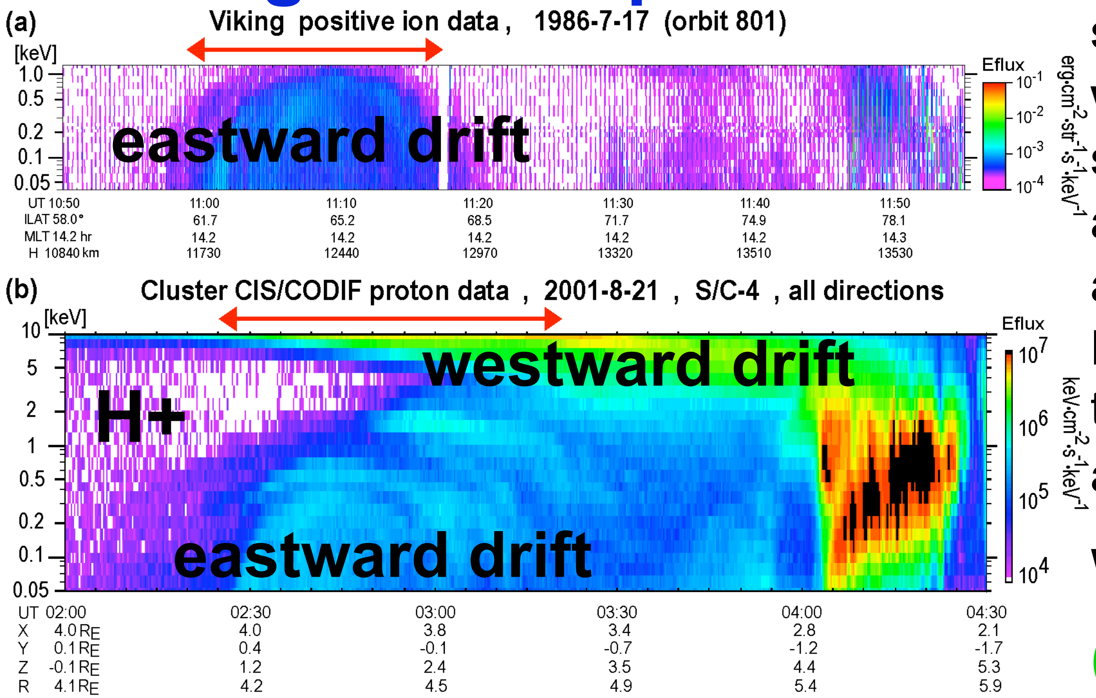
Sub-keV Ring Current Ions: Source, Transport, and O+/H+ difference

M. Yamauchi, R. Lundin, H. Nilsson, S. Arvelius (IRF-Kiruna),
Y. Ebihara (NIPR),
*and **Cluster-CIS** team*

"Wedge-like dispersion"



Sub-keV trapped ions are seen almost all satellites at around L=4-6. They are **wedge-like** energy-latitude dispersed as shown in both Viking data (mid-altitude) and Cluster data (equatorial plane). They are trapped ions drifting eastward, i.e., the ExB drift (including corotation) is stronger than the magnetic drift (∇B and curvature) at this energy range.

We show **(1) Viking statistics (2) Cluster event studies.**

Previous Works

sub-keV ion precipitation @ subauroral region):

•Aureol 1 (400~2500km): Sauvaud et al., 1980

00-06 MLT: increases after substorms.

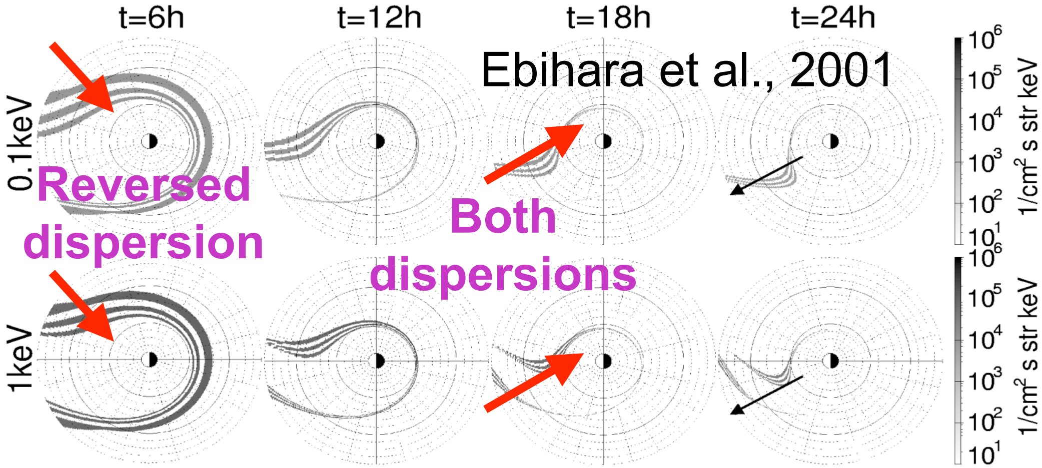
* DMSP F6/F7 (800 km):Newell & Meng, 1986
0830 MLT: correlated with Kp with some hours delay, and event may last a day.

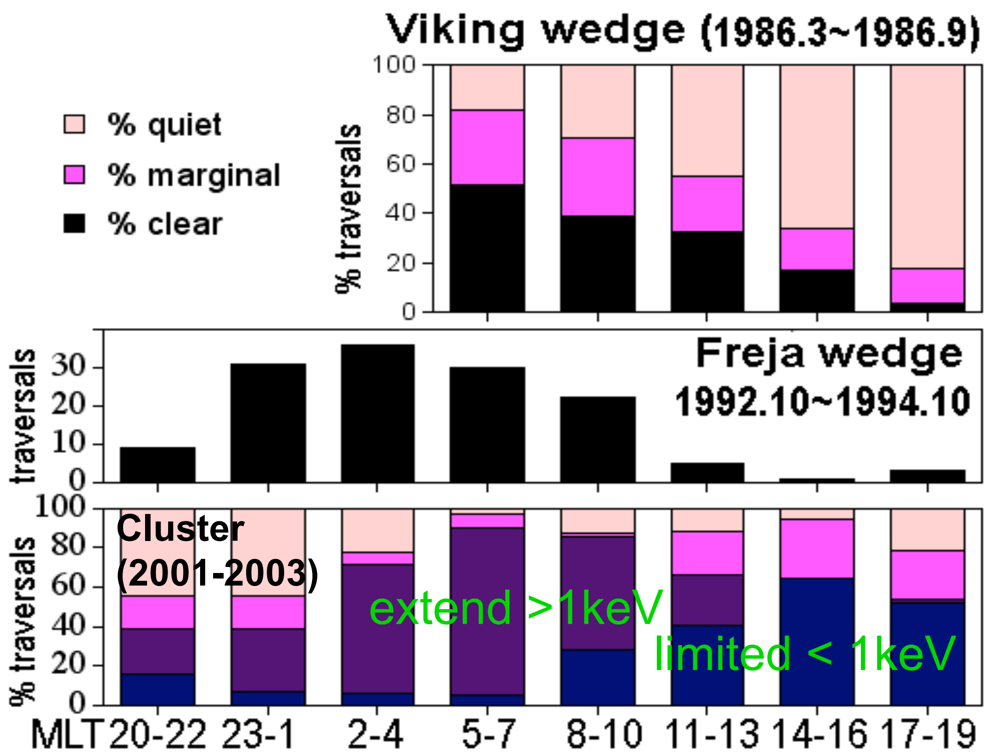
* Viking (2~3 R_E): Yamauchi et al., 1996a,b
"Wedge-like dispersed structures"
modulation by pc-5 pulsation.

* Simulation: Ebihara et al., 2001
drift model (ExB, ∇|B|, and curvature)
many hours after nightside injection
dispersion patterns + MLT dependence.

* Freja/Viking/Cluster: **Yamauchi et al., 2005**
morning peak
O+ at low-altitude / H+ at high-altitude

* others: Shelley et al., 1972; Chappel et al., 1982





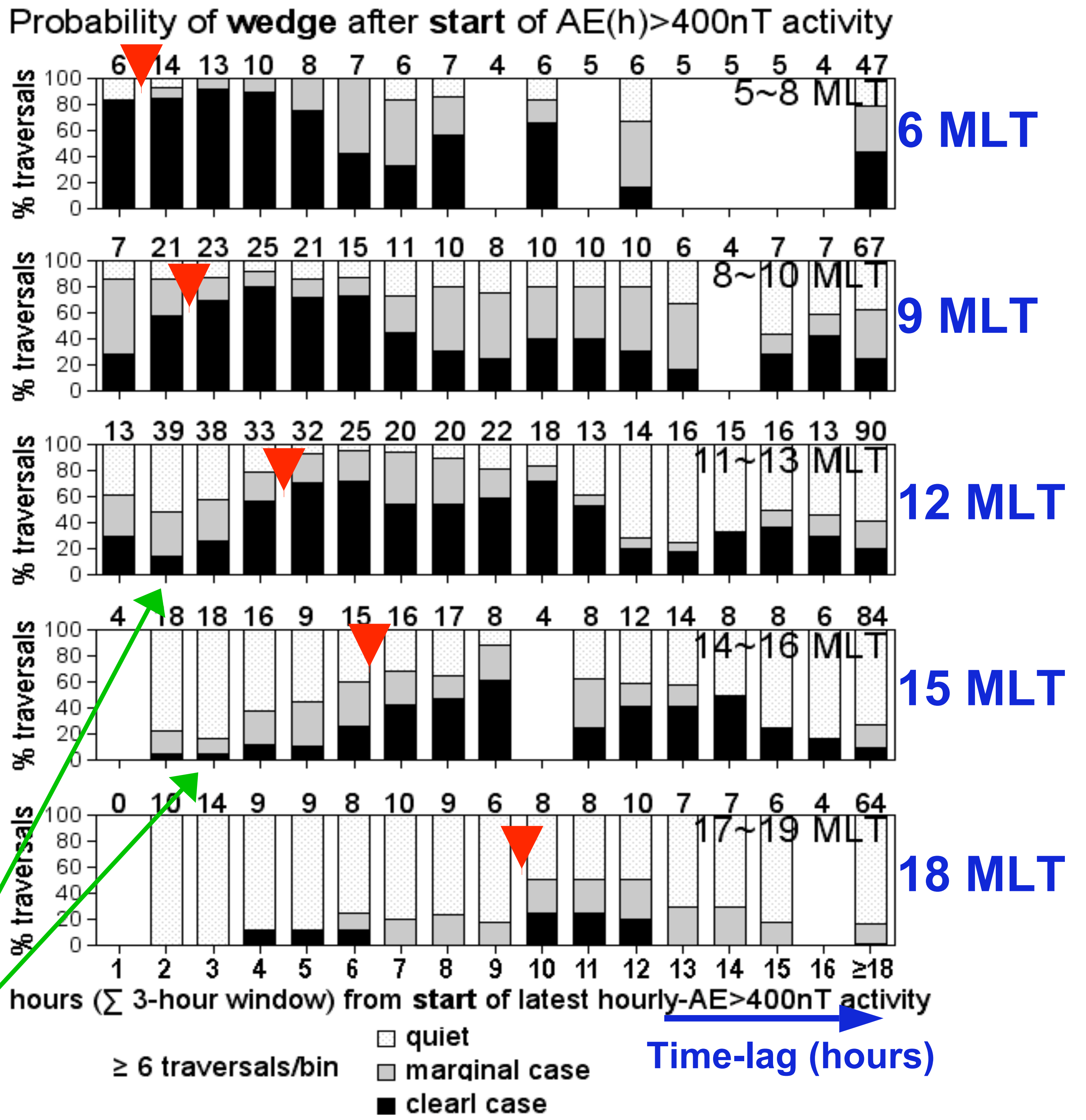
(1) Viking

backward superposed epoch analyses

Probabilities of observing the **wedge-like structure** after the start of AE activity. Probability is calculated from numbers of traversals with/without the structure for each 3-hr bin (3-hr running sum) for each 3-hr MLT bin.

The peak probability moves eastward, while the peak value of the probability decrease as the peak moves eastward.

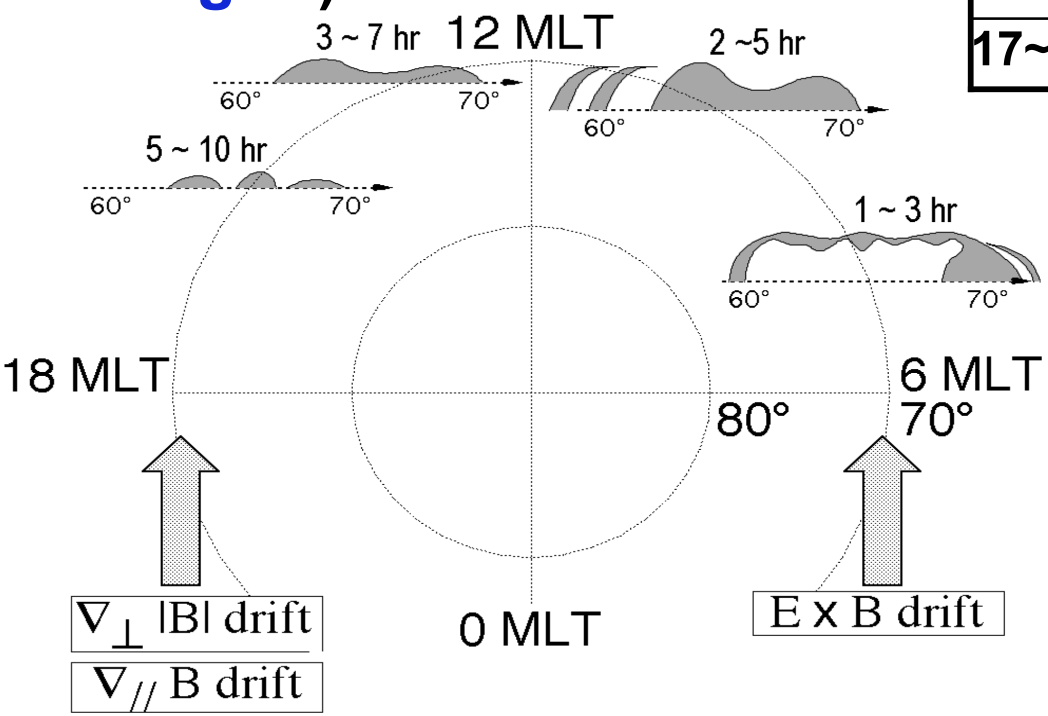
Evacuation is seen (the probability is even lower than asymptotic one)



Viking Summary

The wedge-like structure drifts eastward, and is a fossil of substorm activity (model is right!). Decay time is several hours (charge exchange model is right!).

MLT	Minimum Quiet case After end of 300 nT activity	Asymptotic Quiet case After end of 300 nT activity	Maximum Clear case After start of 400 nT activity
5~7	1~3h (0%)	8~9h (30%)	0~3h (85%)
8~10	2~3h (5%)	9~10h (50%)	2~4h (75%)
11~13	3~5h (10%)	10~11h (70%)	4~6h (70%)
14~16	4~6h (35%)	12~13h (80%)	6~7h (50%)
17~19	6~8h (50%)	14~16h (100%)	10h (25%)



However, it appears much earlier than prediction, suggesting that a substantial amount of "wedge" might be formed in the morning sector during substorms. **We need to identify the source location from event study.**

We have several possibilities

Ion source	dispersion	scenario
night	night	No !
night	morning	(A)
morning	morning	(B) (C) (D)

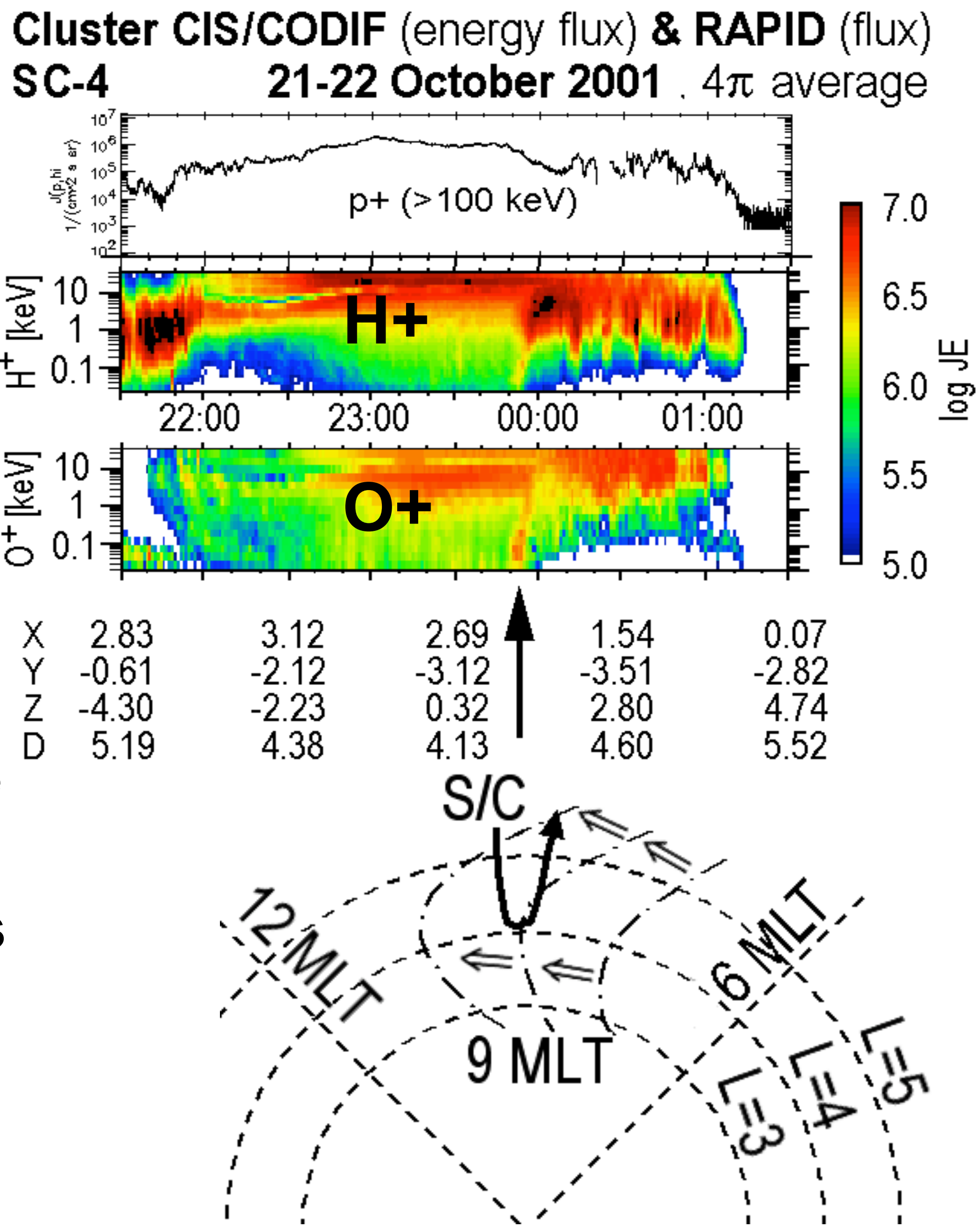
(A) Strong electric field push ions quickly.
(B) Scattering of <10 keV ions
(C) Energetic ions precipitate and sputter ionospheric ions into the space.
(D) Unknown local energization process.

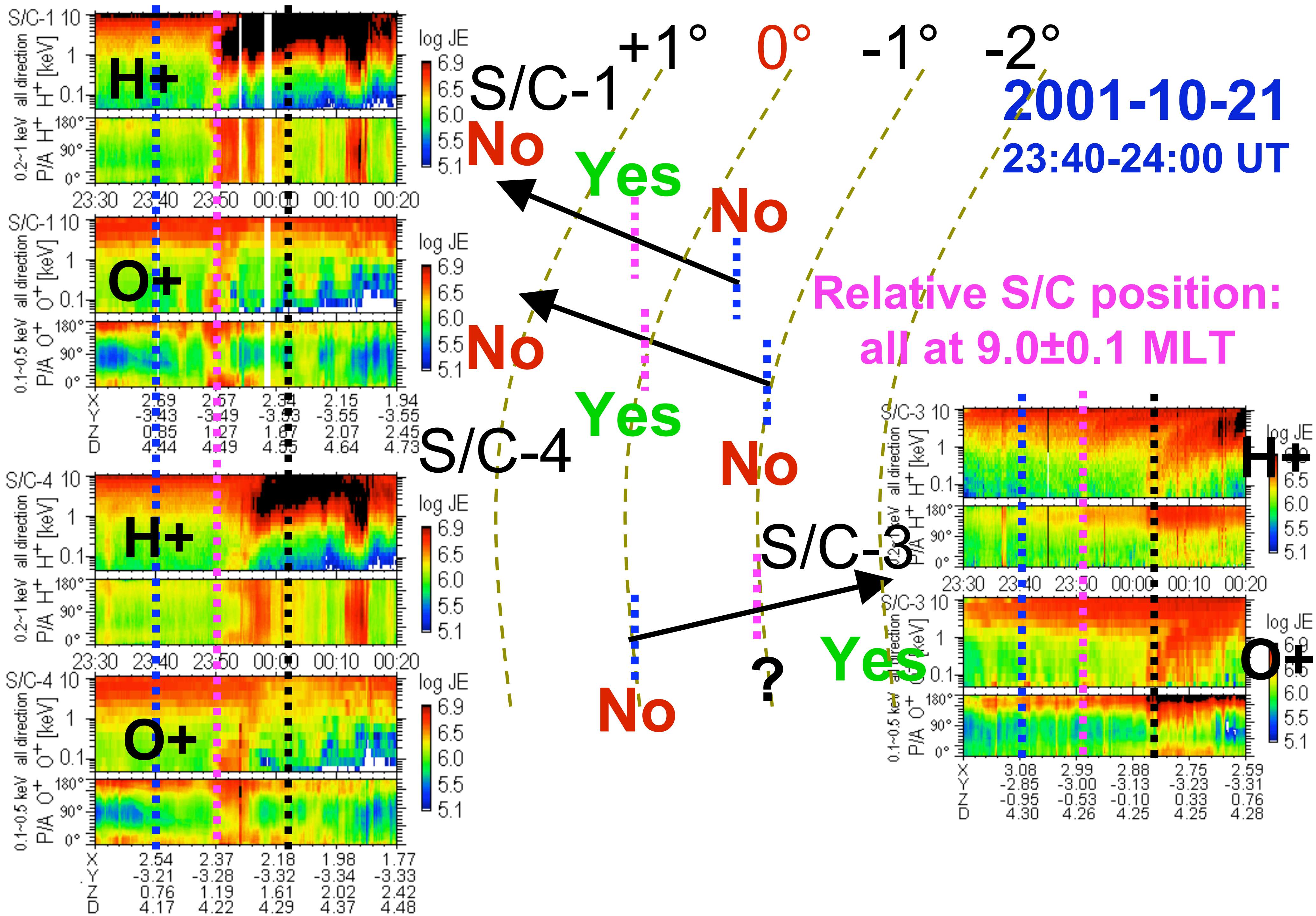
⇒ Need to find events when the wedge is formed during a substorm.

⇒ We found one case. **Wedge is seen only at outbound**.

⇒ **Case study!**

(2) Cluster





2001-10-21
23:40-24:00 UT
+1°
0°
-1°
-2°
S/C-1
S/C-4
S/C-3
No
Yes
No
No
Yes
No
No
?
Yes
Relative S/C position:
all at 9.0±0.1 MLT
H+
O+
log JE

Observation summary

S/C-1 (23:45 UT), S/C-4 (23:50 UT), and S/C-3 (23:40 UT) passed through the same magnetic flux tube at 9 MLT (L≈4).

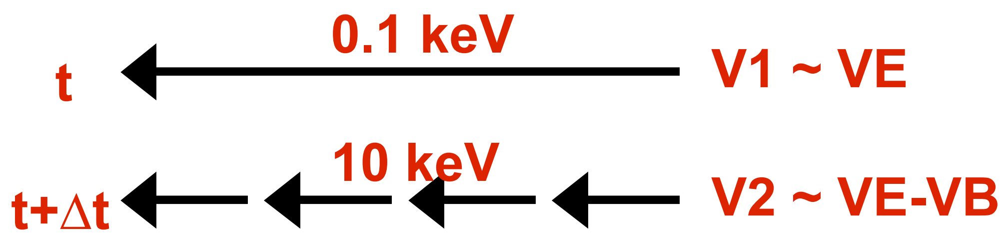
Wedge-like dispersion at 23:50 UT.
No low-energy signature at 23:40 UT.

Butterfly-trapped distribution
⇒ Bounce inside the geomagnetic bottle.
⇒ **Difference between 23:40 UT and 23:50 UT in the same flux tube means an temporal variation** although observation is made in the opposite hemisphere.

VE: eastward ExB drift speed = energy independent, MLT dependent
VB: westward magnetic (∇|B|+curvature) drift velocity = energy dependent
VE >> VB at low energy (<100 eV) and VE ~ VB at high energy (value depends on E-field strength). From dispersion curve, the last-coming ions are 10-20 keV. Therefore, **VE ~ VB at 20 keV in the present case.**

time-of-flight principal

V1 = VE-VB ~ VE @ 0.1 keV
V2 = VE-VB << VE @ 10 keV



V1*t = V2*(t+Δt) **or**

(t+Δt)/Δt = V1/(V1-V2)

~ VE/VB **(note : VB@10 keV)**

= (E/B)*(q*R*B/3*W*g)

~ E [mV/m]/g **or**

t = Δt*E [mV/m]/g - Δt

for observation near equatorial plane, where
E and B are the field strengths,
q is the charge,
R = 4 RE is the geocentric distance,
W = 10 keV is the ion energy, and
g ~ 1, 0.9 &0.7 for 90°, 40° & 0° pitch angles

Dispersion analysis

Pitch angle of the "wedge" is about 40~90°
(g=0.9~1.0) ⇒ **t ≤ (1.1*E[mV/s] - 1) * Δt**

Electric field is 1~3 mV/m for half an hour
⇒ **t = 0.1~2.3*Δt** & **VE = 3~10 km/s**

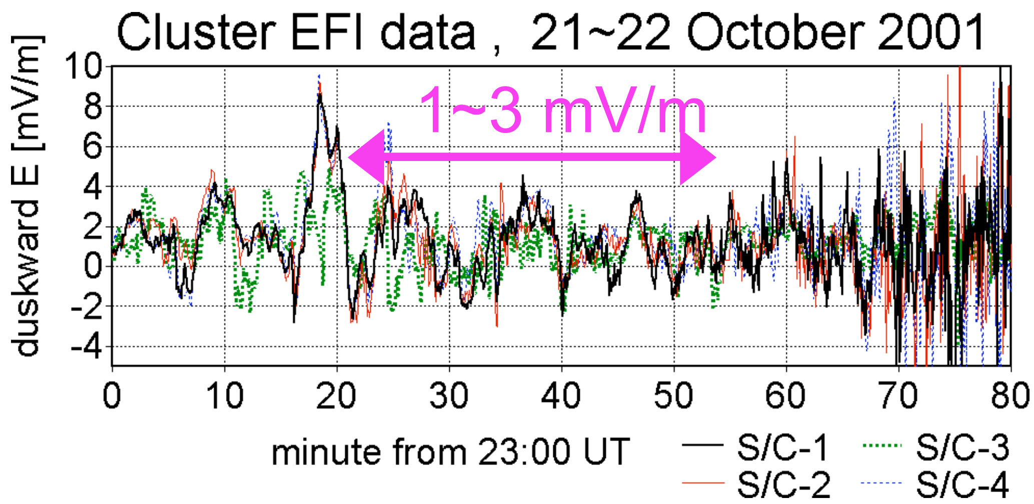
(a) 0.1 keV @ 23:50 UT, S/C-1 ⇐⇒
Nothing @ 23:40 UT, S/C-3 : temporal chance

(b) 10 keV @ 23:53 UT, S/C-1 ⇐⇒
Nothing @ 23:40 UT, S/C-3 : temporal change

(c) 0.1 keV @ 23:50 UT, S/C-1 ⇐⇒
10 keV @ 23:53 UT, S/C-1 : temporal or spatial

Combination of (a)+(b) : **it is temporal change**
⇒ **Δt < 13 min ⇒ t < 30 min before 23:40 UT**
⇒ **drift distance = VE * t < 20000 km**
⇒ **dispersion started at 7~9 MLT.**

Combination of (b)+(c) : **if temporal**
⇒ **Δt~3 min ⇒ t = 0.5~8 min before 23:50 UT**
⇒ **drift distance = VE * t = 100~5000 km**
⇒ **dispersion started at 8~9 MLT.**



On the other hand, we observed O+ "wedge" at 0.05-0.3 keV (20 km/s ~ 50 km/s). The 0.05 keV O+ takes 20~30 min to travel from the ionosphere to the Cluster location along B in best case. From this:

(1) **Source timing is about 20~30 min before, i.e., at 23:20~23:30 UT.**

(2) **The combination (b)+(c) cannot be true**, i.e., the observed dispersion is mostly the spatial structure.

(3) O+ pitch angle is uni-direction, i.e., should **not have been mirror-bounced, endorsing point (1).**

H+/O+ differences

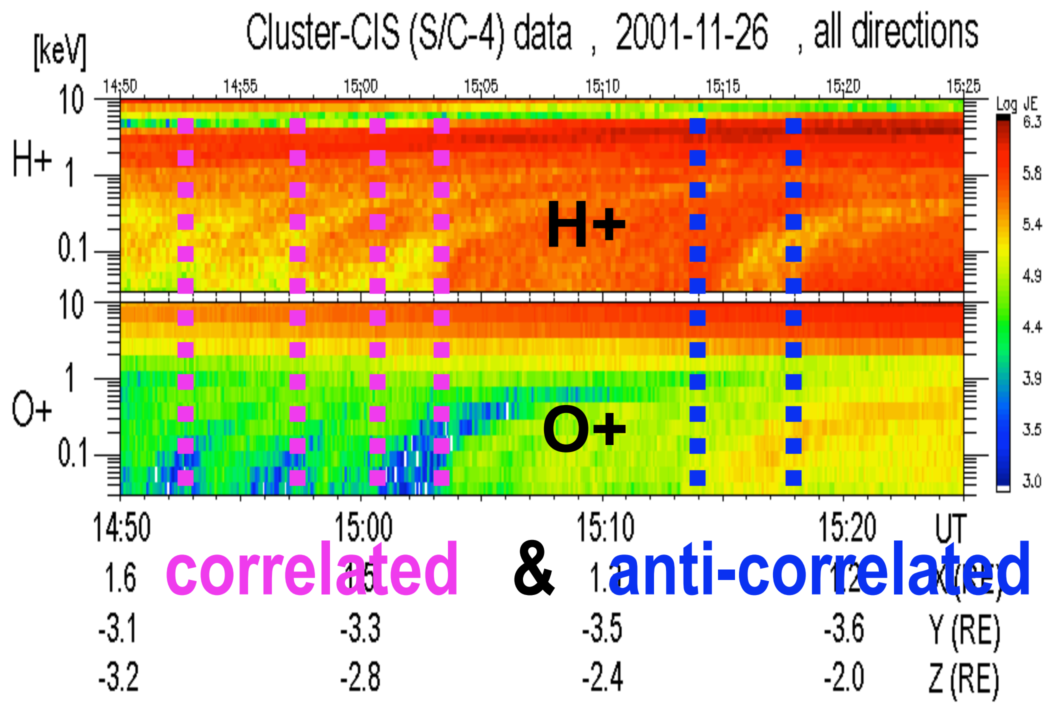
O+ motion ≠ H+ motion

The 2001-10-21 event showed a clear O+/H+ difference inside the wedge, with H+ bounce-averaged feature (with butterfly pitch-angle distribution), whereas O+ is not bounce-averaged.

Statistically the wedge-like structure is O+ rich at low-altitudes (Freja) whereas it is H+ rich as high-altitudes (Cluster).

These fact suggests that **O+ source could be different from H+ source**. We found couple of good Cluster examples that endorse this idea

O+ source ≠ H+ source



Correlation part means that H+ and O+ has the same bounce-average drift motion. Then, **how can we understand the anti-correlation part just 15 minutes later?**

Summary and conclusions

(1) The dispersion might start in the morning for a substantial numbers of the wedge-like structure. This is suggested by the local time distribution, superposed epoch analyses, and a case study on the 2001-10-21 event (source <30 min, <3 RE distance).

(2) Pitch-angle distribution, particularly for O+, suggest ionospheric source (consistent with morning source).

(3) In addition to the altitude dependence of the O+/H+ ratio, O+ are sometimes behaving in a different way from H+.
* non-bounce-average feature (2001-10-21 event).
* correlation and anti-correlation in a single traversal. ⇒ ???

Future task : understand the source of the wedge-like structure for both O+ and H+. This final target is still far away.