Now and Future of Kronian Research

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100th Anniversary

Today's talk

Research topics of Kronian magnetosphere

Now…Cassini brings us many interesting phenomena

- Vortex configuration from KHI
- Flapping and reconnection
- Simultaneous observation of Cassini and HST

Future…

- Statistical research of whole Cassini data to see the long period phenomena, effect of solar cycle, etc.
- Planet – moon(s) interaction
- Numerical simulation

Now | Vortex configuration

Vortex configuration from Cassini observation

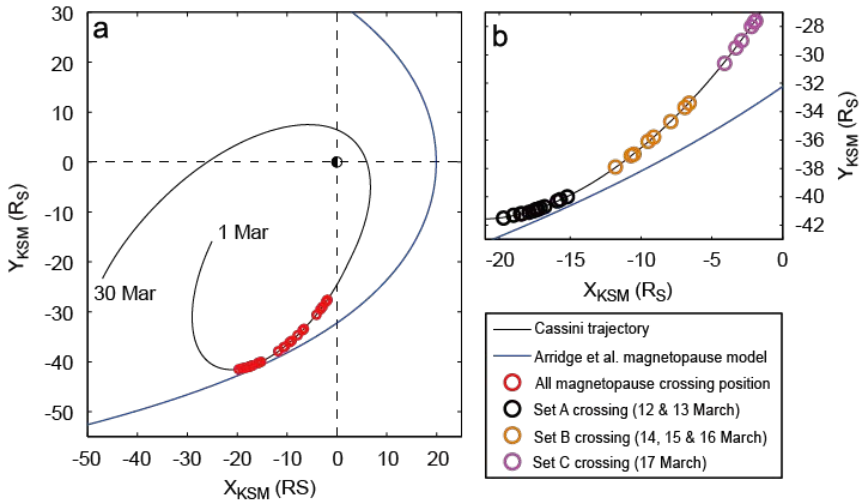


Fig. 1. Cassini's trajectory during March 2006 projected into the x–y plane [Masters et al., 2009].

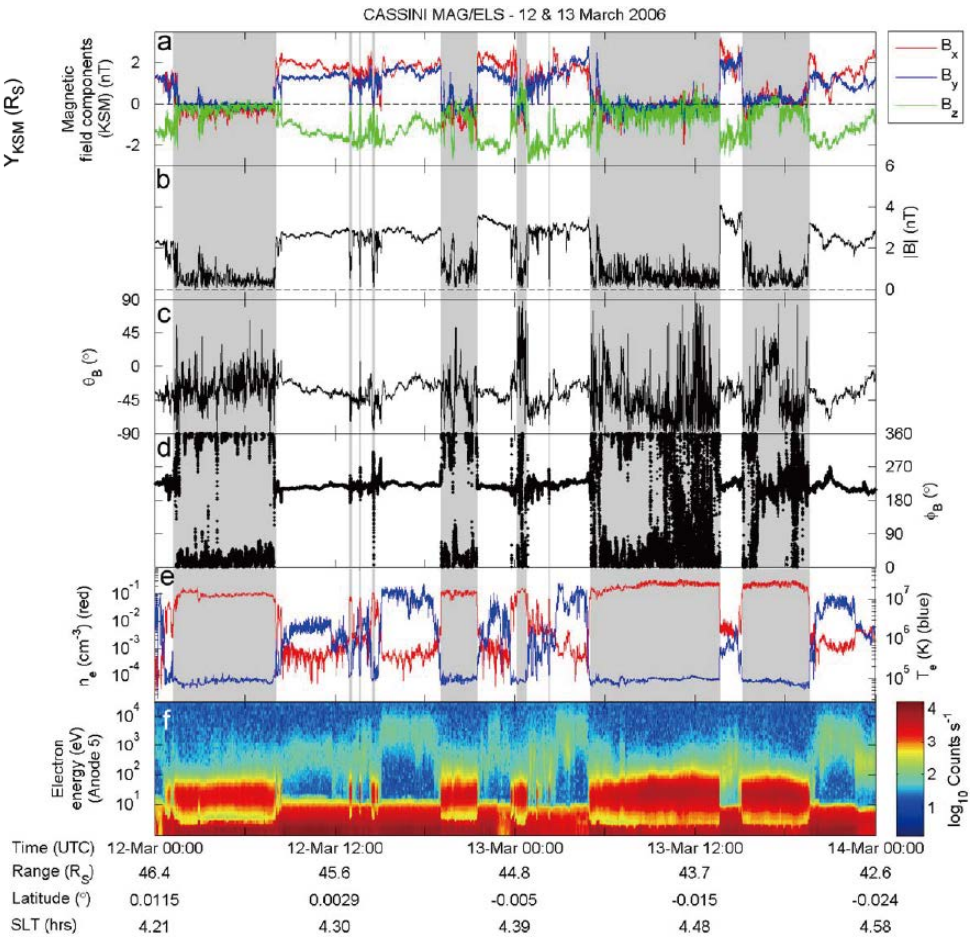


Fig. 2. MAG and ELS data for 12 and 13 March 2006 encompassing the set A magnetopause crossings [Masters et al., 2009].

Now | Vortex configuration

Vortex configuration from Cassini observation

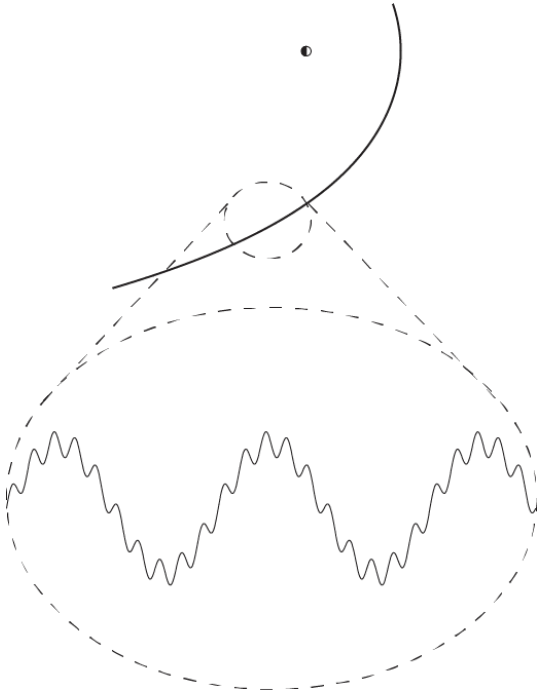


Fig. 3. Schematic illustrating the proposed nature of the wave activity present on Saturn's dawn flank magnetopause [Masters et al., 2009].

The magnetopause is always unstable?

- *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.
- *Cutler et al.* [2011] reported the surface wave due to the KH instability at the dusk side using the Cassini results.

Vortex configuration of Kronian magnetosphere

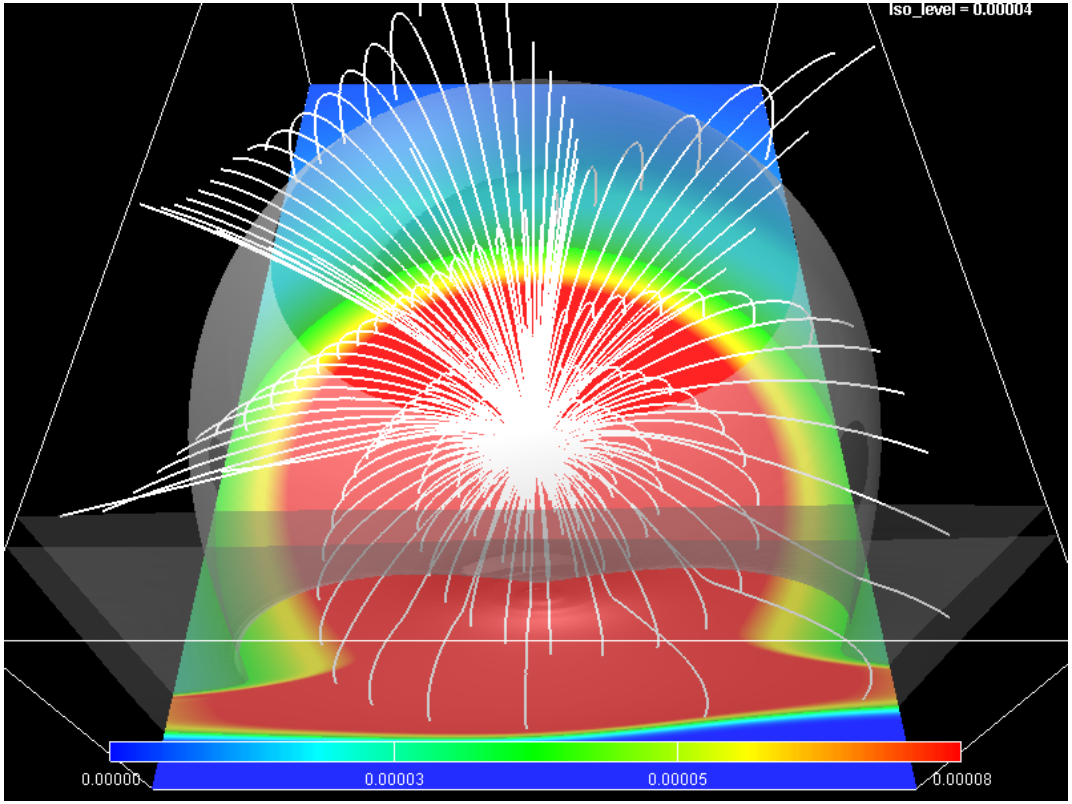


Fig. 4. Movie of the Kronian magnetospheric simulation result. Color spectrum shows the magnitude of magnetic field on the equatorial plane.

Now | Vortex configuration

Vorticity on equatorial plane at three snapshots

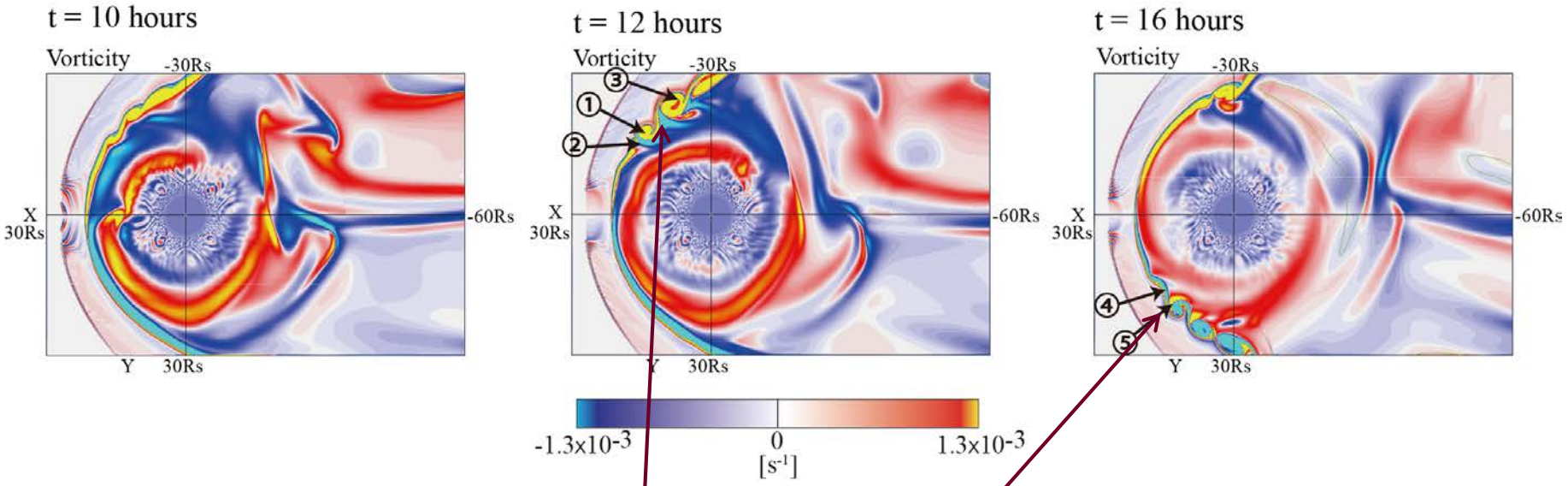


Fig. 5. Vorticity in the Kronian magnetosphere from MHD simulation [Fukazawa et al., 2012]

Vortices are formed both dawn and dusk flank.

Flapping of magnetotail

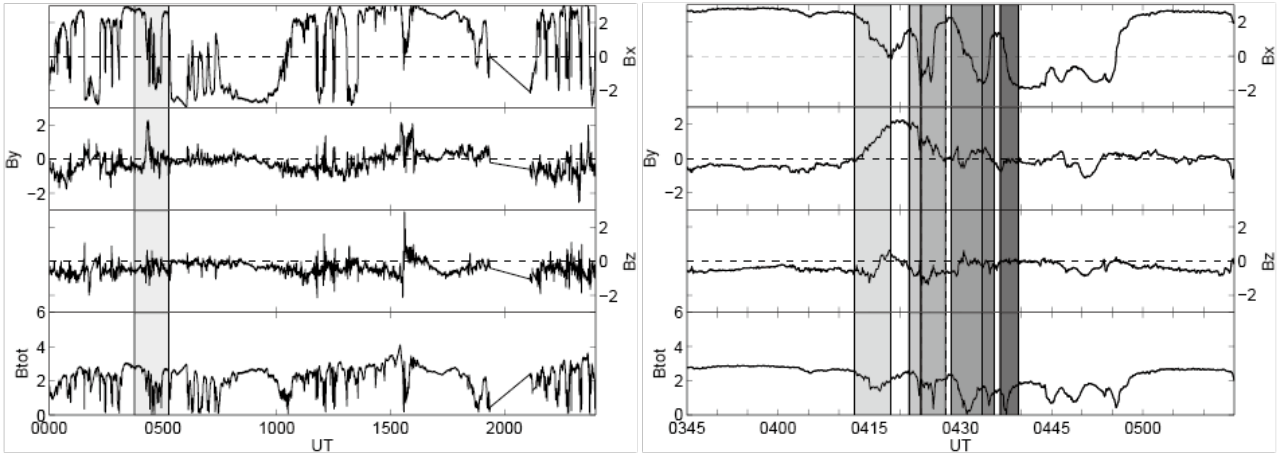


Fig.5. Saturn flapping event on DOY 249. The left panel shows one full day of magnetic field data in KSM coordinates. The right panel shows a zoom in on the yellow shaded part in the left panel, showing the flapping event. The intervals for the MVA analysis are marked with filled areas of different shades of gray. [*Volwerket al., 2013*]

- In the Kronian magnetotail there are various periodicities related to the rotational period of Saturn. discussed in *Arridge et al.* (2011); *Andrews et al.* (2012); *Provan et al.* (2012).
- The current sheet in the Kronian magnetosphere is hinged and located above the rotational equator and adopts a bowl shape over the midnight-dawn-noon LT sectors (*Arridge et al.*, 2008).

Reconnection in the tail

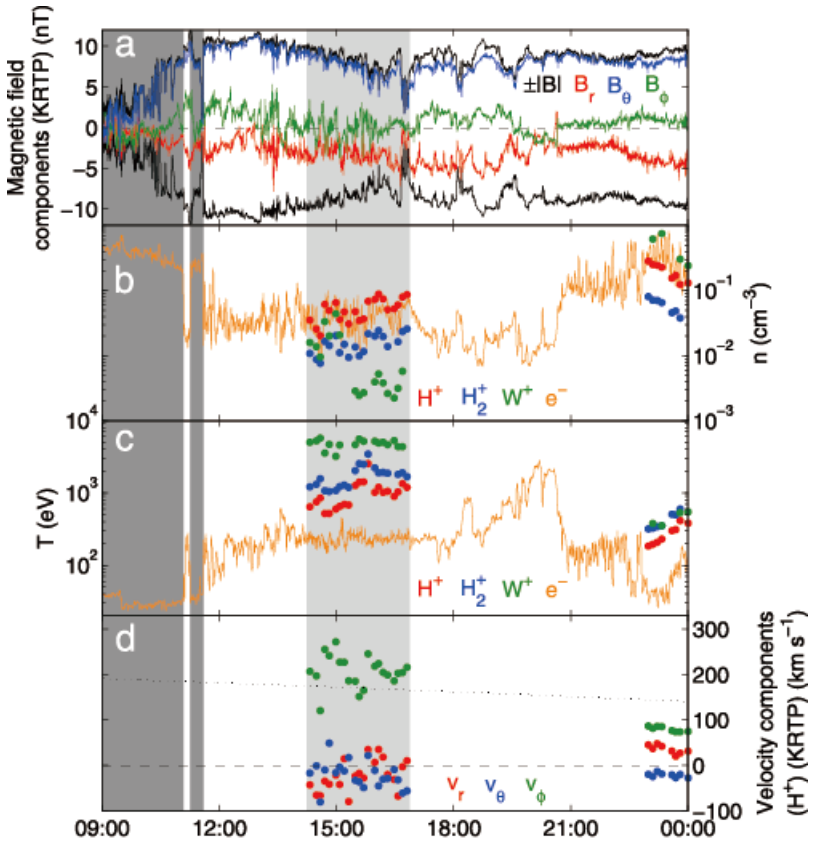


Fig.6. Data taken by Cassini on 10 October 2005 [Masters et al., 2011].

- Cassini data have shown that reconnection happens in Saturn's magnetotail (see e.g., *Jackman et al.*, 2007, 2008; *Masters et al.*, 2011).
- The recurrence rate of these events may be in the region of ~2.4 days (*Jackman et al.*, 2011).

Simultaneous observation of HST and Cassini

- The way to the Saturn, 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.

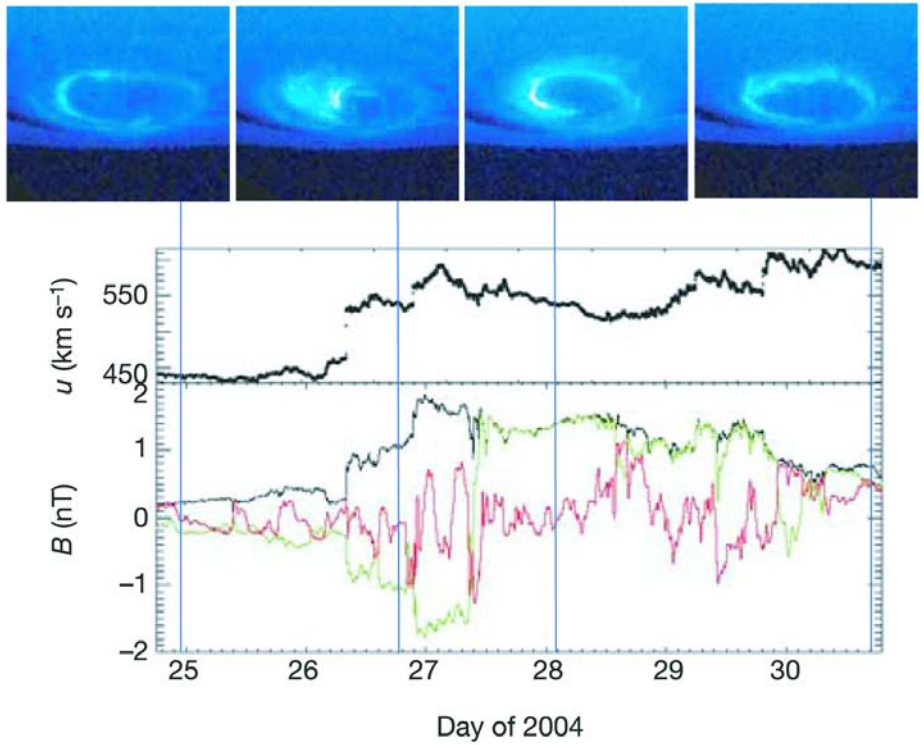


Fig.7. Comparison between HST images and solar wind conditions propagated to Saturn for the period 25–30 January 2004 [Crary et al., 2005].

Now | Simultaneous observation in 2008

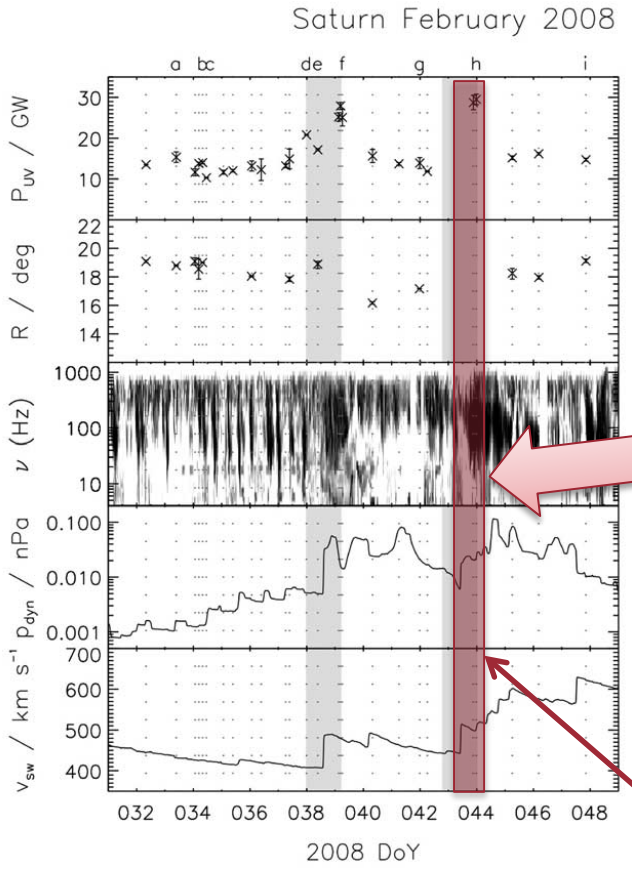


Fig.7. Total auroral power from Saturn's south polar region, best fit auroral oval radius, and SKR emission spectrum compared with propagated solar wind velocity and dynamic pressure in February 2008 [Clarke et al., 2009].

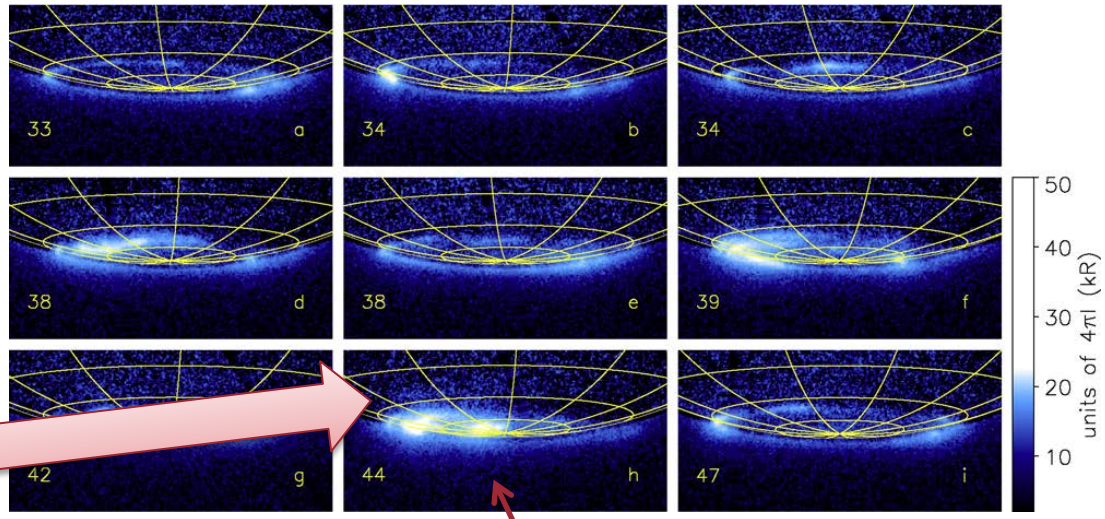


Fig.8. Sample UV images of Saturn's south pole in February 2008 with quiet and disturbed conditions [Clarke et al., 2009].

This period is corresponding to the simulation period.

HST has just observed the UV image during this period.

Now | Simultaneous observation in 2008

Solar wind data from Cassini

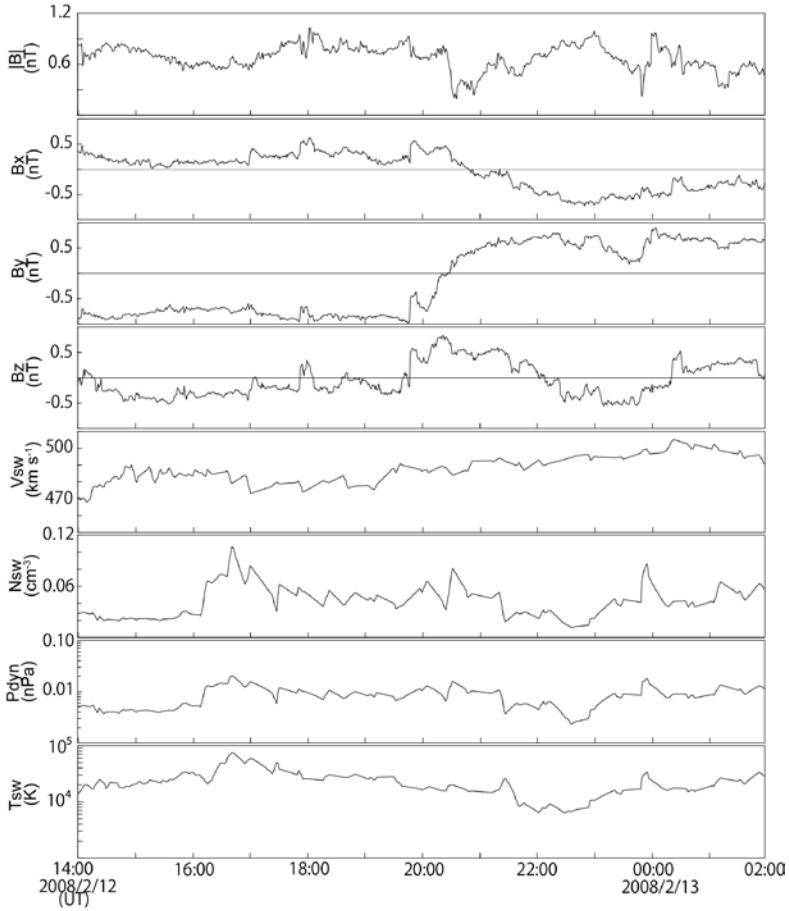


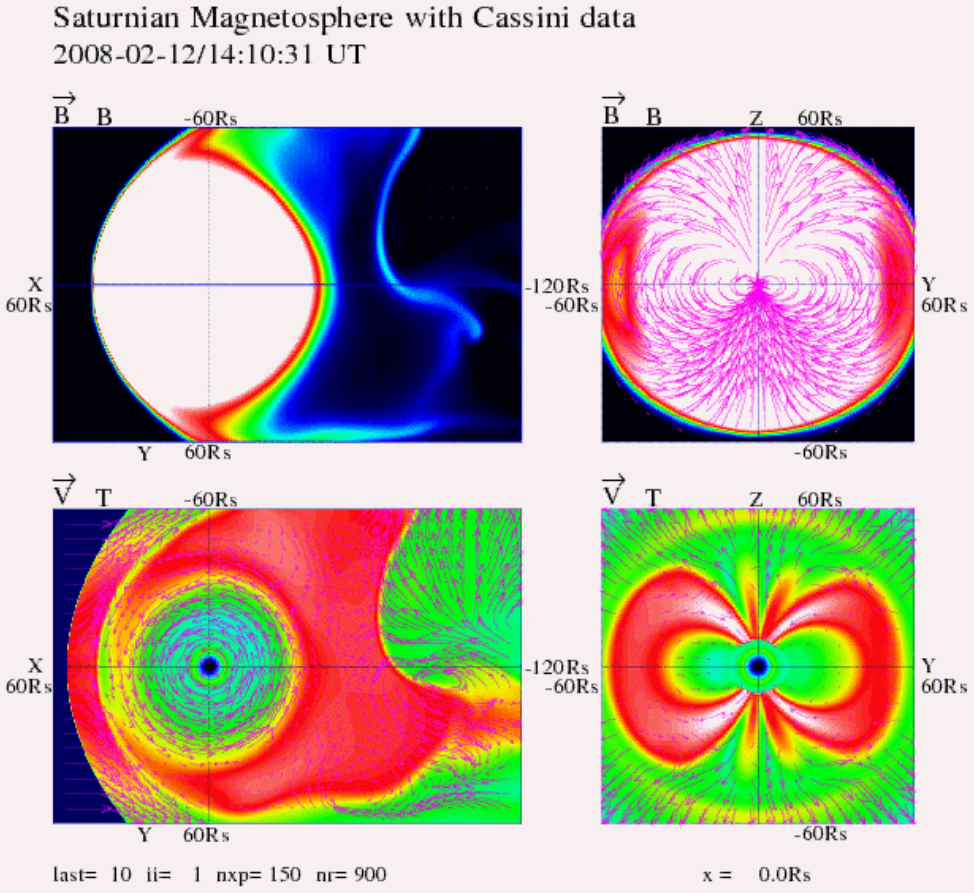
Fig.9. Solar wind condition observed by Cassini.

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.

Perform the simulation using this data!

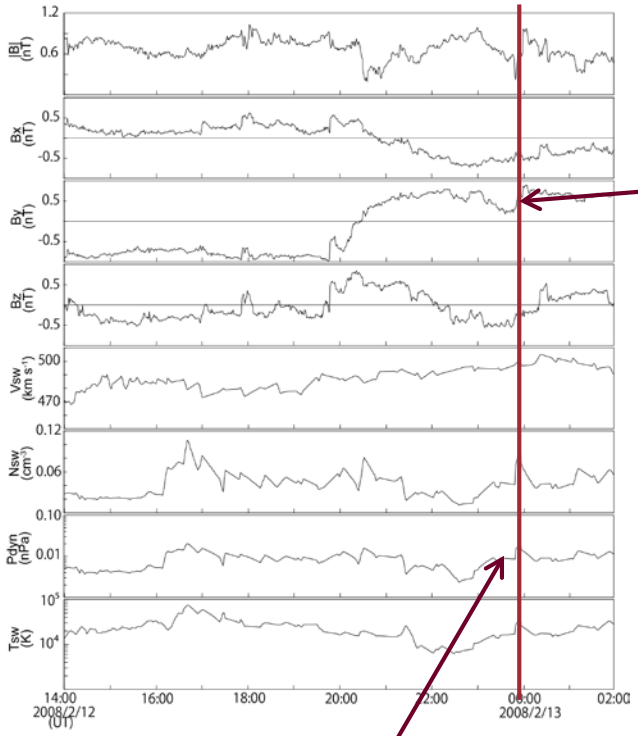
Simulation results using Cassini's solar wind data



- 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.

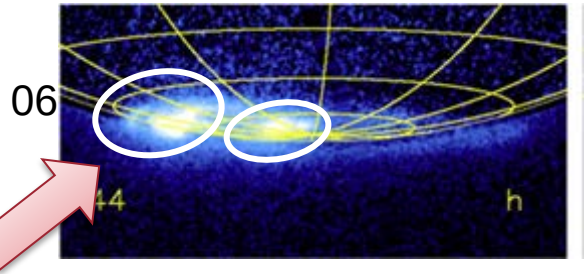
Now | Simultaneous observation in 2008

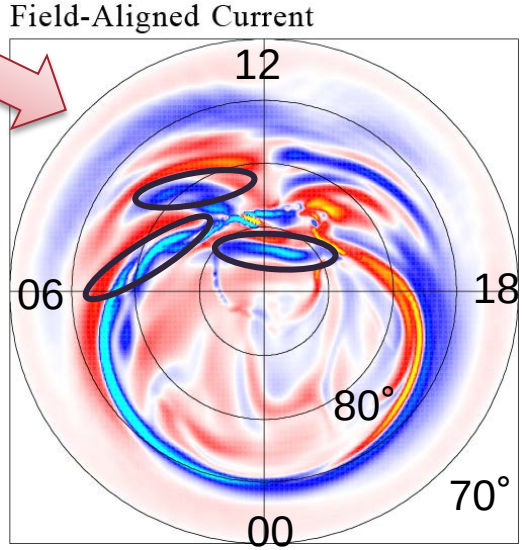
Comparison of Simulation with Observation



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

Future

Need to think after Cassini

Research area

- Statistical research of whole Cassini data to see the long period phenomena, effect of solar cycle, etc.
- Planet – moon (Titian, Enceladus, etc.) interaction
- More collaboration with observation and simulation

Simulation

- High resolution simulation
- MI-coupling
- Non MHD simulation
- Development of computer system

Future | Simulation

Simulation will play more important roles in the absence of Cassini

High resolution simulation

- To see the clear vortex configuration and magnetospheric flow
- To understand the effect of solar wind to the magnetosphere
- To represent the observation phenomena

MI-coupling

- To understand the aurora dynamics

Non MHD simulation

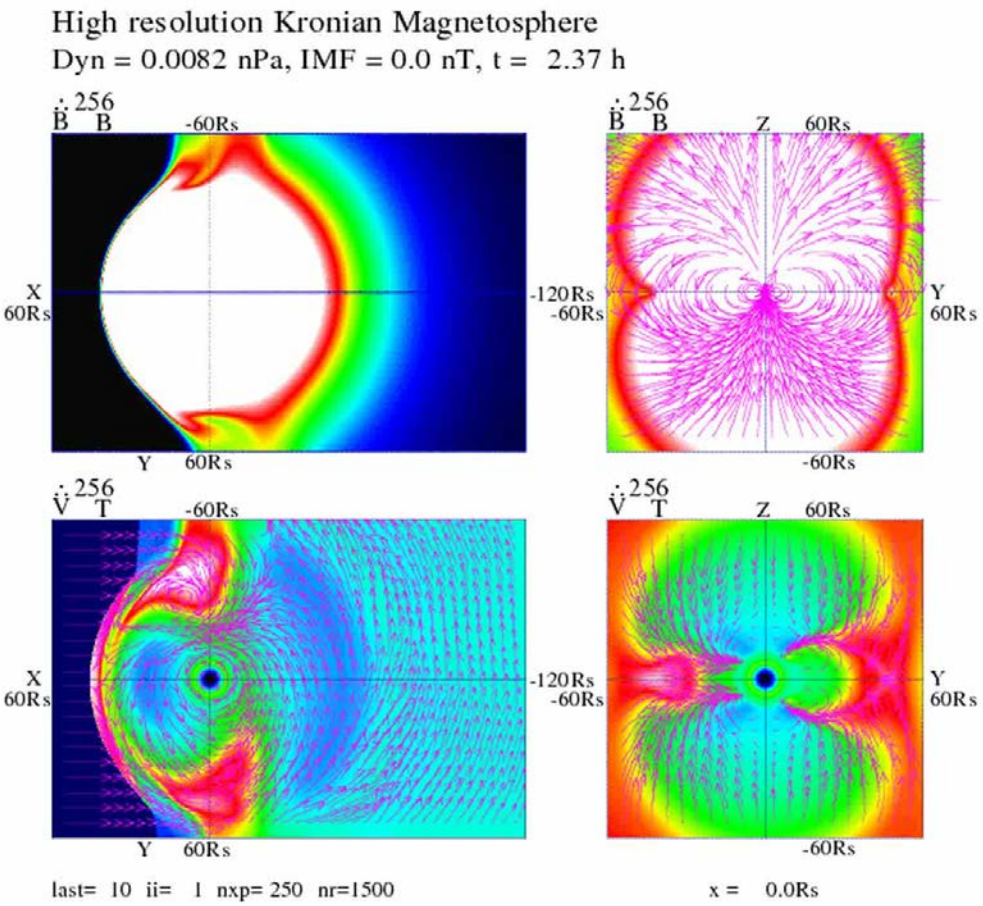
- To see the small scale phenomena

Computer developments

- In the next 5 years the consist of supercomputer will be changed

Future | High resolution simulation

Simulation @ 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

Future | High resolution simulation

Difficulty of large scale computing

Long calculation time is needed

- It takes *one year* to run the simulation without the job waiting time.

Large storage is required

- One time step data size is 700GB and we have 150 sampling data then the all data size is 700 × 150=100TB!!

Hard to analyze the simulation results

- To do with the simulation data, we need over 1TB shared-memory computer.
  →Now I use supercomputer not for the simulation but the analysis.
  →This is not effective because of not interactive operation.

We have to develop the environment of analysis.

Future | High resolution simulation

Next simulation of Kronian magnetosphere

Grid size

- (nx, ny, nz, nmhd) = (6000, 4000, 4000, 8) → about 5.6TB
- Grid spacing is $0.03R_S$

Parallelization

- MPI or new low-memory and high parallel efficiency parallel library to apply the over million process

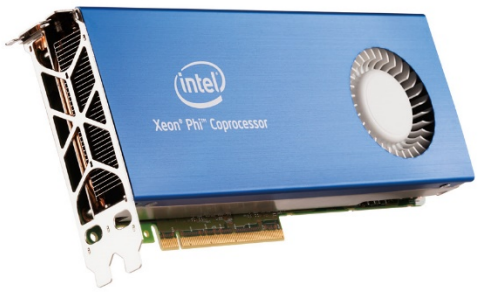
Recently this simulation is started on new supercomputer at Kyushu University.

Future | Development of computer system

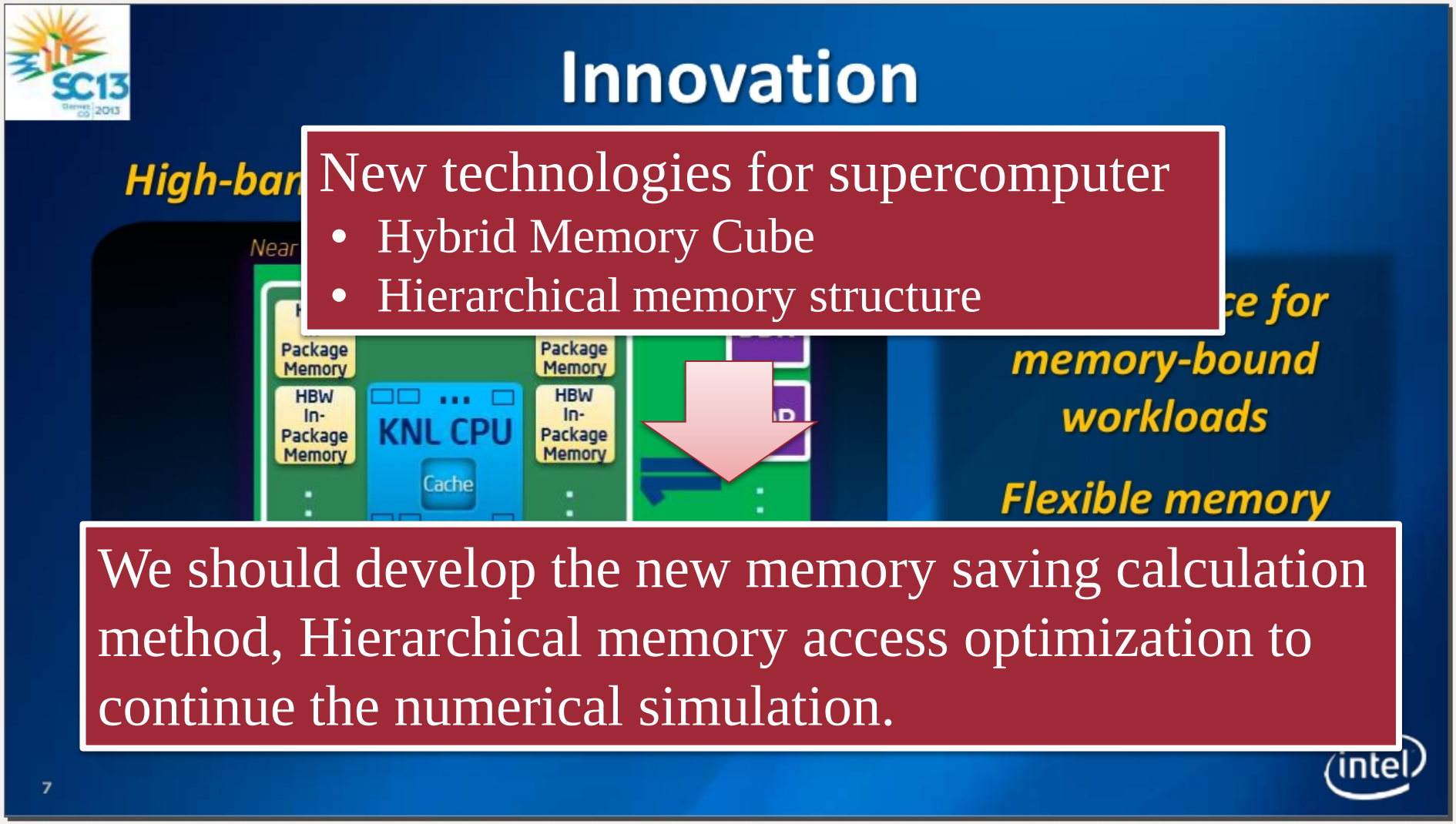
Transition of supercomputer

- Now the scalar type parallel computer is popular.
- Most of high performance computer systems consist of CPU and accelerator.
- Top 1 computer system in 2013 has Xeon and Xeon Phi and achieved 33.86PFlops which is triple performance of K-computer.

Tianhe-2 developed in 2013 (33.86PFlops)



Board of Xeon Phi



New technologies for supercomputer

- Hybrid Memory Cube
- Hierarchical memory structure

We should develop the new memory saving calculation method, Hierarchical memory access optimization to continue the numerical simulation.

Summary

Now and future research topics of Kronian magnetosphere

Now

- Vortex configuration from KHI, flapping and reconnection, simultaneous observation of Cassini and HST
- Simulation also conducted and obtained good results.

Future…

- Statistical research of whole Cassini, planet – moon(s) interaction, etc.
- The high resolution and non MHD simulations will perform according to the computer development.
- However new techniques are needed optimized to the new technologies.