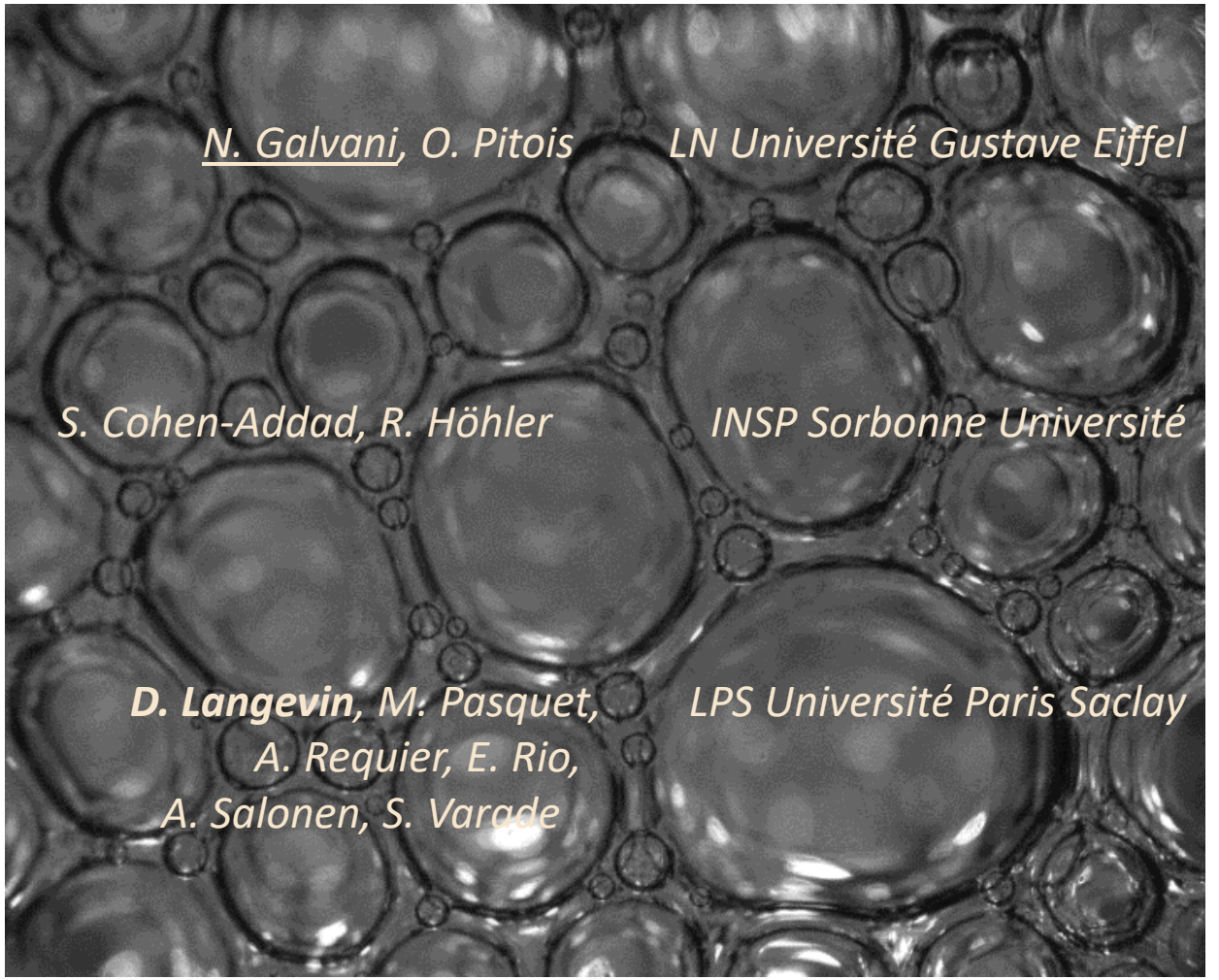
FOAM-C project



N. Galvani, O. Pitois — *LN Université Gustave Eiffel*

S. Cohen-Addad, R. Höhler — *INSP Sorbonne Université*

***D. Langevin**, M. Pasquet, A. Requier, E. Rio, A. Salonen, S. Varade* — *LPS Université Paris Saclay*

Why study foams?



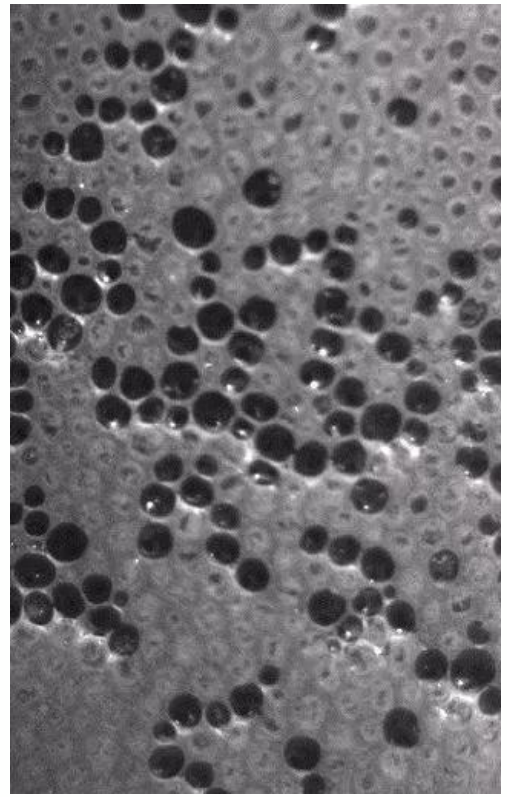
- Food
- Cleaning
- Extraction of resources
- Insulation
- Manufacturing
- Building

Liquid foams

Solidification

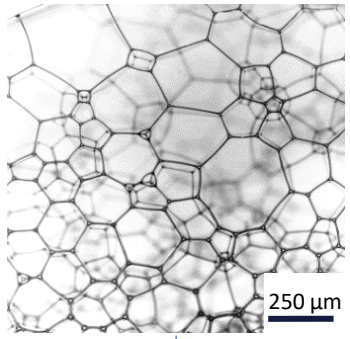
Solid foams

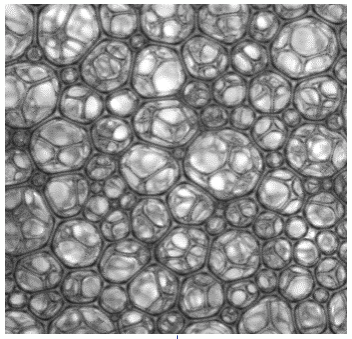
$t_{hardening}$ ~1h

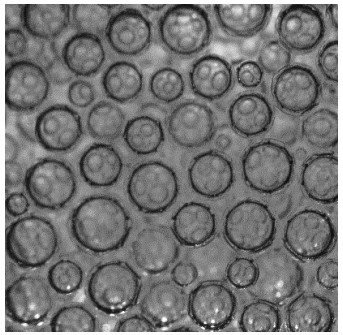


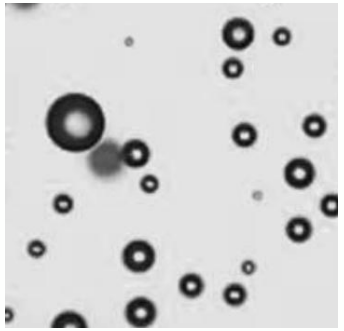
Feneuil (2020)

The need for microgravity







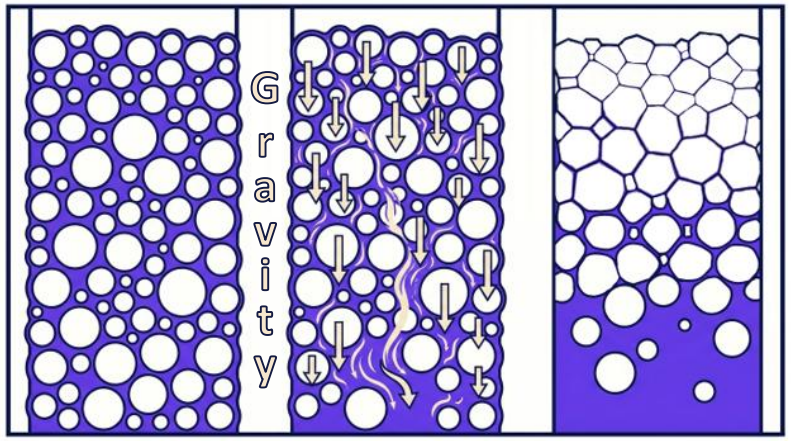


1% 10% $\phi^* \approx 36\%$ 100%

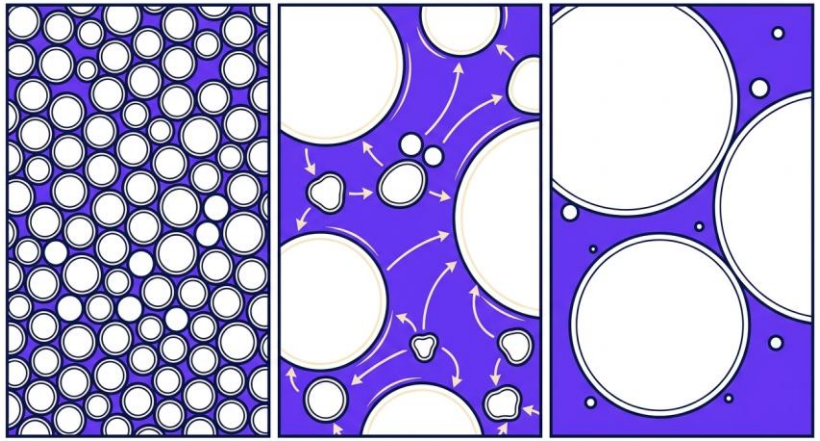
Liquid fraction ϕ

Dry foam | Wet foam | Jamming transition | Bubbly liquid

Drainage

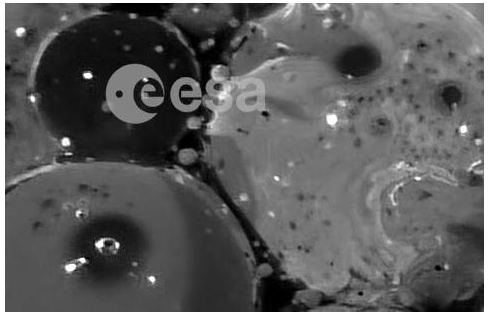


Coarsening



With microgravity, coarsening is disentangled from drainage:
it allows for a systematic study using liquid fraction as a control parameter.

FOAM-C history



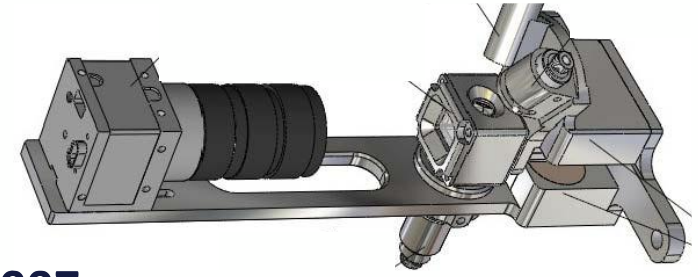
1999-2002

ESA's MAP project *Hydrodynamics of Wet Foams* was conceived and then launched to study wet-foam physics in microgravity, with the long-term goal of an ISS experiment.

2004-2005

Parabolic-flight and MAXUS experiments validated key concepts for foam generation, capillary drainage, optical diagnostics and prototype cell design in microgravity.





2007

Because the original ISS hardware was too costly, the program was simplified and refocused from a broader drainage–rheology facility toward a more feasible coarsening-oriented project, paving the way for FOAM-C.

2009

FOAM-S flew on the ISS and demonstrated that wet foams could be generated and remain stable in microgravity, providing a crucial precursor for FOAM-C.



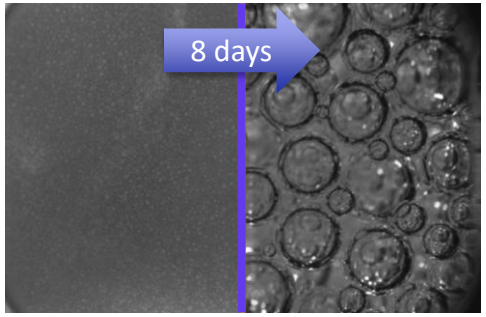


2014

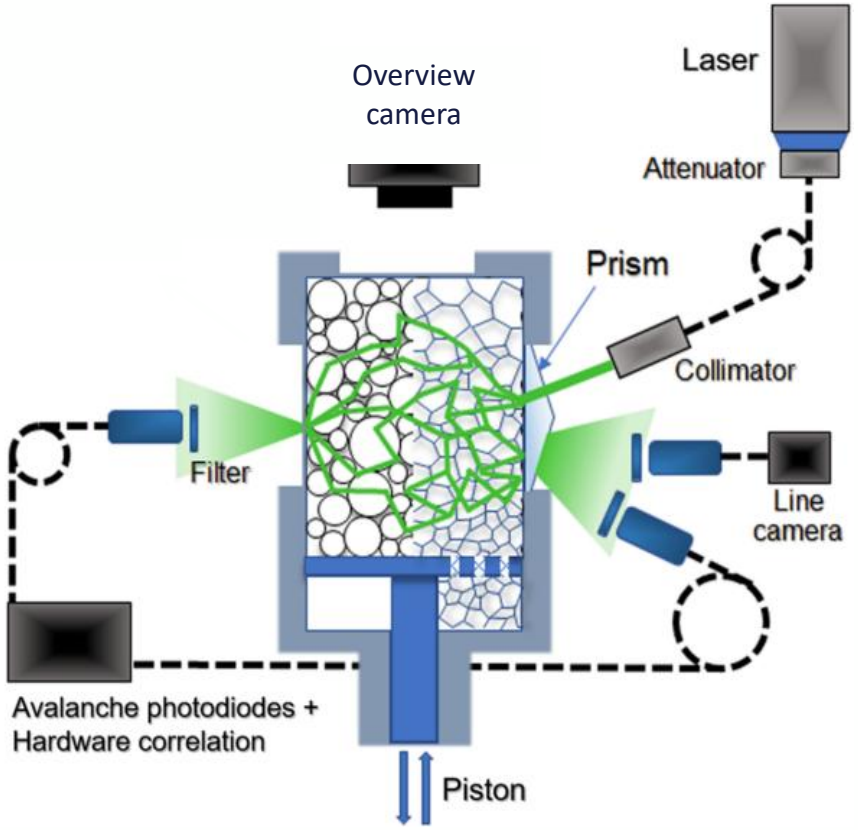
The project matured within a broader soft-matter strategy in FSL, aimed at shared experimental capabilities for foams, emulsions and granular materials in microgravity.

2020-23

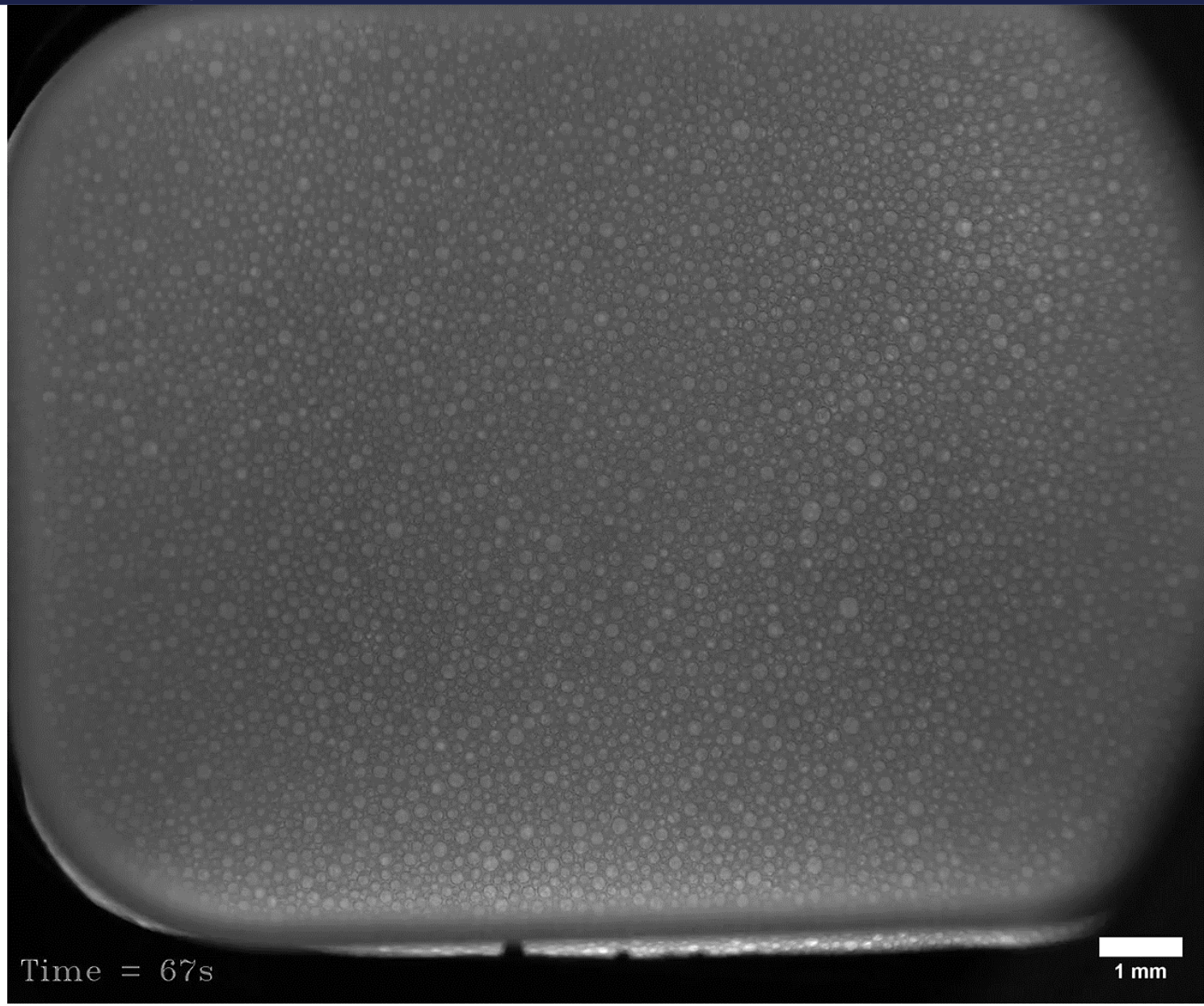
FOAM-C was finally operated on the ISS, with three experimental campaigns that turned two decades of development into scientific results.



FOAM-C experiments



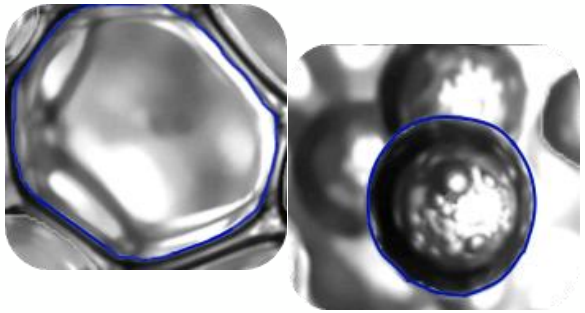
- In place foam generation with controlled ϕ
- Experiments ranging from hours to months
- Data acquisition: Videomicroscopy
  Light scattering



How to analyze TB of data?

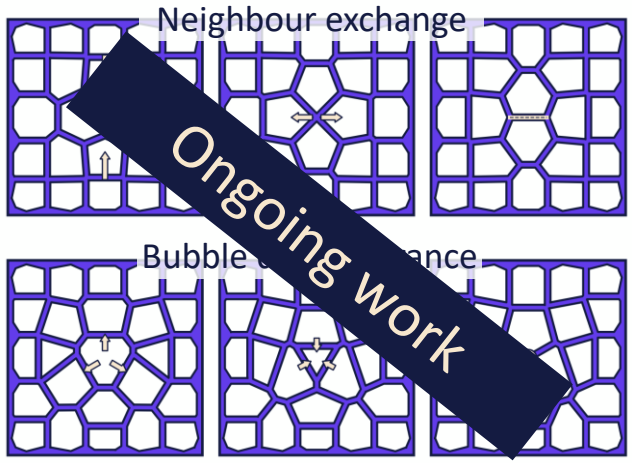
Videomicroscopy

Surface sensitive



Detect bubble area and position

Rearrangements dynamics

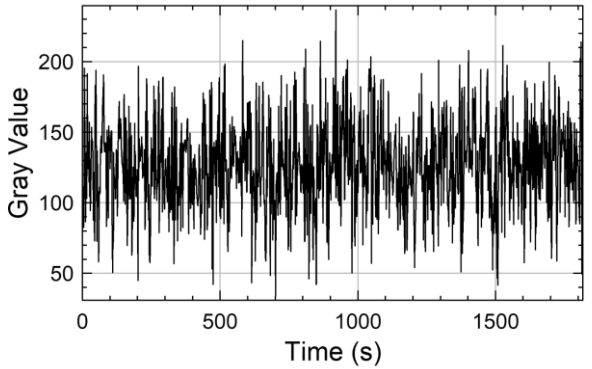


Diffusing-Wave Spectroscopy (DWS)

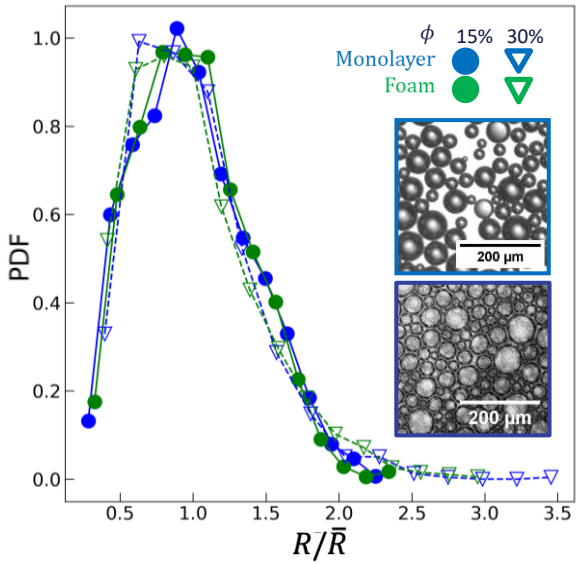
Temporal-correlation of diffused light intensity

Light scattering techniques

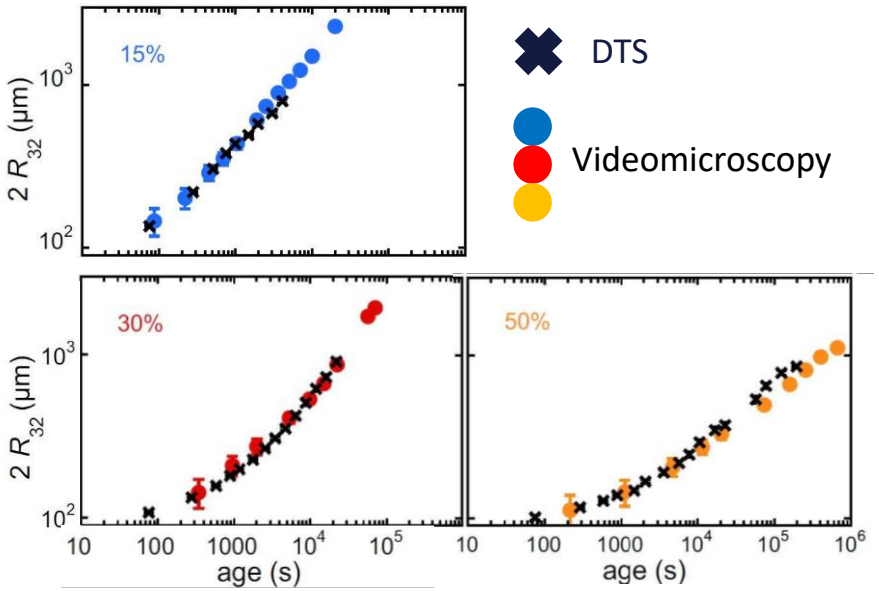
Bulk sensitive



Size distribution



Average growth



Diffuse-Transmission Spectroscopy (DTS)

Variation in transmitted light intensity

Pasquet, Galvani et al, Comp. Rend. Phys. (2023)

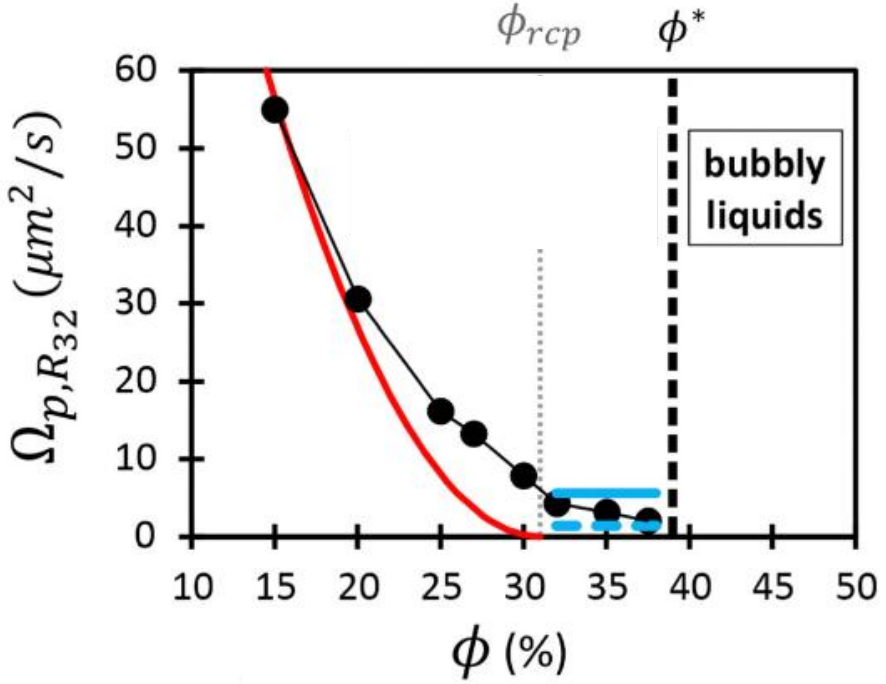
Scientific results: probing the jamming transition

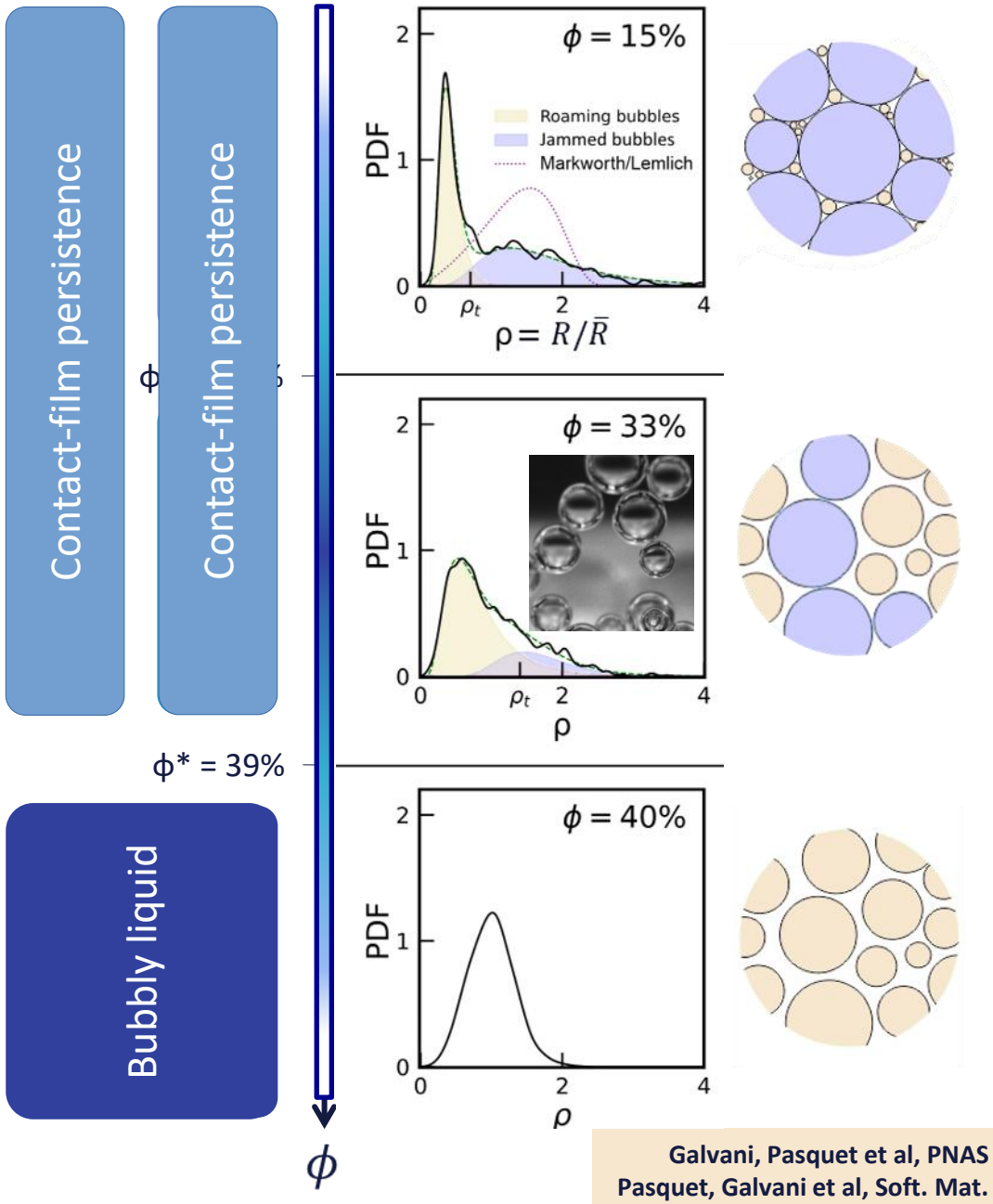
Using only liquid fraction as varying parameter, we investigated the transition from a jammed foam to bubbly liquid correlating coarsening kinetics, foam microstructure and packing simulations.

Coarsening growth law

$$R_{32}^2(t) - R_{32}^2(t_0) = \Omega_{32}(t - t_0)$$

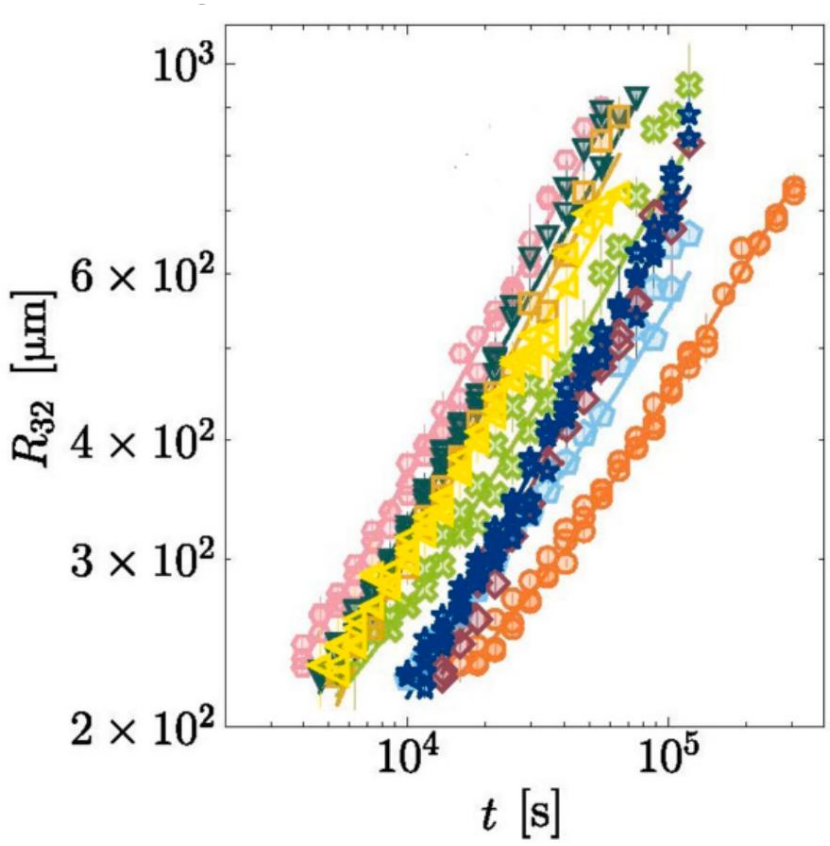
$$\Omega_{32} = \Omega_0 f(\phi)$$





Galvani, Pasquet et al, PNAS (2023)
Pasquet, Galvani et al, Soft. Mat. (2023)

Scientific results: the role of interface chemistry



Parameters:

- Surface tension
- Surfactant concentration
- Liquid viscosity
- Interfacial response
- Bubble adhesion

Weak adhesion

- TTAB 5 g.L^{-1}
- TTAB/DOH 0.05 g.L^{-1}
- TTAB CMC
- TTAB 5 g.L^{-1}, glycerol 20 %

Stronger adhesion

- C12G2 4 g.L^{-1}
- TTAB/DOH 0.2 g.L^{-1}

Irreversible adsorption

- Pluronic 20 g.L^{-1}

Coarsening growth law

$$R_{32}^2(t) - R_{32}^2(t_0) = \Omega_{32}(t - t_0)$$

For all ϕ



Coarsening rate decreases with liquid fraction.

After the jamming transition, film permeability and surface tension are not sufficient to describe the role of surface chemistry.

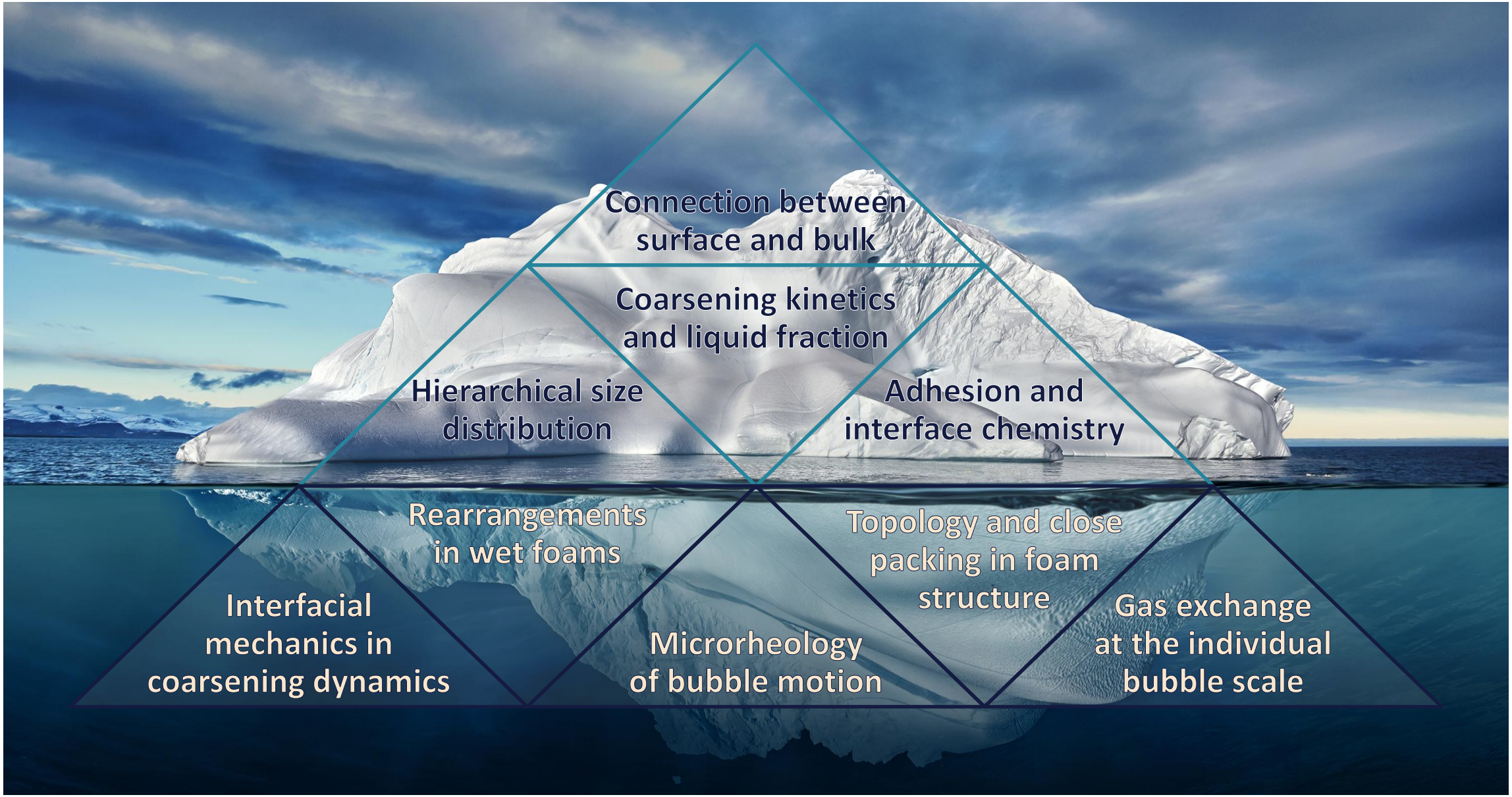
Above jamming



Coarsening rate increases with adhesive forces.

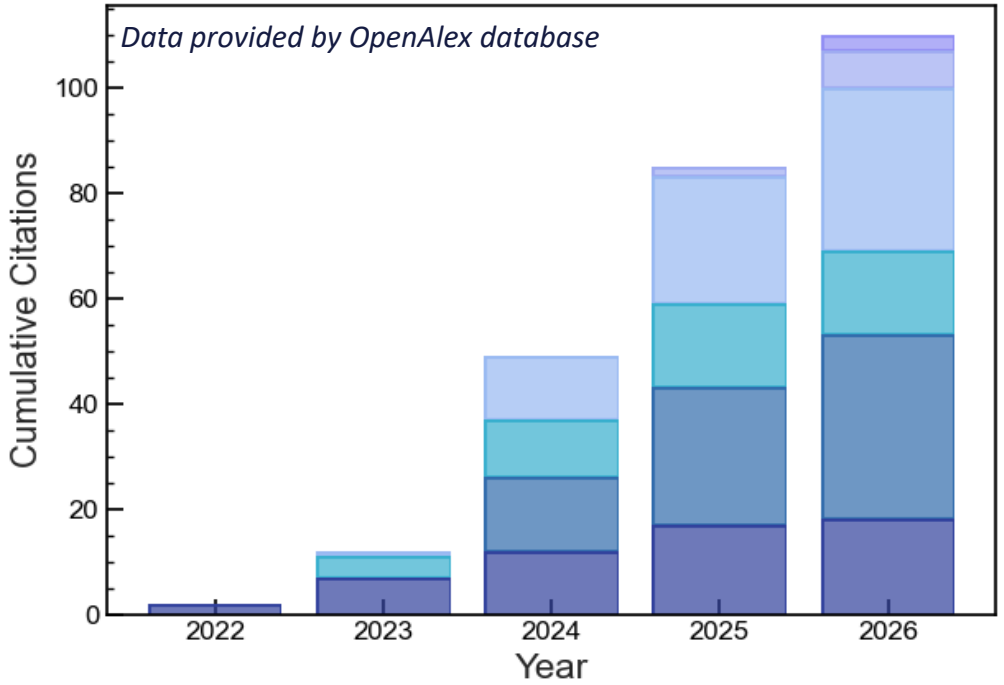
Requier, Varade, Galvani et al, J. Coll. Int. Sci.

We have seen only the tip of the iceberg



The legacy of FOAM-C

6 publications in high-profile journals



Even if recent, these publications are inspiring theoretical studies to update the still uncomplete models, and provide a reference for complex foams with a direct application:

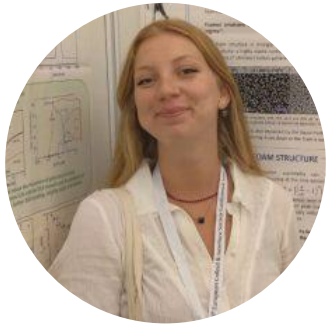
Case study	Application
Foams in porous media	Bulding materials
Foamed emulsions	Food and beauty
Foams particle-loaded	Advanced materials

Dissemination

- 10+ Oral contribution
- 1 Invited speech (*R. Höhler*, EUFOAM 2024)
- 10+ Poster presentations
- 1 thesis award (*M. Pasquet*, 2023 Claudine Hermann Award)
- 1 Industrial partnership (*C. Gehin-Delval*, Nestlé)

3 PhD thesis


Marina Pasquet (2022)

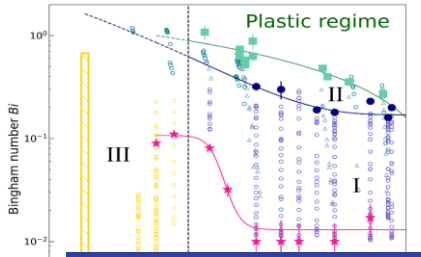

Alice Requier (2024)


Nicolò Galvani (2024)

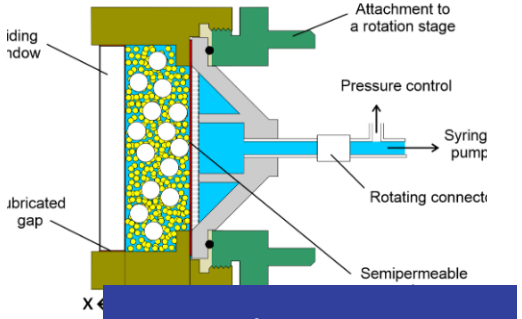
My experience with FOAM-C



Machine learning



Big data analysis



Operando experiments

Growing as a scientist

Being part of an international community

Start of PhD
01/11/2021



End of PhD
10/12/2024



Soft-matter







Space



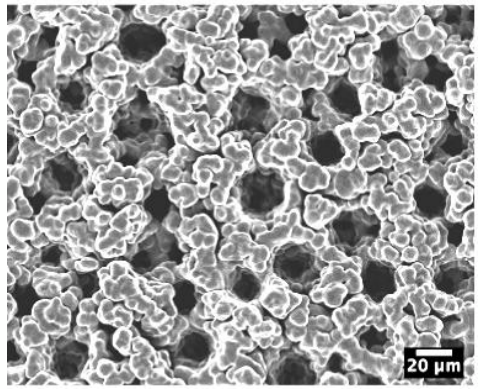


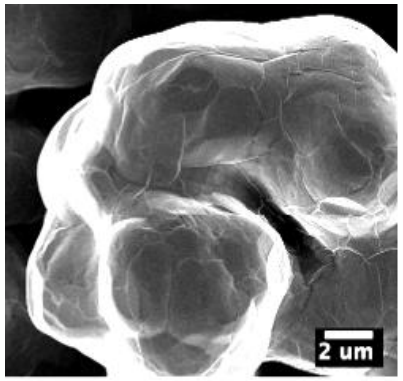






Graphene foam for photocatalysis





Graphene for enhanced thermal mass transport in microgravity

Aims: Improve cooling devices in Space

Applications: Satellites, spacescaft



GRAPHENE FLAGSHIP

LEONARDO

noveSpace

esa

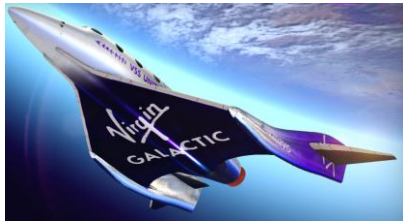
Experiments in microgravity during parabolic flight campaigns 2018-2021

Splashing in microgravity

Aims: Splashing dynamic

Applications: Spray coating in Earth and Space





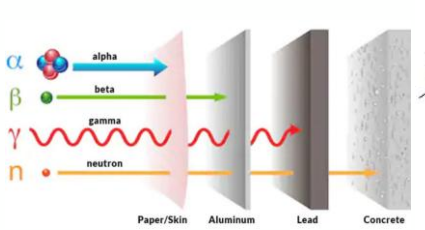
PING (droP Impact iN micro-Gravity) exp in #Galactica01 VIRTUDE-1 mission 2023



Materials for radiation shielding

Aims: Advanced polymeric composites for radiation shielding in low Earth orbits

Applications: Microsatellites protection



SPACE IT UP!

An open hub at the CNR Bologna Research Area

Biospac-ER Hub

CLUST-ER HEALTH · Consiglio Nazionale delle Ricerche · TECNOPOLO BOLOGNA-CNR EMILIA-ROMAGNA · MISTER SMART INNOVATION

Researchers, companies and startups in Emilia-Romagna

A meeting point in Emilia-Romagna for joint projects, prototype development and startup incubation

Hub initiative:
Valentina Benfenati,
CNR-ISOF

Materials, biomaterials and bioelectronics

Technologies for health and space applications, linking materials research with biological testing

First initiatives:

Cell physiology and bioelectronics

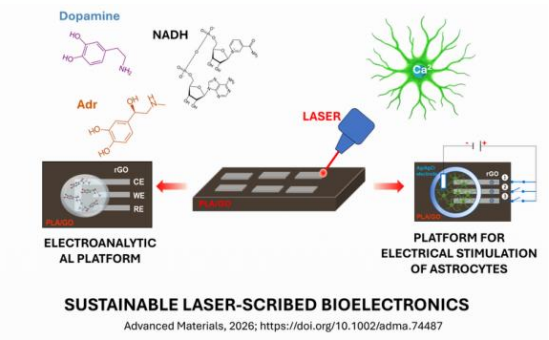


Space platform concept

2D/3D cell platforms Sensing and stimulation for health and space

Valentina Benfenati
CNR-ISOF

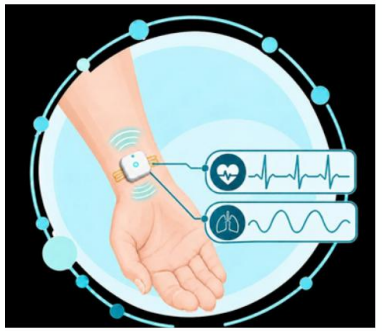
Graphene bioelectronics



Laser-fabricated interfaces for sensing and cell stimulation

Emanuele Treossi
CNR-ISOF

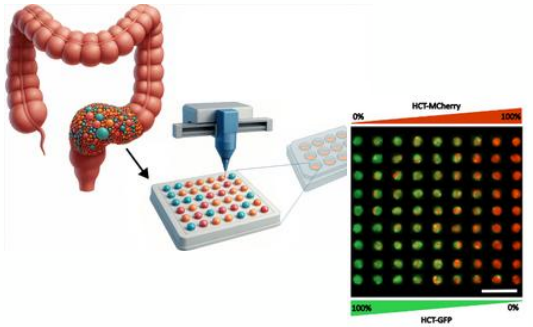
Wearable MEMS patch



Cardiac and respiratory mechanical signals

Matteo Ferri and Fabiola Liscio
HighSenseTech / CNR-ISMN

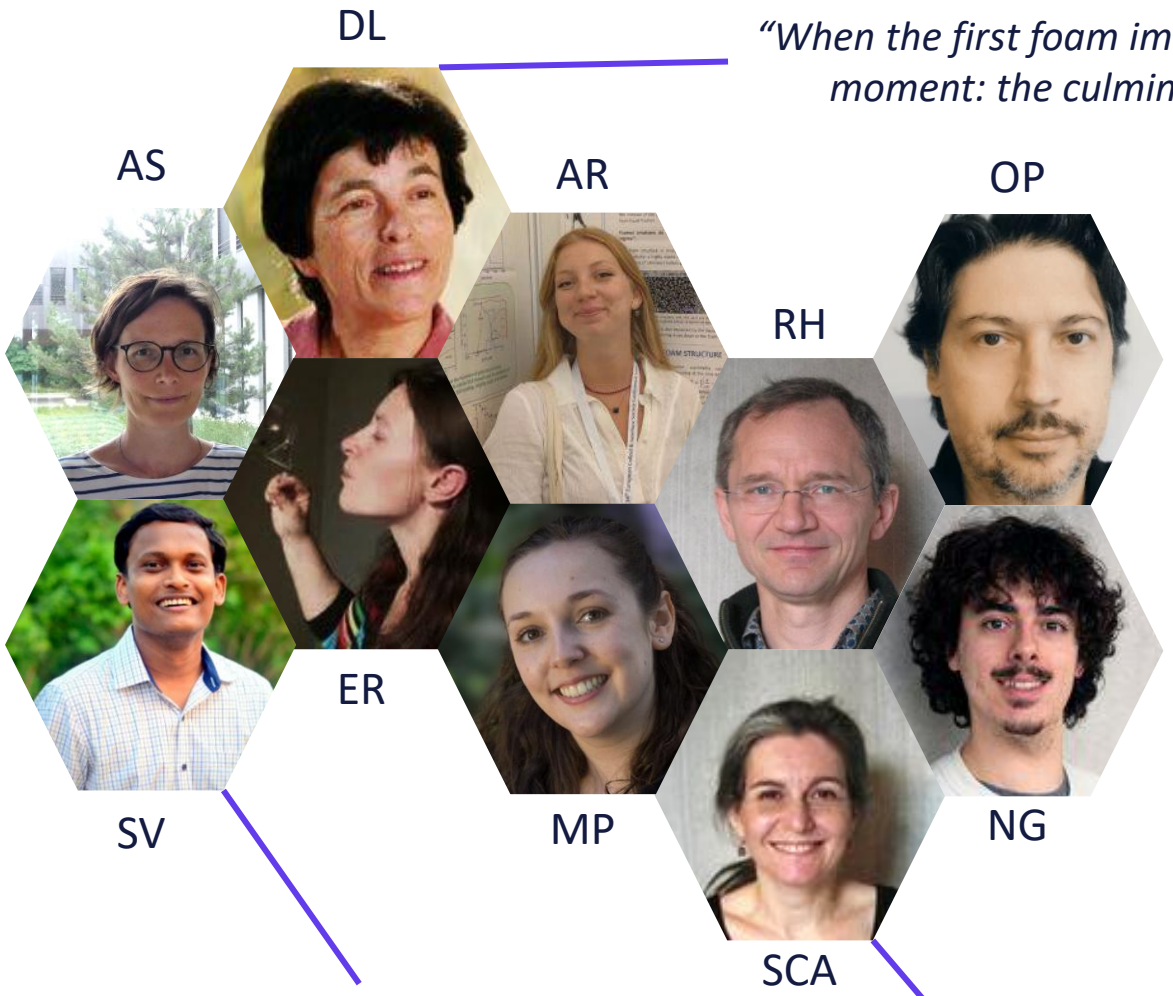
Bioprinting and 3D models



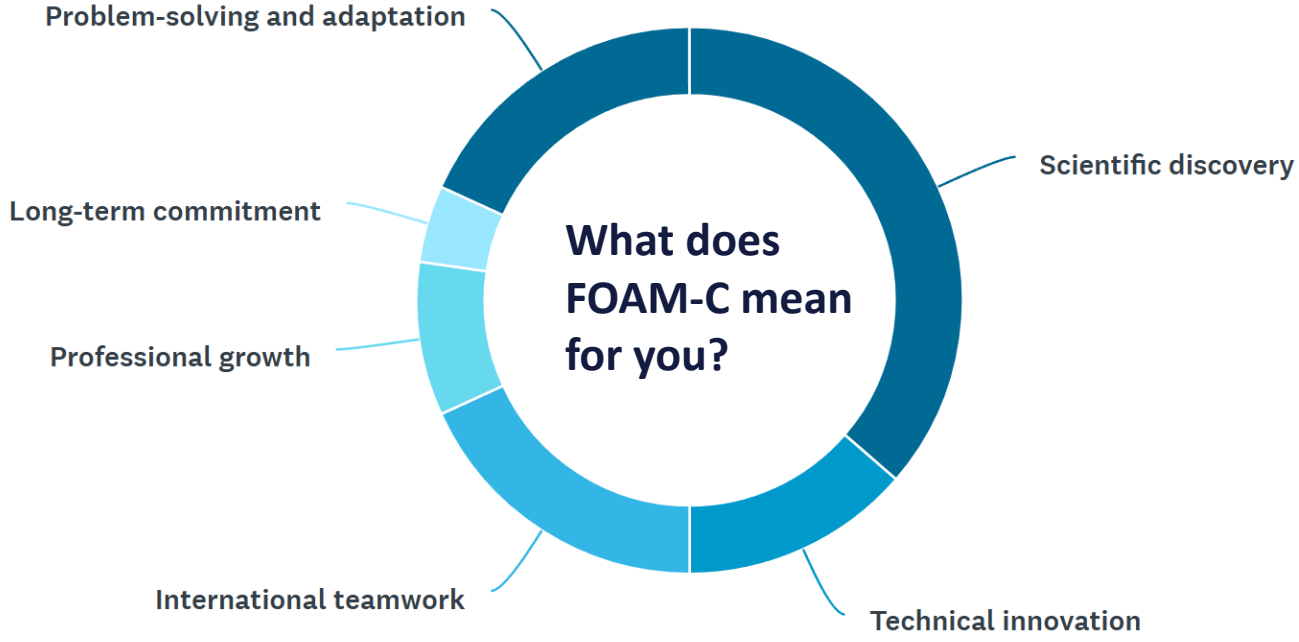
Heterogeneous 3D tissues for biomedical research

Simone Albonetti
CNR-ISMN

A few words from the team



"When the first foam image arrived from the ISS on 9 March 2020, it was an extraordinary moment: the culmination of more than twenty years of work that began in 1999."



"FOAM C gave me the rare chance to study fluid physics beyond Earth's gravity, deepening both my scientific curiosity, appreciation for space-based research and to work with super intelligent people."

"Foam-C mission 1 was launched in March 2020 and went on during the lockdown period. While confined in our homes, we received real time images and data produced by the SMD instrument. It was an unexpected lucky valuable way to pursue experimental work although our labs remained closed for months!"