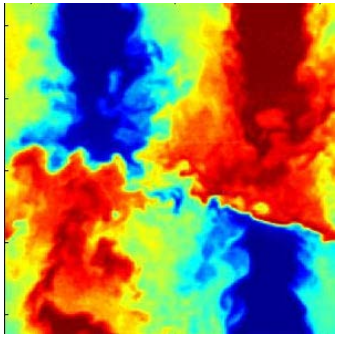
Variable-viscosity mixing in the very near field of a round jet



Luminita Danaila

Benoît Talbot

Bruno Renou

Context and collaborations:

ANR 'Micromixing': B. Renou, J.F. Krawczynski, G. Boutin, F. Thiesset, B. Talbot

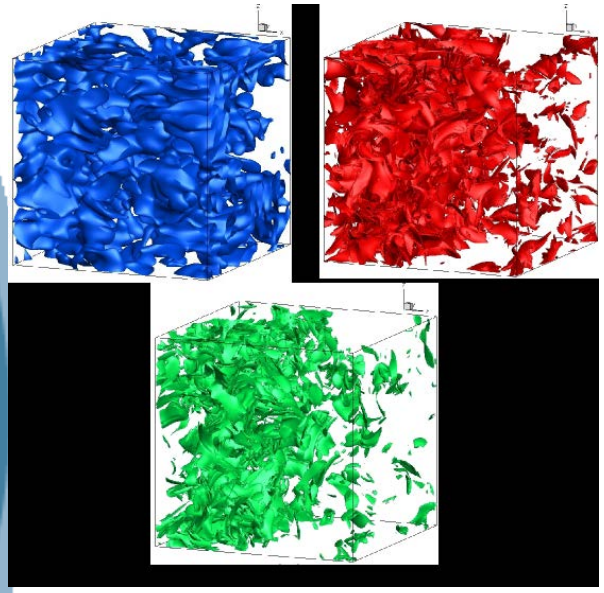
Perspectives :

ANR 'MUVAR': B. Renou, A. Hadjadj, B. Patte-Rouland, A. Chinnayya, N. Taguelmimt

L. Voivenel (Oct. 2012)

F. Anselmet, M. Amielh, L. Pietri (IRPHE)

Active scalar mixing, variable-viscosity



$$Navier-Stokes... + \frac{\partial}{\partial x_j}\left(\mu(f)\frac{\partial u_i}{\partial x_j}\right)$$

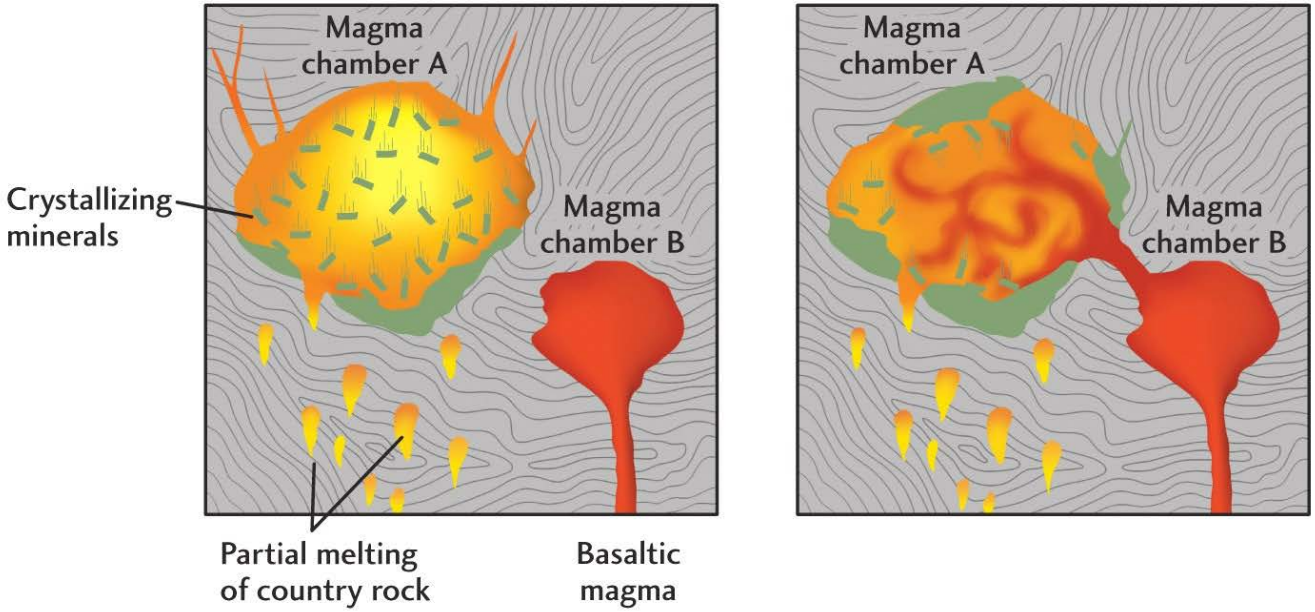
$$\frac{df}{dt} = \frac{\partial}{\partial x_j}\left(D(f)\frac{\partial f}{\partial x_j}\right)$$

Active scalar mixing, variable-viscosity

Important because:

-fundamental aspect (most of the theory deals with homogeneous fluids, passive scalar..)

-practical aspect: initial phase of mixing- combustion, geophysical flows (ratio of viscosities =1000..) etc.

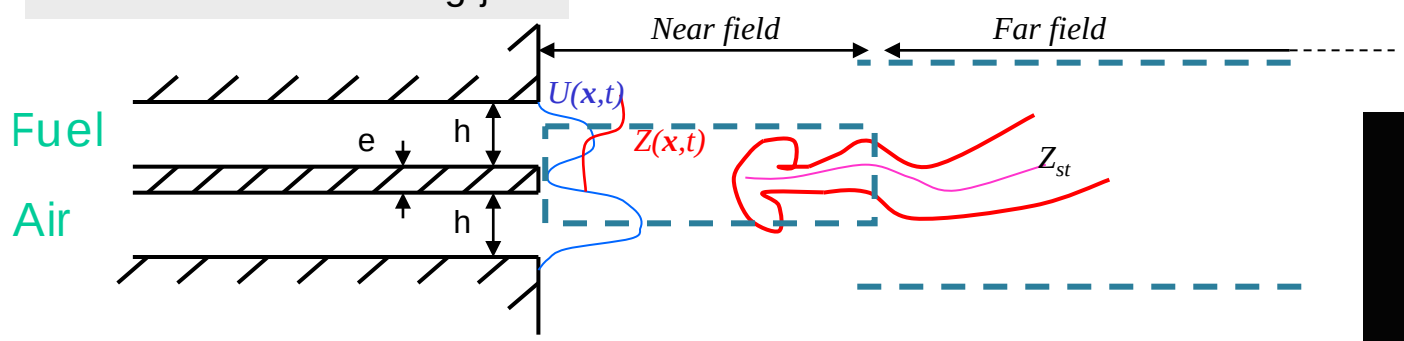


Active scalar mixing, variable-viscosity

Application: MACRO AND MICRO-MIXING FUEL-AIR

- **Both reactants (fuel and oxidizer) are generally injected through distinct channels**
  - **→ merging zone followed by a non-reacting, quasi isothermal partially premixed region**
  - **→ strong effect of turbulence (large and small scales) from the wake, the shear layer and the developed turbulence of the channels**
- **Deep impact on the flame stabilization, structure or propagation**

Two-stream coflowing jets



Etude en cours, couche mélange, N. Taguelmimt

Validation in an axisymmetric Jet (Re_D=7,000)

Probes volumes
Rayleigh (dxL) : 80x200µm
Hot-wire (d,L) : 2.5 µm, 400µm (L/d ~ 160)
Axial distance between volume probes = 800 µm

Detection, conditioning, filtering

Sampling rate Fs = 100 kHz

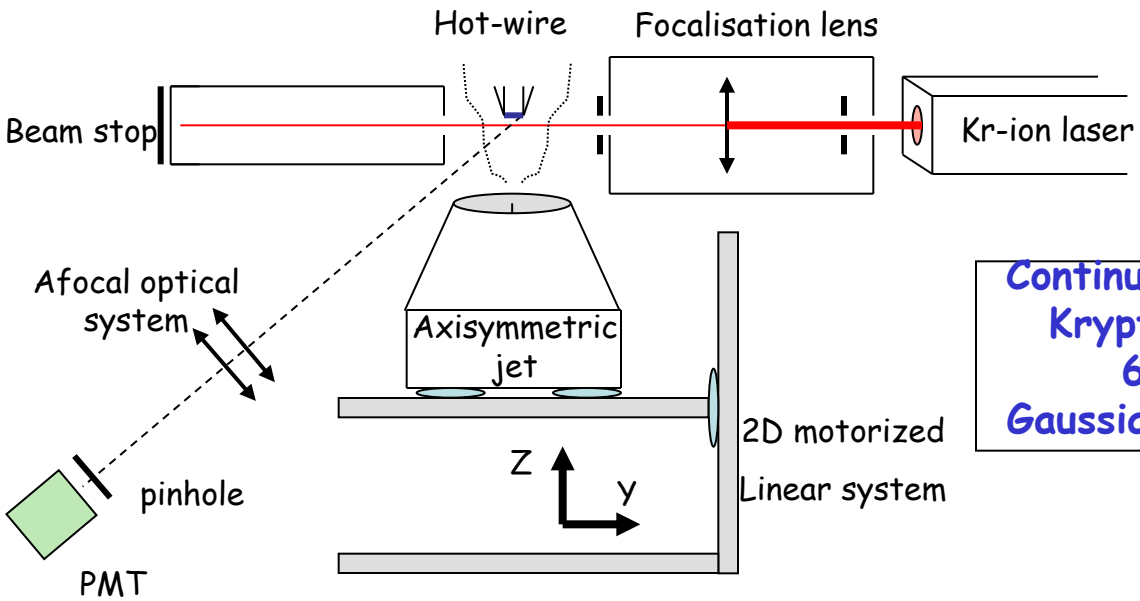
Filtering at 50 kHz (Fs/2) for velocity

Filtering at 35 kHz (Rayleigh)

Low noise PMT : < 0.15 nA

afocal optical system, f/D = 1.5

Fc (Hot-Wire) ~ 40 kHz



Continuous ion Laser
Krypton 676 nm
6 Watts
Gaussian laser beam

Round Jet
d = 5 mm
D_{coflow}=80 mm

B. Talbot et al., Exp. Fluids 2009

Active scalar mixing, variable-viscosity

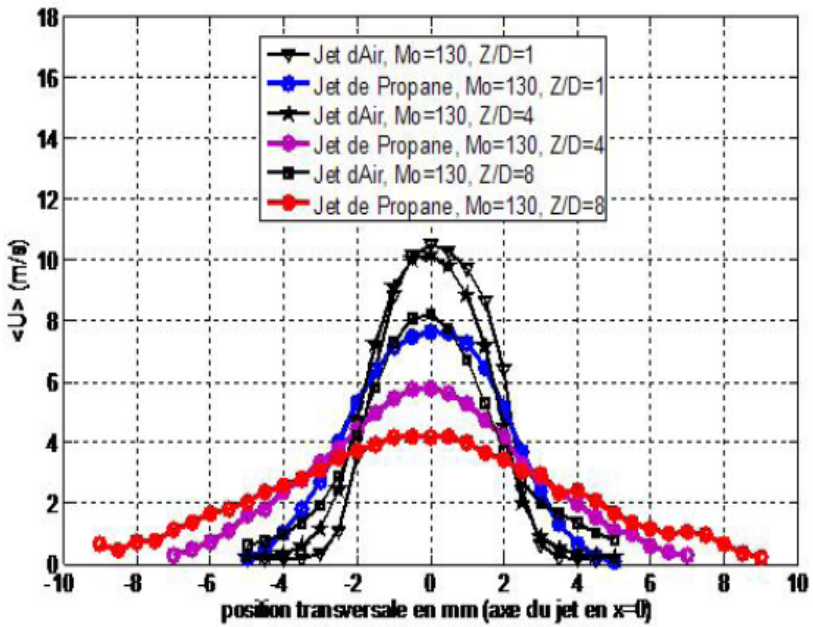
Host fluid = 5 times more viscous than the propane

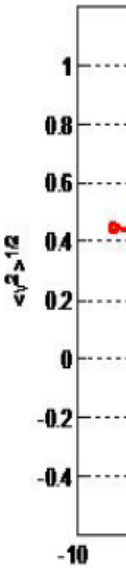
Comparison between C3H8-oxidant jet (VV) and a 'classical' air-ar jet (CV)

VV jet: $\rho'/<\rho> = 5\%$ $\mu'/<\mu> = 18\%$.

→Entrainment + important

→Isotropy and self-similarity are more rapidly attained





Etude en cours, jet propane/air, L. Voivenel

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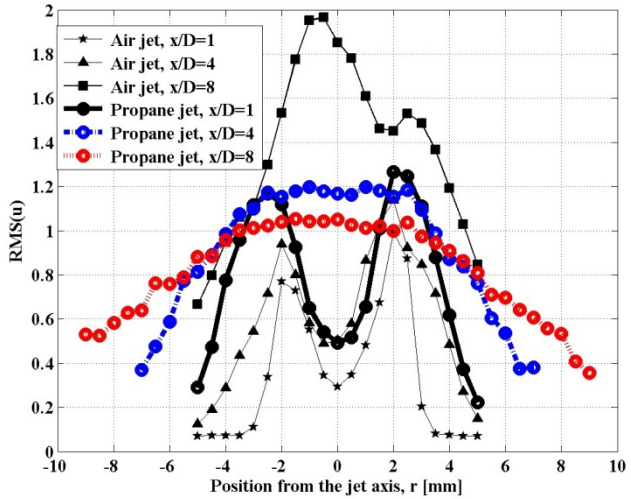
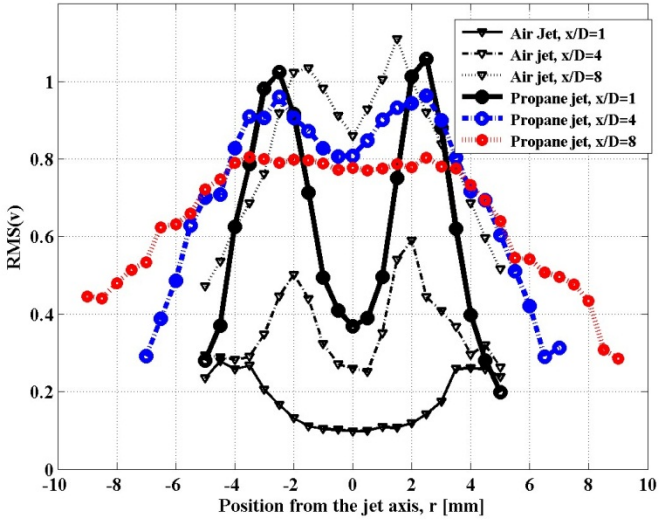




Etude en cours, jet propane/air, L. Voivenel

Active scalar mixing, variable-viscosity

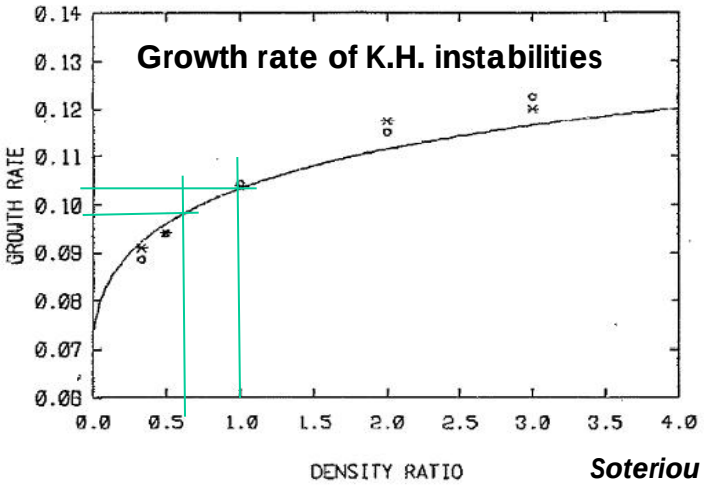
- Kelvin-Helmholtz
- Wake instabilities (recirculation ?)

- ***Density ratio effect (macro-mixing)***

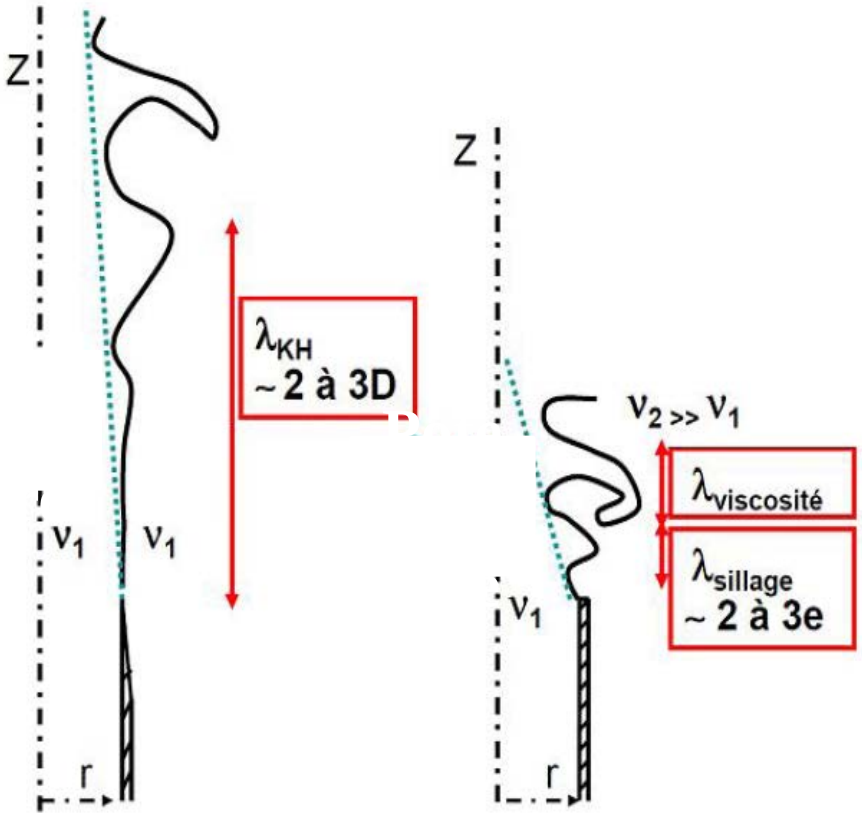
→ Lower density ratio will reduce the growth rate of mixing layer

→ Self similarity should be obtained slower

- ***Viscosity effects (interfacial instabilities)***

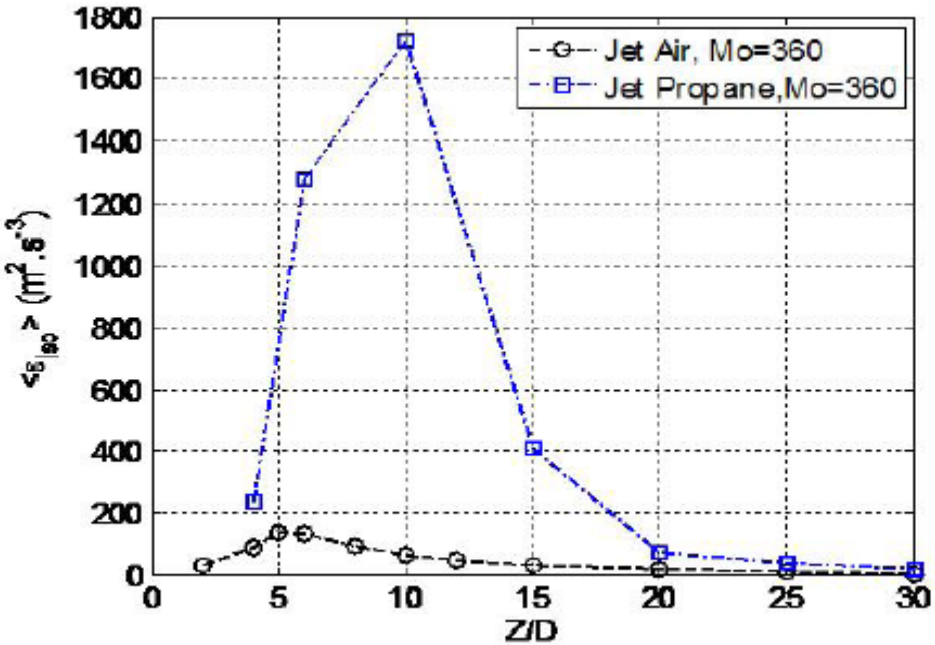


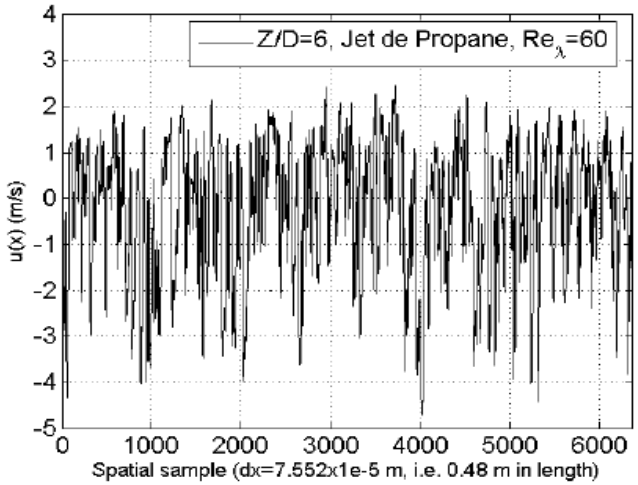
Soteriou et al. (1995)



3-rd effect of viscosity gradient: higher dissipation rate

$$\langle \epsilon_{iso} \rangle = 15 \langle \nu \rangle \left\langle \left(\frac{\partial u}{\partial x} \right)^2 \right\rangle$$





- **High local dissipation rate for propane/air/neon jet**
- **Strong decrease of dissipation rate**
- **But limitation of the experimental determination of the dissipation rate**
- **Towards an additional contribution to energy dissipation …**

Transport equation kinetic energy (ρ=cte, μ≠cte)

Application along the jet centerline (1D):

$$\bar{U}\frac{\partial}{\partial Z}\left[\frac{\overline{u_i^2}}{2}\right]+\frac{\partial \bar{U}}{\partial Z}\left[\overline{u^2}-\overline{v^2}\right]+2\overline{v\frac{\partial}{\partial y}\left(\frac{u_i^2}{2}\right)}$$

$$=\underbrace{-\boxed{\overline{\nu\left(\frac{\partial u_i}{\partial x_j}\right)^2}}}+\underbrace{\boxed{\frac{\partial \bar{\mu}}{\partial Z}\left[\frac{\partial}{\partial Z}\left(\frac{\overline{u_i^2}}{2}\right)+2\frac{\partial}{\partial y}\overline{uv}\right]+3\overline{\frac{\partial \mu'}{\partial Z}\frac{\partial}{\partial Z}\left(\frac{u_i^2}{2}\right)}}}$$

Classical dissipation

Additional dissipation induced by viscosity gradients

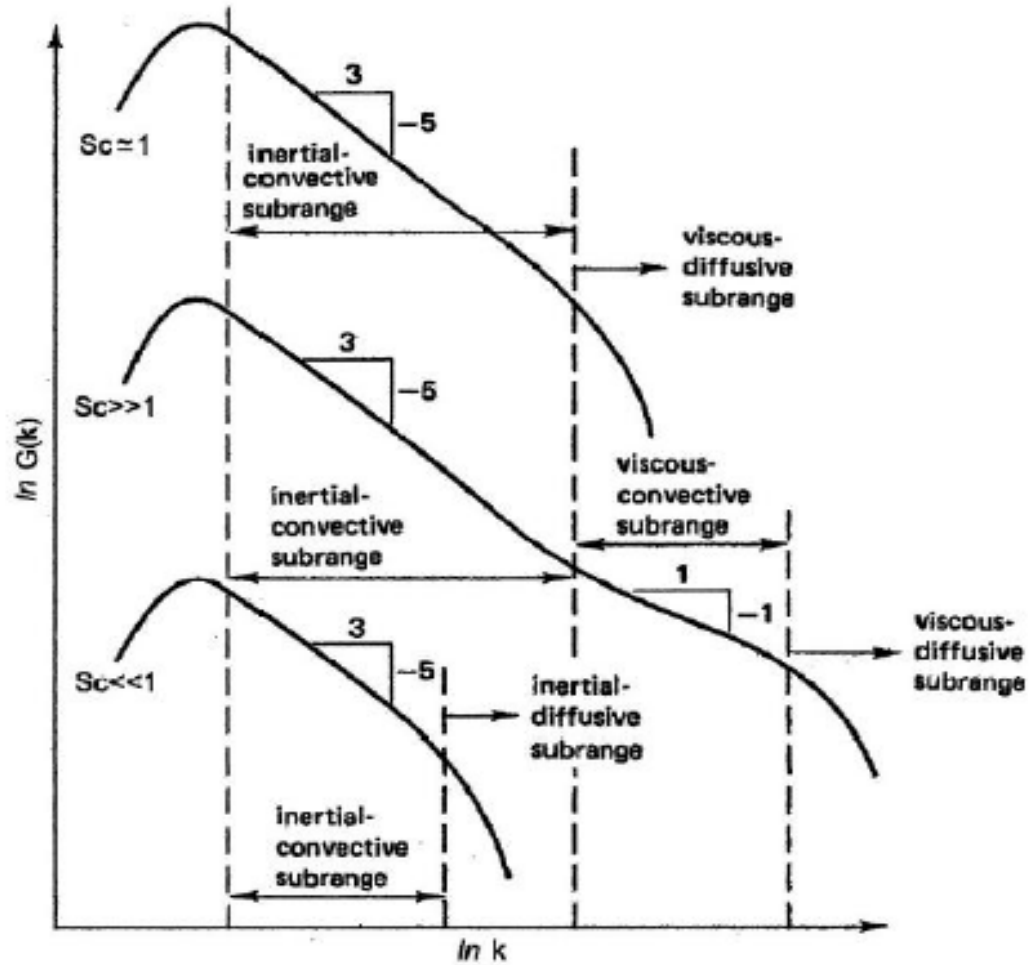
$$\langle\epsilon\rangle_{visc.var.}=\left\langle\nu\left(\frac{\partial u_i}{\partial x_j}\right)^2\right\rangle+\langle\epsilon\rangle_{corr.vitesse/visc.}>\langle\epsilon\rangle_{classique}$$

B. Talbot, L. Danaila & B. Renou, Phys. Scripta 2012

Question: **What would be the scalar spectrum with a variable viscosity fluid?**

- **Obukhov-Corrsin regime?**
- **Batchelor regime?**

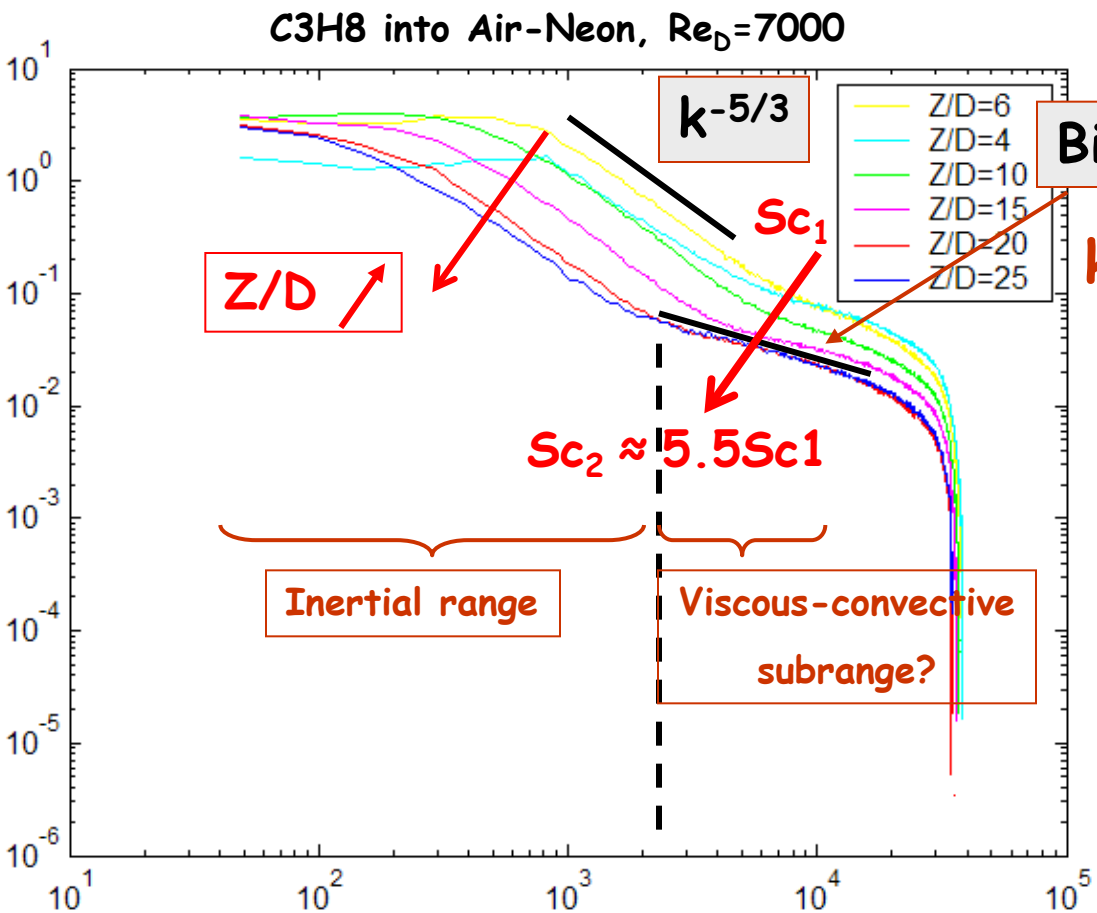
$$Sc = \mu(Y)/\rho(Y)D \neq 1$$



Tennekes & Lumley, MIT Press (1972)

Scalar Spectra (jet near-field region)

1D Scalar spectra along the jet axis



Birth of ~ k^{-1} region

k^{-1} Batchelor regime appears as Schmidt=υ/D grows by a factor of 5.5!!

(with $D_{C3H8-(Air+Ne)}$≈cte)

$$S_Z(\omega) = \frac{S_Z^{meas}(\omega) - S_{noise}^{RLS}(\omega)}{|H_{RLS}(\omega)|^2} \approx S_Z^{meas}(\omega) - S_{noise}^{RLS}(\omega)$$

+ Spatial filtering correction

(Wyngaard 1968)

$S_Z^*(\omega)$