

DE LA RECHERCHE À L'INDUSTRIE

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Digital-Holographic
near-field reconstruction
for
particles characterization
in
astigmatic systems
&
refractive index measurements

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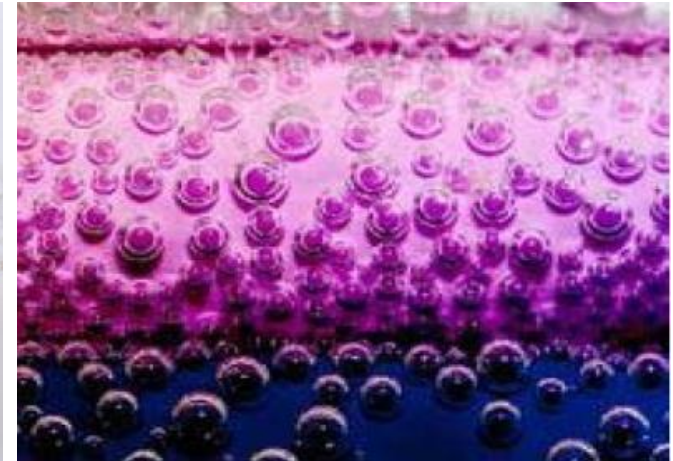
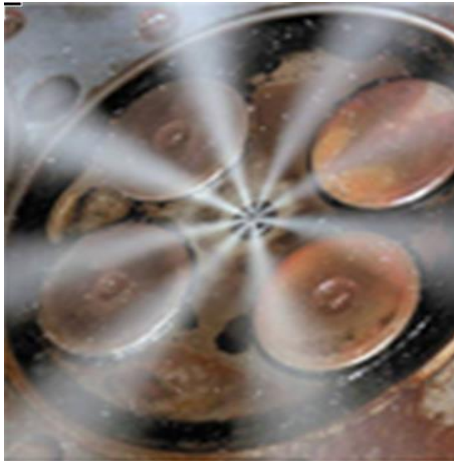
Matthias Sentis is searching for a post-doc!

16th Electromagnetic and Light Scattering Conference
Univ. Maryland, MD, USA / 19-25 March 2017.

Aix-Marseille
université



Raindrops, red blood cells, flies....
Drops, grains and bubbles,...



Size parameter kr from 50 to 12, 000 !

Mechanical, chemical engineering and biological issues:
characterization of drops, grains, bubbles, biological samples...

In their environment!

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Characterization ?

- 3D position and motion (slip velocity, acceleration,...)
- Size (shape, porosity,...)
- Concentration and net fluxes
- Composition and properties (density, mixing fraction, temperature,...)

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Constraints !

- Temporal and spatial resolution (freezing and dynamic tracking)
- Data flow to be minimized
- Complex composition and shaped scatterers, optical aberrations,...
- Large to huge size parameters

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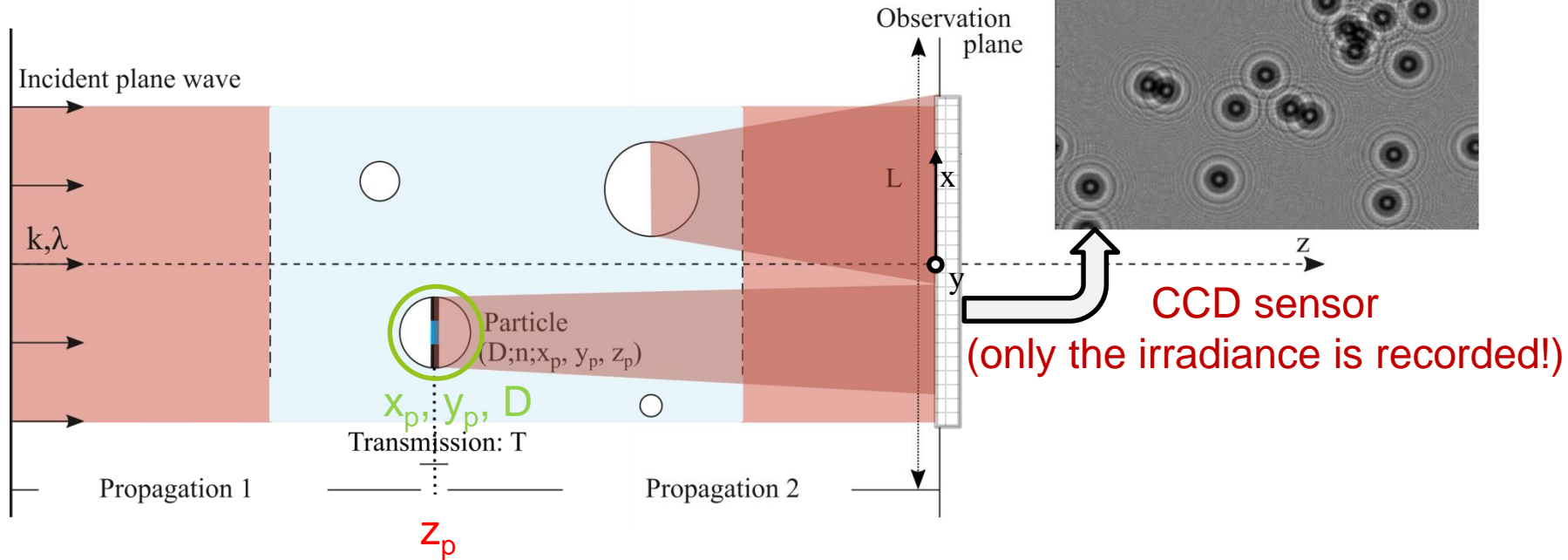
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Digital in-line holography

Principle of digital in-line holography in free space

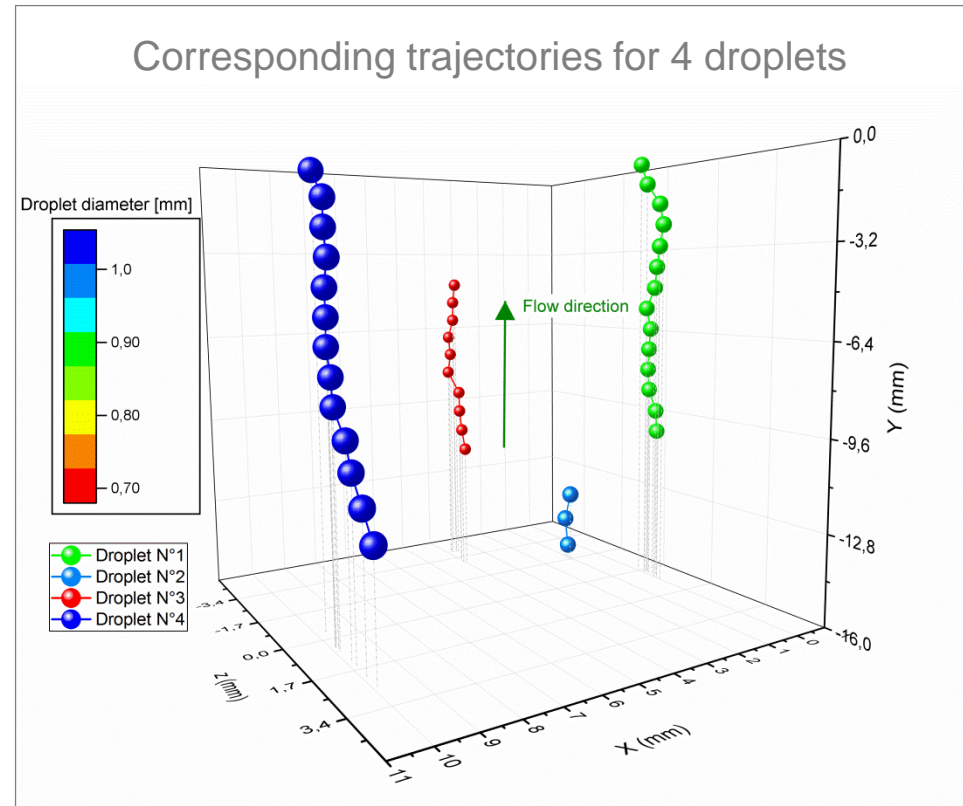
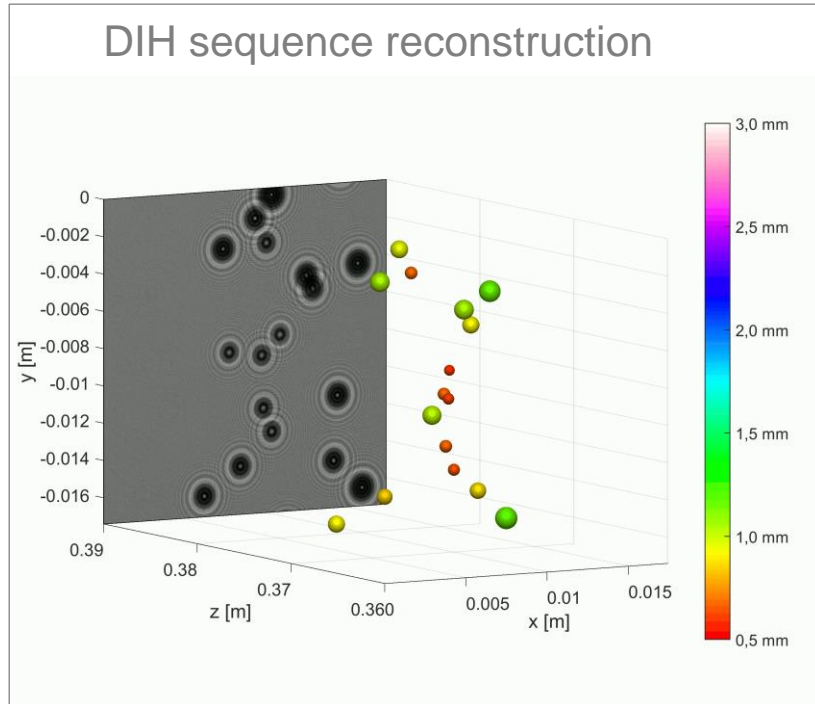
3D reconstruction of the particle flow (size, position, velocity & *acceleration*)



Back propagation of the recorded irradiance for each particle: determination of z_p
(Scalar diffraction theory: Fraunhofer, Fresnel or Rayleigh-Sommerfeld approx.)

Image processing to retrieve x_p, y_p and D

Digital in-line holography, typical results for liquid-liquid droplets of known composition in a rectangular tank

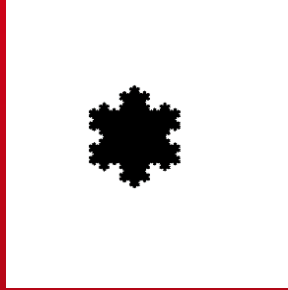
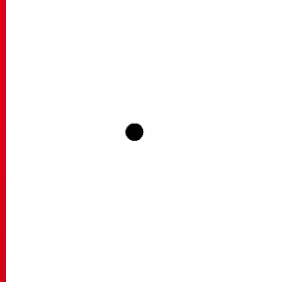


**ACCOUNTING FOR SOME
ASTIGMATISM IN
THE SYSTEM**



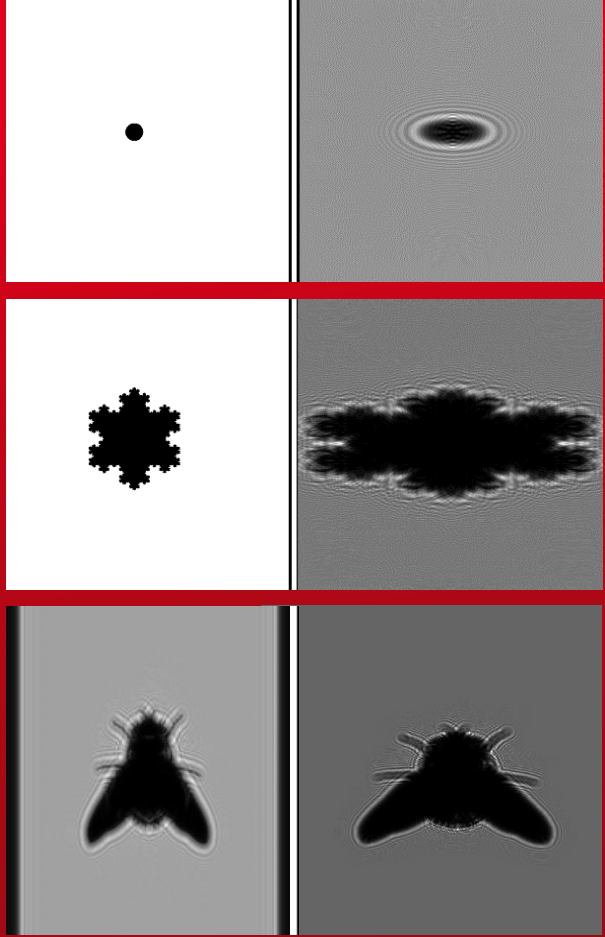
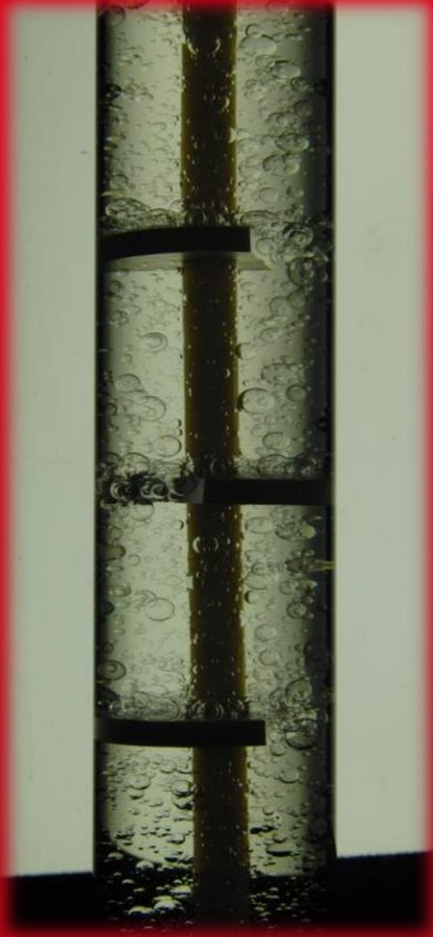
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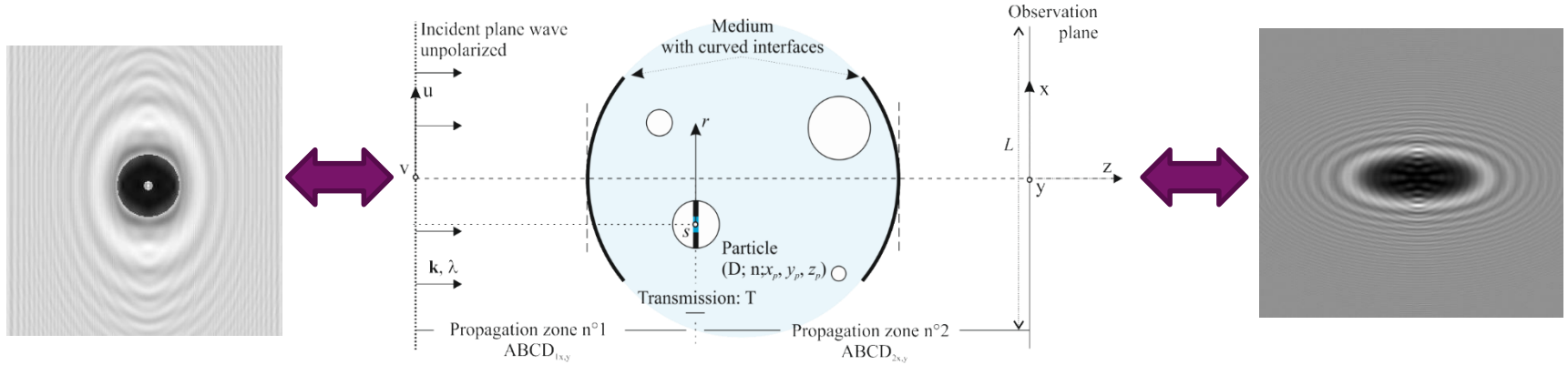
*ILLUSTRATION: IMAGING
THROUGH A
CYLINDRICAL REACTOR*



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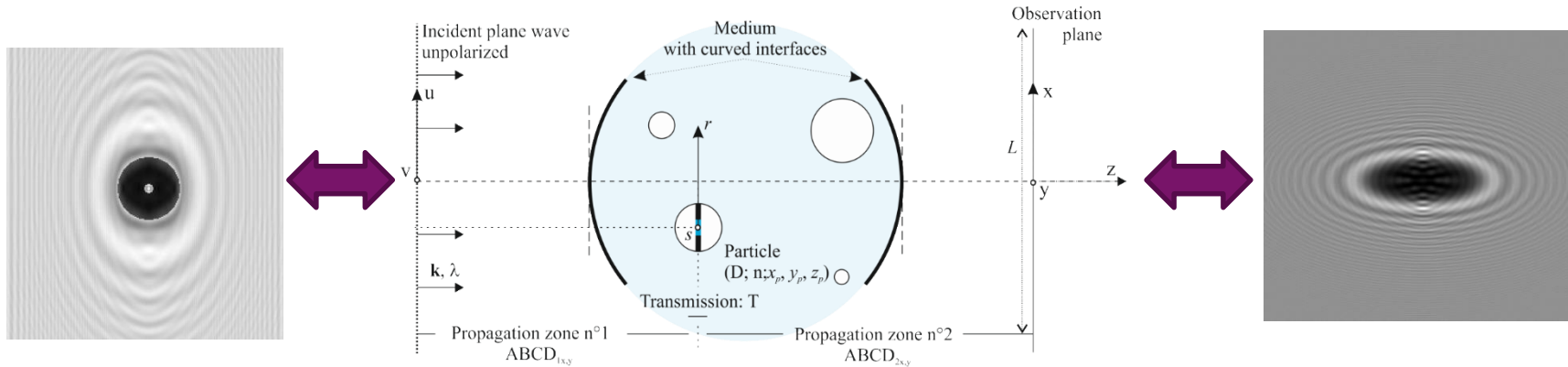
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Previous approaches

- Fractional Fourier Transform (Ozaktas et al, Wiley, 2001)
- Huygens-Fresnel integral with ABCD transfer matrix (Collins et al., JOSA 60, 1970) and particle shape analytical decomposition (Verrier et al. Appl. Optics 53, 2014) (GHFT)



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New approach: “Modified Generalized Huygens-Fresnel Transform (M-GHFT)”

- the diffraction integral is still expressed as a convolution product
- the optical systems contribution is simply accounted with two global ABCD matrices
- same accuracy than with previous approaches **but...**
- **More easy to implement and more efficient numerically than the Fractional Fourier Transform**
- **No restriction of the particle shape and off-axis positioning (/ GHFT)**

Diffracted field with M-GHFT (propagation or backpropagation along z-axis)

$$S_z(x, y) = \frac{\exp(ikz)}{i\lambda A_x A_y \sqrt{B_x B_y}} \exp\left(i\pi \frac{C_x x^2}{\lambda A_x}\right) \exp\left(i\pi \frac{C_y y^2}{\lambda A_y}\right) (S(u, v) * h(u, v)) \left(\frac{x}{A_x}, \frac{y}{A_y}\right)$$

Optical properties of the medium

$$ABCD_x = \begin{bmatrix} A_x & B_x \\ C_x & D_x \end{bmatrix}; ABCD_y = \begin{bmatrix} A_y & B_y \\ C_y & D_y \end{bmatrix};$$

Particle 2D model

Opaque disk model (OD)
Opaque disk and phase
Model (ODP)

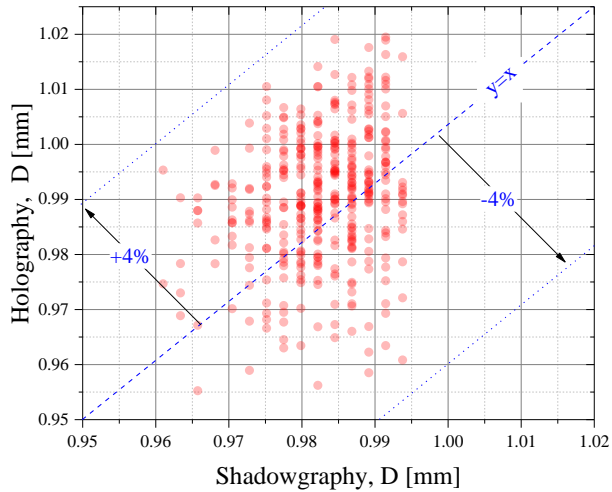
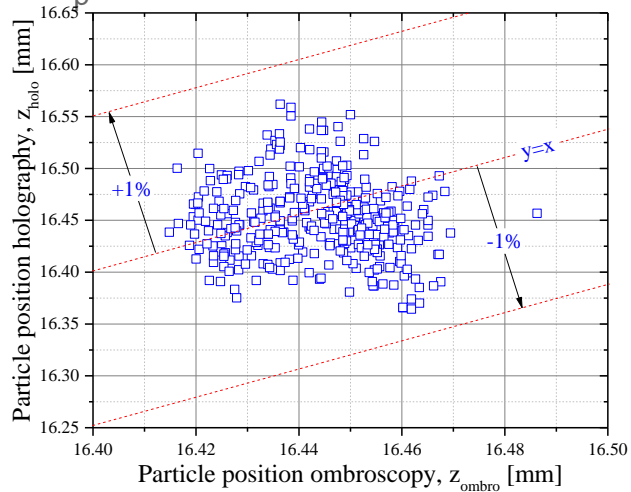
Convolution theorem

$$\mathfrak{T}^{-1}(\mathfrak{T}(S)\mathfrak{T}(h))$$

Fresnel's propagators and sampling conditions:

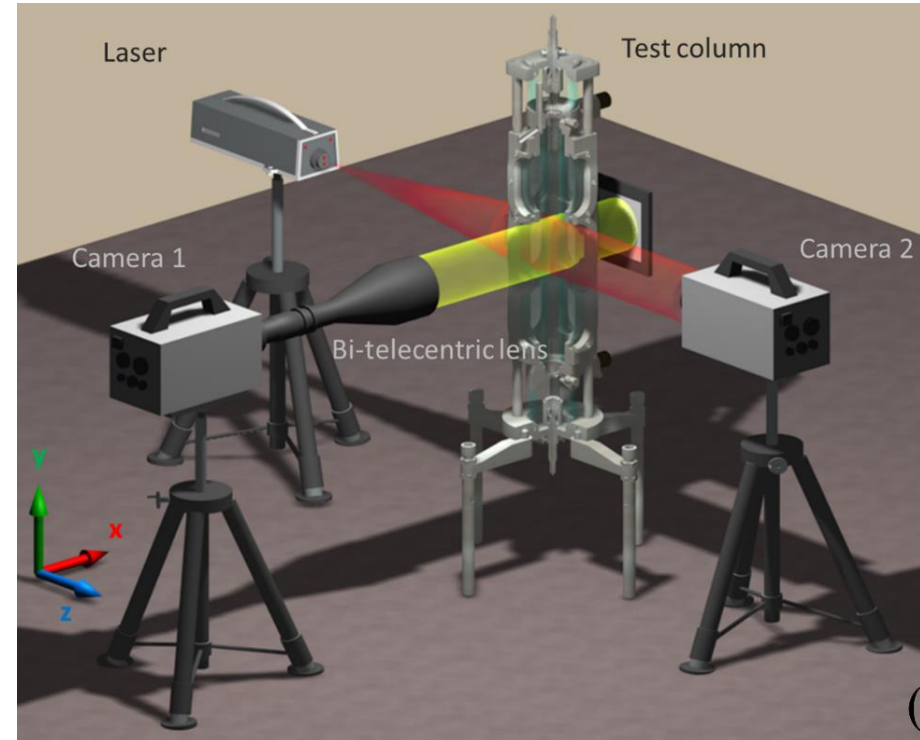
Propagator	Shannon conditions
$h(u, v) = \exp\left(\frac{i\pi u^2}{\lambda A_x B_x}\right) \exp\left(\frac{i\pi v^2}{\lambda A_y B_y}\right)$	$A_x B_x \geq \frac{d_x L}{\lambda} \text{ and } A_y B_y \geq \frac{d_y L}{\lambda}$
$H(f_x, f_y) = \exp\left(-i\pi(A_x B_x f_x^2 + A_y B_y f_y^2)\right)$	$A_x B_x \leq \frac{d_x L}{\lambda} \text{ and } A_y B_y \leq \frac{d_y L}{\lambda}$

400 single droplets

Diameter D : less than 4% deviationPosition z_p : less than 1% deviation

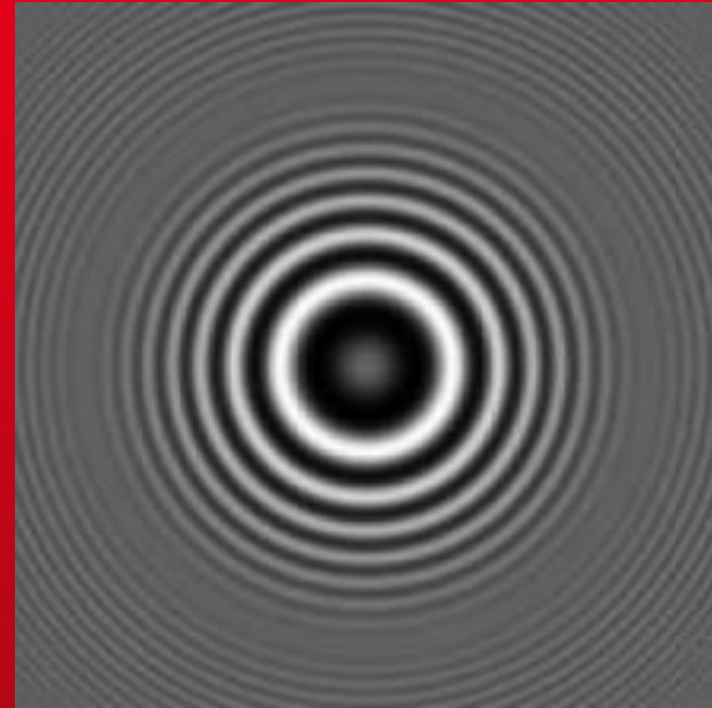
EXPERIMENTAL RESULTS

Digital in-line holography vs shadowgraphy



PARTICLES:

**REFRACTIVE INDEX
MEASUREMENT
(OR RECOGNITION)
????????????????**

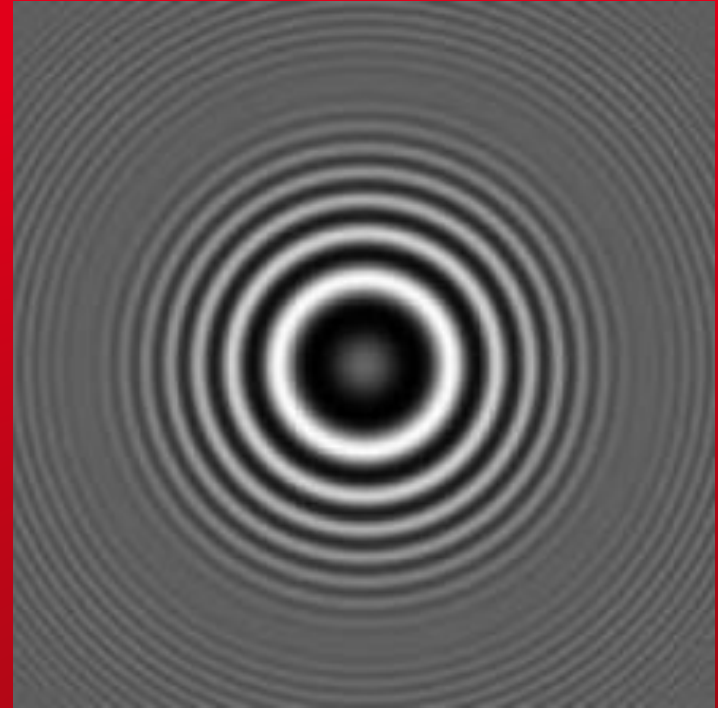


Water or ethanol ?

PARTICLES:

**REFRACTIVE INDEX
MEASUREMENT
(OR RECOGNITION)**

WITH PHOTONIC JET!!!

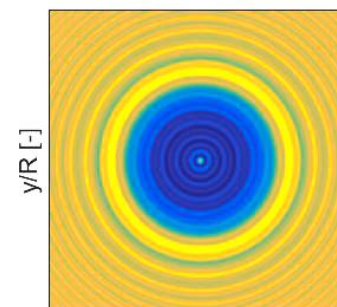
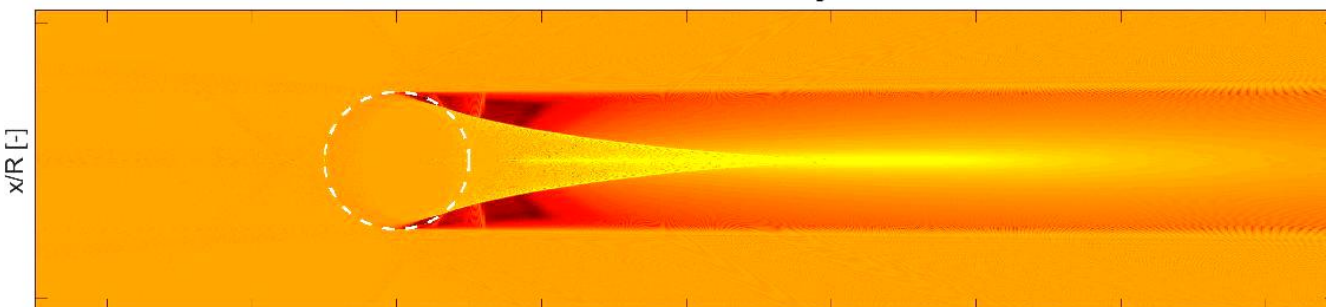


Neither of them, isane in water...

REFRACTIVE INDEX MEASUREMENT (OR RECOGNITION) WITH PHOTONIC JET

Holographic reconstruction of the near intensity field scattered by a spherical particle

Lorenz-Mie theory



REFRACTIVE INDEX MEASUREMENT (OR RECOGNITION) WITH PHOTONIC JET

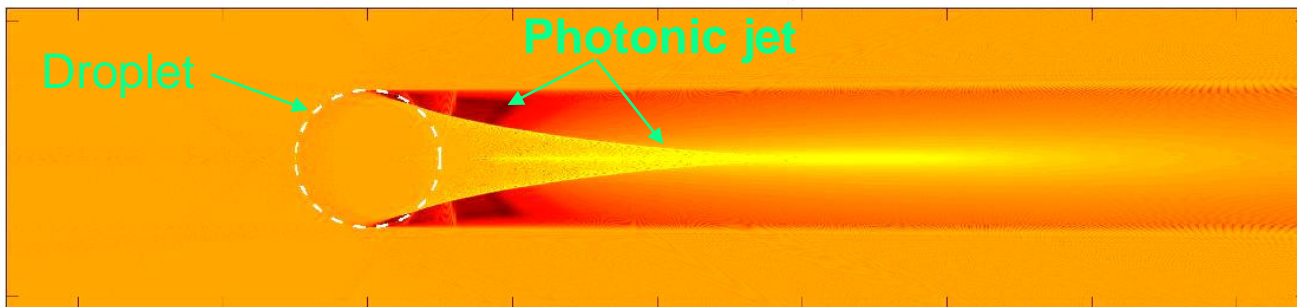
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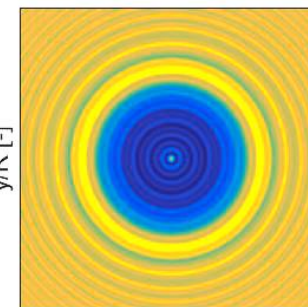
Droplet

Photonic jet

x/R [-]



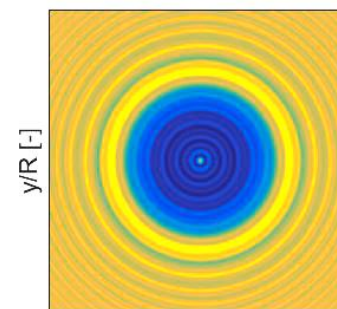
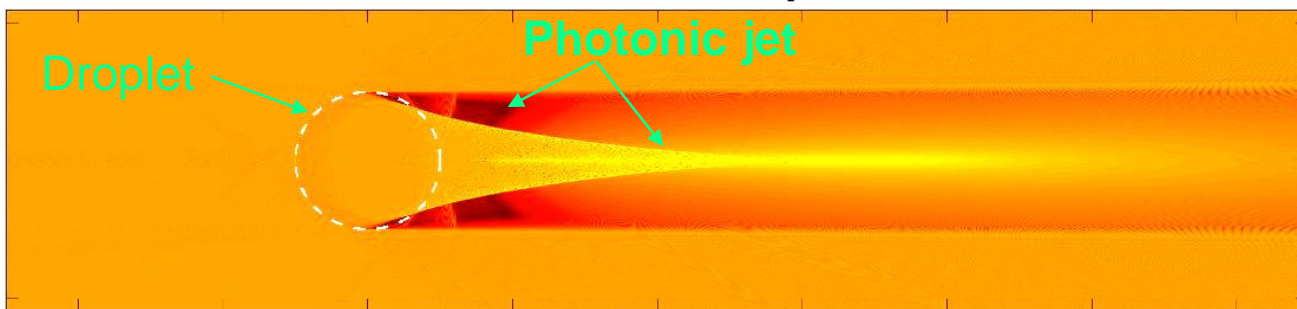
y/R [-]



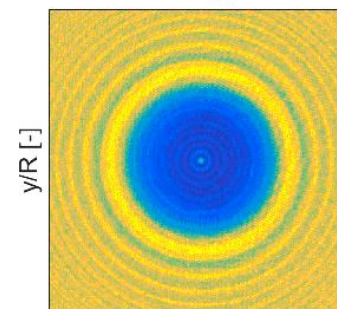
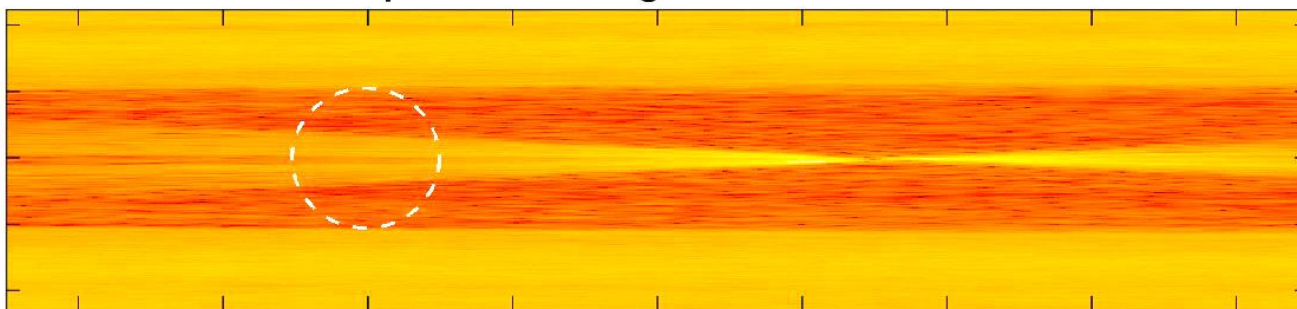
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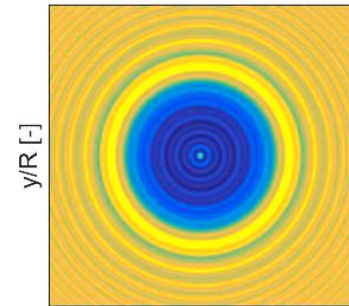
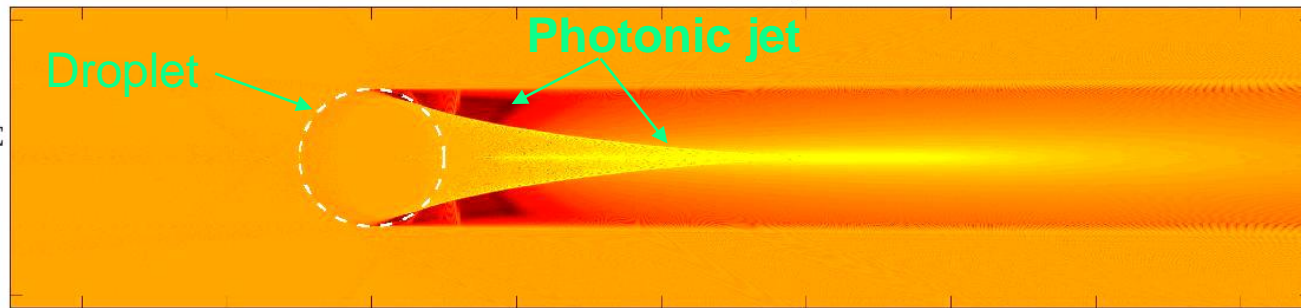
Experimental hologram reconstruction



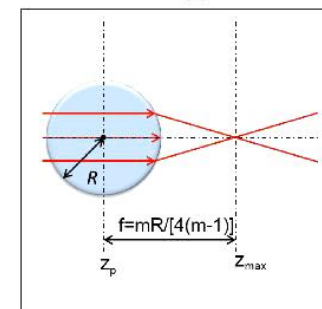
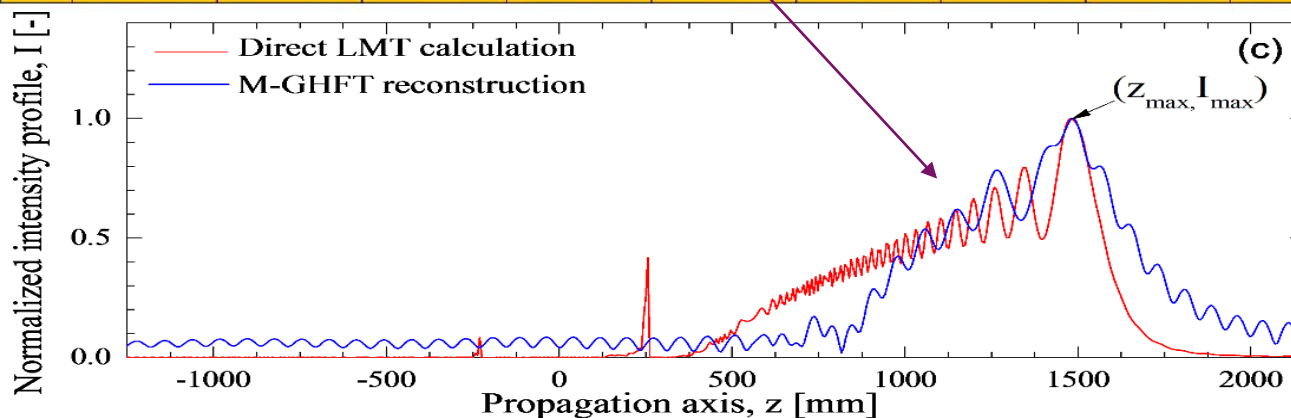
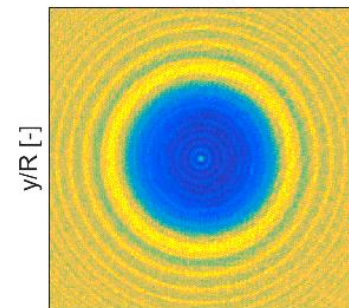
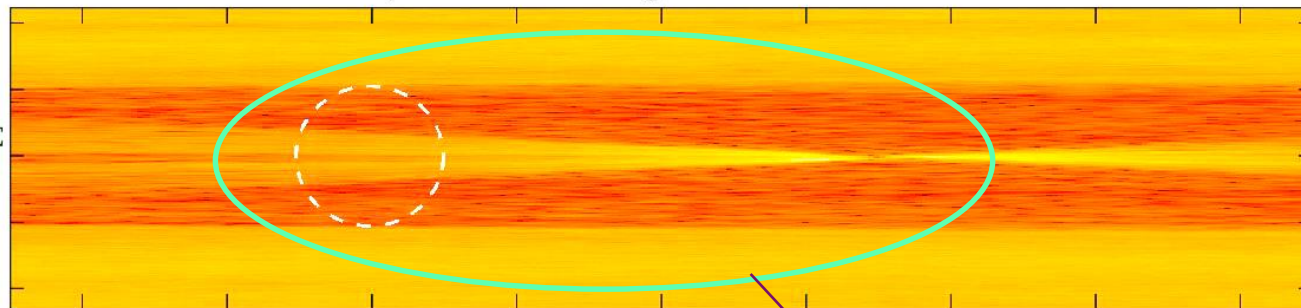
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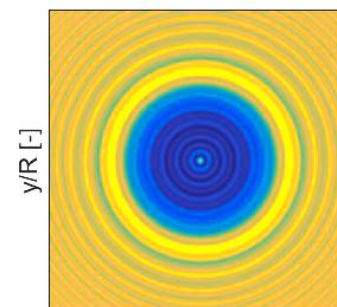
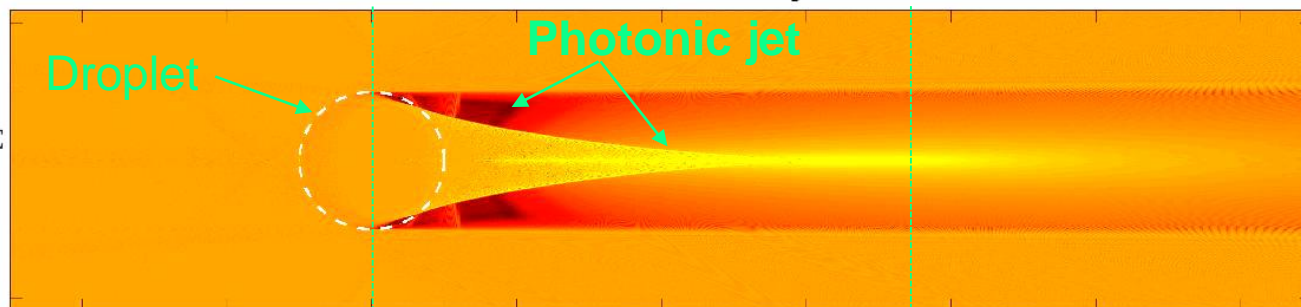
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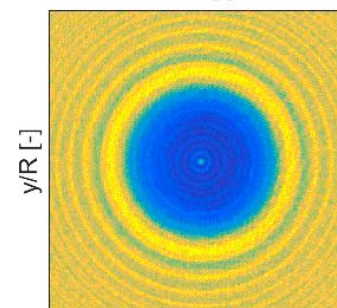
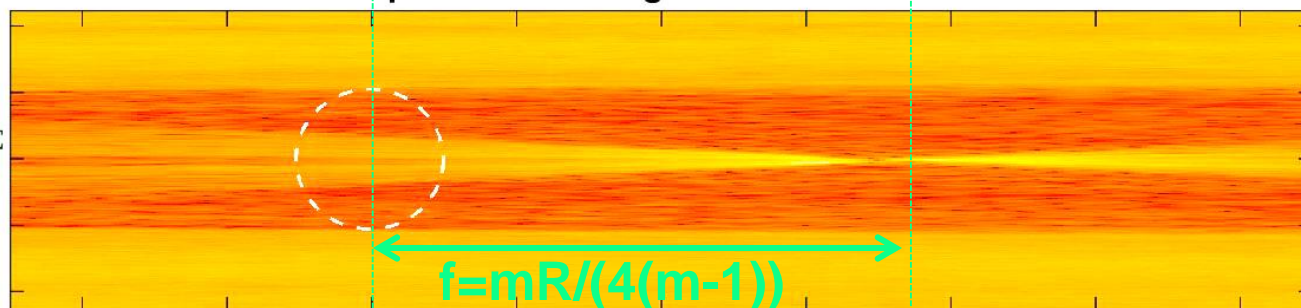
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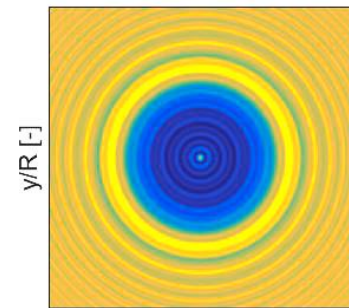
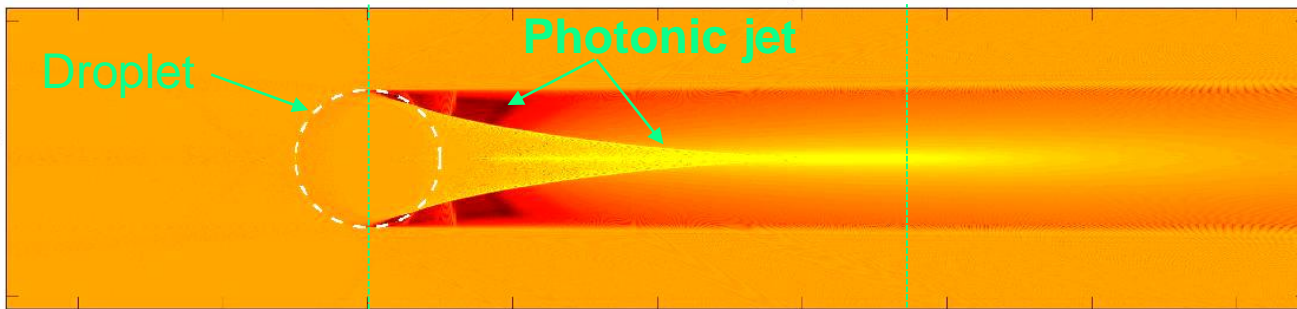
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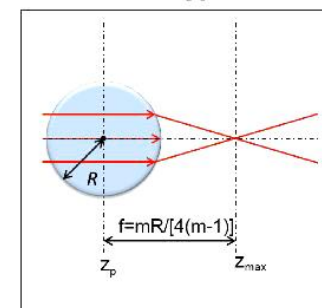
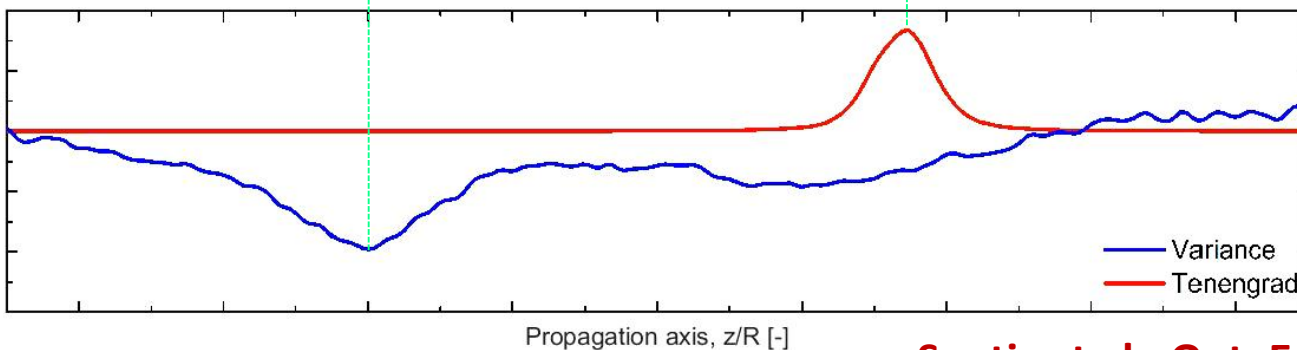
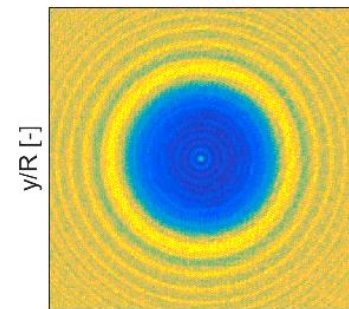
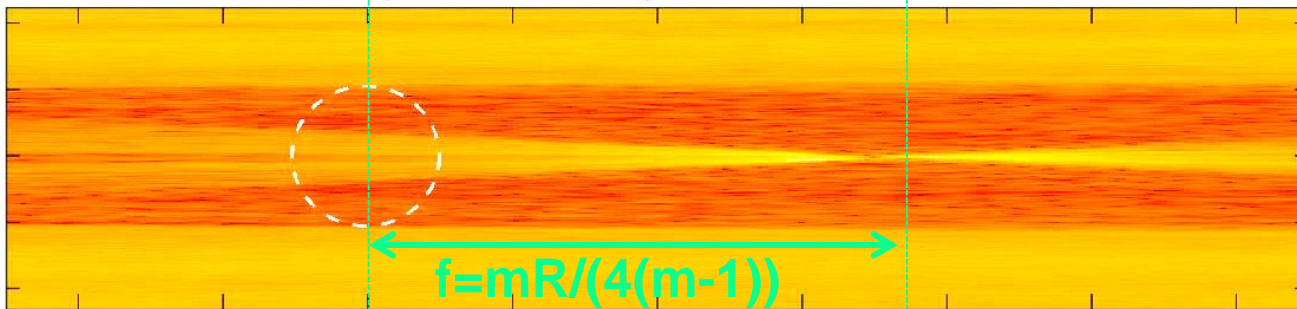
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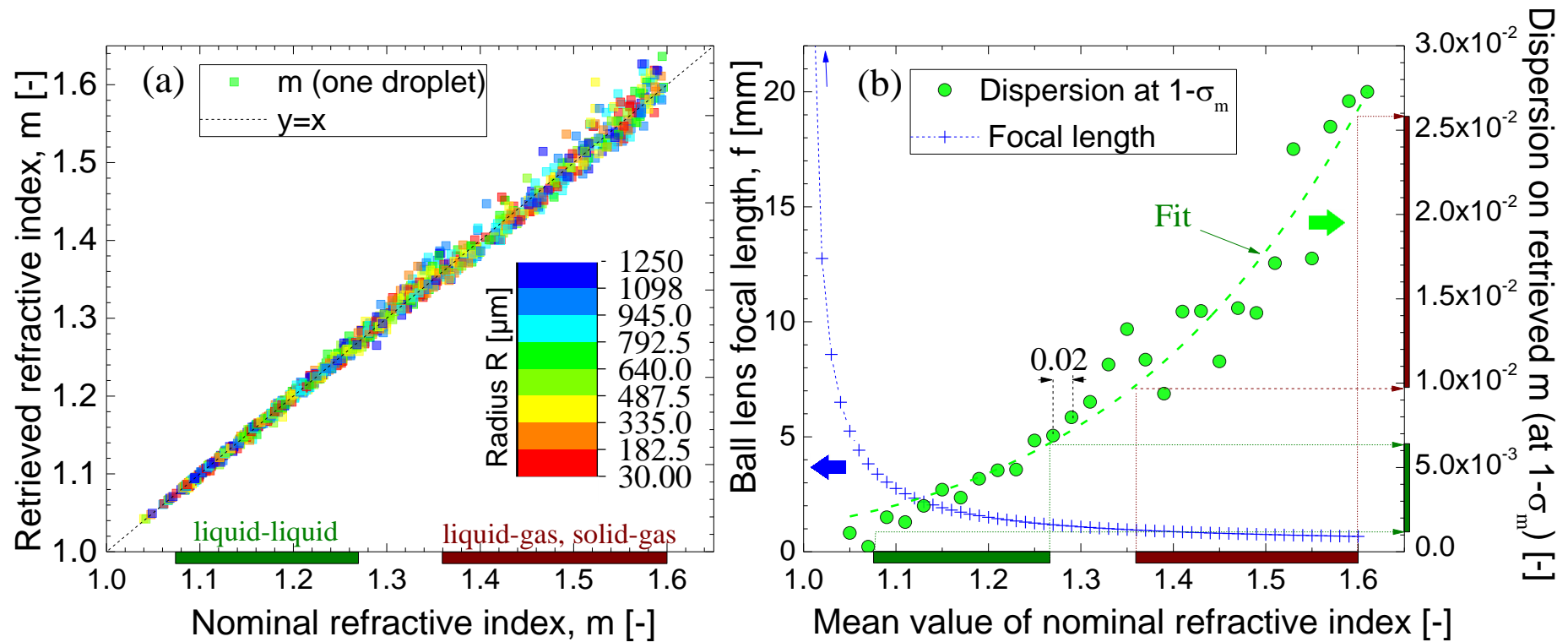


Experimental hologram reconstruction



REFRACTIVE INDEX MEASUREMENT (OR RECOGNITION) WITH PHOTONIC JET

Numerical estimation of the resolution achievable on refractive index
- 1000 holograms generated from randomly parametrized particles (x, y, z, D, m)

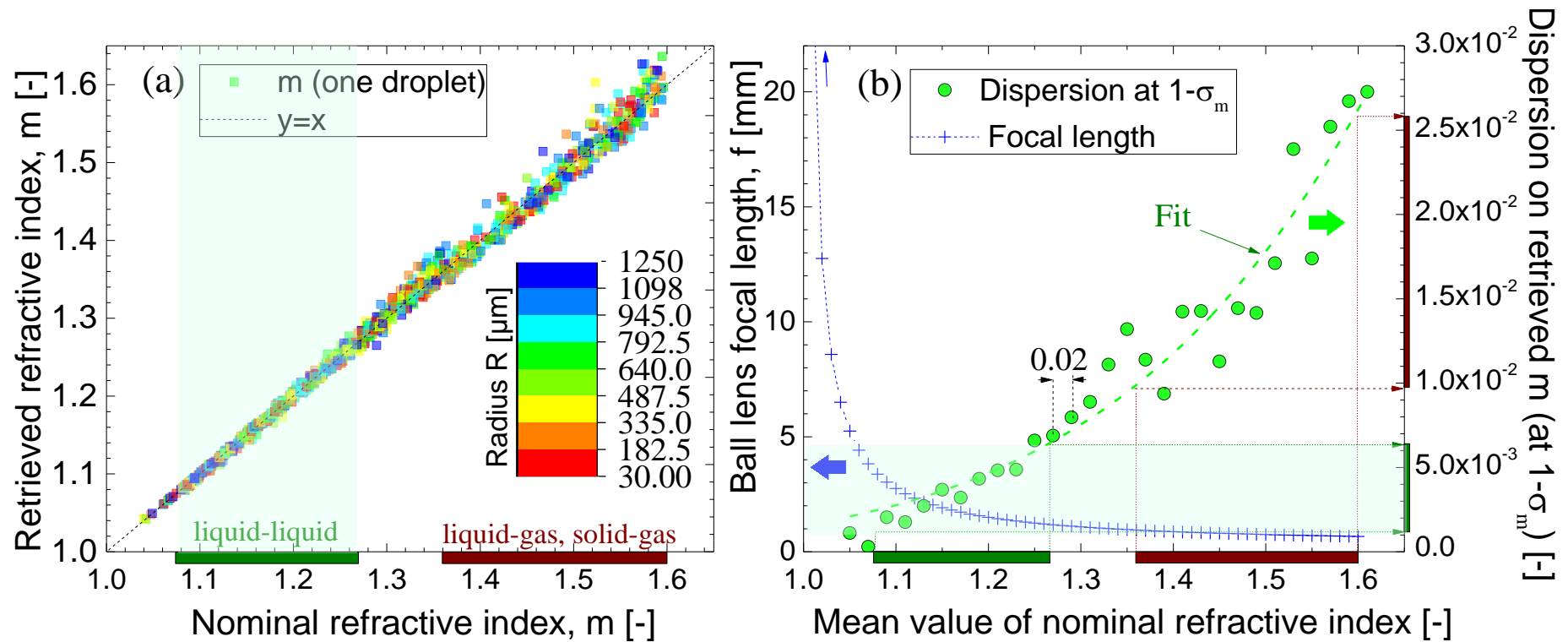


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liquid-liquid systems: better than $6 \cdot 10^{-3}$



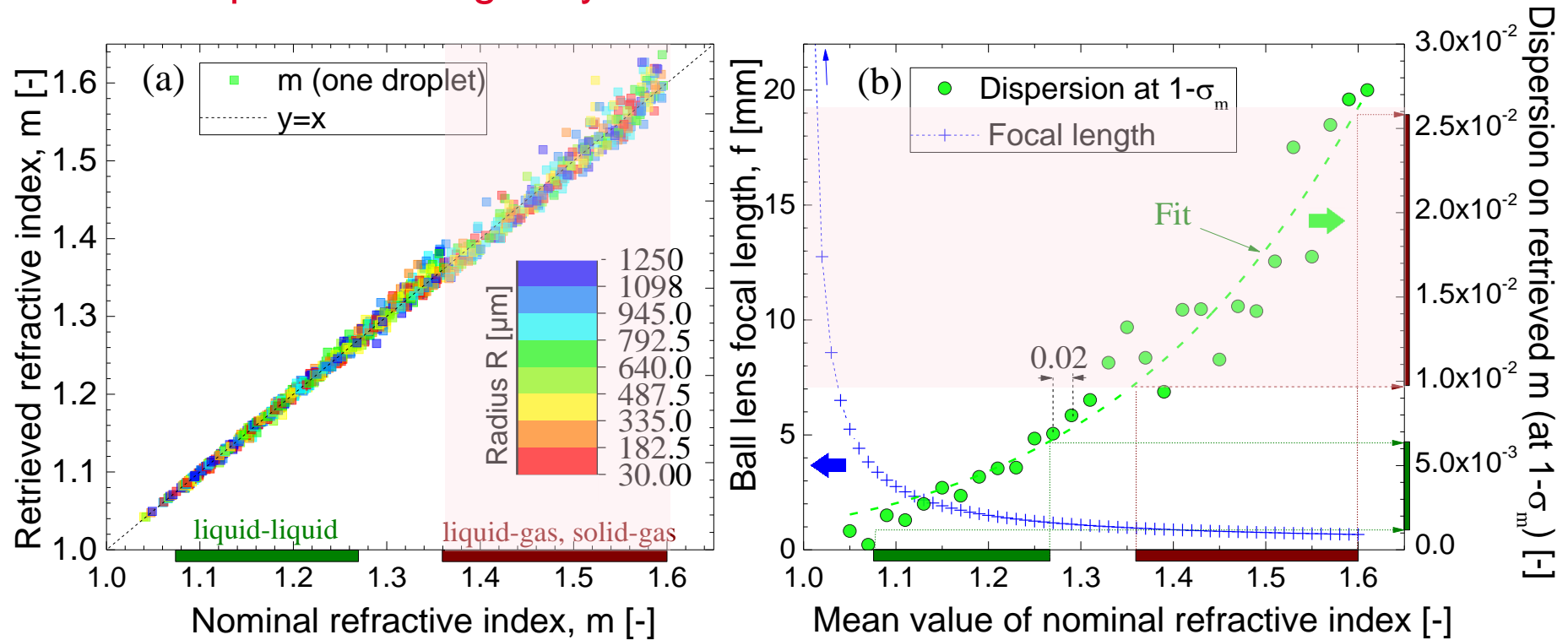
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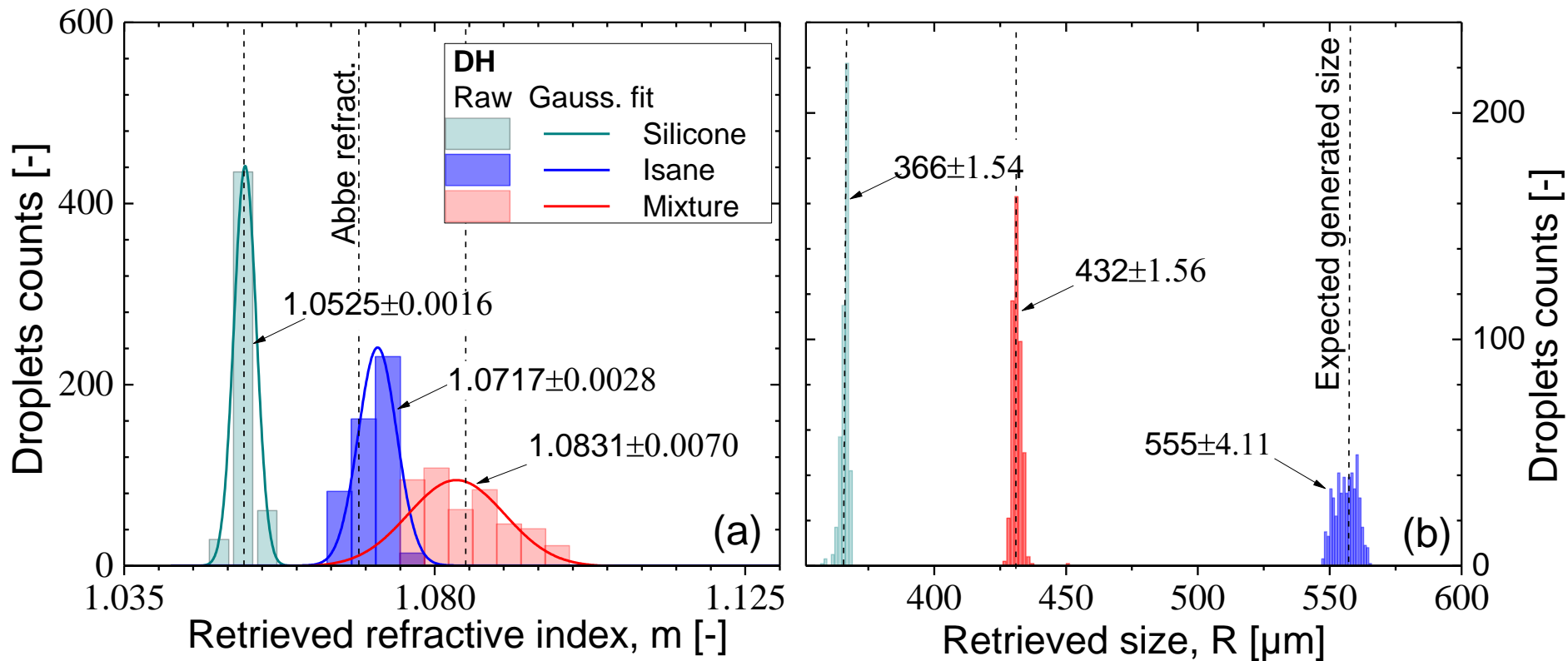
liquid or solid-gas systems: better than $2.5 \cdot 10^{-2}$



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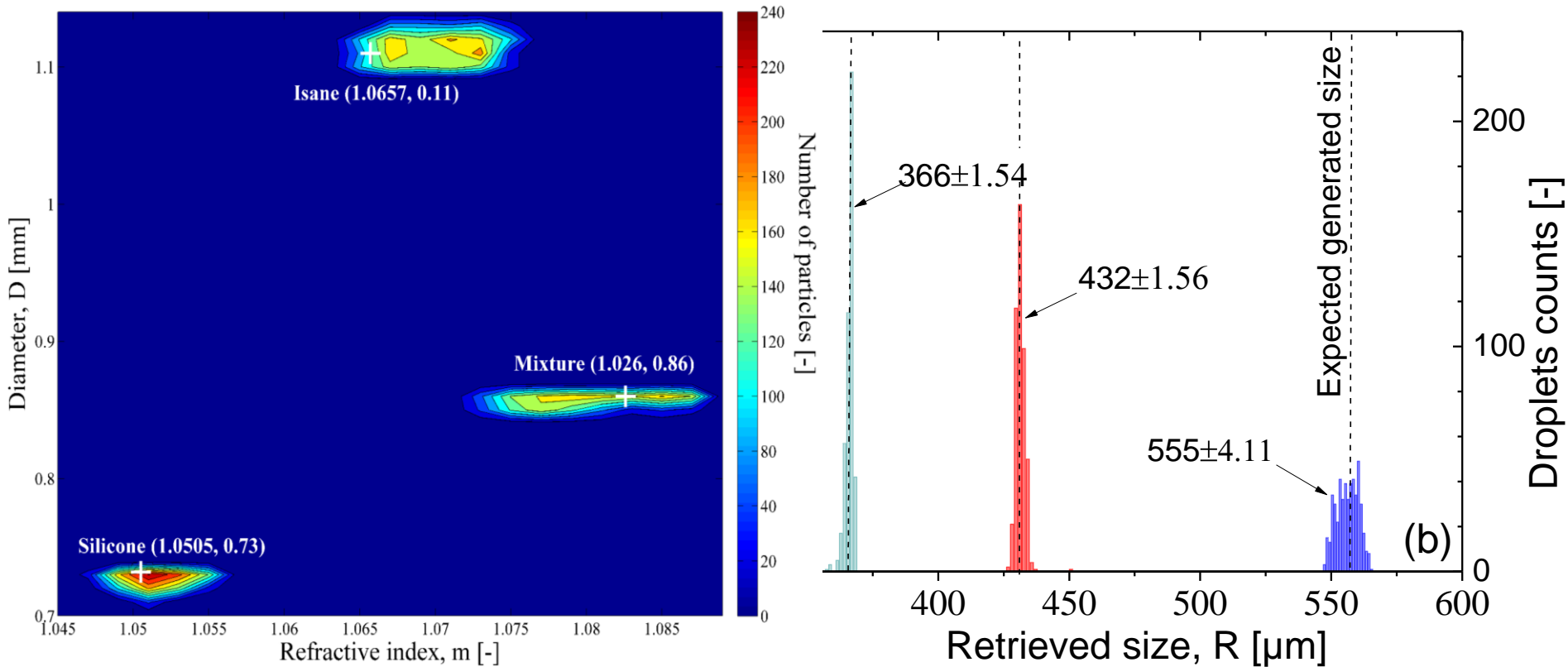
Experimental test on the resolution achievable on refractive index

- two pure fluids and one mixture
- 500 single droplets for each fluids



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- 500 single droplets for each fluids



Digital in-line holography

- Allows 3D reconstructions of particle flows
- Retrieval of some features of the near field

Extension of DH to astigmatic systems (cylindrical case presented)

- Development of a new propagation model
- Near field reconstruction for position assessment

Extension of DH to refractive index measurement

- Near field reconstruction for refractive index assessment

