Stretch rate and displacement speed correlations for increasingly-turbulent premixed flames

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$$s_T = g(\langle \dot{s} \rangle)$$

Turbulent burning velocity a function of mean stretch rate
(Flame Surface Density modelling and other flamelet models)

Stretch rate

$$\frac{1}{A}\frac{dA}{dt}$$

Mean curvature

$$-\frac{1}{2}\nabla \cdot n$$

$$\langle \dot{s} \rangle = \langle a_t \rangle + 2\langle s_d h_m \rangle$$

Strain rate

$$\nabla \quad u - nn : \nabla u$$

Displacement speed

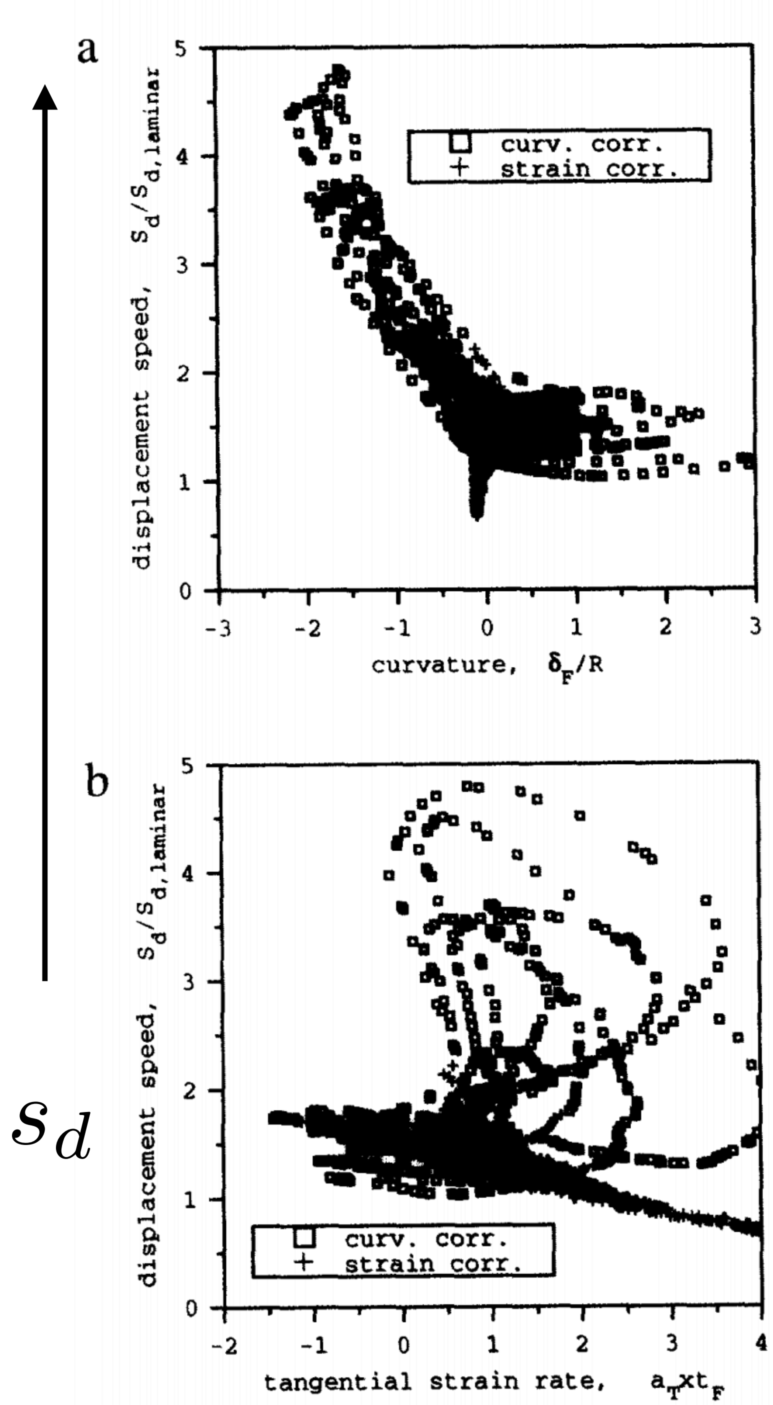
$$\frac{\dot{\omega} + \nabla \cdot (\rho D \nabla c)}{\rho |\nabla c|}$$

Stretch rate a combination of local source-terms on flame surface
a reaction progress variable c iso-contour

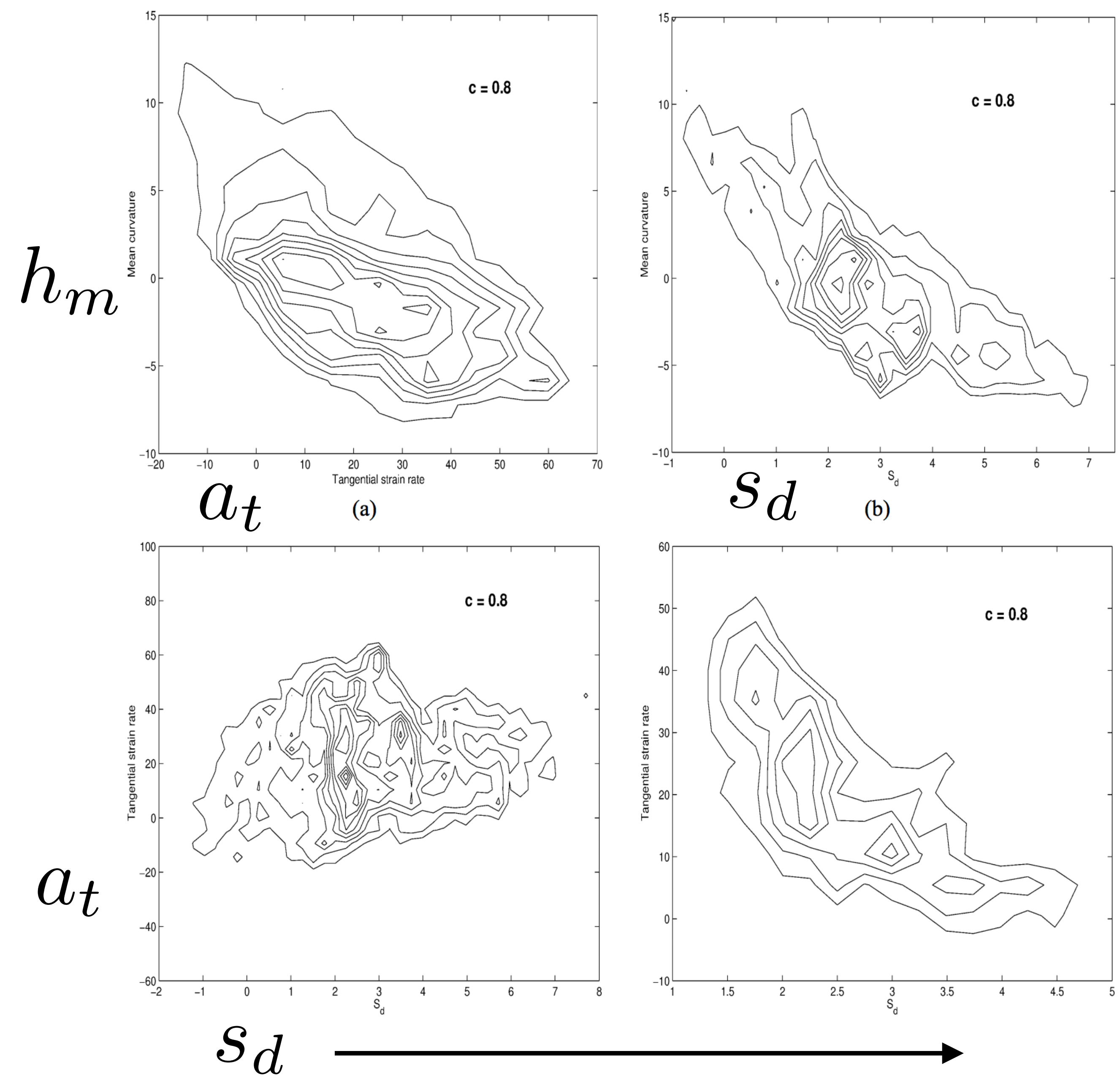
[1] Pope (1988) International Journal of Engineering Science

Stretch rate source-terms

Inter-dependences between stretch rate source-terms key to stretch rate modelling.



2D multi-step chemistry [1]



3D single-step chemistry [2]

[1] Echekki and Chen (1996) Combustion and Flame 106
[2] Chakraborty and Cant (2004) Combustion and Flame 137

Objectives and simulation details

How do these inter-dependences vary with increasing turbulence intensity?

DNS dataset generated by varying turbulence intensity over 5 simulations in an inflow-outflow configuration with NSCBCs by the code: senga2

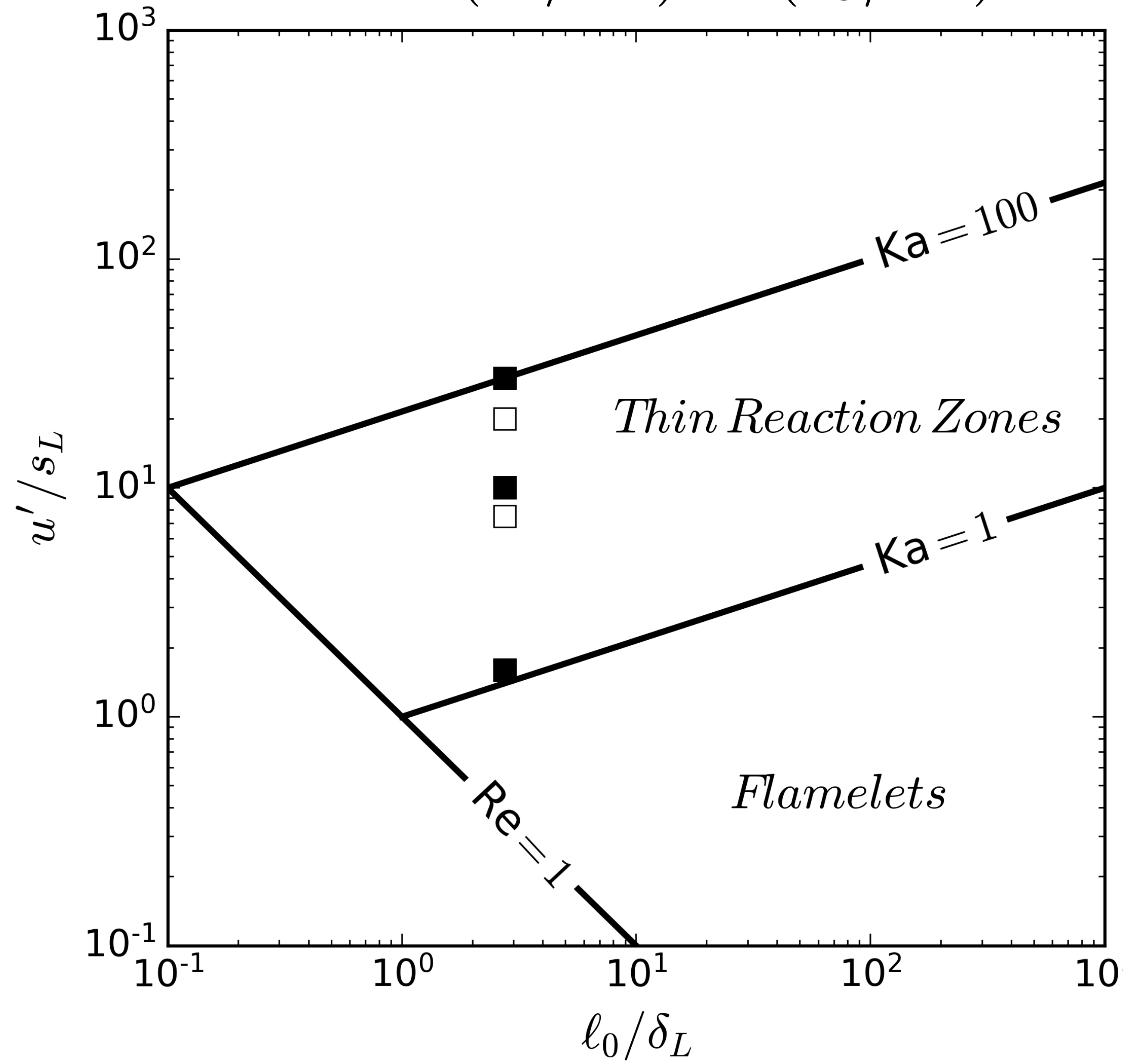
Original simulations [1]
288 x 96 x 96 and 4ETOTs

Latest simulations (supporting)
720 x 240 x 240 and 12 ETOTs

with single-step chemistry

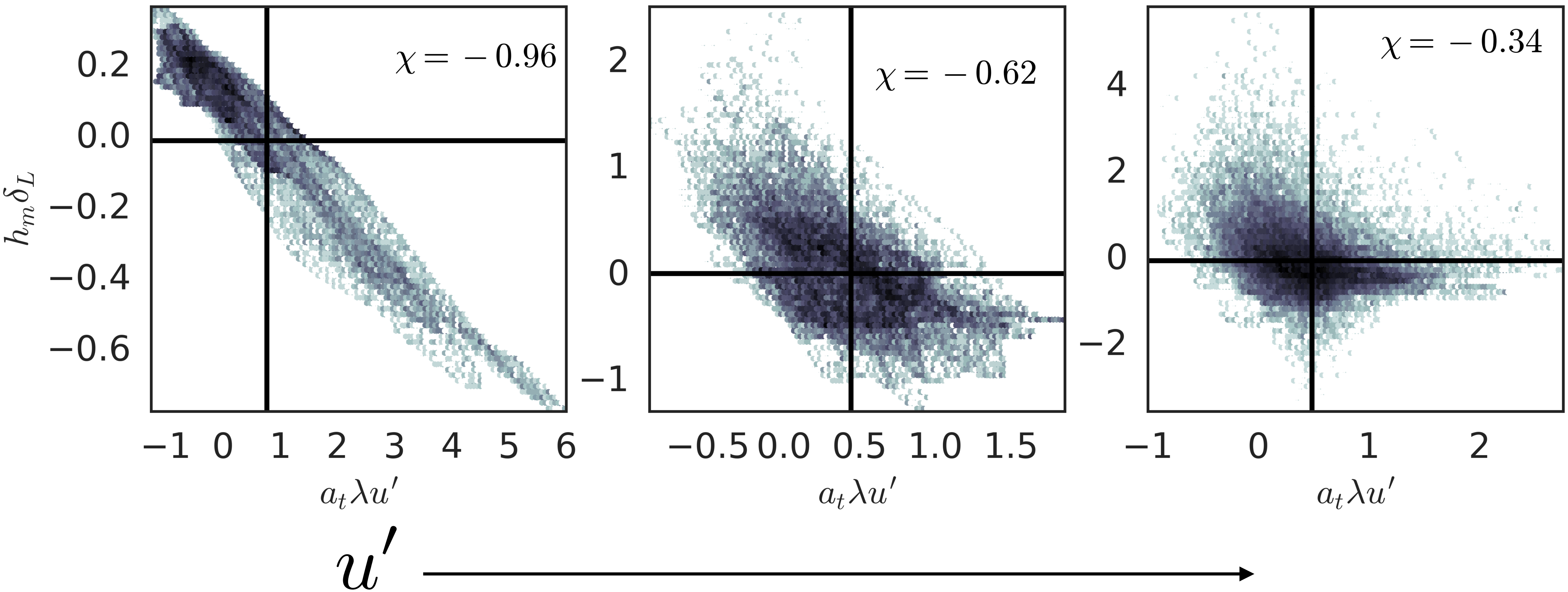
Ka spans TRZ regime.

$$\mathrm{Ka} = (u'/s_L)^{3/2}(\ell_0/\delta_L)^{-1/2}$$



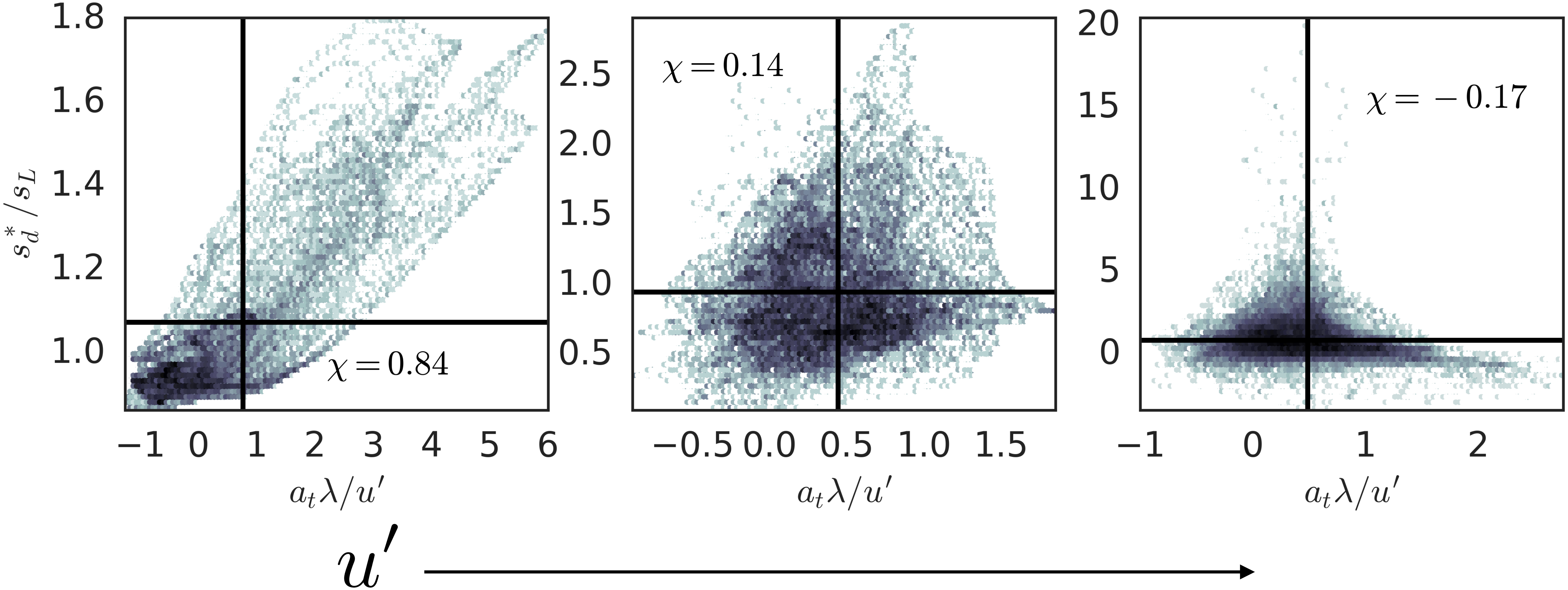
[1] Nivarti and Cant (2017) Proceedings of Combustion Institute 36

Strain and Curvature



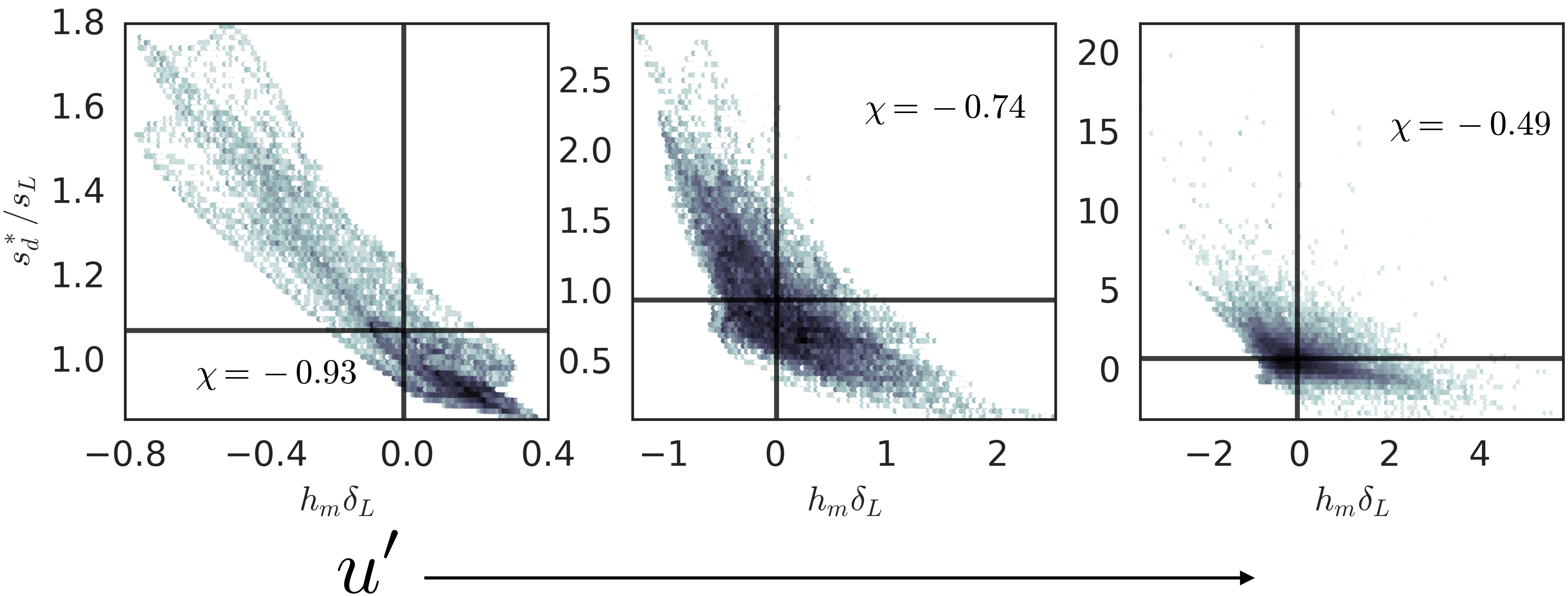
[1] Echekki and Chen (1996) Combustion and Flame 106
[2] Chakraborty and Cant (2004) Combustion and Flame 137

Strain and Displacement speed $s_d^* = \rho s_d / \rho_R$

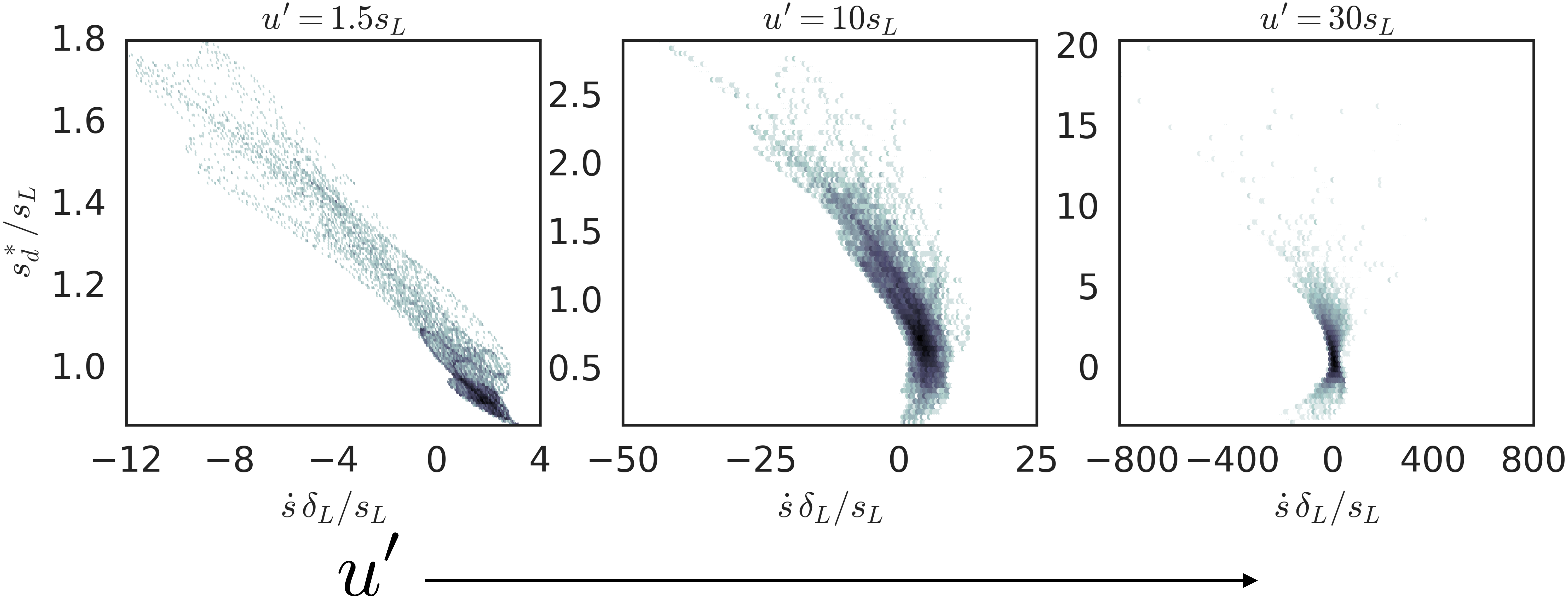


[1] Echekki and Chen (1996) Combustion and Flame 106
[2] Chakraborty and Cant (2004) Combustion and Flame 137

Curvature and Displacement speed

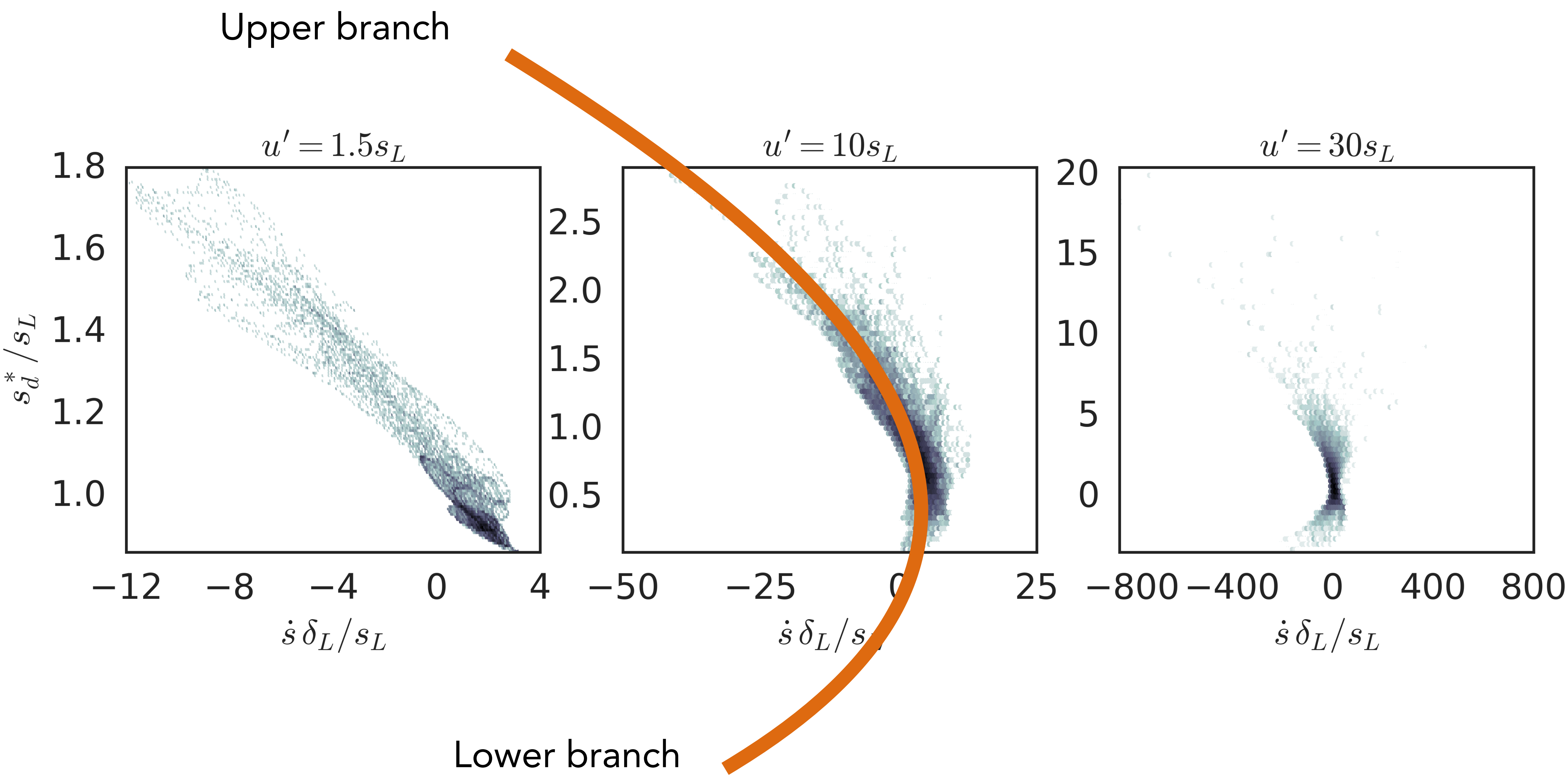


Stretch rate and Displacement speed



[1] Chen and Im (1998) 27th Symposium (International) on Combustion
[2] Chakraborty, Klein and Cant (2006) Proceedings of the Combustion Institute 31

Stretch rate and Displacement speed

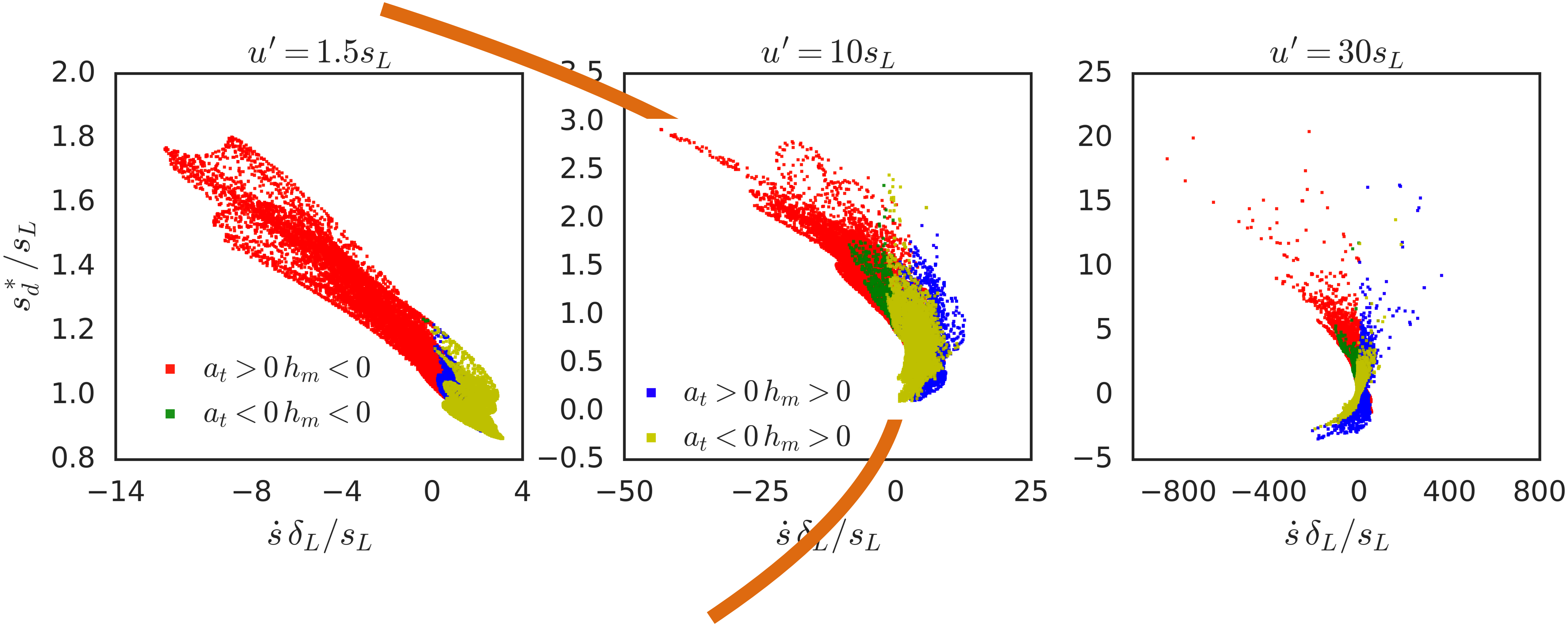


[1] Chen and Im (1998) 27th Symposium (International) on Combustion

[2] Chakraborty, Klein and Cant (2006) Proceedings of the Combustion Institute 31

Stretch rate and Displacement speed

Negative curvatures, positive strain

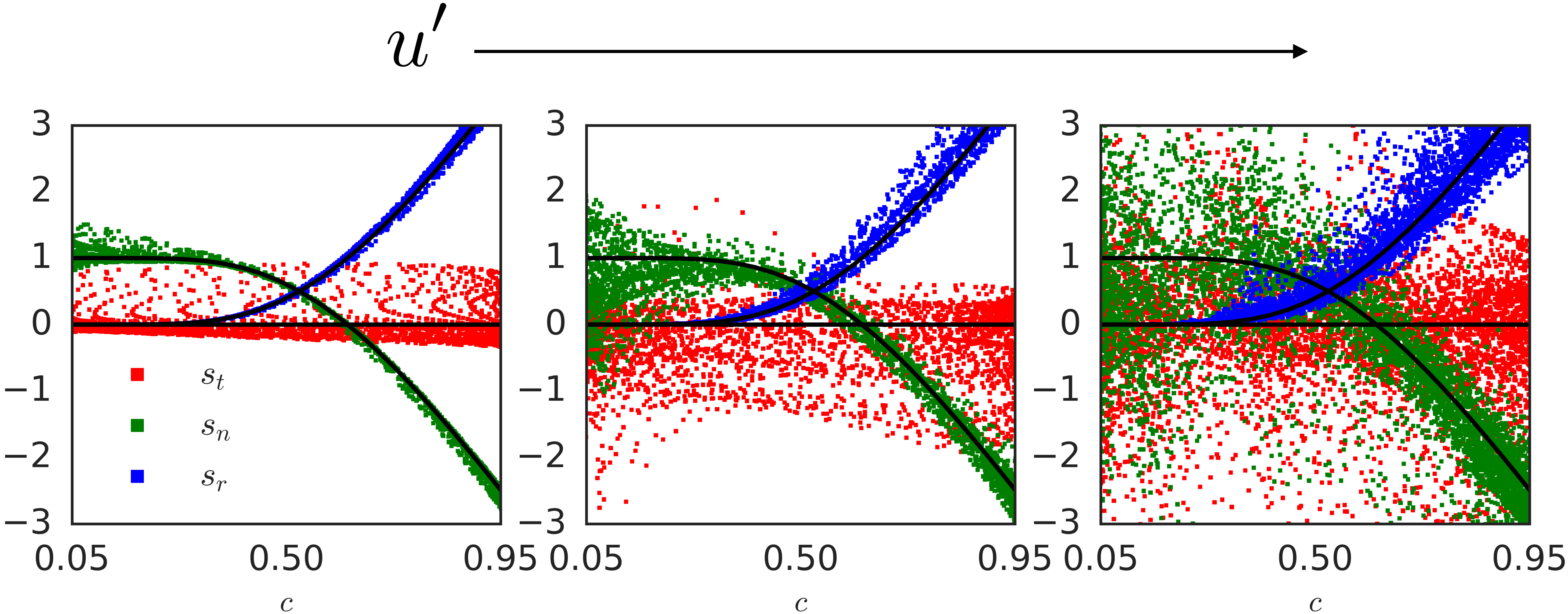


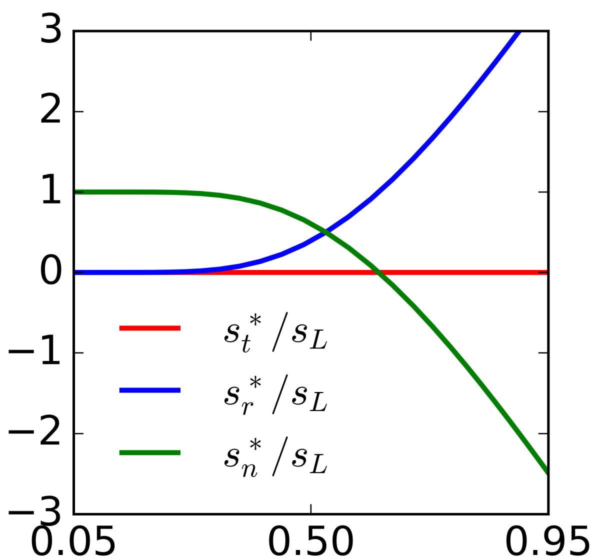
Positive curvature, negative strain

u' →

shift in contributions from different regions of the flame surface points to the underlying competition between strain and curvature

Displacement speed components

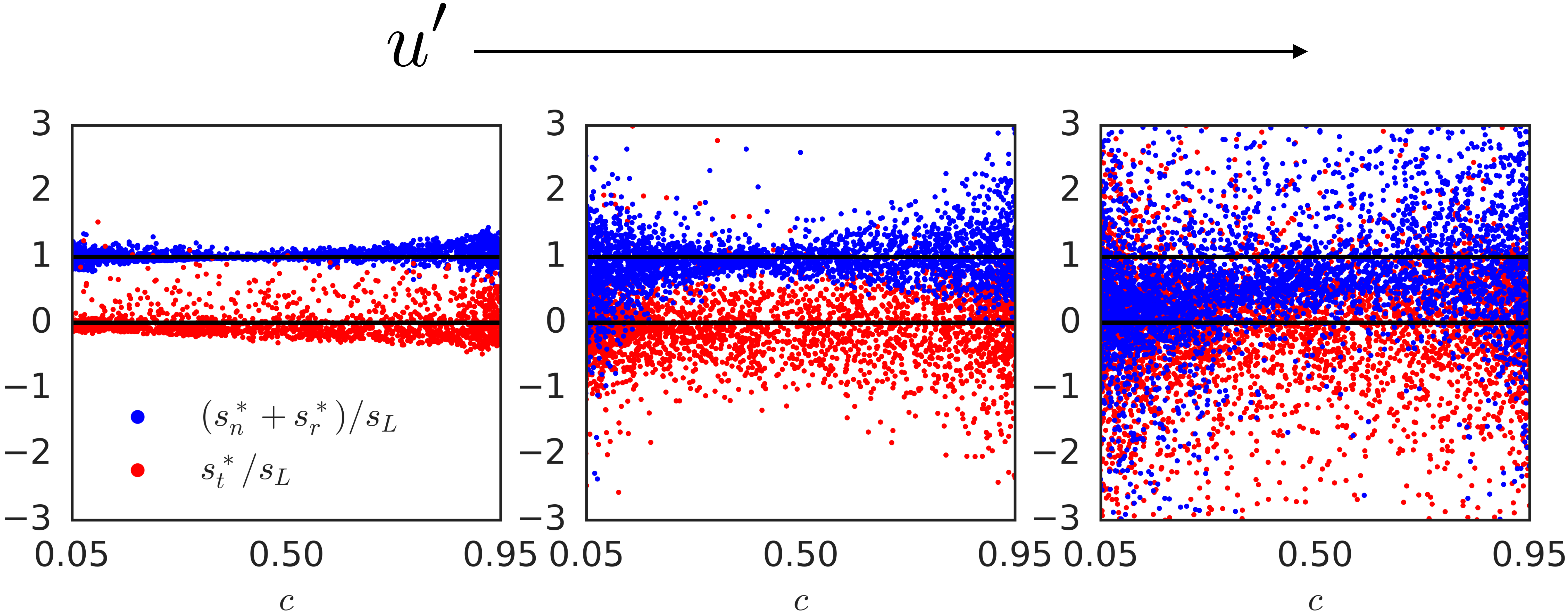


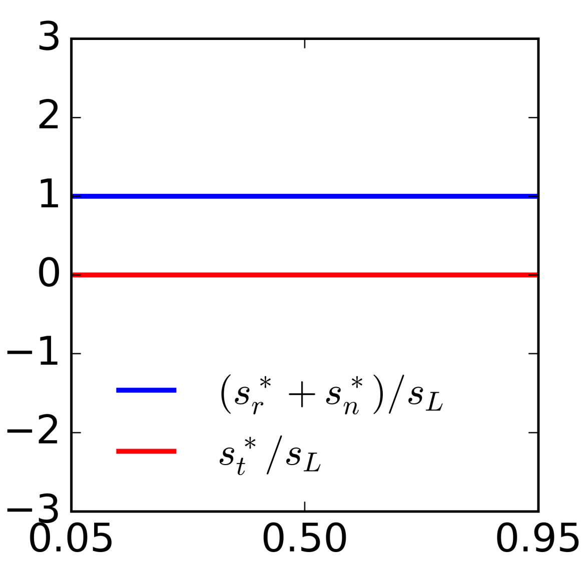


$$s_d = \frac{\dot{\omega}}{\rho|\nabla c|} + \frac{n \cdot \nabla \left(\rho D n \cdot \nabla c\right)}{\rho|\nabla c|} - D\nabla \cdot n$$

s_r $\quad$ s_n $\quad$ s_t

Displacement speed components



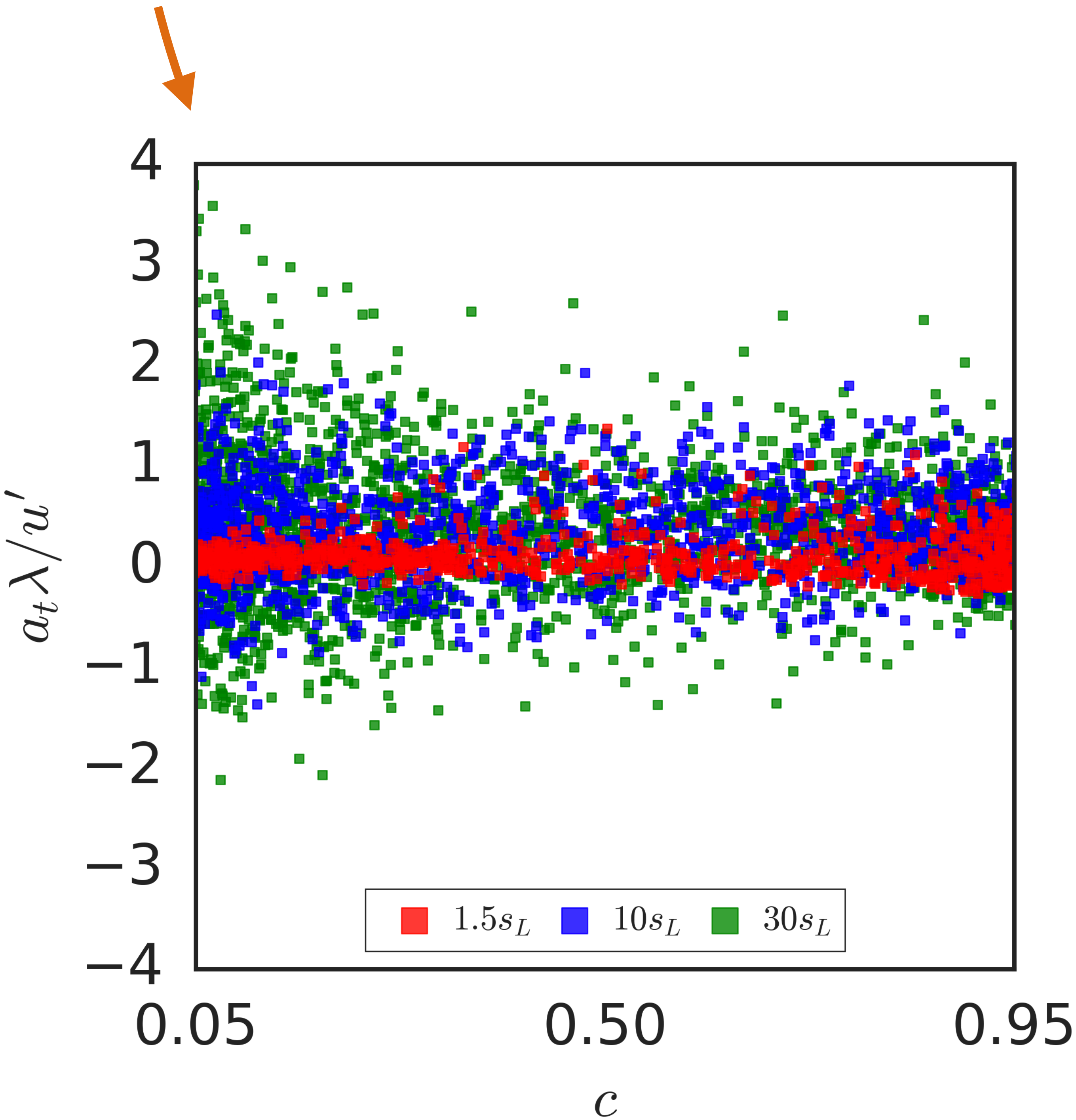


$$s_d = \frac{\dot{\omega}}{\rho|\nabla c|} + \frac{n \cdot \nabla\left(\rho D n \cdot \nabla c\right)}{\rho|\nabla c|} - D\nabla \cdot n$$

s_r s_n s_t

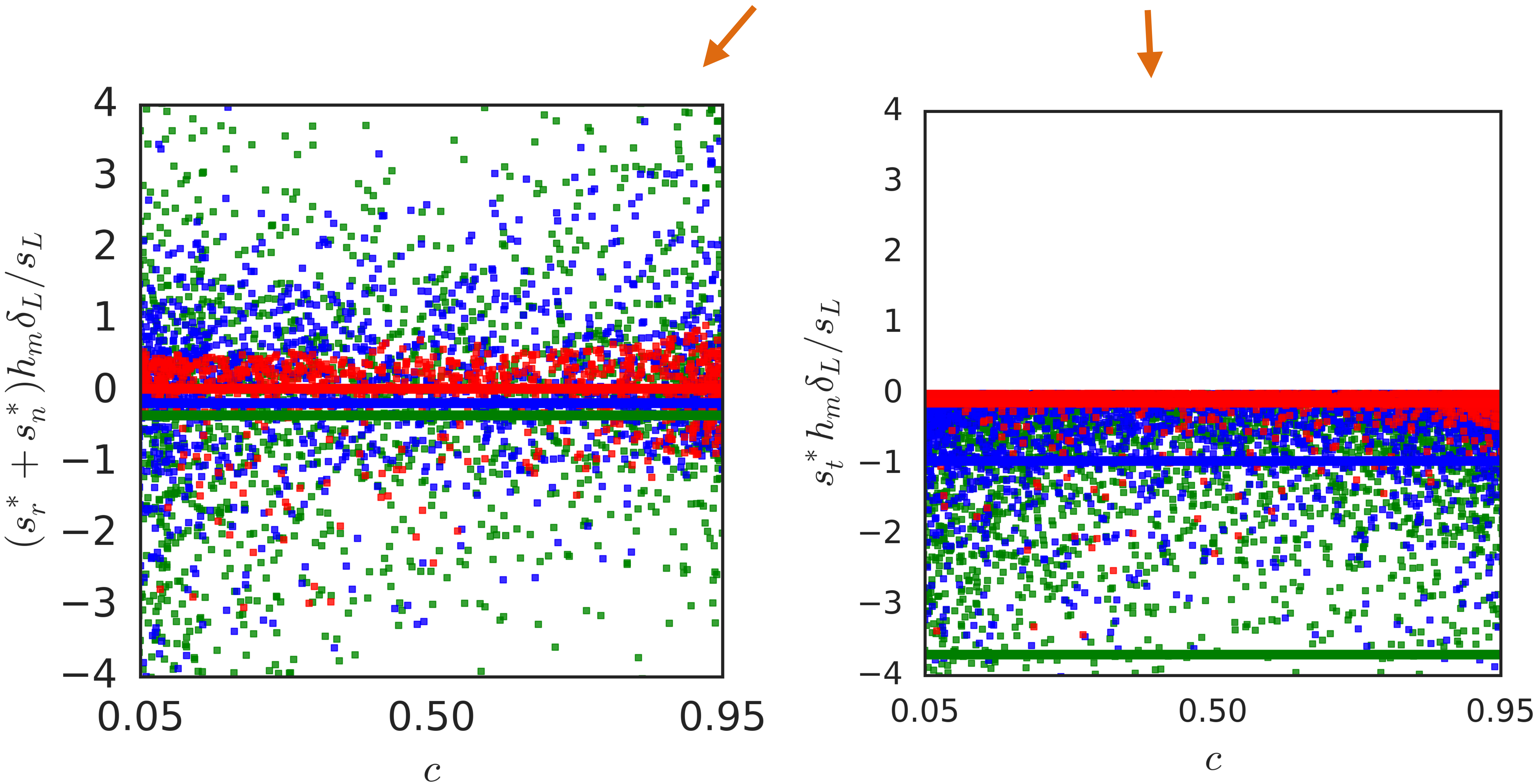
Implications: distribution of strain rate

$$\langle \dot{s} \rangle = \langle a_t \rangle + 2\langle (s_r + s_n) h_m \rangle + 2\langle s_t h_m \rangle$$

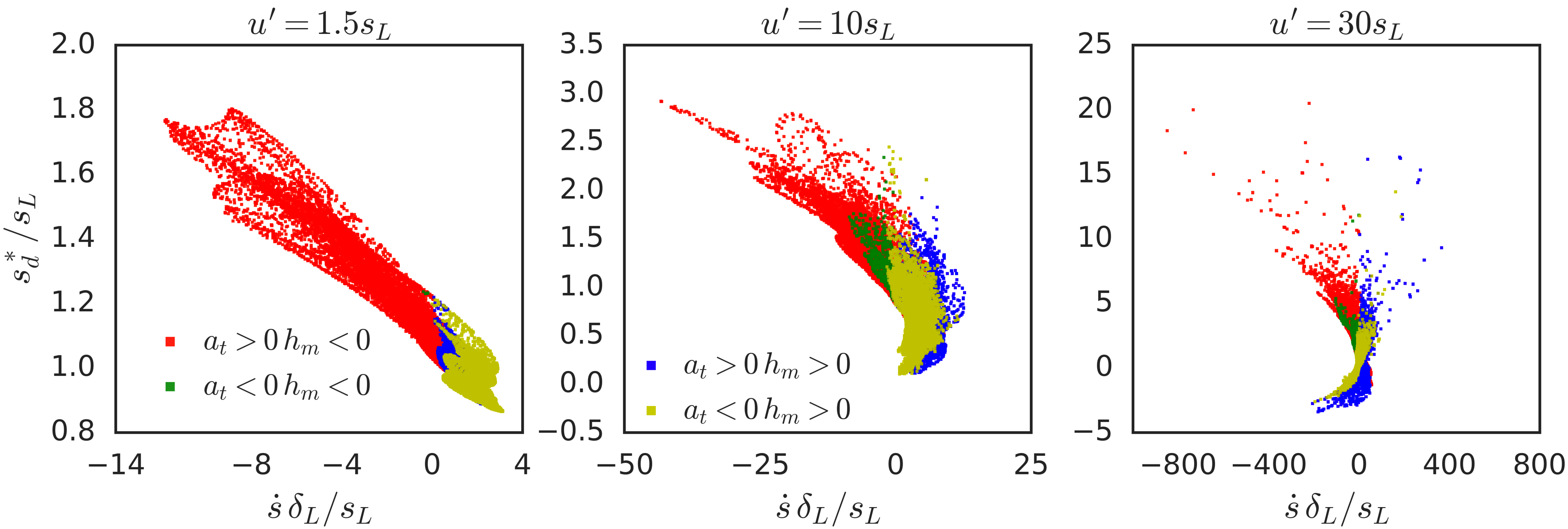


Implications: distribution of propagation rate

$$\langle \dot{s} \rangle = \langle a_t \rangle + 2\langle (s_r + s_n) h_m \rangle - 4D\langle h_m^2 \rangle$$



Conclusions



1. There appears to be no qualitative change in the statistics of displacement speed and its separate components as the turbulence intensity is increased
2. Accurate modelling of the displacement speed appears to be a requirement in order to capture the non-linearities observed in the stretch rate and its components

Publication: Nivarti and Cant (2018) Flow Turbulence and Combustion (accepted)