惑星磁気圏超並列高効率 MHDシミュレーションの開発

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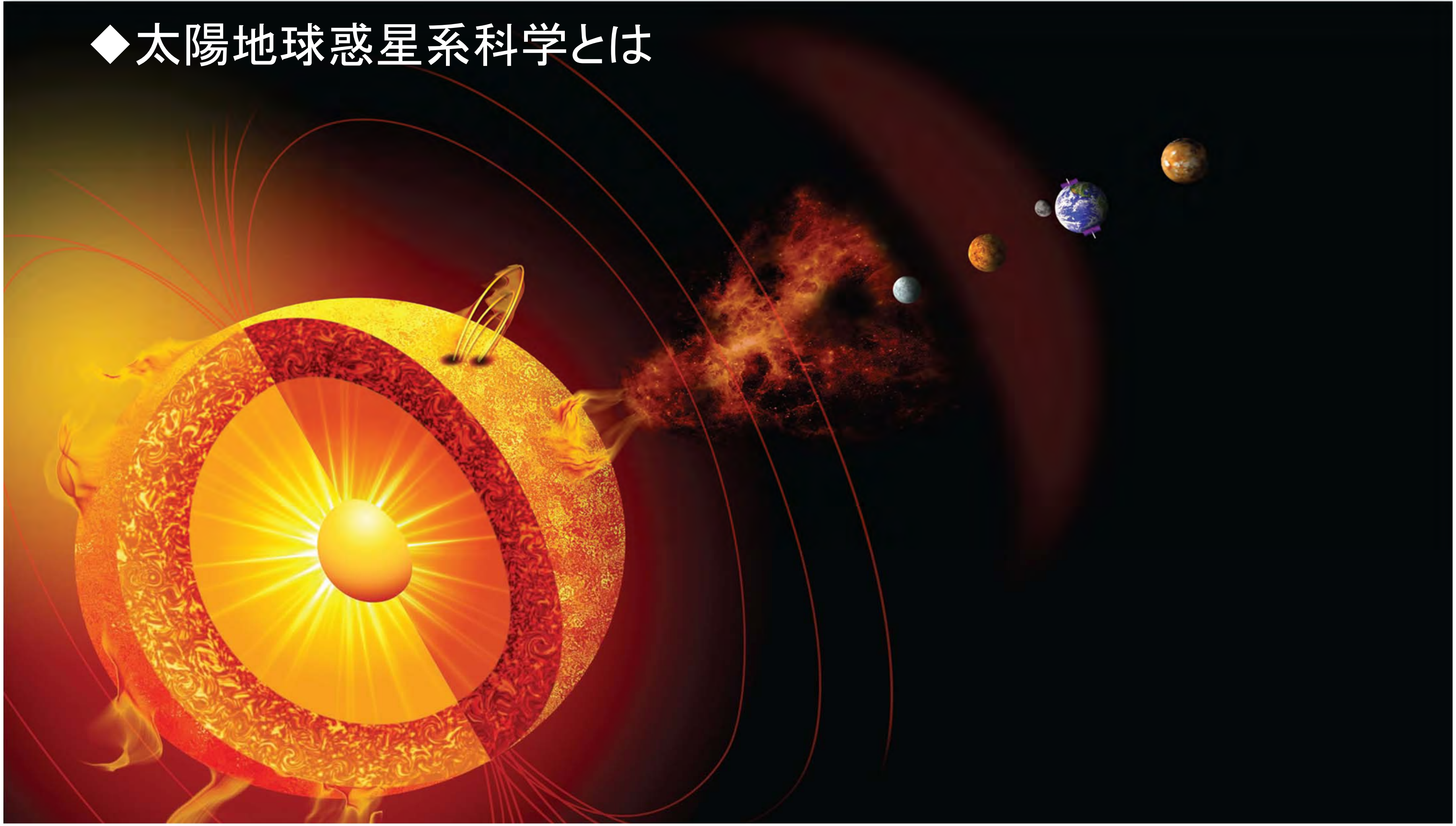
Context

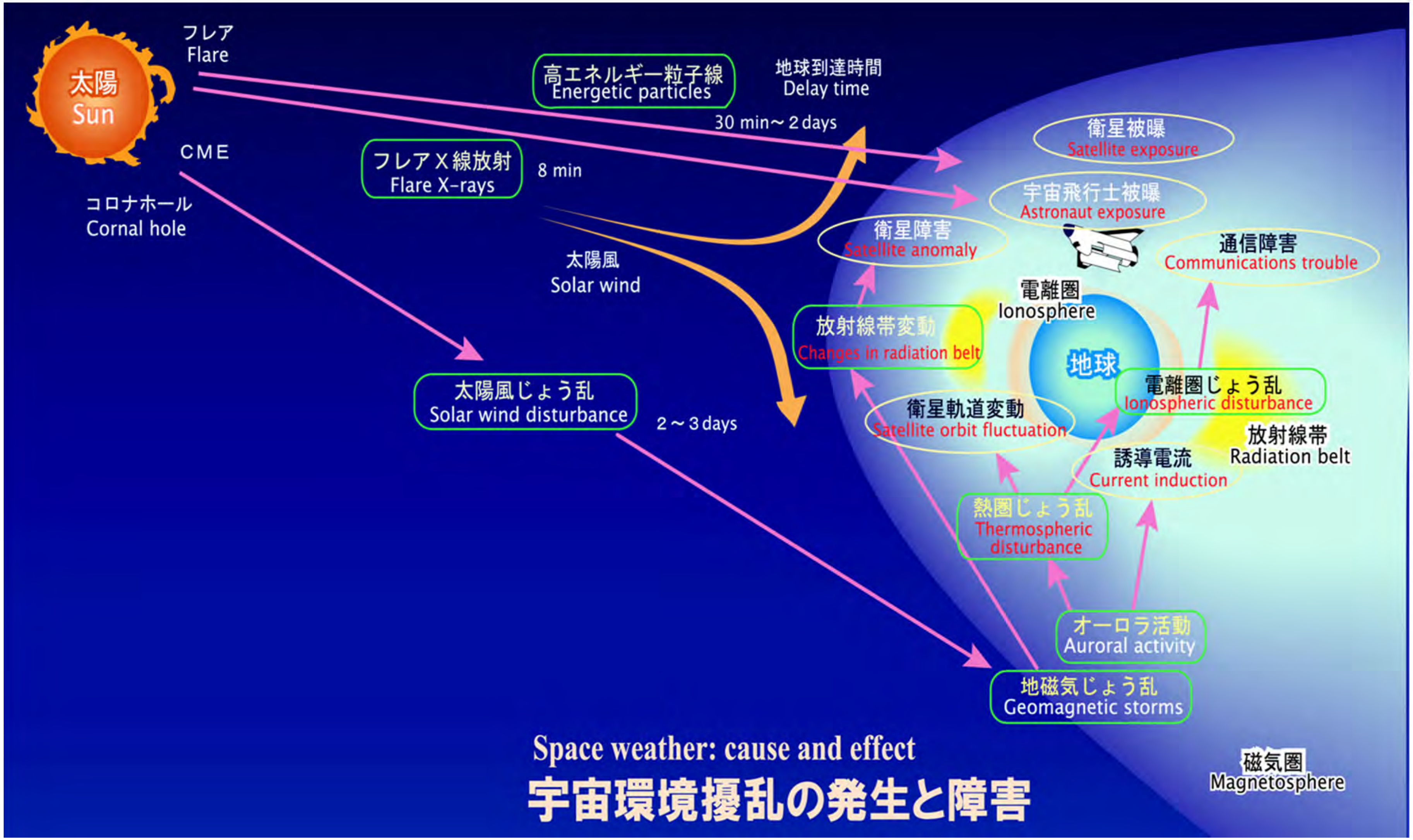
1. Introduction
   - 太陽地球惑星系科学の紹介
   - 土星磁気圏におけるプラズマ対流構造とオーロラ
   - Motivation
2. Simulation Results
3. Aurora configuration and vortices
4. Summary

Introduction -1

◆太陽地球惑星系科学とは



Introduction -2



Space weather: cause and effect

宇宙環境擾乱の発生と障害

Introduction -3

◆地球、木星、土星における電磁気的特徴

	Jupiter	**Saturn**	**Earth**
Magnetic field [nT]	420,000	21,000	31,000
Magnetic polarity	N pole is north	N pole is north	N pole is south
Rotation period [hr]	10	10.65	24
Main plasma source	Io, ionosphere	Enceladus, ionosphere	ionosphere
Equatorial Radius [km]	71,492	60,268	6378
From Sun [A.U.]	5.2	9.55	1

木星は巨大な磁場と豊富なプラズマを持って高速自転する。
土星は豊富なプラズマを持って高速自転する。

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◆地球、土星磁気圏の形

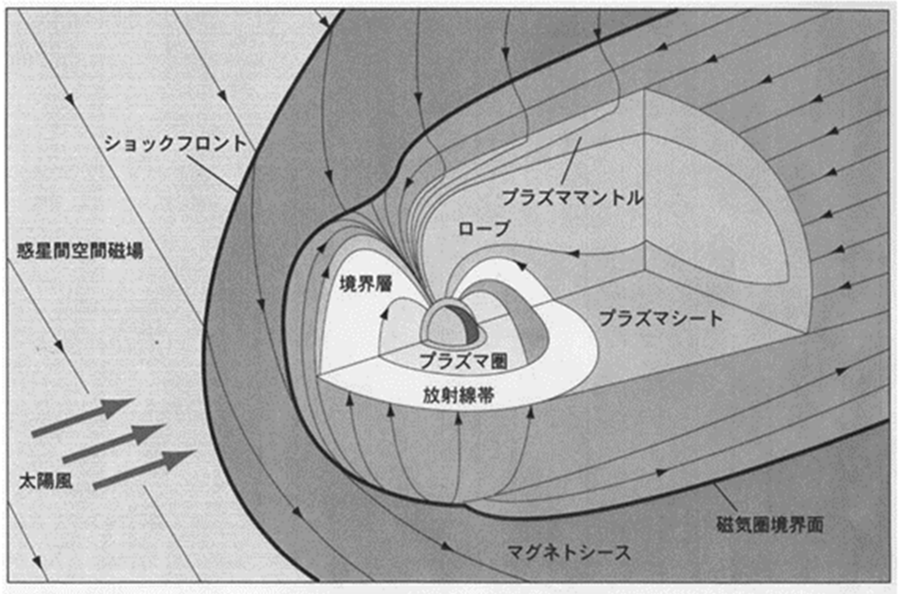


Fig.1. A schematic of Terrestrial magnetosphere

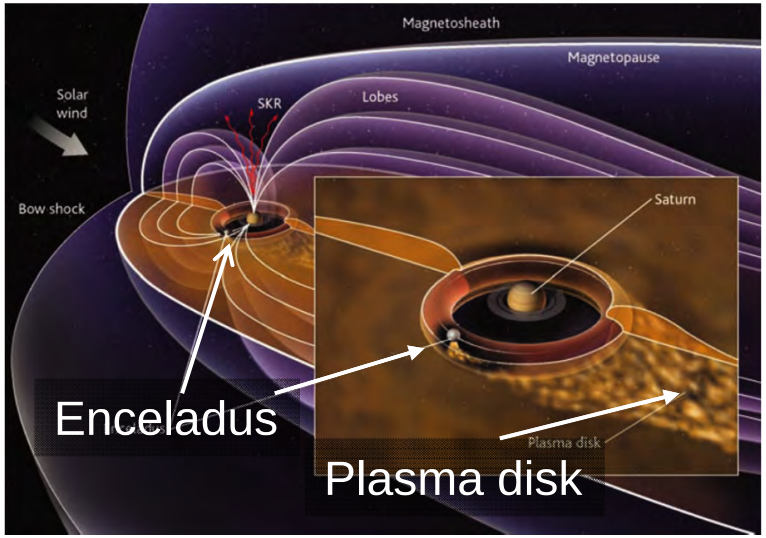
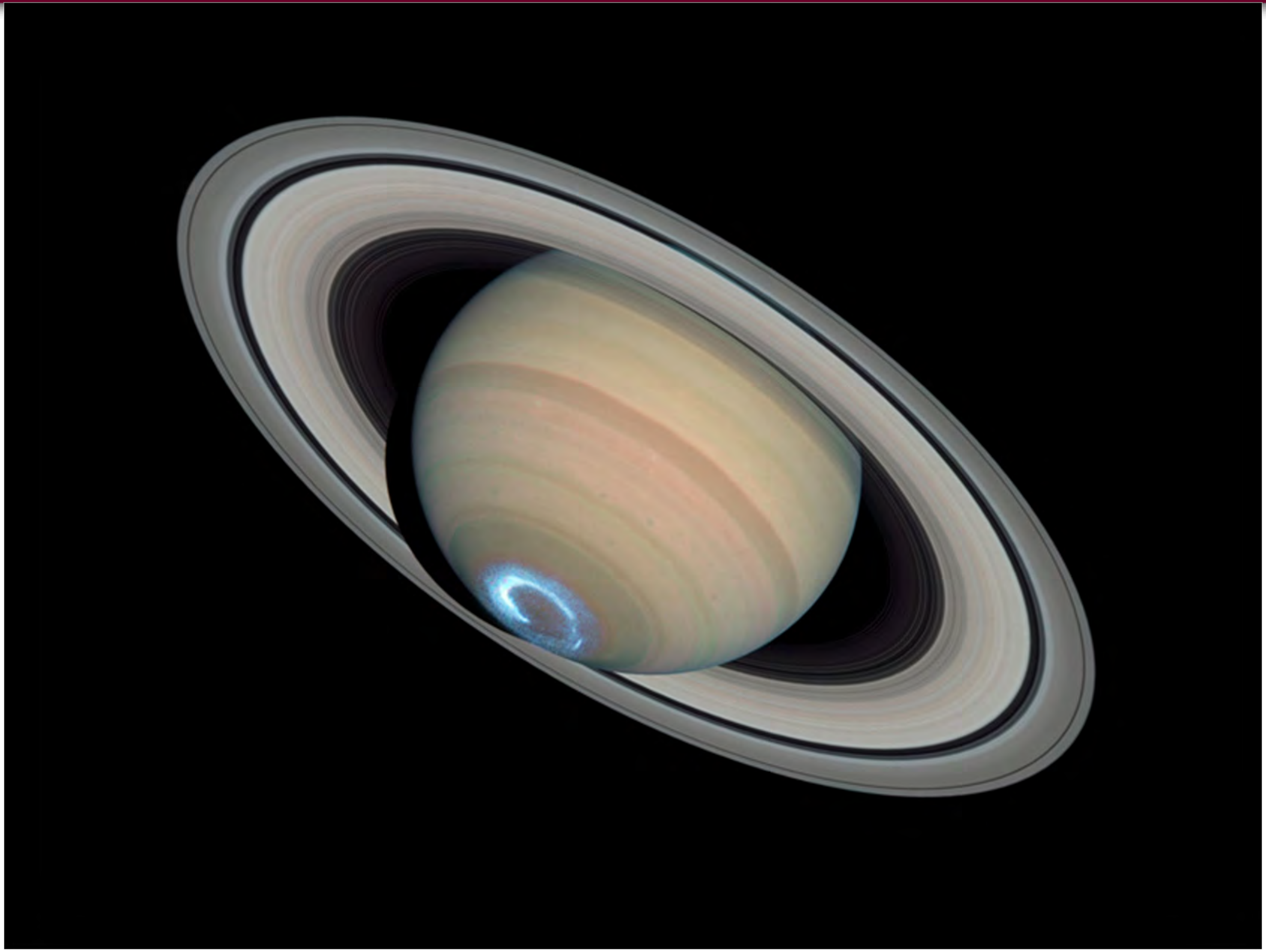


Fig.2. Schematic of Saturn’s magnetosphere [*Kivelson*, 2006]

土星は高速自転しているため、磁気圏内のプラズマ対流が複雑。

Introduction -5



Introduction -6

◆Observation of Saturn's aurora

- ☐A large number of images of Saturn's UV aurorae have become available from the Hubble Space Telescope in the past few years [e.g. *Grodent et al.*, 2005; *Clarke et al.*, 2009; *Nichols et al.*, 2009].

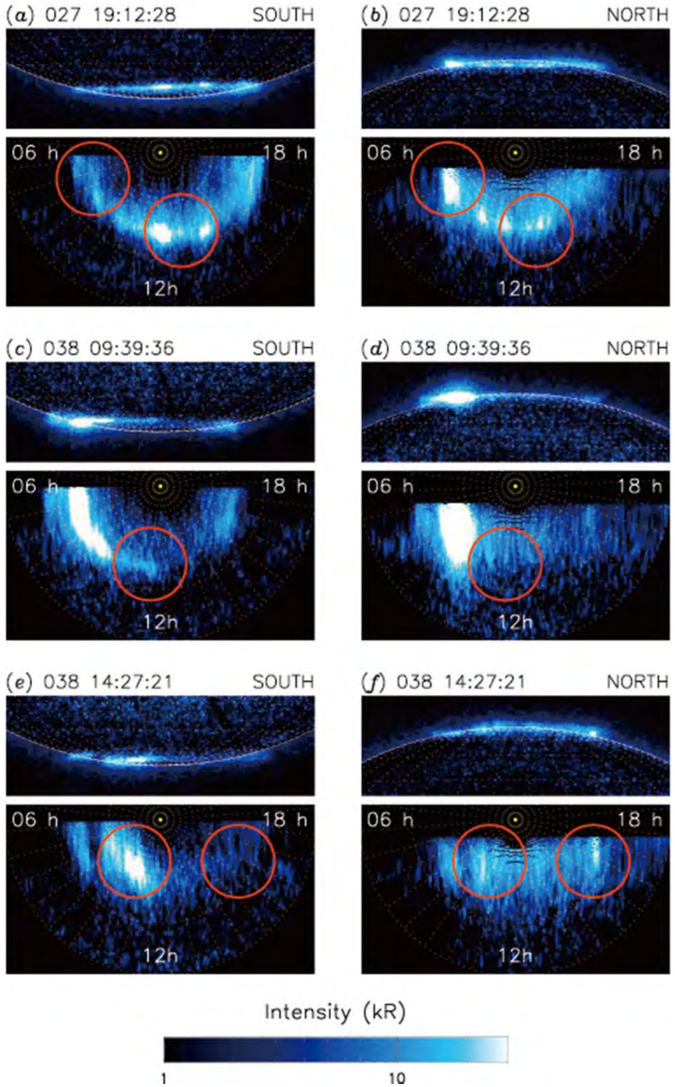


Fig.3. Three examples of images exhibiting hemispherically asymmetric auroral forms[*Nichols et al.*, 2009]. Obvious asymmetries are highlighted by the red circles.

Introduction -7

◆HSTとCassiniの同時観測（2004年）

- □Cassiniが太陽風を観測して(500R$_S$程度上流)、HSTが土星のオーロラを撮像。

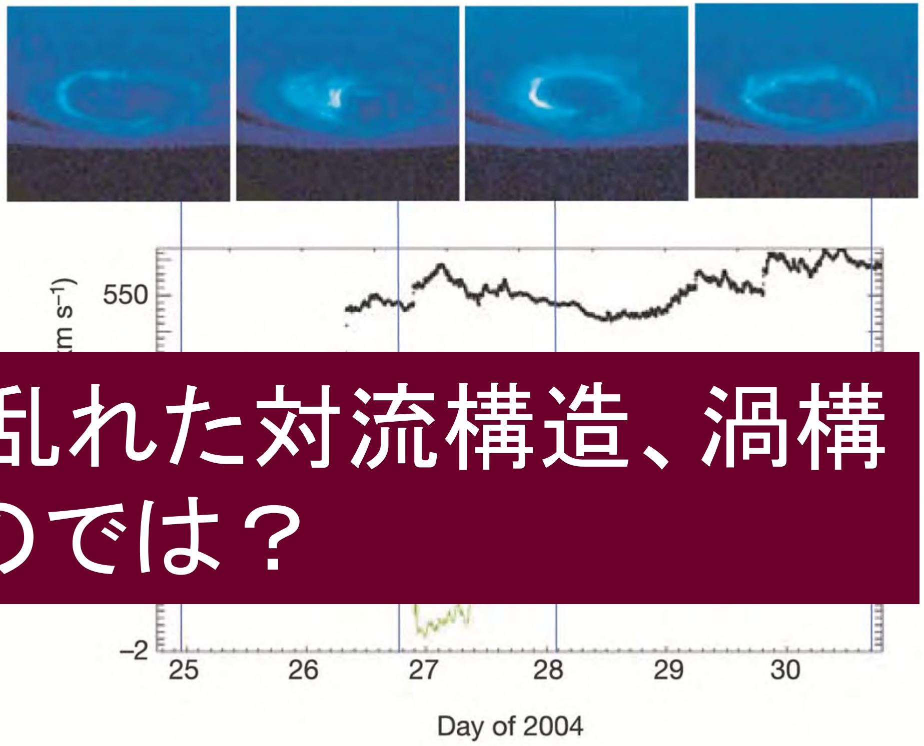


Fig.4. Comparison between HST images and solar wind conditions propagated to Saturn for the period 25–30 January 2004 [*Crary et al.*, 2005]

- □C

土星磁気圏の乱れた対流構造、渦構造に関係するのでは？

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◆土星磁気圏対流構造

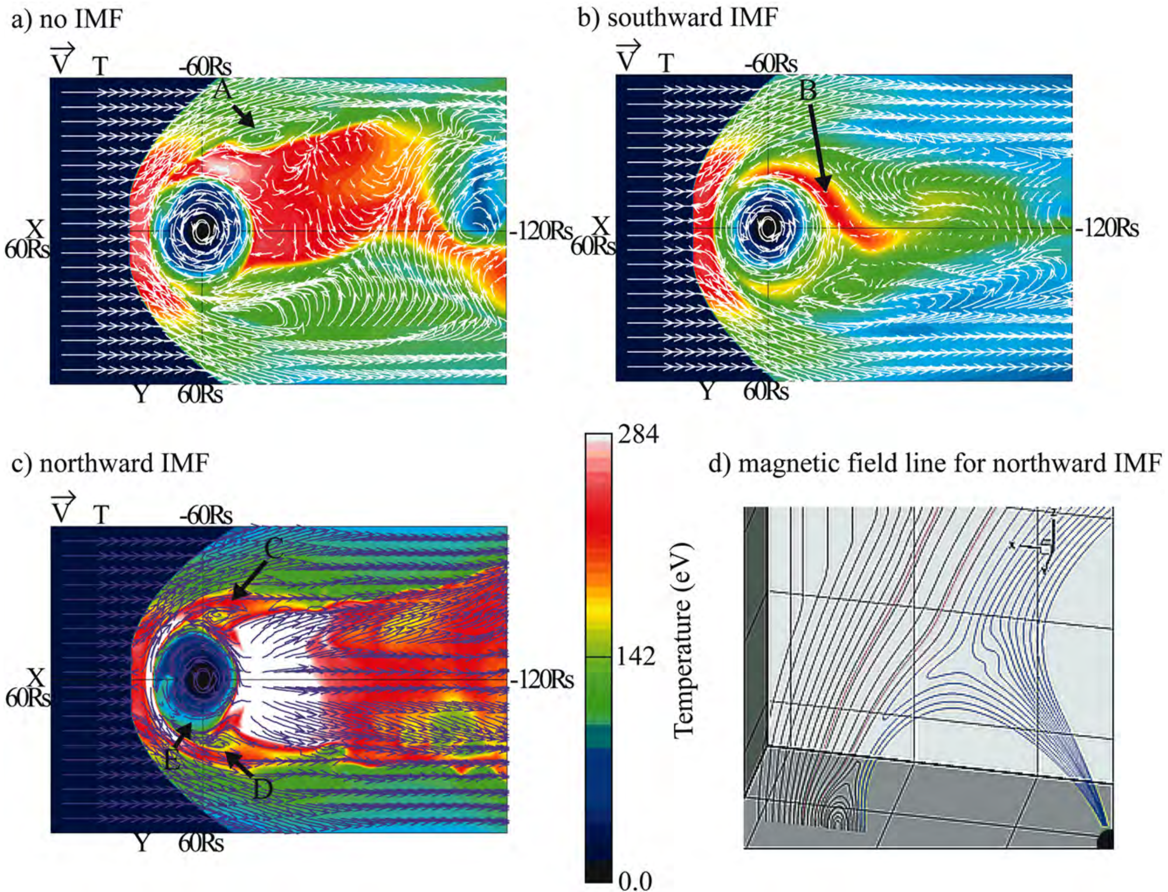
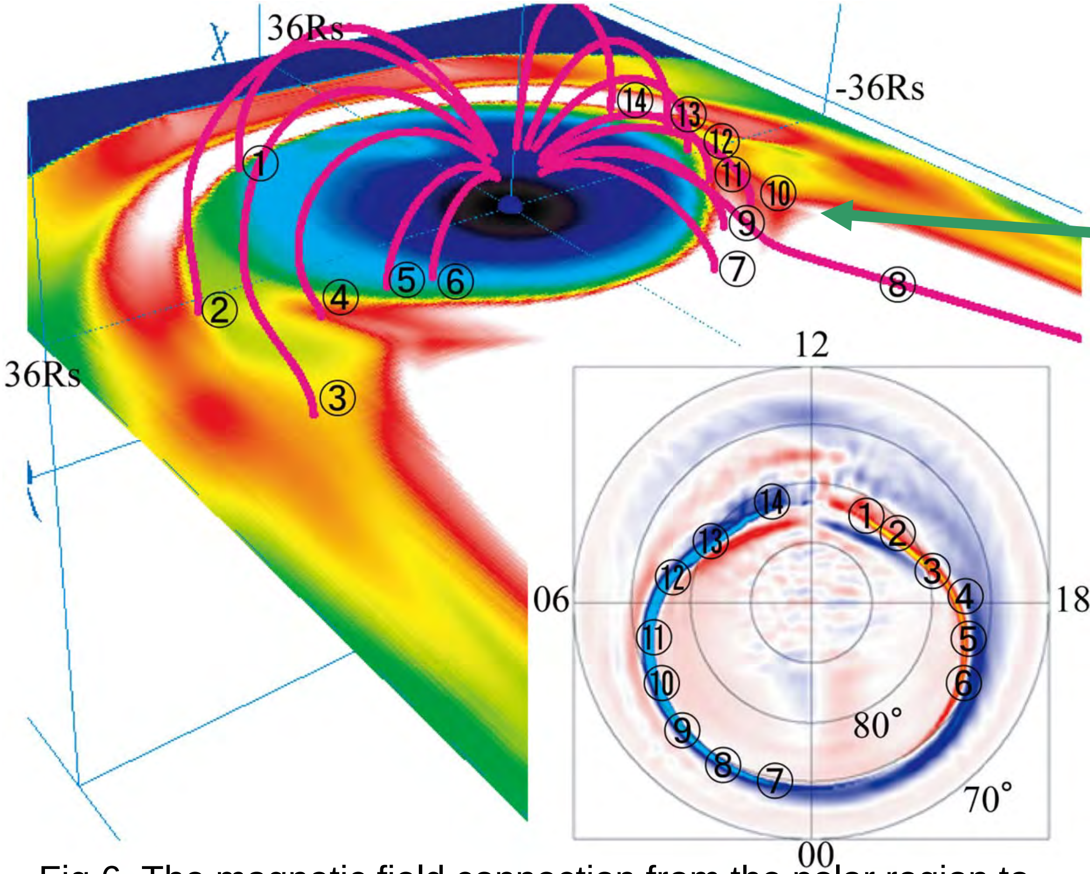


Fig.5. The temperature and flow vectors in the equatorial plane for the simulations with no IMF (a), southward (b) and northward IMF (c) [*Fukazawa et al.*, 2007a]

どの条件においても土星磁気圏では渦構造が発達している。
no IMF、southward IMFではスケールの大きな渦、northward IMFでは小さいが、強い渦が見える。

◆対流構造と沿磁力線電流の関係



dawn側の渦が生成されている場所で上向き沿磁力線電流が強い。

*南極側のプロットなので、左右が反転する。

Fig.6. The magnetic field connection from the polar region to the magnetosphere [*Fukazawa et al.*, 2007a]

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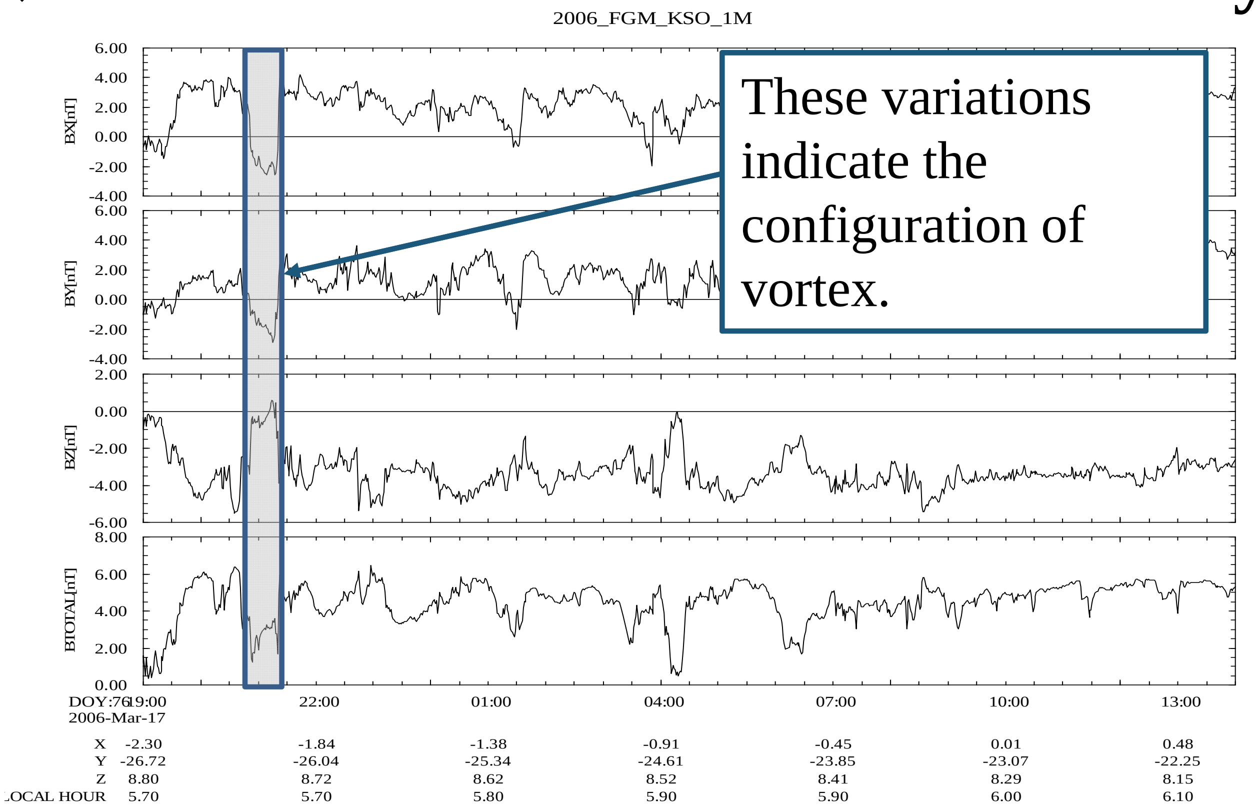
◆Vortex at dawn in the observations by Cassini



These variations indicate the configuration of vortex.

Fig. 7. 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.

Motivation

◆ Study of Kronian aurora from simulation

- ☐ We want to know the effect of magnetospheric convection to the aurora.
- ☐ We do not have an enough spatial resolution to know that.
  - We used 0.3R_S the grid interval in the previous simulations. (in the real distance 0.3 × about 60,000km=18,000km)
  - It is still MHD coverage distance in the Kronian magnetosphere if the rumor radius in the solar wind may be over 100km.

  - We need to run the higher resolution simulation and study the dynamics of Kronian magnetosphere and aurora.

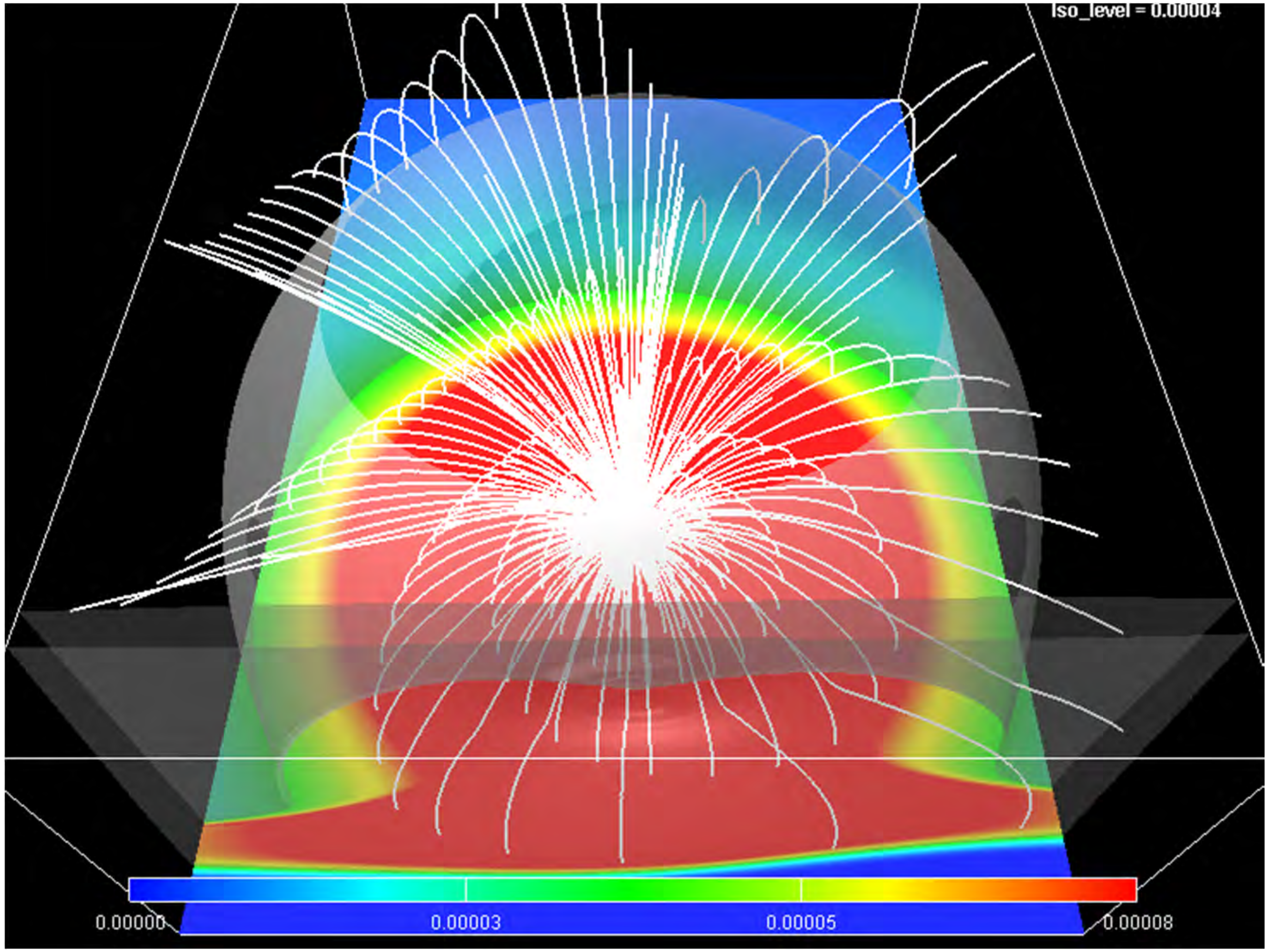
High resolution simulation model

◆Simulation setting

- ☐ Grid size
  - (nx, ny, nz, nmhd) = (1800, 1216, 608, 8)*about 42GB
  - Use 7 times larger memory (300GB) than the grid size in the calculation
  - Write the 300 simulation data for 20 hours in the real time (about 24TB)
  - Grid interval $0.1R_S$
- ☐ Simulations run on the following supercomputer
  - FX1 at the Nagoya University and HA8000 at the University of Tokyo
  - 1024 cores is used for 700 hours (cpu time) as a collaboration research
  - Post processing is performed on M9000 which has the large shared-memory
- ☐ Parallelization by MPI
  - 2 dimensional decomposition with Flat MPI on 1024 cores
- ☐ Solar wind condition
  - Northward IMF = 0.4nT, D_{SW} = 0.0082nPa

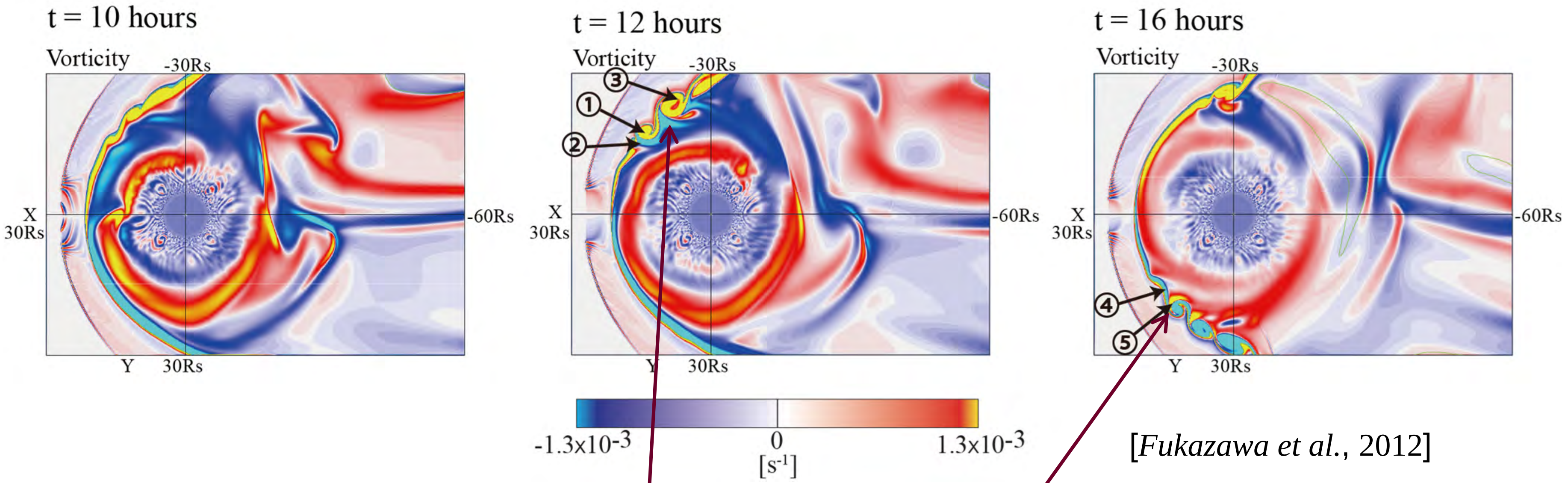
Simulation Results 1

◆**The movie of magnetic field strength**



Simulation Results 2

◆Vorticity on equatorial plane at three snapshots



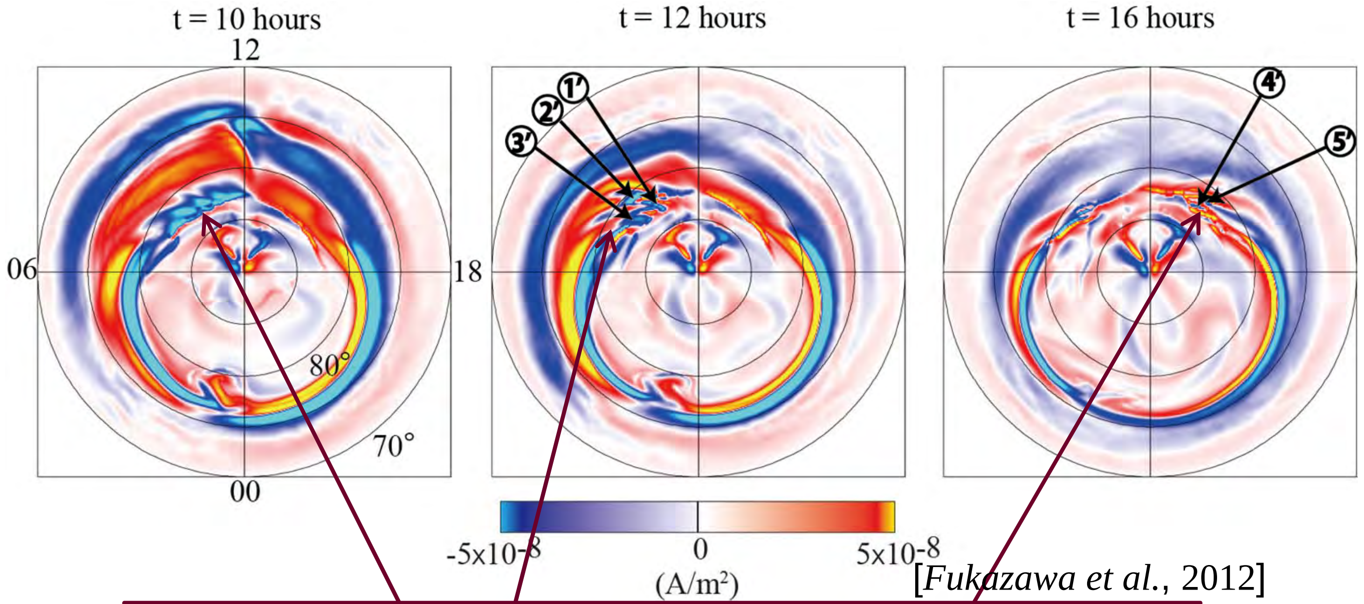
[*Fukazawa et al.*, 2012]

Vortices are formed along the magnetopause

The flow has formed clear vortices which extend 2.7 to 4.1 R_S along the longer axis for these cases.

Discussion 1

◆FACs on polar southern ionosphere



[*Fukazawa et al.*, 2012]

Patchy and spot like feature is appeared

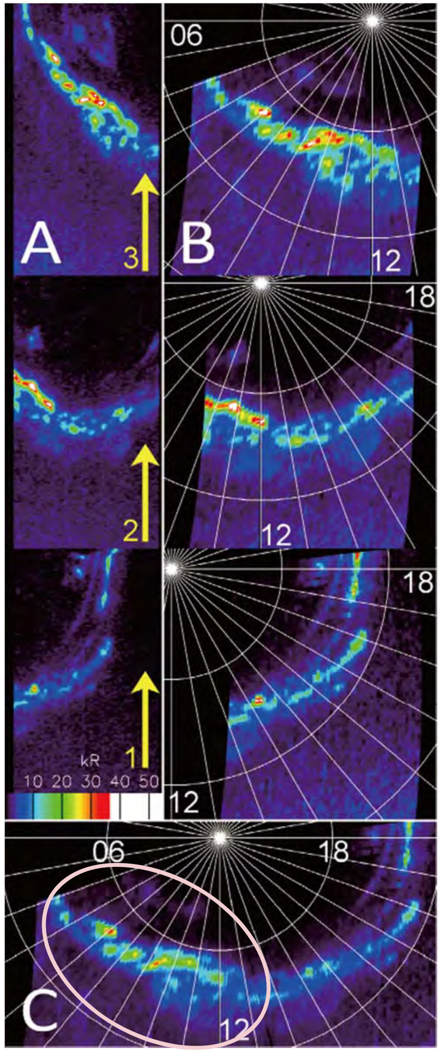


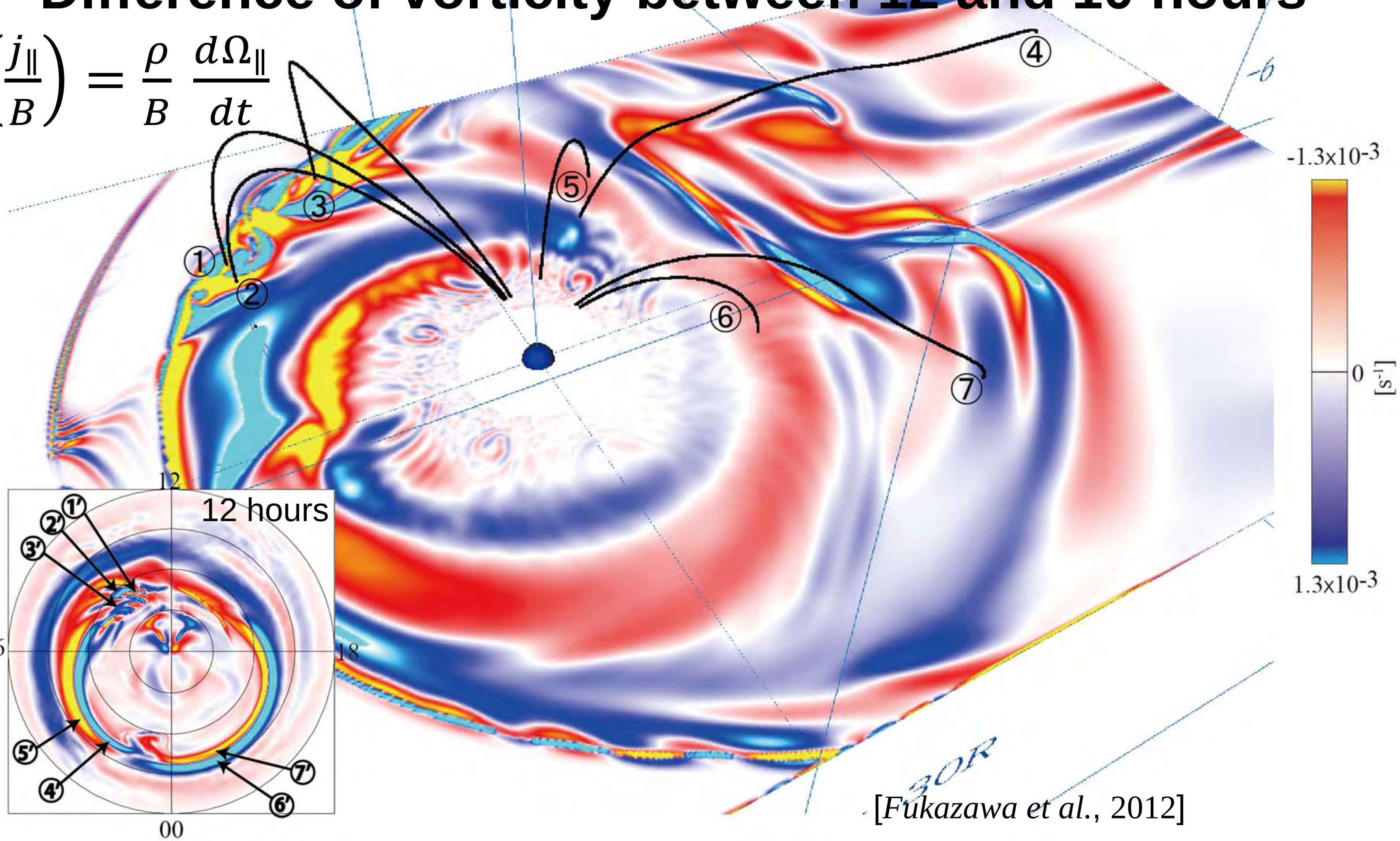
Fig.8. Pseudoimages obtained with the FUV channel of the Cassini - UVIS spectro - imager on DOY 239 (26 August) of 2008. [*Grodent et al.*, 2011]

Discussion 2

◆Relation of FACs to vortex in magnetosphere

Difference of vorticity between 12 and 10 hours

$$B\frac{\partial}{\partial s}\left(\frac{j_{\parallel}}{B}\right) = \frac{\rho}{B}\frac{d\Omega_{\parallel}}{dt}$$

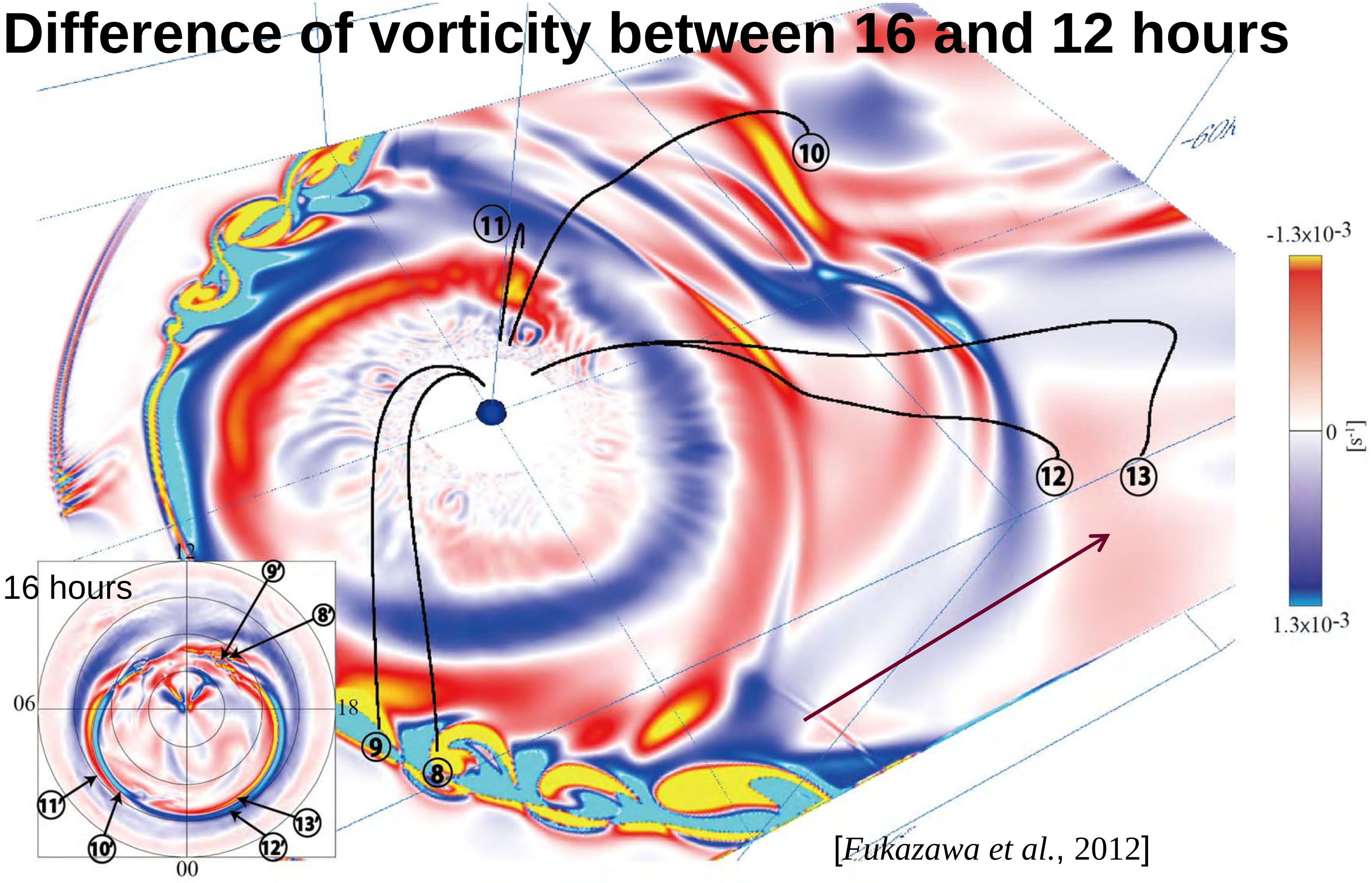


[*Fukazawa et al.*, 2012]

Discussion 3

◆Relation of FACs to vortex in magnetosphere

Difference of vorticity between 16 and 12 hours



[*Fukazawa et al.*, 2012]

Summary

◆惑星磁気圏超並列高効率MHDシミュレーションの開発

- 磁場がある惑星には磁気圏があり、それぞれが特徴的である。
- 土星磁気圏は非常に乱れた対流構造を持っており、その構造とオーロラの発光の関連性が示唆されている。
- 磁気圏という巨大な構造の中で詳細な対流構造を解くには、計算機リソースが必要であり、本プロジェクトで実行が可能となった。
- FX1が混んでいたため、東大T2Kの実行で補完することで、新しい土星磁気圏の計算が行え、きれいな渦構造を得た。
- 計算結果からオーロラ構造を調べた結果、渦構造と最新の土星オーロラ観測結果であるパッチ状構造に関連があることが示唆された。
- 今後は、条件を変えたシミュレーションを引き続き行い、実際の観測された太陽風を利用した計算も行う予定である。