MHD simulation of Kronian magnetosphere with high resolution solar wind data by Cassini

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100th Anniversary

Context

Simulation of the Kronian magnetosphere using the solar wind data observed by Cassini

Introduction

- Previous simulation results of turbulent magnetosphere
- Motivation

Simulation Setting

- Solar wind condition from Cassini

Simulation Results

- Initial simulation results

Summary

Introduction | Turbulent magnetospheric convection

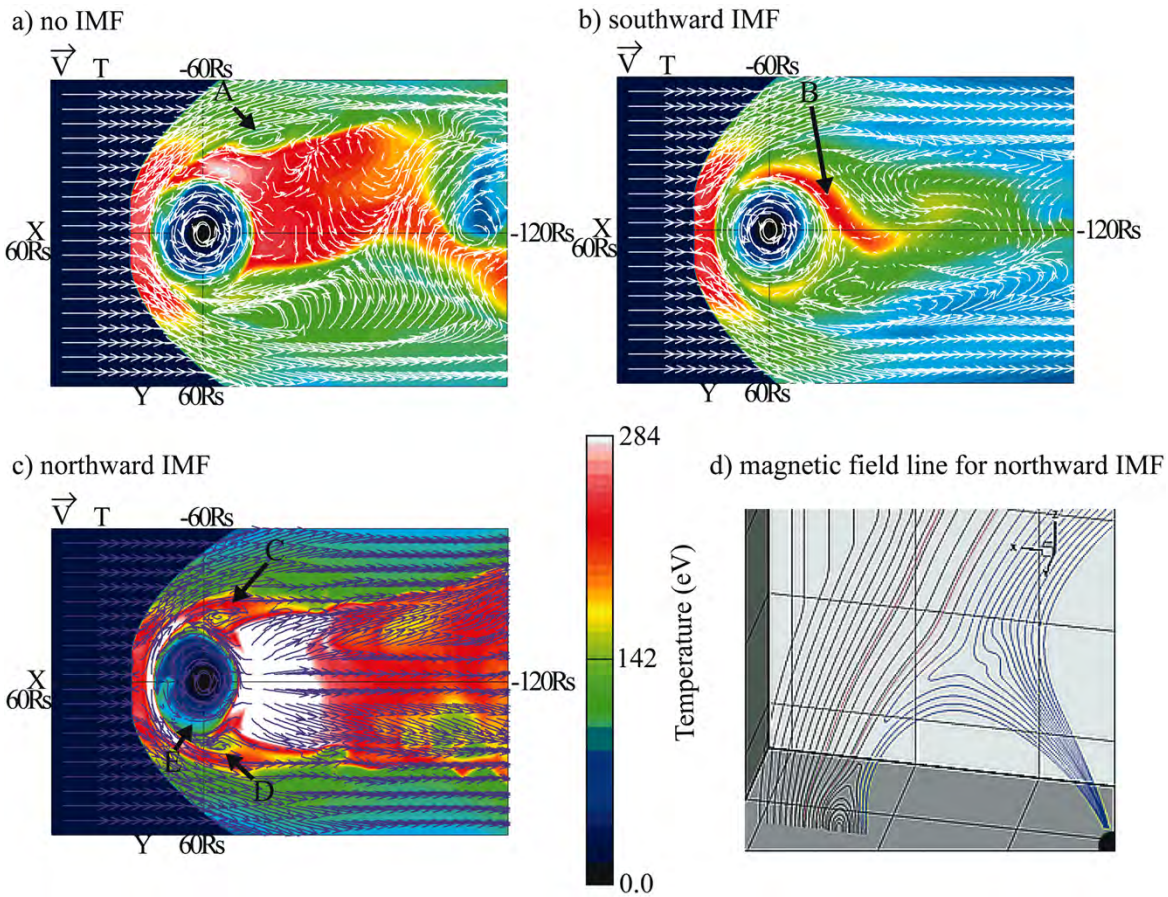
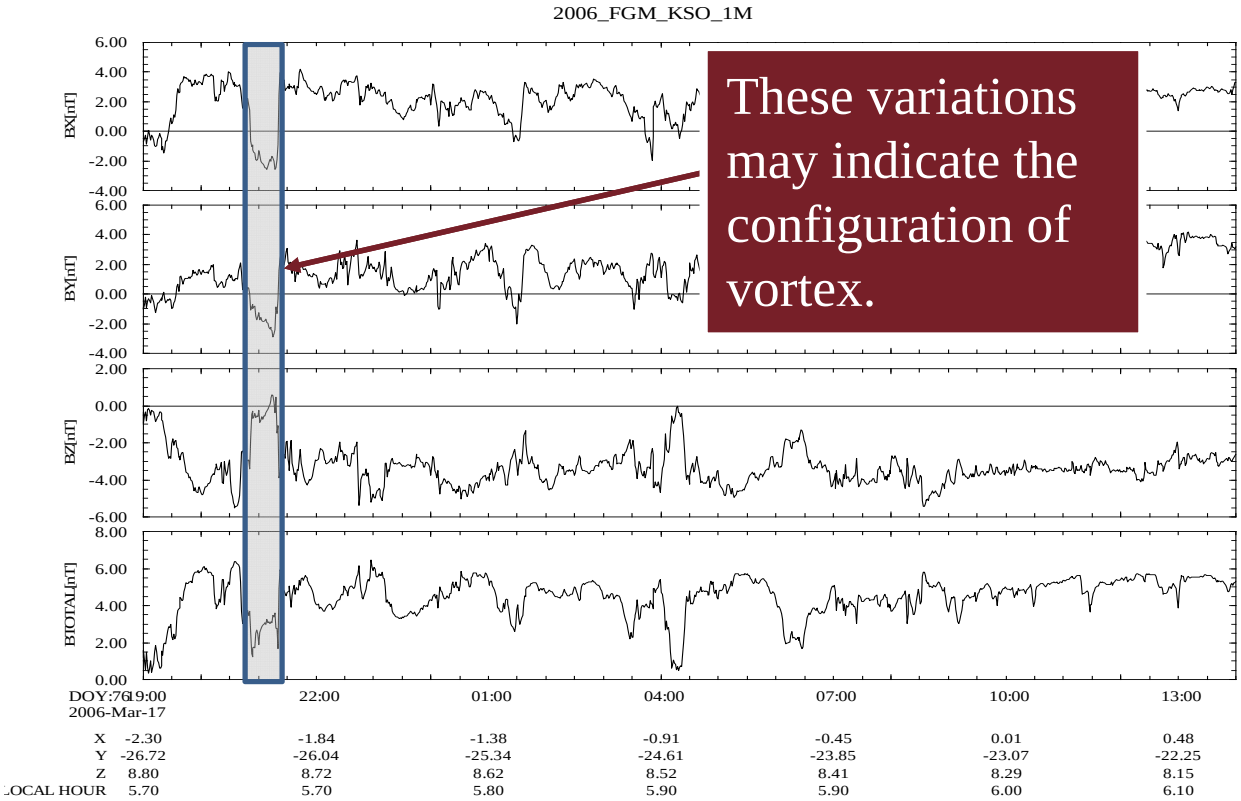


Fig.1. The temperature and flow vectors in the equatorial plane for the simulations with no IMF (a), southward (b) and northward IMF (c) [*Fukazawa et al.*, 2007a]

In our early simulation results, the vortex and turbulent convection are appeared in the Kronian magnetosphere for three IMF (no / southward / northward) cases from the early simulation results.

Introduction | Vortex at dawn in the observations by Cassini



These variations may indicate the configuration of vortex.

Fig. 1. One minute averages of Cassini magnetic field observations in KSO coordinates (X – Saturn to Sun, Z-upward normal to Saturn's orbital plane, Y – completes a right handed system) on March 17 and 18, 2006 [*Walker et al.*, 2011].

Masters et al. [2009] studied Cassini magnetic field and thermal plasma observations at the dawn magnetopause to infer tailward propagating surface waves on the boundary and suggested they were caused by the K-H instability.

Introduction | Simultaneous observation of HST and Cassini

Cassini observed the upstream solar wind of Saturn and HST took the aurora of Saturn

Enhancement of aurora emission at dawn side occurred in the CIR hitting the magnetosphere

Is this phenomena related to the disturbed convection and vortices of Kronian magnetosphere?

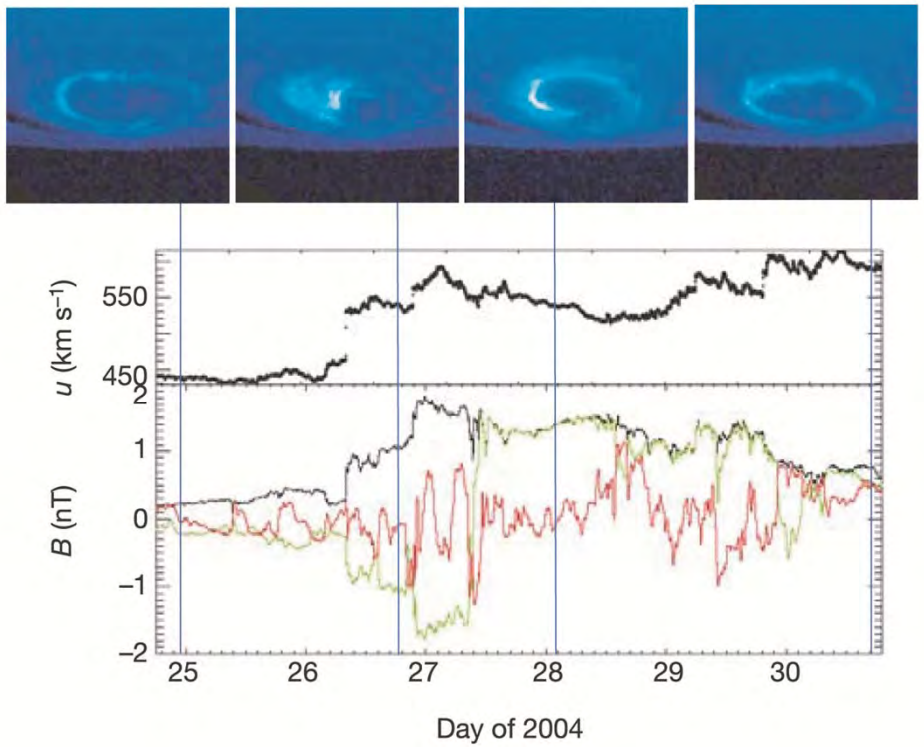


Fig.3. Comparison between HST images and solar wind conditions propagated to Saturn for the period 25–30 January 2004 [*Crary et al.*, 2005].

Introduction | Vorticity on equatorial plane

Recently we can simulate with the fine resolution thanks to the large scale simulation project in Japan.

Vortices are formed along the both dawn and dusk magnetopause

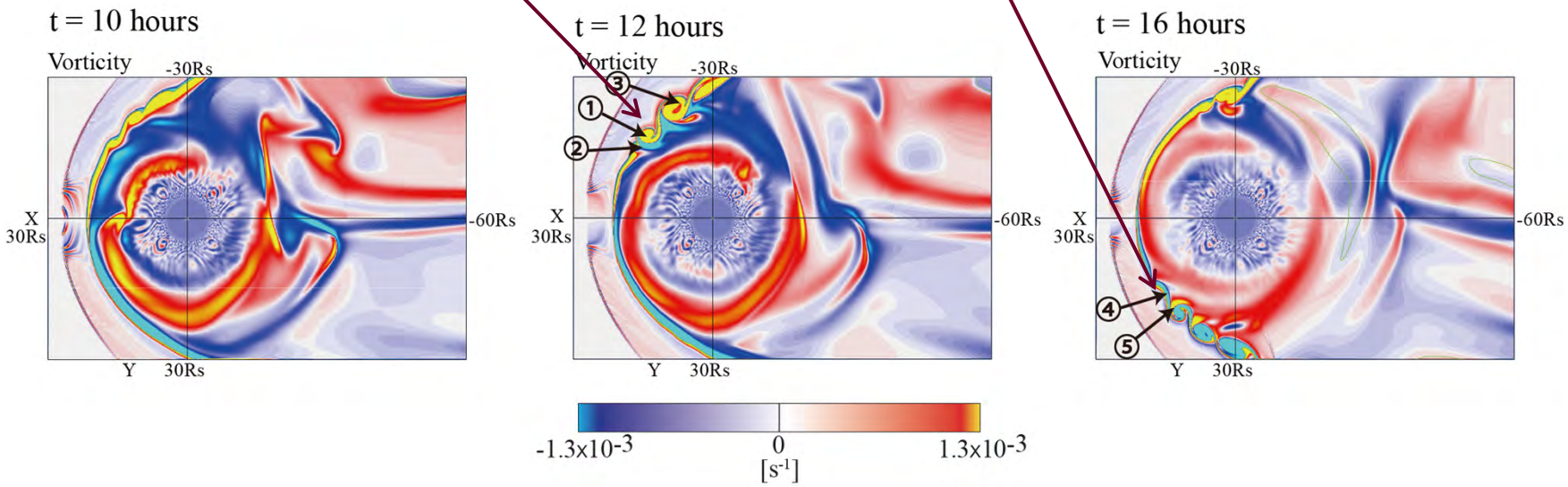


Fig.4. The vorticity parallel to the magnetic field in the equatorial plane at t = 10, 12, and 16 h. Vorticity with blue represents the clockwise motion, and red represents the anticlockwise motion [*Fukazawa et al.*, 2012].

Introduction | FACs on polar southern ionosphere

Patchy and spot like feature is appeared due to the vortices

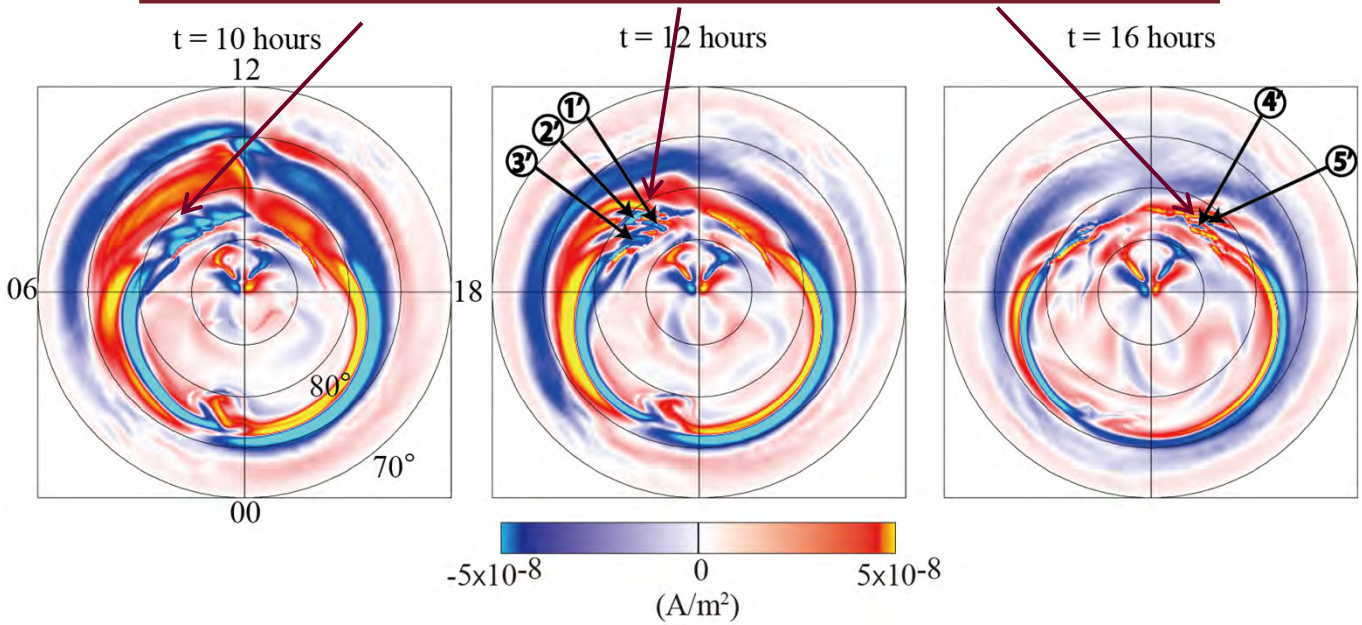


Fig.5. The distribution of field-aligned currents (FACs) in the southern polar cap mapped along the magnetic field lines from the simulation results to the southern ionosphere at t = 10, 12, and 16 h [*Fukazawa et al.*, 2012].

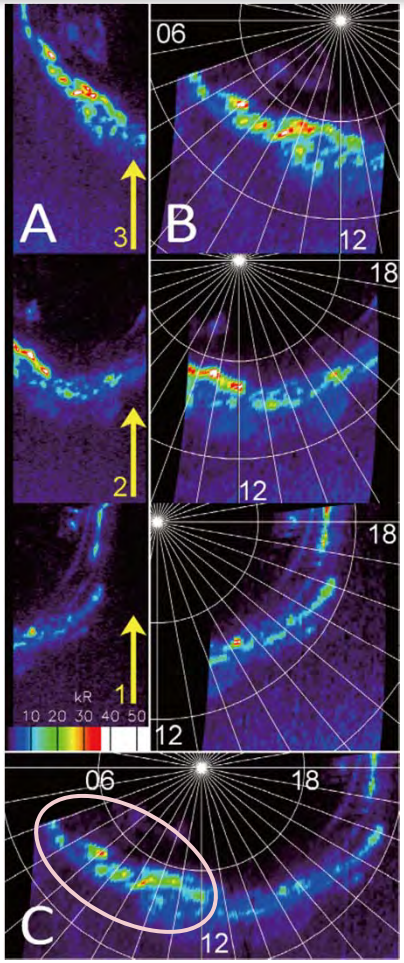


Fig. 6. Pseudoimages obtained with the FUV channel of the Cassini - UVIS spectro - imager on DOY 239 (26 August) of 2008 [*Grodent et al.*, 2011].

Motivation

Simulation of Kronian magnetosphere using the solar wind data observed by Cassini

We want to understand the real relationship between the solar wind effect and response of the Kronian magnetosphere.

In February 2008 Cassini observed the solar wind upstream the Saturn and HST observed the Kronian aurora simultaneously.

Recently we obtain the computer resources and can perform the simulation with fine resolution.

Simulation Setting

Fine resolution (Grid interval 0.1R_S)

- We can obtain the small FACs configuration with this grid spacing

Grid size

- (nx, ny, nz, nmhd) = (1800, 1200, 1200, 8) → about 84GB
- Use 7 times larger memory (600GB) than the grid size in the calculation

Time scale

- Calculate for 12hours in the real time
- To create the initial data (quasi-steady state), we calculated for 40hours.

Simulations run on the supercomputer

- Sugoka X86 cluster (Fujitsu PRIMERGY RX200S6) at the Research Institute for Information Technology, Kyushu University
- 768 cores is available for 2160hours (CPU time) as this collaboration research

Parallelization by MPI

- Three dimensional decomposition

Difficulty of Large Scale Computing

Long calculation time is needed

- It takes *one year* to run this simulation if including the job waiting time.

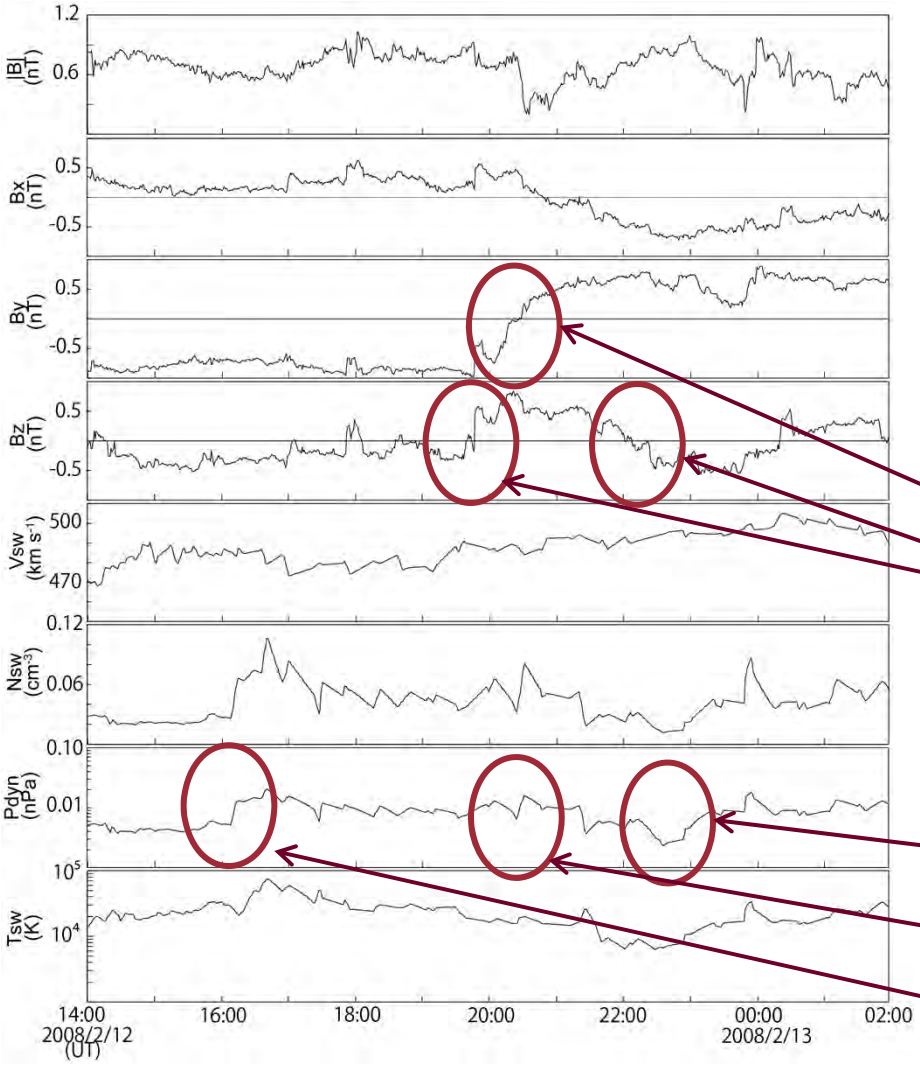
Large storage is required

- One time step data size is 84GB and we have 300 sampling data then the all data size is 84×300=25TB!!
- In addition for the initial simulation data, we have 100 sampling data.
  →Now I use the Gfarm storage on NICT which is the Grid type storage.
  →This storage is connected by network thus the bandwidth is narrow.

Hard to analyze the simulation results

- To do with the simulation data, it need over 256GB shared-memory computer.
  →Now I use supercomputer not only for simulation but for analysis.
  →This is not effective because not interactive operation.

Solar Wind Data from Cassini



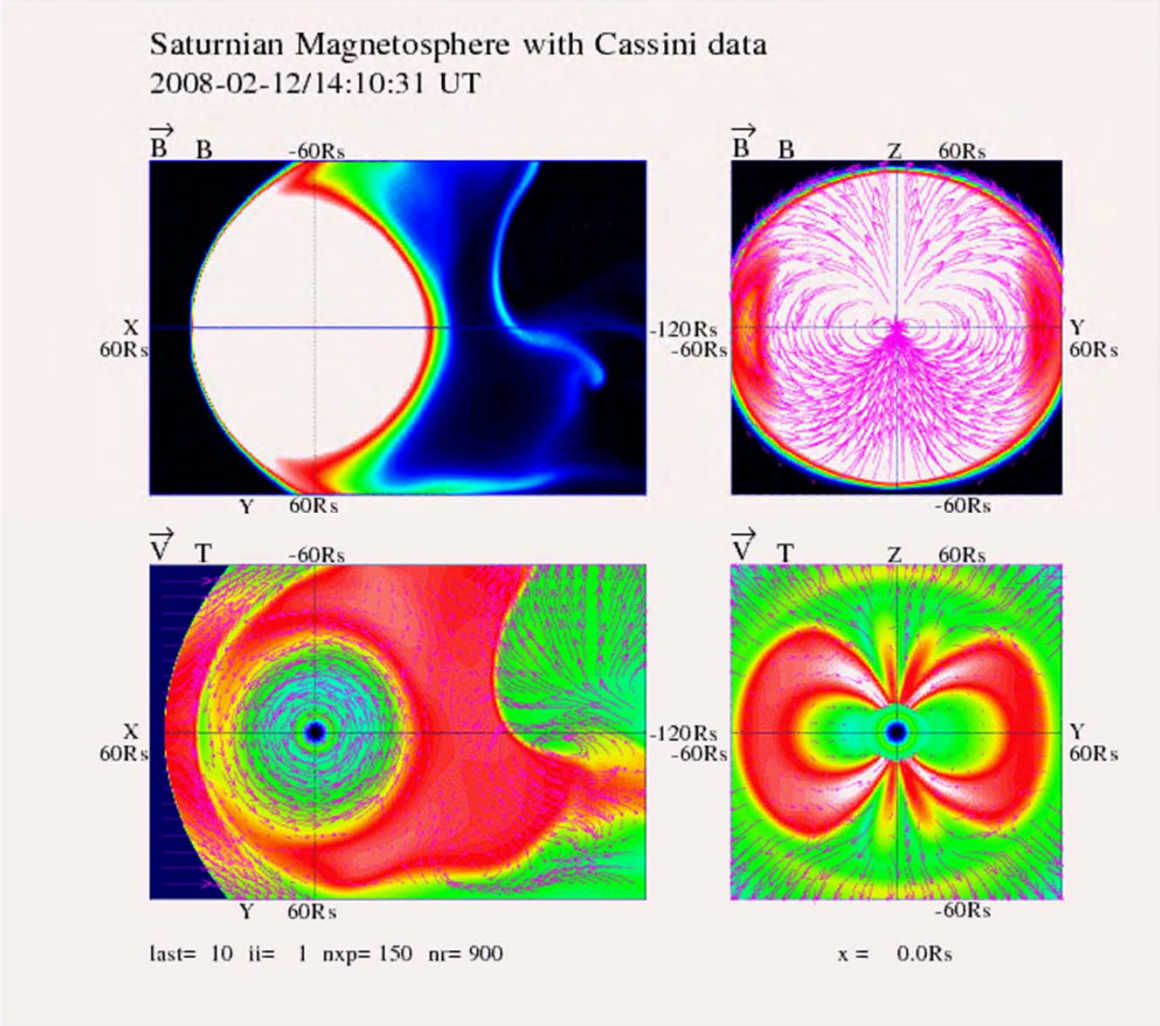
Cassini located at
$(X_{KSM}, Y_{KSM}, Z_{KSM})$ =
$(24.5–26.7R_S, -1.3–3.1R_S, 7.4–13.0R_S)$.

→Cassini was almost upstream the magnetosphere.

Polarity reversal

Enhancement of dynamic pressure

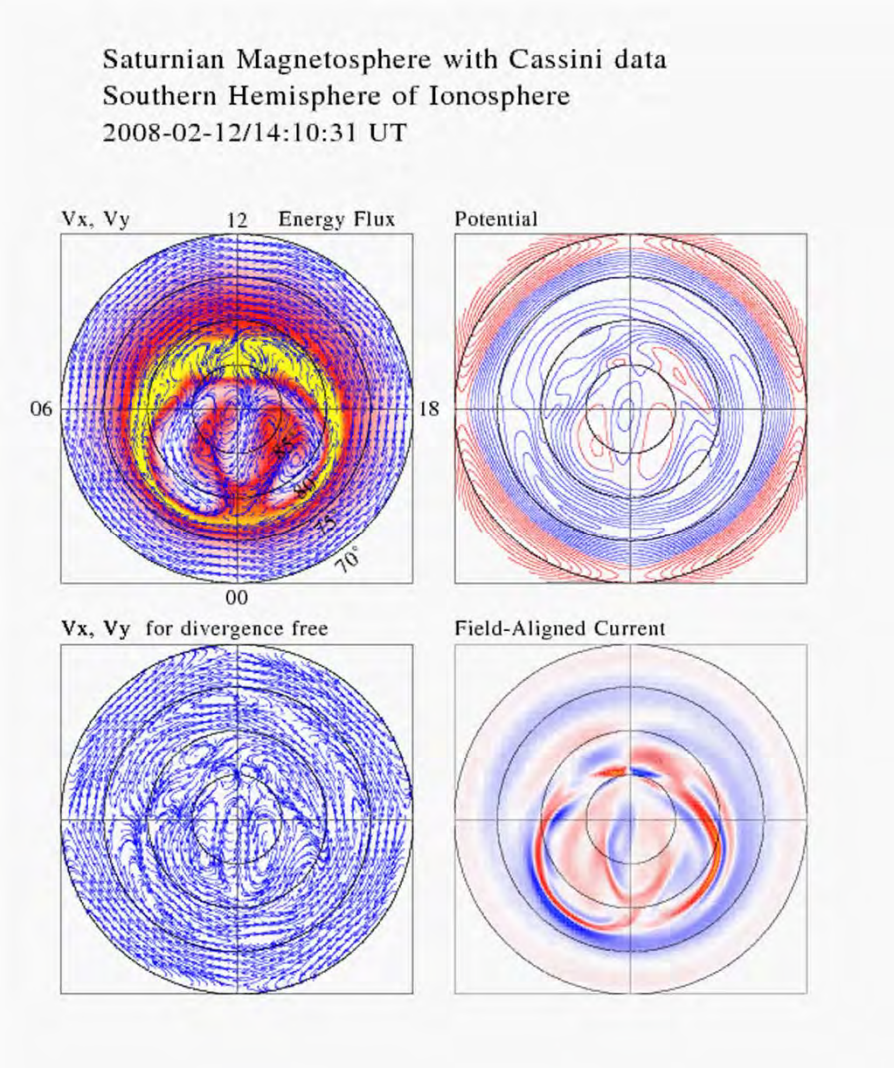
Simulation Results | Movie of equatorial plane



The position of magnetopause is varied dynamically then the magnetospheric convection becomes disturbed.

The big vortices are formed when the shock coming and they move into the tail.

Simulation Results | Configuration of polar ionosphere



When the shock coming, the energy flux expand to lower latitude around 12LT, then its expansion travel through the dawn and dusk to the midnight.

Shock makes the strong FACs and pacthy like configuration around 12LT. After 22:20, strong upward FAC is formed between 80° and 85°.

Observation Results in February 2008

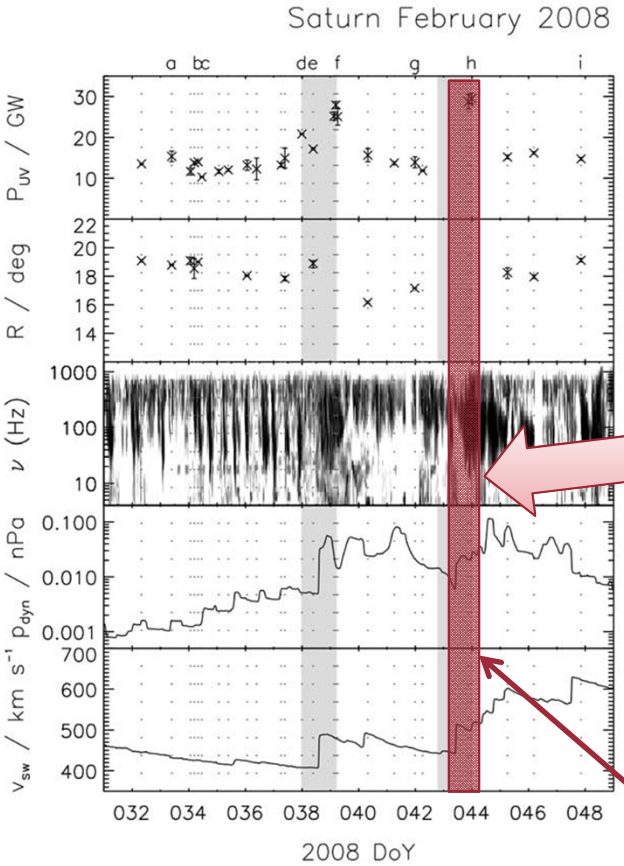


Fig.7. Total auroral power from Saturn's south polar region, best fit auroral oval radius, and SKR emission spectrum compared with propagated solar wind velocity and dynamic pressure in February 2008 [*Clarke et al.*, 2009].

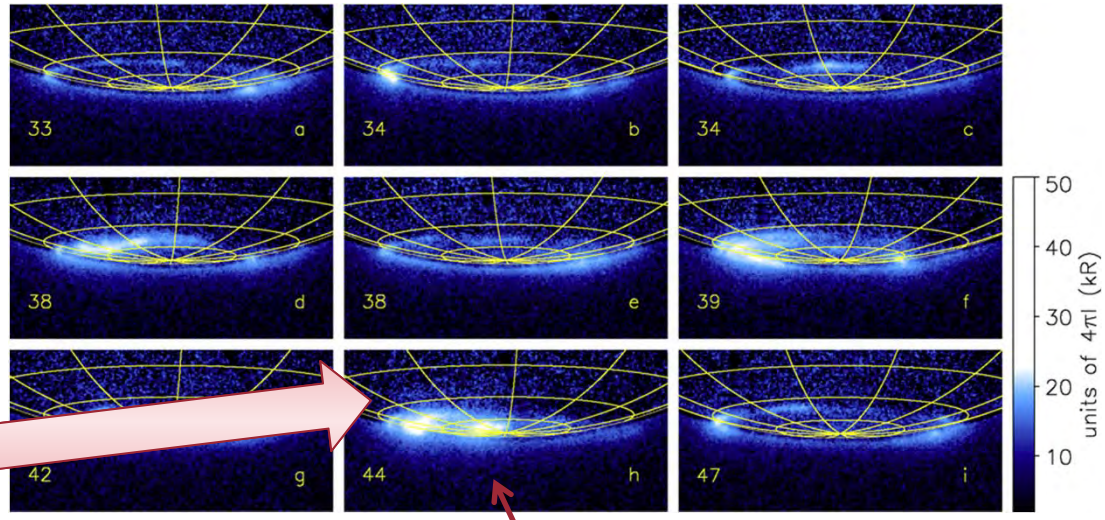
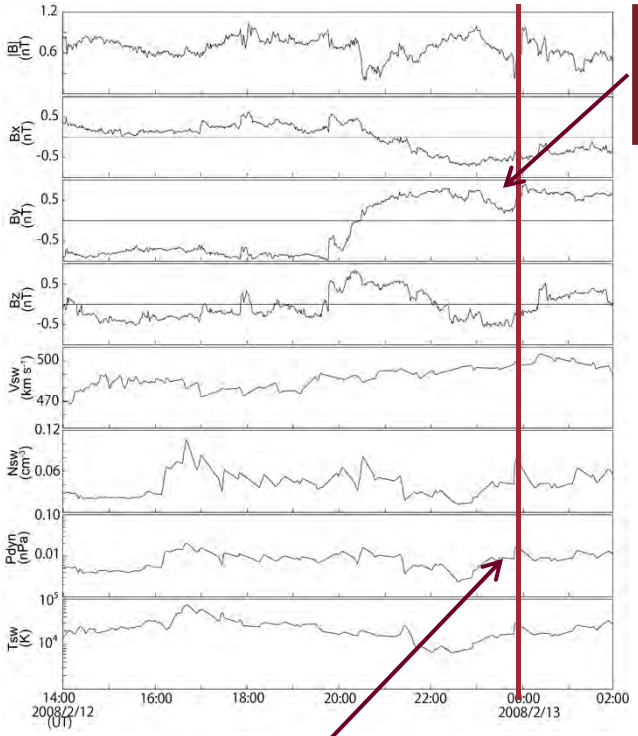


Fig.8. Sample UV images of Saturn's south pole in February 2008 with quiet and disturbed conditions [*Clarke et al.*, 2009].

This period is corresponding to the simulation period.

HST has just observed the UV image during this period.

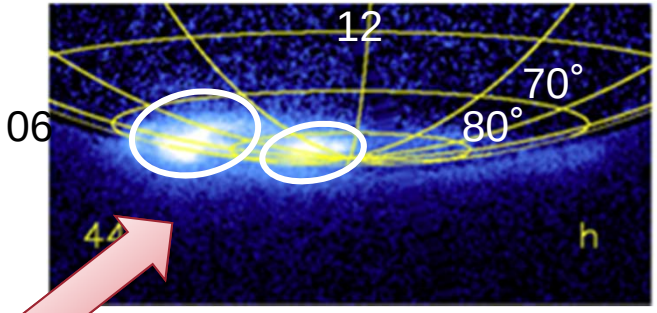
Comparison of Simulation with Observation

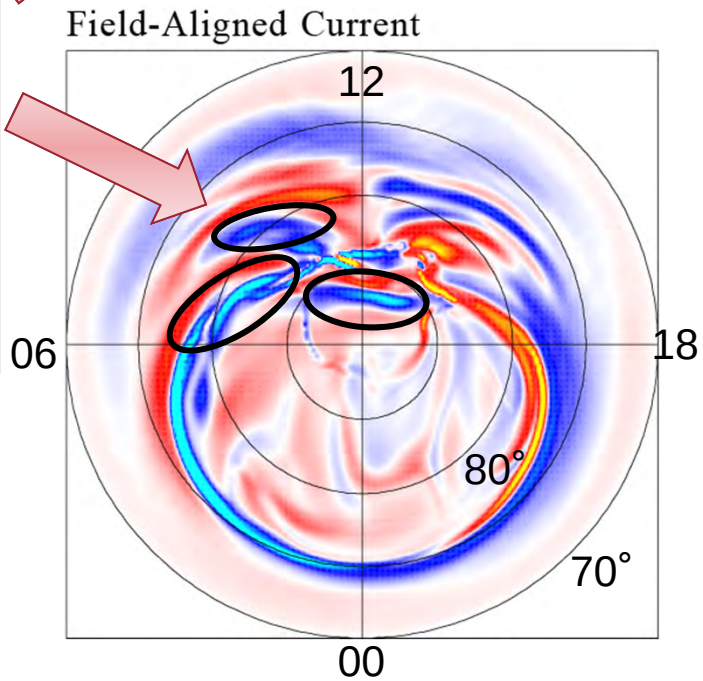


Enhancement of By after the decline

Upward FAC around high latitude may be corresponding to the brightening of observation

Enhancement of dynamic pressure just before becoming 2/13





Summary

Simulation of Kronian magnetosphere using the solar wind data observed by Cassini

- ✓ We are interested in the disturbed convection and vortex of Kronian magnetosphere.
- ✓ Recently we can obtain the small scale configuration of FACs due to the vortex configuration.
- ✓ Using the solar wind data by Cassini, we can get the simulation results of dynamically changing magnetopause and large vortices.
- ✓ A snapshot of simulation results of FACs looks like the image of HST observation, however we should examine more in detail.