Generation of the mean flows by anisotropic forced turbulence

Atefeh

Study NSSL

How does the NSSL form?

It has 2 major properties

- $\rho = \rho' + \overline{\rho}$
- $\boldsymbol{U} = u + \overline{\boldsymbol{U}}.$

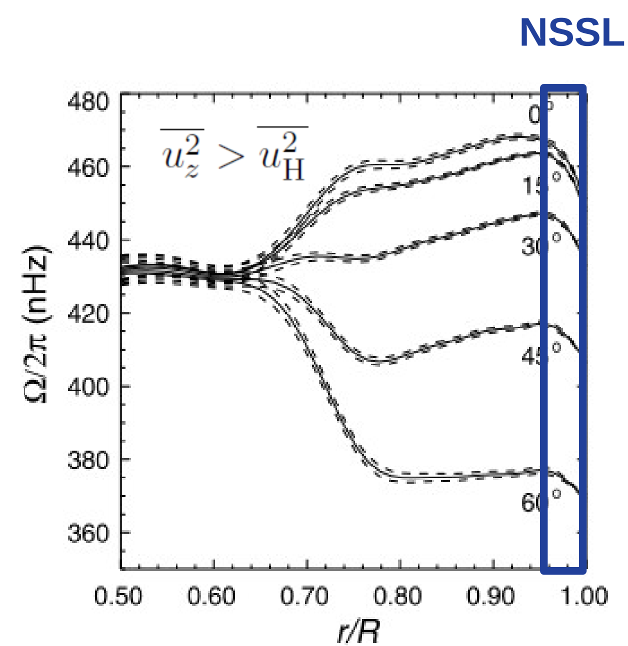
$$Q_{ij} = \overline{u_i u_j}$$

$$\partial_t(\overline{\rho' u_i} + \overline{\rho}\overline{\boldsymbol{U}}_i) + \partial_j(\overline{\rho' u_i u_j} + \overline{\rho' u_j}\,\overline{\boldsymbol{U}}_i + \boxed{\overline{\rho}\,\overline{u_i u_j}} + \overline{\rho' u_i}\,\overline{\boldsymbol{U}}_j) = \ldots$$

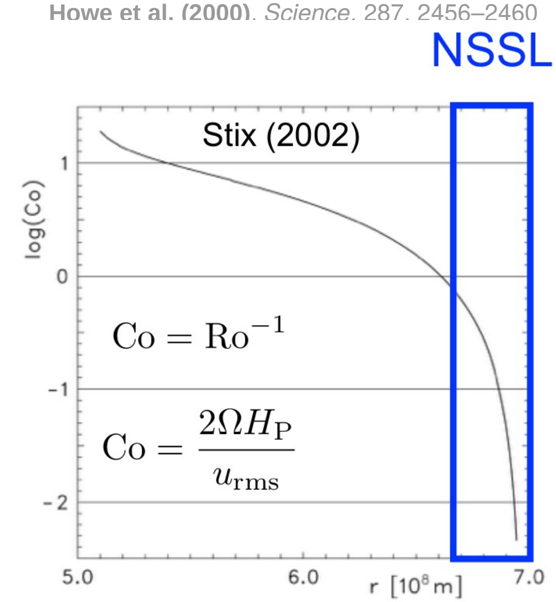
$$Q_{ij} = Q_{ij}^{(\nu)} + Q_{ij}^{(\Lambda)}$$

$$Q_{yz} = -\nu_{\parallel}\frac{\partial \overline{\boldsymbol{U}}_y}{\partial z} + \boxed{\nu_{\parallel} V \sin\theta\Omega,}$$

$$Q_{xy} = \nu_{\perp}\Omega^2 \sin\theta\cos\theta\frac{\partial \overline{\boldsymbol{U}}_y}{\partial z} + \boxed{\nu_{\parallel} H \cos\theta\Omega}$$



Howe et al. (2000). *Science*, 287, 2456–2460



Simulation setup

$$\frac{D\ln\rho}{Dt} = -\boldsymbol{\nabla}\cdot\boldsymbol{U} \qquad p = c_s^2\rho$$

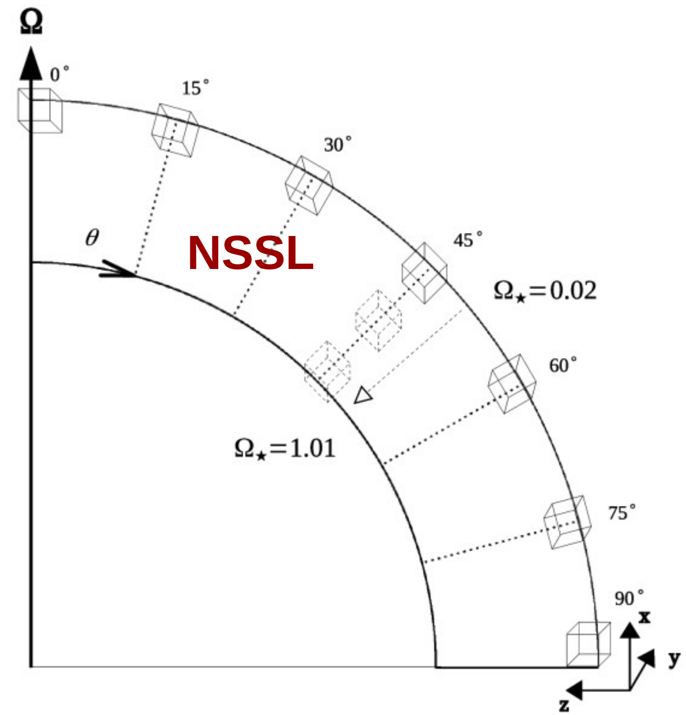
$$\frac{D\boldsymbol{U}}{Dt} = -c_s^2\boldsymbol{\nabla}\ln\rho + \boldsymbol{F}^{\mathrm{visc}} + \boldsymbol{F}^{\mathrm{Coriolis}} + \boxed{\boldsymbol{F}}$$

Brandenburg, A., & Rekowski, B. V. 2001, A&A, 379, 1153

$$\boxed{F(\boldsymbol{x},t) = \Re(\mathbf{N}\cdot\boldsymbol{f}_{\boldsymbol{k}(t)}\exp[i\boldsymbol{k}(t)\cdot\boldsymbol{x} - i\phi(t)])}$$

$$\mathbf{N} = (f_0\delta_{ij} + \delta_{iz}\cos^2\Theta_k f_1/f_0)(kc_s^3/\delta t)^{1/2}$$

$$\boldsymbol{f}_{\boldsymbol{k}} = \frac{\boldsymbol{k}\times\hat{\boldsymbol{e}}}{\sqrt{\boldsymbol{k}^2 - (\boldsymbol{k}\cdot\hat{\boldsymbol{e}})^2}}$$



par	value
L	2π
n	144
ν	10^{-3}
c_s	3
k_f	10
f_0	10^{-6}
f_1	0.04

Measure Lambda-effect

par	value
k_f	10
$u_{\rm rms}$	0.13
Re	13
Ma	0.04

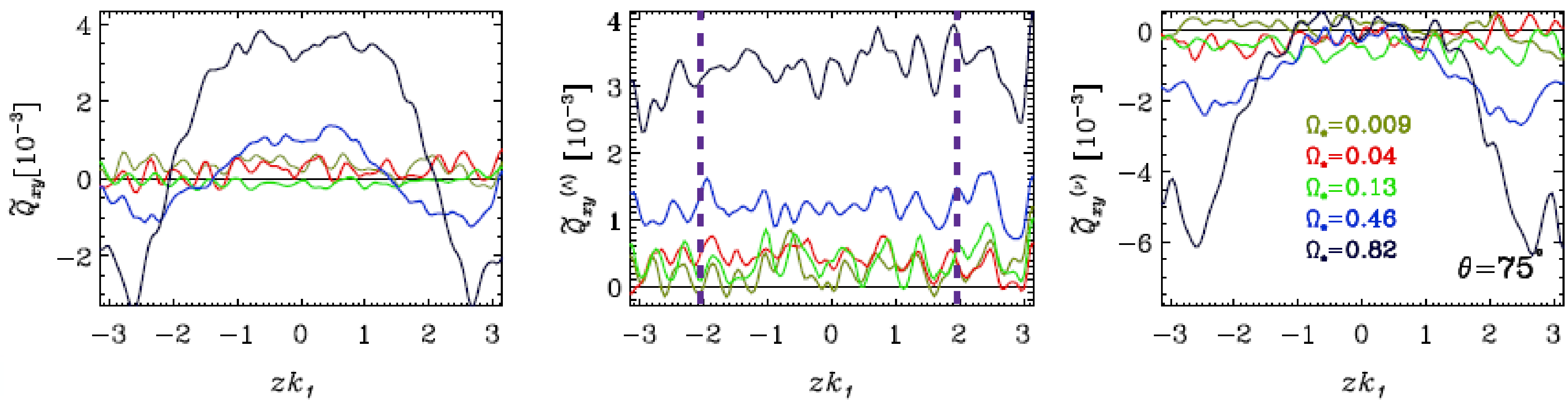
Suppress the mean flow

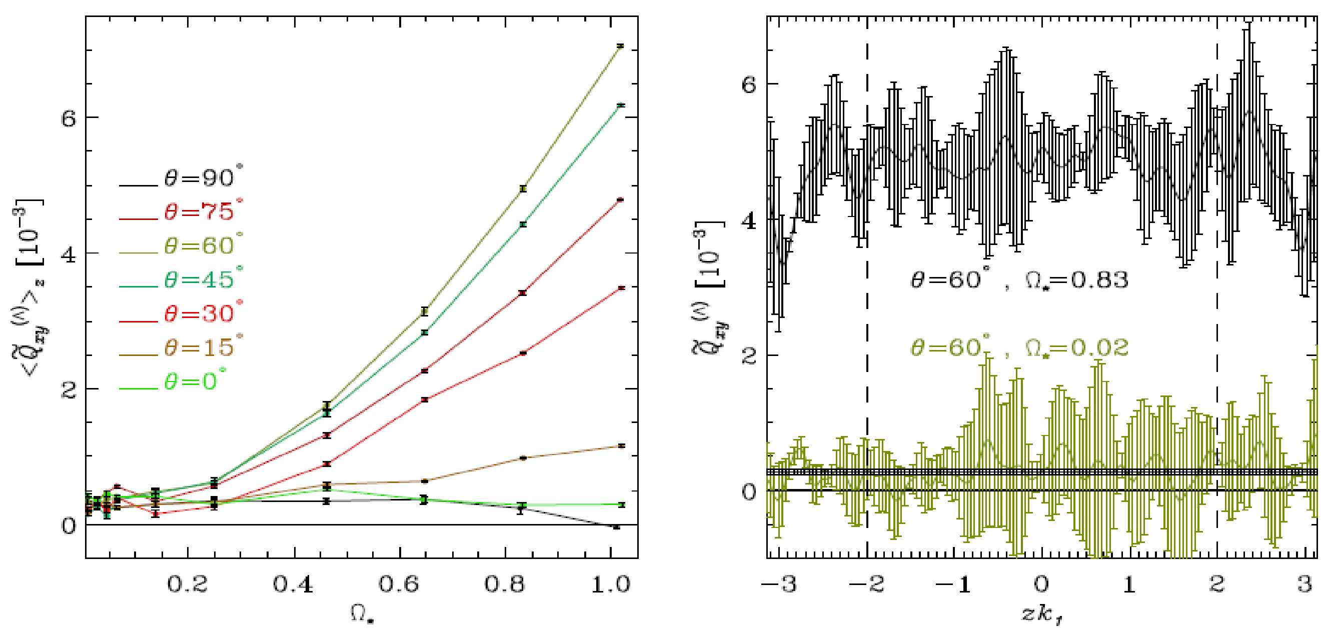
```
&hydro_run_pars
  Omega=0.007
  theta=45.
  lupw_uu=T
  lcalc_uumeanz=T
  lremove_uumeanz_horizontal=T
```

$$Q_{yz} = -\cancel{\nu_{\|} \frac{\partial \overline{U}_y}{\partial z}} + \boxed{\nu_{\|} V \sin\theta\Omega,}$$

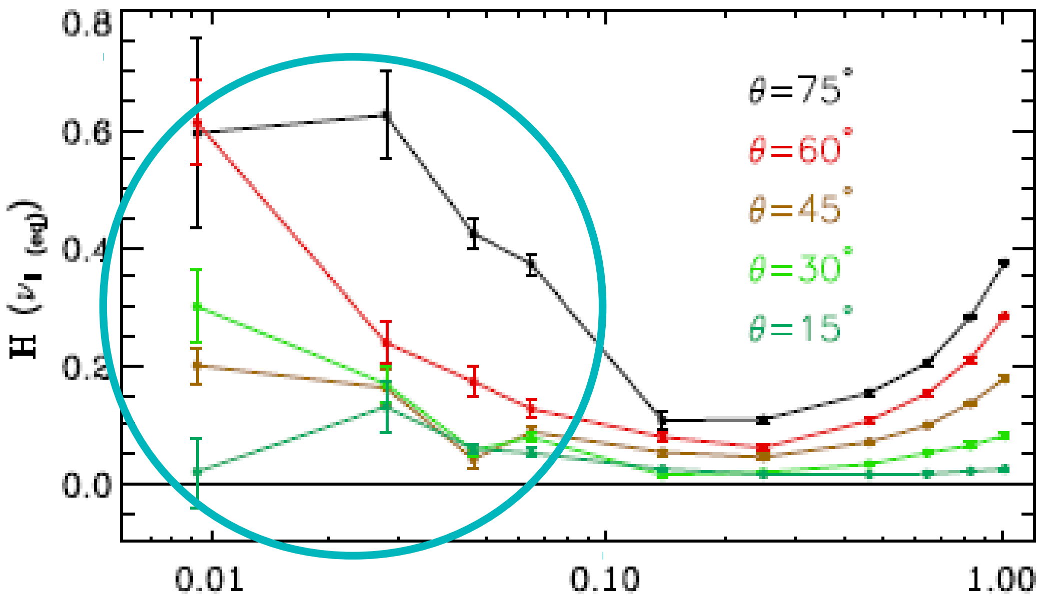
$$\boxed{Q_{xy} = \nu_{\perp}\Omega^2 \sin\theta \cos\theta \cancel{\frac{\partial \overline{U}_y}{\partial z}} + \boxed{\nu_{\|} H \cos\theta\Omega}}$$

$$Q_{xy} = \nu_\perp \Omega^2 \sin\theta \cos\theta \frac{\partial \overline{U}_y}{\partial z} + \nu_\parallel H \cos\theta \Omega$$





Measuring H



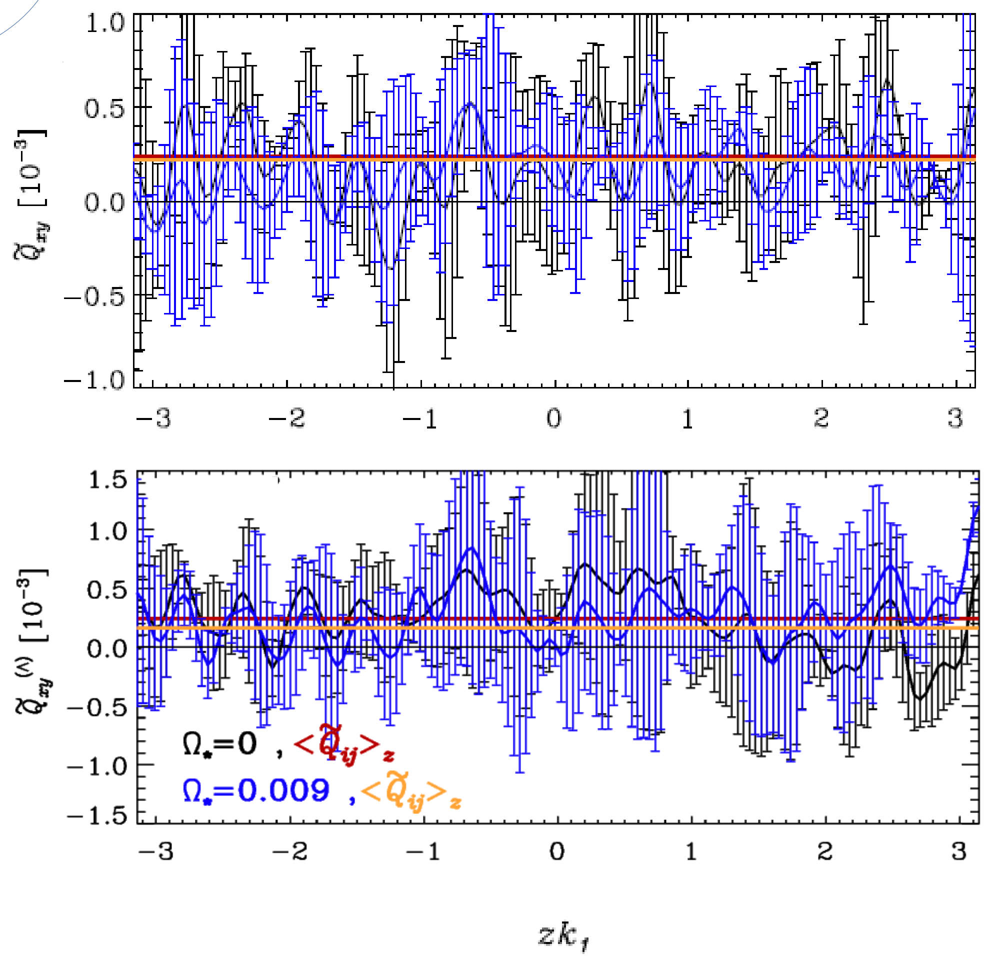
H is larger at low Co numbers!!!!!

$$\widetilde{Q}_{xy}^{(\Lambda)}$$

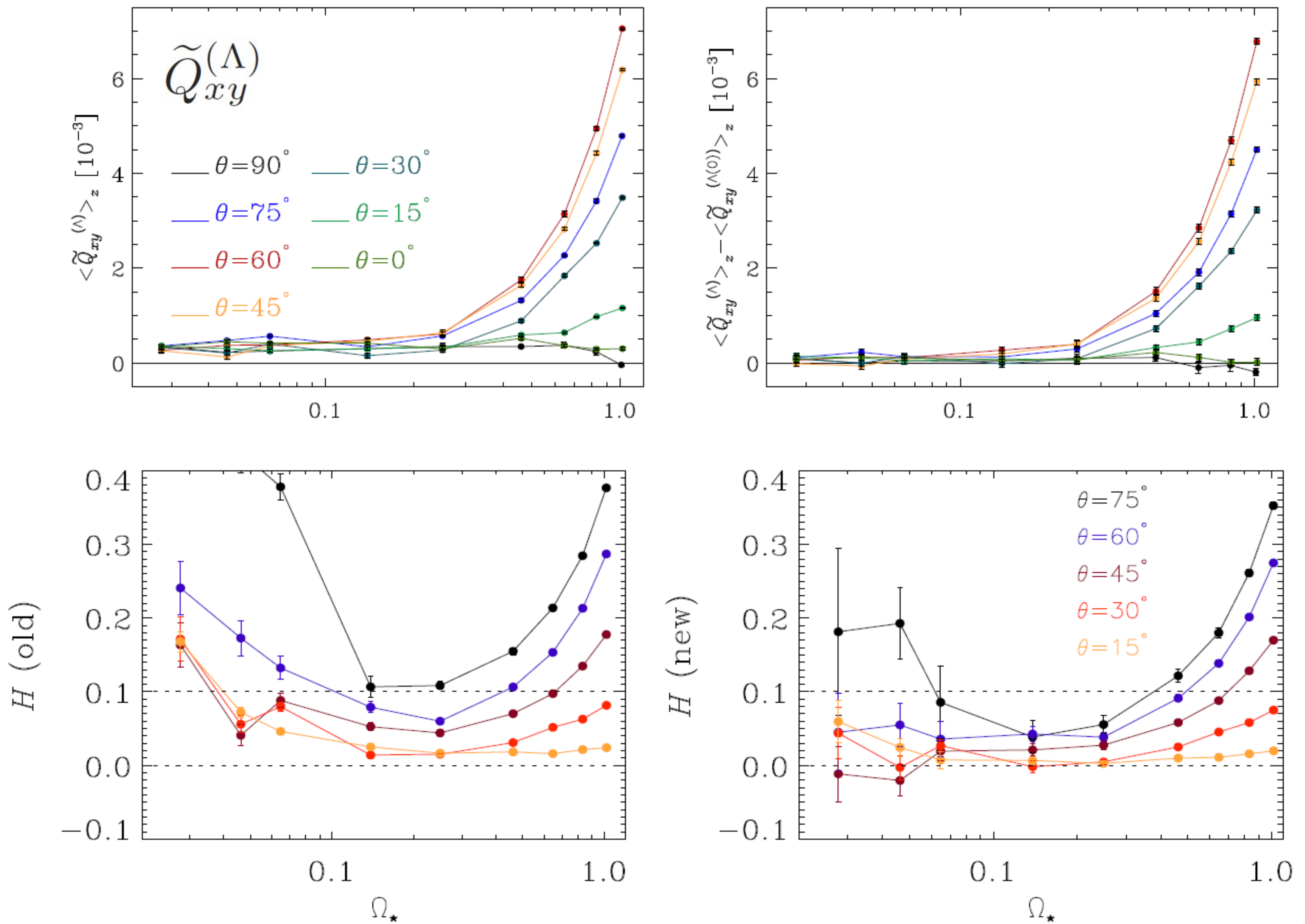
$$\Omega = 0$$

$$Q_{xy} = \cancel{\nu_\perp \Omega^2 \sin\theta \cos\theta \frac{\partial \overline{U}_y}{\partial z}} + \cancel{\nu_\parallel H \cos\theta \Omega}$$

Ω_0	$\Omega_\star$	$\widetilde{Q}_{xy}$	$\widetilde{Q}_{xy}^{(\Lambda)}$
0	0	0.238104	0.244643
0.001	0.009	0.338522	0.164727
0.003	0.02	0.261769	0.356681
0.005	0.04	0.289093	0.472252
0.007	0.06	0.082576	0.562727
0.015	0.13	-0.13879	0.338895
0.027	0.24	-0.08081	0.567694
0.05	0.46	0.480126	1.31954
0.07	0.64	1.53806	2.26650
0.09	0.83	2.88850	3.41278
0.11	1.01	4.47025	4.78796



Correction



$\widetilde{Q}_{xy}^{(\Lambda)}$
θ=90°
θ=30°
θ=75°
θ=15°
θ=60°
θ=0°
θ=45°
$<\widetilde{Q}_{xy}^{(\Lambda)}>_z$ [10^{-3}]
$<\widetilde{Q}_{xy}^{(\Lambda)}>_z - <\widetilde{Q}_{xy}^{(\Lambda(0))}>_z$ [10^{-3}]
H (old)
H (new)
θ=75°
θ=60°
θ=45°
θ=30°
θ=15°
$\Omega_\star$

What can be checked?

1. isotropic forcing with $\Omega = 0$?

2. higher kf?

3. higher Reynolds number?

Isotropic forcing

- Change the amplitude of forcing to get the same Re and kf=10

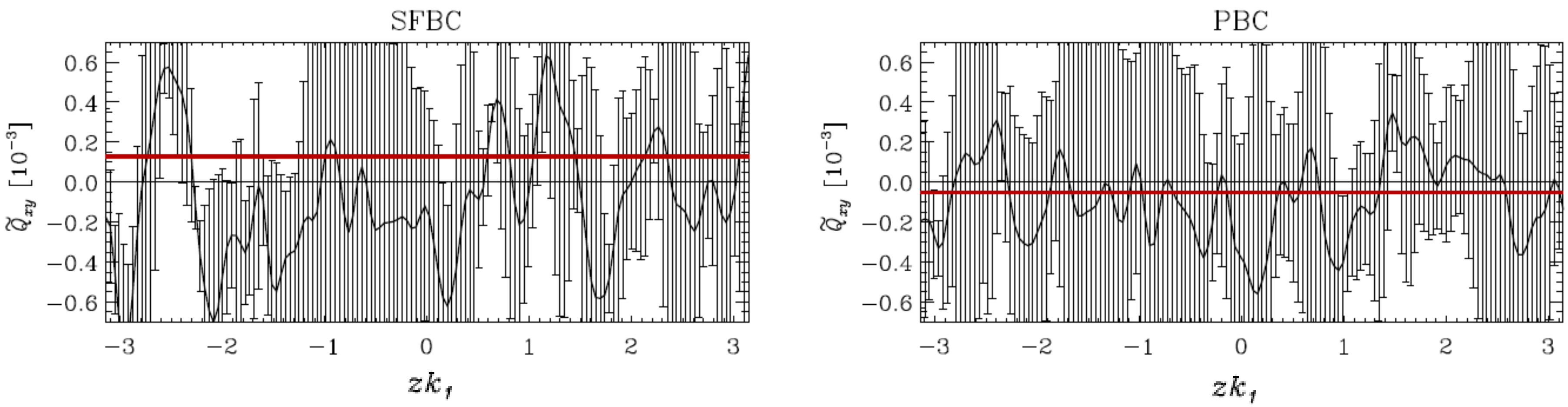


Figure 27: comparison of the Reynolds stress at $\Omega_0 = 0$ both stress-free BC (left panels) and periodic BC (right panels) runs using isotropic forcing. The red line shows the error-weighted mean of stresses.

isotropic

Stresses	SFBC	PBC
$< \tilde{Q}_{xy} >$	0.129018	−0.0515038
$\sigma(< \tilde{Q}_{xy} >)$	0.0327374	0.0496711

anisotropic (SFBC)

$\tilde{Q}_{xy}$	$\tilde{Q}_{xy}^{(\Lambda)}$
0.238104	0.244643

Higher kf & Re

k_f	nu	$u_{\rm rms}$	Re	Re(mesh)	τ
10	$1 \cdot 10^{-3}$	0.13	13	0.9	> 10000
10	$2 \cdot 10^{-4}$	0.17	85	5.9	11000
20	$5 \cdot 10^{-4}$	0.13	13	0.9	> 20000
30	$3 \cdot 10^{-4}$	0.13	15	0.8	> 10000
30	$1 \cdot 10^{-4}$	0.16	54	2.8	> 20000
30	$8 \cdot 10^{-5}$	0.17	69	3.6	> 20000

Re=13,13,15