A gravity driven inverse cascade controls the size distribution of raindrops

Florian Poydenot[1,2], Bruno Andreotti[2]

1. Meteorological Institute, University of Hamburg
2. Laboratoire de Physique de l'Ecole Normale Supérieure (LPENS), Paris, France

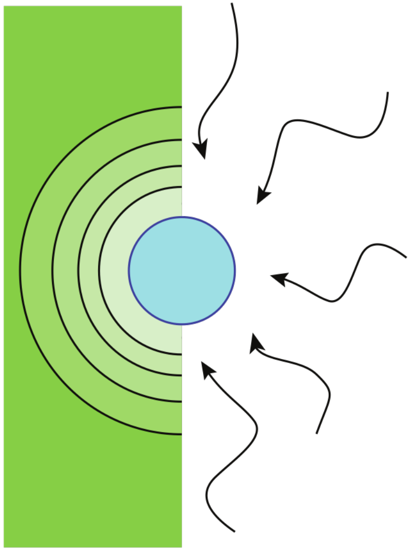
21/03/2025

LPENS
LABORATOIRE DE PHYSIQUE
DE L'ÉCOLE NORMALE SUPÉRIEURE

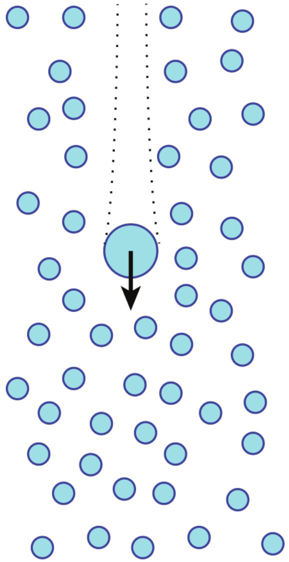
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

The warm rain process

Condensation growth

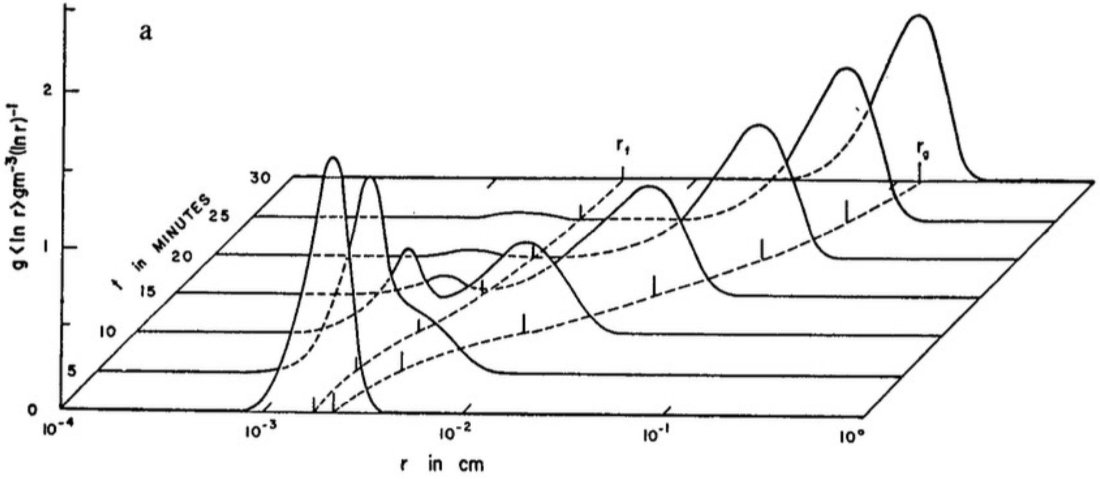


Collision-coalescence:



$$U^t \propto \sqrt{R}$$

Berry & Reinhardt, 1974

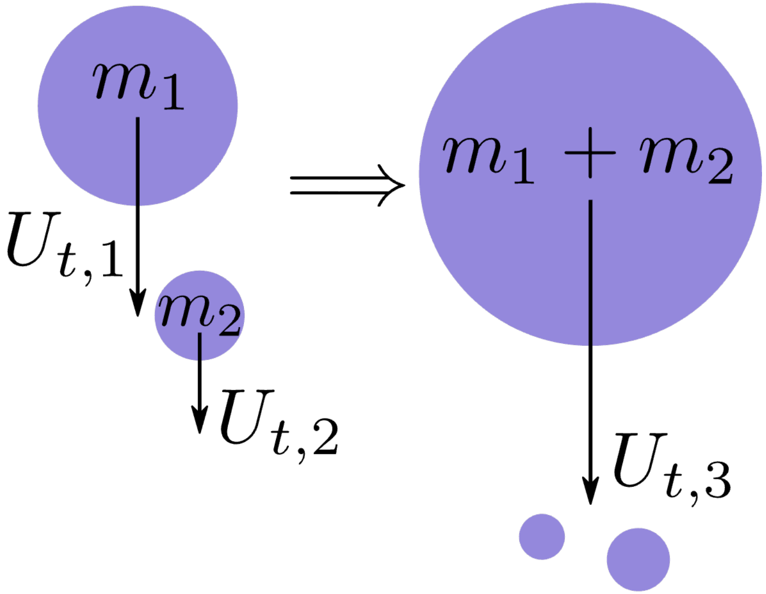


What controls the rain initiation time and the DSD?

Statistical description of growth by collision

$$U^t \propto \sqrt{R}$$

Nonlinear growth process:



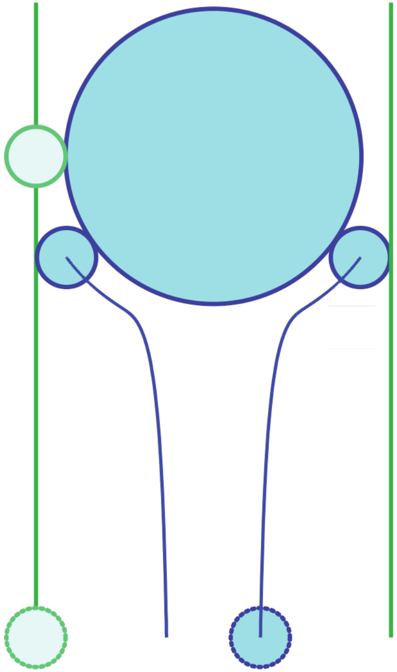
$$\frac{\partial n}{\partial t} = \frac{1}{2} \int_{m_1+m_2=m} \mathrm{d}m_1 \mathrm{d}m_2 \, K_{12} n(m_1) n(m_2) - \int_0^\infty \mathrm{d}m_1 \, K_{12} n(m) n(m_1)$$

Collision kernel:

$$K_{12} = \underbrace{\pi (R_1 + R_2)^2}_{\text{cross-section}} \underbrace{(U_1^t - U_2^t)}_{\text{relative velocity}}$$

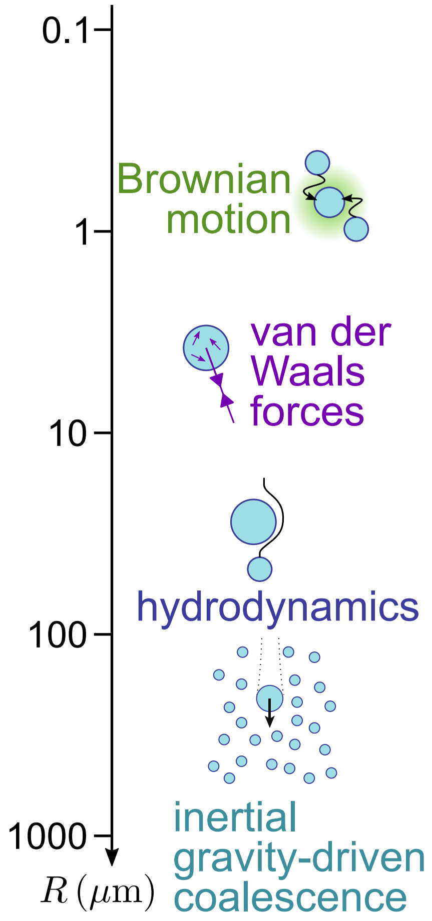
A collision kernel from µm- to mm-size droplets

$$\mathrm{St} = \frac{\tau_{\mathrm{inertia}}}{\tau_{\mathrm{forces}}}$$

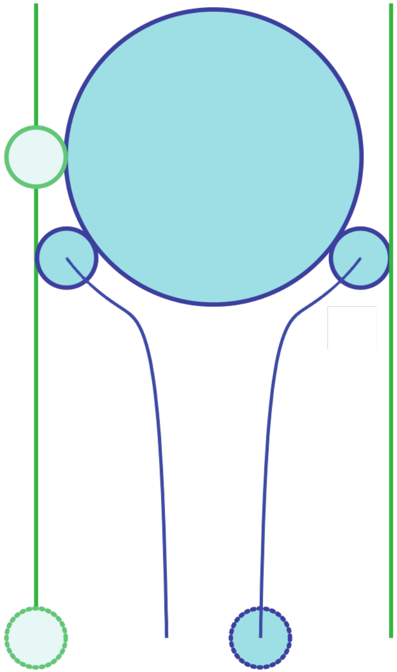


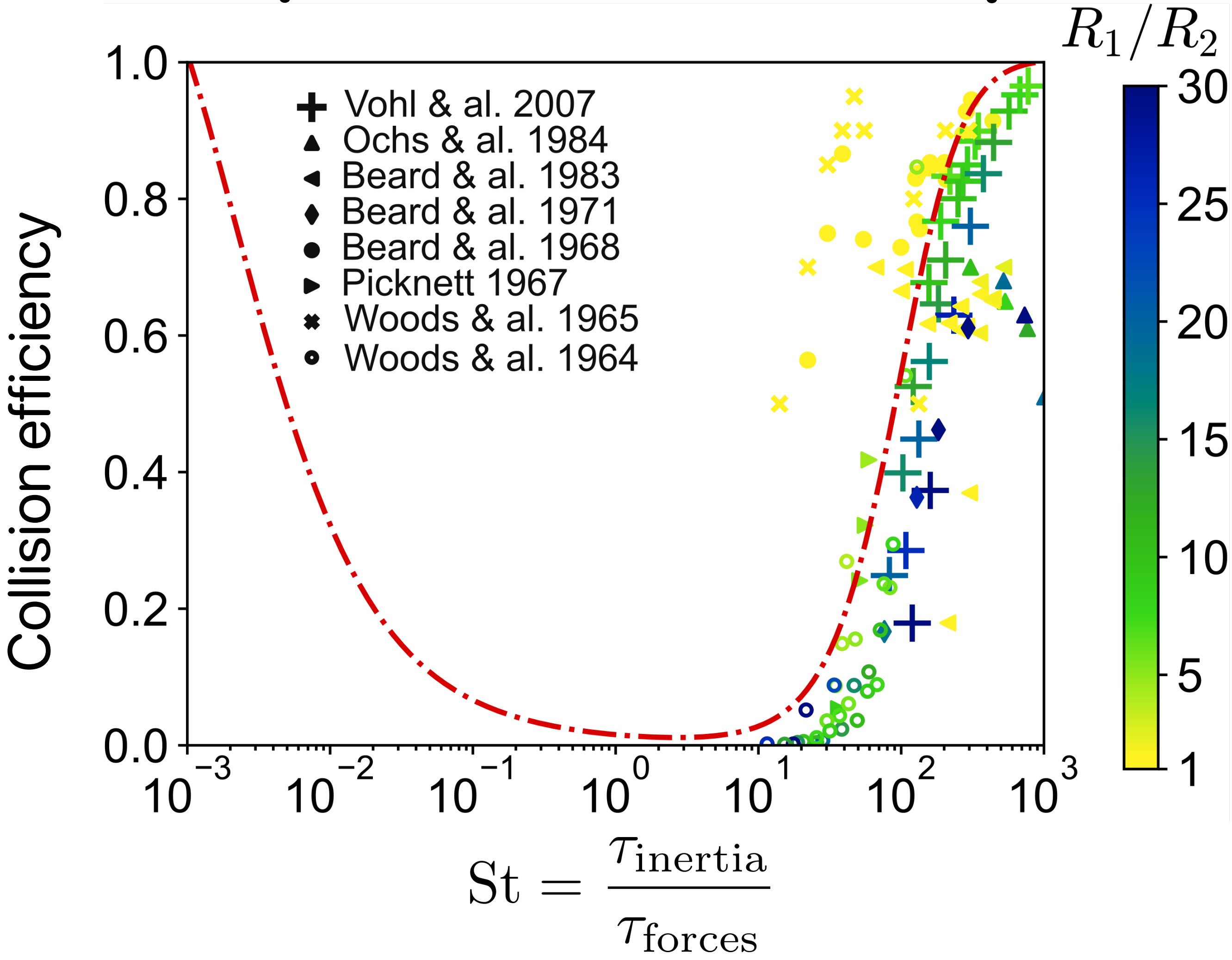
- Monte-Carlo simulation of binary droplet collision
- Taking into account finite Reynolds effects, non-continuum effects in the lubrication film, van der Waals interactions and Brownian motion

F. Poydenot, B. Andreotti, JFM 2024

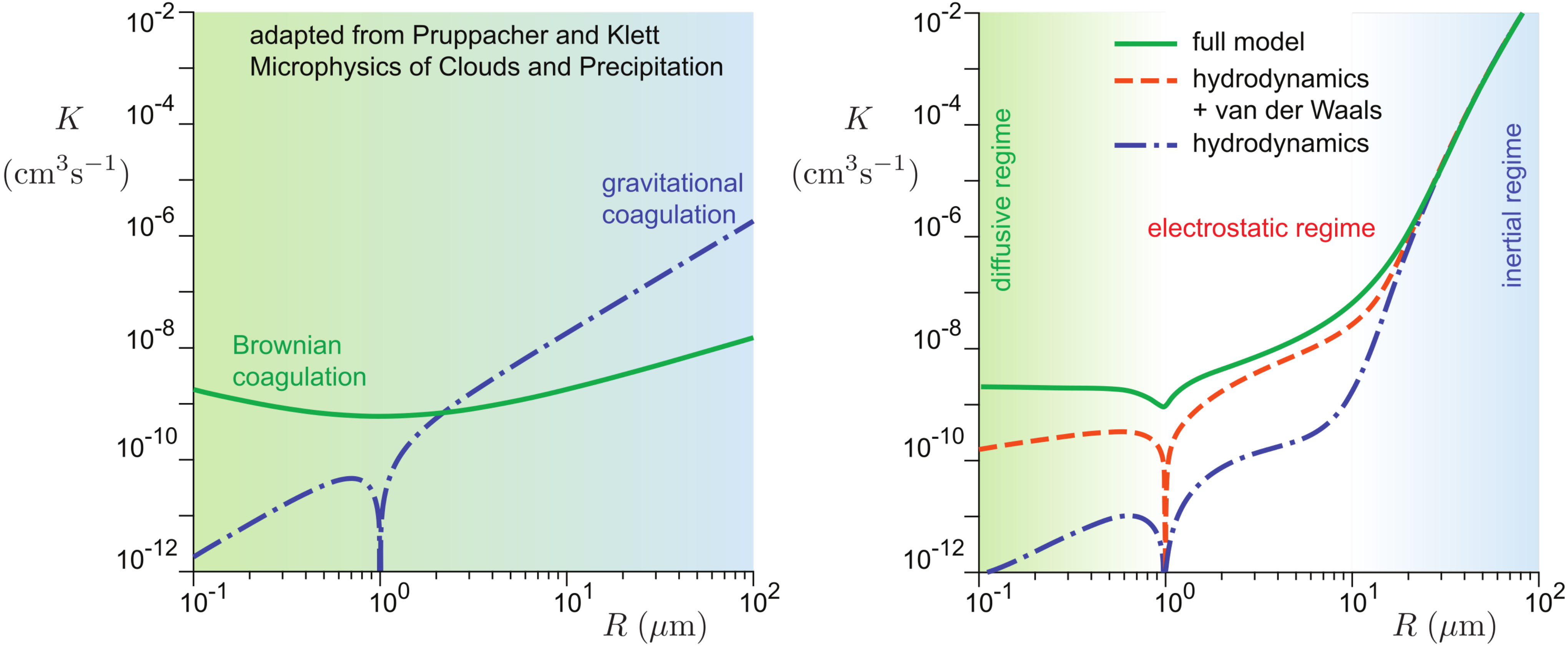


A collision kernel from µm- to mm-size droplets



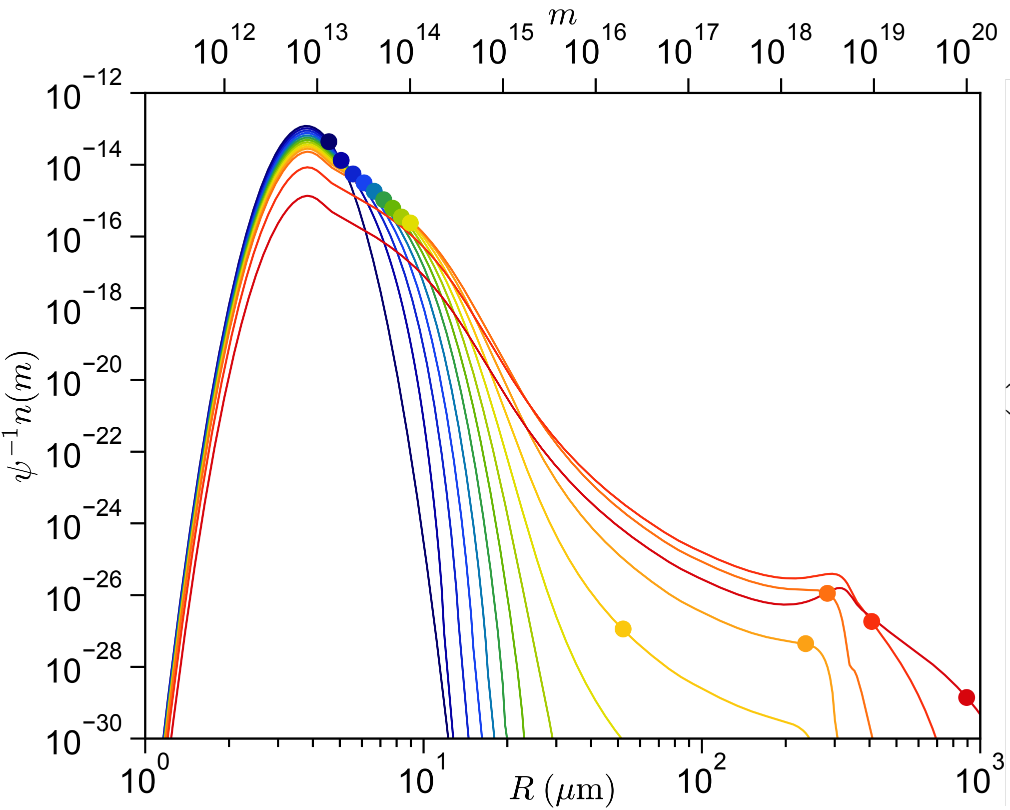


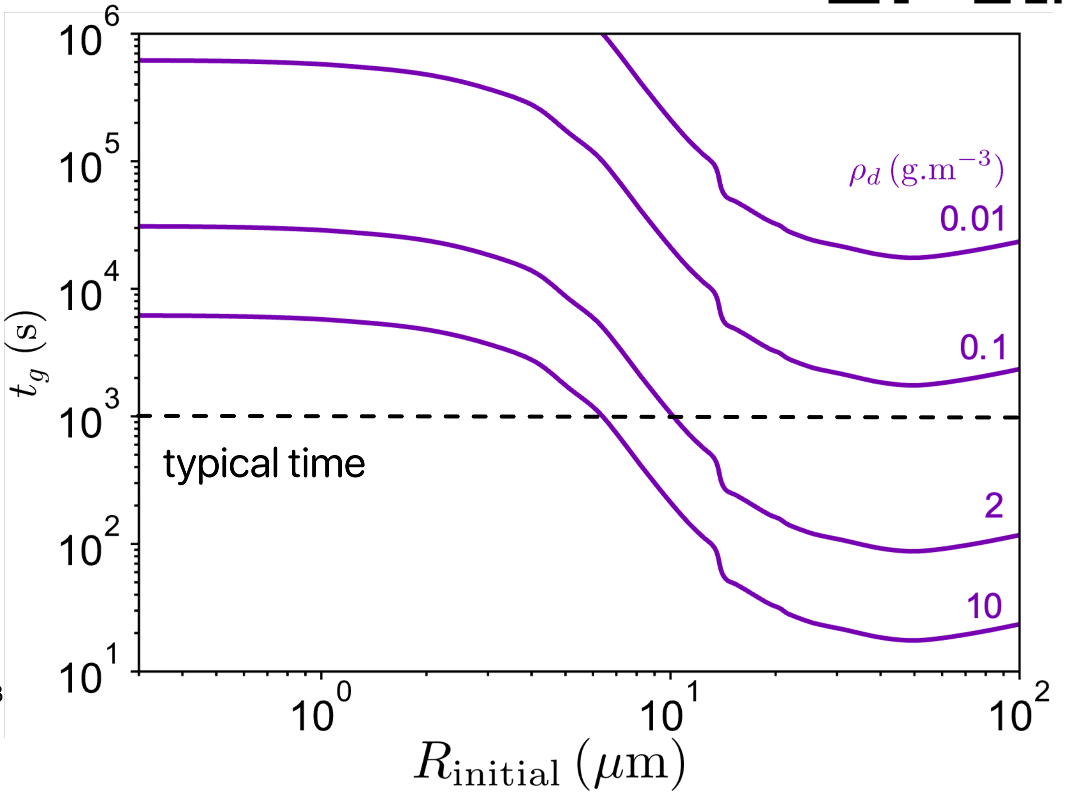
A new picture of the collision kernel



Rain initiation time

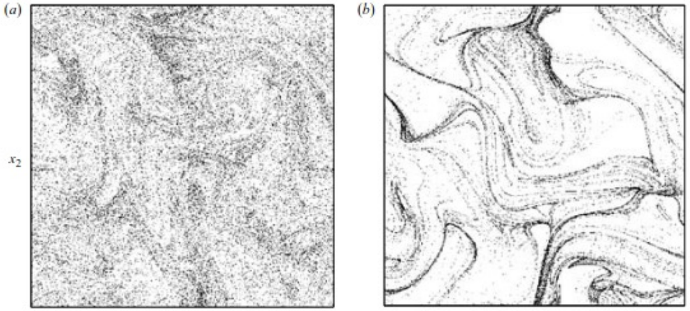
Idealized homogeneous box model
F. Poydenot, B. Andreotti, PRF 2024

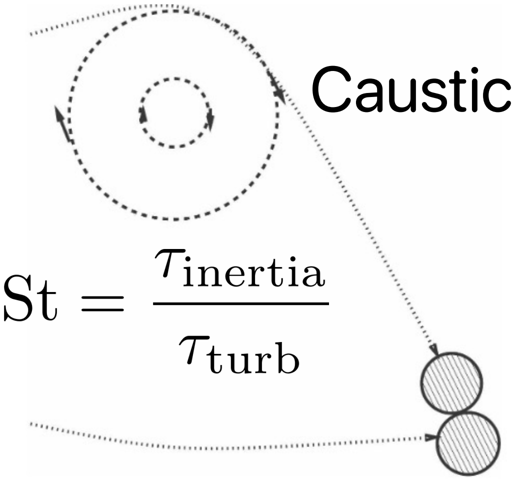




Collisions due to turbulence

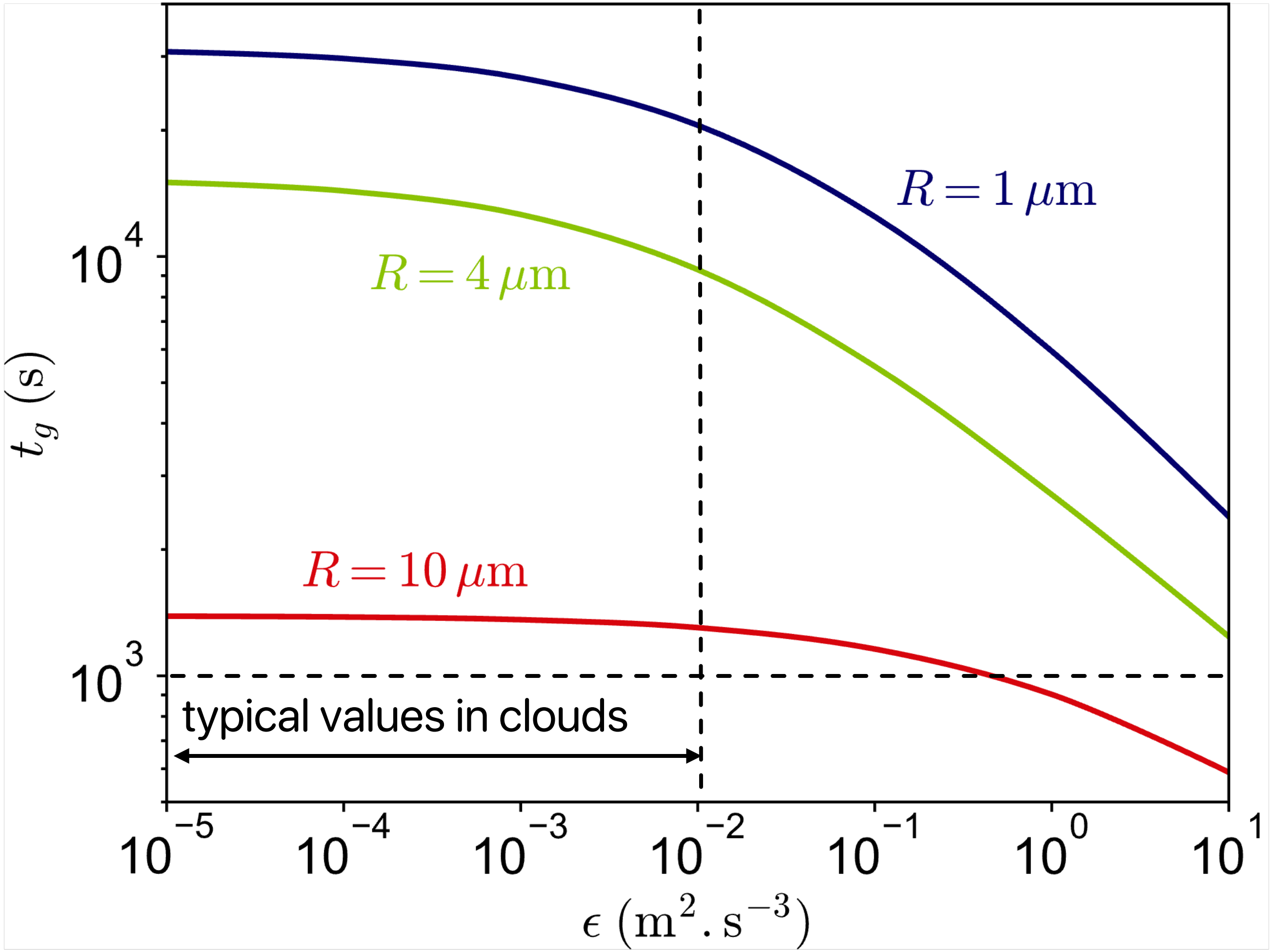
Clustering





Caustics

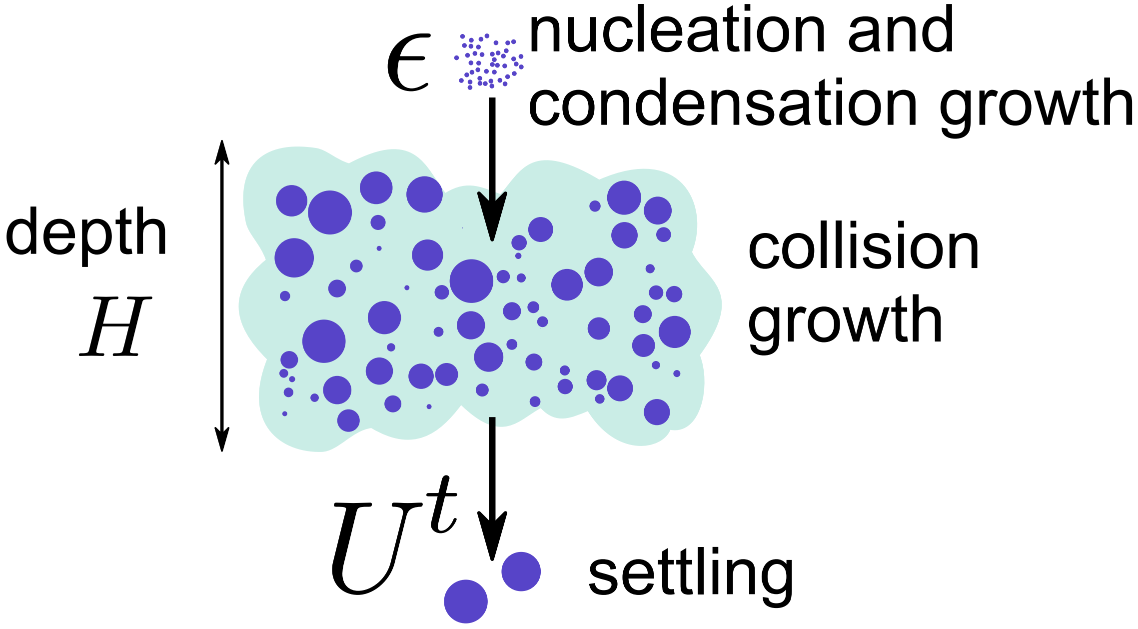
$$\mathrm{St} = \frac{\tau_{\mathrm{inertia}}}{\tau_{\mathrm{turb}}}$$



Bec 2004
Falkovich & Pumir 2007
Pumir & Wilkinson 2016

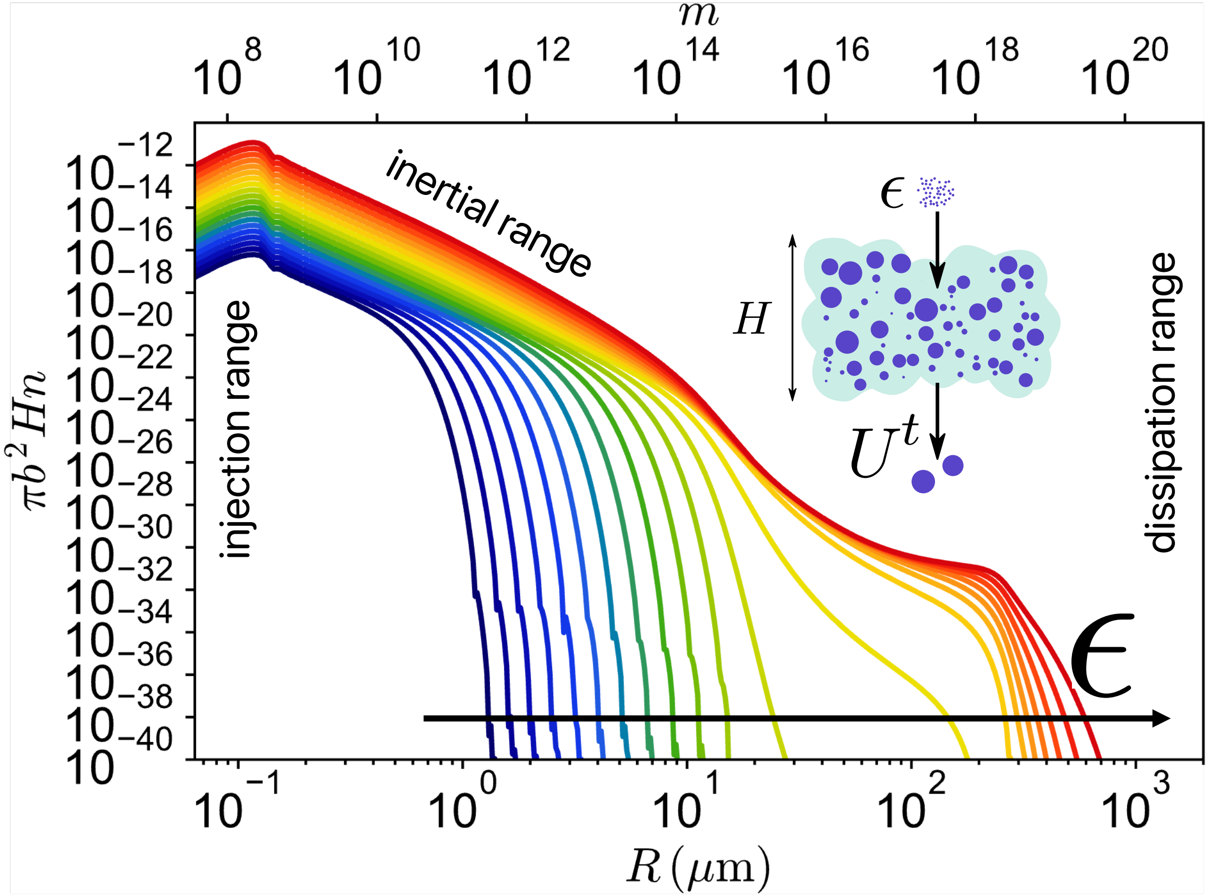
Well-mixed steady-state layer

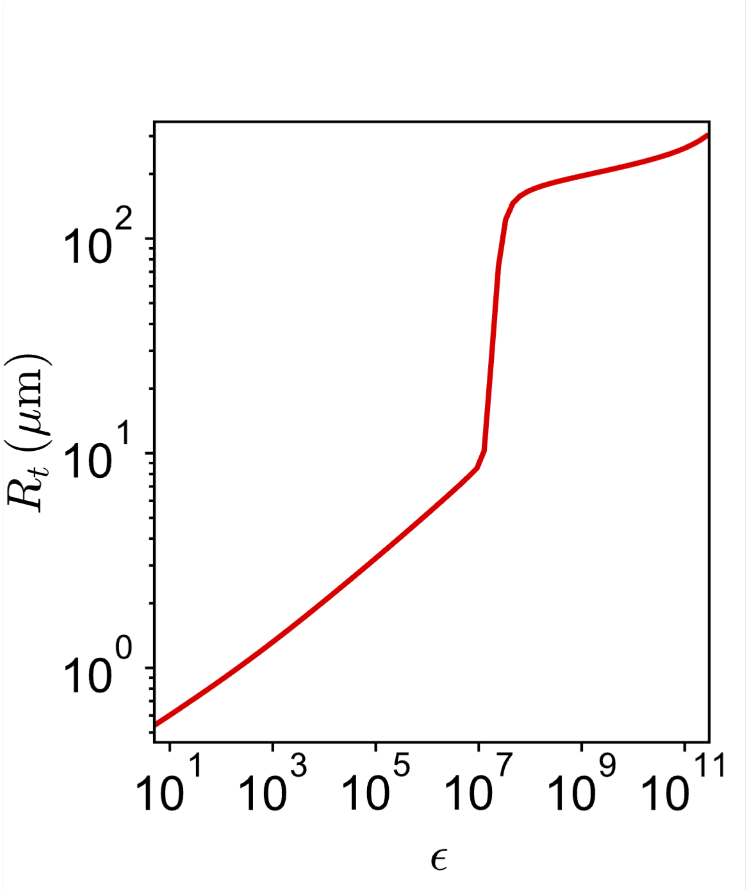
F. Poydenot, B. Andreotti, in prep.



$$\frac{\partial n}{\partial t} = \epsilon + \text{collision terms} - \frac{U^t(m)}{H} n(m)$$

Inverse size cascade

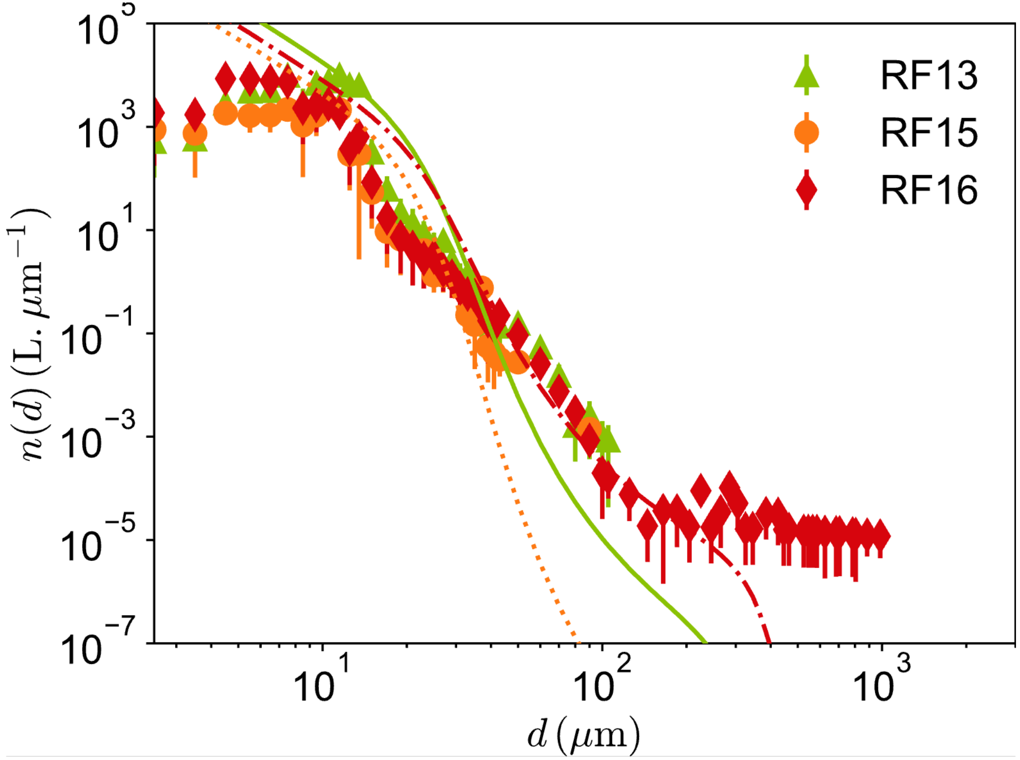


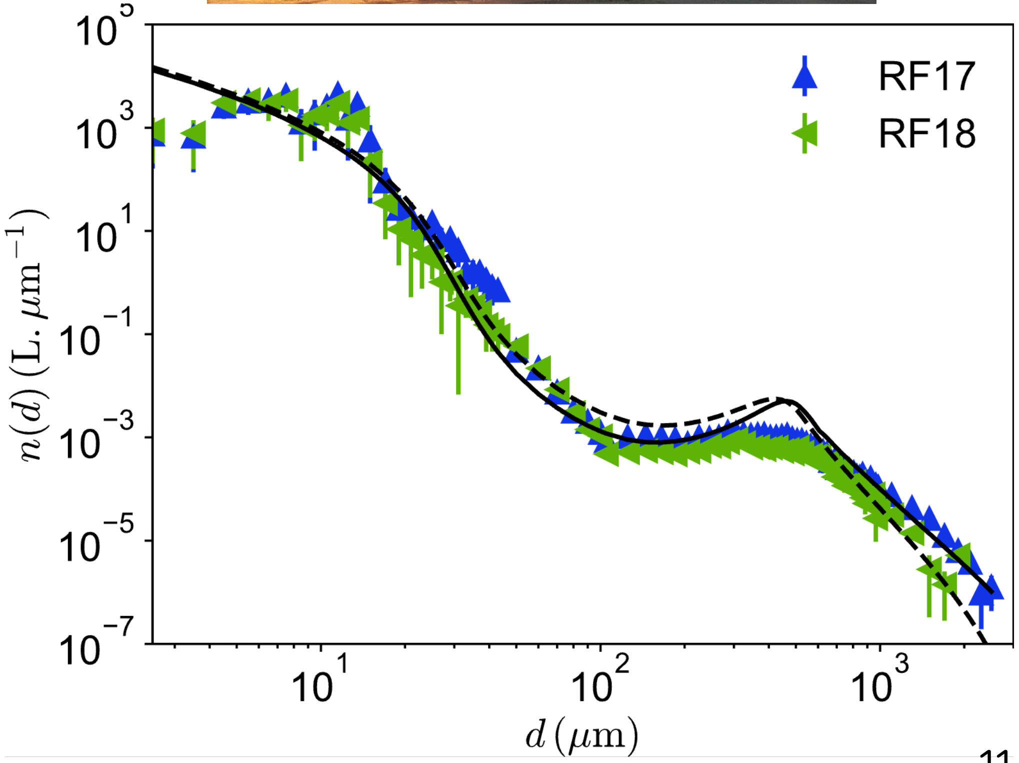


DSDs from the EUREC^{4}A campaign at Barbados

Bony et al. 2022, Caudoux et al. 2021, Coutris 2021

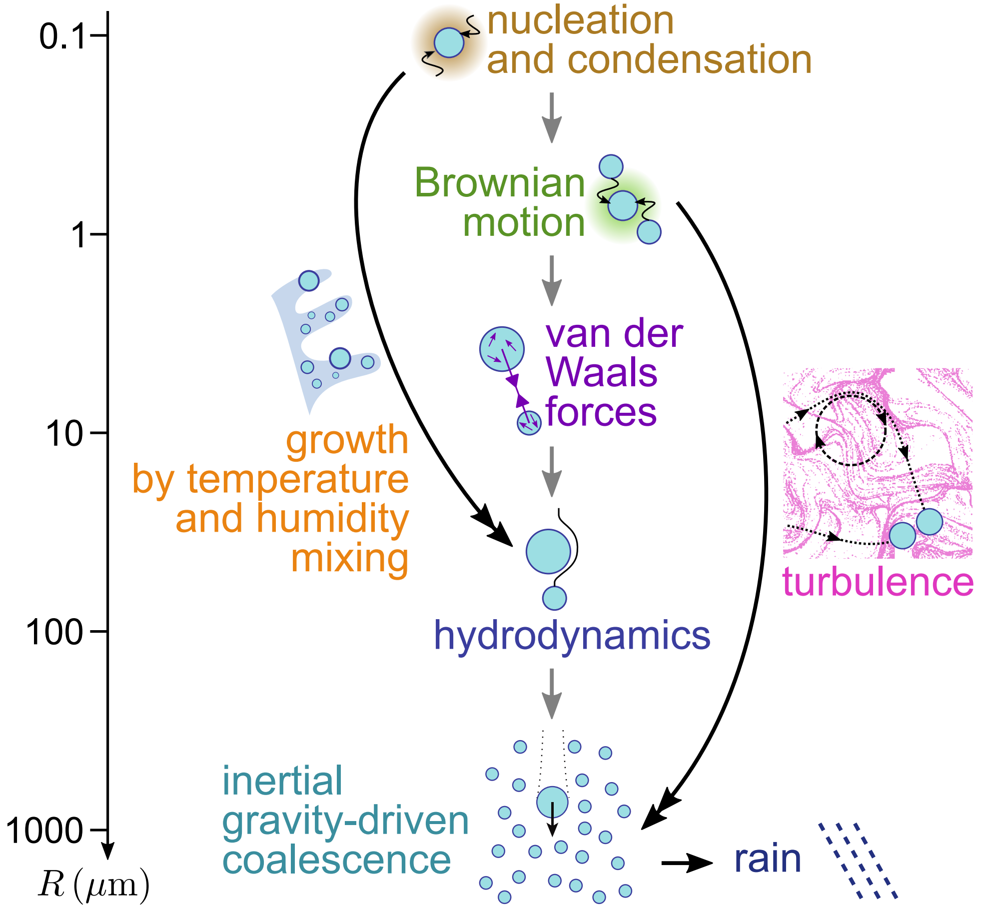
- In-situ airborne DSD measurements at cloud base
- Cloud depth derived from radar measurements





Take home messages

- Van der Waals forces bridge the gap between Brownian motion and inertial collisions
- We can think of the rain DSD as the result of a collision cascade, at the crossover between growth and settling



Inverse size cascade for a self-similar kernel

$$K(\alpha m_1, \alpha m_2) = \alpha^{5/6} K(m_1, m_2)$$