1D numerical simulations of various self similar accelerated turbulent mixing layers using the 2SFK model.

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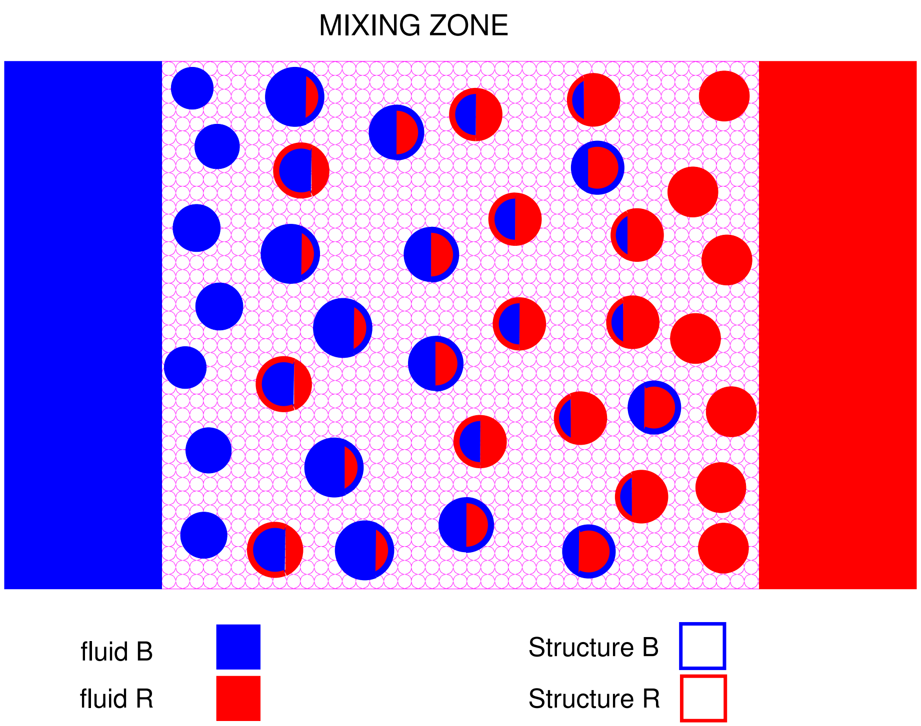
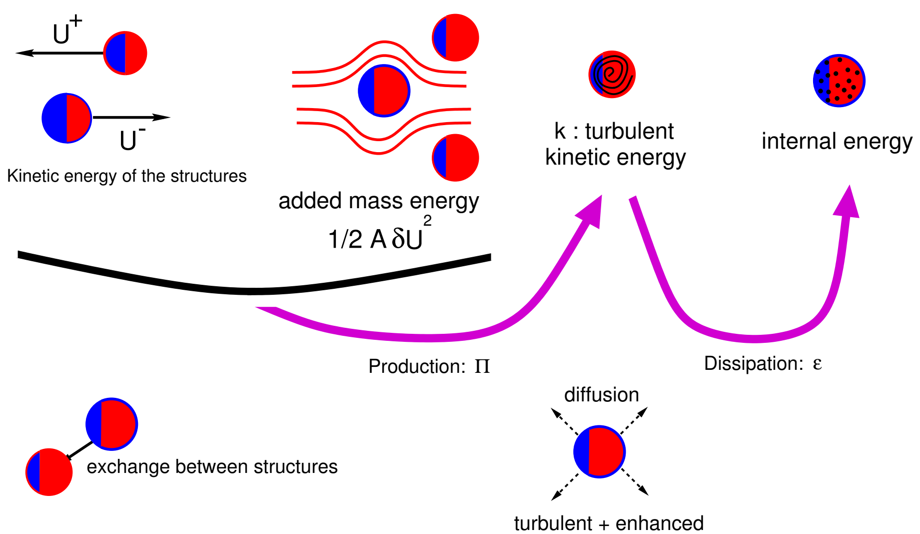
Why introduce the idea of turbulent structure ?



- For developed turbulent regime.
- Aimed at grasping features of the mixing.
- A fluid is a closed system:
  no exchange possible.
- A structure is an open system:
  exchange possible.
  size of structure∼turbulent length scale

Energy chart of 2SFK.



- $KE_{\text{two}} = \frac{1}{2}\alpha^+\rho^+ {U^+}^2 + \frac{1}{2}\alpha^-\rho^- {U^-}^2$

$$= \underbrace{\frac{1}{2}\bar{\rho}V^2}_{KE_{\text{single}}} + \underbrace{\frac{\alpha^+\rho^+\alpha^-\rho^-}{2\bar{\rho}}\,\delta \mathrm{U}^2}_{K_D}$$

KE : Kinetic Energy

K : Turbulent Kinetic Energy

K_D : Directed Energy

- $KE_{\text{single}} + K_{\text{single}} = KE_{\text{two}} + K_{\text{two}}$

✔ $\mathrm{K}_{\text{single}} = \mathrm{K}_{\text{two}} + K_D$

☛ RM: $K_D \ll K_{\text{two}}$; RT: $K_D \sim K_{\text{two}}$

Equations of 2SFK model.

- 2SFK stands for 2-Structure, 2-Fluid and 2-K-ϵ
- Conservation per structure of ...

$$
\begin{aligned}
\text{[fluid mass]}\quad \mathrm{D_t}^{\pm}(\alpha^{\pm}\rho^{\pm}\mathrm{C}^{\mathrm{m}\pm}) &= -\Phi^{m\pm}_{j,j} \mp \Psi^{m} \\
\text{[mass]}\quad \mathrm{D_t}^{\pm}(\alpha^{\pm}\rho^{\pm}) &= \mp\Psi \\
\text{[momentum]}\quad \mathrm{D_t}^{\pm}(\alpha^{\pm}\rho^{\pm}\mathrm{U}_i^{\pm} \pm \mathcal{A}\delta \mathrm{U}_i) &= -\alpha^{\pm}\partial_i(\mathrm{P}+\mathrm{P_t}) + \mathcal{S}_i[\mathcal{A}] \\
&\quad -\alpha^{\pm}\mathrm{Q}_{ij,j} - \left(\mathrm{R}_{ij} - \frac{2}{3}\alpha^{\pm}\rho^{\pm}\mathrm{k}^{\pm}\delta_{ij}\right)_{,j} \mp (D_i + \Psi_i^{H}) \\
\text{[internal energy]}\quad \mathrm{D_t}^{\pm}(\alpha^{\pm}\rho^{\pm}\mathrm{E}^{\pm}) &= -\mathrm{P}(\mathrm{D_t}^{\pm}(\alpha^{\pm}) \pm \Psi^{\alpha}) + \alpha^{\pm}\rho^{\pm}\Sigma^{\pm} + \alpha^{\pm}\rho^{\pm}\epsilon^{\pm} - \Phi^{E\pm}_{j,j} \mp \Psi^{E} \\
\text{[turbulence : k]}\quad \mathrm{D_t}^{\pm}(\alpha^{\pm}\rho^{\pm}\mathrm{k}^{\pm}) &= \frac{2}{3}\rho^{\pm}\mathrm{k}^{\pm}(\mathrm{D_t}^{\pm}(\alpha^{\pm}) \pm \Psi^{\alpha}) + \Pi^{\pm} - \alpha^{\pm}\rho^{\pm}\epsilon^{\pm} - \Phi^{k\pm}_{j,j} \mp \Psi^{k} \\
\text{[dissipation : }\epsilon\text{]}\quad \mathrm{D_t}^{\pm}(\alpha^{\pm}\rho^{\pm}\epsilon^{\pm}) &= -\left(\frac{2}{3}\mathrm{C}_{\epsilon 1} + \mathrm{C}_{\epsilon 3}\right)\rho^{\pm}\epsilon^{\pm}(\mathrm{D_t}^{\pm}(\alpha^{\pm}) \pm \Psi^{\alpha}) + \mathrm{C}_{\epsilon 1}\frac{\epsilon^{\pm}}{k^{\pm}}\Pi^{\pm} - \mathrm{C}_{\epsilon 2}\alpha^{\pm}\rho^{\pm}\frac{\epsilon^{\pm 2}}{k^{\pm}} \\
&\quad -\Phi^{\epsilon\pm}_{j,j} \mp \Psi^{\epsilon}
\end{aligned}
$$

Some closures of flux and exchange.

$$\lambda^{\pm} = \frac{k^{\pm 3/2}}{\epsilon^{\pm}} \quad \text{Turbulent length scale}$$

$$\nu^{\pm} = \mathrm{C}_{\mu} \frac{k^{\pm 2}}{\epsilon^{\pm}} \quad \text{Turbulent viscosity} \quad \mathrm{C}_{\mu} = 0.09$$

$$\lambda = \frac{\lambda^{+4} + \lambda^{-4}}{\lambda^{+3} + \lambda^{-3}} \sim \max(\lambda^{+}, \lambda^{-}) \quad \text{Exchange length scale}$$

$$\omega_{\Psi} = \frac{1}{\mathrm{C}_{\mu}} \frac{\nu^{+} + \nu^{-}}{\lambda^{2}} \quad \text{Exchange time scale}$$

$$D_s^{\pm} = 4\mathrm{C_s}\, \alpha^{+}\alpha^{-}\lambda \,||\, \delta\mathbf{U} \,|| \quad \text{Sifting diffusion}$$

$$D_i + \Psi_i^H = \frac{\alpha^{-}\rho^{-}H_i^{+} + \alpha^{+}\rho^{+}H_i^{-}}{\alpha^{+}\rho^{+} + \alpha^{-}\rho^{-}}\Psi + \mathrm{C_d}\alpha^{+}\alpha^{-}\omega_{\Psi}\frac{(\alpha^{+}\rho^{+})^2 + (\alpha^{-}\rho^{-})^2}{\alpha^{+}\rho^{+} + \alpha^{-}\rho^{-}}(\delta H_i - H_i^o) \quad \text{Drag}$$

$$H_i^o = -\left(1 + \frac{(\alpha^{+}\rho^{+} + \alpha^{-}\rho^{-})\mathcal{A}}{\alpha^{+}\rho^{+}\alpha^{-}\rho^{-}}\right)\left[D_s^{+}\frac{(\alpha^{+}\rho^{+})_{,i}}{\alpha^{+}\rho^{+}} - D_s^{-}\frac{(\alpha^{-}\rho^{-})_{,i}}{\alpha^{-}\rho^{-}}\right] \quad \text{Diffusive drift}$$

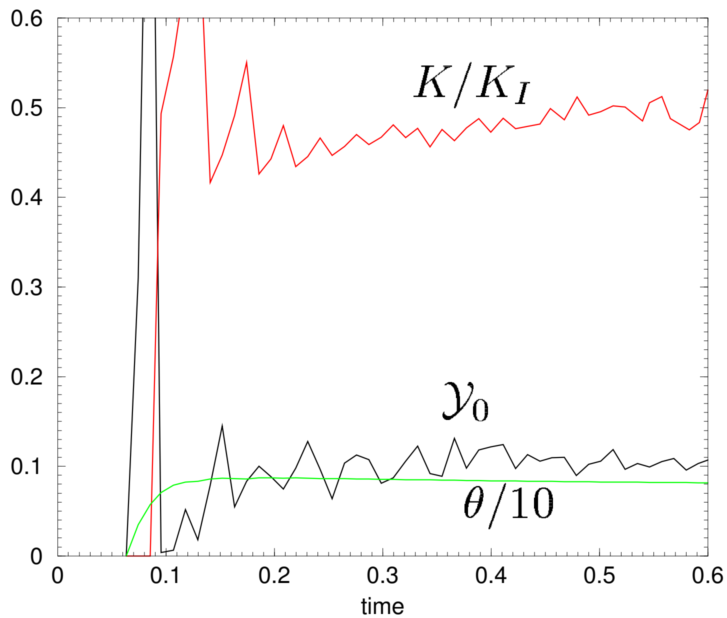
$$\Phi_i^{A\pm} = -\alpha^{\pm}\rho^{\pm}\left(\frac{\nu^{\pm}}{\sigma_A} + D^{\pm}\right)\left[A_{,i}^{\pm} - P_A\left(\frac{\rho_{,i}^{\pm}}{\rho^{\pm 2}} + \sum_m \frac{C_{,i}^{m\pm}}{\rho^{m\pm}}\right)\right] \quad \text{Flux of A}$$

$$\Psi^A = \frac{1}{2}\mathrm{C}_{\epsilon c}\, \alpha^{+}\alpha^{-}\omega_{\Psi}(\alpha^{+}\rho^{+}A^{+} - \alpha^{-}\rho^{-}A^{-}) \quad \text{Exchange of A}$$

Growth rate, mixing rate, level of dissipation ($A_t = 0.2$).

Rayleigh Taylor
Atwood 0.2

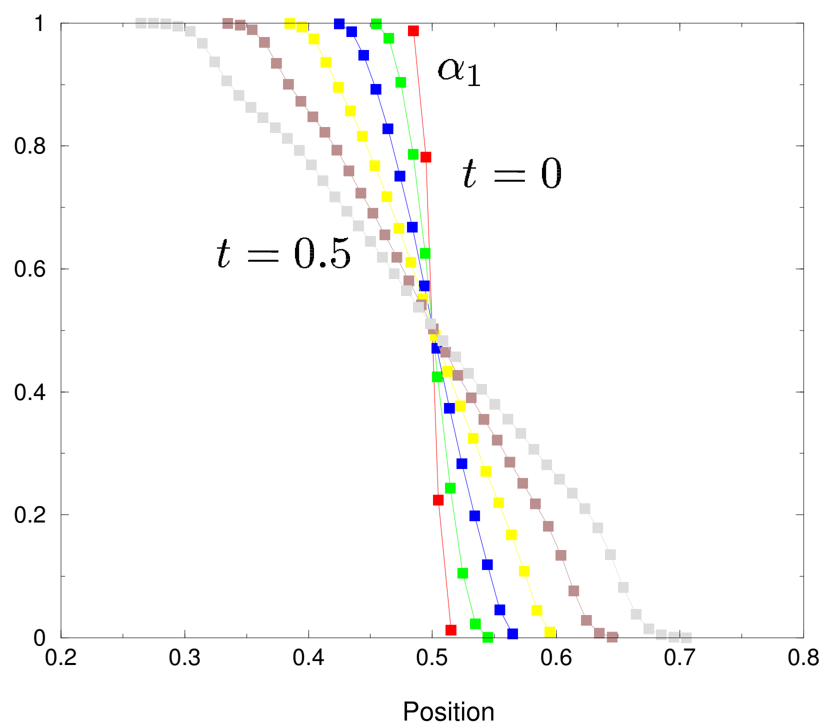
reference:
(α-group results)
$K/KI \sim 0.46$
$\mathcal{Y}_0 \sim 0.12$
$\theta \sim 0.8$



- K is the single-fluid turbulent kinetic energy.
- K_I is the gravitational energy input.
- $\mathcal{Y}_0$ is the growth rate.
- $L(t) = \mathcal{Y}_0 A_t g t^2$
- θ is the molecular mixing rate.

Volume fraction of light fluid (various times).

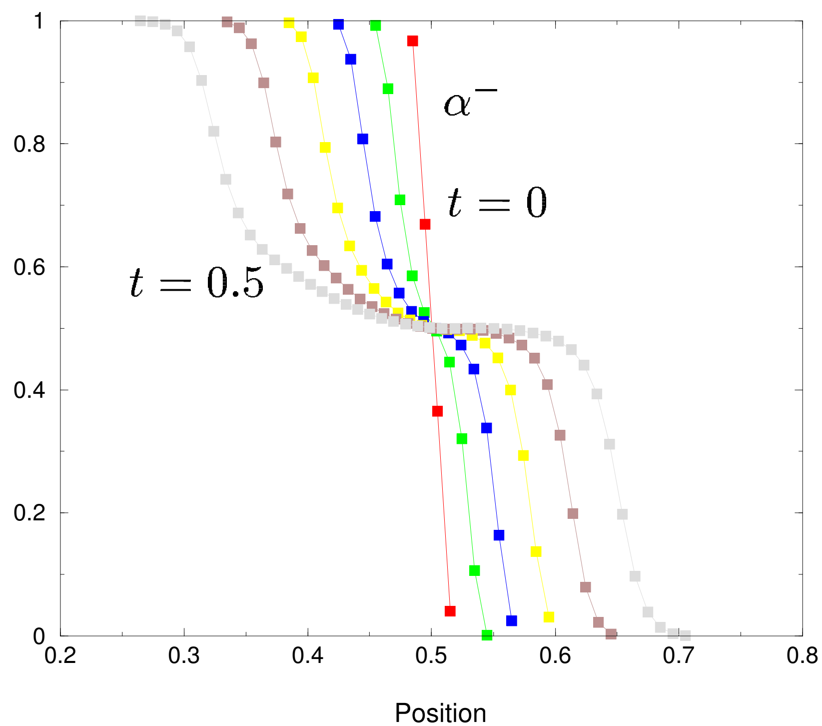
elf similar evolution
developed turbulence
in the TMZ)



- Volume fractions of fluids are linear over the TMZ for low Atwood 0.2. In agreement with EXP and DNS

Volume fraction of light structure (various times).

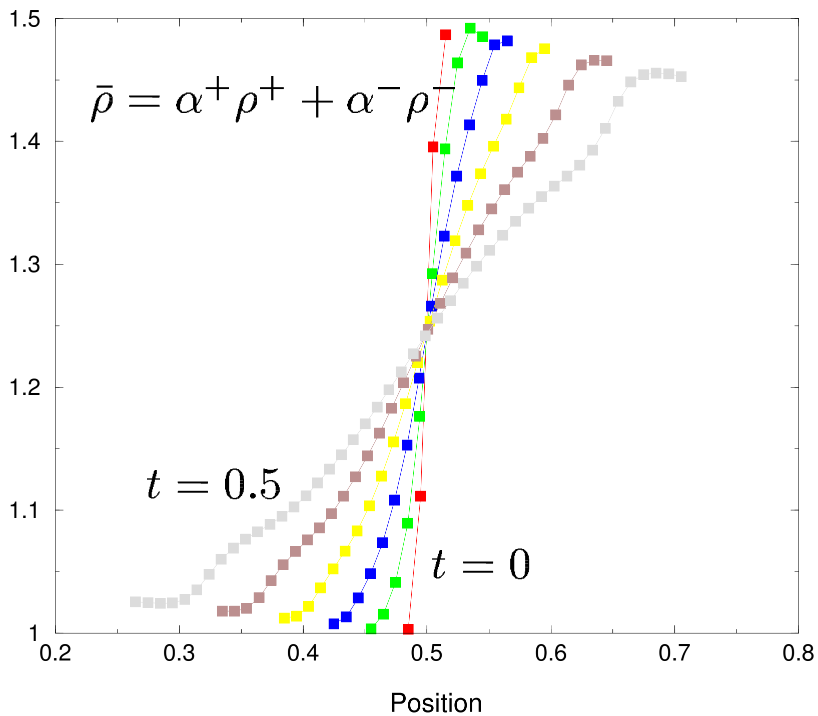
elf similar evolution
developed turbulence
in the TMZ)



- There is a significant part of the TMZ where $\alpha^+ \approx \alpha^-$
- DNS simulation would allow to verify these profiles

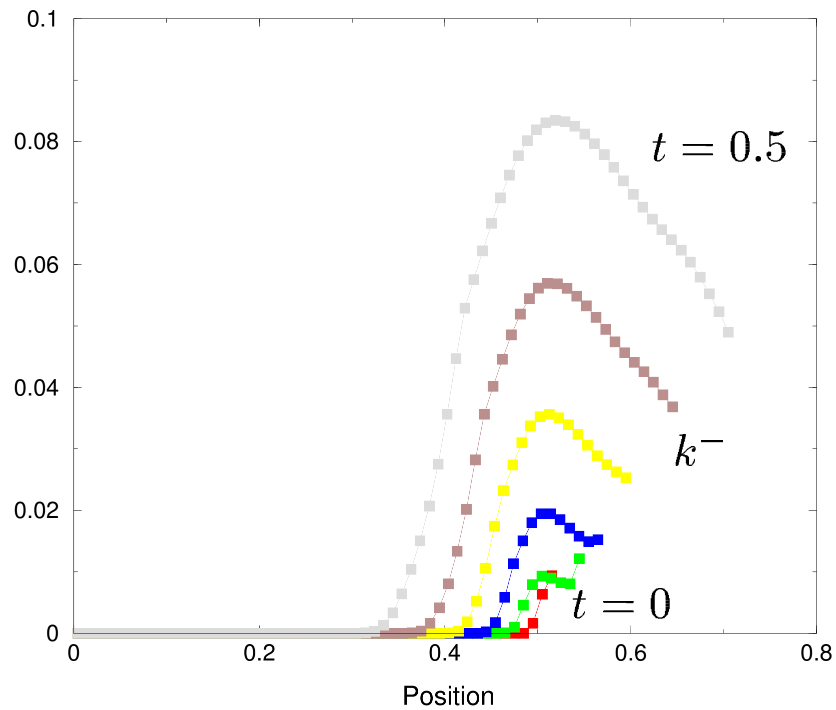
Density profile (various times).

is also equal
o $\alpha_1\rho_1 + \alpha_2\rho_2$.
f two fluids are
ncompressible and since
α_1 and α_2 have
near profiles in the TMZ
➔ $\bar{\rho}$ linear profile

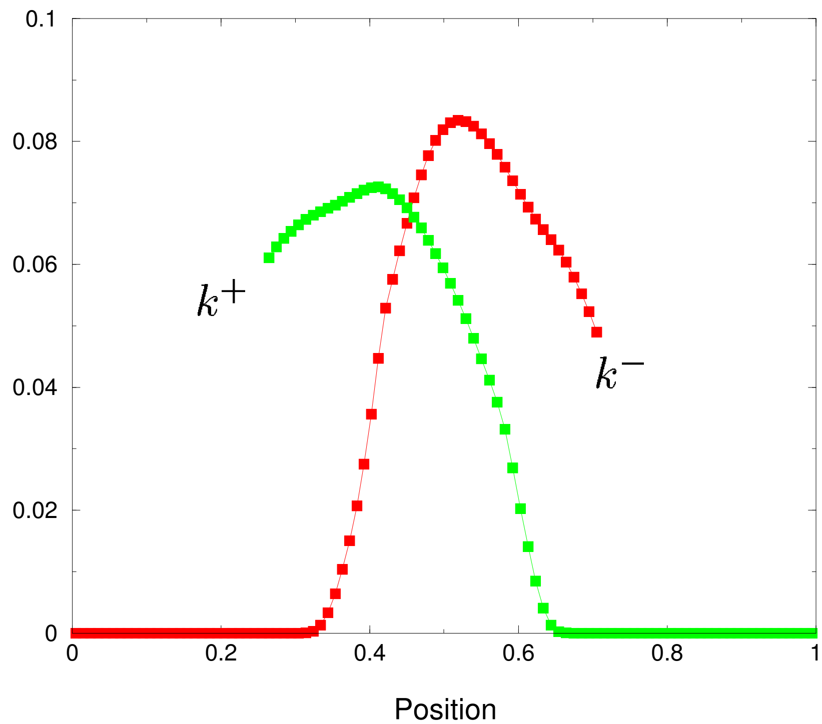


☛ $\bar{\rho}$ roughly linear
ρ_1 and ρ_2 are not strictly incompressible here (value of $\bar{\rho}$ at the edge)

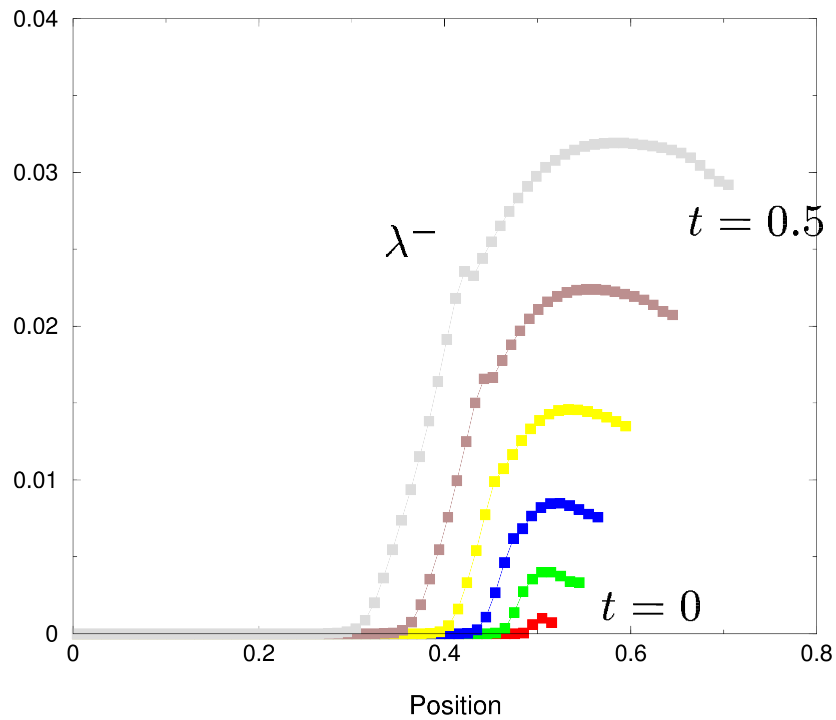
Per mass turbulent kinetic energy (various times).



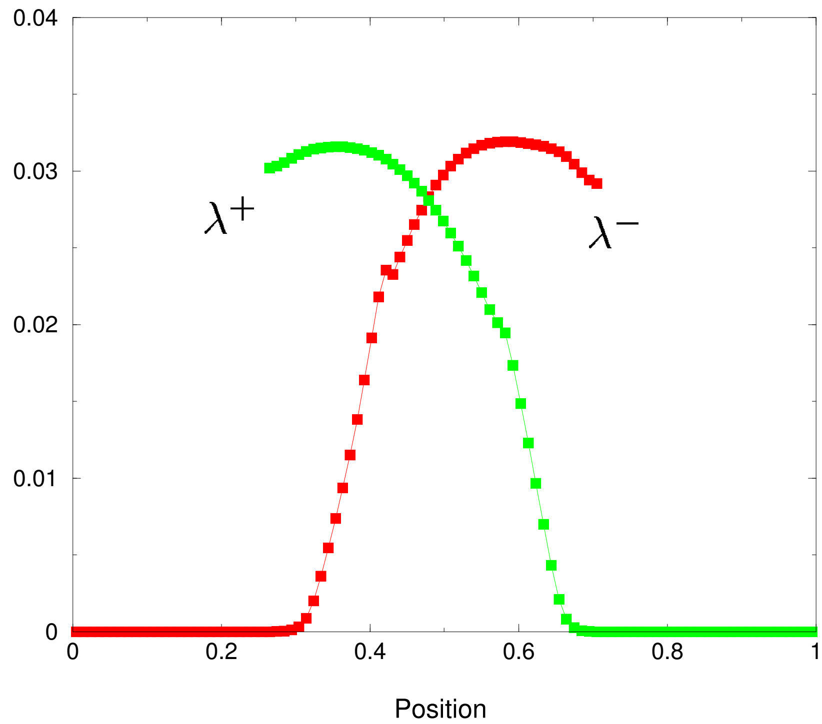
Per mass turbulent kinetic energies (same time).



Turbulent length scale (various times).



Turbulent length scale (same time).



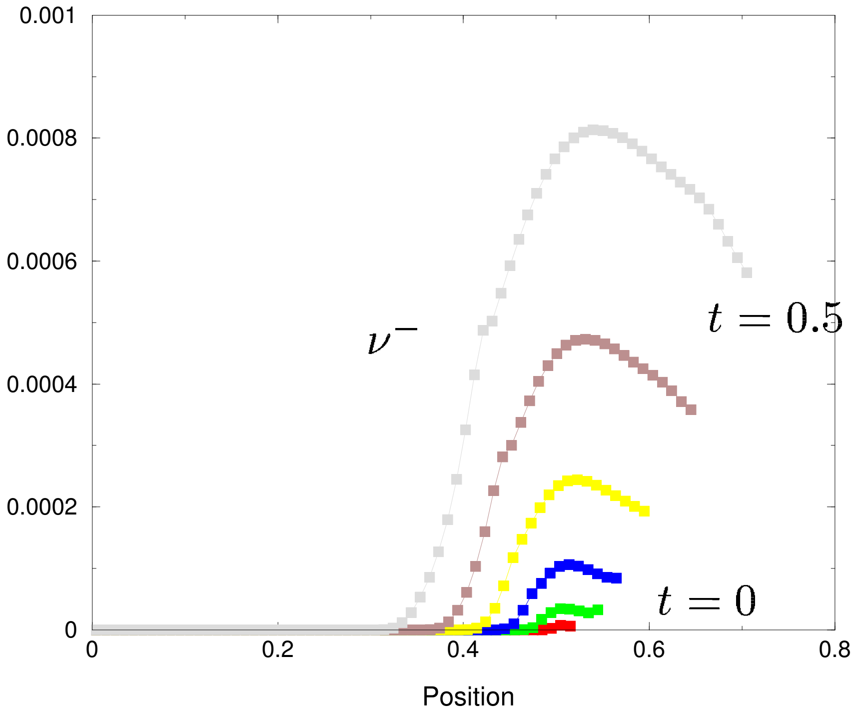
- in this example:

  $\lambda_{\max} \approx 0.03$

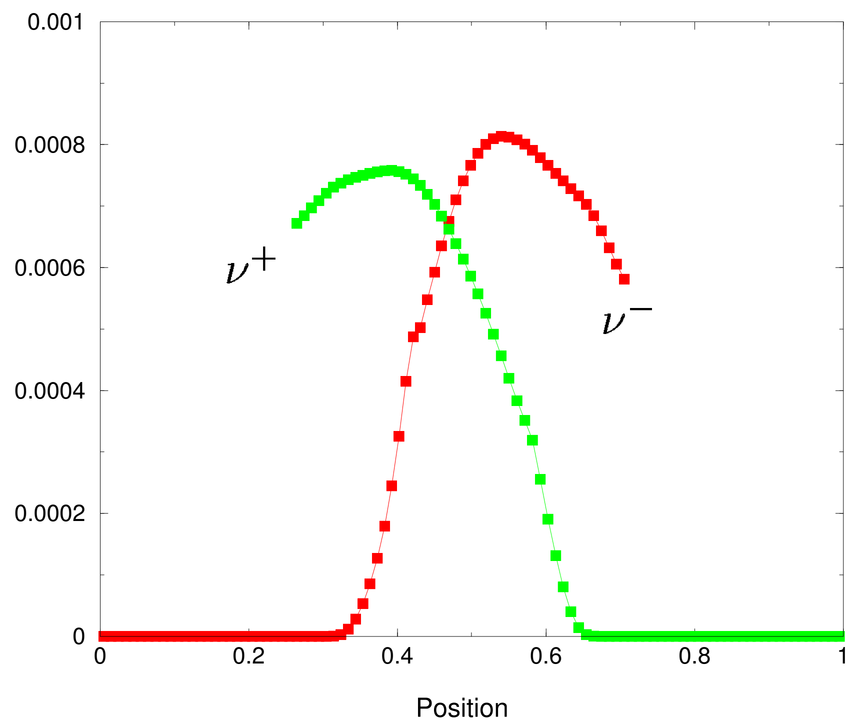
  $L_{\mathrm{TMZ}} \approx 0.4$

  turbulent Knudsen number :0.075

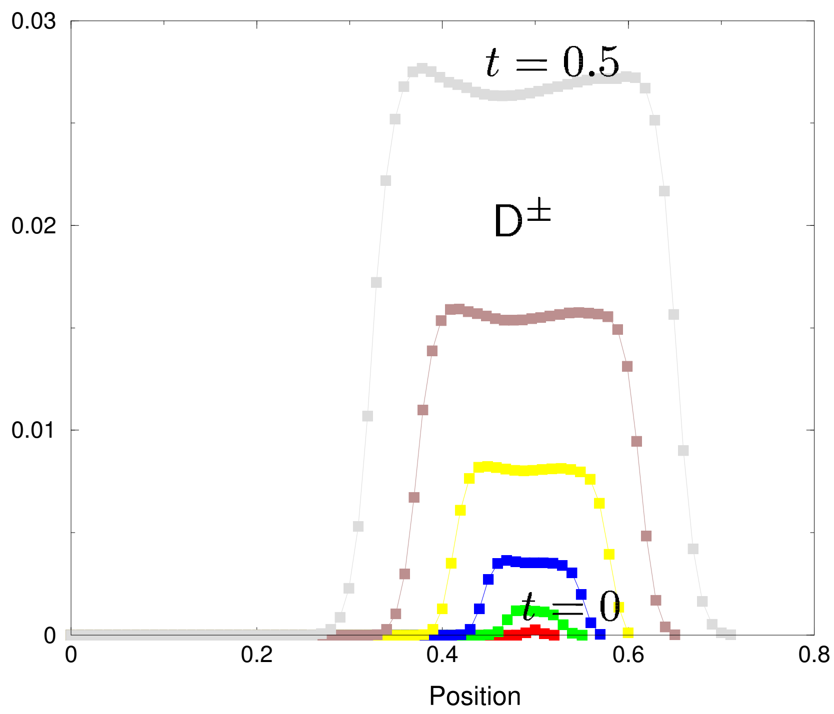
Turbulent viscosity (various times).



Turbulent viscosity (same time).



Diffusion (various times).



- in this example:

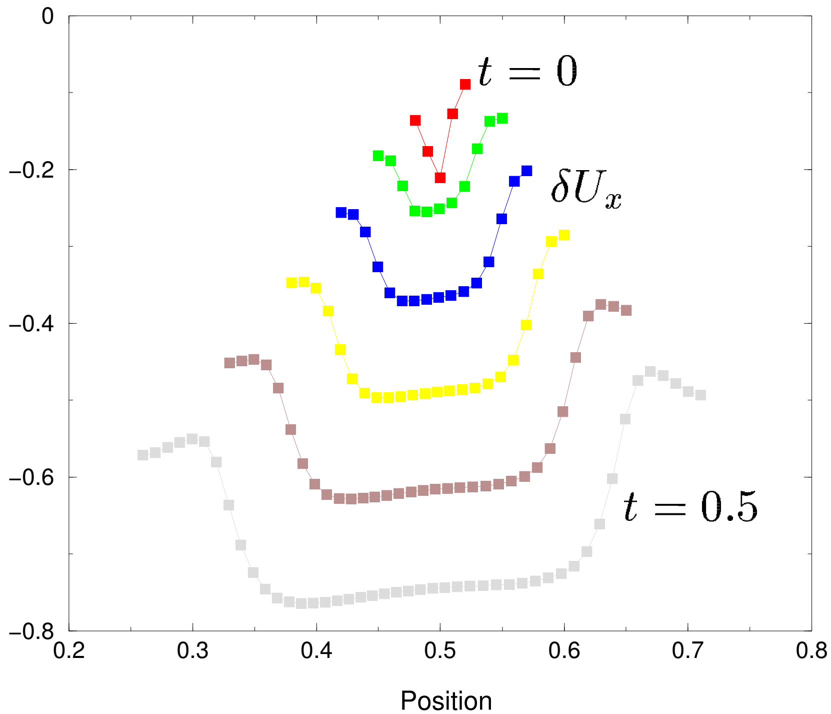
  $D_{\max}(t = 0.5) \approx 0.03$

  $L_{\mathrm{TMZ}}(t = 0.5) \approx 0.4$

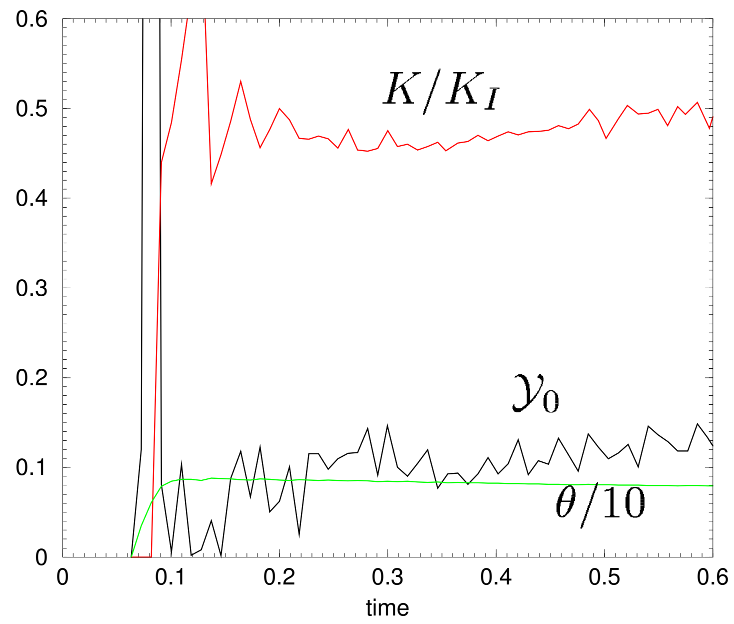
  $\dot{L}_{\mathrm{TMZ}}(t = 0.5) \approx 1.6$

  normalized $D_{\max}$:0.05

δU (various times).



Growth rate, mixing rate, level of dissipation ($A_t = 0.8$).



Volume fraction of light fluid (various times).

elf similar evolution
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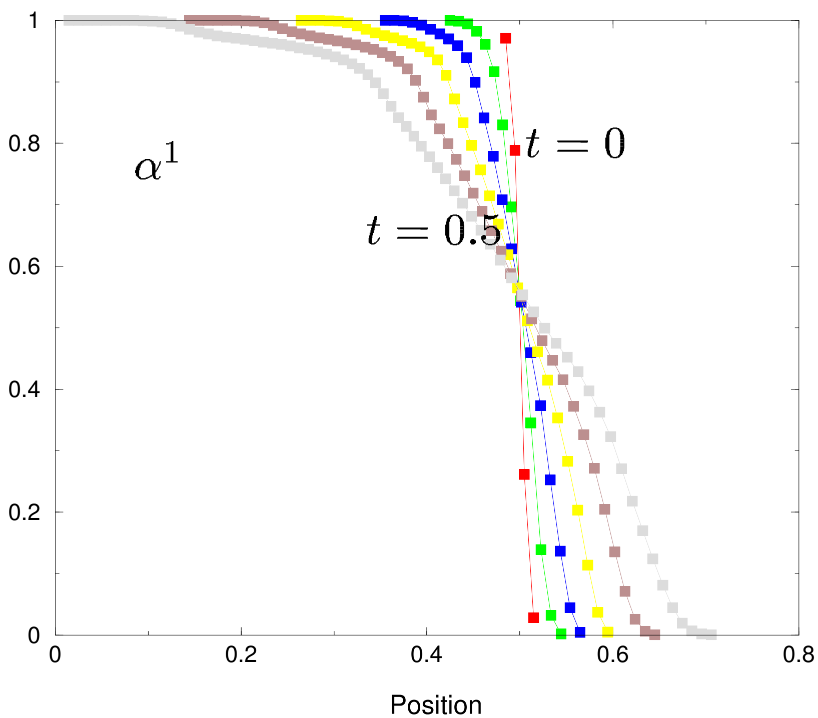

☛ Volume fractions of fluids are not linear over the TMZ for high Atwood 0.8.
In agreement with EXP and DNS