Kelvin-Helmholtz waves at Earth's magnetopause and magnetic reconnection due to KHWs

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2015.9 - present, Postdoc

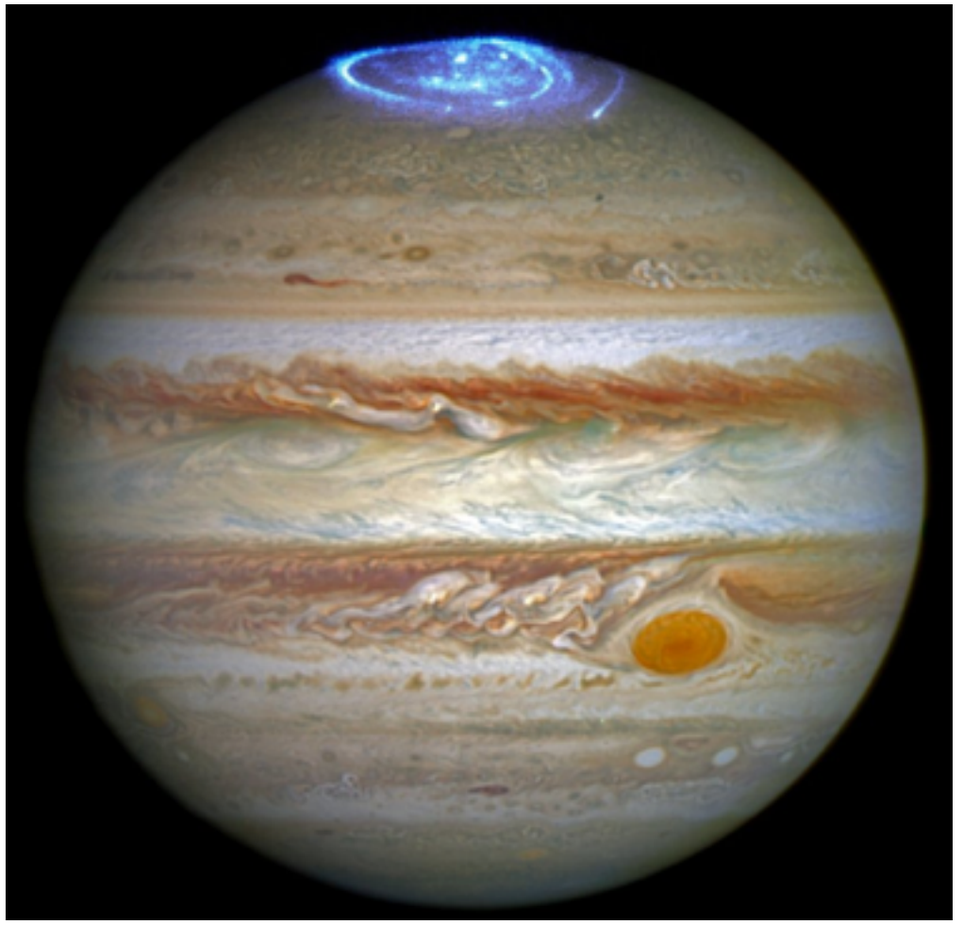
Outline

- Kelvin-Helmholtz waves (KHWs) in space plasma
- KHWs at Earth's magnetopause and transport process
- KHWs studies by Magnetospheric Multiscale (MMS) mission
- Summary

1. Kelvin-Helmholtz waves in space plasma

- Kelvin-Helmholtz waves in nature

The Starry Night, Vincent van Gogh

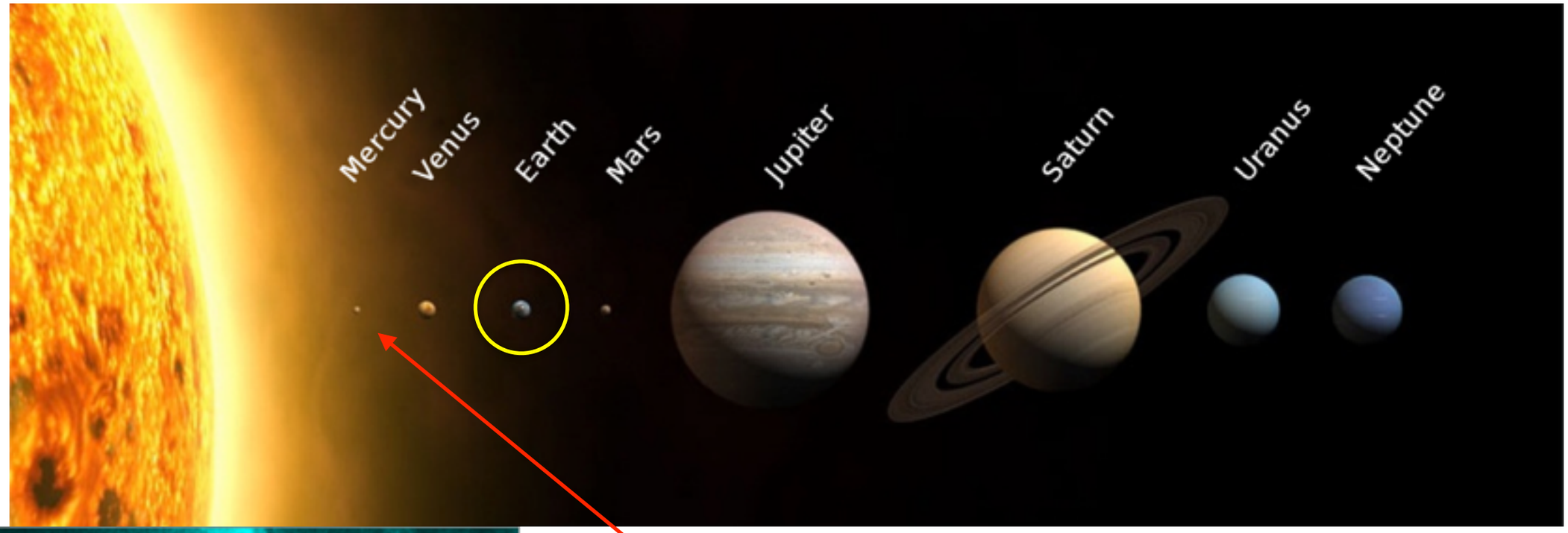


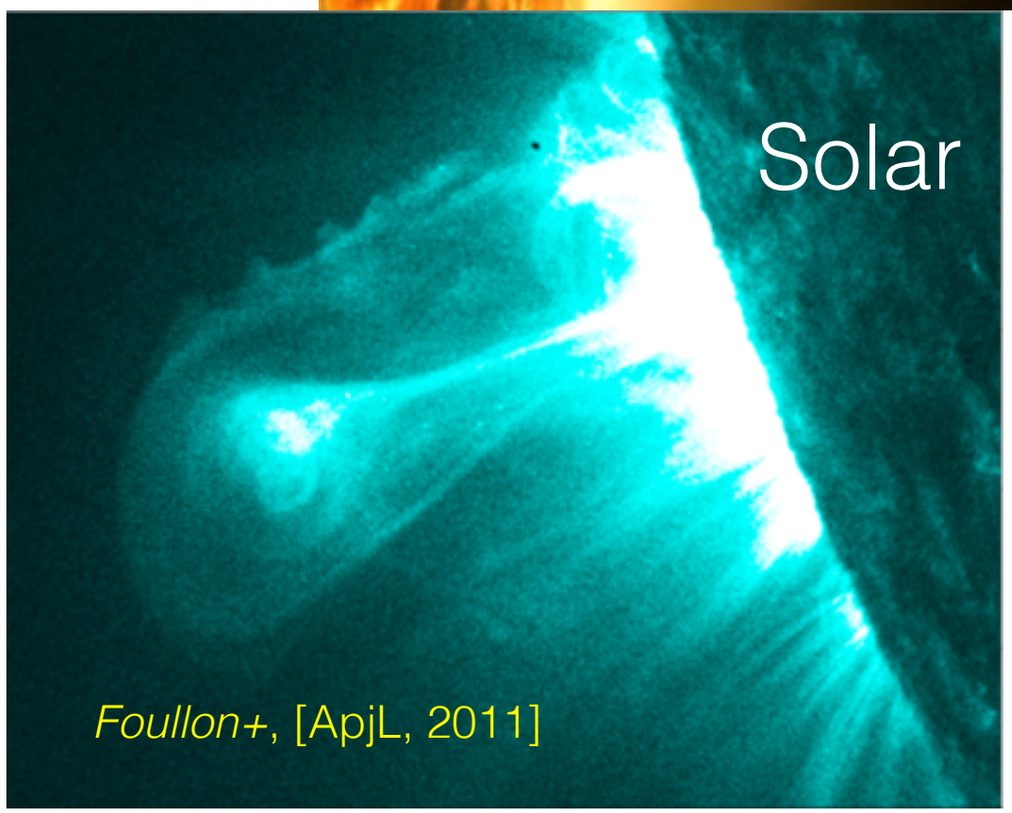
Great Red Spot, Jupiter

Can we see Kelvin-Helmholtz waves in space plasma?

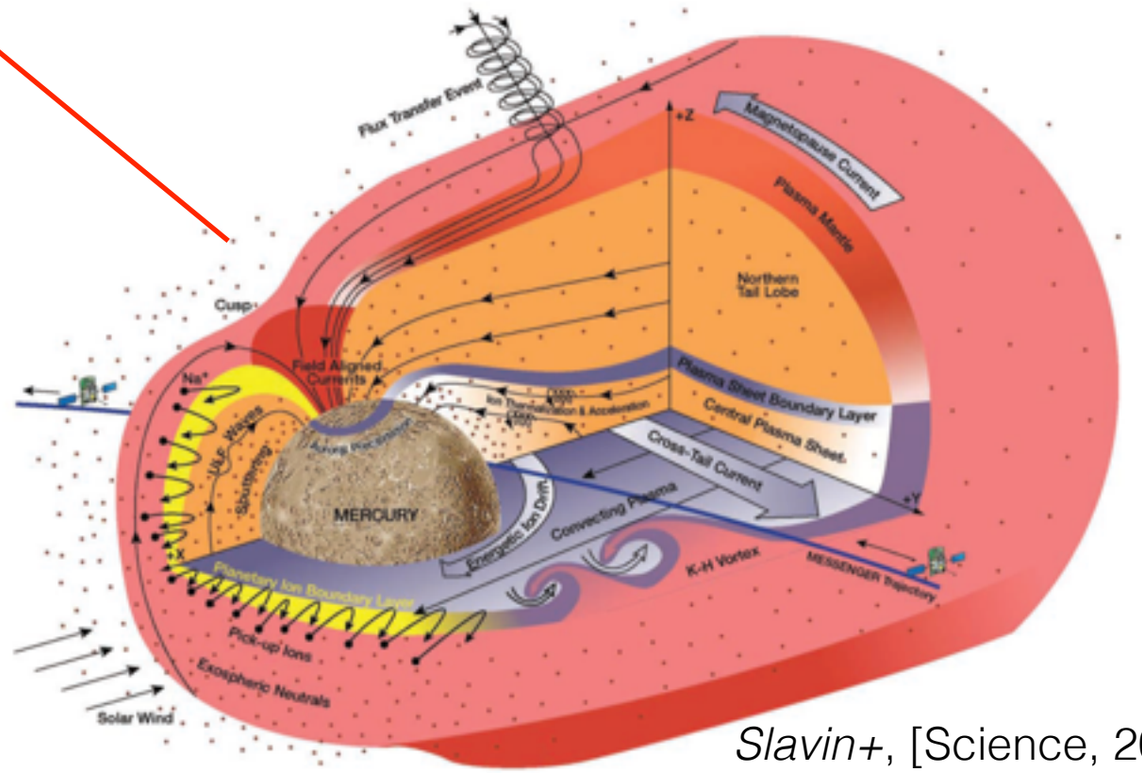
1. Kelvin-Helmholtz waves in space plasma

- Kelvin-Helmholtz waves in space plasma





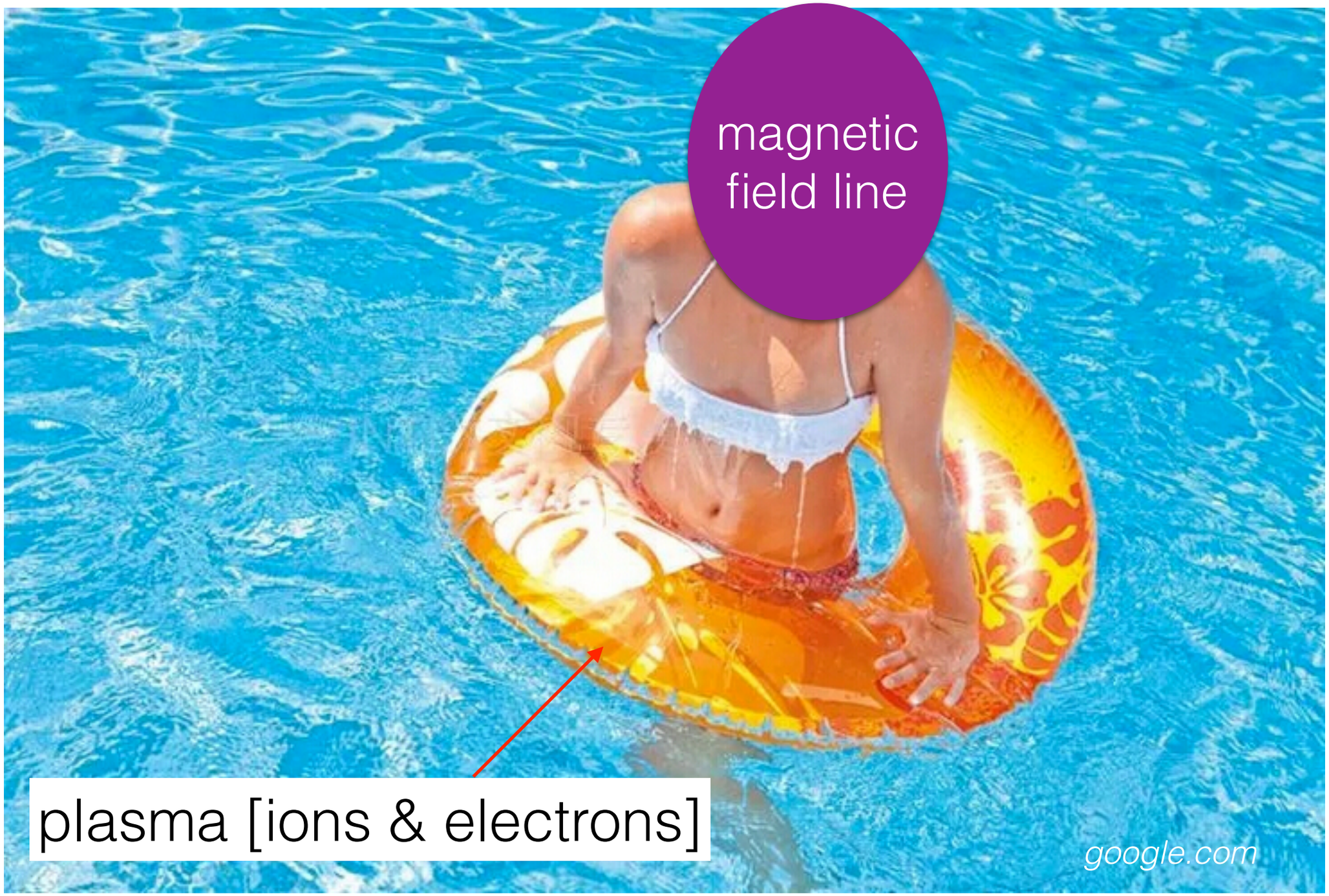
Foullon+, [ApjL, 2011]



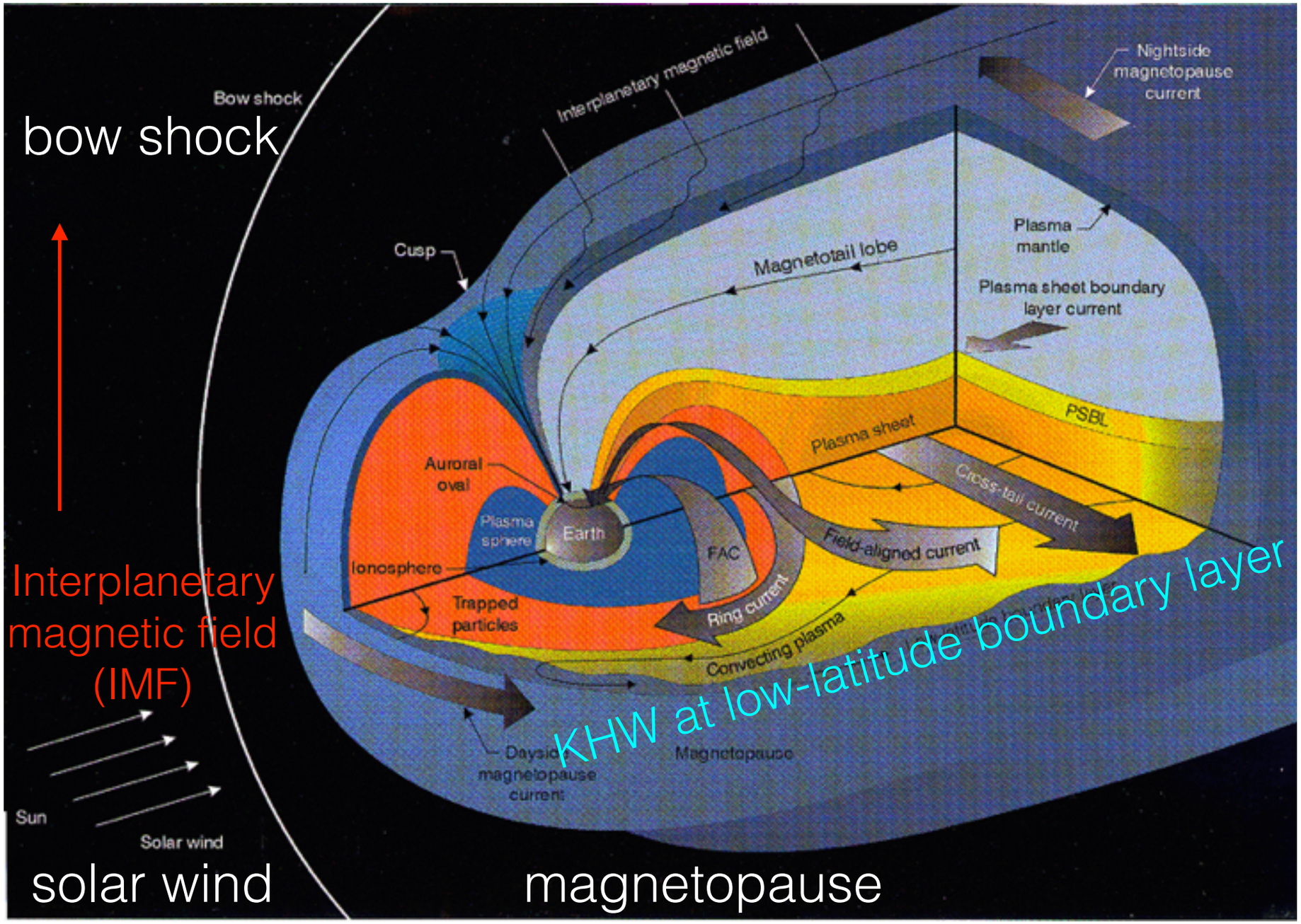
Slavin+, [Science, 2008]

1. Kelvin-Helmholtz waves in space plasma

- Frozen-in condition in space plasma



1. Kelvin-Helmholtz waves in space plasma



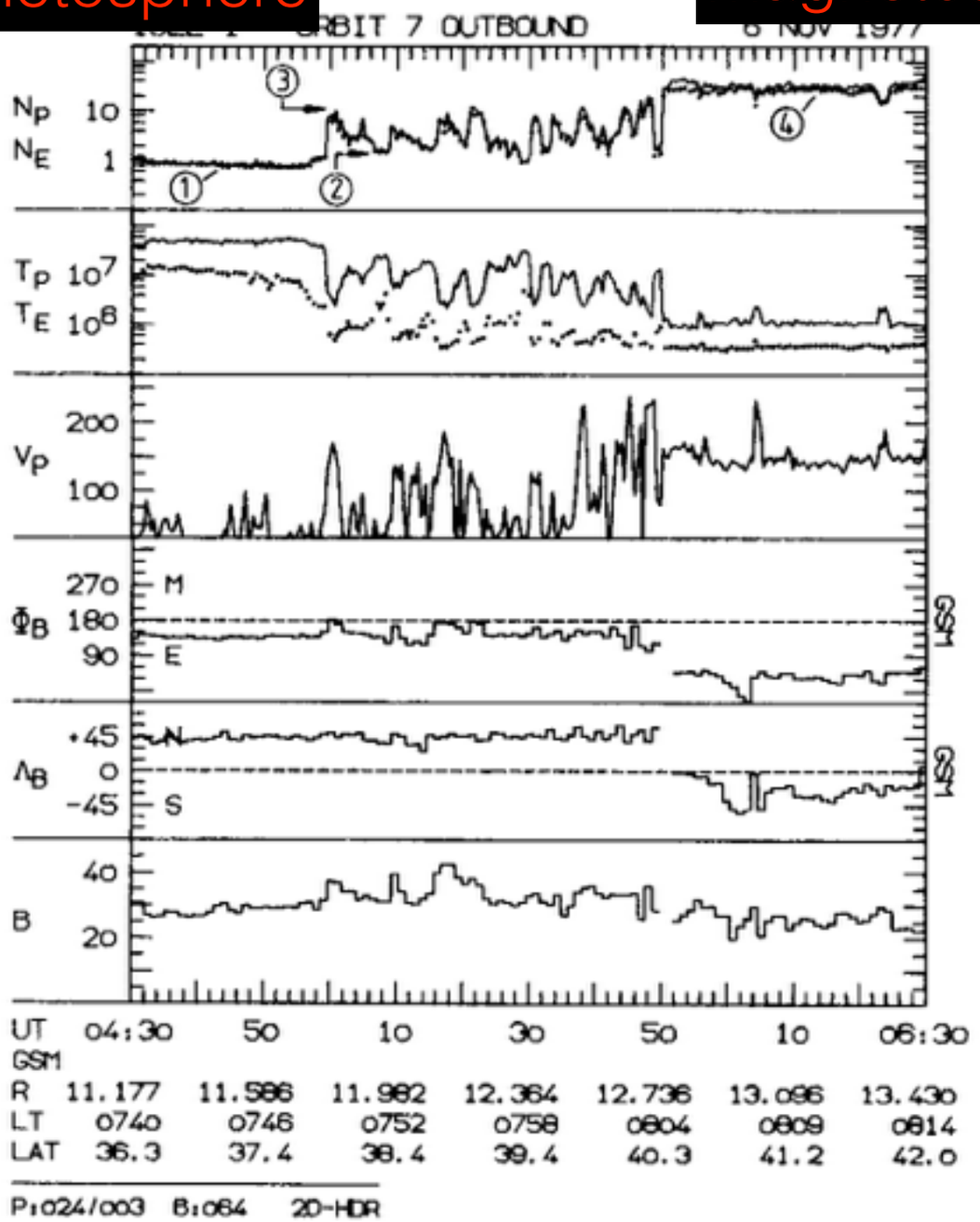
KHW at magnetopause can transfer solar wind energy, momentum, particle into magnetosphere.

2. KHWs at Earth's magnetopause and transport process

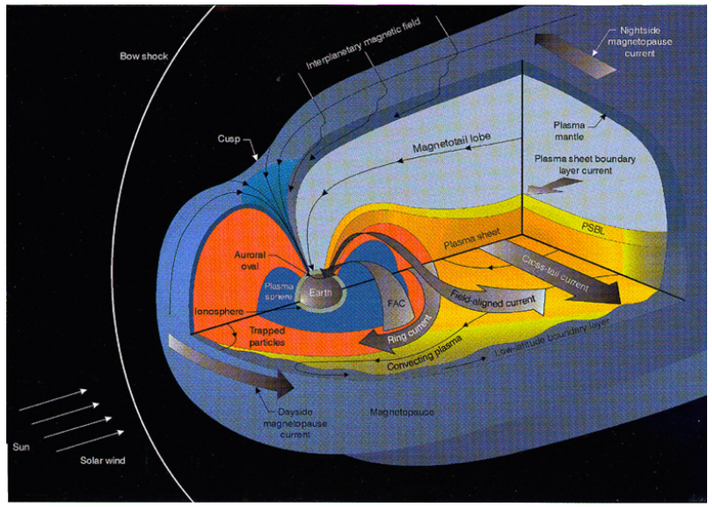
- What does KHW look like?

magnetosphere

magnetosheath



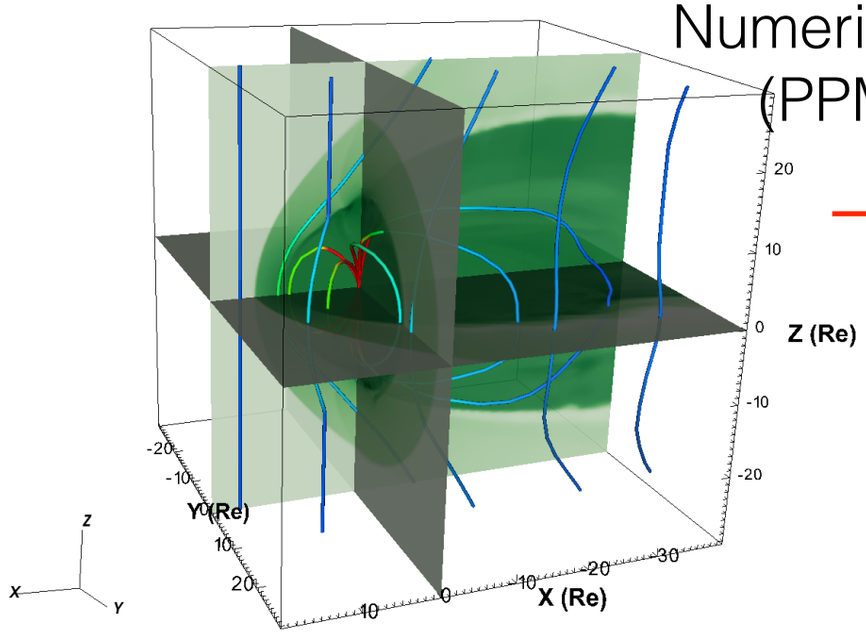
Sckopke+ [JGR, 1981]



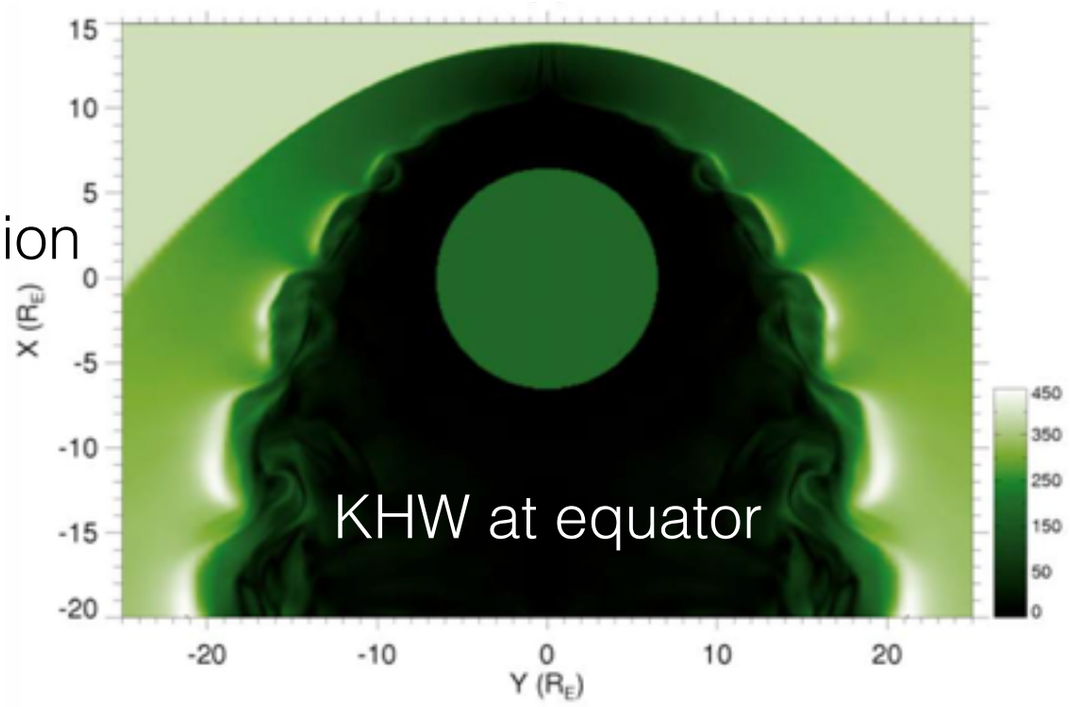
- Probably the first in-situ observation
- ISEE 1 spacecraft
- quasi-periodic (2-5 min) fluctuations of plasma and B-field parameters
- scale: 3-8 Re wavelength
- Tens of KHW cases by Geotail, Cluster, Double Star TC-1, and THEMIS missions

2. KHWs at Earth's magnetopause and transport process

- What does KHW look like?



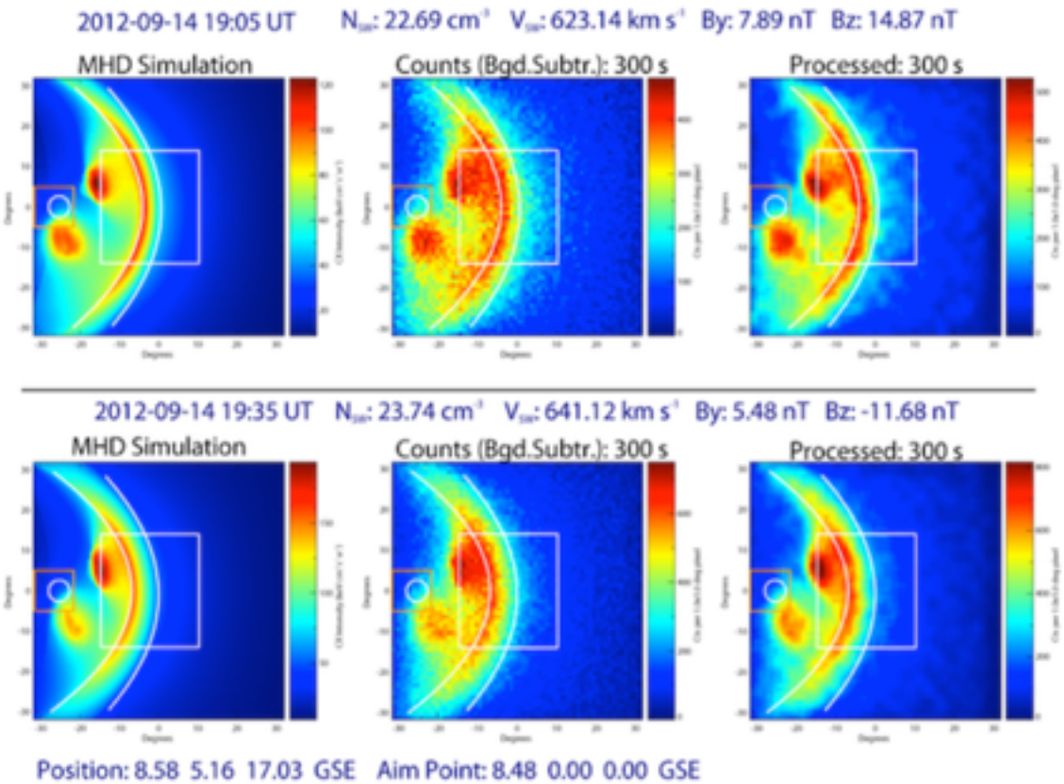
Numerical simulation (PPMLR-MHD)



[*Guo et al.*, JGR, 2010; *Li et al.*, JGR, 2012, 2013; *Lin et al.*, 2014]

Taking pictures of magnetosphere

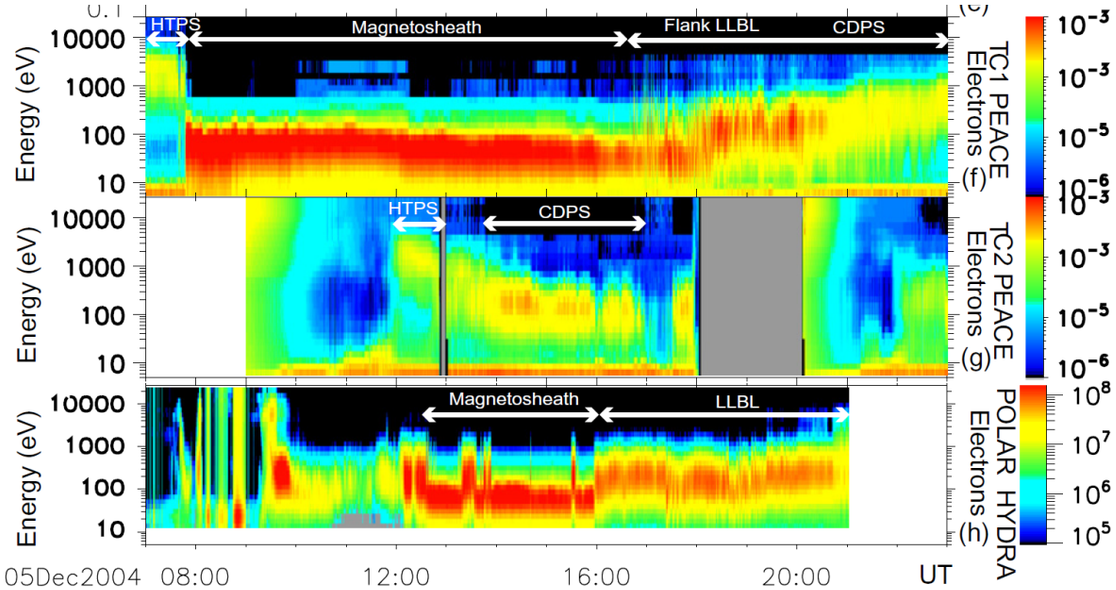
X-ray imager



2. KHWs at Earth's magnetopause and transport process

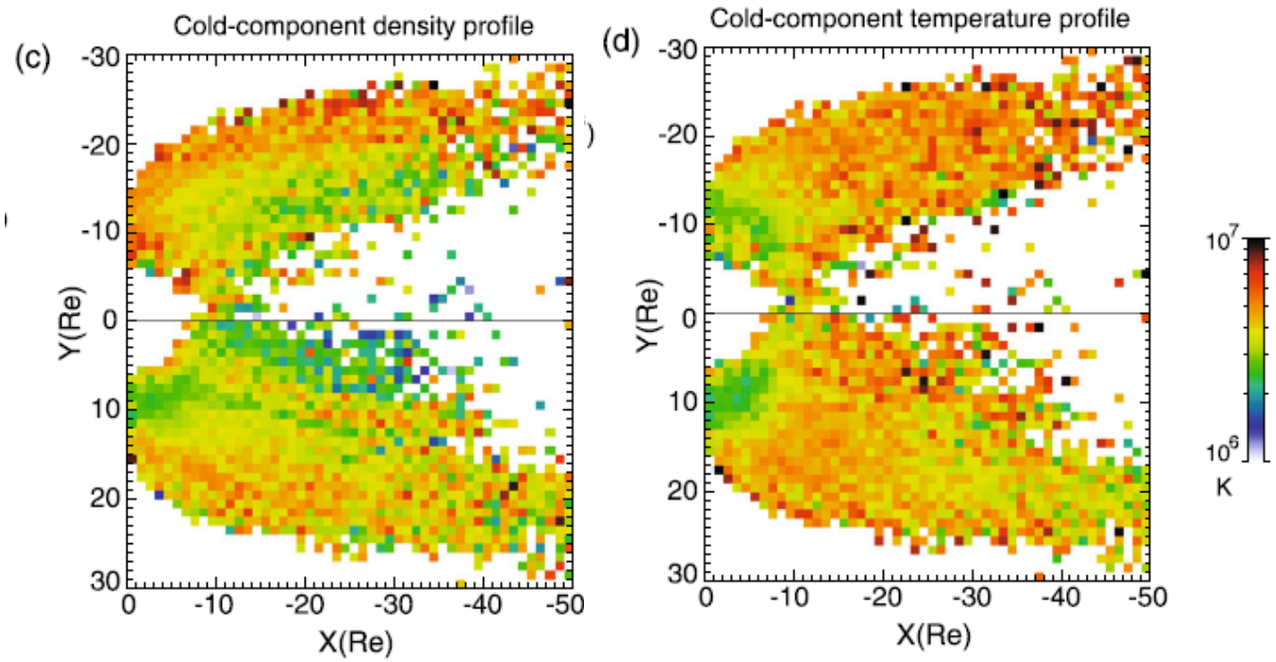
- What can KHW do?

Cold and dense plasma sheet (CDPS) close to MP and inside MSP



[*Taylor et al.*, ASR, 2008]

Statistical study of CDPS during northward IMF

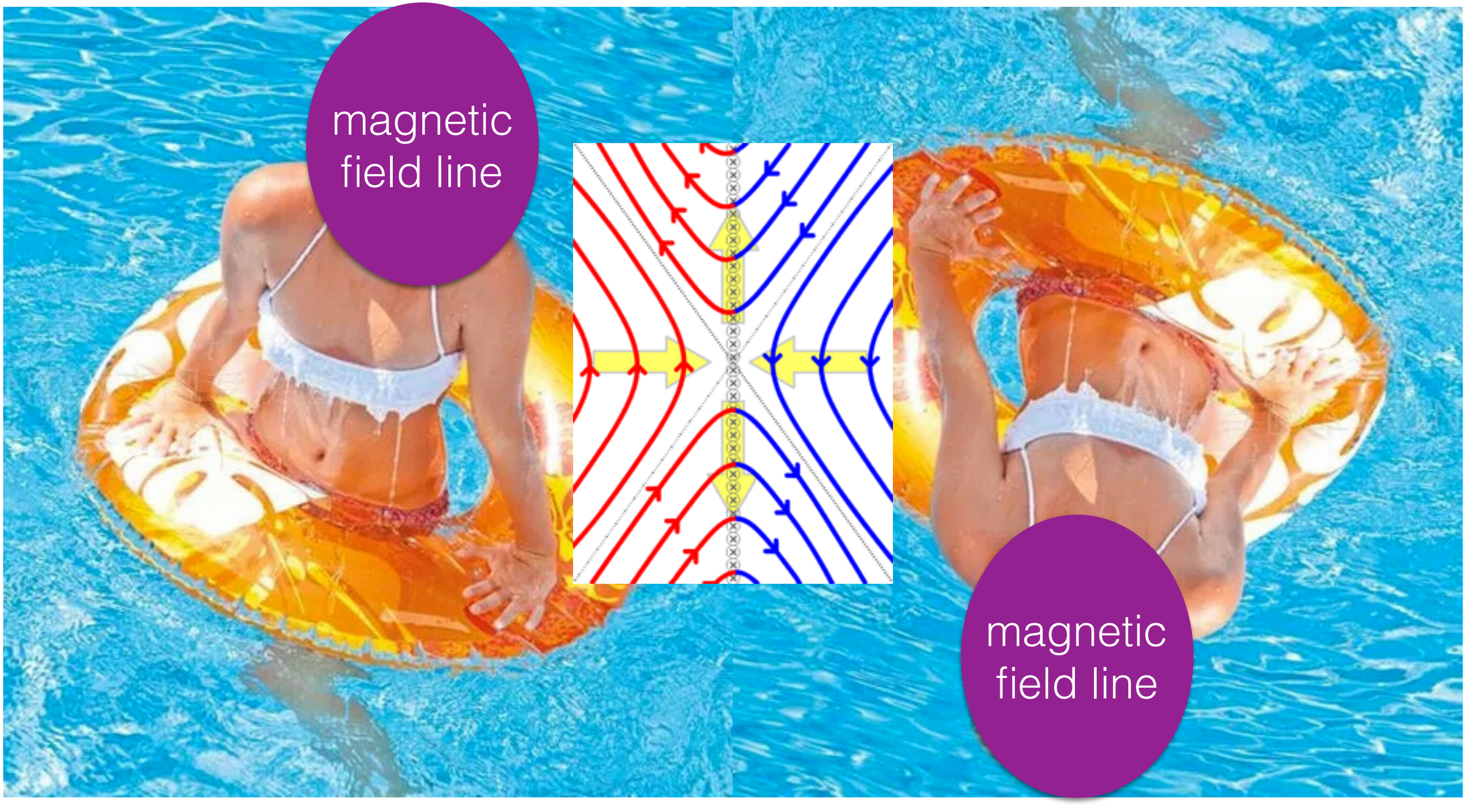


[*Wing et al.*, JGR, 2005]

- Sufficient solar wind plasma transport during northward IMF
- Popular mechanisms
  1. Double cusp or double lobe reconnection
  2. magnetic reconnection due to K-H instability
  3. Kinetic Alfvén waves
  4. Impulsive penetration

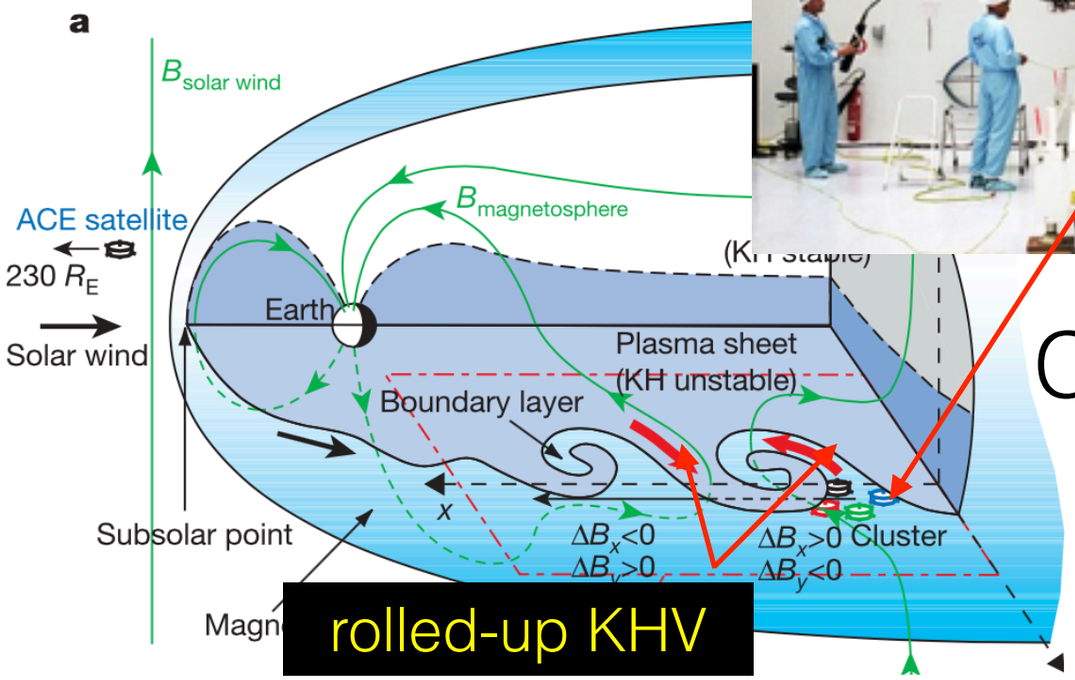
2. KHWs at Earth's magnetopause and transport process

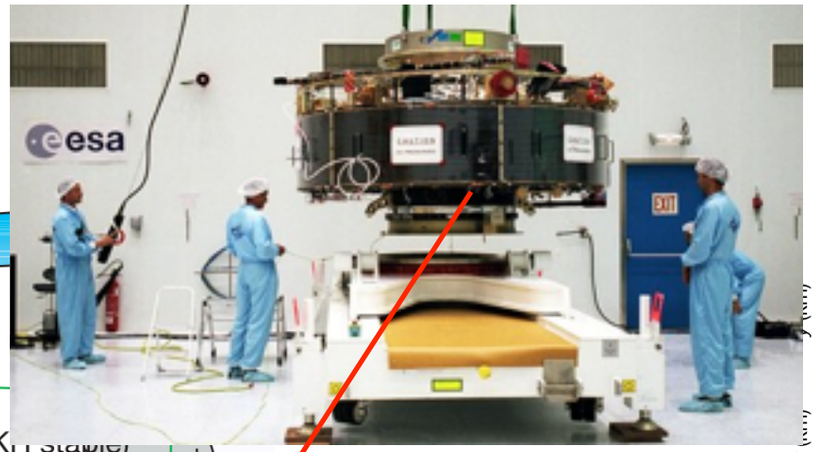
- What is magnetic reconnection?



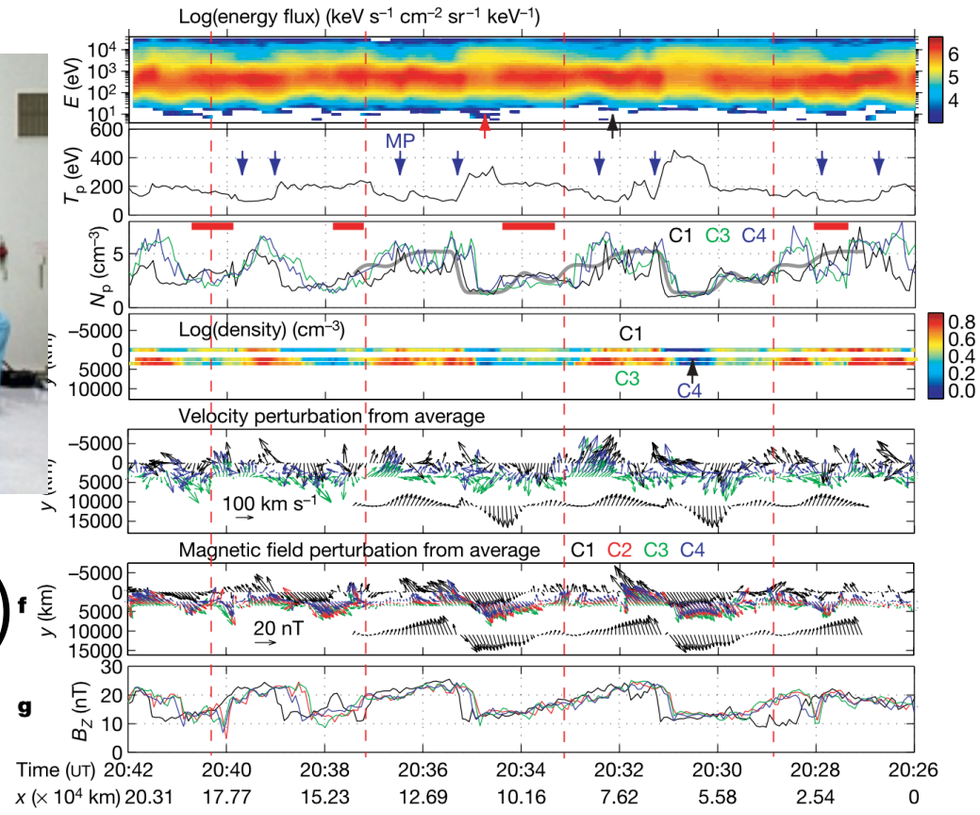
2. KHWs at Earth's magnetopause and transport process

- What can KHW do?





Cluster (X4)

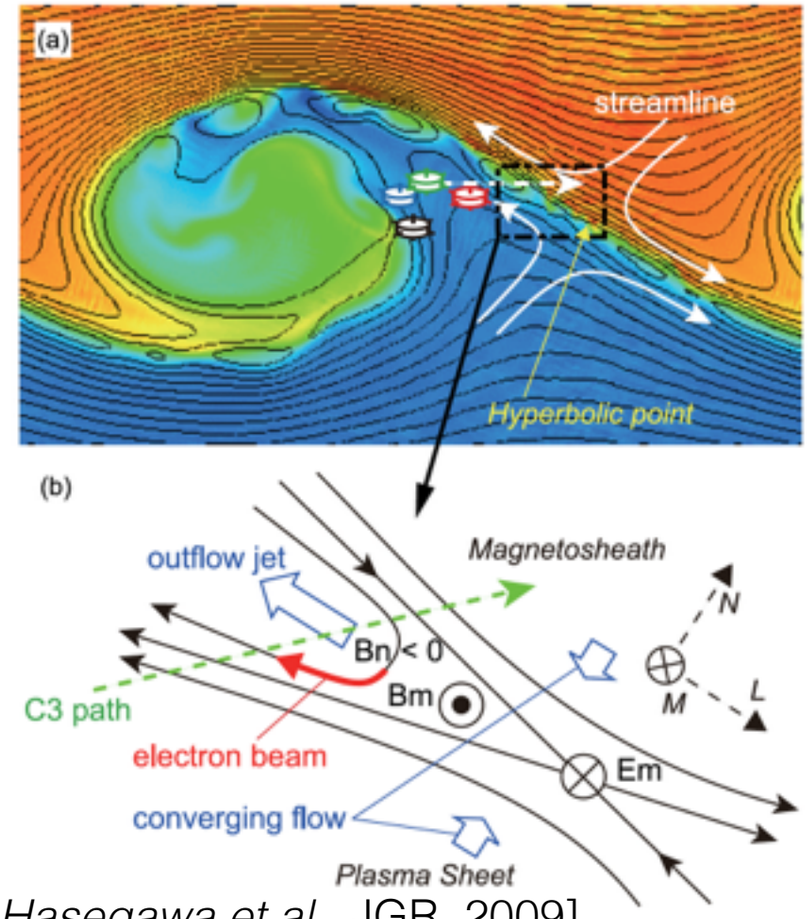


Identification of rolled-up KHV

- *Hasegawa et al.* [Nature, 2004], "Transport of solar wind into Earth's magnetosphere through rolled-up Kelvin-Helmholtz vortices"
- Plasma transport requires the broken of the "frozen-in" condition.
- How is solar wind plasma transported through rolled-up KHW?

2. KHWs at Earth's magnetopause and transport process

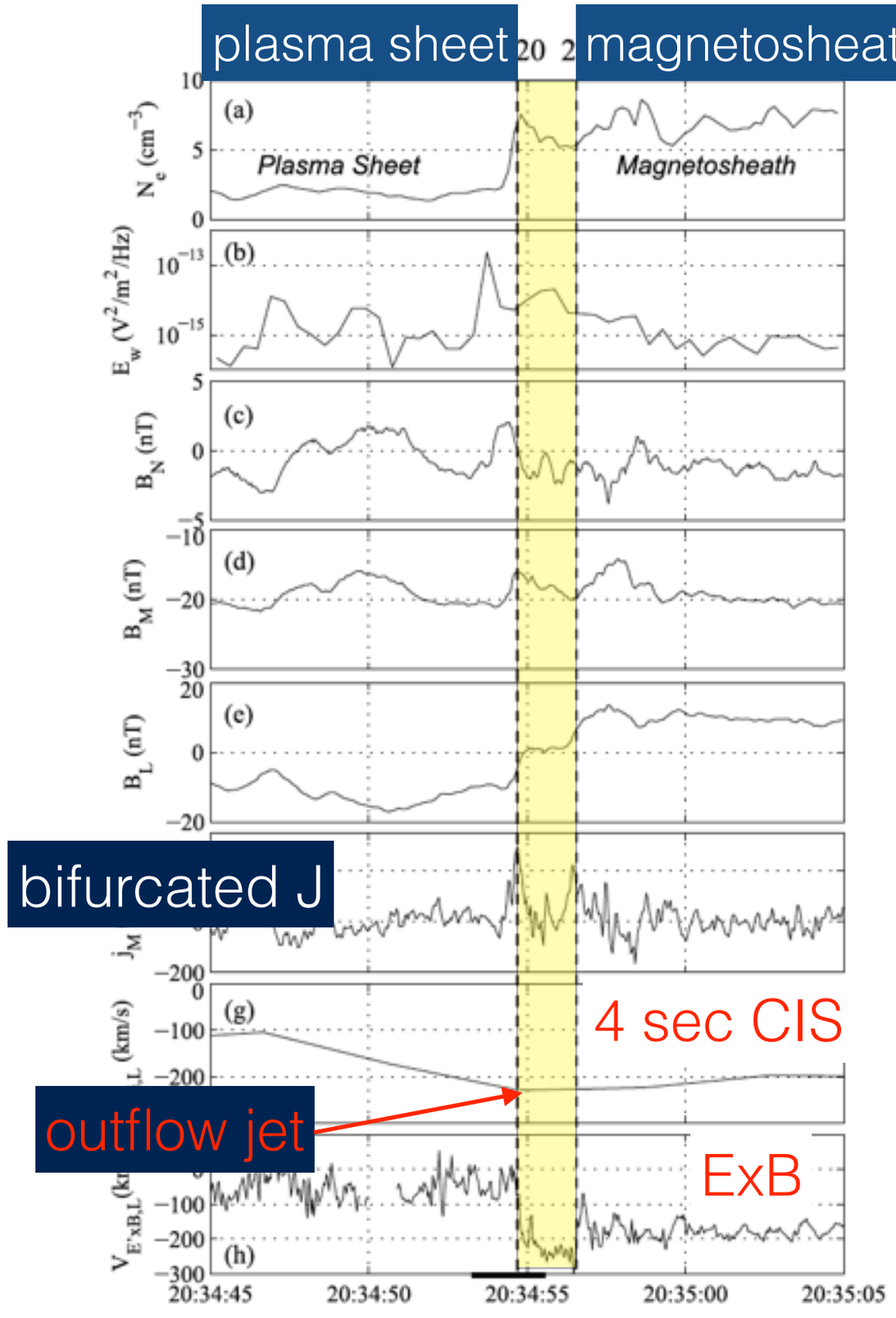
- What can KHW do?



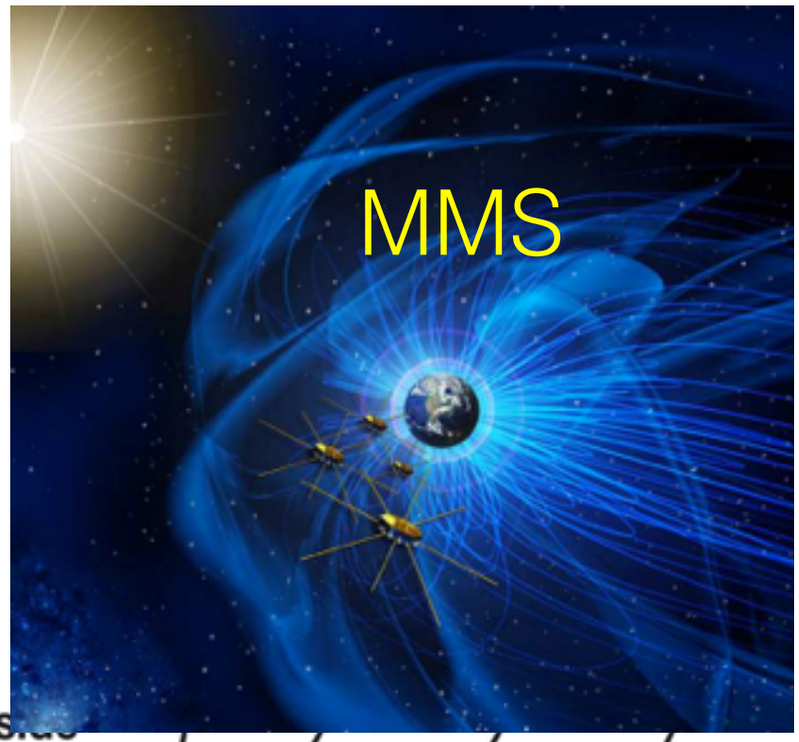
[*Hasegawa et al.*, JGR, 2009]

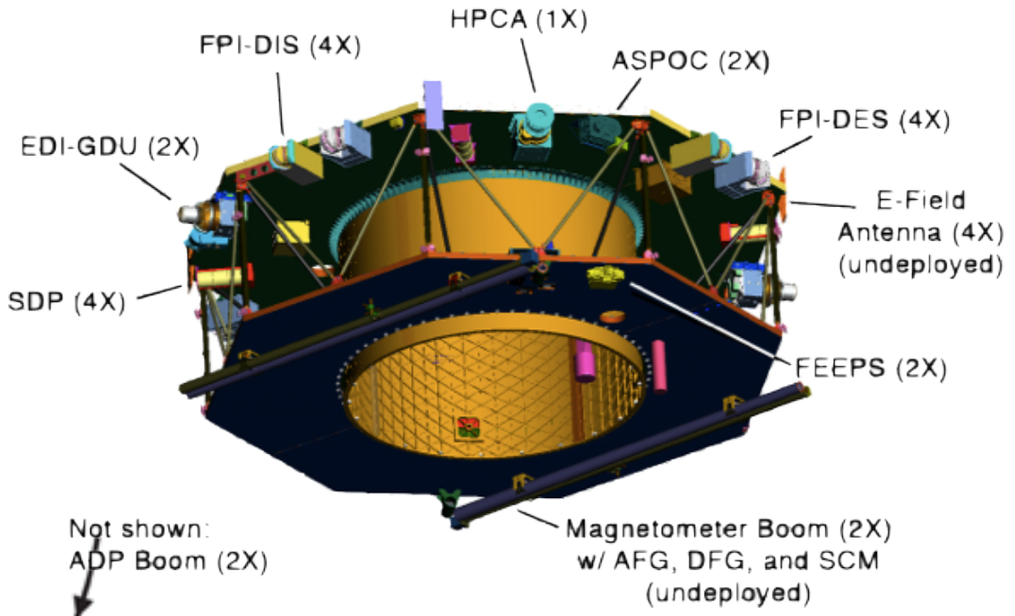
- KHW propagates convectively at MP, e.g. 200 km/s

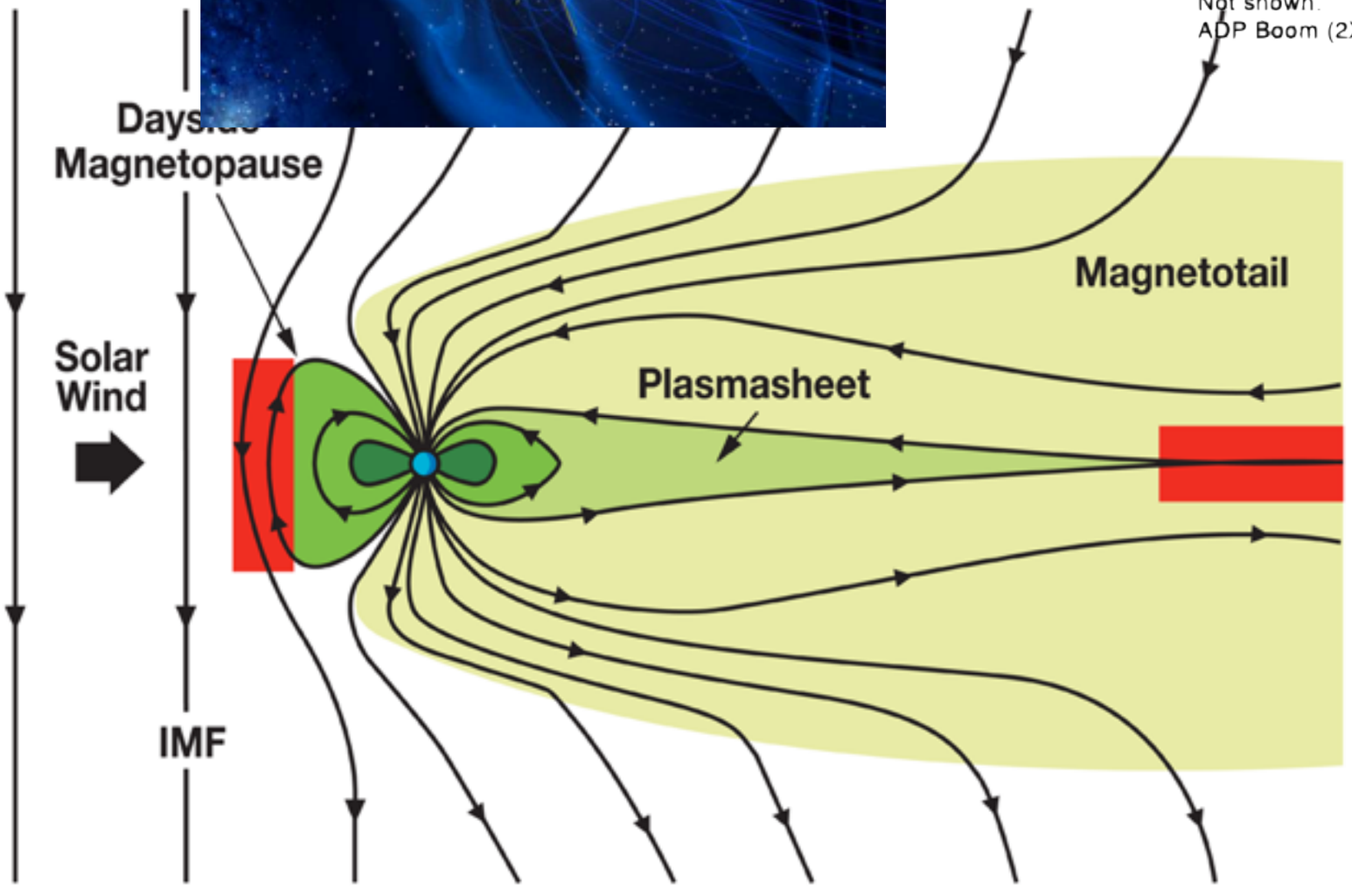
- outflow jet: 200 - 300 km; require better than 1 sec resolution particle instrument



3. KHWs studies by Magnetospheric Multiscale mission

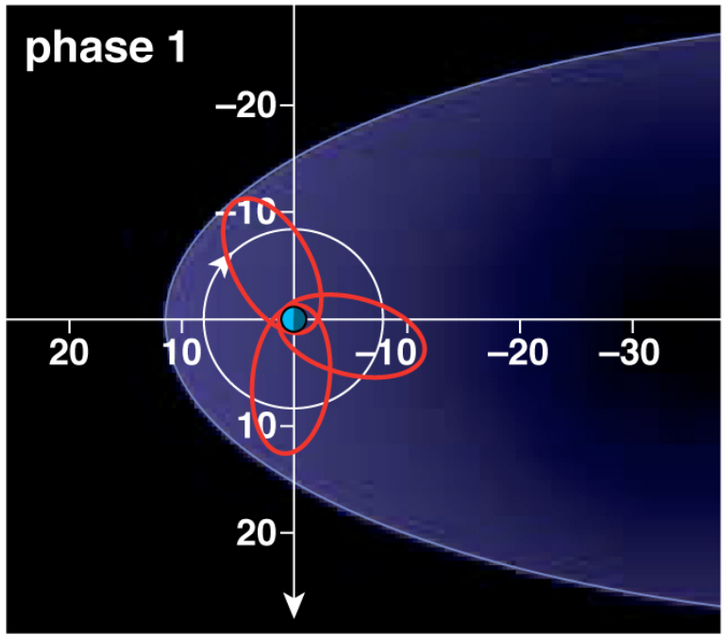


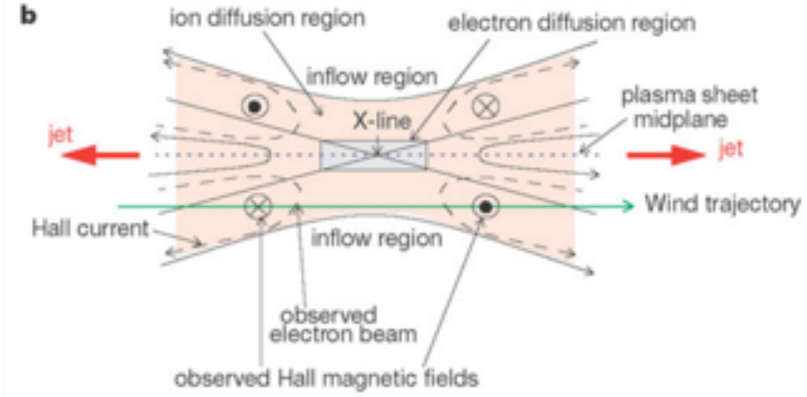


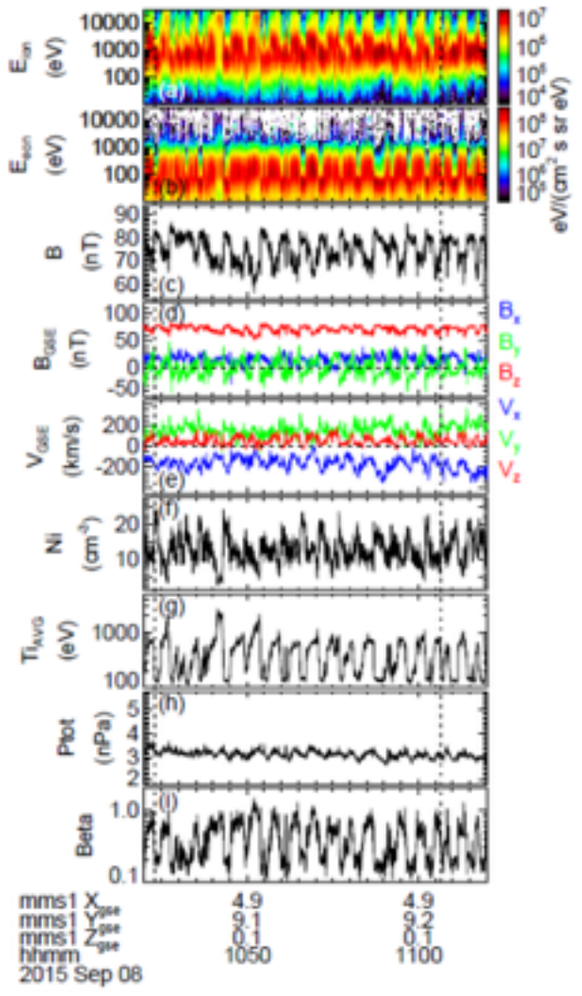


- Launched on March 12 2015
- Science data from Sep. 1st 2015
- Fast plasma investigation (FPI, 4X)
  - 0.15 s for ion & 0.03 s for electron
  - Energy: 10 eV to 30 keV

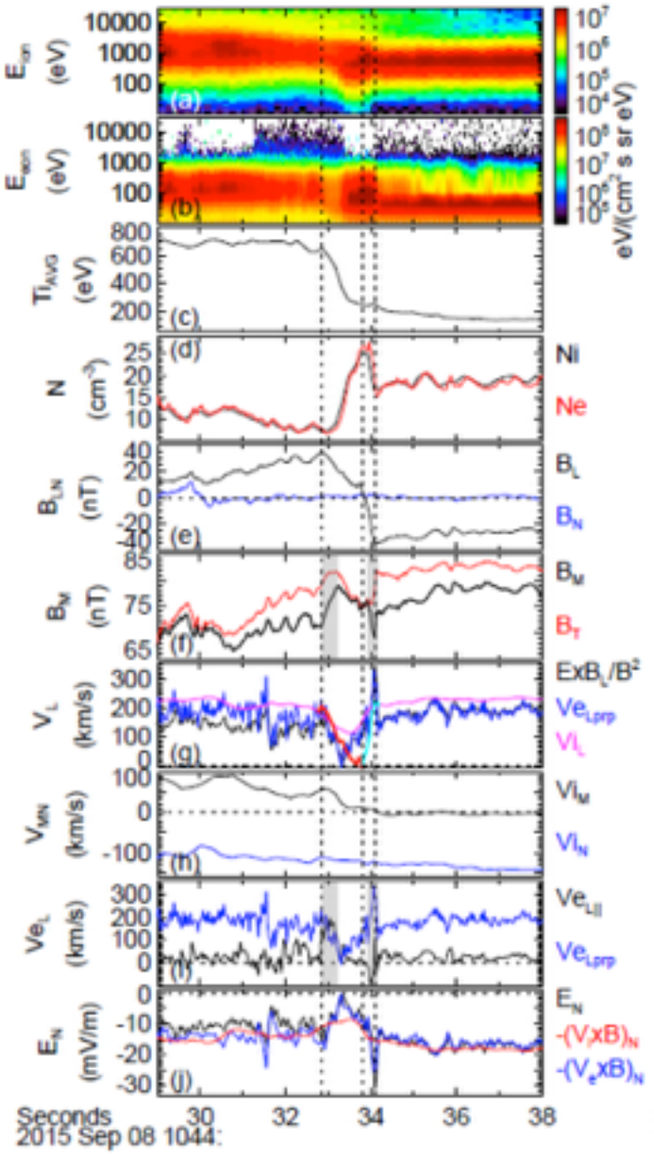
3. KHWs studies by Magnetospheric Multiscale mission





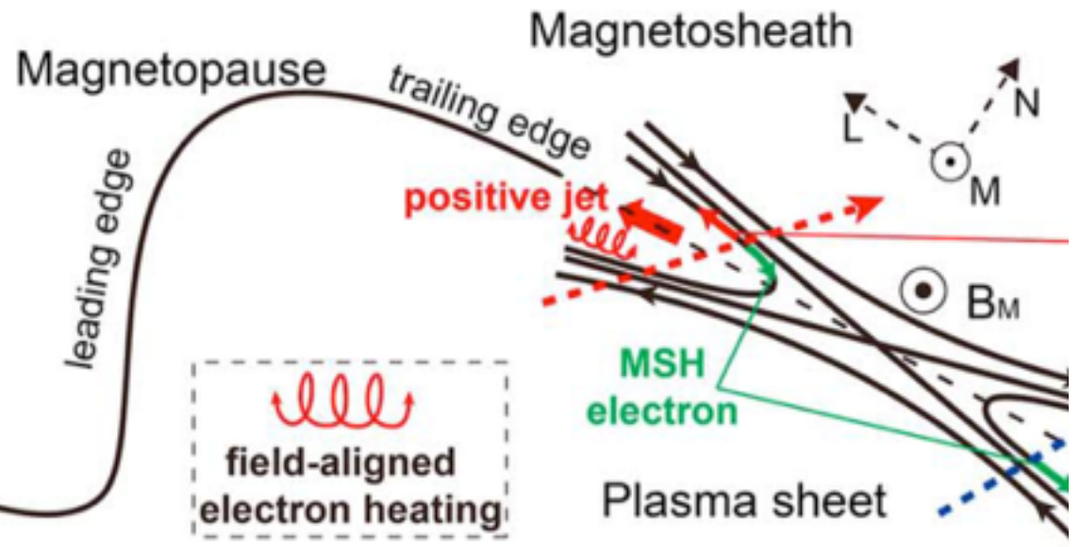


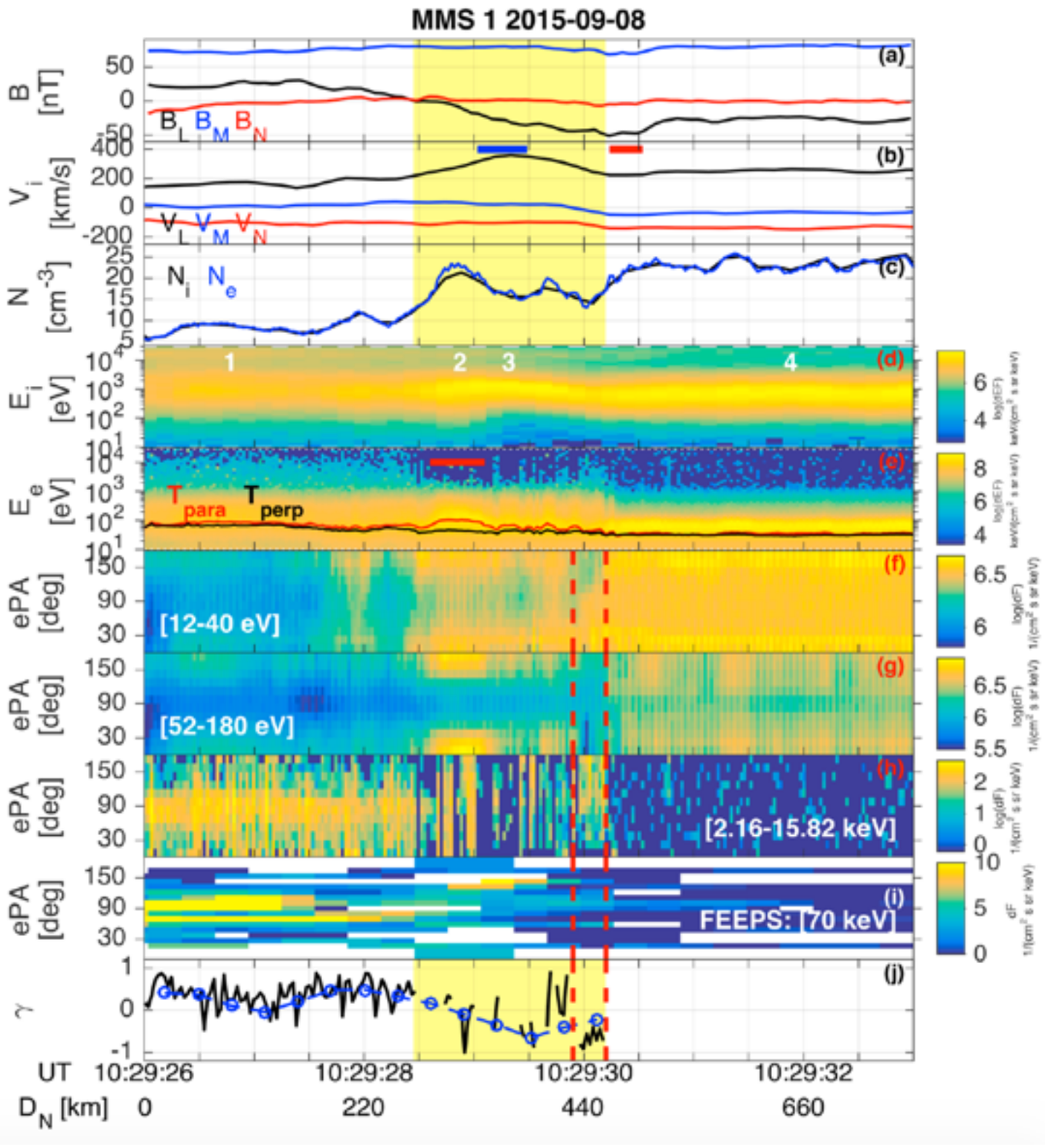
[*Eriksson et al.*, GRL, 2016]



- S. Eriksson (UC) from MMS Scientist-In-the-Loop (SITL) team first noticed the important of KHW event on 2015-09-08.
  1. 22 exhausts in 42 KHW trailing edge crossings
  2. asymmetric Hall E and B field, with strong guide field

3. KHWs studies by Magnetospheric Multiscale mission

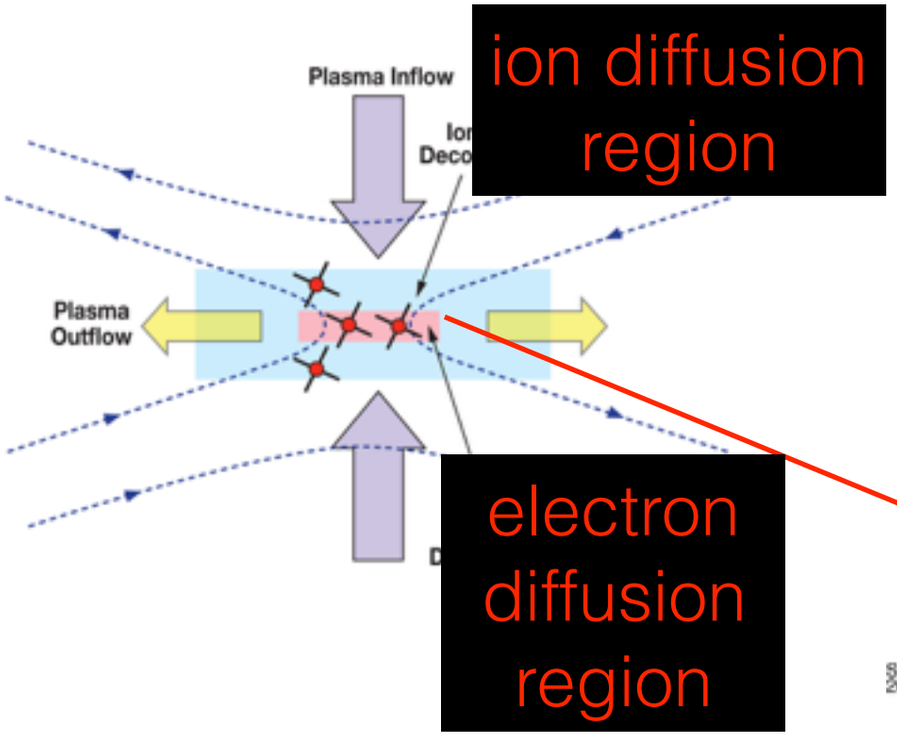




- Reconnection jet
  1. Alfvénic jet; ~ 3 ion-inertial length
  2. strong electron temperature anisotropy
  3. field-aligned heating
  4. MSP electron escape
  5. MSH electron entry

Li+ [GRL, 2016]

3. KHWs studies by Magnetospheric Multiscale mission

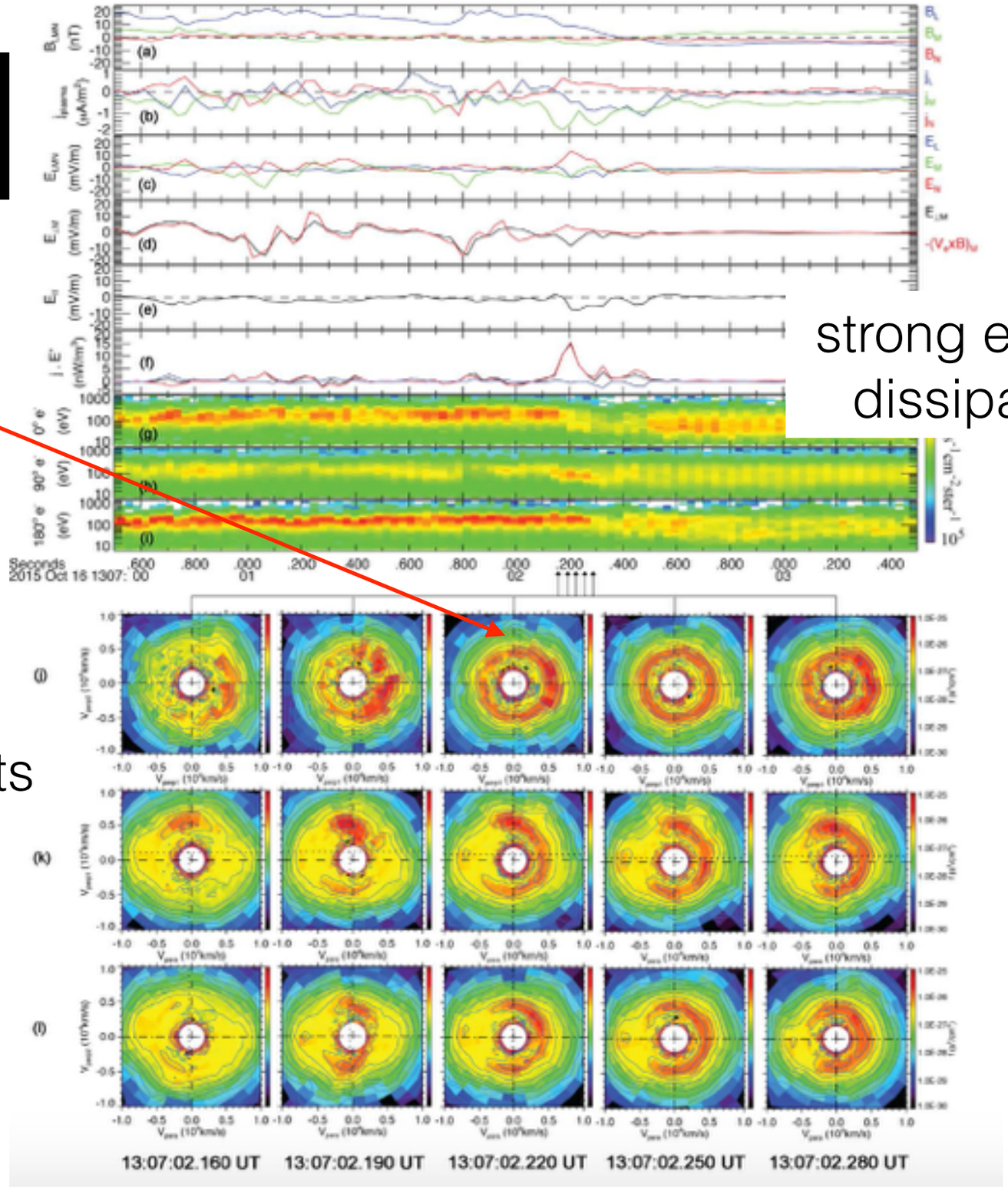


ion diffusion region

electron diffusion region

Burch et al. [Science, 2016]

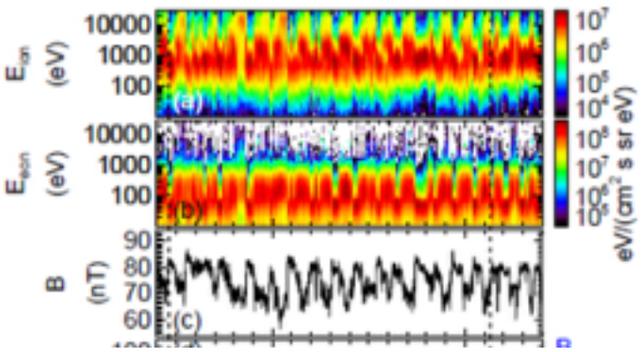
- "Electron-scale measurements of magnetic reconnection in space"
- crescent electron distribution

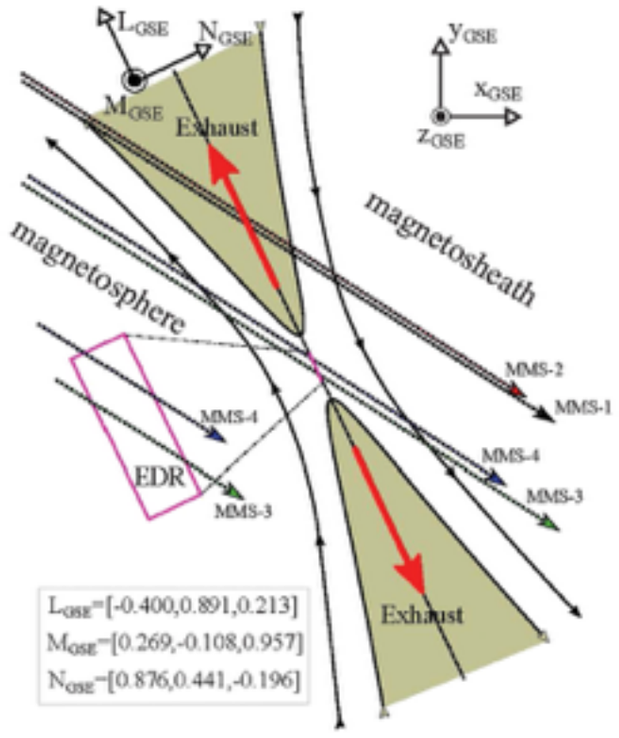


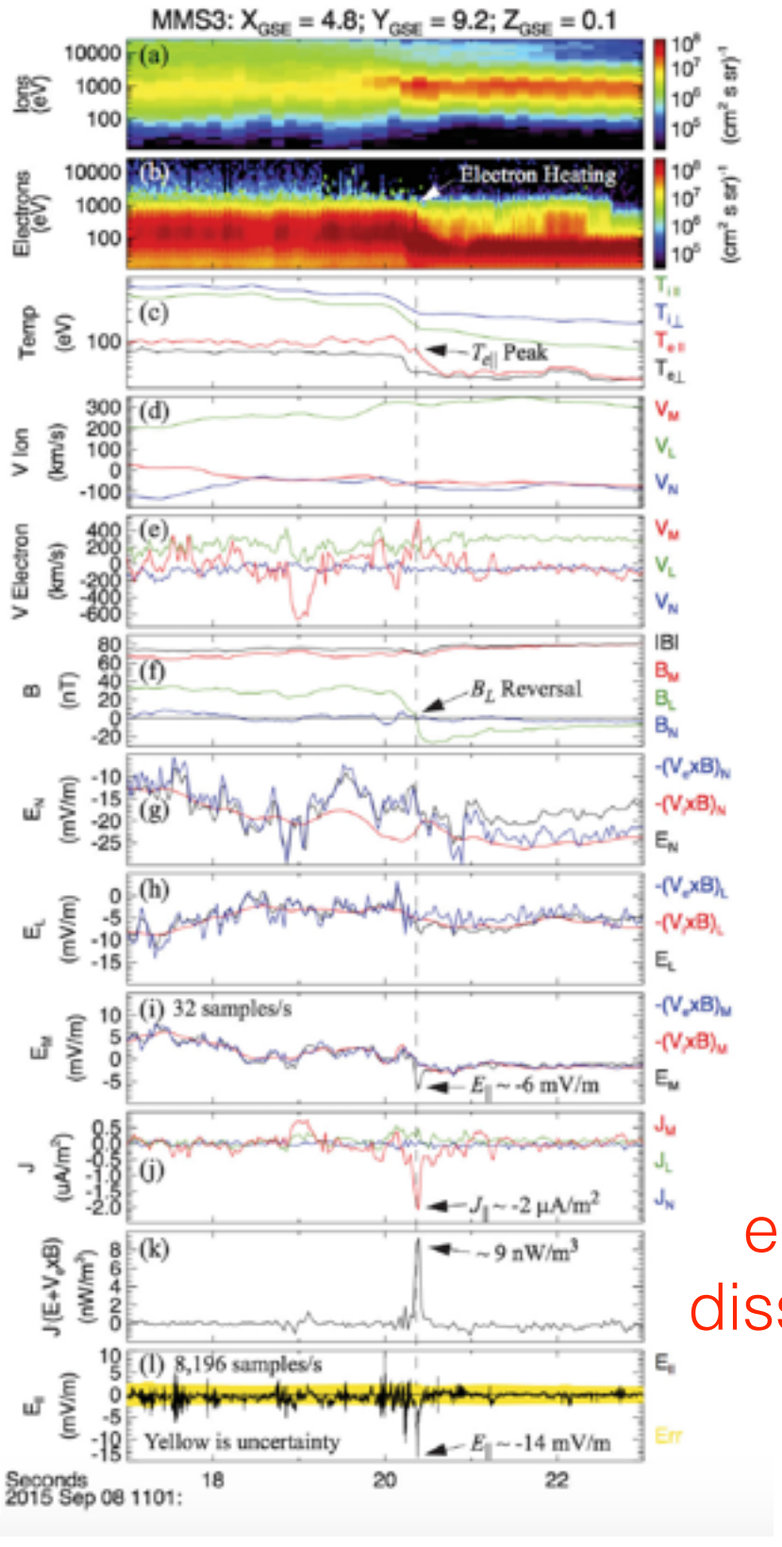
strong energy dissipation

3. KHWs studies by Magnetospheric Multiscale mission

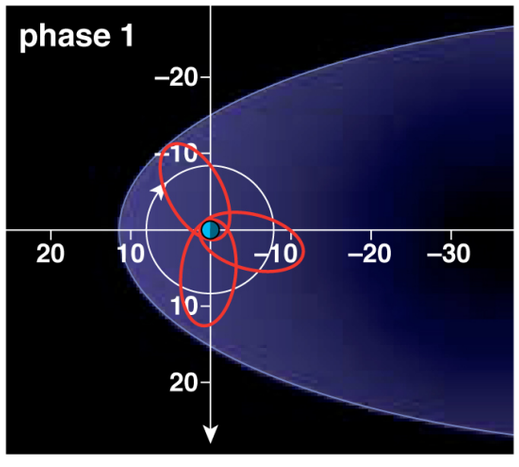
quasi-periodic KHW

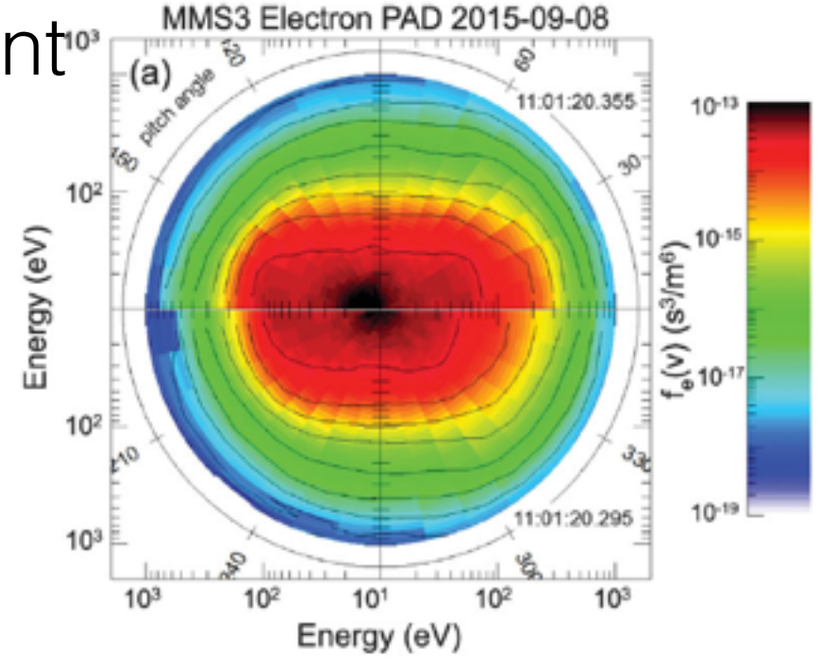






no clear electron crescent





[*Eriksson et al.*, PRL, 2016]

energy dissipation

|| E

4. Summary

- Kelvin-Helmholtz (KH) instability at the Earth's magnetopause is predominantly excited during northward interplanetary magnetic field (IMF).
- The magnetic reconnection due to KHW is firstly studied in detail by using the MMS observations on September 8th 2015. The topics include asymmetric electric and magnetic fields, kinetic evidence, and electron diffusion region (EDR) in the reconnection region due to KHWs.
- Magnetic reconnection due to KH waves is one of the mechanisms to transfer solar wind plasma into the magnetosphere.