PRELIMINARY VERSION

Unfinished at the time
the DVDs are burnt

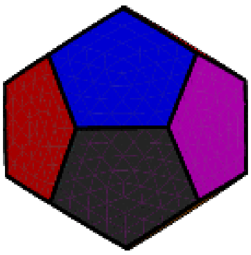
after Sylvie's lecture

Non-destructive probes II

3D images of foams

Thanks to persons who provided the slides :
Michèle Adler
Clément Nizak
Philippe Coussot
Guillaume Ovarlez
James Glazier
Wiebke Drenckhan
Rajmund Mokso
Peter Cloetens
Pascale Verant
Sébastien Courty
Sylvie Cohen-Addad

Simon Cox



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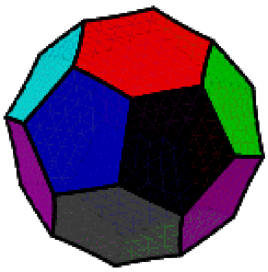

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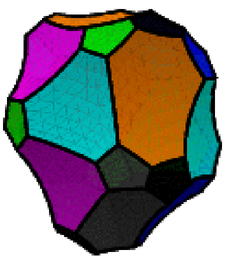
Various numbers of faces



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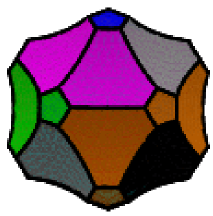

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Plan

- introduction
- magnetic resonance
- optical tomography
- X-ray tomography
- other techniques

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Motivations

- simultaneously measure topology & shape
- control of the structure
- understand the physics in 2D
  then go to 3D for refinments when required

Difficulties specific to 3D

- overcome the scattering
- acquisition time and resolution
- data analysis
- relevent measurements
- physical interpretation
- representation
- 3D visualisation and navigation

What can we image ?

- structure : easy - freeze it
- coarsening : possible - evolves over a day
- drainage : soon possible - but is it useful ?
  evolves over an hour
- rheology : still too fast
  becomes possible for 1D or 2D cuts of 3D images

May I help you select a technique ?

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LCPC Laboratoire Central des Ponts et Chaussées

L'esprit de recherche au cœur des réseaux

Principle

- requires a magnetic field for measurements
  gradient of field for imaging
- probes the environment of nuclei
  spin resonance
- mainly protons = hydrogen atoms
  = probes the water
- vocabulary :
  NMR = nuclear magnetic resonance
  MRI = magnetic resonance imaging

Coarsening

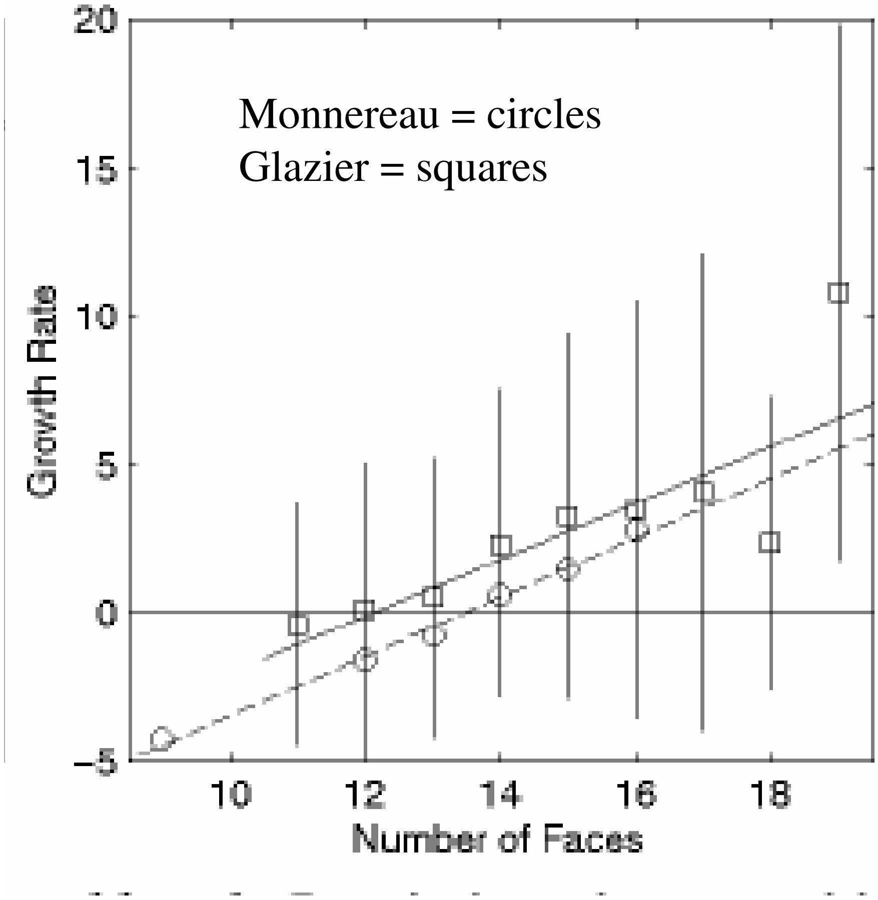
Prause and Glazier

Notre-Dame

Travel inside a foam

QuickTime™ et un décompresseur
codec YUV420 sont requis pour visualiser
cette image.

MRI



To figure out how it is

- ~ 10^2 bubbles
- ~ 10^7 euros
- ~ 10^3 s per image
- ~ 10^6 ~ 10^7 pixels : $(128)^3$ or $(256)^3$
- easier for wet foams
- automatic reconstruction using Potts made difficult by the noise

Rheology

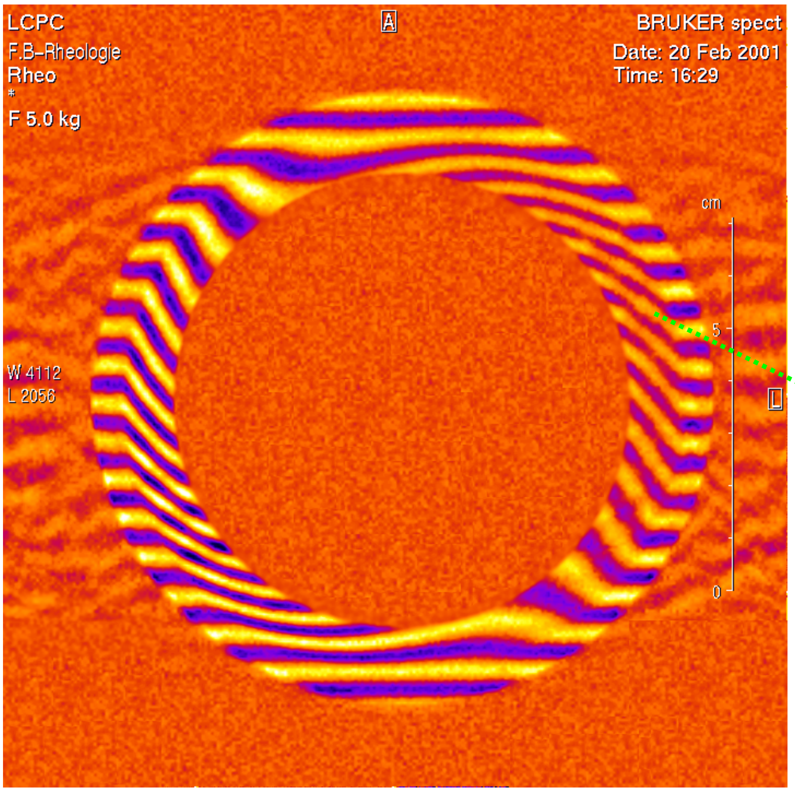
2D then 1D cut

Coussot and coworkers

Marne la Vallée

2

Rheological interpretation of velocity imaging



expliquer gradient

+ couper

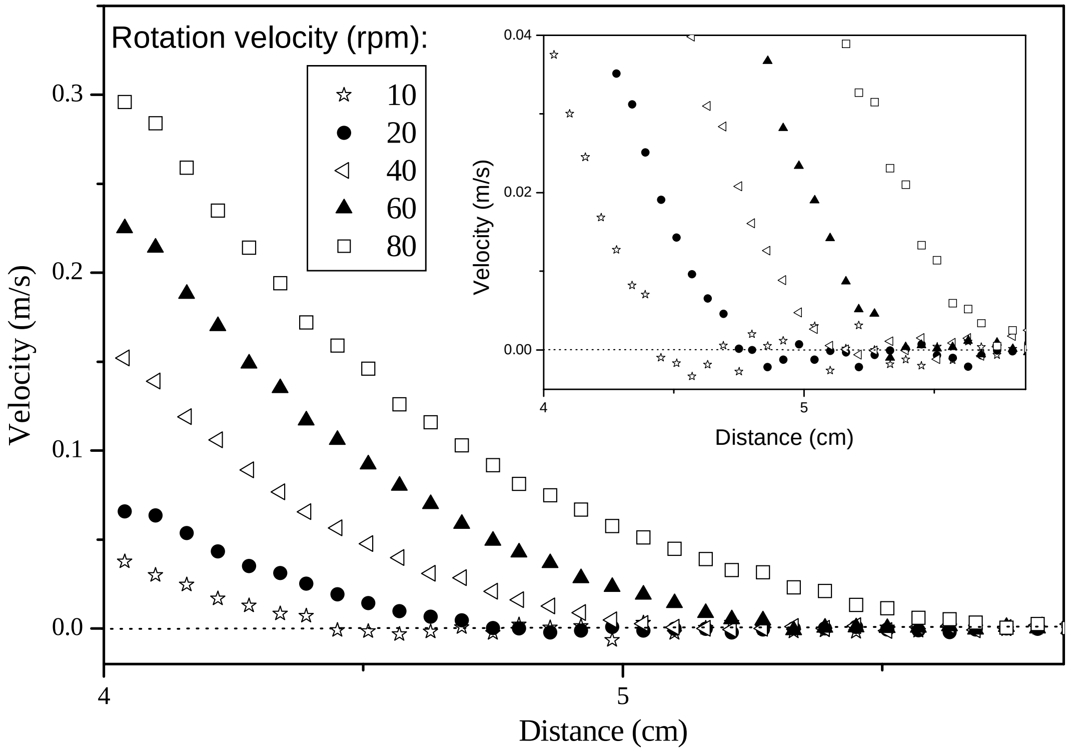
$$\dot{\gamma} = r\frac{\partial (V/r)}{\partial r}$$

$$\tau = \frac{C}{2\pi h r^2}$$

$$\Rightarrow \tau(\dot{\gamma})$$

Bentonite suspension

3 Behavior of pastes: further analysis of velocity profiles



Foam (*Gilette*)

Rodts et al., *Europhys. Lett.*, 69, 636 (2005)

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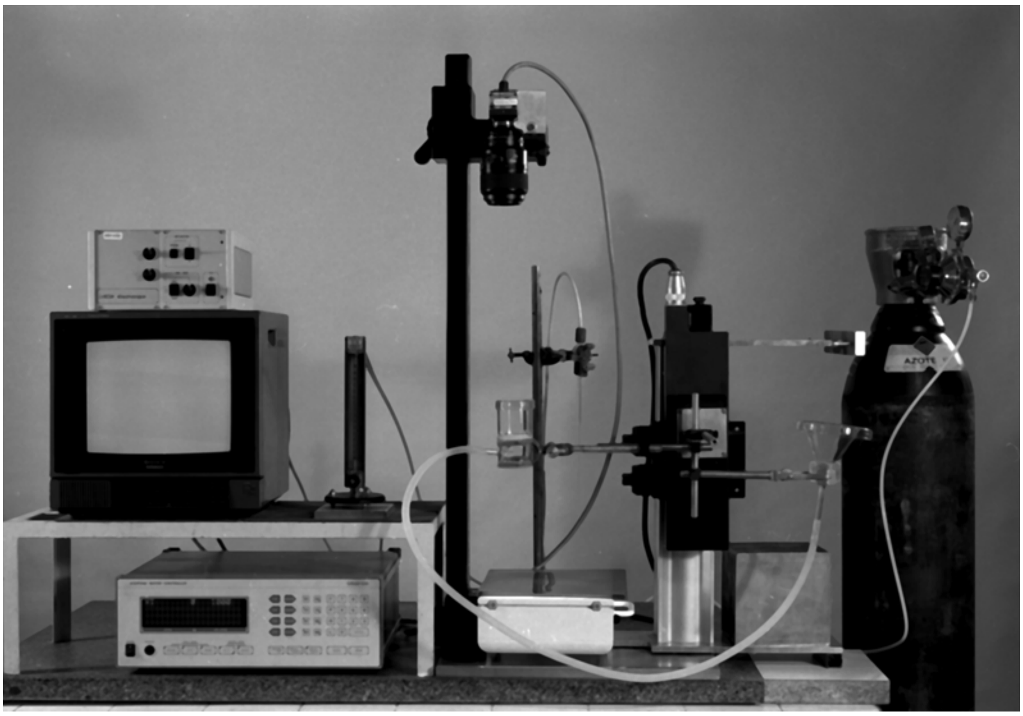
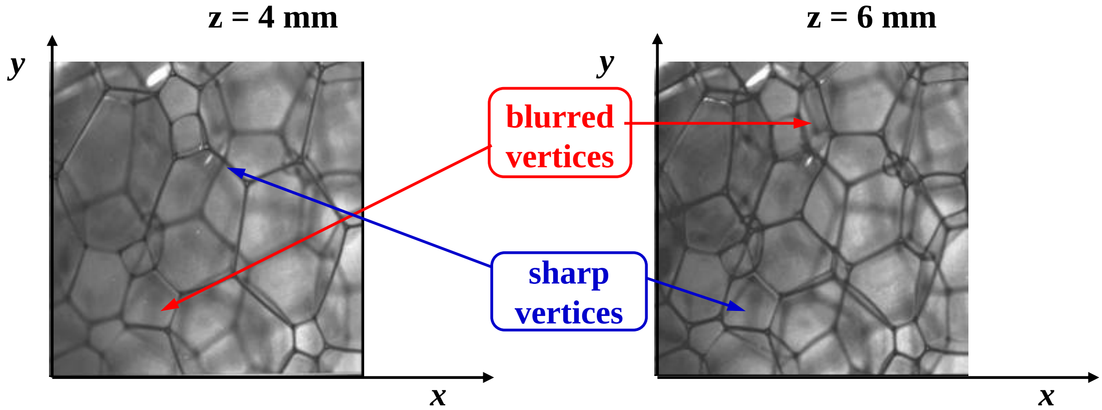
set-up

in Greek, « tomo » = cut
illuminate only a plane, then another one
thus reconstruct plane by plane the whole image

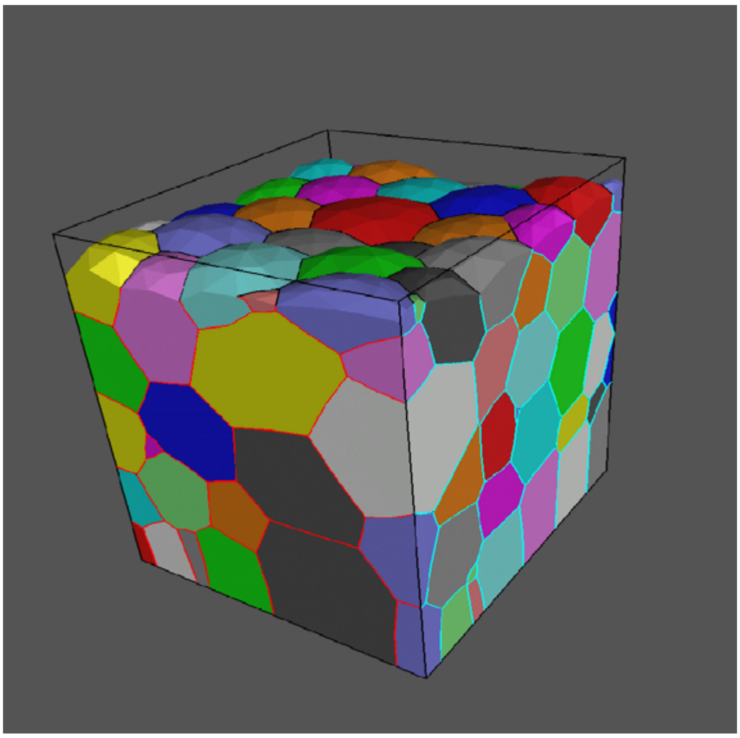




- **transparent liquid films**
- **black Plateau borders**
- **sharp vertices ∈ image z = constant**
- **blurred vertices ∈ ? compare sharpness image / image**

⇒ *x, y, z* for each vertex

reconstructed image

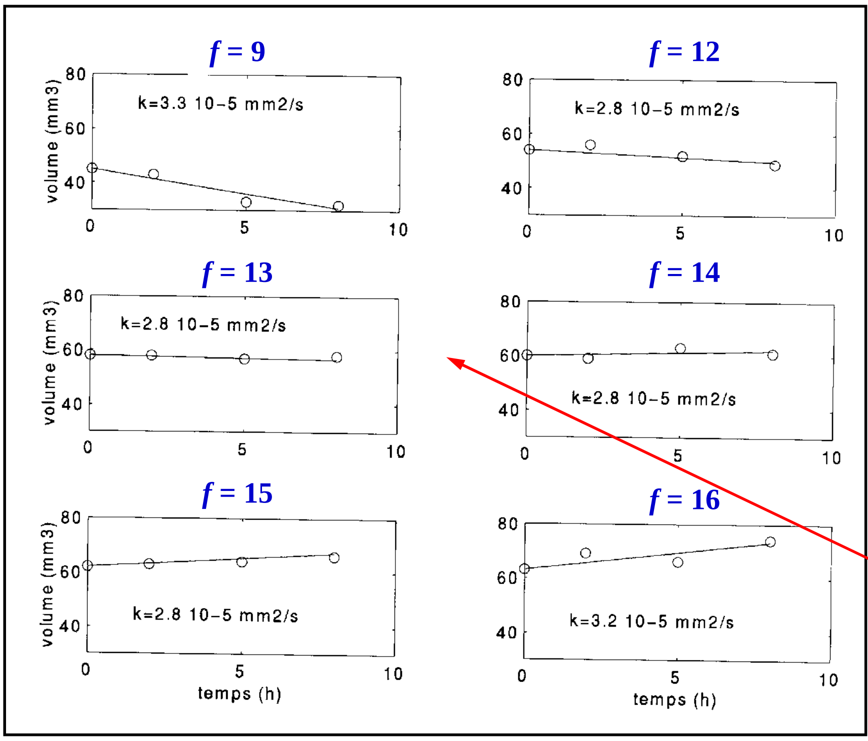


Coarsening

Claire Monnereau & Michèle Adler

Marne la Vallée

Individual bubble growth rate



$$\langle V_f \rangle^{-\frac{1}{3}} \frac{d\langle V_f \rangle}{dt} = k' \, (f - f_0)$$

f_0 = 13,4 = <f>

k' = $2{,}8 \cdot 10^{-5}$ $mm^2 s^{-1}$

sign change !

To figure out how it is

- ~ 10^2 bubbles
- ~ 10^2 euros
- ~ 10 s per image
- camera resolution
- easier for dry foams
- manual reconstruction
  or semi-automatic using Surface Evolver

Rheology

2D cuts

Reinhard Höhler

Sylvie Cohen-Addad

Florence Rouyer

Vincent Labiausse

Marne la Vallée

QuickTime™ et un
décompresseur GIF
sont requis pour visionner cette image.

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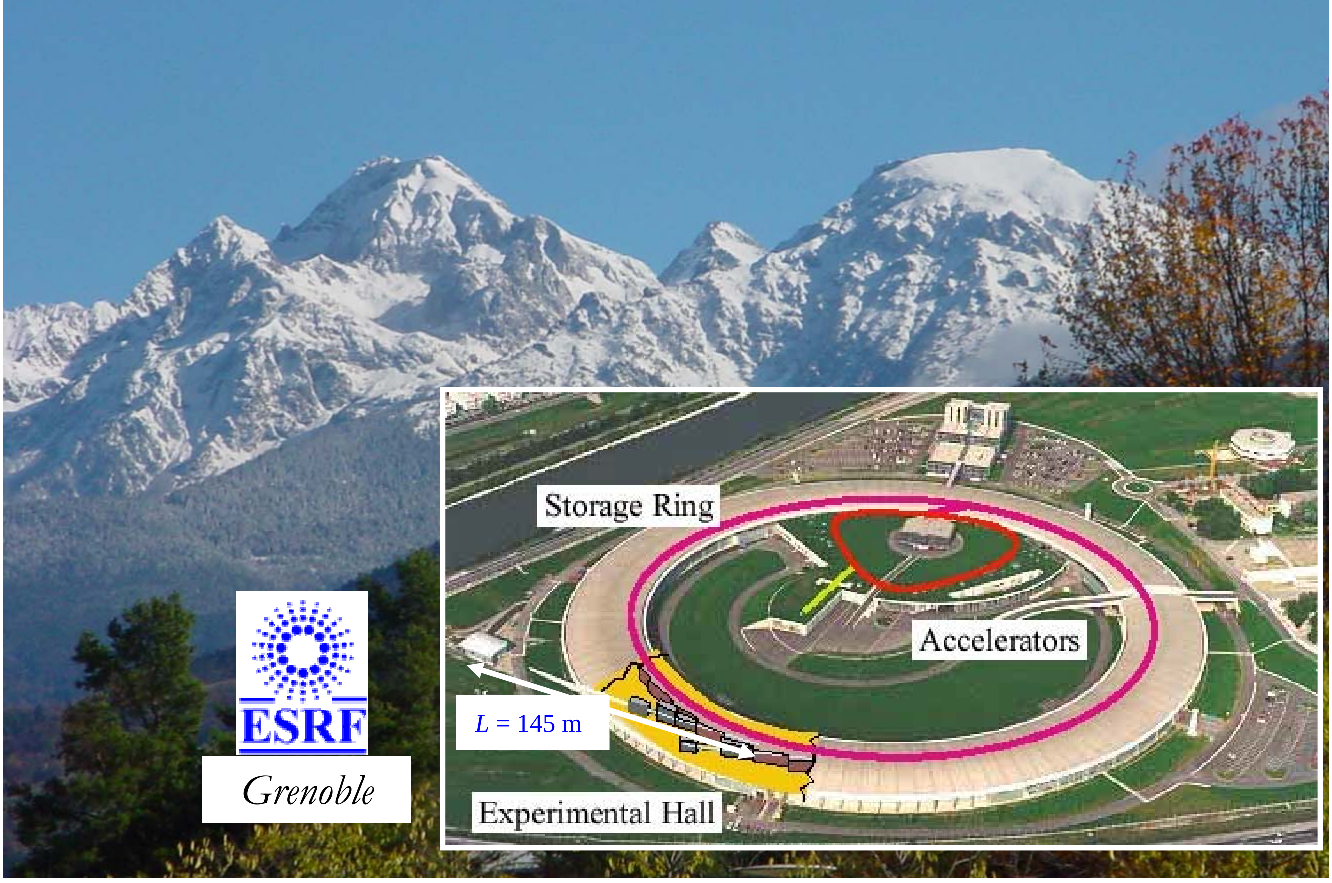
Set-up and principle

Peter Cloetens & Rajmund Mokso
ESRF, Grenoble

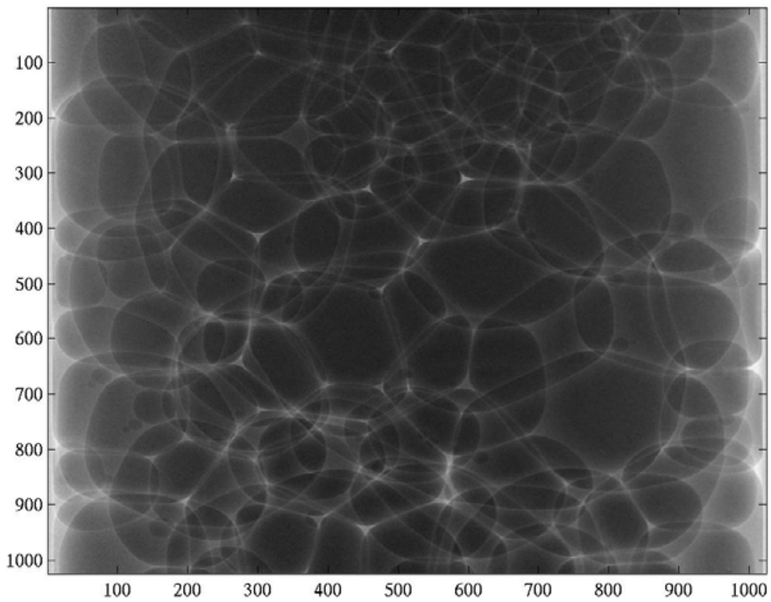
X ray tomography



Acquisition

1 image = 1000 x 1000 pixels

resolution 1-10 µm



absorption
1000 images
under different
angles

4 years ago 30 min
in 2005 : 20 sec

Coll : ESRF, Rennes, Bloomington
tomography by rotation rather than translation

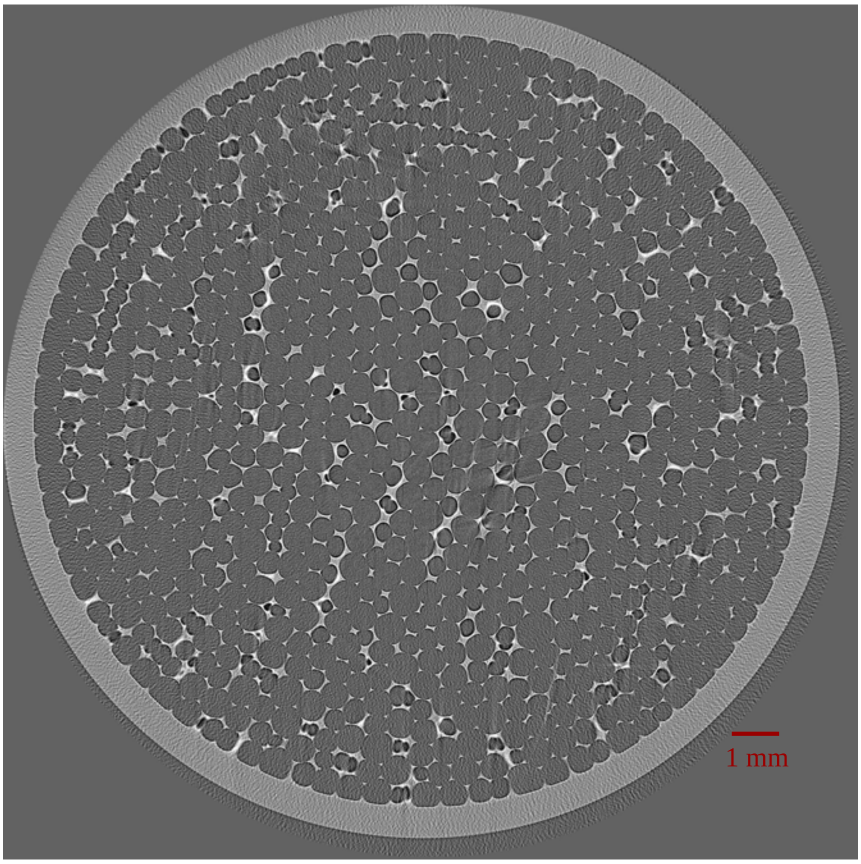
monodisperse, 2000 x 2000 x 1000 pixels

1 picture = 1000 x 1000 pixels = 10 μm resolution
1000 pictures at different angles = 2.5 min
mathematical reconstruction = 3D information

QuickTime™ et un décompresseur sont requis pour visionner cette image.

μ-tomography: a cross section of a reconstructed volume

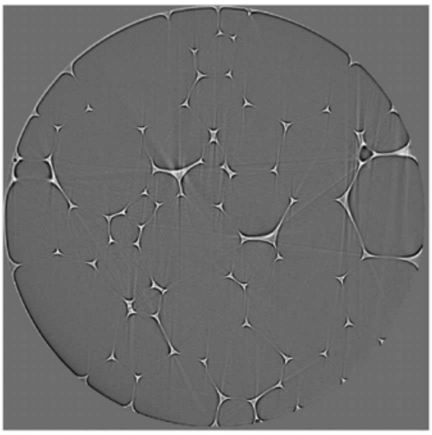
Monodisperse foam of a washing-up liquid with C_6F_{14}

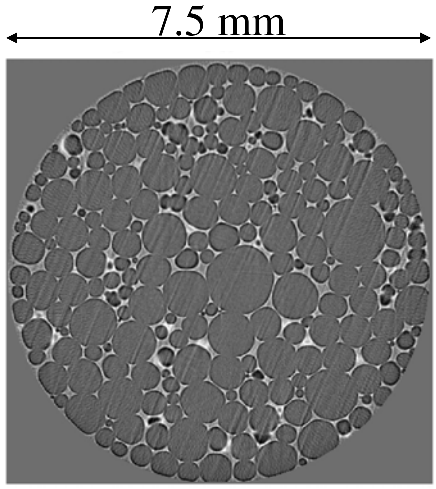


Slice dimensions:
2048x2048 pixels = 1,5 cm

Liquid Foams

Towards the Dry Foam limit (liquid fraction → 0)





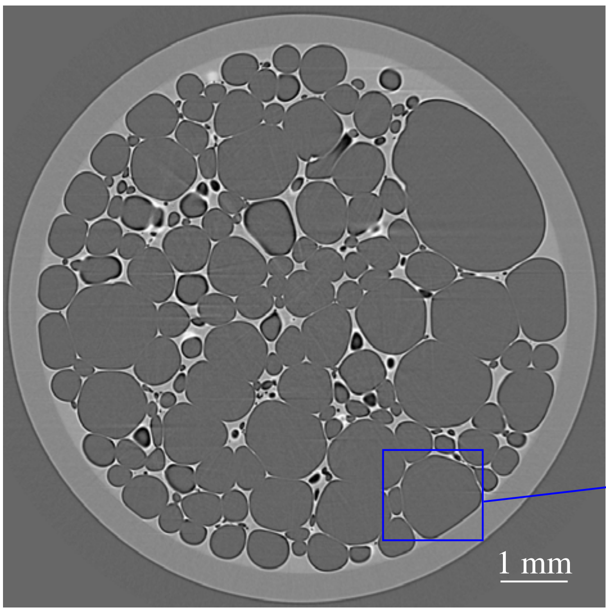
Scan time ~ 20 sec
1024^2 ; 500 projections
40 ms / projection

Scan time ~ 6 sec
512^2 ; 300 projections
20 ms / projection

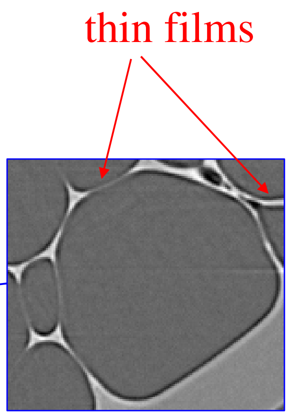
DALSA camera (12 bits): 60 images/s (1024) or 110 images/s (binned)
cf. ID15 High Energy beamline (M. Di Michiel)

R. Mokso, P. Cloetens

Phase Contrast



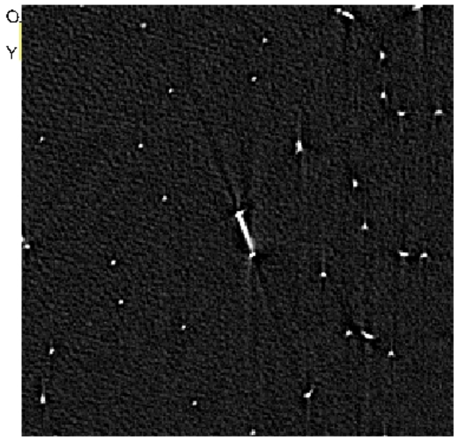
Phase enhancement to visualise liquid films separating bubbles:
Film thickness << voxel size

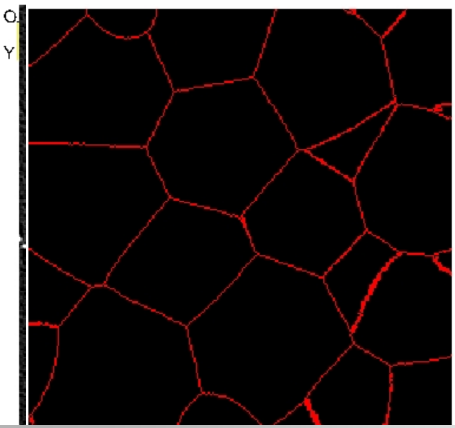


E = 15 keV, Sample-detector distance: 0.15 m

R. Mokso, P. Cloetens

Segmentation of a monodisperse foam - the easy case

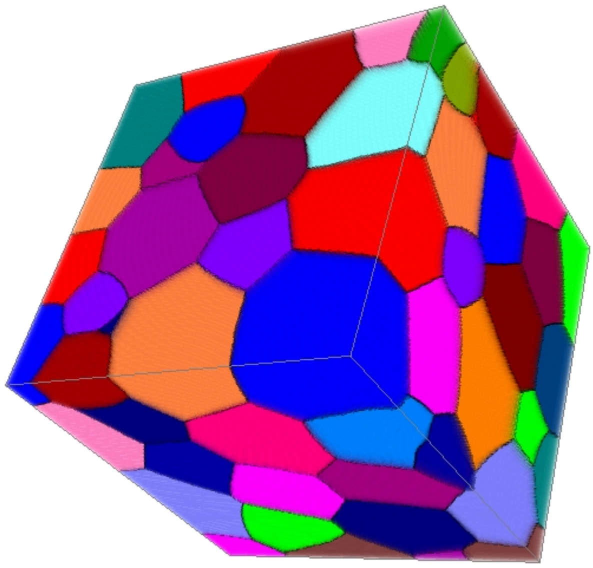




Weighted distance map method using the comercial 3D image processing software Aphelion

Washing-up liquid with C_6F_{14}

Liquid fraction <3%

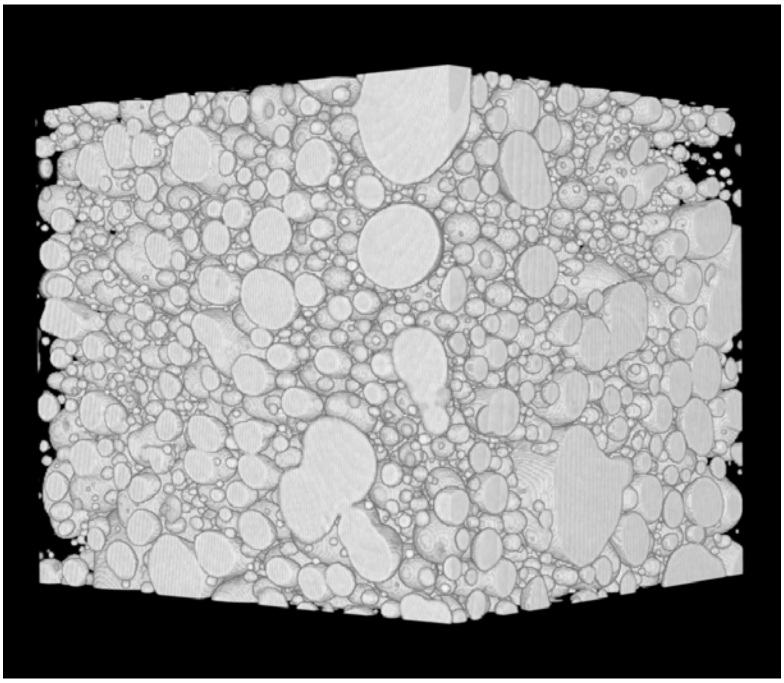


Images

X ray tomography

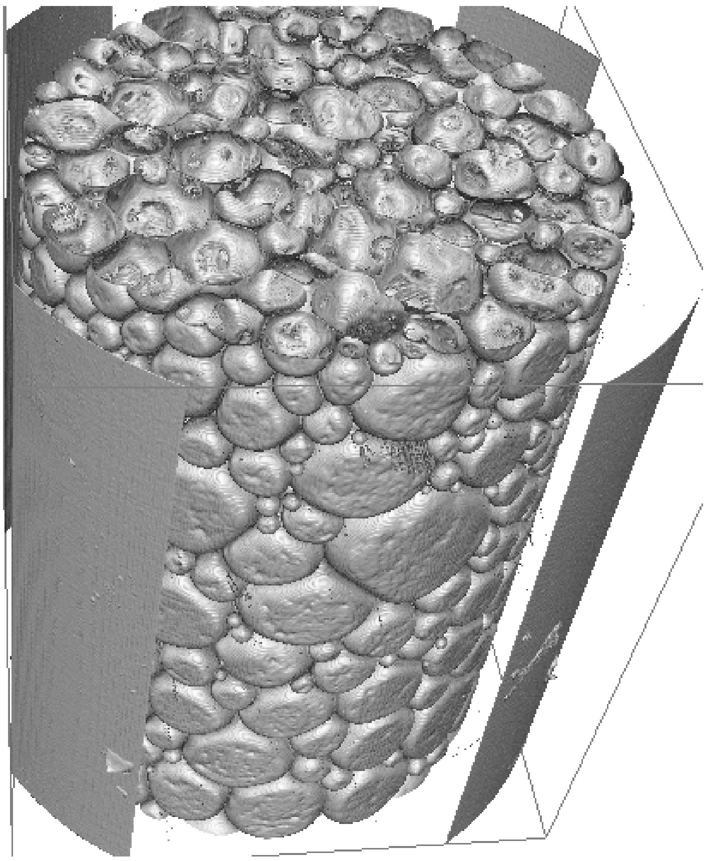
30’ acquisition time

wet and stabilised foam (Nestlé chocolate mousse)



Reconstruction in 3D

with X rays you can see inside without damaging it



bubble representation....

3' acquisition time - shaving foam
liquid fraction 10-15%, moderately stabilised

QuickTime™ et un
décompresseur TIFF (LZW)
sont requis pour visionner cette image.

we can identify each bubble one by one

QuickTime™ et un
décompresseur TIFF (LZW)
sont requis pour visionner cette image.

… Plateau borders

QuickTime™ et un
décompresseur TIFF (LZW)
sont requis pour visionner cette image.

15"-1'30 acquisition time
dishwashing liquid
1 - 3% liquid fraction

To figure out how it is

- ~ 10^6 bubbles
- ~ 10^5 euros / day (free for academics)
- ~ 10 to 10^2 s per image
- ~10^9 pixels (voxels)
- 10^{-6} to 10^{-5} m resolution
- 10^{-2} m sample size

- image easier for wet foams
- reconstruction easier for dry foams
- automatic using Aphelion (or Potts)
- 1 year before you get beam time
- 1 week to perform the experiment
- 1 year to analyse the 10^{12} octets of data

Coarsening

Lambert, Cantat, Delannay (Rennes)

Mokso, Cloetens, FG (Grenoble)

Glazier (Bloomington)

3D
coarsening

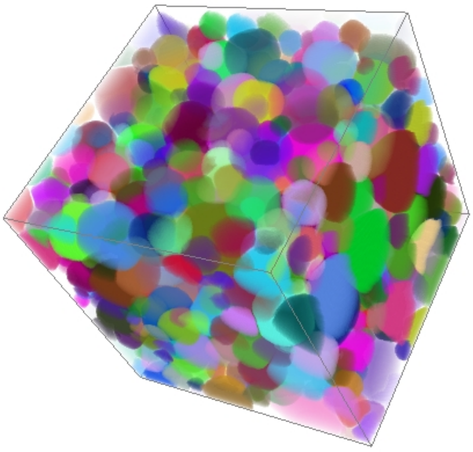
***2D cut of
3D image***

same movie

***projection
of part
of 3D image***

Liquid Foams

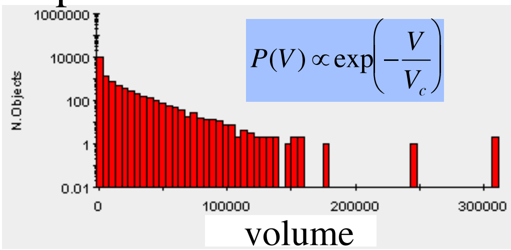
Data Analysis

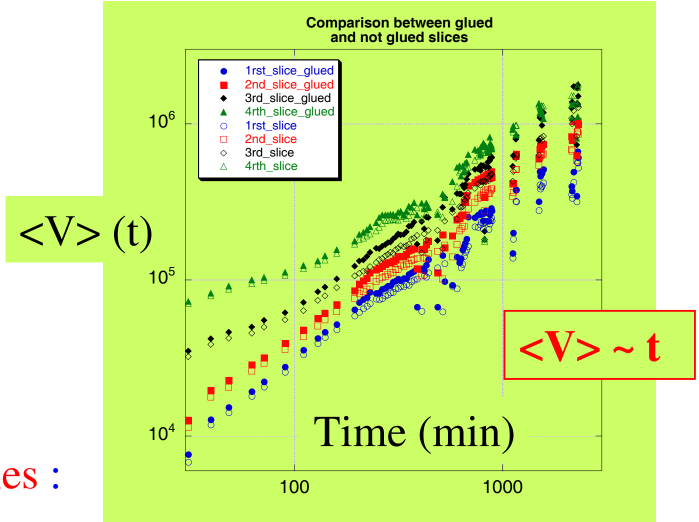


Segmentation
+ labelling
individual bubbles

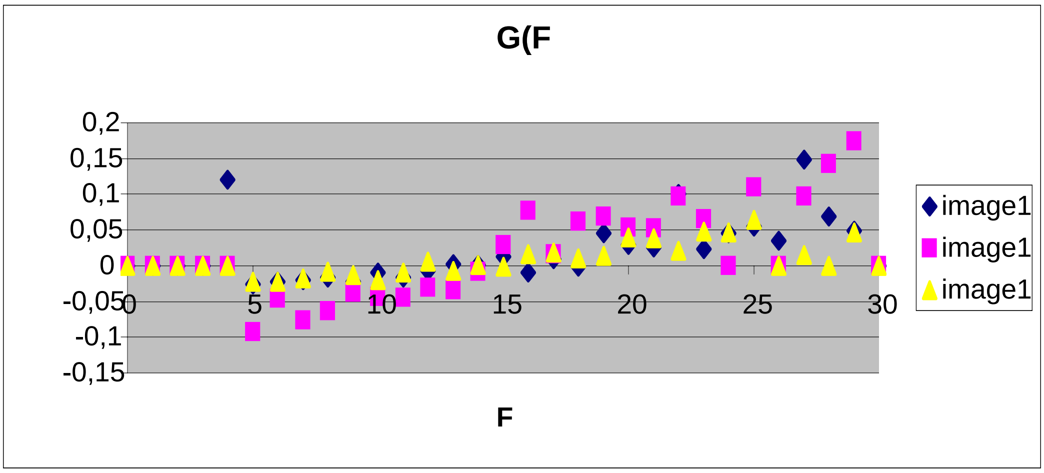
Behaves ~ as dispersed bubbles :
cf. LSW mean field theory

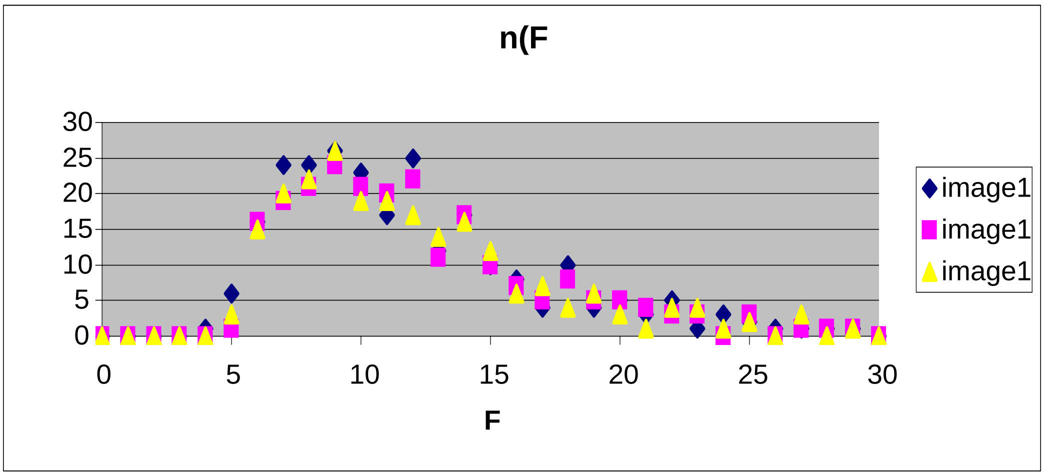
Exponential size distribution





J. Lambert (Univ. Rennes)





data
for dry
foam

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Other techniques

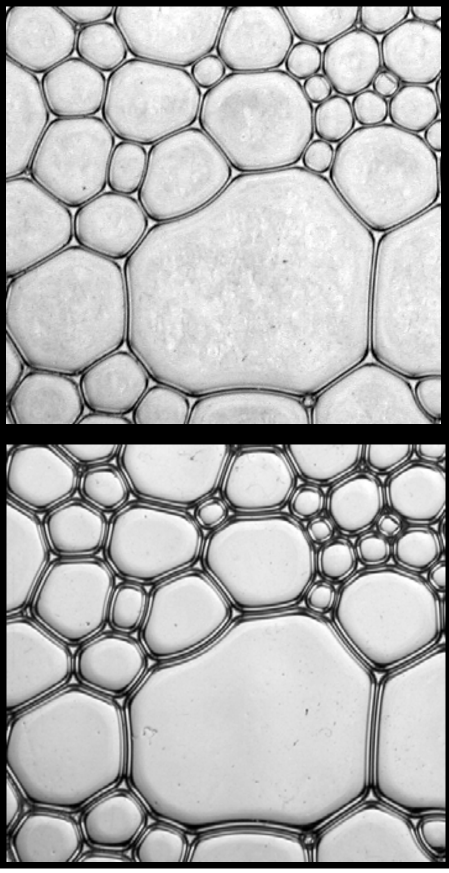
- already applied to foams
  - ray tracing
  - stereo-photography

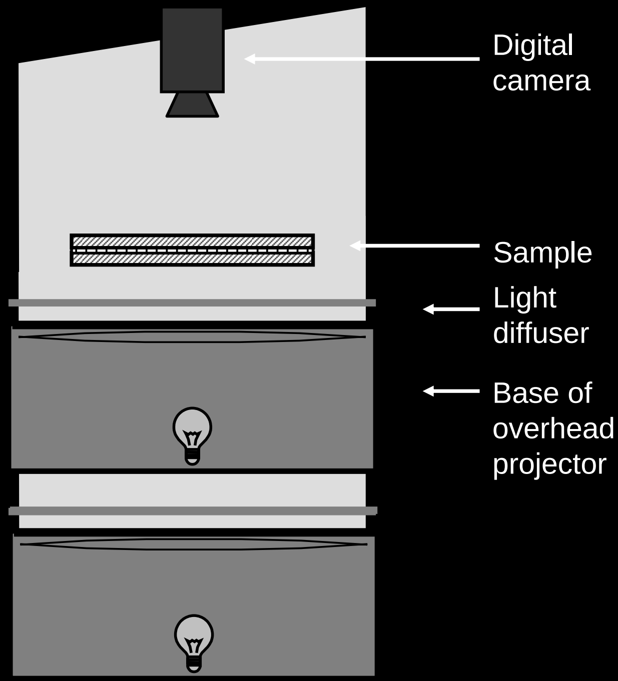
- not yet applied to foams
  - techniques used in biology
  - techniques used in medicine

Ray - tracing

Drenckhan, van der Net

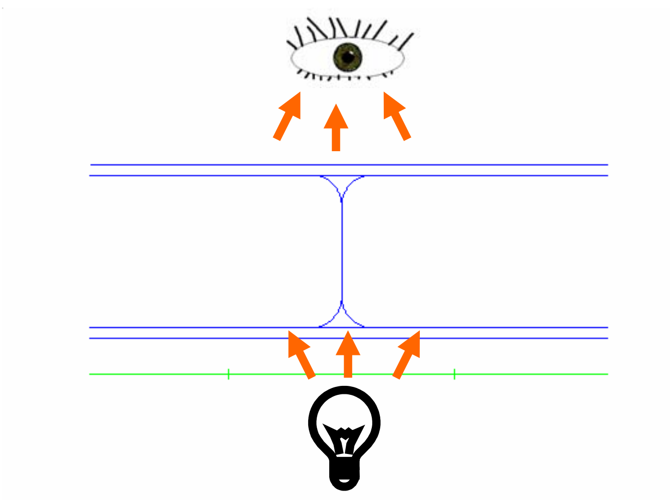
Liquid fraction of 2D FOAMS
– pattern sensitive to lighting condition

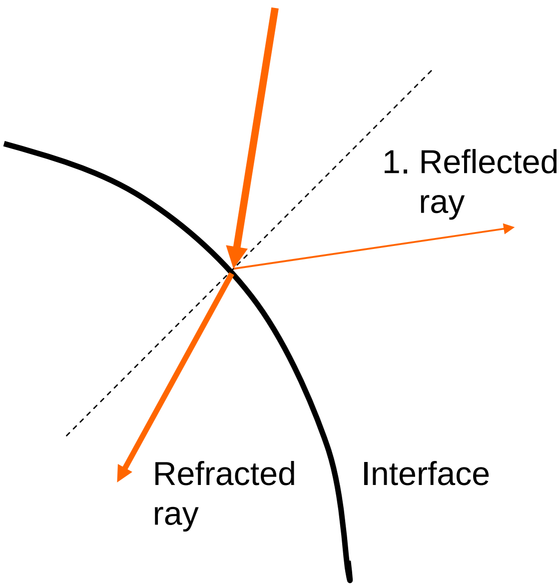




RAYTRACING SIMULATIONS

Principle: follow the path of light rays through the systems, taking into account reflection and refraction at the gas/liquid interface

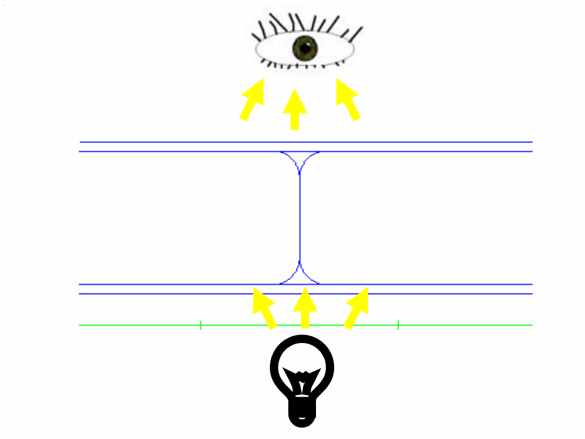




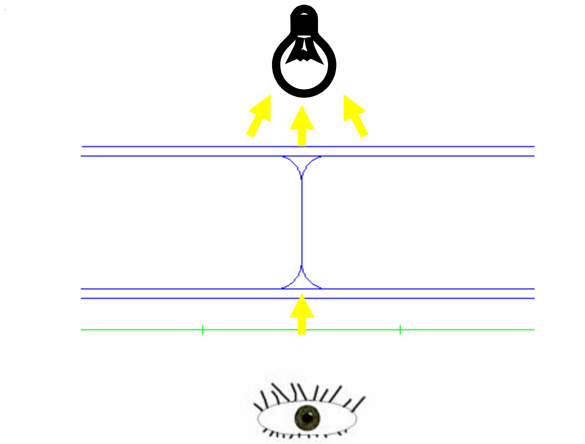
1. **Snell's law (angles)**
2. **Fresnel's law (intensities)**

RAYTRACING SIMULATIONS

Principle 2: use backward raytracing (i.e. follow rays backwards from the eye) to save calculation time

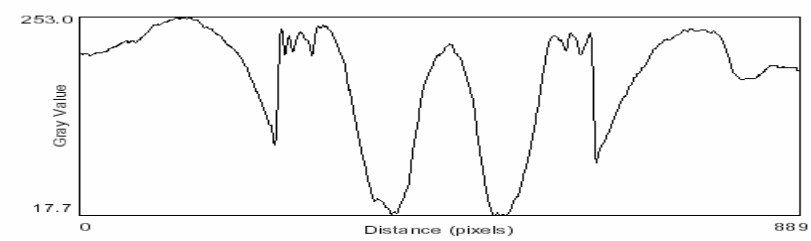


Physical reality

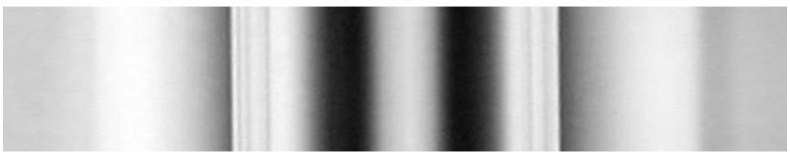


Model

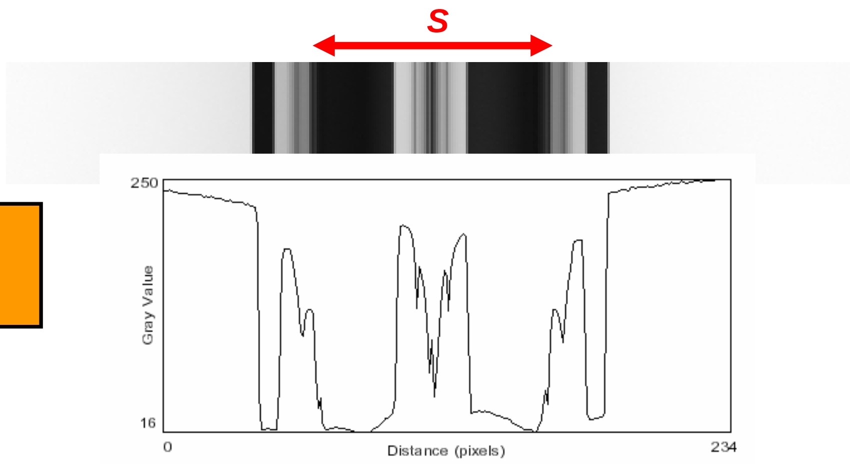
Goal: establish quantitative predictions for experiments



EXPERIMENT



SIMULATION



Example:
Width* = 4 * *S

Stereo-photography

Hilgenfeldt

(after Christian Ver'huis)

2 cameras at different angles

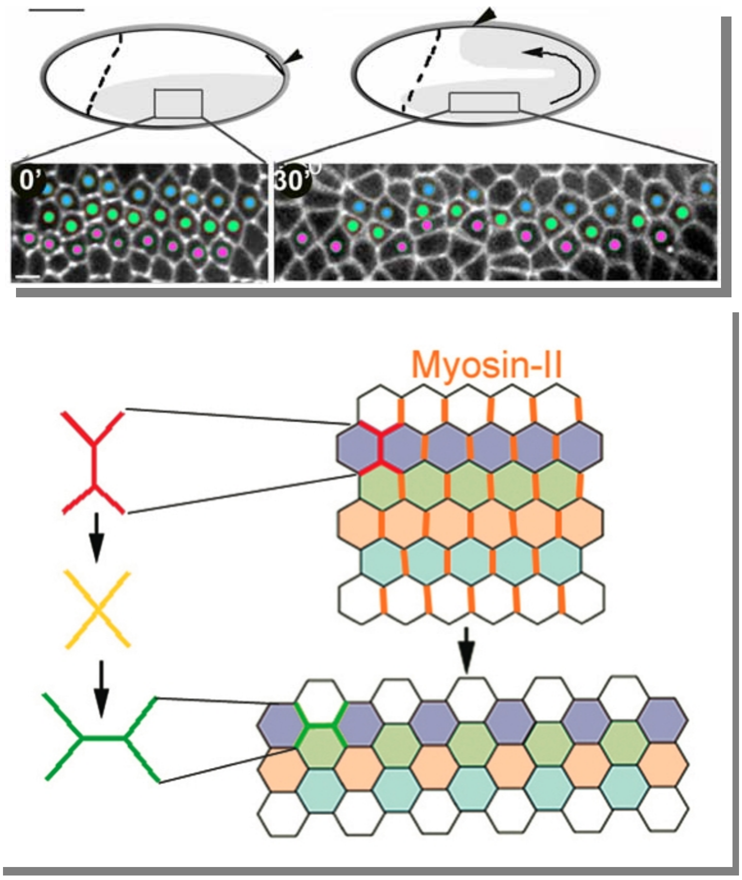
track shrinking tetraedra before T2

deduce the coarsening rate and thus the film thickness

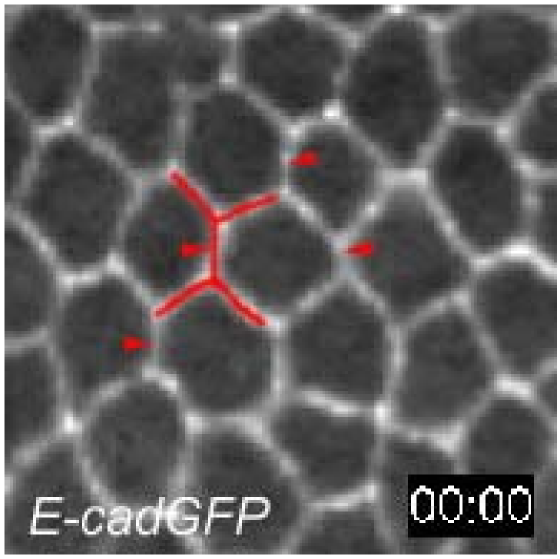
confocal microscopy

Sascha Hilgenfeldt

high-speed confocal microscopy



Drosophila embryo



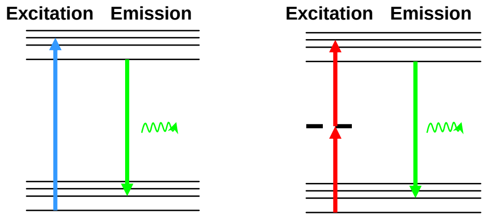
T. Lecuit
(Marseille)

2 photons microscopy

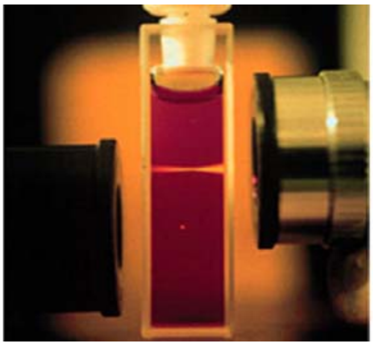
Pascale Vérant, Jean-Claude Vial

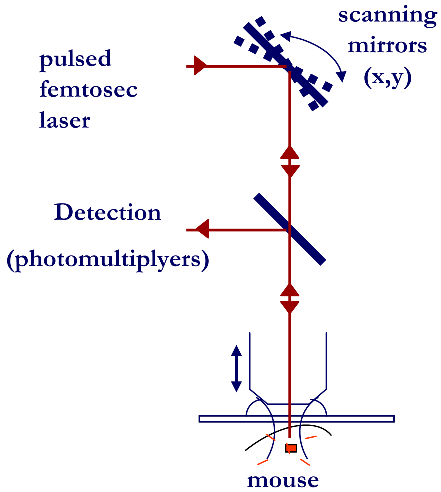
Grenoble

2 photons fluorescence microscopy



One photon excitation **2-photons excitation**





rich man's confocal microscopy :
very non-linear process, intense only at the focal point and for coherent photons = same signal as confocal microscopy but much less noisebecause scattered photons are not detected
field size : 1 mm2 or (0,1 mm)^2= 512 pixels^2 ,
resolution 0,4 microns in XY, 0.8 in Z;
laser : 100 fs, 1W, repetition 12 ns, peak MW
10 plane images in 20 to 80 sec
ok to image 3 to 5 bubble layers

surface

bulk

QuickTime™ et un
décompresseur TIFF (LZW)
sont requis pour visionner cette image.

Other techniques

- poor man's confocal microscopy : structured light or selective plane illumination microscopy
- 3D echography,
- positon emission tomography
- terahertz
- magnetoencephalography
- photoacoustics
- elasticity imaging

and so on ....