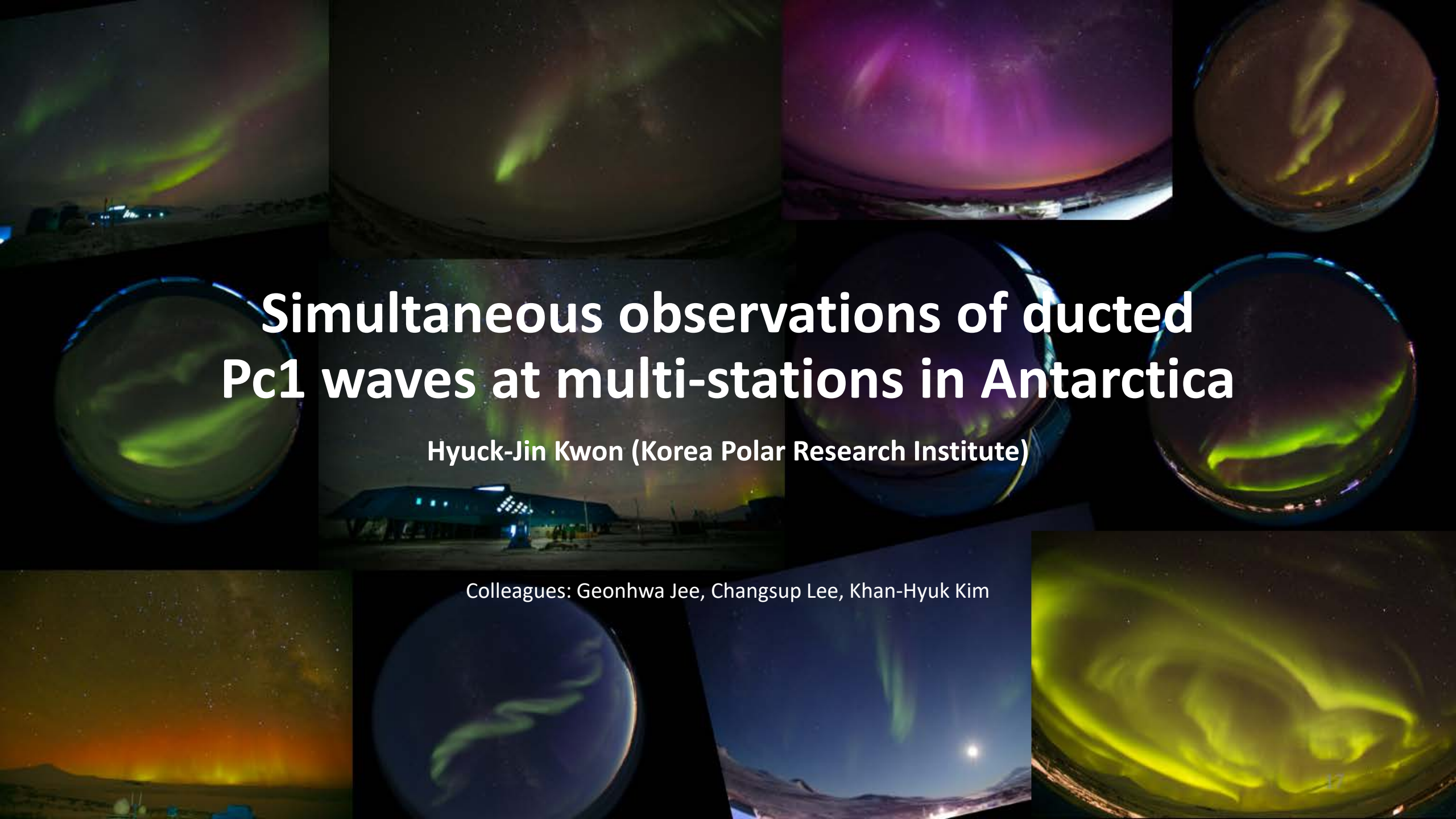


Simultaneous observations of ducted Pc1 waves at multi-stations in Antarctica

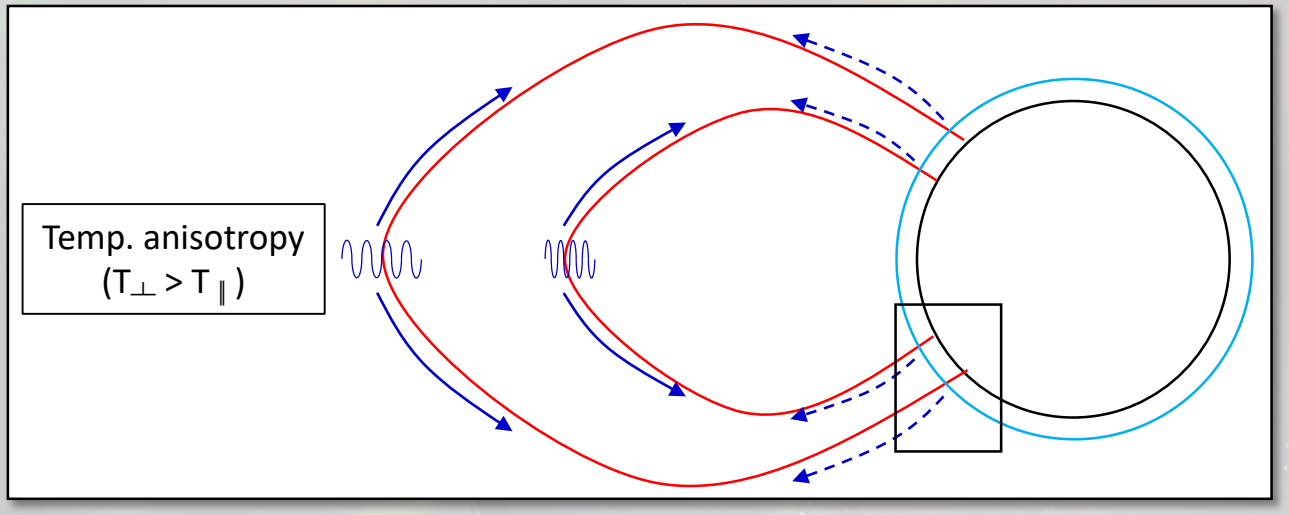
Hyuck-Jin Kwon (Korea Polar Research Institute)

Colleagues: Geonhwa Jee, Changsup Lee, Khan-Hyuk Kim

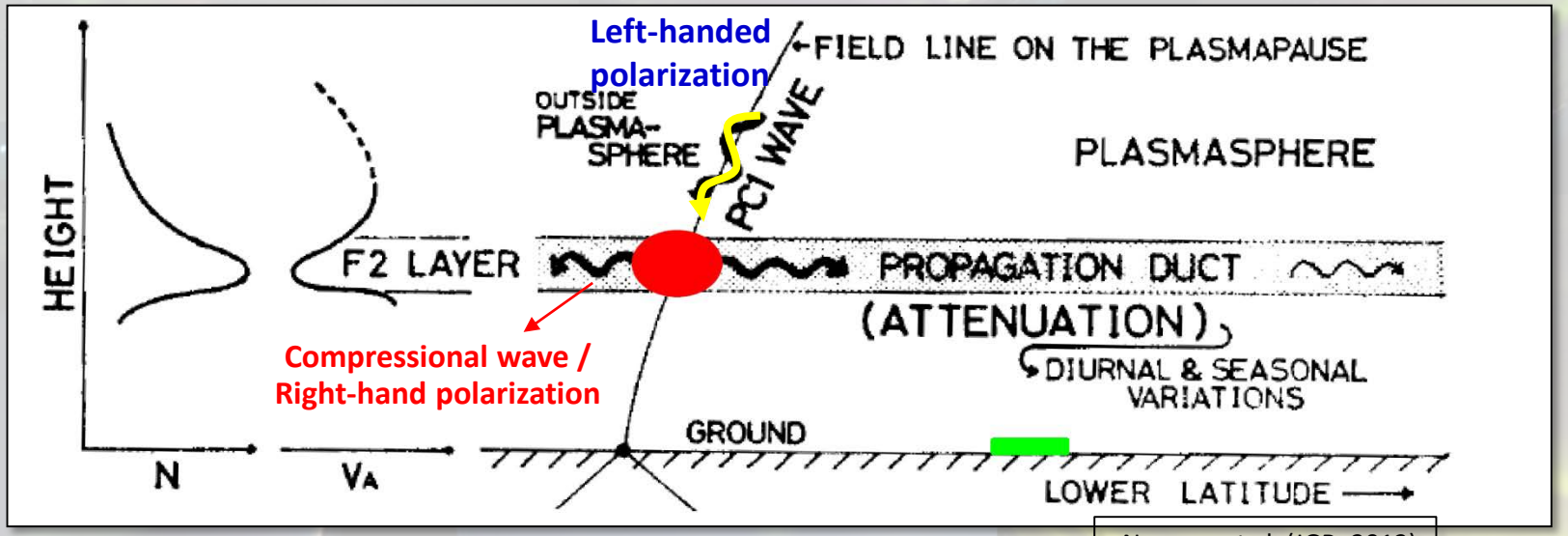
Agenda

- Introduction
- Data set
- Case event
- Statistical event
- Pc1 waves in the ionosphere
- Summary

Introduction



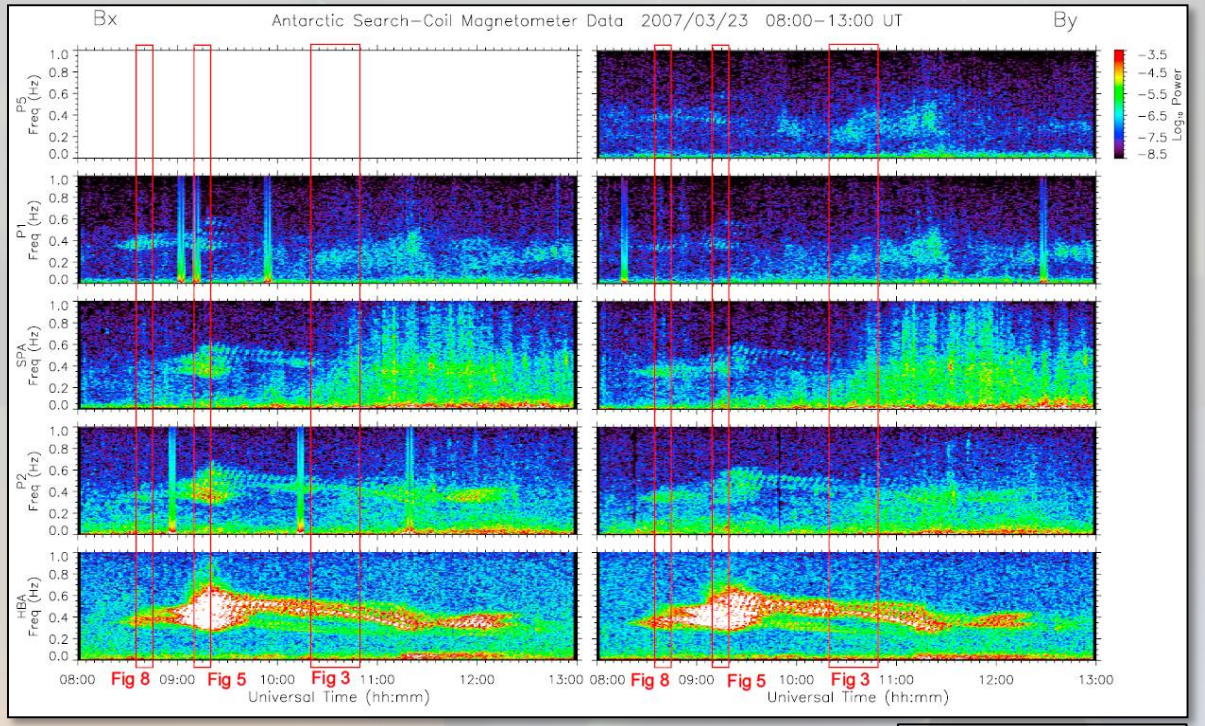
Pulsations type	Periods (s)	Frequency (mHz)
Pc1 (EMIC)	**0.2 – 5**	**200 – 5000**
Pc2	5 – 10	100 – 200



Nomura et al. (JGR, 2012)

Introduction

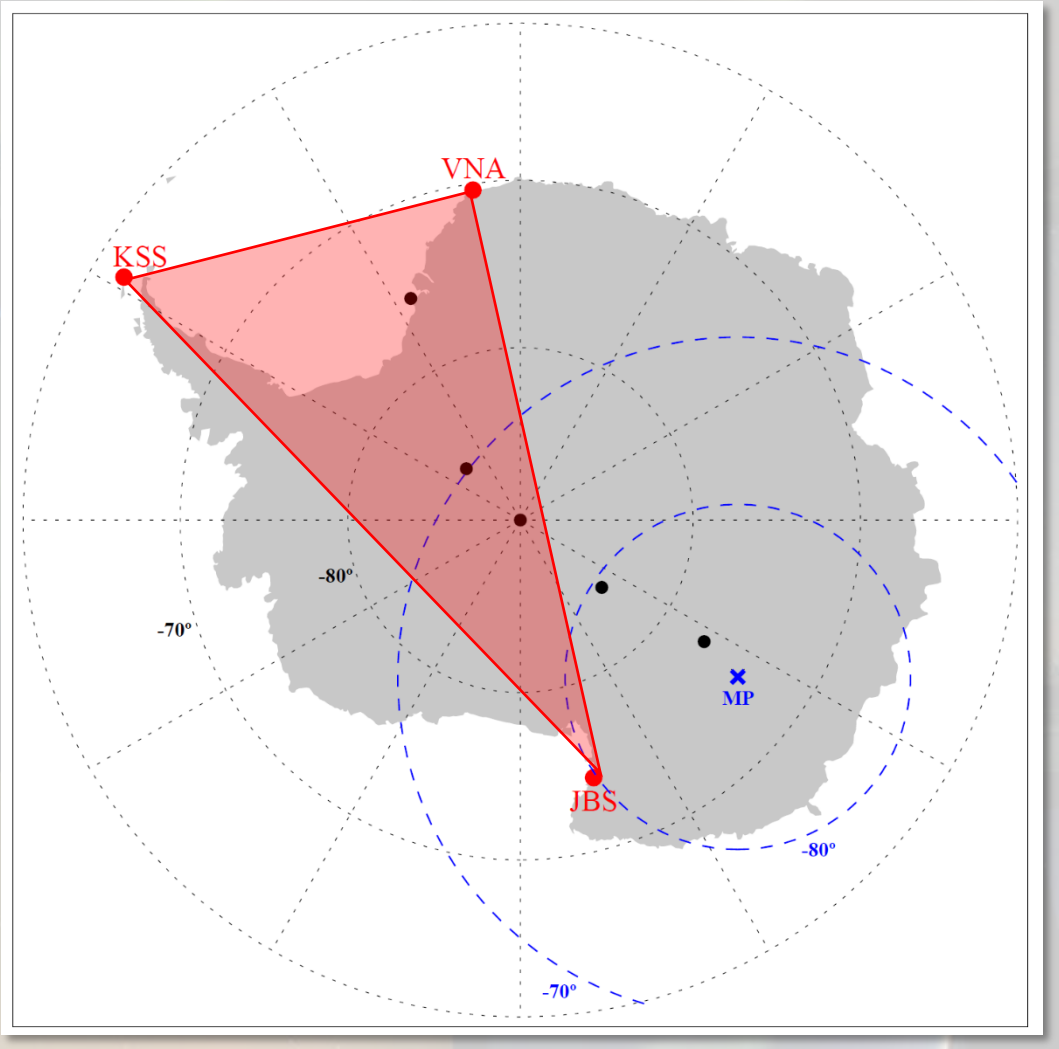
- A waveguide theory for ionospheric propagation of MHD waves and mode conversion through collision processes in the ionosphere [*Tepley and Landshoff*, 1966].
- Duct propagation is most efficient along the magnetic meridian [*Greifinger and Greifinger*, 1973].
- Small attenuation during night hours, but it is large during the day, because increased electron density [*Manchester*, 1966].
- Left handed polarization in space and convert to right handed polarization as propagation in the ionosphere [*Greifinger*, 1972; *Fujita and Tamao*, 1988].



Kim et al.(JGR, 2010)

Paper	Latitudinal range
Fraser (1975)	66.6 – 49.0° N
Hayashi et al. (1981)	75.1 – 53.7° N
Engebretson et al. (2002)	74.0 – 66.5° S
Neudegg et al. (2002)	75.6 – 70.5° S
Kim et al. (2010)	86.7 – 61.2° S

Motivation



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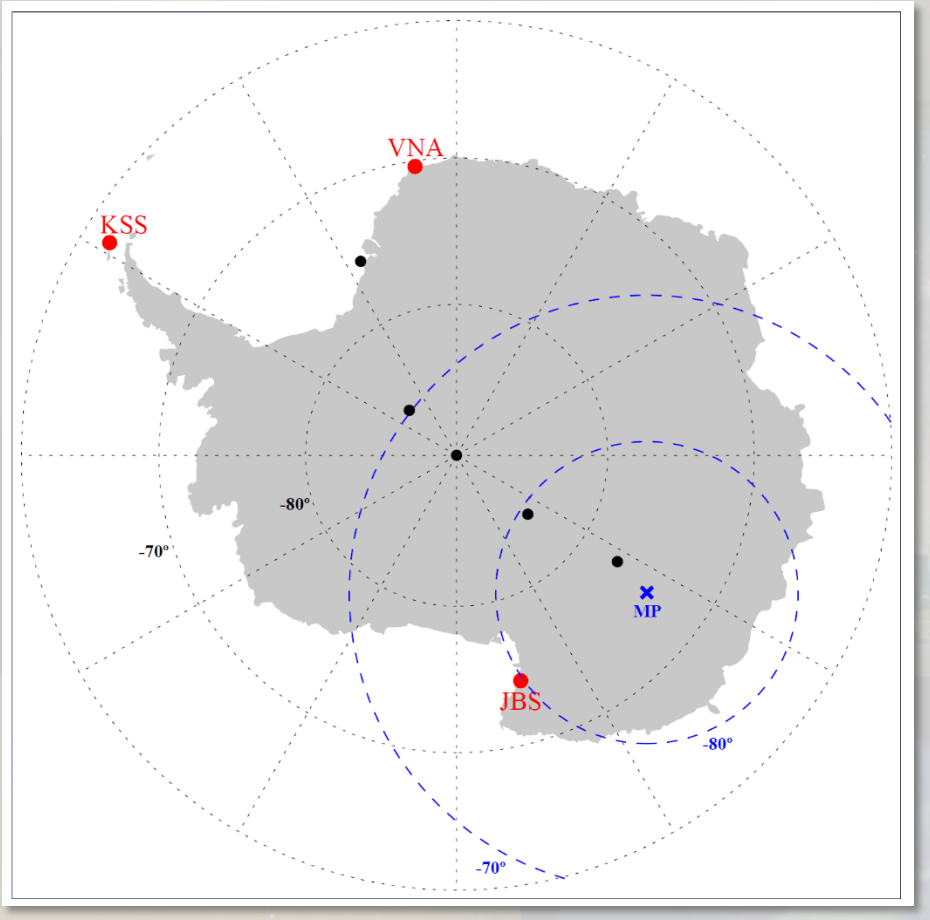
Kim et al. (2010)	86.7 – 61.2° S

Station	GM Lat.	GM Long.
Jang Bogo	79.7° S	54.4° W
Neumayer	60.5° S	42.88° E
King Sejong	48.5° S	12.3° E

Wide range and crossing the plasmapause

Data set



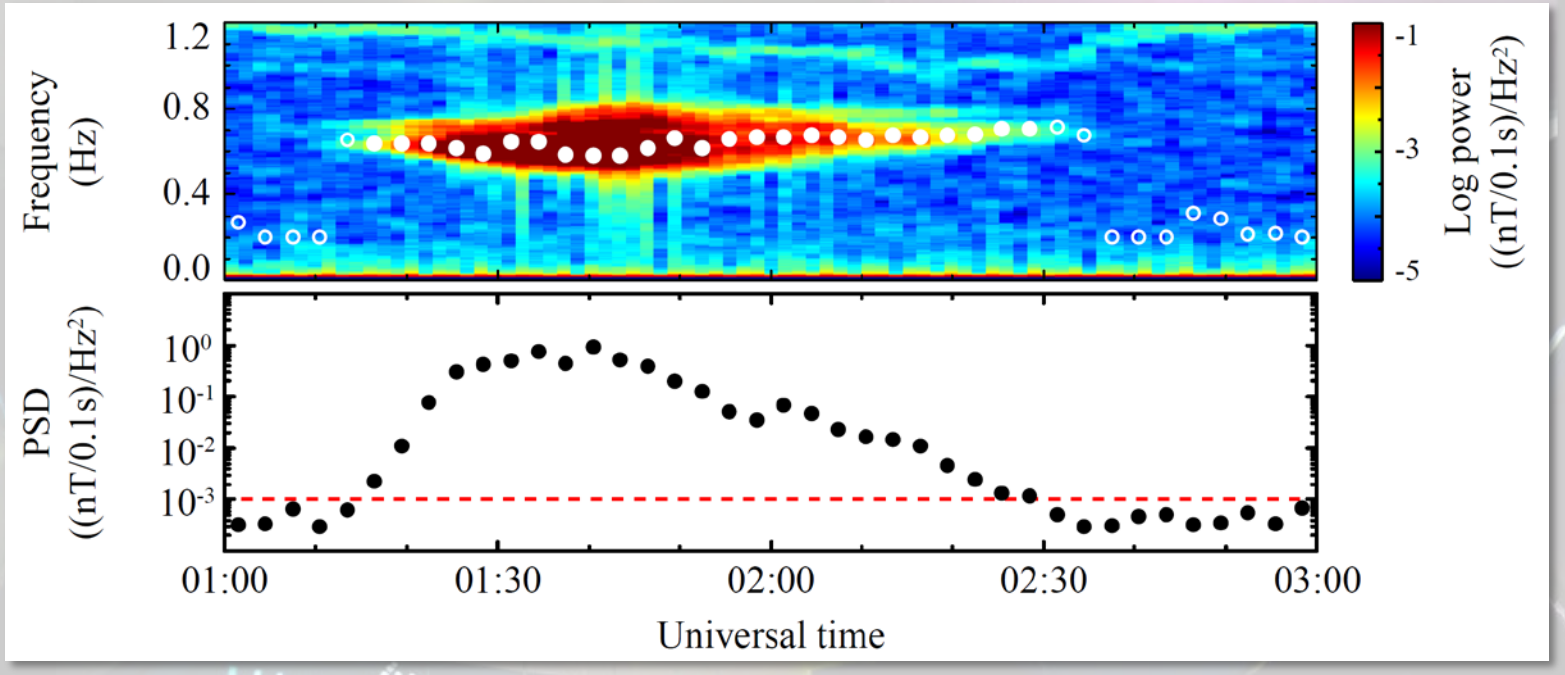
- Ground search-coil magnetometer data

Station	Geographic (deg)	Geomagnetic (deg)	Magnetic local time
Jang Bogo (JBS)	-74.37 / 164.13	-79.72 / -54.43	UT +15.35
Neumayer (VNA)	-70.40 / -8.16	-60.45 / 42.88	UT -4.20
King Sejong (KSS)	-62.13 / -58.47	-48.47 / 12.32	UT -2.17

  - Sampling rate – JBS: 10 Hz / KSS: 20 Hz / VNA: 20 Hz
  - Re-sampled down to 10 Hz
  - Interval: 2019/03 ~ 2019/12

- Swarm data
  - High resolution (50 Hz) magnetic field data → 10 Hz
  - 2nd order poly-fitting
  - Convert coordinates from NEC to BFA (Background Filed Aligned)

Event selection

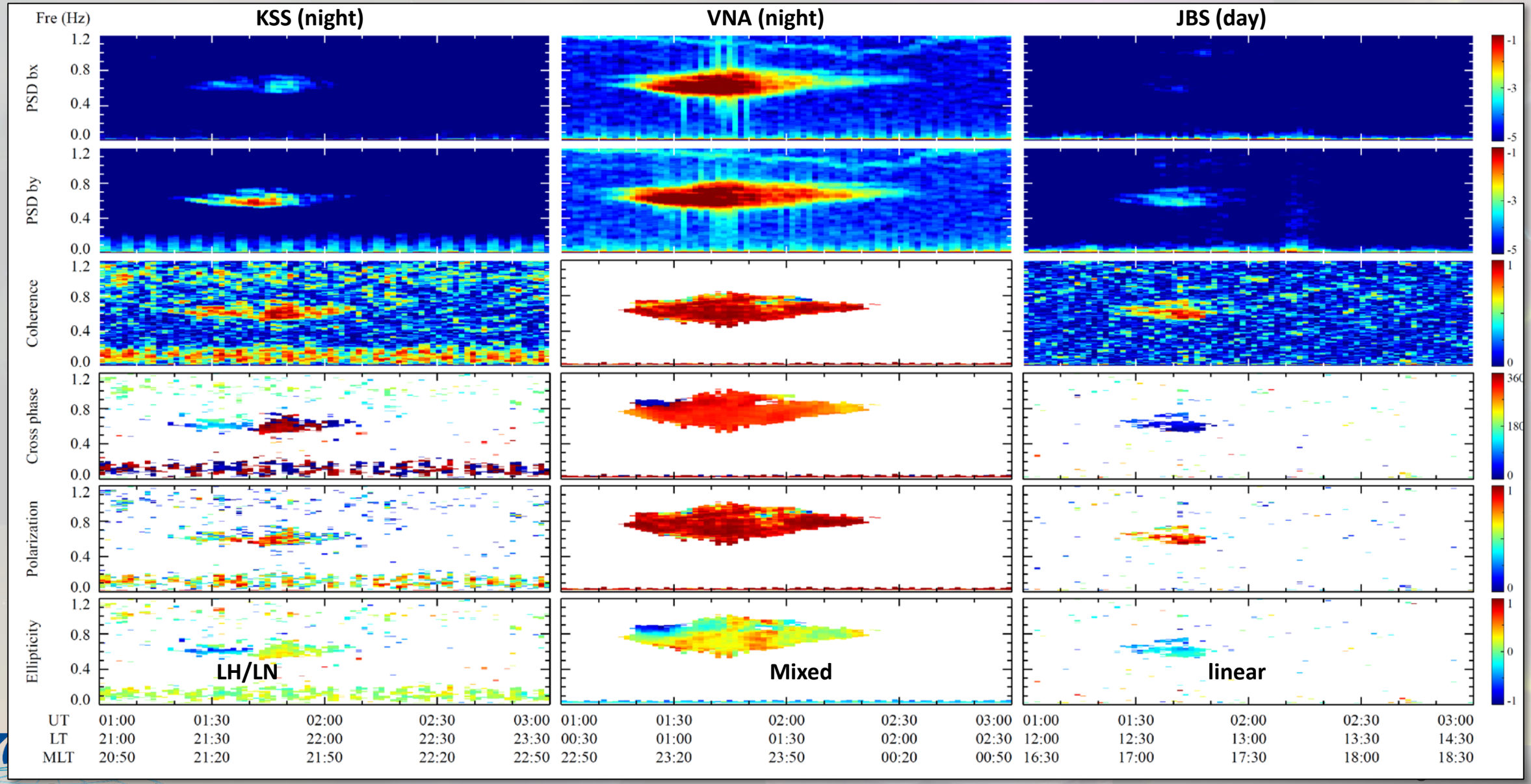


- Transverse component of PSD

$$\mathrm{PSD_{tr}} = \mathrm{PSD_x} + \mathrm{PSD_y}$$

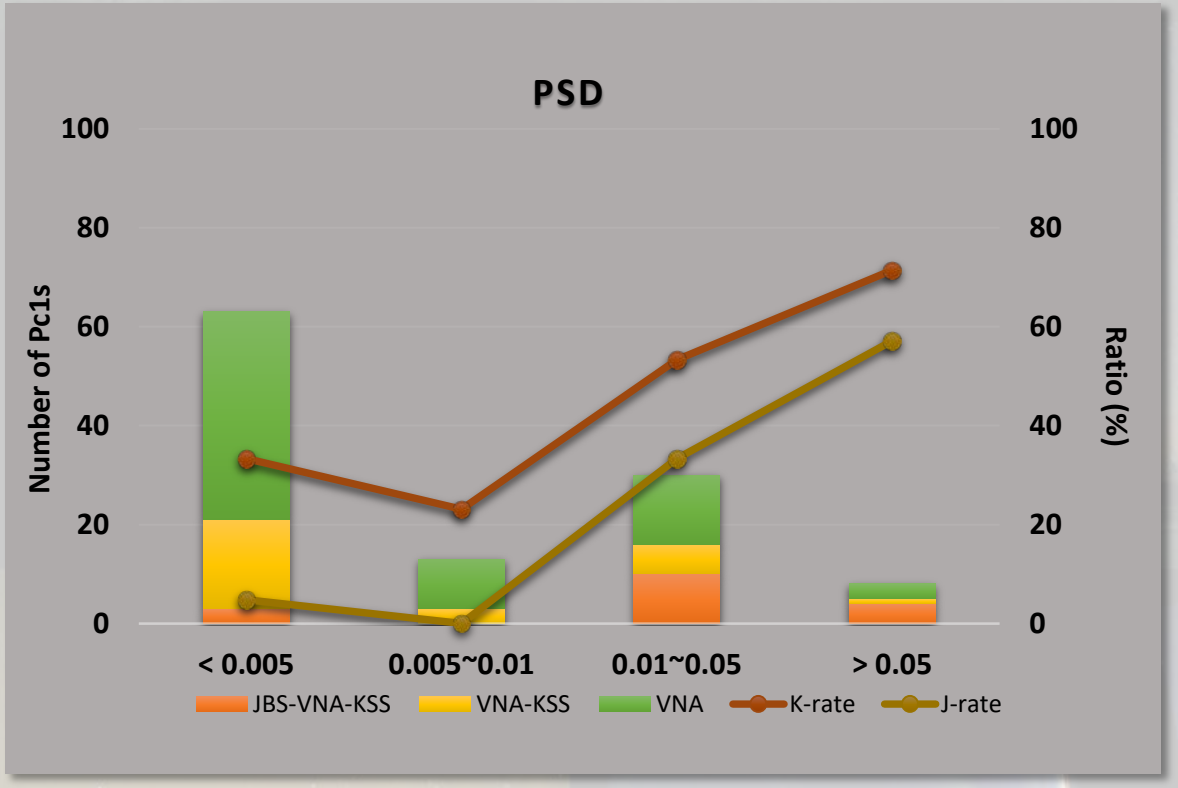
- PSD criteria: 10^{-3} [(nT/0.1s)/Hz^2]
- Low cut off frequency: 200 mHz
- Duration time: over than 10 min

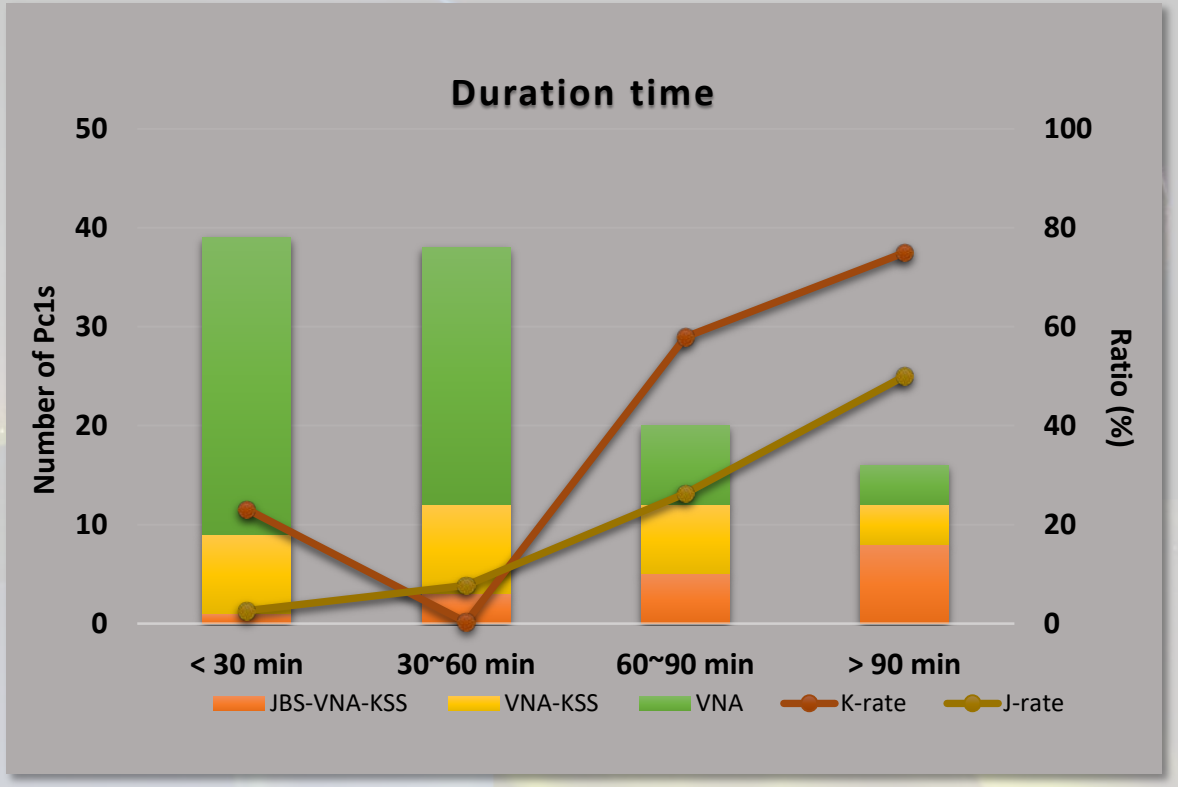
Case event: 28 May 2019



Statistical anlaysis

- Pc1 waves at VNA: 113 events from Mar to Dec in 2019
  - Ducting Pc1: 45 waves at KSS (40%)
  - 17 waves propagating to JBS and KSS (15%)



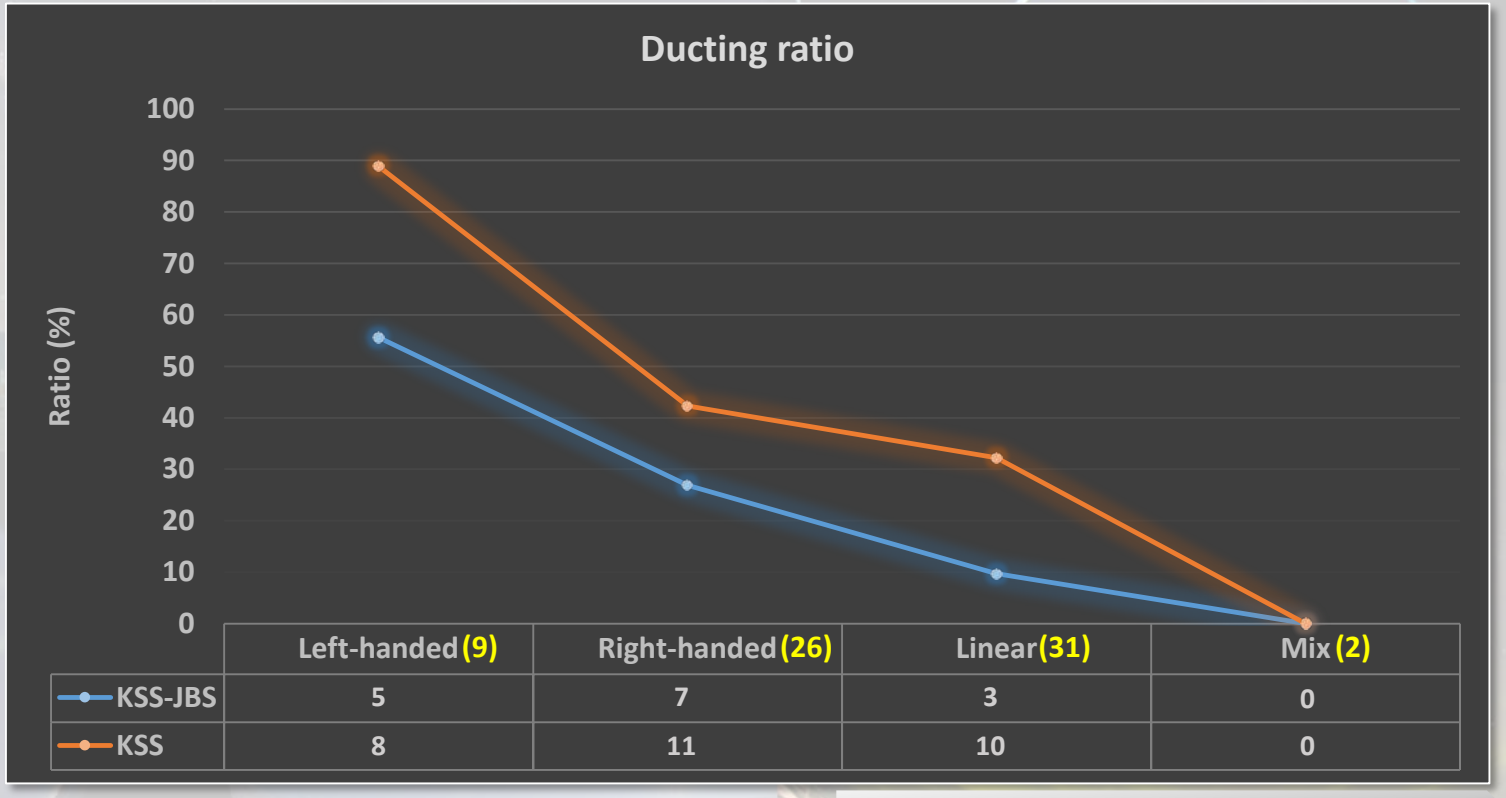


Statistical analysis

	VNA	VNA-KSS	JBS-VNA-KSS
Low coh. ($\gamma < 0.6$)	45	16 (35.6%)	2 (4.4%)
High coh. ($\gamma > 0.6$)	68	29 (42.6%)	15 (22.1%)

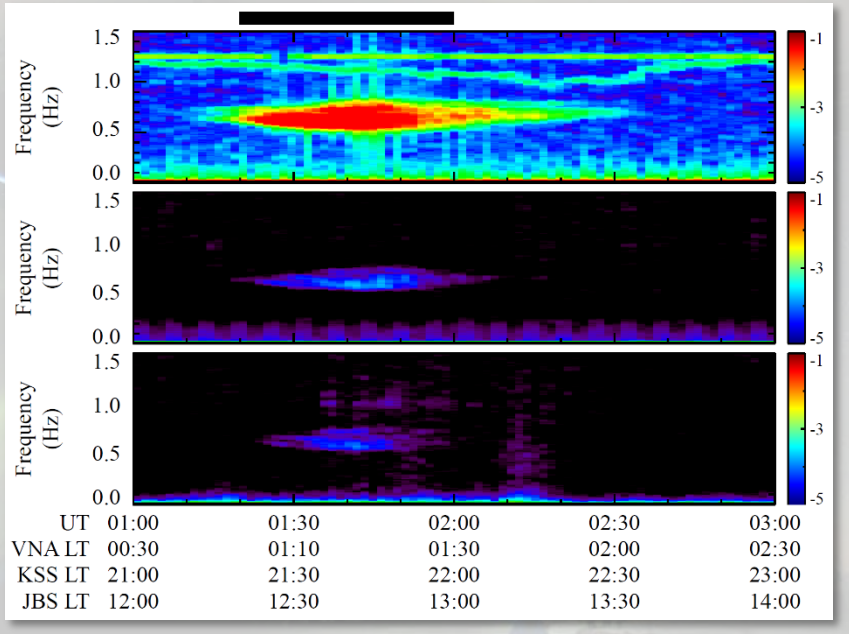
- Pc1 with high coherence propagated far distance than low coherence.
- Most of Pc1 waves observed at VNA are polarized.

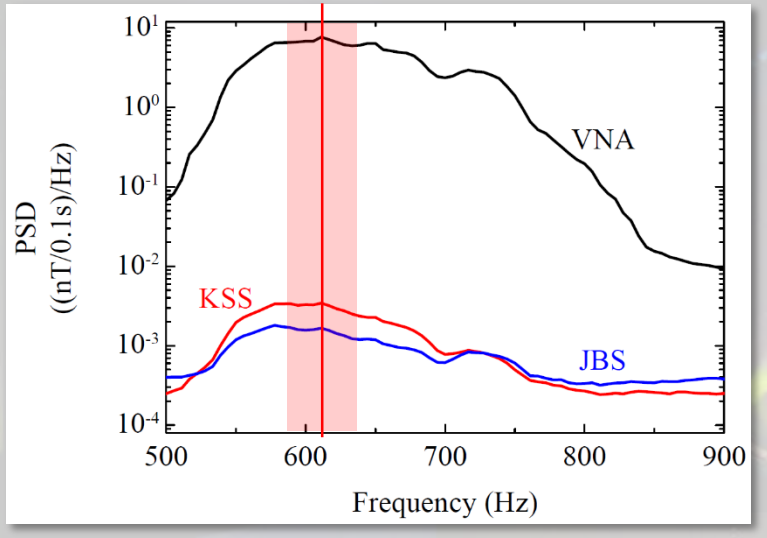
- All high-coh. Pc1s are high-polarized ($R > 0.6$).
- Left handed polarization
  - small number of event
  - direct precipitation from space
  - high possibility of ducting to KSS and JBS
- Other polarization
  - propagating from other source region
  - ducting in the small region than LH



Attenuation factor

- How to determine the attenuation factor?

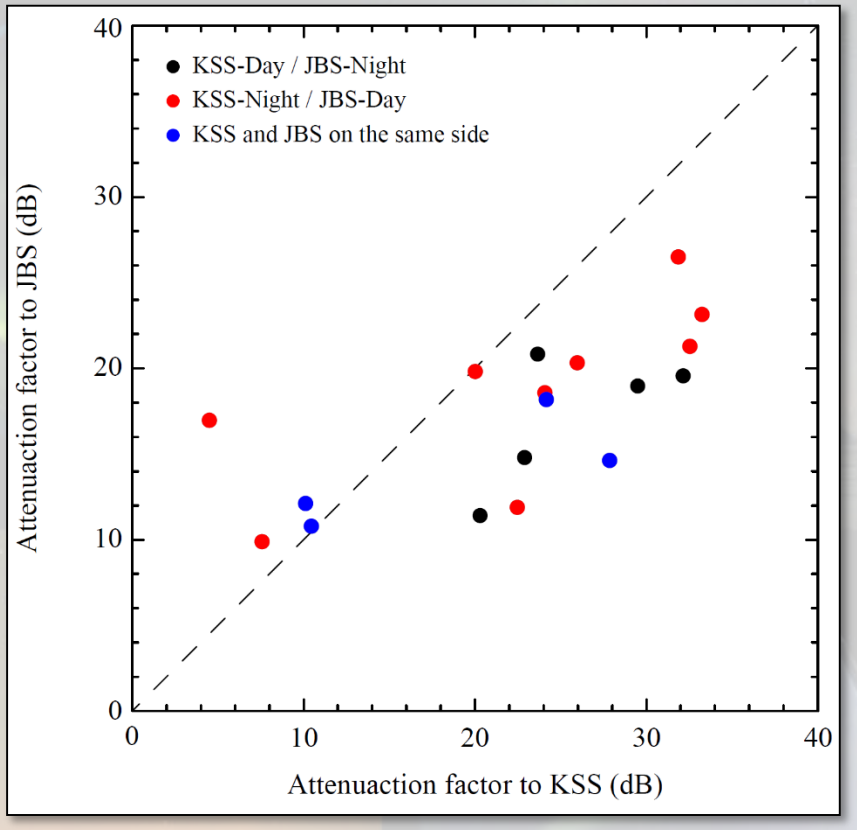


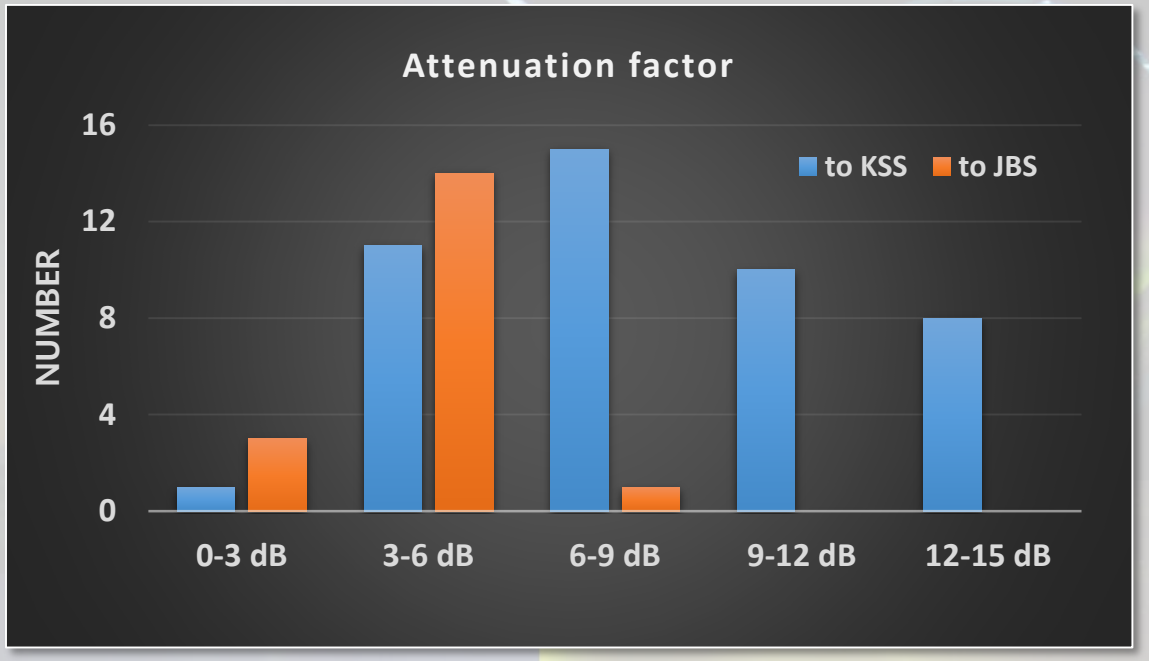


1) Set time interval using dynamic spectrum
2) Find peak frequency ag VNA
3) Integrated PSD in the range of frequency and time

Attenuation factor

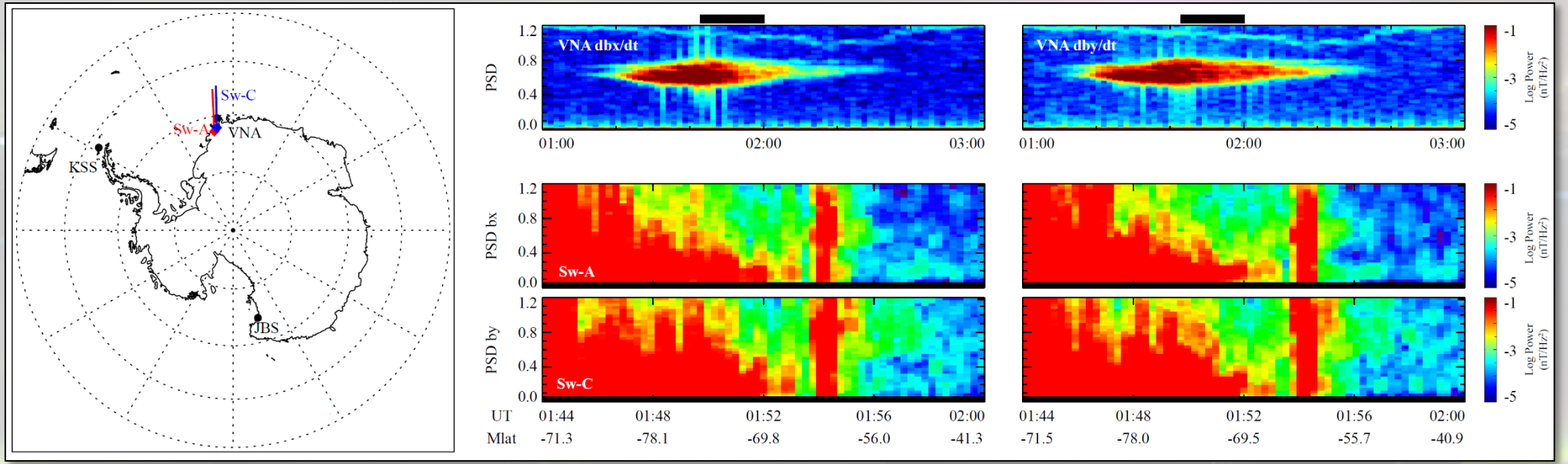
- Attenuation of ducted Pc1 waves are influenced by enhancement of electron density in the ionosphere.
  - Attenuation factors to JBS < Attenuation factors at KSS
  - Not clear sun-light effect: characteristics of polar region (polar night at JBS)

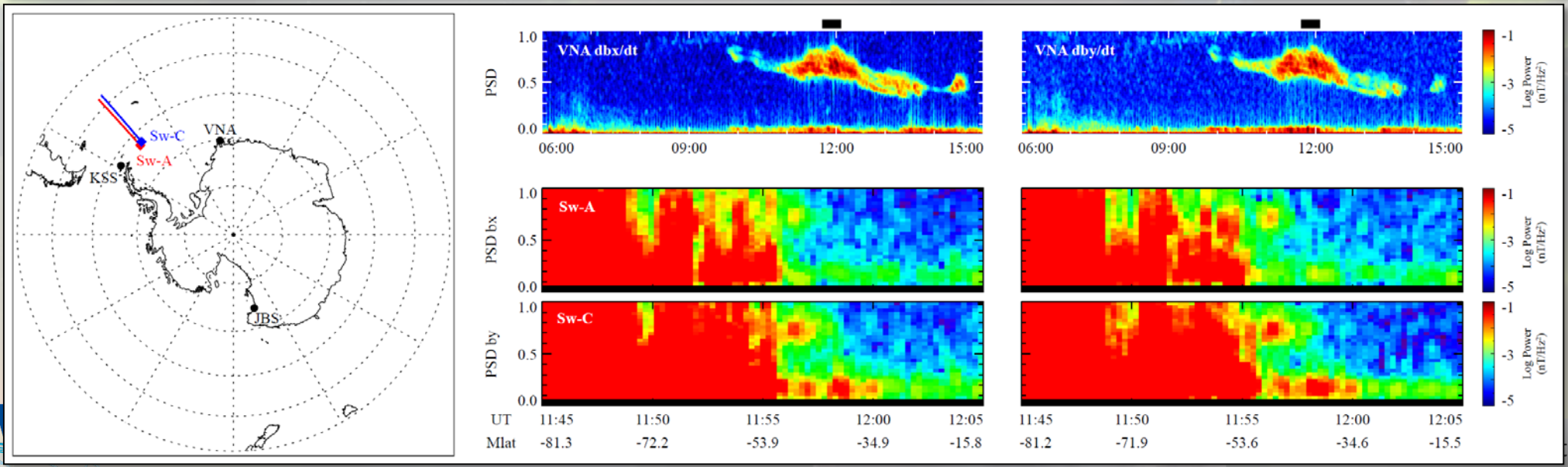




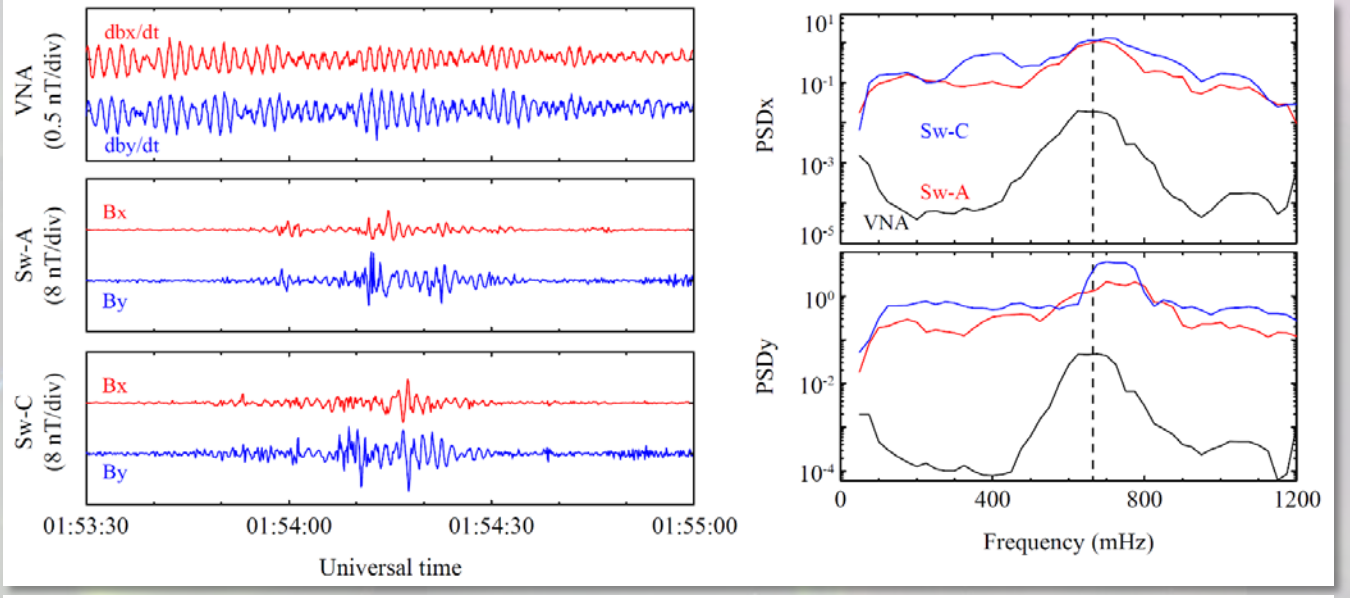
Paper	Attenuation factor
Hayashi et al. (1981)	100 or 25 dB/1000 km
Neudeggg et al. (2000)	41 dB/1000 km
Kim et al. (2010)	8-20 dB/1000 km

Swarm observation

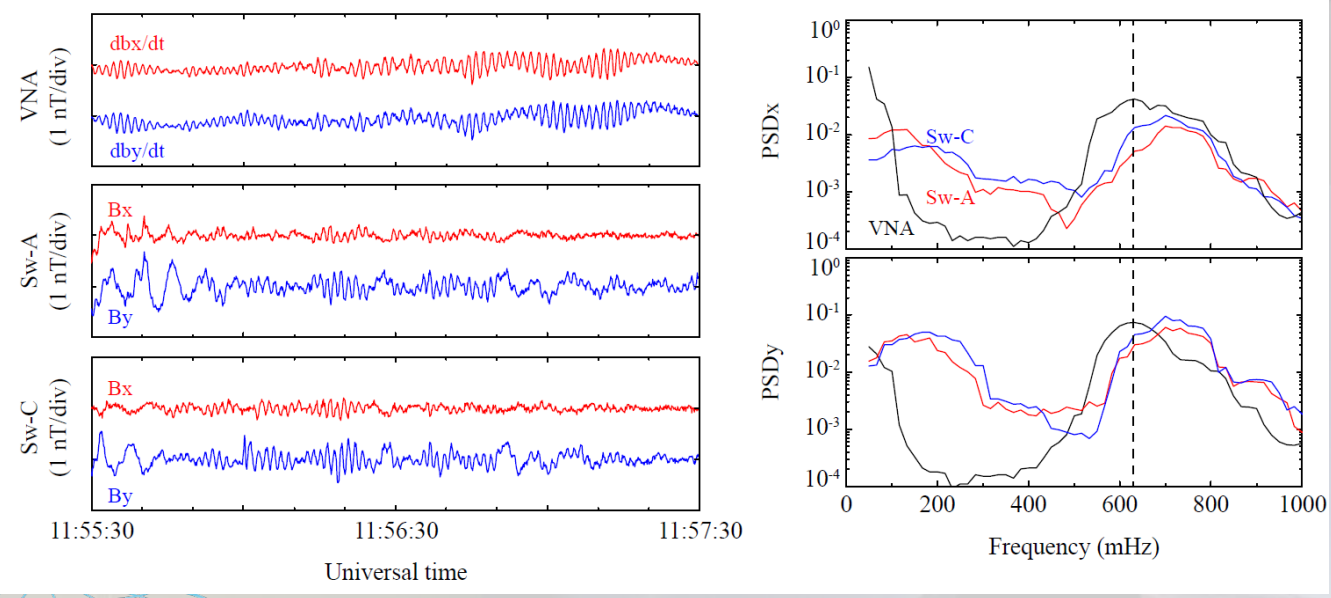




Swarm observation

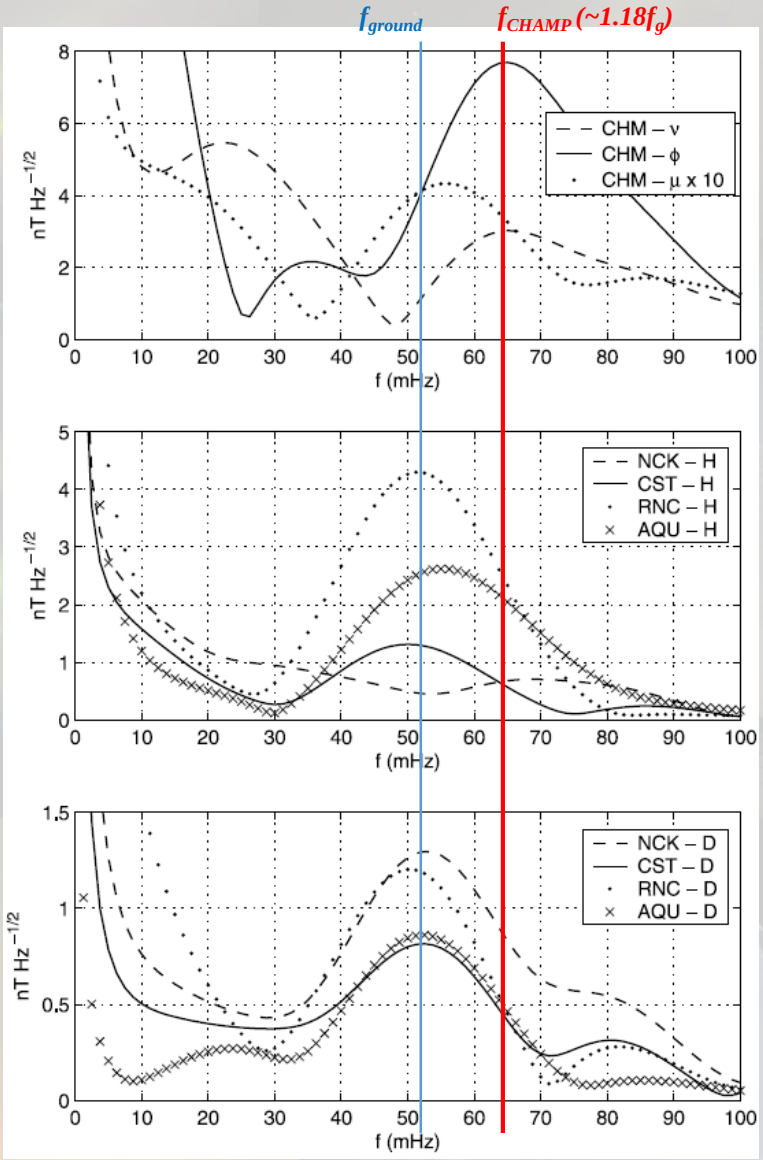


- The foot-points of Swarm is very close to VNA at 01:53 UT.
- Swarm detected broad-band signal.
- Peak frequency at LEO is larger than the frequency of Pc1 wave on the ground.
- $f_S \sim 1.03 f_{VNA}$ for y-component at Swarm-C.

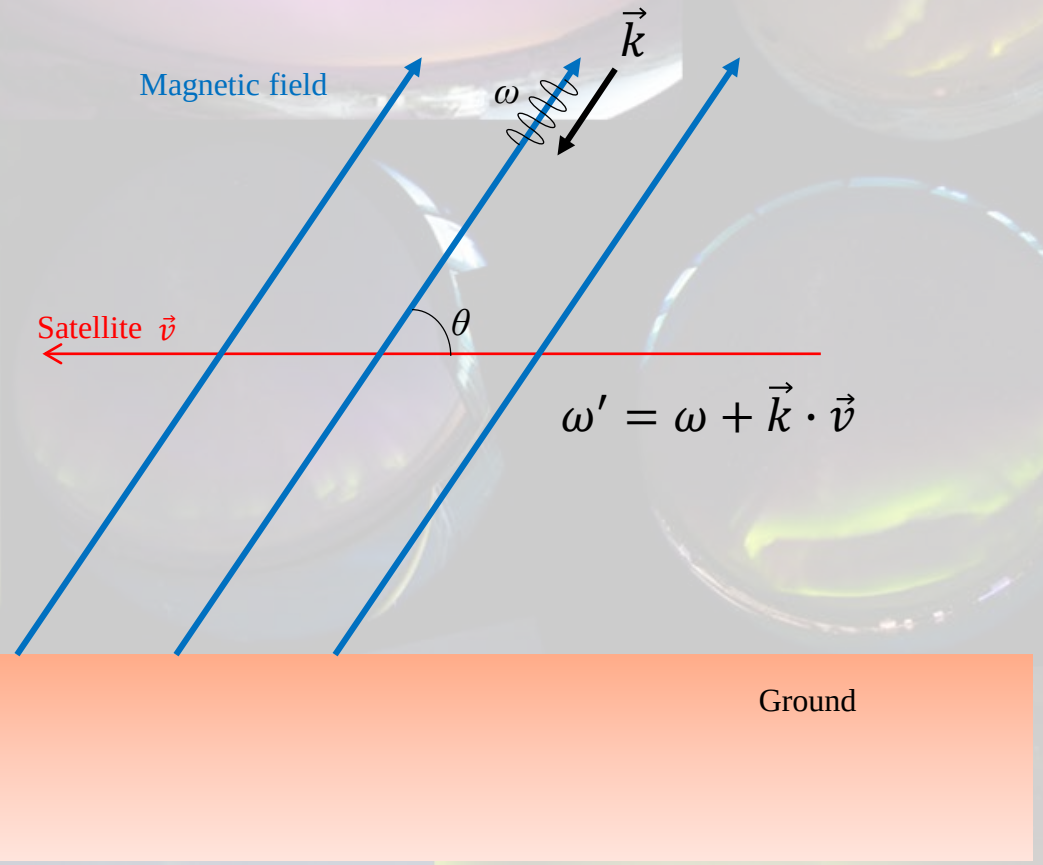


- Swarm probes passed near KSS and VNA from 11:55 to 12:00 UT.
- After crossing aurora oval (~11:55:30 UT), Swarm-A and -C observed ULF waves in the Pc1 band.
- The frequency at Swarm is slightly higher than on the ground ($f_S \sim 1.1 f_{VNA}$). --> Why?

Doppler effect in the ionosphere



Vellante et al. (JGR, 2004)



First identification of Doppler effect in the Pc1 band

Summary

- Statistical analysis of ducted Pc1 waves from Mar to Dec in 2019
  - Total Pc1s at VNA: 113
  - Ducted Pc1s to KSS: 45 (40%) / to JBS: 18 (16%)

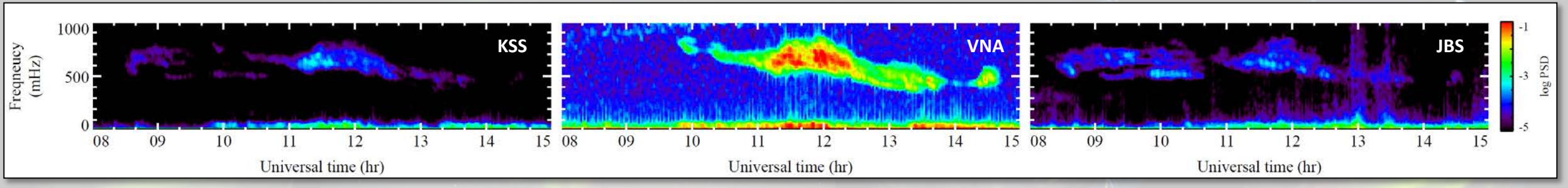
- Proper ducting condition
  - High amplitude / Long duration
  - High coherence and polarization

- Attenuation factor
  - Influenced by the latitudinal dependence of electron density

- LEO satellite observed ducted Pc1 waves
  - Frequency difference because Doppler effect

Future work

- Ducting range
  - distance issue: using other data (e.g., SPA, MCM, and AGO)
  - regional issue: the plasmapause, cusp
  - horizontal propagation: 16 Mar event



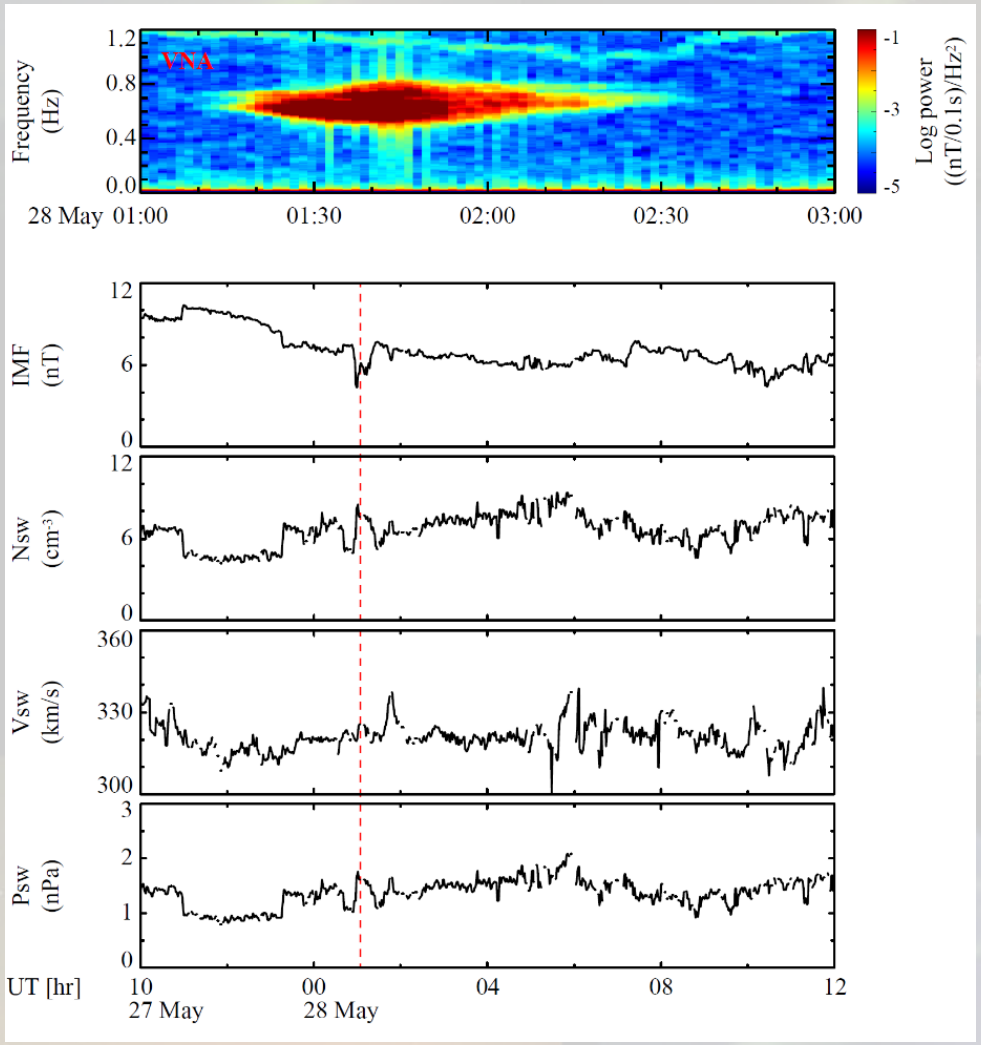
- The variations of polarization during waveguide

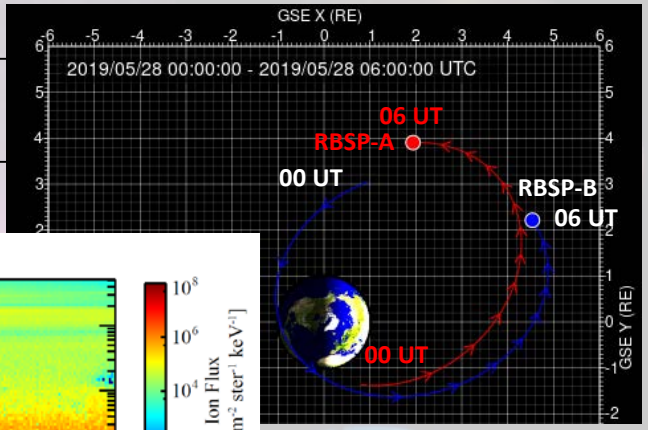
- Confirm Doppler effect in the ionosphere
  - frequency relation between ground station and satellite

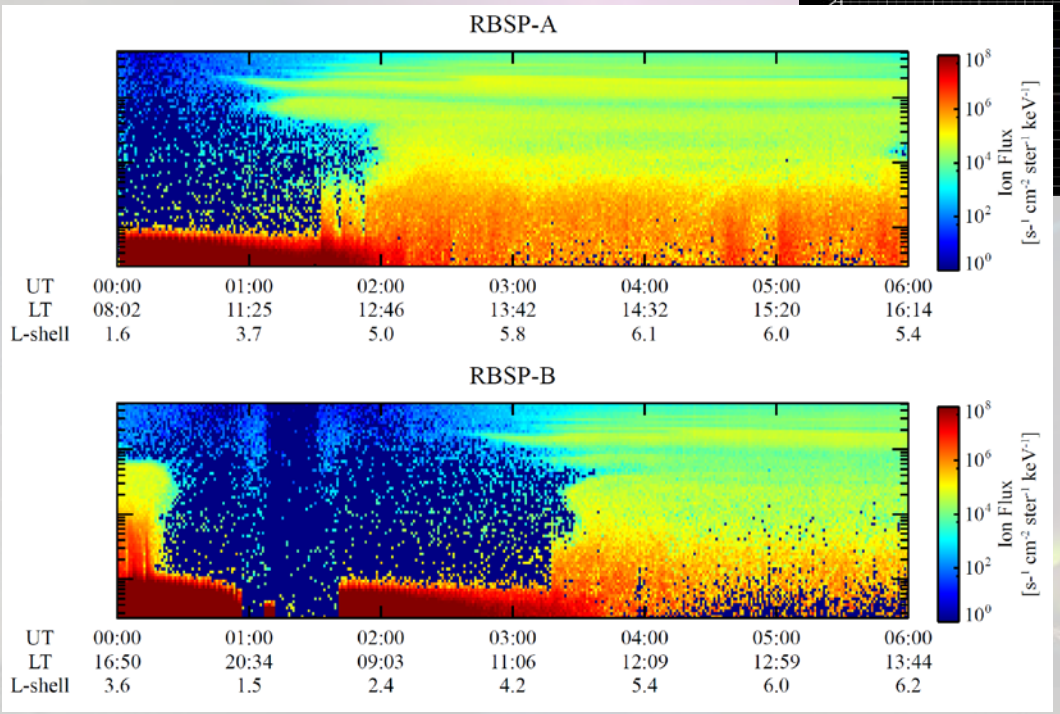

Thank you for you attention

Backup slides

Solar wind condition and plasmapause







- Plasmapause:
  - Night side: L = 3
  - Day side: L = 5
- VNA:

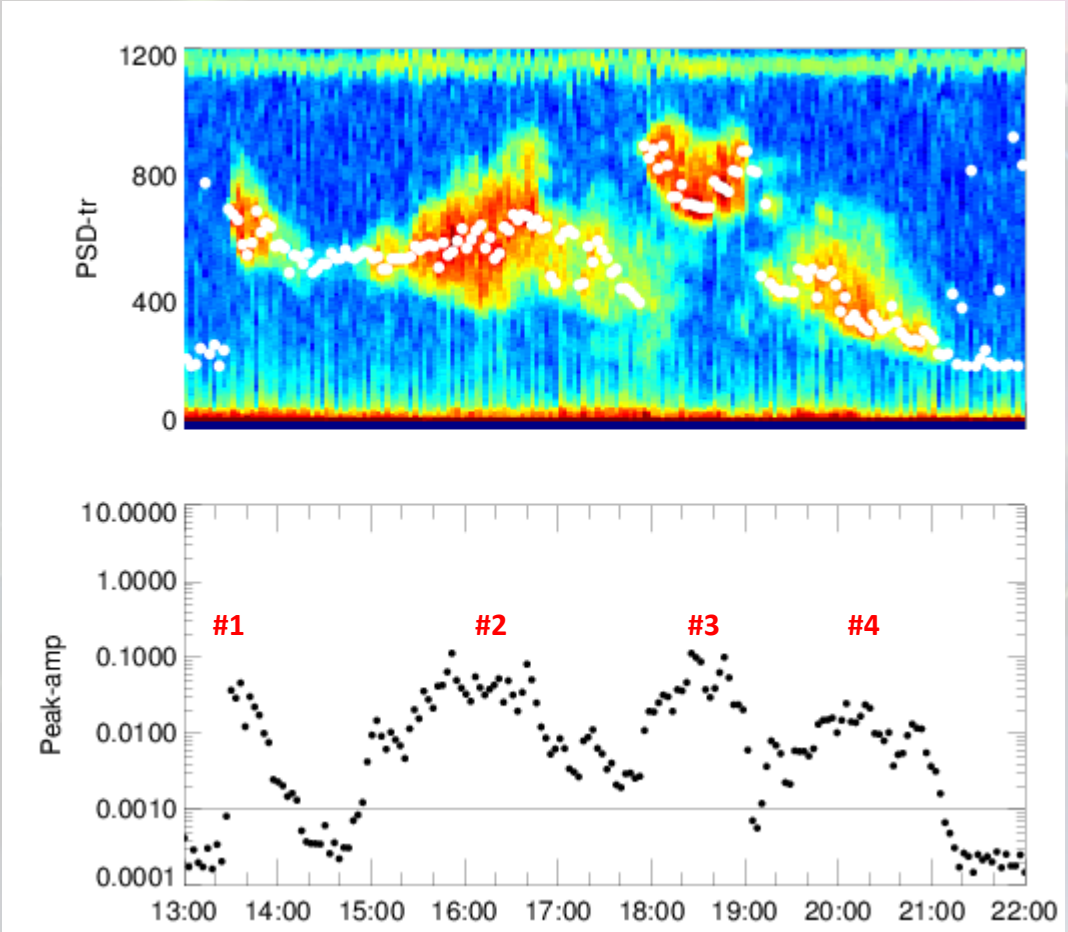
Polarization change

	Left-handed		Right-handed		Linear	
	KSS	JBS	KSS	JBS	KSS	JBS
# of ducted Pc1s	8	5	11	7	10	3
Left-handed	1	1				
Right-handed	4	2	1	3	3	1
Linear	3	2	4	3	5	1
Mix			4	1	2	1

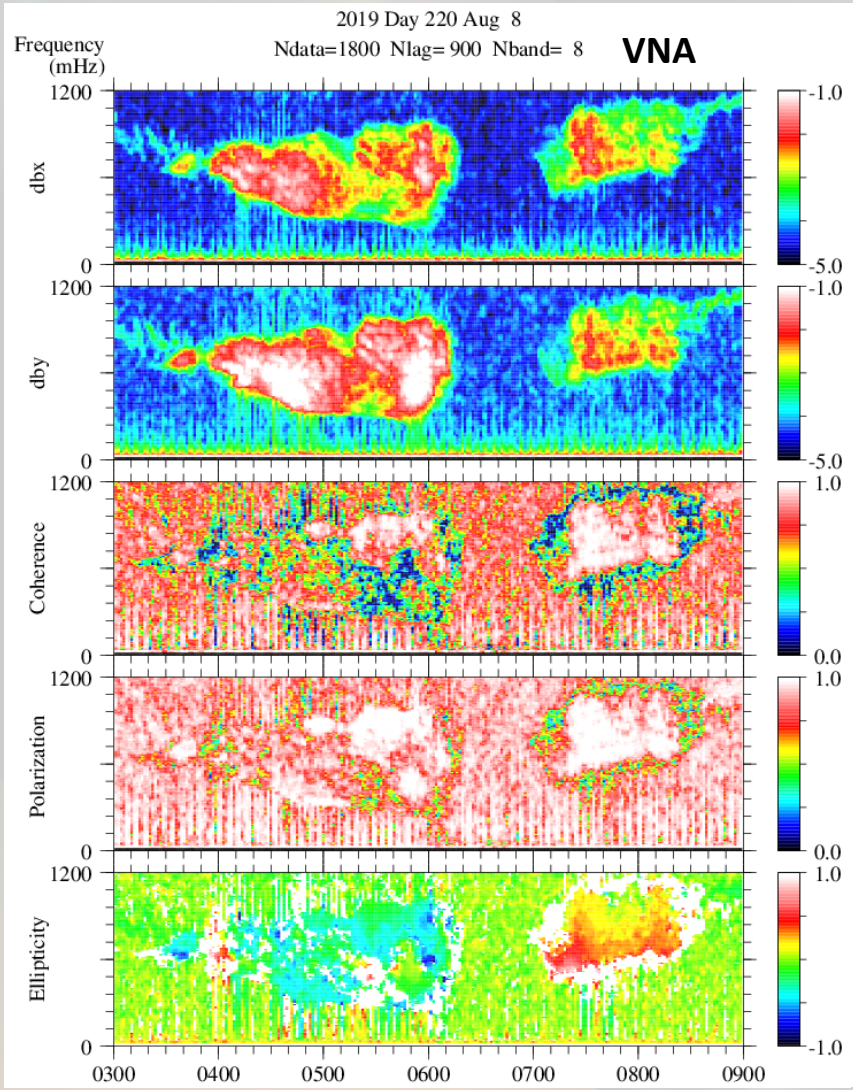
- Polarization changed as waves propagated.
  - from left-handed to right-handed in theory

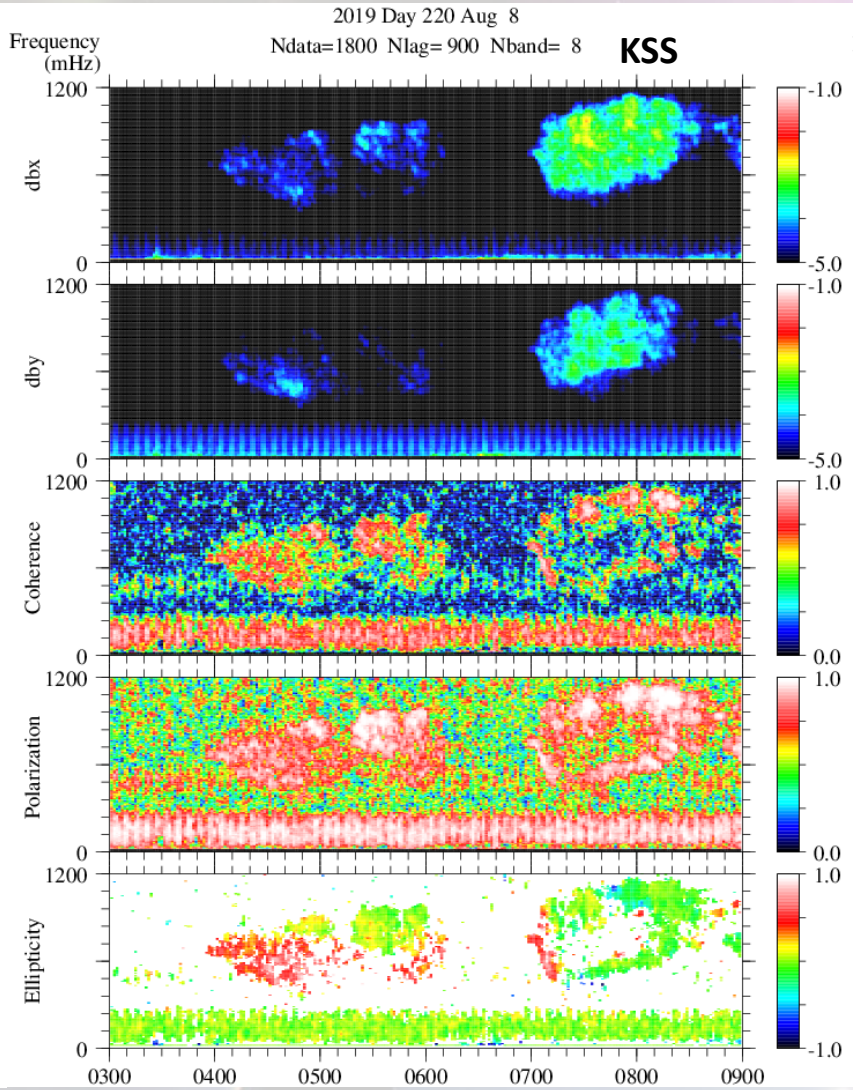
- No left-handed Pc1 waves at KSS and JBS, except when VNA observed Pc1 with left-handed polarization.

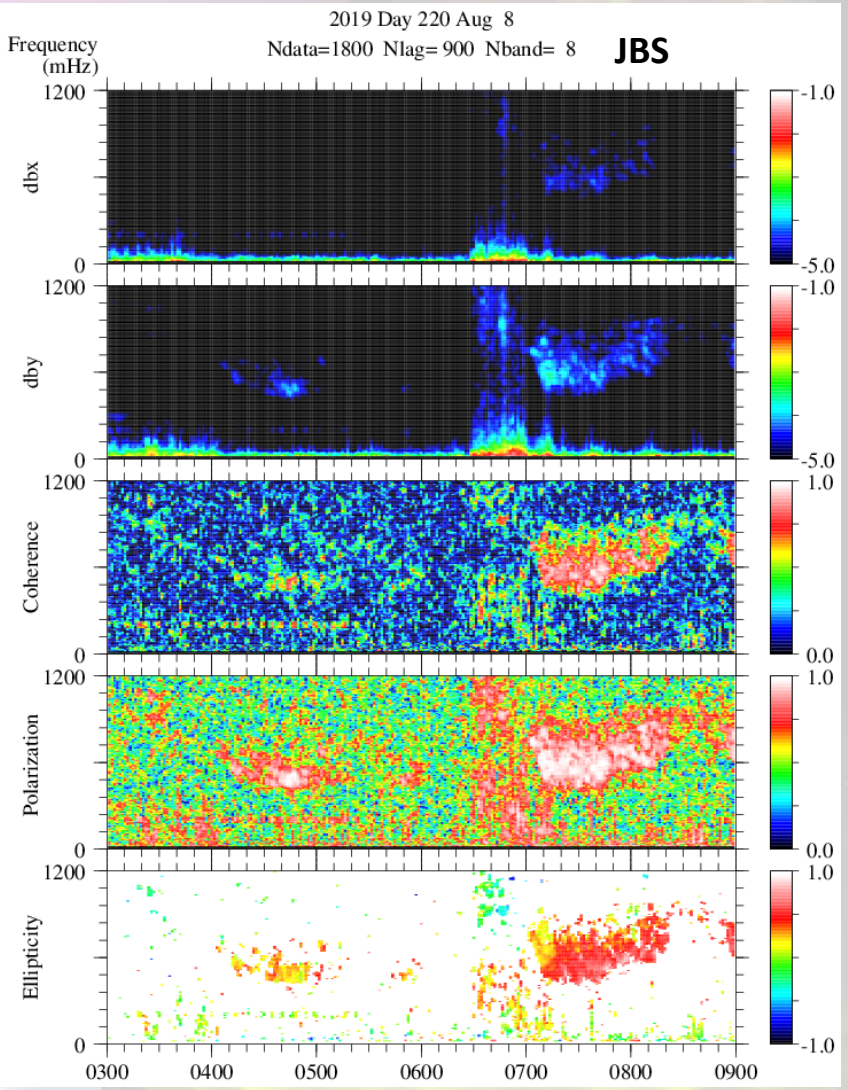
Event selection



Polarization change



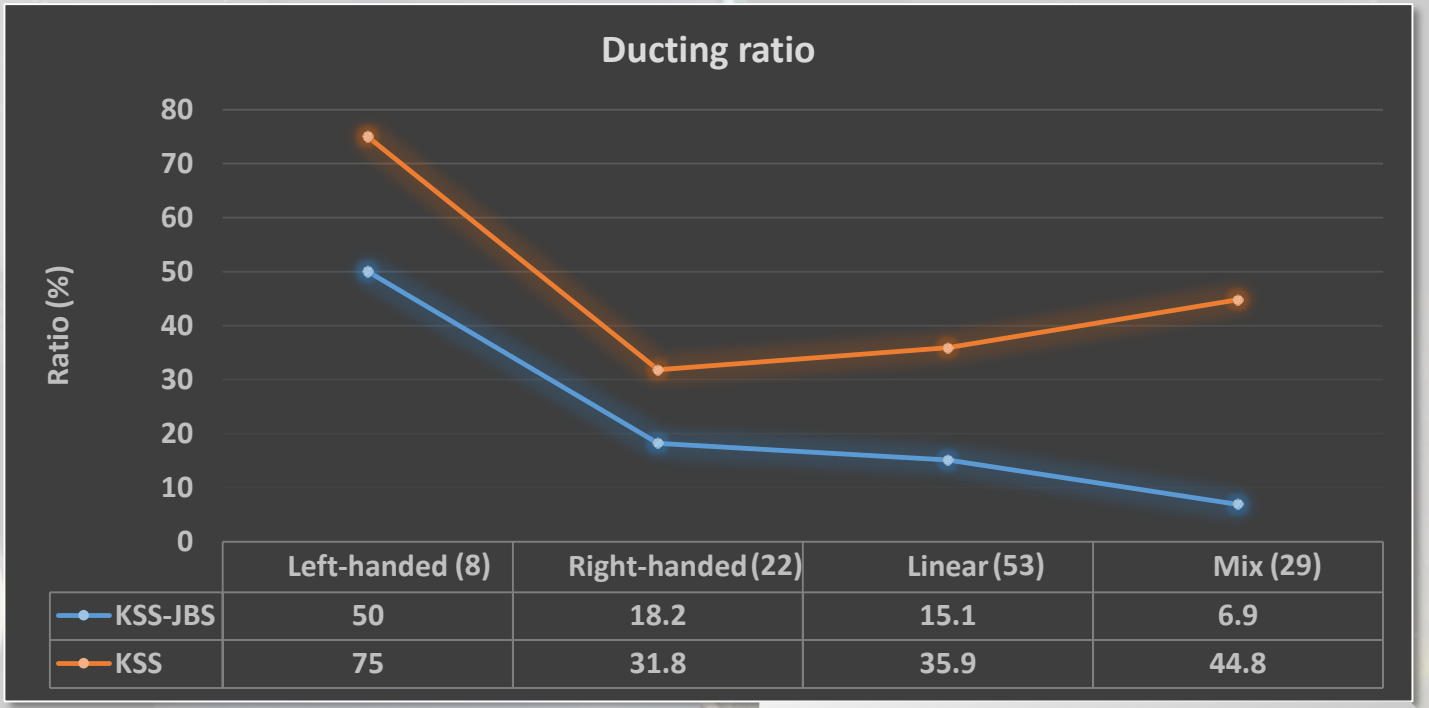




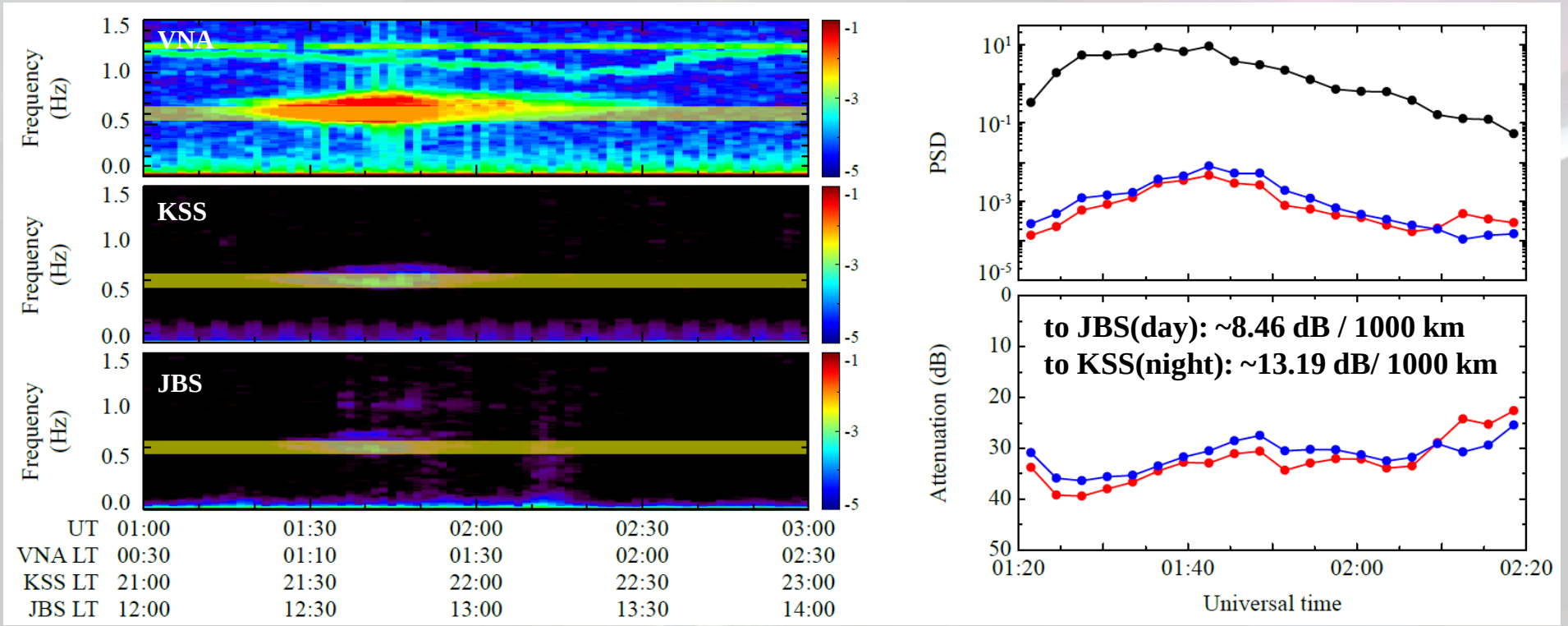
Statistical analysis

	VNA	VNA-KSS	JBS-VNA-KSS
Low coh. (γ< 0.8)	79	28 (35.4%)	7 (8.9%)
High coh.	34	17 (50.0%)	11 (32.4%)
Low pol. (R < 0.6)	1	0	0
High pol.	112	45 (40.2%)	18 (16.1%)

- Most of Pc1 waves at VNA are polarized,



Attenuation factor



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