Statistical signatures of ionospheric ion outflow obtained by IMAGE/LENA: Storm phase dependence

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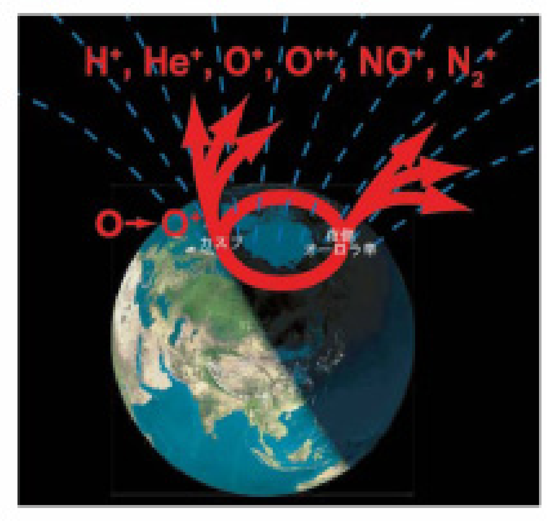
Acknowledgement: the ACE SWEPAM instrument team
and the ACE Science Center (ACE data)

Ionospheric Ion outflow in the high latitude

- ✓Ionospheric ion is considered as one of the important sources of magnetospheric plasma.
- ✓A number of studies have shown that the composition and the amount of the ion outflow depend on the solar activity, the season, and the geomagnetic disturbance.

http://www.stelab.nagoya-u.ac.jp/ste-www1/pub/ste-nl/Newsletter40clr.pdf



- ✓The composition is mainly the proton and the oxygen ion.
- ✓However, there were no studies which showed the storm-phase dependence of the ion outflow.

The mechanism responsible for suprathermal ion outflow

Ion upflow(≪10eV)
(in the topside ionosphere)

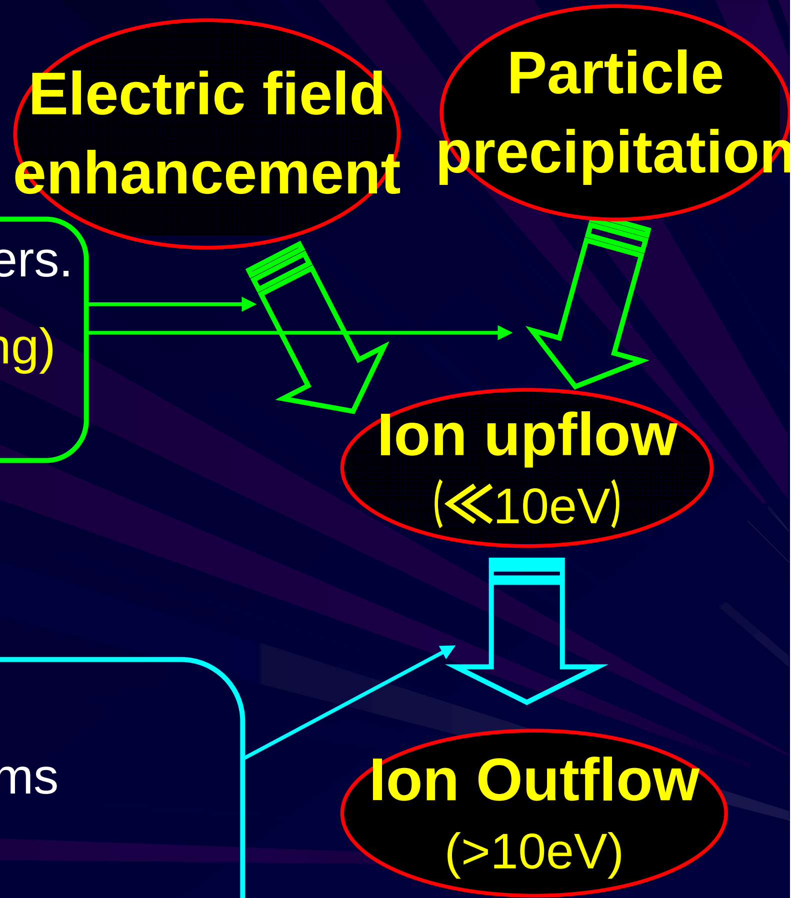
Ion upflow is triggered mainly by two drivers.

✓Electric field enhancement (Joule heating)
✓Soft electron precipitation (<500eV)

Ion outflow(>10eV)

Ion outflow is generated from ion upflow
by various acceleration/heating mechanisms
before reaching the higher altitude.

✓ Parallel electric field
✓ Wave Heating



Data set
2000/06 – 2001/12

IMAGE/LENA

http://lena.gsfc.nasa.gov/

SYM-H index

(running average
with 60min time window)

http://swdcwww.kugi.kyoto-u.ac.jp/

ACE/SWEPAM

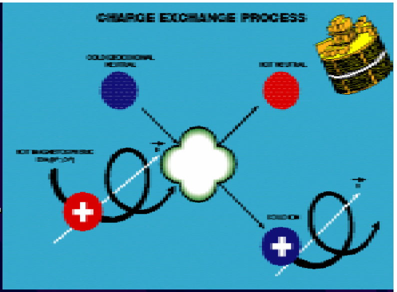
(shifted to the magnetopause)

http://cdaweb.gsfc.nasa.gov/

The IMAGE spacecraft

- •Polar orbit
- •Perigee ~2000km
- •Apogee〜8Re
- •1spin 〜120seconds

http://lena.gsfc.nasa.gov/



The LENA (Low-Energy Neutral Atom) imager

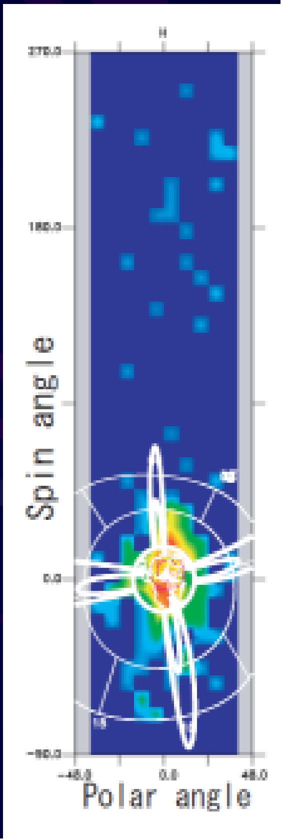
✓A fraction of ion outflow in the magnetosphere are converted into ENA (Energetic neutral atom) via the charge exchange process.

✓Momentums and kinetic energies are not changed by the charge exchange process.

We can investigate the time variation of ion outflow in a short time scale (<1hour) by using data acquired by IMAGE/LENA, which can detect ENA in a low energy.

- •Energy range: 10eV~a few keV
- •Time resolution(2D) : 120seconds (1spin period)
- •Mass range: 1-20amu (mainly hydrogen and oxygen)
- •Angular coverage:

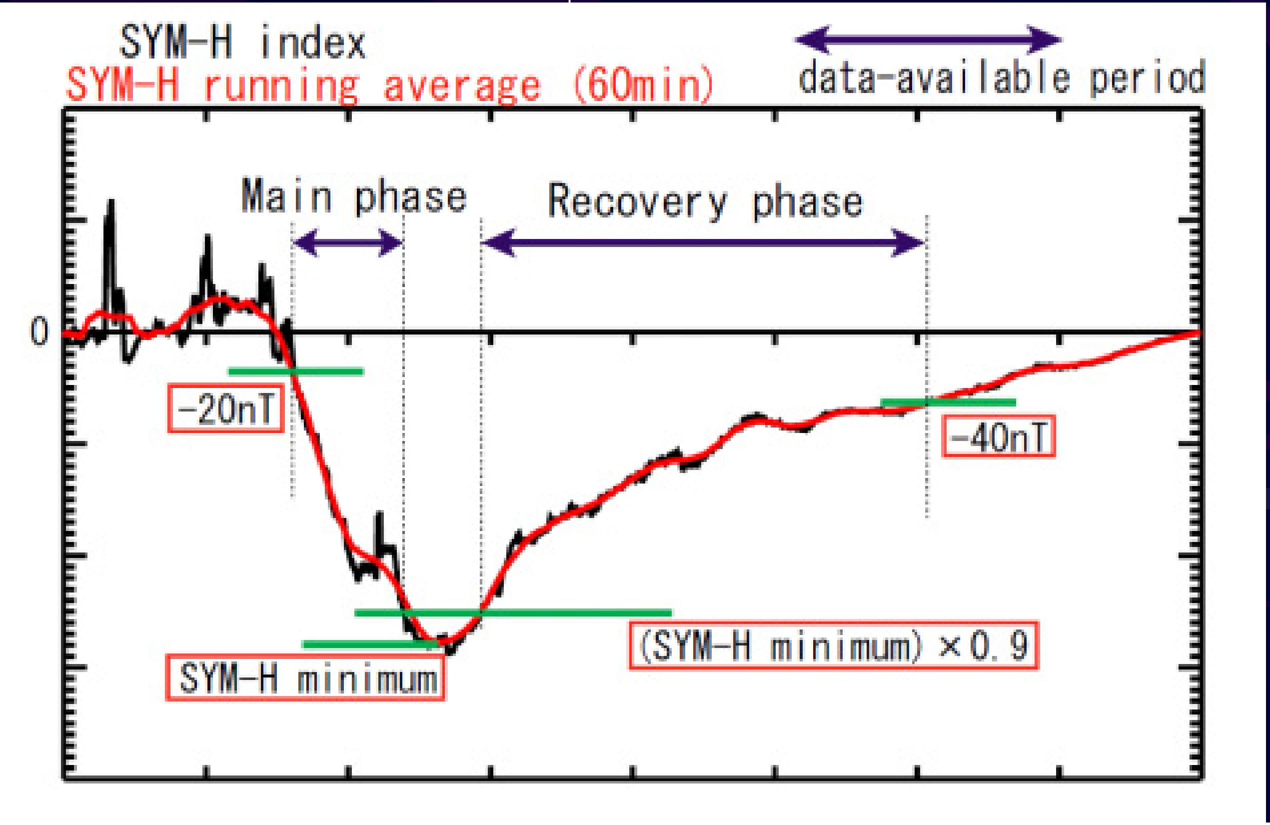
360° (azimuth) ×90° (polar) in 45 ×12 pixels



Target

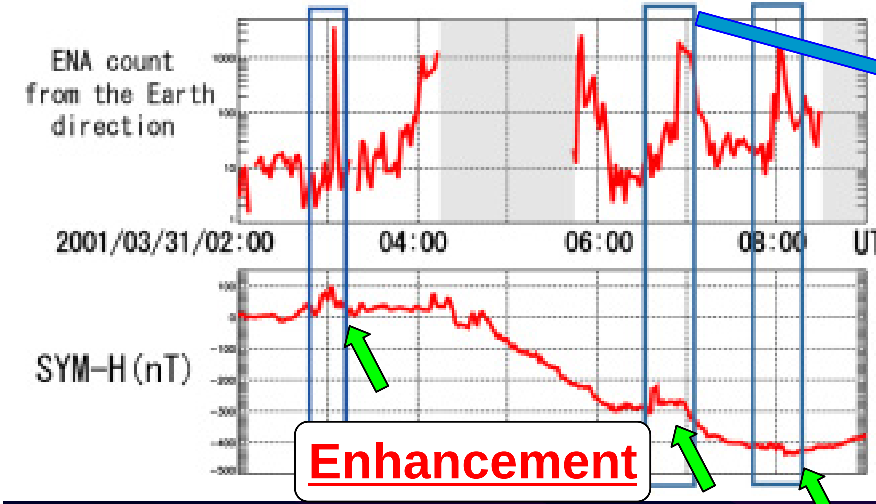
We examine the statistical signature of storm-time ion outflow and reveal the difference between those during the main phase and the recovery phase.

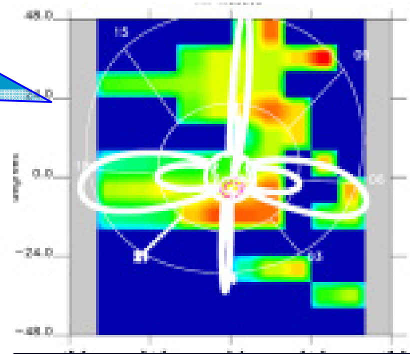
We selected 29 magnetic storms with SYM-H min<-80nT in the period of 2000/06-2001/12. The main phase and the recovery phase were defined as the figures shown below.



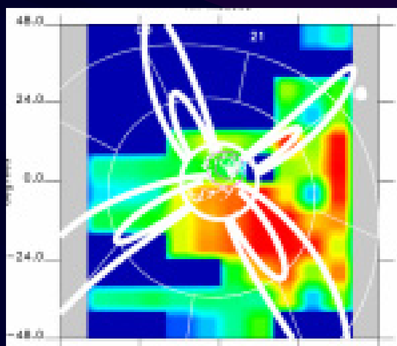
Case study

SW Pd and the SYM-H index may play the important rolls.

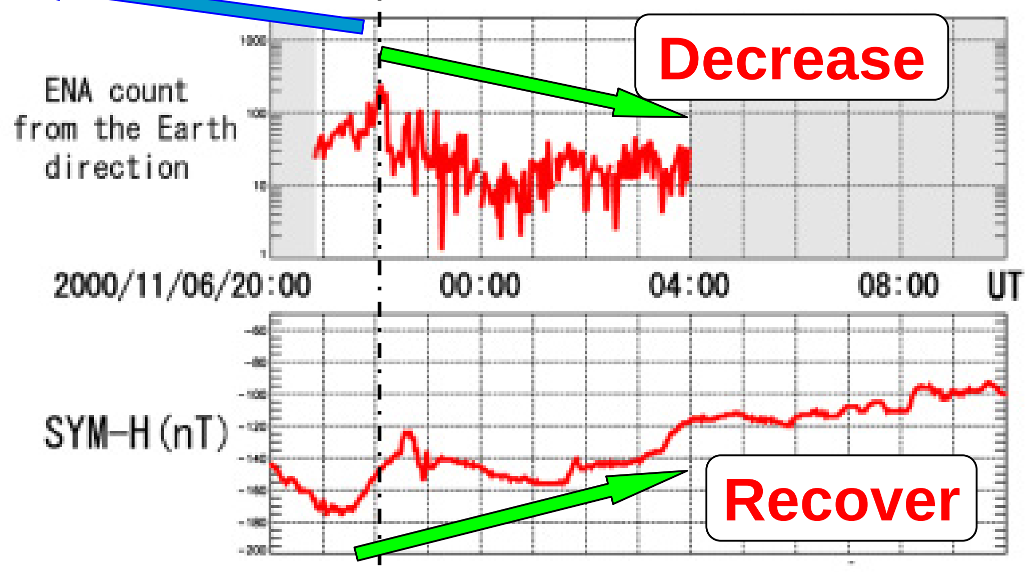




Case1: Main phase (2001/03/31)
During storm main phase,
Sporadic ENA emission enhancements were accompanied by the shocks.

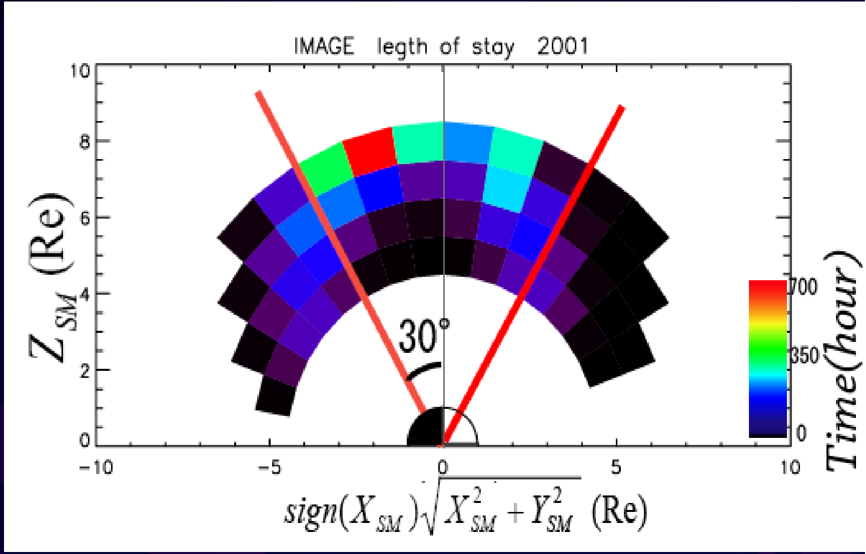


Case2: Recovery phase (2000/11/06)
During the recovery phase,
the amount of ENA emissions is gradually decreased with the recovery of the SYM-H index.



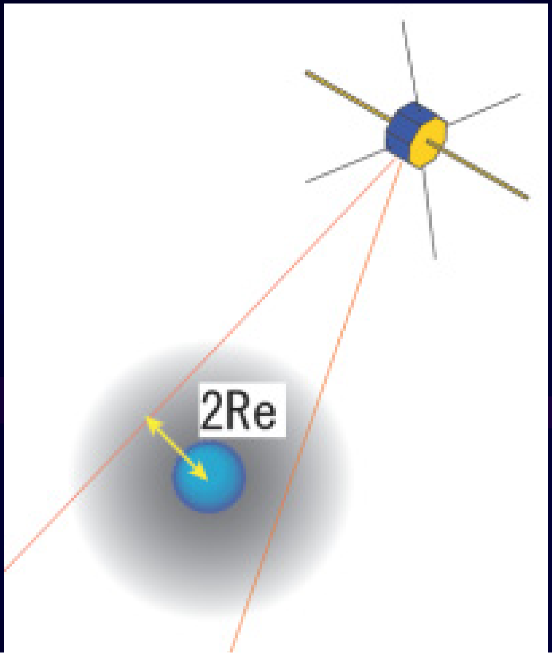
Statistical study

Spatial distribution of the dwelling time of the IMAGE spacecraft in SM coordinates



Position of the IMAGE spacecraft

- Geocentric distance
  4.5Re-8.5Re (near apogee)
- GMLAT>60 °
- The IMAGE spacecraft should stay inside the magnetosphere.
  → Magnetopause model:
  [Shue et al., 1998]



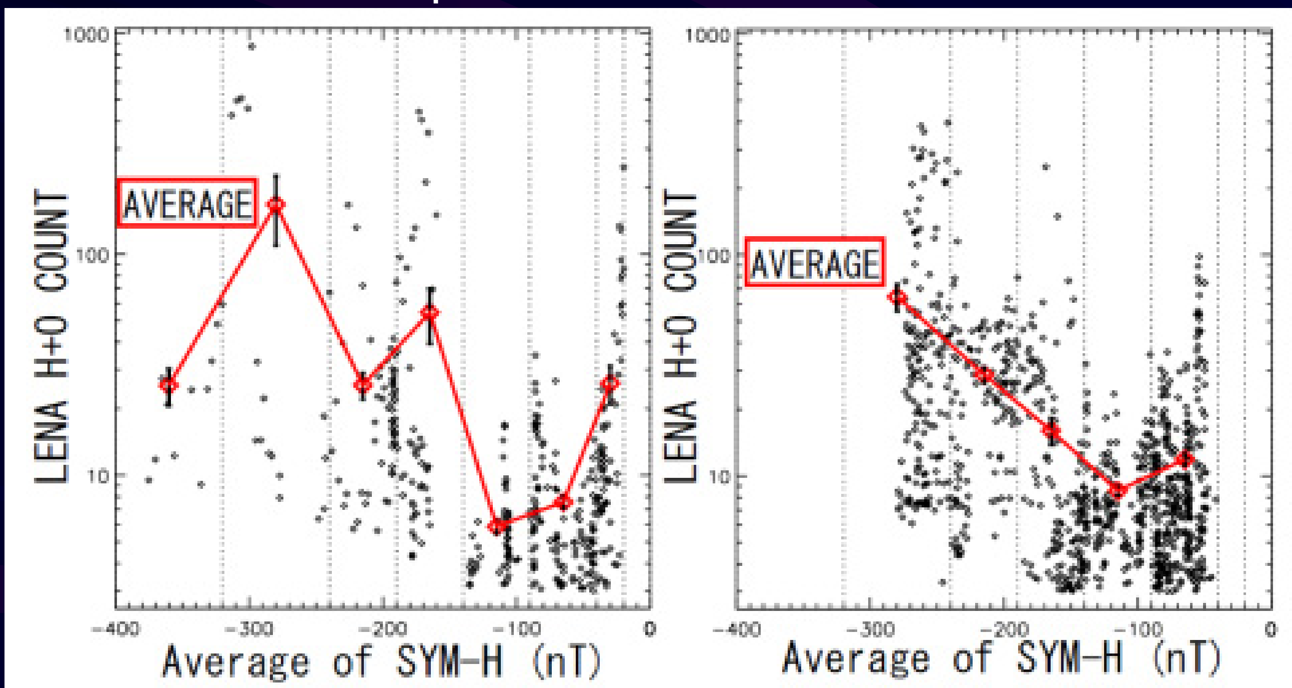
- ENA counts summed over the angular sectors covering the region of geocentric altitude < 2Re
- ENA counts were normalized at r=6Re with assumption that they were generated at r=2.2Re. [Khan et al., 2003]

$$Count_{observed} \propto (r - 2.2)^{-2}$$

$$Count_{normalized} = Count_{observed} \times \left(\frac{r - 2.2}{6.0 - 2.2} \right)^2$$

LENA count (>3count) vs. SYM-H：
Different signatures can be found between two phases.

✓The average value of LENA counts during the recovery phase was increased rather smoothly with decreases of the SYM-H index, while those during the main phase showed overall increase with some bumps and dents.



Main phase
r = -0.396 (data point 377)

Recovery phase
r = -0.474 (data point 939)

Considering the transit time of ENA, LENA count is corresponding to the SYM-H index before 6minutes

How frequently is the LENA count accompanied by an enhancement of solar wind dynamic pressure?

Analysis①

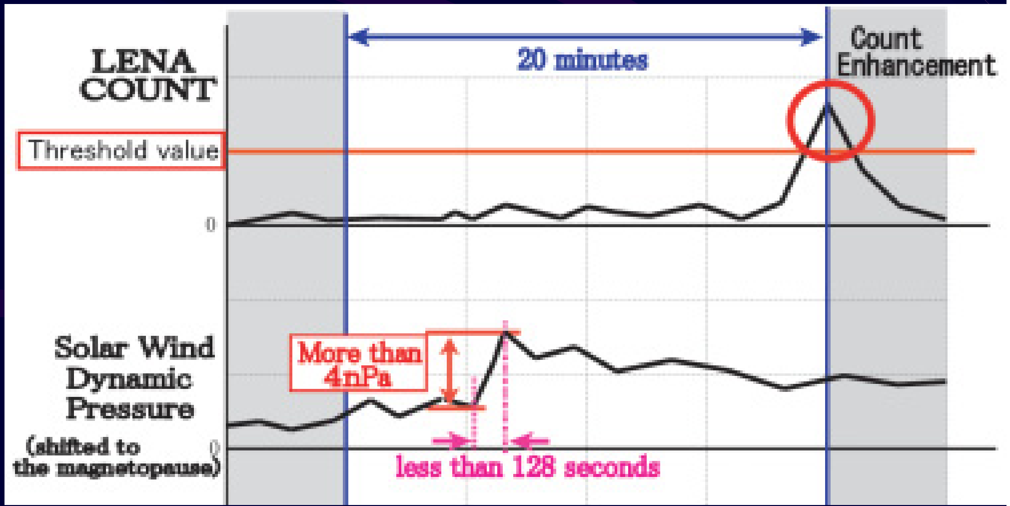
We examined the relation
between the LENA count and the enhancement of solar wind dynamic pressure acquired by ACE/SWEPAM.

- ✓ When the LENA count is larger than a given threshold level, how much is the occurrence probability of that preceded by SW dynamic pressure enhancements within 20min?

Definition of
an enhancement of
solar wind dynamic pressure:

An Increase more than 4nPa
within 128 seconds

(The data are shifted to
the location of Magnetopause)



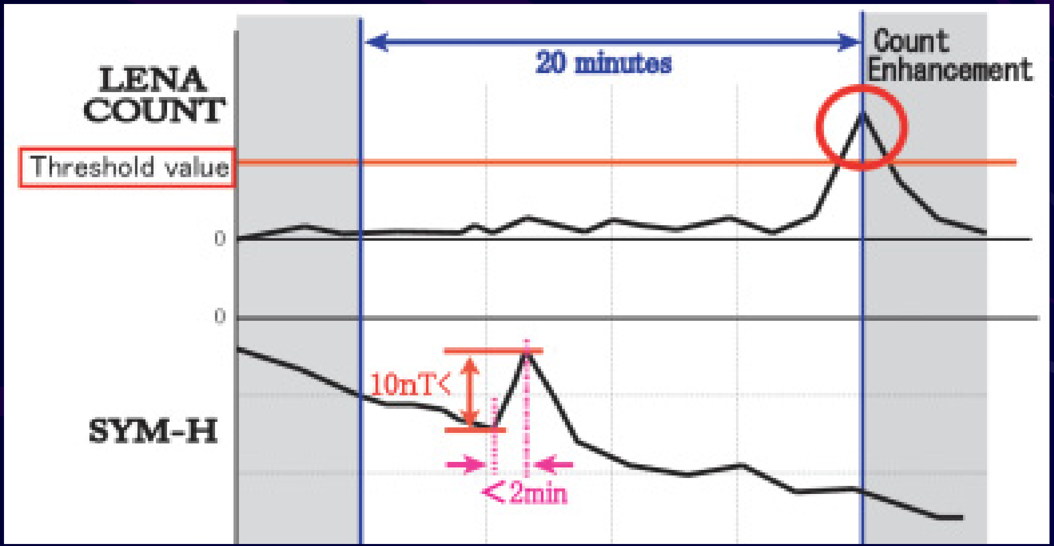
Similar analysis using the SYM-H index, instead of solar wind dynamic pressure

Analysis②

The enhancements of SW dynamic pressure are usually accompanied by those of the SYM-H index. Thus, we used the SYM-H index instead of the SW dynamic pressure in Analysis①.

Definition of an enhancement of the SYM-H index

An Increase more than 10nT within 2 minutes

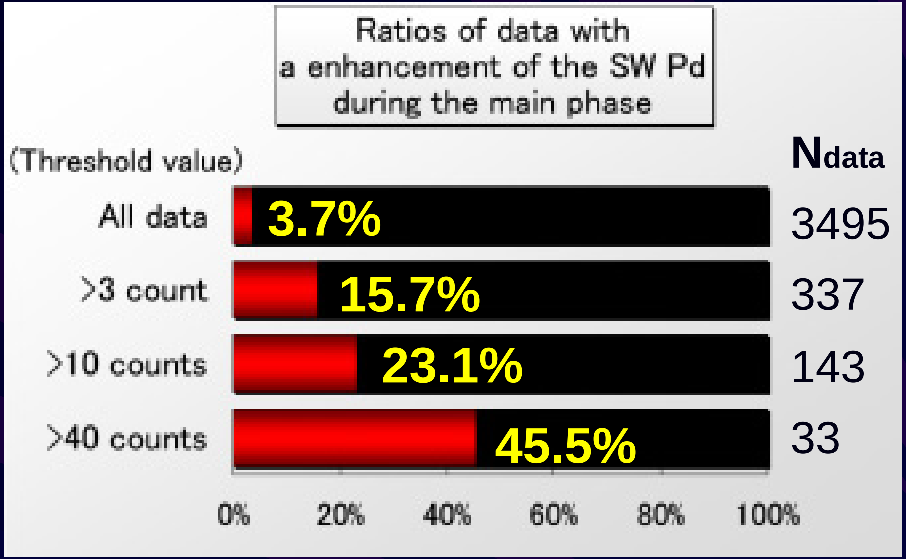


Result: The occurrence probabilities of the LENA count accompanied by SW dynamic pressure enhancements are higher during the main phase than those during the recovery phase.

Results of analysis①

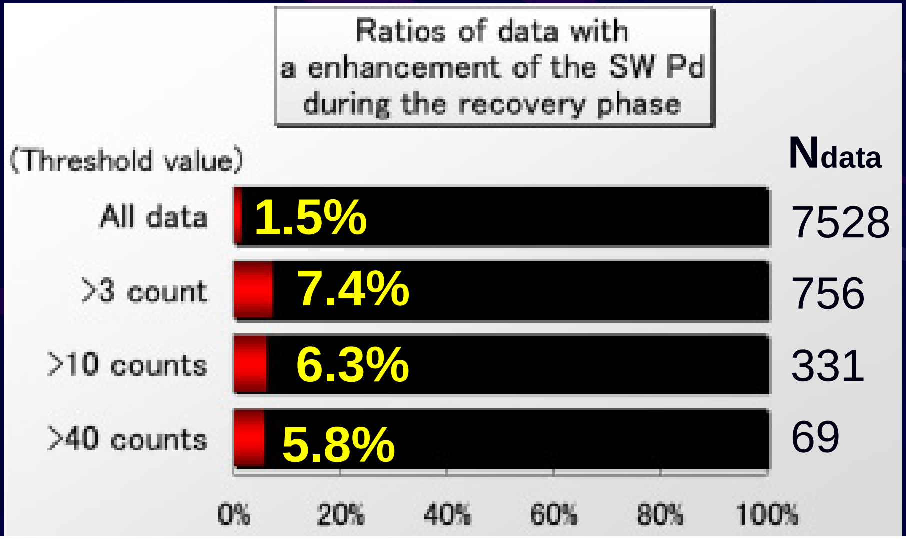
Main phase

The dependence on the enhancement of solar wind dynamic pressure was increased with the rise of the threshold level.



Recovery phase

There was much weaker relation between the LENA count and solar wind dynamic pressure.

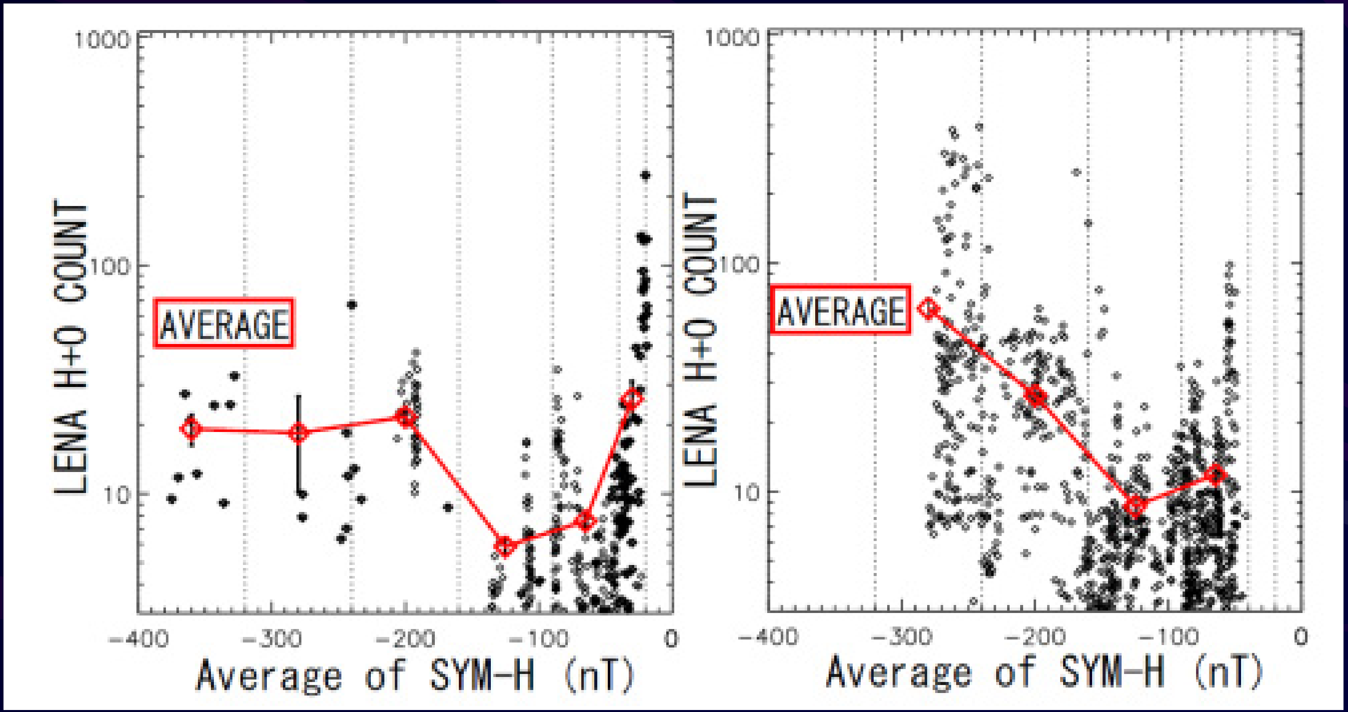


In analysis②,
we also obtained the same results.

Comparison after removing the LENA data with the SW dynamic pressure enhancements:

We could see a lot of LENA counts in a large amount during the recovery phase, while there aren't large counts during the main phase.

✓We removed the LENA data with the SW dynamic pressure enhancements identified by previous analyses.



Main phase
r = -0.190 (data point 296)

Recovery phase
r= -0.474 (data point 878)

Storm recovery phase:

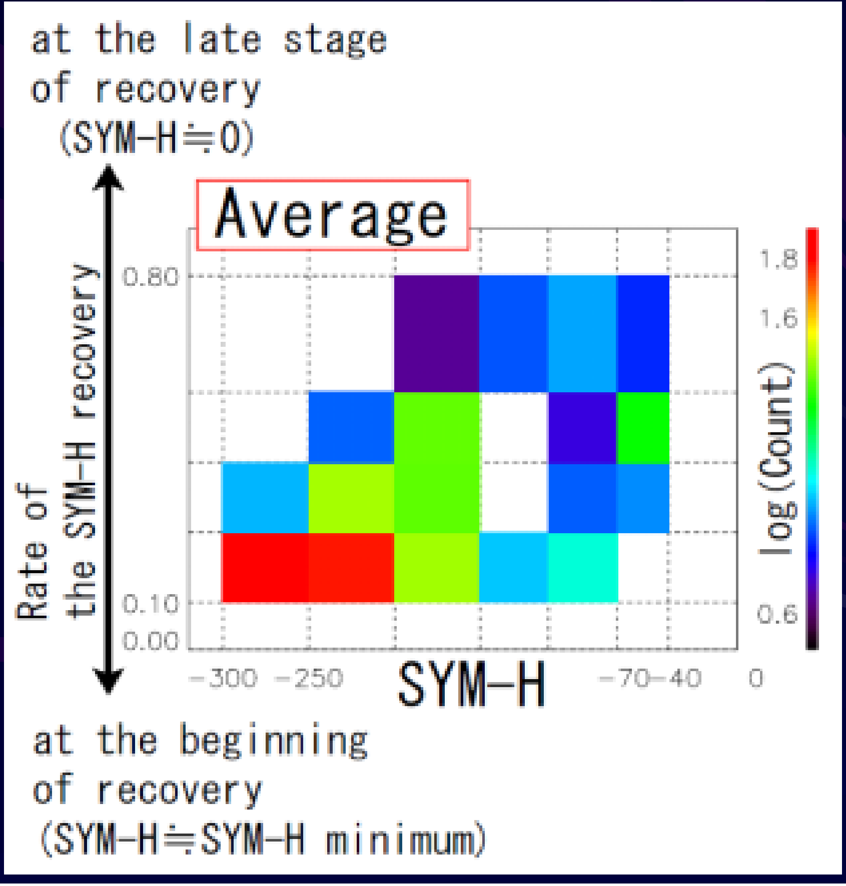
the ENA emission shows high values at the beginning of the SYM-H recovery.

$$Rate\ of\ SYM-H\ recovery = 1-(\mathrm{SYM\text{-}H})/(\mathrm{SYM\text{-}H\ min})$$

(SYM-H min)=(the minimum of the SYM-H index in each storm)

Color scale: average of LENA count in each bin

LENA count showed high values when the SYM-H index was large negative and the rate of SYM-H recovery was small.



Discussion1：storm main phase

✓ Most of the large ENA counts were accompanied by the enhancement of the SW dynamic pressure.

⇩

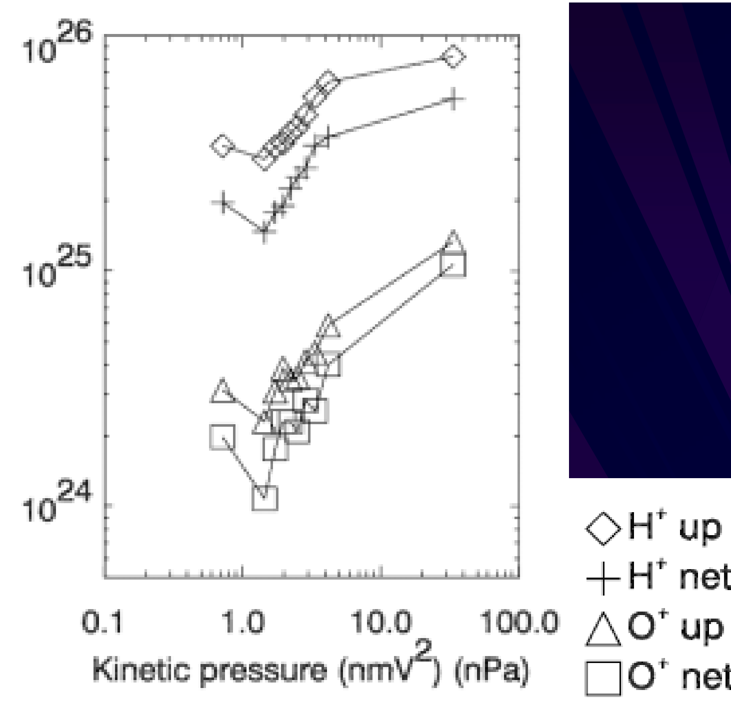
The ion outflow may be generated
by the compression of magnetosphere
or the substorm triggered by an interplanetary shock.

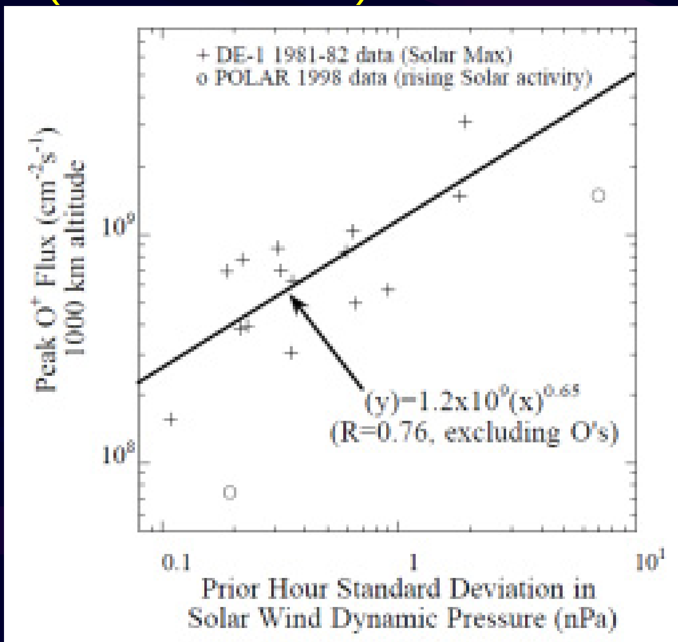
Some previous studies have shown the relation between the ion outflow and the solar wind dynamic pressure

POLAR/TIDE
(0.3eV-50eV)

DE-1/RIMS
(a few eV-50eV)

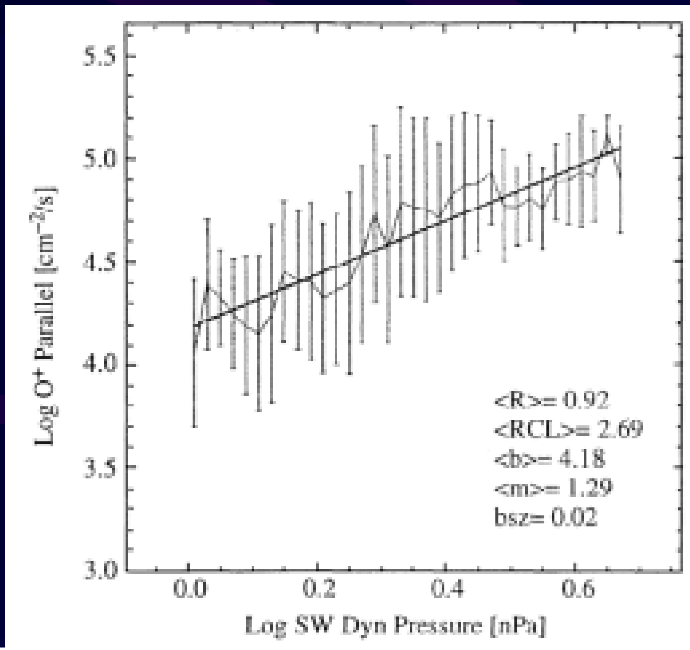
AKEBONO/SMS
(<1eV-70eV)
[Cully et al., 2003]





[Moore et al., 1999]

[Pollock et al., 1988]



POLAR/TIDE
(0.3eV-50eV)
[Elliott et al., 2001]

Discussion2：storm recovery phase

- ✓ During the recovery phase, the ENA emissions showed the highest value at the beginning of recovery phase and decreased with the SYM-H recovery.
- ✓ The occurrence probability of LENA counts accompanied by the sudden increase of the SW dynamic pressure was much lower.

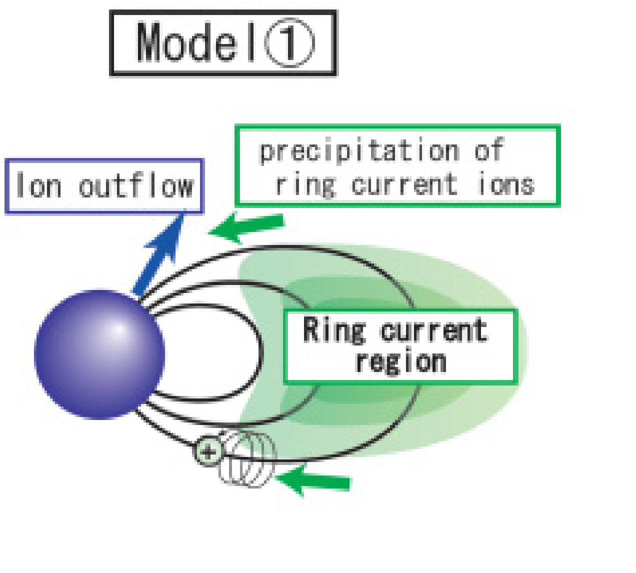
During the recovery phase, there are the particular mechanisms which increase the density or the speed of ion outflow.

	Mechanism	Source of Energy
Increase in the density of the ion outflow	The ionospheric scale height becomes larger.	Particle precipitation from the magnetosphere
		Electric field enhancement in the ionosphere
Increase in the speed of the ion outflow	Ion outflows (upflows) are further accelerated over the polar or auroral region.	Various phenomena inside or outside of the magnetosphere

This phenomenon will not happen because the electric field in the ionosphere is considered to be weaker during the recovery phase than during the main phase.

Discussion2：Recovery phase

Particle precipitation①: the precipitation of ring current ions into the ionosphere

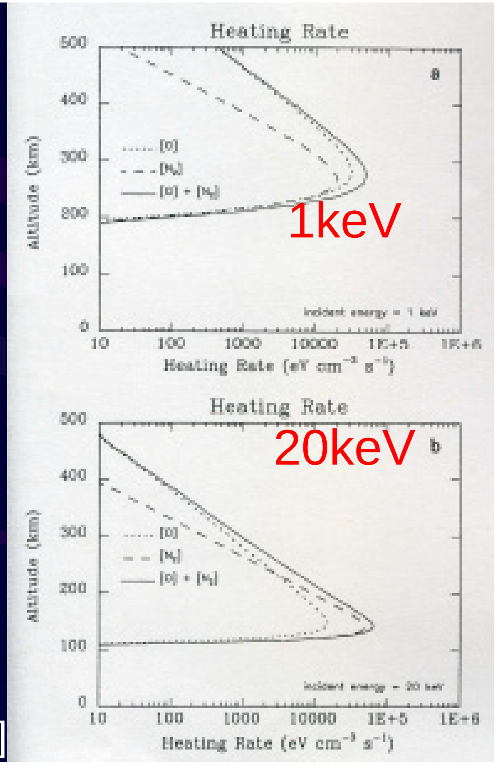


✓Electromagnetic ion cyclotron (EMIC) wave causes pitch angle scattering into the loss cone, and the ring current ions in the loss cone precipitate into the ionosphere.
[Walt and Voss., 2001], [Jordanova et al., 2001]

✓Through the Coulomb collision with precipitating ring current ions, the thermal ions in the topside ionosphere are heated.

✓Ions in energy less than a few keV have the largest effect on the topside ionosphere.
[Ishimoto et al., 1992]

✓However, it may also happen during the main phase..



[Ishimoto et al., 1992]

Discussion2: Recovery phase

Particle precipitation②:

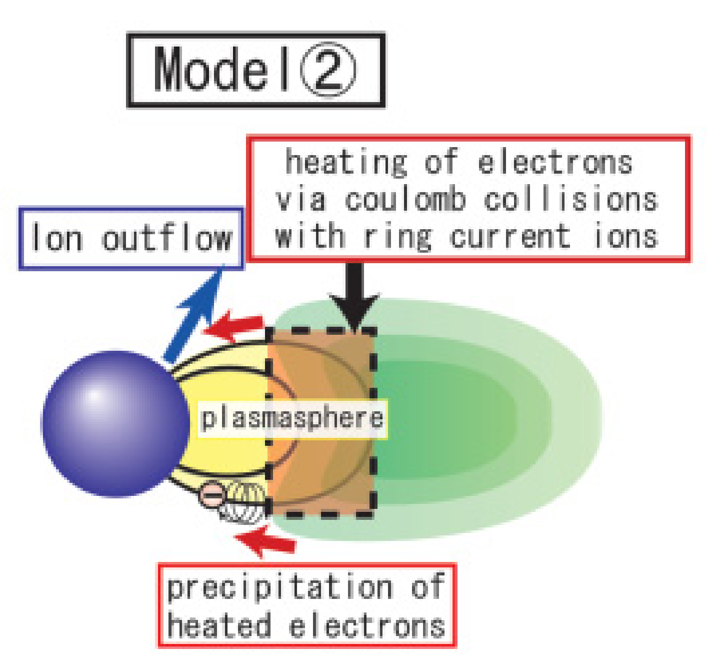
the precipitation of plasmaspheric electrons heated by Coulomb collisions with ring current ions

✓Electrons near the expanding plasmapause are heated by the Coulomb collisions with ring current ions. These heated electrons precipitate into the ionosphere. [Kozyra et al., 1987]

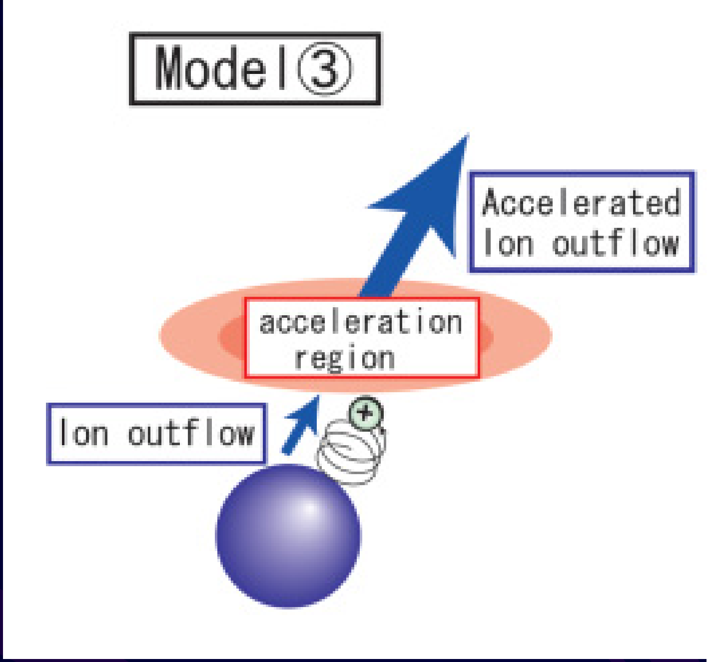
✓This mechanism is considered to be responsible for stable auroral red (SAR) arc in the sub-auroral region.

✓Ring current ions have the strongest effect when their speeds are comparable to those of plasmaspheric thermal electrons. [Liemohn et al., 2000]

$E_{electron}$ =1eV
→ a few keV (proton)
50keV (oxygen)



Further acceleration of the ion outflow (upflow) over the polar or auroral region



✓Wave heating

- Broad-band low-frequency wave (1Hz-10kHz)

(i.e., ion cyclotron resonant heating)

✓Parallel electric field

- Kinetic Alfvén wave
- Double layer above the auroral region

Ion outflows (ion upflows) are further accelerated,
if the mechanisms described above
are effective particularly during the recovery phase.

Discussion2： Recovery phase

The following three models can be proposed
to explain the observations during the recovery phase.

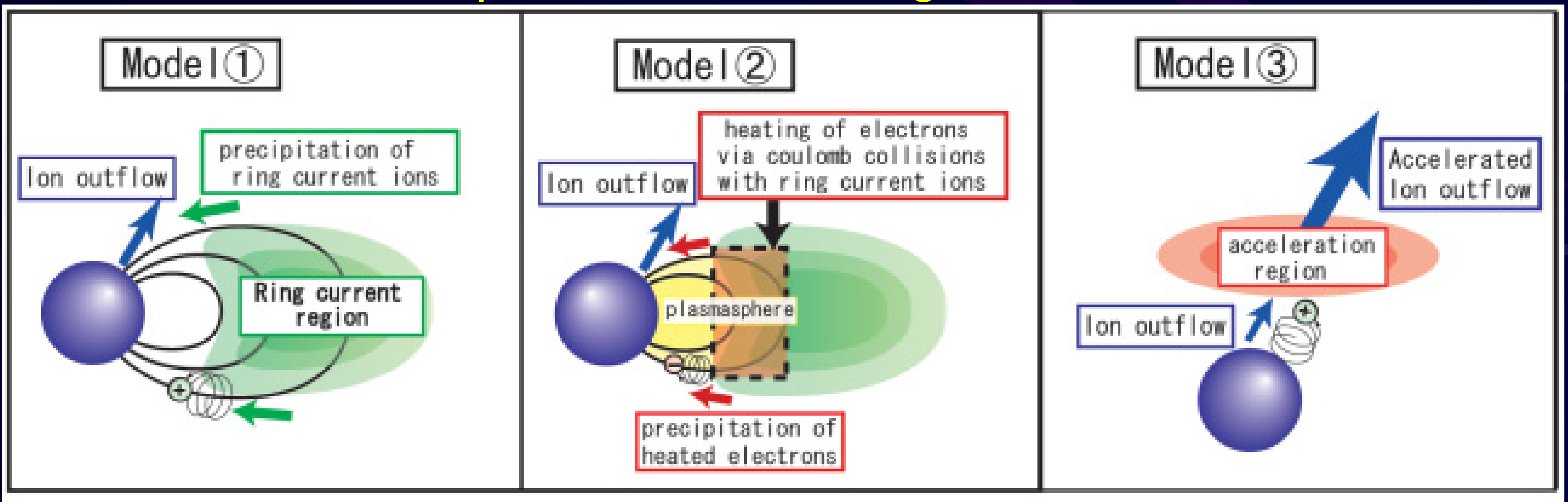
✓ Increase in the density of ion outflow

Model①： the precipitation of ring current ions scattered to the loss cone by EMIC waves.

Model②： the precipitation of plasmaspheric electrons heated by the Coulomb collisions with ring current ions.

✓Increase in the speed of ion outflow

Model③: the further acceleration of ion outflows over the polar or auroral region.



Conclusions

- During the storm main phase, most of ENA emissions from the Earth direction are accompanied by enhancements of the SW dynamic pressure.
- During the recovery phase, the occurrence probability of LENA counts accompanied by enhancements of the SW dynamic pressure was much lower, in contrast to the main phase.
- ENA emissions in a large amount are frequently observed at the beginning of the storm recovery phase.
- The main mechanism responsible for the ion outflow during the magnetic storms can be totally different between during the main phase and during the recovery phase.