Scalar Injection and Turbulence

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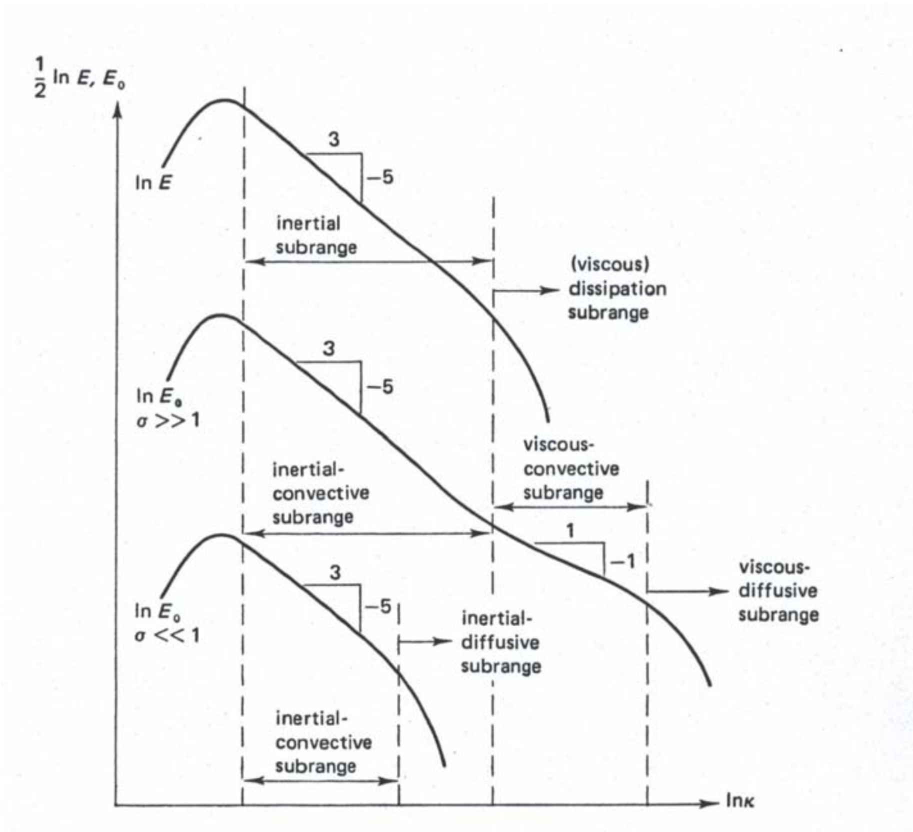
- # The passive scalar problem

a quantity θ (temperature or concentration) is advected by a turbulent velocity field u without any action on it

$$\frac{\partial \theta}{\partial t} + u \cdot \nabla \theta = D \Delta \theta$$

Two connected problems for applications : **mixing** and **injection**

The passive scalar problem



From Tennekes, Lumley, 1972

Classical vision : cascade process

mixing :

how to quench scalar inhomogeneities -» small scales

injection:

how to collect scalar -» large scales -» not universal ?

How to inject a scalar ?

In **Experiments**

mixing layer :

a secondary flow provide scalar

boundary layer:

scalar is collected from a solid (temperature, melting,…)

radiation : microwave heating

…

In **Numerics**

stochastic seeding :

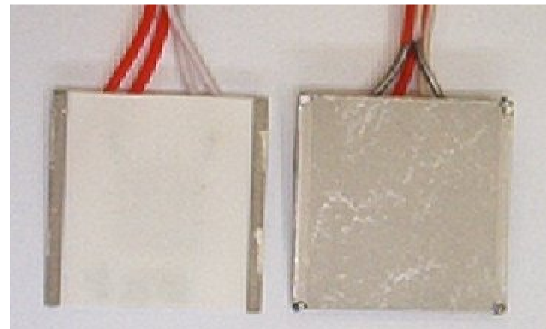
a stochastic scalar field is given as initial condition or added at each time step

mean scalar gradient:

a large scalar gradient is maintained, and feed the fluctuating scalar field

…

How to measure precisely scalar injection : building an appropriate sensor

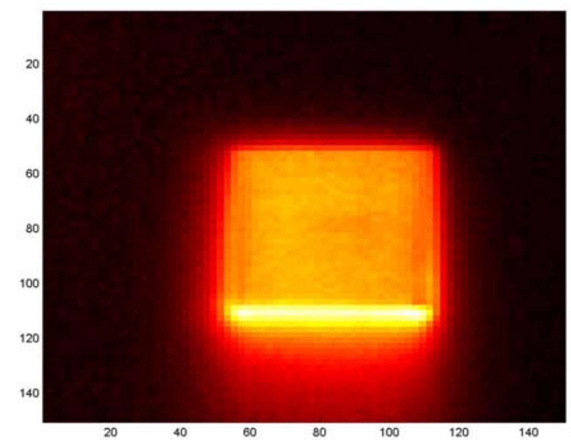


Ceramic substrate Kyocera™
2.42 cm x 2.42 cm

lateral thick
Palladium-silver stripes

thin film of Platinum evaporated
1000 Å

Electronically maintained at constant
electrical resistance : constant temperature



Correction of thermal losses due to
radiation ot conduction in the surroundings

Direct measurement of thermal losses,
i.e. scalar (temperature) injection

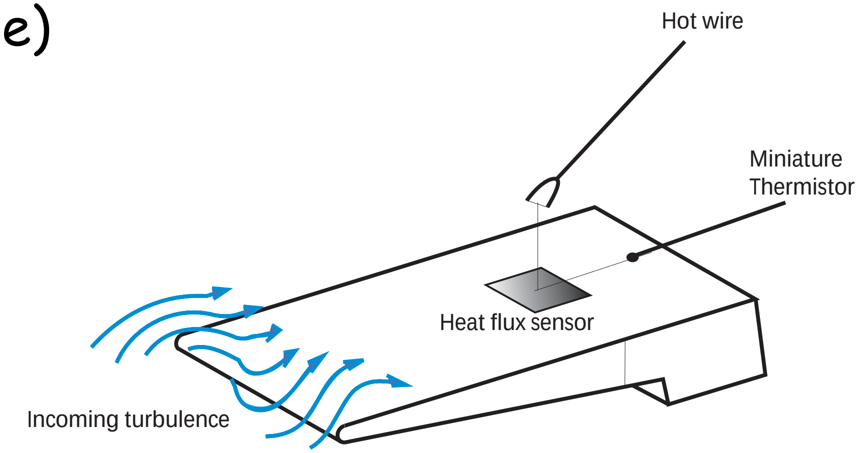
Except for dimensions, similar to hot films
used for friction measurements

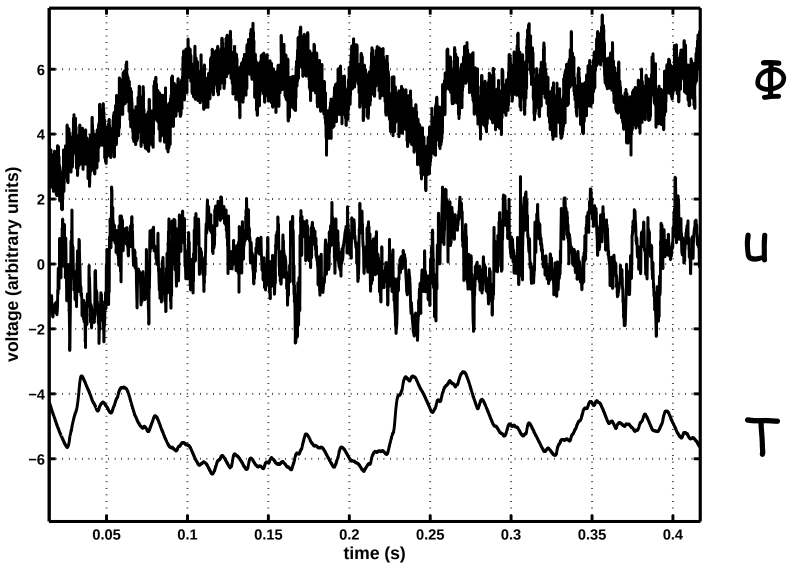
frequency cut-off ~250 Hz, temperature control ~ 0.1 K

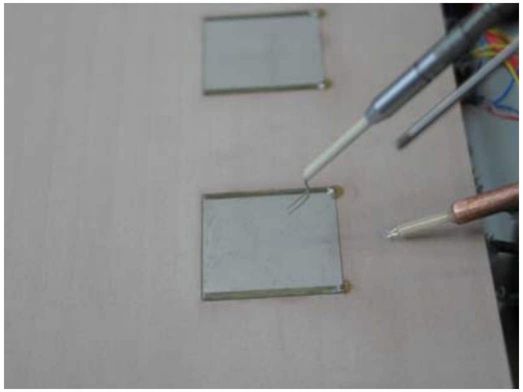
Sensor is flush mounted on a machined resin support, placed in a turbulent jet (square or flat nozzle)

hot wire to get the incoming velocity fluctuations

temperature sensor to get the injected temperature







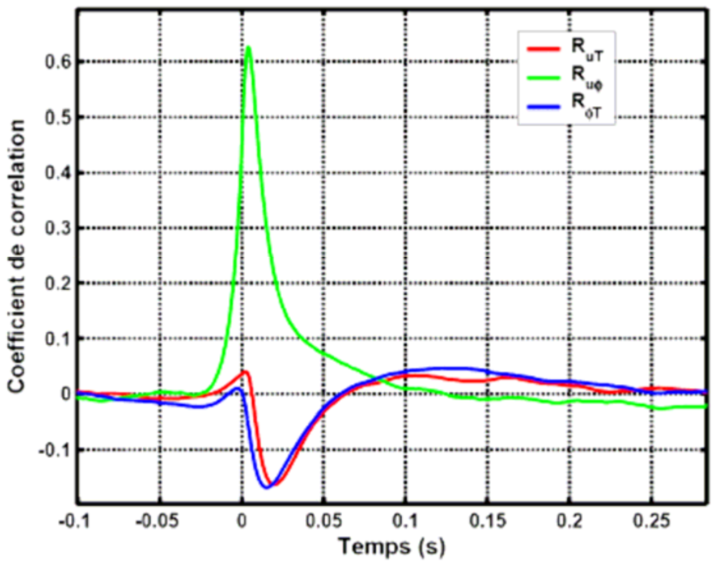
$$\overline{U}_{ext} = 10\ m/s$$

$$L_{11}^{(3)} = 1.58\ cm$$

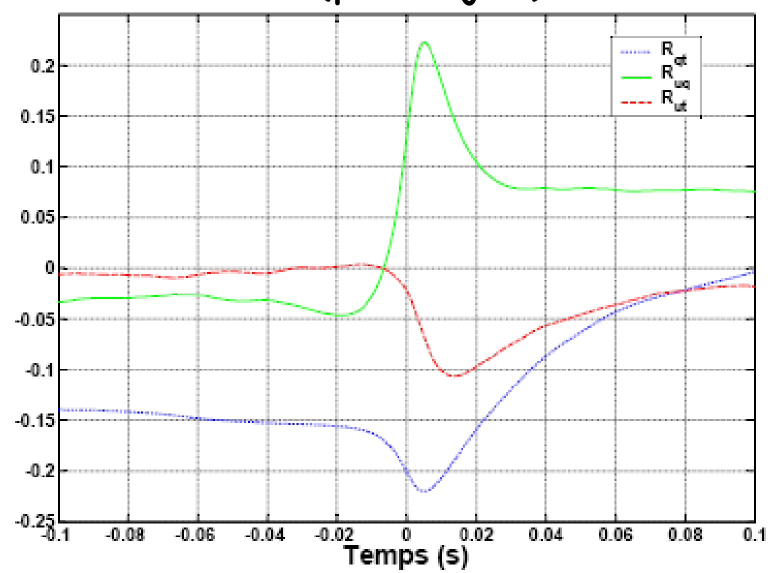
$$\mathrm{Re}_L = \frac{\overline{U}_{ext}\, L_{11}^{(3)}}{\nu} \approx 10^5$$

What about correlations ?

square nozzle



flat nozzle
(plane jet)



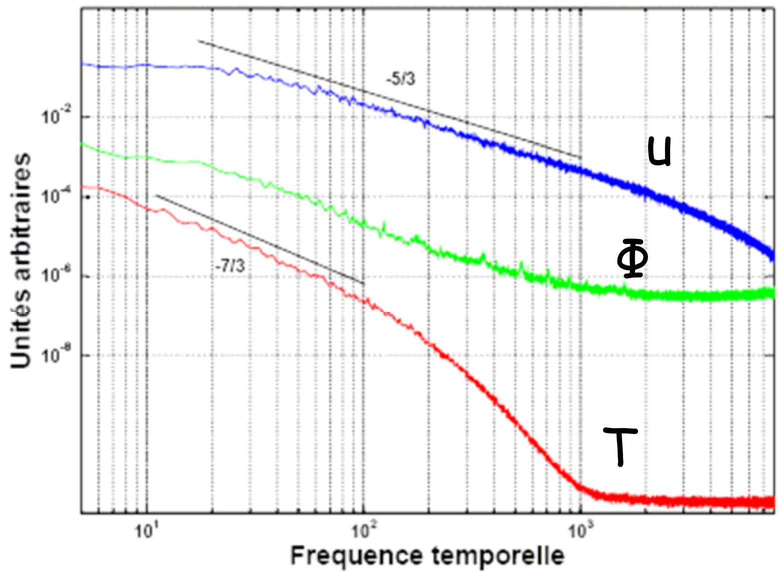
same $\overline{U}_{ext}$, same Re_{λ}

No quantitative universality, but common salient features

-> Dependance on coherent structure geometry

What about temporal spectra ?

power spectrum for incoming velocity and injected temperature, amplitude spectra for heat flux



temperature scaling $f^{-\frac{7}{3}}$

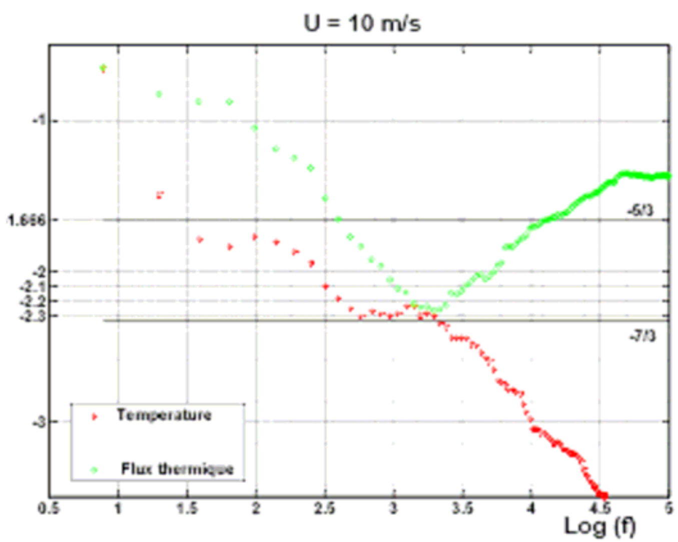
scalar flux $u\theta$ spectrum in homogeneous isotropic turbulence with scalar injection by mean scalar gradient Γ

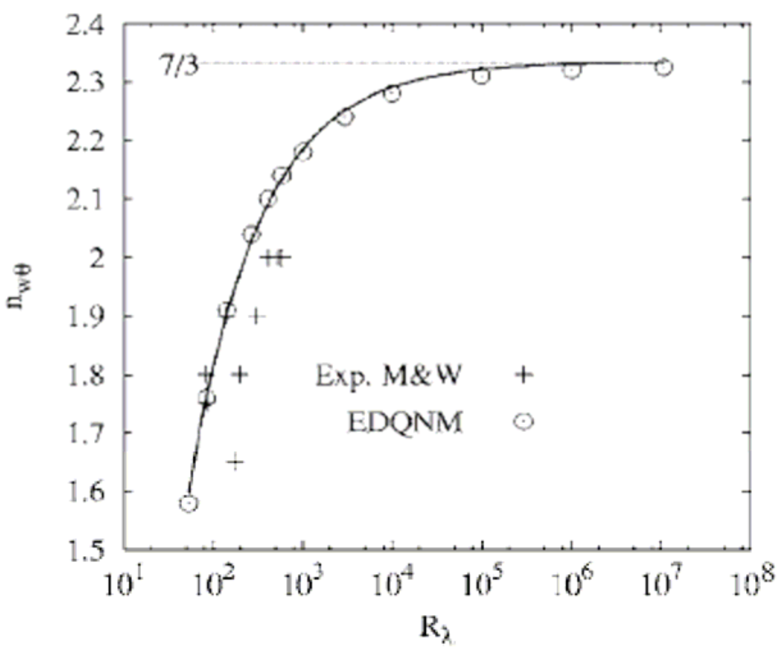
$$F_{\langle u\theta \rangle}(k) = C\,\Gamma\,\varepsilon^{\frac{1}{3}}\,k^{-\frac{7}{3}}$$

Lumley 1953, Bos 2004

What about temporal spectra ?

looking for a heat flux scaling : mean local slope





Bos 2004

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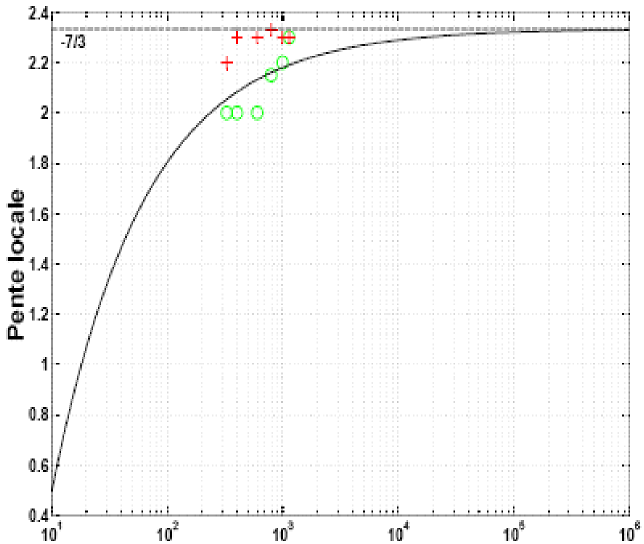

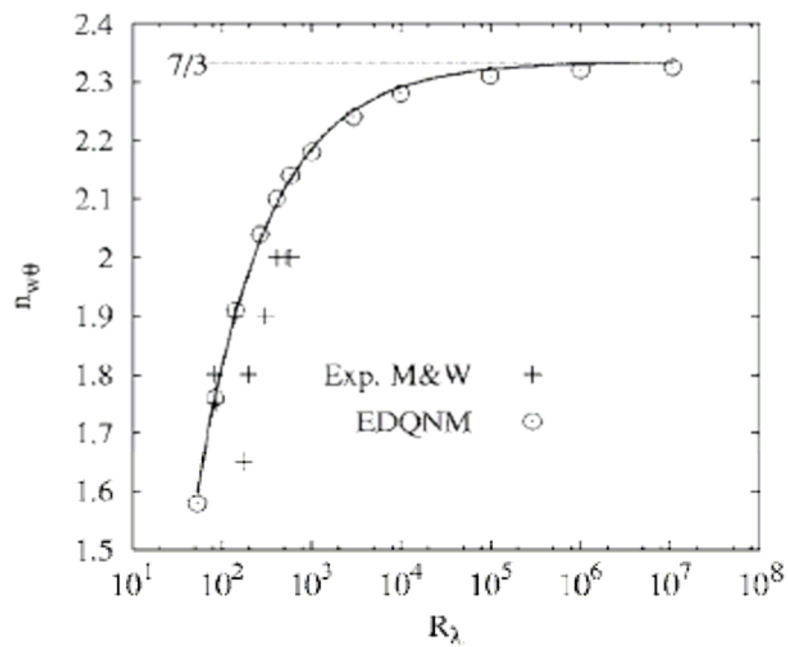

Bos 2004