IMPURITY TRANSPORT IN ITG AND TE MODE DOMINATED TURBULENCE

A. Skyman[†], H. Nordman[†], P. Strand[†], F. Jenko[‡], F. Merz[‡]

[†] Euratom-VR Association, Department of Radio and Space Science, Chalmers University of Technology, SE-412 96 Göteborg, Sweden
[‡] Max-Planck-Institut für Plasmaphysik EURATOM-IPP, D-85748 Garching, Germany

Abstract

The transport properties of impurities is of high relevance for the performance and optimisation of magnetic fusion devices. For instance, impurities from plasma-facing surfaces accumulating in the core dilute the plasma and lead to unacceptable energy loss in the form of radiation.

In the present study, turbulent impurity transport in tokamak plasmas, driven by *Ion Temperature Gradient* (ITG) and *Trapped Electron* (TE) modes, is investigated using fluid and gyrokinetic models. *Quasilinear* (QL) results obtained from the GENE code [1, 2] are compared with fluid results [3] for ITG and TE mode dominated turbulence. Scalings of the *peaking factor* with impurity charge (Z) and various parameters are studied. Of particular interest are conditions favouring an outward convective impurity flux.

Introduction

The transport of a *trace impurity* can locally be described by a *diffusive* and a *convective* part, the former characterized by the diffusion coefficient D_Z, the latter by a convective velocity or "pinch" V_Z, see equation (1) [4]. The *zero flux peaking factor*, $PF_0 = \frac{-RV_Z}{D_Z}\big|_{\Gamma=0}$, is important for fusion plasmas as it quantifies the balance of convective and diffusive transport. This can be seen from equation (1), where Γ_Z is the flux, n_Z the density of the impurity and R the major radius of the tokamak [5]. For the domain studied ∇n_Z is constant: $-\nabla n_Z/n_Z = 1/L_{n_Z}$. Setting $\Gamma_Z = 0$ in equation (1), one can interpret PF_0 as the *gradient of zero flux*.

$$\Gamma_Z = -D_Z \nabla n_Z + n_Z V_Z \Leftrightarrow \frac{R\Gamma}{n_Z} = D_Z \frac{R}{L_{n_Z}} + RV_Z \qquad (1)$$

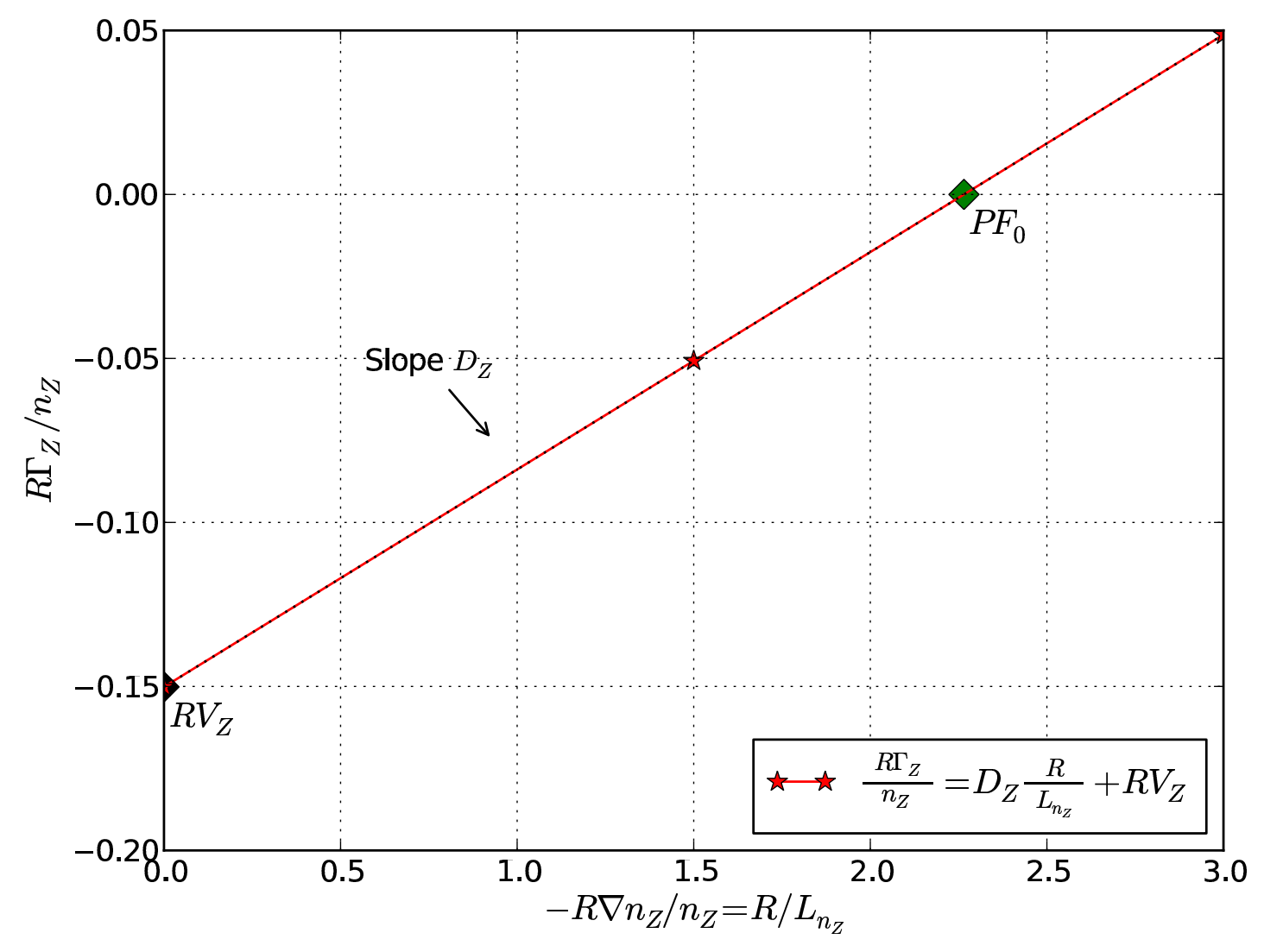

FIGURE 1: Illustration of PF_0 and the linearity of $\Gamma_Z(\nabla n_Z)$ for trace impurities; ITG dominated QL GENE result for Ne with $k\rho = 0.3$

Fluid model: The equations of the Weiland multi-fluid model [3] are:

$$\frac{\partial n_j}{\partial t} + \nabla \cdot \left(n_j \boldsymbol{v}_j\right) = 0, \qquad (2)$$

$$m_{i,Z} n_{i,Z} \frac{\partial v_{||i,Z}}{\partial t} + \nabla_{||}\left(n_{i,Z} T_{i,Z}\right) + n_{i,Z} e \nabla_{||}\varphi = 0, \qquad (3)$$

$$\frac{3}{2} n_j \frac{\mathrm{d}T_j}{\mathrm{d}t} + n_j T_j \nabla \cdot \boldsymbol{v}_j + \nabla \cdot \boldsymbol{q}_j = 0, \qquad (4)$$

for each included species ($j = i, te, Z$ – Deuterium ions, trapped electrons, and trace impurities). From these, and going to the trace impurity limit, i.e. letting $Zf_Z \to 0$ the quasineutrality condition (5), an eigenvalue equation for the ITG and TE modes is obtained. The impurity transport equation (1) can be derived from $\Gamma_{nj} = \langle \delta n_j \boldsymbol{v}_{\boldsymbol{E}\times\boldsymbol{B}} \rangle$, where the averaging is over over all unstable modes for a fixed length scale $k\rho$ of the turbulence [5].

$$\frac{\delta n_e}{n_e} = (1 - Zf_Z)\frac{\delta n_i}{n_i} + Zf_Z \frac{\delta n_Z}{n_Z}, \quad f_Z = \frac{n_Z}{n_e} \qquad (5)$$

Parameters used in quasilinear simulations:

	ITG:	TEM:
T_D/T_e:	1.0	1.0
$\hat{s}$:	0.8	0.8
q_0:	1.4	1.4
ε:	0.14	0.14
$R/L_{T_D}, R/L_{T_Z}$:	7.0	3.0
R/L_{T_e}:	3.0	7.0
$N_x \times N_{ky} \times N_z$	$5 \times 1 \times 24$	$4 \times 1 \times 24$
$N_{v_{\|\|}} \times N_\mu$	64×12	64×12

Scaling with impurity charge Z

The difference between the ITG and TE mode dominated cases shown in figure 2 can be understood from the properties of the convective velocity V_Z in (1). This contains a thermodiffusive term $V_{T_Z} \sim \frac{1}{Z}\frac{R}{L_{T_Z}}$ and a parallel impurity compression term $V_{pZ} \sim \frac{Z}{A_Z}k_{||}^2 \sim \frac{Z}{A_Z q^2}$. The former is generally outward ($V_{T_Z} > 0$) for ITG and inward ($V_{T_Z} < 0$) for TE mode dominated transport, whereas for the latter the opposite is generally the case [5], which yields the high and low Z behaviours observed in the simulations.

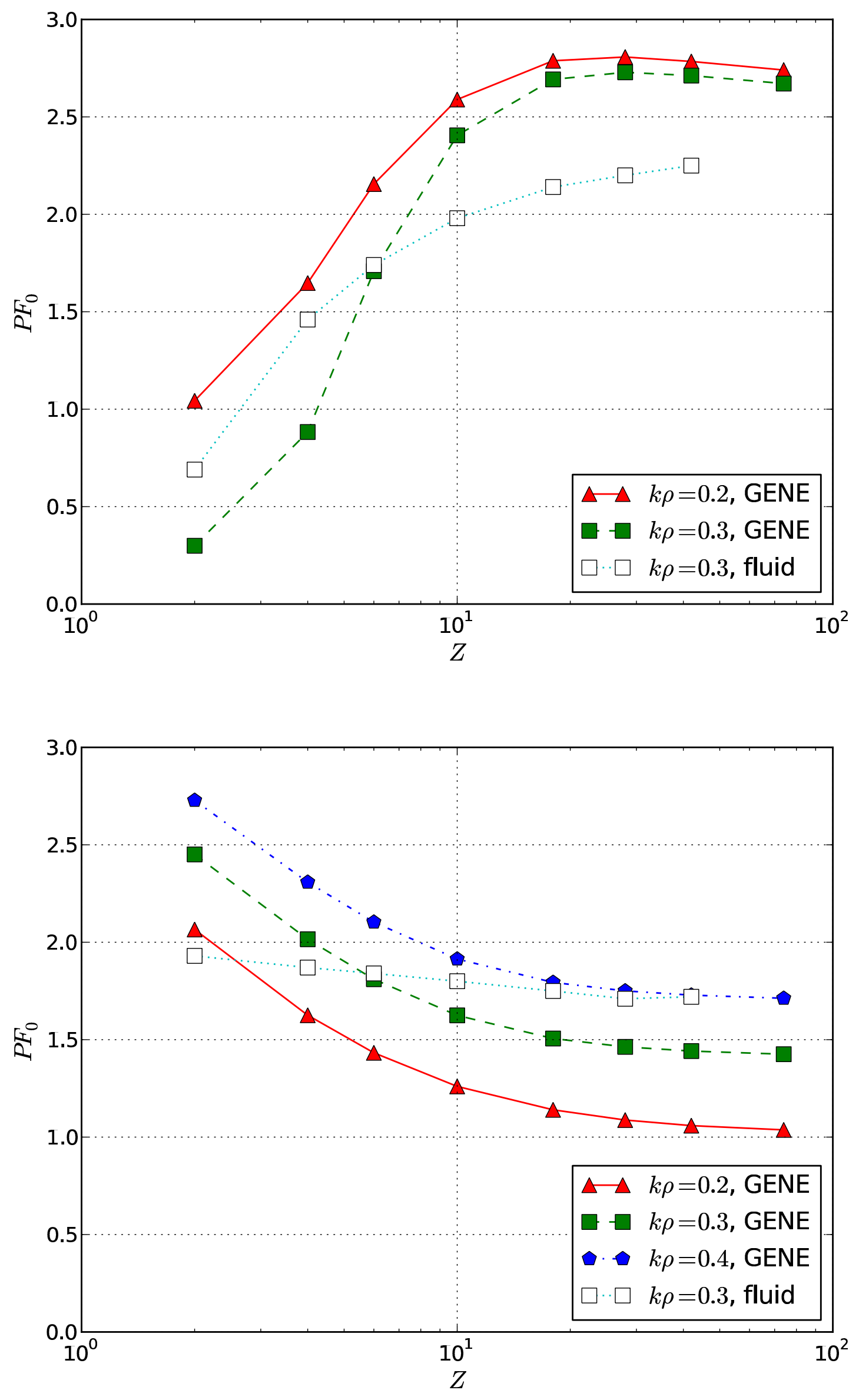

FIGURE 2: Scaling of PF_0 with impurity charge Z for ITG and TE mode cases; comparison of QL GENE and fluid results

Other scalings

Effects of varying the wave number $k\rho$: A weak scaling with the wave number is observed for relevant lengthscales ($k\rho \sim 0.3$).

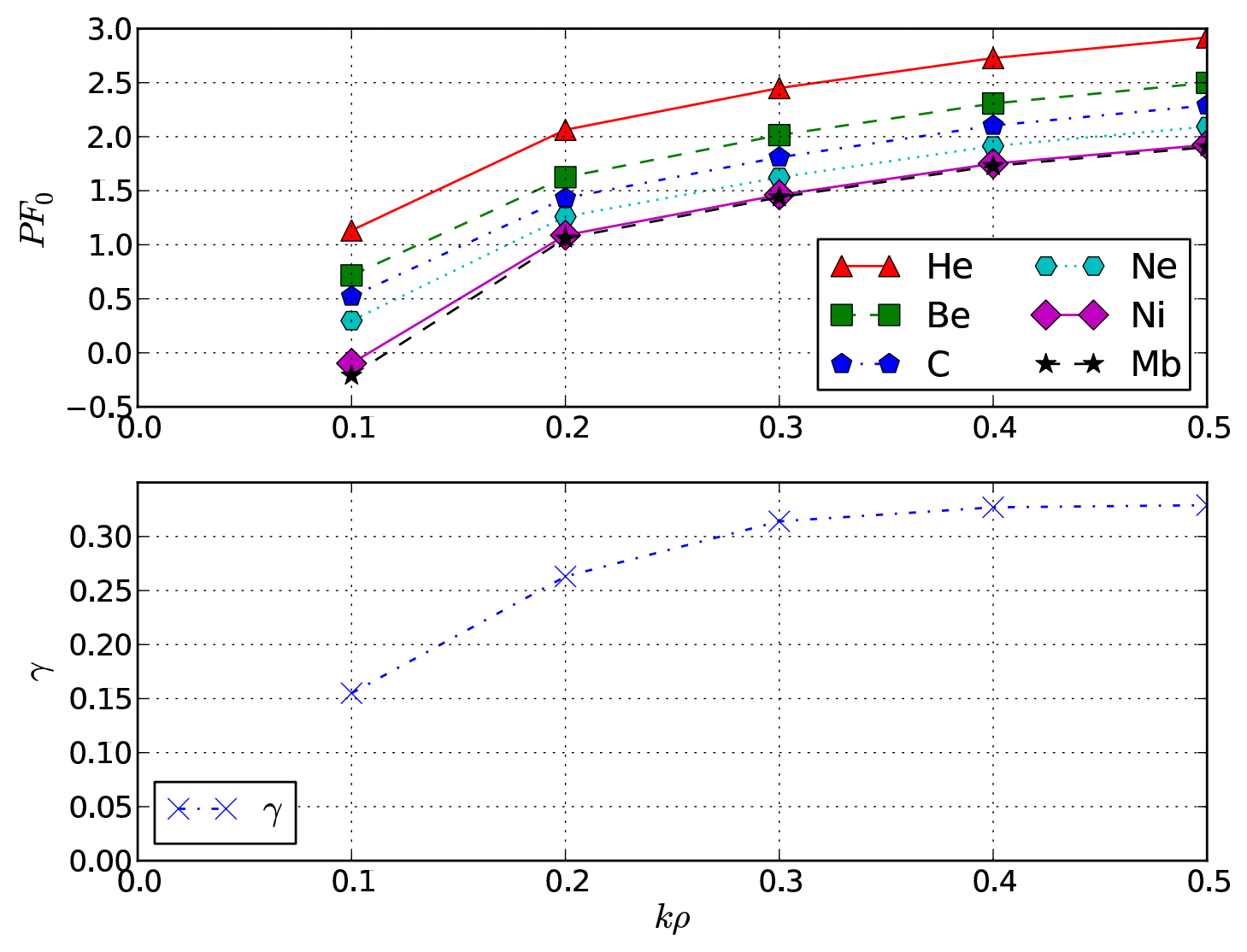

FIGURE 3: Scaling of PF_0 and linear growthrate γ with $k\rho$ for TEM dominated case; QL GENE results

Effects of magnetic shear $\hat{s}$: The effect of magnetic shear on the peaking factor is shown in figure 4. It is worth noting that a flux reversal, i.e. a change of sign in V_Z, occurs for negative $\hat{s}$ for $Z \gtrsim 6$ in the TE mode dominated case, indicating a net outward transport of the heavier elements. Similar trends are not seen in fluid simulations, and this warrants further investigation.

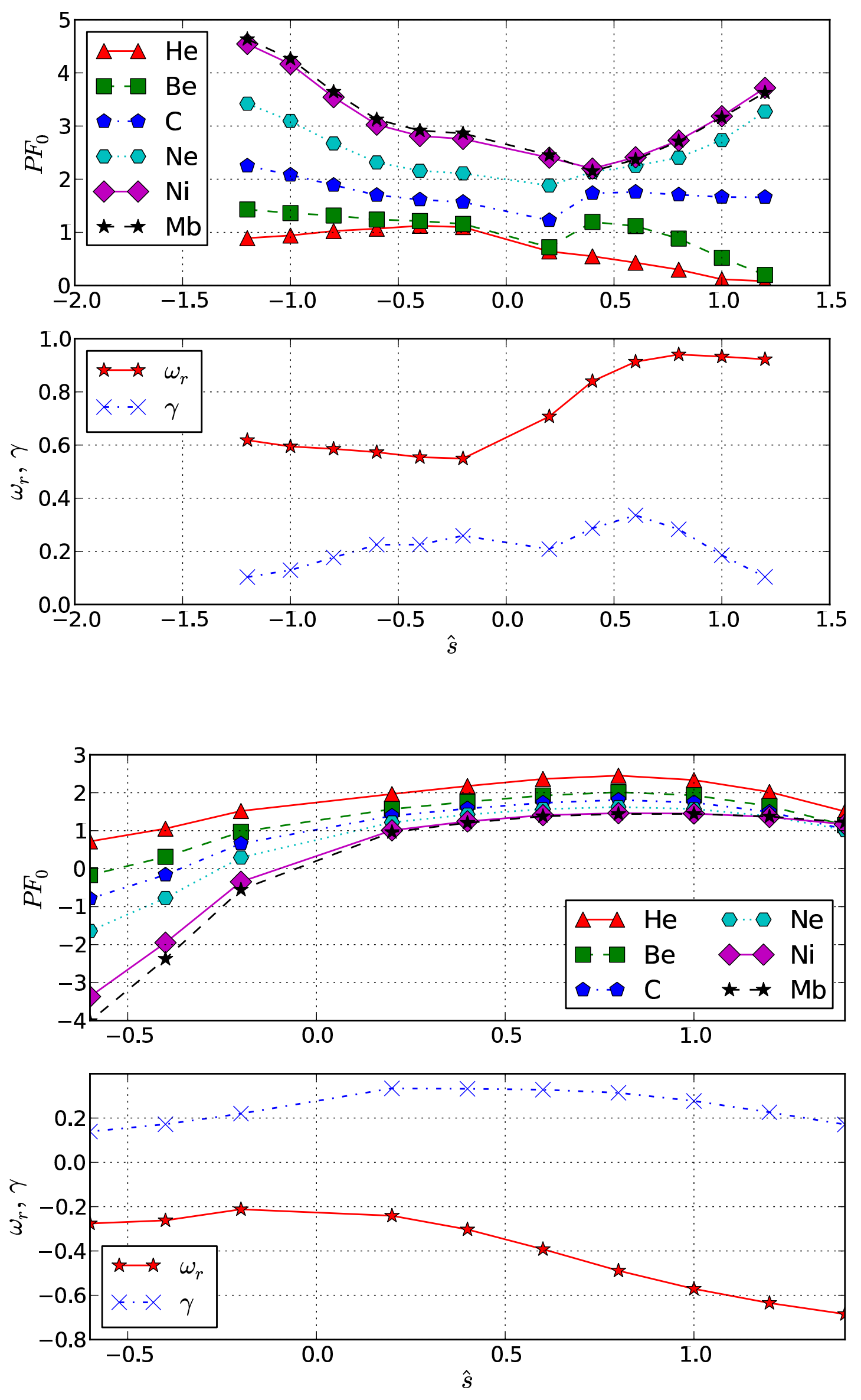

FIGURE 4: Scaling of PF_0, along with linear growthrate γ and real frequency ω_r, with $\hat{s}$ for ITG and TE mode case for $k\rho = 0.3$; QL GENE results

Conclusions and future prospects

- PF_0 increases with the impurity charge Z for ITG mode dominated transport
- For TE mode dominated transport, the opposite holds
- In both cases PF_0 saturates for high Z
- The Z-scaling obtained with QL GENE agrees well with fluid results
- A *flux reversal* is observed for negative $\hat{s}$ in the TEM dominated case, this is not seen in fluid simulations
- For other parameter scalings of PF_0 investigated, weak scalings are observed, in agreement with previous work [4, 6]
- Future work will include *non linear* simulations and more investigations of scenarios favouring *flux reversal*

References

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this poster kills fascists!

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