CHALMERS
UNIVERSITY OF TECHNOLOGY

Kinetic instabilities driven by runaways in tokamaks

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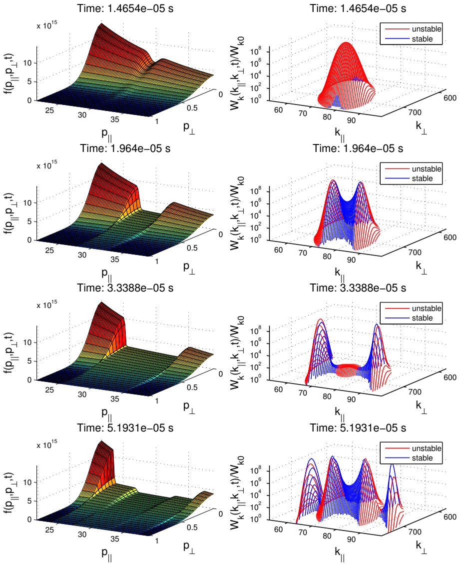
- 2023: Investigate the drive of kinetic instabilities with DREAM
- 2024: Develop a quasi-linear simulation-tool and use it to assess the impact of kinetic instabilities on RE dynamics

High-frequency kinetic instabilities

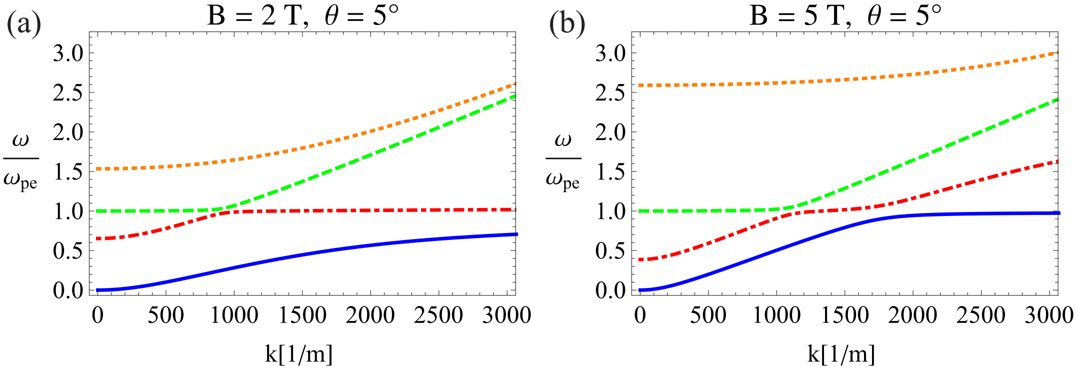
- Approximative solutions of the Fokker Planck equation in relevant limits has been used to study high-frequency electromagnetic instabilities.
- Papers by Pokol & Fülöp et al 2006-2009 concerned the whistler wave instability (WWI).
- Later work Kómár & Pokol et al 2012-2014 concerned a new branch of electromagnetic waves: the extraordinary electron wave (EXEL).
- In the above mentioned works, the value of the collisional damping is oversimplified and overestimated (taken as independent on frequency).

  Corrected in Aleynikov& Breizman NF 2015.



General dispersion relation

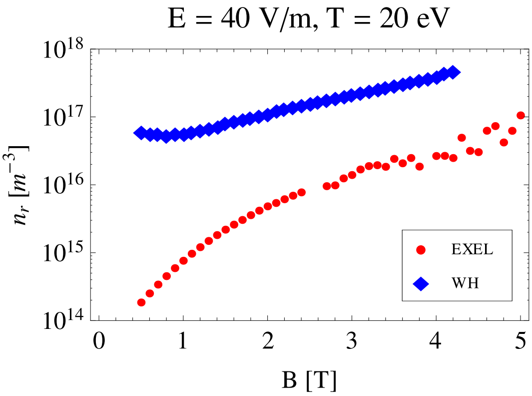
$$\left[\left(\epsilon_{11}-\frac{k_\parallel^2c^2}{\omega^2}\right)\left(\epsilon_{22}-\frac{k^2c^2}{\omega^2}\right)+\epsilon_{12}^2\right]\left(\epsilon_{33}-\frac{k_\perp^2c^2}{\omega^2}\right)-\frac{k_\parallel^2k_\perp^2c^4}{\omega^4}\left(\epsilon_{22}-\frac{k^2c^2}{\omega^2}\right)=0,$$



The solid blue line corresponds to the whistler wave and the red dashed line is the extraordinary electron (EXEL) wave. The branches with higher frequencies are not destabilized by the suprathermal electrons.

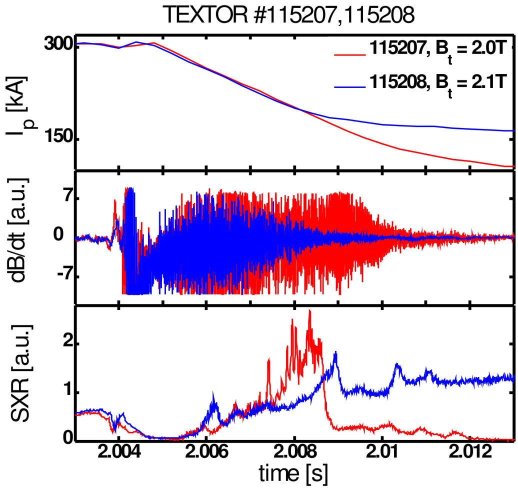
[Kómár et al, JPCS **401** 012012 (2012)]

- Stability thresholds for the most unstable magnetosonic-whistler and EXEL waves in a strong electric field.
- Parameters: $T_e = 20\ \mathrm{eV}$, $n_e = 5 \cdot 10^{19}$ m^{-3}, $Z = 1$, $L_r = 0.1\ \mathrm{m}$
- Orders of magnitude higher number of runaways are required to destabilize the whistlers.
- The collisional damping is incorrect, so the figure is just for illustration of the probable trend.



Can DREAM distribution function be used to calculate the whistler, EXEL, and other instability growth rates? (with Donald Spong and Yashika Ghai)

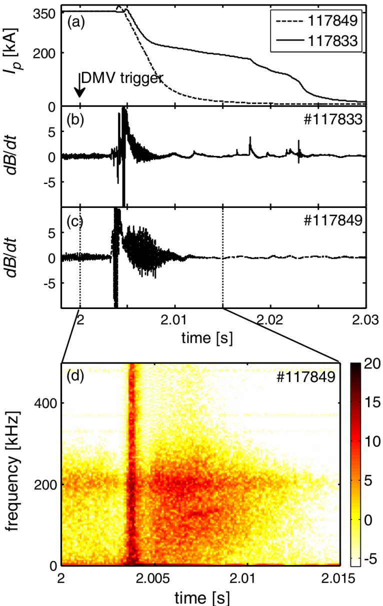
- 115207
  - $B = 2\ \mathrm{T}$
  - decrease in SXR signal
  - large magnetic fluctuations
  - no runaways
- 115208
  - $B = 2.1\ \mathrm{T}$
  - SXR signal increases
  - magnetic fluctuations disappear
  - runaways present



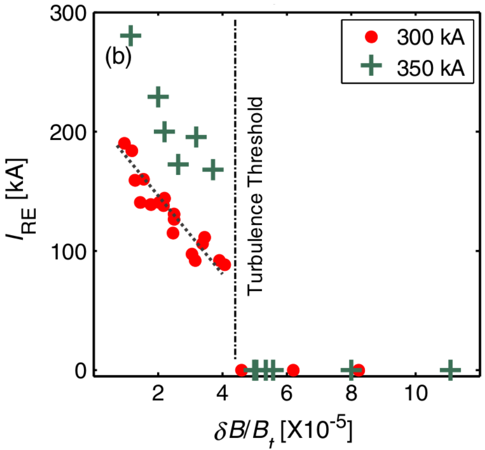
[Koslowski, EFDA project meeting 2012]

[Zeng et al, PRL **110** 235003 (2013)]

- Deliberately triggered disruptions by injection of large amounts of argon.
- Shots 117833 and 117849 are similar except for the toroidal magnetic field and the magnetic turbulence level.
- Frequencies form a wide distribution, most of the power is in the 60–260 kHz range.



- RE current as a function of the maximum magnetic turbulence during the current quench.
- If $\delta B/B$ exceeds a threshold, REs (which may be produced during the current quench) get quickly lost.
- The value of the critical fluctuation amplitude seems to depend only on the toroidal magnetic field and not on the plasma current.



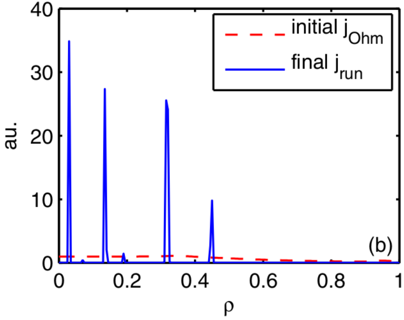
[Zeng et al, PRL **110** 235003 (2013)]

If secondary generation dominates the growth rate becomes

$$\frac{\gamma_e}{\omega}[\%] = \frac{v_A}{|\omega_{ce}|}\frac{\pi n q_0^4 v_A}{\epsilon_0 c_z c}\frac{m_e}{m_i}e^{-\frac{v_A}{c c_Z}}\left(1+\frac{2c}{\alpha v_A}+\frac{2c^2}{\alpha^2 v_A^2}\right)\frac{n_{re,17}}{n_{0,19}}\frac{1}{L_n^s}$$

[Fülöp & Newton PP 2014]

- Expected to be significant at radial locations with large safety factors q_0 and short spatial gradient scale lengths.
- Sometimes the spatial gradients are huge (“soliton” formation, see figure).



[T Fehér et al, PPCF 53 035014, (2011)]

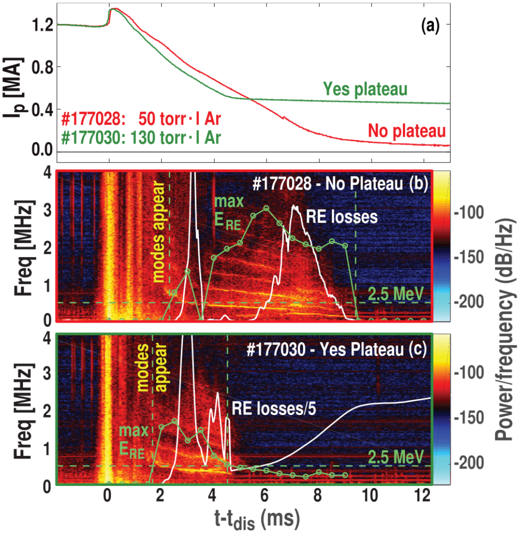
- Initial whistler experiments
  Spong et al PRL (2018)
- Further experiments in 2018-2019 (disruption runaways, varying plasma/antenna spacing, compressional Alfvén waves)
  Lvovskiy et al PPCF 2018, NF 2019, 2020
- Proposed experiments (2021): use upgraded DIII-D diagnostic infrastructure to measure wavenumbers and polarization.
- Upcoming wavenumber measurements could help identify the resonance mechanism

$$\omega - k_{||}v_{||} - k_{\perp}v_D - l\Omega_{ce}/\gamma = 0$$

  Both anomalous Doppler and Cherenkov resonances could be active.
- Related experiments (Paz-Soldan and others): test runaway suppression using new helicon antenna (f=400 to 500 MHz)

Global mode structure calculated by AORSA $\rightarrow$ ASCOT5 (Konsta?), to evaluate the runaway transport in the presence of the waves.

- Alfvén activity can be suppressed or enhanced by varying argon MGI level.
- Smaller MGI volumes lead to more Alfvén activity and decreased runaway current (no plateau case).
- Instabilities appear when runaway energy exceeds 2.5 MeV. Number of modes grow linearly with the maximum energy.
- Frequency spectrum: separate modes from 0.1 to 2.4 MHz, with a spacing of 400 kHz and width 25 kHz. Ion cyclotron frequency 10 MHz.
- Plausible waves between Alfvénic and whistler.



[Lvovskiy, Paz-Soldan et al, PPCF 2018]