Verification of Gyrokinetic Particle Simulation of Device Size Scaling of Turbulent Transport*

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Abstract Verification and historical perspective are presented on the gyrokinetic particle simulations that discovered the device size scaling of turbulent transport and indentified the geometry model as the source of the long-standing disagreement between gyrokinetic particle and continuum simulations.

Keywords: turbulence, transport, tokamak, simulation

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1 Introduction

The subject of device size scaling of turbulent transport in fusion plasmas is an important area of research because of the need to provide physics foundations for the predictive extrapolations of plasma confinement properties from present-day tokamak experiments to larger magnetic fusion devices such as ITER. The issue has therefore been a subject for intense experimental, theoretical, and computational studies and continuing debates in fusion research [1]. A recent study [2] claims to resolve a "long-standing quantitative disagreement" between gyrokinetic particle and continuum simulations [3∼9] by showing that the disagreement is due to an unrealistic geometry model in continuum codes [5∼8]. The purpose of this brief communication is to provide the verification and an accurate historical perspective on the resolution of this critical issue with proper credit assigned by highlighting the key findings from earlier particle simulations that actually discovered [3] the size scaling and also indentified [9] the geometry model as the source of the disagreement.

In a major breakthrough [3], global gyrokinetic particle simulations using the GTC code [10] discovered that ion heat conductivity caused by ion temperature gradient (ITG) turbulence exhibits a gradual transition of device size scaling from the so-called "Bohm" to "gyroBohm" regimes. However, GTC results (Fig. 1, red) were immediately challenged [4] as "qualitatively and quantitatively" incorrect by simulation results from the gyrokinetic continuum GYRO code [5], which observed only gyroBohm scaling. Then a revision of GYRO results (Fig. 1, purple) soon confirmed [6] the gradual transition of size scaling. However, the GTC results for large device size were still criticized to be "quantitatively" incorrect as being much higher than those from GYRO [6] (Fig. 1, purple) as well as from flux-tube simulations (Fig. 1, solid black) using GS2 code [6], GENE code [7], and "Cyclone" benchmark studies [8].

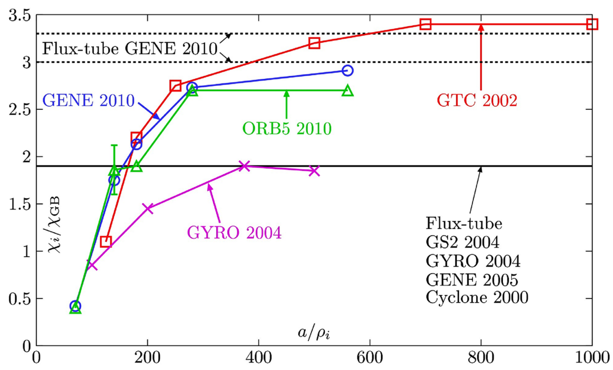

Fig.1 Dependence of ion heat conductivity χ_i on tokamak minor radius a. Simulation data are taken from Ref. [2] (ORB5 2010, GENE 2010, Flux-tube GENE 2010), Ref. [3] (GTC 2002), Ref. [6] (GYRO 2004, Flux-tube GS2 2004 and GYRO 2004), Ref. [7] (Flux-tube GENE 2005), and Ref. [8] (Cyclone 2000) (color online)

Subsequently, further GTC simulations clearly demonstrated [9] that the ITG growth rate and associated transport decrease significantly when the realistic toroidal geometry [3,10] implemented in GTC is artificially modified to mimic the unrealistic "s-α" geometric model [6∼8] implemented in continuum codes. It was accordingly suggested [9] that the difference between the particle and continuum simulation results is caused primarily by the unrealistic "s-α" model. However,

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GYRO [6], GS2 [6], and GENE [7] ignored the findings in this published article [9] and continued to reject the GTC results as being "quantitatively" incorrect. This controversy has caused wide-spread confusion in the fusion community.

Finally, recent systematic gyrokinetic simulation studies that implement the realistic toroidal geometry used in Ref. [3] in both the global particle ORB5 code [2] and the continuum GENE code [2] have not only confirmed (Fig. 1, green, blue, and dotted black) "qualitatively and quantitatively" the correctness of the earlier GTC results with respect to the gradual transition of size scaling [3], but have also verified the earlier suggestion [9] that the unrealistic "s-α" model is responsible for the quantitative differences between the particle and continuum simulations. By taking into account the proper historical perspective described here, it can be concluded that this long-standing controversy on the device size scaling of turbulent transport has indeed been resolved by first-principles simulation studies [2,3,9].

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