TEXAS
The University of Texas at Austin

Kinetic simulations of electron transport in plasmas

relevant for fusion and space applications

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Continuum gyrokinetic simulations of electron transport in FT-2

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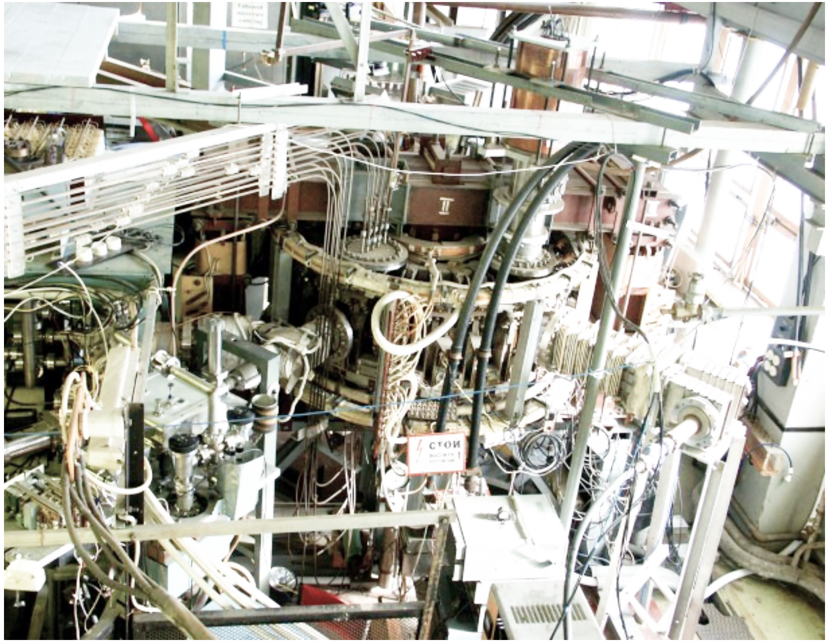
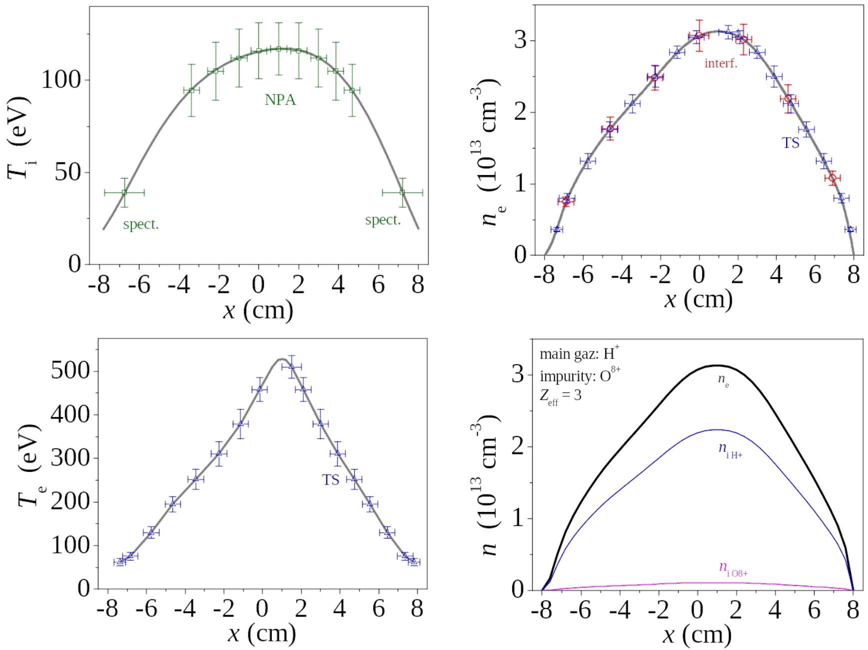
FT-2 tokamak at Ioffe Institute

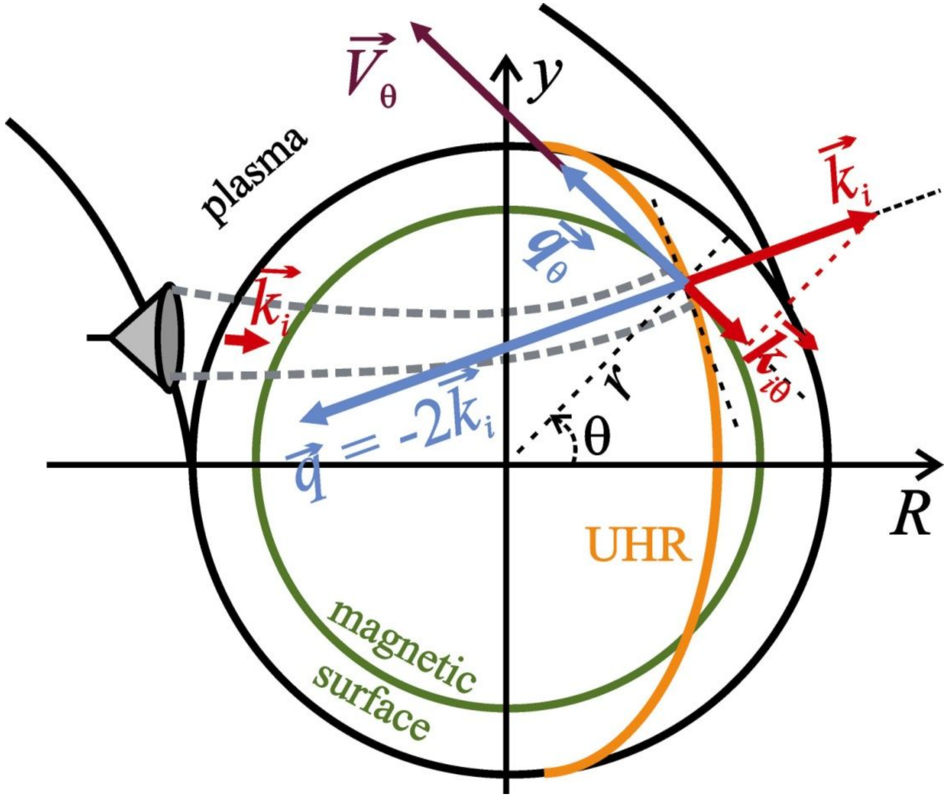




R_0= 0.55 m, a = 0.08 m, B_t= 2.2 T, q =2.1, ŝ =1.1, $O^{6\text{-}8+}$ impurity (Z_{eff}=3), τ=7.1

A D Gurchenko and E Z Gusakov, PPCF 52 124035 (2010)

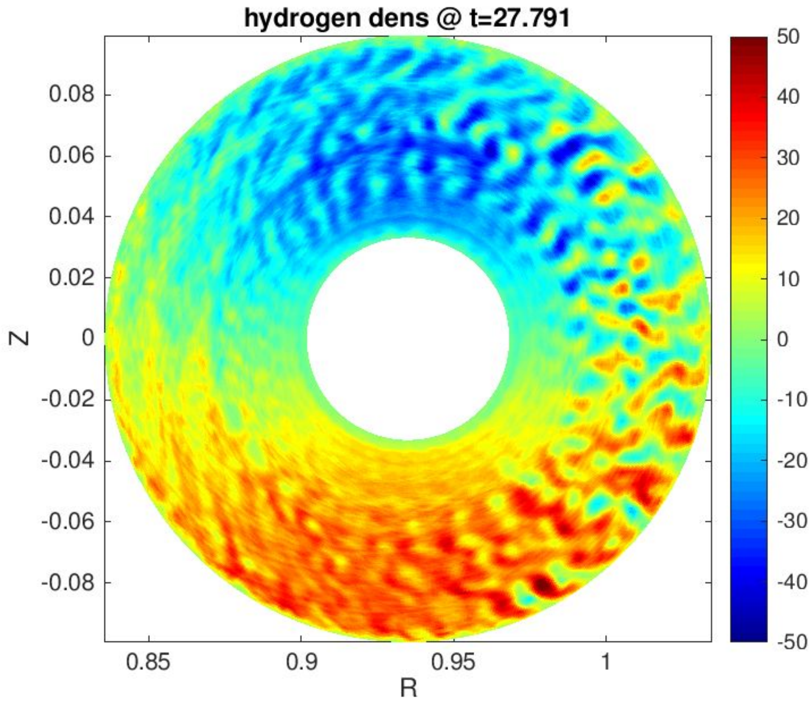
Enhanced scattering



- enhancement at UHR
- k_r range <= 150 /ρ_s
- location through frequency & antenna positioning

The GENE code

- gyrokinetic Eulerian
- electromagnetic
- local / global
- various coll. models & sources
- shaped geometries

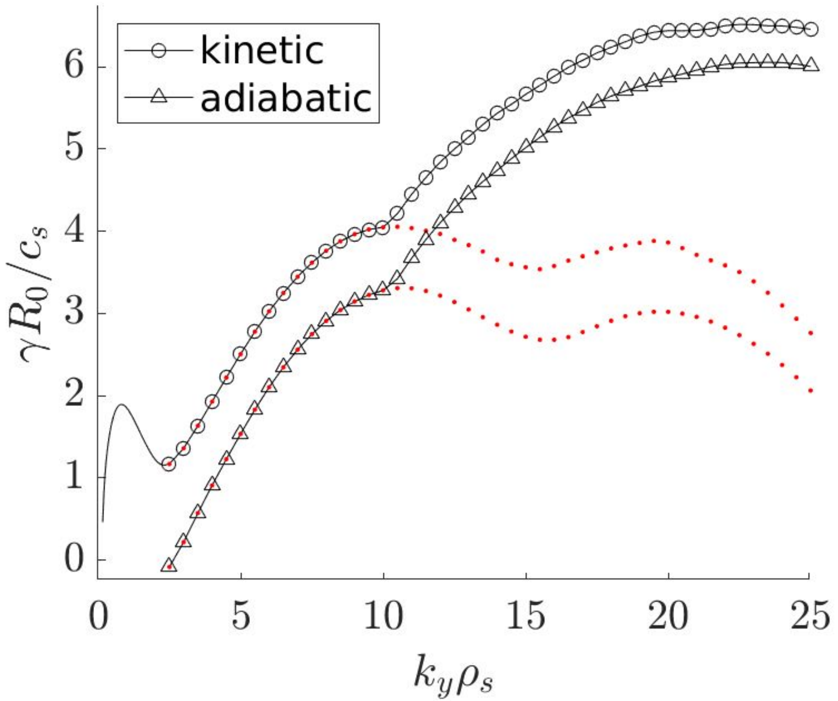


Linear characteristics of FT-2

- low k: TEM
- high k: ETG

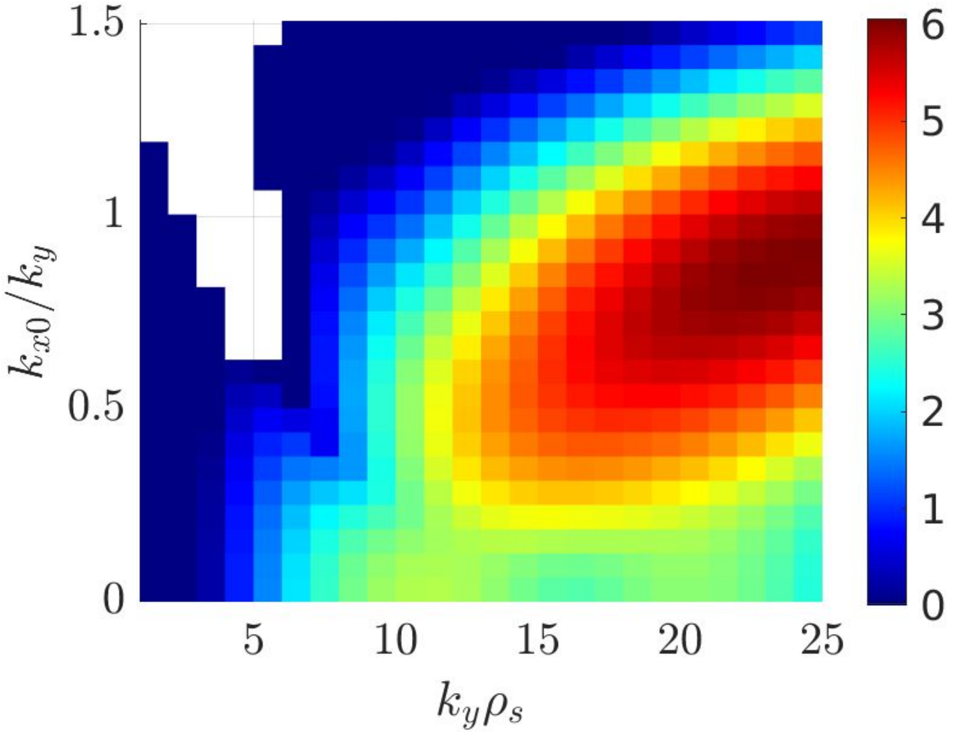
Modes overlap due to Z_{eff}.

ETG is well-known for streamers. Here at high k_y largest growth at finite k_x.



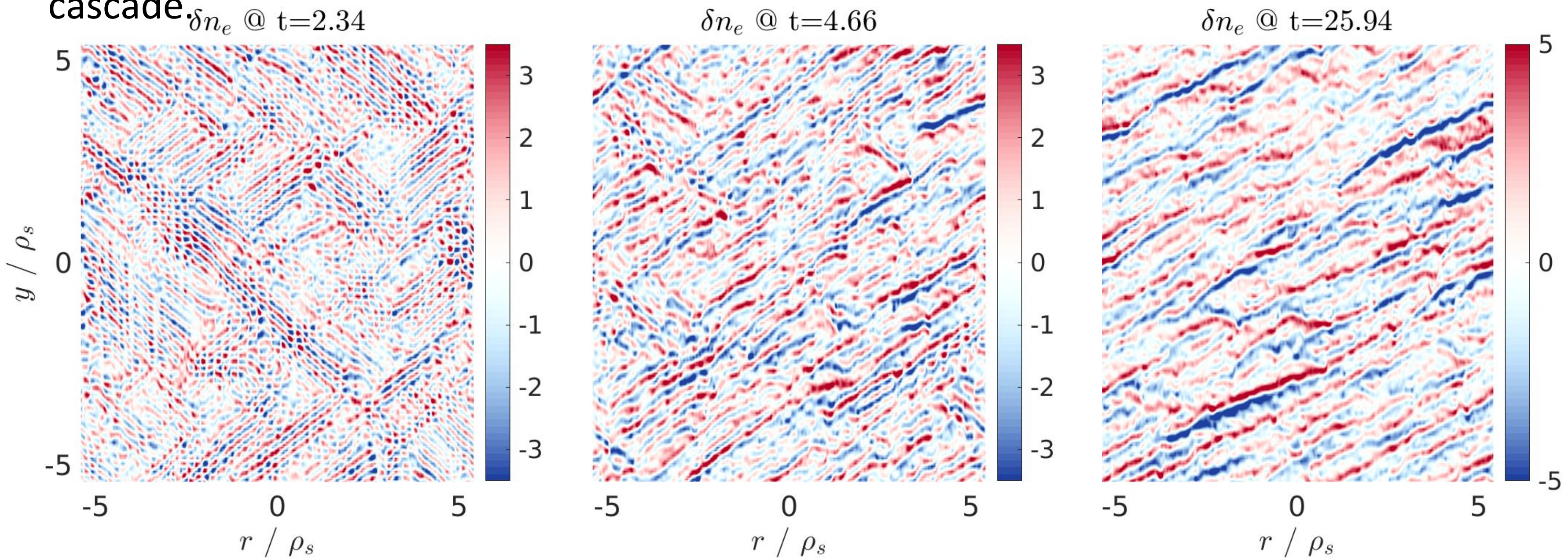
Linear ETG with adiabatic ions

Largest growth rate at high k occurs at a finite ballooning angle.
Growth rate is symmetric with respect to the sign of the ballooning angle.
We find that in nonlinear simulations this symmetry is broken.



Nonlinear simulation

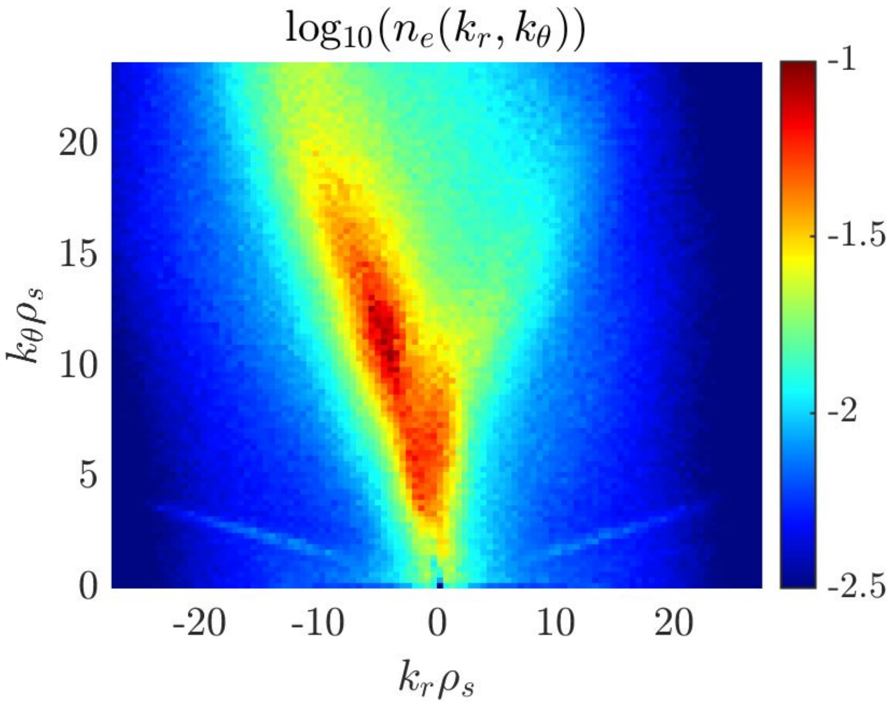
ETG spectrum chooses sign of ballooning angle later in saturation / inverse cascade.



Nonlinear spectrum of ETG turbulence

Spontaneous symmetry breaking a robust and distinct feature of NL simulation with flux-tube GENE.

Direction of broken symmetry depends on the relative directions of plasma current and toroidal field.



Summary of ETG

GENE used in new regime (high ν, τ, Z_{eff}, low T_e).

Largest growth rate of ETG at finite ballooning angle, symmetry spontaneously broken.

Symmetry breaking dependent on directions of B_T, j_p.

Theoretical explanation still elusive.

Paper on this arXiv:2005.14581

PIC simulations relevant to the ECDI

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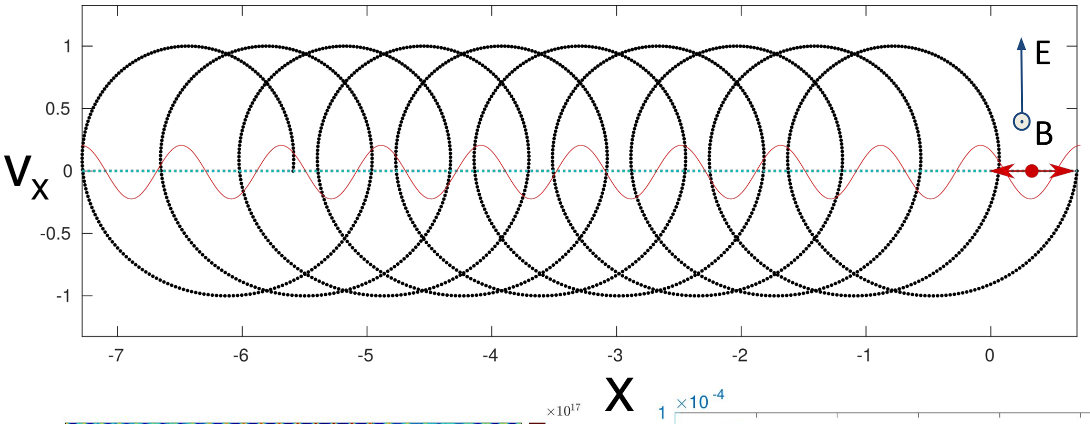
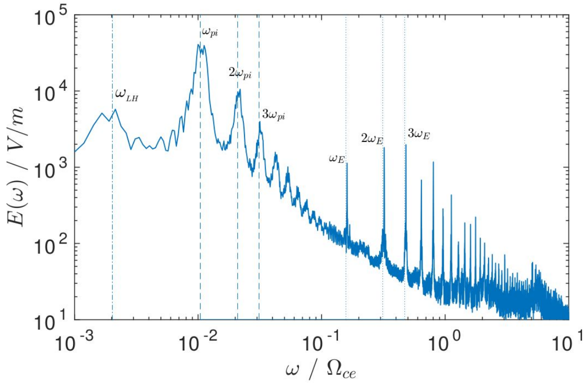
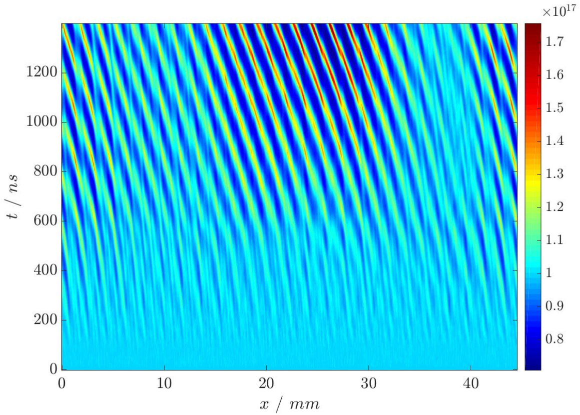
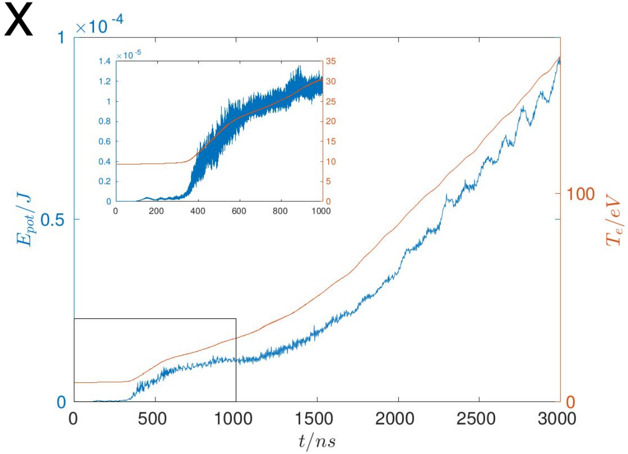
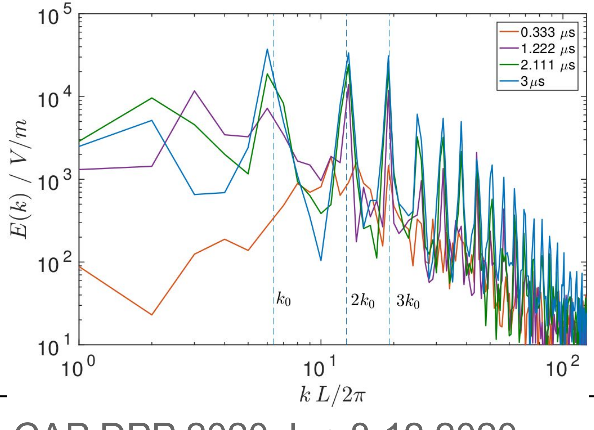
Background (Janhunen PoP 2018)



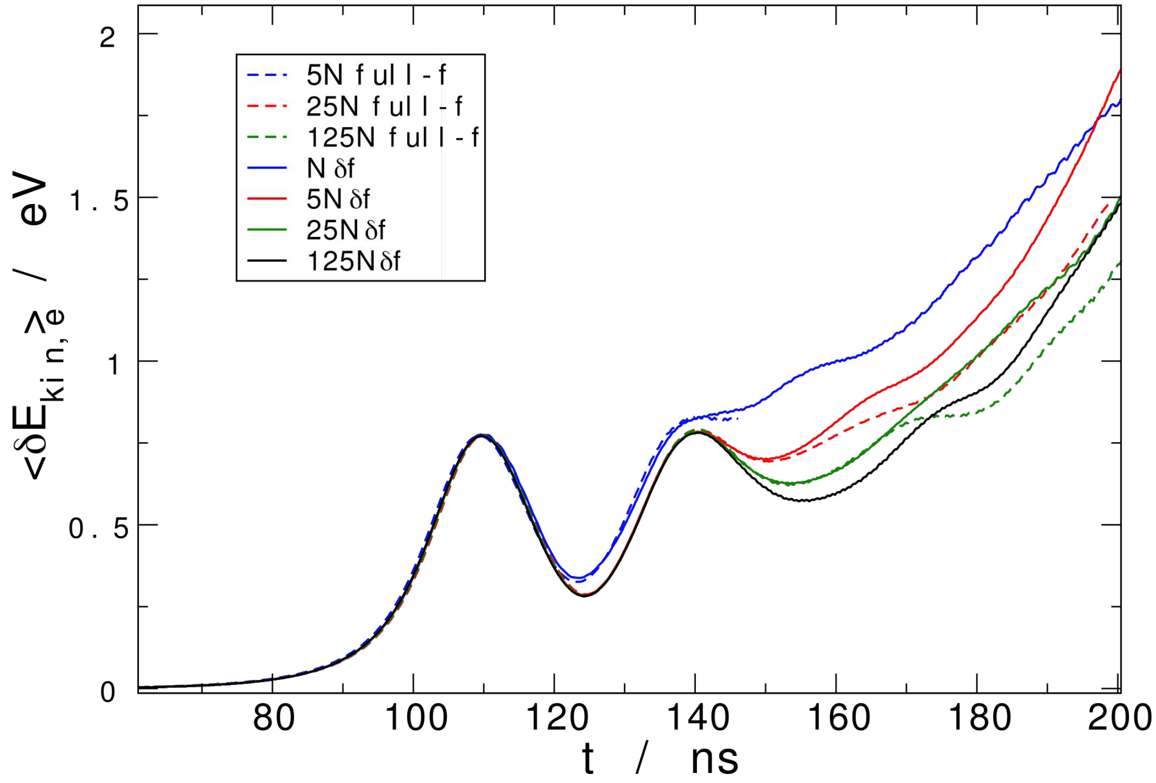








Ridiculous scaling of particle number



Particle number increase seems to make simulation converge to another unknown solution.

Same rate of heating long-term.

PIC noise can affect results in various ways

- artificial collisionality introducing spurious damping (and generation of entropy).
- sampling-noise driven fluctuations interacting with physical modes (detuning).
- exists mostly in accessible physical modes of the system.

Noise is a stochastic model of a deterministic process.

Collisions with finite-sized particles

- Particle size limits interaction due to screening. For sub-Debye ranges collisions can occur.
- Okuda & Birdsall (PoF 13 8 2123): $\nu \approx n v_t \sigma = \dfrac{\pi \omega_{pe}}{16 N_D}$

  for Janhunen et al. PoP 2018: $\nu = 5 \cdot 10^{-6} \omega_{pe}$

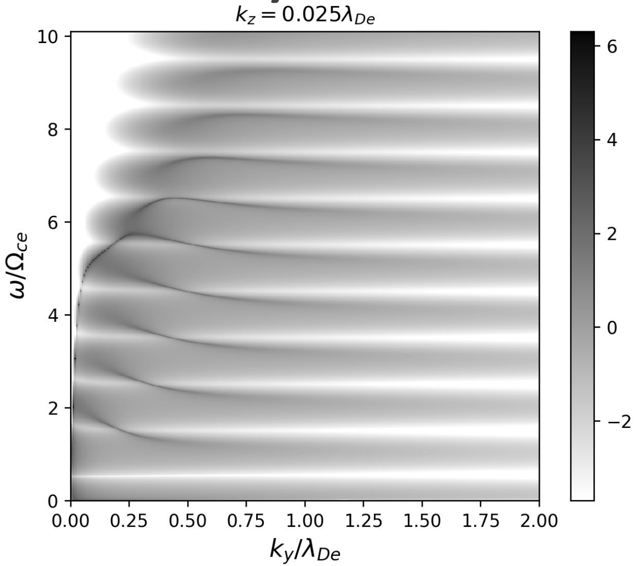
  for Croes et al. 2017: $\nu = 4.5 \cdot 10^{-5} \omega_{pe}$
- Turner (PoP 13 033506):
  - "... kinetic properties of the simulation are appreciably degraded when the $\nu \geq 10^{-4} \omega_{pe}$, ..."

Noise spectrum due to (thermal) fluctuations

- Langdon (PoF 22 163),
  Krommes, Nevins, Decyk:

$$L|E(k,\omega))|^2/8\pi = -\frac{T}{\omega}\Im(\frac{1}{\varepsilon(k,\omega)})$$

$$\langle\frac{E_k^2 L}{8\pi}\rangle = \frac{T_p}{2}\left(1+\frac{k^2\lambda_{De}^2}{S^2(k)W^2(k)}\right)^{-1}$$



- Limiting cases:

$$|e\phi(k,\omega_{pe})/T_e| = \frac{1}{\sqrt{N}k\lambda_{De}}$$

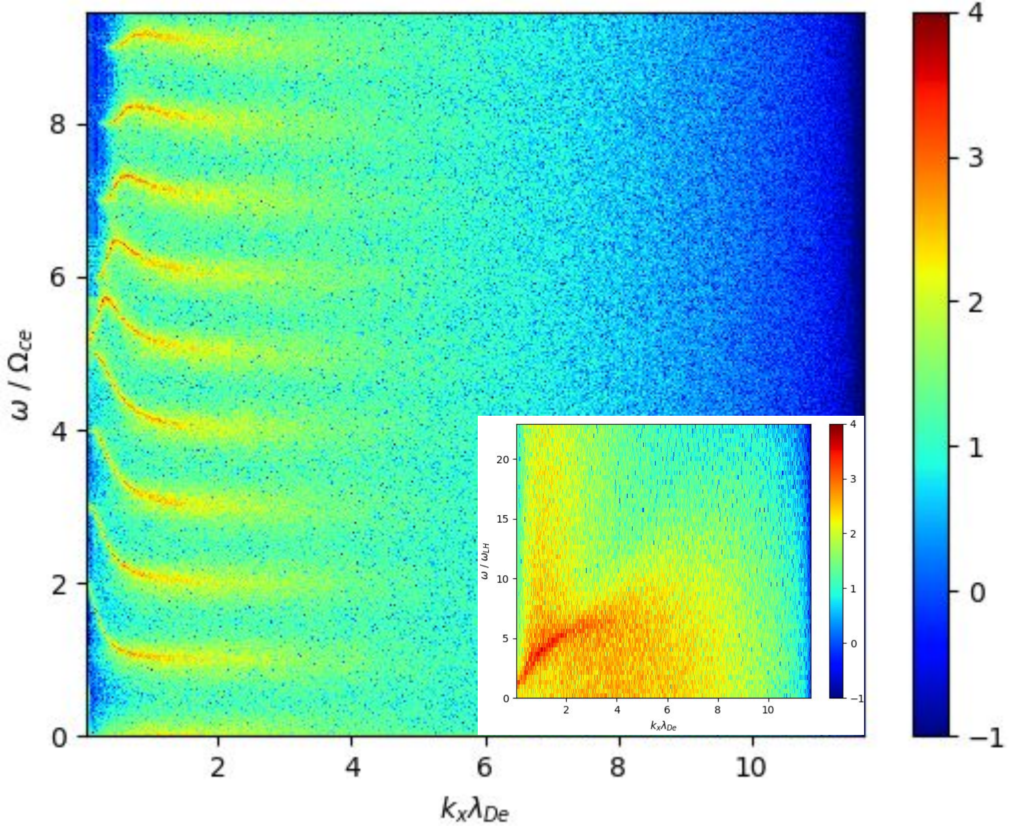
Plasma waves

$$|e\phi(k,\omega_s)/T_e| = \frac{1}{\sqrt{N}}$$

IAW

Noise in a stable system exists in the normal modes of the plasma (here Bernstein modes).

In an unstable system, it will be determined by nonlinear damping.



SymPIC result:B=200 G, T_e=20 eV, T_i=1 eV, n_0=10^{17} 1/m3.

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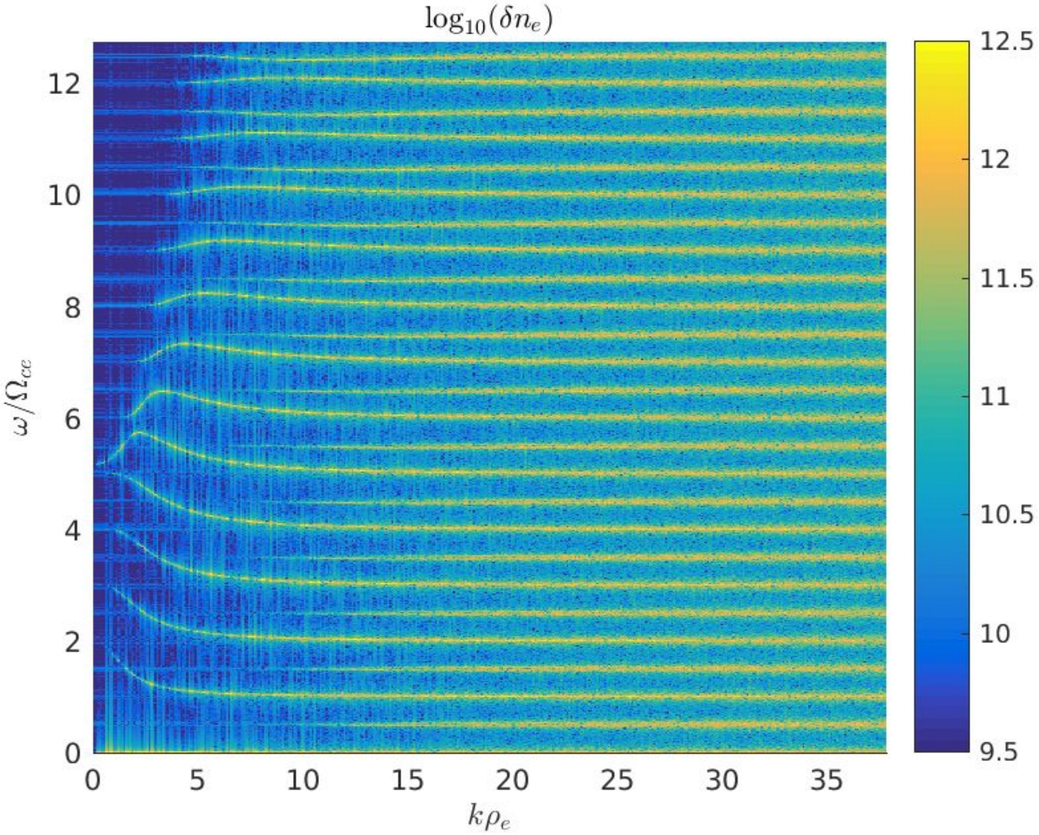


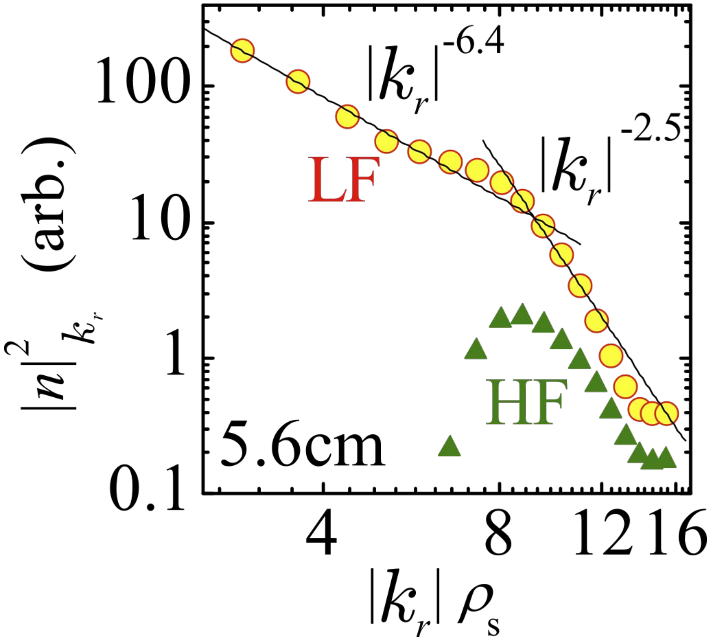
EDIPIC result:B=200 G, T_e=20 eV, T_i=1 eV, n_0=10^{17} 1/m^3.

Conclusions

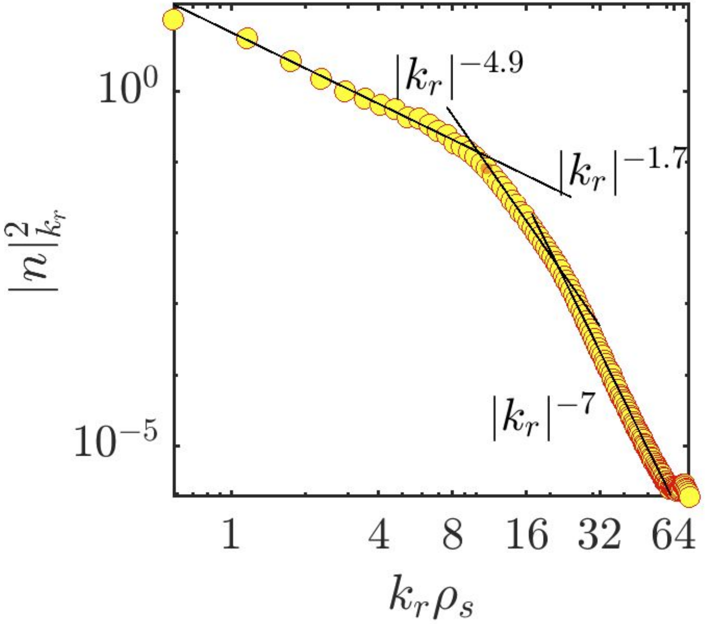
- Particle noise influences through:
  - effective collisionality (helped by finite sized particles).
  - fluctuations induced by thermal noise.
- Noise energy concentrates on physical modes.
- Effect on instability by nonlinear damping.
- Noise could change the nature of ECDI making it unphysical.

Radial spectra for electron density fluctuations

Experimental spectrum



GENE simulation



Transport in ion/electron scales

While 99% of transport happens at ion scales for this case, fluctuations at electron scale still measurable. Electron fluctuations used for measuring E_r, and radial correlation of zonal modes.

GENE transport levels by about 20% higher in electron heat transport (at ion scales) vs. ASTRA; neoclassical transport important (not included in these flux-tube simulations). Also 20% error in experimental profiles.