MOSE
Molecular Simulation Engineering
enabling innovation

"Mesoscopic simulation for the prediction of macroscopic properties of nanostructured systems."

Maurizio Fermeglia

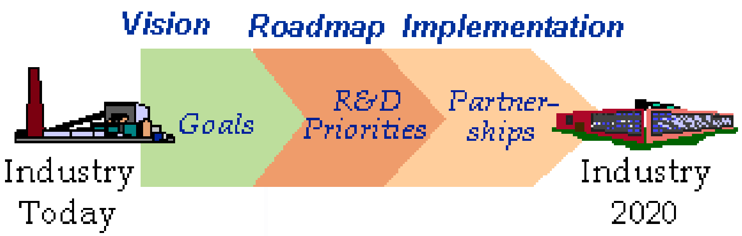
MOSE – DIA - University of Trieste
Via valerio 10, 34127 Trieste (Italy)

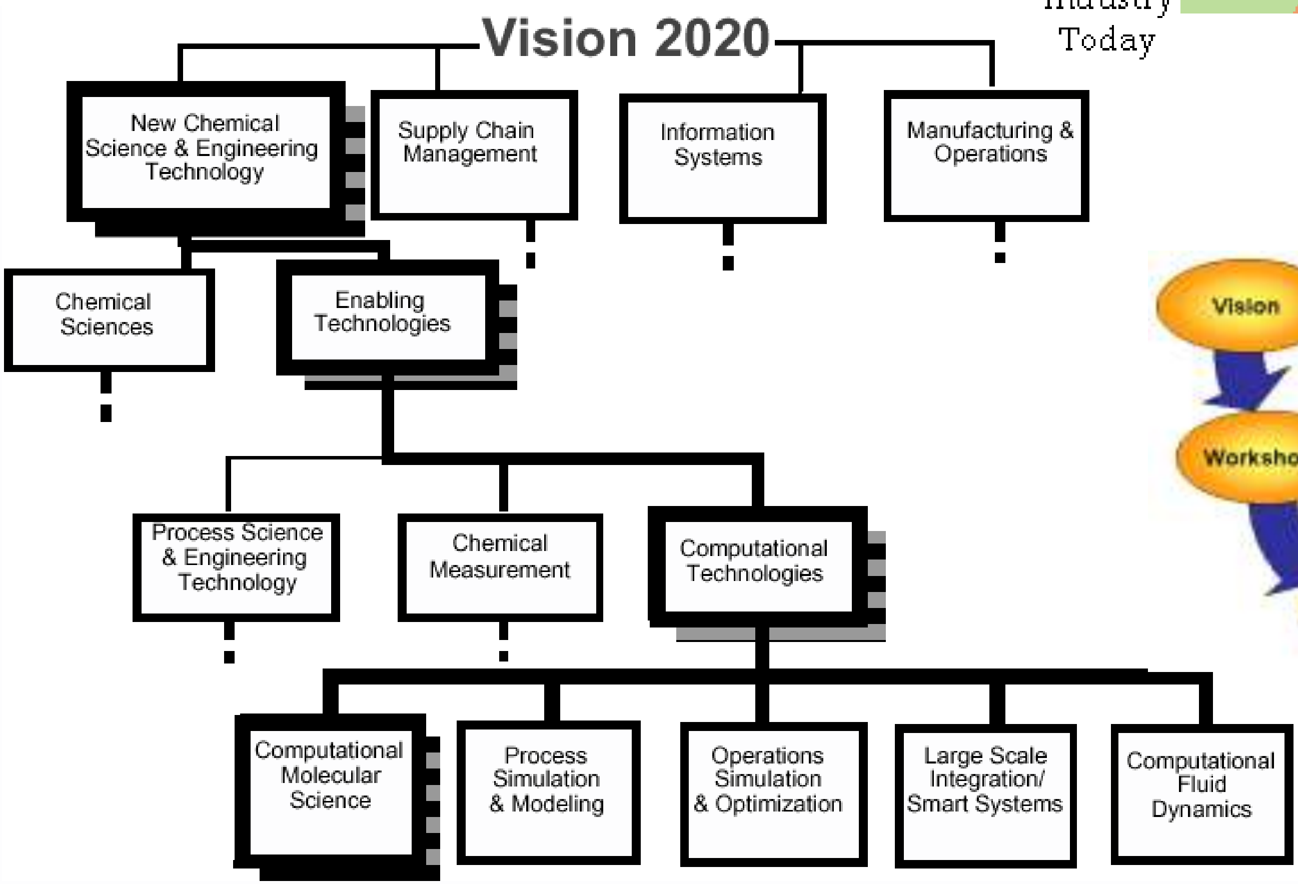
Maurizio.Fermeglia@units.it
mose.units.it

The technology vision 2020

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering *enabling innovation*

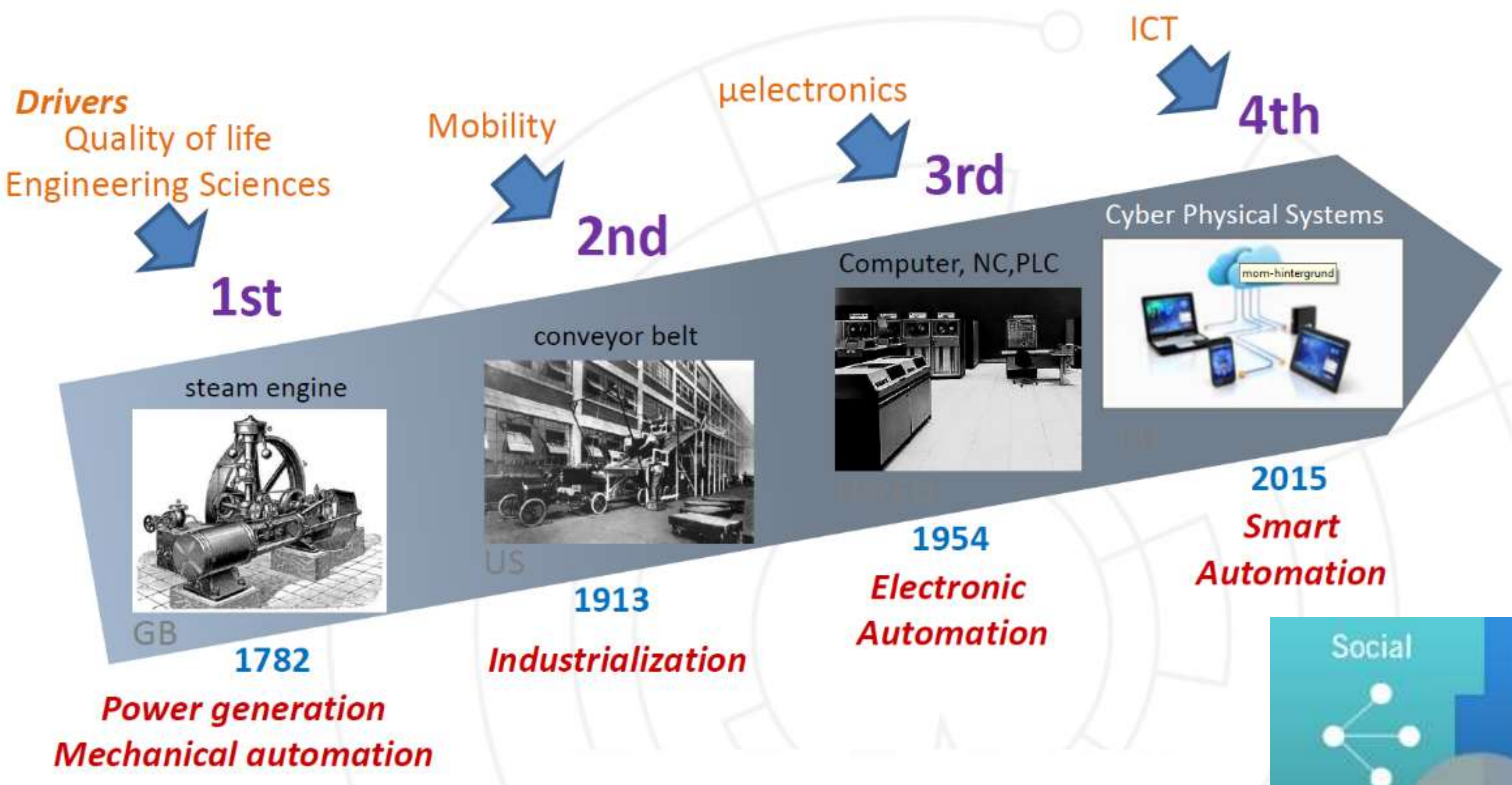




The 4° Industrial revolution – Industry 4.0

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering *enabling innovation*



MATERIALS GENOME INITIATIVE

STRATEGIC PLAN

Nanoscale science and engineering

- Promise of unprecedented understanding and control over basic building blocks and properties of natural and man-made objects

- Recent survey: Nanotechnology Long-term Impacts and Research Directions: 2010 – 2020 **
- Theory, modeling and simulation (TMS)
  - Expected to play key role in nanoscale science and technology
    - INVESTIGATIVE TOOLS: THEORY, MODELING, AND SIMULATION, M. Lundstrom, P. Cummings, M. Alam, M. Ratner, W. Goddard, S. Glotzer, M. Stopa, B. Baird, R. Davis
    - Springer, September 30, 2010
      - Also available on the web at http://www.wtec.org/nano2/

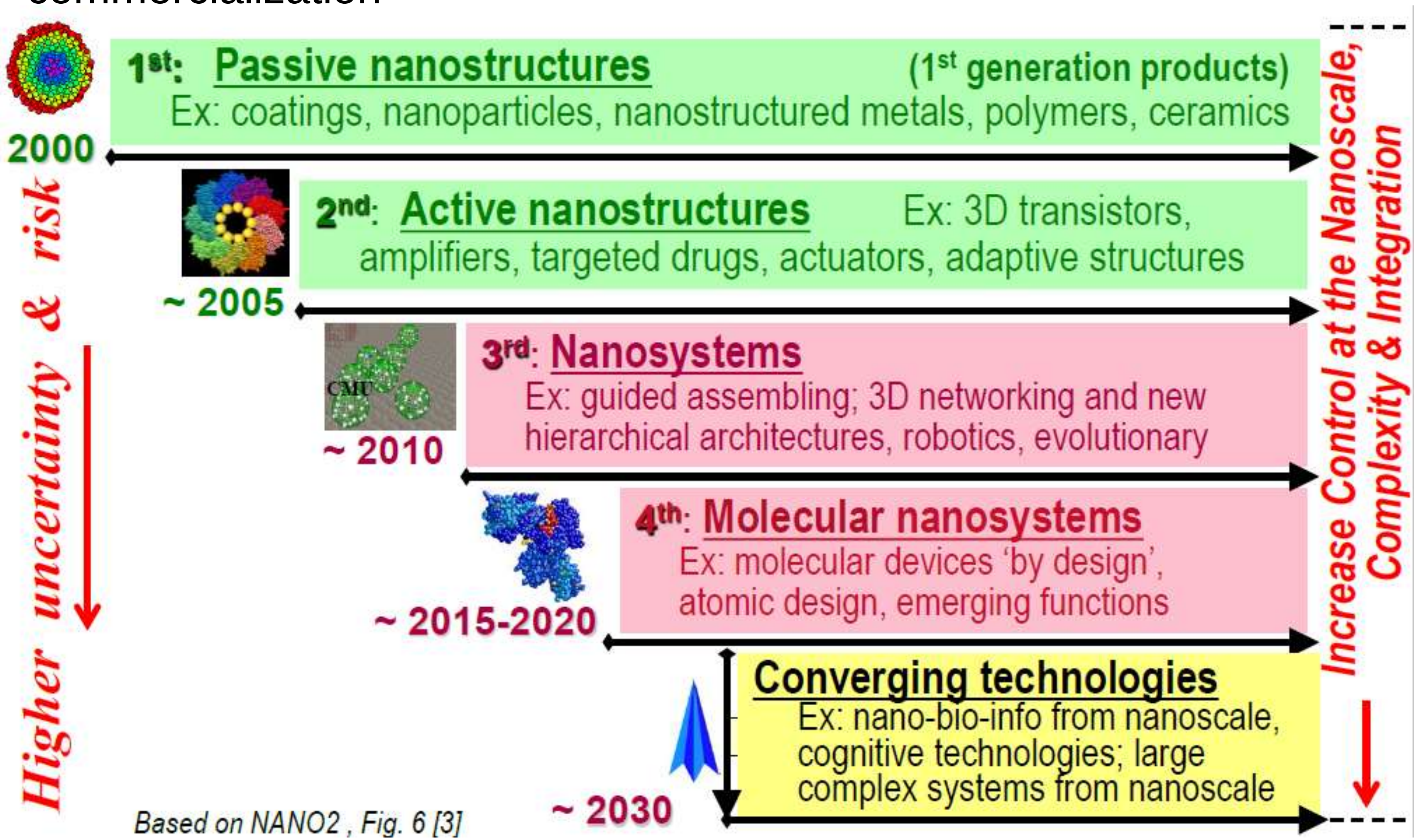
*** M. Roco, FY 2002 National Nanotechnology Investment Budget Request**

**** M.Roco, FY 2010 WTEC, Inc., 2010**

New generation of products and productive processes (2000-2030)

UNIVERSITÀ DEGLI STUDI DI TRIESTE
MOSE
Molecular Simulation Engineering
enabling innovation

- Timeline for beginning of industrial prototyping and nanotechnology commercialization



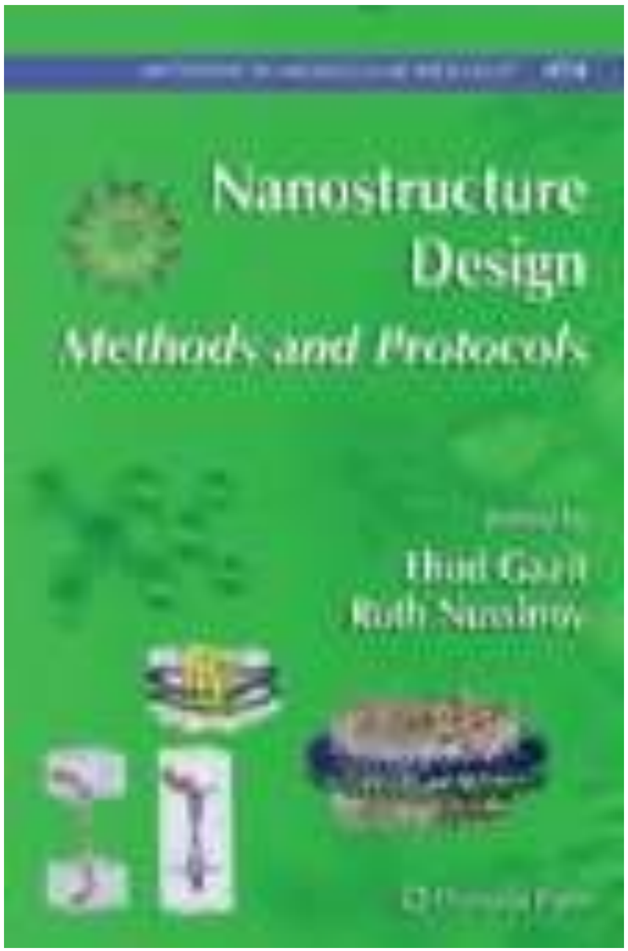
Twelve global trends to 2020

- **Theory, modeling & simulation: x1000 faster, essential design**
- "Direct" measurements – x6000 brighter, accelerate R&D & use
- **A shift from "passive" to "active" nanostructures/nanosystems**
- Nanosystems, some self powered, self repairing, dynamic
- **Penetration of nanotechnology in industry** - toward mass use; catalysts, electronics; innovation– platforms, consortia
- Nano-EHS – **more predictive**, integrated with nanobio & env.
- **Personalized nanomedicine - from monitoring to treatment**
- Photonics, electronics, magnetics – new capabilities, integrated
- Energy photosynthesis, storage use – solar economic by 2015
- Enabling and integrating with new areas – bio, info, cognition
- Earlier preparing nanotechnology workers – system integration
- Governance of nano for societal benefit - institutionalization

Source: MC Roco, April 10 2014

Nanostructures design

Efficient nano structures are obtained from rational design



AND NOT

With a Trial & Error approach

… for the development of multiscale models for complex chemical systems

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE
Molecular Simulation Engineering
enabling innovation

The Nobel Prize in Chemistry 2013
Martin Karplus, Michael Levitt, Arieh Warshel

Share this: 902

The Nobel Prize in Chemistry 2013

Photo: A. Mahmoud
Martin Karplus
Prize share: 1/3

Photo: A. Mahmoud
Michael Levitt
Prize share: 1/3

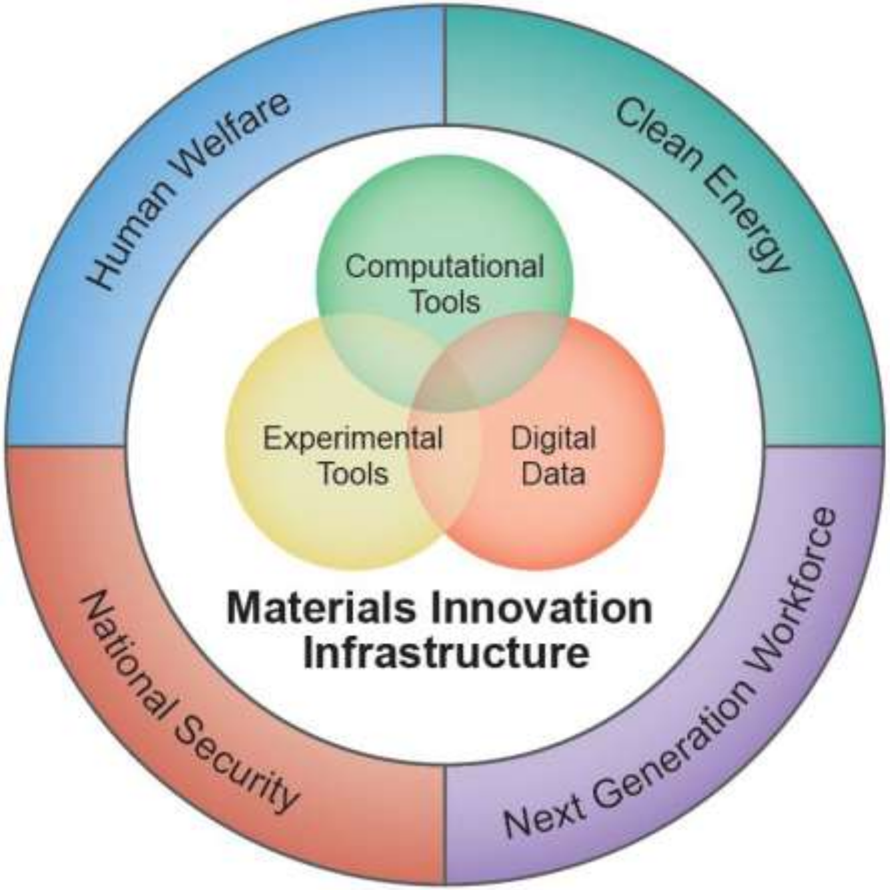
Photo: A. Mahmoud
Arieh Warshel
Prize share: 1/3

The Nobel Prize in Chemistry 2013 was awarded jointly to Martin Karplus, Michael Levitt and Arieh Warshel *"for the development of multiscale models for complex chemical systems"*.

Materials Genome Initiative (MGI)

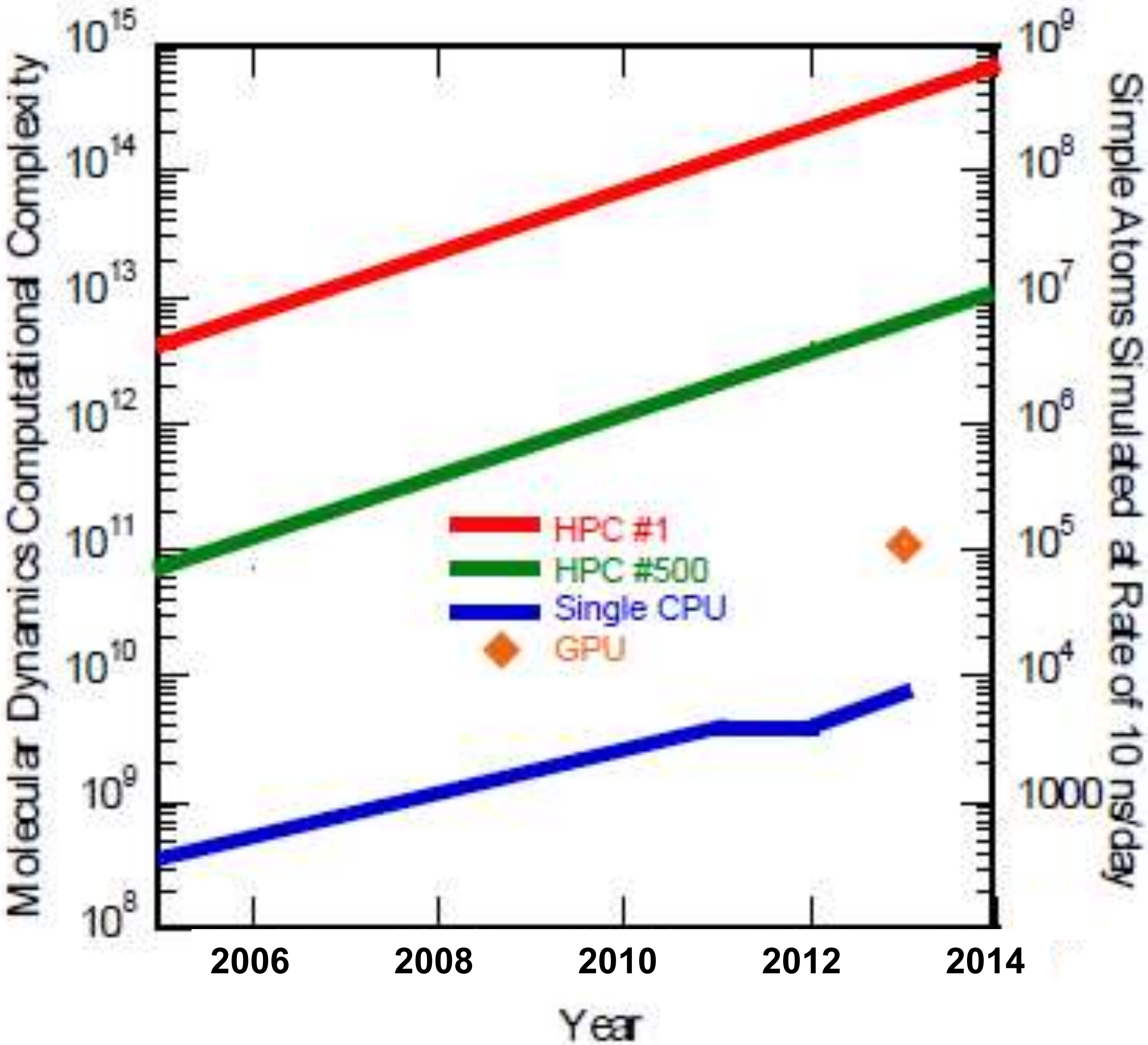
UNIVERSITÀ
DEGLI STUDI DI TRIESTE
MOSE
Molecular Simulation Engineering
enabling innovation

- Developing a materials innovation infrastructure, through advances in and integration of:
  - Computational tools
  - Experimental tools
  - Digital data and informatics
- Achieving National goals in energy, security, and human welfare with advanced materials
- Equipping the next generation materials workforce



TMS: role of GPUs

UNIVERSITÀ DEGLI STUDI DI TRIESTE
MOSE
Molecular Simulation Engineering
enabling innovation



Molecular complexity

N. of time steps * n. atom simulated in one day

Simple atom simulation

For a simple monoatomic fluid is the n. of atoms that can be simulated for 10ns in one day

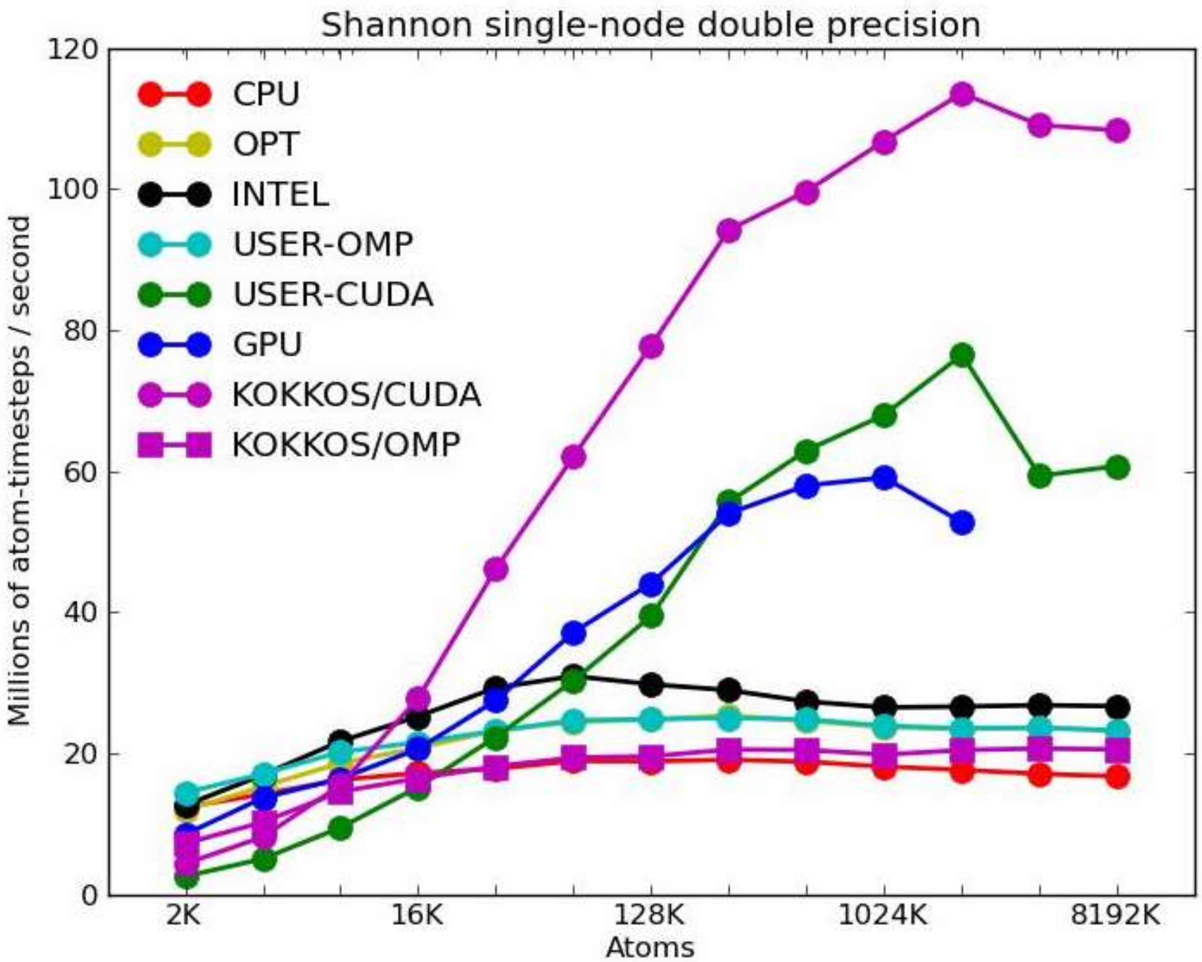
LAMMPS benchmarks for GPU (Kepler) and Intel Xeon Phi – Sept 2014

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering *enabling innovation*

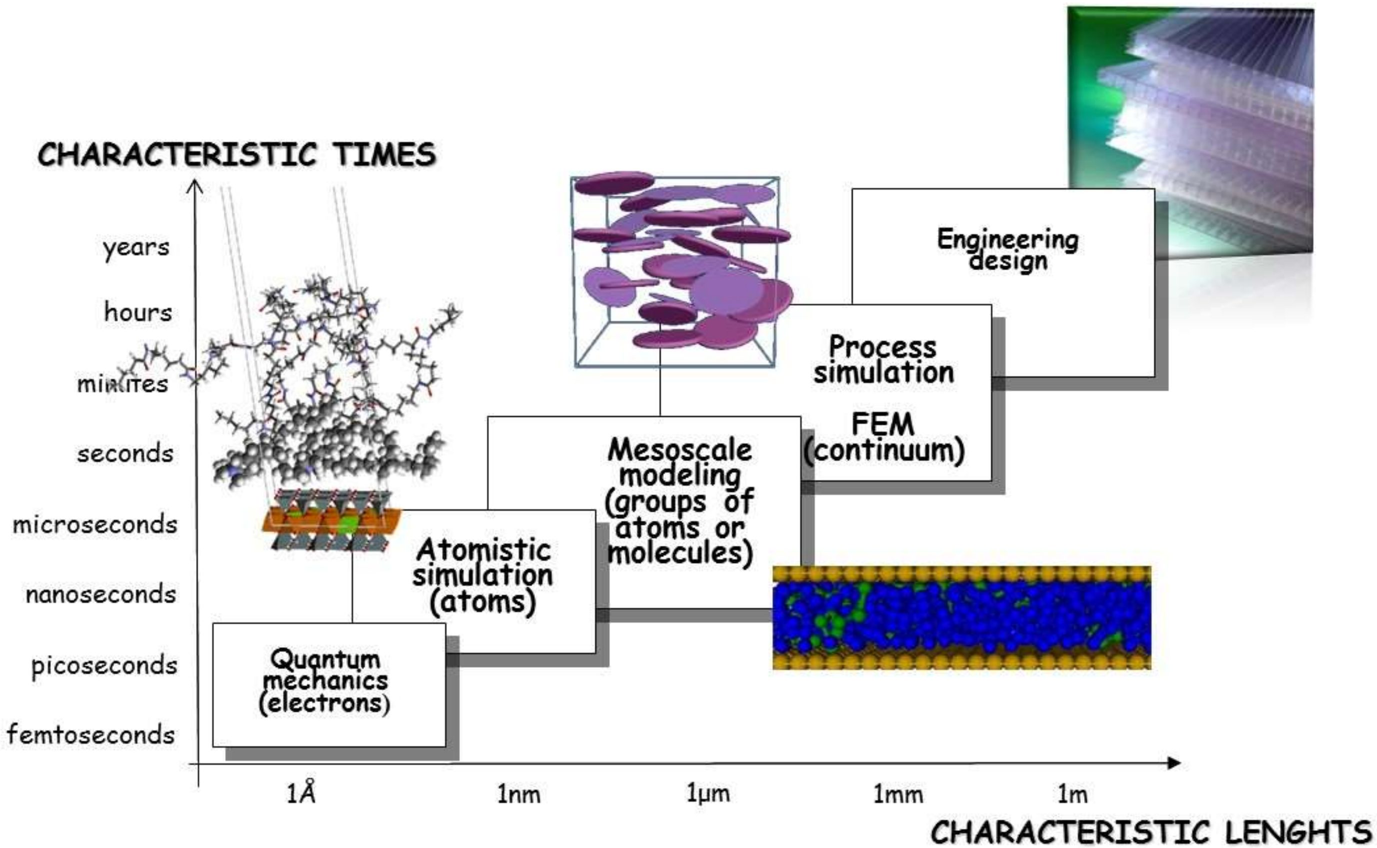
Accelerator packages: GPU, KOKKOS, OPT, USER-CUDA, USER-INTEL, USER-OMP

GPU cluster = Dual 8-core Sandy Bridge Xeons with 2 Kepler GPUs



Multiscale Molecular Modeling

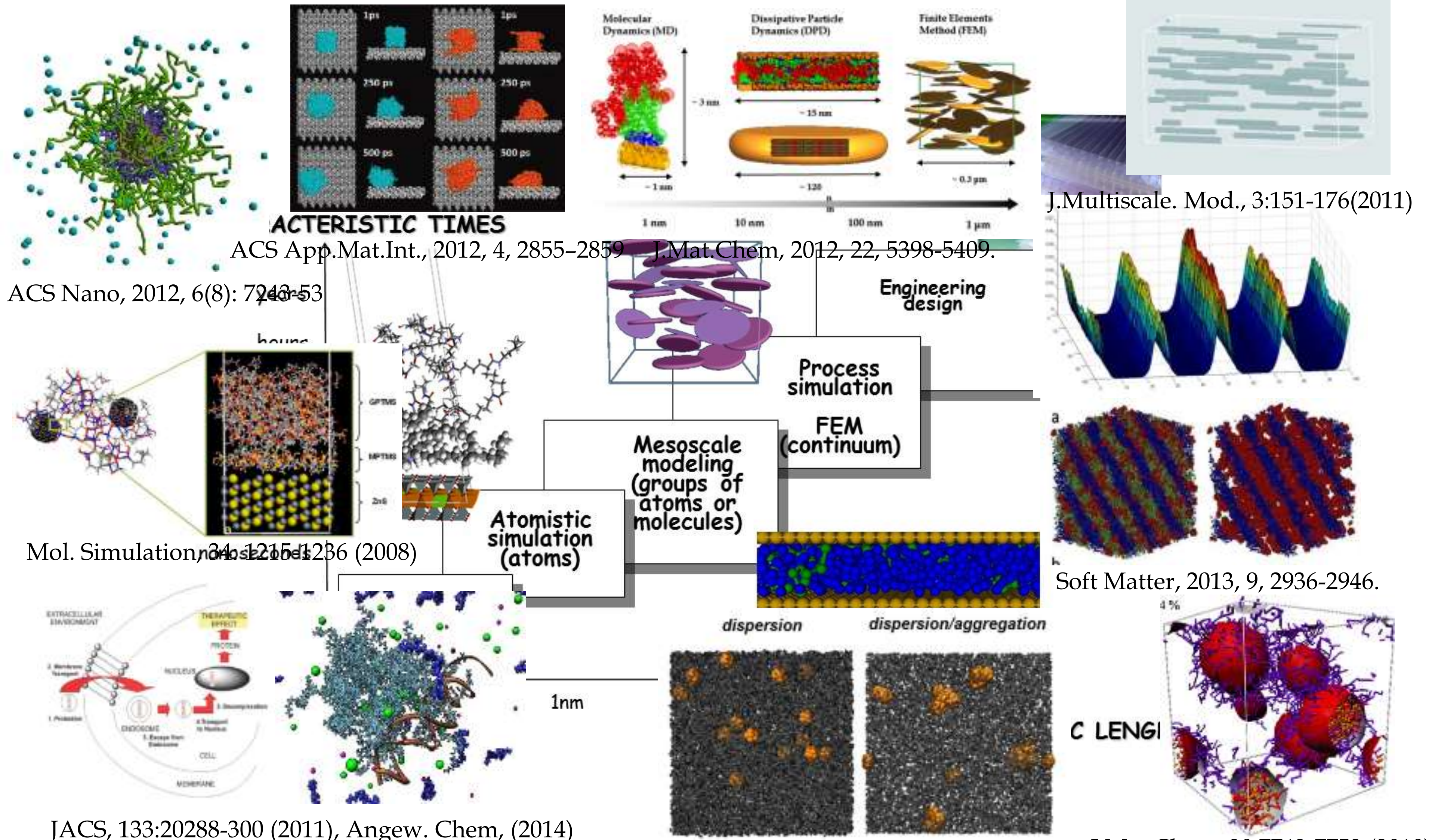
UNIVERSITÀ DEGLI STUDI DI TRIESTE
MOSE
Molecular Simulation Engineering
enabling innovation



Multiscale Molecular Modeling

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE – Molecular Simulation Engineering – *enabling innovation*



ACS Nano, 2012, 6(8): 7243-53

ACS App.Mat.Int., 2012, 4, 2855–2859

J.Mat.Chem, 2012, 22, 5398-5409.

J.Multiscale. Mod., 3:151-176(2011)

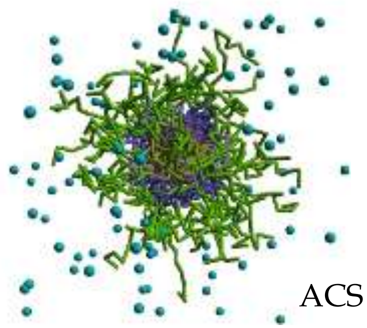
Mol. Simulation, 34: 1215-1236 (2008)

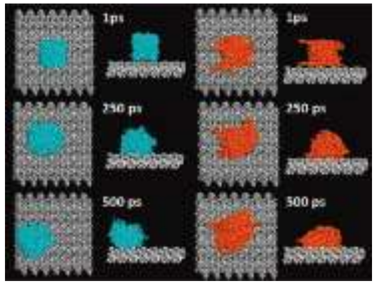
Soft Matter, 2013, 9, 2936-2946.

JACS, 133:20288-300 (2011), Angew. Chem, (2014)

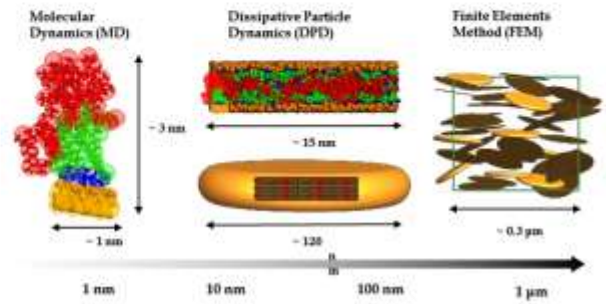
J.Mat.Chem, 20:7742-7753 (2010)

Multiscale Molecular Modeling





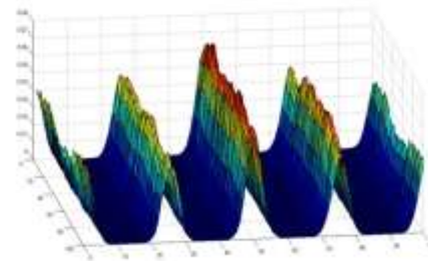
ACS App.Mat.Int., 2012, 4, 2855–2859

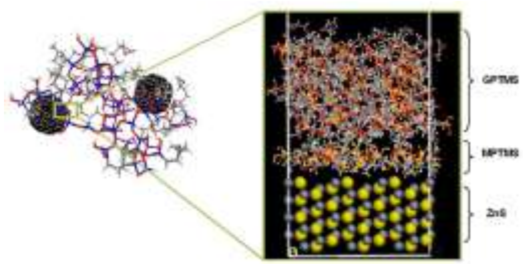


J.Mat.Chem, 2012, 22, 5398-5409.

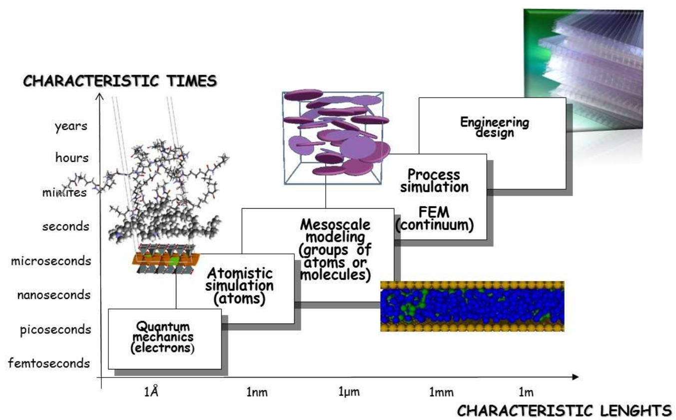
ACS Nano, 2012, 6(8): 7243-53

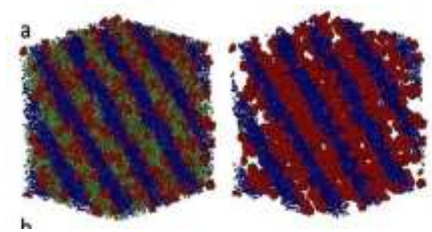
J.Multiscale Mod. 3,151-176(2011)



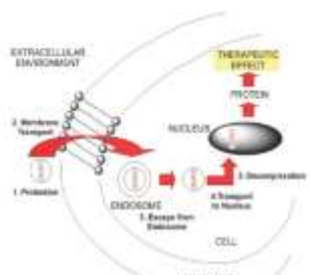


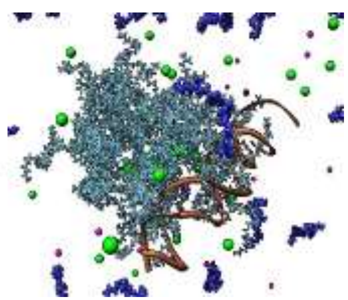
Mol. Simulation, 34: 1215-1236 (2008)



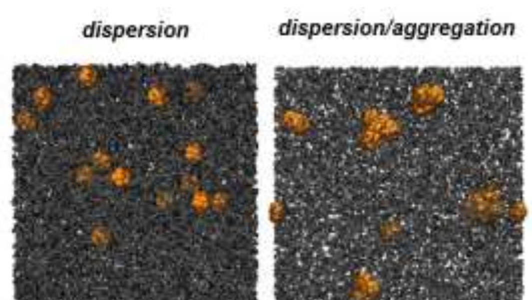


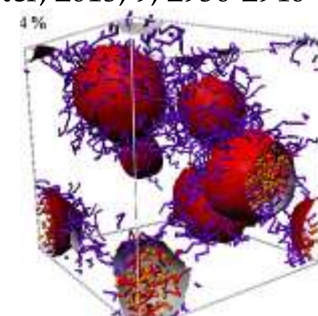
Soft Matter, 2013, 9, 2936-2946





JACS, 133:20288-300 (2011), Angew. Chem, (2014)





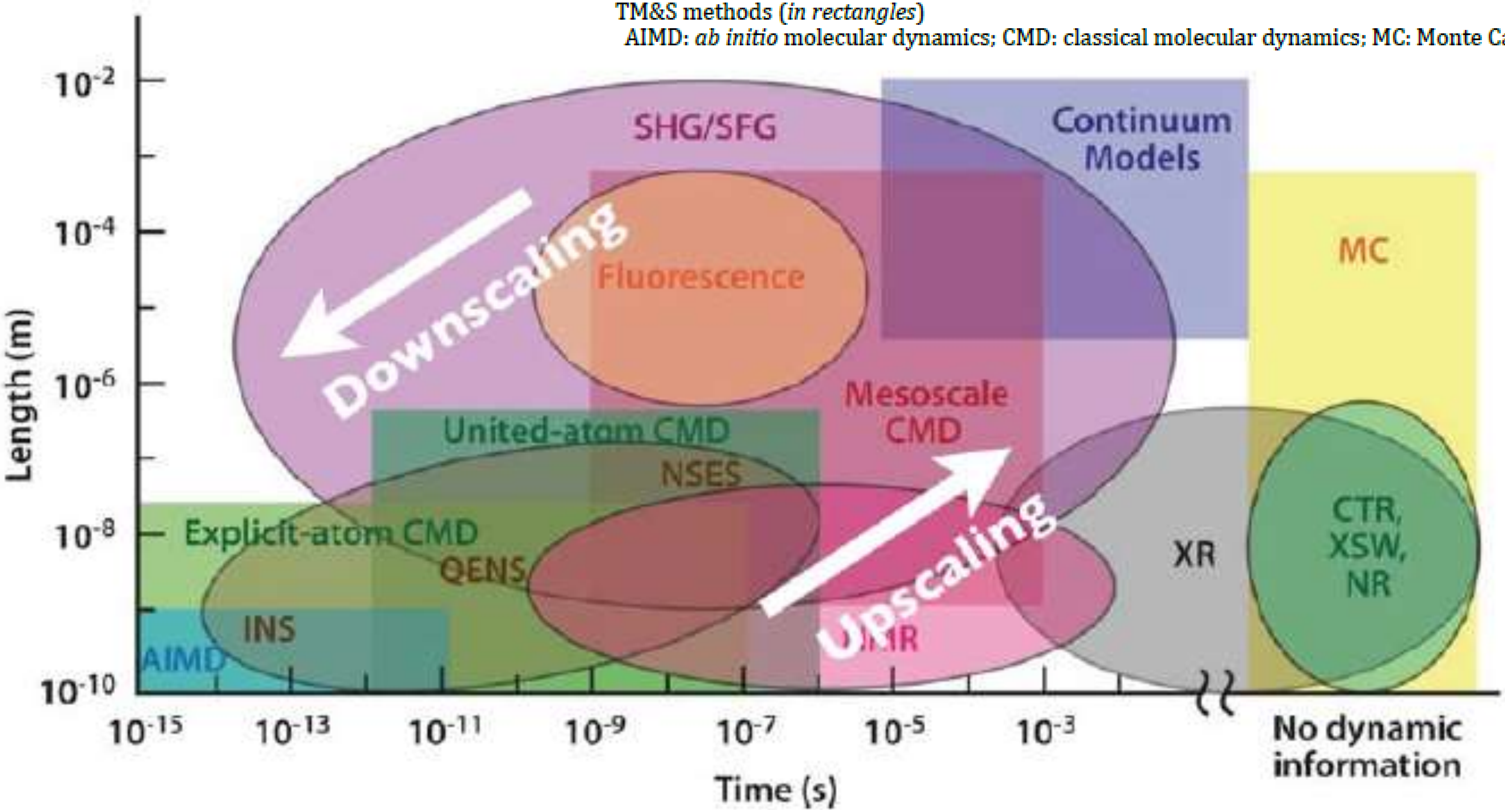
J.Mat.Chem, 20:7742-7753 (2010)

Modelling and experiments

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering *enabling innovation*

<u>Acronyms (and corresponding methods) indicated in the figure:</u>
TM&S methods (*in rectangles*)
AIMD: *ab initio* molecular dynamics; CMD: classical molecular dynamics; MC: Monte Carlo



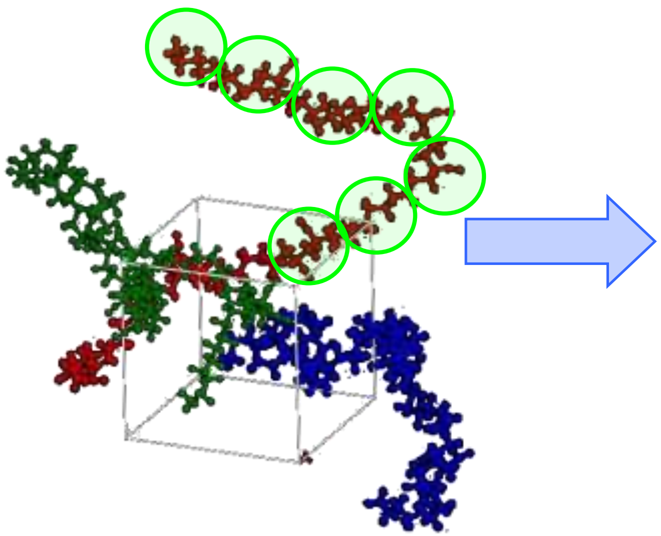
Experimental techniques (*in ovals*)
INS: inelastic neutron scattering; QENS: quasi-elastic neutron scattering; NSES: neutron spin echo spectroscopy; NMR: nuclear magnetic resonance; XR: X-ray reflectivity; SHG: second harmonic generation; SFG: sum frequency generation; CTR: crystal truncation rod (an X-ray method); XSW: X-ray standing wave; NR: neutron reflectivity

Outline of talk

- Introduction
  - Multiscale Molecular Modeling
- Mapping procedure
  - From atomistic simulation to mesoscale
  - From mesoscale to micro FEM
- Applications
  - Functionalized nanoparticles in nanostructured polymer matrices
    - Localization of gold nanoparticles in di-block copolymers
    - Selective placement of magnetic nP in diblock copolymer films
  - Functionalized nanoparticles in un structured polymer matrices
    - Effect of chain length and grafting density
  - Self assembly organization for biomedical applications
    - On nanoparticles
    - Multivalent self assembly building blocks in nanoparticles
- Conclusions

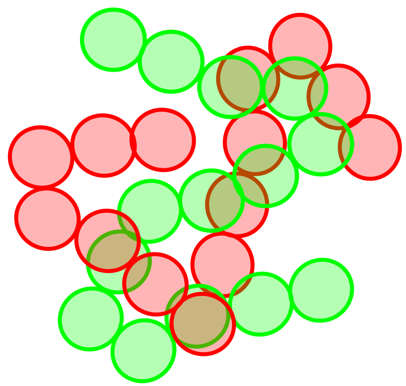
From atoms … to beads

Molecular Dynamics



ForceField based calculations

Dissipative Particle Dynamics



Soft potentials calculations

$$F_i = f\,(a_{ii}, a_{ij}, \ldots, r_c\,)$$

$$\mathbf{f}_i = \sum_{i \neq j} (\mathbf{F}_{ij}^C + \mathbf{F}_{ij}^D + \mathbf{F}_{ij}^R)$$

$$\mathbf{F}_{ij}^C = \begin{cases} a_{ij}(1 - r_{ij})\hat{\mathbf{r}}_{ij} & (r_{ij} < 1) \\ 0 & (r_{ij} \geq 1) \end{cases}$$

$$\mathbf{F}_{ij}^D = -\gamma \omega^D r_{ij} (\hat{\mathbf{r}}_{ij} \cdot \mathbf{v}_{ij}) \hat{\mathbf{r}}_{ij}$$

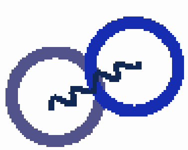
$$\mathbf{F}_{ij}^R = \sigma \omega^R r_{ij} \theta_{ij} \hat{\mathbf{r}}_{ij}$$

Conservative
fluid / system dependent

Dissipative
frictional force, represents viscous resistance within the fluid – accounts for energy loss

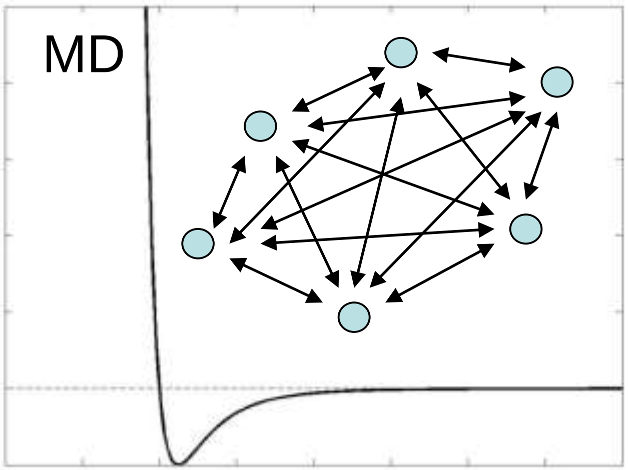
Random
stochastic part, makes up for lost degrees of freedom eliminated after the coarse-graining

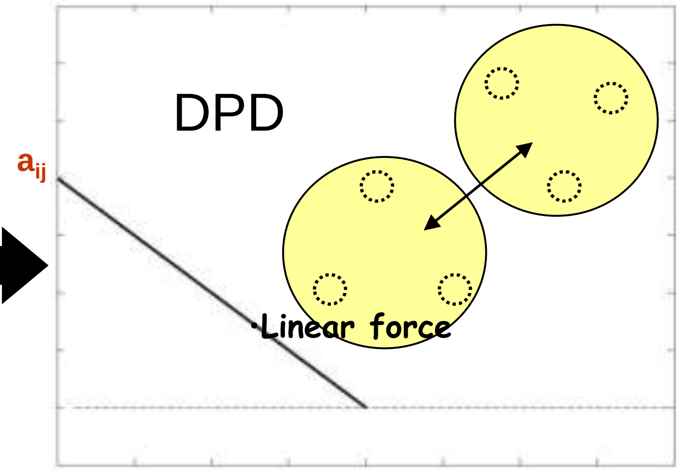
- Polymeric materials are modeled by connecting **beads** by harmonic **springs**



$$f_i = \sum_j C r_{ij}$$

DPD Conservative Force





From Forrest and Sutter, 1995

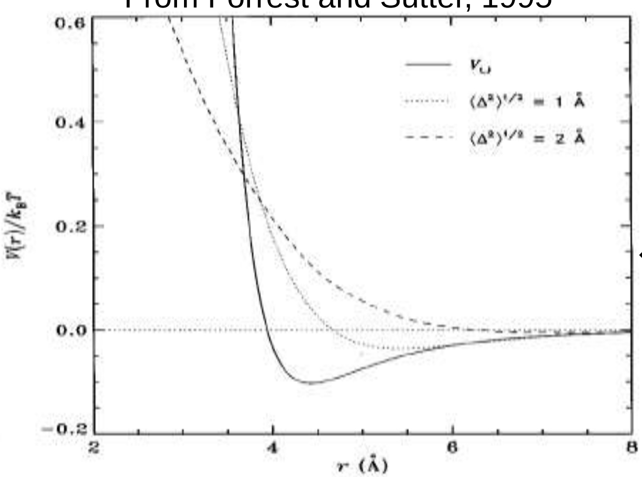
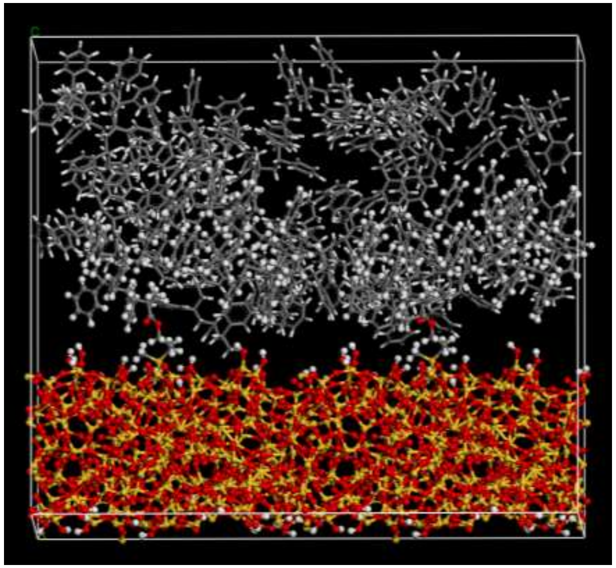


FIG. 3. Comparison of the Lennard-Jones potential (solid curve) used for the nonbonded interactions with the effective potentials obtained after preaveraging with $\langle\Delta^2\rangle^{1/2}=1$ Å (dotted curve) and $\langle\Delta^2\rangle^{1/2}=2$ Å (dashed curve).

- Soft potentials were obtained by averaging the molecular field over the rapidly fluctuating motions of atoms during short time intervals.
- This approach leads to an effective potential similar to one used in DPD.

Parameters for mesoscale models

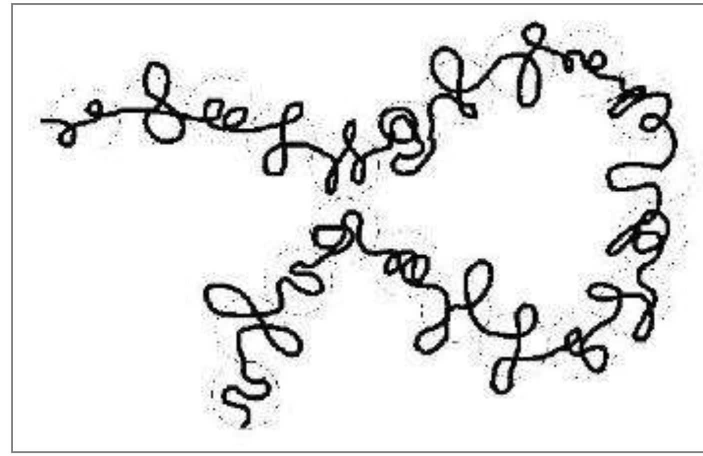
- bead size and Gaussian chain architecture
  - From characteristic ratio (C_∞) in terms of Kuhn length
- bead mobilities M,
  - From bead self diffusion coefficients - MD
- effective Flory-Huggins interactions
  - Method 1: polymer blends, copolymers, spherical nanofillers
    - Differences in non bonded energies between bulk and isolated chain
  - Method 2: nanofillers of any size and shape
    - From energy distribution in MD considering **density distribution** around nanofiller

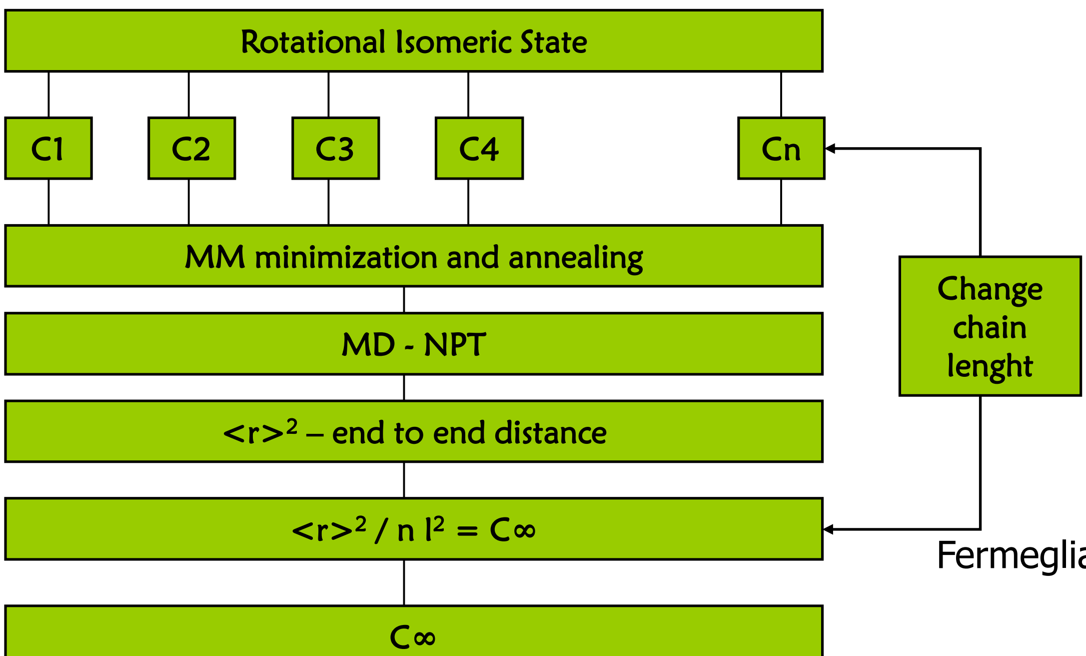


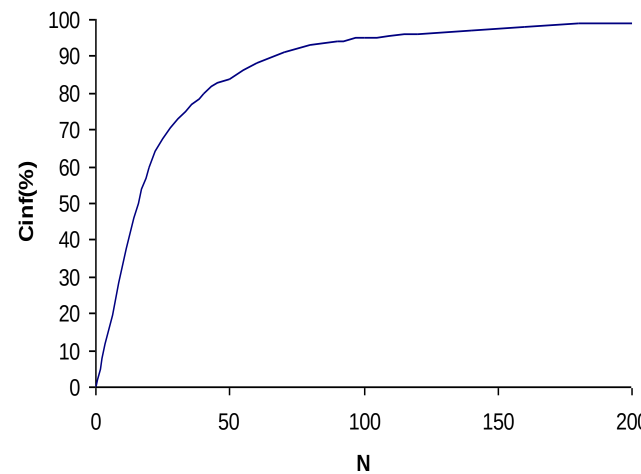
bead size, chain architecture

- MD NPT runs on homo polymers
  - Monomer length
  - C_∞ calculation and Kuhn lenght
  - Chain architecture

$$\begin{cases} \langle r^2 \rangle_0 = C_\infty n l^2 = N L^2 \\ r_{max} = N L \end{cases}$$







Fermeglia, M. et al., Polymer, 47:5979-5989 (2006)

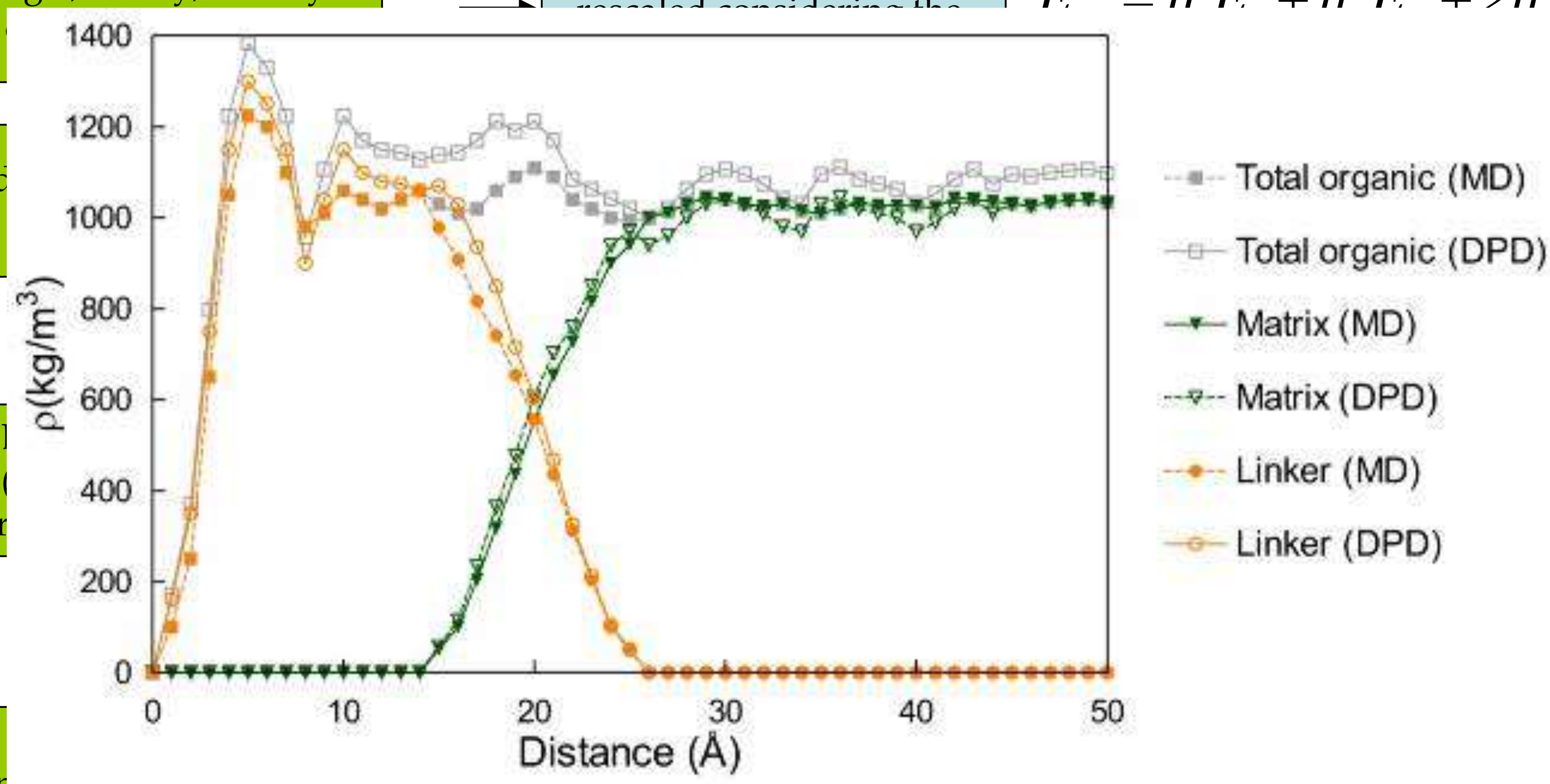
Estimation of DPD parameters from atomistic simulations

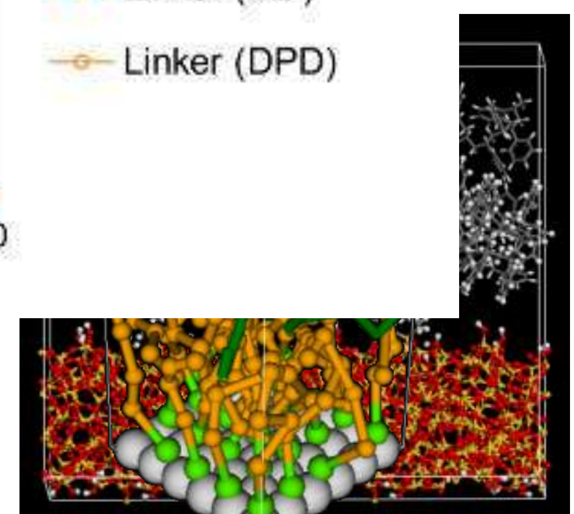
Single, binary, ternary

Binding energies are

Bind

$E^{tot} = n\,E + n\,E + 2n\,E_{ij}$





Density profiles from MD

Density profiles from DPD

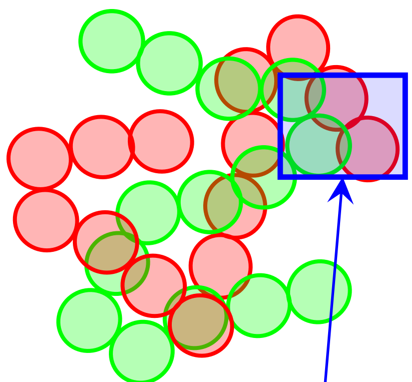
Scocchi et al., J. Phys. Chem. B, (2007), 111, 2143

From beads to micro FEM

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering *enabling innovation*

Dissipative Particle Dynamics

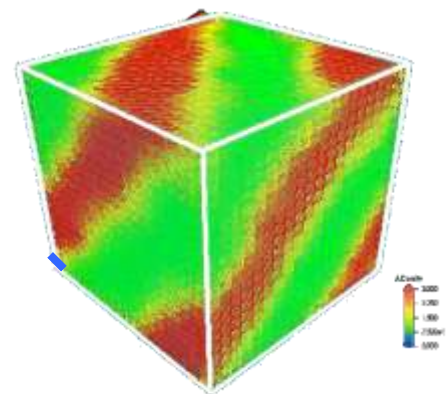


Soft potentials calculations

$$F_i = f\,(a_{ii}, a_{ij}, \ldots, r_c)$$

Characteristic dimension of mesoscopic system

Micro - FEM Simulation



FEM Analysis:

Macroscopic properties

Toth R., Santese F., Pereira S.P., Romero-Nieto D., Pricl S., Fermeglia M., Posocco, **Journal of Materials Chemistry**, 22, 5398-5409 (2012)

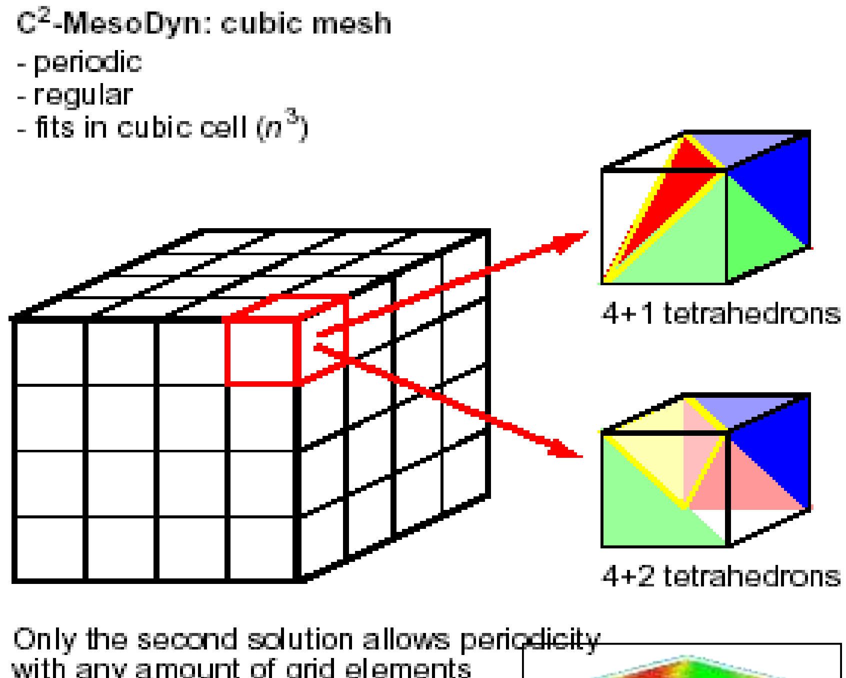
From beads … to micro: fixed grid

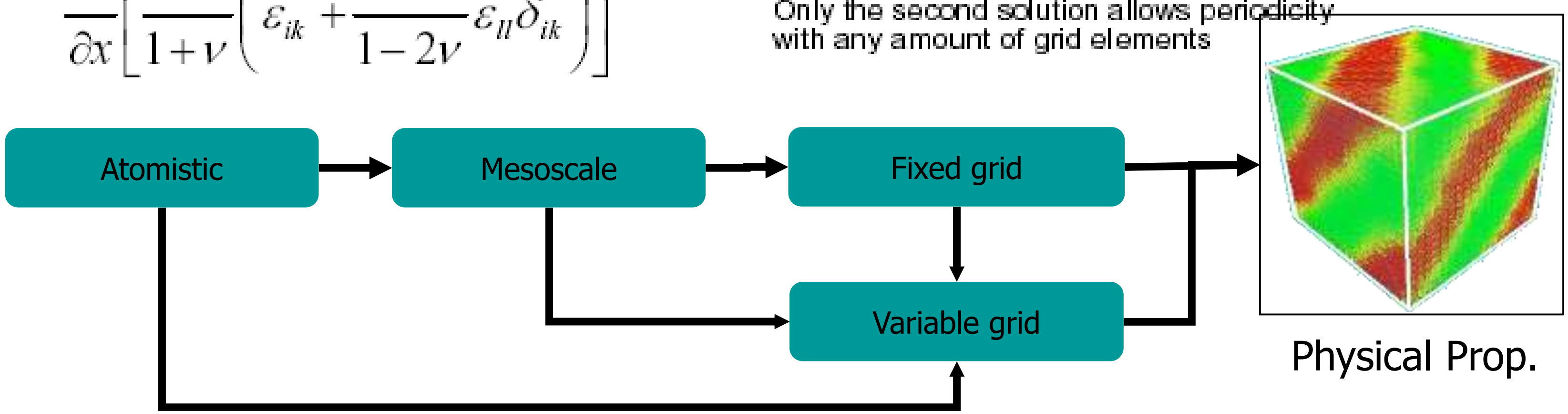
- Geometry: map cubes to Palmyra tetrahedrons
- Laplace equation is solved for electric conductance, diffusion and permeability

$$\mathrm{div}\,\sigma(\mathrm{r})\,\mathrm{grad}\,\varphi = 0$$

- Local deformation allow the calculation of mechanical properties

$$\frac{\partial}{\partial x}\left[\frac{E}{1+\nu}\left(\varepsilon_{ik} + \frac{\nu}{1-2\nu}\varepsilon_{ll}\delta_{ik}\right)\right]$$





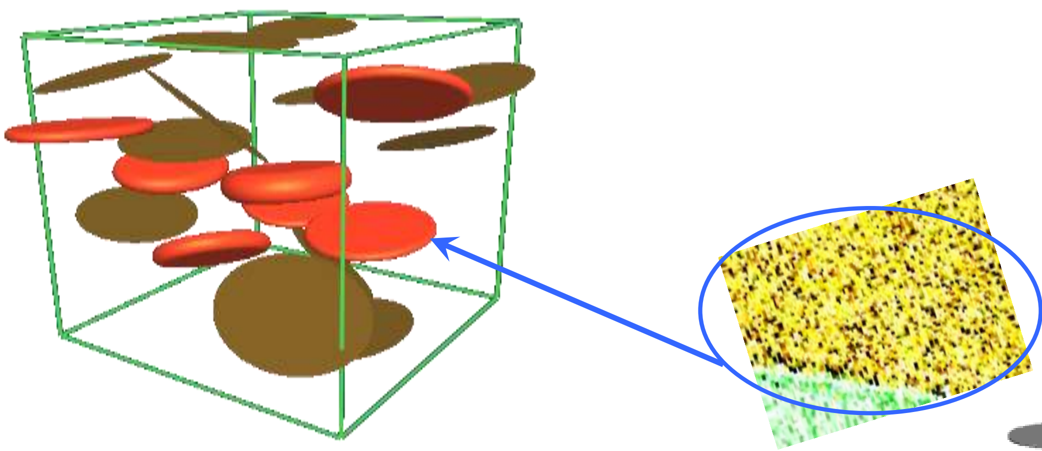
Pereira S.P, Scocchi G., Toth R., Posocco P., Romero-Nieto D., Pricl S., Fermeglia M., Journal of Multiscale Modeling, 3:151-176 (2012)

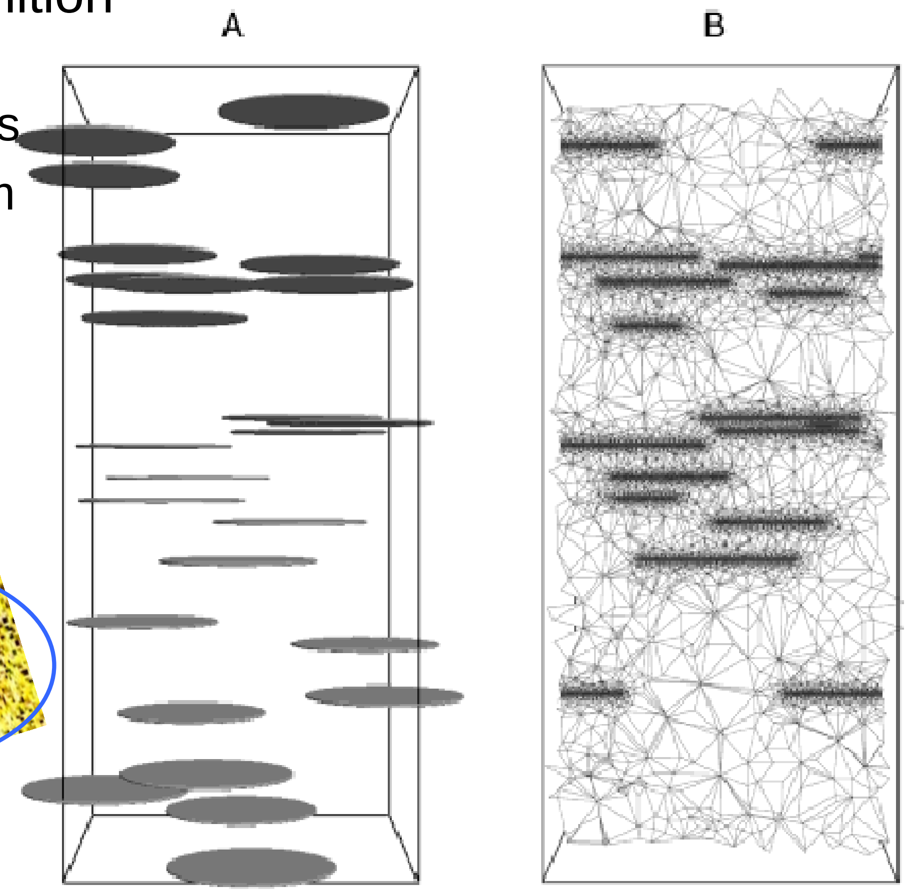
UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering enabling innovation

microFEM modelling: variable grid

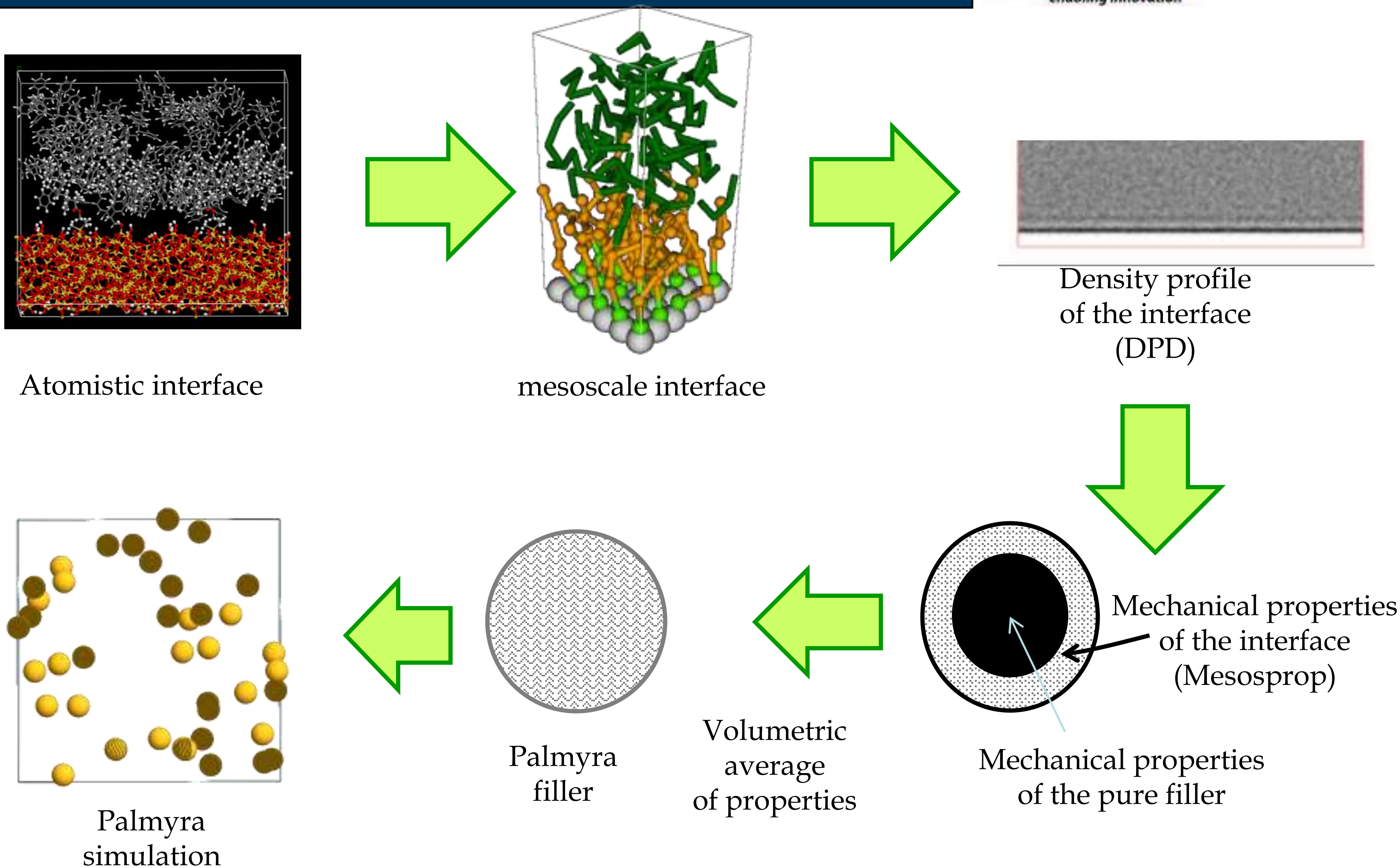
- Platelets orientation
  – Alignement is defined and assigned to each platelet
- Pure component properties definition
  – Properties of the stacks is based on mesoscale simulations
  – Pure component properties from MD or experimental data





Pereira S.P, Scocchi G., Toth R., Posocco P., Romero-Nieto D., Pricl S., Fermeglia M., Journal of Multiscale Modeling, 3:151-176 (2012)

Simulation protocol for core-shell nanoparticles

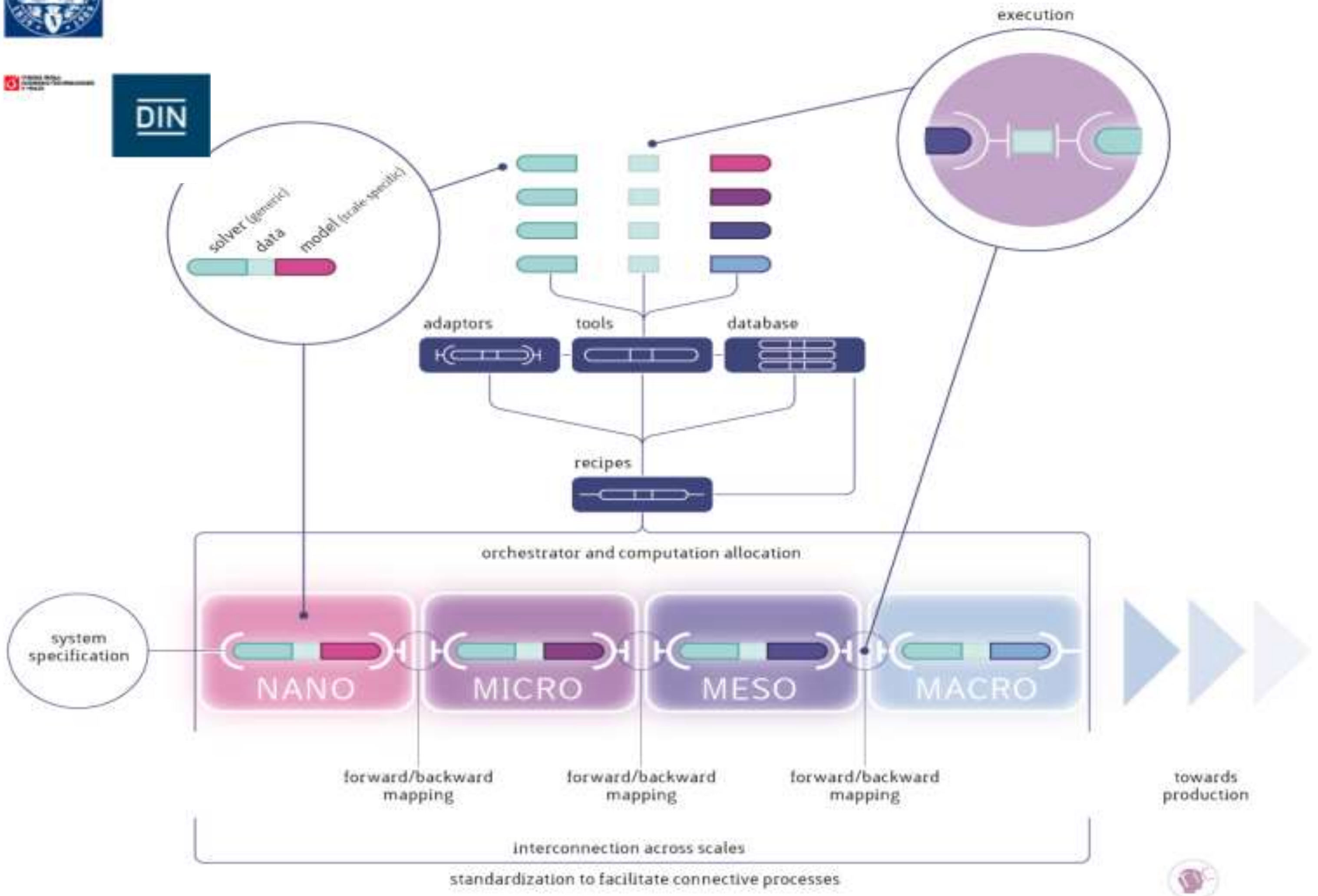


MoDeNa project: Modeling of morphology Development of micro and Nano Structures

UNIVERSITÀ DEGLI STUDI DI TRIESTE

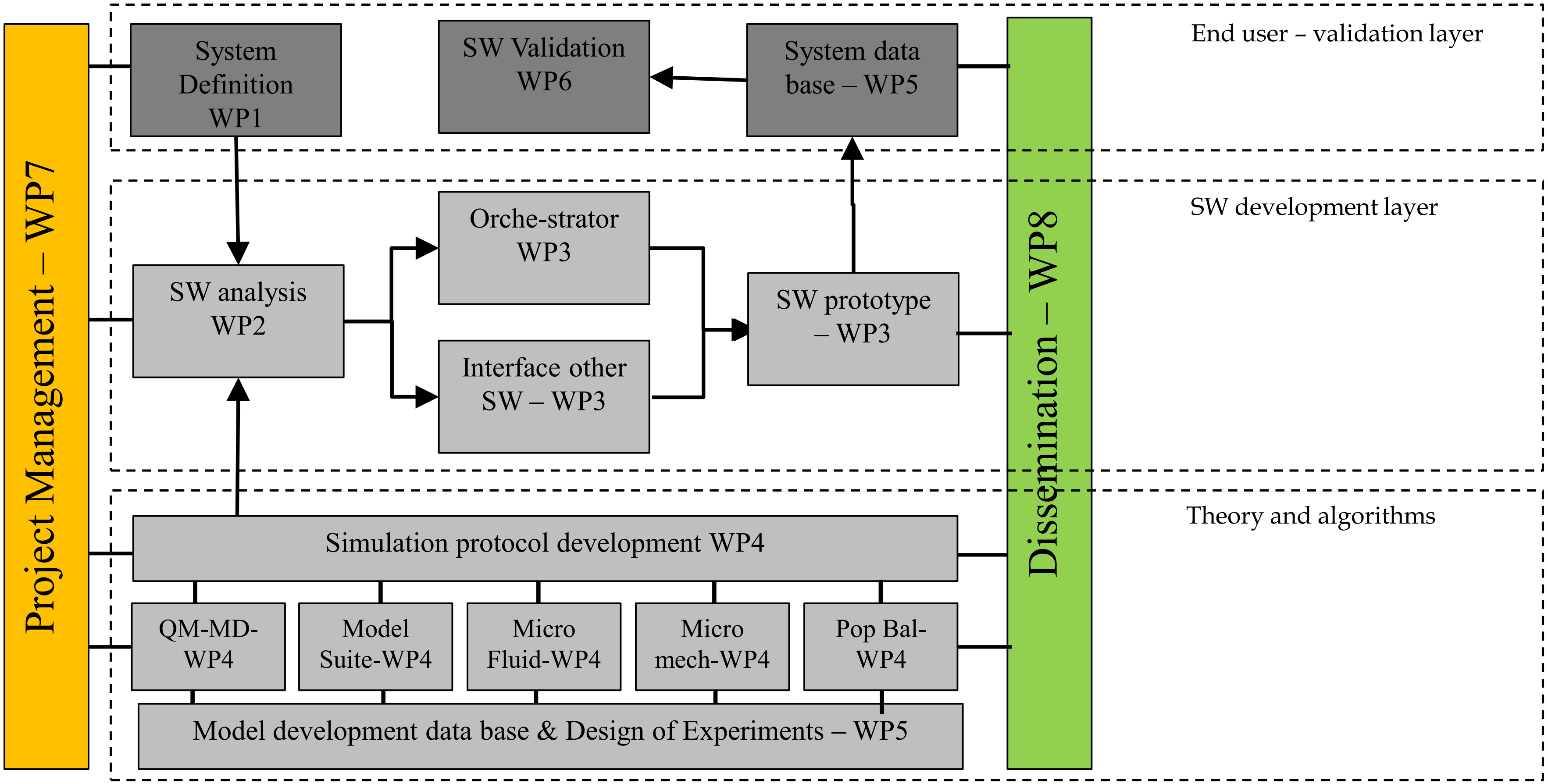
MOSE Molecular Simulation Engineering *enabling innovation*

http://www.modenaproject.eu/



MODENA: Multiscale modeling Framework

http://www.modenaproject.eu/

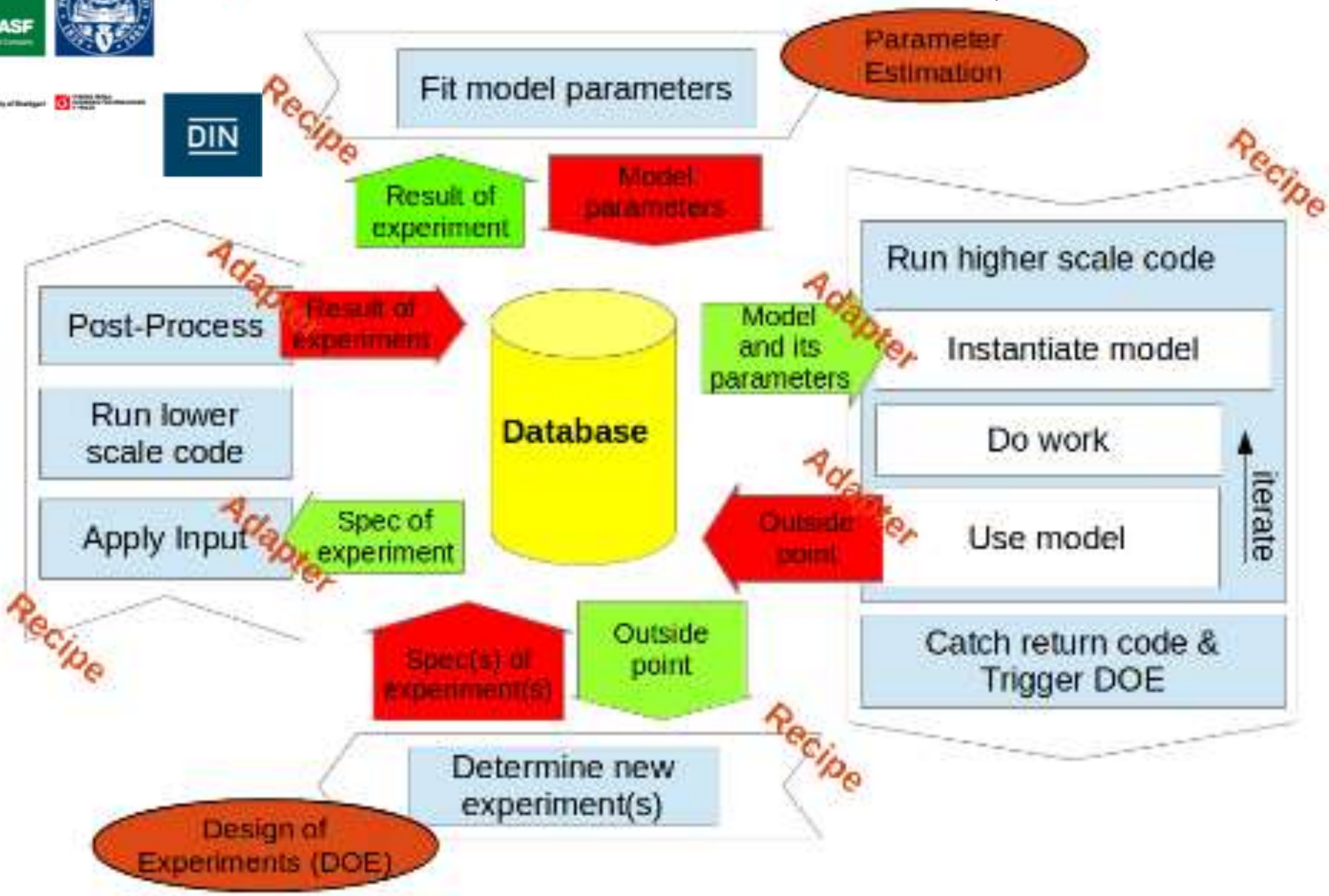


MoDeNa: Multiscale modeling Framework

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering enabling innovation

http://www.modenaproject.eu/



Outline of talk

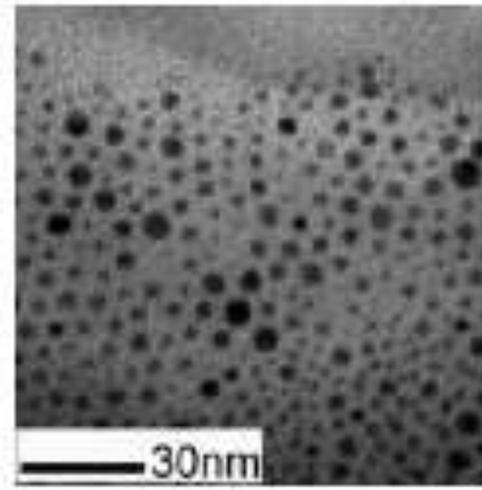
- Introduction
  - Multiscale Molecular Modeling
- Mapping procedure
  - From atomistic simulation to mesoscale
  - From mesoscale to micro FEM
- Applications
  - Functionalized nanoparticles in nanostructured polymer matrices
    - Localization of gold nanoparticles in di-block copolymers
    - Selective placement of magnetic nP in diblock copolymer films
  - Functionalized nanoparticles in un structured polymer matrices
    - Effect of chain length and grafting density
  - Self assembly organization for biomedical applications
    - On nanoparticles
    - Multivalent self assembly building blocks in nanoparticles
- Conclusions

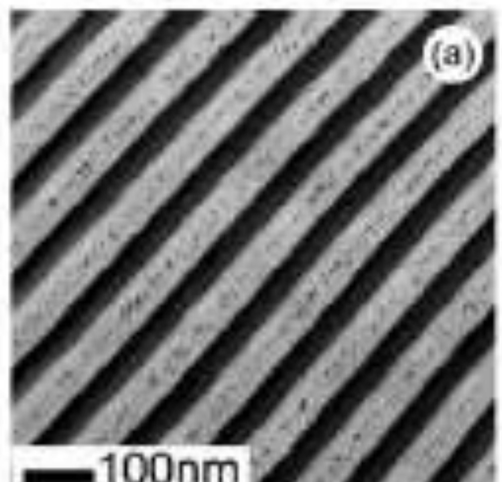
Self assembly of nanoparticles in block copolymers

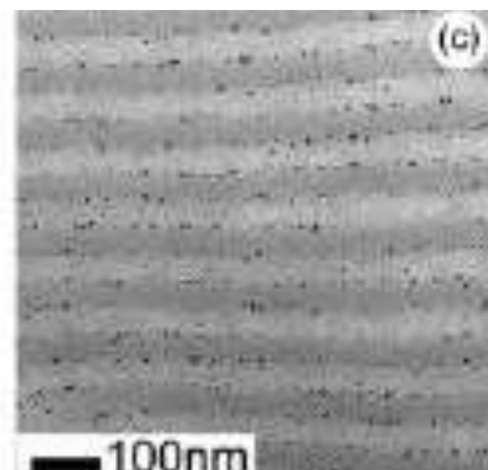
UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE
Molecular Simulation Engineering
enabling innovation

- Organic polymer and inorganic particles mixing (PPNs)
  - PPNs fabrication process via self-assembly
  - By dispersion of particles in diblock copolymers
- Predicted microstructure morphology depends on
  - nature of the system
    - chemistry and architecture of the blocks
    - volume fraction of the nanoparticles
    - strength and type of interactions
  - process conditions
    - temperature
    - shear
- SCOPE: model the system morphology
- Experimental evidence by Chiu et al.
  - poly styrene-2 vinyl pyridine
- Applications:
  - Opto electronic industry



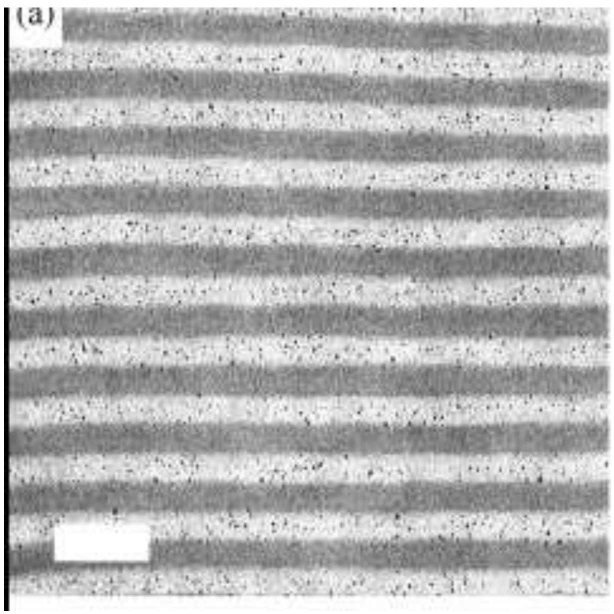


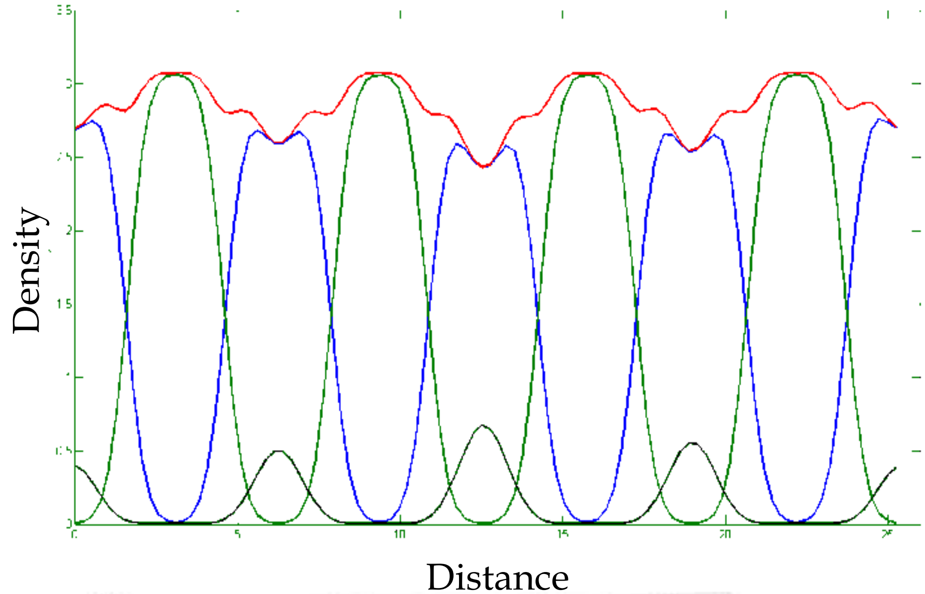


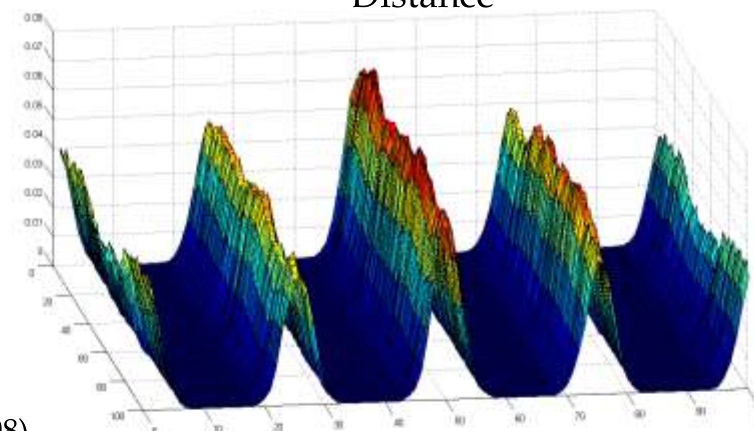
Chiu, J.J, Bumjoon J.K., Kramer E.J. Pine, D.J., **JACS**, 2005, 127, 5036

Lamellae: A (or B) covering

- segregation in the center of the corresponding domain;
- perfect agreement with experimental evidences.



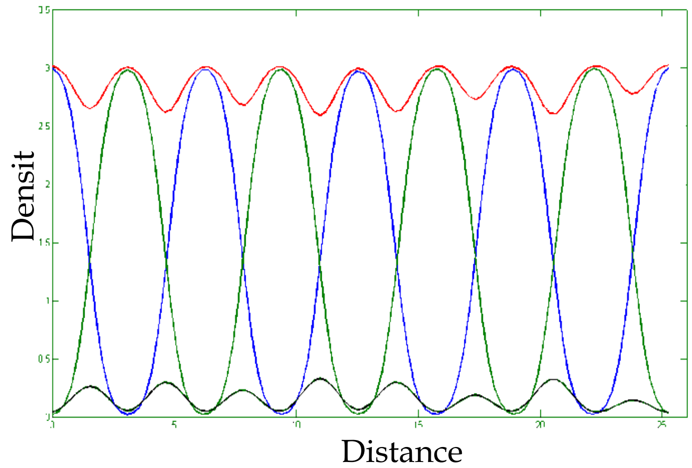


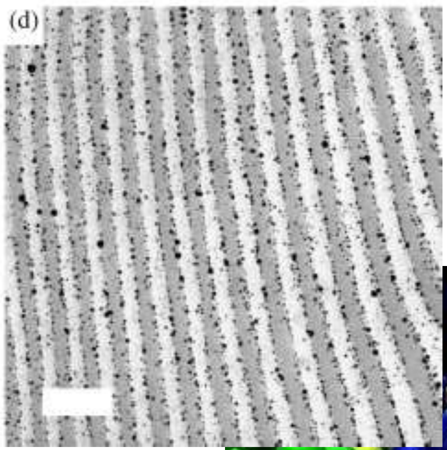


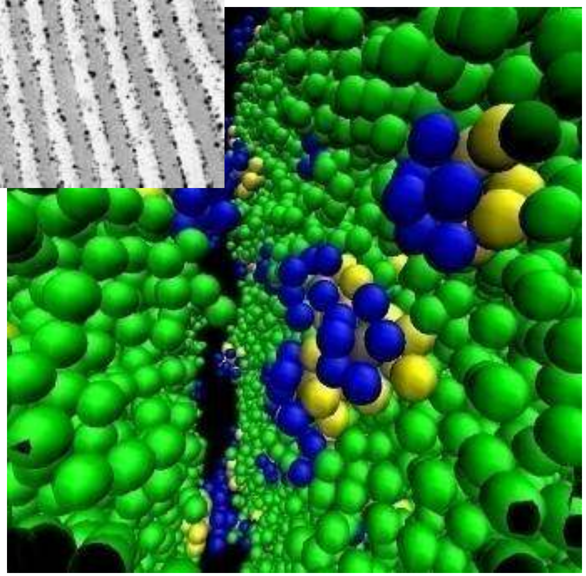
Maly M., Posocco P., Pricl S., Fermeglia M.. **IEC**, 47: 5023-5038 (2008)
Posocco P., Posel Z., Fermeglia M., Lísal M., Pricl S., **J. Mater. Chem.**, 20:10511-10520 (2010)
Posel Z., Posocco P., Fermeglia M., Lisal M., Pricl S., **Soft Matter**, DOI: 10.1039/c2sm27360h (2013)

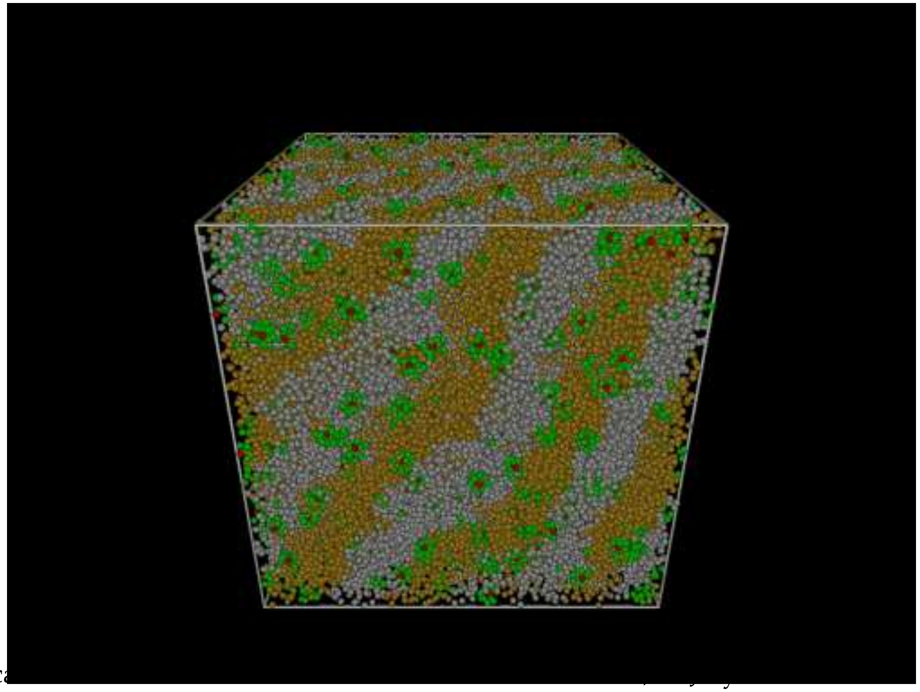
Lamellae: A and B covering (A_6B_6)

- nanoparticles at the interfaces between the A-B blocks
  - Agreement with experiments





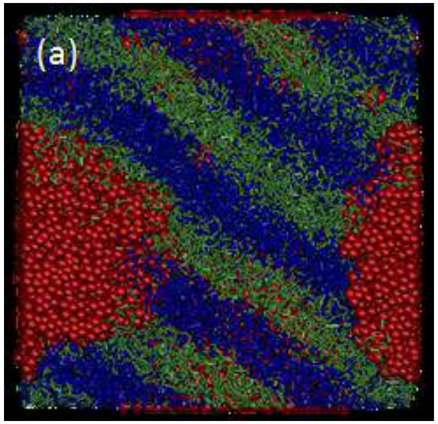


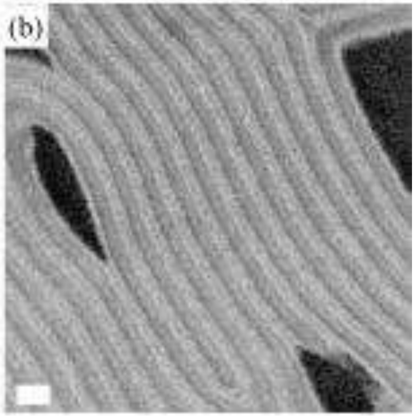


PS grafting only: loading: $\phi_p = 0.2$

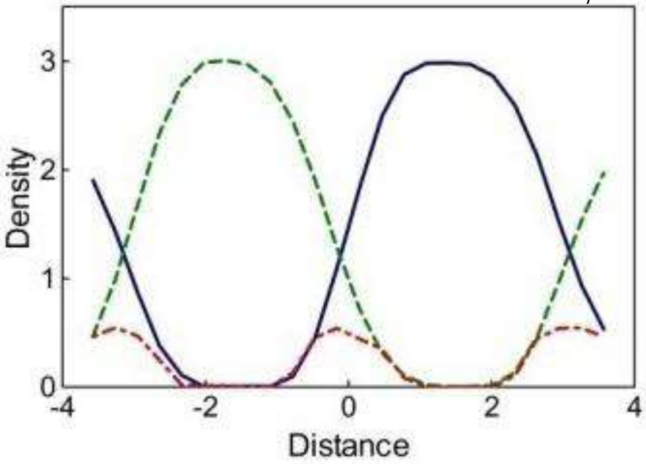
PS4Au8

- For *PS4Au8* system, large regions of nanoparticles (red) – exp. evidence
- Same tendency to migrate to the interface as the PS grafting density decreases
  - Line legend:
    - (green), *PS*;
    - (blue),*PVP*;
    - (red), *Au*.





Kim et al., Macromolecules, 39, 4198, 2006

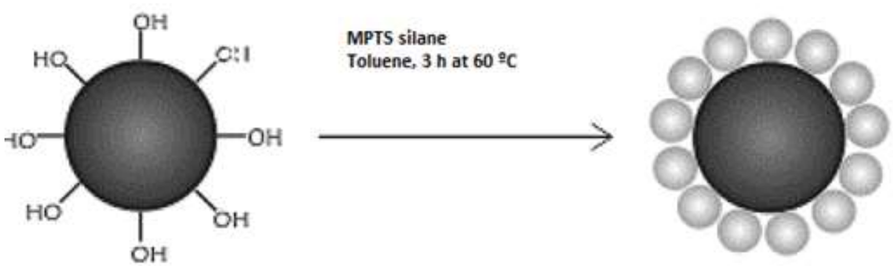


PS1Au11

Posocco P., Posel Z., Fermeglia M., Lísal M., Pricl S., J. Mater. Chem., 20:10511-10520 (2010)
Posel Z., Posocco P., Fermeglia M., Lisal M., Pricl S., Soft Matter, DOI: 10.1039/c2sm27360h (2013)

Selective placement of magnetic nanoparticles in diblock copolymer films

- Goal:
  - NPs selectively placed into the PMMA domains ?
  - Max concentration for preserving lamellar morphology?
  - Verify Mesoscale model (DPD)
- Materials & methods
  - diblock copolymer PS-*b*-PMMA
  - compatibilized magnetic (Fe_3O_4) nanoparticles
  - 1, 2, and 5% wt
  - Solvent vapor annealing



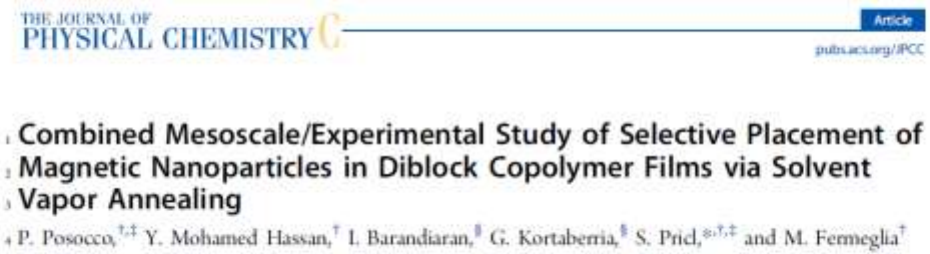
Posocco P., Y. Hassan, I. Barandiaran, G. Kortaberria, Fermeglia M., Lísal M., Pricl S., J. Phys. Chem.C., (2016)

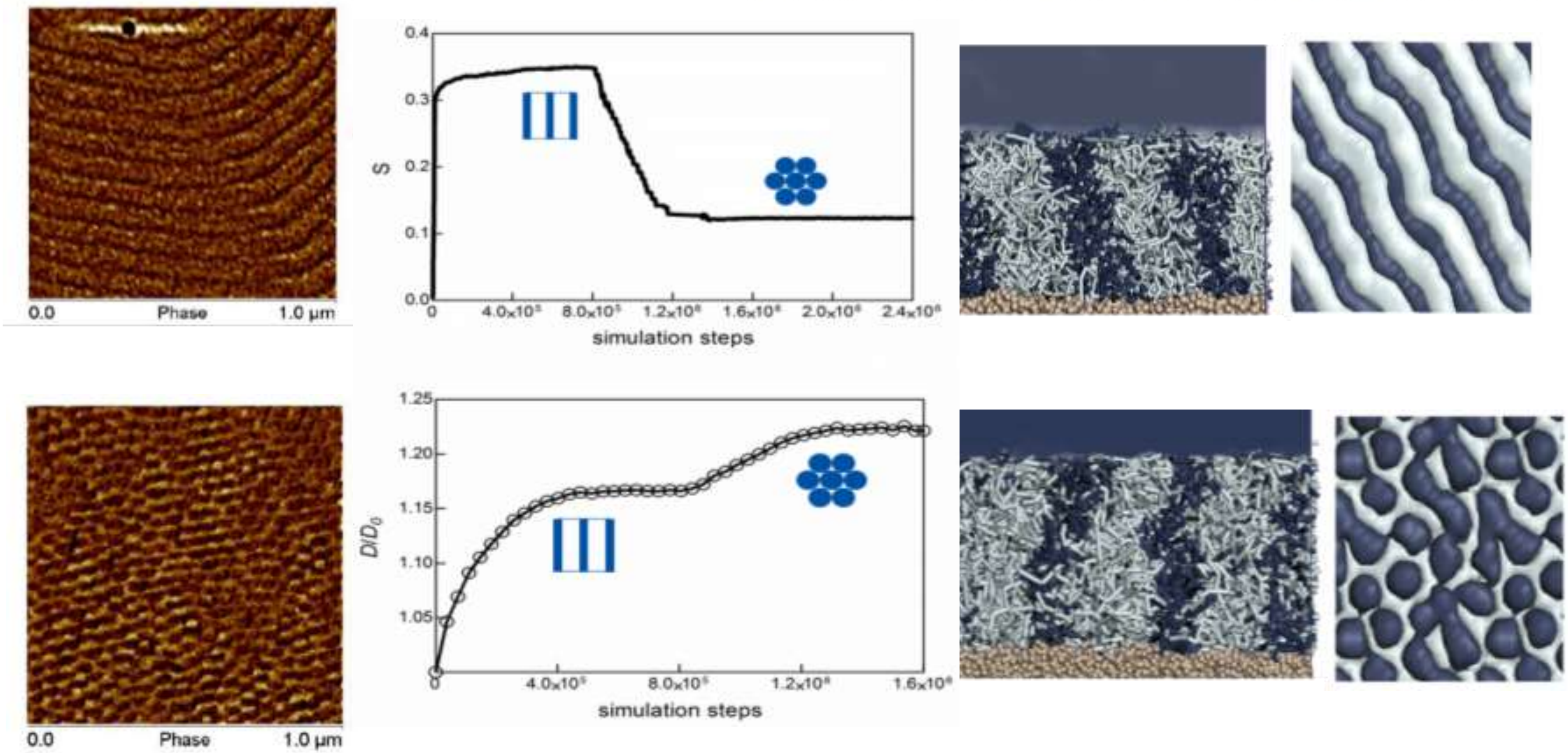
Selective placement of magnetic nanoparticles in diblock copolymer films

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering *enabling innovation*

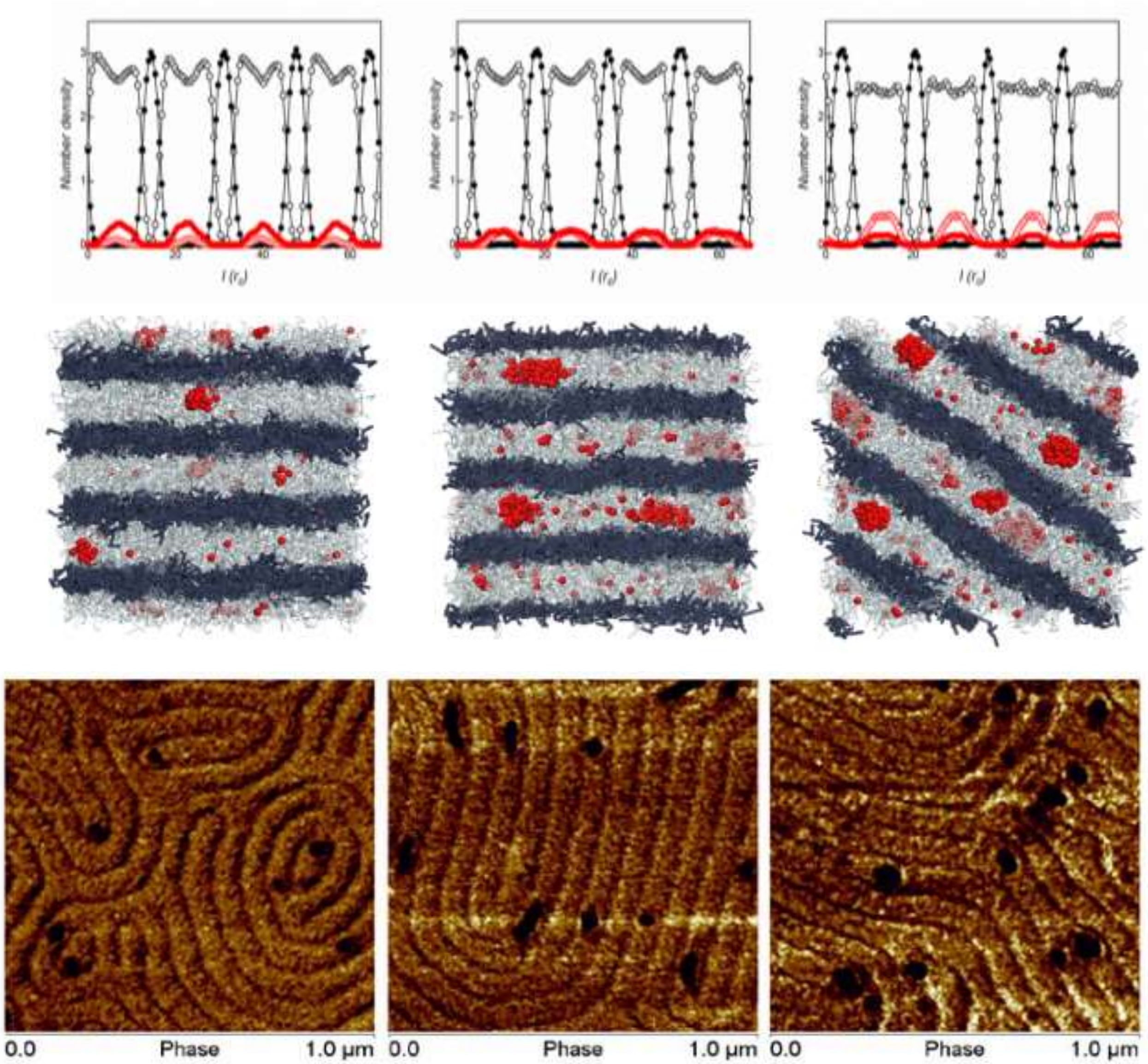
- Diblock copolymer PS-*b*-PMMA lamellar structure with solvent vapor annealing





Selective placement of magnetic nanoparticles in diblock copolymer films

- Placement of (Fe_3O_4) nanoparticles
  - Satisfactory and selective dispersion
  - into the PMMA lamellar-region
  - up to a concentration of 5 wt%
  - cluster formation with dimensions of few NP units
- DPD model is verified and reliable



Outline of talk

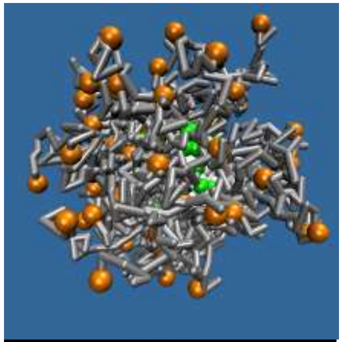
- Introduction
  - Multiscale Molecular Modeling
- Mapping procedure
  - From atomistic simulation to mesoscale
  - From mesoscale to micro FEM
- Applications
  - Functionalized nanoparticles in nanostructured polymer matrices
    - Localization of gold nanoparticles in di-block copolymers
    - Selective placement of magnetic nP in diblock copolymer films
  - Functionalized nanoparticles in un structured polymer matrices
    - Effect of chain length and grafting density
  - Self assembly organization for biomedical applications
    - On nanoparticles
    - Multivalent self assembly building blocks in nanoparticles
- Conclusions

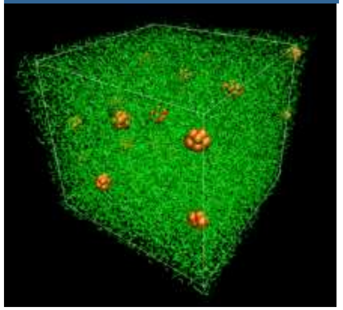
Grafted silica nanoparticles in polymers

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering *enabling innovation*

NanoModel



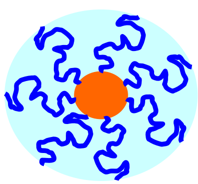
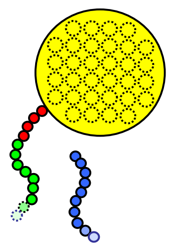


- Particles embedded in a polymer matrix and grafted with polymer chains.
  - Matrix: polydispersity, molecular weight
  - Particles: size, chemical nature, surface treatment
  - Grafting agents: chemical nature, grafting density, molecular weight, polydispersity
- Grafted nanoparticles and semi crystalline polymers
  - Core: amorphous SiO_2 5-10 nm diameter
  - Linker: Si based component
  - Grafted polymer chains: polystyrene 2k – 20k
  - Polymer: amorphous polystyrene 100k

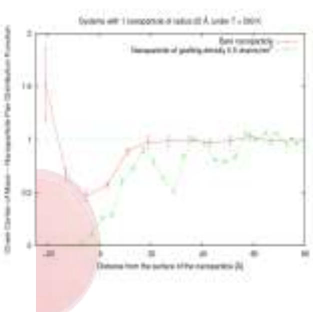
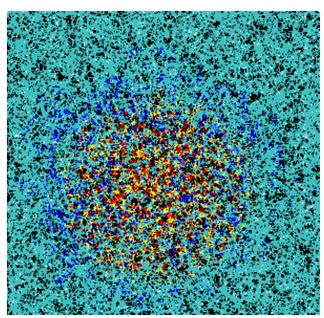
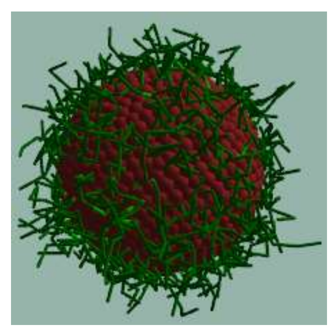
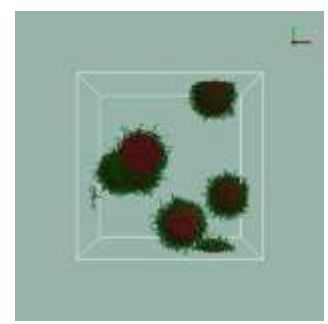
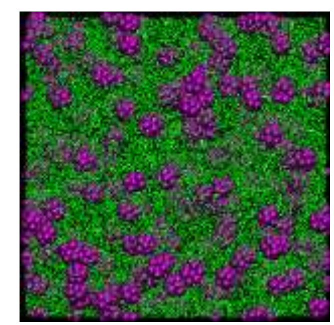
A general view of the project

- Polystyrene – silica grafted nanoparticles: different scales:

Single nP MC	MD & Cg MD	DPD 1:1	DPD 1:n	DPD 1:many

Parameters from: COSMO-RS or MD

Increasing time and length

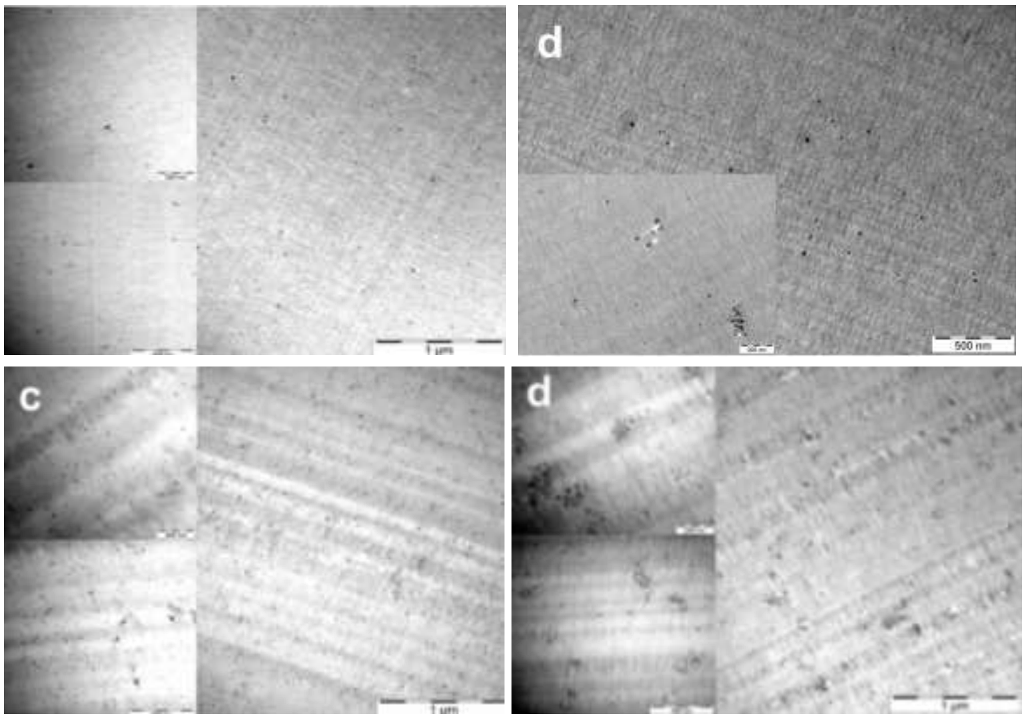
Comparison with experiments – CG level II

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE
Molecular Simulation Engineering
enabling innovation

Concentration ↓ / Grafting density →

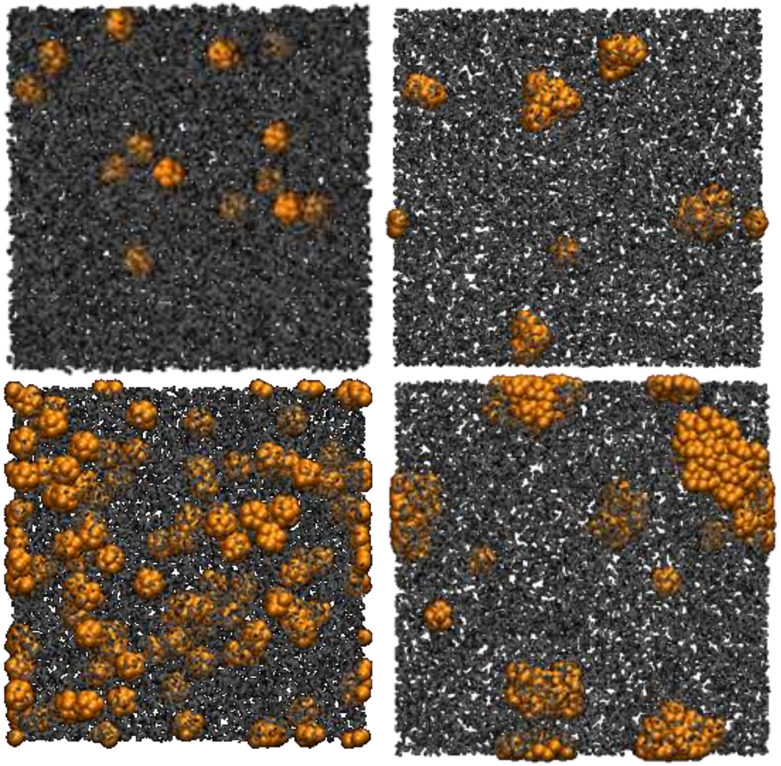
0.5% wt and 0.31 chains/nm^2 | 0.5% wt and 0.82 chains/nm^2



5.0% wt and 0.31 chains/nm^2 | 5.0% wt and 0.82 chains/nm^2

Grafting density

dispersion | ***dispersion/aggregation***



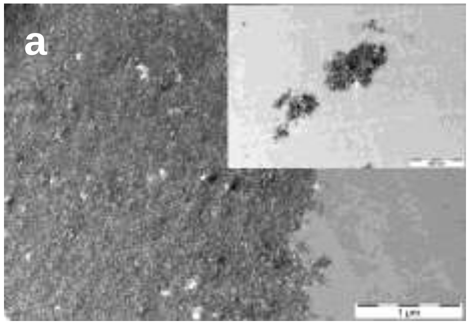
dispersion | ***aggregation***

Aggregation vs. dispersion: effect of grafted chain lenght

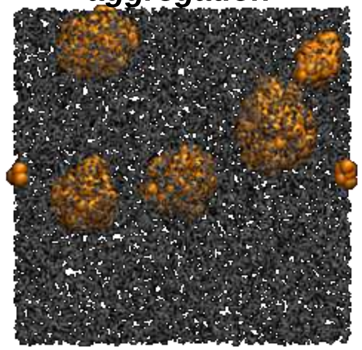
UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering *enabling innovation*

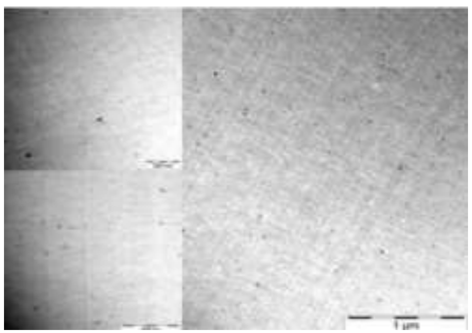
2.5k Da and 0.51 chains/nm^2



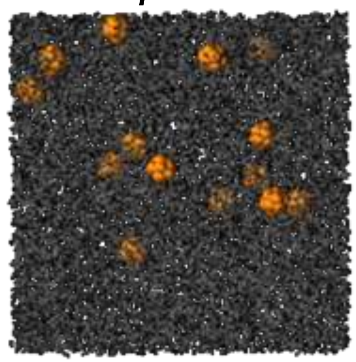
aggregation



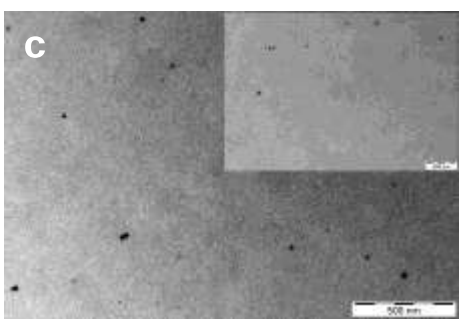
21.3 k Da and 0.31 chains/nm^2



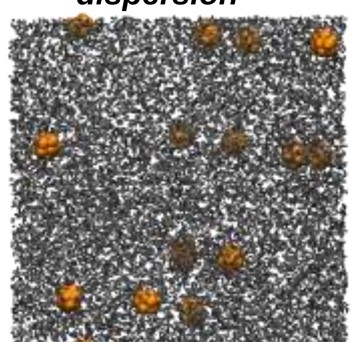
dispersion



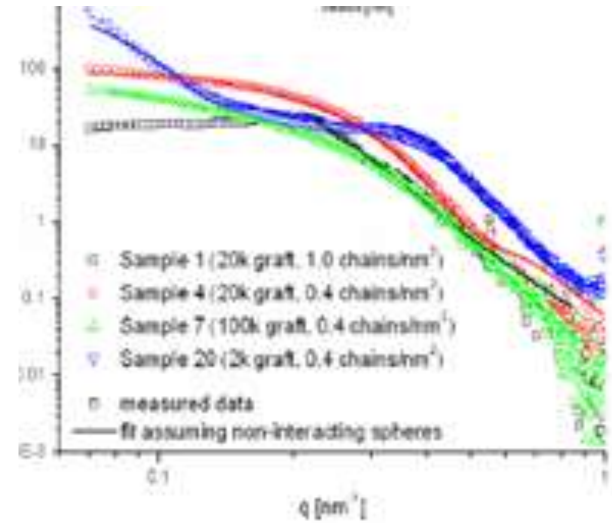
103.7 k Da and 0.53 chains/nm^2



dispersion



Chain length



- Increasing grafted chain length favors uniform distribution of nP in the matrix

Fixed grafted density and PS matrix 100k

Summary of the mechanical properties

% NP	E_C (GPa)	E_C/E_M
Grafting density 0.5 chains/nm²		
1	2.59 (2.60±0.1)	1.03
5	2.94 (2.81±0.2)	1.17
10	3.45	1.37
Grafting density 0.7 chains/nm²		
1	2.62	1.04
5	3.07	1.22
10	3.55	1.41
Grafting density 1 chains/nm²		
1	2.62 (2.75±0.2)	1.04
5	3.34 (2.87±0.1)	1.33

Outline of talk

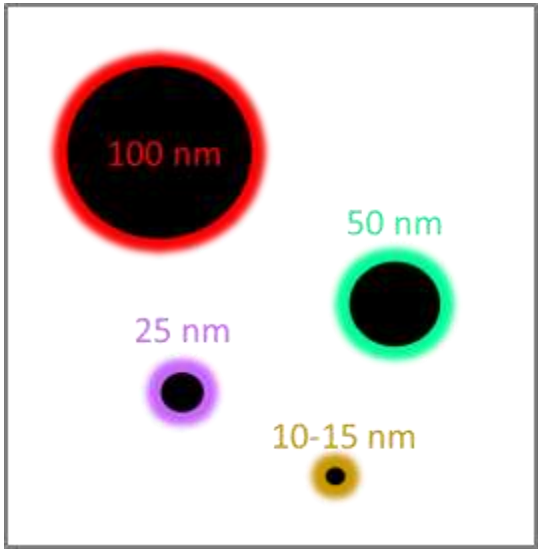
UNIVERSITÀ DEGLI STUDI DI TRIESTE
MOSE Molecular Simulation Engineering enabling innovation

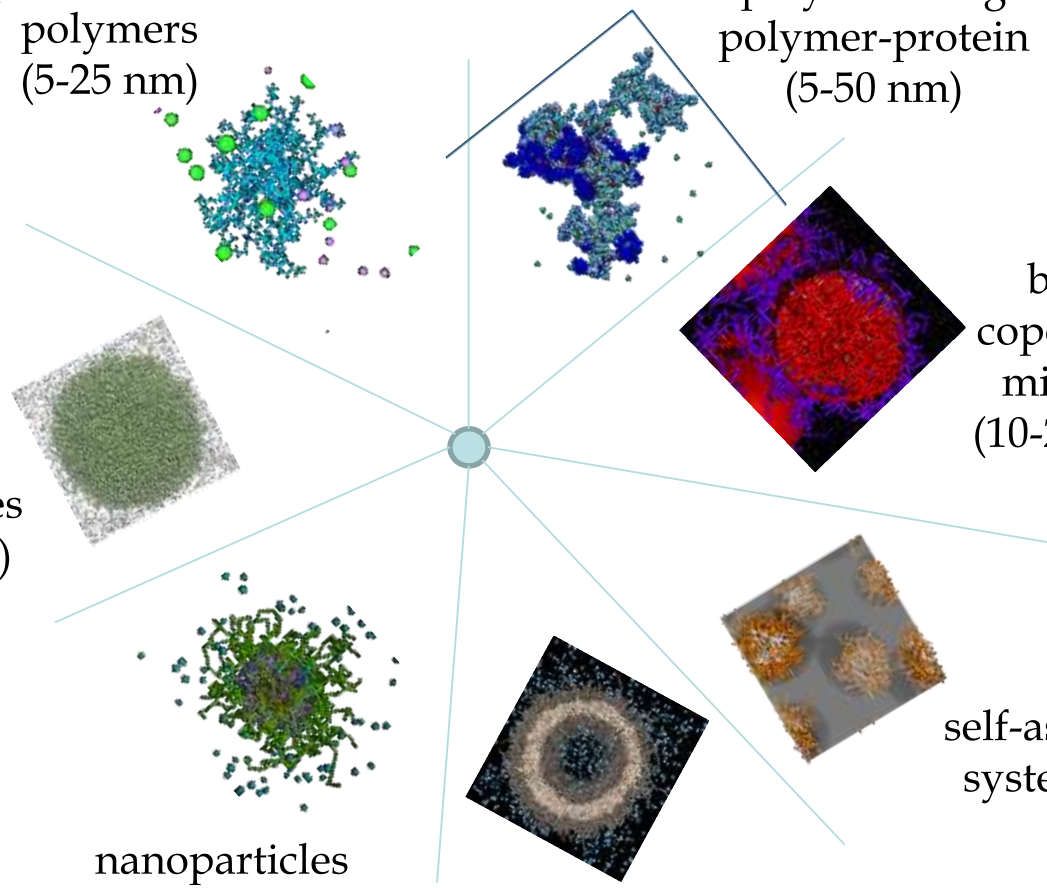
- Introduction
  - Multiscale Molecular Modeling
- Mapping procedure
  - From atomistic simulation to mesoscale
  - From mesoscale to micro FEM
- Applications
  - Functionalized nanoparticles in nanostructured polymer matrices
    - Localization of gold nanoparticles in di-block copolymers
    - Selective placement of magnetic nP in diblock copolymer films
  - Functionalized nanoparticles in un structured polymer matrices
    - Effect of chain length and grafting density
  - Self assembly organization for biomedical applications
    - On nanoparticles
    - Multivalent self assembly building blocks in nanoparticles
- Conclusions

Systems for biomedical applications: 1 – 1000 nm

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering enabling innovation





dendrimers
hyperbrancndhed
polymers
(5-25 nm)

polymer-drug
polymer-protein
(5-50 nm)

block
copolymer
micelles
(10-200nm)

self-assembling
systems (5-25
nm)

liposomes
(80-200nm)

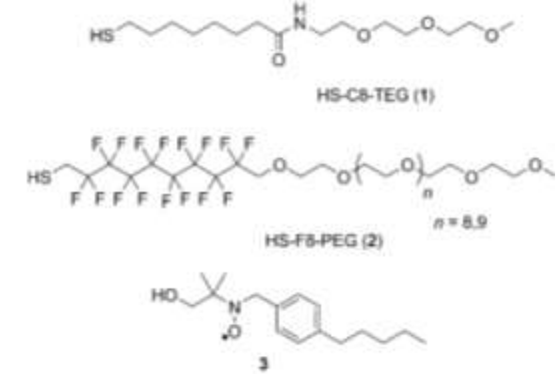
nanoparticles
(2-100 nM)

nanocapsules
(20-1000 nm)

Self assembly of nanostructures on gold nanoparticoles

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE Molecular Simulation Engineering *enabling innovation*

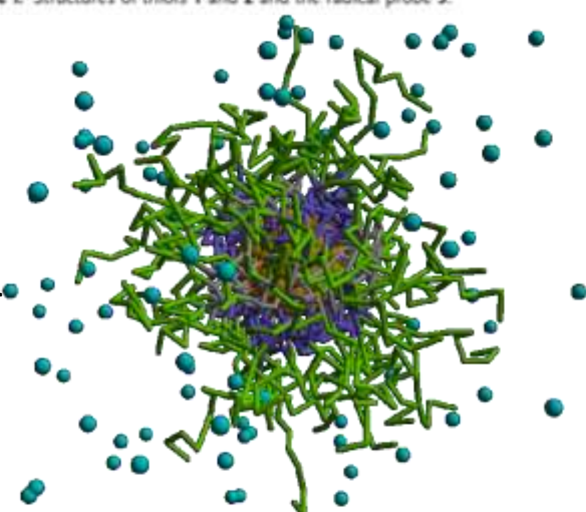


Scheme 1. Structures of thiols 1 and 2 and the radical probe 3.

Table 1: Gold nanoparticles coated with mixtures of thiolates of **1** and **2**.

Sample	R_{SAM}[a]	Core diameter [nm][b]	MPC composition[c]
1	1	2.2 ± 0.4	$Au_{400}(S\text{-}C8\text{-}TEG)_{54}(S\text{-}F8\text{-}PEG)_{54}$
2[d]	1	1.6 ± 0.2	$Au_{150}(S\text{-}C8\text{-}TEG)_{33}(S\text{-}F8\text{-}PEG)_{33}$
3	2.5	2.5 ± 0.4	$Au_{540}(S\text{-}C8\text{-}TEG)_{108}(S\text{-}F8\text{-}PEG)_{43}$
4	4	1.9 ± 0.2	$Au_{230}(S\text{-}C8\text{-}TEG)_{66}(S\text{-}F8\text{-}PEG)_{16}$
5	20	1.9 ± 0.3	$Au_{240}(S\text{-}C8\text{-}TEG)_{68}(S\text{-}F8\text{-}PEG)_{3}$

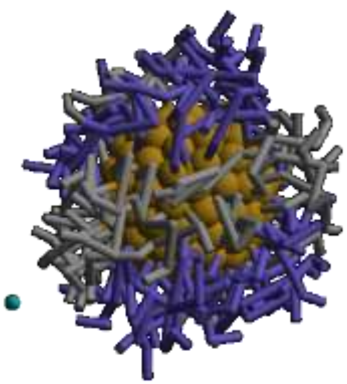
1.



1

Stripes

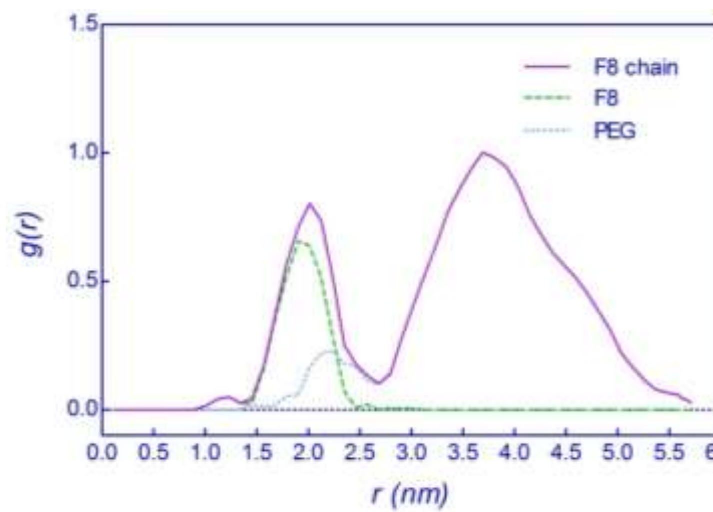
Stripe thickness ~ 0.65-0.7 nm



Color legend:

- solvent=turquoise
- TEG/PEG=green
- C8=grey
- F8=purple
- gold=brown

F8 ~ 1.2+ 3.1 nm
C8 ~ 1.3+ 1.9 nm



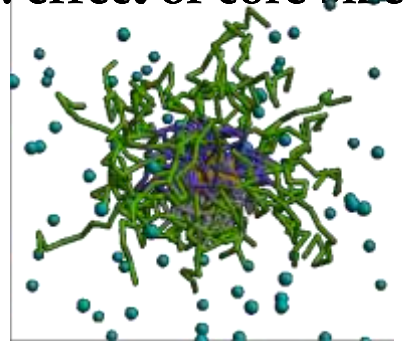
Posocco P, Gentilini C, Bidoggia S, Pace A, Franchi P, Lucarini M, Fermeglia M, Pricl S, Pasquato L., **ACS Nano**, 2012, 6(8):7243-53

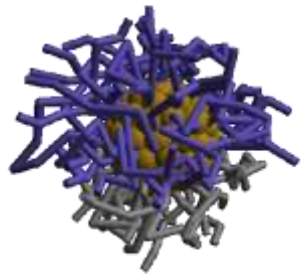
Self assembly of nanostructures on gold nanoparticoles

UNIVERSITÀ DEGLI STUDI DI TRIESTE

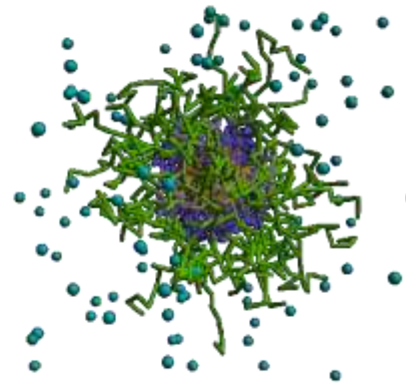
MOSE Molecular Simulation Engineering *enabling innovation*

2: effect of core size

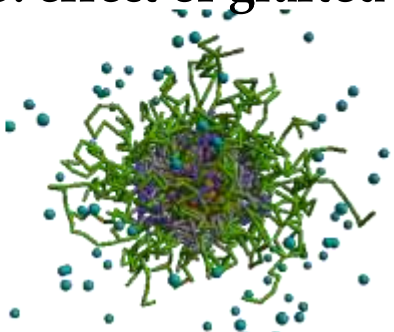


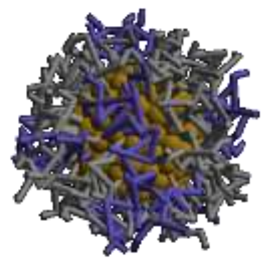


Janus nanoparticle

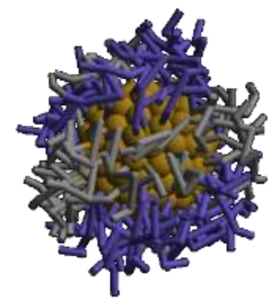


3: effect of grafted composition

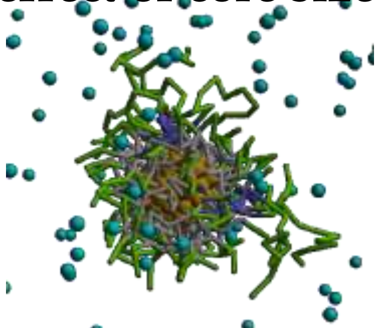


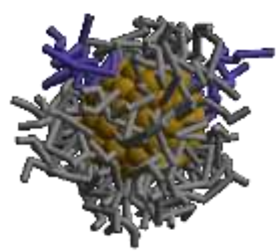


Stripe-like pattern



2: effect of core size





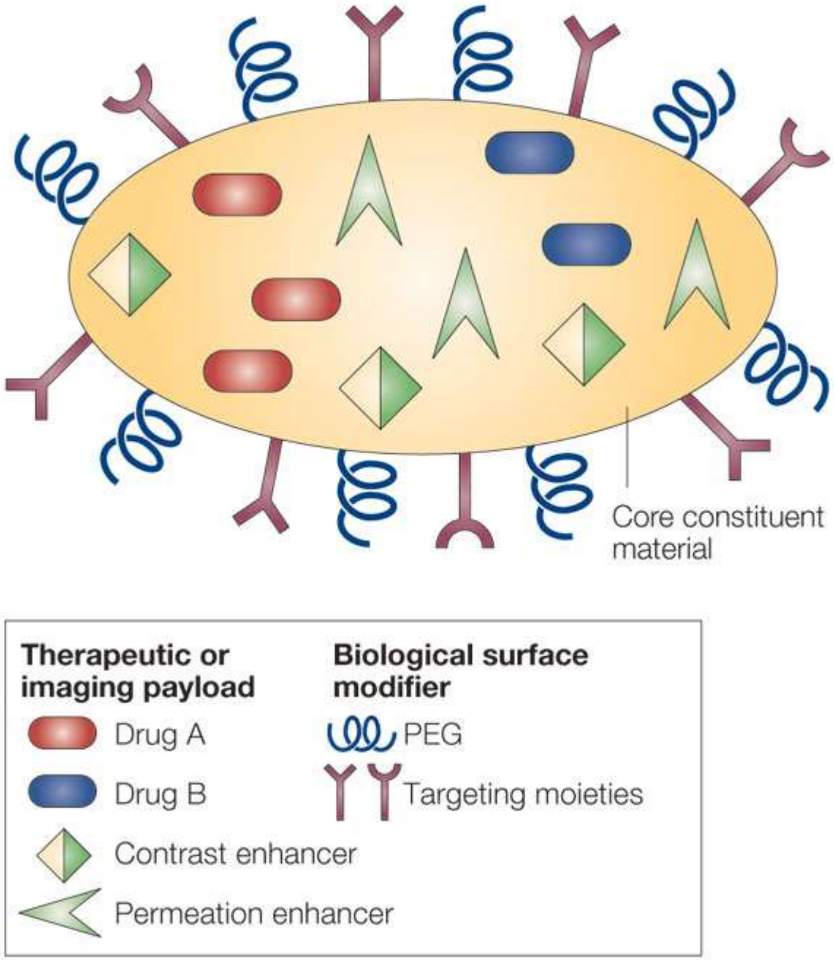
Domains

Color legend:

- solvent=turquoise
- TEG/PEG=green
- C8=grey
- F8=purple
- gold=brown

Multifunctional Nano vectors - Theranostics

- Development of **Nano vectors** for bioactive components:
  - **drug targeting**
  - **controlled release**
- Optimal bioactive concentration remains constant for long time
  - High specify
  - Controlled release
  - Reporting



Nature Reviews | Cancer

Marson D, Laurini E, Posocco P, Fermeglia M, Pricl S., **Nanoscale**. 2015 Feb 19;7(9):3876-87.

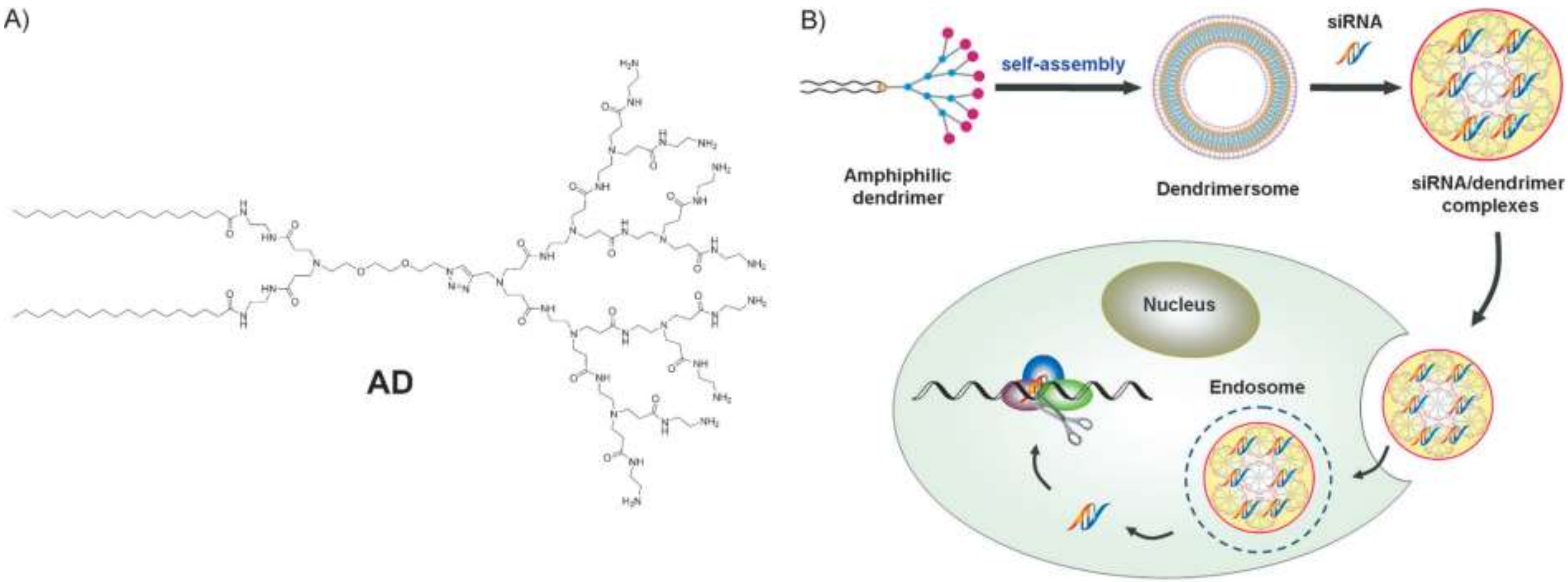
The art of (nano)medicine: perspiration, inspiration, and the 10-year rule

Gene therapy: nucleic acids delivery

UNIVERSITÀ DEGLI STUDI DI TRIESTE

MOSE
Molecular Simulation Engineering
enabling innovation

A. The dendrimer AD and
B. representation of its adaptive self-assembly upon interaction with siRNA for siRNA delivery.



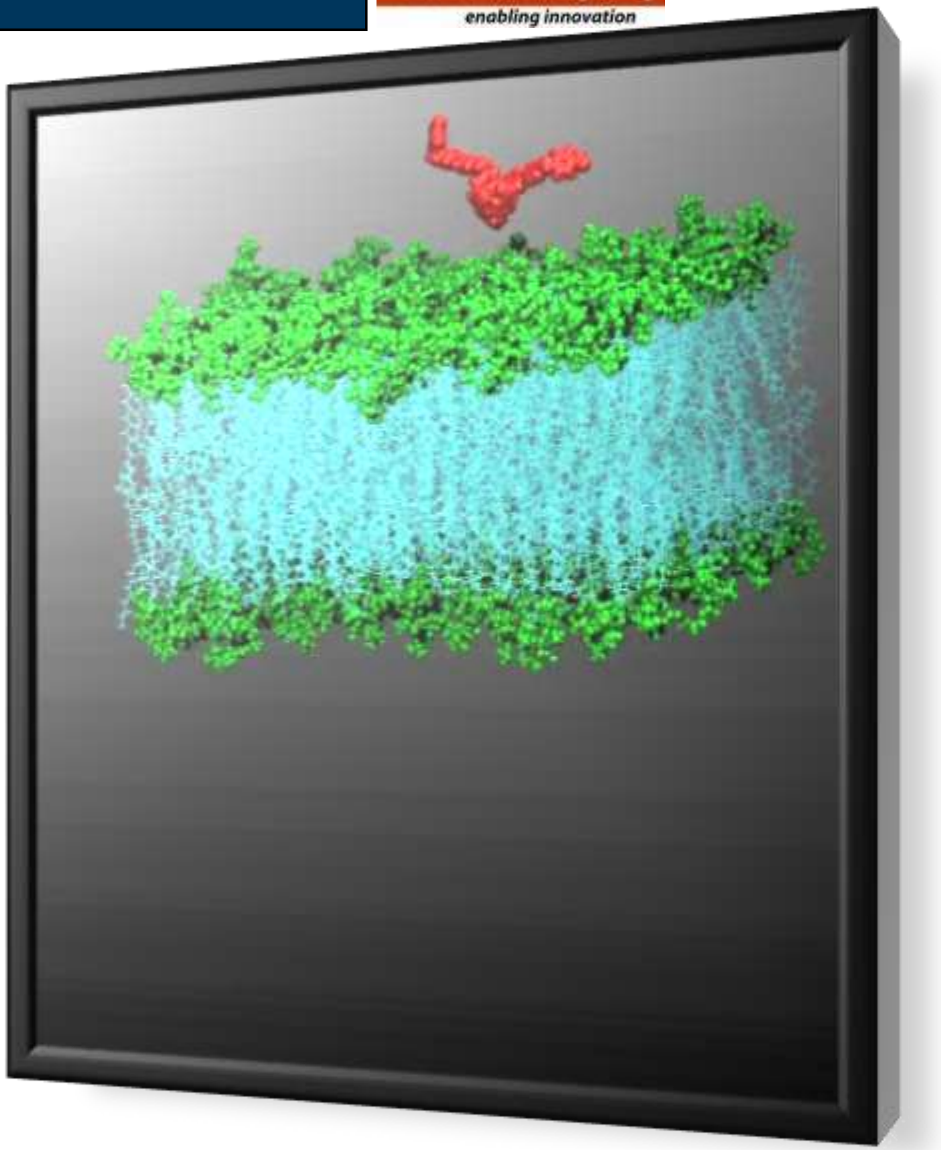
Liu X, Zhou J, Yu T, Chen C, Cheng Q, Sengupta K, Huang Y, Li H, Liu C, Wang Y, Posocco P, Wang M, Cui Q, Giorgio S, Fermeglia M, Qu F, Pricl S, Shi Y, Liang Z, Rocchi P, Rossi JJ, Peng L**., Angew Chem Int Ed Engl**. 2014 Oct 27;53(44):11822

Gene therapy: nucleic acids delivery

UNIVERSITÀ DEGLI STUDI DI TRIESTE

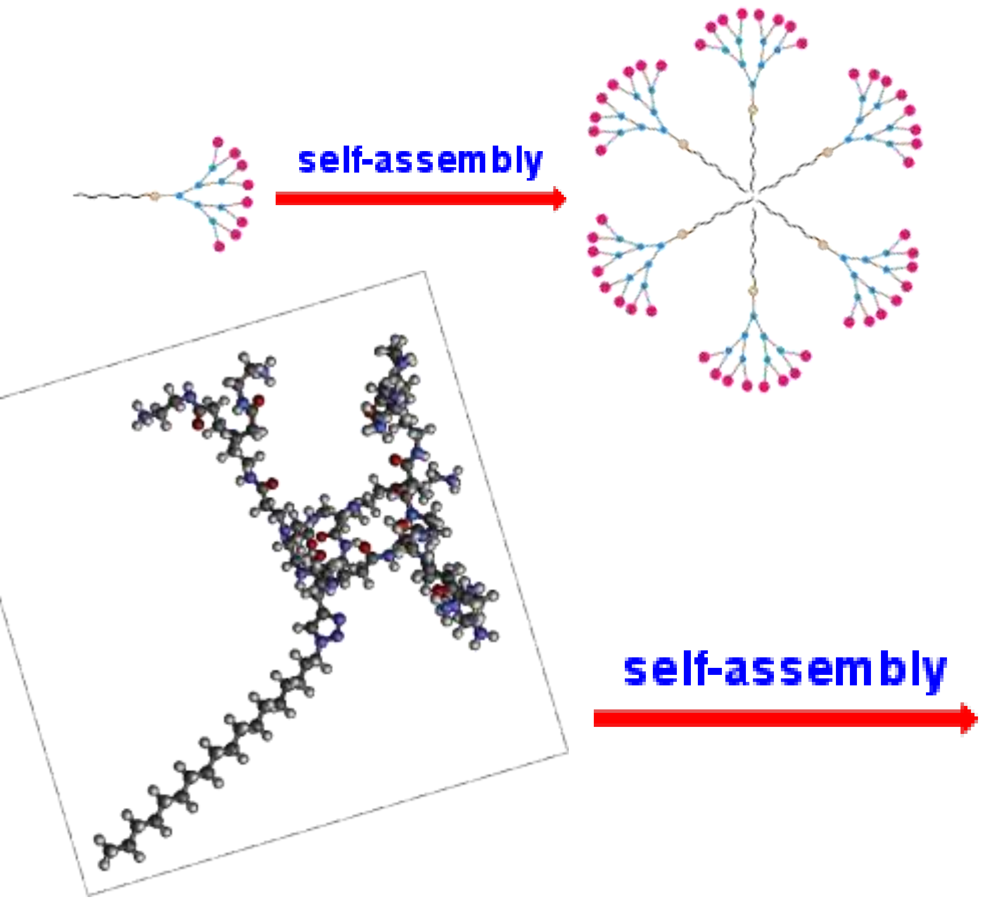
MOSE Molecular Simulation Engineering enabling innovation

- Nano vectors should:
  - Prevent degradations
  - Enhance cellular uptake
  - Improve bio distribution and pharmaco kinectics



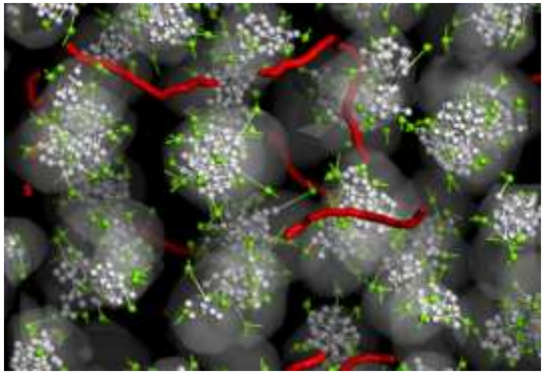
Liu X, Zhou J, Yu T, Chen C, Cheng Q, Sengupta K, Huang Y, Li H, Liu C, Wang Y, Posocco P, Wang M, Cui Q, Giorgio S, Fermeglia M, Qu F, Pricl S, Shi Y, Liang Z, Rocchi P, Rossi JJ, Peng L., **Angew Chem Int Ed Engl**. 2014 Oct 27;53(44):11822

Design and optimization of the nanovector structure

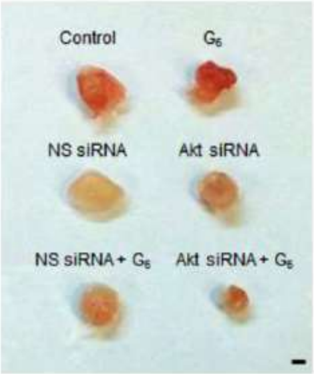


Liu X, Zhou J, Yu T, Chen C, Cheng Q, Sengupta K, Huang Y, Li H, Liu C, Wang Y, Posocco P, Wang M, Cui Q, Giorgio S, Fermeglia M, Qu F, Pricl S, Shi Y, Liang Z, Rocchi P, Rossi JJ, Peng L., **Angew Chem Int Ed Engl**. 2014 Oct 27;53(44):11822

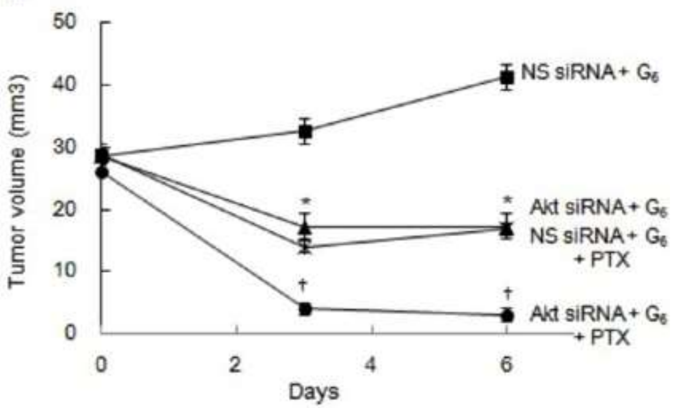
Binding capacity and protection



F



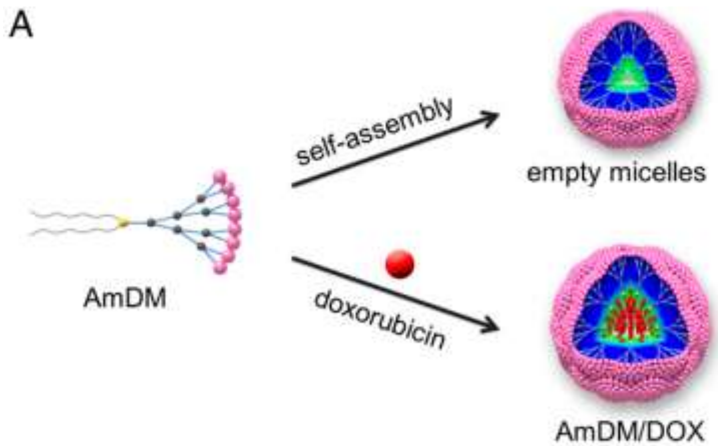
E

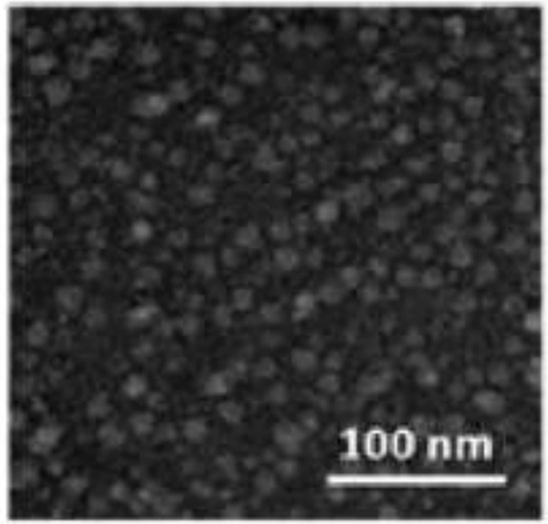


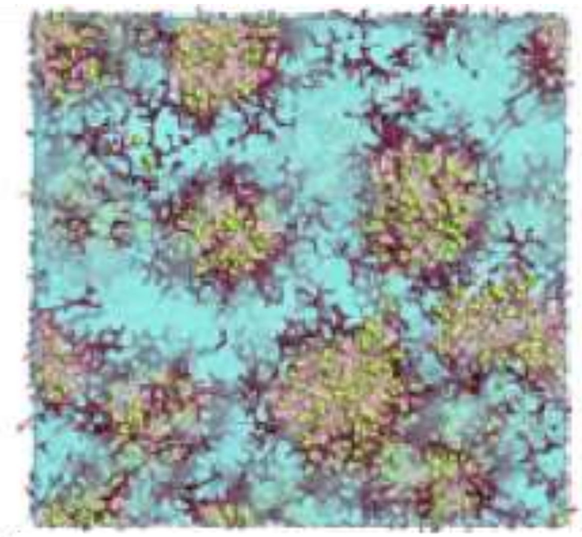
Stephen M. Bromfield, Paola Posocco, Ching W. Chan, Marcelo Calderon, Scott E. Guimond, Jeremy E. Turnbull, Sabrina Pricl and David K. Smith, **Chem. Sci.,** 2014,5, 1484-1492

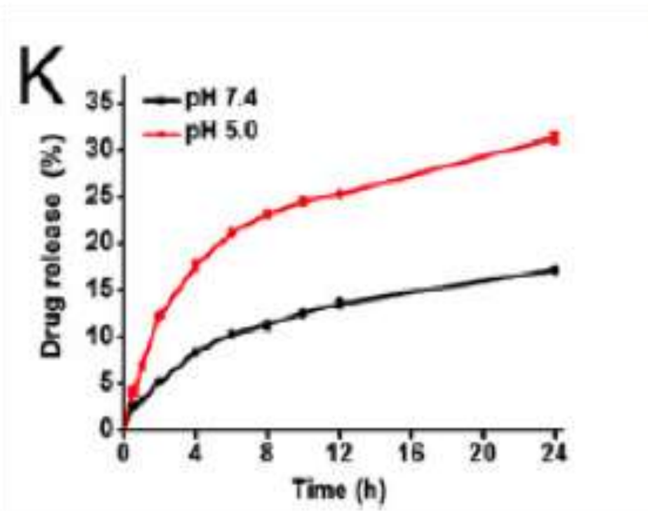
Liu X, Wu J, Yammine M, Zhou J, Posocco P, Viel S, Liu C, Ziarelli F, Fermeglia M, Pricl S, Victorero G, Nguyen C, Erbacher P, Behr JP, Peng L., **Bioconjug Chem**. 2011 Dec 21;22(12):2461-73.

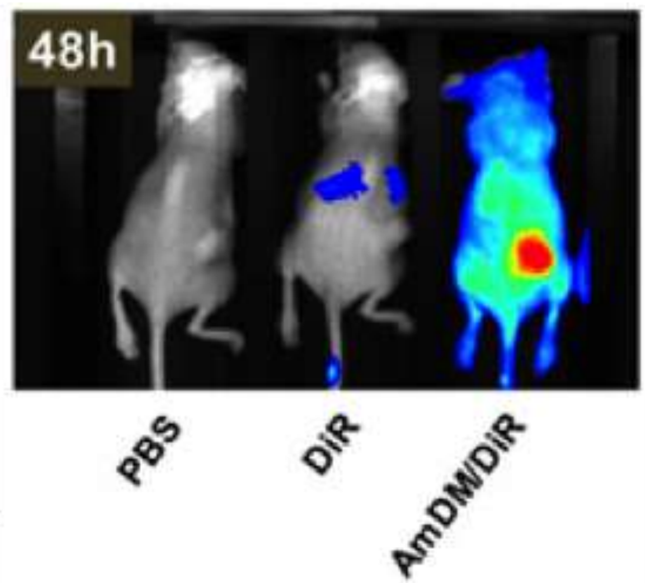
Anticancer drug-loaded spherical nanovectors











Wei T, Chen C, Liu J, Liu C, Posocco P, Liu X, Cheng Q, Huo S, Liang Z, Fermeglia M, **Pricl** S, Liang XJ, Rocchi P, Peng L. , **Proc Natl Acad Sci U S A**. 2015 Mar 10;112(10):2978-83.

Outline of talk

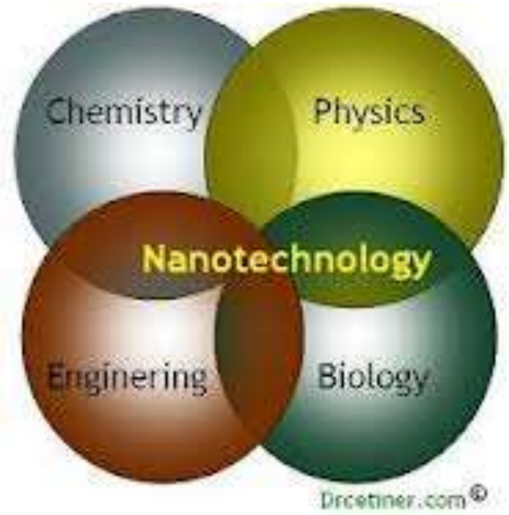
- Introduction
  - Multiscale Molecular Modeling
- Mapping procedure
  - From atomistic simulation to mesoscale
  - From mesoscale to micro FEM
- Applications
  - Functionalized nanoparticles in nanostructured polymer matrices
    - Localization of gold nanoparticles in di-block copolymers
    - Selective placement of magnetic nP in diblock copolymer films
  - Functionalized nanoparticles in un structured polymer matrices
    - Effect of chain length and grafting density
  - Self assembly organization for biomedical applications
    - On nanoparticles
    - Multivalent self assembly building blocks in nanoparticles
- Conclusions

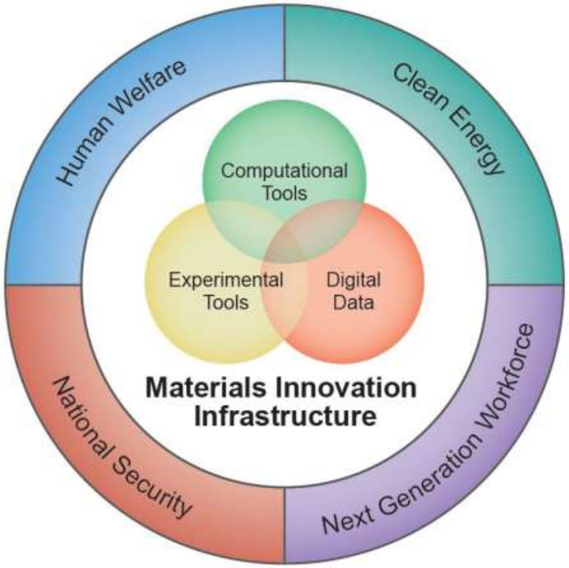
In summary …

- Multiscale molecular modeling protocol
  - Mapping atomistic to mesoscale
  - Mapping mesoscale morphology to microFEM
- Useful for the design of nanostructured systems
  - Interpretation of experiments
  - Virtual ‘nanoscope’
  - Design of active nano materials and nano systems
- From classical nanotechnology to nanomedicne
  - Classical industries (automotive, opto-electronic, polymer…)
  - Pharmaceutical industry
  - Nano medicine
  - Bio based economy
- General design approach for nanostructured materials & systems

Nano-Bio Technology has a bright future

- Nano-bio technology will have in 21 century the same importance that oil, polymers and semi conductors had in the 20 century
- Convergence of ….
  - Society needs and new technologies
  - Experiment and TMS
  - Complex systems and computer power
- What is needed?
  - Basic competences in physics, chemistry and biology
  - Nano Characterization and nano fabrication tools
  - HPC and computational algorithms
  - Strong integration and scientific relationships among hospitals, medical research centers, universities and industries
  - High quality highly integrates university system





Acknowledgments

- Financial support:
  - MODENA EU project
  - Nanomodel EU Project
  - MULTIPRO EU Project
  - Multihybrids EU Project
  - MoMo EU project
  - GreenBoat Design, EU PorFesr
  - NanoStrata – Industry 2015
- People & institutions

MOSE — MOlecular Simulation Engineering — enabling innovation

Sabrina Pricl
Radovan Toth
Paola Posocco
Erik Laurini
Paolo Cosoli
Daniel Romero
Simão P. Pereiraa
Francesca Santese
Valentina Dal Col
Domenico Marson
Tina Stokelj

Martin Lisal
Zbysek Posel

SUPSI — Scuola Universitaria Professionale della Svizzera Italiana

Giulio Scocchi

CULGI

Johannes G.E.M. Fraaije
Jan-Willem Handgraaf

- Dave K. Smith, Anna Barnard & Simon P. Jones, University of York, U.K.
- Nathan P. Gabrielson & Daniel W. Pack, University of Illinois at Urbana Champaign, USA
- Chun-Ho Wong & Hak-Fun Chow, The Chinese University of Hong Kong
- Carlo V. Catapano, Anastasia Malek, IOSI, Bellinzona, Switzerland
- Aaron Tagliabue, Enzio Ragg, University of Milan
- Kostas Karatasos, University of Thessaloniki, Greece
- Lucia Pasquato, University of Trieste
- Sara Padovani, CRP-FIAT,
- Ling Peng group, CNRS, Marseille (F)
- MarcoPierotti, Elena Tamborini, Silvana Pilotti, NCI, Milan
- Giuseppe Mensitieri, University of Naples

Nanomodel Partners