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Low Frequency Turbulence in a High Beta Plasma

V. I. Sotnikov

University of Nevada at Reno, NV 89557

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Sandia National Laboratories

In collaboration with

V. V. Ivanov, R. Presura, E. Yasin, J. Kindel
University of Nevada at Reno, NV 89557, USA

J.N. Leboeuf
JNL Scientific, Casa Grande, AZ 85222, USA

O.G. Onishenko
Institute of Physics of Earth, 123995 Moscow, Russia

B.V. Oliver, T. A. Mehlhorn
Sandia National Laboratories, Albuquerque, NM 87123, USA

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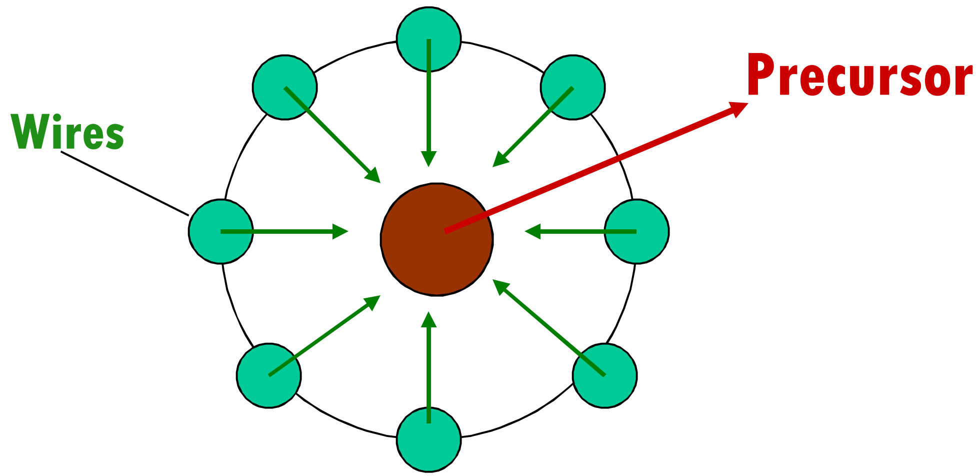
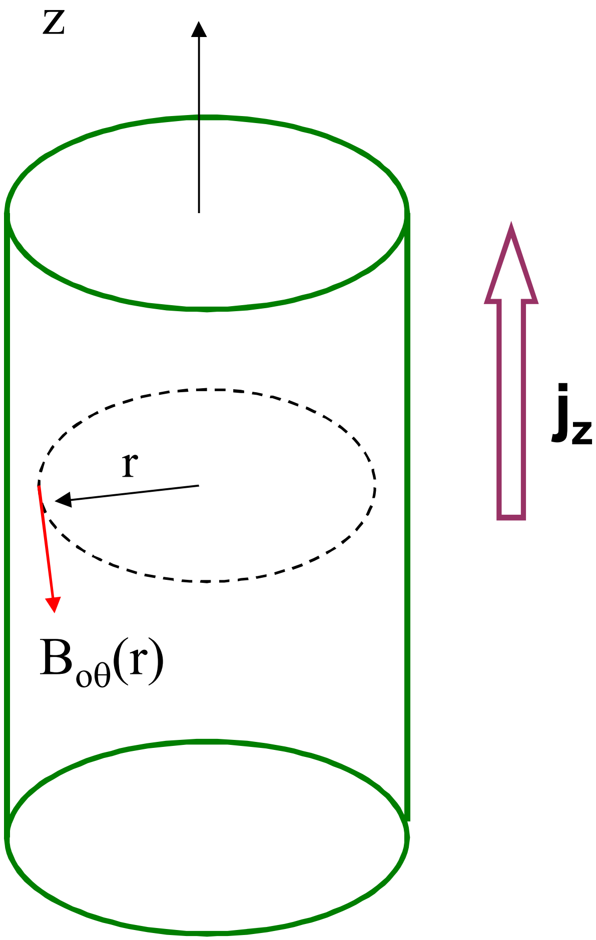
Wire array imploding experiments at NTF

Current in the wire array ~ 1 MA





Plasma parameters in a precursor plasma

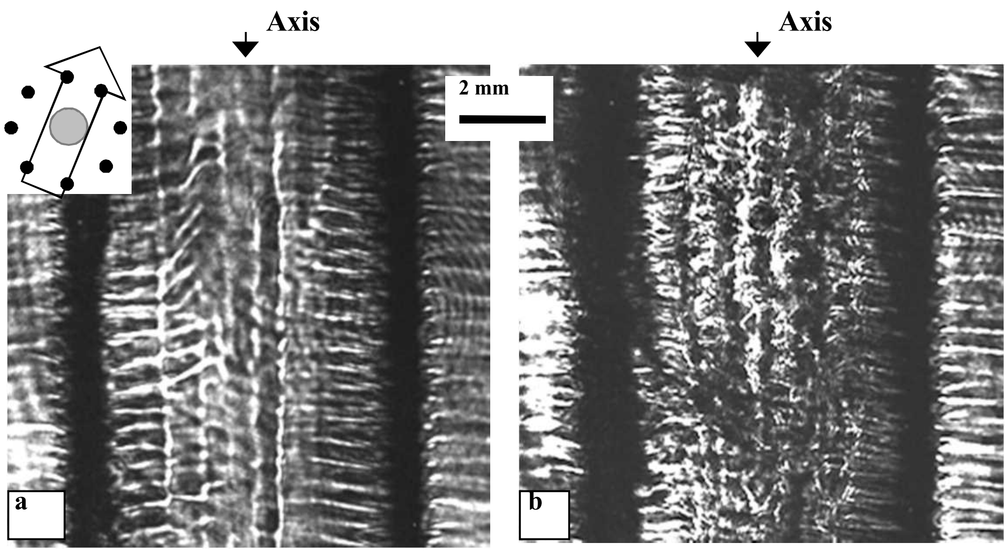
$$n_{0e} = 2.0 \times 10^{19}\ \mathrm{cm}^{-3},\ n_{0i} = 2.0 \times 10^{18}\ \mathrm{cm}^{-3},$$

$$T_i \sim T_e = 50\ \mathrm{eV},\ B_0 = 0.3\ \mathrm{MG}$$

$$\beta = 0.55 \quad \Omega_{cAl} = 1.1 \times 10^{10}\ s^{-1} \quad \omega_{pAL} = 1.4 \times 10^{13}\ s^{-1}$$

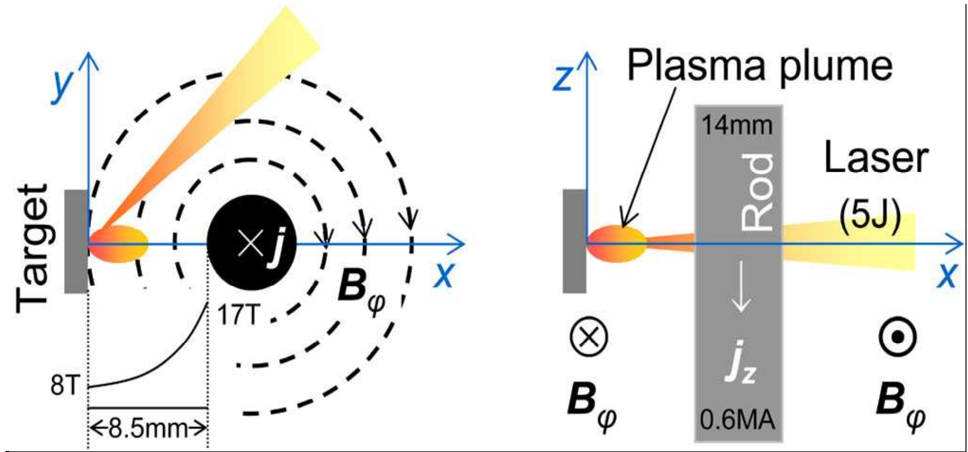
Instability of flute modes in a Z-pinch plasma of a precursor can explain experimentally observed properties of excited perturbations

- Characteristic wavelengths of excited waves ~ 0.1 - 1 mm
- Typical rise time of excited waves ~ 20 ns
- Development of large scale cells on nonlinear stage
- Wave spectrum cascading towards short scales

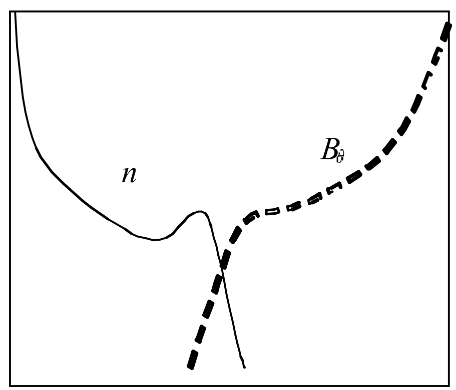


Sotnikov et al., IEEE TPS, 2005; Sotnikov et al., CiCP 2008, to be published

Laboratory Astrophysics Experiments



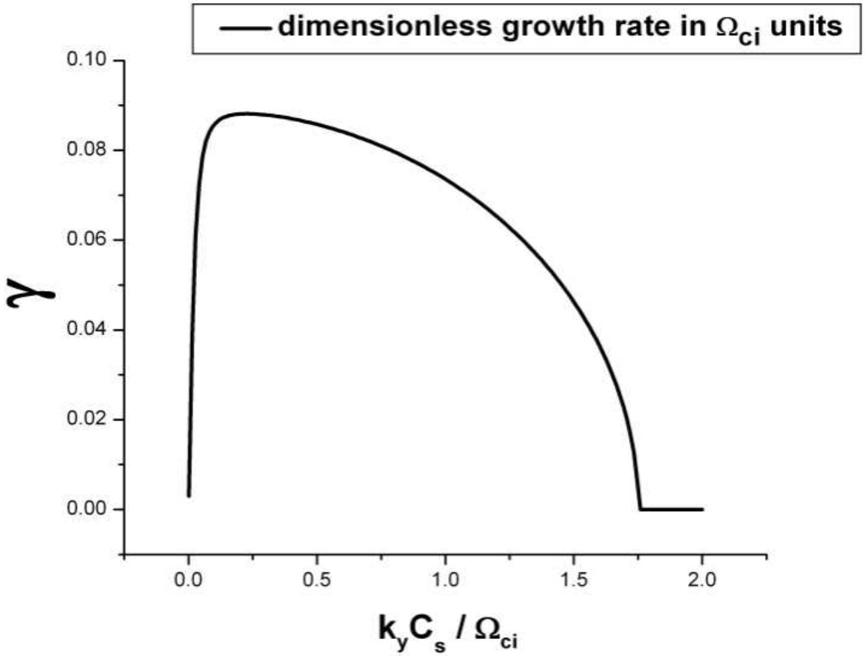
Experimental set-up



Experimental density profile and adjusted magnetic field radial profile

Presura et al., Astrophys. Space Sci., 2006
Sotnikov et al., Astrophys. Space Sci., 2006

Growth rate and frequency of flute modes



Experimentally observed plasma parameters

$$n_{0e} = 2.0\times10^{19}\ \text{cm}^{-3},\ n_{0i} = 2.0\times10^{18}\ \text{cm}^{-3},\ T_i \sim T_e\text{e} = 50\ \text{eV},\ \ B_0 = 0.3\ \text{MG}$$

$$\frac{\omega_{pAl}}{c} = 4\times10^{2}\ cm^{-1} \quad \frac{kc}{\omega_{pAl}} \approx 0.3 \quad \lambda \approx 0.5\ mm \qquad R \approx 1\div3\ mm \qquad g \approx \frac{2V_A^2}{R}$$

$$\gamma \approx 3\times10^{7}\ s^{-1}$$

$$\beta = 0.55 \quad \Omega_{cAl} = 1.1\times10^{10}\ s^{-1} \quad \omega_{\text{pAL}} = 1.4\times10^{13}\ s^{-1}$$

Flute instability

small density perturbation $\delta n \sim \cos(\omega_k t - k_z z)$

⇓

perturbation of "gravitational" force $\delta F_r \sim g\delta n$

⇓

ions drift in axial z-direction

⇓

separation of charge

⇓

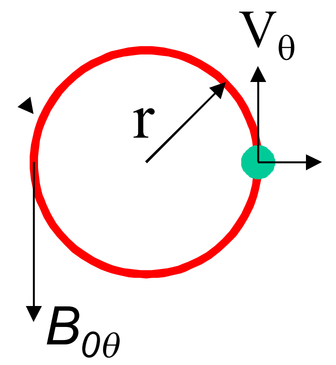
electric field

⇓

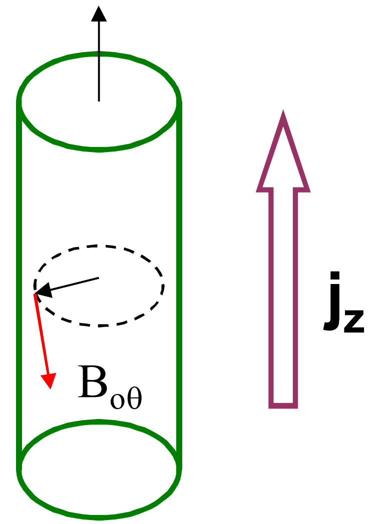
drift motion in *r*-direction brings particles from denser plasma core

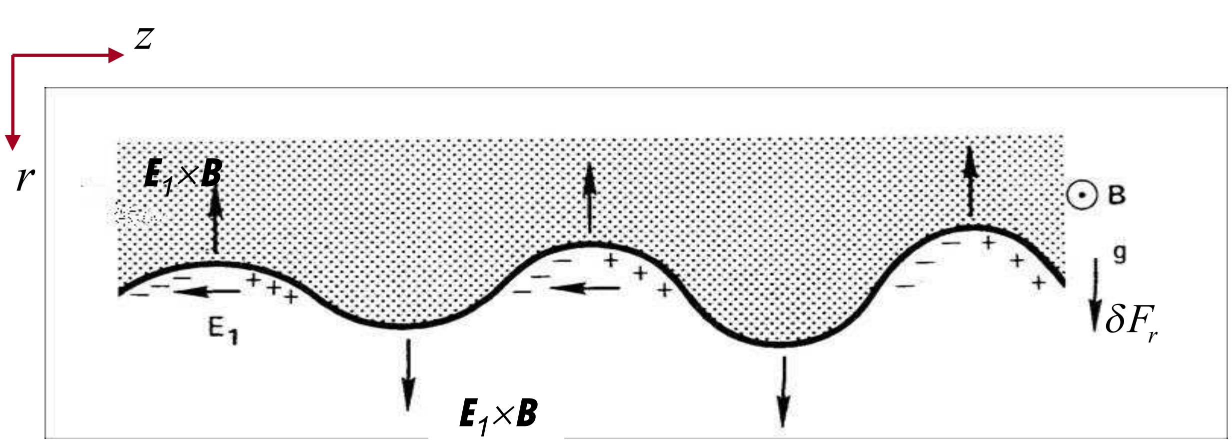
⇓

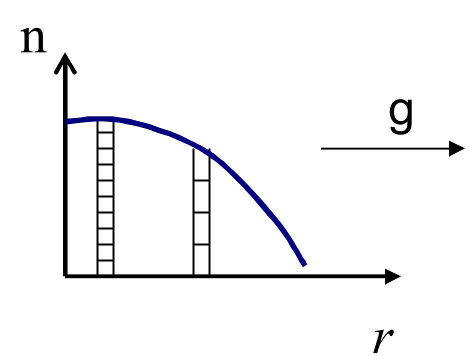
instability



$$g = \frac{V_\theta^2}{r} \approx \frac{V_T^2}{r}$$

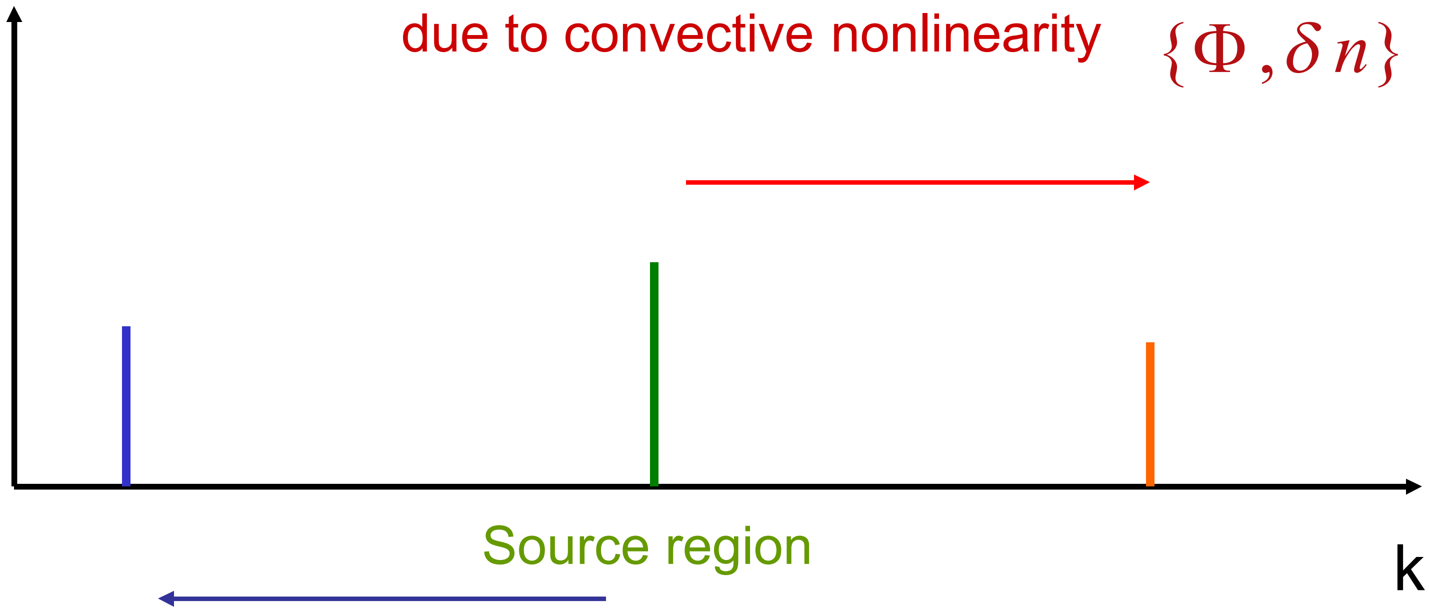






Nonlinear wave cascades

Wave energy cascade to small wavelengths due to convective nonlinearity $\{\Phi, \delta n\}$



Wave energy cascade to large wavelengths and excitation of large scale structures due to polarization drift nonlinearity $\{\Delta_\perp \Phi, \Phi\}$

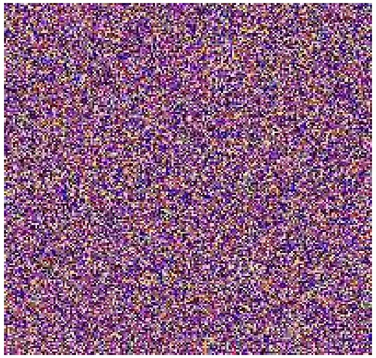
and diamagnetic component of polarization drift nonlinearity $div\{\vec{\nabla}_\perp \Phi, \delta n\}$

Kodama and Pavlenko, PRL 1988; Sandberg et al., PoP 2005.

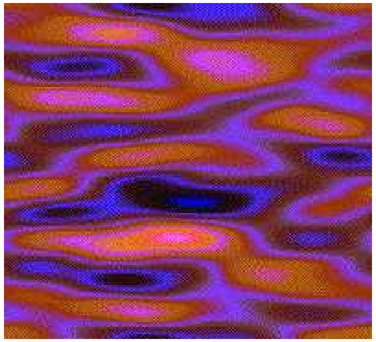
Sotnikov et al., IEEE TPS, 2005; Sotnikov et al., CiCP 2008, to be published

Numerical results

Density in linear stage

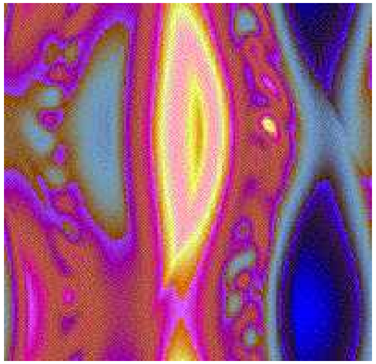


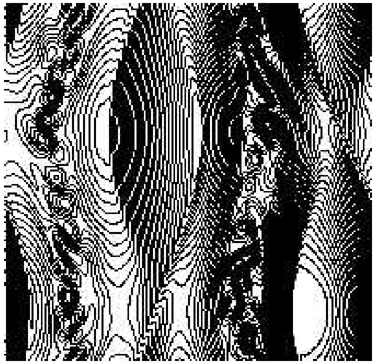
$\Omega_i t = 0$



$\Omega_i t = 1400$

Density in nonlinear stage and formation of dipolar vortices

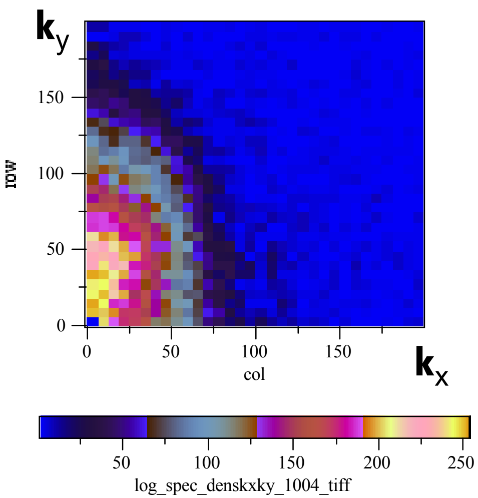




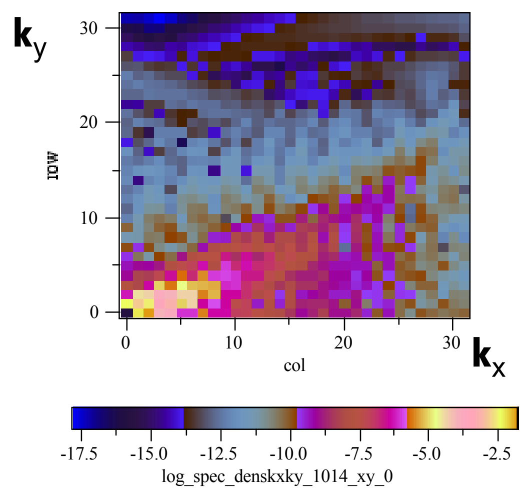
$\Omega_i t = 4600$

Formation of zonal flow on the nonlinear stage

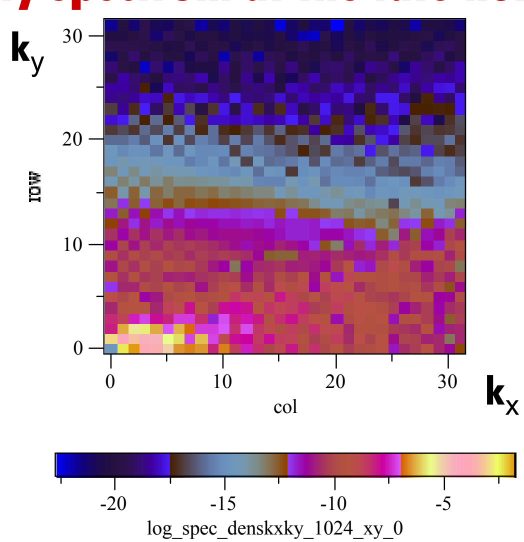
2D density spectrum at the linear stage



2D density spectrum at the early nonlinear stage

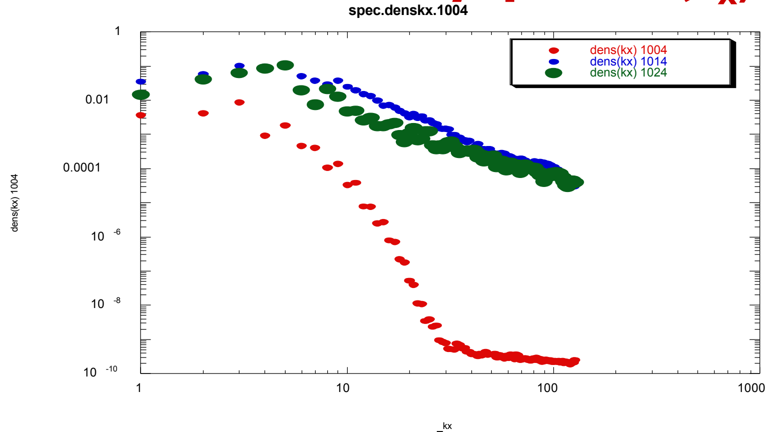


2D density spectrum at the late nonlinear stage



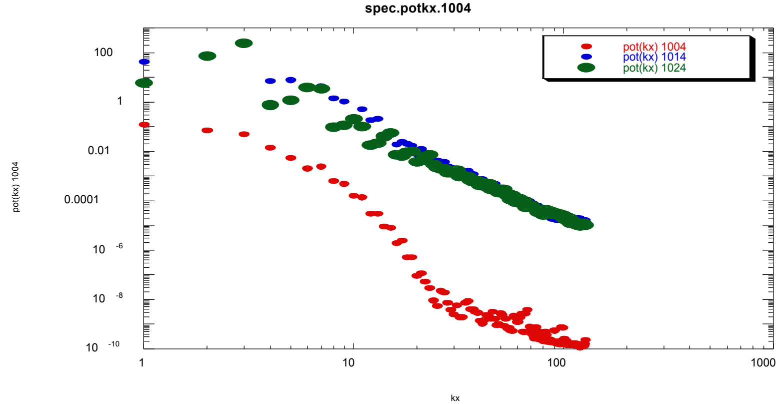
Spectral cascade to short scales

Evolution of the density spectrum (k_x) in time



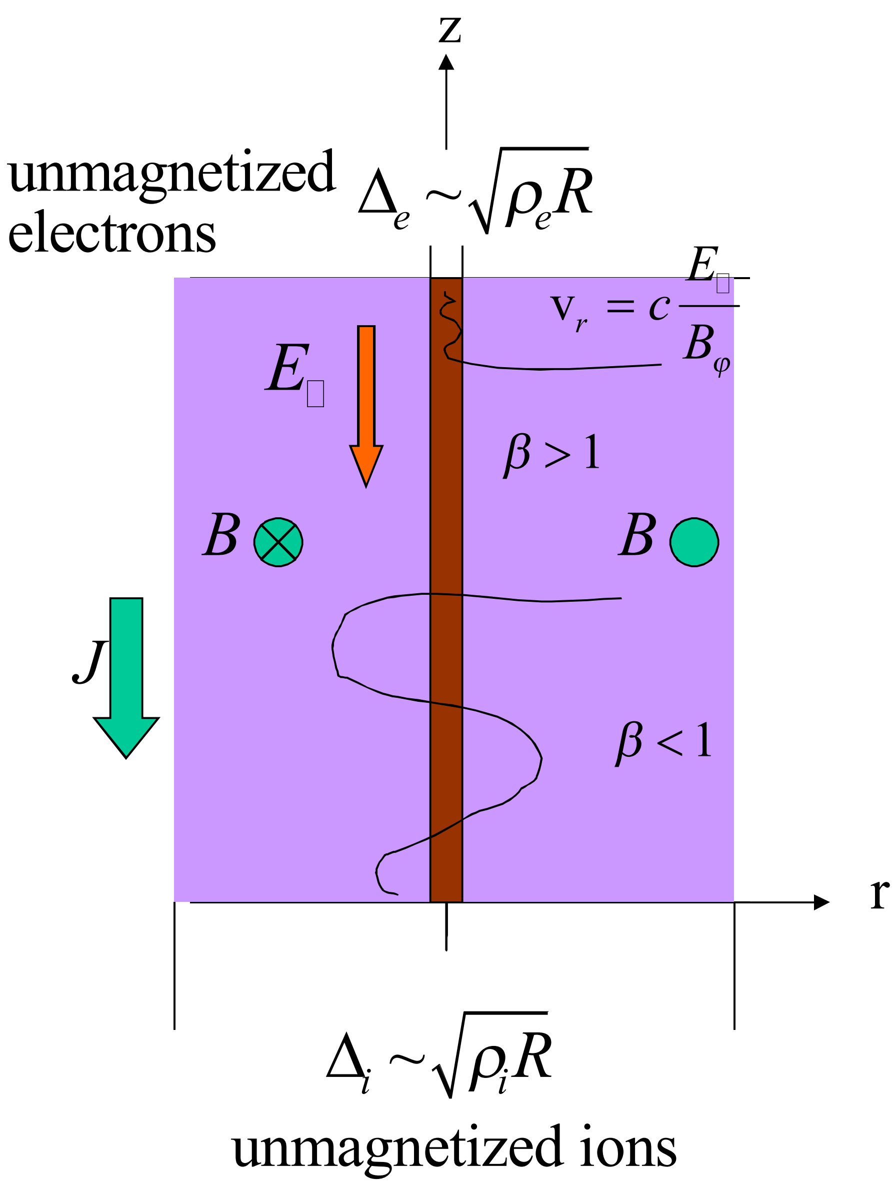
k_x

Evolution of the potential spectrum (k_x) in time



k_x

New ion instability of the Buneman type and associated anomalous resistivity in Z-pinch discharge configuration



Conclusions

- Wave activity experimentally observed in the central region of imploding wire array, where significant part of the current is concentrated, can be connected with excitation of flute-type compressible electromagnetic oscillations in high beta plasma.

- Flute-type instability can be observed in laboratory astrophysics experiments on interaction of laser ablated plasma flow with strong magnetic field.

- Linear dispersion equation for electromagnetic flute-like mode instability has growing solution even in a finite beta plasma. Typical growth time and spatial scales of excited waves are in agreement with experimental data.

- Fluid model of flute turbulence can describe nonlinear dynamics of large scale density and magnetic field structures as well as wave energy cascading towards the short scales observed in experiment.