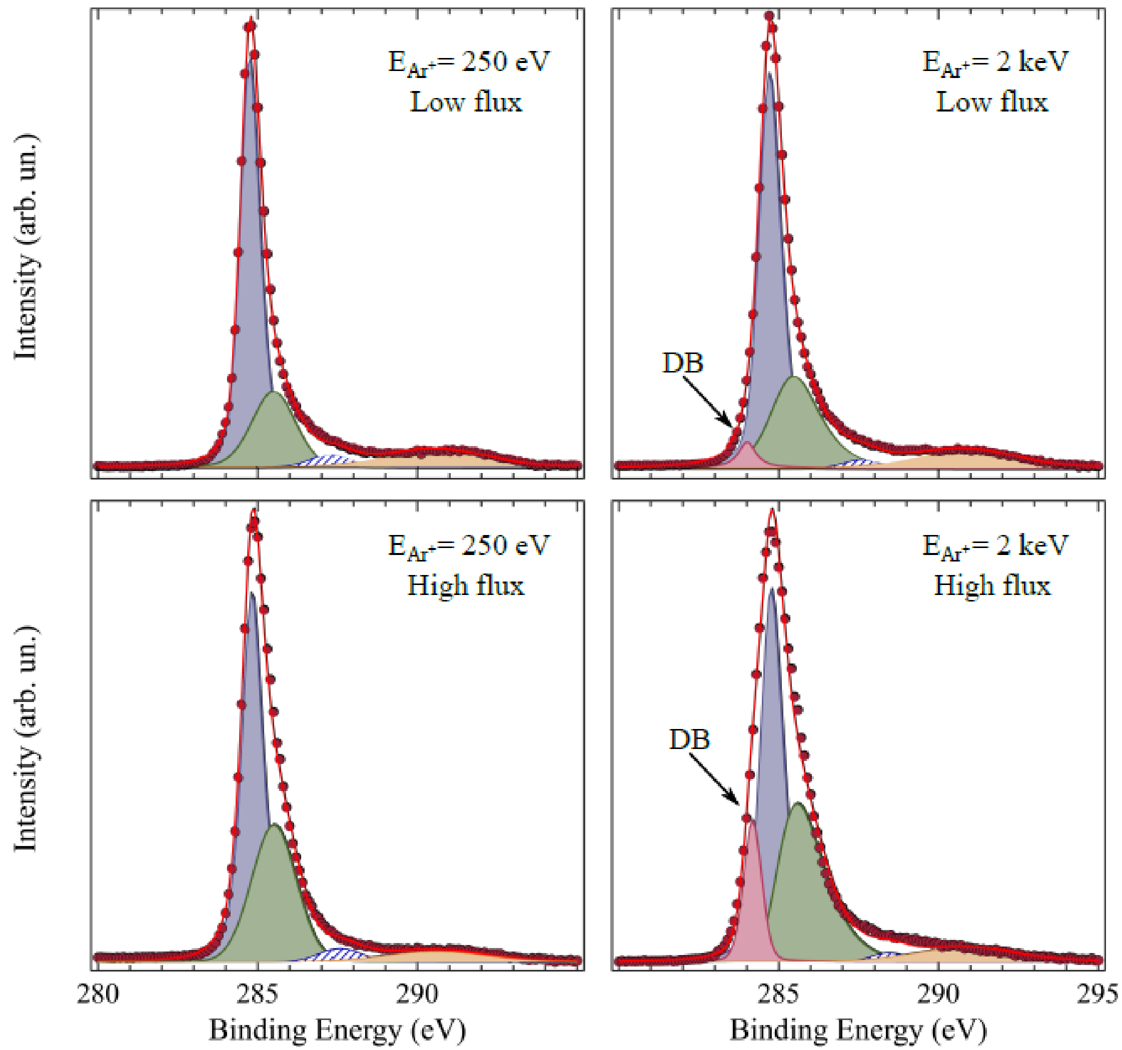


Low Ar energy

High Ar energy

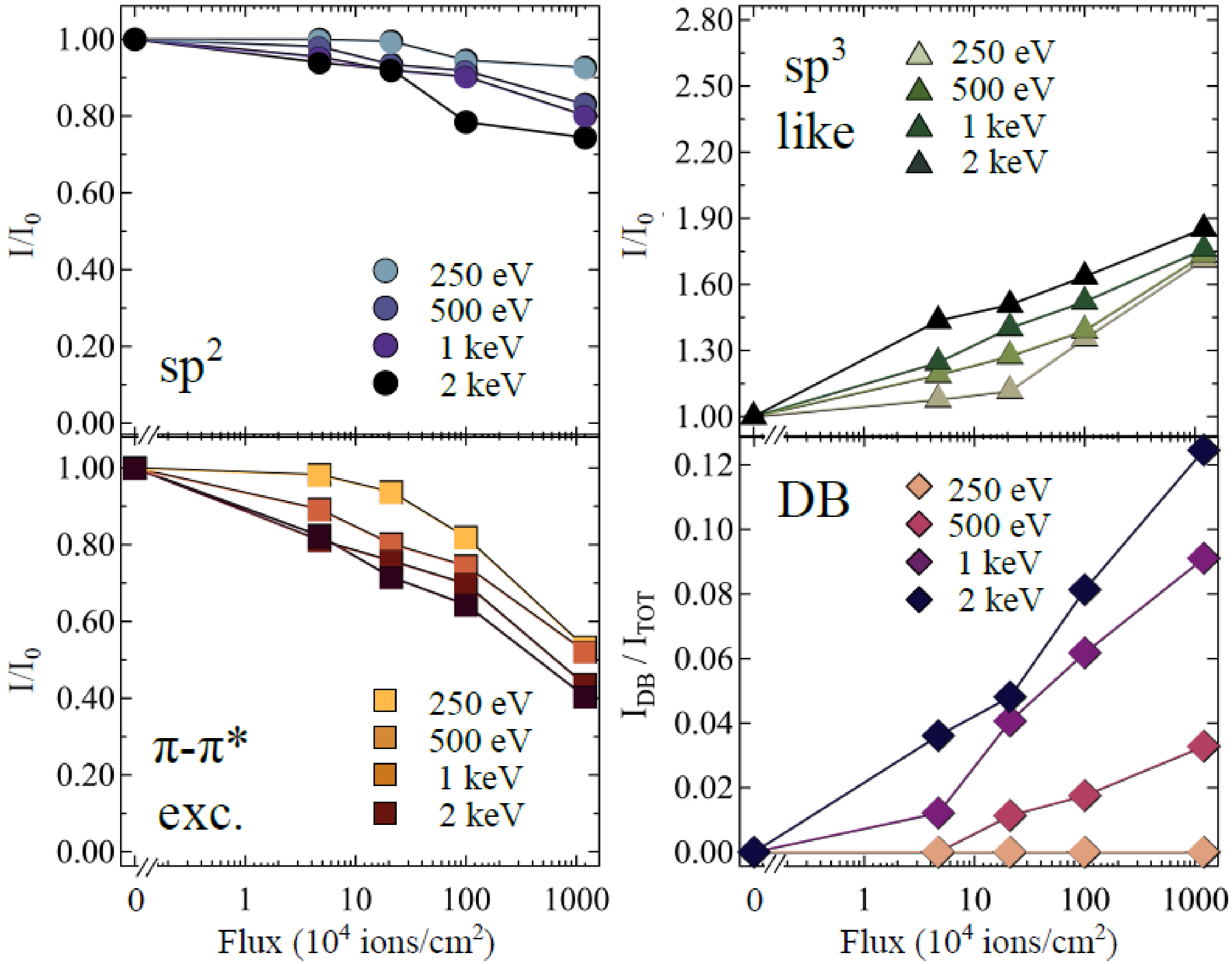
Low ion flux: 4.7 x $10^{14}$ ions/$cm^2$

High ion flux: 1.2 x $10^{17}$ ions/$cm^2$



* at low flux: the $\pi$-$\pi$* excitation most sensitive (reduction of periodicity)

* below 500 eV energy: no DB --> all C atoms in the lattice, no permanent damage



# Conclusions and perspectives

* controlled damage of highly aligned MW-CNT by Ar+  ion bombardment

* demonstrated anisotropy and channeling

* identified the spectral features most sensitive to damage (vs. flux and ion energy)

# Conclusions and perspectives

* controlled damage of highly aligned MW-CNT by Ar+  ion bombardment

* demonstrated anisotropy and channeling

* identified the spectral features most sensitive to damage (vs. flux and ion energy)

* angular dependence of the channeling

* push towards lower flux

# *Acknowledgements*

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SAPIENZA
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UMONS
Université de Mons