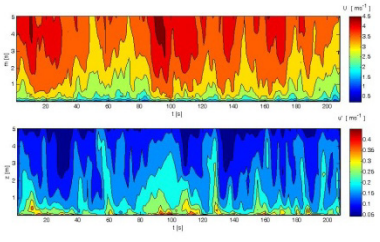
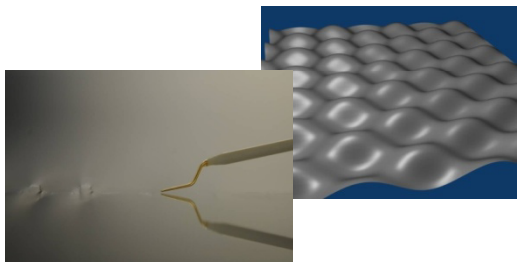
Very large scale motions in smooth and rough wall boundary layers

Beverley J. McKeon

Meredith Metzger (U. Utah), Michele Guala, Jeff LeHew, Ian Jacobi

Graduate Aerospace Laboratories,
California Institute of Technology





Outline

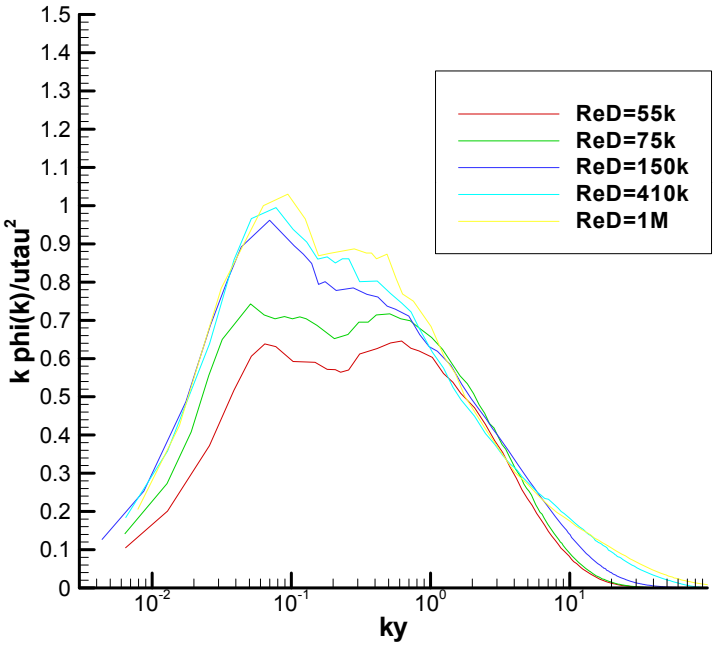
1. Background on the very large scales in wall turbulence

2. Sample transitionally rough wall results

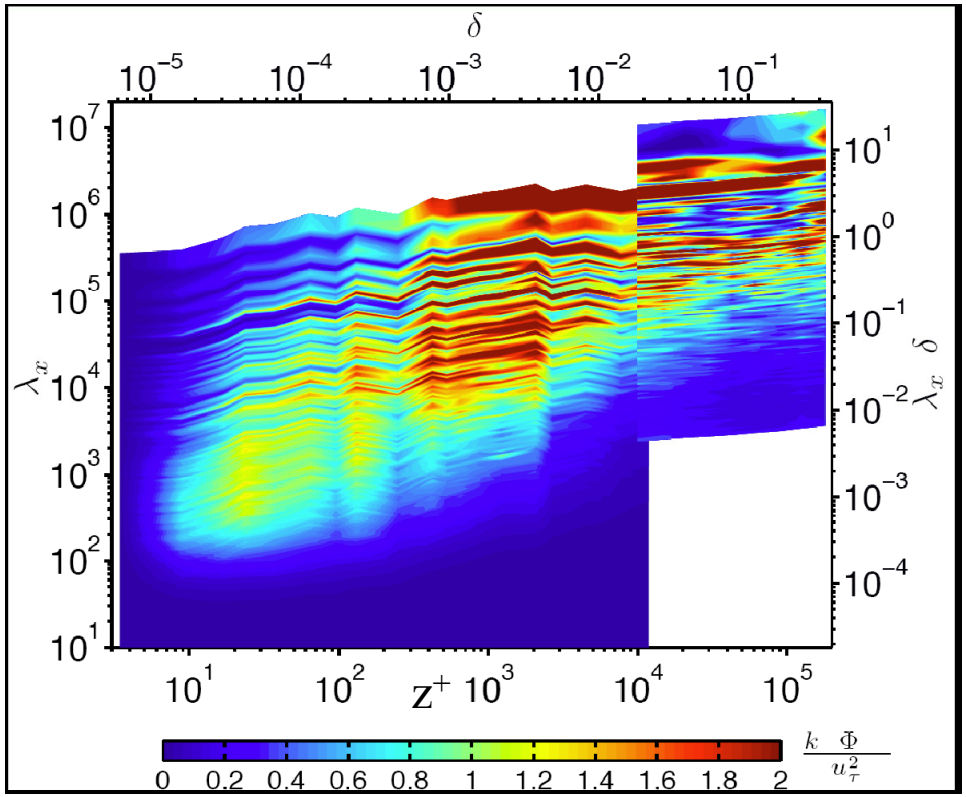
3. A means to manipulate the large-scale signature: "dynamic" roughness
   - Experiments on a spatial impulse of dynamic roughness
   - Simple model for dynamic roughness
   - DNS results

4. Conclusions

Observations of the very large scales



$R^+ = 1.5 \times 10^3 - 2 \times 10^4$



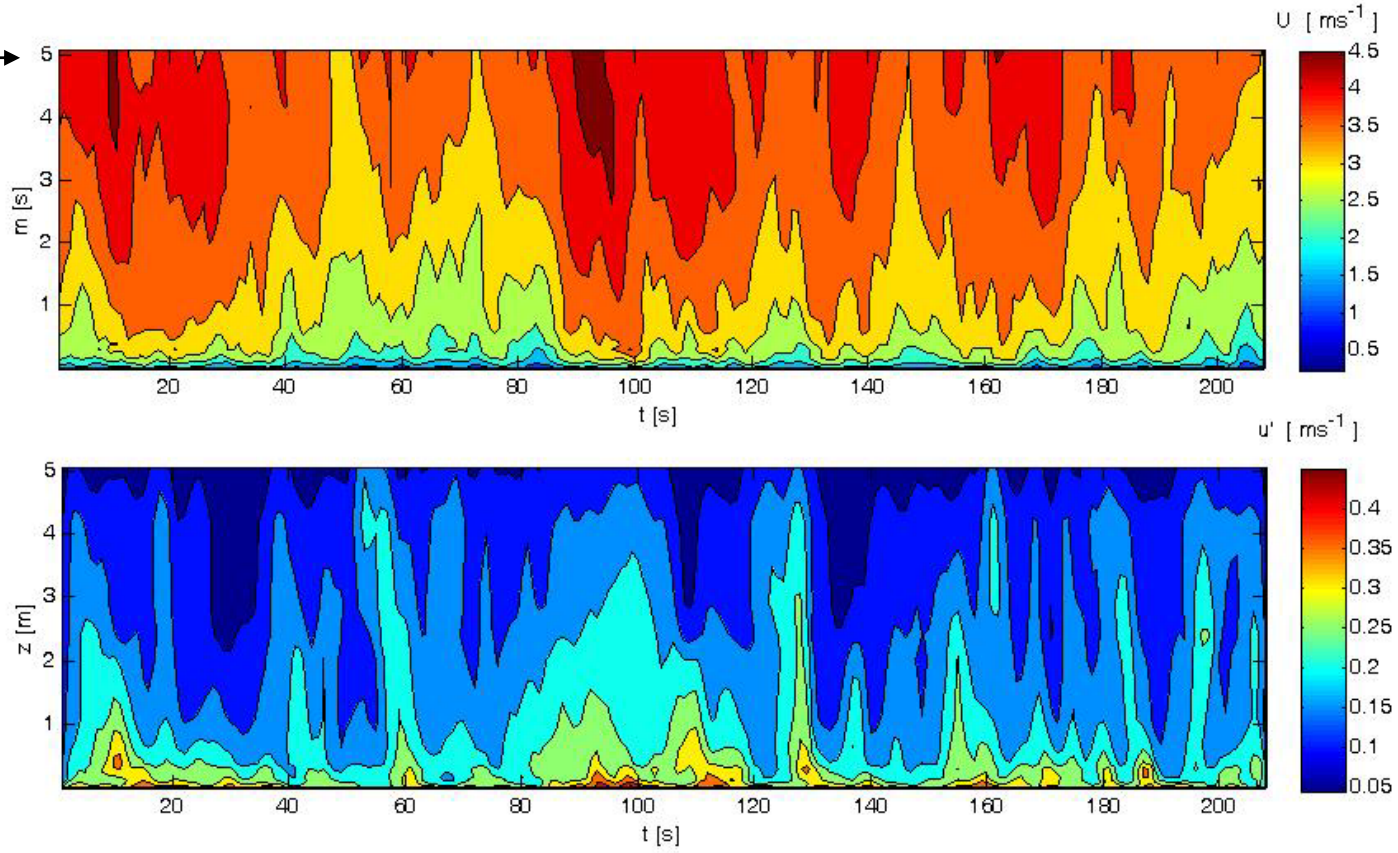
$\delta^+ = O(10^6)$

McKeon & Morrison; Metzger, McKeon & Holmes, PTRSA 365 (2007)

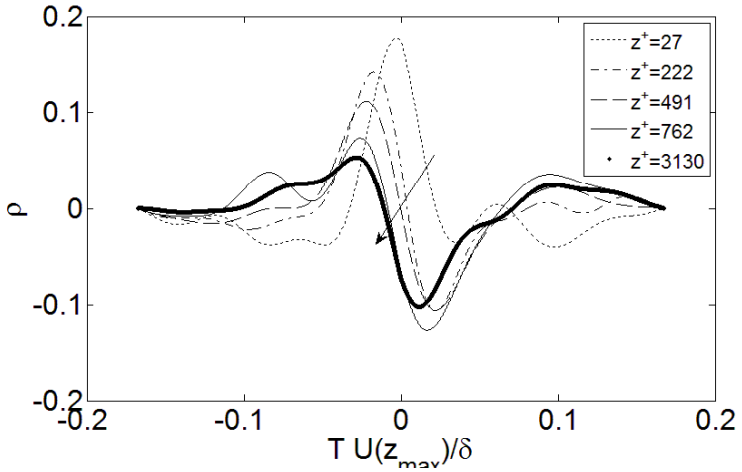
A visual picture (temporal records)

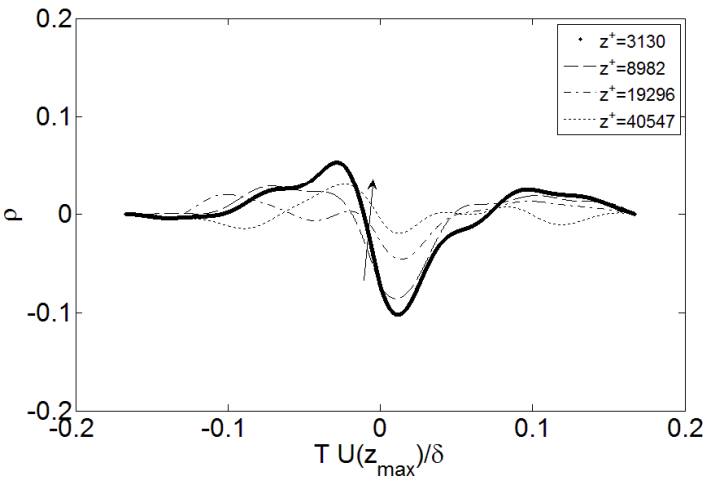
Sliding window – T=1s

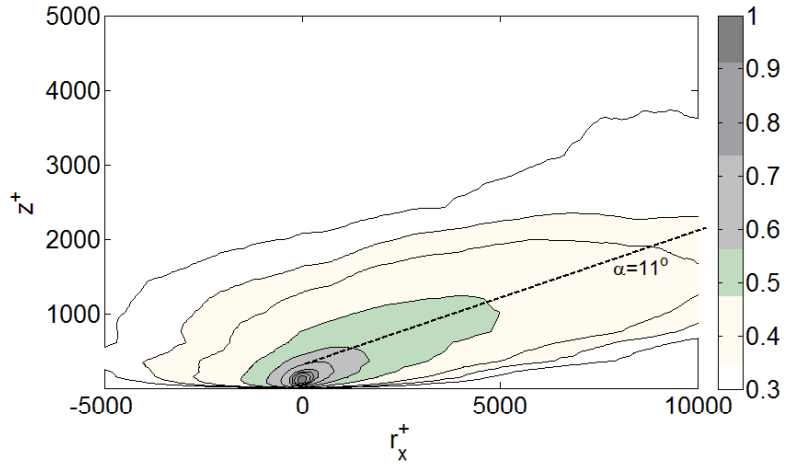
$z/\delta \sim 0.1 \longrightarrow$

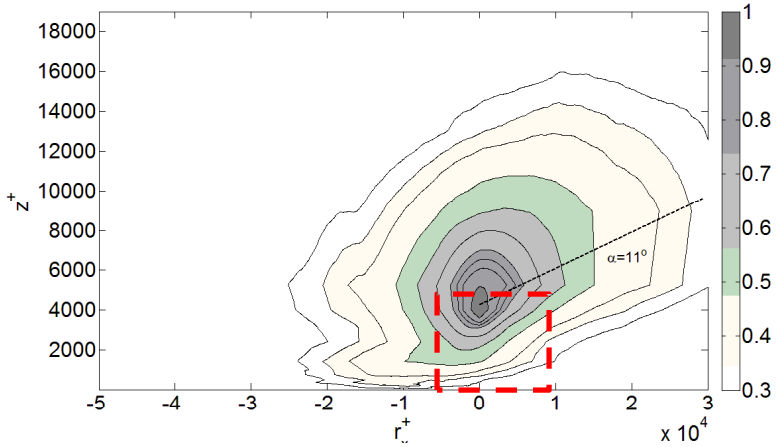


Statistical imprints of dominant motions









Statistical imprints of dominant motions

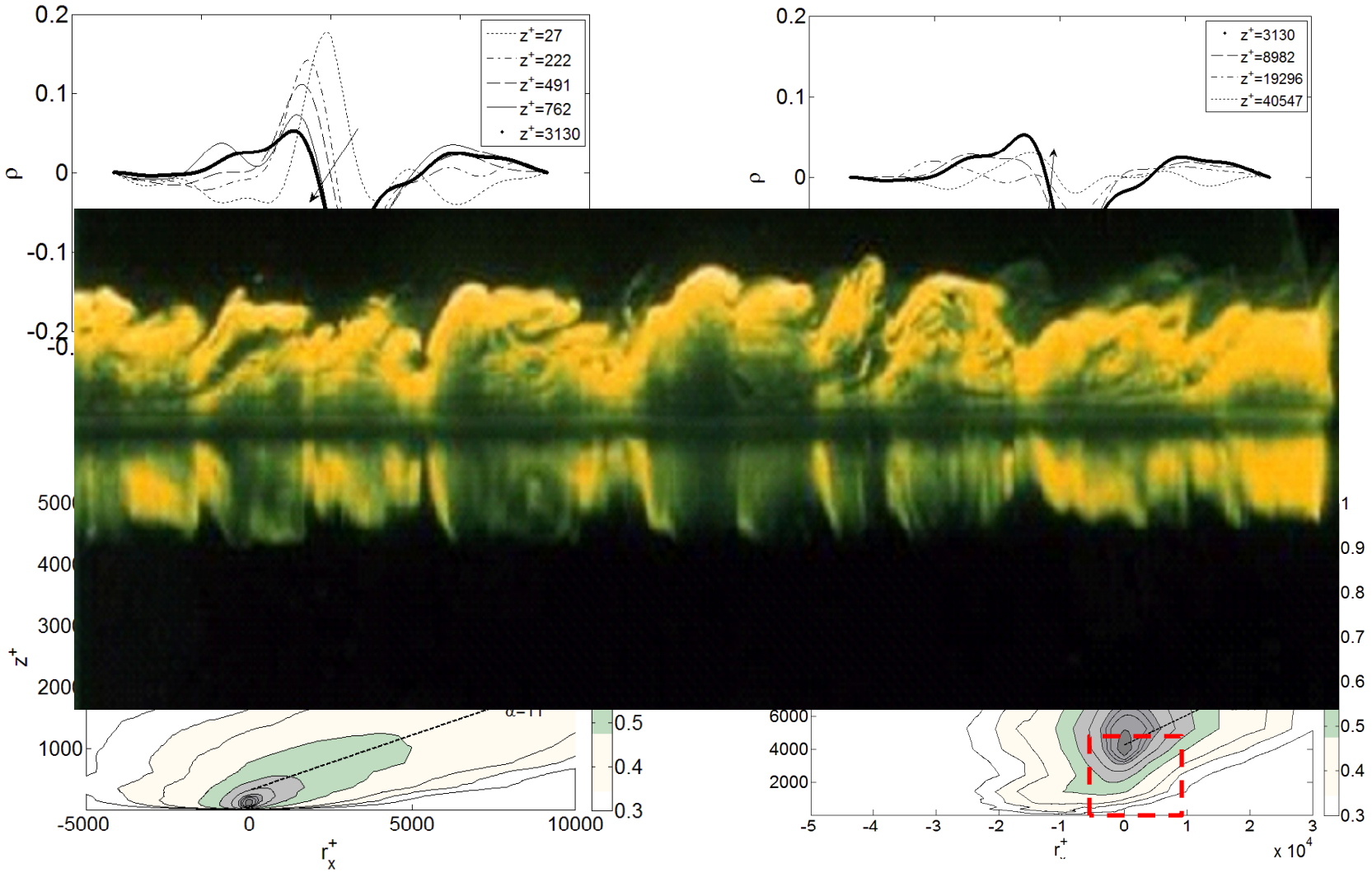
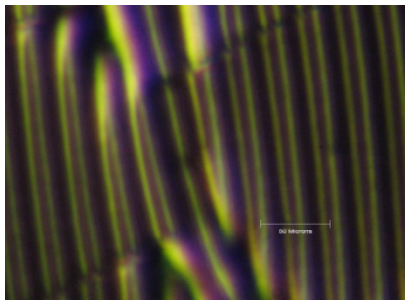


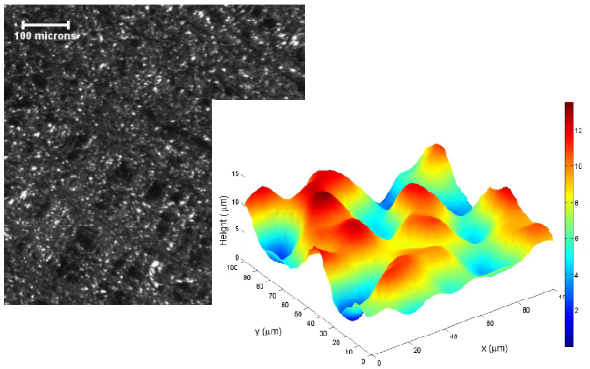
Image: M. Gad-el-Hak

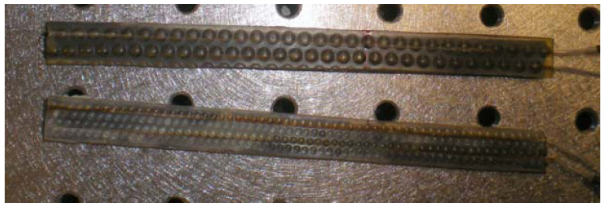
Manipulation of the large scales?

"Dynamic roughness": distributed uniform roughness elements with time-dependent amplitude

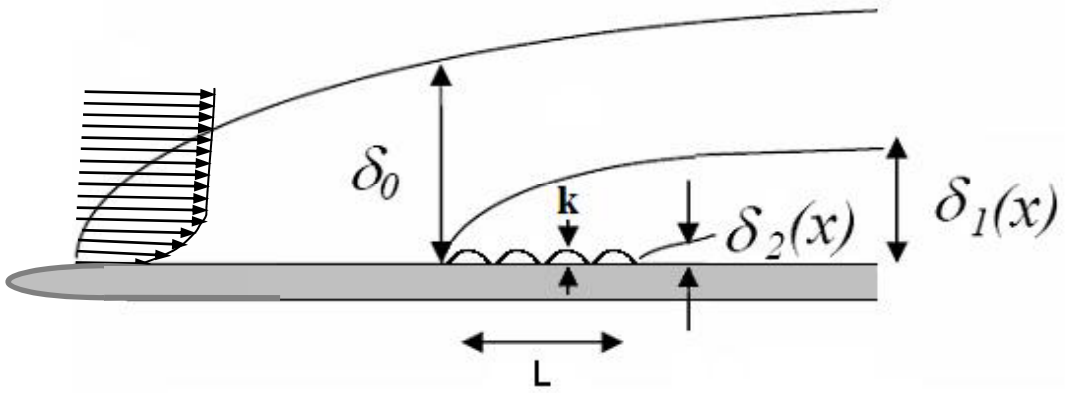
- *Why investigate?*
  - Control possibilities
  - On-demand (on/off) roughness
  - "What additional fundamental understanding of fluid physics can be gained from this new means of activation?"
  - Influence of roughness timescale
  - Structured energy injection





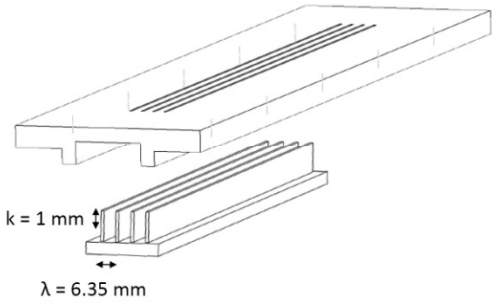


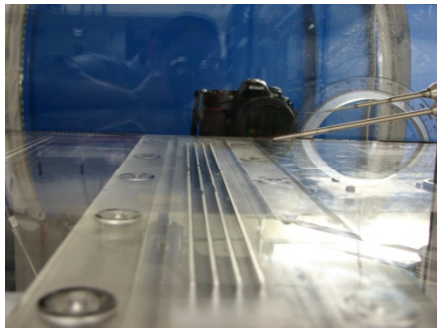
Spatial impulse of dynamic roughness

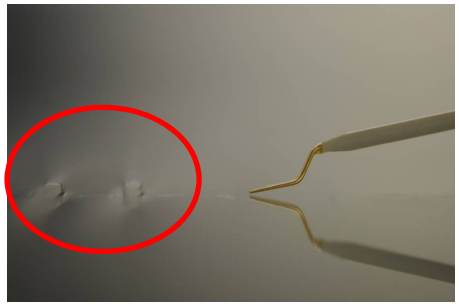


Mechanical approximation to “morphing surface”

- δ^+ = 1000 (at roughness location)
- Length of roughness element: L/δ = 2
- Roughness height, k/δ = 0.05 (k^+ ~ 50)
- Dynamic roughness frequency, fδ/U = 0.025

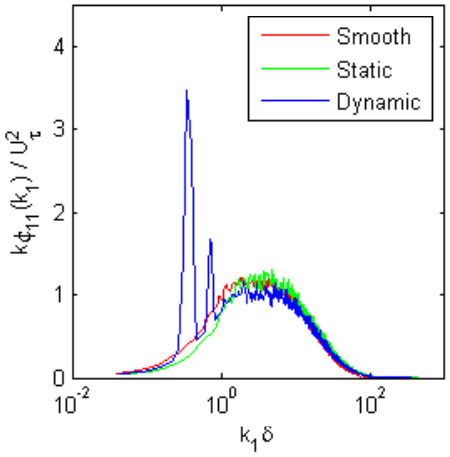


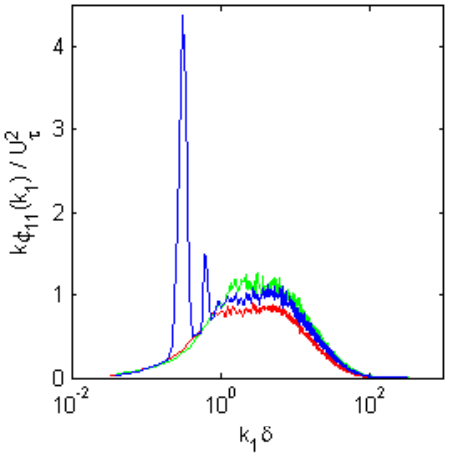




Spectral response, x/δ=2

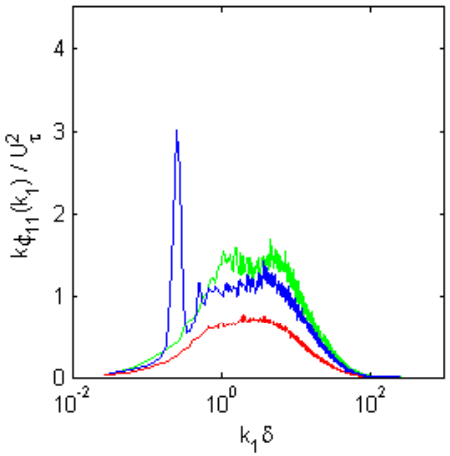
$y^+ = 22$

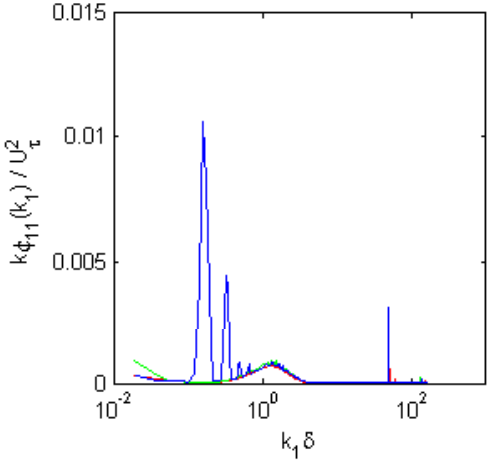




$y^+ = 51$

$y^+ = 157$



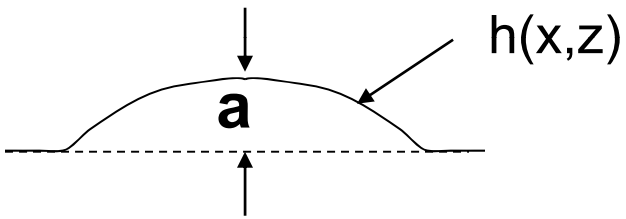


$y^+ = 1686$

Roughness model and DNS

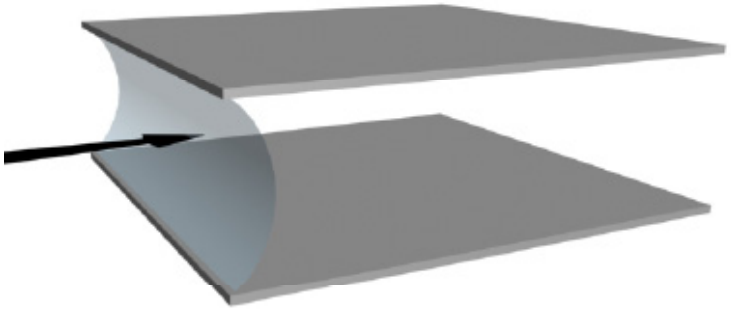
Linearized boundary conditions for oscillating bumps in the spirit of Gaster *et al.*, 1994

$$\gamma(x,z,t) = ah(x,z)\cos\sigma t$$



$$u(k_{x,w},k_{z,w}) = -aH(k_{x,w},k_{z,w})U'_y(0)\cos\sigma t$$
$$v(k_{x,w},k_{z,w}) = -\sigma aH(k_{x,w},k_{z,w})\sin\sigma t$$
$$w(k_{x,w},k_{z,w}) = 0$$

k_x=2, k_z=4, σ=1.45

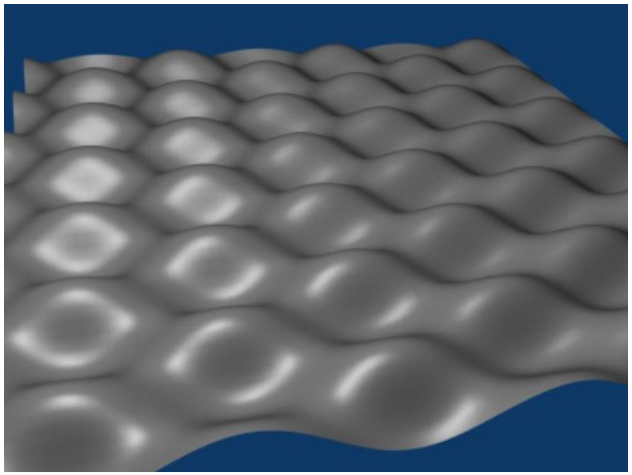


Periodic channel flow DNS of Flores & Jimenez (JFM 2006),

- $3\pi h$ x $1.5\pi h$ box
- time-dependent wall bc's

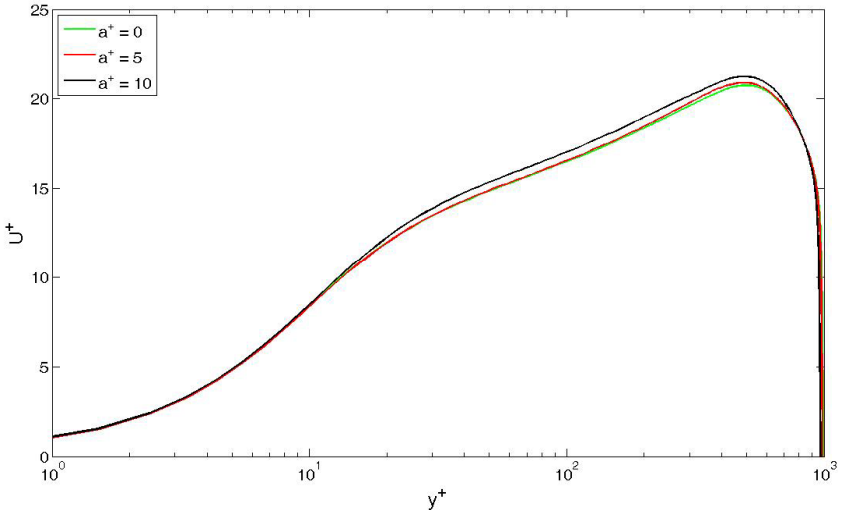
(McKeon, CTR Summer Proceedings, 2008)

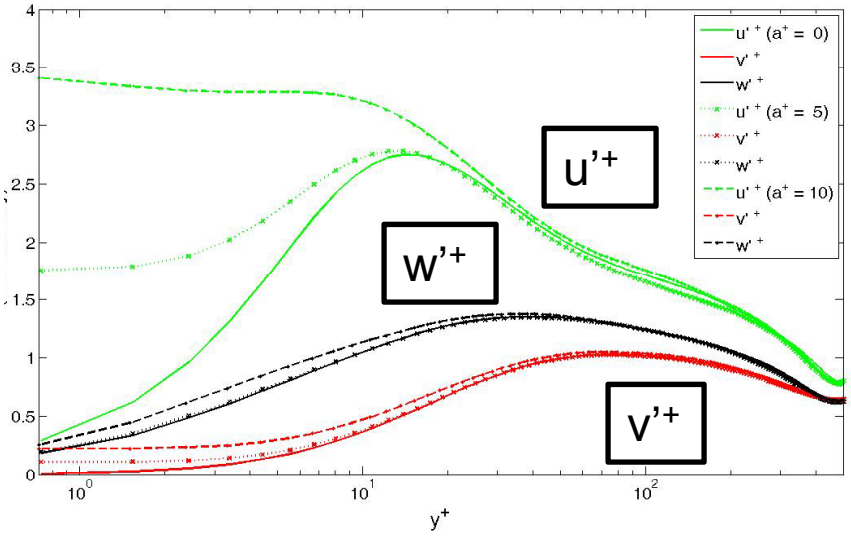
Mean velocity and intensity profiles



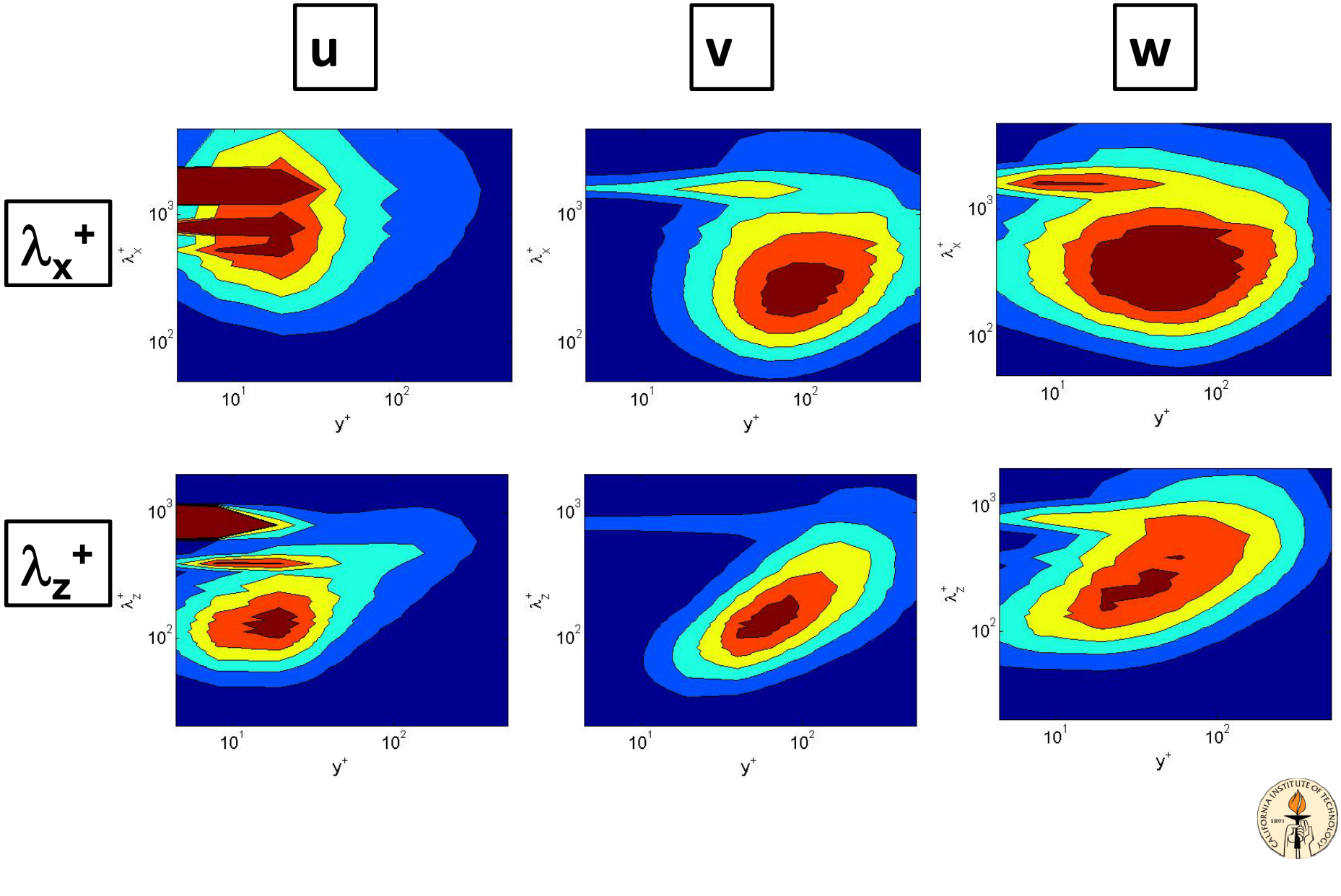
3 cases considered

- $a^+ = 0$, $a/h = 0$
- $a^+ = 5$, $a/h = 0.01$
- $a^+ = 10$, $a/h = 0.02$





Spectral response, $a^+=10$



Conclusions

- Structural skeleton of high Reynolds number flow gives insight into smooth and rough walls
  - modeling implications not yet clear
- Dynamic roughness as a model of “designer” roughness
  - Impose length scale(s) and dominant frequency
  - Irregular roughness well-represented by first “few” POD modes (Christensen, 2009)
- Experiments and simple model demonstrate
  - Harmonics associated with forcing (and w) important
  - Change to the mean profile (skin friction)