Université de Toulouse

IMFT
INSTITUT DE MECANIQUE DES FLUIDES DE TOULOUSE

FLOW BOILING IN MICROGRAVITY: APPLICATION TO COOLING ELECTRONIC COMPONENTS ON SATELLITES

Catherine Colin, Julien Sebilleau,
Wladimir Bergez,

Marine Narcy, Michel Lebon, Esli Trejo,
Erik de Malmazet

cnes

ThalesAlenia
A Thales / Finmeccanica Company Space

esa

Fondation
de Recherche
pour l' Aéronautique
& l' Espace

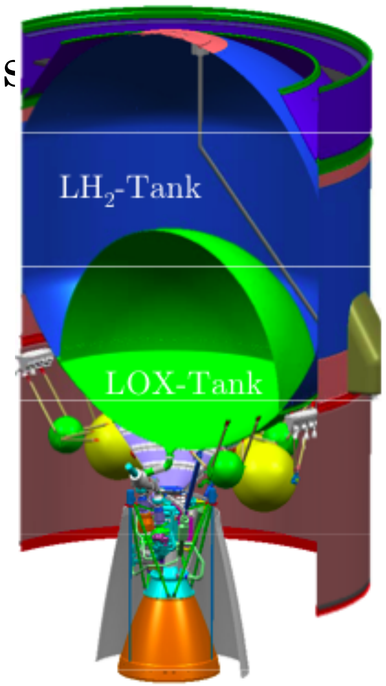
Motivation and context

Studies of two-phase flows with phase changes motivated by nuclear safety issues (Critical Heat Flux, Reactivity Insertion Accidents)

and space applications

re-ignition of cryogenic engines of the launchers (quenching, flow boiling)

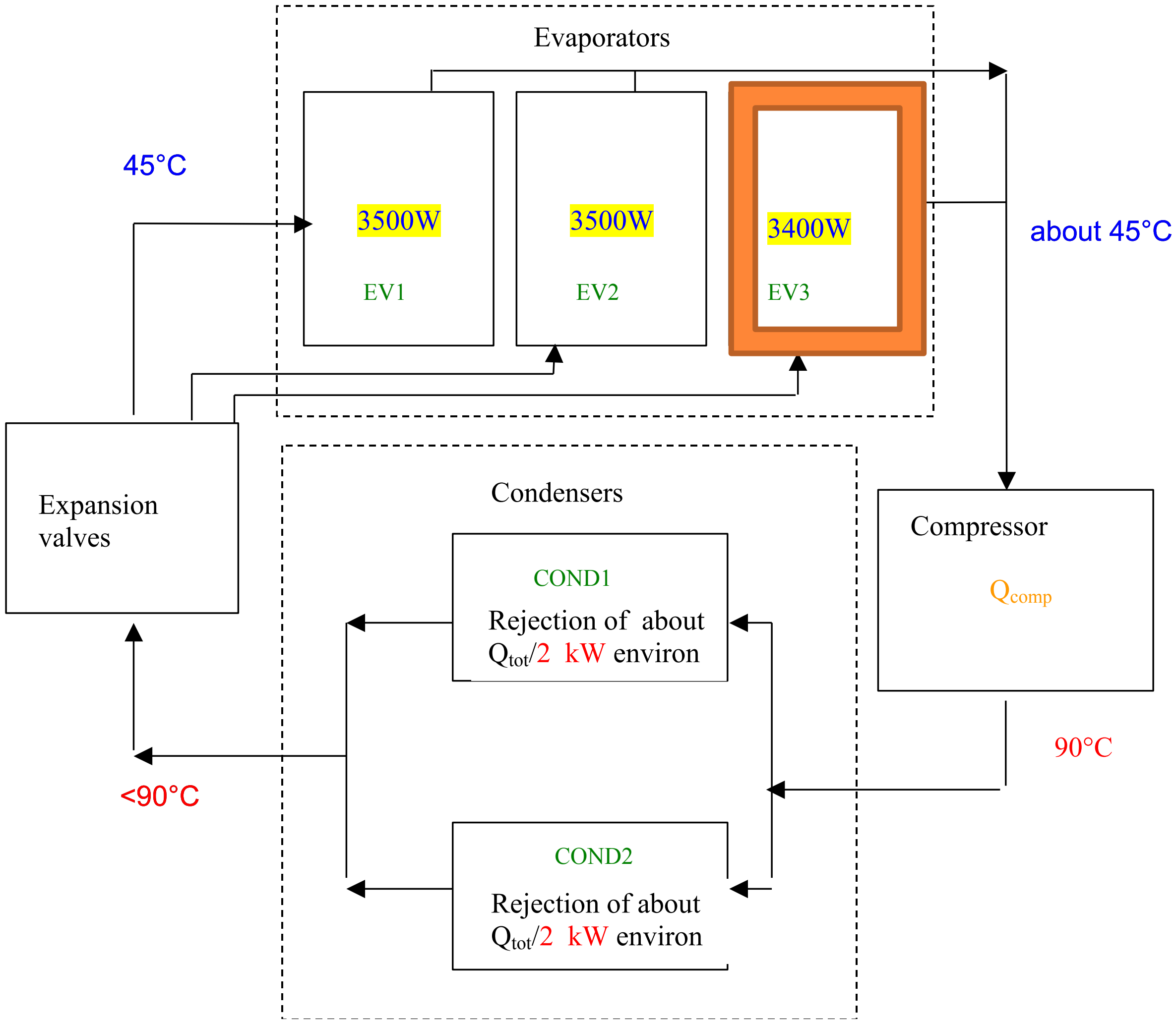
- thermal control of electronic components in satellites



ESC-B/Vinci Engine

Design of a two-phase loop for cooling electronic component of a satellite

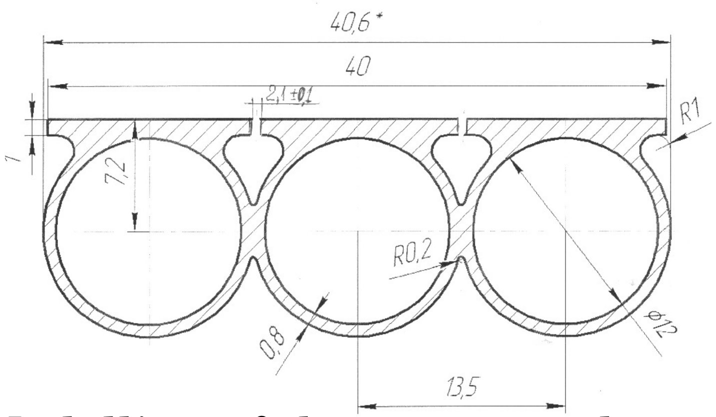
MATRAS Programme of FNRAE (2009-2013)
with THALES ALENIA SPACE



Partners:

Thales Alenia Space
CETHIL Lyon
CEA Grenoble
LAPLACE, Tlse
PPRIME, Poitiers
IMFT, Tlse

DESIGN OF A TWO-PHASE LOOP FOR COOLING ELECTRONIC COMPONENT OF A SATELLITE



Modelling of the pressure drop and heat transfer in the whole panel in microgravity and ground conditions → optimisation of the design 3 tubes of 12mm diameter in parallel (60m) → extraction of 3.4 kW

→development of a 1D model Project of INP-N7 students
→ Building of an experimental set-up for ground and microgravity experiments

ESA MAP Project Multiscale Analysis on Boiling (2008-….)

Boiling investigation at the bubble scale (experiments, DNS, ..)
→ RUBI experiments on the ISS (2019)

Flow Boiling in tube in microgravity

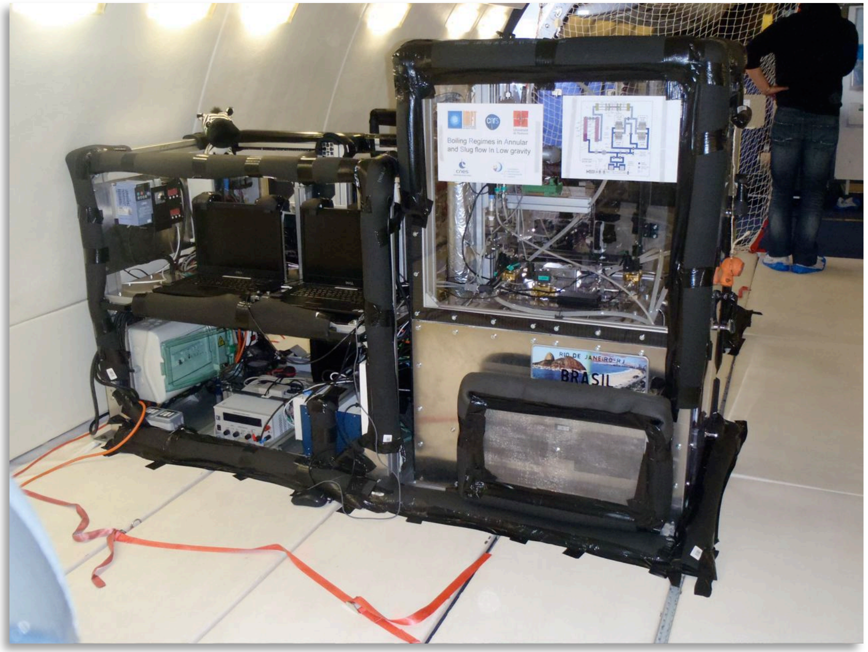
Catherine Colin, IMFT, Univ. Toulouse (FR)	Peter Stephan, TTD, TU Darmstadt (D)	Paolo Di Marco, Univ.Pisa (I)
Giuseppe Zummo, ENEA, Roma (I)	David Brutin, Lounes Tadrist, IUSTI, Univ. Aix Marseille (FR)	Pierre Colinet, TIPs, Univ. Libre de Bruxelles (B)
John Thome, EPF Lausanne (CH)	Marc Miscevic, Pascal Lavieille, LAPLACE, Univ. Toulouse (FR)	Thodoris Karapantsios, AUTH, Thesaloniki (G)
Franck Dubois, Carlo Iorio, MRC, Univ. Libre de Bruxelles (B)	Iztok Golobic,LTT, Univ. Ljubliana (SL)	Oleg Kabov, KIT, Novosibirsk (RU)
Jungho Kim, Univ. Maryland (US)	Philipp Behruzi, Airbus/ DS, Bremen (D)	Julien Hugon, Anthony Delmas, TAS, Cannes (FR)

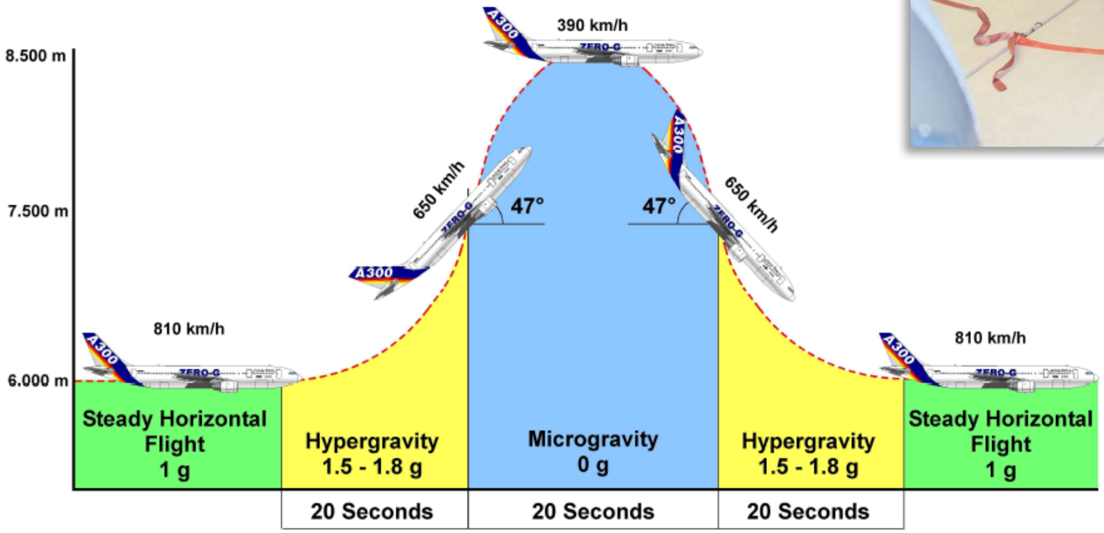
FLOW BOILING IN TUBE

- EXPERIMENTAL SETUP
- MEASUREMENT TECHNIQUES
  - VOID FRACTION
  - WALL SHEAR STRESS
  - HEAT TRANSFER COEFFICIENT
- RESULTS:
- CONCLUSIONS

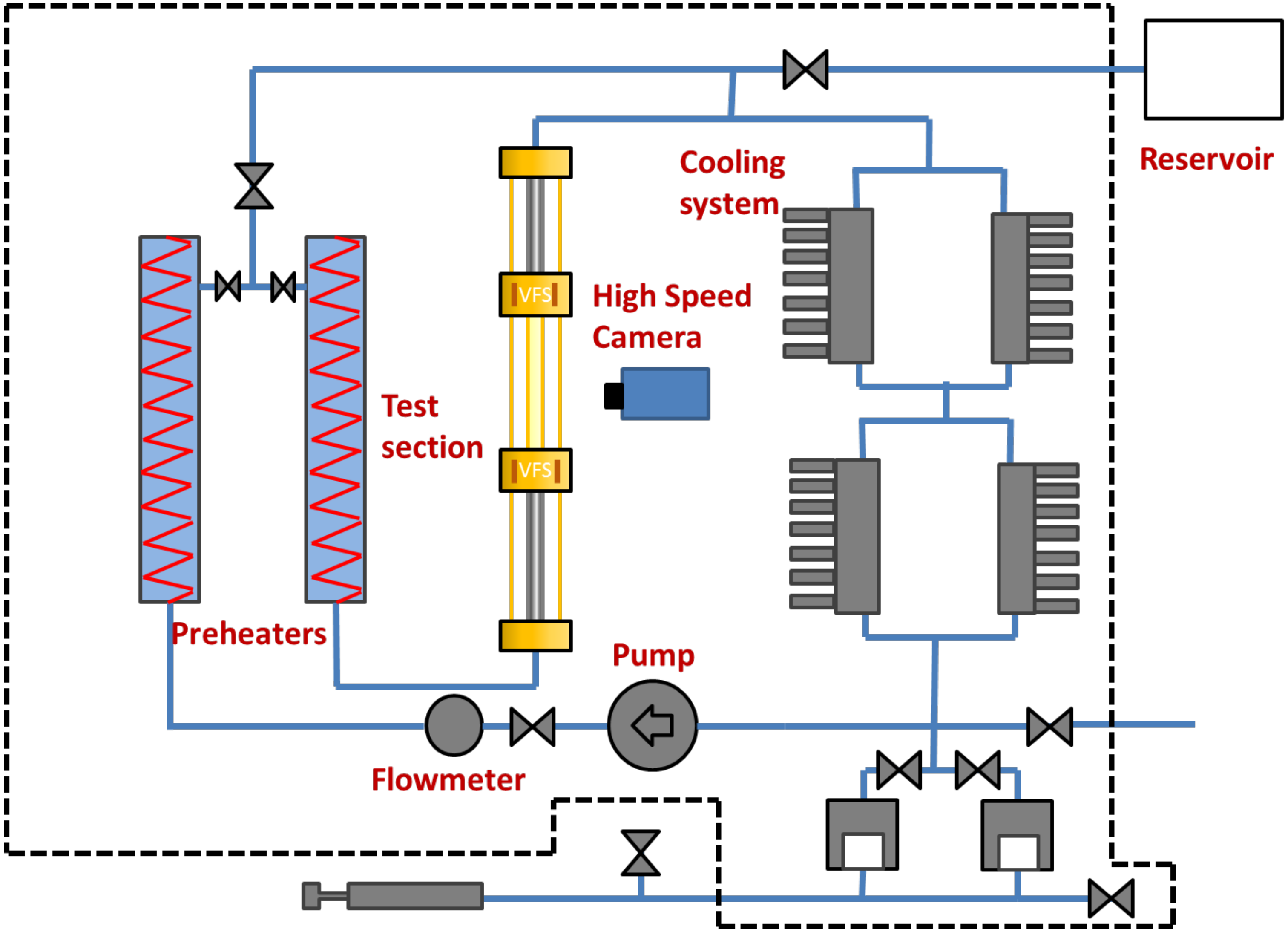
EXPERIMENTAL SETUP

- Designed and built for two-phase flows studies with phase change under microgravity conditions.
- BRASIL: Boiling Regimes in Annular and Slug flow In Low gravity
- G=50-300 kg/m^2/s
- x=0-0.6
- ΔT(subcooled) <10°C
- q= 0.5-4 W/cm^2
- ID= 6 mm
- Fluids HFE7000 – HFE7100

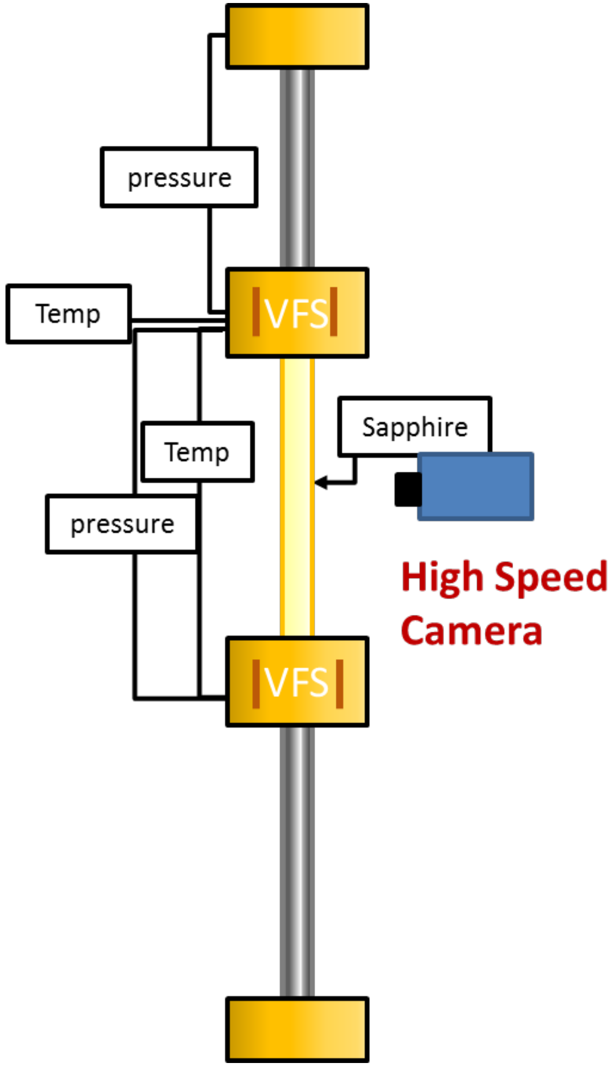




Experimental setup

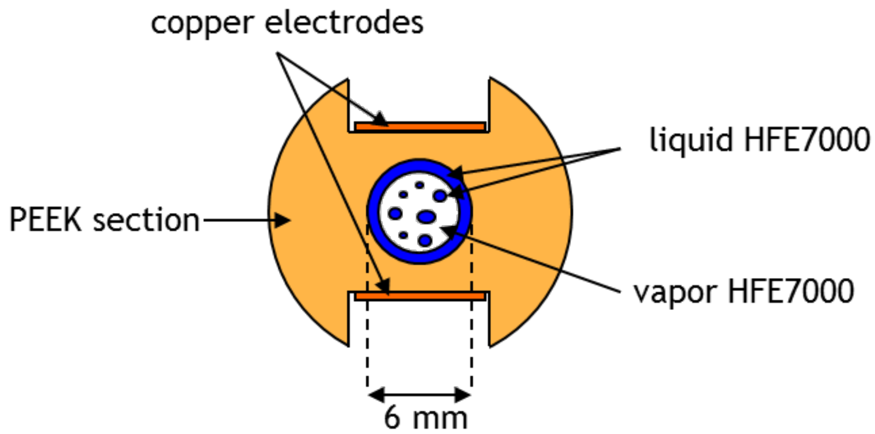


Test section: Sapphire tube

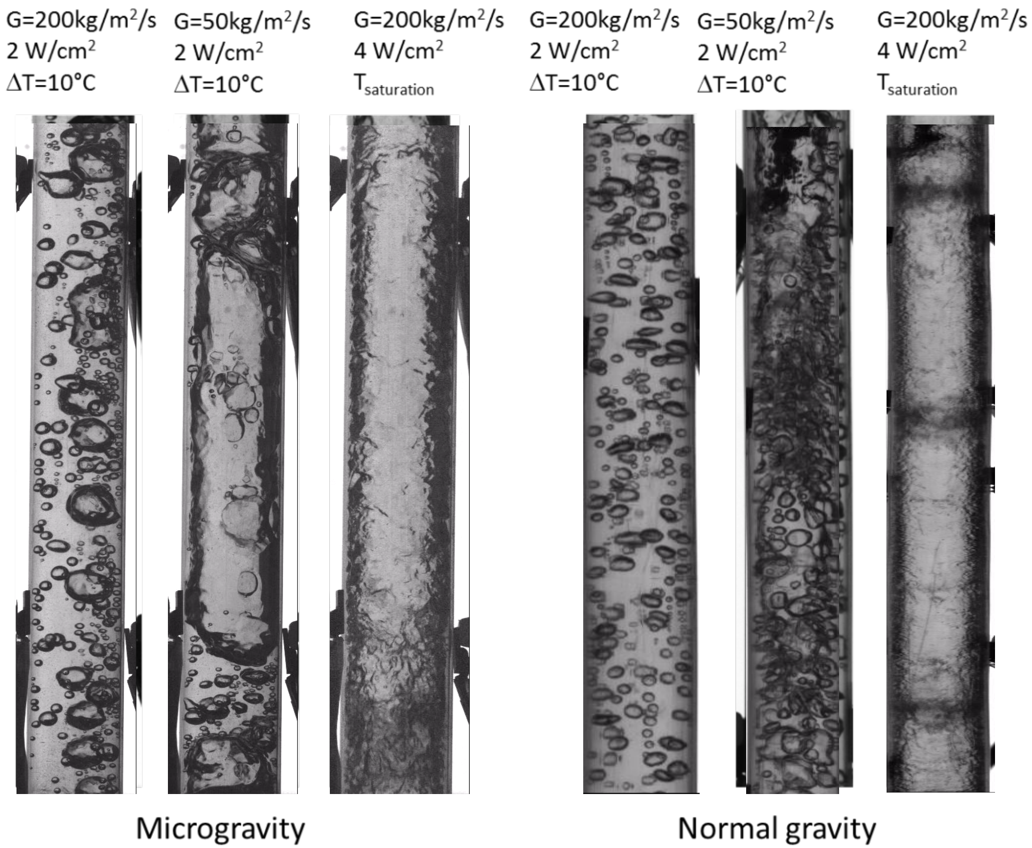


Sapphire tube:

- 200 mm long sapphire tube
- Semi-transparent with an ITO coating for Joule effect heating
- Wall temperature measured by Pt100 probes
- HFE 7000 ->T_{sat}=34°C @ 1 bar
- Pressure drop measurements →wall shear stress
- Capacitance probes →void fraction
- Thermocouples→ liquid enthalpy and quality x



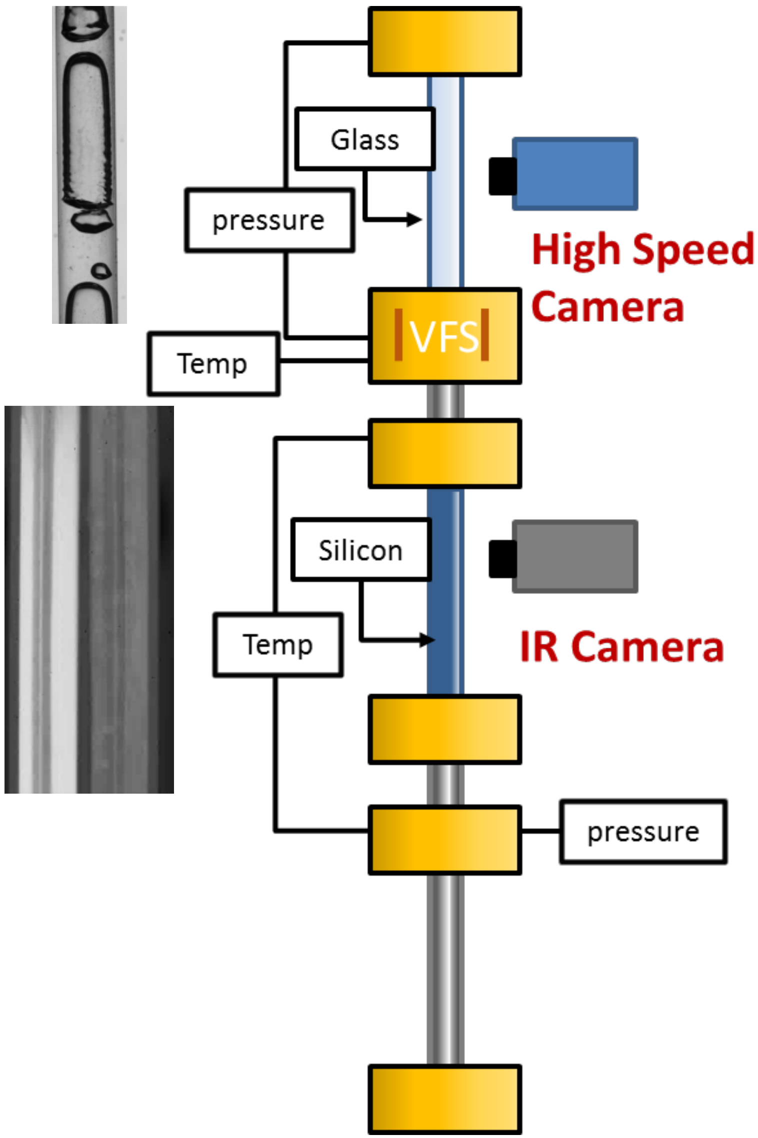
RESULTS: FLOW REGIMES



Influence of gravity:

- Size and shapes of bubbles
- At detachment larger bubble diameter is observed in microgravity.
- Liquid film in annular flow seems smoother

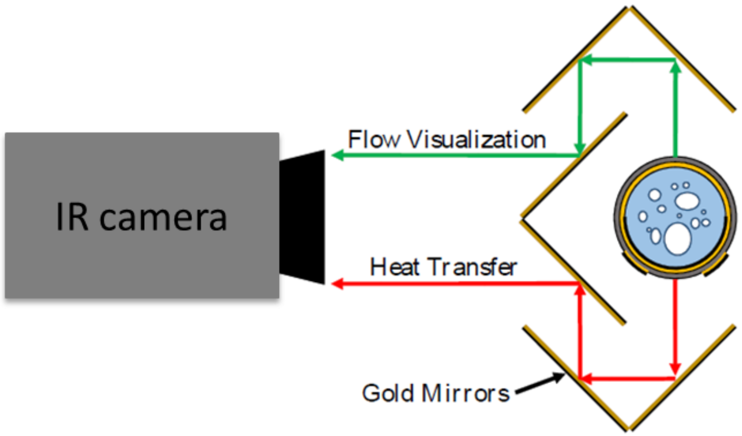
TEST SECTION: SILICON TUBE



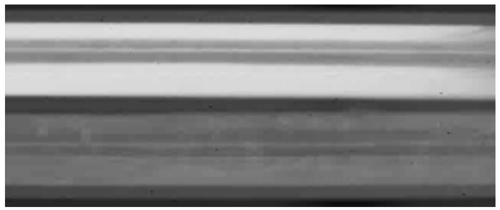
Silicon:

- 100 mm long sapphire tube
- Transparent to the IR camera doped for Joule effect heating
- Wall temperature measured obtained from IR camera visualization
- HFE 7100 -> T_{sat}=61°C @ 1 bar
- ESA's High Resolution IR camera

Measurement of HTC



Flow visualization

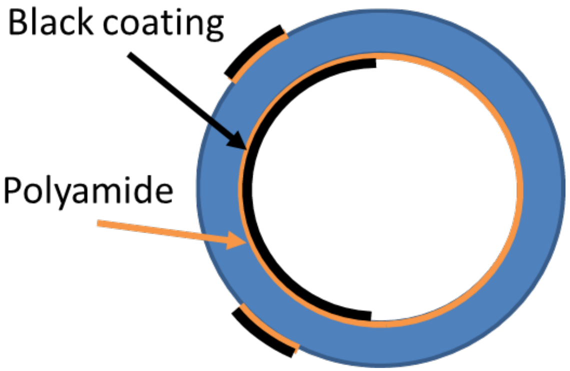


Temperature measurements

$$E_{c,o} = (1 - \varepsilon_s)E_\infty + \varepsilon_s E_{s,o}$$

with $E_{s,o} = F_{\lambda_1 \to \lambda_2} \sigma T_{s,o}^4$

$$E_{c,i} = \rho_{\infty-c} E_\infty + \varepsilon_{si-c} E_{si} + \varepsilon_{T-c} E_T + \tau_{s-c} E_{s,i}$$



$$\rho_{Si} C_{p,Si} \frac{\partial T}{\partial t} = K_{Si} \Delta T + q_{Si}$$

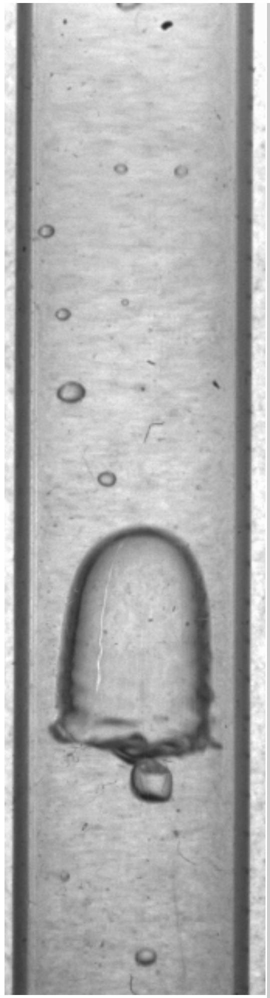
$$h_i = \frac{q}{T_{iw} - T_{i\infty}}$$

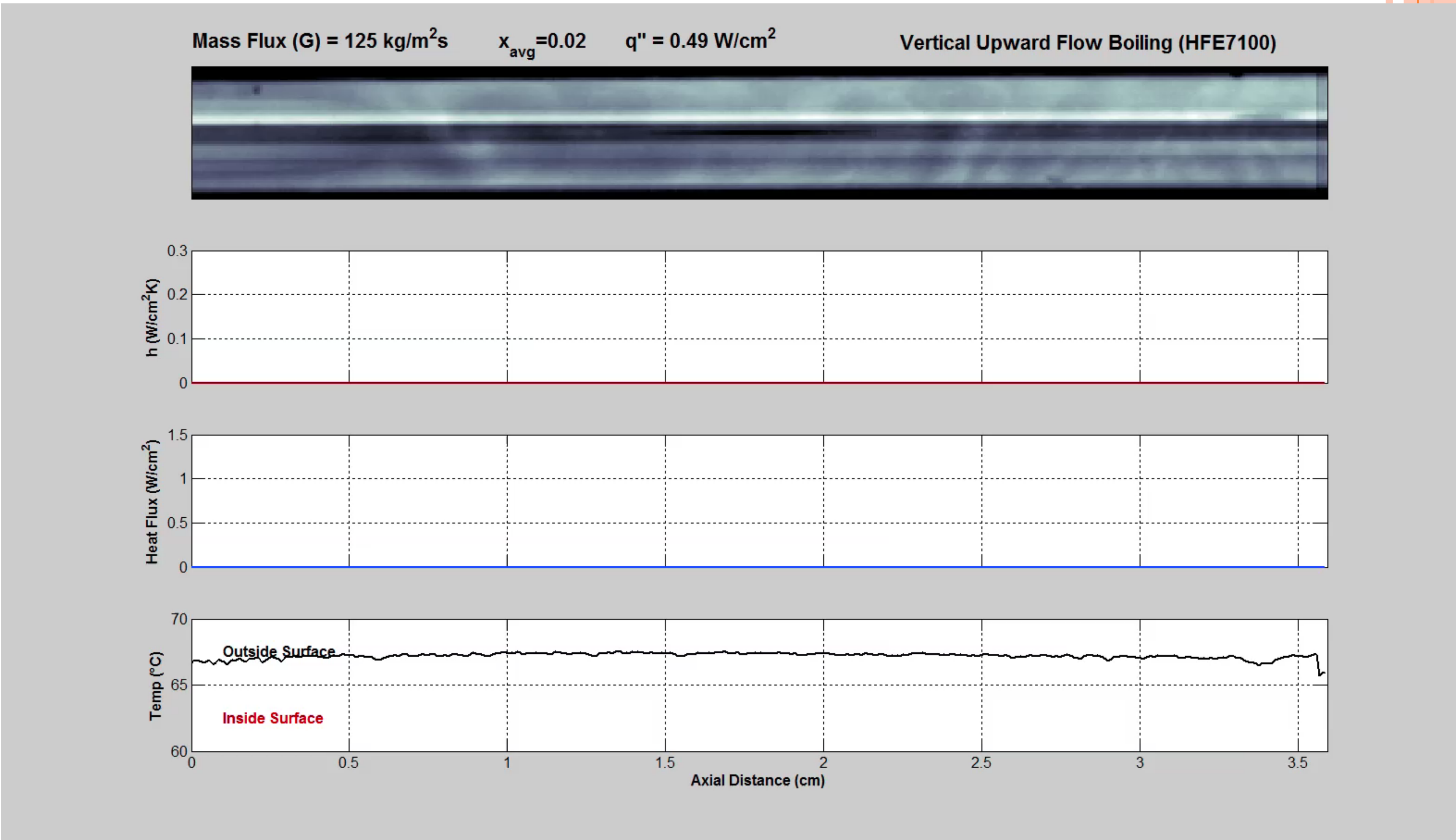
$$\rho_A C_{p,A} \frac{\partial T}{\partial t} = K_A \Delta T$$

$$\rho_P C_{p,P} \frac{\partial T}{\partial t} = K_P \Delta T$$

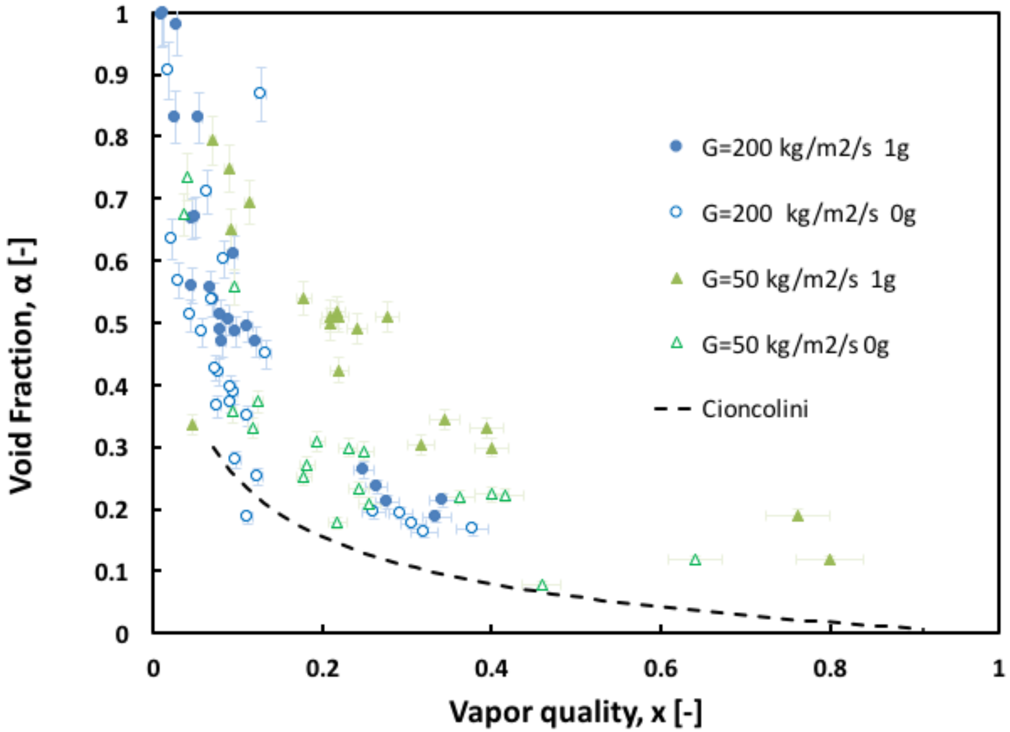
Kim et al. (2012)

HEAT TRANSFER COEFFICIENT IN SLUG FLOW





RESULTS: VOID FRACTION NORMAL VS MICROGRAVITY



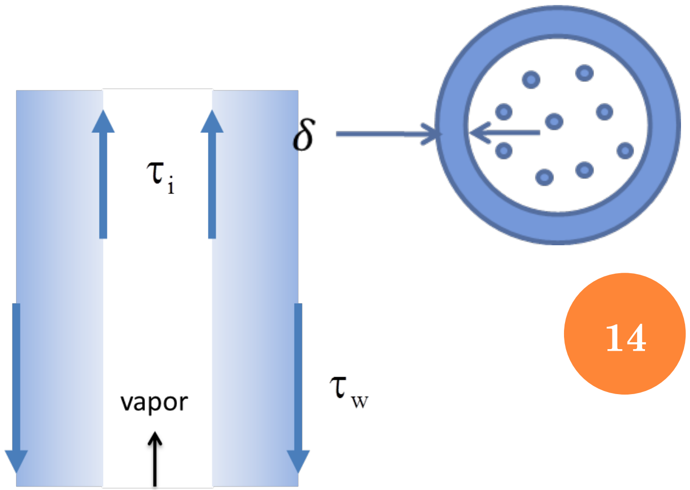
$$\delta = \frac{D}{2}\left(1 - \sqrt{\alpha\frac{\rho_l x + \rho_v(1-x)e}{\rho_l x}}\right)$$

$$e = (1 + 2.79.6\, We_c^{-0.8395})^{-2.209}$$

Cioncolini et Thome (2012)

Evolution of the void fraction as a function of mass flow rate (kg/m^2/s)

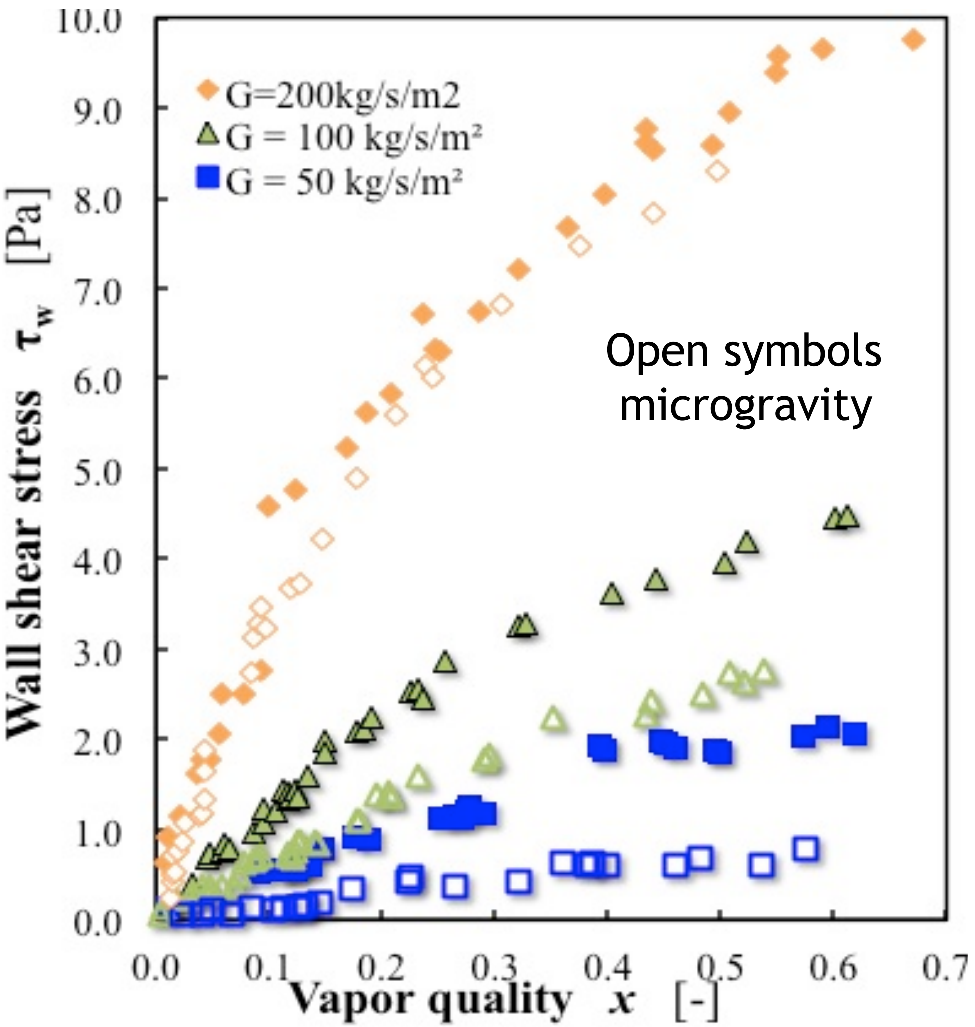
Influence of gravity:
- The liquid film is thicker in 1g.

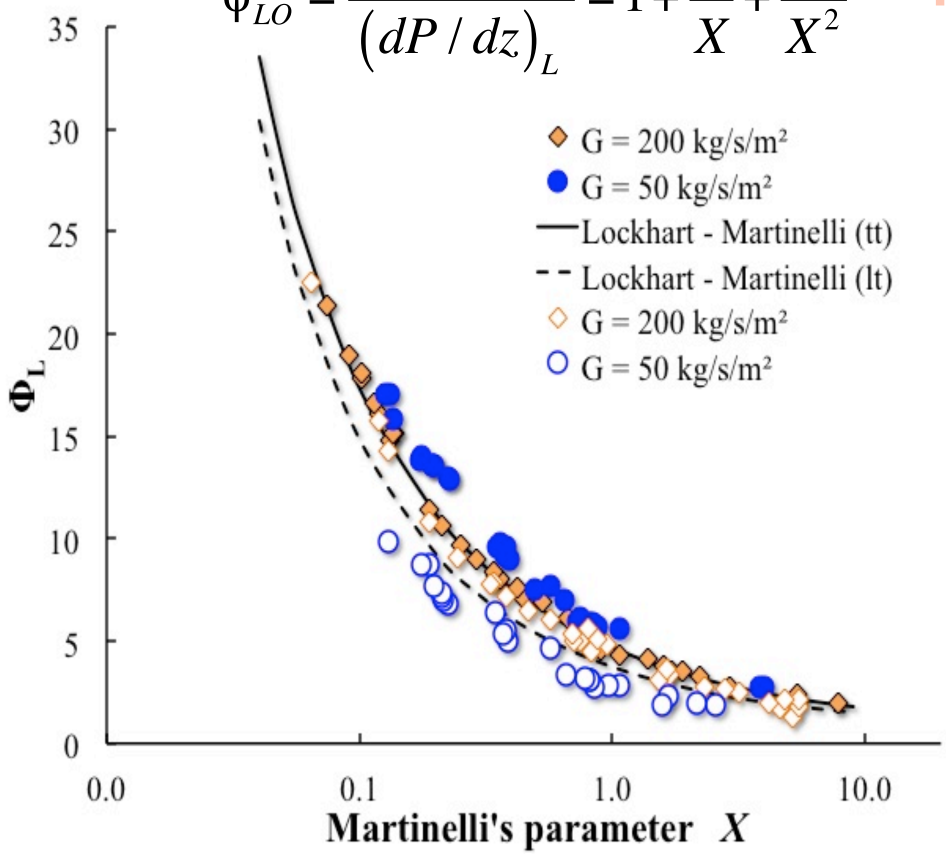


Wall shear stress

$$\frac{dP}{dz} = \frac{4\tau_w}{D} - g\left[\rho_L(1-\alpha) + \rho_G\alpha\right]$$

$$\phi_{LO}^2 = \frac{(dP/dz)_{2\varphi}}{(dP/dz)_L} = 1 + \frac{C}{X} + \frac{1}{X^2}$$





For G>200 kg/m²/s → wall shear stress independant of gravity

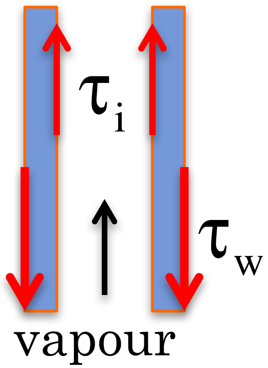
For G<200 kg/m²/s → wall shear stress larger in 1g

→ Good agreement with Lockhart and Martinelli model

Interfacial friction factor for annular flow

$$-(1-\alpha)\frac{dP}{dz}-\frac{4\tau_w}{D}+\frac{4\tau_i\sqrt{\alpha}}{D}-\rho_L g(1-\alpha)=0$$

$$f_i=\frac{\tau_i}{\frac{1}{2}\rho_v\left(U_V-U_L\right)^2}$$

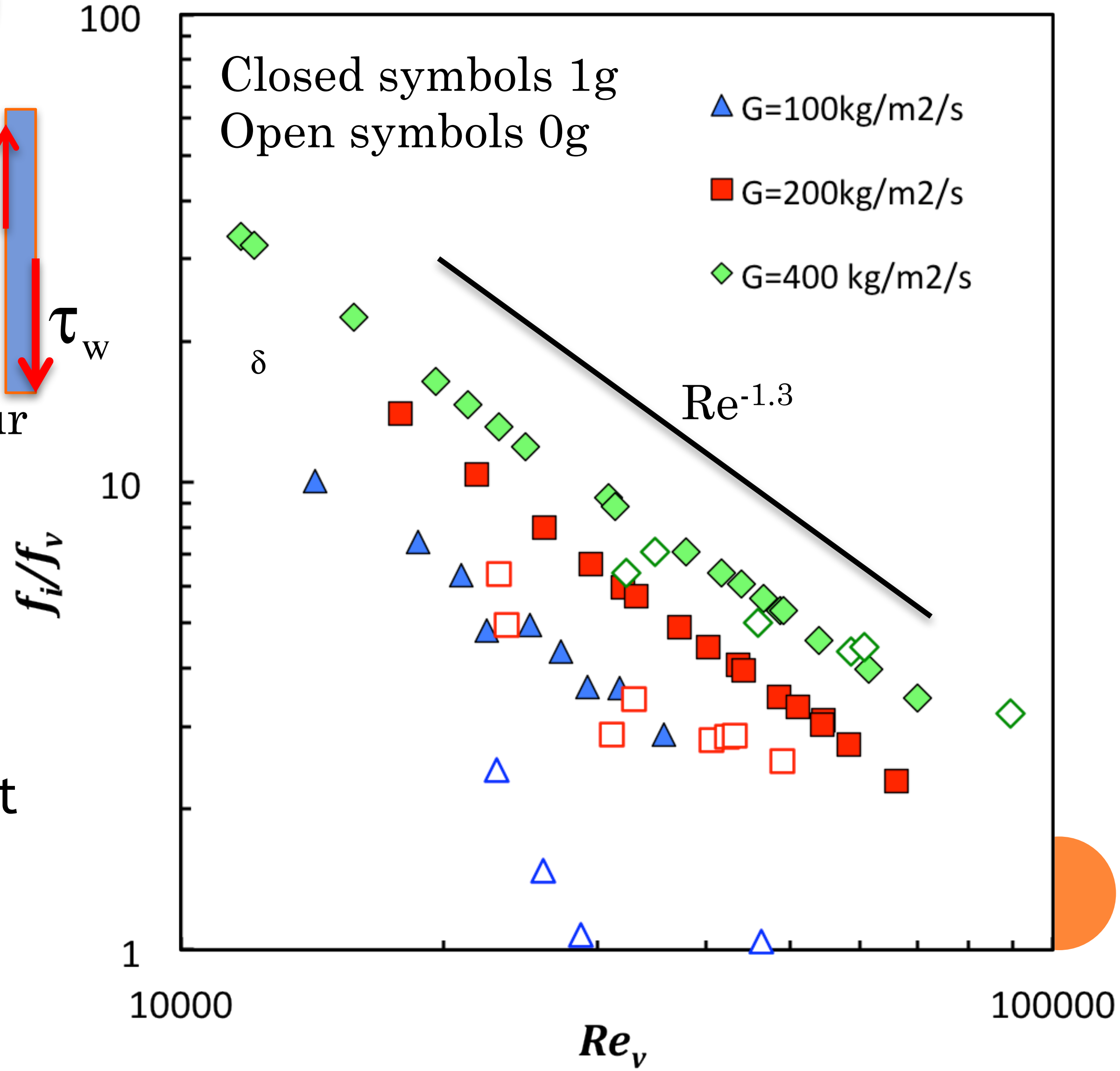


f_i/f_v depends on Re_v and not only on δ

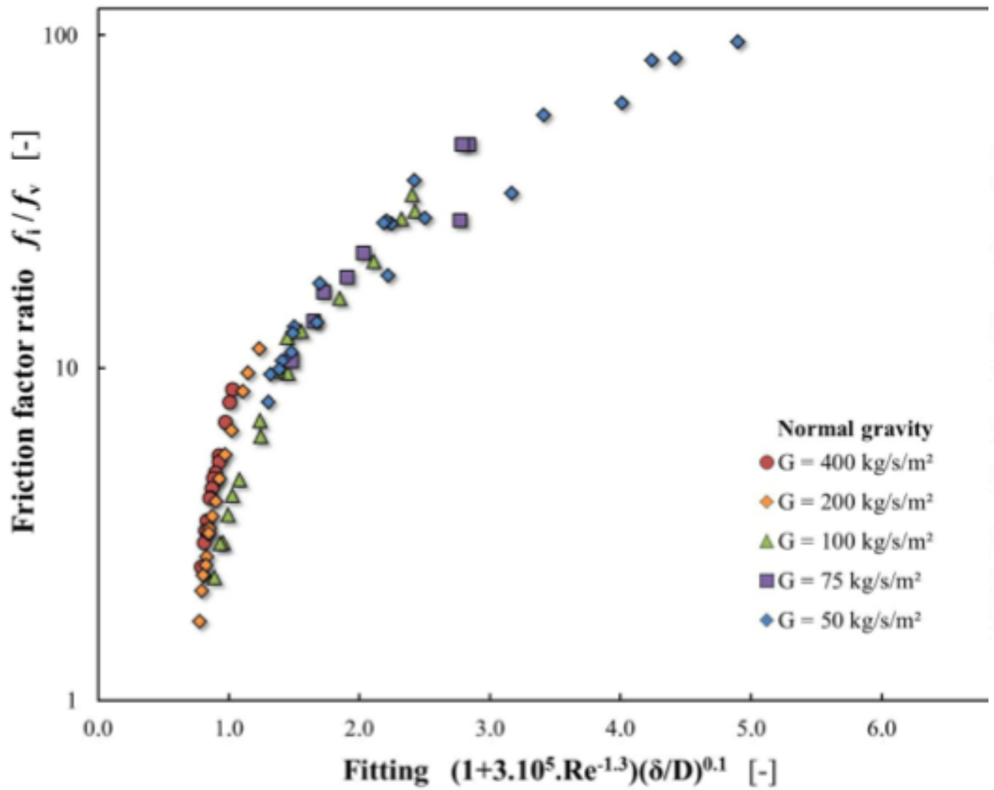
-> not fully rough turbulent flow

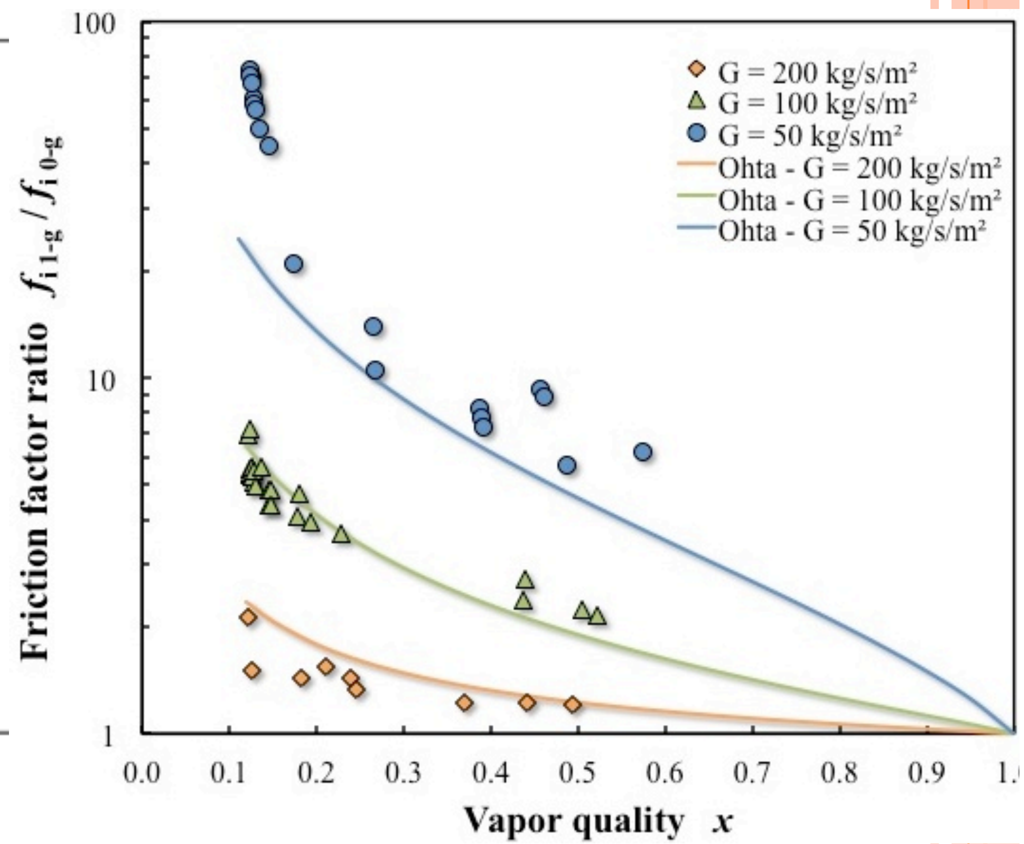
-> Wallis correlation is not adapted

$$f_i=0.005\left(1+300\frac{\delta}{D}\right)$$



INTERFACIAL FRICTION FACTOR FOR ANNULAR FLOW



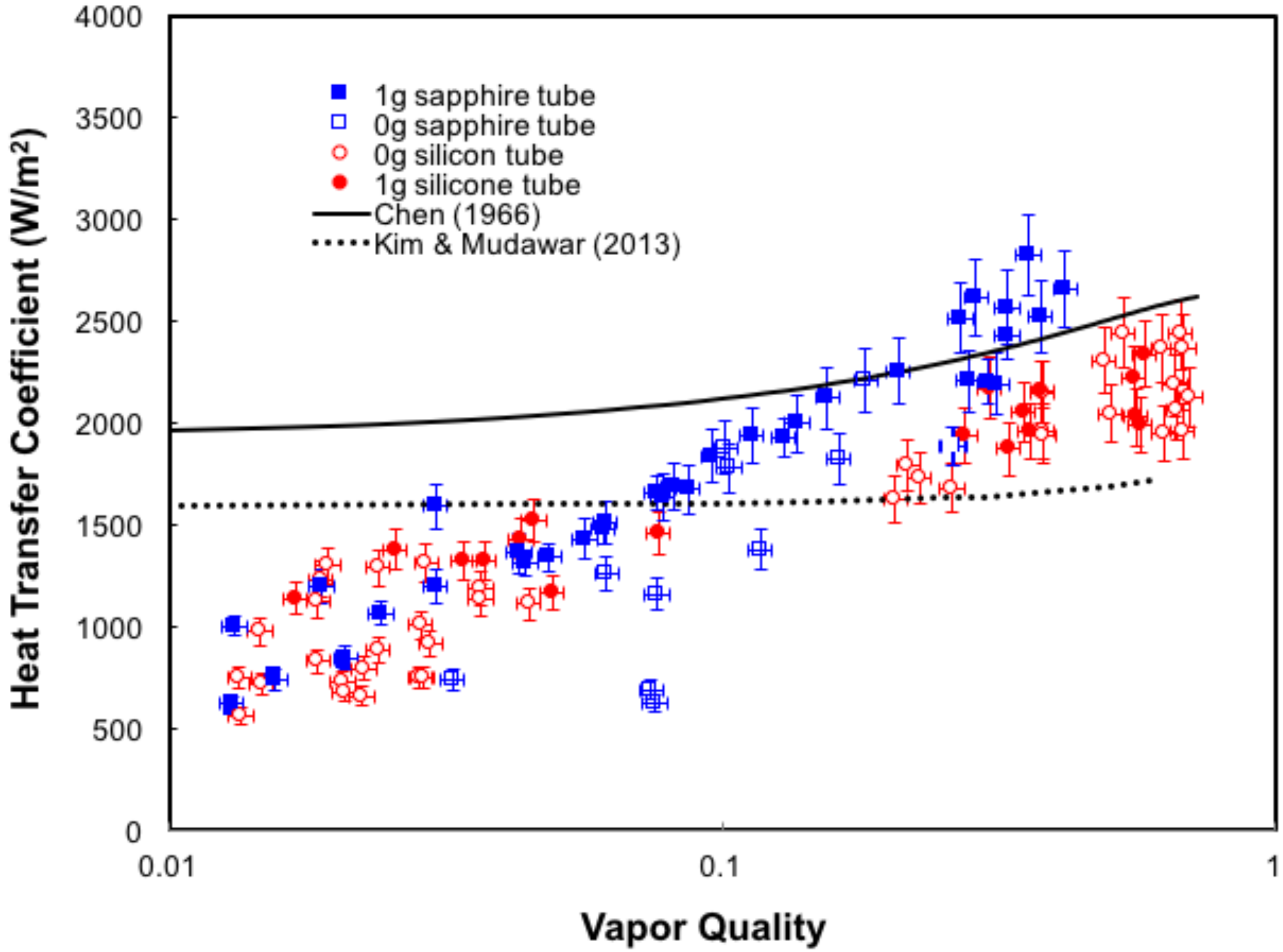


$$\frac{f_i}{f_v} = 1 + 18.3\left[\left(1+\frac{3.10^5}{Re_v^{1.3}}\right)\cdot\left(\frac{\delta}{D}\right)^{0.1} - 0.89\right]$$

$$\frac{f_{i-1g}}{f_{i-0g}} = 1 + 0.08\left(\frac{1-x}{x}\right)^{0.9}\frac{1}{Fr}$$

$$with \quad Fr = \frac{j_L^2}{gD}$$

HEAT TRANSFER COEFFICIENT



Deterioration of the heat transfer in microgravity.

- At lower quality the influence of gravity can be seen,
- At higher quality good agreement with classical correlations.

CONCLUSION

- Study of flow boiling in tube → expertise in specific measurements technics (Thermocouples, Infrared camera, capacitance probes, pressure drops, high-speed video recording and image processing) and in 1 dimensional modelling of two-phase flows.

- Close connexions with industrial partners:
  - Thales Alena Space for the design of two-phase loop for cooling electronic devices
  - Air Liquide : heat and mass transfers in space launchers
  - Snecma moteurs & CNES: chill down of tubes before the re-ignition of space launcher engine (Ariane V programme)
  - IRSN: rapid transient boiling in nuclear reactors (RIA)

Thank you for your attention

- Contact: colin@imft.fr