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Very large scale motions in smooth and rough wall boundary layers

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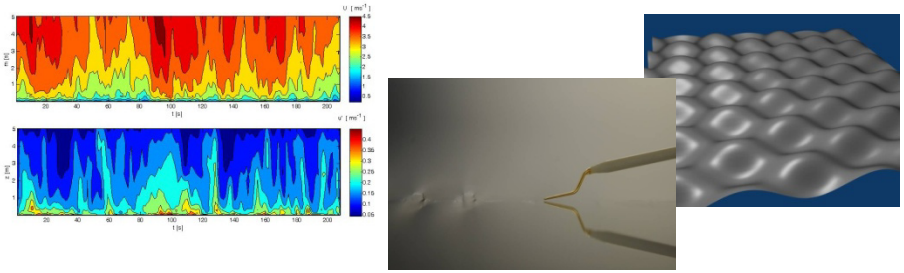


Outline

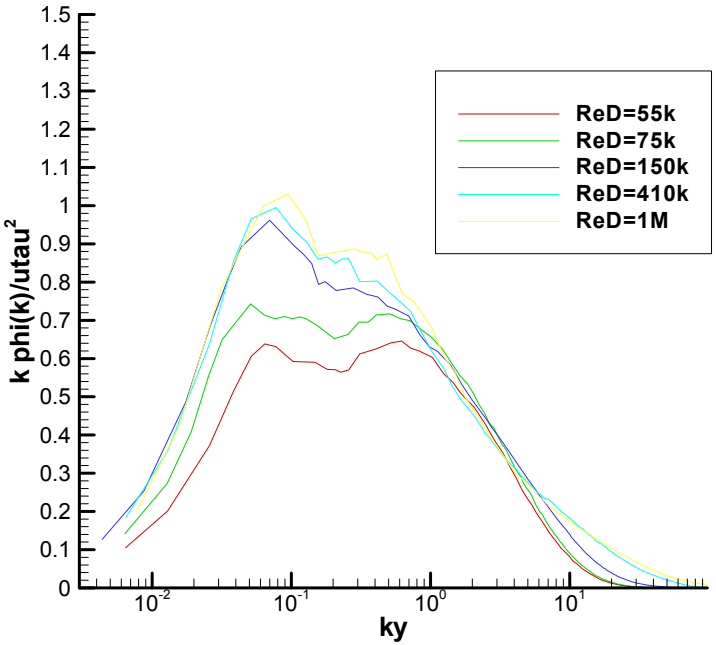
1. Background on the very large scales in wall turbulence

2. Sample transitionally rough wall results

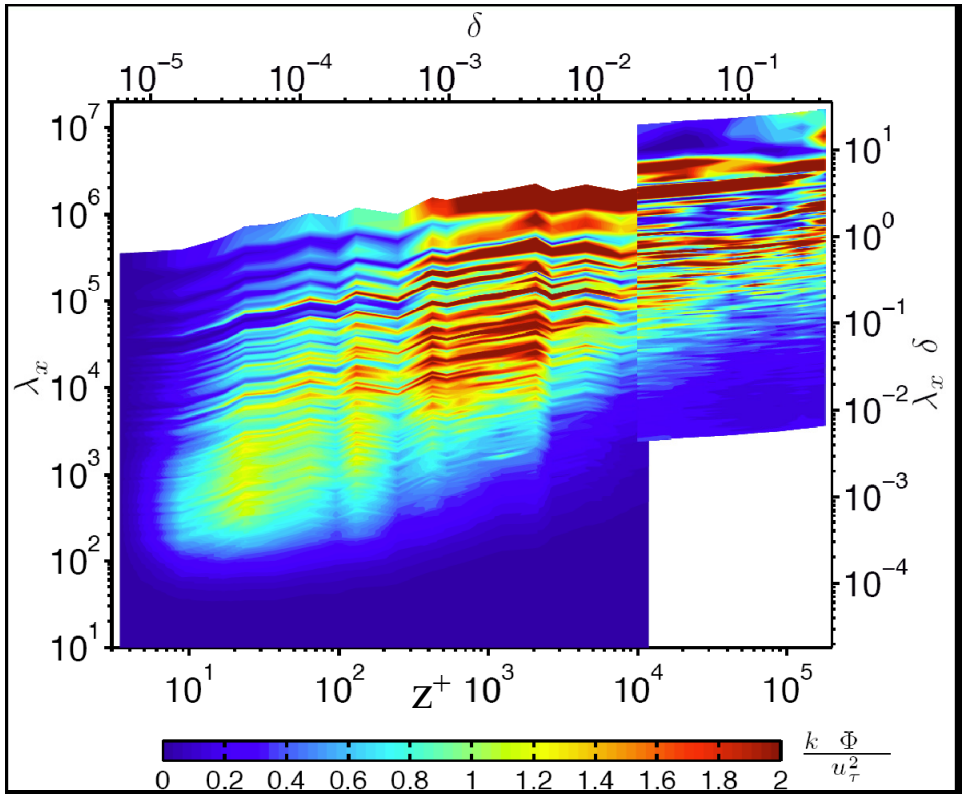
3. A means to manipulate the large-scale signature: "dynamic" roughness
   - Experiments on a spatial impulse of dynamic roughness
   - Simple model for dynamic roughness
   - DNS results

4. Conclusions

Observations of the very large scales



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



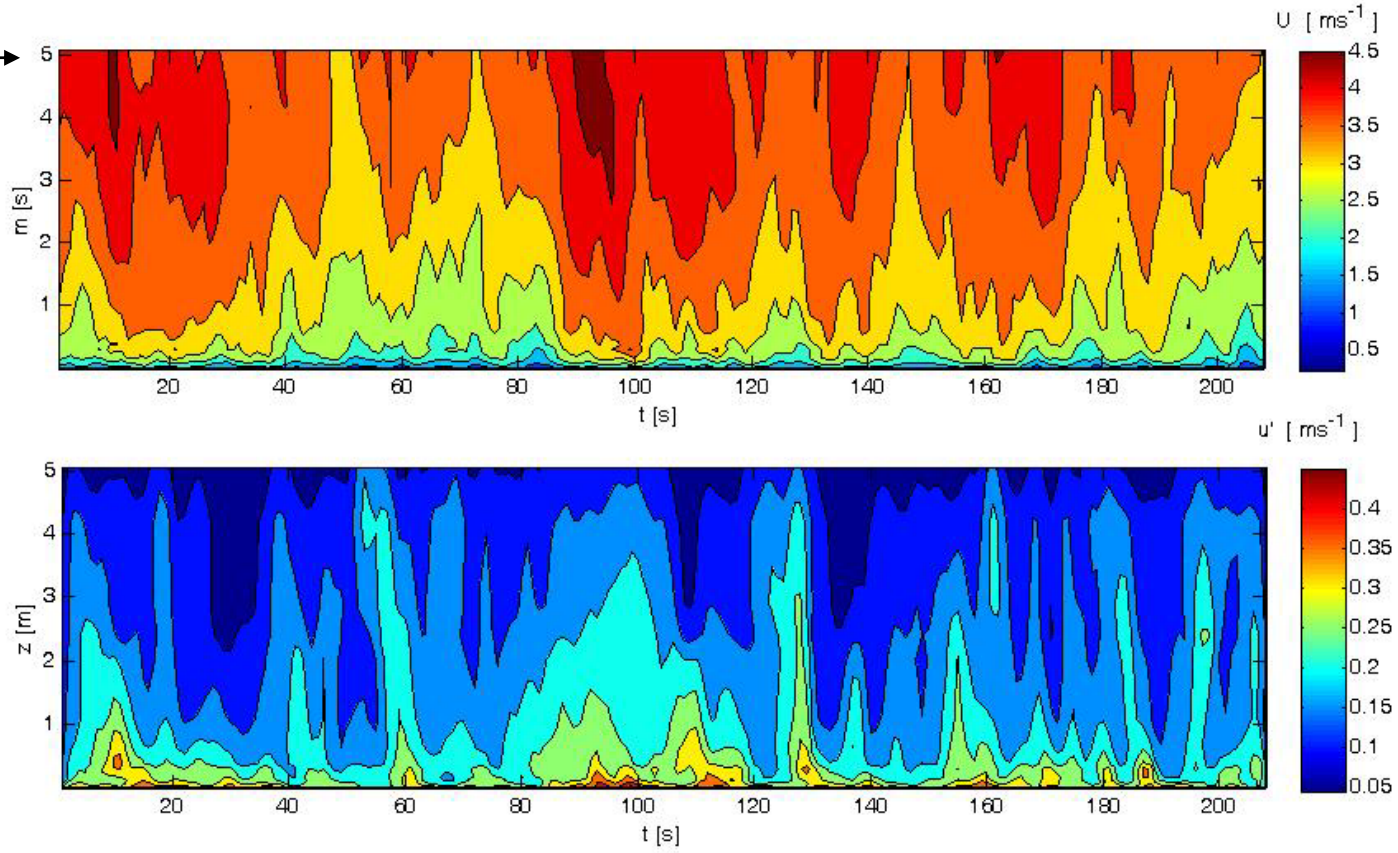
$\delta^+ = O(10^6)$

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

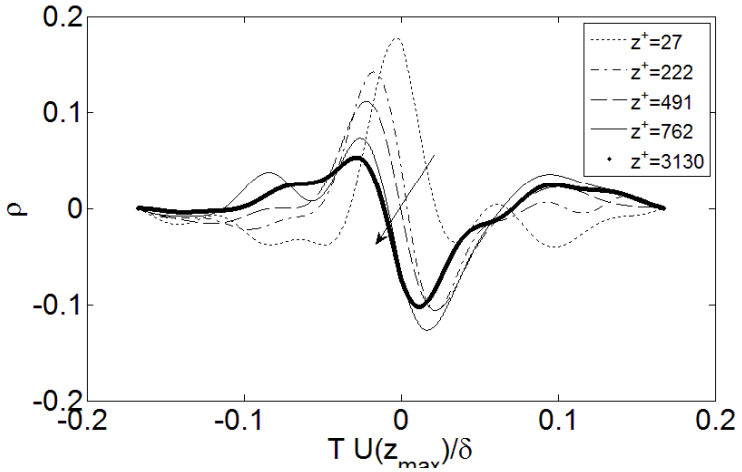
A visual picture (temporal records)

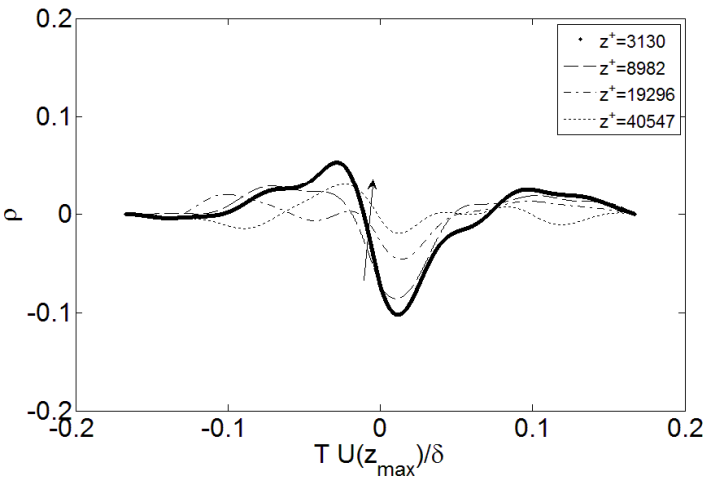
Sliding window – T=1s

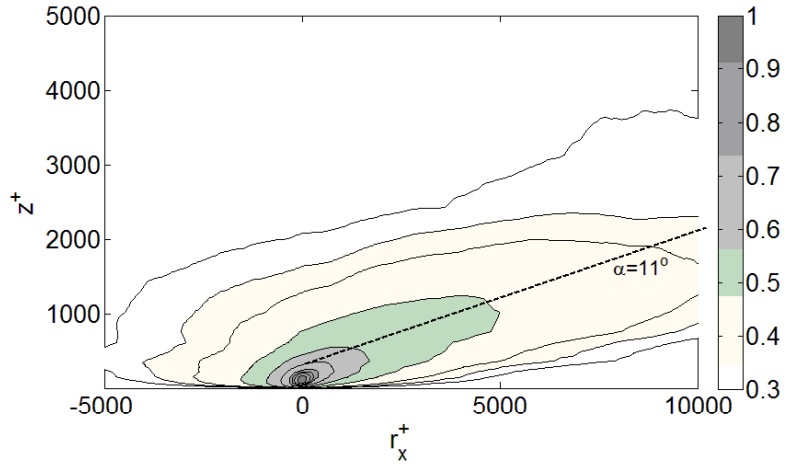
$z/\delta \sim 0.1 \longrightarrow$

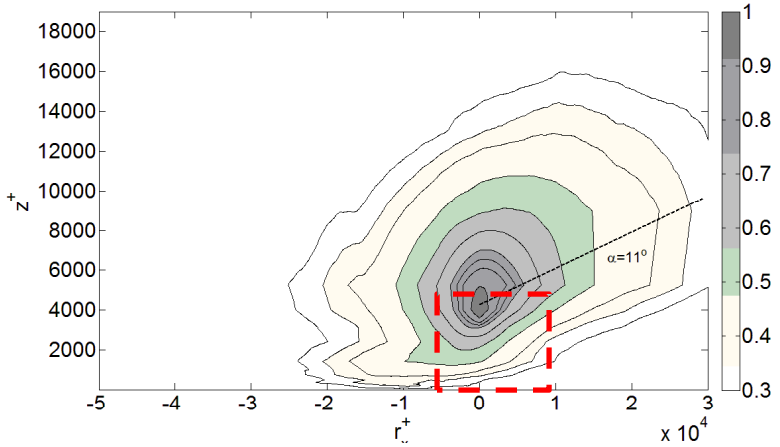


Statistical imprints of dominant motions









Statistical imprints of dominant motions

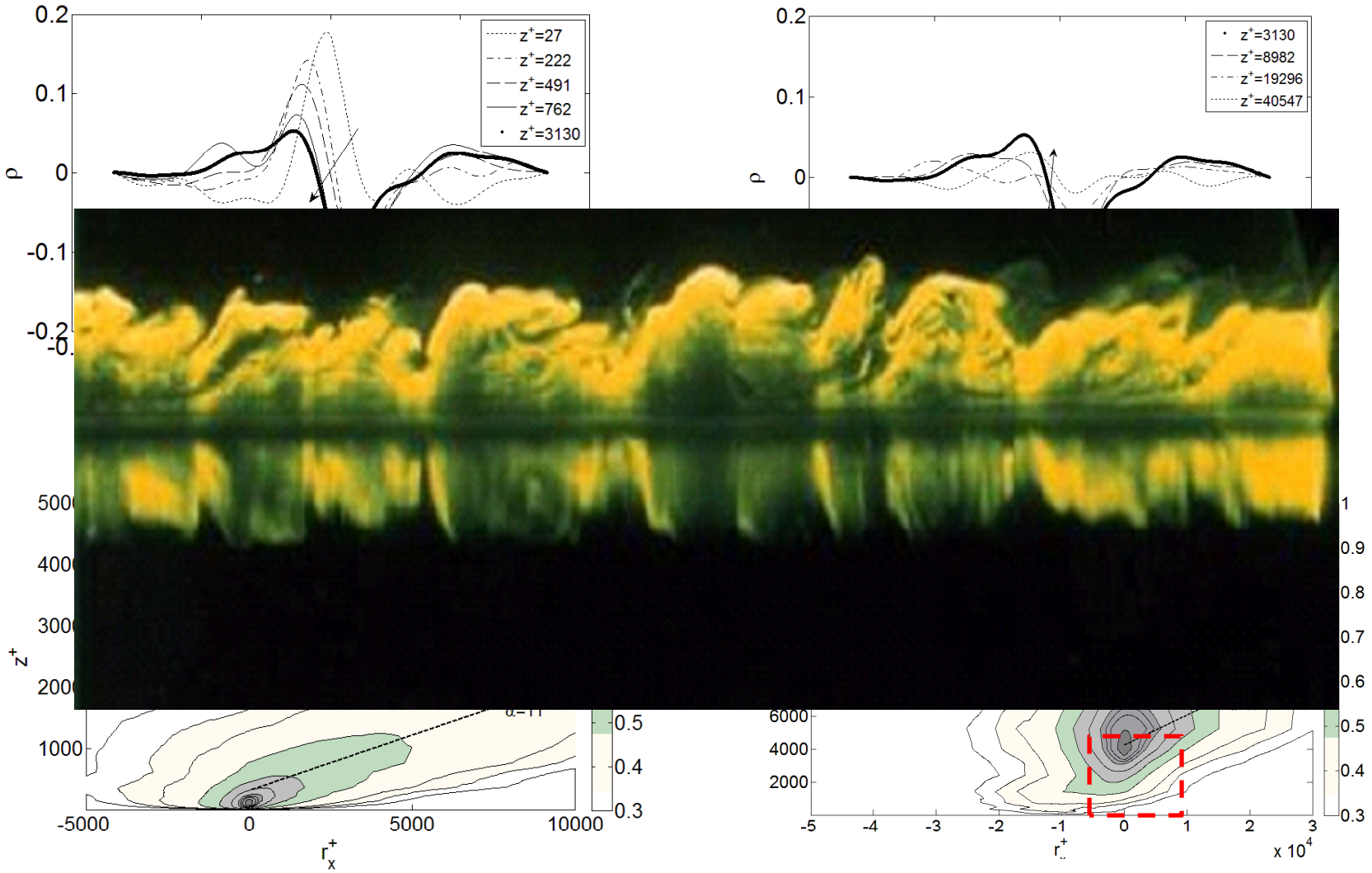
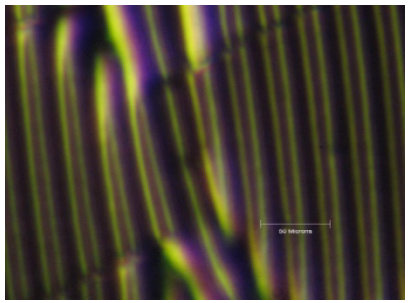


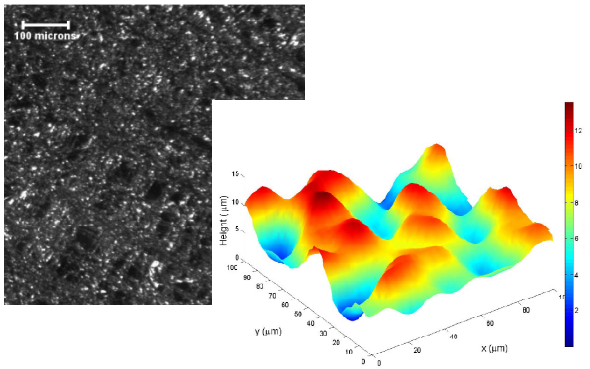
Image: M. Gad-el-Hak

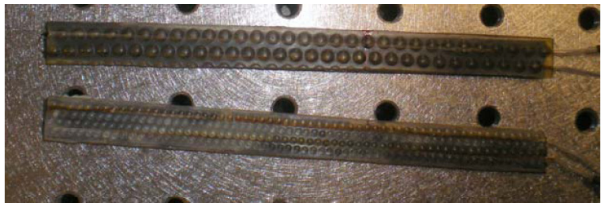
Manipulation of the large scales?

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

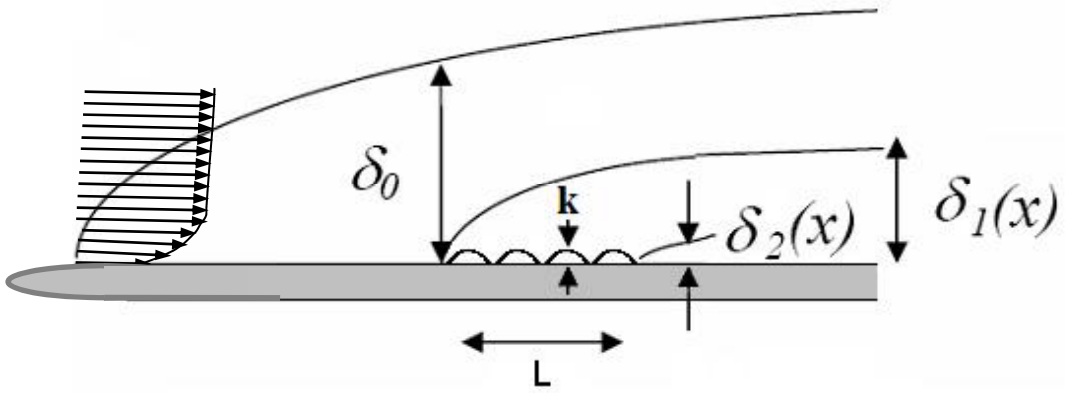
- *Why investigate?*
  - Control possibilities
  - On-demand (on/off) roughness
  - "What additional fundamental understanding of fluid physics can be gained from this new means of activation?"
  - Influence of roughness timescale
  - Structured energy injection





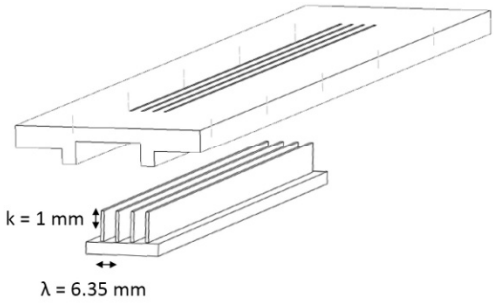


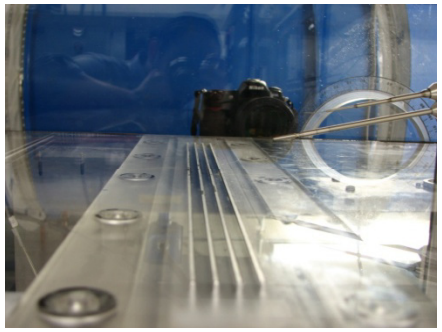
Spatial impulse of dynamic roughness

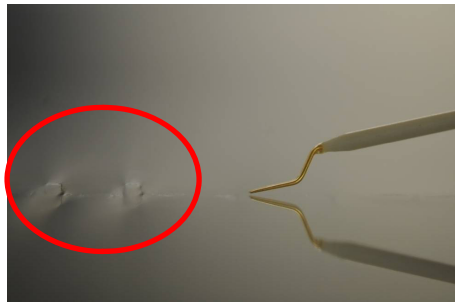


Mechanical approximation to “morphing surface”

- 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

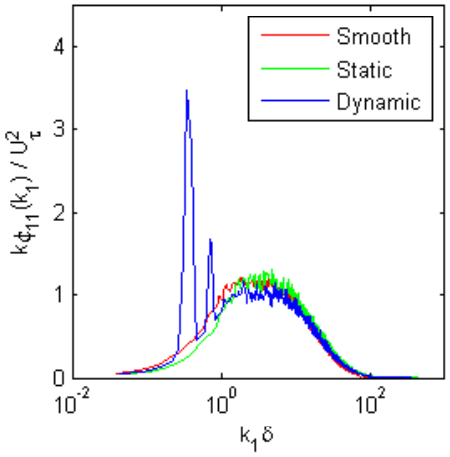


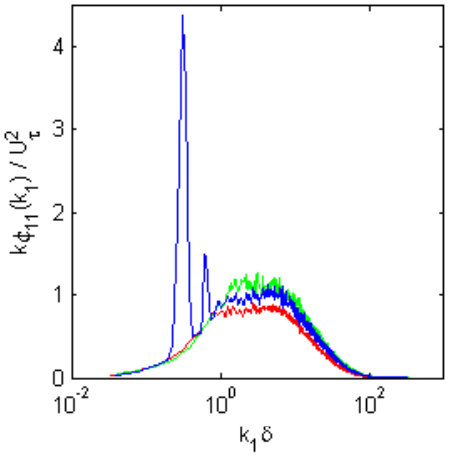




Spectral response, x/δ=2

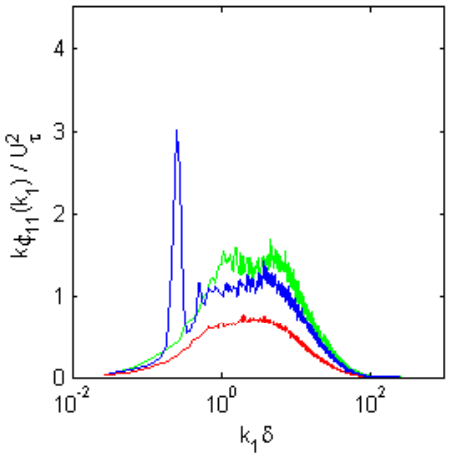
$y^+ = 22$

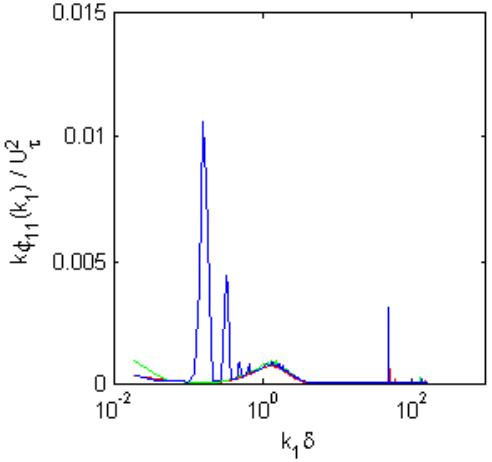




$y^+ = 51$

$y^+ = 157$



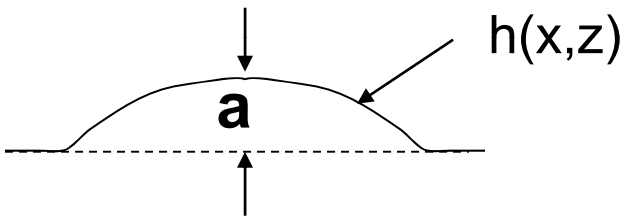


$y^+ = 1686$

Roughness model and DNS

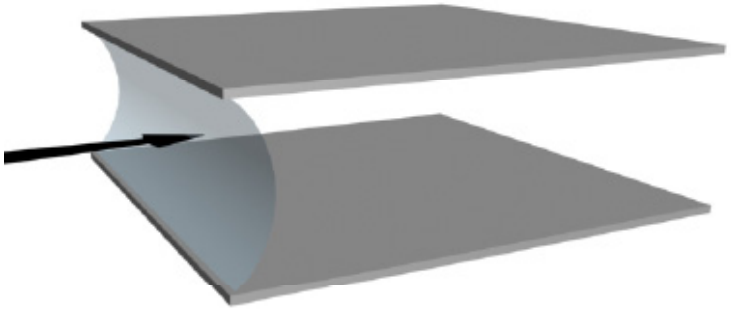
Linearized boundary conditions for oscillating bumps in the spirit of Gaster *et al.*, 1994

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



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

k_x=2, k_z=4, σ=1.45

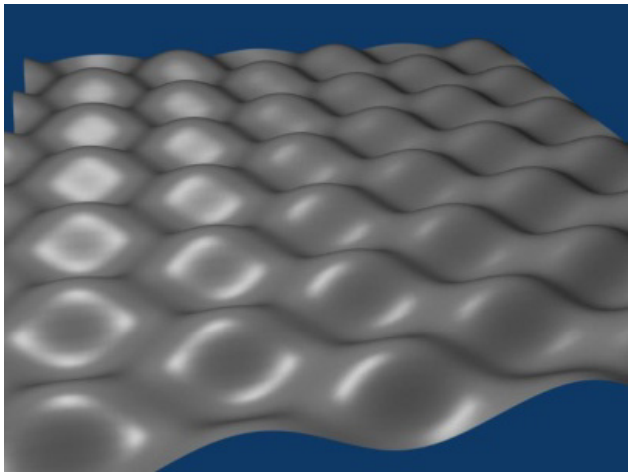


Periodic channel flow DNS of Flores & Jimenez (JFM 2006),

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

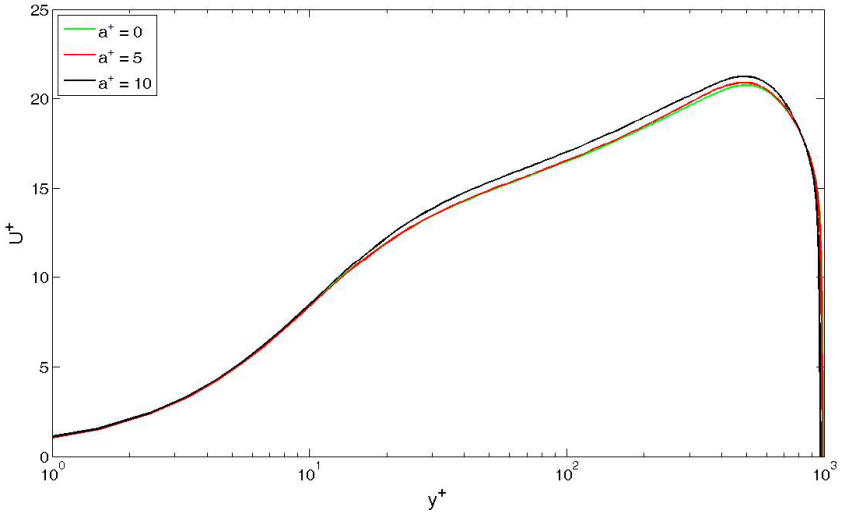
(McKeon, CTR Summer Proceedings, 2008)

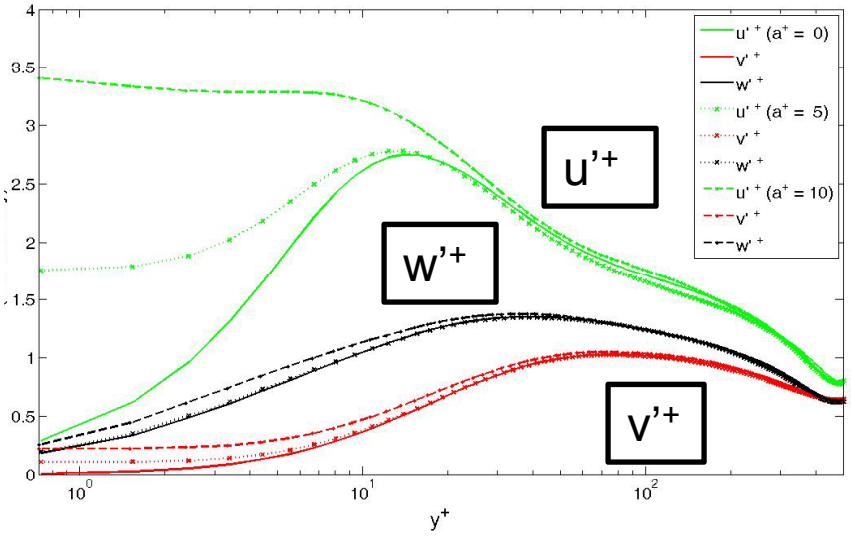
Mean velocity and intensity profiles



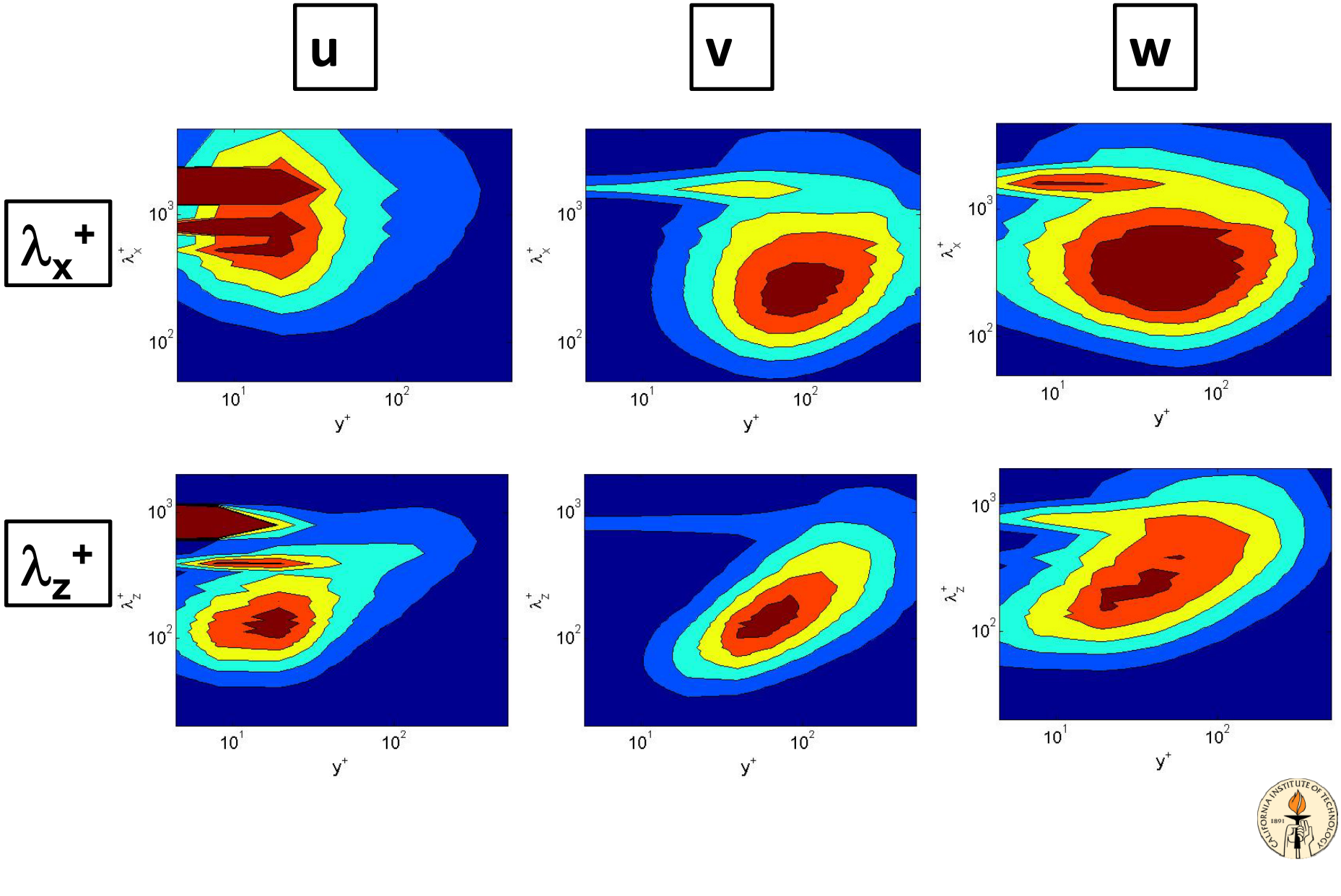
3 cases considered

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





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)