From particle-laden thermals to sugary plumes as models of precipitation-driven flows in planetary interiors.

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In this seminar, I will present several laboratory experiments, complemented by numerical simulations, that aim at modelling particle-laden reactive flows of rain and snow in planetary interiors. The main focus will be iron snow: What can we learn about the settling and remelting of iron crystals in the planetary core of Ganymede (a natural satellite of Jupiter) which nourish a compositional convection at the origin of the planet's magnetic field?

To study the settling of snow flakes, our starting point will be experiments of particle-laden clouds of glass spheres settling in quiescent water after an instantaneous release (figure 1a). The canonical model of entrainment for turbulent thermals by Morton et al. 1956 predicts that buoyant clouds linearly grow during their fall with a universal growth rate. Yet, a systematic variation of the diameter of particles from 5 microns to 1 millimeter reveals that particle-laden clouds grow faster than salt-water clouds of identical buoyancy, and that their growth rate is maximum for a finite particle settling velocity. Going beyond classical interpretations based on the well-known phenomenology of particle-laden turbulent flows, I will present 3D two-way coupled Eulerian simulations of these clouds and show that turbulence is not key to this phenomenon. Laminar simulations recover this maximum entrainment, which is due to the disruption of the cloud structure by particles, weakening its circulation and therefore enhancing the cloud growth. I will conclude this first part with the additional ingredient of planetary rotation when the whole experimental setup is mounted on a spin table, and show the abrupt transition of the thermals to a regime of vortical column when the Coriolis force overcomes the clouds' inertia.

The second part of the seminar will focus on the melting of snow flakes whose molten snow drives compositional convection in the planetary core. I will present an experimental analog of dissolving grains of sugar which are continuously sieved above water, the negatively buoyant sugary water driving compositional convection in the tank. The common observation is the transient formation of a central plume (figure 1b) which reaches a quasi-steady state. Yet, varying the mass rate and size of grains reveals a wealth of behaviours which are analysed in terms of the core physical ingredients forcing the flow. In particular, I will show that for a fixed mass rate, the size of grains controls a transition from a laminar plume forced by the rectilinear fall of large grains to a turbulent lazy plume forced by fast-dissolving small grains, as revealed by home-made fluorescent sugar.

(a) (b)

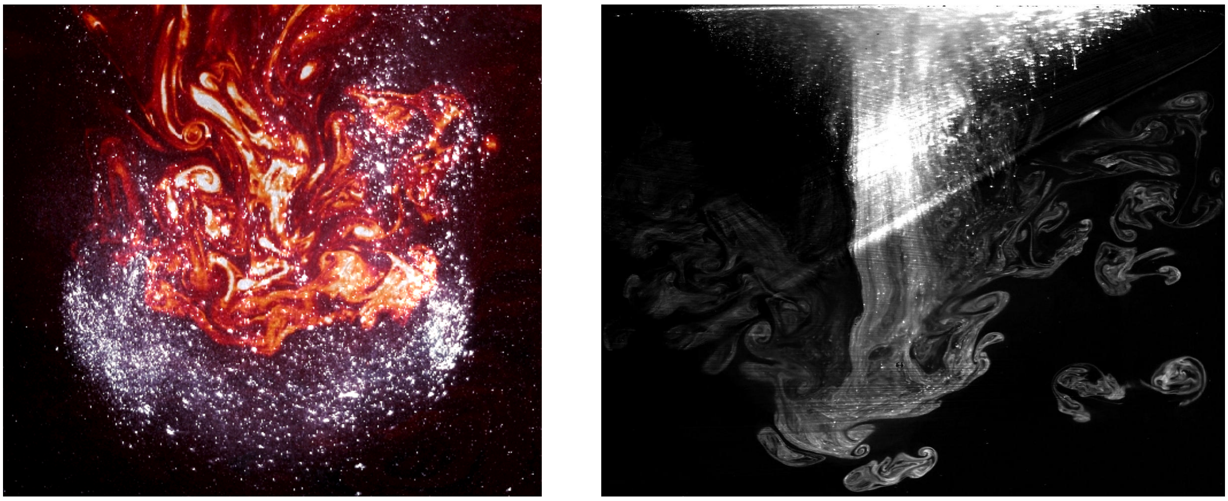

Figure 1: (a) Settling of a mixture of white glass spheres (of mean radius $64\mu m$) with orange dye (rhodamine) in a quiescent ambient. The spheres initially swirl in the dyed fluid before decoupling from turbulence due to their inertia and gravitational drift. (b) When sieving sugar above a tank of still water, grains of sugar dissolve and form a lazy plume which is visualised in a vertical laser sheet (the top of the image is the water free surface). Solid grains (of mean radius $101\mu m$) reflect the laser beam; the negatively buoyant sugary water is also visualised due to the presence of rhodamine in the grains, that is released in the fluid during dissolution.