Sciences in micro-gravity

Jacqueline ETAY

SIMAP Laboratory

SUMMER SCHOOL ON THERMO ACOUSTIC AND SPACE TECHNOLOGIES - RIGA JUNE 17-20 2014

European Programme for Life and Physical Sciences (ELIPS)

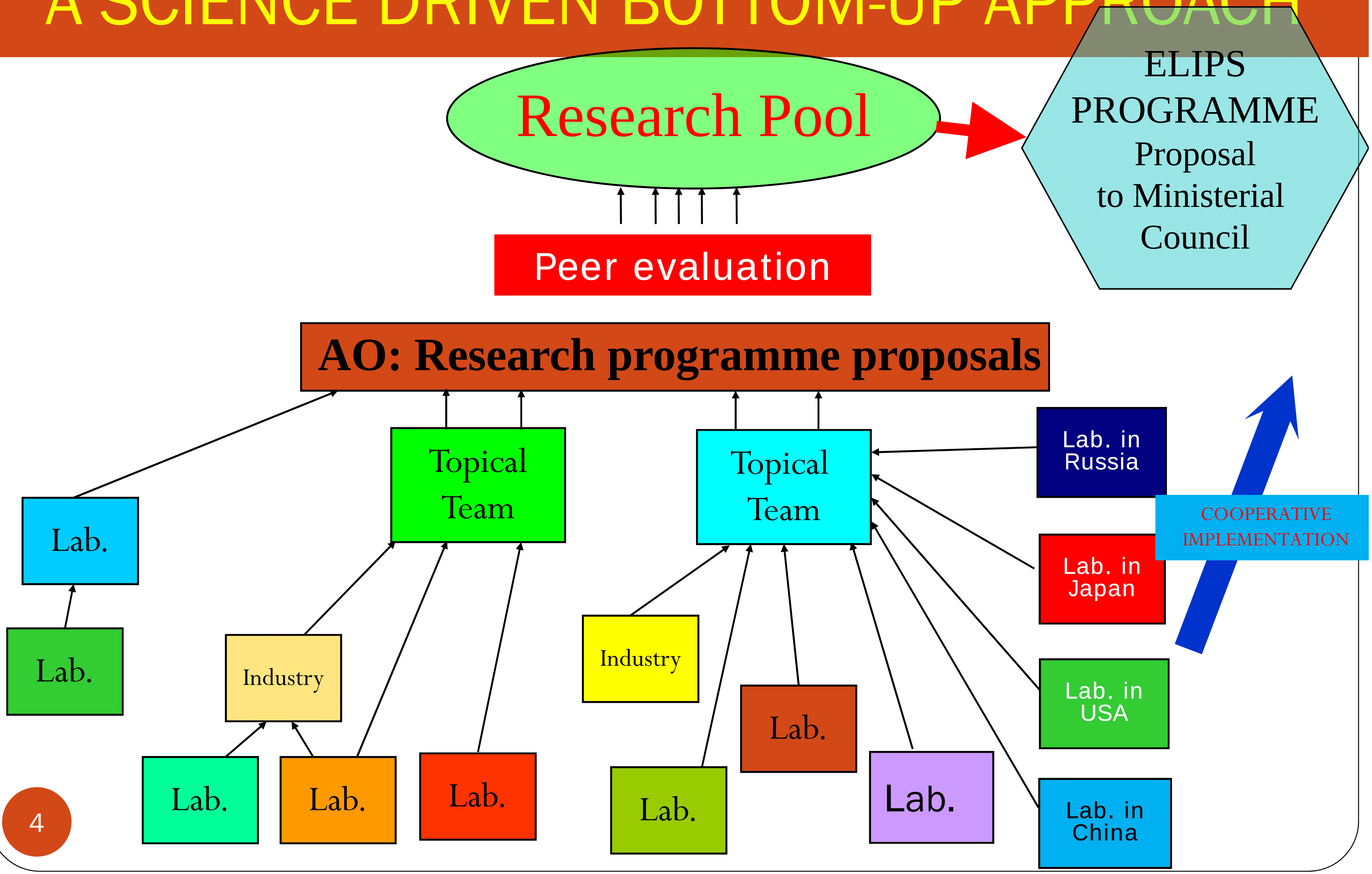
- Now : ELIPS 3
- Physical Sciences Research in Space
  - Physical Sciences Unit : *Head* Olivier Minster
  - New Materials and Energy Unit : David Jarvis
- MISSION STATEMENT
  - Conceive a research programme in space that has an impact commensurate with the investments it represents in terms of instrumentation, launch and in-orbit operations
- STRATEGY
  - Involve a large international team of theorists, modellers, experimentalists and communicators in every project
  - Embed space projects into larger ground-based, application-oriented projects as typically funded by the EC

European Programme for Life and Physical Sciences (ELIPS)

- **ESA implements the joint efforts of 20 Member States**
  - **18 states of the EU: AT, BE, CZ, DE, DK, ES, FI, FR, IT, GR, IE, LU, NL, PT, PO, RO, SE, UK**
  - **plus Norway and Switzerland.**
- The members states that contribute to the optional ELIPS programme are in red

- Other EU states have Cooperation Agreements with ESA: Estonia, Slovenia, Hungary, Cyprus, Latvia, Lithuania and the Slovak Republic (Bulgaria and Malta coming up) anticipating full membership.
- Canada takes part in some programmes under a Cooperation Agreement (and this includes ELIPS)

ELIPS' RESEARCH PLAN: A SCIENCE DRIVEN BOTTOM-UP APPROACH

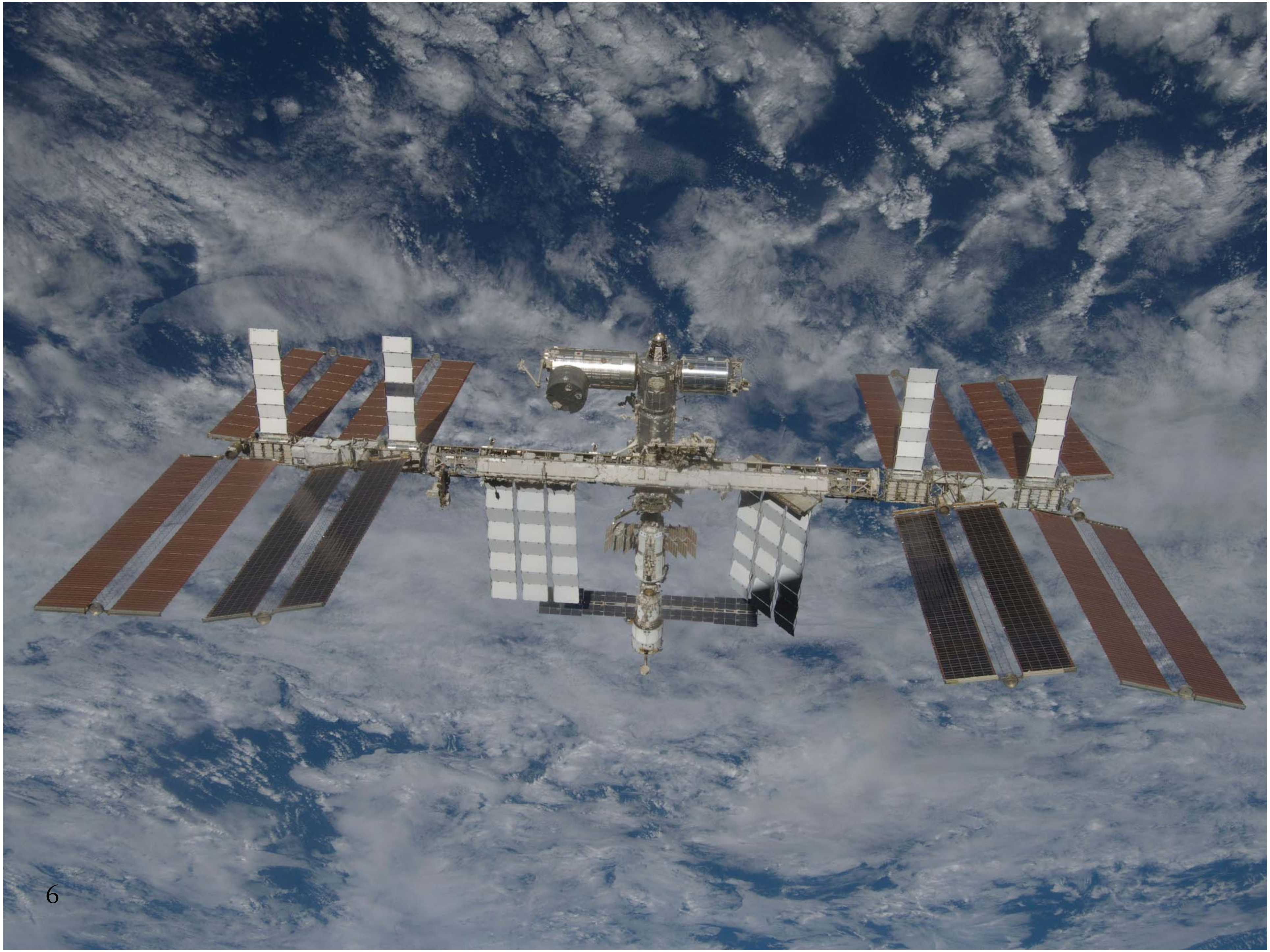


MEANS "AVAILABLE" FOR IMPLEMENTATION

Sounding Rockets
up to 13 min

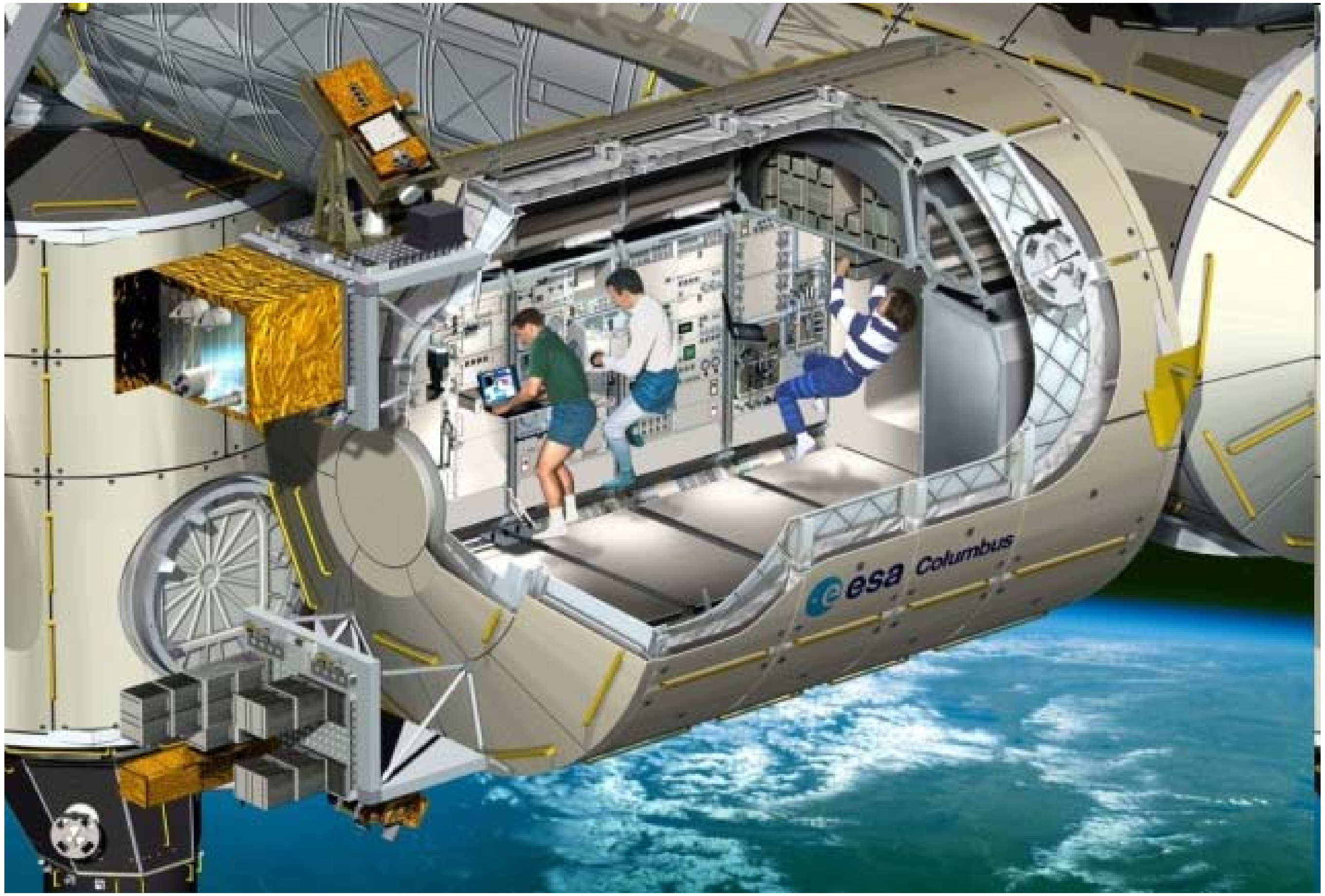
Ground-based Facilities
4.7 – 9 s

Parabolic Flights
20-25 s

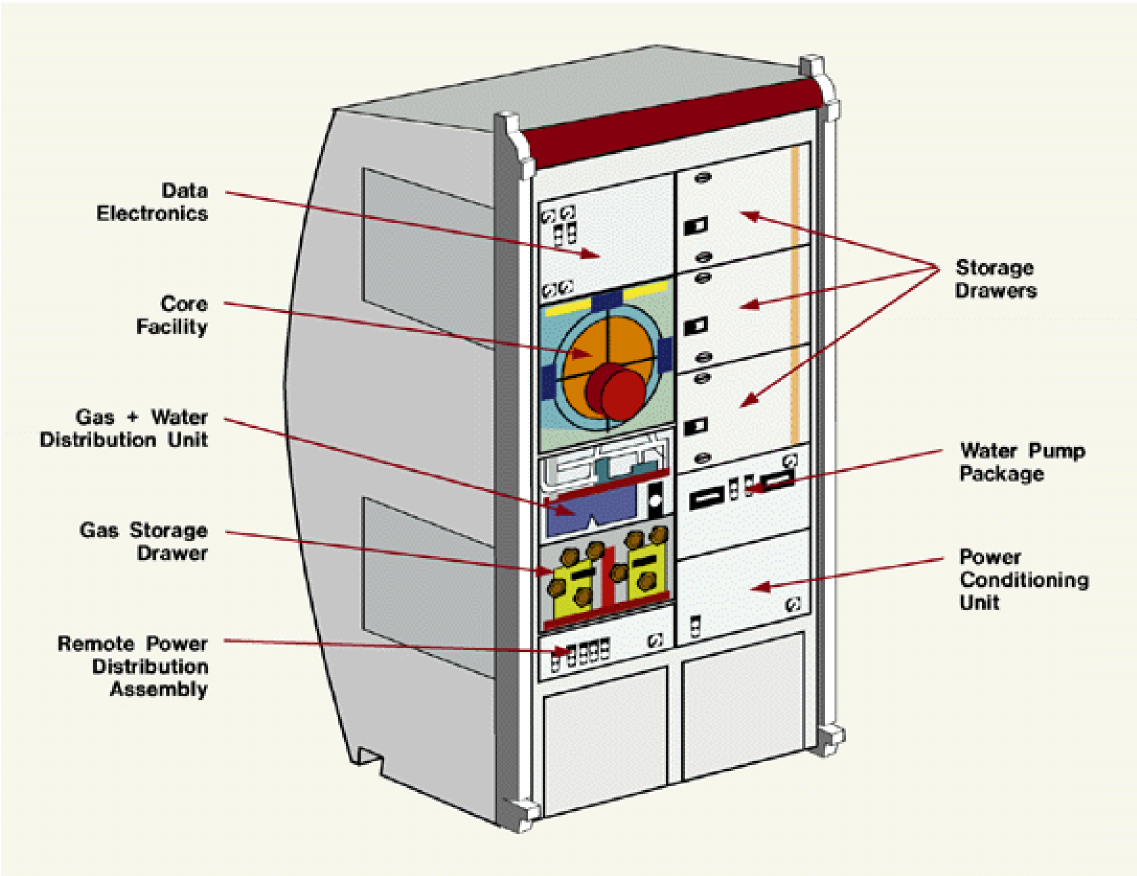


Columbus Modulus

ISS-Columbus modulus



Material Science Laboratory Electromagnetic Levitator (MSL-EML)



APPLICATION-ORIENTED RESEARCH

- When Europe decided to join the ISS project, ESA was asked to identify all potential applications for its utilisation and seek a return on investment.

  => "Research needs not be useless to be fundamental"

- MAP: Microgravity Applications Programme
  - Stimulate the involvement of non-space industry in ELIPS projects
  - gravity effects
    - Cetsol/Micast MAP
    - Thermolab MAP

- These actions demonstrate the potential, but the impact is not commensurate with the investment in space.

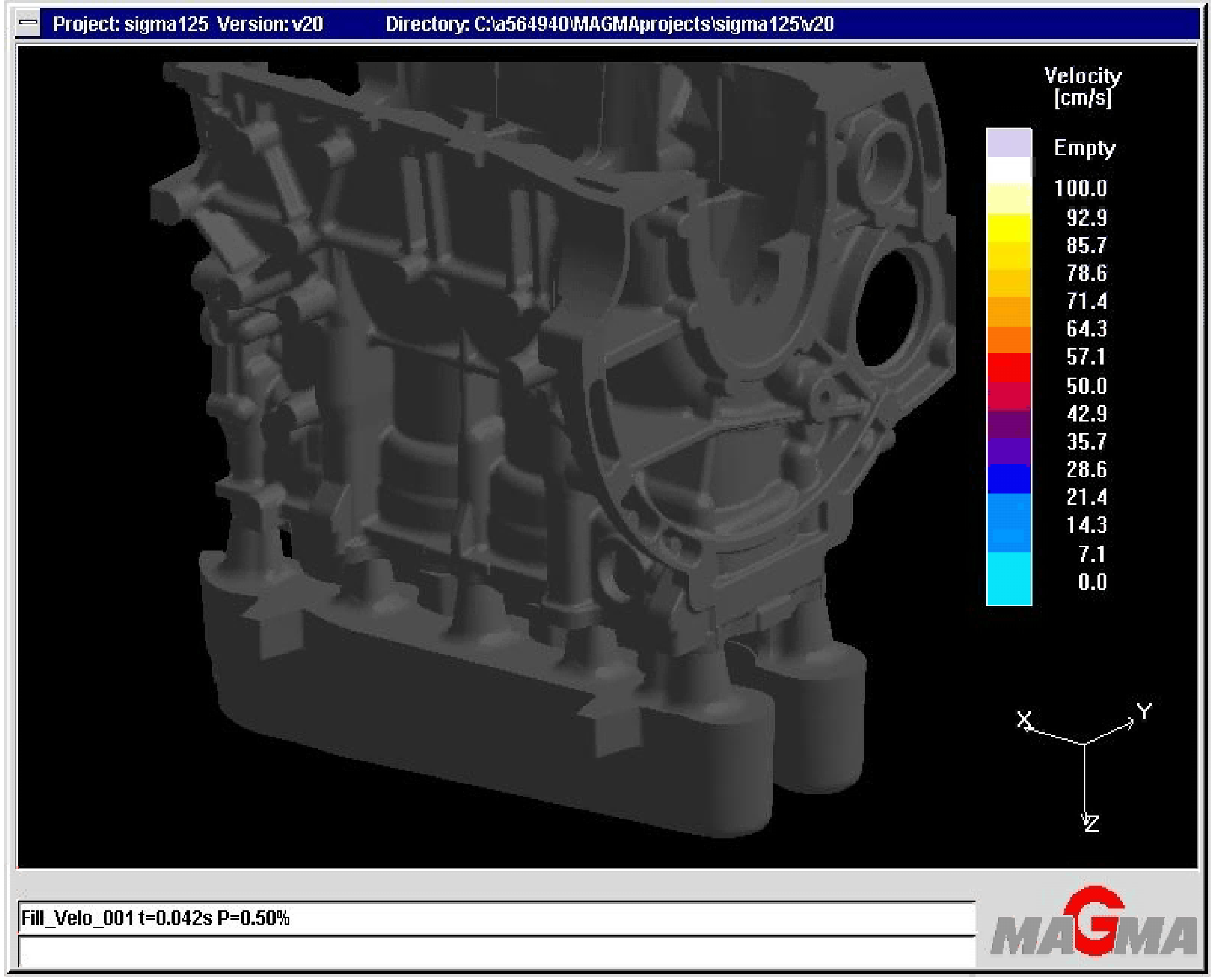
ELIPS-2 Research Cornerstones in Physical Sciences

- FUNDAMENTAL PHYSICS
  - Cold Atom Clocks, Matter Waves, Bose-Einstein Condensates & Quanta
  - Physics of Plasmas and Solid or Liquid Particulates
- FLUID PHYSICS
  - Structure and dynamics of fluids, multi-phase systems and interfaces
  - Combustion
- MATERIALS SCIENCES
  - Materials designed from Fluids
  - Thermophysical properties of Fluids for Advanced Processes
- PREPARATION FOR EXPLORATION
  - Life Support Systems
  - Advanced materials, Fire safety

21st Century Materials

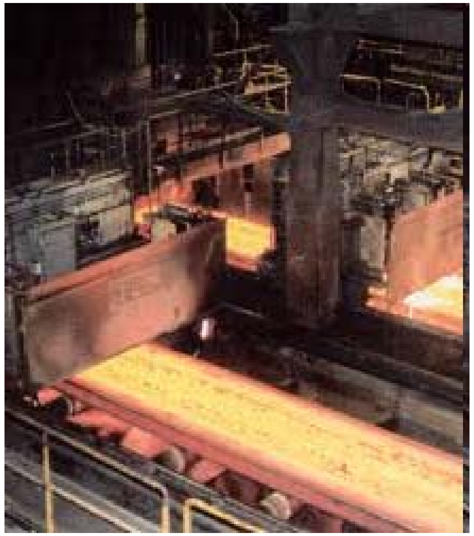
MATERIAL TOPICS UNDER STUDY: lightweight transportation, energy and propulsion systems, catalysis, heat transfer devices, nuclear reactors, superconducting wires, energy-harvesting of waste heat, solar thermal collectors, high-speed computing, high-density digital storage, telecom…

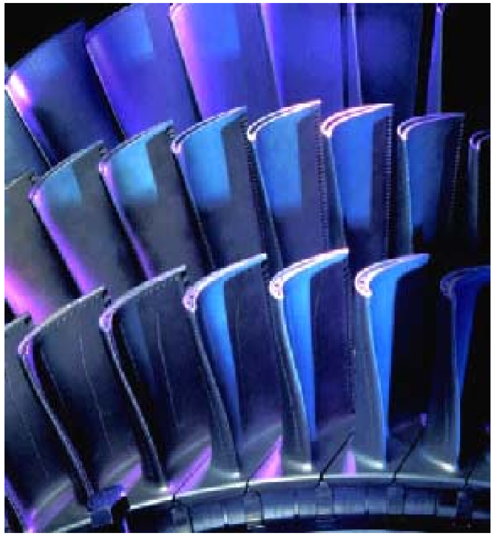
Filling a mould



Challenge in alloys solidification

understanding the CRITICAL LINK between
Process - Structure - Properties





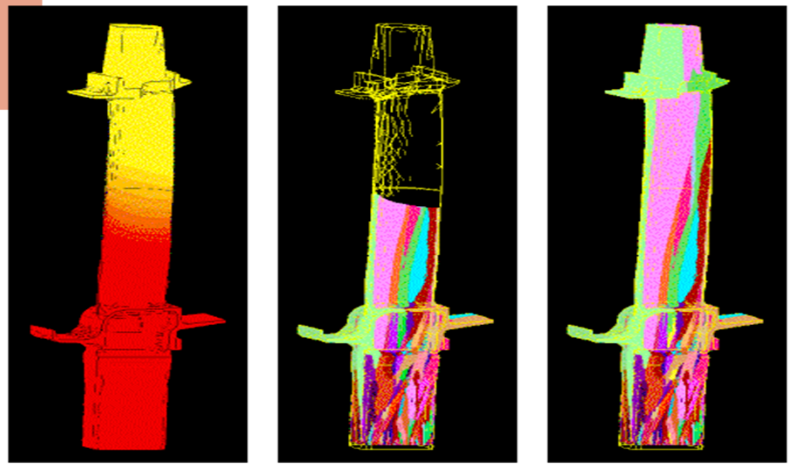
Thermophysical properties ?
Which issues ?

• Elaboration - Process optimisation

Numerical Simulations

Thermophysical properties

???

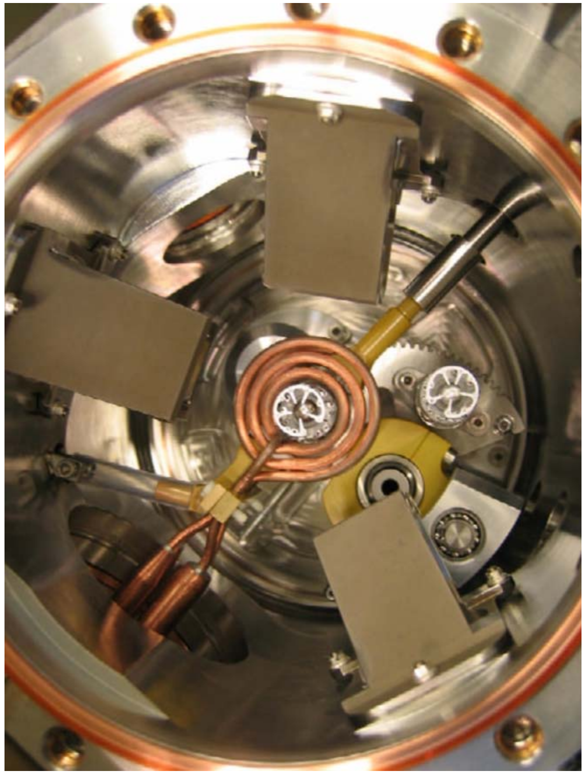


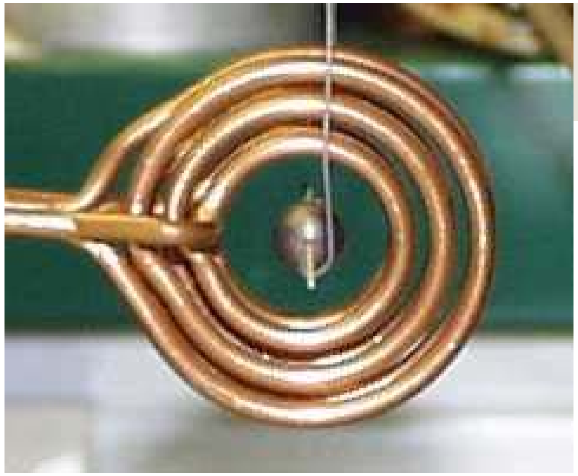
(Courtesy of Astrium)

• Issues : - high temperature
- pollution

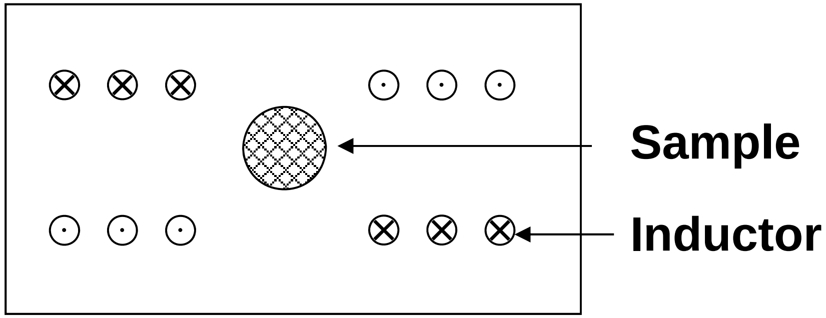
Development of containerless technique in microgravity
use of EM levitation

EML-MSL : Tempus



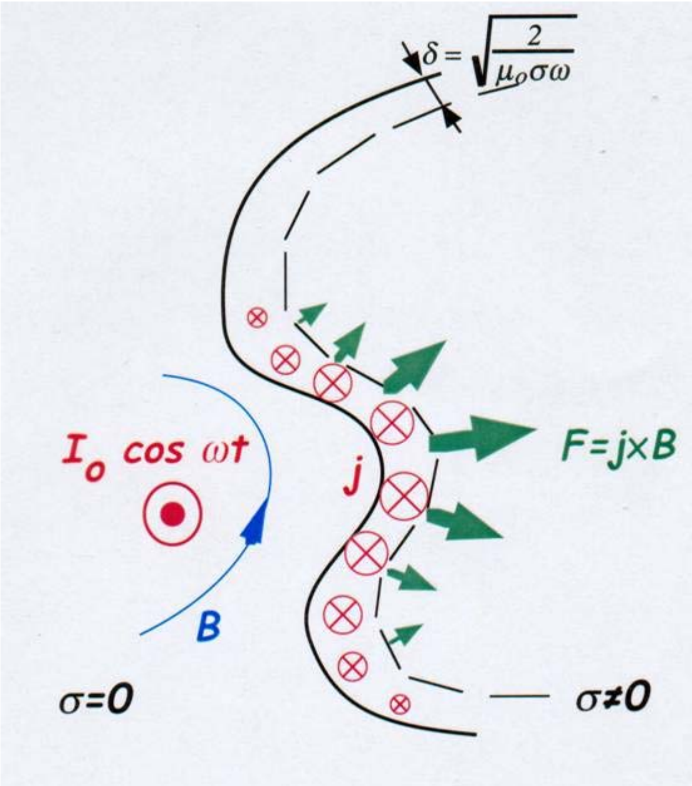


Sources Astrium



- Sample heating possible up to 2000degC
- Pyrometer (resolution 0.1K >600degC, 100Hz)
- 2 cameras (axial, radial high speed) (high speed up to 190kHz)
- Vacuum and inert gas (Ar, He or mixture)
- Trigger needle and chill cooling capability
- Sample container for 18 samples
- Crew activity only for container exchange

Induction Principle



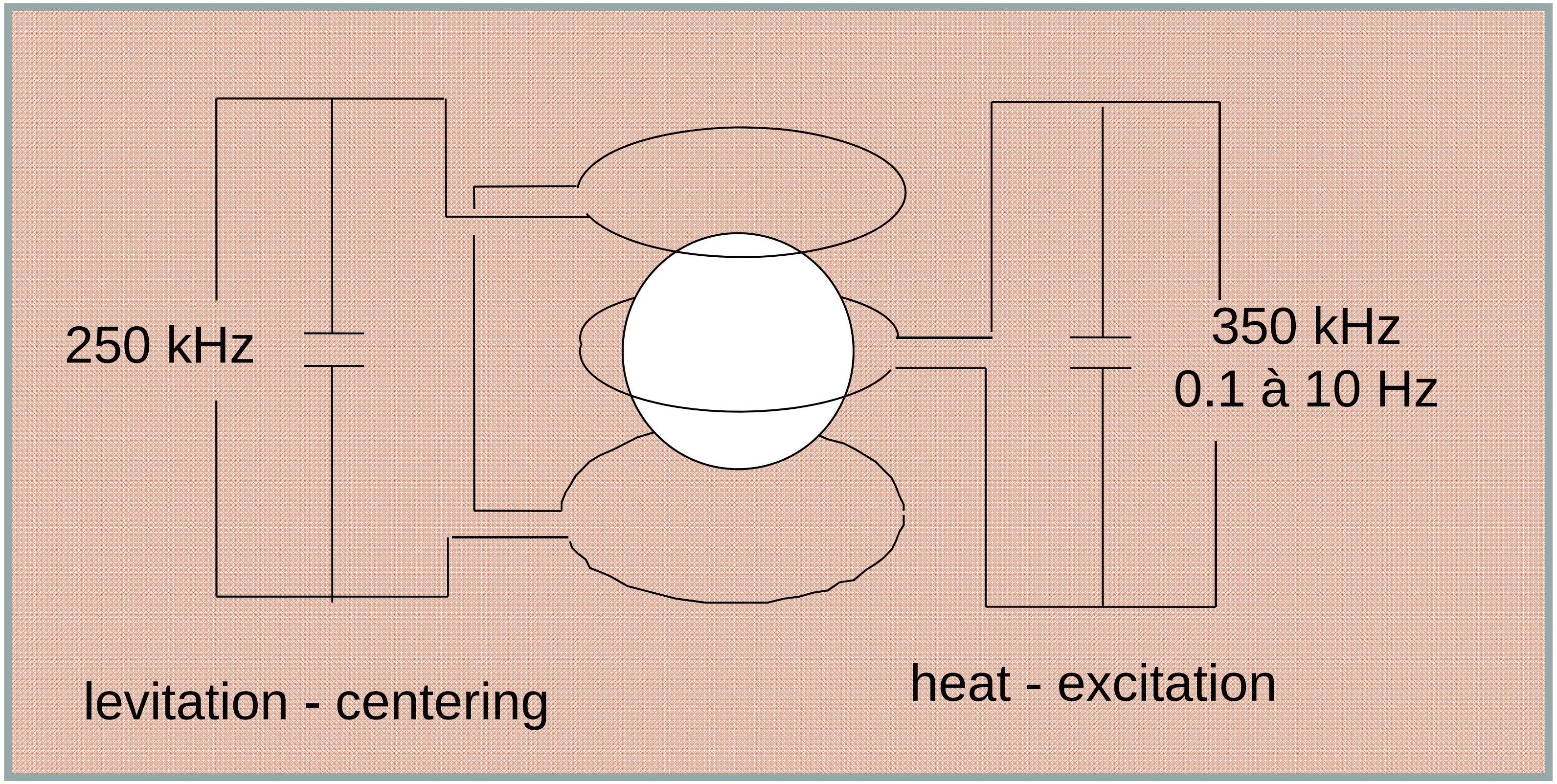
- induced electrical currents

$$j \approx \frac{2|B_s|}{\mu\delta} \cdot e^{n/\delta_m} \cdot \cos\left(\omega t + \frac{n}{\delta} + \frac{\pi}{2}\right)$$

- Joule Power
  => sample heating

- Electromagnetic forces
  => levitation
  => centering
  => stirring

EML-MSL Modulus



EML-MSL Modulus

Controls :

- Positionning
- Heat
- Shaping

Mesurements:

- Interface (video) :
  - oscillation frequency
  - volume mesure
- Temperatures (pyrometry)
- Electrical current and frequencies of the electrical circuit

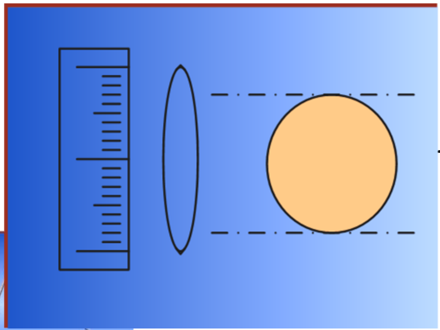
EML-MSL Modulus

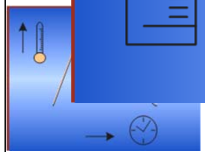
Goals : non contact thermophysical properties measurements

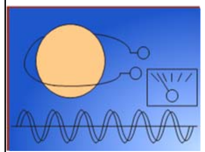
Advantages :

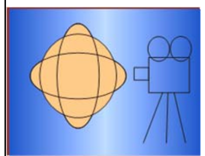
- no sample pollution
- high superheat level allowed
- no-gravity = low electromagnetic stirring

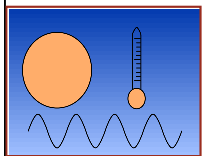
EML-MSL Density Measurement

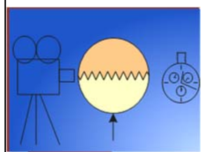










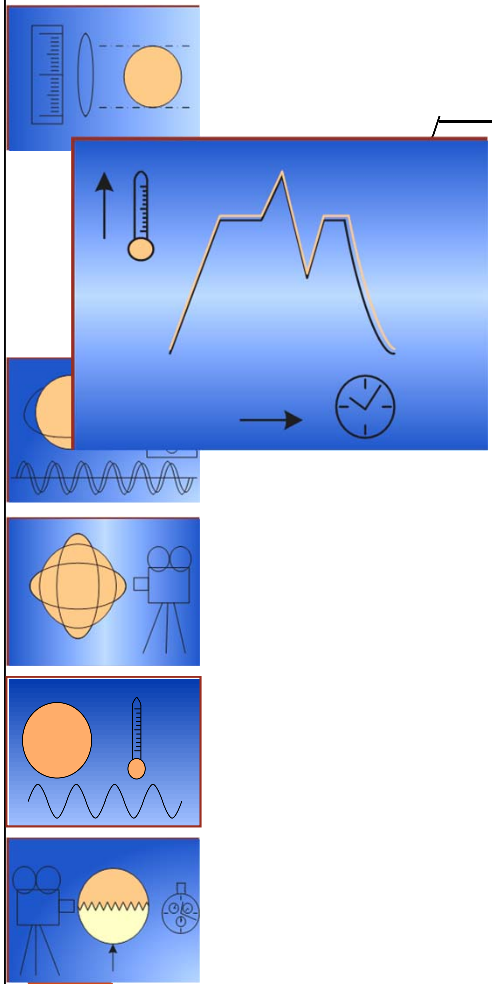


Optical Dilatometry

Follow on a video the interface varying temperature

Volume calculation

EML-MSL Overheat Measurement

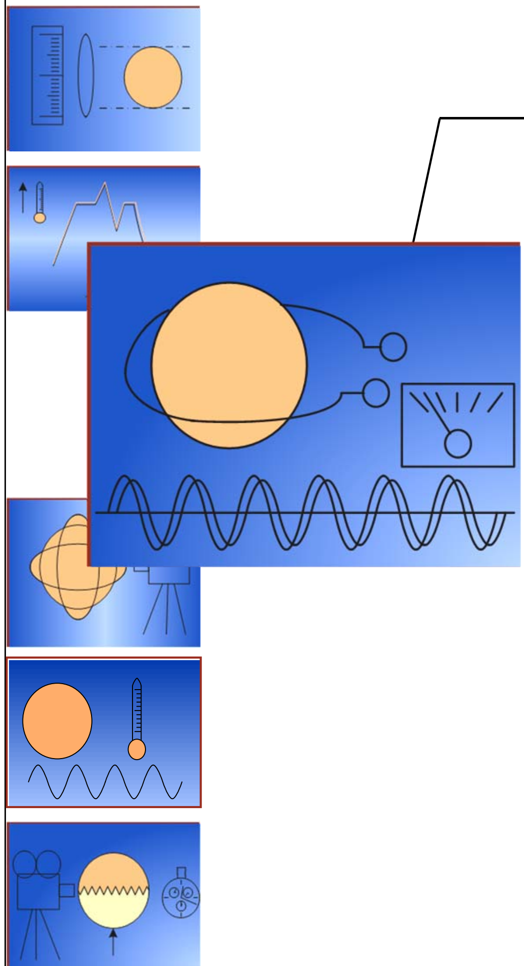


Input : Joule Power

Output : temperature

Deducing : overheat

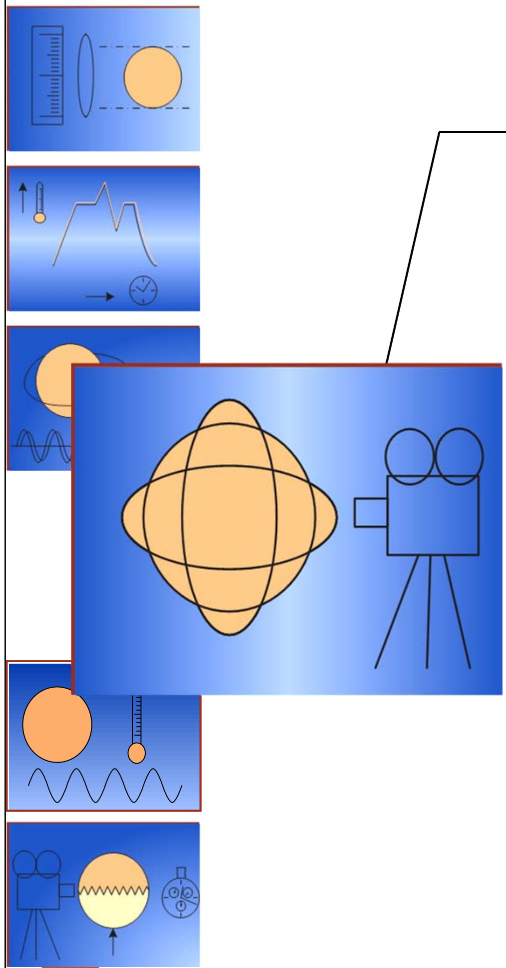
Elect. conductivity measurement



Measure : resonnance frequency of the RLC electrical circuit.

Calculation : electrical conductivity

Surface tension and viscosity

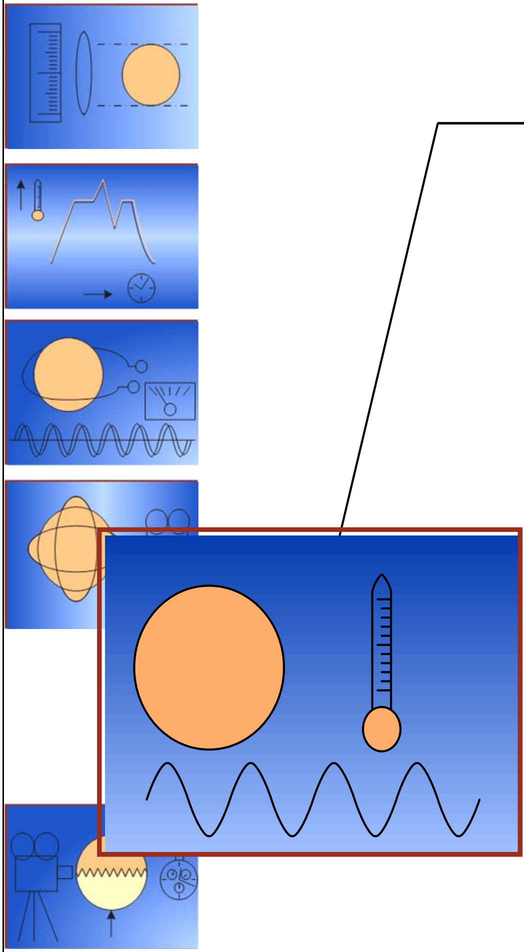


***Input* :** Droplet deformation

***Measure* :** time depending top point position

***Calculation* :** surface tension and viscosity

Heat capacity and thermal conduction

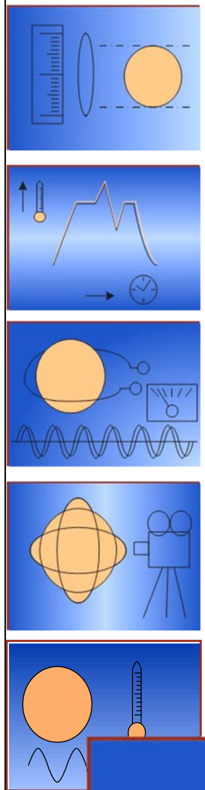


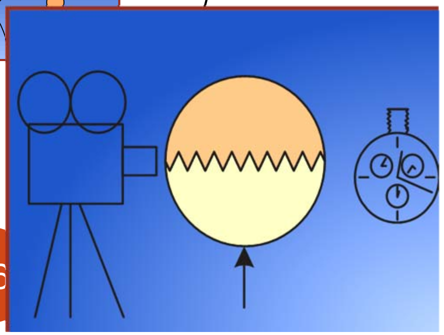
Input **:** Modulation of the Joule Power Heating

Measure **:** temperature

Calculation **:** heat capacity and thermal diffusivity

Solidification structures

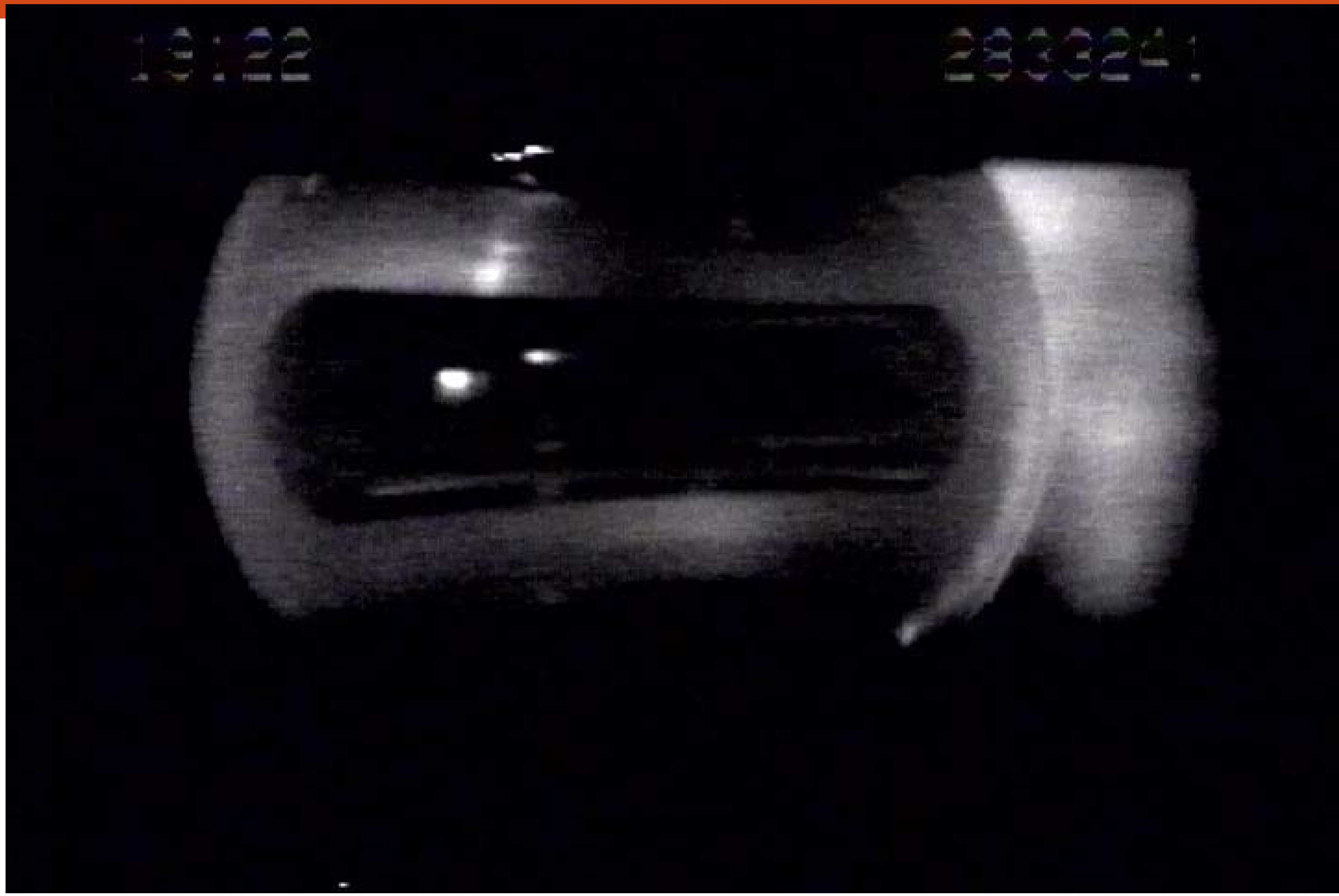




Use of a needle

Measure *:* X-ray + video + image processing

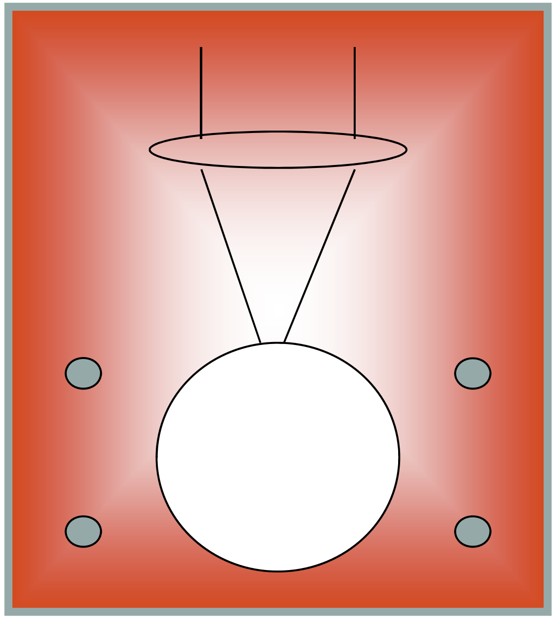
Video Hyers et Wunderlich (2003)

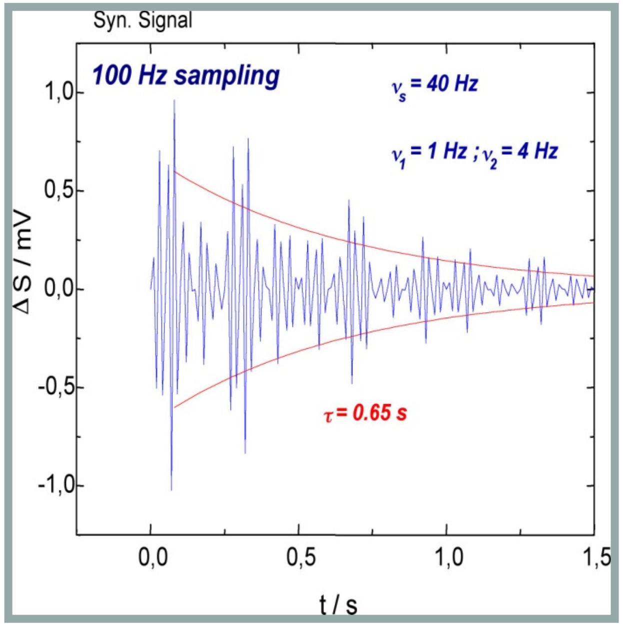


QUESTION

- Does the motion inside the molten sample disturbs the measure ?

Surface tension and viscosity measurements

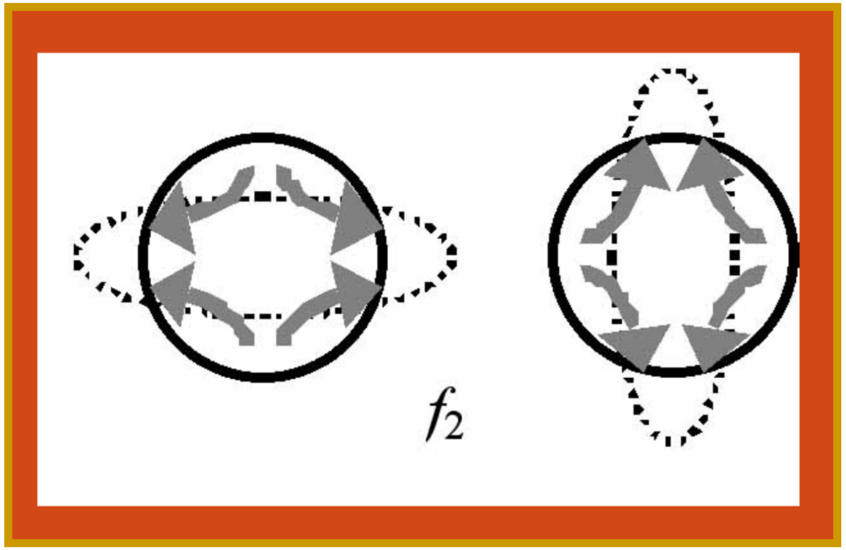




Laser signal - appropriate filter

- modelled and analyzed as damped oscillator

Surface tension and viscosity measurements



Lamb (1975)

Hyp : **Damped oscillator**

Surface tension $\gamma_{th} = \frac{3}{8}\pi \cdot M \cdot f_{measured}^2$

Viscosity $\rho\nu_{th} = \frac{3}{20} \cdot \pi \cdot \frac{M}{a} \cdot \frac{1}{\tau_{measured}}$

Damped harmonic oscillator
Model assumptions

- 1 - **spherical** equilibrium shape of the droplet

- 2 - **small** shape **deviation** from the sphere

- 3 - **potential flow** inside the droplet

- 4 - **no other** flow **source** than the motion generated by the deformation of the equilibrium spherical shape

$\Rightarrow$no electromagnetic stirring

$\Rightarrow$no previous existing motions

Used method for turbulence model

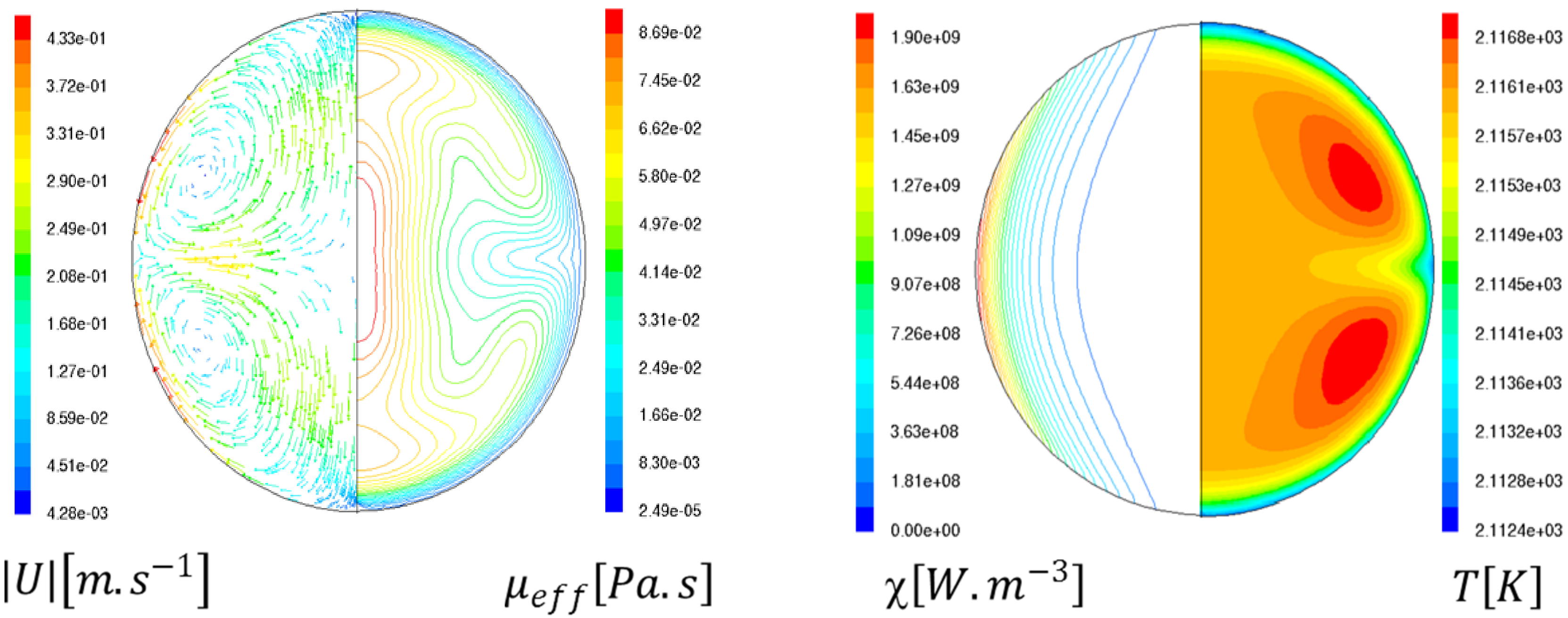
- We choose a k-ε RNG model

- adapted to intermediate case where the turbulence is <u>not fully developed</u>

No friction at the free surface

V. Yakhot and S.A. Orszag, *Renormalization Group Analysis of Turbulence. I. Basic Theory*, J. Sci. Comput. 1 (1) (1986) 3-51.

Results

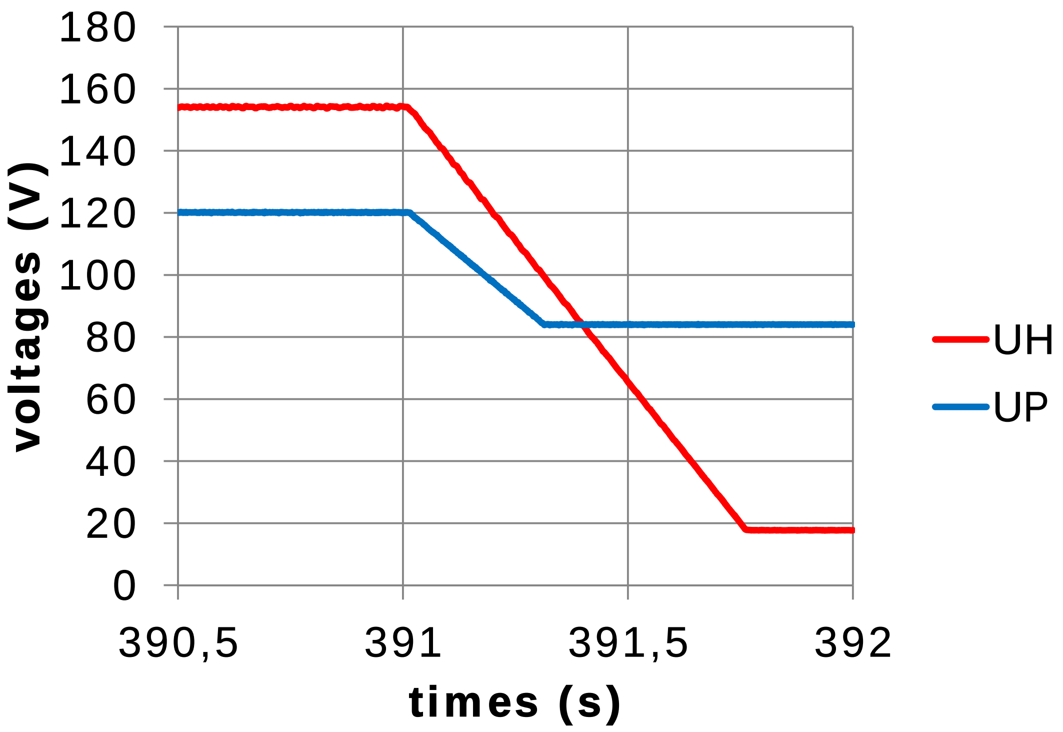


4.33e-01
3.72e-01
3.31e-01
2.90e-01
2.49e-01
2.08e-01
1.68e-01
1.27e-01
8.59e-02
4.51e-02
4.28e-03
8.69e-02
7.45e-02
6.62e-02
5.80e-02
4.97e-02
4.14e-02
3.31e-02
2.49e-02
1.66e-02
8.30e-03
2.49e-05
1.90e+09
1.63e+09
1.45e+09
1.27e+09
1.09e+09
9.07e+08
7.26e+08
5.44e+08
3.63e+08
1.81e+08
0.00e+00
2.1168e+03
2.1161e+03
2.1157e+03
2.1153e+03
2.1149e+03
2.1145e+03
2.1141e+03
2.1136e+03
2.1132e+03
2.1128e+03
2.1124e+03
$|U|[m.s^{-1}]$
$\mu_{eff}[Pa.s]$
$\chi[W.m^{-3}]$
$T[K]$

Stationary flow

- Results similar to Hyers-2005
- 2 counter vortices
- Weak effect of the Positioner
  - 5% of the Joule Power in the sample
  - fluid flows are weakly different.
- Measured temperature well recovered for $\varepsilon=0.52$
- ⚠ $\langle \mu_{turb} \rangle / \mu_o \approx 10$
- Convection leads to equatorial temperature slightly lower than polar temperature

Non stationary calculations



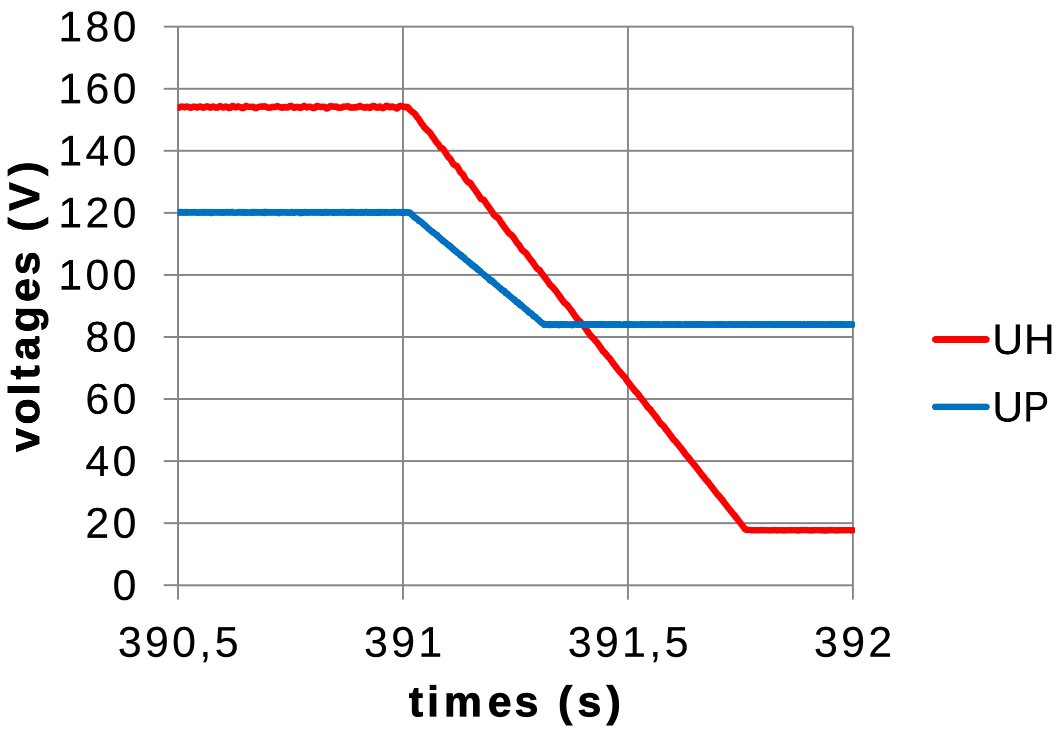
Experimental voltages

UH t=391.02s	UH t=391.76 s
154 V	18 V

UP t=391.02s	UP t=391.31s
120 V	84 V

Δt(H)=0,74 s
Δt(P)=0,29 s

Non stationary calculations



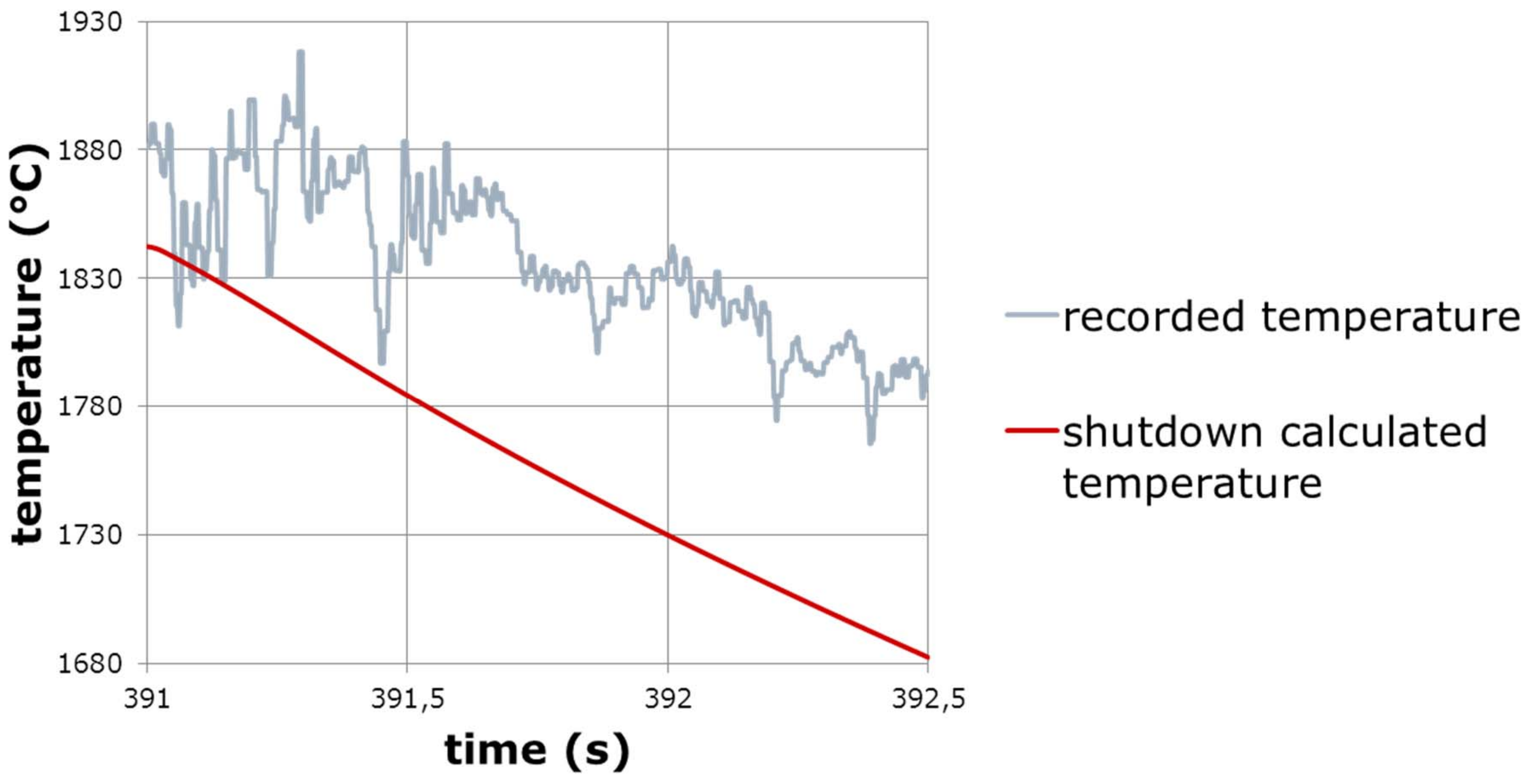
Experimental voltages

UH t=391.02s	UH t=391.76 s
154 V	18 V

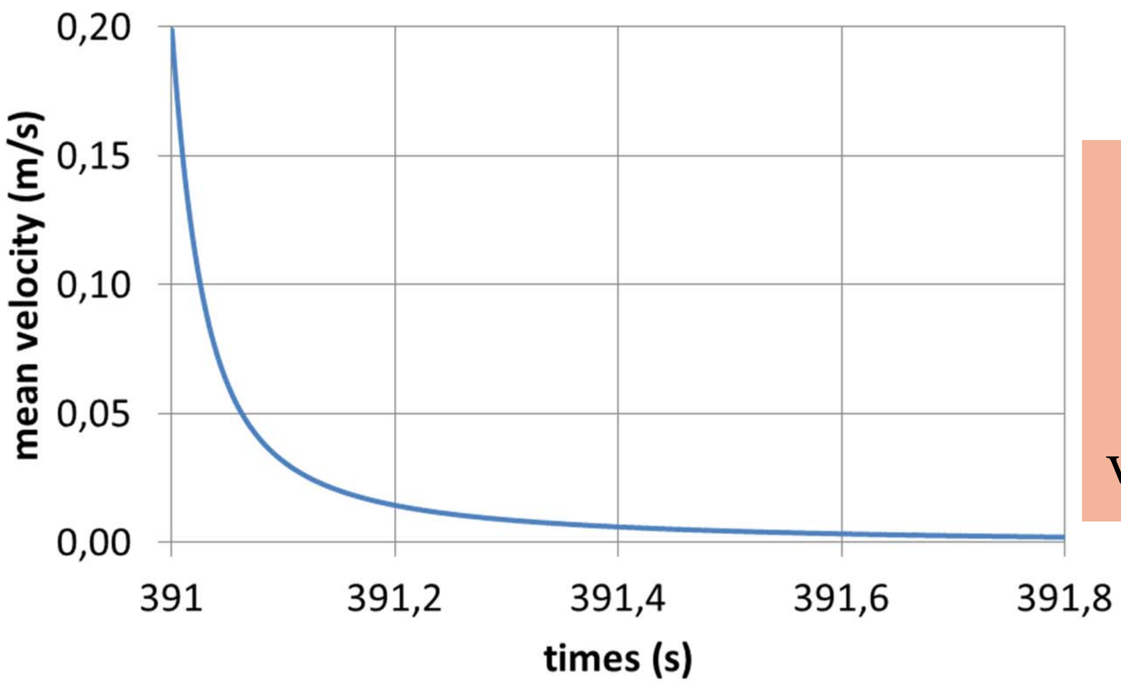
UP t=391.02s	UP t=391.31s
120 V	84 V

$\Delta t(H)=0,74$ s
$\Delta t(P)=0,29$ s

Non stationnary calculations



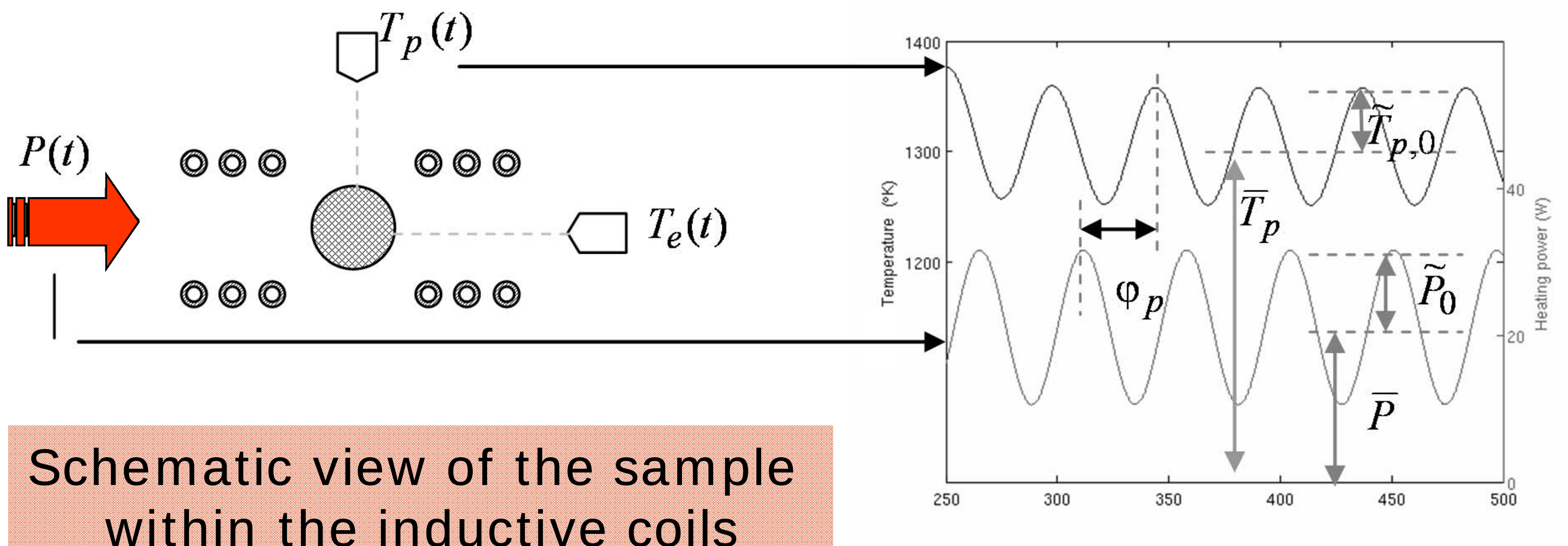
Non stationary mean velocity



Damping time
0.33ms

very short = turbulence

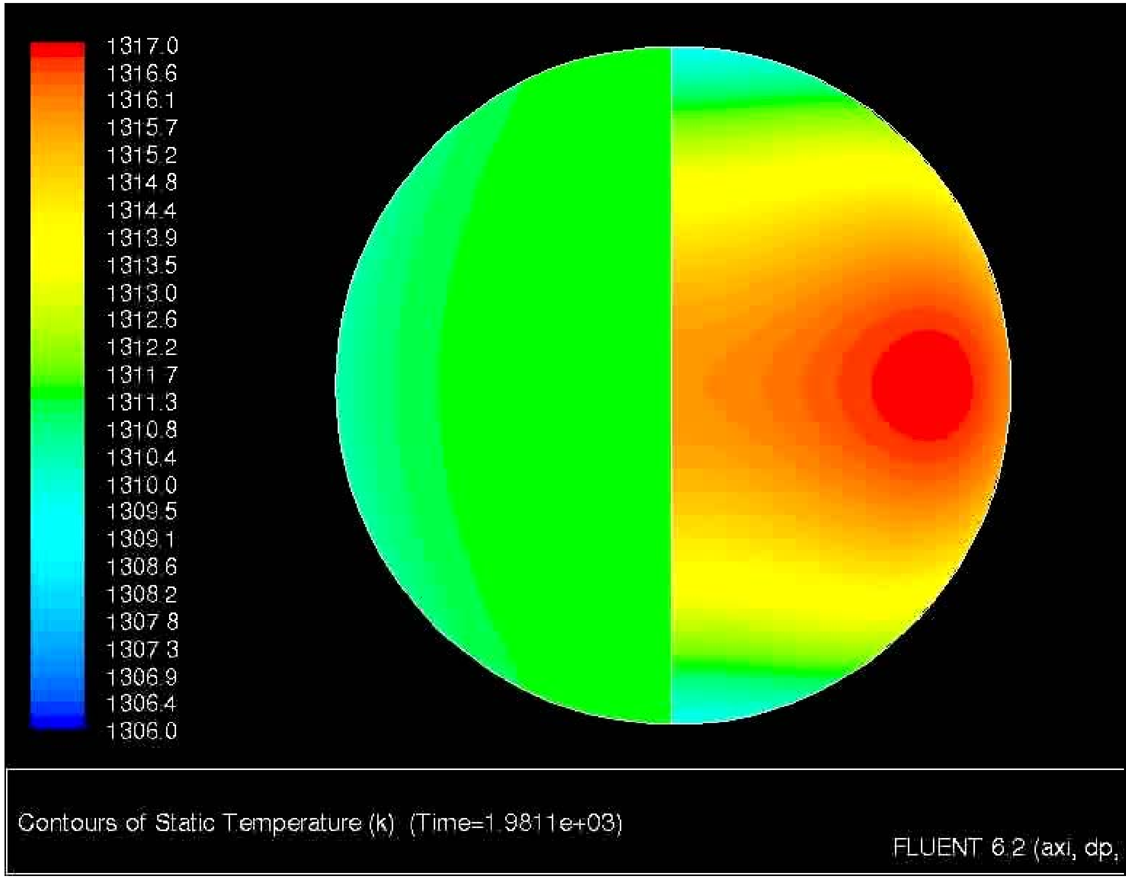
Non-contact calorimetry



Schematic view of the sample within the inductive coils

Input and output signals

Modulated calorimetry -ω_o optimal



Ro=4mm

r=3860 kg.m-3
k_{th}=23.1W.m^{-1}.K^{-1}

f = 380kHz
α= 5%
ω_0=0.56 rad.s^{-1}

left
modulated power

right
temperature

Current Model (Fecht & Johnson – 1993)

$$\tilde{P} = P_o \cos(\omega_o t) \Rightarrow$$

$$C_p = \frac{P_0}{\omega_o T_{p,0}} \frac{1}{\left[1 + (g_e(1 - s_e) + s_e(1 - g_e))Bi\right]}$$

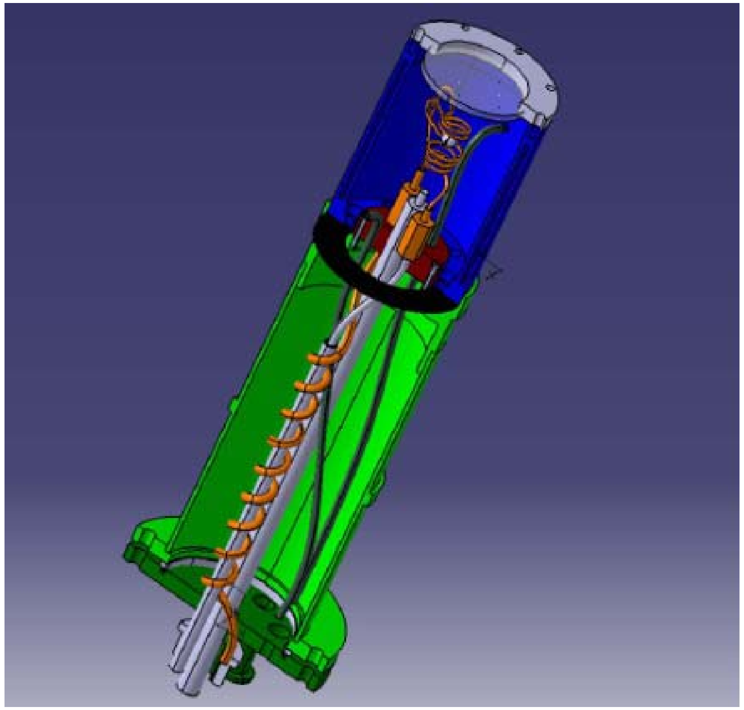
$$\kappa_{th} = \frac{C_p g_e (1 - g_e)\omega_o^2}{4\pi(R - \gamma\delta)\lambda_{ext}}$$

- Biot number $Bi = h_{ext}/h_{int}$
- Decay time $1/\lambda_{ext}$

Sketch of the alternative experimental facility

- Helmholtz DC 5T coil

- EML located inside the DC coil.



Alternative experimental facility

- DC Magnetic field to damp motions
- To reach better thermo-physical properties on earth

Acknowledgement

- At the beginning of the presentation, some slides are taken from Olivier Minster
- The presentation of the EML is taken from Astrium
- This work has been funded by the followings supports
  - *ESA under MAP-Thermolab,*
  - *EC under PI-IMPRESS (Contract Number: NMP3-CT-2004-500635),*
  - *CNES under Material Sciences Program*.