ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
ET PHYSIQUE DE L'UNIVERS, PARIS

Subject title: **Fluid dynamics of giant impacts: Earth's differentiation & Moon's formation**
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Host Team: **IPGP - Dynamique des Fluides Géologiques – UMR7154**
Financing: Doctoral contract with or without teaching assignment
Identified PhD student**: MALLER, Augustin**

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 mantle, and 2 – the origin of the moons of Earth and Mars.

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 the efficiency of chemical transfers between metal and silicates (Rudge et al., 2020; Fischer et al., 2018), which itself depends on the fluid dynamics of the large impacts that formed the Earth.
Each impact released the metallic core of the impactor into a molten silicate magma ocean. Previous investigations showed that the impactor core sank into the magma ocean and mixed with the mantle silicates (Landeau et al. 2014, 2016, 2021). The volume of mixed silicates then controlled the equilibration between metal and silicates (Deguen et al. 2014), and hence the composition of the core and mantle (Rubie et al. 2015).
However, this picture is still incomplete. Previous investigations all assume that the impactor core remains coherent during the impact. This is at odds with geological observations on smaller terrestrial craters, which indicate that the impactor broke-up into hundreds of fragments (Blau et al., 1973). These observations raise an important question: During an Earth-forming collision, did the impactor core fragment into drops? If it did, metal-silicate equilibration was stronger than current estimates.

Moon's formation: The fragmentation and mixing by a giant collision was 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; Hosono et al. 2019). Similarly Mars's moon Phobos may be the result of a giant impact (Rosenblatt and Charnoz 2012, Rosenblatt et al. 2016). However, previous simulations of moon-forming impacts do not easily explain the astonishing isotopic similarities between Earth and the Moon (Zhang et al. 2012) or the compositional similarities between Phobos and Mars' surface (Guiranna et al. 2011). To solve this enigma, we need to know the fraction of Earth's mantle and impactor contained in the ejected fragments.

Objectives of this project:
In this PhD, we will use analogue impact experiments (Fig 1) in order to:
1 – Determine wether the impactor core fragments into drops during a giant impact, and obtain scaling laws for the size of the metal drops as a function of the impact velocity. This is key for understanding the differentiation and composition of the core and mantle.

2 – Measure the fraction of impactor and target materials in the fragments ejected by an impact as a function of the impactor size and velocity. These results will tell us whether a giant impact can produce moons with a composition close to that of the target.

Methods & preliminary results:

During her first two years in IPGP, M. Landeau has developed an experimental setup on liquid impacts that A. Maller is currently using during his M2 project. A. Maller investigates experiments on the impact and fragmentation of a liquid volume, which represents the metallic core of an impactor, into an immiscible water pool, which represents the molten silicate magma ocean. During the first two months of his internship, A. Maller developed a visualization technique known as shadowgraphy to observe the immiscible impactor during its fall in the water pool (Fig.1). To record the flow, we use a Phantom high-speed camera that was recently acquired in the DFG team.

Our preliminary results suggest two regimes. When the inertia of the impactor is comparable to gravity we observe that the impactor remains coherent during the impact (Fig. 1a). In contrast, when inertia is large compared to gravity the impactor fragments into hundreds of droplets (Fig. 1b). Applied to planetary impacts, these results suggest that the impactor core remains coherent during a giant impact but fragments into small droplets during the impact with an impactor smaller than 100km in diameter.

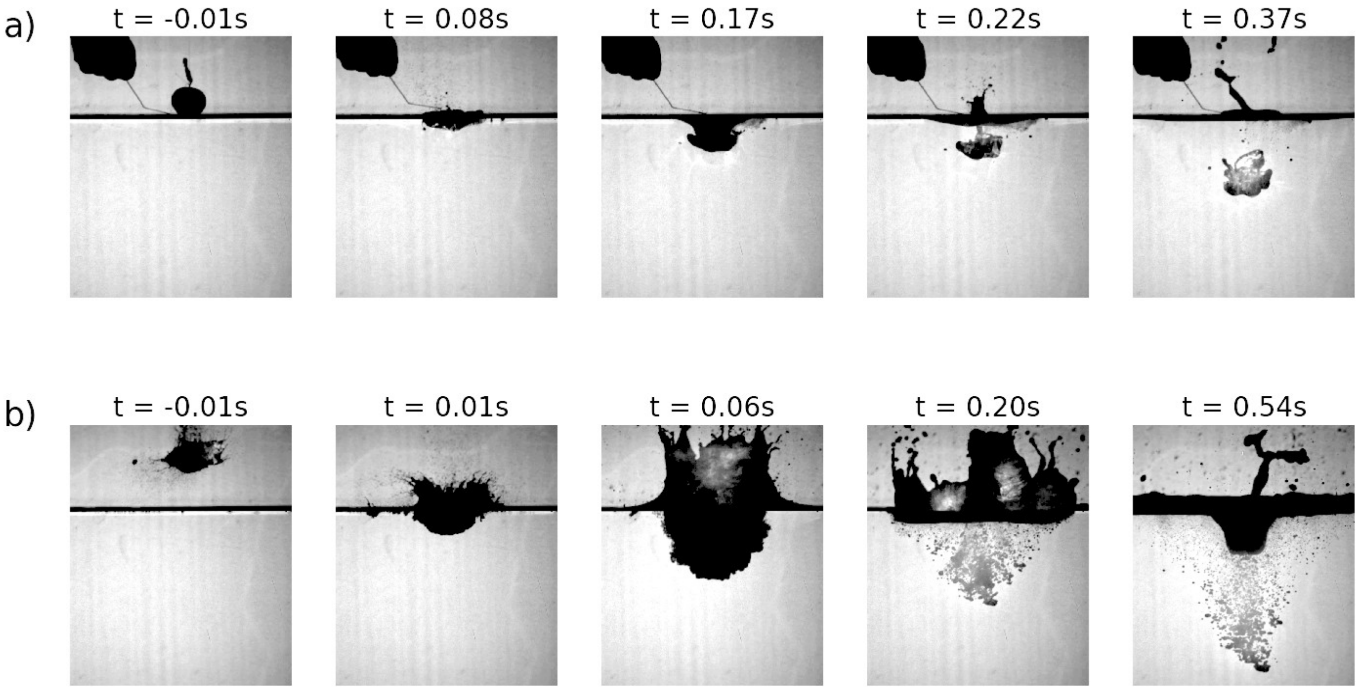

Fig 1. Impact of a liquid volume into an immiscible water pool. Images obtained by A. Maller during his ongoing internship. (a) Impact velocity U=0.6 m/s, the ratio of inertia to gravity is equal to 2. (b) Impact velocity U=4.5m/s, the ratio of inertia to gravity is equal to 100.

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