Probing the transverse coherence of an undulator X-ray beam using brownian particles

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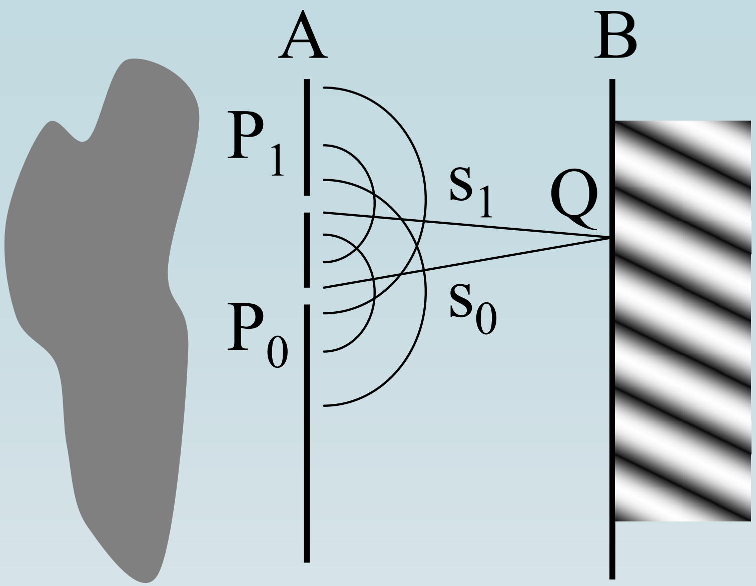
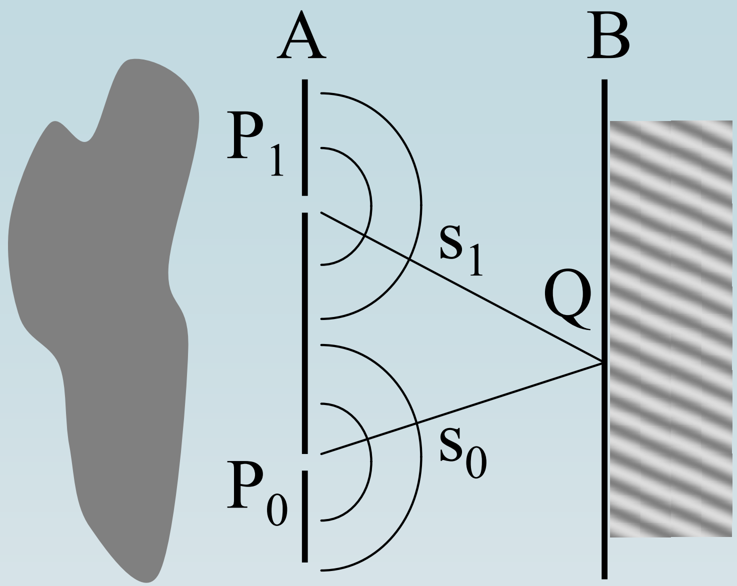
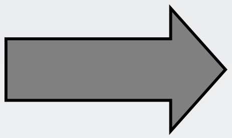




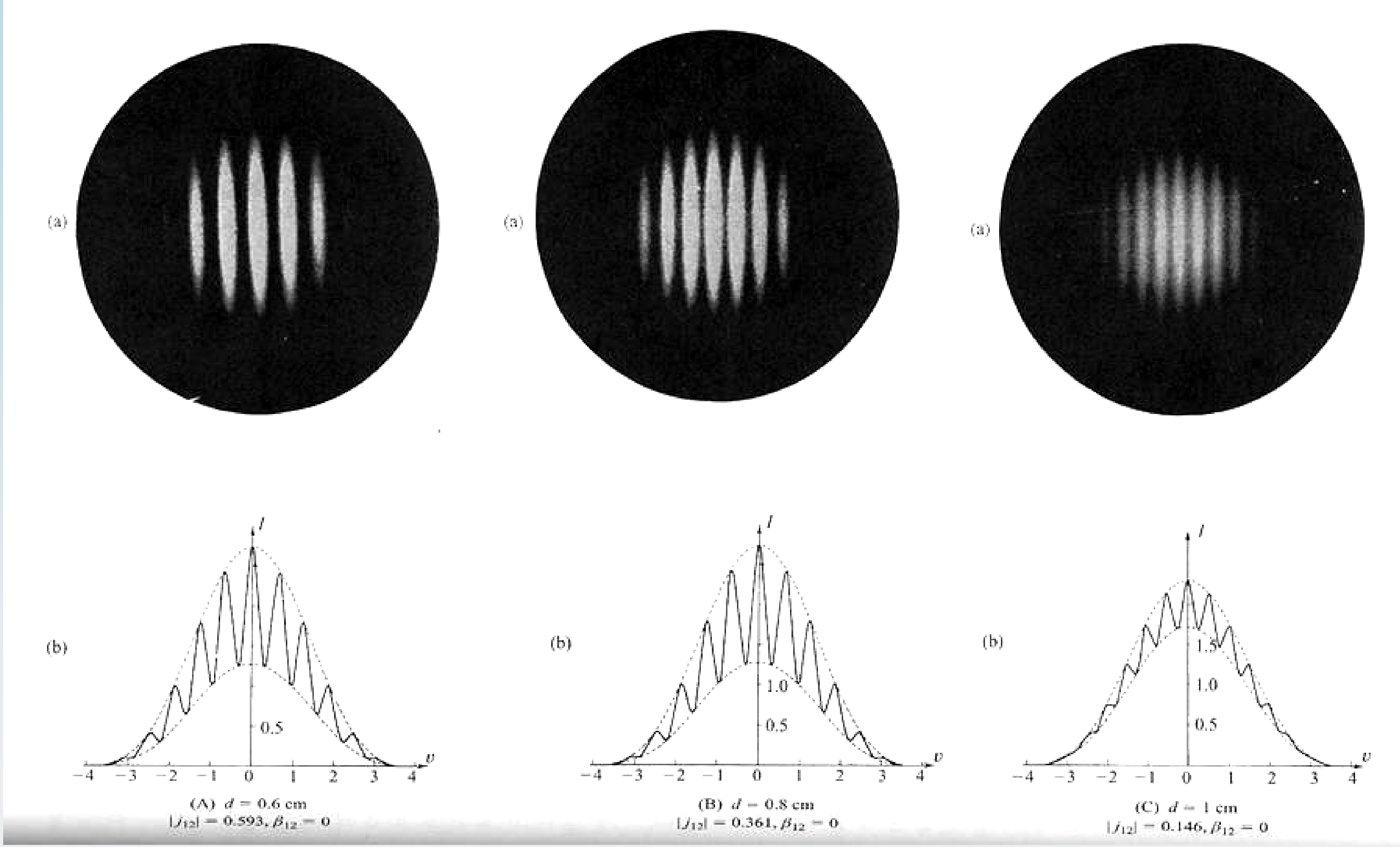
Visibility: $$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

Complex coherence factor:

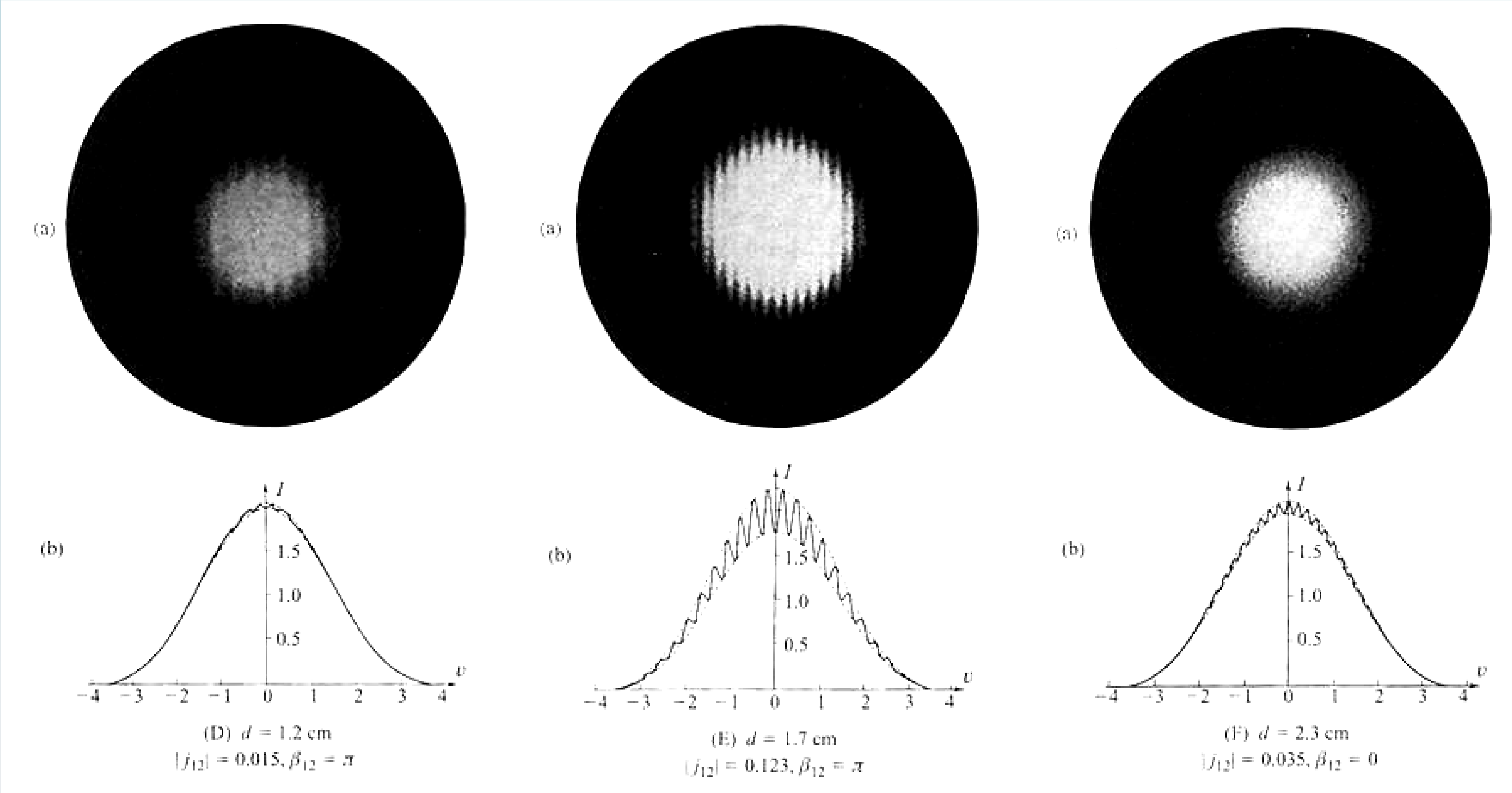
$$\mu(P_0, P_1) = \frac{\langle E(P_0) E^*(P_1) \rangle}{\sqrt{\langle I(P_0) \rangle \langle I(P_1) \rangle}}$$



$$V = |\mu(P_0, P_1)|$$

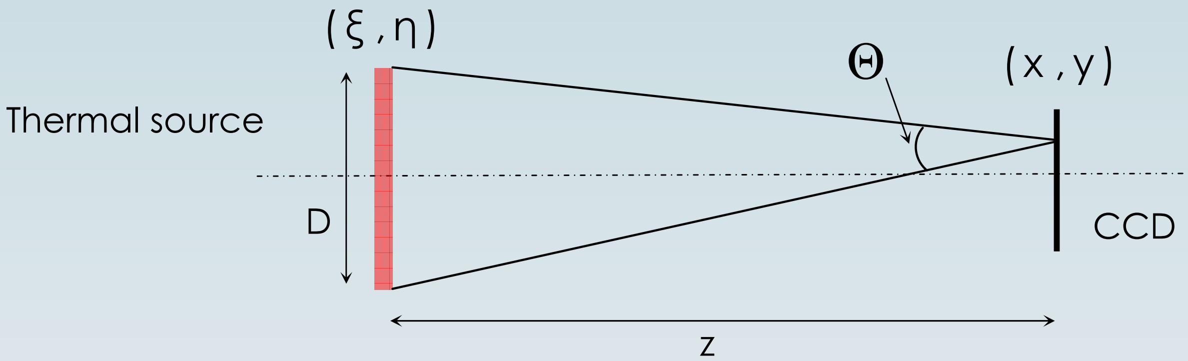


M. Born and E. Wolf,
Principles of Optics



M. Born and E. Wolf,
Principles of Optics

$$< E(x_1, y_1)E^*(x_2, y_2) > \propto \iint I(\xi,\eta)\exp\left[i\,\frac{2\pi}{\lambda z}(\xi\Delta x + \eta\Delta y)\right]d\xi d\eta$$

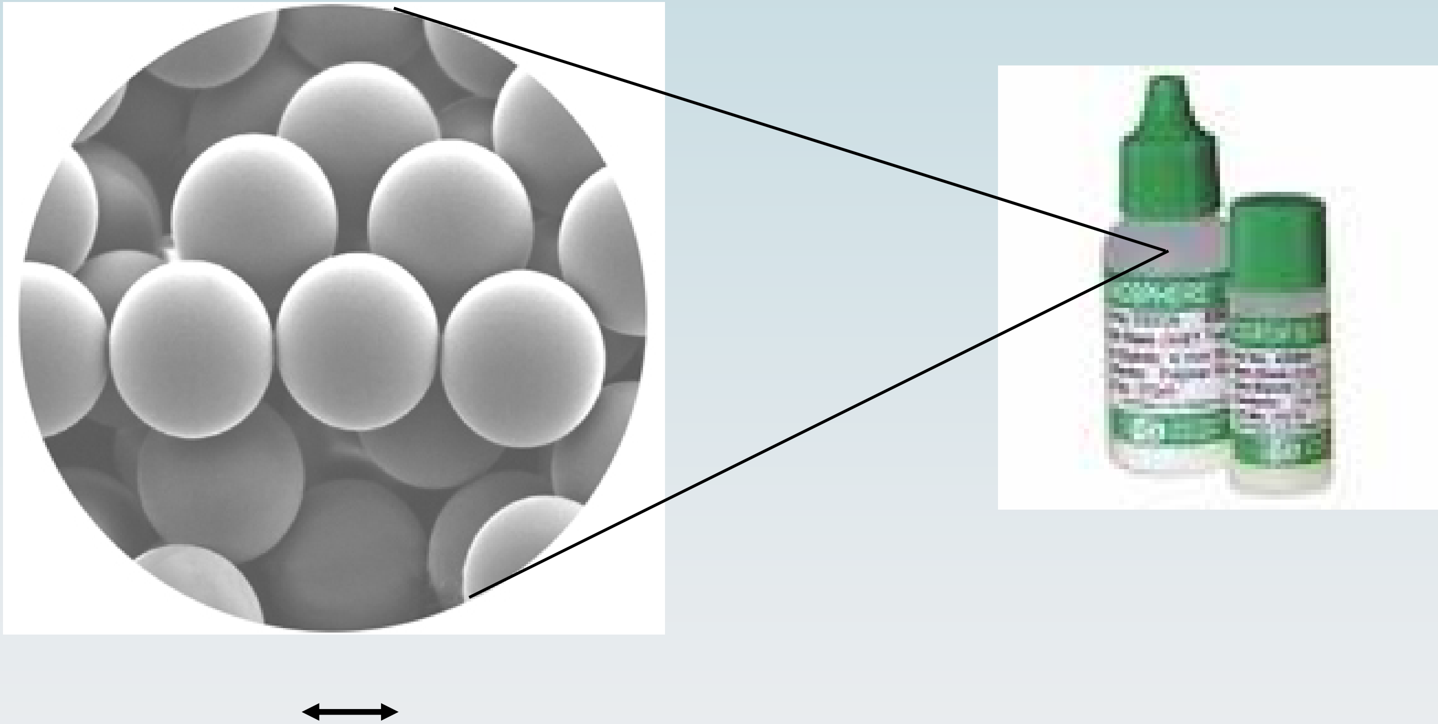


Average size of a coherent patch generated by a thermal source (Van Citter-Zernike theorem)

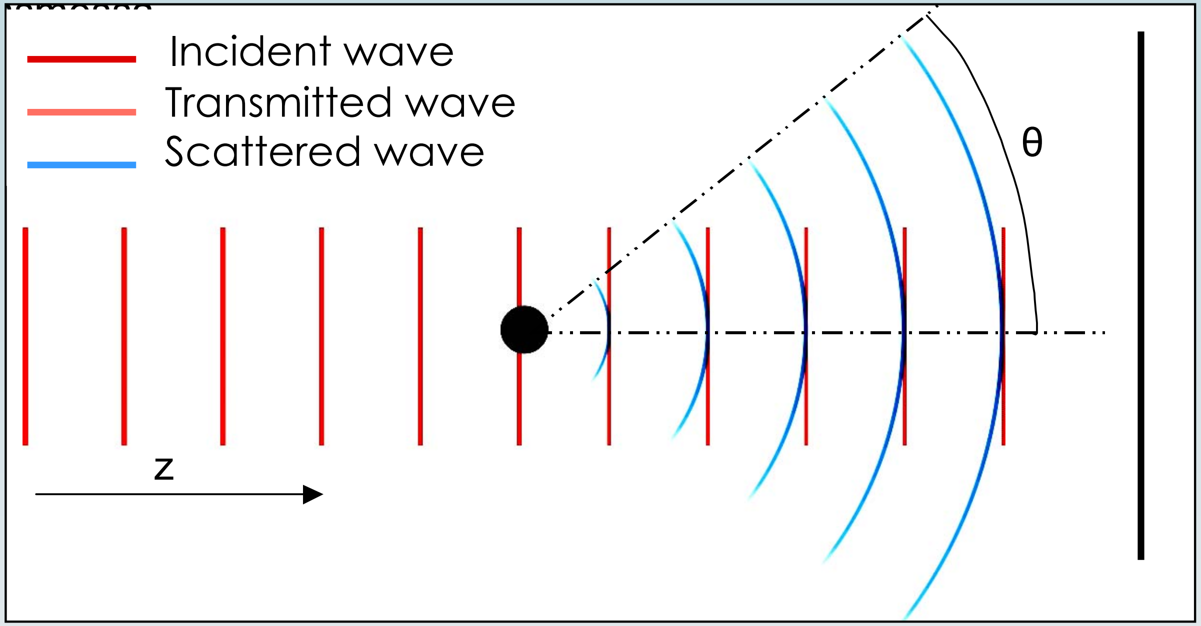
$$d \sim \lambda/\Theta \sim \lambda z/D$$

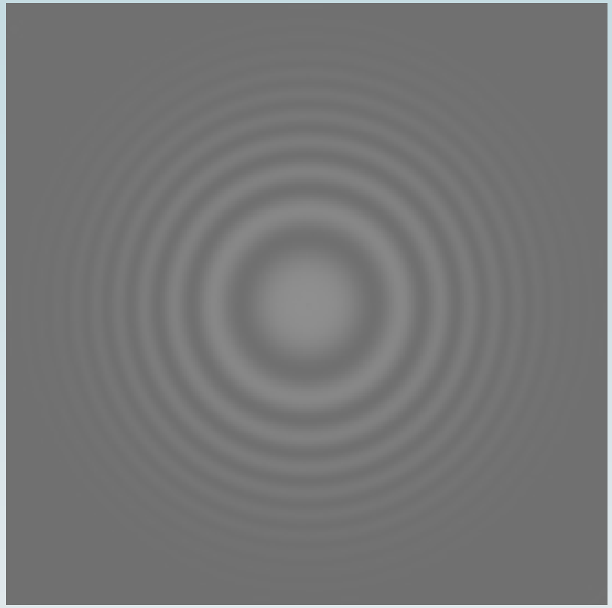
The shape and the size of the coherent patches at the sensor plane depend only on the profile of the source.

Testing coherence with small spheres



450 nm





Interference fringes

Intensity distribution

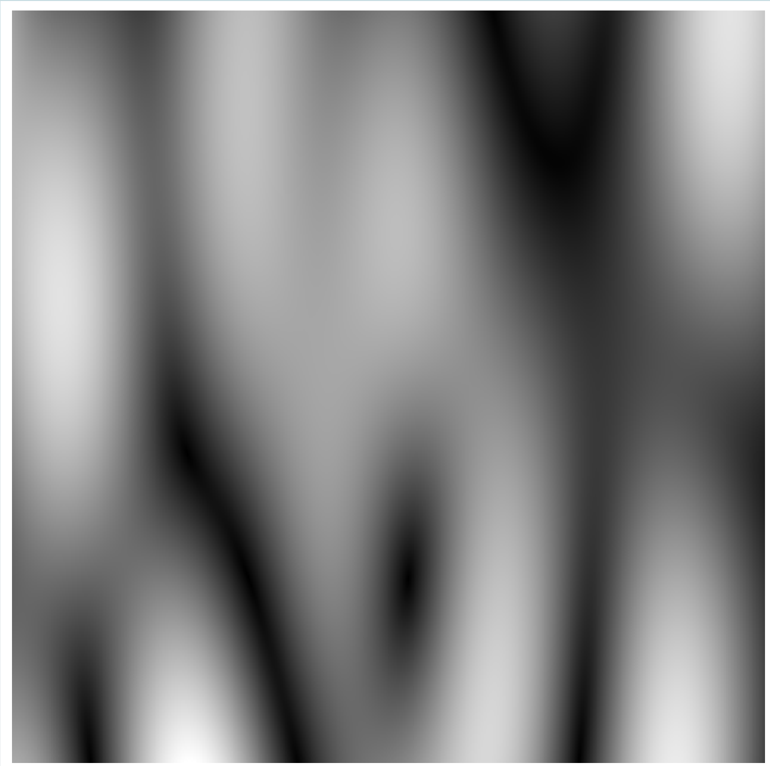
$$I = |E_0 + E_s|^2 = |E_0|^2 + 2\mathrm{Re}(E_0\, E_s) + |E_s|^2$$

Transmitted

Interference (Heterodyne)

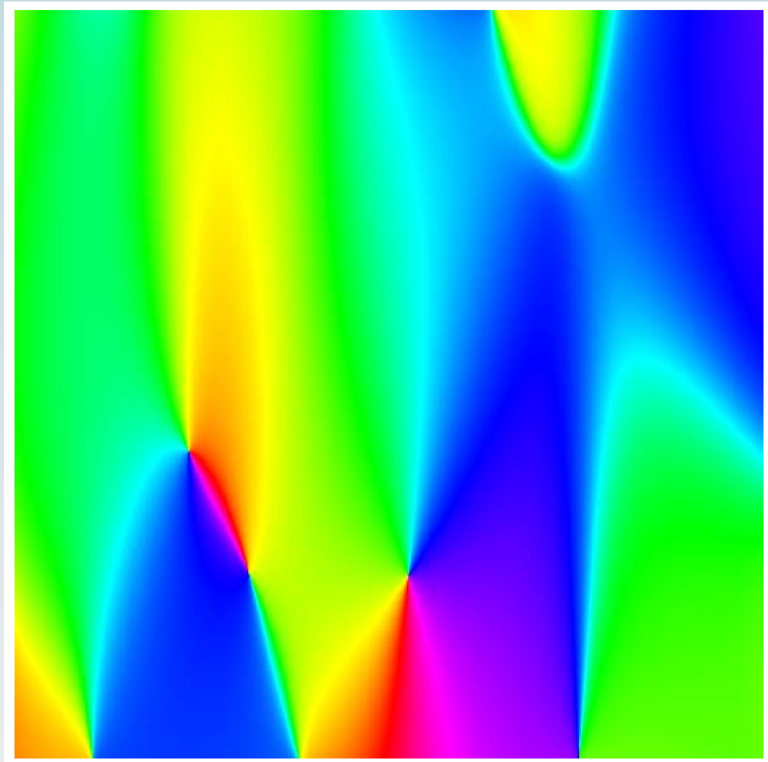
Homodyne

Simulated coherence patches from the synchrotron

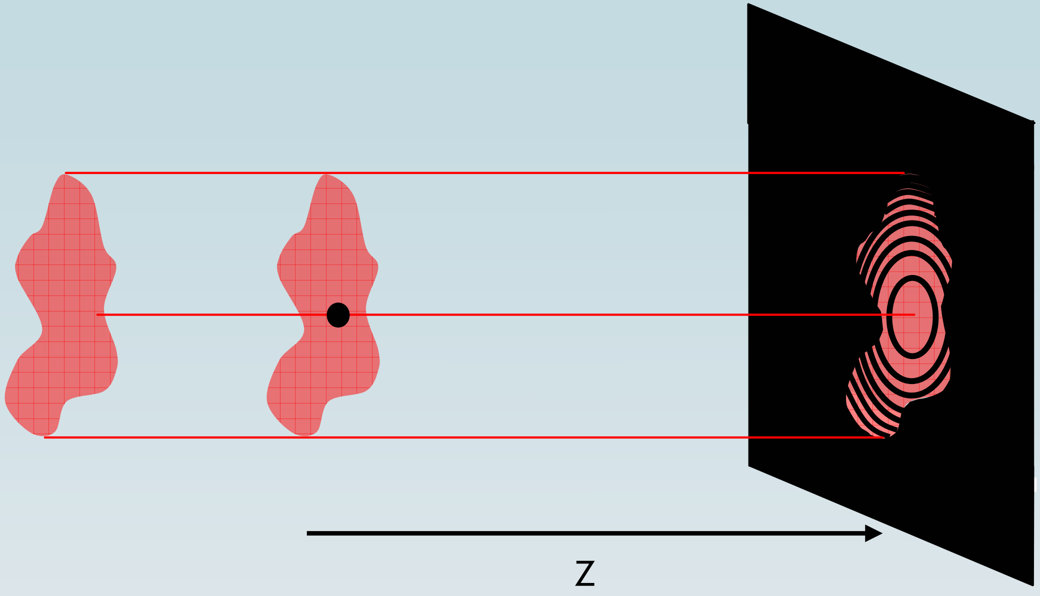


Intensity

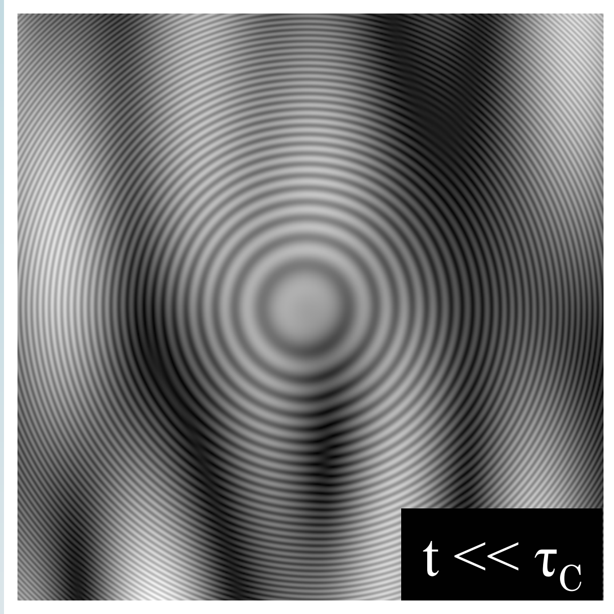
Temporal coherence:
$\tau_C = 10^{-17}$ sec

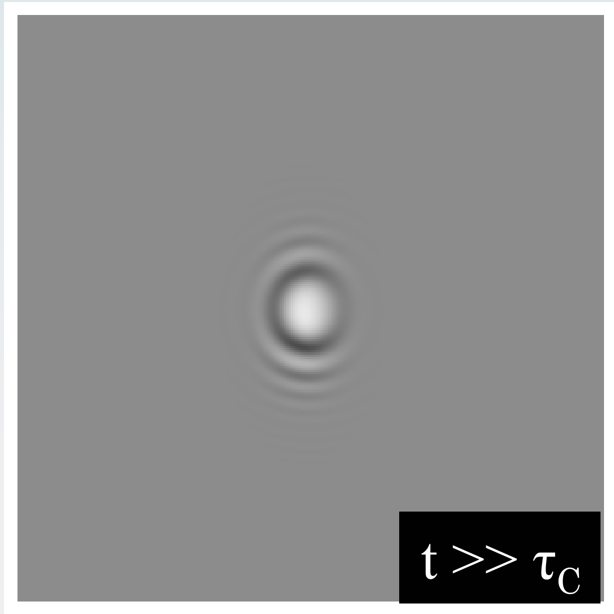


Phase



Simulation

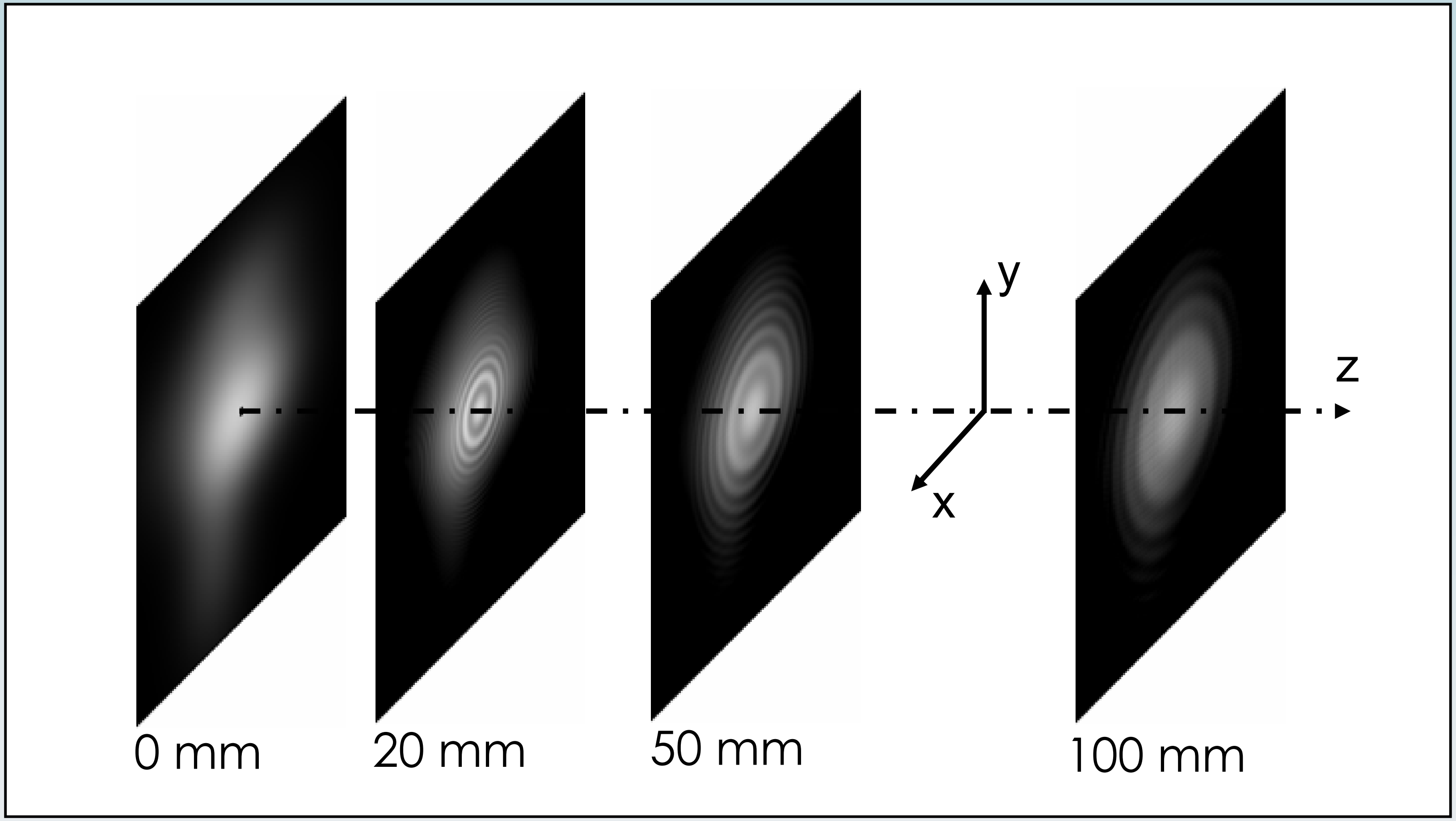


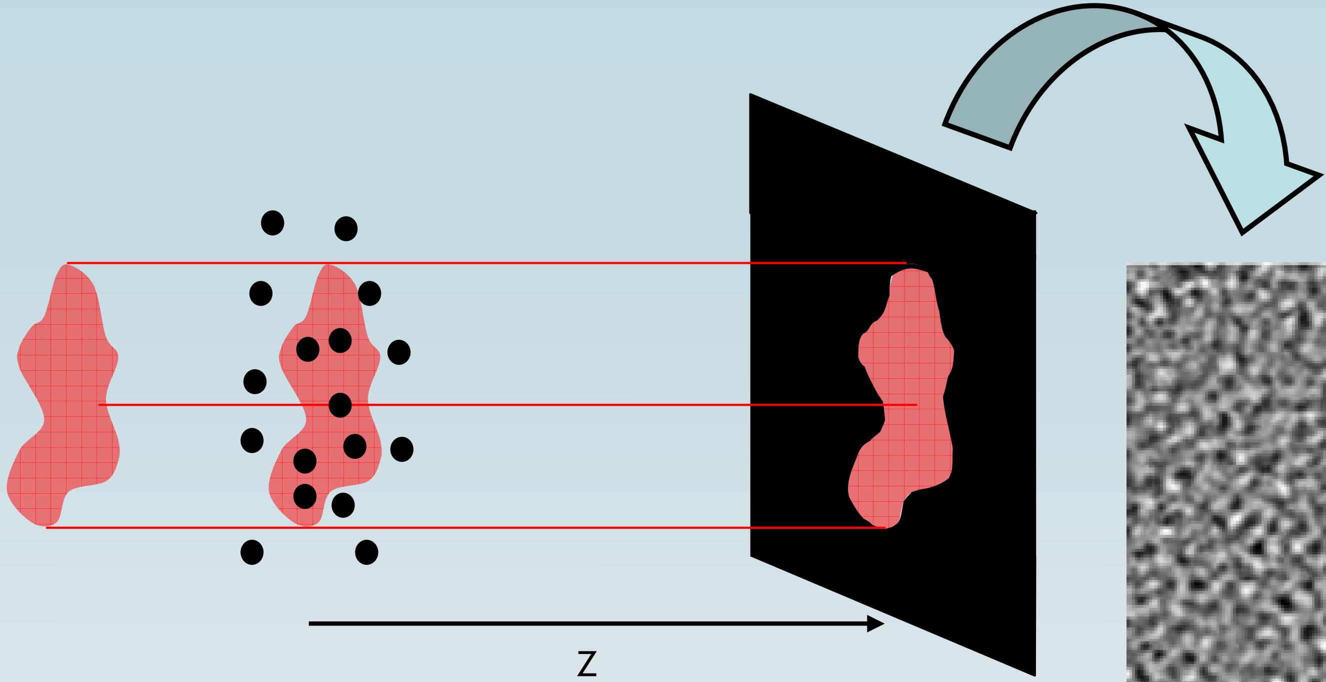


t: exposure time

τ_C: temporal coherence

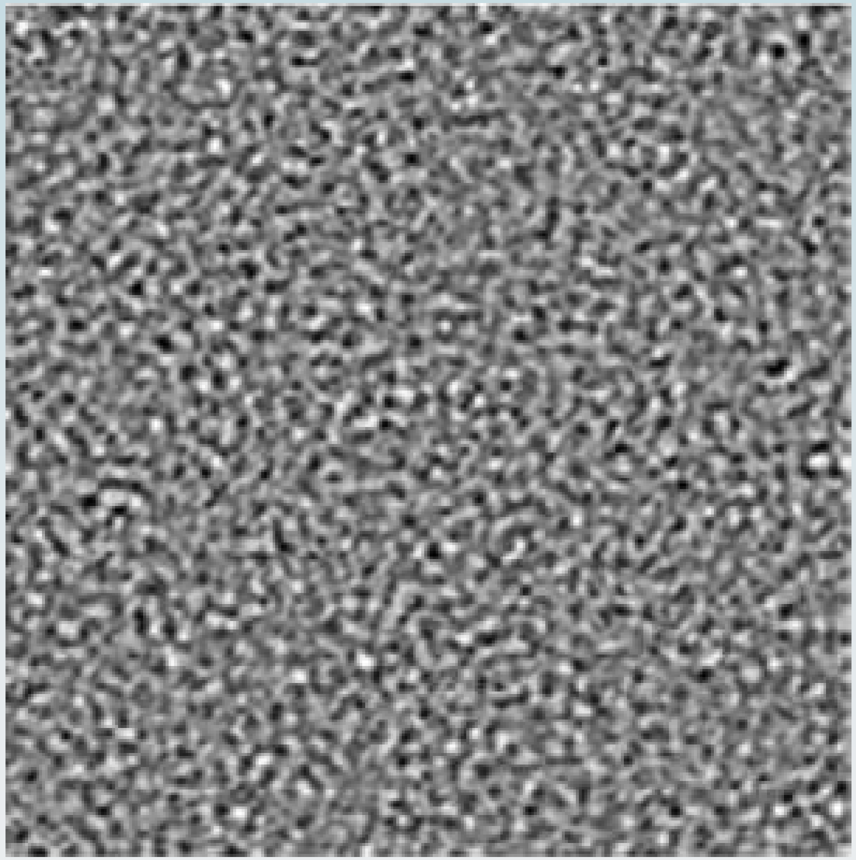
$\tau_C = 10^{-17}$ sec


y
z
x
0 mm
20 mm
50 mm
100 mm

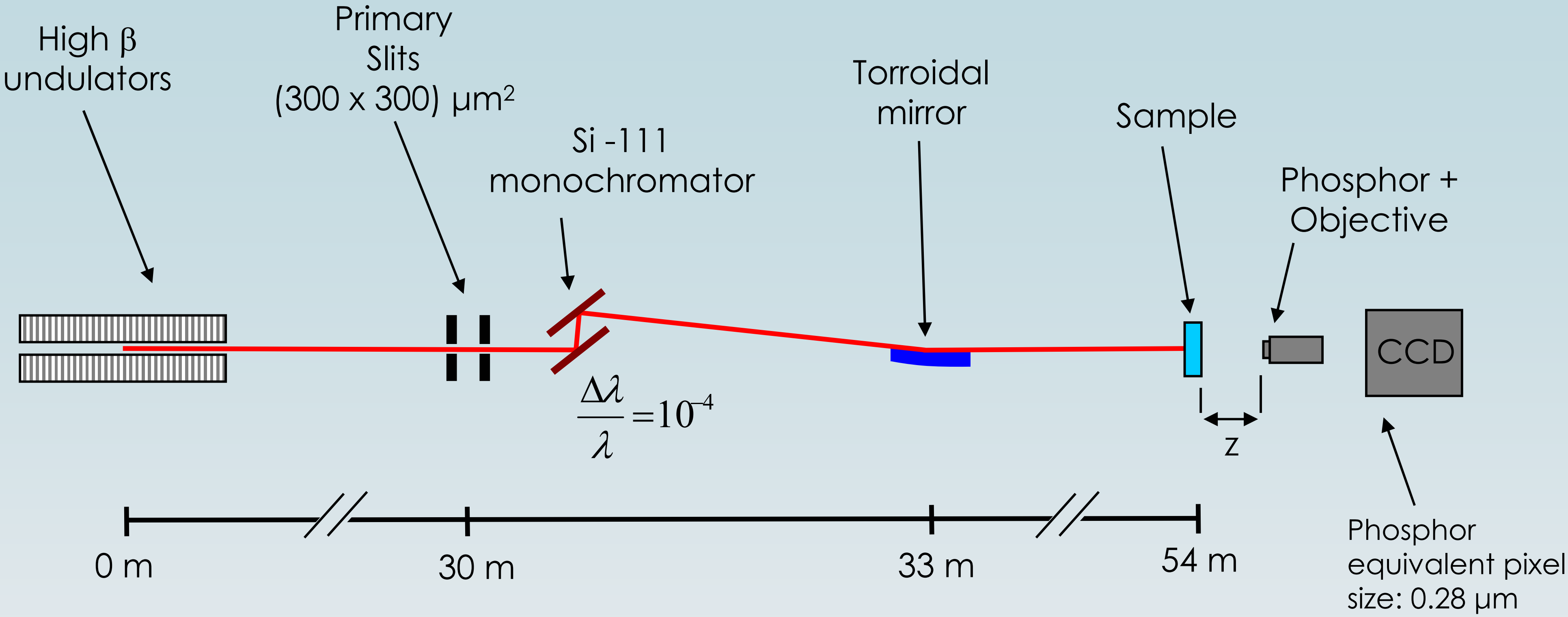


$$I = |E_0 + E_s|^2 = |E_0|^2 + 2\mathrm{Re}(E_0\,E_s) + \cancel{|E_s|^2}$$

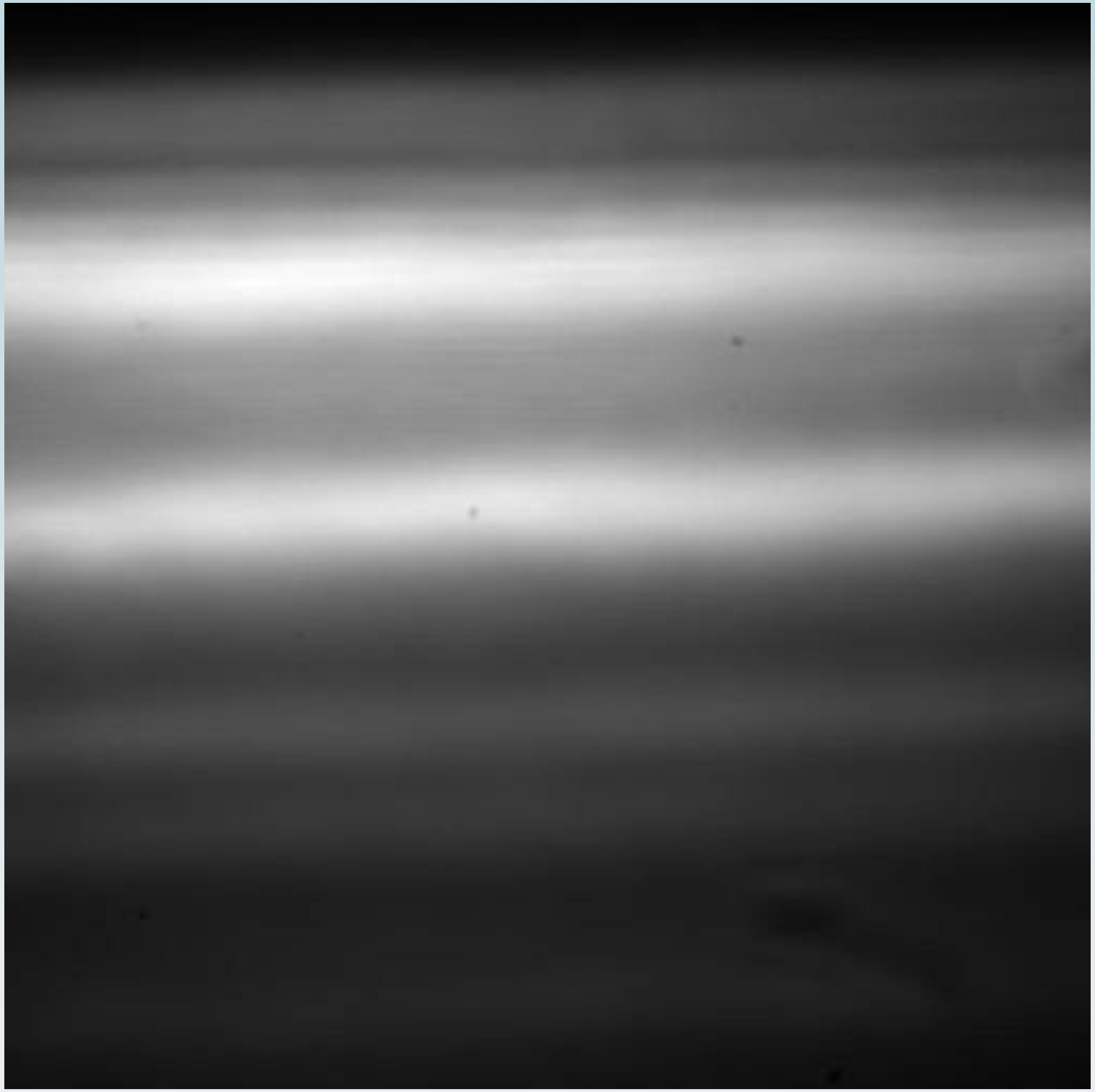
Transmitted — Interference (Heterodyne) — Homodyne



Heterodyne near field X-rays speckles generated by a water suspension of colloidal silica

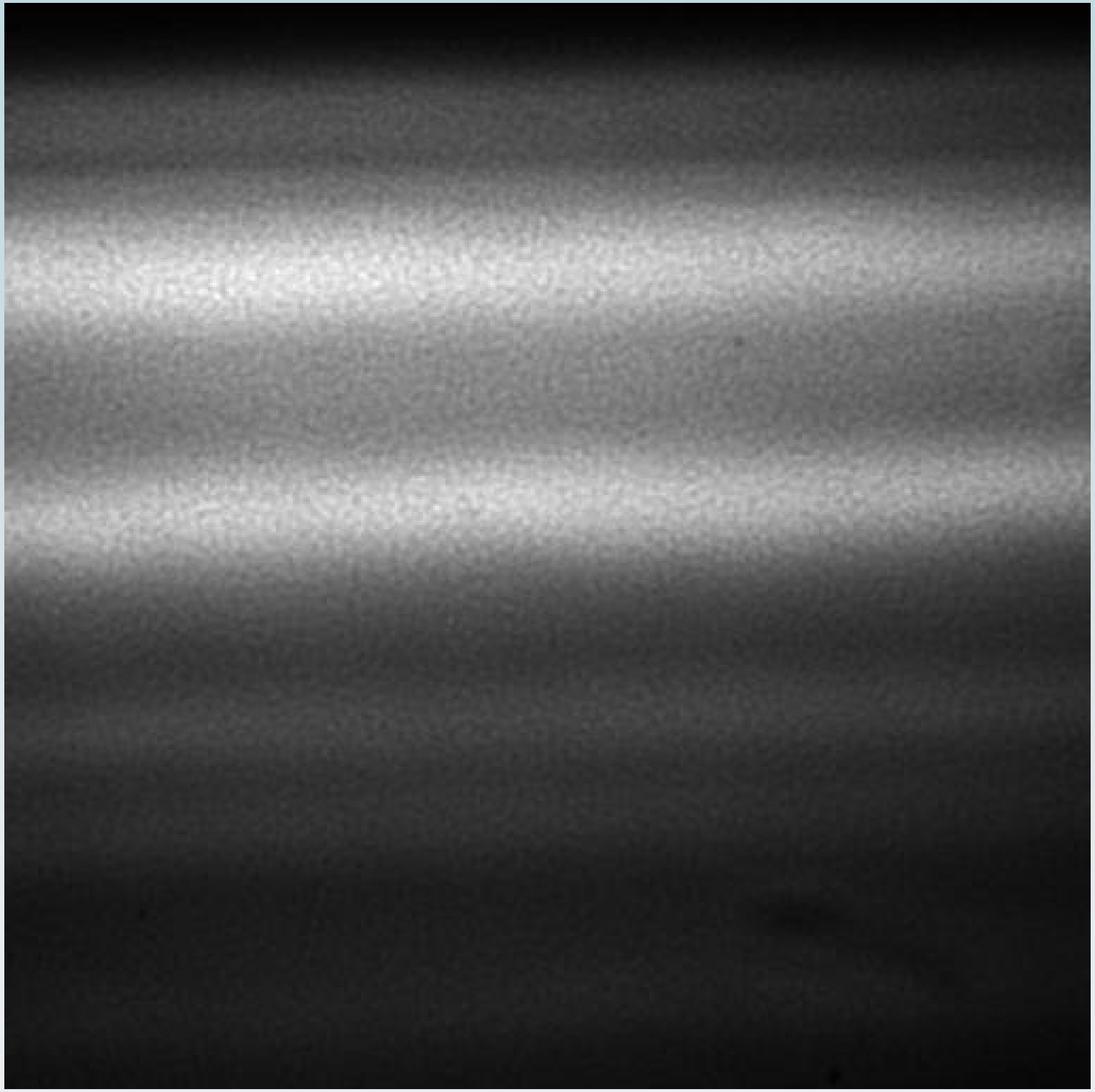


Source output
FWHM (945 x 18) μm²



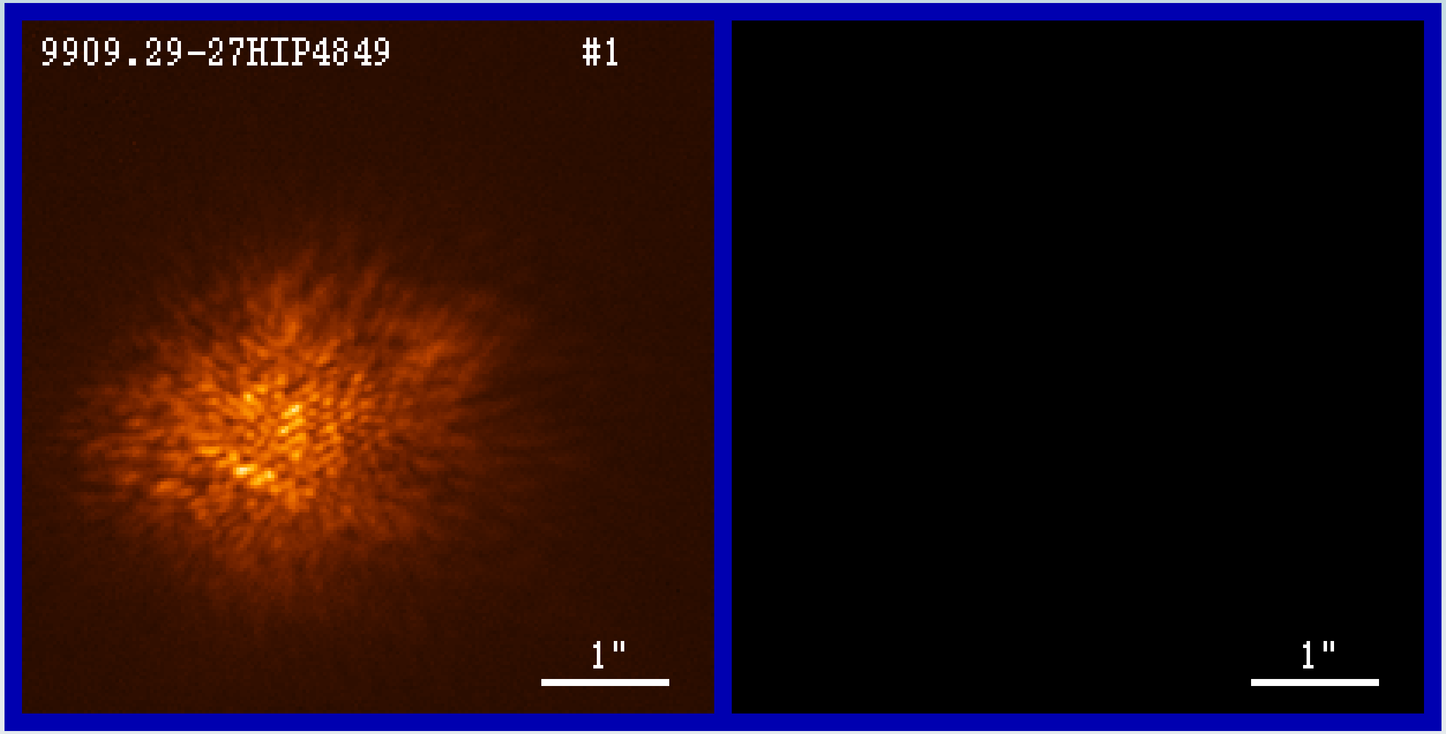
280 µm

$$I = \left|E_0\right|^2$$

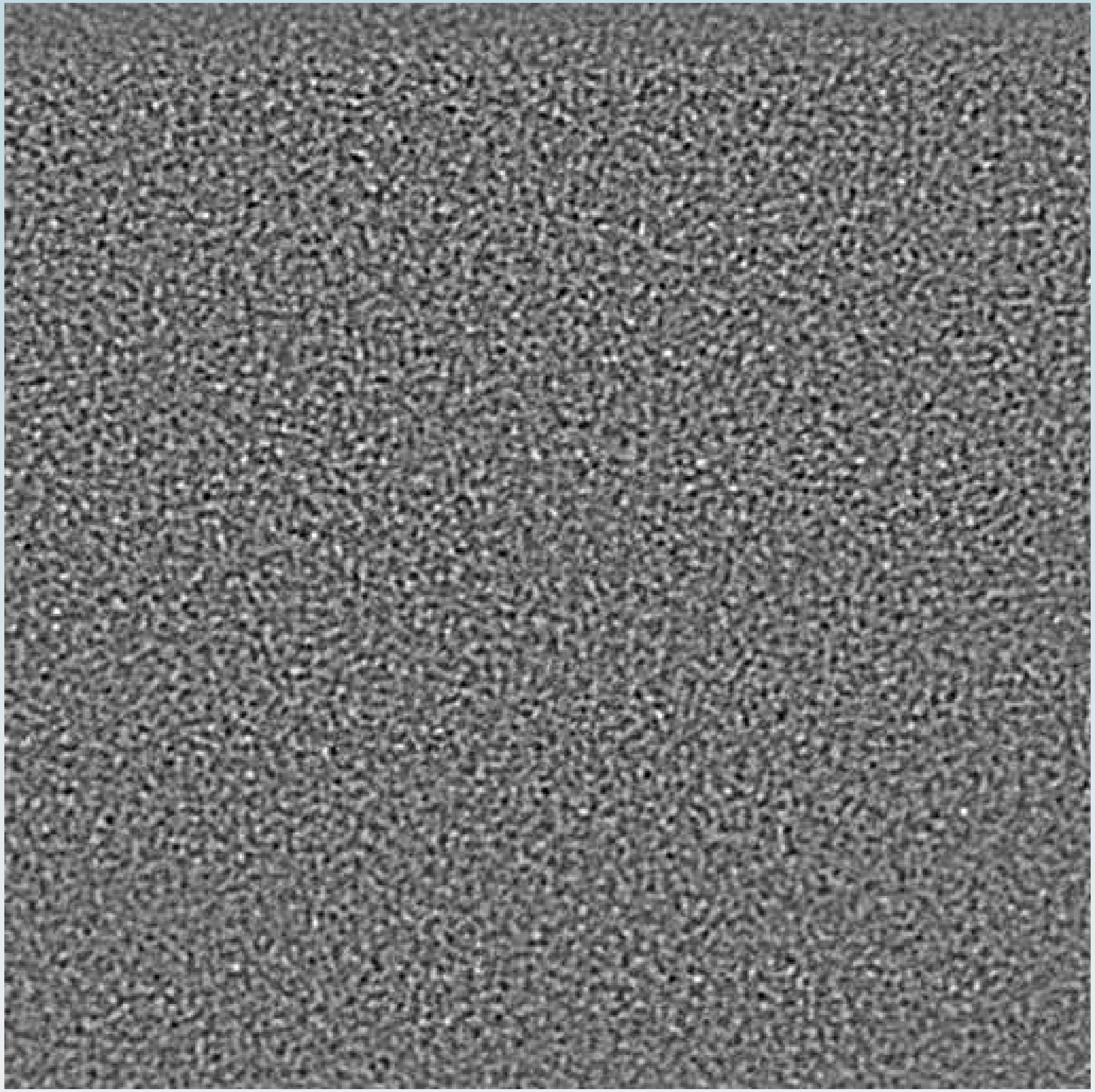


280 µm

$$I = \left|E_0\right|^2 + 2\mathrm{Re}(\,E_0\;E_s\,)$$

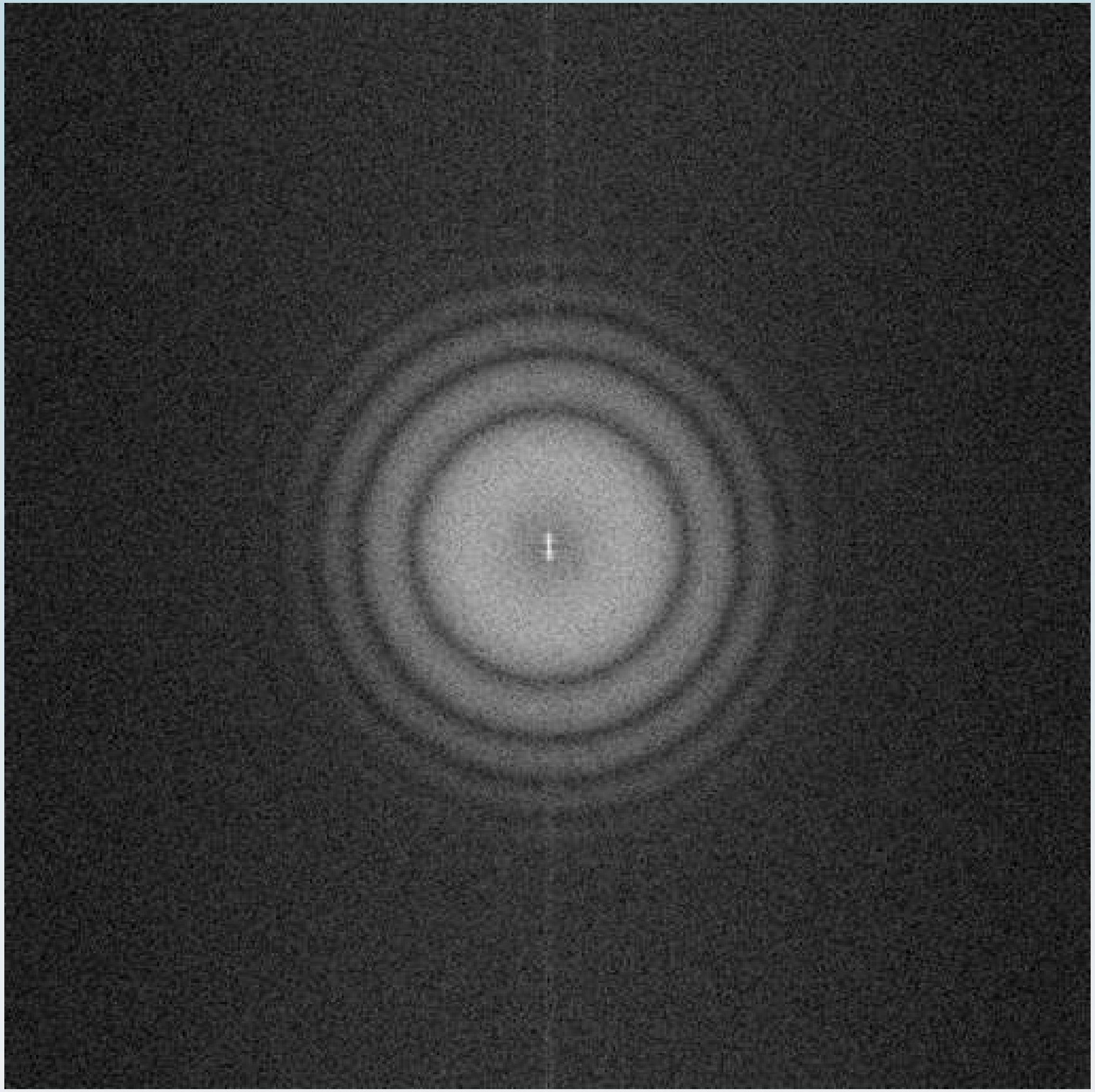


Courtesy of: Gerd Weigelt
Max-Planck-Institut für Radioastronomie, Bonn



280 µm

Cosmetics



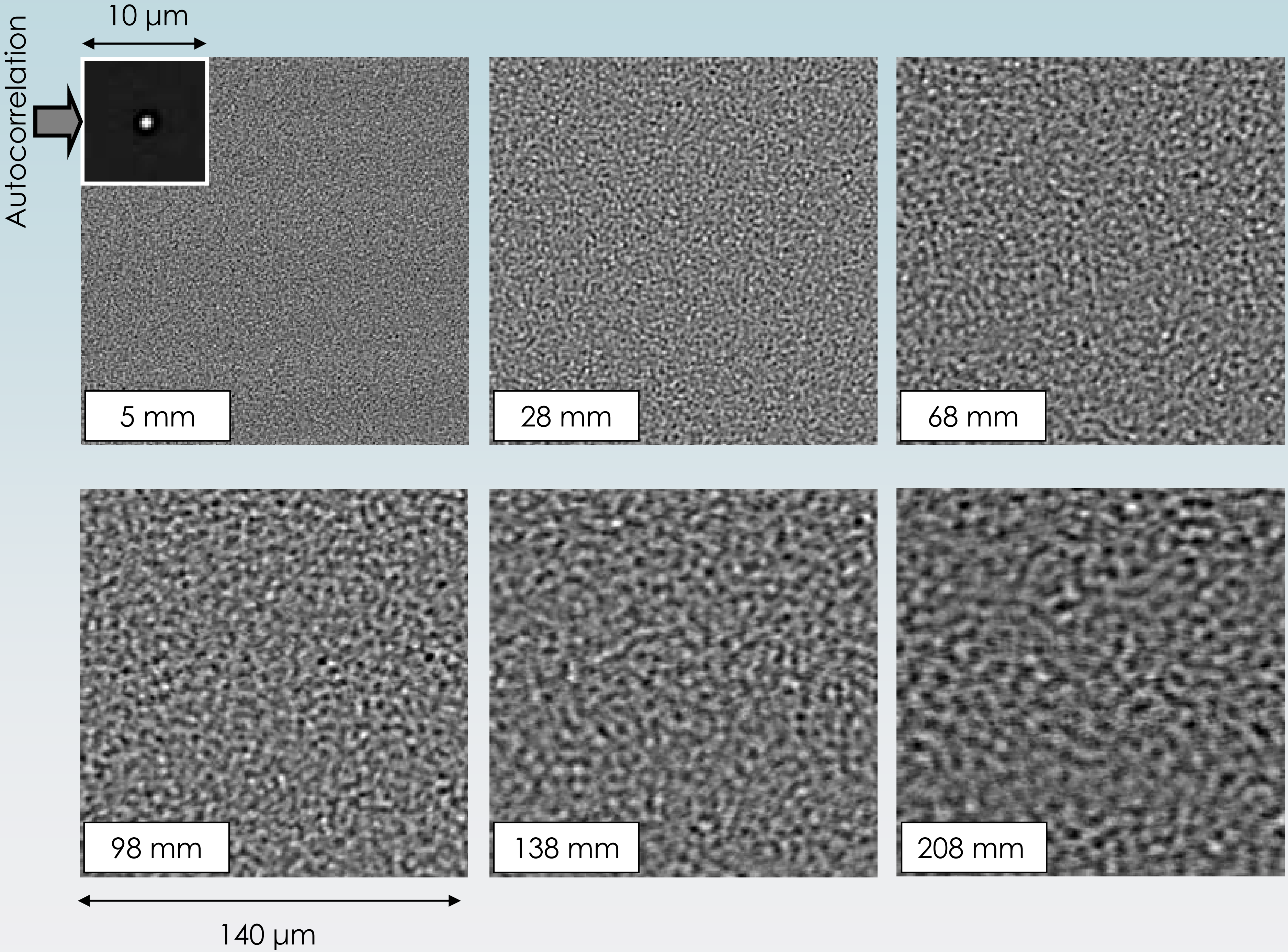
S(q) = I(q) T(q) P(q) C(q) + noise

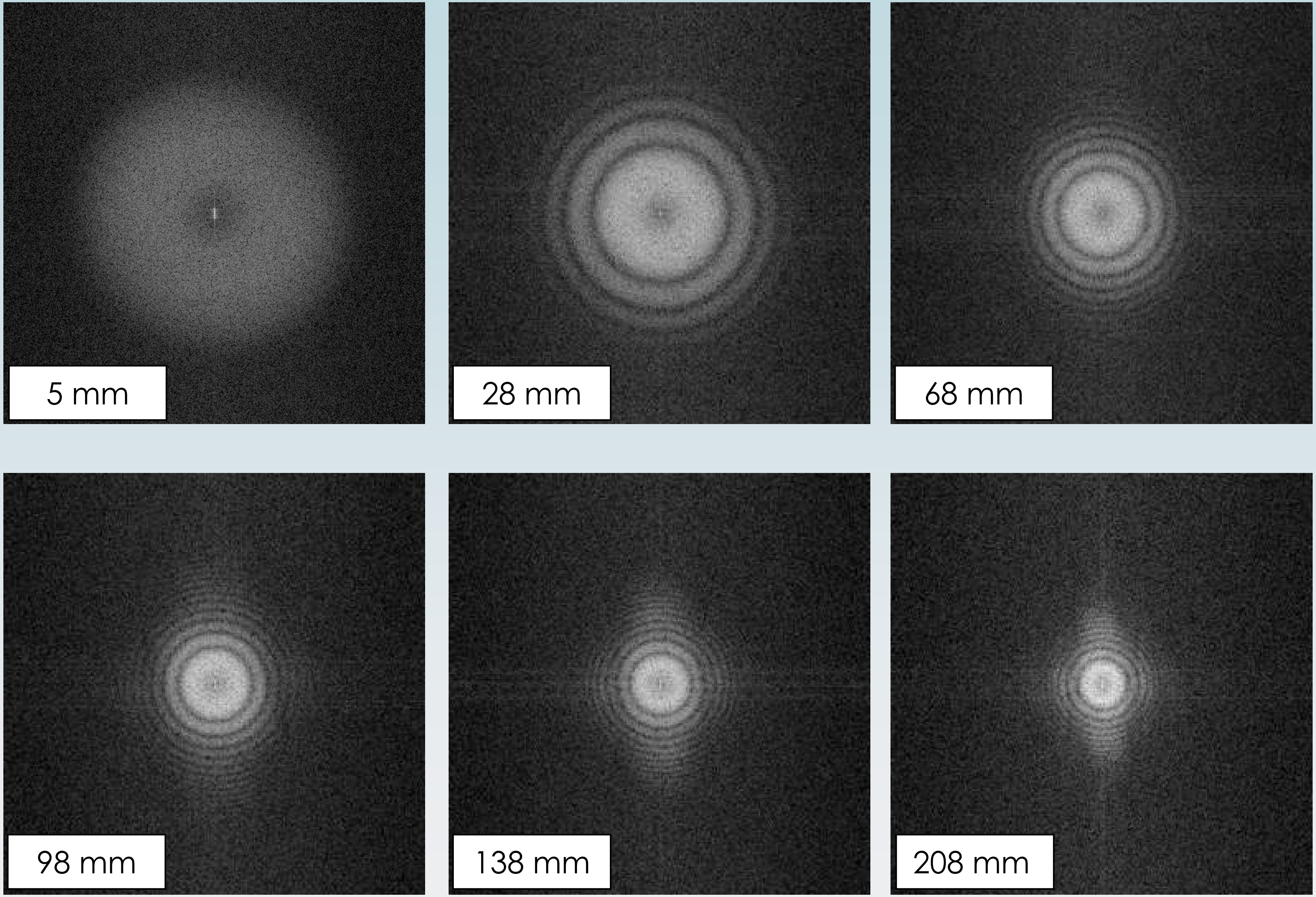
I(q) = Brownian particles form factor (almost flat)

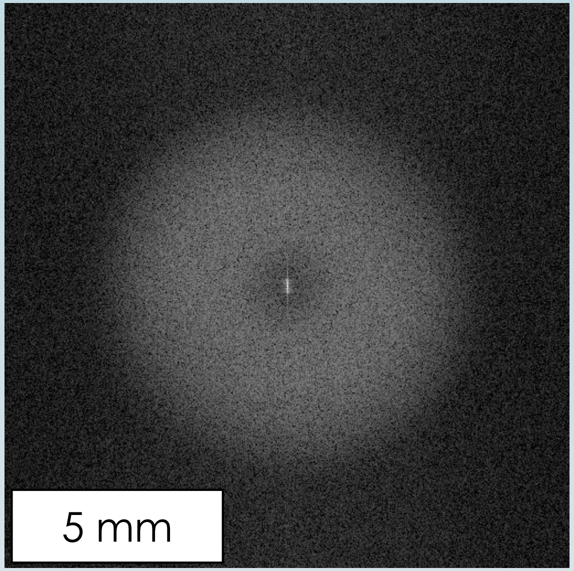
$T(q) = \sin^2(q^2 z/2\,k)$
Talbot transfer function

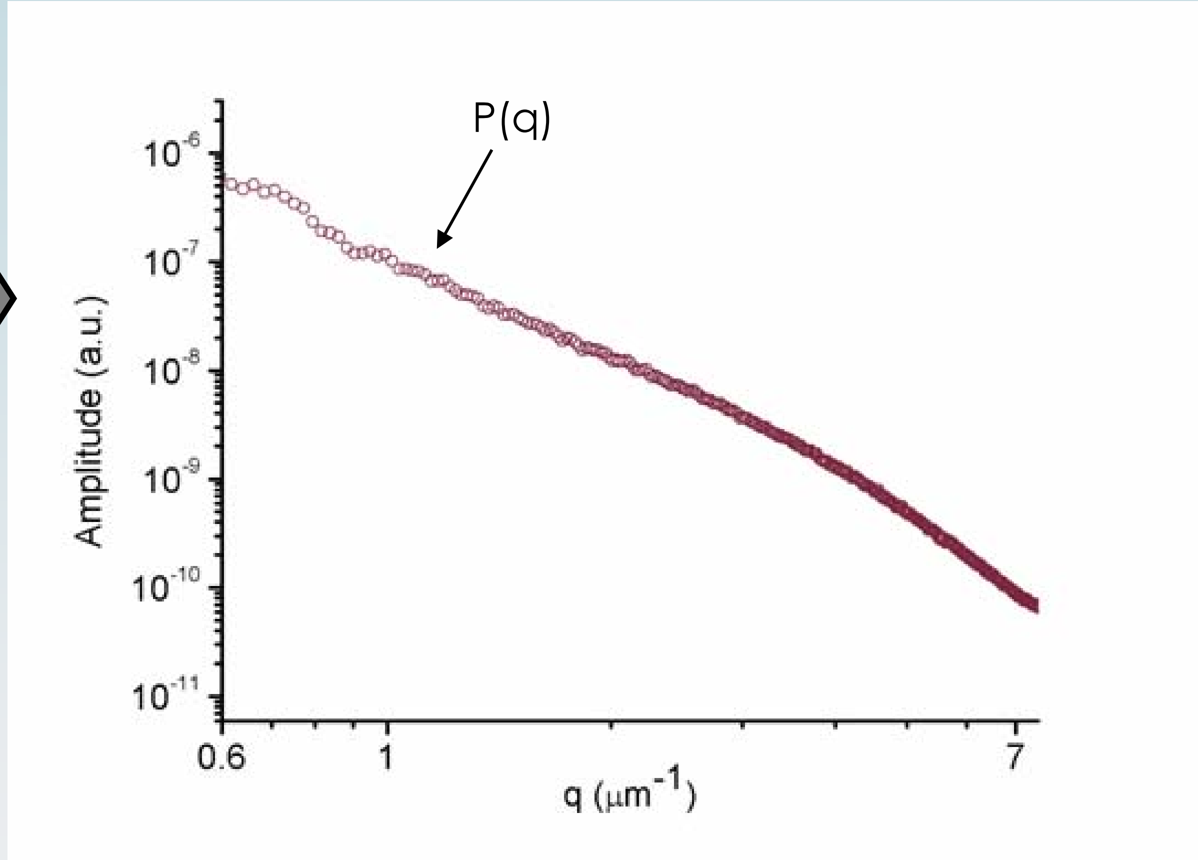
$C(q) = |\mu|^2$

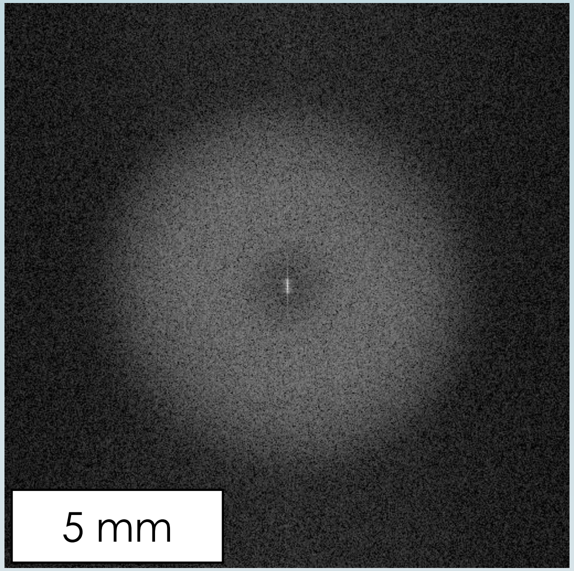
P(q) = Sensor transfer function

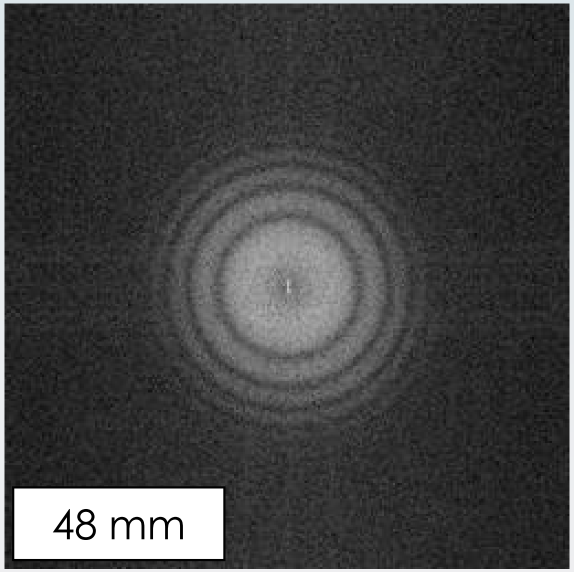

10 µm
Autocorrelation
5 mm
28 mm
68 mm
98 mm
138 mm
208 mm
140 µm

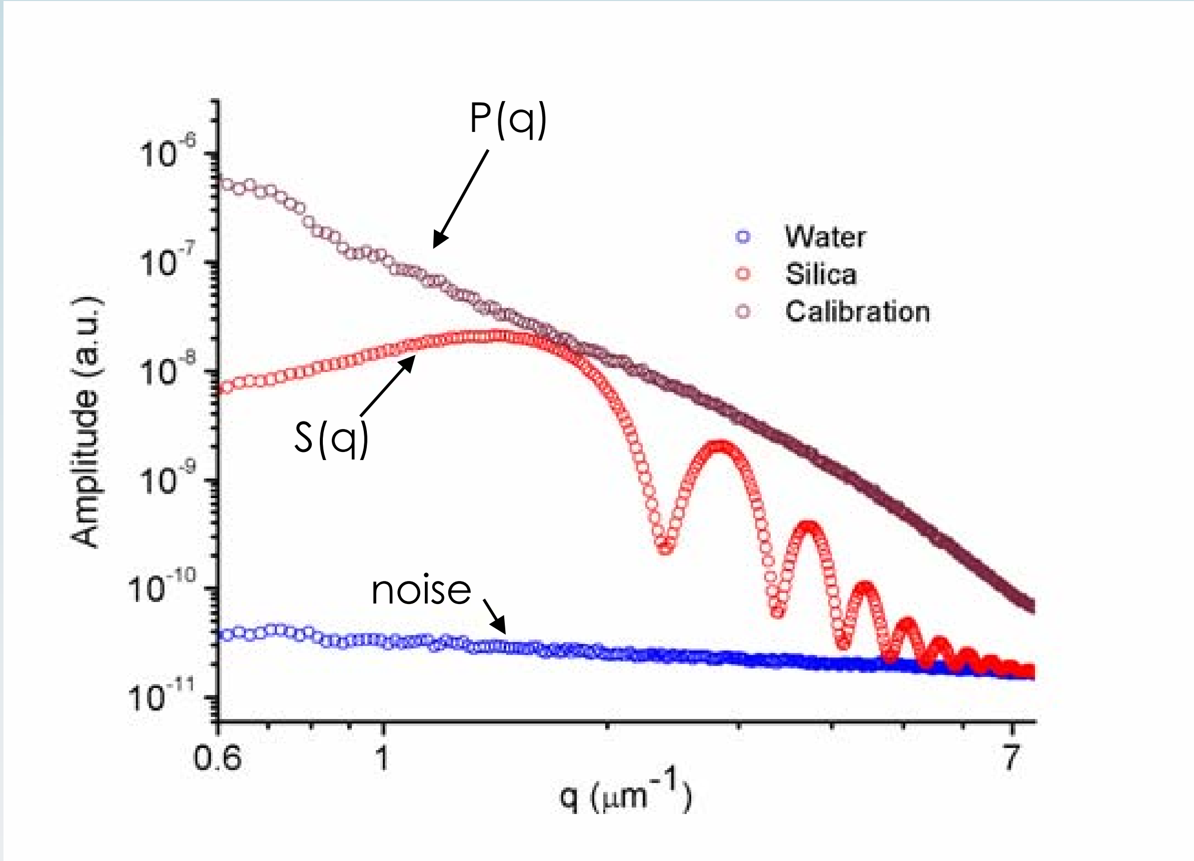

5 mm
28 mm
68 mm
98 mm
138 mm
208 mm

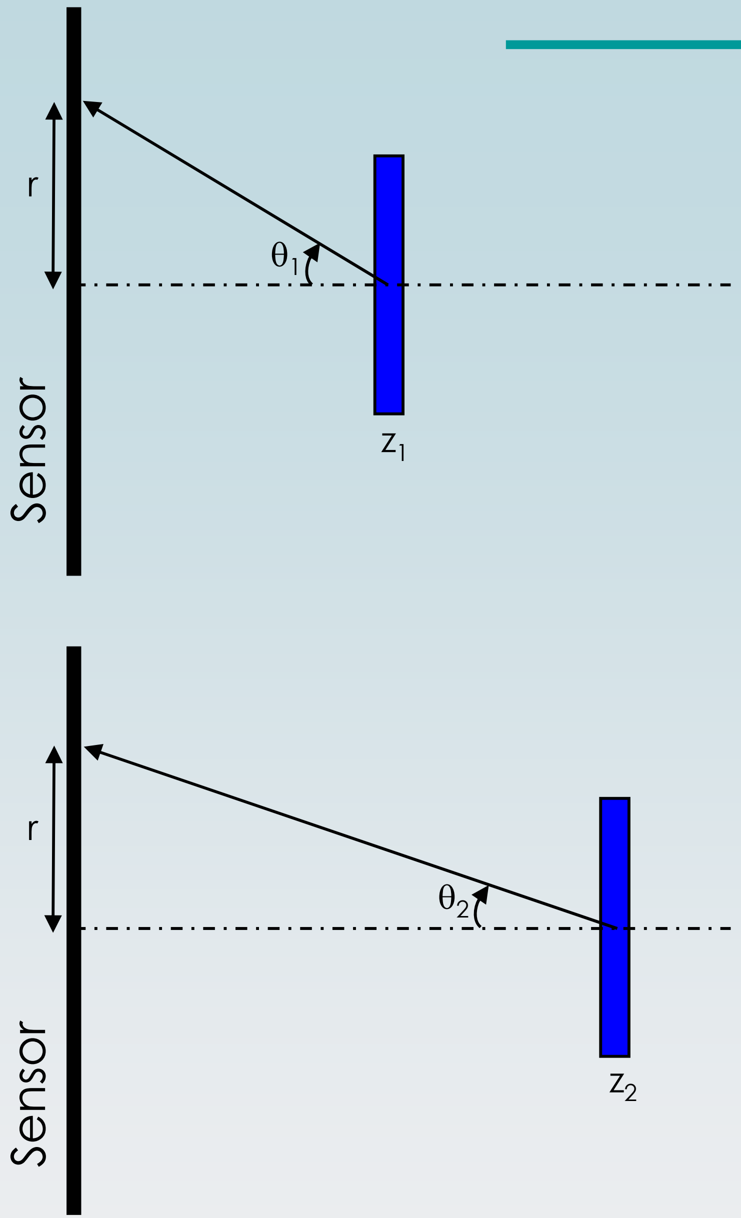

5 mm


P(q)
Amplitude (a.u.)
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
0.6
1
7
q (μm^-1)

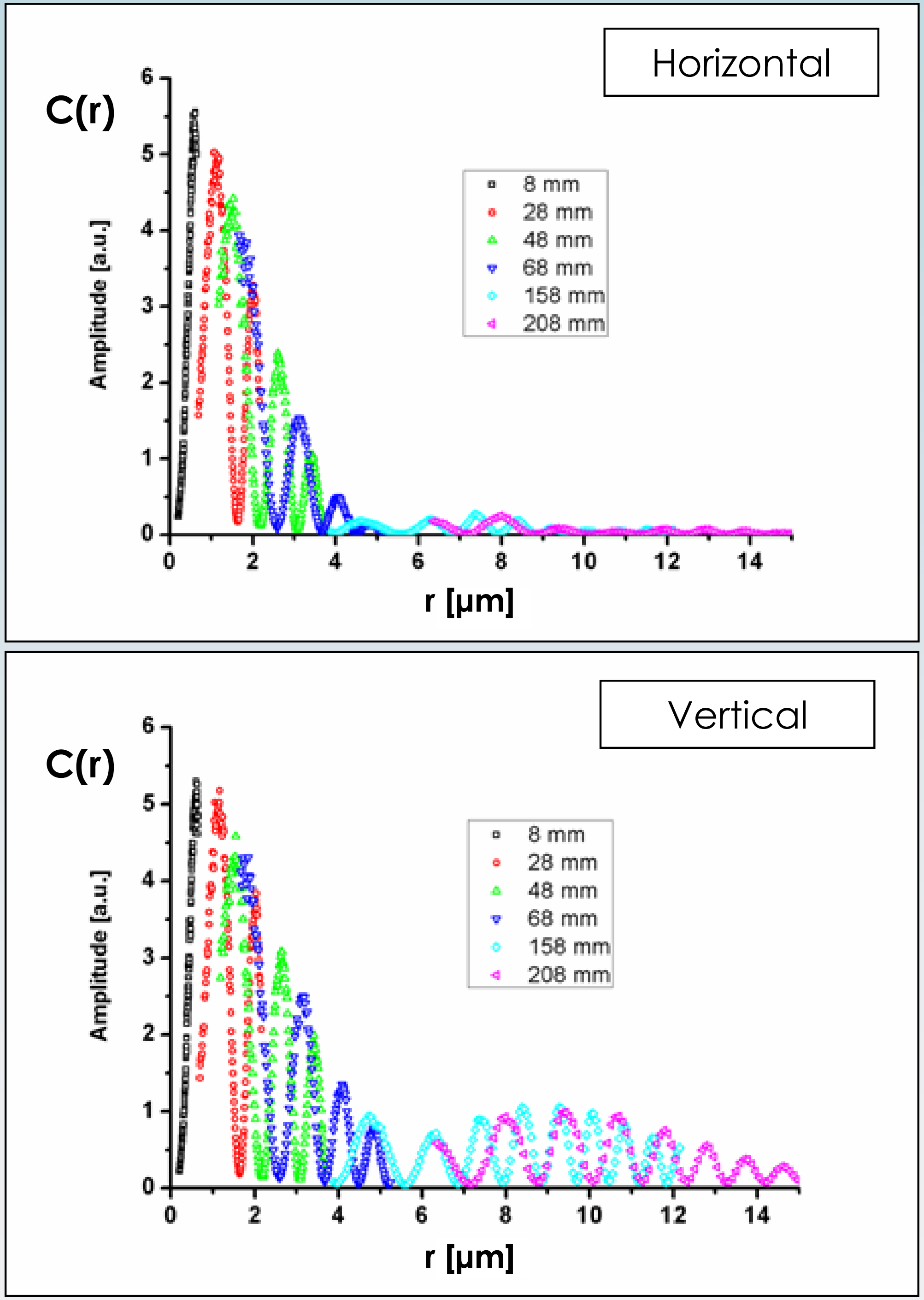

5 mm

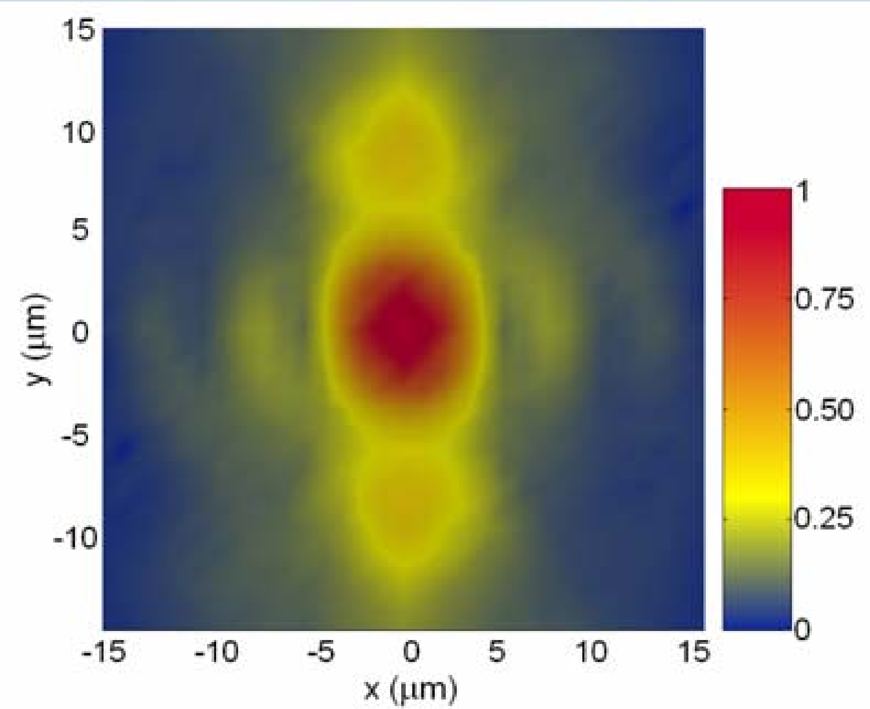

48 mm

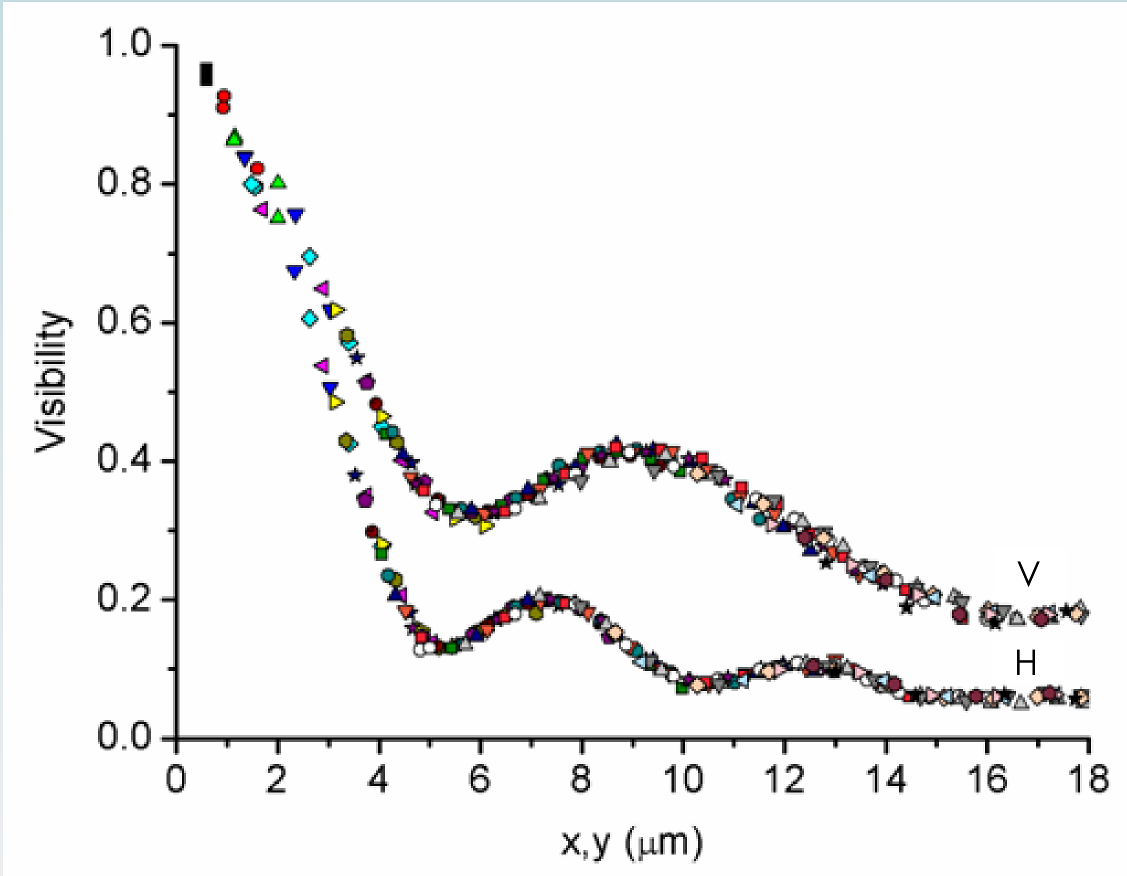

P(q)
S(q)
noise
Water
Silica
Calibration
Amplitude (a.u.)
q (μm⁻¹)
0.6
1
7

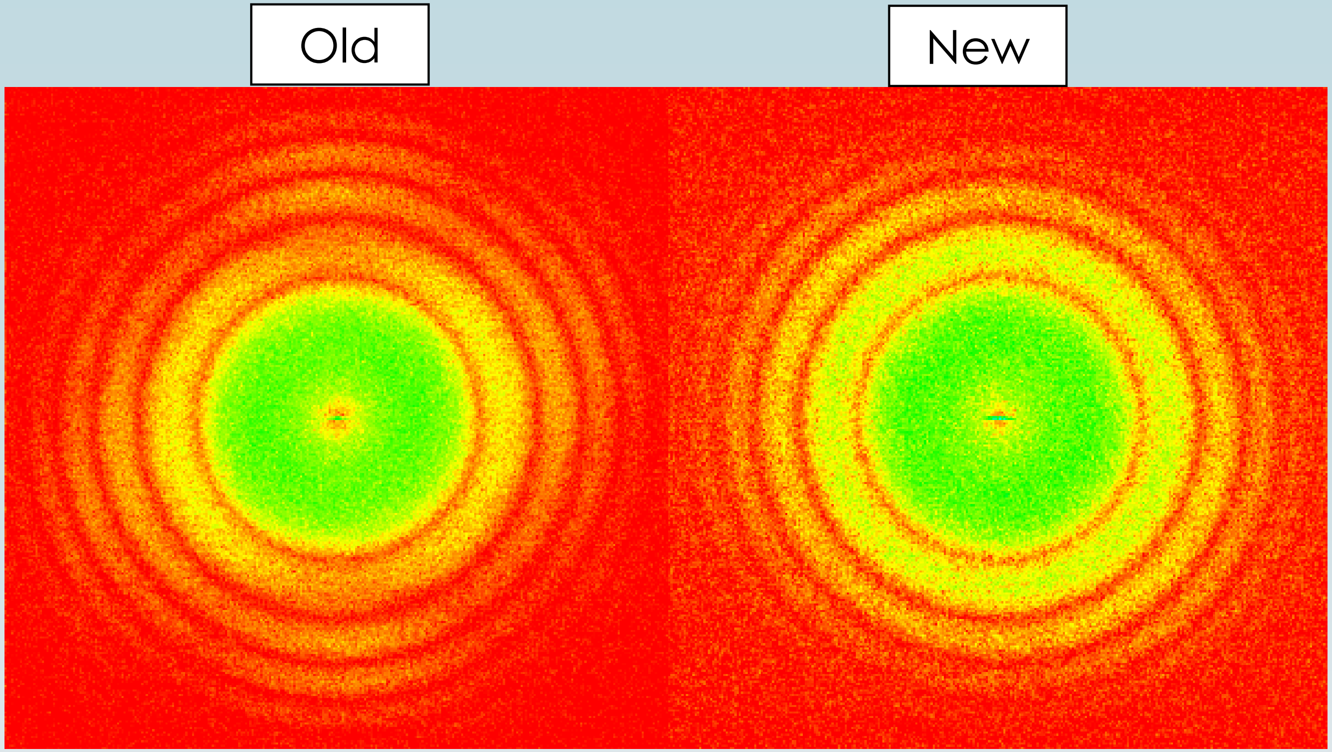


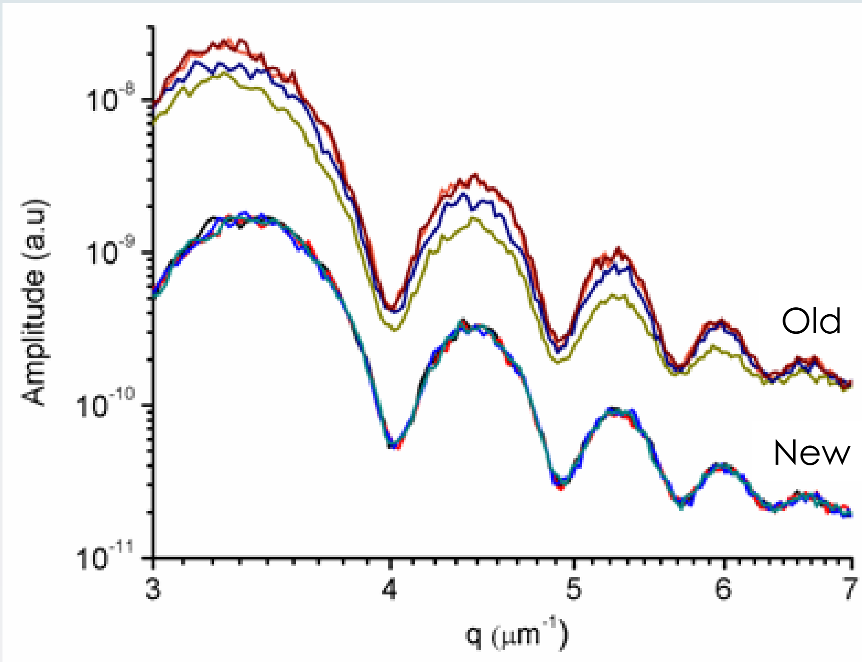
$$r = z\theta = z\frac{q}{k}$$



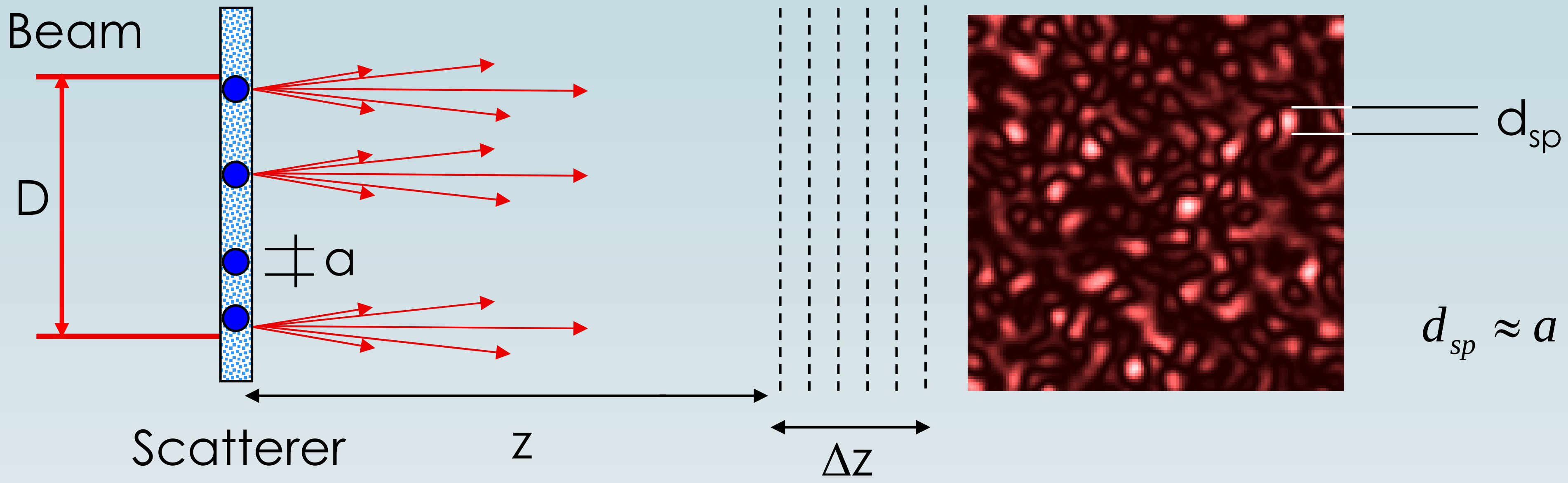

15
10
5
0
-5
-10
y (μm)
-15
-10
-5
0
5
10
15
x (μm)
1
0.75
0.50
0.25
0


1.0
0.8
0.6
0.4
0.2
0.0
Visibility
0
2
4
6
8
10
12
14
16
18
x,y (μm)
V
H


Old
New

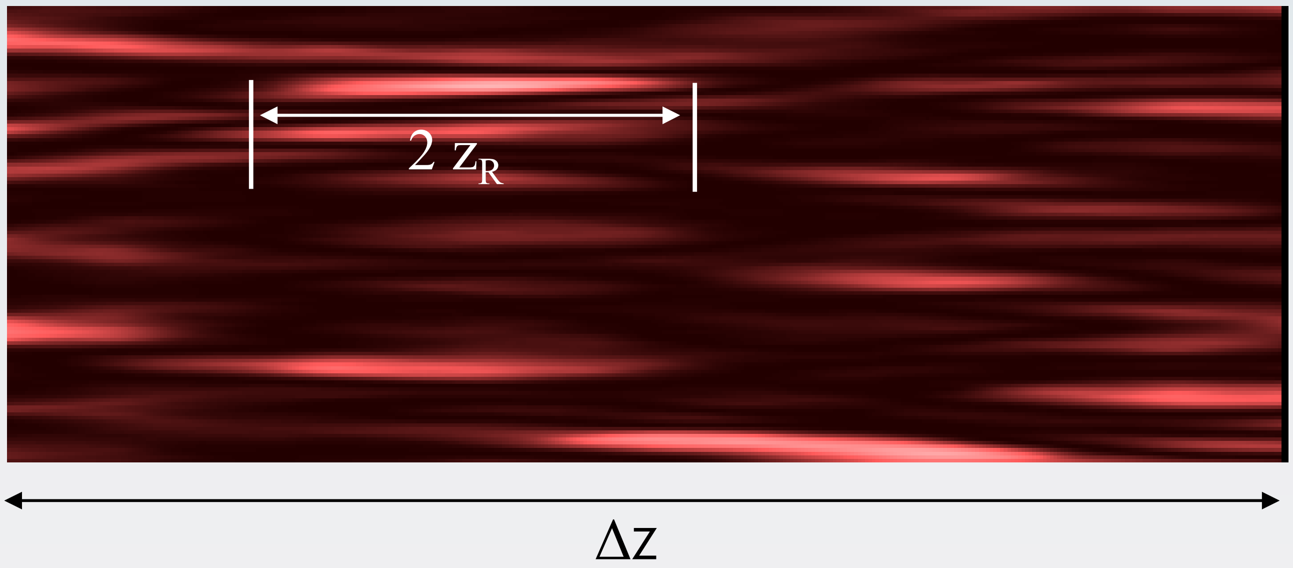

Amplitude (a.u)
10-8
10-9
10-10
10-11
3
4
5
6
7
q (μm-1)
Old
New

Near Field Speckles

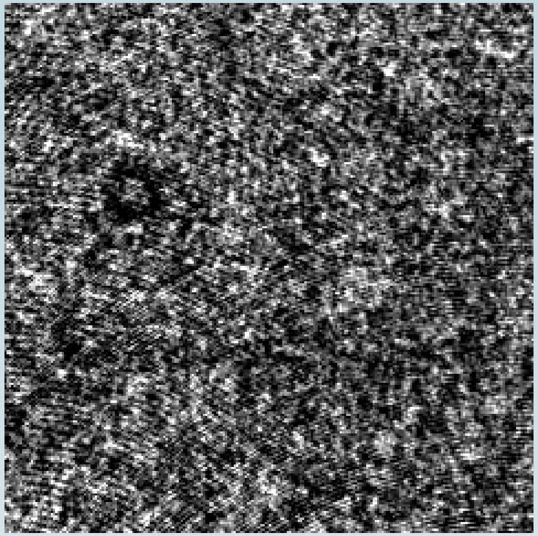


(depth of focus)
$2\,z_R$

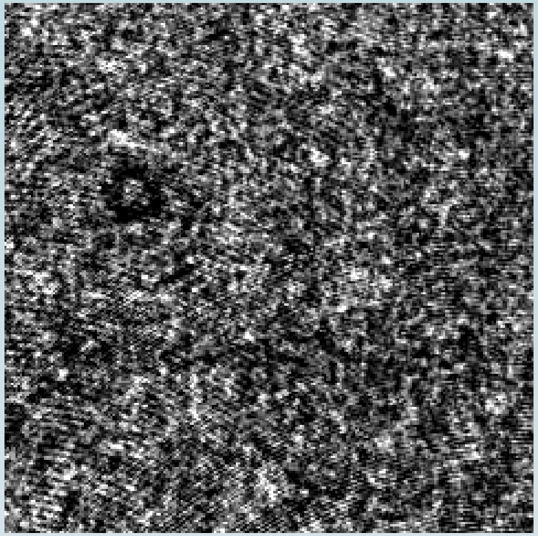
$z_R \approx \dfrac{a^2}{\lambda}$



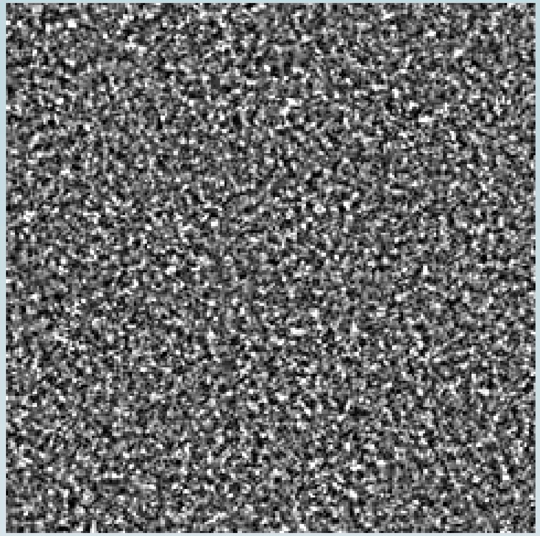
Double frame analysis



f(r,t)



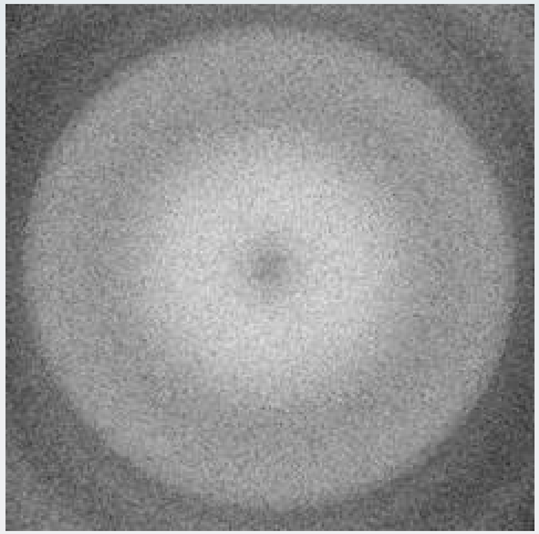
f(r,t+τ)



δf(r,t, τ)

$$\delta f(\mathbf{r},t,\tau) = f(\mathbf{r},t+\tau) - f(\mathbf{r},t) \approx 2\,\mathrm{Re}\left\{ e_s(\mathbf{r},t+\tau) - e_s(\mathbf{r},t) \right\}$$

FFT



Fourier Transform

$$I(\mathbf{q},\tau) \equiv |\,\delta F(\mathbf{q},\tau)\,|^2 \approx I(\mathbf{q}) - \mathrm{Re}\left\{ E(\mathbf{q},t)\,E^*(\mathbf{q},t+\tau) \right\}$$

Static information

Dynamic information