Les Houches Foam School
January 2006

I. Non invasive probes of aqueous foams

II. Rheology
Solid-like response
Yielding and liquid-like response

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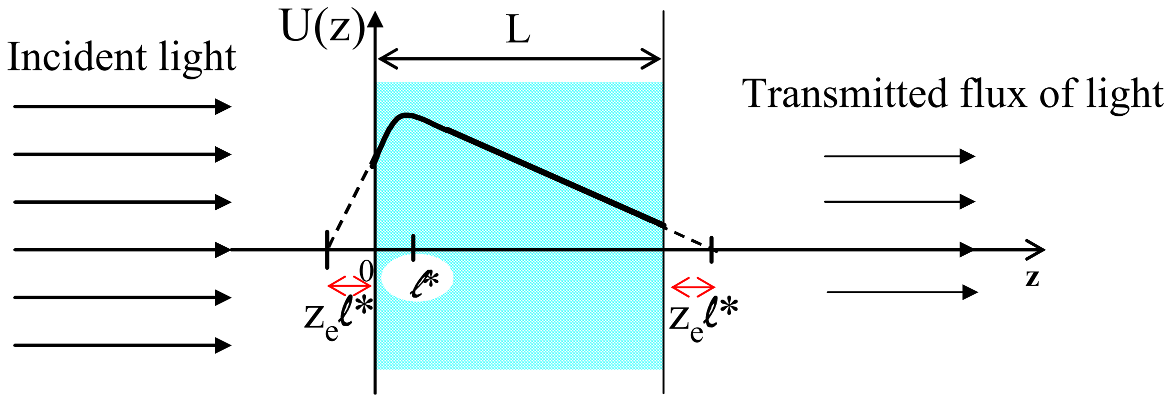
Non-invasive probes of aqueous foams

Multiple light scattering

Electrical conductivity

Acoustic waves

Diffuse transmission of light through a slab



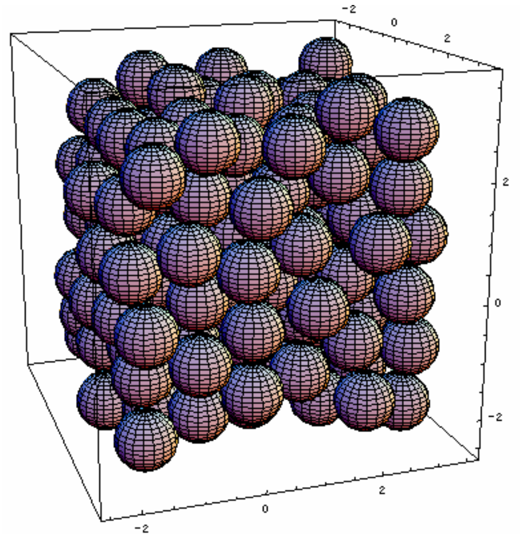
Transmission coefficient

$$T = \frac{1 + z_e}{\frac{L}{\ell^*} + 2\, z_e}$$

Ray tracing simulation of light propagation in a wet foam

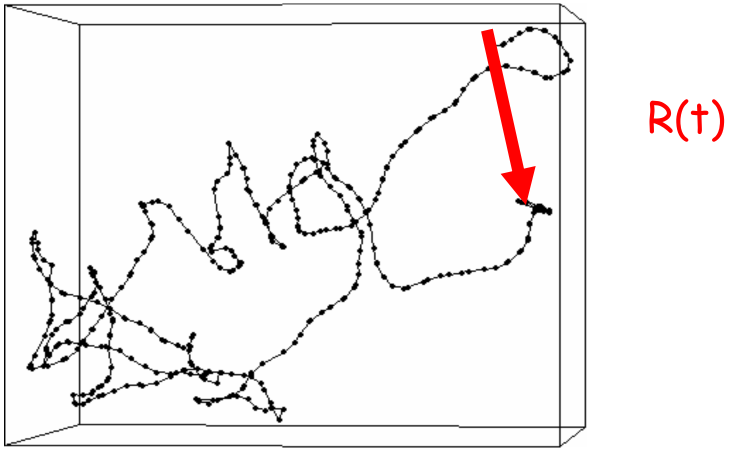
► Light propagation: geometrical optics, ray tracing.

► Random close packing of 1000 bubbles with periodic boundary conditions.

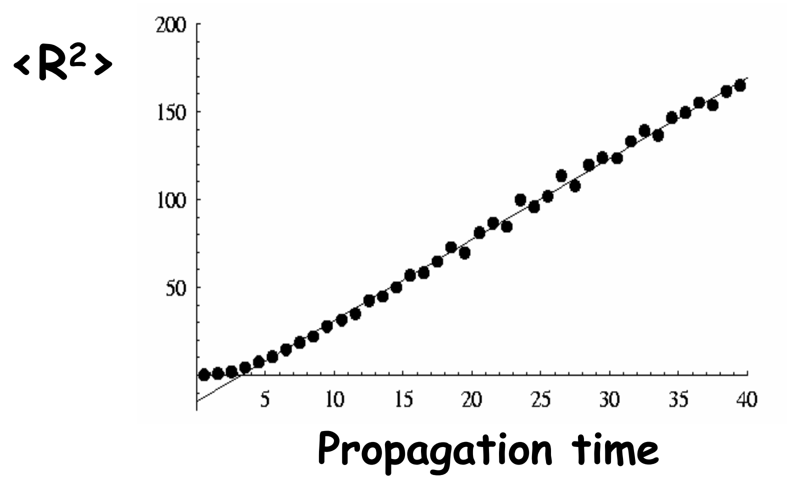


Refractive indices:

n_{inside}, $n_{outside}$

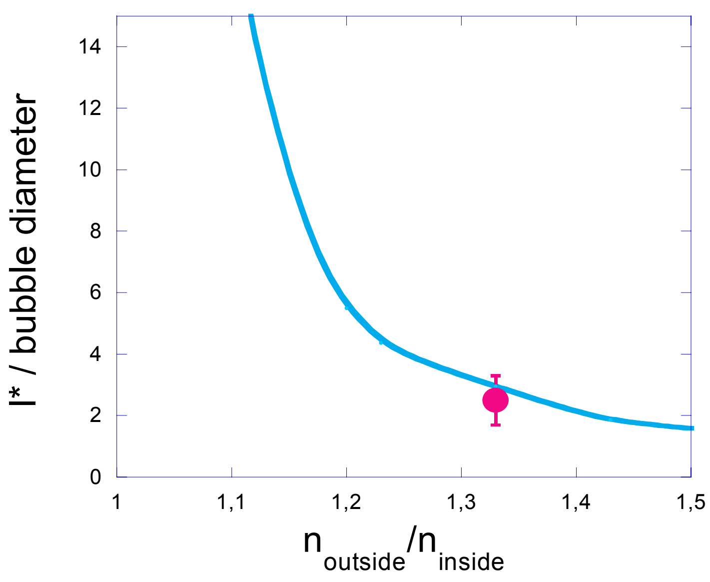


The random walk of a light ray in a wet foam



Diffusion law

$<R^2> = 6 D_l t \qquad D_l = \ell^* c/3$



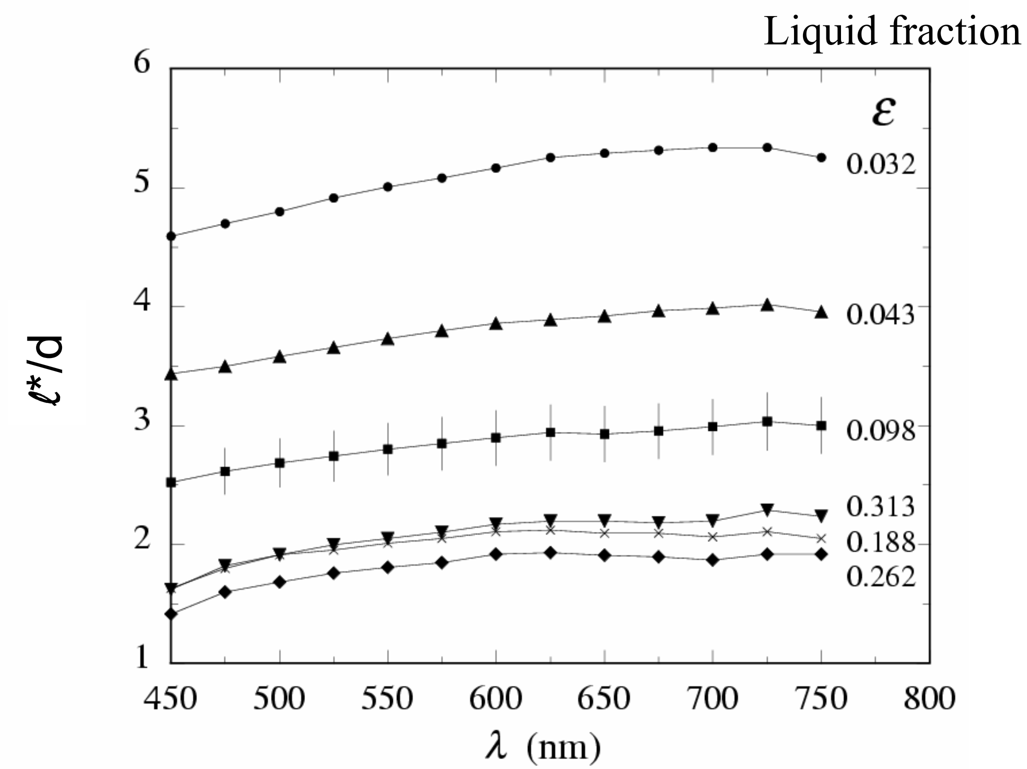
Good agreement with experiments:

Simulation

Diffuse transmission data for wet foams

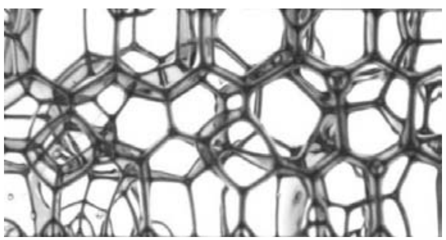
2 necessary conditions for geometrical optics description

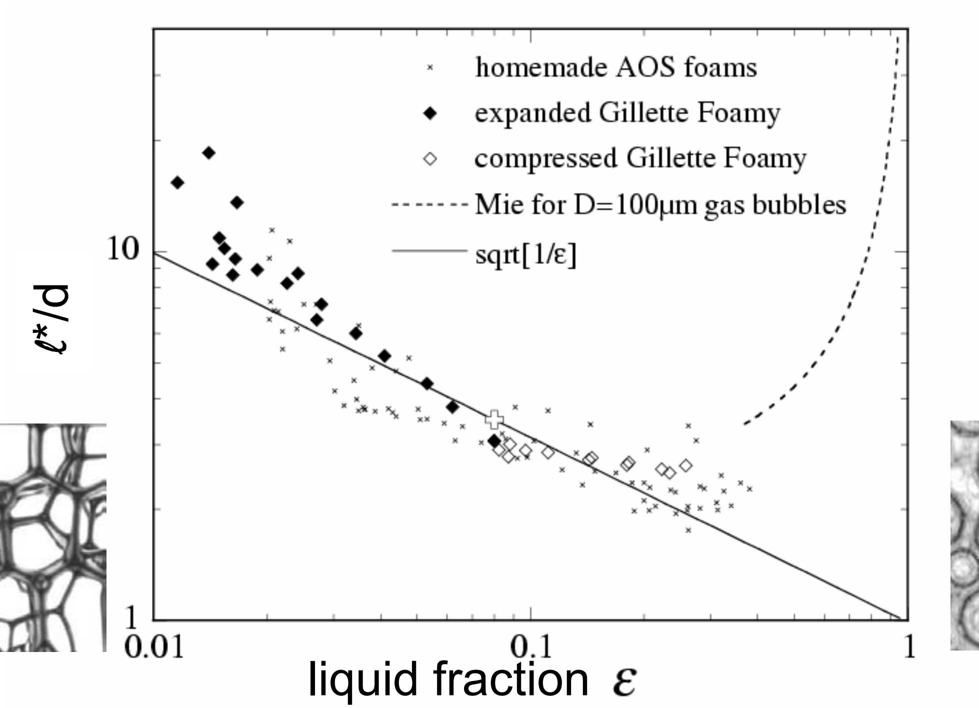
- $\ell^* \propto$ bubble diameter d
- ℓ^*/d depends only very weakly on wavelength

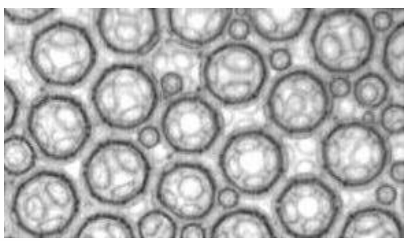


Durian, Weitz, Pine 1991
Vera, Saint-Jalmes, Durian 2001

Dry foams are more transparent than wet foams



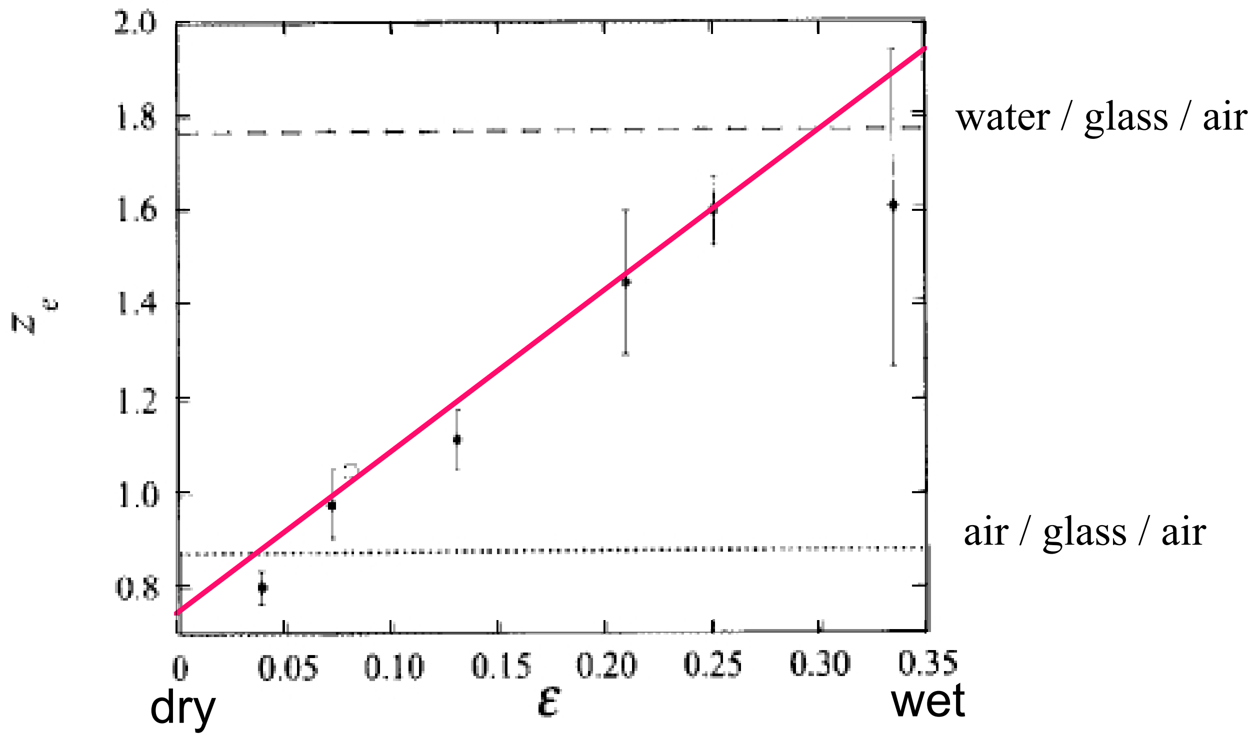




$$\frac{\ell^*}{d} \cong \frac{1}{\sqrt{\varepsilon}}$$

Vera, Saint-Jalmes, Durian 2001

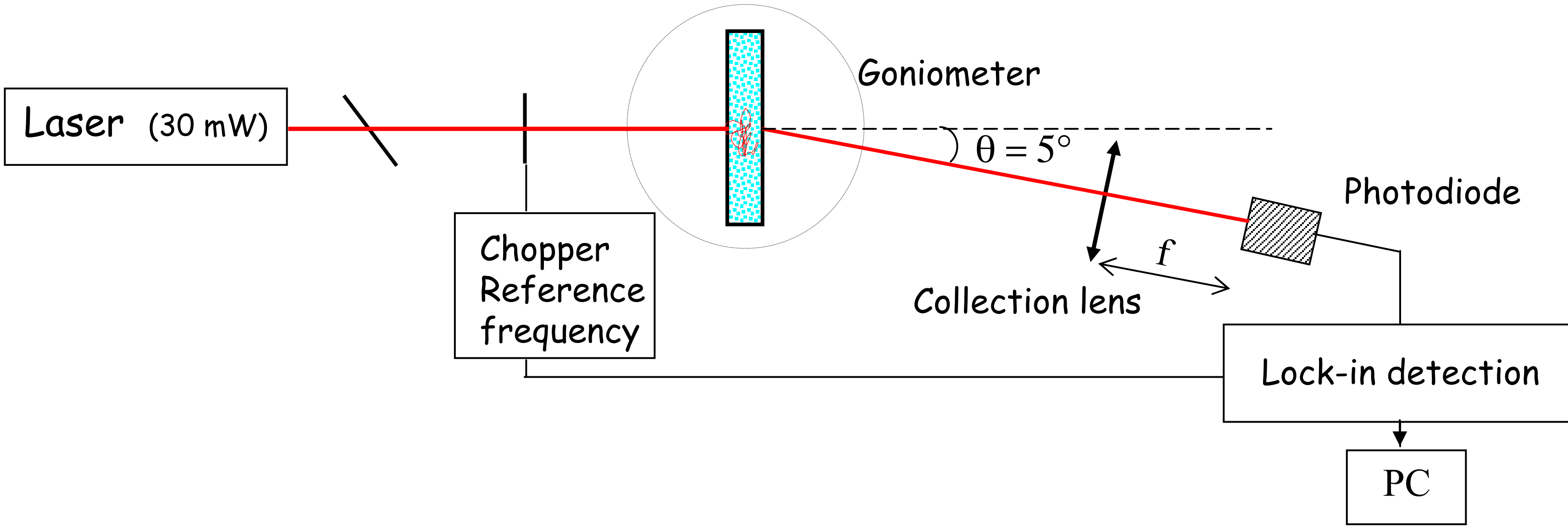
Extrapolation length ratio z_e

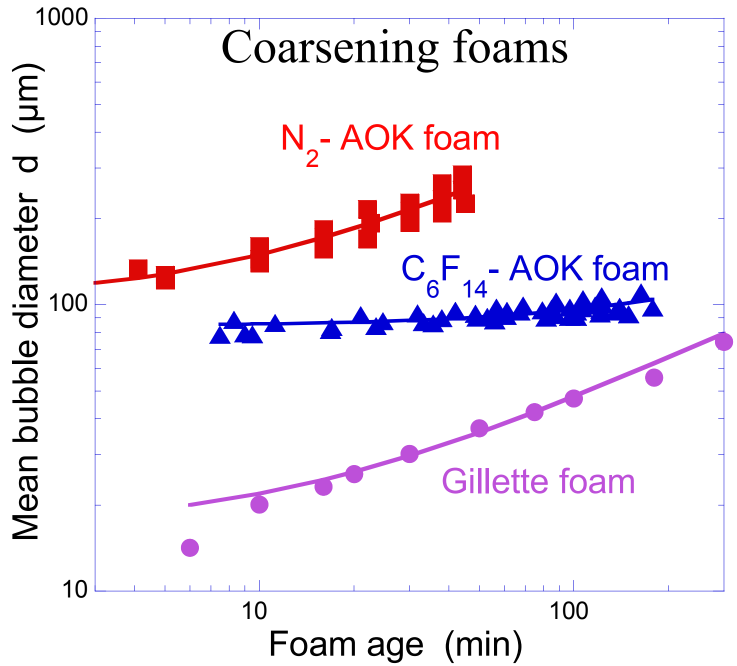


$$z_e \cong 0.74 + 3.44\,\varepsilon$$

Vera, Saint-Jalmes, Durian 2001

Experimental set-up for DTS

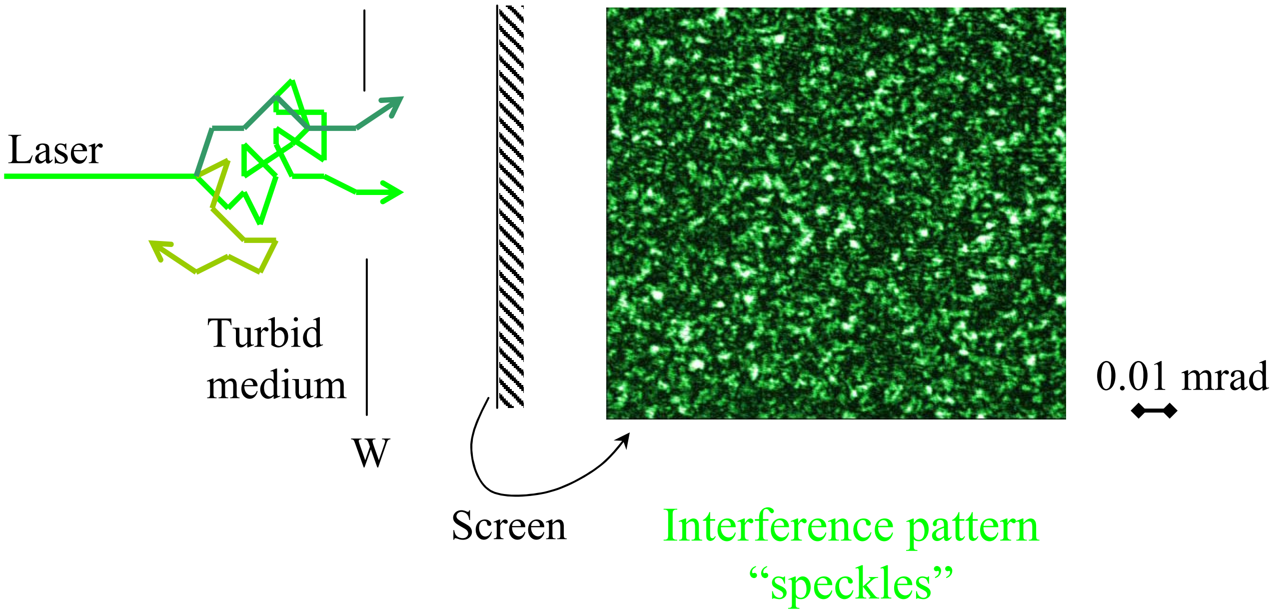




$$d^2 = d_o^{\,2} + K\,(t-t_o)$$

Mullins 1986

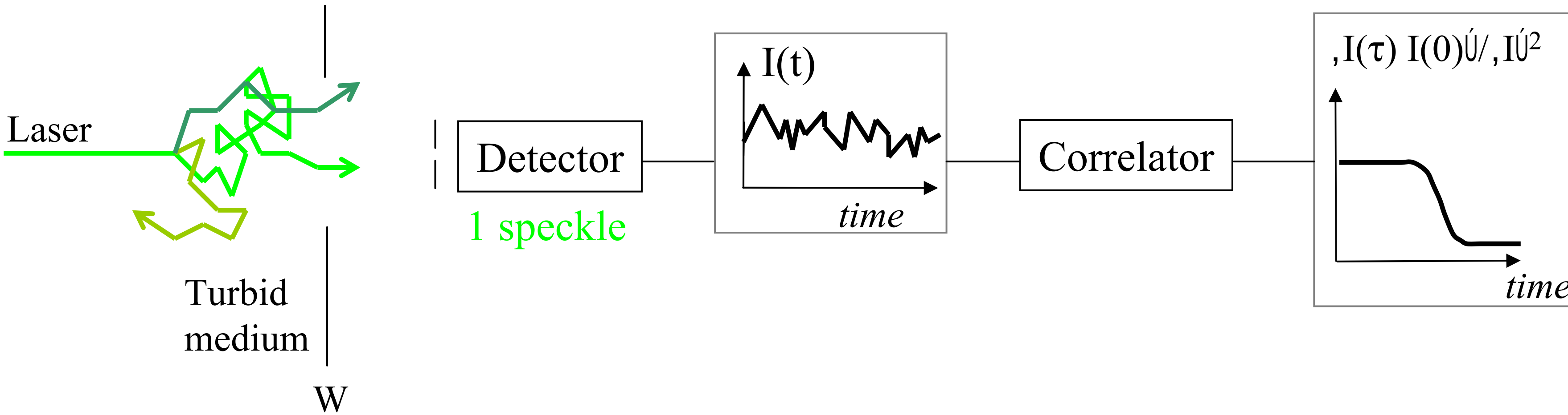
Principle of Diffusing-Wave Spectroscopy



Speckle size

$$\alpha \cong \frac{1}{k\,W}$$

Principle of Diffusing-Wave Spectroscopy



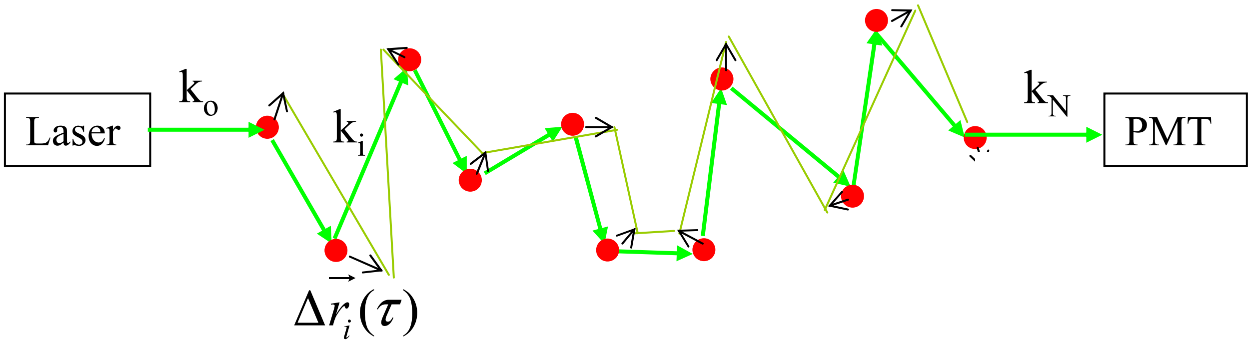
$$g_2(\tau) = \frac{< I(0) \;\; I(\tau) > - < I >^2}{< I^2 > - < I >^2}$$

Weitz, Pine
In "Dynamic light scattering" 1993

DWS formalism

Normalized electrical field correlation function:

$$g_1(\tau) \equiv \frac{<E(0)\, E^*(\tau)>}{<|E|^2>} = \sum_p \frac{<I_p>}{<I>} \left\langle e^{-i\Delta\Phi_p(\tau)} \right\rangle$$

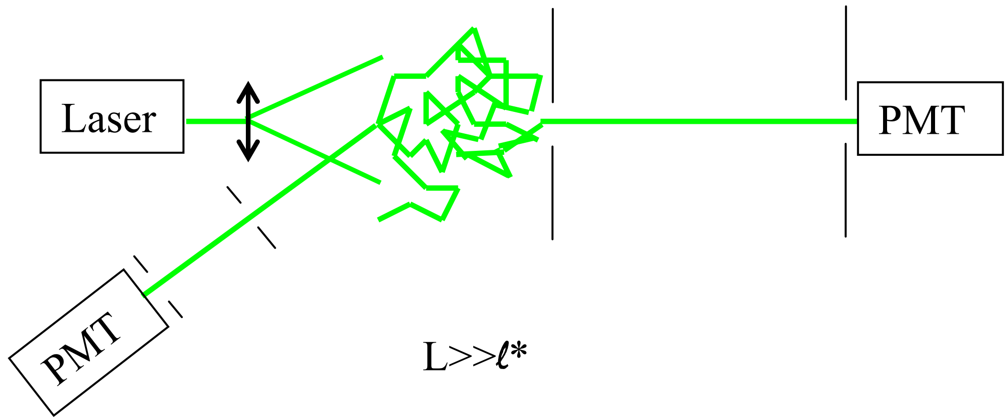


$$g_1(\tau) = \int_0^\infty P(s)\; e^{-2\frac{\tau}{\tau_o}\frac{s}{\ell^*}}\, ds$$

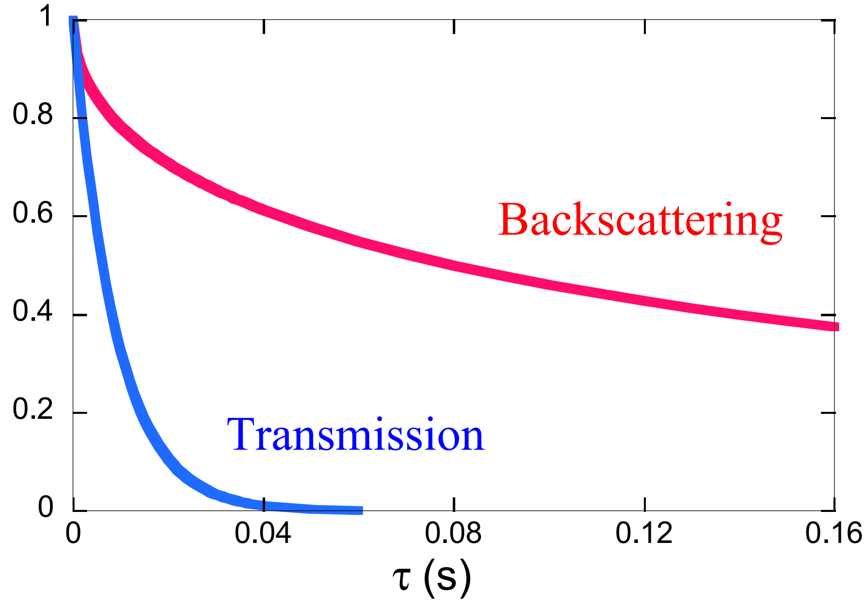
Maret, Wolf 1987

Pine, Weitz, Chaikin, Herbolzeihmer 1988

Transmission versus backscattering geometries



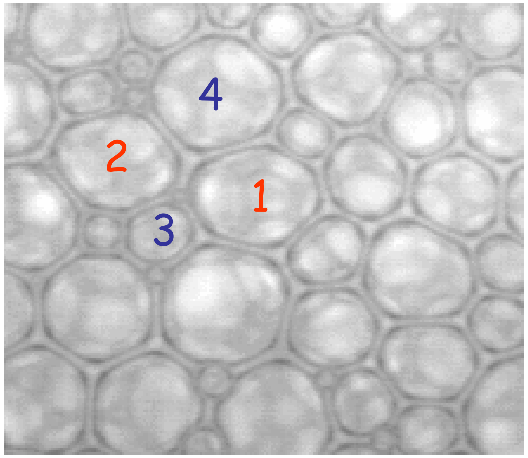
$$g_2(\tau) = \left|g_1(\tau)\right|^2$$

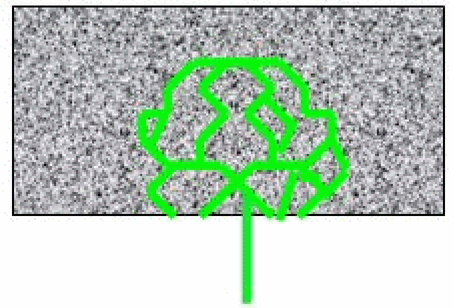


$$g_{1B}(\tau) \cong \exp\left(-(1+z_e)\sqrt{\frac{6\tau}{\tau_o}}\right)$$

$$g_{1T}(\tau) \cong \exp\left(-\left(\frac{L}{\ell^*}\right)^2 \frac{\tau}{\tau_o}\right)$$

Intermittent dynamics in a coarsening foam





Frequency $1/\tau_o$

$$g_1(\tau) = \int_0^\infty P(s)\, g_{1s}(\tau)\, ds$$

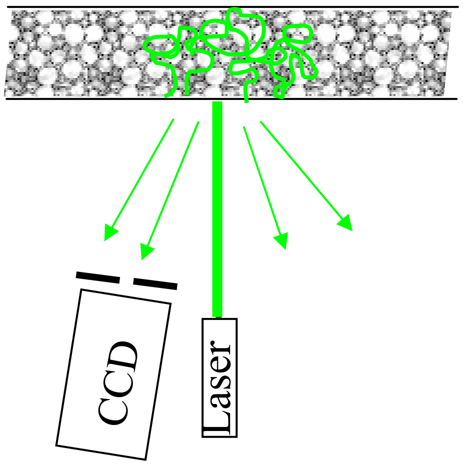
$g_{1s}(\tau)$ is given by the fraction of paths $s = N\,\ell^*$ that do not cross any rearranged zones.

$$g_{1s}(\tau) = e^{-\frac{s}{\ell^*}\frac{\tau}{\tau_o}}$$

Durian, Weitz, Pine 1991

Multispeckle Diffusing-Wave Spectroscopy

For non ergodic or slow dynamics systems



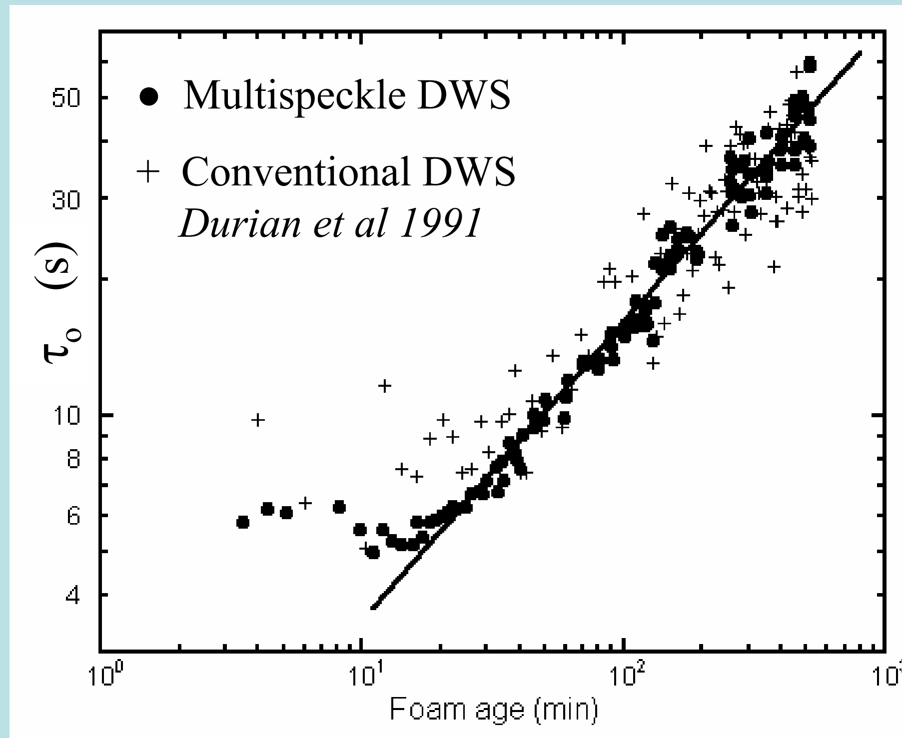
$$g_2(\tau) = \frac{\langle I(0)\ I(\tau)\rangle - \langle I\rangle^2}{\langle I^2\rangle - \langle I\rangle^2}$$

The temporal average for calculating $g_2(\tau)$ is replaced by an average over speckles.

C-A, Höhler 2001

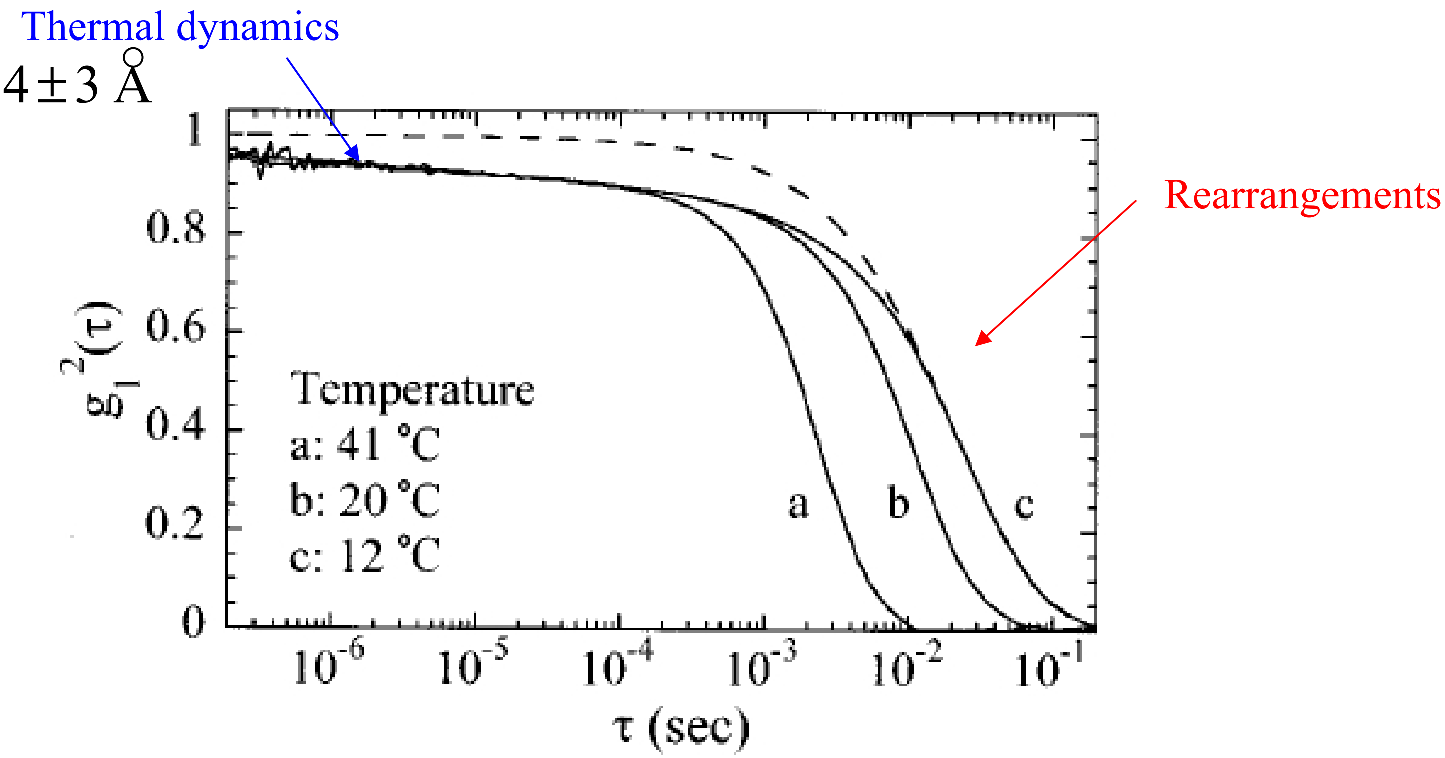
Intermittent dynamics of a coarsening foam

Evolution of average time interval between bubble rearrangements τ_o with foam age:



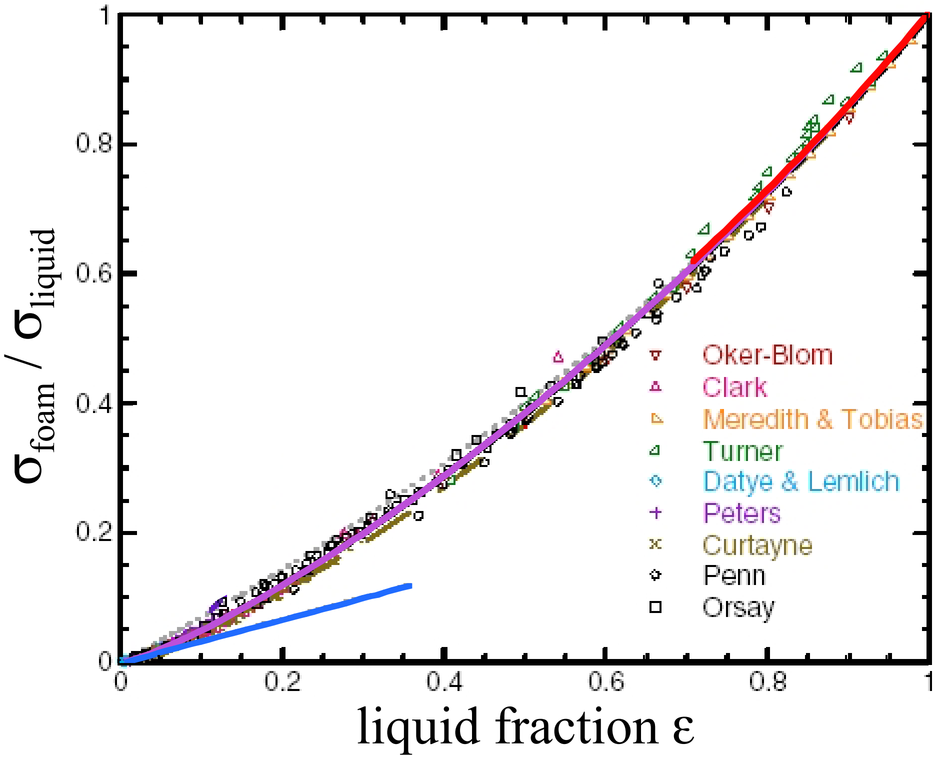
Fast thermal dynamics

$\delta \cong 14 \pm 3$ Å

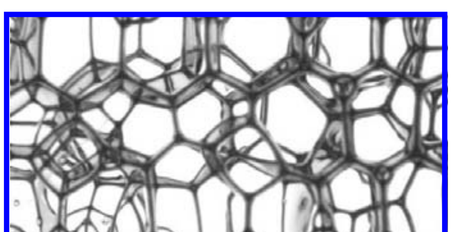


Gopal, Durian 1997

Electrical conductivity



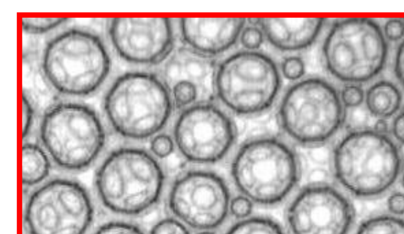
Lemlich 1978
Phelan et al 1996



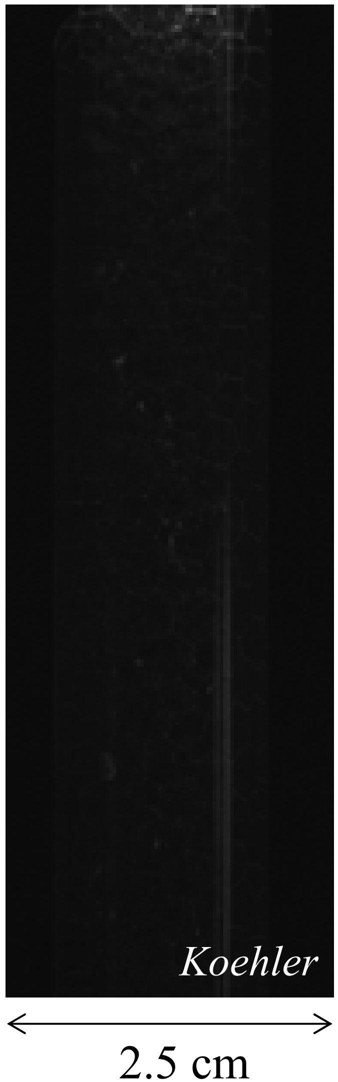
Feitosa, Marze, Saint-Jalmes, Durian 2005

$$\frac{\sigma_{foam}}{\sigma_{liquid}} = \frac{2\,\varepsilon\,(1+12\,\varepsilon)}{6+29\,\varepsilon-9\,\varepsilon^2}$$

Maxwell 1891

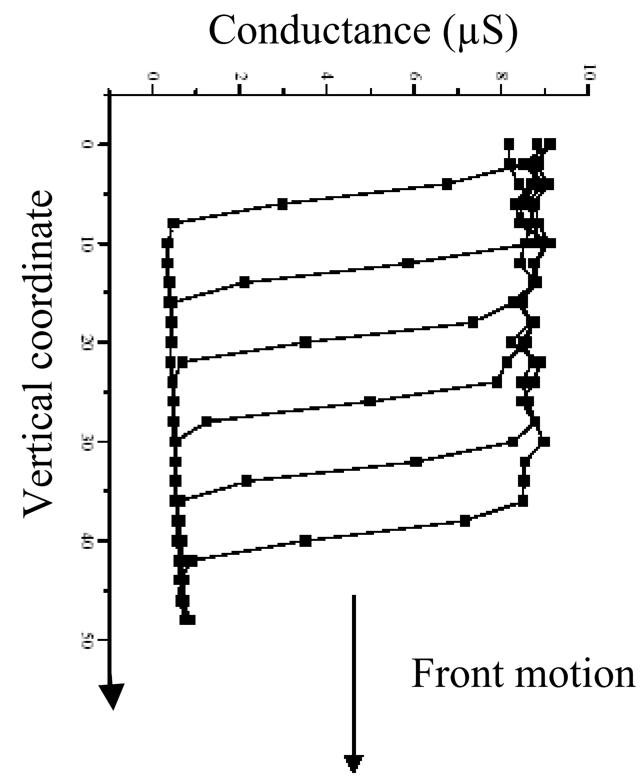


Application to forced drainage



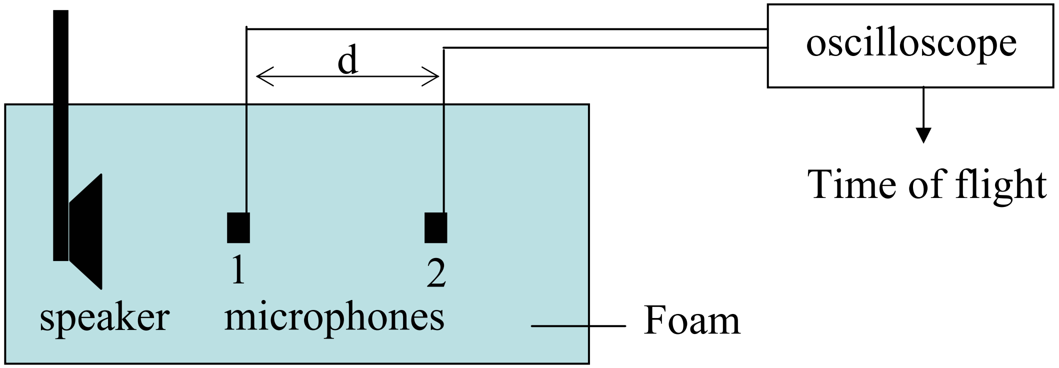
Koehler, Hilgenfeldt, Stone 2000

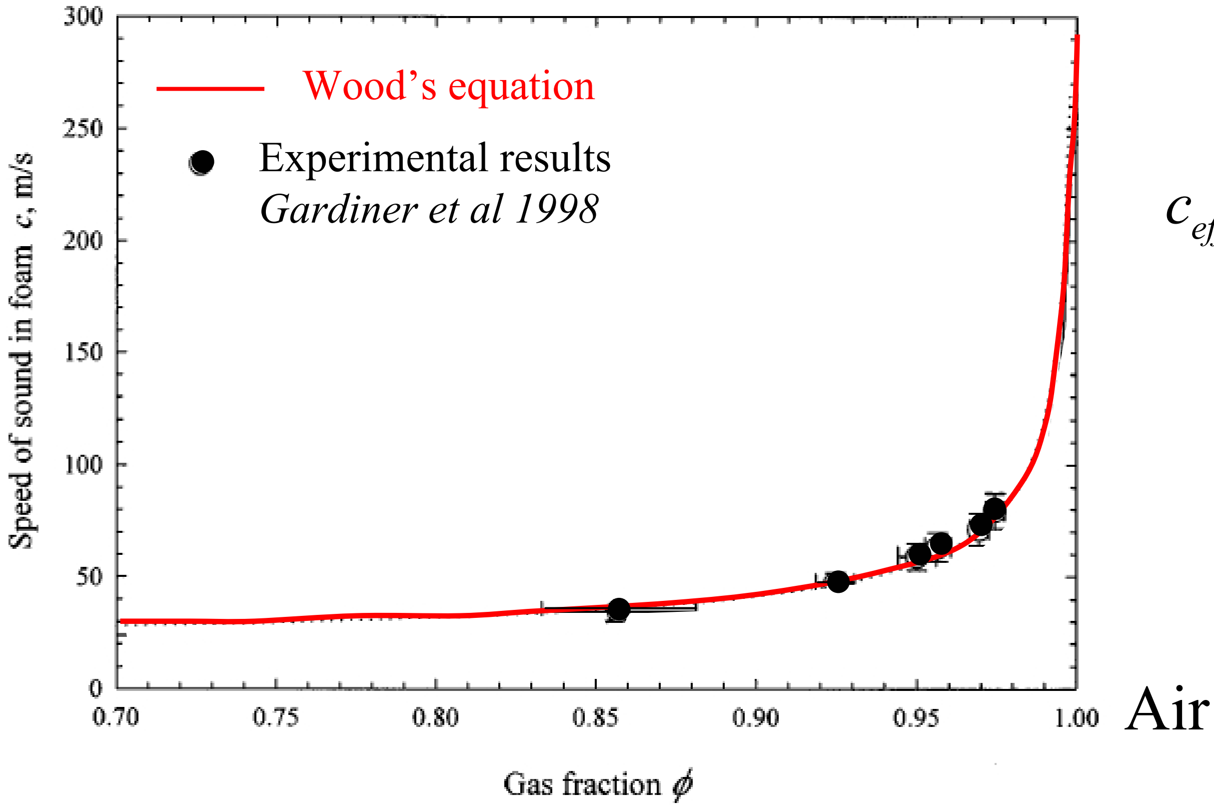
Weaire, Findlay, Verbist 1995
Vera, Saint-Jalmes, Durian 1999
Saint-Jalmes, Langevin 2002
Durand, phD 2002



Sound propagation

Kann et al 1994
Gardiner et al 1998
Mujica, Fauve 2002





$$c_{eff} = \sqrt{\frac{\gamma P}{\varepsilon(1-\varepsilon)\,\rho_{liq}}}$$