Properties of Mercury's plasma environment with BepiColombo

Background: Several space missions are exploring the inner heliosphere (below Mercury orbit), such as PSP and SO, in conjunction with near-Earth probes (WIND, STEREO-A). BepiColombo therefore provides essential measurements between the Sun and the Earth for studying the solar wind/planet interaction, space weather aspects and understanding the energy processes in the dynamics of Mercury's magnetosphere. In the longer term, this research will be a prerequisite for the scientific return of the JUICE mission, dedicated to the exploration of Jupiter and its icy satellites.

The **main goal** of the PhD is to carry out an in situ diagnostics of the local solar wind electrons and characterizing their interaction with a magnetized telluric planet's environment, using new developments in the quasi-thermal noise spectroscopy (QTN) method. Strong scientific return on Parker Solar Probe and BepiColombo missions is expected. For that purpose, the PhD student will used in situ measurement (QTN) from radio instrumentation, data processing and analysis (waves, particles), with possibility of comparing results with 3D MHD simulations and/or theoretical developments.
The proposed PhD project is dedicated to the **first analysis of the SORBET** (Spectroscopie des Ondes Radio et du Bruit Electrostatique Thermique) radio instrument on board the BepiColombo Mercury Magnetospheric Orbiter (MMO). Indeed, SORBET will accurately measure in situ the electron density and total temperature of the plasma to map the dynamics of Mercury's magnetosphere due to its vicinity to the Sun, and its interaction with the solar wind. Tools and methods will be first developed and tested on Parker Solar Probe (PSP) radio observations. These pioneering data will make major clues on the physics of the inner heliosphere and will give a unique opportunity to work on a "hot" topic for a PhD student. This subject will be the **first French BepiColombo thesis**, with a dedicated analysis to SORBET data.

Using sensitive instruments to deduce space plasmas measurements should allow to give constraints on still opening questions on the transport of the energy in the solar wind, its acceleration, and the heating of the corona. Complexity is coming from the collisionless plasma, which cannot be considered to be at equilibrium state. This means that the velocity distribution functions of the particles are not Maxwellians but rather power laws or generalized Lorentzians (named Kappa functions). Remote-sensing observations in the Sun corona and in-situ measurements in the solar wind demonstrate the existence of such features. Despite their small masses, electrons carry extreme ranges of energy from the solar corona to the planets, Mercury being the first encountered. In addition, suprathermal components are essential to understand their radial variation inside Mercury's orbit and the formation of suprathermal tail in the total electron distribution functions. Radio observations and analysis developed in this PhD proposal, especially close comparison of the electron parameters from FIELDS/PSP, and SORBET/BepiColombo, combining ion and electron distributions on both spacecraft, are one of the key method to answer this fundamental purpose. **Groundbreaking results** will be first expected on **PSP**, which will *touch* the Sun corona, i.e., the Sun's atmosphere, since it will pass closer than 9.5 Solar Radii in mid-2024.

An accurate and reliable tool, invented and developed by our team to diagnose space plasmas consists in using the quasi-thermal noise (QTN) method, successfully implemented on many space missions (ISEE, ULYSSES, WIND, STEREO, CASSINI). Based on the continuous analysis of the **SORBET** power spectra of the Plasma Wave Instrument (PWI), this technique is using a passive electric antenna (WPT on BepiColombo), connected to the SORBET sensitive receiver for measuring the electrostatic field spectrum produced by the particle thermal motions. The spectral analysis mainly yields the electron density and temperature with a very good accuracy. By probing the poorly known Hermean's magnetosphere, in particular its exosphere, and ionosphere, which are sensitive to solar perturbations, SORBET will bring new results on the **dynamics of the electrons** such as the transport processes and acceleration mechanisms. SORBET will also monitor the electron properties in the solar wind with a high spectral resolution, since BepiColombo will have major stakes in **space weather**. These analysis are key elements to make **joint comparison** with Parker Solar Probe in the inner heliosphere and other space missions (WIND, STEREO-A) near the Earth.

The student will be immersed in the QTN LESIA experts' team (K. Issautier, P. Dazzi, M. Maksimovic, N. Meyer-Vernet) and will benefit of backgrounds and skills of the technique, initiated by LESIA and recent theoretical developments on the method. The proposal is based on new extensions of the method. Moreover, **the student will benefit of close collaboration with LPP** (L. Hadid and her team), with **direct access on distribution functions. Other collaborations** imply (SSL/Berkeley (US) and the University of Tohoku

(Japan) and other French collaborations (IRAP, LPC2E, LATMOS), since several instruments on BepiColombo are under French responsibility, involved in SNO “BepiColombo magneto”..

During the thesis, the student will have the **opportunity to analyze both 1) SORBET BepiColombo data** during its nominal mission **late 2025 and ii) the current Parker Solar Probe data during its first perihelion near 9.5Rs, expected mid-2024 and the twenty other first Encounters close to the Sun (since 2018)** inside Mercury’s orbit. Processing **radio data** from quasi-thermal noise method will allow to yield a macroscopic solar wind diagnostic, i.e., electron density and temperature in the **inner heliosphere and in Mercury’s environment**. The novelty consists in the **determination of the suprathermal electrons**, which has never been done. Physical processes shaping **electron populations** from the **Sun to Mercury’s environment** are at the heart the thesis. QTN diagnostics on SORBET data in the plasma environment of Mercury will lead to develop the **first 3D model of Mercury’s magnetosphere** (L. Griton, F. Pantellini, LESIA) including realistic time-dependent solar wind and cross compare other different approaches of plasma numerical simulations. Electrons originating from the solar wind are expected to play a key but still u**nknown role in the solar wind-surface interaction at Mercury,** including space-weather effects on the surface and feeding of Mercury’s exosphere.

The PhD concentrates on the following **work plan**:
- WP1: QTN method applied to inner Heliosphere conditions
Bibliography work, Learning the QTN method, application of the simplified “isotropic” version to PSP data not yet analyzed (perihelia 11 to 18) to get electron densities, core and total temperatures. Getting starts with existing numerical tools on PSP and solar wind data access.
- WP2: Extension of the method and application to solar wind PSP data
2.1. Developing new theoretical extensions of QTN to the anisotropic suprathermal populations. Strahl highlight features from plasma and radio data.
2.2. Application to all PSP data Encounters. Analysis of the electron solar wind data, including anisotropy in the inner heliosphere and comparison with other instruments. Development of a most complete electron data base to be archived at CDPP.
- WP3: Extension of QTN to SORBET data in Mercury’s environment in earlier 2026 (coll. LPP)
3.1. Mapping electron populations by densities and suprathermal properties.
3.2. Comparison with electron and ion distribution functions on MEA and MSA instruments on MMO with **LPP scientific team**. Comparison of the electron properties in the solar wind for both PSP and BepiColombo, according to the radial distance and solar activity.
3.3. Comparison of MHD simulations and SORBET/MSA/MEA data in Mercury’s environment using simulation quantities plotted against BepiColombo’s orbit.

Regular meetings as brainstorming on the solar wind from PSP and Mercury’s environment with LESIA & LPP team members. Participation to online international working group meetings, especially the electron and QTN working group for PSP, and Heliospheric Working Group (HEWG) twice per year including SWT on BepiColombo.

Expected results will lead to several **peer-review publications**:
- Large-scale properties of the solar wind, as a function of the radial distance from the Sun, in comparison with other heliospheric probes
- Analysis of the different Encounters of **Parker Solar Probe** (PSP) (end of mission mid-2025)
- Implementation of the **method** tested on PSP for **BepiColombo (Sorbet**/PWI instrument) and comparison with other instruments. This part will need **strong synergy** with both instruments, thanks to long-term **collaborations between LESIA and LPP**. Each of them has direct access to the data.
- Analysis of the first BepiColombo data mid-2026
- Study of the electron **dynamics in Mercury’s magnetosphere**

This PhD project is already half funded by CNES. We ask for another half part of doctoral fellow to IPI.
PhD student will be co-supervised by Léa Griton (Maître de Conférence, Sorbonne University) at 30%.