PASTA / SEEDS campaigns: Emulsion Droplet Dynamics in Microgravity

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Participants

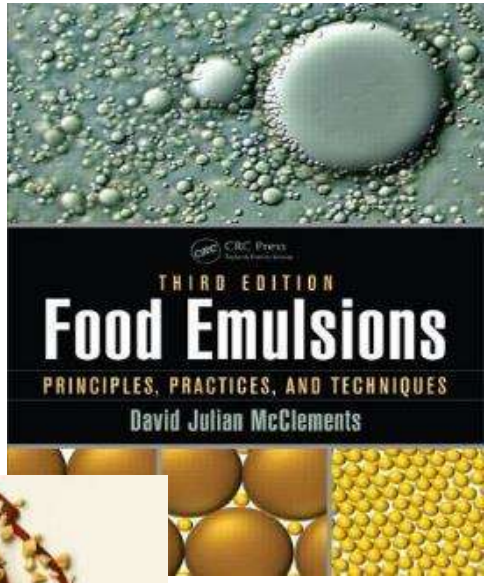
Institution	Participants
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Aix-Marseille Université France	Mickael Antoni

Institution	Participants
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Future Cooking Lab srl Italy	Davide Cassi
Arcofluid sarl France	Jalil Ouazzani
Unilever R&D Colworth United Kingdom	Damiano Rossetti
NIKKOL GROUP / COSMOS-Nikkol Japan	Satoru Hashimoto; Takeshi Misono

Emulsions

-> food science and technology

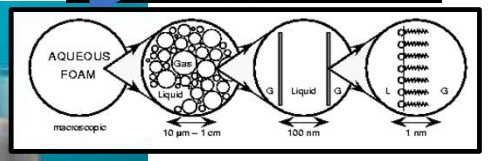










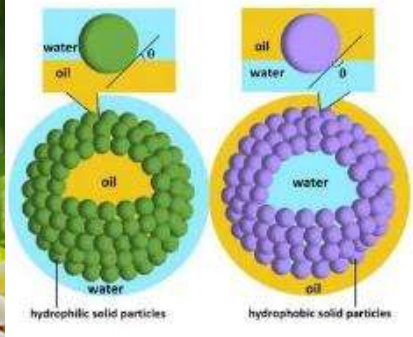


Emulsions

-> food science and technology

-> pharma and cosmetics

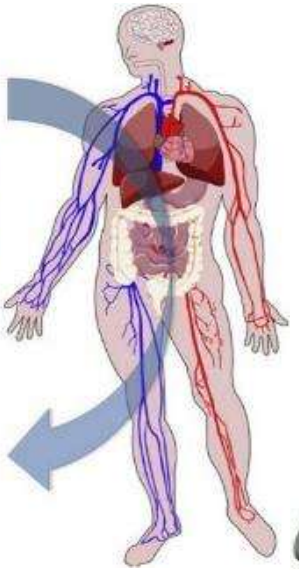




√ Enhanced absorption

√ Controlled release

√ Enhanced stability





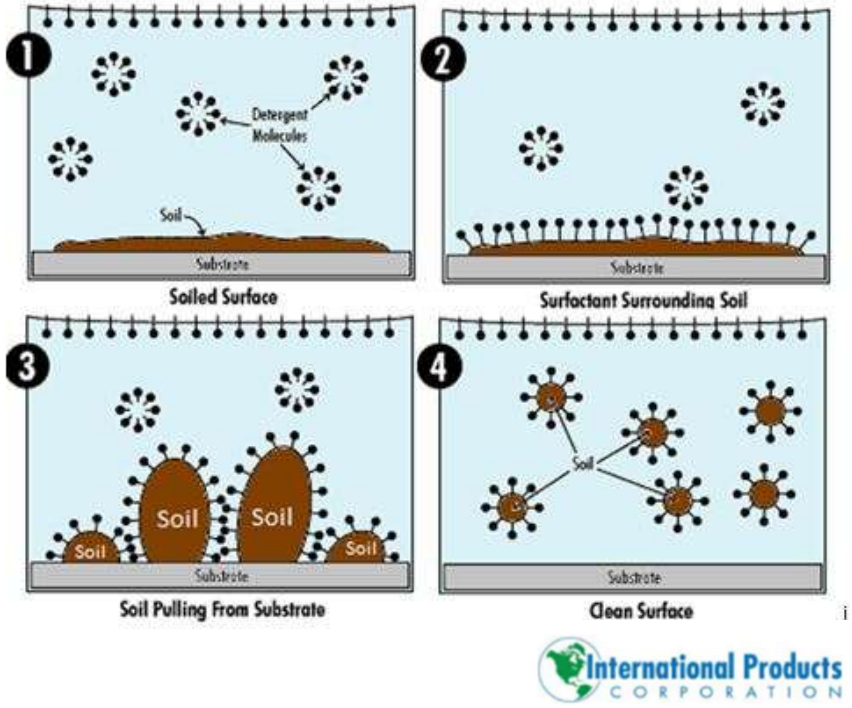
Emulsions

-> food science and technology

-> pharma and cosmetics

-> cleaning





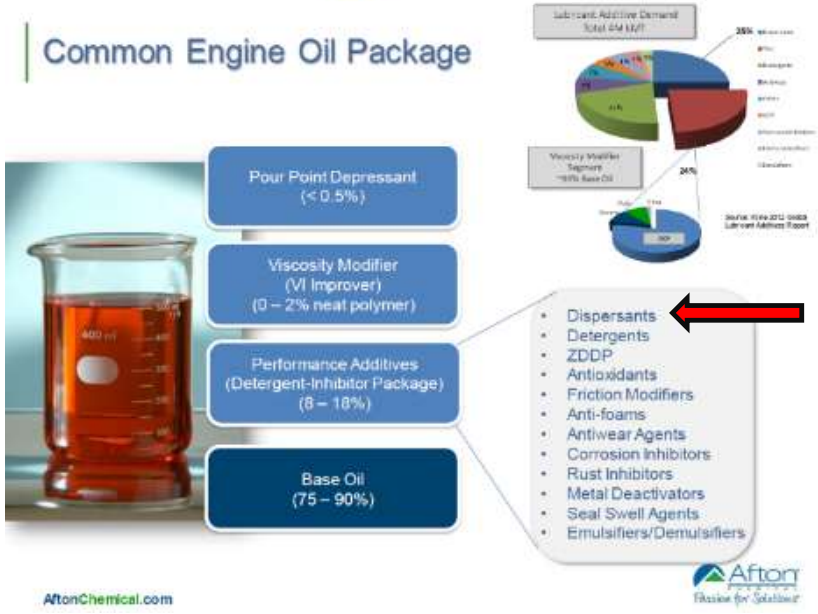
International Products CORPORATION

Emulsions

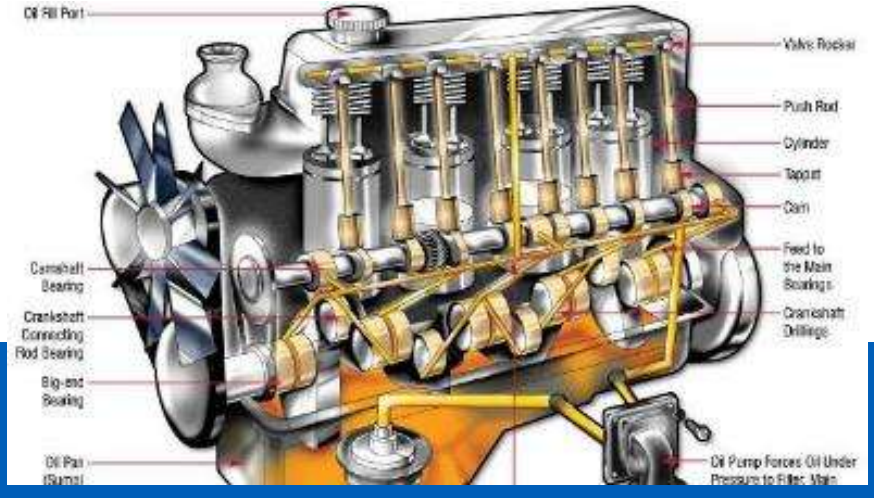
-> food science and technology
-> pharma and cosmetics
-> cleaning
-> lubrication

Courtesy of prof. James K. Ferri

VCU College of Engineering



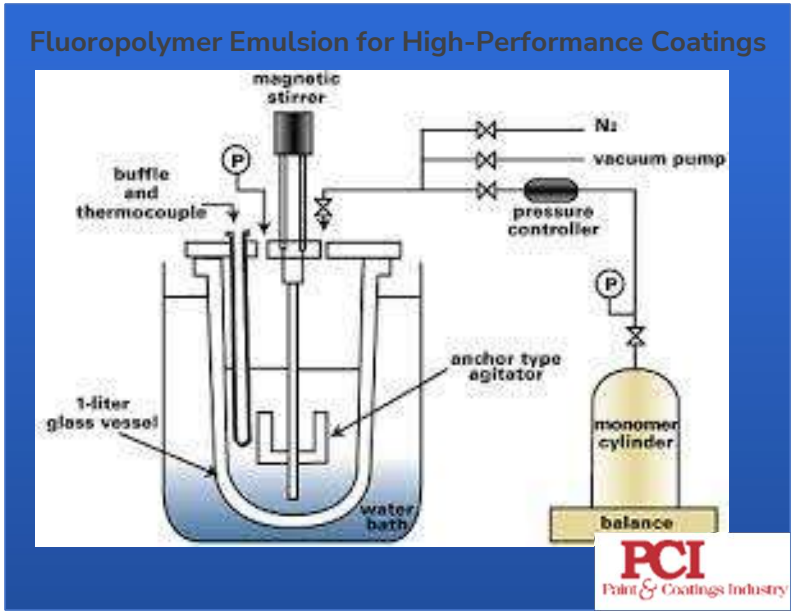
Water is continuously generated by combustion. It is removed from the engine by emulsification in the lubricating oil followed by de-emu in the oil filtering system



Emulsions

-> food science and technology
-> pharma and cosmetics
-> cleaning
-> lubrication
-> paints and coatings





Emulsions

-> food science and technology
-> pharma and cosmetics
-> cleaning
-> lubrication
-> paints and coatings
-> **oil industry**

extraction and processing

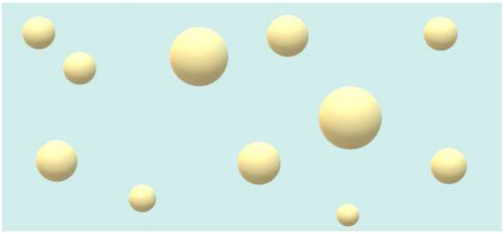




Why emulsions in microgravity

European Space Agency

3 experimental campaigns on the **International Space Station (ISS)**



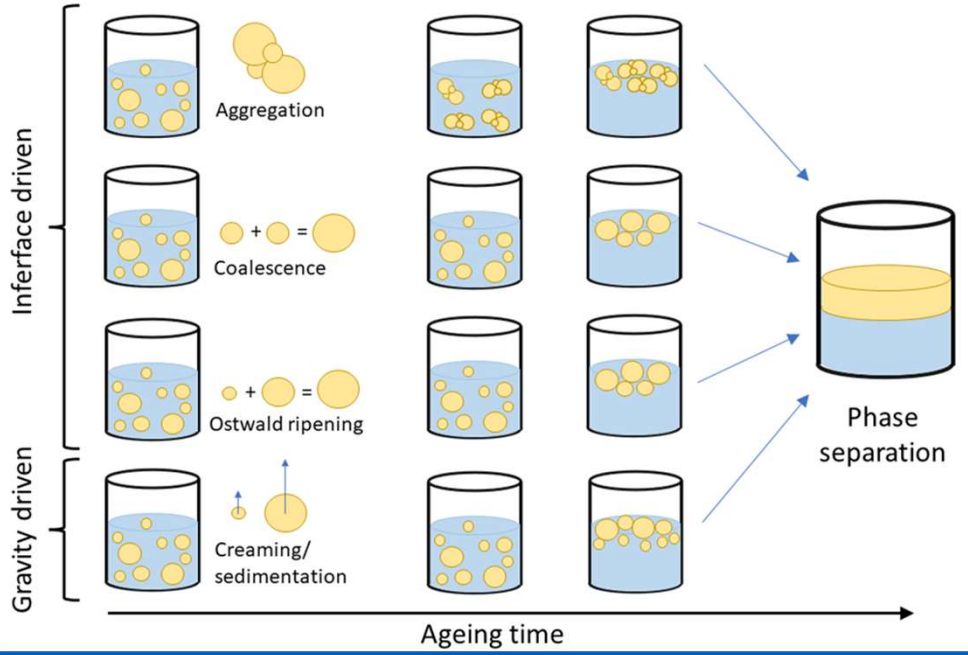
FUNDAMENTAL SCIENCE

By eliminating creaming, we address:

- **intrinsic droplet dynamics**
- **coalescence**
- **emulsion ageing**

APPLICATION

- **Reduction/optimization** of surfactant content in emulsion-based technologies and products
- Towards a **by-design approach** in emulsion technology
- **Enabling technologies for space exploration**



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Continuously Open Research Announcement

SciSpacE Microgravity Application Promotion Programme

esa

European Space Agency

Research Proposal

Project Full Title: **Emulsion Dynamics and Droplet Interfaces**

Project Acronym: EDDI

P.I. Libero Liggieri

2020-2023

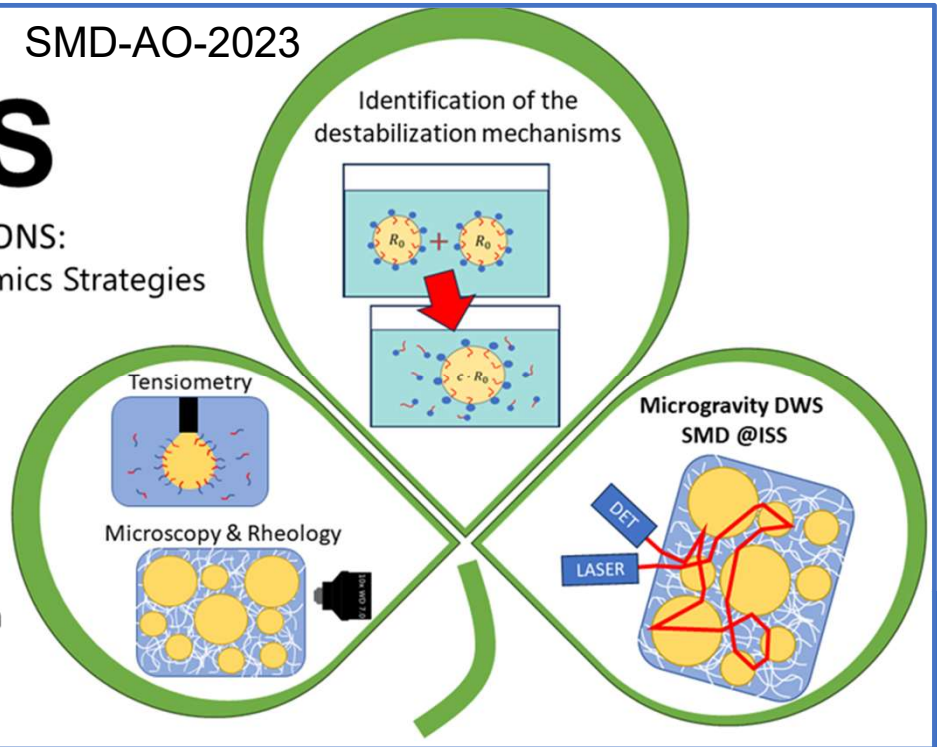
SciSpace Activities: SMD-AO-2023

SEEDS

SUSTAINABLE EMULSIONS:
Exploring Droplet Dynamics Strategies

Towards:

- Understanding emulsion life
- Environmentally friendly surfactants
- Sustainable emulsion technologies

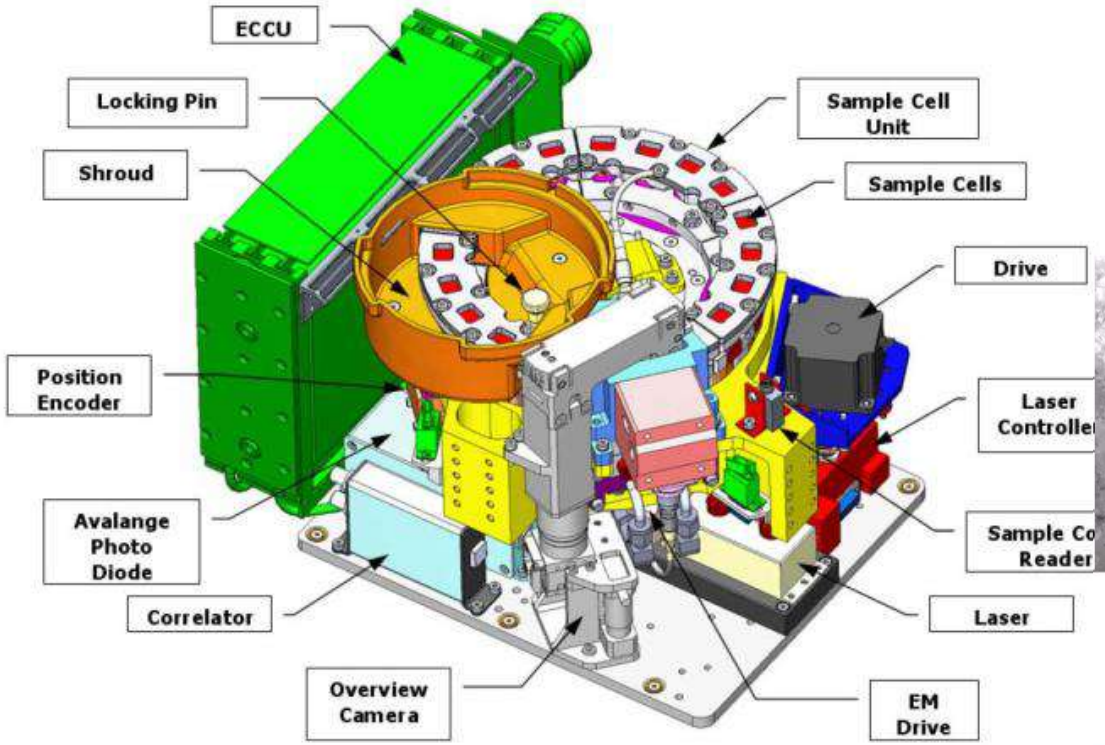


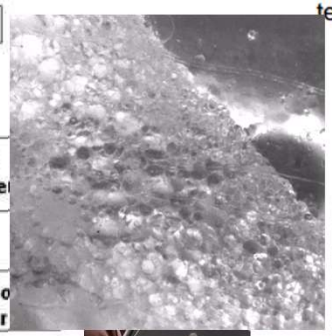
The SOFT MATTER DYNAMICS facility on the ISS:

Diffusing Wave Spectroscopy and Imaging

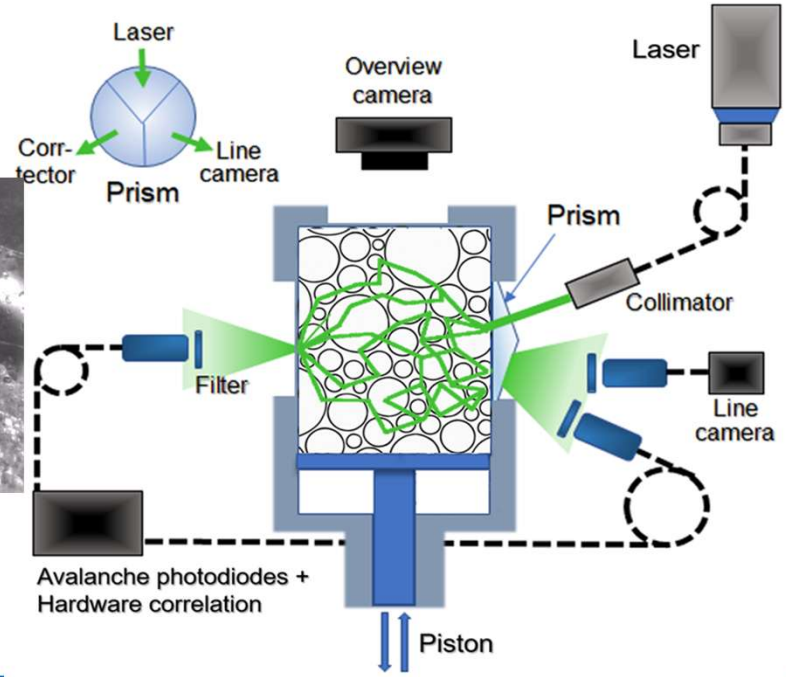
to study foams, emulsions and granular matter

European Space Agency









P. Born et al., Rev. Sci. Instrum. 92 (2021)

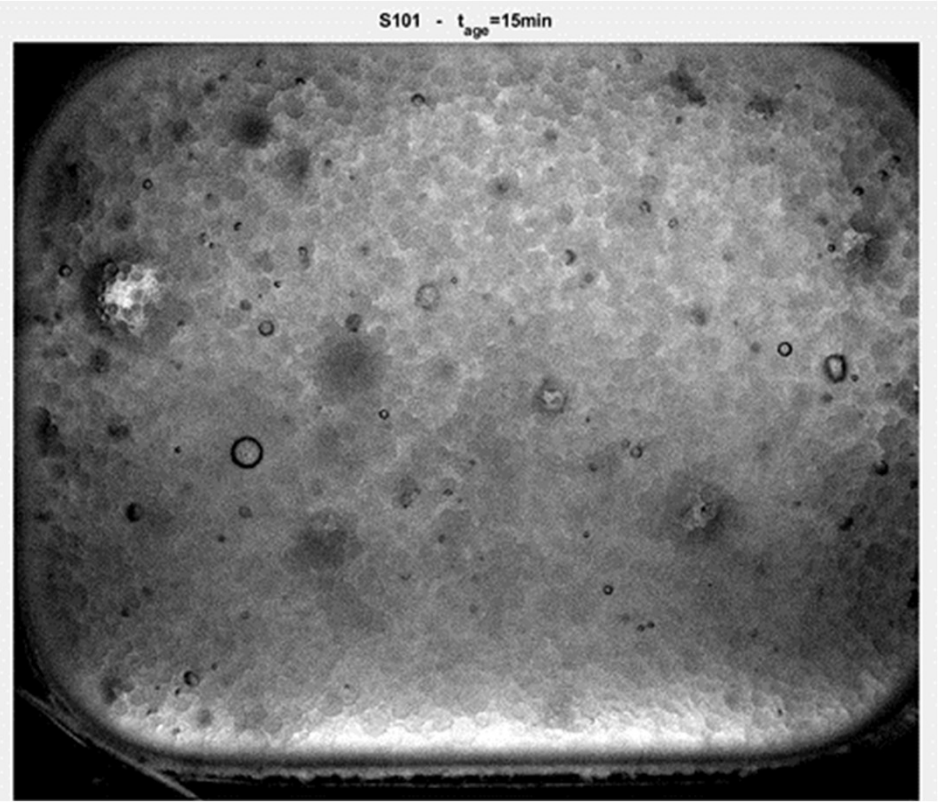
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Samples

- **MCT oil**
  (Miglyol 812N,IOI OLEO,Hamburg, DE)
- **Non-ionic surfactant: $C_{12}EO_{21}$**
  (Nikko Chemicals, JP)
- **Thickener: Xanthan gum 0, 50, 100 ppm**

→ **Emulsions**

$$\Phi_{oil} \sim 10\ \% \rightarrow 50\ \%$$
$$\Phi_{air} = 0\ \rightarrow \sim 6\%$$

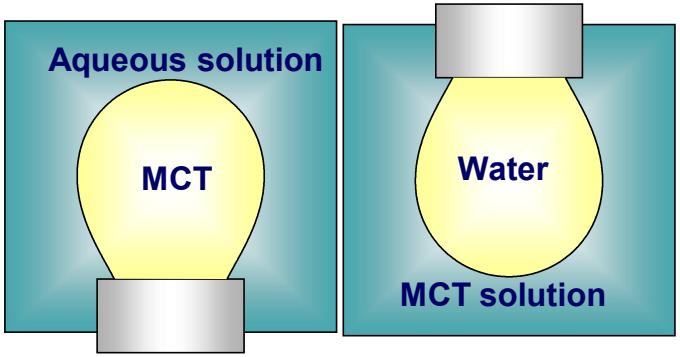


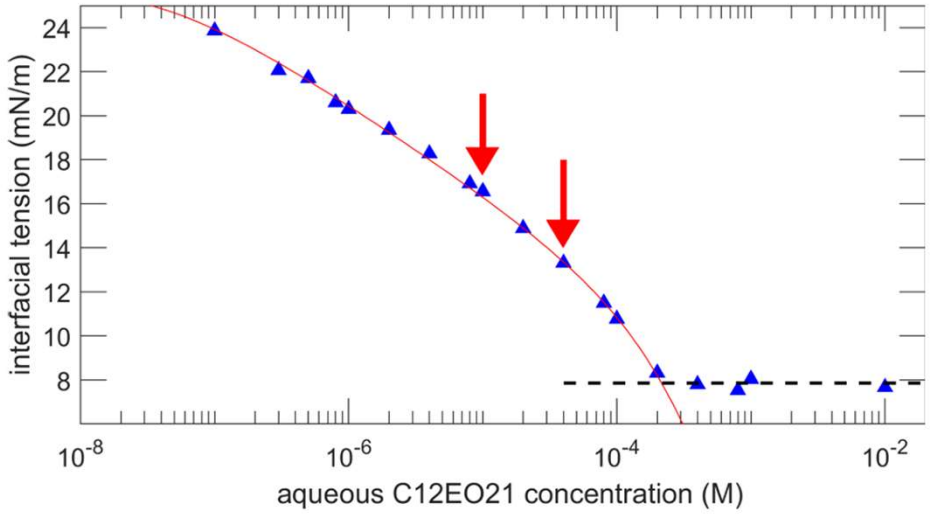
Preparatory work @ICMATE: interfacial properties

Relevant aspects for emulsion evolution

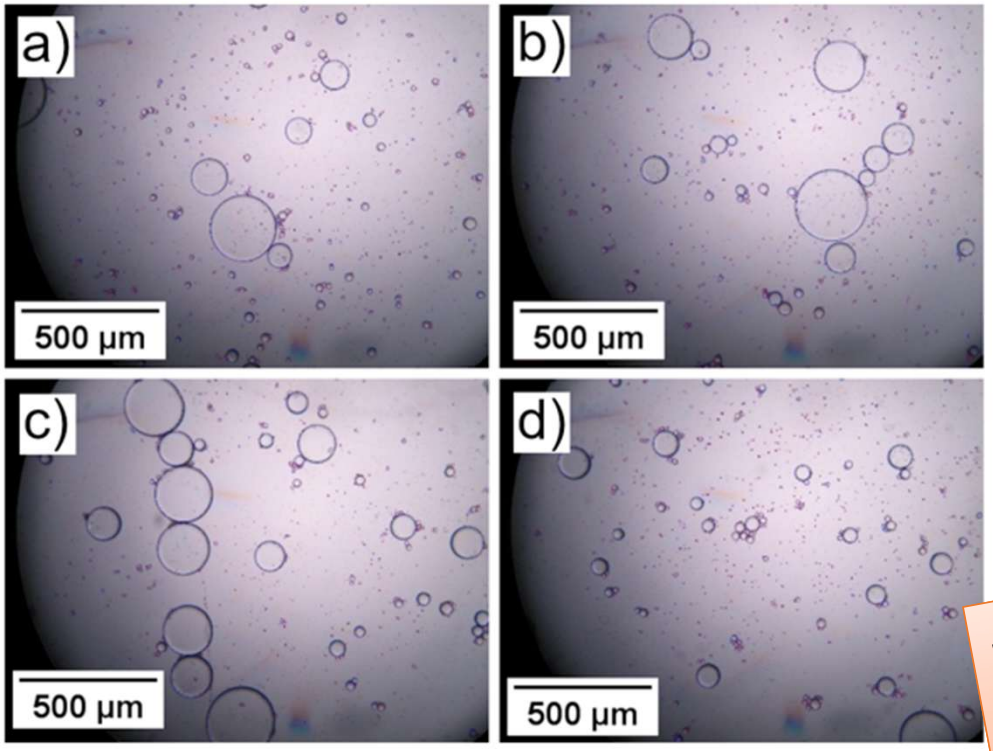
- Adsorption isotherm
- Dilational rheology
- Coverage of the droplet surfaces
- Partitioning

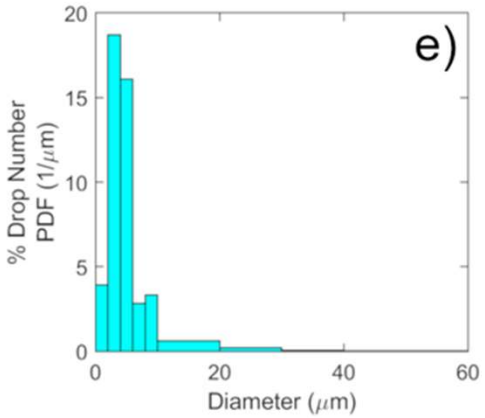
Profile Analysis Tensiometry (PAT) in emerging / pendant drop configuration

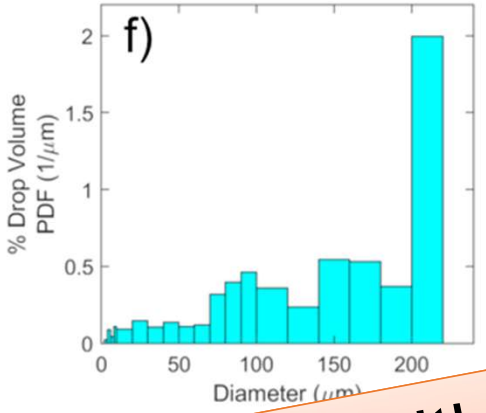




Preparatory work @AUTH: DSD of emulsions







micron-sized drops coexist with very large ones (>100um)

Sample Name	Small drop			
				1.9
			1.8	1.4
		128	0.65	1.0
S111	6.87	108	0.55	4.4
S112	8.38	191	0.35	2.4

Preparatory work @UNIPR

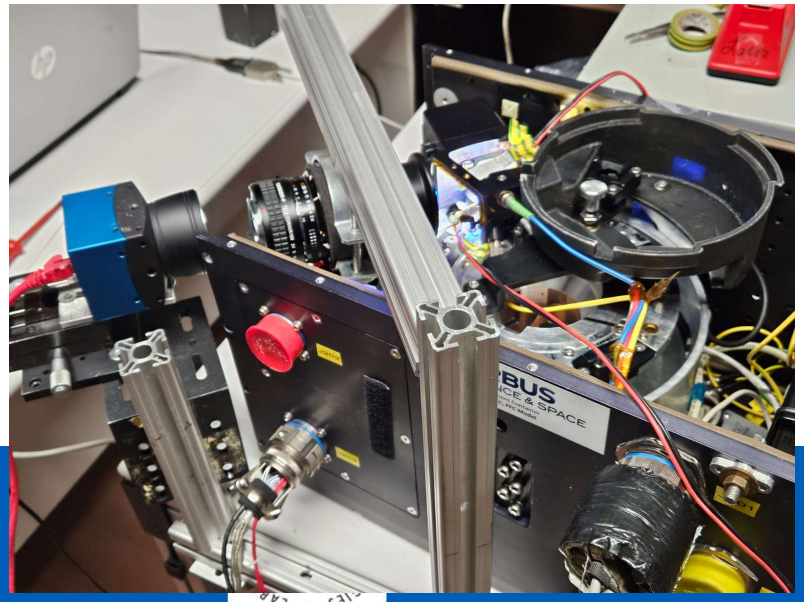


Ground Tests on the «Elegant Breadboard» mock of the SMD facility onboard the ISS:

- Emulsification protocols
- DWS experiments

- In collaboration with AUTH and UNINA: fast imaging of droplet dynamics.
- Here: side view of droplet elongation during a piston stroke





Main parameters describing emulsion “life”:

→Drop size distribution (mean, 2nd, 4th moments…)

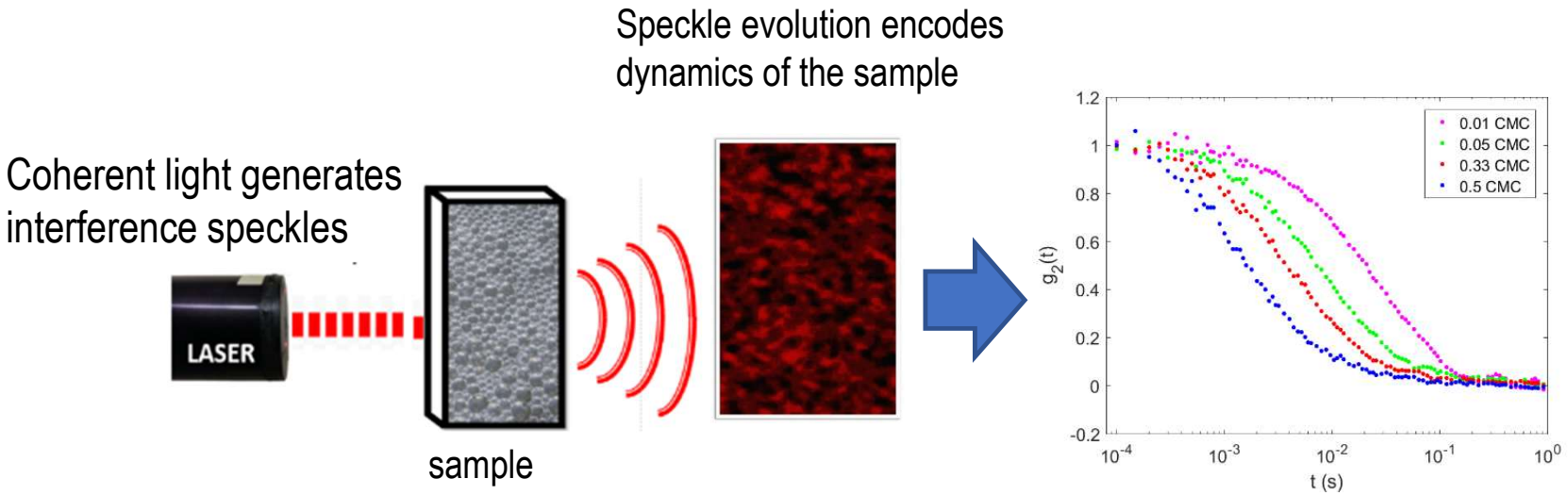
→Drop-drop distance

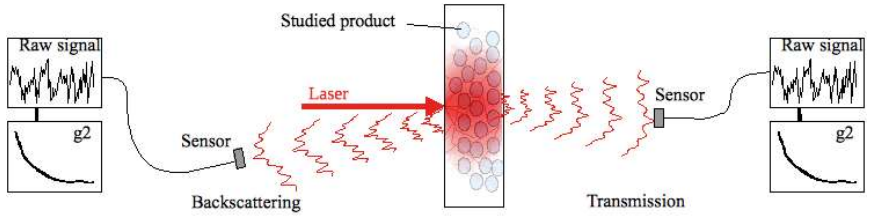
→ Mean displacement

- Brownian motion (diffusion) $\rightarrow < \delta \mathrm{R}^2 > \propto t$
- Ballistic (constant velocity) $\rightarrow < \delta \mathrm{R}^2 > \propto t^2$
- Confinement…

We use Diffusing-Wave Spectroscopy (DWS) to follow the emulsion as a function of age

What is Diffusing-Wave Spectroscopy (DWS)





Classically, from simultaneous BS and transmission experiment one has:

l* - the transport mean free path of light in the sample

τ_0- information on the dynamics of the scattering centers (droplets)

However, finite-sample-effects limit accuracy in discriminating dynamics

→ we developed a new philosophy of analysis of DWS, based on Optical Monte Carlo simulations of light diffusion


Advances in Colloid and Interface Science 288 (2021) 102341

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Advances in Colloid and Interface Science

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Historical Perspective

Recent developments in emulsion characterization: Diffusing Wave Spectroscopy beyond average values

Code is available online:

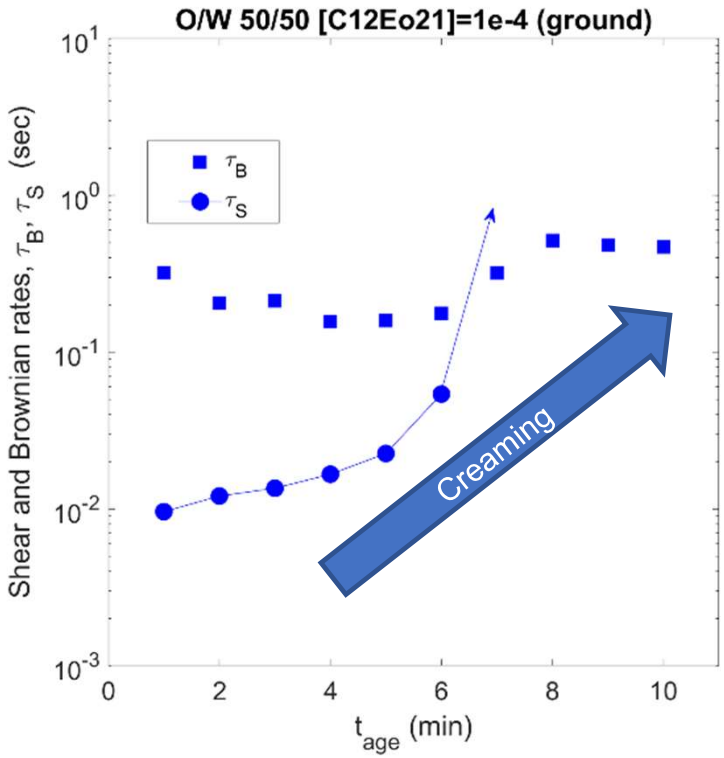
https://github.com/LuigiCristofolini/MonteCarlo_for_DWS

https://www.mathworks.com/matlabcentral/fileexchange/83943-simulate_path_length_distributions

By this analysis, we disentangle Brownian and Ballistic dynamics.



On ground: creaming



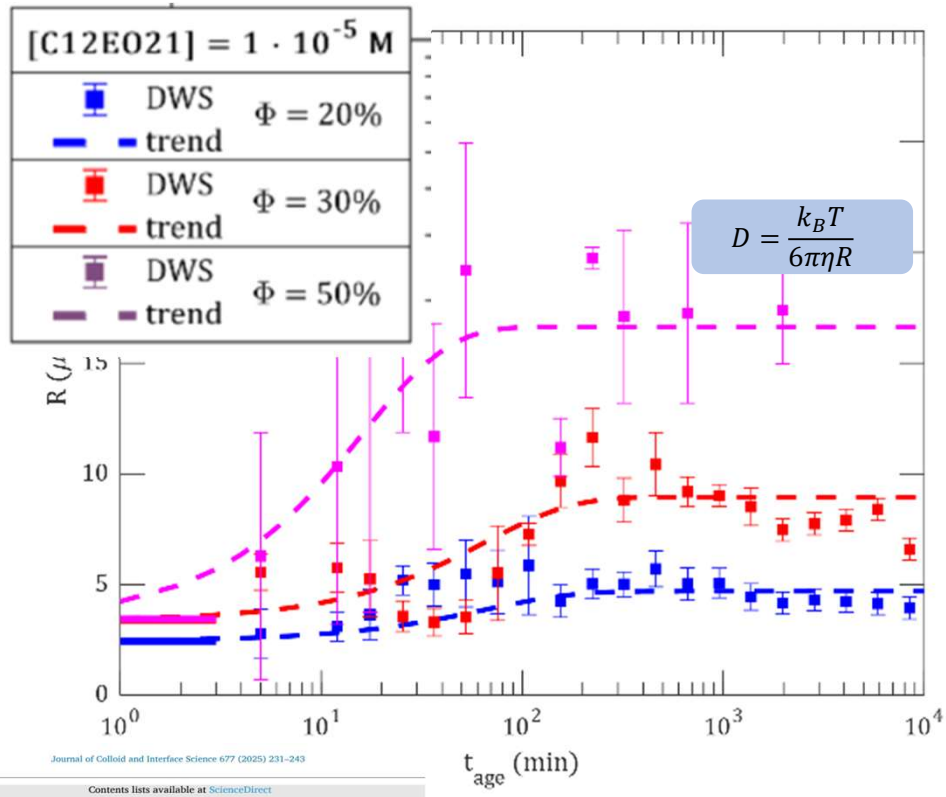
$$g_{1,s}(t) = \exp\left(-\frac{1}{3}\frac{s}{l^*}k_o^2\,(6\boldsymbol{D}t + (\boldsymbol{v}^*t)^2)\right)$$

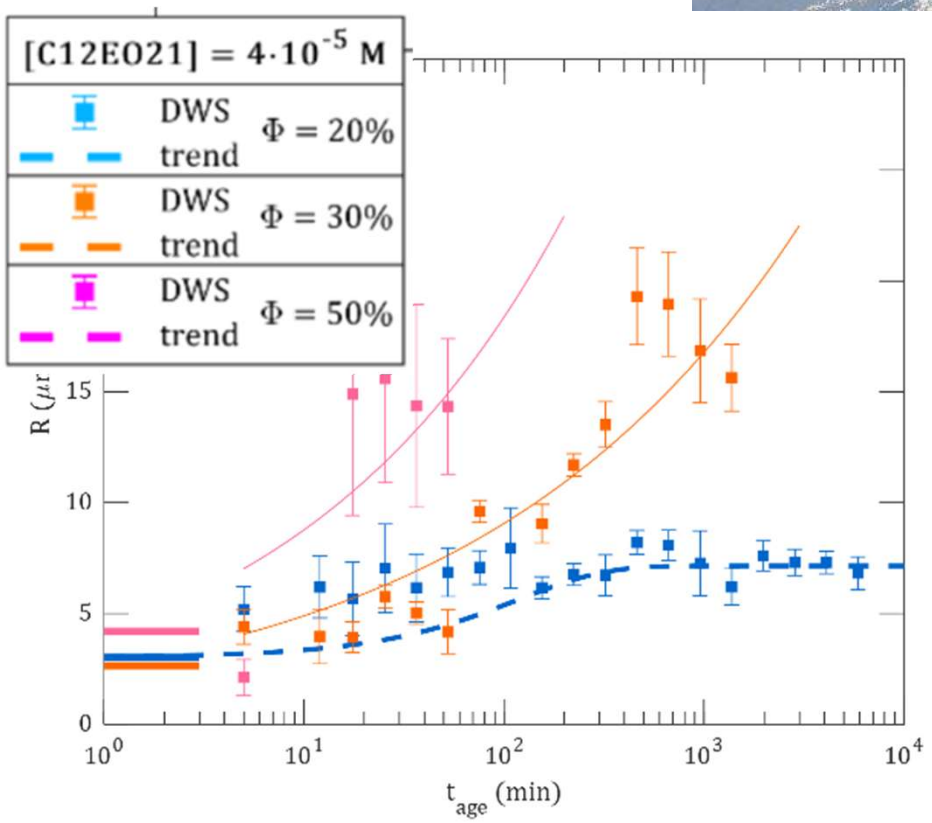
Here, an example of an emulsion in the EBB: Initially, dynamics dominated by creaming: ballistic motion of droplets, ceased after a few minutes, yielding to the stationary Brownian dynamics.

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Microgravity results:
DWS -> Mean drop radius (for the small drops)







Journal of Colloid and Interface Science 677 (2025) 231–243

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Regular Article

Intrinsic dynamics of emulsions: Experiments in microgravity on the International Space Station

V. Lorusso [a,1], D. Orsi [a,1], M. Vaccari [a], F. Ravera [b], E. Santini [b], A.P. Chondrou [c], M. Kostoglou [c], T.D. Karapantsios [c], R. McMillin [d], J.K. Ferri [d], S. Vincent-Bonnieu [e], L. Liggieri [b], L. Cristofolini [a,*]

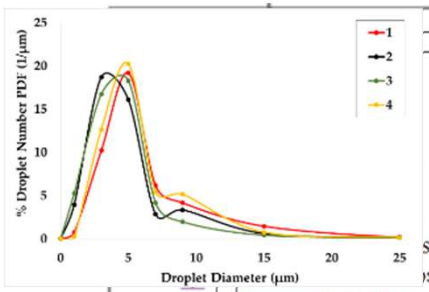
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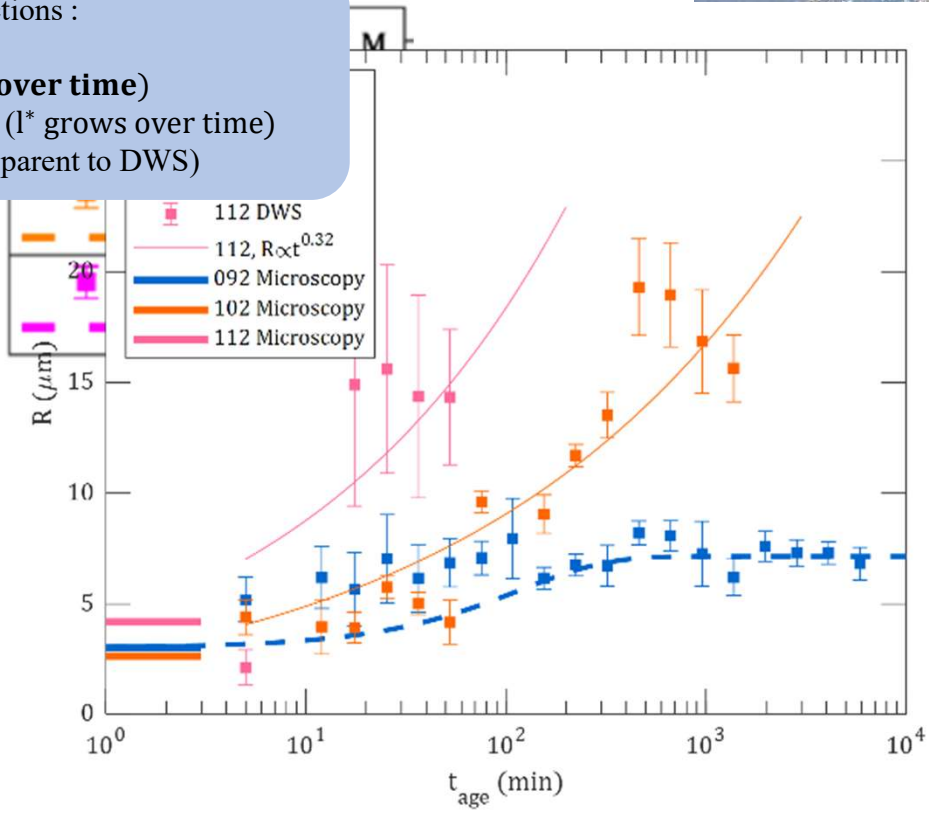
Microgravity results:
DWS -> Mean drop radius (for the small drops)



❖ Bimodal DSD → three types of interactions :

1. **Between two small drops (*R* grows over time)**
2. Between one small and one large drop (l* grows over time)
3. Between two large drops (almost transparent to DWS)





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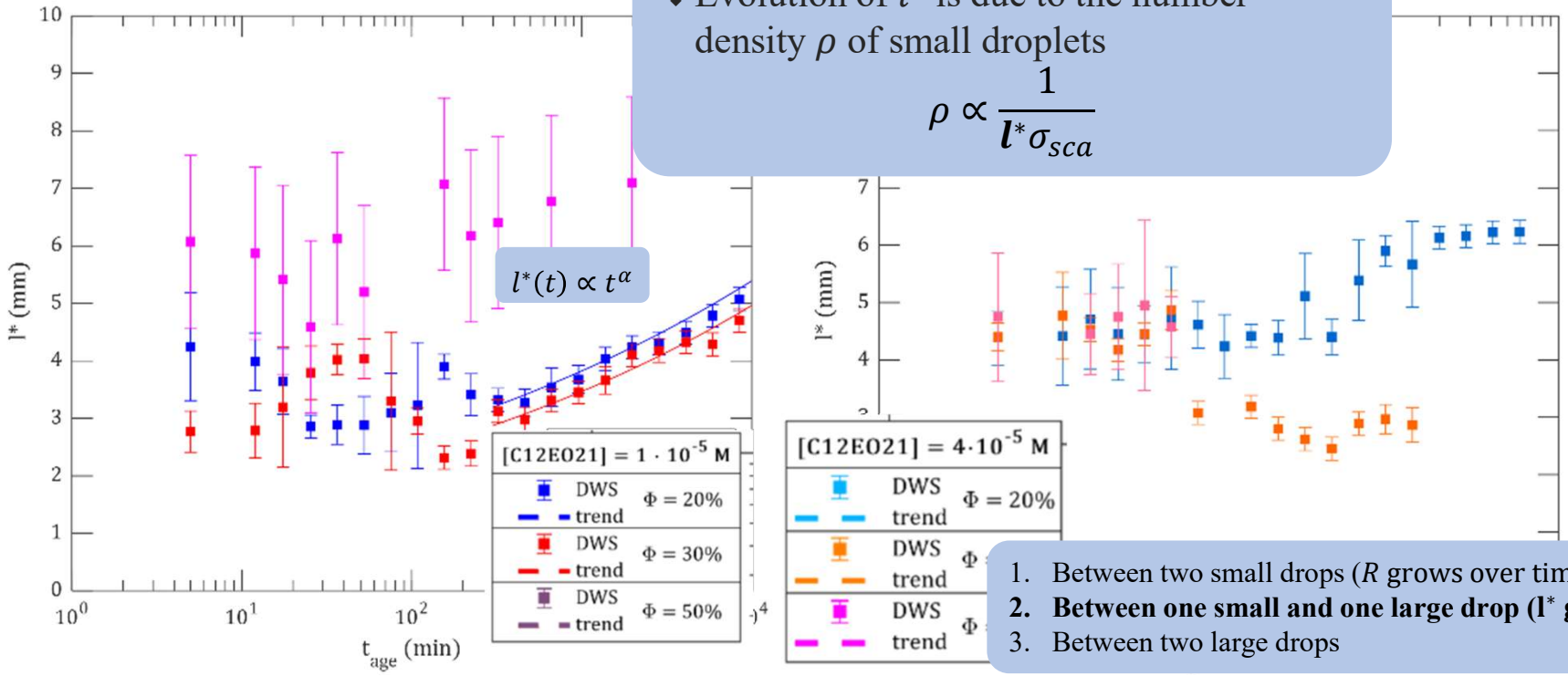
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DWS results: drop density as function of aging, from l*



❖Evolution of l^* is due to the number density ρ of small droplets

$$\rho \propto \frac{1}{l^* \sigma_{sca}}$$



1. Between two small drops (R grows over time)
2. **Between one small and one large drop (l* grows over time)**
3. Between two large drops

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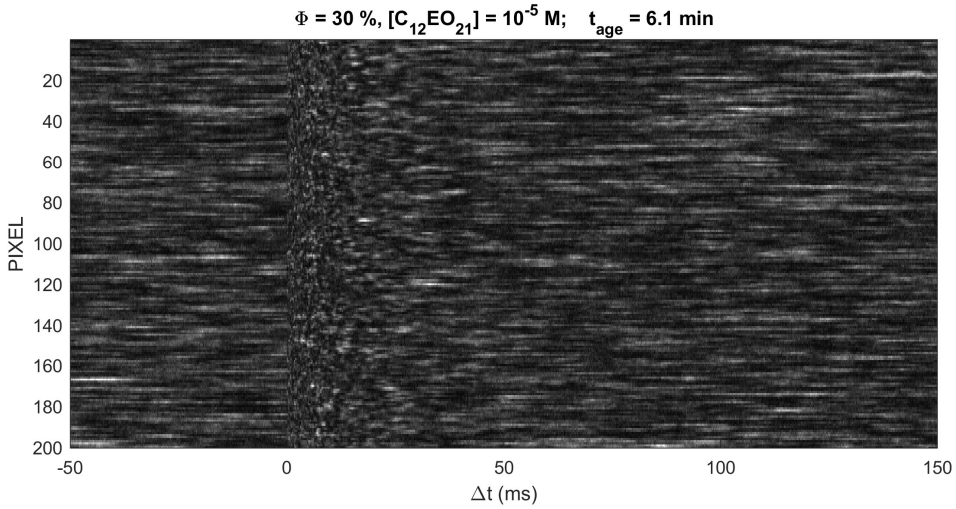
V. Lorusso [a,1], D. Orsi [a,1], M. Vaccari [a], F. Ravera [b], E. Santini [b], A.P. Chondrou [c], M. Kostoglou [c], T.D. Karapantsios [c], R. McMillin [d], J.K. Ferri [d], S. Vincent-Bonnieu [e], L. Liggieri [b], L. Cristofolini [a,*]

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So far: average values,

but we also observe dynamic bursts

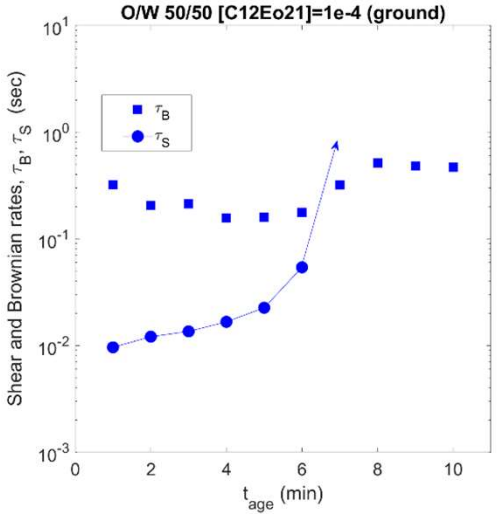
Multispeckle/multipixel analysis



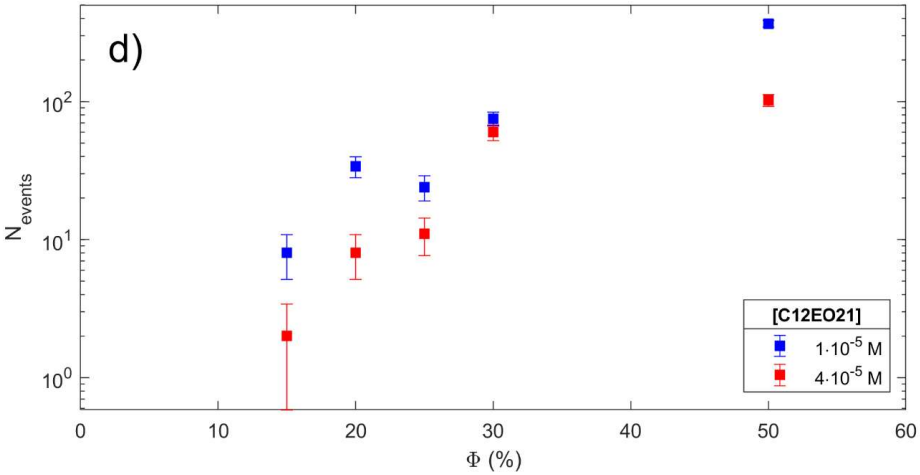
ballistic motion (on earth) and in microgravity

on earth:creaming







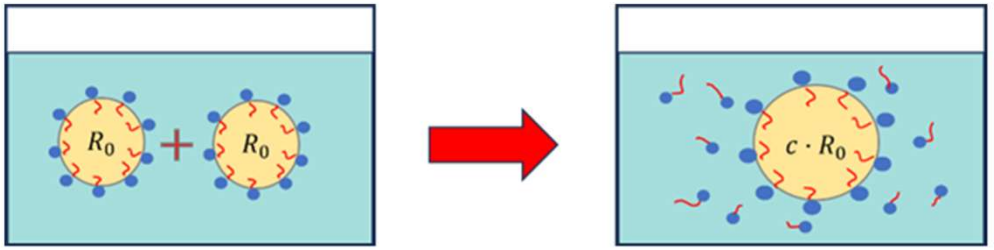


In microgravity…

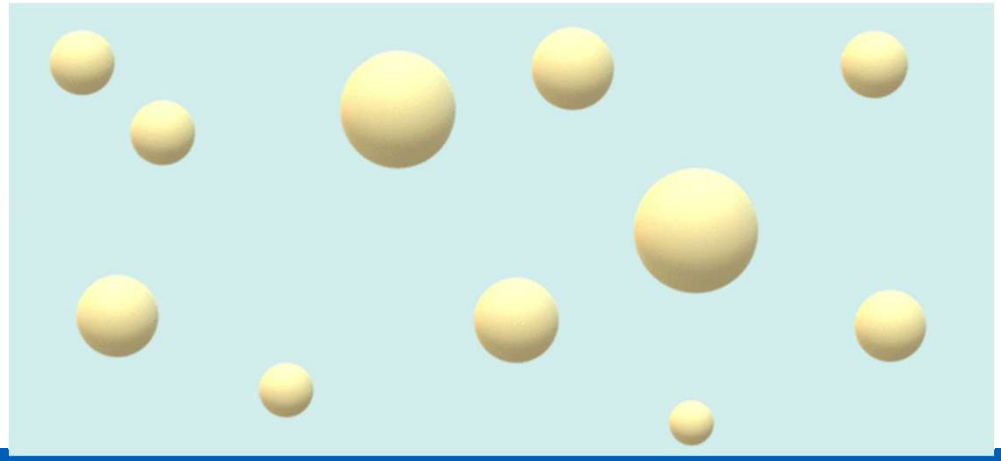
No creaming ➔ballistic motion tracks drop coalescence

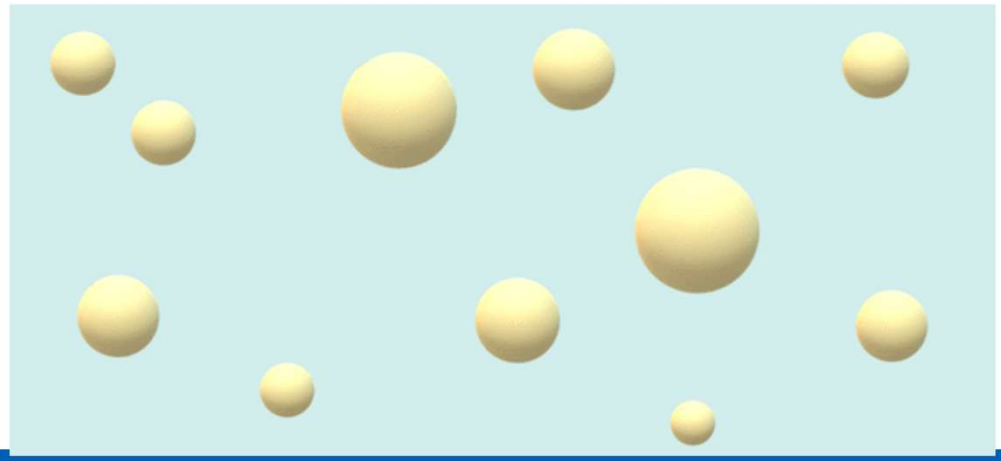
What is the mechanism?

Marangoni-like effects ?



Hydrodynamic correlations?



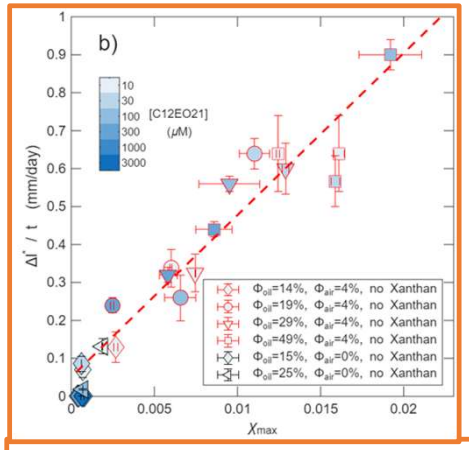


Time resolved (2 times) correlation function

$$c_I(t,\tau) = \frac{\langle I_p(t)\, I_p(t+\tau)\rangle_p}{\langle I_p(t)\,\rangle\langle I_p(t+\tau)\,\rangle_p}$$

Lessons Learnt

- **Importance of having a calibration sample in orbit** to spot any anomaly
- **Flexibility of protocols and rapid interaction** with operators fundamental to adapt to unexpected situations
- **Importance of hands-on experience (EBB, MRT)** to avoid science-fictional approaches
- **On-board data processing** could reduce the large volume of data currently being transferred (sometimes, limited data transfer reduced the number of experiments)
- **Real-time processing of environmental diagnostics**, like MMA accelerometer would help planning
- **Air emerged serendipitously as a key factor** even at 4-5%: only a minor impact on the DWS signal, as from initial simulations and analysis, but was unexpectedly linked to the onset of transient dynamics, influencing both event amplitude and frequency.
- **Broader surfactant screening was missed**: additional Nikkol surfactants would have allowed us to explore the role of HLB, as originally planned for the cancelled campaigns
- **In situ sample production (microfluidics),** better than the carousel, could be more efficient for screening multiple samples
  → Adaptive, on-demand sample formulation,
  → Better control of droplet/bubble size distributions



Perspectives of microgravity investigations of emulsions (a personal view)

- Microgravity provideds new tools to investigate the (de)emulsification process
- Identify the mechanism driving the emulsion destabilization (air, Xhanthan) and discriminate coalescence events
- More info on drop interactions from OVC images, still to be analyzed
- Emulsion- based technologies to enable long flights, ISRU …

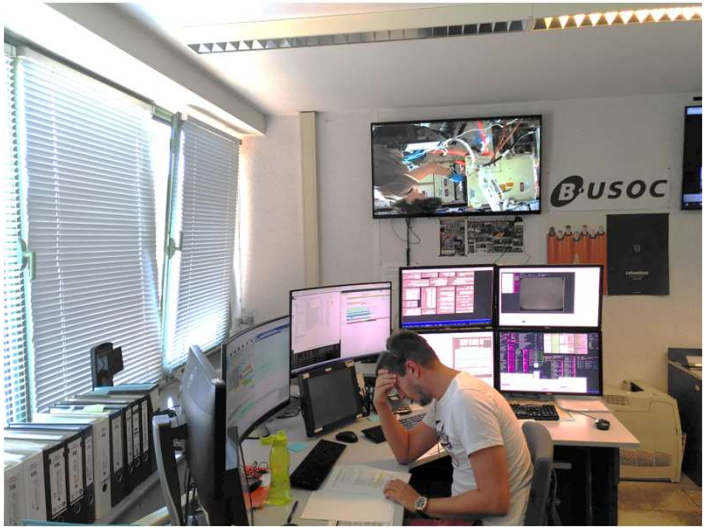
Thanks to
Denis Van Hoof, Yenn Arijs
and all B.USOC staff

for their valuable suggestions and continuous support











Thanks to ESA, to Libero Liggieri and to all the part[illegible] of the EDDI / SE[illegible]

Thank you for your attention

- ESA MAP «EDDI» (Contract
- ESA Topical Team «Foams and Emulsions Technology »
- ASI Topical Team «ECOES» bando prot. n. DC-DSR-UCO-2022-015
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