Liquid thread break-up and formation of satellite droplets

Luís H. Carnevale[1], Piotr Deuar[1], Zhizhao Che[2], Panagiotis E.Theodorakis[1]

1. Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
2. State Key Laboratory of Engines, Tianjin University, 300072 Tianjin, China

carnevale@ifpan.edu.pl

Introduction

Key Concept: The formation of droplets from a liquid jet is influenced by fluid properties and thermal fluctuations.
Aim: Understand the mechanism of break-up that leads to the formation of droplets and satellite droplets at the molecular scale.
Applications: Inkjet printing, microfluidic devices

Model and Methodology

Method: Many-body dissipative particle dynamics simulations of a cylindrical liquid geometry were realized with the goal to reproduce the Rayleigh-Plateau instability with fluids of different properties. MPDP was chosen for this problem due to its lower computational cost when compared to traditional MD.

Analysis: To obtain a characteristic wavelength that leads to break-up, the following density correlation function was used:

$$G(r,\delta z) = \frac{\langle \rho(r,\phi,z)\rho(r,\phi,z+\delta z)\rangle_{z,\phi,T}}{\langle \rho^2(r)\rangle_{z,\phi,T}}$$

And a cluster analysis was done post break-up to study the size distribution of the formed droplets

Results

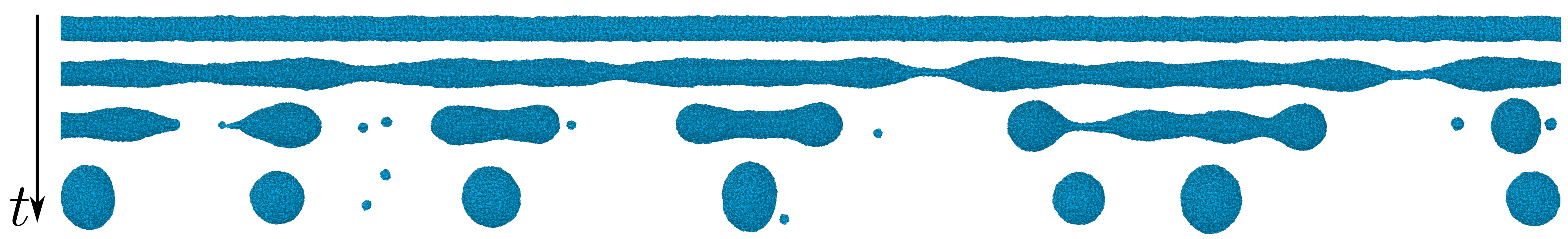

Figure: Time evolution of a liquid thread breaking into main droplets with the presence of satellite droplets.

Relevant break-up non-dimensional numbers are the Ohnesorge (Oh) and the Thermal Capillary (Th) numbers and the reduced wavenumber χ:

$$\mathrm{Th} = l_T/R_0, \quad l_T = \sqrt{k_B T/\sigma}$$

$$\mathrm{Oh} = \mu/\sqrt{\rho\sigma R_0}, \quad \chi = 2\pi R_0/\lambda$$

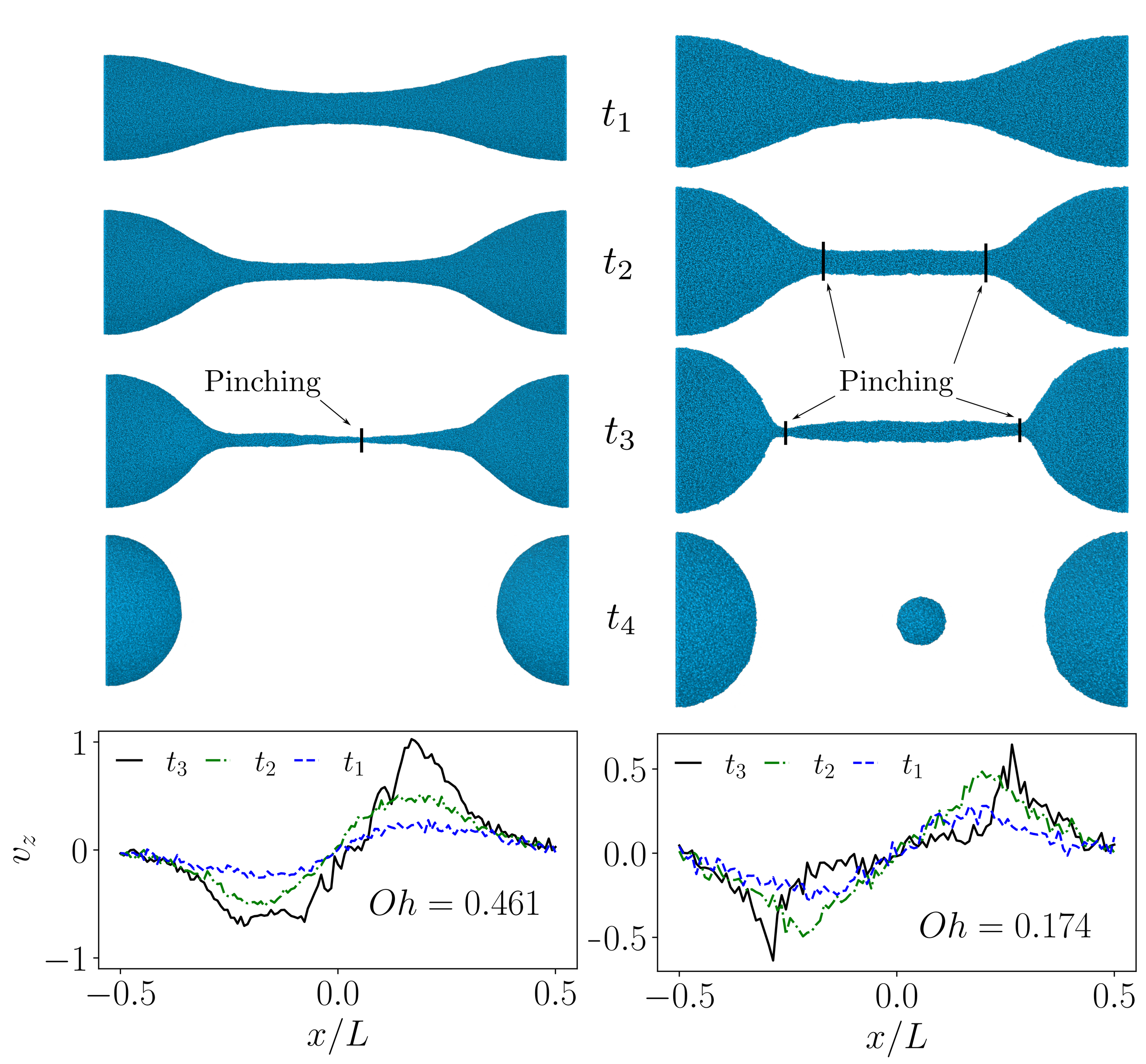

Figure: Break-up of different fluids leading to the formation (or not) of a satellite droplet and the advection of the pinching point with the axial velocity gradient.

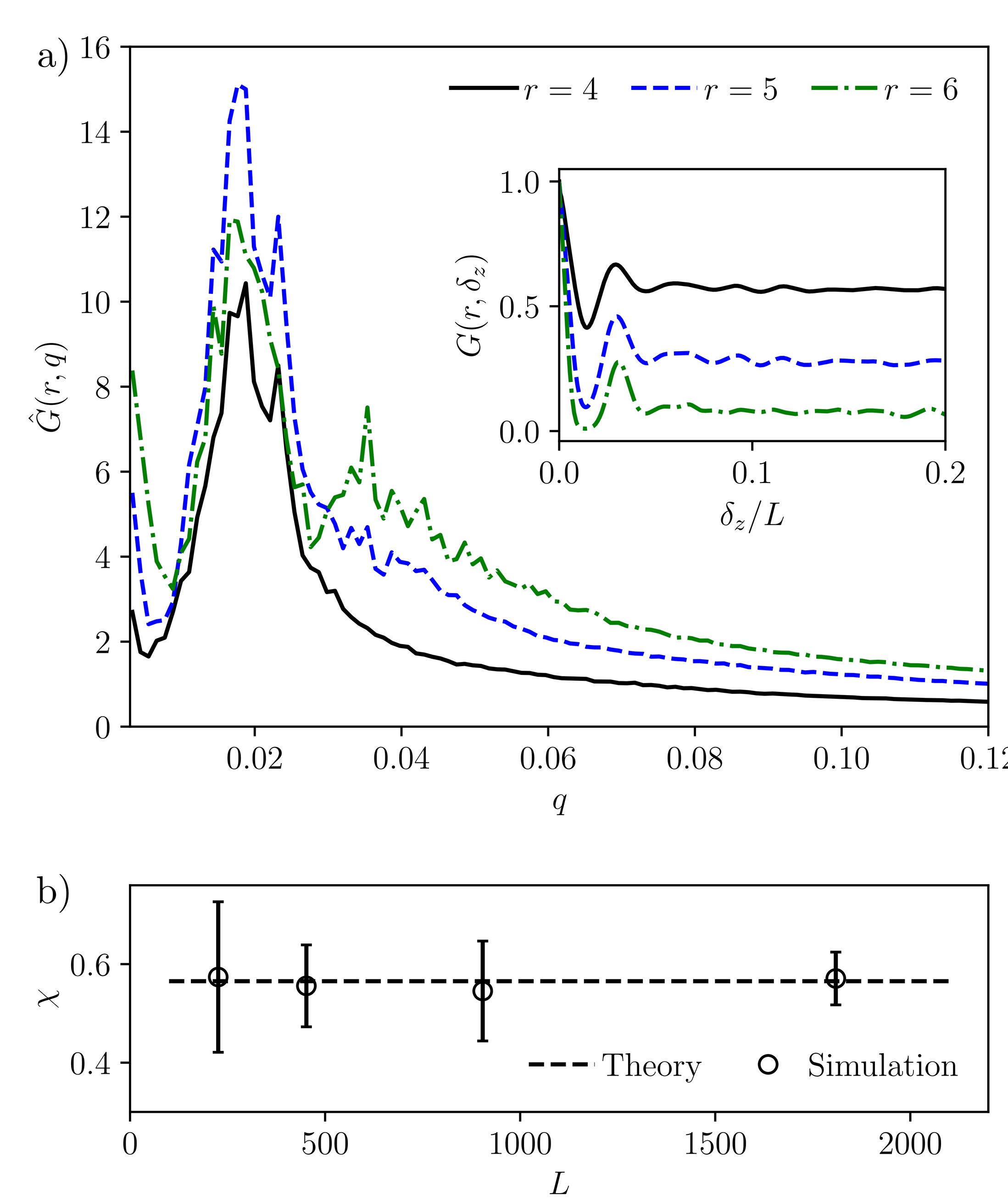

Figure: a) Measurement of the density correlation (inset) and its Fourier transform showing a clear peak around the characteristic wavelength; b) Influence of the thread length on the measurement .

Results

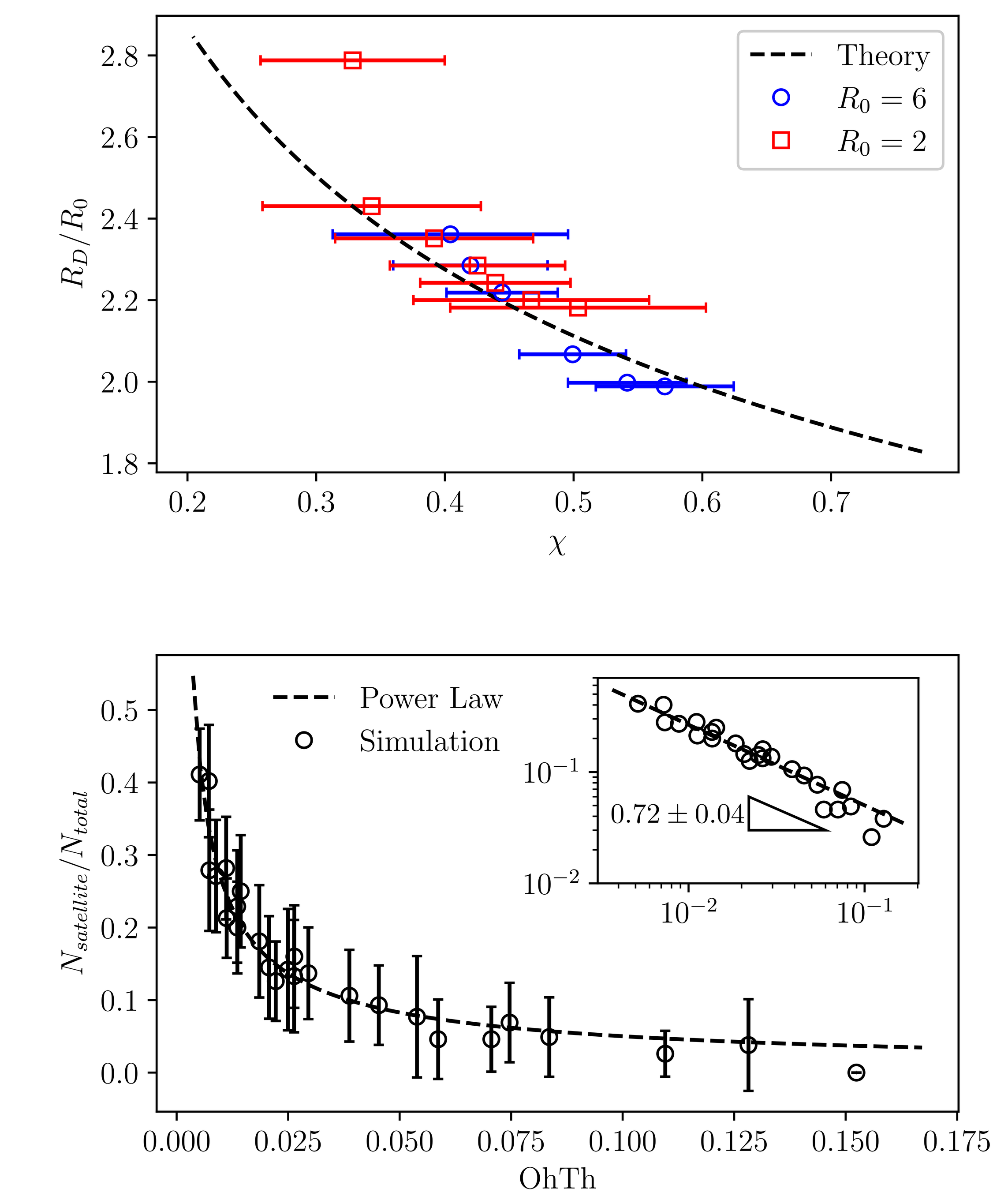

Figure: a) Dependence of the main droplet radius on χ; b) Ratio of satellite droplets formed as a function of Oh and Th.

Conclusions

- Radius of main droplets depends on χ ;
- Thermal Capillary number and Ohnesorge number influence the probability of forming satellite droplets;
- Pinching points are formed in the regions of highest axial velocity gradient.

References:
1. J M Montanero and A M Gañán-Calvo 2020 Rep. Prog. Phys. 83 097001
2. Jiayi Zhao, Nan Zhou, Kaixuan Zhang, Shuo Chen, Yang Liu, and Yuxiang Wang Phys. Rev. E 102, 023116 (2020)

Acknowledgment:
This research has been supported by the National Science Centre, Poland, under grant No. 2019/34/E/ST3/00232. This research was supported in part by PLGrid Infrastructure.