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



Laboratoire de Physique des Plasmas

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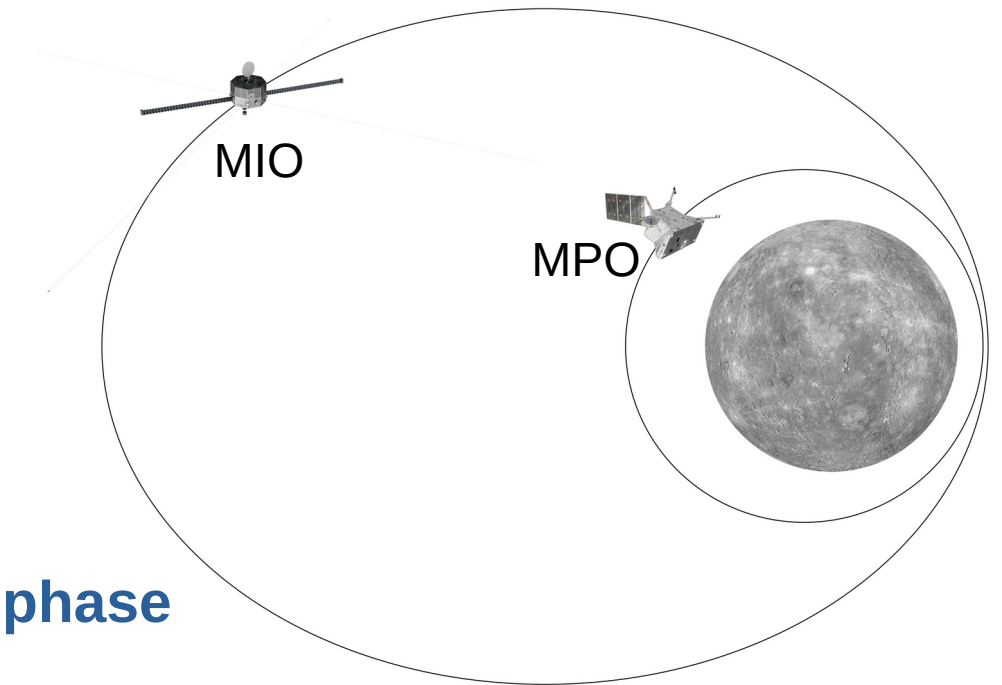
Magnétosphère de mErcure lors de TempêtEs sOlaires (METEO) IPI project

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**



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

BepiColombo insights



Global simulations insights

Magnétosphère de mErcure lors de TempêtEs sOlaires (METEO) project



What questions do we want to address ?

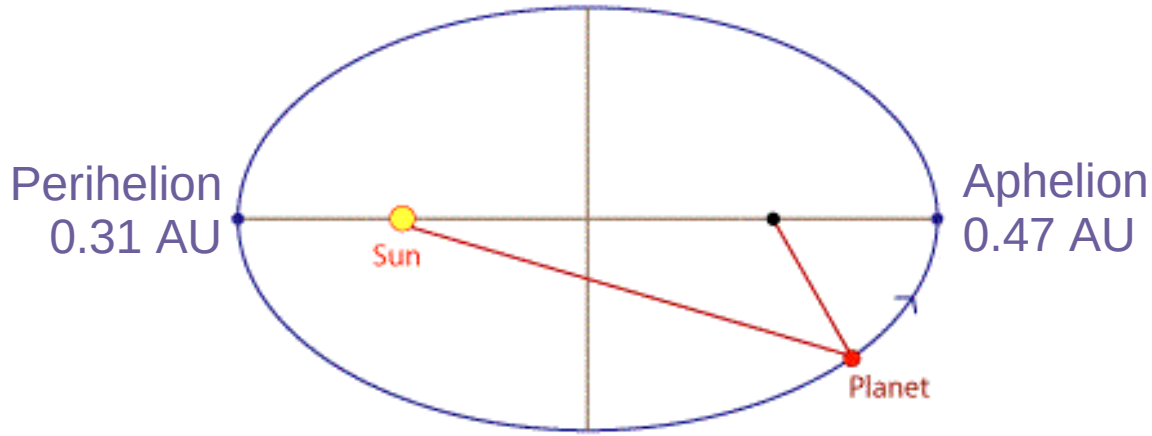
- **weak magnetic field + intense & highly variable interplanetary conditions**
 - boundaries possibly squeezed close/into the surface ?
 - interplanetary particles precipitation rate dynamics ?
- **planetary heavy ions dynamics (exosphere), such as Na, K, O, ...**
 - How does their dynamics change along 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 ($\beta = 0.18$)		1.5e5 ($\beta = 0.26$)		$\beta \geq 1$
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

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

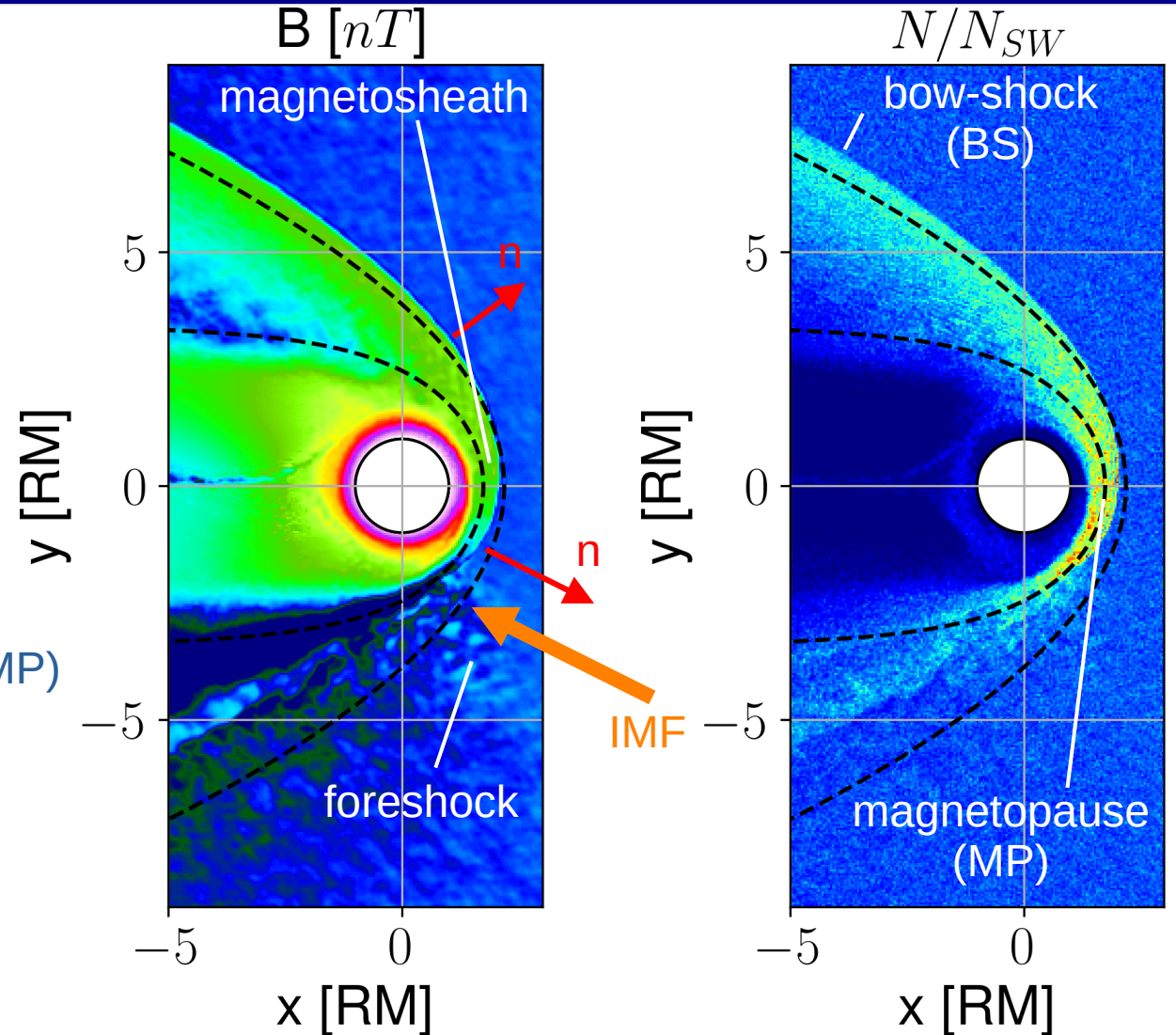
$$D_p = \rho_{SW} V_{SW}^2$$

Global Scale Magnetic System Dynamics

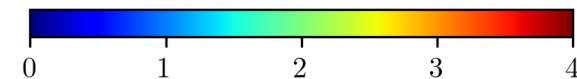
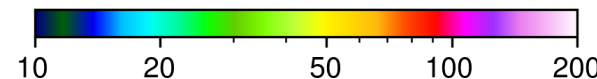
Aphelion Slow Solar Wind (low dynamic pressure and Alfvénic Mach number)



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



model by Winslow+ 2013



- 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

Global Scale Magnetic System Dynamics

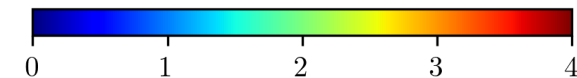
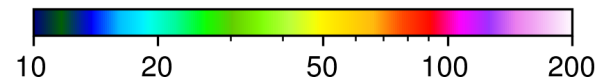
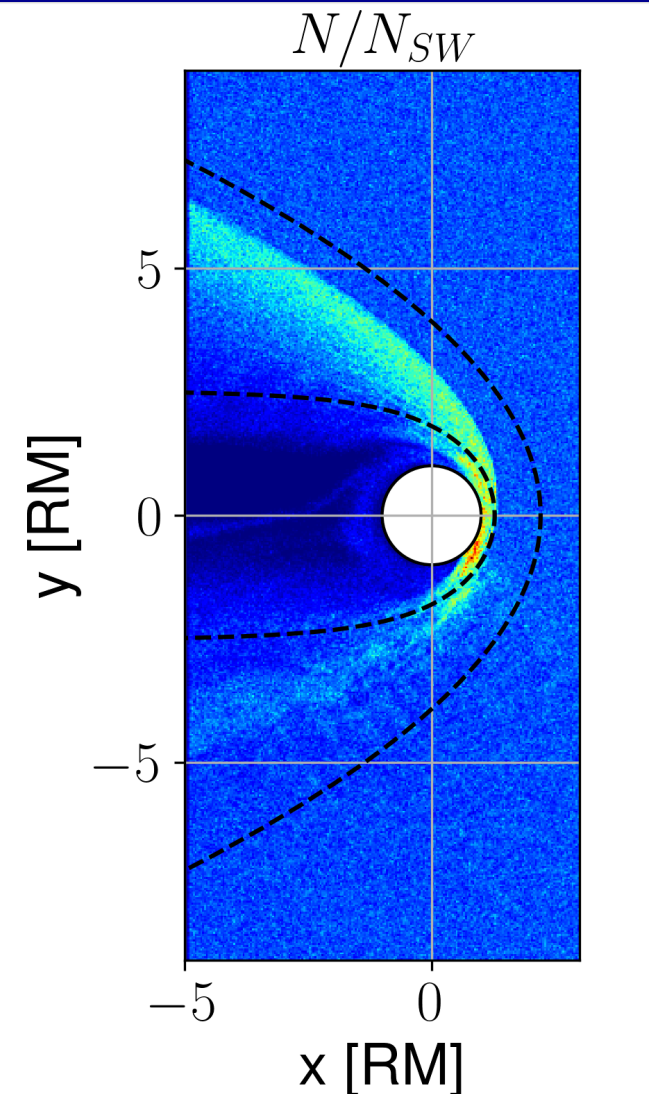
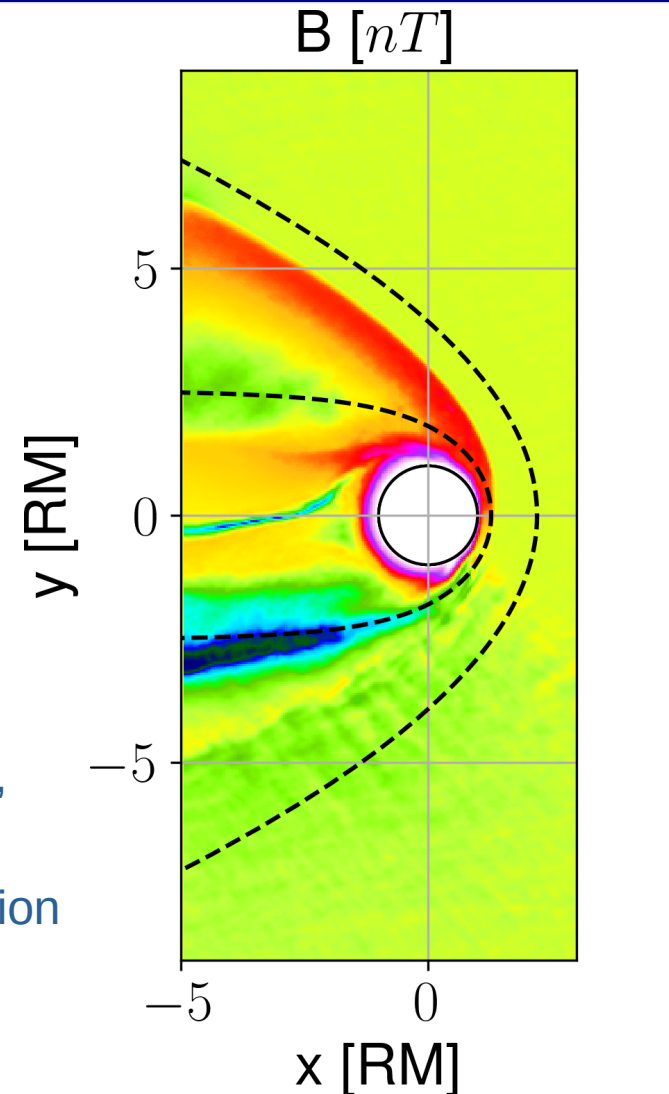
Perihelion Fast Solar Wind (increasing dynamic pressure)



	45
N [cm ⁻³]	100
V [km.s ⁻¹]	450
T [K]	1.5e5 ($\beta = 0.26$)
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

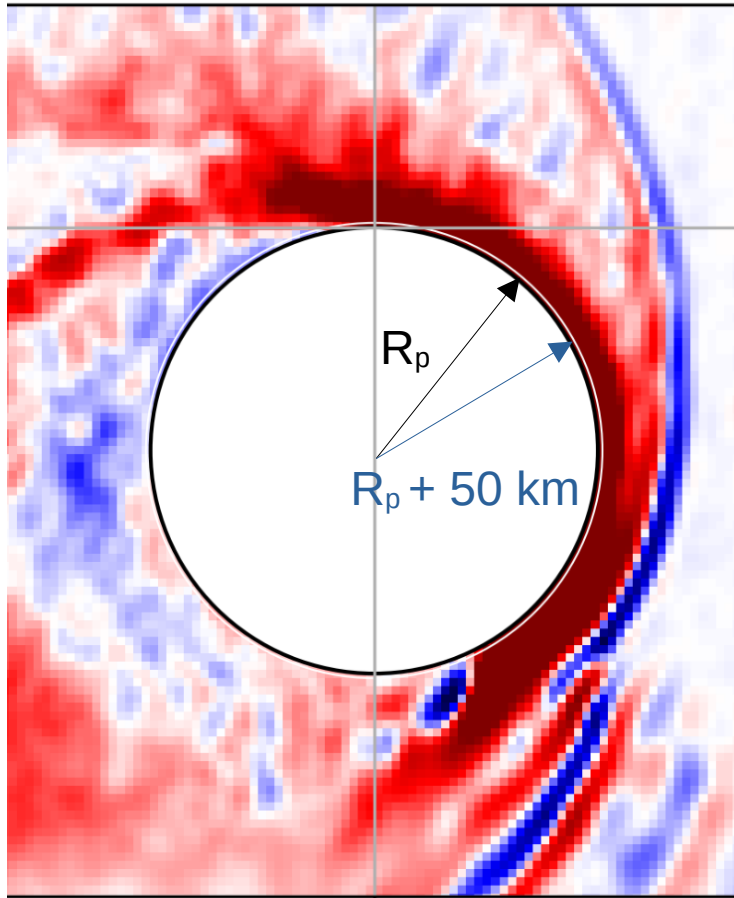


Precipitating Interplanetary Ions Flux

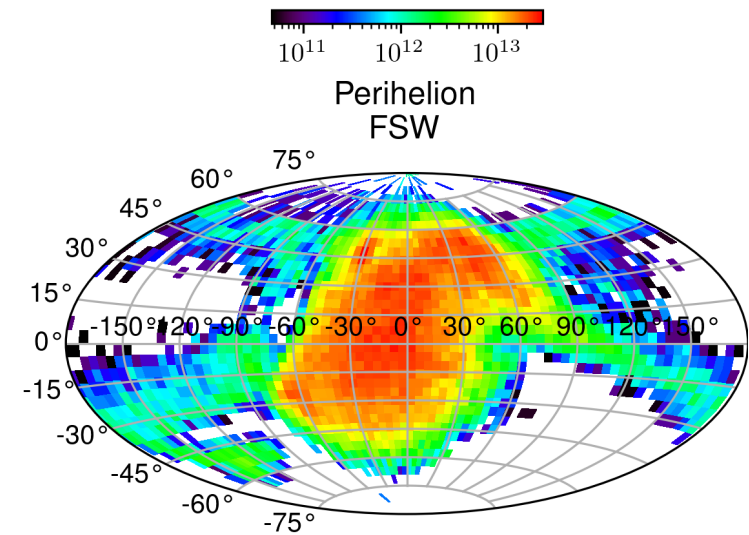
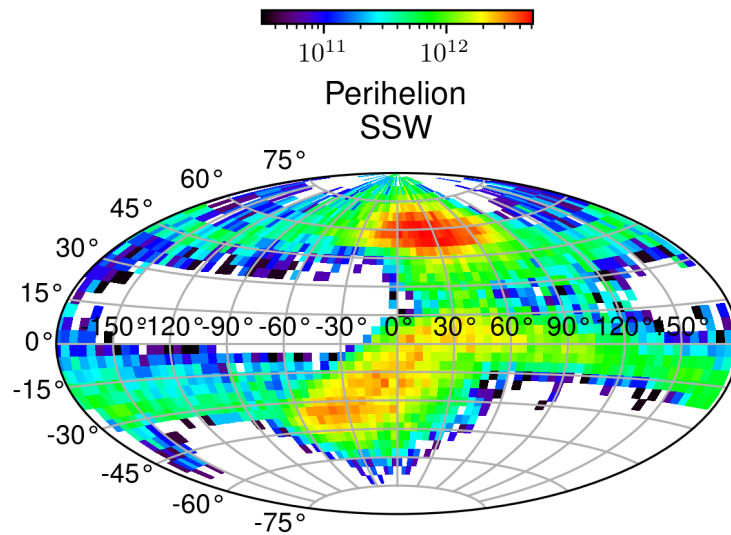
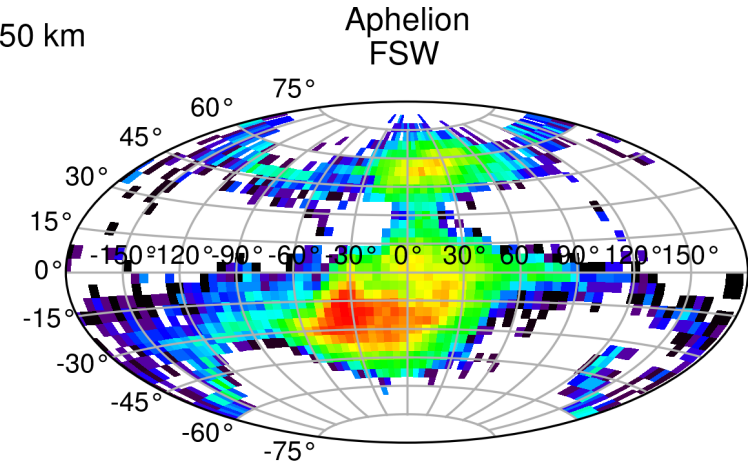
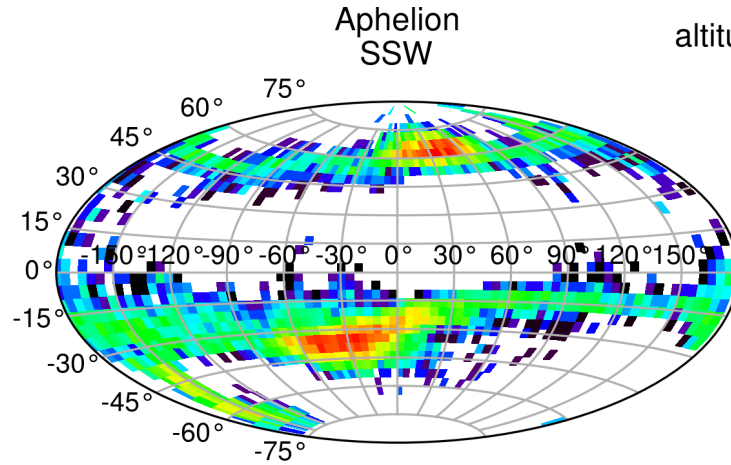
Planetary Maps



Jy-XY



0
x [RM]



10¹¹ 10¹² 10¹³

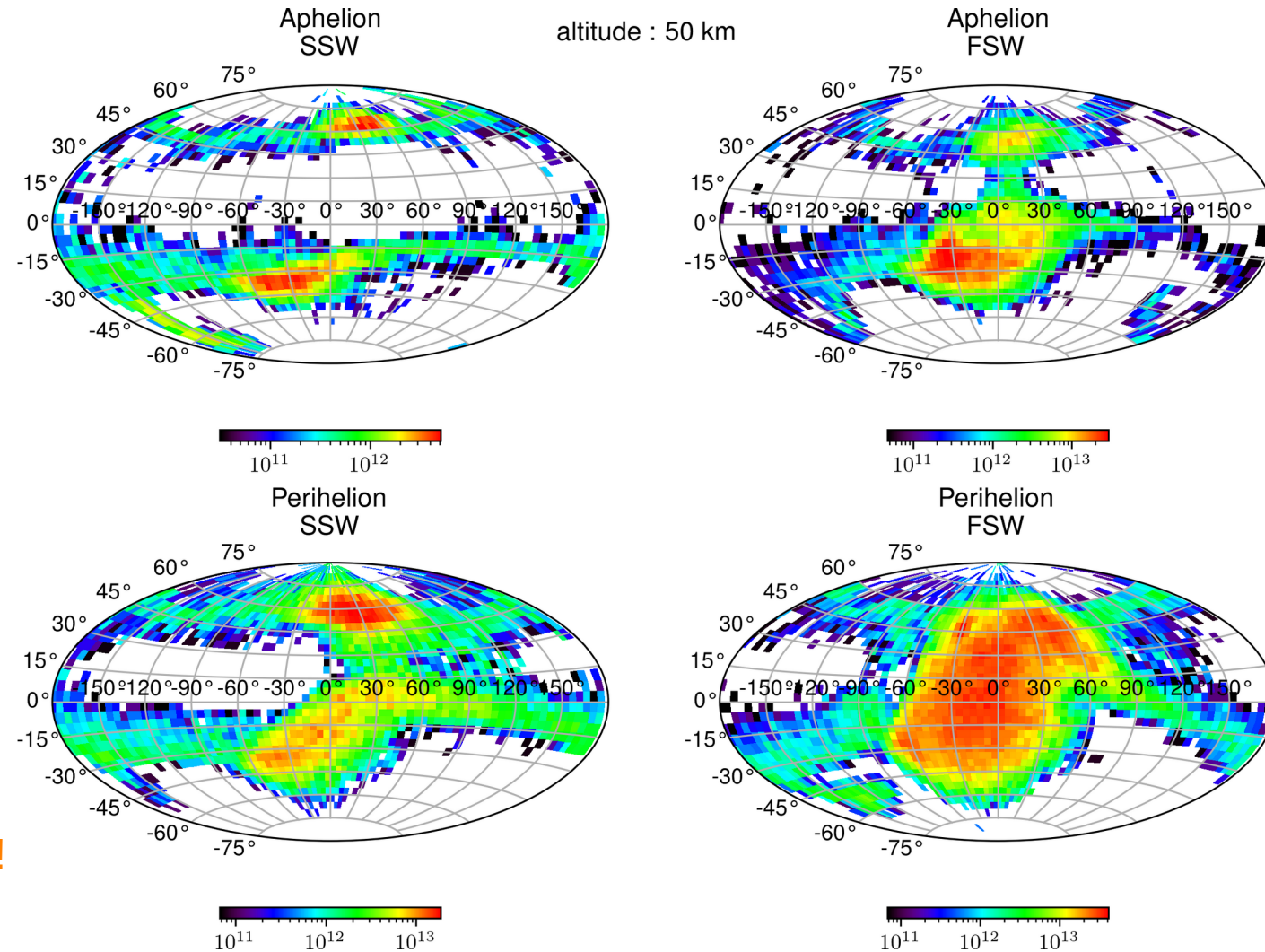
10¹¹ 10¹² 10¹³

Precipitating Interplanetary Ions Flux

Space distribution

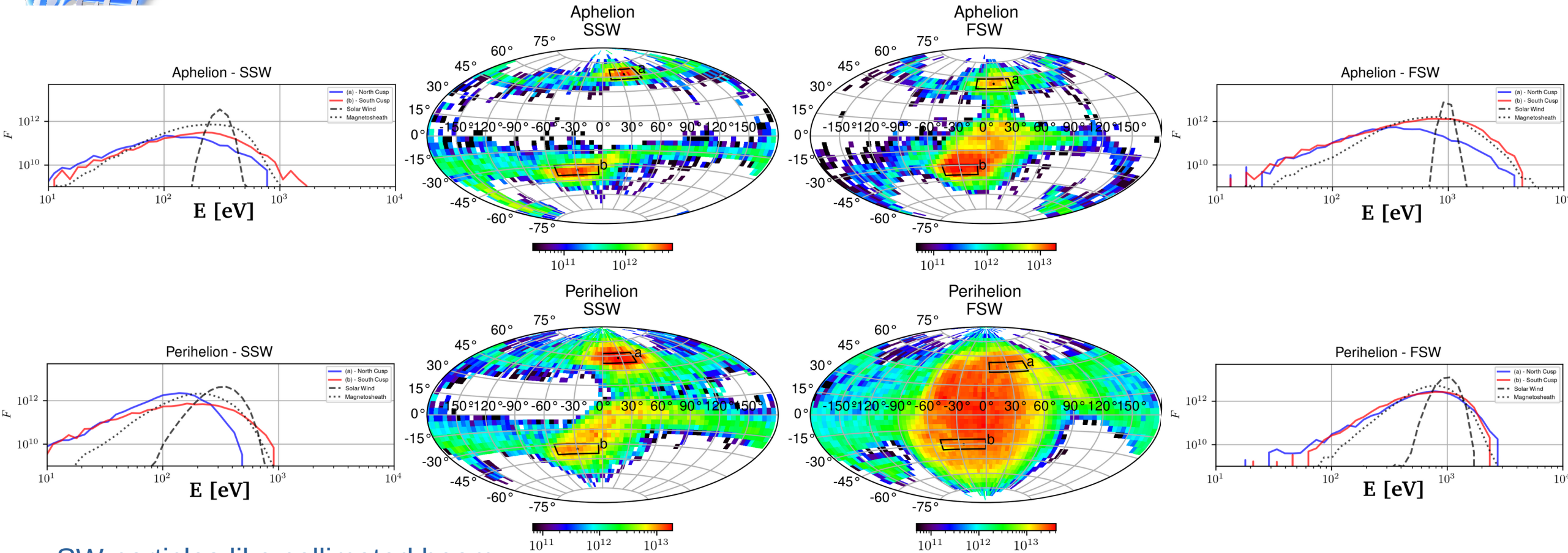


- Cusp precipitation peaks in all cases
- Cusp peaks
 - * displaced from meridian plane
 - * higher latitudes in SSW
 - * lower latitudes in FSW
 - * southern cusp larger for Aphelion
 - * northern cusp larger for Perihelion
- Significant equatorial signatures in Perihelion
- Upon severe conditions (PFSW), 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
- 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

E [eV]

Conclusions & Outlook

What did we learn so far ?



- Mercury's near-planet environment dynamics highly affected with the interplanetary conditions
 - different interplanetary conditions along its orbit → significant different response
 - difficult to predict it with statistical-based models
 - average conditions
 - mostly polar observations
 - difficult interpretation in certain regions
 - importance of foreshock
 - strong influence bow-shock behavior
 - planetary magnetic boundaries can be remarkably compressed (FSW and/or Perihelion)
 - interplanetary particles can interact with planet's surface :
 - from the polar cusps
 - but also at equatorial level in highly compressed scenarios
 - most of particles coming from magnetosheath
- multi-spacecraft missions - global computer simulations synergy for a mutual predictive/orientative strategy
- **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