Single Particle -ICP-MS fundamentals

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et de physico-chimie
pour l'environnement et les matériaux

Commission européenne

Co-funded by the Horizon 2020 Framework Programme of the European Union under the grant N° *952306*

UNTWIN

Nanomaterials and nanotechnology

- **Nanomaterials and nanoparticles used in an increasing number of industrial and consumer products**
- **Size-related special properties: reactivity, electrical and optical properties**

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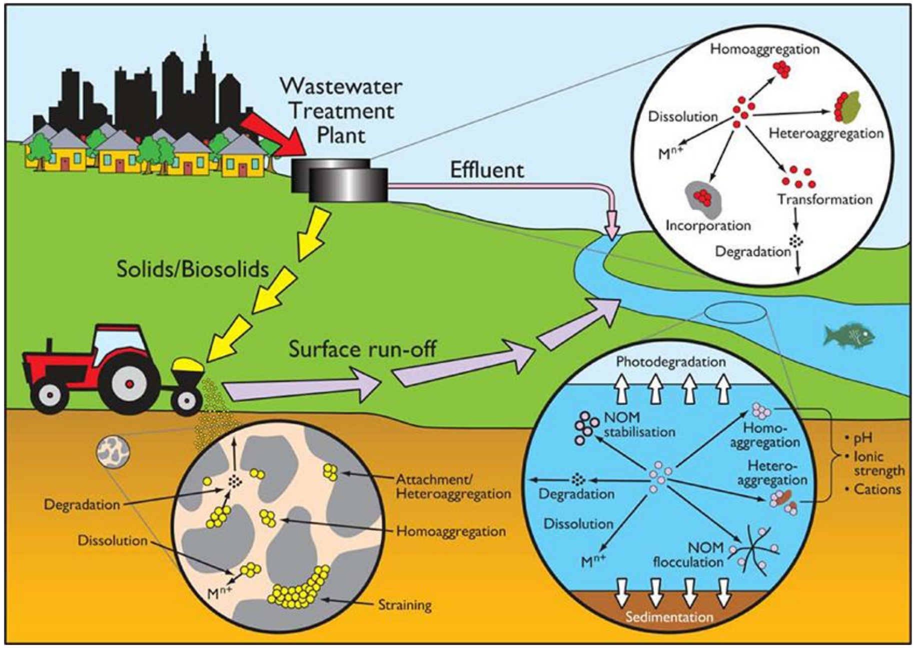
Nanomaterials and nanotechnology

Which are the consequences?

Increasingly used of nanomaterials in different fields

NPs Release into the environment

Interaction with environment and human being



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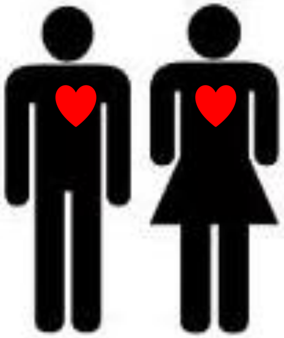
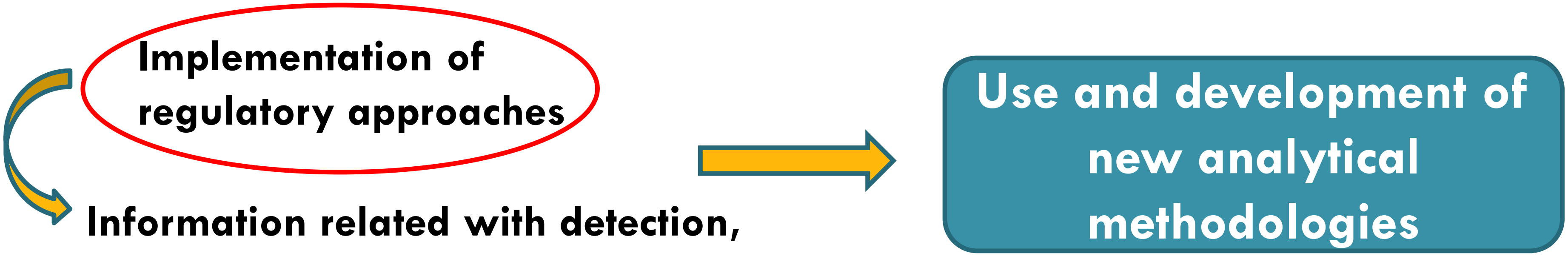
Nanomaterials and nanotechnology



REGULATORY APPROACHES that guarantee the sustainability of Nanotechnology



Implementation of regulatory approaches

Information related with detection, characterization and quantification of nanomaterials

Use and development of new analytical methodologies

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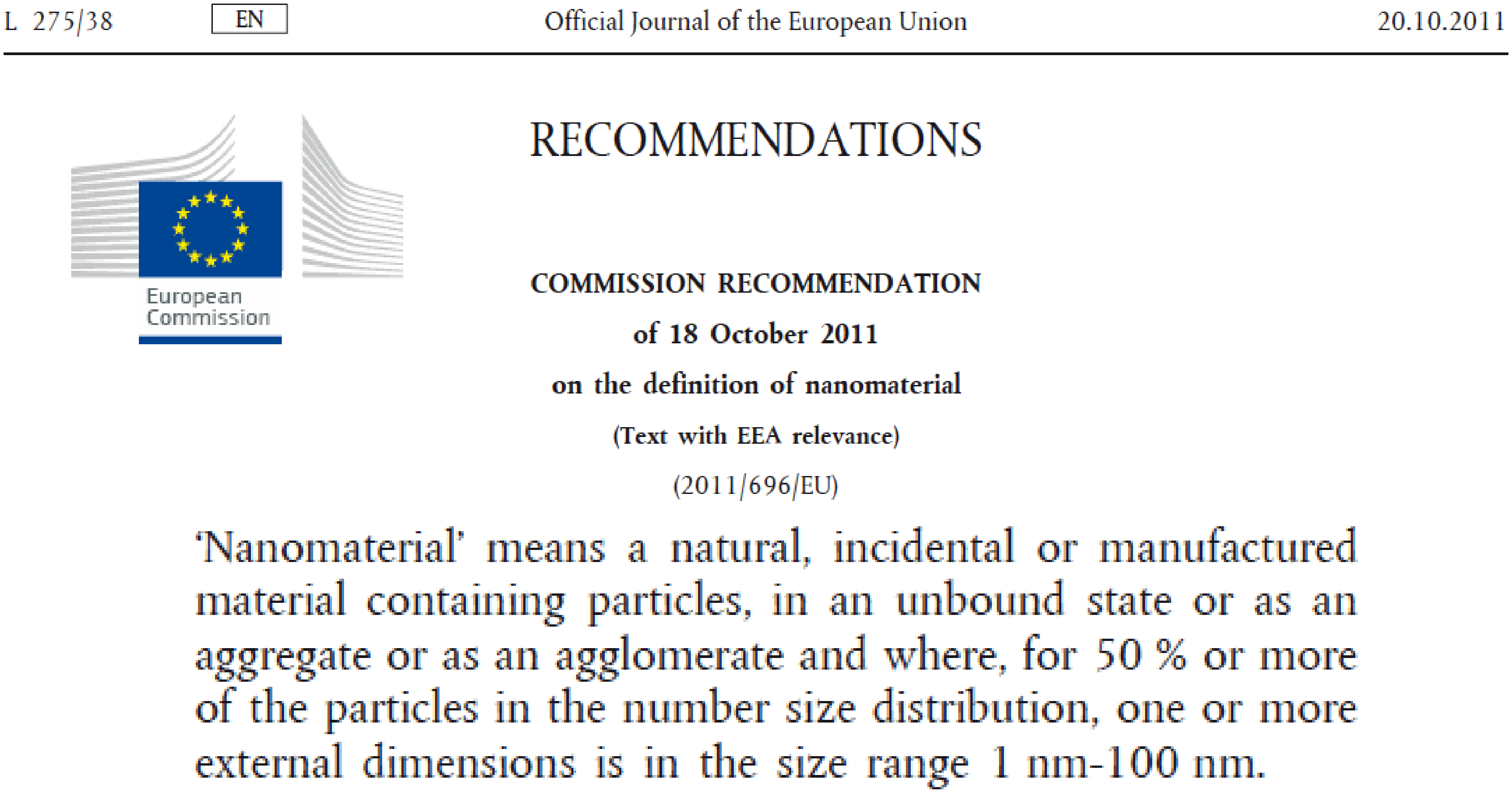
Nanomaterials and nanotechnology



L 275/38 EN Official Journal of the European Union 20.10.2011

RECOMMENDATIONS

COMMISSION RECOMMENDATION

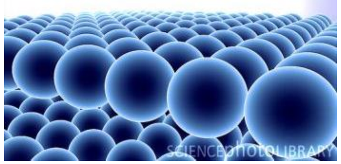
of 18 October 2011

on the definition of nanomaterial

(Text with EEA relevance)

(2011/696/EU)

'Nanomaterial' means a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm-100 nm.



length range approximately from 1 - 100 nm

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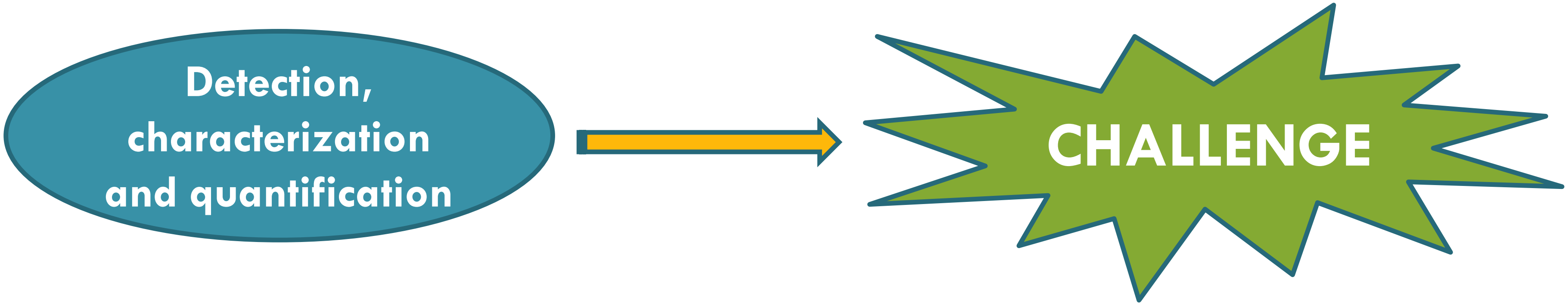
Analysis of nanomaterials



- **NPs present in environmentally relevant concentrations: ppb or ppt**

- **Huge amount of information needed:**
  1. **Detect the presence of NPs,**
  2. **Identify the type of NPs (chemical composition)**
  3. **NP characterization (size, shape, surface characteristics…)**
  4. **Number concentrations**
  5. **Identify new species**

Use of (new) specific and sensitive methods of analysis

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Analysis of nanomaterials

Analytical techniques

- **Ensemble techniques**
  - **Dynamic light scattering (DLS)**
  - **Small-Angle X-ray Scattering (SAXS)**
  - **X-Ray Diffraction (XRD)**
- **Counting techniques**
  - **Electron microscopy (EM)**
  - **Nanoparticle tracking analysis (NTA)**
  - **Atomic Force microscopy (AFM)**
- **Separation techniques**
  - **Hydrodynamic chromatography (HDC)**
  - **Size exclusion chromatography (SEC)**
  - **Field Flow Fractionation (FFF)**

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Analysis of nanomaterials

Analytical techniques

Ensemble techniques

☐ **Dynamic Light Scattering (DLS)**

☐ **Small-Angle X-ray Scattering (SAXS)**

☐ **X-Ray Diffraction (XRD)**

✓ **Information about number-based size distributions**

x **Only reliable for nearly monodisperse particles**

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Analysis of nanomaterials

Analytical techniques

Counting techniques

- ☐ Electron Microscopy (EM)
- ☐ Atomic Force Microscopy (AFM)
- ☐ Nanoparticle Tracking Analysis (NTA)

✓ Analysis particle by particle

x **High number of measurements must be performed**

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Analysis of nanomaterials

Analytical techniques

Separation techniques

- ☐ **Hydrodynamic chromatography (HDC)**
- ☐ **Size exclusion chromatography (SEC)**
- ☐ **Field-Flow Fractionation (FFF)**

✓ **Separation into monodisperse fractions**

x **Optimization for each type of sample needed**

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Analysis of nanomaterials

Analytical techniques

Single Particle Inductively coupled plasma mass spectrometry (SP-ICP-MS)

Different types of information that can be obtained:

- The presence of the element in its dissolved and nanoparticulate form
- The size distribution or the mass distribution per nanoparticle
- The mass concentration of the dissolved element and nanoparticles
- The number concentration of nanoparticles

➡ **Ultra trace metal analysis: Limit of detection at the level of ATTOGRAM: 10^{-18} g**

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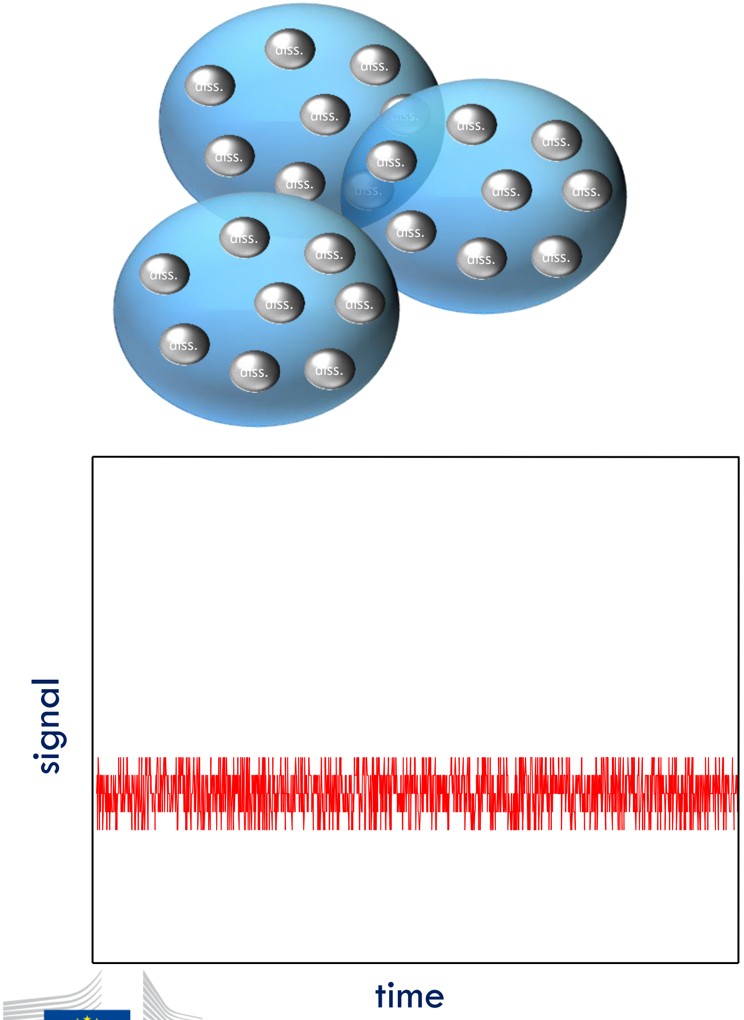
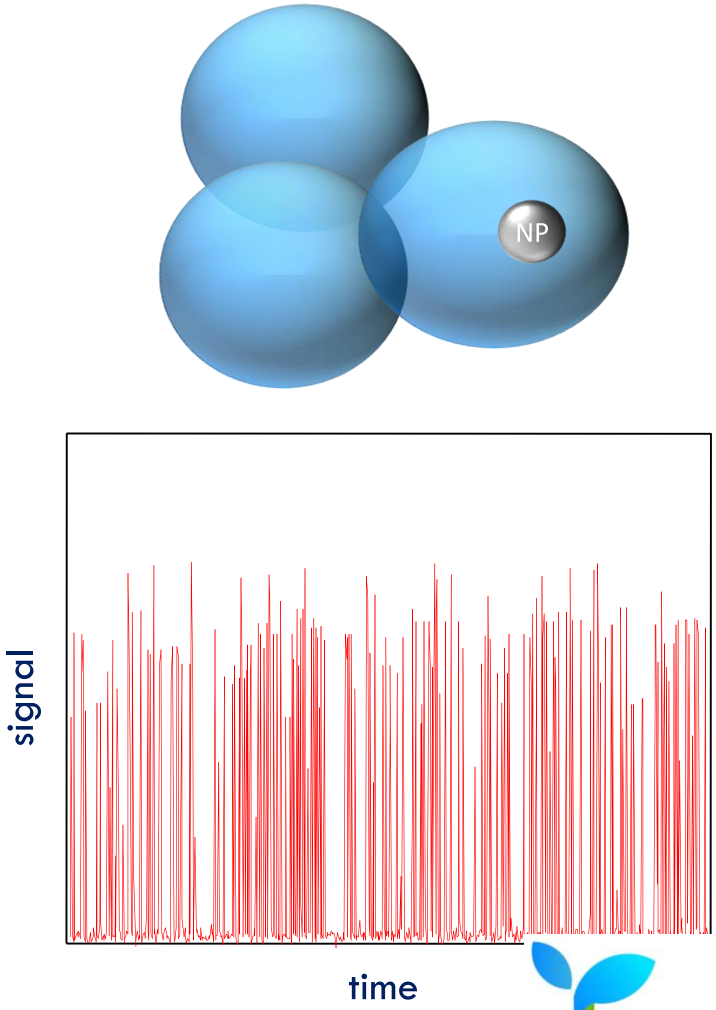
Single Particle ICP-MS: principals and theory

Dissolved form



Nanoparticulated form



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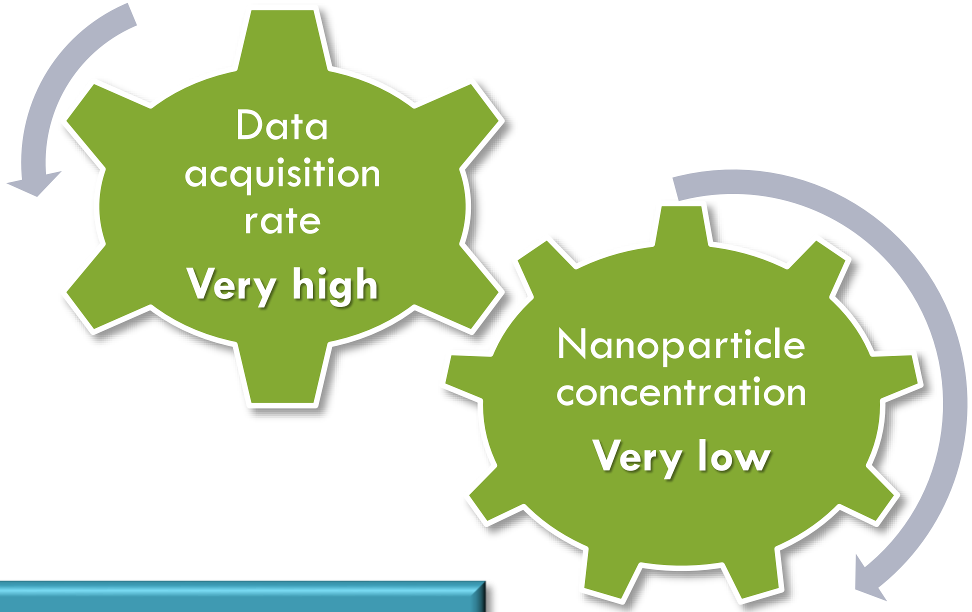
Single Particle ICP-MS: principals and theory



Data acquisition rate

Very high

Nanoparticle concentration

Very low

< 10 ms/ reading (> 100Hz)

≤ 10^8 nanoparticles L^{-1}

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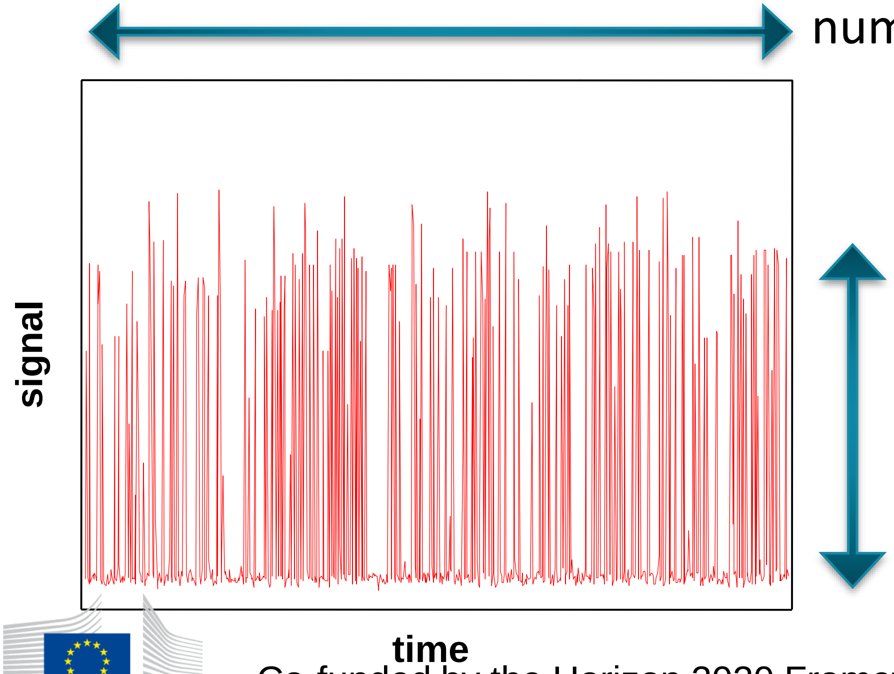
Single Particle ICP-MS: principals and theory

1 pulse = 1 nanoparticle



number of pulses = ***K*** nanoparticle concentration

pulse intensity = ***K*** atoms per nanoparticle

= ***K'*** NP mass = ***K''*** NP size

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Evolution of Single Particle ICP-MS

2003	2011	2014	2018	??
Conception SP-ICP-MS	1st application nano	1st commercial instrument dedicated	Characterization	Maturity

The "Prehistory":

- Analyse 'single particle' mode: 90's avec ICP-OES
- Applications: analysis of aerosols, suspended particles in air, microparticles and cells

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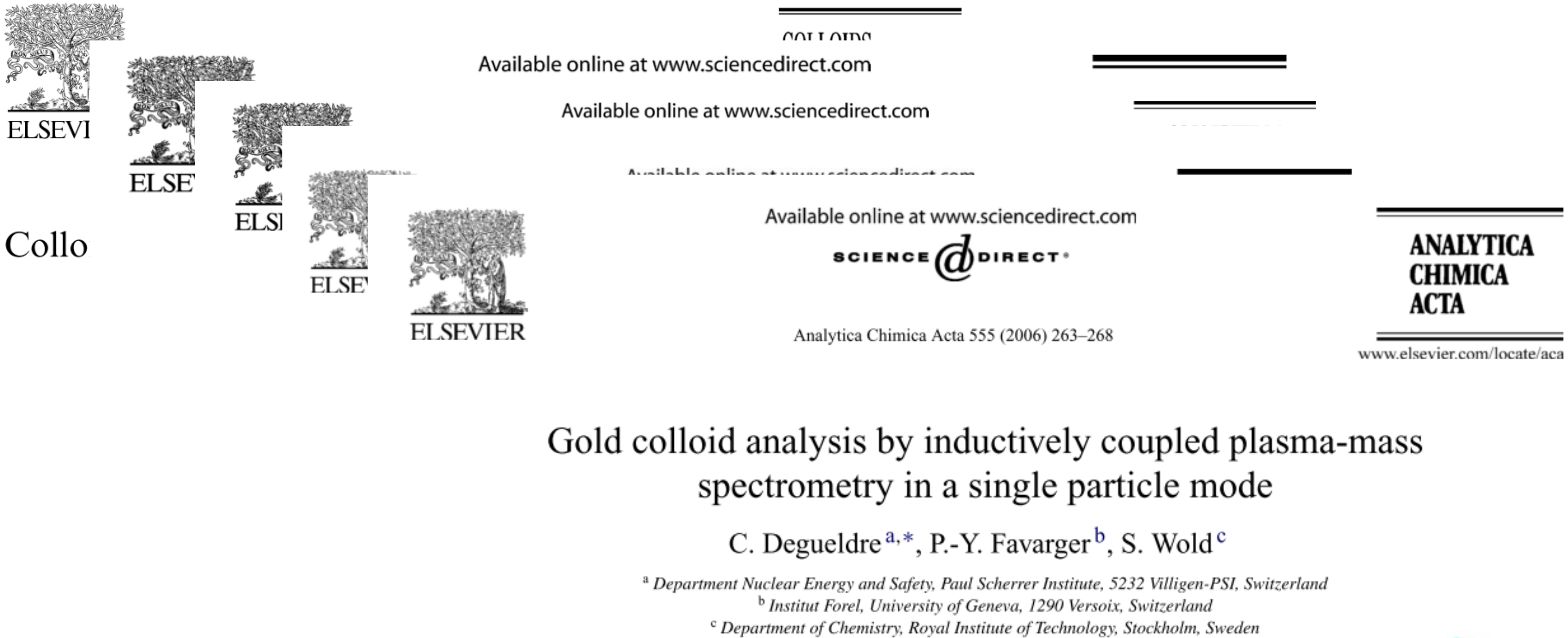

Collo

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Analytica Chimica Acta 555 (2006) 263–268

ANALYTICA CHIMICA ACTA

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Gold colloid analysis by inductively coupled plasma-mass spectrometry in a single particle mode

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[a] Department Nuclear Energy and Safety, Paul Scherrer Institute, 5232 Villigen-PSI, Switzerland
[b] Institut Forel, University of Geneva, 1290 Versoix, Switzerland
[c] Department of Chemistry, Royal Institute of Technology, Stockholm, Sweden

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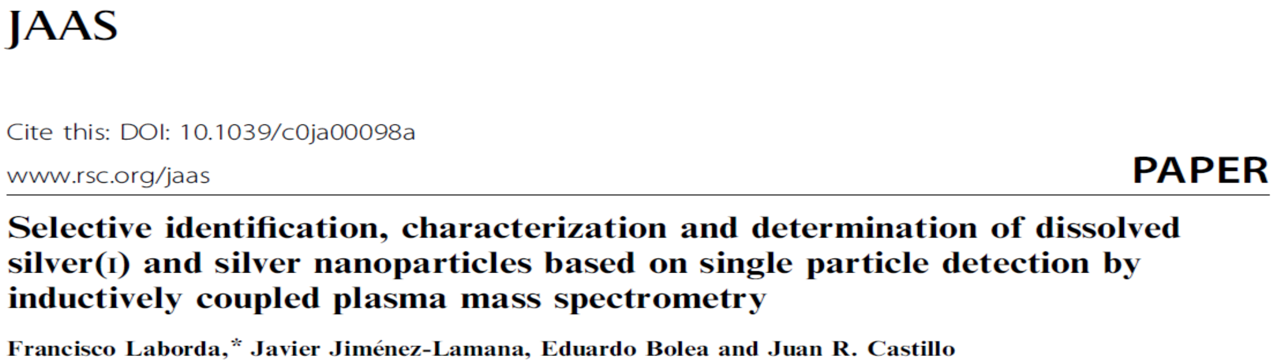

JAAS

Cite this: DOI: 10.1039/c0ja00098a

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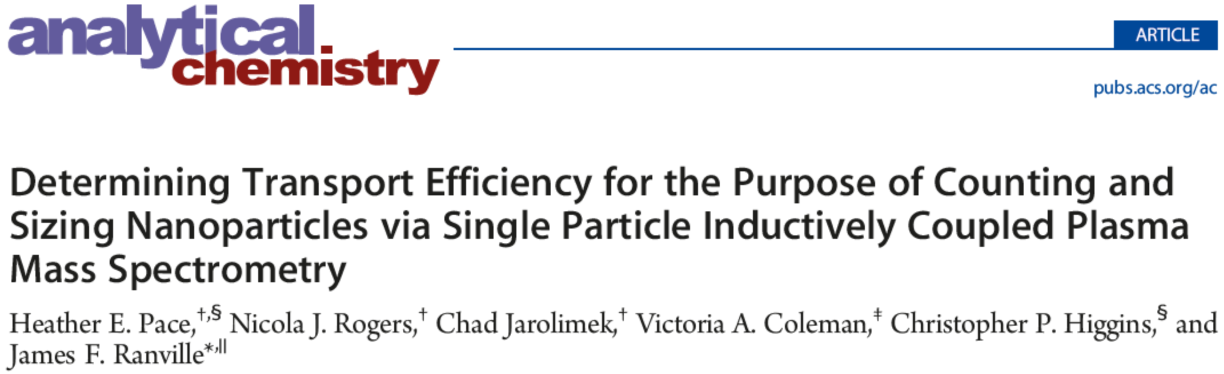
PAPER

Selective identification, characterization and determination of dissolved silver(I) and silver nanoparticles based on single particle detection by inductively coupled plasma mass spectrometry

Francisco Laborda,* Javier Jiménez-Lamana, Eduardo Bolea and Juan R. Castillo



analytical chemistry

ARTICLE

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Determining Transport Efficiency for the Purpose of Counting and Sizing Nanoparticles via Single Particle Inductively Coupled Plasma Mass Spectrometry

Heather E. Pace,[†,§] Nicola J. Rogers,[†] Chad Jarolimek,[†] Victoria A. Coleman,[‡] Christopher P. Higgins,[§] and James F. Ranville[*,∥]

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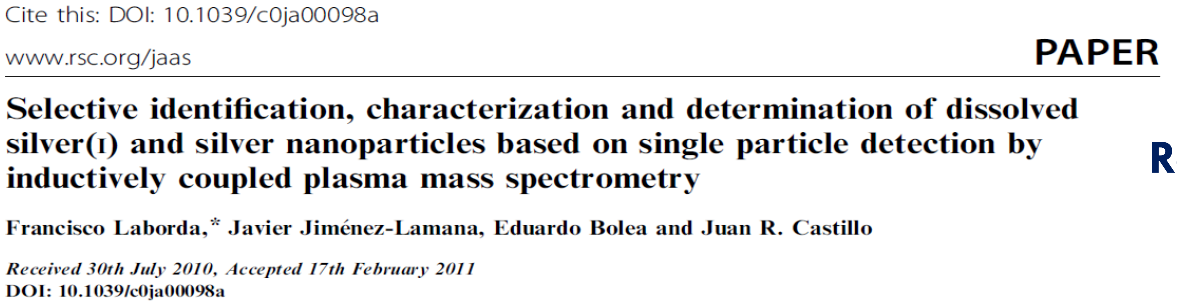
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Received 30th July 2010, Accepted 17th February 2011
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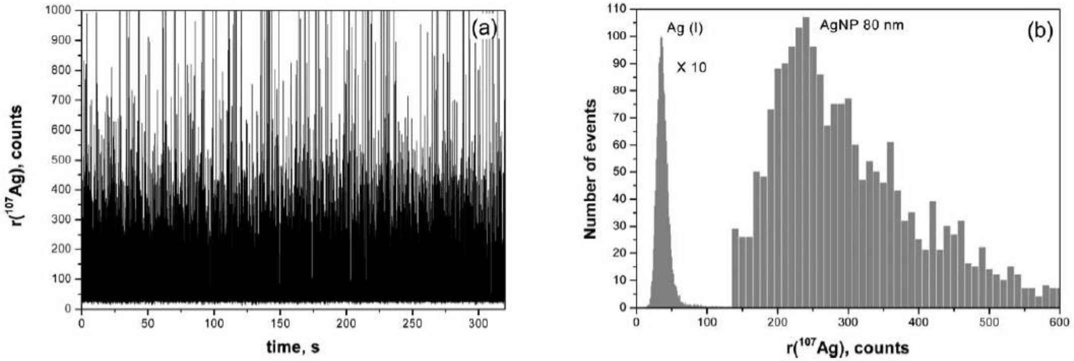
Redefined the basis of SP-ICP-MS

The first study to demonstrate one of the main advantages of SP-ICP-MS: its capability to determine selectively the analyte in its dissolved and nanoparticulate form in a single analysis and without a previous separation step



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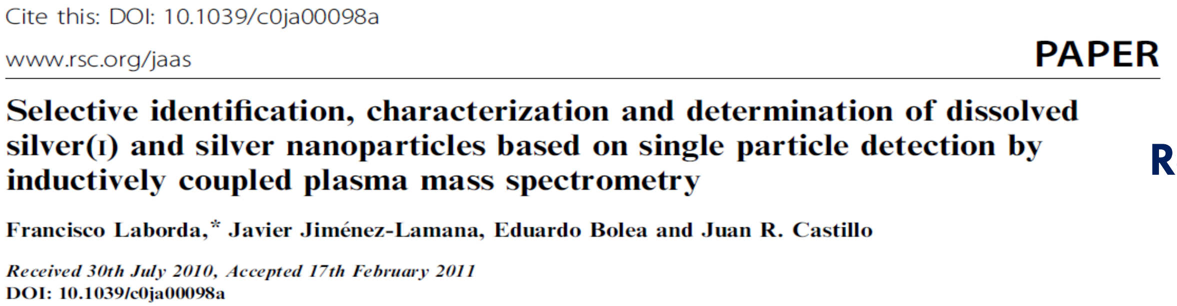

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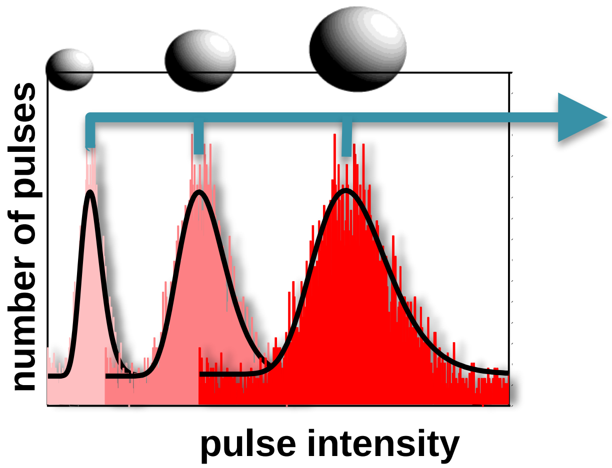

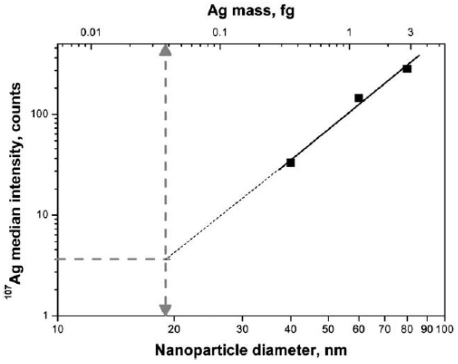

Use of standards with the same chemical composition to obtain the size distribution of AgNPs

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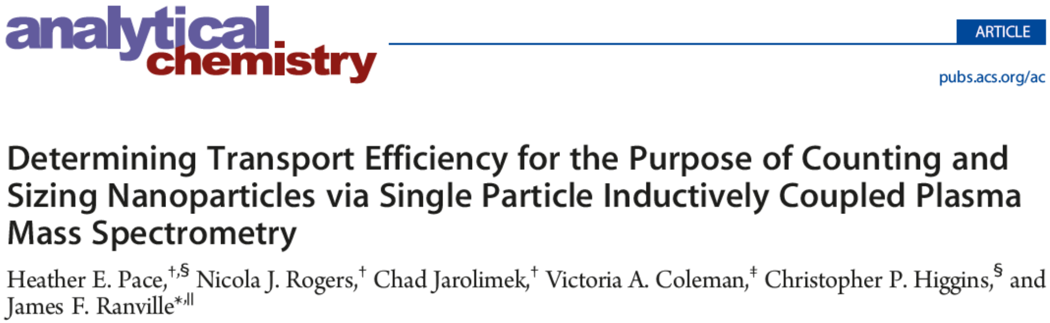
Evolution of Single Particle ICP-MS

2003 | 2011 | 2014 | 2018 | ??

- **Conception SP-ICP-MS**
- **1st application nano**
- **1st commercial instrument dedicated**
- **Characterization**
- **Maturity**



analytical chemistry

ARTICLE

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Determining Transport Efficiency for the Purpose of Counting and Sizing Nanoparticles via Single Particle Inductively Coupled Plasma Mass Spectrometry

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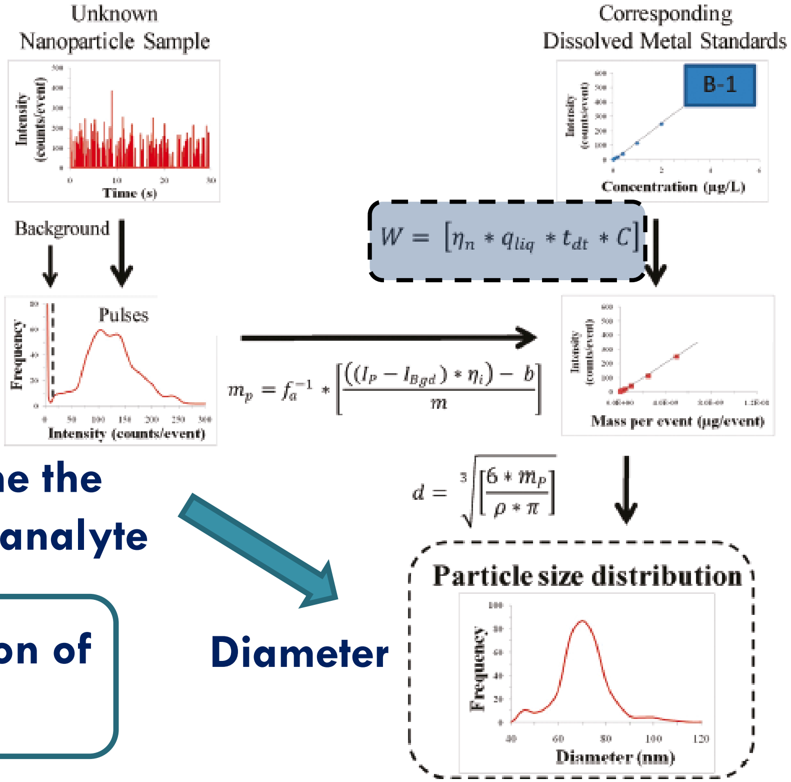
Dissolved Standard

Standard of the same element analysed → **Determine the mass of analyte** → **Diameter**



$$W = [\eta_n * q_{liq} * t_{dt} * C]$$

$$m_p = f_a^{-1} * \left[\frac{((I_P - I_{Bgd}) * \eta_i) - b}{m}\right]$$

$$d = \sqrt[3]{\left[\frac{6 * m_p}{\rho * \pi}\right]}$$

This procedure involves the calculation of Transport efficiency

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Evolution of Single Particle ICP-MS

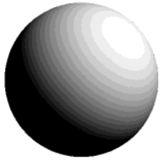
2003	2011	2014	2018	??
Conception SP-ICP-MS	1st application nano	1st commercial instrument dedicated	Characterization	Maturity

Transport efficiency (η_{neb}): defined as the ratio between the nanoparticles detected with respect to the nanoparticles introduced in the nebulizer

It requires the use of reference materials: NPs standards well characterized (known size and nanoparticle number concentration) and monodisperse

Most used from the : U.S National Institute of Standards and Technology

But also: Nanocomposix, BBI…



NIST RM 8012 Au 30 nm
NIST RM 8013 Au 60 nm

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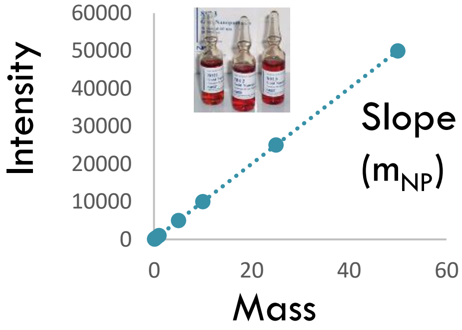
Evolution of Single Particle ICP-MS

Transport efficiency (η_{neb}): **defined as the ratio between the nanoparticles detected with respect to the nanoparticles introduced in the nebulizer**

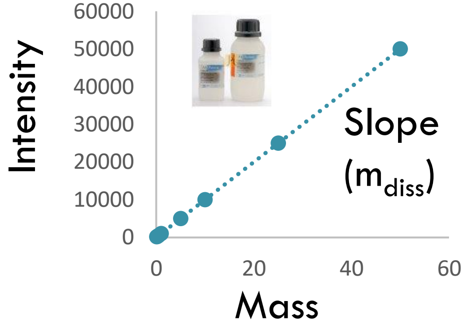
There are 3 methods: waste collection, particle size and particle frequency

particle size method

Calibration curve of reference NPS



Calibration curve of dissolved element



If

- **Ionization efficiency of NPs = 100 %**
- **Atoms dissolved and atoms NP same behaviour in the plasma**

$$\boxed{\eta_{neb} = \frac{m_{diss}}{m_{NP}}}$$

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Evolution of Single Particle ICP-MS

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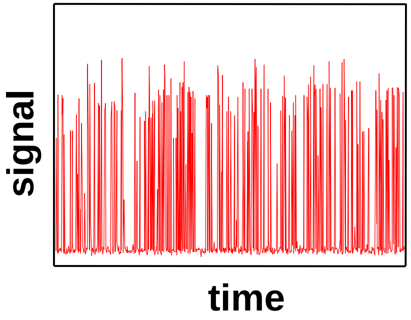
Transport efficiency (η_{neb}): defined as the ratio between the nanoparticles detected with respect to the nanoparticles introduced in the nebulizer

There are 3 methods: waste collection, particle size and particle frequency

particle frequency method



determination of the particle frequency (particle/s) of a suspension of reference NP of known NP number concentration

$$\eta_{neb} = \frac{f_{NP}}{Q_{sam} N_{NP}}$$

f_{NP}: *particle frequency*
Q_{sam}: *sample uptake flow*
N_{NP}: *NP number conc*

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Evolution of Single Particle ICP-MS

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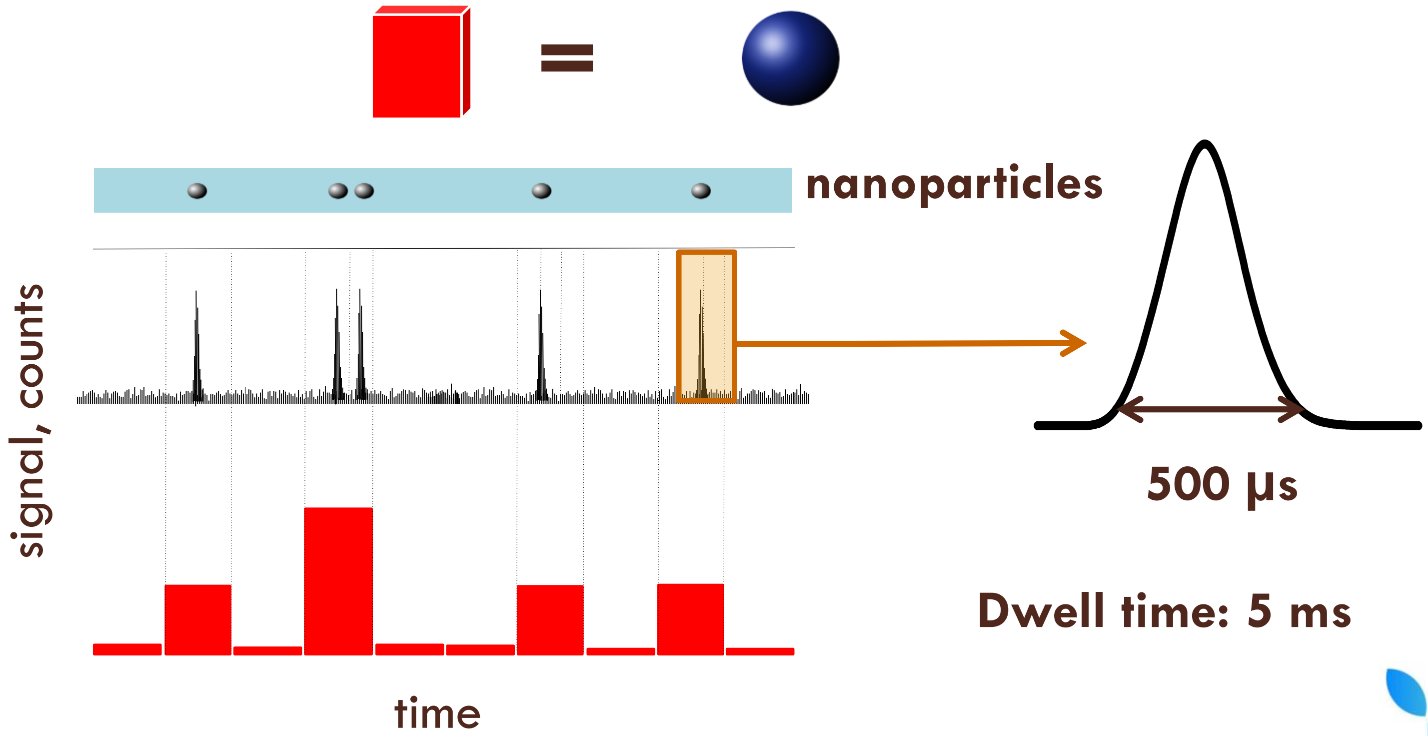
1 pulse = 1 nanoparticle



Dwell time: 5 ms

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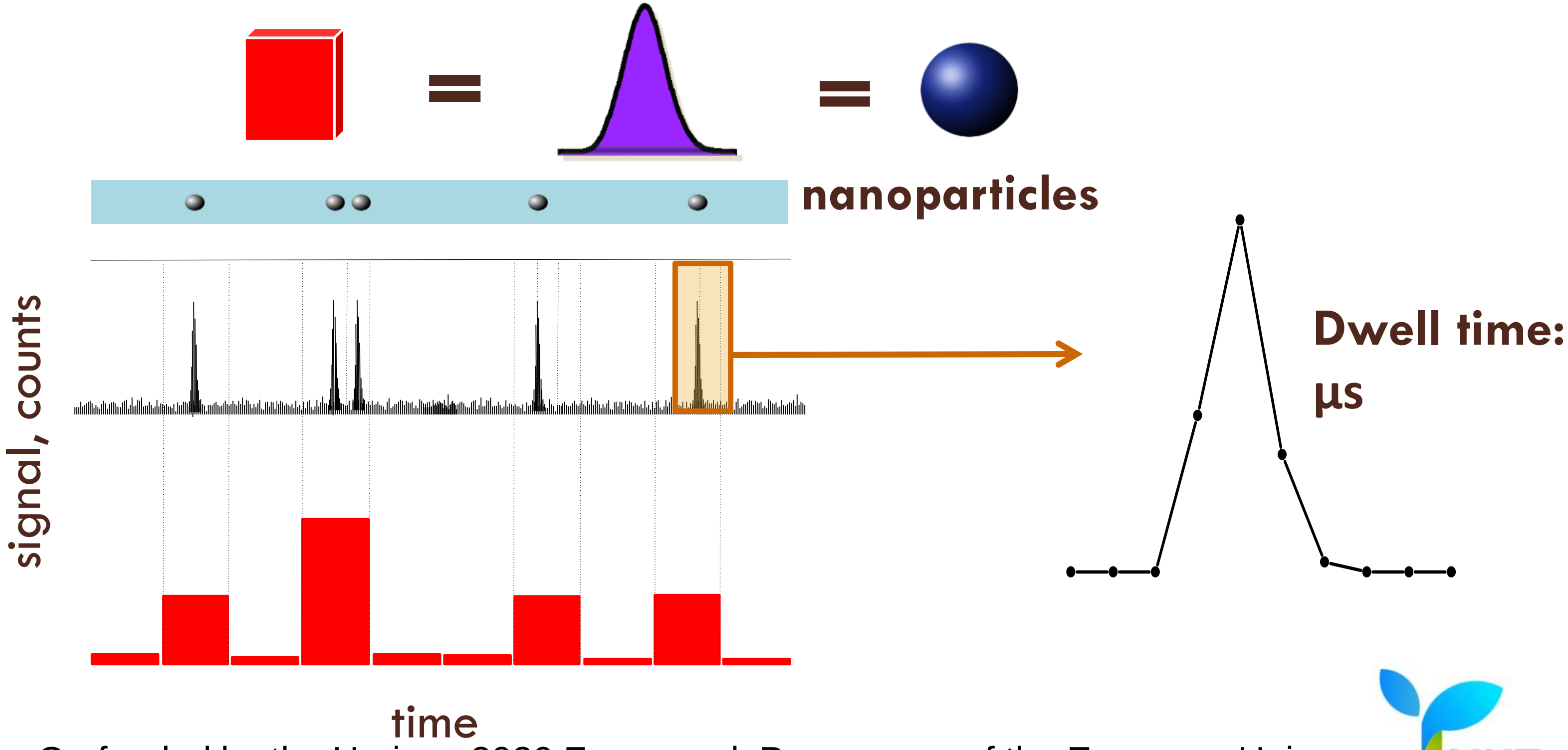
Evolution of Single Particle ICP-MS

1 pulse = 1 transient signal = 1 nanoparticle



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Anal Bioanal Chem (2014) 406:3835–3843
DOI 10.1007/s00216-013-7559-9

RESEARCH PAPER

International inter
of Ag nanoparticle

Thomas P. J. Linsinger • Ruud P

analytical chemistry

Article

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Post hoc Interlaborato
Measurements of NIST

Antonio R. Montoro Bustos,*,† El

†Material Measurement Laboratory, ‡Inforr
Bureau Drive, Gaithersburg, Maryland 208

Anal Bioanal Chem (2017) 409:4839–4848
DOI 10.1007/s00216-017-0427-2

CrossMark

RESEARCH PAPER

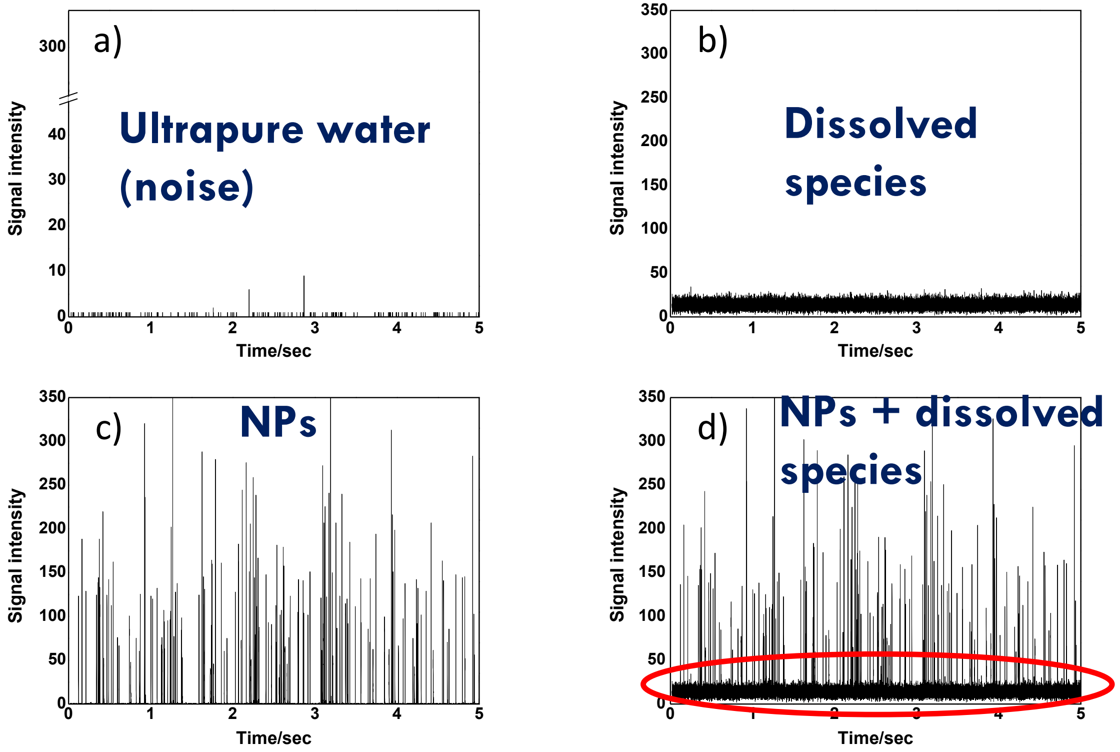
Results of an interlaboratory method performance study for the size determination and quantification of silver nanoparticles in chicken meat by single-particle inductively coupled plasma mass spectrometry (sp-ICP-MS)

Stefan Weigel[1,2] • Ruud Peters[1] • Katrin Loeschner[3] • Ringo Grombe[4] • Thomas P. J. Linsinger[4]

Co-funded by the Horizon 2020 Framework Programme of the European Union
under the grant N° *952306*

Information obtained by Single Particle ICP-MS

each sample containing nanoparticles is measured by monitoring the element of interest according to the corresponding mass-to-charge ratio (m/z) during several seconds or minutes



Very useful for screening purposes!

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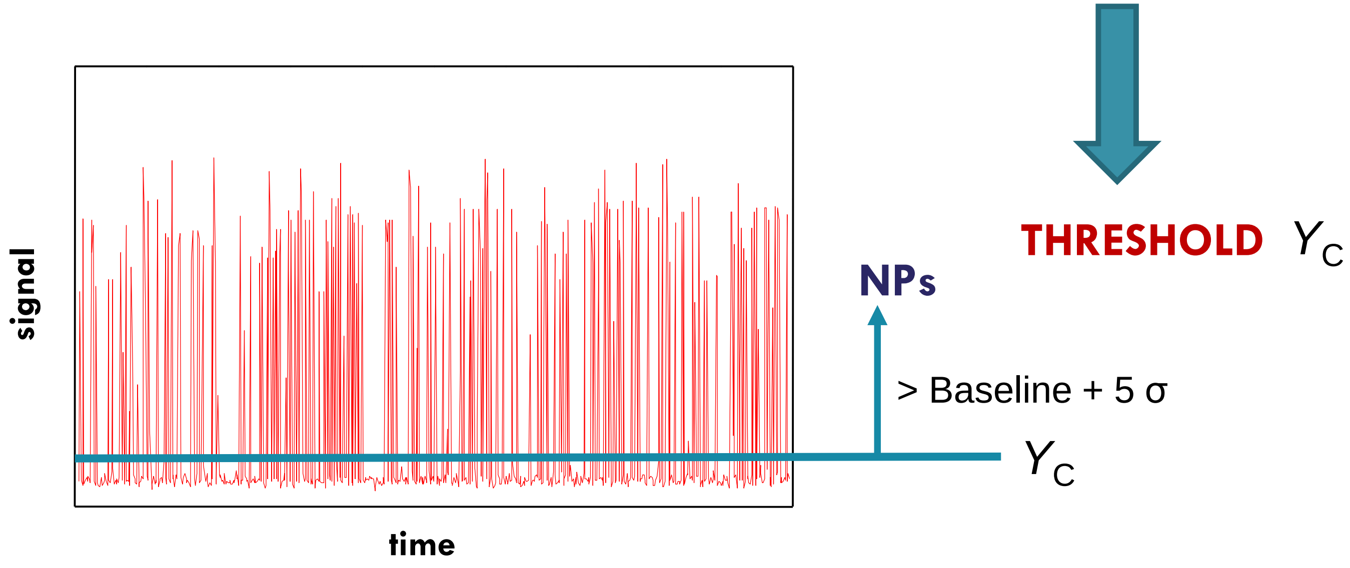
Information obtained by Single Particle ICP-MS

- The frequency of the detected pulses is directly related with the NP concentration in the sample
- We need to discriminate between signals coming from the nanoparticle and signal due to the background/dissolved element



Counting the number of pulses > the threshold → $$C_{NP} = \frac{N}{Q_{sam}\eta_{neb}t_i}$$

Σ signal > the threshold → **Mass concentration of NPs**

Σ signal < the threshold → **Mass concentration of dissolved element**

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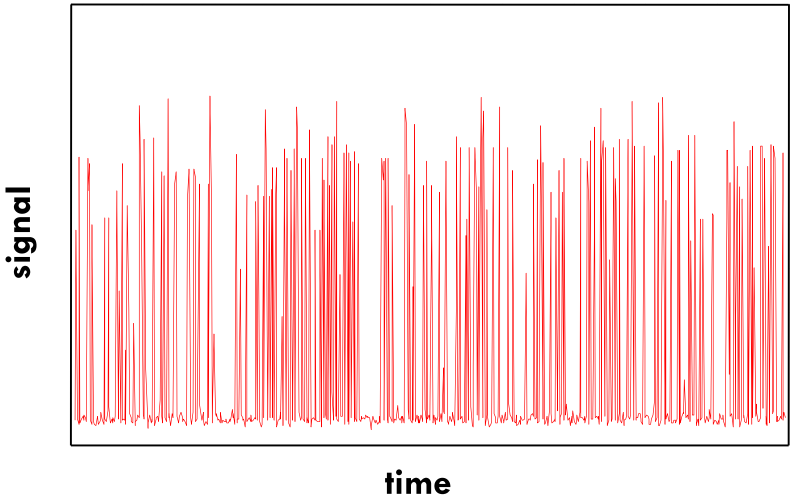
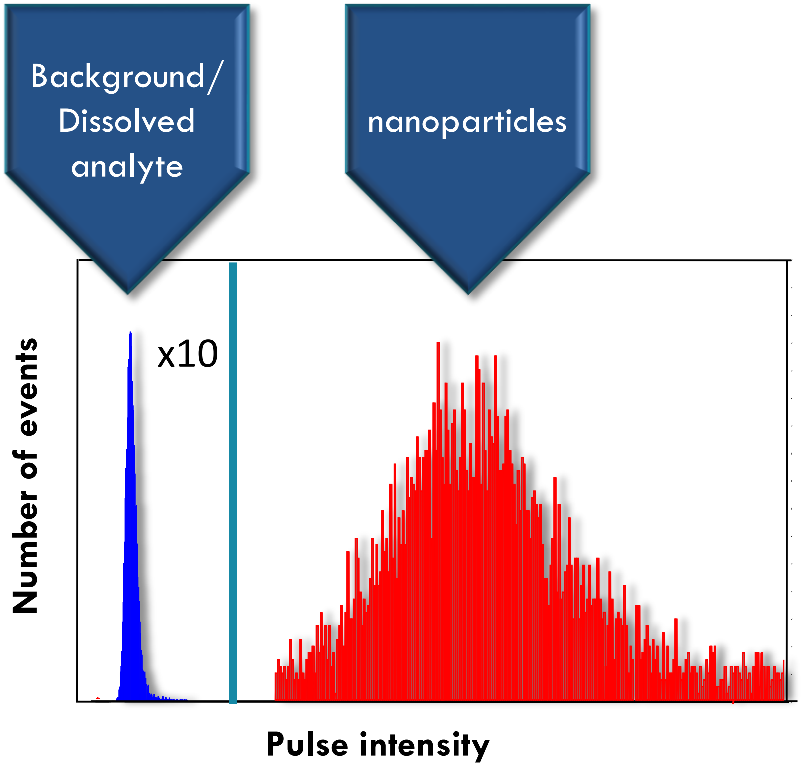
Information obtained by Single Particle ICP-MS

Time scan → **histogram**





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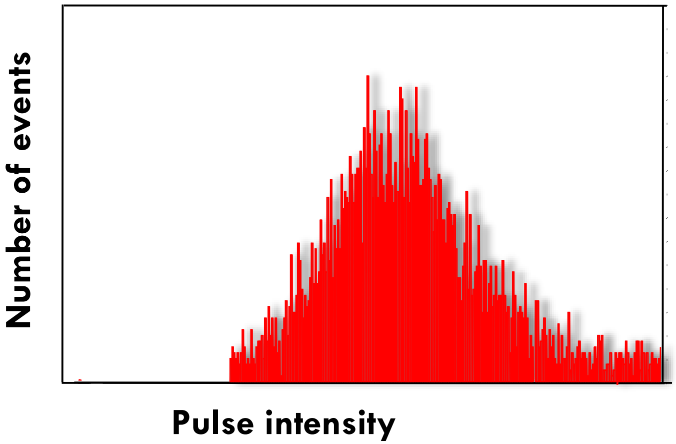

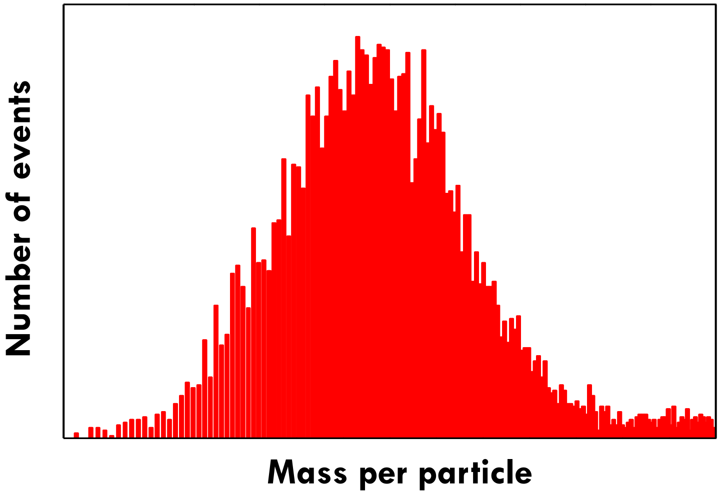

dissolved standard

- Transport efficiency
- sample flow rate

size??

Particle information:
- Composition
- Density
- Shape

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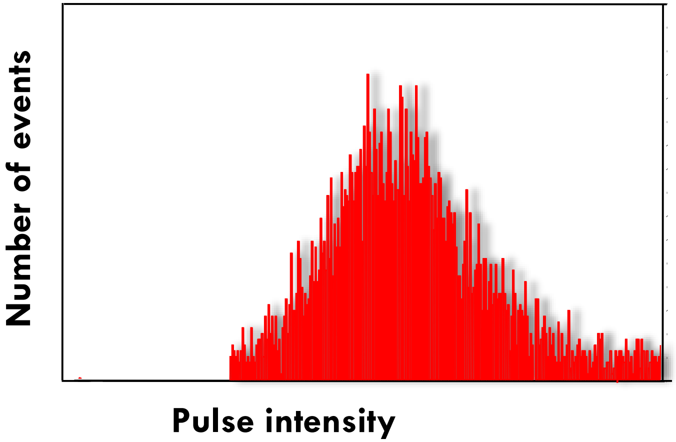
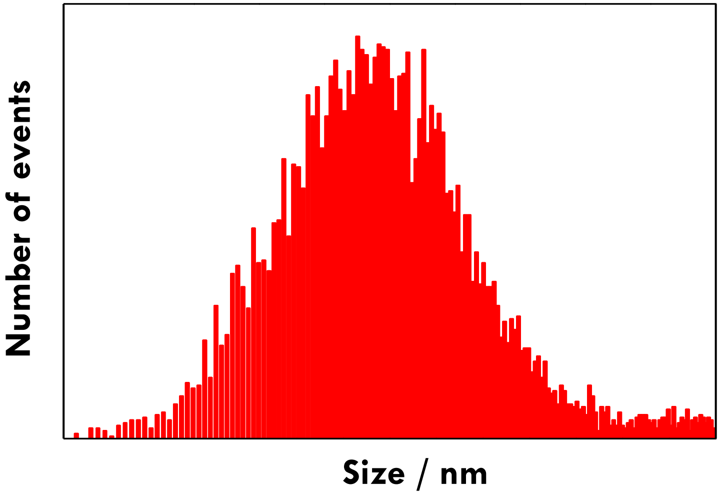
Information obtained by Single Particle ICP-MS





dissolved
standard

- Transport efficiency
- sample flow rate

$$d = \sqrt[3]{\frac{6m_{NP}}{\rho\pi}}$$

size!!

Particle information:

- Composition
- Density
- Shape

Co-funded by the Horizon 2020 Framework Programme of the European Union under the grant N° *952306*

Single Particle ICP-MS: applications

Environmental Waters

Occurrence of AgNPs and dissolved silver in influents and effluents of Waste Water Treatment Plant (WWTP)

- **Influents: 200 ng L^{-1} Ag-bearing NPs + 520 ng L^{-1} dissolved Ag**
- **Effluents: 100 ng L^{-1} Ag-bearing NPs + 60 ng L^{-1} dissolved Ag**

Mitrano et al. *Environ. Toxicol. Chem.* **2012**

Determination of anthropogenic nanoparticles in surface waters

- **Ti-bearing nanoparticles found in Old Danube Lake during a 12 months sampling period**
- **Highest concentration in summer (release of TiO_2NPs from sunscreens)**

Gondikas et al. *Environ. Sci. Technol.* **2014**

Occurrence of silver-, titanium- and cerium-bearing nanoparticles in the Barcelona catchment area

- **The three studied metal containing nanoparticles were detected in the Besòs River Basin**
- **Ce-bearing nanoparticles observed in river waters were related to the natural occurrence of the mineral Monazite (by monitoring the Ce/La ratio)**

Sanchis et al. *Environ. Sci. Technol.* **2020**

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Co-funded by the Horizon 2020 Framework Programme of the European Union under the grant N° *952306*

UNTWIN

Single Particle ICP-MS: applications

Plants uptake

Interaction of AuNPs with tomato plants

- **Uptake of intact 40 nm AuNPs**

Dan et al. *Environ. Sci. Technol.* **2015**

Uptake of PdNPs, CeO_2NPs and TiO_2 NPs by edible plants

- **Preferential uptake of smaller NPs**

Kinska et al. *Sci. Total Environ.* **2018**

Wojcieszek et al. *Sci. Total Environ.* **2019**

Wojcieszek et al. *Front. Environ. Sci.* **2020**

Accumulation of CeO_2NPs in cucumber, tomato, soybean, and pumpkin

- **Presence of dissolved Ce and particulate Ce in all plant tissues**
- **This transformation is thought to happen at the root surfaces**

Dan et al. *Anal. Bioanal. Chem.* **2016**

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Single Particle ICP-MS: applications

Exposed organisms

Quantification of AgNPs and dissolved Ag in *Daphnia magna* hemolymph after exposure

- **Concentrations of both silver forms in the hemolymph exceeded the initial AgNPs concentration**
- **Confirmation of accumulation during filter feeding**

Scanlan et al. *ACS Nano* **2013**

Bioaccumulation of AuNPs and AgNPs exposed to zebrafish (*Danio rerio*)

- **Larger amount of AgNPs in the liver compared to AuNPs**

Kyung et al. *Chemosphere* **2018**

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UNTWIN

Single Particle ICP-MS: applications

Food

AgNPs in homogenized chicken meat

- **Previous separation of NPs by AF4**
- **Intact AgNPs in the meat**

Loeschner et al. *Anal. Bioanal. Chem.* **2013**

TiO_2 NPs in chewing gums

- **Detection of TiO_2 of sizes ranging 40 to 200 nm in chewing gums after water extraction**

Candas-Zapico et al. *Talanta* **2018**

Presence of PbNPs from ammunition in game meat

- **Pb-containing NPs with sizes from 75 to 750 nm were detected in game meat shot with lead containing bullets**

Kollander et al. *Anal. Bioanal. Chem.* **2017**

Analysis of environmental samples: scenarios

complexity

type 1	Samples spiked with standards > LD
type 2	Samples spiked with standards < LD
type 3	Naturally occurring nanoparticles
type 4	Carbon-based nanoparticles

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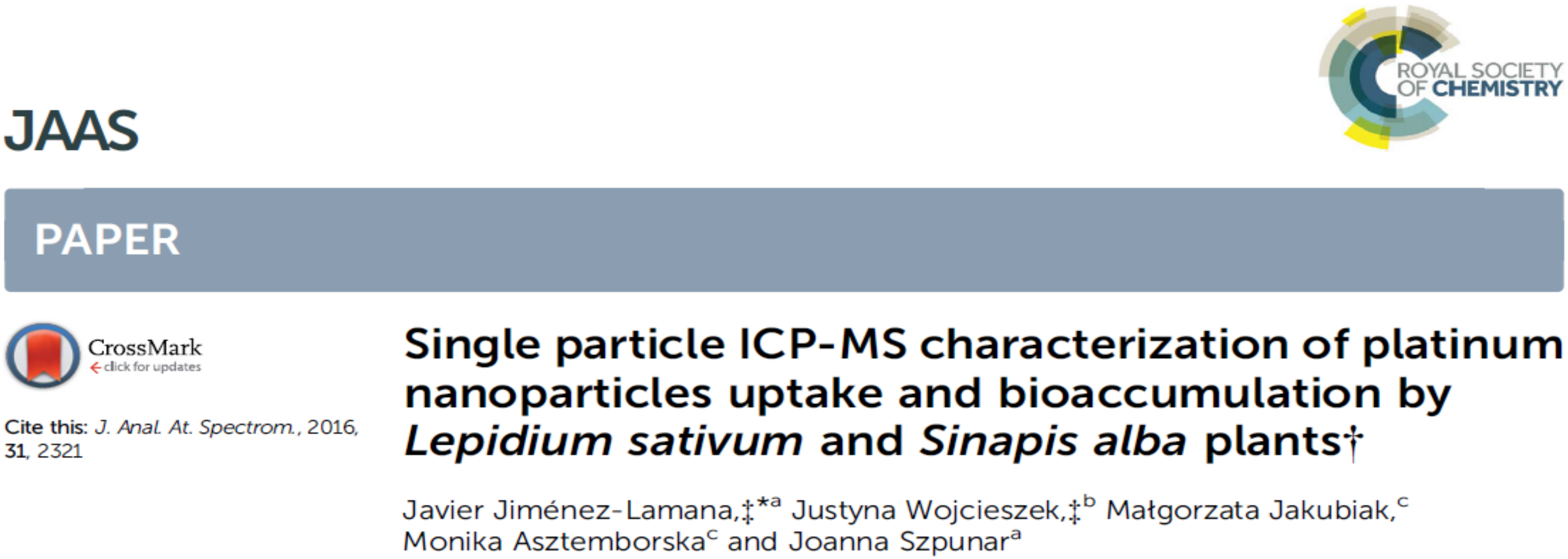
Practical case: PtNPs characterization in plants



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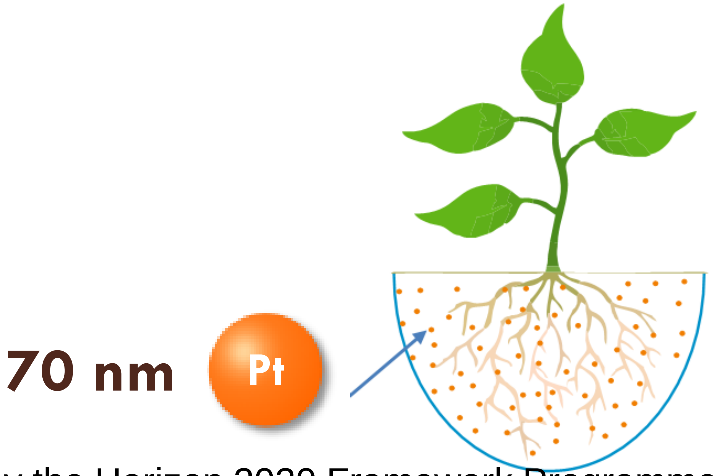
Cite this: *J. Anal. At. Spectrom.*, 2016, **31**, 2321

Single particle ICP-MS characterization of platinum nanoparticles uptake and bioaccumulation by *Lepidium sativum* and *Sinapis alba* plants†

Javier Jiménez-Lamana,‡*[a] Justyna Wojcieszek,‡[b] Małgorzata Jakubiak,[c] Monika Asztemborska[c] and Joanna Szpunar[a]



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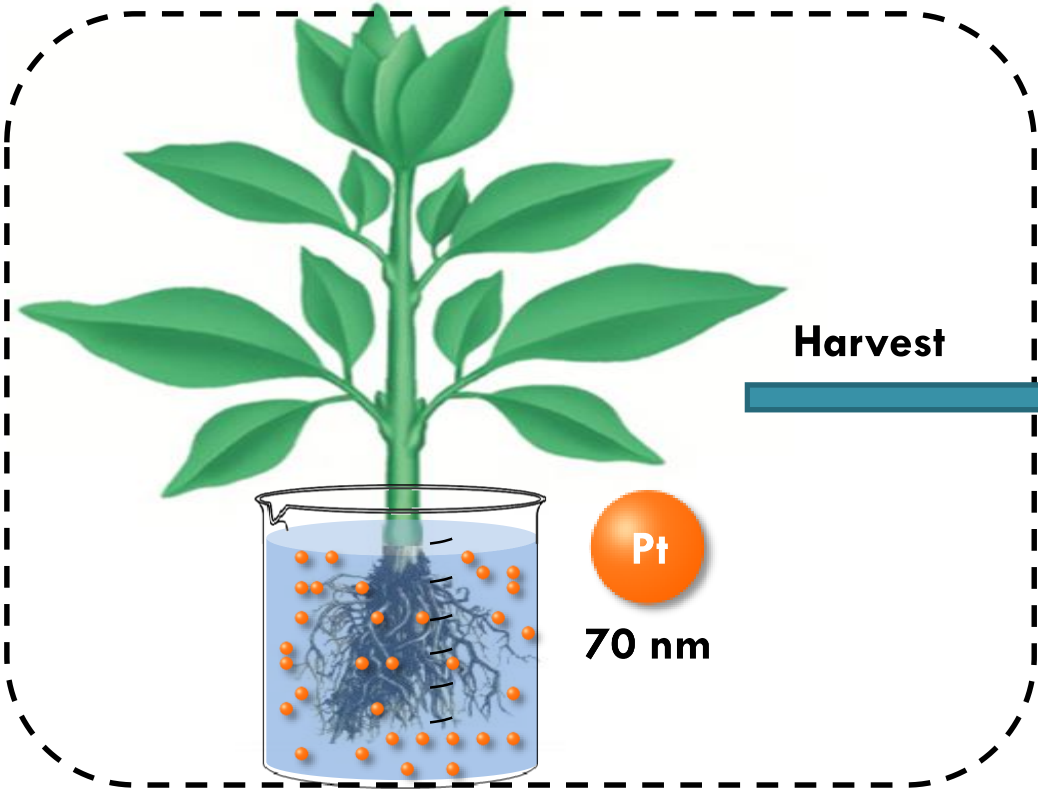
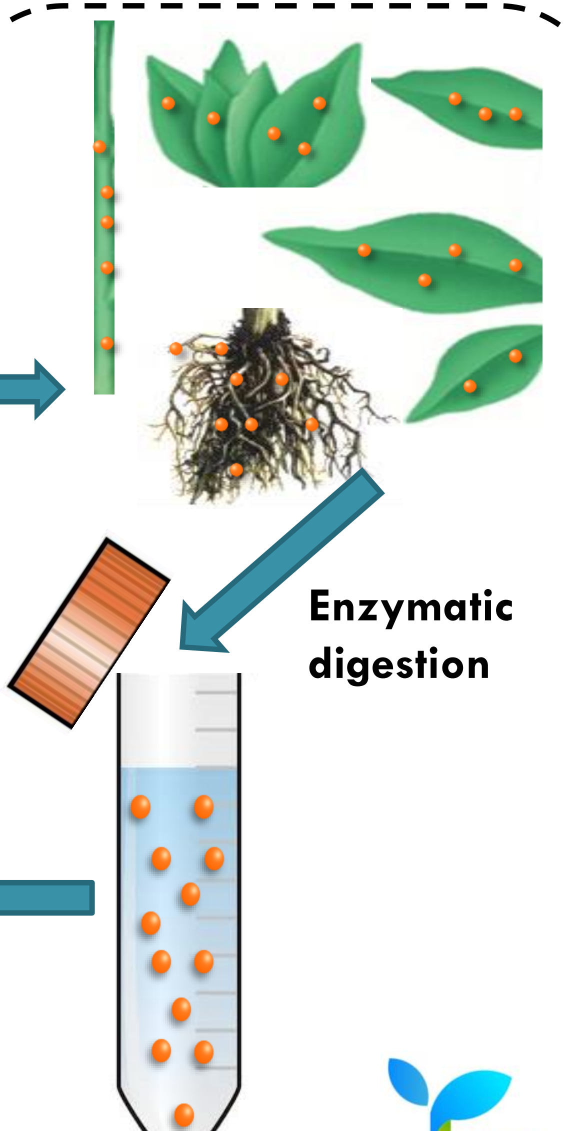
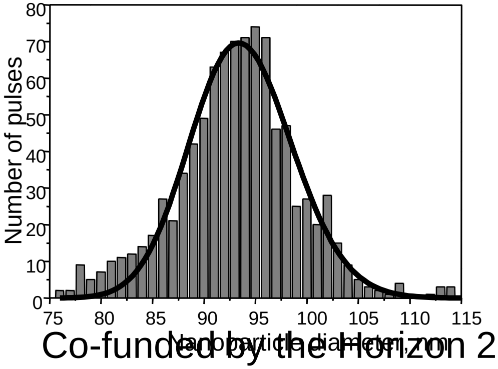
Practical case: PtNPs characterization in plants







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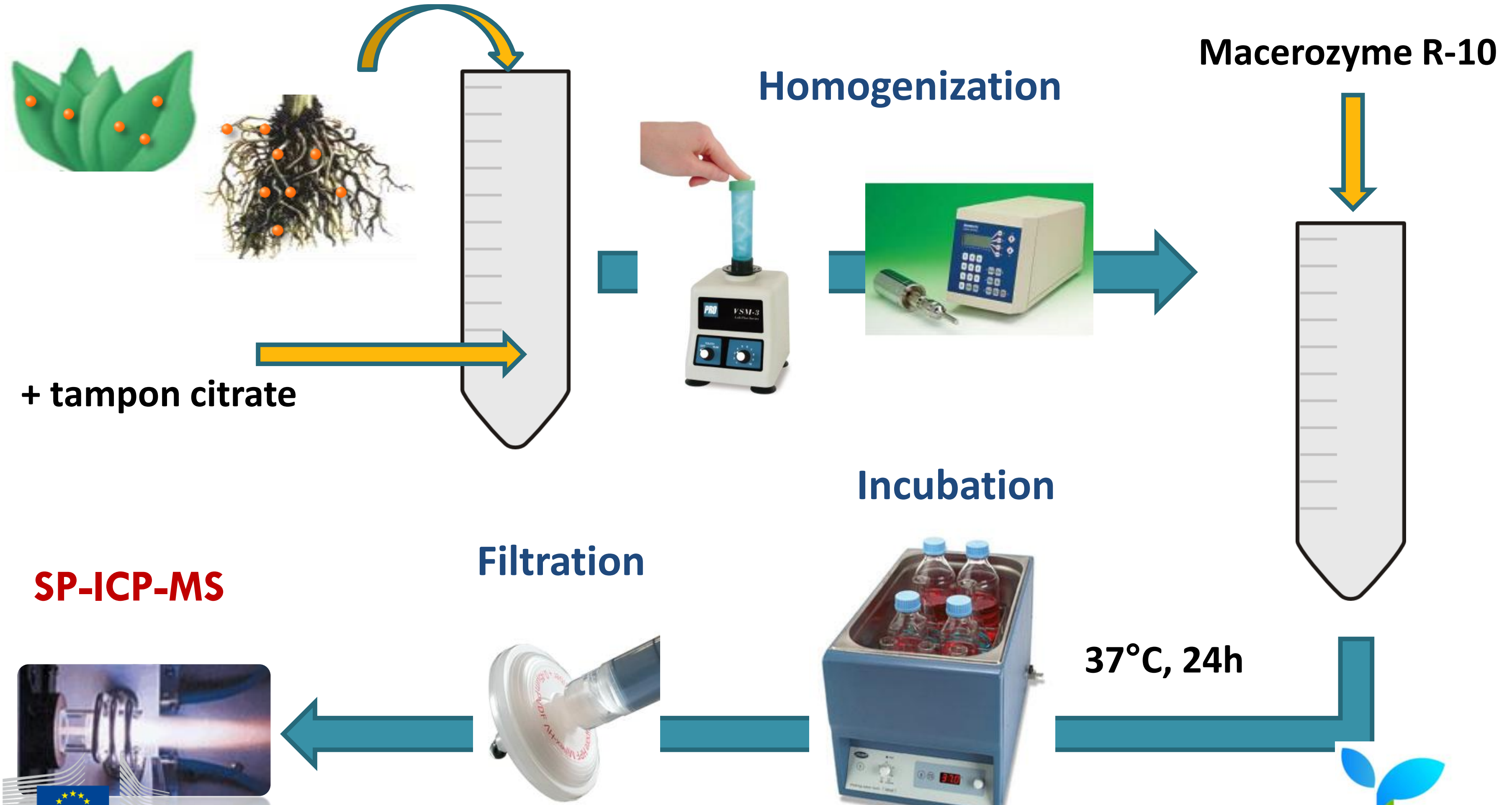
Practical case: PtNPs characterization in plants

Sample preparation: enzymatic digestion



+ tampon citrate

Homogenization

Macerozyme R-10

Incubation

37°C, 24h

Filtration

SP-ICP-MS

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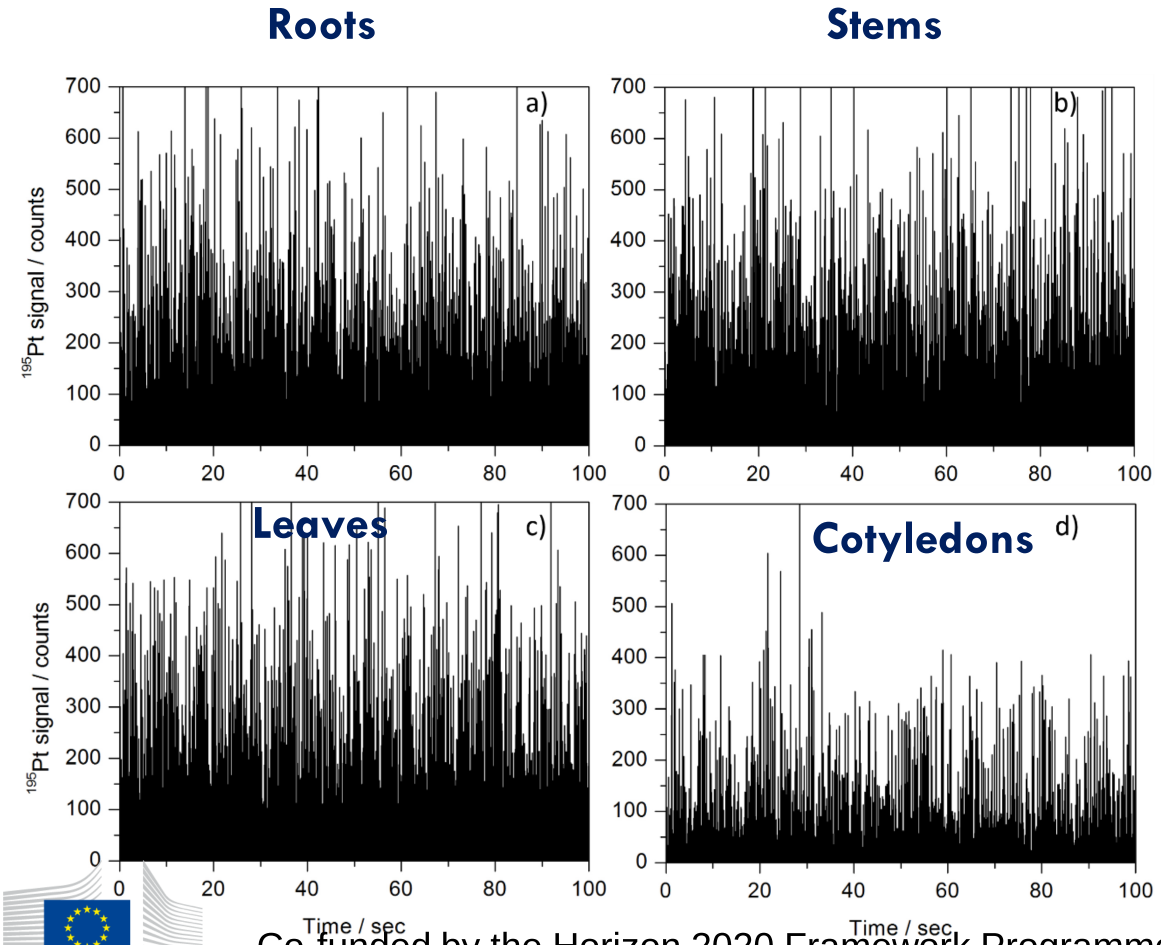
Practical case: PtNPs characterization in plants

SP-ICP-MS analysis

Sinapis alba



Sample	Number of NPs / NP L^{-1}
Leaves	5.30 x 10^{8}
Cotyledons	2.85 x 10^{8}
Stems	3.11 x10^{10}
Roots	6.18 x 10^{11}

- Presence of NPs

- NPs transported to above ground organs

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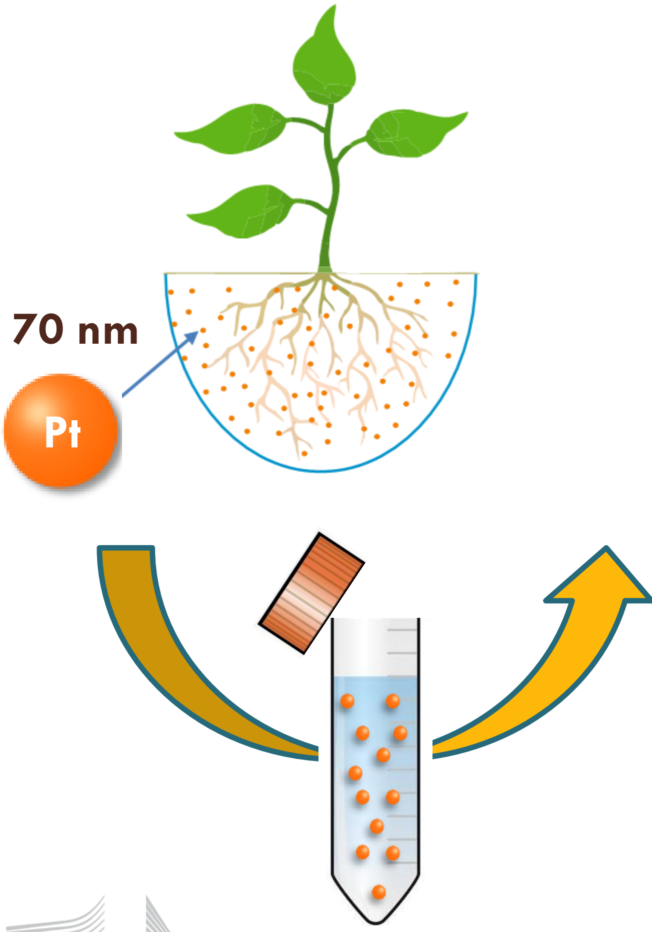
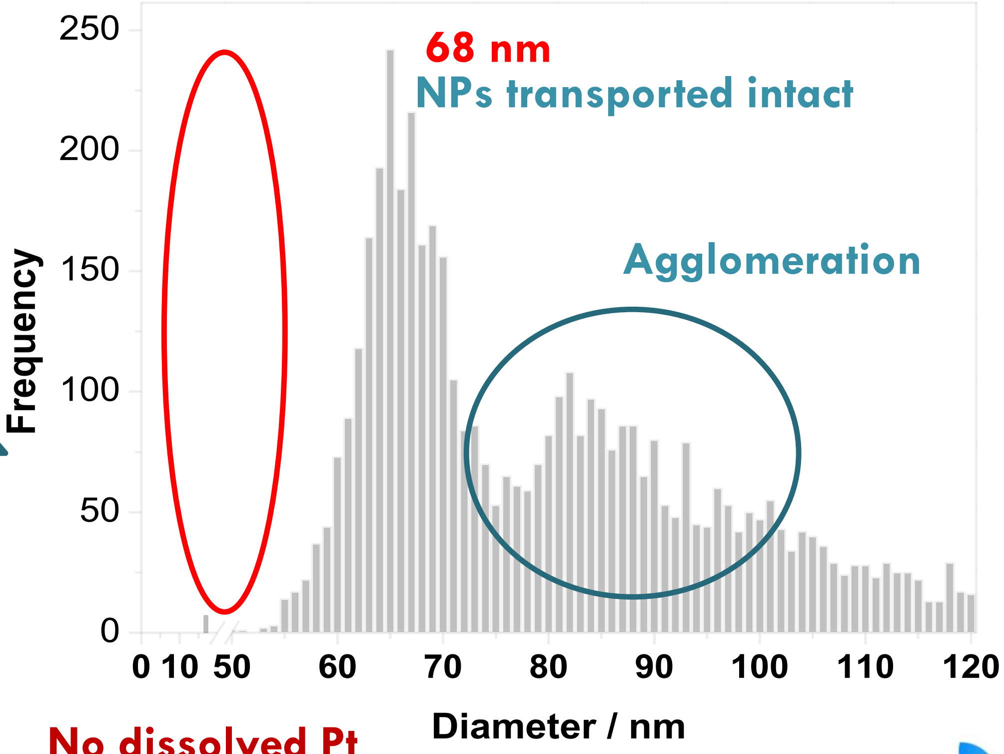
Practical case: PtNPs characterization in plants

Known composition, shape and size > LD





68 nm
NPs transported intact

Agglomeration

No dissolved Pt

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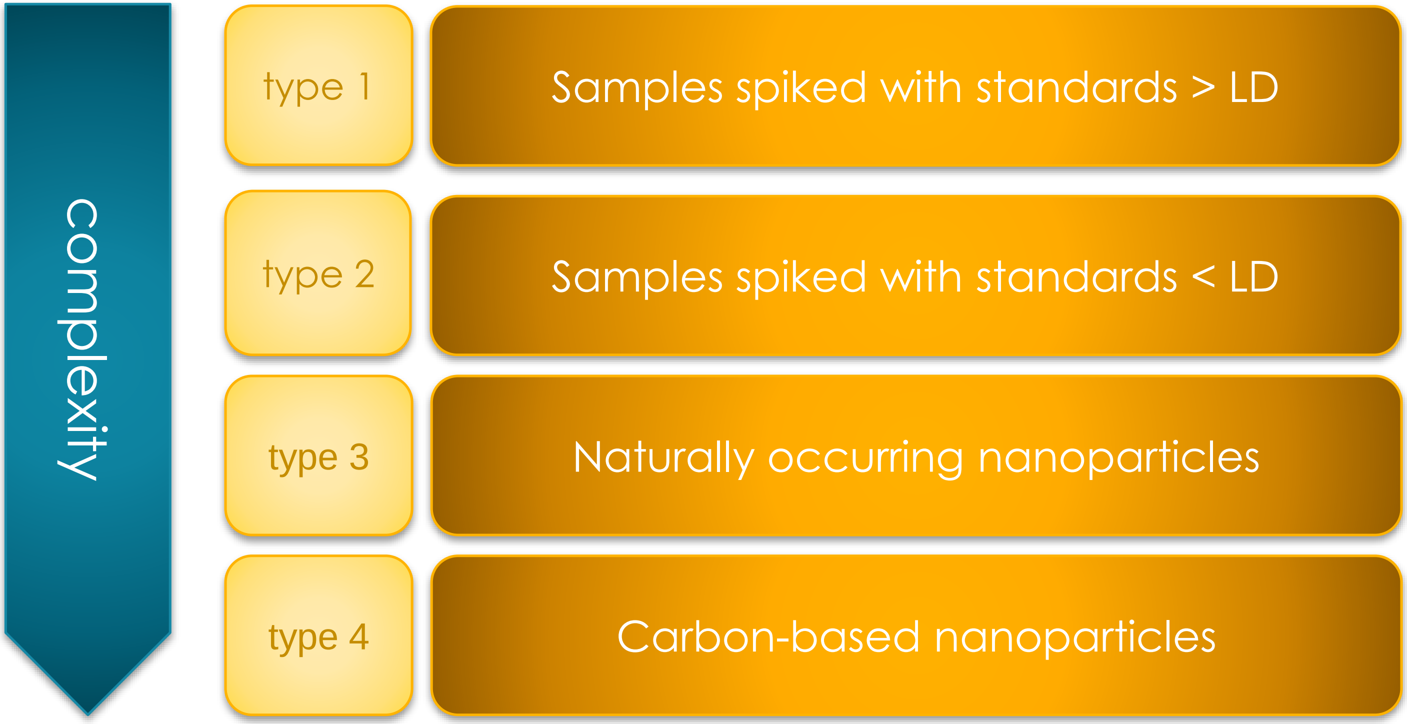
Analysis of environmental samples: scenarios



type 1	Samples spiked with standards > LD
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type 4	Carbon-based nanoparticles

Co-funded by the Horizon 2020 Framework Programme of the European Union
under the grant N° *952306*

Practical case: AgNPs in lake water

Contents lists available at ScienceDirect

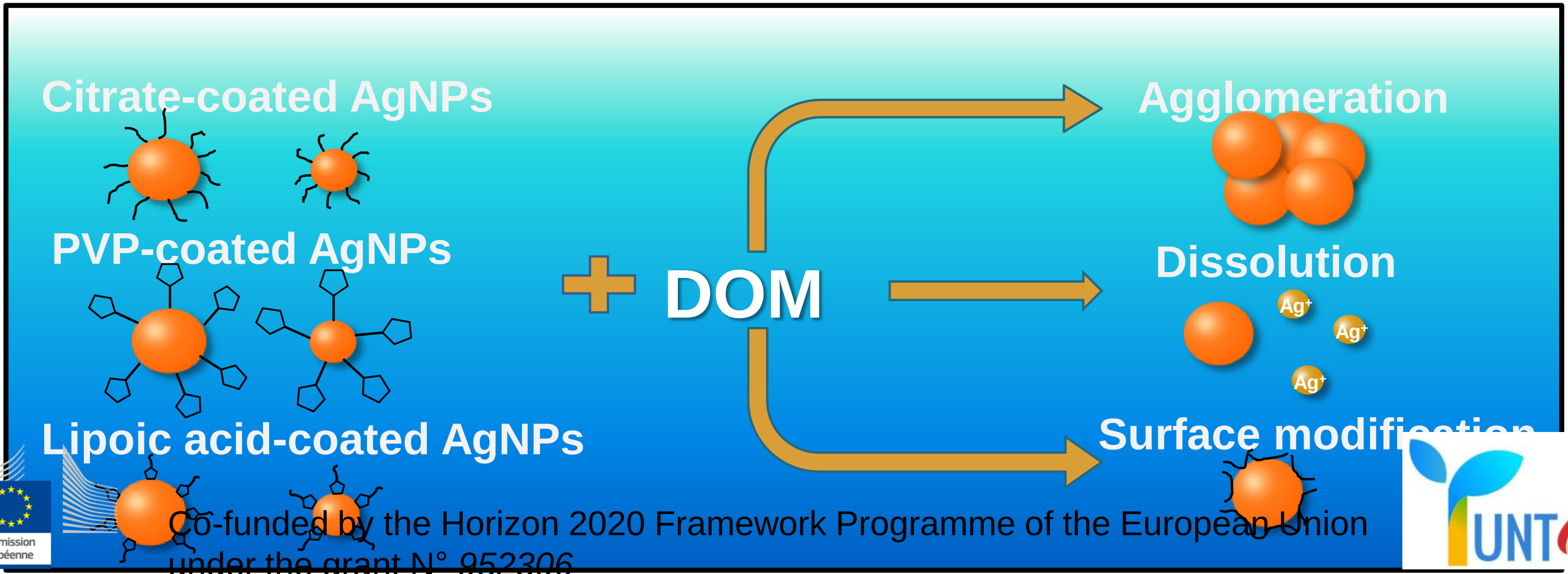
Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Silver nanoparticle behaviour in lake water depends on their surface coating

Javier Jiménez-Lamana *,[1], Vera I. Slaveykova *

Environmental Biogeochemistry and Ecotoxicology, Institute F.-A. Forel, Faculty of Sciences, University of Geneva, Uni Carl Vogt, 66 Bvd. Carl Vogt, CH-1211 Geneva, Switzerland



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Practical case: AgNPs in lake water

50 nm

20 nm

- Citrate
- PVP
- Lipoic acid

+

- LW
- LW + SRHA
- LW + EPS

SP-ICP-MS

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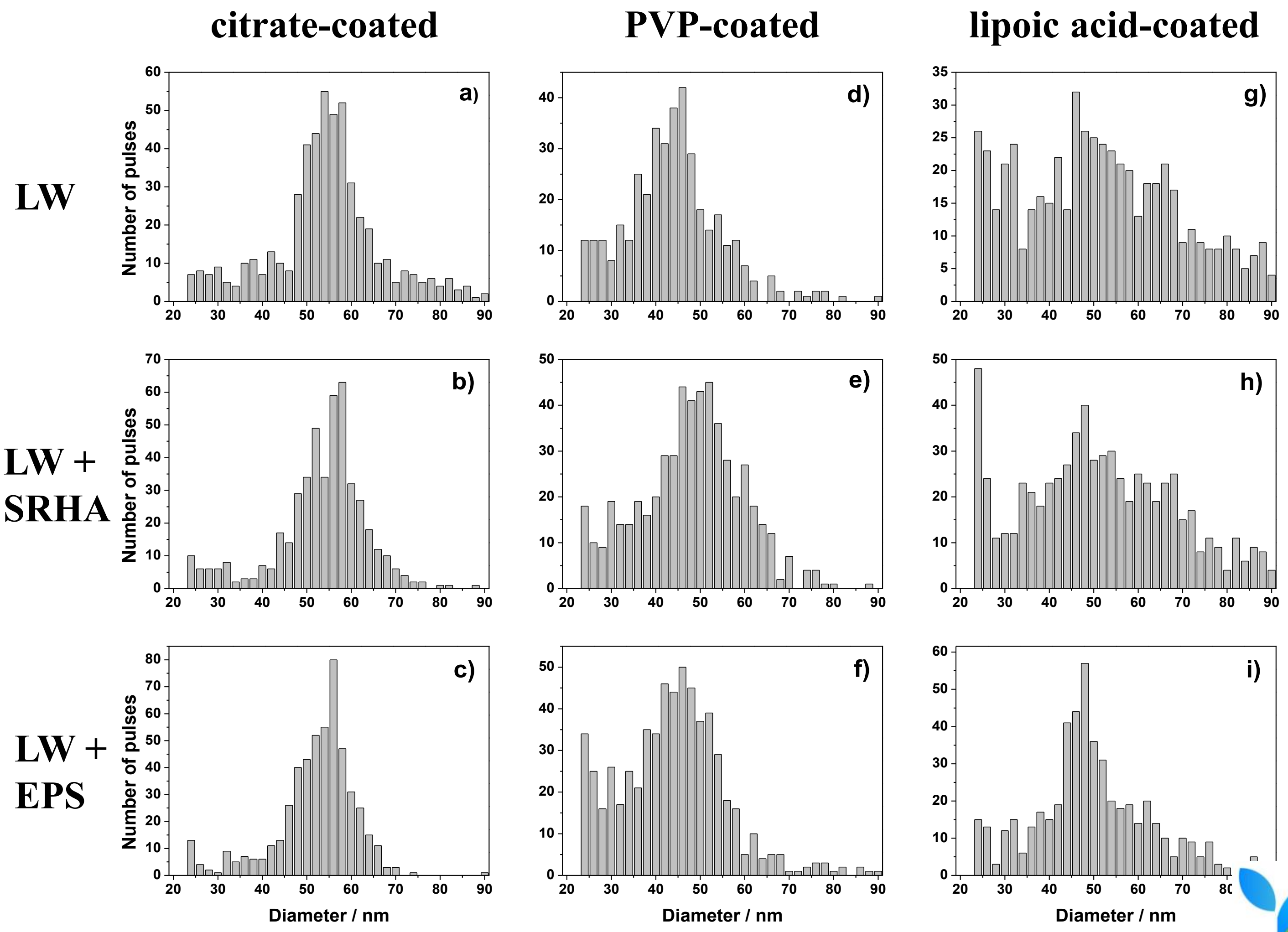
Practical case: AgNPs in lake water

50 nm AgNPs



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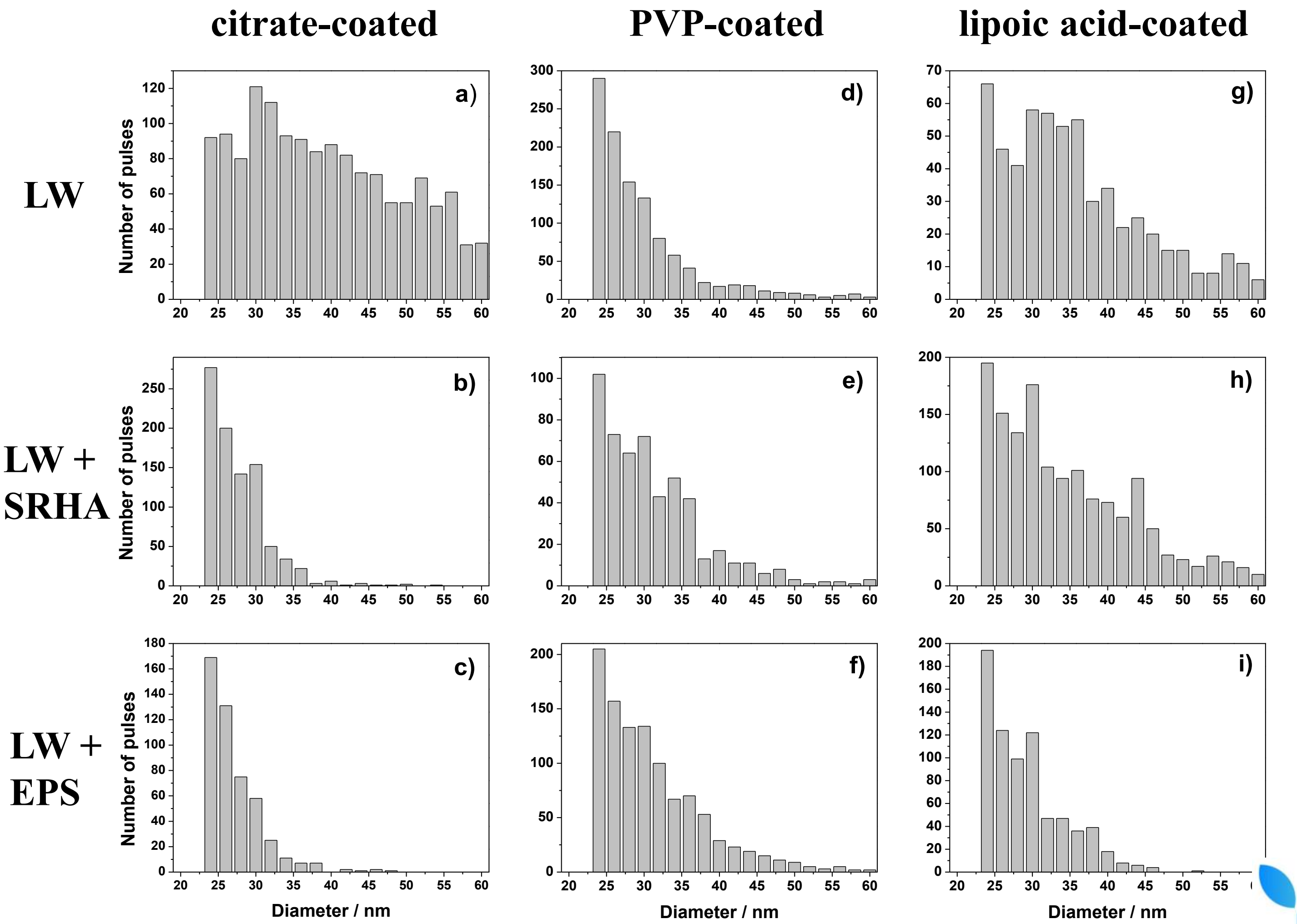
Practical case: AgNPs in lake water

20 nm AgNPs **Known composition, shape and size < LD**



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Practical case: AgNPs in lake water

50 nm
20 nm

- Citrate
- PVP
- Lipoic acid

+

- LW
- LW + SRHA
- LW + EPS

AsFlFFF-UV-Vis

SP-ICP-MS

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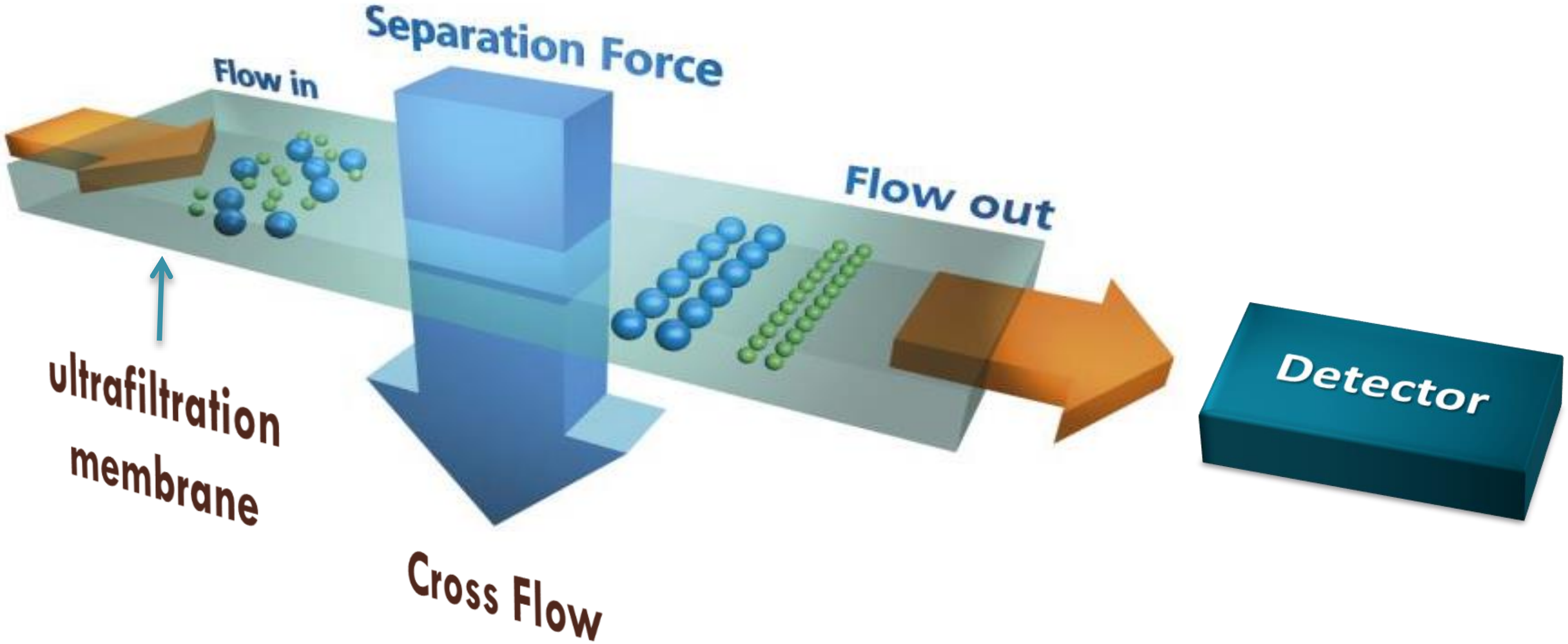
Practical case: AgNPs in lake water

Separation technique where species are size-separated in a thin open channel with laminar flow under the influence of a perpendicular external field



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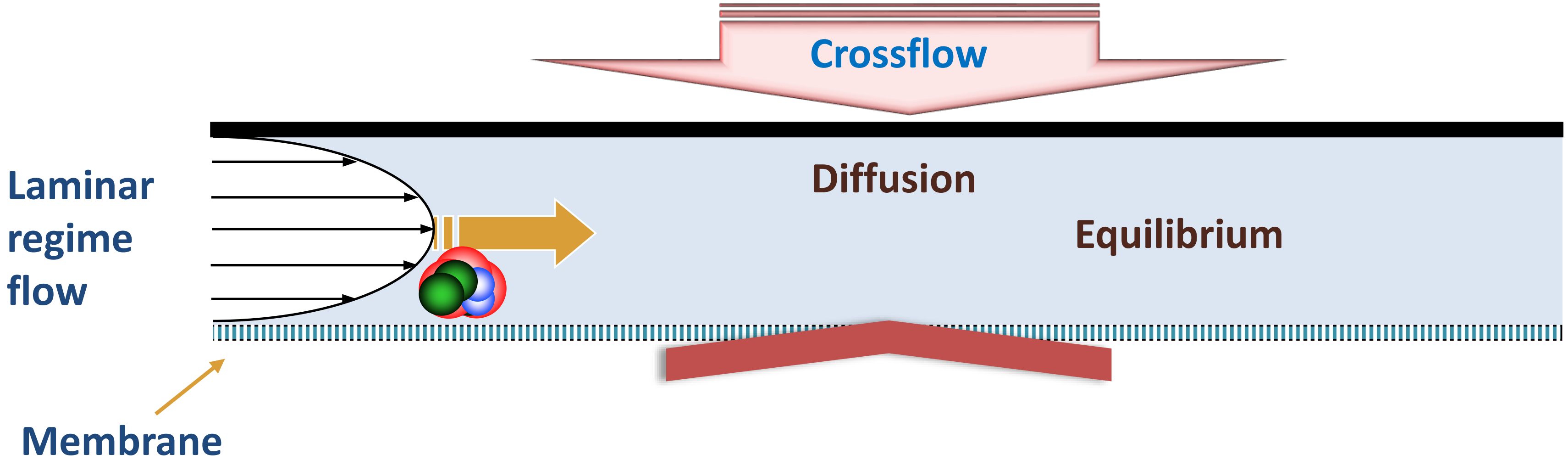
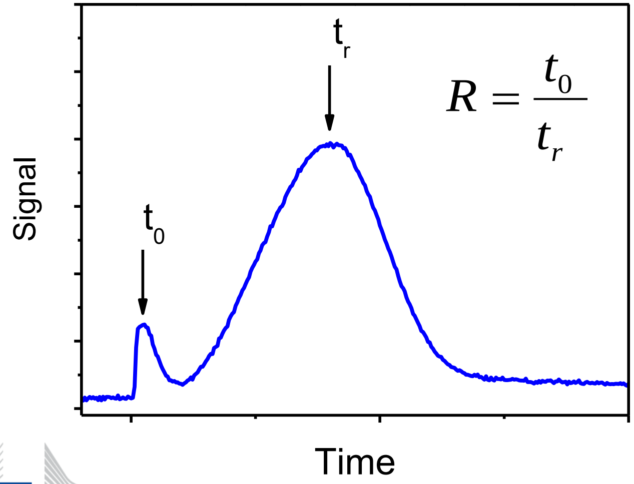
Practical case: AgNPs in lake water





$$R = \frac{t_0}{t_r}$$

$$\boxed{t_r \propto D \propto d}$$

Hydrodynamic diameter

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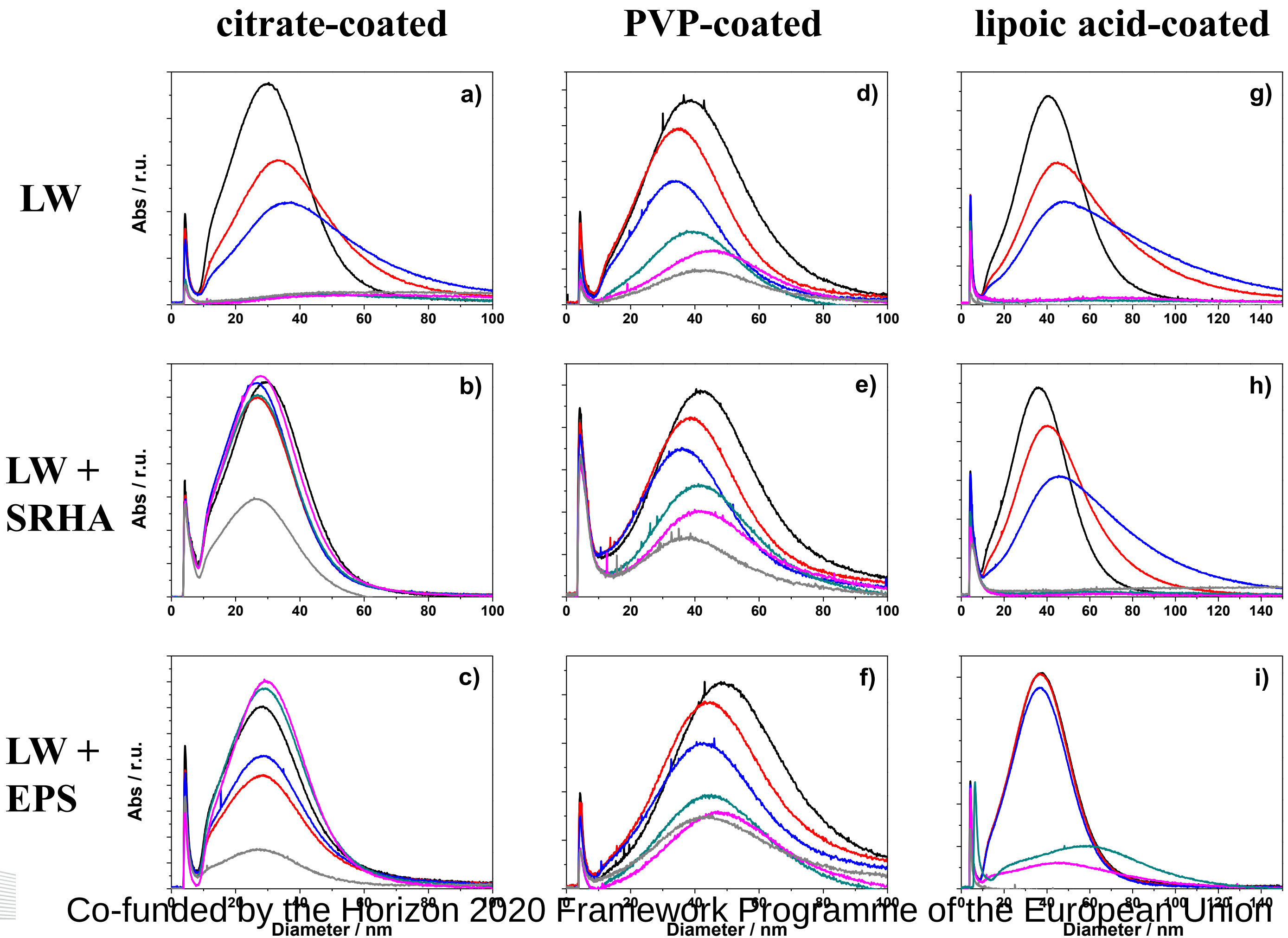
Practical case: AgNPs in lake water

20 nm AgNPs

Asymmetric field-flow fractionation



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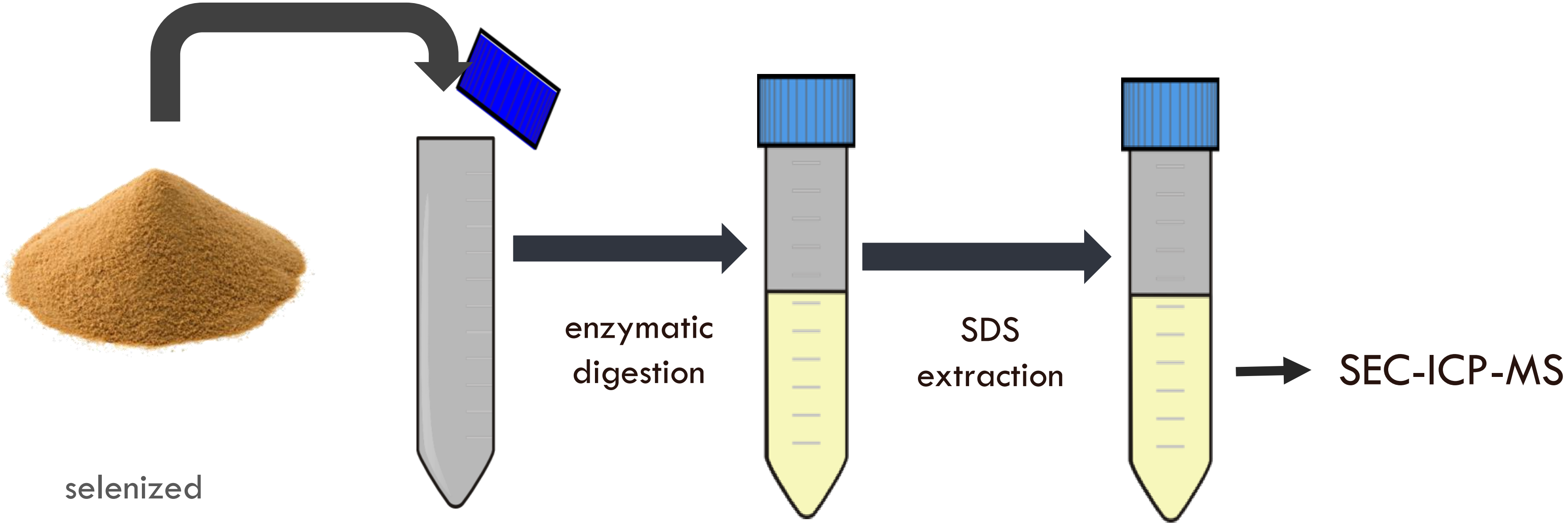
Biogenic SeNPs in yeast

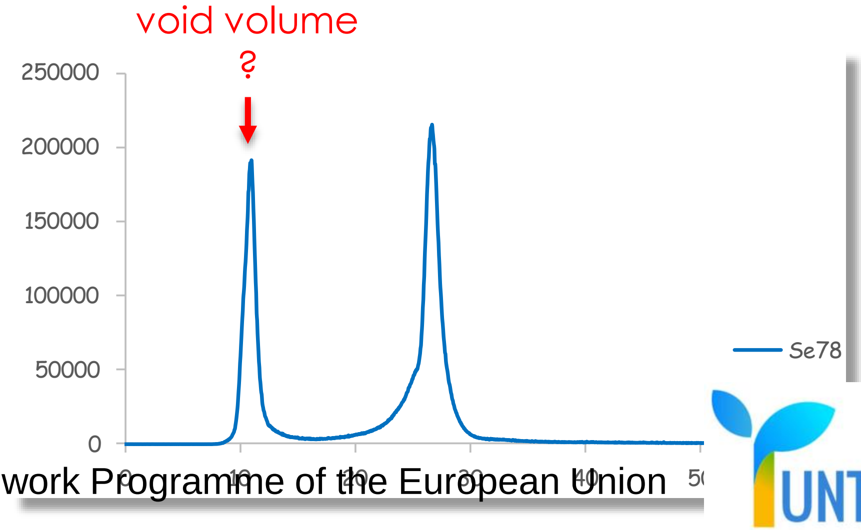


selenized yeast

enzymatic digestion

SDS extraction

SEC-ICP-MS



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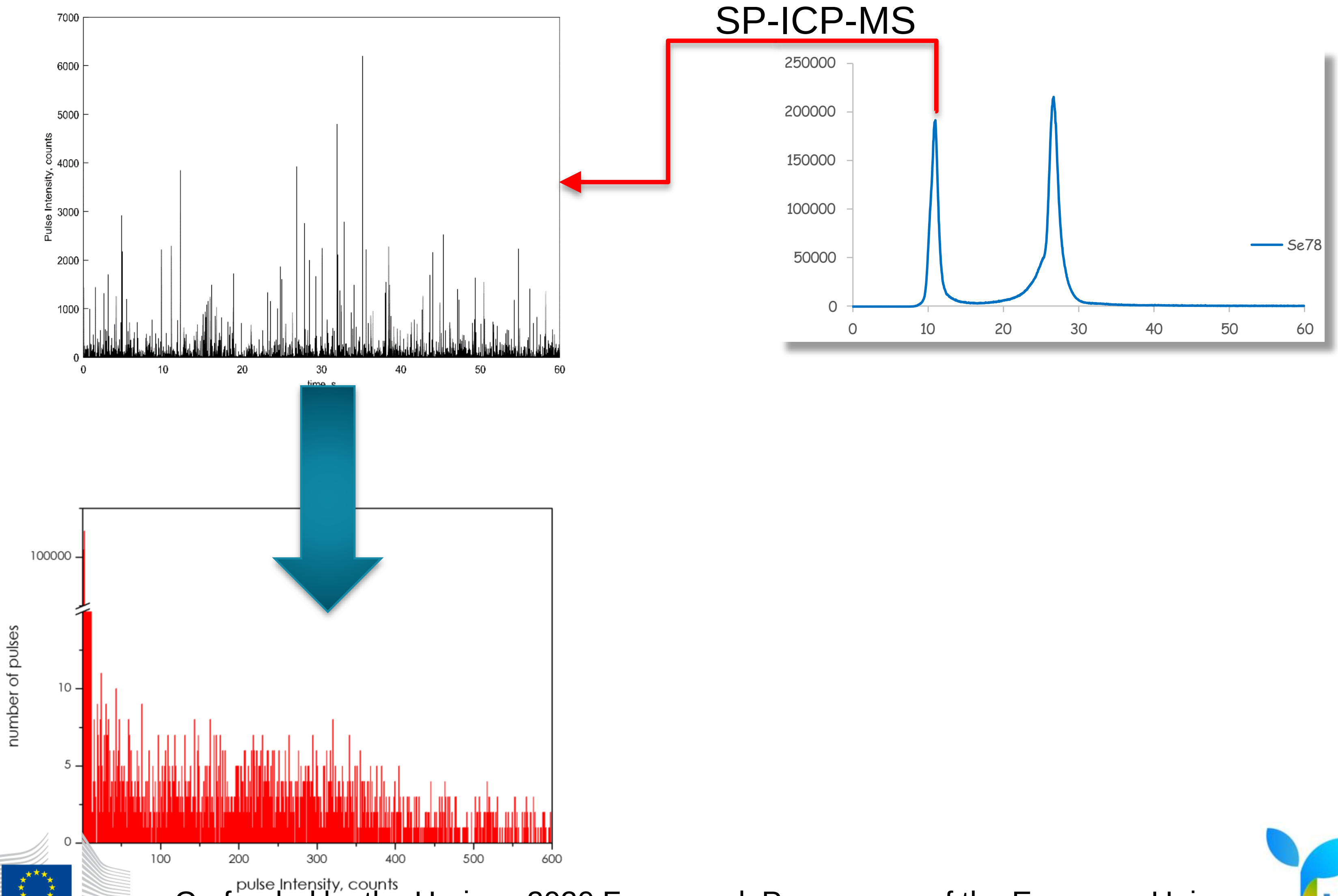
Biogenic SeNPs in yeast



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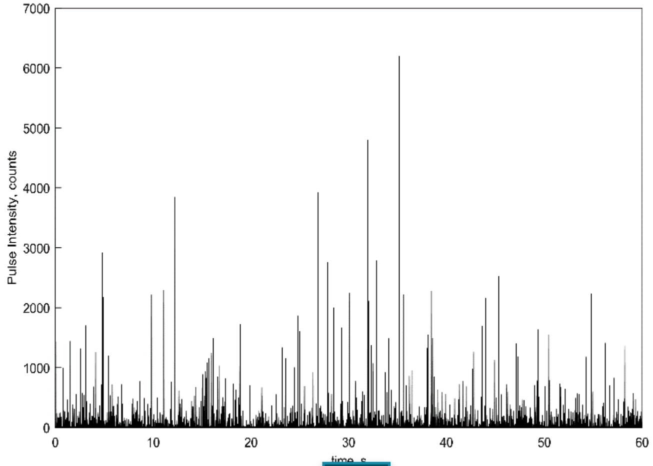
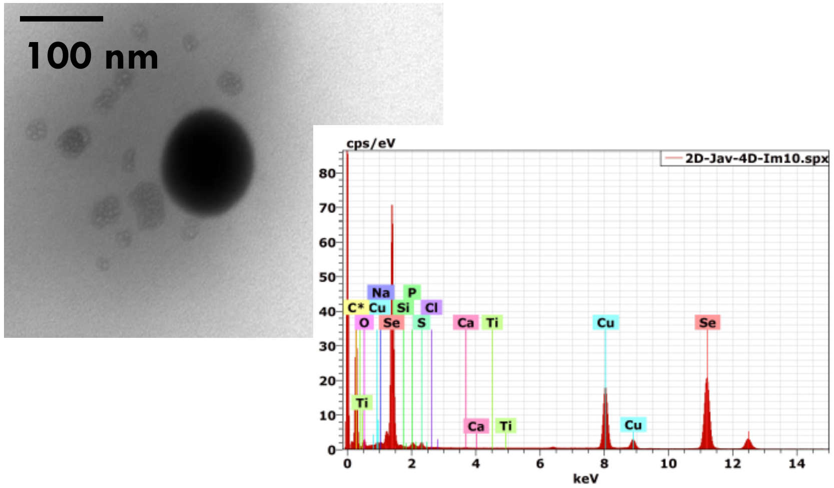
Biogenic SeNPs in yeast



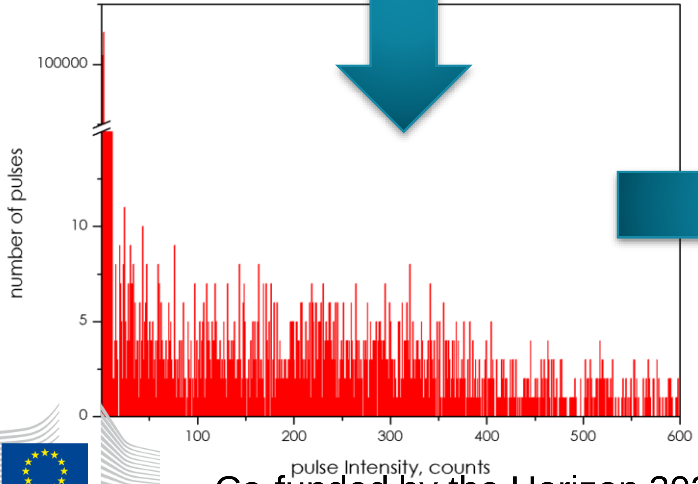
TEM-EDS analysis

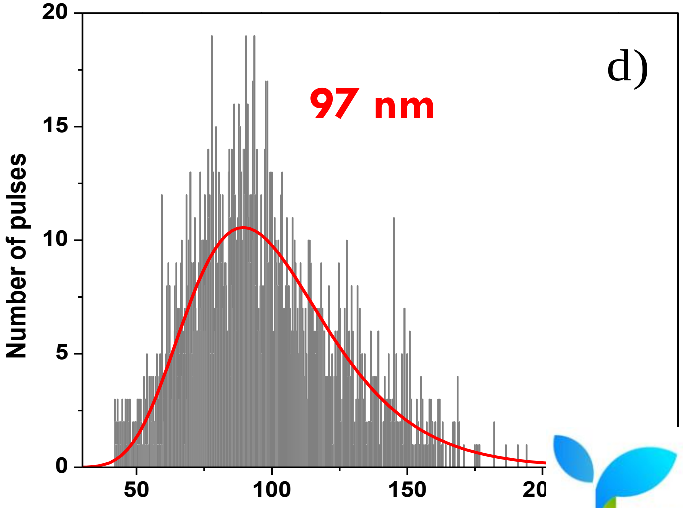


selenium

density: 4.81 g cm^{-3}

spheres





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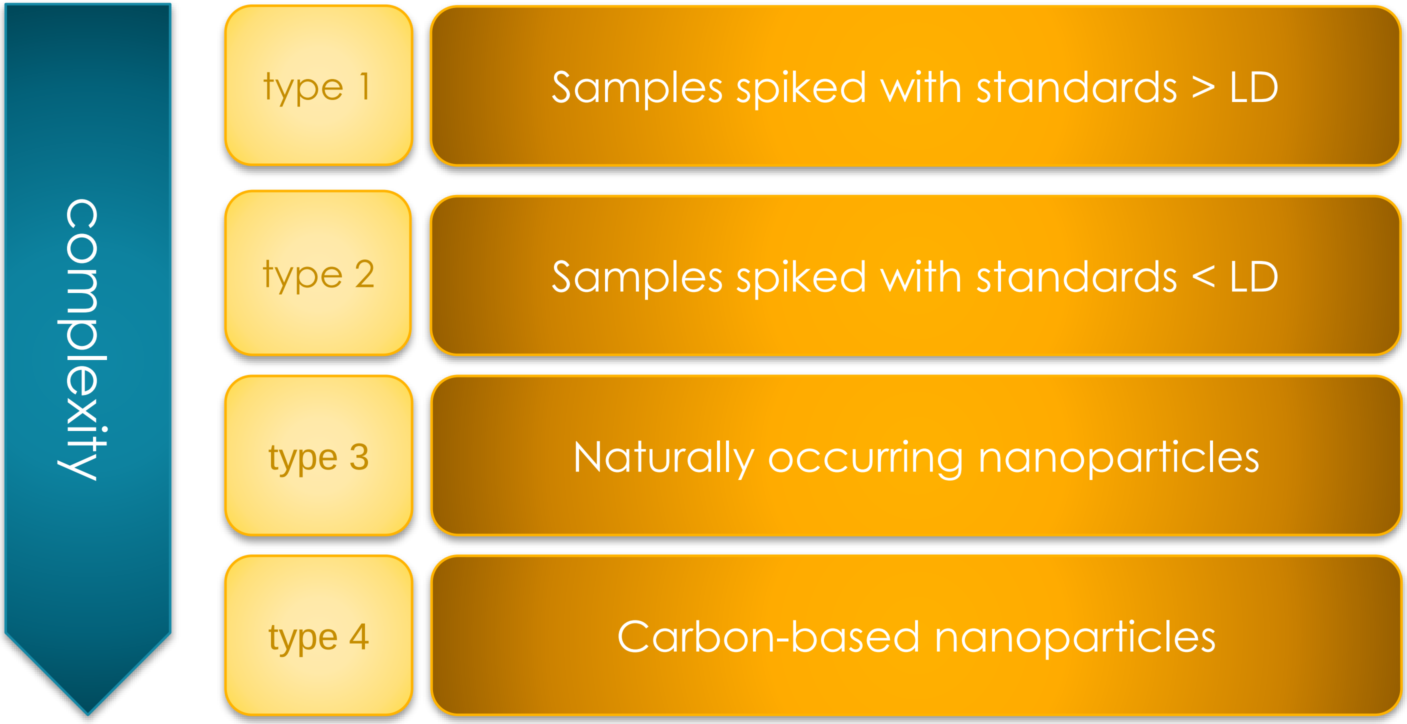
Analysis of environmental samples: scenarios



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SP-ICP-MS applied to plastic particles

✓ For inorganic nanoparticles

- SP-ICP-MS is widely used for the analysis of metallic nanoparticles
- Its excellent sensitivity (detection at the attogram level) allows the characterization of nanoparticles with sizes down to 10 nm

✗ For carbon based nanoparticles

- C is not sensitive towards ICP-MS due to its low ionization efficiency (< 5 %) and high ionization potential (11.26 eV)
- The background of ^{12}C is very high due the presence of carbon in water and air
- ^{13}C is not sensitive enough due to its low abundance (1.1 %)

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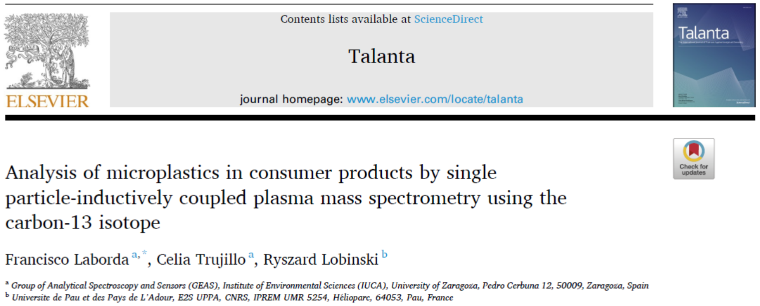
SP-ICP-MS applied to plastic particles



Contents lists available at ScienceDirect

Talanta

journal homepage: www.elsevier.com/locate/talanta

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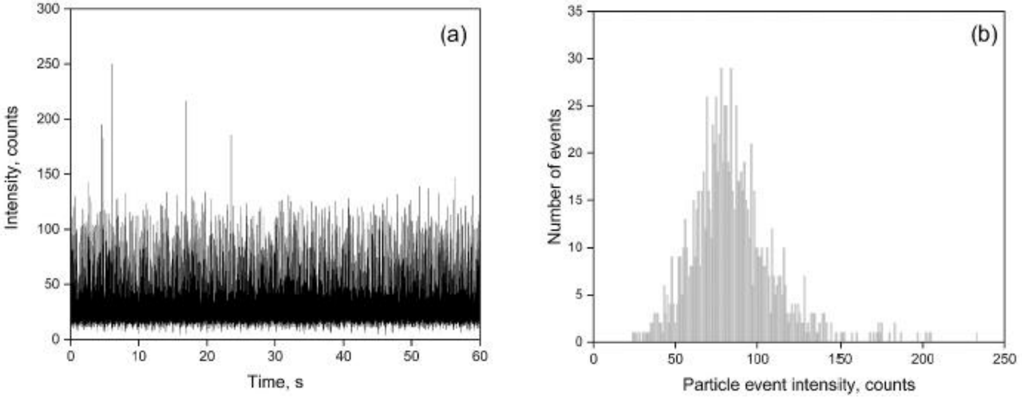
Analysis of microplastics in consumer products by single particle-inductively coupled plasma mass spectrometry using the carbon-13 isotope

Francisco Laborda [a,*], Celia Trujillo [a], Ryszard Lobinski [b]

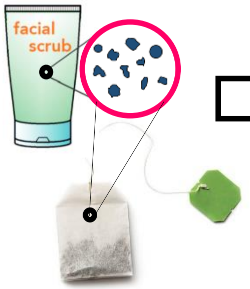
[a] Group of Analytical Spectroscopy and Sensors (GEAS), Institute of Environmental Sciences (IUCA), University of Zaragoza, Pedro Cerbuna 12, 50009, Zaragoza, Spain
[b] Université de Pau et des Pays de L'Adour, E2S UPPA, CNRS, IPREM UMR 5254, Hélioparc, 64053, Pau, France

Laborda et al. *Talanta* **2021**

Detection and quantification of 1.2-5 µm PS microplastics by monitoring ^{13}C

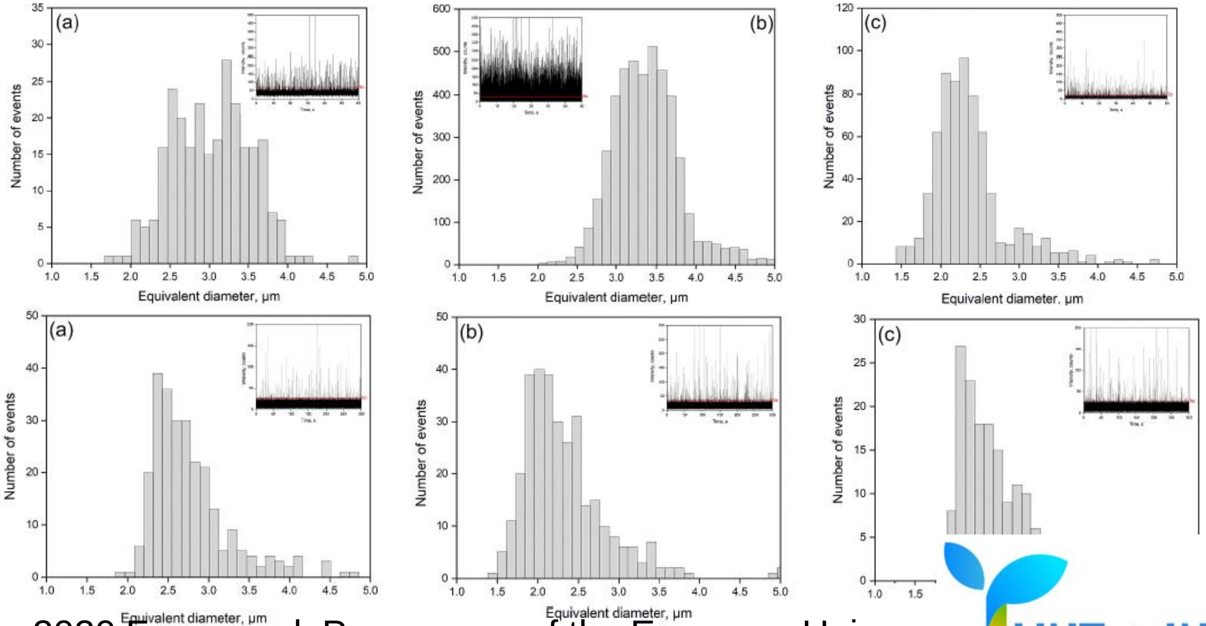


Applied to screening in food packaging and personal care products



Microplastics

SP-ICP-MS



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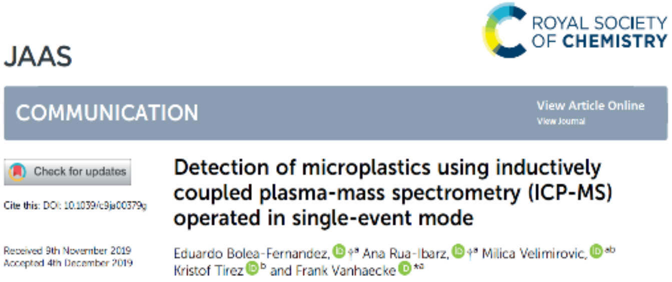
SP-ICP-MS applied to plastic particles

Bolea-Fernandez et al. *RSC* **2020**



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Cite this: DOI: 10.1039/c9ja00379g

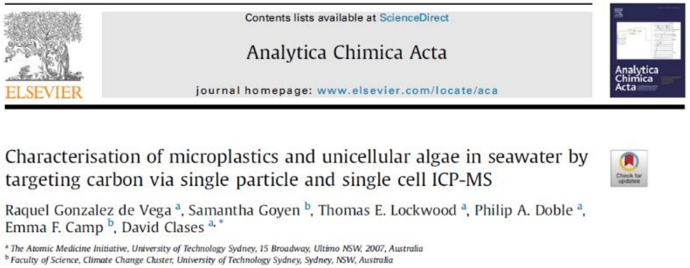
Received 9th November 2019
Accepted 4th December 2019

Detection of microplastics using inductively coupled plasma-mass spectrometry (ICP-MS) operated in single-event mode

Eduardo Bolea-Fernandez, †[a] Ana Rua-Ibarz, †[a] Milica Velimirovic, [ab] Kristof Tirez [b] and Frank Vanhaecke [*a]

- Determine size and number concentration of spherical polystyrene microspheres of 1 and 2.5 µm by monitoring ^{13}C
- Number based concentrations were assessed by comparing ^{13}C-related events with the events detected when monitoring the ^{165}Ho signal for 2.5 mm lanthanide-doped polystyrene beads

Gonzalez de Vega et al. *Analytica Chimica Acta* **2021**



ELSEVIER

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Analytica Chimica Acta

journal homepage: www.elsevier.com/locate/aca

Characterisation of microplastics and unicellular algae in seawater by targeting carbon via single particle and single cell ICP-MS

Check for updates

Raquel Gonzalez de Vega [a], Samantha Goyen [b], Thomas E. Lockwood [a], Philip A. Doble [a], Emma F. Camp [b], David Clases [a,*]

[a] The Atomic Medicine Initiative, University of Technology Sydney, 15 Broadway, Ultimo NSW, 2007, Australia
[b] Faculty of Science, Climate Change Cluster, University of Technology Sydney, Sydney, NSW, Australia

- Development of an SP/SC ICP-MS method for the analysis of C-based microestructures in a particle-by-particle basis
- Achieved a size detection limit of 0.6 µm for PS-based microplastics by monitoring ^{12}C

Commission européenne

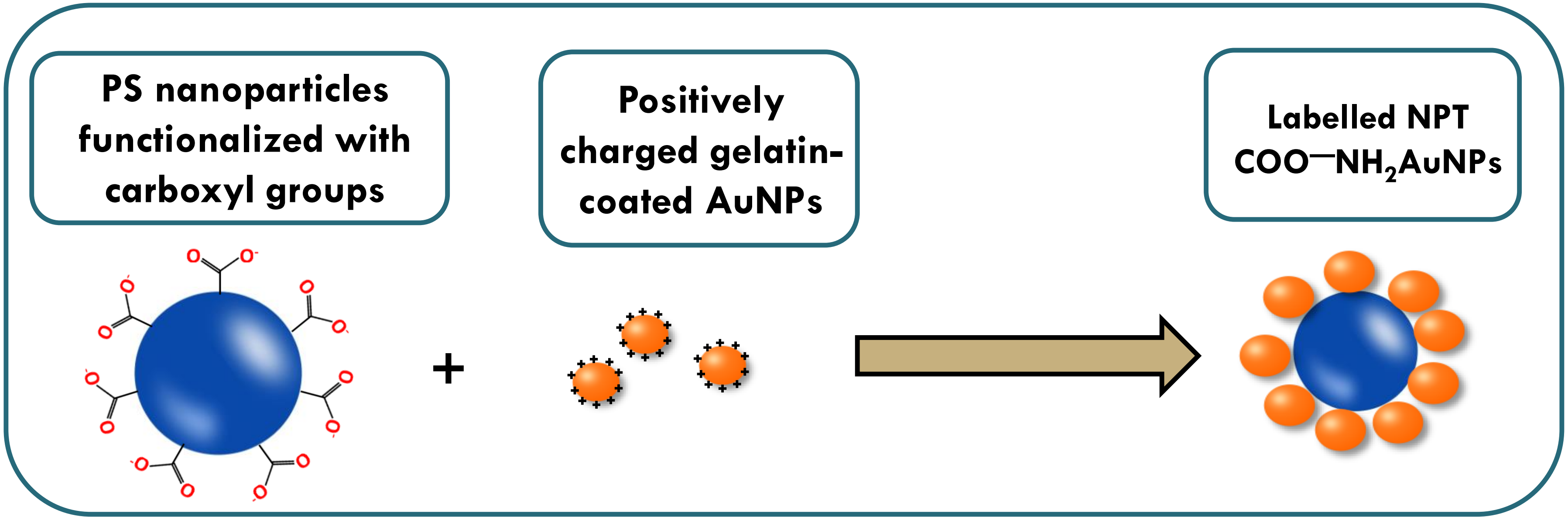
Co-funded by the Horizon 2020 Framework Programme of the European Union under the grant N° *952306*

UNTWIN

SP-ICP-MS applied to plastic particles

How to make the invisible nanoplastics visible to ICP-MS?

→ **Nanoplastics labelled with specific metal probes**



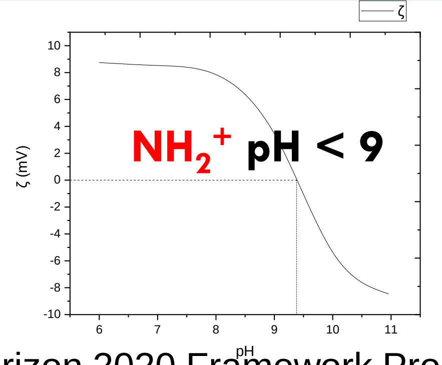
PS nanoparticles functionalized with carboxyl groups

\+

Positively charged gelatin-coated AuNPs

Labelled NPT $COO^{-}NH_2AuNPs$

COO^- pH > 5



NH_2^+ pH < 9

At working pH (6-8):
labelling through electrostatic interactions
COO^- (NPTs surface)
NH_2^+ (AuNPs

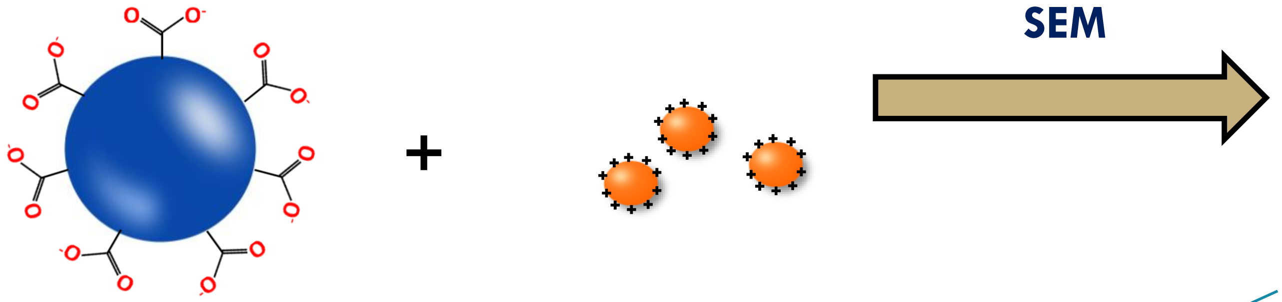
Co-funded by the Horizon 2020 Framework Programme of the European Union under the grant N° *952306*

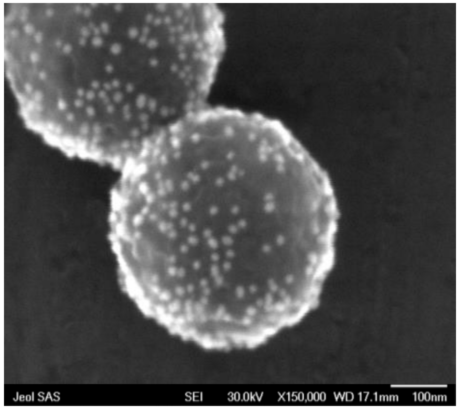
SP-ICP-MS applied to plastic particles

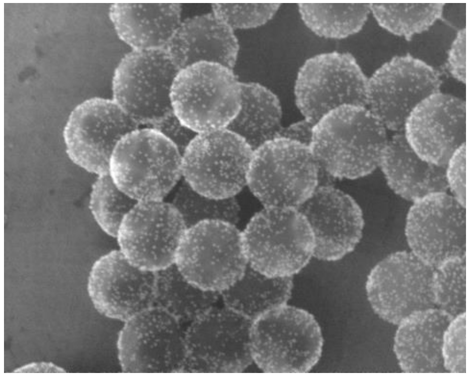
Labelling of nanoplastics with AuNPs as specific metal probes

PS nanoparticles
420 nm

AuNPs@gel
17 nm



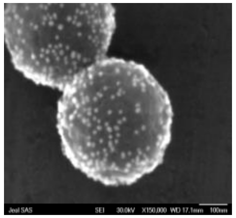




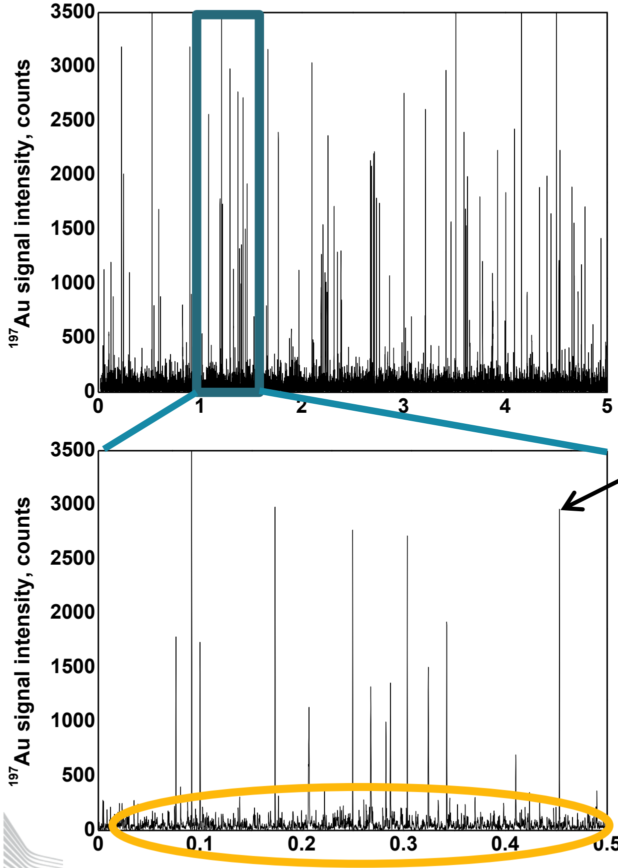
- **Successful labelling of NPTs**
- **Homogeneous Au coverage**
- **Significant number of AuNPs and hence enough Au mass for ICP**

Co-funded by the Horizon 2020 Framework Programme of the European Union under the grant N° *952306*

SP-ICP-MS applied to plastic particles



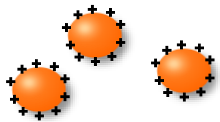
Suspension of conjugates
NPTs-AuNPs@gel

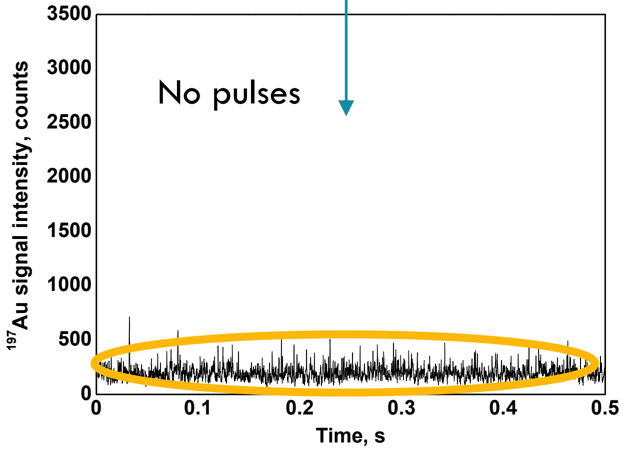


Each NPTs-AuNPs conjugate produces a cloud of Au ions that produces a discrete signal pulse due to AuNPs in surface.

"Background"
Due to free AuNPs

AuNPs@gel
17 nm





No pulses

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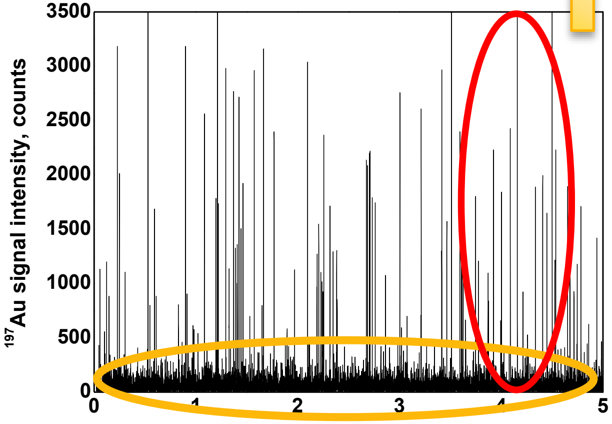
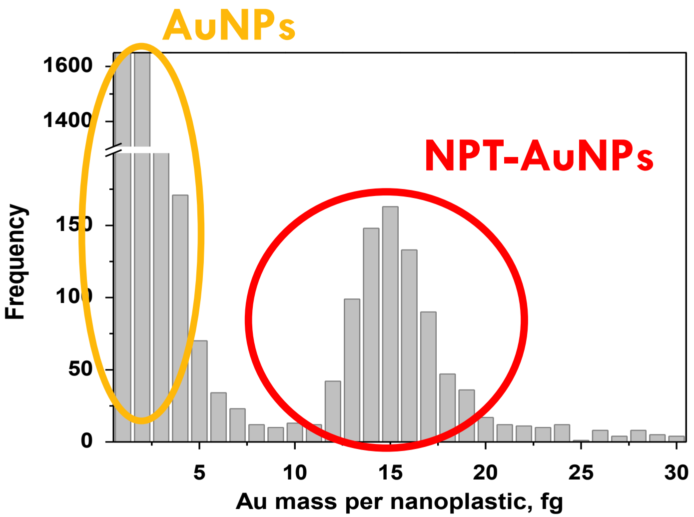
SP-ICP-MS applied to plastic particles

Each intensity can be converted into mass sorbed on each NPT for the evaluation of the mass distribution

$$m_{sorb}(ag) = \frac{Ip}{s} * q * t_d * \eta * 10^6$$





We observe 2 types of signal: the first one due to presence of free AuNPs and the second one due the NPTs labelled

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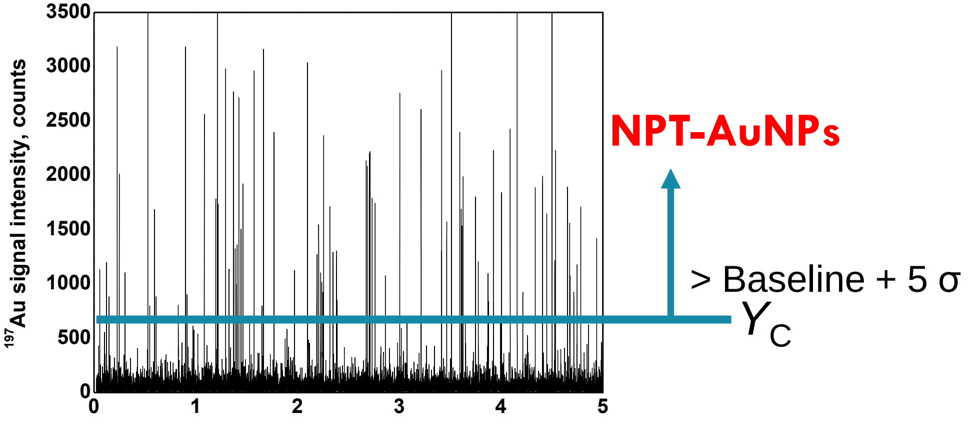
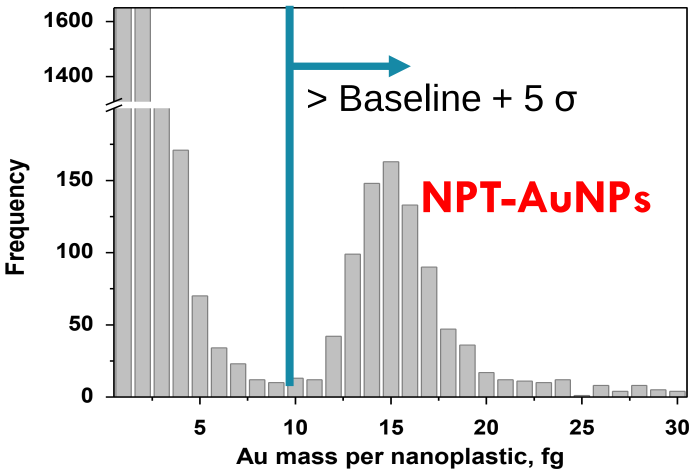
SP-ICP-MS applied to plastic particles





Nanoplastic	Size, nm	Theoretical concentration, NPTs L^{-1}	Experimental concentration, NPTs L^{-1}	Average Au mass per NPT, fg	Average number of AuNPs per NPT
PS22	420 ± 20	6.42 x 10^7	6.25 ± 0.36 x 10^7	14.4 ± 1.4	290 ± 28

good agreement between theoretical and experimental values

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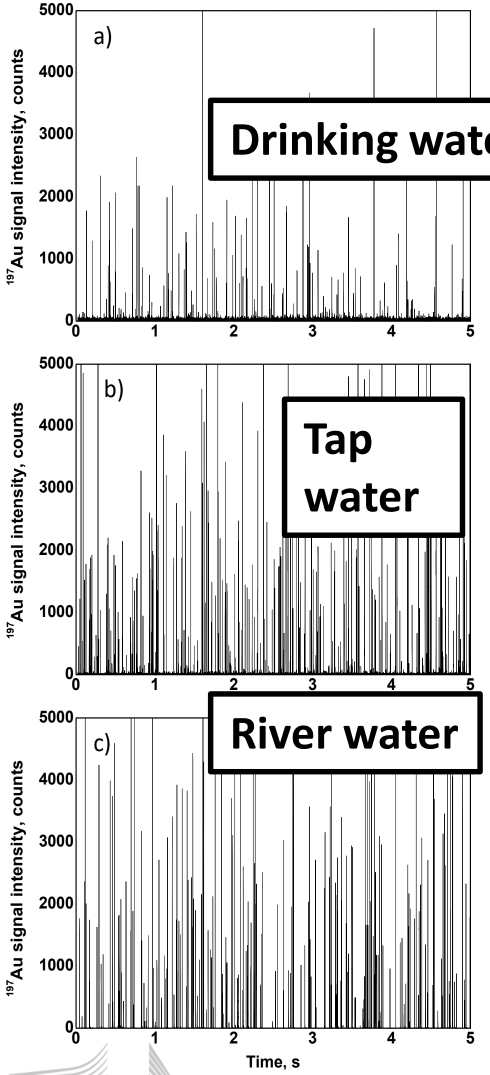
SP-ICP-MS applied to plastic particles



Detection and quantification on water samples

Water sample	Theoretical concentration, NPTs L^{-1}	Experimental concentration, NPTs L^{-1}	Average Au mass per NPT, fg
Drinking water	5.46 x 10^7	5.74 ± 0.19 x 10^7	7.4 ± 0.1
Tap water	2.23 x 10^8	2.00 ± 0.07 x 10^8	13.1 ± 0.4
River water	2.15 x 10^8	2.12 ± 0.07 x 10^8	13.2 ± 0.2
Ultra pure water	6.42 x 10^7	6.25 ± 0.36 x 10^7	14.4 ± 1.4

- ✓ **Nanoplastics well detected in all the matrix**
- ✓ **Au mass per NPT for drinking water and tap water close to the value obtained with ultra pure water**

Hypothesis: higher conductivity of drinking water may influence the electrostatic interaction between negative and positive charges

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Take-home message

- Single particle ICP-MS is a powerful technique.
- SP-ICP-MS can detect particulate forms of elements at very low concentrations.
- SP-ICP-MS cannot size unknown particles by itself.
- Additional techniques are needed to know the nature of the particles.
- SP-ICP-MS must be used in combination with other characterization techniques to analyze real-world samples.

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