Sujet de thèse: **Nouvelles techniques de mesure de la tension de surface de particules microniques et sub-microniques : application à la formation des nuages**

Thesis title: **New techniques for the surface tension measurement of micron and sub-micron-size particles: application to cloud formation**

Supervisor: B. Noziere, barbara.noziere@ircelyon.univ-lyon1.fr
Co-supervisor: E. Ehret, eric.ehret@ircelyon.univ-lyon1.fr

Description of the subject

1. Context and objectives

In spite of many decades of investigation, the formation of clouds in the atmosphere is still difficult to predict and is the largest source of uncertainties in atmospheric and climate models. **One of the key parameters controlling these processes,** but also the least studied and least understood, **is the surface tension of the forming droplets**. The reasons for this knowledge gap is mostly experimental as, until recently, there was no technique able to measure the surface tension of micron and sub-micron size atmospheric particles, and the contribution of surface-active compounds (or "surfactants") to these processes was not suspected (Nozière et al., *Nature Communications*, 2014; Nozière, *Science*, 2016; *La Recherche*, 2017). In recent years, thanks to the development of new analytical methods, our group demonstrated the presence of such compounds in atmospheric aerosols, thus the importance of measuring the surface tension of atmospheric particles to better predict cloud formation (Ekström et al., *Biogeoscience*, 2009; Baduel et al., *Atmospheric Environment*, 2012; Gérard et al., *Environmental Science & Technology*, 2016). The first techniques to measure the surface tension of micron-size particles then started to be explored in the scientific community, such as optical tweezers (Bzdek et al., *Chemical Science*, 2016) and Atomic Force Microscopy (AFM) (*Yazdanpanah et al., Langmuir* 2008; Morris et al., *Chemical Science* 2015), the latter being applicable to particles even in the submicron range. But these techniques are still very exploratory and have not been applied to atmospheric particles so far.

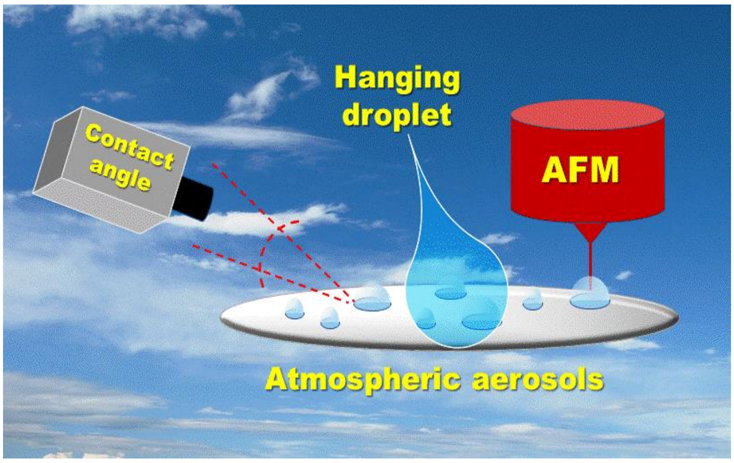

Fig. 1: Illustration of the different methods to be used in this PhD thesis to investigate the surface tension of atmospheric aerosols.

The objective of this PhD is to develop and compare two new techniques to measure the surface tension of micron and submicron-size particles, contact angle measurement and **AFM, and apply them to atmospheric particles**. These techniques will be compared to the "hanging droplet technique" used until now for atmospheric particles, which requires larger sample volumes. This will solve an important controversy on whether the sample volume affects the results. The results obtained with the three techniques on atmospheric particles will also show for the first time the differences between the surface tension of individual particles and the average surface tension values obtained by the hanging droplet technique. Simple model calculations will be performed to determine which ones of these values predict best the Cloud Condensation Nuclei numbers in the atmosphere. **This topic is at the cutting edge of its discipline, as illustrated by the recent articles in high-impact journals, and should significantly improve the prediction of cloud formation in the atmosphere.**

2. Proposed work

The proposed work consists of three main tasks:

Task A. Surface tension measurement from contact angle

In this first task, a new method will be developed to determine the surface tension of sub-micron particles from their contact angle. The work will be performed with a tensiometer, already available at Ircelyon and used previously for the hanging droplet technique, and is not expected to require any major experimental modification. The development will mostly reside in the determination of the relevant type of measurements (advancing, receding, or stable contact angle), equations, or empirical approach to link contact angle and surface tension values (Cwikel et al., *Langmuir*, 2010), based on the literature and on experiments with laboratory-generated particles of known composition.

Task B. Surface tension measurement by Atomic Force Microscopy (AFM)

This second task will consist in developing surface tension measurement with AFM, recently illustrated by Yazdanpanah et al. (*2008*) and Morris et al. (*2015*). This development will be much more difficult experimentally and involve much more risk than the first task, and rely heavily on the expertise of the co-supervisor, Dr. Ehret, in AFM technique. An atomic force microscope, available in the group, will be modified and adapted. The AFM will be used in force mode, in which the tip of the instrument is not scanned across the surface as in imaging mode, but placed above the center of the liquid droplets, where forces distance curves are measured. This force data will be used to calculate the surface tension of the droplet. This method will require specific tips, referred to as nanoneedles, designed for obtaining force distance curves in liquid droplets. The AFM will be calibrated with standard liquids to quantify the force exerted on the tip and the radius of the needle. Using this method, the surface tension of individual sub-micrometer droplets will be measured in a way analogous to the Wilhelmy plate. The technique will be validated with laboratory-generated particles of known composition.

Task C. Comparison with the “hanging droplet” technique and application to atmospheric particles

Once validated, these techniques will be compared to the one developed in the group and used until now for atmospheric particles (“hanging droplet technique”) (Ekström et al., *Biogeoscience*, 2009; Baduel et al., *Atmospheric Environment*, 2012; Nozière et al., *Nature Communications*, 2014, Gérard et al., *Environmental Science & Technology*, 2016; Nozière et al. *Journal of Visualized Experiments*, 2017). The results on laboratory-generated particles of known composition will determine if the sample volume affects the results, which is currently an important debate. These techniques will then be applied to atmospheric aerosols collected in various regions, using an aerosol sampler available in our group. The results obtained by the different techniques for the same particle population will show for the first time the differences between the surface tension of individual particles and the average surface tension given by the hanging droplet technique. Simple model calculations will be performed to determine which ones of these values predict best the Cloud Condensation Nuclei numbers in the atmosphere.

The development of these new techniques and the ability to measure the surface tension of individual atmospheric particles will place our group at the leading edge in atmospheric science.

Profile of the candidate: A solid background (Master) in physical chemistry, and some interests for the environment and the development of experimental techniques.

IRCELYON • UMR 5256
2 avenue Albert Einstein • F-69626 Villeurbanne Cedex
tél. +33 [0] 472 445 300 • fax +33 [0] 472 445 399
http://www.ircelyon.univ-lyon1.fr