Potential Fluctuations Associated with Energetic-Particle Induced Geodesic Acoustic Mode and Alfvén eigenmodes in the LHD plasmas

T. Ido\textsuperscript{a,b}, A. Shimizu\textsuperscript{a}, M. Nishiura\textsuperscript{a}, S. Kato\textsuperscript{a}, Y. Yoshimura\textsuperscript{a}, K. Toi\textsuperscript{a,b}, F. Watanabe\textsuperscript{c}, S. Satake\textsuperscript{a}, K. Ida\textsuperscript{a}, M. Yoshinuma\textsuperscript{a}, K. Itoh\textsuperscript{a}, S. Kubo\textsuperscript{a,b}, T. Shimozuma\textsuperscript{a}, H. Igami\textsuperscript{a}, H. Takahashi\textsuperscript{a}, and the LHD experiment group

\textsuperscript{a} National Institute for Fusion Science, Oroshi-cho, Toki-shi, Gifu, 509-5292, Japan

\textsuperscript{b} Nagoya University, Nagoya 464-8603, Japan

\textsuperscript{c} Kyoto University, Kyoto 606-8502, Japan

ido@LHD.nifs.ac.jp
Geodesic acoustic mode (GAM): a branch of zonal flow

Turbulence driven GAM
Nonlinear coupling of micro-turbulence
\( \phi, \tilde{v}_p, \tilde{n}_e \)

Energetic-particle induced GAM
Velocity space anisotropy in the energetic particle distribution function

Global GAM (GGAM) - MHD -


Energetic-particle-induced GAM (EGAM) - Kinetic -


(LHD: Toi K et al, 2010 Phys. Rev. Lett. 105, 145003)

In this study, \( \tilde{\phi} \) is measured locally and directly using a heavy ion beam probe in the LHD plasmas.
Heavy Ion Beam Probe on LHD

Heavy Ion Beam Probe (HIBP)

Electrostatic potential profile \( \phi(r) \) and fluctuation \( \tilde{\phi} \), and Density fluctuation \( \tilde{n}_e \)

<table>
<thead>
<tr>
<th>Temporal resolution</th>
<th>&lt; 500 kHz</th>
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<tbody>
<tr>
<td>Spatial resolution</td>
<td>a few cm</td>
</tr>
<tr>
<td>Energy resolution ( \frac{\Delta E_b}{E_b} )</td>
<td>&gt; 2.5 \times 10^{-5} \ (33 \text{ eV in this experiment})</td>
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</table>
Experimental conditions

$B_t = 1.5$ T, No gas puff, $E_{HIBP} = 1.375$ MeV

Balanced NB (H, 170 keV) Co. 2.3 + Cntr 2.0 MW

ECCD from 1.0 s to 1.6 s. 300 kW
These modes are observed only in plasmas with the tangential NBI.
Characteristics of the GAM frequency mode

- Mode structure
- Temperature dependence of the frequency
- Potential fluctuation ($E_r$ fluctuation)

Toroidal mode number

Phase difference between magnetic probes

Frequency

$$f_{GAM} = \frac{\sqrt{2}}{2\pi R_0} \sqrt{\frac{T_e + \frac{7}{4}T_i}{M_i}} G$$

Toroidal mode number ($n$) = 0.
Spatial distribution of AEs and GAM

(Averaged potential)

Potential Fluctuation

\[ \tilde{B}_p \text{ [Mironov coil]} \]

Power

\[ \text{Frequency (kHz)} \]

\[ \text{Frequency (kHz)} \]

\[ \text{Frequency (kHz)} \]
Electrostatic potential fluctuation of the GAM

- Amplitude: 300V_{rms} (Maximum 900V)
  - It cannot be explained by the fluctuation of the magnetic surface.
- The potential fluctuation is localized in the central region.
  - $E_r$ fluctuation = Flow fluctuation

The $n = 0$ mode is the GAM accompanied by the flow fluctuation.
The GAM observed in the envelope of the high-frequency turbulence

The GAM affects the temporal behavior of the high frequency turbulence.

Candidate mechanisms of the modulation

- Doppler shift by $\vec{E}_r$
- Dynamic shearing by $\nabla \vec{E}_r$

(k.ltoh, et al., PPCF 47 (2005) 451.)
Candidates for the modulation

(1) Doppler shift due to the flow associated with the GAM

(2) Shearing by the GAM

The shear flow of the GAM is not sufficient to suppress the turbulence.
K. Hallatschek, PRL, 86 (2001) 1223
K. Itoh, PPCF, 47 (2005) 451

(Y. Kishimoto, J. Plasma and Fusion Res., 76, 1292 (2000) Fig. 6)
Another $n=0$ mode in the monotonic magnetic shear

**Monotonic shear**  **Reversed shear**

Co-ECCD

ECH

**Constant** at the GAM frequency ($n = 0$)

**Upward-shift** of the frequency ($n = 0$)
Summary

• The energetic-particle induced GAM is observed directly and locally by the HIBP. (Temperature dependence of the frequency, \( n = 0 \), and \( \phi \))

• The large electrostatic potential fluctuation is localized in the central region of the plasmas. \( |\tilde{\phi}_{GAM}| \) is several hundreds volts (< 1 kV).

• The localized potential fluctuation indicates the radial electric field fluctuation associated with the GAM.

• The energetic-particle induced GAM affects the temporal behavior of the high frequency turbulence.

• \( n = 0 \) mode with the upward shift of the frequency is observed in plasmas with the monotonic rotational transform profile.
• The start frequency is in the GAM frequency range.
• The \( n = 0 \) mode also locates in the central region.