Europa's interaction with the jovian plasma from hybrid simulation

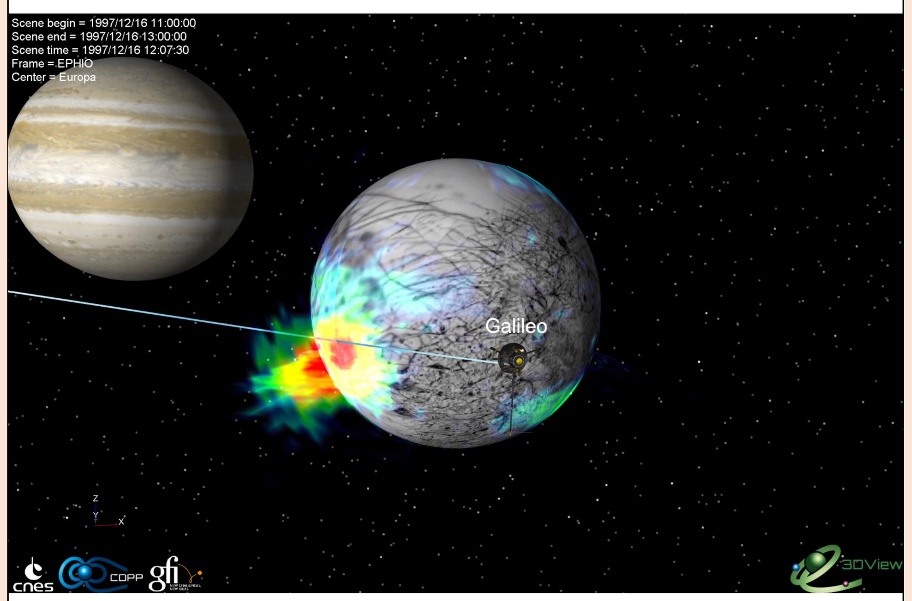
Claire Baskevitch[1,2], Ronan Modolo[1], Baptiste Cecconi[2]

1- UMR8190, LATMOS (CNRS/Sorbonne Université), 4 place Jussieu, 75252 Paris, France

2- UMR8109, LESIA Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Université de Paris, 5 place Jules Janssen, 92195 Meudon, France

Europa

- Europa is the **smallest of the Galilean moons** with a radius of **1560km**. Its **orbital radius** is about **9 Jovian radii**.
- Under its icy crust lies a **liquid salt ocean** generating convective currents that **induce a weak magnetic eld**. Presence of **water vapour plumes** ejected from the surface and located at the south pole was discovered by HST.
- Its tenuous **atmosphere** is mainly composed of **O2** (sputtering), **H2O** (sublimation and sputtering) and **H2**.
- The **ionosphere** is mainly composed of **O2+** and **O+**, whose main ionization reactions are **electronic impact** .
- The **plasma** in the vicinity of Europa is composed of **oxygen and sulphide ions**, which originate from Europa's ionosphere and Io's torus.



JUICE (JUpiter ICy moons Explorer), ESA

- Explore the three icy moons of Jupiter: Ganymede, Europa and Callisto.
- Launch : spring or summer 2023
- Arriving in 2031
- 2 flybys of Europa
- Mission of ~5 years

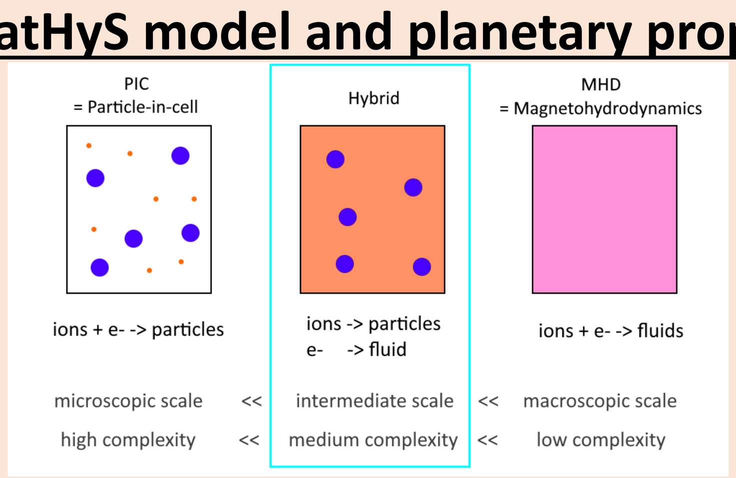
Europa Clipper, NASA

- Launch : 2024
- Arriving in 2031
- ~53 flybys of Europa
- Mission of ~3,5 years

Modelling Europa's environment

- Interaction of the jovian plasma and Europa : **describing the electromagnetic fields, the exchanges of momentum and energy quantities**
- In fine: to **prepare the scientific returns of JUICE**.

LatHyS model and planetary properties

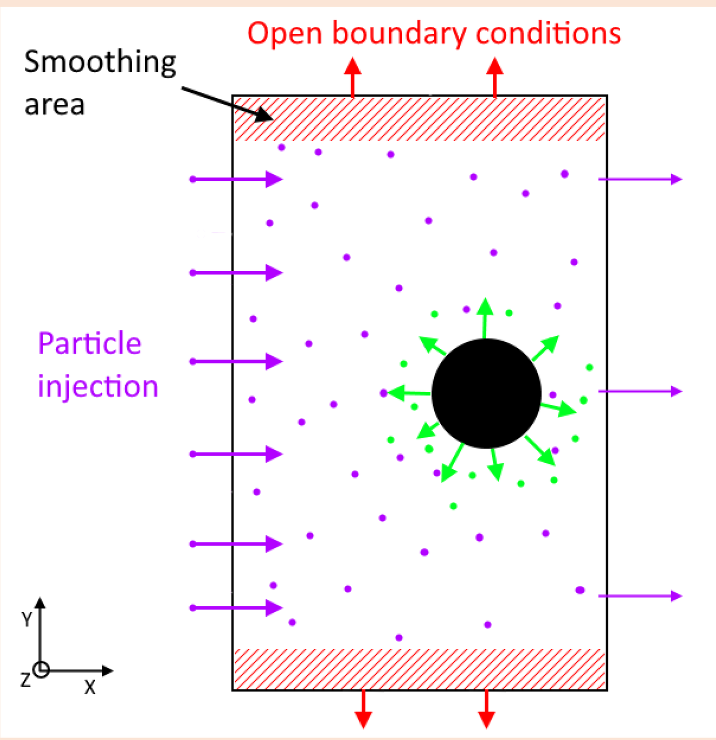


- LatHyS : hybrid, 3D, multi-species, parallelized simulation model of the plasma-planetary environment interaction
- The term hybrid refers to the representation of ions as particles and electrons as a fluid in the simulation
- Electromagnetic fields are computed self-consistenty

- $B_{jov} = (65, -173, -412) nT$ corresponding to an average value of the jovian field between inbound and outbound pass (Harris et al. 2021) during the Galileo E4 flyby.
- Induced magnetic field represented by a centered dipole (Harris et al. 2021).
- Plasma composition (Paterson et al. 1999, Harris et al. 2021) :
  - $O^+, U_{jov} = (100,0,0) km.s^{-1}, n_{O^+} = 20\ cm^{-3}$
- Ionosphere (O_2^+) :
  - At beginning of the simulation : it follows a spherical symmetry profile of two height scales (240 and 440km, Kliore et al. 1997) and a maximum density at the surface has been taken to $2500 cm^{-3}$ which is less dense than $5000 cm^{-3}$ of the radio-occultation observations (Kliore et al. 1997) but comparable to the MHD findings (Harris et al. 2021).
  - A still background ionosphere composed of 50% of the ionosphere created at the beginning of the simulation.
  - Ionization processes are present to feed the ionosphere :
    - electronic impact (Rubin et al. 2015).
    - charge exchange (Lindsay & Stebbings 2005).
    - photoionization (Huebner et al. 1992, Rubin et al. 2015). we can take into account the angle between the direction of arrival of photons and the incident plasma.
- Atmosphere : O_2, static, spherical symmetry profile (Rubin et al. 2015, Harris et al. 2021)
- Spatial resolution – cartesian grid : $100 km$
- Box size : $X \in [-8{,}5, 4{,}5] R_E, Y \in [-10, 10] R_E, Z \in [-15, 15] R_E$

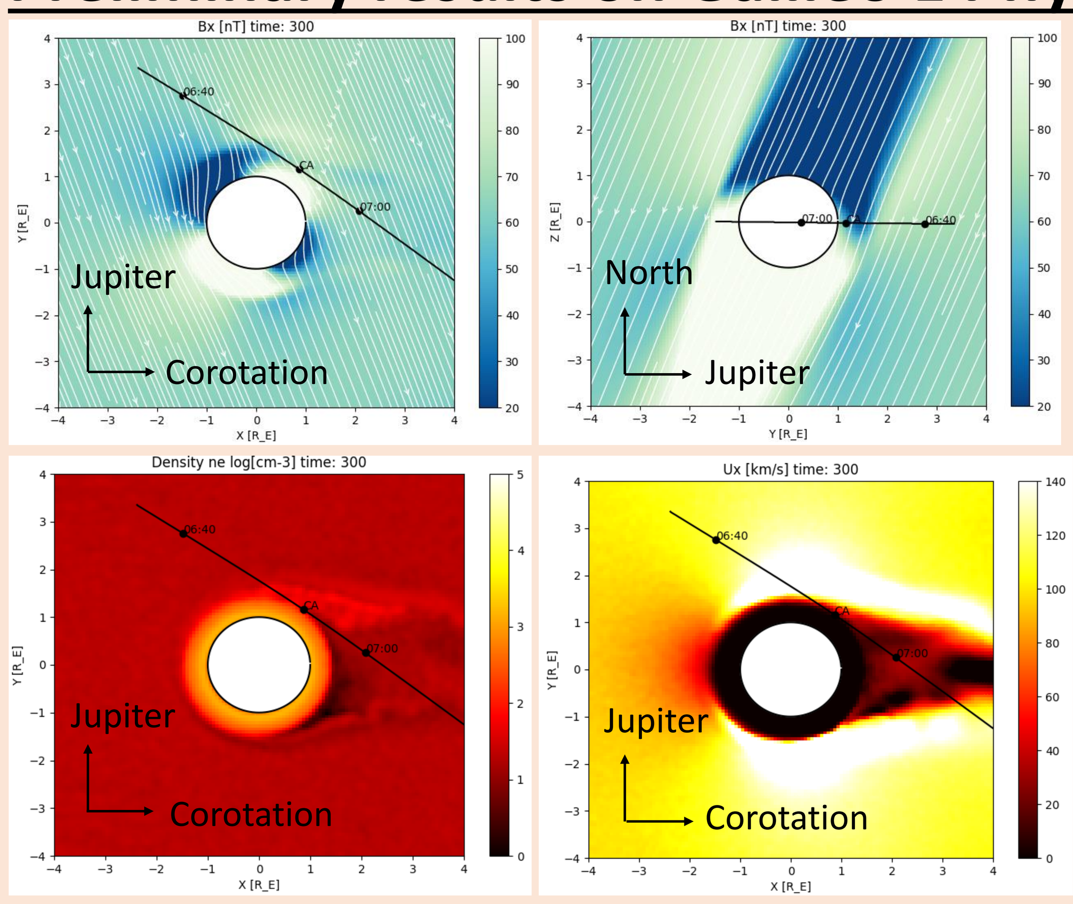
- Numerical resources :
  - Memory : $\sim 300 - 400 GB$
  - Execution time : 5 days for 30 000 iterations
  - Number of cpus : 288 -> 3 nodes of 96 cpus

Working on an optimisation method



- Periodic boundary conditions on Y and Z axes on electromagnetic fields and particles -> need a big simulation box and thus a lot of numerical resources (cpus and memory) and execution time.
- Development of "Open boundary conditions":
  - Field values not communicated between the boundaries
  - Smoothing region of 10 cells on the magnetic field to reduce perturbations generated by the open boundary conditions
  - Particle velocity reset to pristine magnetospheric value and periodic boundaries applied

Preliminary results on Galileo E4 flyby

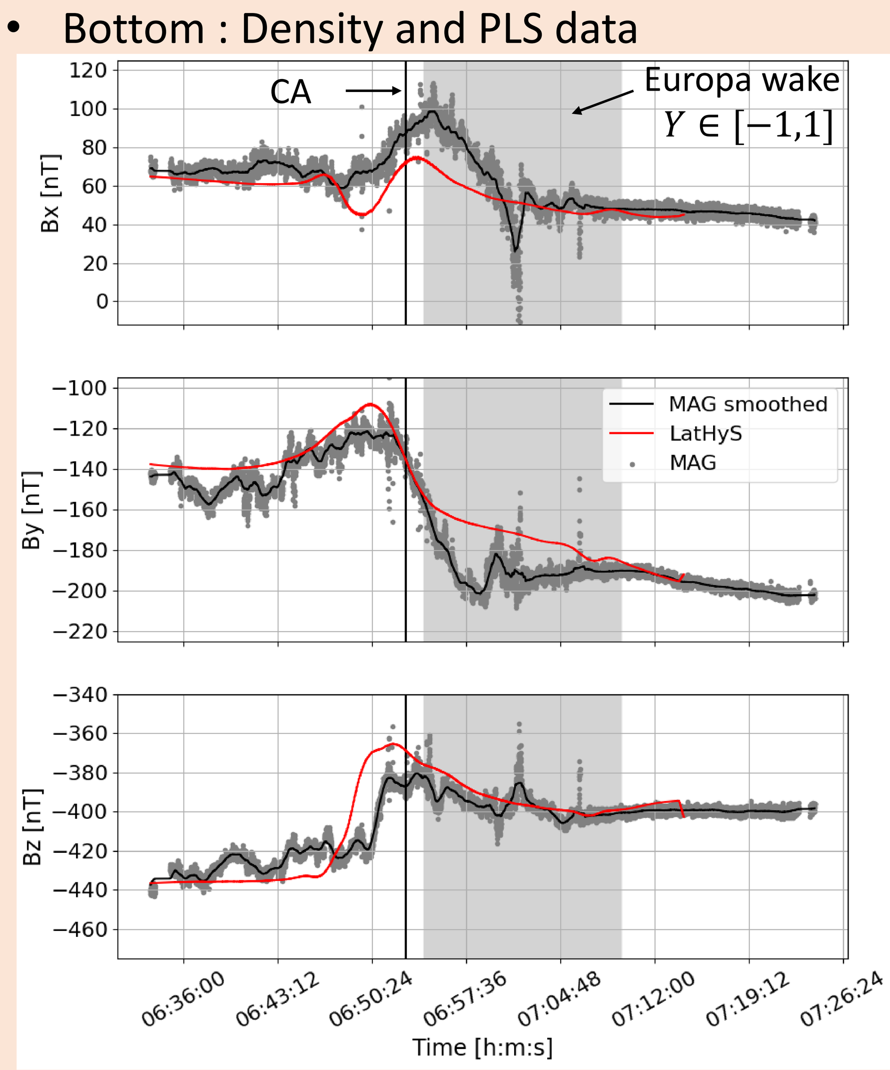


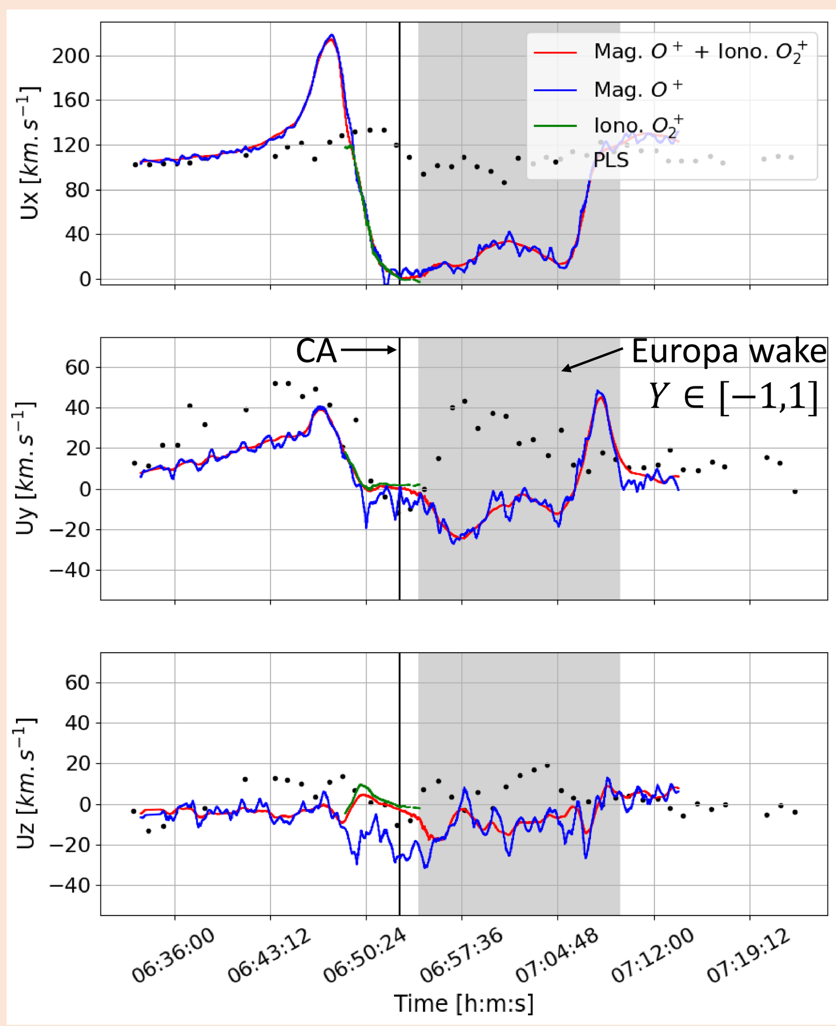
- The spacecraft followed an oblique trajectory, close to the equator and crossing the wake side.
- The Galileo E4 flyby occurred on 1996/12/19.

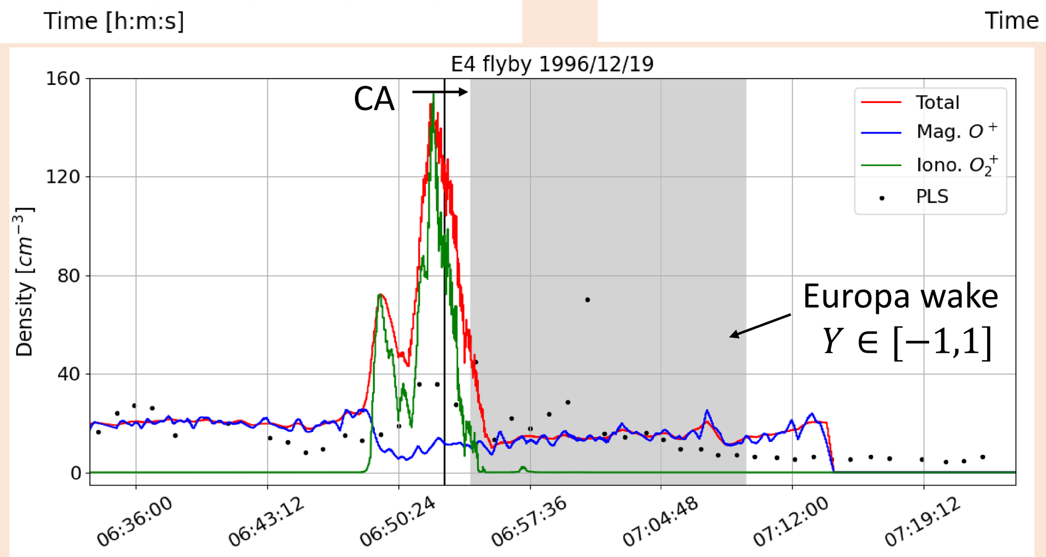
- Simulation results :
  - Bx (top),
  - Electron density (bottom left)
  - Ux (bottom right)

Comparison with Galileo observations :

- Left : Magnetic field and Magnetometer data
- Right : Velocity and PLS data
- Bottom : Density and PLS data







- Fair representation of the magnetic field
- The background ionosphere, simulating ion-neutral collisions, generates a decrease of the electric field. This implies that the global velocity of the particles tends towards 0 and that the particles accumulate around Europa, increasing the density.

Perspective

- Ion-neutral collisions need to be better handled.
- Refine the use of the conductivity's resistive term which also affects the ionospheric escape (under development and not used in the presented simulation)A
- Add an exosphere from the EGM simulation (Oza, Leblanc et al. 2018,2019) that will allow to look at the effects of a plume
- Improve the spatial resolution to at least 50km by using the multigrid mode of LatHyS (Leclercq et al. 2015)