Convergence Studies of ITG using GTC

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Workshop on Long Time Simulations of Kinetic Plasmas

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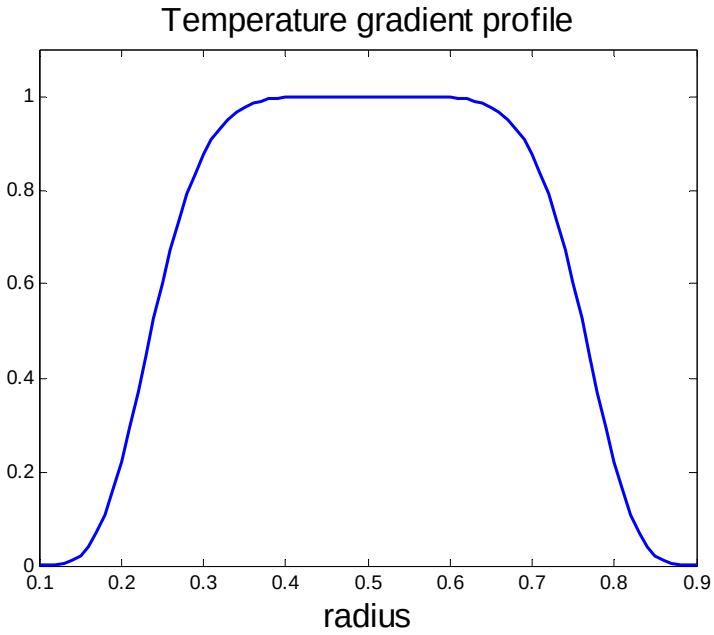
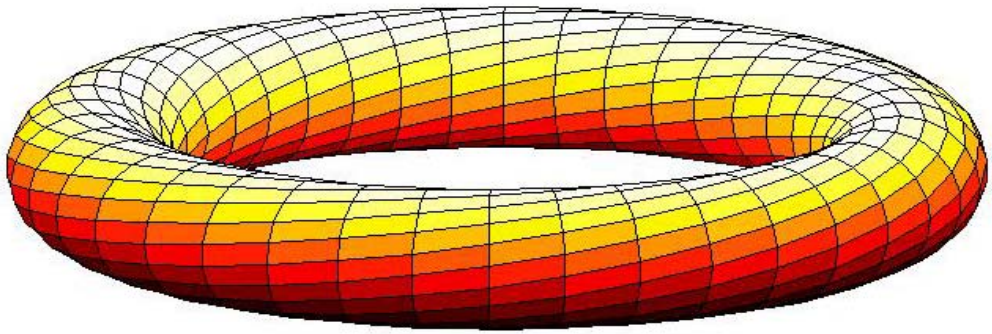
The Cyclone base case

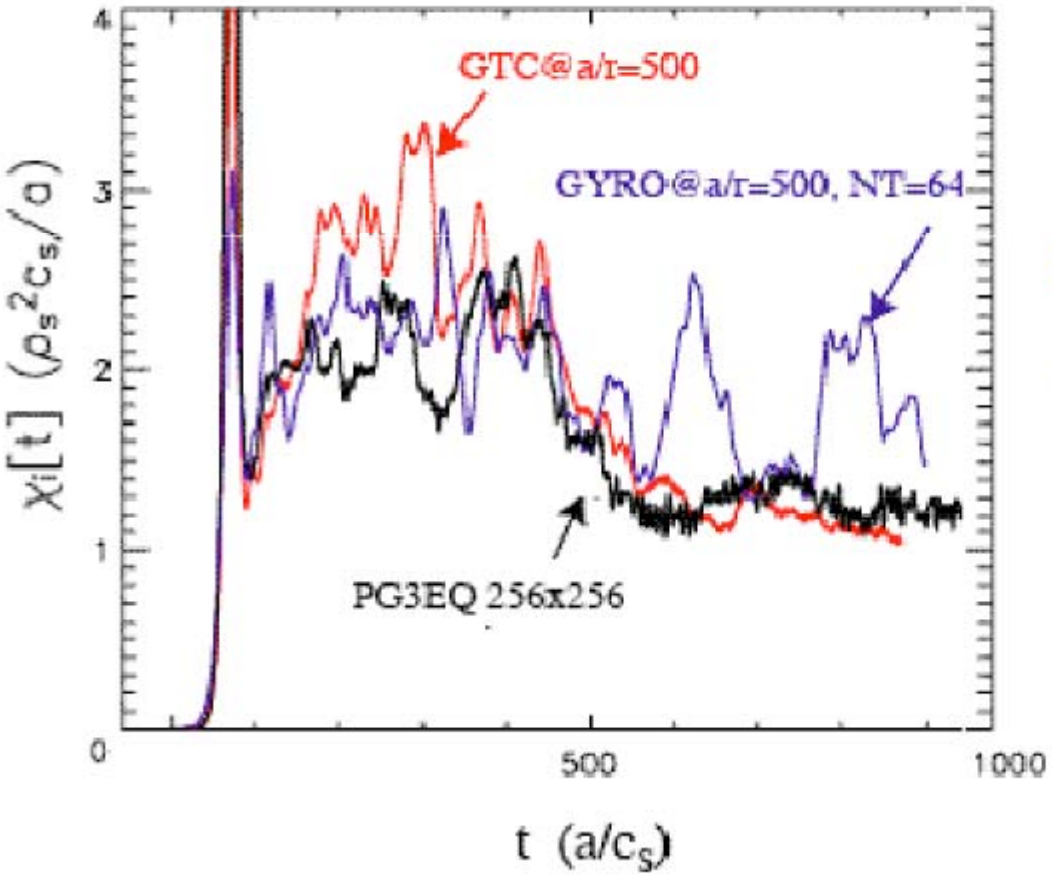
- Multi-code study of ion temperature gradient (ITG) turbulence in model tokamak (circular cross-section, large aspect ratio s-alpha model equilibrium) Dimits'2000.
- Local parameters (at r/a = 0.5) based on real experiment in the DIII-D tokamak.
- GTC is a global code so we use the gradient profile below.
- Extensively used and studied but questions still remain to this date.





"Long time" comparisons of ITG turbulence GTC/GYRO/PG3EQ (Nevins '04)

- Although the 3 codes seem to agree very well, in my opinion, there were still questions about the late time behavior.



Code Comparisons:

GTC - Particle Code

GYRO - Continuum Code

PG3EQ - Particle Code

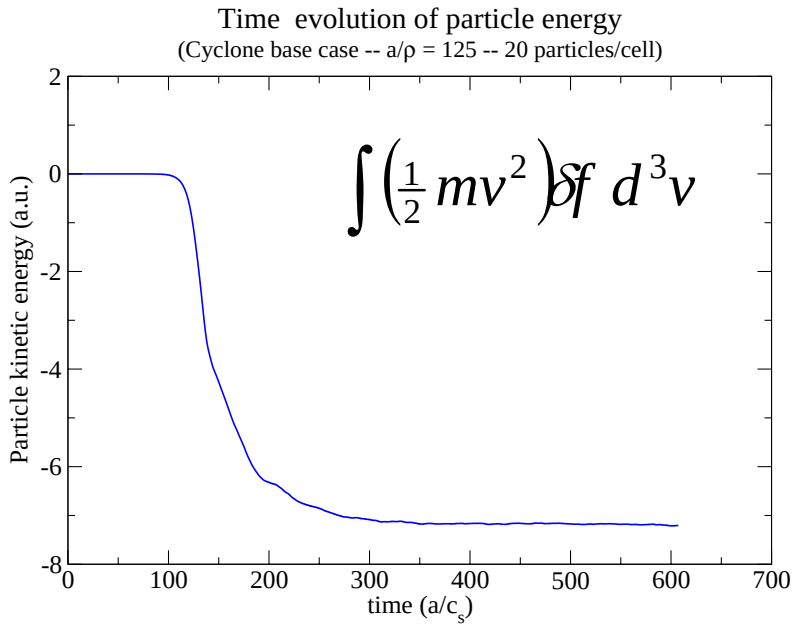
Energy conservation in the system requires the velocity-space non-linearity

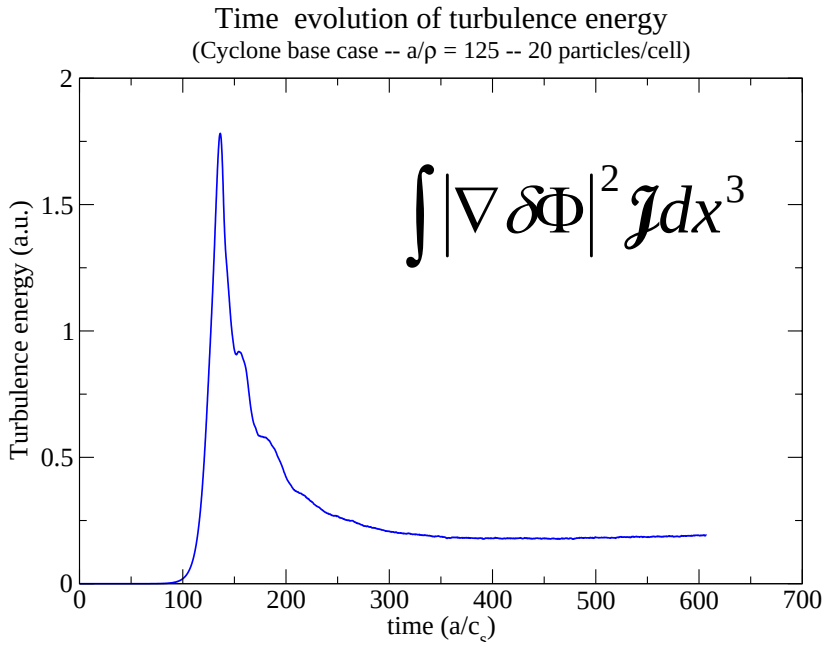
- The velocity-space non-linearity is essential to conserve energy in the simulations.
- This extra term is small for conventional gyrokinetic ordering.
- Implementation in a continuum code requires a large number of velocity space grid points.
- Easy to include in PIC codes since it does not involve a velocity-space grid.
- In a PIC code, one can see the energy transfer between the particles and the turbulence waves when the velocity-space non-linearity is included.

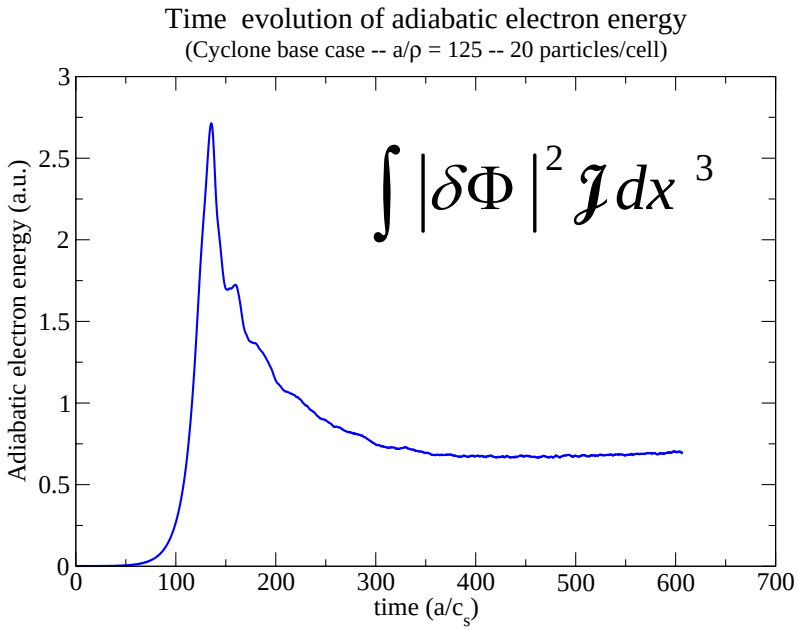
Energy not conserved anyway because of fixed temperature profile

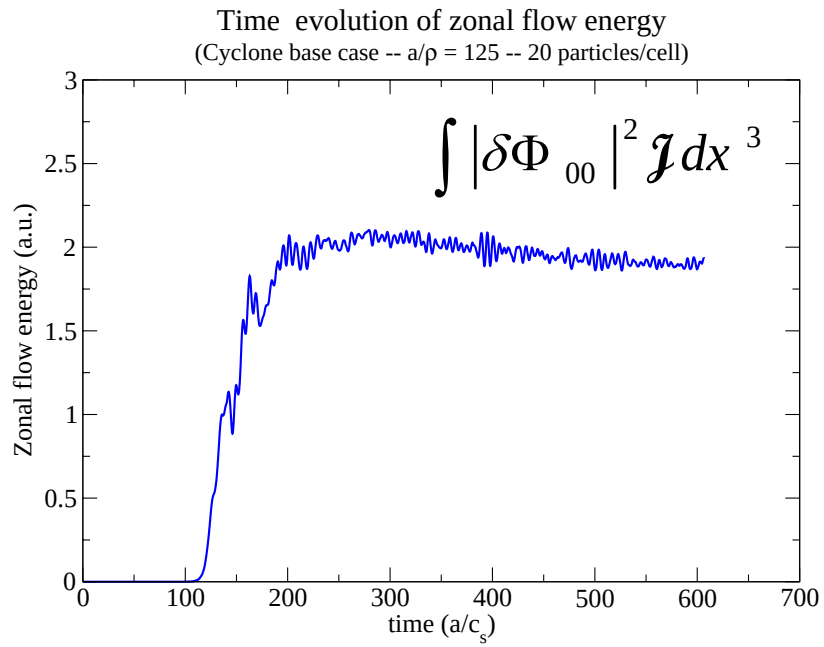
- In most simulations of ITG turbulence, it is common practice not to allow the temperature profile to relax.
- The justification is that in experiments, particles from the other regions of the plasma replenish the lost particles/energy and maintain the profile.
- Flux tube codes maintain the profile by default.
- GTC has the option to maintain the profile through a heat bath.
- However, we can also let the profile relax.

Energy conservation in GTC with velocity-space non-linearity and no T restoration

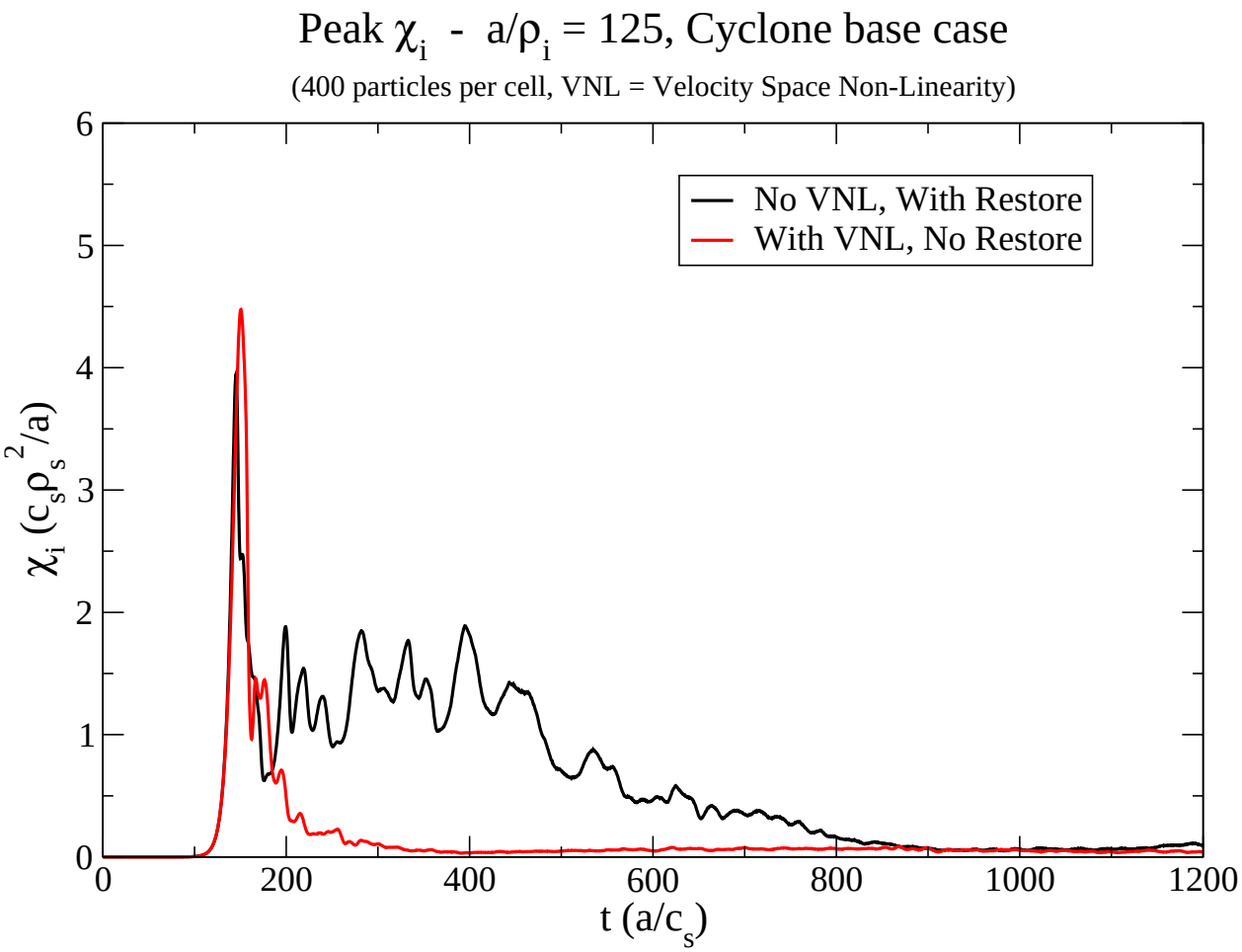




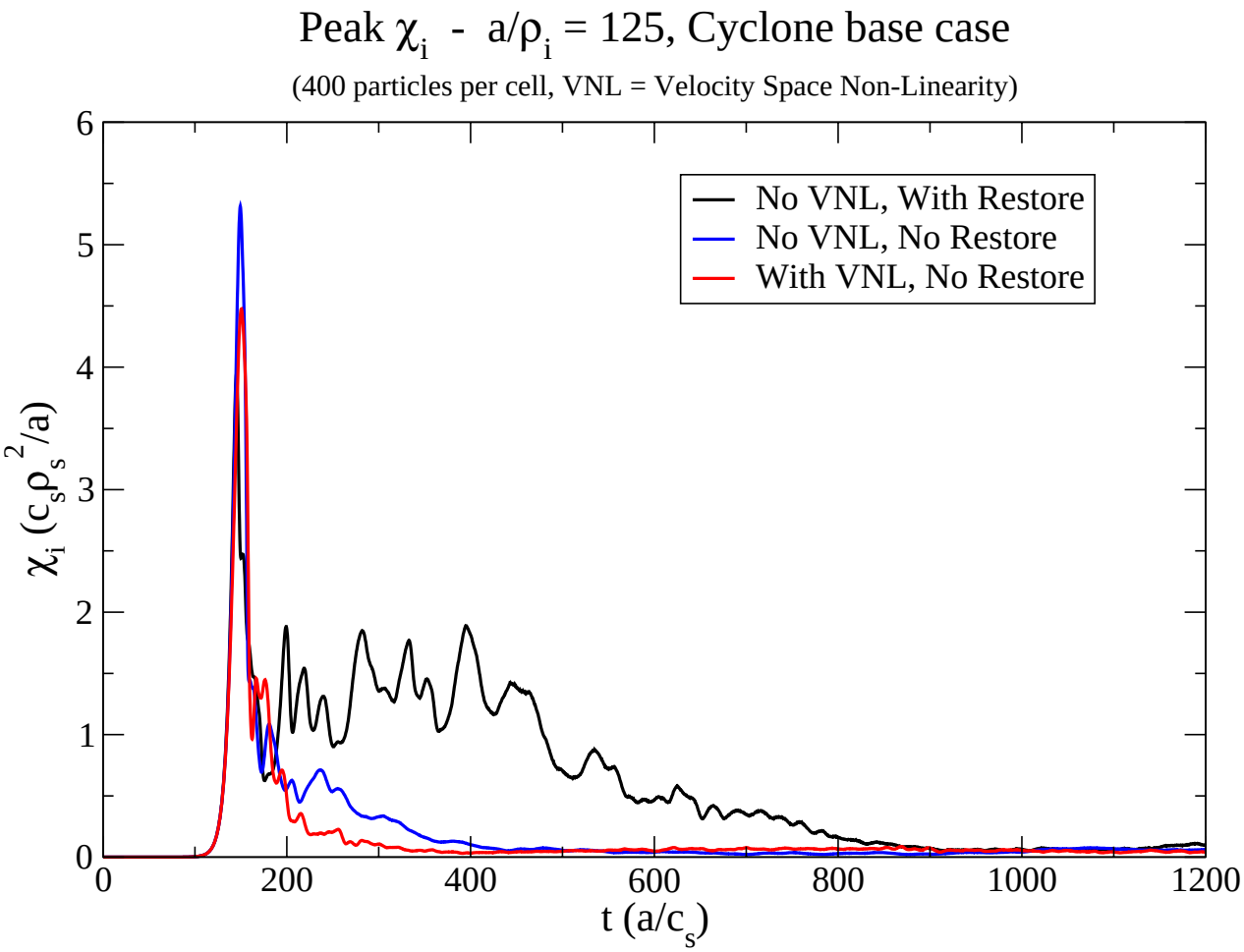




Simulation with velocity-space non-linearity and without profile restoration

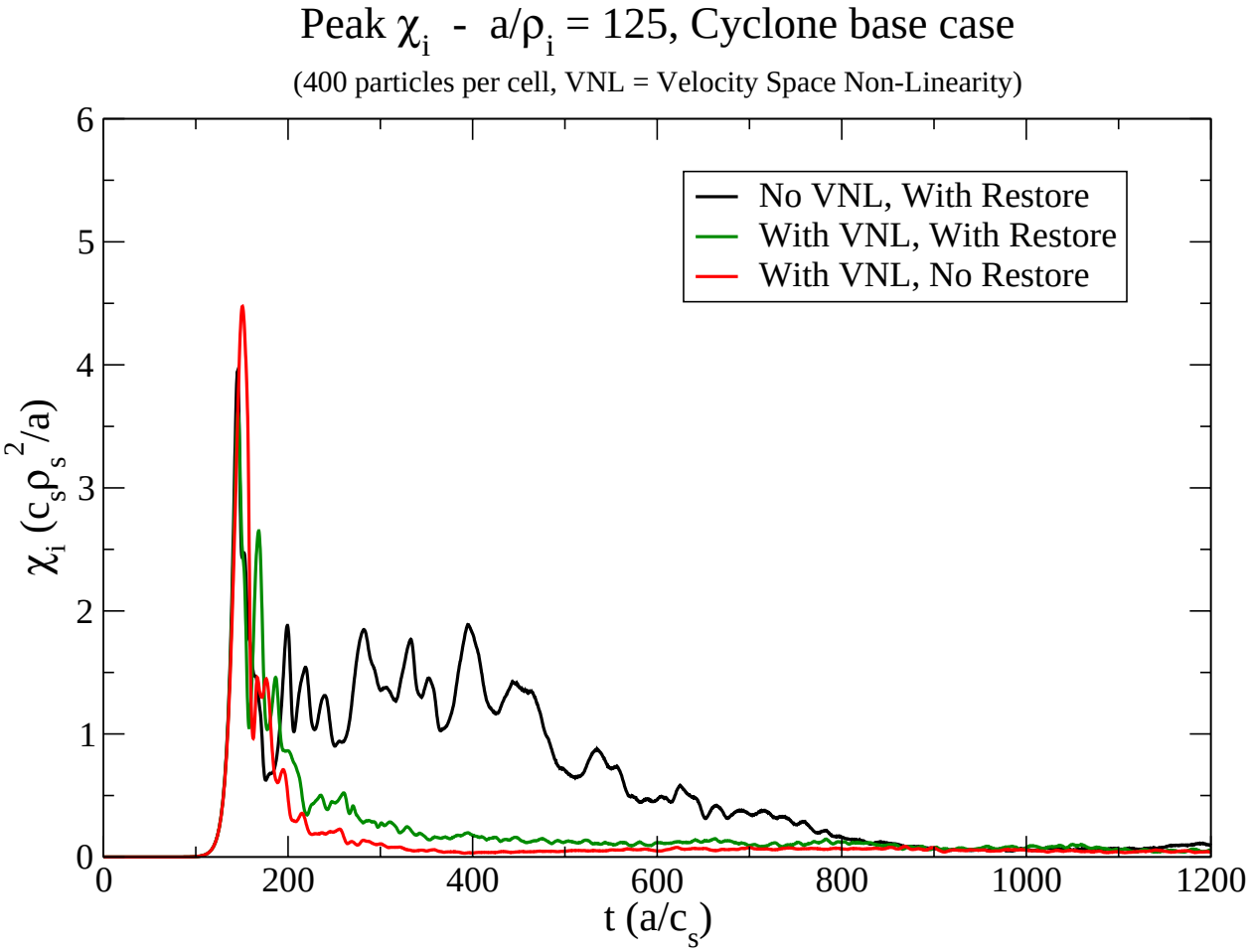


Which of the 2 effects is most important? V-space non-linearity or T profile restoration?



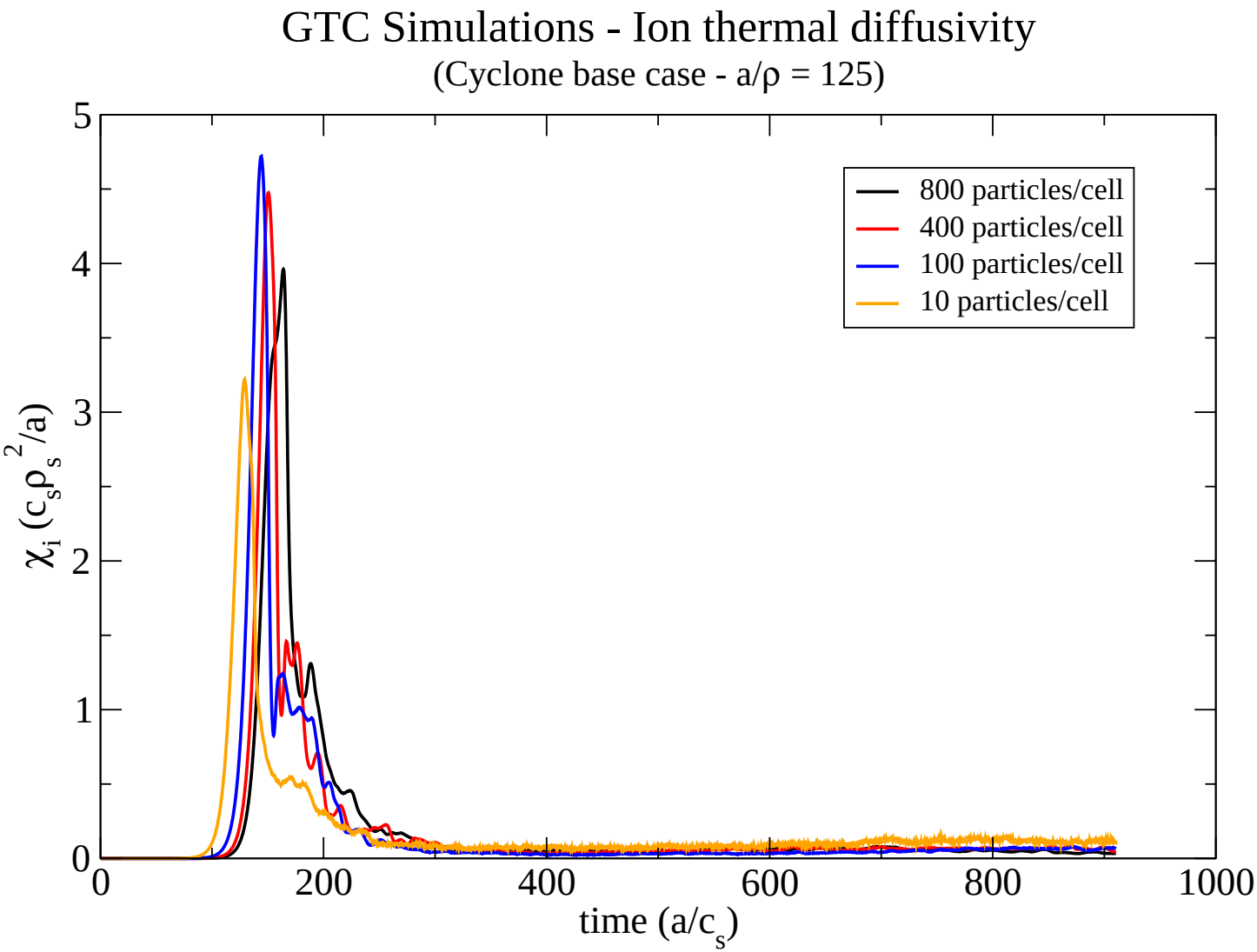
- Seems that the profile restoration is the main reason for the drop, right?

But wait...

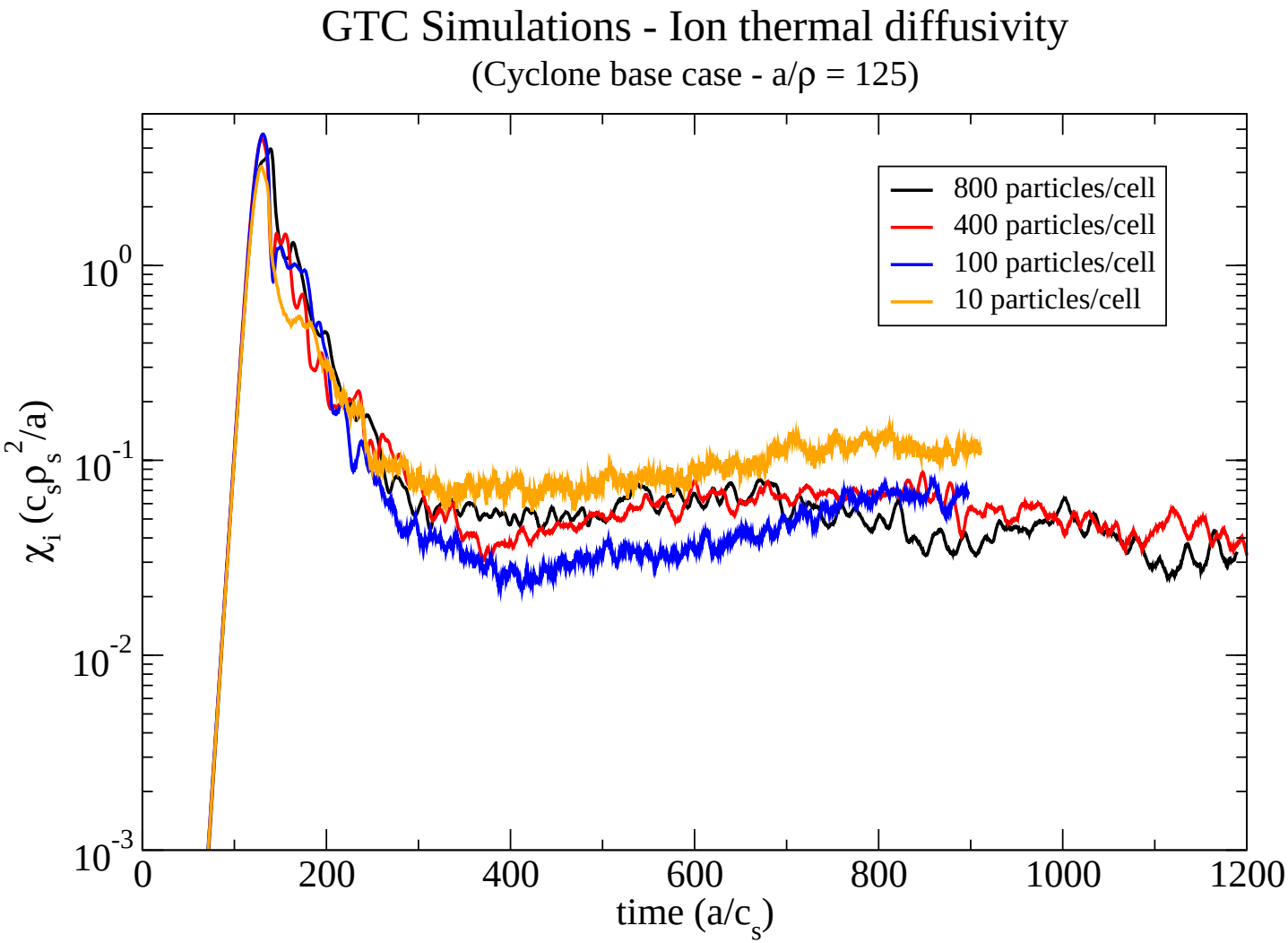


- The profile restoration has little effect when the velocity-space non-linearity is included. Need to investigate further…

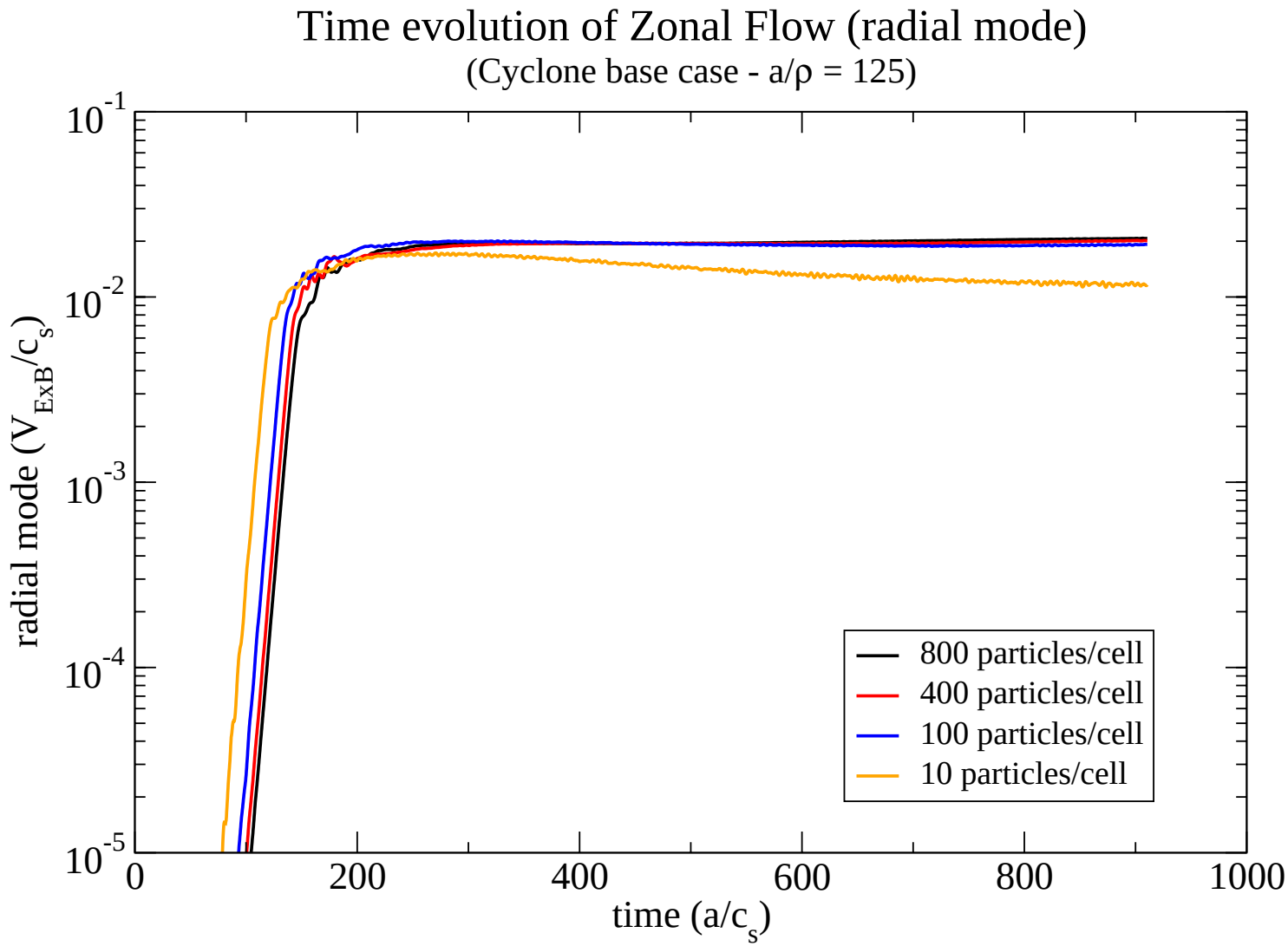
Convergence study on the ORNL CRAY X1E



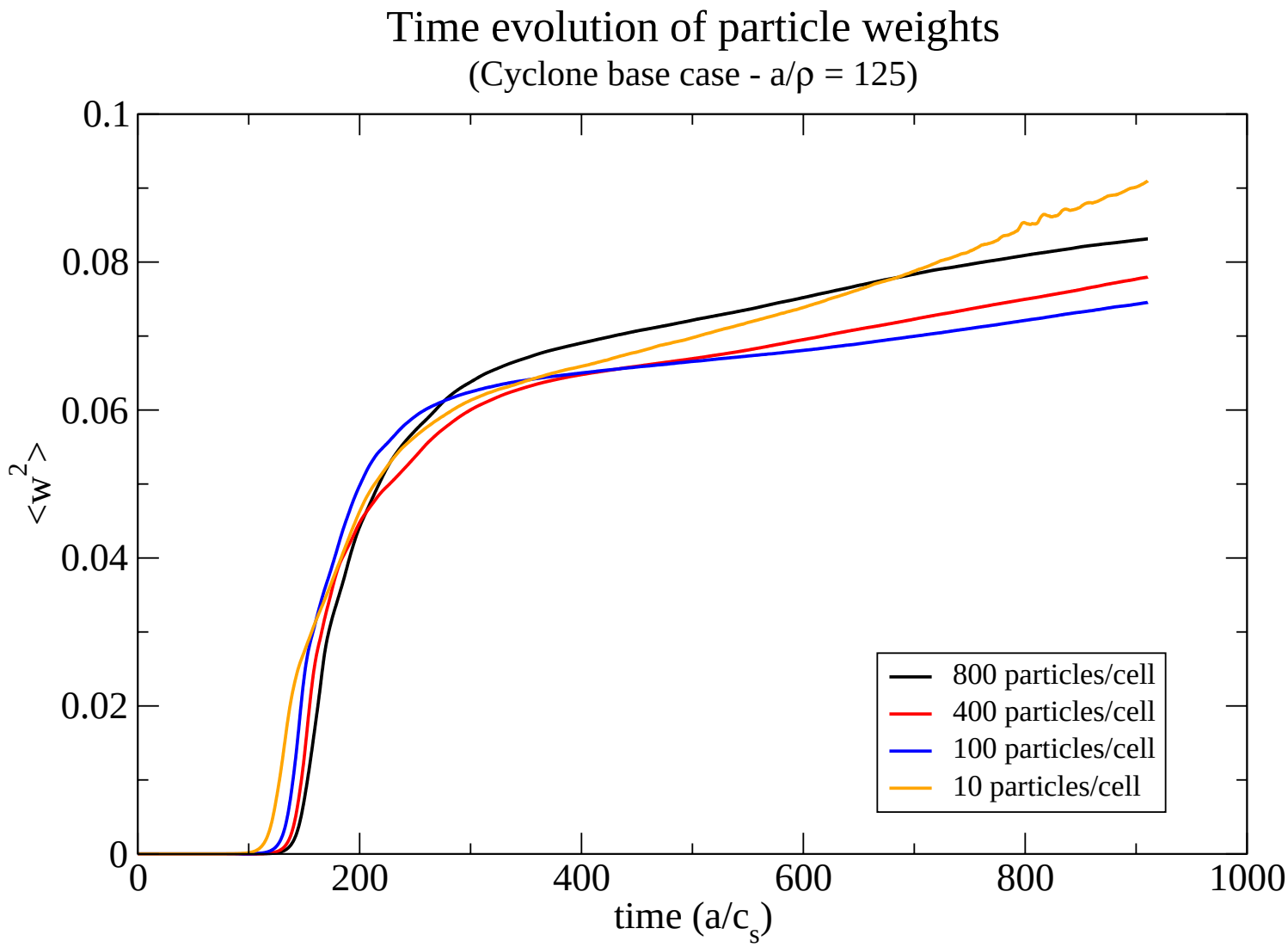
Log scale, shifted, and longer…



Zonal flow convergence

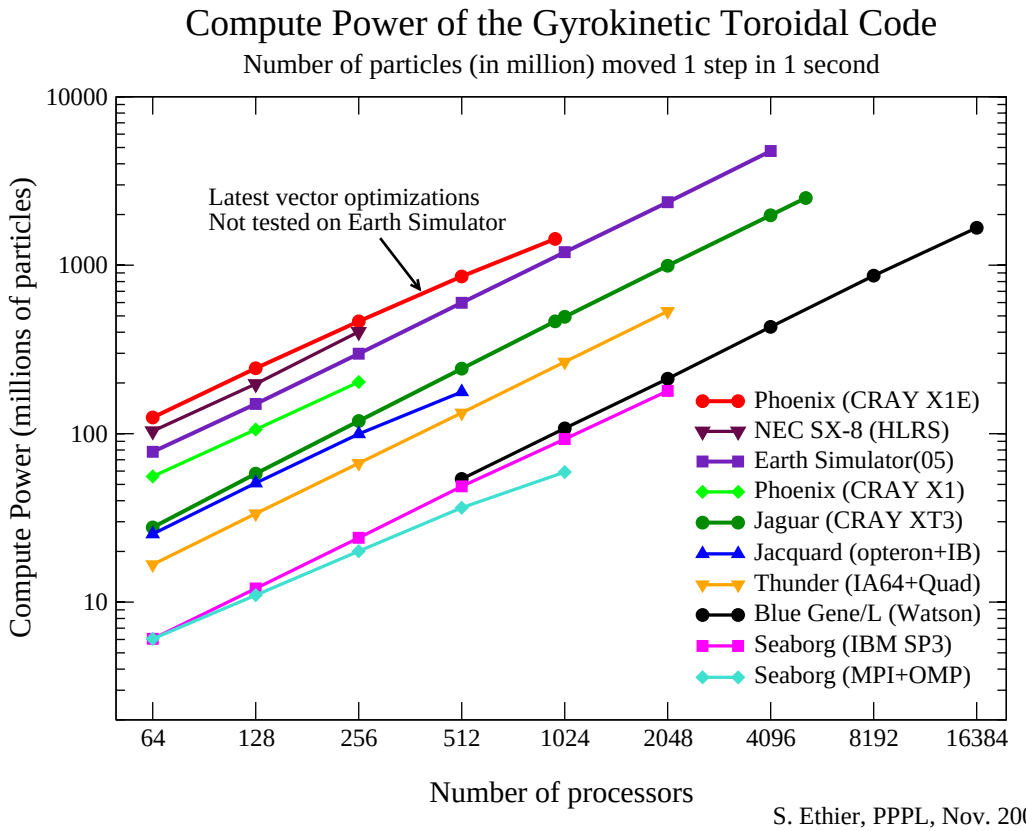


Evolution of particle weights



The ORNL NCCS Leadership computers allow GTC to run record-size simulations

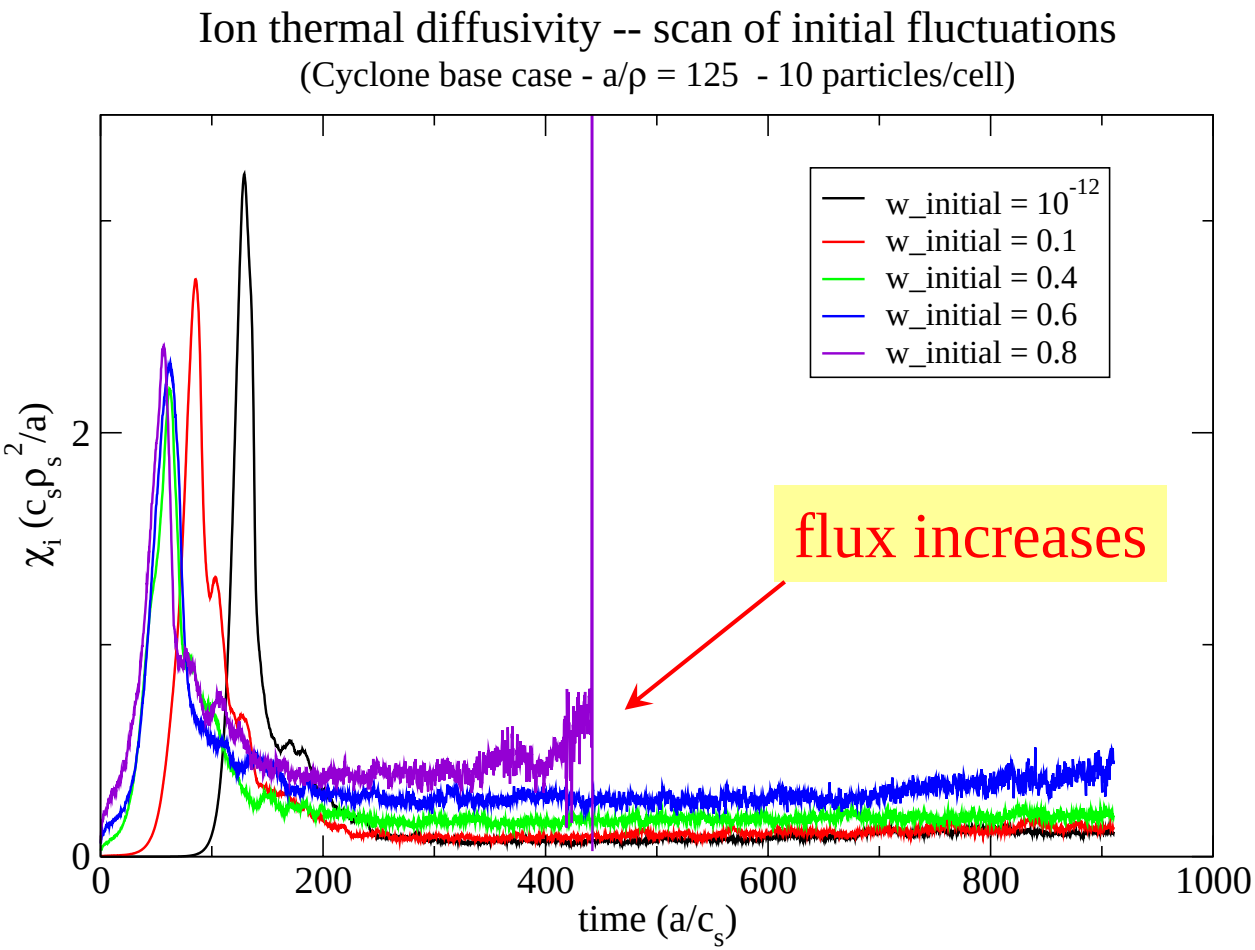
- The CRAY XT3 allowed us to run a 28-billion particle ETG simulation!
- We used 4,800 processors.
- The XT3, Jaguar, is about to be upgraded to 10,000+ processors!
- As for the CRAY X1E, it has the fastest single-processor available to us



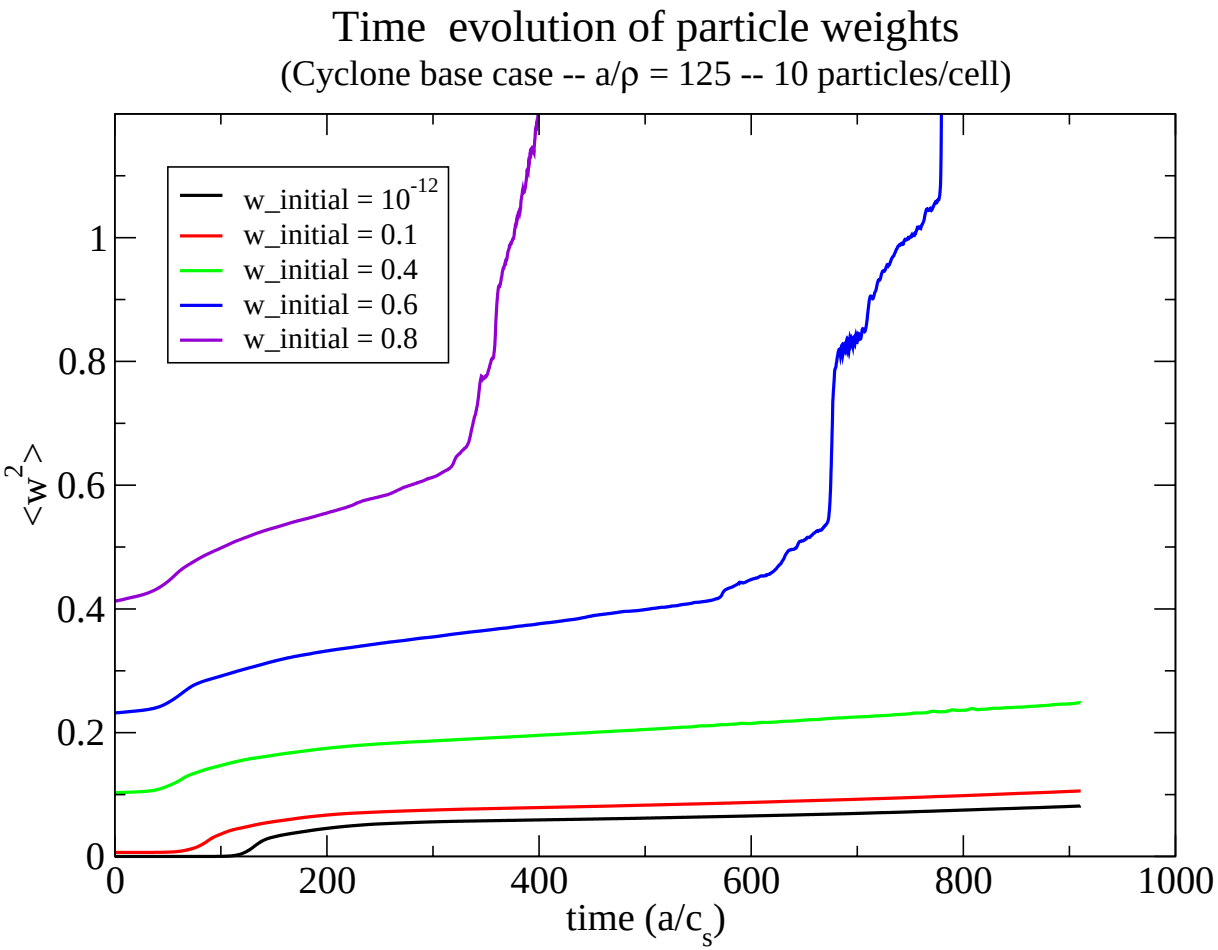
S. Ethier, PPPL, Nov. 2005

What does noise look like?

- Let's start several simulations with different levels of fluctuations



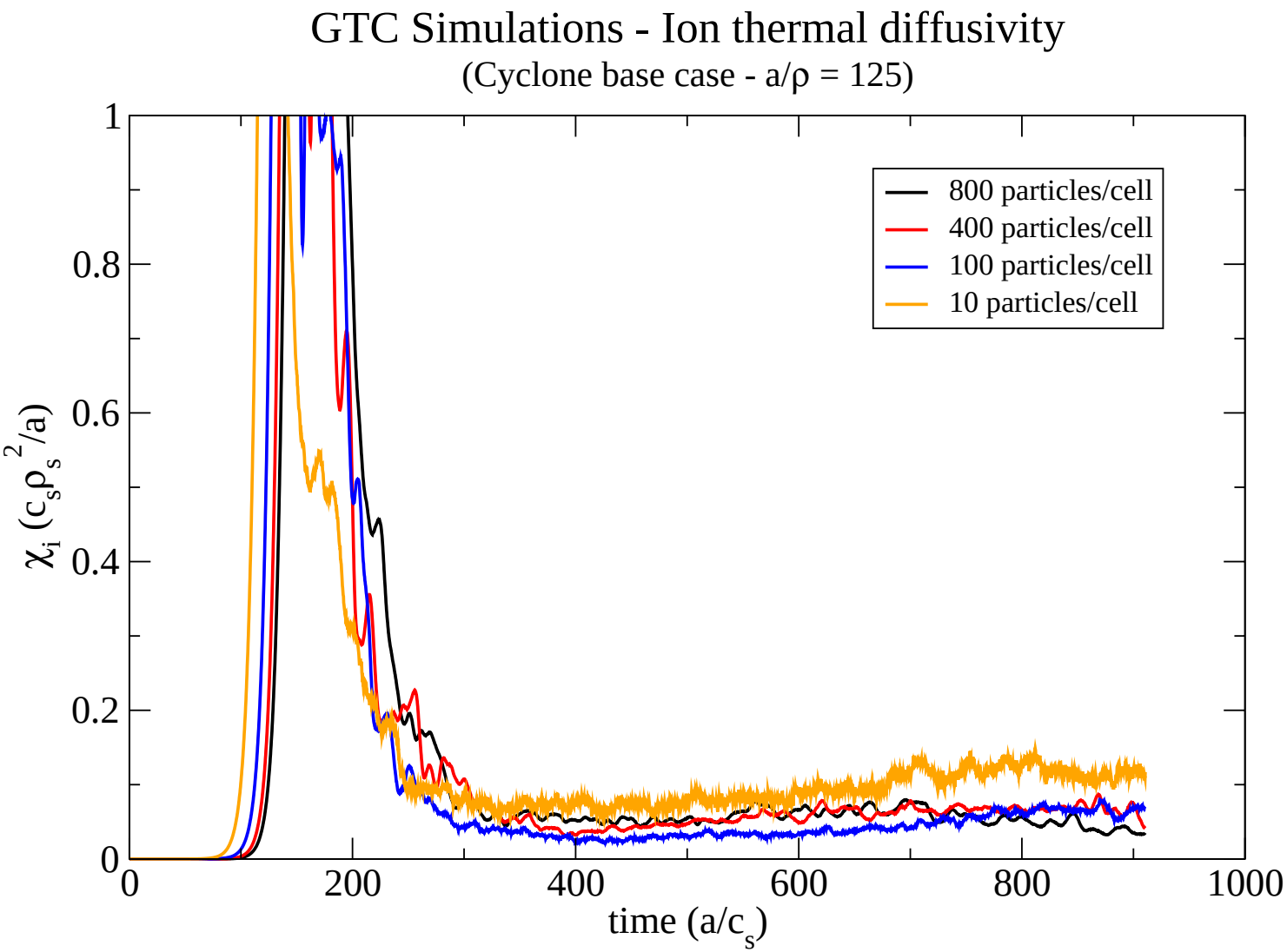
How about the weights?



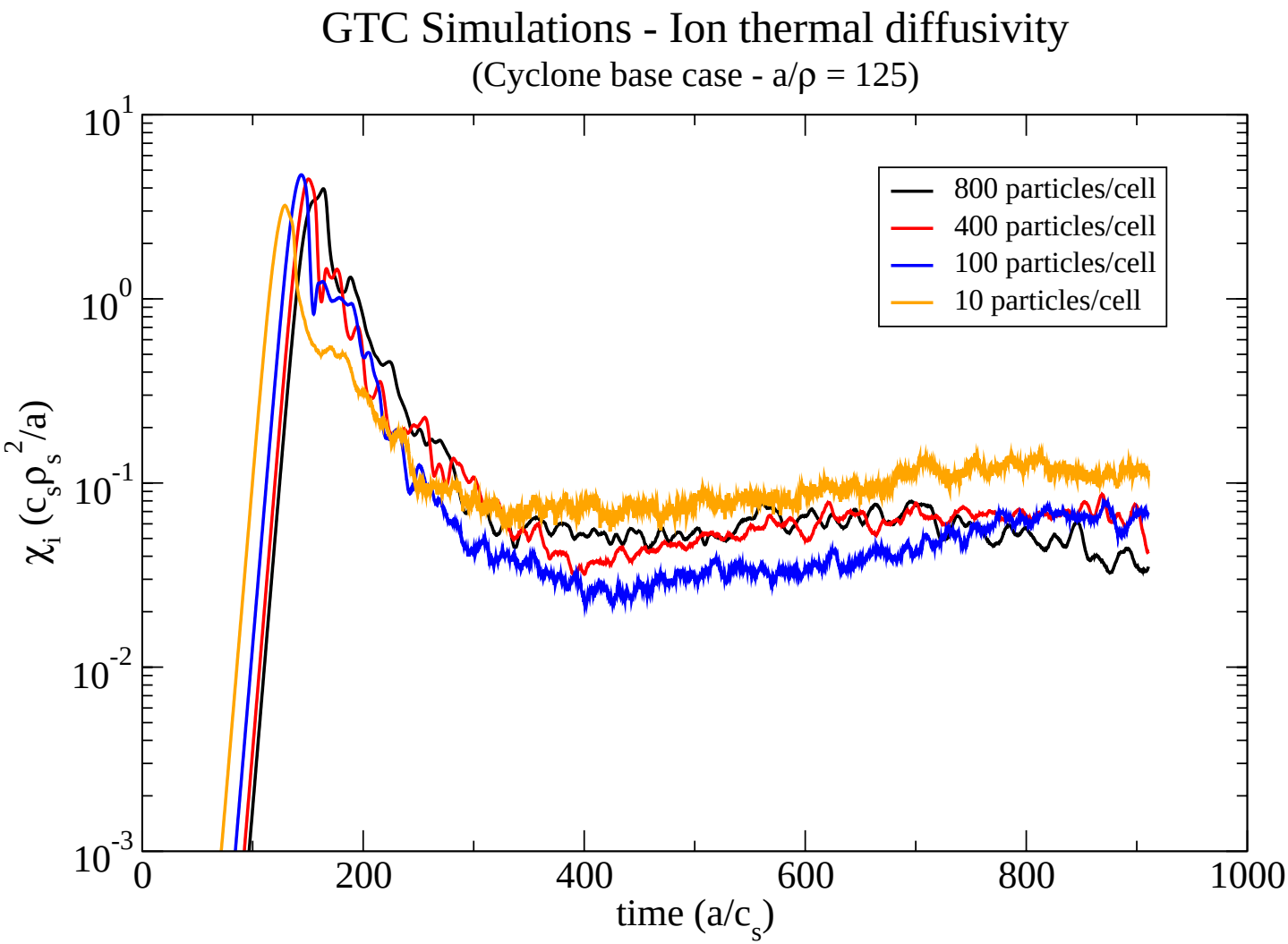
Conclusion

- Velocity-space non-linearity is essential for energy conservation.
- The turbulent steady state can be achieved faster with this additional non-linear channel (in addition to the usual ExB non-linearity).
- ITG simulations are well-converged in terms of number of particles used.

Zoom in on low level



Log scale…


GTC Simulations - Ion thermal diffusivity
(Cyclone base case - a/ρ = 125)
800 particles/cell
400 particles/cell
100 particles/cell
10 particles/cell
χ_i ($c_s\rho_s^2$/a)
time (a/c_s)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
200
400
600
800
1000