Focusing light through complex media by wavefront shaping

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Light perturbation :

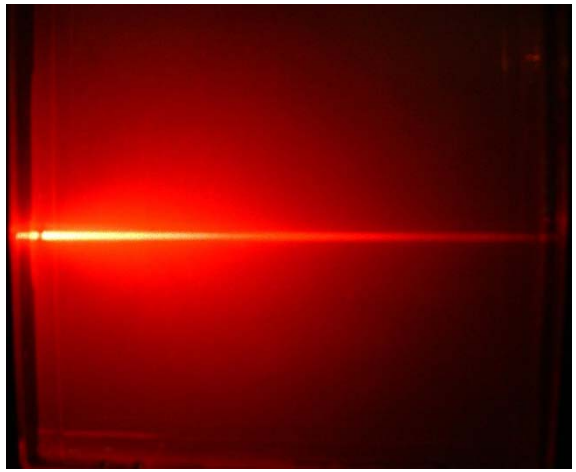
two regimes of perturbations :

- *turbulence :*
  continuous (weak) phase aberrations → effectively mitigated by adaptive optics
- *turbidity :* strong multiple scattering →  ?

Imaging in depth in scattering media

→ Conventionally : information from unscattered (*'ballistic'*) light only

but



Beer-Lambert Law: Exponential decay of the ballistic light

$$I = I_0 \exp\left[-n(\quad)L\right]$$

ABSORPTION AND SCATTERING CROSS SECTION

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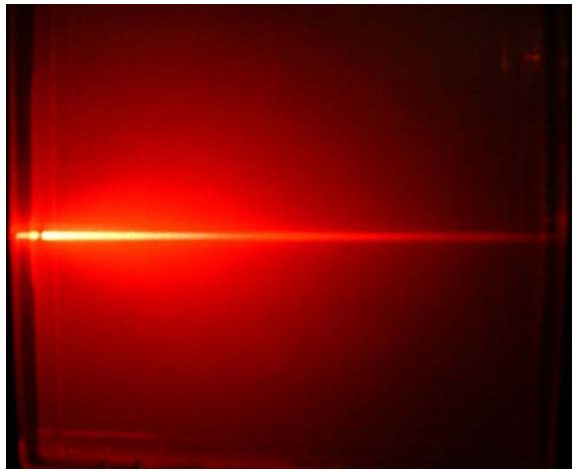


Beer-Lambert Law: Exponential decay of the ballistic light

→ No imaging beyond a fews hundreds microns in living tissues

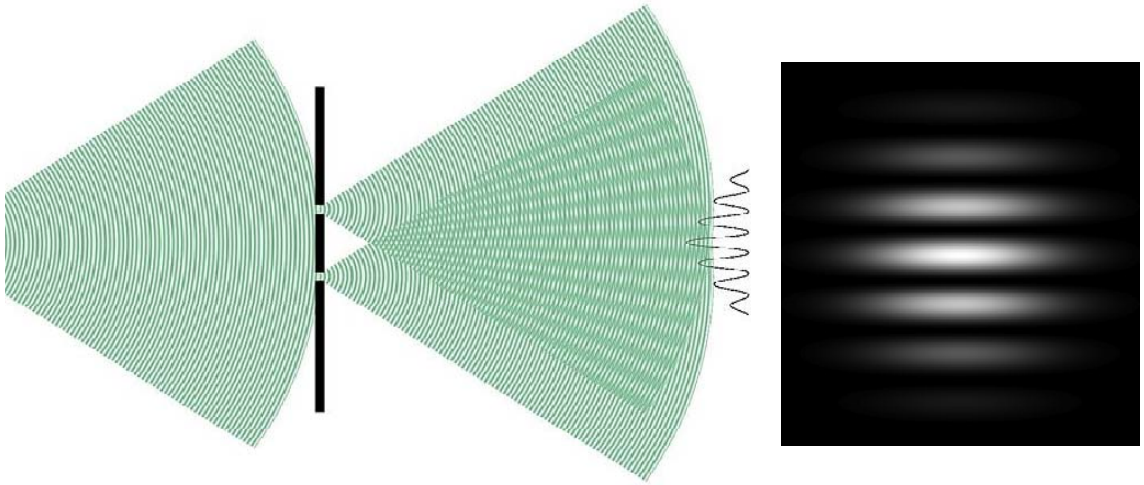
CAN WE GO DEEPER?

Scattering, a coherent process

Young's slit experiment

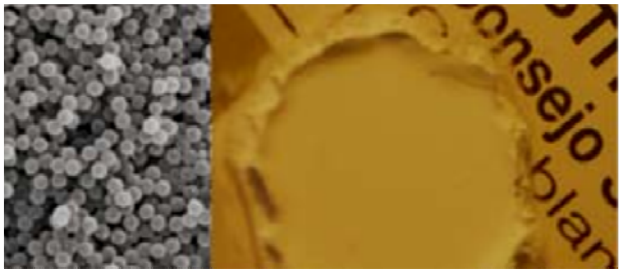
➔ two wave interference

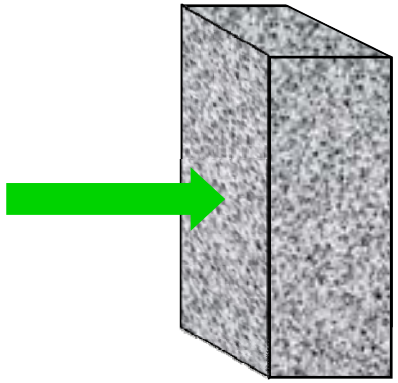
➔ Fringes



Multiple scattering

thin layer of white paint
(particle size ≤ 1 µm)

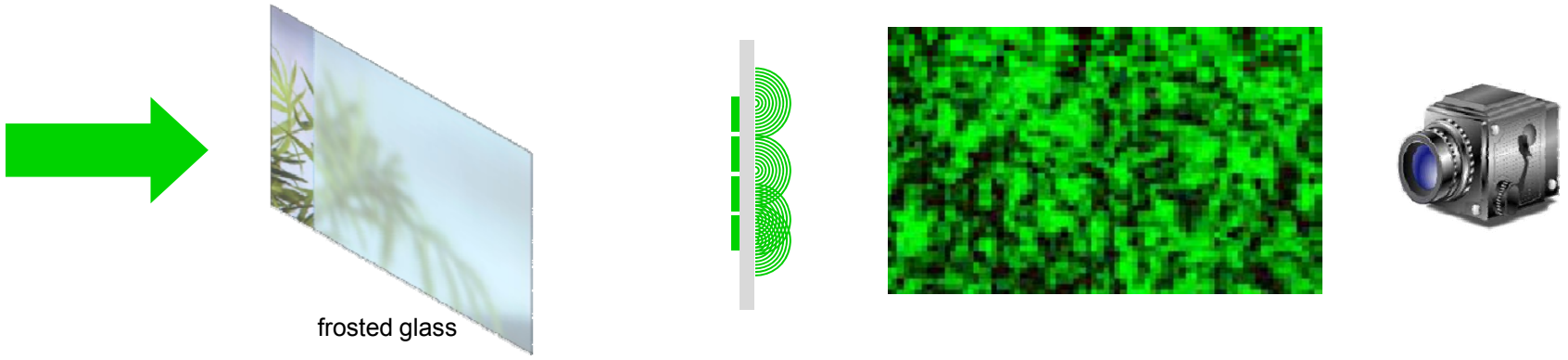




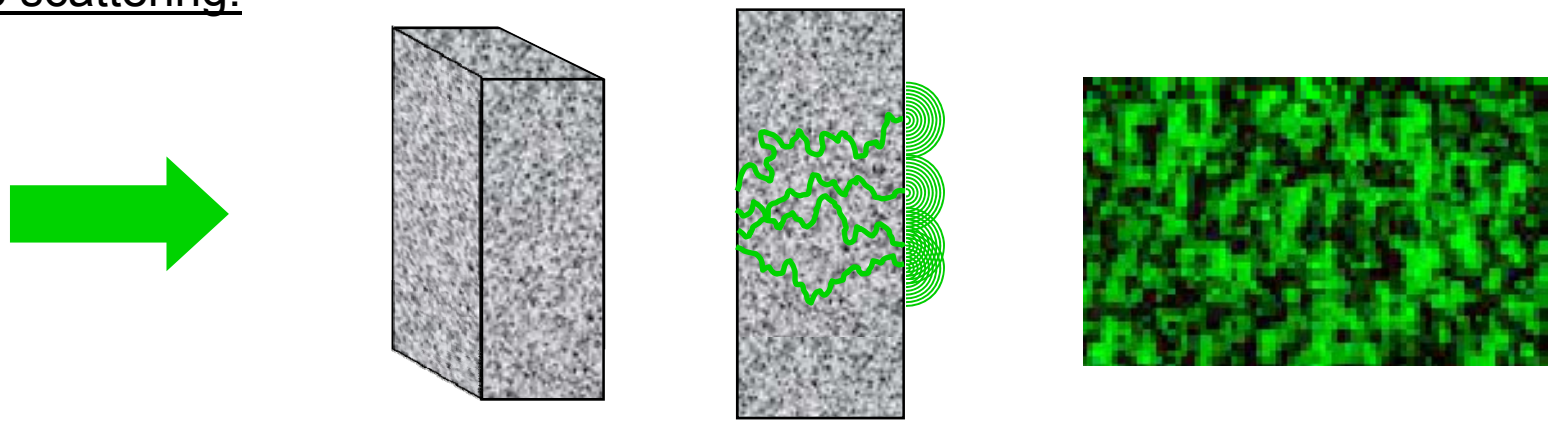
?

Scattering, a coherent process

Surface scattering :



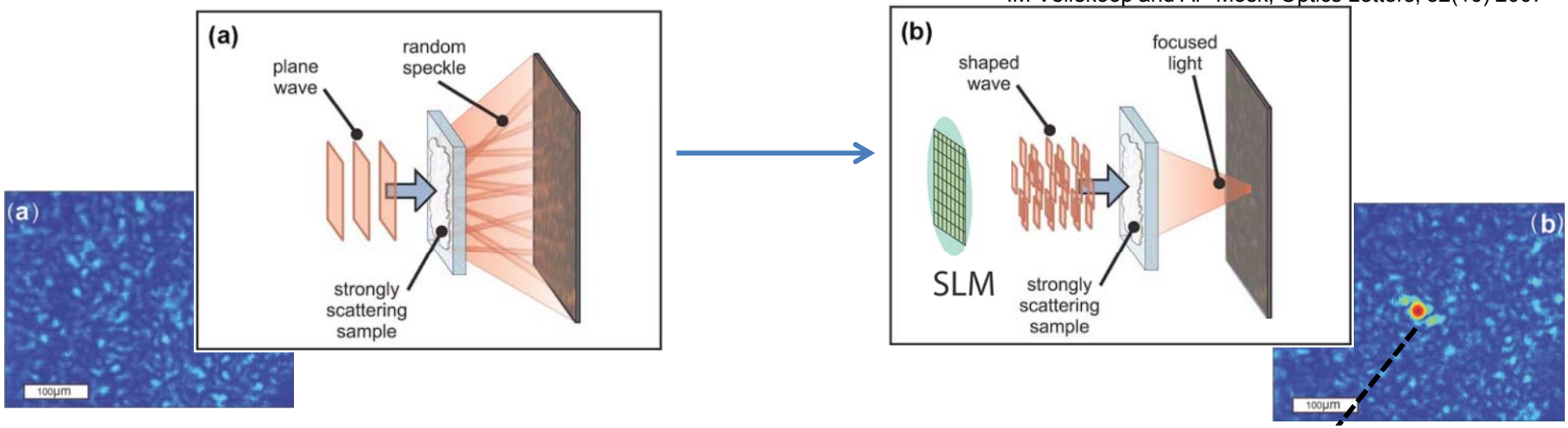
Volume scattering:

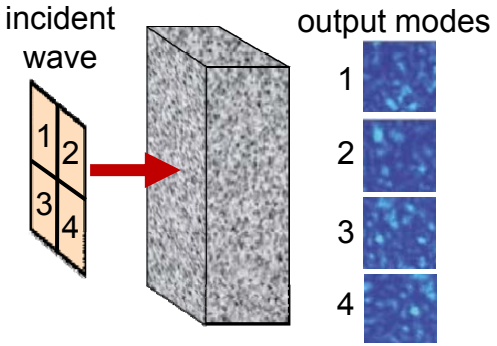


Speckle results from multiple interferences between a multiplicity of random paths

Focusing through a complex media

IM Vellekoop and AP Mosk, Optics Letters, 32(16) 2007





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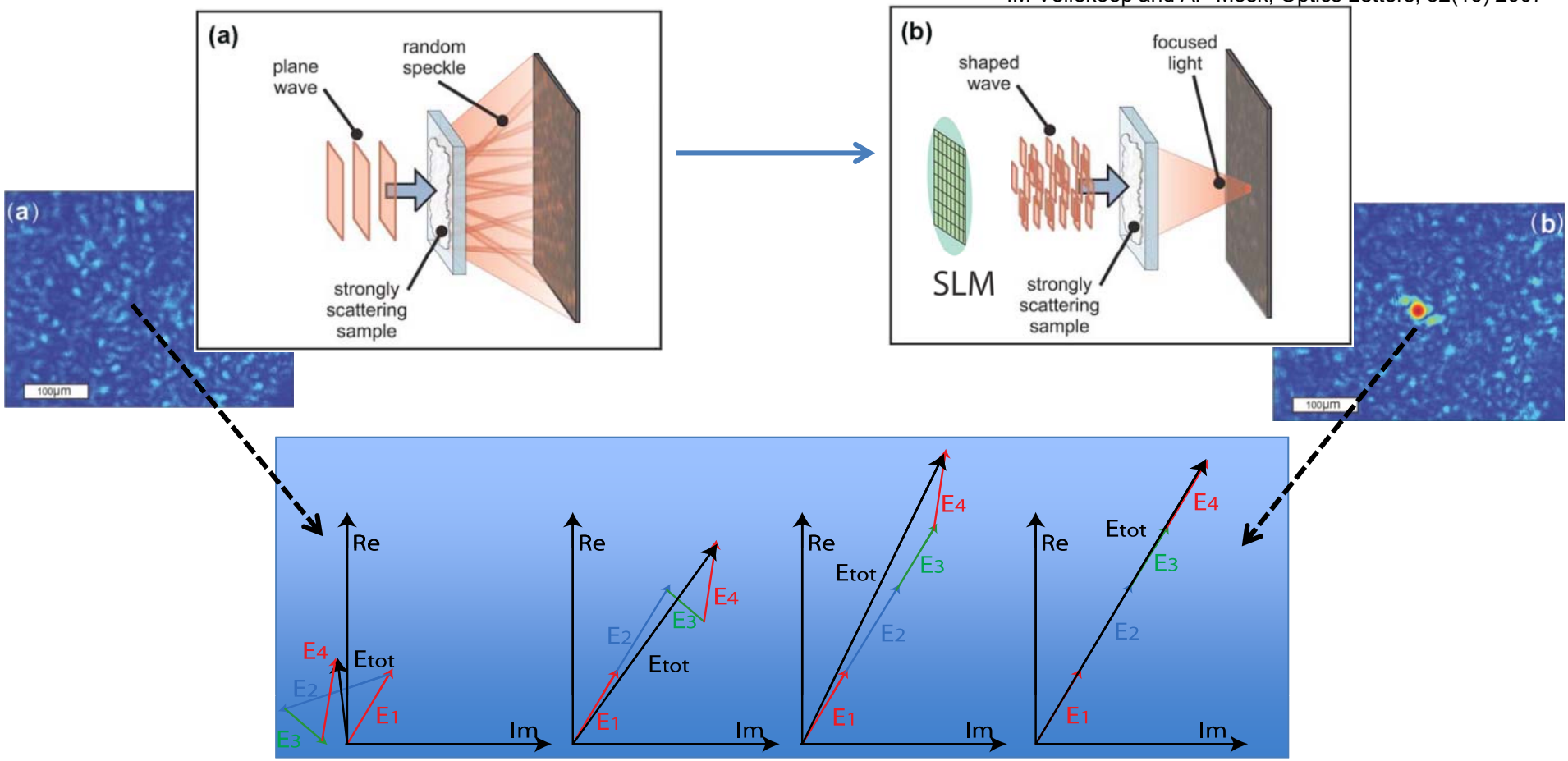
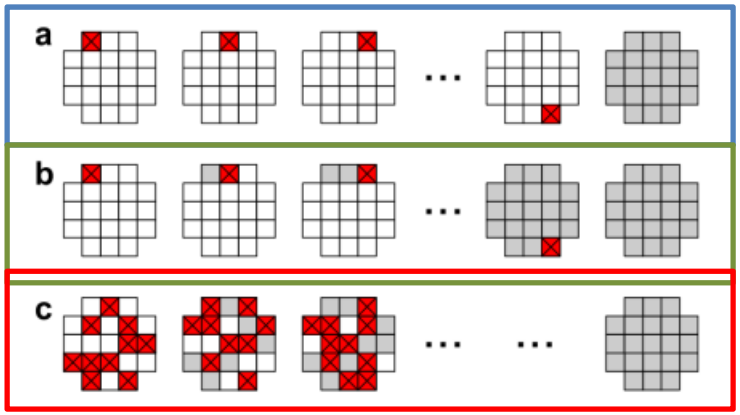
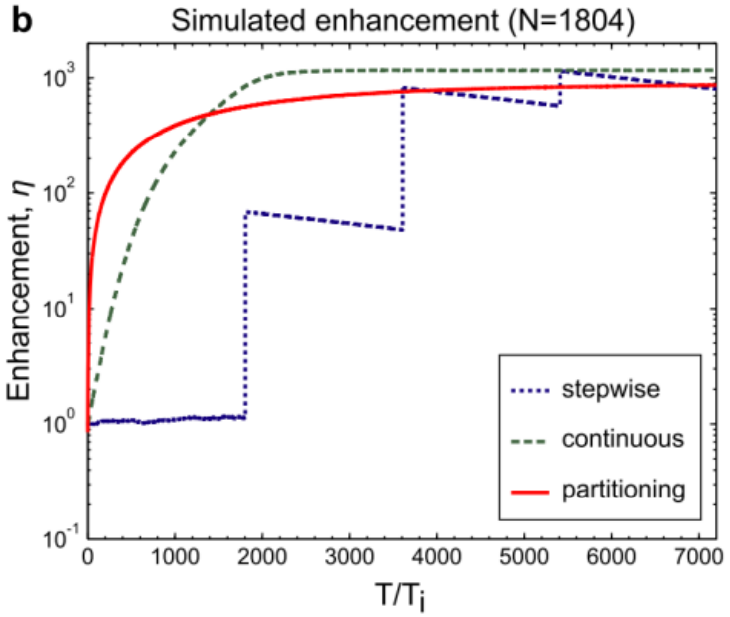


→ It is possible to shape these modes in phase to obtain a constructive interference on a single speckle grain (Equivalent to phase-conjugation)

Two ways to achieve focusing : optimization

different algorithms

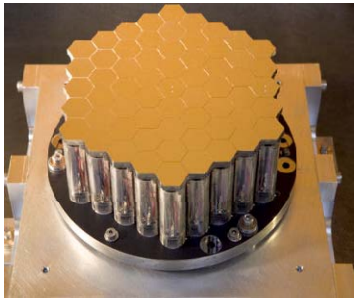


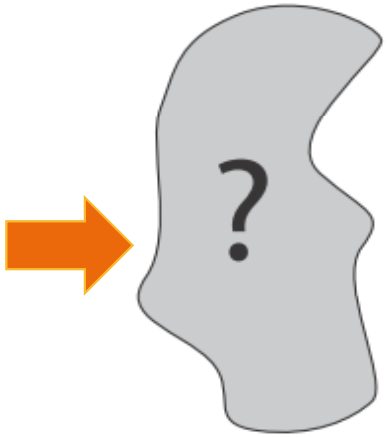


- Independent action of pixels → easy convergence of optimization
- SNR proportional to the number of pixels controlled

I.M. Vellekoop, A.P. Mosk / Optics Communications 281 (2008) 3071–3080

Two ways to achieve focusing : transmission matrix





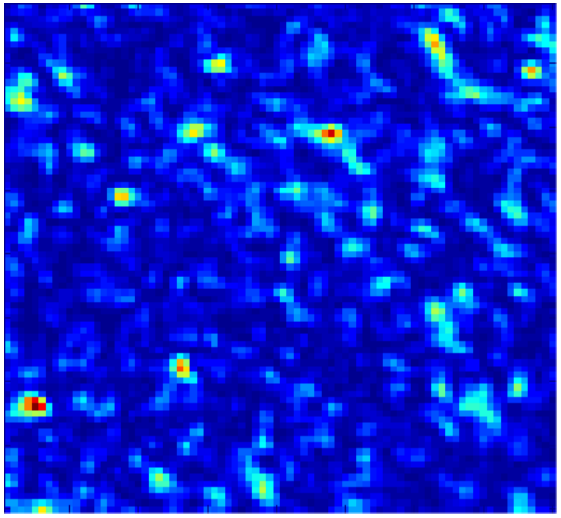
SLM : array of pixels | **Linear system** | **CCD camera : array of pixels**

$$H = \begin{pmatrix} h_{1,1} & h_{1,2} & \dots & h_{1,N} \\ h_{2,1} & h_{2,2} & \dots & h_{2,N} \\ \vdots & & \ddots & \vdots \\ h_{M,1} & h_{M,2} & \dots & h_{M,N} \end{pmatrix}$$

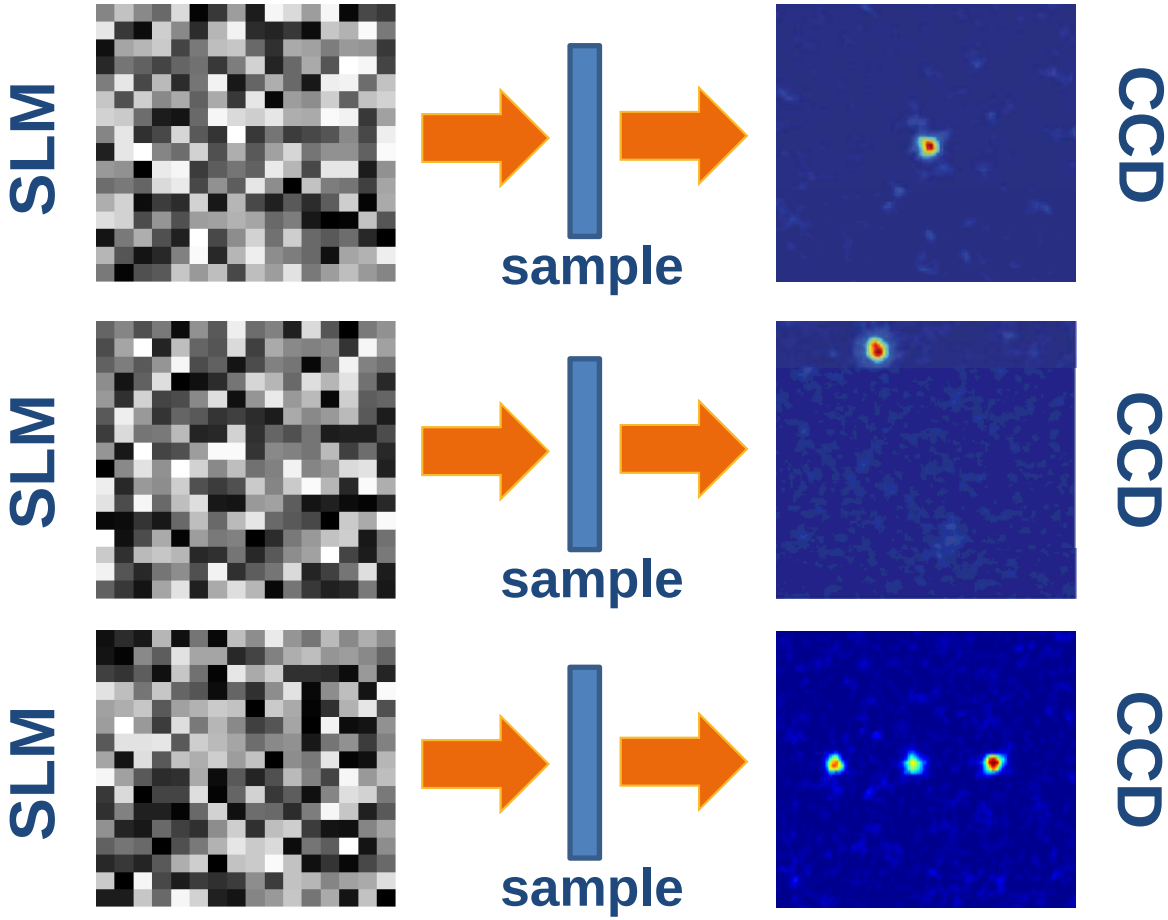
→ Measurement possible, permitting : focusing / image reconstruction

S. M. Popoff, G. Lerosey, R. Carminati, M. Fink, A. C. Boccara, S. Gigan, Phys. Rev. Lett. 104, 100601 (2010)

Two ways to achieve focusing : transmission matrix



Plane wave illumination

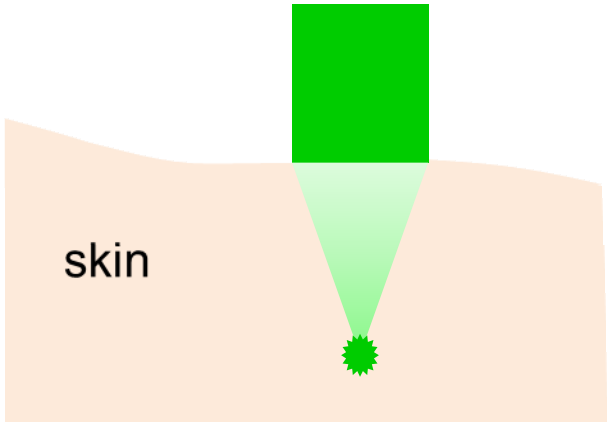


S. M. Popoff, G. Lerosey, R. Carminati, M. Fink, A. C. Boccara, S. Gigan, Phys. Rev. Lett. 104, 100601 (2010)

Focusing in biological tissues

→ biological tissues are multiply scattering media:

→ Is it possible to focus inside ?



- Light delivery :
  - destruction of localized tissues (e.g. cancerous cells)
  - excitation of specialized molecules so that they would be able to deliver drugs *in situ* or be activated at the right place
- Non-invasive imaging inside tissues

Why is it not already done ?

Focusing in biological tissues

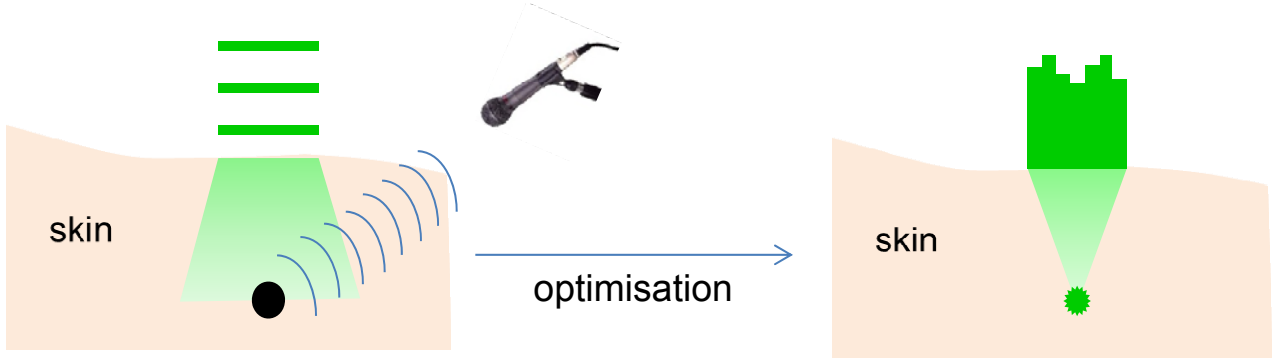
Problems :

❖ Not possible to use a camera

→ Need for a beacon/artificial star that we can optimize on :

- With sound : *e.g.* photo-acoustic
- in light : *e.g.* fluorescence

for example :



❖ Living tissues, a continuously evolving media

Decoherence time ~ 1-10 ms → necessity to optimize within this time

Phase control devices

Spatial light modulator (SLM)
(liquid cristals)

>1 million of pixels
stroke : 1 microns
frame rate : 50Hz

↓

too slow

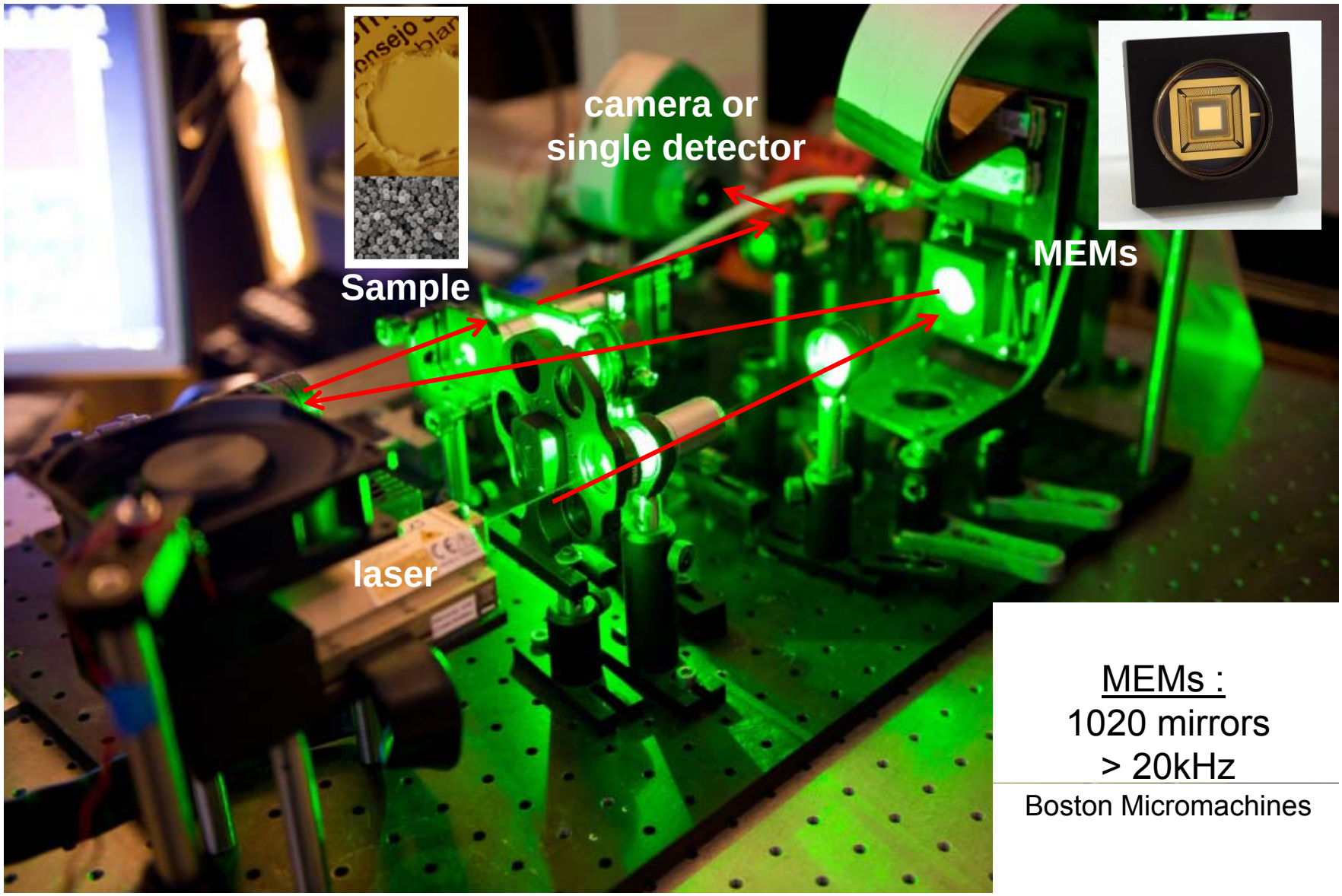
Deformable mirrors
(piezo actuators, magnetic, electric …)

continuous or **segmented**
max ~ thousands actuators
stroke : typ tens microns
frame rate > kHz

↓

our solution

Experimental setup



MEMs :
1020 mirrors
> 20kHz

Boston Micromachines

Conclusions and perspectives

- Focusing through a complex medium

- Possibility to overcome beer-Lamber law to achieve focusing and imaging beyond a strongly scattering medium

- Closed-loop control for focusing by optimization : the premises

  - feedback given by a single detector (photomultiplier)

  - currently: acquisition through a PC mezzanine DAQ card

→ acquisition rate too slow for the moment … latency of 10 ms …

→ Limited calculation required but high speed closed-loop necessary
Is FPGA a solution ?
Can your community help?

The team - acknowledgments

The team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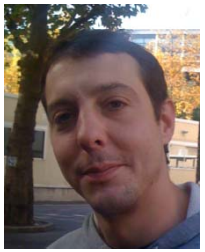
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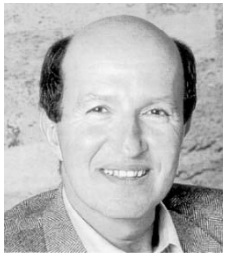
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collaborations

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