Feb. 16, 2015

Numerical Simulation of Jovian and Kronian Magnetospheric Configuration

Keiichiro FUKAZAWA[1, 2]

1. Academic Center for Computing and Media Studies, Kyoto University
2. CREST, JST

Context

Jovian and Kronian magnetosphere from MHD simulation

Jovian magnetosphere

- Global configuration of magnetospheric convection
- Variation of BS and MP location
- Magnetospheric convection with low dynamic pressure
- Recent simulation

Kronian magnetosphere

- Turbulent convection in the simulation and observation
- Vortex and aurora emission using the Cassini solar wind data
- Latest simulation results

Summary

Global Configuration of Jupiter

Global magnetospheric convection

From internal process to combination of internal and external prosecces

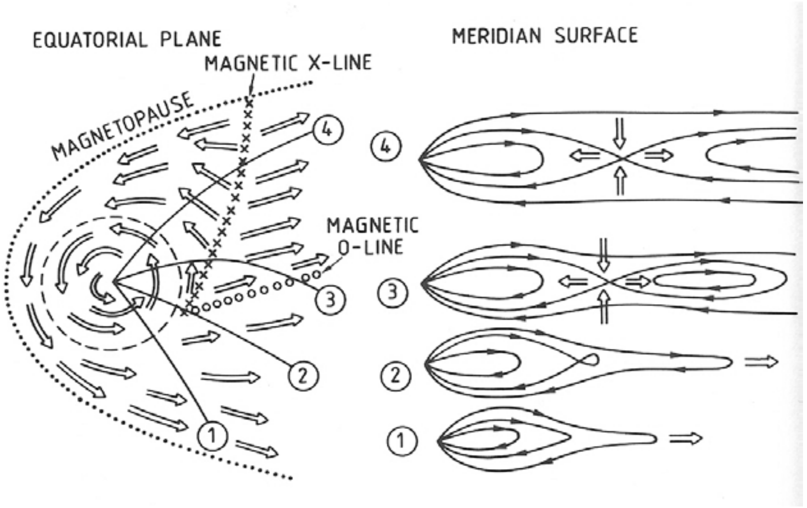


Fig.1. Qualitative sketch of plasma flow in the equatorial plane (left) and of the associated magnetic field and plasma in a sequence of meridian surfaces (right) expected from the planetary wind model [*Vasyliunas*, 1983]

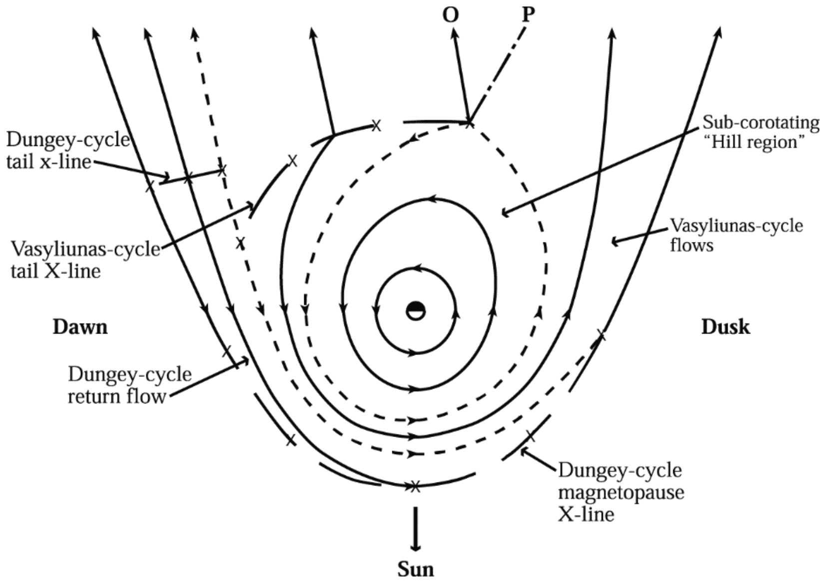


Fig.2. Sketch of the flows in the jovian equatorial Plane [*Cowley et al.*, 2003]

Latest Global Simulation

High resolution simulation

Now we can perform 1,000 times higher resolution simulation in 2000

- Grid interval : 0.15R_J
- Inner boundary location : 7 R_J

- Using average solar wind dynamic pressure, we do not see the interesting phenomena…
  → How about the low dynamic pressure?

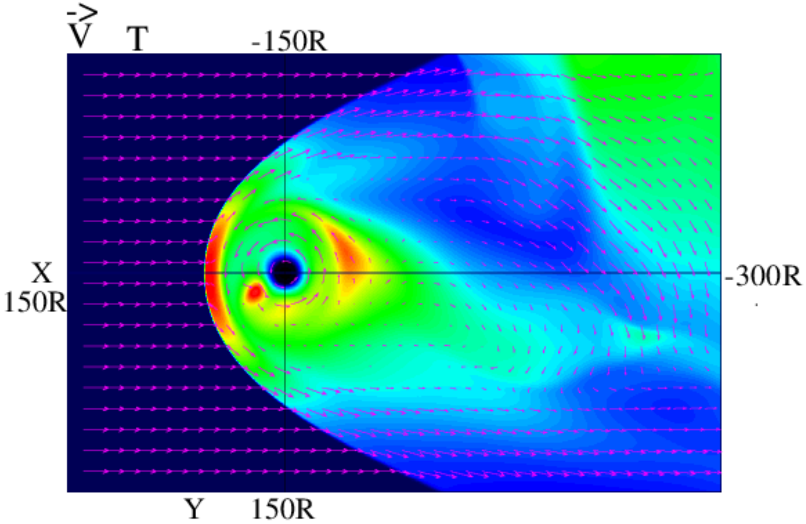
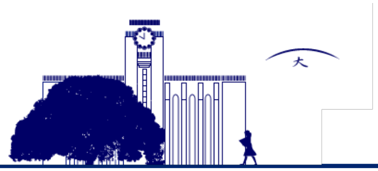
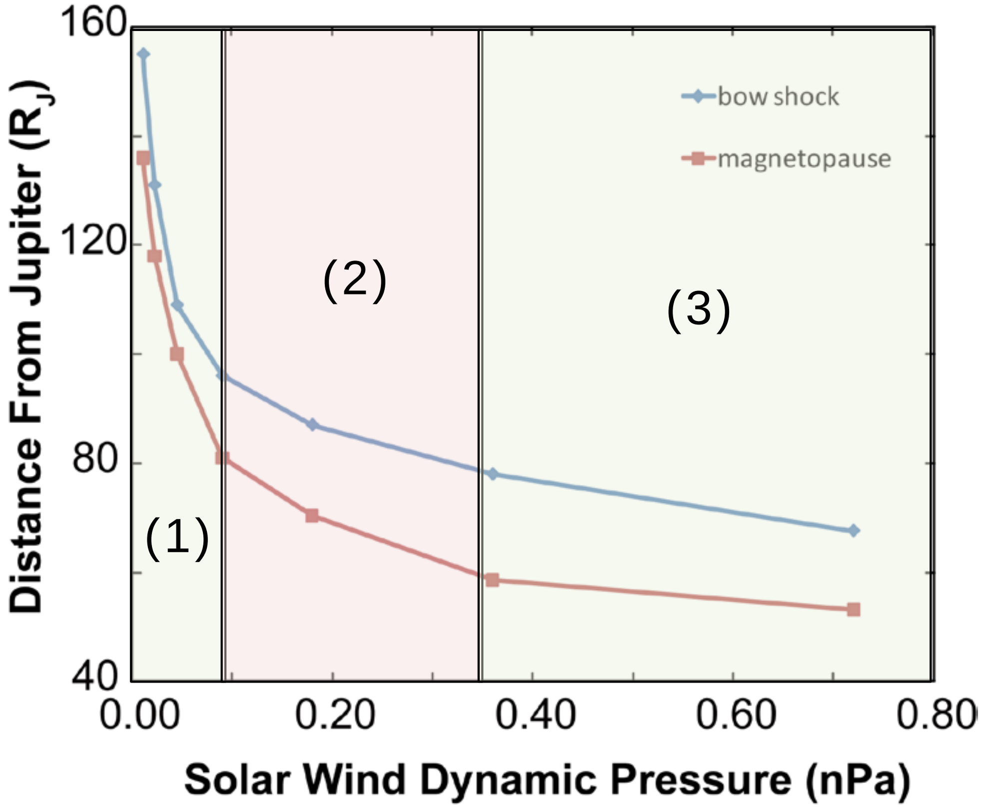


Fig.3. Plasma temperature and flow vector on the equatorial plane



Variation of Jovian magnetosphere

Dependence of BS and MP to dynamic pressure



(1) Soft magnetosphere
(sponge?)

(2) Medium

(3) Rigid magnetosphere

Jupiter may have 3 types of magnetospheric cofiguration responding to the solar wind.

Fig.4. Location of BS and MP as a function of P_{dyn} from MHD simulation

京都大学
KYOTO UNIVERSITY

Variation of Jovian magnetosphere

Dynamically changing BS and MP from observation

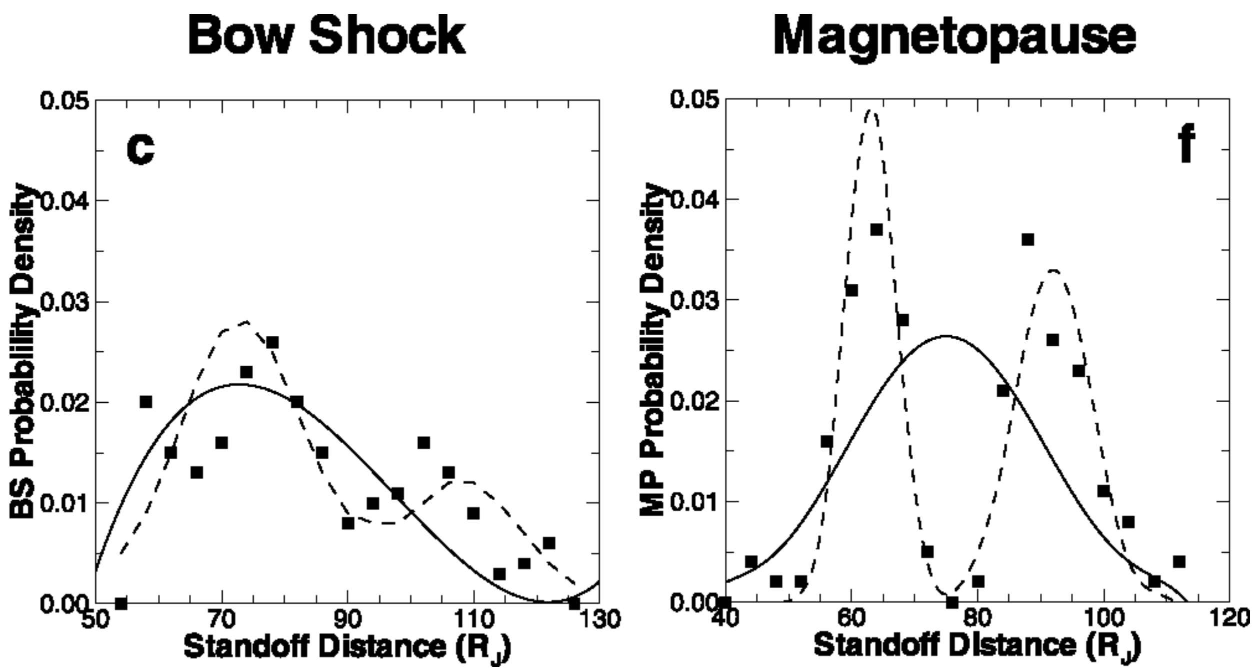


Fig.5. Probability density of bow shock and magnetopause [*Joy et al.,* 2002]

Low Dynamic Pressure Simulation

Periodic plasmoid ejection 1

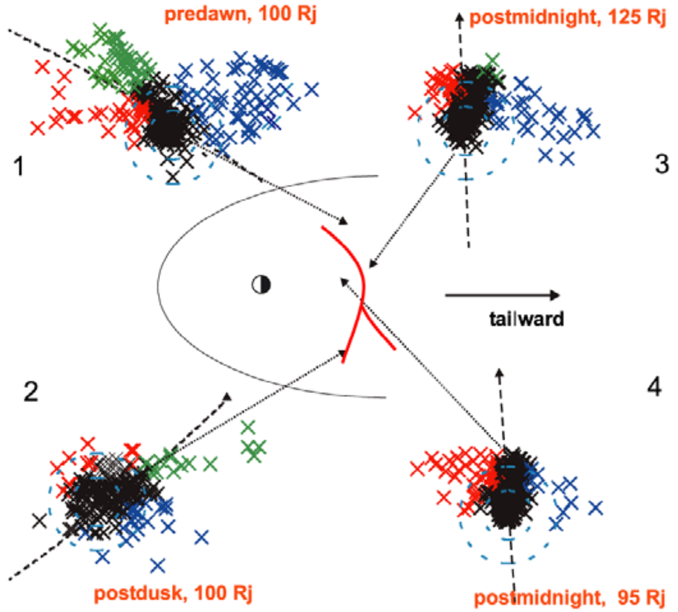


Fig.6. Distribution of flow directions from Galileo [*Woch et al.*, 2002]

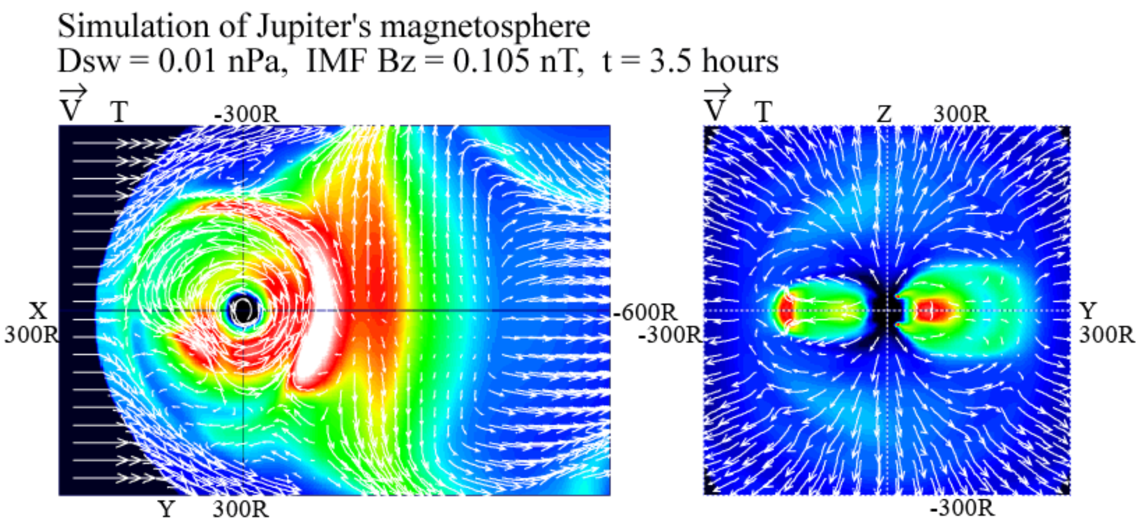


Fig. 7 Jovian periodic plasmoid ejection from MHD simulation [*Fukazawa et al.*, *GRL*, 2005]

京都大学
KYOTO UNIVERSITY

Low Dynamic Pressure Simulation

Periodic plasmoid ejecrion 2

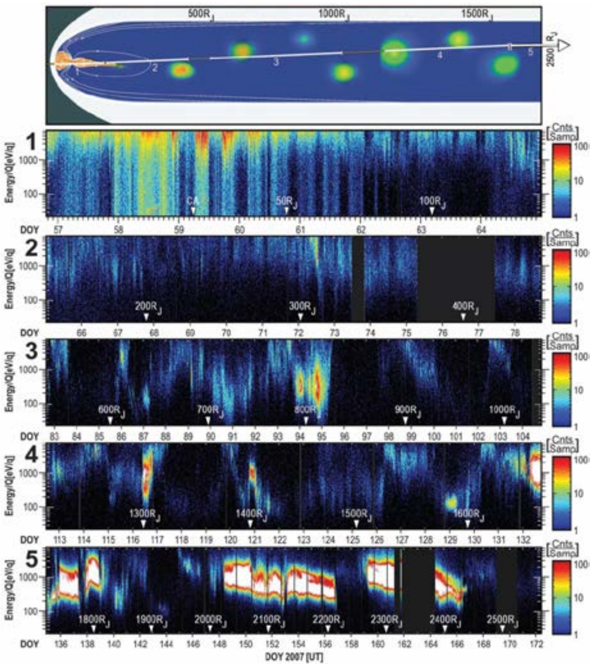


Fig.8. Plasma observations from just after NH’s inbound crossing of Jupiter’s. [*McComas et al.*, 2007]

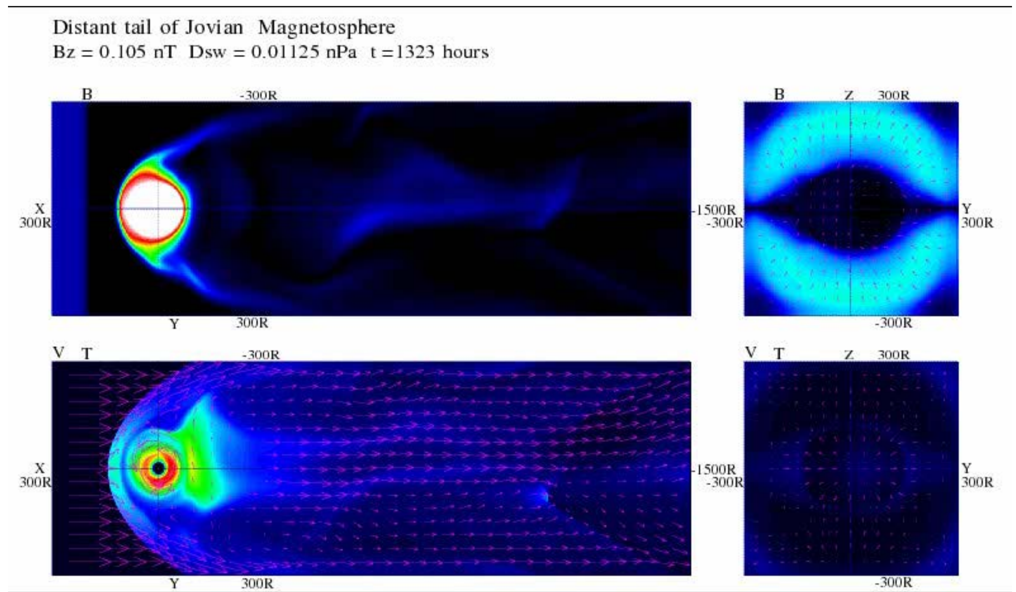
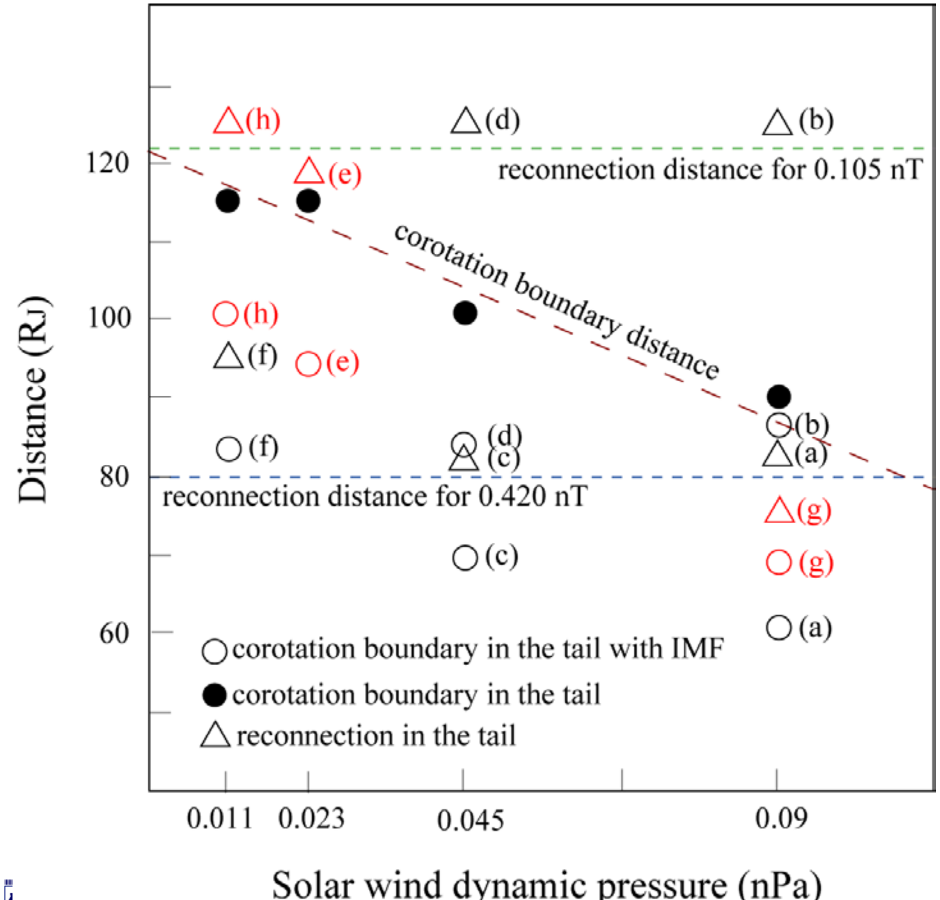


Fig. 9 Jovian periodic plasmoid ejection from long tail MHD simulation [*Fukazawa et al.*, *JGR*, 2010]

Relation of Plasmid and Pressure

Dynamic pressure mainly controls the corotation region



Corotation boundary determined by dynamic pressure.

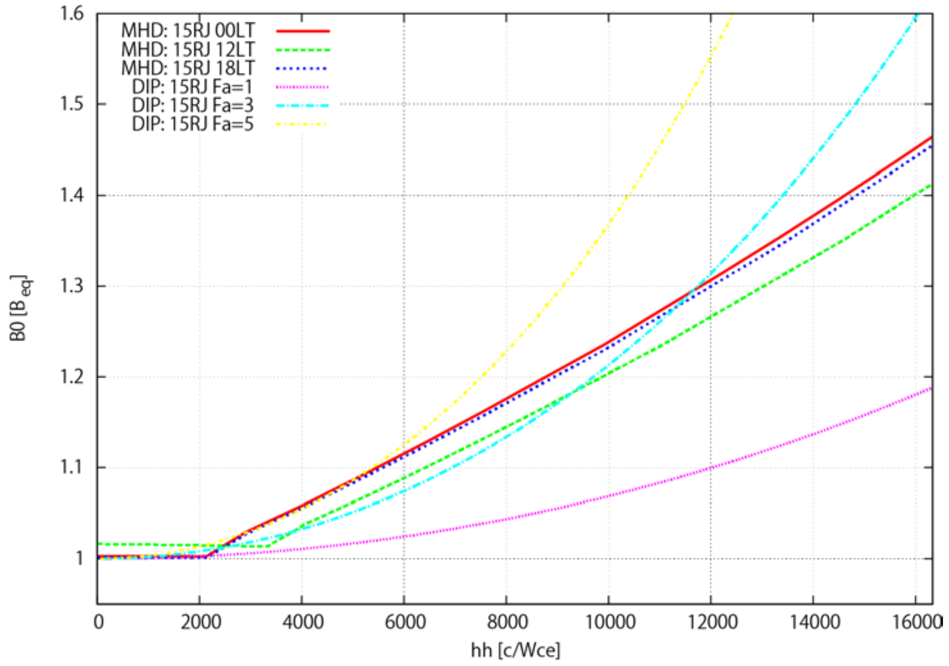
Reconnection distance depends on IMF.

Periodic plasmoid ejection generates if reconnection (△) occurs nearby corotation boundary (○) and does not occur at much inner boundary (●).

Recent Global Simulation

Coupling simulation of electron hybrid simulation and MHD simulation

Katoh's electron hybrid simulation uses the magnetic field data from the results of MHD simulation



京都大学
KYOTO UNIVERSITY

Context

Jovian and Kronian magnetosphere from MHD simulation

Jovian magnetosphere

- Global configuration of magnetospheric convection
- Variation of BS and MP location
- Magnetospheric convection with low dynamic pressure
- Recent simulation

Kronian magnetosphere

- Turbulent convection in the simulation and observation
- Vortex and aurora emission using the Cassini solar wind data
- Latest simulation results

Summary

Turbulent magnetospheric convection

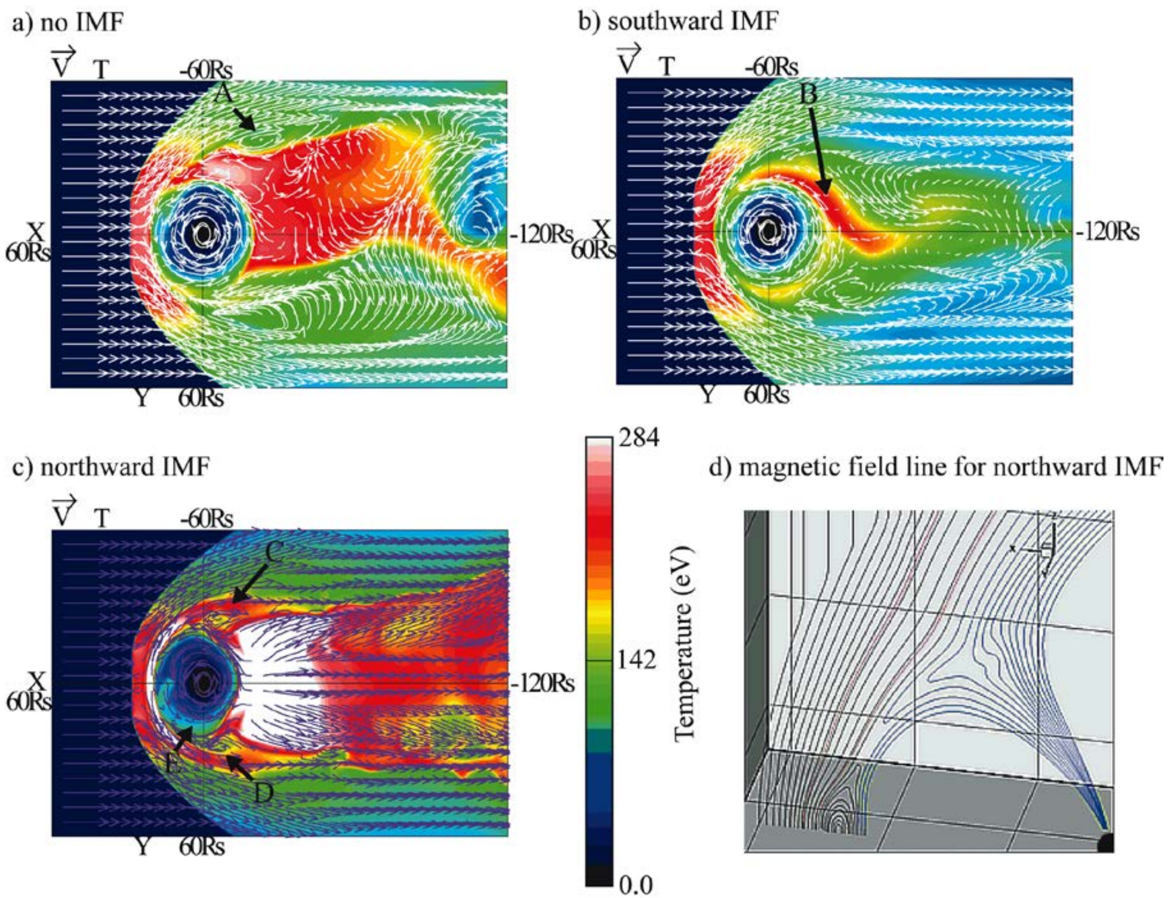
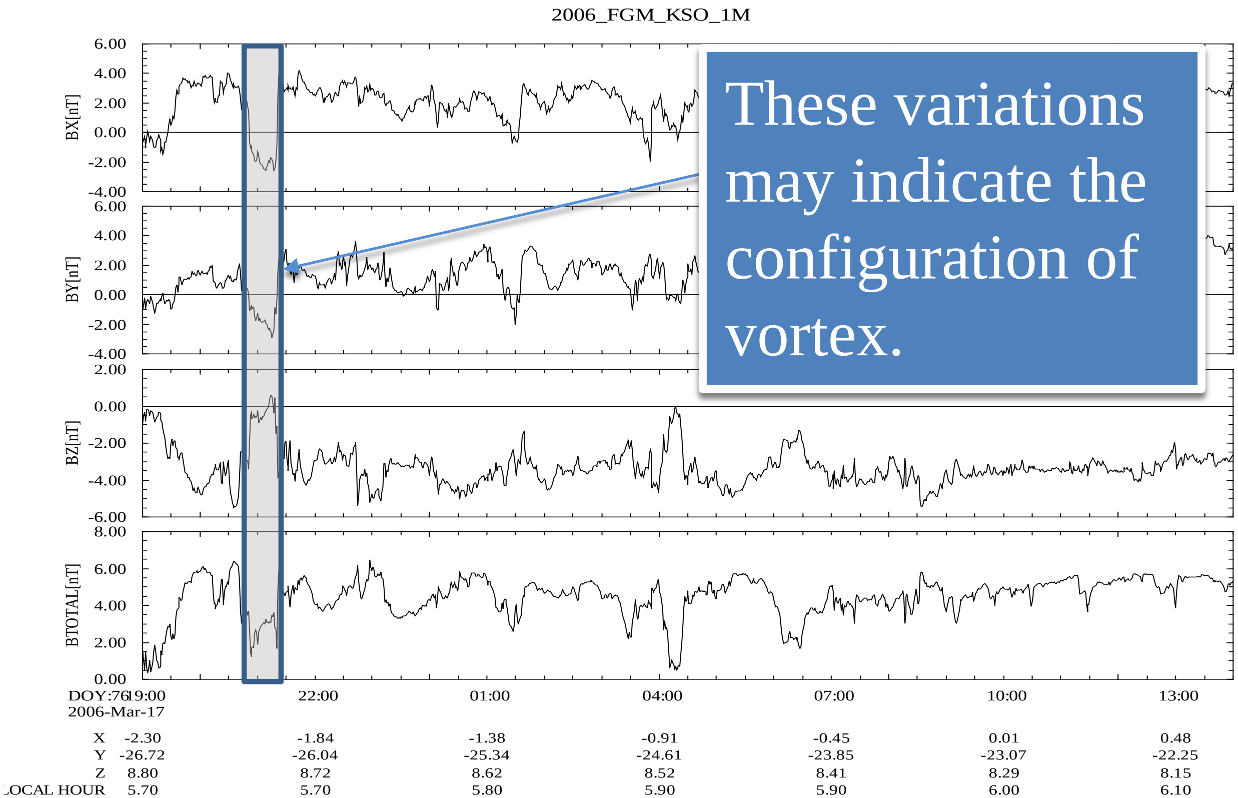


Fig.10. The temperature and flow vectors in the equatorial plane for the simulations with no IMF (a), southward (b) and northward IMF (c) [*Fukazawa et al.*, 2007a]

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.

Vortex in the observations by Cassini



These variations may indicate the configuration of vortex.

Fig. 11. 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.

京都大学
KYOTO UNIVERSITY

Clear Vorticity in the Simulation

Then we can simulate with the fine resolution.

Vortices are formed along the both dawn and dusk magnetopause

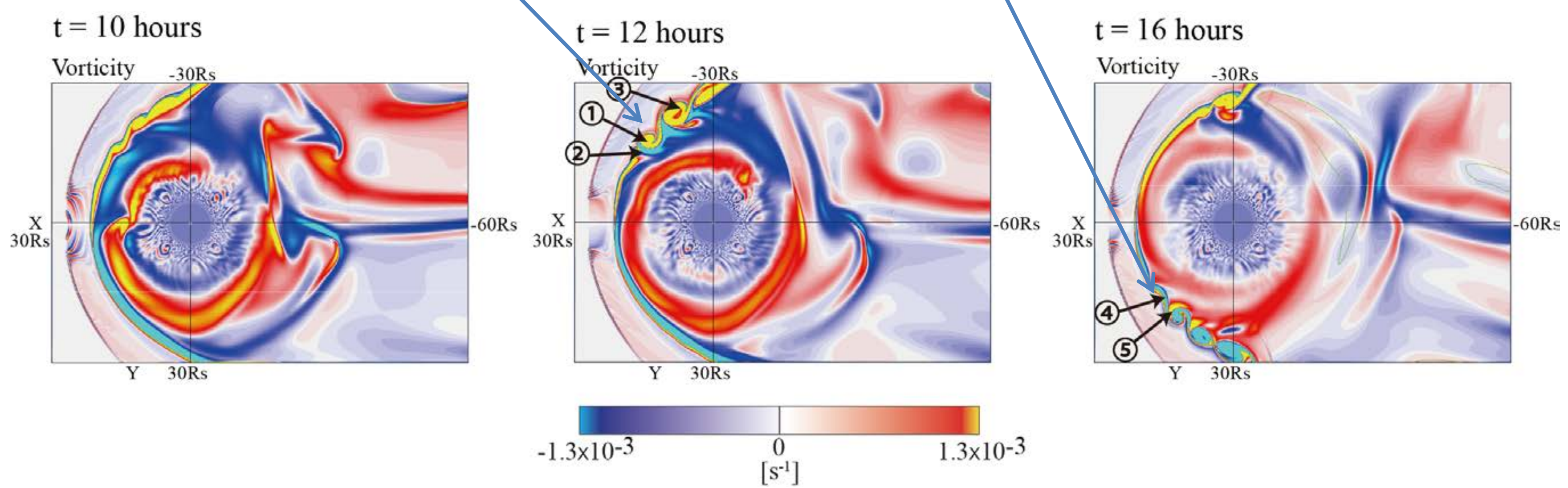


Fig.12. The vorticity parallel to the magnetic field in the equatorial plane at t = 10, 12, and 16 h. Vorticity with blue represents the clockwise motion, and red represents the anticlockwise motion [*Fukazawa et al.*, 2012].

FACs on polar southern ionosphere

Patchy and spot like feature is appeared due to the vortices

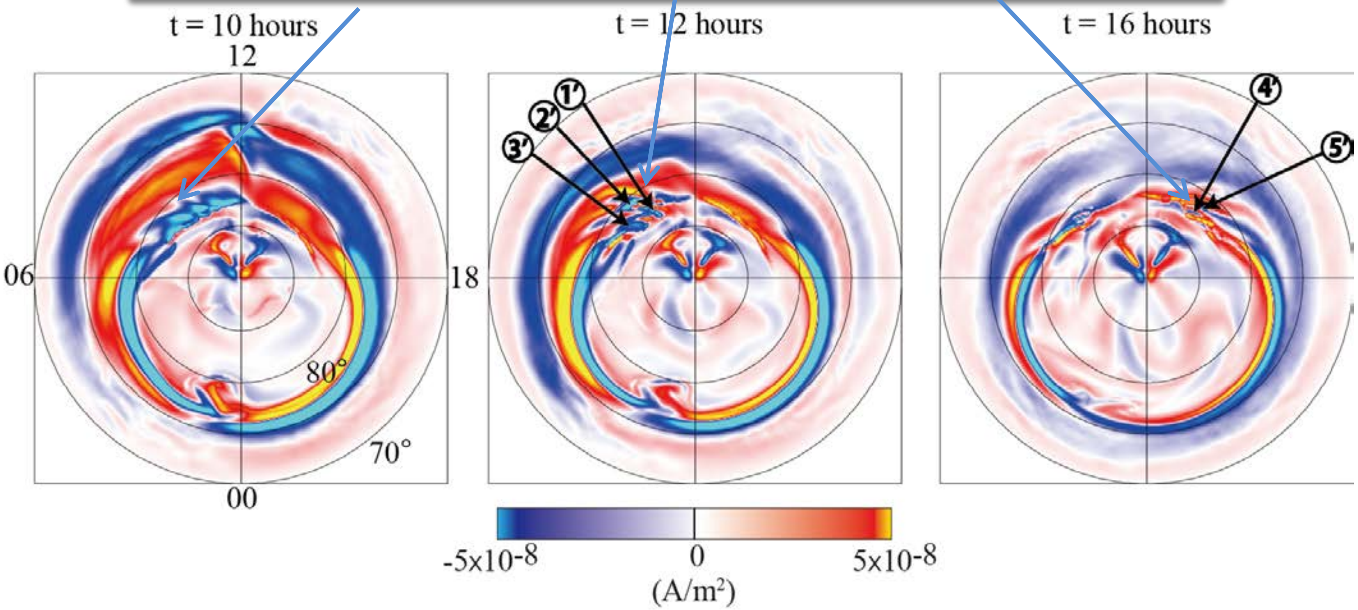


Fig.13. The distribution of field-aligned currents (FACs) in the southern polar cap mapped along the magnetic field lines from the simulation results to the southern ionosphere at t = 10, 12, and 16 h [*Fukazawa et al.*, 2012].

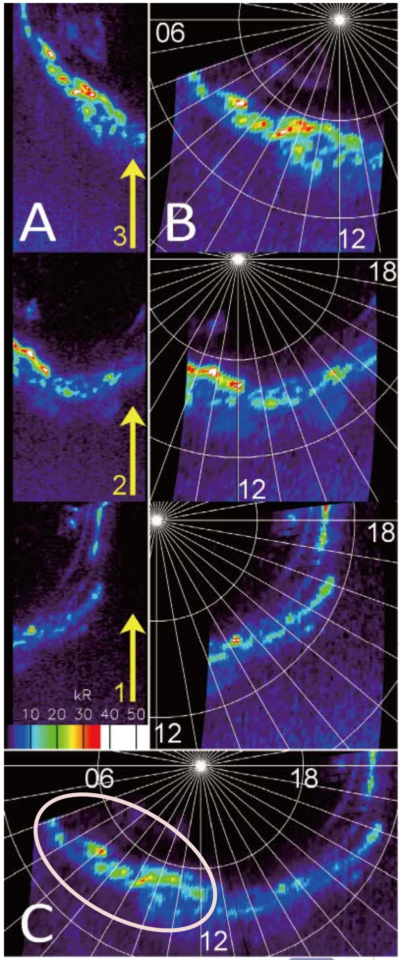
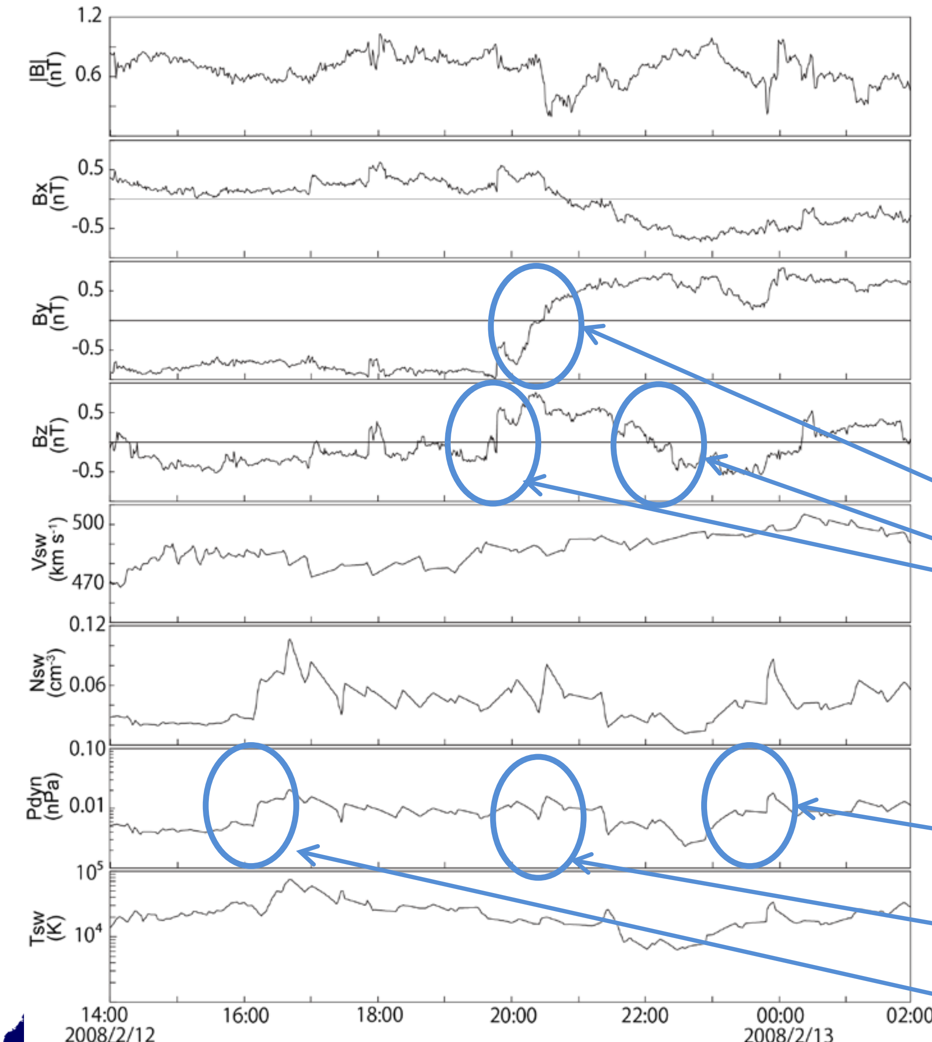


Fig. 14. Pseudoimages obtained with the FUV channel of the Cassini - UVIS spectro - imager on DOY 239 (26 August) of 2008 [*Grodent et al.*, 2011].

京都大学
KYOTO UNIVERSITY

Solar Wind Data from Cassini



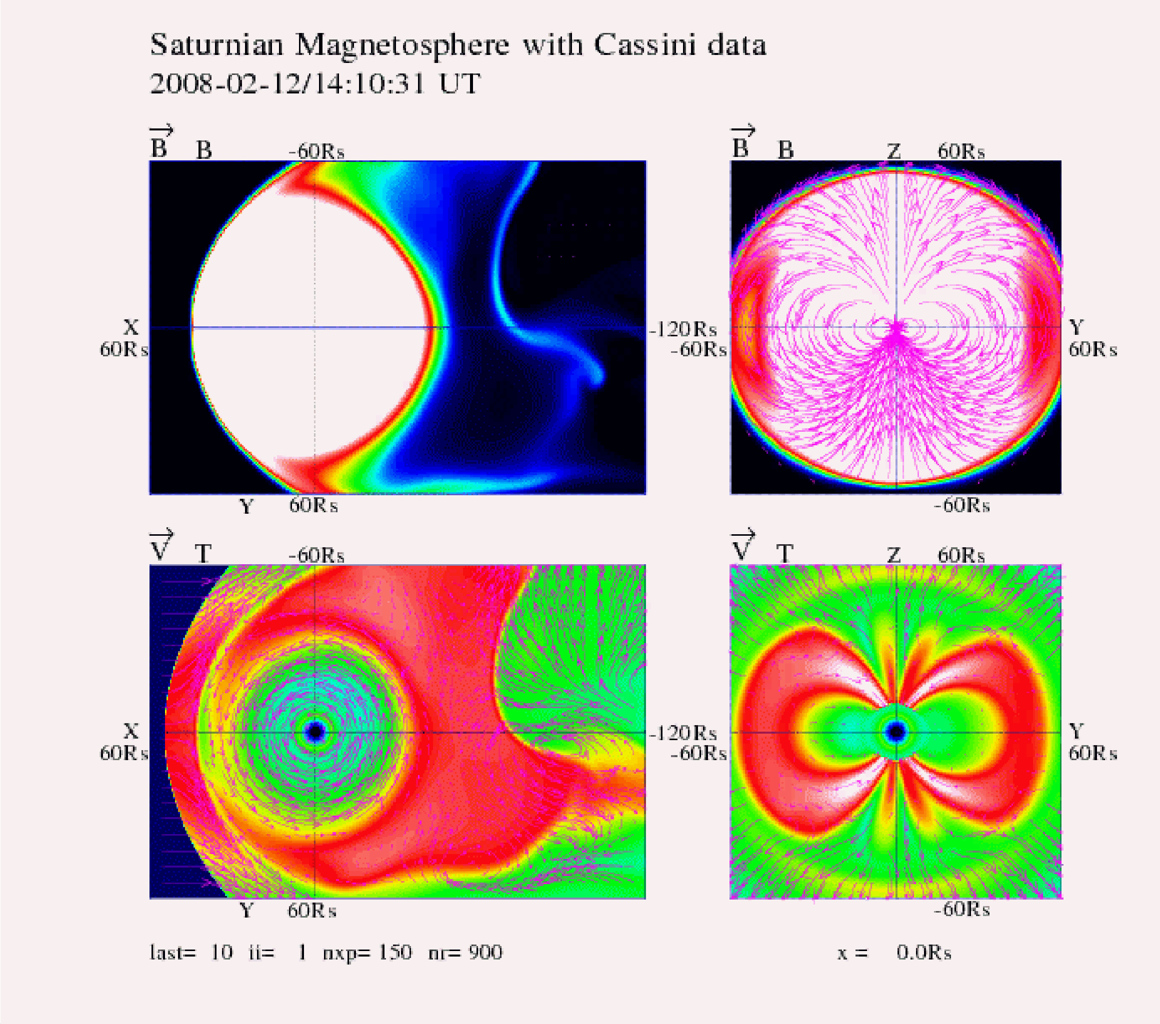
Cassini located at $(X_{KSM}, Y_{KSM}, Z_{KSM})$ = $(24.5–26.7R_S, -1.3–3.1R_S, 7.4–13.0R_S)$.

→Cassini was almost upstream the magnetosphere.

Polarity reversal

Enhancement of dynamic pressure

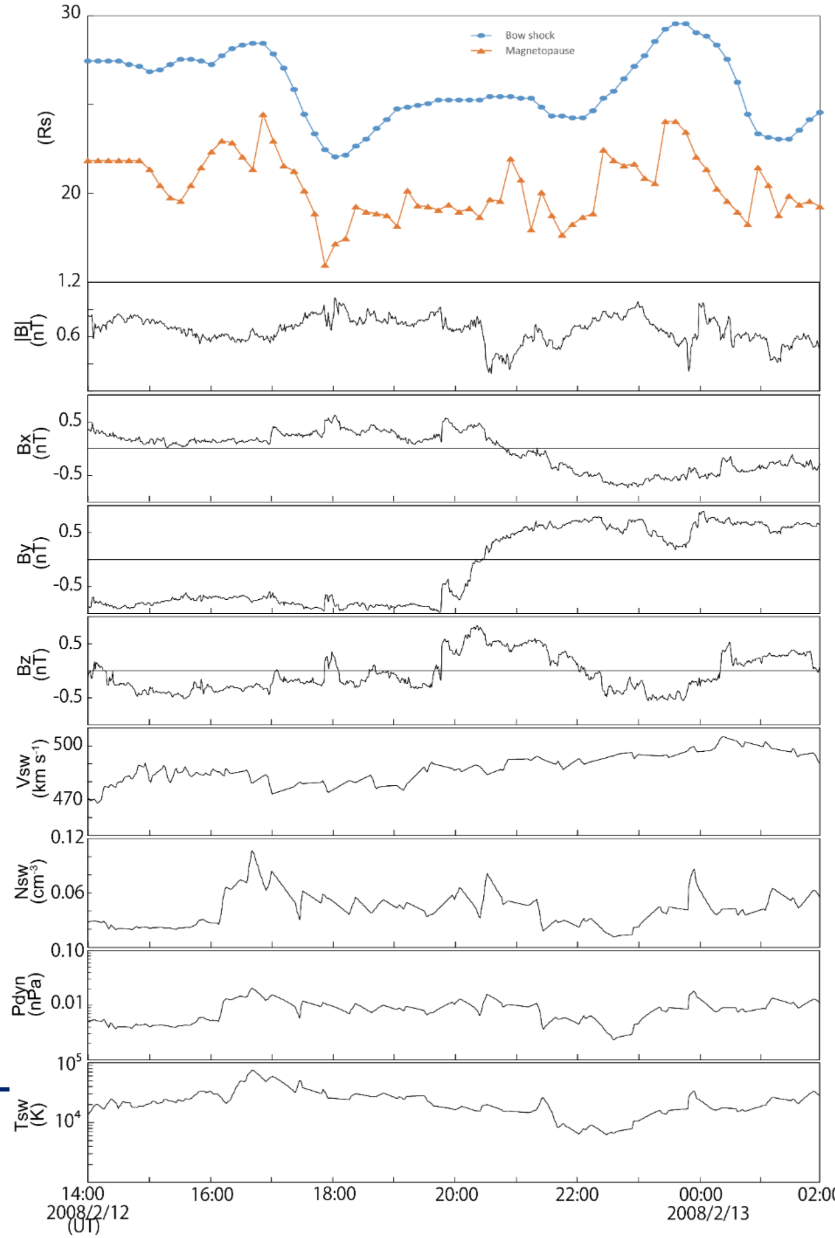
Simulation Results | Movie of equatorial plane



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.

Location of BS and MP from Simulation



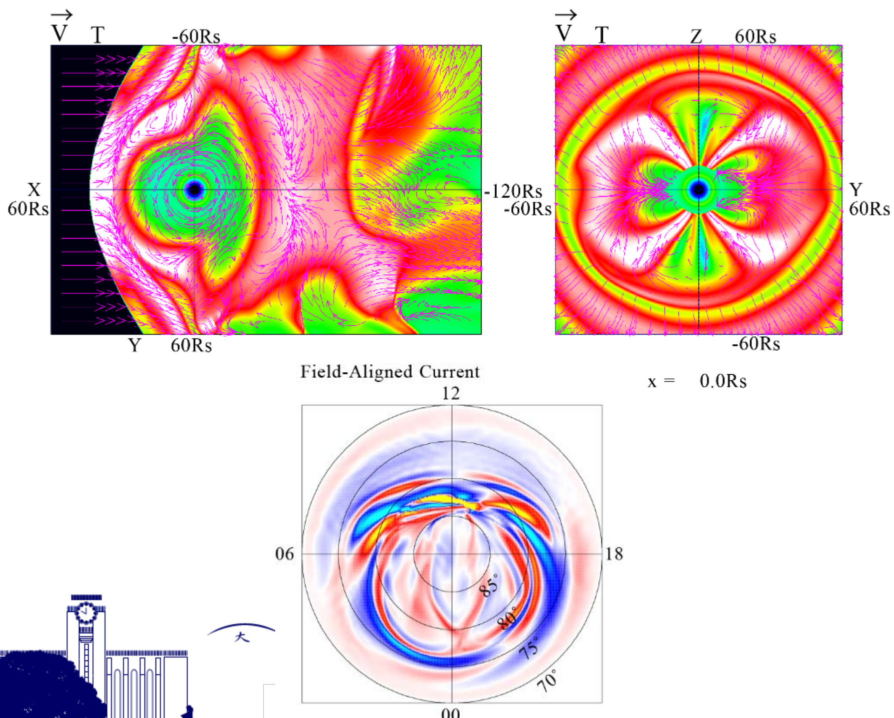
京都大学
KYOTO UNIVERSITY

Effect of dynamic pressure

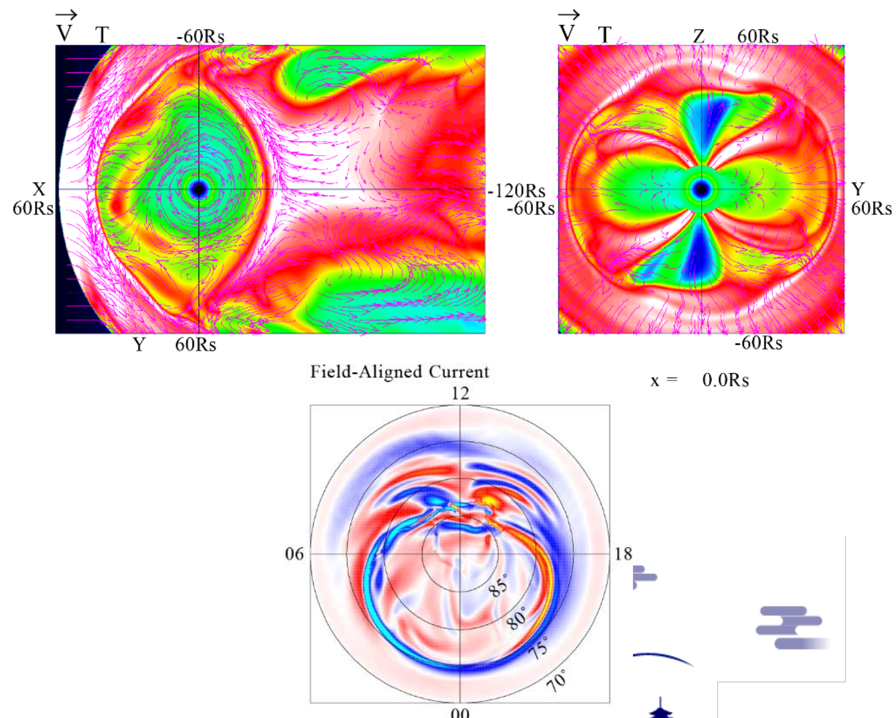
Location of bow shock and magnetopause dynamically changes

- BS:22.6 R_S, MP:17.2 R_S on the subsolar point at minimum (0.01 nPa)
- BS:27.6 R_S, MP:24.2 R_S on the subsolar point at maximum (0.0025 nPa)
- These locations have 122% (BS) and 140% (MP) differences.

Minimum case (18:10)



Maximum case (23:50)

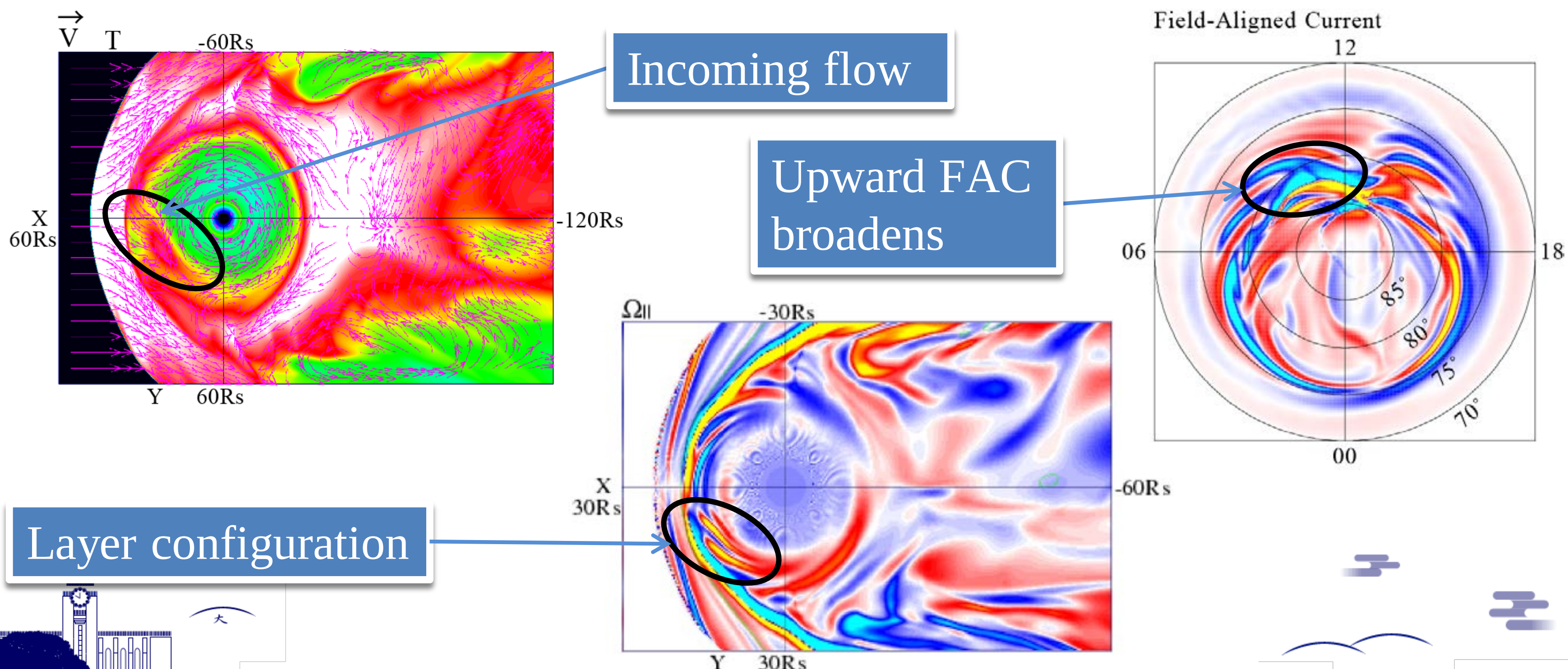


京都大学
KYOTO UNIVERSITY

Effect of IMF

Northward turning creates the layer configuration of flow

- Reconnection occurs around subsolar point then the flow comes into the magnetosphere.
- This also makes the enhancement of upward field-aligned current.



Observation Results in February 2008

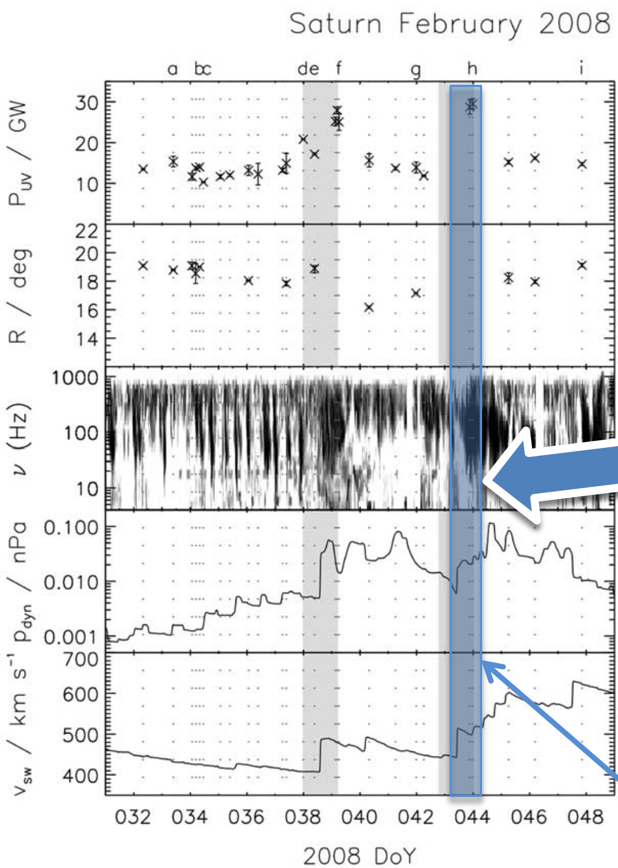


Fig.7. Total auroral power from Saturn's south polar region, best fit auroral oval radius, and SKR emission spectrum compared with propagated solar wind velocity and dynamic pressure in February 2008 [*Clarke et al.*, 2009].

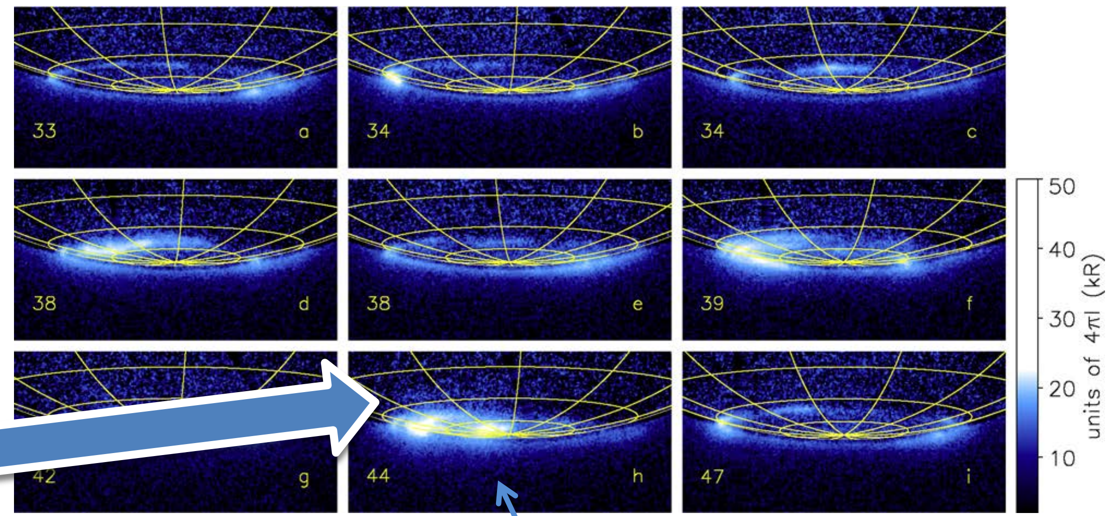
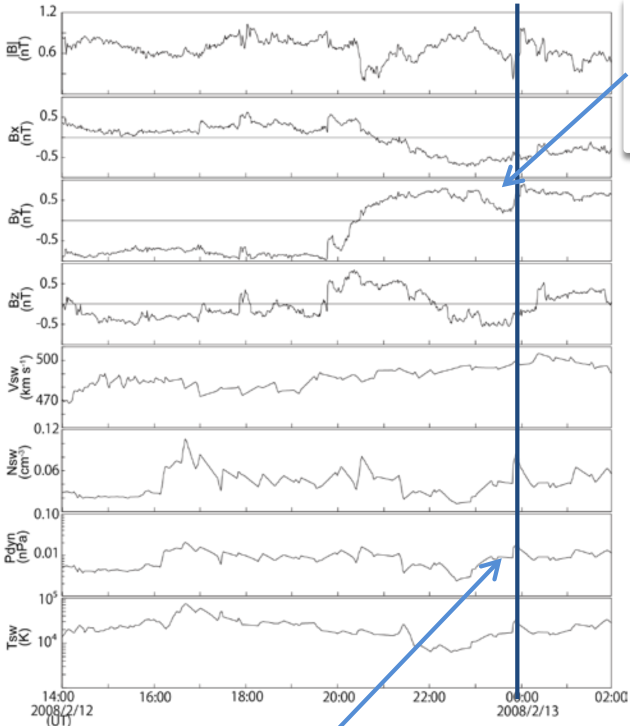


Fig.8. Sample UV images of Saturn's south pole in February 2008 with quiet and disturbed conditions [*Clarke et al.*, 2009].

This period is corresponding to the simulation period.

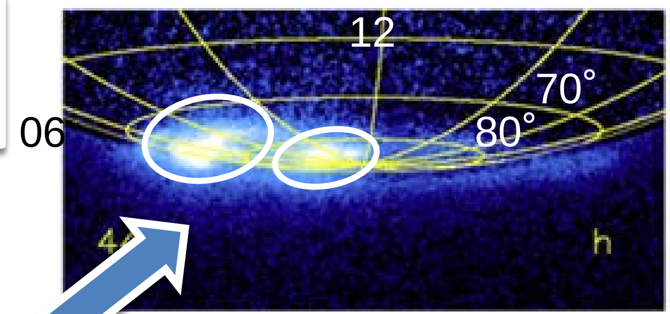
HST has just observed the UV image during this period.

Comparison of Simulation with Observation

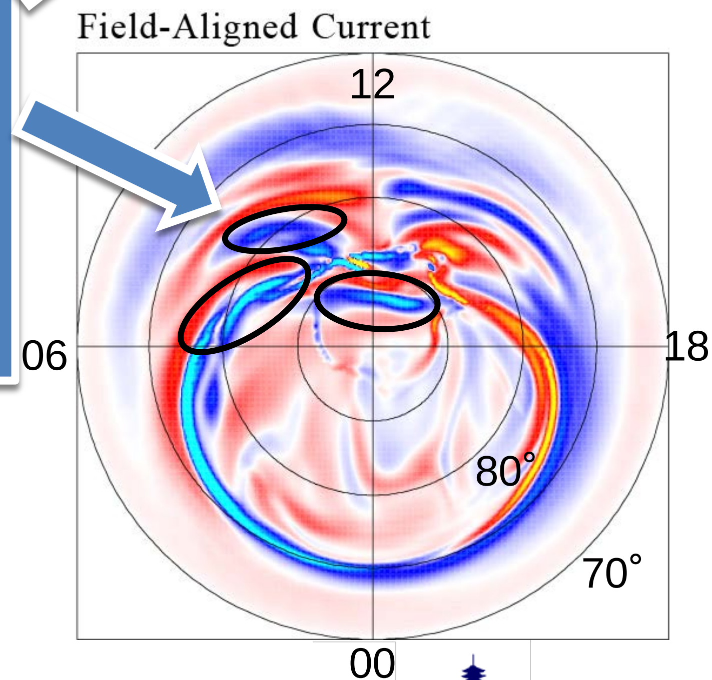


Enhancement of By after the decline

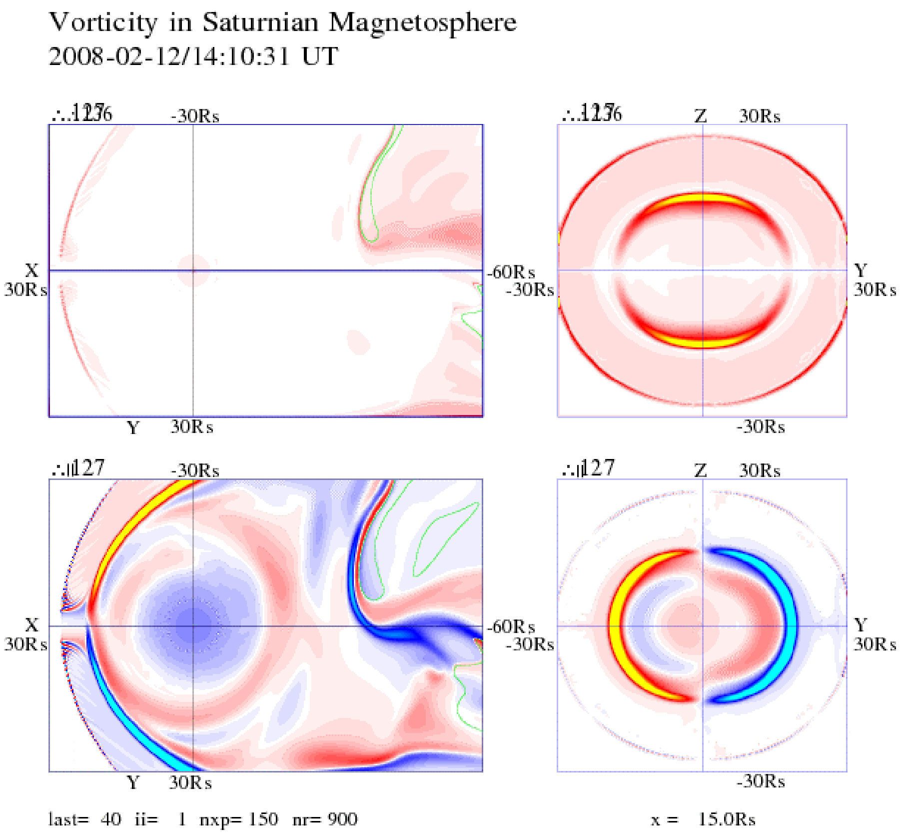
Enhancement of dynamic pressure just before becoming 2/13

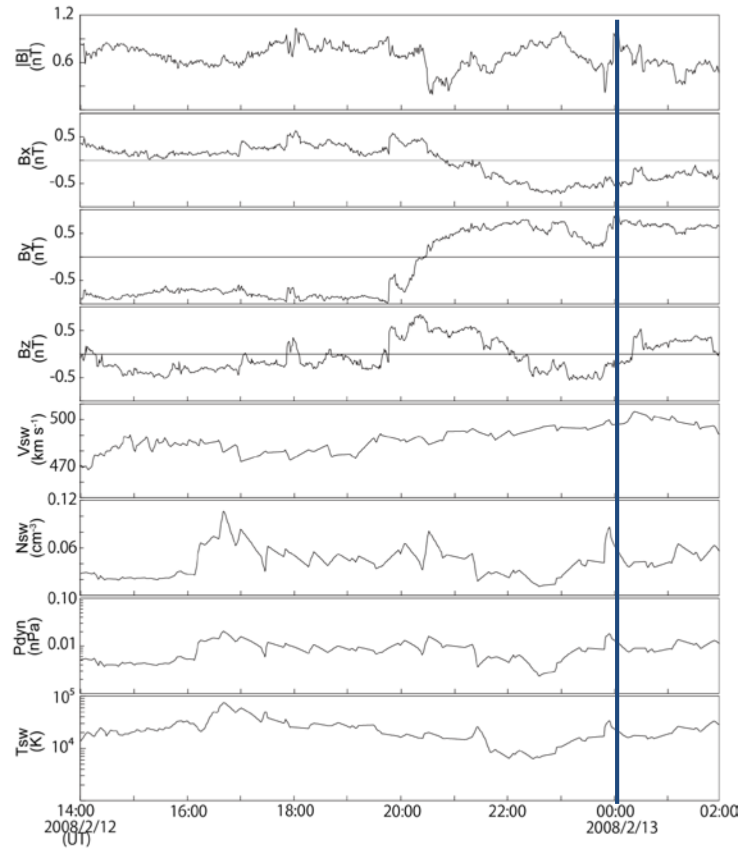


Upward FAC around high latitude may be corresponding to the brightening of observation



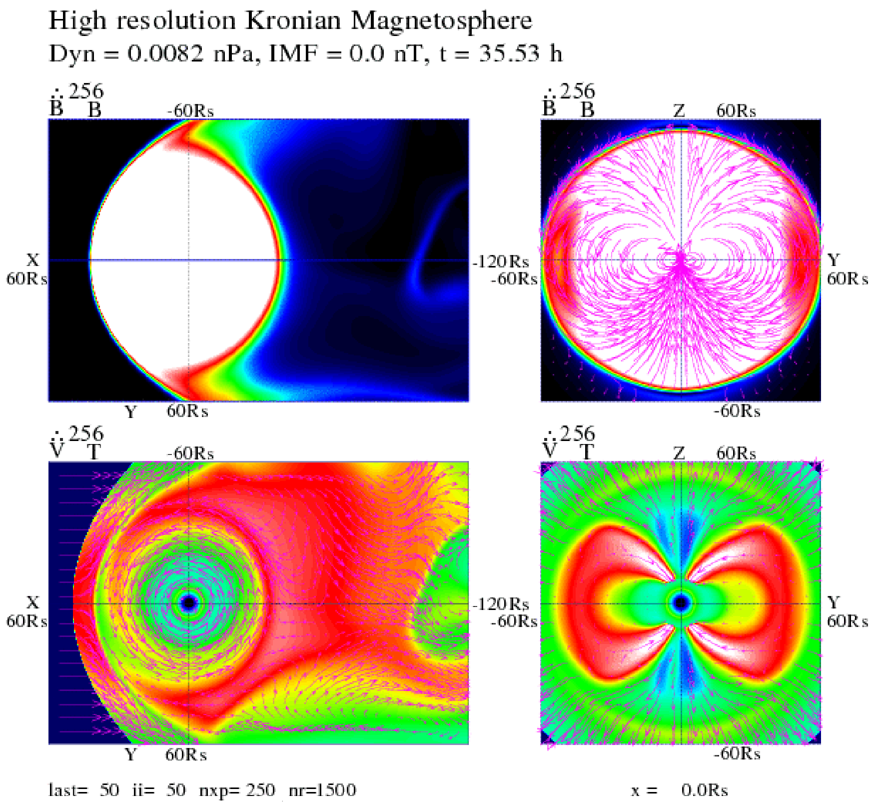
Vorticity from Simulation





Recent High Resolution Simulation

Simulation with no IMF@ FX10



Grid size

- (nx, ny, nz, nmhd) = (3000, 2000, 2000, 8) → about 700GB
- Use 7 times larger memory (5TB) than the grid size in the calculation
- Grid spacing is $0.06R_S$ (3600km)

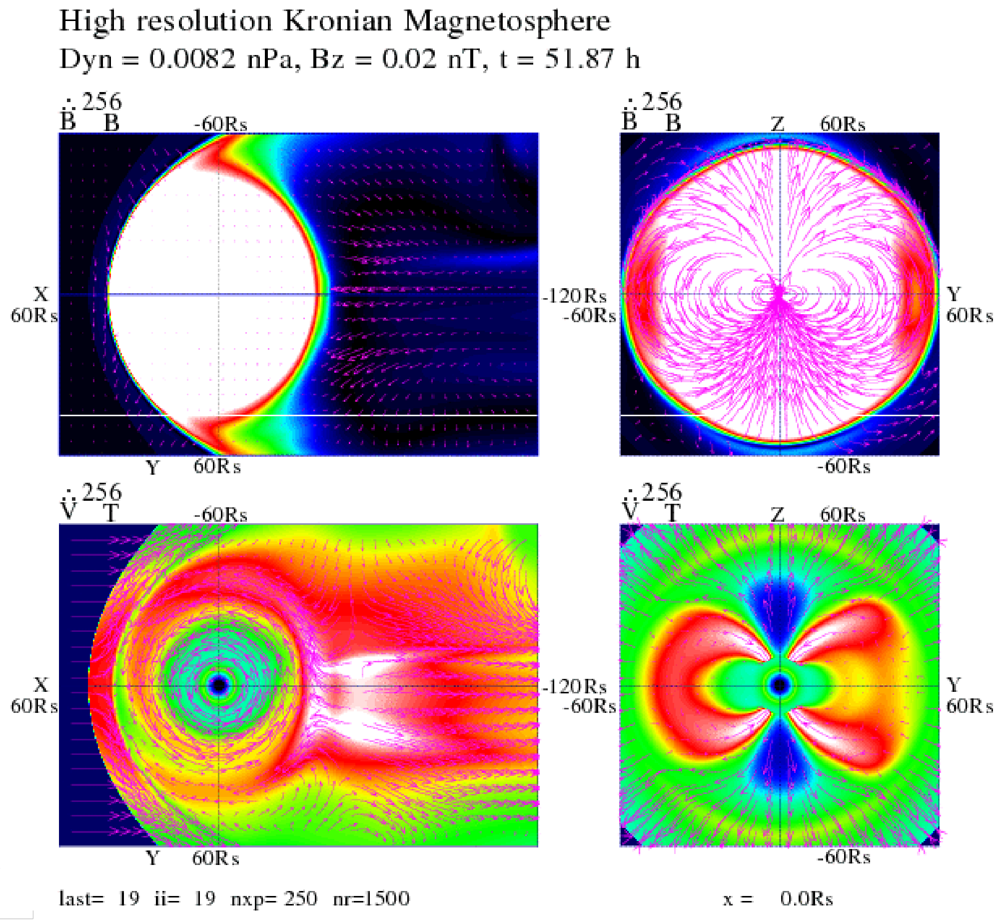
Time scale

- Calculate for 35hours in the real time

京都大学
KYOTO UNIVERSITY

Recent High Resolution Simulation

Simulation with weak northward IMF@ FX10

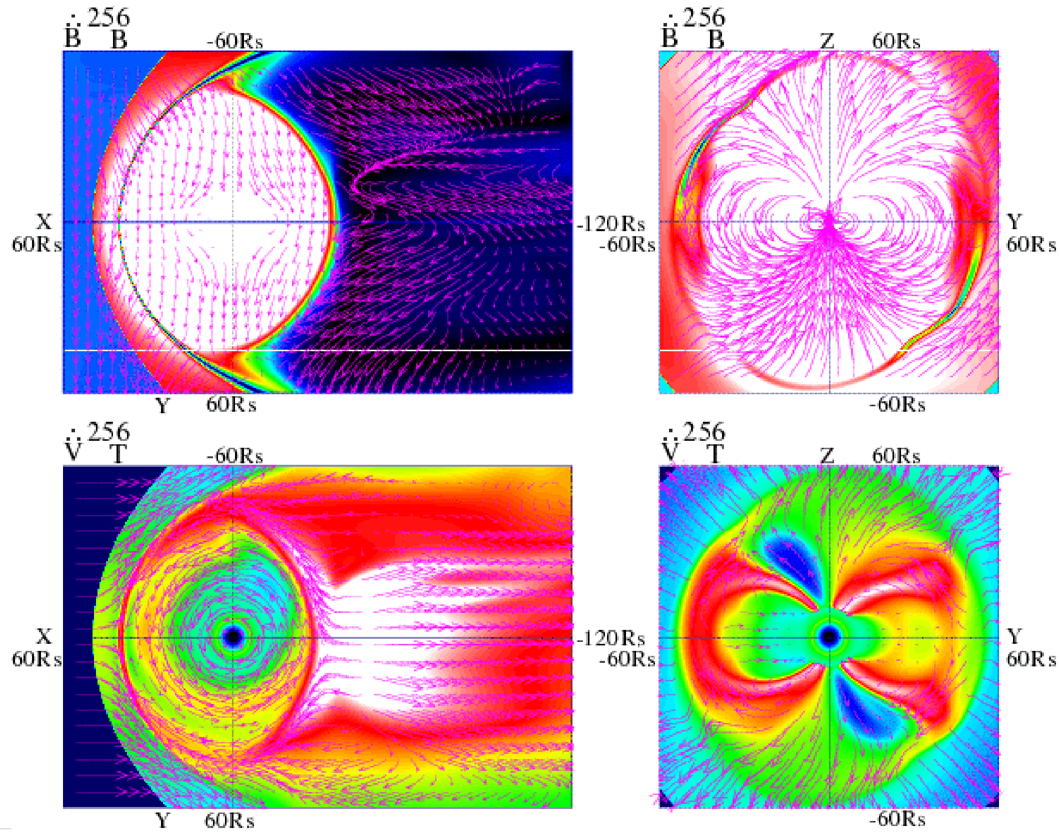


Recent High Resolution Simulation

Simulation with IMF $B_Y = B_Z$ @ FX10

High resolution Kronian Magnetosphere

Dyn = 0.0082 nPa, By = Bz = 0.4 nT, t = 47.33 h

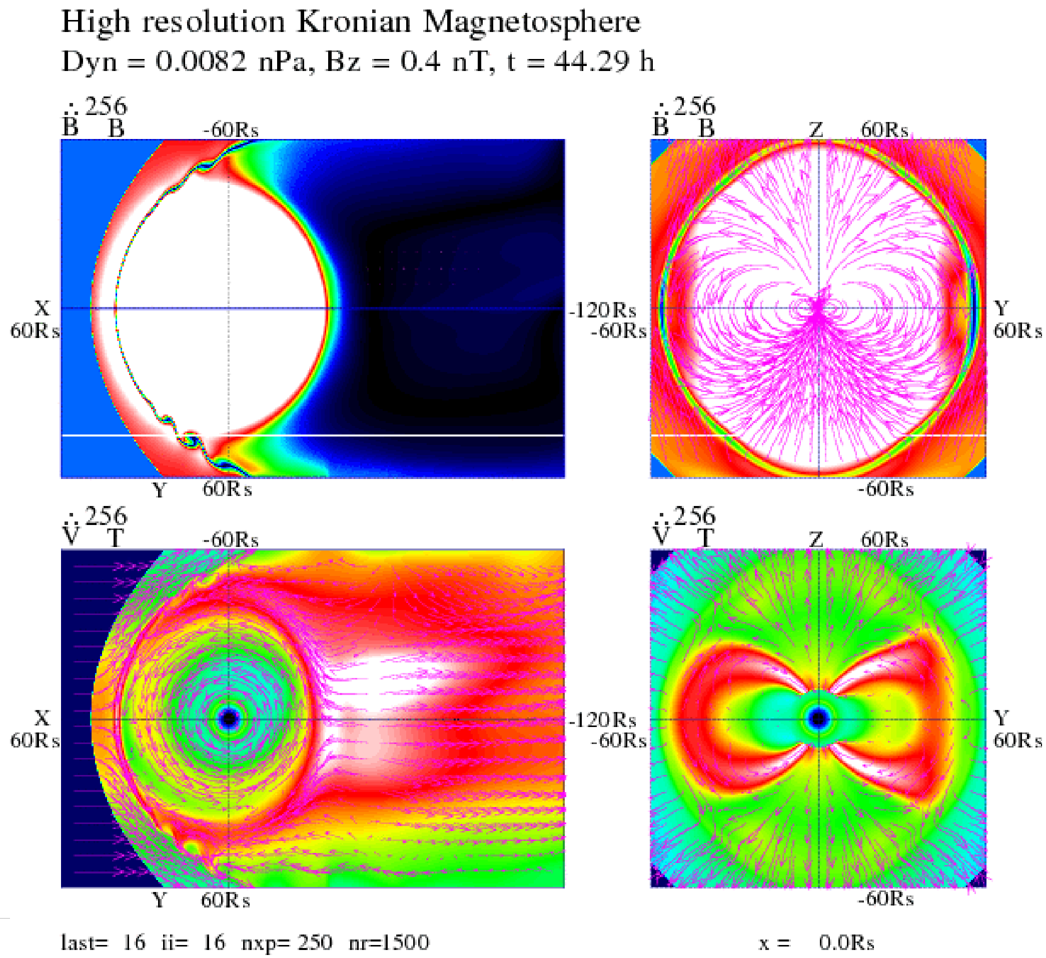


last= 50 ii= 50 nxp= 250 nr=1500 x = 0.0Rs

京都大学
KYOTO UNIVERSITY

Recent High Resolution Simulation

Simulation with medium northward IMF@ FX10



Summary

Global configuration of Jovian and Kronian magnetosphere from numerical simulations

- Jupiter
  - ✓ From high resolution simulation we do not get the interesting phenomena.
  - ✓ Past simulation results suggest the low dynamic pressure reproduces the interesting phenomena due to the corotation region.
- Saturn
  - ✓ Kronian magnetosphere well responds to the solar wind and a lot of phenomena are appeared in the magnetosphere.
  - ✓ To see vortex we need medium magnitude of northward IMF.