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

OBSERVATIONS OF A MAGNETOSPHERIC WAVE GENERATED BY A MOVING PLASMA INHOMOGENEITY

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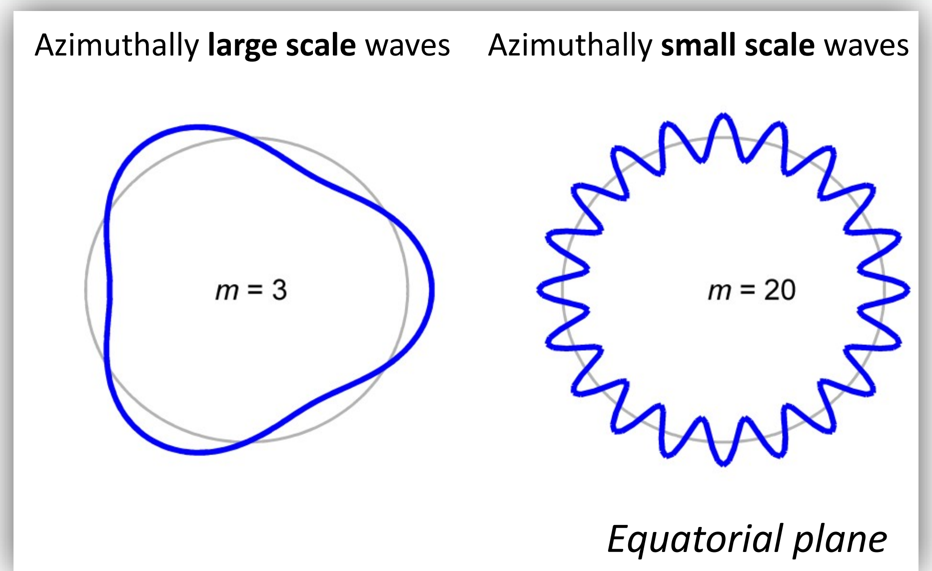
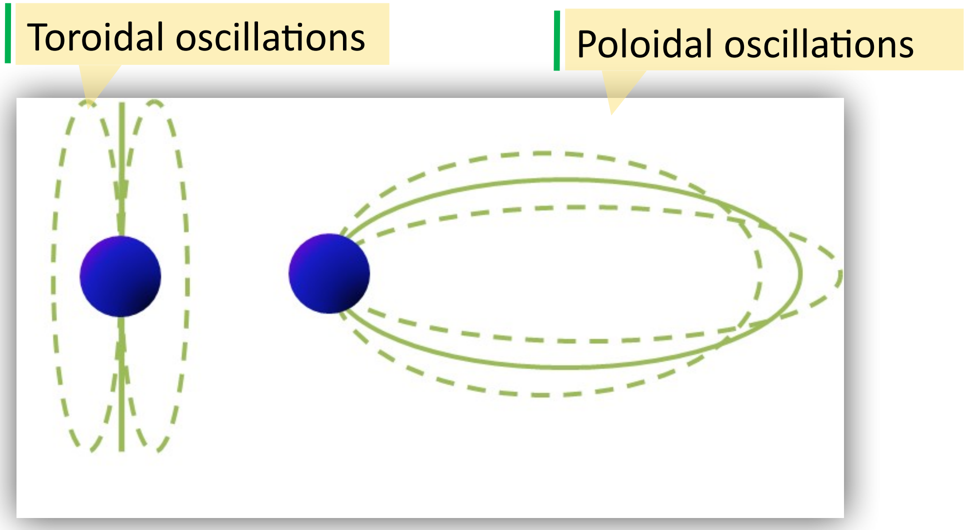
15th Russian-Chinese Workshop on Space Weather

ULF waves in the magnetosphere





- **Toroidal modes (small *m*)**

  Source beyond the magnetosphere or via solar wind – magnetosphere interaction, antisunward propagation in the magnetosphere

- **Poloidal modes (large *m*)**

  Interaction with charged particles

  Predominantly westward propagation (interaction with protons / positively charged particles)

  Based on radar observations, 10–15 % of the waves propagate westward (positive m)

  Waves with m>0 can effectively interact with electrons

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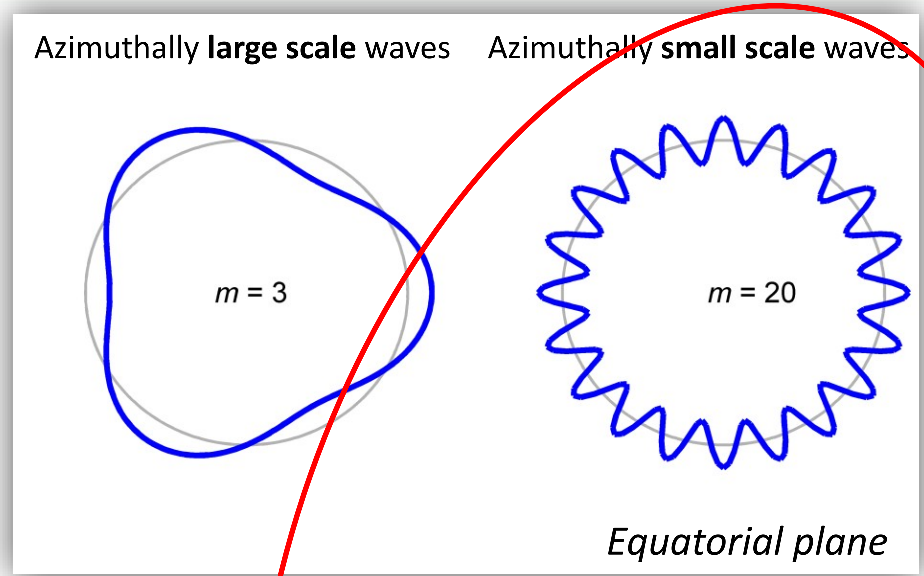

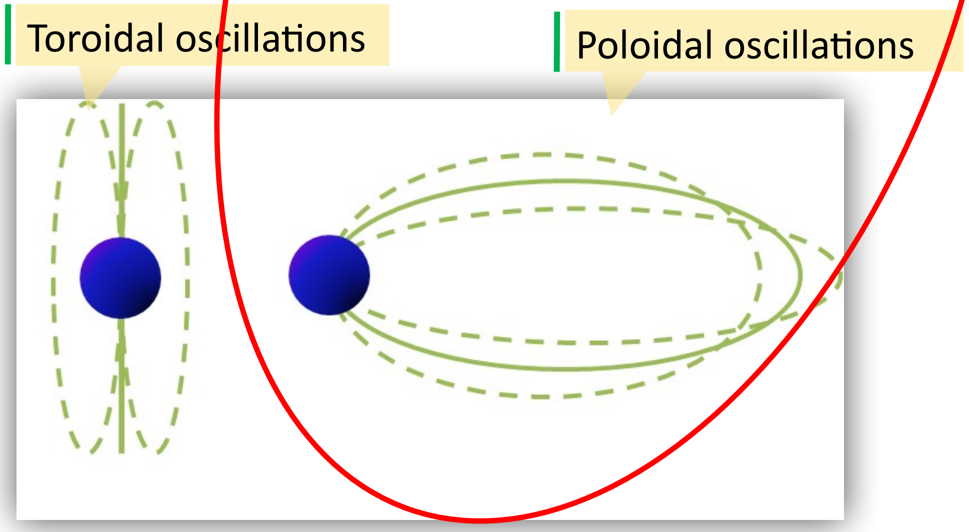

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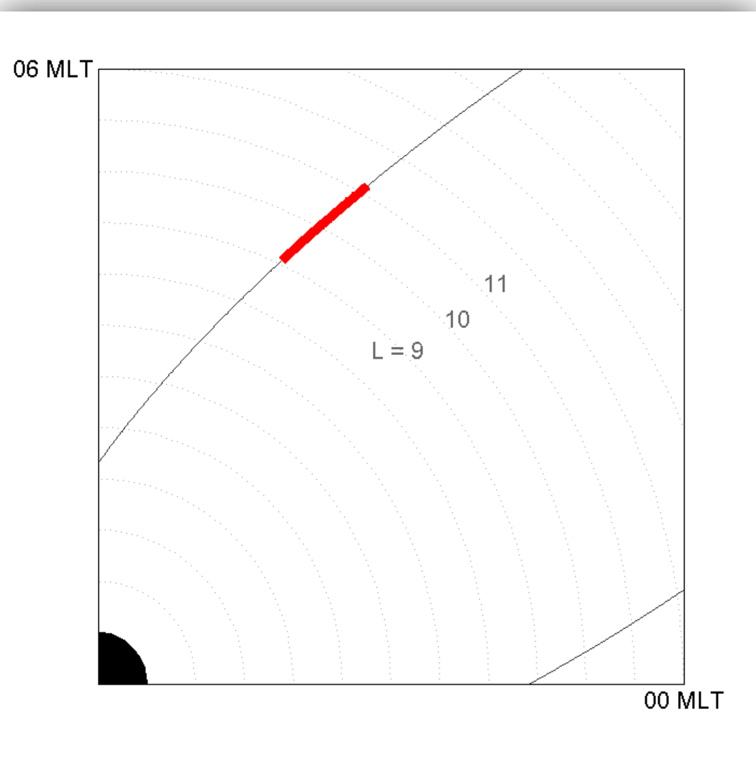
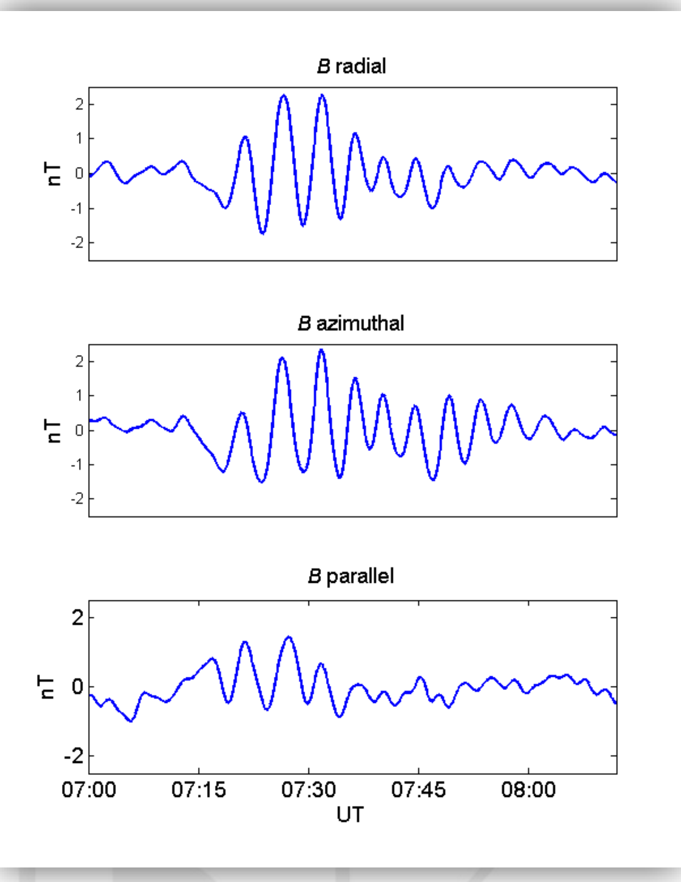
7 July 2020 MMS observations

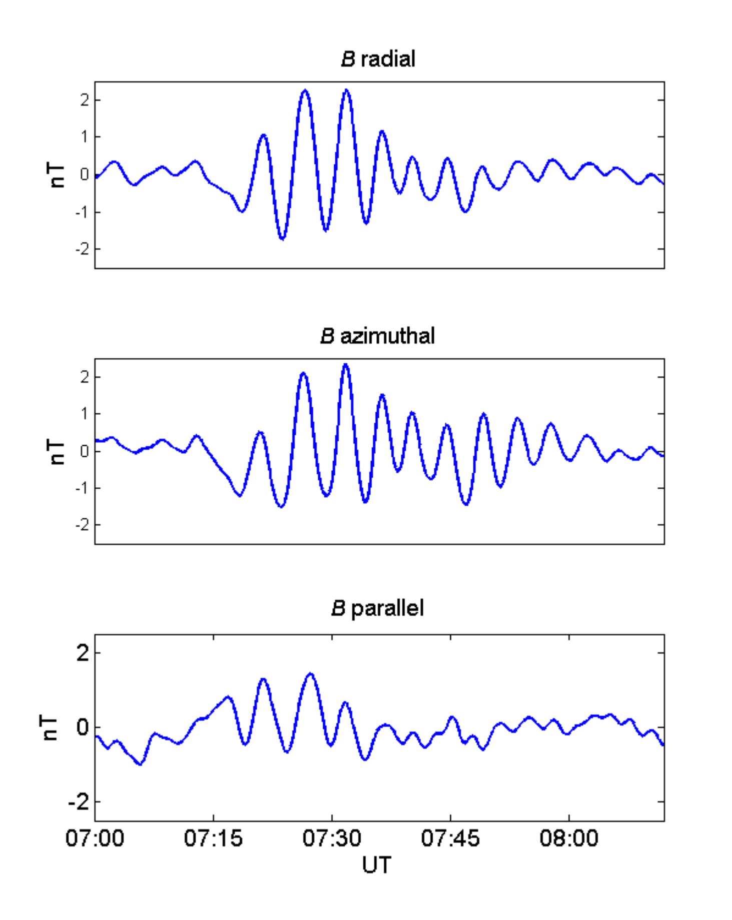


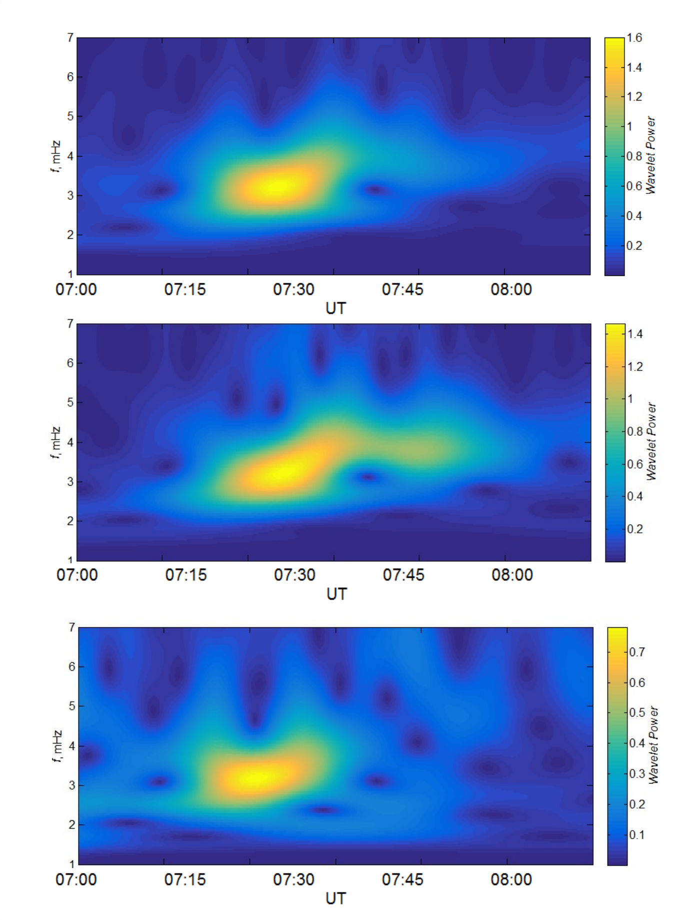
Post midnight sector of the magnetosphere, spacecraft were moving towards the Earth *L* shells 12–10



The radial, azimuthal and parallel components of the magnetic field registered with the MMS1 spacecraft

7 July 2020 MMS observations

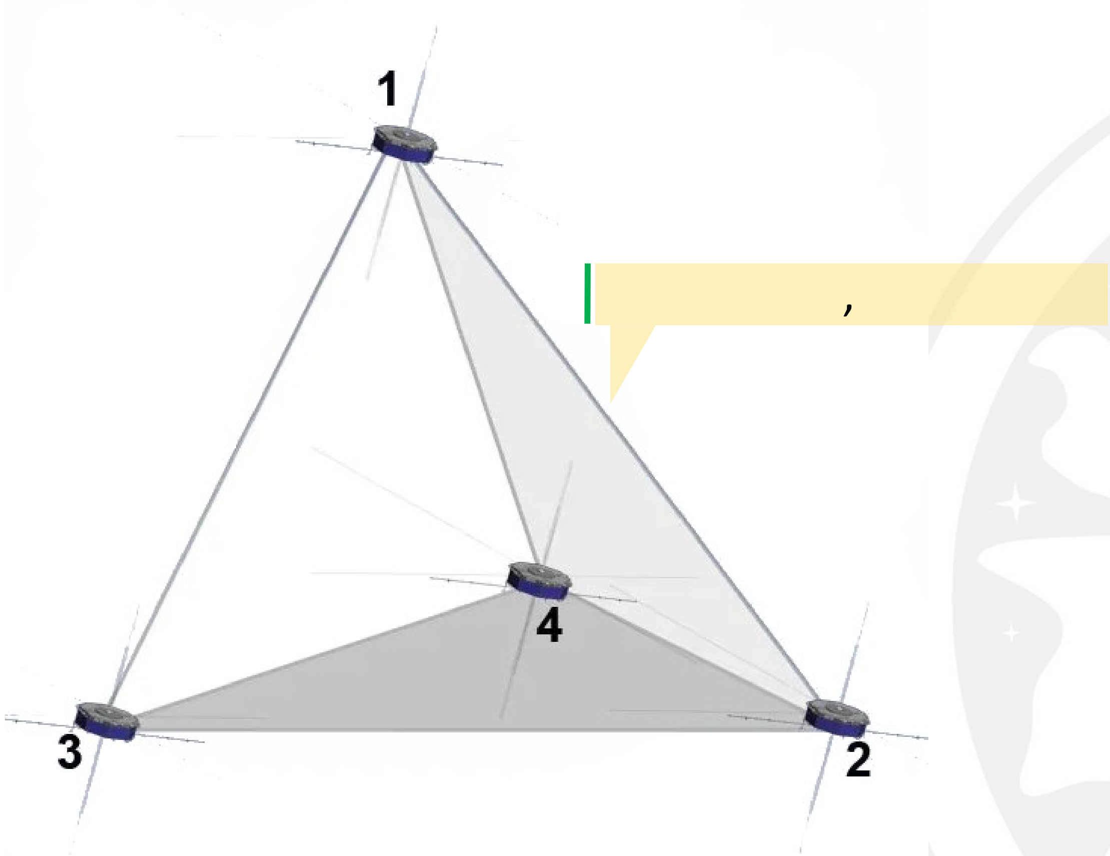




Azimuthal wavenumber *m* estimation

GSE coordinate system

are known



Azimuthal wavenumber *m* estimation

GSE coordinate system

are known

⇩

in GSE

⇩

in the local coordinate system,
oriented with the local magnetic field

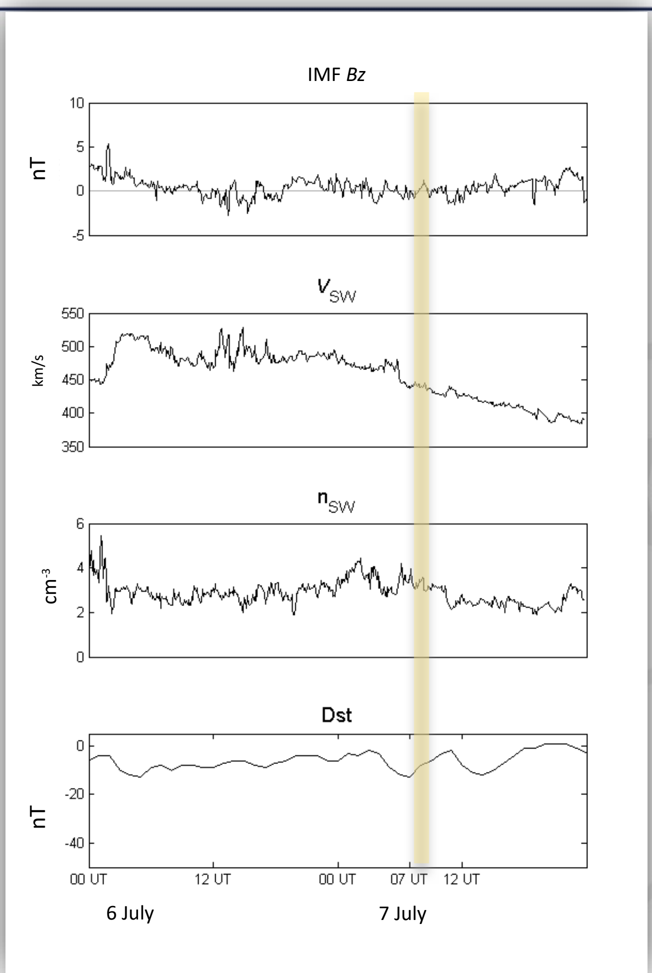
Geomagnetic conditions

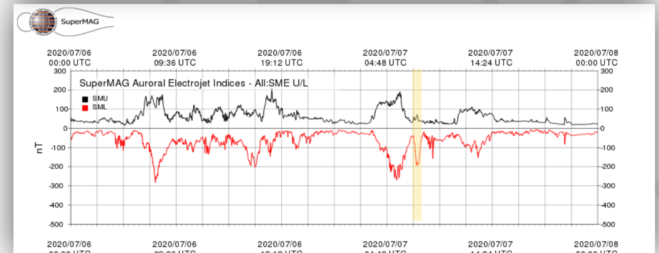
Azimuthal wavenumber *m* ≈ +25.

Large *m* eastward propagation, in the direction of the electron drift in the magnetosphere

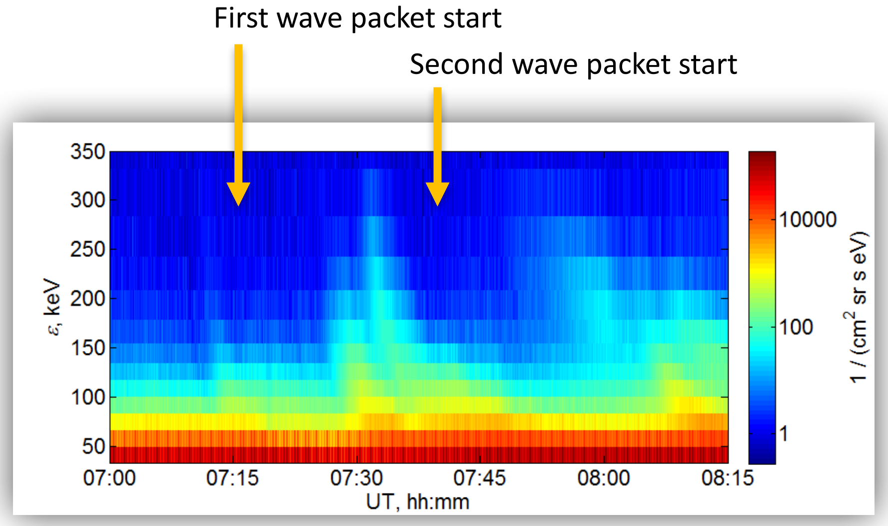
SML index -200 at 0730 UT

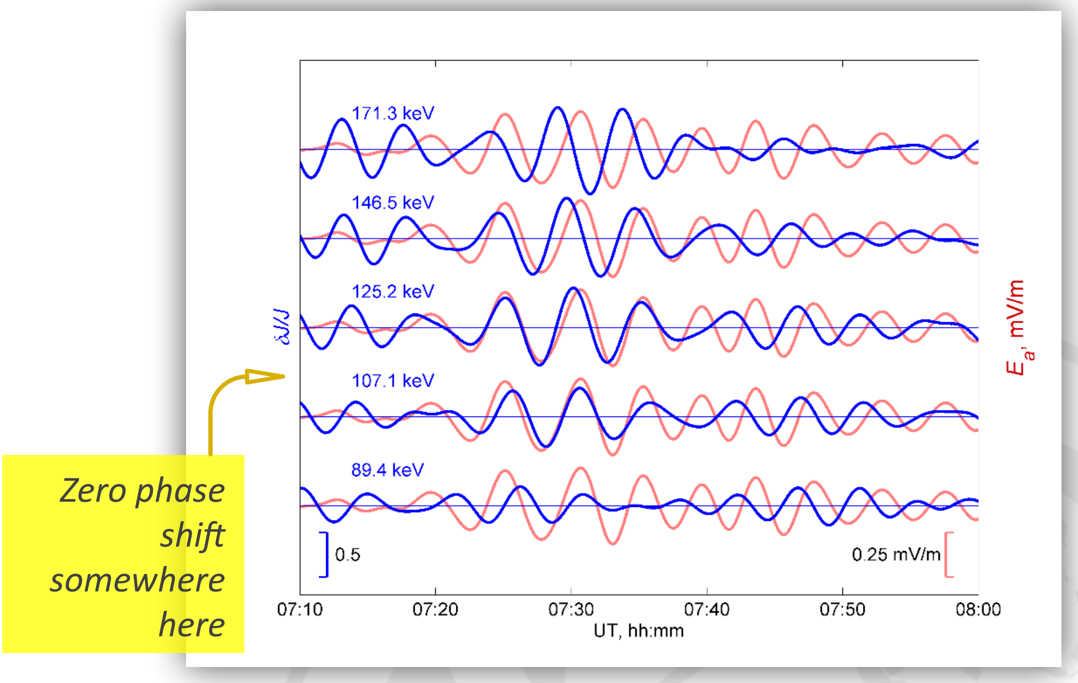
Substorm could result in electron injection in the magnetosphere





Electron flux modulation



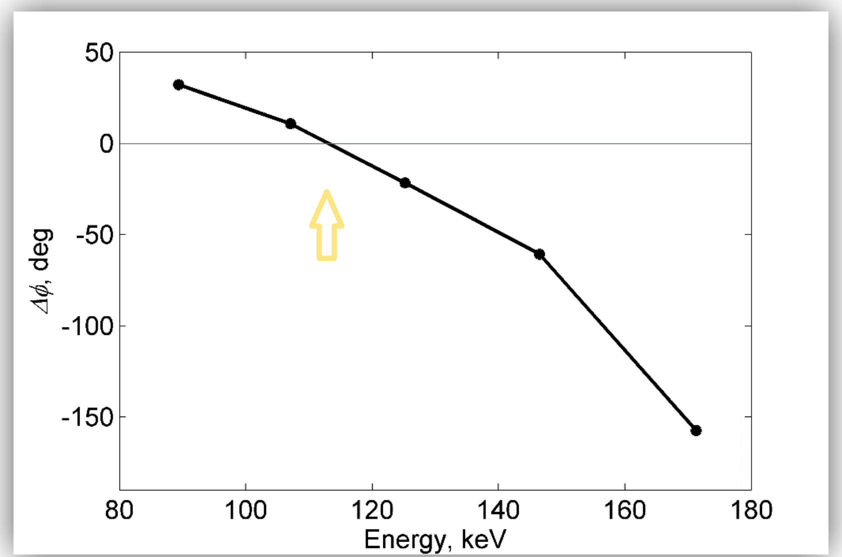


Intensity of omnidirectional electron flux at different energies

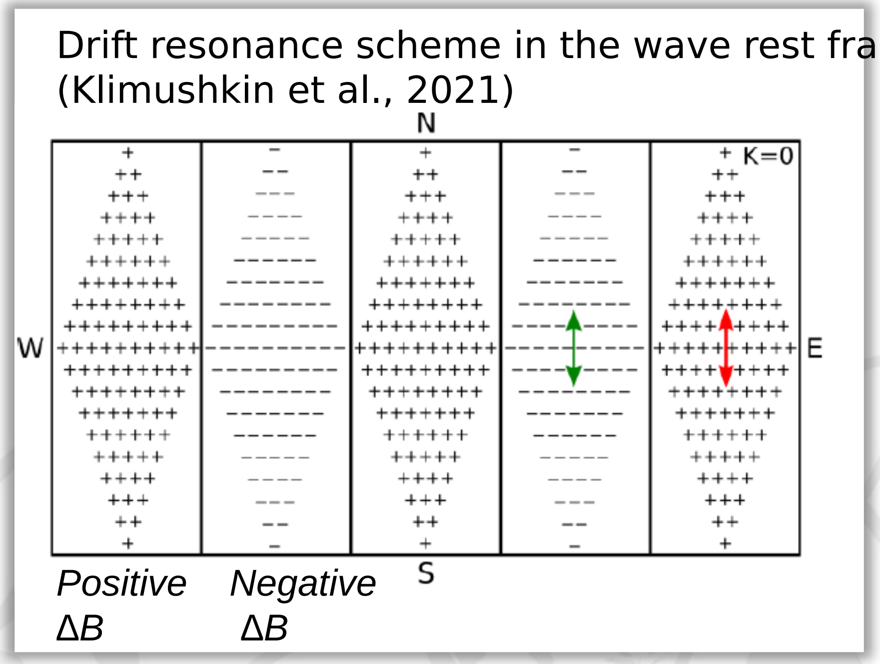
Relative **electron flux *δJ/J*** oscillations for energies 89.4 to 171.3 keV and the **azimuthal electric field *E_a*** oscillations filtered in the 3–8 min period range

Phase shift between ***E_a*** *and* ***δJ/J*** is zero at some energy between 107.1 and 125.2 keV. Electron flux phase is ahead of the electric field phase for higher energies, and is behind for lower energies. This is a typical feature of the Alfvén field line resonance.

Drift resonance condition



Cross-phase $\Delta\varphi$ between the azimuthal electric field E_a and relative electron flux $\delta J/J$ oscillations for different energies at the maximum of the flux oscillations.
The zero phase shift corresponds to energy close to **113** keV.



<u>Drift resonance</u>: $\omega - m\bar{\omega}_d = 0$

With m = +25, ω = 0,02 rad/s: ω_d = 0,008 rad/s

$$\bar{\omega}_d \approx -\frac{3\upsilon^2}{\omega_{c,eq}L^2}(0.35 + 0.15\sin\alpha_0)$$ (Hamlin et al., 1961)

for a dipole magnetic field the resonant energy for electrons should be $W \approx$ **40** keV

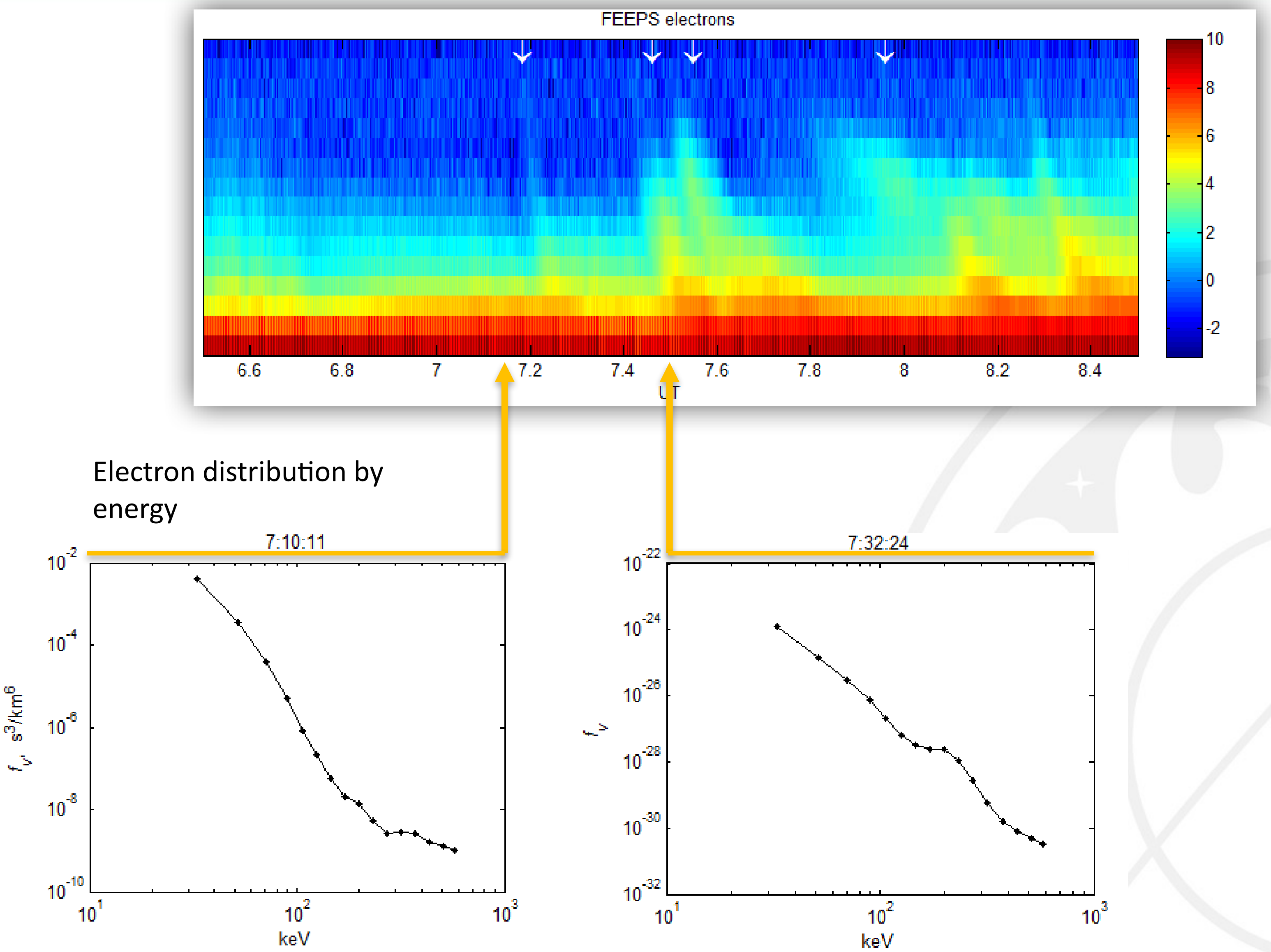
However, for an arbitrary magnetic field configuration, the drift resonance condition

$$\omega - \vec{k}_\perp \vec{u}_d = 0,$$

$$\vec{u}_d = \frac{\varepsilon c}{qB}\left[\vec{e}_\parallel \times \frac{\vec{\nabla}B}{B}\right]$$ (for pitch angle 90°)

This holds for the **113 keV** electrons!

Conditions for instability



Electron distribution by energy

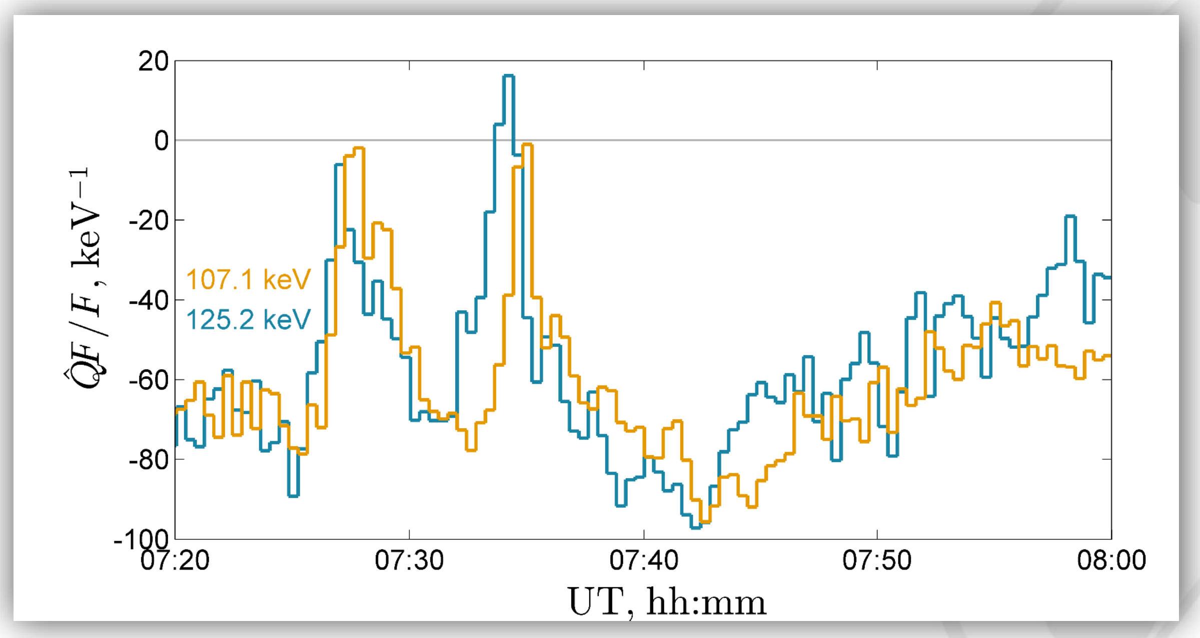
Conditions for instability

The condition for an instability growth in the magnetic field with an arbitrary (non-dipole) configuration (Southwood, 1976)

$$\frac{1}{F_0}\frac{\partial F_0}{\partial \varepsilon} + \frac{1}{\omega}\frac{c}{qB}\left[\vec{k}_{tr} \times \vec{e}_{pr}\right]\frac{\vec{\nabla} F_0}{F_0} > 0$$

Distribution function growth with energy increase *(bump on tail)*

Electron distribution function spatial gradient



Plasma instability did not generate the wave

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Then what?

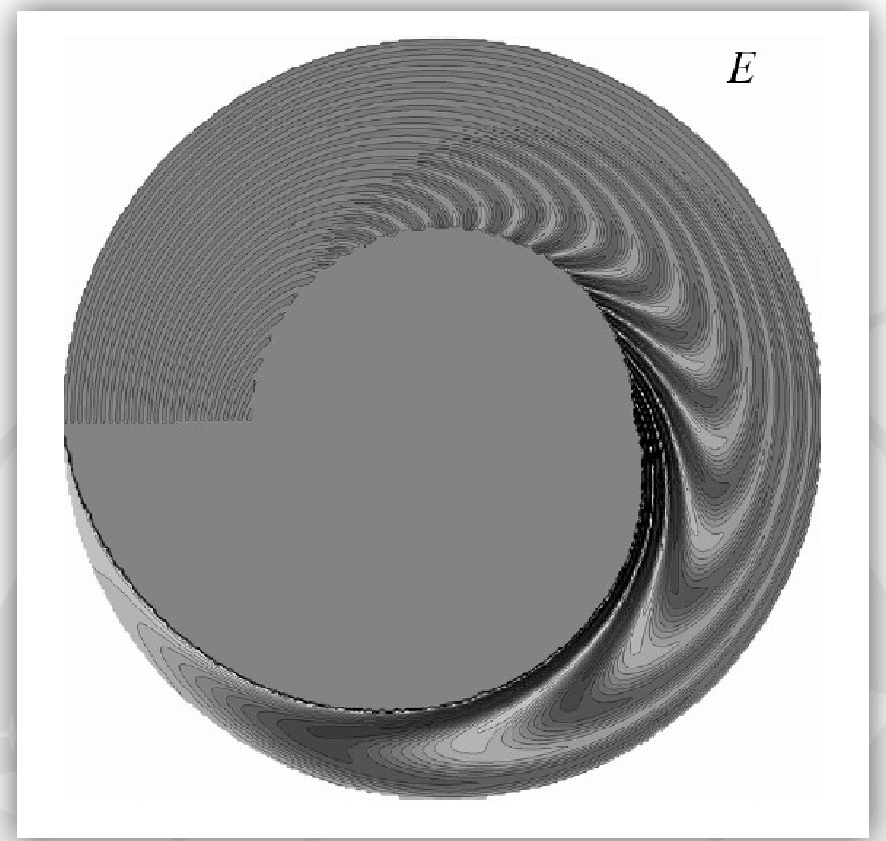
Alfvén wave generation by an alternating current

A cloud of energetic particles with a finite size can be represented as an alternating current. Such current can generate Alfvén waves (Akhiezer et al., 1967, 1975).

In the magnetosphere, a population of azimuthally drifting substorm-injected ions/electrons can be such cloud emitting Alfvén waves (Guglielmi, Zolotukhina, 1980; Mager, Klimushkin, 2008).

Some properties of this type of interacion:

- A waves is observed simultaneously with a particle registration at the observation point
- $m \sim \omega_A/\omega_d$.
- A wave is narrowly localized across *L.*
- A wave transforms from a poloidal to a toroidal one. When the amplitude is highest, a wave has mixed polarization



The electric field of a wave (Mager, Klimushkin, 2008)

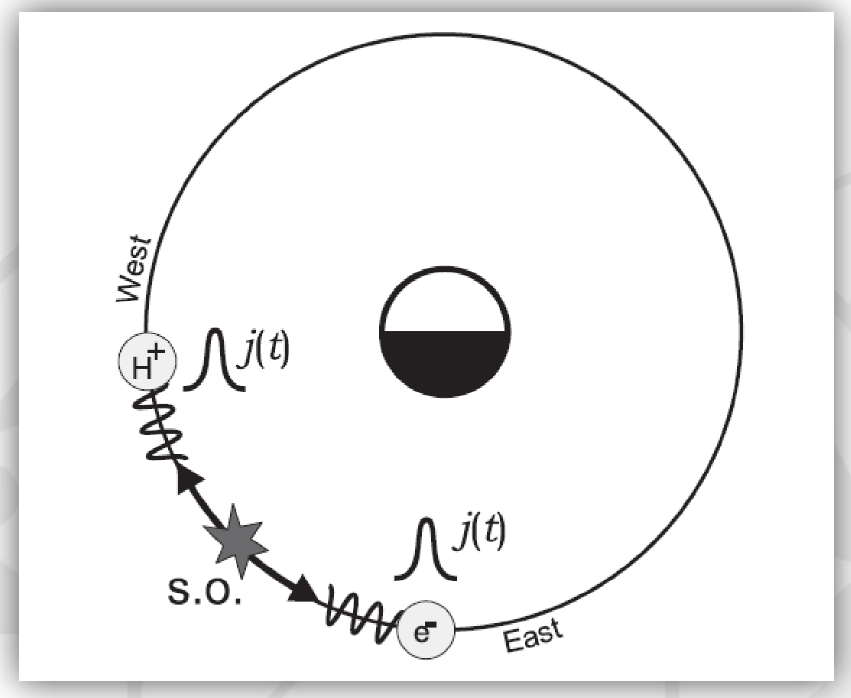
Summary

- A westward ULF wave with the azimuthal wave number *m* = +25 was observed in the postmidnight magnetosphere with the MMS spacecraft constellation

- A flux of substorm-injected electrons modulated with the wave frequency (~3 mHz) was registered with the zero phase shift between the flux and $\boldsymbol{E_a}$ for the electron energy ~**113** keV

- The drift resonance with electrons is shown for this case, however, the criteria for plasma instabilities that could generate the wave are not met here

- The wave could have been generated by electrons forming a moving plasma inhomogeneity that, as an alternating current, can be a wave source



(James et al., 2013)

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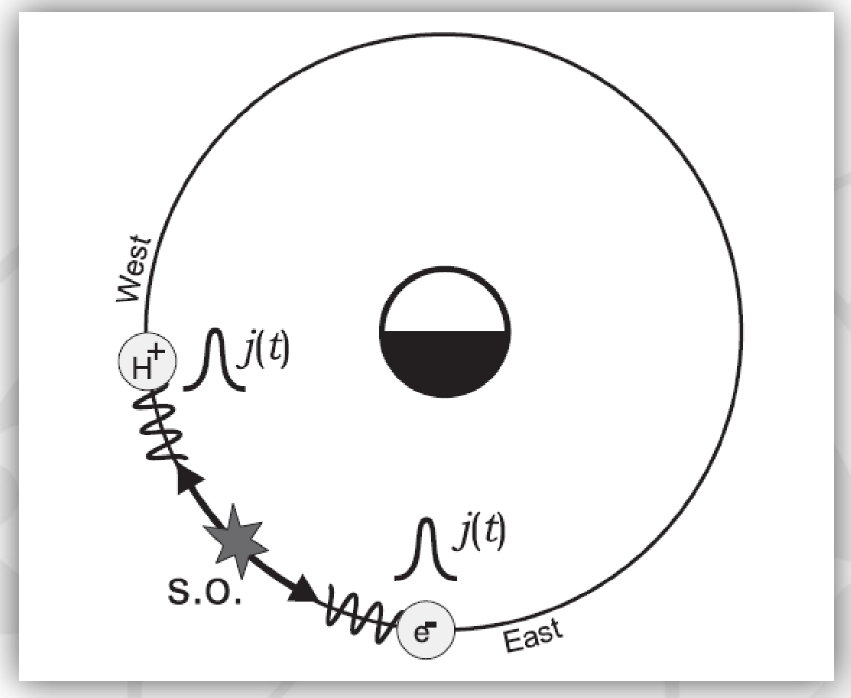

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Thank you