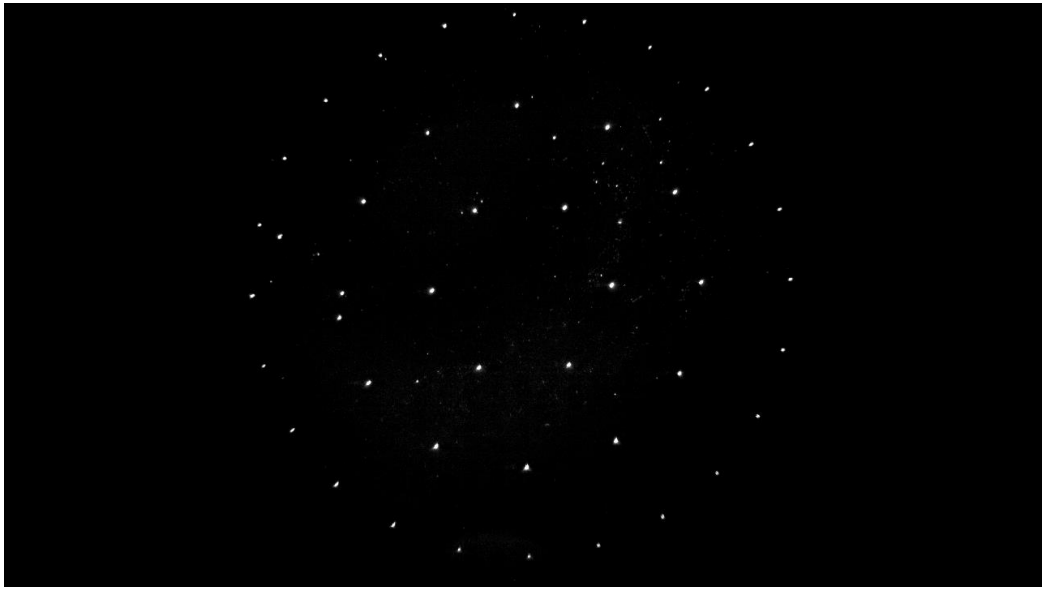
Bag it!

Intensifying with ultrasound and microfluidics



PROCESS INTENSIFICATION NETWORK

June 21st 2016, Newcastle UK

David Fernandez Rivas
Mesoscale Chemical Systems
MESA+ INSTITUTE FOR NANOTECHNOLOGY
UNIVERSITY OF TWENTE.

BμBCLEAN

Jeb Berrier, a regular American man, makes a pledge to stop using plastic bags at the grocery store and has his life completely changed.

Initial release: September 1, 2011 (USA)

Director: Suzan Beraza

Screenplay: Michelle Curry Wright

Music composed by: Larry Groupé

Producers: Suzan Beraza, Michelle Hill

WINNER
Best of Festival Award
MONTEREY
BLUE OCEANS FILM FESTIVAL

WINNER
Audience Choice Award
FLAGSTAFF
MOUNTAINFILM FILM FESTIVAL

WINNER
Audience Choice Award
MOUNTAINFILM
IN TELLURIDE FILM FESTIVAL

WINNER
Audience Choice Award
ASHLAND
INDEPENDENT FILM FESTIVAL

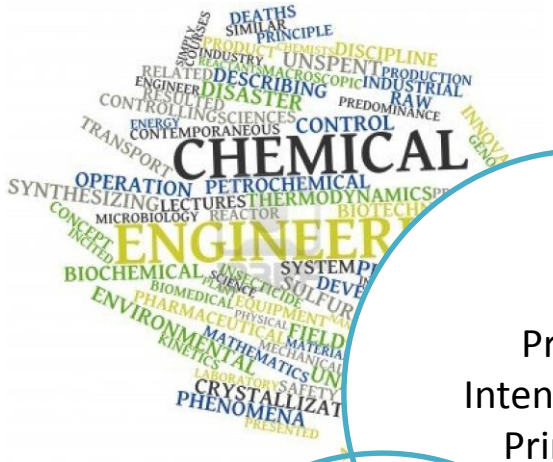
WINNER
Audience Choice Award and Second Place
WILD & SCENIC
FILM FESTIVAL

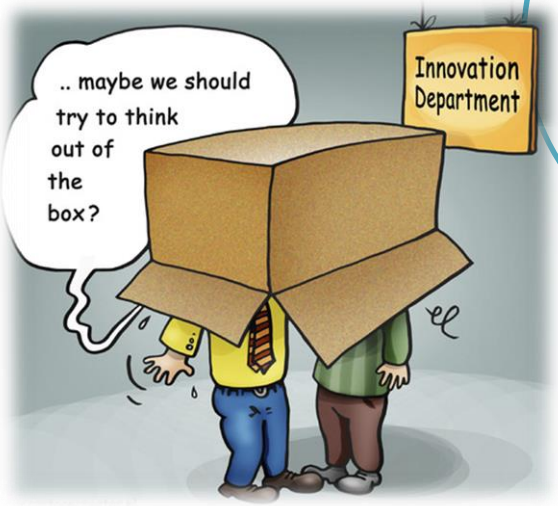
Outline

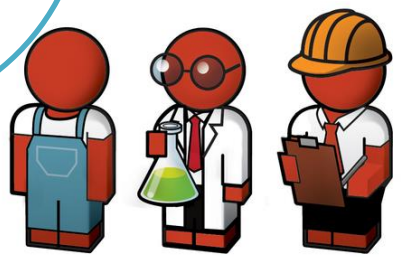
- New PI Principles course in Twente
- Scaling up a microreactor (unaware intensification)
- Bagging valorization benefits
- Future Intensification

PI course in Twente

MSc level

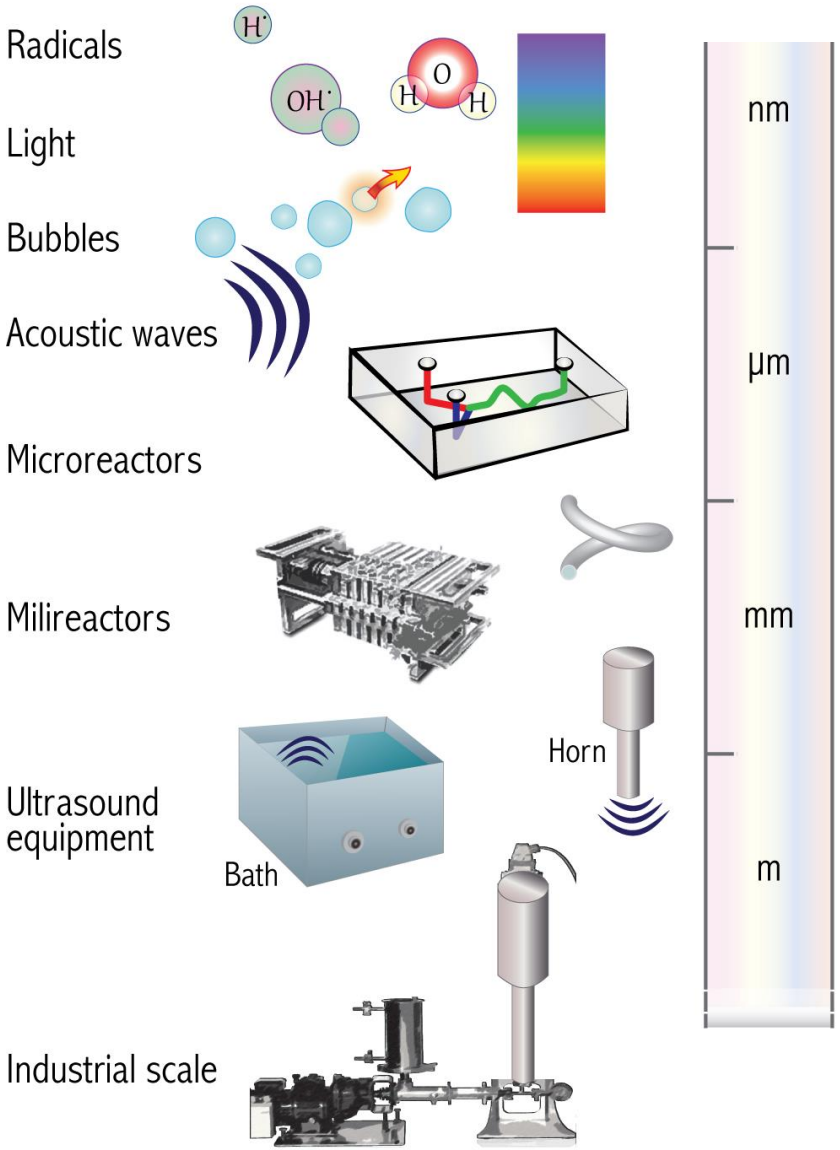






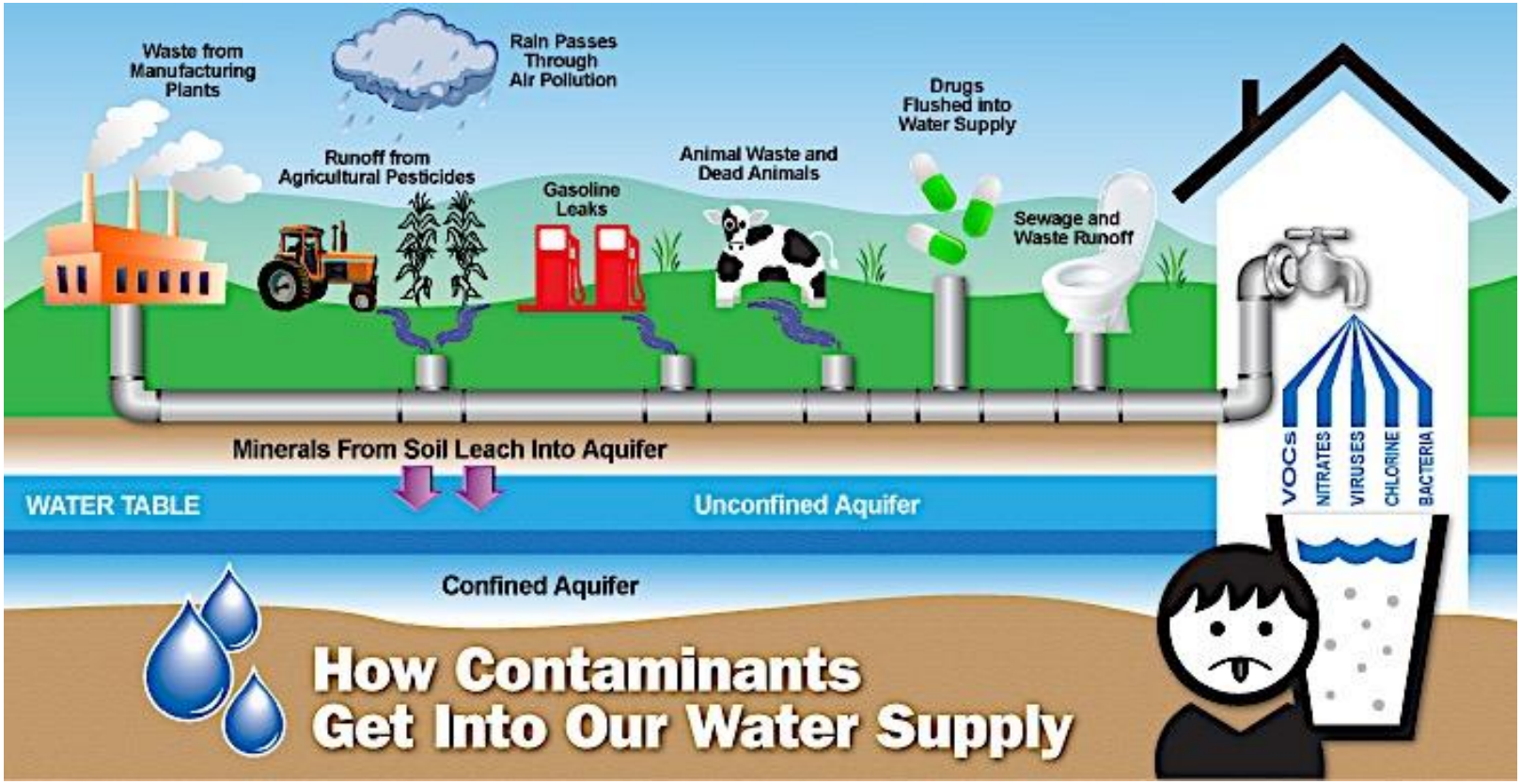
littlemetaldog

Scales and terminology of this talk

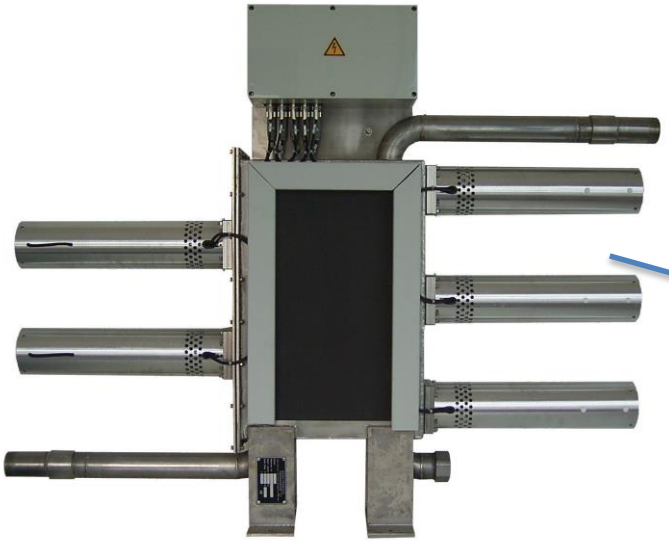


D Fernandez Rivas and S Kuhn, Synergy of Microfluidics and Ultrasound, to appear in Current Chemistry, 2016

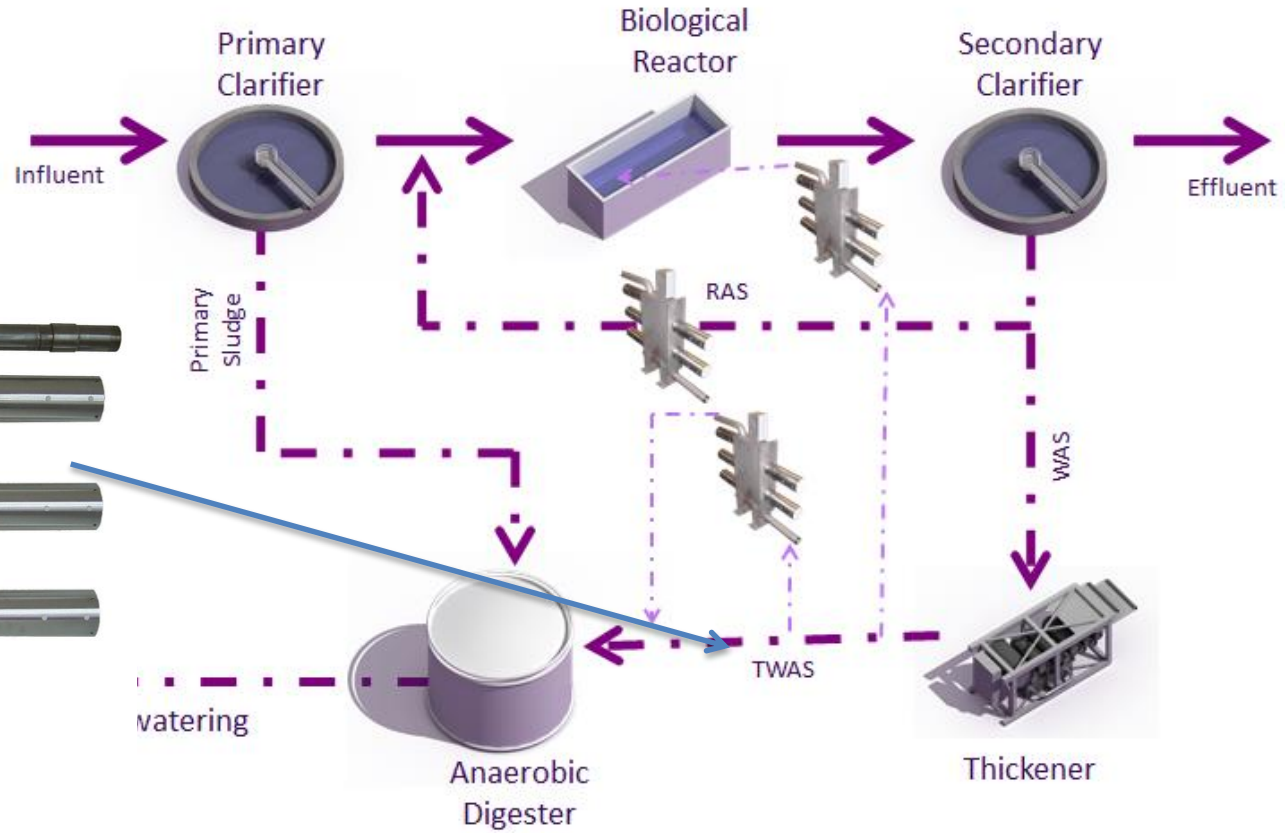
Why is water treatment important?



Among the many examples



SonolyzerTM Unit



Ultrasound applied at high intensity at 20 to 35 kHz generates cavitation.

Creates extreme mechanical shear forces that disintegrates biomass in wastewater.

What can one bubble do?

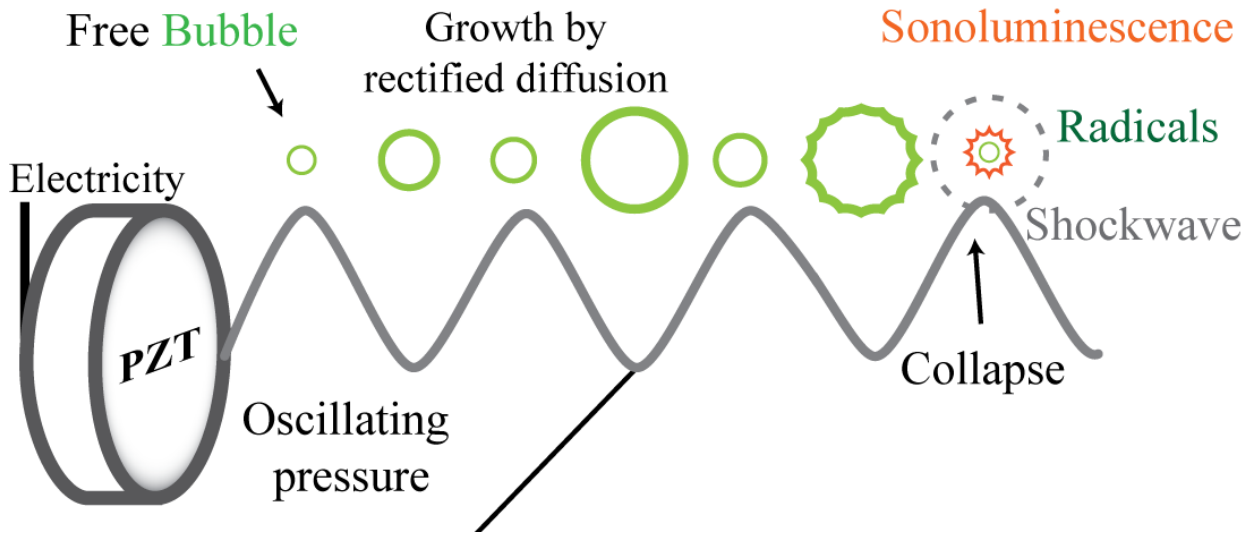
Not these type of bubbles!!

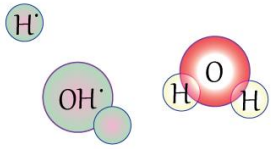
Bubble toohbrush (vimeo.com/104998226)

Difficult Experiments

D. Fernandez Quayside, Newcastle June 2016
D. Fernandez Rivas & S. Wissman, Sattelite bar, EPFL, Dec. 2015

There is more than meets the eye …

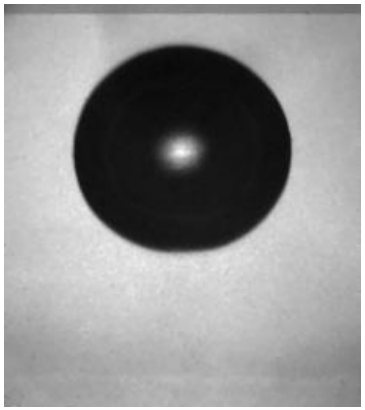


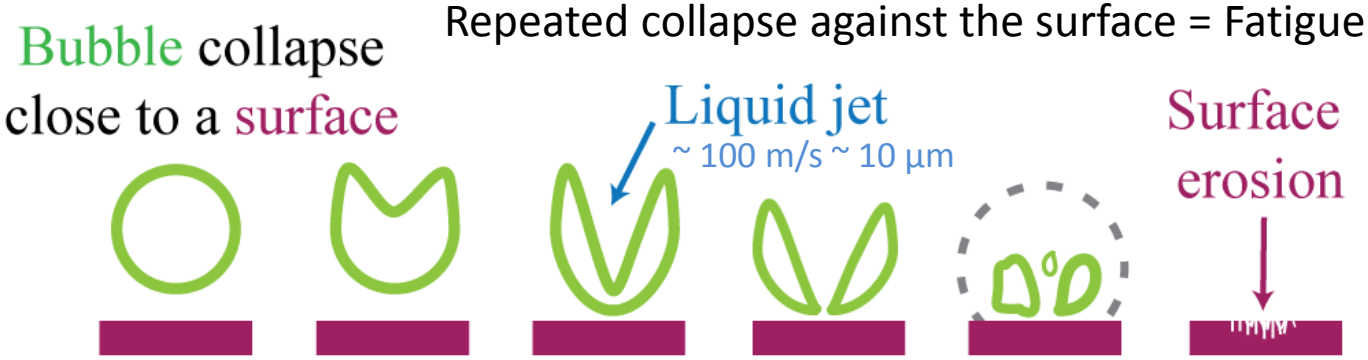


$$X_{US} = \frac{\Delta H \, dN_{rad}/dt}{P_{US}}$$

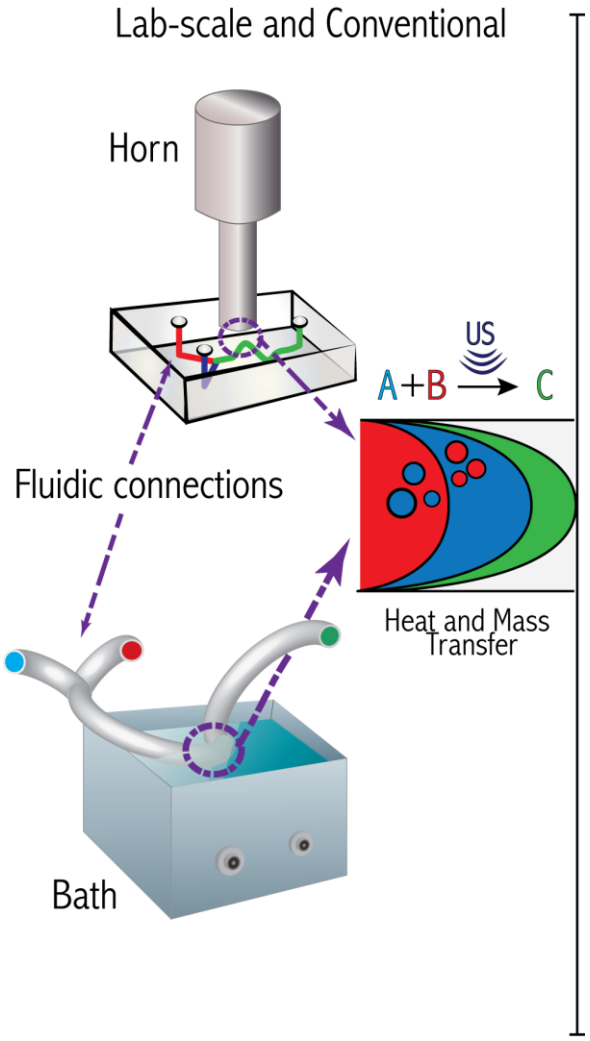
Low efficiencies
~10^{-5} – 10^{-6}

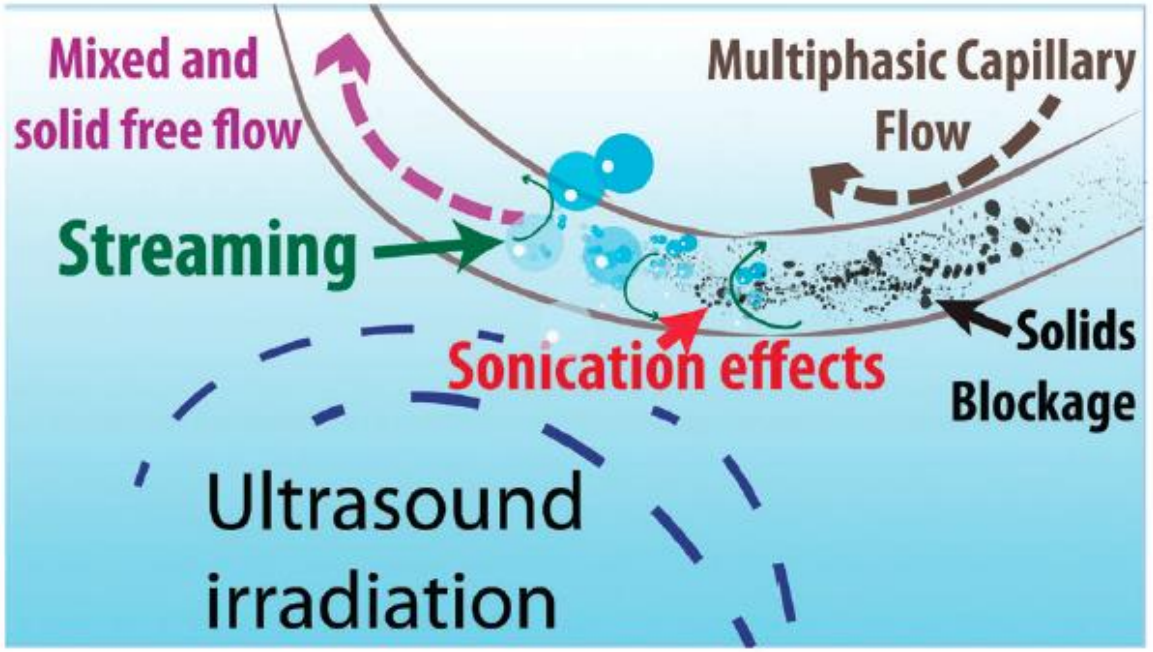
Collapse against a surface





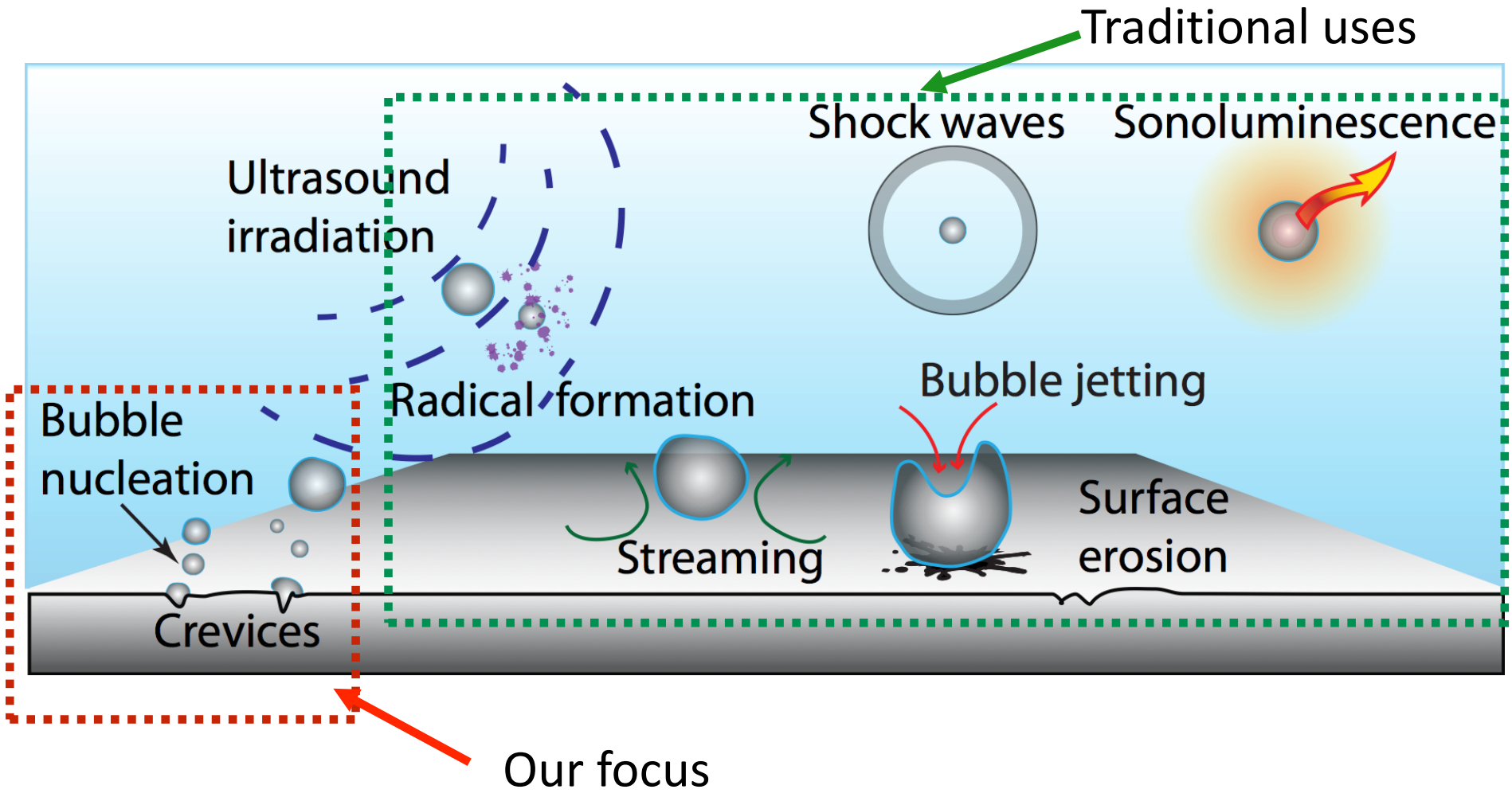
Bubbles + Ultrasound + µFluidics





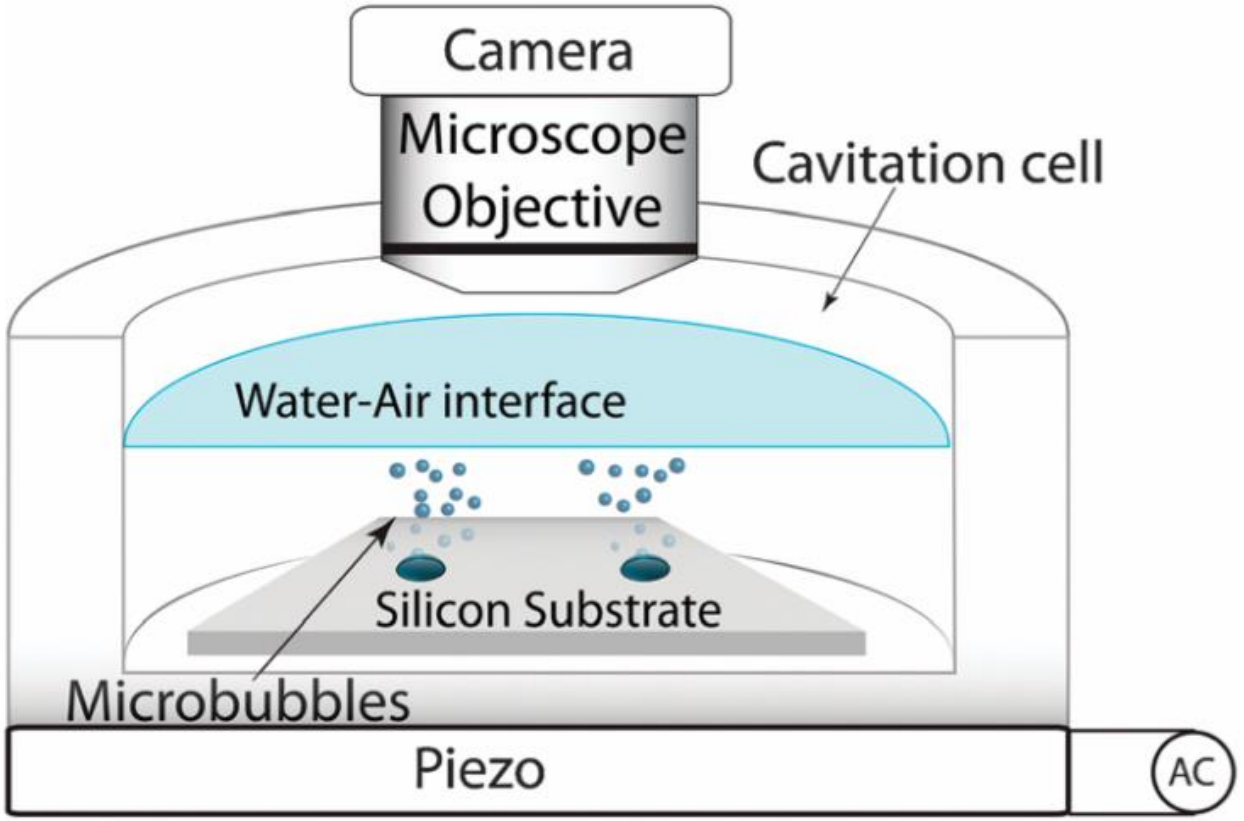
Fernandez Rivas, et al., Chemical Communications. 48 (89), 10935 - 10947 (2012).
D Fernandez Rivas and S Kuhn, Synergy of Microfluidics and Ultrasound, to appear in Current Chemistry, 2016

Bubbles + Ultrasound



Fernandez Rivas, et al., Chemical Communications. 48 (89), 10935 - 10947 (2012).

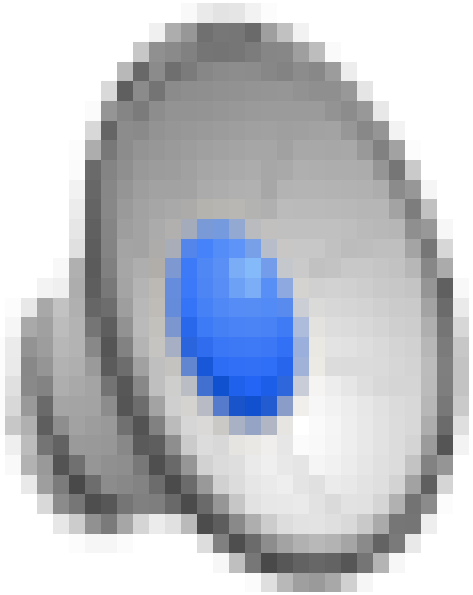
Micro-Sono-Reactor



Total volume ~ 300 µl

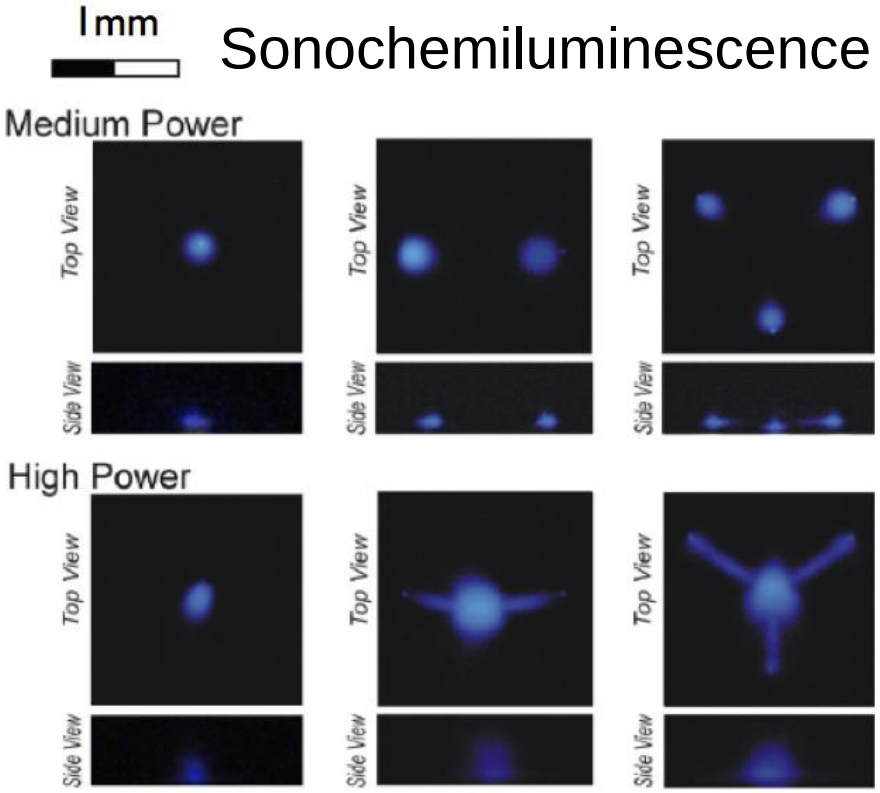
Fernandez Rivas, et al., Chemical Communications. 48 (89), 10935 - 10947 (2012).

Controlling cavitation as f(x,y,z,t)



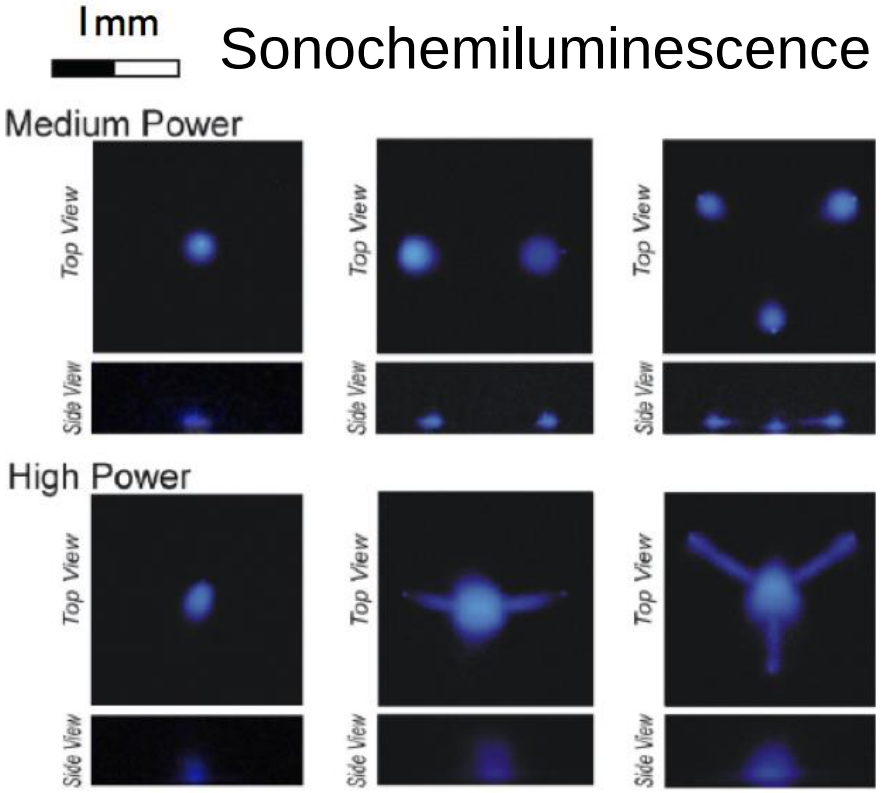
D. Fernandez Rivas et al., American Physical Society, 65th Annual Fall Division of Fluid Dynamics Meeting, 2012. Gallery of Fluid Motion.

Physical and chemical effects



D. Fernandez Rivas et. al,
Angewandte Chemie Int. Ed.,
(49) 9699 - 9701. (2010).

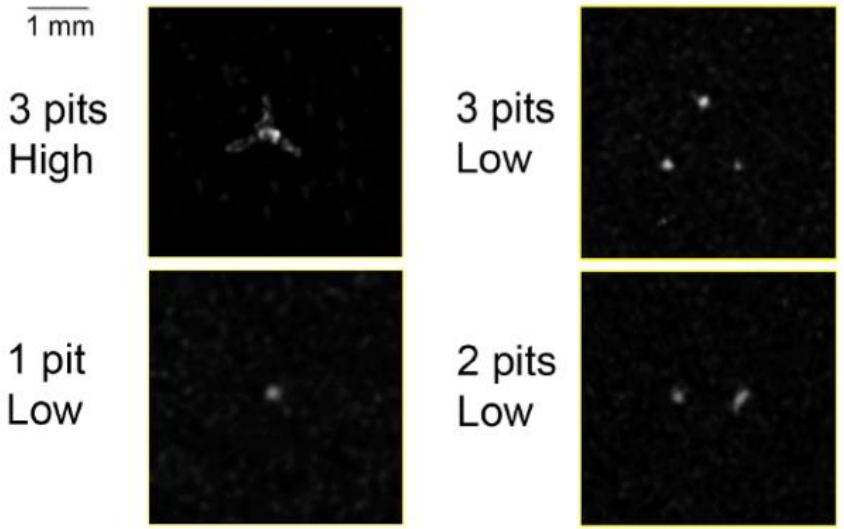
Physical and chemical effects



Sonochemiluminescence

D. Fernandez Rivas et. al,
Angewandte Chemie Int. Ed.,
(49) 9699 - 9701. (2010).

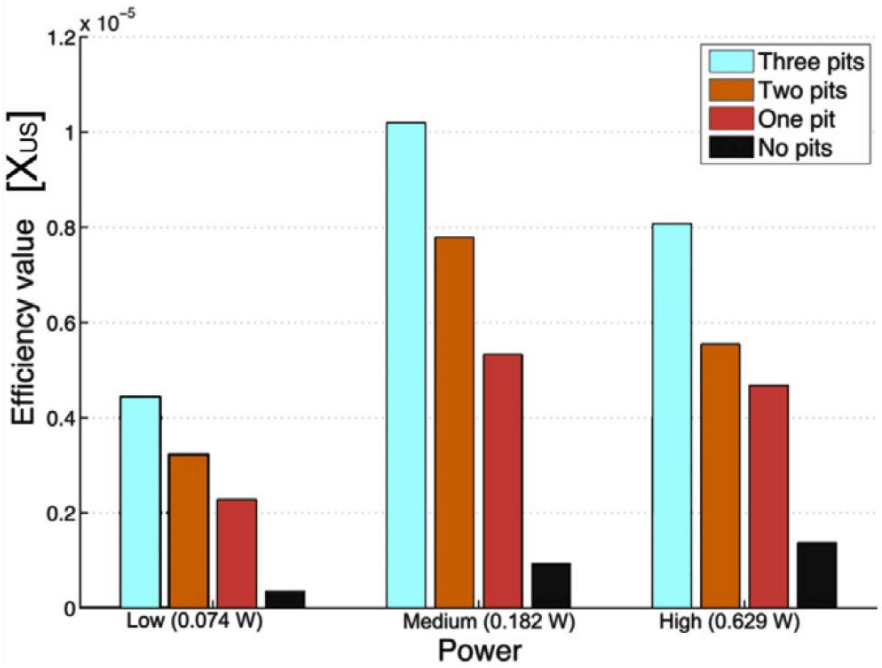
Sonoluminescence

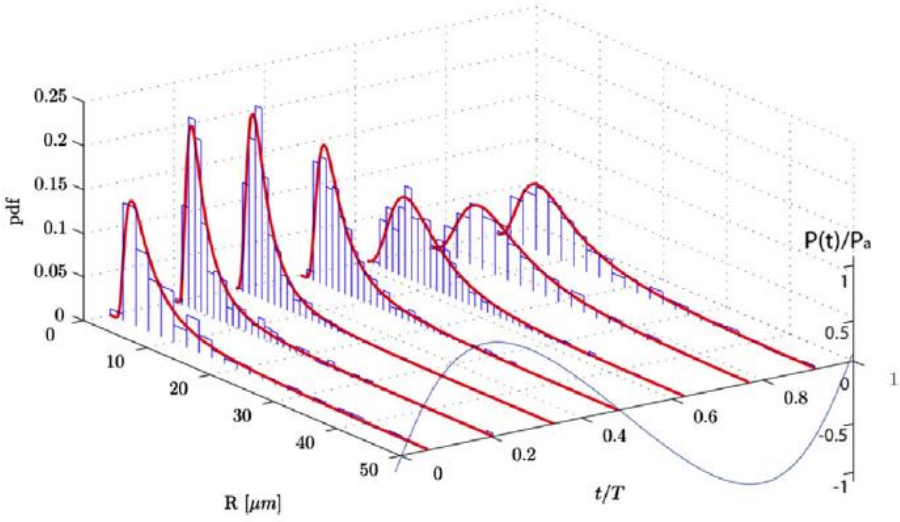


D. Fernandez Rivas et. al,
Ultrasonic Sonochemistry.,
(19) 1252-1259. (2012).

Power and efficiency

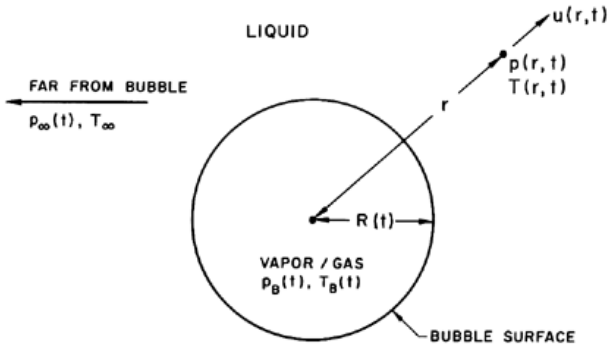
$$X_{US} = \frac{\Delta H \, dN_{rad}/dt}{P_{US}}$$

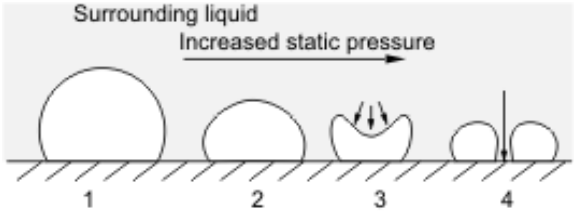




D. Fernandez Rivas, et al. Ultrasonic Sonochemistry. (**20**) 510-524. (2013).

Where is the Energy going?

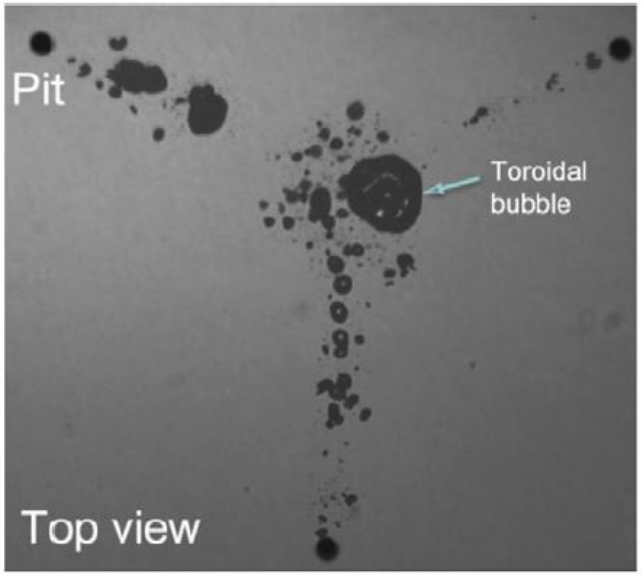


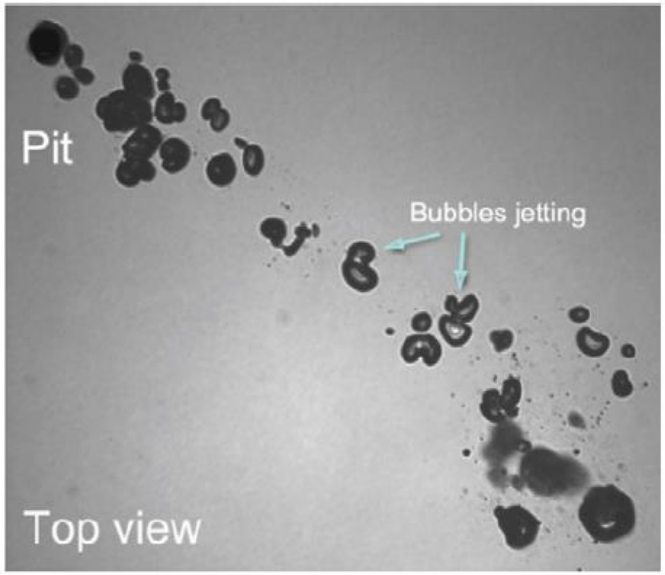


Cavitation bubble imploding close to a fixed surface generating a jet (4) of the surrounding liquid.

en.wikipedia.org

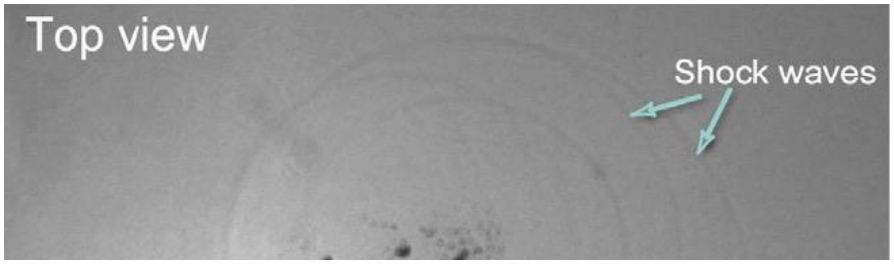
Bubble rebound, Jet

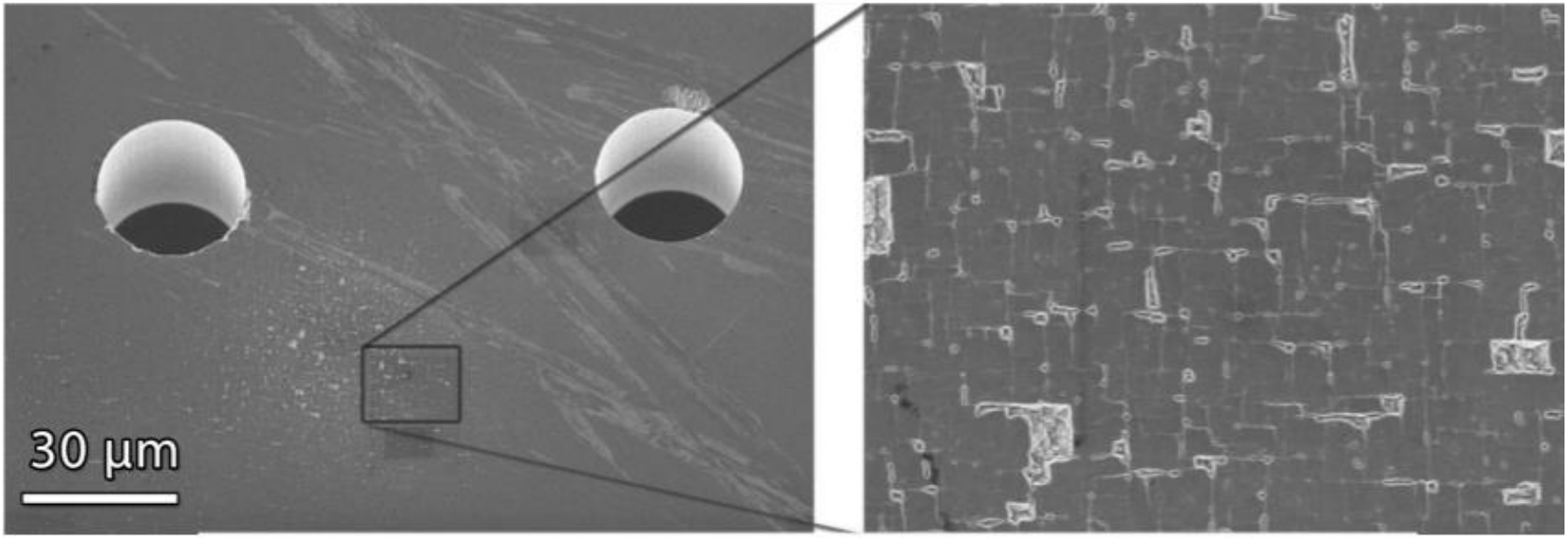


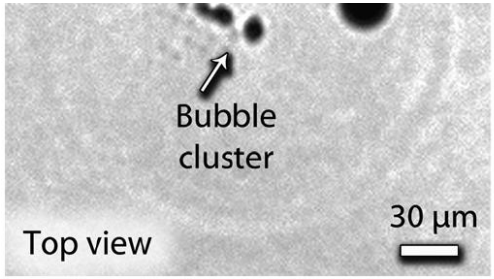


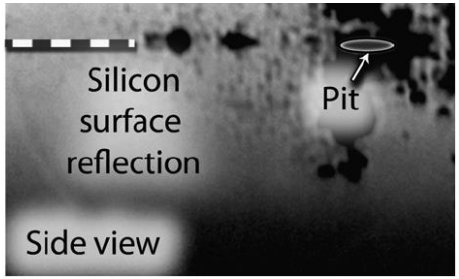
D. Fernandez Rivas, et al. Ultrasonic Sonochemistry. (20) 510-524. (2013).

Jetting, shockwaves and erosion



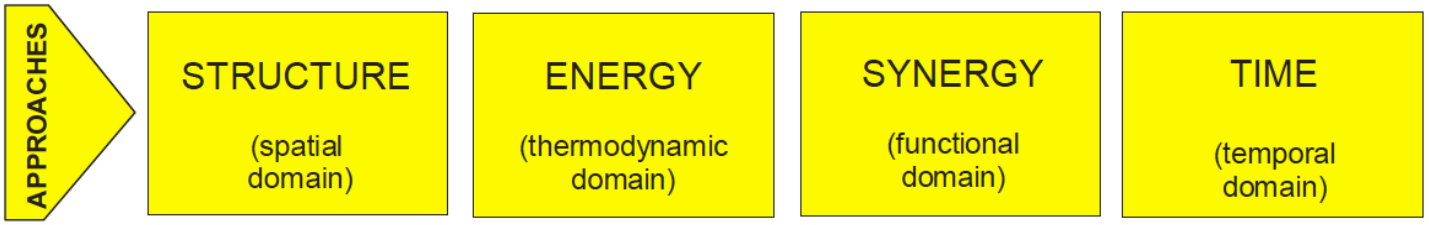






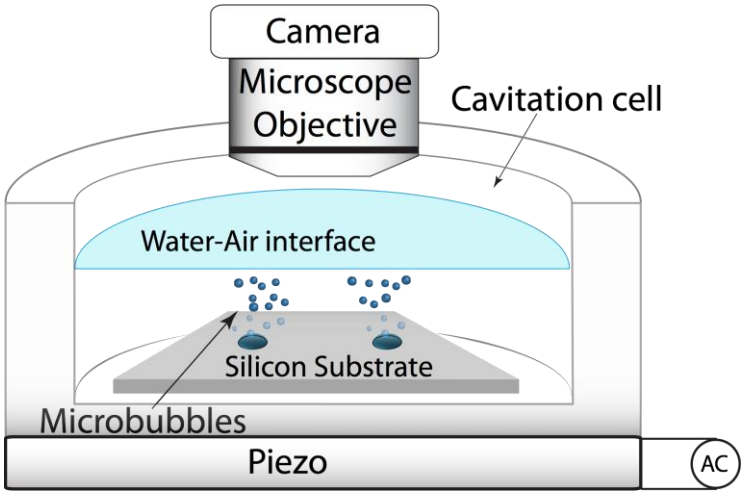
Rivas, et al. Ultrasonic Sonochemistry. (20) 510-524. (2013).

Can we identify PI in all that?



Structure, Energy, Synergy, Time—The Fundamentals of Process Intensification

Tom Van Gerven† and Andrzej Stankiewicz*



- Structure – Surface of the reactor
- Time – Ultrasound
- Energy - Alternative

Can we make bubbles work for us?

Make radicals or clean … ?

Utilization - Valorization

Quality	Reproducibility	Faster	Less chemicals

Ready to ship / Webshop

But don’t buy it yet…

Until you see if it works

or not

with your own eyes!

BuBble bags

BuBCLEAN

Patent WO/2015/144918

How to scale-up?

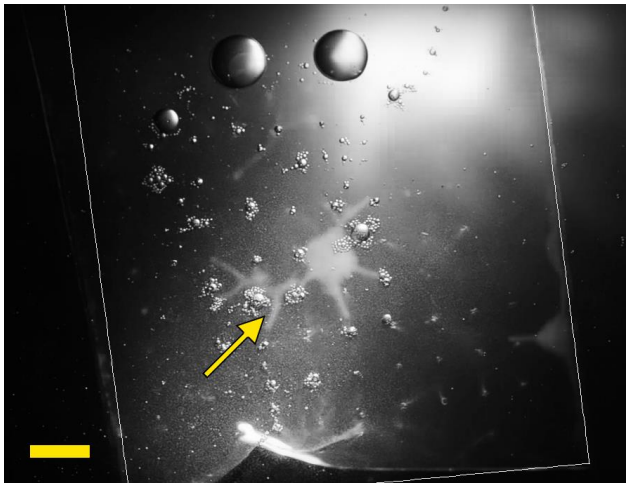
To clean arbitrary shaped objects?

Or for other uses?

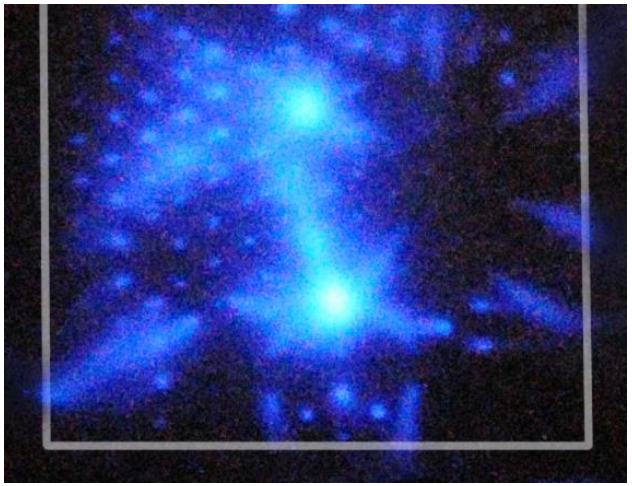
-Emulsification
-Graphene
-Nanoparticle synthesis
-Crystallization
- …

Bags, cavitation and plastic

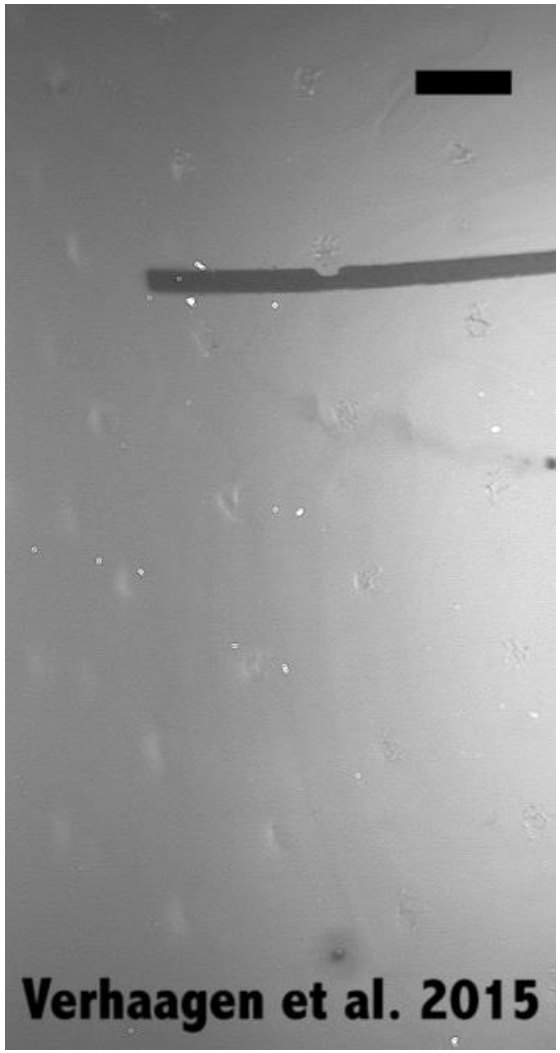
Poly-propylene ~10-100 mL



Visible bubbles



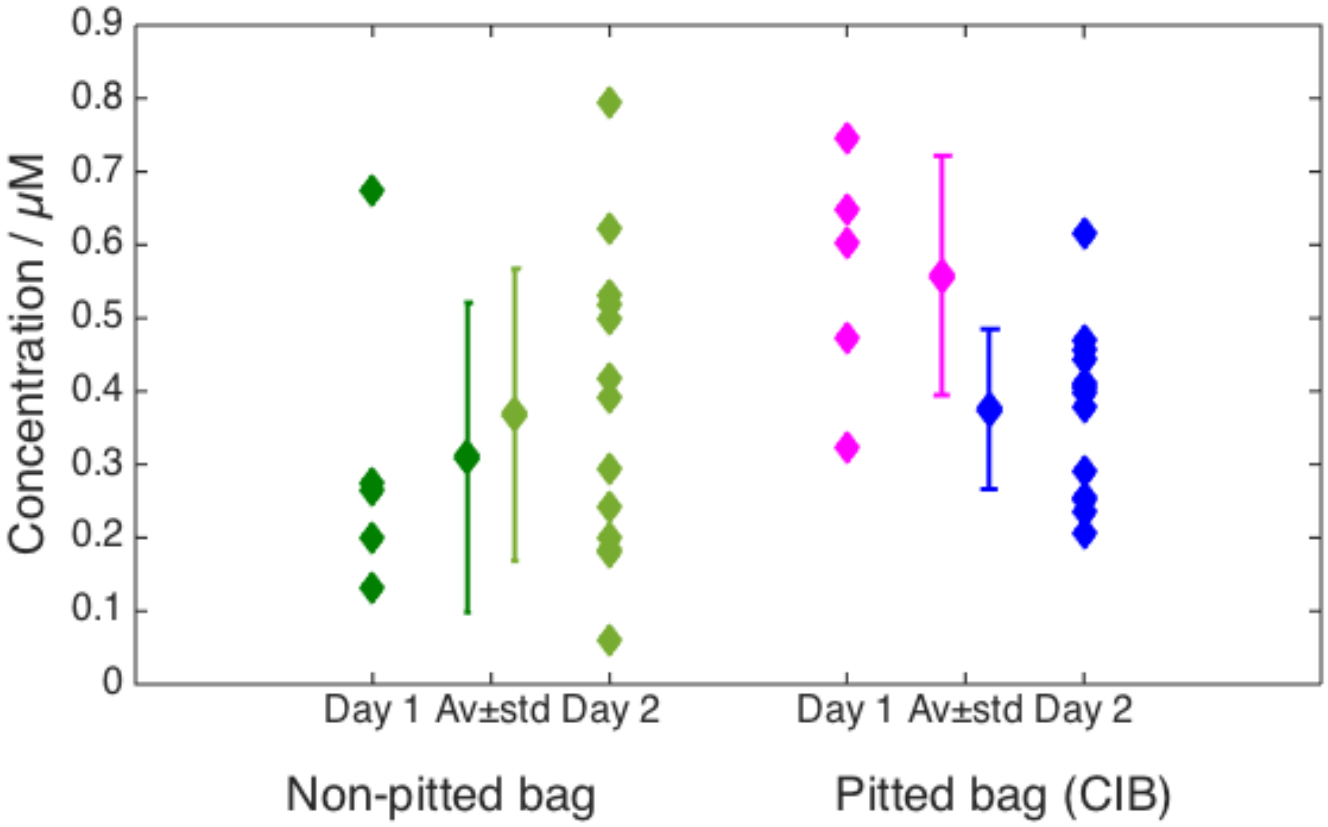
Sonochemiluminescence



Verhaagen, B., et al. (2016). *ChemistrySelect*, *1*(2), 136–139.

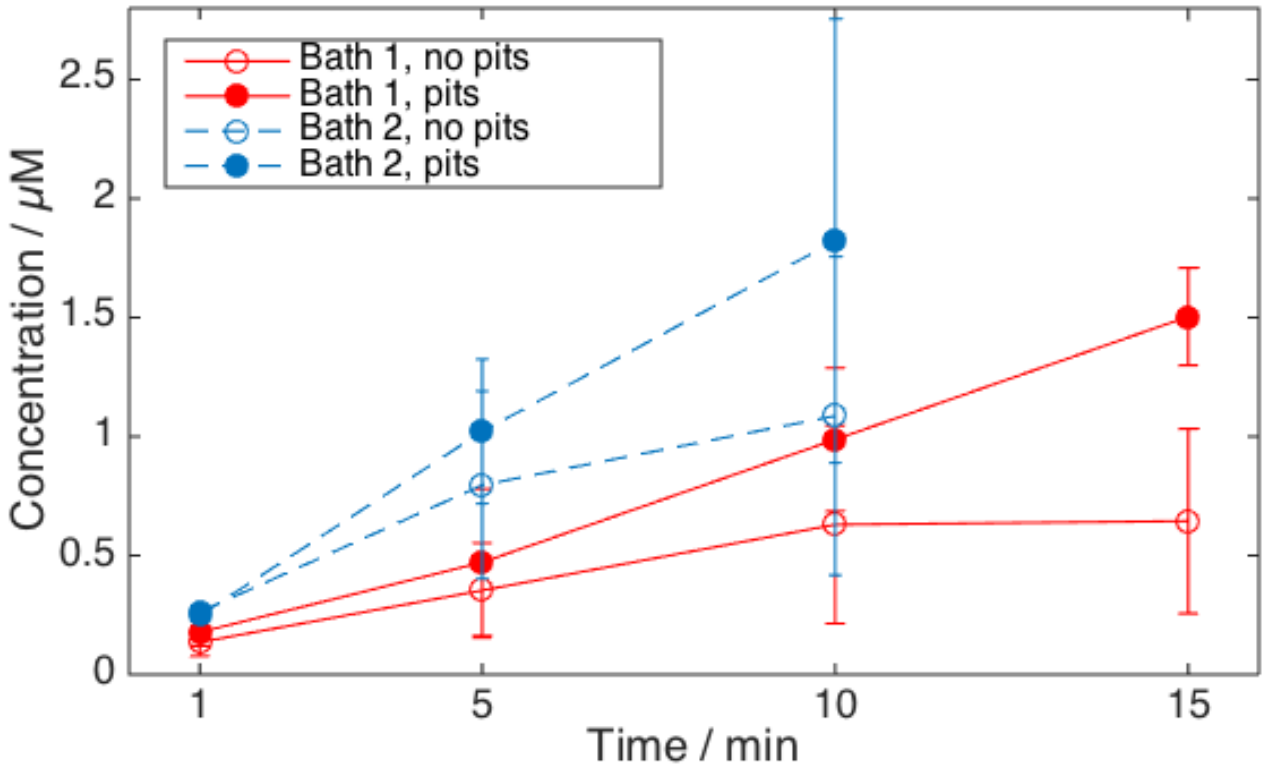
Does it work better?

Radical generation ($OH^{\cdot}$)



Verhaagen, B., et al. (2016). *ChemistrySelect*, *1*(2), 136–139.

Does it work better?



Ultrasonic bath 1: 35 kHz (24.2 W/L – 427 kPa, uncertainty of 24%)
Ultrasonic bath 2: 45 kHz (33.3 W/L - 364 kPa).
The 50 µm thick bags allow for 79.4-86.0% of ultrasound transmision.

Verhaagen, B., et al. (2016). *ChemistrySelect*, *1*(2), 136–139.

Does it scales?

$$X_{US} = \frac{\Delta H \, dN_{rad}/dt}{P_{US}}$$

Energy efficiencies after 5 minutes

	Bath 1		Bath 2	
	Non-pitted bag	CIB	Non-pitted bag	CIB
Efficiency (10^{-8})	1.4	1.9	9.1	13.2
Efficiency (10^{-5}), corrected	1.8	2.5	3.3	4.7

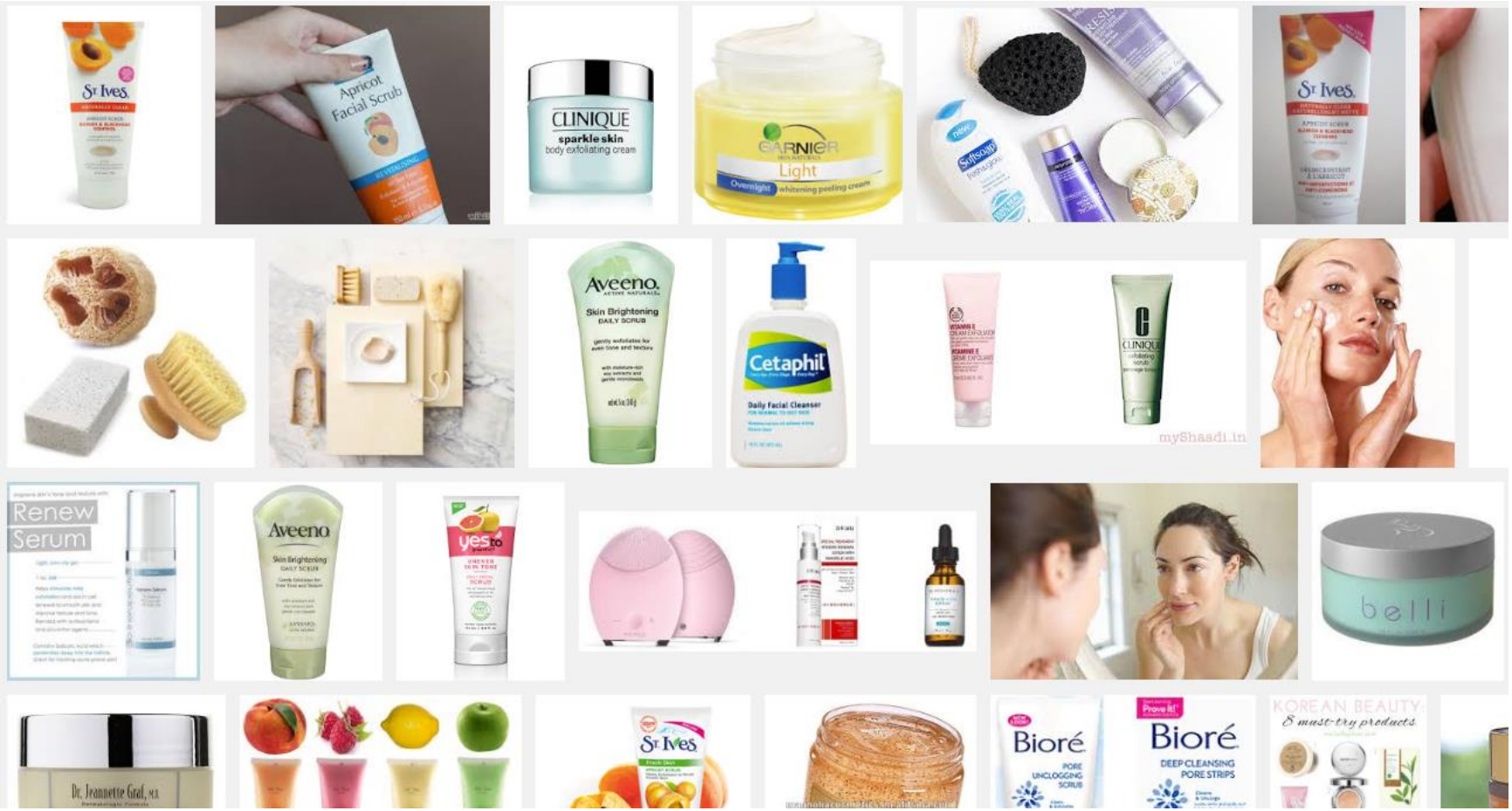
The microreactor was scaled-up 25 times, with a five-fold increase of its efficiency.

The efficiency was increased up to 45.1% compared to bags without pits.

Efficiencies are underestimated (ratio of bag to bath volume).

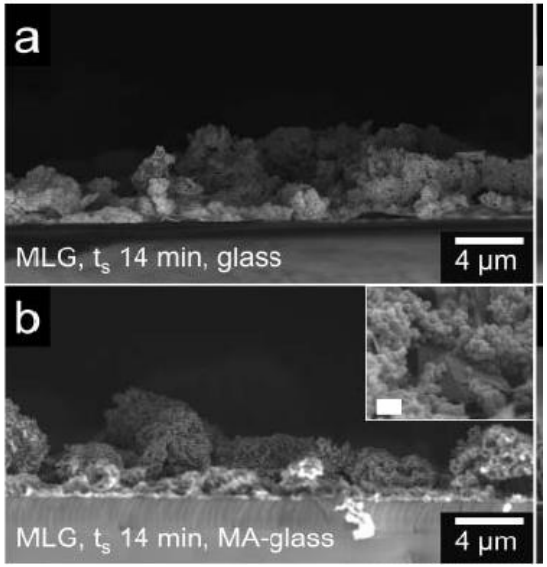
Verhaagen, B., et al. (2016). *ChemistrySelect*, *1*(2), 136–139.

Do you exfoliate?

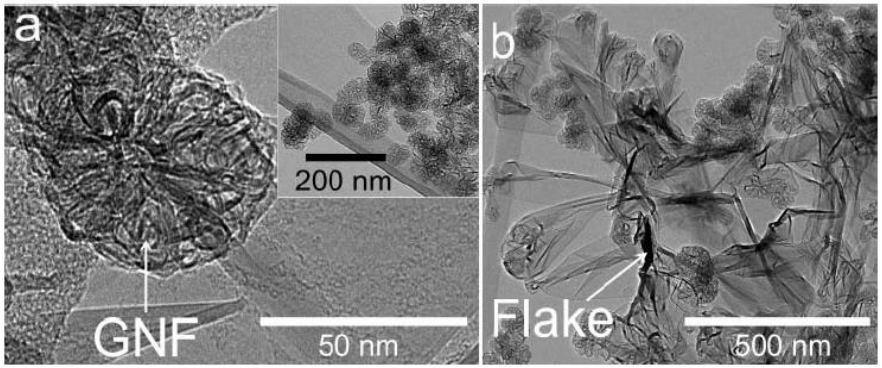


Nanomaterials Exfoliation

Graphene: a two-dimensional carbon allotrope with excellent optoelectronic properties of use to engineer devices, and functional materials.



Exfoliation of graphene, carbon nanoflower/graphene suspensions and LFP/graphene have
caught attention.

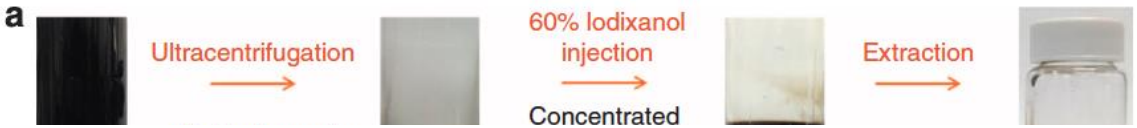


Some want to open up the flower.

by S-Petra

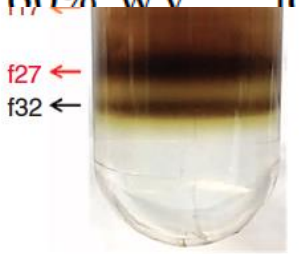
Modesto-López, L, et al, (2015) Films of Graphene Nanomaterials Formed by Ultrasonic Spraying of Their Stable Suspensions, Aerosol Science and Technology, 49:1, 45-56, DOI: 10.1080/02786826.2014.991438

It is not easy to deal with nanomaterials



Methods

Dispersion and density gradient ultracentrifugation. One gram of MoS_2 powder (American Elements) was dispersed in 70 ml of 2% w v^{-1} Pluronic F68 (BASF) aqueous solution via ultrasonication using a 0.125-inch tip in a steel beaker at 25 W for 2 h. Then, 32 ml of dispersion was carefully added on top of a 6 ml underlayer of 60% w v^{-1} iodixanol and ultracentrifuged at 32 kr p m for 24 h at



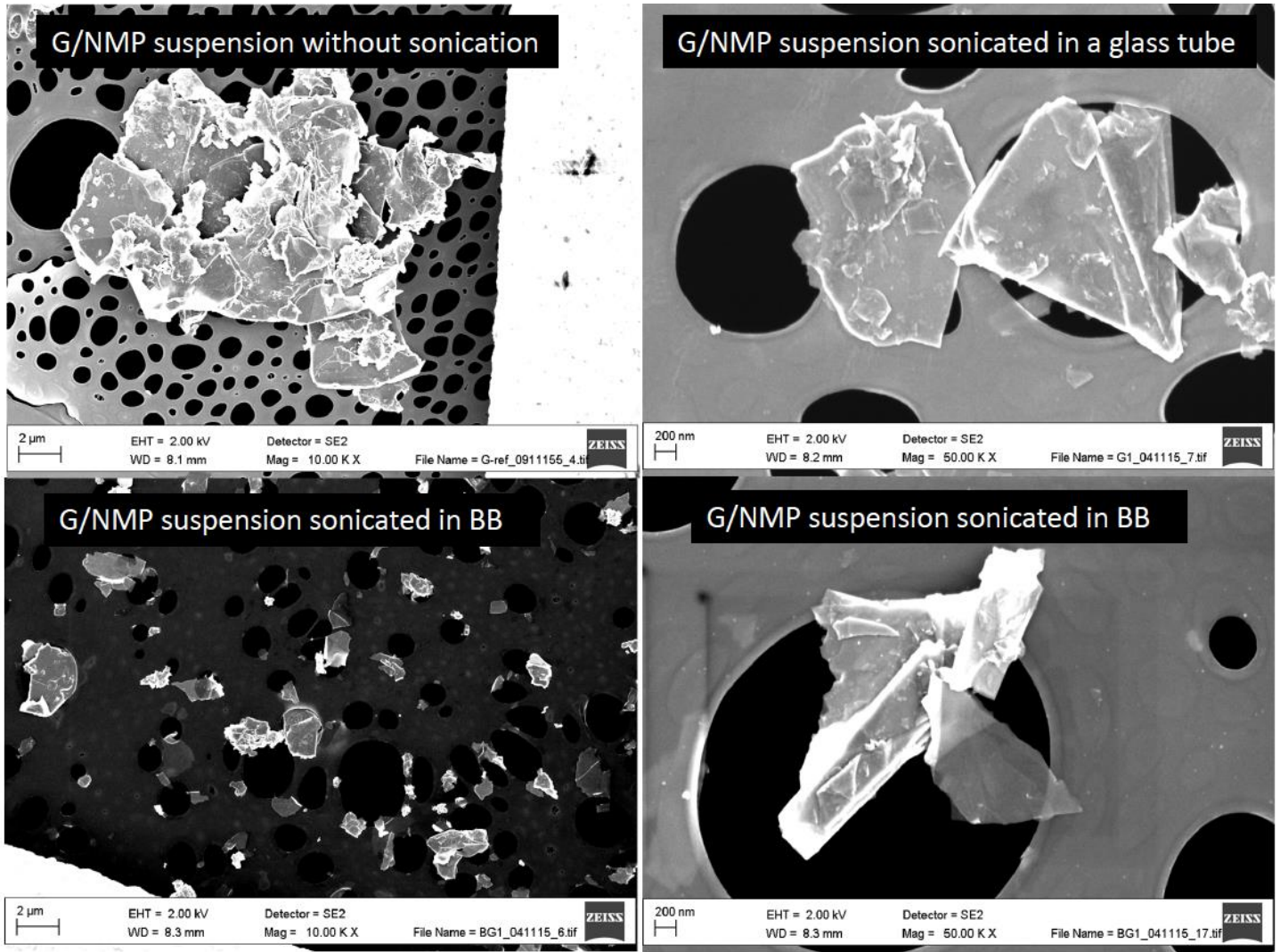
2 hours!!!?

J. Kang, J.-W. T. Seo, D. Alducin, A. Ponce, M. J. Yacaman, M. C. Hersam, *Nature Communications* **2014**, *5*, 5478.

Exfoliating with bubbles

Graphene flakes agglomerate, yet sonication with bubble bags "stretch them";

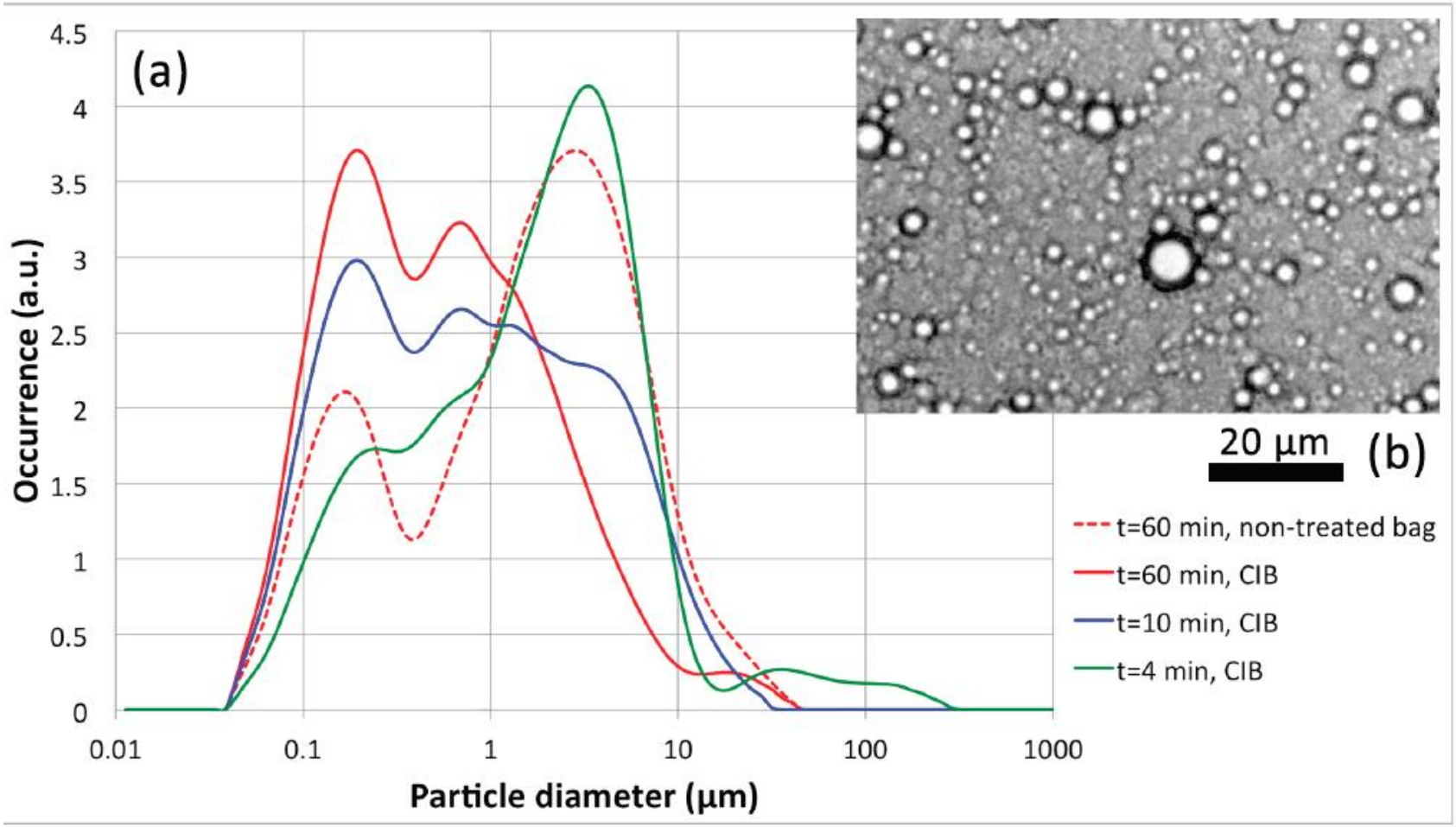
The suspensions are stable for several months.



UNIVERSITY OF EASTERN FINLAND

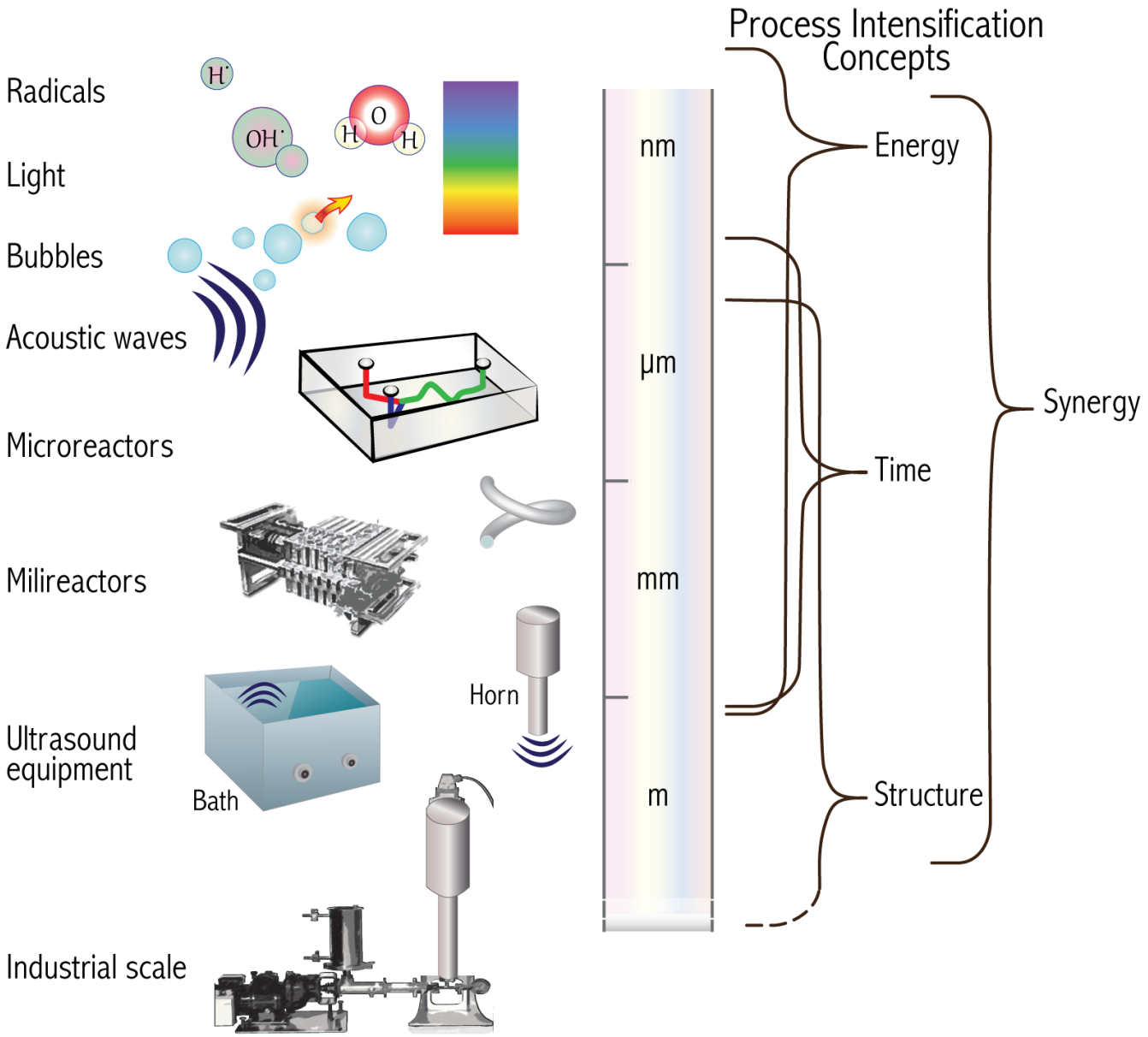
Making emulsions

Hexadecane 15% in SDS aqueous solution.



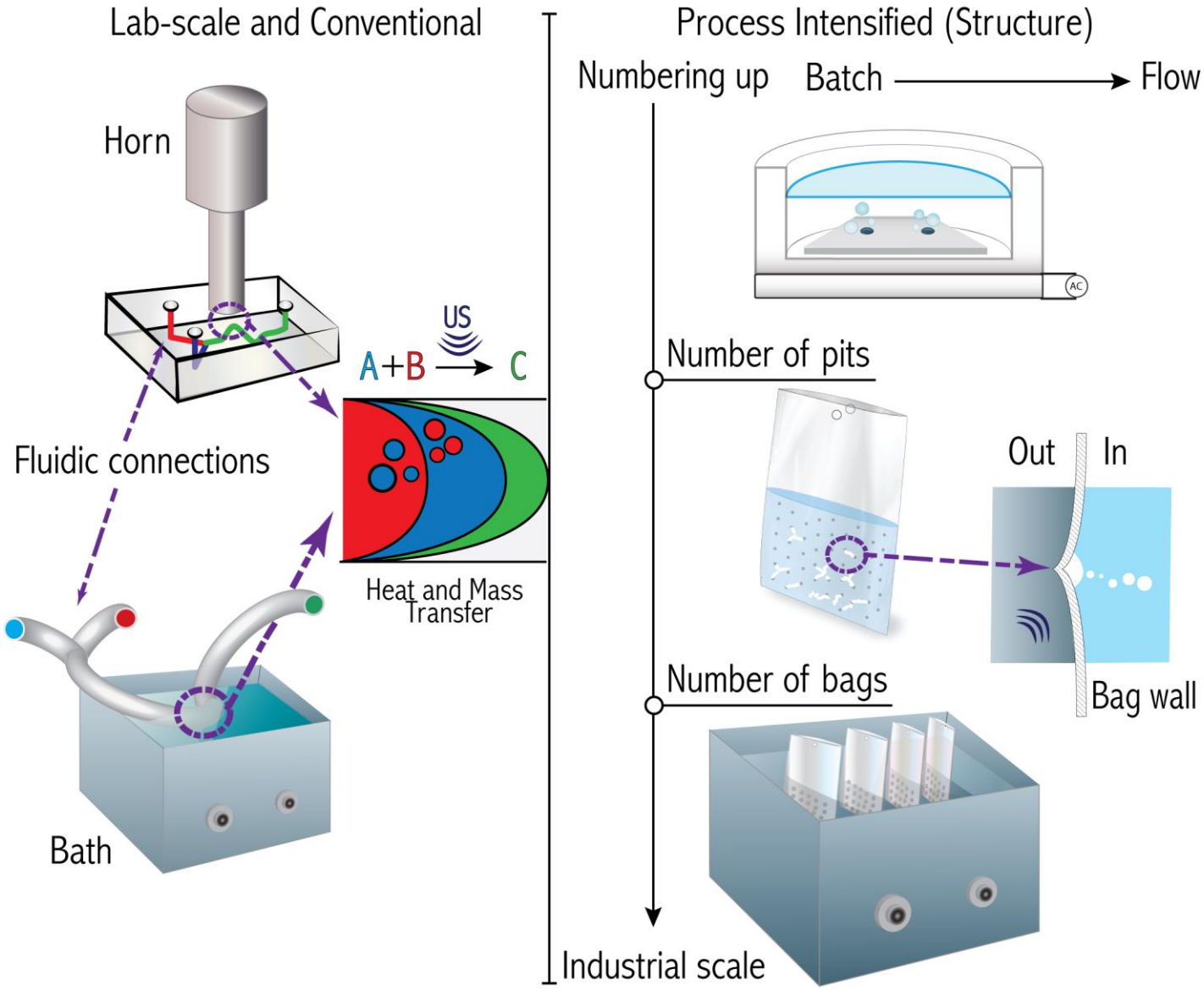
Rivas, D.F., et al, 2015. A novel ultrasonic cavitation enhancer. *Journal of Physics: Conference Series* (Vol. 656, No. 1, p. 012112).

PI + US + µFluidics



D Fernandez Rivas and S Kuhn, Synergy of Microfluidics and Ultrasound, to appear in Current Chemistry, 2016

Present and future



D Fernandez Rivas and S Kuhn, Synergy of Microfluidics and Ultrasound, to appear in Current Chemistry, 2016

Wrapping it up

- Bubbles can be useful at different scales
- Taming bubbles is possible with crevices
- Scaling-up is “in the bag”
- Many bubbles to come …

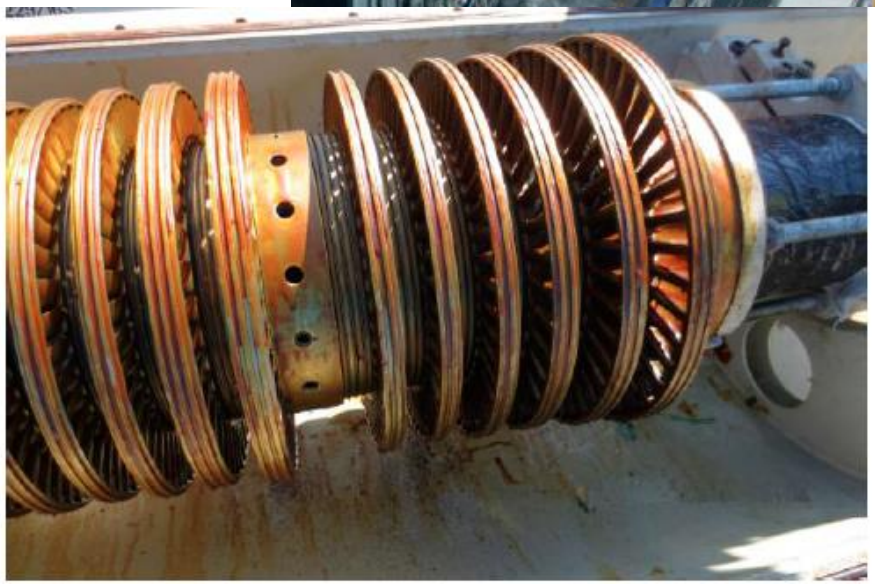
Another use of “bubbles” …

Thank you for your time …
any questions?

Many collaborators made possible the results presented

UNIVERSITY OF TWENTE. PHYSICS OF FLUIDS. MESA+ INSTITUTE FOR NANOTECHNOLOGY BμBCLEAN UNIVERSIDAD DE SEVILLA WAGENINGEN UR

Small bubbles for large scales



Turbine rotor - vóór ultrasone reiniging

Turbine rotor - na ultrasone reiniging