Core momentum transport and flow shear suppression of turbulence

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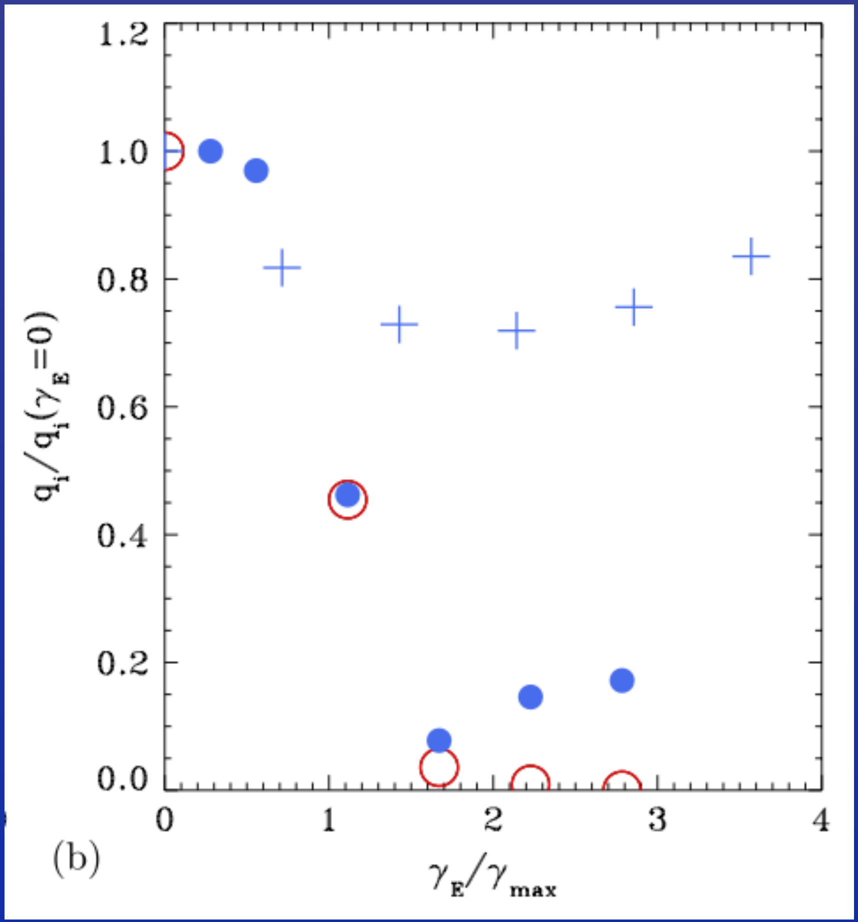
Motivation



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Model equations

- High flow GK (Artun '94) with subsidiary expansion in Mach:

$$\left(\frac{\partial}{\partial t} + \mathbf{u}\cdot\nabla\right) h + \left(v_\parallel + \langle \mathbf{v}_E \rangle + \mathbf{v}_M\right)\cdot\nabla h - \langle C[h]\rangle$$

$$= \frac{qF_0}{T}\left(\frac{\partial}{\partial t} + \mathbf{u}\cdot\nabla\right)\varphi - \langle \mathbf{v}_E\rangle\cdot\nabla\psi\left(\frac{\partial F_0}{\partial \psi} + v_\parallel \frac{\partial u_\parallel}{\partial \psi}\frac{qF_0}{T}\right)$$

- Focus on flow shear (no coriolis) by ordering $u' \sim v_t/L$ but $u \sim M v_t$, i.e. $L_u \sim ML$

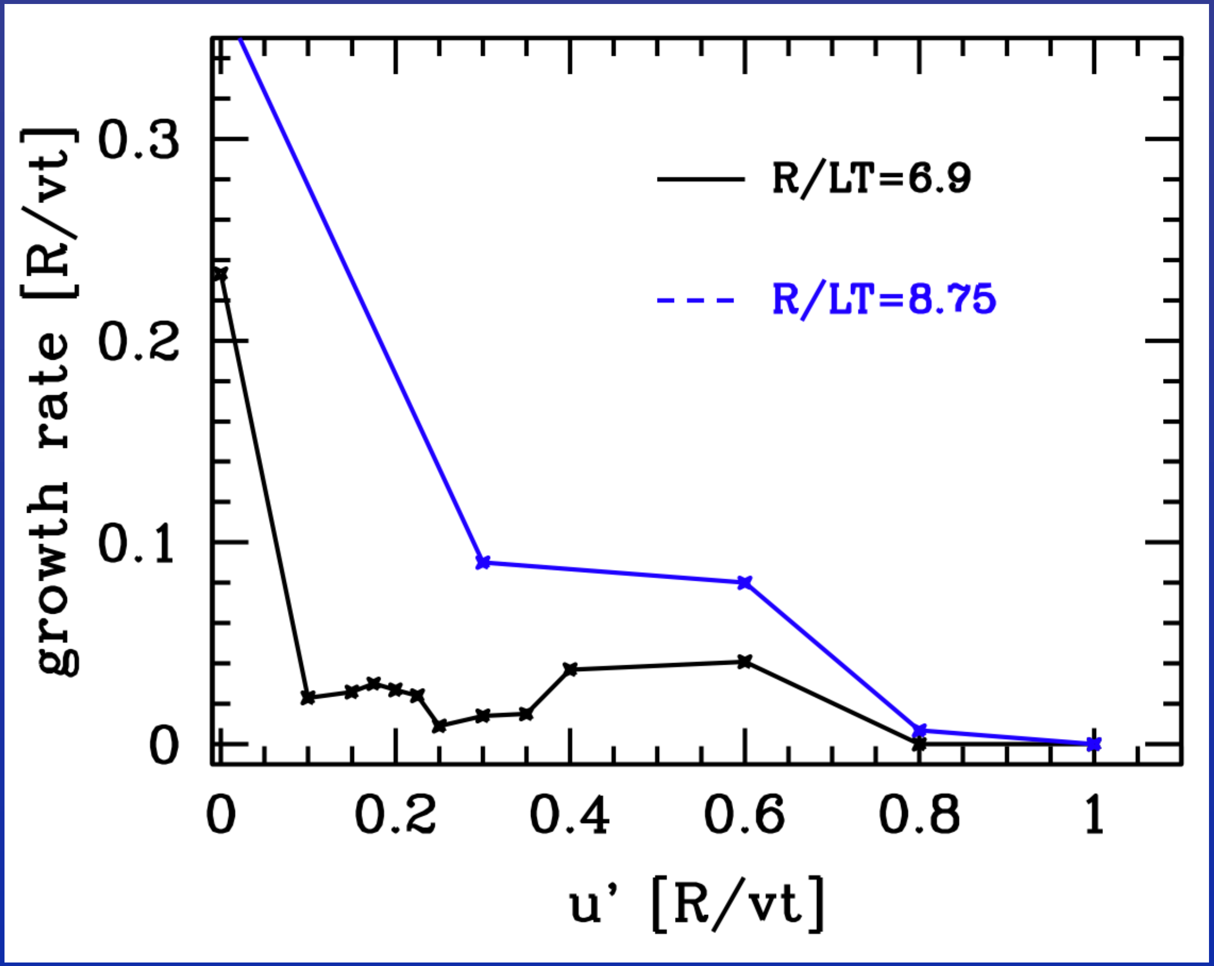
Numerical model

- Local, nonlinear gyrokinetic simulations
- Simulation reference frame chosen so u=0 at center of domain
- Make change of variable $k_x(t) = k_x(0) + k_y u' t$ (Hammett '06):

$$\frac{\partial h}{\partial t} + \left(v_{\|} + \langle \mathbf{v}_E \rangle + \mathbf{v}_M\right) \cdot \nabla h - \langle C[h] \rangle$$

$$= \frac{qF_0}{T}\frac{\partial \varphi}{\partial t} - \langle \mathbf{v}_E \rangle \cdot \nabla \psi \left(\frac{\partial F_0}{\partial \psi} + v_{\|} \frac{\partial u_{\|}}{\partial \psi} \frac{qF_0}{T} \right)$$

Results: stability



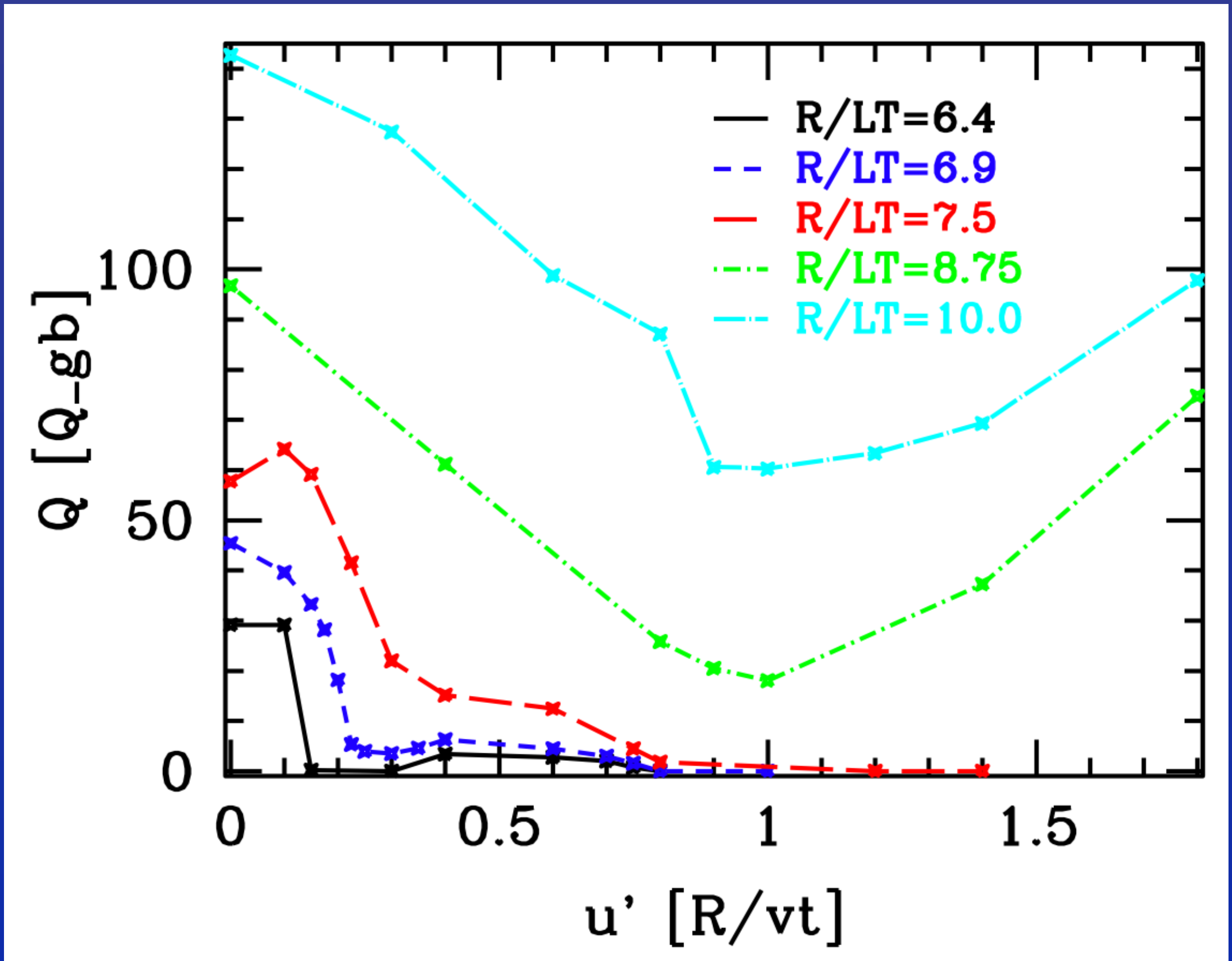
Cyclone base-case parameters

Linearly stabilized for u' ~ 1

Transiently unstable beyond u'~1

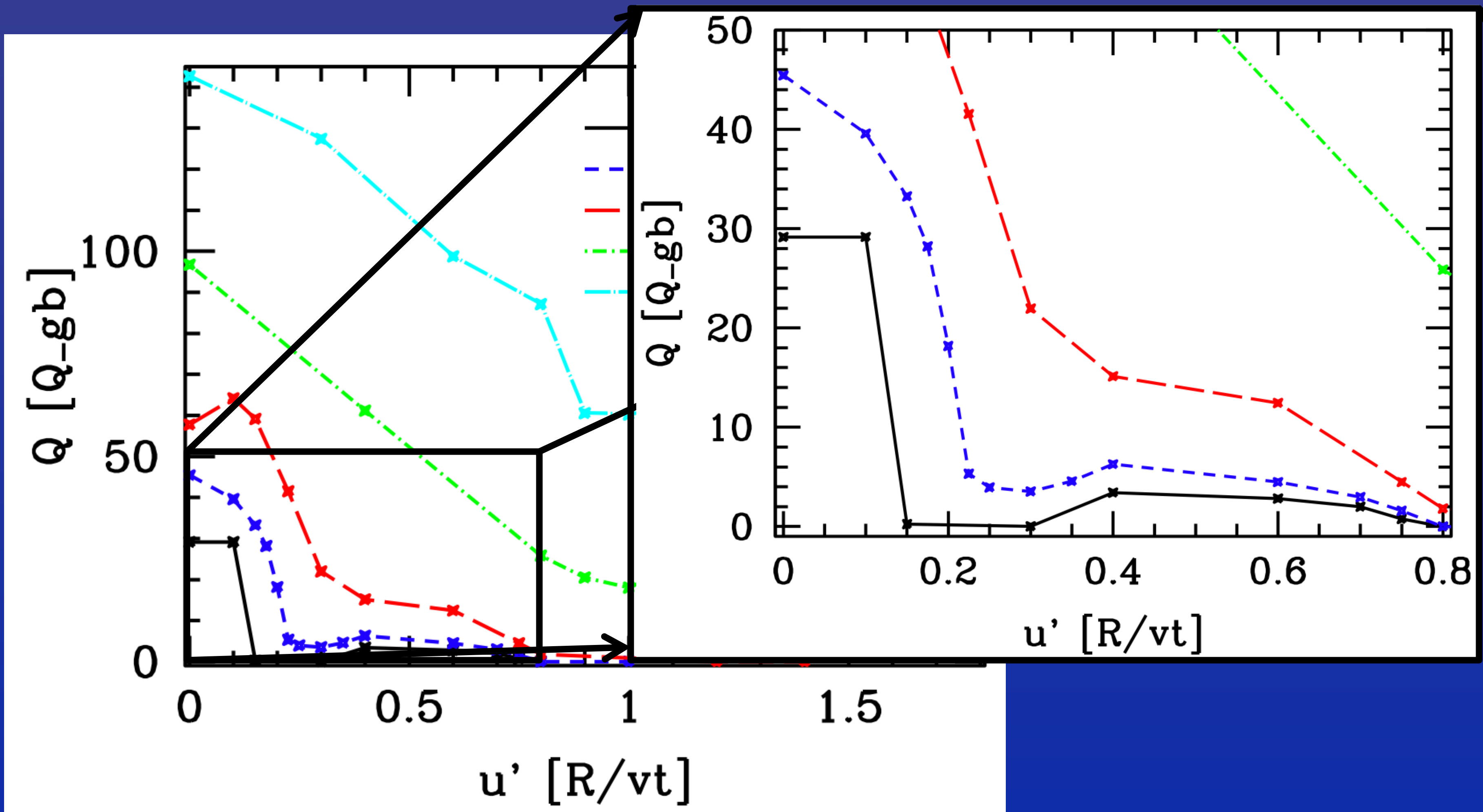
Results: heat flux

$$Q = \int d^3v \left(\frac{mv^2}{2}\right)\left(\mathbf{v}_E \cdot \frac{\nabla\psi}{|\nabla\psi|}\right)\delta f$$

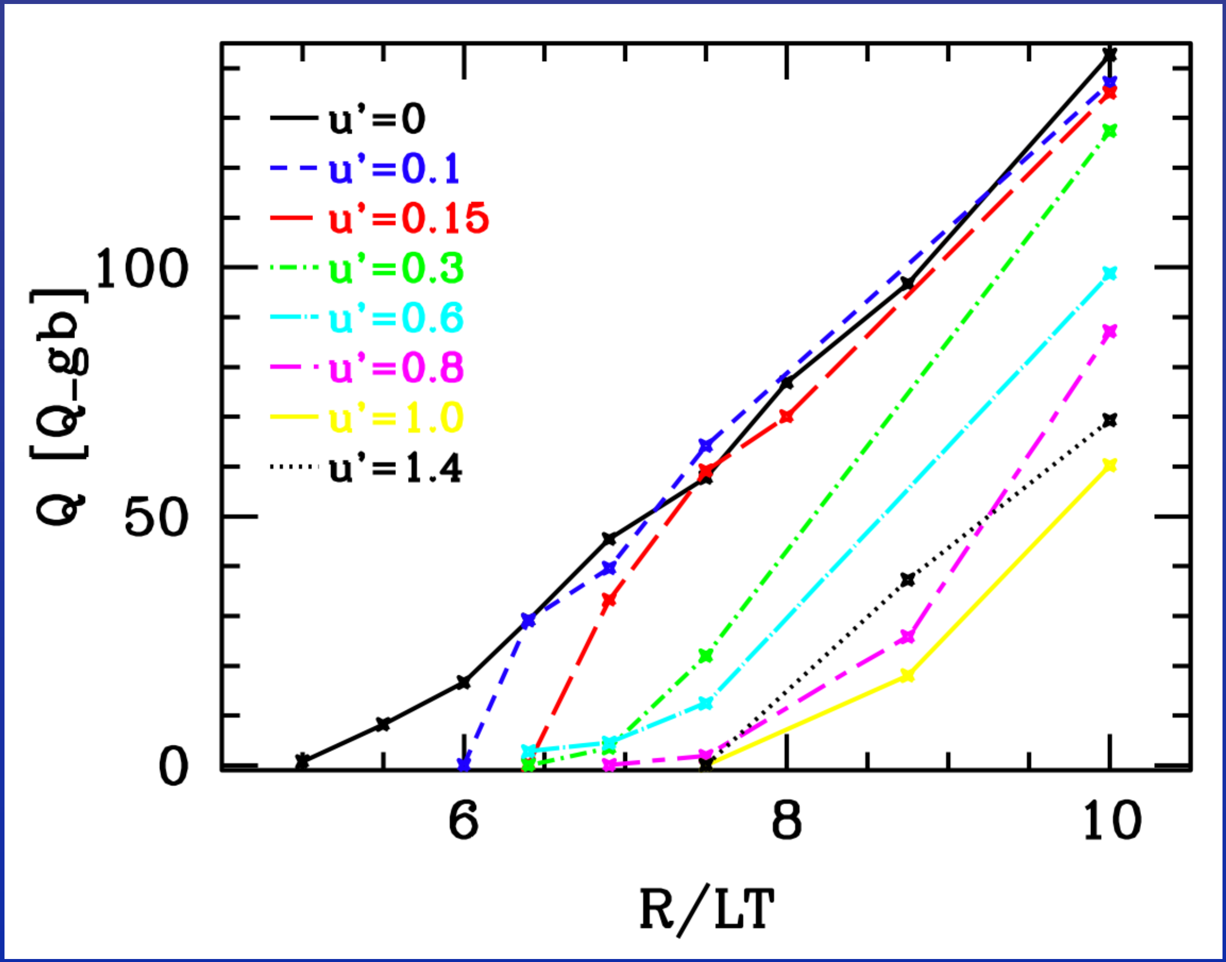


Subcritical turbulence beyond u'~1

Results: heat flux

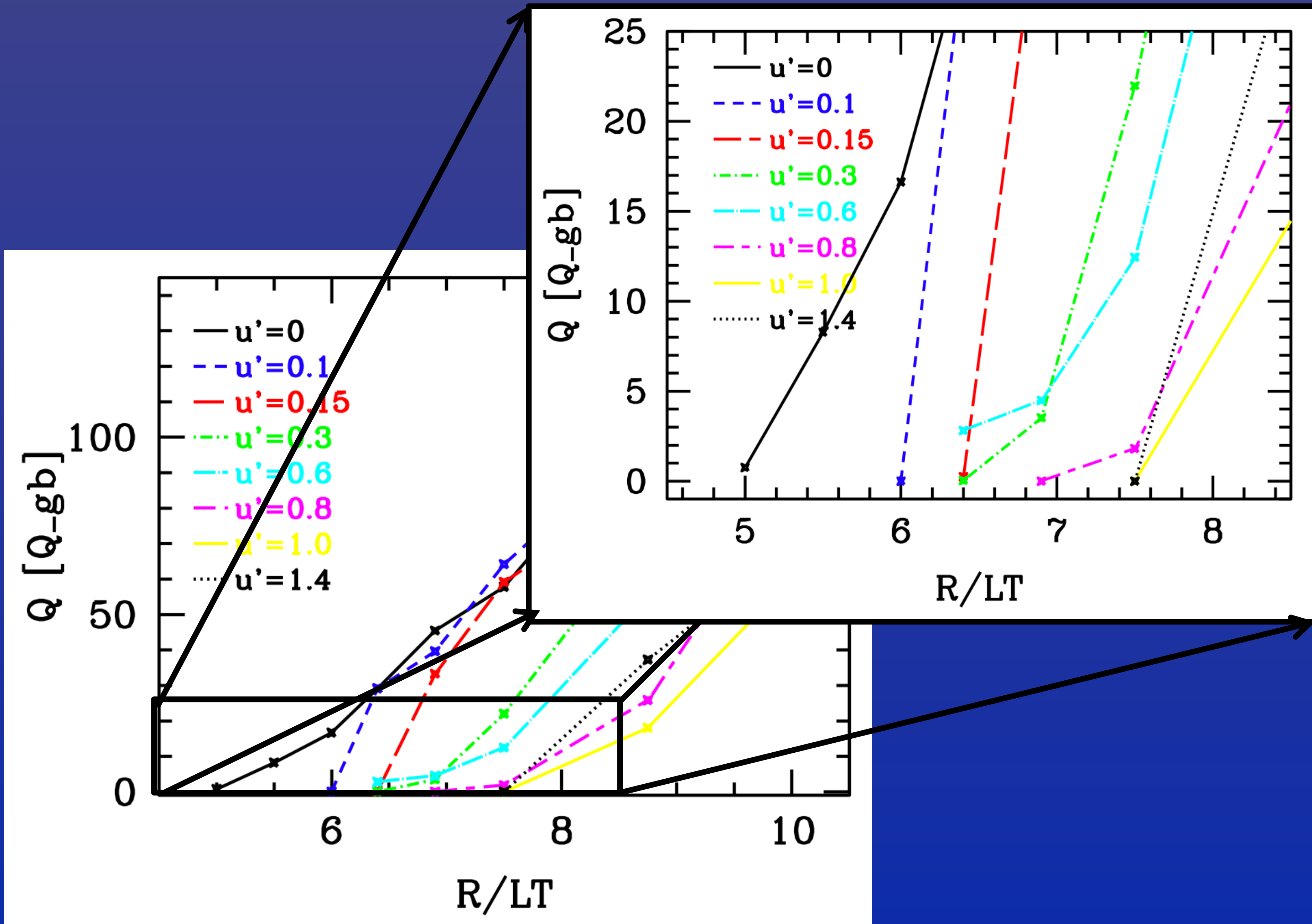


Results: stiffness



Does flow shear shift critical gradient or decrease stiffness?

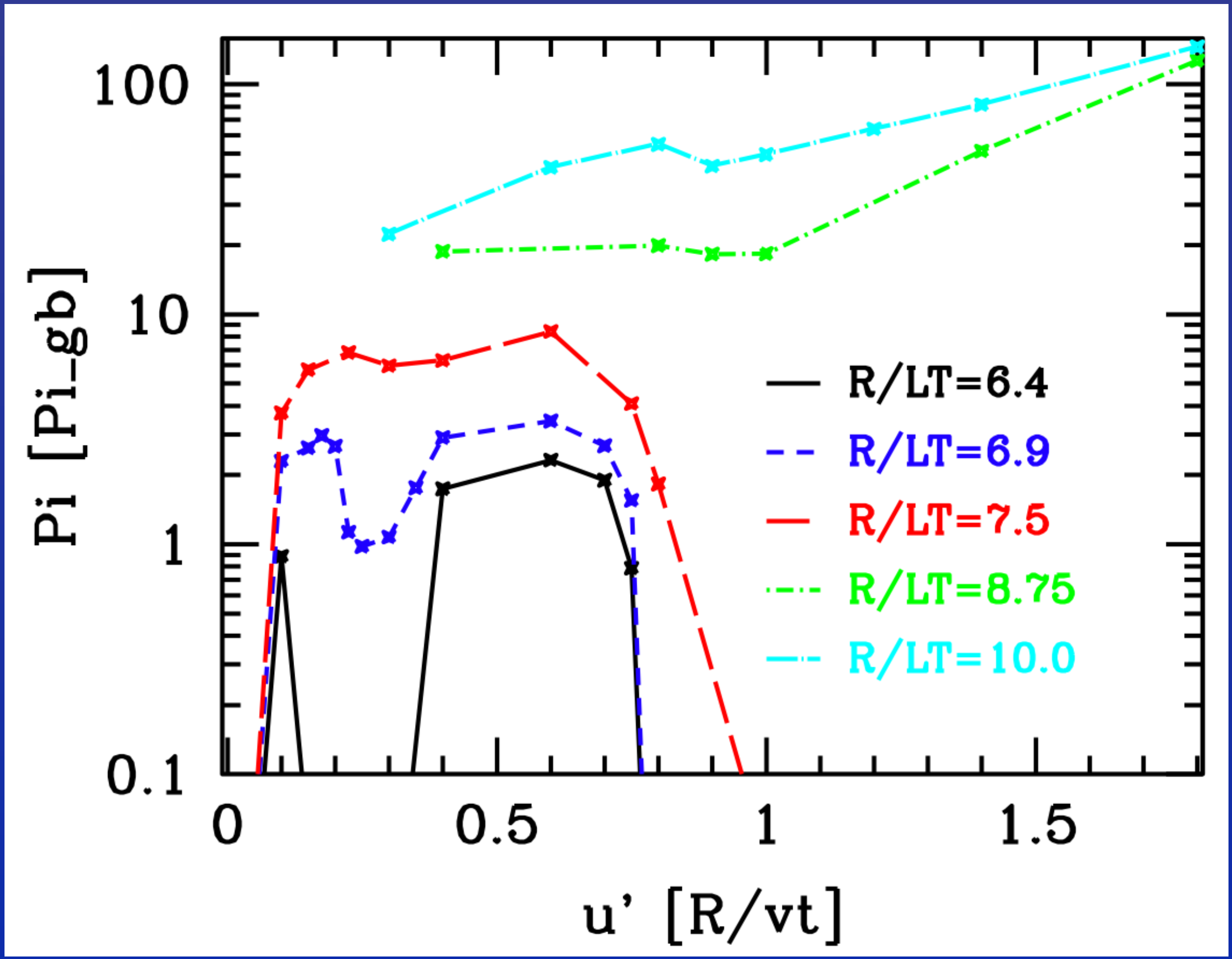
General shifting of critical gradient without much relaxation



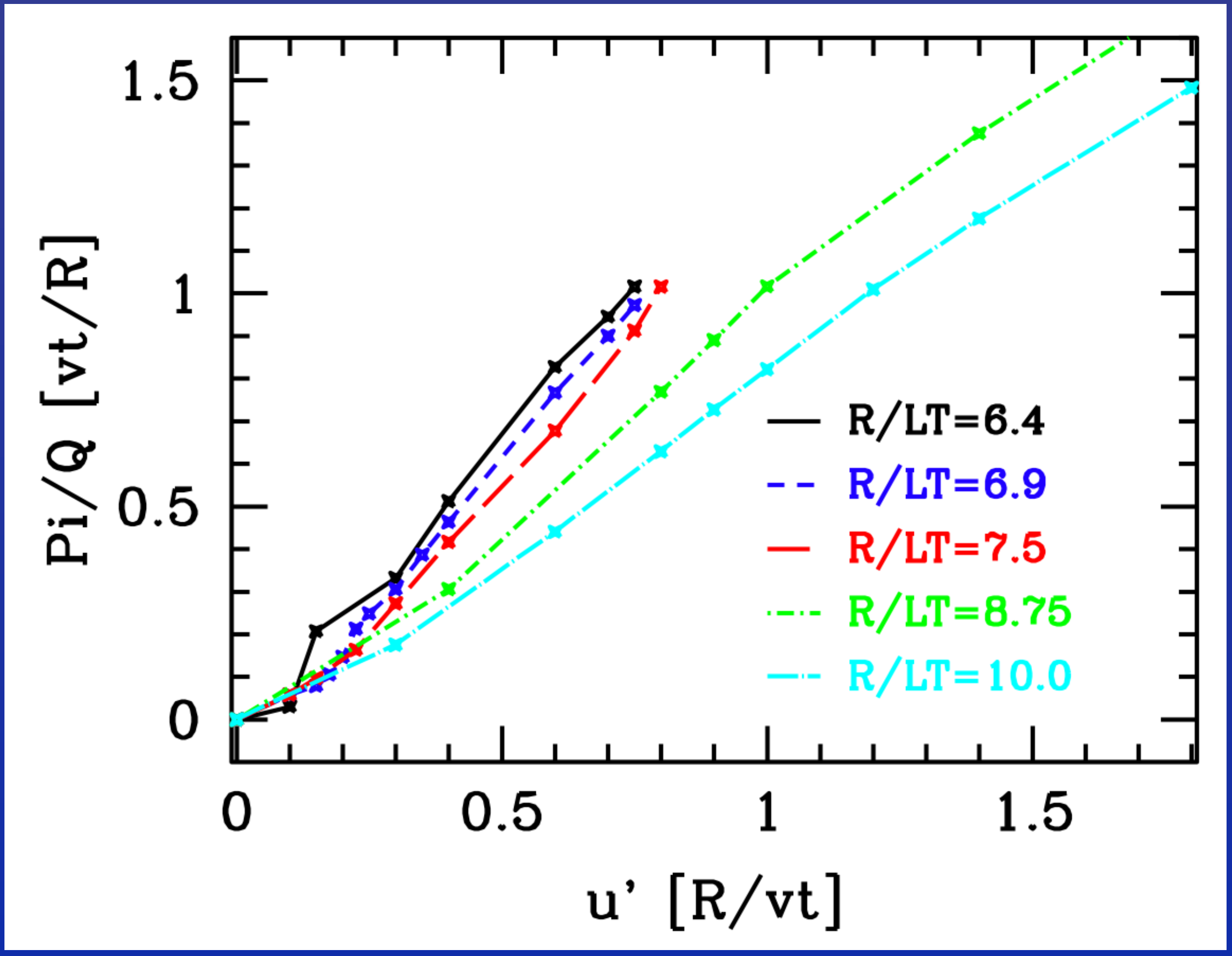
u'=0
u'=0.1
u'=0.15
u'=0.3
u'=0.6
u'=0.8
u'=1.0
u'=1.4
Q [Q-gb]
R/LT

Results: momentum flux

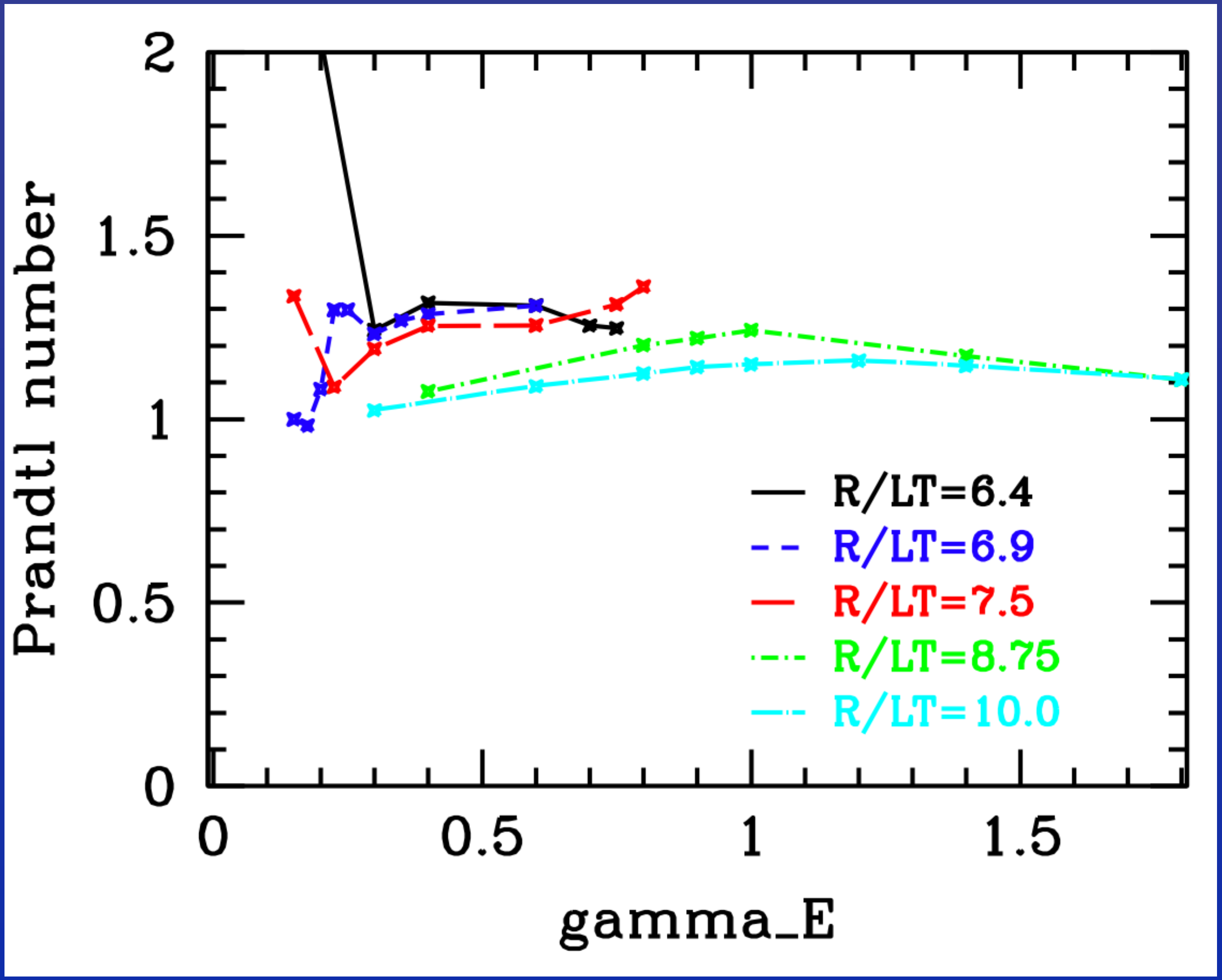
$$\Pi = \int d^3v \, (mR^2 \mathbf{v} \cdot \nabla\phi) \left(\mathbf{v}_E \cdot \frac{\nabla\psi}{|\nabla\psi|} \right) \delta f$$



Results: flux ratio



Prandtl number



Conclusions

- Flow shear can both suppress and drive turbulent heat and momentum flux
- Subcritical turbulence present when flow shear sufficiently large
- Dependence of stiffness on flow shear nontrivial, but has general property that stiffness increases with flow shear when ITG dominant and decreases with flow shear when PVG dominant
- Empirically constant Prandtl number. Universality?