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Cold ion outflow and the transport to the inner magnetosphere

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◆Very high-density cold plasma (from the cleft ion fountain)

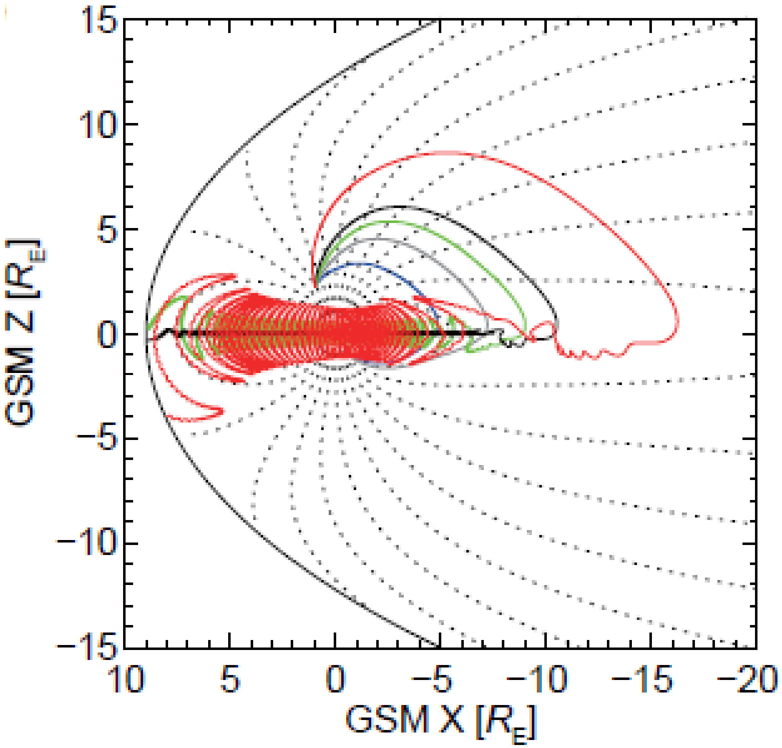


Fig. Trajectories of O^+ assuming geomagnetically active condition [Kitamura, Ph.D. Thesis, 2012]

2, 3, 4, 5, and 10 km/s
at 9000 km altitude

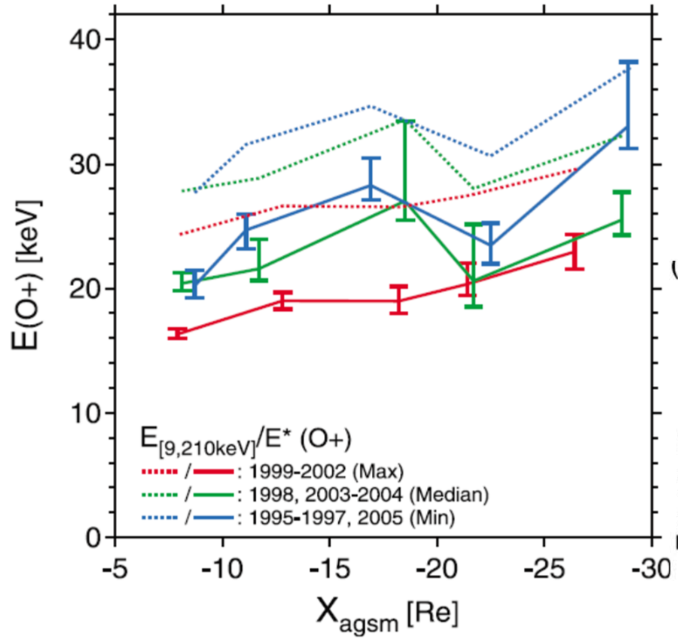
0.33 eV, 0.75 eV, 1.33 eV,
2.09 eV, 8.37 eV

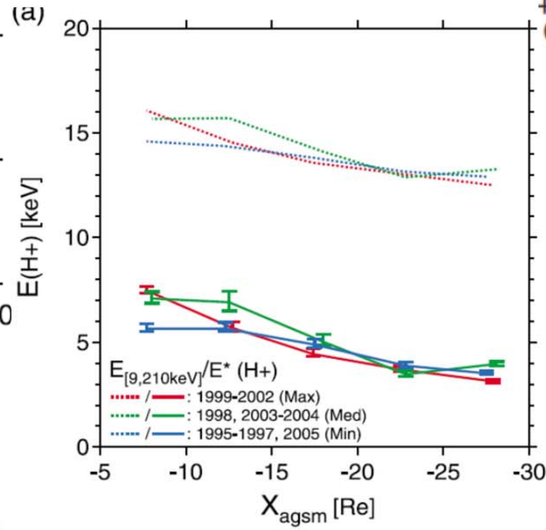
Kitamura et al. [2010a, 2010b, 2012]

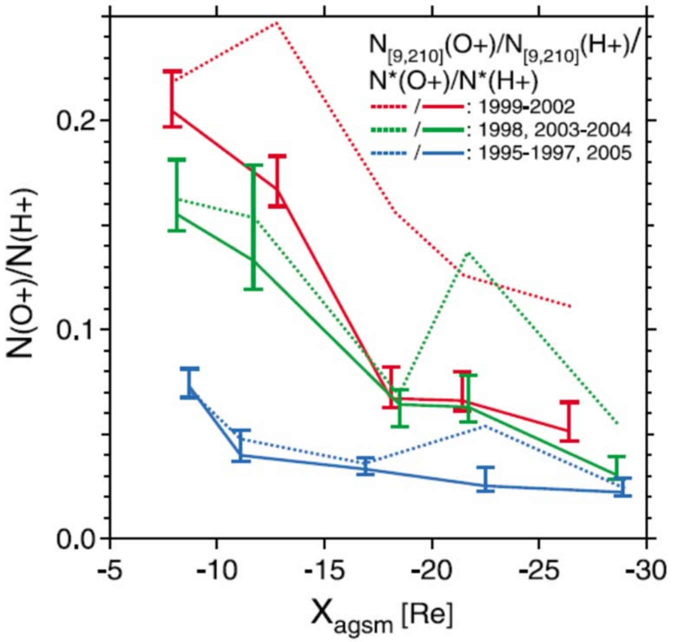
- Large scale electron density enhancements in the polar cap at the altitude of ~9000 km were detected around the main phases of geomagnetic storms at solar maximum.
- The high-density plasma (~100–7000 /cm^3) are likely related to the lowest energy part of the cleft ion fountain (<10 eV in the spacecraft flame).
- The O^+ will be able to reach the equatorial plane (>−15 R_E in XGSM).
- The temperature of O^+ was ~0.01–3 eV at the lobe.

In the trajectory calculations, ions are accelerated at the current sheet, while ions are accelerated at the lobe-plasma sheet boundary based on the MMS observations.

◆Number density ratio (O^+/H^+) and average energy of H^+ and O^+







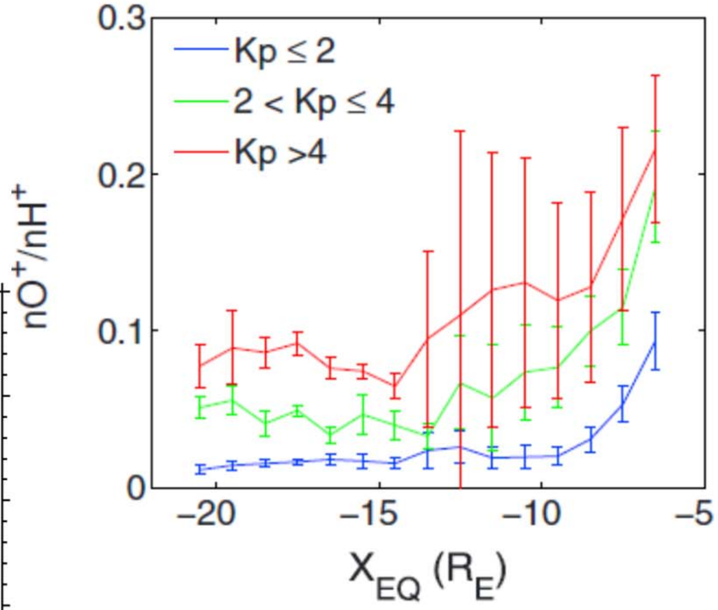
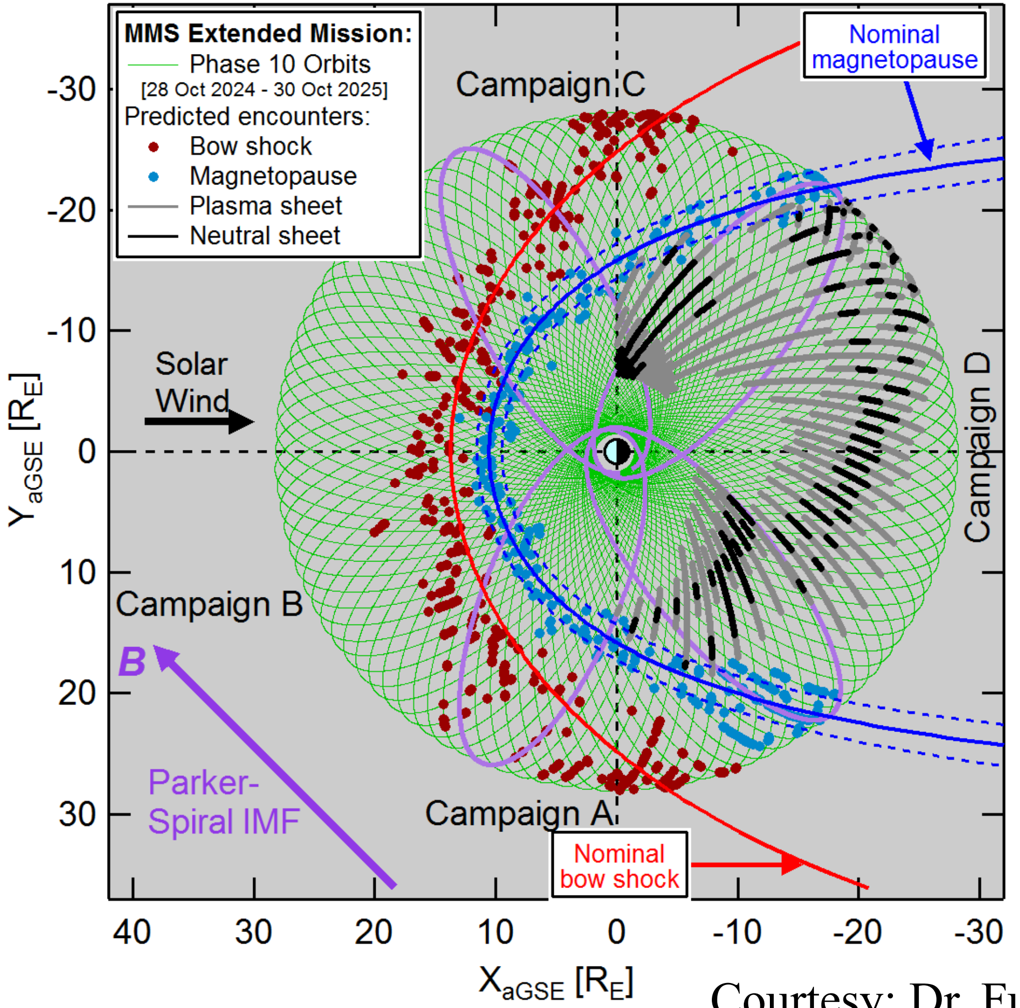


Fig. Density ratio between H^+ and O^+ [Maggiolo and Kistler, 2014]

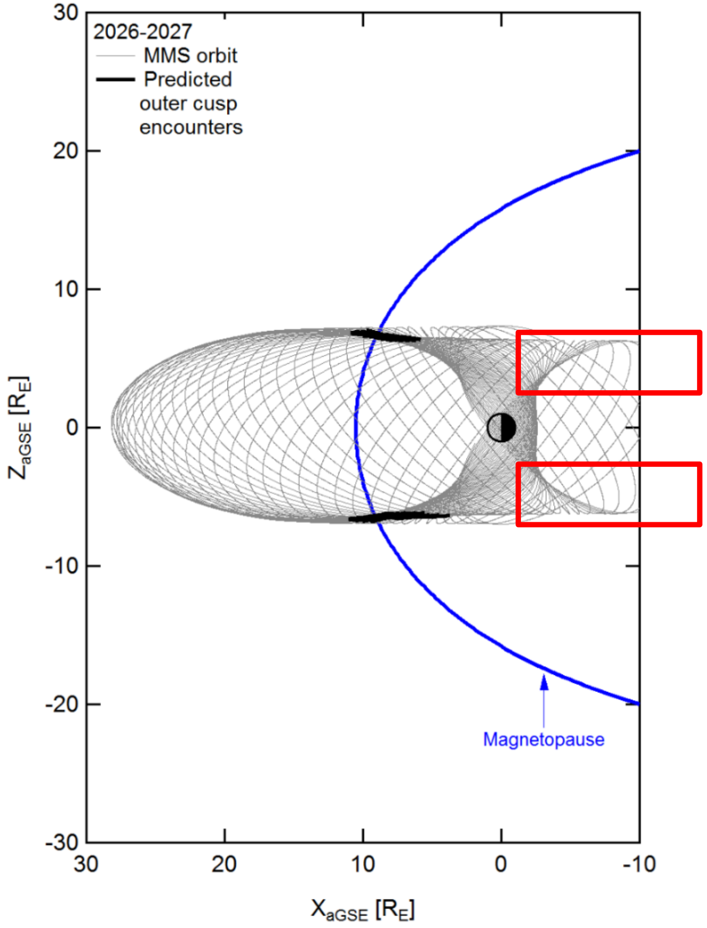
Fig. Average energy of O^+ (top left), average energy of H^+ (center), and number density ratio between O^+ and H^+ (bottom left) during geomagnetically active times (*SYM-H* < −25 nT) [Ohtani et al., 2011].

The very-low-energy component of O^+ in the cleft ion fountain reaches the region where the high O^+/H^+ number density ratio during active times (>−15 R_E in XGSM) [Maggiolo and Kistler, 2014; Ohtani et al., 2011].

◆MMS observation at the next solar maximum



Courtesy: Dr. Fuselier



Courtesy: Dr. Petrinec

Next solar maximum will become an excellent chance to observe cold ions around the near-Earth tail lobe and acceleration of the ions at the lobe-plasma sheet boundary by MMS that have FPI, HPCA, and ASPOC.

Reference

Kitamura, N., Y. Nishimura, T. Ono, A. Kumamoto, A. Shinbori, M. Iizima, A. Matsuoka, and M. R. Hairston (2010a), Temporal variations and spatial extent of the electron density enhancements in the polar magnetosphere during geomagnetic storms, *Journal of Geophysical Research*, *115*(A7), A00J02.
https://doi.org/10.1029/2009JA014499

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https://doi.org/10.1029/2010JA015601

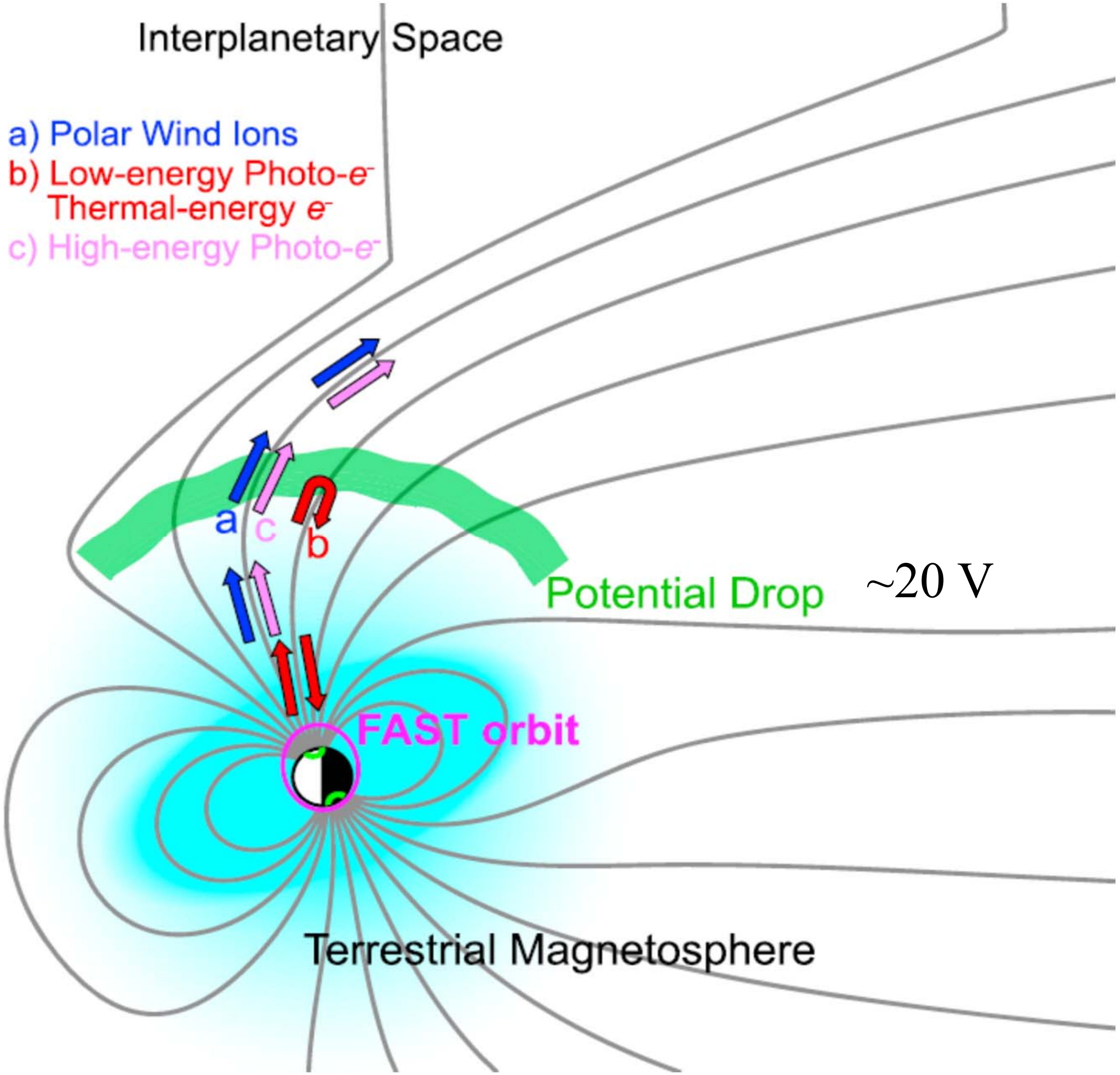
Kitamura, N., Y. Nishimura, M. O. Chandler, T. E. Moore, N. Terada, T. Ono, A. Shinbori, and A. Kumamoto (2012), Storm-time electron density enhancement in the cleft ion fountain, *Journal of Geophysical Research*, *117*(A11), A11212.
https://doi.org/10.1029/2012JA017900

Maggiolo, R., and L. M. Kistler (2014), Spatial variation in the plasma sheet composition: Dependence on geomagnetic and solar activity, *Journal of Geophysical Research: Space Physics*, *119*(4), 2836–2857.
https://doi.org/10.1029/2013JA019517

Ohtani, S., M. Nosé, S. P. Christon, and A. T. Y. Lui (2011), Energetic O^+ and H^+ ions in the plasma sheet: Implications for the transport of ionospheric ions, *Journal of Geophysical Research*, *116*(A10), A10211.
https://doi.org/10.1029/2011JA016532

Backup

◆Potential drop at high altitudes in the lobe and the acceleration of (polar wind) ions



The effect of the potential drop (~20 V) generated by the effect of photoelectrons for the ion trajectories in the magnetosphere has not been studied.

Except for large geomagnetic storms

Kitamura et al. [2015]

◆Storm-time observations of electron density enhancements

- 10–100 times larger electron density than quiet-time level in the polar cap
  [e.g., Tu et al., 2004, 2007; Kitamura et al., 2010a, 2010b]
- Large scale (noon-midnight and dawn-dusk directions)
  [Kitamura et al., 2010a, 2010b]
- Cold low-energy upflowing O^+ ions
  [Kitamura et al., 2010b]

Electron density enhancements likely correspond to large scale low-energy O^+ ion outflows.

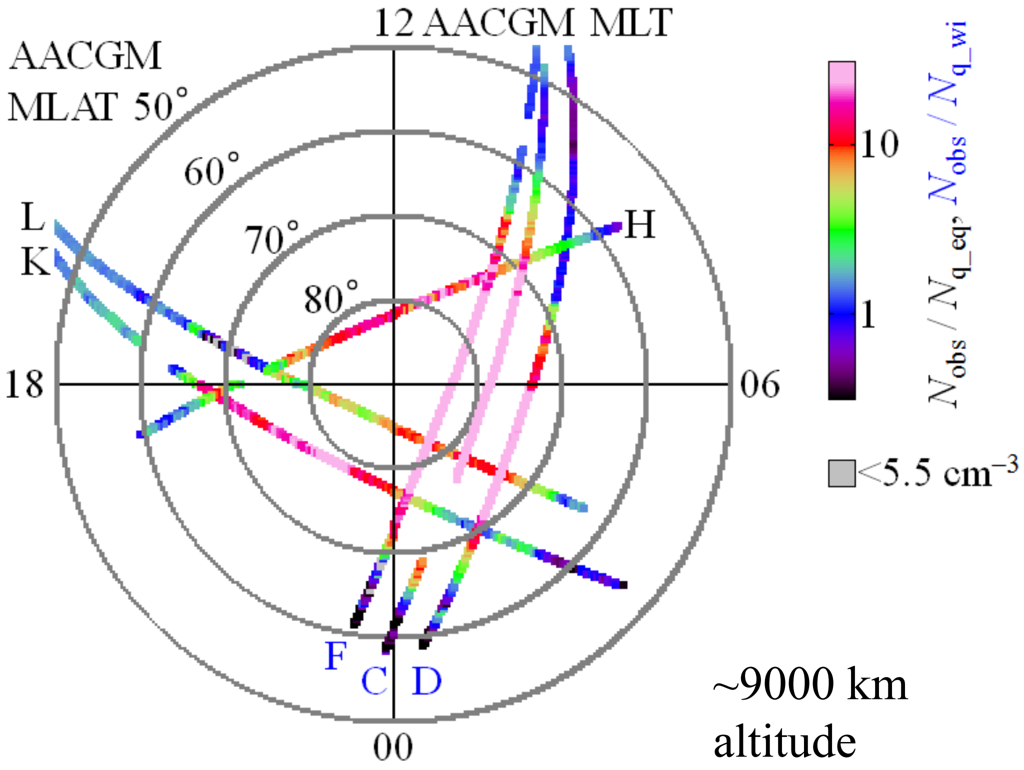


Fig. Polar plot of the measured electron densities during geomagnetic storms normalized relative to the quiet-time level in equinox or winter. [Kitamura et al., 2010a]

Reference

Kitamura, N., Y. Nishimura, T. Ono, A. Kumamoto, A. Shinbori, M. Iizima, A. Matsuoka, and M. R. Hairston (2010a), Temporal variations and spatial extent of the electron density enhancements in the polar magnetosphere during geomagnetic storms, *Journal of Geophysical Research*, *115*(A7), A00J02.
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https://doi.org/10.1029/2012JA017900

Kitamura, N., K. Seki, Y. Nishimura, and J. P. McFadden (2015), Limited impact of escaping photoelectrons on the terrestrial polar wind flux in the polar cap, Geophysical Research Letters, *42*, 3106–3113.
https://doi.org/10.1002/2015GL063452

Maggiolo, R., and L. M. Kistler (2014), Spatial variation in the plasma sheet composition: Dependence on geomagnetic and solar activity, *Journal of Geophysical Research: Space Physics*, *119*(4), 2836–2857.
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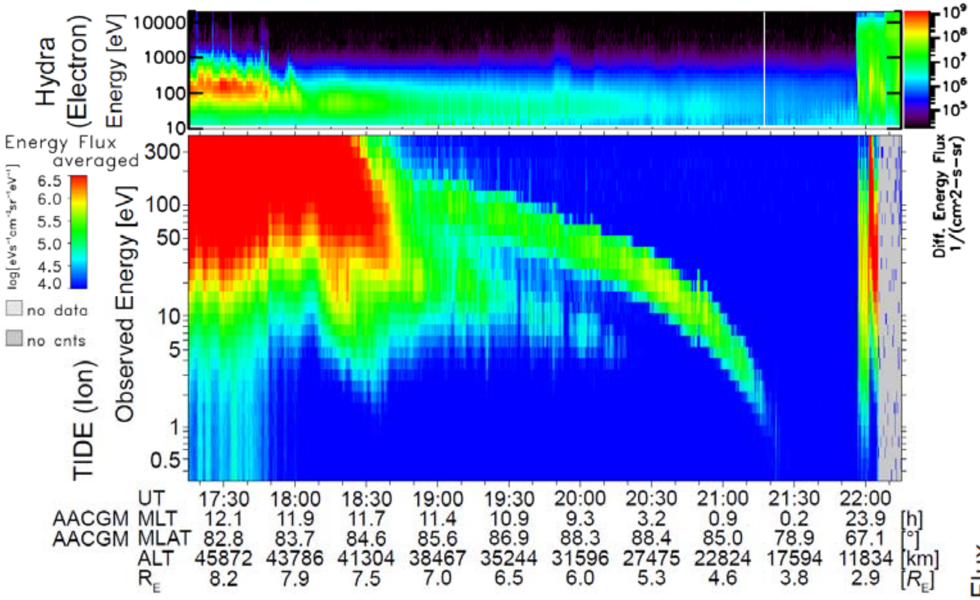
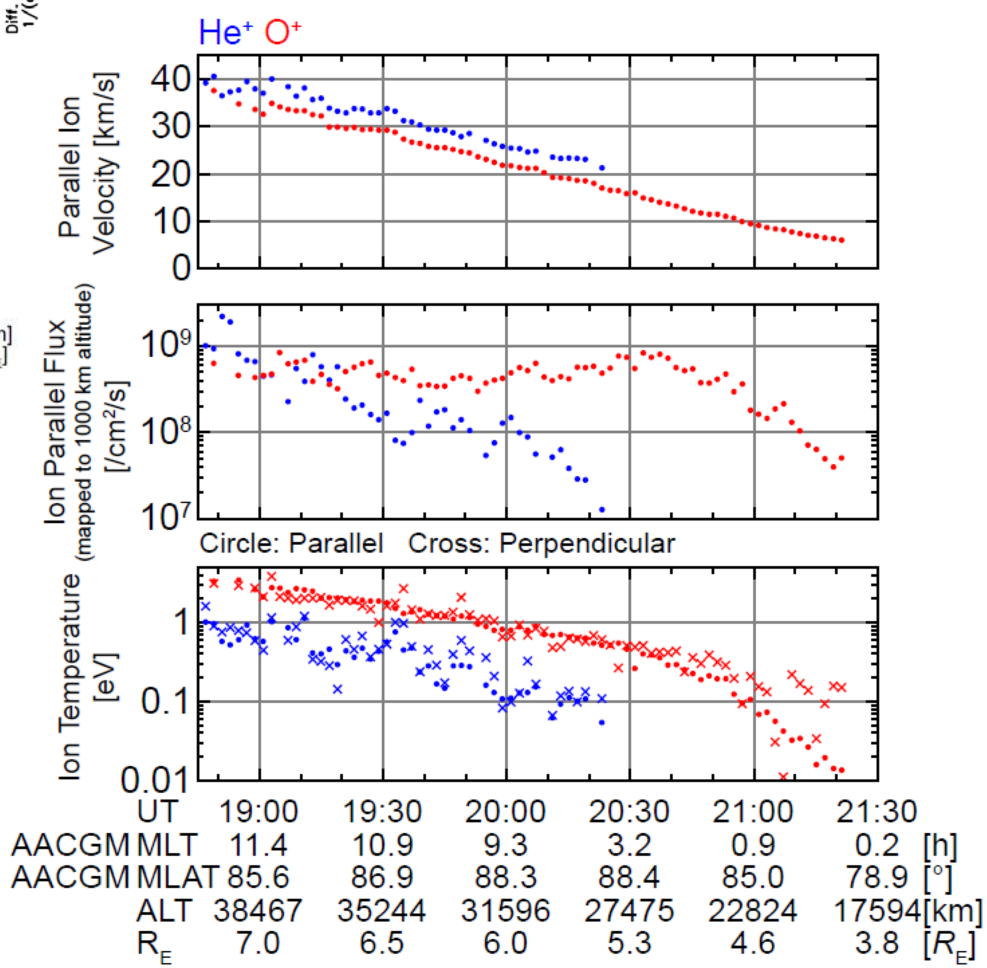
https://doi.org/10.1029/2011JA016532

◆High density ions in the polar cap (lobe)



- Velocity dispersion
- Almost equal parallel velocities of O^+ and He^+ ions (small effect of field-aligned electric field in the polar cap)
- Wide region of O^+ ion upflows (at least ~80° AACGM MLAT in the nightside at ~4 R_E)
- Large fluxes (~5 × 10^8 /cm²/s) of O^+ ions
- Low temperature of ions in the polar cap (mostly <3 eV)



Kitamura et al. [2012]

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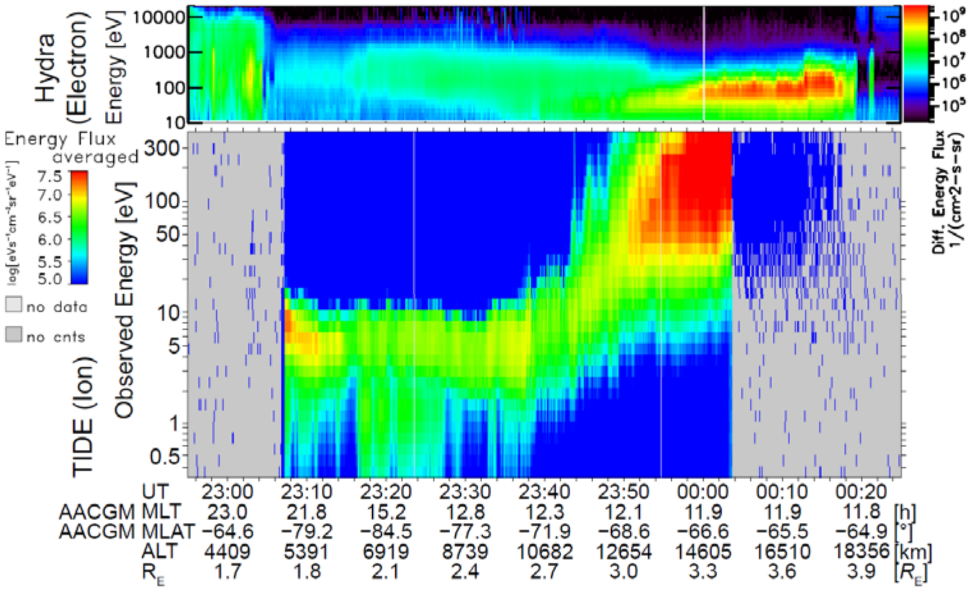
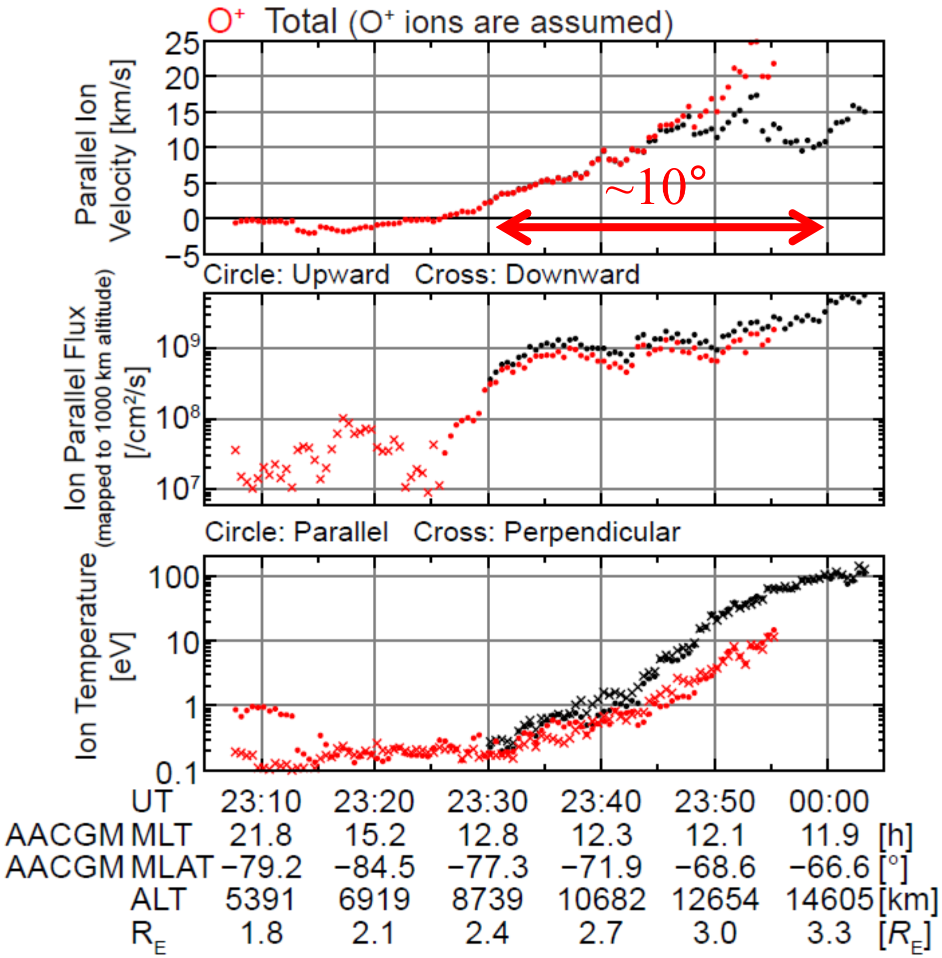
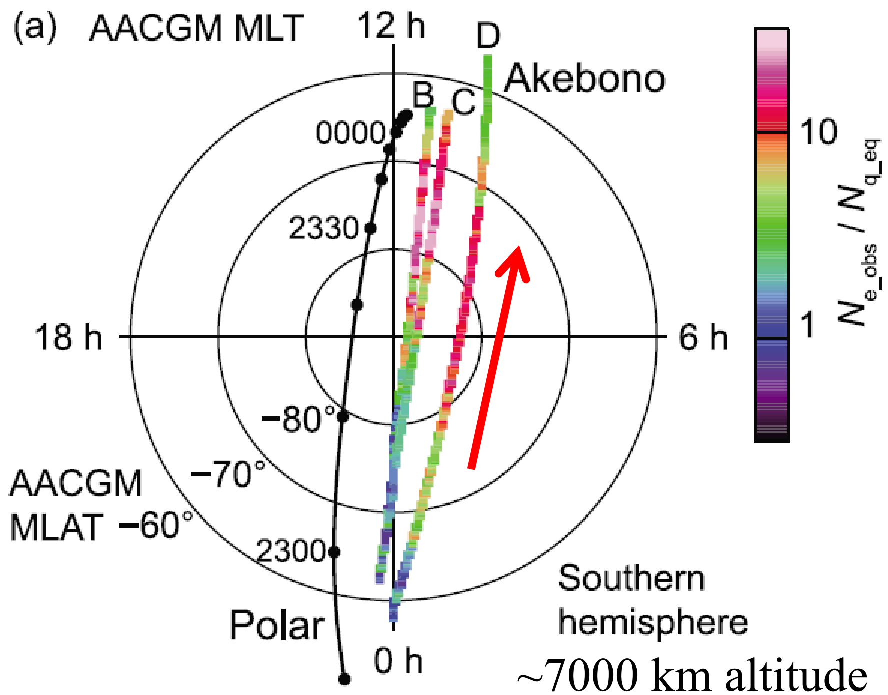


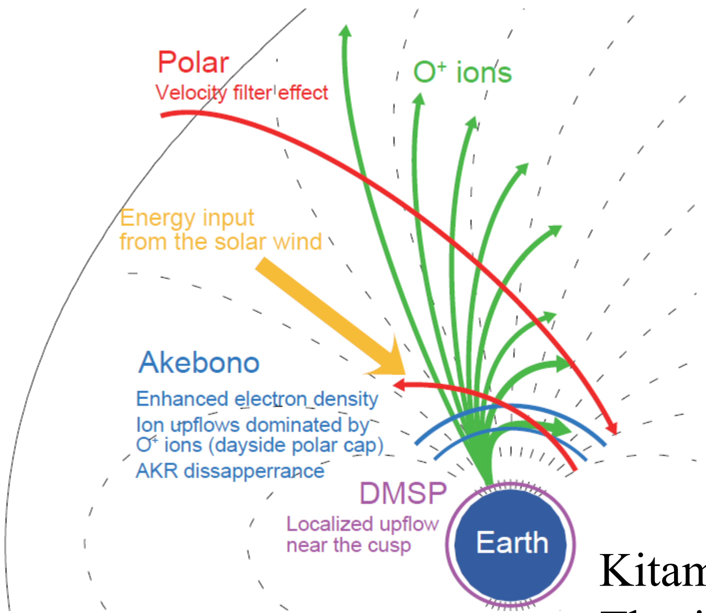


- Velocity dispersion
- Wide region of ion outflows (>2 km/s within ~10° from the cusp at ~2.4 R_E) compared to the cusp (~1.6°)
- Large fluxes (~10^9 /cm^2/s) even low-speed O^+ ions (~5 km/s = ~2 eV)
- Low temperature of O^+ ions in the polar cap (mostly <1 eV)

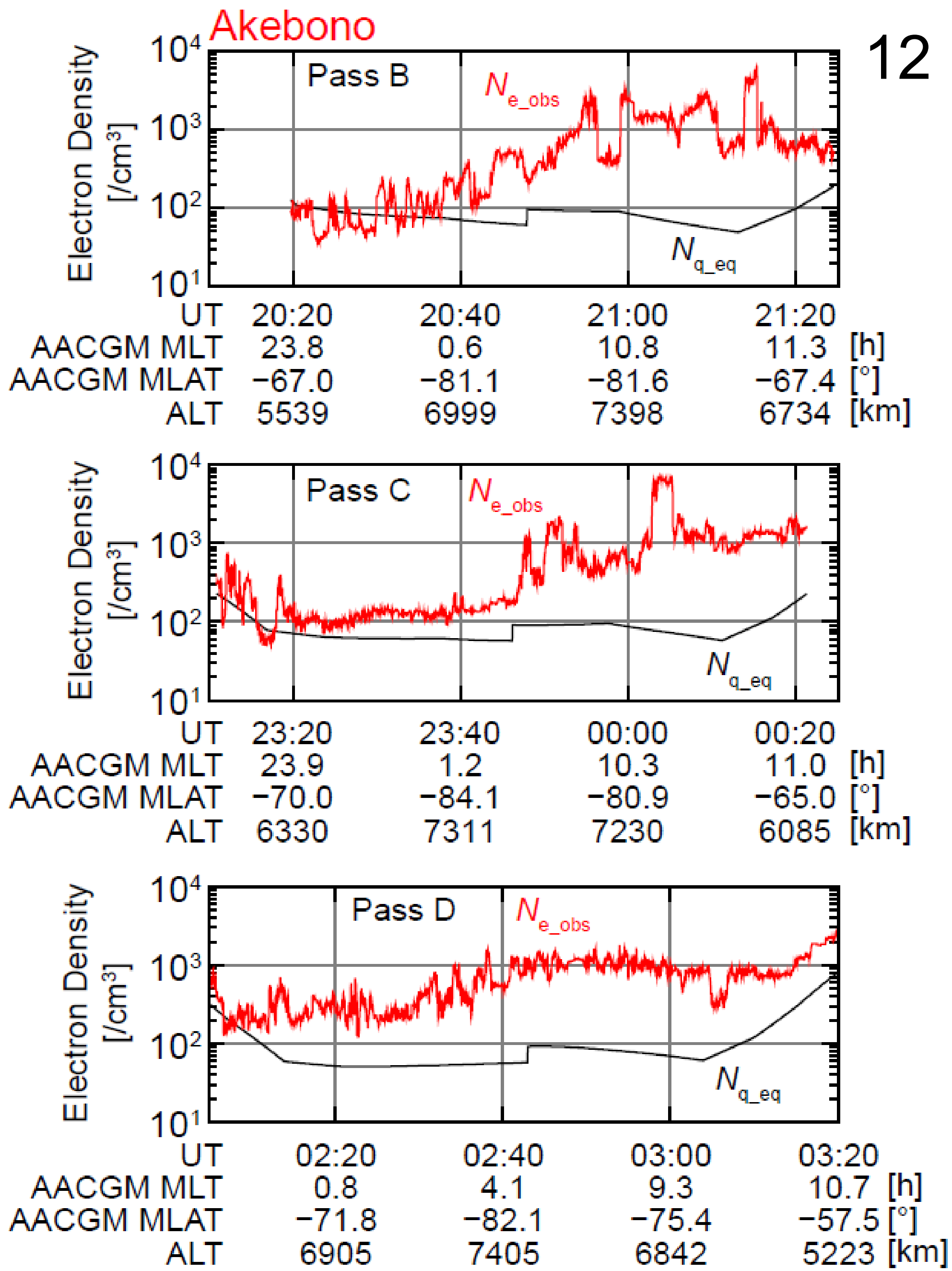
Kitamura et al. [2012]



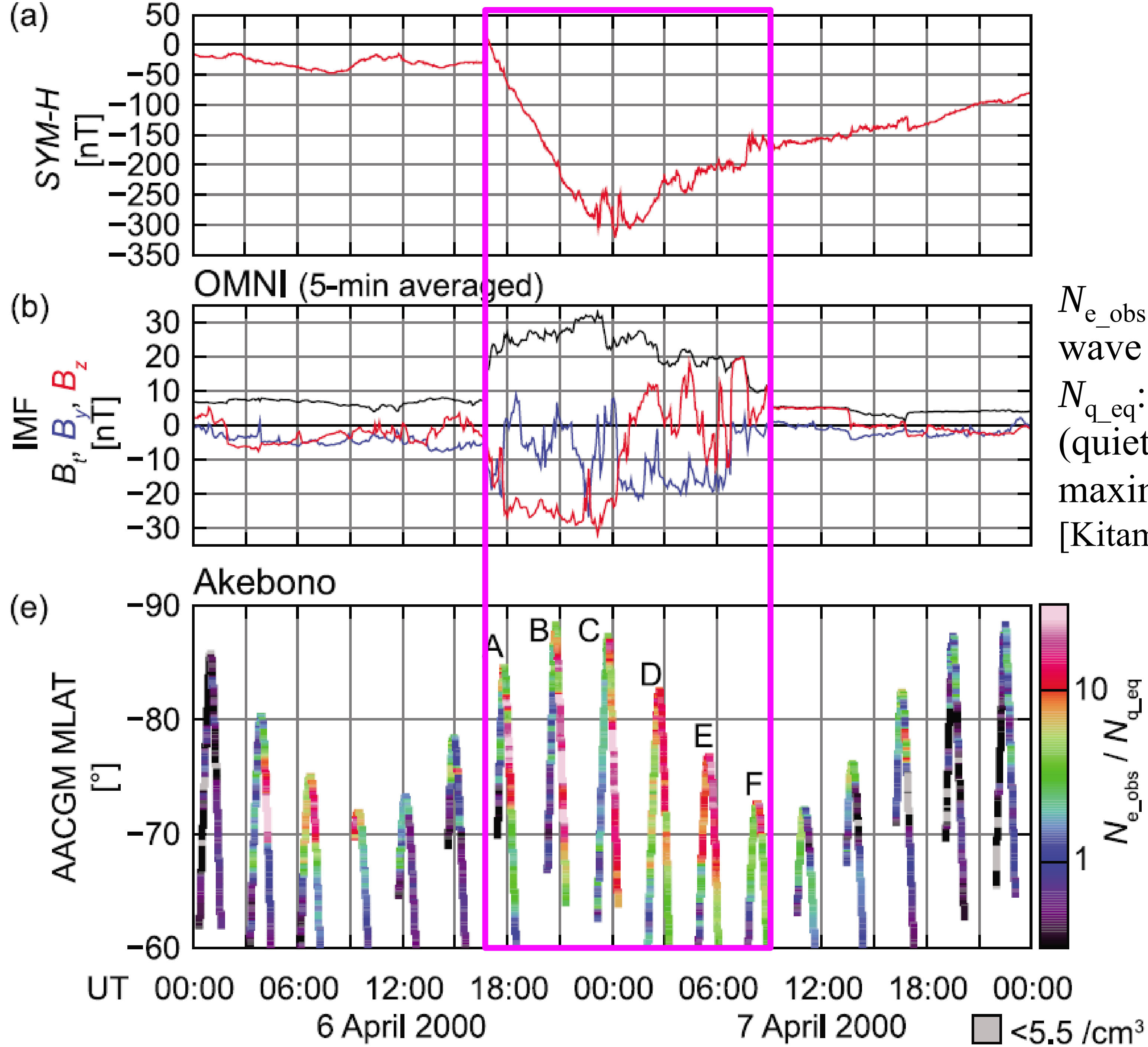
~7000 km altitude
(Akebono)



Kitamura Ph.D.
Thesis [2012]



Kitamura et al. [2012]



N_{e_obs}: derived by wave observations

N_{q_eq}: empirical model (quiet-time at solar maximum in equinox) [Kitamura et al., 2009]

Akebono ~7000 km altitude

Kitamura et al. [2012]

◆Electron density enhancement

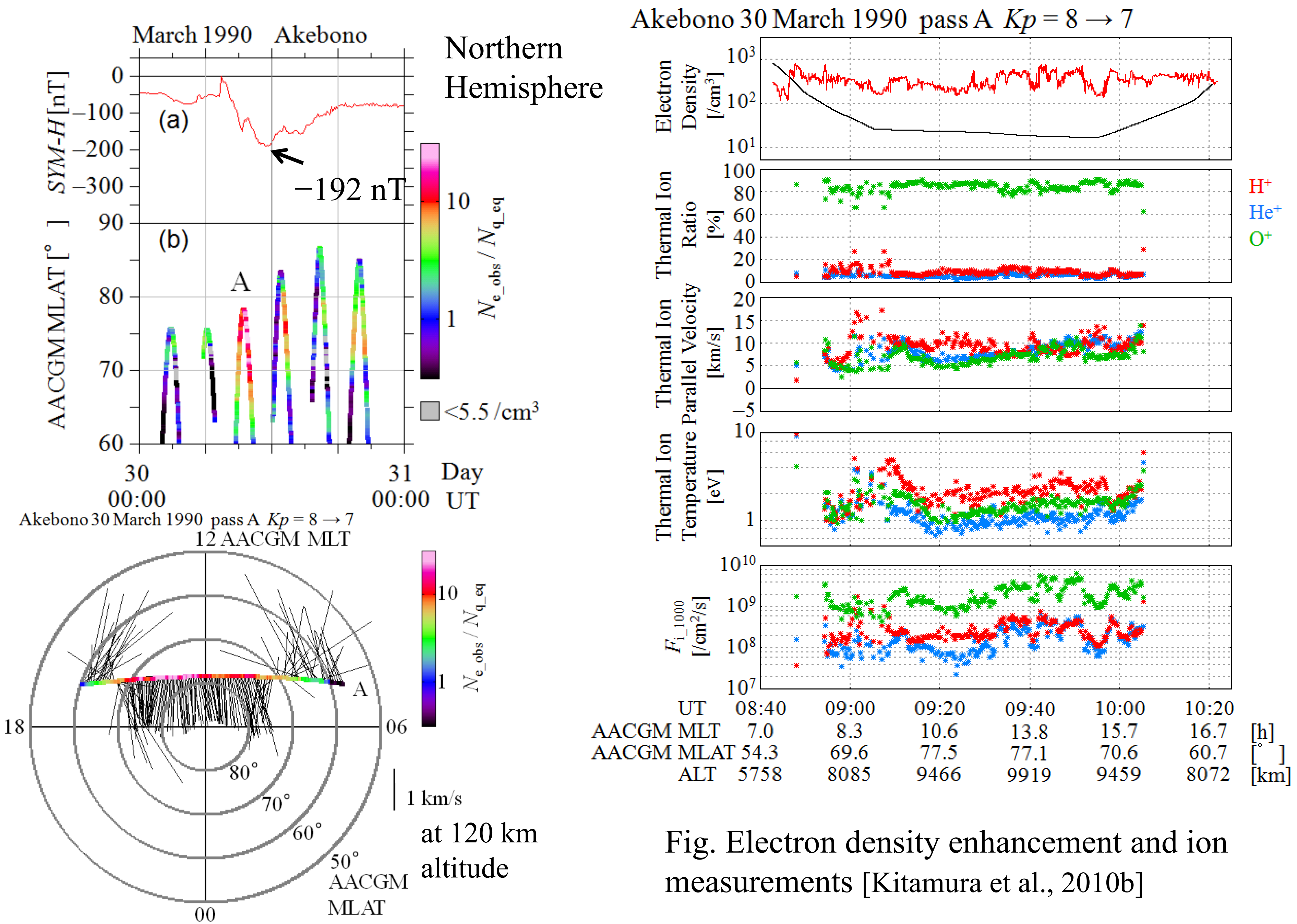


Fig. Electron density enhancement and ion measurements [Kitamura et al., 2010b]

◆Trajectory calculation of O^+

2, 3, 4, 5, and 10 km/s
at 9000 km altitude

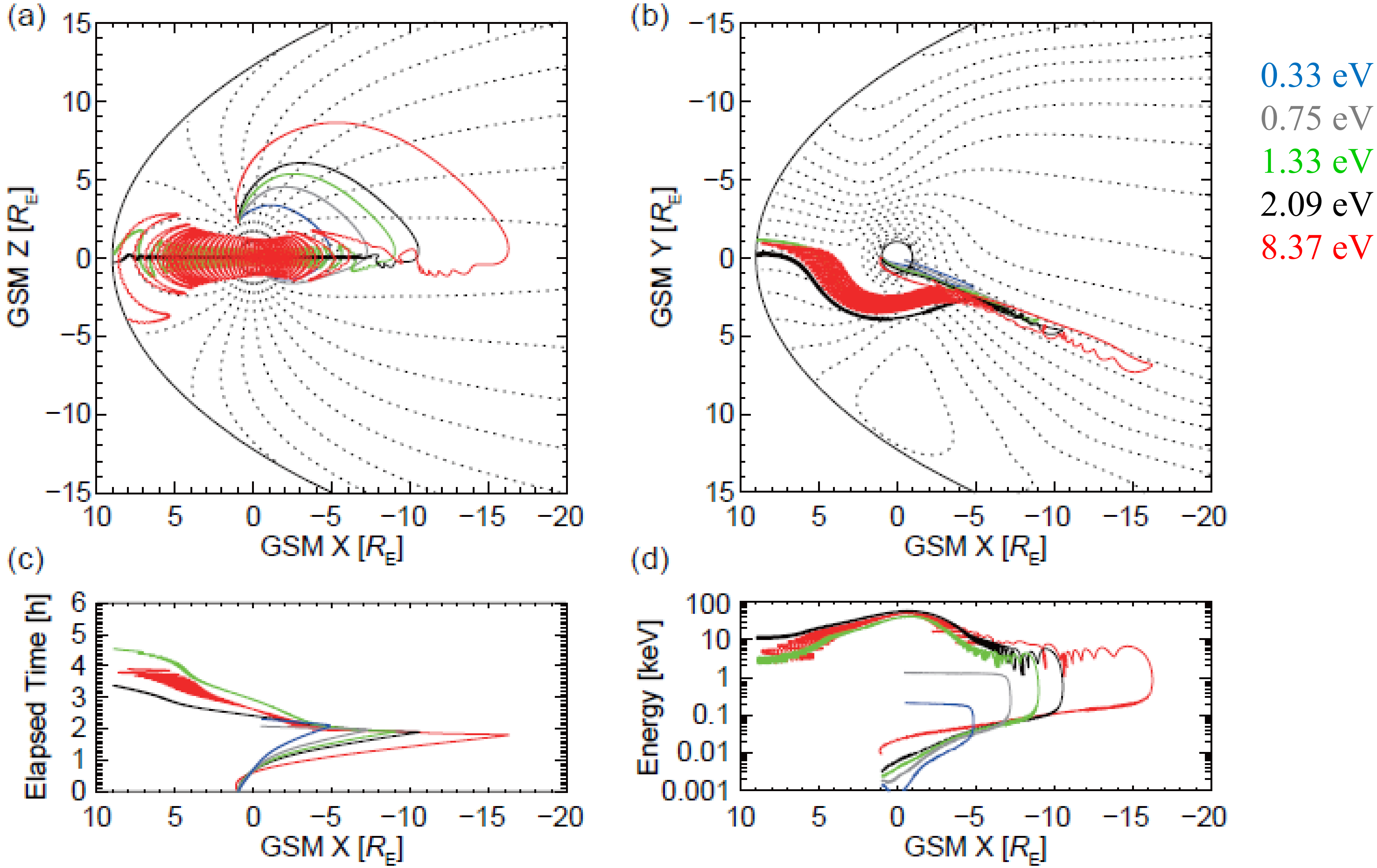
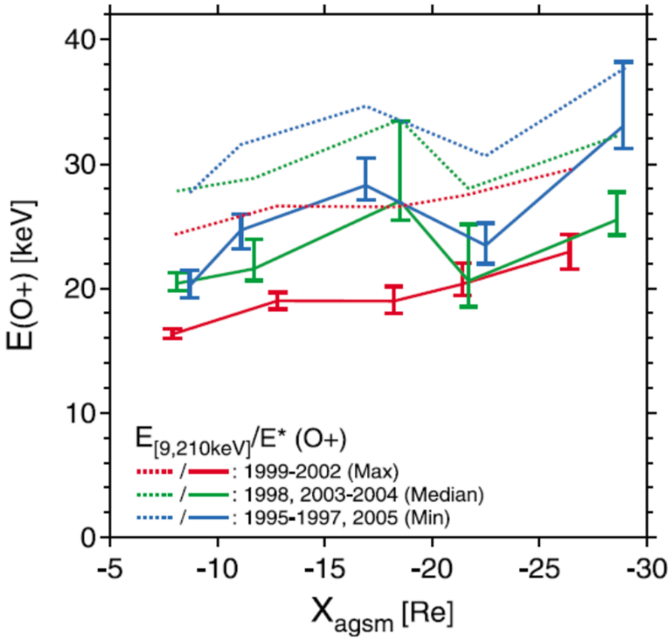
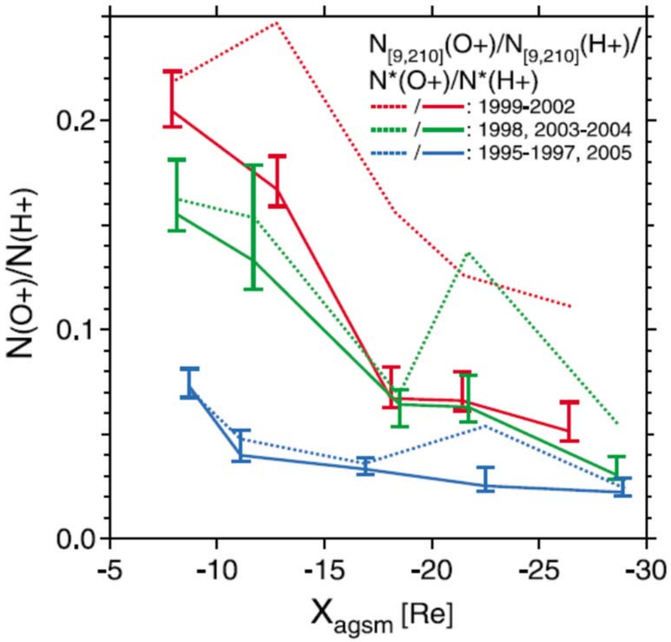
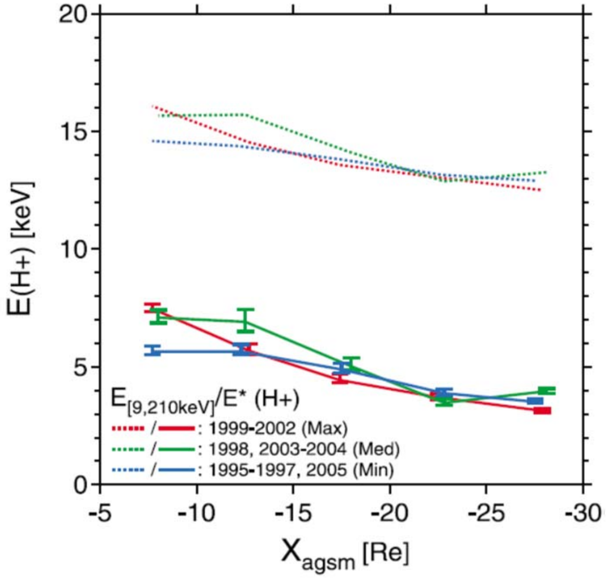


Fig. Trajectories of O^+ ions assuming geomagnetically active condition
[Kitamura, Ph.D. Thesis, 2012]

◆Number density ratio (O^+/H^+) and average energy of H^+ and O^+







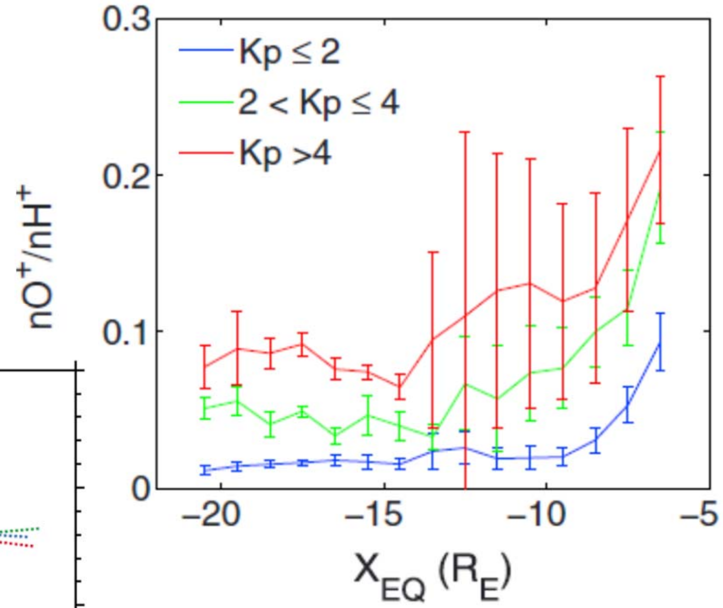
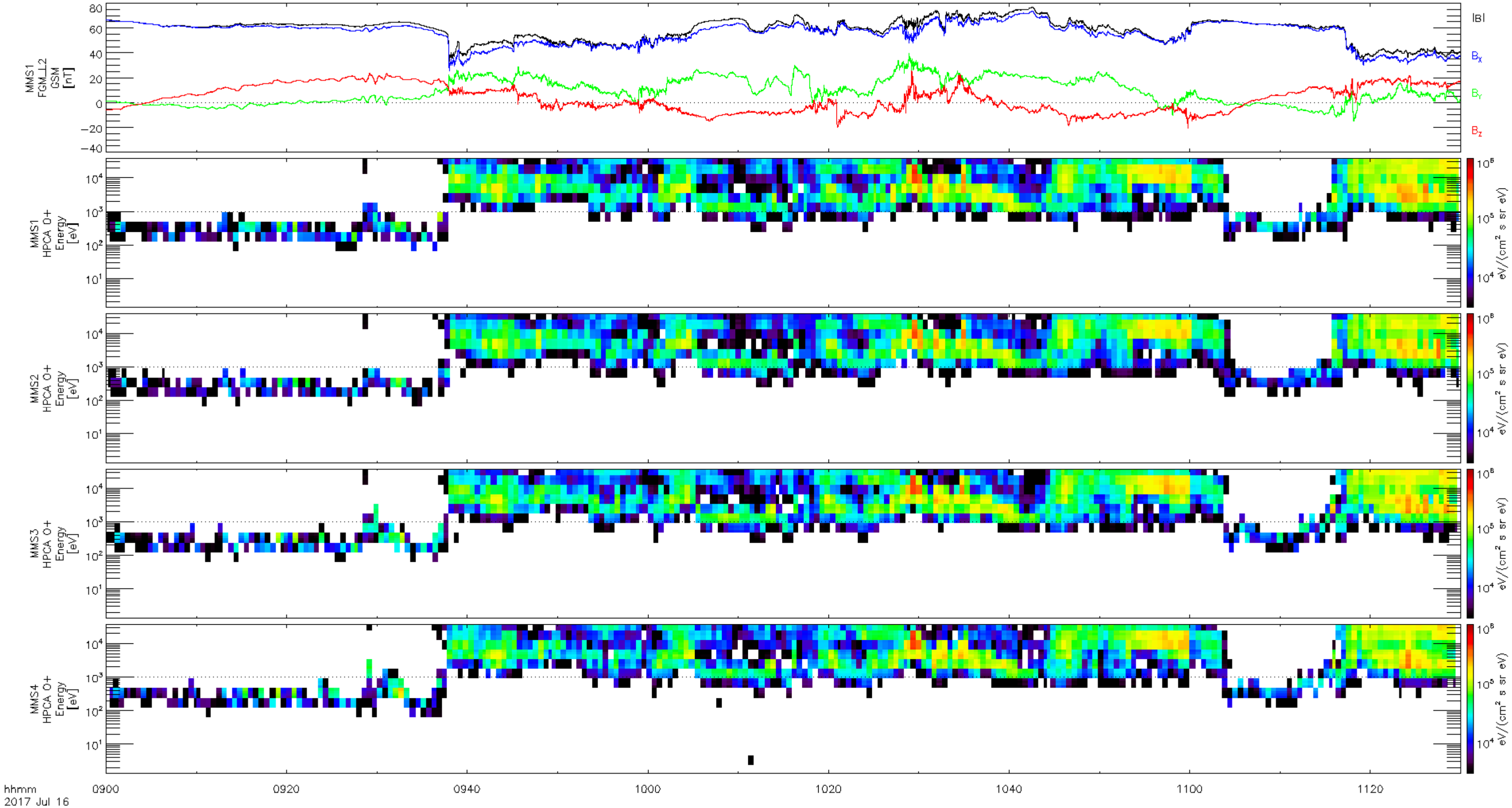


Fig. Density ratio between H^+ and O^+ [Maggiolo and Kistler, 2014]

Fig. Average energy of O^+ (top left), average energy of H^+ (center), and number density ratio between O^+ and H^+ (bottom left) during geomagnetically active times (*SYM-H* < -25 nT) [Ohtani et al., 2011].

◆July 16, 2017 (Dst: −10→−17 nT) (min Dst: −72 nT)

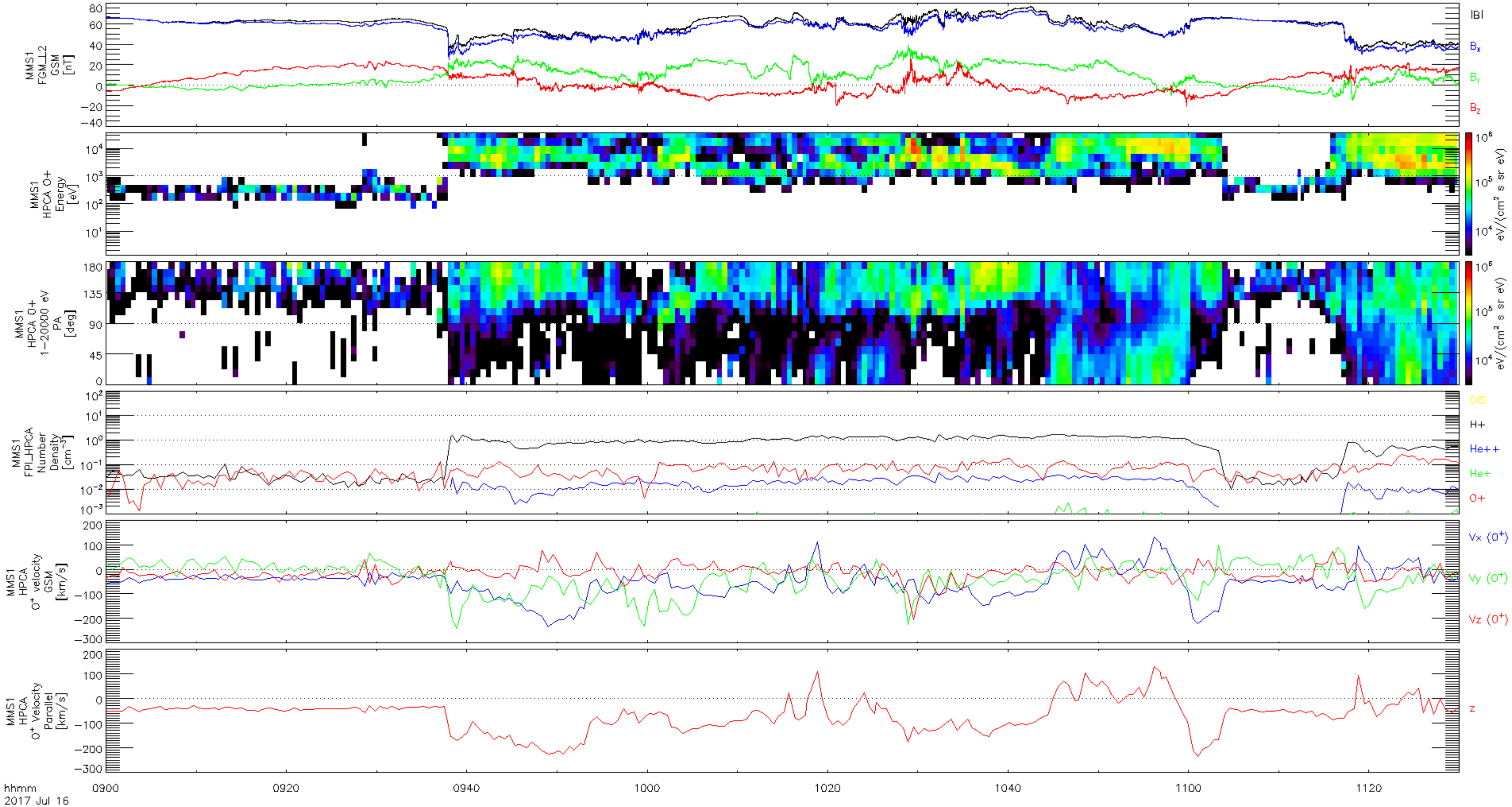


GSM X: −13→−10 R_E, GSM Y: ~−2 R_E

The lobe was filled by O^+ (<1 keV).

Was O^+ continuous from the lobe to plasma sheet (>1 keV)?

◆July 16, 2017 (Dst: −10→−17 nT) (min Dst: −72 nT)



Almost continuous density of O^+ from lobe to plasma sheet (~0.05 /cm^3)

Increase in parallel velocity of O^+ at the boundary