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Introduction to Optofluidics

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Digital in-line holographic microscopy: an alternative tool to visualization of microfluidics

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Digital In-line Holographic Microscopy: an alternative tool to visualization of microfluidcs

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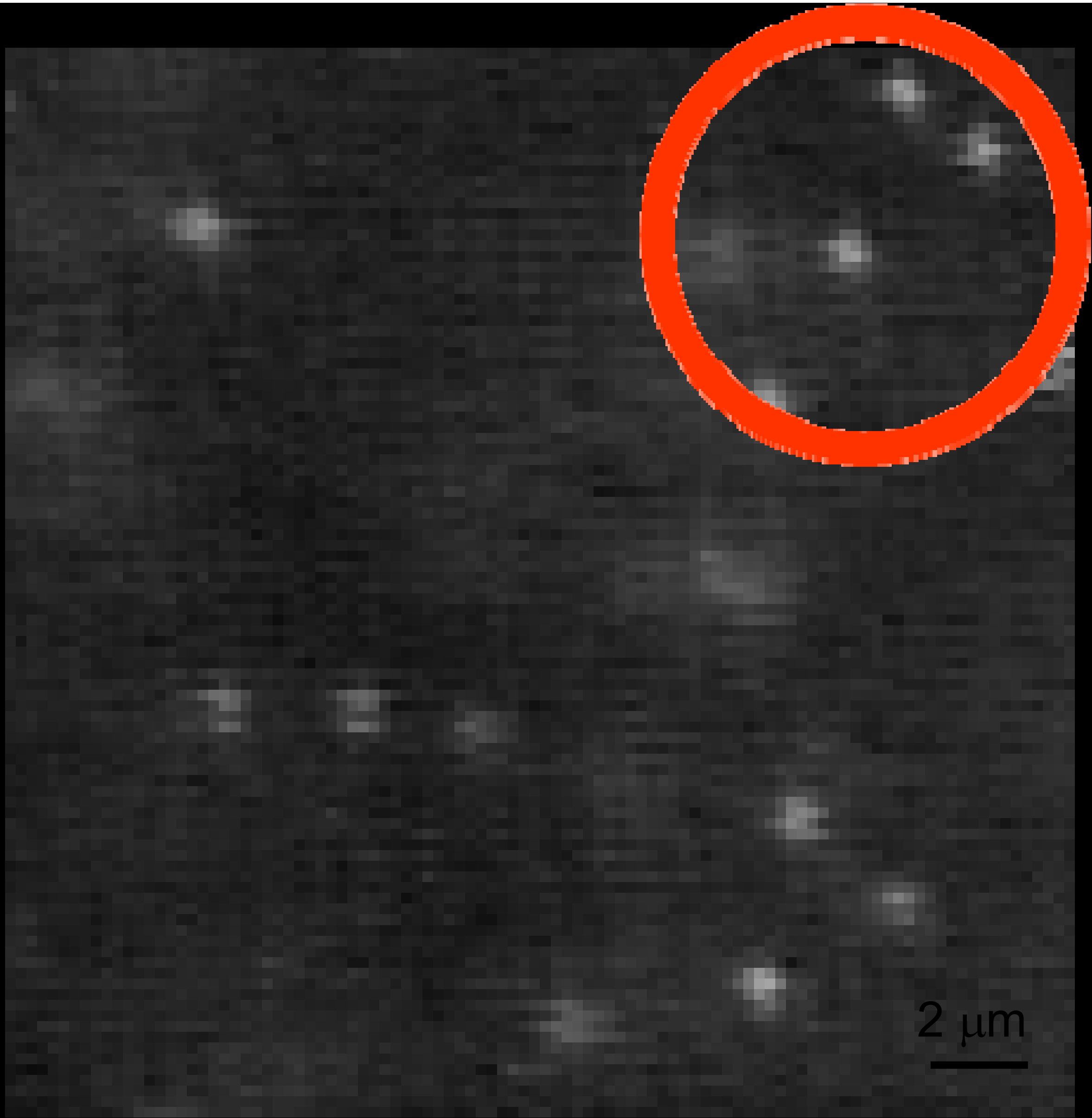
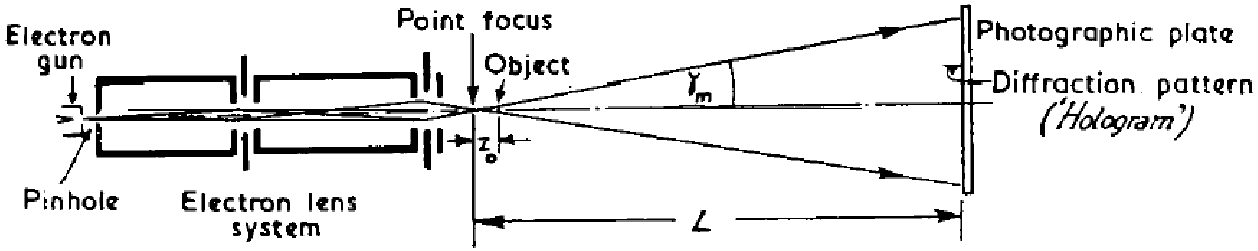
Introduction to Optofluidics
ICTP, Trieste 2009



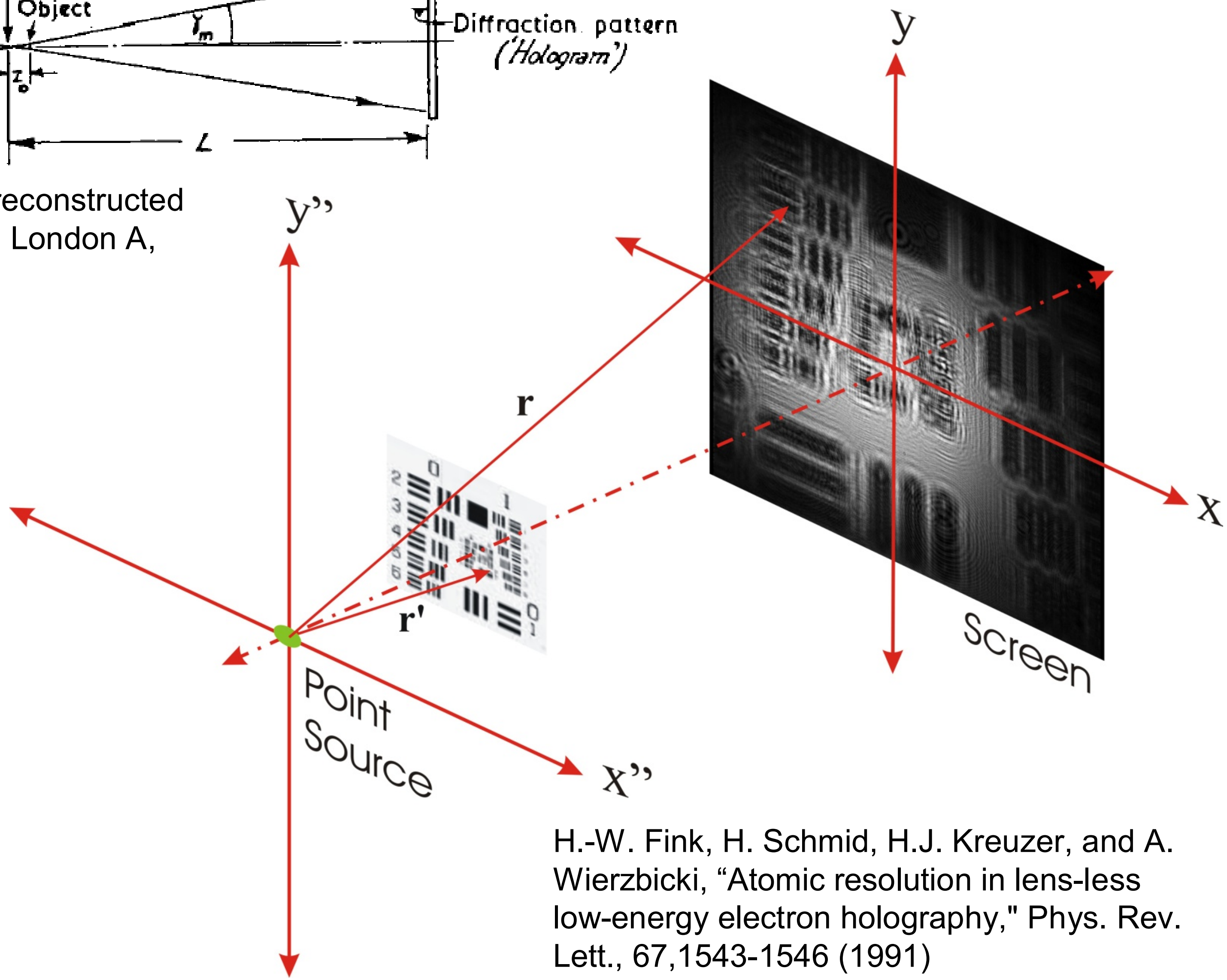
Optical microscopy.
60X microscope objective. Depth of field 0.4 μm

DIGITAL IN-LINE HOLOGRAPHIC MICROSCOPY

- Recording



D. Gabor, "Microscopy by reconstructed wave-fronts," Proc. R. Soc. London A, 197, 454, (1949)



H.-W. Fink, H. Schmid, H.J. Kreuzer, and A. Wierzbicki, "Atomic resolution in lens-less low-energy electron holography," Phys. Rev. Lett., 67,1543-1546 (1991)

DIGITAL IN-LINE HOLOGRAPHIC MICROSCOPY

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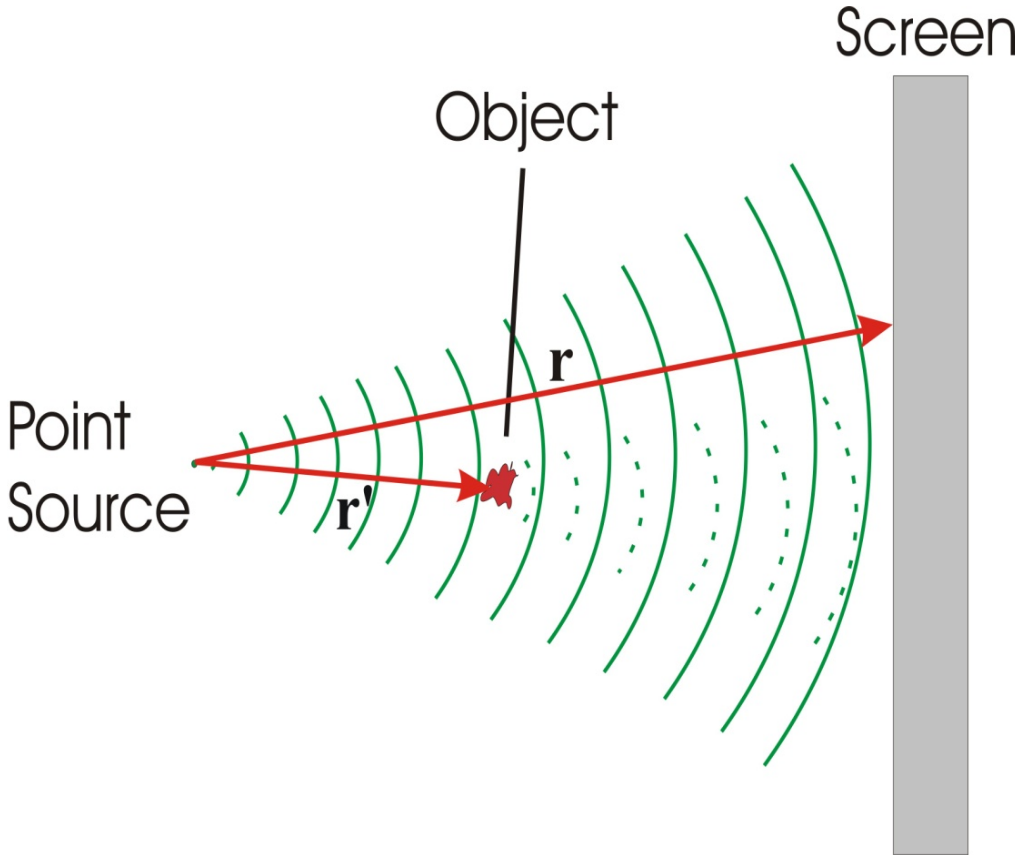


$$I(\mathbf{r}) = \left| A_{ref}(\mathbf{r}) + A_{scat}(\mathbf{r}) \right|^2$$

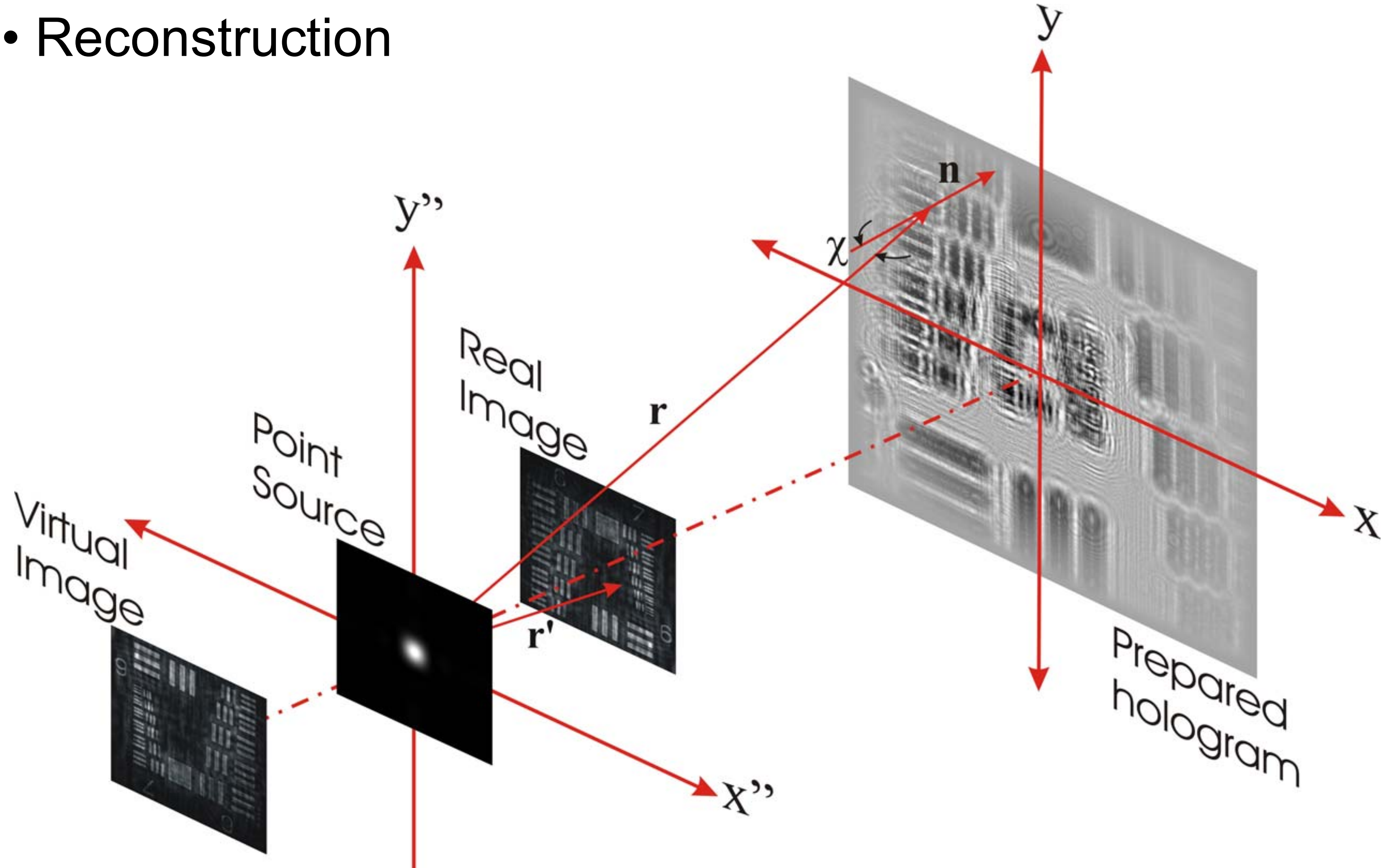
Prepared hologram

$$\tilde{I}(\mathbf{r}) = I(\mathbf{r}) - \left| A_{ref}(\mathbf{r}) \right|^2$$

$$\tilde{I}(\mathbf{r}) = [A^*_{ref}(\mathbf{r}) A_{scat}(\mathbf{r}) + A_{ref}(\mathbf{r}) A^*_{scat}(\mathbf{r})] + \left| A_{scat}(\mathbf{r}) \right|^2$$

DIGITAL IN-LINE HOLOGRAPHIC MICROSCOPY

- Reconstruction

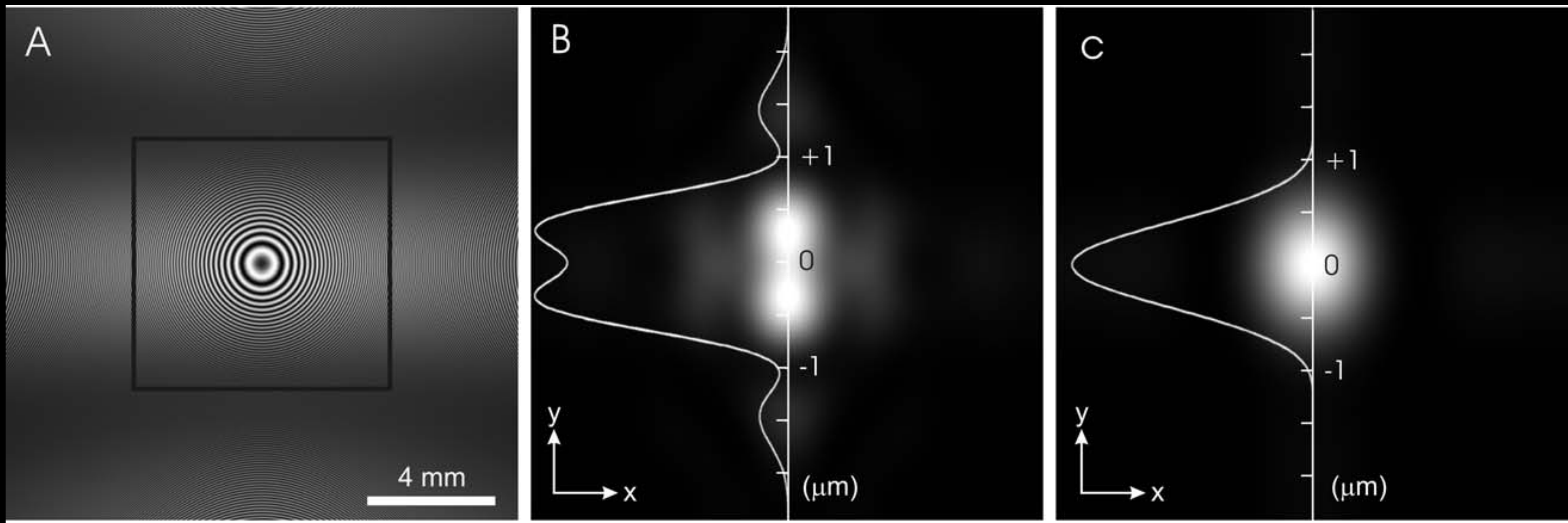


$$A_{scat}(\mathbf{r}') = -\frac{iA_{ref}}{r\lambda} \iint_{Screen} \tilde{I}(\mathbf{r}) \frac{\exp\left[ik\frac{|\mathbf{r}\cdot\mathbf{r}'|}{r}\right]}{|\mathbf{r}-\mathbf{r}'|} dS_{\mathbf{r}}$$

Kirchhoff-Helmholtz transform.

DIGITAL IN-LINE HOLOGRAPHIC MICROSCOPY

- Lateral Resolution



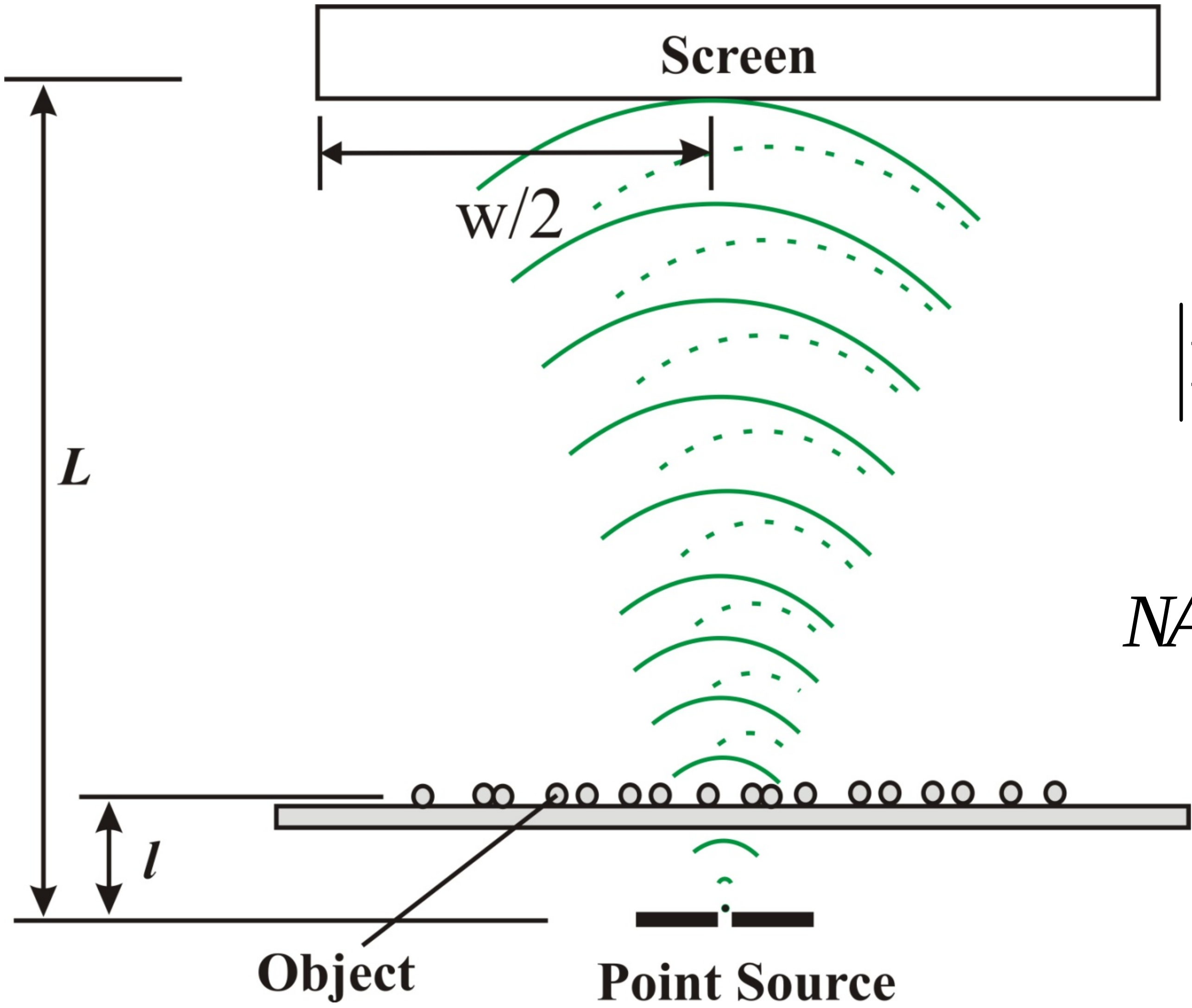
Test of lateral resolution. A: simulated hologram of two points close to the optical axis and 0.8 μm apart, taken with a blue laser λ=4730Å with an aperture of 0.5 (0.28 for the inner square). B: reconstruction from the full hologram with the insert showing submicron resolution. C: the same for the smaller hologram losing resolution.

$$\left|\mathbf{r}_2 - \mathbf{r}_1\right| \geq \frac{\lambda}{2NA}$$

J. Garcia-Sucerquia, et. al. “Digital In-line Holography Microscopy,” Appl. Opt. **45**, 836-850 (2006) .

DIGITAL IN-LINE HOLOGRAPHIC MICROSCOPY

- Lateral Resolution



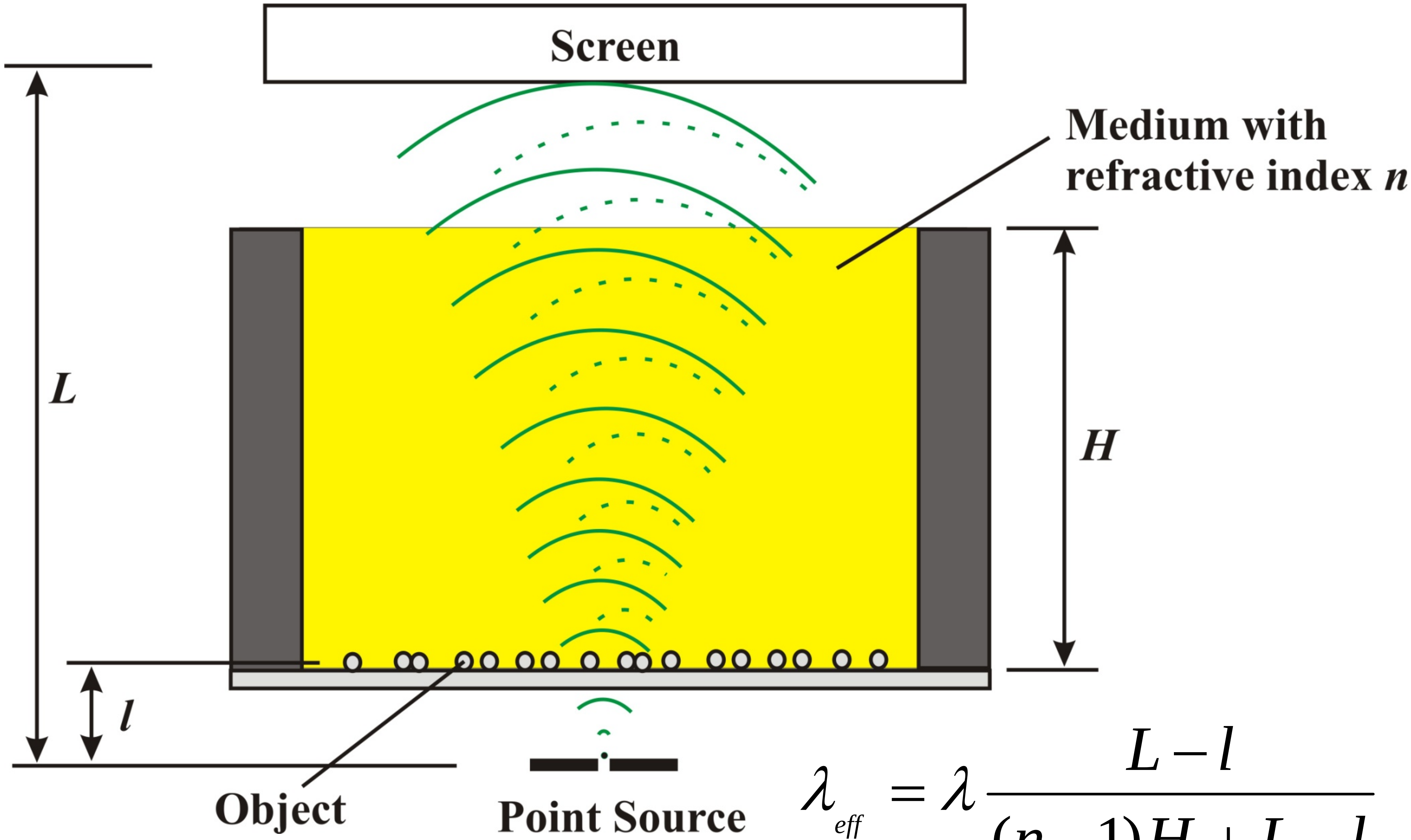
$$|\mathbf{r}_2 - \mathbf{r}_1| \geq \frac{\lambda}{2NA}$$

$$NA = \frac{W}{2\sqrt{(W/2)^2 + L^2}}$$

J. Garcia-Sucerquia, et. al. “Digital In-line Holography Microscopy,” Appl. Opt. **45**, 836-850 (2006)

DIGITAL IN-LINE HOLOGRAPHIC MICROSCOPY

- Enhancement of Lateral Resolution

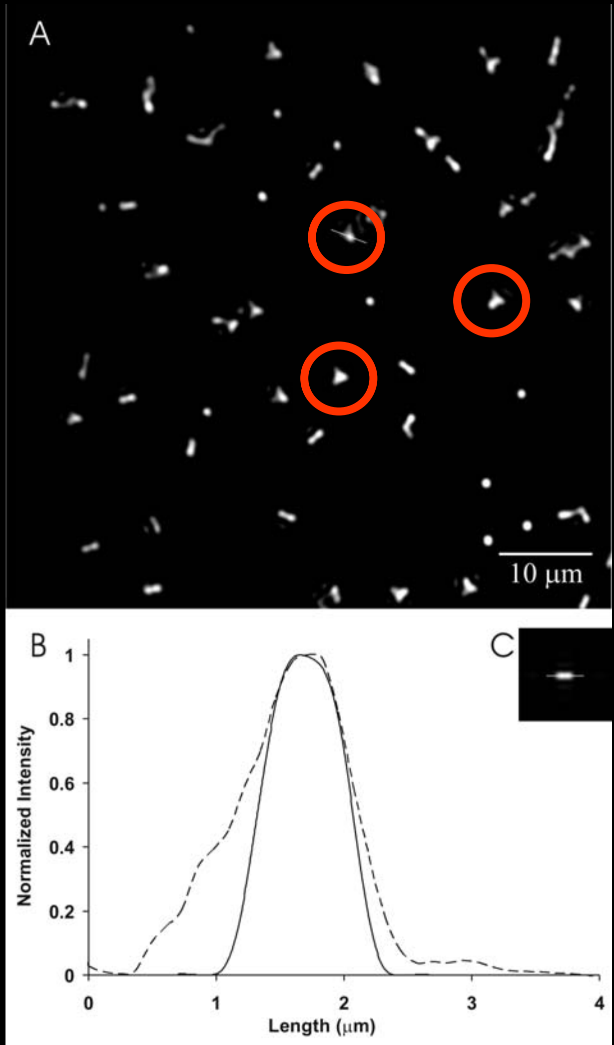


$$\lambda_{eff} = \lambda \frac{L-l}{(n-1)H + L - l}$$

J. Garcia-Sucerquia, et. al. “Immersion Digital In-line Holography Microscopy,” Opt. Lett. **31**, 1211-1213 (2006)

DIGITAL IN-LINE HOLOGRAPHIC MICROSCOPY

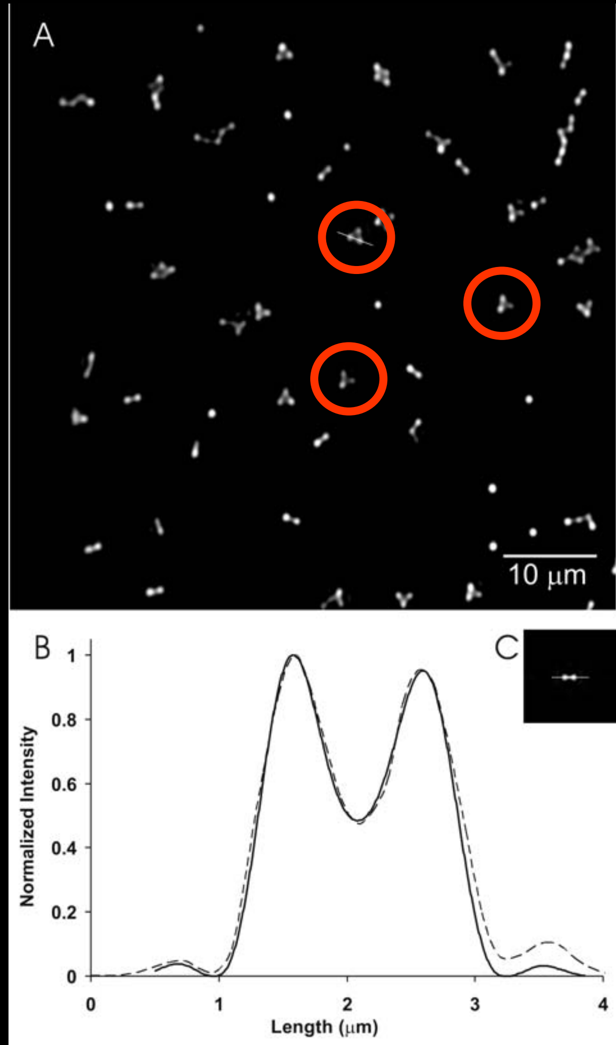
- Enhancement of Lateral Resolution



Empty chamber (n=1, H= 0 mm, λ_{eff}= 532 nm)

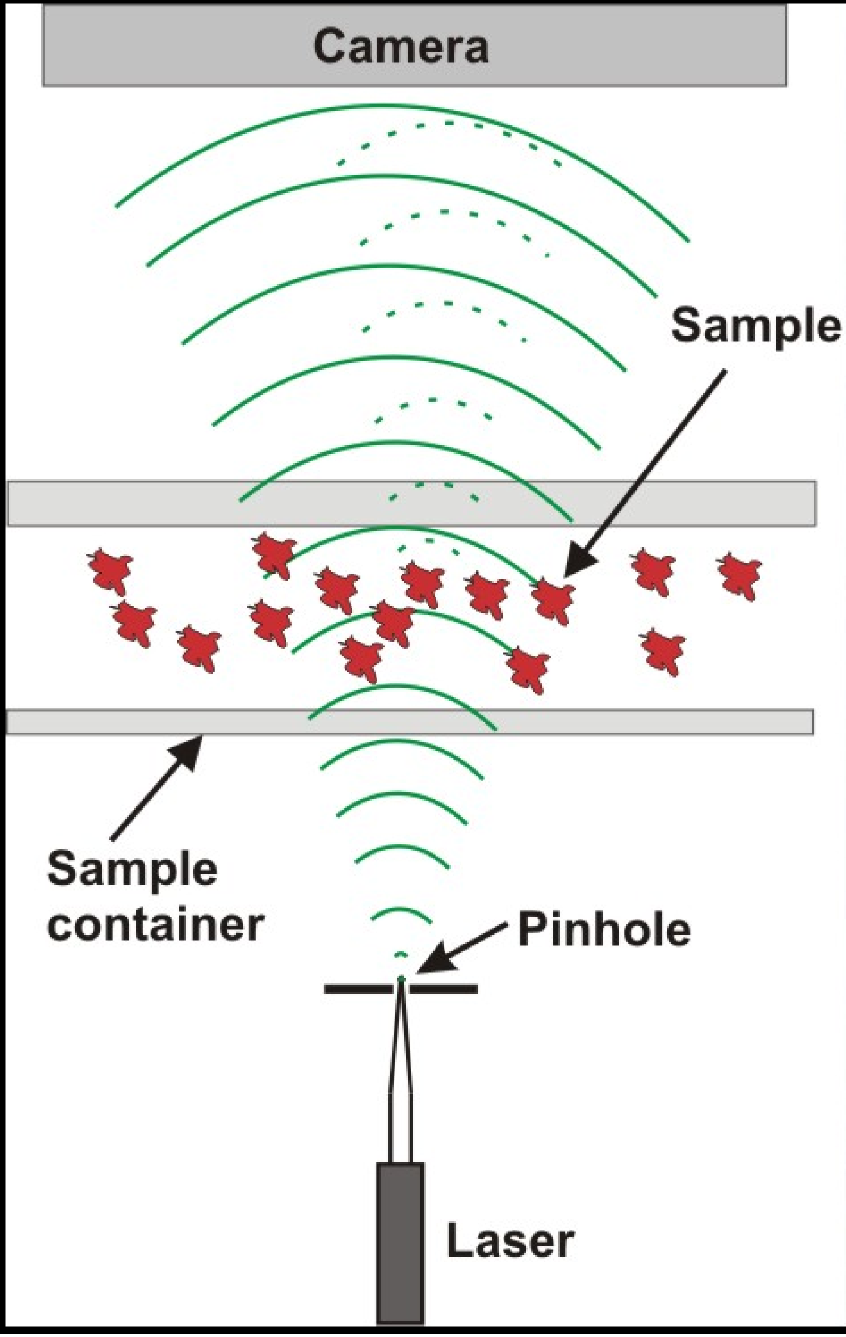
1.09 µm diameter latex beads on a cover slip.
λ=532 nm
L=15 mm
l=0.3 mm

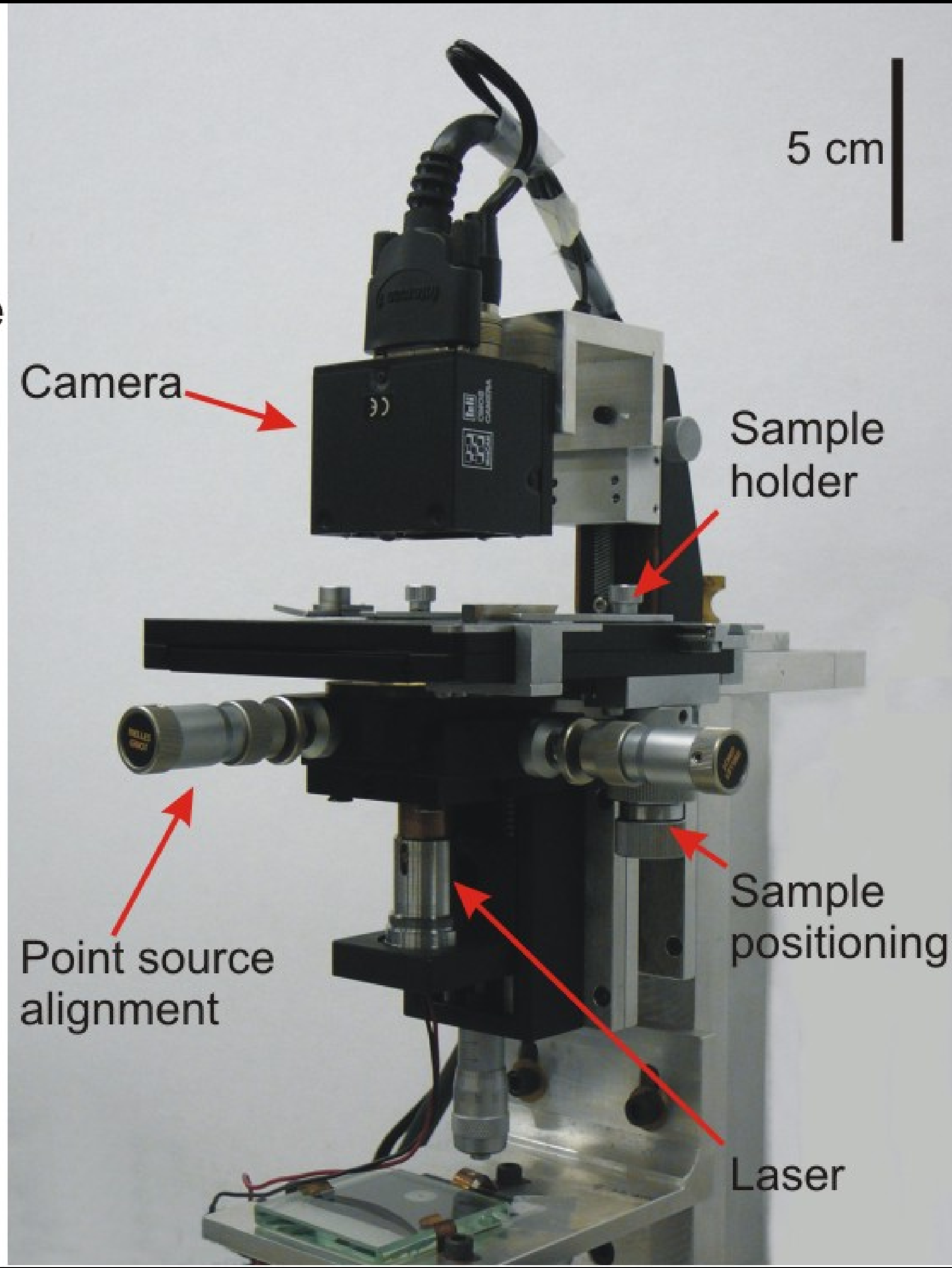
J. Garcia-Sucerquia, et. al. "Immersion Digital In-line Holography Microscopy," Opt. Lett. **31**, 1211-1213 (2006)



Chamber with oil (n=1.515, H= 12 mm, λ_{eff}= 374 nm)

THE ACTUAL IMPLEMENTATION

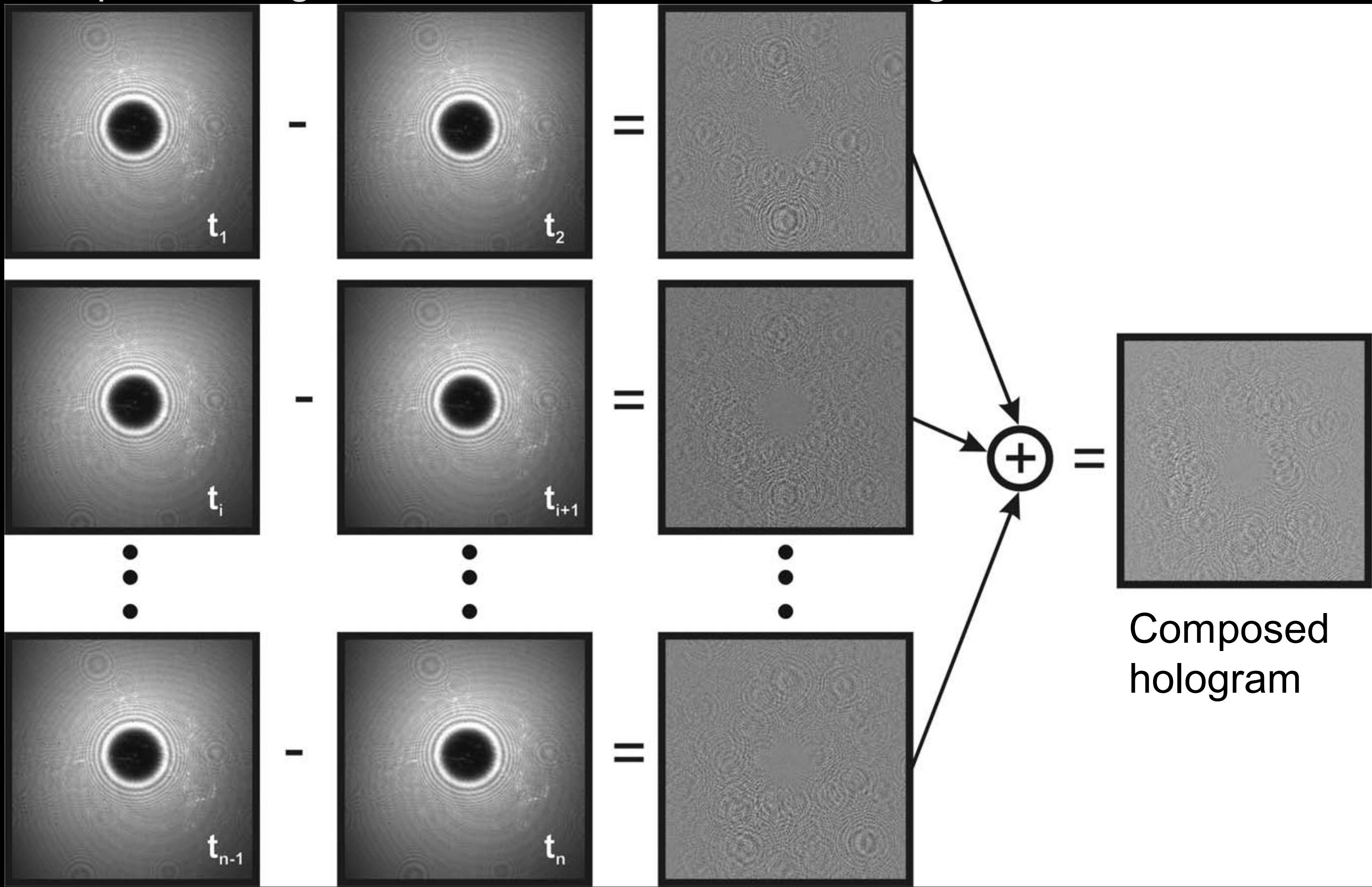




APPLICATIONS

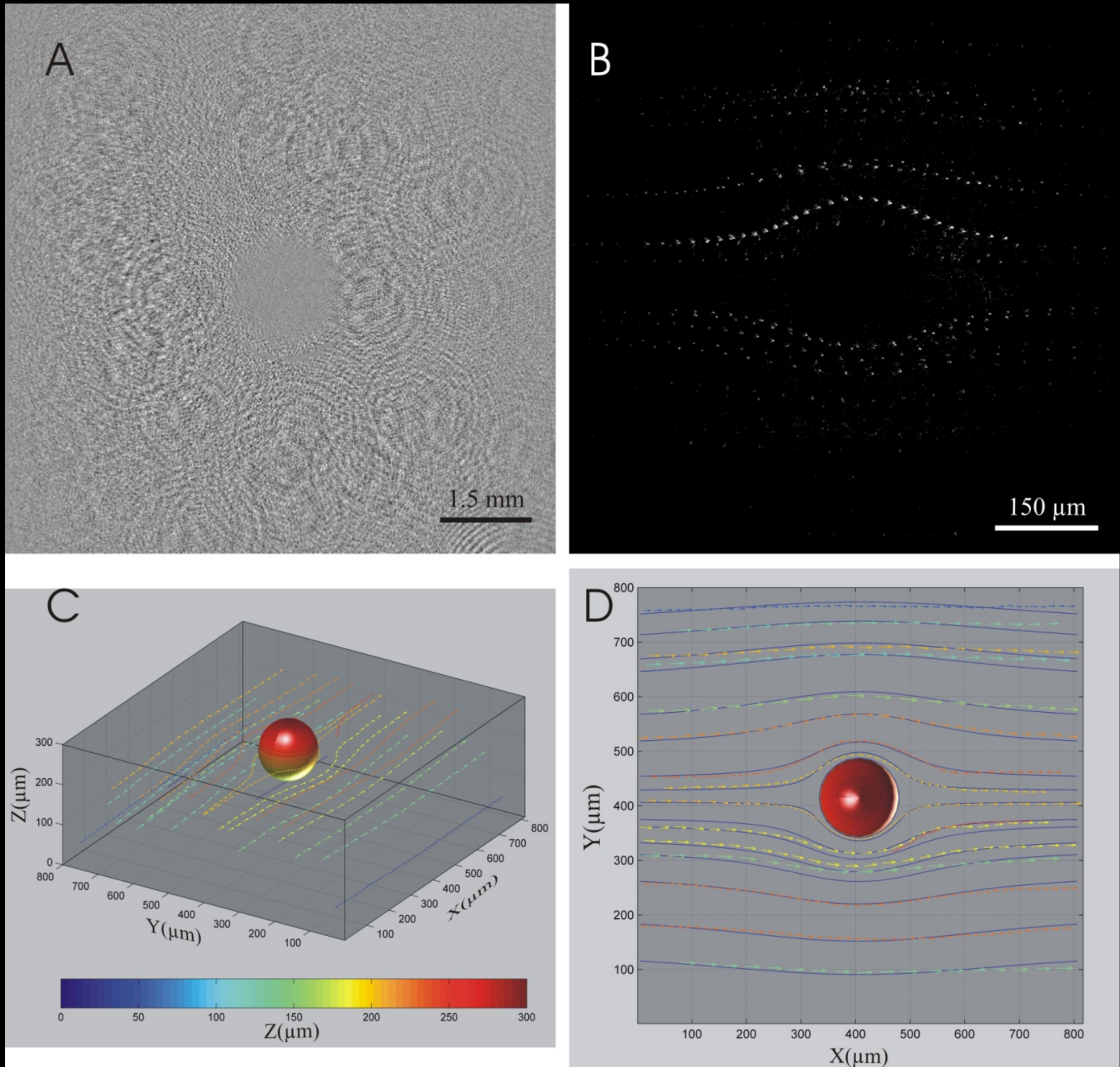
- Four dimensional tracking in micro-channels

Acquired holograms Difference holograms



APPLICATIONS

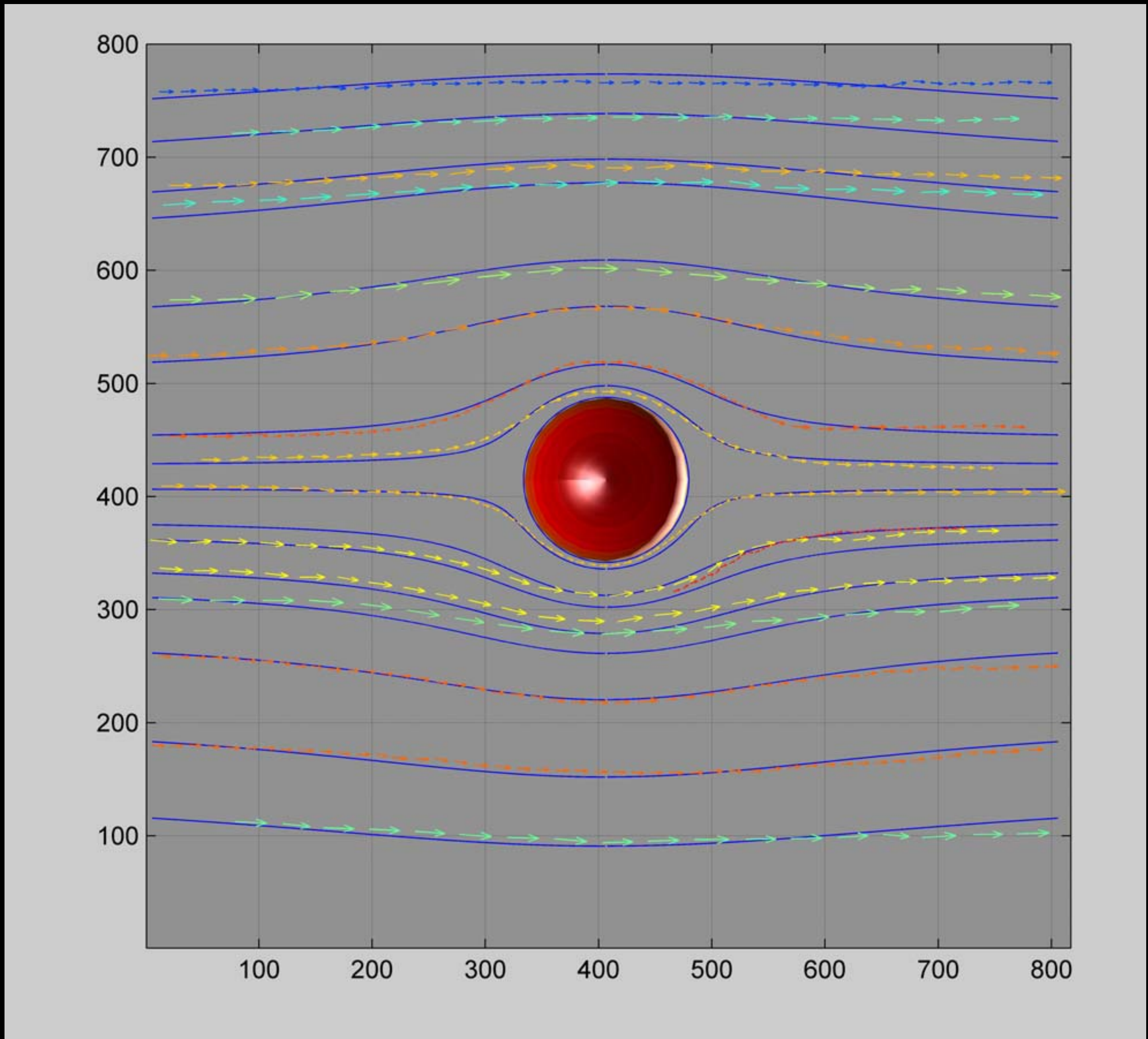
- Microfluidic Studies



Stokes' flow around a fixed sphere. 60 holograms were taken at intervals of 0.17 s to generate a difference hologram, panel A. Panel B shows one of 60 reconstructions made to render the field velocity shown in panel C. In panel D the solid blue lines represent the solution to the Navier-Stokes equation for our experiment and the arrows correspond to the measured velocity field.

APPLICATIONS

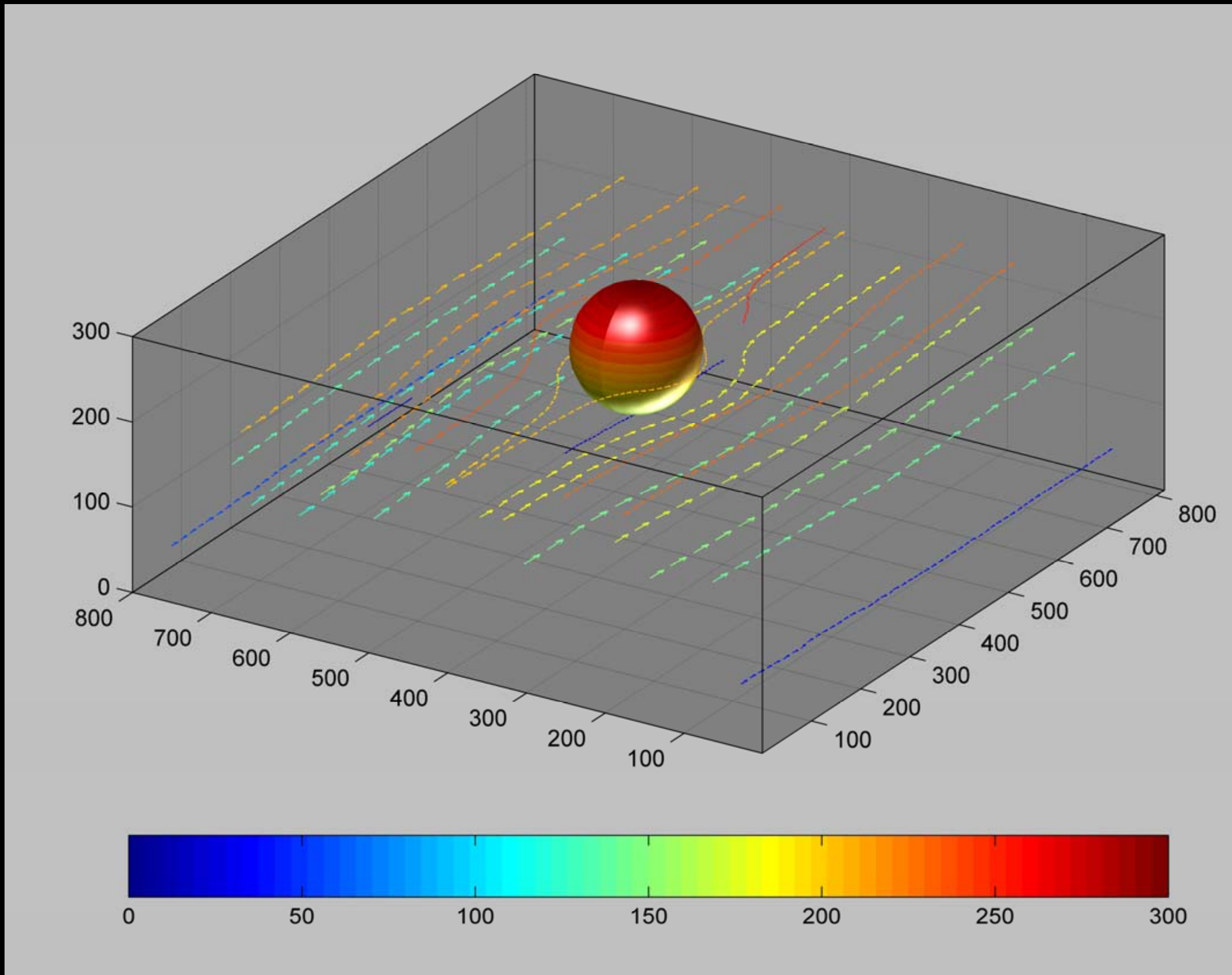
• Microfluidic Studies



The solid blue lines represent the solution to the Navier-Stokes equation for our experiment and the arrows correspond to the measured velocity field.

APPLICATIONS

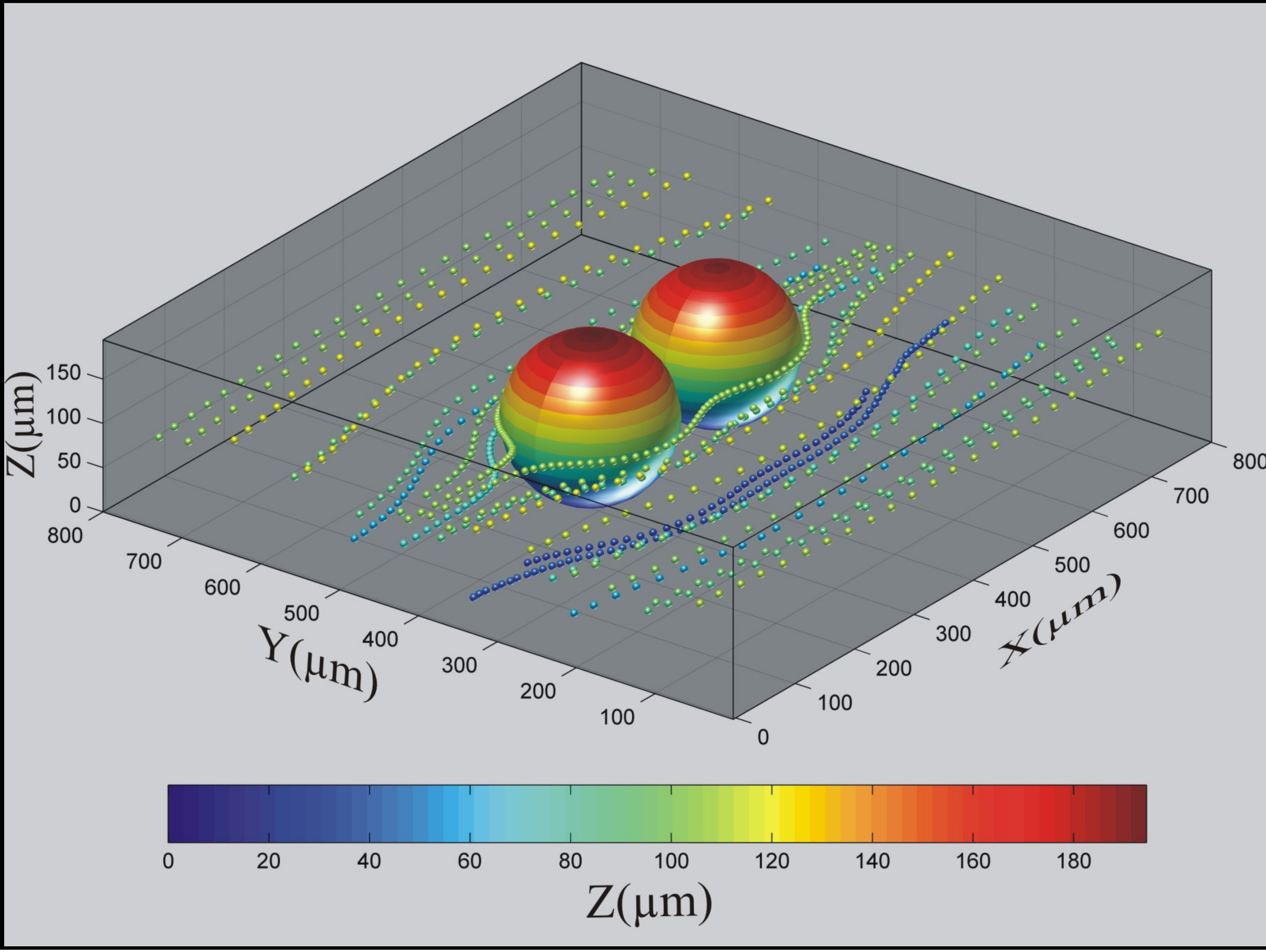
- Microfluidic Studies

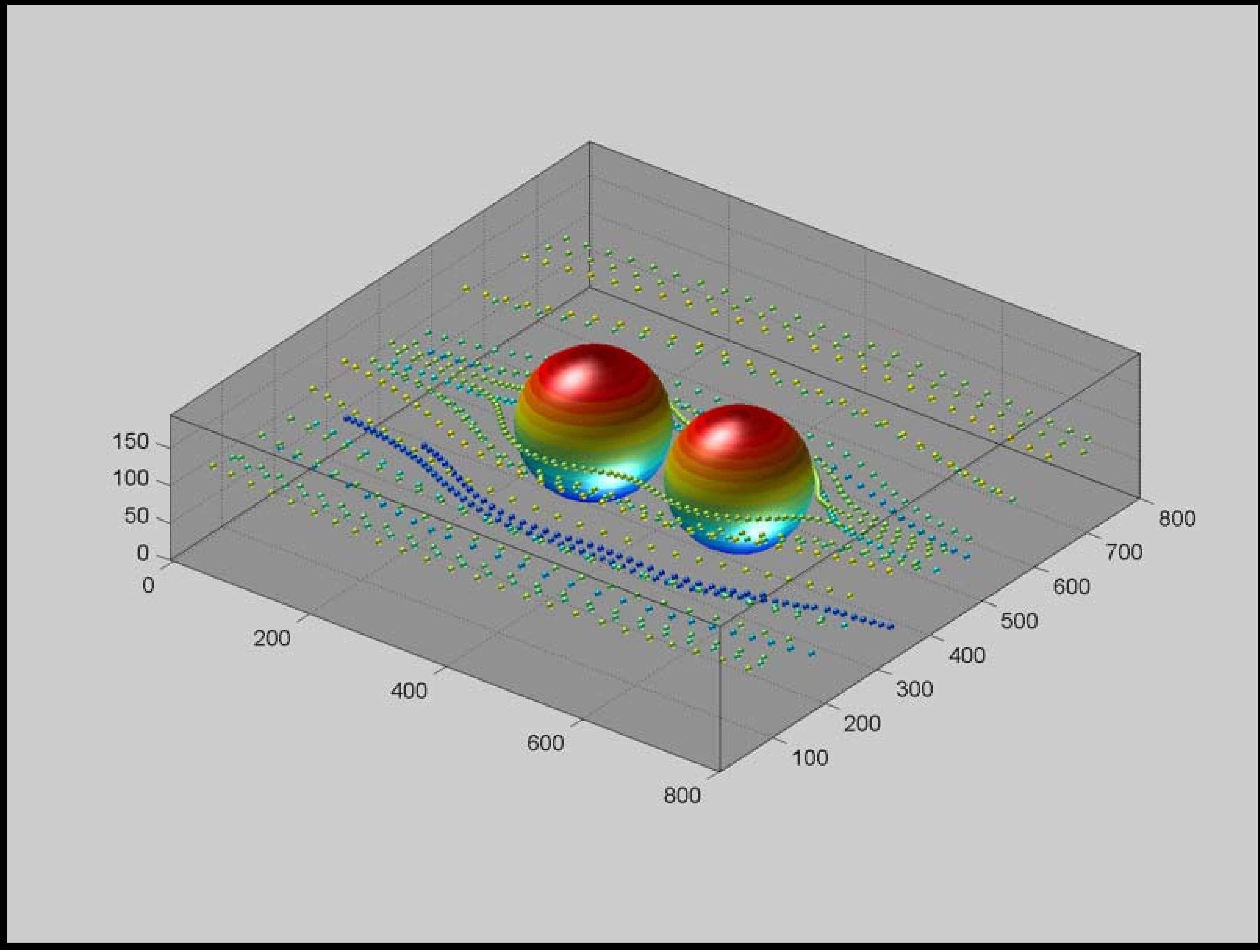


Velocity field rendered from the reconstruction of the 60 holograms.

APPLICATIONS

- Microfluidc studies




150
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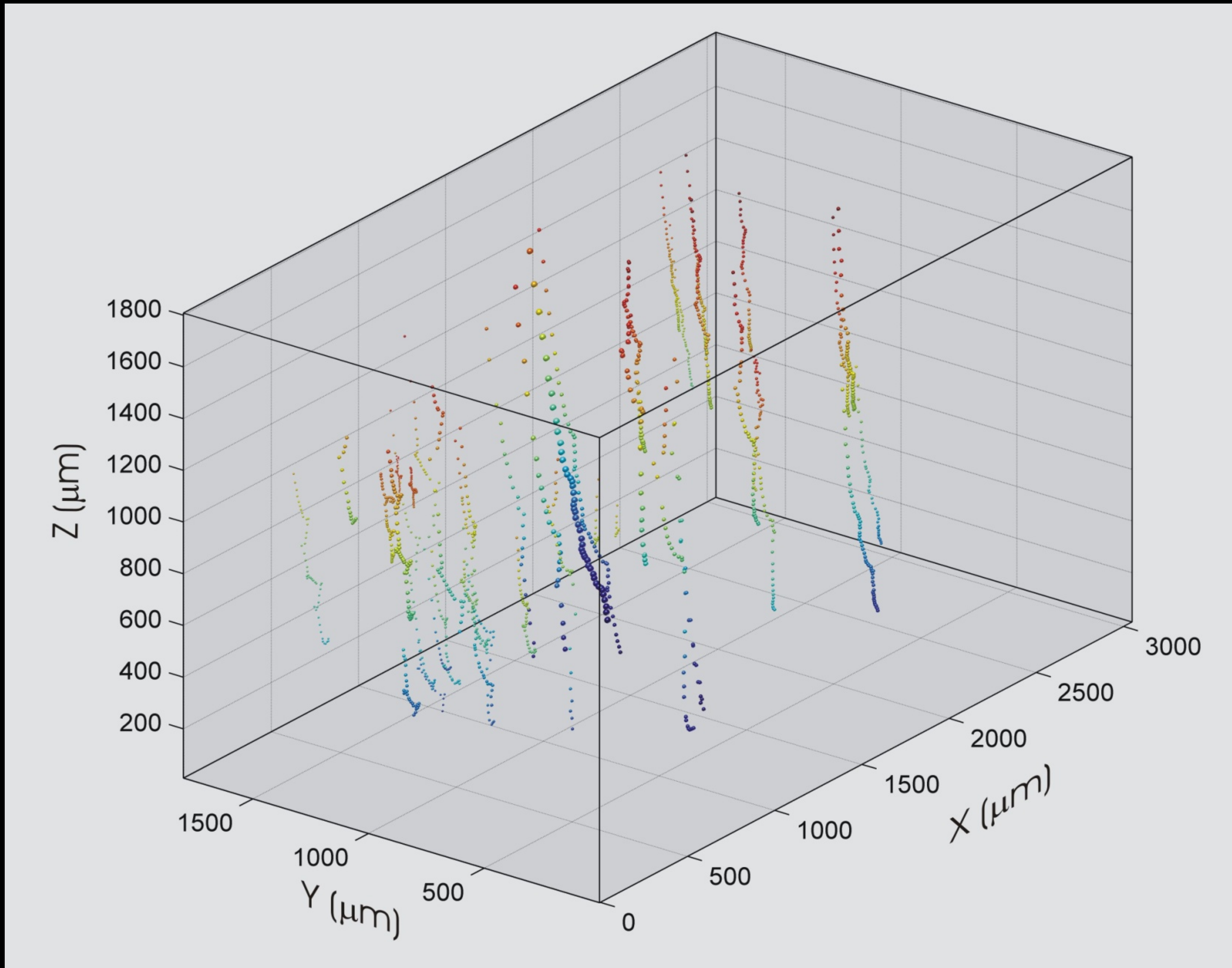
700
800

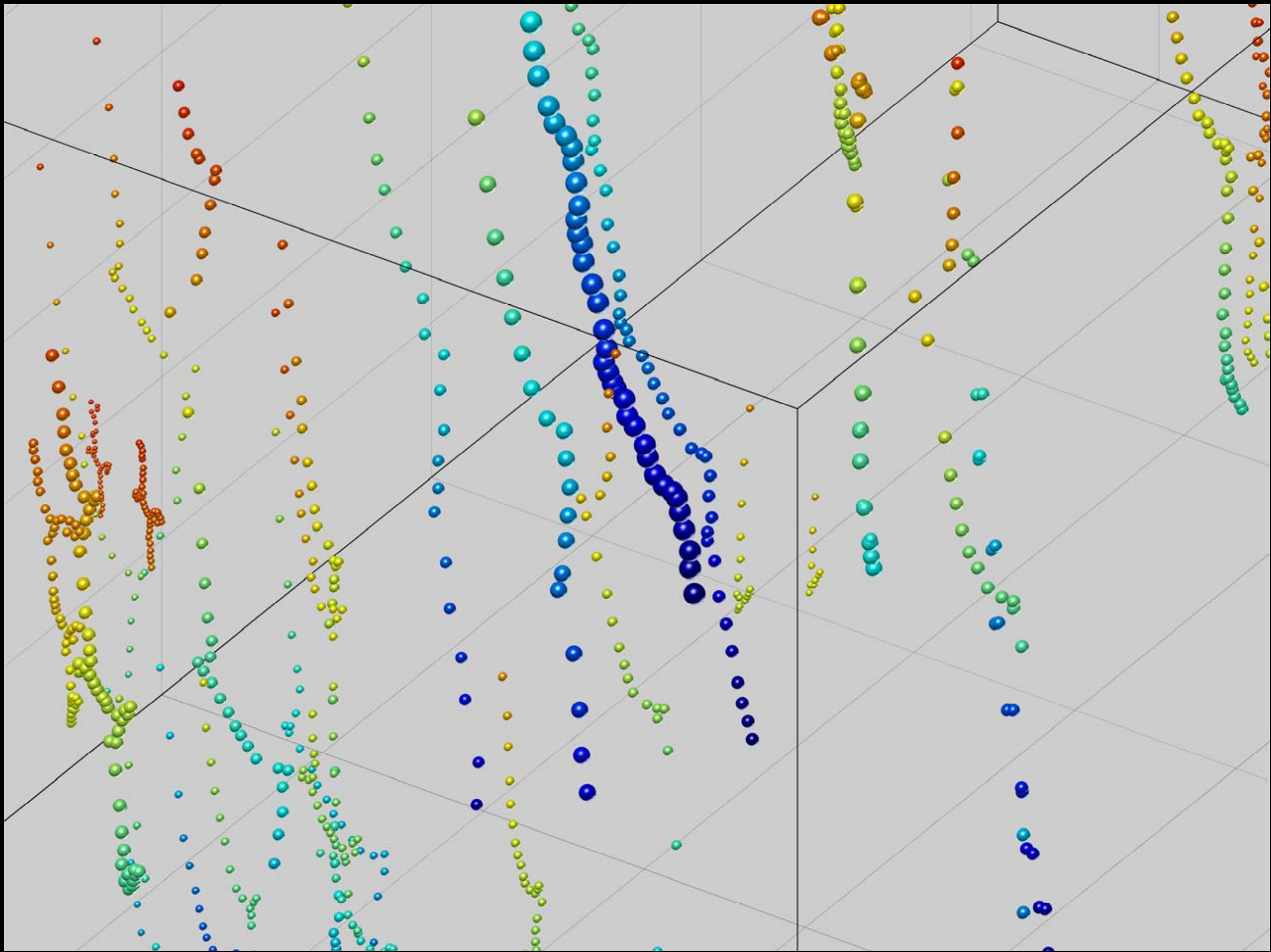
APPLICATIONS

- Four dimensional bubble convection tracking



APPLICATIONS

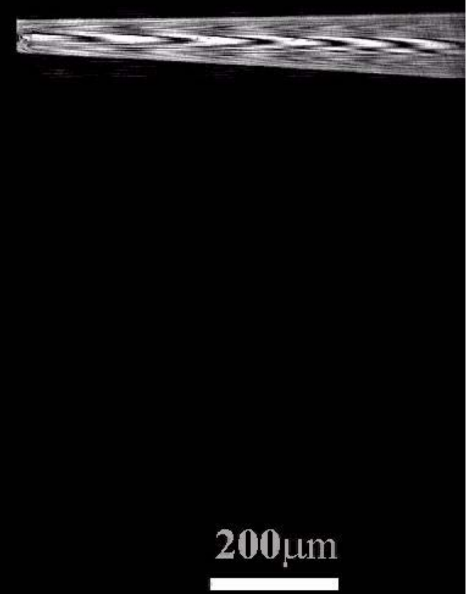
- Four dimensional bubble convection tracking



APPLICATIONS

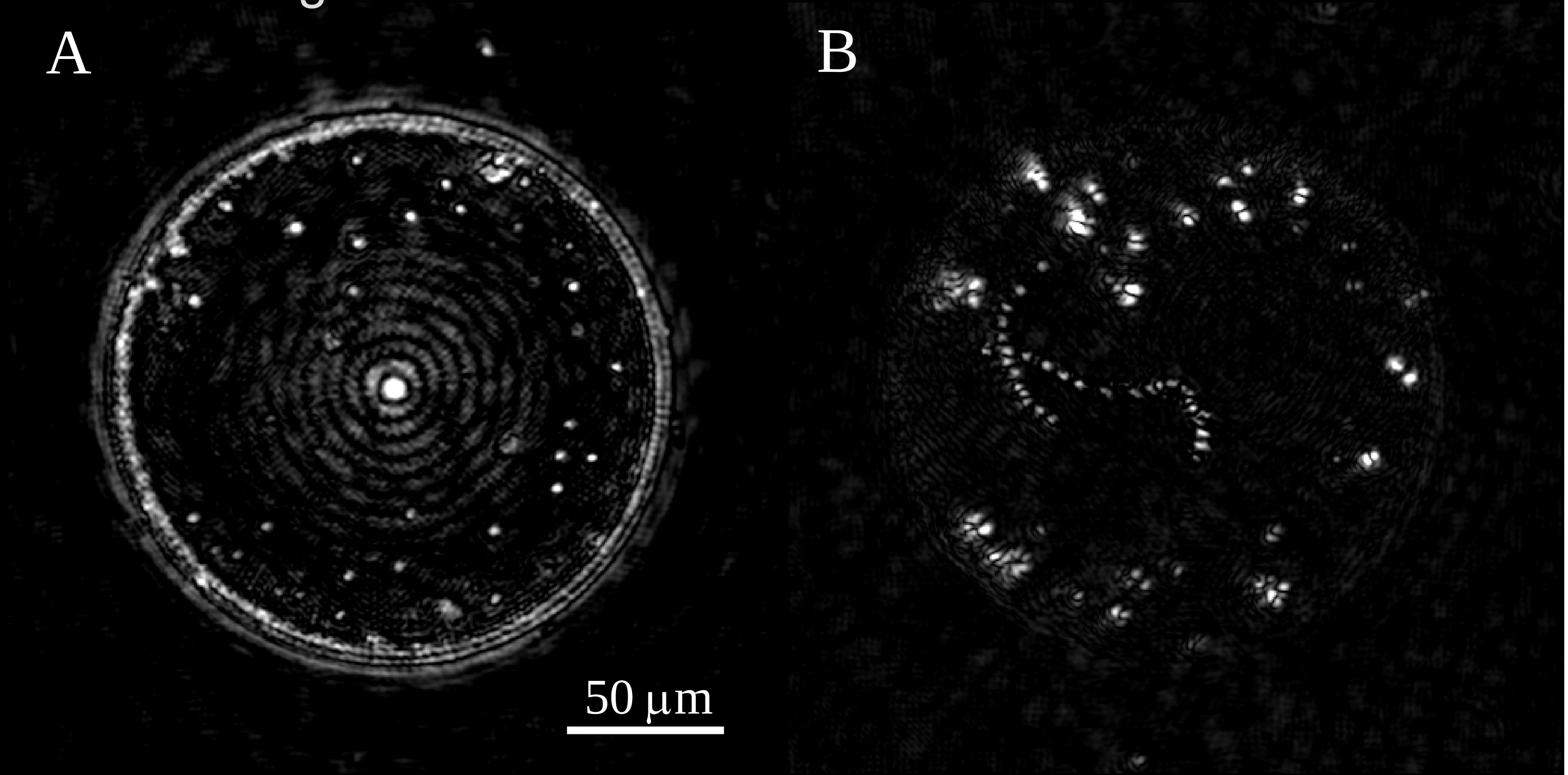
- Watching Triton® X-100 injection into water

Triton® X-100 oil viscosity = 240 cP. 270 times larger than water



APPLICATIONS

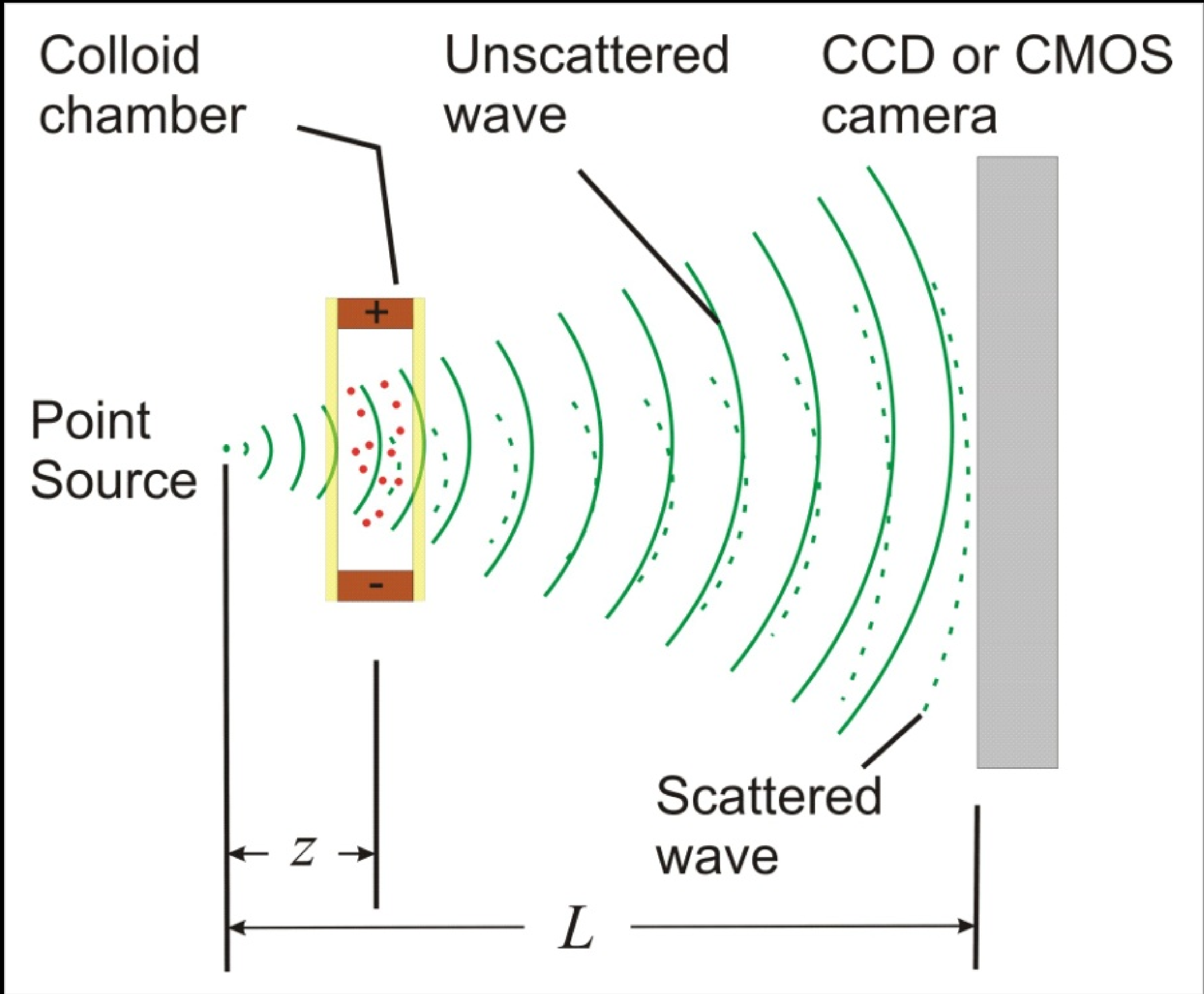
- Watching inside cells



Bacteria in a diatom (coscinodiscus wailesii). A: reconstruction from one hologram showing the siliceous outer shell with labiate processes (bright spots). B: reconstruction from a composed hologram. green laser, 0. 5 μM pinhole, pinhole to sample (diatom) 1 mm and numerical aperture of 0.22.

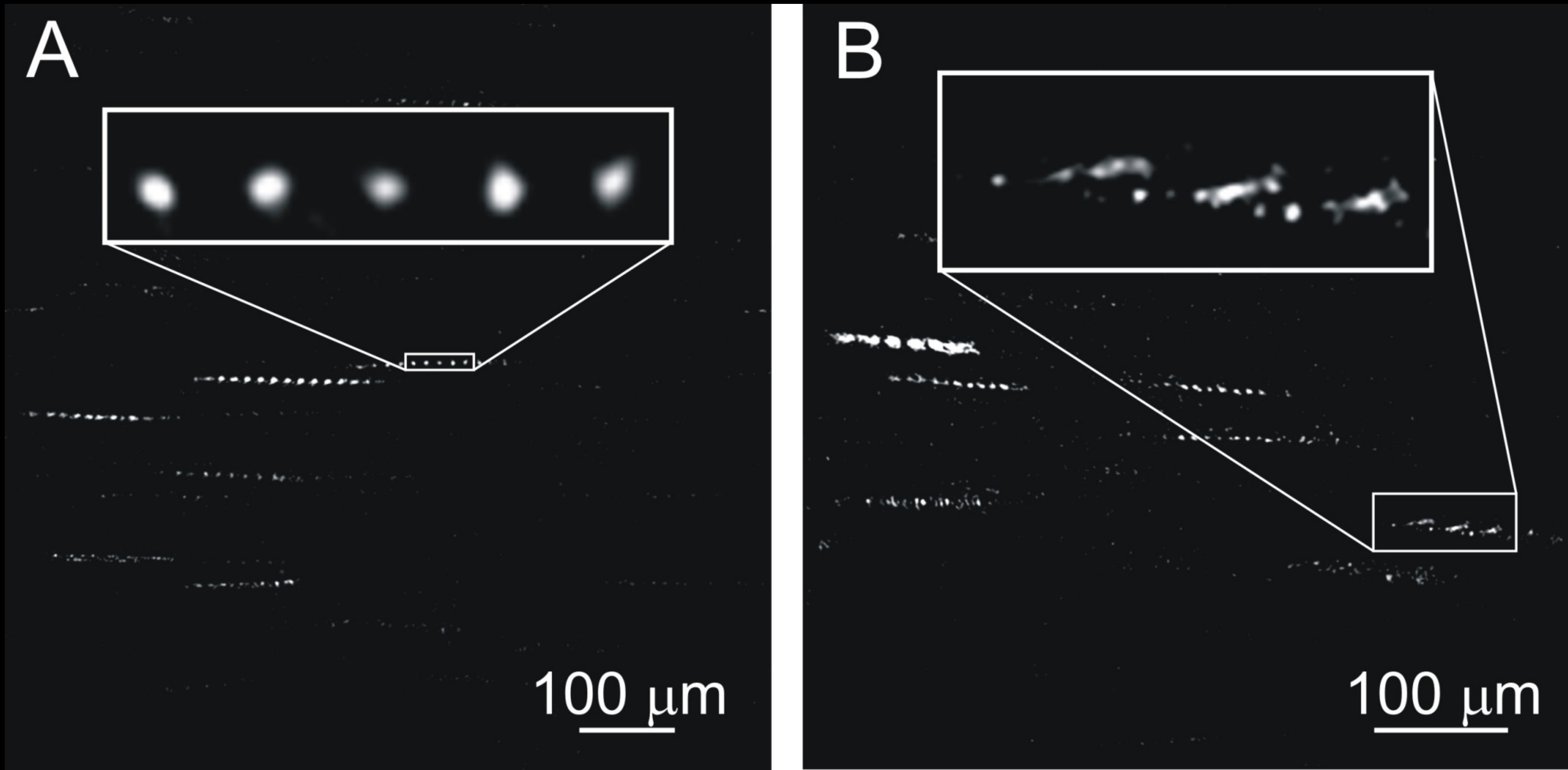
APPLICATIONS

- Electrokinetic studies



APPLICATIONS

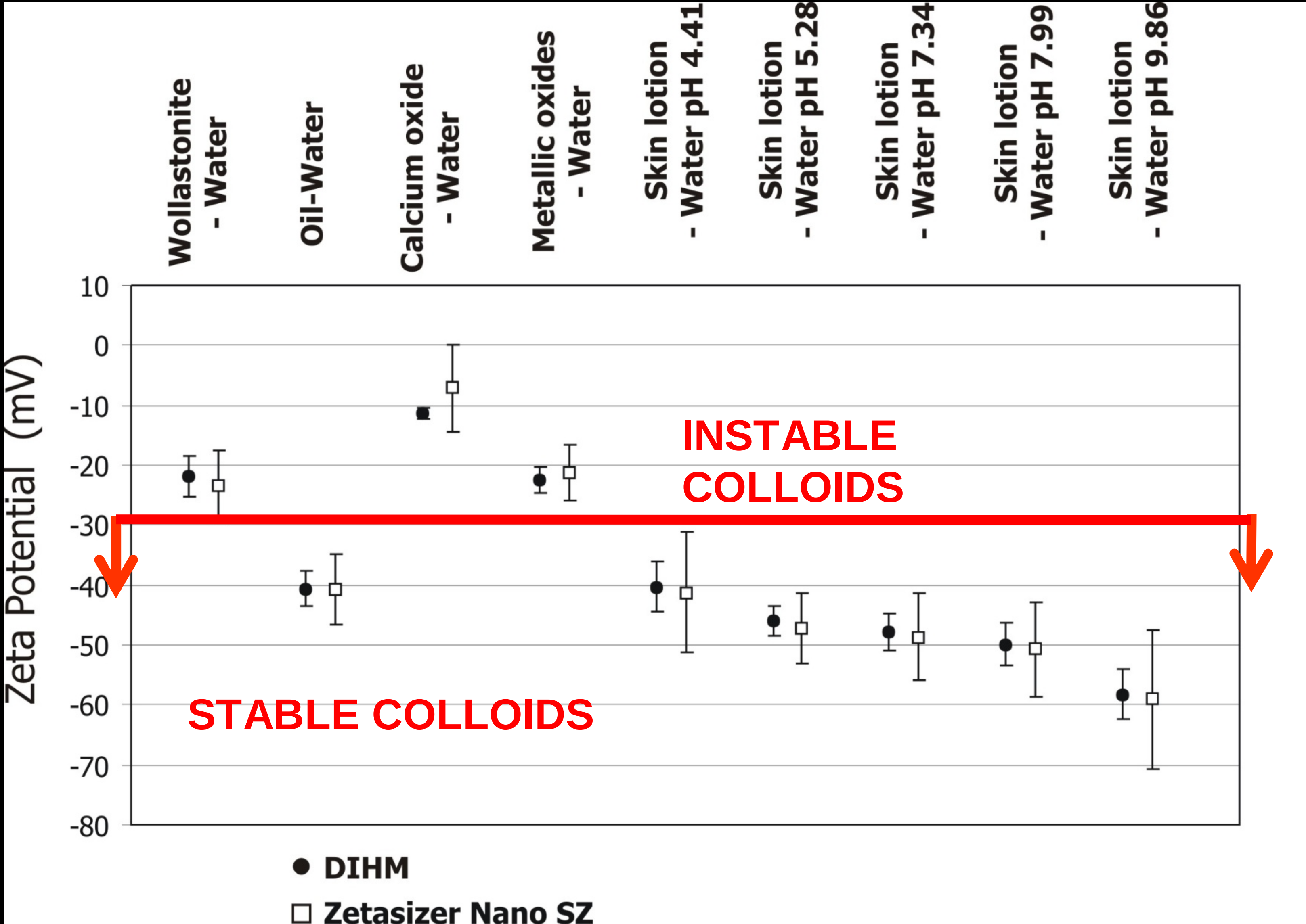
- Electrokinetic studies



Trajectories for particles of different shapes and sizes. Averaging over samples leads to an electrophoretic velocity of (10.1 ± 0.3) μm/s. The individual tracking of particles allows one studying multi- dispersed colloids.

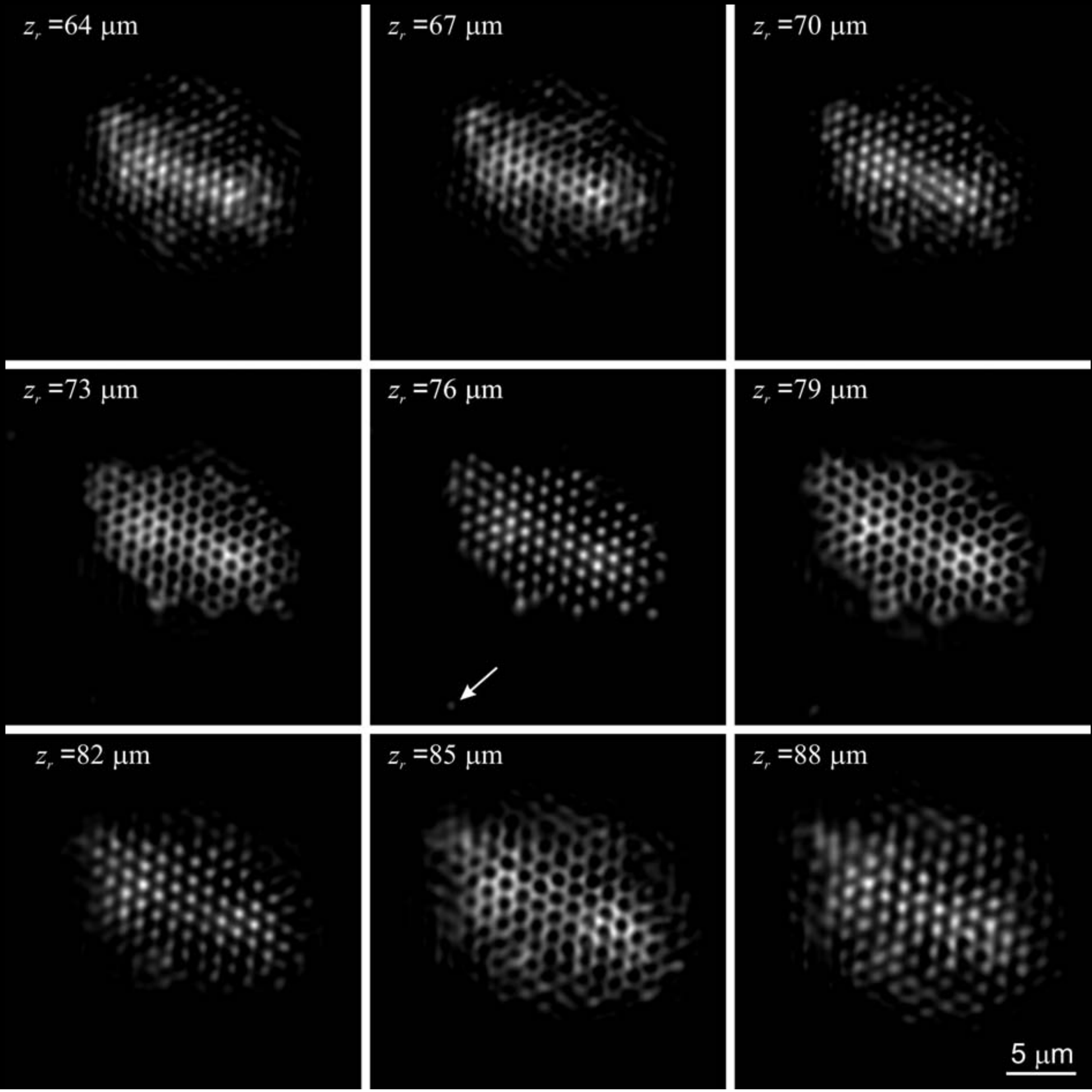
APPLICATIONS

- Electrokinetic studies. Result comparison between DIHM and a commercial equipment



APPLICATIONS

- Talbot effect of self-organised monolayers



For a two-dimensional array that follows:

$$P_x / P_y = \sqrt{n_1 / n_2}$$

the Talbot distance is

$$Z_T = \nu \, 2 a^2 / \lambda$$

J. Garcia-Sucerquia, et. al., "High resolution Talbot self-imaging applied to structural characterization of self-assembled monolayers of microspheres", Appl. Opt. **47**, 4723-4728 (2008)

SUMMARY

•GABOR'S INVENTION OF HOLOGRAPHY HAS HELPED TO IMPROVE THE IMAGING CAPABILITIES IN DIFFERENT FIELS.

•DIGITAL IN-LINE HOLOGRAPHIC MICROSCOPY (DIHM) IS THE SIMPLEST DIGITAL APPROACH TO GABOR'S IDEAS THAT ALLOWS NUMERICALLY RECOVERING THE COMPLEX WAVEFRONT OF SCATTERED WAVES; THE HARDWARE REQUIRED IS A LASER, A SPATIAL FILTER AND A CAMERA.

•THANKS TO THE LARGE DEPTH OF FIELD OF DIHM ONE STRIKING APPLICATION OF THIS MICROSCOPY TECHNIQUE IS THE VISUALIZATION OF MICROFLUIDICS.

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