Development of a remote sensing technique for airborne droplets and particles using the glory and speckle pattern

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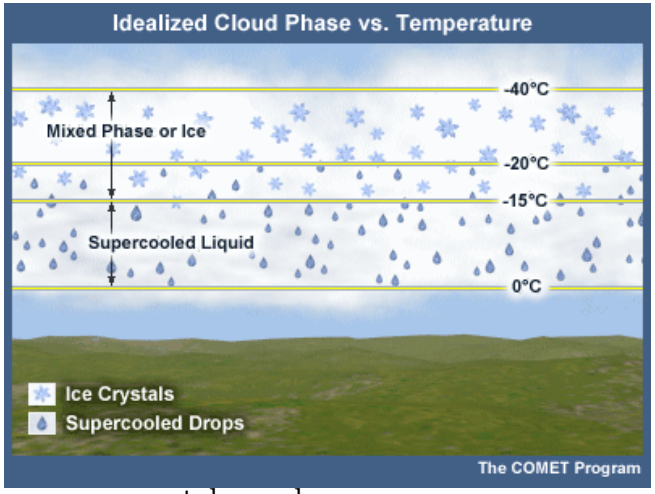
Vrije Universiteit Brussel

Introduction

source: www.nasa.gov

Airplanes → high number of incidents in the last decades due to **ice crystals** in convective clouds:

- Engine power losses
- Instrumentation failure



source: www.meted.ucar.edu

Two flight conditions inside clouds:

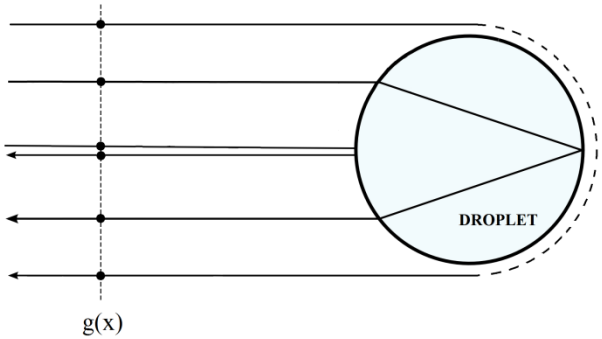
- Supercooled Liquid water Droplets (SLD)
- Ice crystals

Ice crystals are **not detected** by current on-board instrumentation!

Mason et al (2006)

Backscattering of light by particles

Water droplet:



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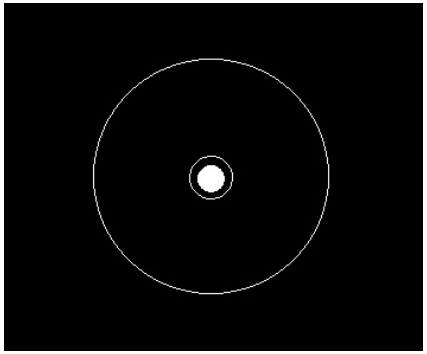
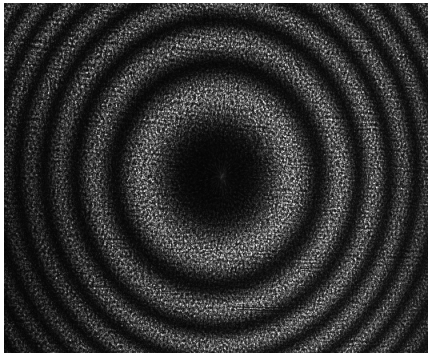
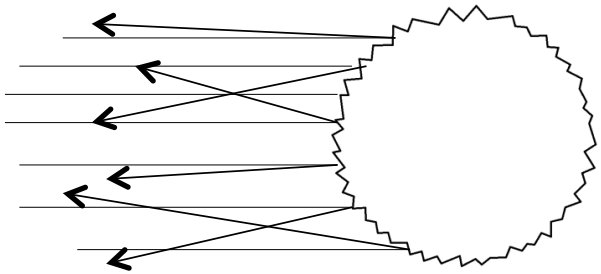


Out-of-focus:



Irregular particle:



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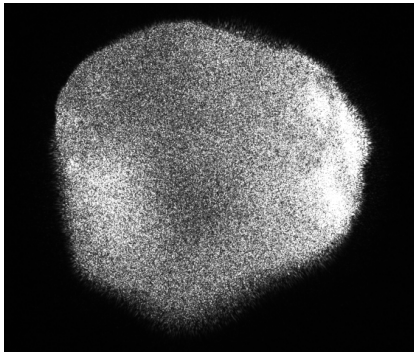
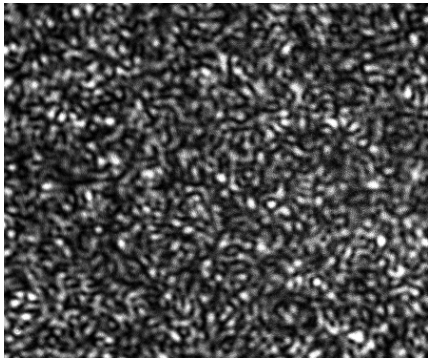
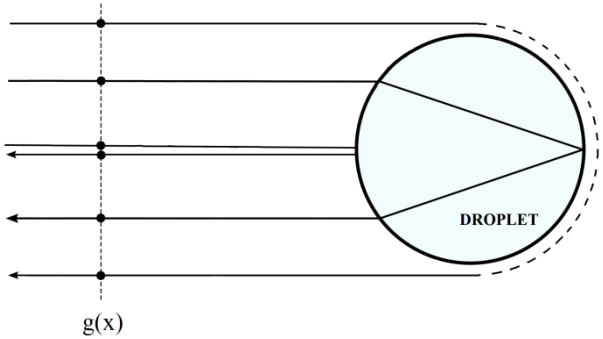
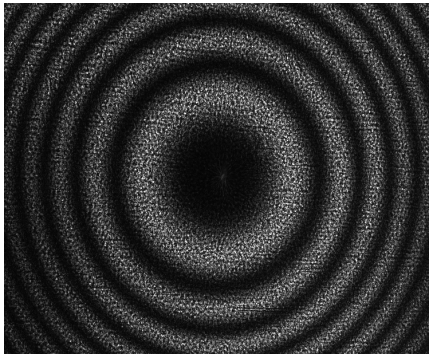


Out-of-focus:

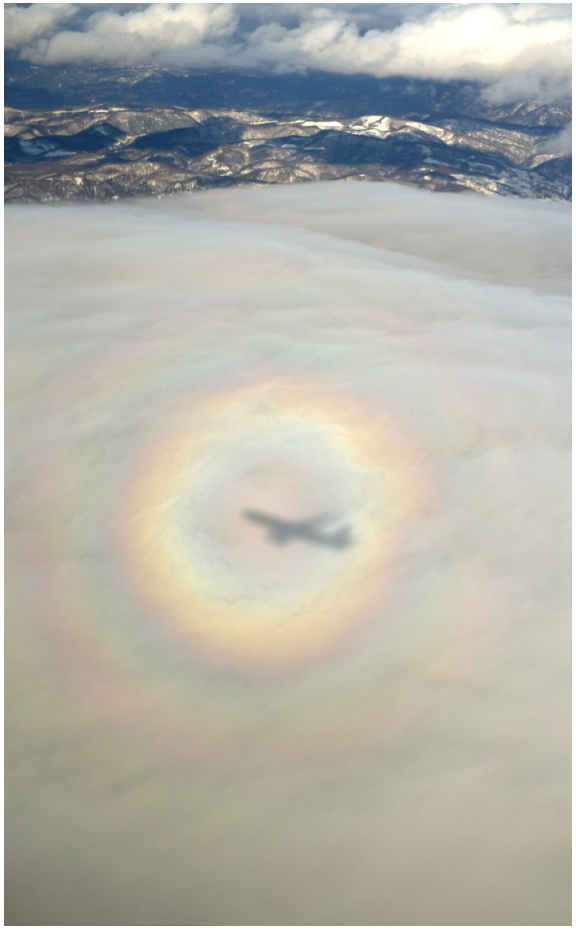


Measuring spherical particles: The glory pattern





The glory phenomenon

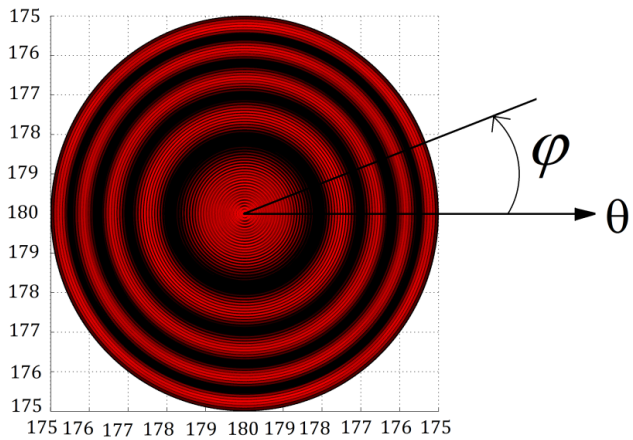


Interference pattern created from the light scattered by water droplets

Lorentz-Mie theory

Lorentz-Mie theory: analytical solution to the scattering problem for

homogeneous spheres



$$i_1 = \left| \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} \left[a_n \pi_n \cos\theta + b_n \tau_n \cos\theta \right] \right|^2$$

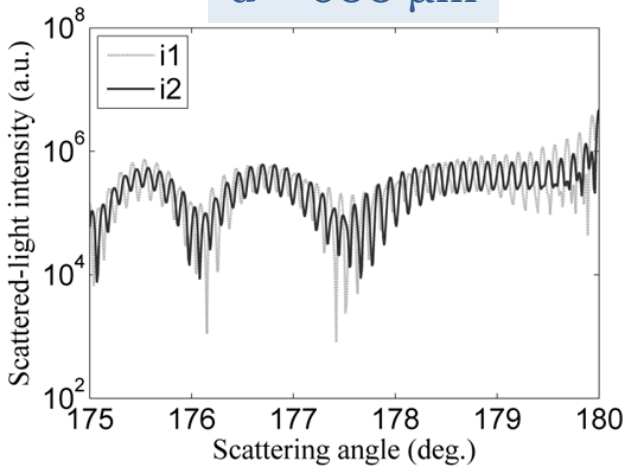
$$i_2 = \left| \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} \left[a_n \tau_n \cos\theta + b_n \pi_n \cos\theta \right] \right|^2$$

$$I = \frac{I_b}{(k_o r)^2} \left[i_1(\theta) \, sin^2(\varphi) + i_2(\theta) \, cos^2(\varphi) \right]$$

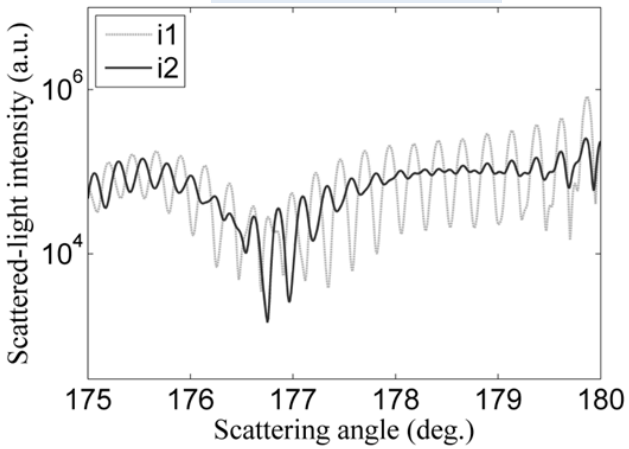
van de Hulst (1981)

Lorenz-Mie theory

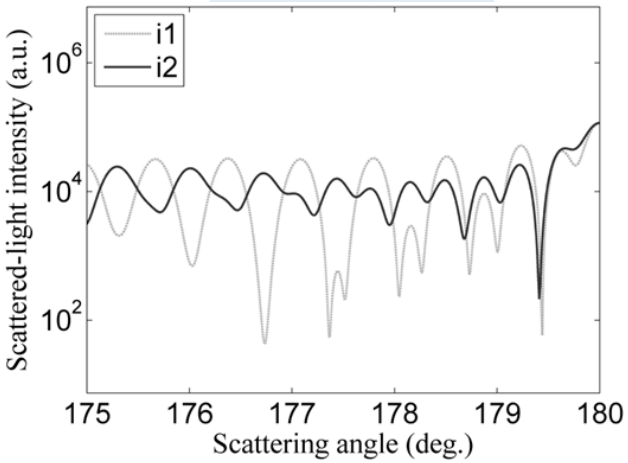
d = 600 µm



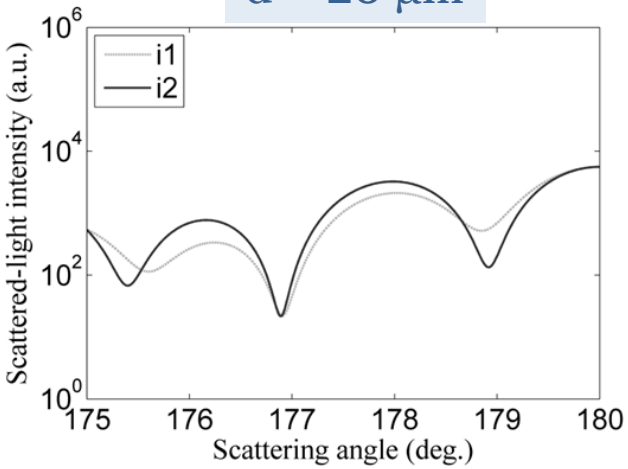
d = 300 µm



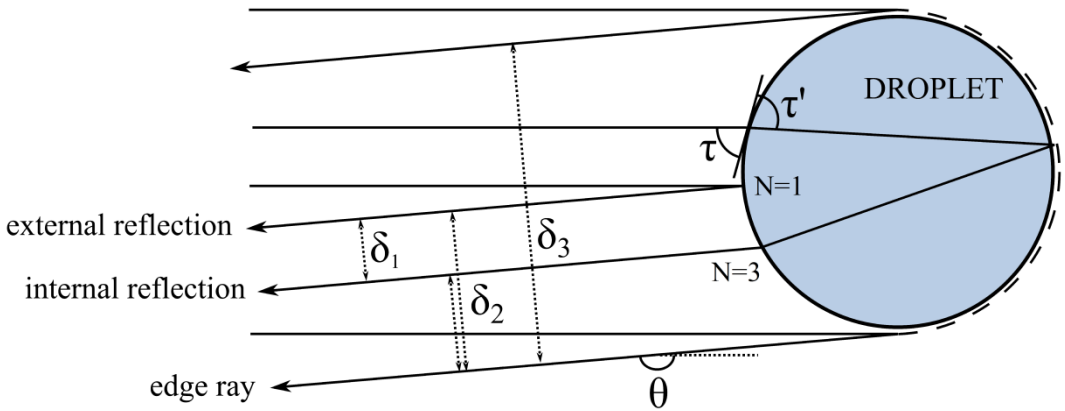
d = 100 µm



d = 20 µm

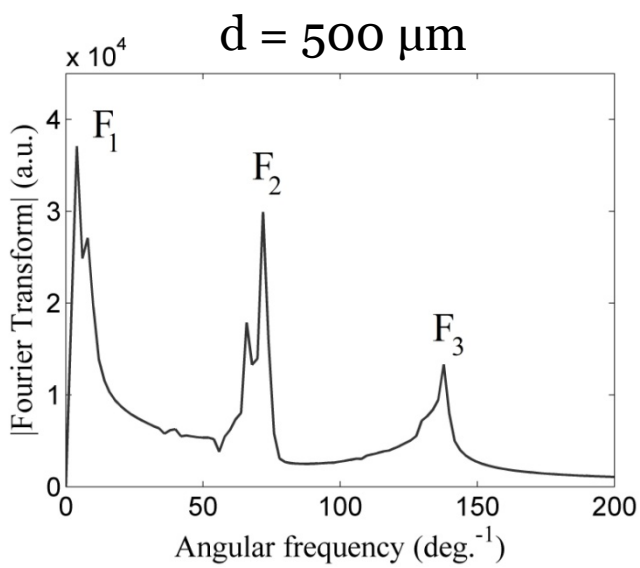


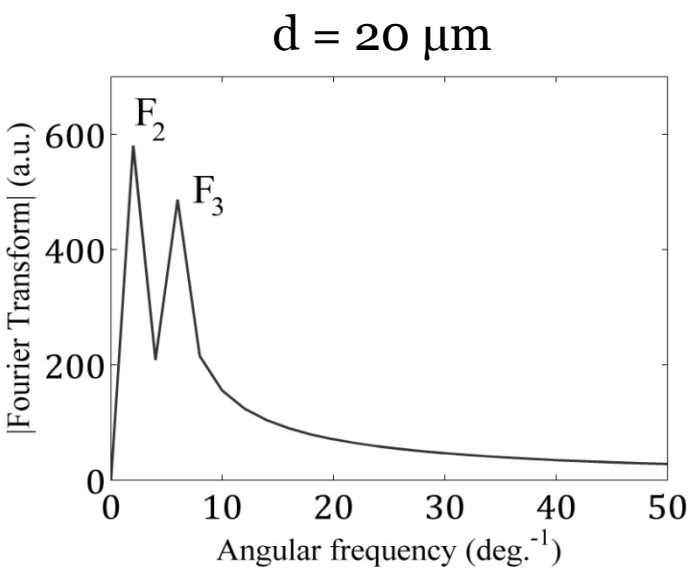
Geometrical optics



Young's double-slit experiment:

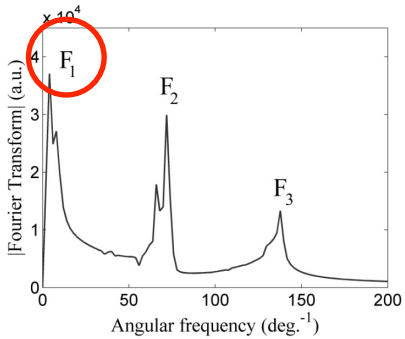
$$F_i = \delta_i / \lambda$$

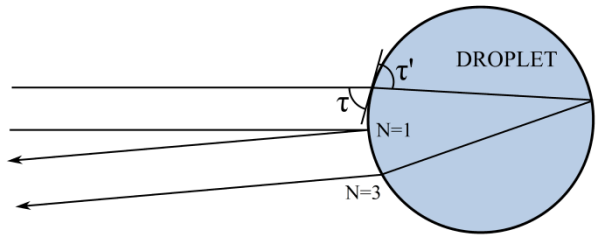


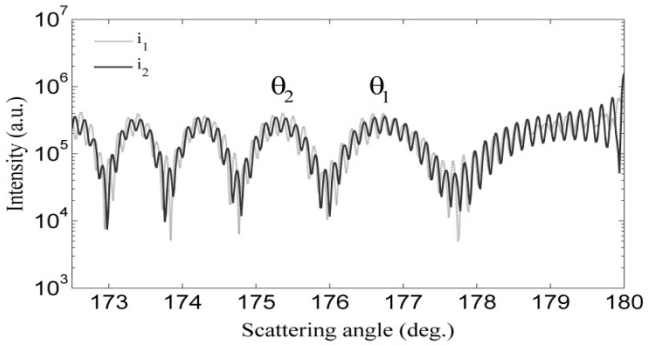


Geometrical optics: Lowest frequency

- **Big droplets →** dominant frequency: $\mathbf{F_1}$







- <u>Phase of a ray:</u>

$$\beta = \frac{2\pi d}{\lambda}(\sin\tau - (N-1)m\sin\tau')$$

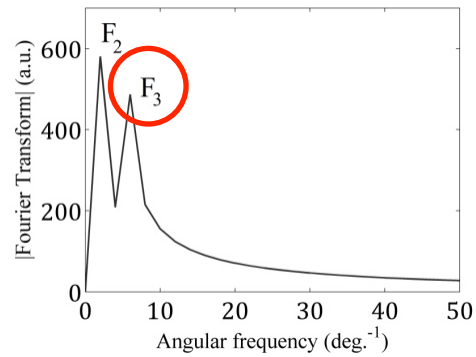
$$\begin{cases} \beta_{N1} = \dfrac{2\pi d}{\lambda}\sin\tau_{N1} + \pi \\ \beta_{N3} = \dfrac{2\pi d}{\lambda}(\sin\tau_{N3} - 2m\sin\tau'_{N3}) + 2\pi \end{cases}$$

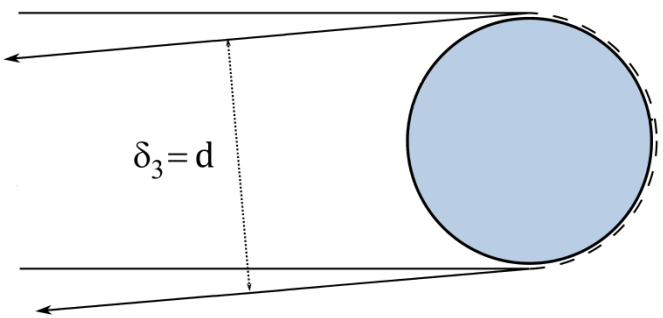
$$d = \lambda(\sin\tau_{N1\theta 1} - \sin\tau_{N1\theta 2} - \sin\tau_{N3\theta 1} + \sin\tau_{N3\theta 2} + 2m\sin\tau'_{N3\theta 1} - 2m\sin\tau'_{N3\theta 2})^{-1}$$

Gonzalez Ruiz et al (2014)

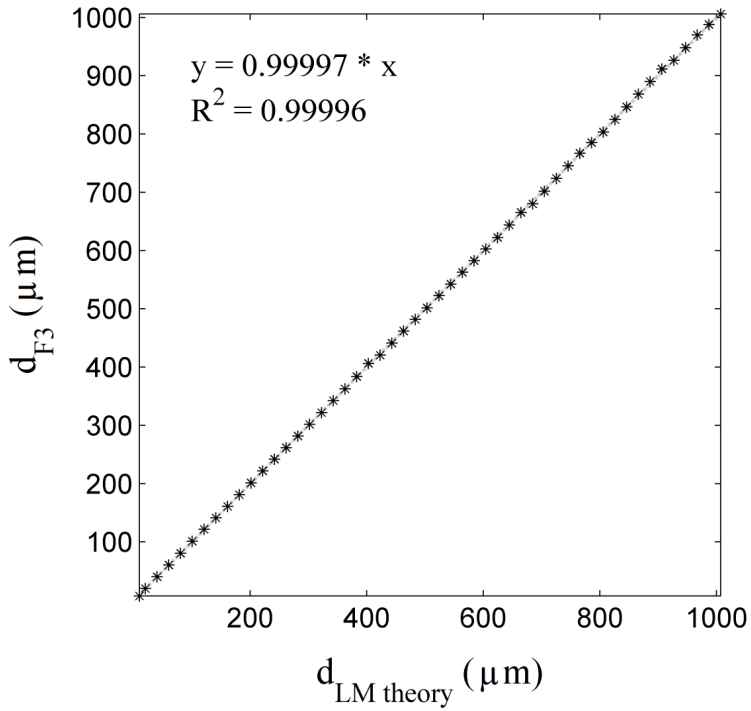
Geometrical optics: Highest frequency

- **Small droplets →** high frequencies are dominant



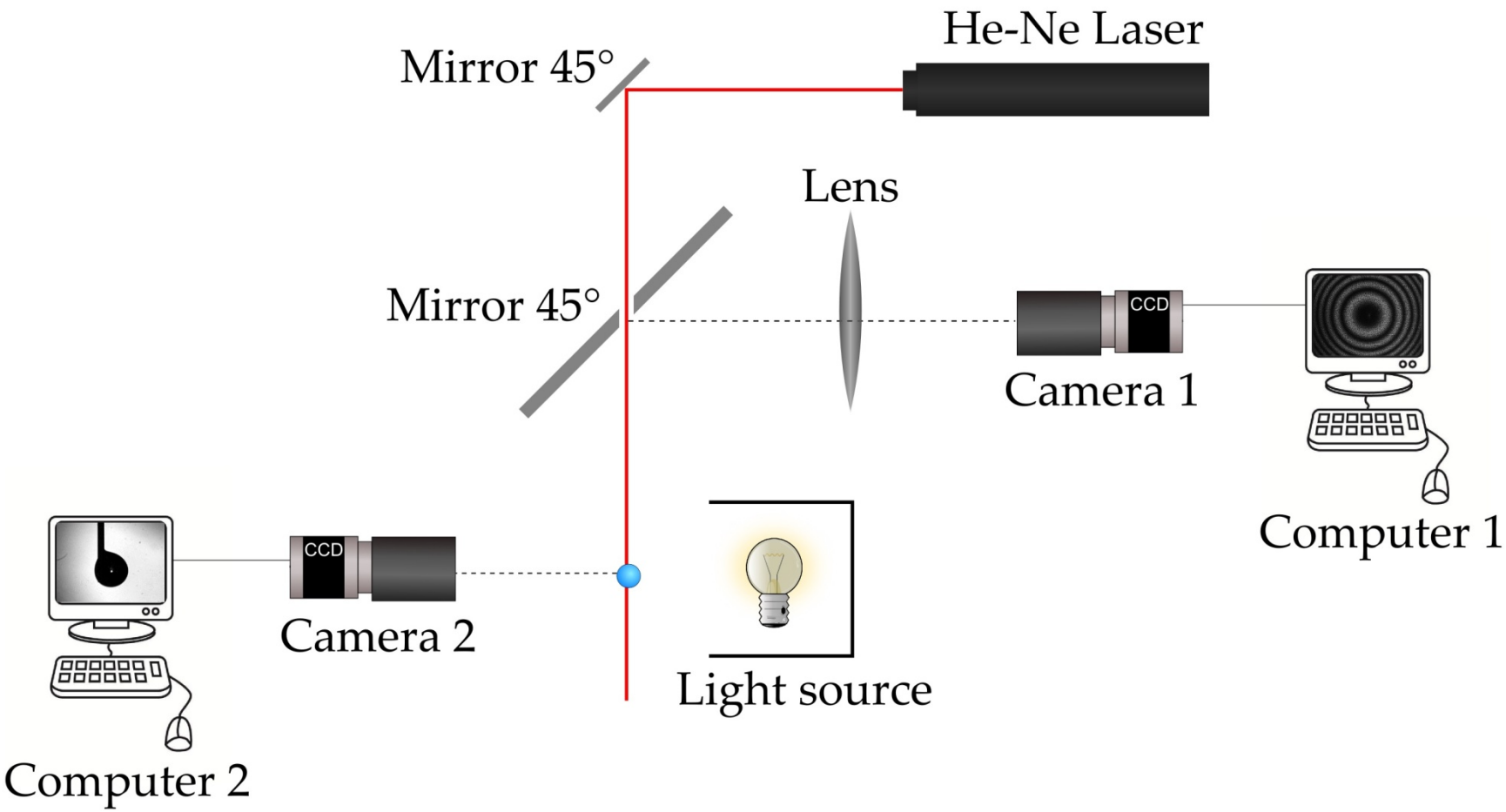


$$d = \delta_3 = F_3 \lambda$$



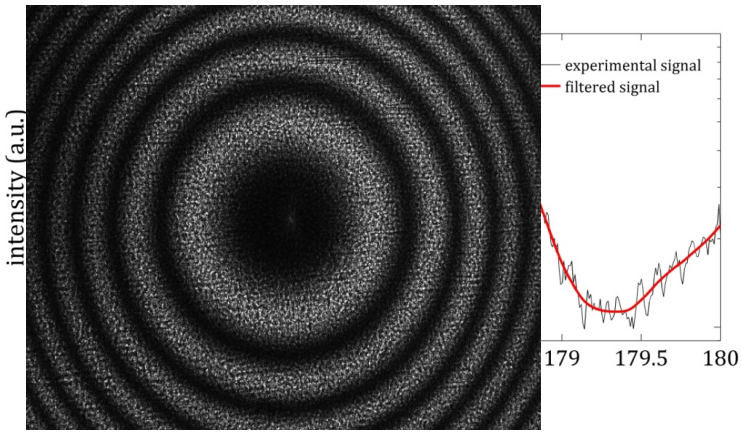
Vetrano et al (2015)

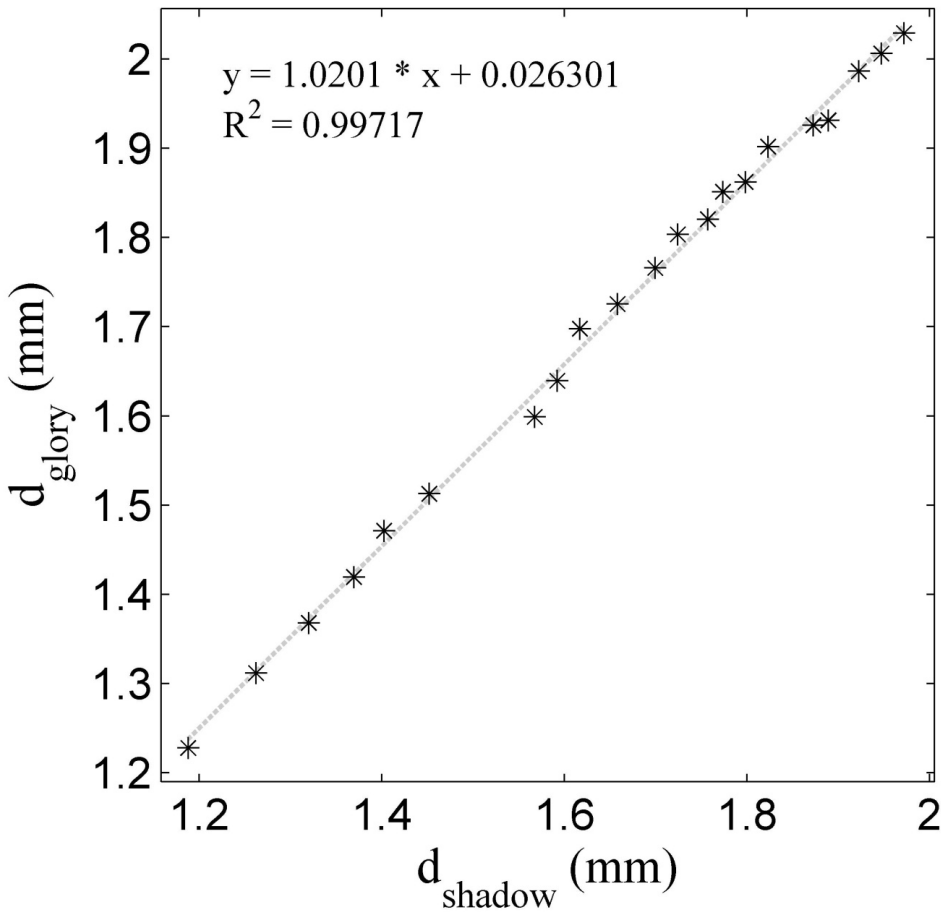
Experimental study



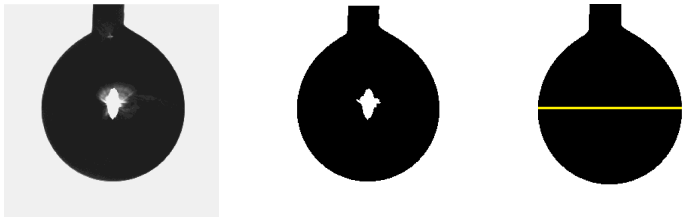
Experimental study

- Glory measurements:

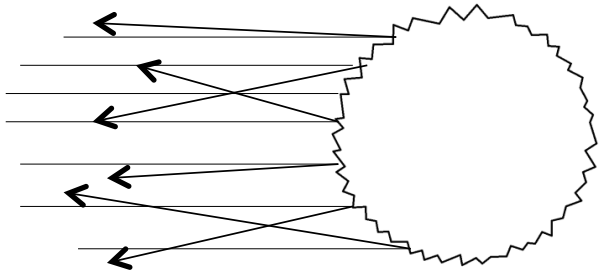


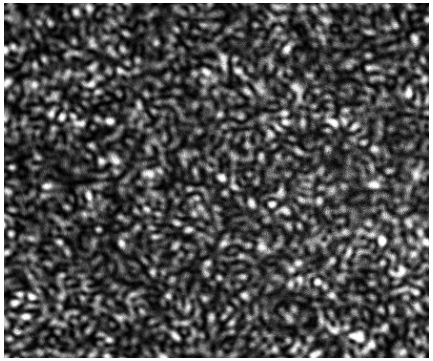


- Shadowgraphy measurements:



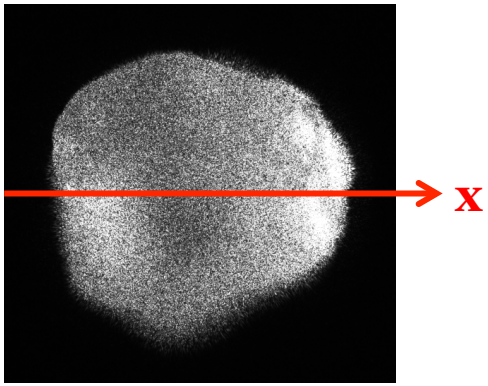
Measuring irregular particles: The speckle pattern

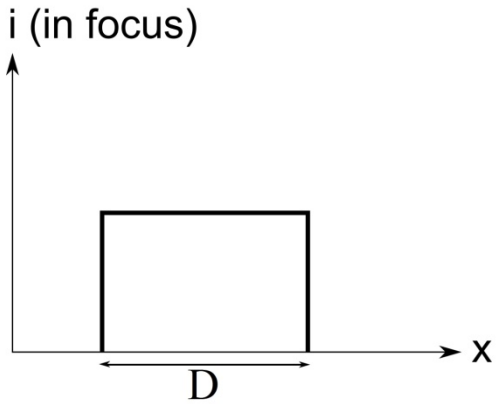


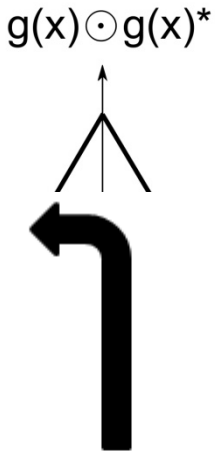


Wiener-Khintchine theorem

- In focus:



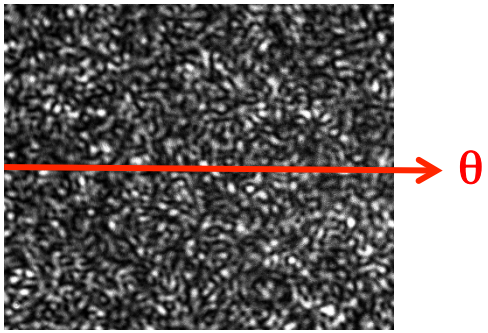


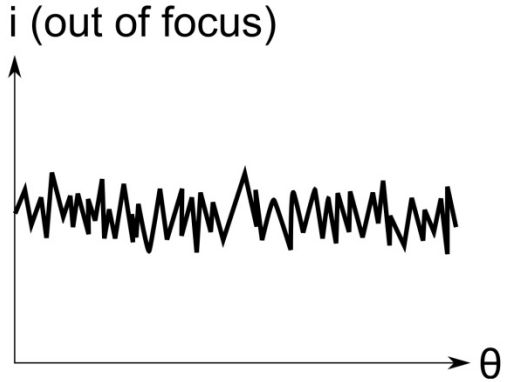


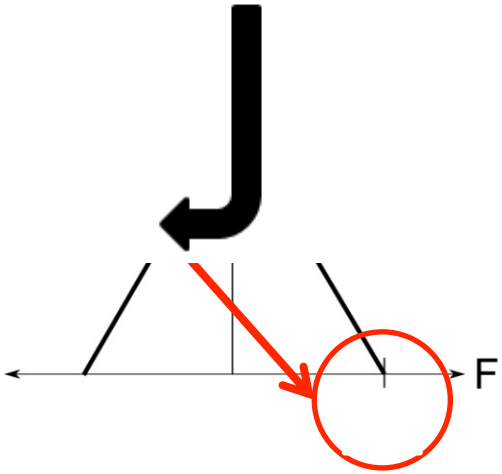
$F_D = D/\lambda$

$g(x) \odot g^*(x) = F\{i(\theta)\}$

- Out of focus:

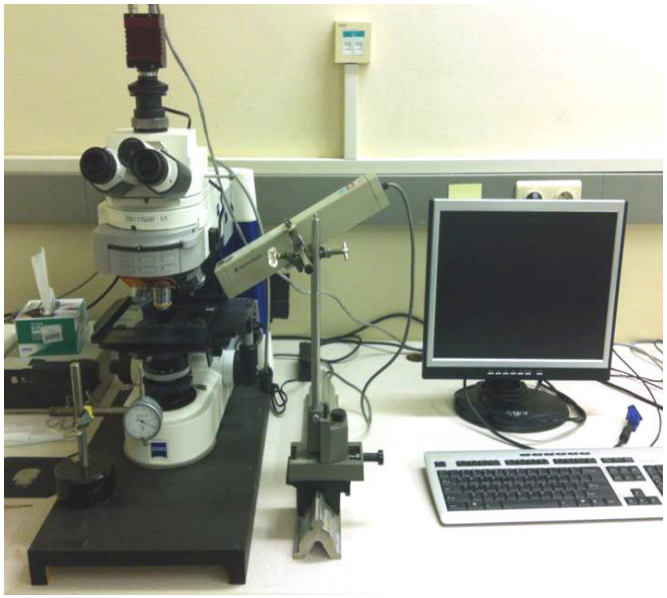


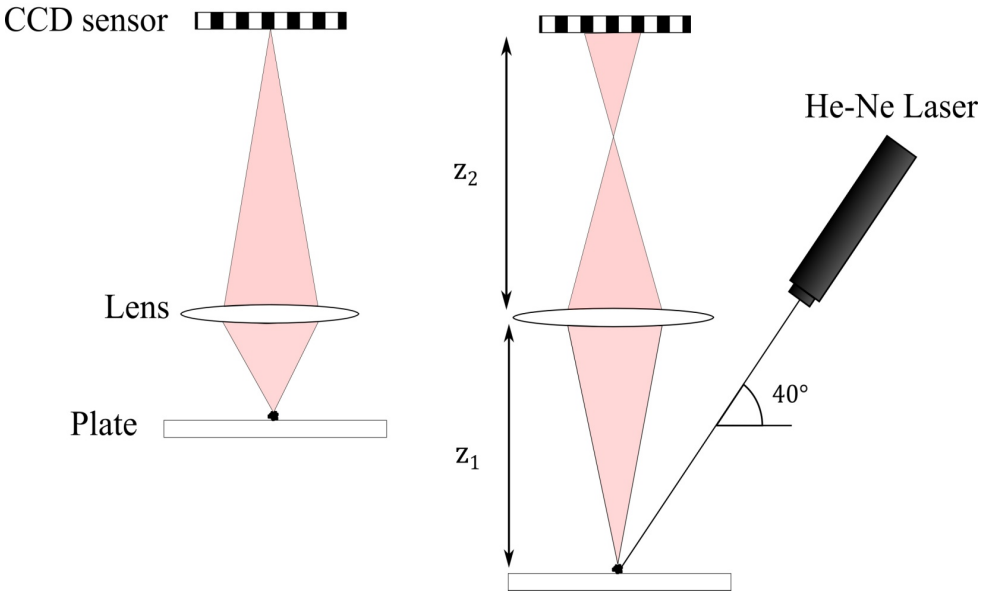




Gonzalez Ruiz (2014), Garcia Carrascal (2014)

Experimental study

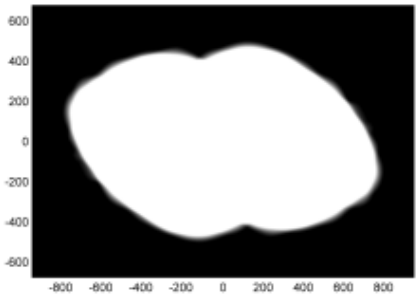


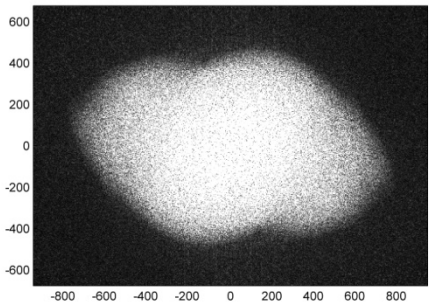


particle

⇩

autocorrelation



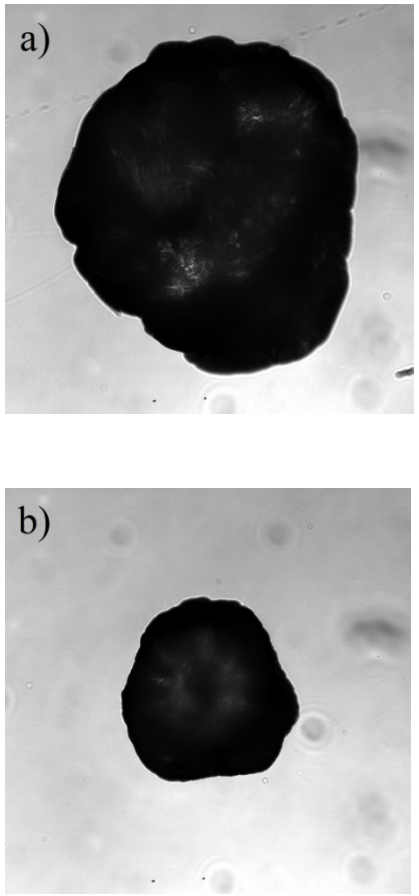


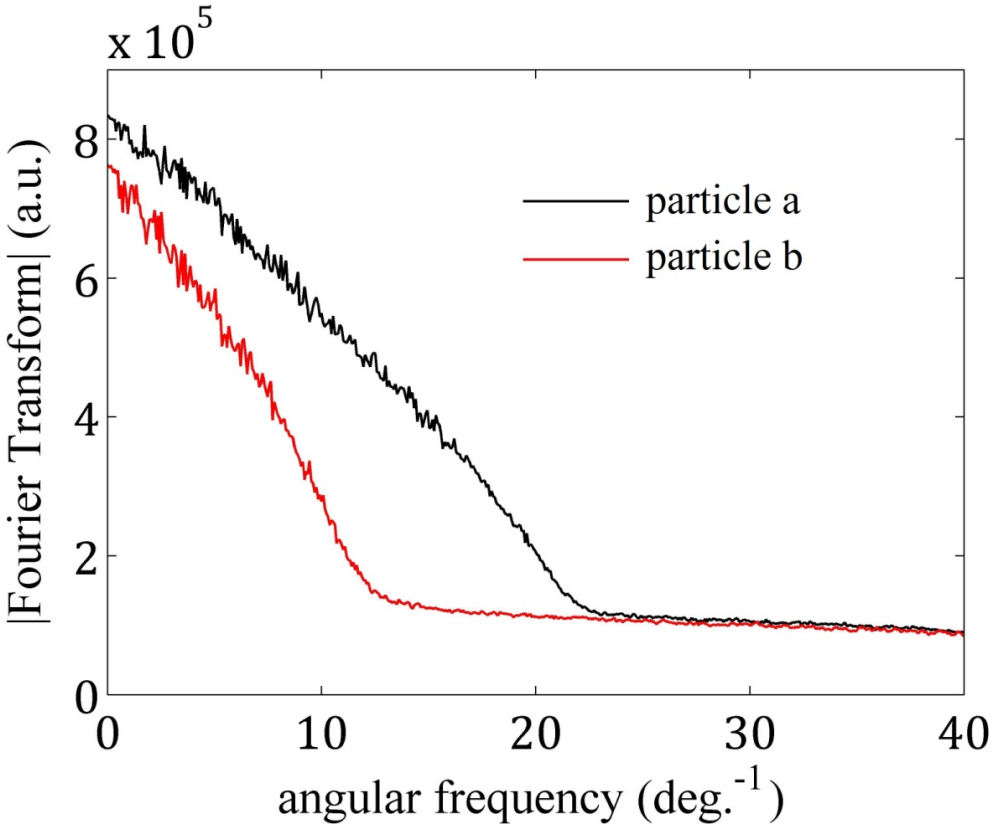
speckle pattern

⇩

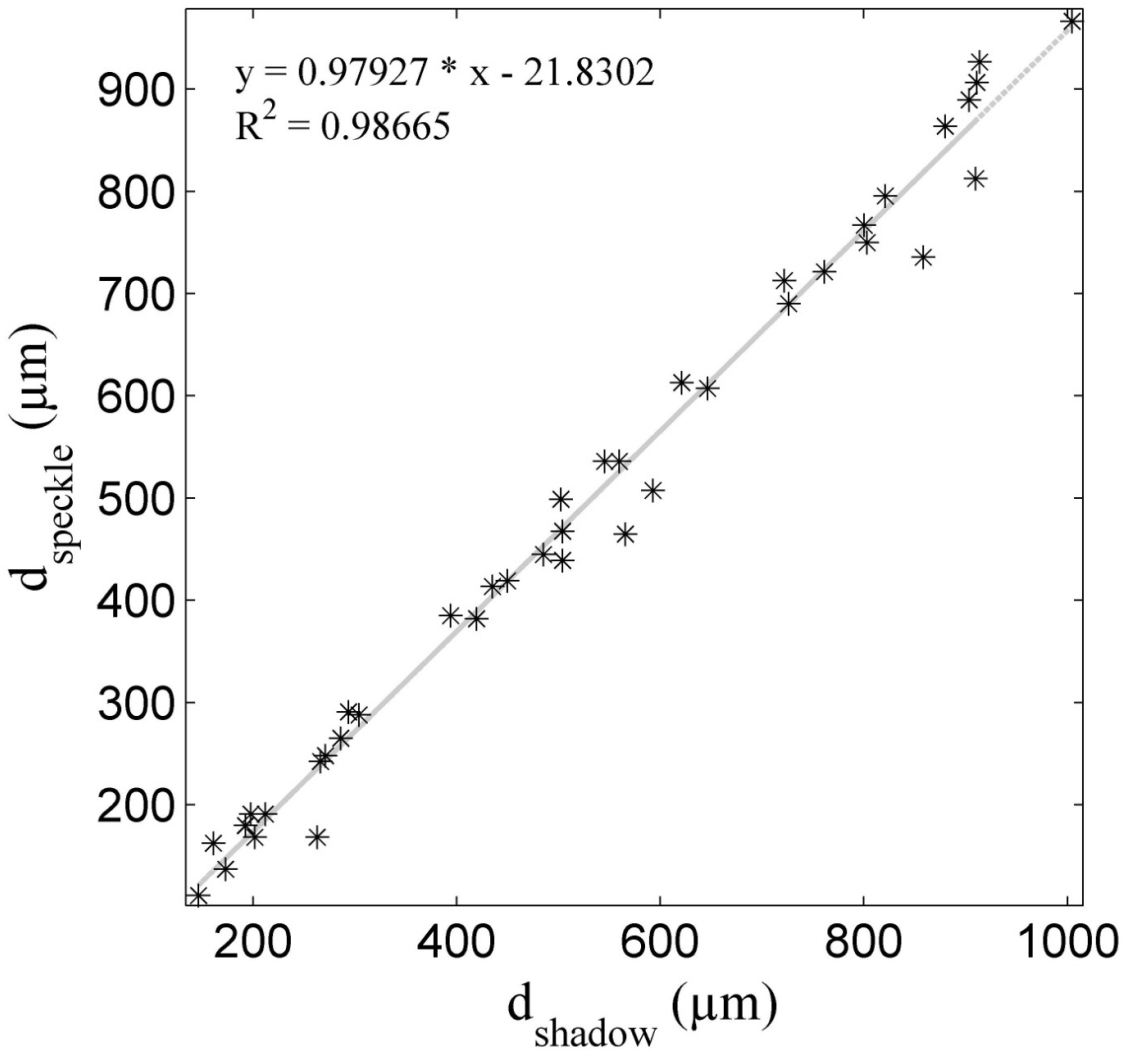
Fourier Transform

Experimental study





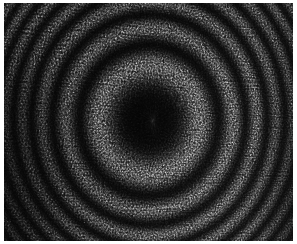
Experimental study



Conclusions

BACKSCATTERED LIGHT

water droplet



GLORY PATTERN

big droplets:

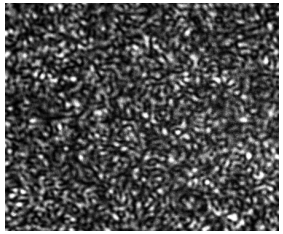
$d = f(\theta_1, \theta_2)$

small droplets:

$d = f(F_3)$

irregular particle

SPECKLE PATTERN



$D = f(F_D)$

Thank you for your attention!