How does a drop solidify when spreading on a cold substrate ?

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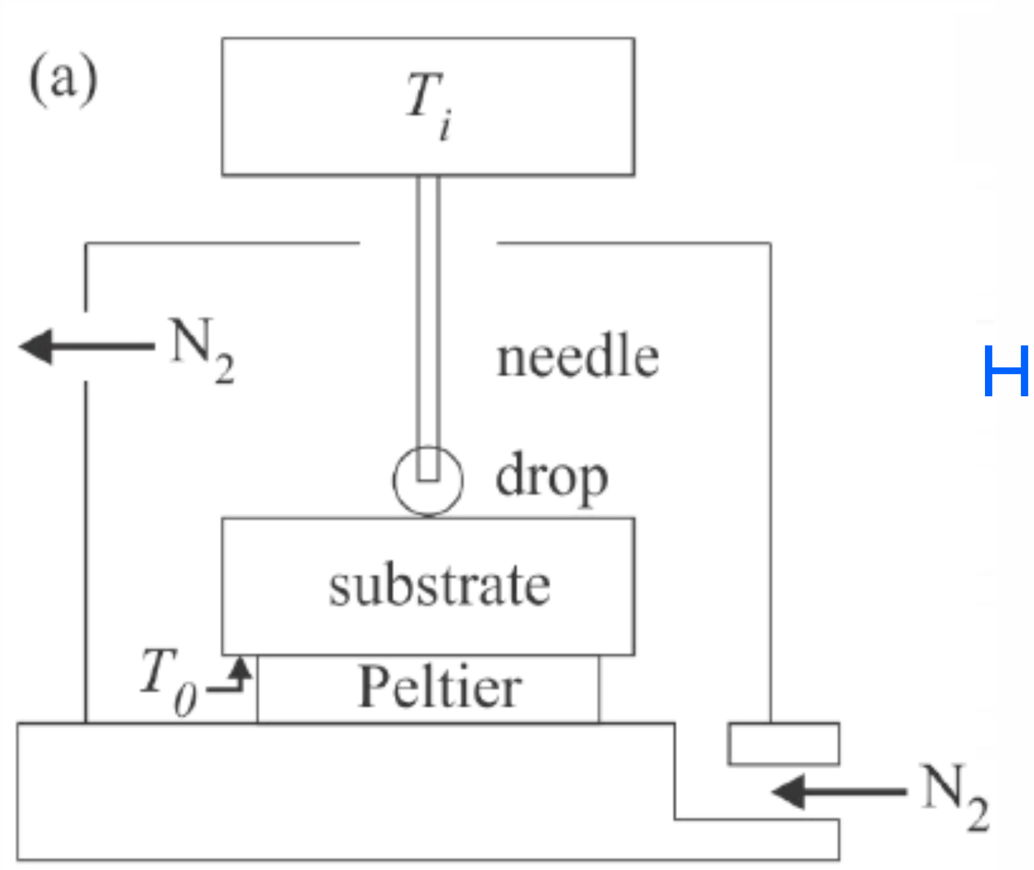
Experimental setup & conditions

Liquid : hexadecane (no subcooling, T_f = 18°C) - Simple spreading (We<<1) perfect wetting θ =0)



Highly-conductive and poorly-conductive substrates : copper and glass

T_i between 20°C and 48°C

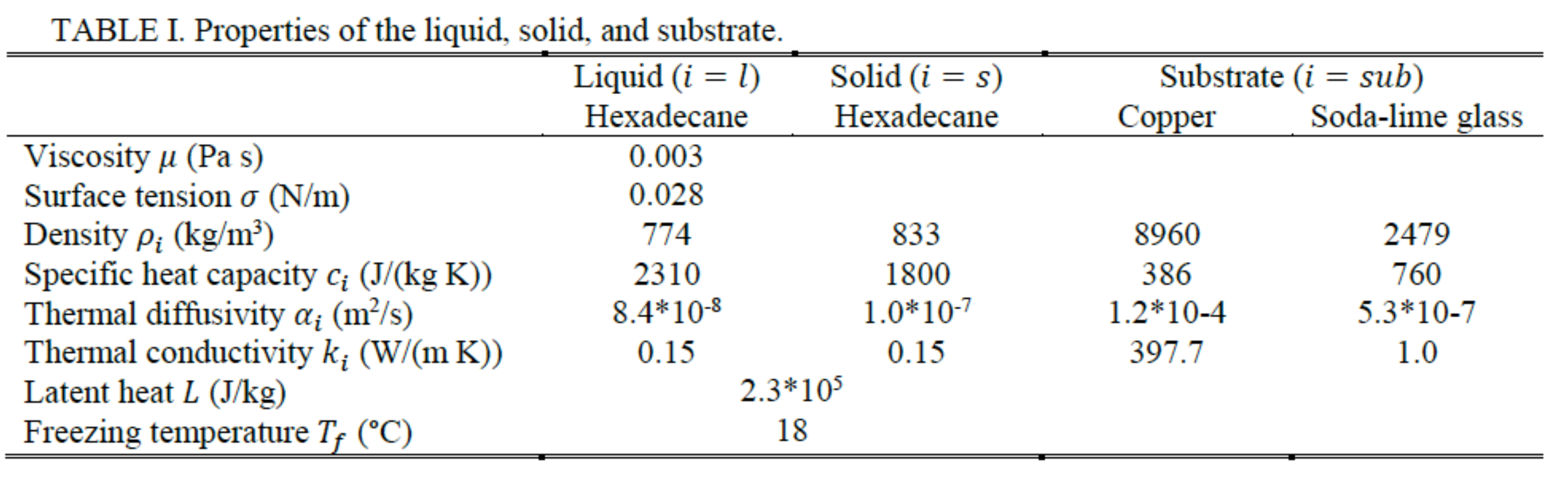
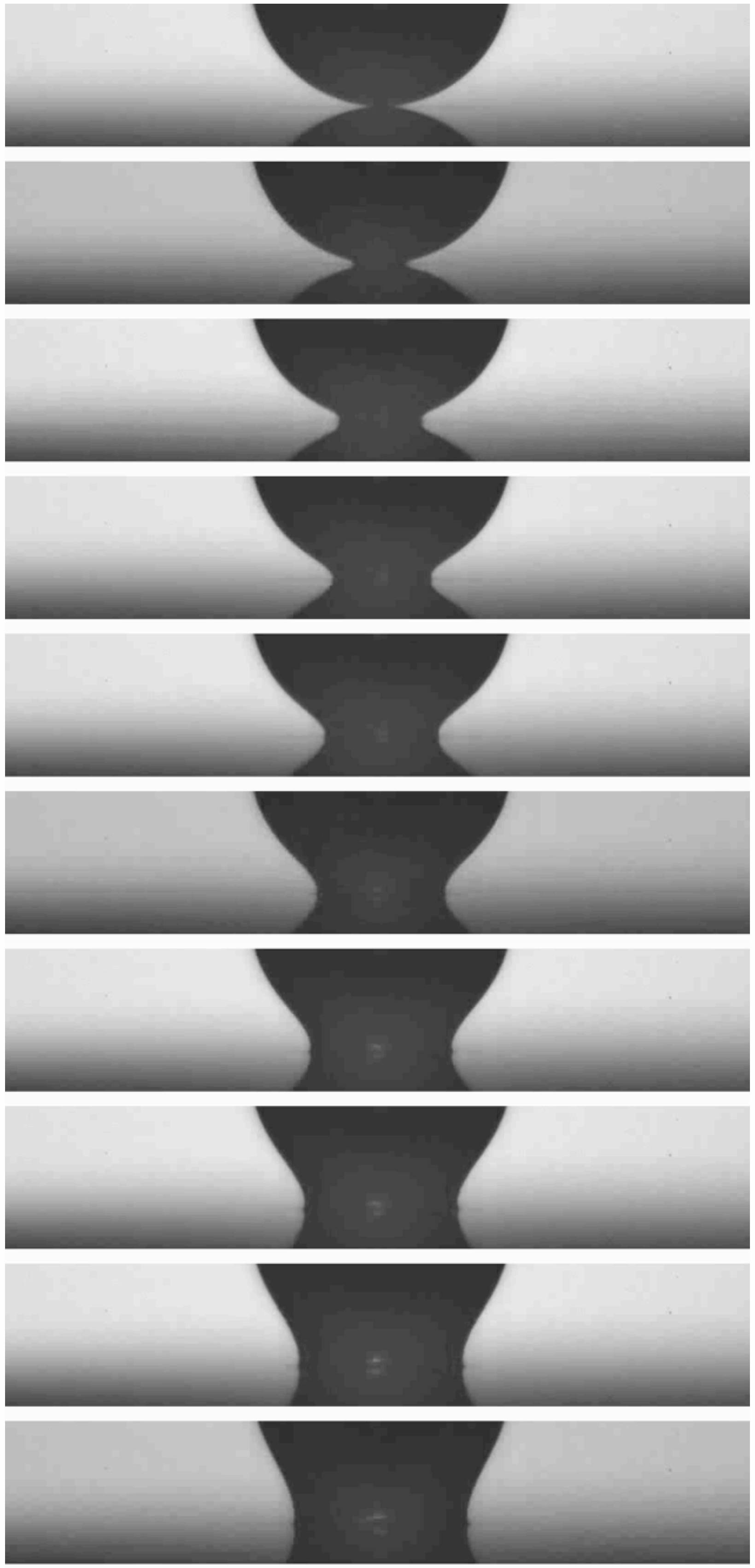


TABLE I. Properties of the liquid, solid, and substrate.

	Liquid ($i = l$) Hexadecane	Solid ($i = s$) Hexadecane	Substrate ($i = sub$) Copper	 Soda-lime glass
Viscosity μ (Pa s)	0.003			
Surface tension σ (N/m)	0.028			
Density ρ_i (kg/m^3)	774	833	8960	2479
Specific heat capacity c_i (J/(kg K))	2310	1800	386	760
Thermal diffusivity α_i (m^2/s)	$8.4*10^{-8}$	$1.0*10^{-7}$	1.2*10-4	5.3*10-7
Thermal conductivity k_i (W/(m K))	0.15	0.15	397.7	1.0
Latent heat L (J/kg)	$2.3*10^5$			
Freezing temperature T_f (°C)	18			

Typical sequence ...



First millisecond

$T_{sub} < T_f$ (18°C)

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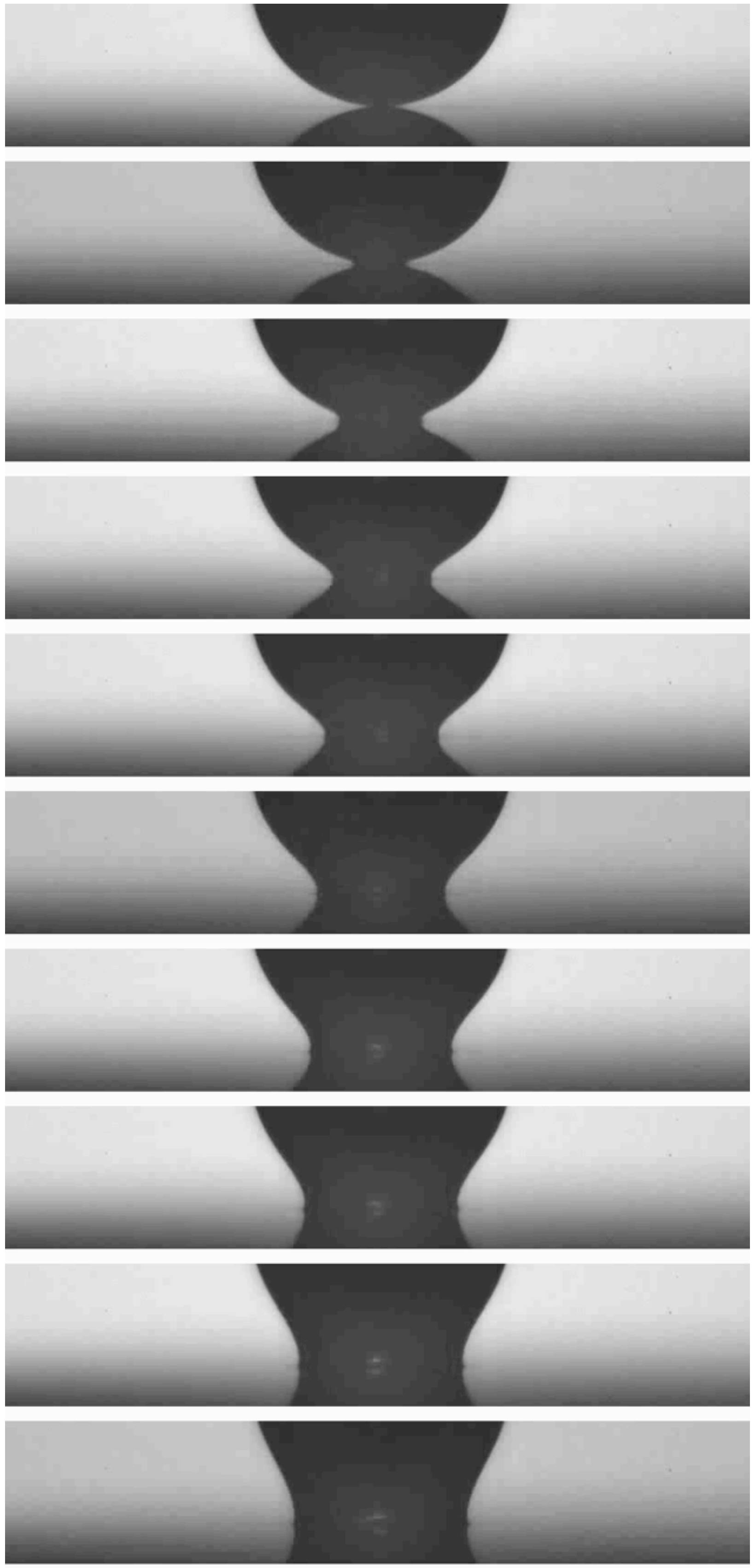

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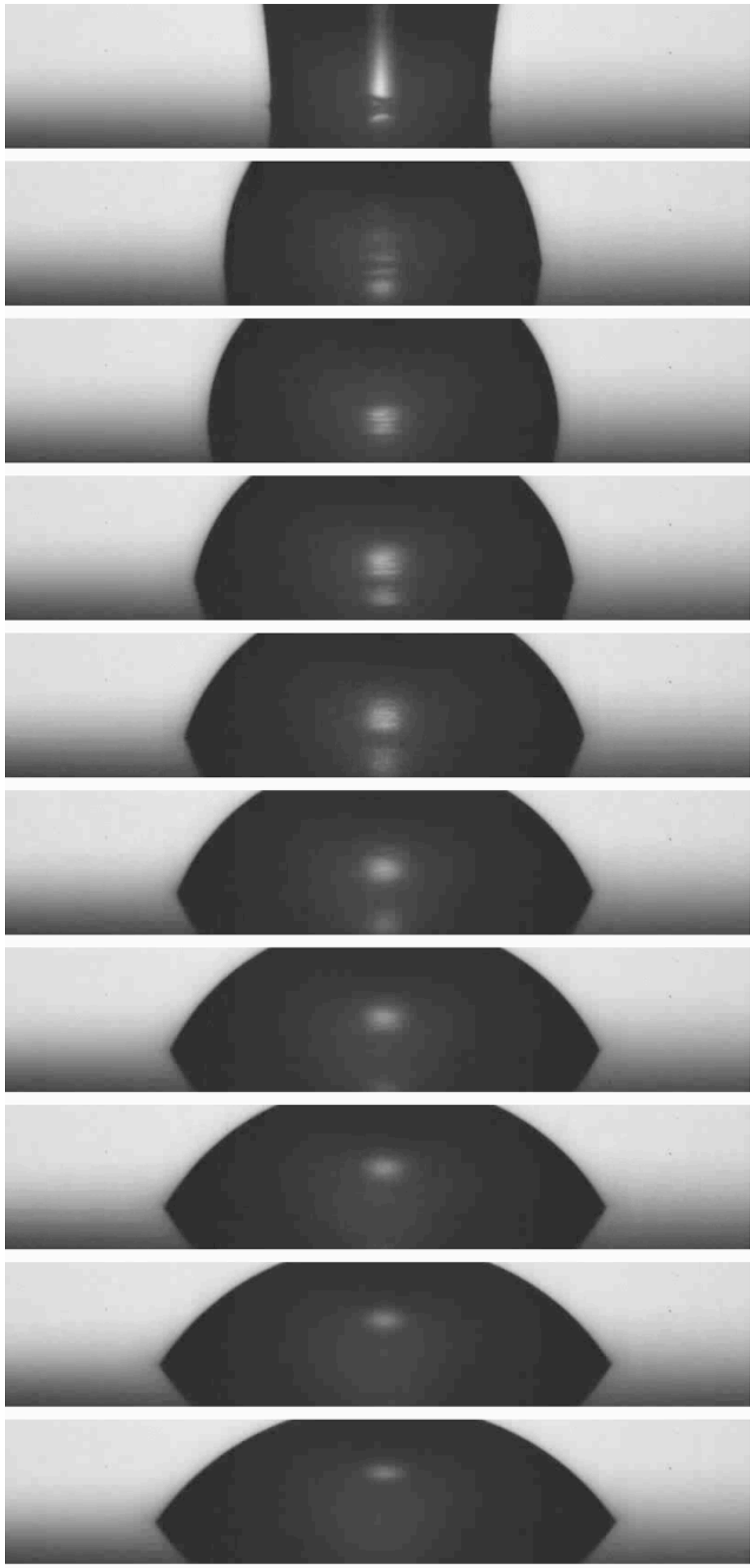
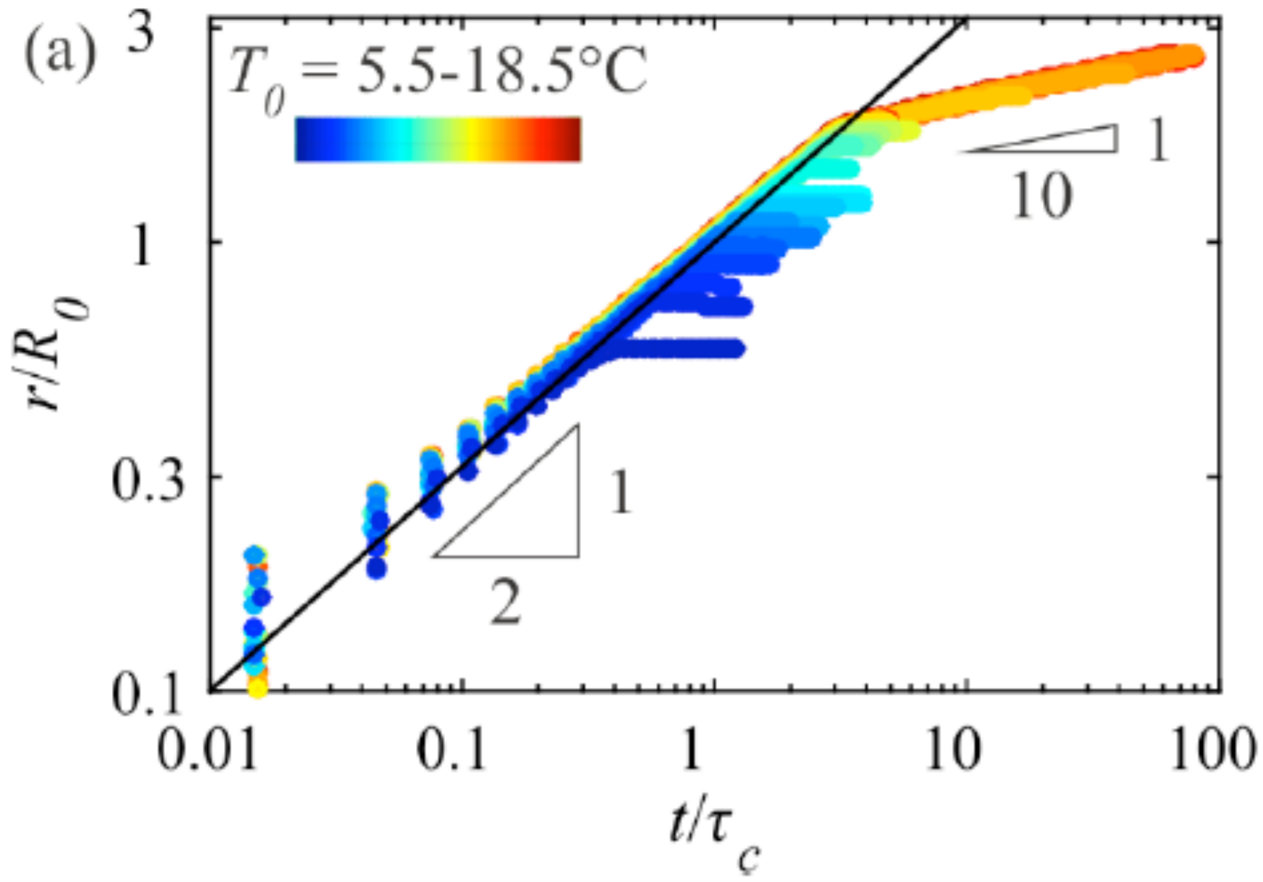


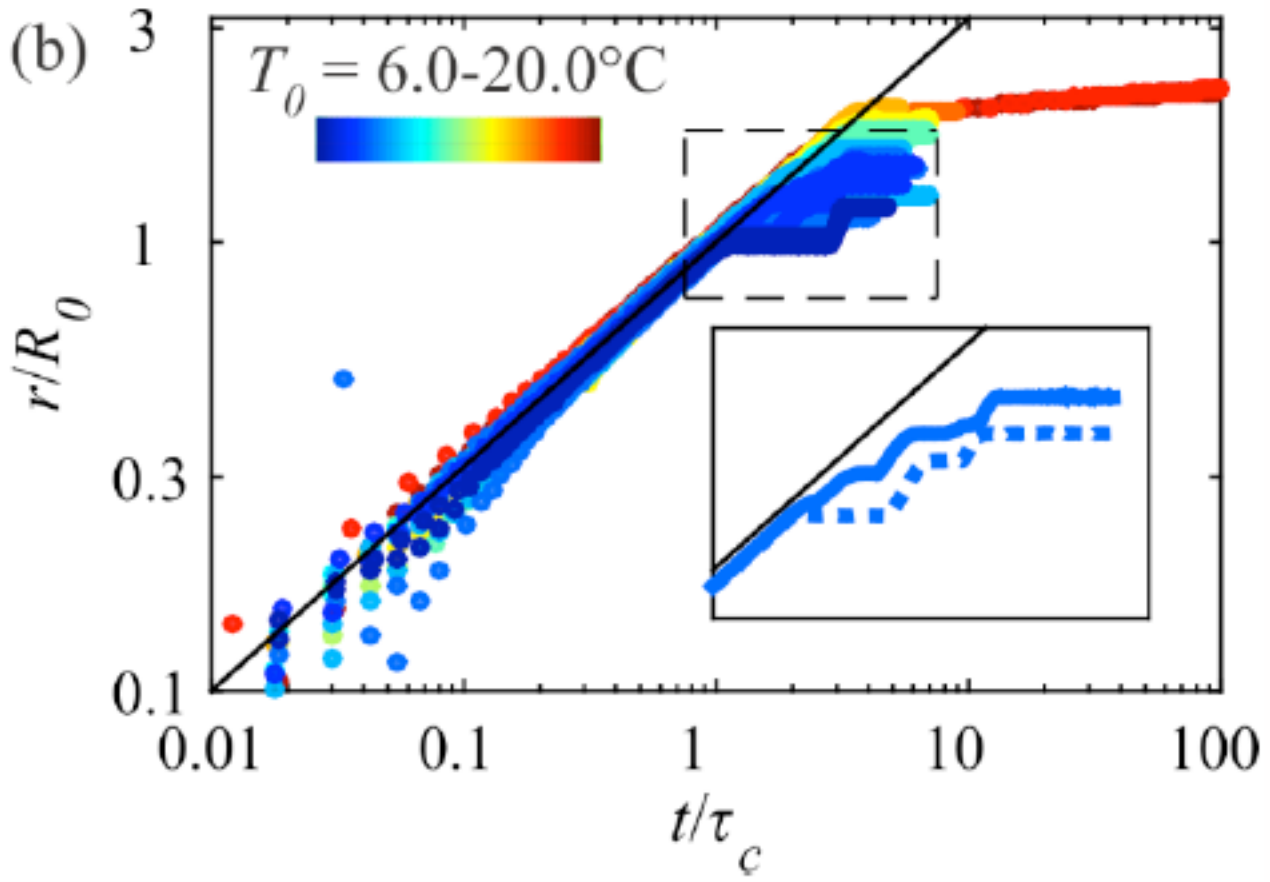
Last 20 ms

Spreading dynamics : results

Conductive substrate



Non-conductive substrate



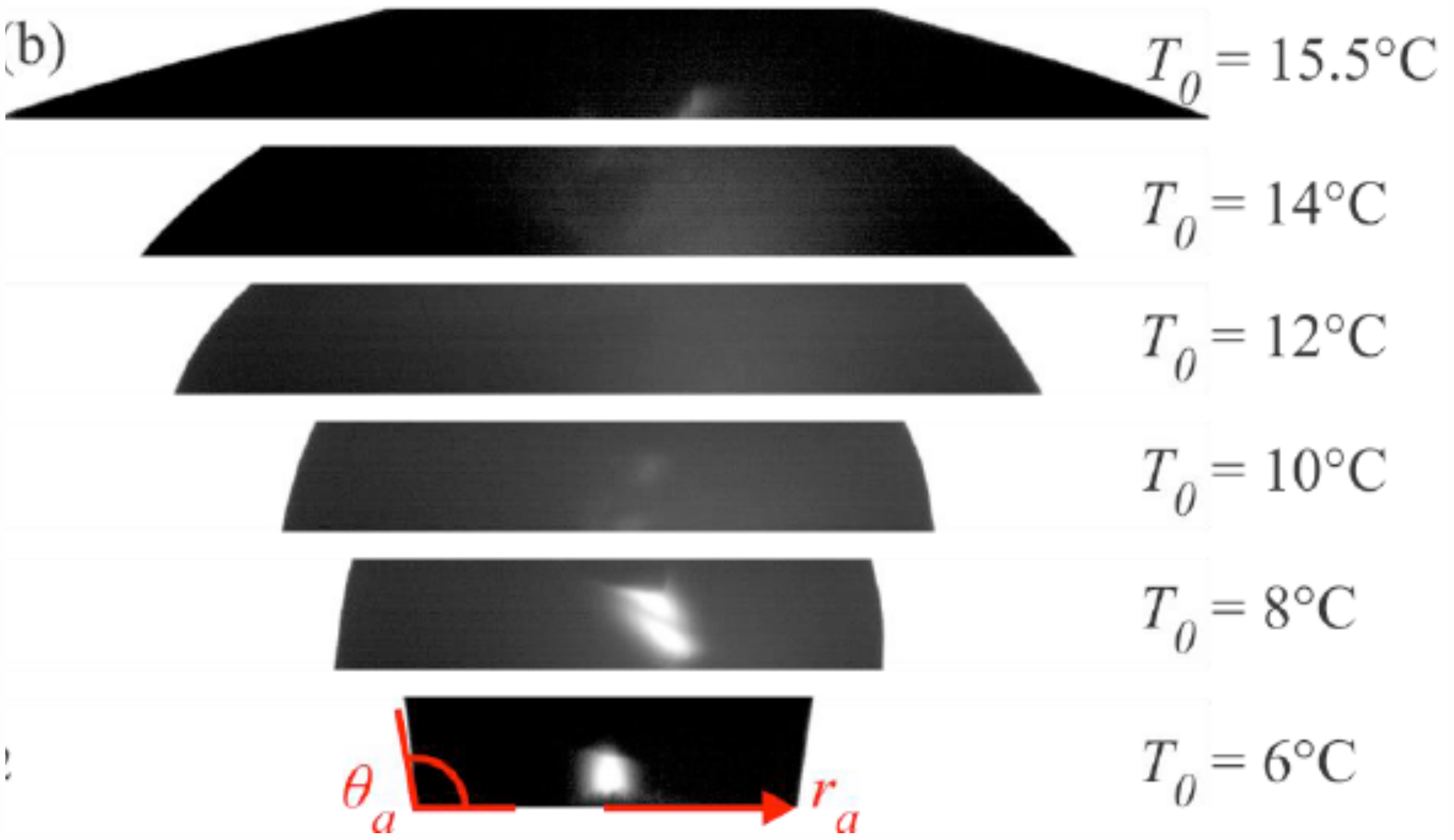
Two regimes of spreading :

Early time : $\frac{r}{R_0} \sim \left(\frac{t}{\tau_c}\right)^{\frac{1}{2}}$ balance between inertia and capillarity

$$\rho \left(\frac{dr}{dt}\right)^2 \sim \frac{\gamma R_0}{r^2}$$

Substrate temperature

Final shapes

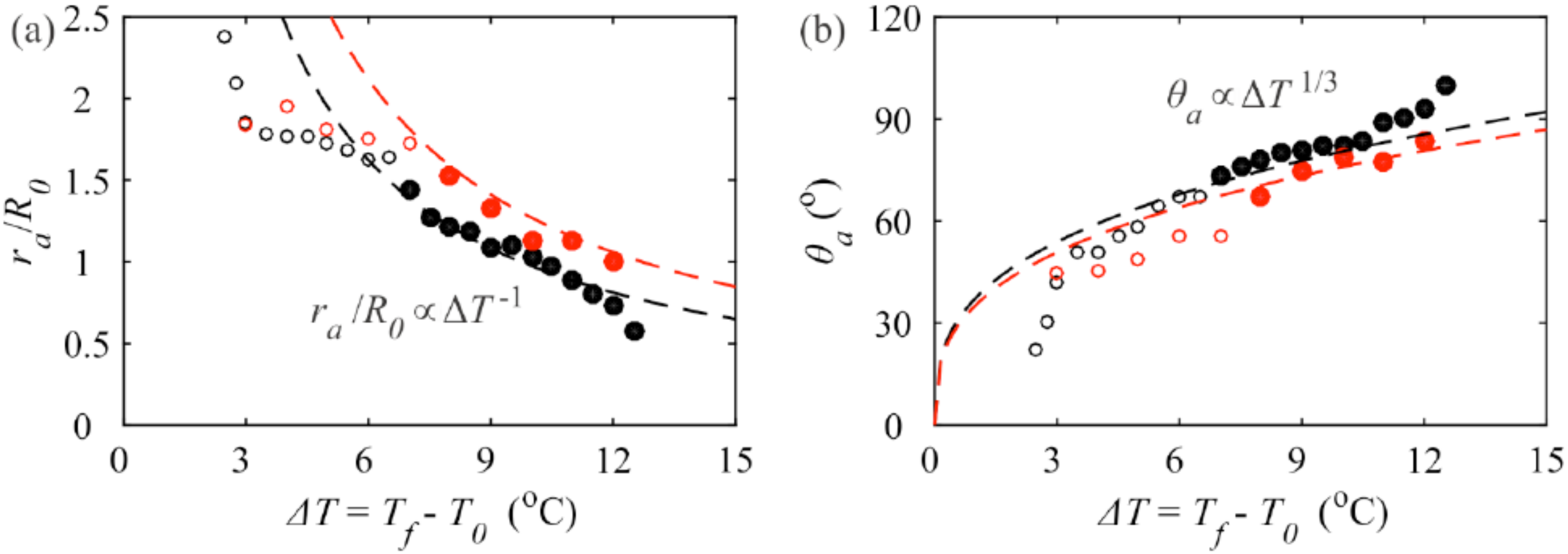


Surprising facts :

The drop can spread on a substrate where $T_0 < T_m$!

Very weak dependence on injected liquid temperature !

Radius of arrest



● Copper, arrest in inertial (early) regime

○ Copper, arrest in viscous (late) regime

● Glass, arrest in viscous (late) regime

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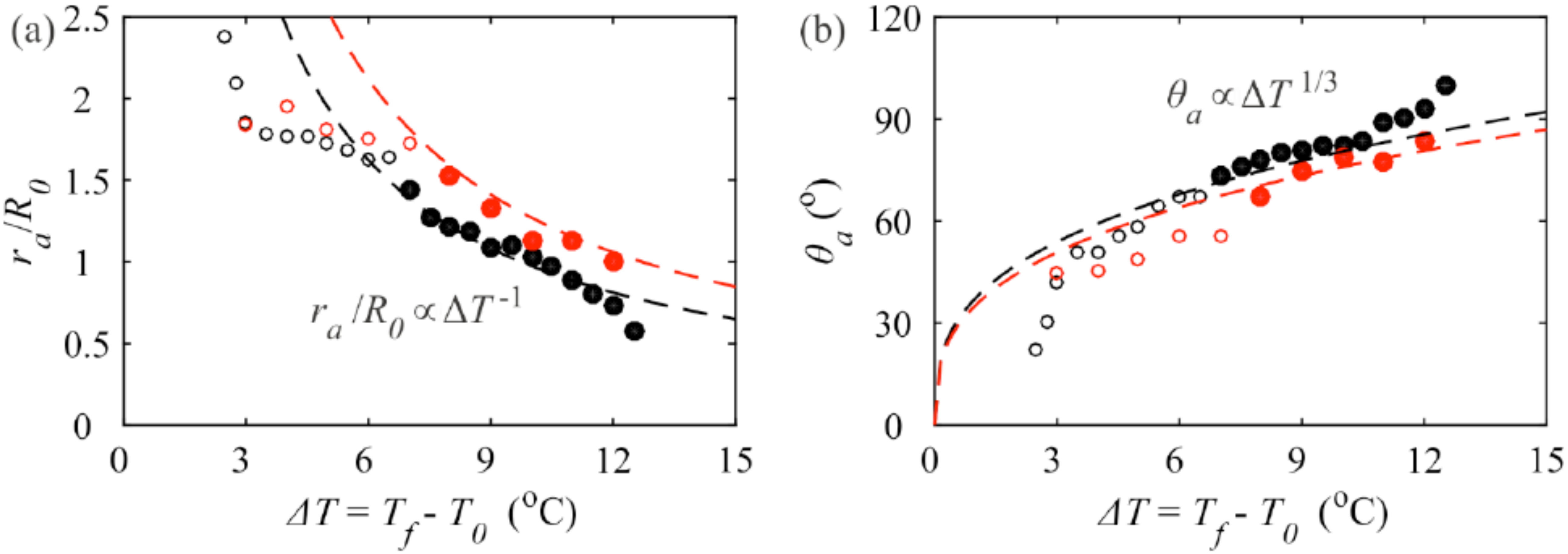

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Kinetic undercooling : $T_f - T_{front} = v_{front}/\kappa$

Main fact : temperature is minimal at CL ! $T_{cl} = T_{cl,a} = T_f - v_{cl,a}/\kappa$

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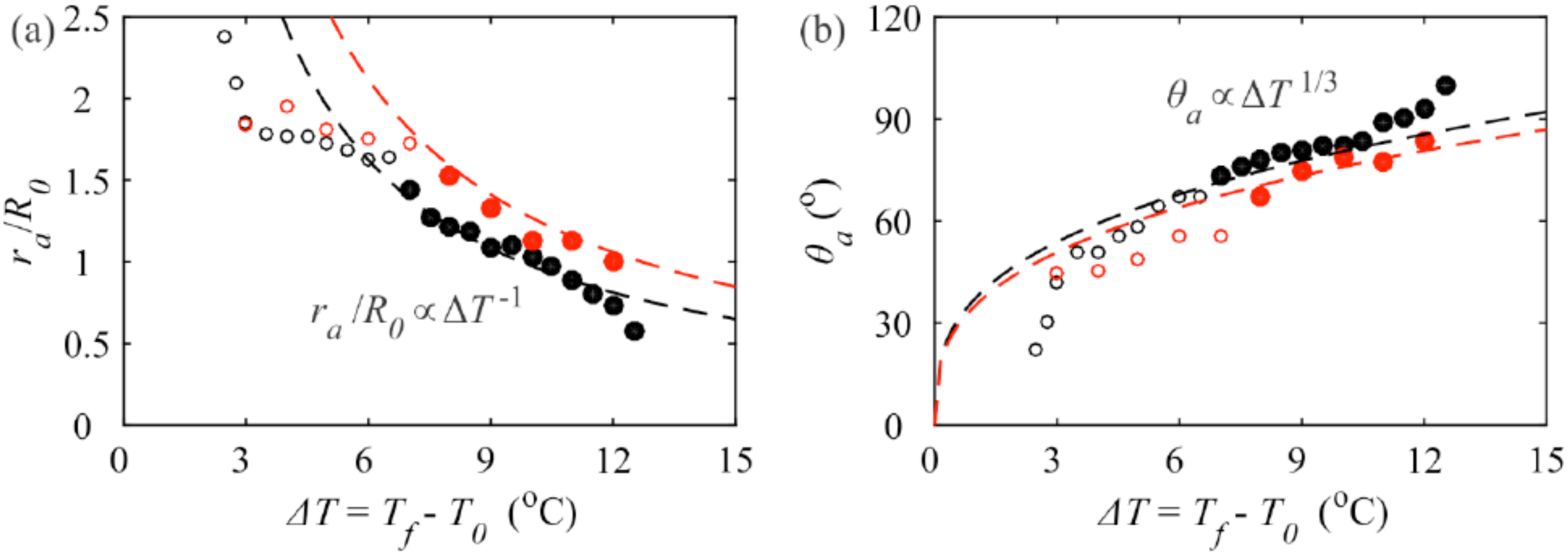

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$$\longrightarrow \boxed{r_a/R_0 = R_0/(2\tau_c\kappa\Delta T) \propto \Delta T^{-1}}$$

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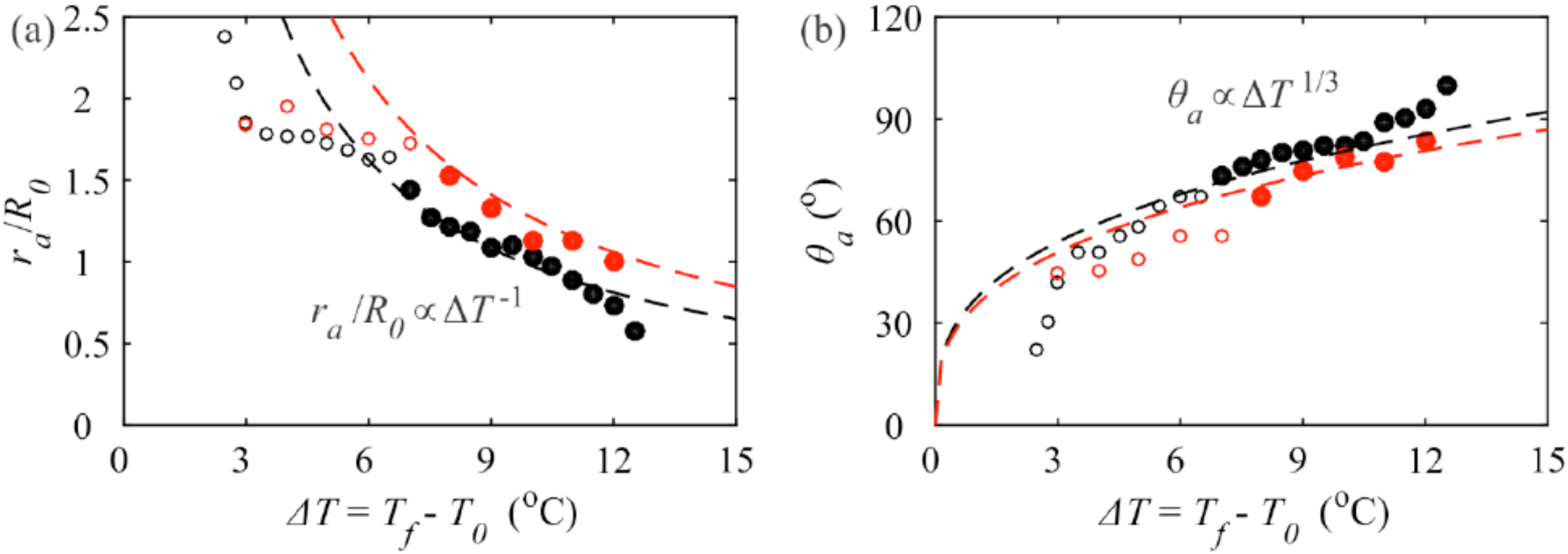

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Cox-Voinov's law :

$$\longrightarrow \boxed{\theta_a = [9\mu\ln(R_o/l)\,\kappa\Delta T/\sigma]^{1/3} \propto \Delta T^{1/3}}$$

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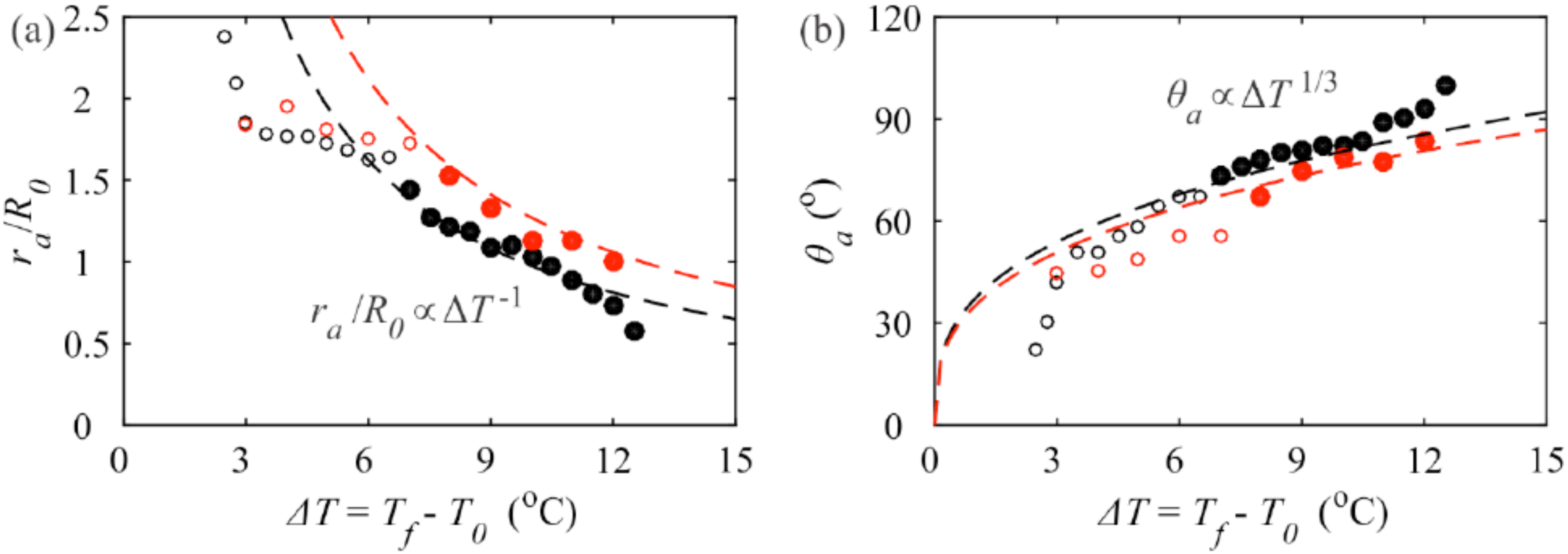

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K = 0.011 m/(s K)

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