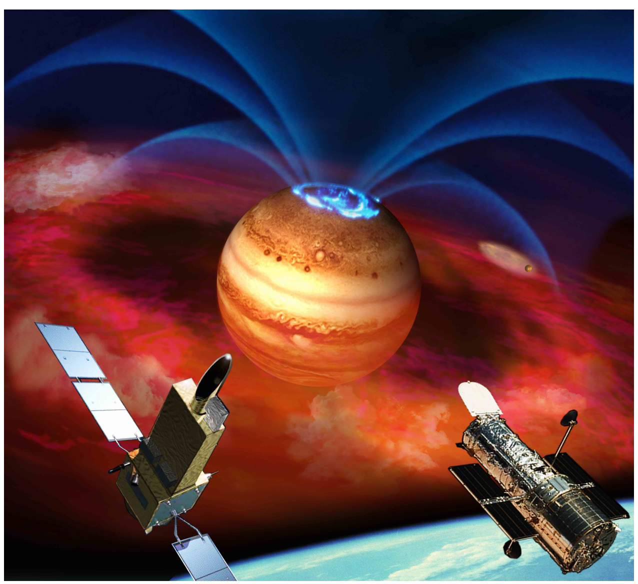
RIBF seminar 2018/01/30

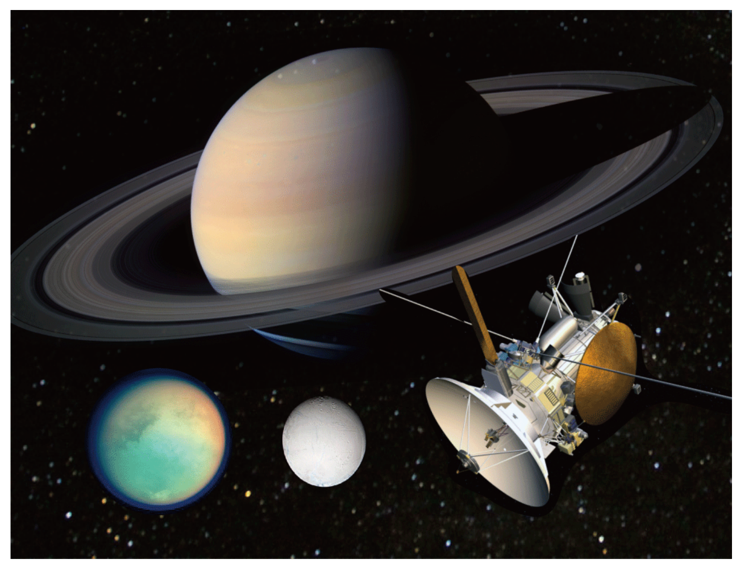
Transient brightening of Jupiter's aurora observed by the Hisaki satellite and Hubble Space Telescope during approach phase of the Juno spacecraft

Tomoki Kimura (Tamagawa Lab.)

About myself

- Name: Tomoki KIMURA
- Lab: Tamagawa lab.
- Expertise: space plasma, magnetosphere, gas giants, icy moons
- Missions
  - JAXA planetary space telescope Hisaki
  - ESA/JAXA Icy Moon Exploration JUICE
  - Associate of Juno, Cassini, & Galileo





Our first principle

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial B}{\partial t}$$

$$\nabla \times \boldsymbol{B} = \mu_0 \left(\boldsymbol{j} + \epsilon_0 \frac{\partial \boldsymbol{E}}{\partial t} \right)$$

$$\frac{\partial f_s}{\partial t} + \mathbf{v} \cdot \nabla f_s + \frac{q_s}{m_s} (\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \nabla_{\mathbf{v}} f_s = 0$$

$$f_s\left(x, y, z, v_x, v_y, v_z\right)$$

Contents

1. Basic background
2. Dynamics of Jupiter’s magnetosphere
3. Recent paper: Hisaki-HST-Juno collaboration
4. Future plans

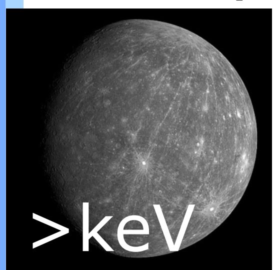
Basic background

My final goal

Universally understand how high energy space plasma works at magnetized rotating bodies

stronger B-field, faster rotation, higher energy plasma

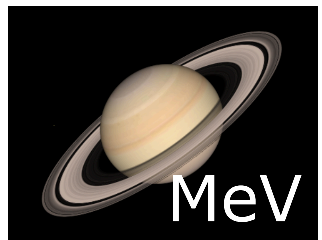
Mercury



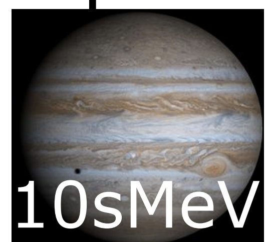
Earth

100keV

Saturn

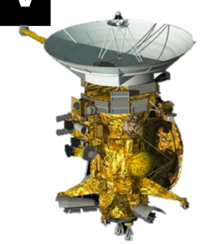


Jupiter



Neutron stars

High energy (<50MeV) plasma irradiation

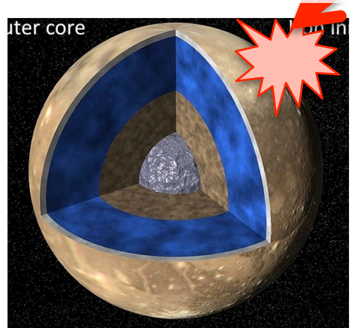


Exploration possible

Exploration impossible

synthesis of organic comp.

Titan



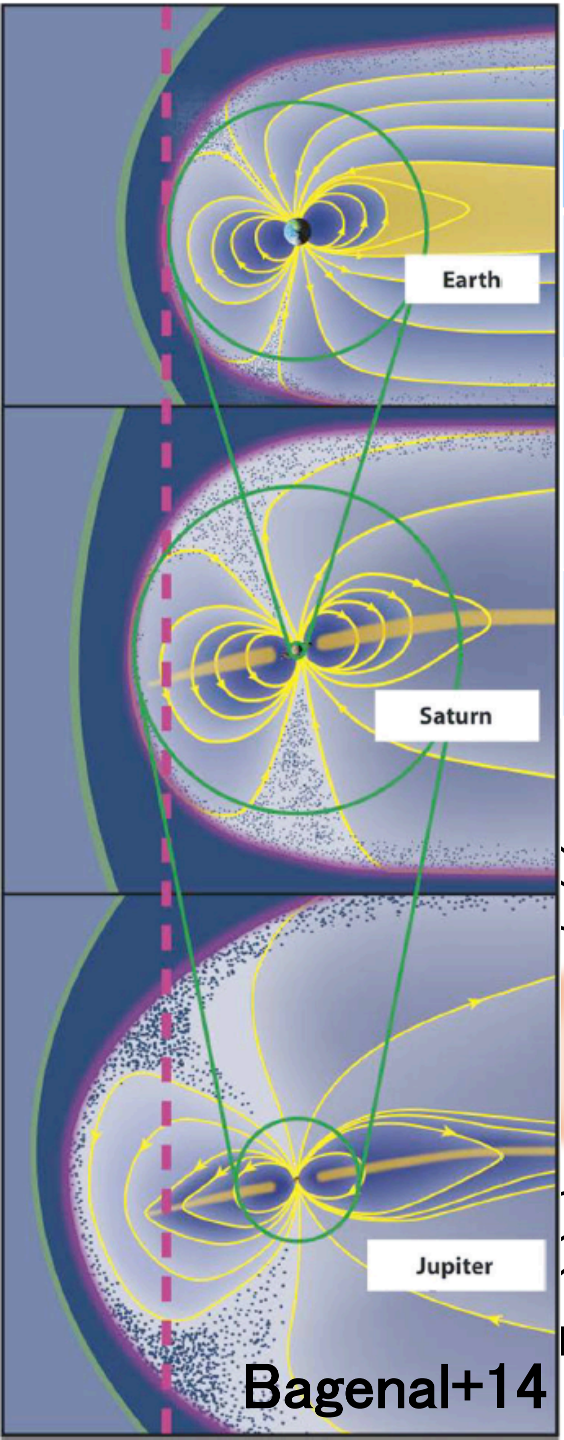
alteration of ice

Europa

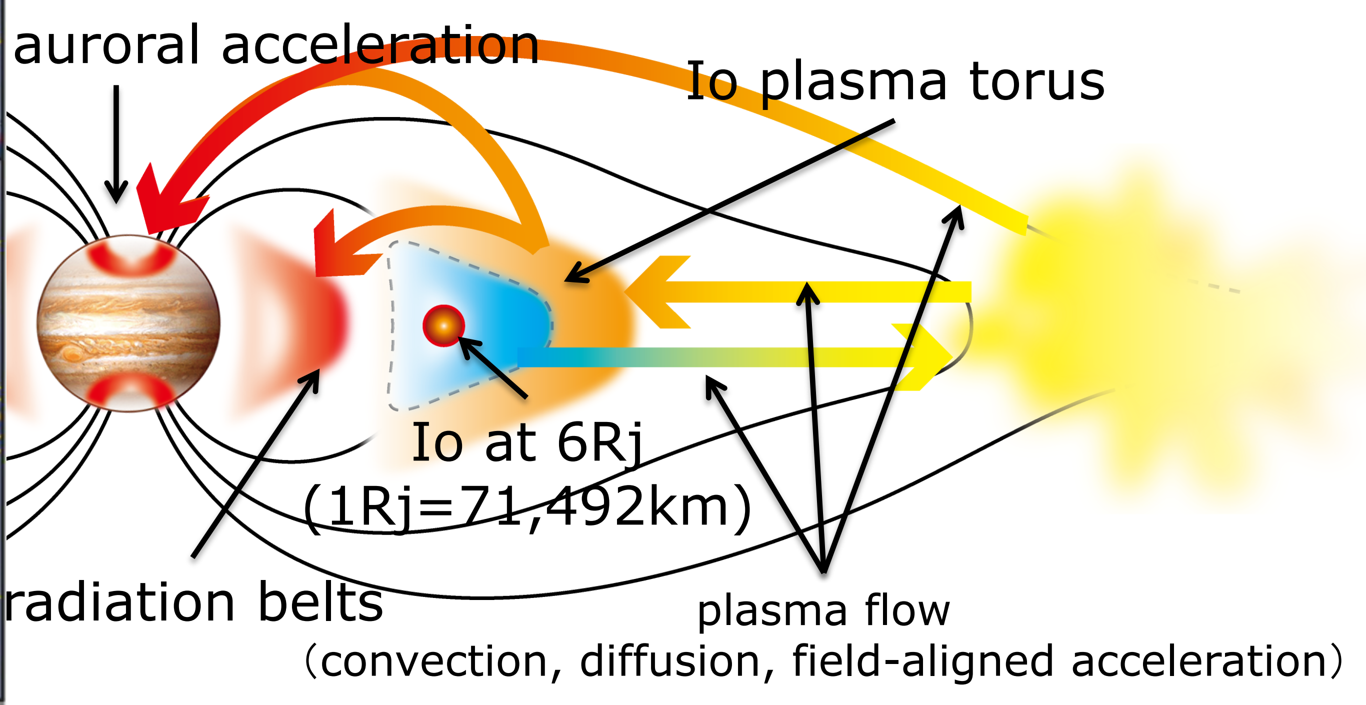
Ganymede

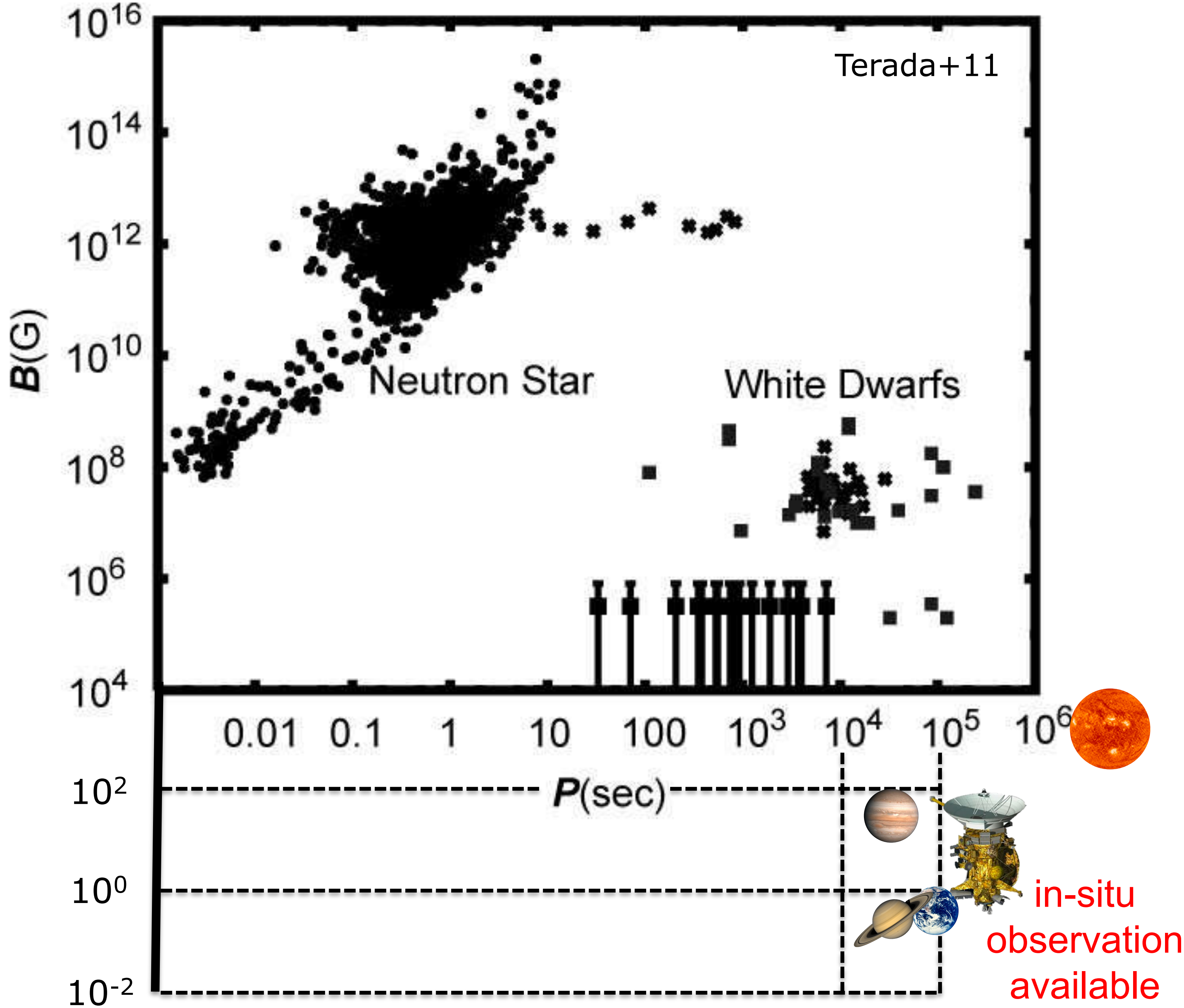
High energy plasma at Saturn & Jupiter works as chemical/physical energy source at ‘habitable’ moons

Planetary parameters



	Earth	Jupiter	Saturn
Spin period (hr)	24	9.92	10.56
Magnetic moment (Earth=1)	1	20,000	600
Plasma source (kg/s)	5	260-1400	12-250

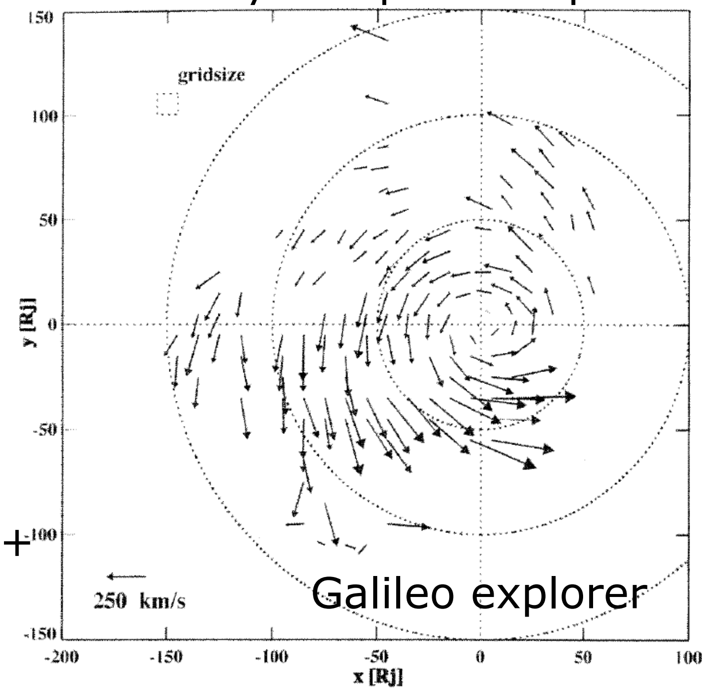




Terada+11
B(G)
10^16
10^14
10^12
10^10
10^8
10^6
10^4
10^2
10^0
10^-2
Neutron Star
White Dwarfs
0.01
0.1
1
10
100
10^3
10^4
10^5
10^6
P(sec)
in-situ
observation
available

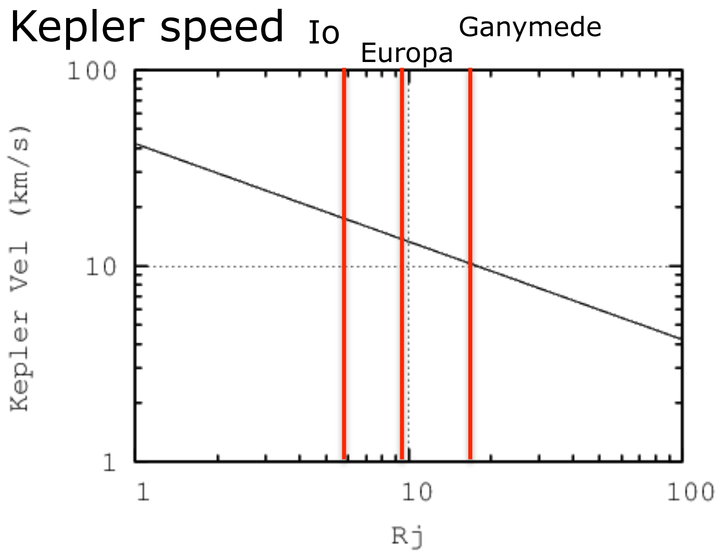
Rotating magnetosphere

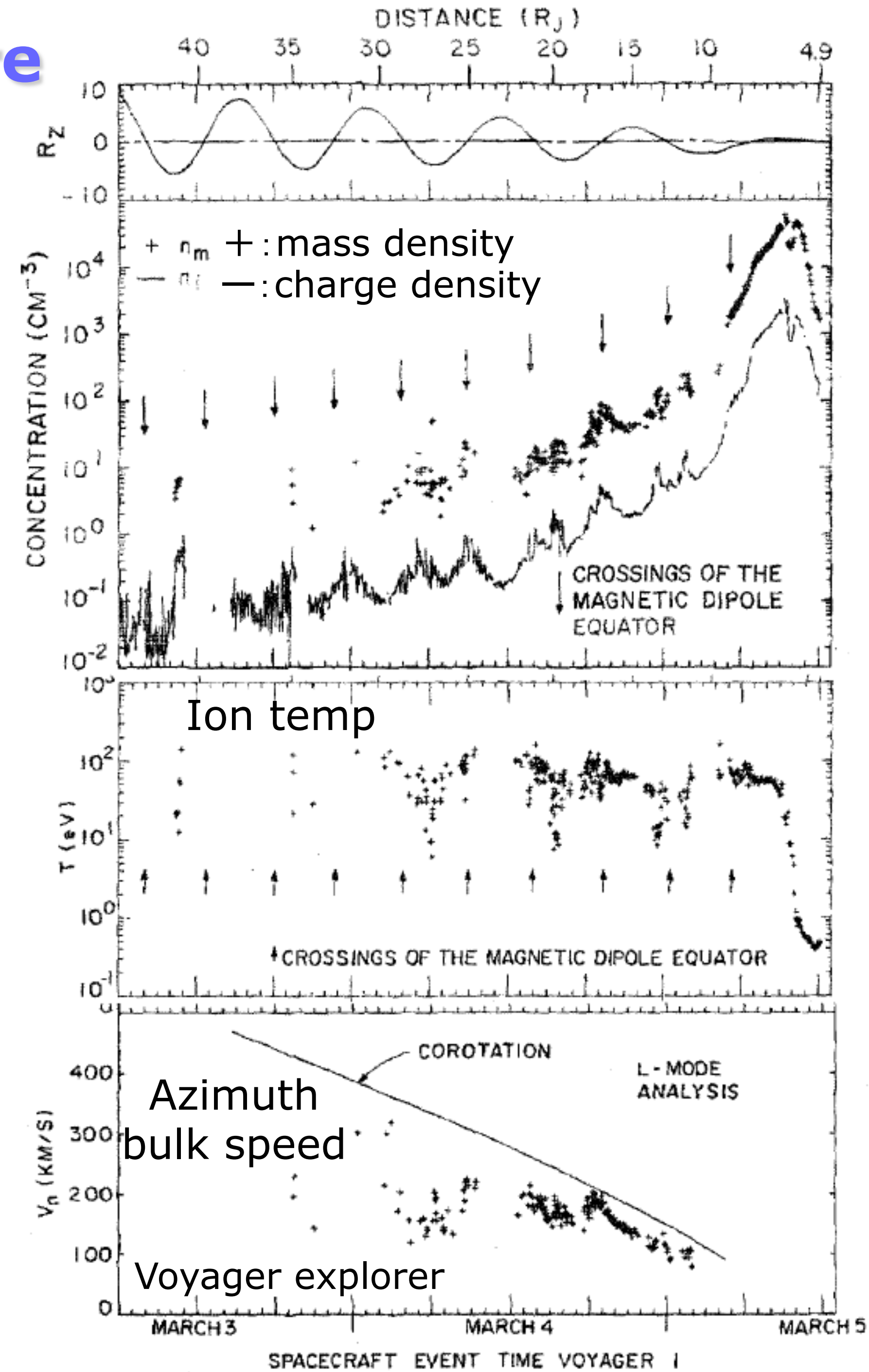
Bulk velocity in equatorial plane



Khurana+04

Kepler speed





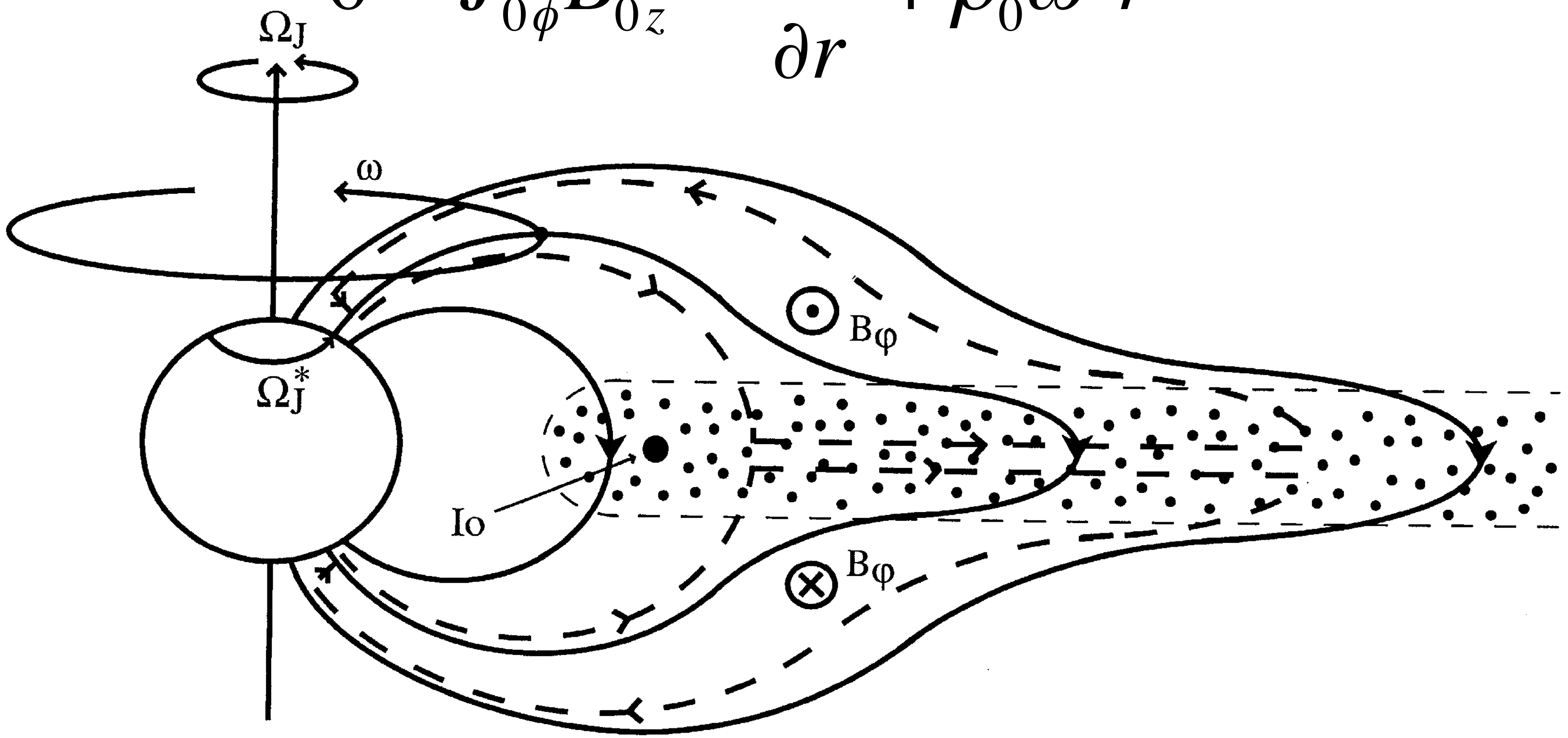
Steady state

Force balance in equatorial magnetosphere

$$\dot{\rho}\mathbf{\Omega} \times \mathbf{r} + 2\rho\mathbf{\Omega} \times \dot{\mathbf{r}} + \rho\mathbf{\Omega} \times (\mathbf{\Omega} \times \mathbf{r}) + \nabla \cdot \mathbf{P} = \mathbf{j} \times \mathbf{B_0},$$

approximately

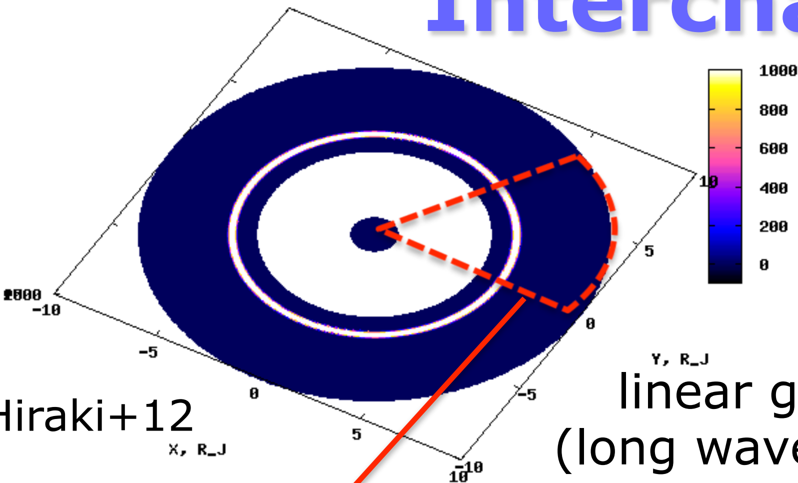
$$0 \sim J_{0\phi} B_{0z} - \frac{\partial p_0}{\partial r} + \rho_0 \omega^2 r$$



Cowley and Bunce, 01

Dynamics of Jupiter's magnetosphere

Interchange instability



Hiraki+12

Force balance around the Io plasma torus

$$0 = \vec{j} \times \vec{B} - \nabla p + \rho \vec{g}$$

linear growth rate
(long wavelength limit)

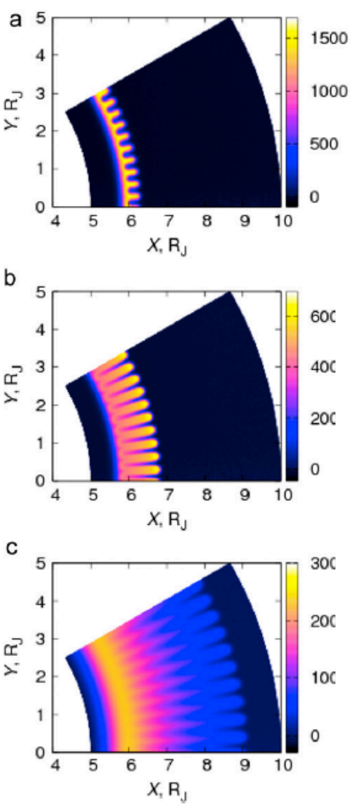
$$\gamma = \sqrt{\frac{g}{\left[-\frac{d}{dr}\ln\rho\right]}} \sim \sqrt{\frac{r\Omega_j^2}{r/\alpha}} = \sqrt{\alpha}\,\Omega_j$$

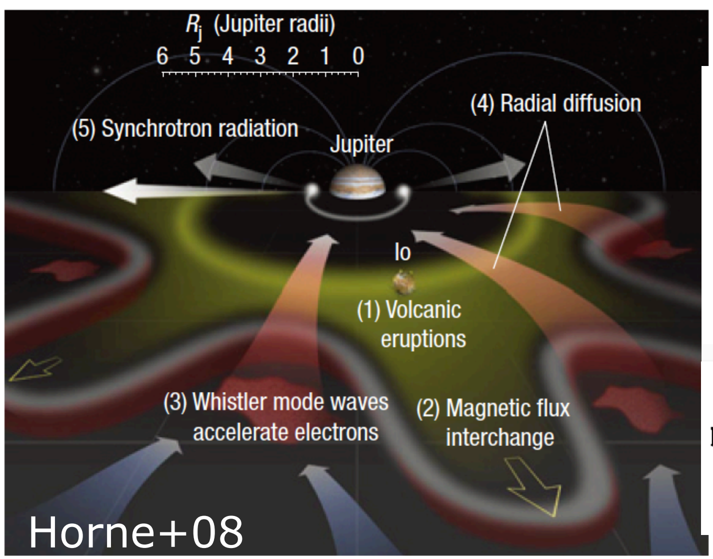
$$\rho(r) \propto r^{-\alpha}$$

Treumann&Baumjohann97

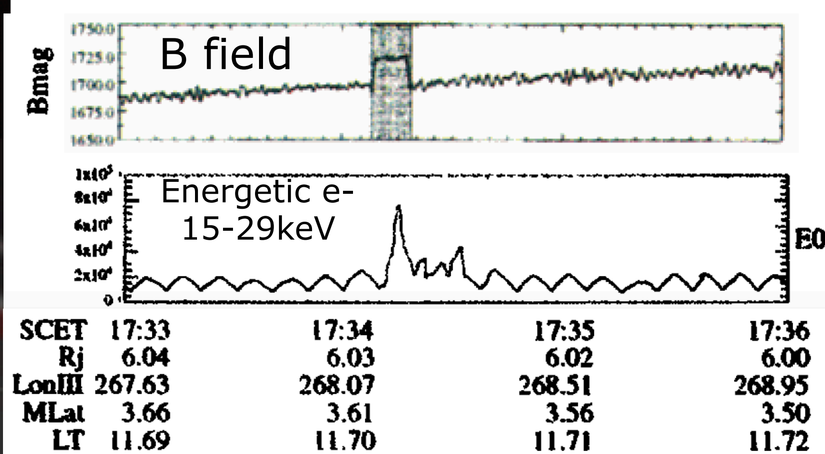
Power of perturbation growth within one rotation

$$\gamma T_{rot} = \sqrt{\alpha}\,\Omega_j T_{rot} >> 1$$





Galileo in-situ data



Thorne+97

Electromagnetic coupling with planet

Hill+01

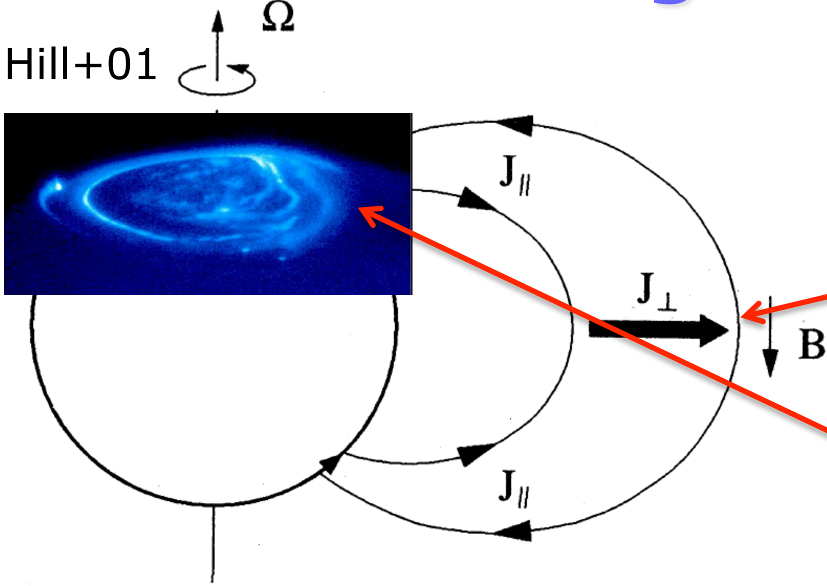
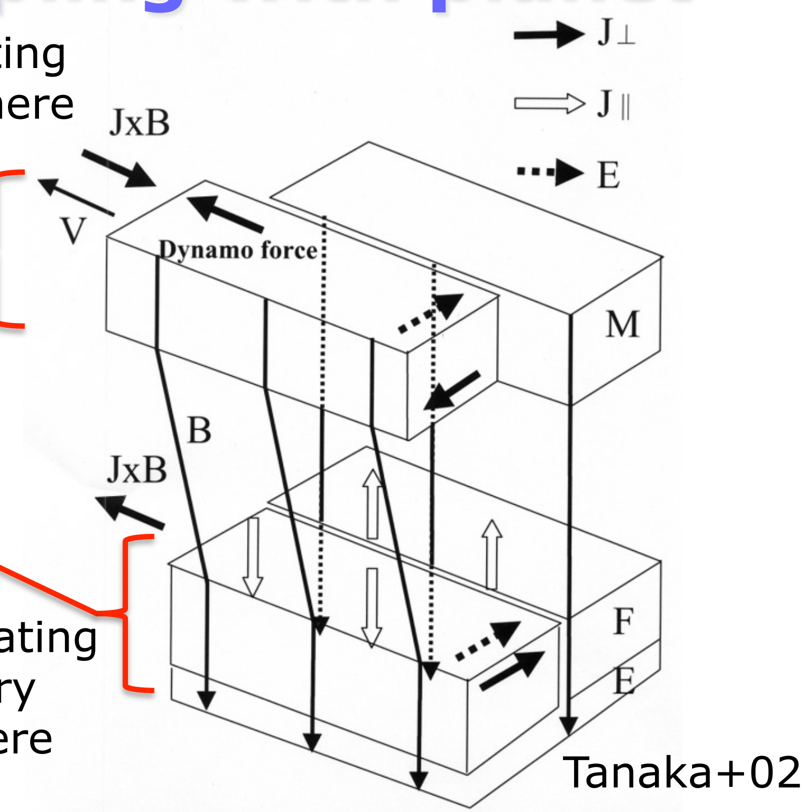


Figure 1. Topology of the meridional current system that delivers angular momentum from Jupiter's atmosphere to its magnetosphere.

Sub-corotating magnetosphere



Rigidly rotating planetary ionosphere

Tanaka+02

Ionosphere:

JxB force by latitudinal current

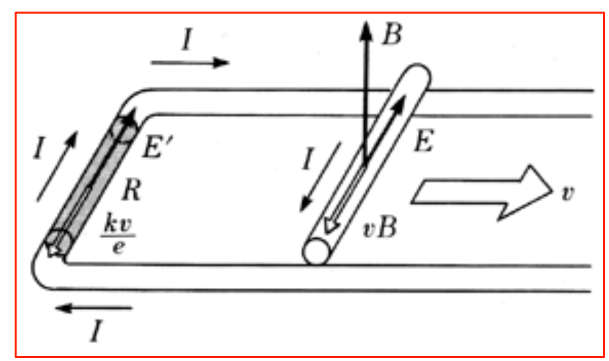
$$J_\theta = \Sigma E_\theta = -\Sigma v_\phi B_r = \Sigma B_r R_J \sin\theta\left(\omega_J - \boxed{\omega(\theta)}\right)$$

$$T_i = J_\theta B_r R_J \sin\theta$$

Magnetosphere:

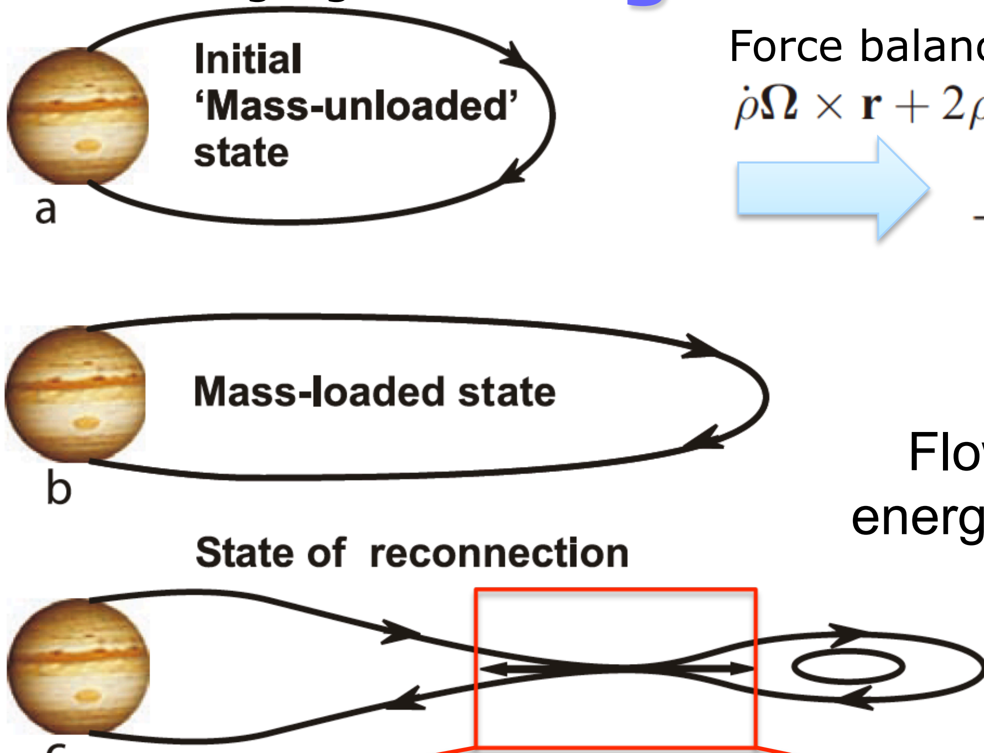
Angular momentum conservation

$$T_m = r J_r B_\theta = \rho v_r \frac{\partial}{\partial r}\left(\boxed{\omega(r)}\, r^2\right)$$



Magnetic reconnection

Krongerg+07

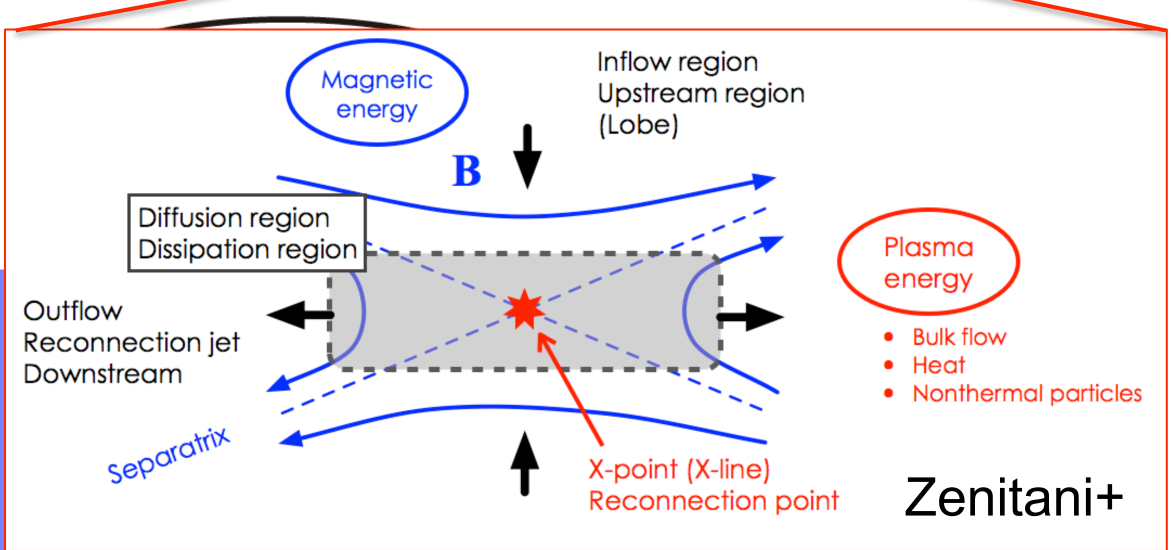


Force balance in the middle/outer magnetosphere

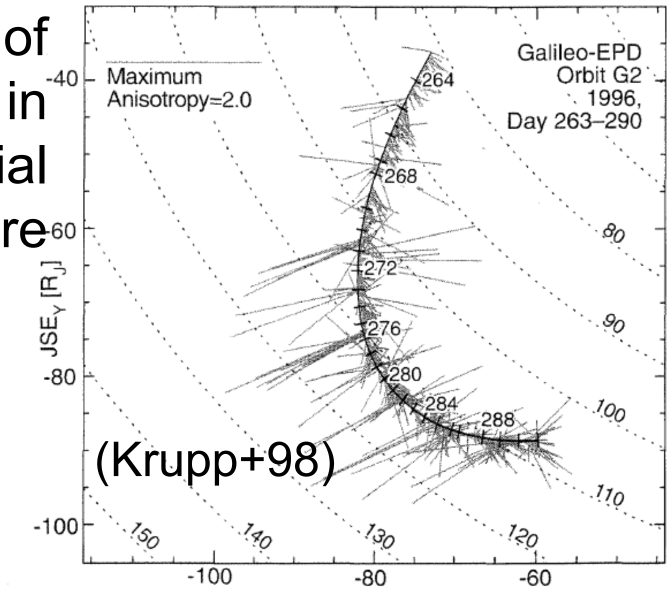
$$\dot{\rho}\boldsymbol{\Omega} \times \mathbf{r} + 2\rho\boldsymbol{\Omega} \times \dot{\mathbf{r}} + \rho\boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \mathbf{r}) + \nabla \cdot \mathbf{P} = \mathbf{j} \times \mathbf{B}_0,$$

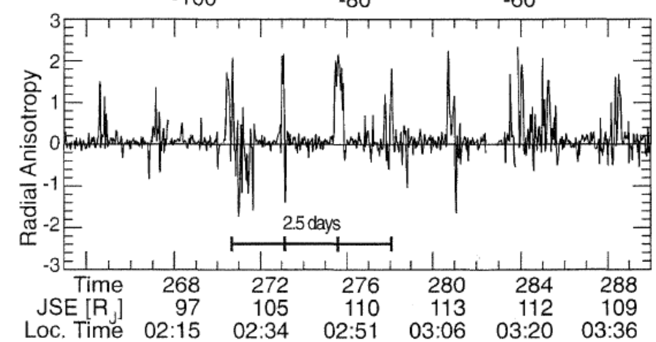
$$-\frac{B_r B_\theta}{\mu_0 d} \simeq \boxed{\rho}\Omega^2 r - \frac{\partial P}{\partial r}.$$

variable due to mass loading

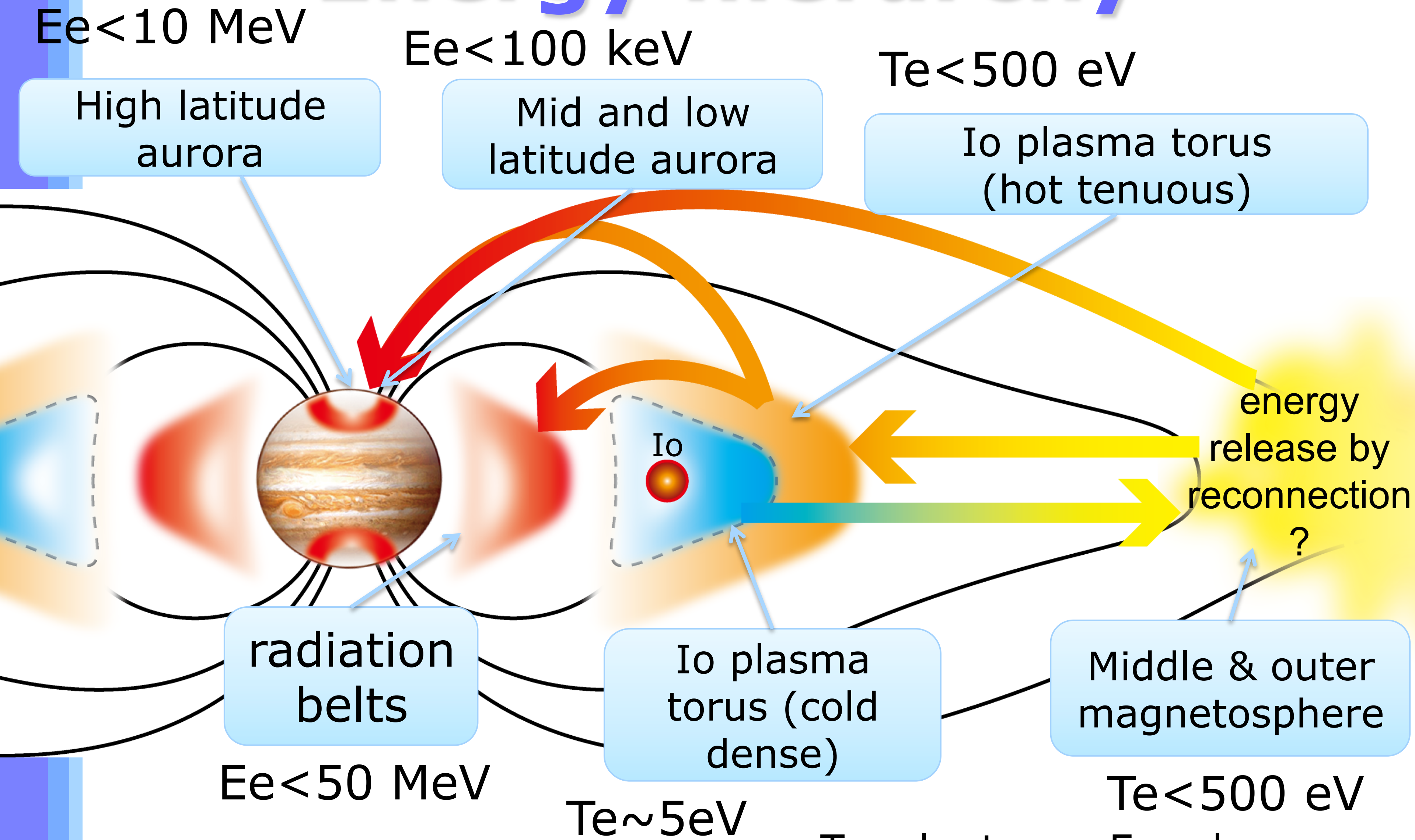


Flow vector of energetic ions in equatorial m'sphere

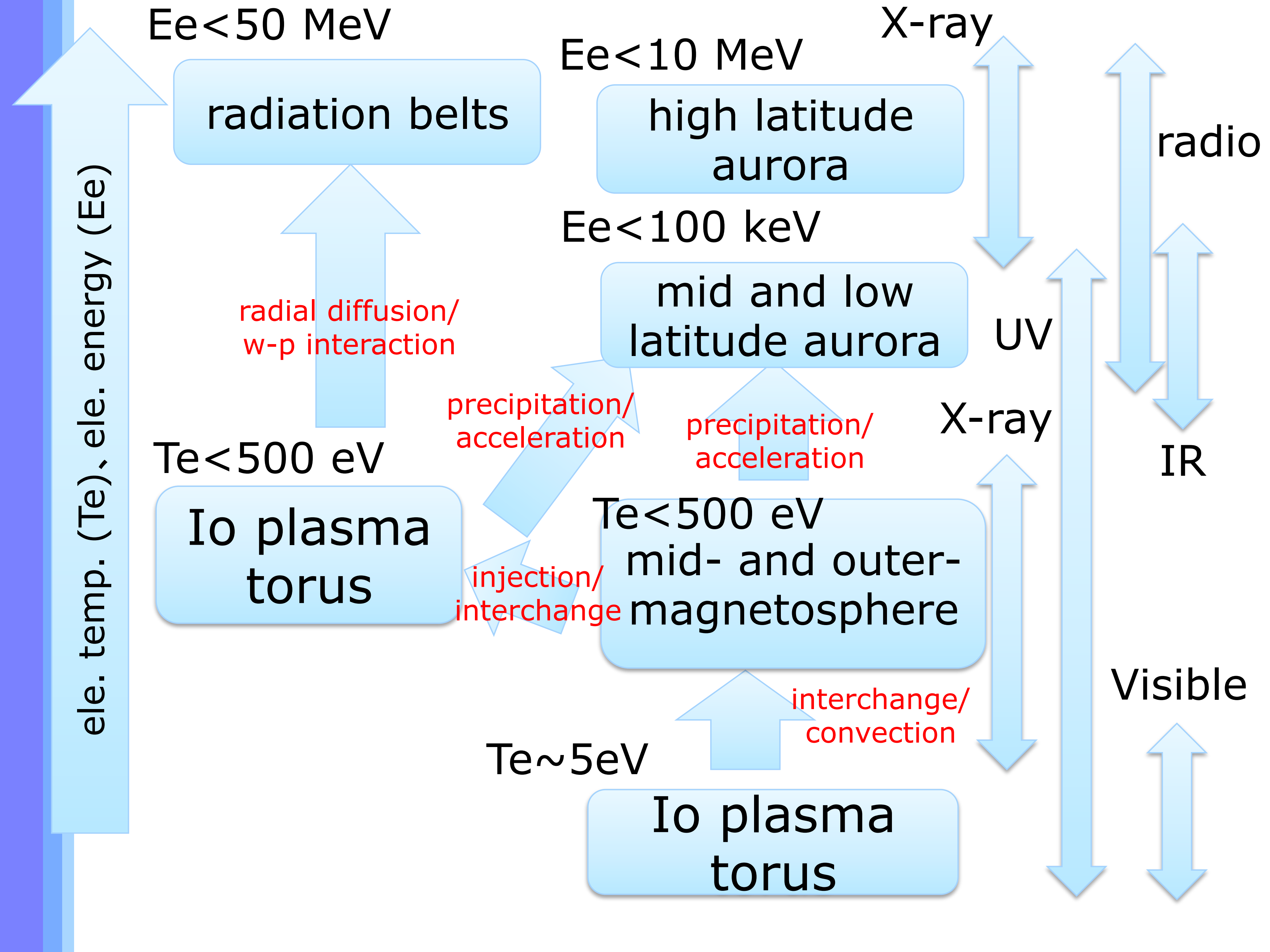




Energy hierarchy



Te: ele. temp、Ee: ele energy
blue：low energy、red：high energy
black：Jupiter's B-field



Ee<50 MeV
radiation belts
Ee<10 MeV
high latitude aurora
X-ray
radio
Ee<100 keV
mid and low latitude aurora
UV
radial diffusion/ w-p interaction
precipitation/ acceleration
precipitation/ acceleration
X-ray
IR
Te<500 eV
Io plasma torus
Te<500 eV
mid- and outer- magnetosphere
injection/ interchange
interchange/ convection
Visible
Te~5eV
Io plasma torus
ele. temp. (Te), ele. energy (Ee)

Big questions

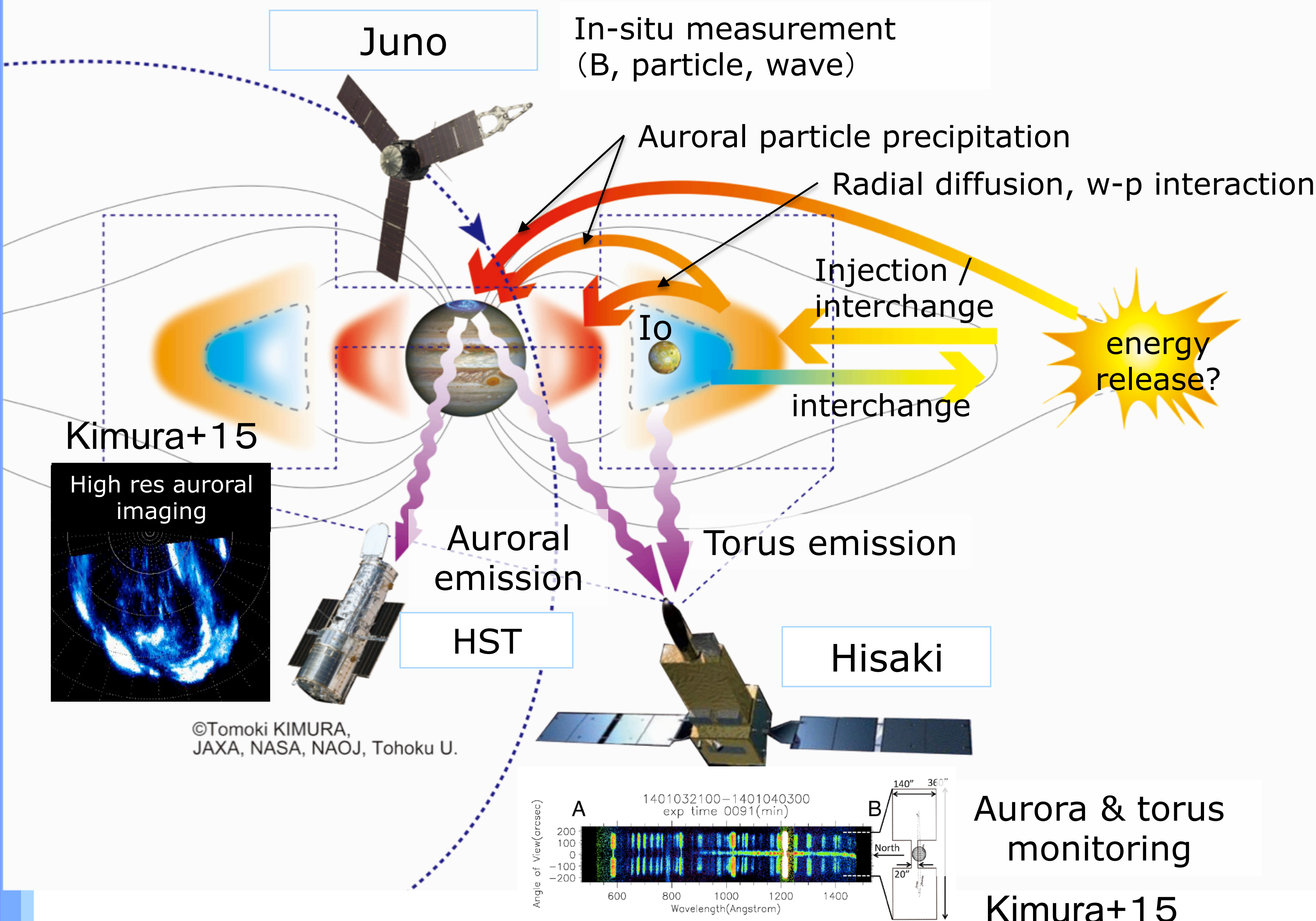
- How mass, momentum, and energy are dynamically transferred in rotating magnetosphere
  - Transfer from planet/moon to m’sphere is dominant.
  - How about from m’sphere to planet?
  - Especially in radial direction?
- How some plasmas are accelerated up to 50 MeV by electromagnetic coupling btw planet and m’sphere?

Transient brightening of Jupiter's aurora observed by the Hisaki satellite and Hubble Space Telescope during approach phase of the Juno spacecraft

Tomoki Kimura (RIKEN),

Jonathan D Nichols (Leicester U), Rebecca Gray, Sarah V Badman (Lancaster U) , Chihiro Tao (NICT), Go Murakami (JAXA), Atsushi Yamazaki (JAXA), Fuminori Tsuchiya (Tohoku U), Kazuo Yoshioka (U of Tokyo), George B Clark (APL), Denis C Grodent (U of Liège), Hajime Kita (Tohoku U), I. Yoshikawa (U of Tokyo) Masaki Fujimoto (JAXA), and Hisaki Science Team

Jupiter observing campaign 2016-present

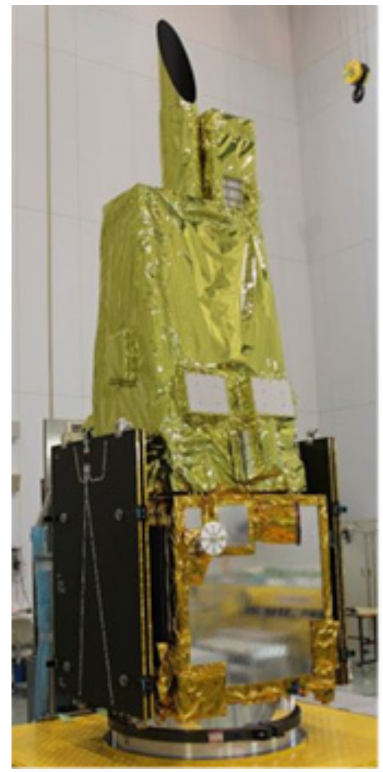


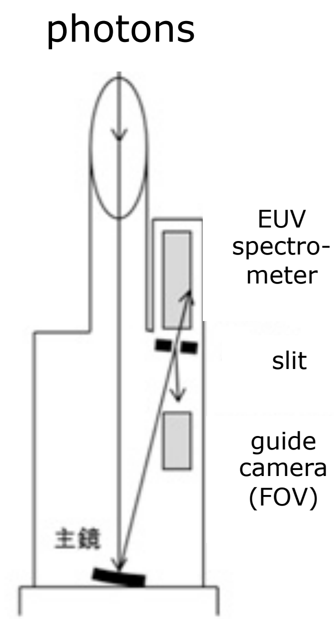
Hisaki satellite mission

- Earth-orbiting Extreme Ultraviolet (EUV) spectroscopic mission
- First mission of the ISAS/JAXA Small scientific satellite series
- Observation targets : Mercury, Venus, Mars, Jupiter, and Saturn

Major specifications

- Launch date : 14^{th} Sep 2013
- Weight : 330kg
- Size : 1m×1m×4m
- Orbit : 950km×1150km (LEO)
- Inclination: 31 deg
- Mission life : >1 year
- Pointing accuracy : ±2 arcmin (improved to ±5arc-sec by using a guide camera FOV)





EUV spectrometer "EXCEED" onboard Hisaki

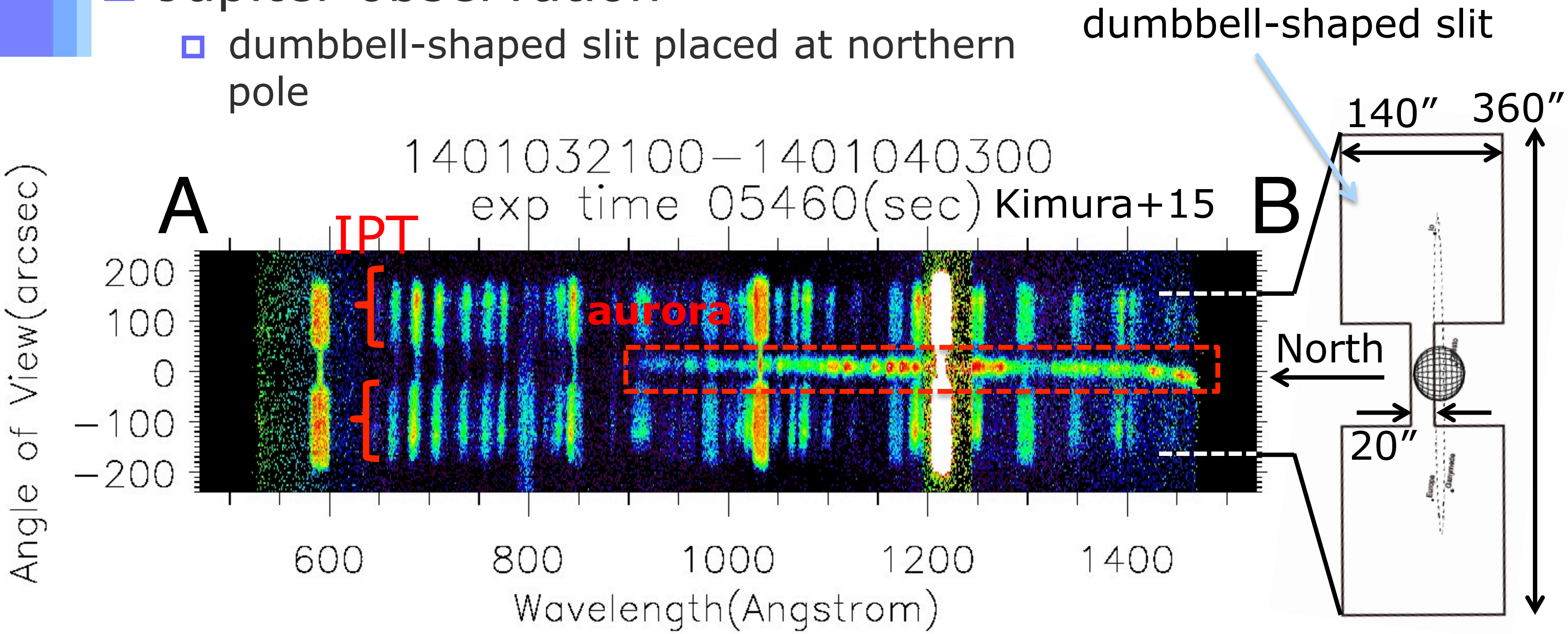
Led by ISAS/JAXA, Univ. of Tokyo, and Tohoku Univ.

Dataset

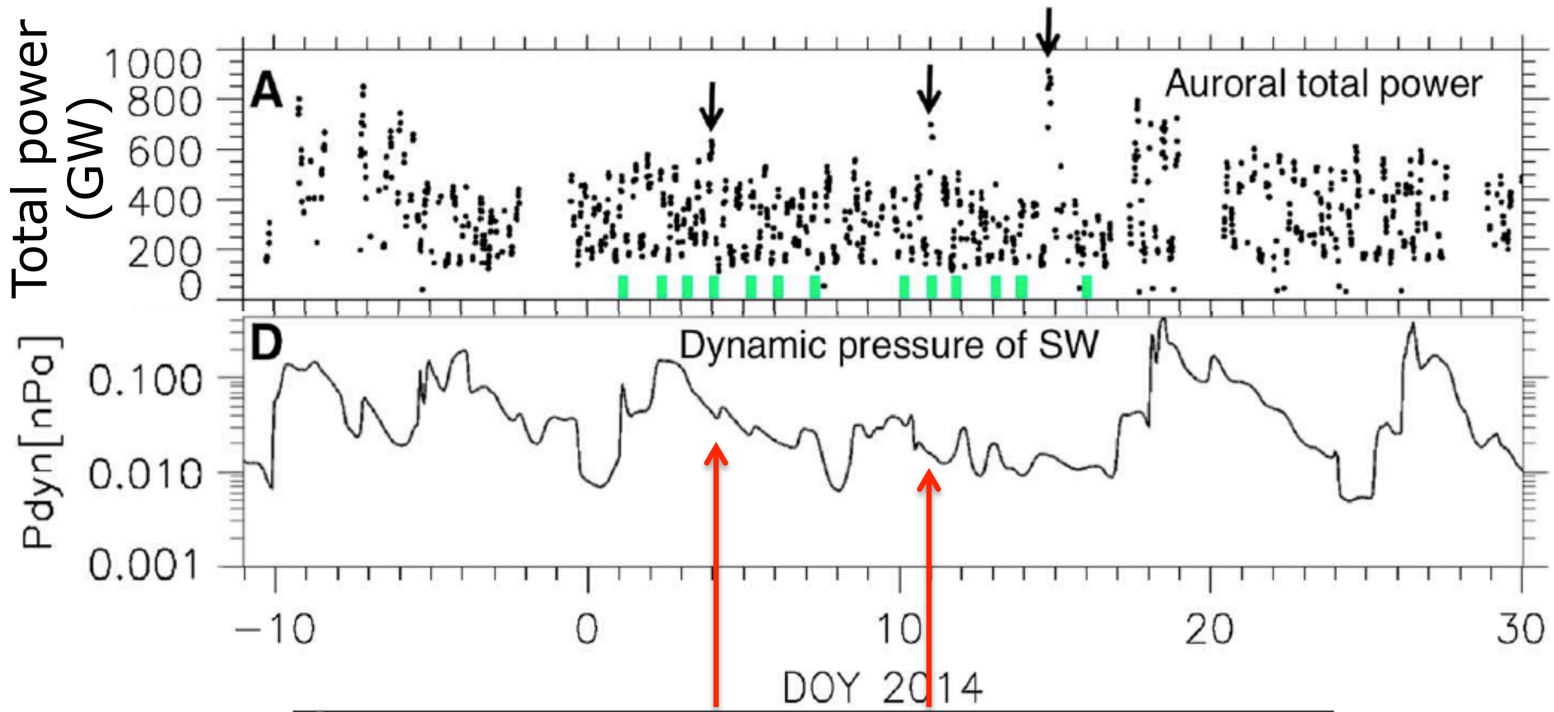
- EUV spectrometer "EXCEED"

Wavelength range	60 – 145 nm
Spatial resolution (for Jupiter mode)	17″ (~1Rj around opposition)
Field of view	360″ (~20Rj)
Spectral resolution (FWHM)	~1.0 nm (140″ slit)
Effective area	2cm^2 @100nm

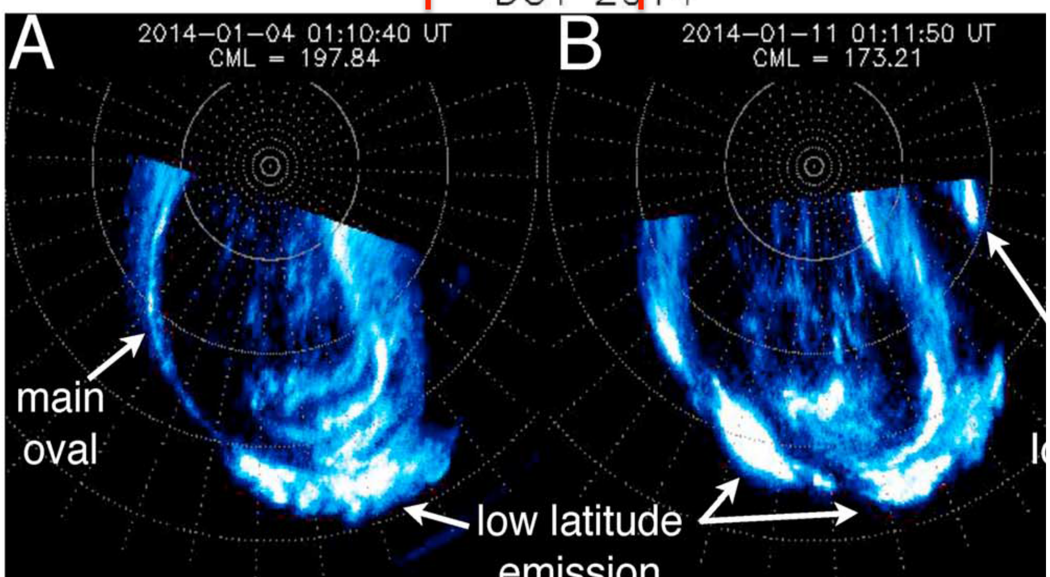
- Jupiter observation
  - dumbbell-shaped slit placed at northern pole



Internally-driven transient aurora

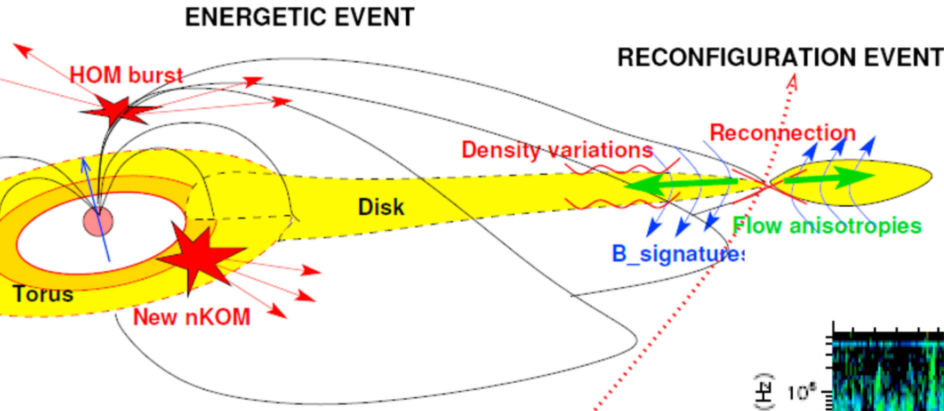


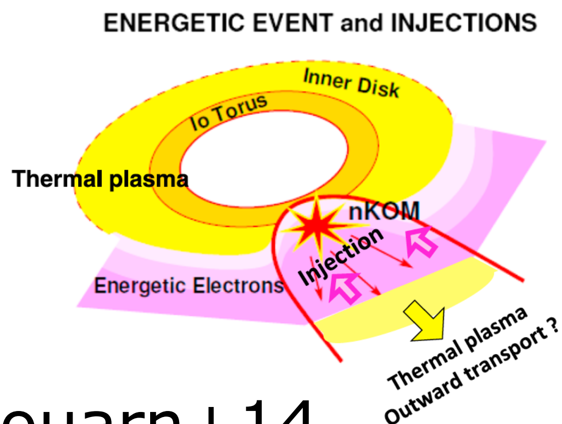
Structure of transient aurora (HST)

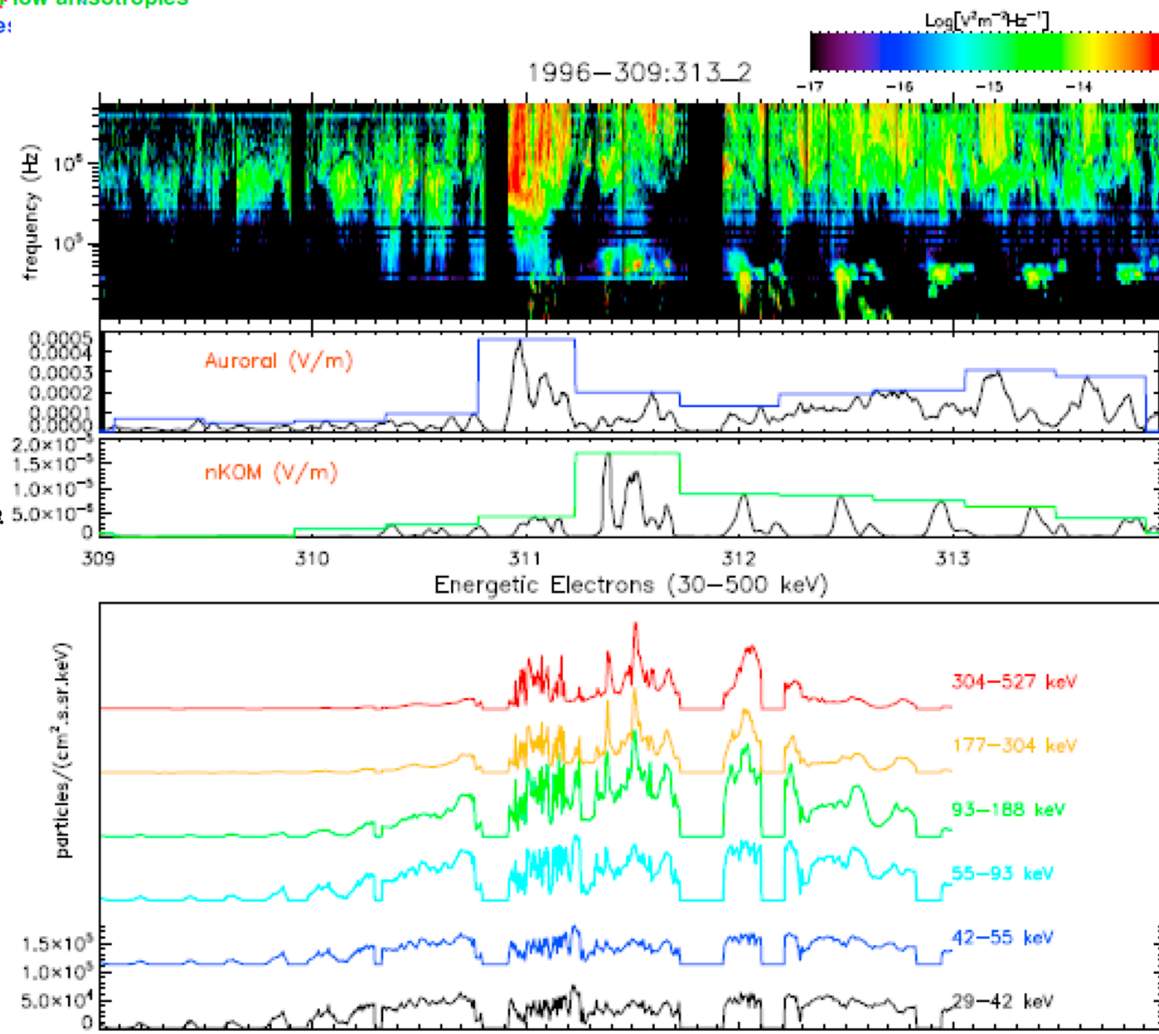


Kimura+15

Interpretation: energetic event





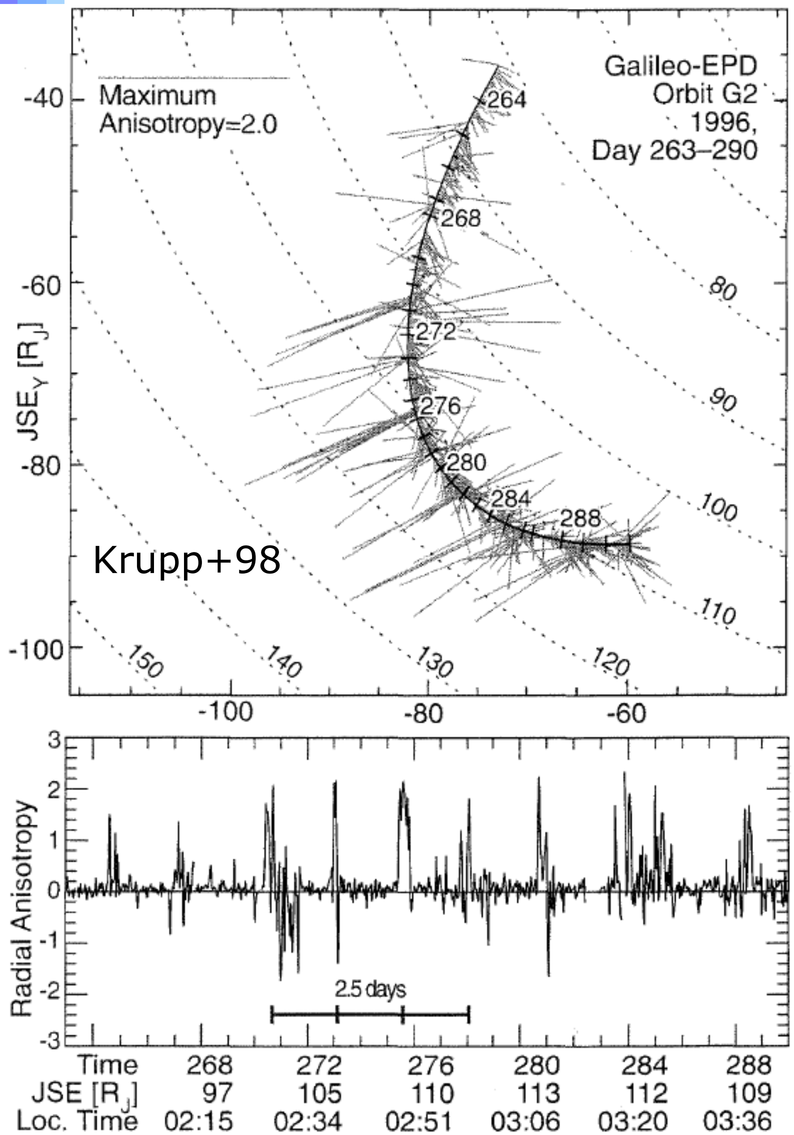


Louarn+14

(Louarn et al., 1998, 2000, 2007, 2014)

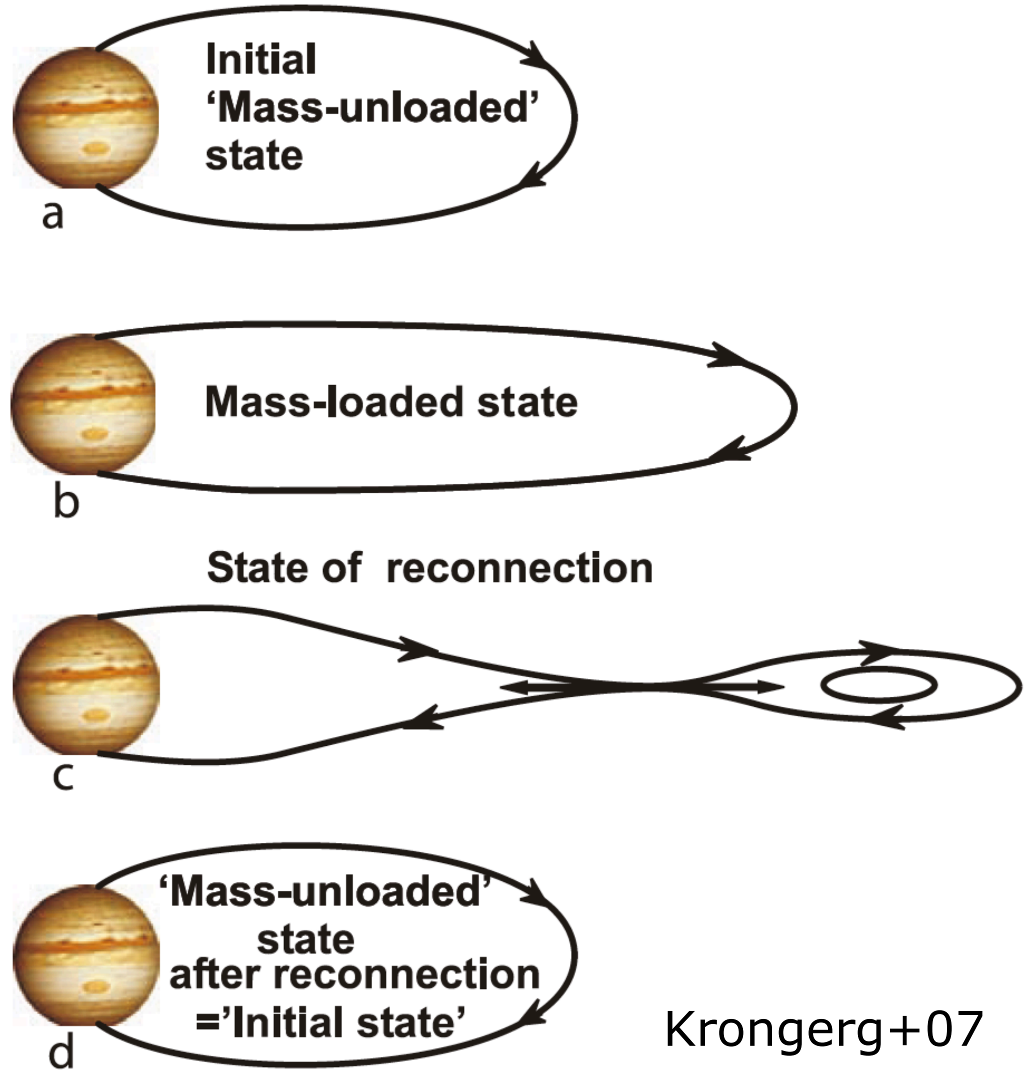
Magnetic reconnection

Flow vector of energetic ions
in tail region (Krupp+98)



force balance in plasma sheet (Vasyliunas+83)

$$\dot{\rho}\mathbf{\Omega} \times \mathbf{r} + 2\rho\mathbf{\Omega} \times \dot{\mathbf{r}} + \rho\mathbf{\Omega} \times (\mathbf{\Omega} \times \mathbf{r}) + \nabla \cdot \mathbf{P} = \mathbf{j} \times \mathbf{B}_0,$$



Krongerg+07

Problem

1. Temporal and spatial evolutions of the transient aurora and energetic events were not resolved by previous observations
2. Because of lack of continuous monitoring that spans duration of transient aurora

Purpose

1. Investigate temporal sequence of transient aurora based on continuous monitoring of aurora with Hisaki & HST
2. Discuss spatio-temporal evolution of energetic event

Overview

Emitted Power of Northern aurora

IMF |B|

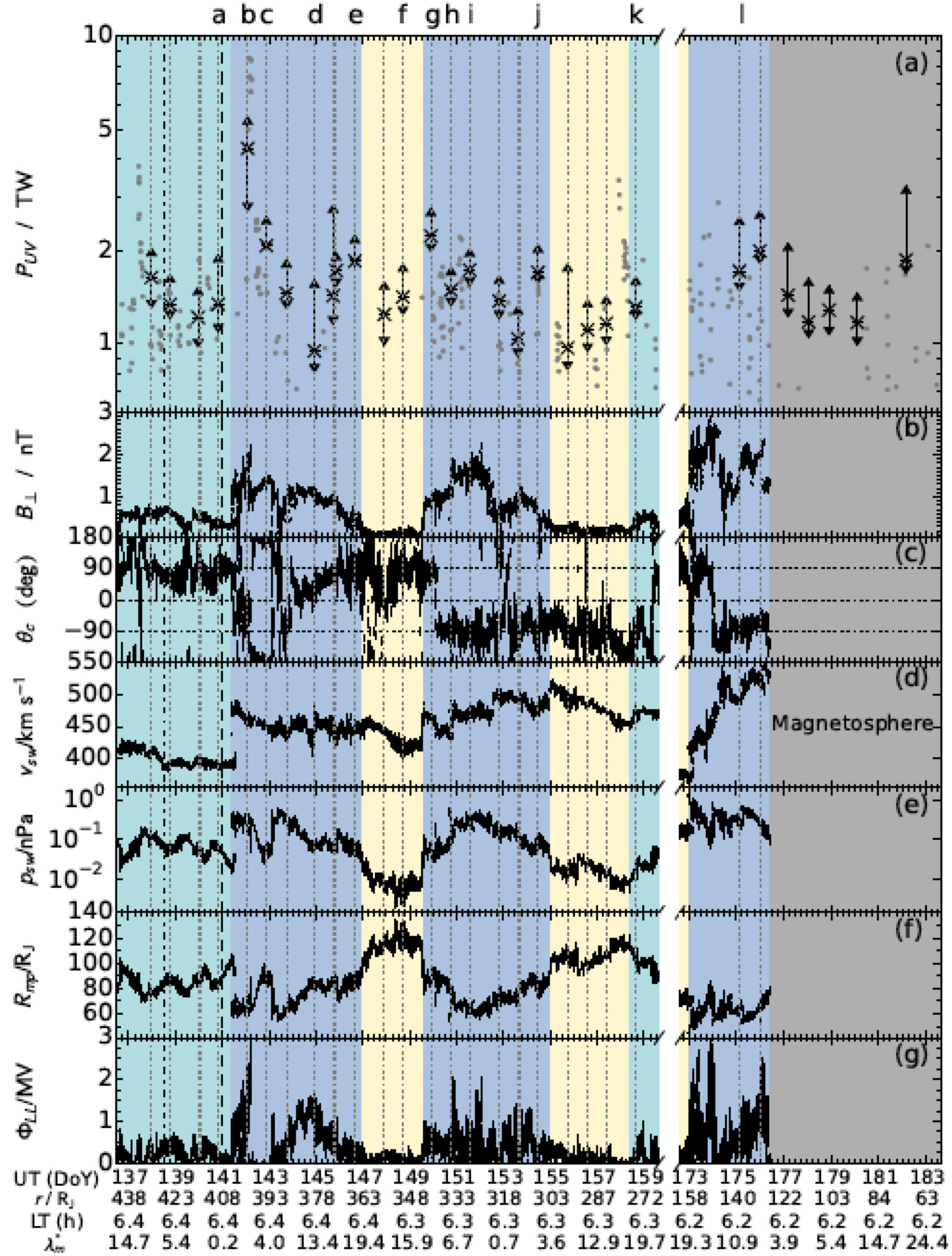
IMF clock angle

SW radial velocity

SW dynamic pressure

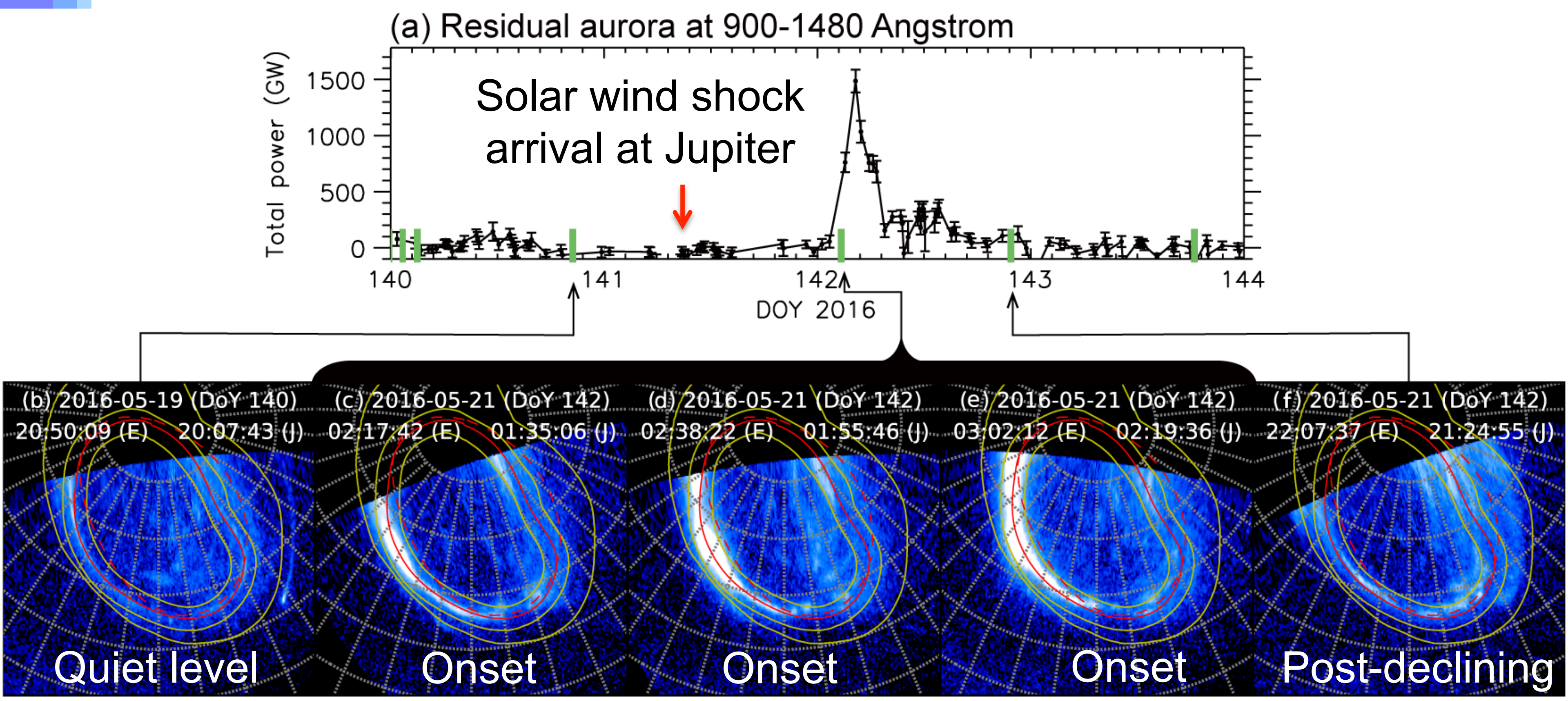
Magnetopause stand-off distance

Reconnection voltage



Nichols+17

Observation result



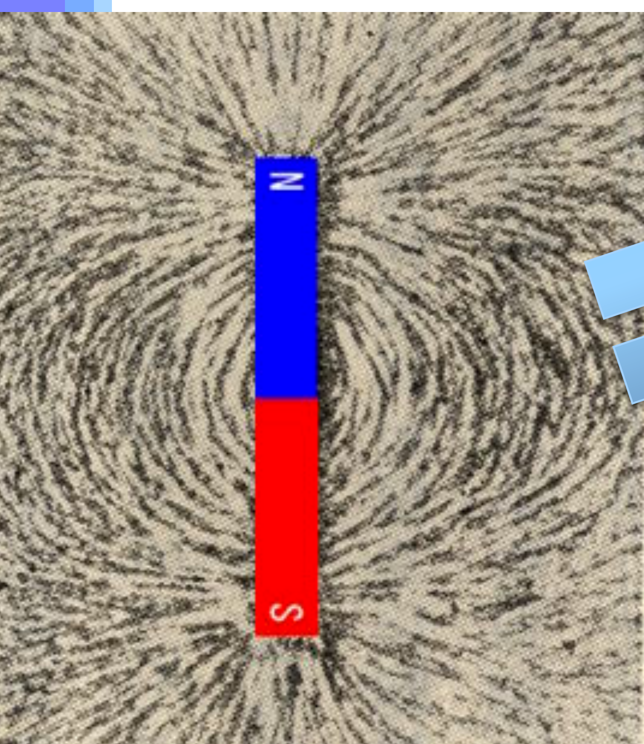
Kimura+17

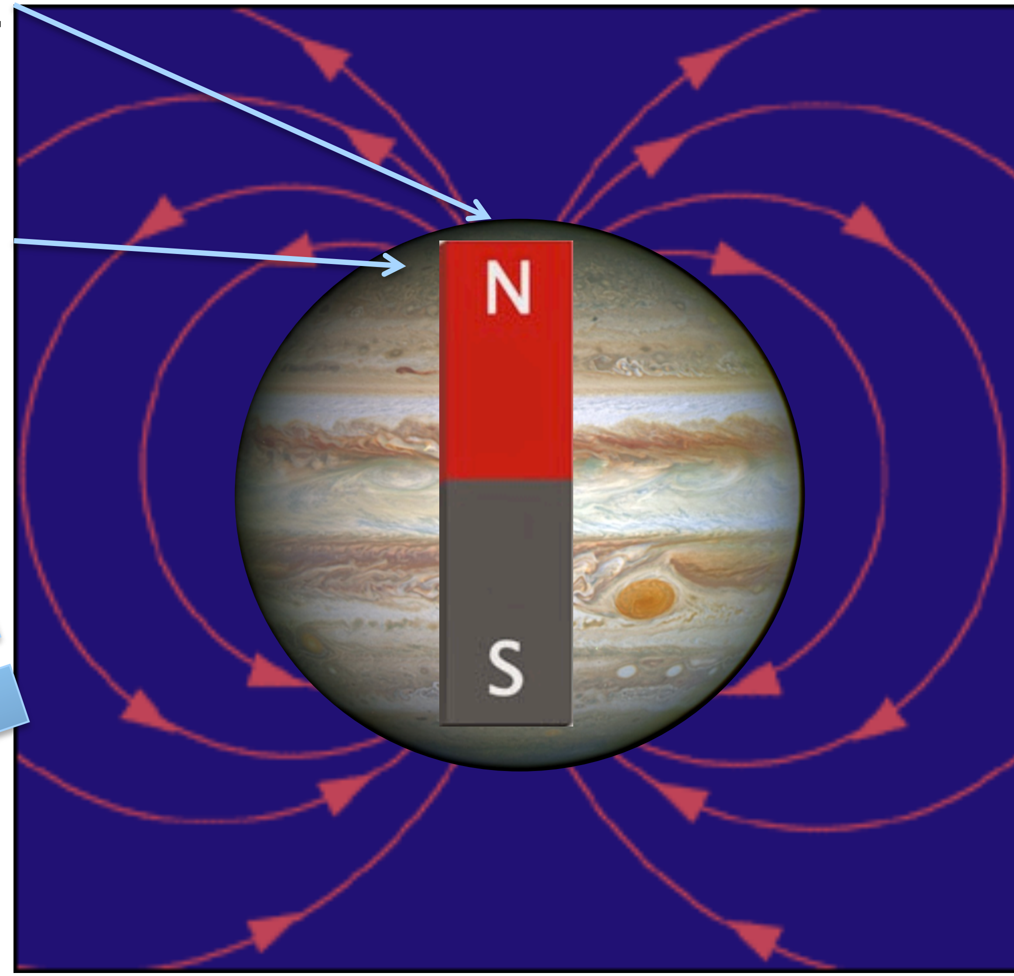
1. Aurora at higher latitude brighten
2. Aurora at lower latitude followed

What auroral latitude means?

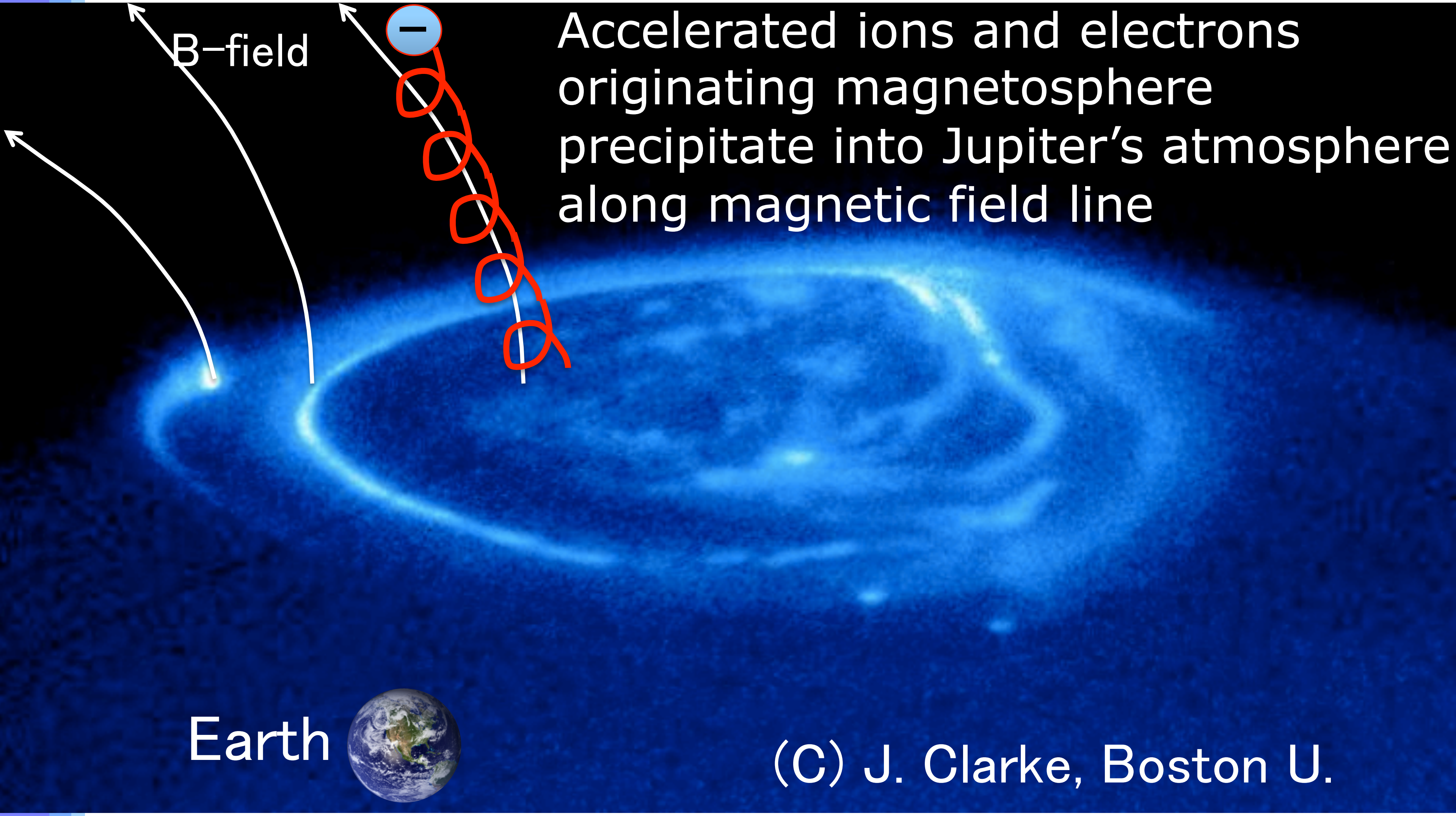
Higher latitudes map to magnetospheric regions far from Jupiter

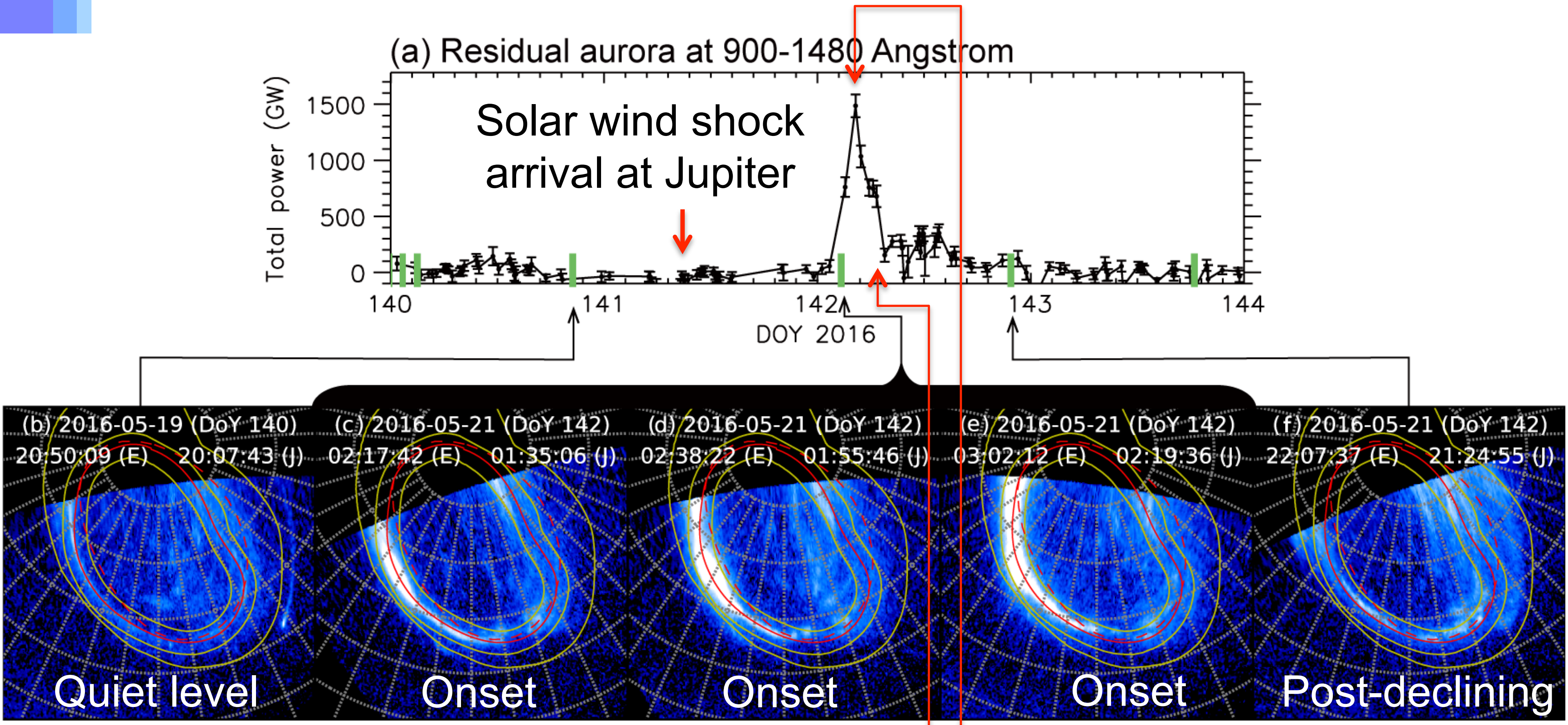
Lower latitudes map to magnetospheric regions close to Jupiter



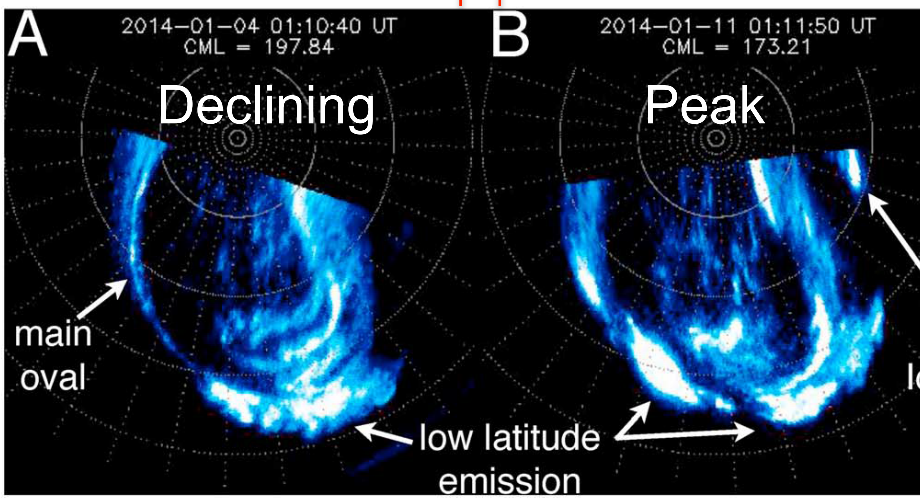


What auroral latitude means?





Kimura+17 in press



Kimura+15

Energetic event expands from outer/middle to inner m'sphere

Temporal sequence

Auroral timescale

energy release at outer m'sphere?

Onset

higher lat aurora initiation with expansion in latitude and longitude

a few hours

Peak

continuing higher lat aurora, lower lat aurora initiation

high energy plasma appearance around Jupiter

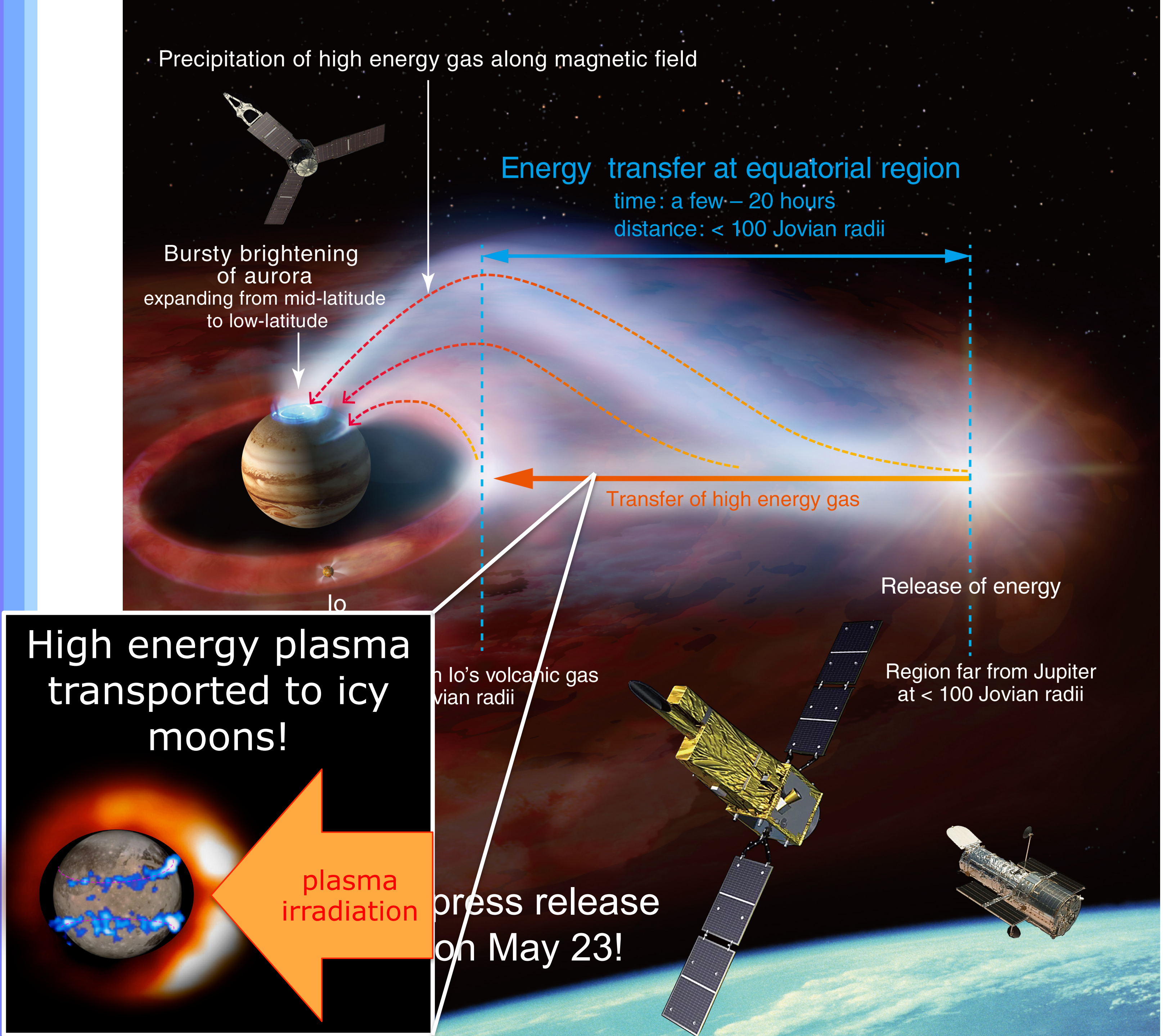
1-2 rotations

Declining

higher lat aurora dissipation, continuing lower lat aurora

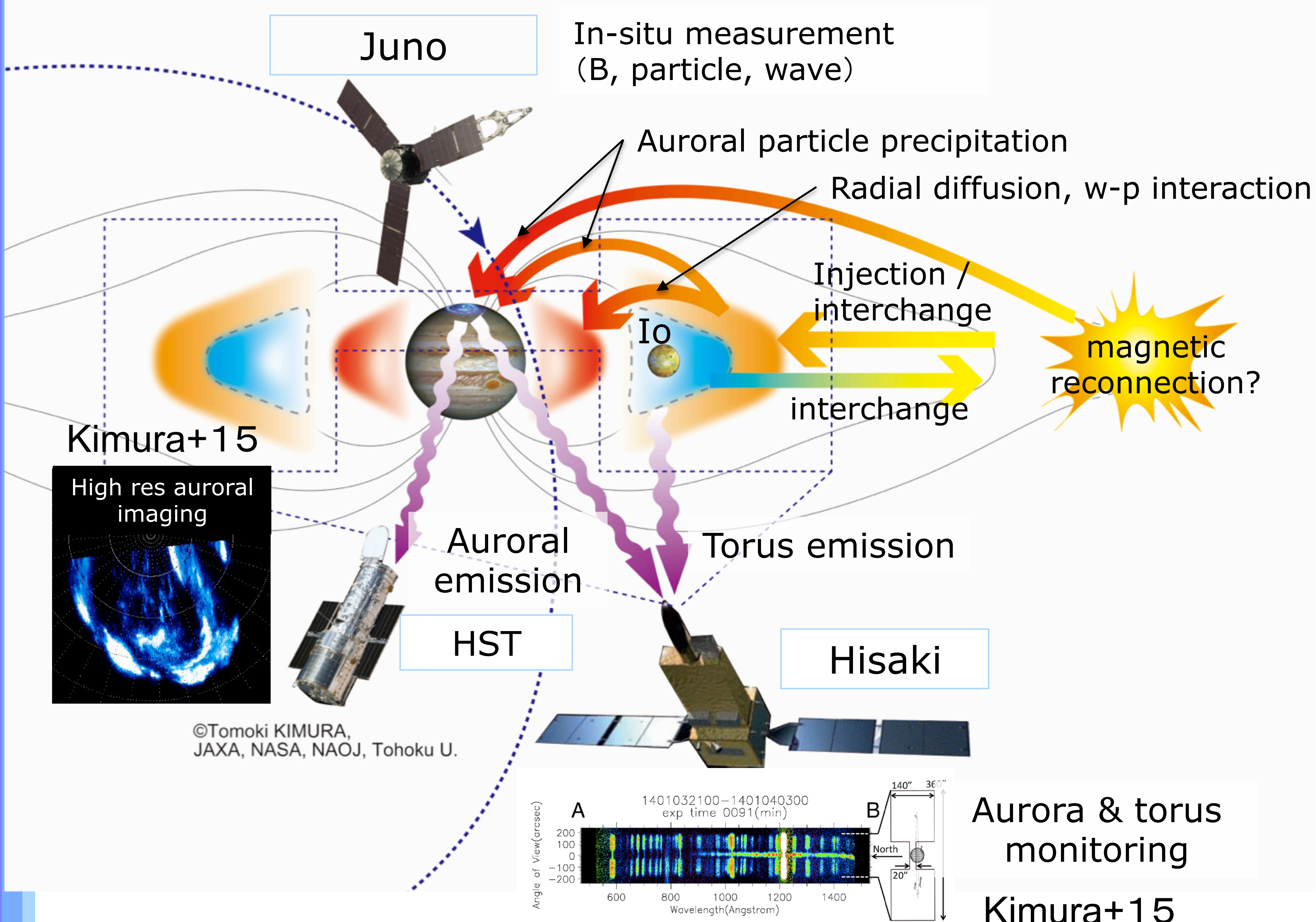
Post-declining

remnant lower lat aurora


Precipitation of high energy gas along magnetic field
Energy transfer at equatorial region
time: a few – 20 hours
distance: < 100 Jovian radii
Bursty brightening of aurora
expanding from mid-latitude to low-latitude
Transfer of high energy gas
Io
Release of energy
Io’s volcanic gas
Region far from Jupiter at < 100 Jovian radii
High energy plasma transported to icy moons!
plasma irradiation
press release
May 23!

FUTURE PLANS

In-situ measurements at pole



Future: impact to icy moons

- JUICE: 2030-
- Europa Clipper: mid 2020s?
- Explorers will flyby Europa and orbit Ganymede
- Comprehensive measurement of surface spectra, magnetic field, atmosphere, and plasma