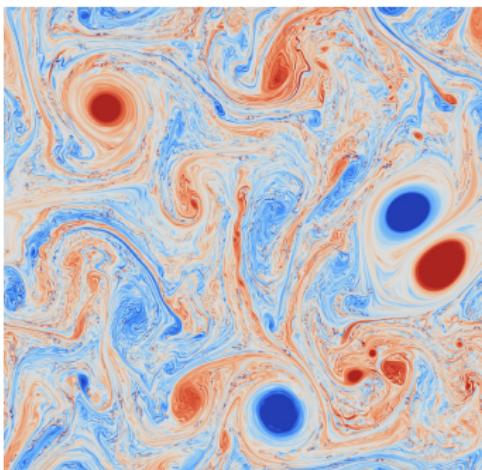


# Turbulence,

Lecture 1: The 'Where', the 'Who', the 'Why'  
and the 'What'

Alexandros Alexakis



# Where is Turbulence met ?

**everywhere...**

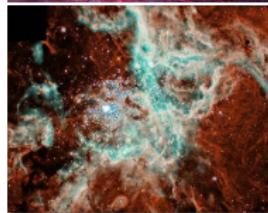
Astrophysics, Atmospheric physics, weather prediction, geophysics, engineering, aviation, Industry, ...



# Where is Turbulence met?



- Galaxies  
 $10^{23}$  m



- Nebula  
 $10^{18}$  m



- Solar Wind  
 $10^{11}$  m



- Stellar convection  
 $10^9$  m



- Atmosphere  
 $10^7$  m



- Ocean  
 $10^5$  m



- Navy  
 $10^2$  m



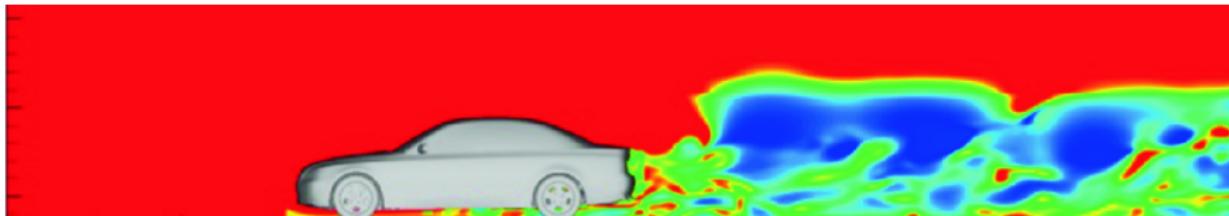
- Coffee  
 $10^{-1}$  m

# Who is interested in Turbulence?

## Turbulence in science

- **Mathematics:** Analysis, singularity formation, existence of solutions etc (Millennium Prize by the Clay Mathematics Institute)
- **Nonlinear physics, Dynamical systems:** Bifurcations, Chaos, spontaneous stochasticity etc)
- **Statistical physics:** (Large degrees of freedom, Out of equilibrium, intermittency, anomalous exponents, etc)
- **Earth Sciences** (Atmosphere, Oceanography, Climate)
- **Astrophysics** (Stellar and planetary interior, interstellar medium, nebula clouds...)
- **Engineering** (Naval, aircraft and car industry, ...)

# Why is turbulence important



- In the absence of turbulence

$$U \simeq 72 \text{ km/h}, \quad L \simeq 2 \text{ m}, \quad \nu = 1.5 \cdot 10^{-5} \text{ m}^2/\text{s}, \quad \rho = 1.2 \text{ kg/m}^3$$

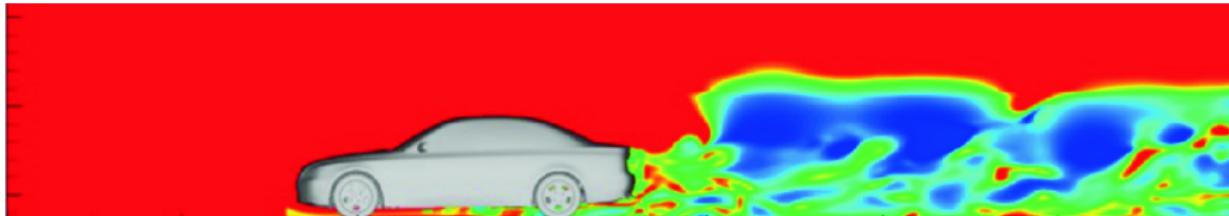
rate of energy dissipation (drag)

$$\epsilon \sim (\rho L^3)(\nu U^2/L^2) = 0.014 \text{ kg m}^2/\text{s}^3$$

- In the presence of turbulence rate of energy dissipation (drag)

$$\epsilon \sim (\rho L^3)(U^3/L) = 38000 \text{ kg m}^2/\text{s}^3$$

# Why is turbulence important?

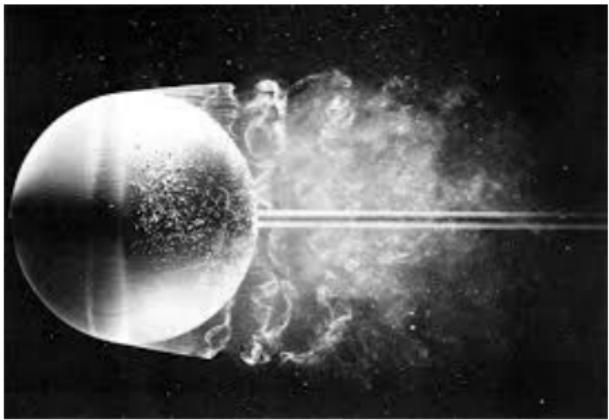
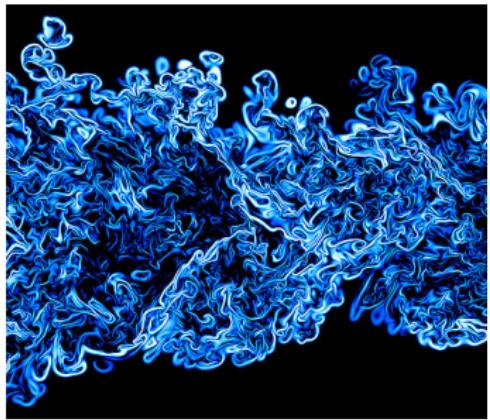


$$\begin{aligned}\frac{\text{Turbulent dissipation rate}}{\text{Laminar dissipation rate}} &= \frac{(\rho L^3)(U^3/L)}{(\rho L^3)(\nu U^2/L^2)} \\ &= \frac{UL}{\nu} \\ &= \mathbf{Re} \\ &= 2.6 \cdot 10^6\end{aligned}$$

$$Re = \frac{UL}{\nu} = \frac{L^2/\nu}{L/U} = \frac{\text{viscous time scale}}{\text{advection time scale}}$$

# What is turbulence?

# What is turbulence?



# What is turbulence?



← Turbulence

← First Bifurcations

← Laminar

# What is turbulence?

**No clear commonly accepted definition of turbulence exists!**

Some observations

- Erratic (random) motions
- Unpredictability
- A large range of scales excited from large to small
- Structures exists but are **not** periodic in space or time
- Strong dissipation

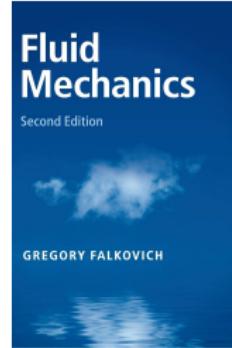
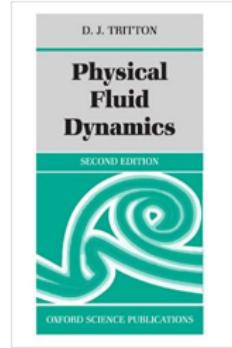
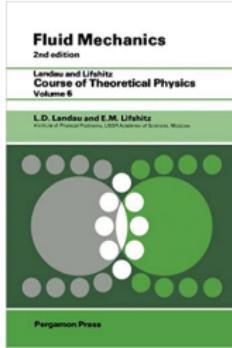
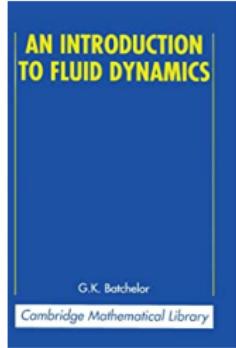
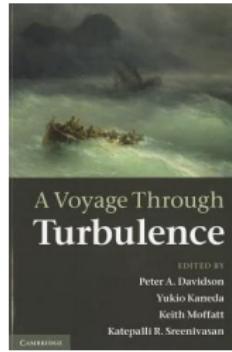
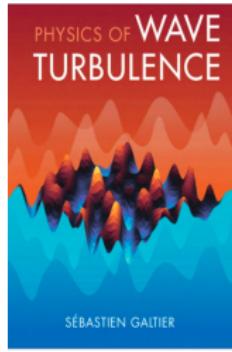
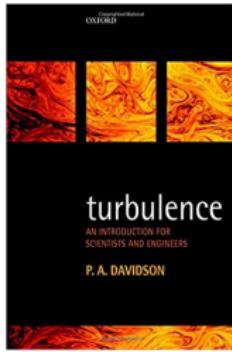
# What is turbulence?

## My personal definition

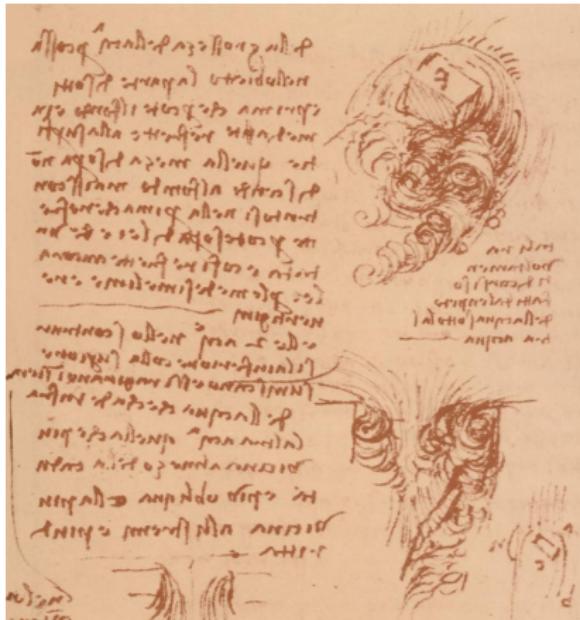
We will say that a 3D flow is turbulent if

- **It is chaotic** (phase space trajectories are unstable: the slightest perturbation will lead to a different state thus leading to unpredictability)
- **It involves a large range of scales** ( many degrees of freedom )
- **Energy is dissipated at a scale much different than the scale it is injected** (ie there is a Cascade )
- **It is a strongly out of equilibrium process**

# Turbulence: Books



# Turbulence: Books



## TURBULENCE

*Uriel Frisch*



Thank you  
for your attention!