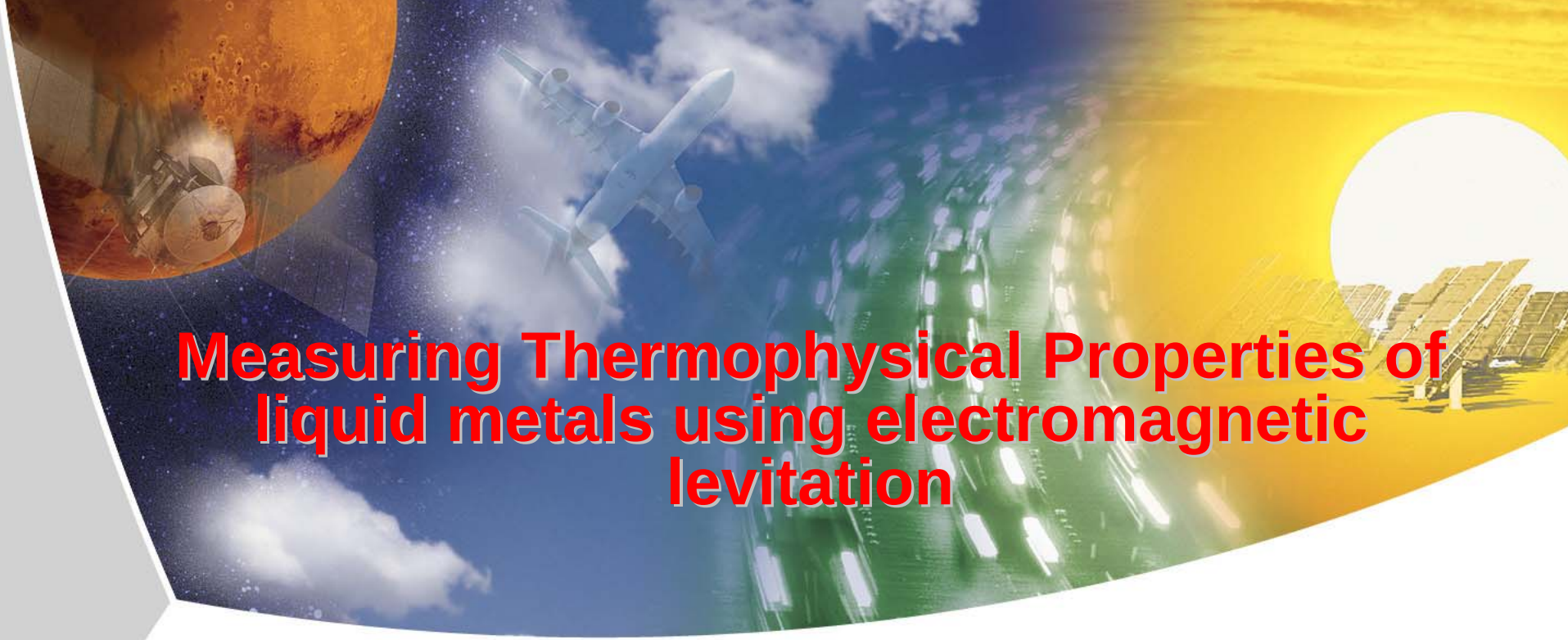


Measuring Thermophysical Properties of liquid metals using electromagnetic levitation

Iván Egry
Institut für Materialphysik im Weltraum

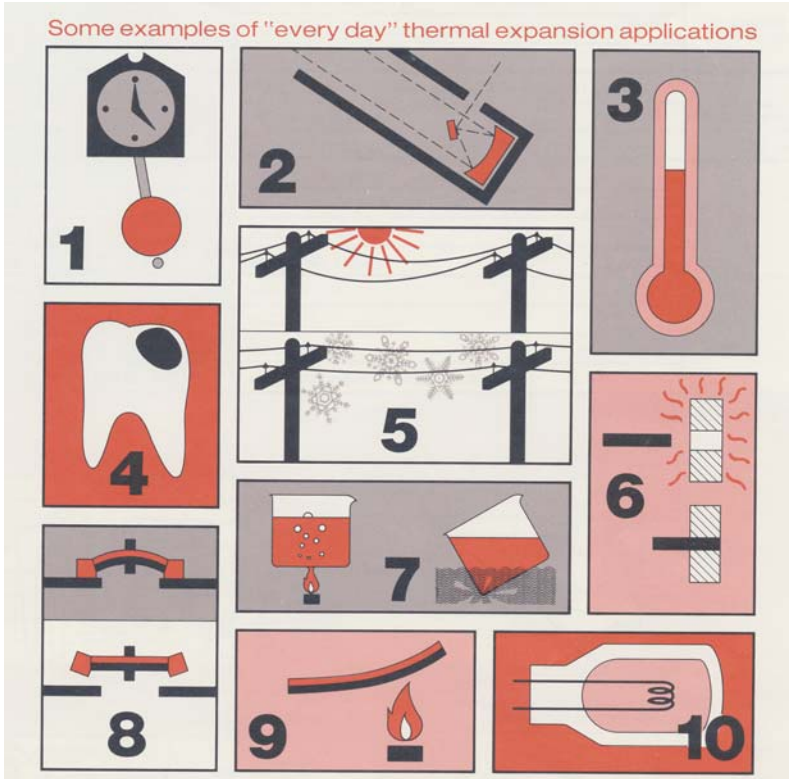
GTT Workshop

Herzogenrath, 5. 6. 2008

Deutsches Zentrum
DLR für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Outline

- **Introduction**
  - The Institute
  - Relevance
  - Materials
  - Microgravity
- **Electromagnetic Levitation**
- **Macroscopic Properties**
  - (Density)
  - Surface Tension
  - (Viscosity)
- **Summary**



Institut für Materialphysik im Weltraum
Institute for Materials Physics in Space

- **Tasks**
  - Utilisation of space environment for materials science (microgravity)
  - Investigation of materials for and from space (enabling technolgies, exploration)
  - Support to external users of space platforms
  - Complementary ground-based research on soft matter
    - Solidification (Herlach, Ratke)
    - Thermophysical properties (Egry)
    - Structure and Dynamics (Meyer)
    - Molecular Dynamics (Horbach)

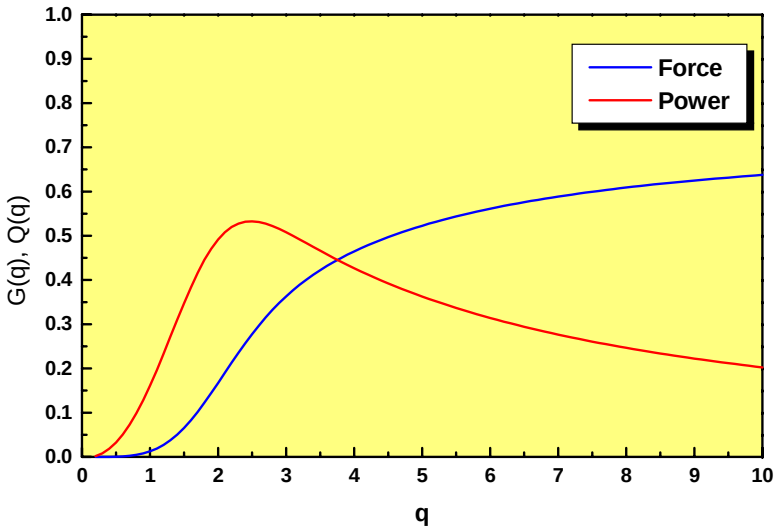
Materials

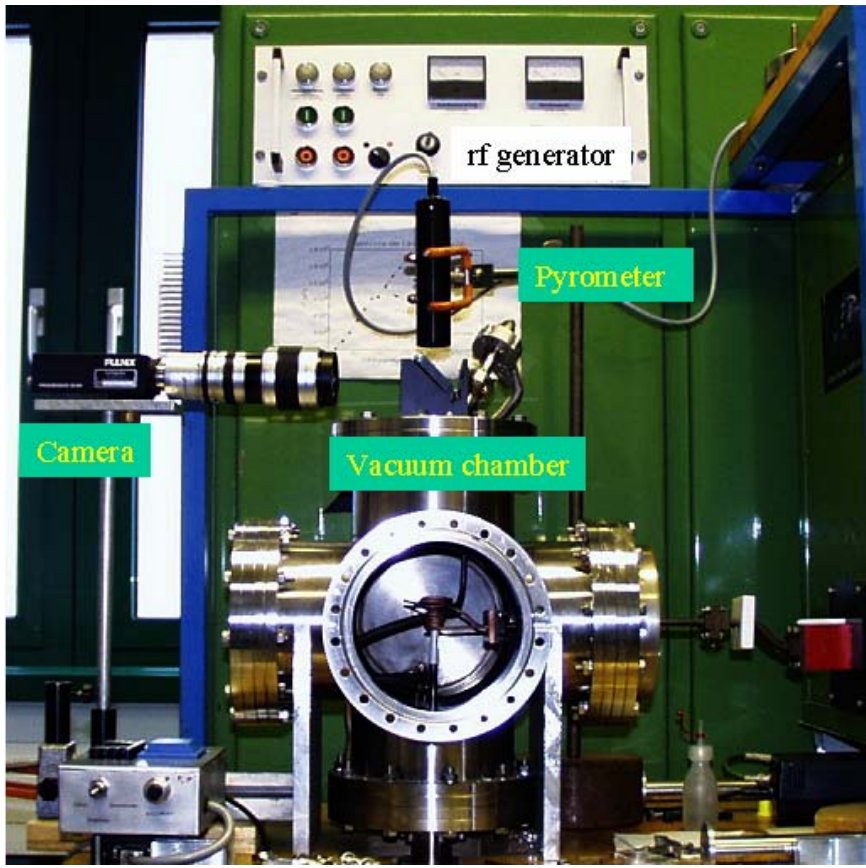
- **Academic interest**
  - Elemental melts:
    <u>benchmarks</u>
    Au, Ag, Cu, Fe, Ni, Co, ...
  - Alloys
    <u>Excess quantities</u>
    - (metastable) monotectics
      Cu-Co, Cu-Fe, Ag-Cu-Ni
    - Intermetallics
      Al-Ni

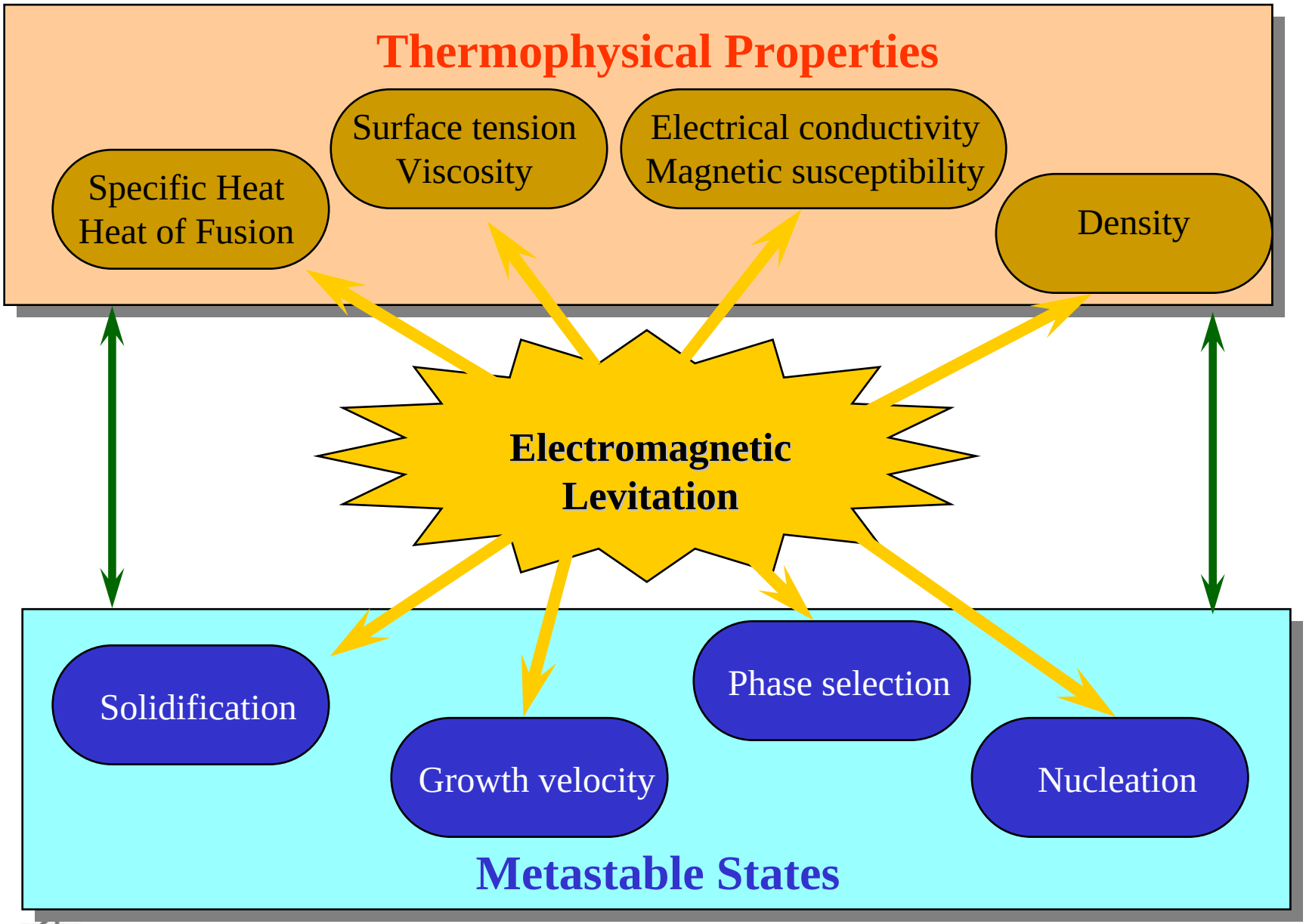
- **Industrial interest**
  - Lightweight alloys
    Al-Fe, Al-Ni, Al-Cu
  - Ni-based superalloys
    CMSX-4
    Rene N90
  - Ti-Aluminides
    Ti-Al-V, Ti-Al-Nb
    Ti-Al-Ta

Electromagnetic Levitation

- Containerless processing of metals
- Inert atmosphere (He, Ar)
- Small samples (1g)
- High temperatures (1000<T<2000 °C)
- Non-contact-diagnostics



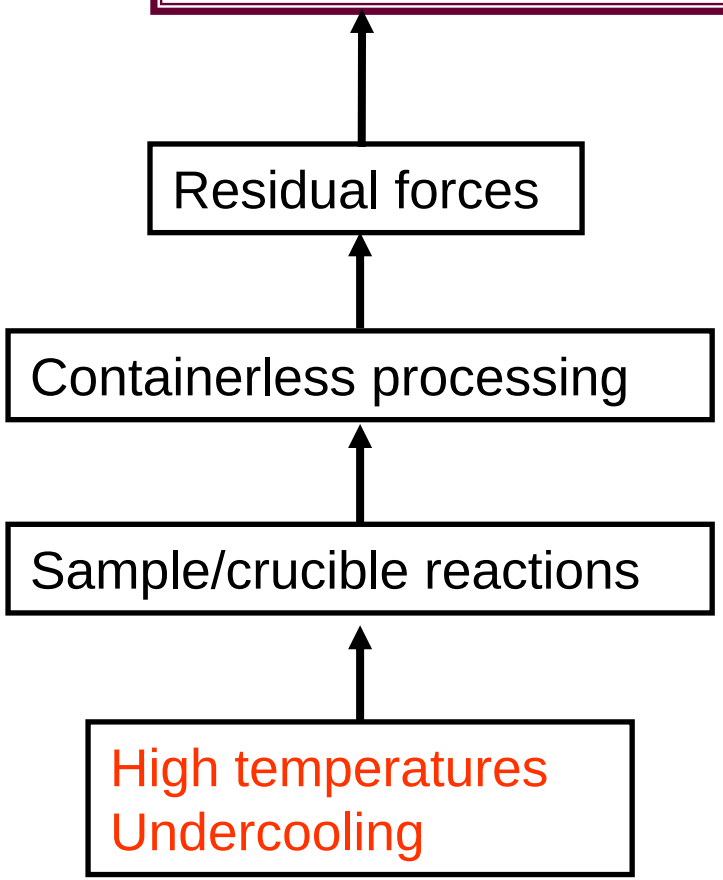



Thermophysical Properties
Specific Heat
Heat of Fusion
Surface tension
Viscosity
Electrical conductivity
Magnetic susceptibility
Density
Electromagnetic
Levitation
Solidification
Growth velocity
Phase selection
Nucleation
Metastable States

Microgravity

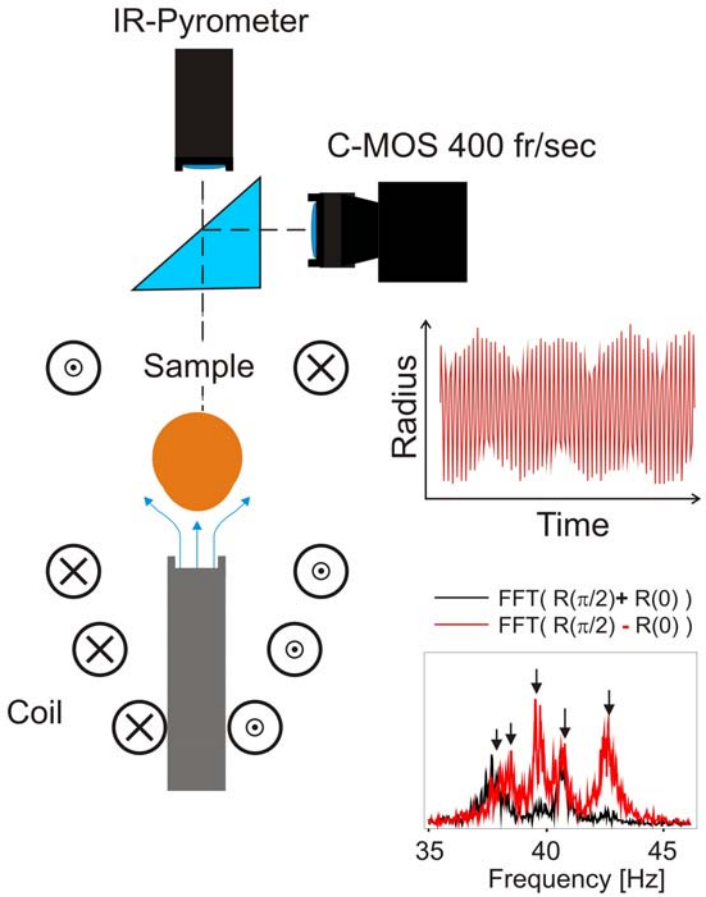
- **Advantages**
  - No convection
  - No buoyancy or sedimentation
  - Containerless processing
- **Opportunities**
  - Parabolic Flights
    Zero-g Airbus
  - Sounding Rockets
    TEXUS, MAXUS
  - ISS
    COLUMBUS

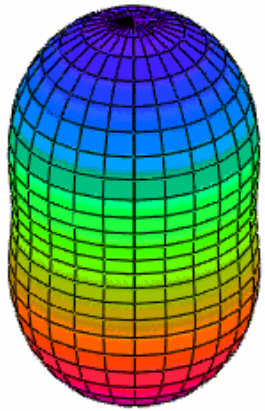
Electromagnetic Levitation in Microgravity

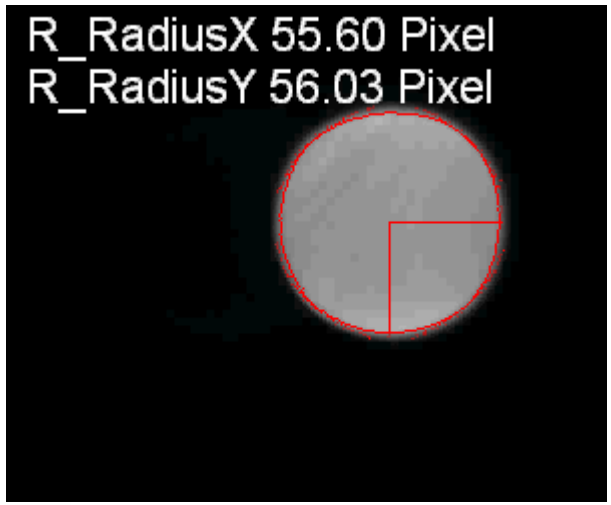


- additional properties (e.g. specific heat)
- new materials (e.g. vitralloys)
- extended temperature range (500°C - 2500°C)
- improved accuracy (100% - 1000%)

Surface Tension- Oscillating Drop







$$R(t) = R_0\left(1+\sum_n \varepsilon_n \cos(\omega_{2,n}\, t+\alpha)\right)$$

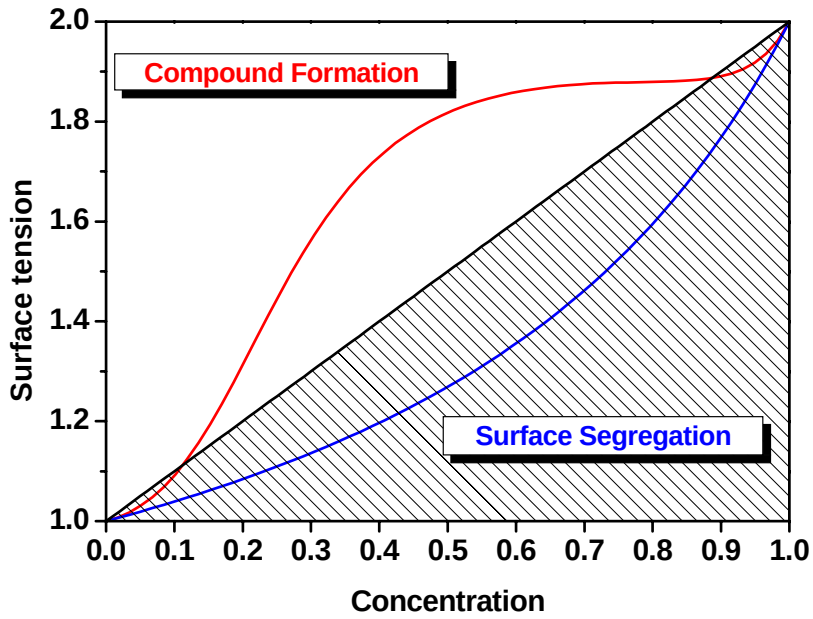
$$\frac{1}{5}\sum_n \omega_{2,n}^2 = \frac{32\pi}{3}\frac{\gamma}{M} + 1.9\,\overline{\Omega_{tr}^2} + 0.3\,(\overline{\Omega_{tr}^2})^{-4}(g/a)^2$$

Surface Tension - Results

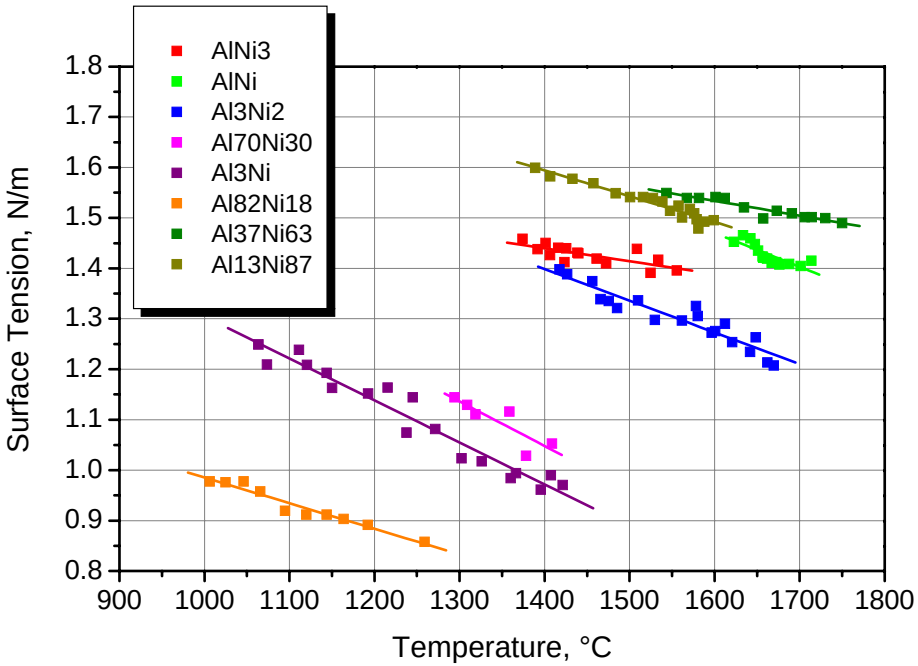
- Linear temperature dependence
  $\gamma(T) = \gamma_m + \gamma' (T - T_m)$
- Generally negative temperature coefficient $\gamma' < 0$
- Generally surface segregation
  $\gamma_{AB} < c_A\gamma_A + c_B\gamma_B$
- Link to thermodynamics via Butler equation

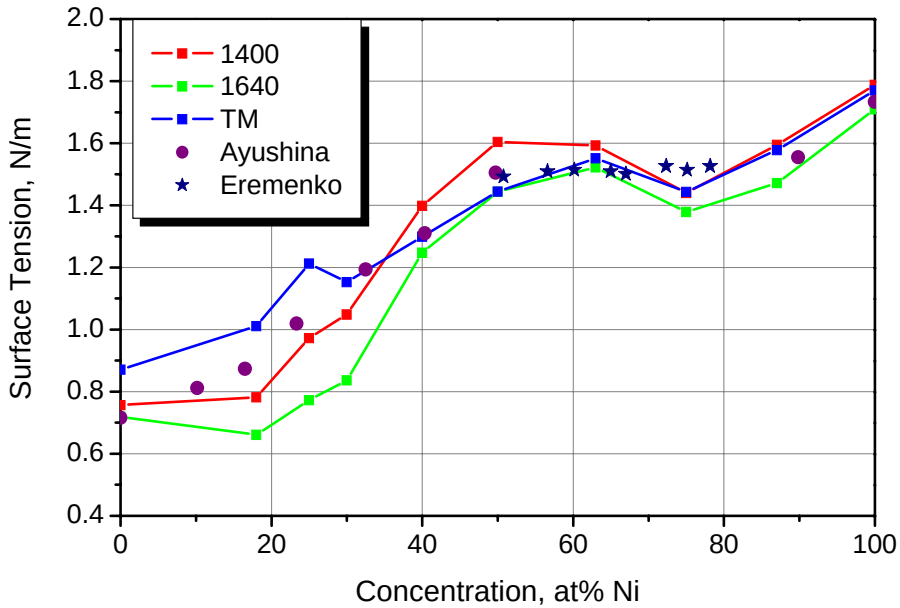
$$\gamma = \gamma_A + \frac{RT}{A_A}\ln\frac{c_A^S}{c_A} + \frac{\Delta G_A^E}{A_A}$$

$$= \gamma_B + \frac{RT}{A_B}\ln\frac{c_B^S}{c_B} + \frac{\Delta G_B^E}{A_B}$$

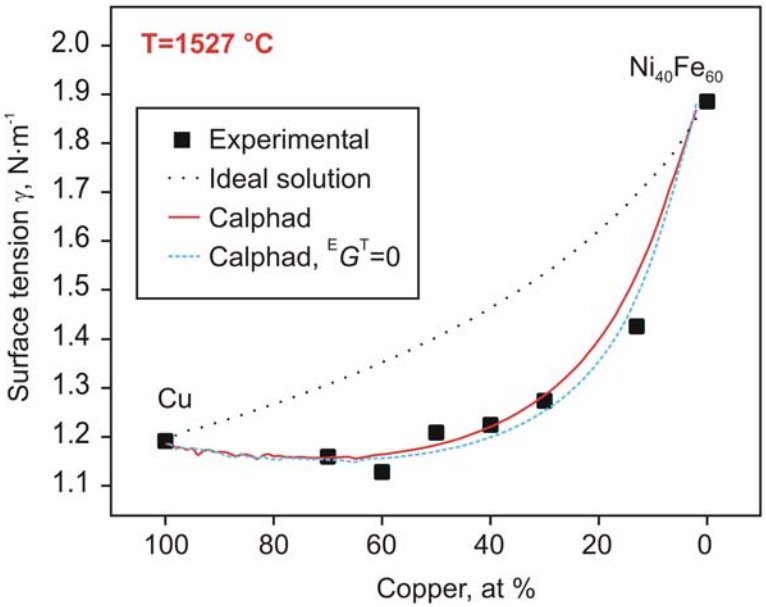


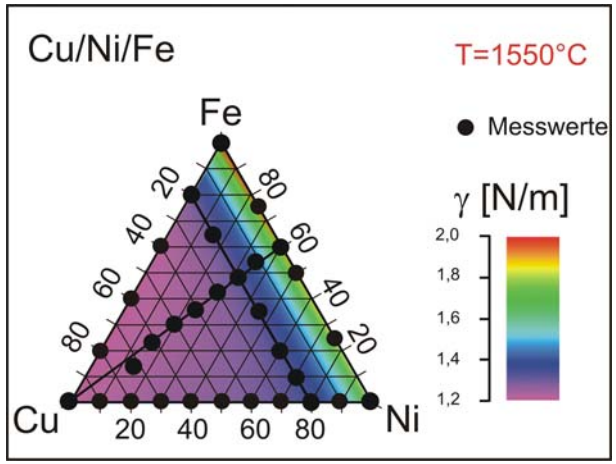
Surface Tension – Al-Ni

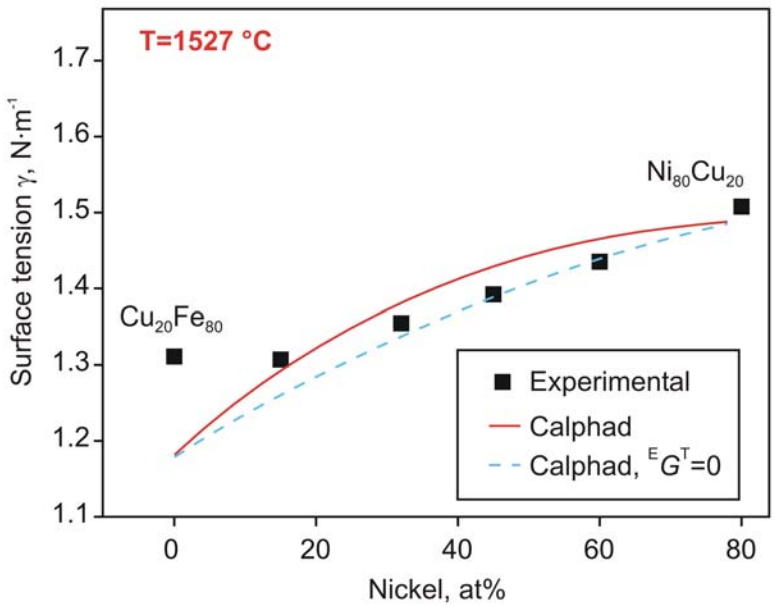




Surface Tension – Cu-Fe-Ni







Summary

- Structure and properties of (multicomponent) liquid metals are important quantities, but still not well understood
- Unique interdisciplinary research field
- Powerful tools available for their investigation (levitation, x-rays/neutrons, microgravity)
- Links between thermophysical properties, structure and thermodynamics need to be explored