

## DESCRIPTION D'UN PROJET DE THÈSE FINANCÉ - ÉCOLE DOCTORALE « Matière, Molécules, Matériaux & Géosciences »

### 🚩 INFORMATIONS GÉNÉRALES

<b>Titre de la thèse :</b> Impact of gas and ions filled ices on the structure and evolution of large ocean worlds
<b>Champ disciplinaire 1 :</b> Planetary sciences <b>Champ disciplinaire 2 :</b> Mineral physics
<b>Trois mots-clés :</b> Planetary interior, Internal dynamics ; Thermodynamics
<b>Unité d'accueil (préciser si temps partagé entre plusieurs sites) :</b> Laboratoire de Planétologie et Géosciences, UMR 6112
<b>Nom, prénom du directeur de thèse (HDR indispensable) :</b> Gabriel Tobie <b>Adresse mail :</b> gabriel.tobie@univ-nantes.fr <b>Nom, prénom du co-directeur (le cas échéant) (HDR indispensable) :</b> <b>Adresse mail :</b> <b>Nom, prénom du co-encadrant de thèse 1 (le cas échéant) :</b> Gaël Choblet <b>Adresse mail :</b> gael.choblet@univ-nantes.fr <b>Nom, prénom du co-encadrant de thèse 2 (le cas échéant) :</b> Livia Bove <b>Adresse mail :</b> livia.bove@upmc.fr
<b>Contact(s) (adresse postale) :</b> LPG, 2 rue de la Houssinière, BP 92208, 44322 Nantes cedex

Une fois complété, merci d'enregistrer ce document au format pdf avec le nom suivant : Nom du Directeur thèse\_Unité.pdf

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## 🚩 DESCRIPTION SCIENTIFIQUE DU PROJET DE THÈSE

### Description du sujet : contexte, objectifs, méthodologie (1 page maximum)

Exploration of Jupiter's and Saturn's system by space missions (Galileo, Cassini-Huygens) revealed that some of their icy moons possess a salt water ocean under their cold icy surface. Observations of various sulfate and chlorinated salts on the surface of Europa and Ganymede as well as in the eruptive plume of Enceladus suggest an oceanic origin and put some constraints on the possible oceanic composition. For the largest moons (Ganymede, Callisto and Titan), due to high pressure reached in their deep interior, the existence of high pressure ice phases capable of incorporating into their lattice large amounts of salt compounds, called salt-filled ices, may strongly affect the chemical differentiation processes leading to the formation of subsurface oceans. Similarly to the case of salty ices, light gas compounds, such as  $H_2$ ,  $CH_4$  and  $N_2$ , may also be incorporated in filled-ice structures, and thus could be stored in the deep interior and sporadically released during the interior evolution. These icy moons likely formed from a complex mixture of ices, organics and silicate minerals, which subsequently evolves as their interior progressively warm up and chemically differentiate. Beyond large ice moons, similar processes may affect the thermo-chemical structure and evolution of water-rich exoplanets and their atmosphere composition. Storage and transport of salt and light gas compounds by filled-ice phases may have a major impact on the chemical evolution and hence the habitability of these ocean worlds.

The present PhD project is part of the ANR project "EXOTIC-ICES" (2024-2028), involving three laboratories in France (IMPMC, LPG, IPGP), dedicated to the characterization of the exotic properties of gas and ions filled ices under extreme conditions and their implications for water-rich planetary interiors. In this context, the goal of the PhD work is to determine under which planetary contexts, salt and gas filled-ice phases may exist and to characterize their impacts on the internal structure, dynamics and chemical evolution of large icy moons and extrasolar water-rich planets. This modeling work will rely on the experimental data and ab initio calculations provided by the project partners (IMPMC & IPGP in Paris) regarding the stability and properties of filled-ice phases. Using thermal convection codes and 1D parameterized models, we will quantify how much  $H_2$  and  $CH_4$  may be released by water-rock interactions and thermal degradation of organic compounds, stored in filled-ice phases and subsequently transported through the hydrosphere to the surface. These models will be used to predict the release rate of  $H_2/CH_4$  through time and its impact on the atmosphere evolution of Titan and water-rich exoplanets, such as Trappist-1 planets. Salt-ice-water interactions will also be modeled throughout the evolution of these ice-rich interiors from accretion to present, and will be used to predict the partitioning of salt compounds between the ocean and the high-pressure ice mantle. Using the model results, synthetic density and electric conductivity profiles considering different salt contents and distributions will be constructed and will be used to predict the magnetic and gravimetric signatures of salt partitioning between the ocean and the high-pressure ice layer in preparation of the ESA Juice mission.

### Application information:

Candidates must have a master degree and/or an engineering degree with knowledge in geophysics, planetary sciences, astrophysics, fluid dynamics and/or mineral physics. Good skills in numerical modeling and programming are expected. Previous experience on a related topic/field will be a particularly valuable asset. Good oral and written communication skills in English are also required.

Applications should include a CV and a cover letter, as well as the contact information of Master thesis' supervisor and another referees in the academic field. They should be posted by responding to the relevant vacancy using the following link: <https://emploi.cnrs.fr/Offres/Doctorant/UMR6112-GABTOB-002/Default.aspx>. An interview will be carried out for successful applications. The desired start date for the thesis is the beginning of October 2024.

Work conditions:

The thesis work will be carried out under the supervision of Gabriel Tobie (LPG), Gaël Choblet (LPG) and Livia Bove (IMPMP), as part of the ANR EXOTIC-ICES project, coordinated by L. Bove (IMPMP) and in partnership with LPG and IPGP. The recruited person will be attached to the 3MG Doctoral School (Matter, Materials and Geosciences), and to the Graduate Program Earth and Planetary Sciences of Nantes University. The recruited person will carry out their work within the Laboratory of Planetology and Geosciences (LPG – UMR 6112) , located on the campus of the UFR Sciences and Techniques of Nantes University (bat. 4, 2 rue de la Houssinière, 44322 Nantes) and will be placed under the responsibility of the Director of the UMR.

The Laboratory of Planetology and Geosciences Laboratory (LPG - UMR 6112) is a multidisciplinary research unit created in 2000 and spread across 3 sites: Nantes University, University of Angers and University of Le Mans. LPG is a major international player in the field of Earth and Universe Sciences. The laboratory's objects of study extend over a very broad disciplinary spectrum currently divided into three themes. His research is part of past, current and planned international space missions to the telluric and icy bodies of the solar system. On Earth, research concerns geosciences in the broad sense, from the interior and surface of the Earth (imaging, observations, analyzes and modeling, in the fields of geophysics, geochemistry and digital technology) to the themes of environment and paleoenvironments, with numerous missions on land and at sea.

The recruited person will mainly work on the “Planets and Moons” theme of the LPG, and will be required to collaborate with various teacher-researchers and researchers from the LPG and partner laboratories as part of the ANR EXOTIC-ICES project. International travel is expected.

**Compétences scientifiques et techniques requises pour le candidat :**

- Master degree in Planetary Sciences, Geophysics, Physics
- Good knowledge in programming (python, fortran)
- Good knowledge in planetary sciences, geophysics, fluid dynamics
- Good level in english

**ENCADREMENT DE LA THÈSE<sup>1</sup>**

<b>Nom de l'unité d'accueil :</b> Laboratoire de Planétologie et Géosciences	<b>Nom de l'équipe d'accueil :</b> Planètes & Lunes
<b>Nom du directeur de l'unité :</b> Benoit Langlais	<b>Nom du responsable de l'équipe :</b> Stéphane Le Mouélic/Sabrina Carpy
<b>Coordonnées du directeur de l'unité :</b> Benoit.langlais@univ-nantes.fr	<b>Coordonnées du responsable de l'équipe :</b>
<b>Directeur de thèse</b> Nom, prénom : Tobie, Gabriel Fonction : Directeur de recherche au CNRS Date d'obtention de l'HDR : 2018 Employeur : CNRS Taux d'encadrement doctoral dans le présent sujet : 40% Taux d'encadrement doctoral en cours (directions et co-directions) : 50% Nombre de directions/co-directions de thèse en cours : 1	
<b>Co-directeur (le cas échéant)</b> Nom, Prénom : Fonction :	

<sup>1</sup> Dans l'ED 3MG, si 1 scientifique dans la direction de la thèse = 100% d'encadrement doctoral ; si 2/3 personnes impliquées dans l'encadrement de la thèse, un taux de 40% minimum est exigé pour l'HDR directeur et 30% pour les autres encadrants.

<p>Date de l'obtention de l'HDR :</p> <p>Employeur :</p> <p>École doctorale de rattachement :</p> <p>Taux d'encadrement doctoral dans le présent projet :</p> <p>Taux d'encadrement doctoral en cours (directions/co-directions/co-encadrements):</p> <p>Nombre de directions/co-directions/co-encadrements de thèse en cours :</p>
<p><b>Co-encadrant de thèse 1 (le cas échéant)</b></p> <p>Nom, prénom : Choblet, Gaël</p> <p>Fonction : Directeur de recherche au CNRS</p> <p>Titulaire de l'HDR : <input checked="" type="checkbox"/> oui    <input type="checkbox"/> non    Si oui, date d'obtention de l'HDR :</p> <p>Employeur : CNRS</p> <p>École doctorale de rattachement : ED 3MG</p> <p>Taux d'encadrement doctoral dans le présent projet :</p> <p>Taux d'encadrement doctoral en cours (directions/co-directions/co-encadrements):</p> <p>Nombre de directions/co-directions/co-encadrements de thèse en cours :</p>
<p><b>Co-encadrant de thèse 2 (le cas échéant)</b></p> <p>Nom, prénom : Bove, Livia</p> <p>Fonction : Directrice de recherche au CNRS</p> <p>Titulaire de l'HDR : <input checked="" type="checkbox"/> oui    <input type="checkbox"/> non    Si oui, date d'obtention de l'HDR :</p> <p>Employeur : CNRS</p> <p>École doctorale de rattachement :</p> <p>Taux d'encadrement doctoral dans le présent projet :</p> <p>Taux d'encadrement doctoral en cours (directions/co-directions/co-encadrements) :</p> <p>Nombre de directions/co-directions/co-encadrements de thèse en cours :</p>
<p><b>Partenaire privé (si financement CIFRE, privé...)</b></p> <p>Nom, prénom :</p> <p>Fonction :</p> <p>Entreprise :</p> <p>Taux d'encadrement doctoral dans le présent projet :</p> <p>Taux d'encadrement doctoral en cours (directions/co-directions/co-encadrements) :</p> <p>Nombre de directions/co-directions/co-encadrements de thèse en cours :</p>

**Partenaire international (si thèse en co-tutelle)**

Nom, prénom :

Fonction :

Employeur :

Taux d'encadrement doctoral dans le présent projet :

Taux d'encadrement doctoral en cours (directions/co-directions/co-encadrements) :

Nombre de directions/co-directions/co-encadrements de thèse en cours :

 FINANCEMENT DE LA THÈSE

<b>Origine(s) du financement de la thèse : ANR EXOTIC-ICES</b>
<b>Montant brut mensuel :</b>
<b>État du financement de la thèse : Acquis</b>
<b>Date du début/durée du financement de la thèse : 01/10/2024</b>