The Earth's Inner Magnetosphere and Space Weather

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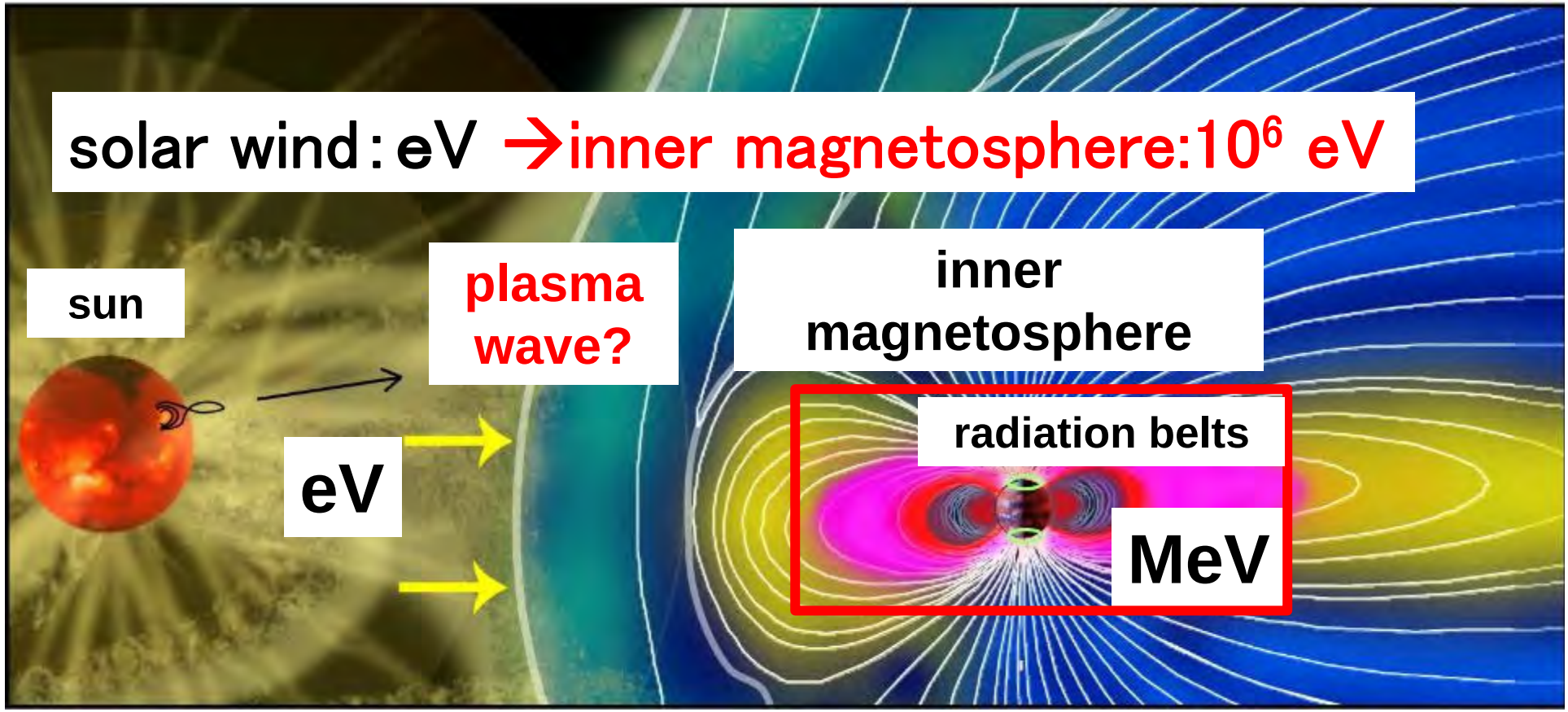
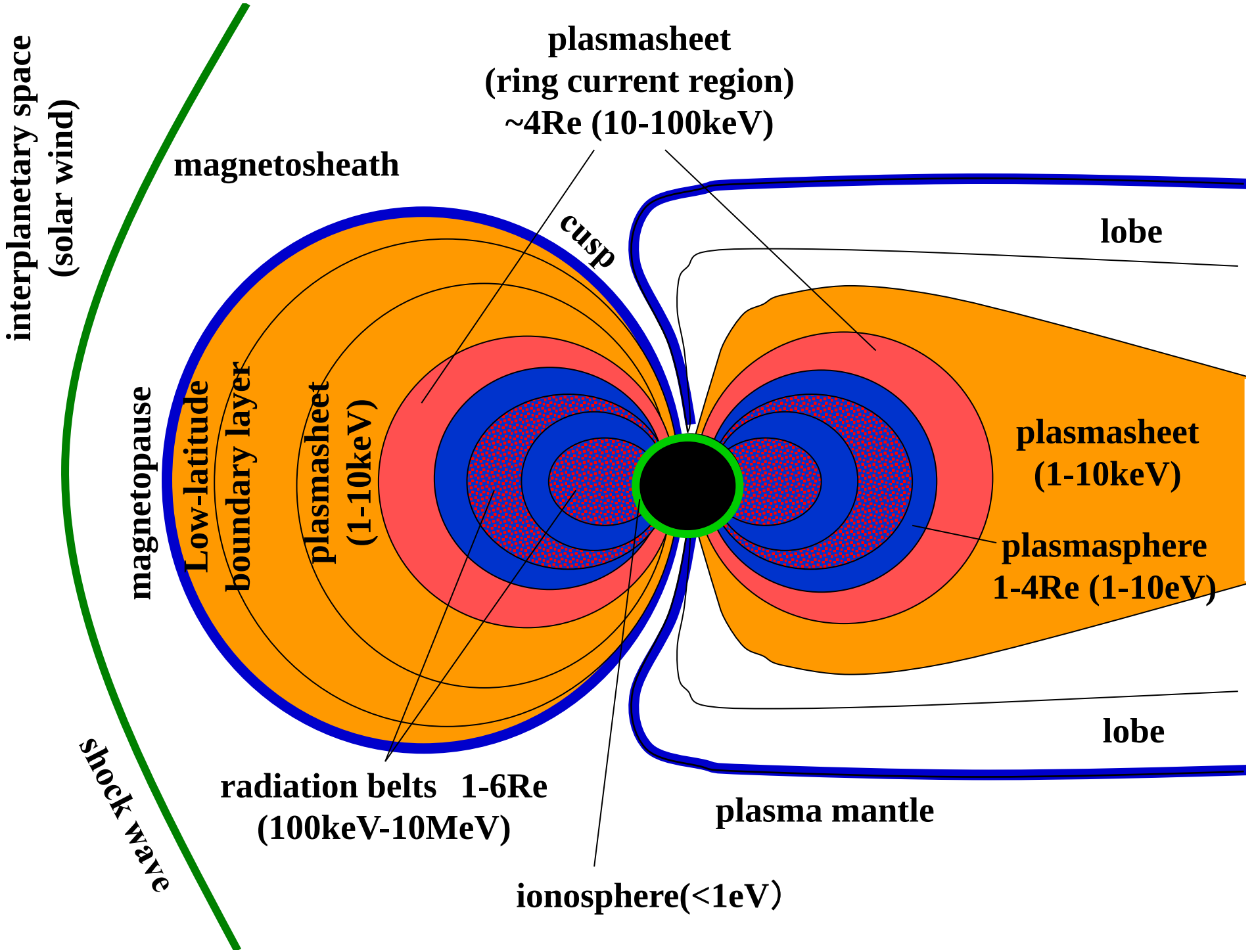
For ISWI Space Weather Workshop, November 3, 2021, online

Inner Magnetosphere

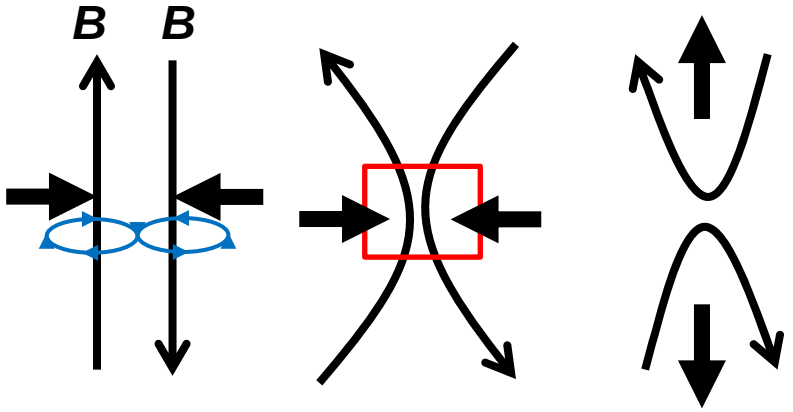
- **Particle acceleration without collision**

→ MHD processes and wave-particle interaction are essentially important




interplanetary space
(solar wind)
shock wave
magnetosheath
plasmasheet
(ring current region)
~4Re (10-100keV)
cusp
lobe
magnetopause
Low-latitude
boundary layer
plasmasheet
(1-10keV)
plasmasheet
(1-10keV)
plasmasphere
1-4Re (1-10eV)
lobe
radiation belts 1-6Re
(100keV-10MeV)
plasma mantle
ionosphere(<1eV）

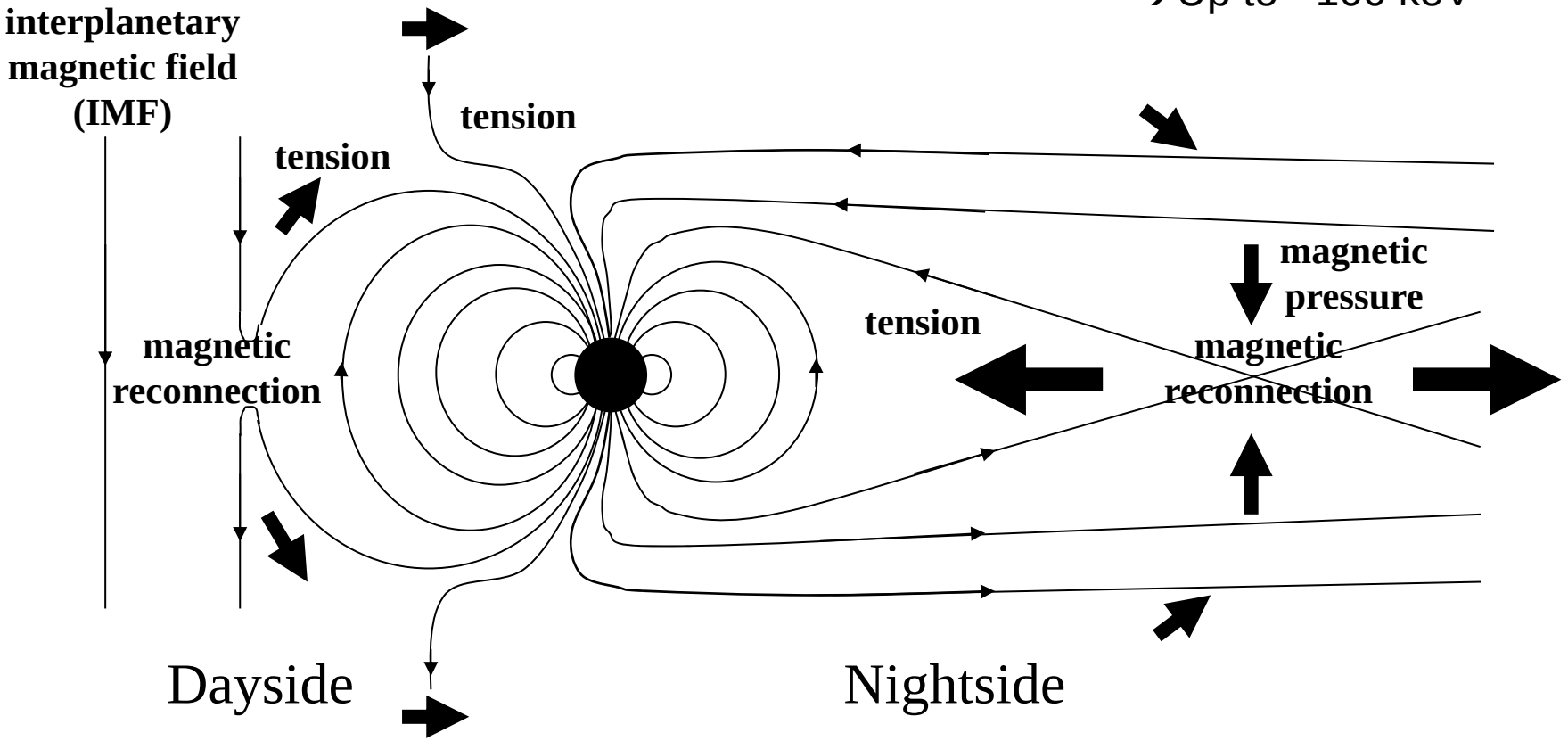
magnetic reconnection

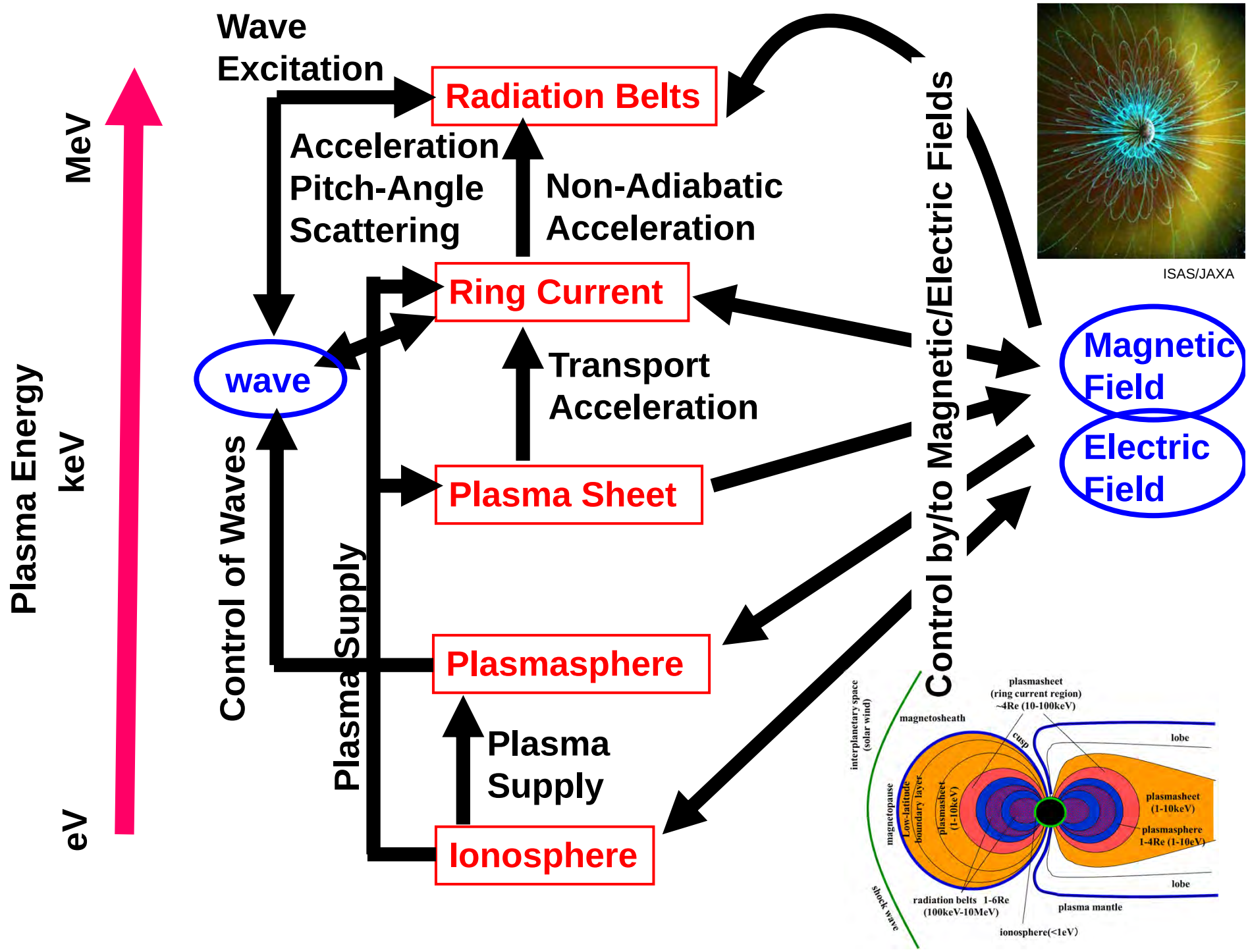


$$\mu = \frac{\frac{1}{2}mv_{\perp}^2}{B} = \frac{E_{\perp}}{B} = const$$

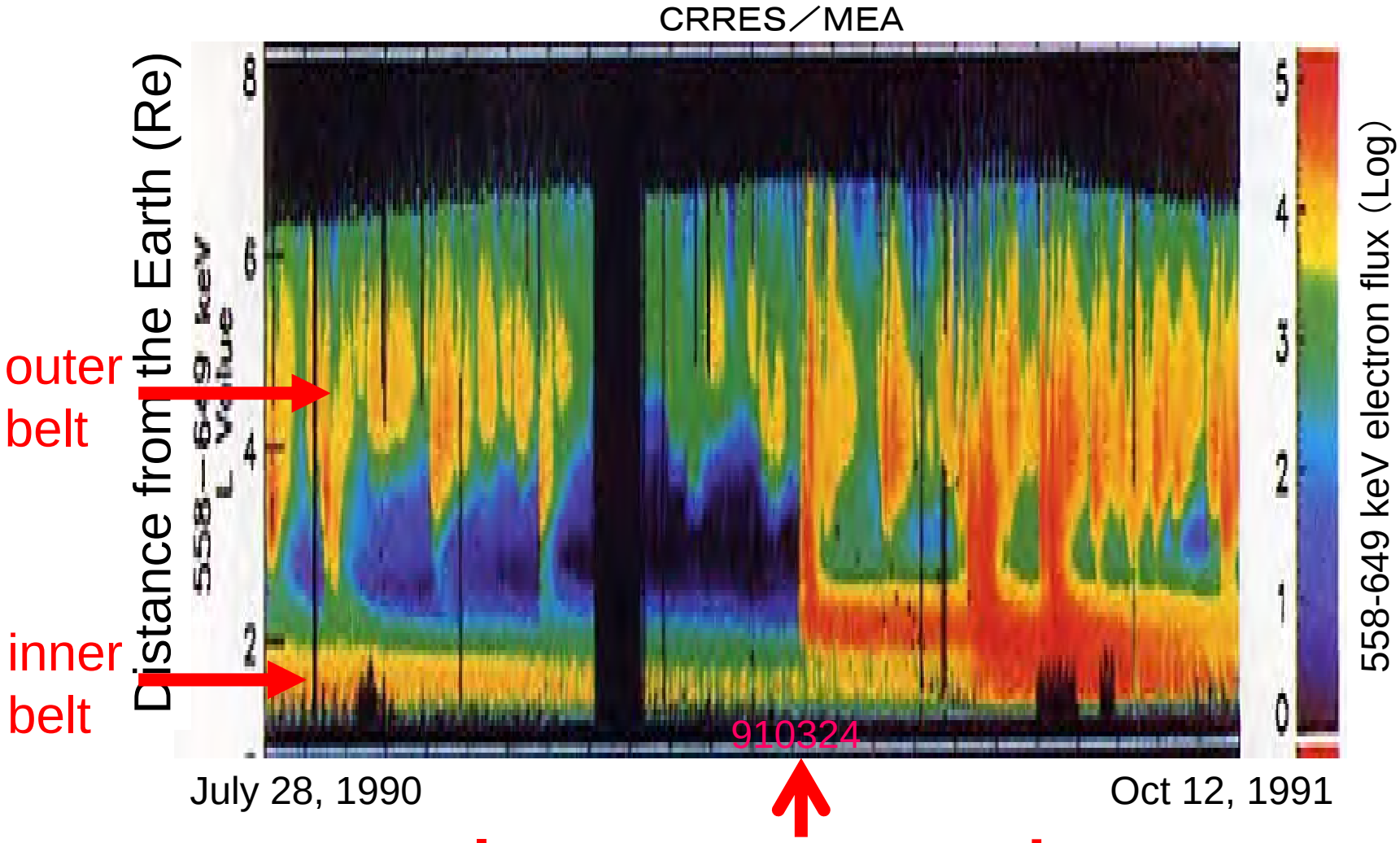
$$B\ increase \rightarrow E_{\perp}\ increase$$

→Betatron Acceleration
→Up to ~100 keV




Wave
Excitation
Radiation Belts
Acceleration
Pitch-Angle
Scattering
Non-Adiabatic
Acceleration
Ring Current
wave
Transport
Acceleration
Plasma Sheet
Plasmasphere
Plasma
Supply
Ionosphere
Plasma Energy
MeV
keV
eV
Control of Waves
Plasma Supply
Control by/to Magnetic/Electric Fields
Magnetic
Field
Electric
Field
ISAS/JAXA
plasmasheet
(ring current region)
~4Re (10-100keV)
magnetosheath
interplanetary space
(solar wind)
cusp
lobe
magnetopause
Low-latitude
boundary layer
plasmasheet
(1-10keV)
plasmasheet
(1-10keV)
plasmasphere
1-4Re (1-10eV)
lobe
radiation belts 1-6Re
(100keV-10MeV)
plasma mantle
shock wave
ionosphere(<1eV)

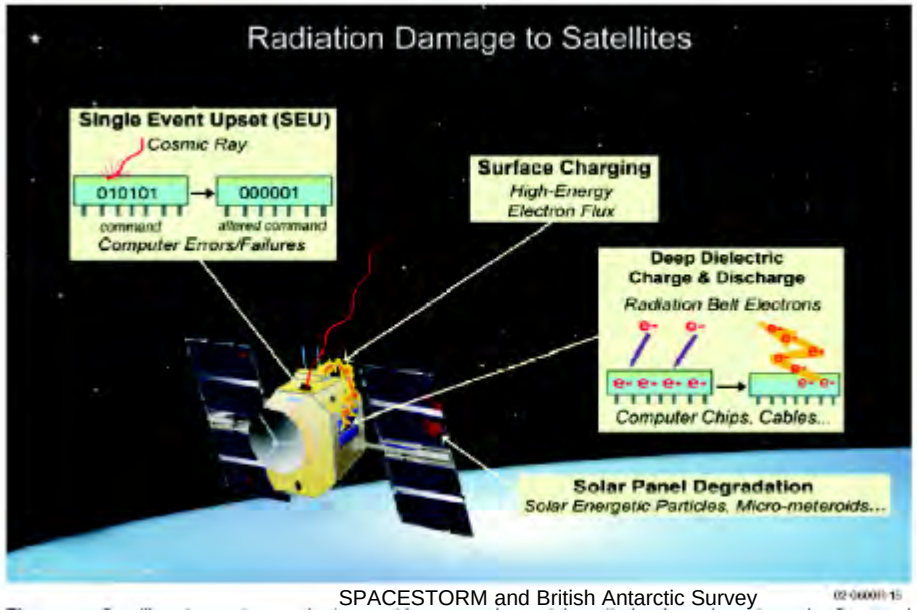
Dynamic variation of radiation belt electrons



large geomagnetic storm caused by CME from the sun

Li and Temerin (Space Sci. Rev., 2001, https://link.springer.com/content/pdf/10.1023/A:1005221108016.pdf)

High-energy particles gives danger in space for human beings.



SPACESTORM and British Antarctic Survey

Radiation dose for astronauts

Satellite anomaly by high-energy particles

Satellite failure by magnetic storm (Jan. 23, 1994, Asahi Evening News)

Storm blows Canada's satellites

OTTAWA—A massive electromagnetic storm knocked out Canada's two communications satellites, and one of them may be lost for ever and become an expensive piece of space junk, the operating company Telesat Canada said Friday.

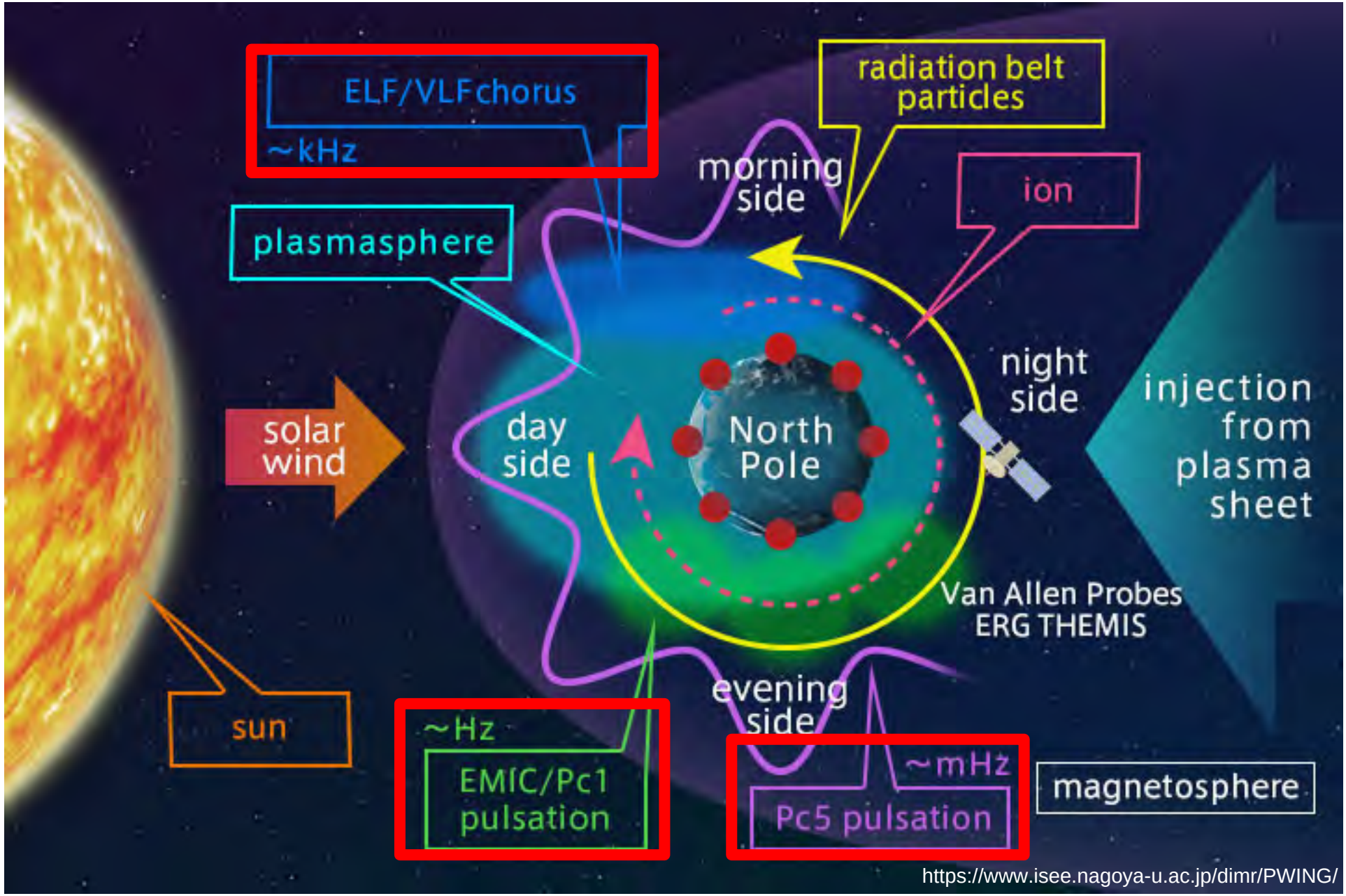
Telesat executives said a unusual localized storm caused short-circuits on its Anik E-1 and E-2 satellites Thursday, disrupting telephone, television and data transmission services across Canada.

Engineers managed to reposition the first unit eight hours later, but the second, Canada's main broadcasting satellite, is spinning out of control and pointing away from Earth.

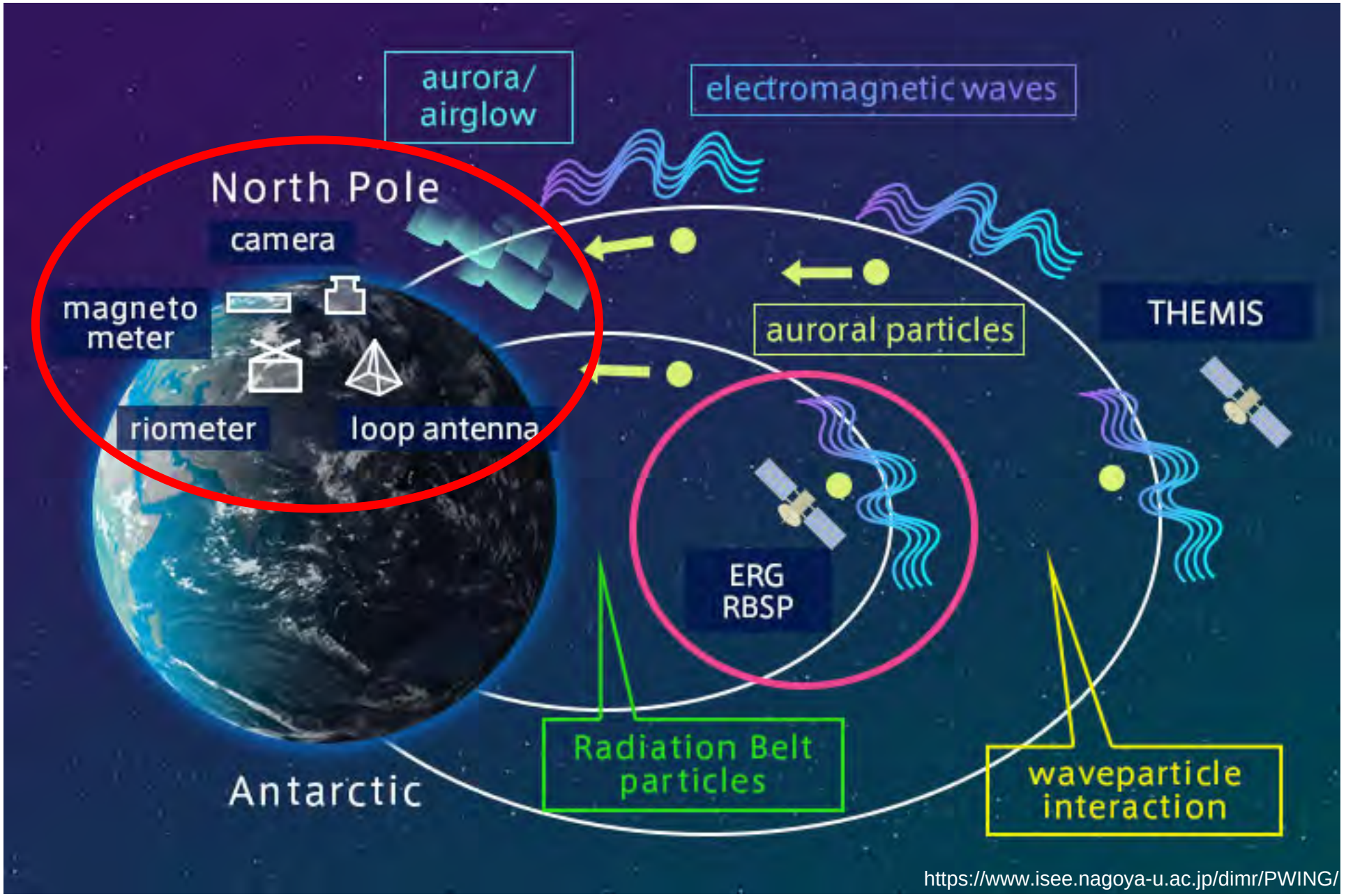
Compiled from Reuter and The Associated Press

$$f_c = \frac{\omega_c}{2\pi} = \frac{eB}{2\pi m} \qquad B = 100\ nT \rightarrow$$ proton: $f_c = 1.5\ Hz$ = ~1 Hz
electron: $f_c = 2800\ Hz$ = ~1 kHz

Hz & kHz

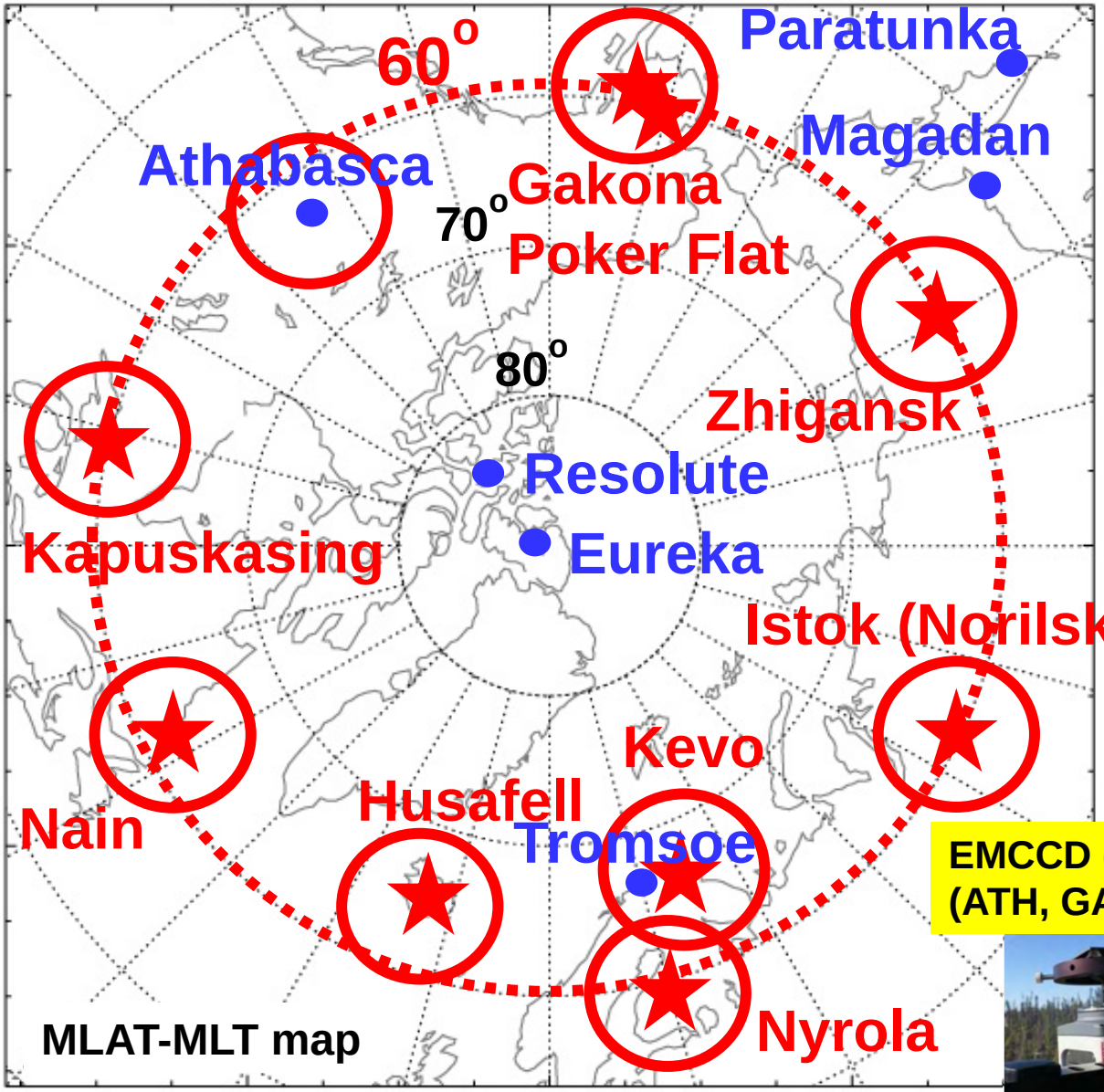


Phenomena in the magnetosphere can be monitored on the ground.



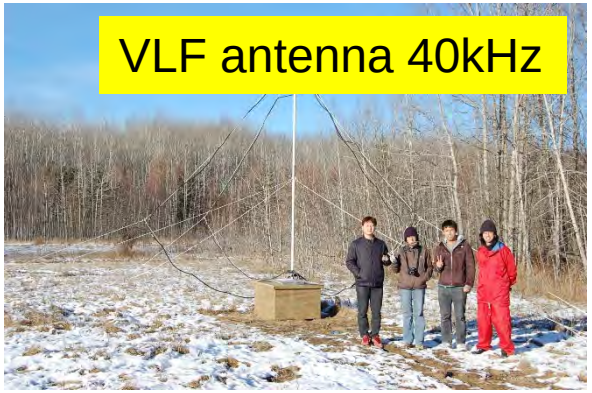
Ground-based stations of the PWING Project (2016-2021).

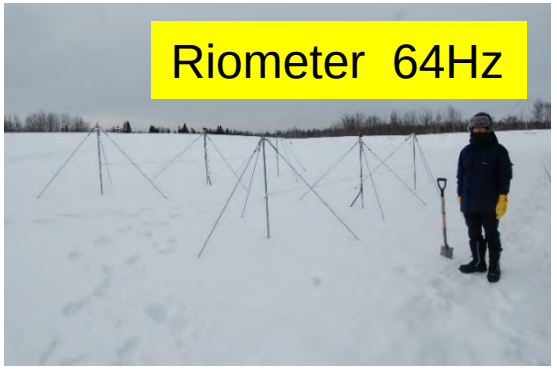
● **Existing sites** ★ **New sites**



http://www.isee.nagoya-u.ac.jp/dimr/PWING/

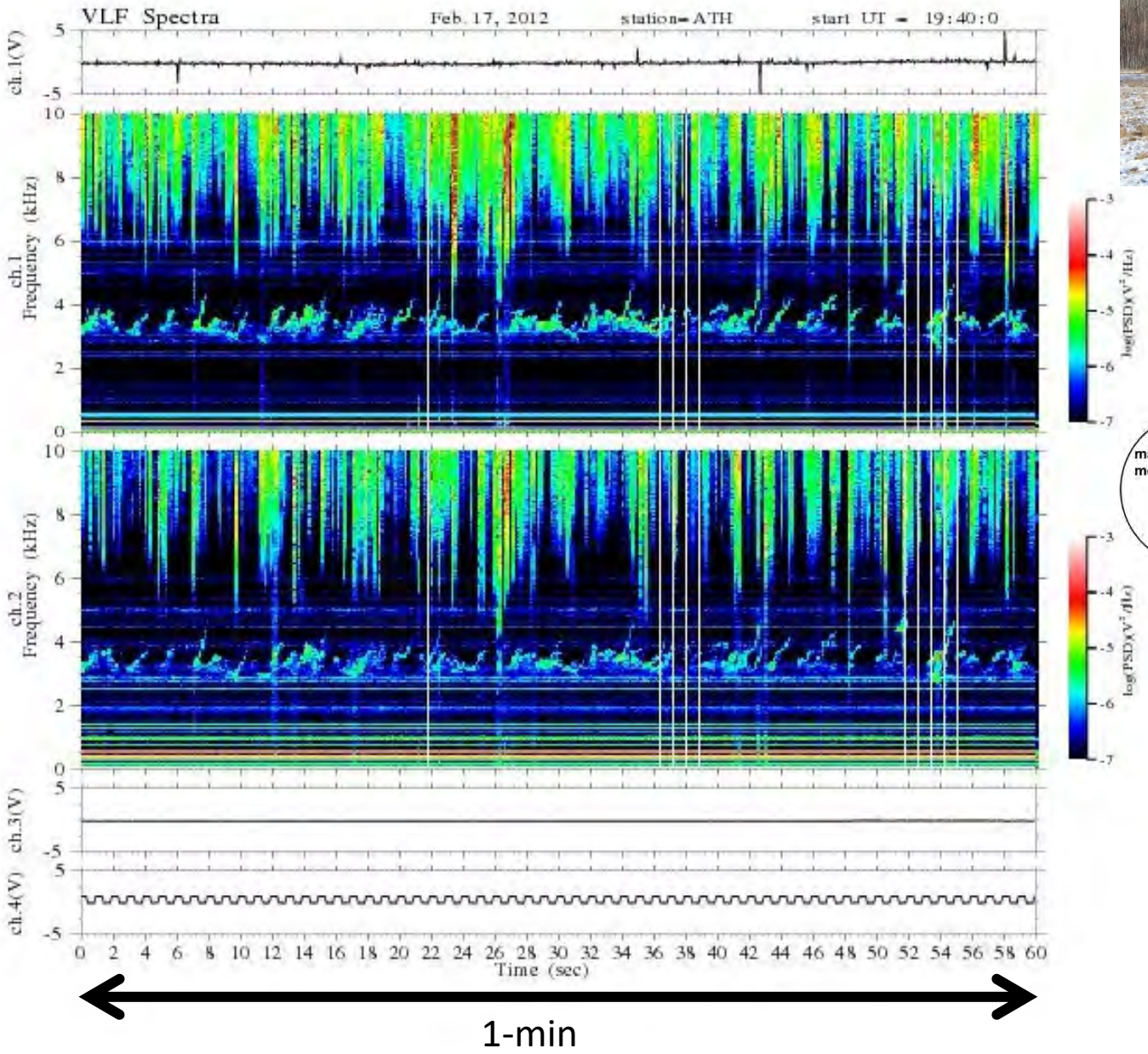
Induction magnetometer 64Hz

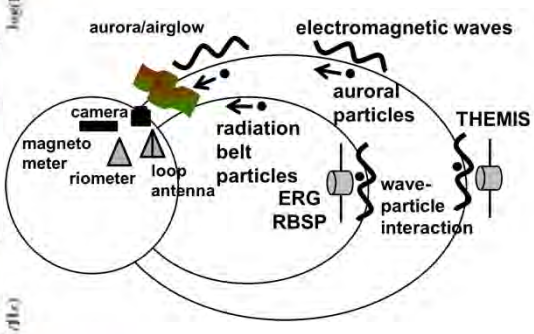




EMCCD (100Hz)
(ATH, GAK, KEV)

ELF/VLF waves in the magnetosphere



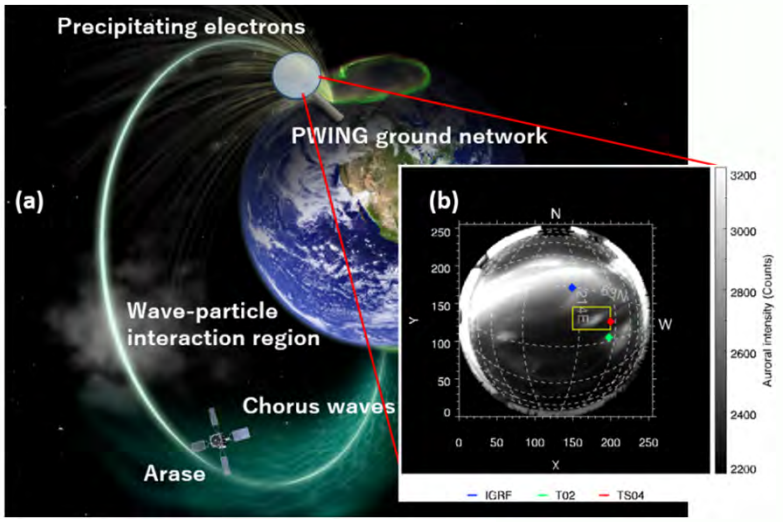


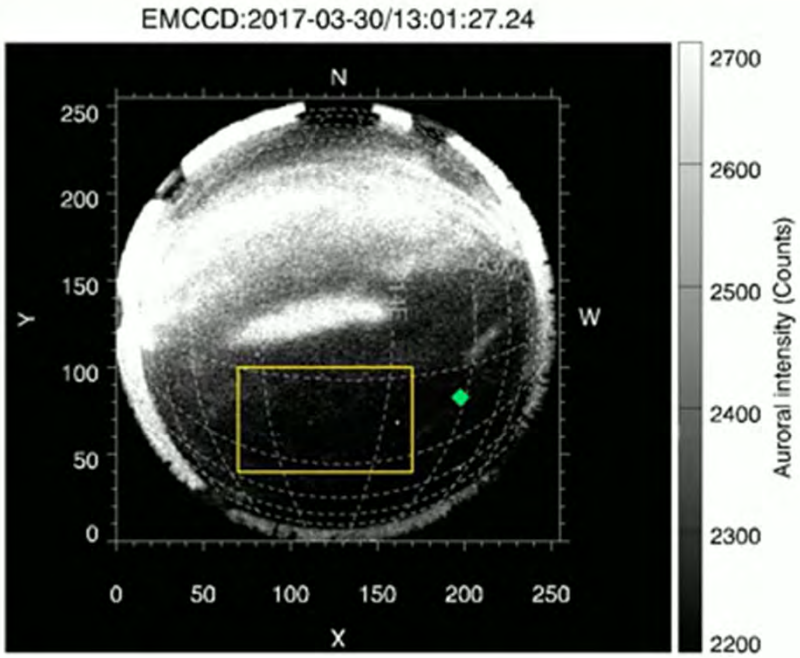
Click here for Ch.1 sound

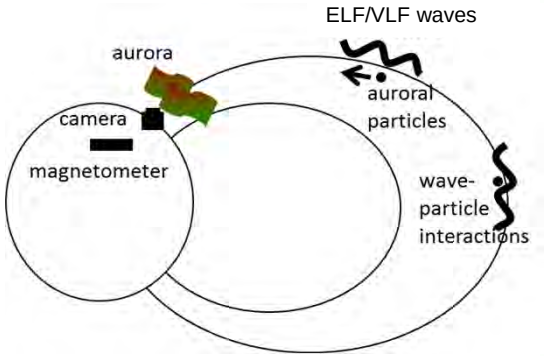
Shiokawa et al. (JGR, 2014, doi:10.1002/2014JA020161)

Pulsating aurora and chorus correspondence

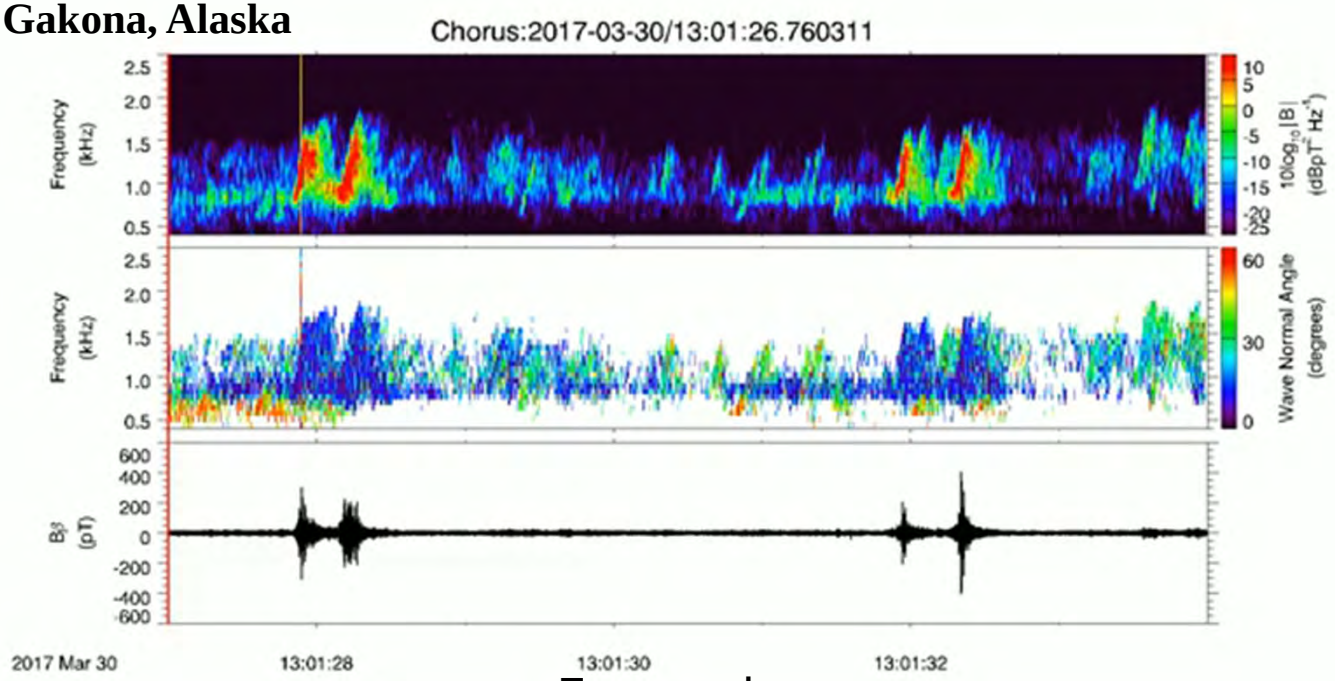
kHz







Gakona, Alaska



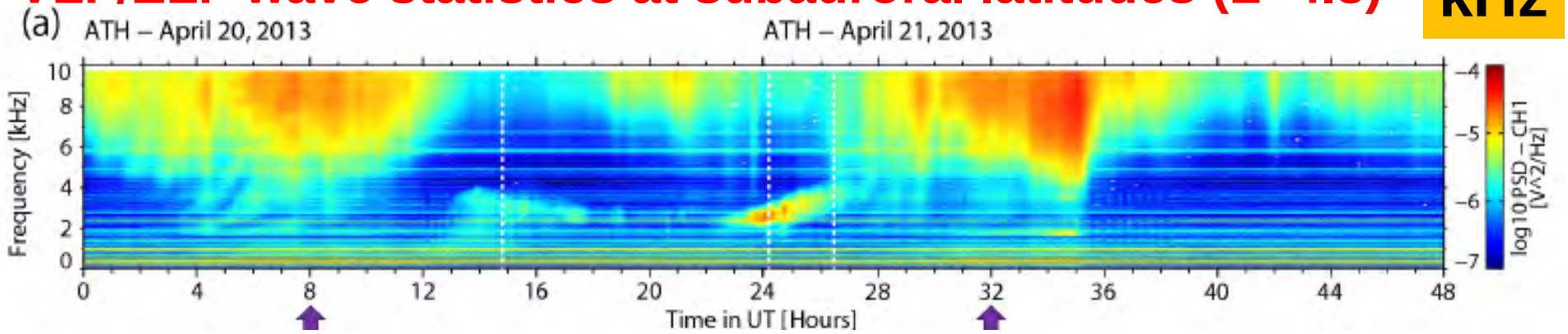
7 seconds

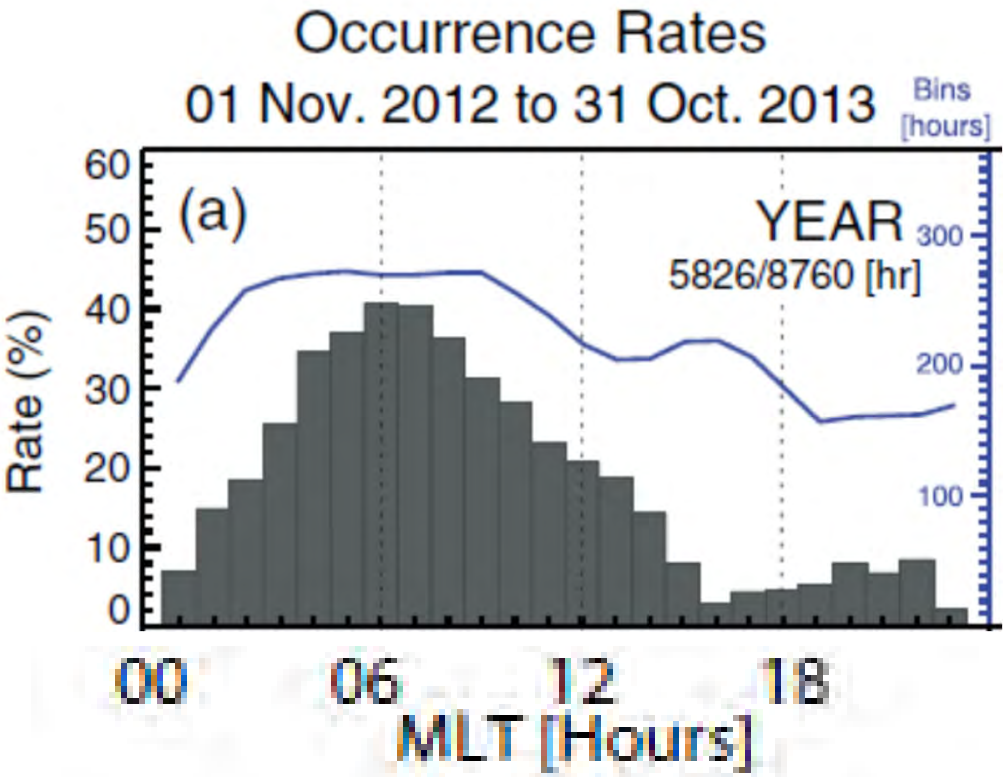
Ozaki et al.
(Nature Comm., 2019)

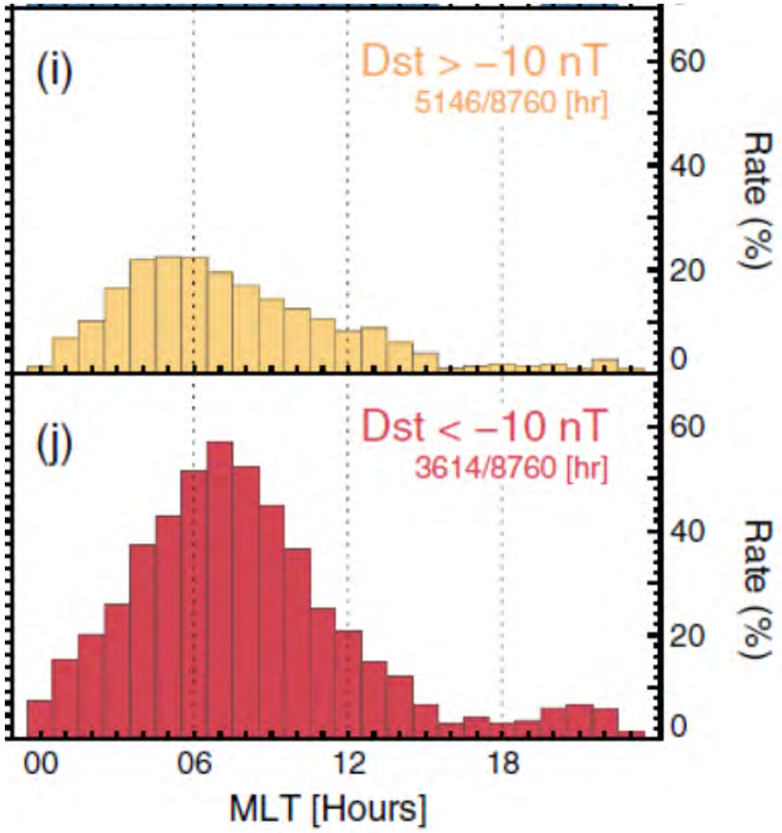
https://doi.org/10.1038/s41467-018-07996-z

VLF/ELF wave statistics at subauroral latitudes (L=4.3)

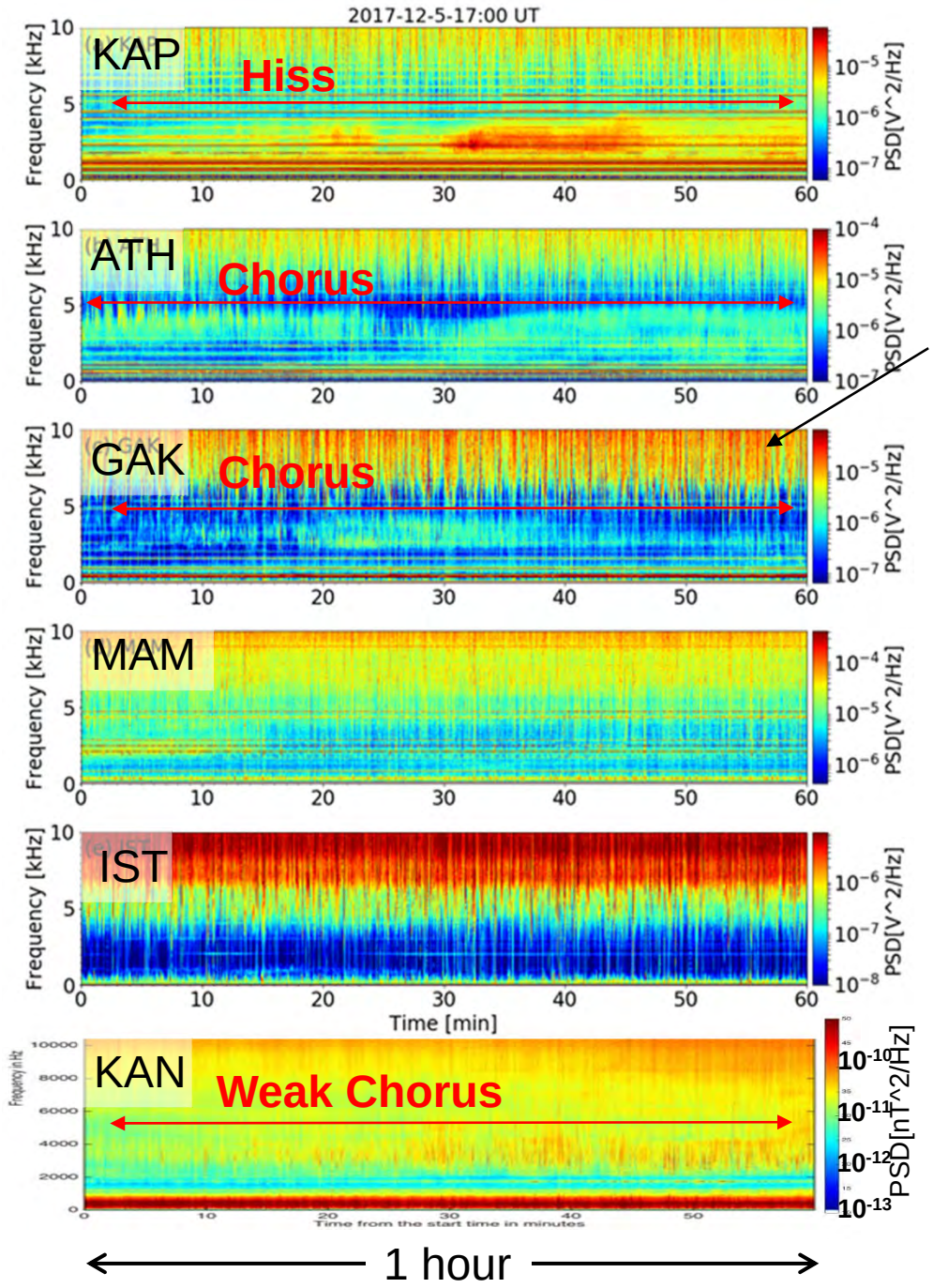
kHz







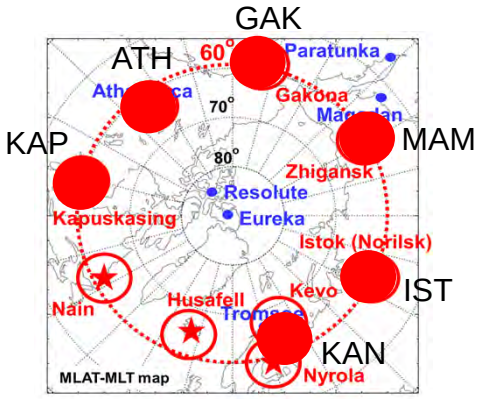
Martinez-Calderon et al. (JGR, 2015)
doi:10.1002/2015JA021347

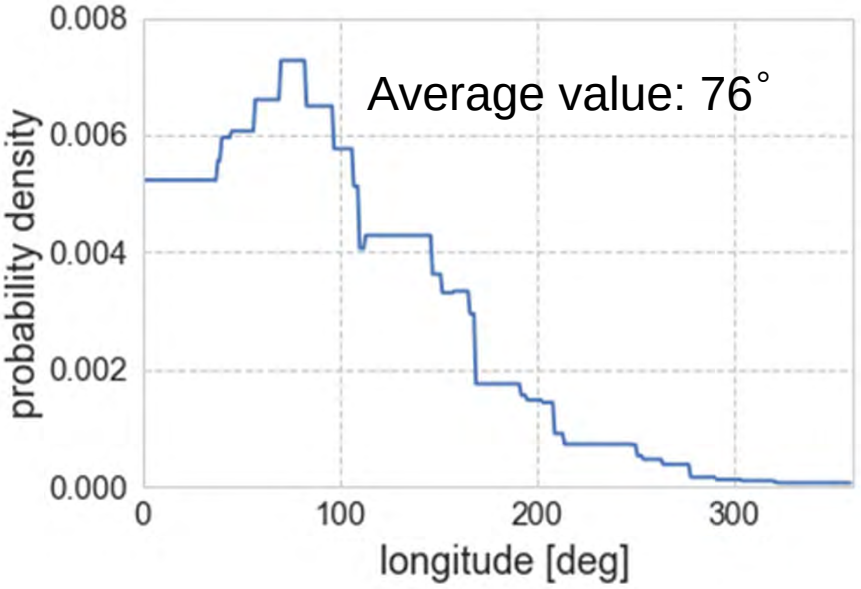


Lightning noise

Takeshita et al. (JGR, 2019)
https://doi.org/10.1029/2019JA026810

kHz



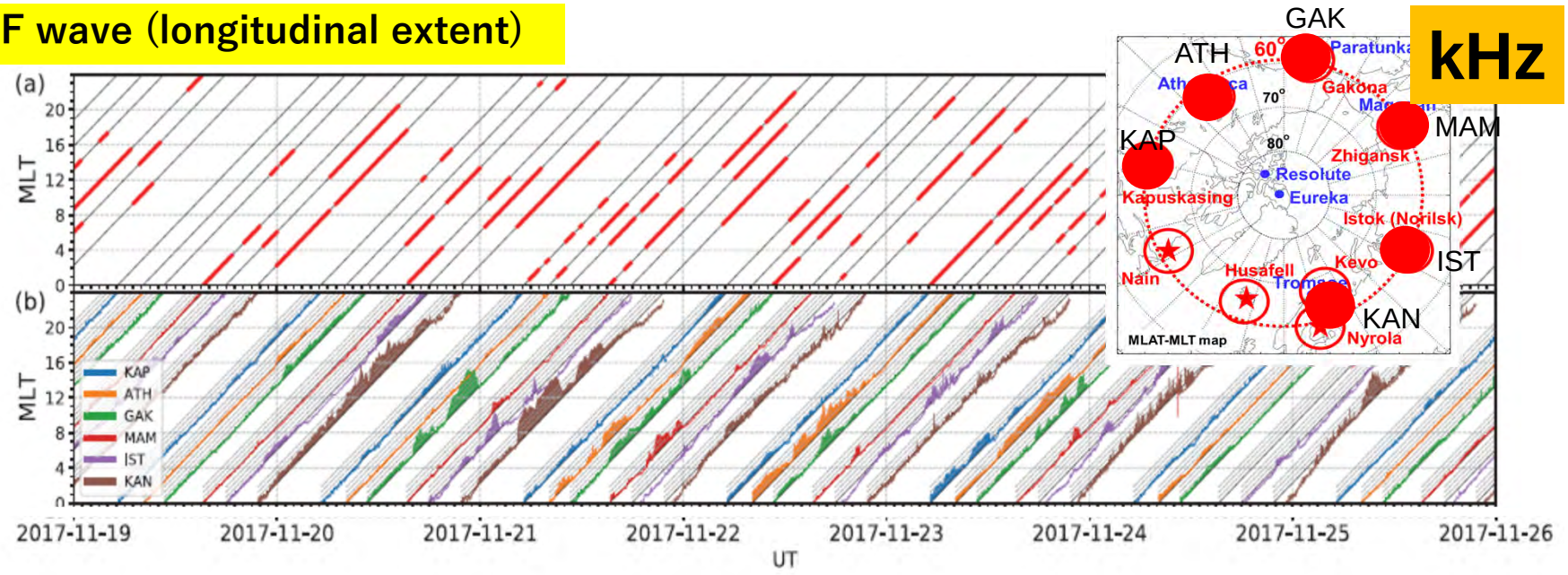


Probability density of longitudinal extent.

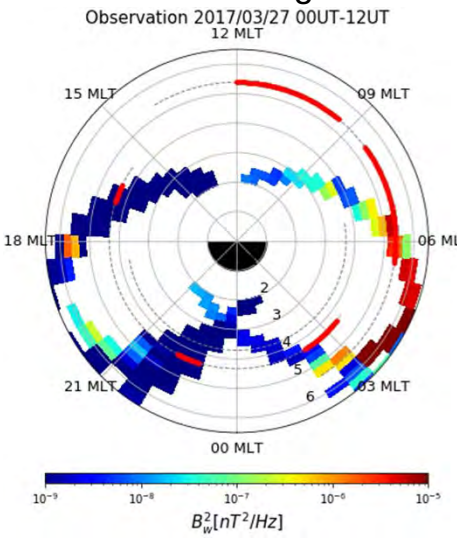
Longitudinal extent of ELF/VLF waves is ~76 degree on average, based on 2-month observations at 6 stations.

ELF/VLF wave (longitudinal extent)

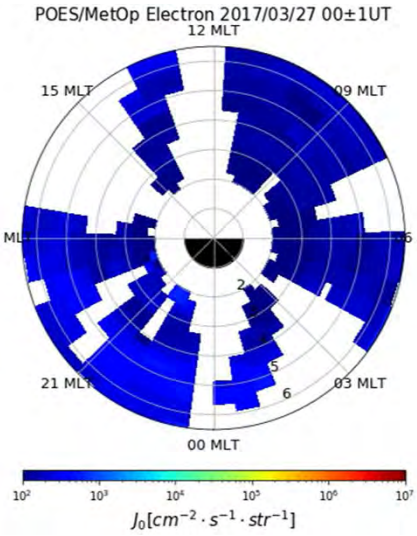
PWING ground



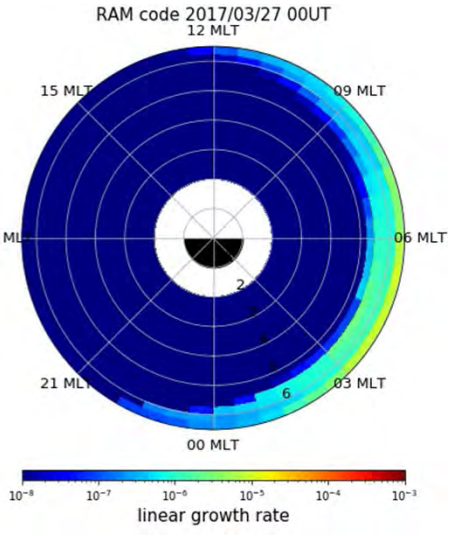
Arase/RBSP/ground



NOAA/POES



RAM-SCB Model



Takeshita et al. (JGR, 2021, https://doi.org/10.1029/2020JA028216)

ELF/VLF wave (longitudinal extent)

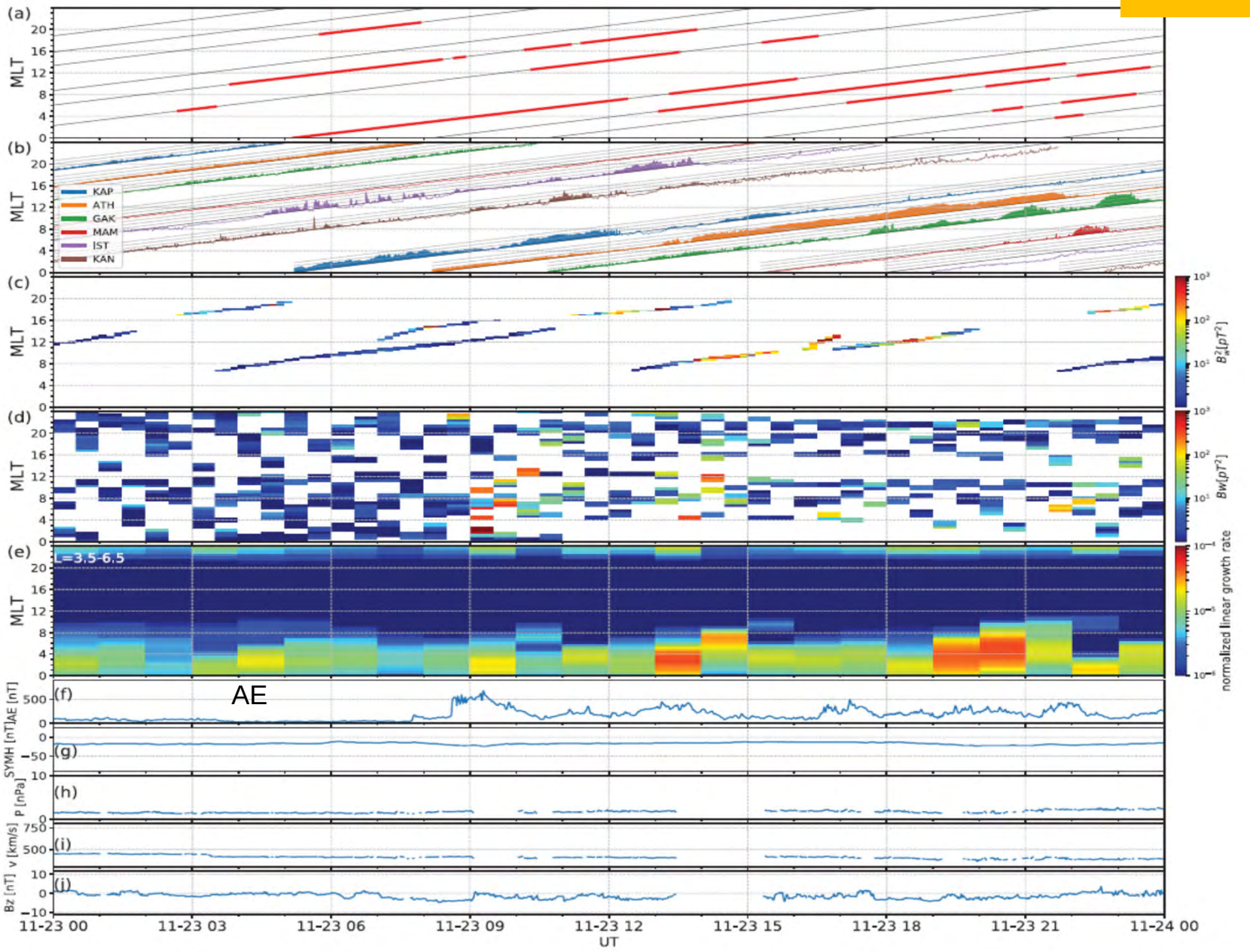
kHz

PWING ground

Arase RBSP

NOAA/ POES

RAM-SCB Model

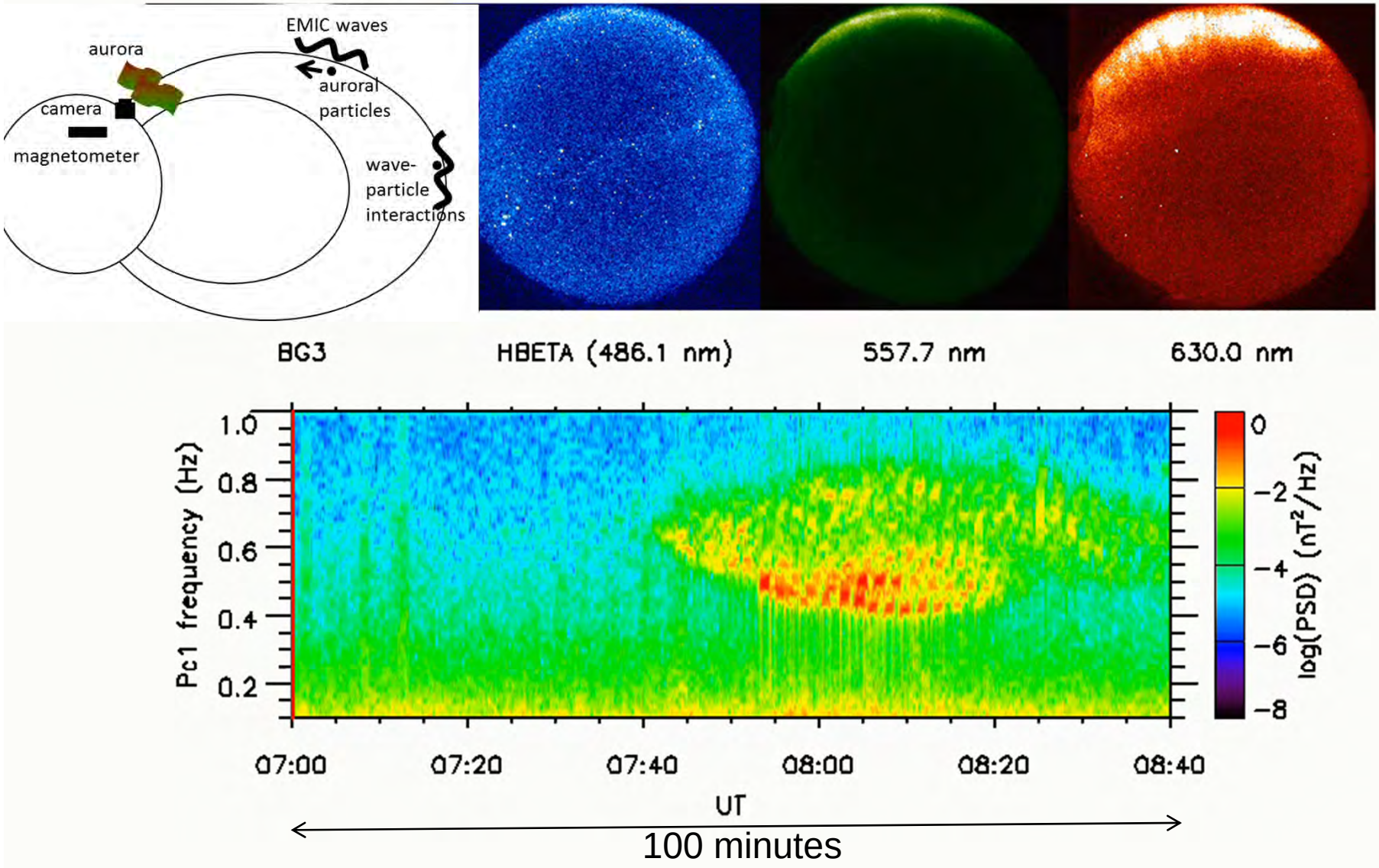


Takeshita et al. (JGR, 2021, https://doi.org/10.1029/2020JA028216)

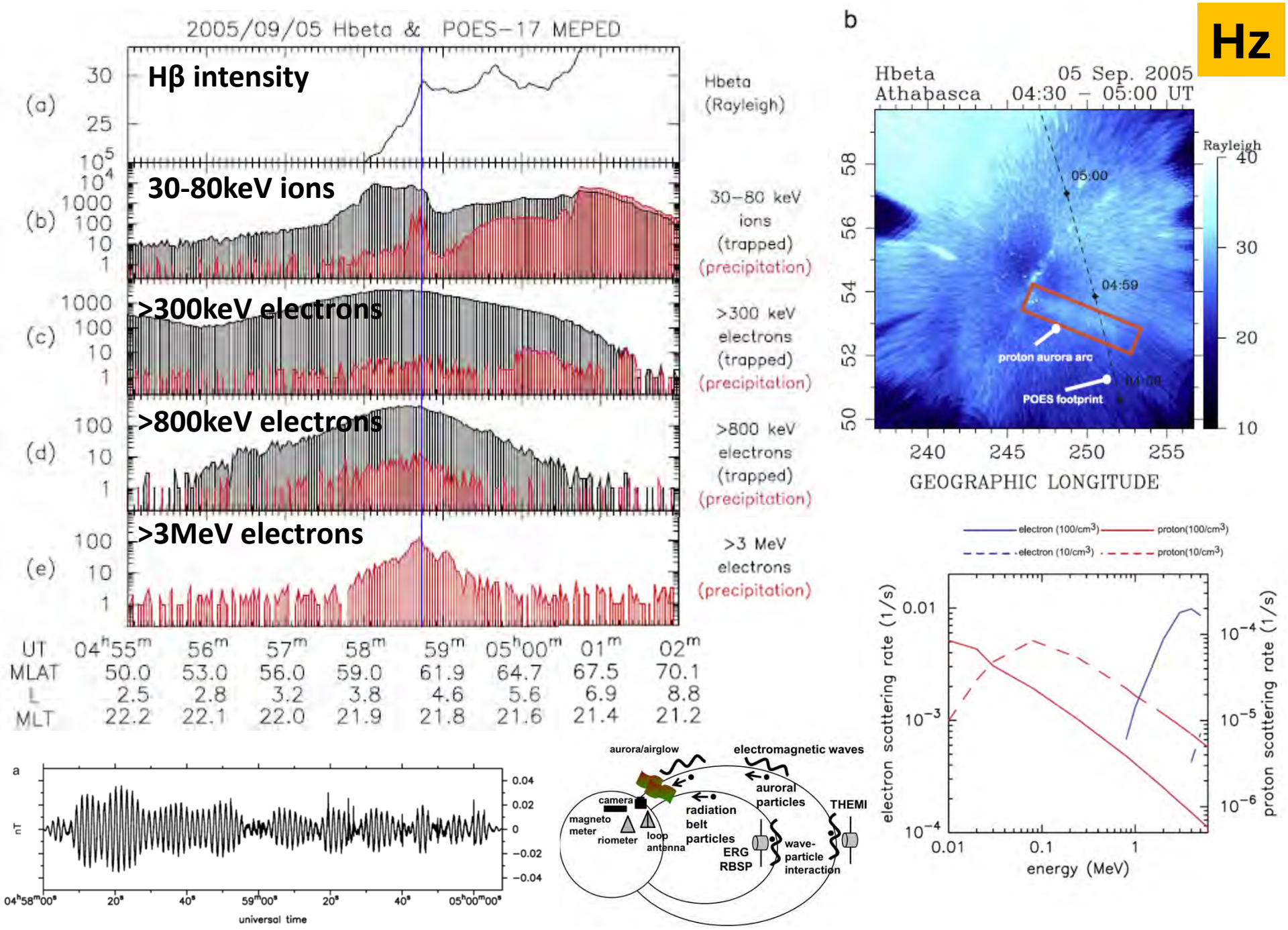
Isolated proton aurora and EMIC(Pc1) waves

07:00:00 UT, 12 November, 2015

Hz



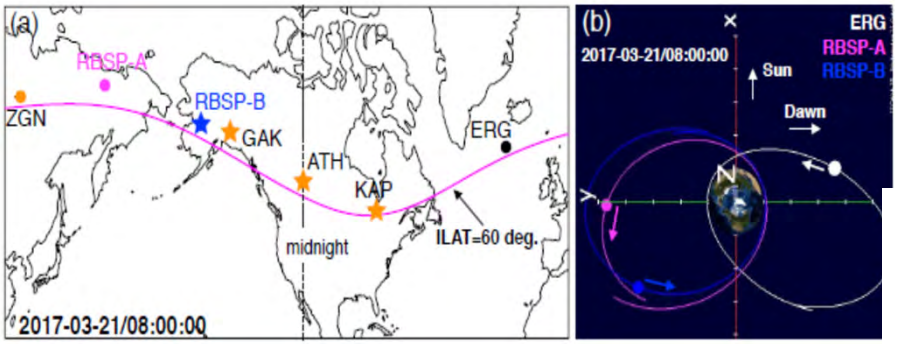
Ozaki et al. (GRL, 2016, doi:10.1002/2016GL070008)
also see: Nomura et al. (JGR, 2016, doi:10.1002/2015JA021681) and Sakaguchi et al. (AGUbook, 2016)

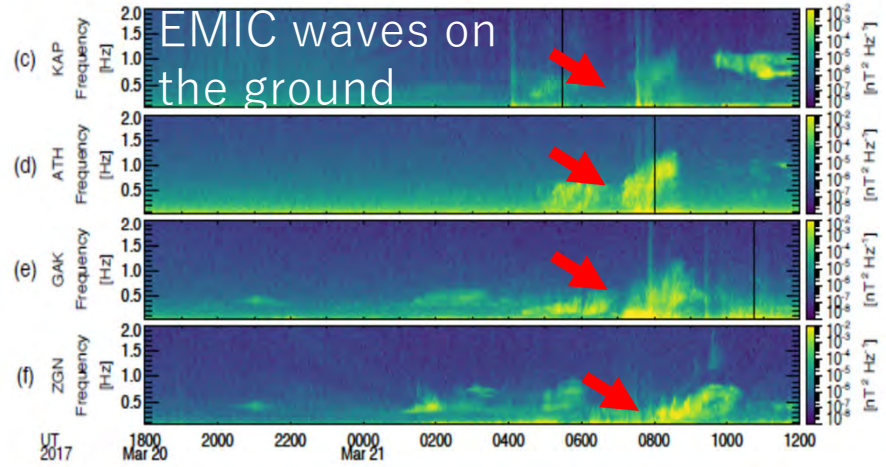


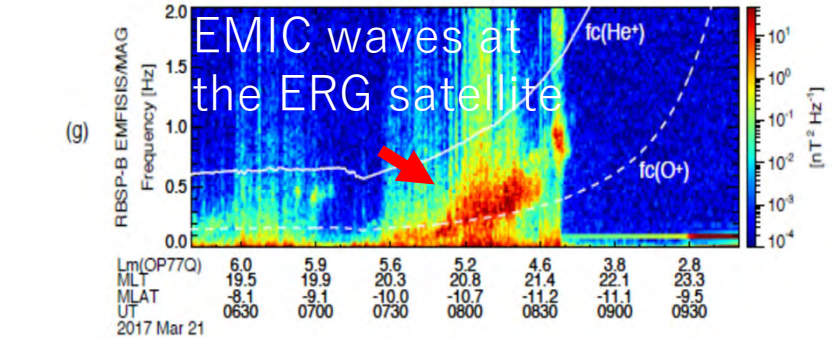
Hz

Miyoshi et al. (GRL, 2008, doi:10.1029/2008GL035727)

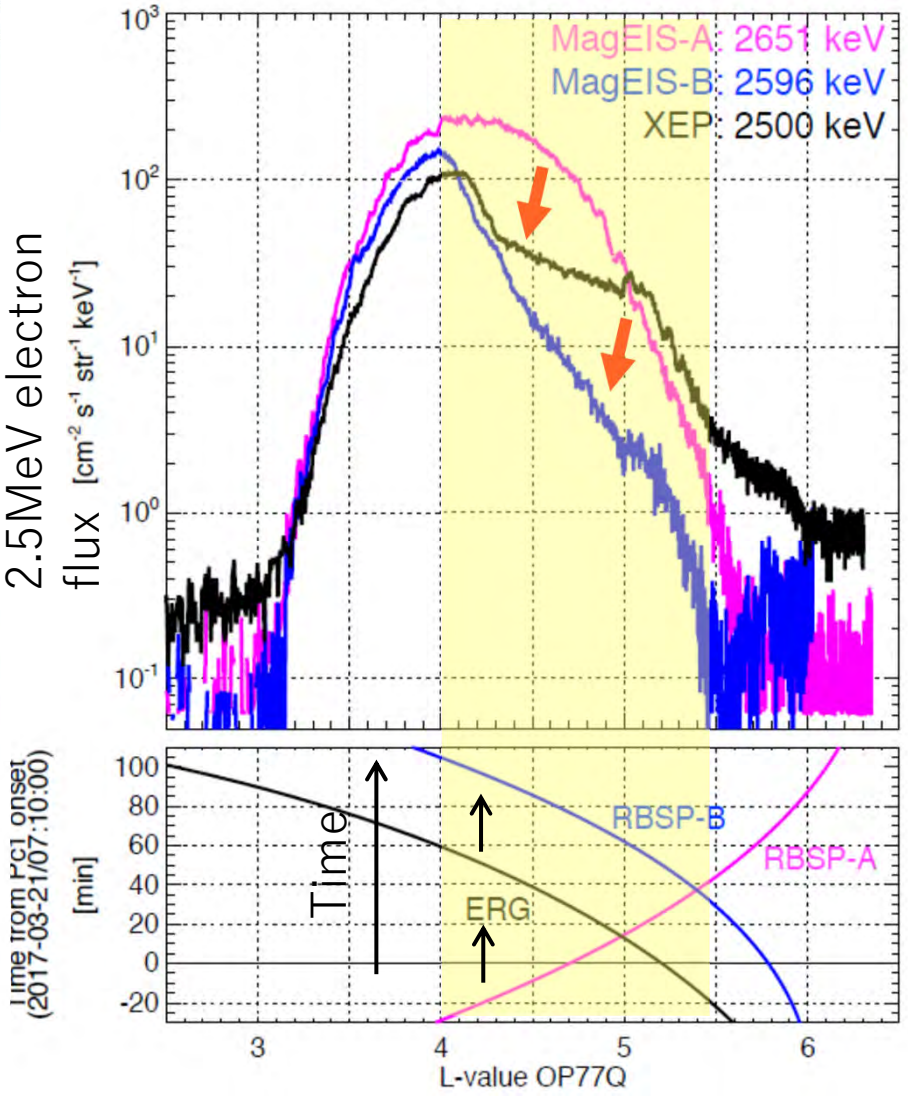
Location of ground stations and satellites



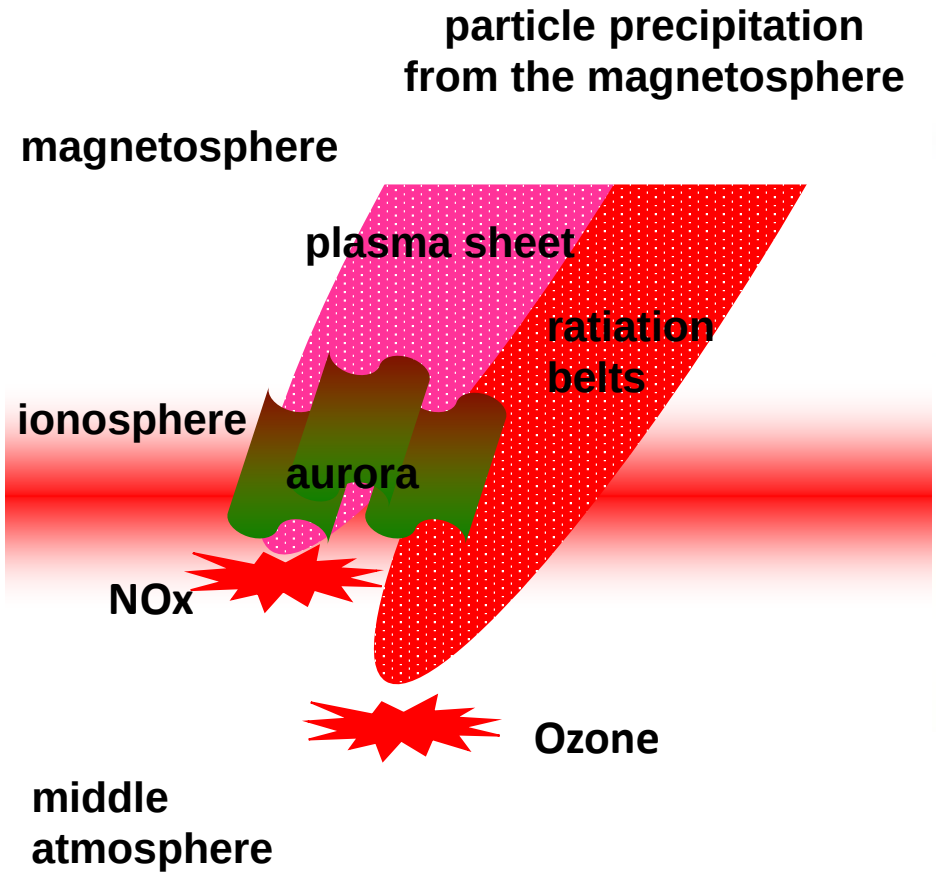


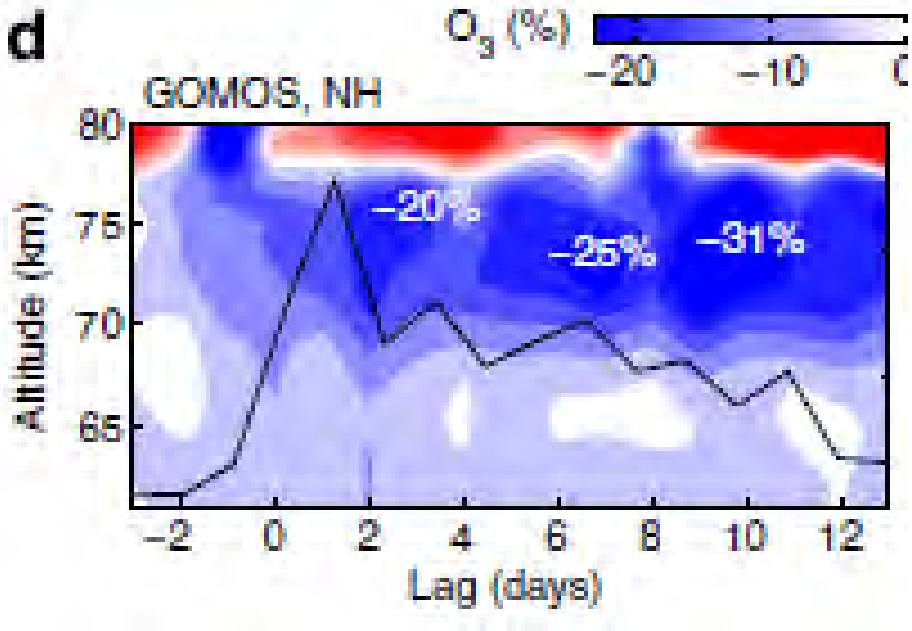


Kurita et al. (GRL, 2018)
https://doi.org/10.1029/2018GL080262



Loss of 2.5MeV radiation belt electrons by ERG and RBSP satellites associated with global EMIC waves

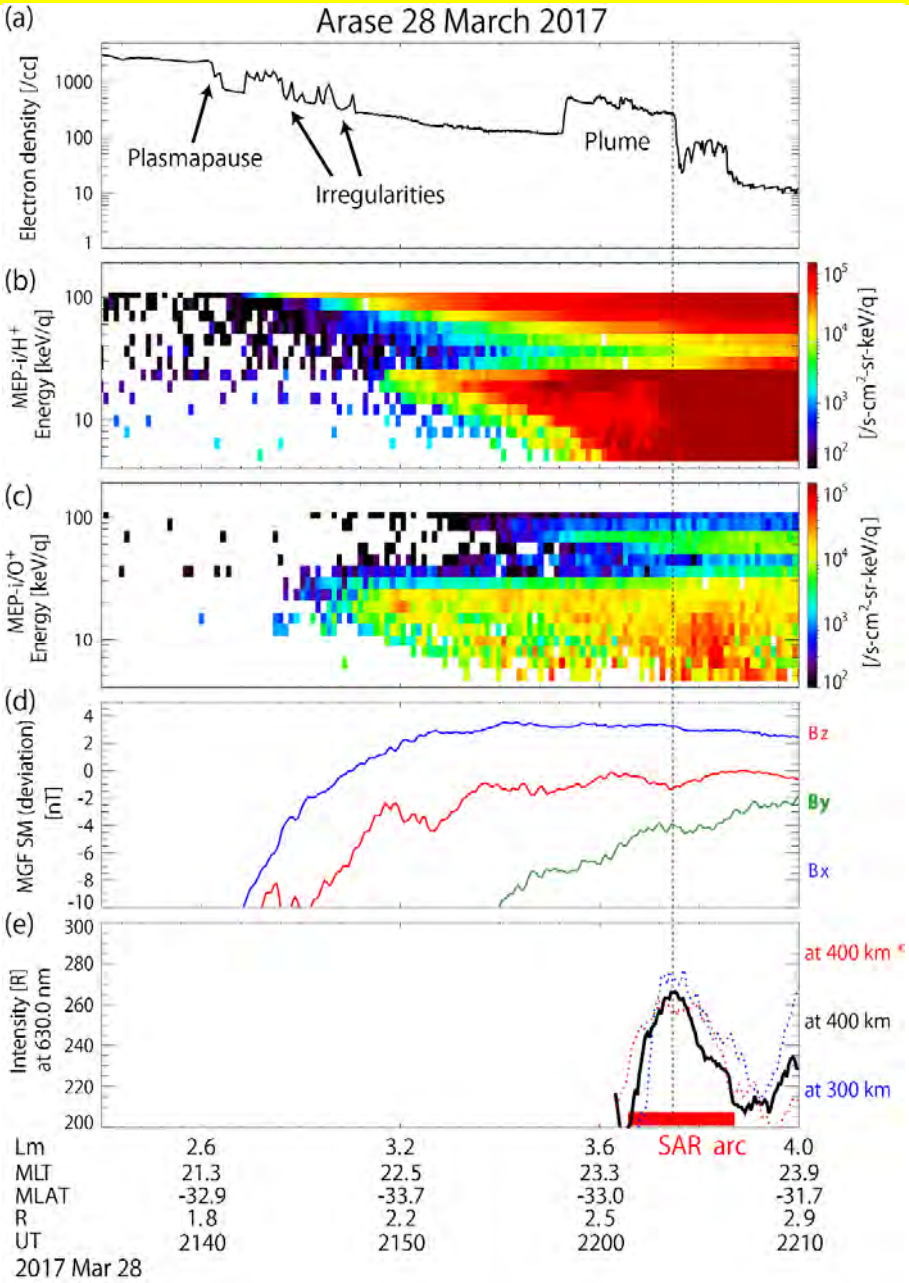


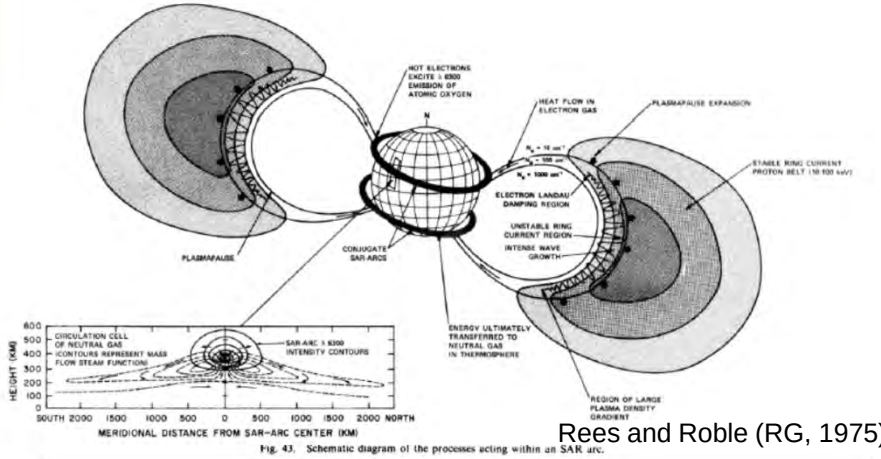


First evidence for radiation belt electron precipitation impact on atmospheric ozone in long term.

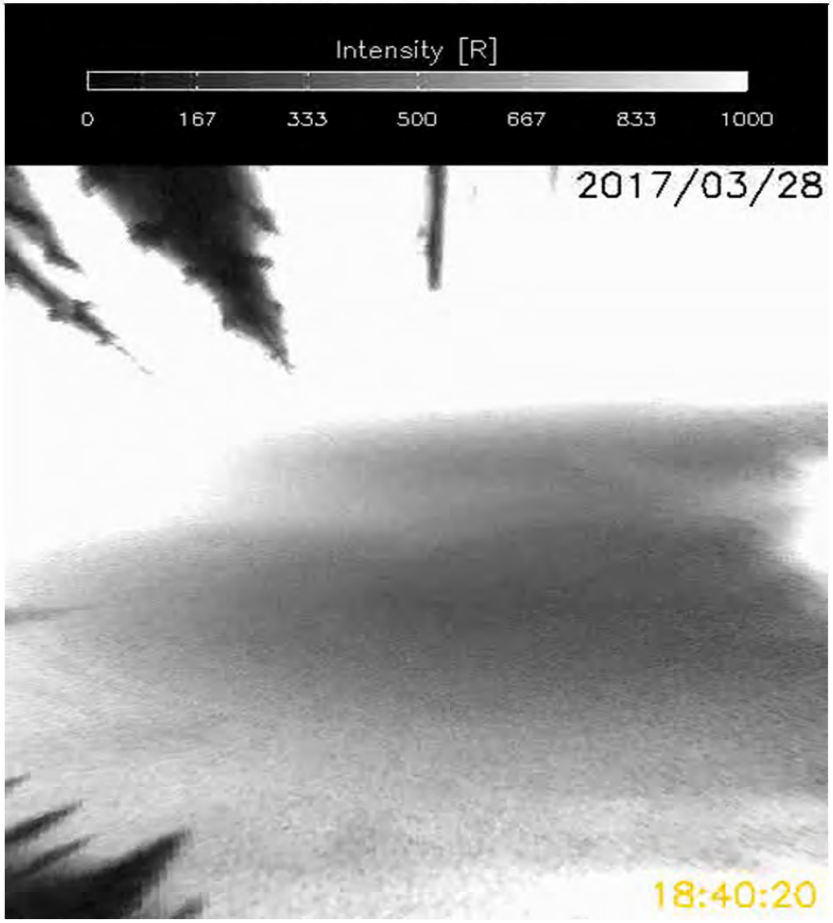
Andersson et al. (Nature Comm., 2014, DOI: 10.1038/ncomms6197)

SAR arc source plasma (overlap of ring current and plasmasphere)





Rees and Roble (RG, 1975)



Inaba et al. (JGR, 2020, 2021, https://doi.org/10.1029/2020JA028068, https://doi.org/10.1029/2020JA029081)

Summary

- Inner magnetosphere contains wide-energy range (eV-MeV) plasma.
- The plasma acceleration is caused by earthward injection to ~100 keV (plasma sheet) and interaction with mHz (Pc5), Hz (ion cyclotron), kHz (electron cyclotron) waves to ~1 MeV (radiation belts) that is hazardous for human activity in space
- Wide energy plasma, waves, and E- and B-fields forms complicated system for acceleration and loss of plasma.
- Recent multi-point ground network at subauroral latitudes and RBSP/Arase satellites in the inner magnetosphere provides various characteristics of wave-particle interaction.
- But quantitative understanding is still limited. Connection of micro-scale and global scale processes is necessary.
- Energetic particle precipitation (EPP) may change atmospheric dynamics through ozone destruction.