

## Laser-Induced Plasmas in Liquids

D. Amans, A. Chemin, G. Ledoux, V. Motto-Ros, C. Dujardin

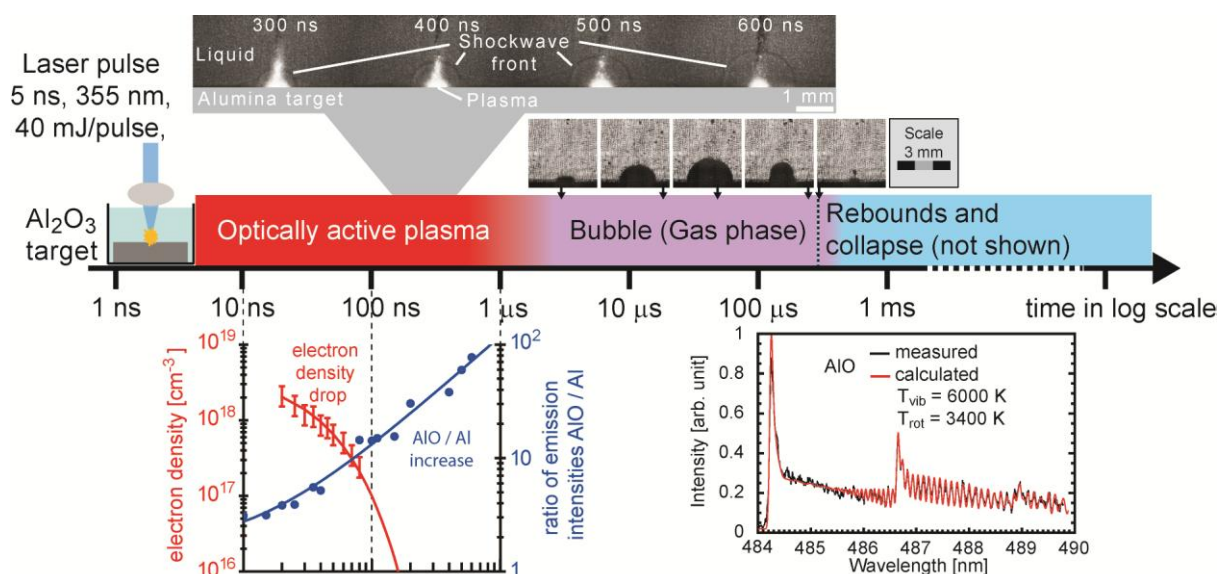
Univ Lyon, Univ Claude Bernard Lyon 1, CNRS, Institut Lumière Matière, F-69622, Villeurbanne, France.

### Abstract

Laser-induced plasmas in liquids display particular thermodynamics conditions as they are characterized by a high electron density and low temperatures. The growing interest in their study stems from the need to reach a better control and a better reproducibility over at least two experimental methods: (i) Laser-Induced Breakdown Spectroscopy (LIBS), an analytical method which deserves being applied underwater, and (ii) laser generation of nanoparticles in liquids which is a versatile method to easily produce stable colloids.

Laser-generated plasmas in liquids are highly transient and exhibit a fast cooling because of the plasma-liquid interaction. On the one hand, the fast cooling helps to nucleate and stabilize nanoparticles with metastable crystal structure. On the other hand, the low temperatures tend to avoid emission from ions and species with high-energy excited states. Therefore, mainly emissions from diatomic molecules and neutral atomic species are observed underwater. In this context, assessing the condition of local thermodynamic equilibrium (LTE) requires criteria associated with the molecular degrees of freedom, i.e. rotations and vibrations [1]. Indeed, the commonly employed criteria for LTE (such as the McWhirter criterion) have not been defined to address internal molecular degrees of freedom.

We will present time-resolved plasma spectroscopy performed on underwater plasma [2-3], including assessment on their chemical composition, temperatures measurement (vibrational and rotational), and electron density measurement. We will then discuss on the local thermodynamic equilibrium in the framework of plasma containing diatomic molecules.



**Figure 1.** In situ characterization of laser-generated plasmas underwater. At the top, the spatial distribution of the plasma is observed from shadowgraph imaging, as well as the laser-induced shockwave. The time frame gives some insight into the different characteristic times, including the plasma lifetime. Bottom left, the figure displays the electron density measurement and the chemical composition deduced from plasma spectroscopy. Bottom right, a representative high resolution AIO rovibronic spectrum and the corresponding fit performed to obtain the AIO rotational temperature.

### References:

- [1] J. Lam, V. Motto-Ros, D. Misiak, C. Dujardin, G. Ledoux, D. Amans, *Spectrochimica Acta Part B*, 101, 86-92 (2014).
- [2] J. Lam, D. Amans, F. Chaput, M. Diouf, G. Ledoux, N. Mary, K. Masenelli-Varlot, V. Motto-Ros, C. Dujardin, *Phys. Chem. Chem. Phys.*, 16, 963-973 (2014).
- [3] D. Amans, M. Diouf, J. Lam, G. Ledoux, C. Dujardin, *J. Colloid Interface Sci.*, 489, 114-125 (2017).