# New insights into the consequences of different interplanetary conditions on the near-Hermean environment

Laboratoire de Physique des Plasmas

Emanuele Cazzola[(1)], Dominique Fontaine[(1)], Ronan Modolo[(2)]

(1) Laboratoire de Physique des Plasmas (LPP)

(2) Laboratoire ATMospheres, Observations Spatiales (LATMOS)

**Magnétosphère de mErcure lors de TempêtEs sOlaires (METEO) IPI project**

LATMOS SORBONNE UNIVERSITÉ Initiative Physique des Infinis Alliance Sorbonne Université

**PNST : colloque scientifique & de prospective**
**Marseille, 8-12 janvier 2024**

# BepiColombo Mission

## Why do we need it ?

- Past visits to Mercury: MARINER-10 [fly-bys], MESSENGER [fly-bys + orbit]

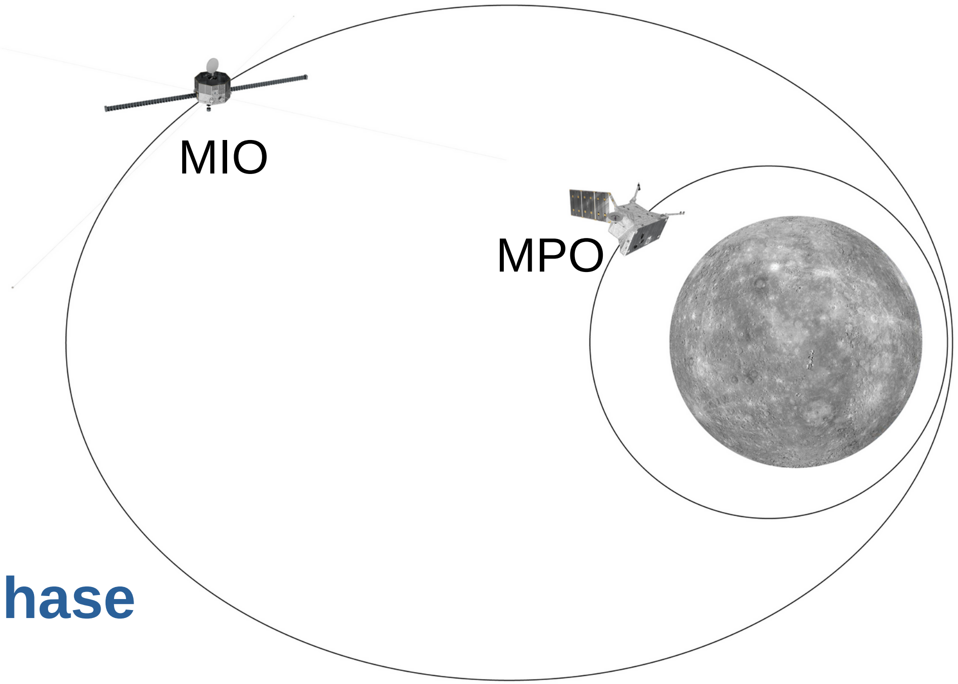
  → single spacecrafts !

- **BepiColombo: ESA-JAXA two orbiters mission :**

  **- Mercury Planetary Orbiter (MPO)**

  **- Mercury Magnetospheric Orbiter (MMO / MIO)**

  - **Launch: 20 October 2018**
  - **Arrival at Mercury: 5 December 2025**
  - **9 (Earth-Venus-Mercury) fly-bys before operative phase**




*from ESA BepiColombo webpage*

**First observations of the coupled Solar Wind – Inner Magnetosphere dynamics !**

BepiColombo insights ⟺ sinergy ⟺ Global simulations insights

# Magnétosphère de mErcure lors de TempêtEs sOlaires (METEO) project

## What questions do we want to address ?

LPP

→ **weak magnetic field + intense & highly variable interplanetary conditions**
- → boundaries possibly squeezed close/into the surface ?
- → interplanetary particles precipitation rate dynamics ?

→ **planetary heavy ions dynamics (exosphere), such as Na, K, O, ...**
- → How does their dynamics change along the orbit and with different SW velocity ?

→ **possible presence of a current system**
- → intensity and pattern in such a different and dynamical magnetic environment ?
- → where does it close to in absence of ionosphere ?

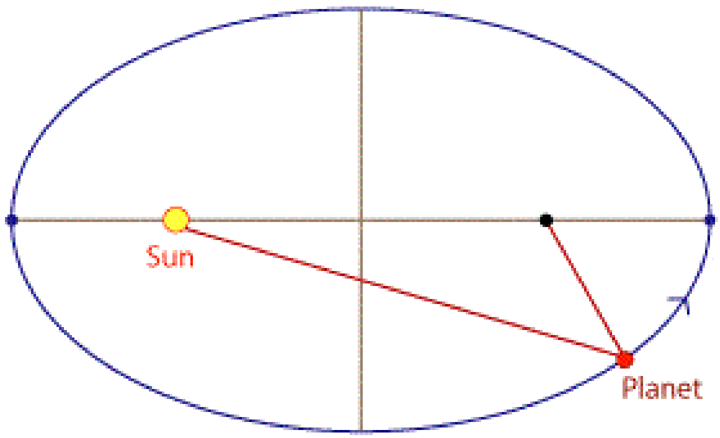
→ **properties of bow-shock and foreshock**
- → Quasi-radial properties under intense SW conditions
- → same structures (i.e., SLAMS or plasmoids) ?

→ **Also … how do all the above respond under extreme solar events ?**

→ **3D global hybrid simulations (LatHyS)**

# Interplanetary Environments

## Scenarios feats




- → **Comparing Aphelion vs Perihelion conditions**
- → **Comparing slow vs fast winds effects**
- → **Poorly simulated quasi-radial scenario**
- → **Comparing effects of different $D_p$ & $M_A$**

*values from Sun+2022*

| | Interplanetary Medium @ Mercury | | | | Interplanetary Medium @ Earth |
|---|---|---|---|---|---|
| | Aphelion SSW | Aphelion FSW | Perihelion SSW | Perihelion FSW | average |
| B [nT] | 15 | | 45 | | 6-10 |
| N [cm-3] | 40 | | 100 | | 3-10 |
| V [km.s-1] | 250 | 450 | 250 | 450 | 250-700 |
| T [K] | 3e4 (β = 0.18) | | 1.5e5 (β = 0.26) | | β ≥ 1 |
| Clock angle | 25° | | 17° | | 45° |
| Cone angle | 0° | | 0° | | 0° |
| Dynamic pressure - $D_p$ [nPa] | 4.18 | 13.54 | 10.45 | 33.87 | 1-6 |
| Alfvénic Mach number - $M_A$ | 4.8 | 8.6 | 2.53 | 4.56 | 3-10 |

$$M_A = \frac{V_{SW}}{V_A}$$

$$D_p = \rho_{SW} V_{SW}^2$$

# Global Scale Magnetic System Dynamics

## Aphelion Slow Solar Wind (low dynamic pressure and Alfvenic Mach number)

| | |
|---|---|
| | 15 |
| N [cm-3] | 40 |
| V [km.s-1] | 250 |
| T [K] | 3e4 (β = 0.18) |
| Clock angle | 25 |
| Cone angle | 0 |
| $D_p$ [nPa] | 4.18 |
| $M_A$ | 4.8 |

→ Development of an Earth-like magnetic system (BS & MP)

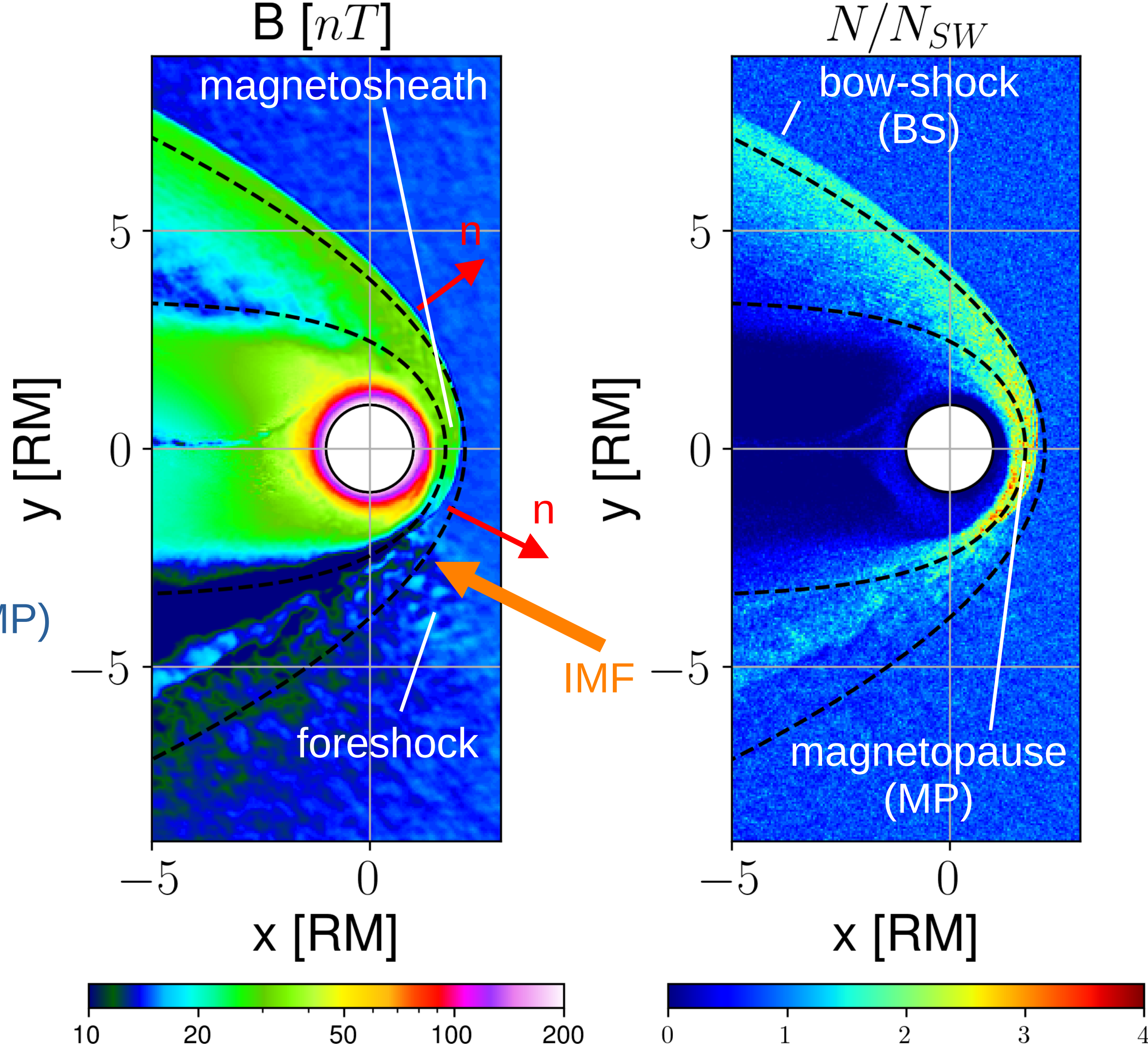
→ BS / MP well described by a paraboloid and by models

  * e.g., Winslow+ 2013

→ Foreshock and its effects on the bow-shock boundary

  * Magnetosheath thinned and limited to one side

  * Current possibly connected with magnetosphere




model by Winslow+ 2013

# Global Scale Magnetic System Dynamics

## Perihelion Fast Solar Wind (increasing dynamic pressure)

| | |
|---|---|
| | 45 |
| N [cm-3] | 100 |
| V [km.s-1] | 450 |
| T [K] | 1.5e5 (β = 0.26) |
| Clock angle | 17 |
| Cone angle | 0 |
| $D_p$ [nPa] | 33.87 |
| $M_A$ | 4.56 |

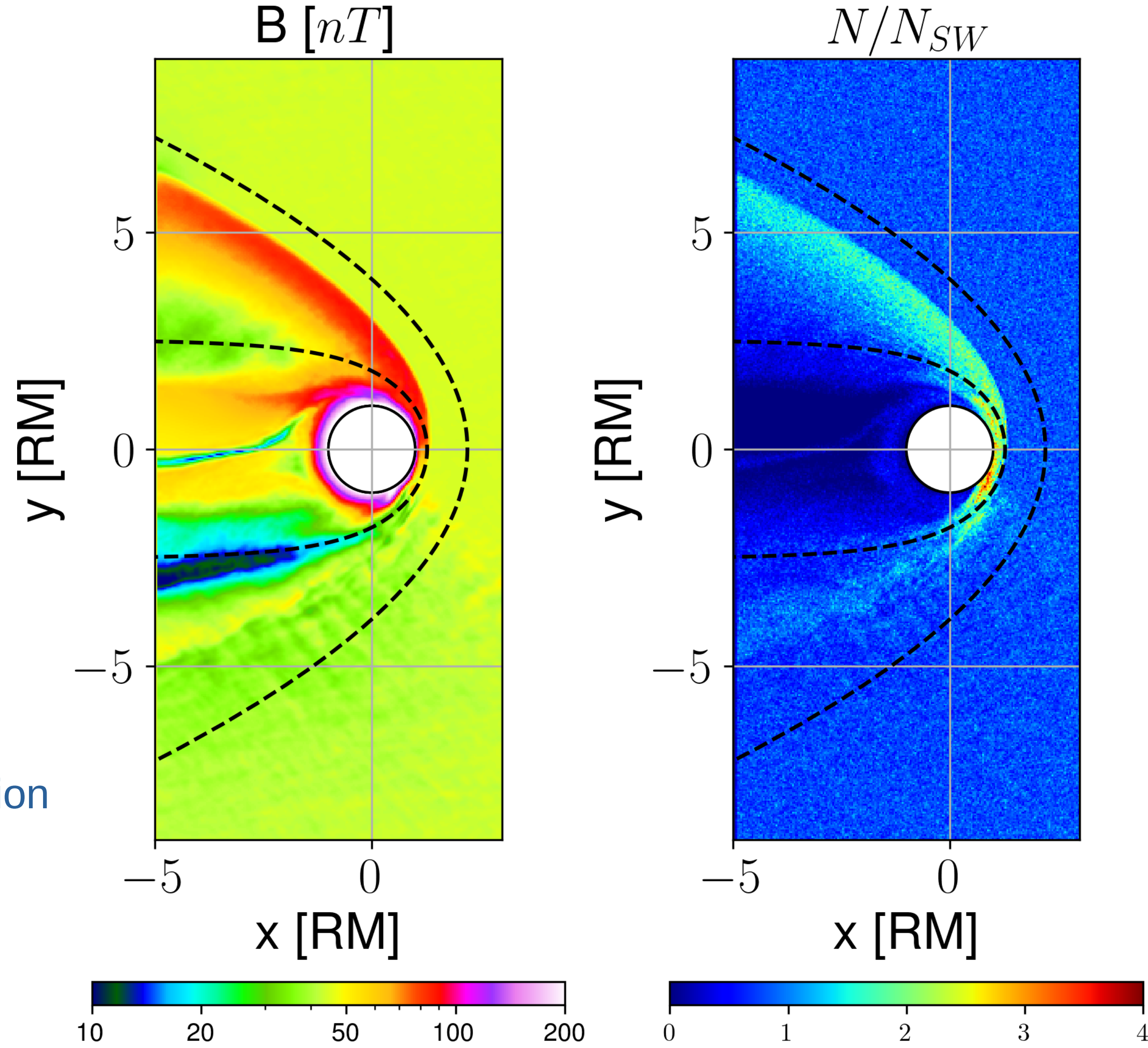
→ Bow-shock highly compressed

→ Bow-shock shape globally represented by a paraboloid, yet reduced size compared to model

→ Departs from paraboloid description in the subsolar region

→ Very thin magnetosheath

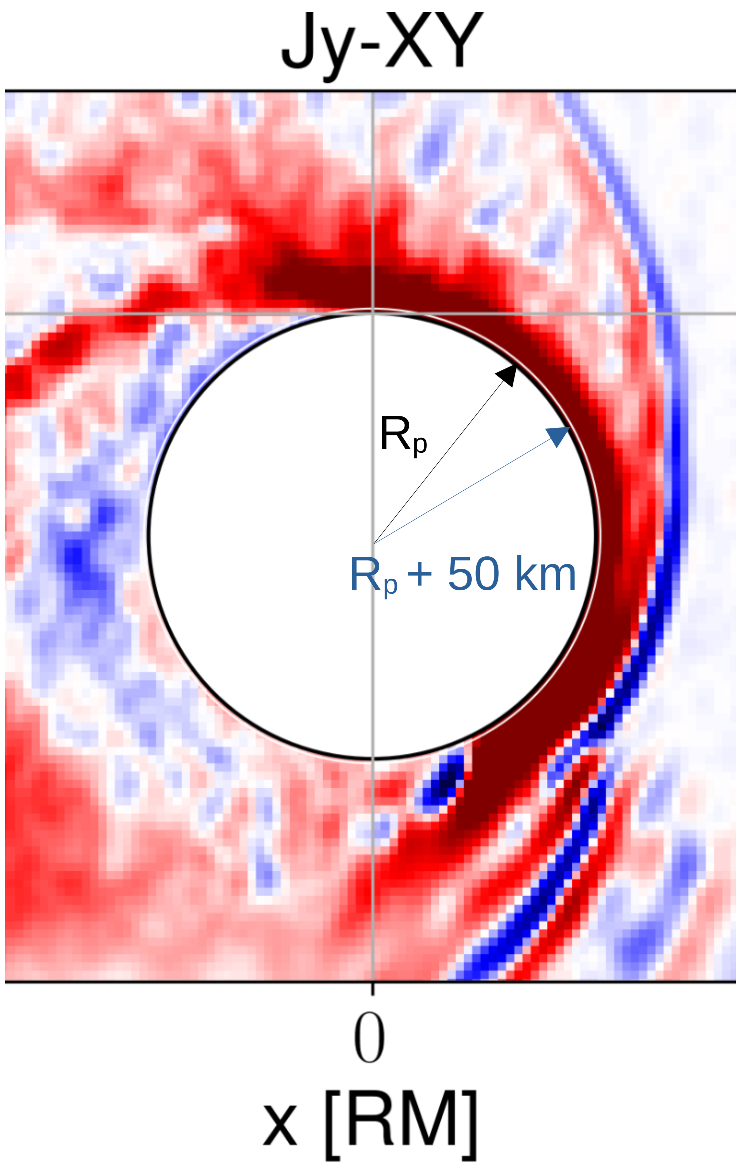
→ Intense foreshock

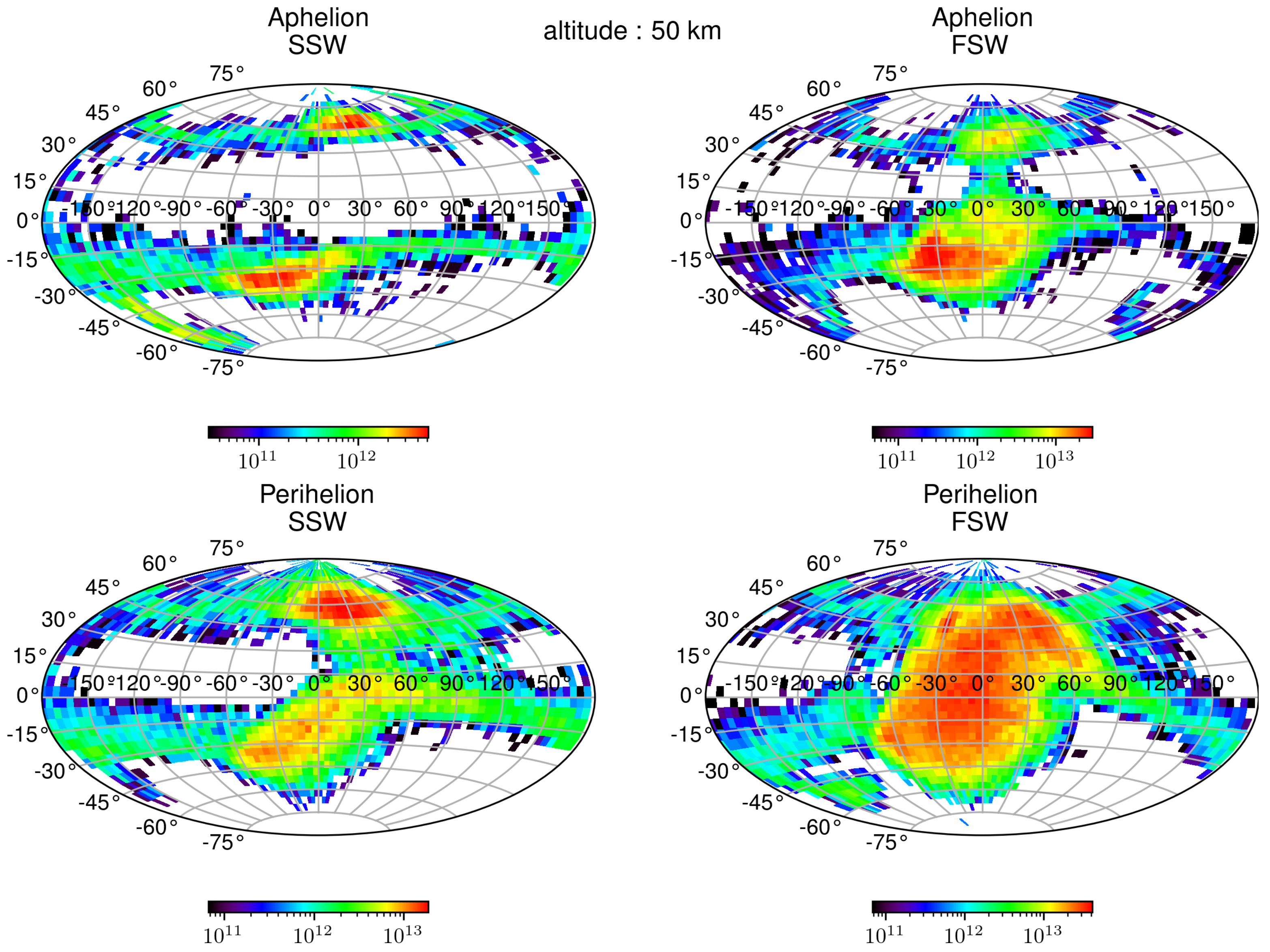



model by Winslow+ 2013

# Precipitating Interplanetary Ions Flux

## Planetary Maps



# Precipitating Interplanetary Ions Flux

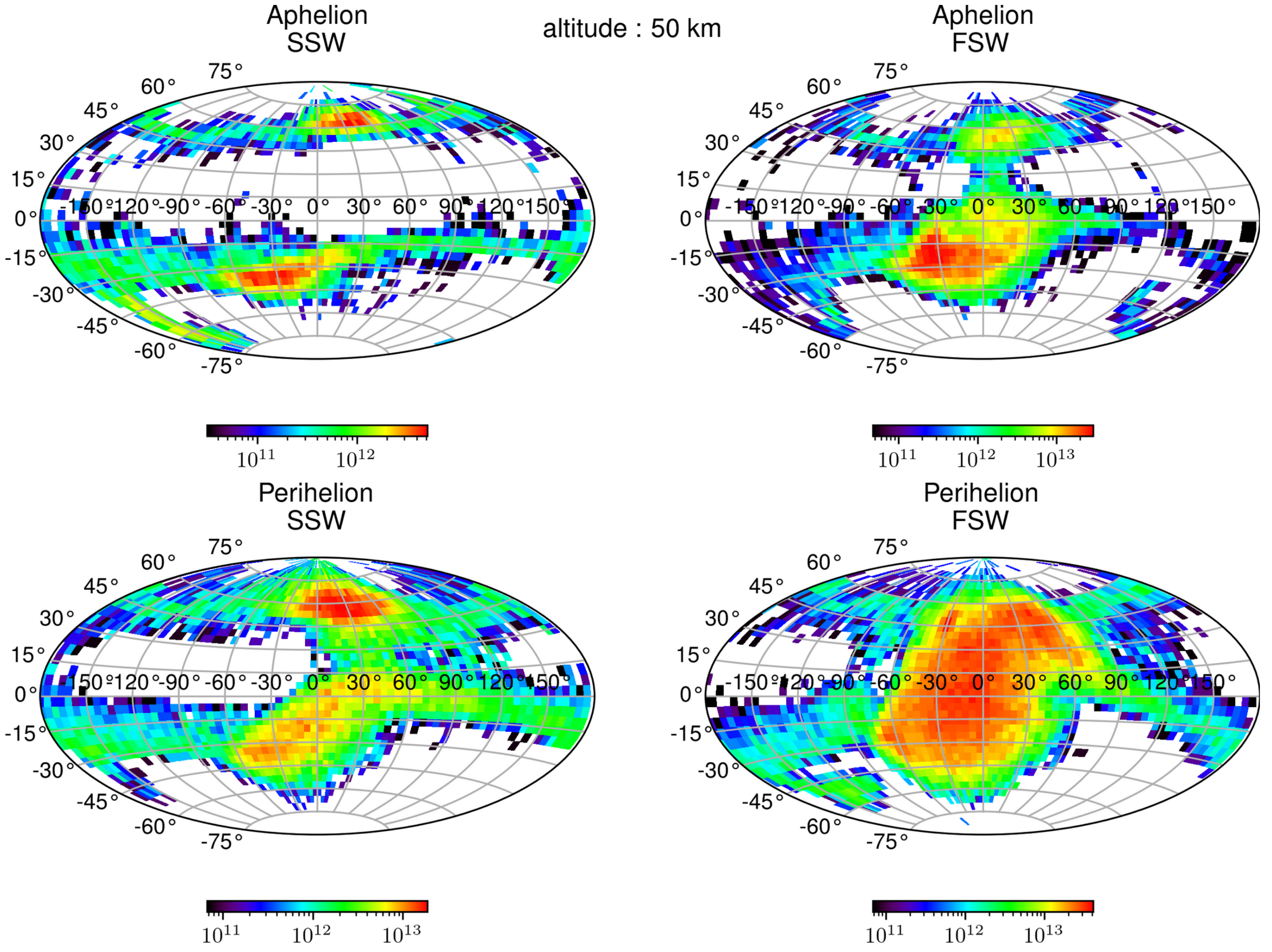
## Space distribution

→ Cusp precipitation peaks in all cases

→ Cusp peaks
  * displaced from meridian plane
  * higher latitudes in SSW
  * lower latitudes in FSW
  * southern cusp larger for Aphelion
  * northern cusp larger for Perihelion

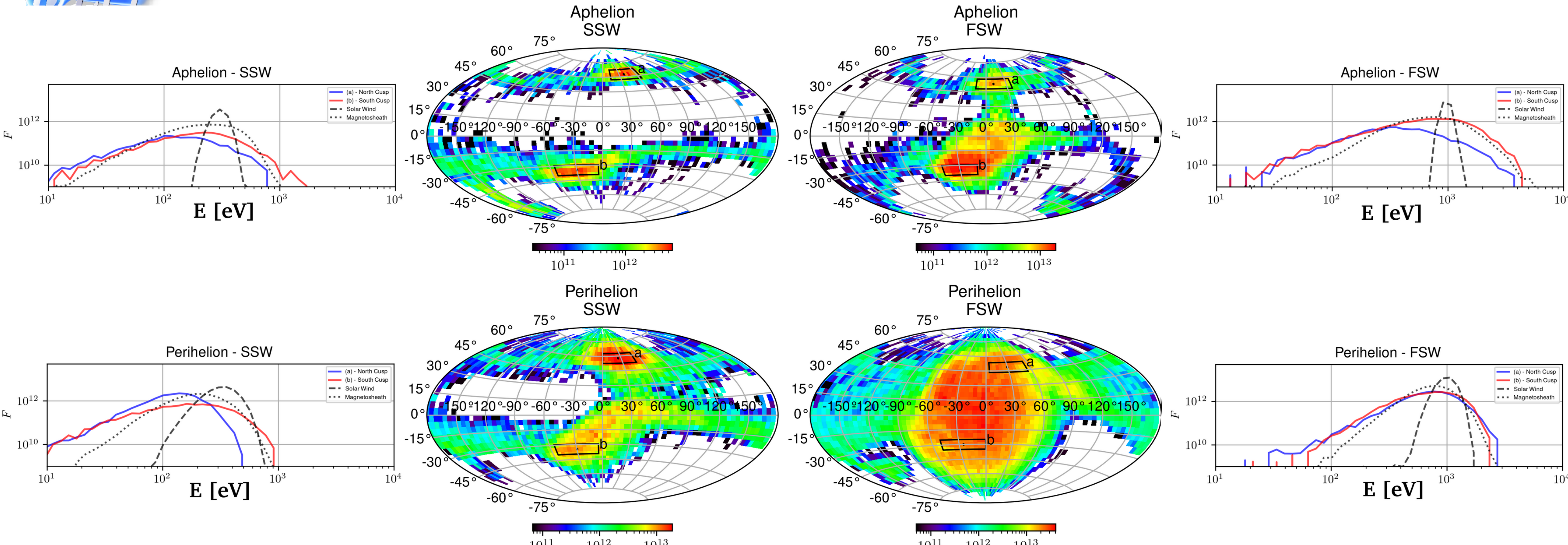
→ Significant equatorial signatures in Perihelion

→ Upon severe conditions (PFSW), particles able to precipitate all over the subsolar region
  → expected outcome in case of solar events !



# Precipitating Interplanetary Ions Flux

## Energy distribution




- → SW particles like collimated beam
- → Magnetosheath particles hotter and more energetic

E [eV]

- → Particles precipitating into southern cusps globally more energetic than those into northern cusps
- → E distribution more in line with Msh E distribution
- → Flux peaks E always < SW flux peak  E

# Conclusions & Outlook

## What did we learn so far ?

→ Mercury's near-planet environment dynamics <u>highly affected</u> with the interplanetary conditions

- → <u>different interplanetary conditions</u> along its orbit → <u>significant different response</u>
  - → <u>difficult to predict</u> it with statistical-based models
    - - average conditions
    - - mostly polar observations
    - - difficult interpretation in certain regions
  - → <u>importance of foreshock</u>
    - - strong influence bow-shock behavior
- → <u>planetary magnetic boundaries</u> can be <u>remarkably compressed (FSW and/or Perihelion)</u>
  - → <u>interplanetary particles</u> can <u>interact</u> with planet's surface :
    - - from the <u>polar cusps</u>
    - - but also at <u>equatorial level</u> in highly compressed scenarios
    - - most of <u>particles coming from magnetosheath</u>

→ <u>multi-spacecraft missions</u> - <u>global computer simulations synergy</u> for a <u>mutual predictive/orientative strategy</u>

→ **in case of extreme solar events (CMEs or CIRs), the situation can become even more severe**

# Thank you !

# Q&A

Laboratoire de Physique des Plasmas