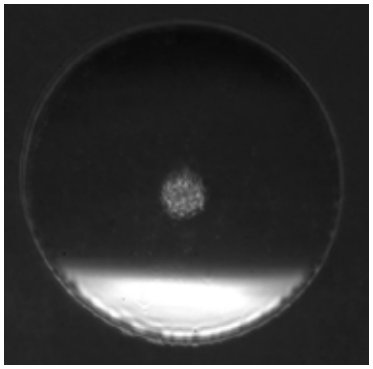
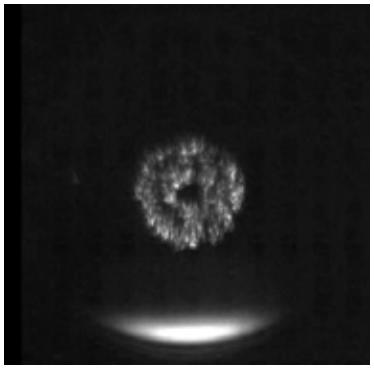
Durham University

Particle Migration in Drying Drops





Jack Goodall - Colin Bain
Department of Chemistry, Durham University, UK

Why Drops?

Drying drops useful in many situations

- Graphics printing
- Crop spraying
- Coatings
- Printed electronics
- Biosensors
- 3D printing

Inkjet Printing

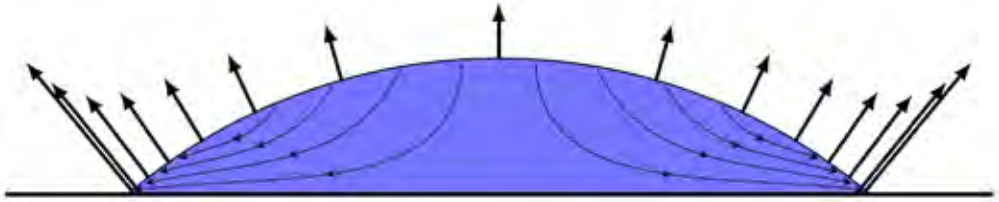
Not just desktop printers!

- High resolution
- Localised
- Low-waste
- Contact-free

The Coffee Ring Effect

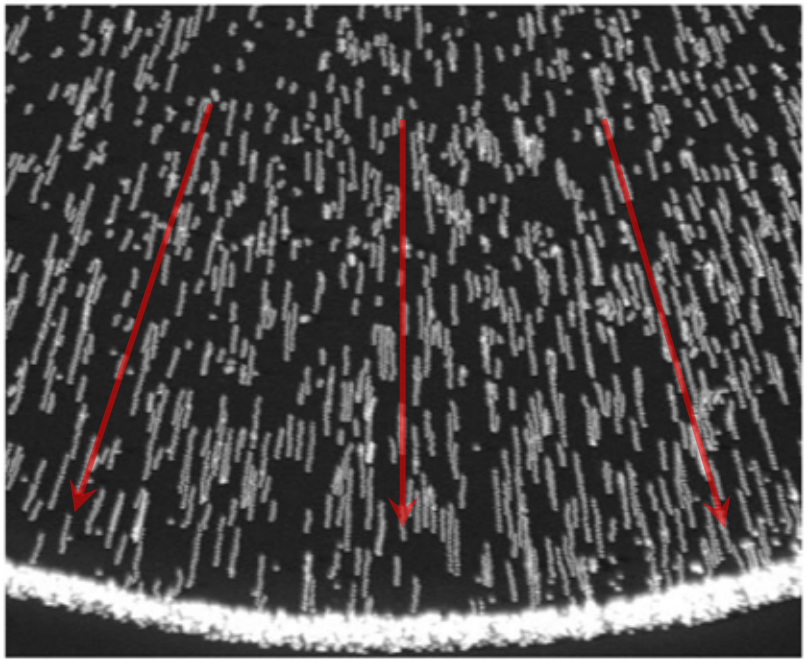
Simple requirements:

- Volatile fluid (evaporation!)
- Pinned contact line (uneven evaporative flux)



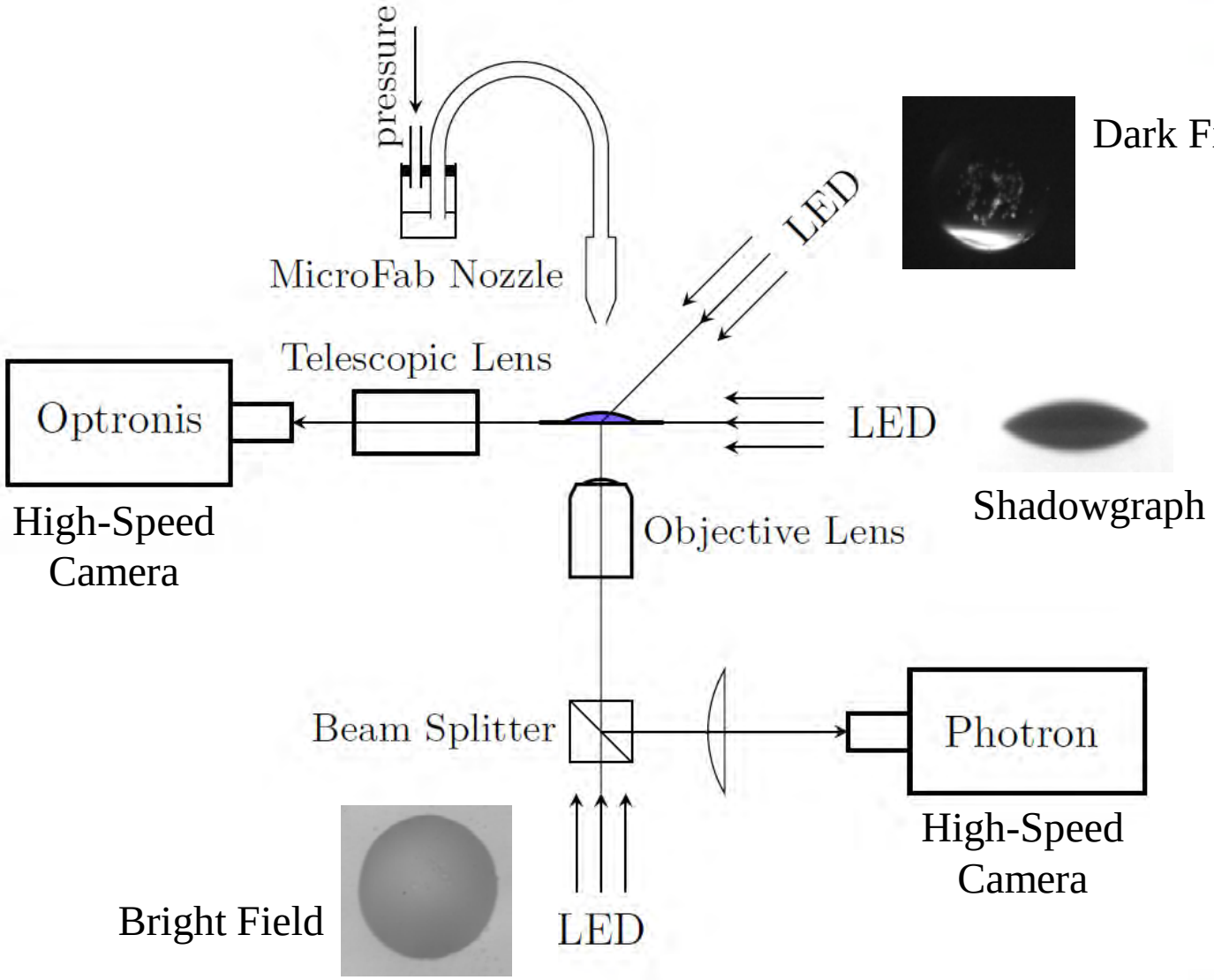
Þ Convective flow

Þ **Ring stain**



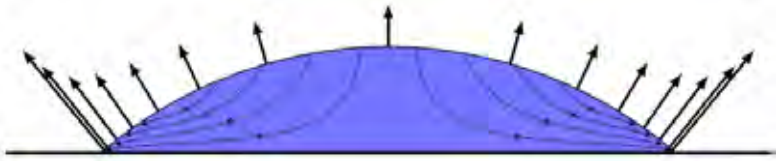
R. D. Deegan, O. Bakajin, T. F. Dupont, G. Huber, S. R. Nagel and T. A. Witten, *Nature*, 1997, **389**, 827–829.

The Experimental Rig

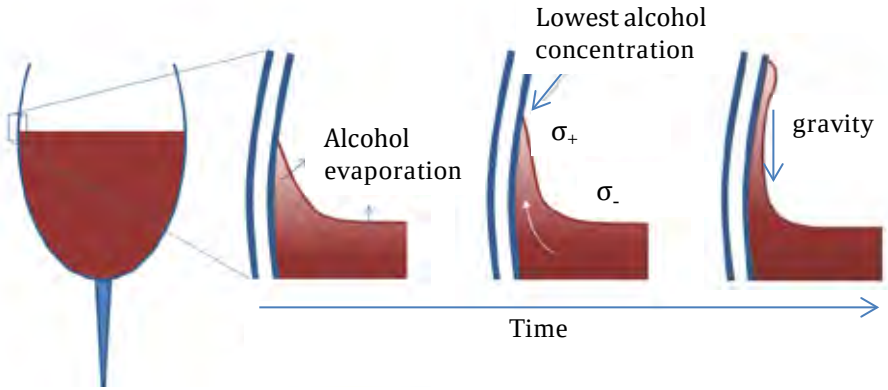


Binary Solvent Mixtures

Different solvents have different vapour pressures and surface tensions.



- Concentration gradients
- Surface tension gradients → Marangoni stresses



σ_+ : high surface tension

Tears of Wine and the Marangoni Effect, *Comsol Blogs*, (accessed 11 May 2018).

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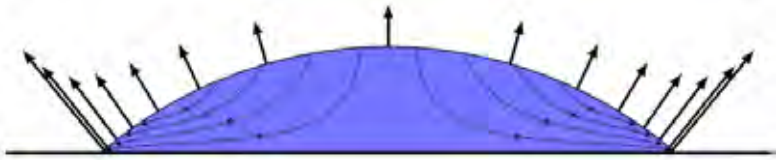
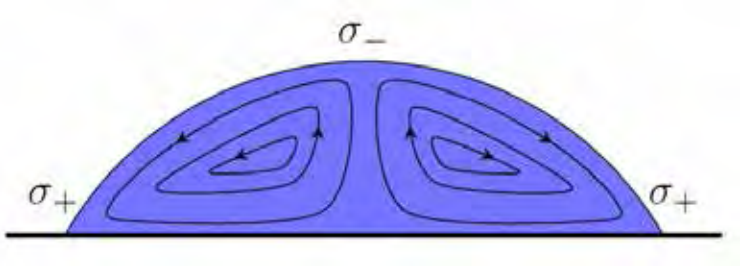


- Concentration gradients
- Surface tension gradients → Marangoni stresses
- **Internal Flows**

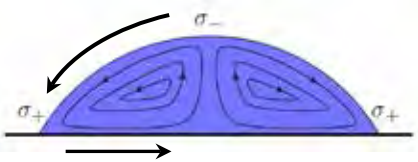
More volatile solvent has *higher* surface tension



Ethanol – Water Mixture

Ethanol – Water Mixtures

50 µm



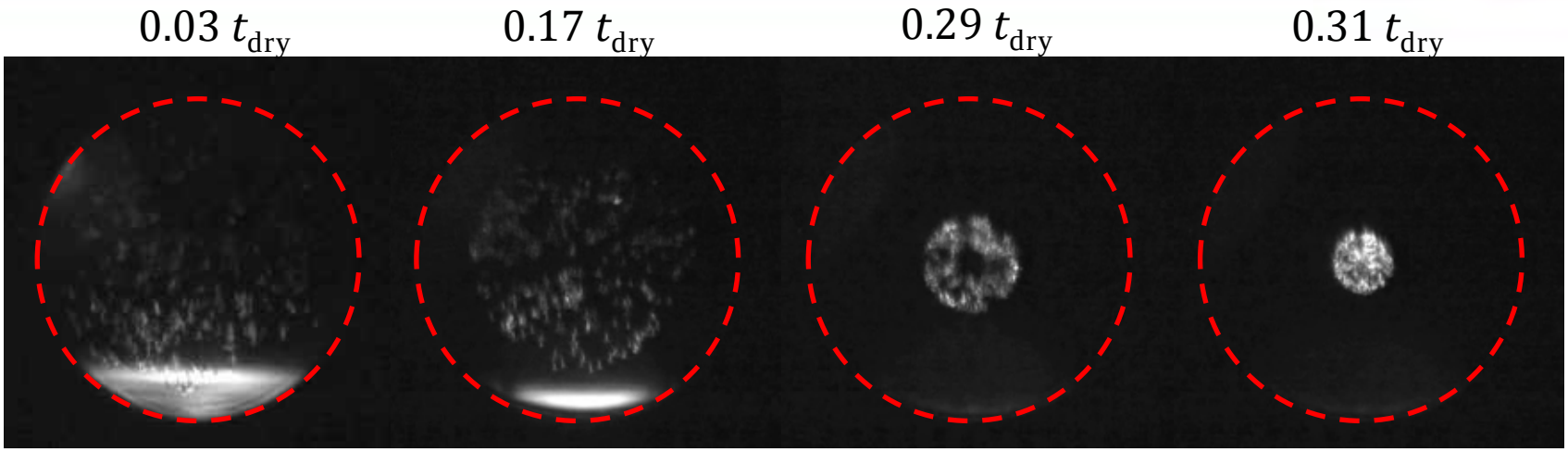
V = 180 pL
θ = 34 °
R = 70 µm

50%v Ethanol
50%v Water

0.015%v 1 µm Sterically stabilised polystyrene particles

Playback slowed down ~44 ×
First 35% of drying shown.

Particle Migration



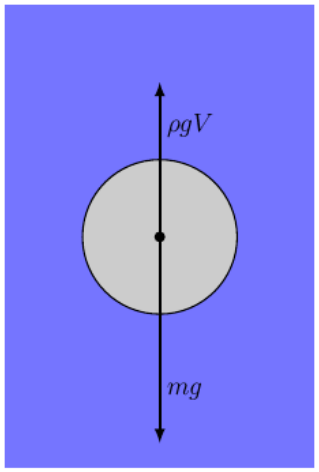
Possible Mechanisms?

Particles have low Reynolds Numbers so would be expected to follow streamlines rather than migrate.

Particle Migration

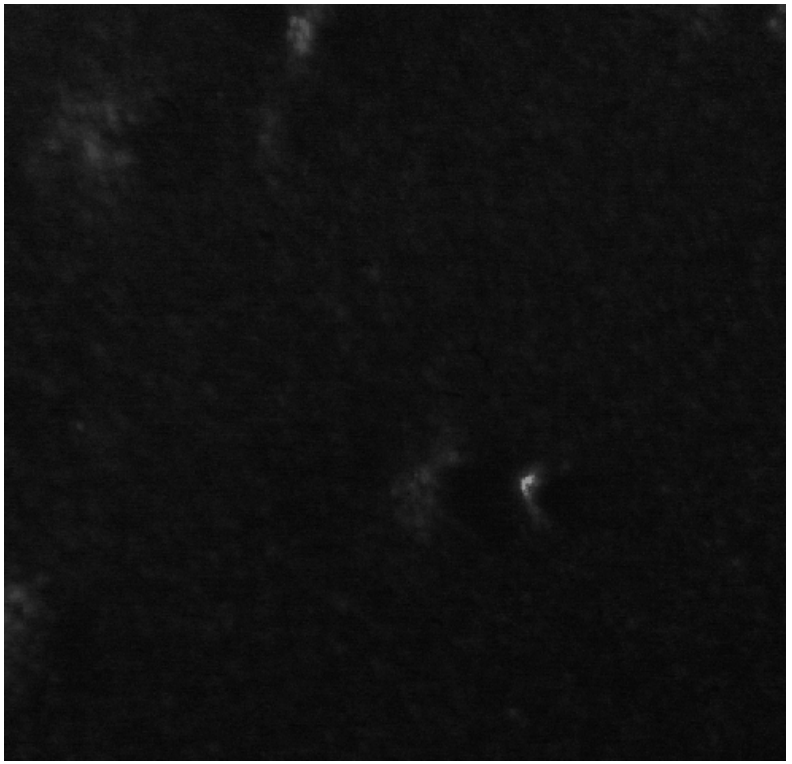
Possible Mechanisms?

- Hydrodynamic
  - § Buoyancy
  - § Shear Induced



50%v Ethanol
50%v Water

0.5%v 3 µm
0.01%v 1 µm
0.05%v 600 nm
0.5%v 200 nm
PS spheres



Collected Group Radius Scales as $a^{0.25}$

E. L. Talbot, L. Yang, C. D. Bain, *unpublished*, 2014

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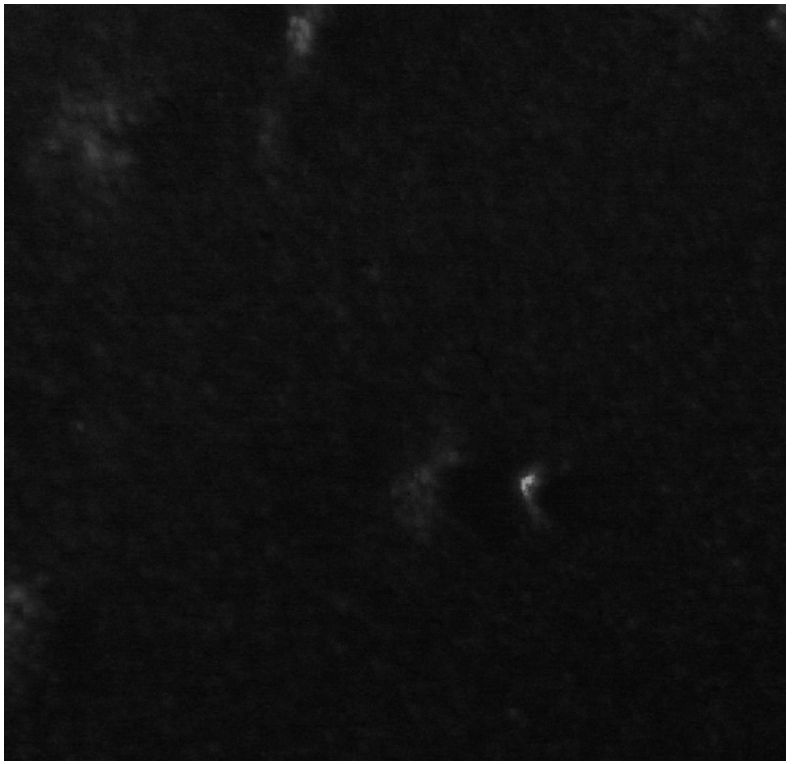

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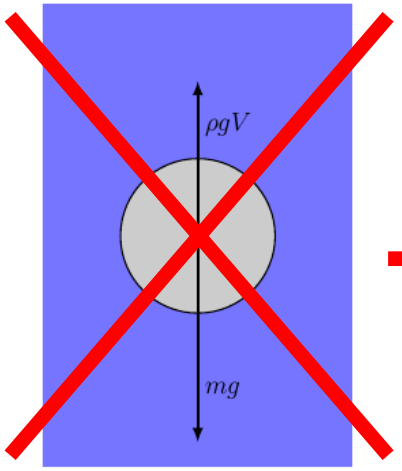


~~Shear~~

- Collisions

- Chemophoresis/ Diffusiophoresis → Reverse the concentration gradient!

Droplets in Ethanol Vapour

Water + 0.02%v 1 µm PS
Playback slowed down ~17×
V = 200 pL

50 µm

50%v Ethanol
50%v Water + 0.02%v 1 µm PS
Playback slowed down ~13×
V = 155 pL

Droplets in Ethanol Vapour

Water + 0.02%v 1 µm PS
Playback slowed down ~17×
V = 200 pL

50 µm

50%v Ethanol
50%v Water + 0.02%v 1 µm PS
Playback slowed down ~13×
V = 155 pL

Particle Migration from Solutes

We have also observed particle migration in single solvent systems containing solutes.

Sucrose

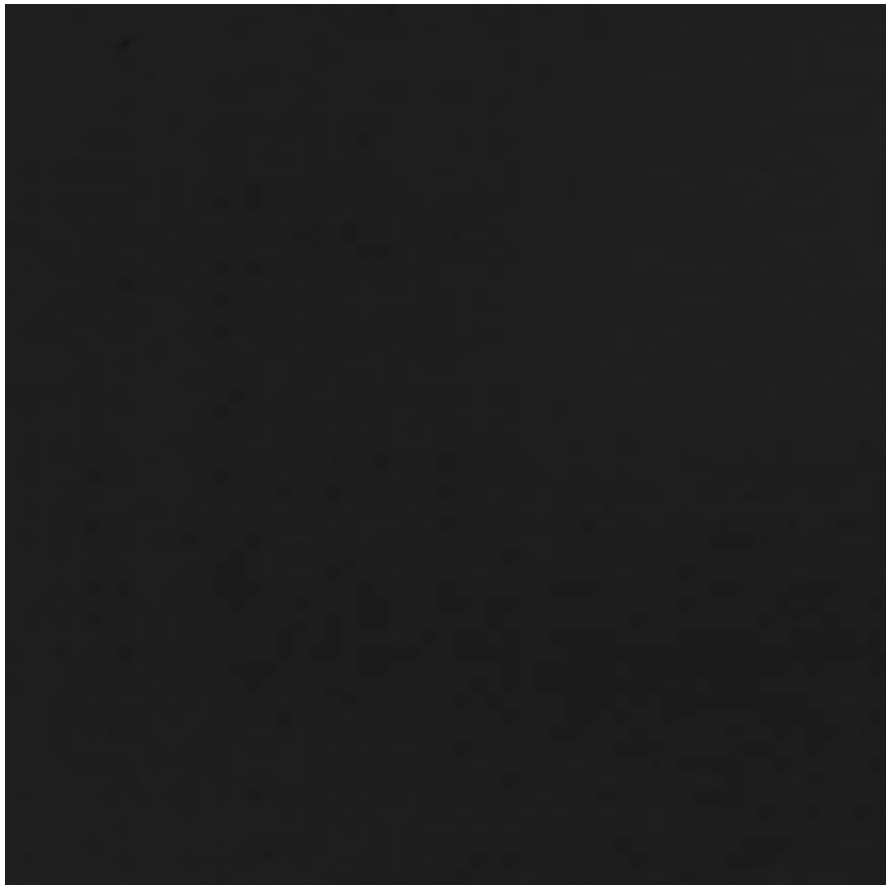
- *Highly* viscous at high concentrations
- Humectant.

© Foodnavigator

R. M. Power, S. H. Simpson, J. P. Reid and A. J. Hudson, *Chem. Sci.*, 2013, **4**, 2597–2604.

Sucrose Solutions

50 µm



V = 330 pL
θ = 40 °
R = 80 µm

Water
16 wt% Sucrose

0.015%v 1 µm
Sterically
stabilised
polystyrene
particles

Playback slowed down ~6×

Conclusions

- Particle migration in solvent mixtures
- Particle migration in solutions
- Weak particle size dependence
- Not linked to Marangoni flows.

Aknowledgements

Baingroup

Collaborators

University of BRISTOL

UNIVERSITY OF LEEDS

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