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COMSOL CONFERENCE 2018 LAUSANNE

# Simulation of an aerodynamic furnace for high temperature data acquisition using Comsol® Multiphysics

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# LEVITATION METHODS

| Method | samples | heating | Typical size (mm) | Main limitations |
|---|---|---|---|---|
| Acoustic | Any | Laser | 0,5-3 | Limited temperature |
| Aerodynamic | Any | Laser | 0,7-3 | Gas footprint ? |
| Electrostatic | Any | Laser | 1-4 | Require stable electrical charge on sample |
| Electromagnetic | Conductor | RF/laser | 2-10 | conductors |
| Optical | Non reflective | Laser | 0,0001 | Very small samples |
| Gas film | Any | Radiative | Up to 30 | Limited temperature |

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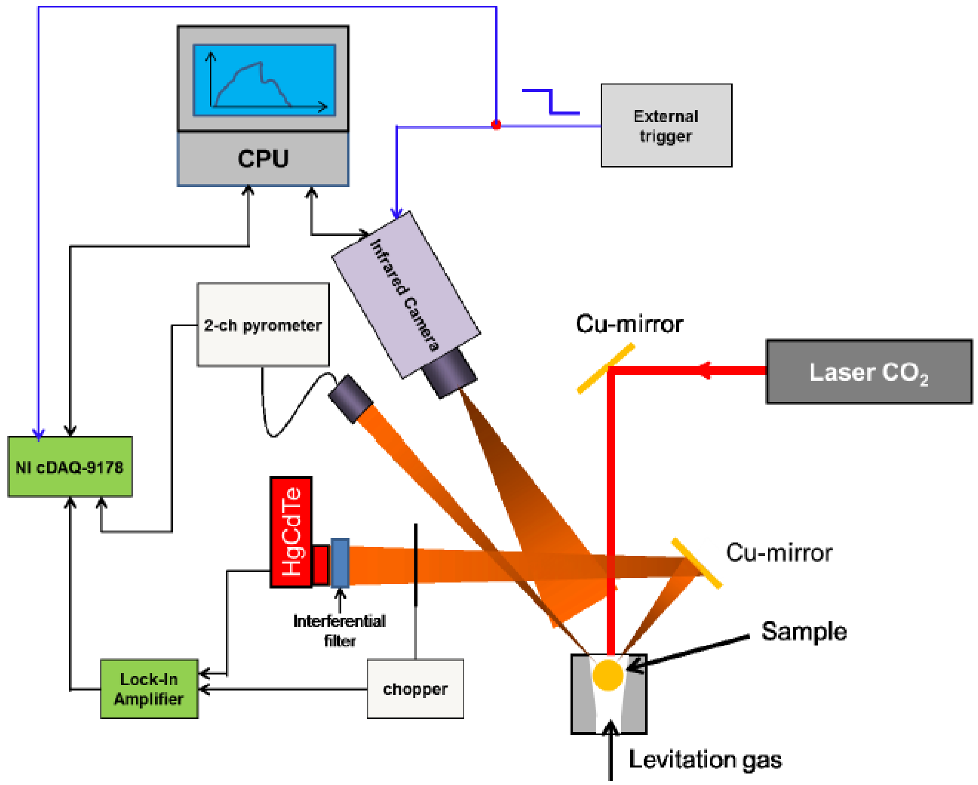
# ATTILHA EXPERIMENTAL SETUP




**A**dvanced **T**emperature and **T**hermodynamic **I**nvestigation by **L**aser **H**eating **A**pproach

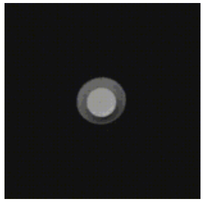
Spherical sample heated by laser up to 3200 K.

**Pyrometer** for temperature

**Infrared Camera** for position and volume

Oscillations :

- **Surface Tension**
- **Viscosity**

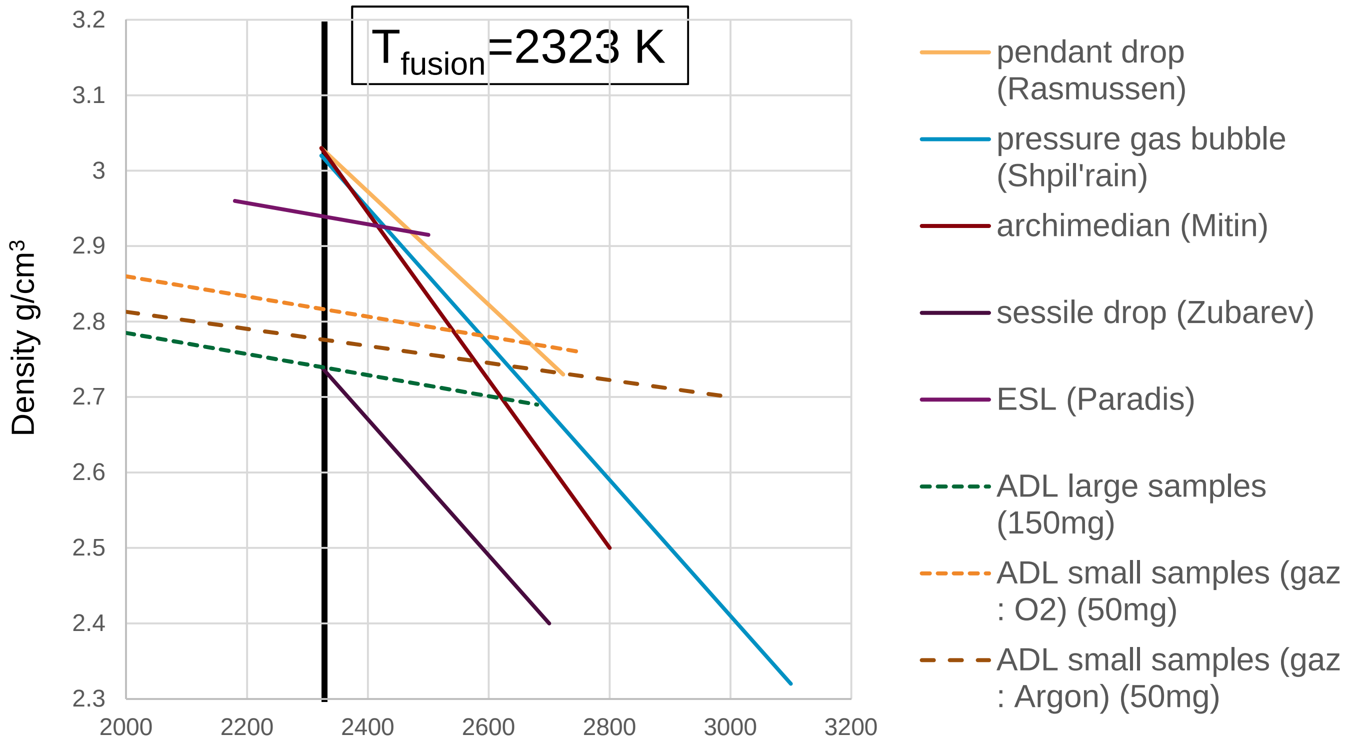


- Laser cut off :

- **Density as function of temperature**
- **Specific Heat Capacity**

Aerodynamic levitation : access to undercooled liquids – very large temperature range

# EVALUATION OF LIQUID ALUMINA DENSITY AS A FUNCTION OF TEMPERATURE –QUICK REVIEW

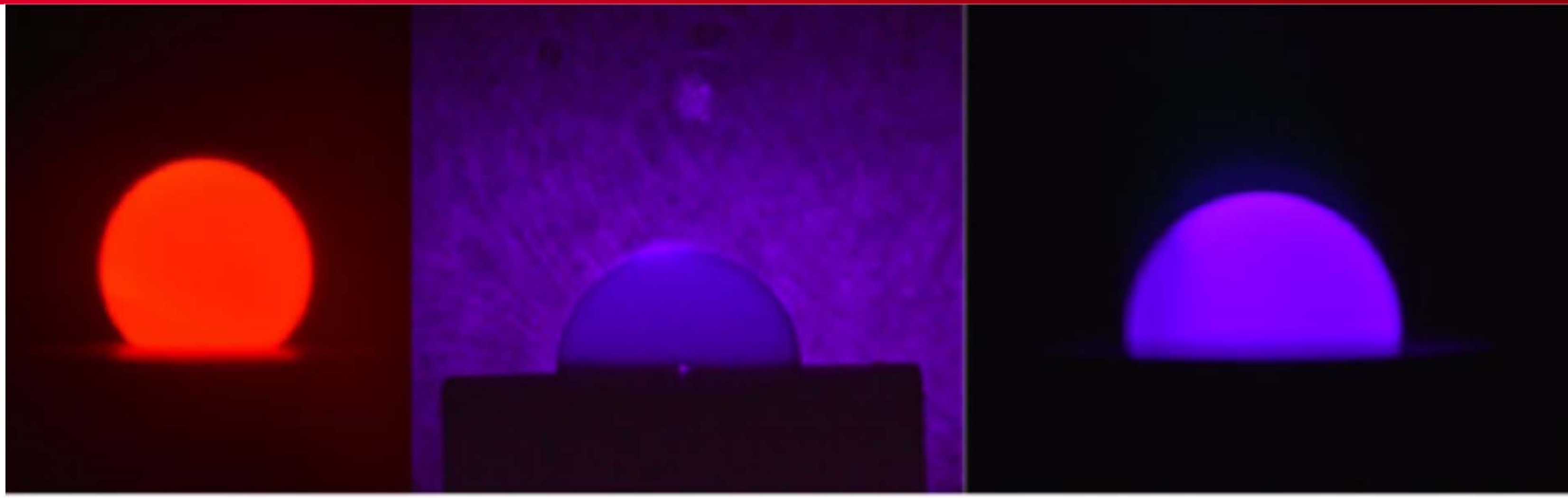


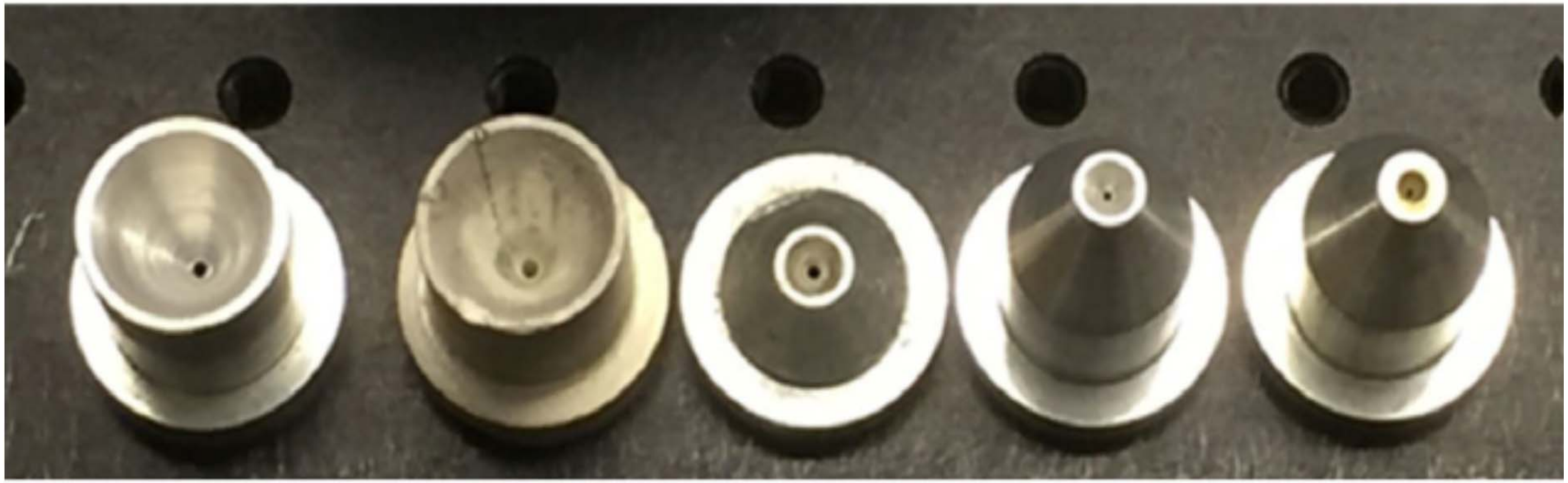

Apparent **Chemical contamination** for container based technics (pendant drop, archimedian, pressure bubble)

Similar **trends** for containerless (levitation) technics (ESL and ADL)

But **ADL** give **lower values** at fusion point, dependent of sample size and levitation gas type !

# SIDE VIEW OF MOLTEN OXIDES LEVITATION AND TYPICAL NOOZLES*





Density currently evaluated assuming **spherical shape**

* : C.J. Benmore and Weber aerodynamic levitation ,supercooled liquid and glass formation, advances in physics X, 2:3 737-736.

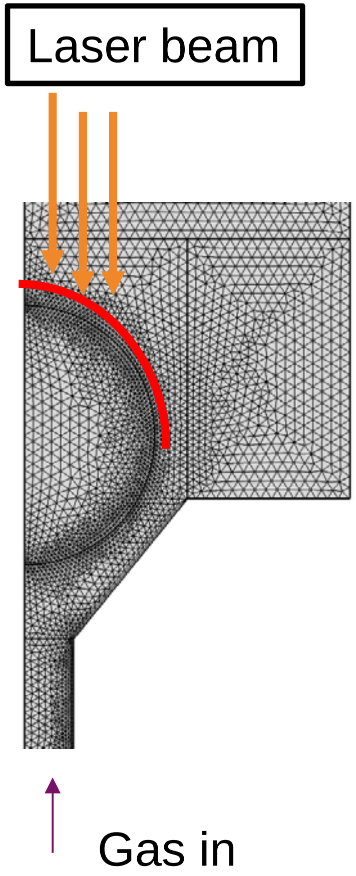
# QUESTION :

Is the liquid levitated sample really spheric ?

Lets have a look using ….

Comsol® Multiphysics

# COMPUTATIONAL METHODOLOGY 1/2




Challenges :

- Temperature gradient (**1000 K / 10 µm**) close to LG interface
- Sample position in noozle: major impact on gas flow
- Strong Marangoni effect due to temperature gradient (200K) inside sample before laser cut-off

Software :

**Heat + Microfluidic Comsol® modules + moving mesh ALE**

(first order Winslow smoothing for LG interface temporal evolution)

# COMPUTATIONAL METHODOLOGY 2/2

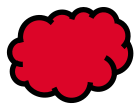
Convergence strategy :

Preliminary thermomechanical solution :
**Undeformable** spherical sample – **no gravity** – **ramping** viscosity

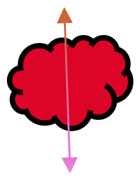
Controlled temporal iteration until stationary solution :

Balance internal and external forces at LG interface

$\delta T$ = 1 e-08 s   $\Delta T$ = 1.e-04 s



Vertical stabilization of sample

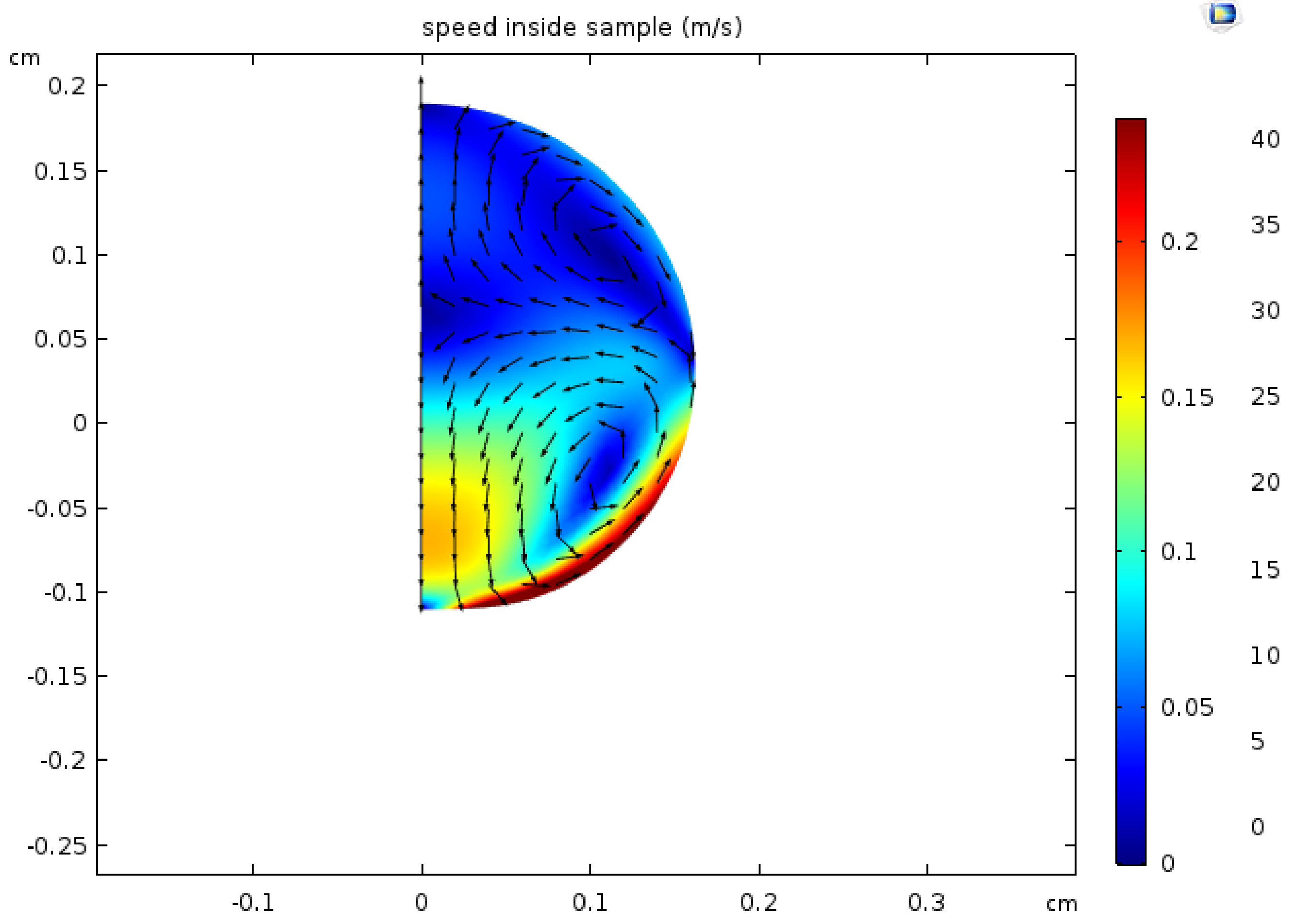


$\delta T$ = 1 e-05 s   $\Delta T$ = 1.e-02 s

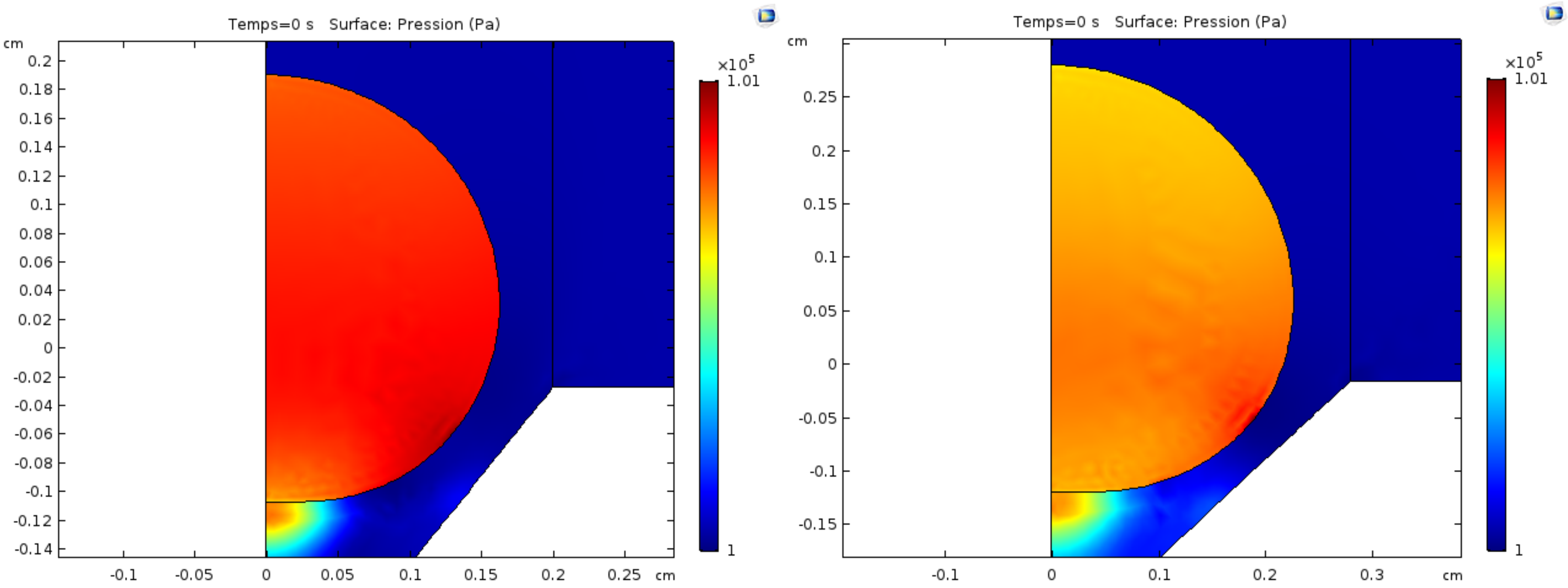
Convergence of internal liquid flow

$\delta T$ = 0,001 s   $\Delta T$ = 2 s

# FLUID VELOCITY RESULTS



# IS THE SAMPLE SPHERICAL ? COMSOL ANSWER:



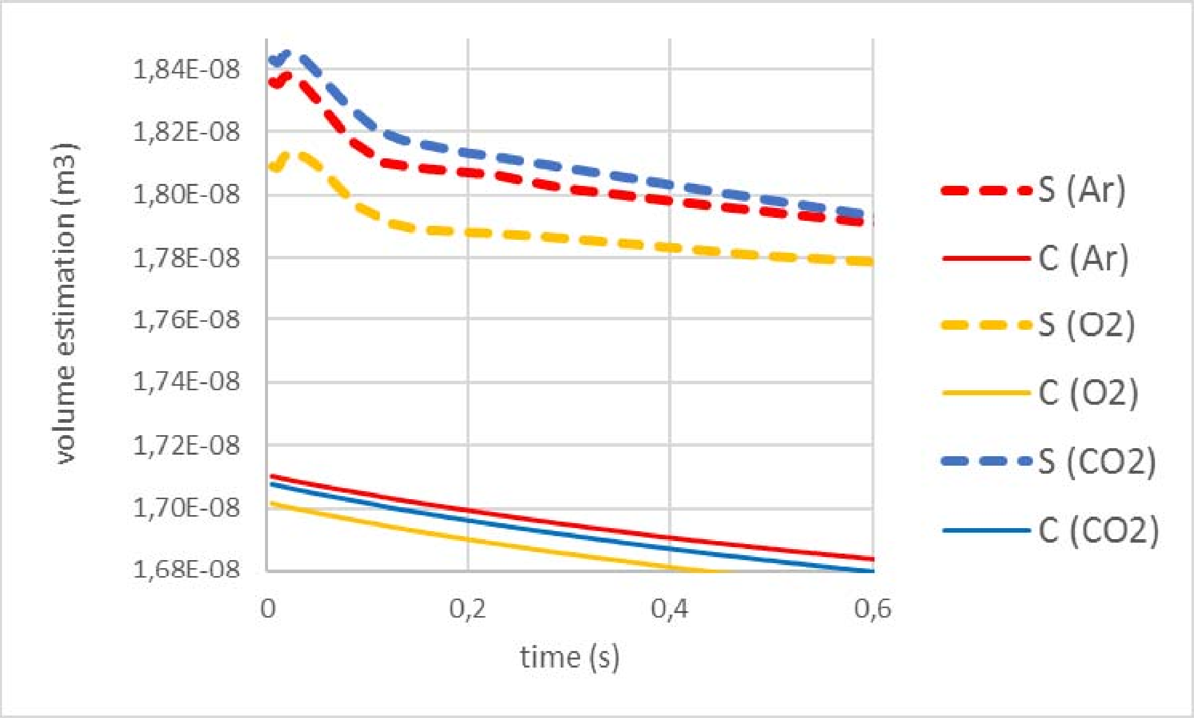

50 mg alumina

130 mg alumina

The **TOP** of the sample remains **spherical**

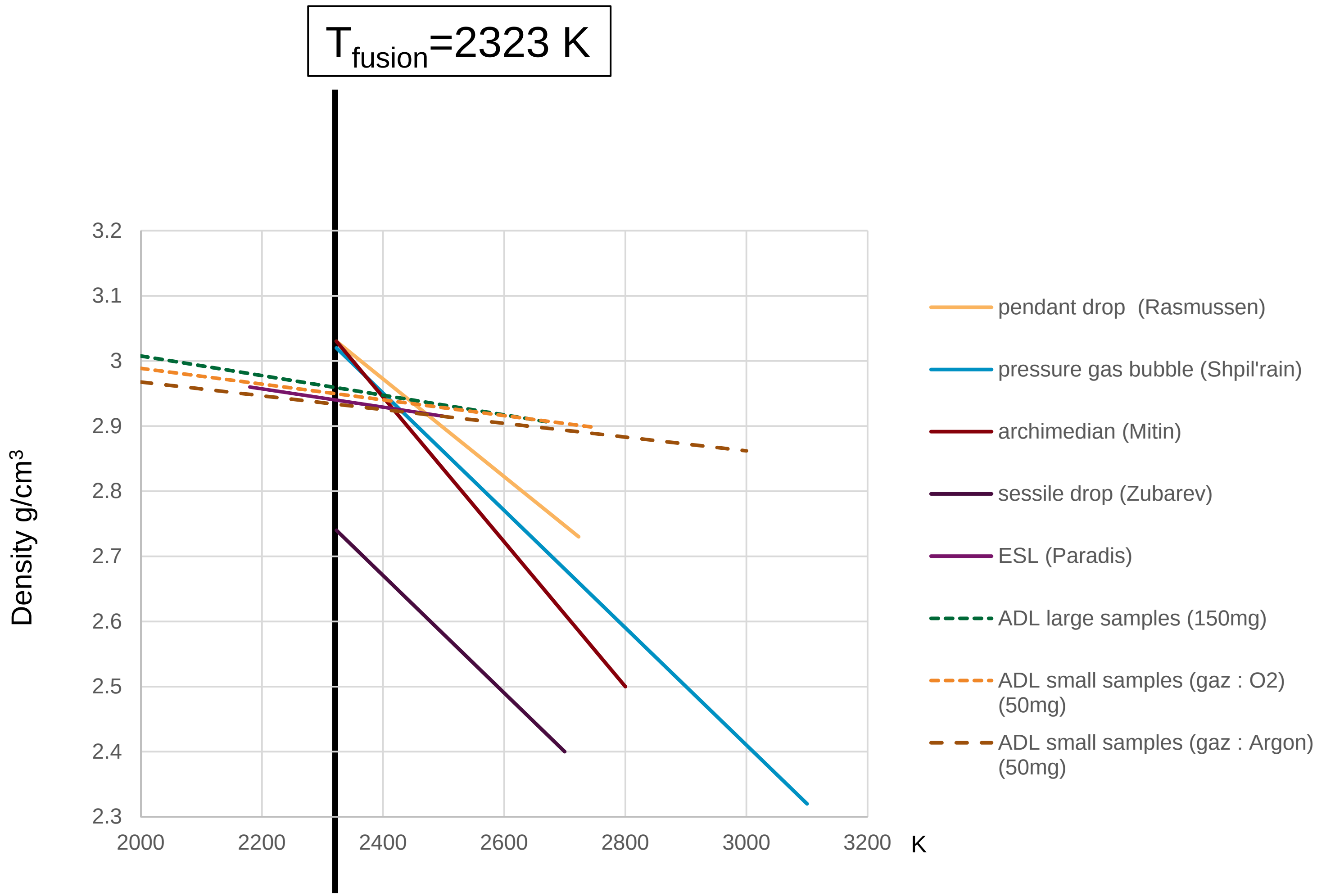
The **BOTTOM** get more and more deformed as its size increases

# VOLUME ESTIMATION AFTER LASER CUT-OFF FOR VARIOUS LEVITATION GAS




S : assuming spherical approximation
C : volume calculated by Comsol

# DENSITY ESTIMATION WITH CORRECTED VOLUME



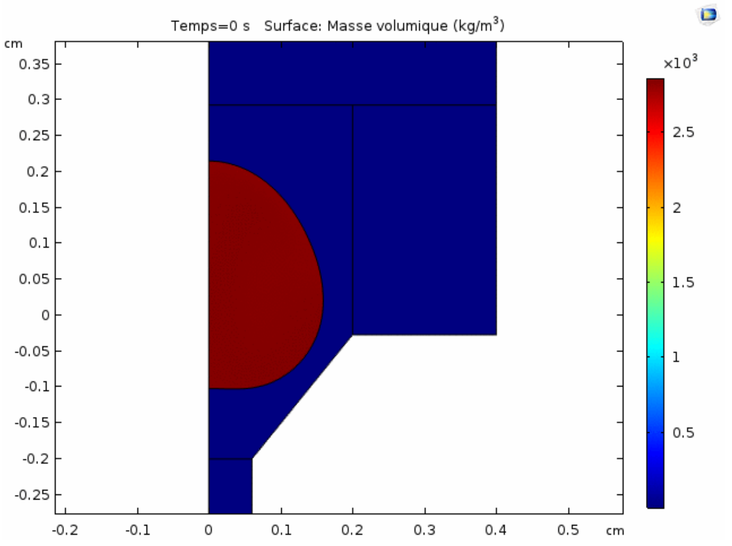

Levitation technics give now similar results.
Difference at fusion probably due to recalescence of the sample

# CONCLUSION :

Using Comsol® multiphysics it seems possible to adjust the **density evaluation** of aerodynamic levitation

On going work on other thermodynamical data :

- **heat capacity**
- **viscosity**
- **surface tension**



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# Thank you for your attention !

# Questions and comments are welcome !

SL1

# CURRENT HEAT CAPACITY AND TEMPERATURE EVALUATION HYPOTHESIS

Main hypothesis (similar to other levitation technics) **only radiative decay after laser cut-off**:

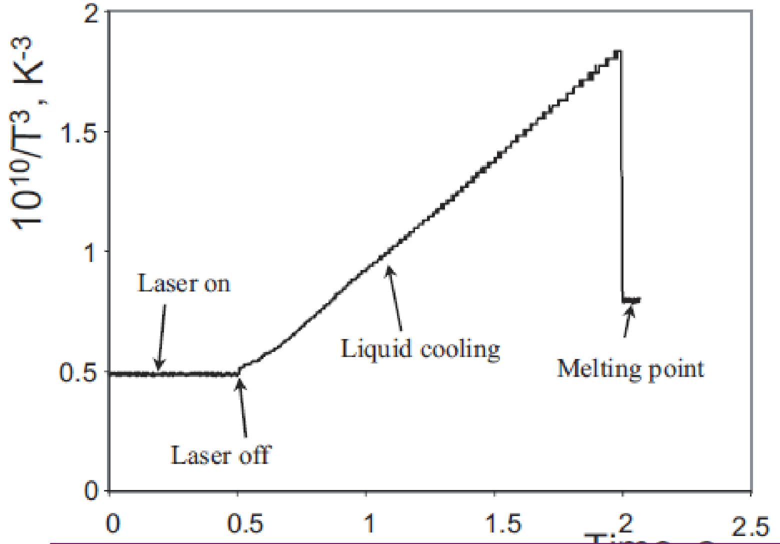
$$\frac{\mathrm{d}Q_R}{\mathrm{d}t} = \varepsilon k_B S(T^4 - T_0^4) \cong \varepsilon k_B S T^4 \qquad (1)$$

Energy balance on sample

$$mC_p \mathrm{d}T + \mathrm{d}Q_R = 0 \qquad (2)$$

$$\frac{\mathrm{d}T}{\mathrm{d}t} = -\frac{\varepsilon k_B S T^4}{mC_p}$$

$$\frac{C_p}{\varepsilon} = -\frac{k_B S d(\frac{1}{T^3})/dt}{m}$$




Apparently true but not proven …

$Q_R$ radiative heat
$t$ time
ε hemispherical total emissivity
$k_B$ Stefan Boltzmann constant
$S$ surface
$T$ sample temperature
$T_0$ ambient temperature
$m$ sample mass
$C_p$ specific heat capacity

**Folie 15**

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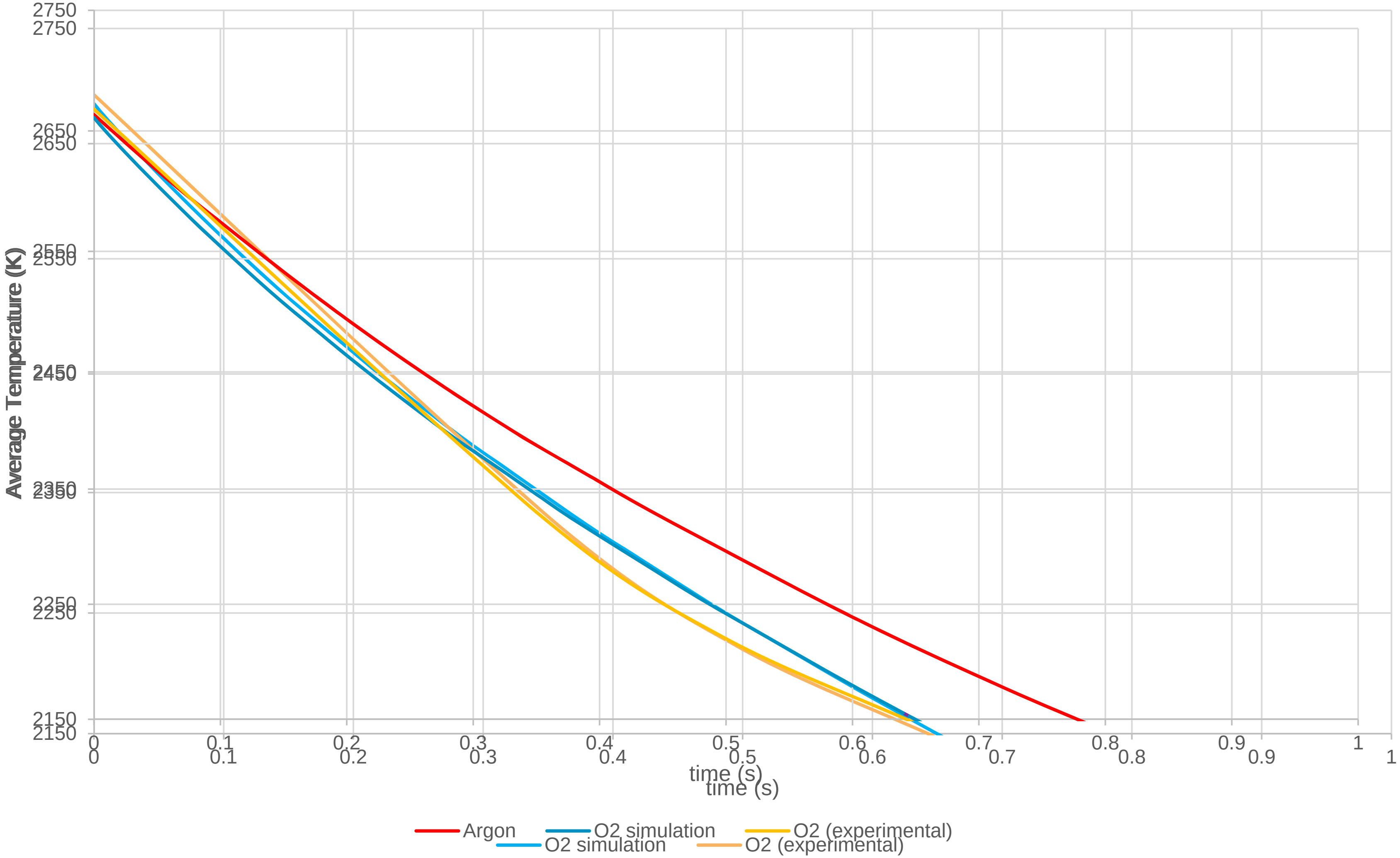
**SL1** SOLDI Luca; 16.02.2017

# INFLUENCE OF LEVITATION GAS ON TEMPERATURE DECAY




Decay is not purely radiative and depends on gas conductivity

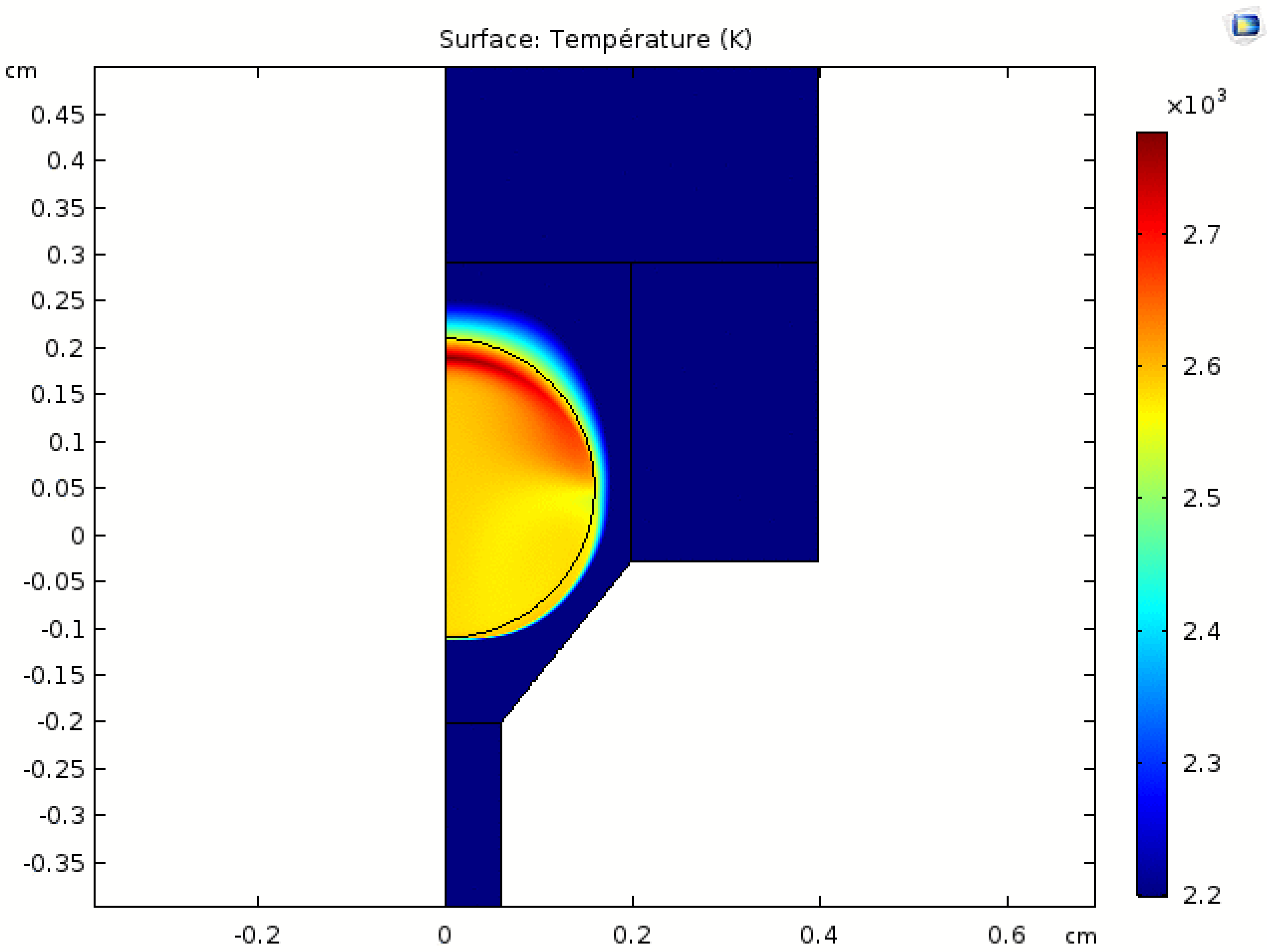
# THERMODYNAMIC DATA AT DIFFERENT TEMPERATURES

| T=300 K | Air | Xenon | Oxygen | Argon | Helium |
|---|---|---|---|---|---|
| Conductivity (W/mK) | 0,026 | 0,0055 | 0,026 | 0,018 | 0,152 |
| Viscosity ($10^{-5}$ Pas) | 1,82 | 2,2 | 1,95 | 2,1 | 0,88 |

| T=3000 K | Air | Oxygen | Argon |
|---|---|---|---|
| Conductivity (W/mK) (e) | 0,383 | 0,802 | 0,09 |
| Viscosity ($10^{-5}$ Pas) (e) | 8,58 | 9,49 | 10 |

Hypothesis : air /oxygen at thermal equilibrium

# TEMPERATURE EVOLUTION AFTER LASER CUT-OFF




Temperature get homogeneised in a few ms