First Laboratory Observation on Controlled Mitigation of Energetic Electrons by Whistlers

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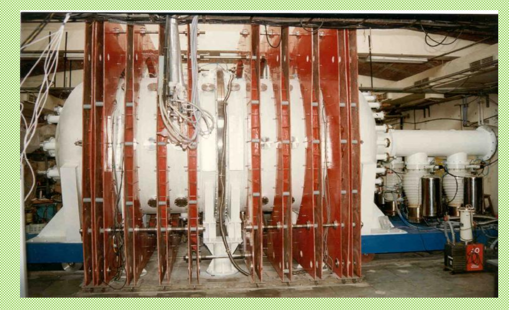


Introduction

• Relativistic energetic electrons can drive Whistlers unstable in space and tokamak plasmas.

• Whistlers are excited by Energetic electrons, Pitch angle scattering, Trapped particles, Temperature anisotropy, Loss cone, Beams, loop antennas etc.

• Recent experiments in DIII-D tokamak has interlinked whistler activities with mitigation of Runaway electrons however this is inferred by indirect diagnosis.

• In LVPD, whistlers has been excited in a magnetic mirror like configuration. They have been characterized by understanding the frequency spectra, field polarization and correlation properties between density and magnetic field fluctuations.

$$\omega_{ci} << \omega_{tur} < \omega_{ce}, \quad C[n_e, B_z] = -ve$$

•The present paper discussed controlled experiment in laboratory to determine the growth of whistlers with discharge potential (i.e. energetic electron energy).

Experiment Setup (LVPD)

Experimental Parameters

Rev. Sci. Instrum.72, 3864 (2001)

Rev. Sci. Instrum.85, 033507 (2014)

B_z (G)	- 6.2
B_{EEF}(G)	160 ($B_z \perp B_{EEF}$)
V_d (V)	-50V - -90V
I_d (A)	180-200
I_{fil} (A)	700A-750
T_{plasma} (ms)	~9.2
T_{EEF} (ms)	~13
P_{base} (mbar)	2 X 10^{-6}
P_{ar} (mbar)	4 X 10^{-4}

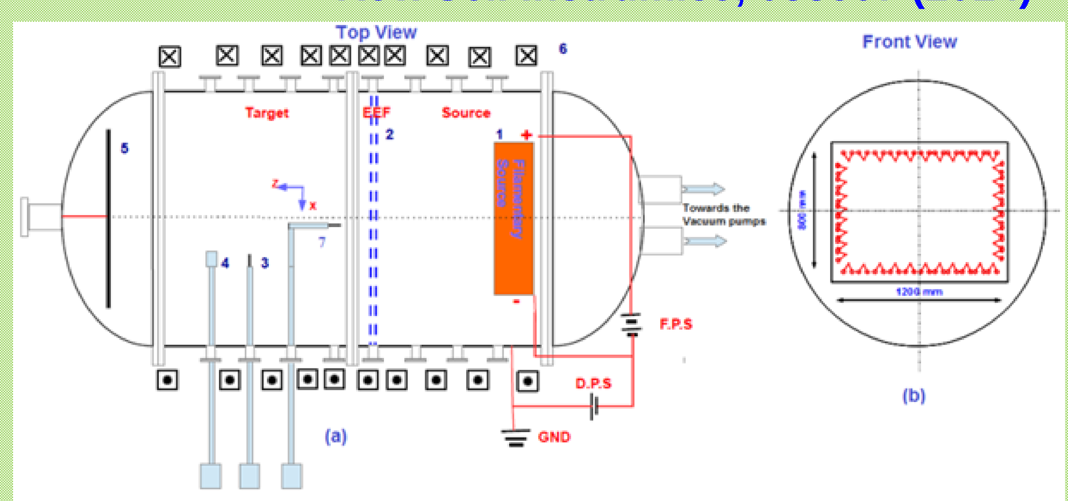


Fig. 1. (a) Schematic view of LVPD experimental system and (b) cross sectional view showing filament arrangements.

Magnetic field Configuration & V_f profile

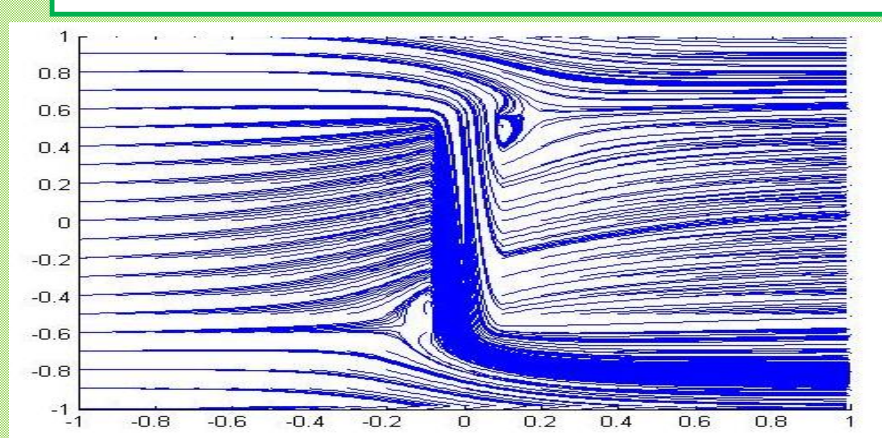


Fig. 2. Simulated combined Magnetic field (Asymmetric) profile in LVPD (B_z+ B_{EEF}).

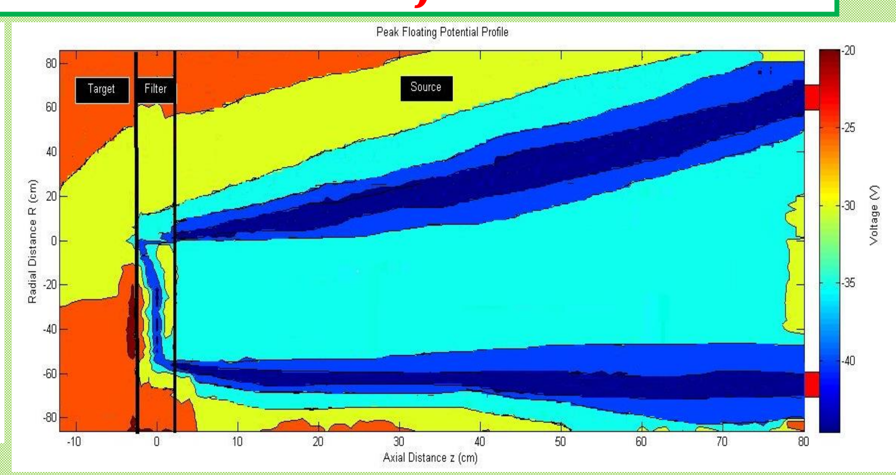


Fig. 3. Surface plot of peak floating potential (mimics presence of energetic electrons) measured in LVPD at a resolution of 1cm (X- Z plane).

➢ Magnetic field is Asymmetric with activated EEF and the potential scan shows a belt like formation with energetic electrons.

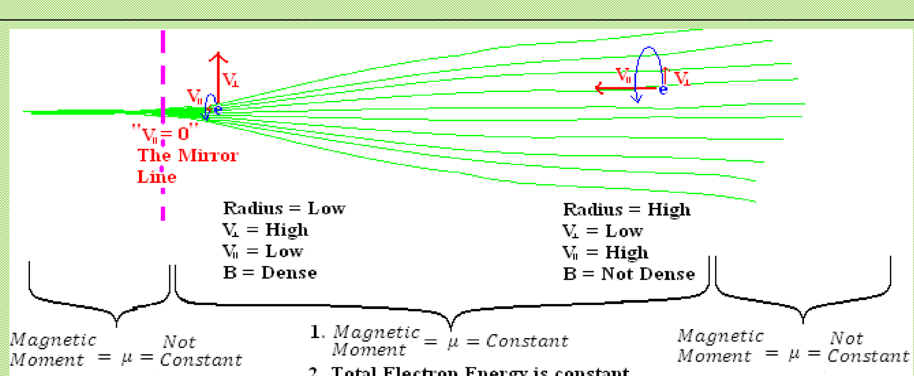
➢ Correlated, enhanced density and magnetic fluctuations observed in the belt. $C_{n_e,B_z} \sim -0.9$.

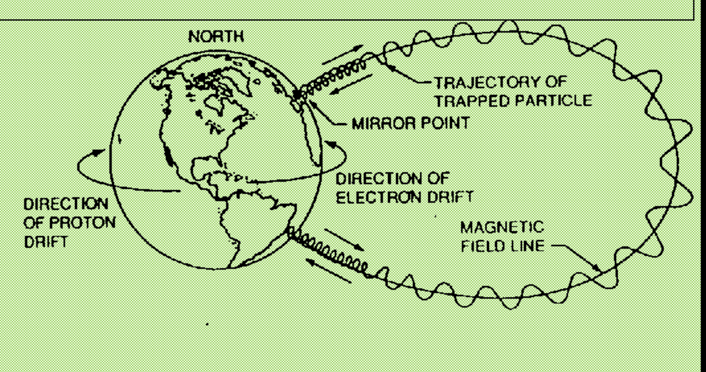
➢Fluctuation power resides in the frequency band 45 kHz < f < 60 kHz.

➢ Wave Polarization varies with frequency (< 100 kHz).

➢ Wave Phase velocity dominates with V_z> V_y. ($k_\perp >> k_{||}$)

➢ Wave characteristics identifies it as low freq. highly oblique Whistler modes.





Ref: Phys. Plasmas 24, 102118 (2017)

Whistler Growth

We assumed strong analogy for growth of whistlers with electron temperature in laboratory, space and tokamak plasmas. This also is seen correlated to mitigation of energetic electrons.

T. Fulop et al. estimated the whistler growth threshold with runaway density and electron temperature.

$$\frac{n_{re}}{n_0} \approx \frac{Z^2 B_T}{20 T_e^{1.5}}$$

They found that growth is inversely proportional to the $T_e^{1.5}$.

Growth of the mode in LVPD due to reflected particles is found inversely proportional to square root of electron temperature

$$\frac{n_r}{n_0} \approx \frac{K}{4} \frac{n_0}{B_0 T_{eb}^{0.5}}$$

The Astrophysical Journal 280, 405(1984)

Results and Discussions

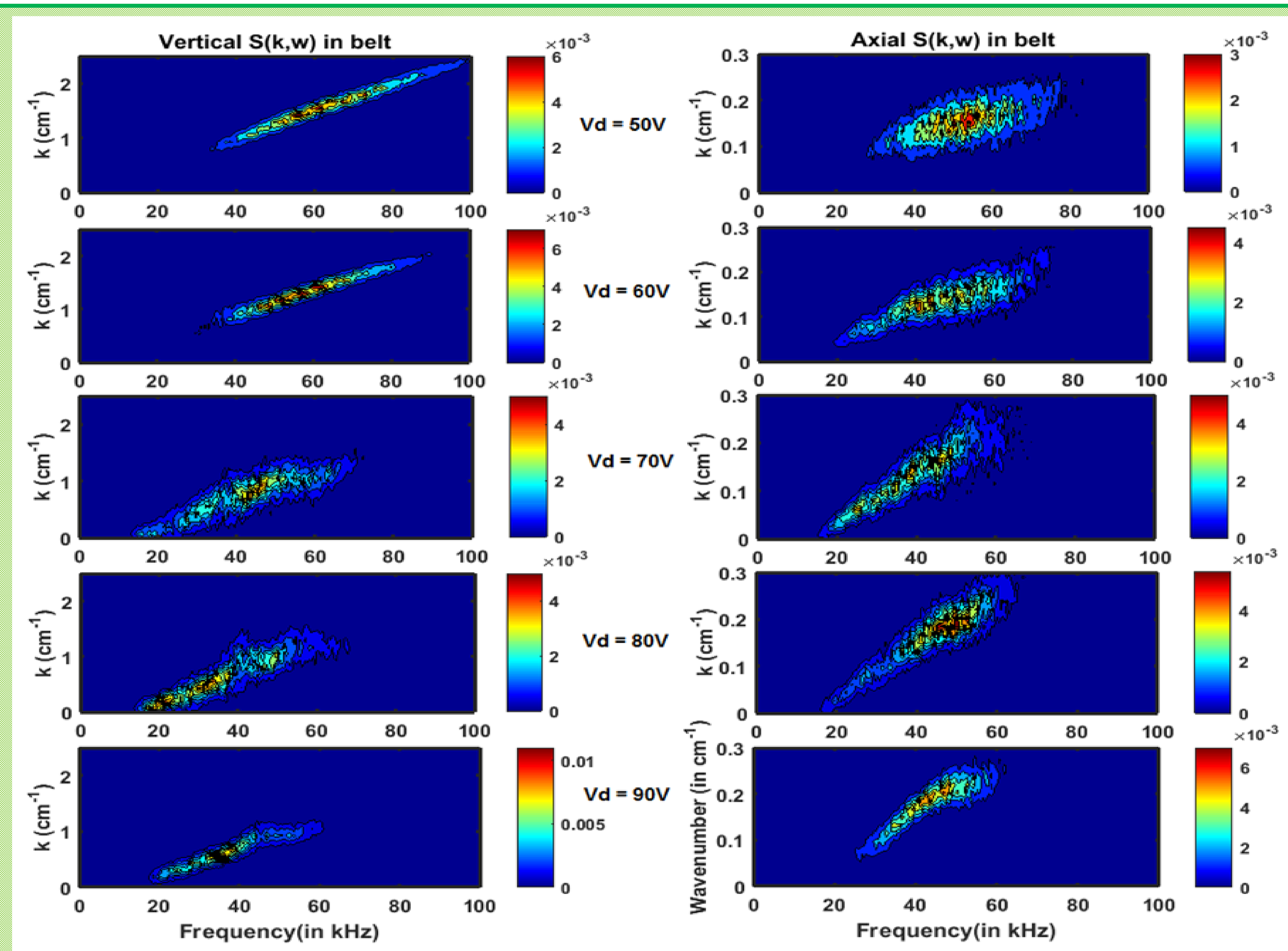


Fig. 4. Frequency- wave number spectra of density fluctuations for the perpendicular (left) and axial (right) directions for different discharge potentials.

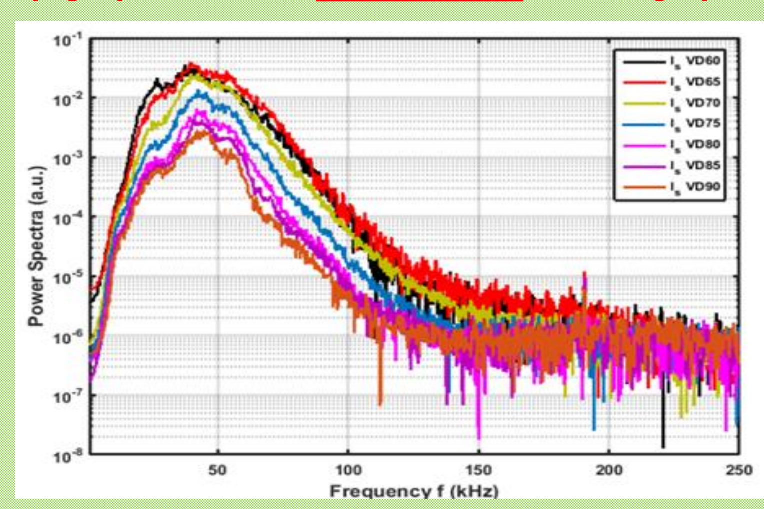


Fig. 5. Auto power spectrum of density fluctuations at different discharge potentials.

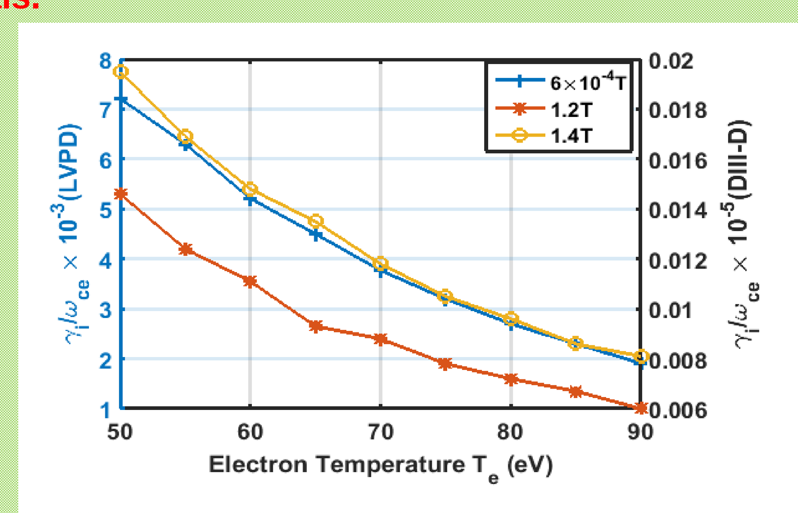


Fig. 6. A comparison of whistler growth estimated from experimental parameters of D-III D and LVPD.

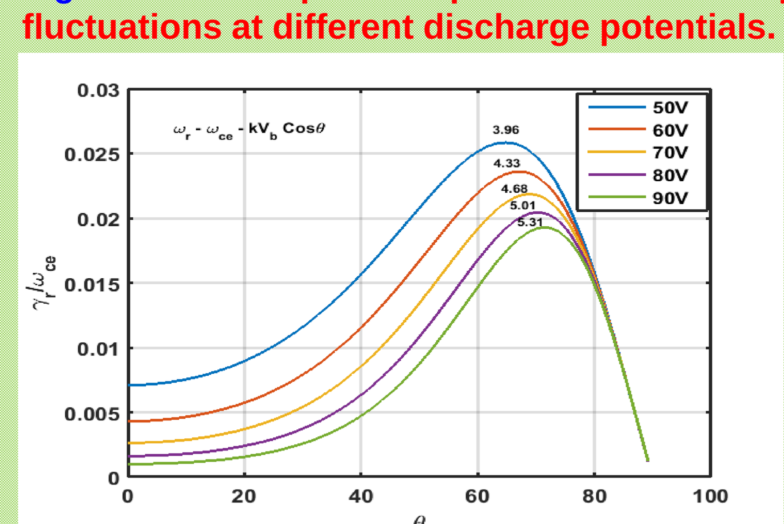


Fig. 7. Whistler growth rate at different electron energies is plotted with propagation angle. (A theoretical estimation is obtained for the experimental data.)

Summary & Conclusion

➢ The linear analysis shows that the growth rate for whistlers is inversely proportional to the square root of electron temperature.

➢ Similar trend is observed with DIII-D data (Sponge et al, PRL, 120, 2018) with numerical calculations done by Fulop et al (POP, 13, 062506, 2006).

➢ Observations in LVPD may not directly impact tokamak physics but indeed yes, these may open up new direction for developing an understanding on correlation between whistler activity and energetic electrons.

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