# DEPARTMENT MECHANICS AND PHYSICS OF FLUIDS

**Head**
**Prof. Tomasz Kowalewski**

The Department has 2 Sections:

- **Modelling in Medicine and Biology**
- **Viscous and Thermal Flows**

**Staff: 15 persons + 7 PhD students**

| | |
|---|---|
| **professors:** | **2** |
| **associate professors:** | **3** |
| **senior researchers:** | **7** |
| **research assistants:** | **2** |
| **technician:** | **1** |

# DEPARTMENT OF MECHANICS AND PHYSICS OF FLUIDS

## International Projects 2002-2006

| | |
|---|---|
| FLOXCOM | – Low NOx Flameless Gas-Turbine Combustor |
| PIVNET2 | – Particle Image Velocimetry for Industry |
| EMMA | – Emulsions with Nanoparticles for New Materials |
| ABIOMED | – CoE Applied Biomedical Modelling and Diagnostics |
| METRO | – Metallurgical Training Online |
| NADIA | – New Automotive Components Designed |
| COST21 | – Physics of droplets |

Several bilateral projects with France (CNRS), Israel (Technion), Australia (UNSW), UK( UCL), Spain (UA), USA (MIT, ASU, Yale)

# DEPARTMENT OF MECHANICS AND PHYSICS OF FLUIDS

## Research Projects

- Dispersed media, Stokes flow, hydrodynamic interactions in suspensions
- Microflows experiment and simulation (molecular dynamics, dissipative particles)
- Effective transport coefficients, Padee approximants
- Natural convection, flow with phase change, solidification
- Free surface flow: droplets, emulsions, liquid jets, vapour bubbles
- Electrospinning of nano-fibres – experiment and modelling
- Experimental and computational modelling of convective flow in the atmosphere
- Hydrodynamic interactions in atmospheric clouds
- Flow of granular media
- Particle Image Velocimetry and Thermometry, validation of CFD codes
- Dynamics of peptide and DNA chains, stochasticity in gene expression
- Mathematical description of superfluidity
- Hall thruster model, physics of plasma

IPPT PAN

# Theoretical and numerical expertise

- Molecular Dynamics – modelling micro and nano flow properties
- Dissipative Particles Dynamics – micro and macro scale modelling
- Multi-particle hydrodynamic interactions (Stokeslets)
- Turbulent internal flow, numerical modelling and analysis
- Natural convection with phase transition, solidification, crystal growth, experimental benchmarks
- Simulation of atmospheric flow for small scale models – turbulent natural convection in complex terrain
- Free surface flow: droplets, emulsions, liquid jets, vapour bubbles
- Image processing, Particle Image Velocimetry & Thermometry
- Electrospinning of nano-fibres
- Dynamics of peptide and DNA chains, gene expression, early immune response
- Reaction-diffusion equations, bio patterns formation
- Applications of Dynamical Systems, Stochastic Processes to Biological Systems
- Asymptotic methods in partial differential equations
- Effective transport coefficients, viscous flow, Padee approximants
- Kinetic theory of gases and some problems of dynamical systems
- Mathematical description of superfluidity
- Plasma physics, Hall thruster

# Numerical Codes

**Available computer codes & hardware:**

- Simulation of  hydrodynamic interactions (Stokeslets)
- Electrospinning numerical model
- Numerical model of electric propulsion systems (Hall thrusters)
- Dissipative Particle Dynamics and Molecular Dynamics
- Finite volume and mesh-free CFD schemes
- Commercial CFD codes Fluent & Fidap

* * * *

- Cluster of Unix workstations (20 CPUs, 36GB RAM) LINK
- Access to high performance supercomputers

# Experimental labs

**Main task: validation of numerical models**

**Accuracy of Numerical Modelling ?**

**Model verification**

**Model validation**

- **Physical model verification**
- **Numerical model verification**
- **Experimental validation**

**Full field measurements**

# Experimental labs

## Methods

**Transient full field measurements:**

- **Particle Image Velocimetry (2D, 3D)**
- **Particle Image Thermography**
- **Infrared Thermography**
- **Electrical Conductance Tomography**
- **Shadowgraphy, Schlieren, Interferometry**

# Experimental labs

## Equipment

- **Full Field Measurements:**
  - High Speed Camera (up to 40 000 frames per second)
  - 2D & 3D high resolution PIV system (1.2 K x 1K)
  - PIV systems with 3 CCD colour and B&w cameras
  - High speed PIV, microPIV system.
  - Laser CW Ar 3W
  - Double Pulse Laser Nd-YAG (2 x 30 mJ), 10ns
- **Point Measurements:**
  - 3 components hotwire sensors (100kHz)
  - High accuracy temperature recording (±0.01K)
  - Precise pressure transducers

# Experimental labs

**Equipment -> expected soon for our new lab**

- High speed laser for micro-PIV
- Atomic Force Microscope
- Environmental Scanning Electron Microscope
- Laser scanning microscope
- Nano-manipulator System
- Clean room for nano- and bio- experimentation
- Nanotomograph

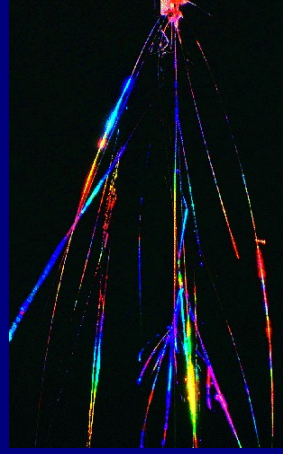
Lab-on-Chip, manipulating molecules, DNA in pore, gene expressio

# Snapshots form laboratory projects

- Nanofibres by electrospinning
- Vapour bubble growth and detachment during boiling
- FLOXCOM - cold flow modelling of a gas turbine: EC project in of the 5th Framework Program
- Natural convection with phase transition, solidification, crystal growth: numerical modelling and experimental validation
- Simulation of atmospheric flow
- Microflow of emulsion
- Hydrodynamic interactions in suspensions

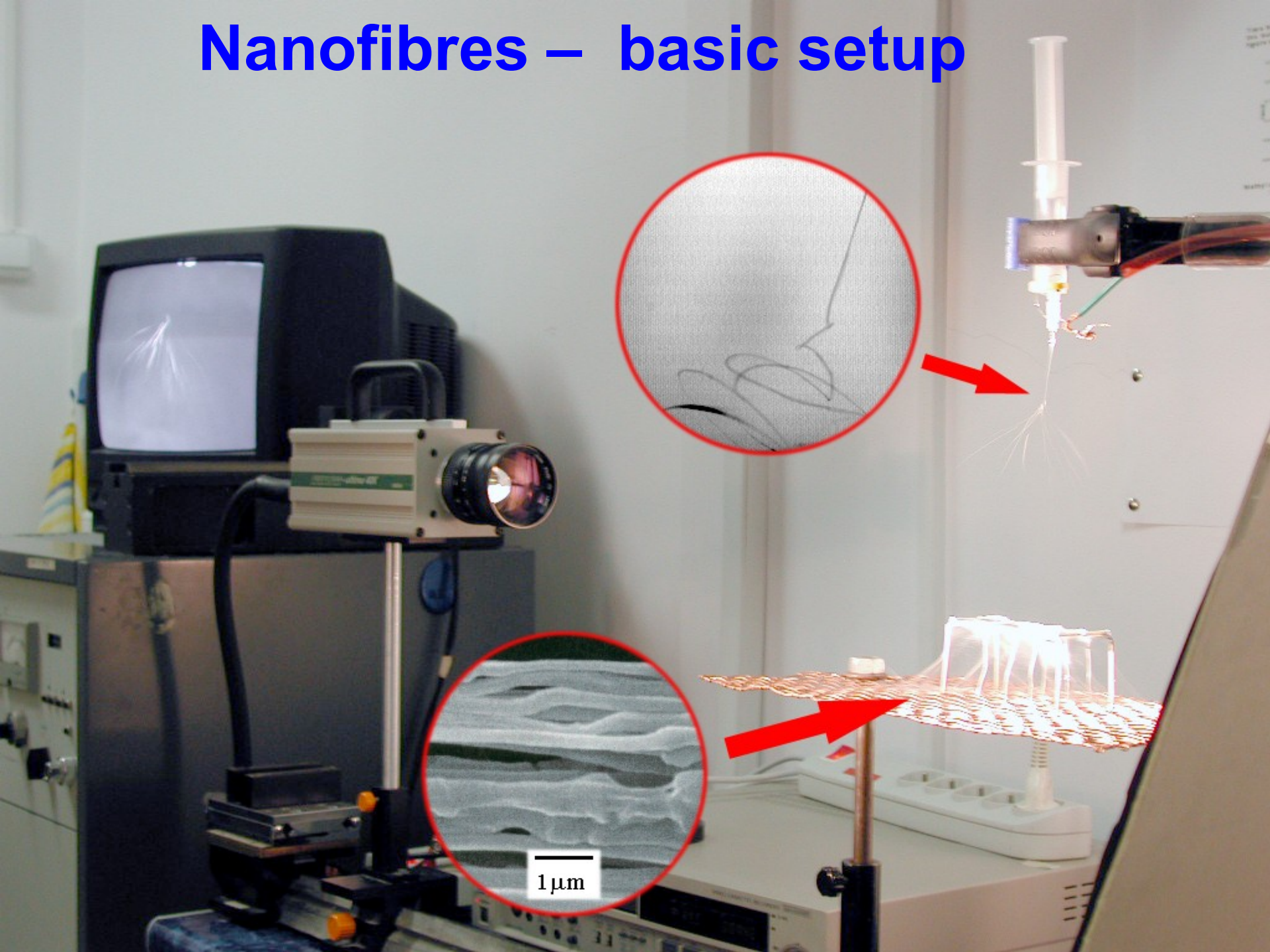
# NANOFIBRES

## by electro-spinning of polymer solutions



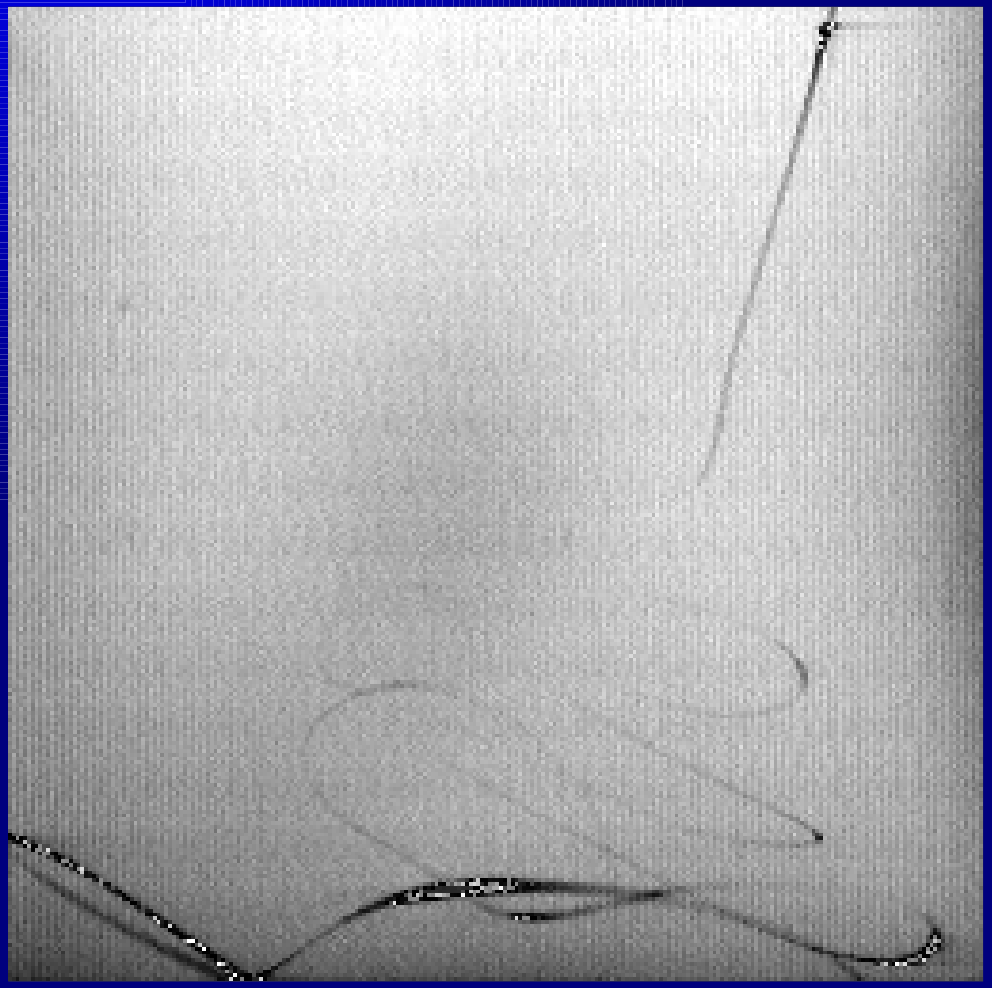
- Increase of the surface to volume ratio -> solar and light sails and mirrors in space
- Reduction of characteristic dimension -> nano-biotechnology, tissue engineering, chemical catalysts, electronic devices
- Bio-active fibres: catalysis of tissue cells growth
- Mechanical properties improvement -> new materials and composite materials by alignment in arrays and ropes

# Nanofibres – basic setup

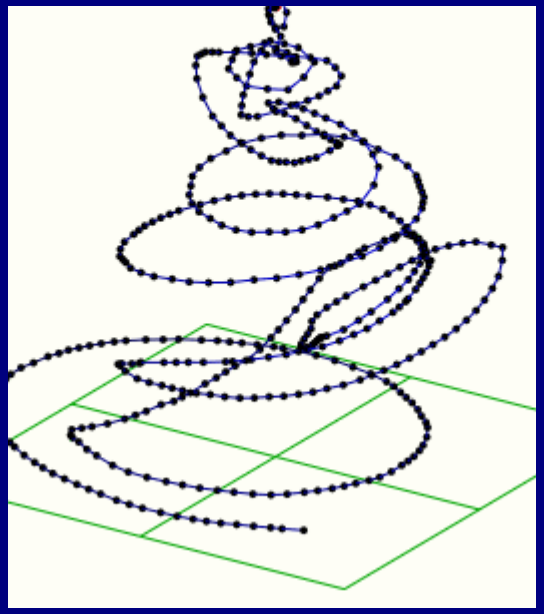


# Electrospinning observed at 4500fps

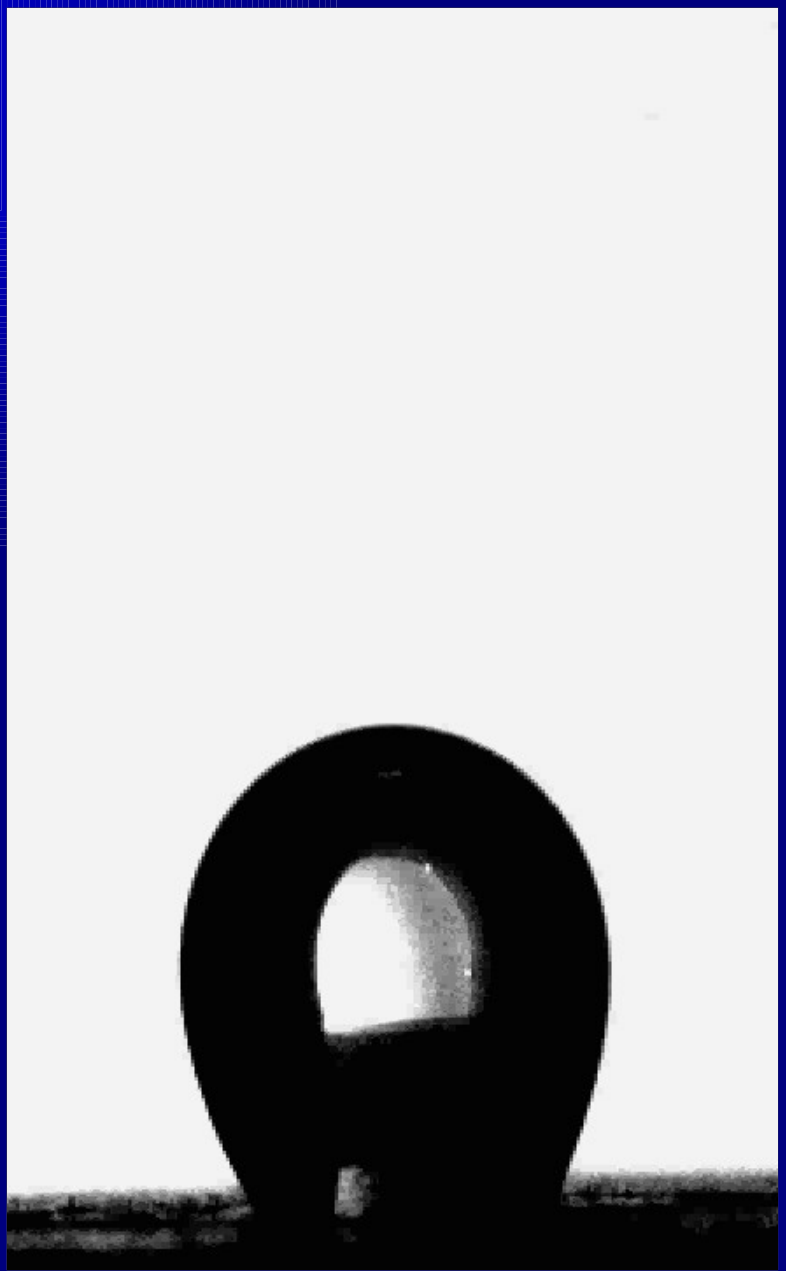
5 cm



Average velocity of the fibre: 2 m/s

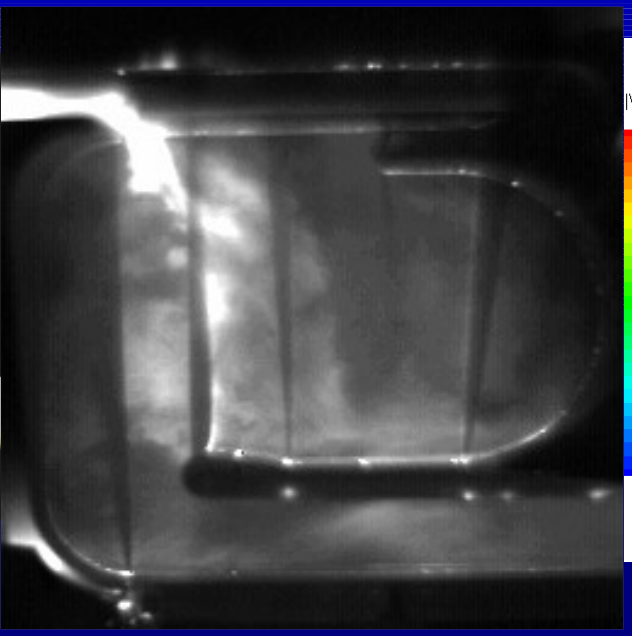


# Vapour bubble growth

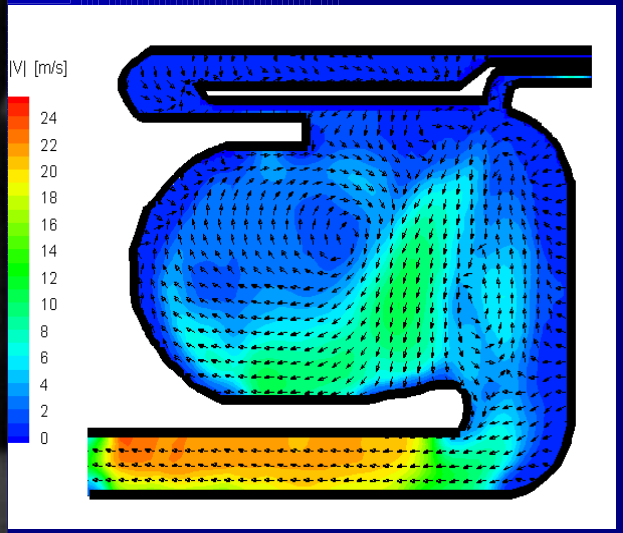


# FLOXCOM PROJECT 5FP UE

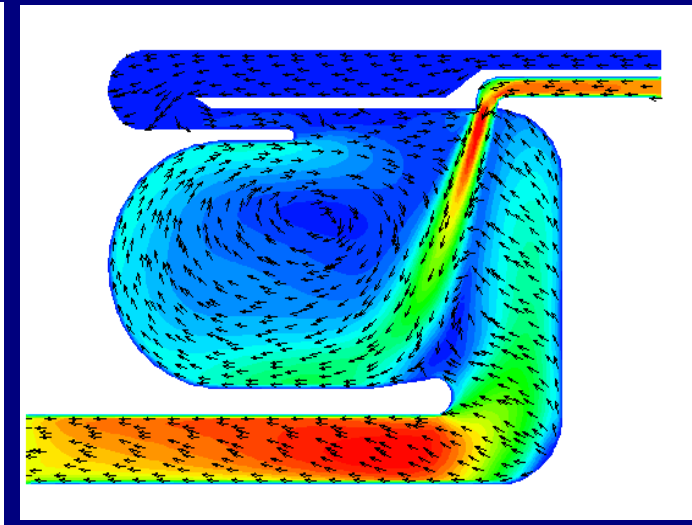
## Experiment - Validation - Simulation - Optimizing



Optimising Gas Turbine Combustor




PIV velocity flow analysis

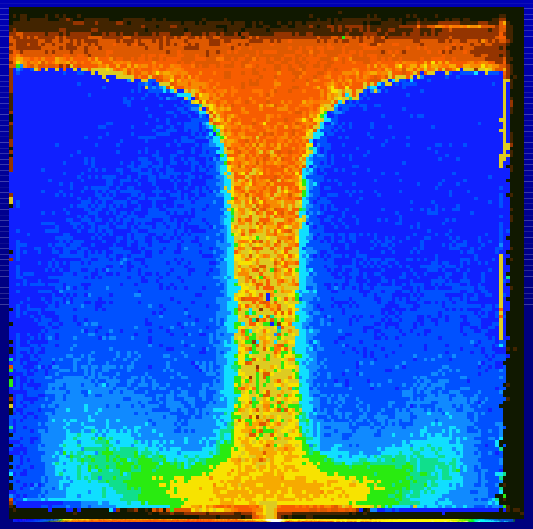


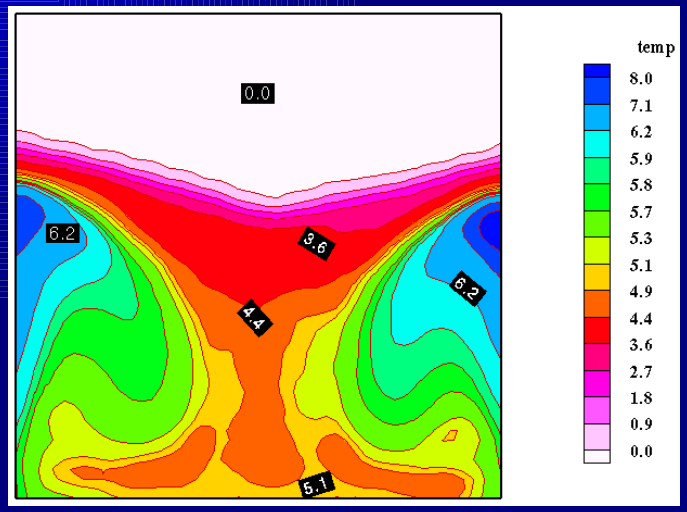
Numerical simulation Fluent

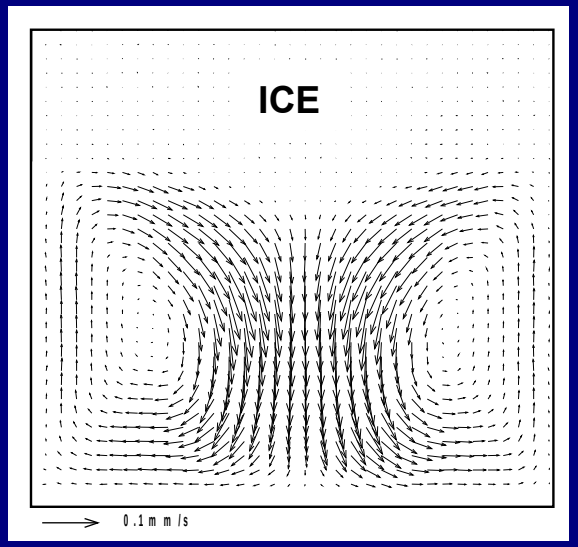
http://floxcom.ippt.gov.pl

# CRYSTAL GROWTH SIMULATION

## Particle Image Velocimetry and Thermometry



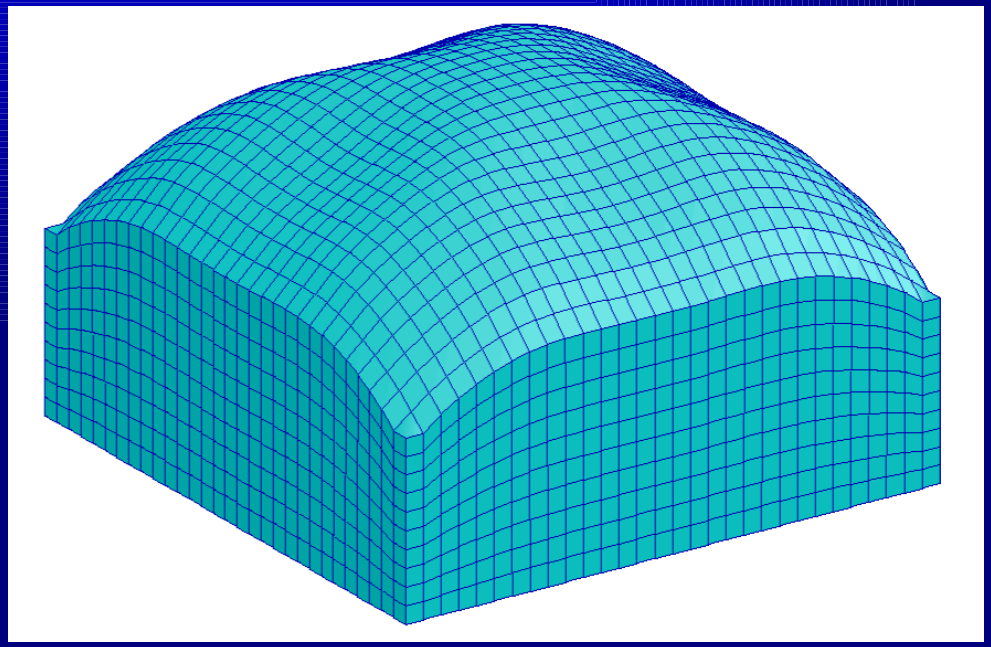


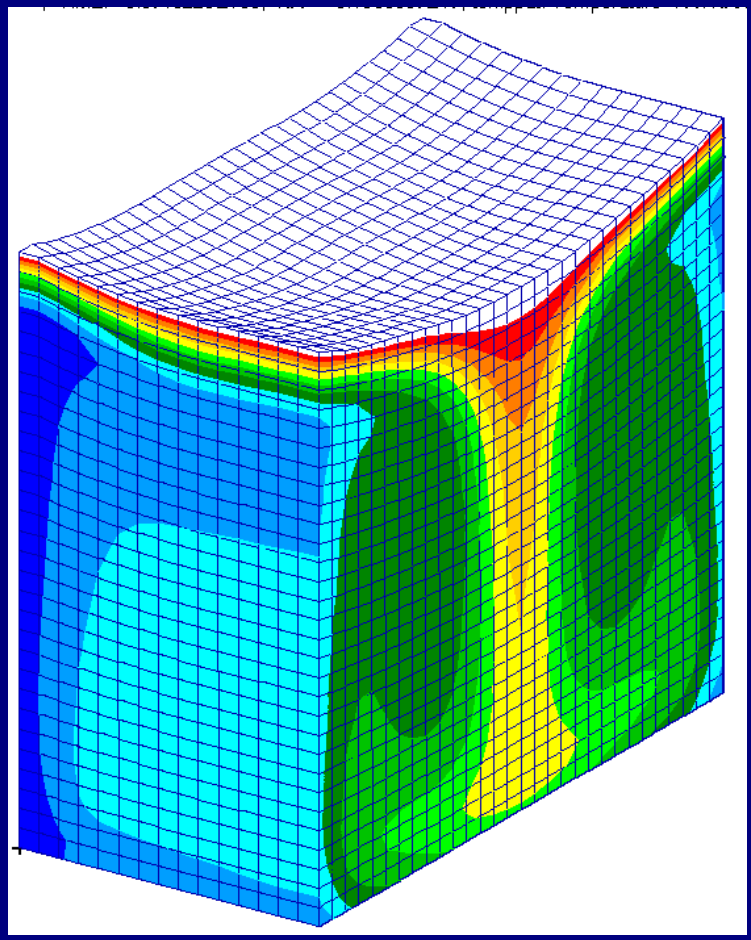




Temperature and velocity full field measurements

# Numerical Model

## Lid Cooled Cavity

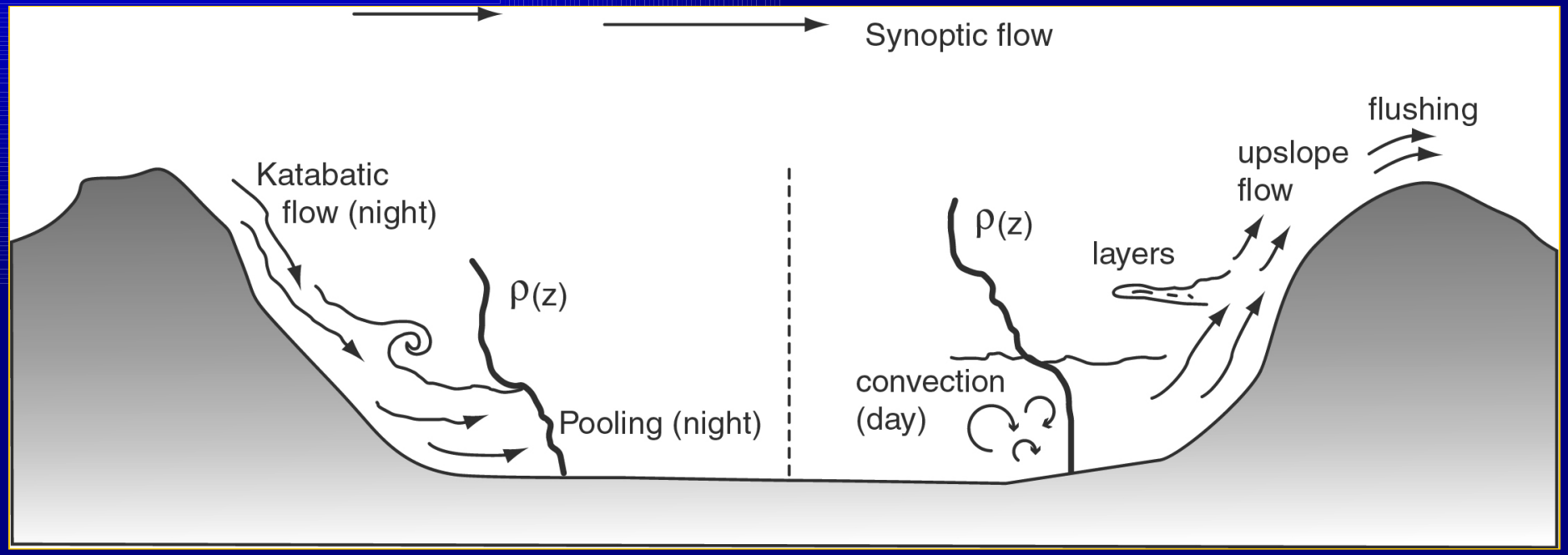




Computational grid for ice and fluid domains

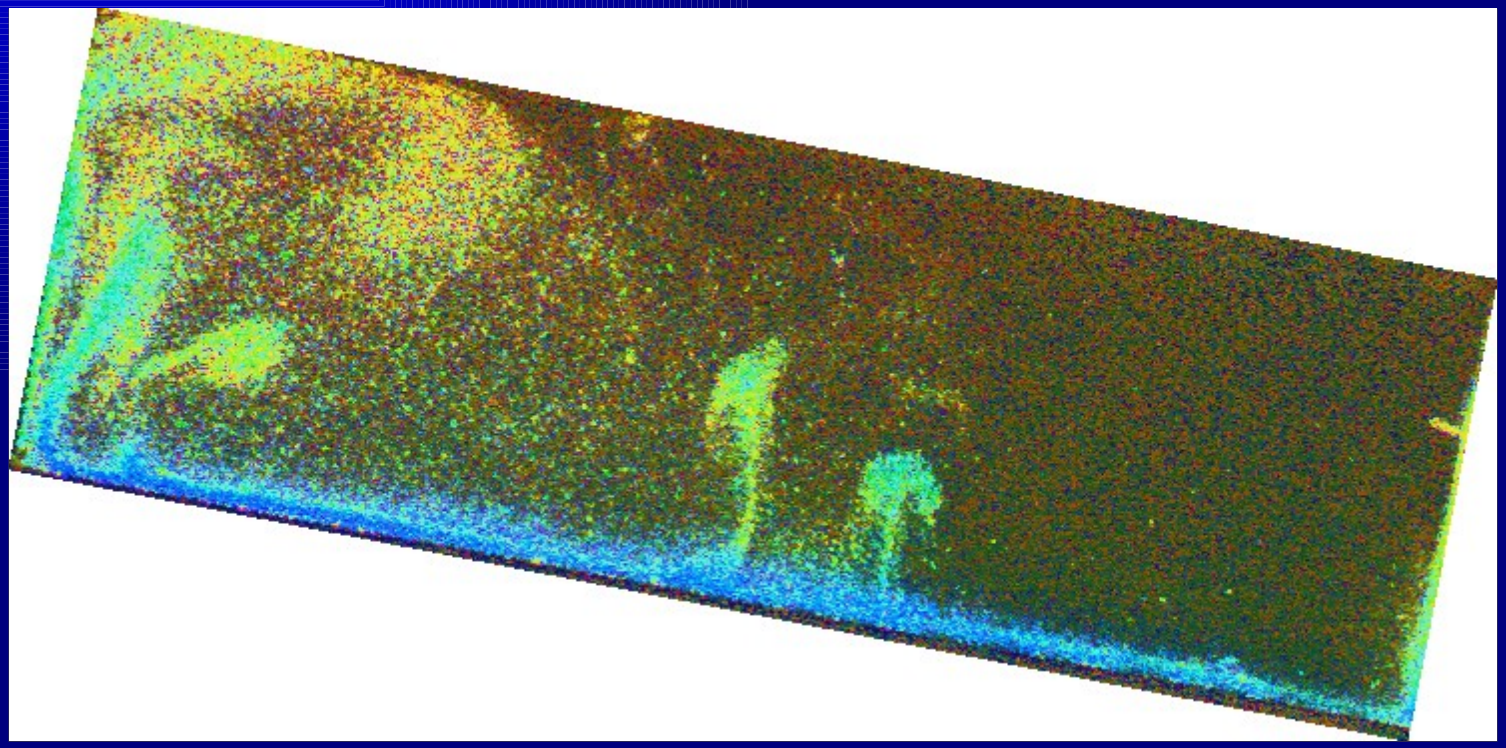
**t= 500 sec; $T_{ext}$= +20°C, $T_c$= -10°C.**

# Vertical Transport and Mixing in Complex-Terrain




**Schematic of the flow in a complex terrain basin**

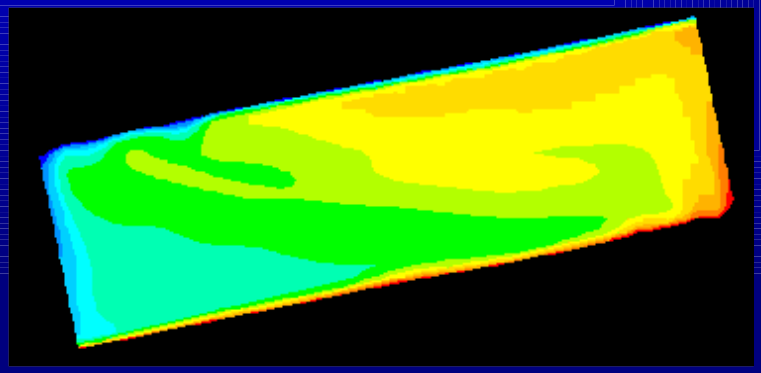
# Vertical Transport and Mixing in Complex-Terrain
## Laboratory Scale

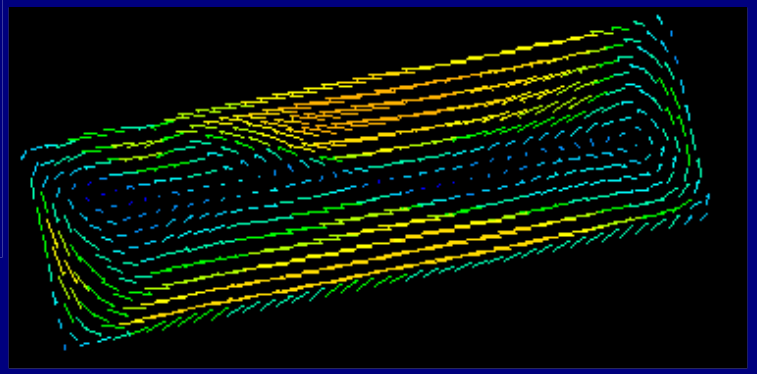


A thermal aloft generated over slope
hot bottom wall & cold top wall

**Thermal eruptions visualized by TLC**

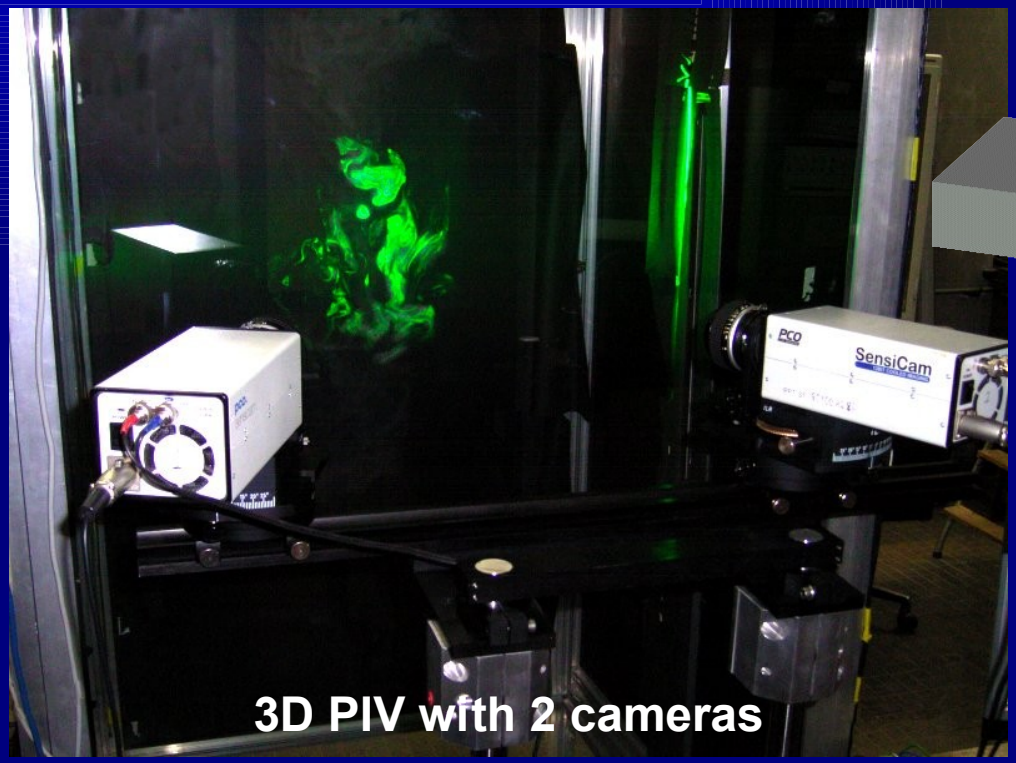
# Vertical Transport and Mixing in Complex-Terrain Laboratory Scale



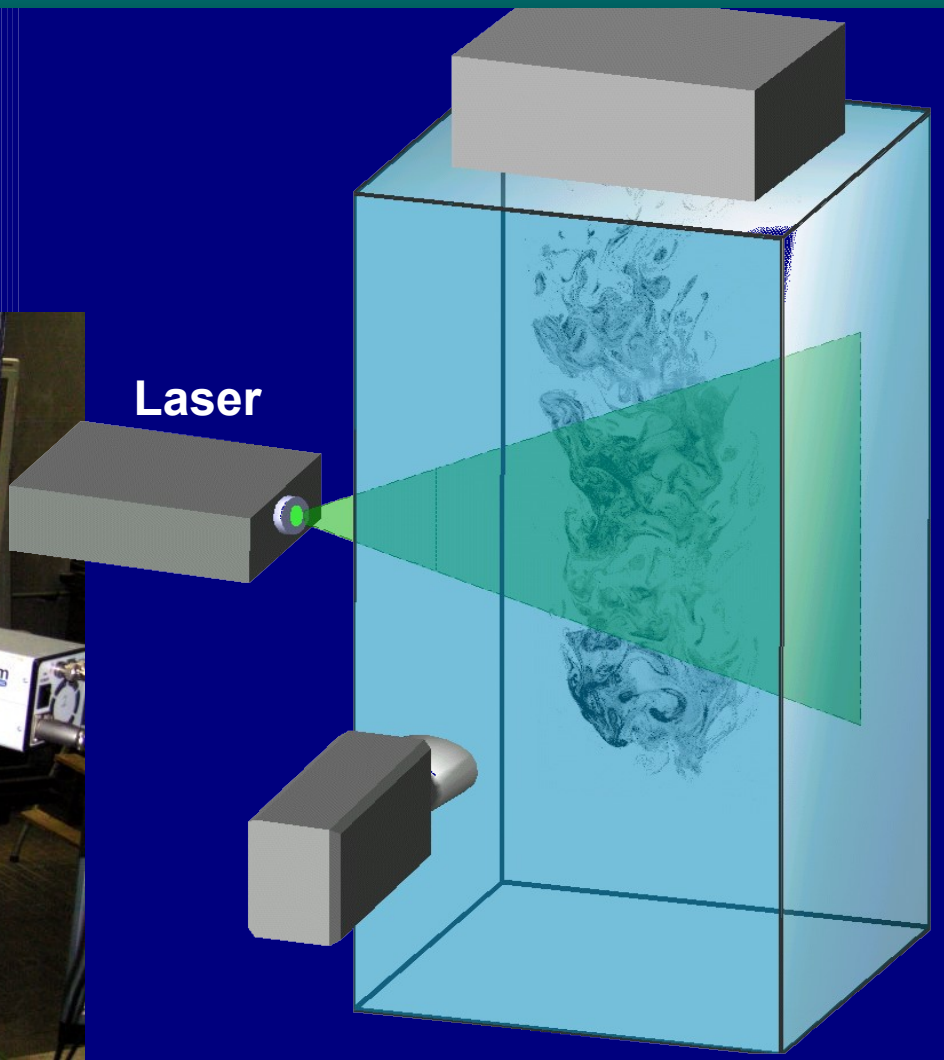


**Numerical solution (Fluent) for temperature and velocity field**

# Cloud Turbulence in Laboratory Scale




3D PIV with 2 cameras

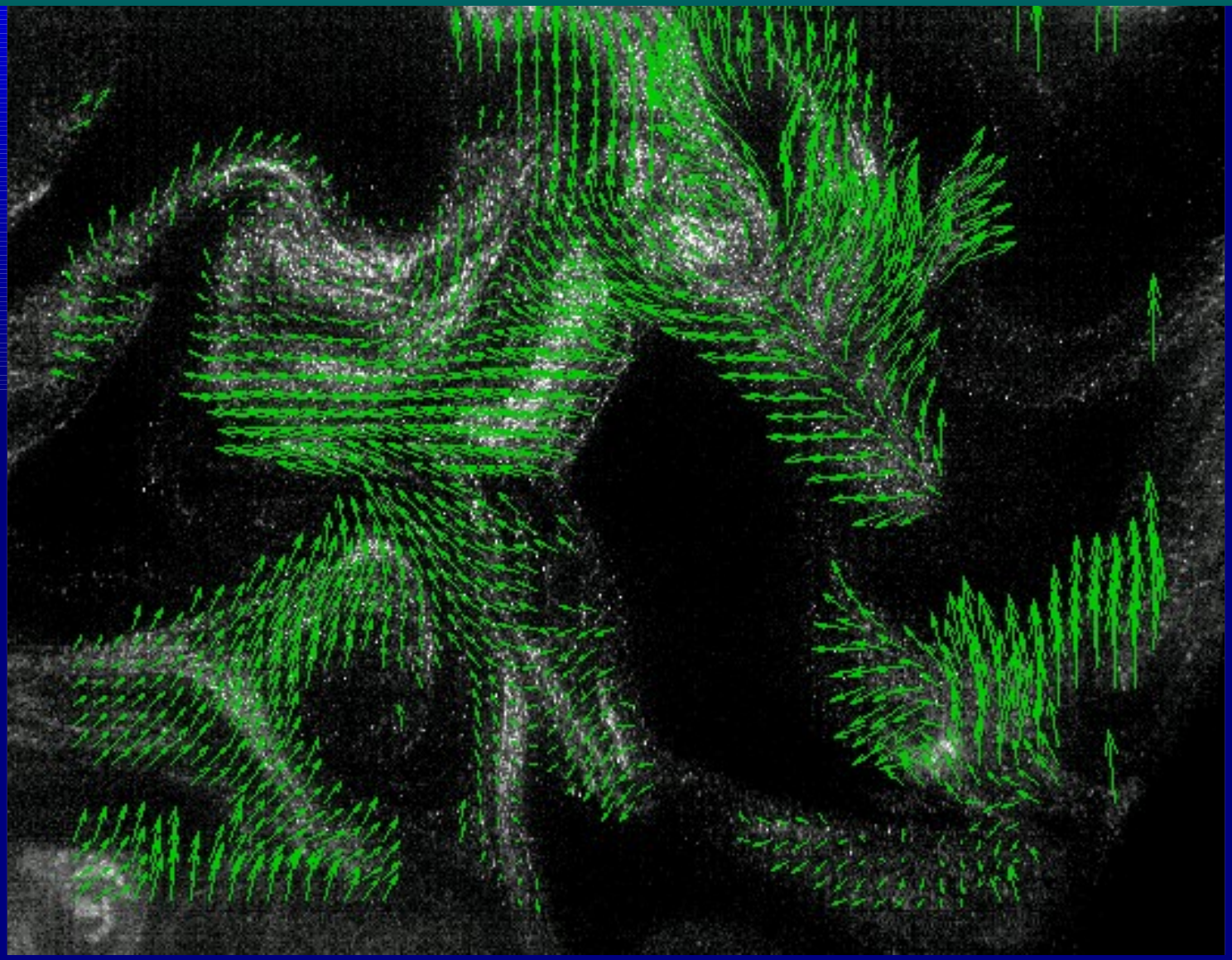



Cloud chamber

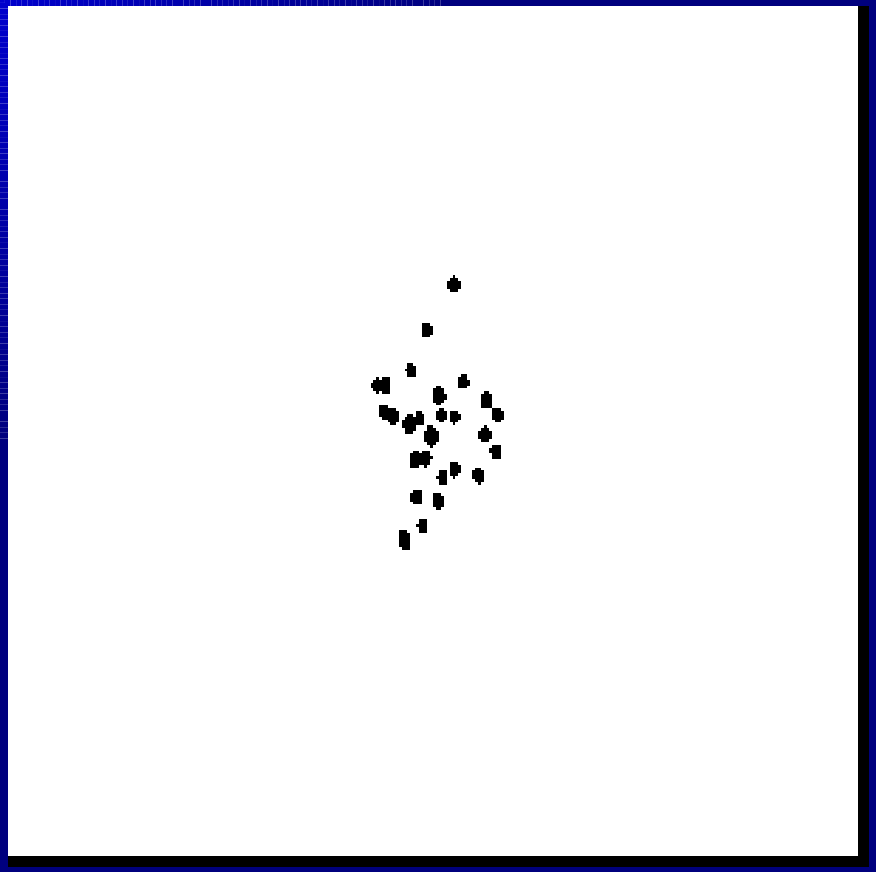
# Cloud Turbulence in Laboratory Scale

Laser with light guiding arm

# Flow interaction with cloud droplets
# PIV evaluated velocity field

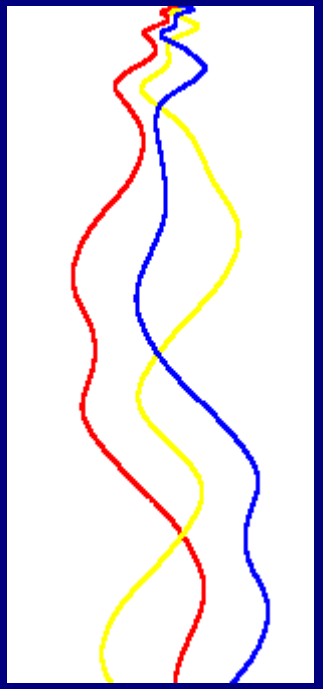


# Hydrodynamic Interaction of Particles



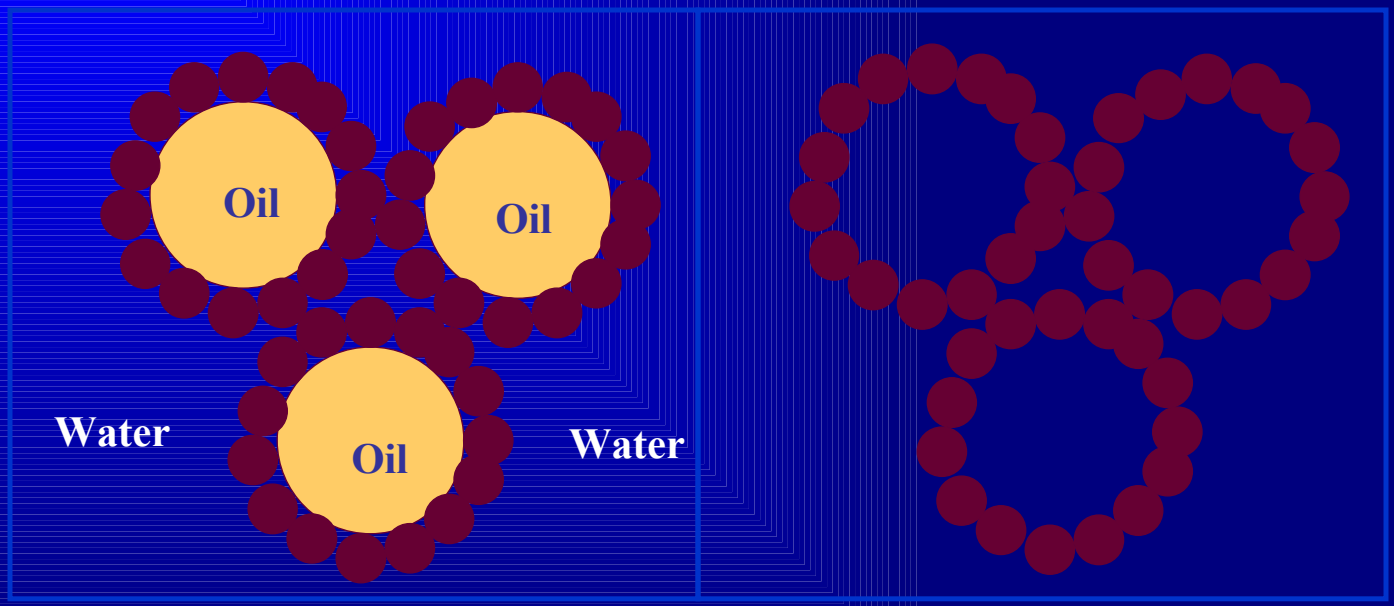
Numerical solution – ensemble of particles falling down
In viscous fluid

# Hydrodynamic Interaction of Particles



Chaotic particle tracks

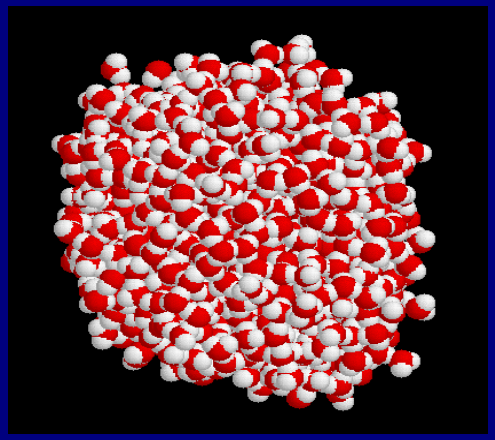
Experimental setup following ensemble of particles falling down in viscous fluid



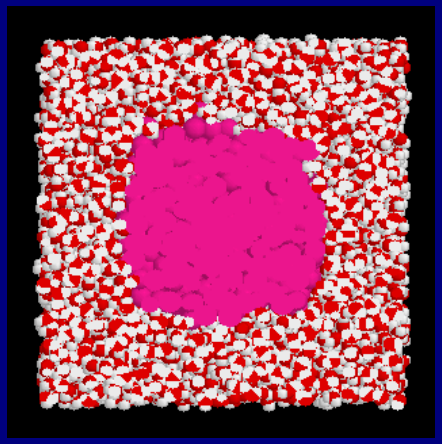

**The nanomaterial:**

* light
* strong
* flexible
* thin

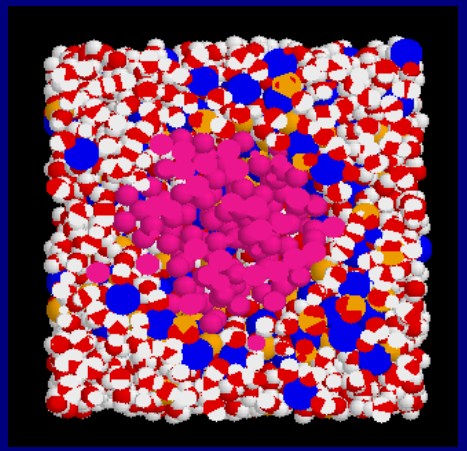
## Simulations by the molecular dynamics method



Water drop in vacuum



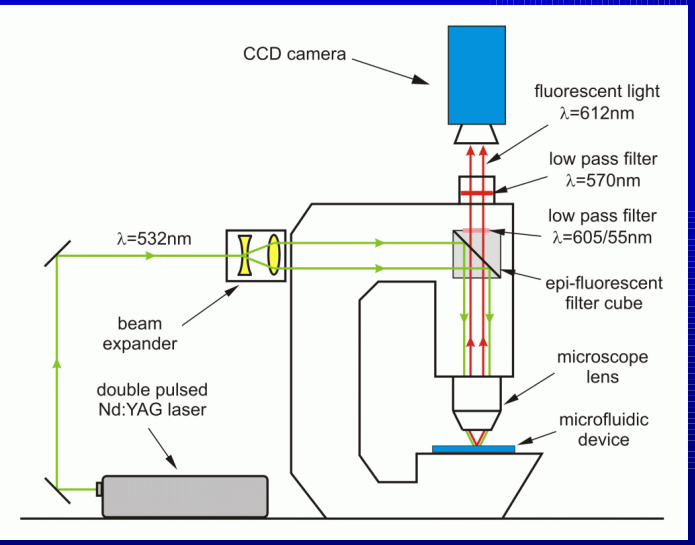
Oil drop in water



Interaction of soap with oil droplet in water

Emulsion with nanoparticles

# Micro-Flow Diagnostics



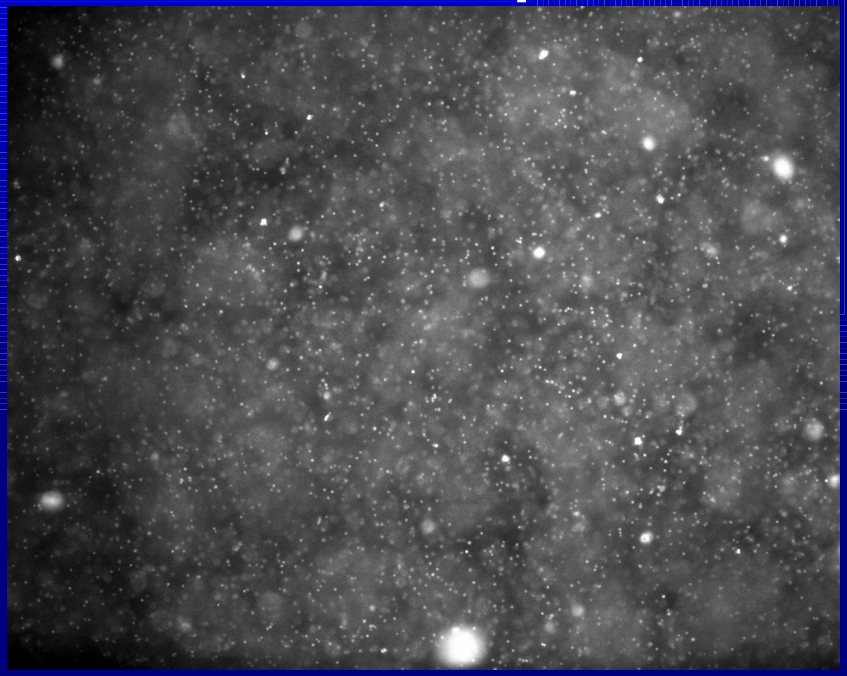

## Experimental setup

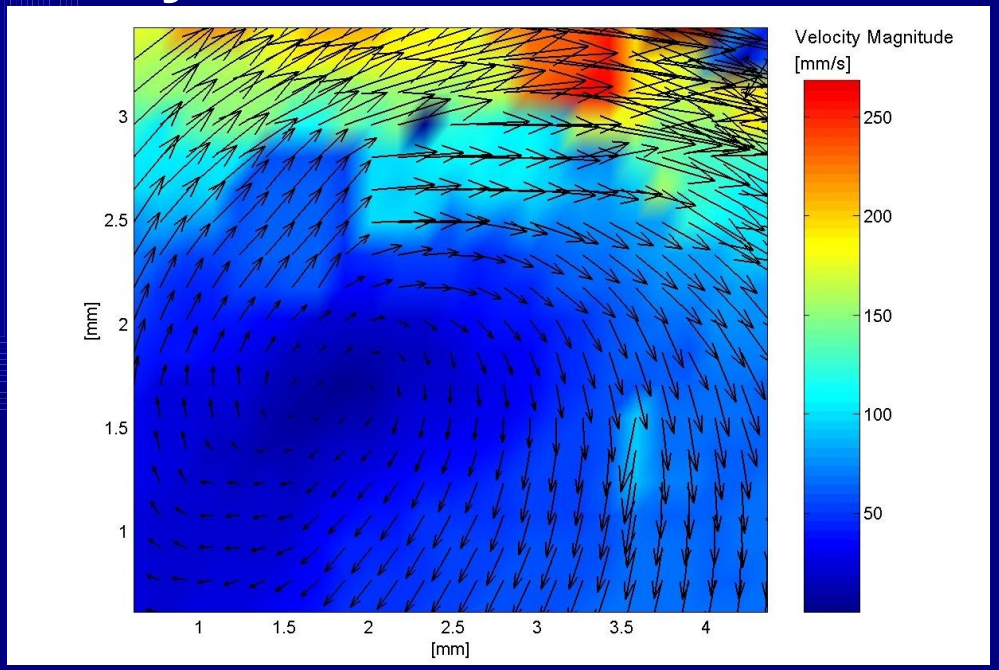
- epi-fluorescent microscope (Nikon ECLIPSE E-50i)
- double pulse Nd-Yag Laser (30mJ per pulse)
- high resolution PIV Camera (PCO SensiCam)
- high speed camera (PCO 1200 hs)
- experimental cell

**Fluorescent particles under microscope**

# Micro-Flow Diagnostics

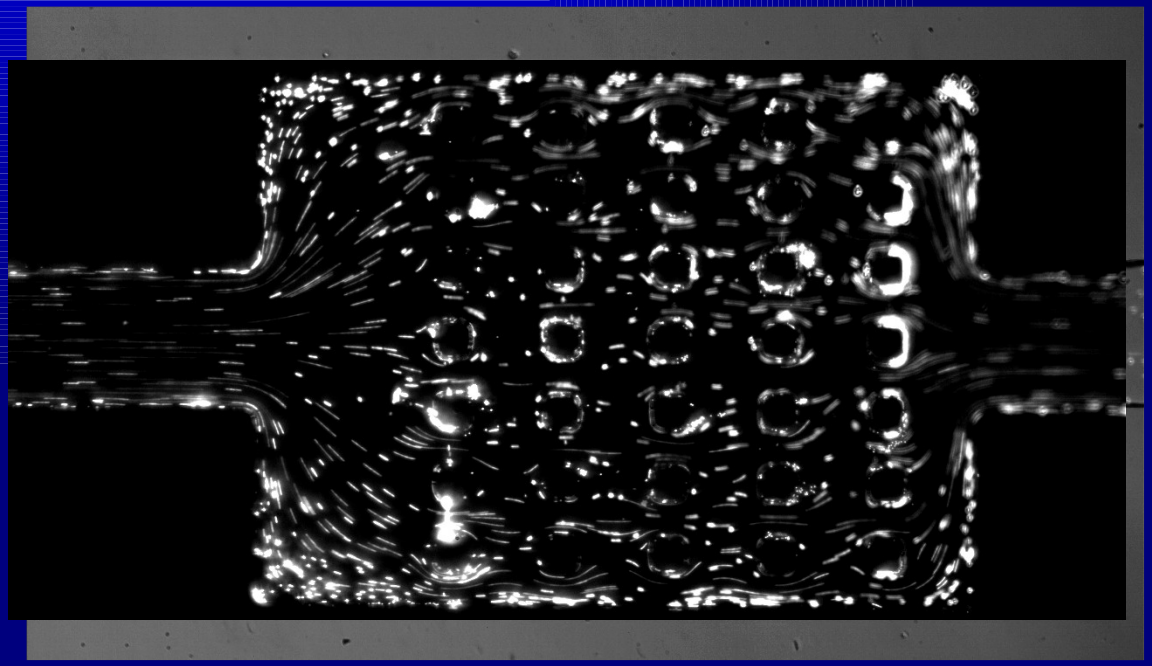
## µPIV flow velocity evaluation






~ 4 mm

# Micro-PIV application for flow visualization



1536 μm

20fps

Laser Ar CW 5W

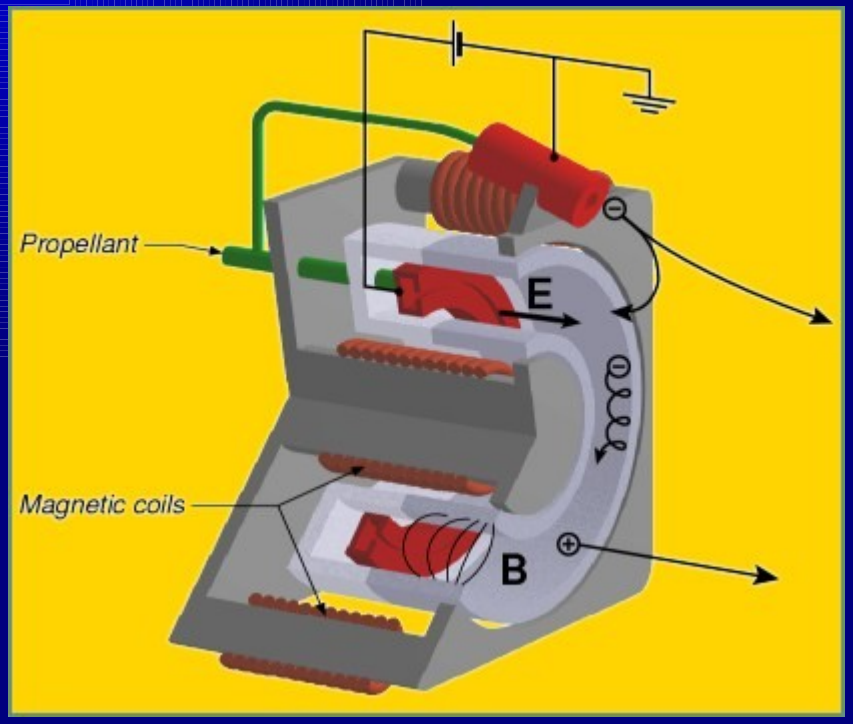
fluorescence light

Flow passing micro-palisade

Channel width : 200μm, fluorescent tracers 2μm

# Hall Thruster

## Rocket propulsion with electric or electromagnetic fields



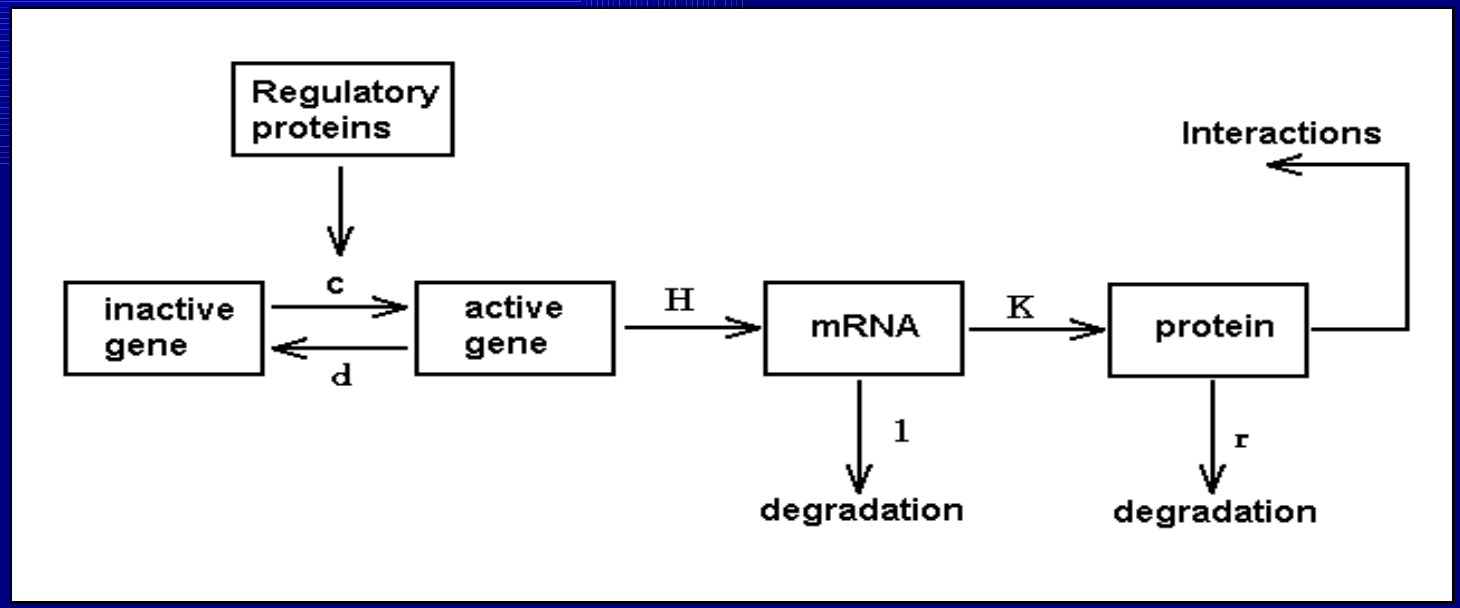

**Numerical solution of advanced electric propulsion systems**

# Selected bio- projects

## Gene expression in eukaryotes

## Stochastic model of regulation of a single gene

Simplified schematic of gene expression
Regulatory proteins change gene status




$$\mathbf{I}nactive\ gene \xrightarrow{c(y(t))} \mathbf{A}ctive\ gene, \qquad \mathbf{I} \xleftarrow{b(y(t))} \mathbf{A}$$

$y(t)$ - protein level, $c$, $d$ – transformation rates between **A** and **I** states

# Selected bio- projects

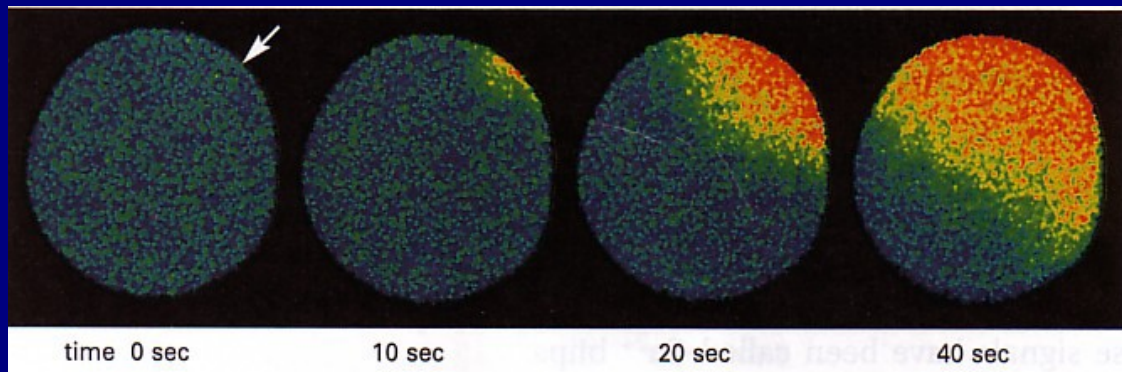
## *Calcium waves*

Influence of coupling between chemical and mechanical effects on the existence and properties of such waves. Reaction-diffusion equations for the calcium and various buffer proteins concentrations, coupled with the equations of the balance of mechanical forces in the tissue. Existence of more complex solutions representing the merging of two travelling waves.

## *Pattern formation*

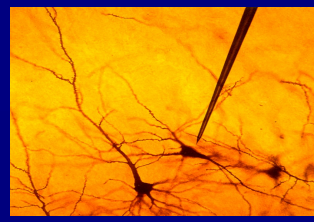
Formation of bone patterns during vertebrate limb morphogenesis. Existence and properties of solutions to new models of chondrogenesis. Patterns may be obtained via the Turing bifurcation.

The existence of traveling wave solutions in a mechanochemical model of skin pattern formation was proved for two different cases of the tissues.

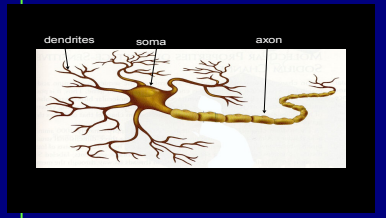


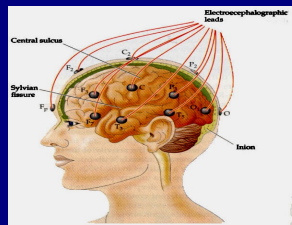
# Selected bio- projects

## Mutual Information and Redundancy of Spontaneous Communication between Cortical Neurons



- Question in neural information processing => how neurons cooperate to transmit information?
- We study spike trains (being carriers of information) generated by neighboring neurons from the primary visual cortex in the awake, freely moving rat.
- To estimate these parameters concept of complexity is applied
- Analysis revealed that while the value of RMI oscillated slightly around an average value, the redundancy exhibited a behavior characterized by a higher variability.



# Some statistical data

**2002 - 2006**

- Journal papers – **96**
- Conference papers – **75**
- Master thesis – **5**
- PhD thesis – **2**
- Habilitations – **3**
- Professorships – **1**
- Organized conferences – **7**
- National grants (KBN-PL) – **16 + 3 zew.**
  - total budget - **1.8 mln PLN**
- International grants – **7 + 1 COST**
  - total budget - **3.73 mln PLN** (NADIA until 2010)
- Hardware investments approx. **0.6 mln PLN**

**List of publications since 2002-** **see LINK here**