Splashing transition and freezing

Rodolphe Grivet[1]
Axel Huerre[2], Thomas Séon[3], Christophe Josserand[1]

[1] Laboratoire d'Hydrodynamique (LadHyX), UMR 7646 CNRS-Ecole Polytechnique, IP Paris, 91128 Palaiseau, France
[2] MSC,UMR 7057, CNRS-Université Paris Cité, 75013 Paris, France
[3] Institut Jean Le Rond ∂'Alembert, UMR 7190, CNRS-Sorbonne Université, F-75005 Paris, France

Motivation-context

- Splashing is a crucial feature in multiphase flows
- Crucial to control (good or bad depending on the applications)
- Splashing transition still a subject of debate (inertia-viscous-capillary interplay)
- Recent results on the role of air pressure, general theories (splashing number, Gordillo-Riboux, etc…)
- Question: does the temperature affect the splashing transition beside simply the variation of the physical parameters?

Splashing transition on ethanol

$U_0 = 2.86\,\mathrm{m\,.\,s^{-1}}$

$U_0 = 1.13\,\mathrm{m\,.\,s^{-1}}$

Qualitative observation (water)

Same impact parameters, but different **release heights**

$$T_s = T_{amb}$$

$U_0 = 5.5\ \mathrm{m\,.\,s^{-1}}$

$U_0 = 2.53\ \mathrm{m\,.\,s^{-1}}$

ralentis x780

Qualitative observation

Same impact parameters, but different **temperatures**

$$U_0 = 2.65 \mathrm{m\,.\,s^{-1}}$$

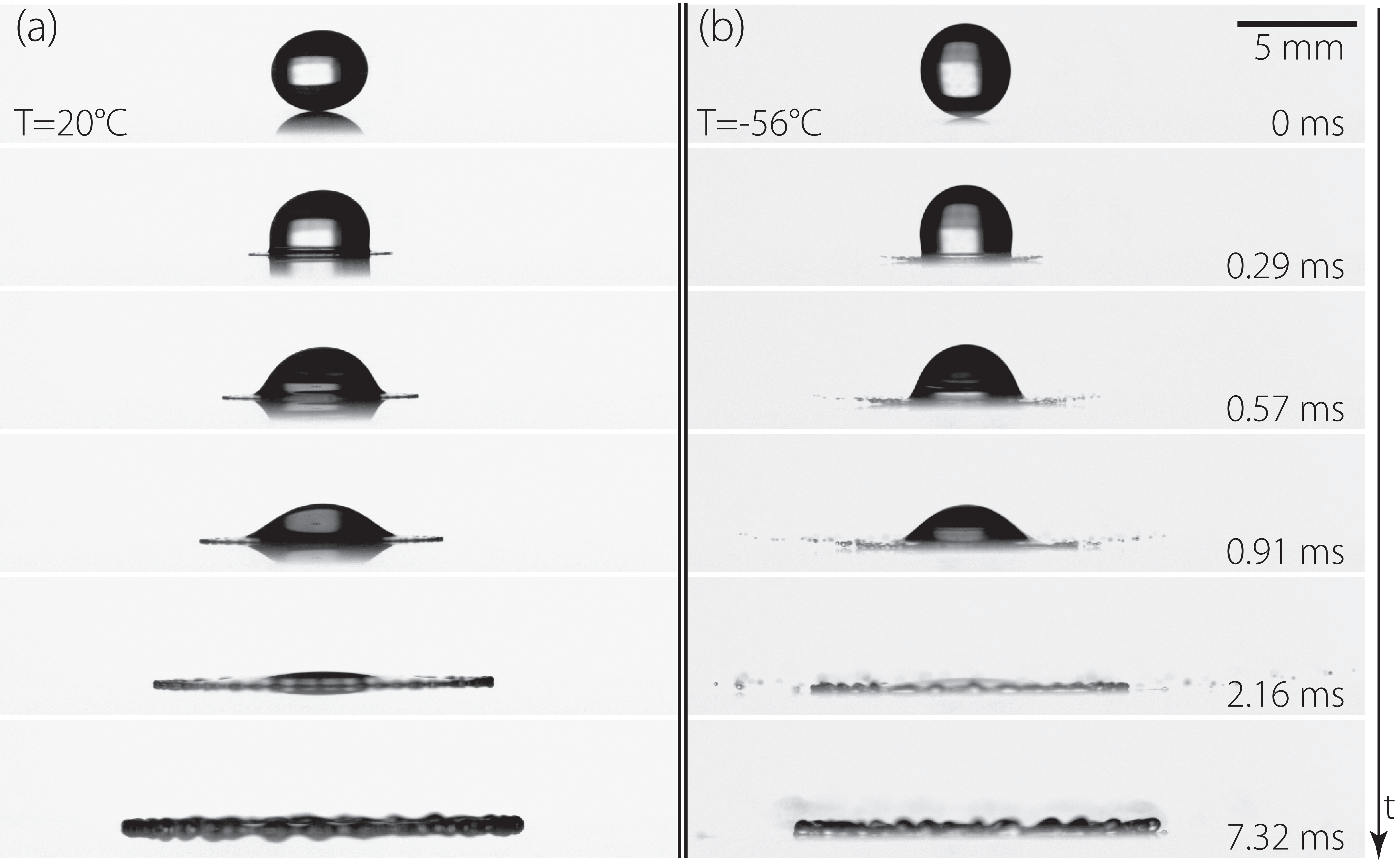
$T_s = T_{amb}$

$T_s = -\,55°\mathrm{C}$

ralentis x750

Qualitative observation

Same impact parameters, but different **temperatures**

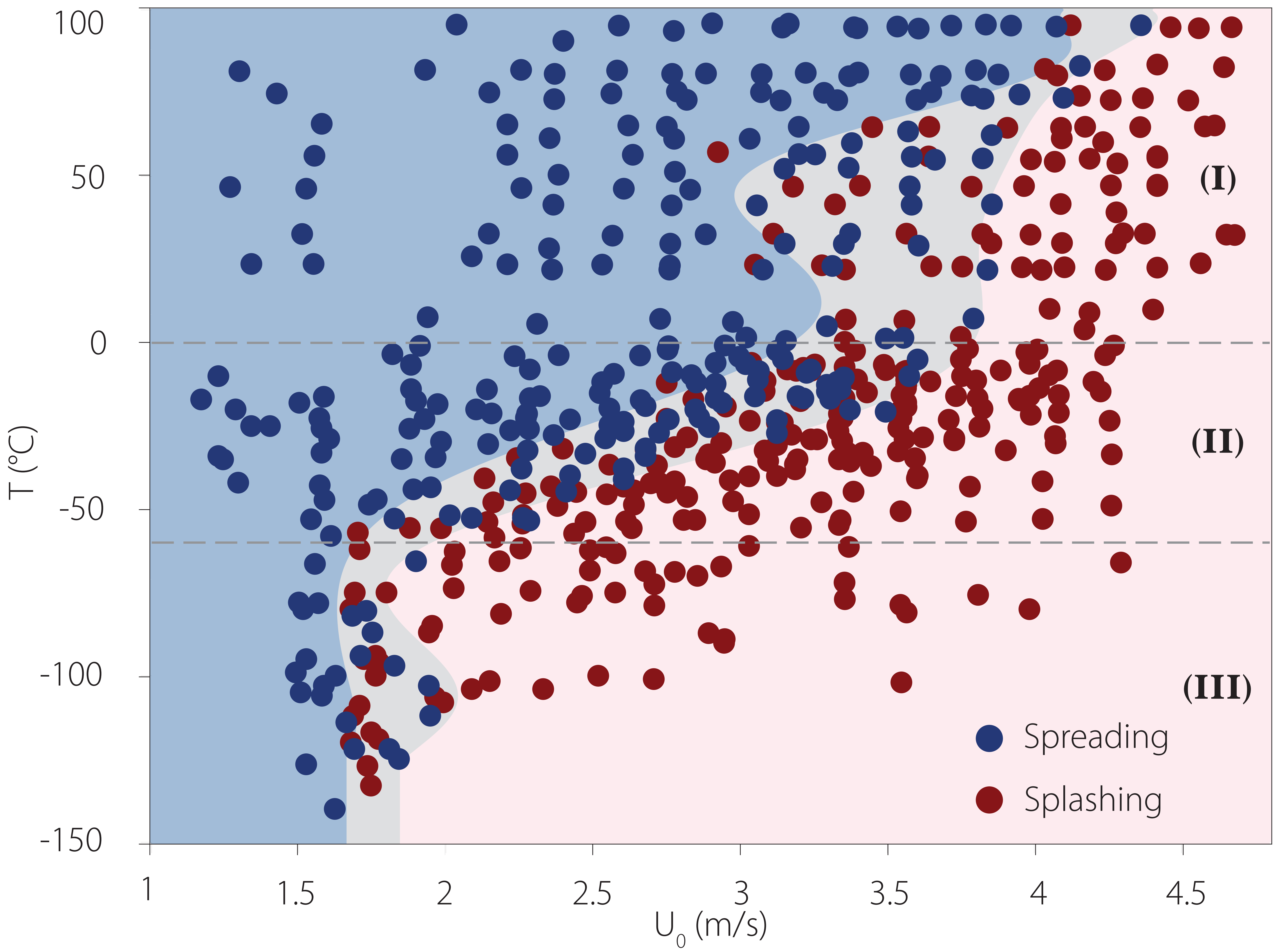


$U_0 = 2.65\mathrm{m\,.\,s^{-1}}$

Three steps in splashing:

- Ejected corolla
- Fragmentation
- Classical lamella spreading

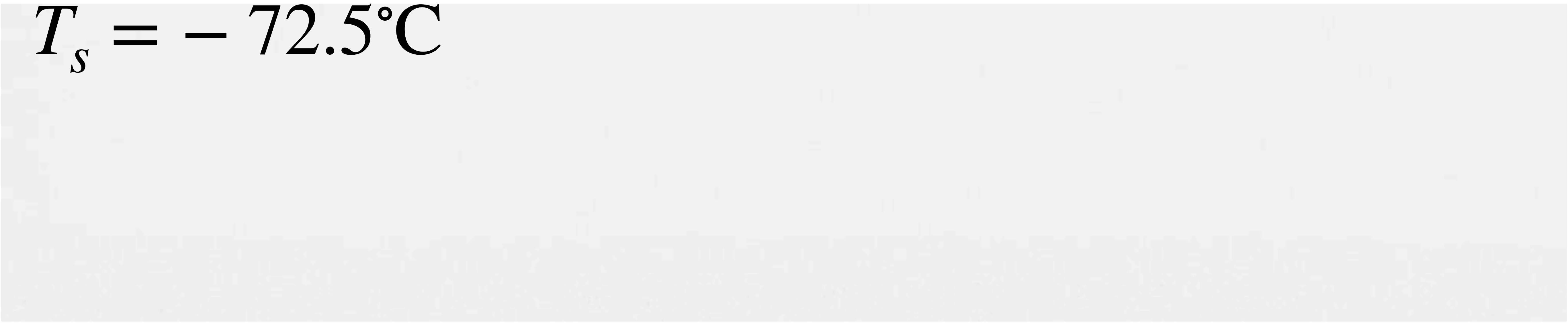
Phase diagram



Three main regions:

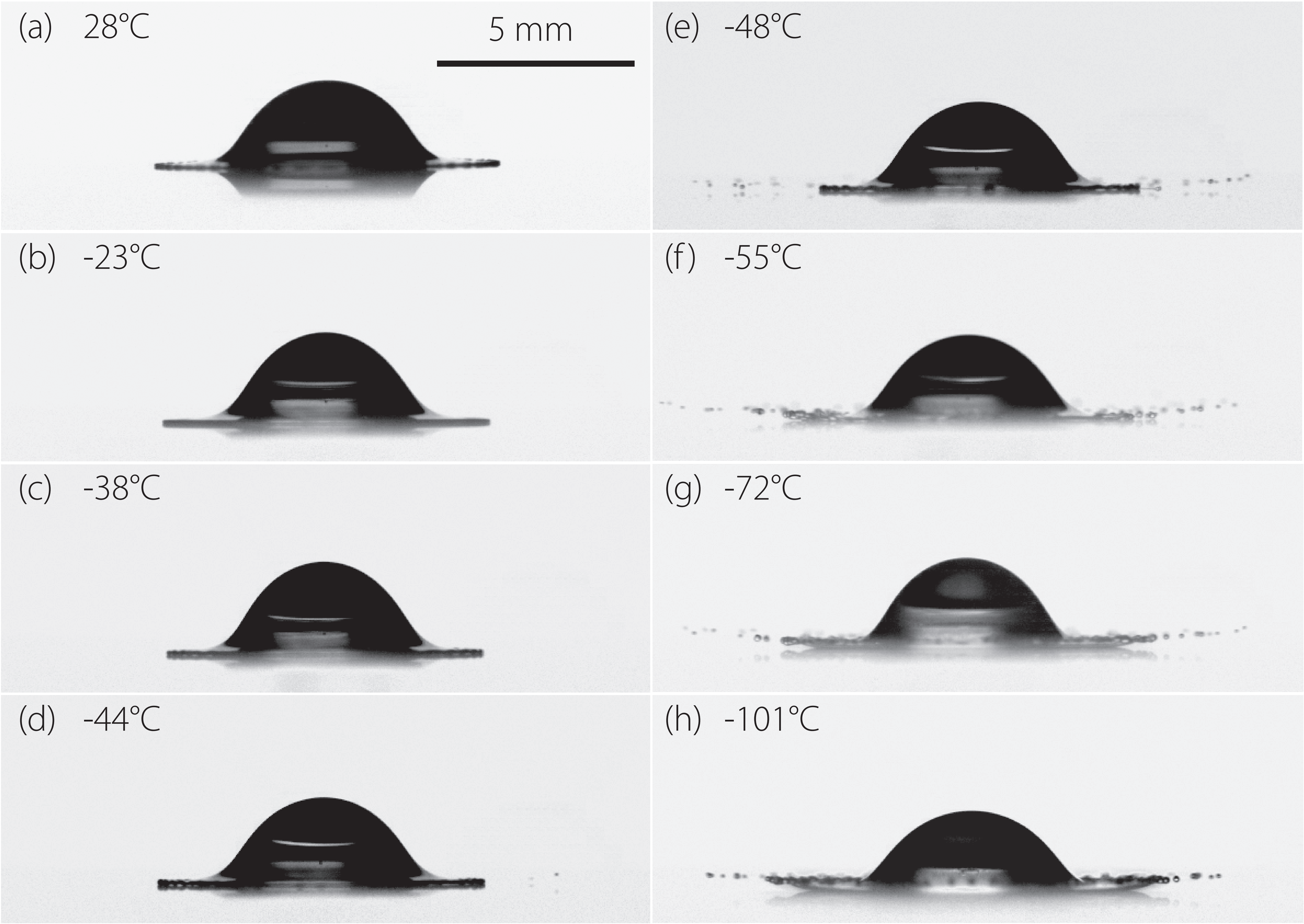
- (I) positive temperatures: no strong influence of temperature
- (II) Down to -60°C: strong variation of threshold
- (III) Below -60°C: Critical threshold reached at $U_0^* \approx 1.7\,\mathrm{m\,.\,s^{-1}}$

Splashing outlook at various temperatures



$U_0 = 2.65 \mathrm{m.s^{-1}}$

Splashing outlook at characteristic impact time



$U_0 = 2.65 \mathrm{m}\,.\,\mathrm{s}^{-1}$

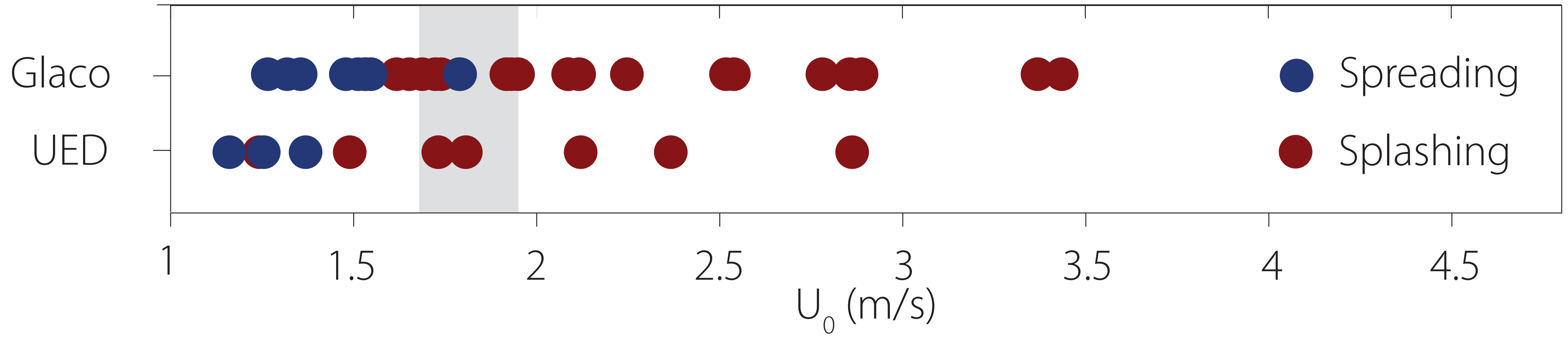
Splash outcome varies with undercooling

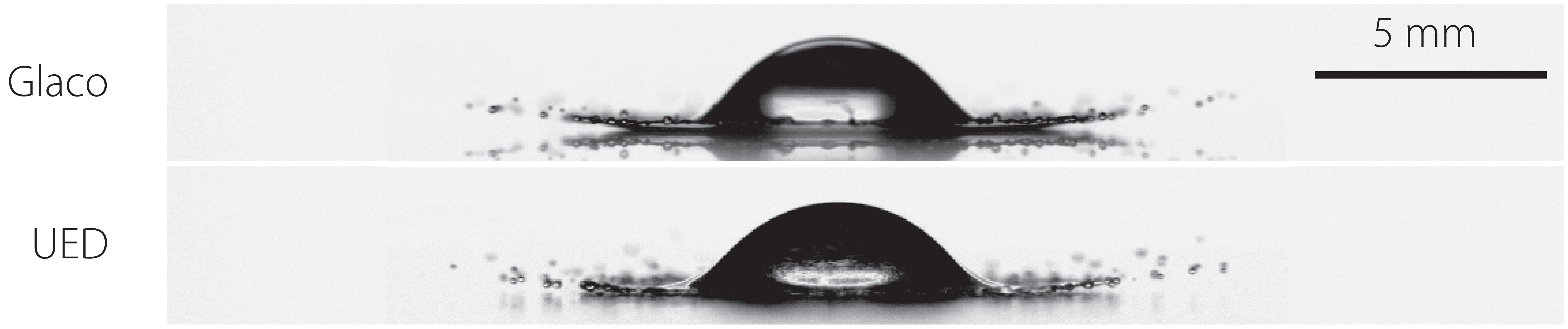
- (a-c) identical: no splash
- number of ejected droplet and duration of ejection increases with ΔT
- (g-h) seem identical

Potential scenarii for splashing?

- Air density/viscosity vary with temperature close to the substrate (not enough)
- Liquid viscosity varies with temperature (not enough)
- Surface tension
- Other possibility?

Splashing behavior on superhydrophic substrates

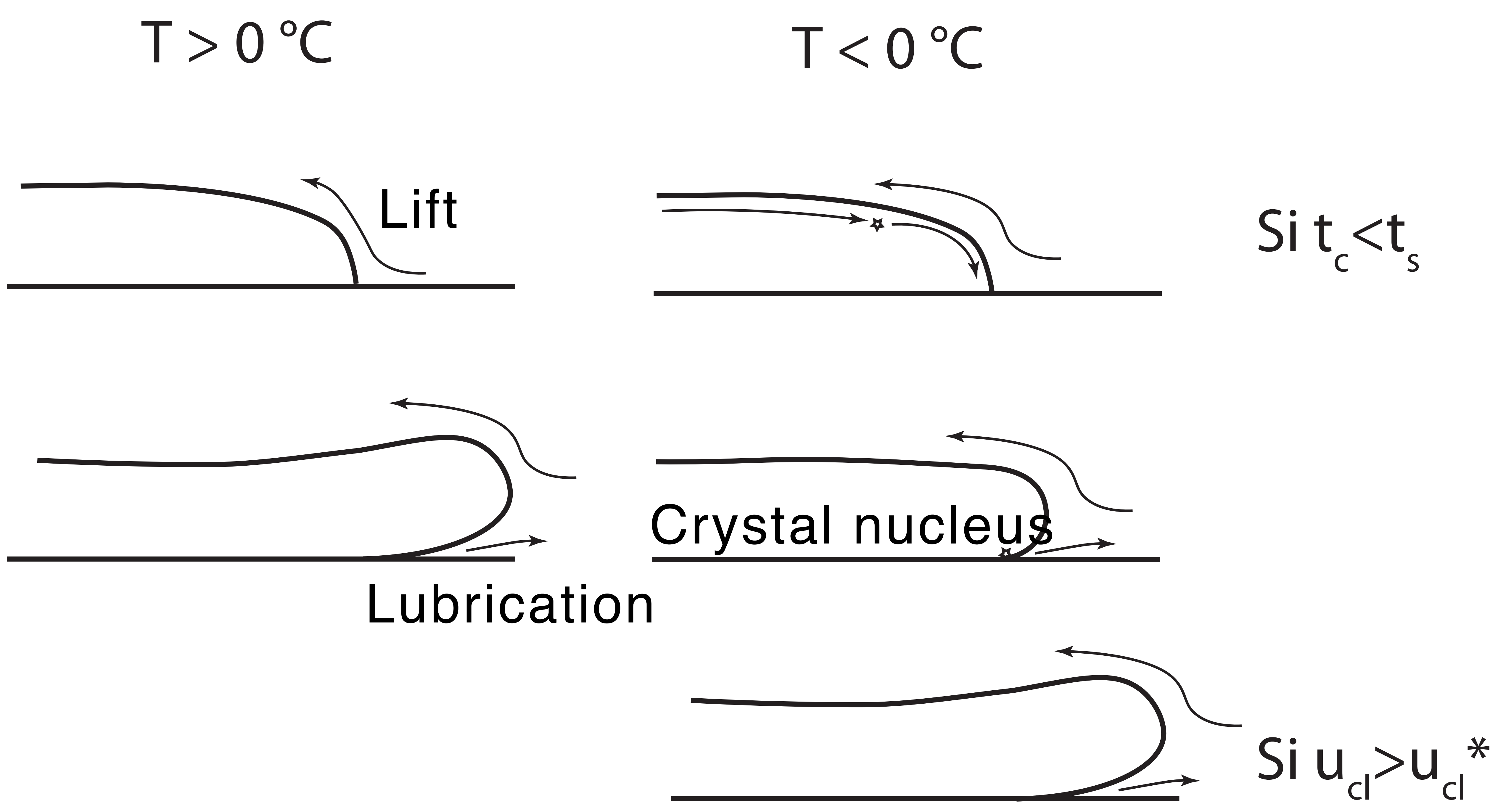




Two substrates covered with SH coatings, at T_{amb}

- splashing threshold decreased
- approximately the same value as in Region (III)
- Splashing outlook close to what is seen in Region (III)

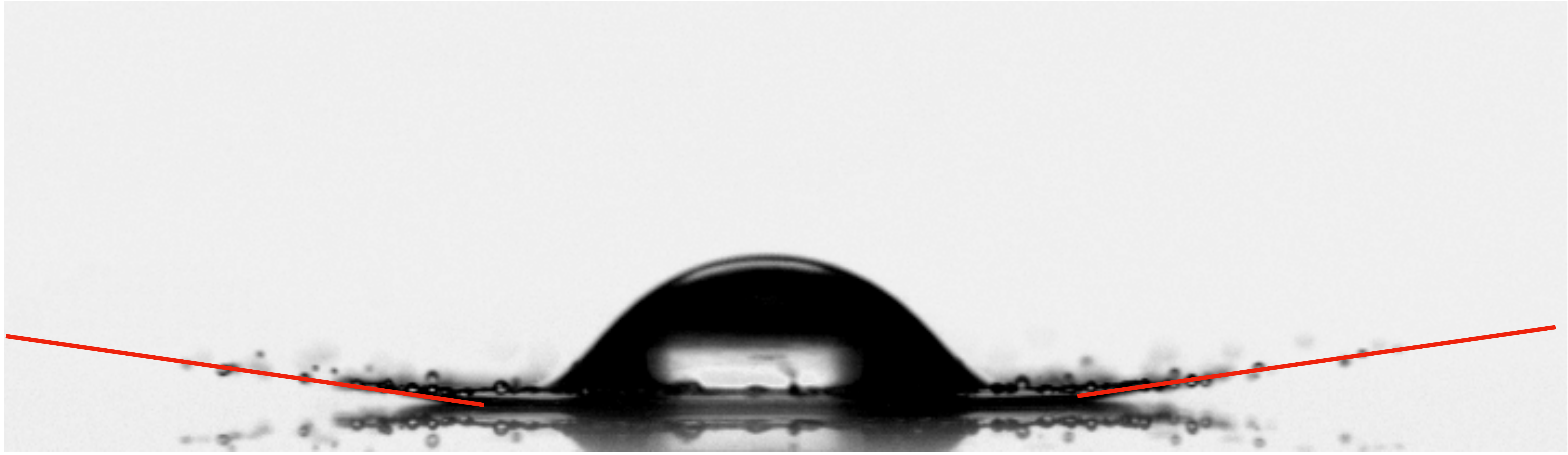
What mechanism?



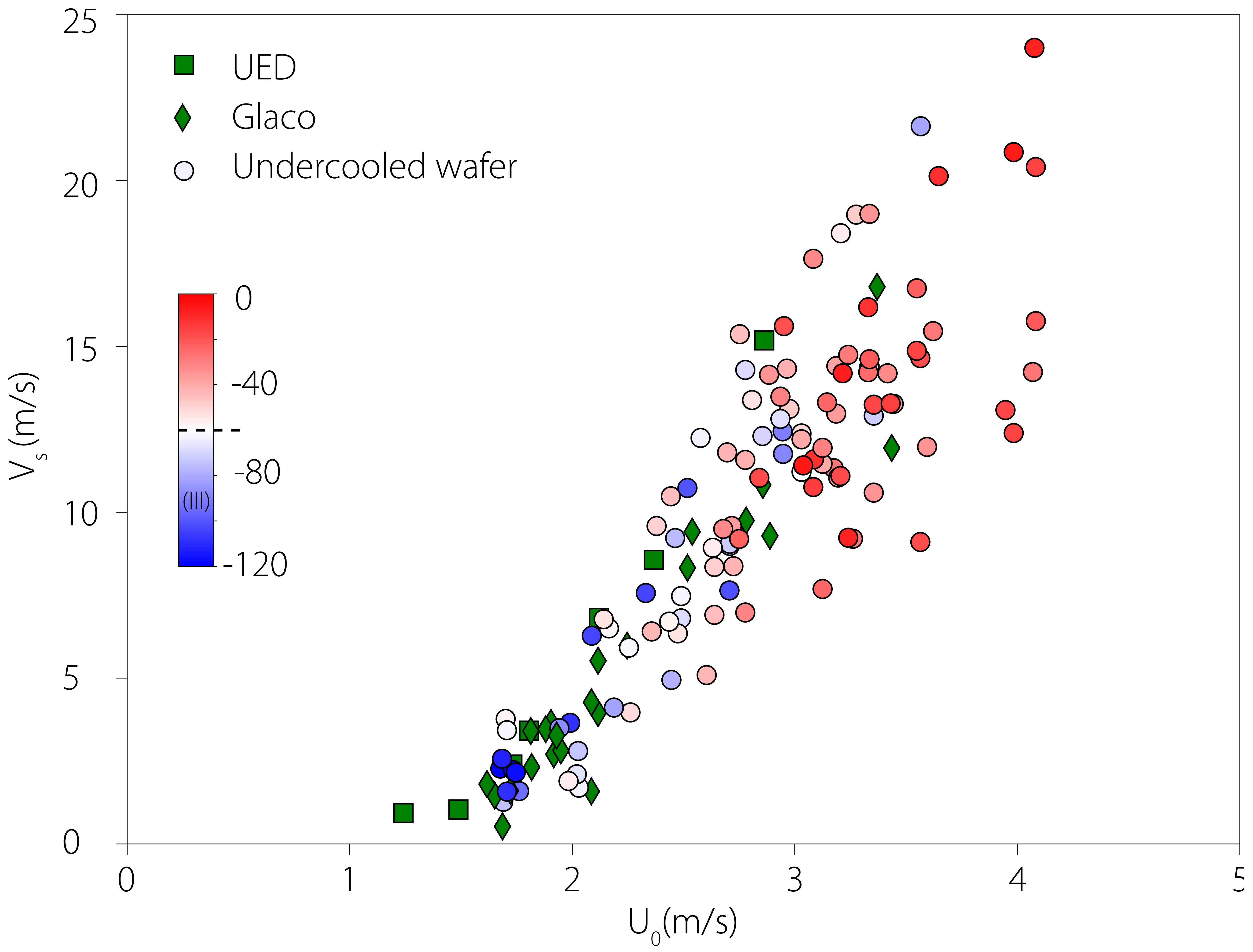
- A crystal nucleus acts as a defect an increases the maximum advancing angle of the lamella
- If the lamella goes sufficiently quickly at that time, is entraps air, and then levitates

Characterization of splashing behavior

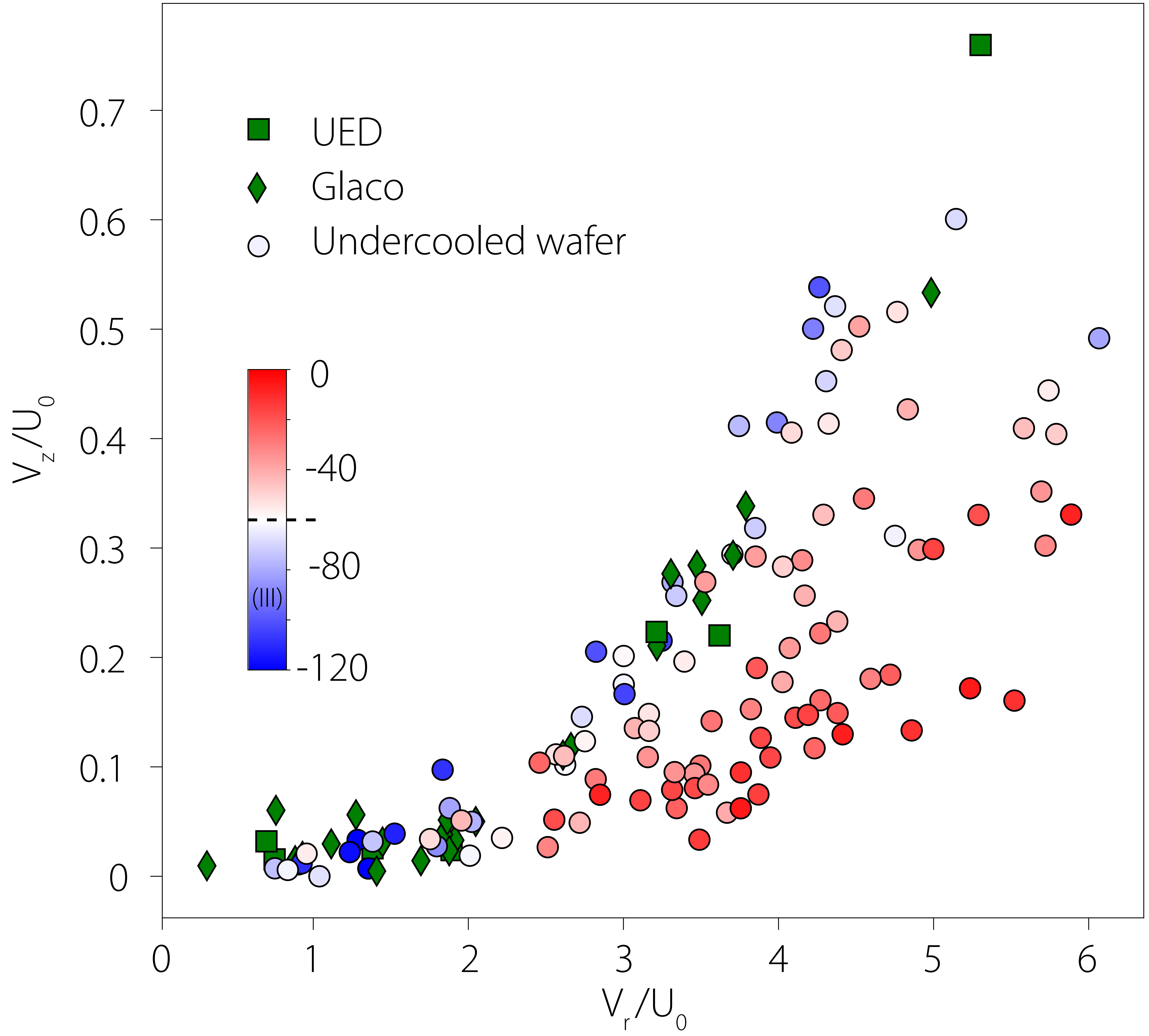
- When possible ($U_0 < 4\,\mathrm{m\,.\,s^{-1}}$) left and right fastest droplets are tracked
- Tracking provides both the velocity and the ejection angle:
  - Secondary droplet velocity norm V_s
  - Vertical velocity V_v
  - Horizontal (radial) velocity V_r



Characterization of splashing behavior



Characterization of splashing behavior



- Wettability influences the ejection angle
- Undercooling increases the angle
- All points of Region (III) collapse on the superhydrophobic asymptotic curve

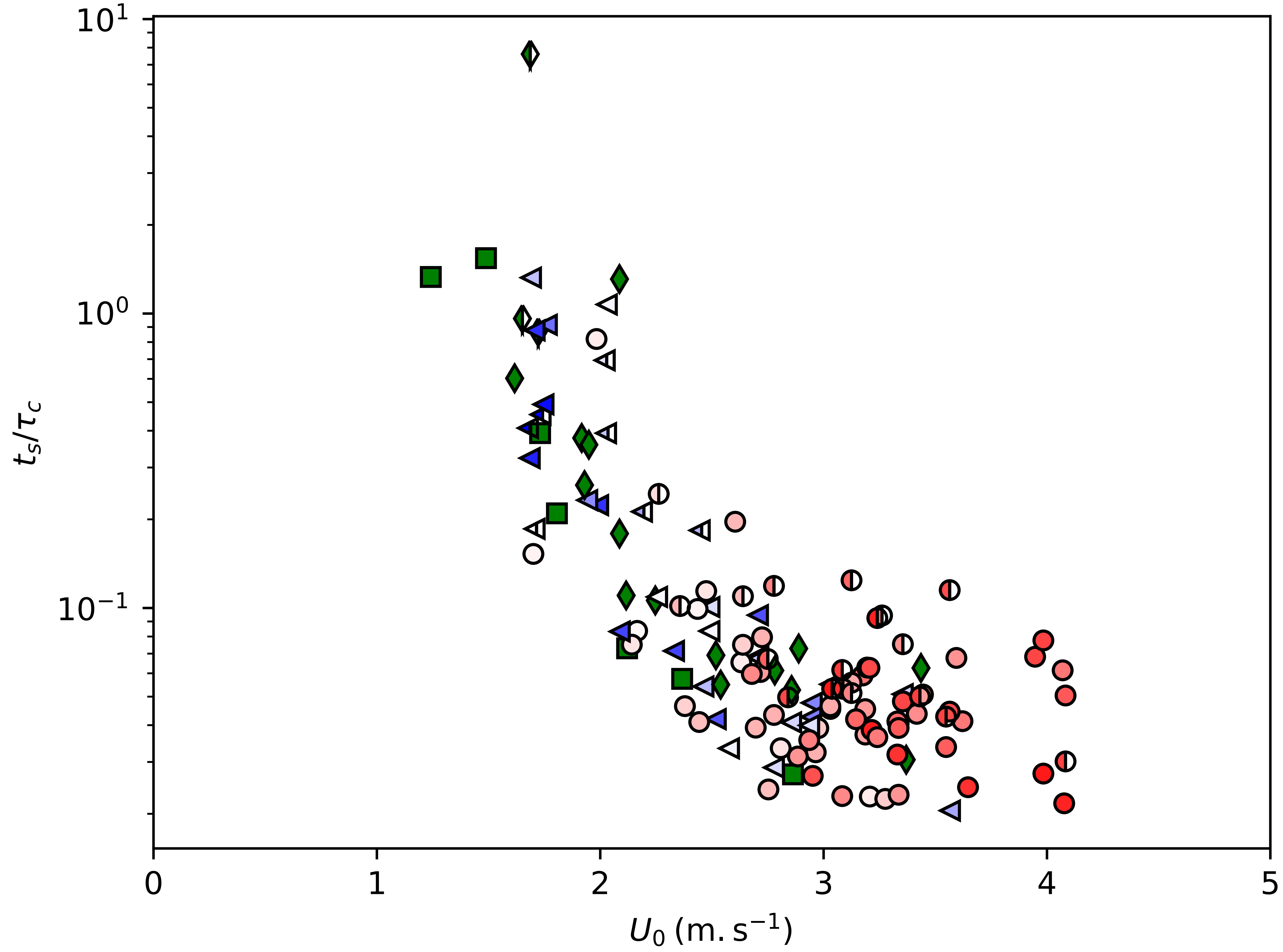
Conclusions

- Splashing transition is enhanced as the substrate temperature decreases
- Strong variations when going below freezing temperature
- « Plateau-like » region for cold enough substrate
- Splashing velocity/geometry there is similar to splashing on super-hydrophobic surface
- Explanation: ice crystal makes the drop « surface-phobic »!
- **Summer school INTERFREEZE « Freezing & Interfaces » 1-5 May 2023, Cargèse**

Appendix

Characterization of splashing behavior

- Assuming classical spreading for the lamella and that secondary drops have the lamella velocity at time of ejection



- The time of drop ejection is always smaller than the characteristic time