
Subject title: **Fluid dynamics of giant impacts: Earth's differentiation & Moon's formation**
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Financing: Doctoral contract with or without teaching assignment
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Much of Earth's mass formed 4.5 Gyrs ago by high-energy collisions between planetary embryos. These giant impacts set the initial composition and temperature for the long-term evolution of the Earth. During this PhD, we will use analogue laboratory experiments to investigate two major consequences of these impacts: 1 - the differentiation of the core and the mantle, and 2 - the formation of the Moon.

Motivations:

Earth's differentiation: Based on tungsten isotopes, we know that the Earth formed, and differentiated into a metallic core and a silicate mantle, in about 100 Myrs. However this timing strongly depends on how mixed metal and silicates were during, and after, each Earth-forming collision (Rudge et al., 2020; Fischer et al., 2018).

Each impact released the metallic core of the impactor into a molten silicate magma ocean. Fluid dynamics investigations showed that the impactor core formed a turbulent cloud in which metal fragmented into drops and mixed with a finite volume of the mantle silicates (Landeau et al. 2014, 2016; Deguen et al. 2014). This mixing controlled chemical equilibration between metal and silicates, and therefore the composition of the core and the mantle (Rubie et al. 2015, Suer et al. 2017).

However, several ingredients are missing to fully assess metal-silicate mixing and equilibration. Previous investigations all neglect the impactor inertia and its effects on mixing. In addition, we still do not know the size of the metal drops formed following a collision.

Moon's formation: The fragmentation and mixing by a giant collision were also crucial during the formation of the Moon. Thanks to numerical simulations, we know that, during a giant impact, fragments were ejected, and re-coalesced to form satellites, such as the Moon (Canup 2004, 2012; Cúk & Stewart, 2012; Hosono et al. 2019). However, impact simulations do not easily explain the astonishing isotopic similarities between the Earth and the Moon (Zhang et al. 2012). To solve this enigma, we need to know the fraction of Earth's mantle and impactor contained in the ejected fragments. This, again, requires accurate modeling of mixing down to small scales.

Objectives of this project:

In this PhD, we will investigate fragmentation and mixing following a giant impact using analogue laboratory experiments. We plan to:

1 – obtain the first scaling laws for the size of the metal drops formed after a giant impact, especially as a function of the impact velocity. This is key for understanding core-mantle differentiation.

2 – predict the fraction of impactor and target materials in the fragments ejected by an impact. This will help to refine the model of Moon formation and explain isotopic observations.

Methods & preliminary results:

During a giant impact, the energy is so high that an ocean of magma forms immediately after the impact. To mimic such a collision, we will use fluid dynamics laboratory experiments on the impact and fragmentation of a liquid volume into a pool of another immiscible liquid. In contrast with simulations, these experiments produce small scales and turbulence, which are crucial in quantifying metal-silicate equilibration and the origin of the fragments ejected by an impact.

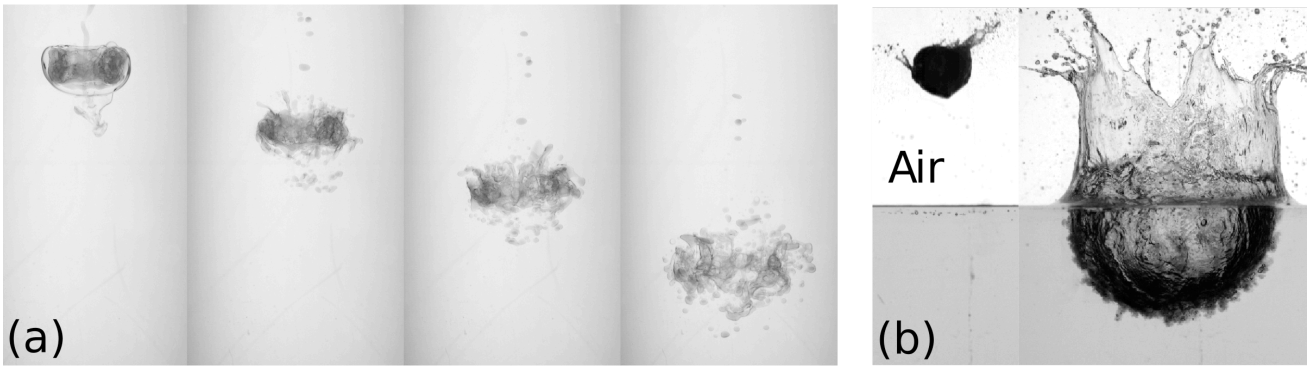

Figure 1 – (a) Fragmentation of a liquid volume, representing the impactor core, into another immiscible liquid, representing the magma ocean, from the master's thesis of T. Lorand. (b) Liquid impact from Landeau et al. (sub.).

Following an impact, the impactor forms a ring-shaped structure known as a vortex ring (Landeau et al., 2017). During his master's project, T. Lorand has investigated these rings in immiscible liquids (figure 1a). We investigated the transition from laminar to turbulent vortex rings, in which the shape of the ring becomes self-similar. Our regime diagram confirmed that the Weber number, which measures the importance of inertia to surface tension, controls this transition. We are currently extracting scalings on the size of the drops formed in these turbulent rings. These will tell us the size of metal drops in a magma ocean following an impact (objective 1).

The above experiments lack an impact stage. To include this, we will investigate the impact of a liquid volume into another immiscible liquid, varying the impact velocity (figure 1b, objective 1).

We will then apply impact experiments to the formation of the Moon (objective 2). In experiments, we observe a splash, which eject drops (figure 1b). These drops are an analogue for the ejected materials that formed the Moon. Using a dyed impactor, we will measure the fraction of impactor and target in the splash.

During her first two years as MCF, M. Landeau has developed an experimental setup on liquid impacts that is ready to use for this project. To visualize the flow, we will use a Phantom high-speed camera that was recently acquired in the DFG team of IPGP.

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