Gyrofluid Studies on Avalanche-like Transport and Formation of Transport Barrier

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ABSTRACT

- We analyzed evolution of corrugated structures using gyrofluid code developed by Yagi[1].
- From the simple calculation using model equations and traffic jam model [2], spatial scale and the life time of corrugated structures are affected by collisional diffusion and neoclassical poloidal flow.
- Our simulation results reproduce the tendency suggested by our calculation and traffic jam model.

BACKGROUND

- Recent experiments in KSTAR have exhibited the evidence of the non-diffusive avalanche-like electron heat transport events without MHD instabilities[3].
- Also, gyrokinetic simulations showed corrugated structures of δT and correlated $E \times B$ staircase structures [4,5].
- Theories explaining the profile corrugation :
  1) Vorticity mixing based on Self-Organized Criticality (SOC) dynamics[6]
  2) Traffic jam model [2]
- Based on traffic jam model, with

$$\partial_t \delta T + \lambda \delta T \partial_x \delta T = \chi_2 \partial_x^2 \delta T - \chi_4 \partial_x^4 \delta T - \tau \partial_t^2 \delta T$$

scale length of the structure is $\Delta_{max}^2 = \frac{2\sqrt{\chi_2 \chi_4}}{\lambda \delta T_0}$ and $\gamma_{max} = \frac{\lambda \delta T_0}{2\sqrt{\chi_2 \tau}}$

Model equation and primary analysis

3-field gyrofluid equations used in code [1]

- Ion continuity equation

$$\Rightarrow \frac{dW}{dt} + \kappa_n \frac{1}{r}\frac{\partial \Phi}{\partial \theta} + A\nabla_\parallel V = \epsilon \widehat{\omega}_d F + \rho_* \frac{1}{r}\frac{\partial}{\partial r}\left(r \frac{q}{\epsilon} \mu_{nc} U_P\right) - \rho_*^2 \mu \nabla_\perp^4 F \qquad (1)$$

- Ion parallel velocity equation

$$\Rightarrow \frac{dV}{dt} = -A\nabla_\parallel F + 4\mu \nabla_\perp^2 V - \mu_{nc} U_P - A\sqrt{\frac{1}{\tau}\frac{2}{5}}\sqrt{\pi}|\nabla_\parallel| V + \frac{2}{5} A \nabla_\parallel T \qquad (2)$$

- Ion thermal equation

$$\Rightarrow \frac{3}{2} n_0(r)\left(\frac{dT}{dt} + \kappa_T \frac{1}{r}\frac{\partial \phi}{\partial \theta}\right) - T_i(r)\left(\frac{dn}{dt} + \kappa_n \frac{1}{r}\frac{\partial \phi}{\partial \theta}\right) = \frac{5}{2\tau}\epsilon \widehat{\omega}_d T - \frac{9}{5\sqrt{\pi}} A|\nabla_\parallel| T + \frac{2}{5} A \nabla_\parallel V + \chi_\perp \nabla_\perp^2 T + S_T \qquad (3)$$

$W = n - \nabla_\perp^2 F$: generalized vorticity $F = \phi + p/\tau$: generalized potential

$U_P = V + \rho_* \frac{q}{\varepsilon}\left(\frac{\partial F}{\partial r} - \kappa_{nc}\frac{dT}{dr}\right)$: poloidal velocity

$$\kappa_{nc} = \frac{1}{1 + \nu_{*i}^2 \epsilon^3}\left(\frac{1.17 - 0.35\nu_{*i}^{1/2}}{1 + 0.7\nu_{*i}^{1/2}} - 2.1\nu_{*i}^2 \epsilon^3\right)$$

Primary analysis based on traffic jam model

For (0,0) mode, assume $V_\parallel \sim 0$ and high aspect ratio limit.

Then, model equation becomes

$\mu_{nc} U_P = 0, \delta F = \kappa_{nc} \delta T$ or $\delta n = \delta \phi = \left(\kappa_{nc} - \frac{1+\tau}{\tau}\right)\delta T$

$$\frac{d}{dt}(\delta n - \rho_*^2 \nabla_\perp^2 \kappa_{nc} \delta T) = -\rho_*^2 \mu \nabla_\perp^4 \kappa_{nc} \delta T$$

$$\frac{3}{2} n_0 \frac{d\delta T}{dt} - T_0 \frac{d\delta n}{dt} = \chi_\perp \nabla_\perp^2 \delta T$$

$$\Rightarrow \frac{3}{2}\frac{n_0}{T_0}\frac{d\delta T}{dt} = \frac{\chi_\perp}{T_0}\nabla_\perp^2 \delta T - \rho_*^2 \mu \kappa_{nc} \nabla_\perp^4 \delta T - \frac{\rho_*^2 \kappa_{nc}}{\chi_\perp}\left(\frac{3}{2} n_0 + \left(\frac{(1+\tau)}{\tau} - \kappa_{nc}\right) T_0\right)\frac{d^2 \delta T}{dt^2}, \qquad (4)$$

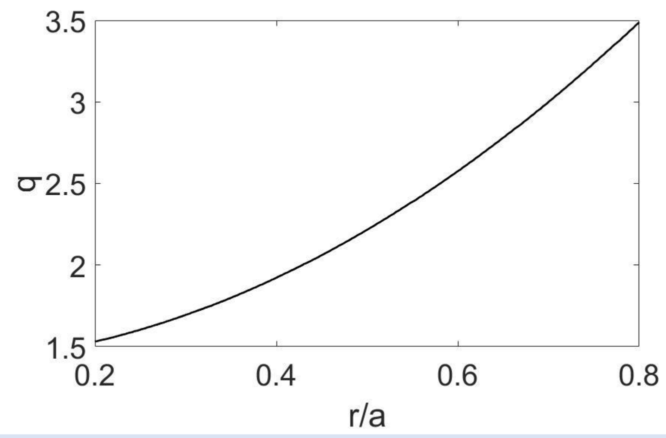
which is similar to traffic jam model [2].

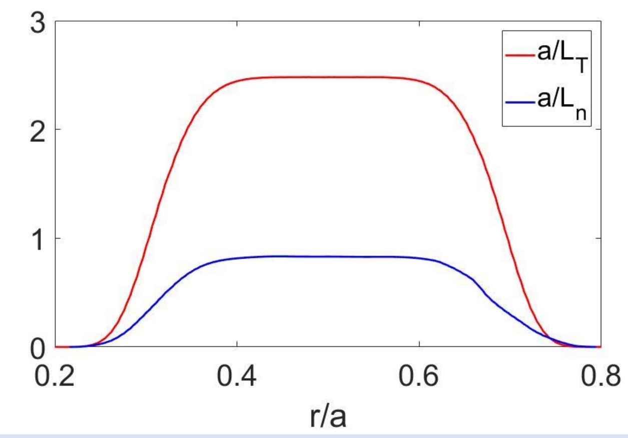
Based on simple analysis, as κ_{nc}, μ and $\chi_\perp$ increase, spatial scale of corrugated structure increases but its growth rate decreases.

Thus, structures won't sustain for longer time.

Initial setup

- R=1.8m, a=0.67m, $B_T = 2.5T$
- Shaping effects are considered ($\Delta = 0.1$, $\kappa = 1.5$, $\delta = 0.3$)
- Profile is fixed by external heat source.



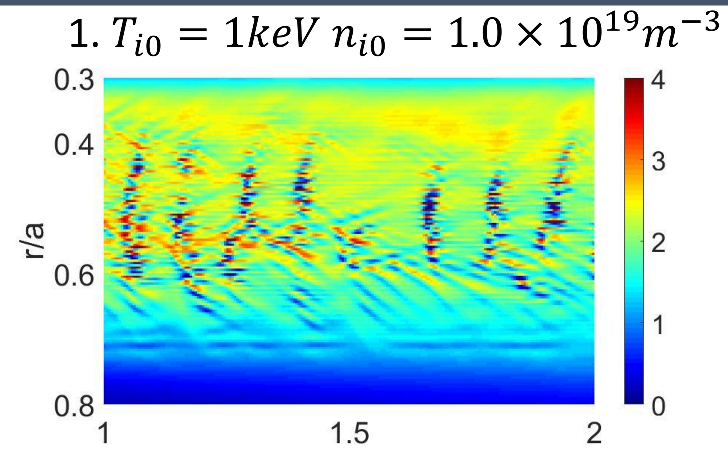


Results & analysis

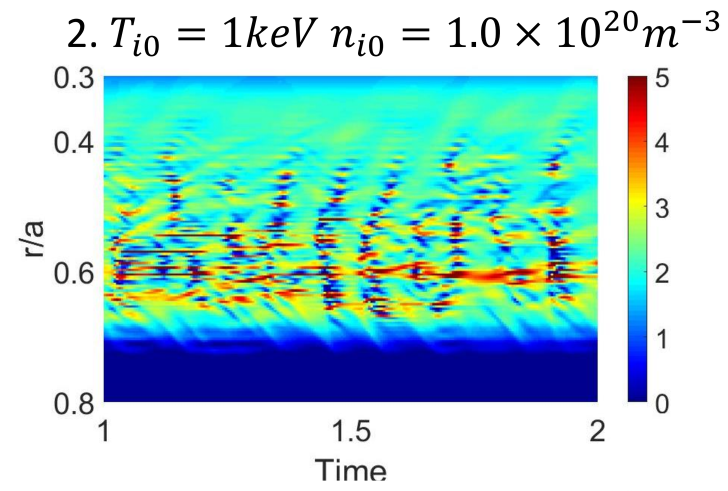
Check the effects of κ_{nc}

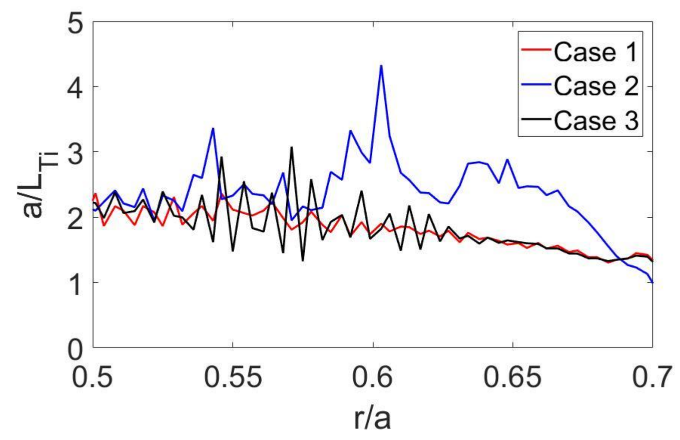
- Above 3 figures contour plot of a/L_{Ti}
- Linear growth rate of ITG instability is the same.
- Corrugated structures sustain for a longer time for lower κ_{nc} cases.
- Below figure : time averaged (t=1-2) a/L_{Ti}
- Scale length of structures : Case2 > Case 1 > Case 3

1. $T_{i0} = 1keV$ $n_{i0} = 1.0 \times 10^{19} m^{-3}$

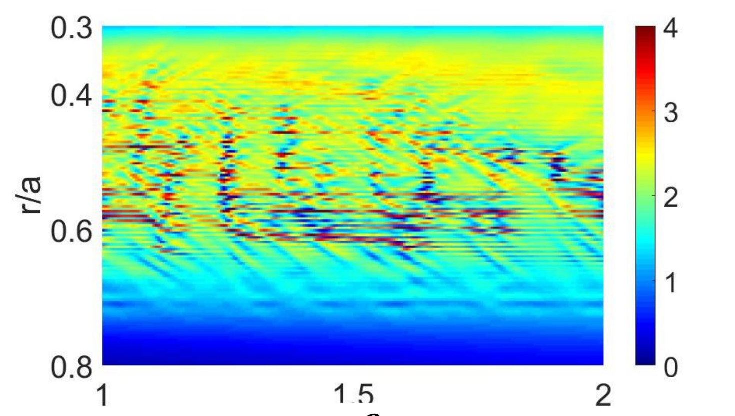


2. $T_{i0} = 1keV$ $n_{i0} = 1.0 \times 10^{20} m^{-3}$





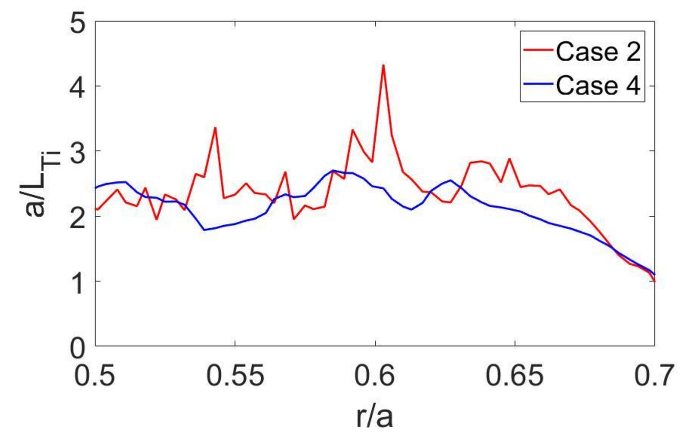
3. $T_{i0} = 1keV$ $n_{i0} = 1.0 \times 10^{19} m^{-3}$
Setting $\kappa_{nc} = 0$



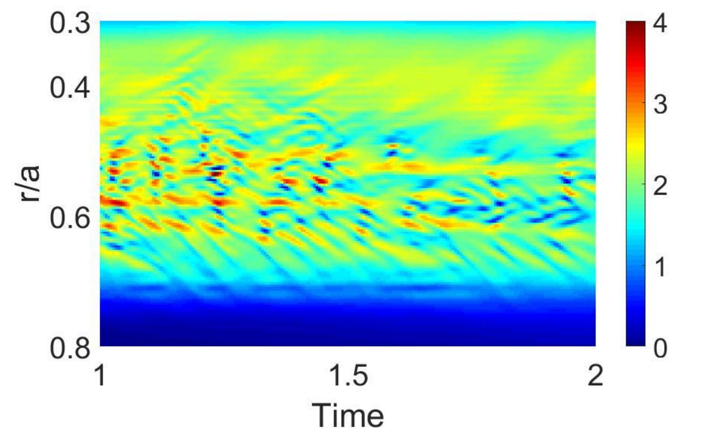
Time $[a^2/\rho_s c_s]$

Check the effects of μ and $\chi_\perp$

- Similar analysis based on Eq. (4) is adjustable.



4. $T_{i0} = 1keV$ $n_{i0} = 1.0 \times 10^{20} m^{-3}$
Set 10 times higher μ and $\chi_\perp$



CONCLUSION & Future Work

- Corrugated structures of a/L_{Ti} are observed in gyrofluid simulations.
- Their tendency follows the prediction by primary analysis using model equations and traffic jam model.
- In the future, radial correlation length and correlation time will be calculated and check the tendency based on our analysis.

ACKNOWLEDGEMENTS / REFERENCES

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