# Observation of non-gyrotropy of electrons caused by wave-particle interaction with intense whistler mode waves in mirror mode structures in the magnetosheath

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## 1. Introduction

### ◆Whistler mode waves in magnetic field intensity troughs in the magnetosheath

•Frequency below electron cyclotron frequency (~0.1–0.5 $f_{ce}$)
•R-mode polarization and small wave normal angle in most cases
✓Generated from electron temperature anisotropy ($T_{e\_para} < T_{e\_perp}$)
✓Generated around minimum-B along a field-line

[e.g., Zhang et al., 1998; Baumjohann et al., 1999; Giagkiozis et al., 2018]

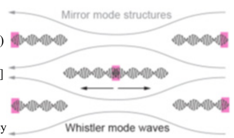


Fig. Schematic of mirror mode structure and whistler mode waves

Resonance condition (cyclotron resonance)

$$V_R = \omega - \Omega_{ce}/k_{para}$$

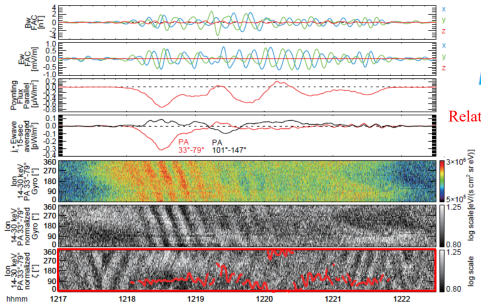
$V_R$: Resonance velocity
$\omega$: Wave angular frequency
$\Omega_{ce}$: Electron cyclotron angular frequency
$k_{para}$: Wave number (parallel to **B**)

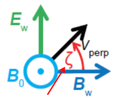
### ◆Mirror mode structures

•Frequency (in the plasma rest frame): 0
•Free energy source: temperature anisotropy of ions ($T_{i\_para} < T_{i\_perp}$)
✓Compressional (anti-correlation between the magnetic and plasma pressures)

[e.g., Kaufmann et al., 1970; Tsurutani et al., 1982; Fazakerley and Southwood, 1994]

### ◆Nongyrotropy rotating with waves (EMIC waves [Kitamura et al., *Science*, 2018])



Relative phase angle: ζ

For EMIC waves at the outer magnetosphere, the wave period (~15 s) was much longer than the temporal resolution of FPI-DIS (0.15 s).

To identify nongyrotropy rotating with the wave is the first step to investigate energy exchange between the wave and particles in detail.

Here, we show observations of nongyrotropy of electrons during an intense whistler mode wave event in the magnetosheath.

## 2. Dataset and Analysis Method

•**FGM:** 16 vectors/s (Fast Survey) (Used as the background magnetic field ($\mathbf{B}_0$))
•**SCM:** 8192 vectors/s (Burst data) } Filter: 25–140 Hz
•**EDP:** 8192 vectors/s (Burst data) } Filter: 25–140 Hz
•**FPI-DES:** Time-tagged data (v3.4.0) (Not lossy compressed interval only)
(~195 µs/step << wave period ~10 ms < 30 ms (Original temporal resolution of DES))
Angular resolution: 11.25° (32 (Azimuth) × 16 (Elevation) (=512) pixels)

Spacecraft separation: ~7 km (< wavelength of whistler mode waves)

Data from all spacecraft are combined after a correction using relative total electron pressures.

1. Some correction of look directions and additional flat fielding in gyro direction
2. Sort by relative phase angle (ζ) and average differential energy fluxes ($F$) in each 22.5° bin
3. Normalization by averaged differential energy flux ($F_{avg}$) (average of 3 original data (~90 ms) at all ζ bins in each energy and pitch angle (11.25° resolution) bin)

Significance of $F - F_{avg}$ in each ζ bin are estimated as $(F - F_{avg})\sqrt{N} / F_{avg}$, where $N$ is the total of counts.

## 4. Result

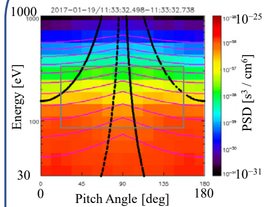


Fig. Phase space densities (PSD) with cyclotron and Landau resonance velocities, and some diffusion curves

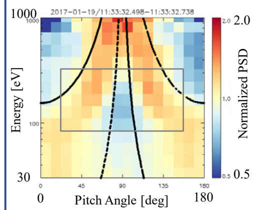
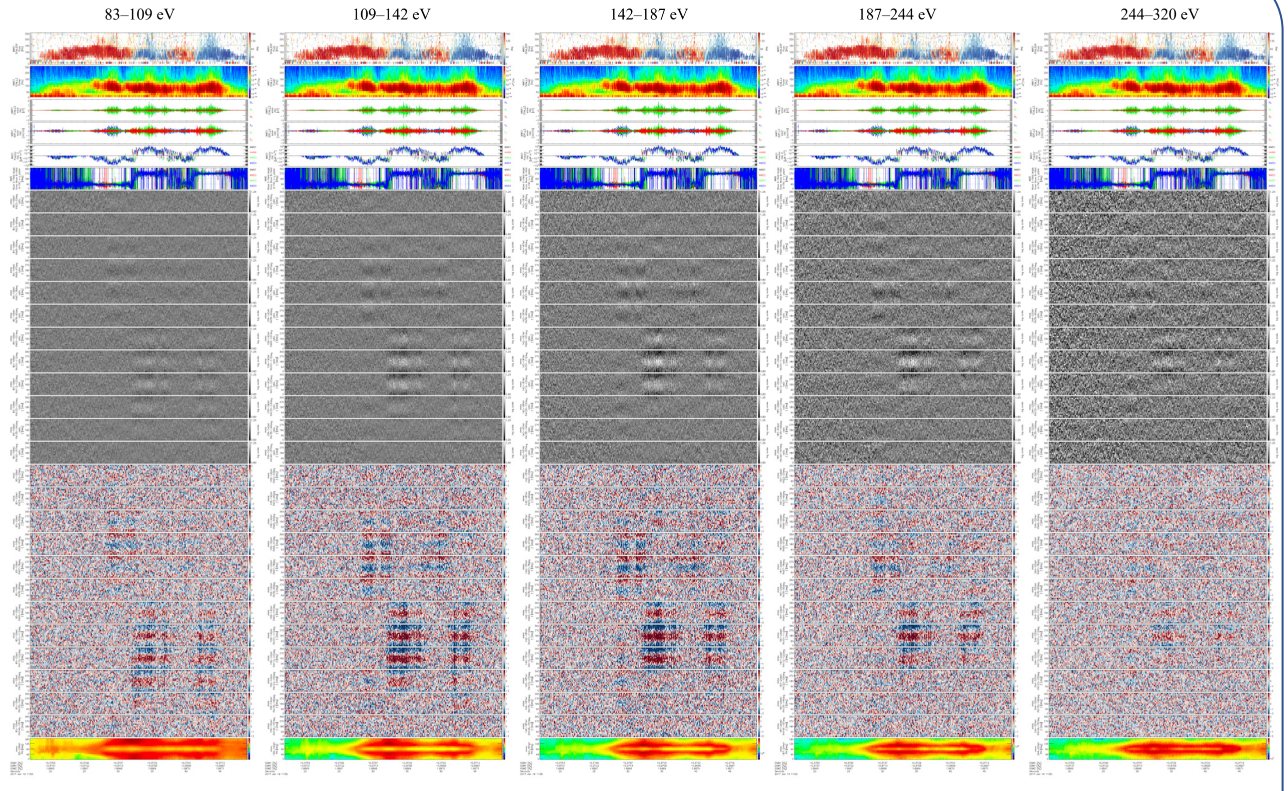


Fig. PSD normalized by the average of those in each energy bin with cyclotron and Landau resonance velocities

At low energies (<100 eV), the PSD is large in the direction parallel to the magnetic field. At medium energies (several hundred electron volts) it shows a butterfly distribution. At relatively high energies (~1 keV) it shows a pancake distribution.
[e.g., Kitamura et al., *JGR*, 2020]

Around the cyclotron resonance velocity, the PSD tends to be larger on the side near the pitch angle of 90°.
→Preferrable for the growth of whistler mode waves



Figs. Spectrum (0–250 Hz) of angle between the pointing flux and the magnetic field, power spectrum (0–250 Hz) of the magnetic field (MMS1 SCM), the magnetic field waveform (MMS1 SCM), the electric field waveform (MMS1 EDP), the parallel component of the pointing flux to the magnetic field, phase of the wave electric field with respect to the wave magnetic field, ζ-dependence of the normalized electron distribution in each 11.25° pitch angle (22.5°–167.5°) (color range: 0.8–1.25), significance of deviation from gyro-averaged flux in each 11.25° pitch angle bin (22.5°–167.5°) (color range: −2–2), and pitch angle distribution of electrons.

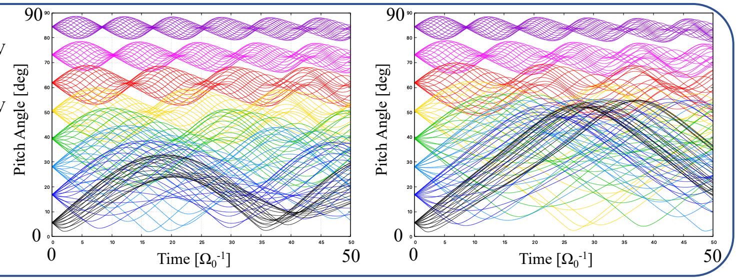
## 4. Discussion

A characteristic non-gyrotropic ζ-distribution of electrons is identified at the velocity much slower than the cyclotron resonance (apparently outside the trapping velocity around the resonance), and the region corresponds roughly to the side where the pitch angle is closer to 90° than the peak of the butterfly distribution.
→Distortion of the pitch angle distribution associated with non-resonant interaction probably appears as the characteristic ζ-distribution.

Left:
Energy = 96.34 eV
($v_c$ = 5821 km/s)
Right:
Energy = 165.1 eV
($v_c$ = 7621 km/s)

$f_p/f_c$ = 79
$B_w/B_0$ = 0.03

Various initial ζ
(Calculated by M. Kitahara)




## 5. Conclusion

•Non-gyrotropy of electrons associated with the non-resonant interaction was observed.

•The non-gyrotropy was much clearer than that around the cyclotron resonance or Landau resonance, even if it exists.