Impact of poloidal convective cells on transport processes with kinetic electrons

P2-18

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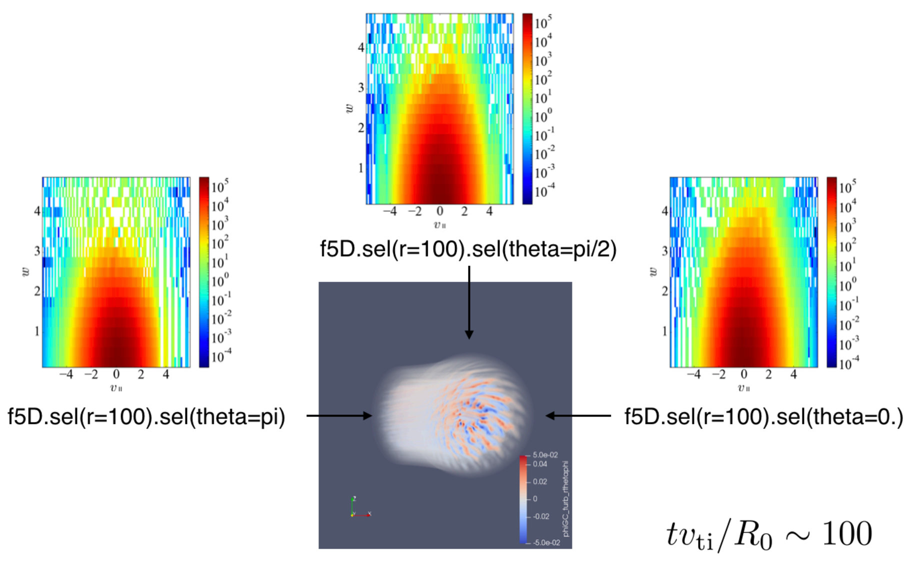
Recently, a lot of attentions have been paid to the role of poloidal asymmetries of electrostatic potential (convective cells) in magnetic confined plasmas. Since this kind of structures can be driven by plasma turbulence and they are instrumental in neoclassical transport, consistent modeling of turbulence and neoclassical transport by full-F gyrokinetic code is essential to study this effect. Unfortunately, the conventional electron model used in full-F code filters out the convective cells, we could not have studied their impact on transport. In the present work, we use the newly proposed electron model which can handle the convective cells and compare the results using the previous model. It turned out that the damping rate and frequency of Geodesic acoustic mode are modified due to the filter. In the flux-driven turbulence simulation, it turned out that the convective cells enhance the neoclassical transport but do not have large impacts on profile formation.

Background: 5D full-F gyrokinetic simulation

Problem size: $\sim 10^{10}$ **High simulation cost**

3D Space: (r, θ, ϕ) **2D velocity space:** $(v_\parallel, \mu)$



$tv_{\rm ti}/R_0 \sim 100$

- **First principle full-f 5D gyrokinetic model is employed for plasma turbulence simulation [1,2]**
  Resolving machine scale (~ m) with turbulence mesh (~ cm)
- **Solving profile and fluctuation without scale separation (full-F approach)**
  Modeling neoclassical and turbulence transport consistently
- **Simplified model employed (e.g. adiabatic electron model) compared to local flux tube code due to larger simulation costs**
  Introducing kinetic electrons for modeling Trapped Electron Mode (TEM)

[1] Y. Idomura et al., Comput. Phys. Commun (2008)
[2] V. Grandgirard et al, Comput. Phys. Commun (2016)

Hybrid electron models in full-F gyrokinetic simulation codes

Idomura JCP 2016 [3]

Turbulent component:

$$-\nabla_\perp \cdot \frac{\rho_{\rm ti}^2}{\lambda_{\rm De}^2}\nabla_\perp \phi_{n\neq 0} + \frac{\alpha_p}{\lambda_{\rm De}^2}\phi_{n\neq 0} = 4\pi e\left[n_i - n_{e,t}\right]_{n\neq 0}$$

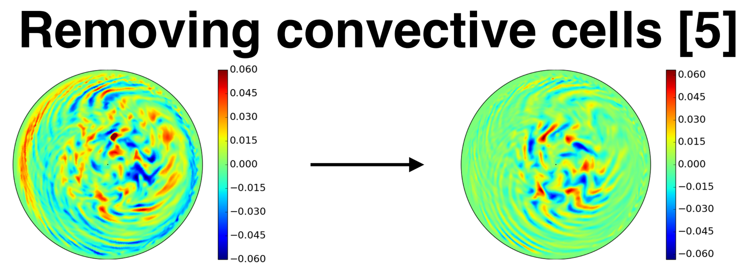
n=0 component:

$$-\nabla_\perp \cdot \frac{\rho_{ti}^2}{\lambda_{De}^2}\nabla_\perp \phi_{n=0} = 4\pi e[n_i - n_{e,t} - n_{e,p}]_{n=0}$$

+

$$\phi_{n=0, m\neq 0} \to 0$$

Removing convective cells [5]



Lanti CPC 2019 [4]

Turbulent component:

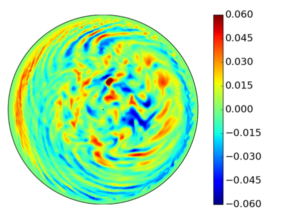
$$-\nabla_\perp \cdot \frac{\rho_{\rm ti}^2}{\lambda_{\rm De}^2}\nabla_\perp \phi_{n\neq 0} + \frac{\alpha_p}{\lambda_{\rm De}^2}\phi_{n\neq 0} = 4\pi e\left[n_i - n_{e,t}\right]_{n\neq 0}$$

n=0 component:

$$-\nabla_\perp \cdot \frac{\rho_{ti}^2}{\lambda_{De}^2}\nabla_\perp \phi_{n=0} = 4\pi e[n_i - n_{e,t} - \langle n_{e,p}\rangle - n_{e,p}\frac{e\tilde{\phi}_{n=0}}{T_e}]_{n=0}$$

No numerical filter on ϕ

Keeping convective cells



- **The hybrid electron models for nonlinear simulations must satisfy the following properties**

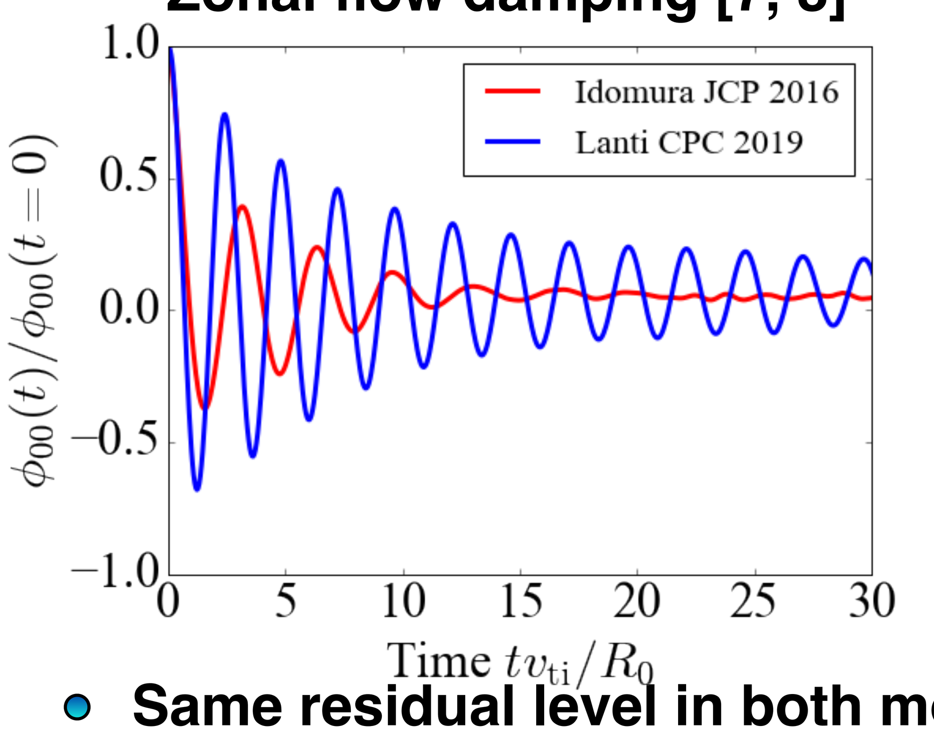
	Idomura JCP 2016	Lanti CPC 2019
GAM damping	Frequency, damping rate modified	Frequency and damping rate agreed with SW theory
Zonal flow residual	Agreed with RH theory	Agreed with RH theory
Ambipolar condition	Ambipolar condiiton satisfied	Ambipolar condiiton satisfied
Convective cells	**Filtered out**	**Present**

- **Both model suppresses passing electrons to avoid numerical instability which stems from the lack of electromagnetic effects in full-F codes**
- **Dynamics of convective cells may matter main species [5], Impurities [6]**

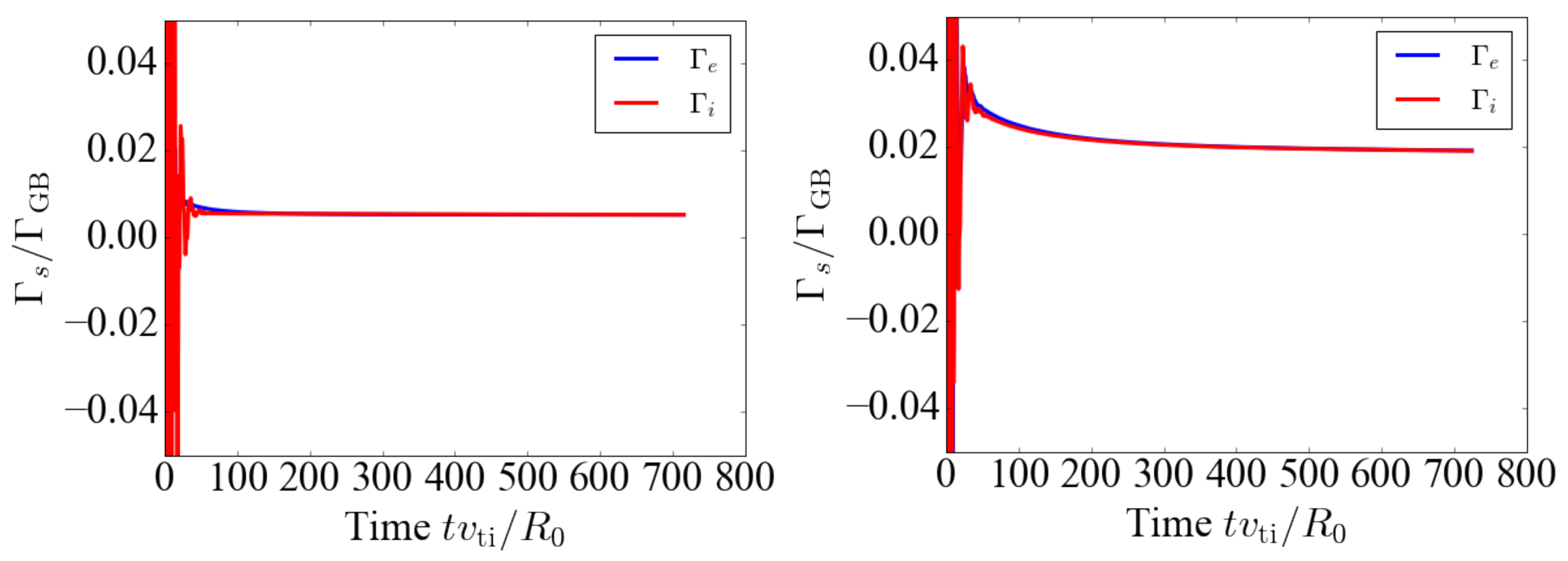
[3] Y. Idomura et al., J. Comput. Phys. (2016)
[4] E. Lanti et al, Comput. Phys. Commun (2019)
[5] Y. Asahi et al, Plasma Phys. Control. Fusion (2019)
[6] P. Donnel et al, Plasma Phys. Control. Fusion (2019)

Model verification: Zonal flow damping and Ambipolar condition

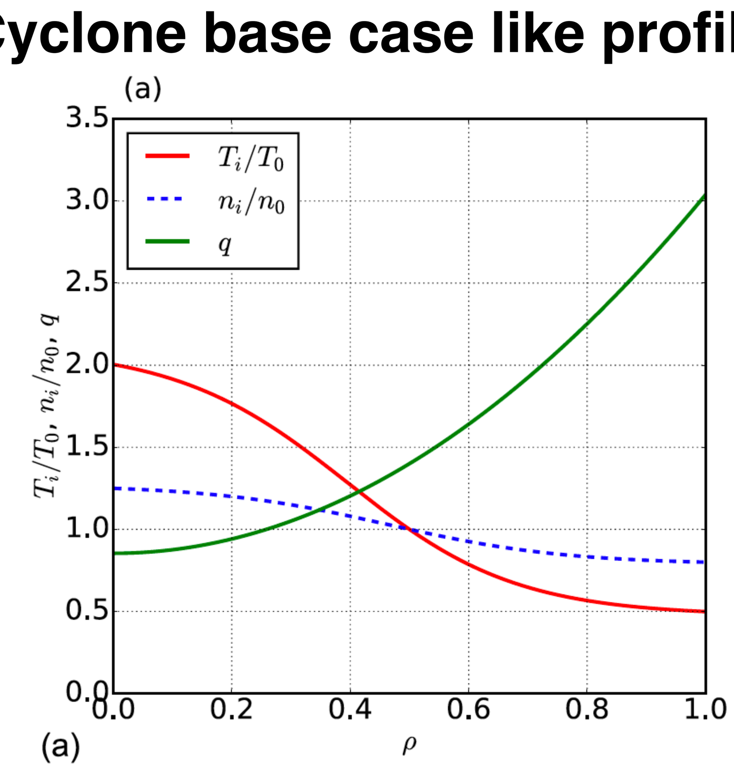
Zonal flow damping [7, 8]



Ambipolar condition in neoclassical limit



Cyclone base case like profile

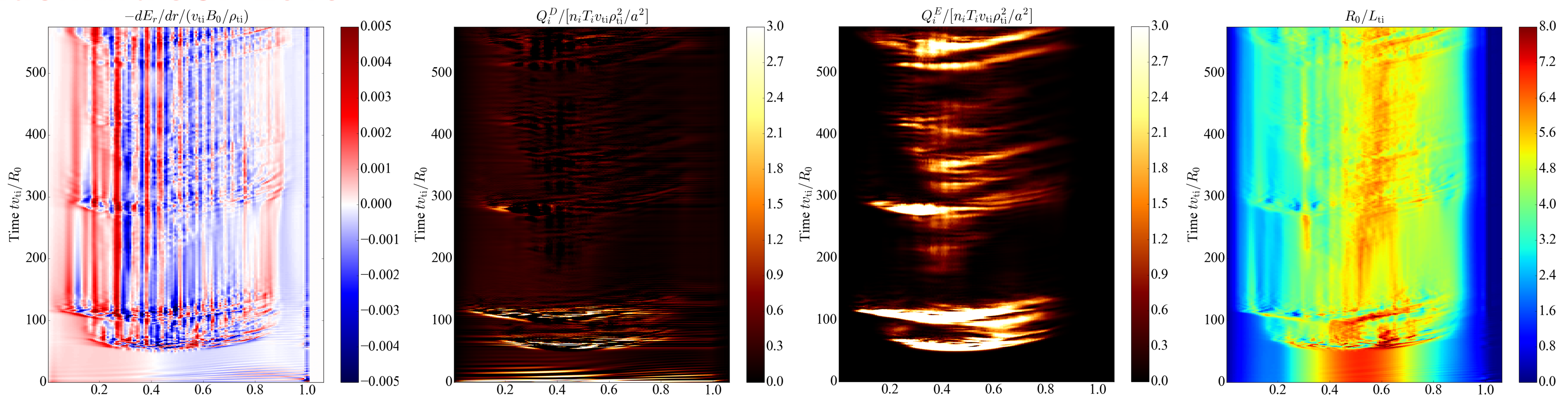


- **Same residual level in both model**
- **Lower damping rate and higher frequency in Lanti's model**
- **Ambipolar condition satisfied in both models**
- **Difference in the amplitude can be explained by convective cells**
  Particle transport by magnetic drift can be enhanced by convective cells [5,6]

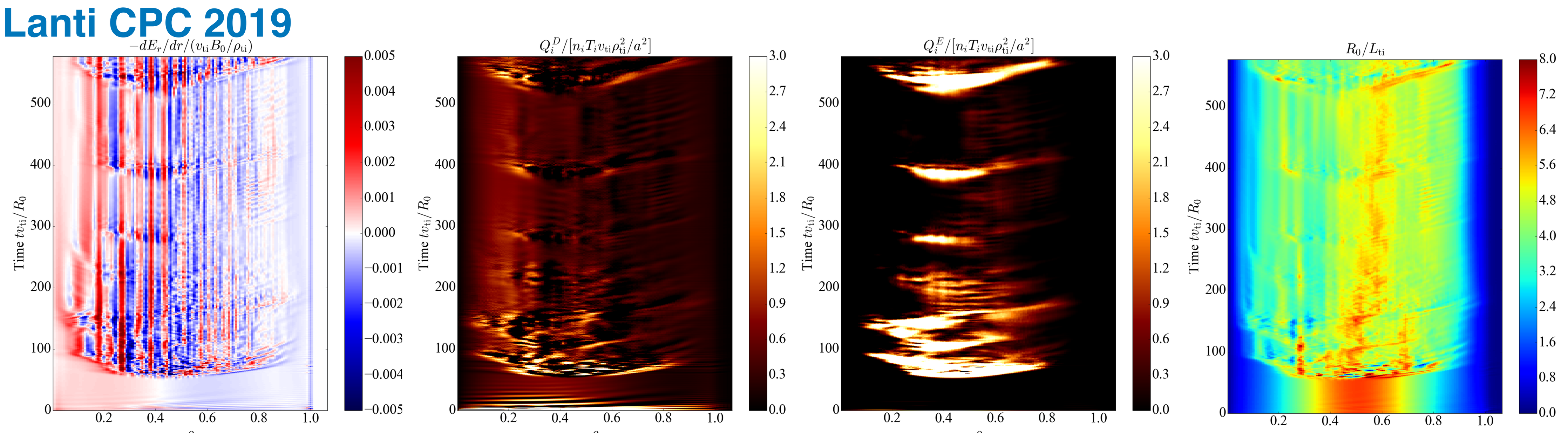
[7] H. Sugama et al., J. Plasma Phys. (2006)
[8] M. N. Rosenbluth, et al., Phys. Rev. Lett. (1998)

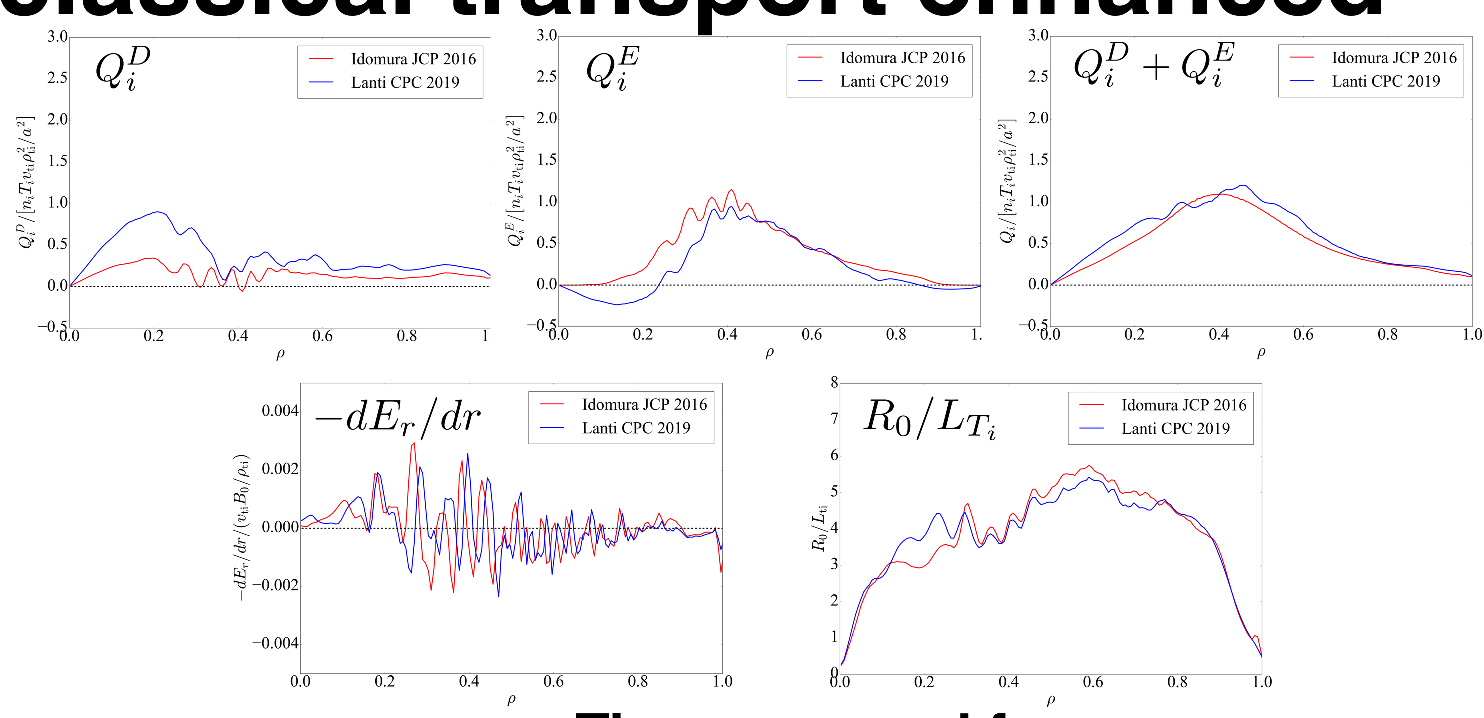
Impact of convective cells on transport: neoclassical transport enhanced

Idomura JCP 2016



Lanti CPC 2019





Time averaged for $tv_{\rm ti}/R_0 = 200 \sim 550$

Input power 2MW, $\nu_* \sim 0.01$

- **ExB flow shear, ion temperature gradient and total energy flux is almost the same**
  Convective cells have few impacts on turbulence transport
- **The enhanced energy transport by magnetic drift**
  Convective cells reduce the energy transport by ExB flow

Conclusions

- Verifications of hybrid electron models for **zonal flow damping and ambipolar condition**
- Convective cells **enhance the energy transport by magnetic drift**