INSTITUTE OF SOLAR-TERRESTRIAL PHYSICS
SIBERIAN BRANCH OF RUSSIAN ACADEMY OF SCIENCES

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# GENERATION OF GEOMAGNETIC PULSATIONS Pc4-5 BY ENERGETIC PARTICLES' FLUXES IN THE DAYSIDE MAGNETOSPHERE

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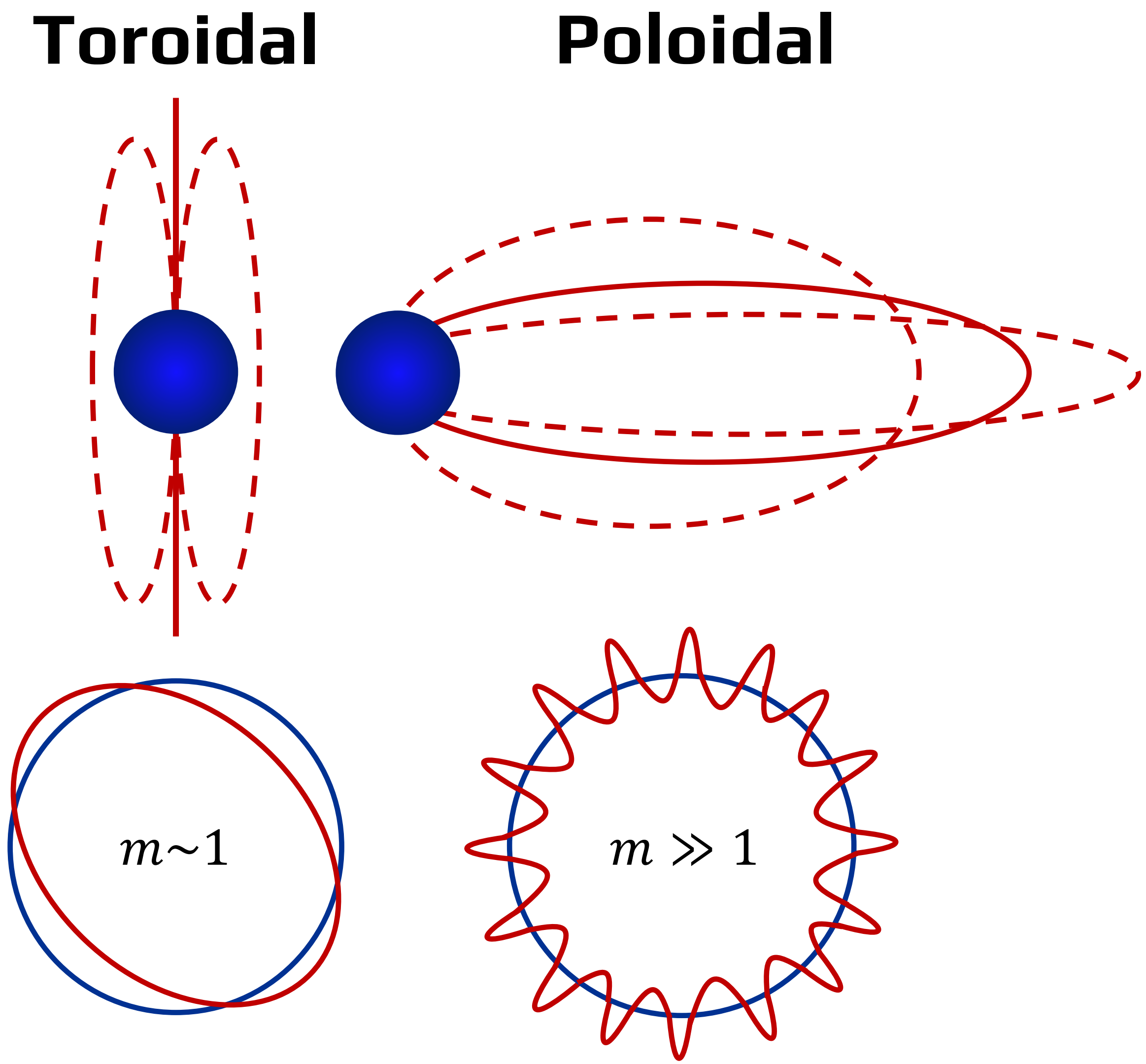
# Ultra-Low Frequency wave in magnetosphere

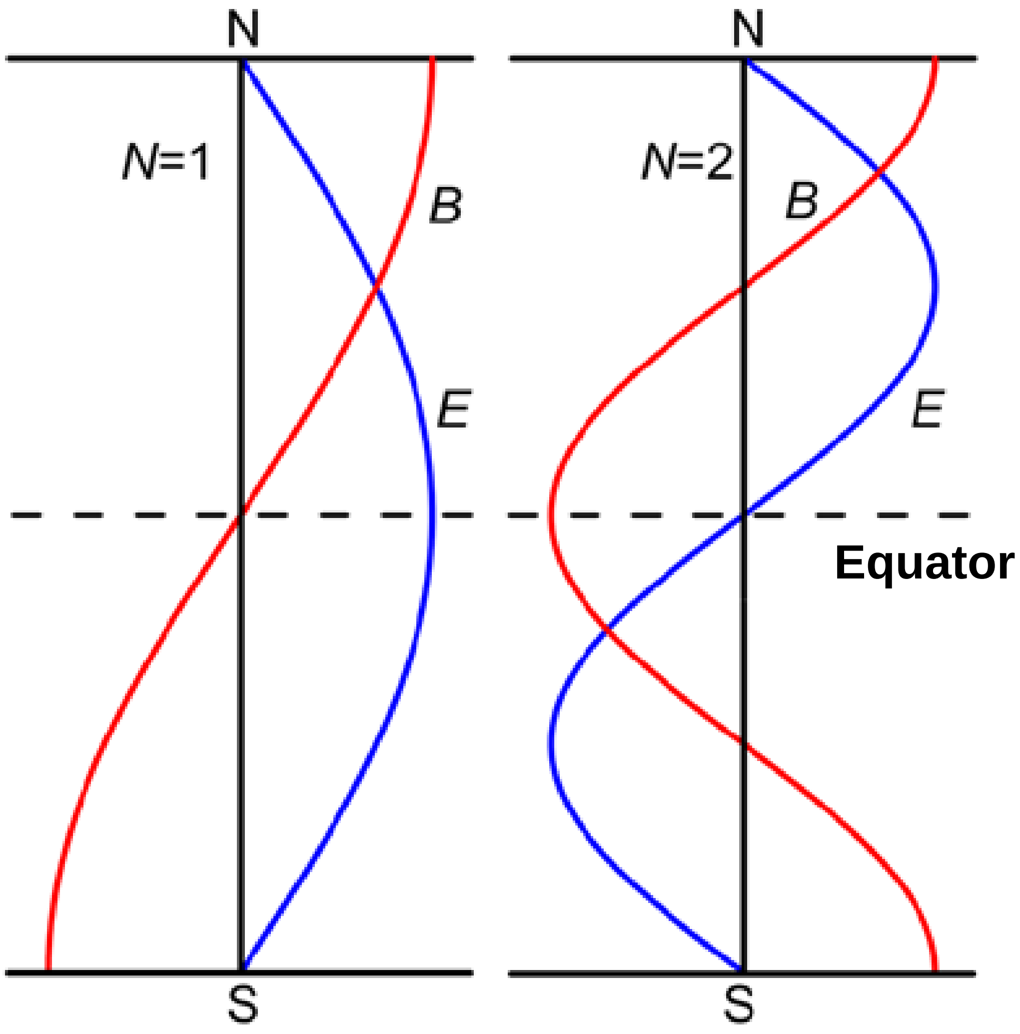



- Toroidal Alfven waves ($m$~1);
- Poloidal Alfven waves ($m \gg 1$);
- Compressional waves ($m$~1)

Generation associated with sources in the solar wind

Generation inside magnetosphere

# Drift-bounce resonance theory




**Drift-bounce resonance conditions**

[Southwood and Kivelson, 1981,1982]:

$$\omega - m\overline{\omega_d} - k\omega_b = 0$$

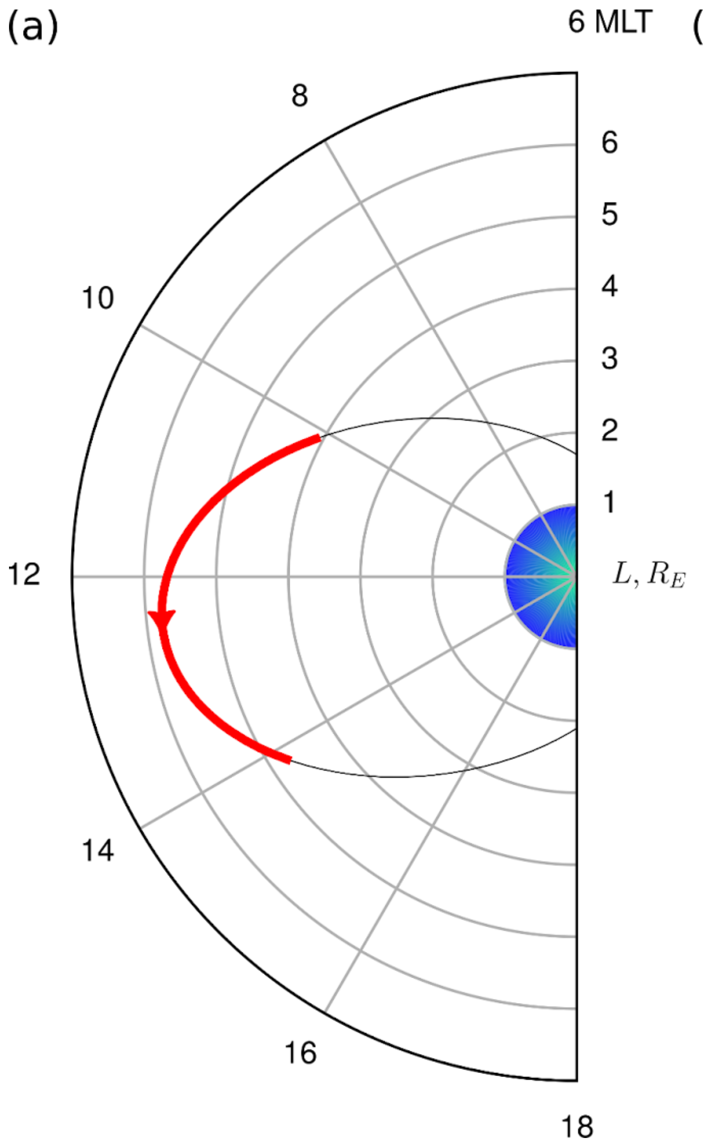
where $\omega$ – wave frequency, $\omega_b$ и $\overline{\omega_d}$ – bounce frequency and drift frequency averaged over bounce period, $m$ – azimuthal wavenumber

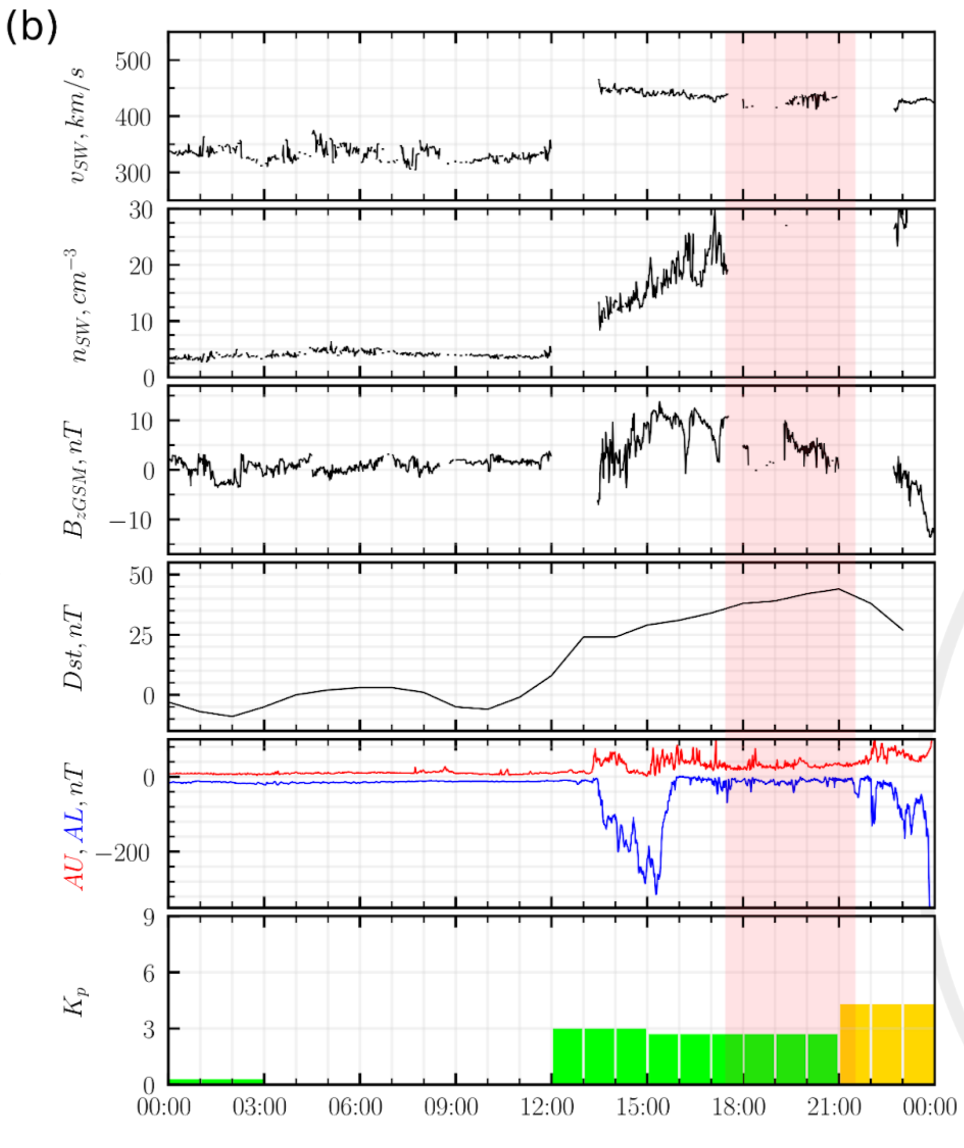
**In general case** [Hamlin, 1961]**:**

$$\overline{\omega_d} = -\frac{6\varepsilon \cdot (0.35 + 0.15 \sin \alpha_0)}{qB_{0L}(LR_\oplus)^2}$$

$$\omega_b = \frac{\pi}{LR_\oplus \cdot (1.3 - 0.56 \sin \alpha_0)} \sqrt{\frac{\varepsilon}{2m_{par}}}$$

# Event 15 February 2014



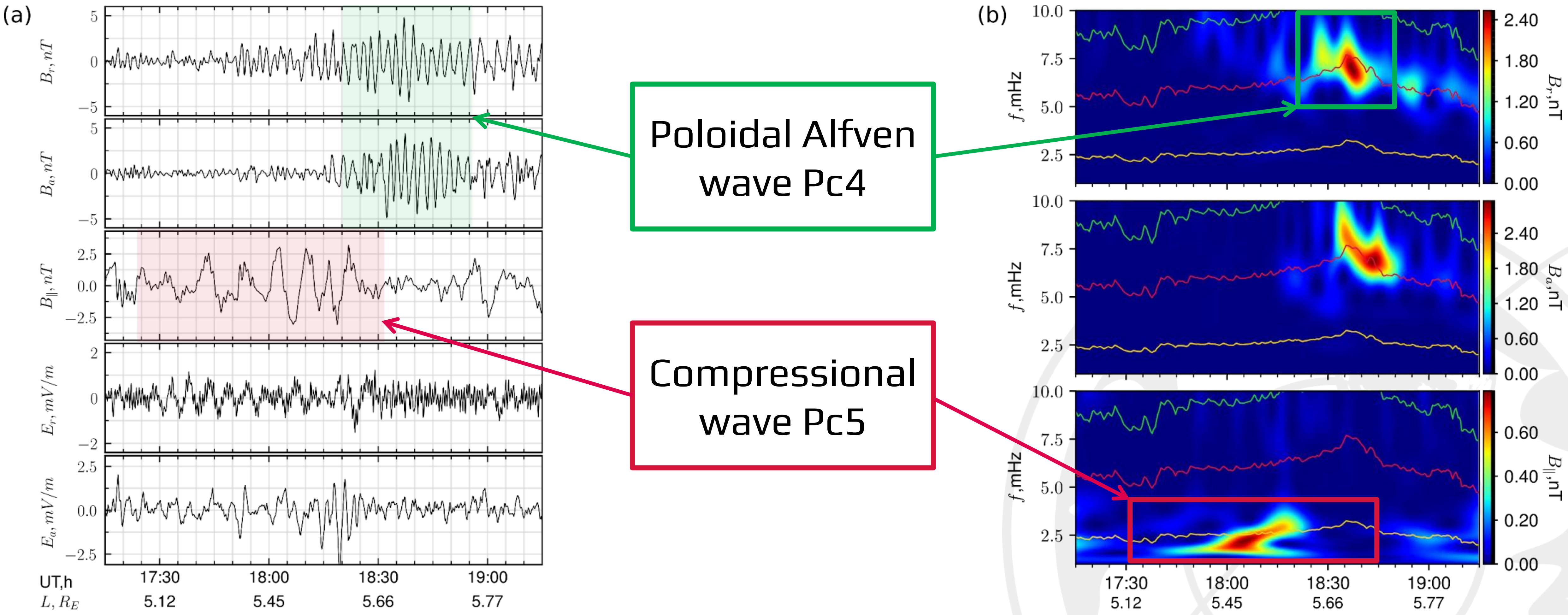

**Mission:** Van Allen Probe (RBSPA)

**Observation time of RBSPA:** 16:30-21:30 UT

**Magnetosphere sector:** dayside

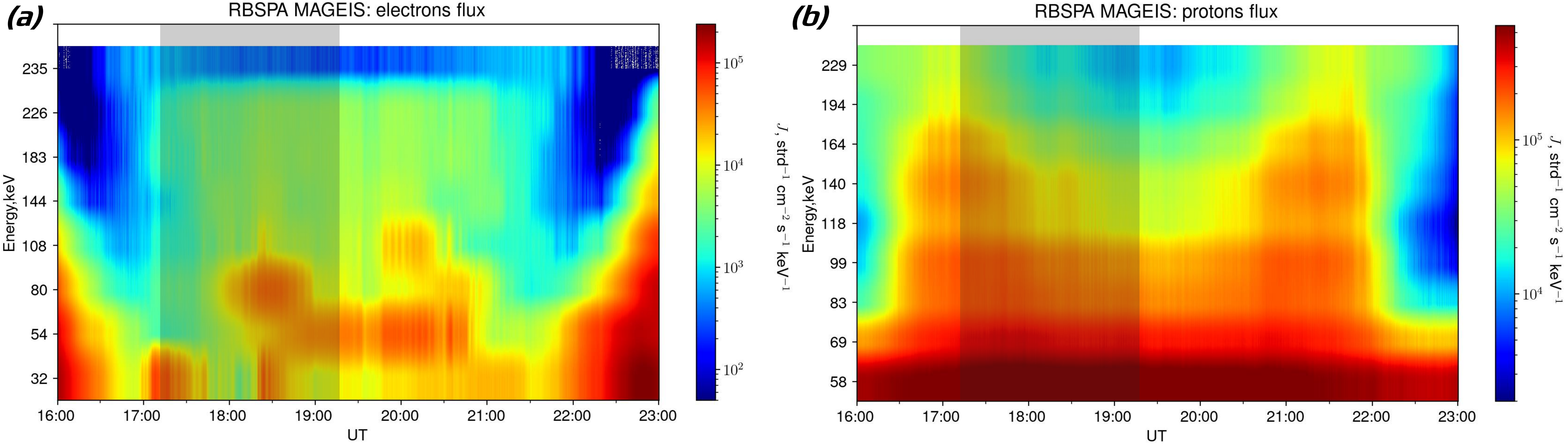
*The time interval corresponding to the RBSPA trajectory on Fig. (a) is underlined with a **red** rectangle*

# ULF waves: electromagnetic field



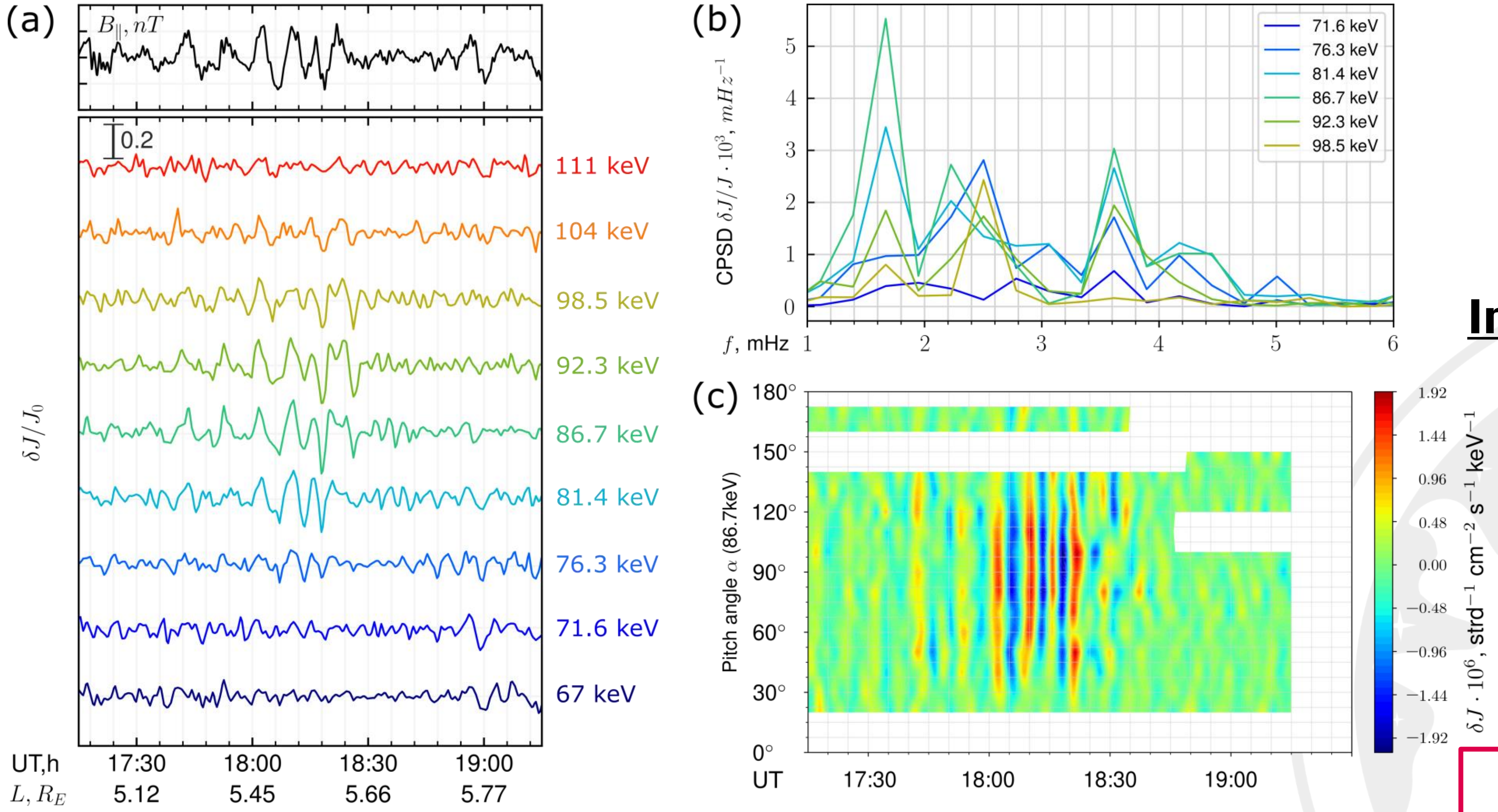

(a) Oscillations in the magnetic and electric fields (b) Wavelet spectra of the corresponding magnetic field oscillations. The yellow, red and green lines indicate the calculated values of natural toroidal Alfven frequencies for the 1st, 2nd and 3rd harmonics, respectively

# Modulation in particle fluxes




Differential fluxes of energetic electrons (a) and protons (b)

# Compressional Pc5 wave and electron fluxes




(a) Residual electron flux oscillations (δJ/J) for different energies, where δJ and J are perturbed and unperutbed fluxes, respectively, separated by filtration. (b) Cross power spectral density (CPSD) for several energy channels. (c) Pitch angle distribution of δJ for 86.7 keV

**Type of interaction:**

drift resonance

**Resonance energy:**

80-90 keV

**Interaction frequency:**

1.65 mHz

**Wave harmonic:**

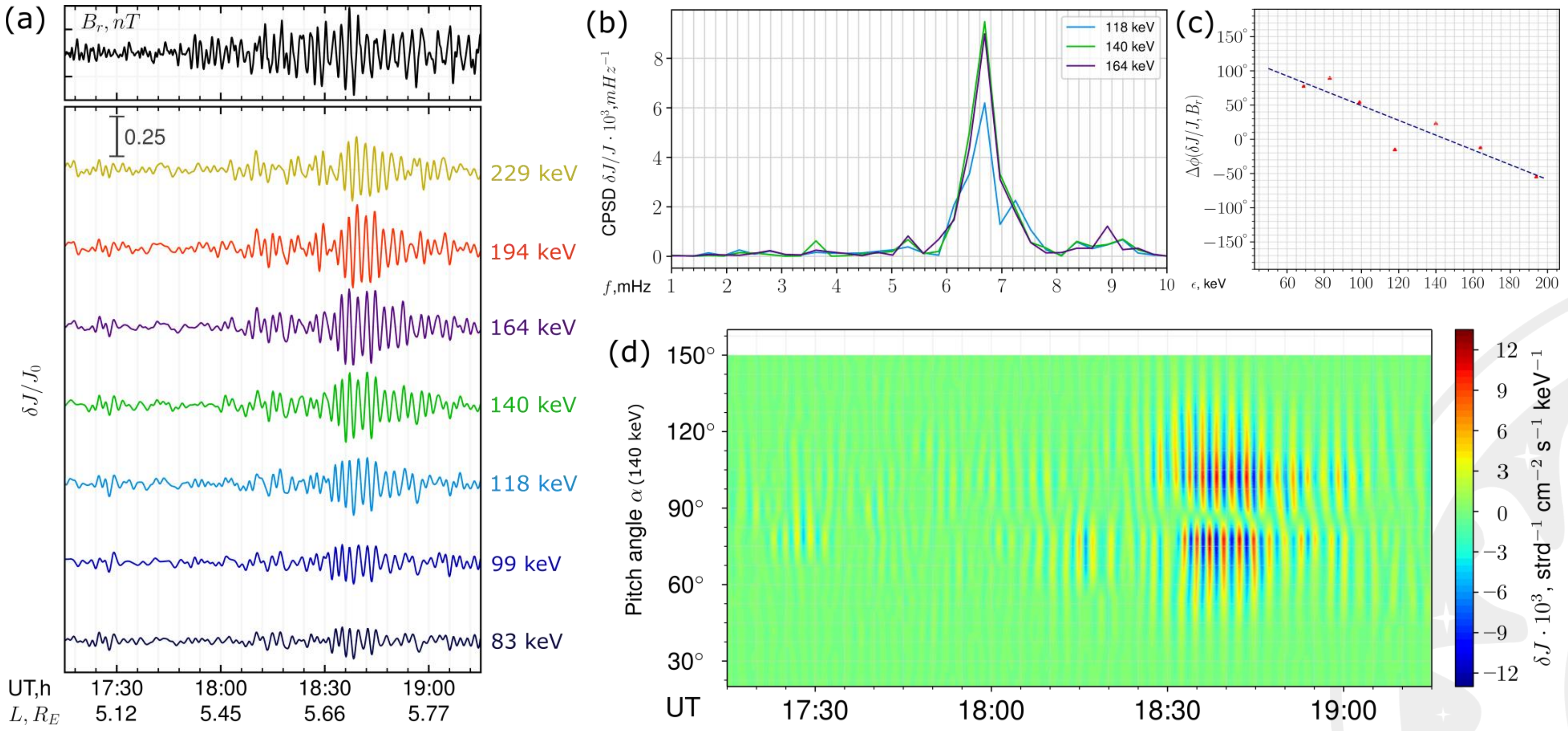
$N = 1$

**$m$ -number:**

$m = 11\ (k = 0)$

$$m = \frac{\omega - k\omega_b}{\overline{\omega_d}}$$

# Poloidal Pc4 wave and proton fluxes




(a) Residual proton flux oscillations (δJ/J) for different energies. (b) Cross power spectral density (CPSD) for several energy channels. (c) Phase shift between residual proton flux (δJ/J) and radial magnetic field $B_r$ by energy (d) Pitch angle distribution of δJ for 140 keV

**Type of interaction:**
drift-bounce resonance

**Resonance energy:**
140-150 keV

**Interaction frequency:**
6.5 mHz

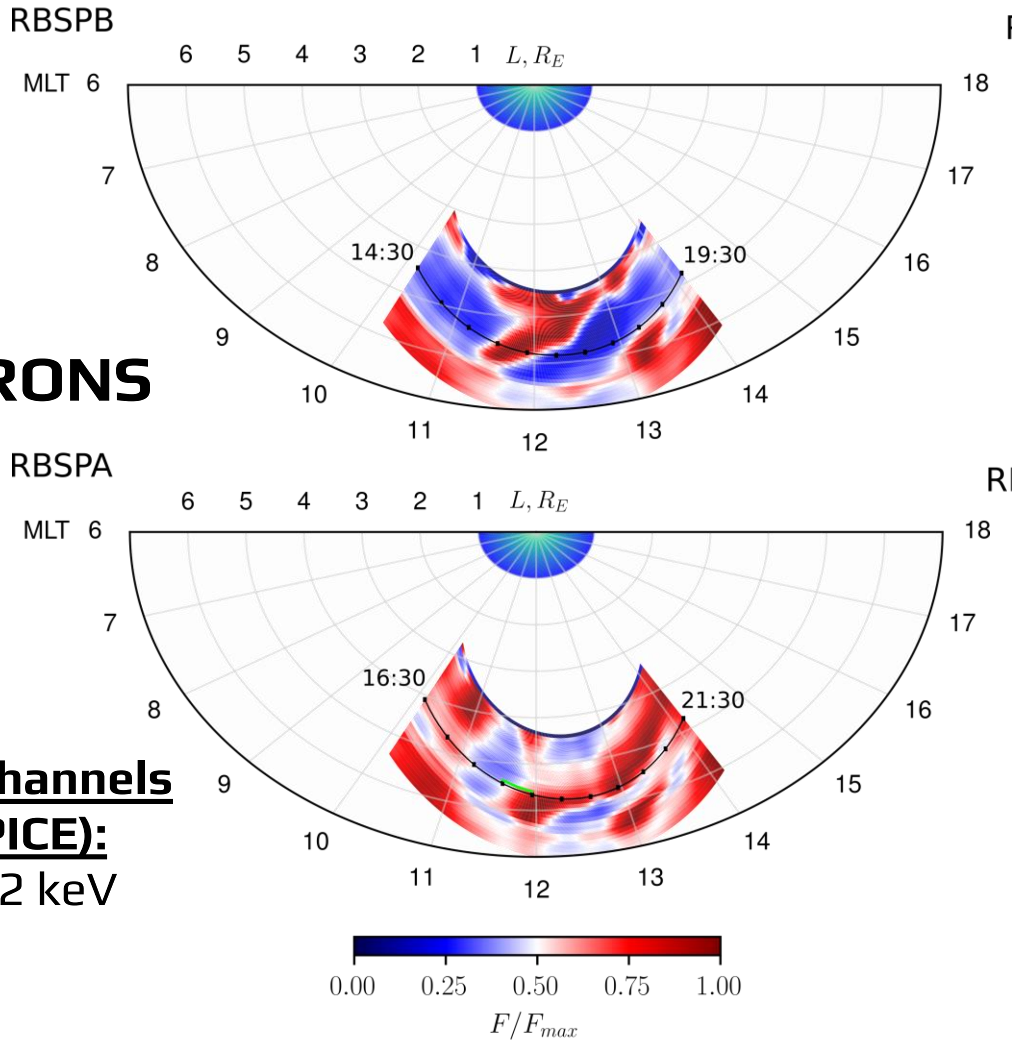
**Wave harmonic:**
$N = 2$

**Azimuthal wavenumber:**
$m = -230\ (k = -1)$
$m = 180\ (k = 1)$

Two ULF waves?

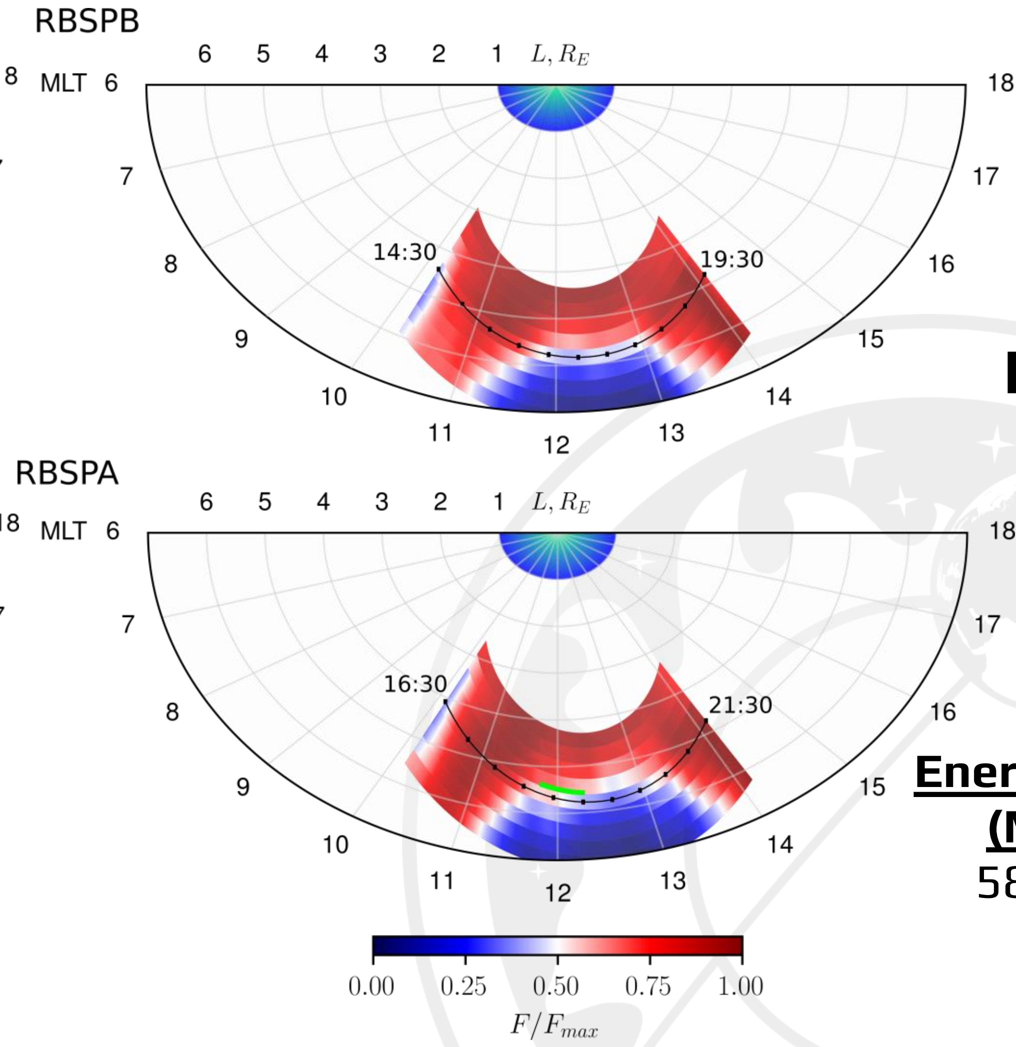
# What is the source?

**ELECTRONS**




**<u>Energy channels (RBSPICE):</u>**
20 -152 keV

**PROTONS**

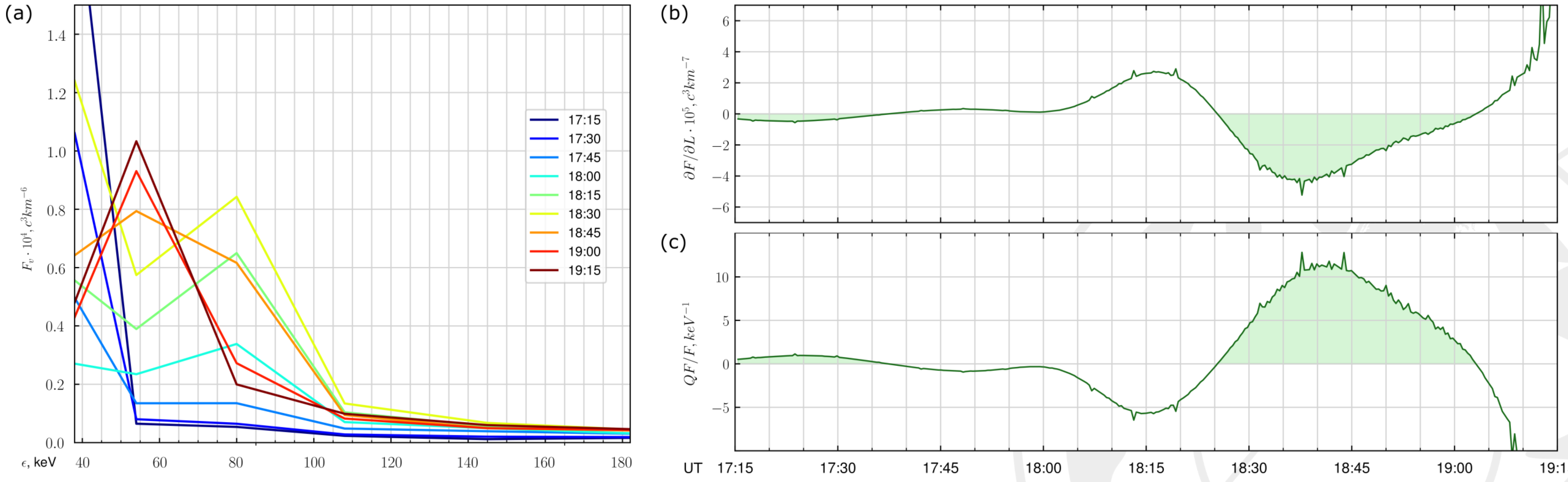



**<u>Energy channels (MAGEIS):</u>**
58-230 keV

Distribution function for electrons (left) and protons (right) along spacecraft trajectories RBSPB and RBSPA.
The black line shows the spacecraft trajectories. Markers delimit time intervals of 30 minutes.
**Green lines** show time interval of wave-particle interaction

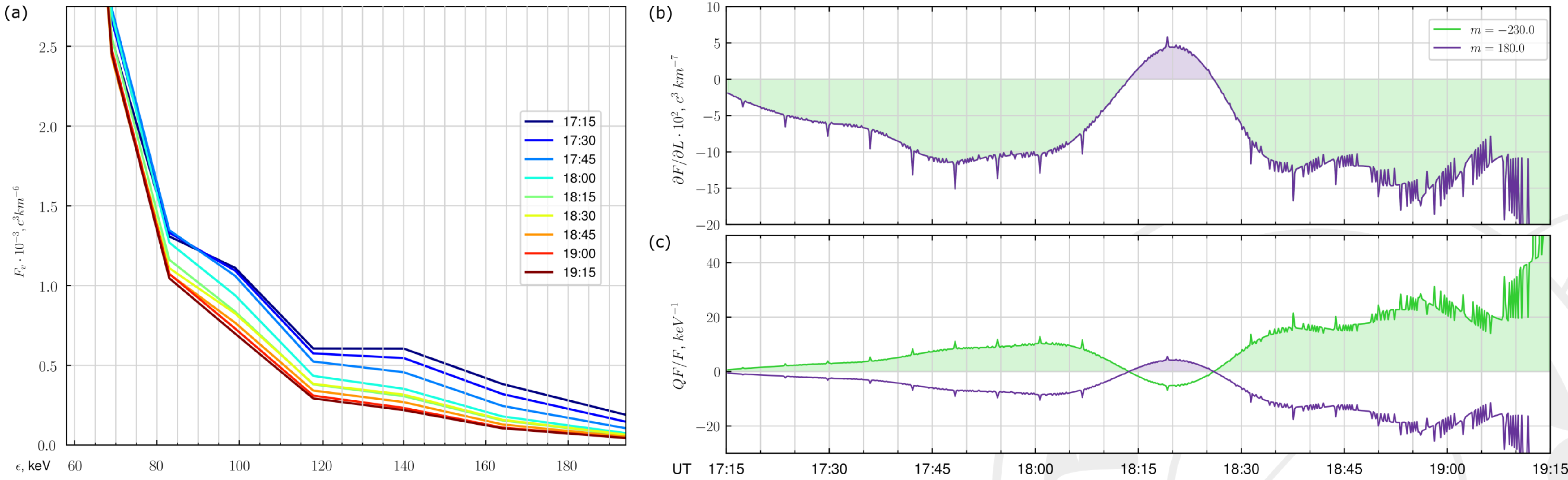
# Generation mechanism: electron-generated wave

**Instability condition** [Southwood et. al., 1969]: $\hat{Q}F = \left[\frac{\partial F}{\partial \varepsilon} + \frac{m}{\omega}\frac{c}{qB_{eq}L}\frac{\partial F}{\partial L}\right]_{\varepsilon_{res}}$




(a) The electron distribution function $f_v$ for different times in the event interval. (b) Radial gradient of electron distibution function with energy 86.7 keV. (c) The instability condition for electron flux with energy 86.7 keV

# Generation mechanism: proton-generated wave




(a) The proton distribution function $f_v$ for different times in the event interval (b) Radial gradient of proton distibution function with energy 140 keV. (c) The instability condition for proton flux with energy 140 keV.

The **green** and **purple** colors in Fig. (b) and (c) correspond to the ULF-wave with frequency 6.5 mHz, but differen azimuthal wavenumber $m = -230$ and $m = 180$, respectively

# Conclusion

- The simultaneous generation of several ULF waves by proton and electron fluxes was registered;
- Both gradient and bump-on-tail instabilities contributed to ULF waves generation
- ULF waves were generated by motion of stable clouds of energetic particles presumably resulting from magnetic substorms

**Characteristics of ULF waves in 15 February 2014 event**

| Wave Frequency | Particles | Resonance energy, keV | Resonance type | m | Wave harmonics | Generation mechanism |
|---|---|---|---|---|---|---|
| 1,65 mHz (Pc5) | Electrons | $\approx 80 - 90$ | Drift | 11 | 1 | Gradient and bump-on-tail instabilities |
| 6,5 mHz (Pc4) | Protons | $\approx 140 - 150$ | Drift-bounce | $-230\ (k=-1)$<br>$180\ (k=1)$ | 2 | Gradient and bump-on-tail instabilities |

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# Thank you for your attention!

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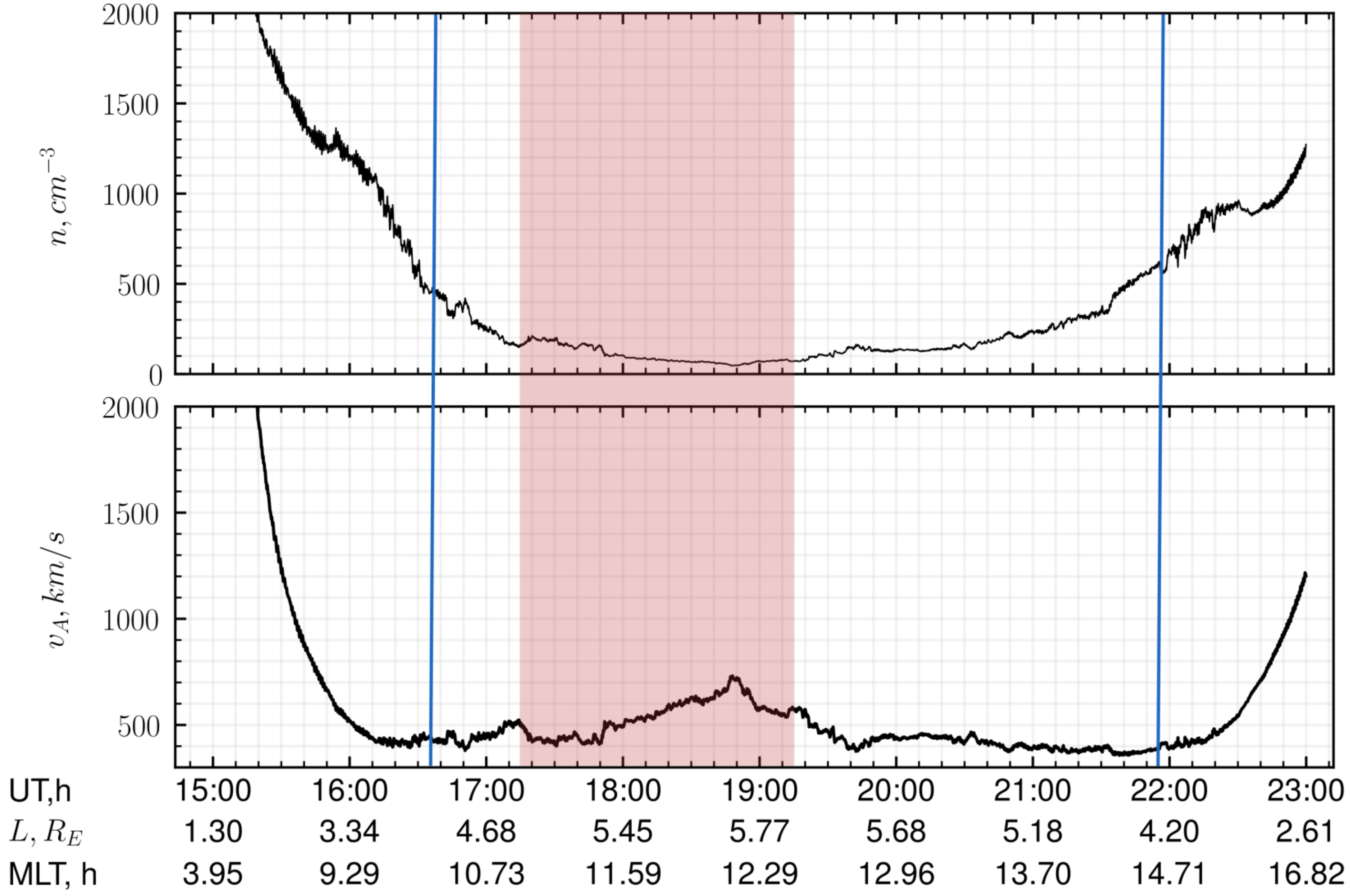
# Supporting materials

# Event 15 February 2014




Oscillations were observed out of plasmasphere

Electron density and calculated Alfven speed. The **red rectangle** indicates the time interval in which the oscillations are studied. **Blue lines** show plasmapause positionl

# Azimuthal wavenumber

Drift-bounce resonance conditions[1,2]:

$$\omega - m\overline{\omega_d} - k\omega_b = 0$$

where $\omega$ – wave frequency, $\omega_b$ и $\overline{\omega_d}$ – bounce frequency and drift frequency averaged over bounce period [3], $m$ – azimuthal wavenumber

<table>
<tr><th>Wave Frequency</th><th>Particles</th><th>Resonance energy, keV</th><th>Resonance type</th><th>m</th><th>Wave harmonics [1-2]</th></tr>
<tr><td>1,65 mHz (Pc5)</td><td>Electrons</td><td>$\approx 80 - 90$</td><td>Drift</td><td>$11$</td><td>1</td></tr>
<tr><td rowspan="2">6,5 mHz (Pc4)</td><td rowspan="2">Protons</td><td rowspan="2">$\approx 140 - 150$</td><td rowspan="2">Drift-bounce</td><td>$-230\ (k = -1)$</td><td rowspan="2">2</td></tr>
<tr><td>$180\ (k = 1)$</td></tr>
</table>

*[1] Southwood and Kivelson, 1981* *[2] Southwood and Kivelson, 1982* *[3] Hamlin, 1961*


16