Stability of (Radially) Stratified (Thin) Disks

Bryan Johnson and Charles Gammie

University of Illinois at Urbana-Champaign

Physics of Astrophysical Outflows and Accretion Disks
KITP, Santa Barbara, CA

May 27, 2005

Background

• Motivation: investigate recent claims of a local, hydrodynamic instability in radially-stratified Keplerian disks (Klahr & Bodenheimer 2003, Klahr 2004: the "Global Baroclinic Instability")

• Klahr & Bodenheimer (2003) performed global simulations with a radial entropy gradient (locally unstable to convection in the absence of shear), observed vortices and outward angular momentum transport in the presence of shear

• Such a mechanism could be extremely important for understanding accretion in low-ionization disks

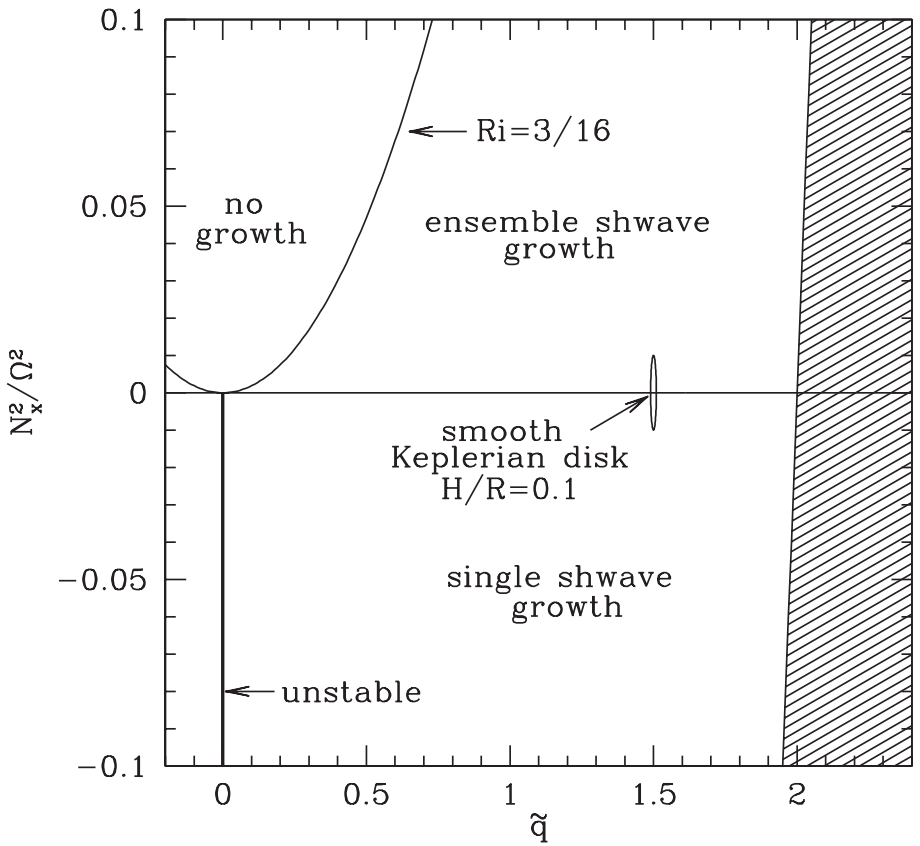
• These results are surprising since the shear rate is much higher than the growth rate of convective instability

11. Is the "Global Baroclinic Instability" a local instability?

    i.e.,

    Is convective instability stabilized by differential rotation?

Linear Theory Results

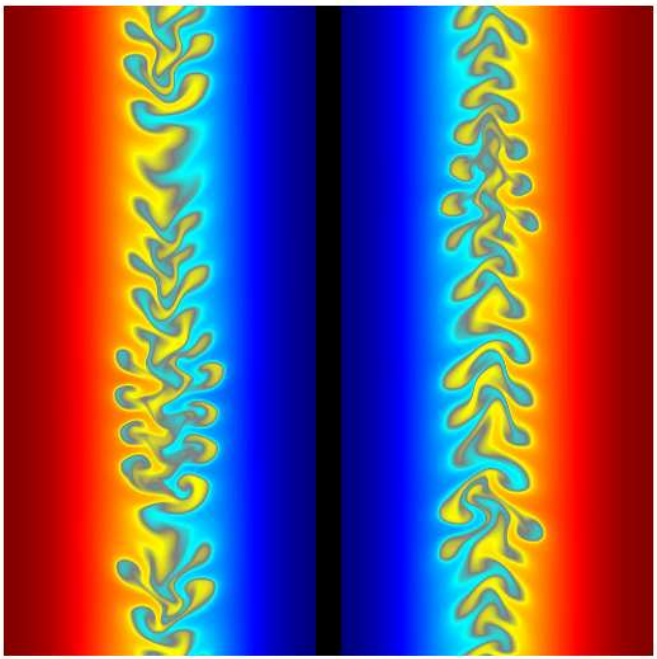


$$N_x^2 \equiv -\frac{c_s^2}{L_S L_P}$$

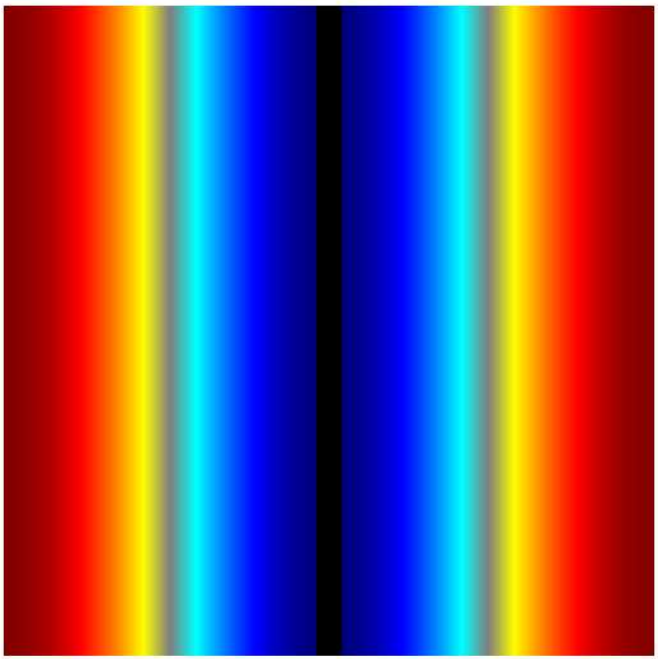
$$\tilde{q} \simeq -\frac{d\ln\Omega}{d\ln r}$$

$$\mathrm{Ri} \equiv \frac{N_x^2}{(\tilde{q}\Omega)^2}$$

Nonlinear Results

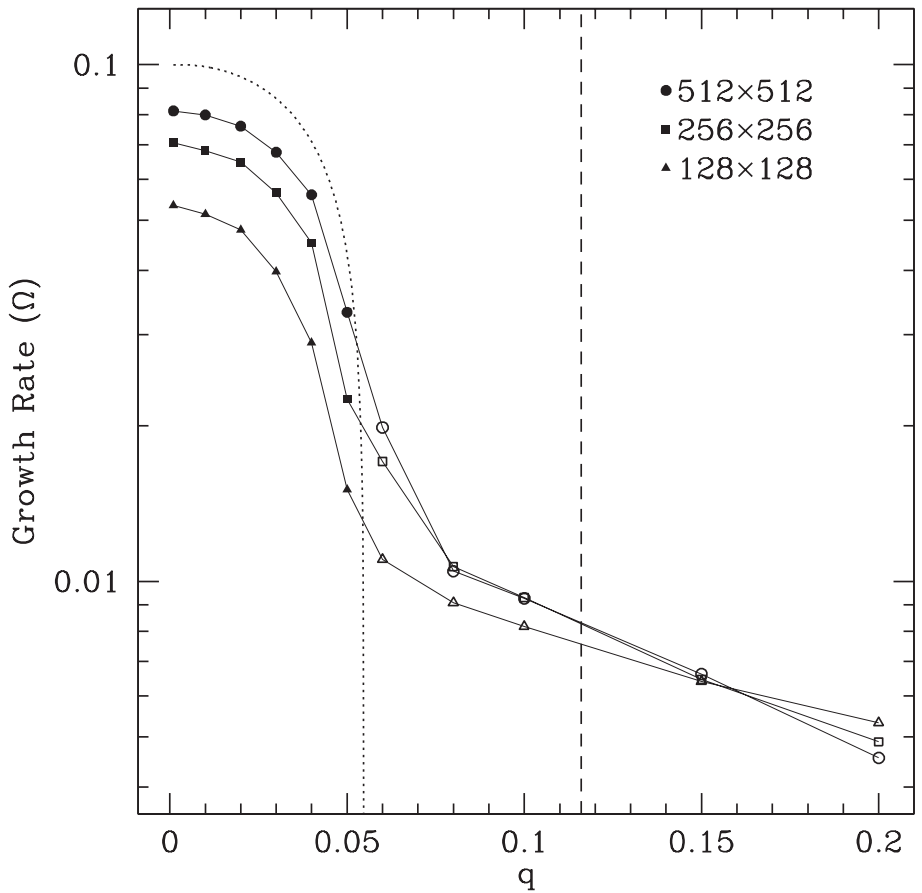


$q = 0$

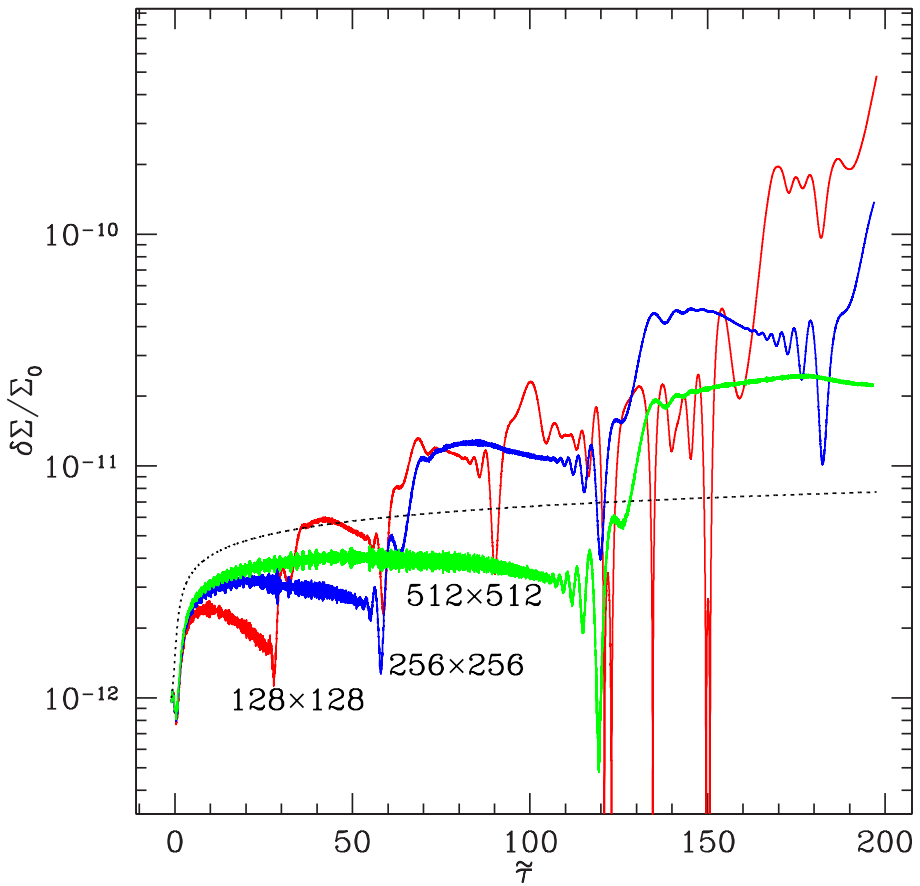


$q = \frac{3}{2}$

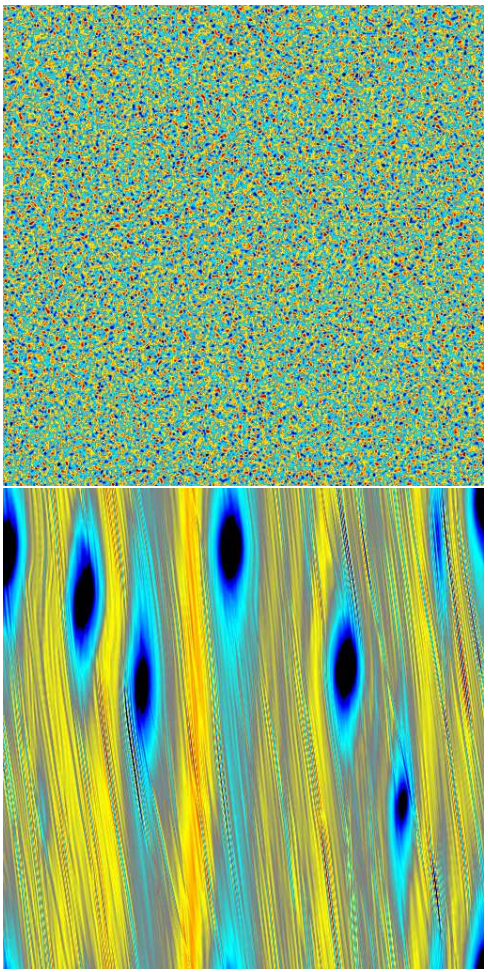
Suppression of Convective Instability by Shear



Numerical Growth Due to Aliasing

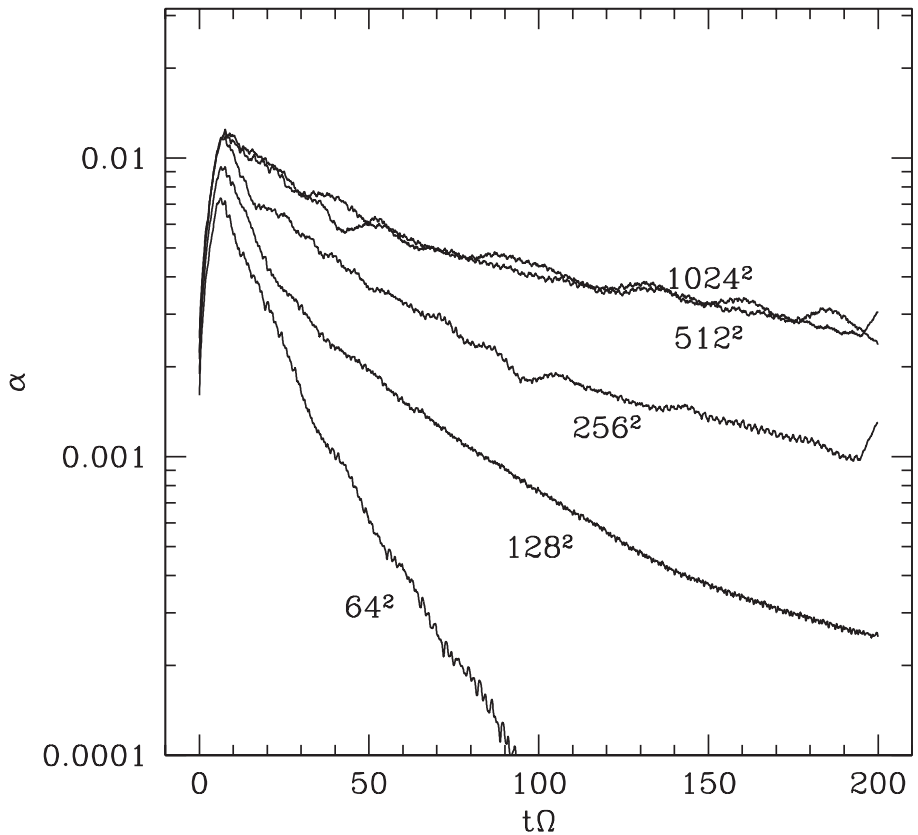


Vortices Driving Compressive Waves



- Nonlinear vortical perturbations result in long-lived vortices that generate compressive waves
- Compressive waves provide an outward flux of angular momentum that decays as $t^{-1/2}$
- These are 2D vortices, likely to be unstable in 3D (Kerswell 2002, Barranco & Marcus 2005)
- Strong vertical stratification away from the midplane may stabilize 2D vortices

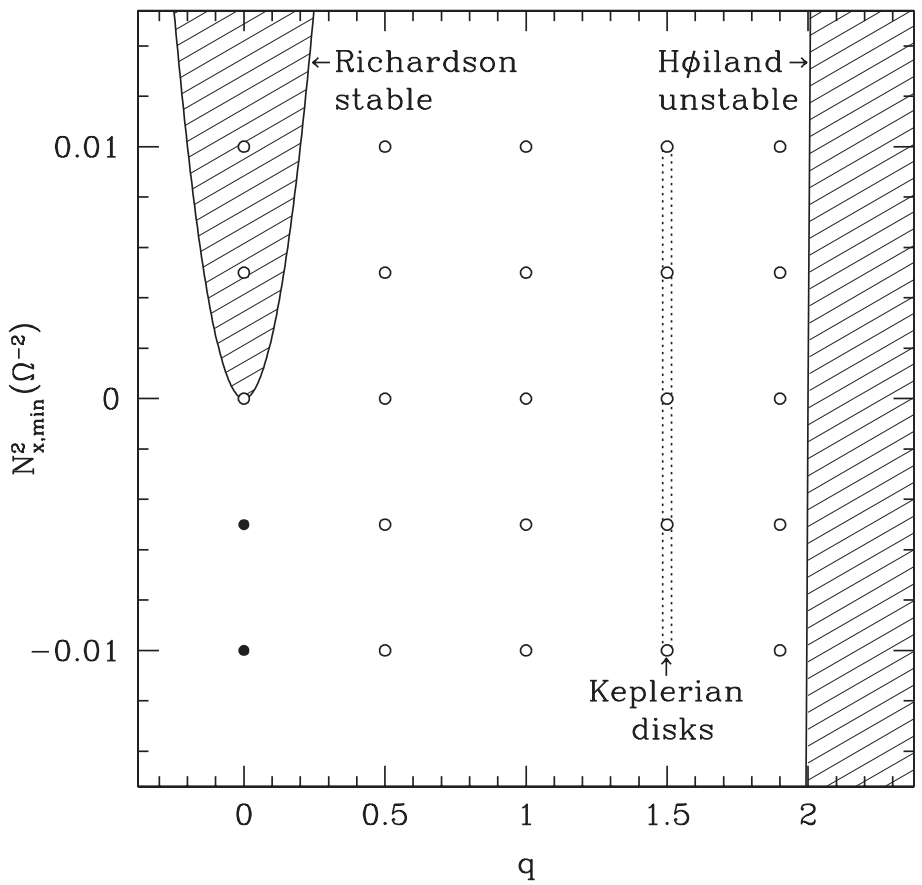
Transport due to Compressive Waves



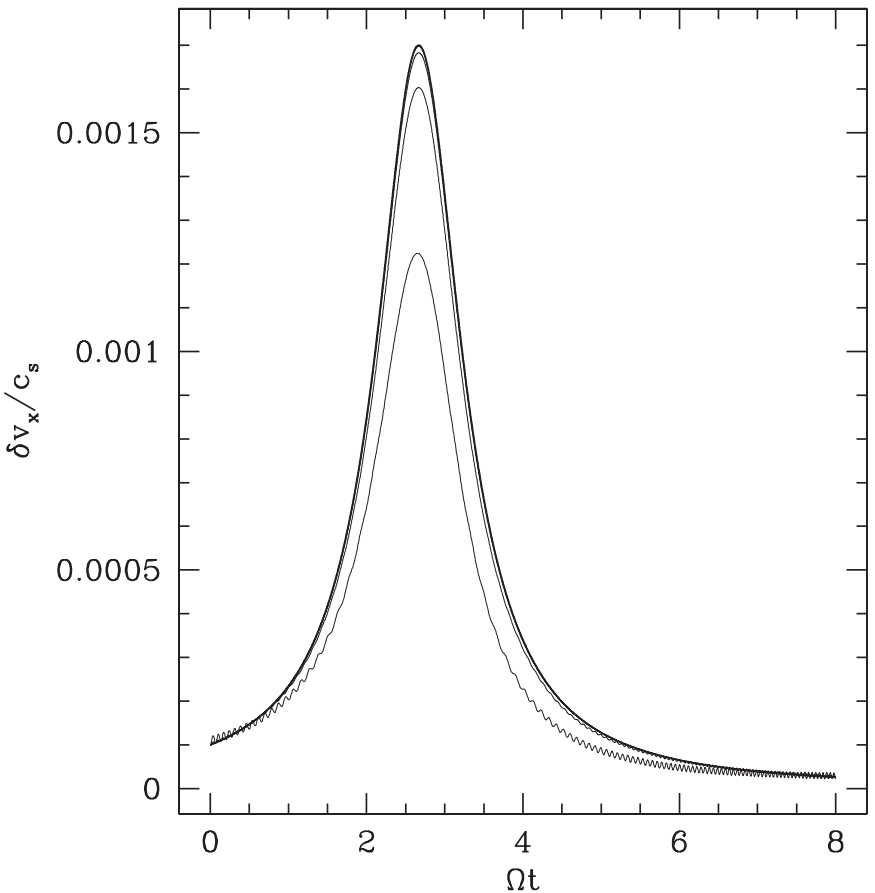
Summary

- Is convective instability stabilized by differential rotation? Yes.
- No evidence for nonlinear instability in local simulations
- "Global Baroclinic Instability" is either global or nonexistent
- Vortices driving compressive waves can provide a significant, albeit decaying, flux of angular momentum

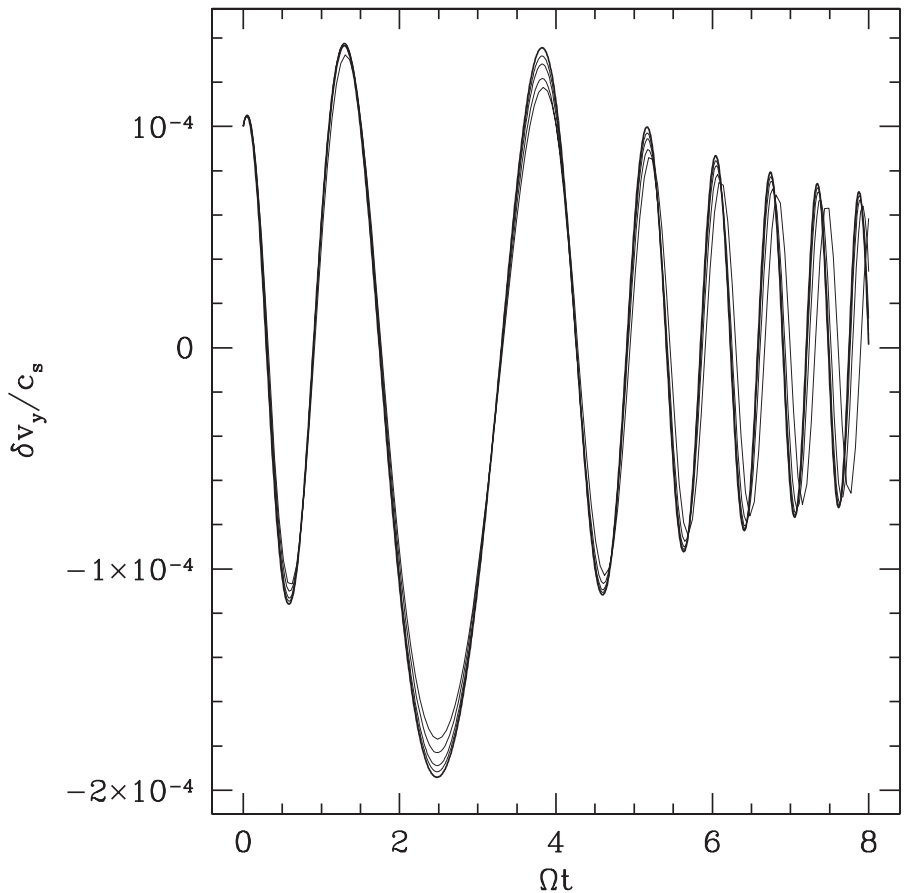
Nonlinear Parameter Survey



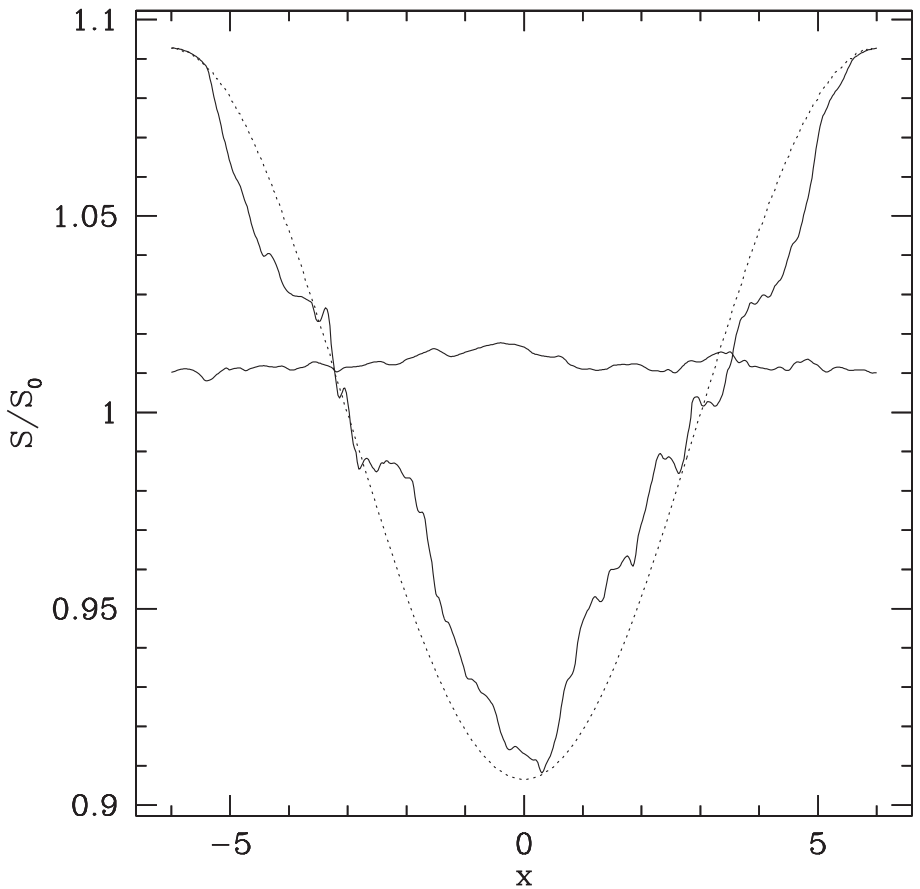
Linear Theory Test: Incompressive Perturbation



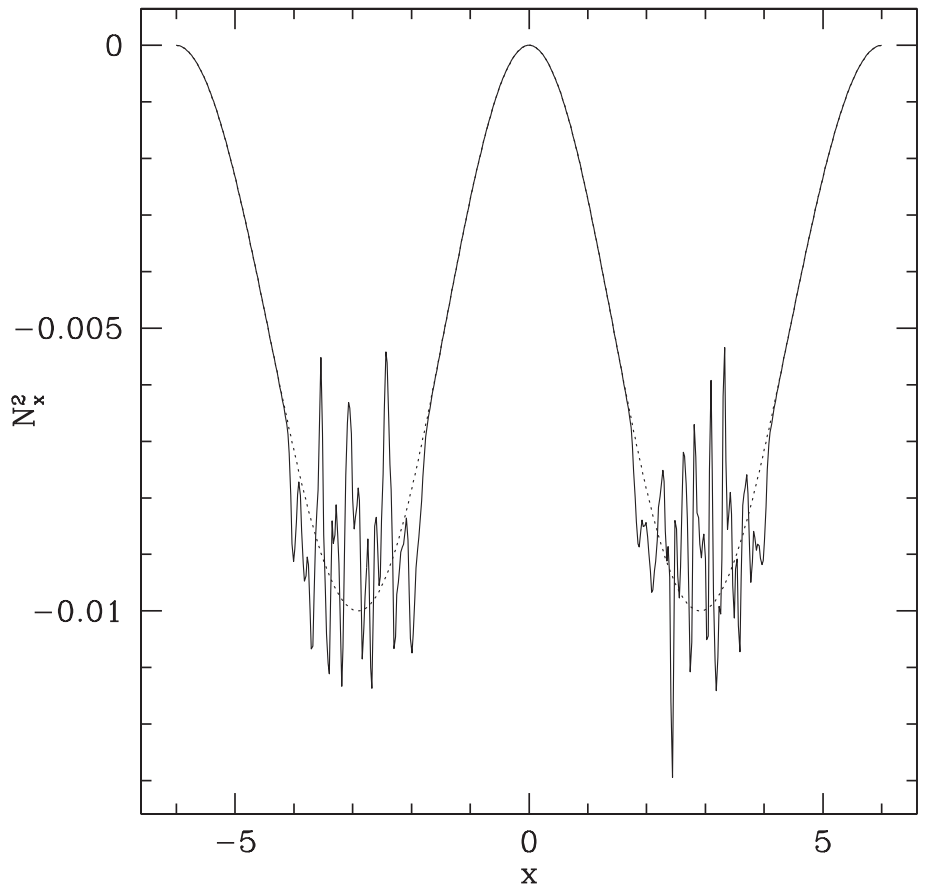
Linear Theory Test: Compressive Perturbation



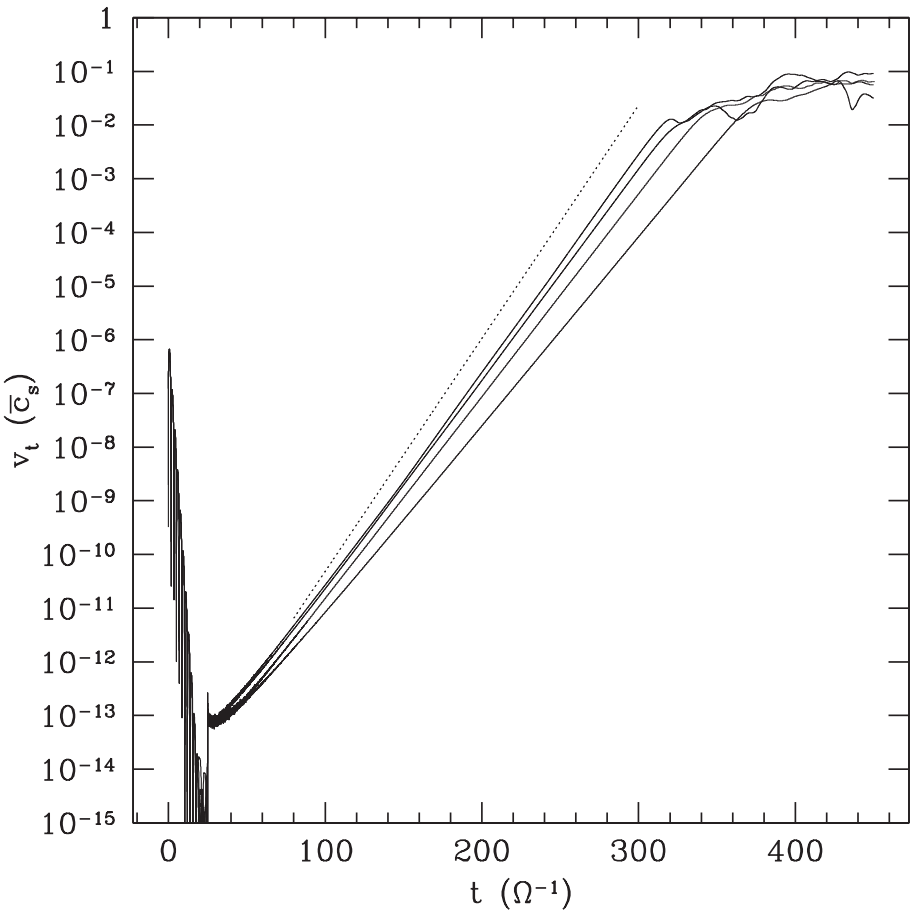
Radial Entropy Profile



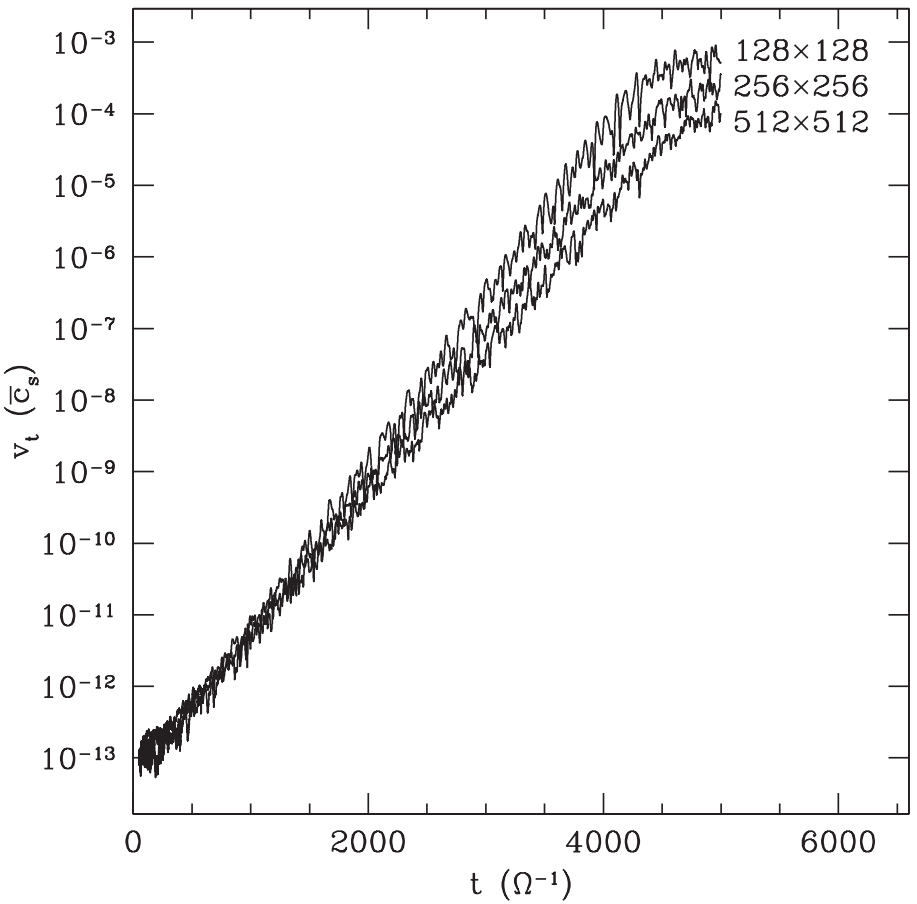
Radial Brunt-Väisälä Frequency



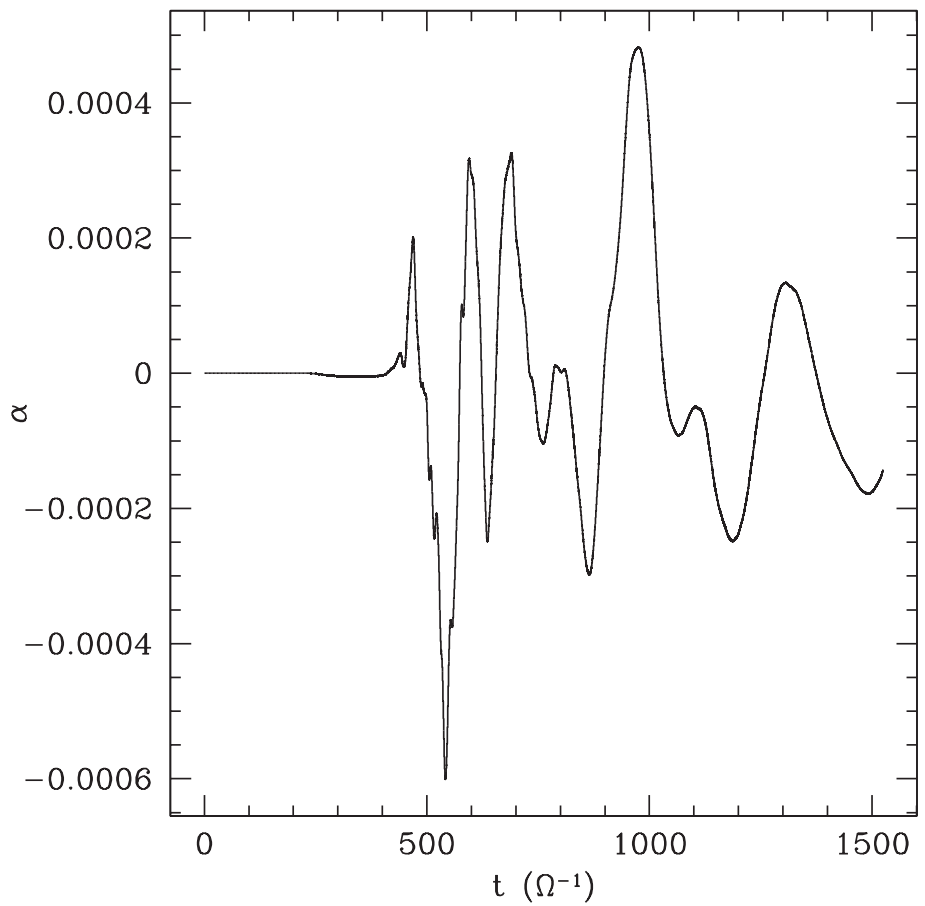
Growth Rate Measurement with $q = 0$



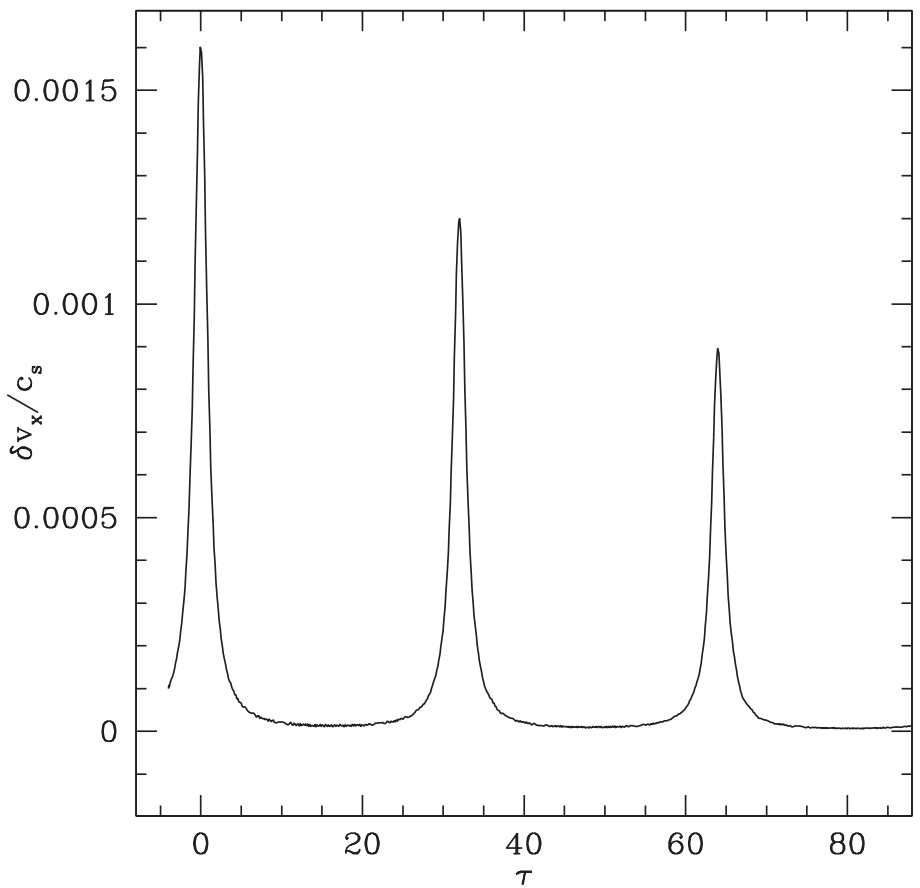
Growth Rate Measurement with $q = 0.2$



Transport due to Convection



Aliasing



Potential Vorticity and Velocity Divergence