Laser-Generated Proton Beams for High-Precision Ultra-Fast Crystal Synthesis

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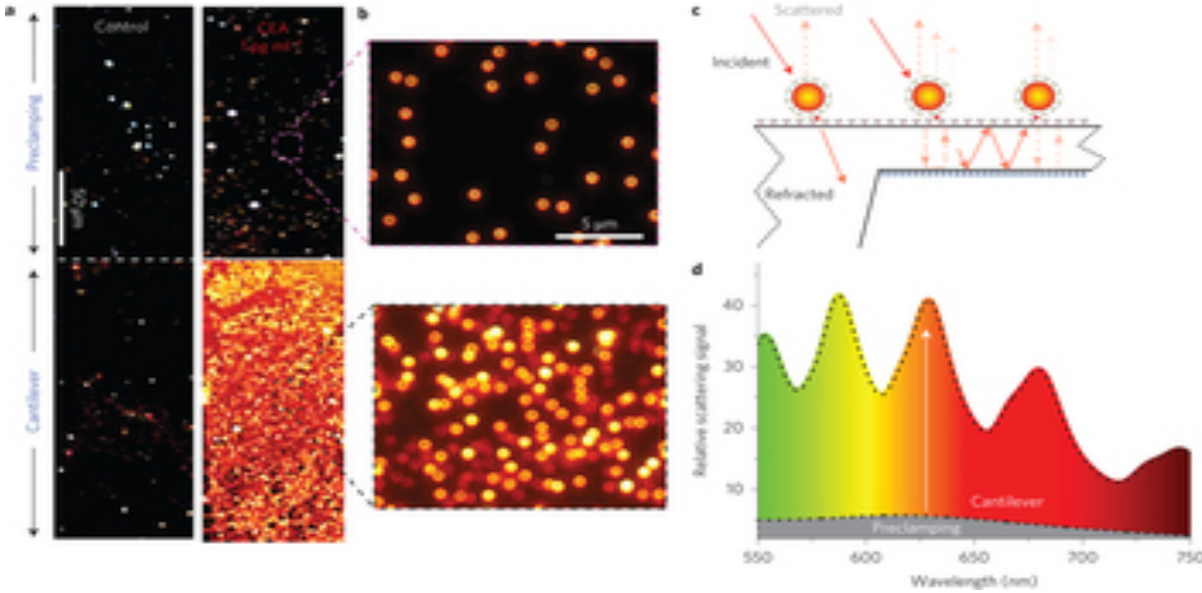
Larger Context: Applications of laser-driven particle accelerations – multidisciplinary fields

Materials/ Nanoparticle business worth several G$ with two-digit-increase

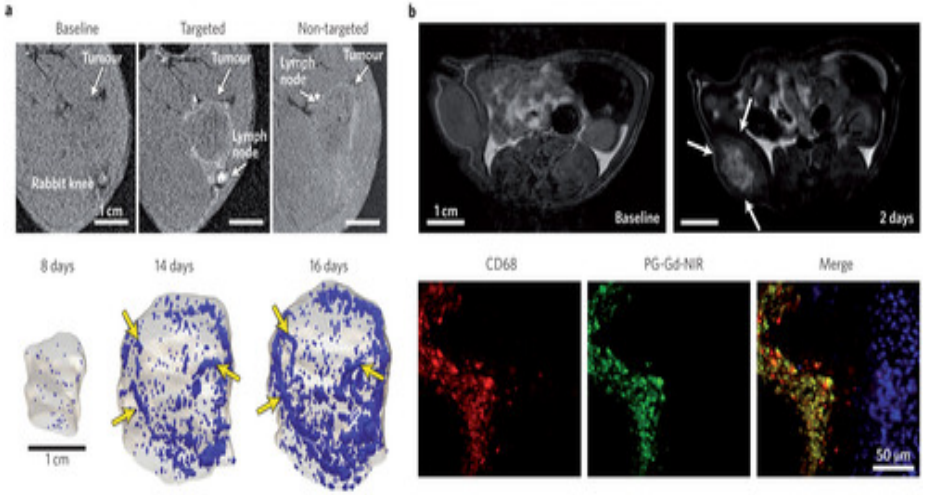
Nanomaterials in medicine and nano-imaging

"Detection of cancer biomarkers in serum using a hybrid mechanical and optoplasmonic nanosensor", *Nature Nanotechnology* 9,1047–1053, (2014) - Gold nanoparticles act as biosensors in cancer cell detection

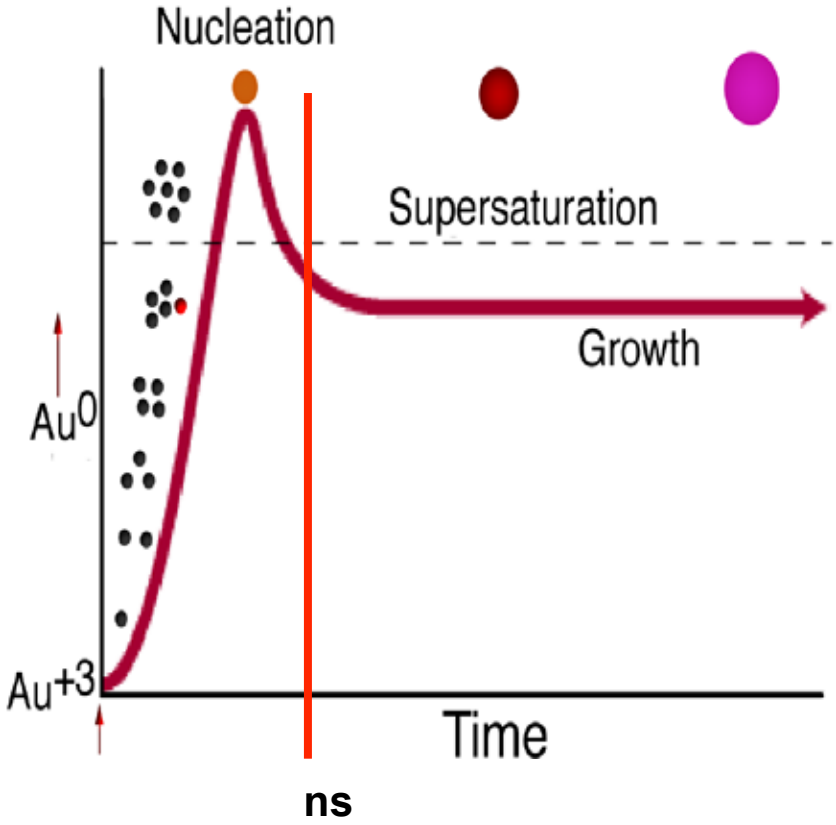


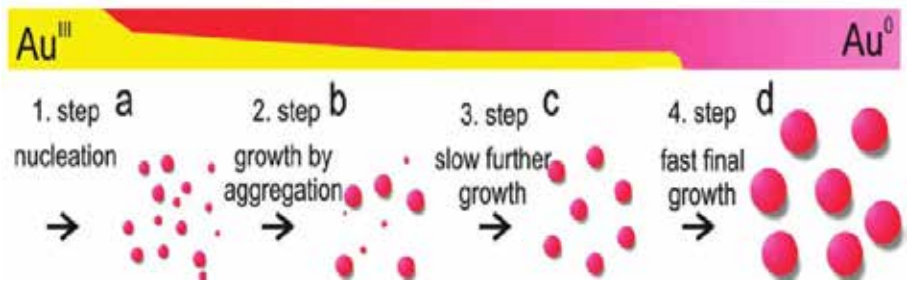
"A targeted approach to cancer imaging and therapy", *Nature Materials* 13,110–115 (2014)

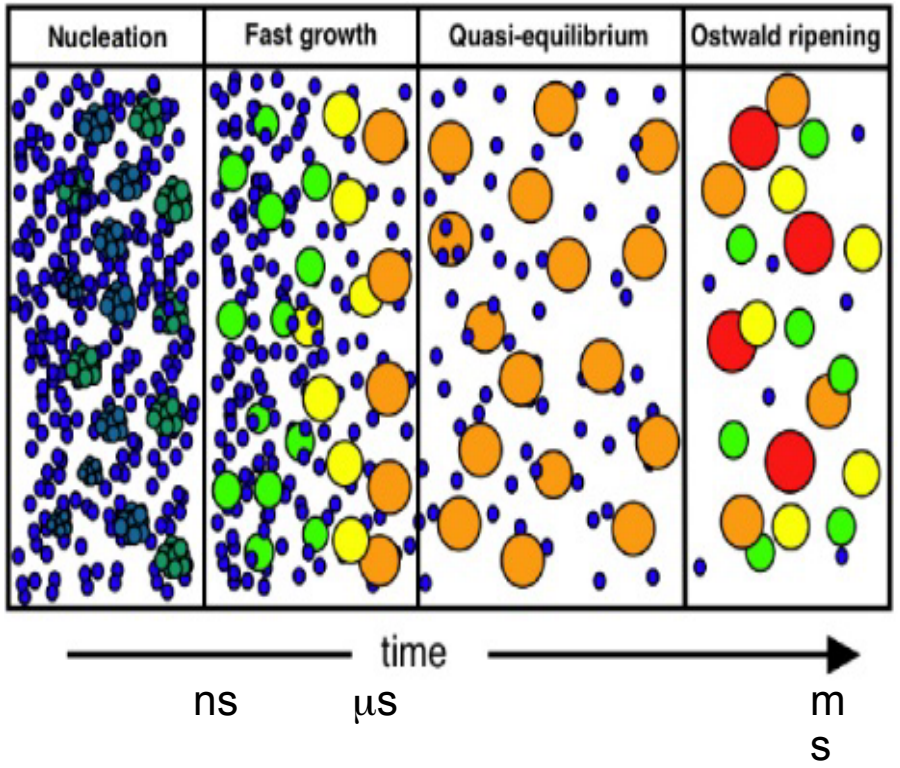
Nanoparticle-based imaging plays a crucial role in cancer diagnosis and treatment. Here, we discuss the modalities used for molecular imaging of the tumour microenvironment and image-guided interventions including drug delivery, surgery and ablation therapy.



Conventional NP growth



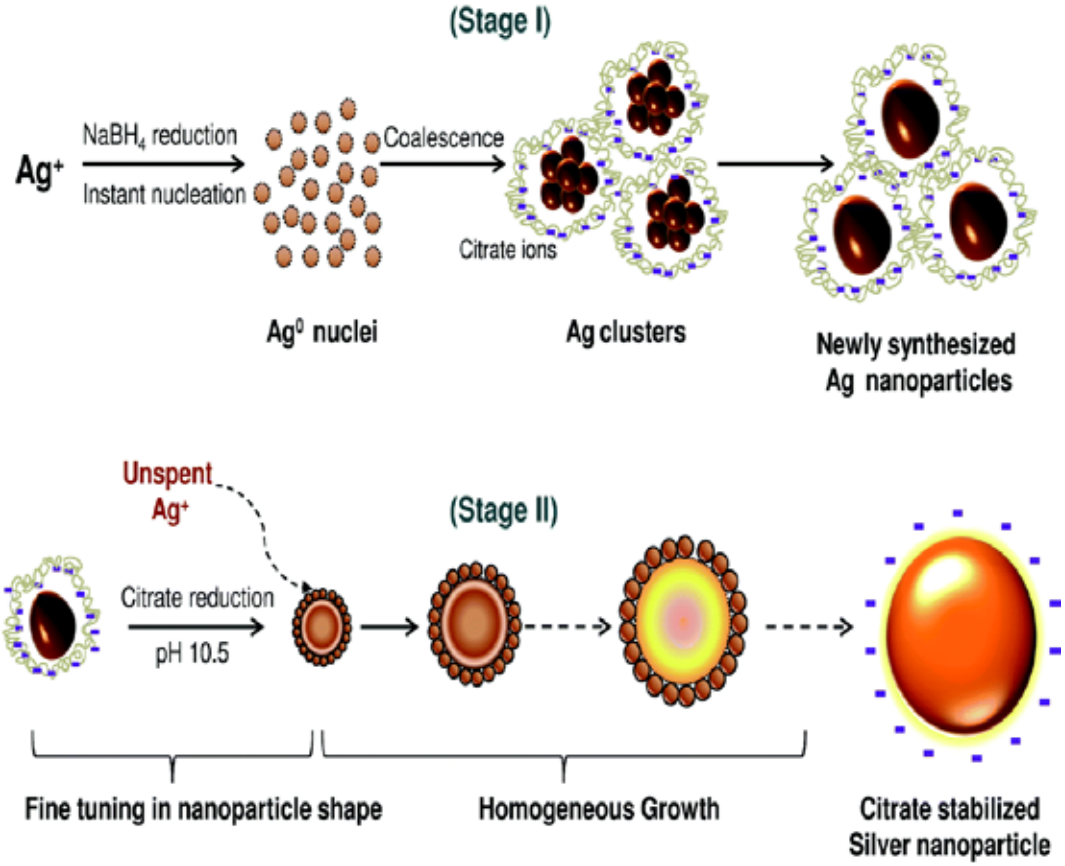


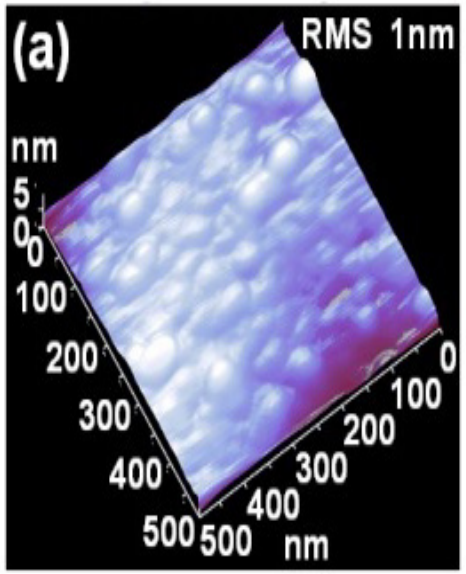


Methods for nanomaterials using Chemical methods

Chemical methods: the nucleation phase starts with a chemical reaction

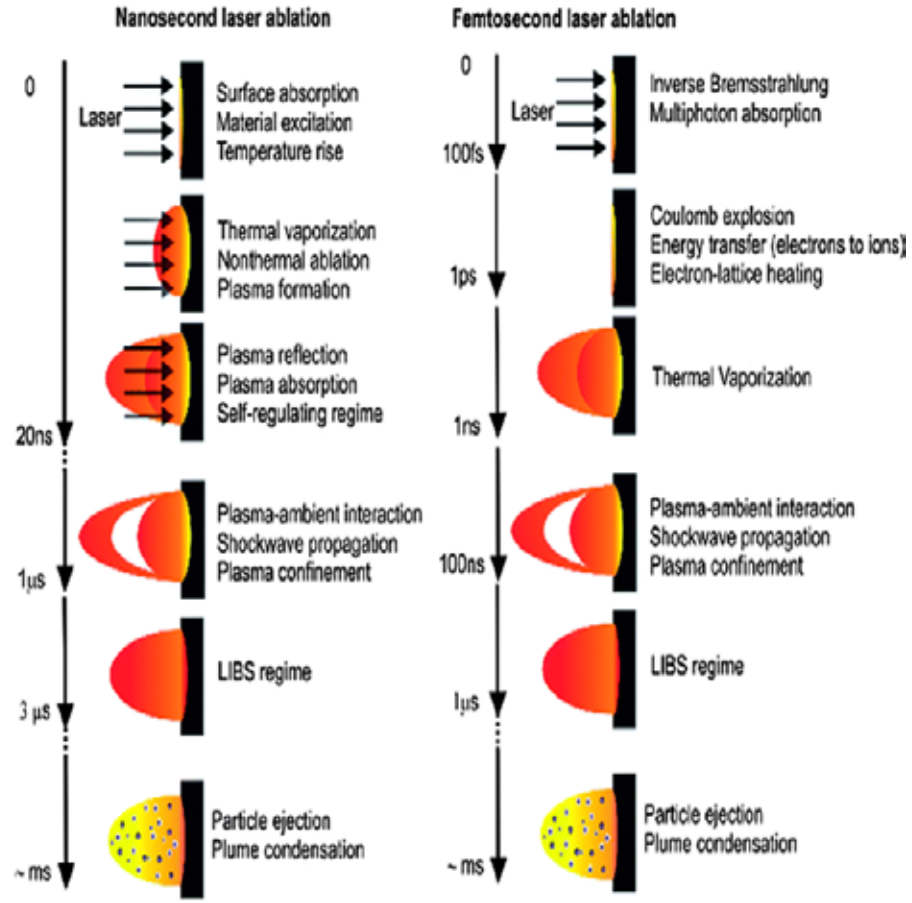
Advantage: Good control of nucleation phase (time of reaction in the order of ns).
Problem: formation of a surfactant shell on the nanomaterials which strongly affect the nanoparticle's properties



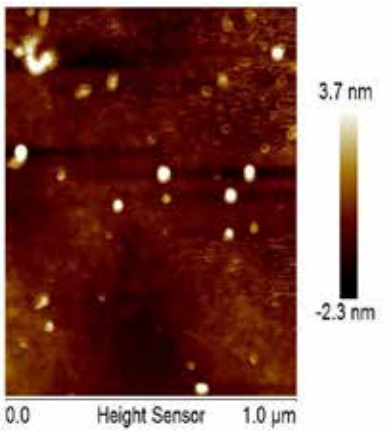


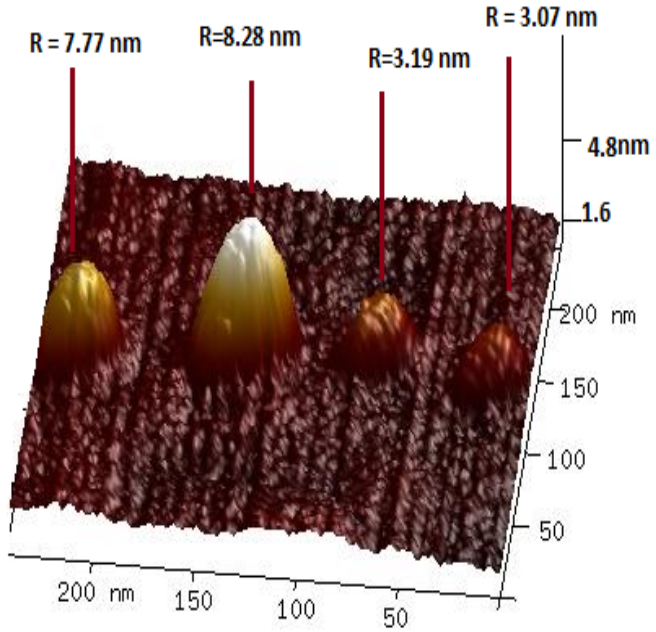
Methods for nanomaterials using Physical methods

Physical methods (i.e. laser based): the nucleation phase starts with an evaporation of atoms from a surface



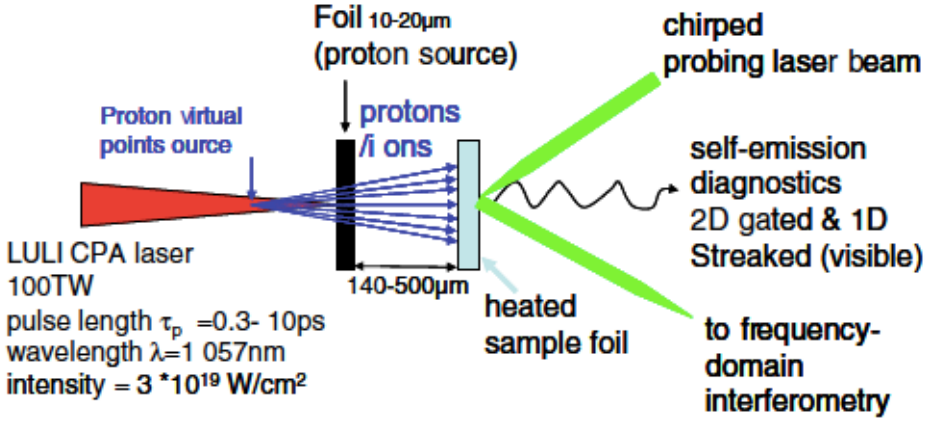
Vantage: Good control on the chemical composition of nanomaterials.
Problem: the control of particle dimensions and shape is difficult. The particle aggregation is slow with the consequent formation of big particles and aggregates



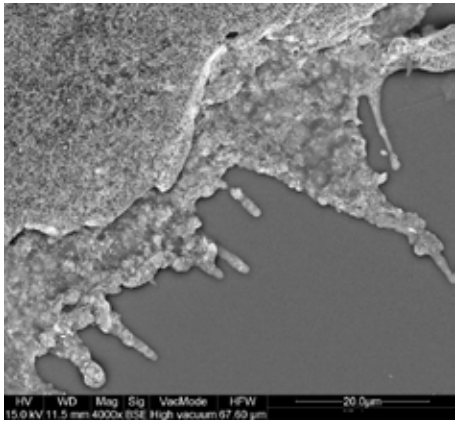


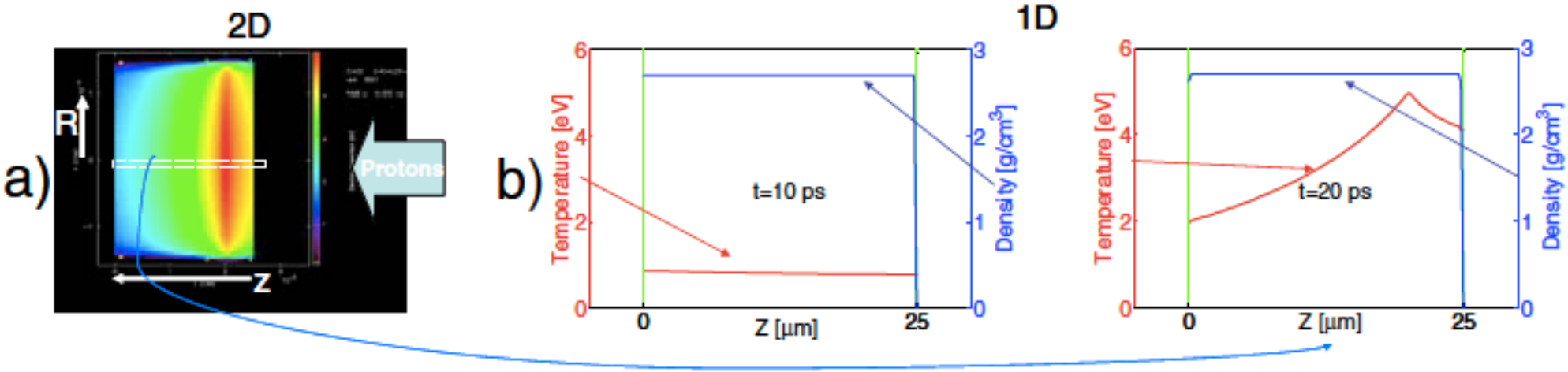
Laser driven protons can generate high-temperatures in a very short time – useful for NP growth ?

Laser driven protons can generate high-temperatures in a very short time:



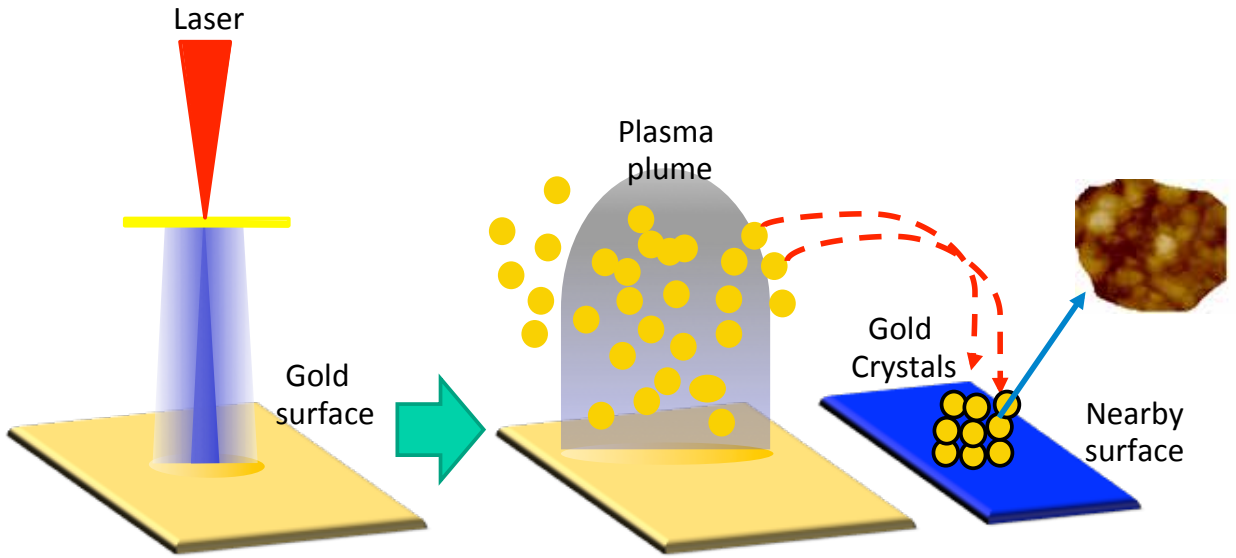
Melted Si surface

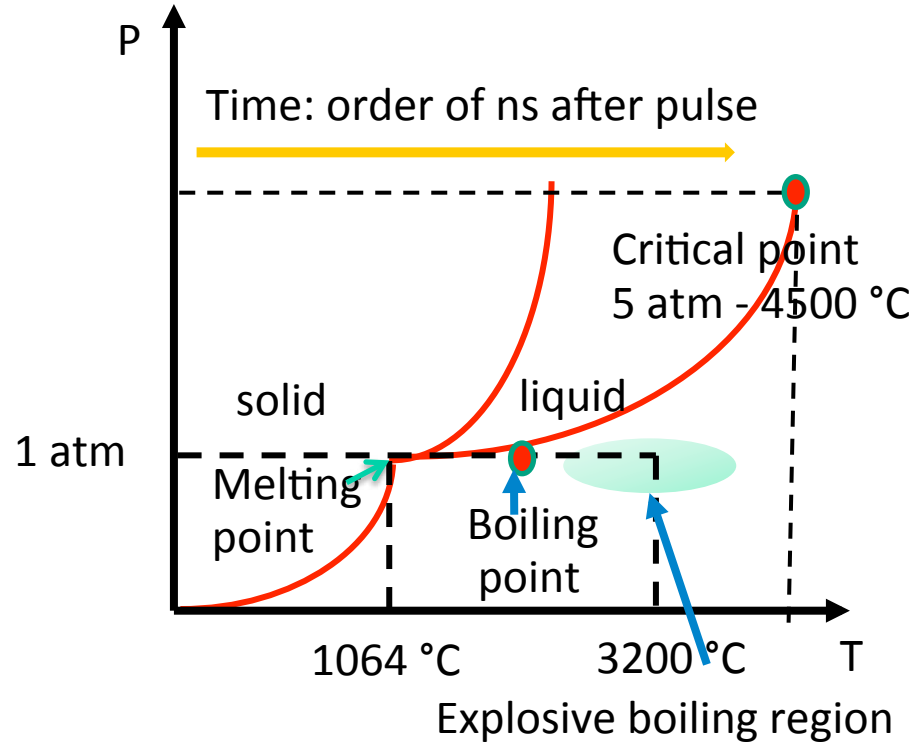




P. K. Patel et al., Phys. Rev. Lett. **91**, 125004 (2003)
P. Antici et al., J. Phys. IV France, 133, 1077 (2006)

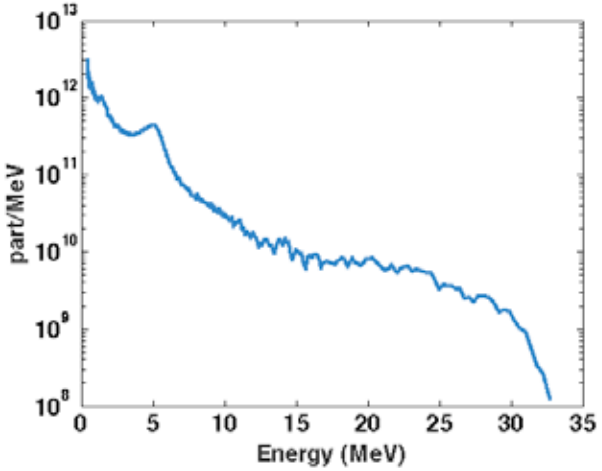
Laser-Driven Proton Ablation (LDPA) mechanism



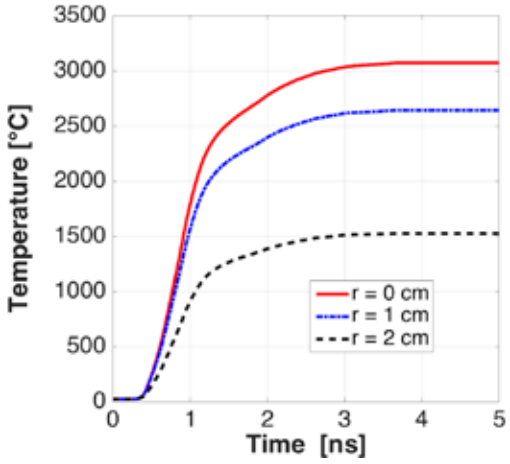


- Proton irradiation
- Temperature increases above boiling point in sub-ns timescale
- «Explosive boiling» with formation of plasma plume
- Aggregation of microparticles in plasma plume and formation of supersonic jet
- Deposition of particle on close surfaces

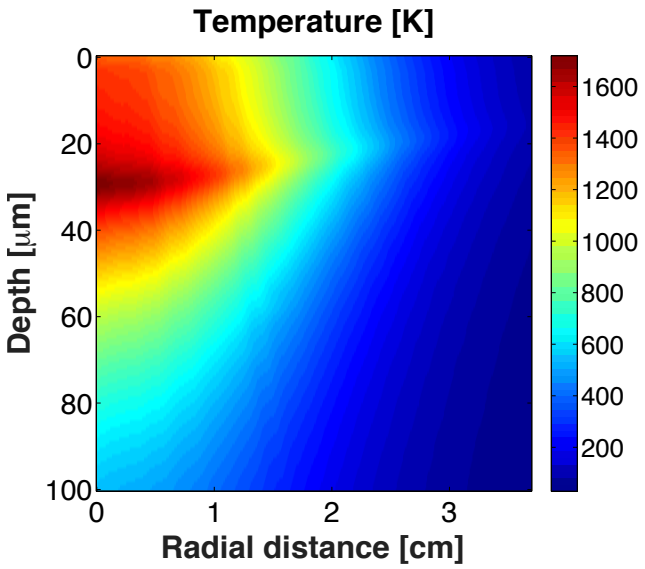
Energy Deposition code confirms Explosive Boiling conditions



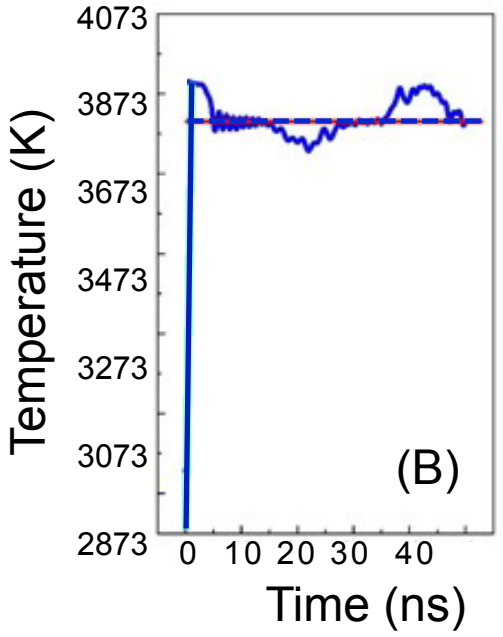
Typical TITAN spectrum



Temperature on the Gold target surface

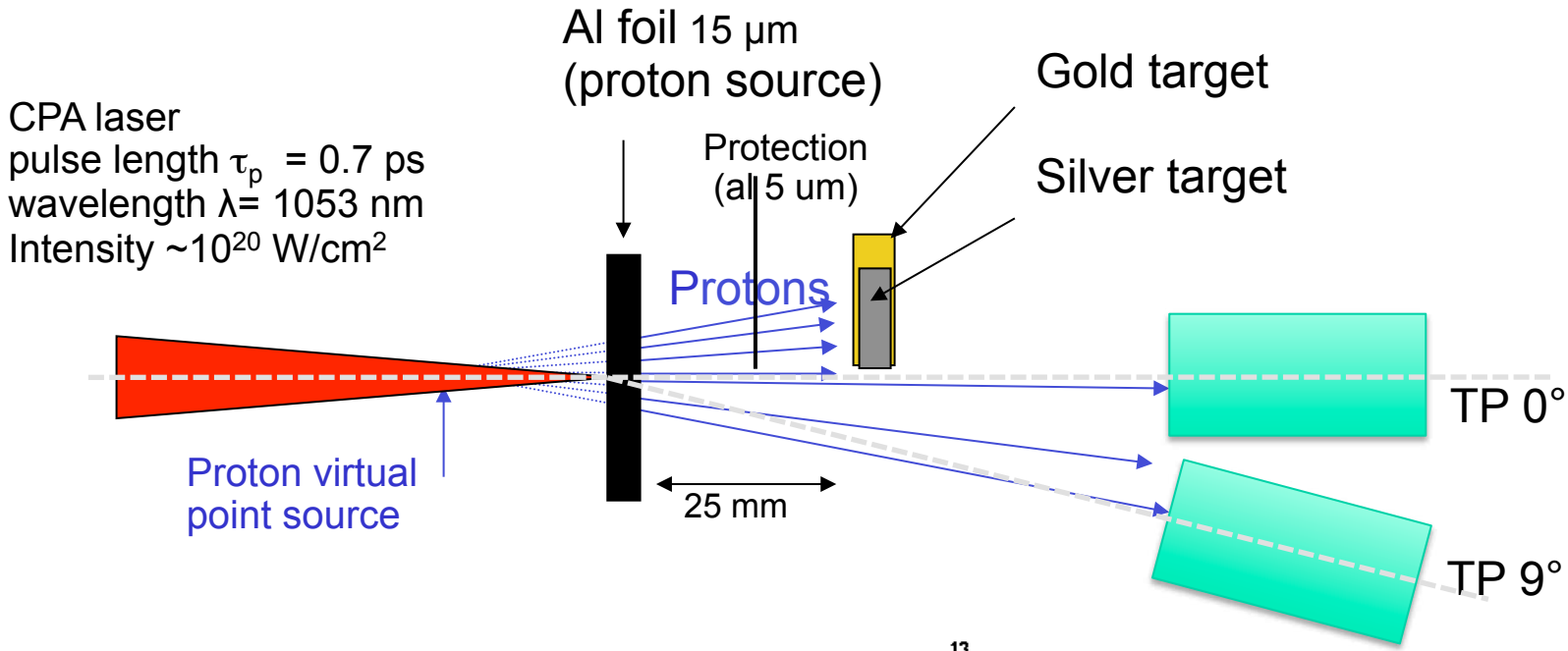


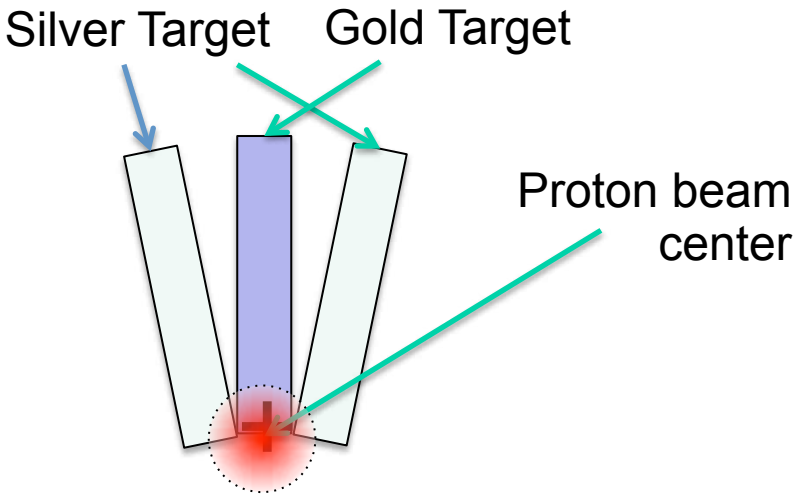
Temperature map after 900 ps

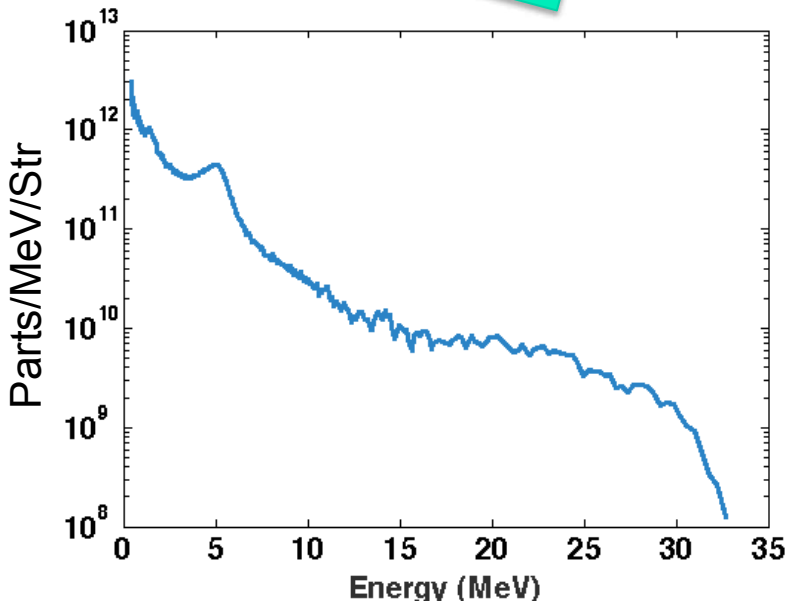


Proton heated target at distance of 2.5 cm from the source

Experimental verification on TITAN (JLF)

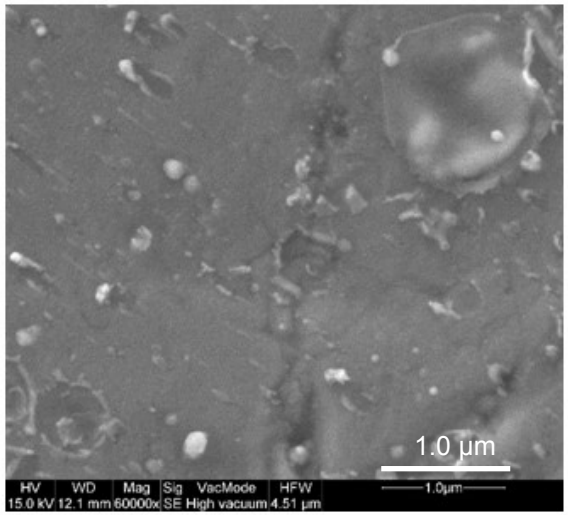




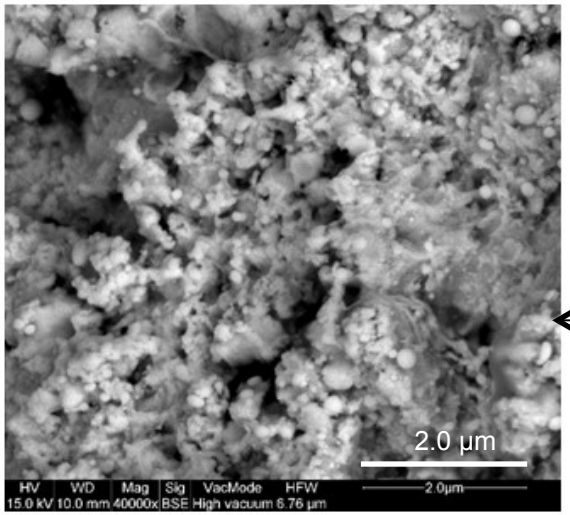


Explosive Boiling texture on the gold target

Gold Target before



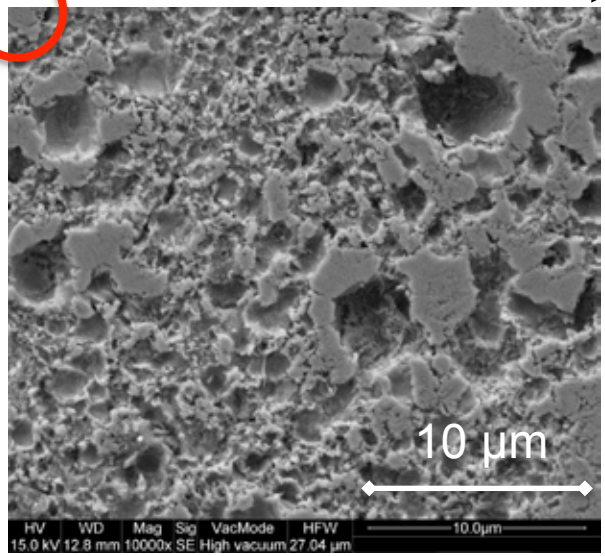
Gold Target after



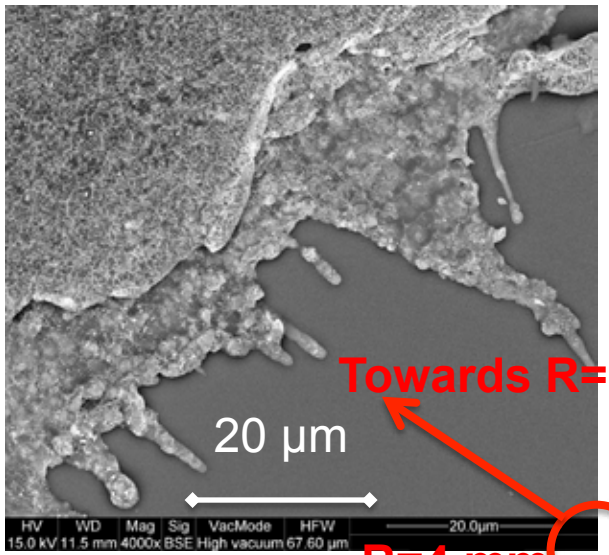
R=~1 mm

Massive erosion of gold

R=0 mm



Melting of gold

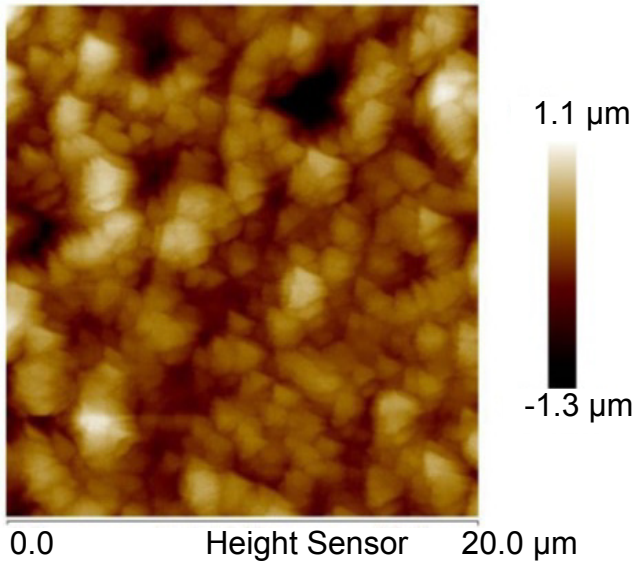


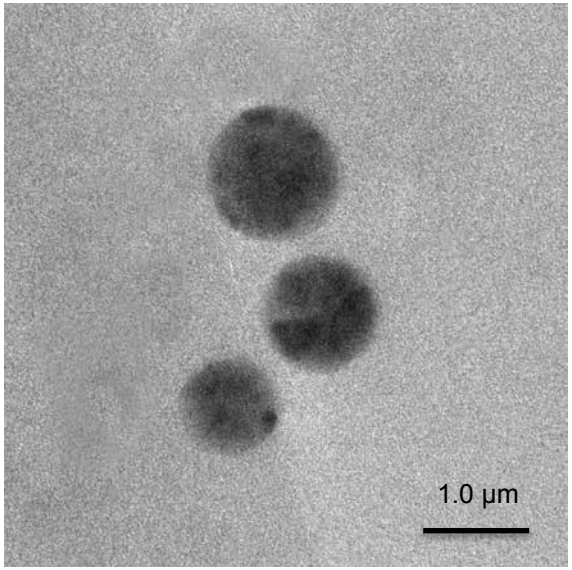
Towards R=0

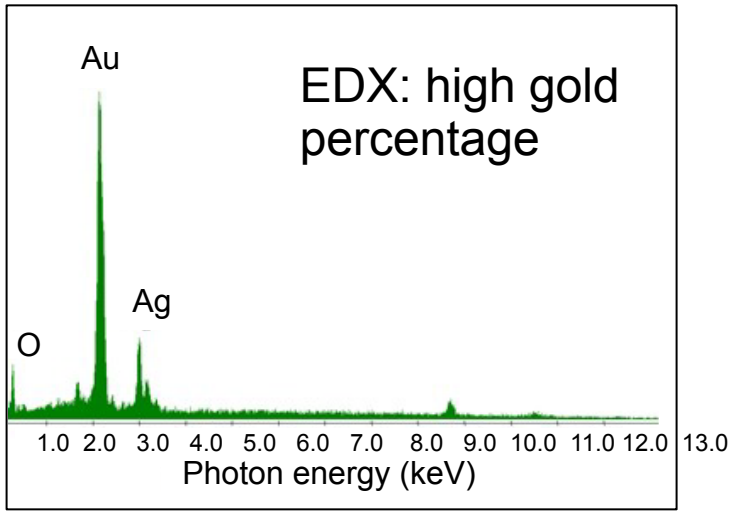
R=4 mm

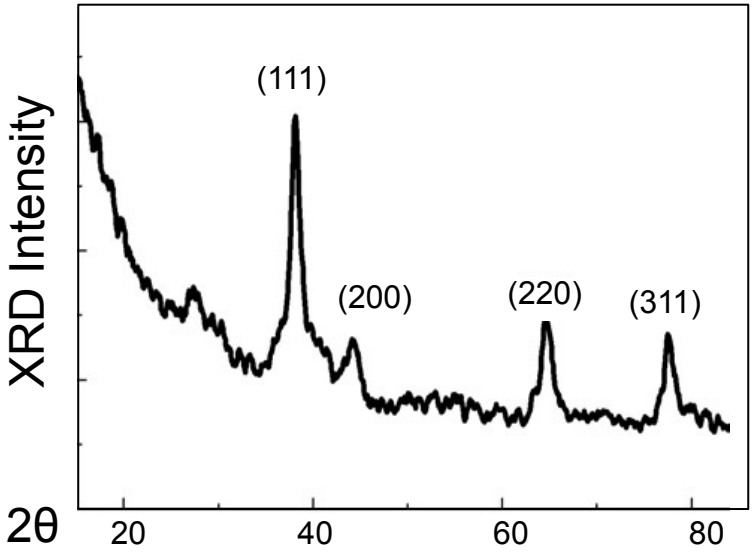
SEM images

Nanoparticle production on the Silver target

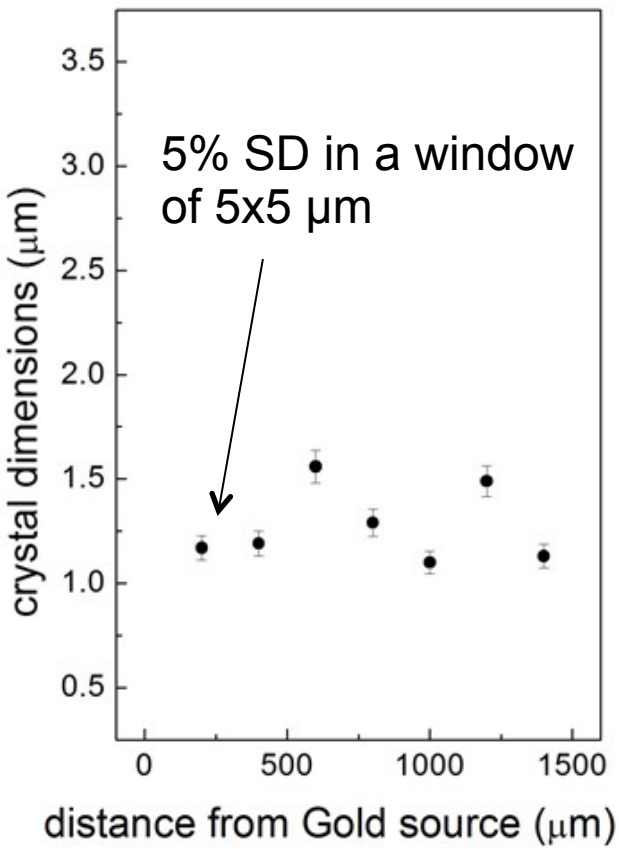


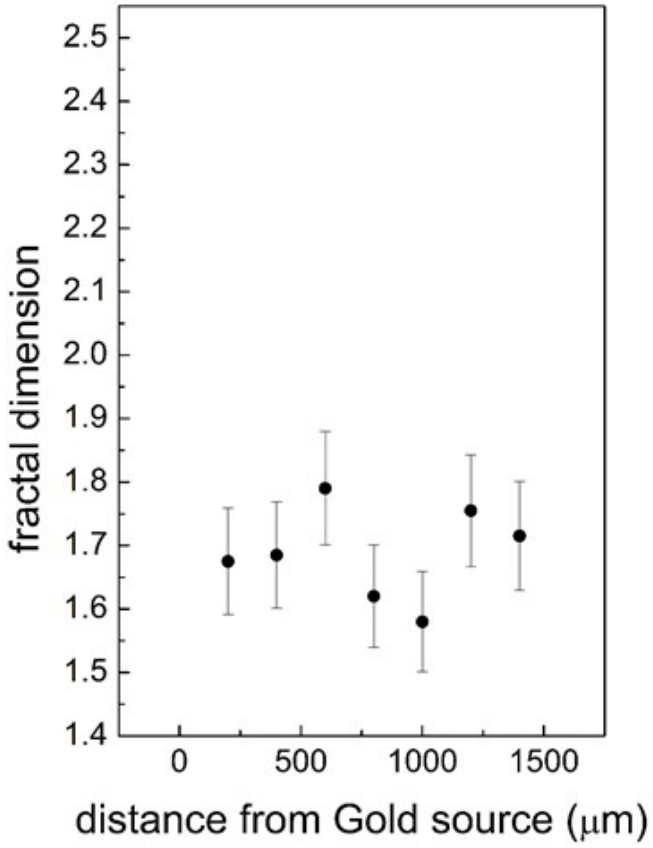


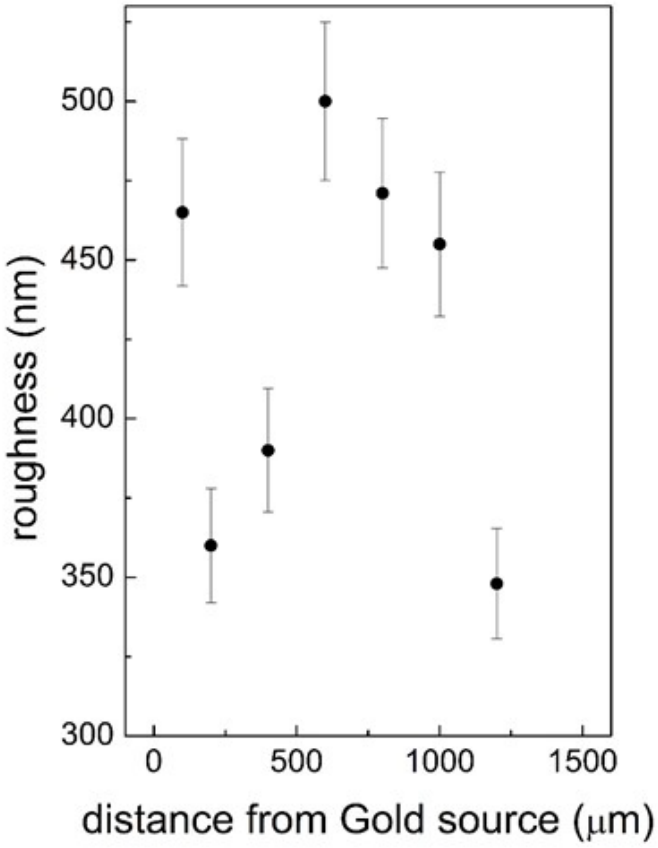




Statistics of the Gold Nanoparticles







M. Barberio et al., Scientific Report (published online 2 Oct 2017)
P. Antici, M. Barberio, Patent Pending US 14448.128

Thank you for your attention !

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