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

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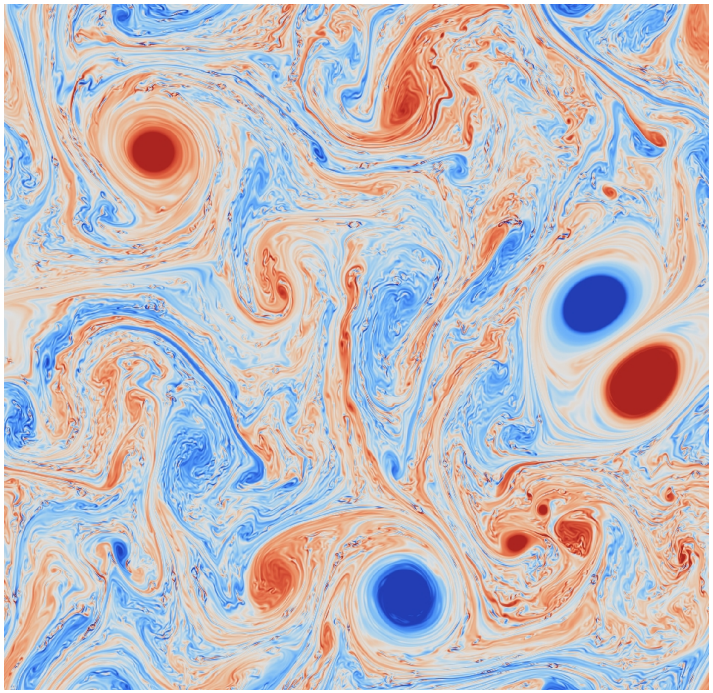
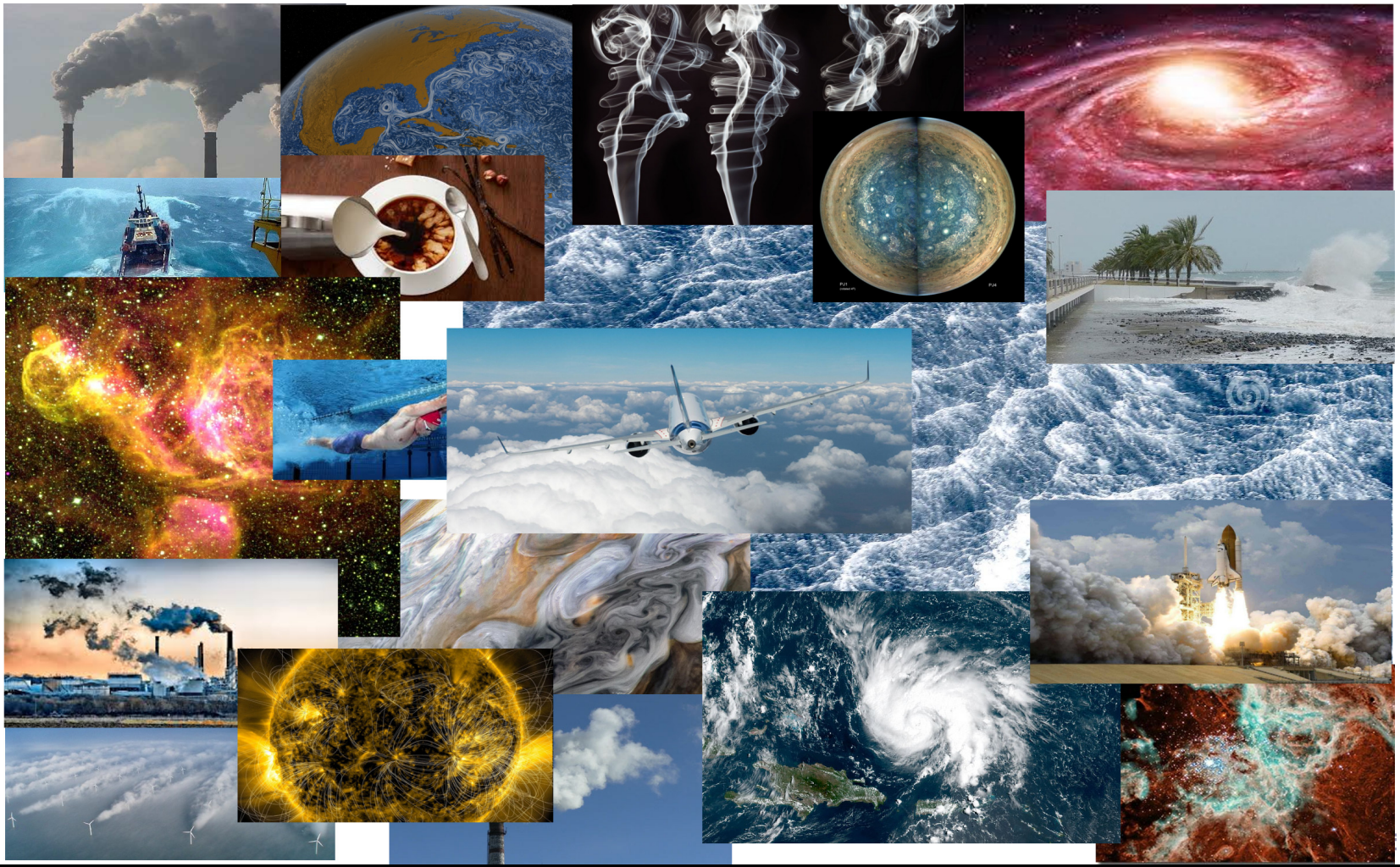


Where is Turbulence met ?

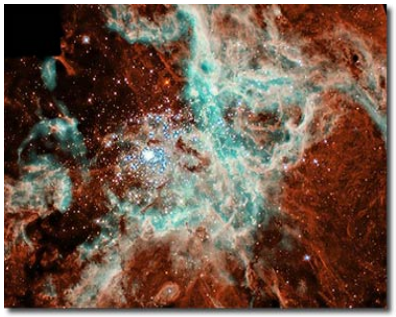
everywhere...

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

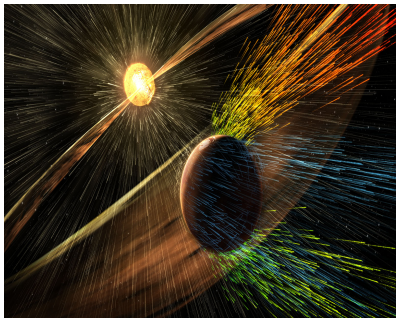


Where is Turbulence met?

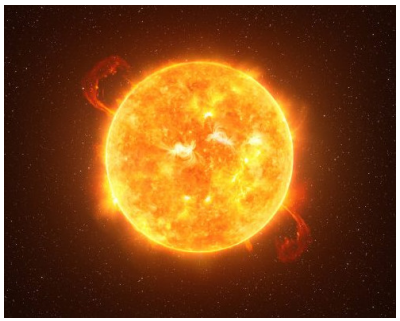
- Galaxies
  10^{23} m



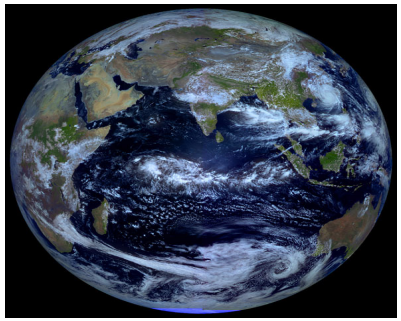
- Nebula
  10^{18} m



- Solar Wind
  10^{11} m



- Stelar 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** (Stelar and planetary interior, intertelar medium, nebula clouds...)
- **Engineering** (Naval, aircraft and car industry, ...)

Why is turbulence important

- In the absence of turbulence

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

  rate of energy dissipation (drag)

  $$\epsilon \sim (\rho L^3)(\nu U^2/L^2) = 0.014kgm^2/s^3$$

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

  $$\epsilon \sim (\rho L^3)(U^3/L) = 38000kgm^2/s^3$$

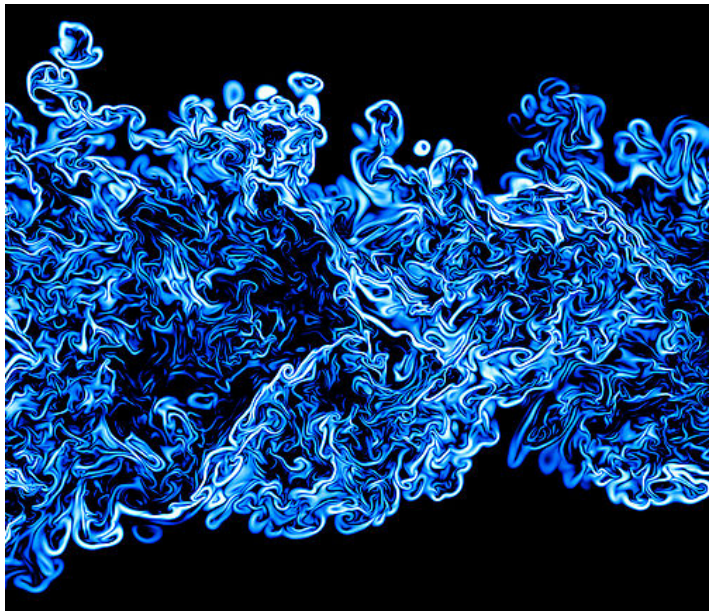
Why is turbulence important?

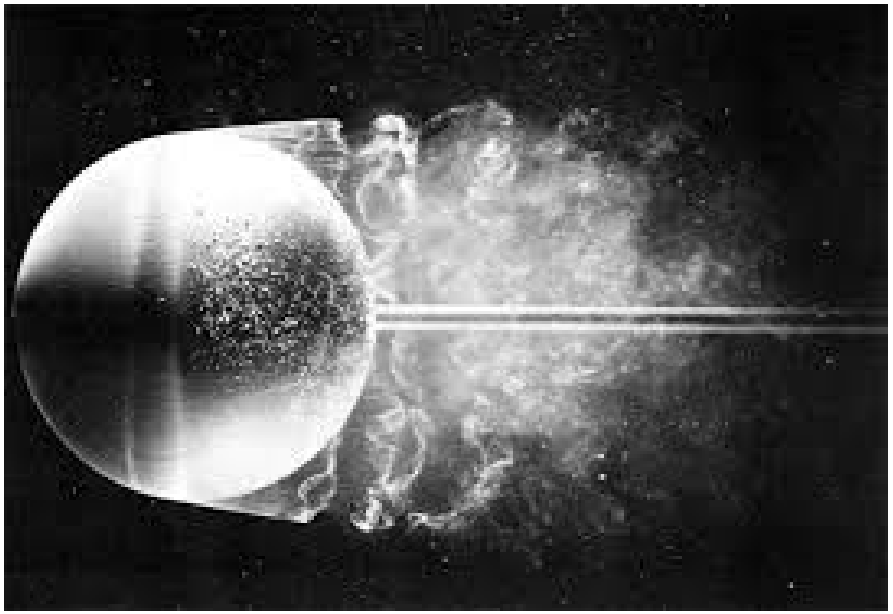
$$\begin{aligned}
\frac{\text{Turbulent dissipation rate}}{\text{Laminar dissipation rate}} &= \frac{(\rho L^3)(U^3/L)}{(\rho L^3)(\nu U^2/L^2)} \\
&= \frac{UL}{\nu} \\
&= \mathbf{Re} \\
&= 2.6 \cdot 10^6
\end{aligned}$$

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

What is turbulence?

What is turbulence?





What is turbulence?

Turbulence

First Bifuracations

Laminar

What is turbulence?

No clear commonly accepted definition of turbulence exists!

Some observations

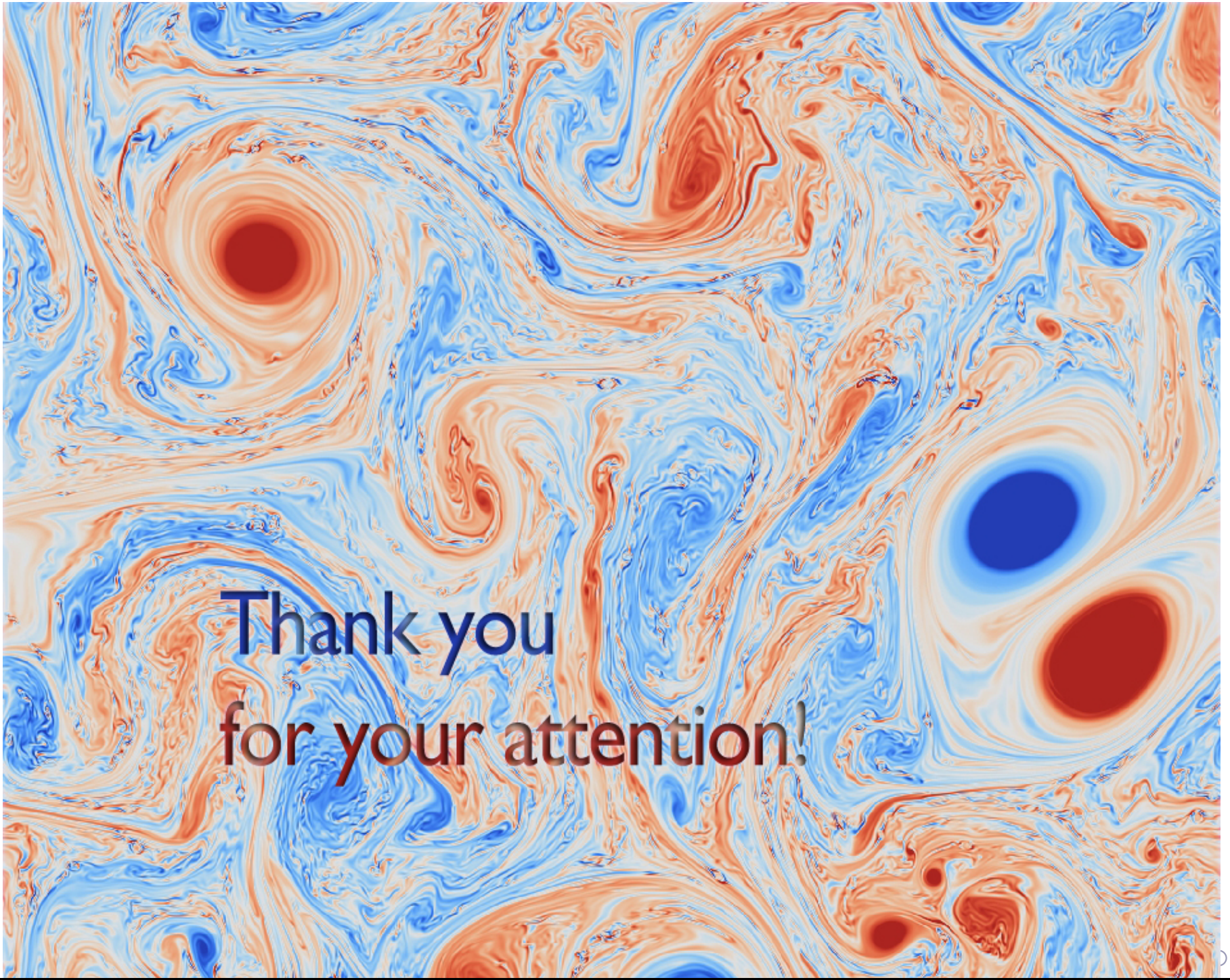
- Erratic (random) motions
- Unpredictability
- A large range of scales excited from large to small
- Structures exists but are **not** periodic is pace or time
- Strong dissipation

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 whose mean behavior could be predicted)
- **Energy is dissipated at a scale much different than the scale it is injected** (or was initially injected)
- **It is a strongly out of equilibrium process**


Thank you
for your attention!