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Master Thesis

Stabilizing Global Simulation in GKW by the Introduction of the Parallel Electric Field $E_{\parallel}$

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This thesis is dedicated to my cat **Leo**
who is part of our family since July 2020.
He is the kindest cat I ever own and very playful.
For a long life together.

I love you.

Manuel Lippert
November 21, 2023

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Abstract

Ion temperature gradient-driven turbulence (ITG) close to marginal stability exhibits zonal flow pattern formation on mesoscales, so-called $\mathrm{E} \times \mathrm{B}$ staircase structures. Such pattern formation has been observed in local gradient-driven flux-tube simulations as well as global gradient-driven and global flux-driven studies.

To reduce the computational effort for the simulations lower input parameter of GKW (Gyro Kinetic Workshop) were tested to find the optimum of minimum resolution for the performed simulations.

For convenience, a `python` script (`slurm_monitor.py`) was written to monitor the simulation on the `btrzx1`-cluster and start/restart until the completion criterion is fulfilled.

Furthermore, it is shown by multiple box size convergence scans that a mesoscale pattern size of $\sim 57 - 76\,\rho$ is inherent to ITG-driven turbulence with Cyclone Base Case parameters in the local limit. This outcome also implies that a typical scale for avalanche-like transport is inherent to ITG-driven turbulence.

Zusammenfassung

Ionen-Temperaturgradienten getriebene Turbulenzen (ITG) weisen nahe niedriger Stabilität Zonal Flow Strukturbildungen, sogenannte $\mathrm{E}\times\mathrm{B}$ Treppenstrukturen, auf Mesoskalen auf. Solche Strukturbildungen wurden sowohl in lokal gradientengetriebene Flussschlauchsimulationen als auch in global gradientengetriebenen und global flussgetriebenen Untersuchungen entdeckt.

Um den Aufwand der Berechnungen der Simulationen zu reduzieren wurden mehrere kleinere Inputparameter für GKW (Gyro Kinetic Workshop) getestet um die optimal kleinste Auflösung für die ausgeführten Simulationen zu finden.

Der Einfachheit halber wurde ein `python`-Skript (`slurm_monitor.py`) geschrieben, was Simulationen auf den `btrzx1`-Cluster überwacht und gegebenenfalls startet/neustartet bis das Kriterium zur Vollendung erfüllt ist.

Weiterhin wurde doch mehrere radiale konvergierende Boxgrößen-Scans gezeigt, dass eine Mesoskalengröße von $\sim 57 - 76\,\rho$ inhärent zur ITG getriebenen Turbulenz mit Cyclone Base Parameter in lokalen Limit ist. Dieses Ergebnis impliziert auch, dass eine typische Skala für den lawinenenartig Transport inhärent für die ITG getriebene Turbulenz ist.

Declaration

The author declares that the materials presented in this thesis are his own work, unless explicitly stated otherwise. This thesis is based on

> Lippert, M., Rath, F. & Peeters, A. G. 2023 Size convergence of the E×B staircase pattern in flux tube simulations of ion temperature gradient-driven turbulence. *Phys. of Plasmas* **30** (7)

and is a further iteration of this publication (brief communication). It provides additional plots and paragraphs that were included in the publication. The brief communication can be found in Appendix **??**.

Additionally, the author states that every information, except data, regarding this thesis can be found under the GitHub Repository with the link `https://github.com/ManeLippert/Bachelorthesis-Shearingrate-Convergence`.

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CHAPTER

1

Motivation

Ion temperature gradient driven turbulence close to marginal stability exhibits zonal flow pattern formation on mesoscales, so-called $\mathrm{E}\times\mathrm{B}$ staircase structures[1]. Such pattern formation has been observed in local gradient-driven flux-tube simulations[7,9], including collisions[14] and background $\mathrm{E}\times\mathrm{B}$ shear[9], local flux-driven realizations including mean electric field shear[10], as well as global gradient-driven[6,12,11] and global flux-driven[1,2,13,3,4] studies. In global studies, spanning a larger fraction of the minor radius, multiple radial repetitions of staircase structures are usually observed, with a typical pattern size of several ten Larmor radii. By contrast, in the aforementioned local studies the radial size of $\mathrm{E}\times\mathrm{B}$ staircase structures is always found to converge to the radial box size of the flux tube domain. The above observations lead to the question:

Does the basic pattern size always converges to the box size, or is there a typical mesoscale size inherent to staircase structures also in a local flux-tube description?

The latter case would imply that it is not necessarily global physics, i.e., profile effects, that set

(i) the radial size of the $\mathrm{E}\times\mathrm{B}$ staircase pattern

(ii) the scale of avalanche-like transport events.

These transport events are usually restricted to $\mathrm{E}\times\mathrm{B}$ staircase structures and considered as a nonlocal transport mechanism[1].

In this bachlor thesis the above question is addressed through a box size convergence scan of the same cases close to the nonlinear threshold for turbulence generation as studied in Ref. 7.

CHAPTER

Plasma Physics, Zonal Flows and Gyrokinetic Theory

2

CHAPTER

3

Methods and Material

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4

Results and Discussion

The performed simulations for this chapter are documented in Appendix **??**.

CHAPTER

5

Conclusion

In this thesis the minimal resolution for simulations with GKW in the Cyclone Base parameter were observed in which the number of grid points for the parallel velocity $N_{\nu_\parallel}$ could be reduced from 64 to 48, which halfed the time until suppression of turbulence.

Additionally, the active development of a restart script in `python3` led to further convenience during the task of performing simulations on the `btrzx1` cluster.

Through careful tests this bachelor thesis confirms the radial size convergence of the $\mathrm{E} \times \mathrm{B}$ staircase pattern in local gyrokinetic flux tube simulations of ion temperature gradient (ITG)-driven turbulence. A mesoscale pattern size of $\sim 57 - 76\,\rho$ is found to be intrinsic to ITG-driven turbulence for Cyclone Base Case parameters. This length scale is somewhat larger compared to results from global studies with finite ρ_*, which report of a few $10\,\rho$[1], and has to be considered the proper mesoscale in the local limit $\rho_* \to 0$. The occurrence of this mesoscale implies that non-locality, in terms of Ref. 1, is inherent to ITG-driven turbulence, since avalanches are spatially organized by the $\mathrm{E} \times \mathrm{B}$ staircase pattern[6,1,8,7].

CHAPTER

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Appendix

CHAPTER 7

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Eidesstattliche Erklärung

Hiermit erkläre ich, Manuel Lippert, dass ich die vorliegende Arbeit selbständig und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Alle Stellen,

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Bayreuth, den 30.06.2023

Manuel Lippert