Theory and modeling in simplified magnetic configurations

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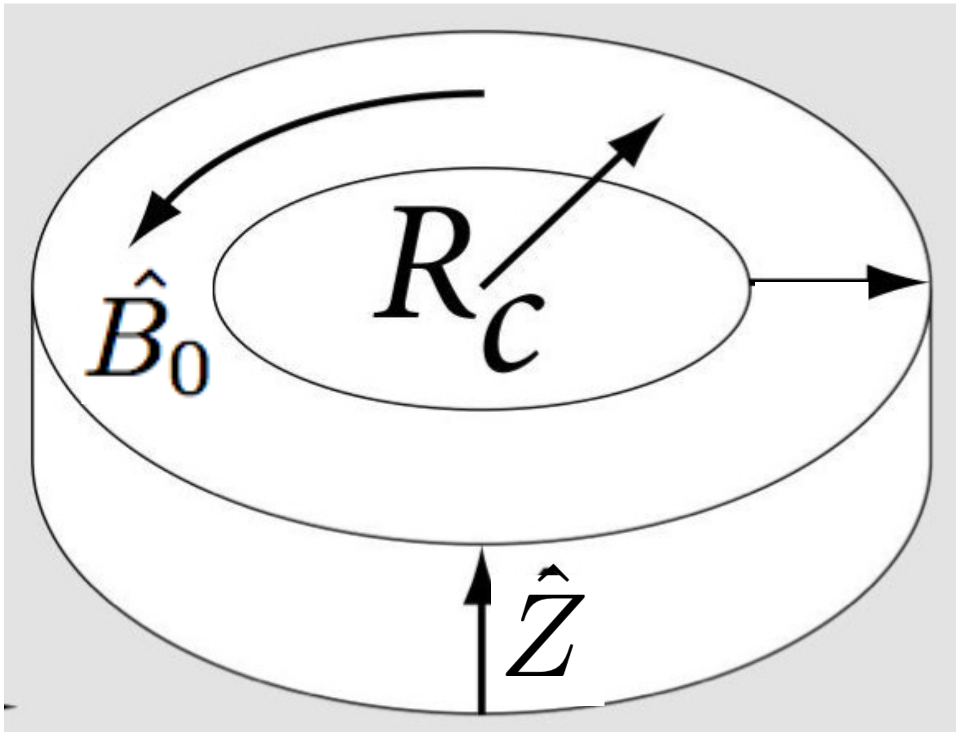
Z-pinch: why do we care?



Simplified test-bed for theory with key physics included!

- Azimuthal magnetic field generated by current in Z (B~1/R).
- Curvature and grad B present, but no variation in magnitude of B along field
- No trapped particles, 2D instead of 3D

Z-pinch stability

- Unstable to ideal interchange mode at large pressure gradient and to entropy mode at moderate pressure gradient
- Kinetic treatment necessary to get stability boundary:

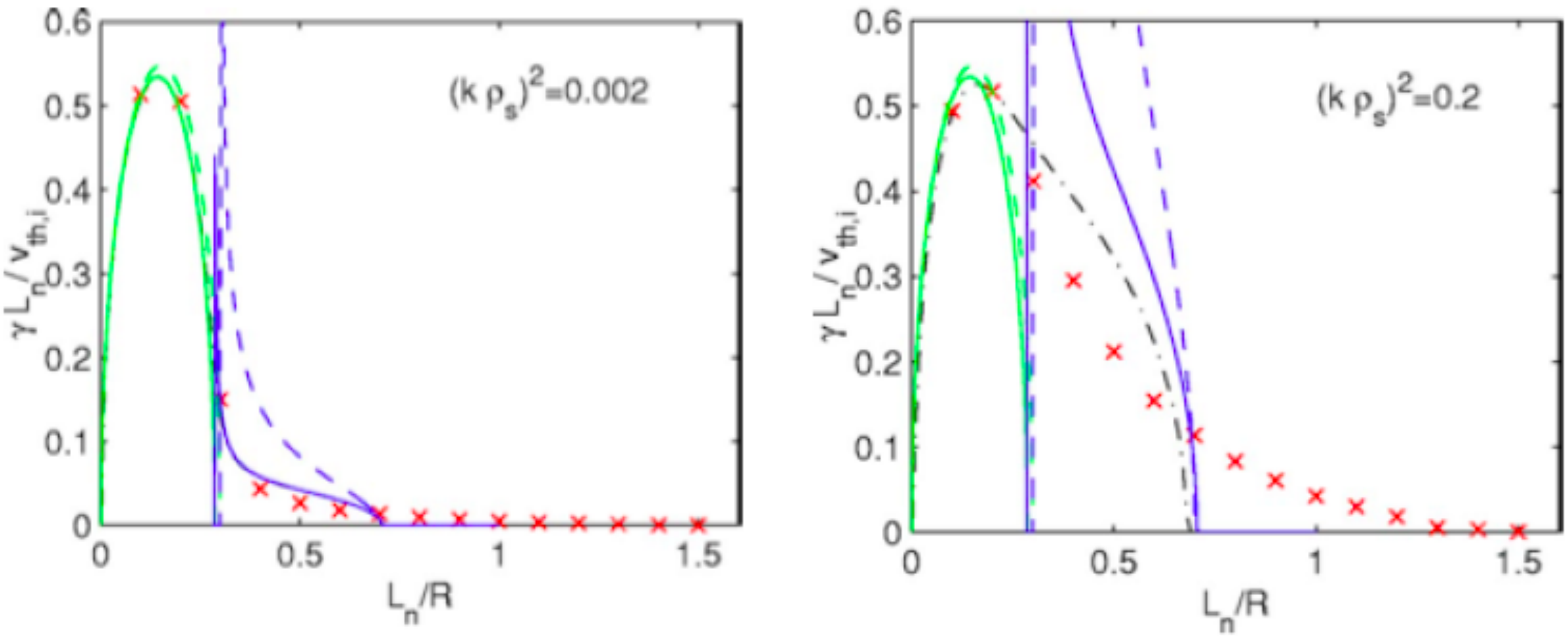
Low beta, long wavelength, T'=0, collisionless

$$|R/L_n|_{crit} = \frac{2(1+\tau)}{\pi(1+\tau) - k_\perp^2 \rho_i^2 (\pi - 2)}$$

$$\omega \frac{|L_n|}{v_{th,i}} = \frac{\left[(1+\tau)\left(\frac{\pi}{2}|R/L_n| - 1\right) - k_\perp^2 \rho_i^2 |R/L_n| (\pi/2 - 1)\right]^2}{2\pi (1+\tau^3)^2 |R/L_n|^3} \left(\tau^2 - 1 \pm 2\tau^{3/2} i\right) k_\perp \rho_i$$

Z-pinch stability

Ricci et al. (2006)



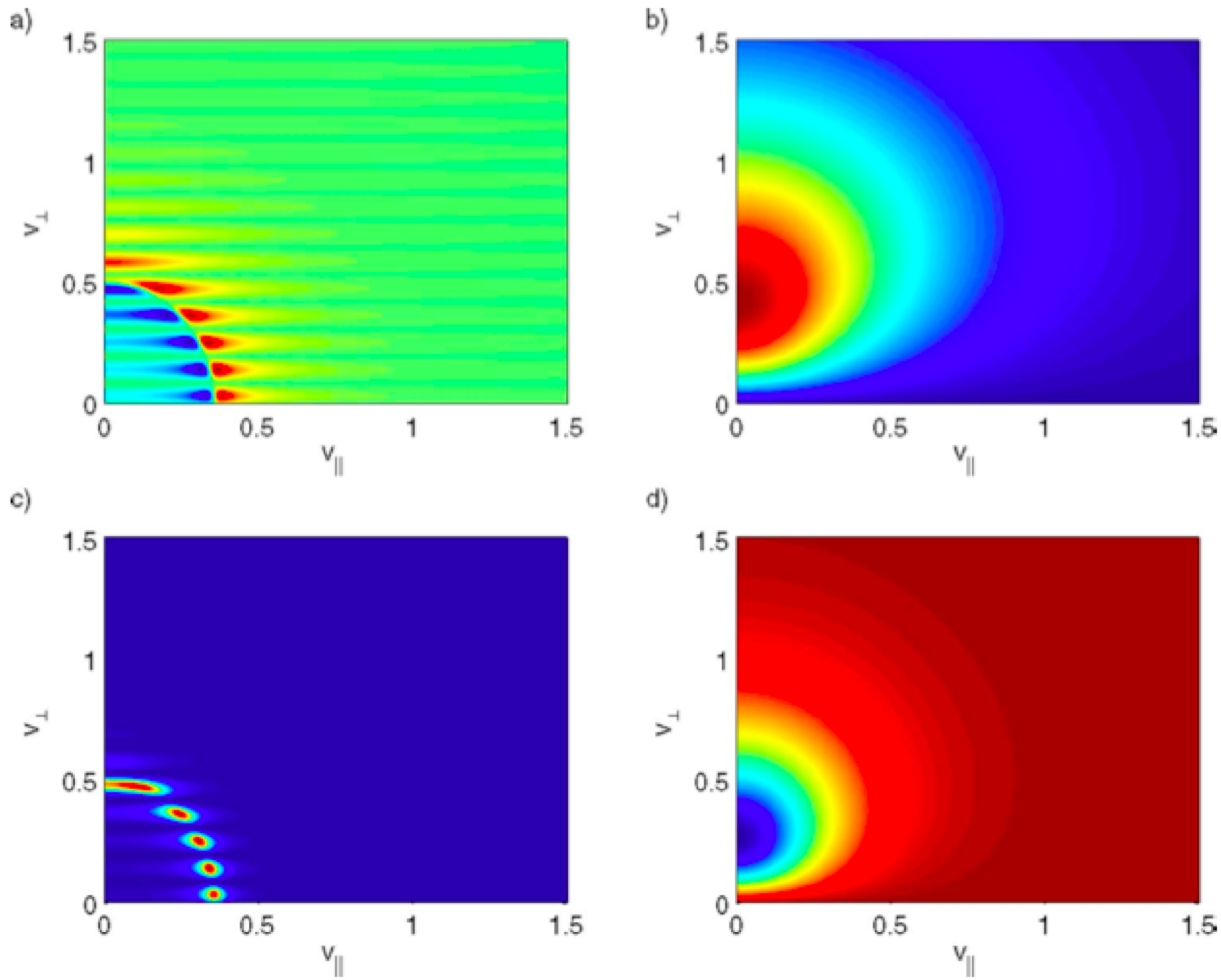
Red = GK, Black = gyrofluid, Blue = fluid entropy mode, Green = interchange mode

Z-pinch kinetics

$$\frac{L_n}{R} = 0.5$$

$$k_\perp \rho = 38$$

Ricci et al. (2006)

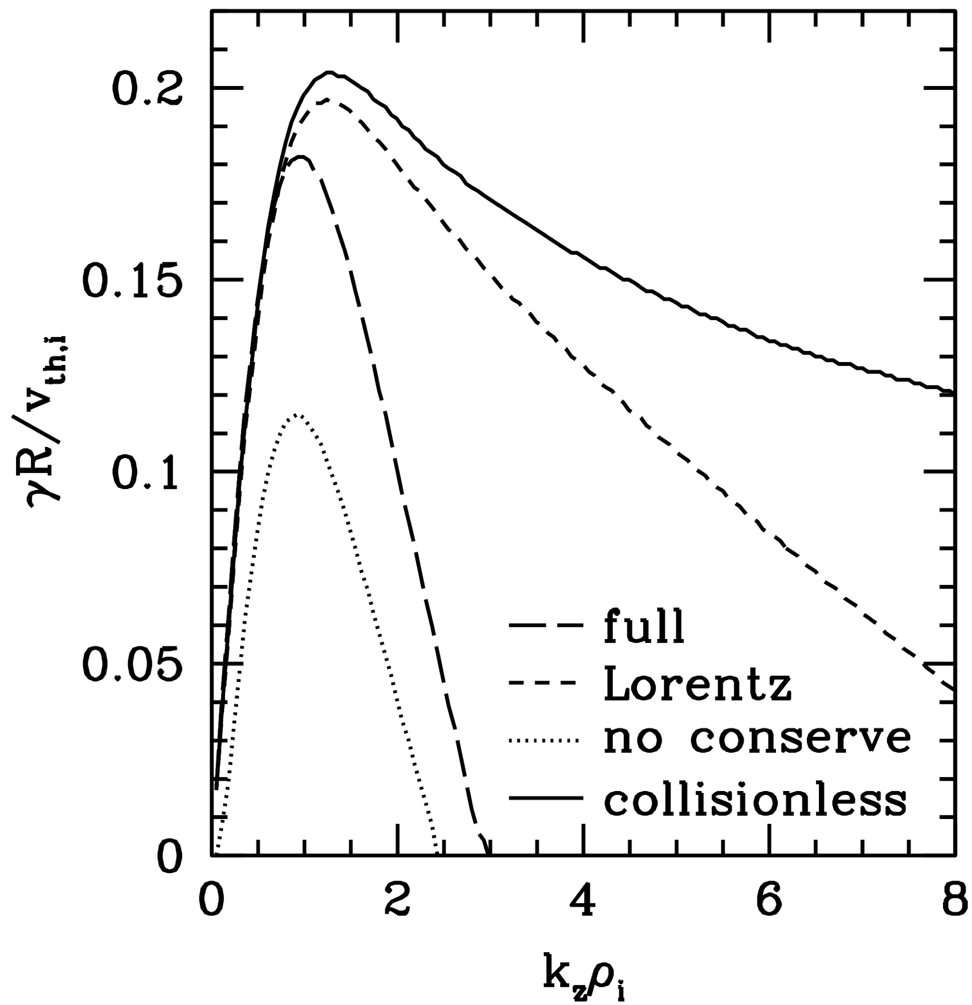


Effect of collisions

- Z-pinch used to test model collision operator for gyrokinetics

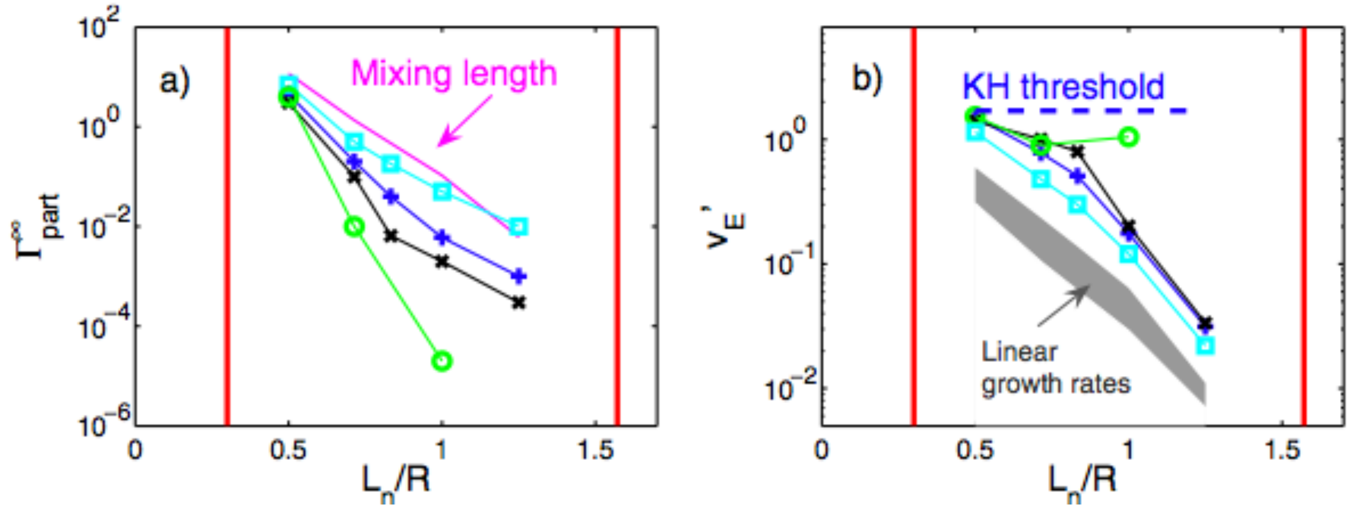
$$\frac{L_n}{R} = 0.5$$

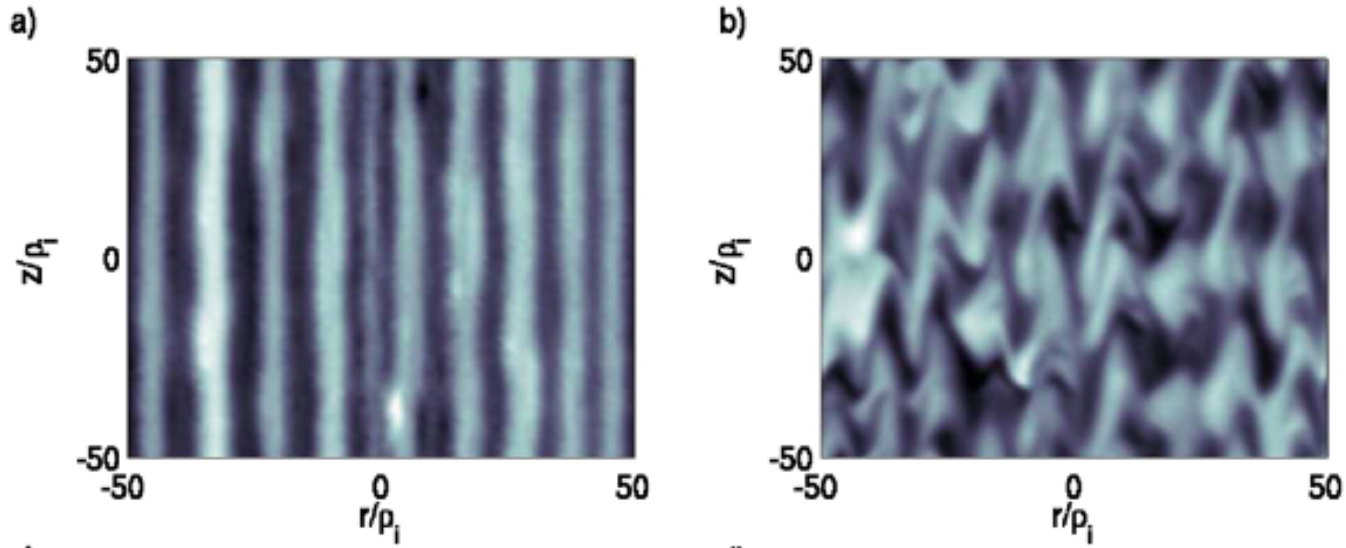
Barnes et al. (2009)



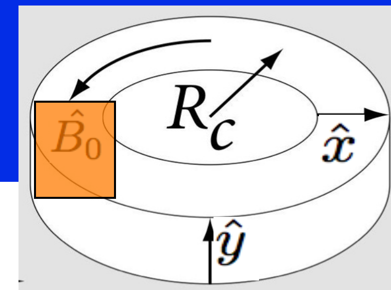
Zonal flow physics

Ricci et al. (2006)

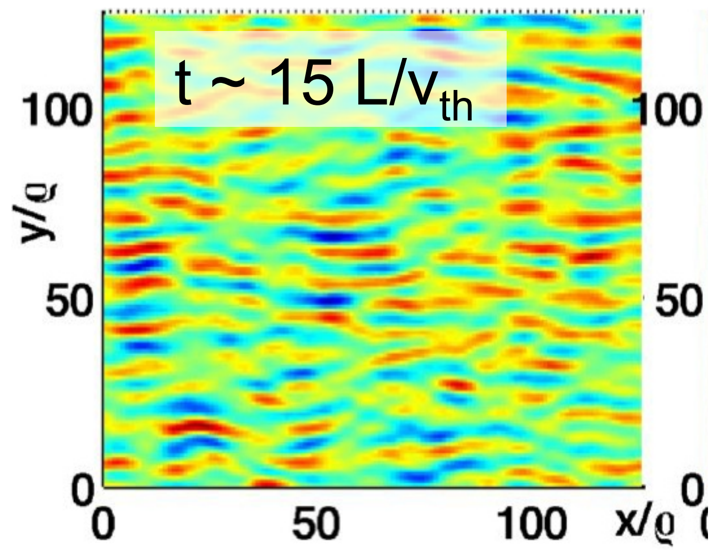




GSP benchmark

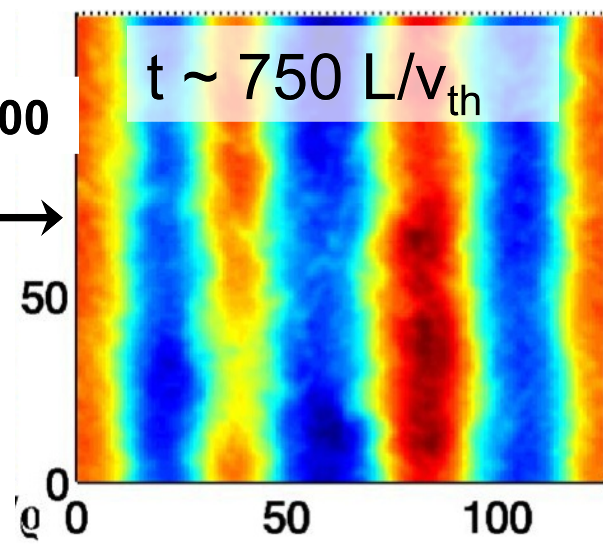


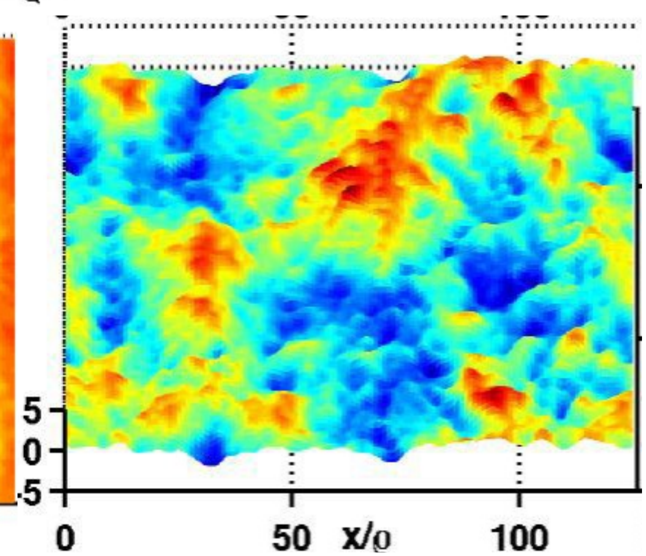
Linear phase - growing k_y modes



Surface plots of electrostatic potential, $\Phi(x,y)$

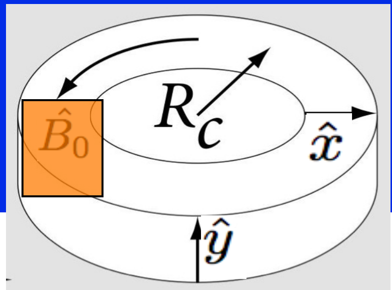
Nonlinear phase - steady zonal flow with background turbulence



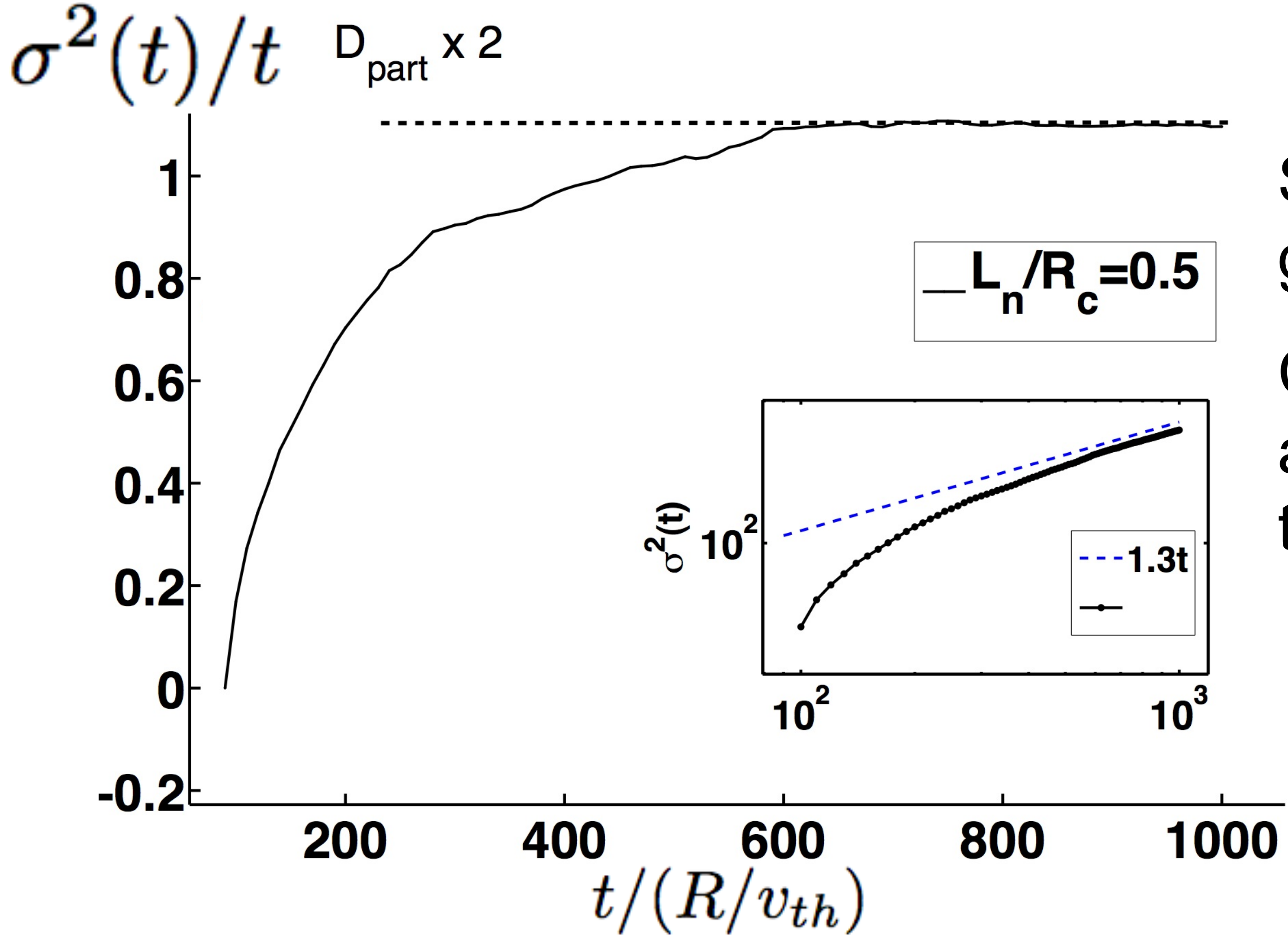


Courtesy K. Gustafson

Particle diffusion in presence of zonal flows



c.f. Manfredi & Dendy PRL 1996; Zhang *et al* PRL 2008; Sanchez et al PRL 2008; Hauff *et al* PRL 2009



Strongest gradient tested

Clearly diffusive after $t = 600\ R/v_{th}$.

Courtesy K. Gustafson

Conclusions

- Range of interesting physics requires kinetic treatment
- Kinetic treatment made more tractable (analytically and numerically) by using simplified magnetic configuration