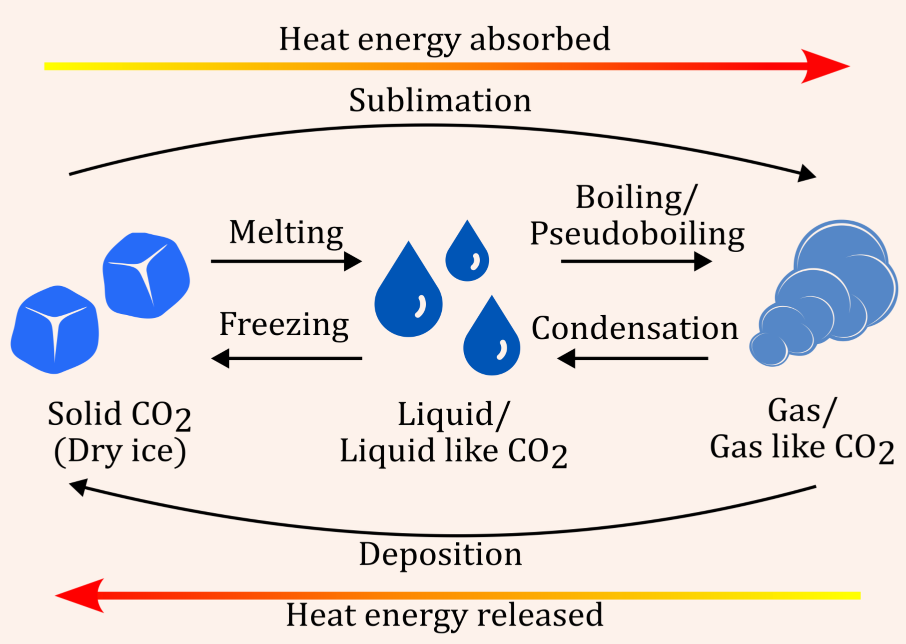
Investigating CO_2 Phase Change Phenomena

From Fundamental Physics to Engineering Applications



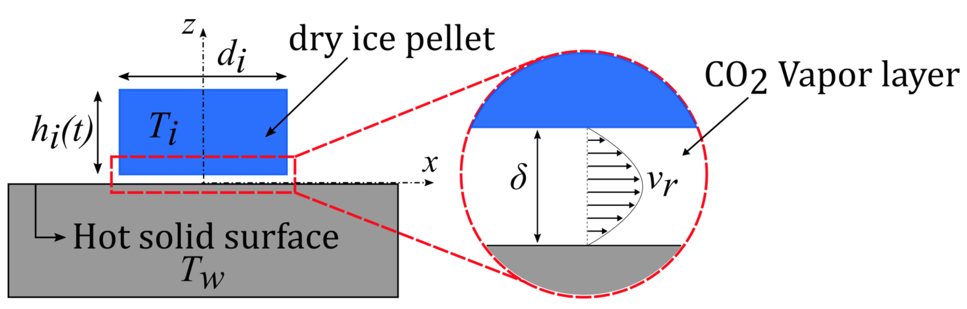
Importance of CO_2 phase transitions

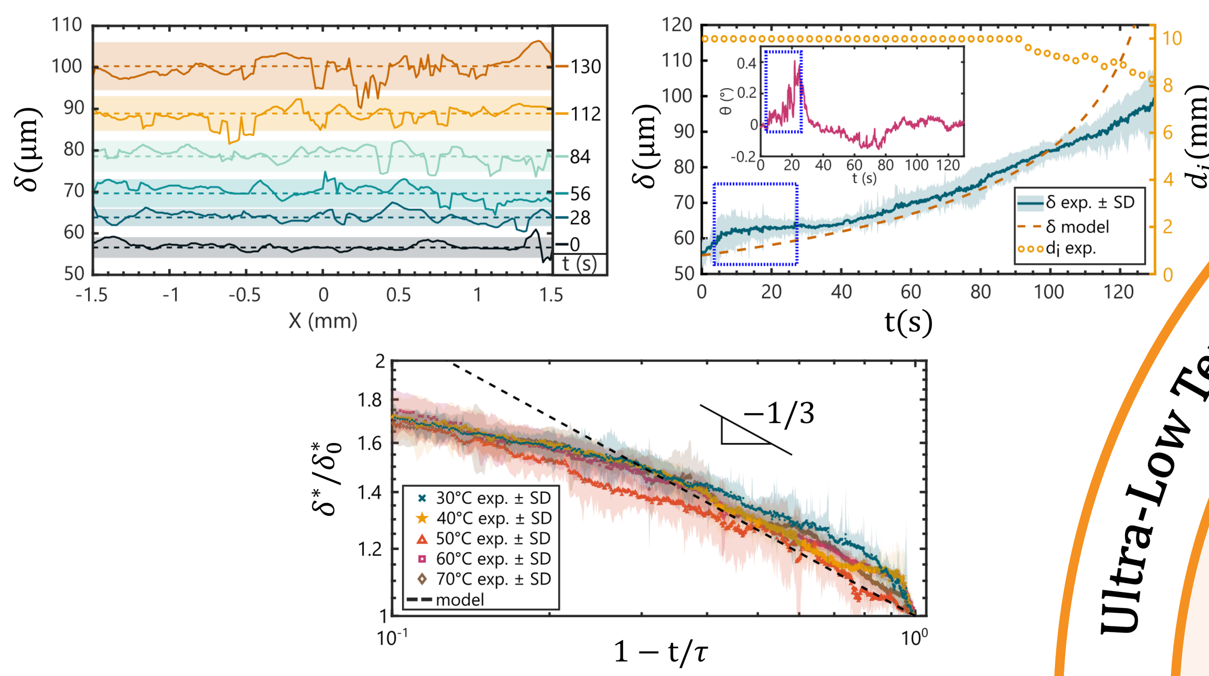
- **CO_2 as a natural working fluid :** Low GWP (1), non-toxic, non-flammable, and cost-effective.
- **Engineering relevance :** Sublimation, deposition, and (pseudo)boiling play key roles in cooling, storage, and power systems.
- **Importance :** High phase-change enthalpy and heat capacity enable efficient thermal management.
- **Research Focus :** Understanding heat and mass transport at phase interfaces for optimized CO_2-based thermal systems.

Sublimation ($p < 5$ bar; $T < -56$ °C)

- **Heat Transfer Investigation:** Analyzing interaction between solid CO_2 and hot solid surfaces (e.g. walls of evaporator) is crucial in quantifying cooling effect and designing efficient refrigeration system.

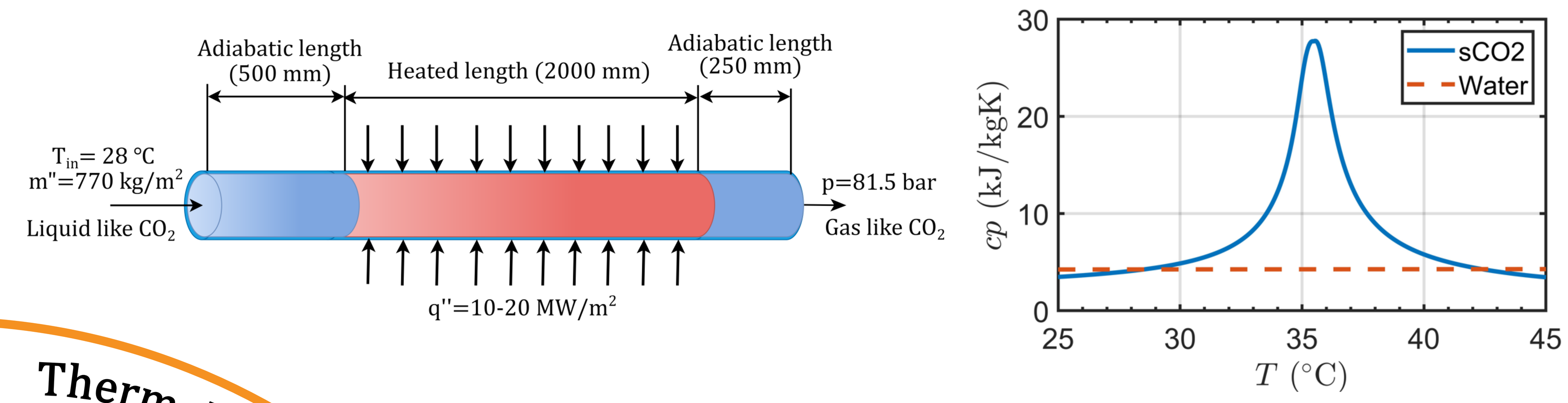
CO_2 vapor layer insulates dry ice from the hot solid wall (Leidenfrost effect)!



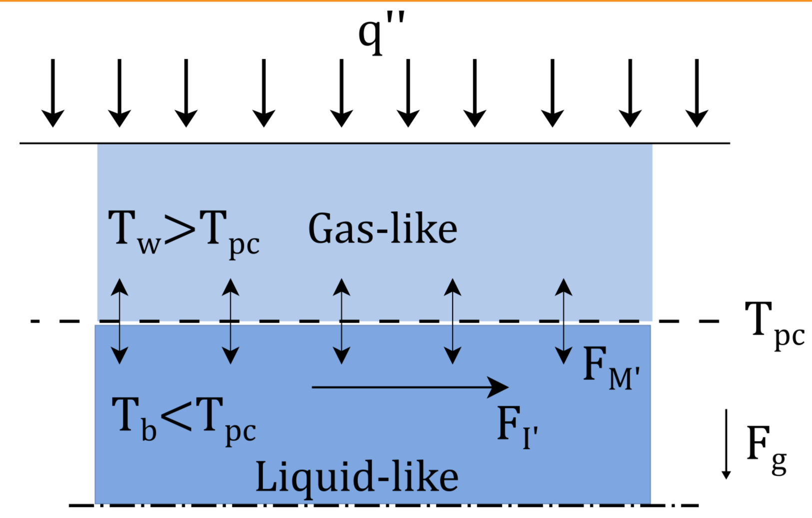


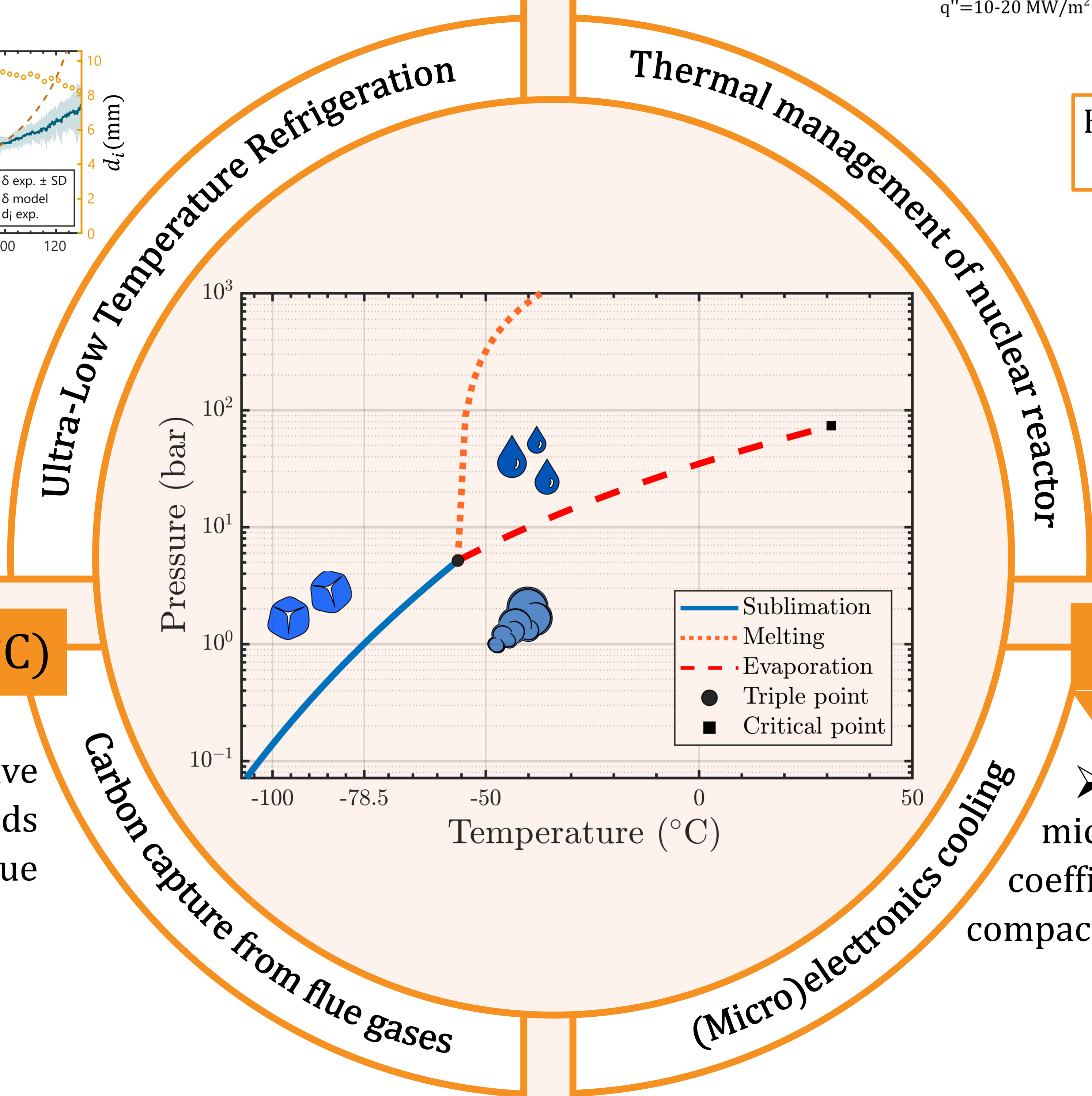
Supercritical Pseudo-boiling ($p > 74$ bar; $T > 31$°C)

- **Extreme Heat Flux Studies:** Evaluating heat and flow characteristics of sCO_2 under high thermal loads (10-20 MW/m^2) is crucial for mitigating hazards, and lifetime of the nuclear reactor.



Heat transfer deterioration occurs when $F_{I'} << F_{M'}$ (Leidenfrost-like effect)!

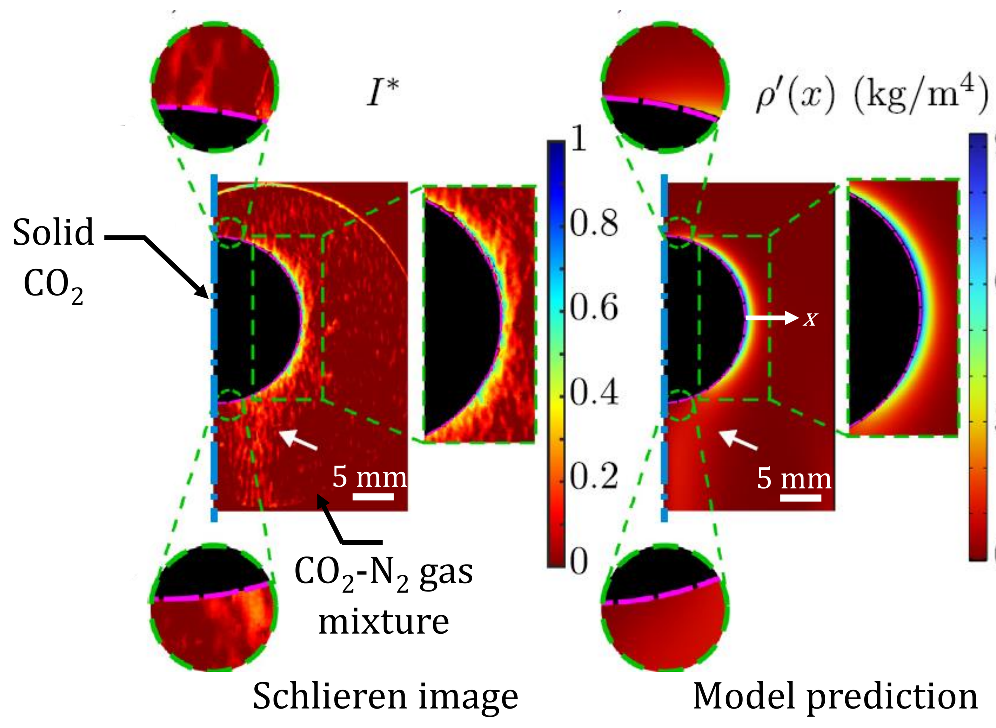


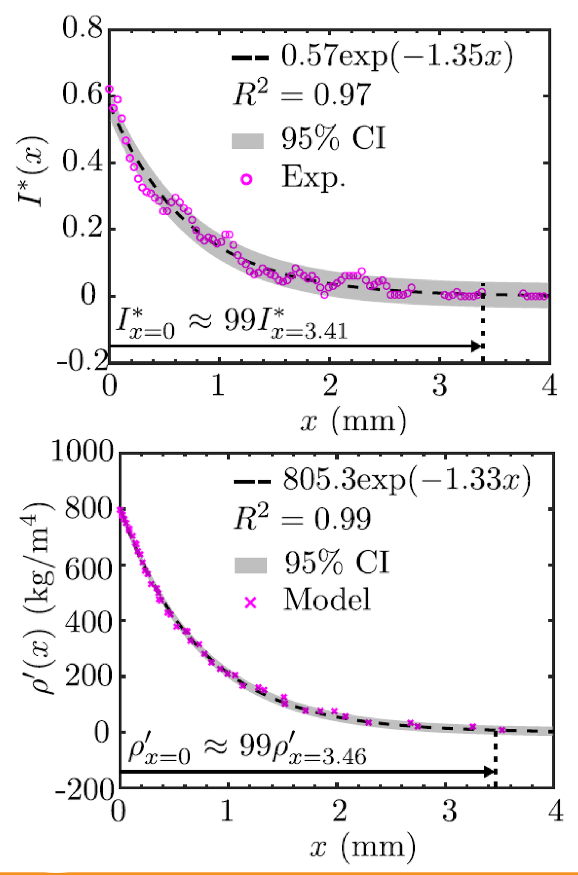


Deposition ($p \sim 1$ bar; $T < -80$ °C)

- **Cryogenic CO_2 Capture:** A potential alternative to conventional carbon capture methods especially for low CO_2 concentrations in flue gases (8-15 %Vol).

Temperature and concentration gradients drive CO_2 deposition at phase changing interface!

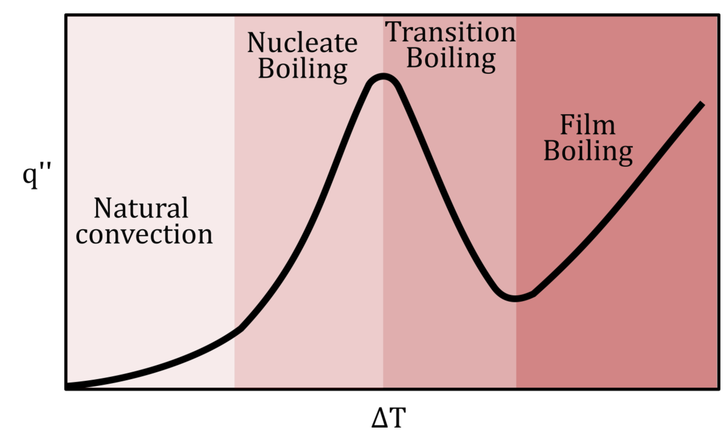


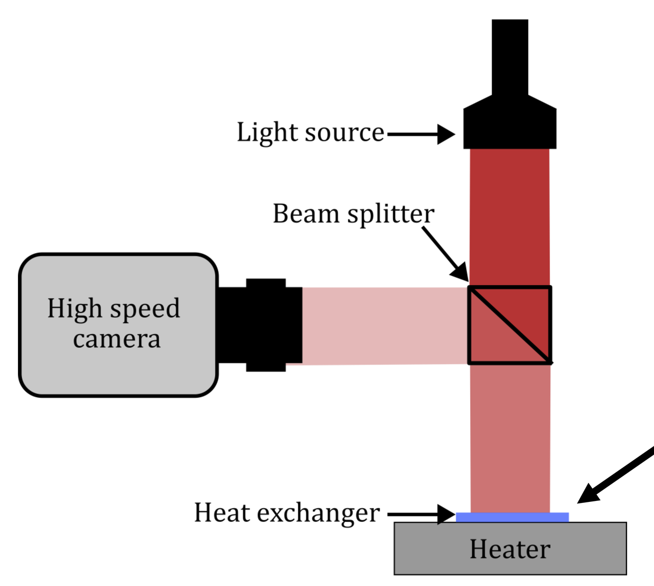


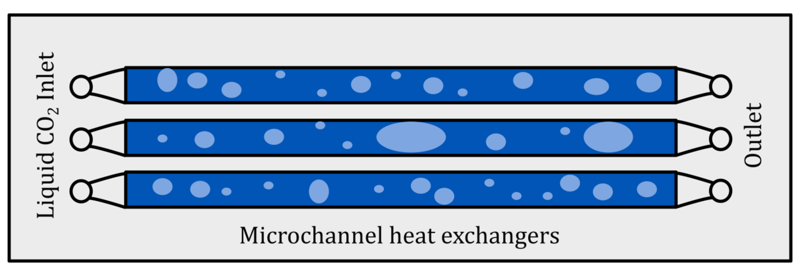
Boiling ($p > 5$ bar; $T > -20$°C)

- **Electronics Cooling:** Boiling CO_2 in microchannels offers high heat transfer coefficients to cool electronic components in compact spaces.

Identifying boiling regimes is important for heat transfer efficiency of high heat flux cooling systems!







Methodologies

- **Experimental Techniques:** Thermometry, High speed imaging, Schlieren imaging, Non-invasive capacitive technique.
- **Numerical Modeling:** Moving mesh method, Fixed grid (Enthalpy/equivalent capacity method), Conjugate heat transfer.
- **Analytical Modeling:** Classical Stefan problem, Scaling laws for phase change, Thermodynamic and transport properties analysis.

References

Dr. ir. Abhishek Purandare
University of Twente
a.s.purandare@utwente.nl

UNIVERSITY OF TWENTE.

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