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

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Titre du sujet :

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More than 60 years after the Apollo missions first deployed seismometers on the Moon, a new era of international lunar seismology is emerging. In 2026, two missions are expected to land in the Moon's polar regions and deploy new seismic instruments. The first is China's Chang'e 7 mission, scheduled for launch in august 2026. The second is a U.S.-led mission under NASA's Commercial Lunar Payload Services (CLPS) program, which will deliver the Farside Seismic Suite (FSS), planned to be launched in october 2026 . Unlike the Apollo-era seismic network, which was restricted to the lunar nearside, these new deployments will provide the first seismic data from the farside and polar regions, offering an opportunity to study the Moon's internal and near-surface structure in unexplored terrains.

A key motivation for exploring the lunar poles is the detection and characterization of water ice. Since its identification in Apollo samples and through remote sensing (e.g., neutron, RF radar and IR and UV spectroscopy), the Moon is no longer considered completely dry. In-situ resource utilization (ISRU) has made mapping and quantifying lunar ice one of the central goals of polar exploration. Notably, one objective of Chang'e 7 is to investigate lunar ice deposits, with a landing planned near Shackleton Crater—a region adjacent to a permanently shadowed area thought to be favorable for ice retention.

This thesis aims to integrate seismic and remote sensing data to investigate the shallow subsurface structure and assess the distribution of lunar ice in the polar region. The research will focus on the following three themes:

1. Subsurface Structure Analysis Using Seismic Data
   Using seismic techniques such as spectral analysis and coda wave studies, we will characterize the one-dimensional (1D) subsurface structure beneath the landing site, with a particular focus on attenuation and scattering properties (e.g. Xiao et al., 2023 ; Menina et al., 2021 ; 2023). Long-duration seismic codas—typical in lunar data—are a result of strong scattering in the regolith and low attenuation under dry conditions. The presence of subsurface ice is expected to significantly alter these properties, providing a seismic fingerprint of ice content. By combining velocity structure with attenuation and scattering analyses, we aim to constrain the vertical distribution of ice. If data quality allows, temporal variations (e.g., diurnal changes in very shallow attenuation due to thermal effects) will also be explored in high frequency data.

2. Mapping Surface Ice Distribution Using Remote Sensing
   Recent studies have demonstrated that ultraviolet (UV) reflectance data can reveal the presence and behavior of lunar surface ice (Hayne et al., 2015; Hendrix et al., 2019). These observations confirmed exposed water ice in cold traps below ~110 K and identified a dynamic layer of adsorbed water migrating with temperature changes. This thesis will apply similar methods—focusing on the vicinity of the landing site—to produce high-resolution ice distribution maps and inform seismic interpretation and possible correlations between remote sensing and seismic properties of the surface and subsurface respectivelly

3. 3D Seismic Simulations Constrained by Remote Sensing Data
   The final component will involve three-dimensional seismic simulations incorporating surface ice distribution as inferred from UV observations. Using tools such as OpenSWPC (Maeda et al., 2017; Onodera et al., 2022), we will model seismic wave propagation through heterogeneous icy regolith. These simulations aim to constrain the 3D geometry and depth extent of ice deposits, offering valuable insights for future ISRU planning.

If both Chang'e 7 and FSS operate successfully, comparative analysis between the two sites—Shackleton Crater and Schrödinger Basin—will be conducted. As Schrödinger lies further from permanently shadowed regions, it provides a natural control site with lower ice potential. This comparison will be critical for understanding regional variability in polar ice distribution.