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# Resonance effects on turbulent particle pinches

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## Introduction

Anomalous inward particle transport can play an important role in the peaking of particle profiles and thus in the performance of toroidal fusion energy devices. Here we define turbulent particle pinches as negative effective anomalous particle diffusivities.

In this work we have investigated how the effective particle diffusivity is affected by using the density response from either a fluid or a kinetic description. This is done in a quasi-linear two-fluid system for electrostatic ion temperature gradient and trapped electron modes with analytical expressions for the ion and electron density response.

## Physical model

We have used the fluid density response from what is generally known as the Weiland model and the kinetic density response from a gyrokinetic equation [Nilsson *et al.*].

The fluid ion density response is given as

$$\frac{\delta n_i}{n_i} = \frac{e\phi}{T_e}\left(-\tau + \frac{\omega_{\star e} + \tau\omega + \tau\omega_{Di}\left(1+\frac{5}{3}\delta\right)\left(\frac{\omega_{\star i}}{\omega}\left(\frac{2}{3}-\eta_i\right)-\frac{2}{3}\right) + FLR + f_1(v_\parallel) + f_2(\nu)}{\omega - \frac{5}{3}\omega_{Di}\left(1+\frac{2}{3}\delta\right) + f_3(\nu)}\right) \tag{1}$$

where $FLR = -k^2\rho_s^2\left(\omega - \omega_{\star i}(1+\eta_i)\right)$ gives the finite larmor radius effects and where $\delta = \omega_{Di}/\left(\omega - \frac{5}{3}\omega_{Di}\right)$.

Notations we use are $\phi$ for the electrostatic potential, $f_t$ for the fraction of trapped electrons, $\tau$ for the electron to ion temperature ratio, $n$, $T$ and $R$ for density, temperature and large radius, and $m$, $v$ and $e$ for mass, velocity and elementary charge. Indexes $i$ and $e$ are used for ions and electrons. We also use $\omega = \omega_r + i\gamma$ for the complex eigenvalue and $\omega_\star$ and $\omega_D$ for the diamagnetic and magnetic drift frequencies.

We use dimensionless variables for the length scales, $\eta = L_n/L_T$ and $\varepsilon_n = 2L_n/R$ where $L_n$ and $L_T$ are the density and temperature length scales ($L_f = -f/(df/dr)$ where $r$ is the radial coordinate and $f = n, T$).

The kinetic ion density response is given as

$$\frac{\delta n_i}{n_i} = \frac{e\phi}{T_i}\left(-1+\int\frac{\omega-\omega_{\star i}\left(1+\eta_i\left(\frac{m_i v^2}{2T_i}-\frac{3}{2}\right)\right)}{\omega-\omega_{Di}\frac{v_\parallel^2+v_\perp^2/2}{v_{thermal}^2}+f_4(v_\parallel)+f_5(v)}J_0^2\left(\frac{k_{\perp v}}{\omega_{ci}}\right)f_{Mi}d^3v\right) \tag{2}$$

where $J_0$ is a Bessel function and $f_{Mi}$ is a Maxwellian distribution function. This can be rewritten and divided into principal and resonance parts as

$$\frac{\delta n_i}{n_i} = \frac{e\phi}{T_i}(-1+P+i\Delta) \tag{3}$$

where $P$ denotes the principal part and $\Delta$ the kinetic drift resonance part of equation (2).

When effects of collisions are included the terms $f(v)$ in equations (1) and (2) are non-zero imaginary function [Nilsson and Weiland]. Similarly parallel ion motion gives non-zero $f(v_\parallel)$ functions.

We have used the ion density responses from above and the corresponding electron density responses to form dispersion functions from the quasi-neutrality condition. The dispersion functions are solved giving the eigenvalues and eigenvectors of the two different descriptions. These have been used to calculate an effective particle diffusivity for the electrons, $D_e$, according to [Weiland]

$$D = \frac{-f_t\varepsilon_n\gamma^2}{\omega_{De}k_r^2}Im\left(\frac{\delta n_e}{n_e}\Big/\frac{e\phi}{T_e}\right). \tag{4}$$

**Results and discussion**

We have done parameter studies in various parameter regions, examining both experimental conditions and theoretically important limits. In Figure 1 results using the standard case parameters [Waltz *et al.*] are shown. The kinetic density response gives a reduced pinch, mainly due to the smaller ITG growth rate. Collisions reduce particle pinches for both models, which is in accordance with the general knowledge.

The difference between the two models is how many resonance terms that are included. The fluid density response only includes resonant terms up to the order where the fluid equations are closed while the kinetic density response goes to infinite order in terms of fluid equations. Ignoring the resonance part of the kinetic density response (i.e. when $\Delta = 0$) gives a reduced outward transport. In order to recover the same result with both models the resonance of the fluid density response needs to be ignorable at the same time.

The kinetic density response reduces the particle pinch as compared to the fluid density response. This is in accordance with previous studies where the particle pinch effects of gyro-fluid and fluid closure terms were compared [Eriksson *et al.*]. There it was found that dissipative ef-

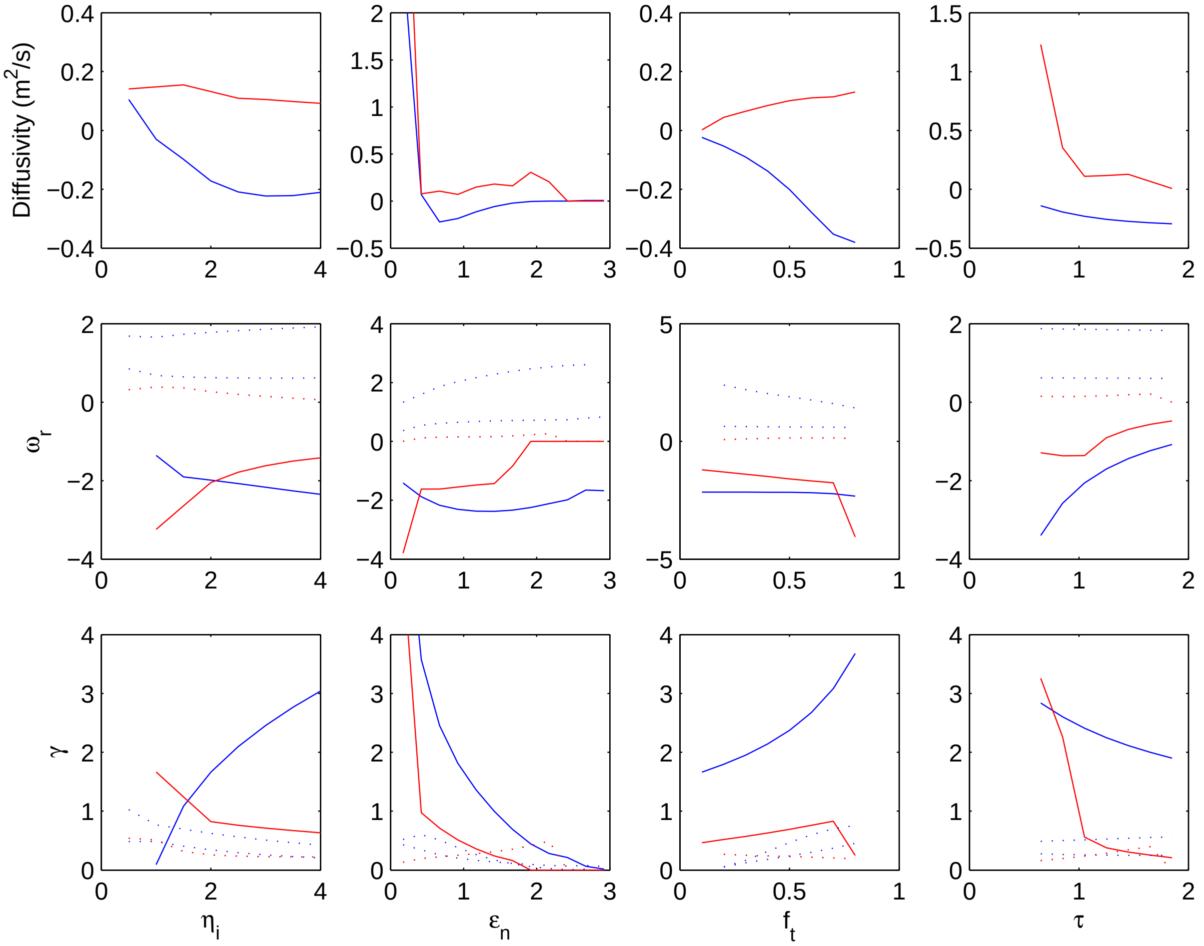


Figure 1: *Effective particle diffusivity for the fluid (blue) and the kinetic (red) model; the ITG (solid) and TE (dotted) eigenvalues are also shown. Density and temperature length scales ($\eta_i$ and $\varepsilon_n$) as well as trapped electron fraction ($f_t$) and temperature ratio ($\tau$) are varied around the standard case parameters ($\varepsilon_n = 0.7$, $\eta_i = \eta_e = 3$, $\tau = 1$, $f_t = 0.5$, magnetic shear=1, q=2, and no elongation).*

fects (such as gyro-fluid closure terms and kinetic resonances in the density response) reduce particle pinches compared to non-dissipative fluid models.

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