



Hybrid multi-grids simulations of Ganymede's magnetosphere

Ludivine Leclercq, Ronan Modolo, François Leblanc

► To cite this version:

Ludivine Leclercq, Ronan Modolo, François Leblanc. Hybrid multi-grids simulations of Ganymede's magnetosphere. AGU Fall Meeting 2015, Dec 2015, San Francisco, United States. pp.SM31B-2492. insu-01250873

HAL Id: insu-01250873

<https://insu.hal.science/insu-01250873>

Submitted on 14 Jan 2016

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Ganymede is a unique object :

- **Biggest moon** of our solar system
- Only satellite which has its own **intrinsic magnetic field** leading to the formation of a **small magnetosphere**
- Magnetosphere of Ganymede is **embedded in the Jovian magnetosphere** : only known case of interaction between two magnetospheres (Kivelson et al. 1996).
- Formation of **Alfvén wings**

2- Description of the model

Hybrid formalism :

- Ions have a **kinetic description** and are represented by **macroparticles** that have a mass, a charge and a weight (=number of physical particles that represents the macroparticle)
- e^- described as an **inertialess fluid** to ensure the **quasi-neutrality** of the plasma. Represented by a **Maxwellian distribution**.

Maxwell's equations used in the model :

$\nabla \cdot B = 0$ (1) Conservation magnetic flux equation

$\nabla \times E = -\frac{\partial B}{\partial t}$ (2) Faraday's equation

$\nabla \times B = \mu_0 (J_e + J_i) + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$ (3) Ampere's equation

Negligible since we consider only low frequencies phenomena

Numerical model :

- **Current Advance Method** and **Cyclic Leapfrog** (CAM-CL)
- Matthews et al. 1994
- Considerable reduction of time computation
- Multiple ion species treated with **only one pass** through the particle data

Motion of the ions :

$$\frac{dv_s}{dt} = \frac{q_s}{m_s} (E + v_s \times B)$$

Electron momentum equation :

$$n_e m_e \frac{du_e}{dt} = 0 = -en_e (E + u_e \times B) - \nabla \cdot \bar{P}_e \quad (4)$$

$$(4)+(3) = E = \frac{-J \times B}{\rho} + \frac{(\nabla \times B) \times B}{\mu_0 \rho} - \frac{\nabla p_e}{\rho}$$

- Ions : Motion equations integrated with a **leapfrog scheme**
- The model is parallelized with MPI (Message Passing Interface) thanks to domain decomposition methods

1- Abstract

Interaction modeled by a 3D parallel multi-species hybrid model based on a CAM-CL algorithm (Mathews et al. 1994) :

- **Generic model** applied to Mars (Modolo et al. 2005; 2006 and 2012), Titan (Modolo et al. 2007, Modolo and Chateaur 2008) or Mercury (Richer et al. 2012).
- **Maxwell's equations** are solved to compute the temporal evolution of electromagnetic field.
- Description of the the dynamics of the magnetospheric plasma and Ganymede's ionospheric plasma
- Simulations results are presented and compared to magnetometer and particle observations obtained during G1 and G2 Galileo flybys.

3- Ingredients of the model

Incident plasma parameters (from G1 flyby) :

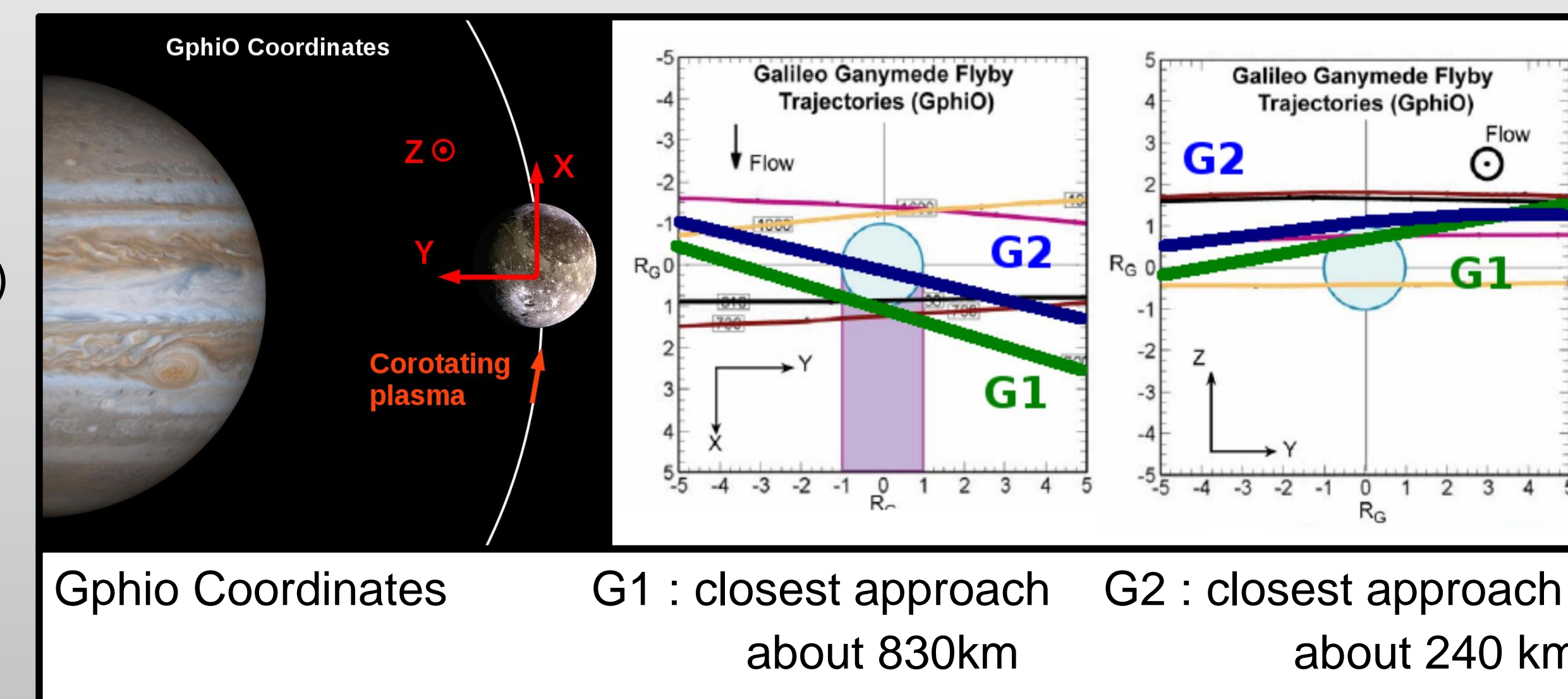
- Flow velocity : 140km/s (Williams et al. 1997)
- Electron density : 4cm⁻³ (Galileo PWS, Gurnett et al. 1996)
- 2 ion species : O⁺(3,47cm⁻³) and H⁺(0,53cm⁻³) (Kivelson et al. 2006 ; Cooper et al. 2001)
- Jovian magnetic field (KK97 model, Khurana, 1997) B=(0,-79,-79) nT

Ganymede's ionosphere :

- O⁺ (5000cm⁻³ at the surface, from our hypothesis)
- H=125km (Paty and Winglee 2004)

Ganymede's magnetosphere :

- About 720 nT at the equator (Kivelson et al. 2002)
- Magnetic dipole implemented at initialization distortion leading to the formation of a magnetosphere



4- Numerical parameters

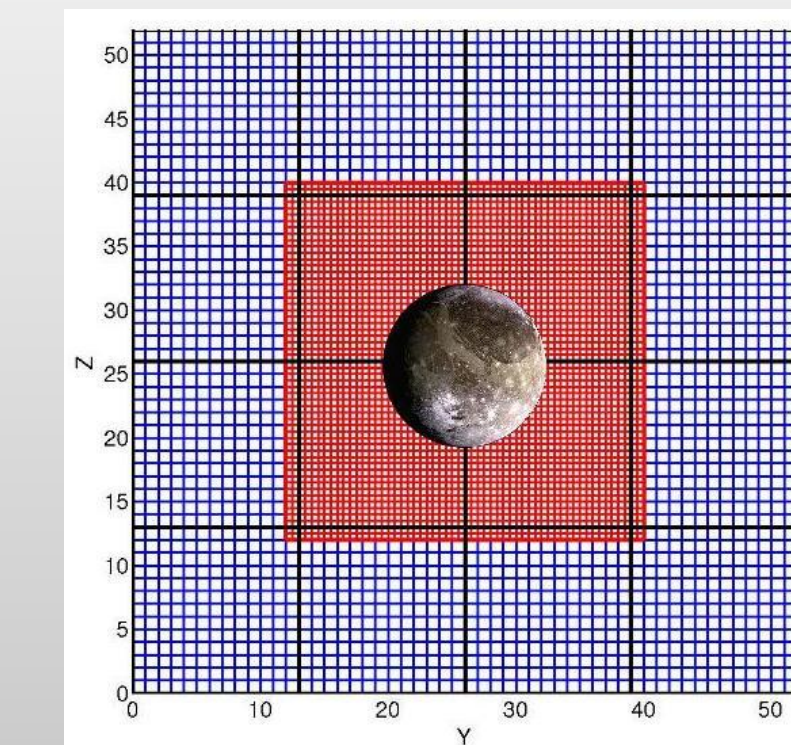
- Fields and particle moments computed on a cartesian grid
- Simulation box size : -12 R_G<X<6 R_G ; -18 R_G<Y<18 R_G ; -27 R_G<Z<27 R_G

2 runs :

1) **Uniform grid - Δx=240 km**

2) **Multi-grids - Δx=120 km at close vicinity of Ganymede (6,3 R_G×11 R_G×11 R_G) - 240 km elsewhere**

- Jovian plasma : 10 macroparticles/cell
- Ionosphere :
- Simulation time = 200 O⁺ gyromotions ; dt=0.005Ω⁻¹_{O⁺}
- 256 CPUs – Restitution time about 9,5 days



Multi-grids method described in Leclercq et al., JCP, 2015

6- Conclusions and perspectives

Conclusions:

- Importance of kinetic effects (ion gyromotion)
- Importance of the multi-species aspect
- Results improved by spatial resolution refinement
- Good agreement between our model and Galileo measurements

Perspectives:

- Add species in the ionosphere
- Add charge exchange reactions, photoproduction, electron impact ionization
- Compute ion precipitating flux at surface
- Couple with our 3D multi-species parallel exospheric model based on Monte Carlo methods (Turc et al., 2014). See Figure 6.
- Couple with our ionospheric model (Leblanc et al., in prep). See Figure 7.

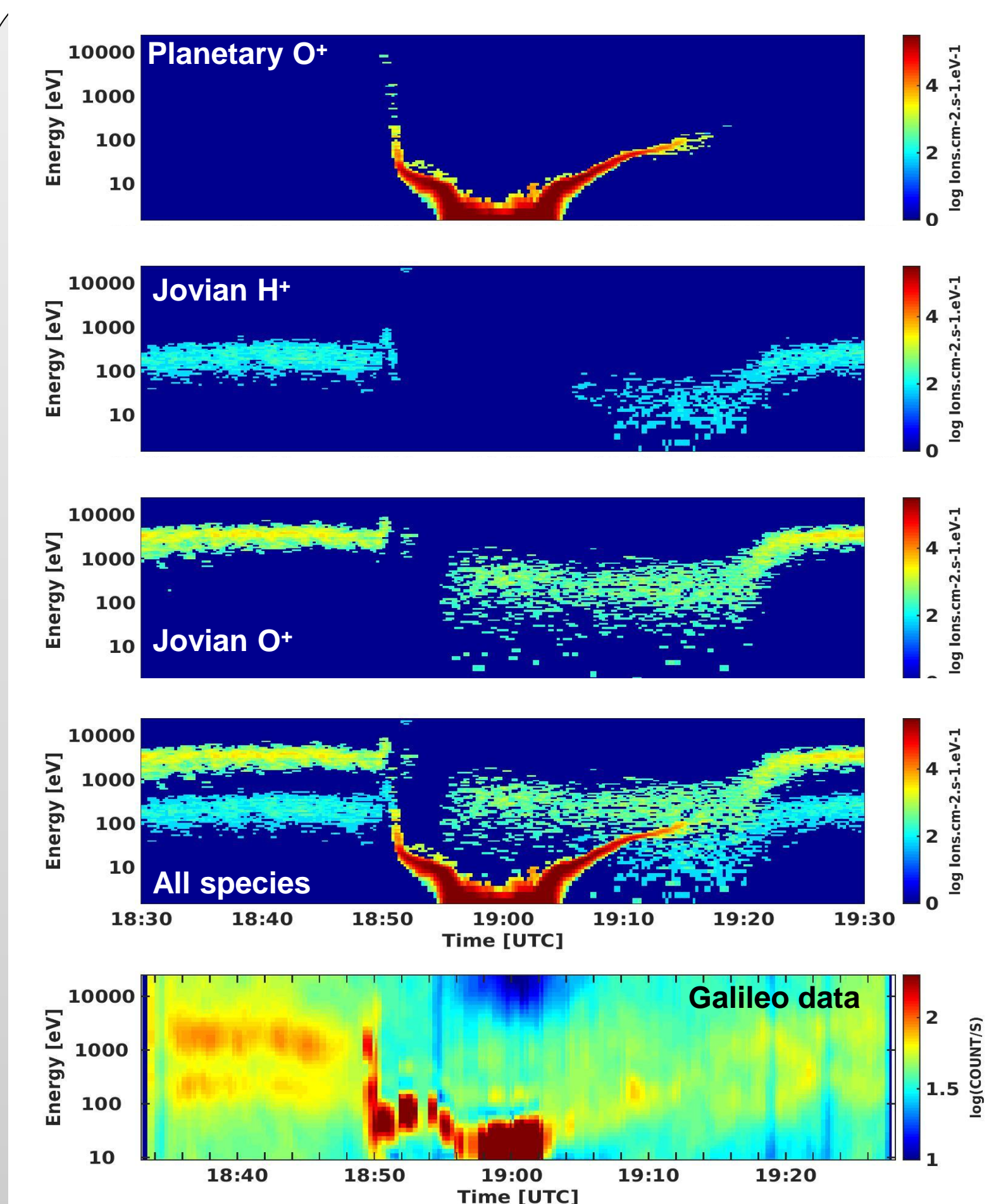
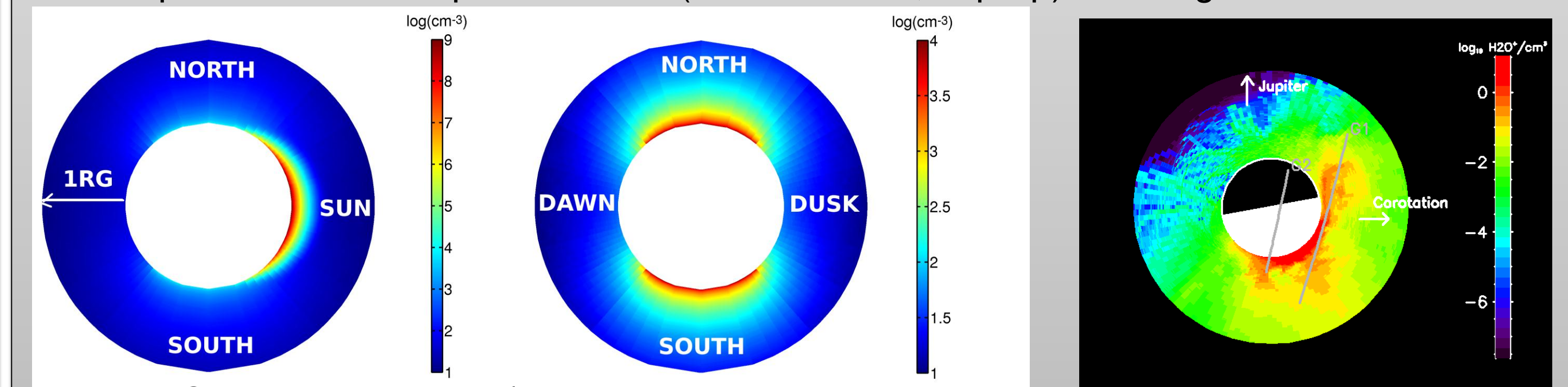


Figure 1: Ion energy spectra during G2 flyby. Bottom: Galileo measurements. Top: Different species of our simulation (RUN 2)

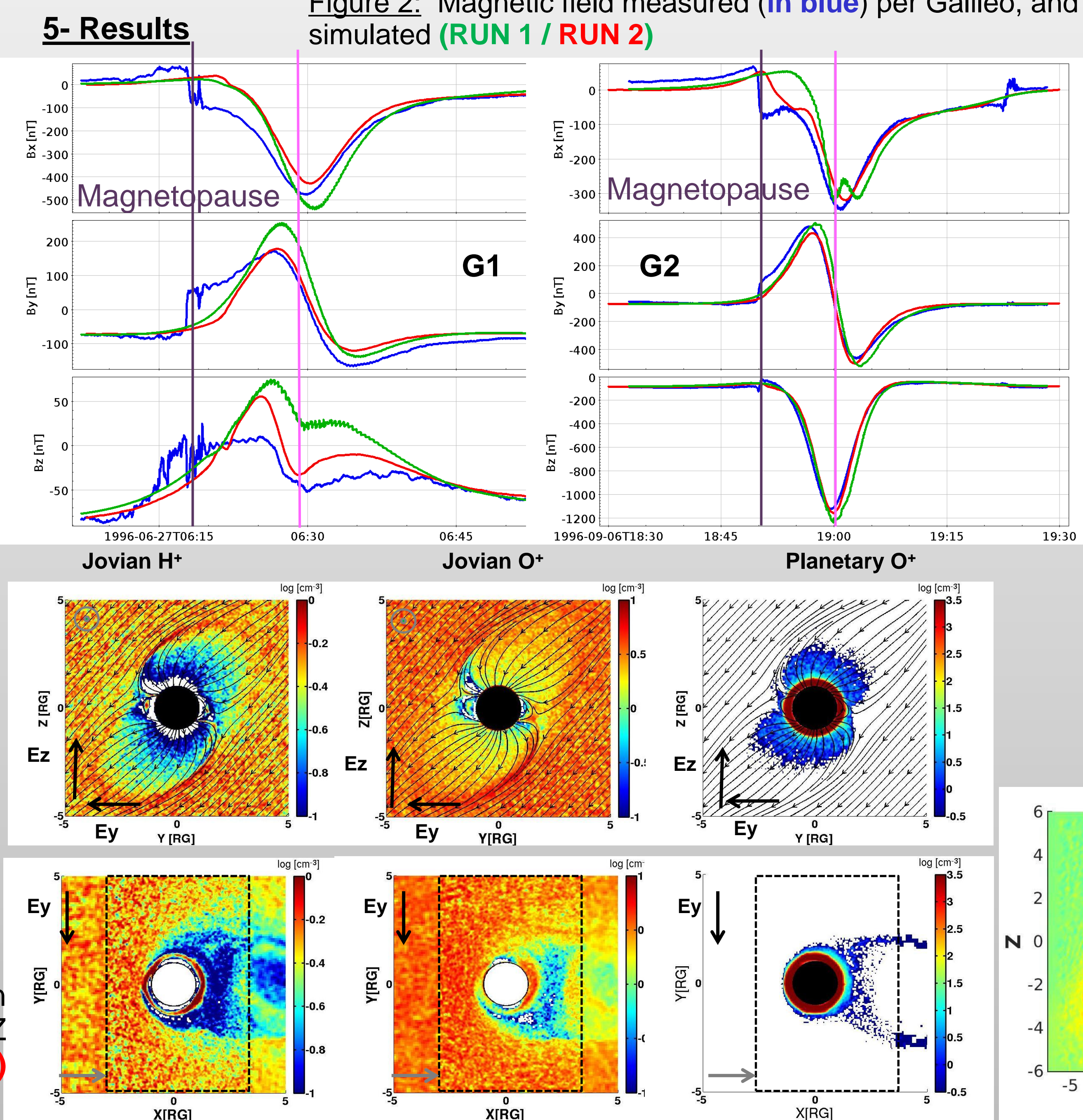


Figure 3: Densities of Jovian H+ (left), Jovian O+ (middle) and Planetary O+ (right) in the YZ (top) and XY (bottom) planes (RUN 2)

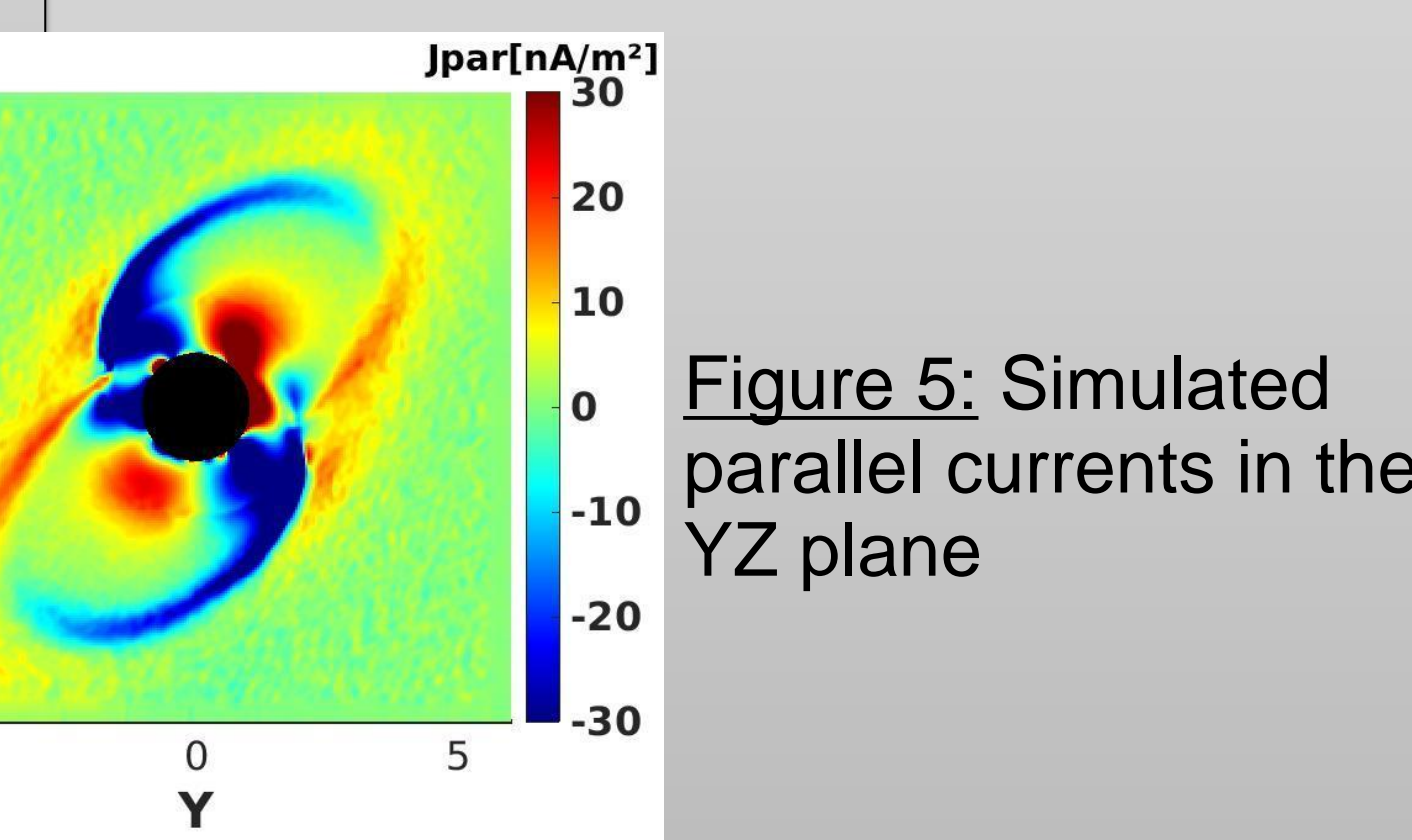


Figure 5: Simulated parallel currents in the YZ plane