Investigation of the formation process of the high-pressure regions driving SAPS fine structures found by Arase-SuperDARN observations

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[e.g., Erickson et al., 2002; Mishin et al., 2003; Foster et al., 2004]

Mishin and Burke (2005):
- wave-like electromagnetic field variations in the magnetosphere
- its wavelength coincided with the scales of the flow variation observed in the ionosphere

CRRES @magnetosphere

E-field variations
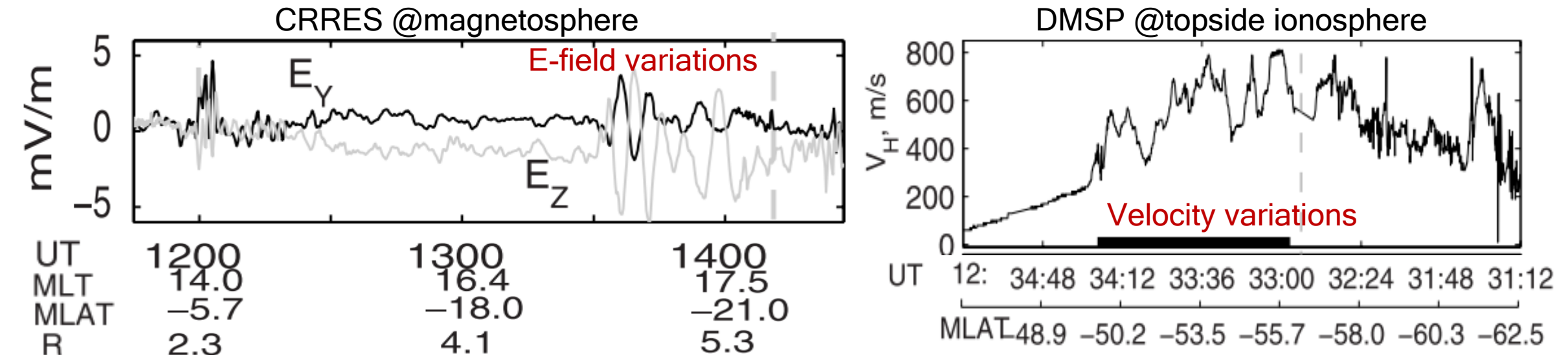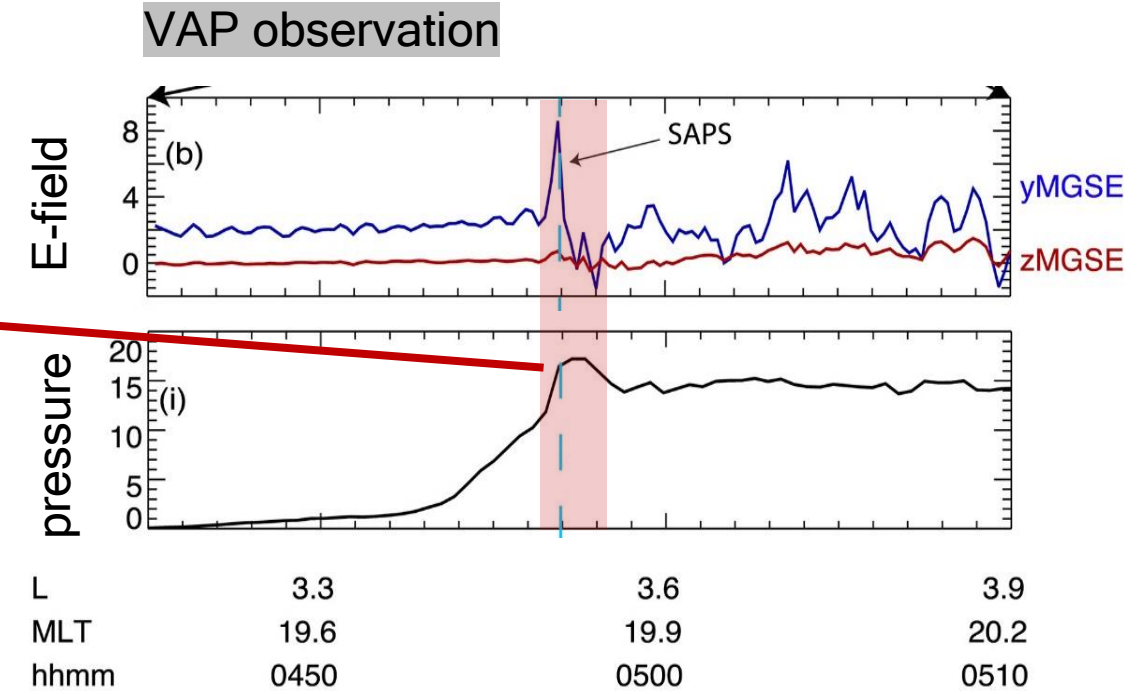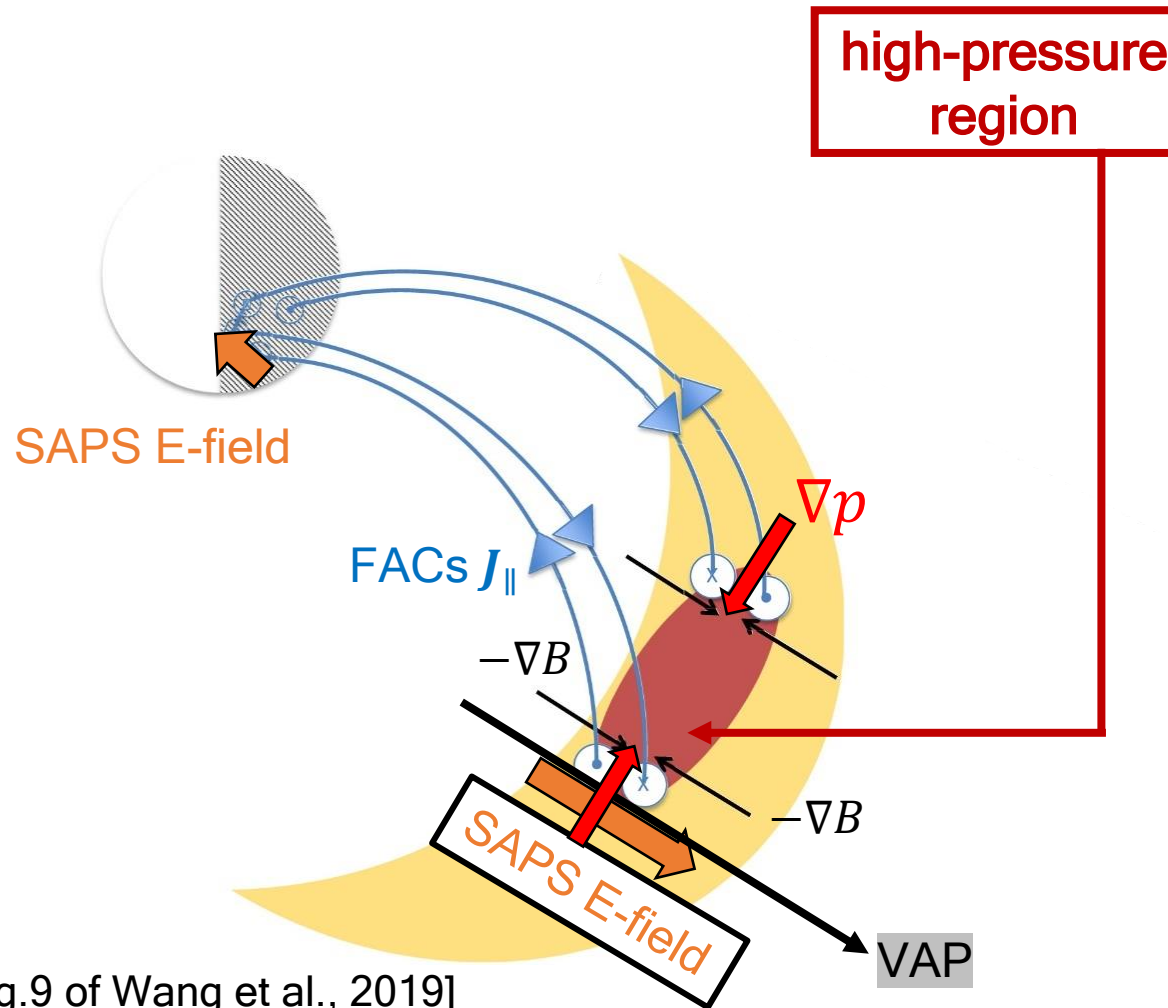
DMSP @topside ionosphere

Velocity variations

Fig.3 and 8 of Mishin & Burke (2005)

Questions about SAPS with variations:
- ◆ Spatial or temporal?
- ◆ Source of variations?

mesoscale SAPS observation [Wang et al., 2019]
→current generator theory [Anderson et al., 1993] was
applied to fine-structured SAPS

VAP observation

high-pressure region

SAPS E-field

FACs $J_\parallel$

∇p

$-\nabla B$

$-\nabla B$

SAPS E-field

VAP

[Fig.9 of Wang et al., 2019]

Verification:
◆ Source: magnetospheric hot ion?
◆ Originated from spatial structures?
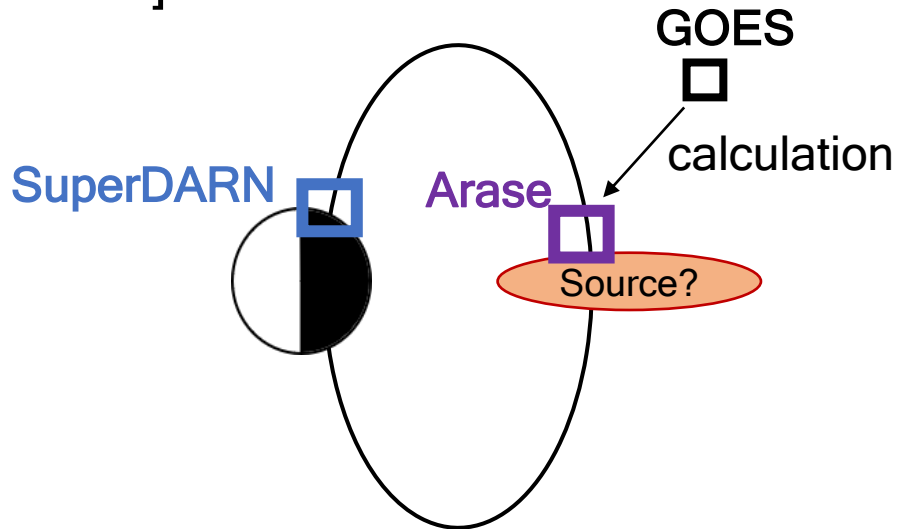   (SAPS fine structures, SAPS-FS)

A two-dimensional analysis based on the
M-I conjugated observation is needed.

[purpose]

> To discuss the formation process of SAPS-FS
> ◆ distinguishing spatial or temporal variations
> ◆ revealing the source plasma of SAPS-FS

[dataset]

GOES

calculation

SuperDARN   Arase

Source?

SuperDARN (Christmas Valley East, CVE):
• verify spatial or temporal variations
• infer two-dimensional pictures of SAPS source plasma

+

Arase [Miyoshi, Shinohara et al., 2018]
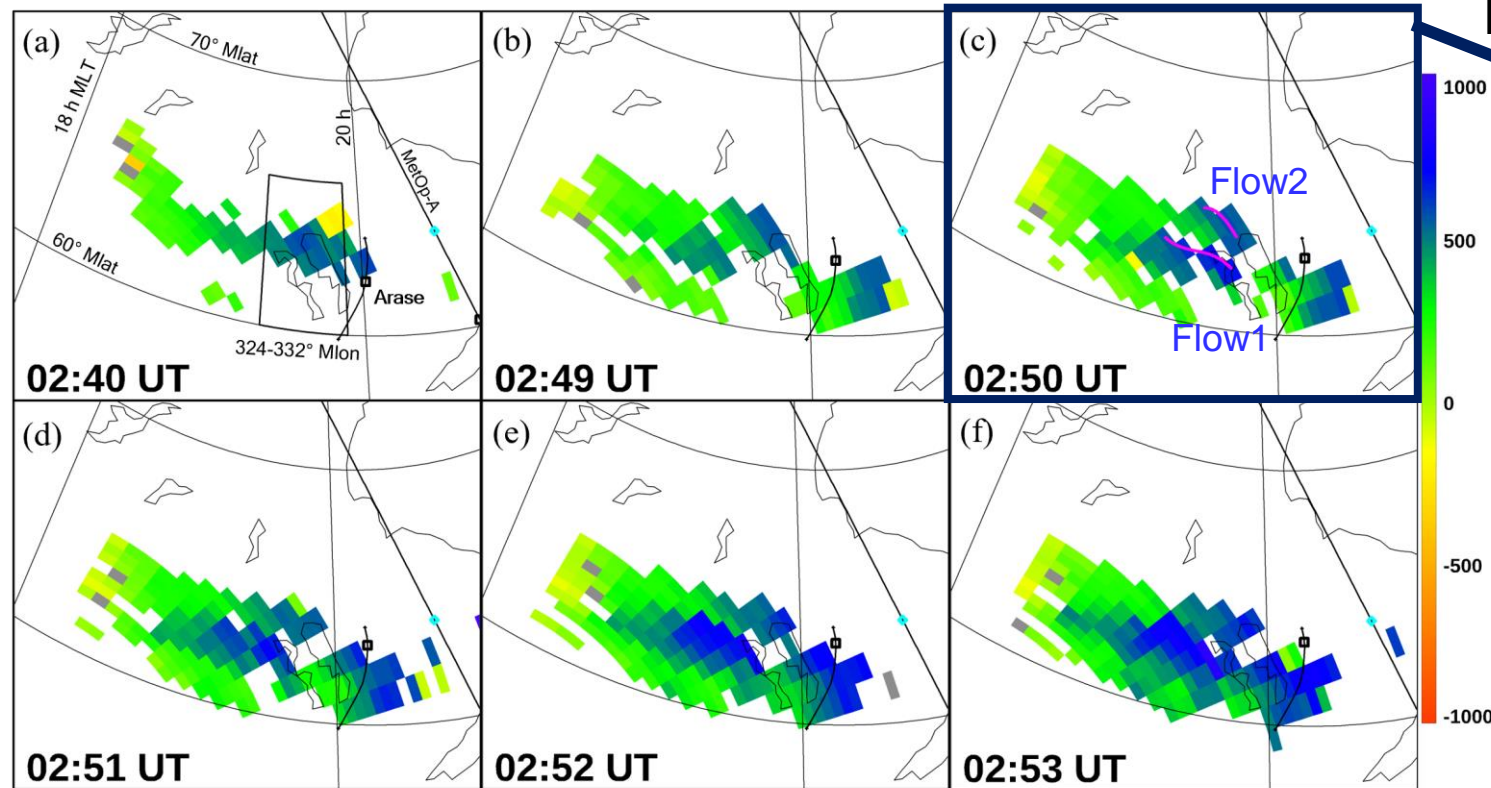• measure plasma conditions and electromagnetic fields

+

GOES, Upstream calculation
• investigate the origin of the source plasma
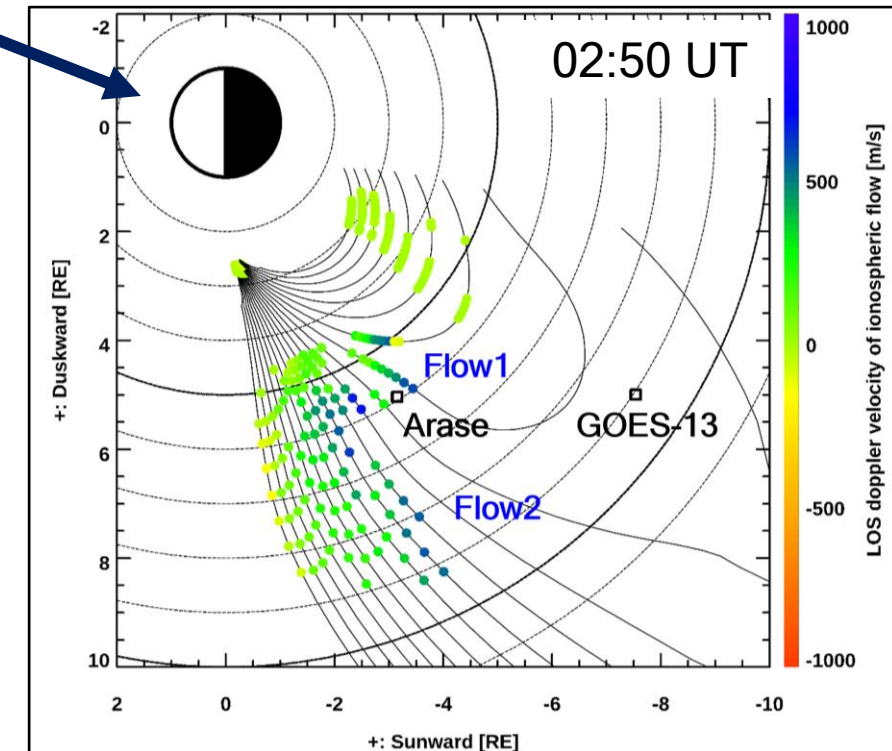
[approach]
◆ investigating FAC, electric field, and hot ion's pressure distributions in the magnetosphere
◆ verifying the applicability of CG theory to SPAS-FS   [e.g., Wang et al., 2019; Makeravich & Bristow, 2014]
◆ considering the transport and formation of source regions

Blue: Doppler velocity toward the radar

projection IGRF+T04s*

Magnetic equator

(a) 70° Mlat, 18 h MLT, 20 h, MetOp-A, 60° Mlat, Arase, 324-332° Mlon, 02:40 UT
(b) 02:49 UT
(c) Flow2, Flow1, 02:50 UT
(d) 02:51 UT
(e) 02:52 UT
(f) 02:53 UT

02:50 UT

◆ latitudinal interval ~1.7°(±0.3°)
◆ SAPS-FS kept their structures and moved equatorward with 0.3 km/s

T04s* [Tsyganenko & Sitnov, 2005]

projection

	Flow1	Flow2
projected location [R_E]	6	8
	Flow1-Flow2	
Time interval expected to be observed by Arase [sec]	4×10^2	
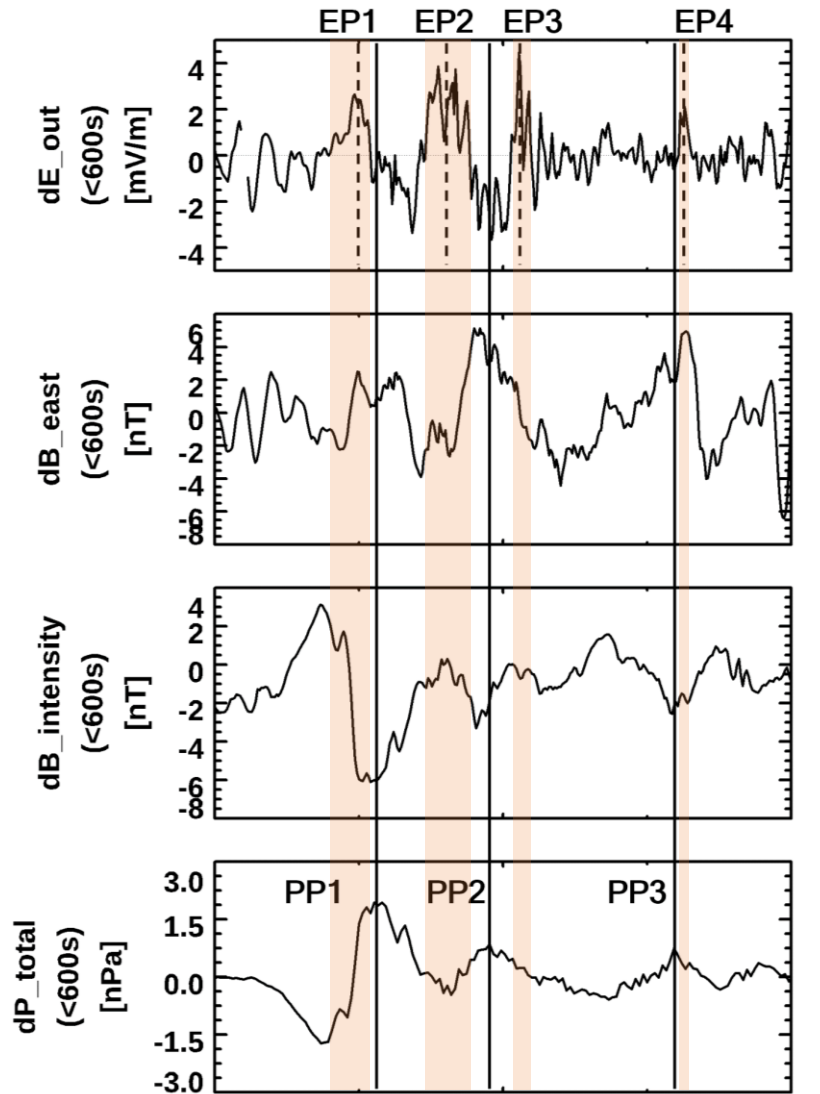
PP1-3 coincided with
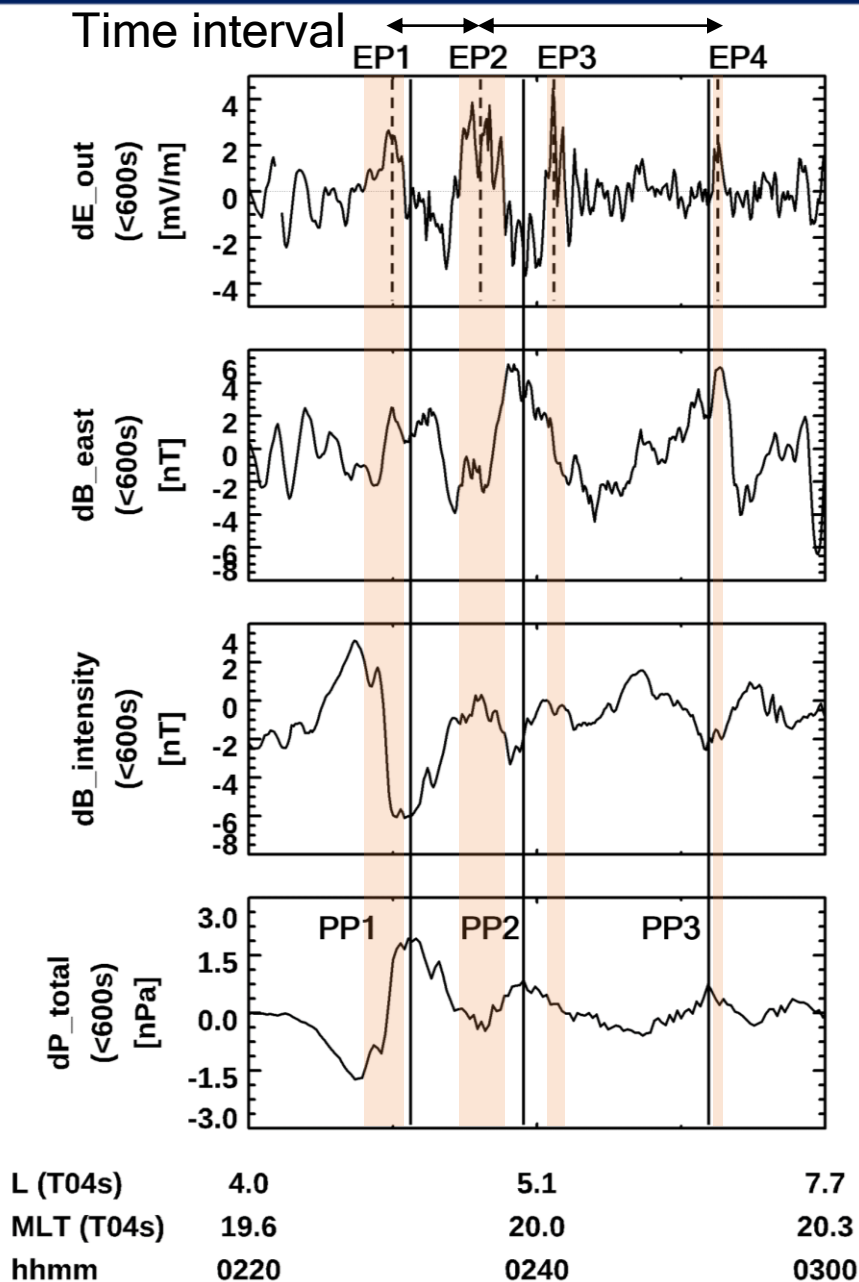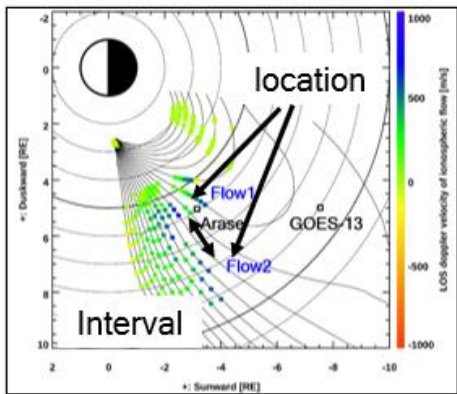・(c) local minimum of B intensity (←diamagnetic effect)
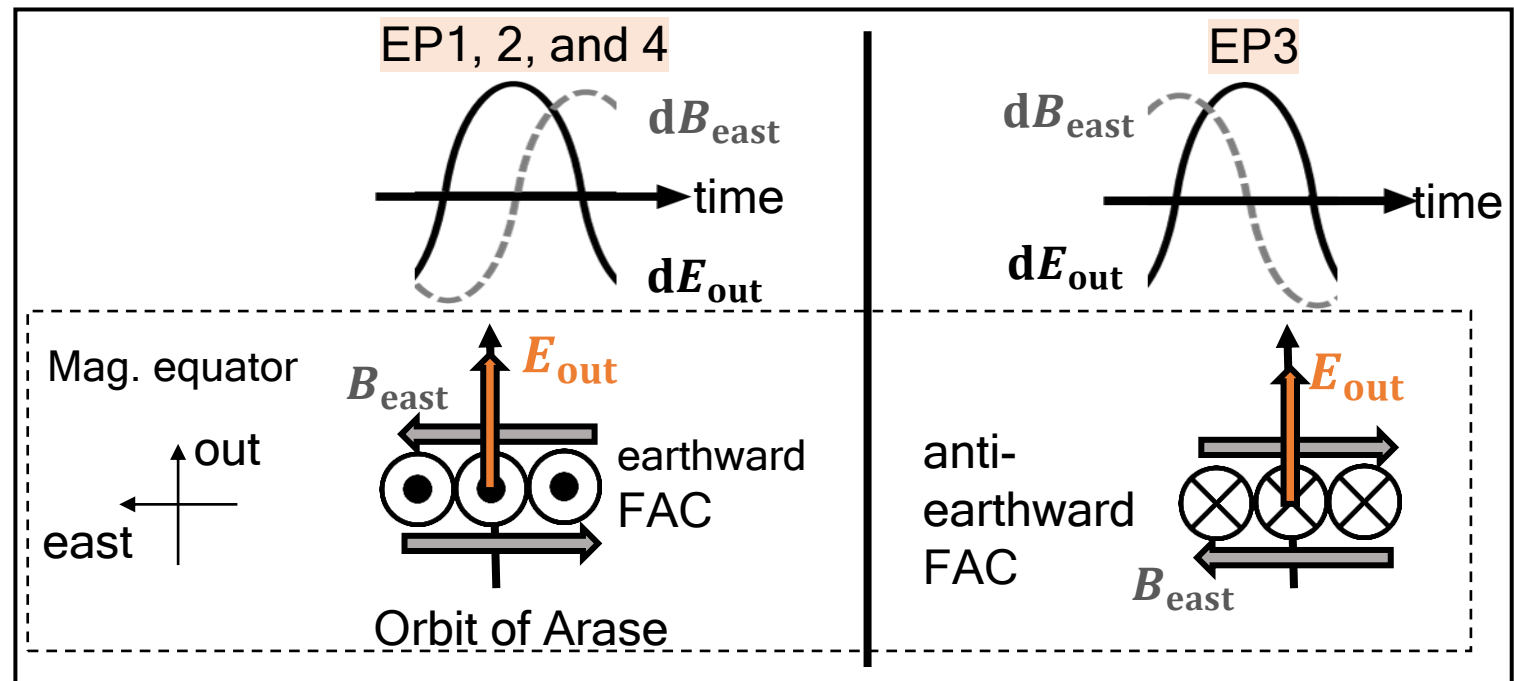
EP1, 2, and 4 can be interpreted with the current generator.
[e.g., Wang et al., 2014]

EP3 is possible to be derived from ionospheric effect.
[e.g., Streltsov and Mishin, 2003]

Time interval

Locations and time intervals of EP1, 2, and 4 on the magnetic equator

	SuperDARN		Arase		
	Flow1	Flow2	EP1	EP2	EP4
Projected location [R_E]	6	8	4.5	4.8	6.6
	Flow1-Flow2		EP1-EP2		EP2-EP4
Time interval [s]	4×10^2		3.8×10^2		1.0×10^3

One-to-one correspondence was not confirmed.
However, it was supported that <u>the corresponding structures were formed in both the ionosphere and magnetosphere.</u>
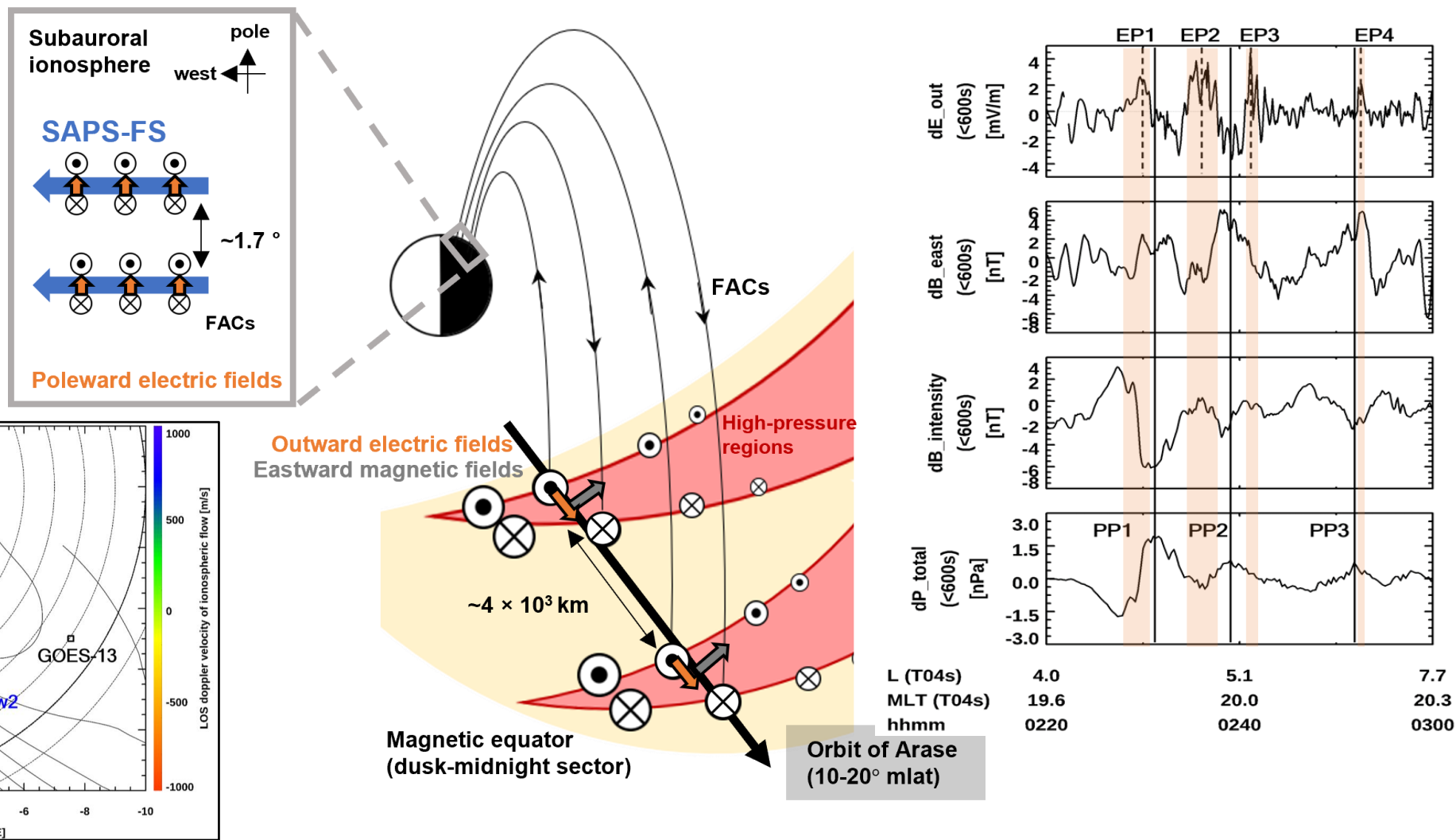
◆ Fine-structured E-fields were found in both the ionosphere and magnetosphere.
◆ They could be interpreted with current generator theory.

➡ The transport and formation process of the source regions?

Simulation model

- Spatial range: L=2 to 8, 0h to 24h MLT

The followings are considered:
- E × B drift, gradient B. drift
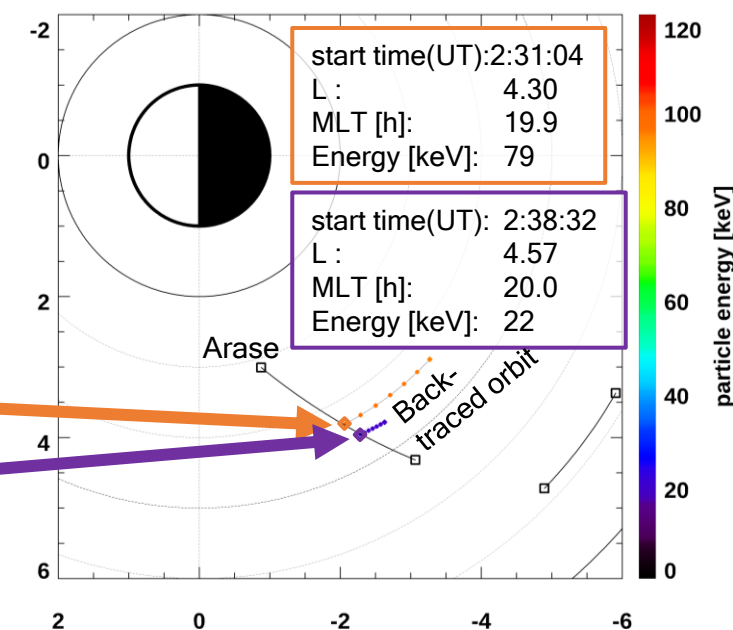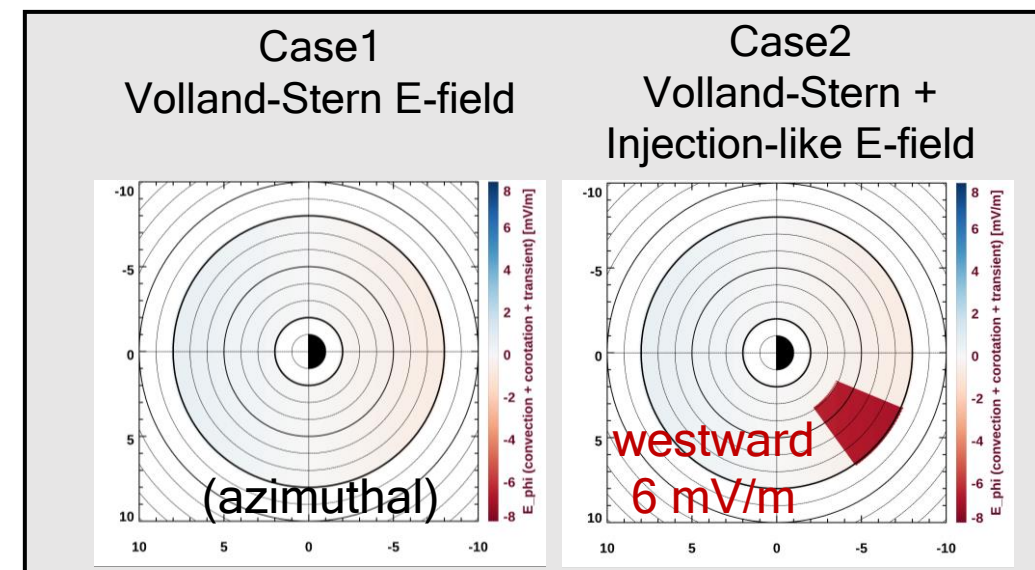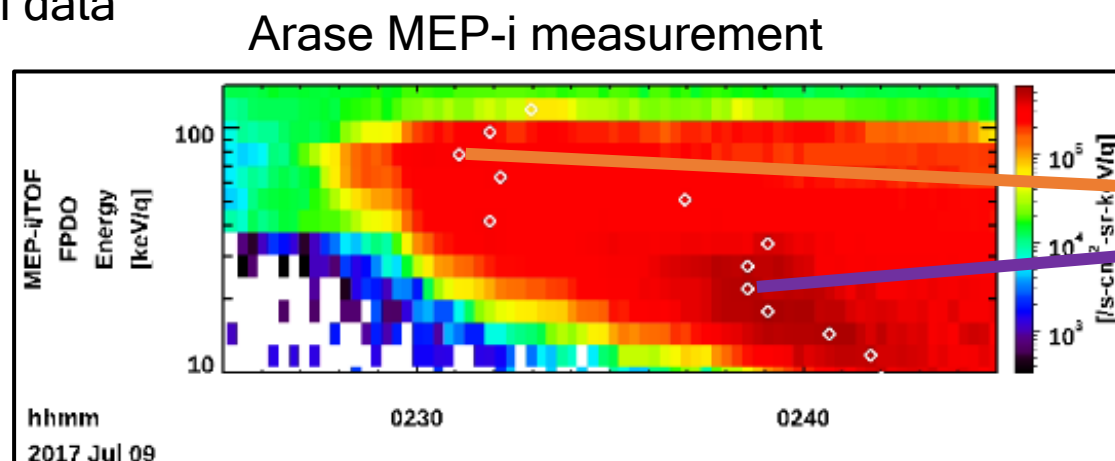- Betatron acceleration due to dB/dt
- Background:

Case1: Volland-Stern E-field [Volland (1973); Maynard & Chen]
Case2: Volland-Stern + injection-like E-field (based on the injection speed reported by Reeves et al., 1996)

Case1
Volland-Stern E-field

(azimuthal)

Case2
Volland-Stern +
Injection-like E-field

westward
6 mV/m

Initial conditions of particles

:determined based on the
Arase's position and MEP-i data

Arase MEP-i measurement

White markers:
proton flux enhancements
in each energy bin

start time(UT):2:31:04
L :   4.30
MLT [h]:   19.9
Energy [keV]: 79

start time(UT): 2:38:32
L :   4.57
MLT [h]:   20.0
Energy [keV]: 22

Arase

Back-traced orbit

particle energy [keV]

◆Calculated drift path in injection E-field case (Case2) is more reasonable.
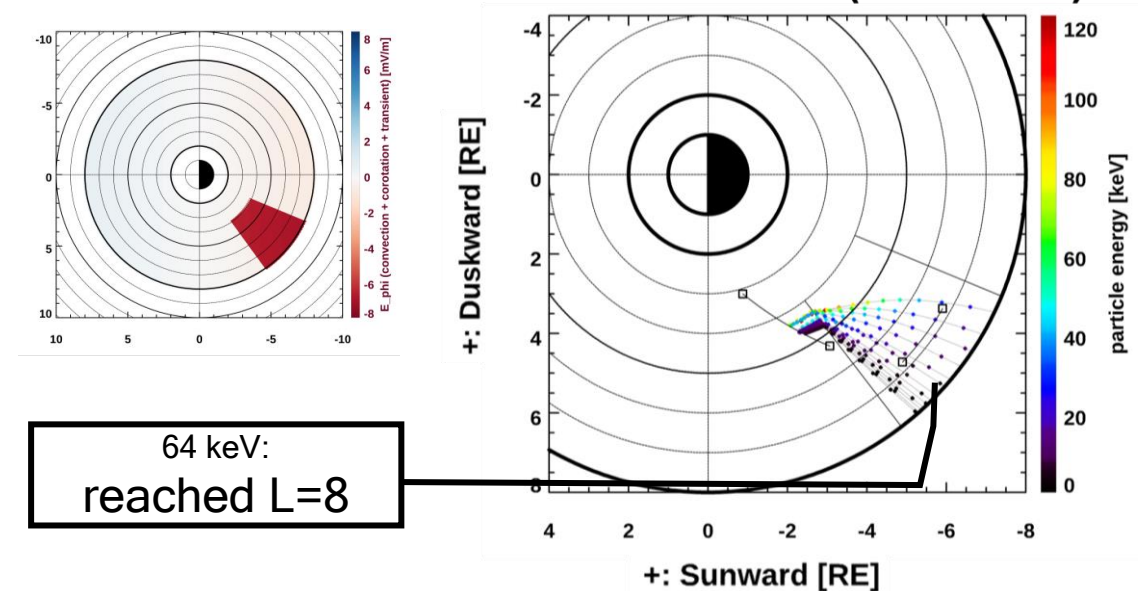
Case1 simple convection
- >~50 keV protons stayed at L~3 – 4.
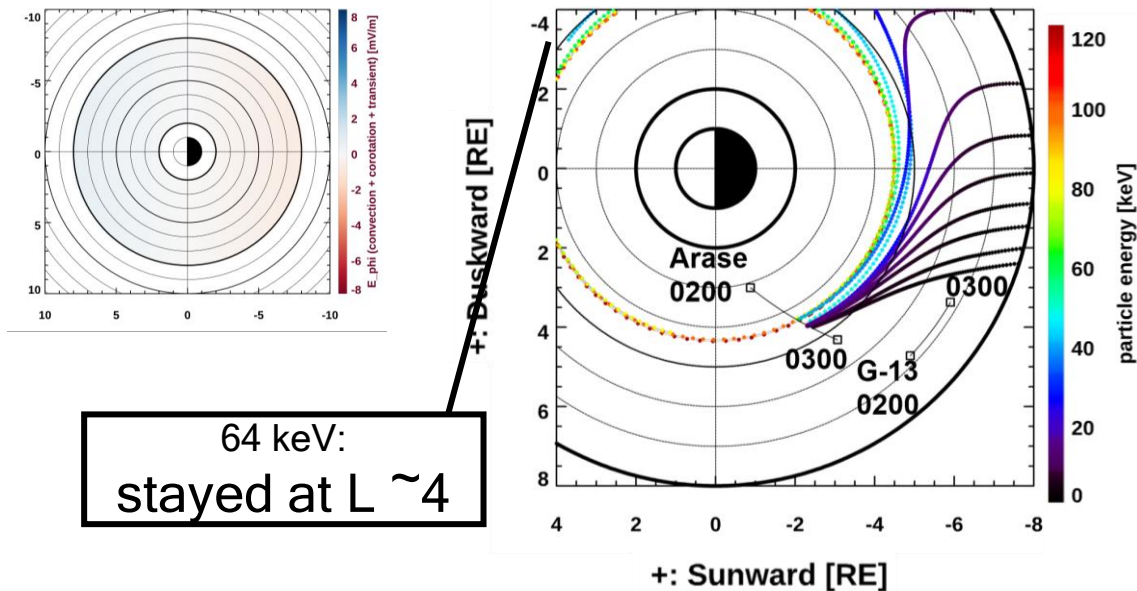
Case2 additional E-field
- all protons reached L=8.

64 keV:
stayed at L ~4

64 keV:
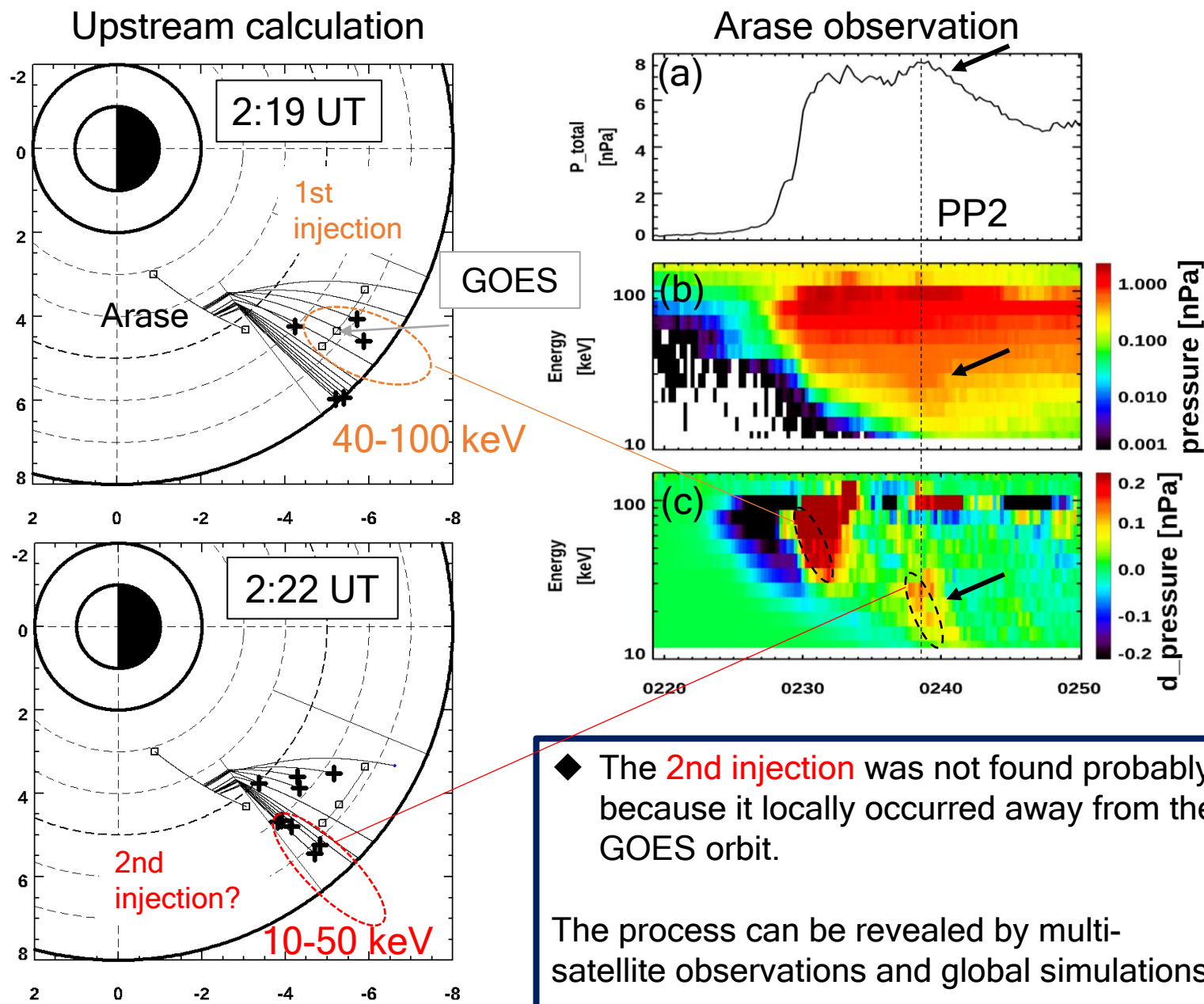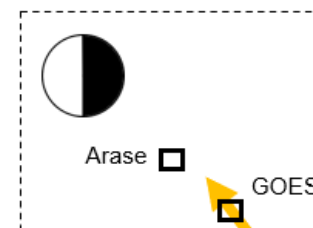reached L=8

◆GOES-13 observed single injection prior to SAPS-FS
The estimated injection speed ~31 km/s was consistent with previous studies [e.g., Reeves et al., 1996]

◆ Hot protons were likely to be transported with injection electric field

Upstream calculation

2:19 UT

1st injection

GOES

Arase

40-100 keV

2:22 UT

2nd injection?

10-50 keV

Arase observation

(a)

PP2

(b)

(c)

◆ The 2nd injection was not found probably because it locally occurred away from the GOES orbit.

The process can be revealed by multi-satellite observations and global simulations.

single injection

Arase
GOES
1st injection

Arase observation

(a)

(b)

Multiple injections

Arase
GOES
2nd injection

(a)

(b)

Multiple E-fields can form the pressure peaks.

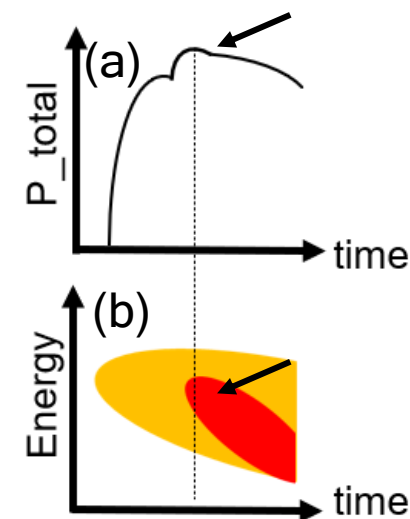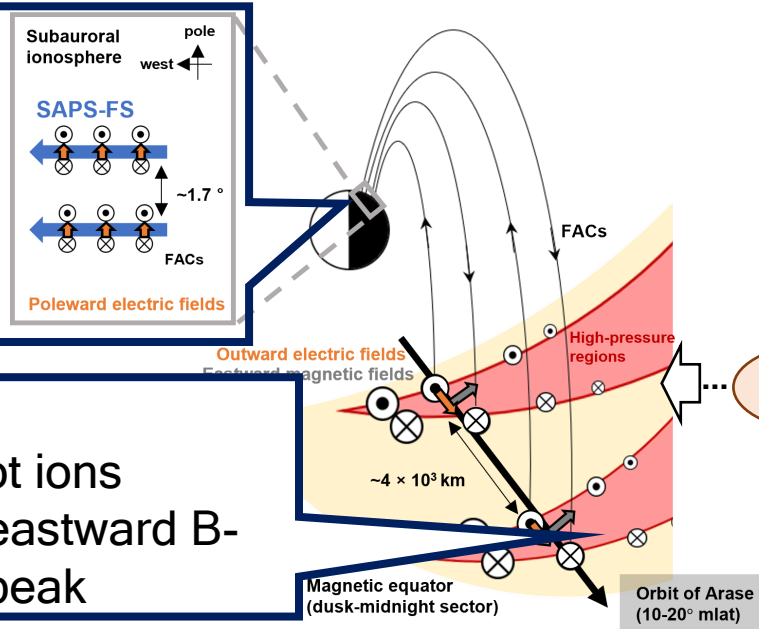**Purpose:** discussion about the formation process of SAPS-FS based on the conjugated observations of 2D radar and magnetospheric satellite

Results:

SuperDARN CVE
◆ Fine-structured flows moved with keeping their structures

Subauroral ionosphere
pole
west

SAPS-FS

~1.7 °

FACs

Poleward electric fields

GOES-13
◆ single **injection**
→hot ions originated from the injection

Outward electric fields
Eastward magnetic fields

FACs

High-pressure regions

injection

Arase
◆ E-field variations and hot ions
◆ E-field and increase of eastward B-field near the pressure peak

~4 × 10³ km

Magnetic equator (dusk-midnight sector)

Orbit of Arase (10-20° mlat)
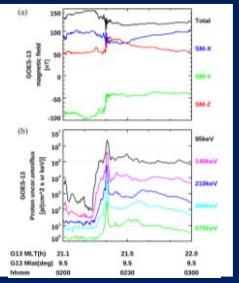
◆ hot proton could come from the nightside plasma sheet if any additional E fields were formed by injections
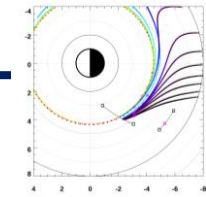
Discussion:
◆ SAPS-FS analyzed in this study can be explained with **current generator theory**.
    : **Multiple fine high-pressure regions** extending in the azimuthal direction
      (Estimated FAC density based on DMSP-Arase observations support the model)
◆ Injection possibly contributes to the transport of the source plasma of **SAPS-FS**

Remained questions:
◆ The contribution of the ionospheric feedback effect
◆ The formation process of the ion pressure peaks

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- Foster et al., (2004). Millstone Hill coherent-scatter radar observations of electric field variability in the sub-auroral polarization stream. *Geophysical Research Letters*, 31(21), 0094-8276. https://doi.org/10.1029/2004GL021271

- Mishin and Burke (2005). Stormtime coupling of the ring current, plasmasphere, and topside ionosphere: Electromagnetic and plasma disturbances. Journal of Geophysical Research: Space Physics, 110(A7), 1-13. https://doi.org/10.1029/2005JA011021

- Miyoshi and Shinohara et al. (2018). Geospace exploration project Arase. *Earth, Planets and Space*, 70(1). https://doi.org/10.1186/s40623-018-0862-0

- Reeves et al. (1996). Radial propagation of substorm injections. In E. J. Rolfe, & B. Kaldeich (Eds.), ESA SP-389International Conference on Substorms, *Proceedings of the 3rd International Conference held in Versailles*, 12-17 May 1996, (pp. 579-585). Paris: European Space Agency.

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- Wang et al., (2019). Multi-instrument Observations of Mesoscale Enhancement of Subauroral Polarization Stream Associated With an Injection. *Journal of Geophysical Research: Space Physics*, 124(3), 1770-1784. https://doi.org/10.1029/2019JA026535

- Wang et al., (2014). The spatial distribution of region 2 field-aligned currents relative to subauroral polarization stream. *Annales Geophysicae*, *32*(5), 533-542. https://doi.org/10.5194/angeo-32-533-2014