Strukturen in der Plasmaturbulenz

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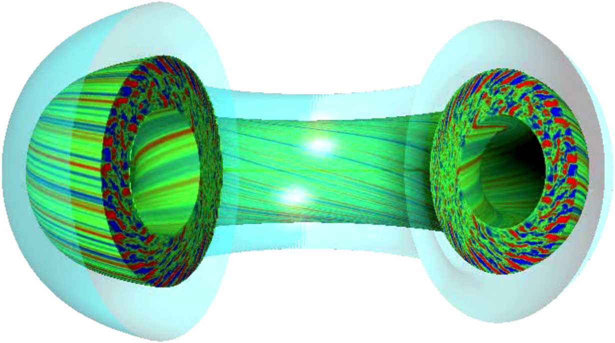
Vergleich zu 3D Numerik



Inhalt

- Gleichungen
- Tracerteilchen in zonal flows
- Turing-Instabilitäten

Die Grundgleichungen

$$\underbrace{\left(\frac{\partial}{\partial t} + D\right)(\delta - \nabla_\perp^2)\Phi} = -\frac{\partial \Phi}{\partial y} + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) + \nu(\nabla_\perp^6)\Phi - \{\Phi, \nabla_\perp^2 \Phi\} - \alpha \Phi^3$$

$$\left(\frac{\partial}{\partial t} + D\right) p = -(1+\eta)\frac{\partial \Phi}{\partial y} - \chi \nabla_\perp^4 p + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) - \{\Phi, p\} - \alpha p^3$$

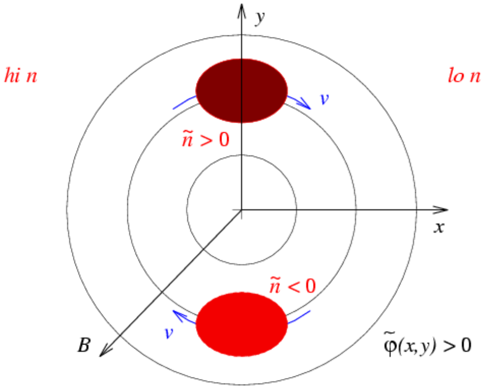
Für endliche Werte von k_y, $\delta(k_y) = 1$.
$\delta(0) = 0$: ITG,
$\delta(0) = 1$: ETG.

ExB-Drift

$$\left(\frac{\partial}{\partial t} + D\right)(\delta - \nabla_\perp^2)\Phi = \underbrace{-\frac{\partial \Phi}{\partial y}} + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) + \nu(\nabla_\perp^6)\Phi - \{\Phi, \nabla_\perp^2 \Phi\} - \alpha\Phi^3$$

$$\left(\frac{\partial}{\partial t} + D\right) p = -(1+\eta)\frac{\partial \Phi}{\partial y} - \chi\nabla_\perp^4 p + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) - \{\Phi, p\} - \alpha p^3$$

E x B Motion in a Background Gradient



--> excitation of $\tilde{n}$ ahead of $\tilde{\varphi}$ in v-direction

Kopplung der Felder

$$\left(\frac{\partial}{\partial t} + D\right)(\delta - \nabla_\perp^2)\Phi = -\frac{\partial \Phi}{\partial y} + \underbrace{\epsilon(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y})} + \nu(\nabla_\perp^6)\Phi - \{\Phi, \nabla_\perp^2 \Phi\} - \alpha\Phi$$

$$\left(\frac{\partial}{\partial t} + D\right) p = -(1+\eta)\frac{\partial \Phi}{\partial y} - \chi\nabla_\perp^4 p + \underbrace{\epsilon(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y})} - \{\Phi, p\} - \alpha p^3$$

Diffusion

$$\left(\frac{\partial}{\partial t} + D\right)(\delta - \nabla_\perp^2)\Phi = -\frac{\partial \Phi}{\partial y} + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) + \underbrace{\nu(\nabla_\perp^6)\Phi} - \{\Phi, \nabla_\perp^2 \Phi\} - \alpha\Phi^3$$

$$\left(\frac{\partial}{\partial t} + D\right) p = -(1+\eta)\frac{\partial \Phi}{\partial y} - \underbrace{\chi \nabla_\perp^4 p} + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) - \{\Phi, p\} - \alpha p^3$$

Kopplung

$$\left(\frac{\partial}{\partial t} + D\right)(\delta - \nabla_\perp^2)\Phi = -\frac{\partial \Phi}{\partial y} + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) + \nu(\nabla_\perp^6)\Phi - \{\Phi, \nabla_\perp^2 \Phi\} - \alpha \Phi^3$$

$$\left(\frac{\partial}{\partial t} + D\right) p = \underbrace{-(1+\eta)\frac{\partial \Phi}{\partial y}} - \chi \nabla_\perp^4 p + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) - \{\Phi, p\} - \alpha p^3$$

Nichtlinearitäten

$$\left(\frac{\partial}{\partial t} + D\right)(\delta - \nabla_\perp^2)\Phi = -\frac{\partial \Phi}{\partial y} + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) + \nu(\nabla_\perp^6)\Phi \underbrace{-\{\Phi, \nabla_\perp^2 \Phi\}} - \alpha\Phi^3$$

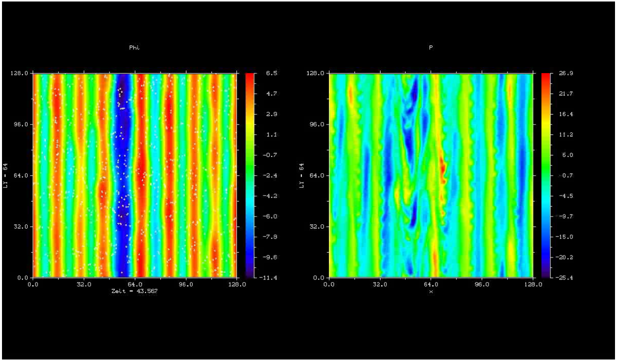
$$\left(\frac{\partial}{\partial t} + D\right) p = -(1+\eta)\frac{\partial \Phi}{\partial y} - \chi\nabla_\perp^4 p + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) \underbrace{-\{\Phi, p\}} - \alpha p^3$$

zusätzliche Dämpfung

$$\left(\frac{\partial}{\partial t} + D\right)(\delta - \nabla_\perp^2)\Phi = -\frac{\partial \Phi}{\partial y} + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) + \nu(\nabla_\perp^6)\Phi - \{\Phi, \nabla_\perp^2 \Phi\} \underbrace{-\alpha\Phi^3}$$

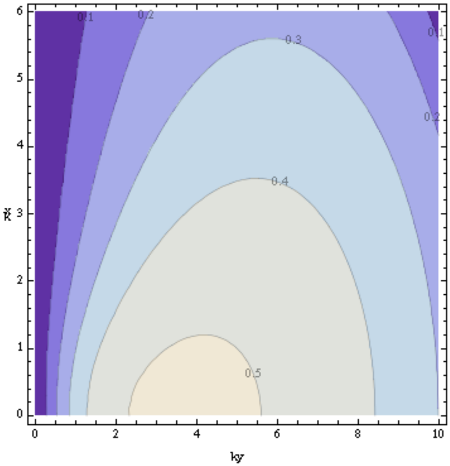
$$\left(\frac{\partial}{\partial t} + D\right) p = -(1+\eta)\frac{\partial \Phi}{\partial y} - \chi\nabla_\perp^4 p + \epsilon\left(\frac{\partial p}{\partial y} + \frac{\partial \Phi}{\partial y}\right) - \{\Phi, p\} \underbrace{-\alpha p^3}$$

ITG-Turbulenz ohne Korrekturterm, D=0

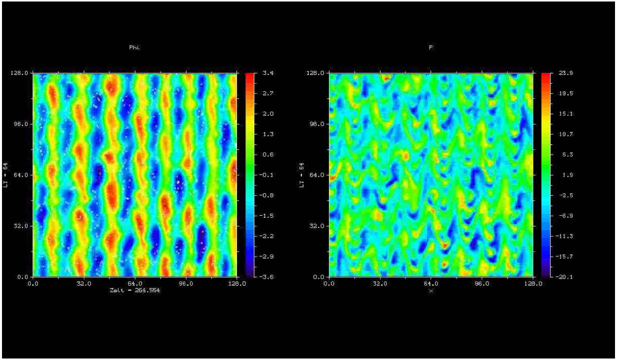


Berechnung der linearen Wachstumsraten:

$\phi = \phi_0 \cdot e^{-i(\omega t + k_x x + k_y y)}$, $p = p_0 \cdot e^{-i(\omega t + k_x x + k_y y)}$



Gedämpfte zonal flows, D=0,04



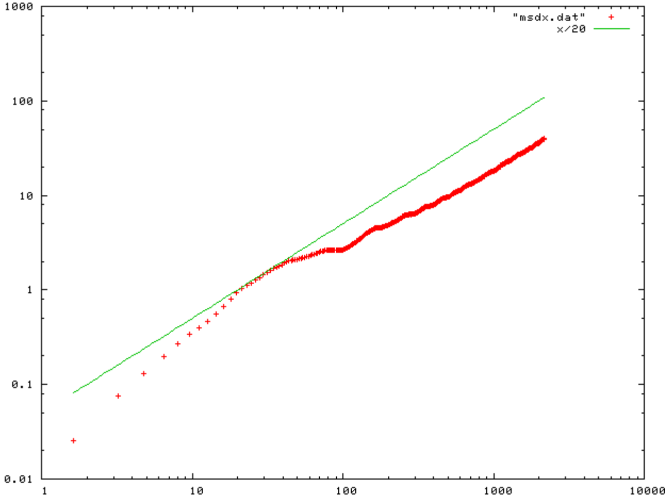
Energiebilanz

$$\frac{\partial E}{\partial t} = \underbrace{-(1+\eta)\int dA \frac{\partial \phi}{\partial y} p}_{=+(1+\eta)Q} - \nu \int dA (\nabla^3 \phi)^2 - \chi \int dA (\nabla_\perp^2 p)^2)$$

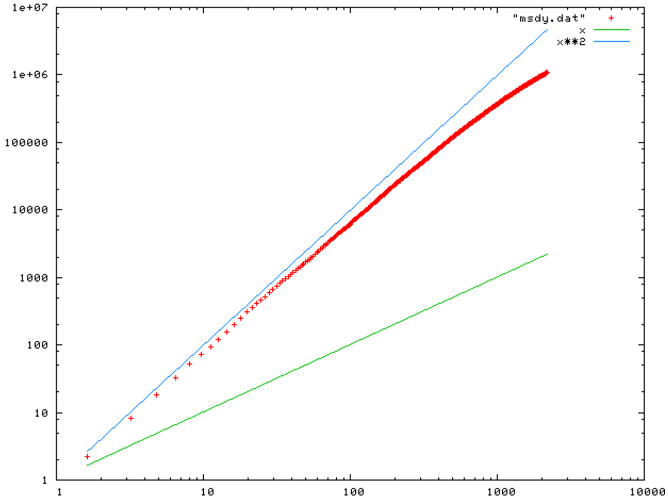
$$-D \int dA p^2 = 0$$

Transport in ITG-Turbulenz

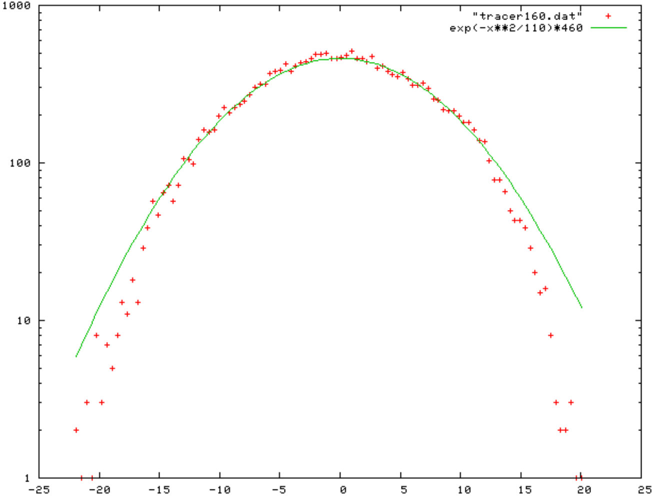
Mean square displacement in x-Richtung für schwache zonal flows.

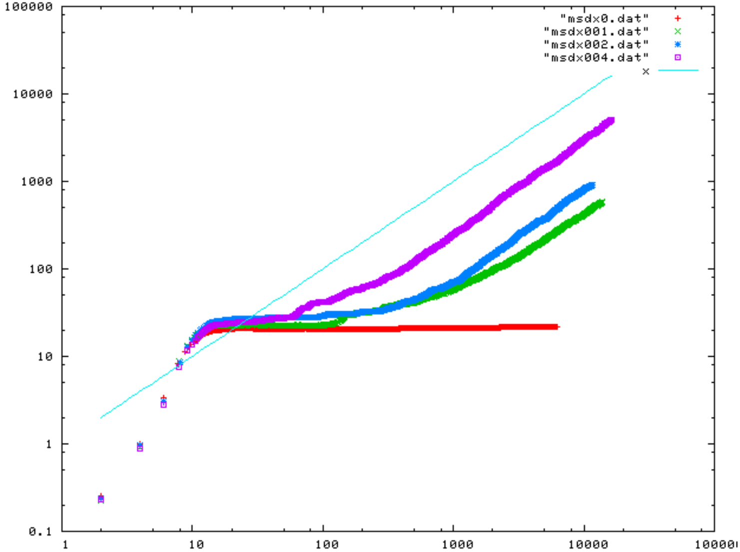


Mean square displacement in y-Richtung für schwache zonal flows.

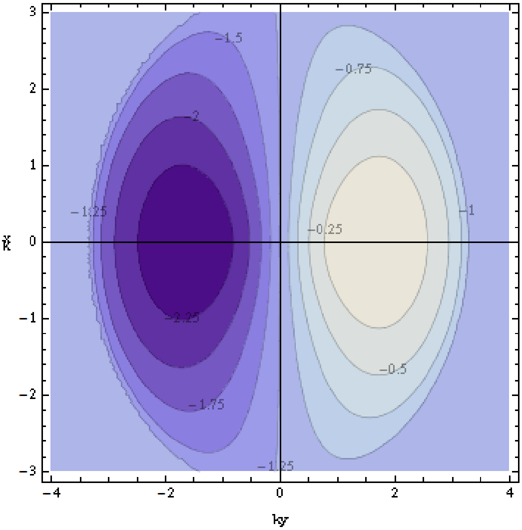


PDF in x-Richtung



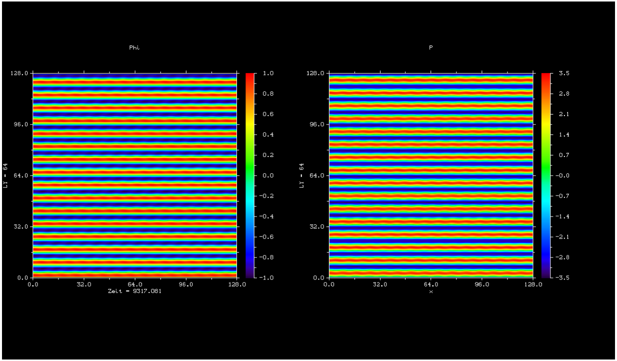

"msdx0.dat"
"msdx001.dat"
"msdx002.dat"
"msdx004.dat"
x
100000
10000
1000
100
10
1
0.1
1
10
100
1000
10000
100000

Turingartige Instabilitäten

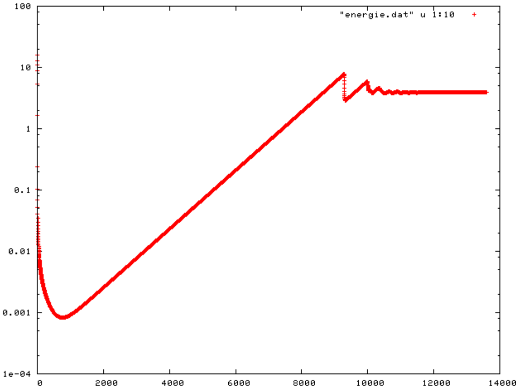


Schwelle: D=1,2322

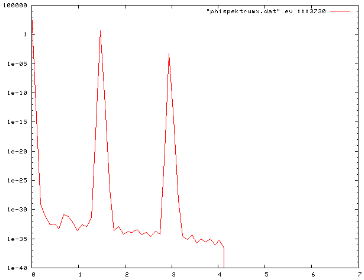
D=1,231


Phi
P
128.0
96.0
64.0
32.0
0.0
LY - 64
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
3.5
2.8
2.1
1.4
0.7
-0.0
-0.7
-1.4
-2.1
-2.8
-3.5
Zeit = 9317.081
x

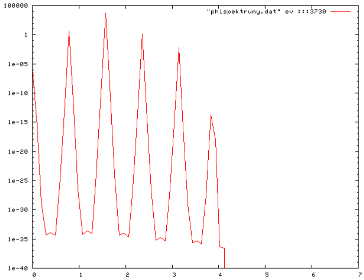
Zeitlicher Verlauf der Gesamtenergie im System bei D=1,2315



Spektren der Turing-Instabilitäten für D=1,231

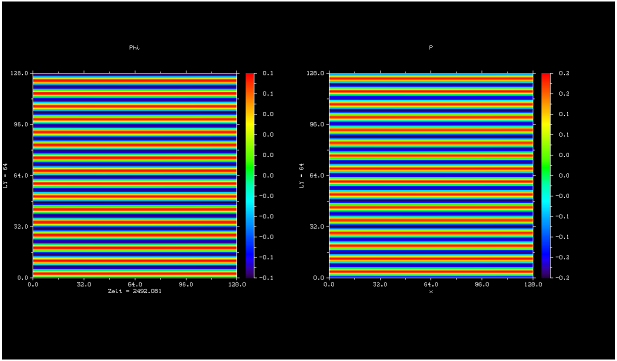


kx

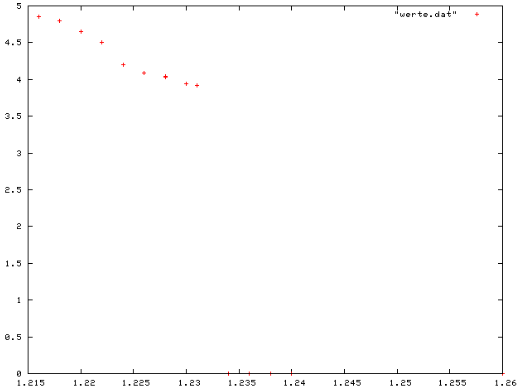


ky

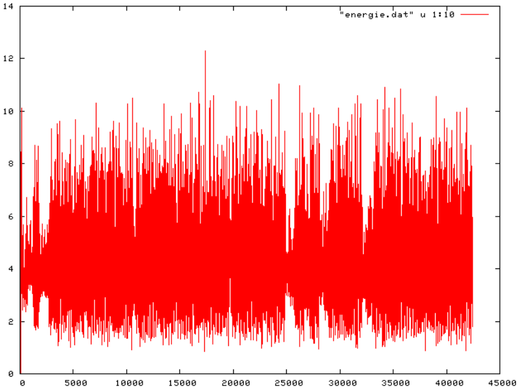
D=1,121


Phi
P
128.0
96.0
64.0
32.0
0.0
LY - 64
0.0
32.0
64.0
96.0
128.0
Zeit = 2492.081
x

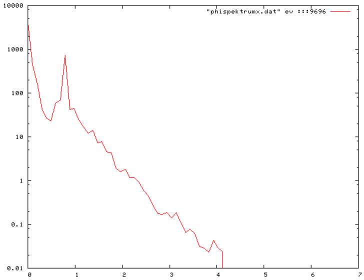
Sättigungsniveas für verschiedene Wachstumsraten



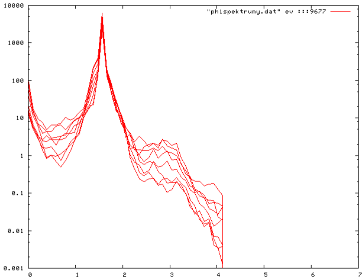
Starke Fluktuationen för größere Wachstumsraten



Spektren der Turing-Instabilitäten für D=1,19



kx



ky

Zusammenfassung

- Gleichungen zeigen wesentliche Phänomene
- Transporteigenschaften werden qualitativ reproduziert
- Weitere Untersuchungen der Turing-artigen Strukturen notwendig

Vielen Dank für die Aufmerksamkeit!