PhD subject

Name of the laboratory: **Laboratoire d'Astrophysique de Marseille**

PhD advisor: Olivier Mousis
Email and address: olivier.mousis@lam.fr, Université d'Aix-Marseille & Centre National de la Recherche Scientifique, 38 rue Frédéric Joliot-Curie – 13388 Marseille Cedex, France.

Co-advisor: Bertrand Devouard, devouard@cerege.fr, CEREGE, Technopôle de l'Arbois, BP80 – 13545 Aix-en-Provence, France

Subject's title: **Formation conditions of refractory materials in planetary environments**

Subject description:

The proposed work takes place in the context of the study of the formation and evolution of telluric planets, small rock bodies and satellites of the solar system. The work aims at focusing on the composition of the refractory materials (oxides, silicates and metal, mostly, as opposed to low-temperature organics and ices) that formed consecutively to the cooling of the protosolar nebula, or as a result of very high temperature transient events such as those caused by collisions that have strongly marked the history of the system. In the end, these refractory materials agglomerated with each other and formed the building blocks of the various planets and small bodies of the Solar System. The aim of this work is to determine the formation conditions at very high temperatures leading to the condensation of solids, or alternatively liquids (subsequently crystallized under cooling) in i) low pressure gaseous environments such as the inner part of the primitive nebula and ii) in denser and higher-temperature environments such as those generated during impacts between planetoids. Many laboratory data exist on the crystallization of solids from a vapor phase but, unfortunately, very few are available on the gas-liquid equilibrium beyond 1600° C. The first objective of the thesis will be to develop a numerical code based on the principle of Gibbs free energy minimization and dedicated to the determination of the composition of the solids formed by condensation and crystallization via the study of gas-liquid equilibria under the formation conditions of the solid bodies of the solar system. Similar codes, such as HSC Chemistry (Outotec), have been developed for the industry and are currently used in planetary science, but they only focus on high-temperature solid-gas equilibria and do not incorporate the liquid phase.

Once implemented, the thermodynamic code will be used to provide answers to questions relevant to two distinct areas of planetary sciences. A part of the study will be devoted to the comparison of the results of our code regarding two types of objects available and likely to be analyzed in the laboratory: meteorites chondrules and Earth impact glasses, two areas of expertise of the Planetology team of CEREGE. The chondrules, millimetric droplets partially recrystallized, are the most frequently observed objects in meteorites. Classically they are believed to have formed consecutively to a fast and warm event in the protosolar nebula, and constitute the first materials accreted by planetary bodies. However, after a consensus that lasted 40 years, there is increasing evidence for an alternate origin of the chondrules that could have formed through the condensation of dense gas plumes following collisions between small protoplanetary bodies. Impact glasses and tektites formed on Earth following meteoritic impacts probably also result from the condensation of a very high-temperature plasma. The composition and thermal history of these objects will be investigated through the results of thermodynamic modeling and the existing astronomical observations.

Another part of the study will consist in determining the composition of planetesimals that formed at close distances from the Sun. The composition of the refractory materials condensed under these conditions is poorly known and could have implications for the origin of Mercury, which is located at 0.4 Astronomical Unit from the Sun and possesses a metallic core surrounded by a thin silicate layer. The thermodynamic code will also provide constraints on the composition of moons (Phobos, Deimos, Moon, etc.) that were formed following a collisional process. This type of model, describing the composition of minerals as a function of their condensation temperature, should also improve our knowledge of the asteroid formation time scales of the Main Belt by comparing their compositions with those obtained via modeling. In addition, the numerical code will be used to better understand the composition of the magmatic oceans and silicate atmospheres thought to exist in some exoplanetary environments such as Corot 7b.

This work takes place in the context of the Solar System exploration via robotic missions, among which the MMX mission from the Japanese space agency JAXA is intended to explore the martian moon Phobos, with a planned launch in 2022.

Skills: The proposed topic includes an important modeling component. Good computer skills (FORTRAN programming, UNIX shells, etc) are necessary. Candidate must have strong knowledge in thermodynamics, physics, planetary sciences, mineralogy or numerical modeling. The work will benefit from collaborations in an international environment, so a good knowledge of English is required.