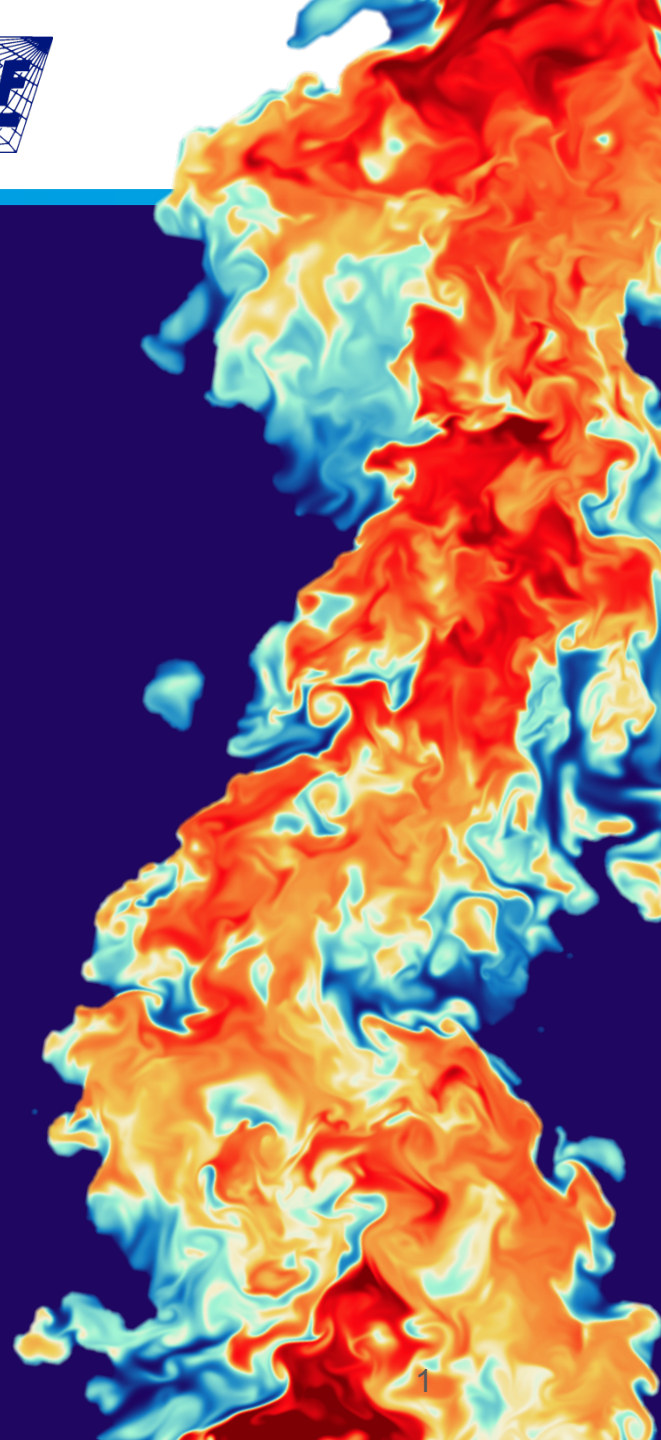
Scalar transport across the turbulent/non-turbulent interface in jets: Schmidt number effects

Tiago Silva and Carlos B. Silva



69th APS/DFD meeting 2016 - Portland, OR

DNS OF NEWTONIAN FLUIDS

- **Planar turbulent jet (*PJET*)**

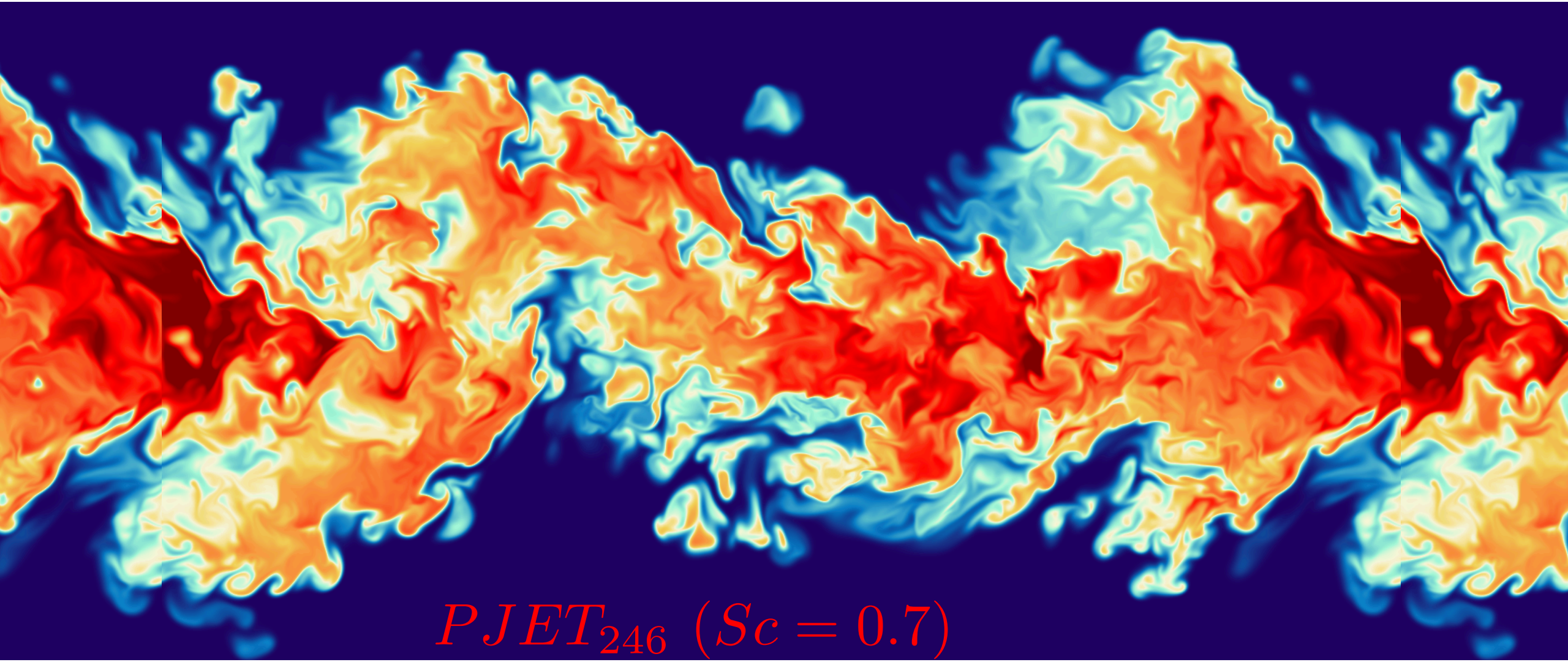
	Re_H	Sc	Re_λ	$(N_x \times N_y \times N_z)$	Δ_x/η	η_{OC}/η	η_B/η
$PJET_{142}$	3000	7.0	142	$(1536 \times 1536 \times 768)$	1.1	0.23	0.37
$PJET_{208}$	6000	3.0	208	$(1536 \times 1536 \times 768)$	1.5	0.44	0.58
$PJET_{236}$	8000	0.07	236	$(1536 \times 1536 \times 768)$	2.3	7.4	3.8
$PJET_{246}$	8000	0.7	246	$(1536 \times 1536 \times 768)$	2.3	1.3	1.2

$$\lambda^2 = \frac{u'^2}{(\partial u'/\partial x)^2}, \qquad \eta = \left(\frac{\nu^3}{\varepsilon}\right)^{1/4}, \qquad \eta_{OC} = \frac{\eta}{Sc^{3/4}}, \qquad \eta_B = \frac{\eta}{Sc^{1/2}},$$

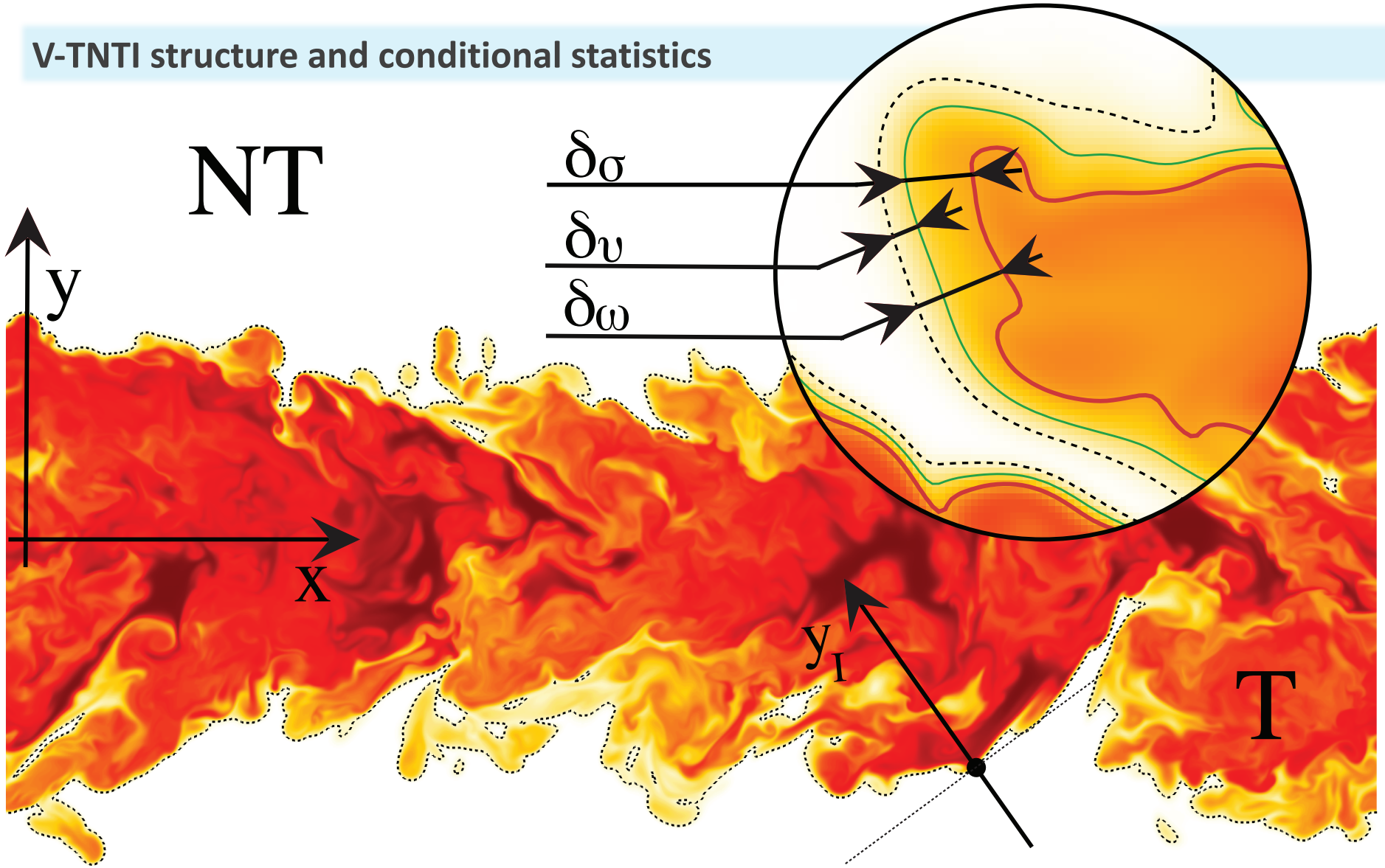
$$Re_\lambda = u'\lambda/\nu$$

PASSIVE SCALAR FIELD

The behavior of the scalar gradient across the turbulent/non-turbulent interface in jets



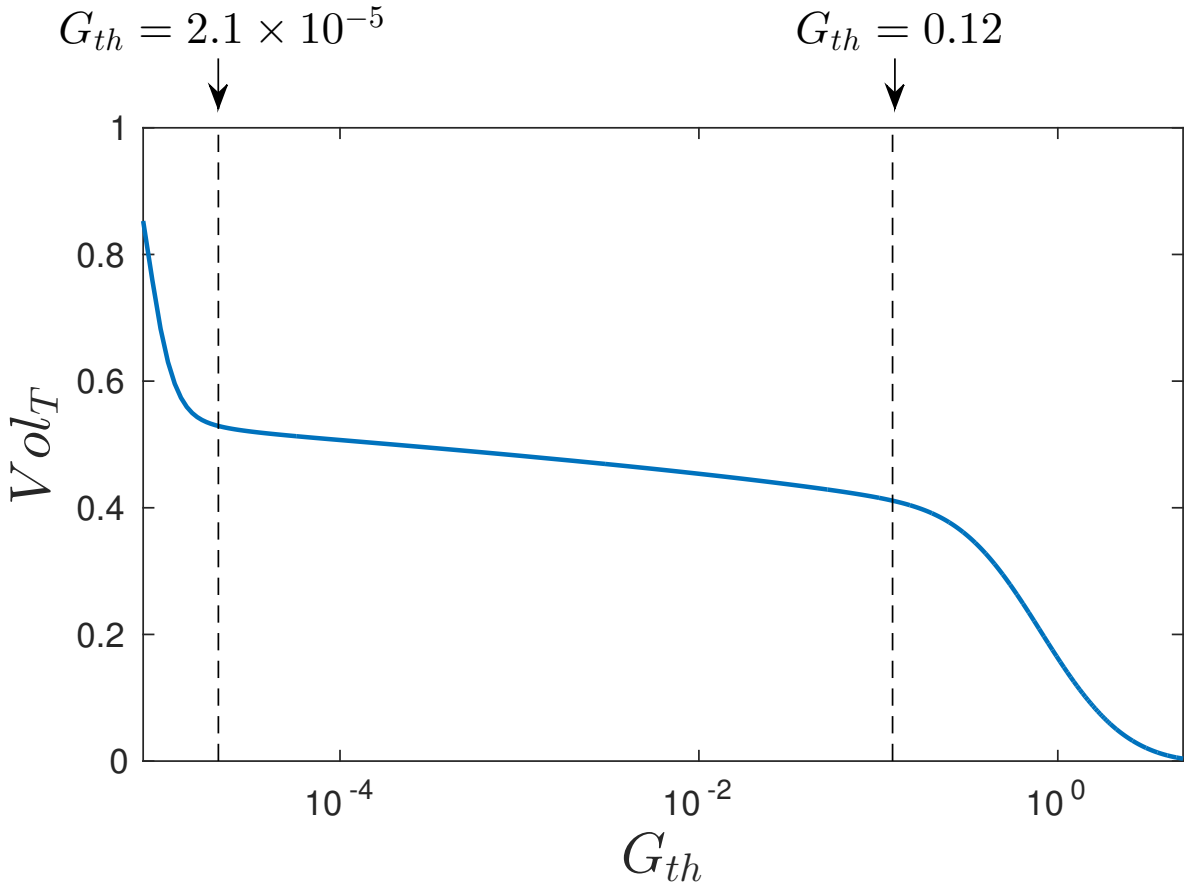
V-TNTI structure and conditional statistics



$$\delta_\nu \sim \eta$$

$$\delta_\sigma \sim 10\eta$$

$$\delta_\omega \sim 10\eta$$



a) Turbulent flow fraction method applied to scalar gradient norm

$$PJET_{236}\ (Sc = 0.07)$$

$$\mathbf{G} = \nabla\theta$$

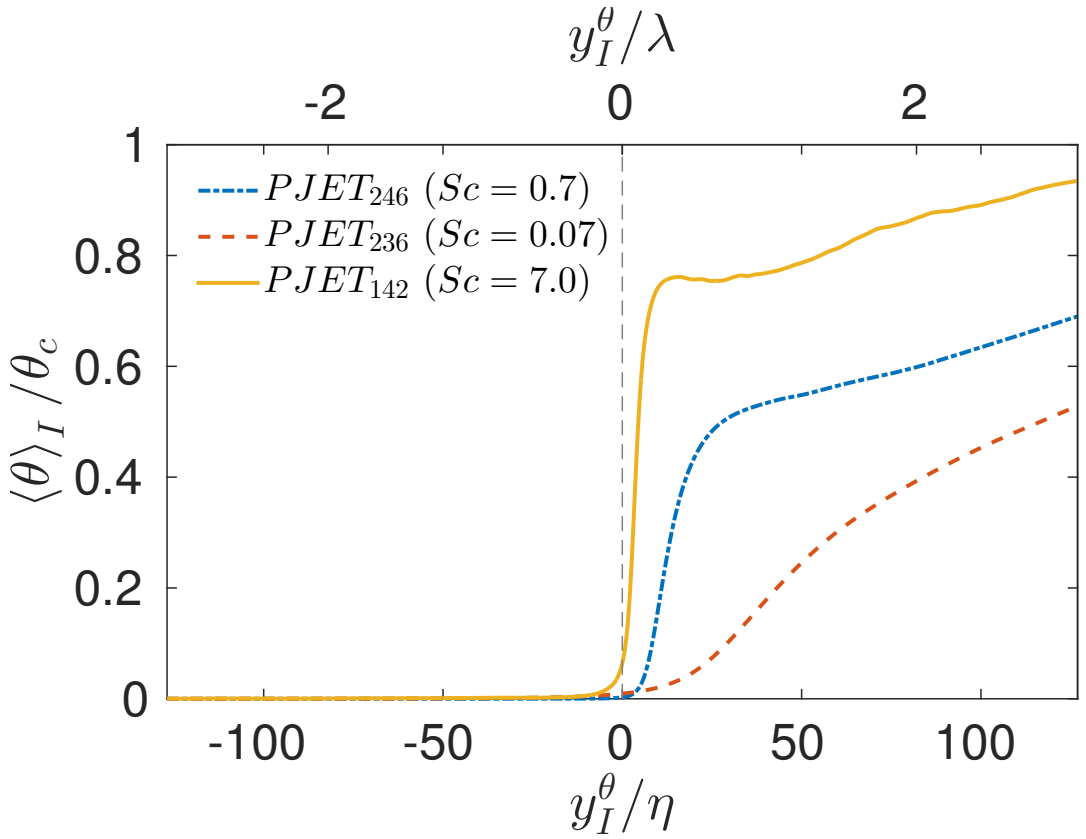
- Turbulent flow fraction method (da Silva *et al.* 2014)
- Very small volume fraction variation for:

$$2.1 \times 10^{-5} < G_{th} < 0.12$$

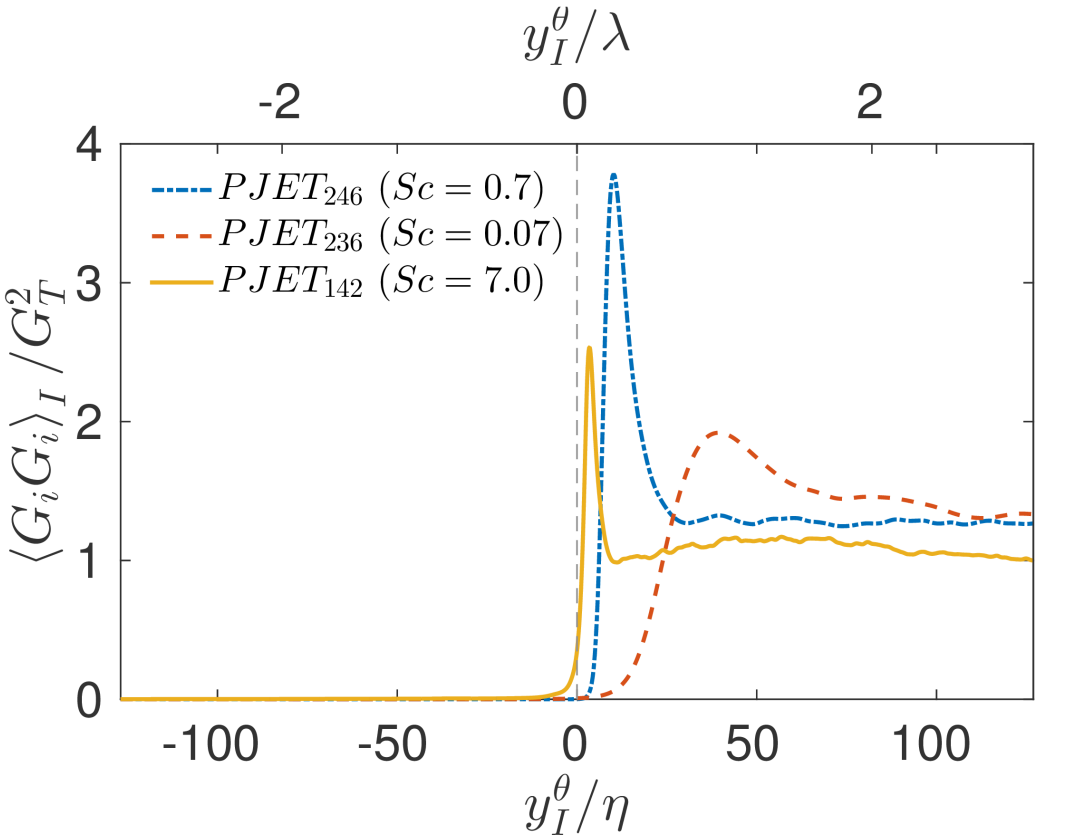
$G_{th} = 0.105$ used

PASSIVE SCALAR INTERFACE DETECTION

Conditional statistics applied to passive scalar gradient

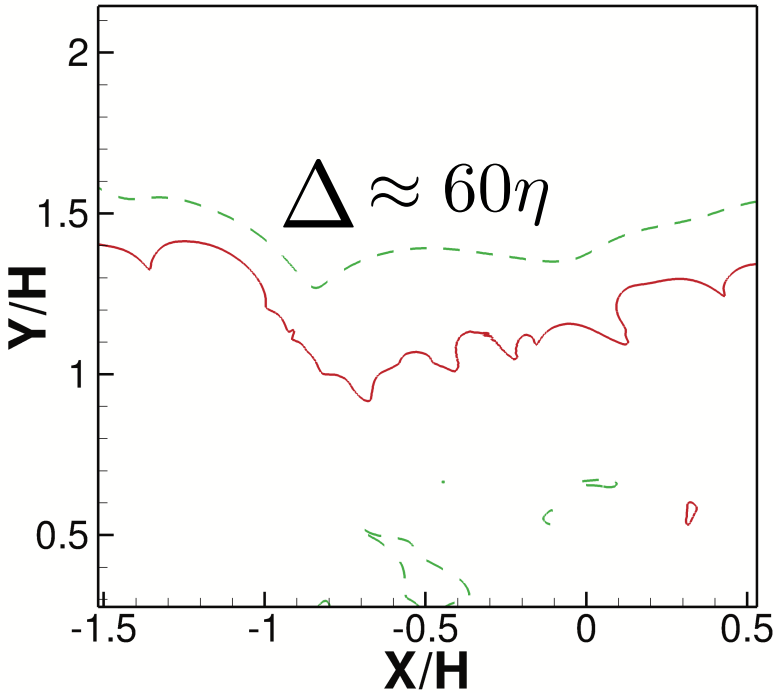


a) Scalar concentration conditional statistics in relation to the S-TNTI

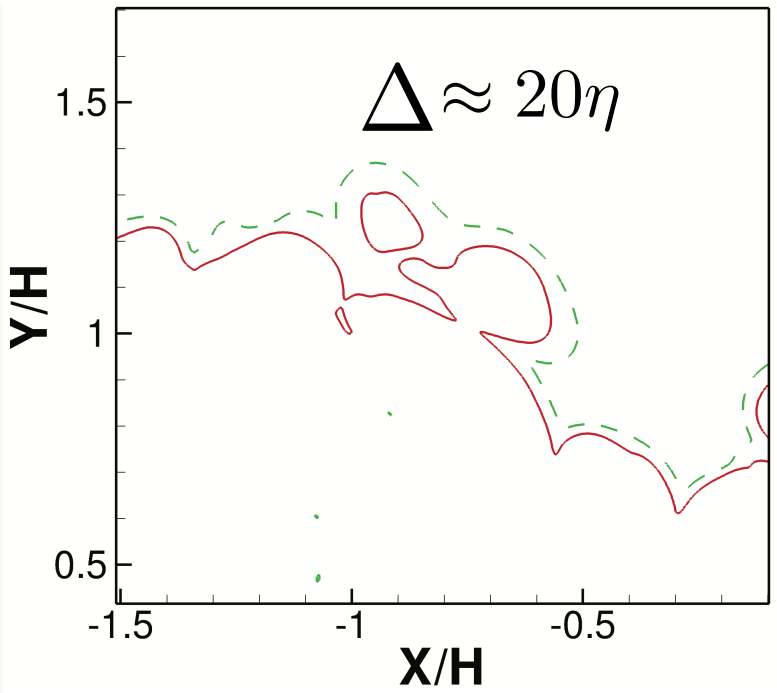


b) Scalar gradient conditional statistics in relation to the S-TNTI

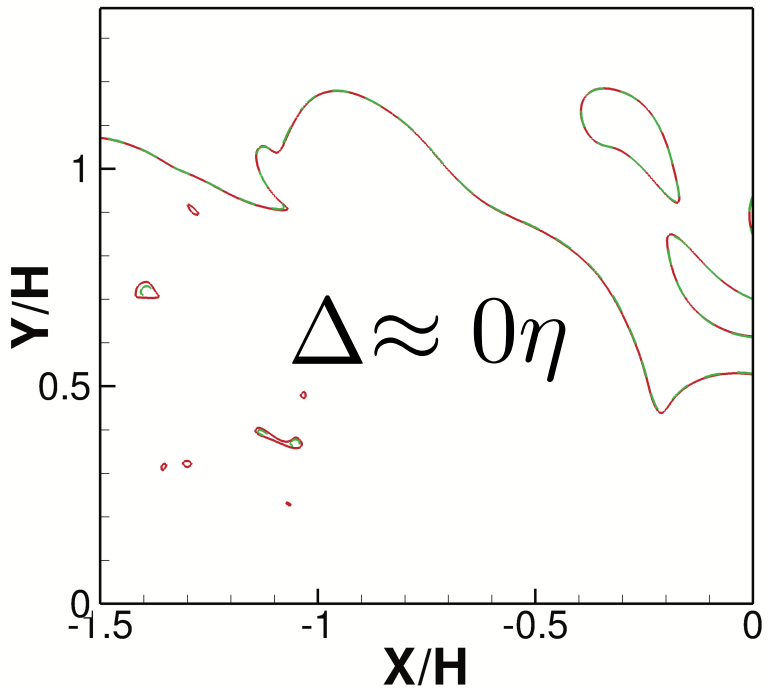
Vorticity interface Scalar gradient interface



a) $PJET_{236}$ (Sc = 0.07)



b) $PJET_{246}$ (Sc = 0.7)

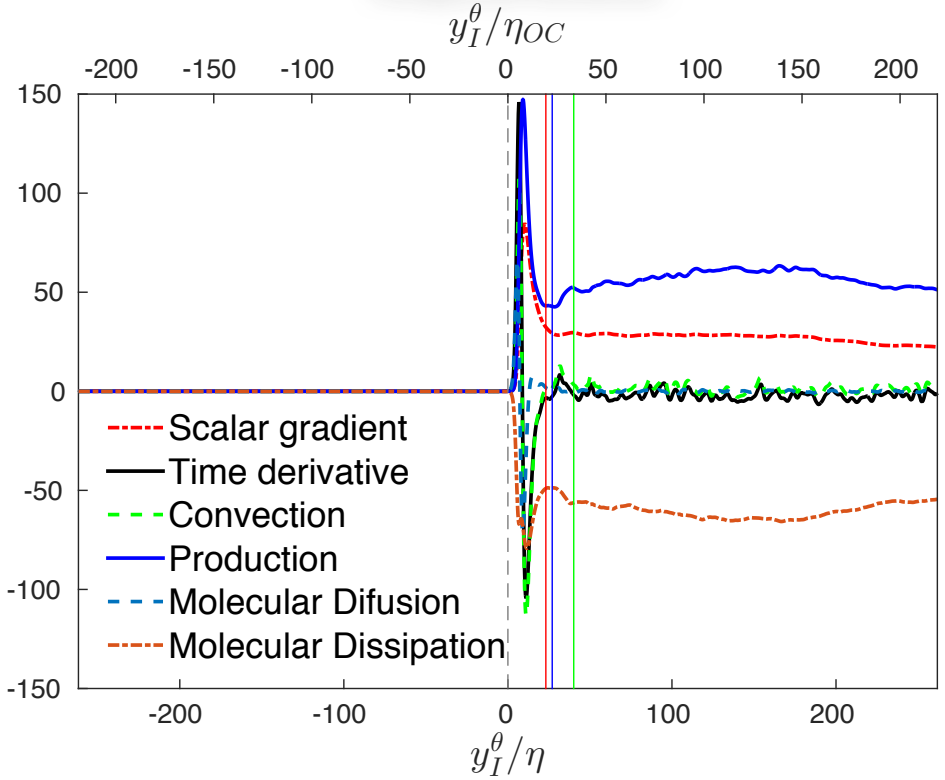


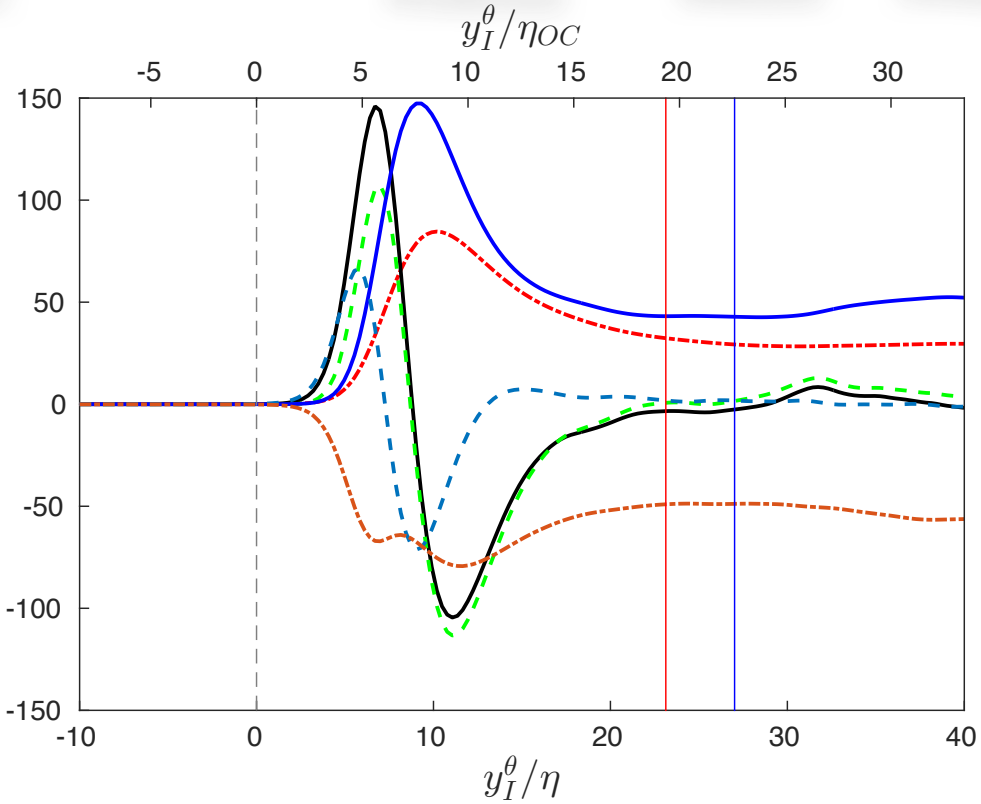
c) $PJET_{142}$ (Sc = 7.0)

SCALAR GRADIENT BUDGETS NEAR THE S-TNTI

Sc=0.7

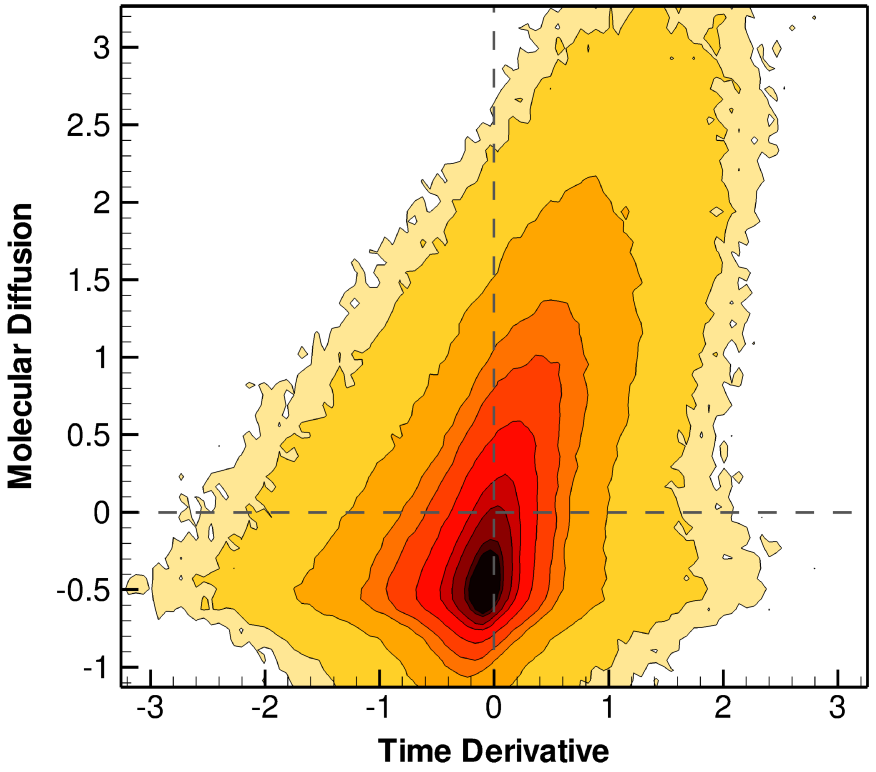
$$\underbrace{\frac{\partial \mathbf{G_i}^2/2}{\partial t}}_{\text{Temporal Variation}} = \underbrace{-\left(\mathbf{U}(x_I+x_0)-\mathbf{U}(x_0)-\mathbf{V}_P^G\right)\cdot\left(\nabla \boldsymbol{G_i}^2/2\right)}_{\text{Advection}} + \underbrace{\boldsymbol{G_i G_j S}_{ij}}_{\text{Production}} + \underbrace{\nu\nabla^2\left(\boldsymbol{G}^2/2\right)}_{\text{Diffusion}} - \underbrace{\nu\left(\nabla\boldsymbol{\omega}\right)^2}_{\text{Dissipation}}$$



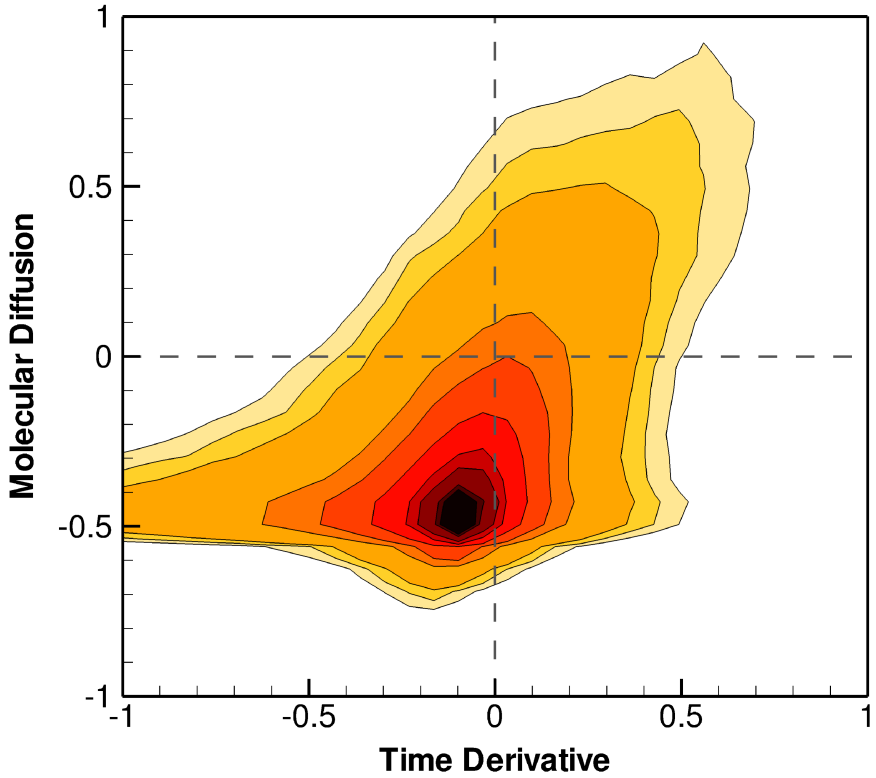


SCALAR GRADIENT GOVERNING MECHANISMS NEAR THE S-TNTI

Sc=0.7



a) JPDF of temporal variation and molecular diffusion at DSL

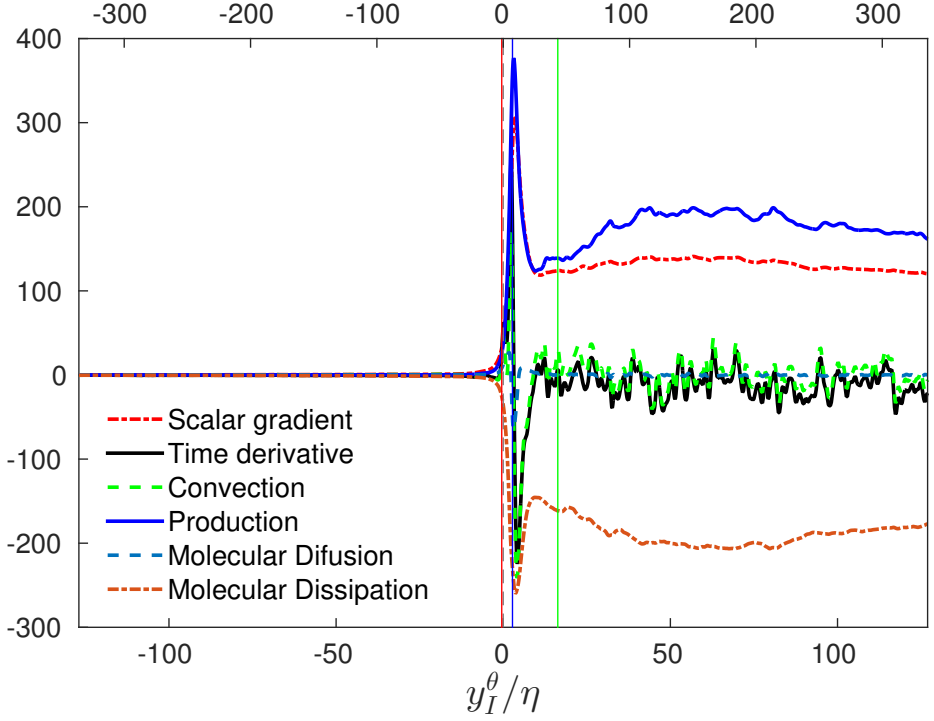


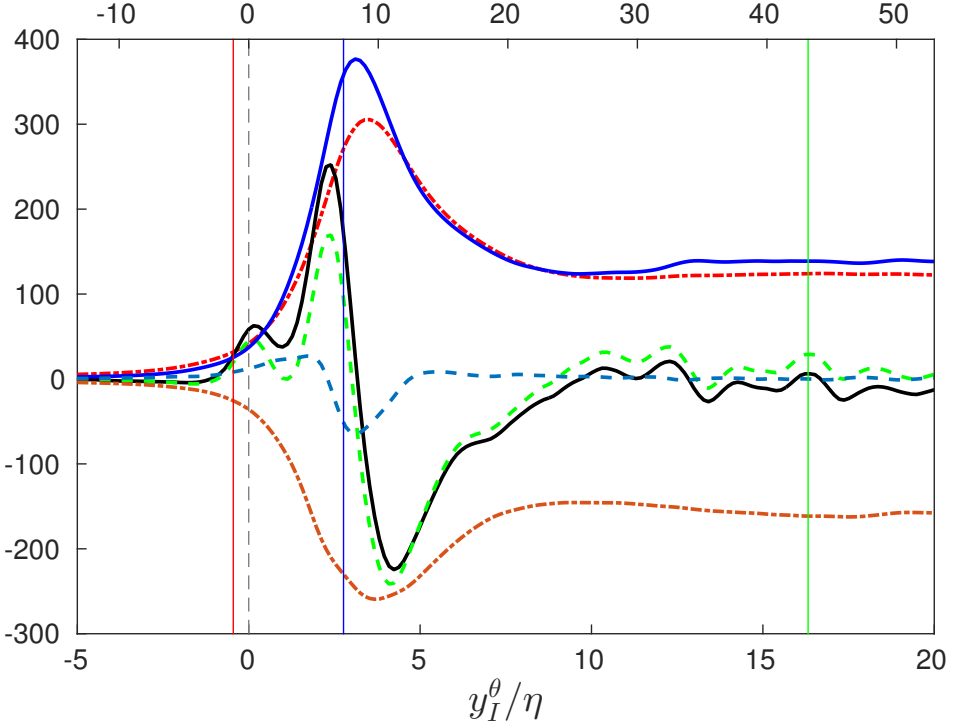
b) JPDF of temporal variation and molecular diffusion at max convection peak

SCALAR GRADIENT BUDGETS NEAR THE S-TNTI

Sc=7.0

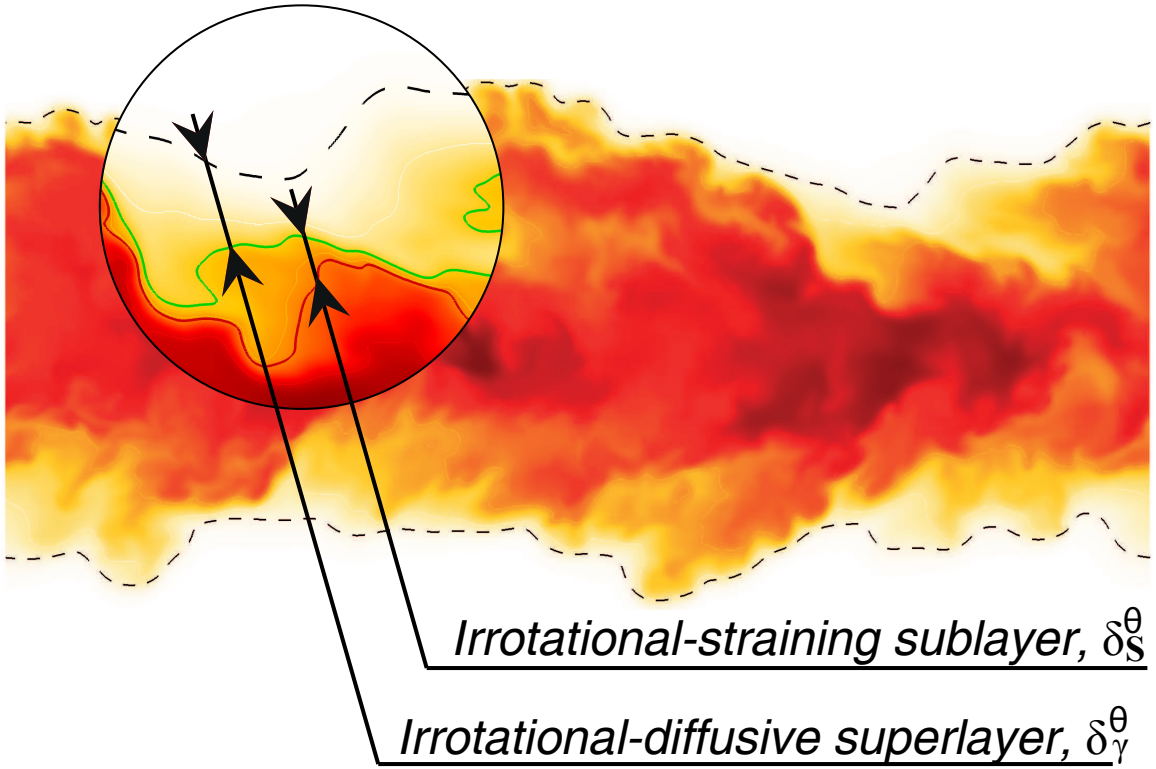
$$\underbrace{\frac{\partial \mathbf{G_i}^2/2}{\partial t}}_{\text{Temporal Variation}} = \underbrace{-\left(\mathbf{U}(x_I+x_0)-\mathbf{U}(x_0)-\mathbf{V}_P^G\right)\cdot\left(\nabla \boldsymbol{G_i}^2/2\right)}_{\text{Advection}} + \underbrace{\boldsymbol{G_i G_j S}_{ij}}_{\text{Production}} + \underbrace{\nu\nabla^2\left(\boldsymbol{G}^2/2\right)}_{\text{Diffusion}} - \underbrace{\nu\left(\nabla\boldsymbol{\omega}\right)^2}_{\text{Dissipation}}$$



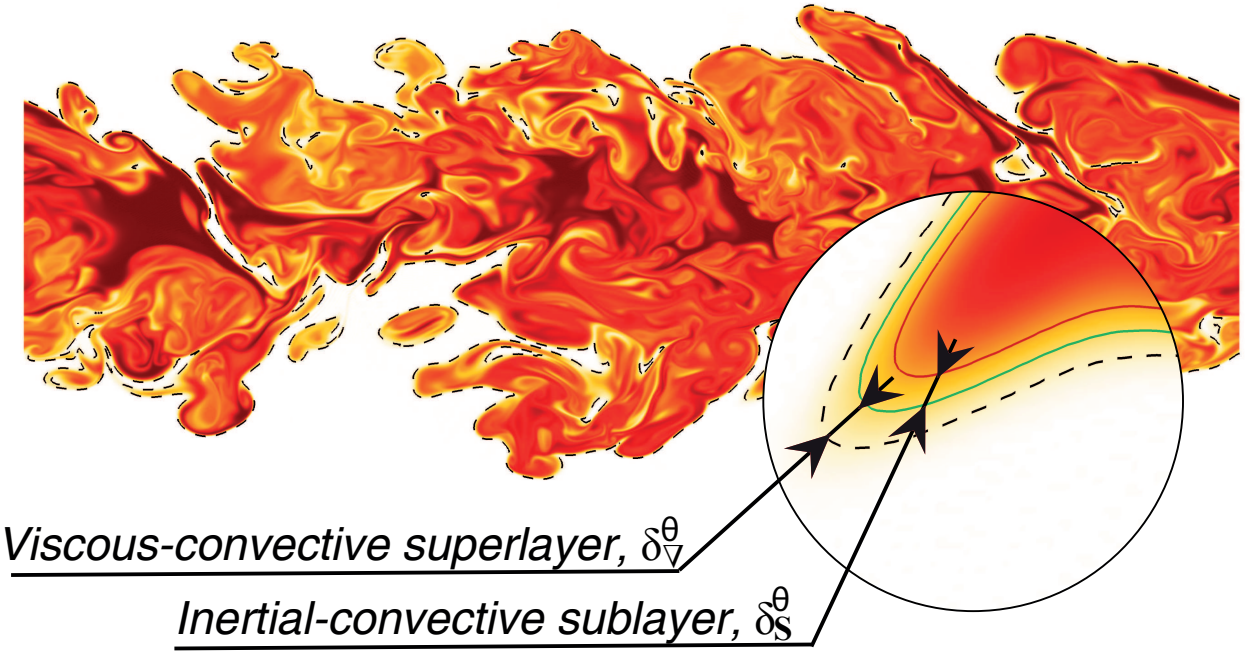


PASSIVE SCALAR INTERFACE STRUCTURE

Sublayers and governing mechanisms



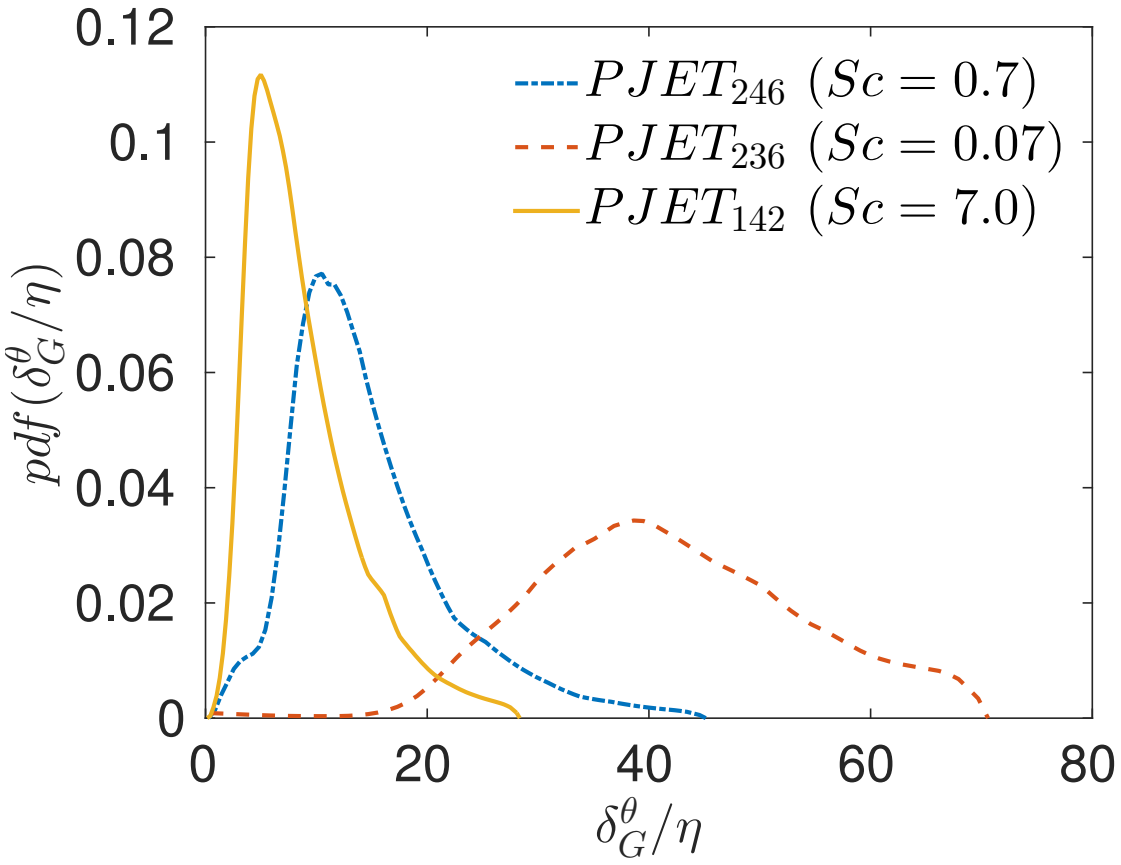
a) Sc ≤ 1

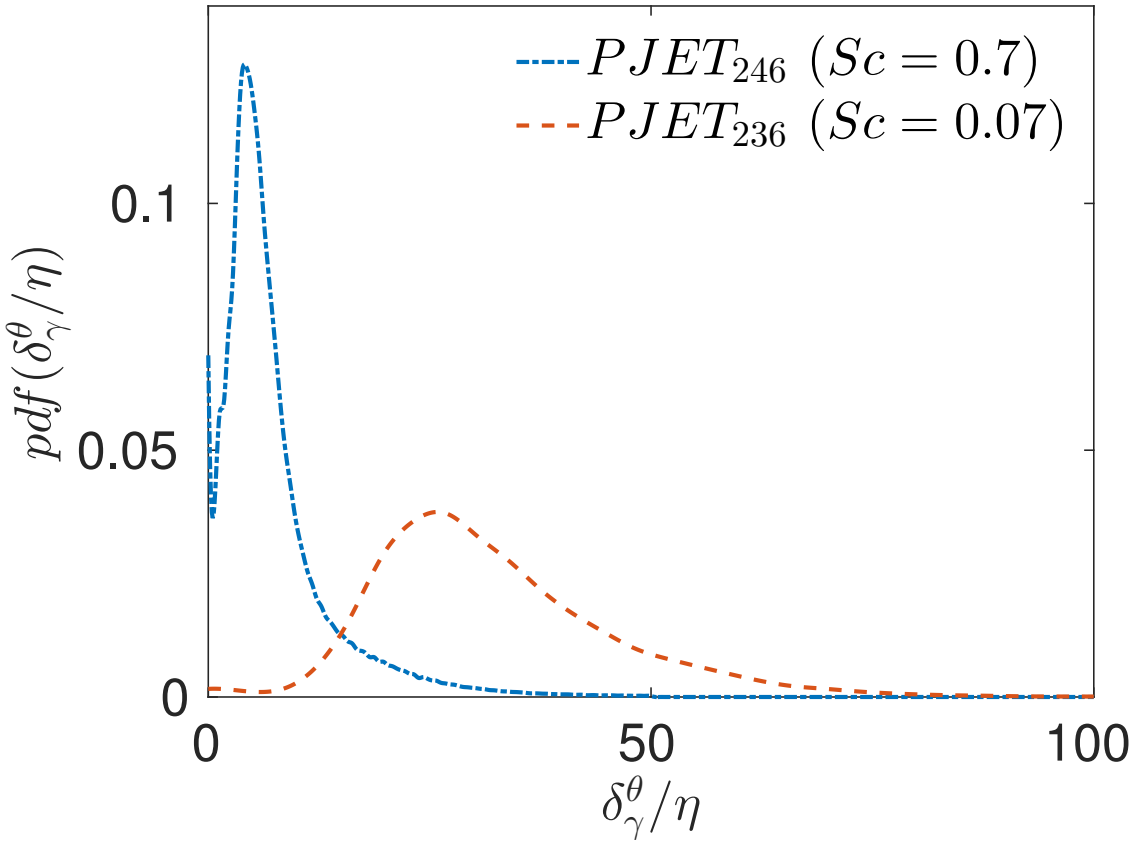


b) Sc > 1

PASSIVE SCALAR INTERFACE STRUCTURE

Sub-layers thicknesses





CONCLUSIONS

- **Passive scalar gradient field:**
  - Scalar Mixing:
    - $Sc \leq 1$
      - Irrotational-diffusive superlayer – molecular diffusion governs the mixing;
      - Irrotational-straining sublayer – advection and production govern;
    - $Sc > 1$
      - Viscous-convective superlayer – advection governs the mixing;
      - Inertial-convective sublayer – production governs.