Bow shock behaviors under low MA SW: Geotail observations and global simulations

or

Our impression on CCMC from the first experience

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The background

- Masaki Fujimoto: local simulations (particle and fluid), spacecraft data analysis focusing mainly on kinetic aspects of plasma physics

- Masaki N Nishino: spacecraft data analysis (“*THE* Geotail specialist”) with main interest on boundary layer/plasma transport

- The Japanese magnetospheric community:

  Two groups working on global MHD simulations

As we were convinced that coupling simulation results with the curious observations under low density SW should make the story most exciting.

Indeed we have tried to work with one of them, but …

Low-density SW: First report

Gosling et al. (1982)

- sub-Alfvénic solar wind seen by ISEE 3
- ISEE 2 was near the magnetopause on the duskside

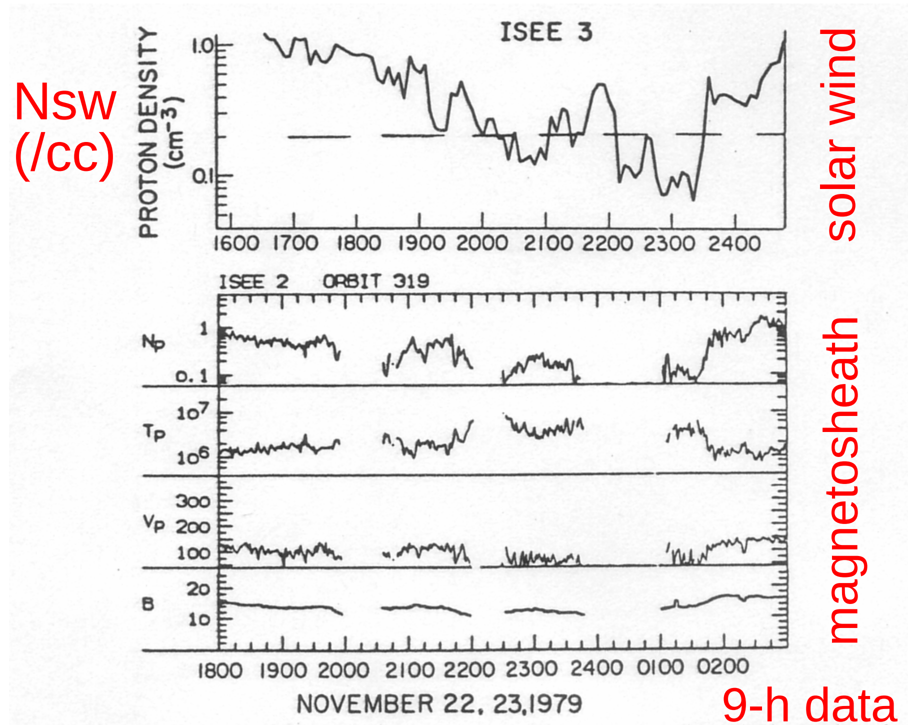
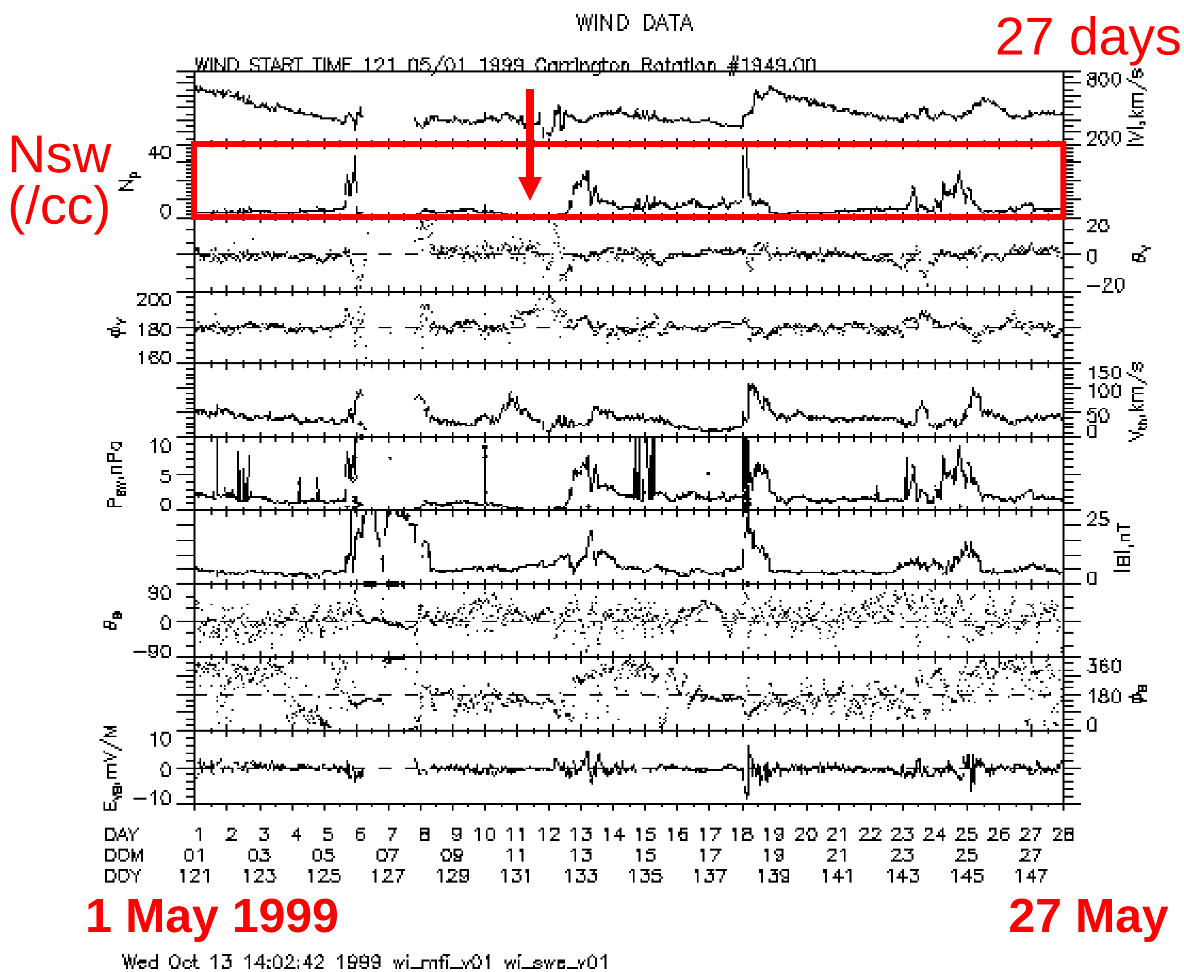


Fig. 7. Solar wind density (top) and magnetosheath ion density (N_p), temperature (T_p), flow speed (V_p), and field strength on November 22, and 23, 1979. The units of N_p, T_p, V_p, and B are cm^{-3}, °k, $km\ s^{-1}$, and nT, respectively. Major gaps in the magnetosheath data correspond to ISEE 2 transits into the magnetosphere. The horizontal dashed line in the upper panel separates super-Alfvénic and sub-Alfvénic solar wind flow.

The famous event in the last solar-cycle: May 11-12 1999



Statistics of low-density SW

- **Low occurrence ratio**
- **Relation to the sunspot number**

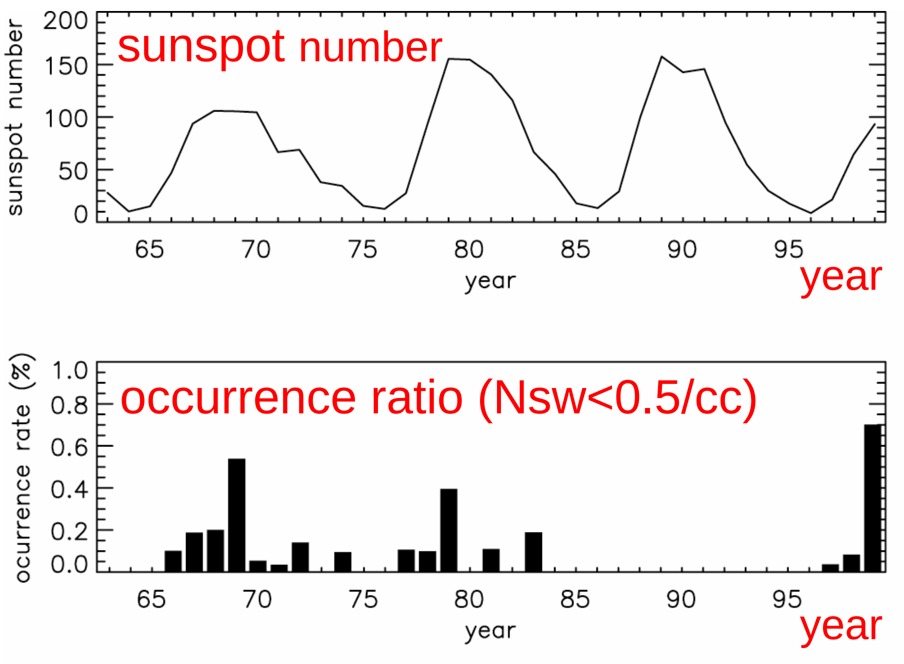
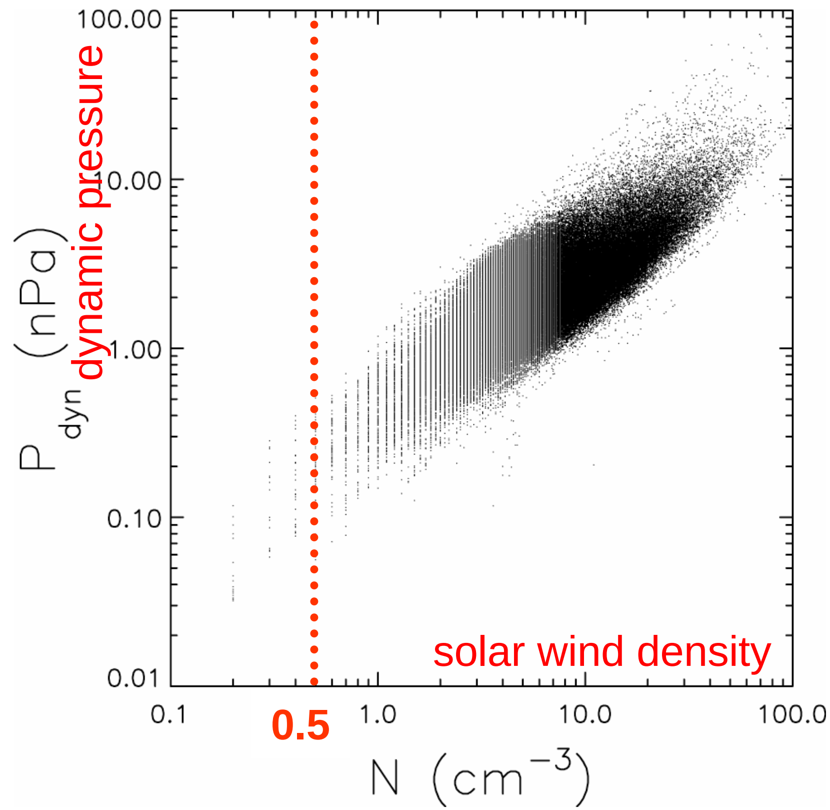


Fig. 3. Yearly sunspot numbers and annual occurrence rates of low-density solar wind (density 0.5 cm^{-3} or less).

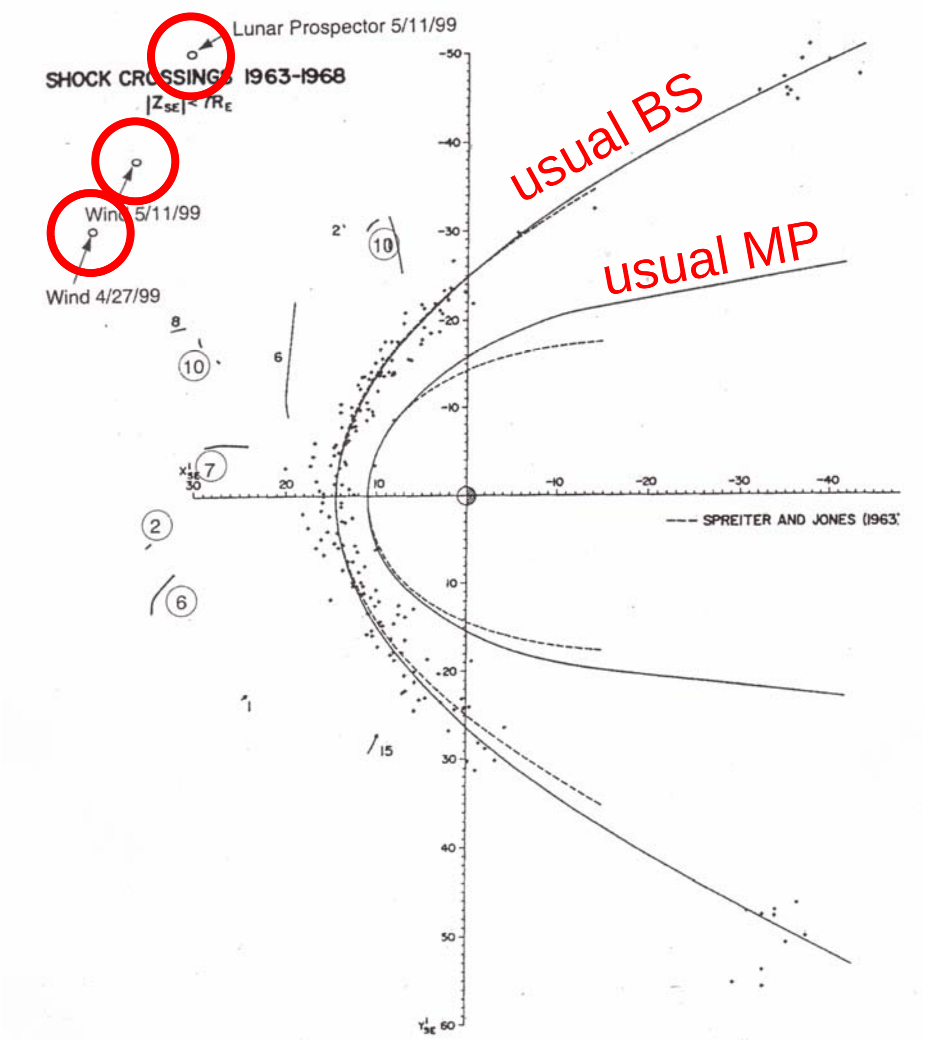


Watari et al. 1999

Low density = low sonic Mach number
Unusual BS location

Sunward expansion of the BS

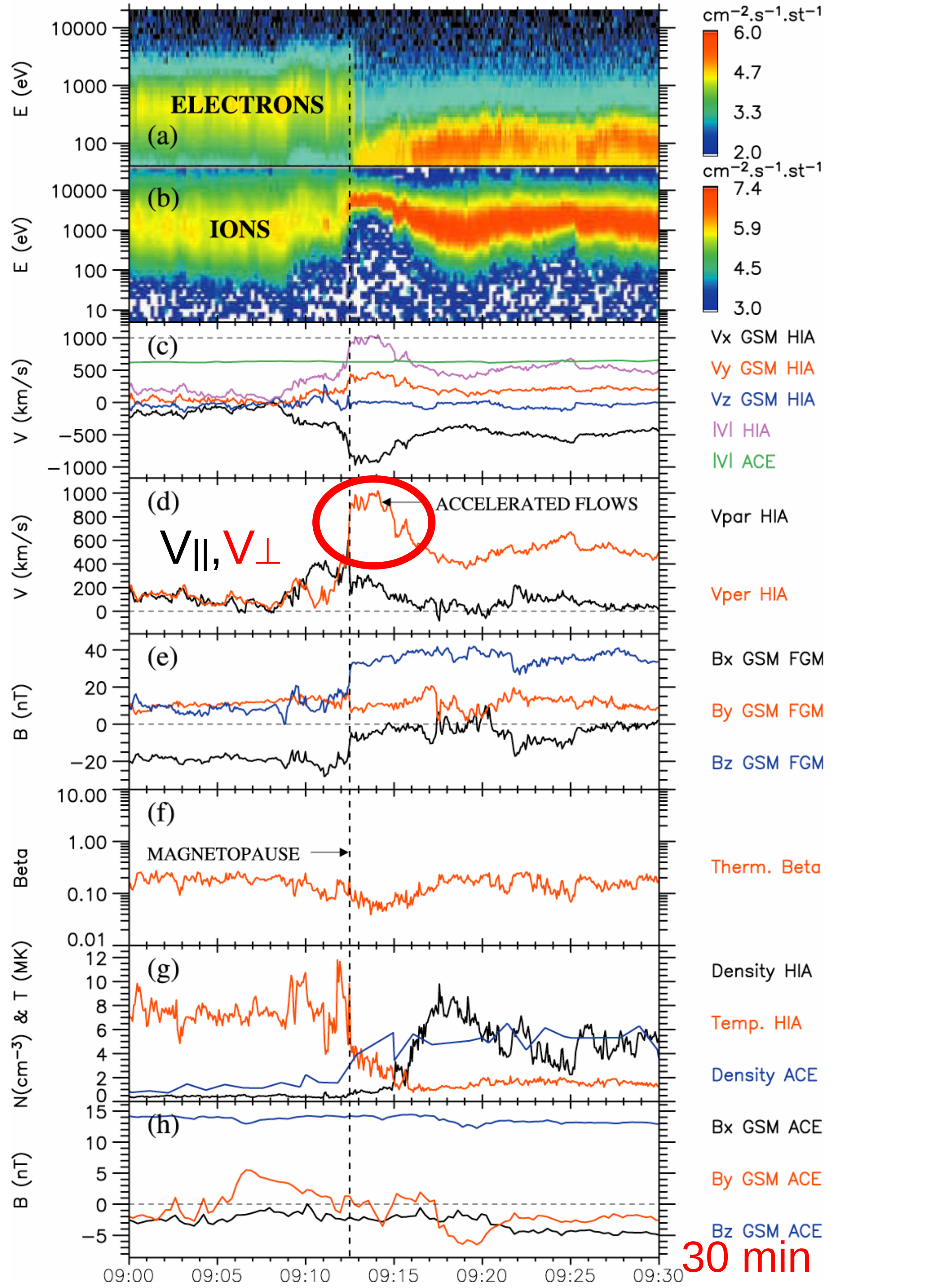
- **observed by Wind and LP**
- **far upstream of the usual location**
  X>40 Re (Apr and Mar 1999)



Low-density
= low Alfven Mach number

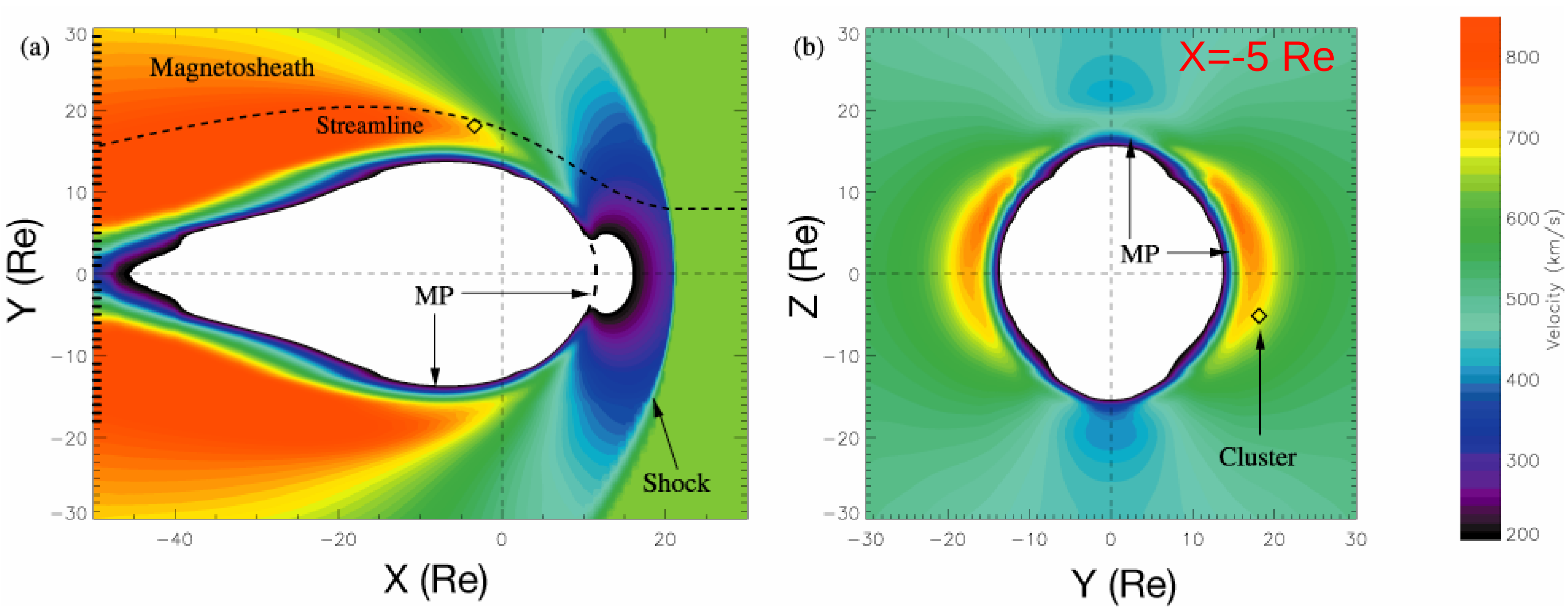
Chance for
more magnetic effects
to be visible!

- **Lavraud et al. GRL (2007)**
- **Cluster observation**
  - **jet in the magnetosheath**
  - **near the magnetopause**
  - **under low-density solar wind**

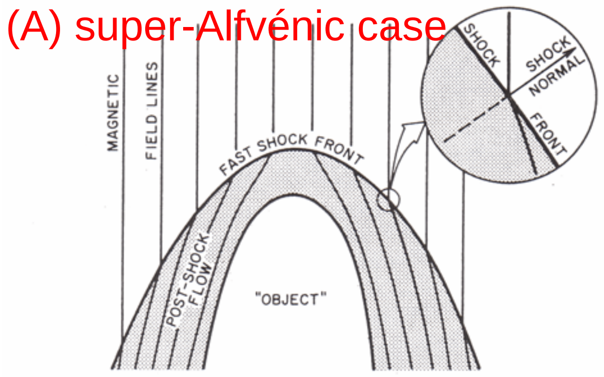


Mechanism revealed by CCMC simulations

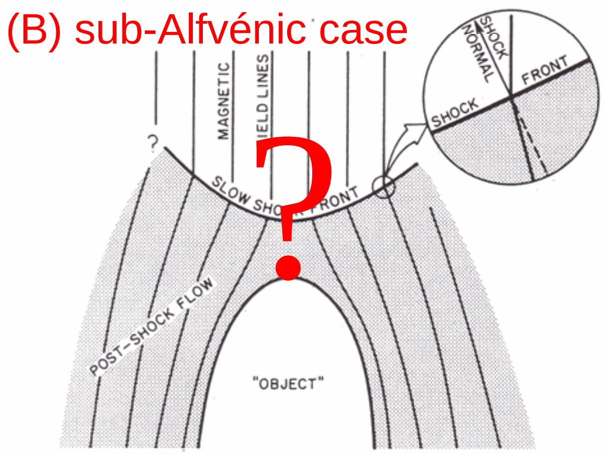
- **Lavraud et al. GRL (2007)**
  - **global MHD simulation**
- **acceleration mechanism**
  - **magnetic tension force**
  - **magnetic pressure gradient**



A more extreme case can be of more fun



a. Spatial Configuration of a "Fast" Bow Shock



b. Proposed Spatial Configuration of a "Slow" Bow Shock

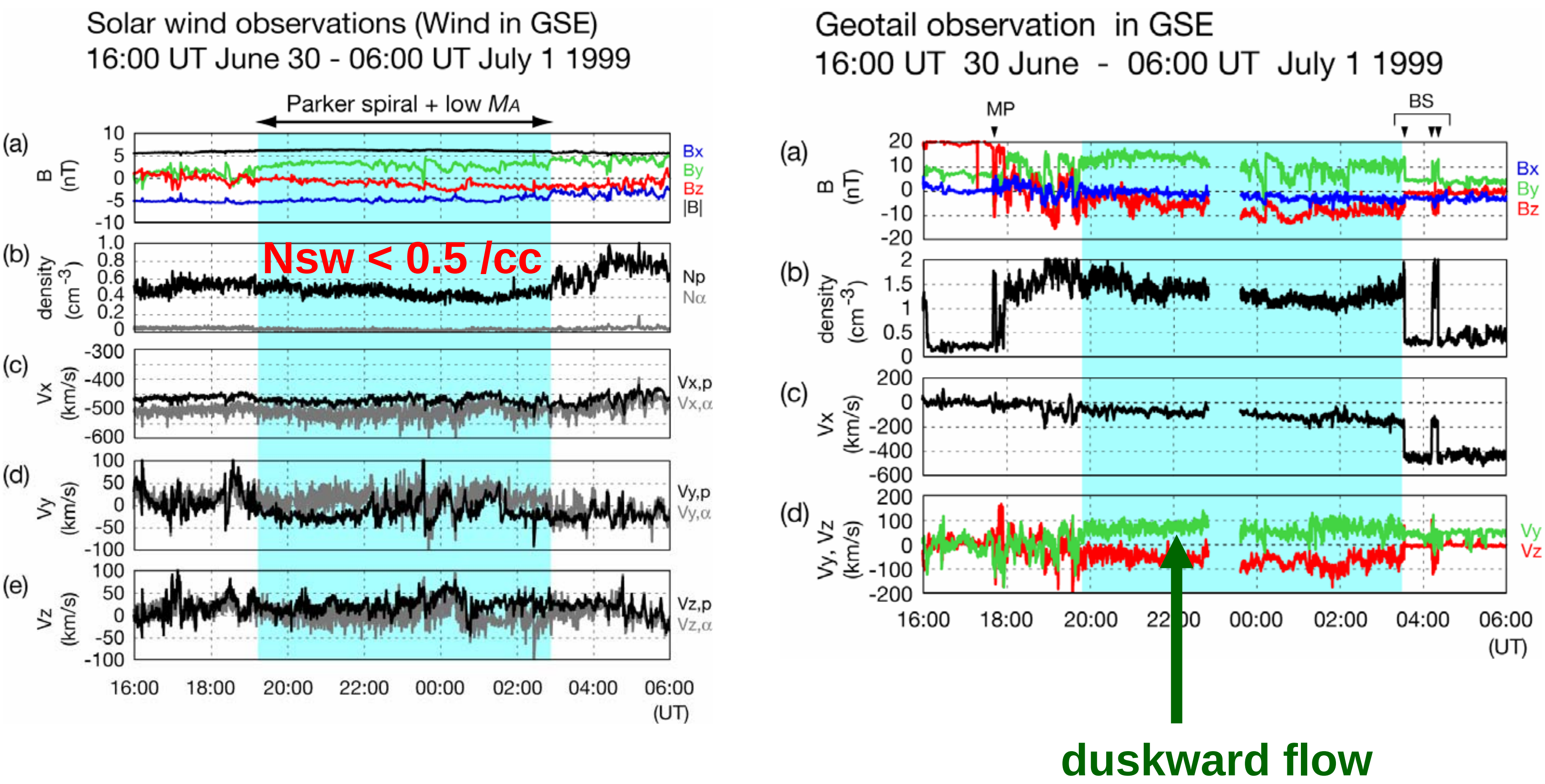
a slow-mode BS

(Hundhausen et al. 1987)

- **reverse curvature of the BS ?**
  - **under radial IMF**

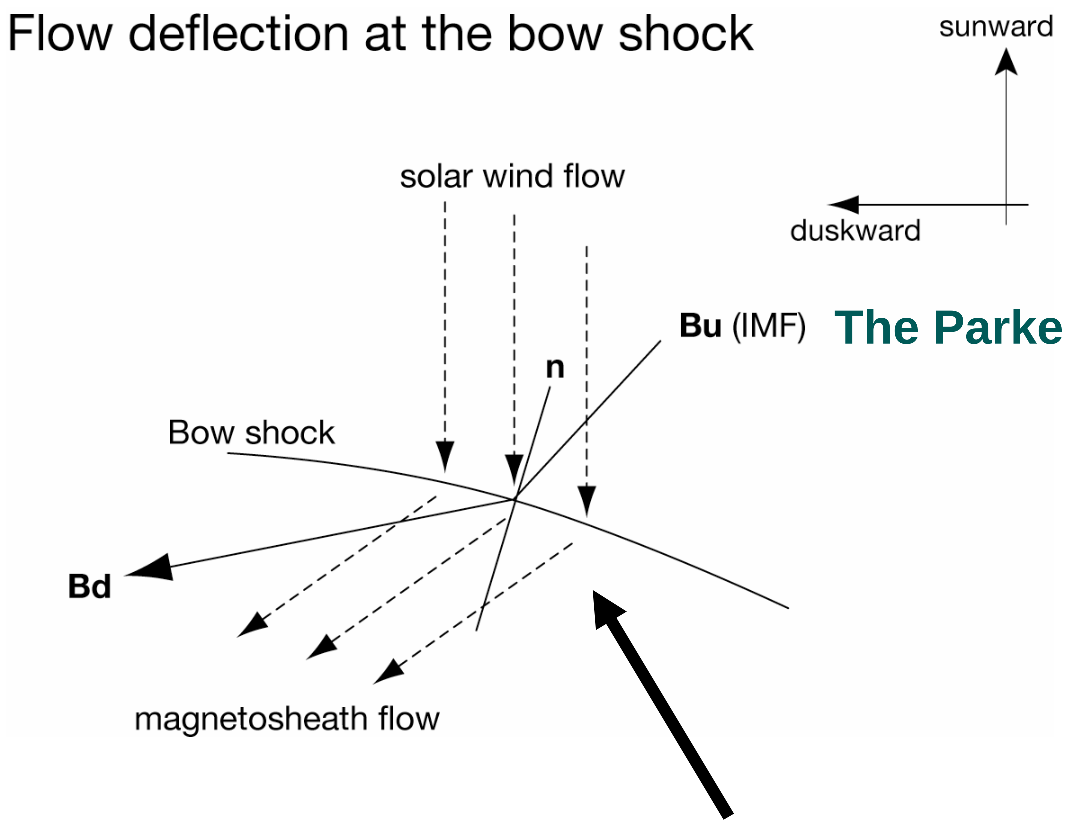
GT observations:
An equally curious feature detected

Concurrent SW: low denisty, Parker spiral



What occurs at the bow shock

- **flow deflection**
  - **duskward** flow in the magnetosheath on the **dawnside**



The Parker spiral

not simple gas dynamics but magnetic field-dominated dynamics

Should be nice to demonstrate it by global MHD simulations beyond the simple local argument

- We had worked for years with a global simulationist in Japan but

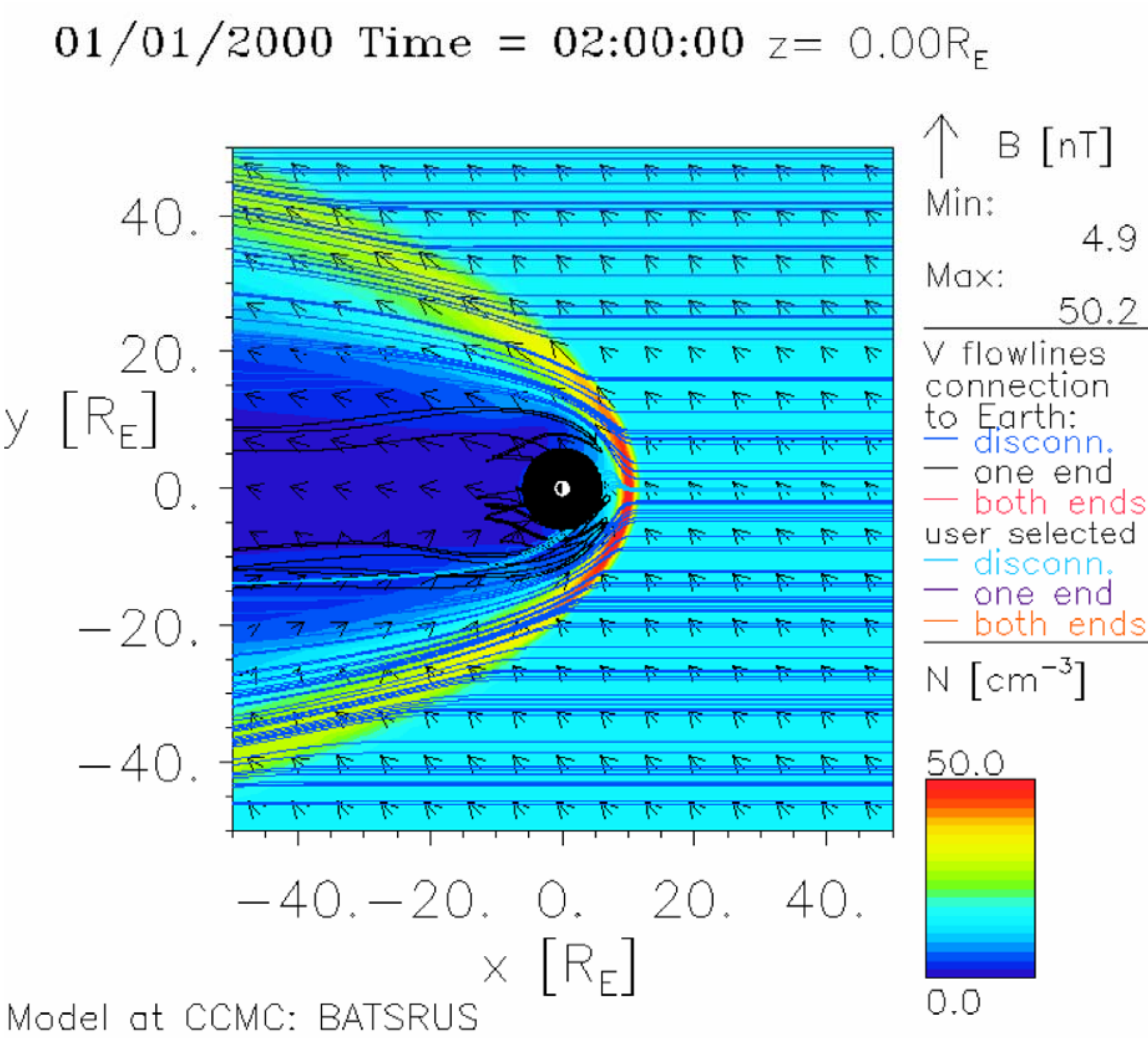
- Curious but rare: not truly exciting for a space-weather oriented person
- Demanding: requires dedicated works such as survey over parameter space and fine-tuning of simulation setting

- After all, we could not reach a publishable level.

- Then Nishino, after reading Lavraud et al GRL07 paper, happen to realize that handling this issue via CCMC can be worth giving a try.
- We still had the concern that it may be too demanding but we decided to give it a try.

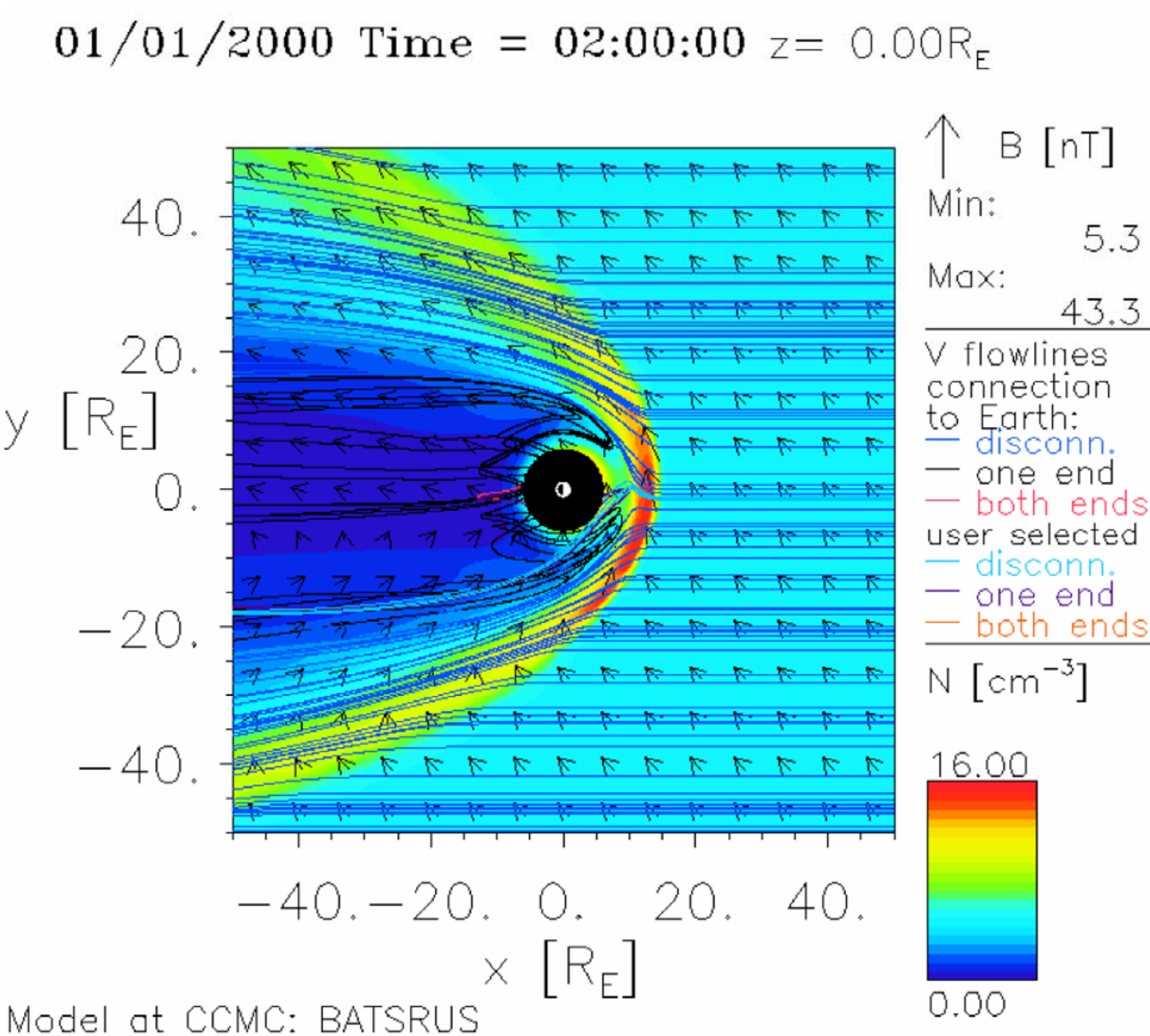
Learn by experience:
the first run with a normal SW condition MA=5.4

- SW conditions
  - normal SW parameters
  - Parker spiral IMF
  - MA=5.4
- output
  - quasi-symmetric MSH in shape



Approaching: slightly low MA=3.2

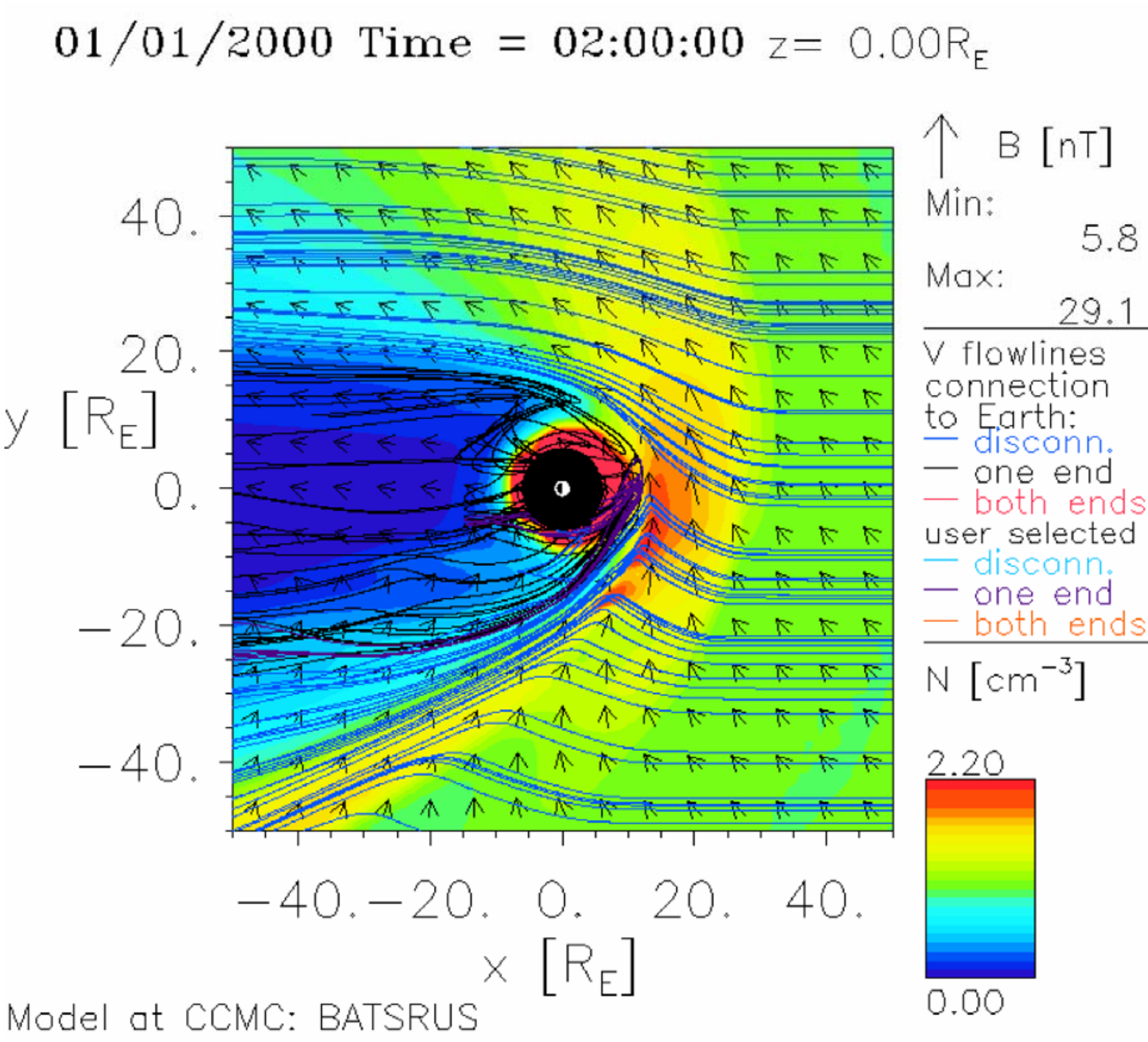
- SW conditions
  - MA=3.2
  - Parker spiral IMF
- output
  - slight asymmetry in shape



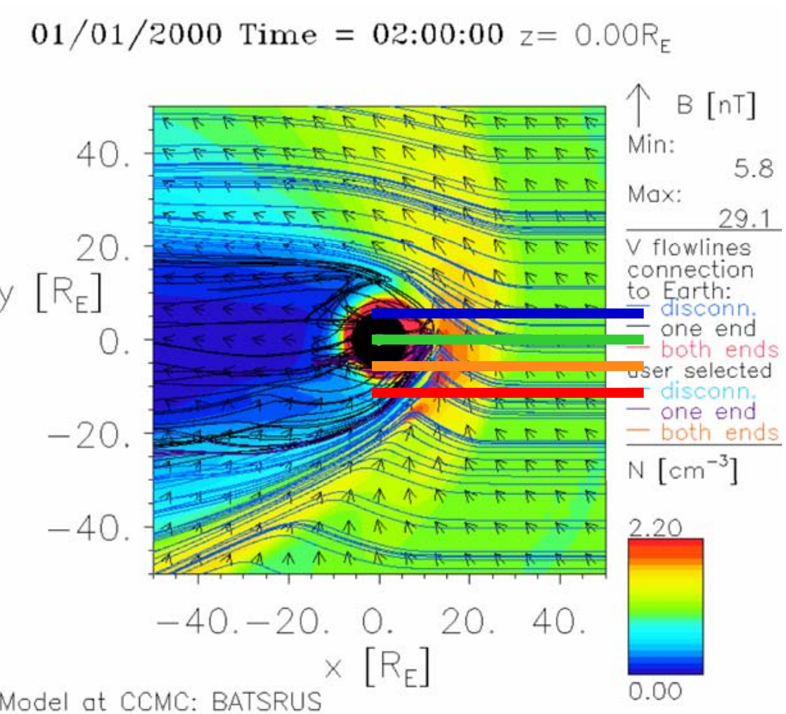
The target case MA=1.4

- **upstream conditions (low MA, Parker spiral)**
  - **B=(-10, 10, 0) nT, |B|=14.14 nT, Clock Angle: 90.0 deg**
  - **Tsw=10 eV**
  - **Nsw=1 cm^{-3}**
  - **Vsw=(-432, 0, 0) km/s**
  - **MA=1.4, beta=0.02 … magnetic field dominated SW**
- **size of simulation box**
  - **X=+100, –682 Re**
  - **Y, Z=±284 Re**

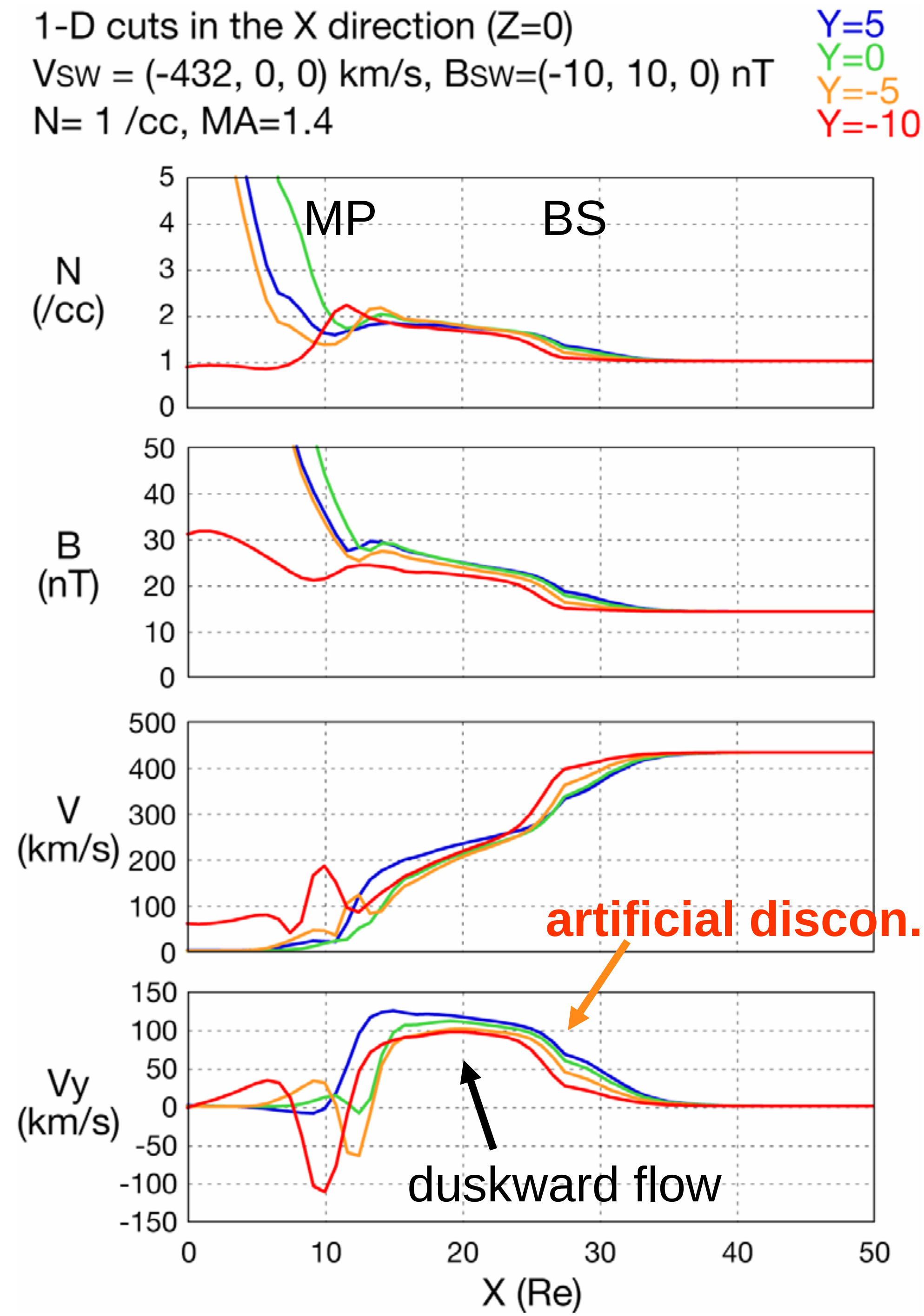
- thickening of the magnetosheath
- unusual BS location
- flow deflection at the BS
  - **duskward flows in the magnetosheath under Parker spiral IMF**
- dawn-dusk asymmetry of the magnetosphere in shape



1-D cuts



01/01/2000 Time = 02:00:00 z= 0.00R_E
B [nT]
Min: 5.8
Max: 29.1
V flowlines
connection
to Earth:
disconn.
one end
both ends
user selected
disconn.
one end
both ends
N [cm^-3]
2.20
0.00
y [R_E]
x [R_E]
40.
20.
0.
-20.
-40.
-40. -20. 0. 20. 40.
Model at CCMC: BATSRUS



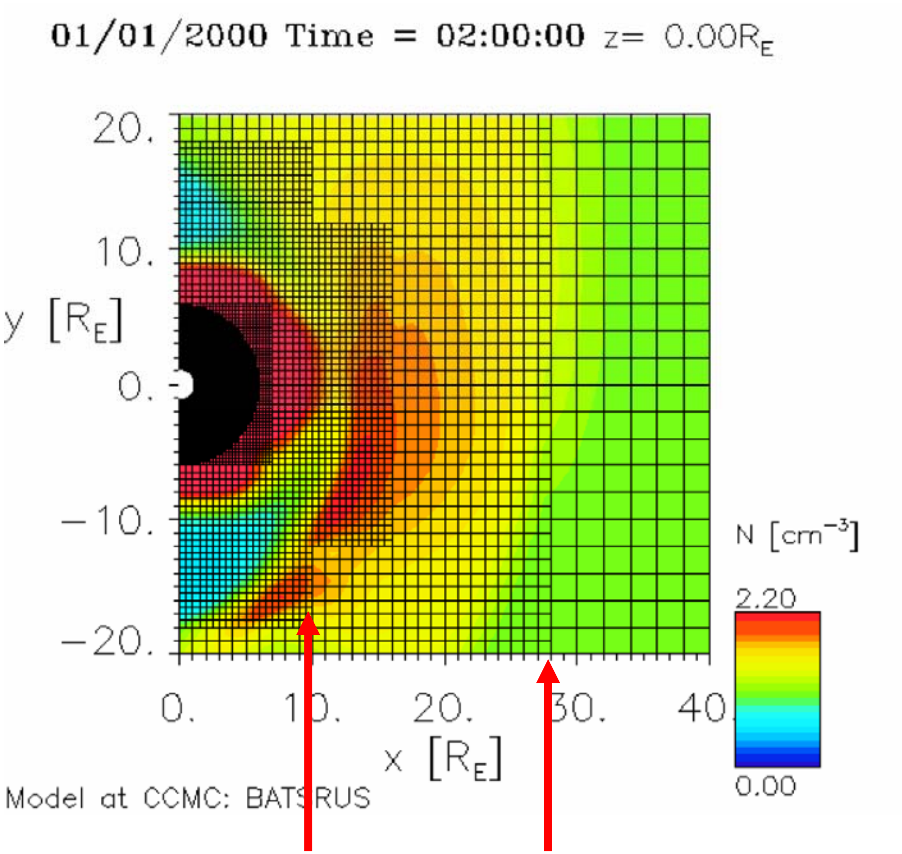
1-D cuts in the X direction (Z=0)
Vsw = (-432, 0, 0) km/s, Bsw=(-10, 10, 0) nT
N= 1 /cc, MA=1.4
Y=5
Y=0
Y=-5
Y=-10
N (/cc)
B (nT)
V (km/s)
Vy (km/s)
MP
BS
artificial discon.
duskward flow
X (Re)
0
10
20
30
40
50

Re-setting the grids

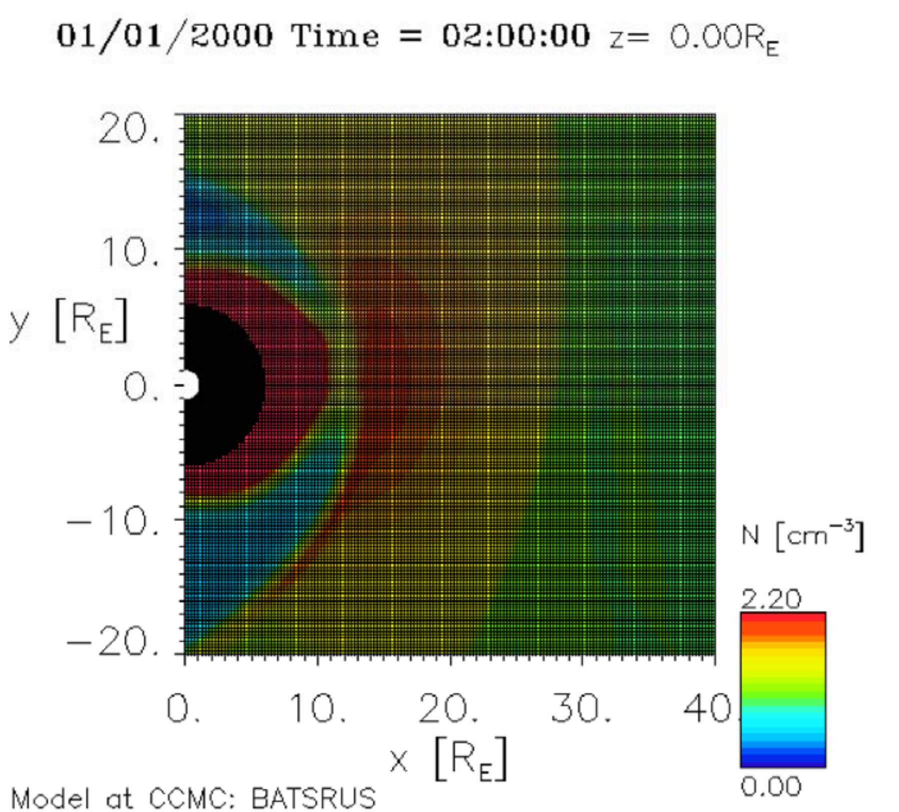
- The artificial discontinuity in the MSH is due to the border across which the grid size changes (0.25/0.5 Re).
- This is not problem for a normal case but is a problem in this case where the bow shock is located much farther upstream.

- We asked the CCMC staffs to change locations of the border of the grid size as well as the grid size itself.
- Request for such a demanding run was accepted simply via exchange of a few email messages!

before and after

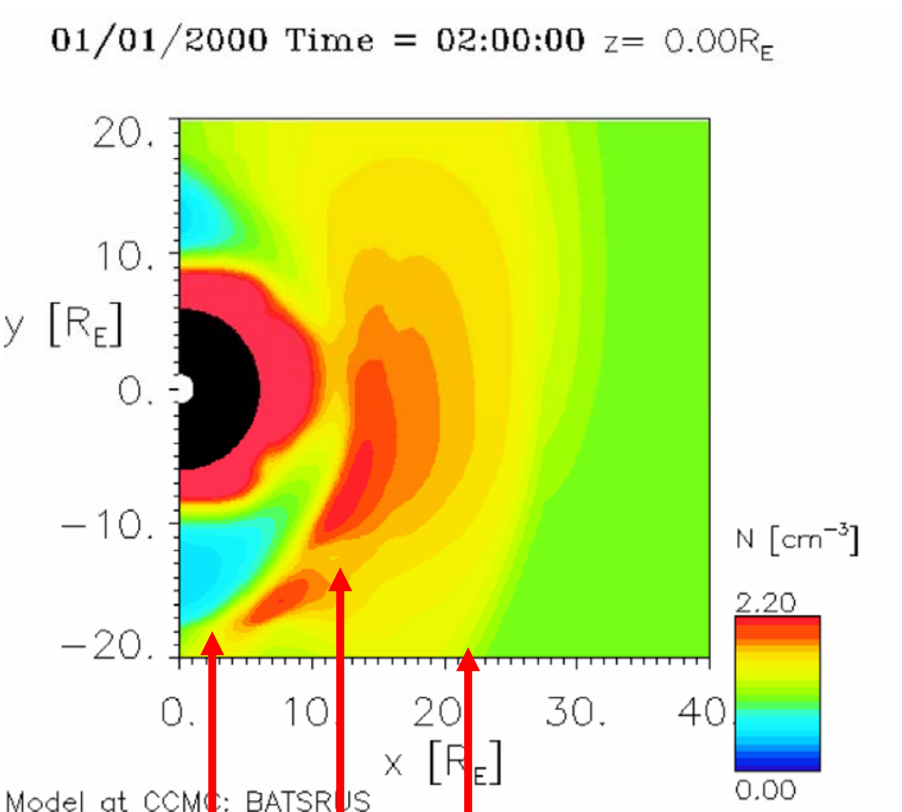


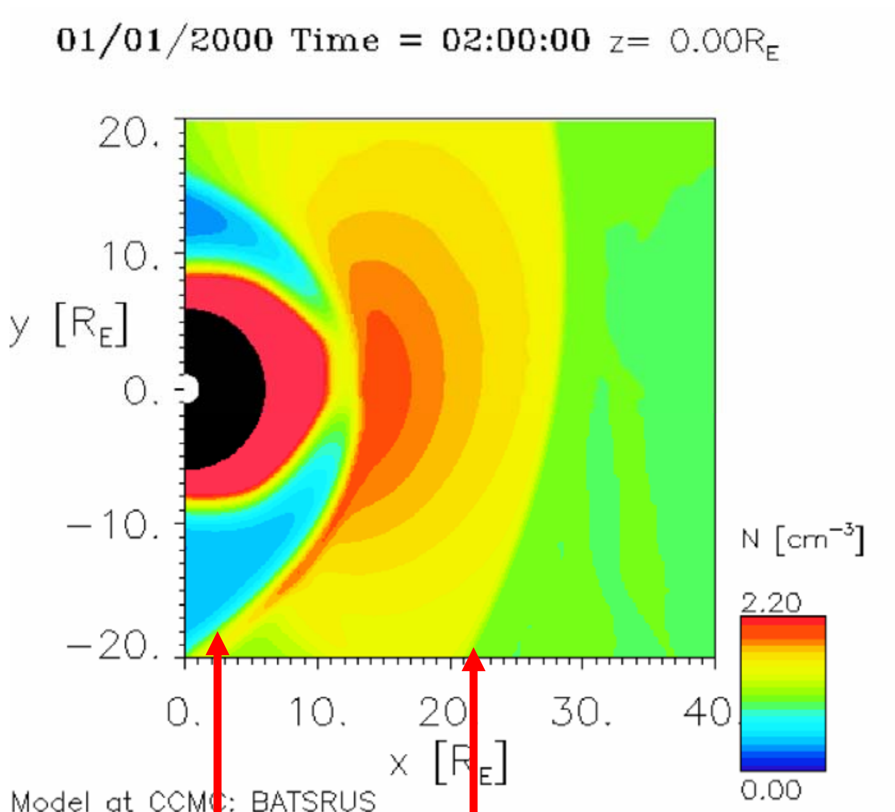
borders of grid size



no border in the near-Earth region

before and after





MP BS

artificial structures
due to the grid-size borders

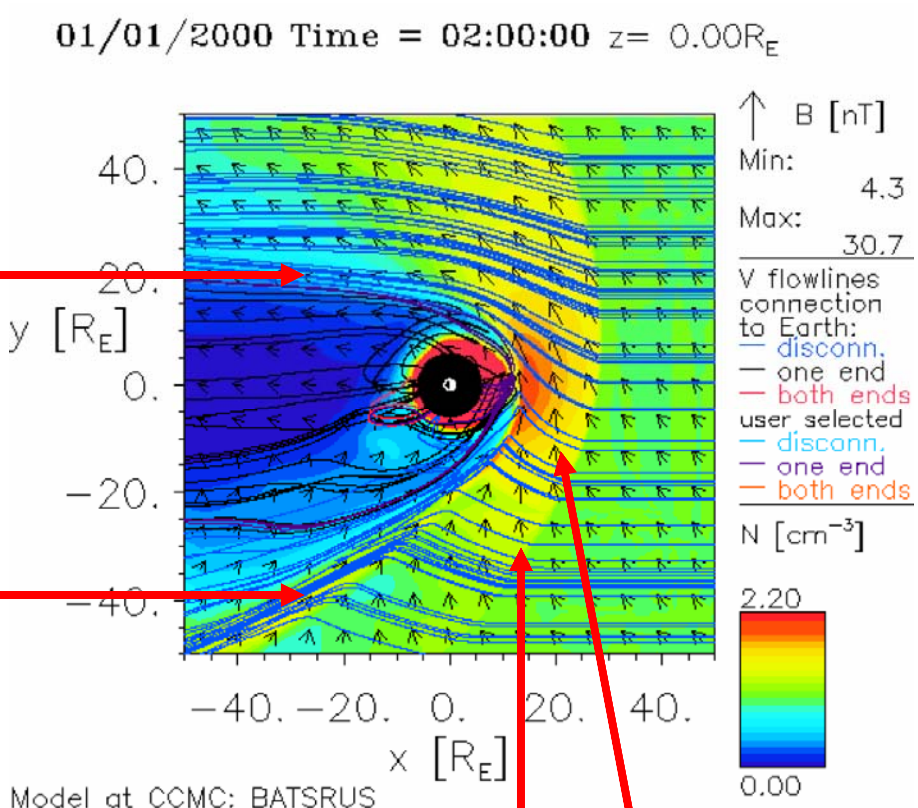
MP BS

No artificial structures !

Finally: Real synergy between obs and sim

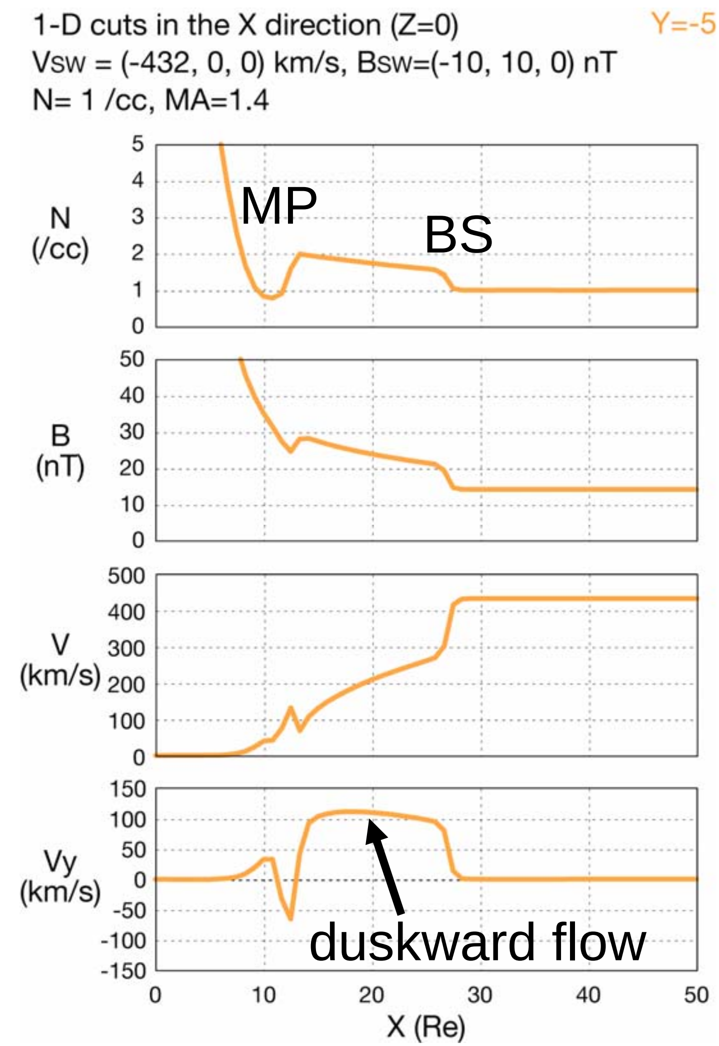
dusk MP
Y=+20 Re

dawn MP
Y=-40 Re



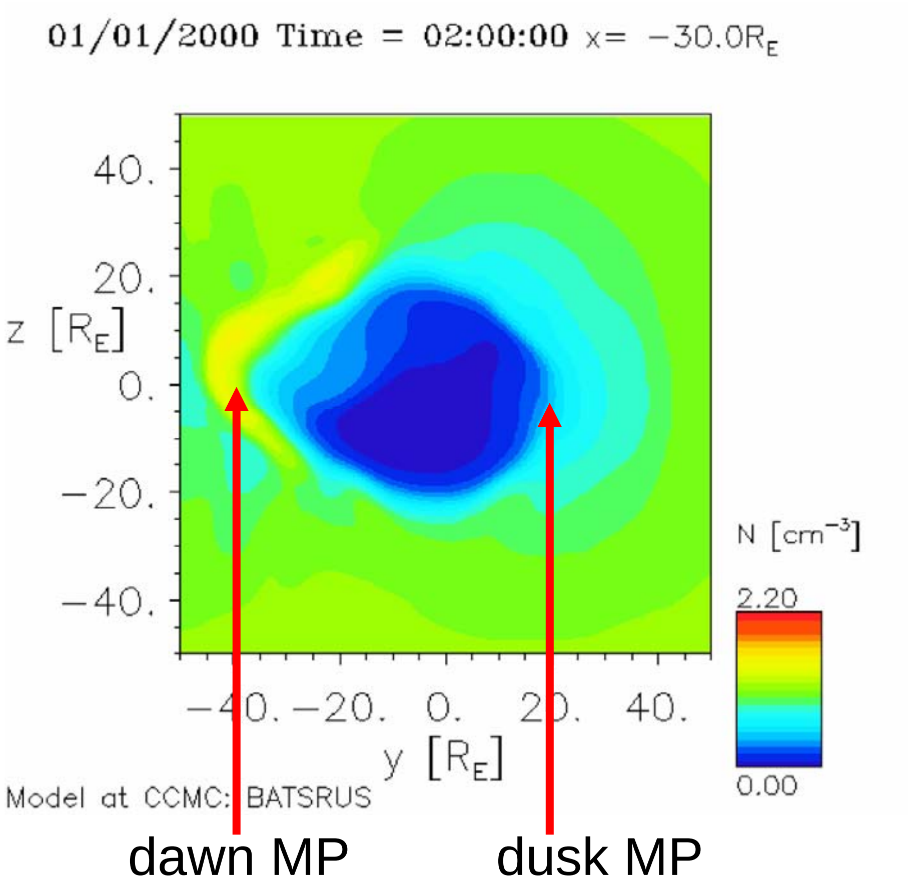
BS

duskward flows

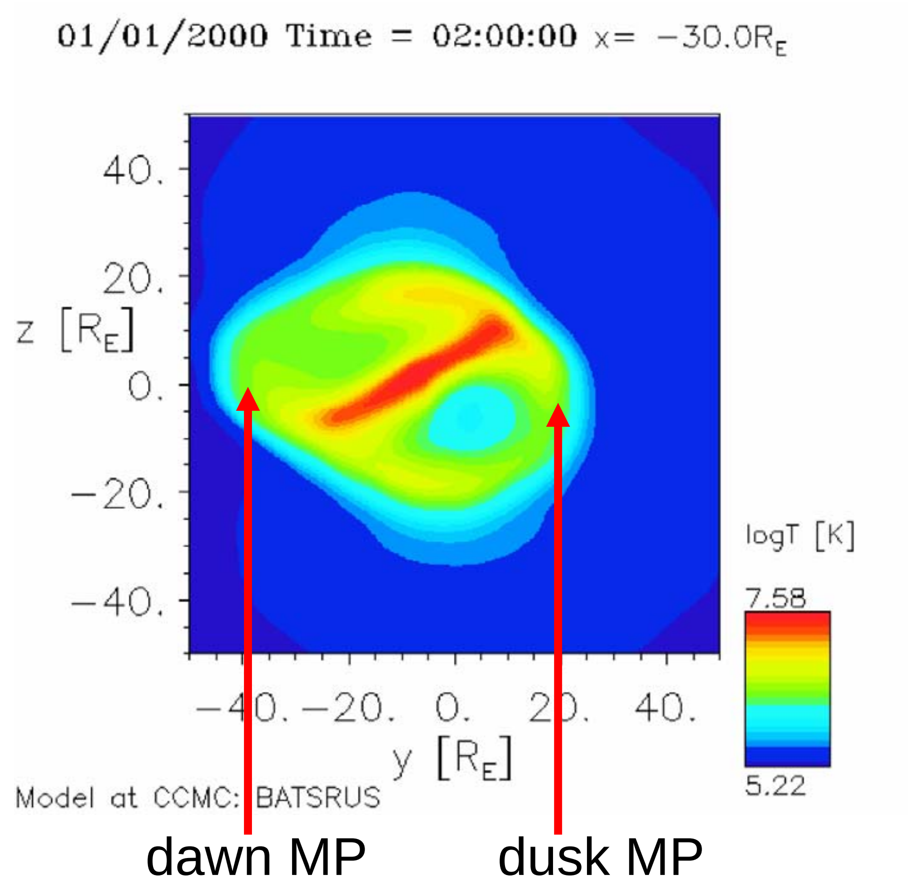


Dawn-dusk asymmetry at X=-30 Re

Density



Temperature



Summary

- **Hearty thanks to the CCMC staffs!**
- **Synergy between observations and (global) simulations is important and can be rather easy via CCMC**

  - It is not just a reporduction of observations

This is exactly what we have been doing with local simulations, but CCMC enables us to do the same with global simulations.

Summary

- **Hearty thanks to the CCMC staffs!**
- **Synergy between observations and (global) simulations is important and can be rather easy via CCMC**

  - It is not just a reporduction of observations

Ideas at ISAS space plasma group for utilizing the power of CCMC

- More on the magnetosphere under low MA SW
- Geotail/Cluster/THEMIS studies

  (tail-structure before substorm onset, BBF-dipolarization relationship, …)
- Heliosphere simulation coupled with Hinode-VEX-Geotail/ACE/STEREO-MEX data study
- Heliosphere simulation coupled with ground-based observations of Mercury’s sodium atmosphere
- Mercury magnetosphere

  (science preparation for the BepiColombo mission)