Impact of Io's volcanic activity to environment and dynamics in the Jovian magnetosphere : from HISAKI results

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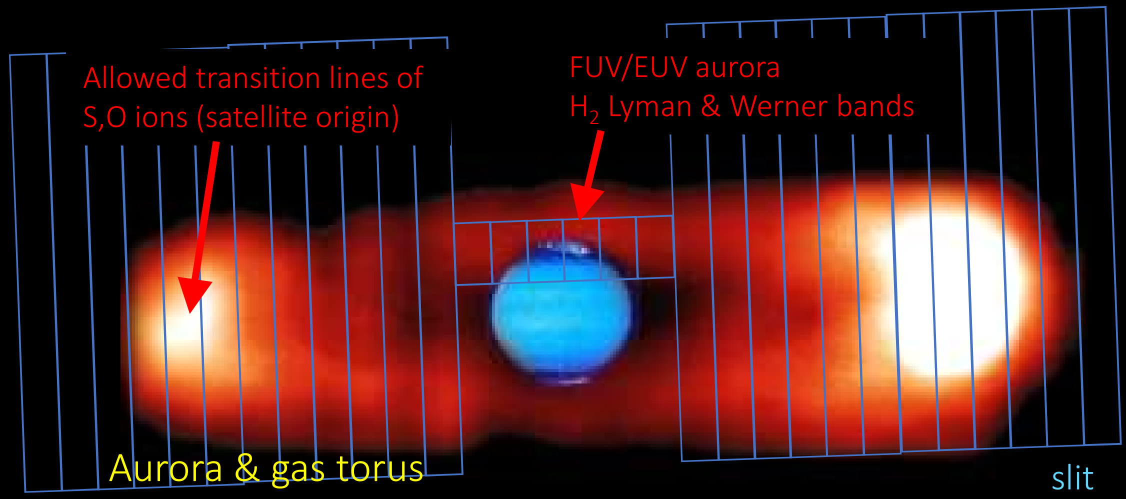
The Hisaki satellite

- Launch : Sep 14, 2013,
- Size : 1m × 1m × 4m
- Orbit : 950km × 1150km (LEO)
- Inclination: 30 deg
- Orbital period : 106 min

EUV spectrograph (EXCEED): Major specifications

- Wavelength range: 55-145nm
- Spectral resolution: 0.4-1.0nm
- Spatial coverage ~370 arc-sec
- Spatial resolution : 17 arc-sec

Difficult to observe a moon itself
But designed to observed plasma torus and aurora simultaneously

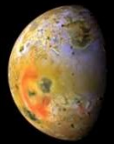


Energy flow from outer to inner part of magnetosphere

Mission periods
(Primary) 2013-09 - 2014-11
(Extended 1) 2014-12 - 2017-03
(Extended 2) 2017-04 - 2020-03

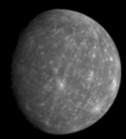
Yoshioka et al. 2013, Yoshikawa et al. 2014, Yamazaki et al. 2014

Summary of the HISAKI findings

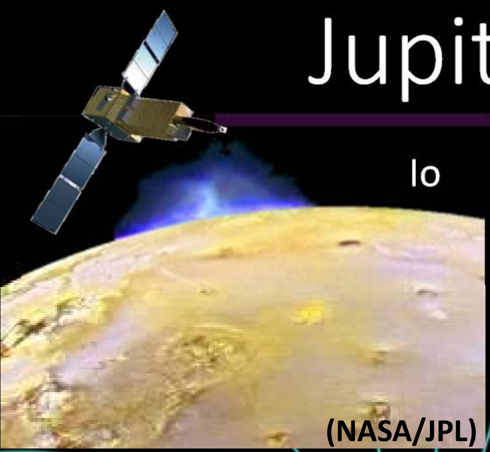


- Jupiter
  1. Internally driven energy release process & inward transport of the energy
     Yoshioka et al. 2014, Kimura et al. 2015, Badman et al. 2015,
     Yoshikawa et al. 2016, 2017, Suzuki et al. 2018
  2. Solar wind influence on the magnetosphere (plasma torus, radiation belt, and aurora)
     Kimura et al. 2016, Tao et al. 2016a, 2016b, Kita et al. 2016,
     Murakami et al. 2016, Han et al. 2018, Kita et al. 2019
  3. Mass input (from volcanos at Io) to the magnetosphere
     Yoneda et al. 2015, Kimura et al. 2018, Tao et al. 2018, Tsuchiya et al. 2018,
     Yoshioka et al. 2018, Koga et al. 2018a, 2018b
  4. Plasma heating due to Satellite(Io)-magnetosphere interaction
     Tsuchiya et al. 2015
  5. New plasma torus lines and energy states: Hikida et al. 2018

- Venus
  - Periodic air grow: Masunaga et al. 2015, 2017
  - Detection of N_2 LBH Bands: Nara et al. 2018
- Saturn：Enceradus oxygen gas torus
- Geocorona：Geomagnetic storm response   Kuwabara et al. 2016
- Marcury's exosphere, Comet coma and tail
- EUV stars, Intersteller wind (He cone）

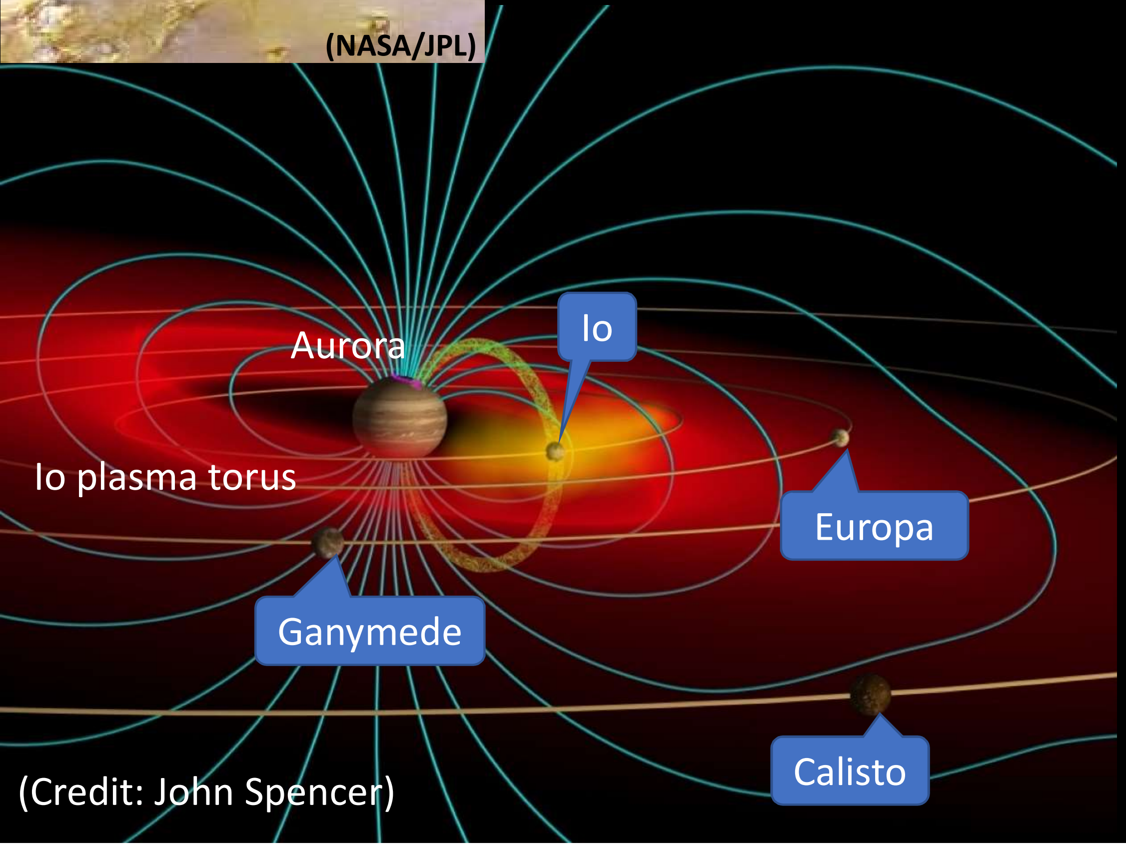


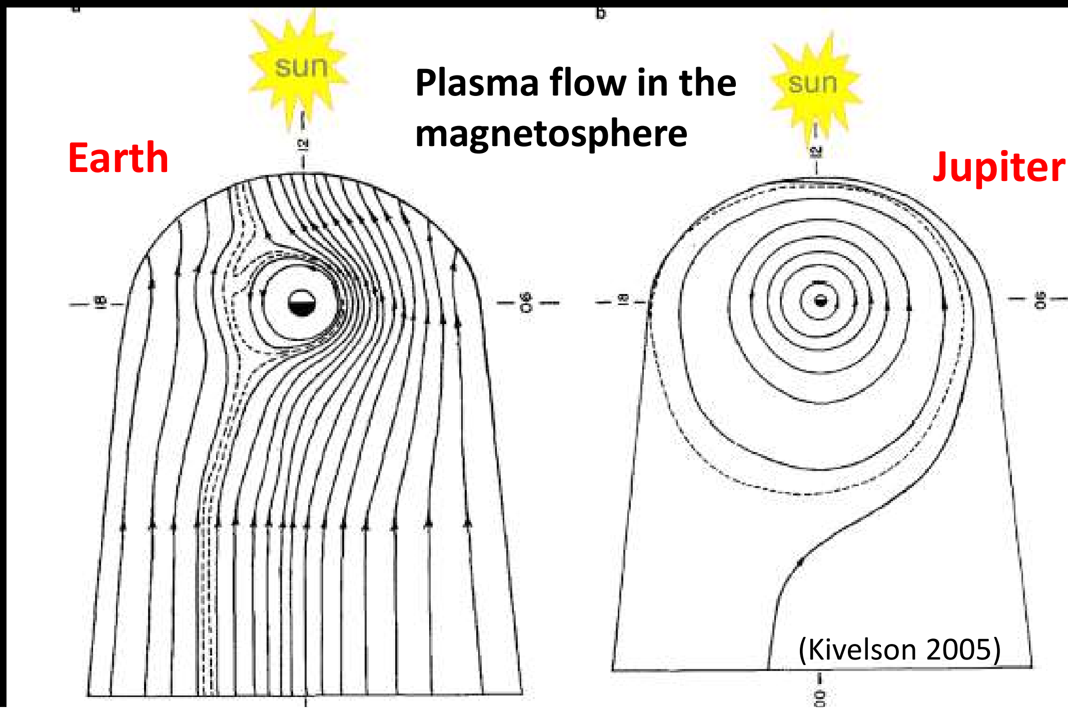
Jupiter: Rotation dominant magnetosphere



- Strongest magnetic field
- Rapid rotation (~10 hours)
- Dominant plasma source at Io
  (1ton/s, 90% of mass of plasma)

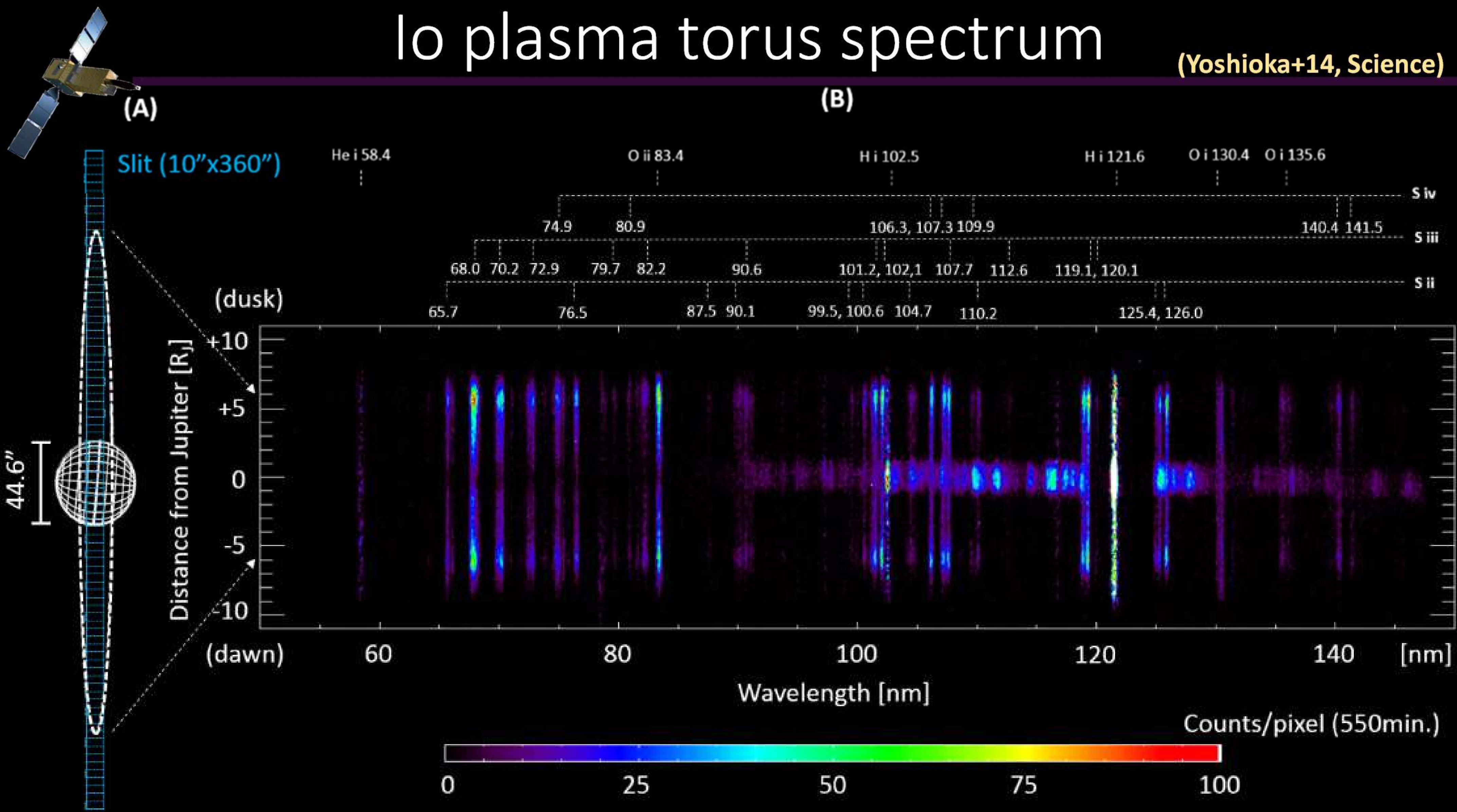
Due to strong azimuthal flow, the magnetosphere is filled with iogenic ions (sulfur and oxygen). (including orbits of icy satellites)



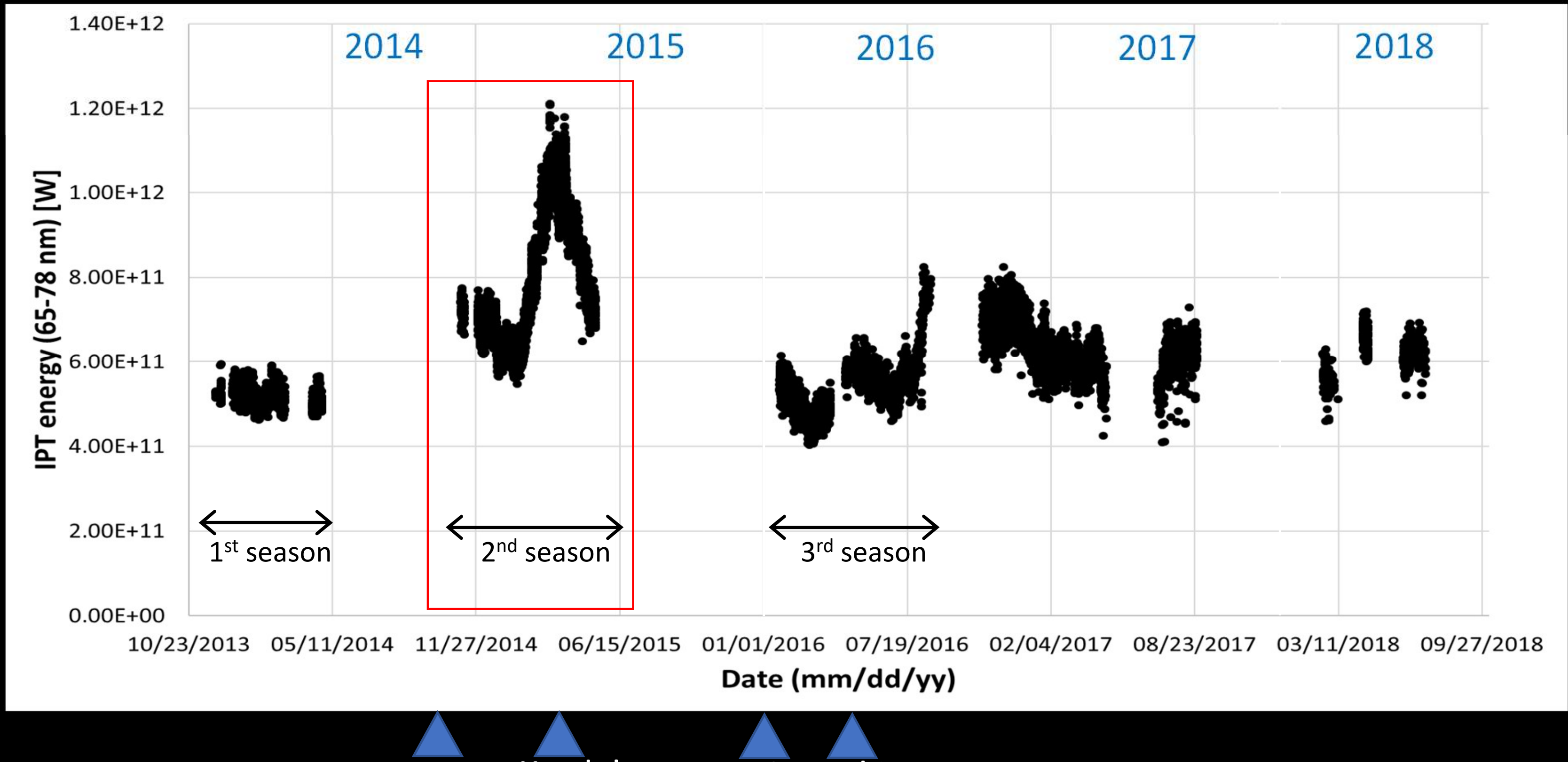


Io plasma torus spectrum

(Yoshioka+14, Science)



Io plasma torus intensity by Hisaki (for 5 years)



(From IR observation: de Kleer and de Pater, 2016, 2017)

Io plasma torus was quiet during 1st season (Dec. 2013-Apr.2014).

Io plasma torus was variable since 2nd season (mainly) due to volcanic activities at Io.

HISAKI 2015

Volcanic activity
(IR observation)

Io's atmosphere

Volcanic contribution to the atmosphere formation ?

How to escape the neutral gas ?

Neutral cloud

ionization

Io plasma torus

Inter-change instability (Yoshioka et al. 2014)

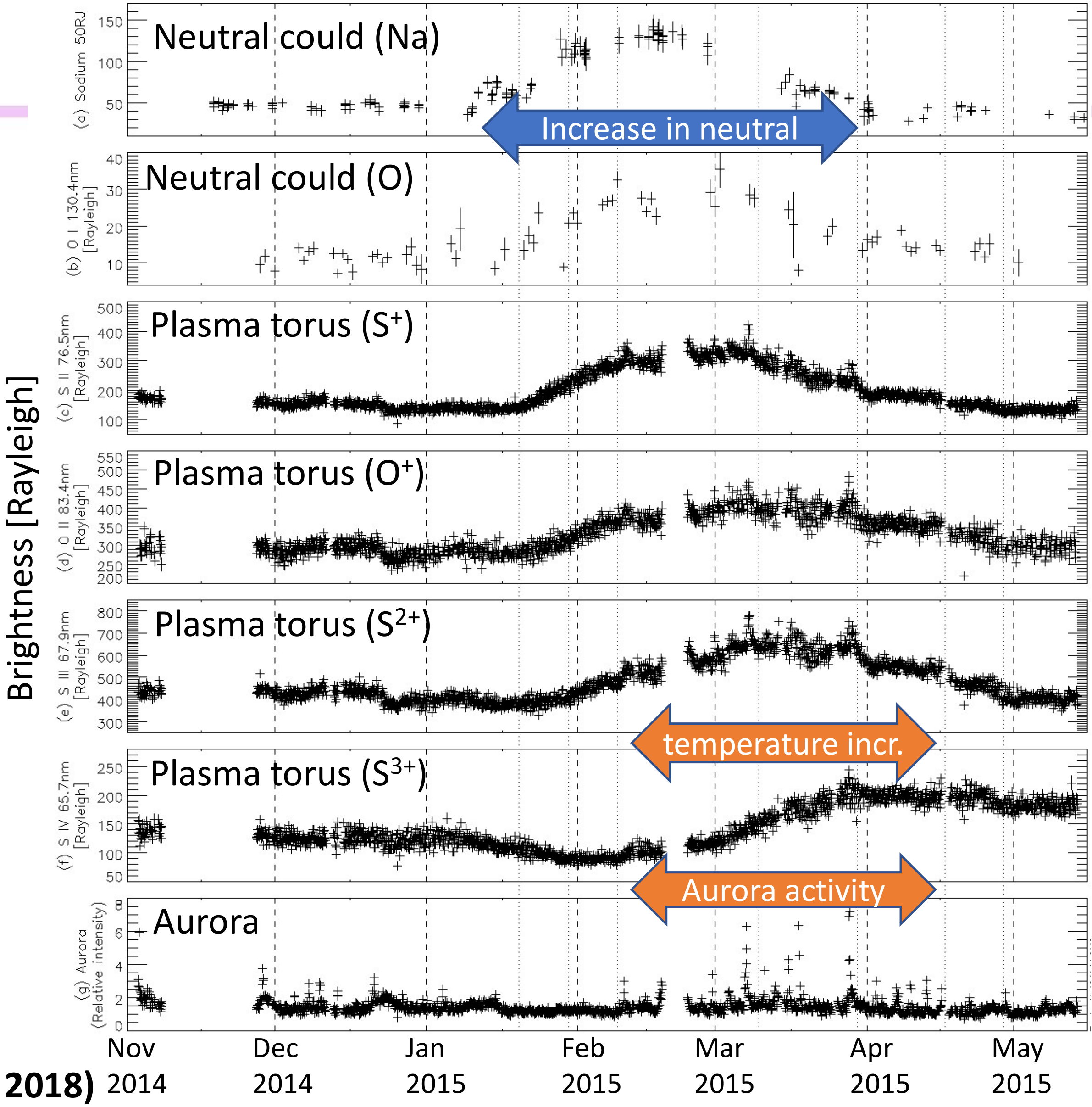
Outer magnetosphere

transition energy release (Kimura et al. 2018)

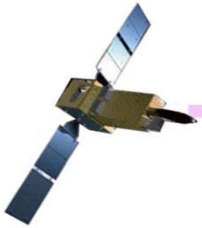
Activation of aurora

How to transport the energy ?
How to heat the plasma ?

Plasma heating in Io plasma torus

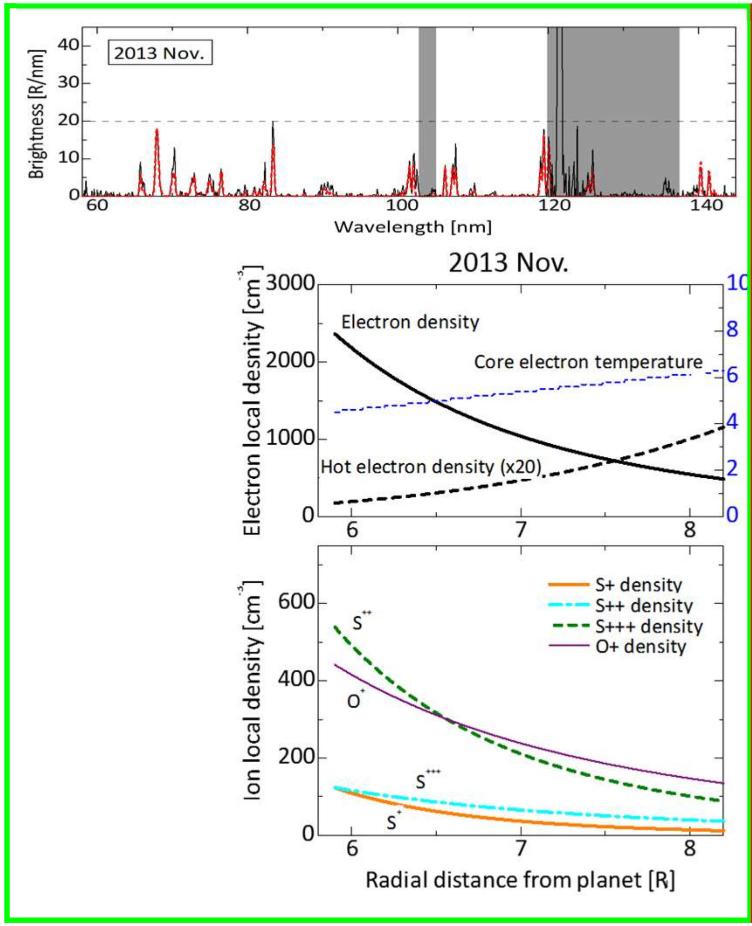


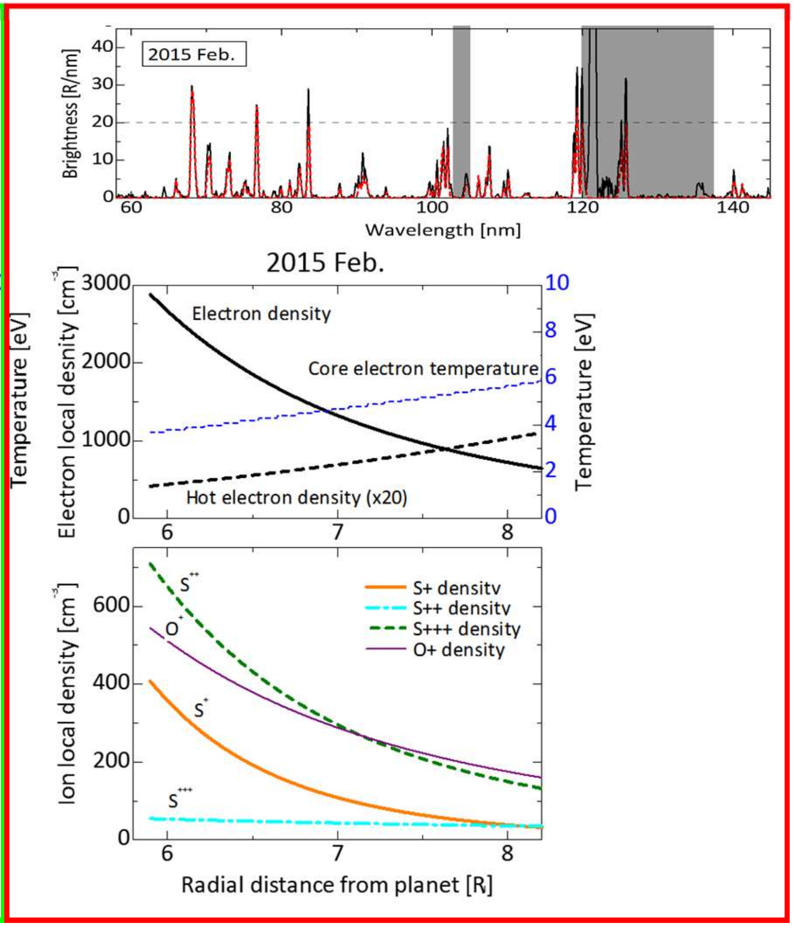
(Tsuchiya et al. 2018)



Plasma parameters during Quiet vs Active period (Volcanically)

Yoshioka et al. 2018





Hisaki data

↓ Spectrum analysis

Radial distribution of plasma density and temperature

Electron density@5.9R_J : 20%↑

Ion density@5.9R_J : 40%↑

↓
- Mass conservation law
- Hot electron cooling via Coulomb interaction

Estimation of neutral source rate & inward and outward timescales (Next slide)

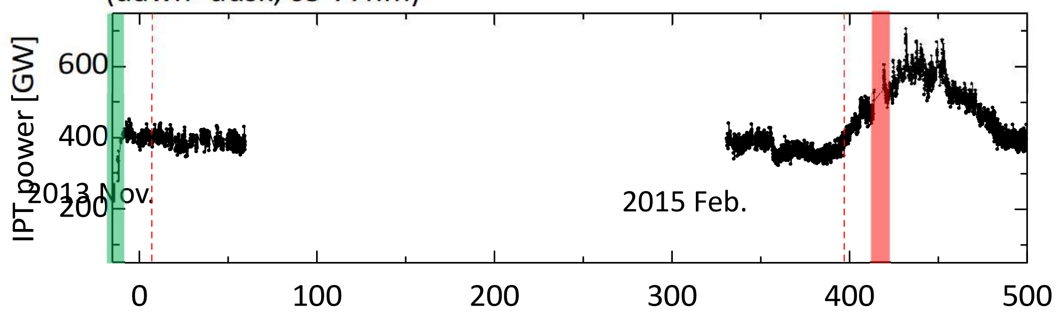
In/Out flow (Dependence on the volcanic activity)

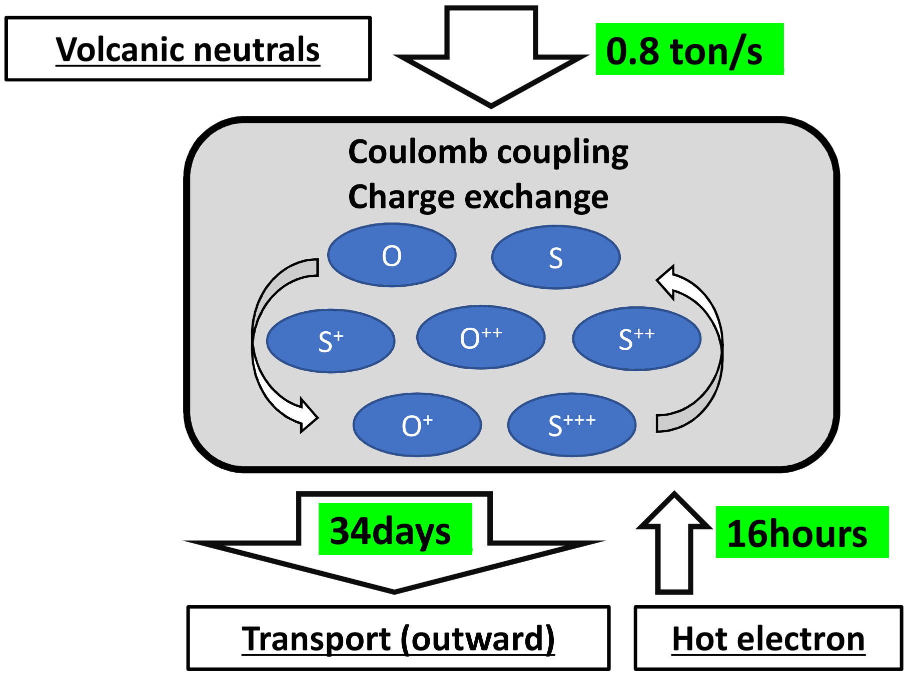
Physical-chemistry model [Yoshioka et al, 2018]

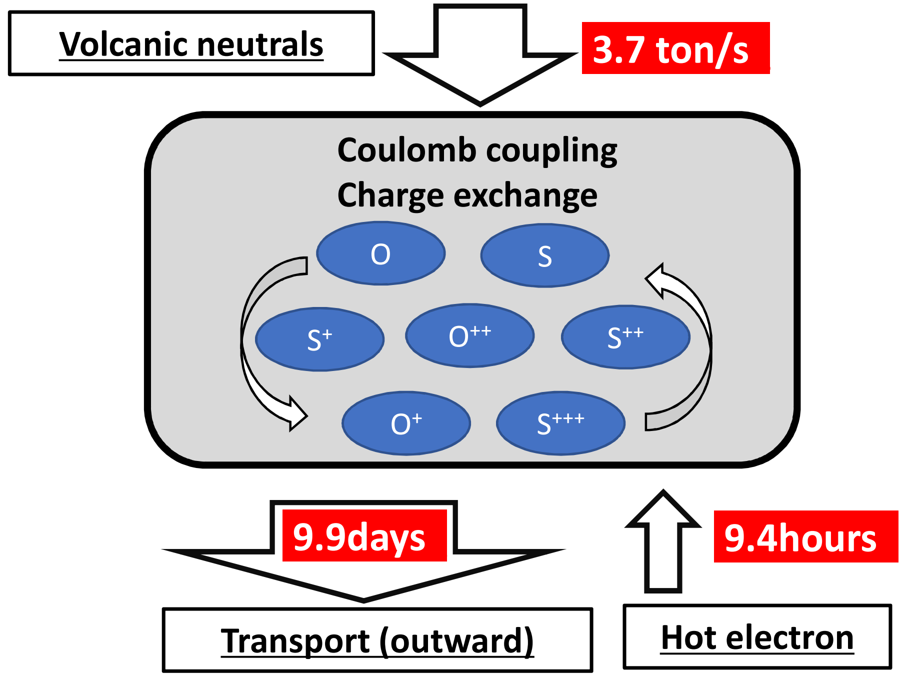
Estimation of neutral source rate & inward and outward timescales

Increases in inward and outward timescales associated with Io's volcanic eruption

Yoshioka et al. 2018







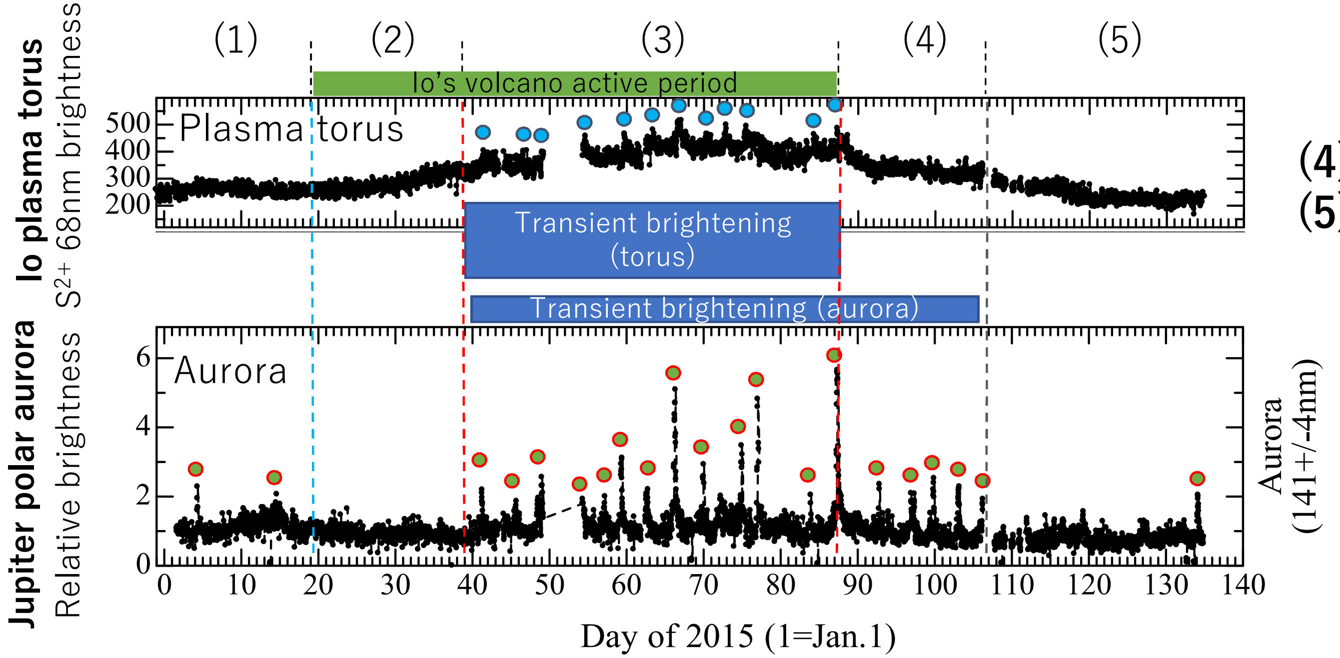
Enhancement of radial plasma circulation

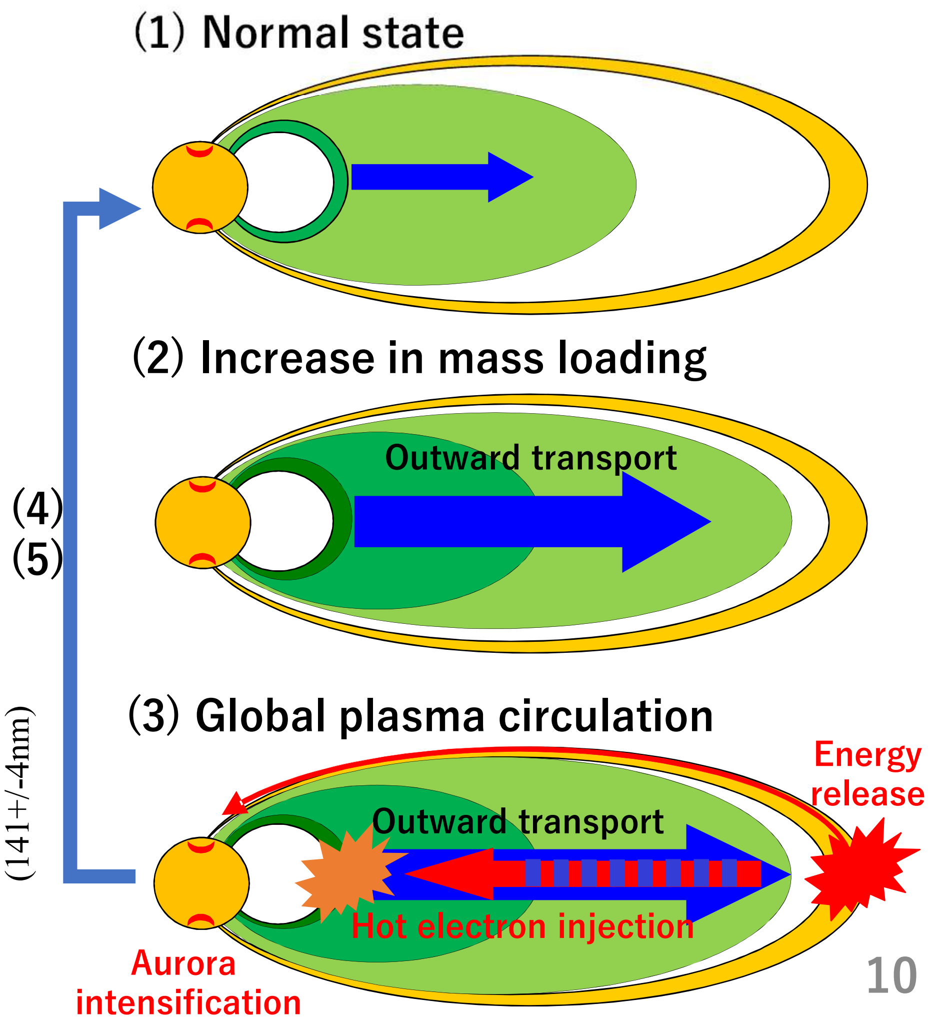
Tsuchiya et al. 2018

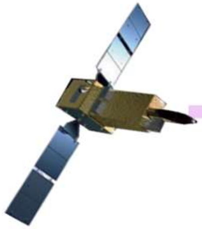
- DOY 19-90 : Volcanic eruption at Io & Increased plasma supply
- DOY 25-90 : Enhanced plasma transport from inner to middle magnetosphere
- DOY 40-90 : Series of short-lived aurora brightening + plasma torus brightening

An analytical model has been developed by Kimura et al. (2018)

What is happening between inner and outer M'sphere ? -> JUICE







Energy transport from outer to inner M’spheres

Pairs of brightening of plasma in inner magnetosphere and aurorae

Brightening of aurora (middle/outer magnetosphere) is earlier than that of the Io plasma torus by ~10 hours.

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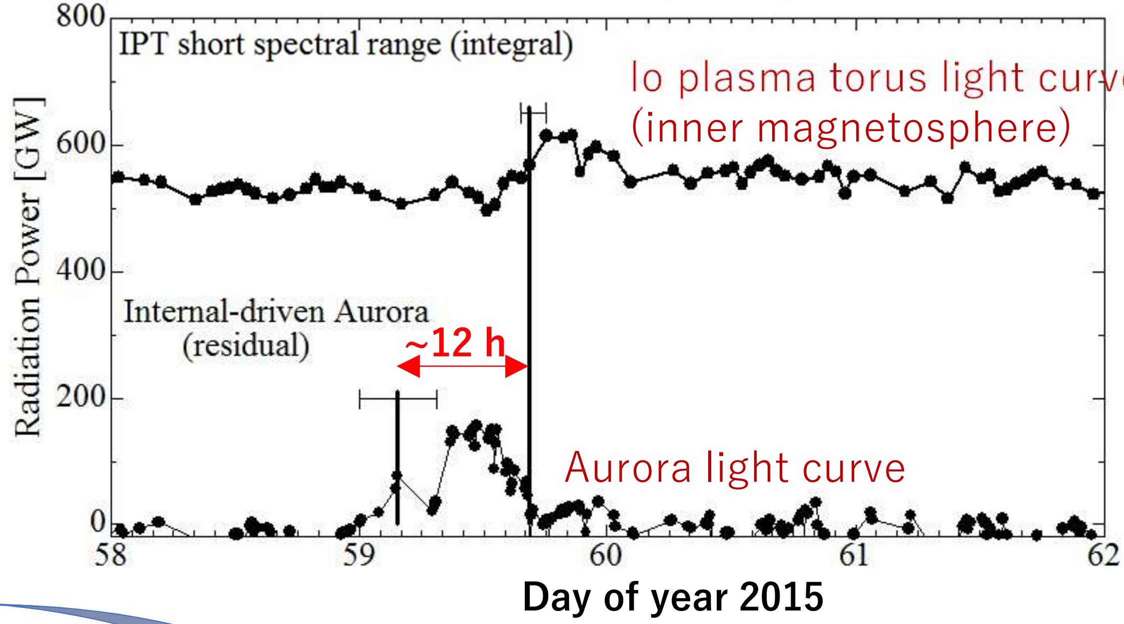
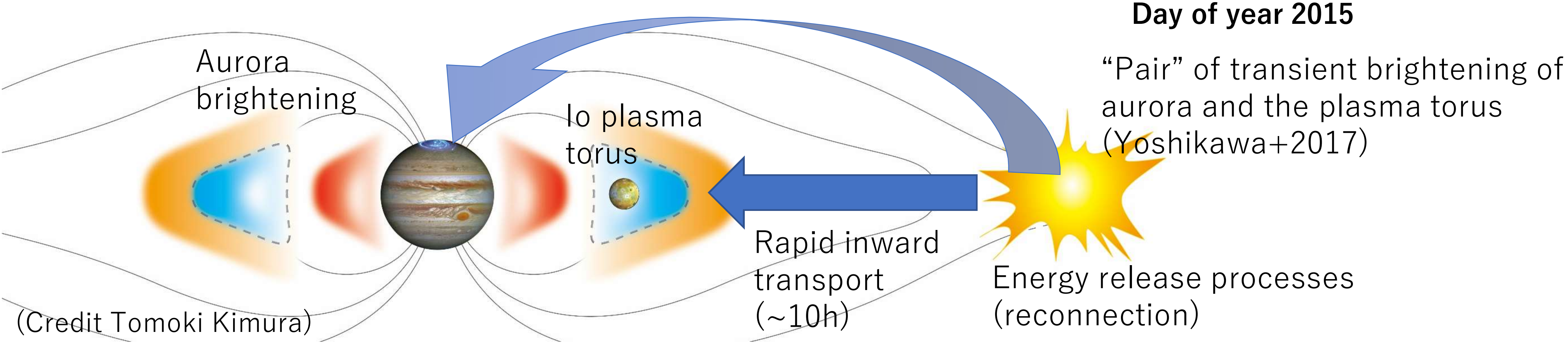
Evidence of fast radial transport of energy in the rotation dominant magnetosphere.

Yoshikawa et al. 2016, 2017, Suzuki et al. 2018





Summary

Volcanic activity
(IR observation)

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Io's atmosphere

↓

Neutral cloud

↓ **ionization**

Io plasma torus

↓ **Inter-change instability (Yoshioka et al. 2014)**

Outer magnetosphere

↓ **transition energy release (Kimura et al. 2018)**

Activation of aurora

↓

Plasma heating in Io plasma torus

Volcanic contribution to the atmosphere formation ?

How to escape the neutral gas ?

How to transport the energy ?
How to heat the plasma ?

- Extreme Ultraviolet (EUV) spectroscopy is the powerful tool to study mass and energy flows in the Jovian magnetosphere.
- Future Jupiter missions will play important role to find what is happening in the region between inner and outer magnetosphere.
- Spatially resolved monitoring observations of Io is needed to resolve formation of the atmosphere and escape from it.