# HELIOSARES – magnetosphere

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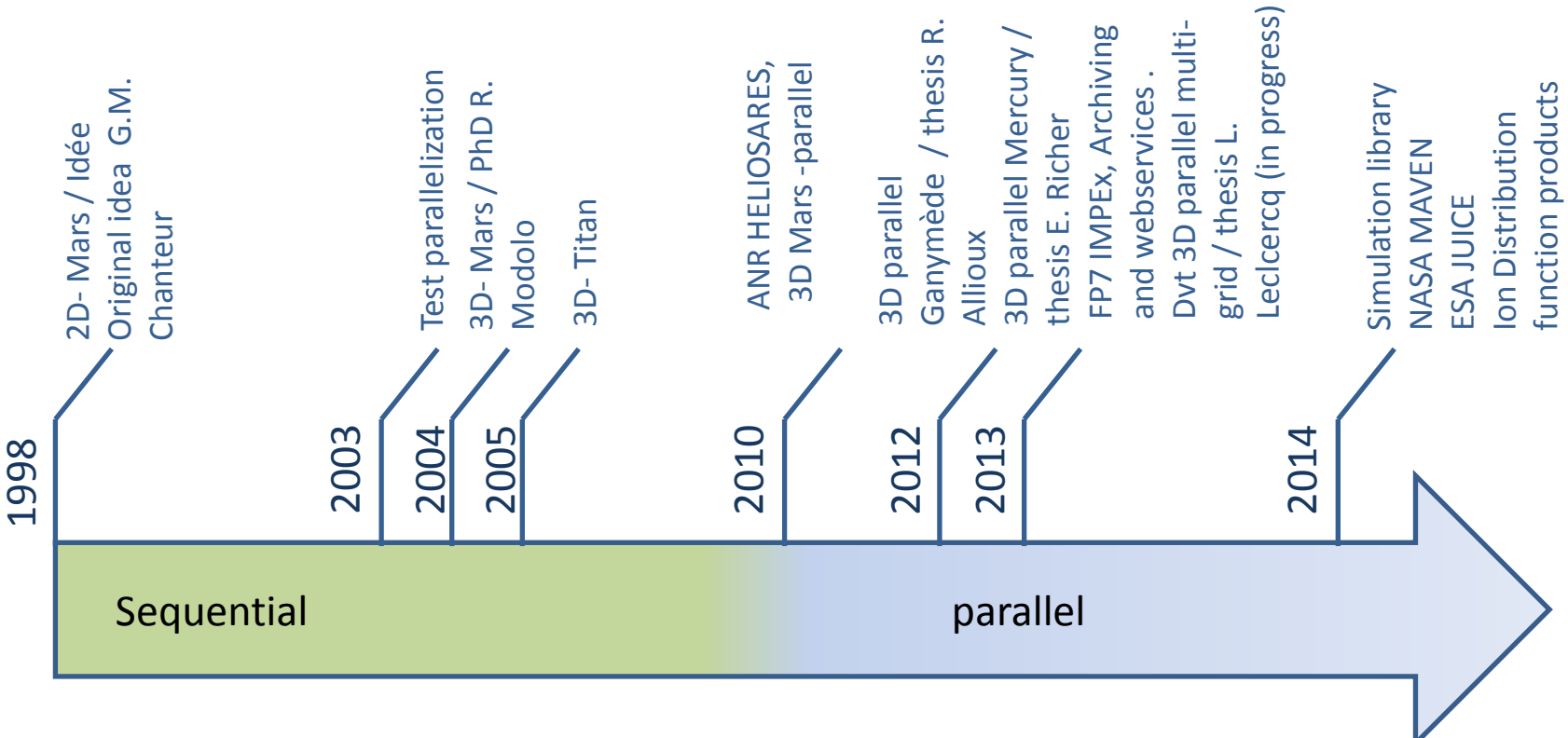
LATMOS - Paris

# Synthesis of the Task 1.

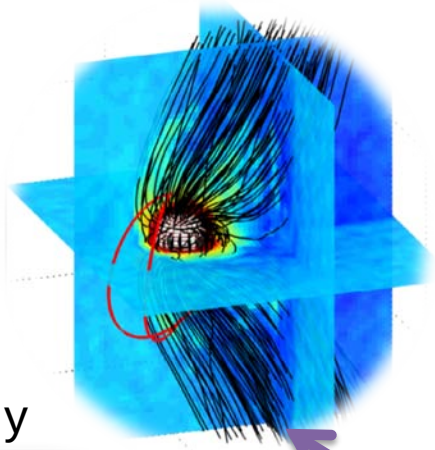
- Task 1.1 – Curvilenar grid *abandonned*
- Task 1.2 – Parallelization *achieved*
- Task 1.3 – Implementation of ionosperic Boundaries *achieved*
- Task 1.4 - Implementation of Crustal magnetic fields *achieved*
- Task 1.5 - Interfaces for the magnetospheric model *achieved*



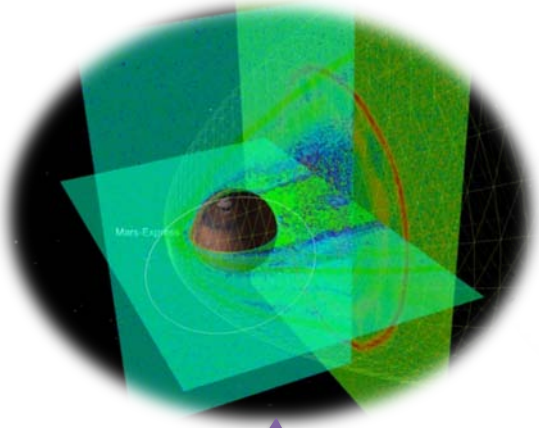
# 3D parallelized generic hybrid model

**Hybrid formalism** : kinetic description for ions and fluid description of electrons + Maxwell's equations

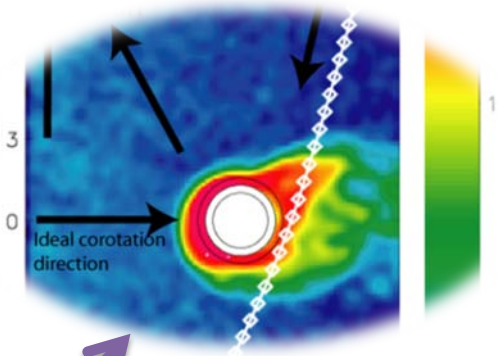
Ganymede



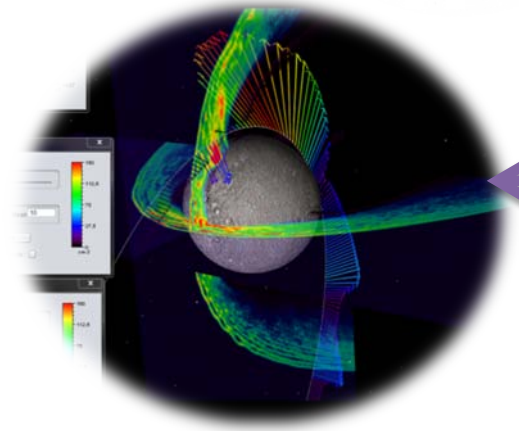
Mars



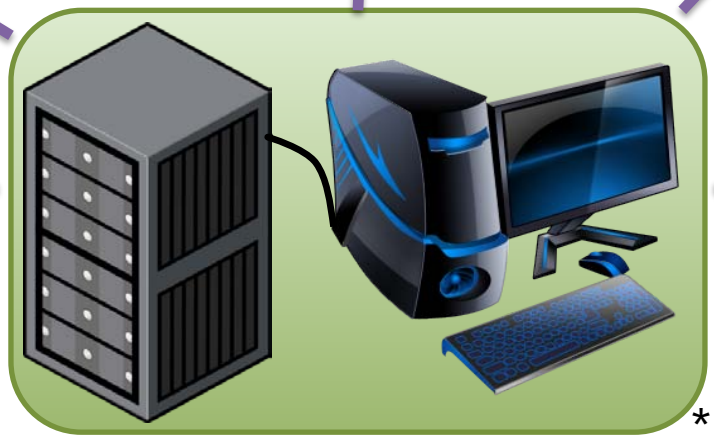
Titan

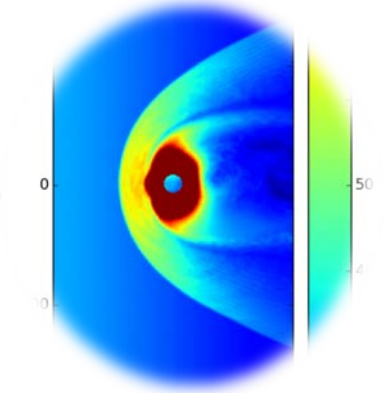



Mercury



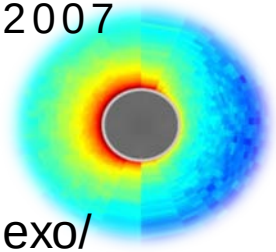
Magnetic cloud vs BS*

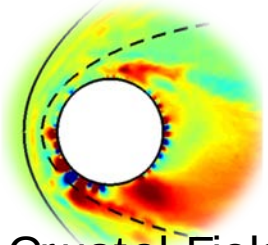




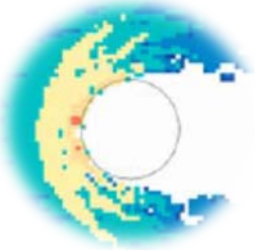
* Extension by L. Turc, LPP

Exospheric coupling
Chaufray et al, 2007



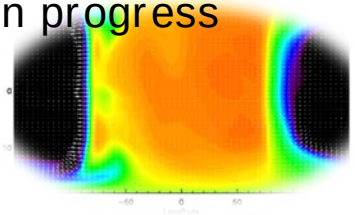


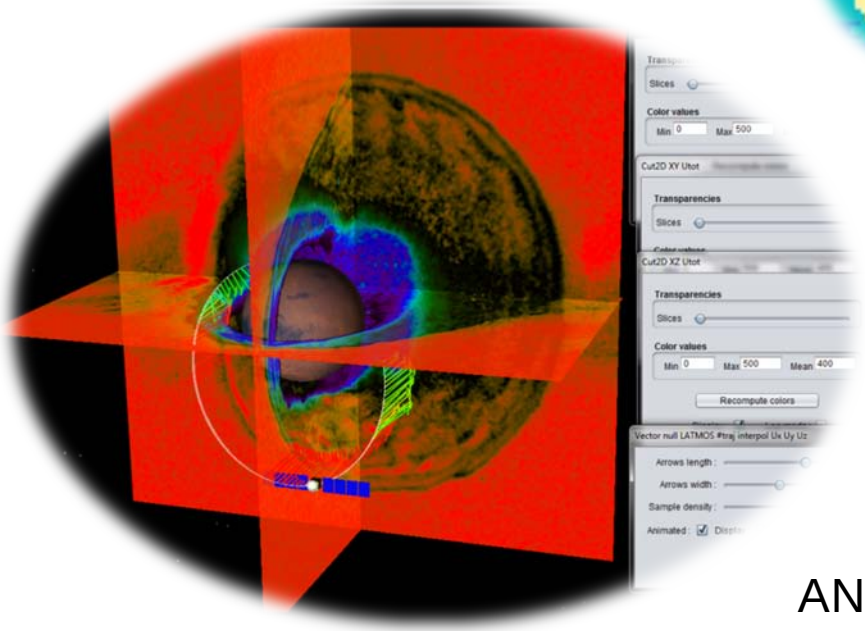
Crustal Fields
Hess et al, 2014



He++ atm. Capture
Chanteur et al, 2009

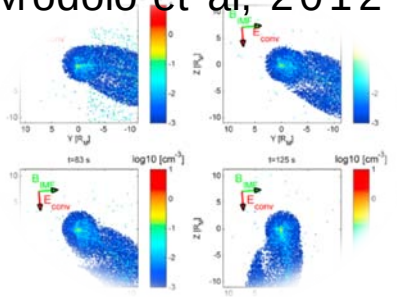
Thermo/ iono/ exo/ magneto coupling
In progress





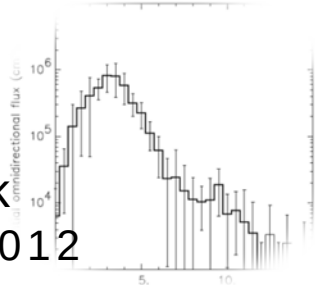
Martian X-ray
Koutroumpa et al, 2012

Transient events
Modolo et al, 2012

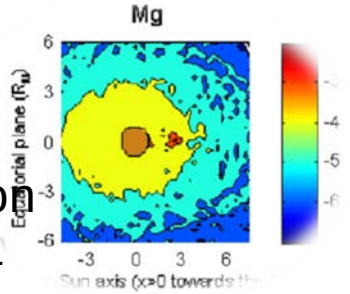


Modolo et al, 2005,2006, 2014 in prep

ANR HELIOSARES
FP7 IMPEx
MAVEN / NASA



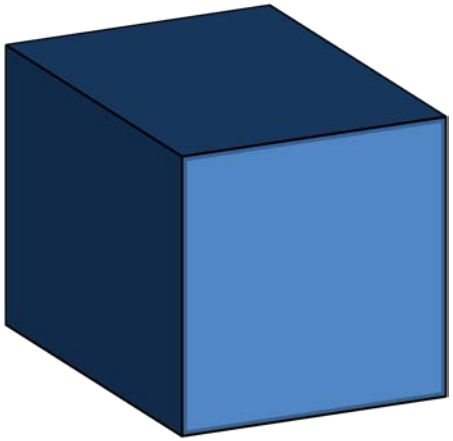
Ion foreshock
Richer et al, 2012




Phobos interaction
Cipriani et al, 2011

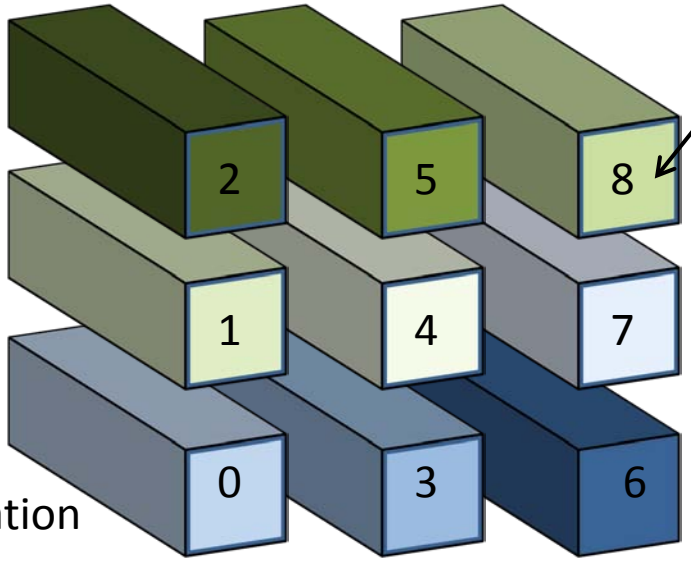
# Parallelization

Global simulation domain



Split in sub-domains

⇒



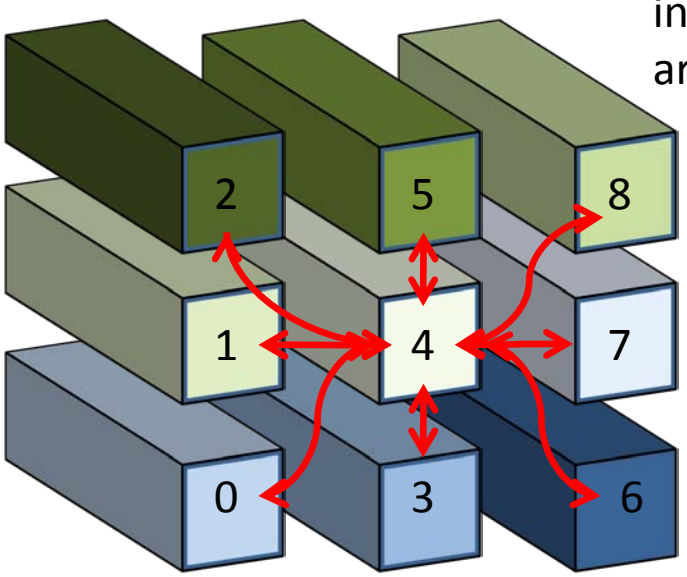

When simulation Ends, processes information are gathered

Temporal evolution of the simulation

⇓

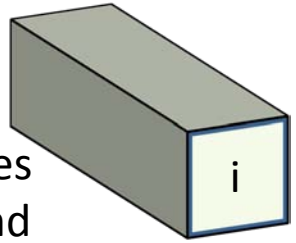
Process « i » is responsible for a sub-domain (mini-simulation)

For t=0 to end ⇒ X simulations are computed in parallel ☺ !




Example for process #4

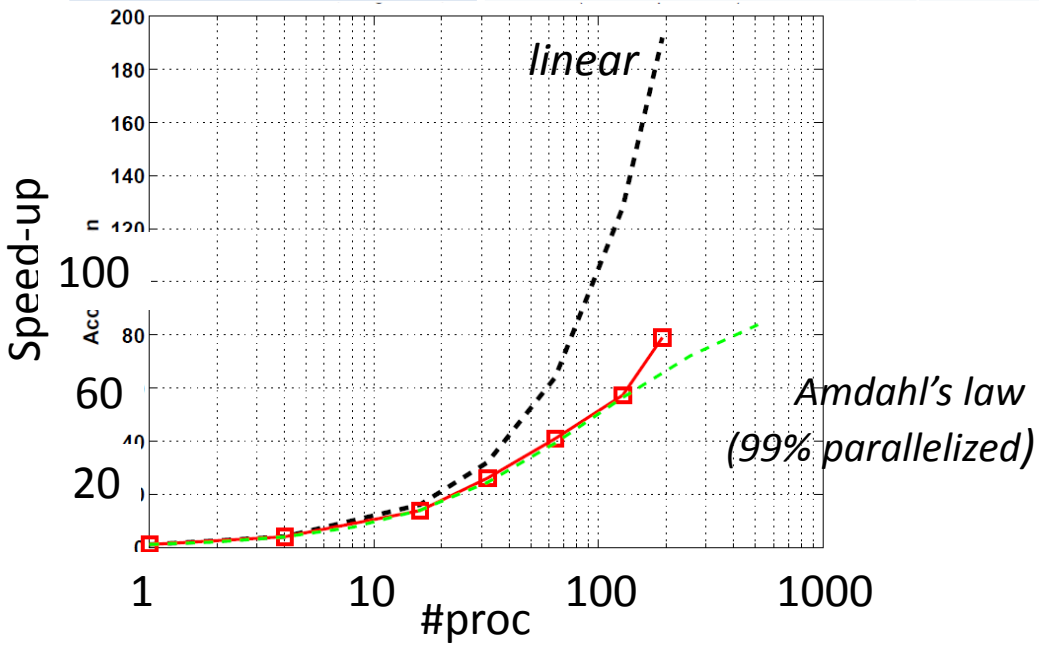
⇐




At each time step, processes exchange particles, field and moments with neighbours' processes

# General information and model performances

| | Low Resolution | Medium Resolution | High Resolution |
|---|---|---|---|
| **Spatial step** | 160 km | 80 km | 50 km |
| **Grid** | 128x246x248 | 200x380x380 | 320x610x610 |
| **# of particles** | $40 \times 10^6$ | $326 \times 10^6$ | $1.5 \times 10^9$ |
| **# time steps** | 18000 | 18000 | 26000 |
| **CPU time** | 1726h | 6150h | 56000h |
| **Memory** | 20Gb | 66Gb | 500Gb |
| **#CPU, #nodes** | 64 / 2 | 64 / 2 | 192 / 3 |
| **Restitution time** | 27h | 96h | 300h |




Excellent platform (CICLAD), comm. Internodes efficient

-good behaviour of the code

Time allocated for the code at IDRIS (French supercomputer center) – project ~550 000 h

- Diversity of neutral environment description :
  - •Analytical density profiles
  - •Load 3D from thermosphere GCM model :

    *LMD MGCM, Paris, F. Forget, F. Gonzalez-Galindo,JY. Chaufray*
    *Univ. Michigan, S. Bougher*
  - •Load 3D exosphere: *LATMOS Monte Carlo model, F. Leblanc, JY Chaufray*
- Many charged species are represented :

  Mars : $H^+_{sw}$, $He^{++}$, $H^+_{pl}$, $O^+$, $O_2^+$,$CO_2^+$ *(,$H_2^+$, $He^+$ )*

  2 electronic fluids (solar wind / ionospheric)
- Plasma/neutral coupling taken into account self-consistently, distinction between ionisation processes

  - *Photoionisation* $\Rightarrow$ $h\nu + X \rightarrow X^+ + e^-$
  - *Electronic impacts* $\Rightarrow$ $X + e^- \rightarrow X^+ + 2e^-$
  - *Charge exchange reactions* $\Rightarrow$ $M^+ + X \rightarrow M + X^+$

**Ionization rates are computed locally from neutral densities and ionisation frequencies or cross sections**

- Simplified ionospheric chemistry *(the 9th most important reactions)*

  *Possibility of **loading 3D ionospheric profiles** (LMD – MGCM ionosphere / theroretical profiles)*
- Crustal fields (60th order spherical harmonics)

**Solar EUV variability :** Solar min vs Solar max

ISSI (D. Brain) inputs

RunA : Solar min, no exosphere, SW nominal conditions

RunB : Identical to RunA + exosphere

RunC : Solar max, SW nominal conditions

**Ion escaping flux $_{x}10^{23}$ ions/s**

| | O+ | O2+ | H+pl |
|---|---|---|---|
| RUN A | 2.2 | 0.1 | 120. |
| RUN B | 4.3 | 1.3 | 330 |
| RUN C | 28. | 7.8 | 160 |

MeX vs MAVEN estimates might tackle this driver

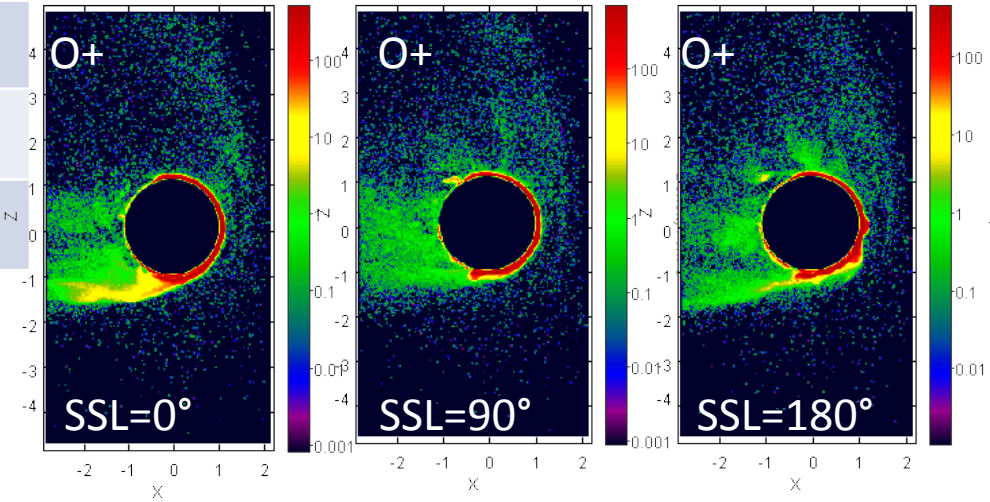
However ion loss due to **seasonal variation** might be addressed by MAVEN in complement to numerical models.

**CF variability :** RunC + CF @ SSL=0°, 90°, 180°, 270°

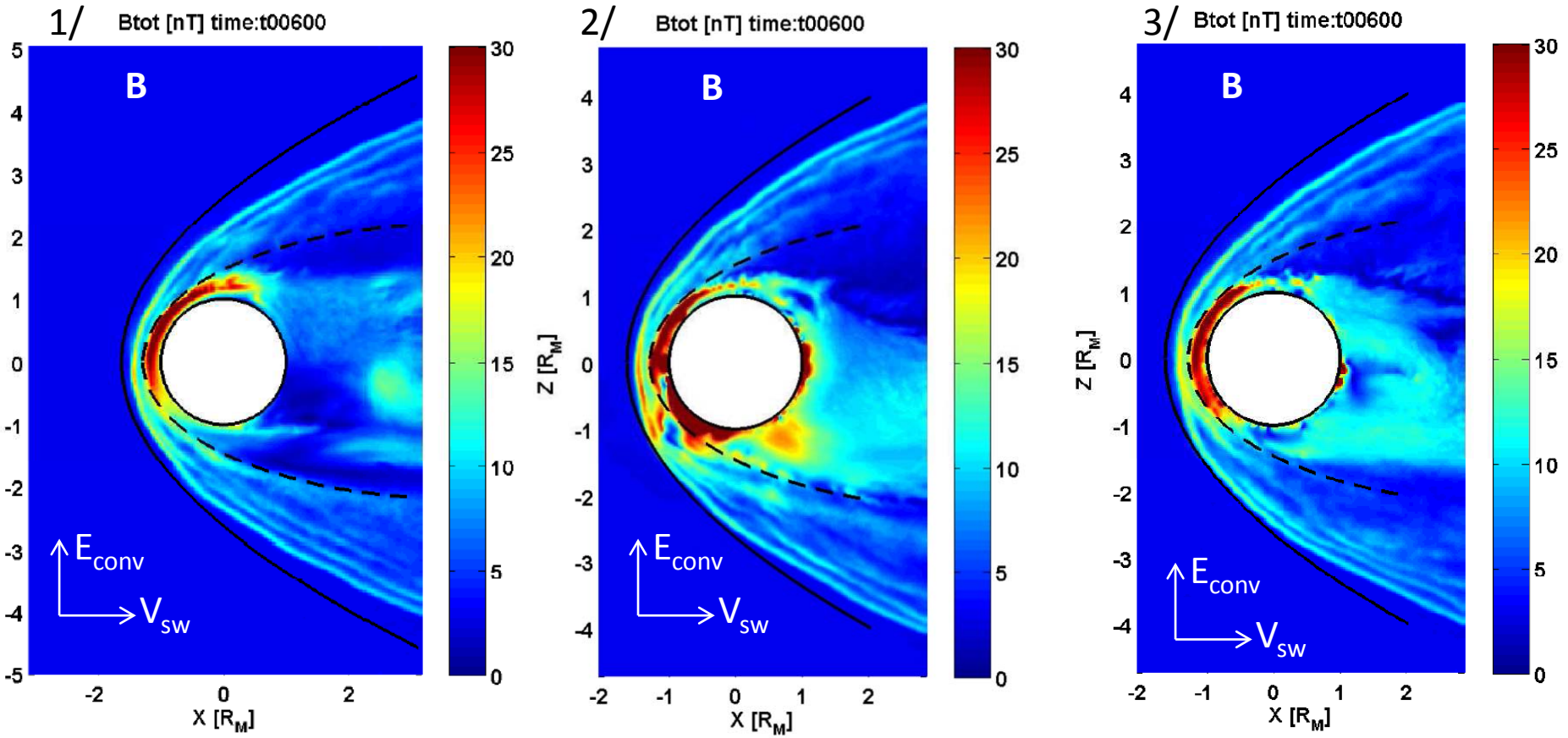
**O+ Ion escaping flux $_{x}10^{23}$ ions/s**

| | w/o CF | SSL=0° | SSL=90° | SSL=180° | SSL=270° |
|---|---|---|---|---|---|
| RunC | 28 | 23. | 25. | 24. | 24. |

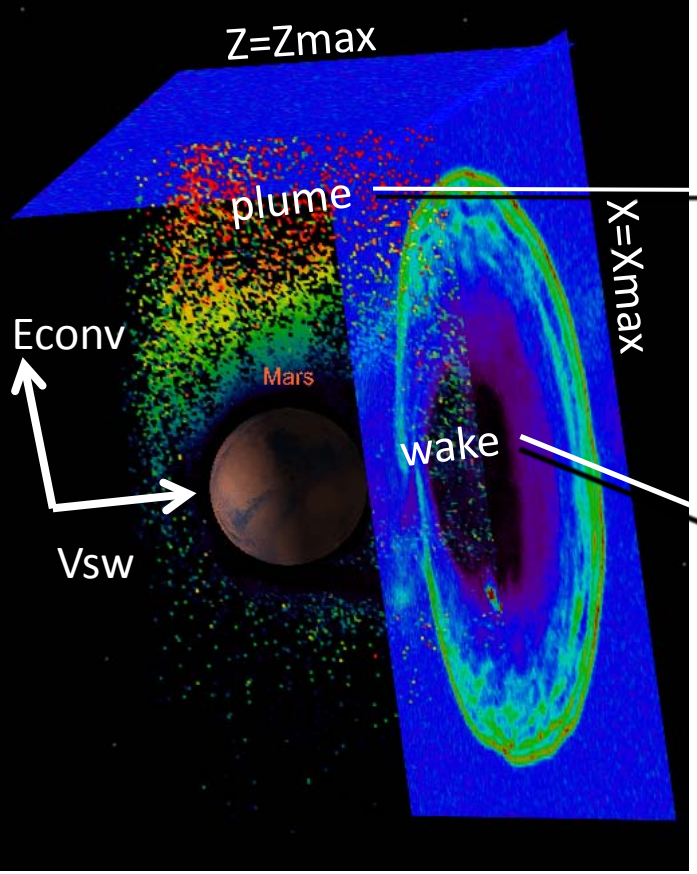
Less than 20% of variability due to CF position, in agreement with Ma et al

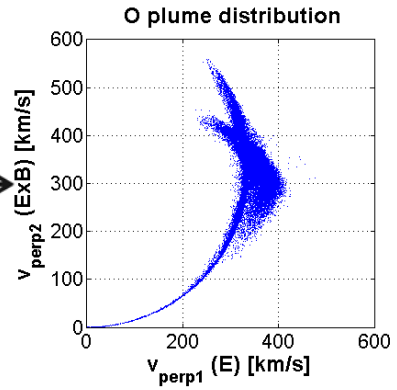


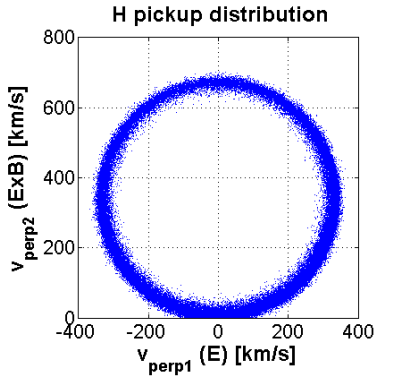

However slight different ion dynamic patterns are expected, suggesting different signatures for the same MAVEN orbit.

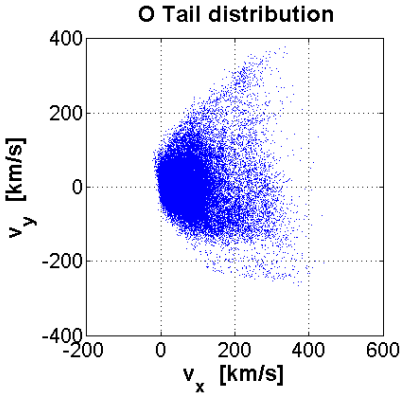


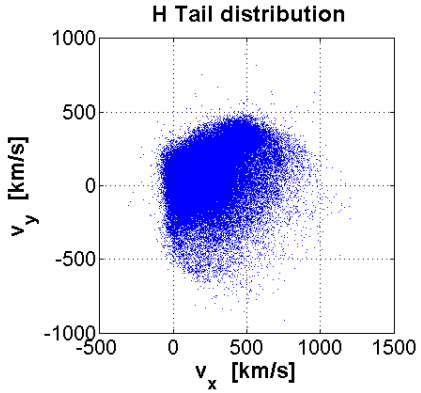

- BS position seems not affected by crustal fields presence and orientation
- MPB is locally affected
- Crustal fields change the magnetic topology of the induced magnetosphere




Nominal SW condition (Quiet)
N=4 cm-3, V=400 km/s, B=3nT
Parker spirale
F10.7=240 (solar max),
SSL=180° (CF @noon)

Escaping flux ($\times 10^{24}$ ions/s)

| | Total | X=Xmax (-4.3 Rm) | Z=Zmax (6.6 Rm) |
|---|---|---|---|
| O+ | 2.8 | 1.2 (43%) | 1.6 (57%) |
| O2+ | 0.3 | 0.2 (66%) | 0.1 (33%) |
| H+pl | 38.3 | 26.3 (68%) | 2.7 (7%) |

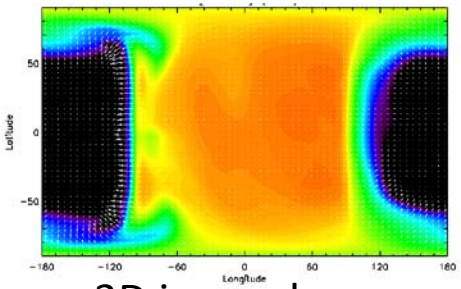
- According to the simulation half of the O+ escaping flux is tailward and the other half is +Eward
- Possibility to discriminate with the distribution function

# The Martian environment from the solar wind to its thermosphere

**Thread :** to get accurate ion escaping flux and investigate seasonal effect on planetary plasma we need an accurate ionospheric description

**Constraining factor :** Hybrid (magnetospheric) spatial grid size (> 50 km ~ few times neutral scale heights)

**Procedure :** coupling with ionospheric and thermospheric model to get a a 3D ionosphere + exospheric model (3D exosphere)




3D thermosphere

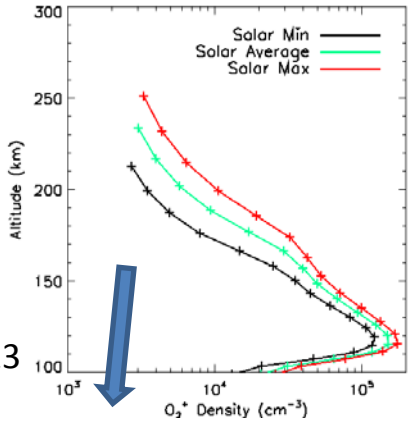
Forget et al, 1999

Gonzalez-Galindo et al, 2009

3D ionosphere

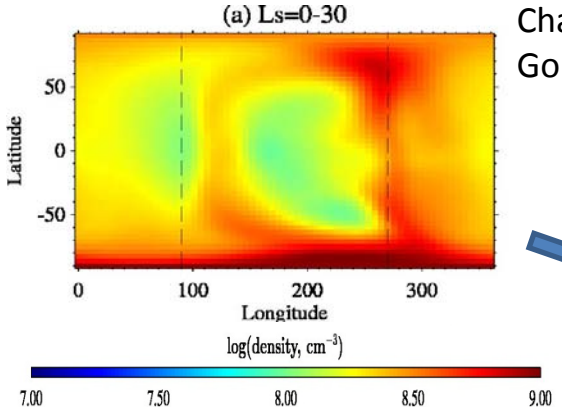
Chaufray et al, 2014, in rev.

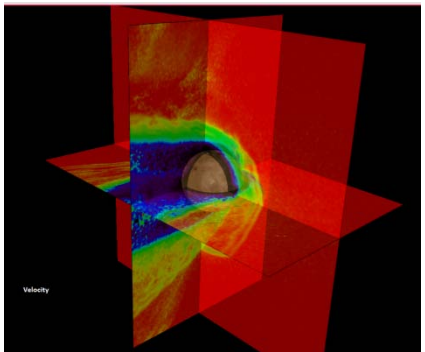
Gonzalez-Galindo et al, 2013

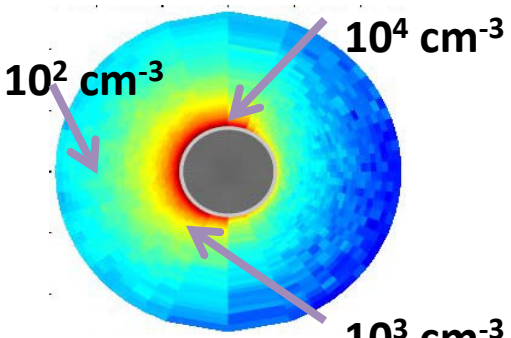



3D exosphere

Yagi et al, 2012



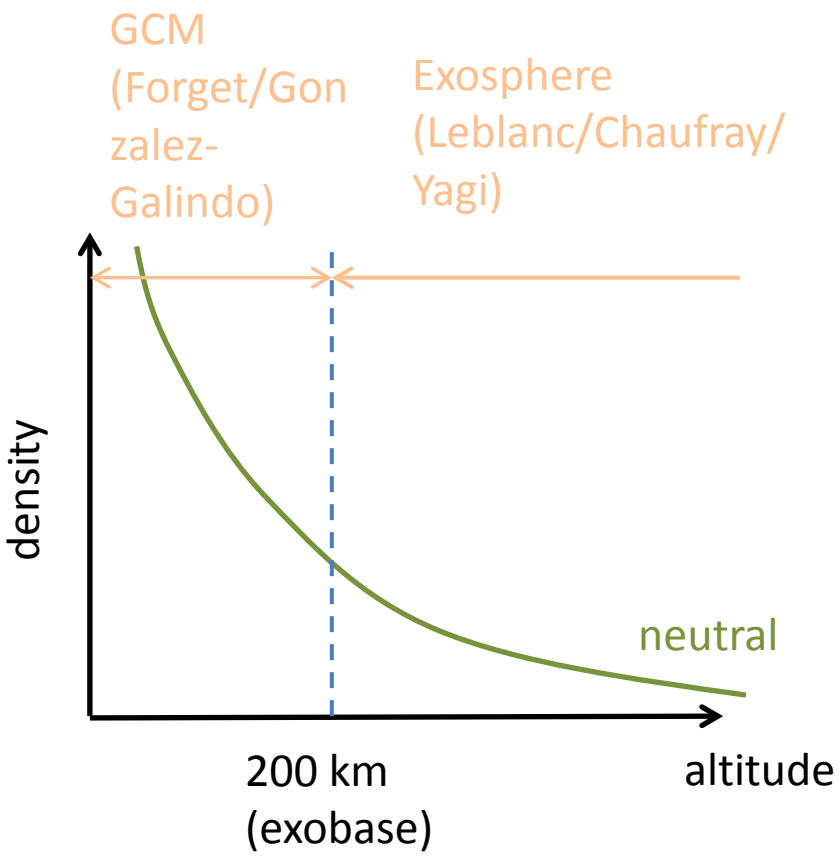



3D hybrid

Modolo et al, 2014, in prep

Hess et al, 2014, in prep

# Loading neutral environment (thermosphere+exosphere)




Neutral reservoir :

- Load GCM thermosphere up to 200 km altitude
  O and CO2
- Load exosphere from 200 km
  CO2
  O thermal + Non thermal component

H loading (both GCM and Exosphere) will be implemented soon.
Now we assume spherical density profile

- Loading MTGCM thermosphere (Univ. Michigan) implemented for O and CO2.

- Neutral environment does not evolve in time

# Scenarios for ionospheric-magnetospheric coupling

## Scenario 1

**No coupling**

*Initialisation*

- Load 3D thermosphere + exosphere

⇒compute production

⇒Assume photochemical equilibrium below 200km

⇒ ionospheric density profile

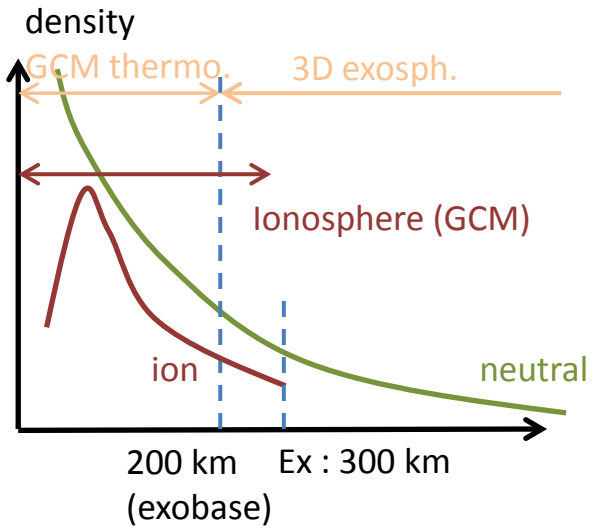
*Temporal scheme*

- Compute local production
- Inject particles if needed

## Scenario 2

*Initialisation*

- Load 3D thermosphere + exosphere
- Load ion density profiles from GCM




*Temporal scheme*

- Compute local production *q*
- Inject particles if needed (*q > 0*)

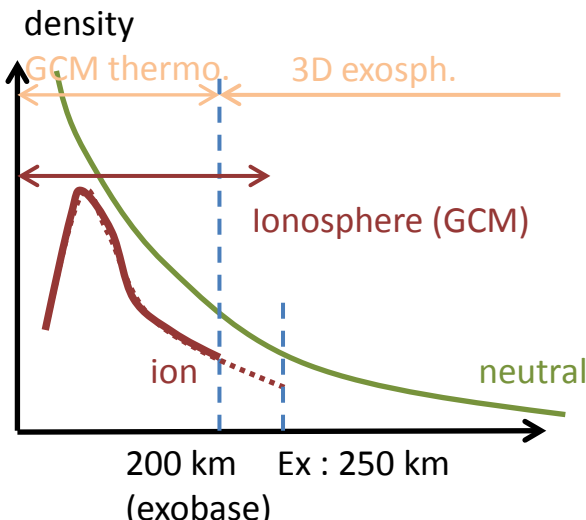
## Scenario 3

*Initialisation*

Same as scenario 2

*Temporal scheme*

- « Impose » ion density below 250 km
- Compute production above 250 km
- Inject particles if needed to keep ion density profile and, if q>0, above 250 km



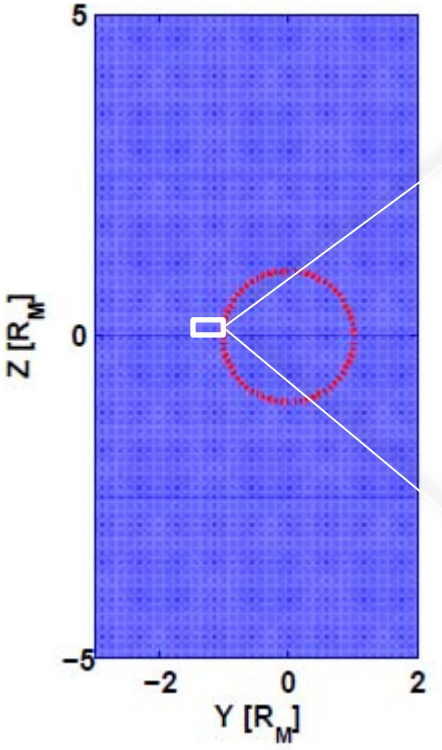
# Loading Ionospheric profiles (O+, CO2+, O2+,H+) at initialisation

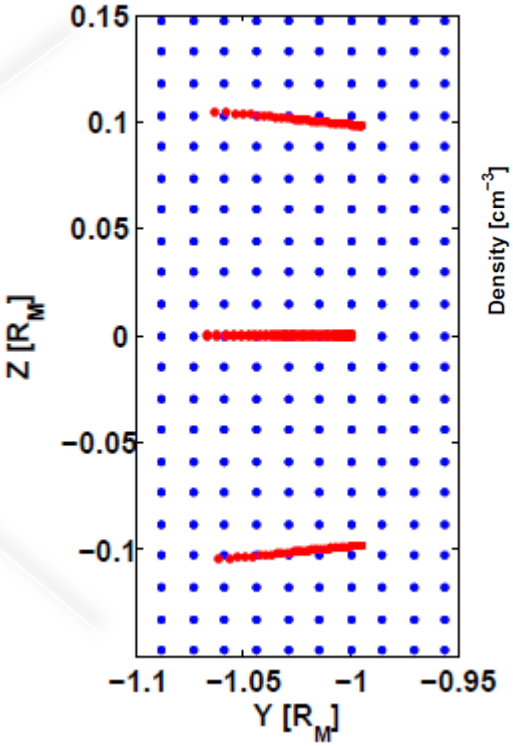
LS **90°**, Solar Activity : **Moderate**

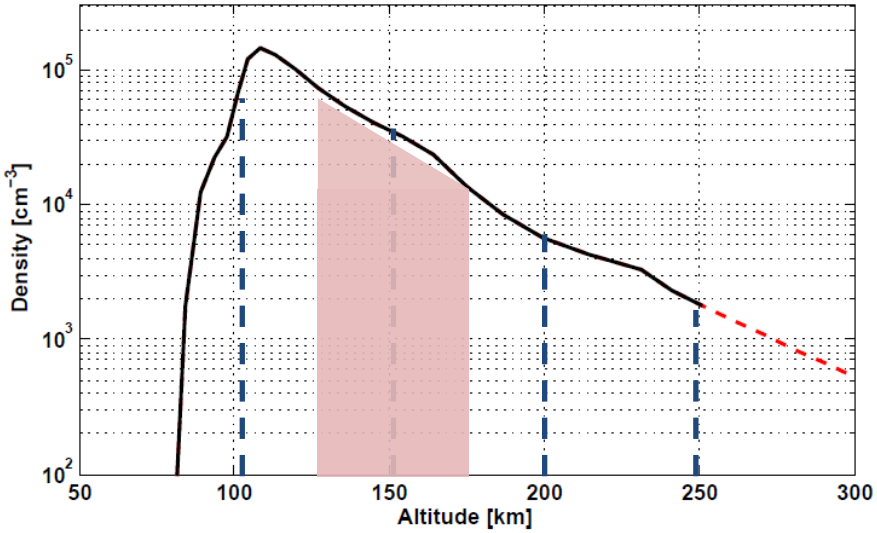
Hybrid and GCM grid

- Hybrid grid (50 km resolution /cartesian)
- GCM grid (5.5° x3.5° , r variable ~1-5 km)

Extrapolation of ionospheric profiles
⇒ Reach a minimum altitude of 250 km (even on the nightside)



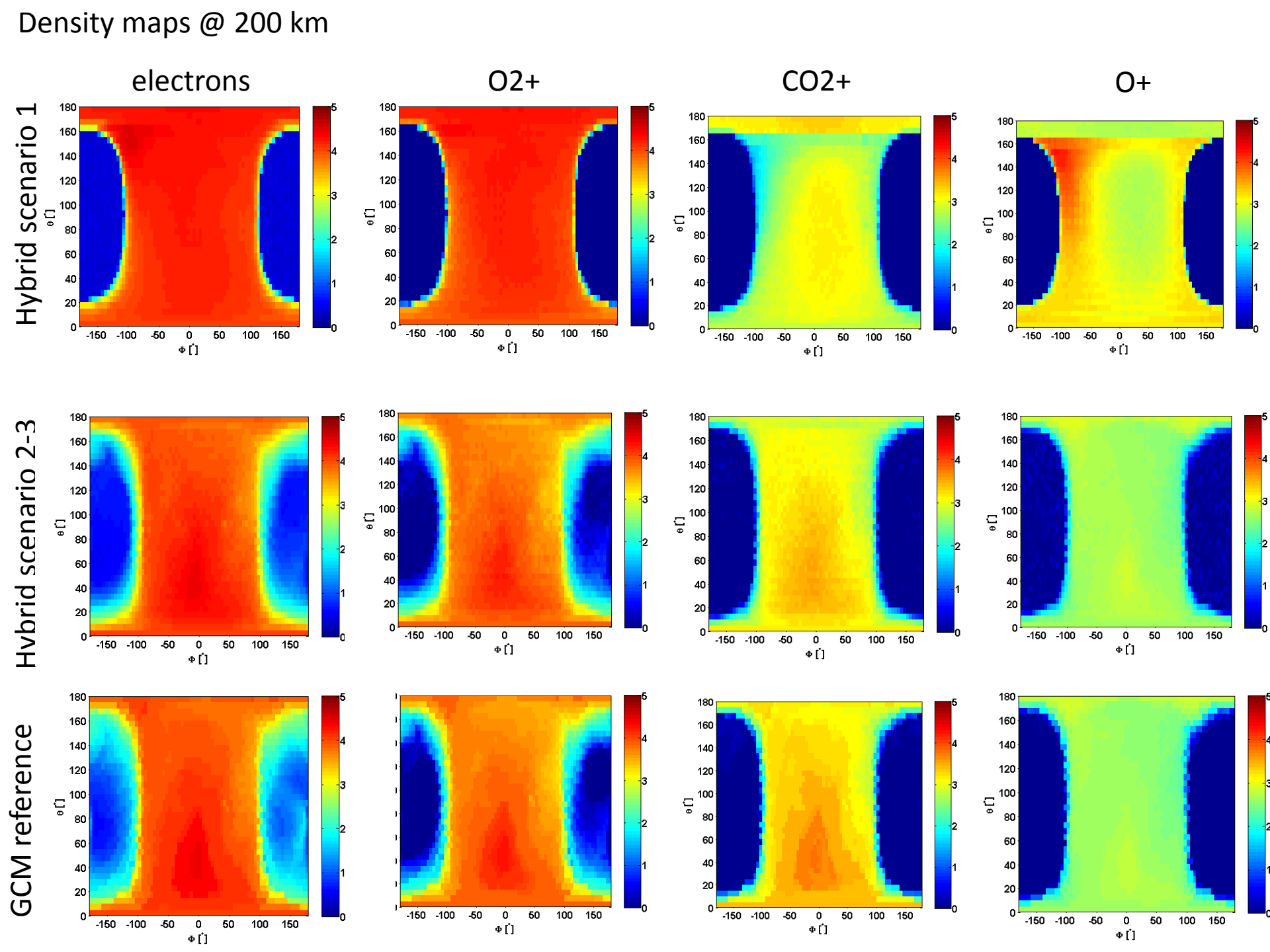




Integrate the GCM particle content over one hybrid cell and affect this content inside the volume of one hybrid cell

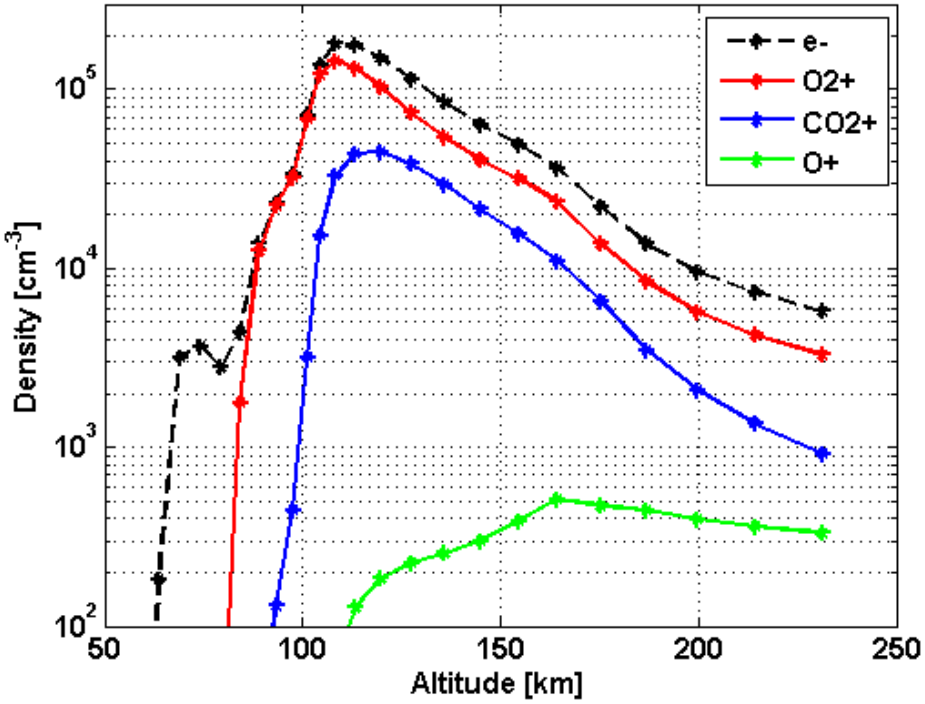
A relatively accurate ionospheric content is described in the hybrid code

# Density maps @ 200 km

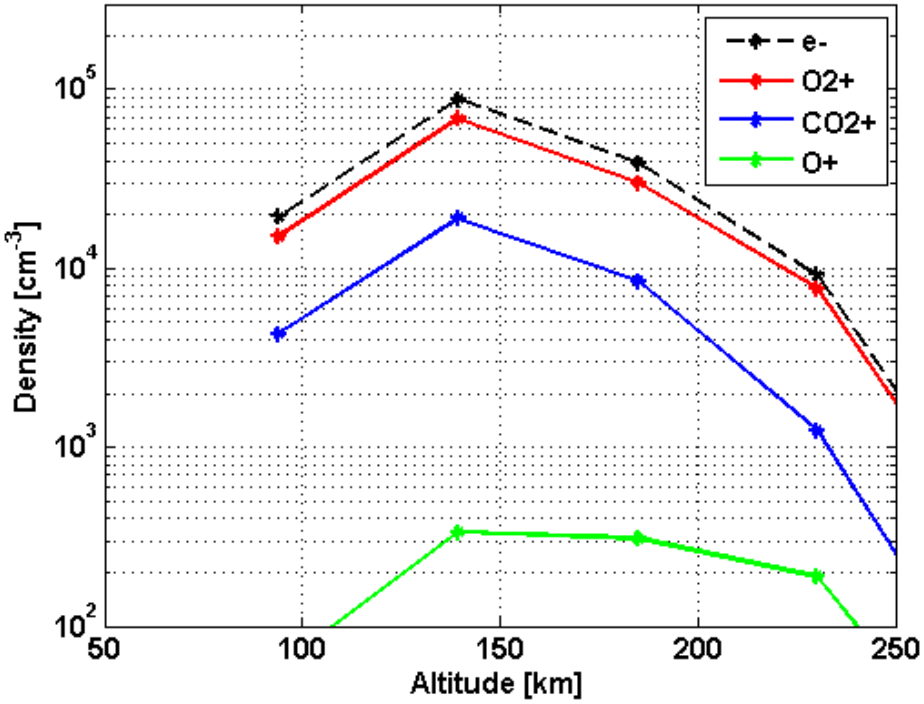


# Subsolar density profiles : LMD-MGCM-ionosphere / Hybrid

LMD-MGCM-ionosphere

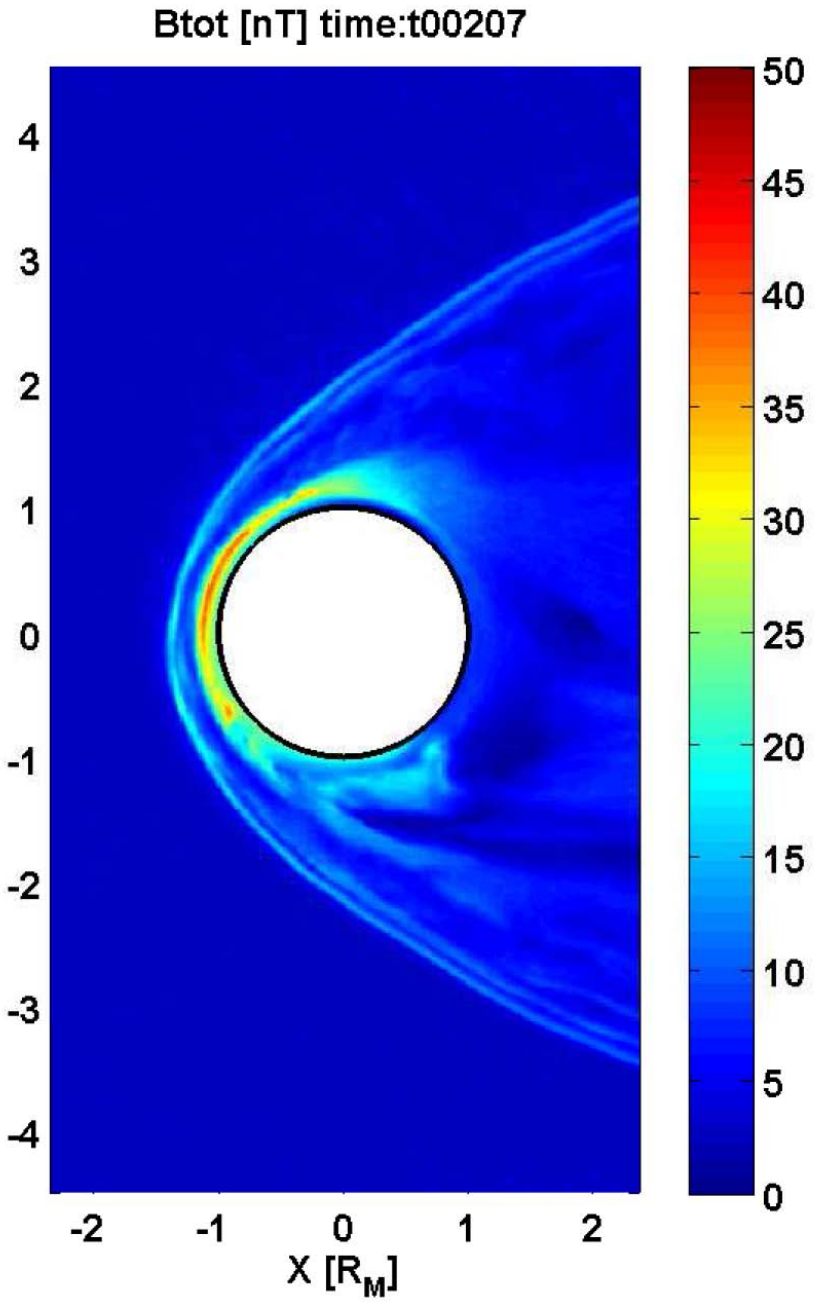


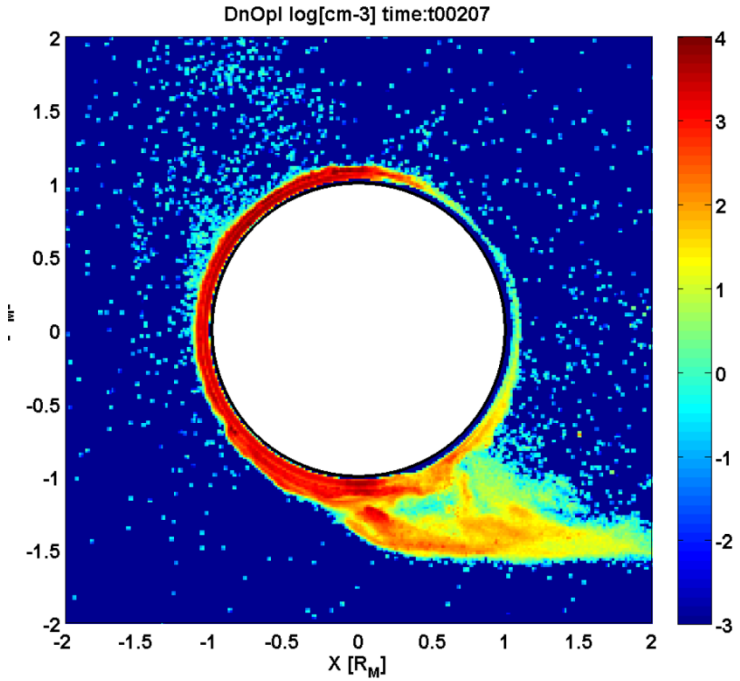

Hybrid




Uniform grid size : $\Delta x$=50km

# Preliminary results




- Early/(not stationnary) diagnostic time
- Still in progress

# Hybrid Library

impex.latmos.ipsl.fr/LatHyS.htm

LatHyS — LATMOS HYBRID SIMULATIONS

About LatHyS  Use policy  LATMOS  IMPEX

Data tree:  SAMP

- Mars
  - Simulations
    - LatHyS_Mars_14_01_13@Latmos_Hybrid_Simulation_Datat
    - LatHyS_Mars_13_02_13@Latmos_Hybrid_Simulation_Datat
    - LatHyS_Mars_18_01_13@Latmos_Hybrid_Simulation_Datat
    - LatHyS_Mars_23_01_13@Latmos_Hybrid_Simulation_Datat
    - LatHyS_Mars_27_01_13@Latmos_Hybrid_Simulation_Datat
      - 3DCubes
        - IonComposition
        - ElectricField
        - MagneticField
          - Mag/3D
        - ThermalPlasma
      - 2DCuts
    - LatHyS_Mars_03_01_14@Latmos_Hybrid_Simulation_Datat
    - LatHyS_Mars_09_01_14@Latmos_Hybrid_Simulation_Datat
  - Spacecraft
- Mercury
- Ganymede

Filter:

**Data Information:**
*Mag/3D*

**Product Type:** 3DCubes
**MeasurementType:** MagneticField

**Contents:**

MagneticField

Download

**Run Information:**
*LatHyS_Mars_27_01_13*

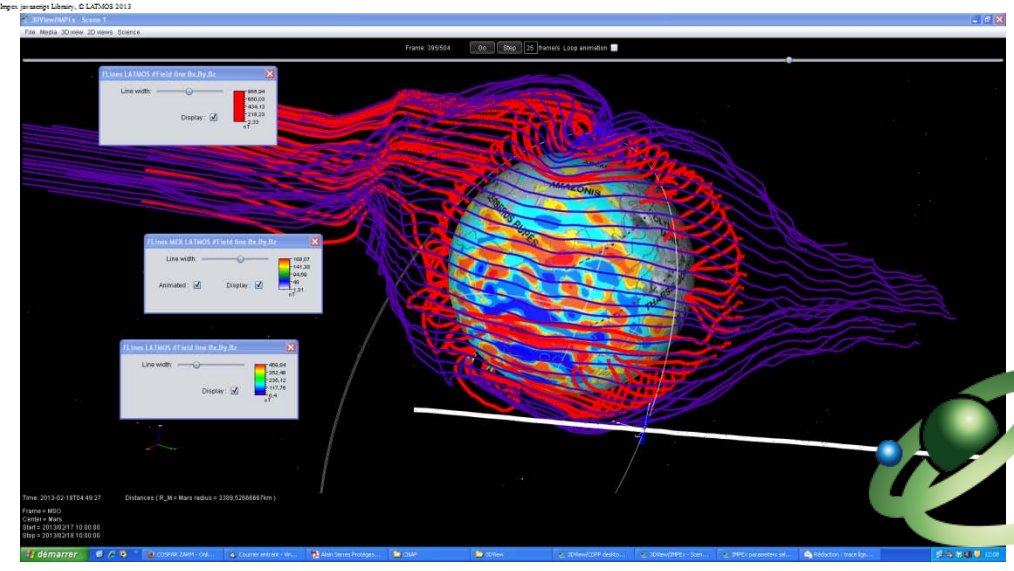
**Simulated Region:** Mars
**Reference Frame:** MSO, Cartesian

**Domain:** x∈[-7180.1,9389.4] km
y∈[-15879.1,15934.3] km
z∈[-15879.1,15934.3] km

**Cell size:** 82.8 82.8 82.8 km
**Sub Solar Longitude:** 270.00°

**Solar wind properties:**
***IMF value:*** 3.001 nT
***IMF cone angle:*** 57.10°
***IMF:*** (1.63,-2.52,0.00) nT
***Density:*** 2.84E+00 cm-3
***Velocity:*** 485.00 km/s
***Density:*** 2.70E+00 cm^-3
***Velocity:*** 485.00 km/s
***Density:*** 1.42E-01 cm^-3
***Velocity:*** 485.00 km/s
***Solar UV Flux @ 10.7:*** 236.00

- **Solar wind populations:**
- **Ionosphere populations:**
- **Exosphere populations:**



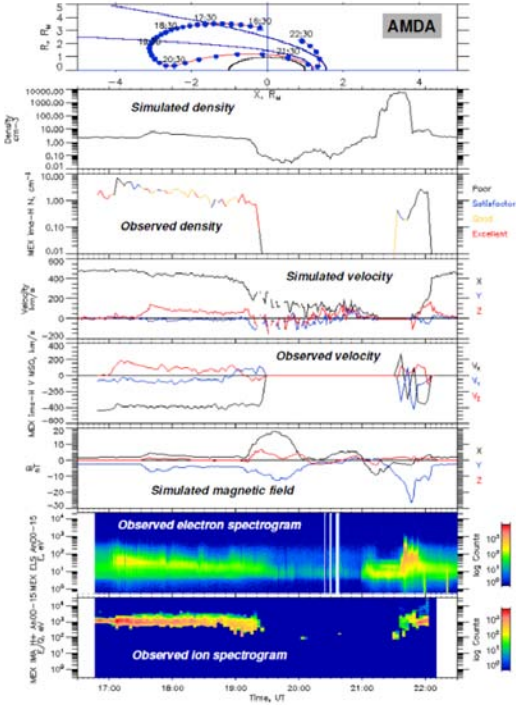

Workspace Explorer

resources | operations | jobs

Filter : None

- Parameters
  - Local Data
  - Remote Data
    - VexMag@Graz
    - MAPSKP@IRAP
    - THEMIS@IRAP
    - MODELS@LATMOS
      - MarsExpress
        - Hybrid_LATMOS_Mars_12_08_12
          - IonComposition
            - CO2
            - Hes
            - Hpl
            - Hsw
            - O2p
            - Opl
          - ElectricField
          - MagneticFie
            - Mag
          - ThermalPlas
    - CDAWeb@NASA
  - My Data
- Derived Parameters
- Aliases
- Time Tables
  - My Time Tables
- My Files

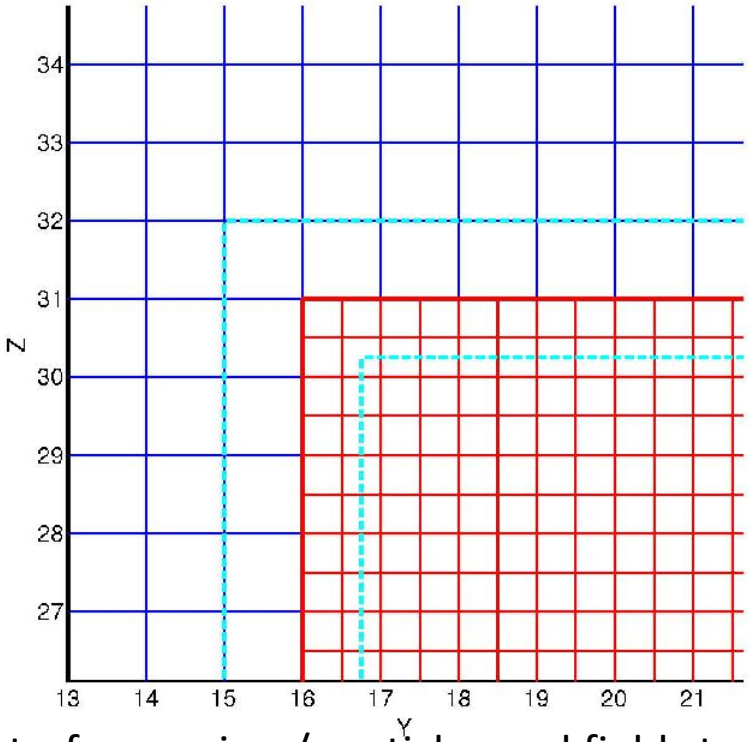
Amda
Versatile web tool for Space Physics
MULTI DATASET VISUALISATION AND DOWNLOAD
VISUAL AND AUTOMATED EVENT SEARCH AND DATA MINING
CATALOGUE GENERATION AND EXPLOITATION
REMOTE ACCESS TO DATA, MODEL AND INPUT, DEXTRES VIA VO TOOLS AND STANDARDS



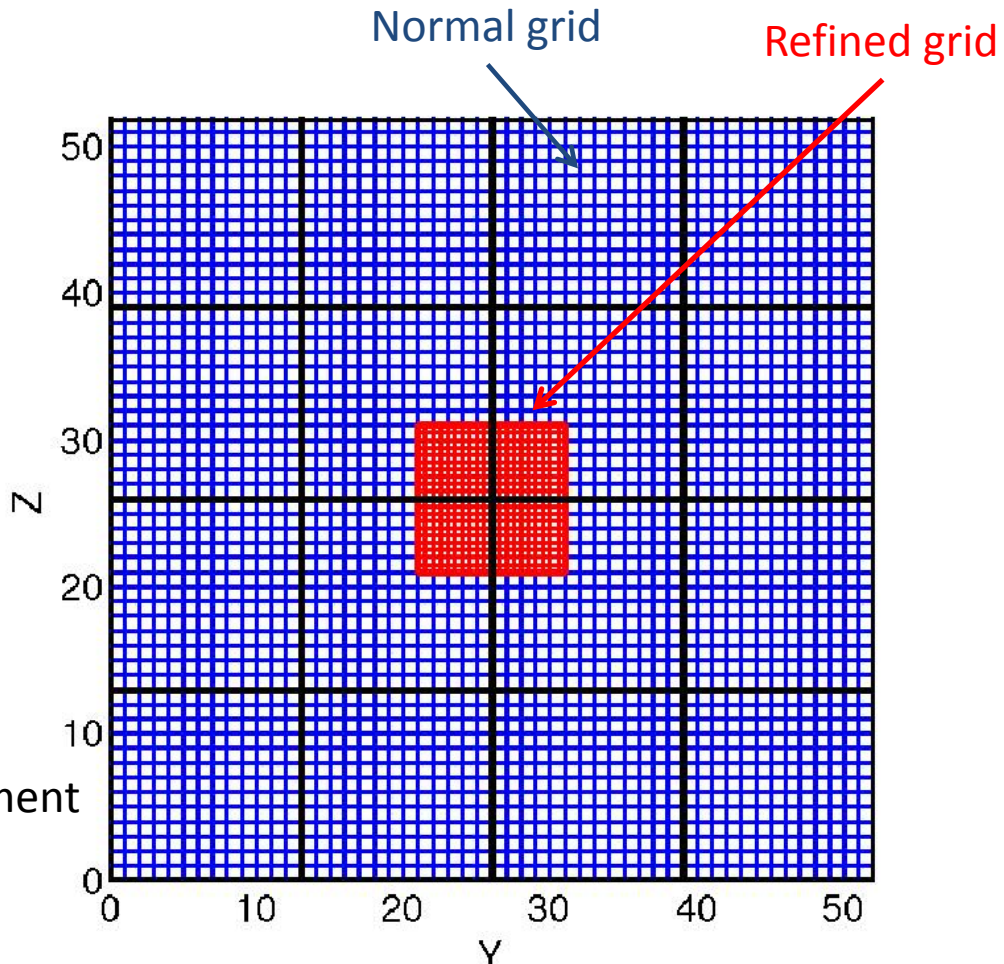
# Perspective and work in progress

- Nested-grid development – **L. Leclercq**, PhD LATMOS

Objectives : Improving spatial resolution close to the obstacle
/ Optimisation of calculation

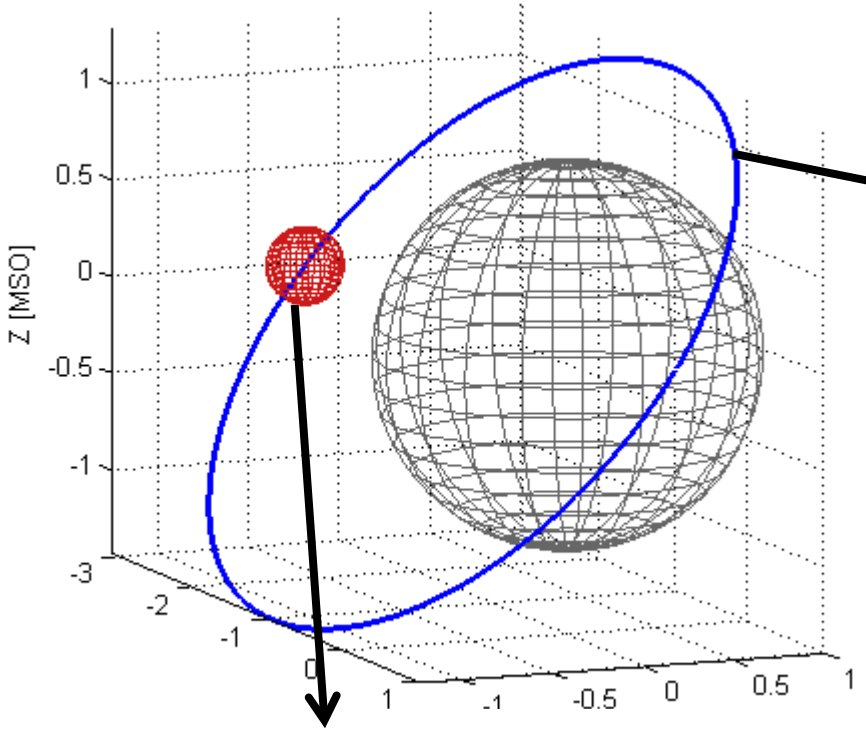



Interface region / particles and fields treatment

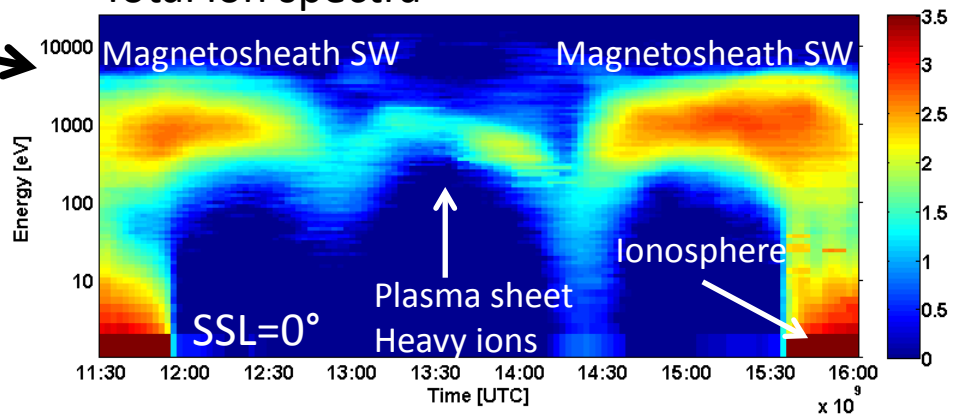


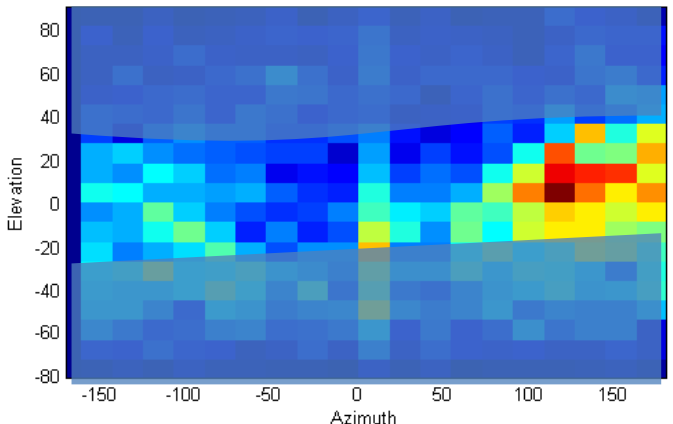
# Ion spectra and Distribution function

- Get distribution function in 3D space and 3D velocity space for each *s* ion species $f(\vec{r},\vec{v},s)$




Total ion spectra



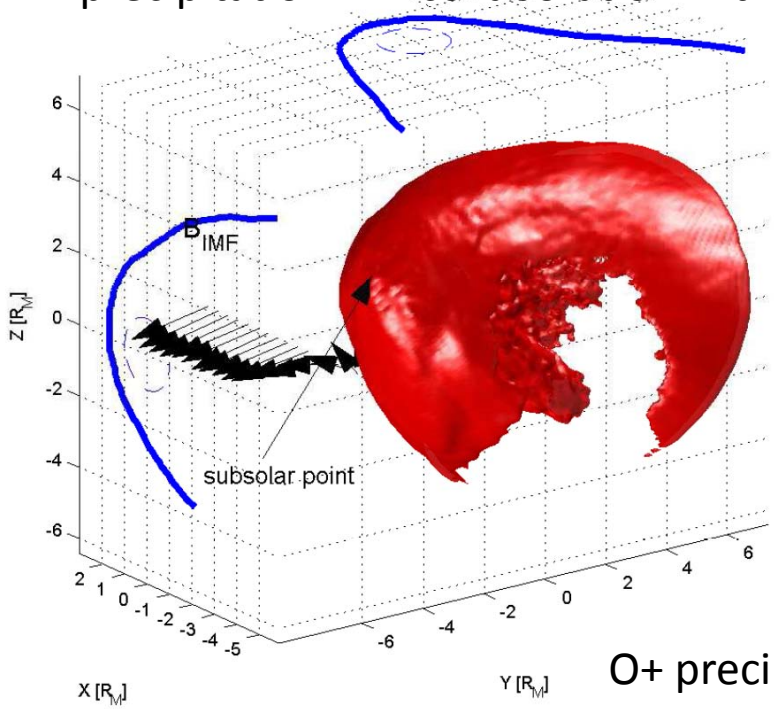




•3D distribution of species *s* at spatial position **r** ⇒ moment (n,**v**,T) can also be computed from Distribution

•If S/C attitude and instrument FOV known possibility to apply real FOV, compare observed and simulated distribution

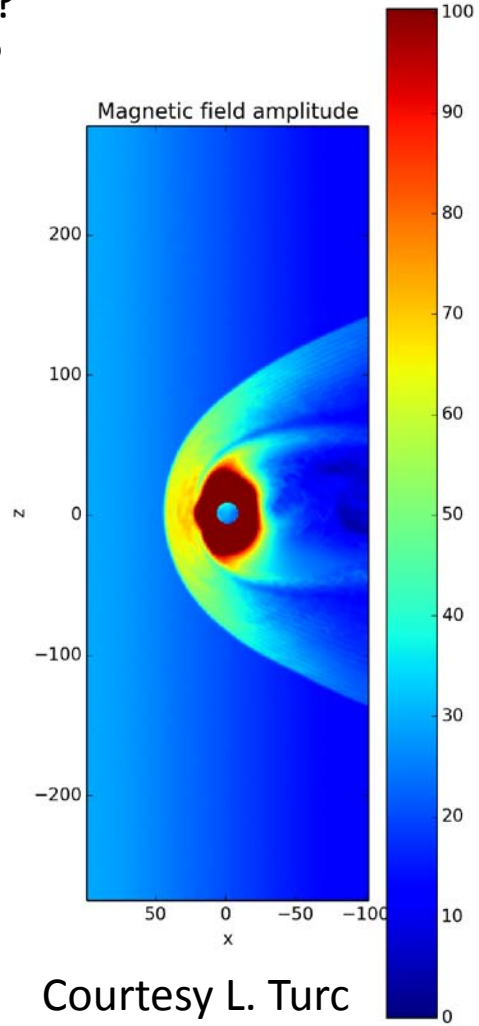
# Transient and extreme events

• Investigations on the effect of IMF rotation on induced magnetosphere and particle precipitation… in collaboration with S. Curry, SSL, Berkeley



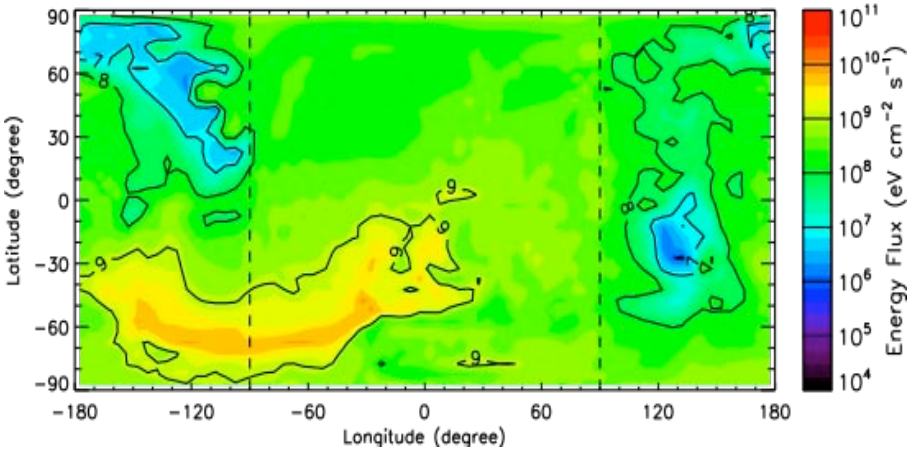

• Effects of Pmag increase ?
• Effects of Pdyn increase ?
….

• Toward Interaction with CMEs

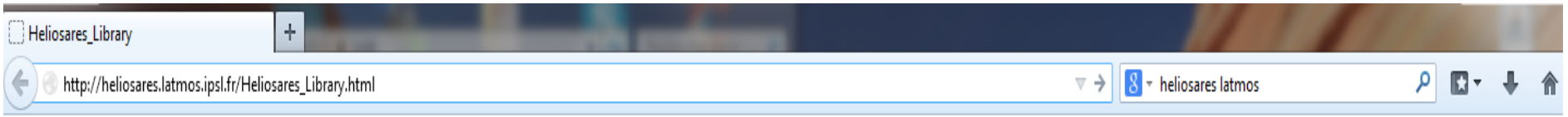



Courtesy L. Turc

O+ precipitation map



# Contribution to MAVEN Model Library




List of runs planned to be done using the hybrid magnetospheric model, the LMD Global Circulation Model (including a dynamically uncoupled ionosphere) and the exospheric model. The hybrid simulations will be done by coupling all three models.

**Solar Activity ( F10.7 -cm / solar cycle) : 120 (Moderate Sun activity)**

| Parameters | | LMD-GCM+Ionosphere | Exosphere | Hybrid+GCM+Exo | | | |
|---|---|---|---|---|---|---|---|
| **Seasons and dust scenario** (and link to data) | Ls (season) | 0, 90, 180, 270 | 0, 90, 180, 270 | 90, 180, 270 | 270 | 270 | 270 |
| | Tau (CR) for dust | 0.5 (0.003) | 0.5 (0.003) | 0.5 (0.003) | 0.5 (0.003) | 0.5 (0.003) | 0.5 (0.003) |
| **Planetary longitude** | Sub-solar B-crustal orientation (180W is maximum field location) | | | 180W (noon) | 180W (noon) | 180W (noon) | 90 W (dawn) |
| **Solar wind conditions** | N (#/cm$^3$) | | | 4.0 | 4.0 | 4.0 | 4.0 |
| | V(km/s) | | | 400. | 400. | 400. | 400. |
| | B(nT) | | | 3.0 | 3.0 | 3.0 | 3.0 |
| | IMF Orientation | | | Normal | Cone angle 0° | Cone angle 90° | Normal |

# Summary

- **3D parallel multi-species hybrid model developped for planetary environments :**

  -Mars -Ganymede

  -Mercury -Titan
- **High spatial resolution achieved for a kinetic model (Mars : 50 km uniform grid)**
- **Coupling with GCM (LMD GCM or MTGCM, Bougher's model) and exospheric models** => consistent and realistic description of neutral coronae
- Implementation of **crustal fields**
- 'Full' **coupling thermosphere-exosphere-ionosphere-magnetosphere** in progress …
- Release of simulation results. Hybrid library interoperable with Visualization tools (3D, time series …)
- Many applications …

*……. Task 1 validated ☺*