TEMPUS – A microgravity electromagnetic levitation facility for parabolic flights

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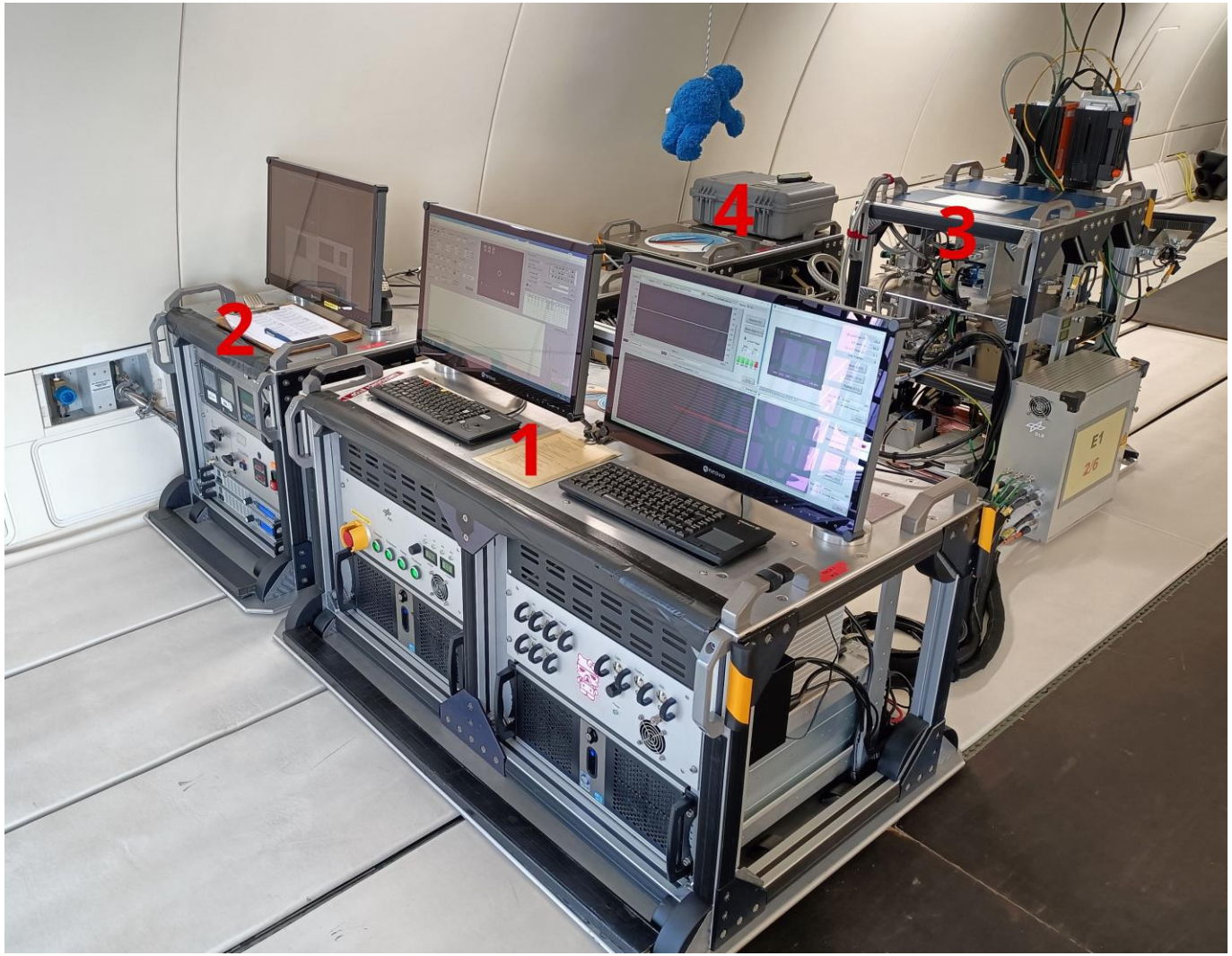
DLR

TEMPUS in A310 parabolic flight aircraft



1. **“Control-rack”**
   - Experiment control PC
   - Data acquisition PC

2. **“Generator-rack”**
   - Power supply
   - RF generator
   - Gas, vacuum controller
   - Sample transfer control

3. **“Experiment-rack”**
   - Experiment chamber
   - Measurement devices

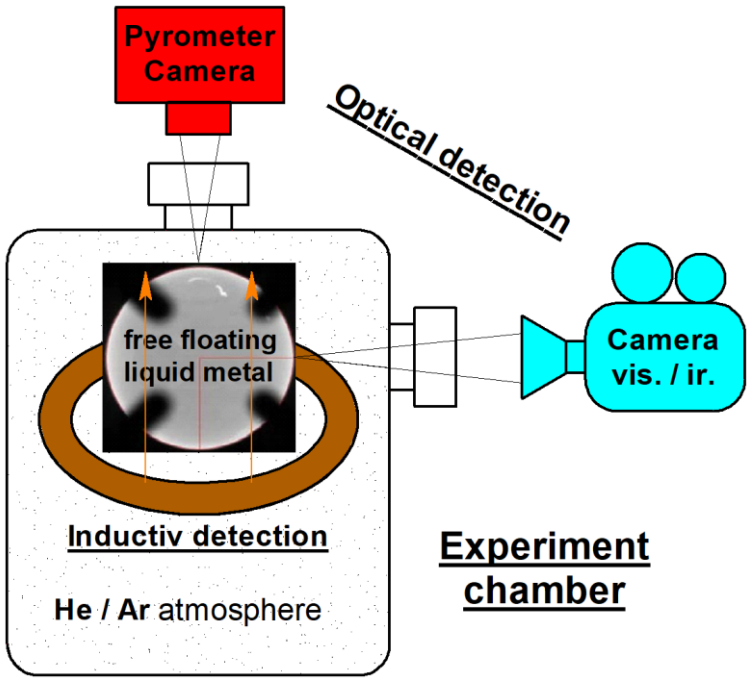
4. **“Supply-rack”**
   - Gas bottles
   - Cooling system

Purpose of TEMPUS

Non-invasive processing of high temperature **liquid** **metals** and **semiconductors**

TEMPUS provides:

- **Containerless handling** of **spherical** droplets
- **Contactless** measurement methods
- **Clean** experimental environment (He / Ar)



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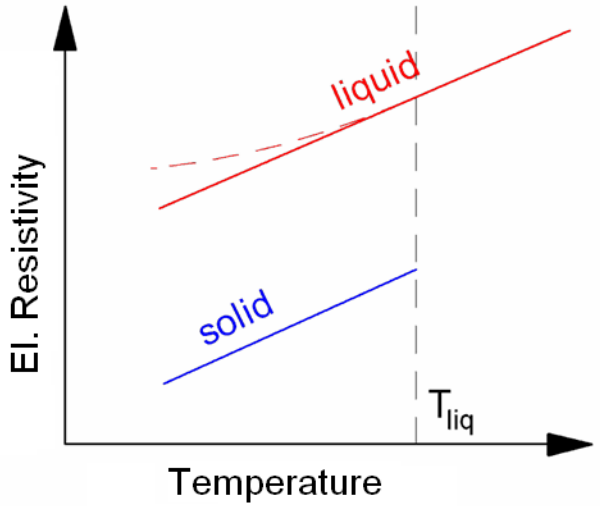
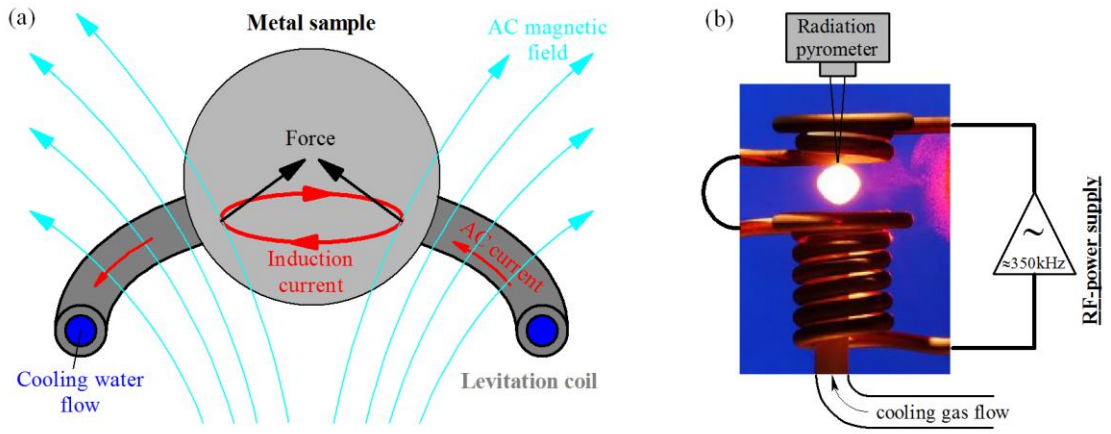
Benefit

- **Minimal** external **impact** on liquid
- **No** external **nucleation** triggered solidification
  - ⇒ **Undercooled** temp.-range accessible
    - ⇒ **Enlarged** temperature-range
    - ⇒ **Structure formation** in liquids



Containerless handling and **melting** of metallic liquids by **“Electromagnetic Levitation”**

On ground



Principle

Hf-magnetic field ⇒ Induction of **eddy currents**

⇒ **Lorentz force** $\propto -\mathbf{B}\cdot\nabla\mathbf{B}$

⇒ **Ohmic heating** $\propto B^2$

Problem (strong levitation force)

⇒ **Deformed** droplet shape

⇒ **Strong** fluid flows

⇒ **Poor** heat control

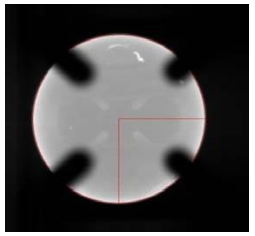
Under weightlessness (TEMPUS)

Advantage (weak levitation force)

⇒ **Well def. spherical** droplet shape

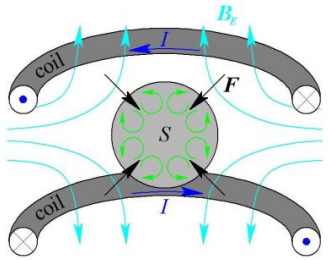
⇒ **Weak** fluid flow

⇒ **Independent** heat control



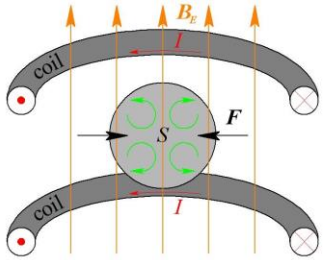
Principle

2 separate superposed HF magnetic fields



Quadrupole field

- **Strong** pos. force $\propto -\mathbf{B}\cdot\nabla\mathbf{B}$
- **Weak** heating power $\propto B^2$



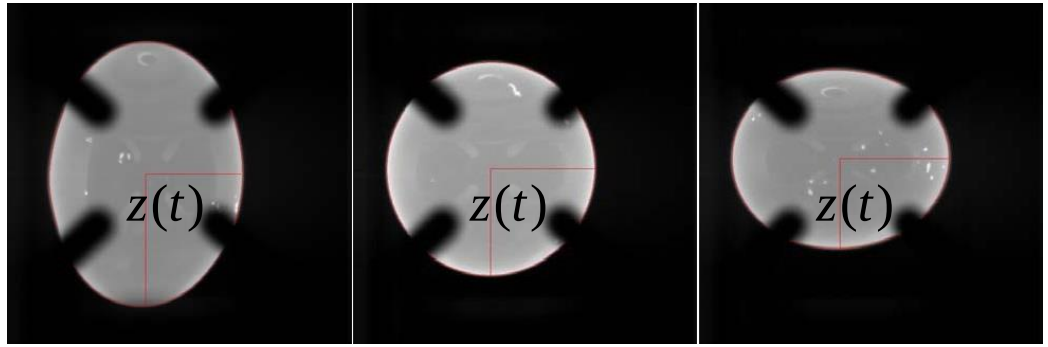
Heating field

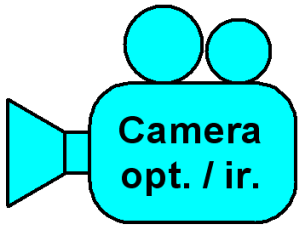
- **Weak** pos. force $\propto -\mathbf{B}\cdot\nabla\mathbf{B}$
- **Strong** heat. power $\propto B^2$

Noninvasive experimental methods

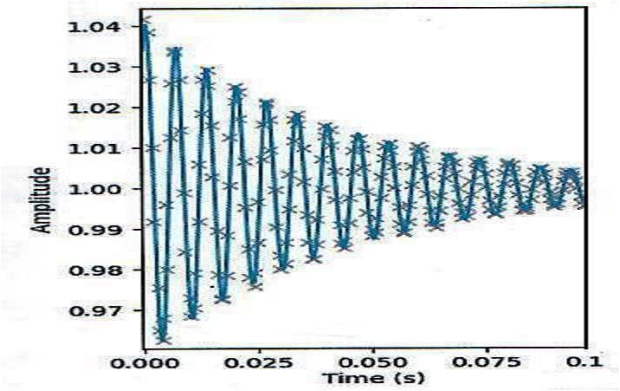
A. Measurement of surface tension and viscosity

1. Excitation of droplet oscillations





2. Contactless edge detection (optical, inductive)



Fit with:

$$z(t) = R + \Delta z_0 \cos(\omega t) e^{-t/\tau}$$

$\Rightarrow$ damping time: τ

$\Rightarrow$ frequency: ω

3. Evaluation:

$$\eta = \frac{\rho_M R^2}{5} \frac{1}{\tau}$$

Lamb equation

η: viscosity; τ: damping time

$$\gamma = \frac{\rho_M R^3}{8} \omega^2$$

Rayleigh equation

γ: surface tension; ω: frequency

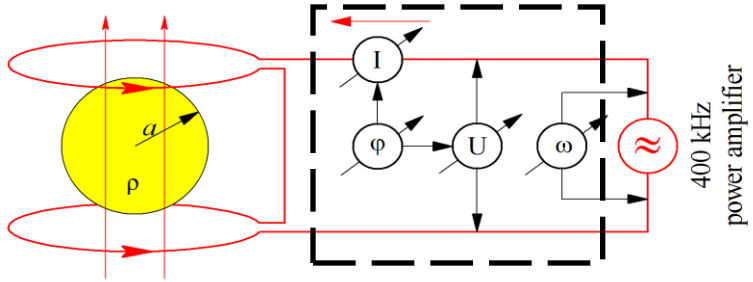
Conditions

- **Spherical droplet**
- **Negligible fluid flow**

< satisfied in TEMPUS **>**

B. Inductive measurement method

Induct. Meas. of drop **impedance**



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Conditions

- **Spherical** droplet
- **Homog.** mag. field

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Sample properties

$\rho(T)$: **Electrical resistivity**

$a(T)$: **Radius (density)**

C. Detection and modeling of rapid solidification

Condition

- **Containerless** processing
- **High speed** camera

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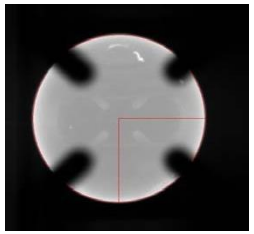
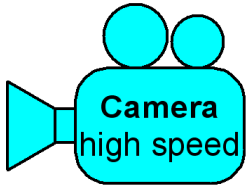
Undercooled drop





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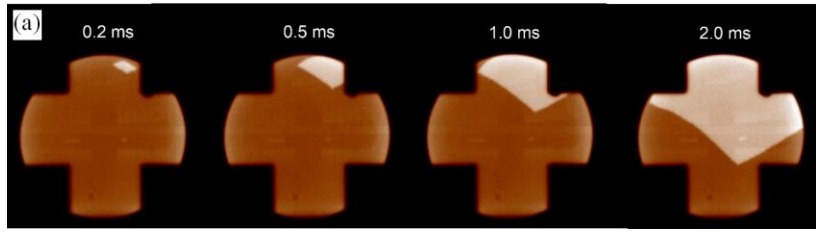
Solidification front at **30.000 frames/s**



Condition

- **Spherical** droplet

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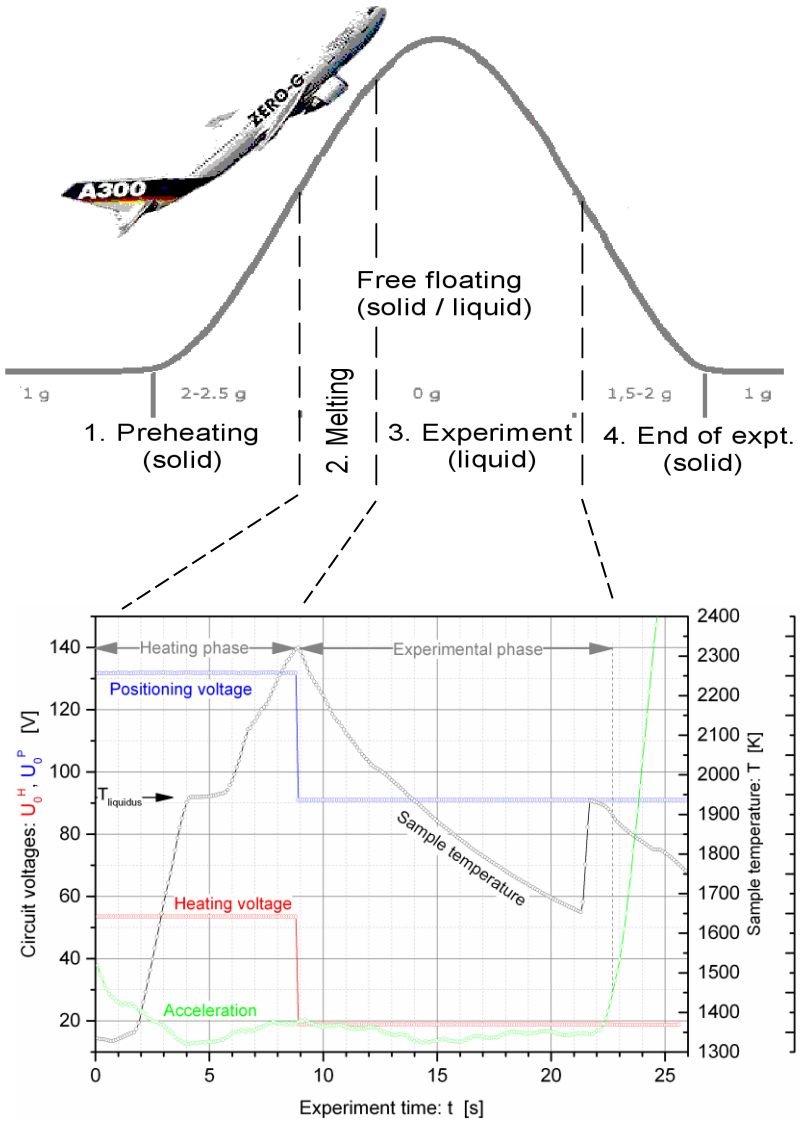
Modeled front

Experiment sequence



Temp.-Time diagram

1. **Preheating phase** (Start of sequence, ~1.8g)
   - **Solid** sample on pedestal
   - **heated** just below melting temperature
   - in **Ar atmosphere** (poor heat conducting)

2. **Heating phase** (Beginning of parabola, ~10^{-2}g, ~8sec)
   - **Sample transfer** to magnetic levitation field
   - Start of auto. **process control** and **data acquisition**
   - Heating, **melting**, overheating (strong fields)

3. **Experimental phase** (Parabola, ~10^{-2}g, ~14sec)
   - **Reduction** of **magnetic** fields to min. level
     ⇒ **Low** external **impact** on liquid sample
   - **Experiment** on cooling **liquid sample**
   - Exchange: **Ar** → **He** (to boost the cooling)

4. **End** of experiment (End of sequence, 1.8g)
   - **Solidified** sample on pedestal
   - Stop of **process control** and **data acquisition**
   - Exchange: **He** → **Ar**

Parabolic flight issues

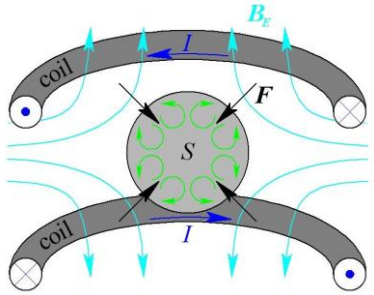
- **Parabolic flights** (with TEMPUS on board) are **operated** by **Novespace** from airport **Bordeaux**
- There is typically **1 TEMPUS parabolic flight campaign** of **3 flight days** each year
- Each **TEMPUS campaign** comprises **12 – 15 experiments** with **15 - 20 samples**
- **Interested scientists (PI)** can apply with an **experiment** at:
  - ESA
  - DLR, Space Administration,
  - Institute for Frontier Materials in Space, DLR
    Mitja.Beckers@dlr.de

- If selected there is an extensive **experiment preparation program** together with the **PI**
  - **Result: Experiment control file** (temperature ranges, instrument settings, etc.)
  - **Readjustment during the flight** by the PI and the TEMPUS operators

Summary

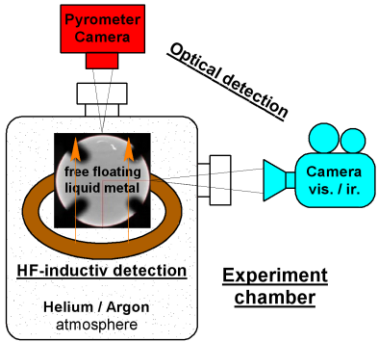
TEMPUS odds

- **Free floating** (levitated) **spherical** metal droplet
- **Contactless** measurement methods
- **Clean** experimental environment (He / Ar)



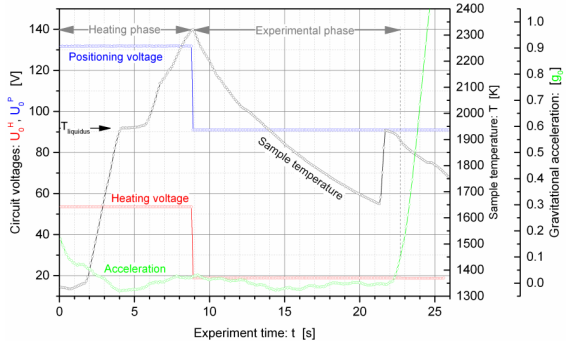
Noninvasive experimental methods

- **Optical:** Meas. of temperature, surface tension, viscosity
- **Inductive:** Meas. of el. resistivity, thermal expansion (density)
- **High speed video:** Detection of rapid solidification



TEMPUS drawbacks

- **Short** eff. experiment time: ~14sec
- Residual **accelerations:** $>10^{-2}$g



TEMPUS team

Thank you !