# The terrestrial exosphere observed by space satellites

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# The terrestrial exosphere

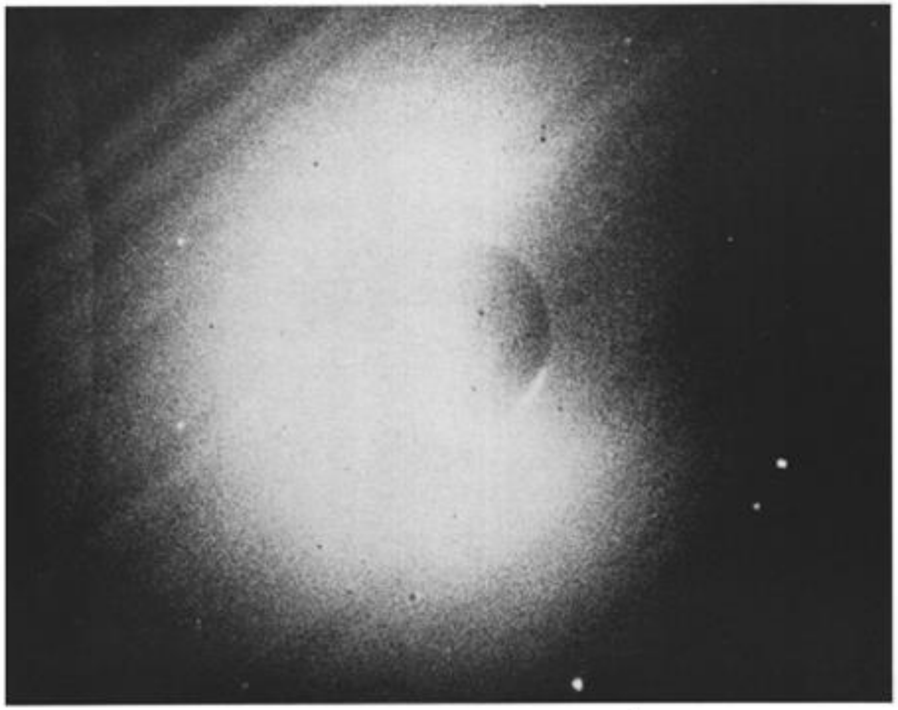

**Fig. 1.1 The hydrogen lyman α emission**
[Carruthers et al., 1976]

- FOV : ~10 $R_E$
- wavelength : 1050-1600 A

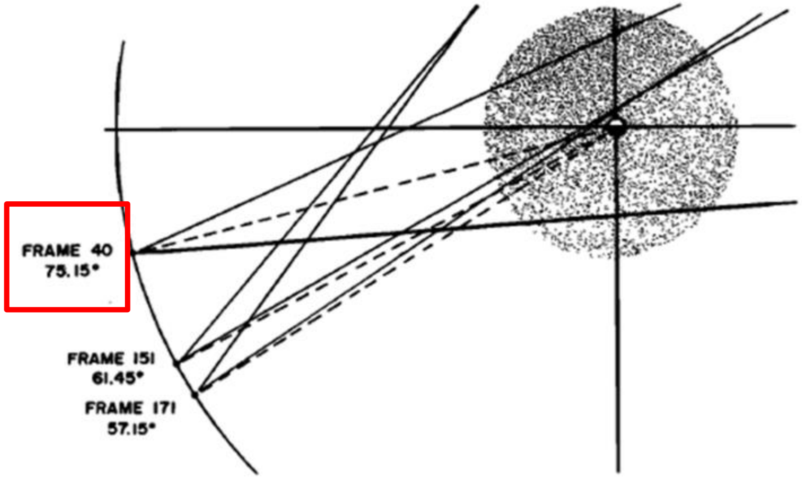

Fig. 2. Viewing geometry for the S-201 observations of the geocorona during the Apollo 16 mission.

**Fig. 1.2 Geometry of Apollo-16 observation**
[Carruthers et al., 1976]

**Hydrogen atoms in exosphere resonantly scatter sunlight.**
**⇒ build the geocorona (wl:121.6 nm).**

**No imagery of the geocorona had been observed since that of Apollo-16.**

# Geocoronal observations

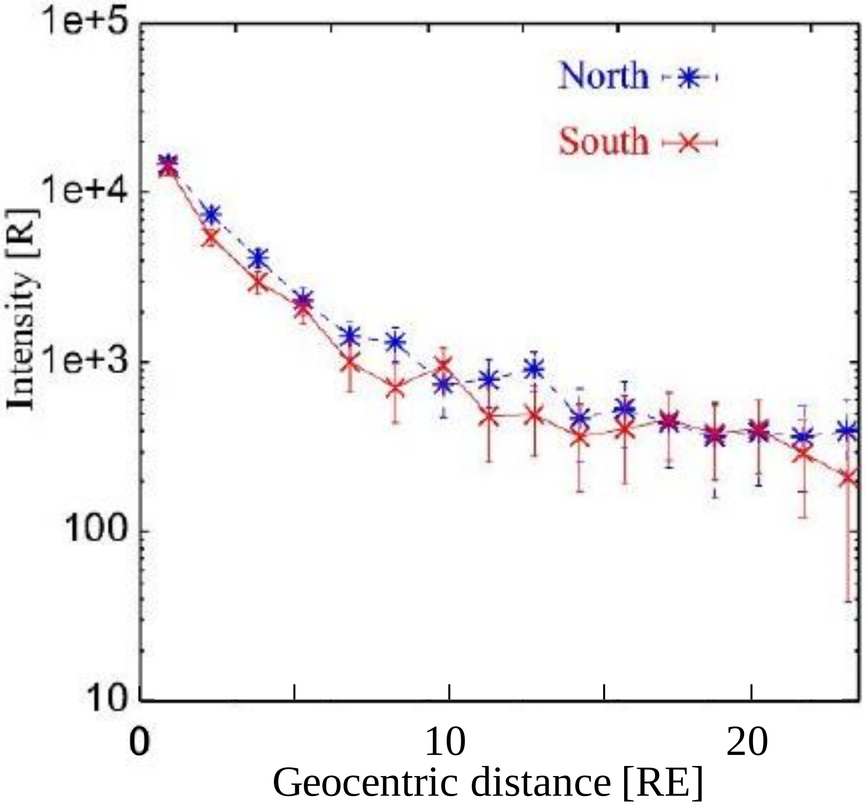

**Fig. 1.3 Lyman α profile observed by NOZOMI satellite**
[Tsuchiya, 2003]

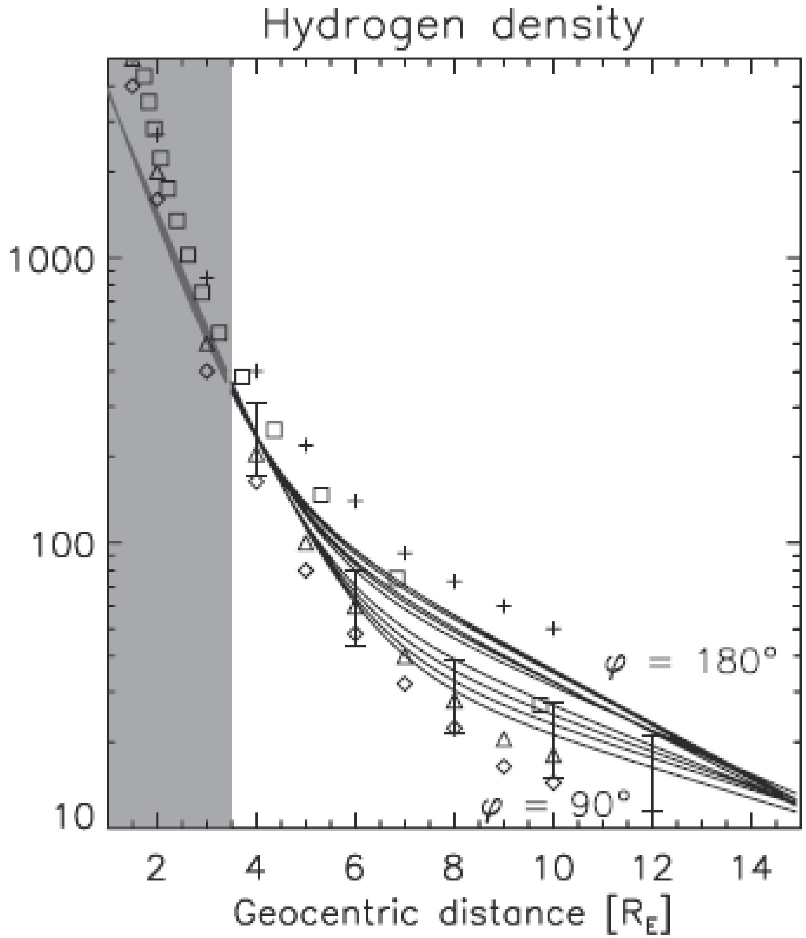

**Fig. 1.4 Nightside density profile of hydrogen atoms observed by IMAGE satellite**
[Østgaard et al., 2003]

**NOZOMI observation shows that the distribution of hydrogen atoms expands to ~20$R_E$**

# The terrestrial plasmasphere

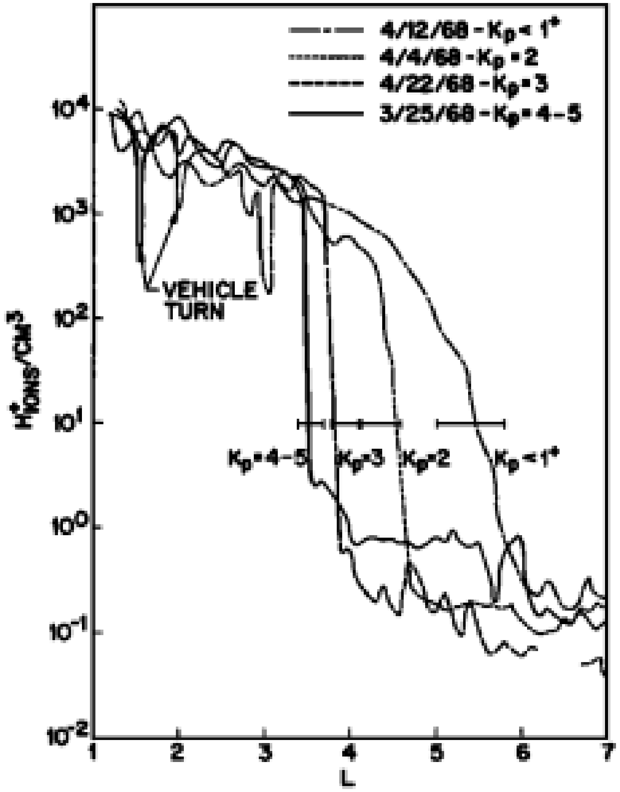

**Fig. 1.5 Shape of plasmasphere in response to variations of geomagnetic activity**
[Chappell et al., 1970]

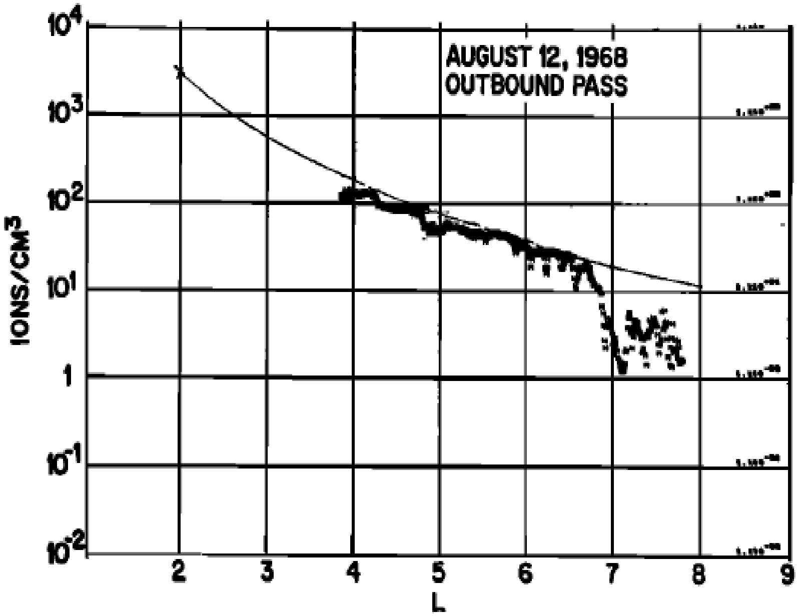

**Fig. 1.6 Density distribution of ions observed by OGO-5 satellite**
[Chappell et al., 1970]

- The solid line represents a $1/R^4$ profile.

**The shape of plasmasphere changes in response to variations of geomagnetic activity.**

**Lpp=6-0.6Kp**

# The correlation between Dst index and amount of hydrogen atoms

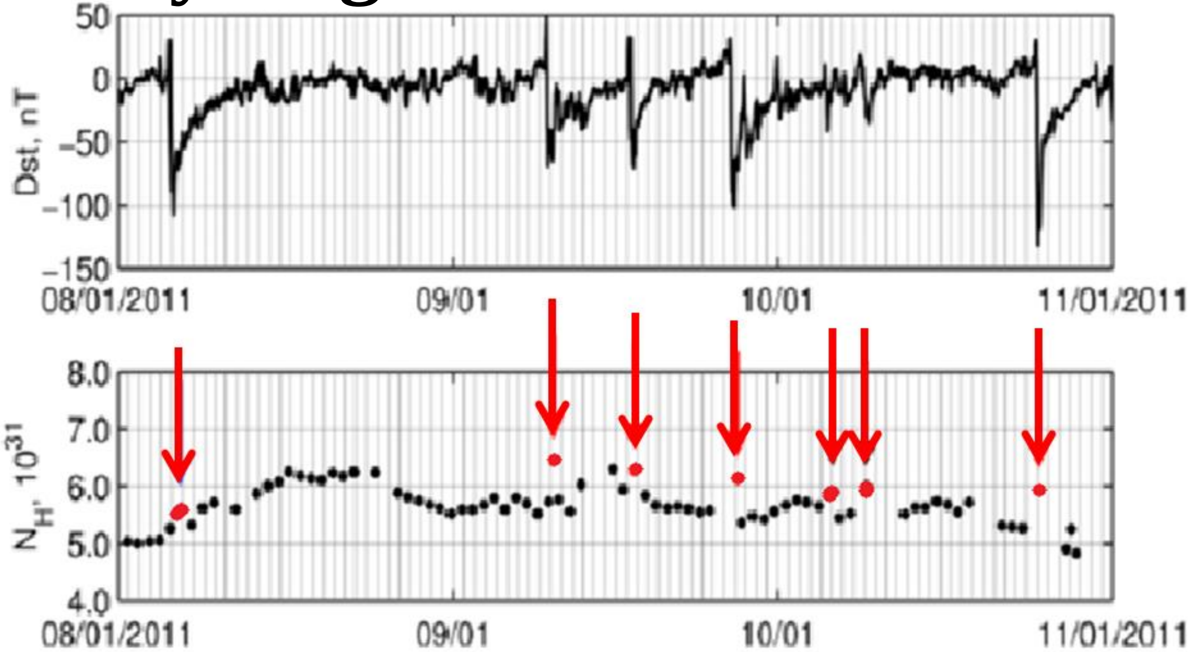

**Fig. 1.7 Correlation between Dst index and amount of hydrogen atoms**
[Bailey and Gruntman, 2013]

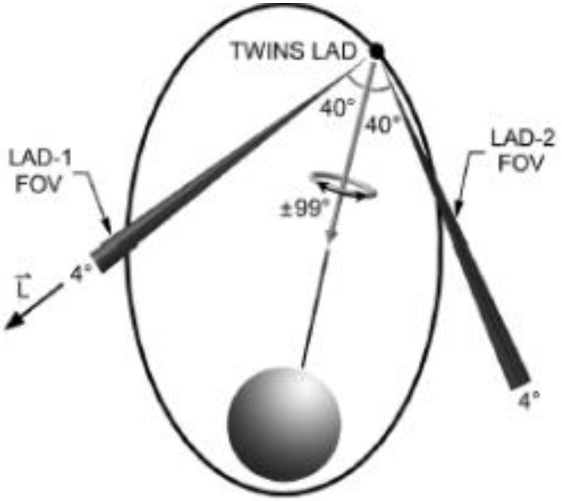

**Fig. 1.8 Geometry of TWINS satellite observation**
[Bailey and Gruntman, 2013]

**<u>hydrogen atoms increase 6~17% during magnetic storms.</u>**

**⇒ The mechanism is not elucidated.**

# The increases of hydrogen atoms observed by HISAKI satellite during magnetic storms

# The correlation between Dst index and amount of hydrogen atoms observed by HISAKI

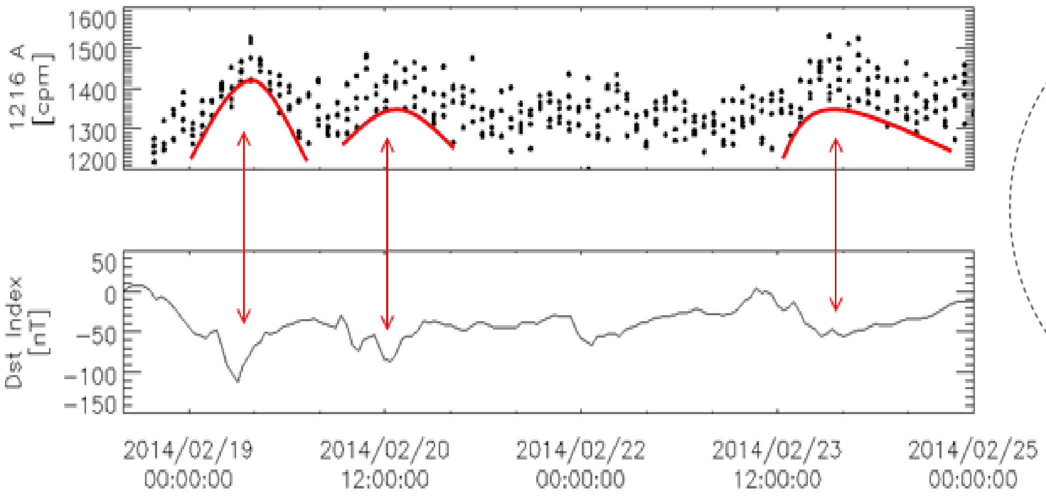

**Fig. 2.1 Correlation between amount of hydrogen atoms and Dst index**

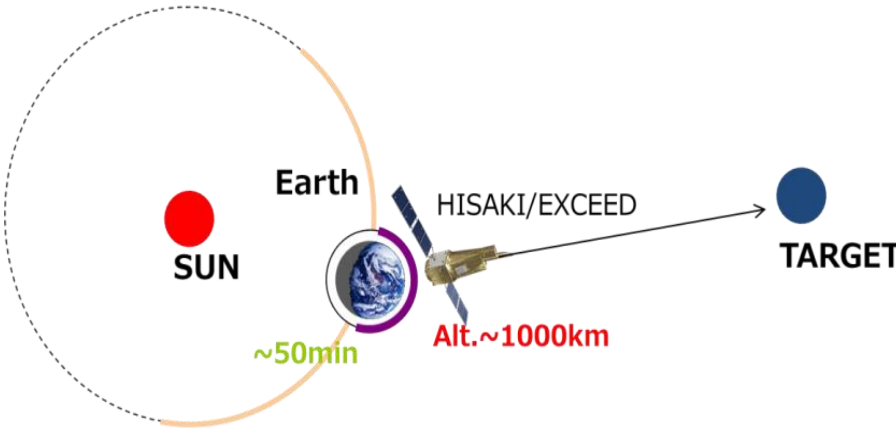

**Fig. 2.2 Geometry of HISAKI satellite observation**

**HISAKI also observed the increases of hydrogen atoms during magnetic storms.**

**⇒ In 19th February, increase rate is ~20%.**

# Mechanism of increases of hydrogen atoms

Based on the equation of continuity, we consider the intensity (density in LOS) fluctuation observed before and after occurrence of a magnetic storm.

$$\boxed{\frac{\partial n}{\partial t}} + \underbrace{\nabla \cdot (nv)}_{\text{Change in flow}} = \underbrace{P}_{\text{Production rate}} - \underbrace{L}_{\text{Loss rate}}$$

↑

Hydrogen atoms increased when HISAKI was observing.

# The mechanism of increase of hydrogen atoms during magnetic storms.

## Estimate of flow rate

$$\frac{\partial n}{\partial t} + \nabla \cdot (nv) = P - L$$

**① Variation of density (in LOS) with expansion of the thermosphere**

Variation of density at 1000km:

$7 \times 10^4$ [/cc] ⇒ $5 \times 10^4$ [/cc]

Variation of temperature at 1000km:

920 [K] ⇒ 960 [K]

If hydrostatic equilibrium is established column density in LOS is calculated as follows.

$$\boldsymbol{n(z) = n(z_0)\,[T(z_0)/T(z)]\,exp[-\int_{z_0}^{z} dz/H(z)]}$$

**Quiet time : $6 \times 10^{12}$ [/cm$^2$]**
**Disturbed time: $5 \times 10^{12}$ [/cm$^2$]**

~20%

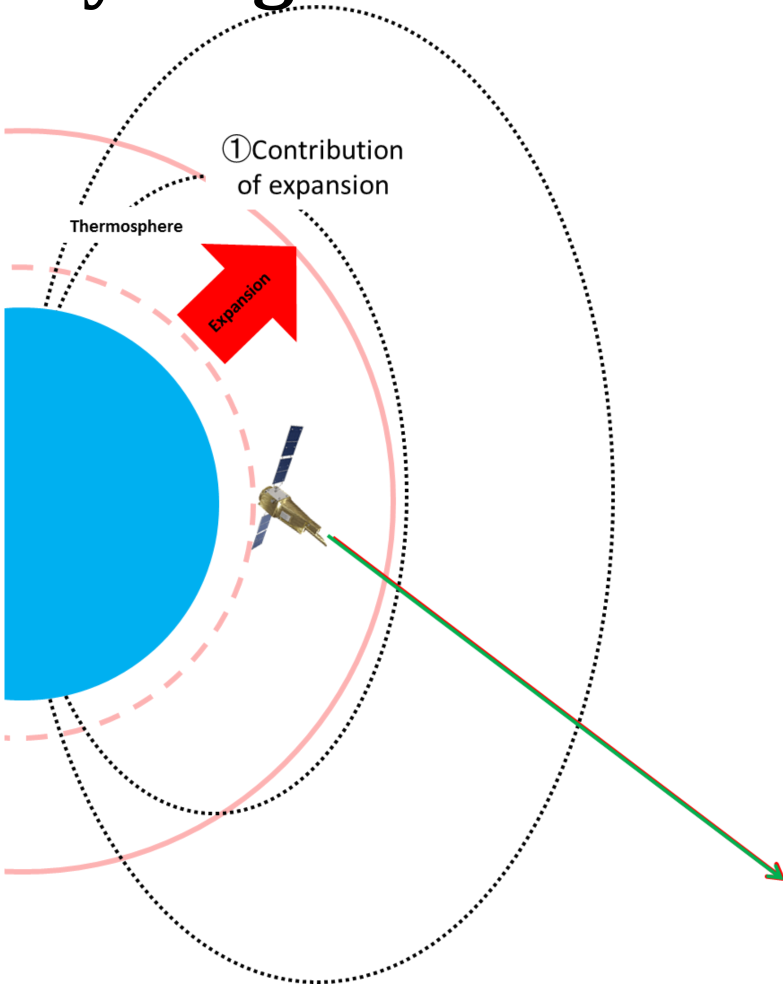

**Fig. 2.3 Expansion of the thermoshpere**

**⇒ Hydrogen atoms decreased about 20 % during the magnetic storm.**

# The mechanism of increase of hydrogen atoms during magnetic storms.

## Estimate of production rate

$$\frac{\partial n}{\partial t} + \nabla \cdot (nv) = P - L$$

## ② Charge exchange in the plasmasphere

~~$H + H^{+*} \rightarrow H^{+} + H^{*}$~~ equation [1]

This reaction is negligible because H amount doesn't change before and after collision.

$He + H^{+*} \rightarrow He^{+} + H^{*}$ equation [2]

**Plasmasphere shrinks**

**Ion density in LOS decreases, but fluctuations of He and O are negligible compared with variation in $H^{+}$ density at high altitude.**

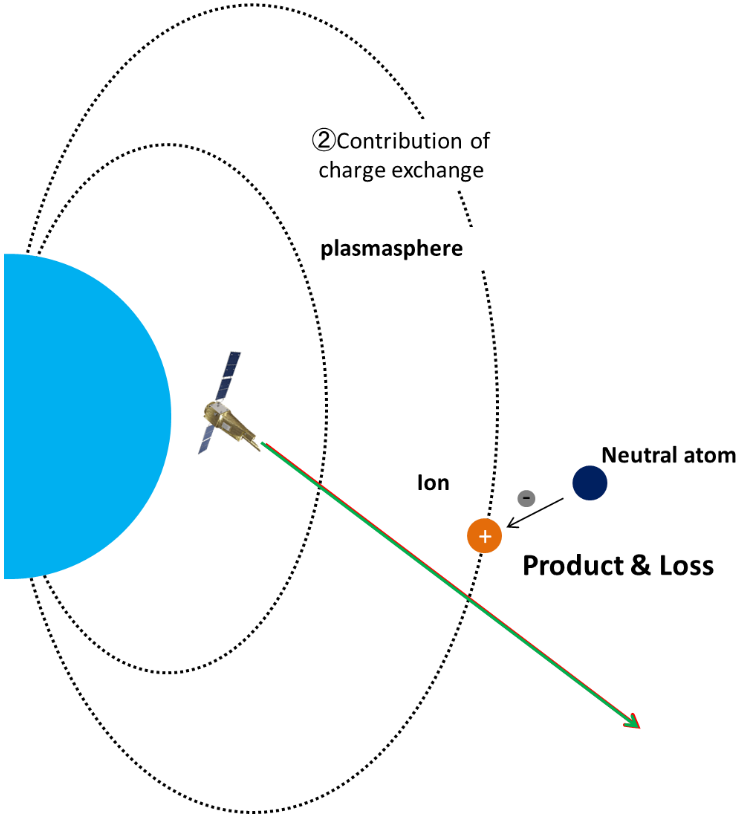

Fig. 2.4 charge exchange in the plasmasphere

**⇒ P(production rate) is negligible during the magnetic storm.**

# The mechanism of increase of hydrogen atoms during magnetic storms.

## Estimate of production rate

$$\frac{\partial n}{\partial t} + \nabla \cdot (nv) = P - L$$

## ② Charge exchange in the plasmasphere

~~$H + H^{+*} \rightarrow H^{+} + H^{*}$~~ **equation [3]**

This reaction is negligible because H amount doesn't change before and after collision.

$H + He^{+*} \rightarrow H^{+} + He^{*}$ **equation [4]**

Collision frequency decreases

**Plasmasphere shrinks**

**Density of He+ in LOS decreases**

**Collision frequency decreases**

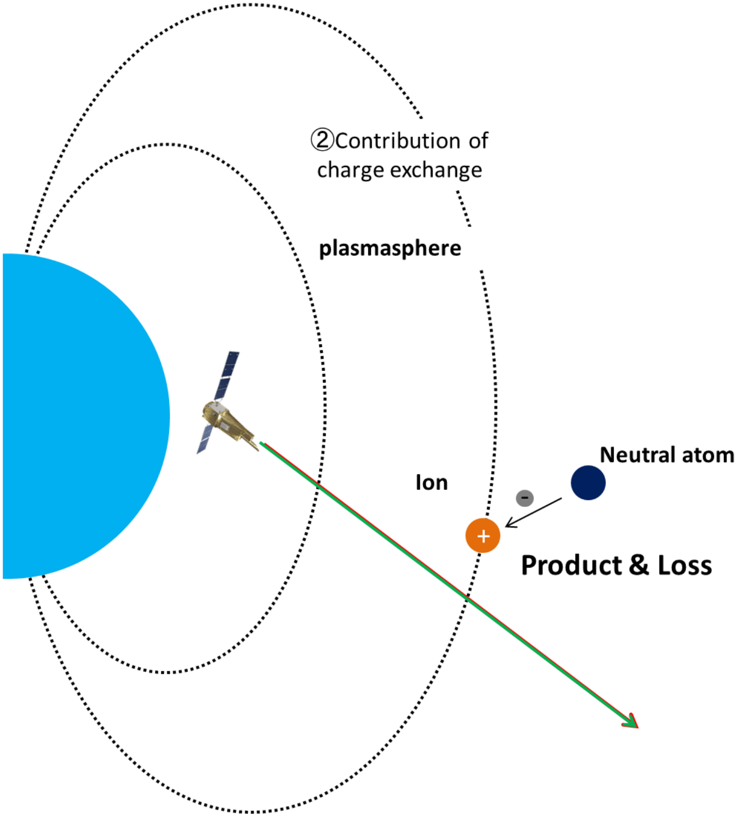

**Fig. 2.5 charge exchange in the plasmasphere**

Supposed parameter

- ◆ The position of plasmapause
- ◆ Density distribution of helium ions
- ◆ Density distribution of hydrogen atoms
- ◆ Collision cross-section and energy of incident particle

**⇒ L (Loss rate) decreases during the magnetic storm.**

# Density distributions of H atoms and He ions

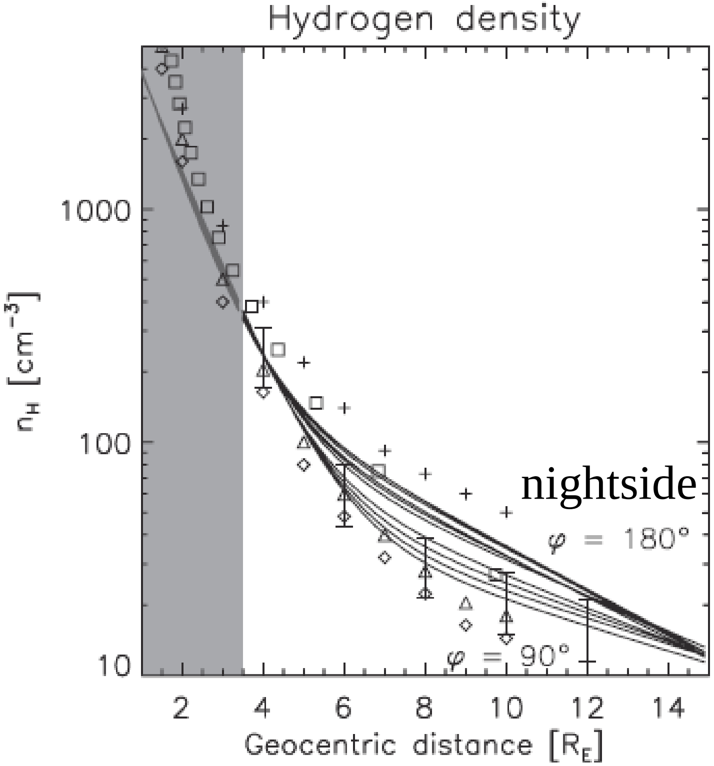

**Fig. 2.6 Nightside density profile of hydrogen atoms observed by IMAGE satellite**
[Østgaard et al., 2003]

⇒ We used this nightside H distribution

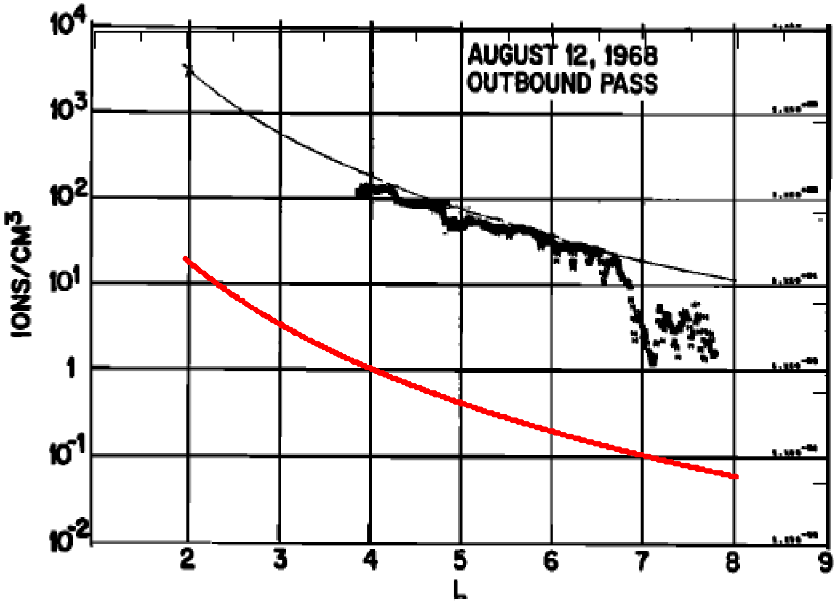

**Fig. 2.7 Plasmaspheric ion distribution observed by OGO-5 satellite**
[Chappell et al., 1970]

- The red line represents $He^+$ density.

⇒ We used this density profile.

**If position of plasmapause for Kp index is determined,**
**the abundance of $He^+$ in the plasmasphere can be decided.**

# Comparison of observation and calculation

Collision cross-section σ : $10^{-16}$ [$cm^2$]
Energy of incident particle E : 4 [eV]

## ① Charge exchange in the plasmasphere

The collision frequency per unit time f is

$$f = N_H \sigma v \text{ [/sec] equation [5]}$$

The collision frequency per unit space N is

$$N = N_{He^+} \times f \text{ [/sec/cm}^3\text{] equation [6]}$$

The total collision frequency $N_{total}$ is

$$N_{total} = N \times L \text{ [/sec/cm}^2\text{] equation [7]}$$

Where, L is distance along the line of sight , NH and $NHe^+$ are density of hydrogen atoms and Helium ions, respectively

**Quiet time : $8 \times 10^4$ [/sec/$cm^2$]**
**disturbed time : $4 \times 10^4$ [/sec/$cm^2$]**

⬇ **~50%**

⇒ **L (Loss rate) decreased about 50 %**
**during a magnetic storm.**

# The mechanism of increase of hydrogen atoms during magnetic storms.

Equation of continuity is summarized as follows.

**Increase** **Decrease** **Maintain** **Decrease**

$$\frac{\partial n}{\partial t} + \nabla \cdot (nv) = P - L$$

**⇒ Thermospheric and plasmaspheric responses cause fluctuation of density in LOS.**