Modeling the interaction between Callisto's neutral and ionized environments and the Jovian magnetosphere

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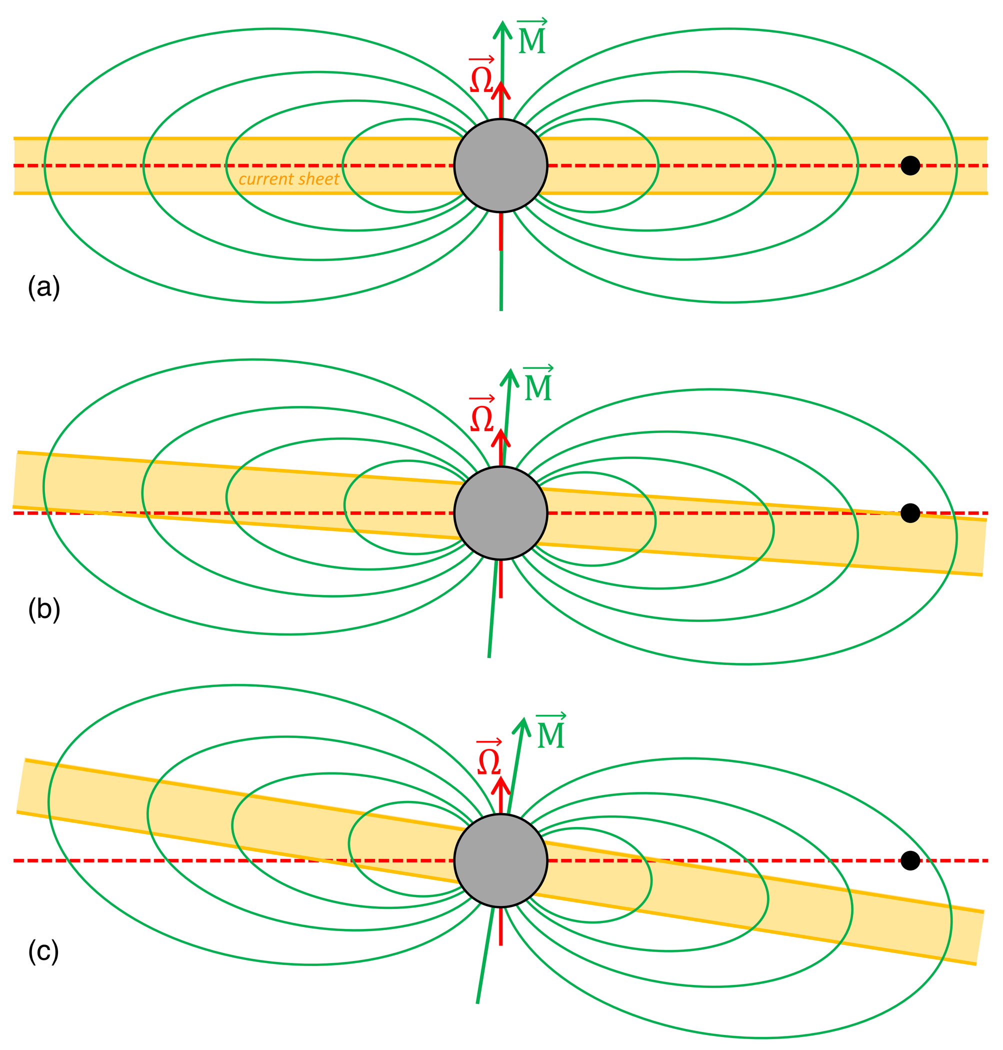
1. Context

Launched on April 14, 2023, ESA's **JUICE mission** is scheduled to reach Jupiter by 2031 to study the **likelihood of subglacial oceans** on three of its Galilean moons: **Europa, Ganymede and Callisto**.

In preparation for the mission's arrival, **simulations** describing the **moons' neutral and ionized environments** need to be carried out. Such simulations already exist for Ganymede and Europa, and have yet to be developed for Callisto.

Figure 1. Schematic representation of the impact of the magnetic moment tilt on the evolution of Callisto's orbital environment, adapted from *[Liuzzo, 2018]*. (a) Callisto at the center of the current sheet. (b) Intermediate position of Callisto. (c) Callisto in the lobe of the magnetodisk.



2. Callisto in the Jovian magnetosphere

The **Jovian magnetosphere** is a cavity in the solar wind where the influence of the Jovian magnetic field dominates. Most of the Jovian plasma is confined around the **centrifugal equator** (close to the magnetic equator) in a zone known as the **current sheet**, and is in corotation with Jupiter.

Callisto's orbital environment is **highly variable** for several reasons:

- the axis of Jupiter's magnetic dipole is inclined at around 10° to the planet's axis of rotation;
- Jupiter's rotation period is much shorter than Callisto's (10h ≪ 400.8h);
- Callisto is the Galilean moon furthest from Jupiter ($R_C \approx 26.3R_J$).

The moon therefore oscillates between **two extremes**: the **center of the current sheet** and the **lobe of the magnetodisk** (Fig. 1).

Callisto interacts with the Jovian magnetosphere (magnetic field and plasma), resulting in an **induced magnetic field**. Callisto has a **tenuous atmosphere** composed mainly of O2 and CO2, as well as an **ionosphere**.

Figure 3. Measured and averaged magnetic field intensity (Juno-MAG) and electron density (Juno-JADE) for the 8 time intervals found.

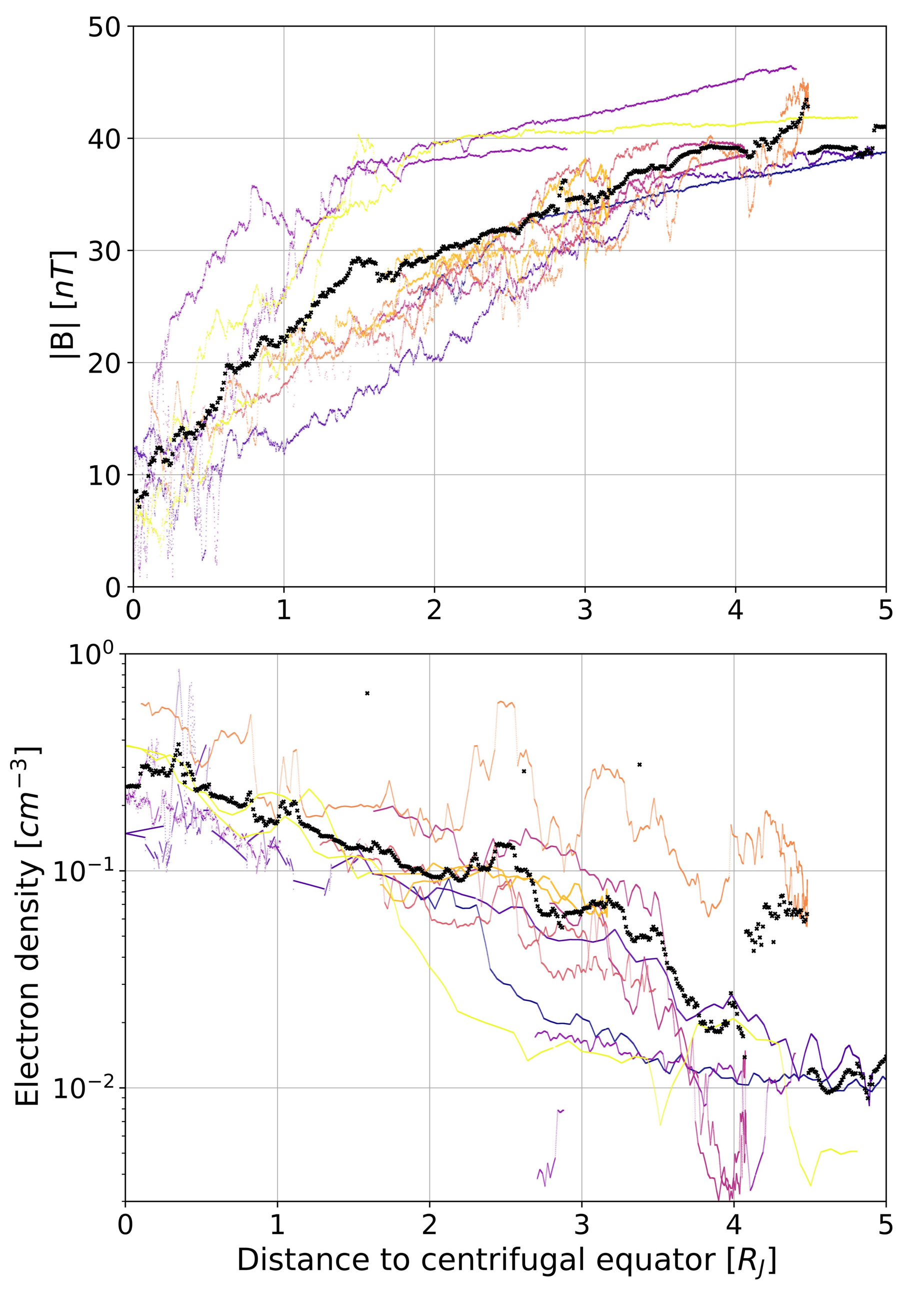
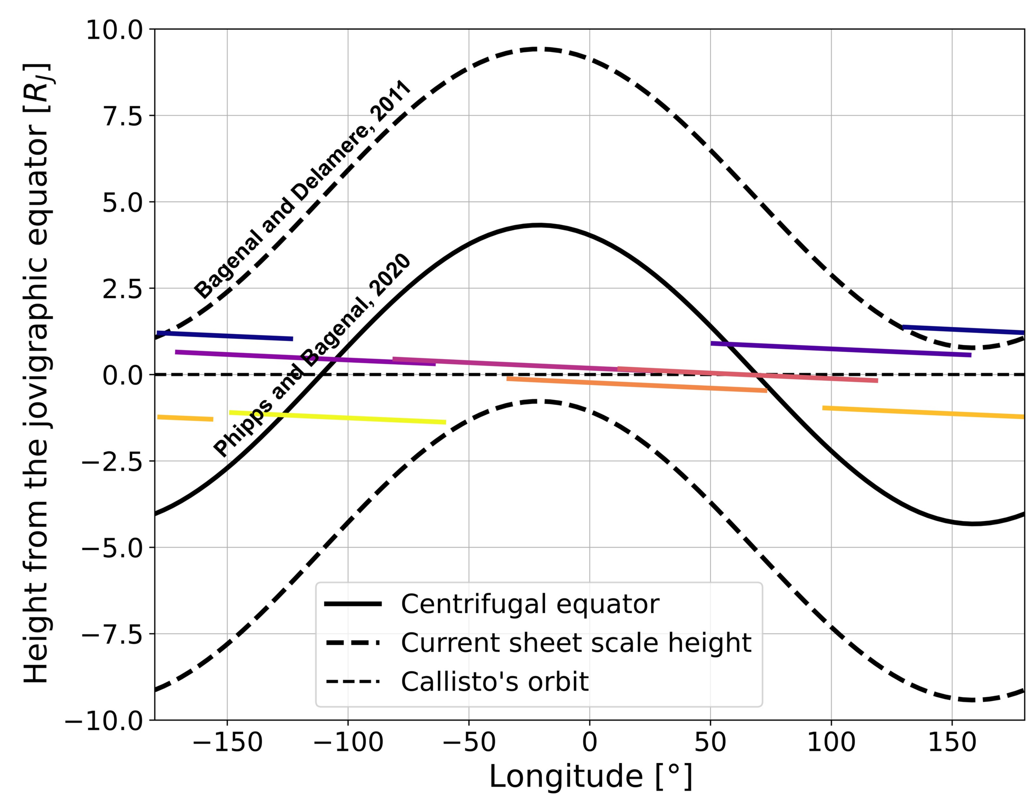


Figure 2. Trajectory of Juno for the 8 time intervals where it is in the vicinity of Callisto's orbit. Position of the centrifugal equator according to [*Phipps and Bagenal, 2020*] model, corresponding roughly to the center of the current sheet. Scale height of the current sheet according to *[Bagenal and Delamere, 2011]* model.



3. Juno in Callisto orbital environment

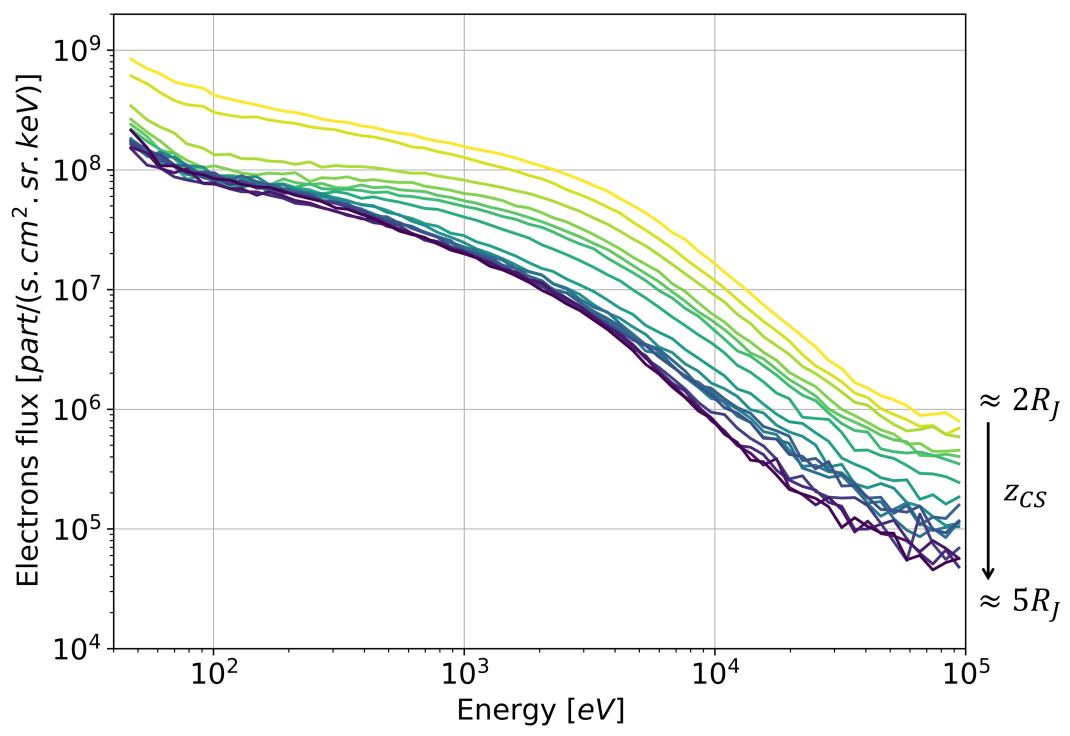
NASA's **Juno mission**, studying the planet Jupiter, carries several measuring instruments, including a magnetometer (**MAG**) and two energetic particle detectors (**JADE** and **JEDI**).

Although Juno didn't do any Callisto's flyby, its trajectory did cross Callisto's orbital environment several times, providing an opportunity to characterize it. Using the AMDA database, **8 usable time intervals** during which **Juno crossed Callisto's orbit** were identified. Using models of the current sheet, Juno's position relative to it can be traced in these intervals (Fig. 2).

The data collected clearly show that **at the center of the current sheet**, the **magnetic field** is **weaker** (4nT vs. 40nT resp.) and the **plasma denser** ($0.3cm^{-3}$ vs. $0.01cm^{-3}$ for electrons resp.) **than outside it**, as expected (Fig. 3).

The **electron flux spectrum** also shows a decrease with distance from the center of the current sheet (Fig. 4).

Figure 4. Electrons flux spectrum for different heights from the center of the current sheet (Juno-JADE). Spectra derived from average on sub-intervals of the 1st time interval identified.



4. LatHyS model

LatHyS (= Latmos Hybrid Simulation) is a model for **simulating planetary plasma environments**, developed mainly at Latmos (Fig. 5).

This model has already been used to simulate the **interaction between moons and a planet's magnetosphere** (Ganymede, Europa).

In order to simulate the interaction between Callisto and the Jovian magnetosphere, it is necessary to add a new **"environment" module** to the LatHyS code specifically dedicated to the moon (Fig. 6).

Figure 6. LatHyS model graph representing all existing modules and their connections.

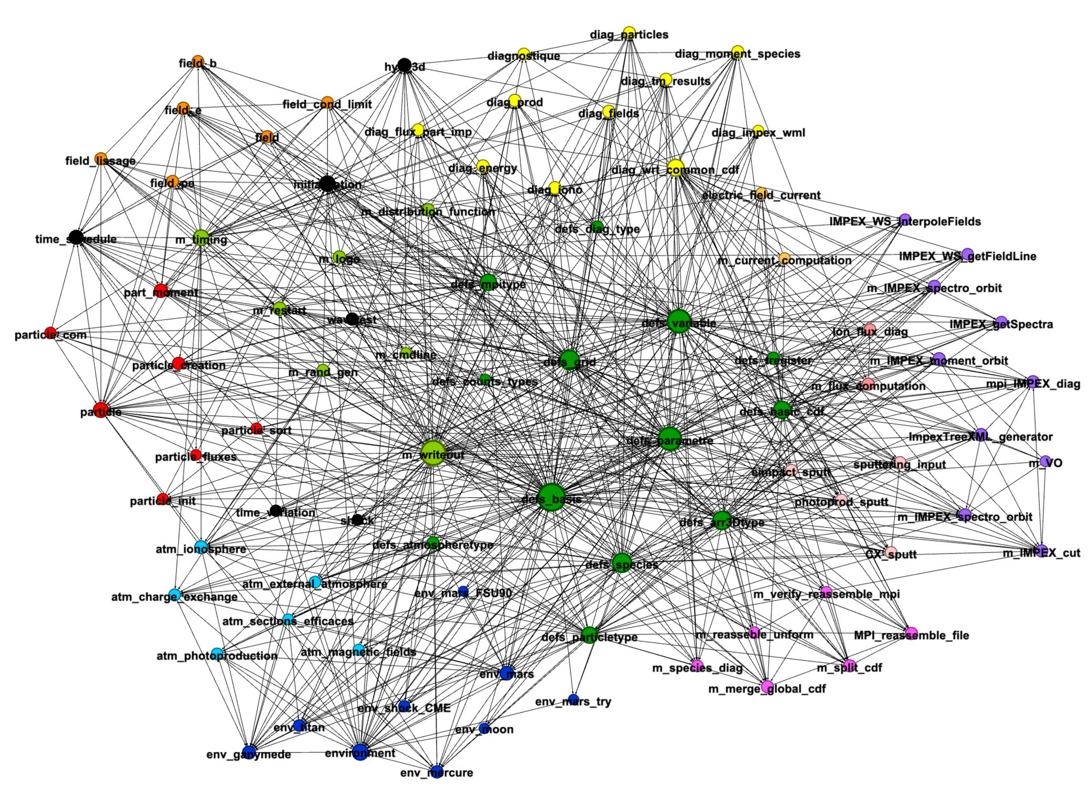
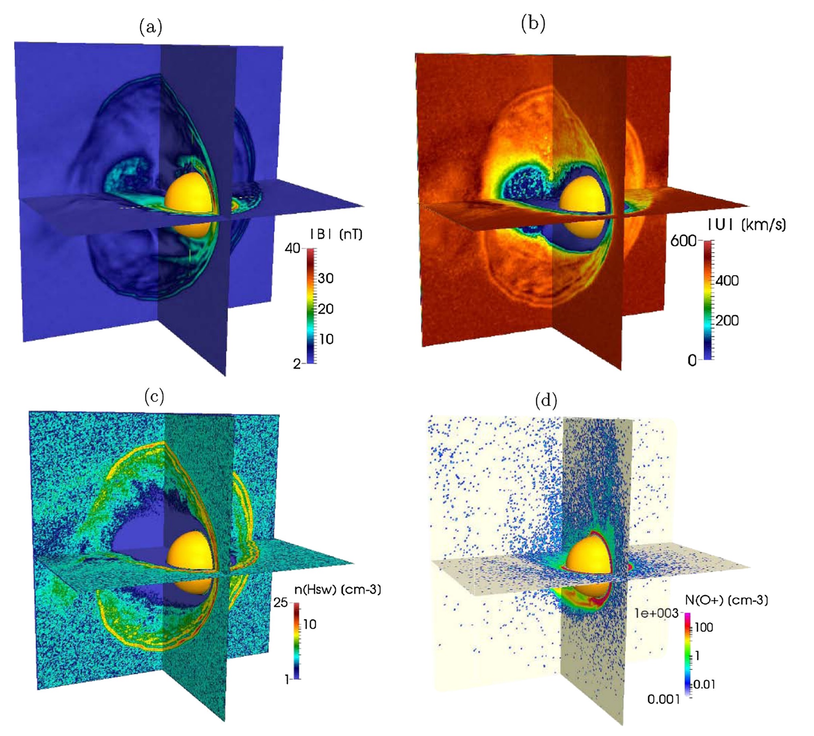


Figure 5. Example of 3D LatHyS outputs for Mars case from *[Modolo et al., 2016]*. (a) The magnetic field intensity. (b) The plasma bulk speed. (c) The solar wind protons number density. (d) The O+ ions number density.



5. First simulations

At present, only the **flow of Jovian plasma** is simulated, in the presence of the **Jovian magnetic field** and in the **absence of a moon**. The aim of these initial simulations is to ensure that the simulation runs smoothly in the absence of obstacles.

6. Prospects

The next step is to **add the various simulation components one by one**: the moon as a spherical obstacle, its induced magnetic field, a neutral atmosphere and an ionosphere. The boundary conditions used will also have to be improved. A **coupling with the EGM** (= Exospheric Global Model) is planned to improve the relevance of the simulation. It will be useful to **compare the simulation outputs with Callisto's flybys by Galileo**.

At the same time, work will continue on characterizing Callisto's orbital environment, in particular with regard to the properties of electron and ion fluxes from the Jovian plasma (Juno data).

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References

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