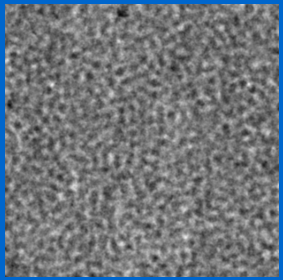
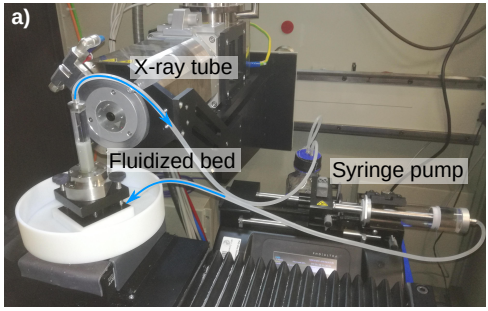
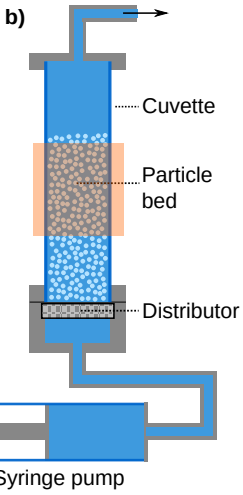
Measuring granular dynamics with X-ray Digital Fourier Analysis (X-DFA)



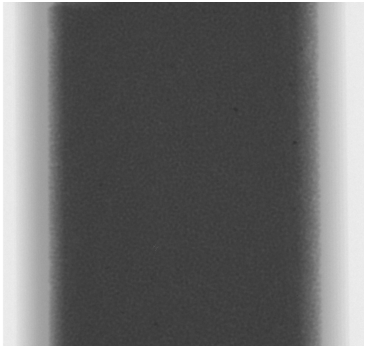
In collaboration with M. Escobedo & S. Egelhaaf, University of Düsseldorf

The system: A liquid fluidized bed





Radiogram



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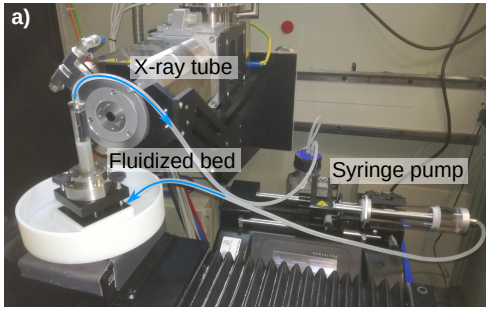
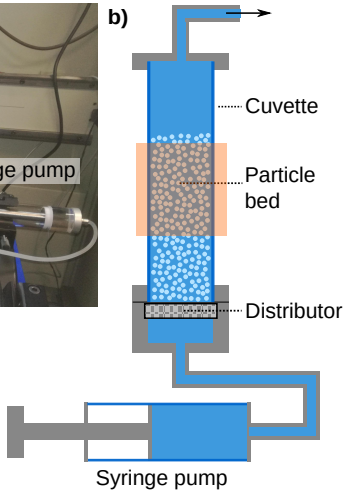
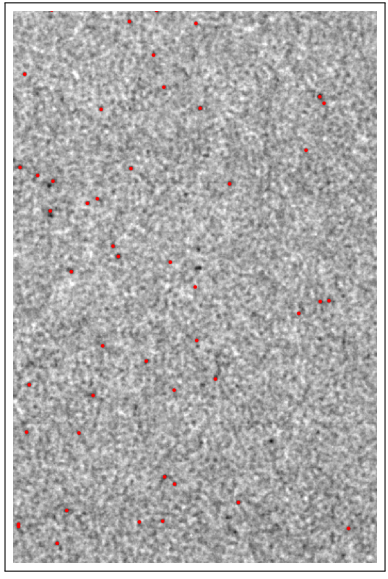




Particle tracking

Contrast: $\rho_{tracer} > \rho_{bed}$



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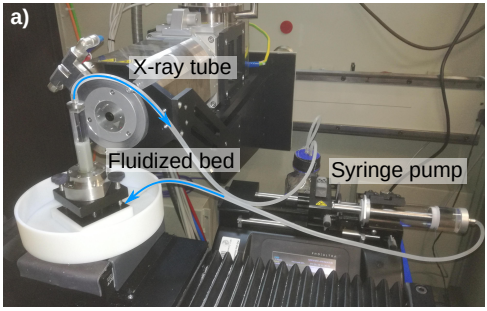

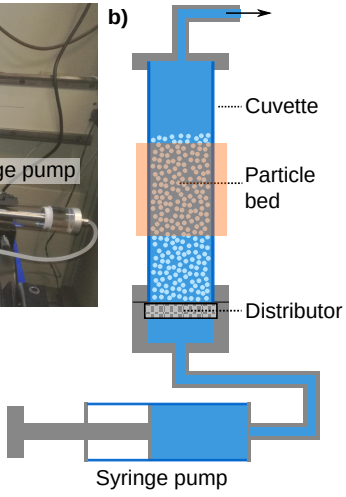

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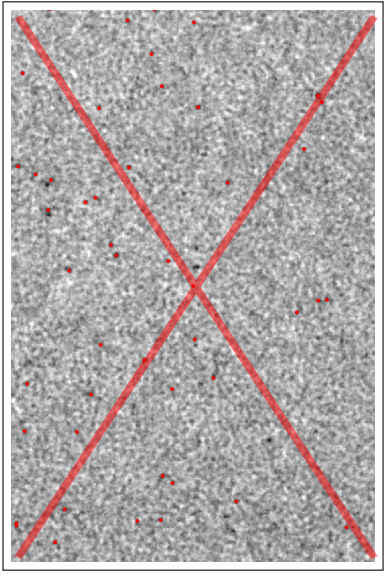

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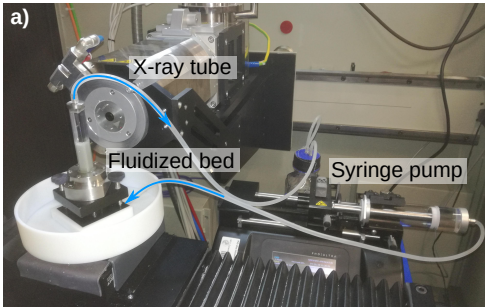
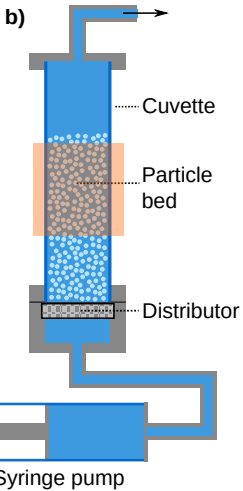
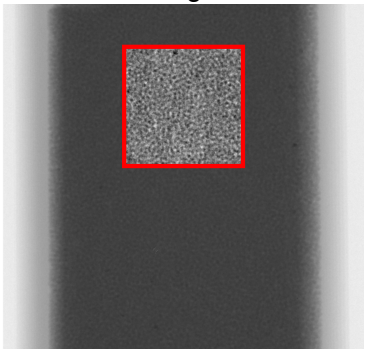
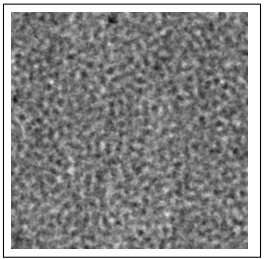




Radiogram





Differential Dynamic Microscopy (DDM)

	Up to now	This work
System	Dispersion, gels	Fluidized bed
Particles	Colloids < 1 μm	Granulates $(150 - 180)$ μm
Volume fraction	$\Phi \leq 0.33$	$0.45 < \Phi < 0.56$
Imaging	Light microscopy	X-ray radiography
Dynamics	Brownian motion, caging, glassy, collective motion	

Giavazzi *et al*, PRE **80**, 031403 (2009)

Extending
Differential Dynamic Microscopy (DDM)
to X-ray imaging

	Up to now	This work
System	Dispersion, gels	Fluidized bed
Particles	Colloids < 1 μm	Granulates $(150 - 180)$ μm
Volume fraction	$\Phi \leq 0.33$	$0.45 < \Phi < 0.56$
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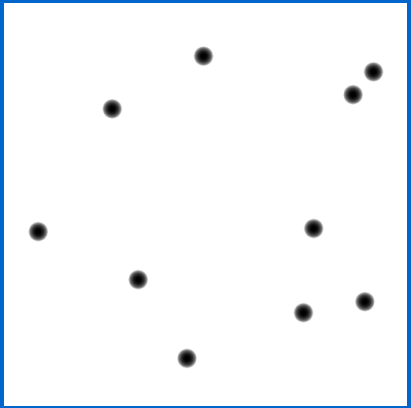
Digital Fourier Analysis of X-Ray radiograms (X-DFA)

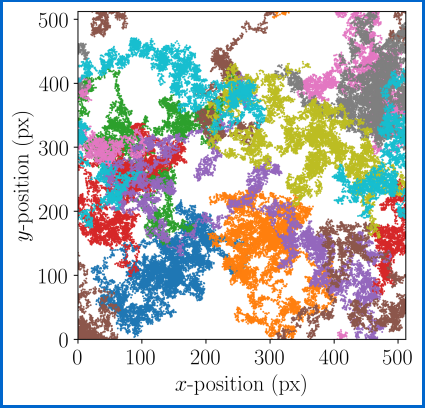
Giavazzi *et al*, PRE **80**, 031403 (2009)

Introduction to X-ray Digital Fourier Analysis (X-DFA)

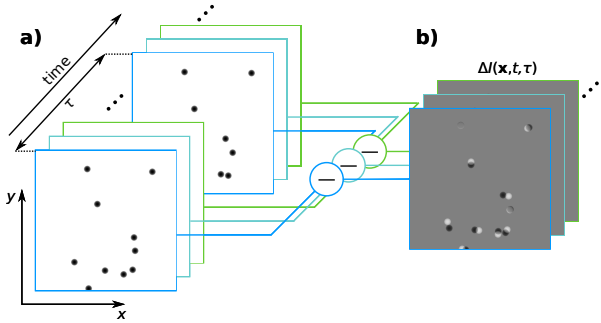
Synthetic radiograms



Particle trajectory



The image structure function $D(\mathbf{q}, \tau)$



Giavazzi *et al*, PRE **80**, 031403 (2009)

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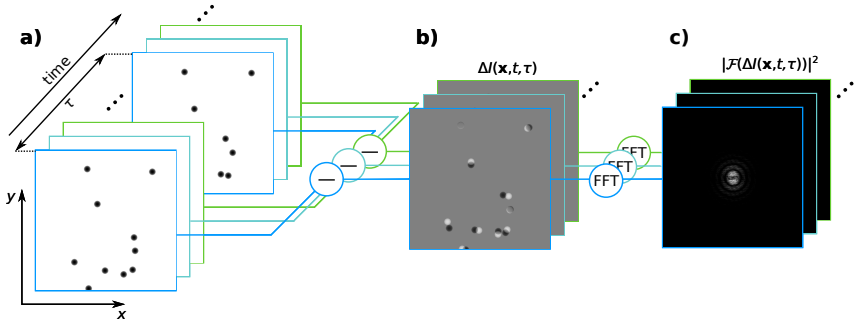

Giavazzi *et al*, PRE **80**, 031403 (2009)

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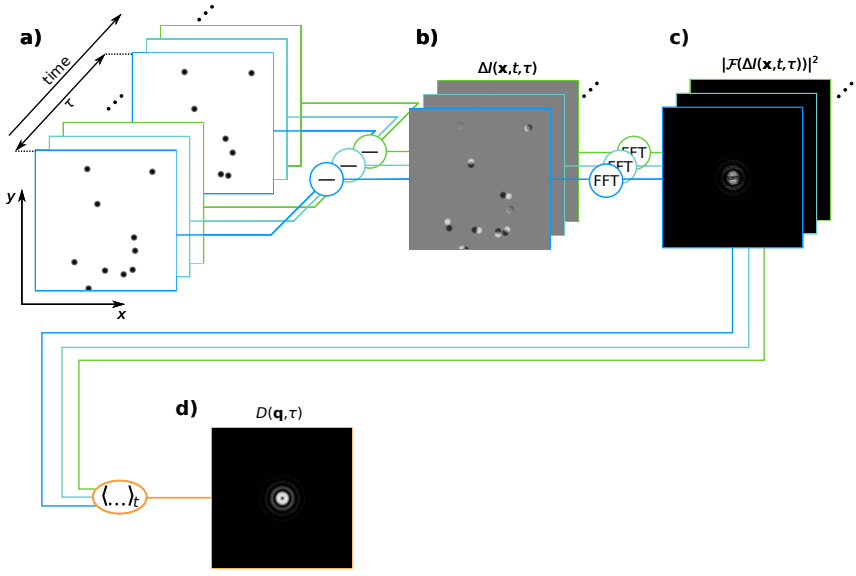

Giavazzi *et al*, PRE **80**, 031403 (2009)

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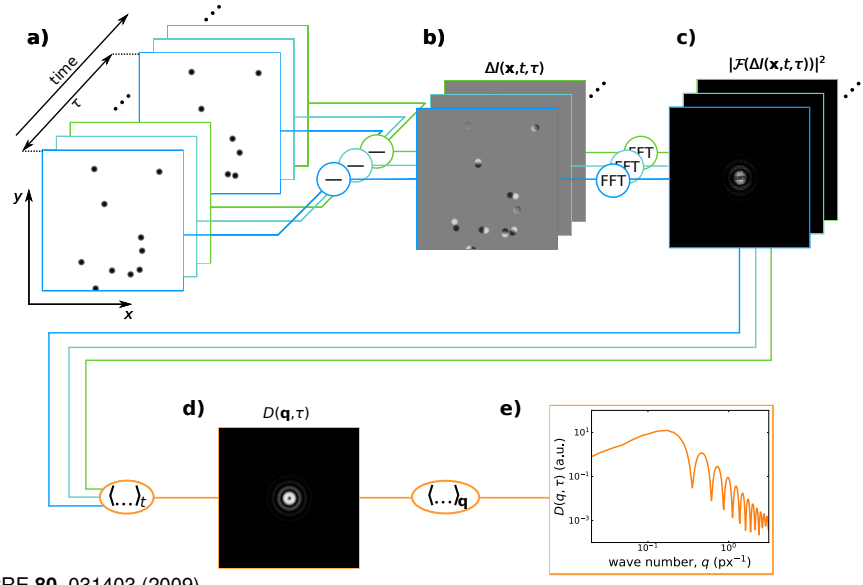

Giavazzi *et al*, PRE **80**, 031403 (2009)

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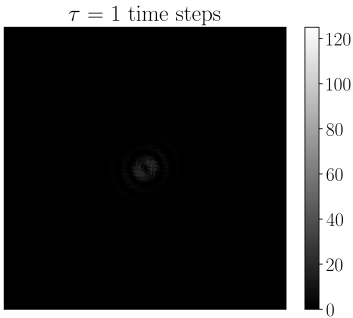
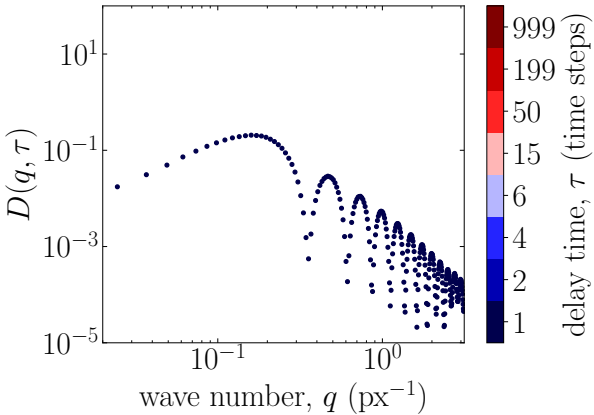
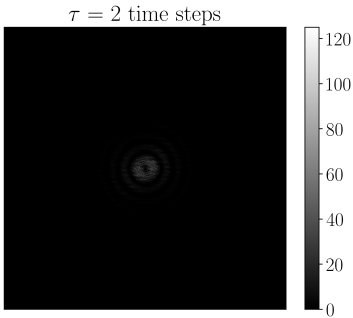


Time averaging: $D(\mathbf{q}, \tau) = \langle |\mathscr{F}(\Delta I)|^2 \rangle_t$

Azimuthal averaging: $D(\mathbf{q}, \tau) \rightarrow D(q, \tau)$ ...



The image structure function $D(q, \tau)$



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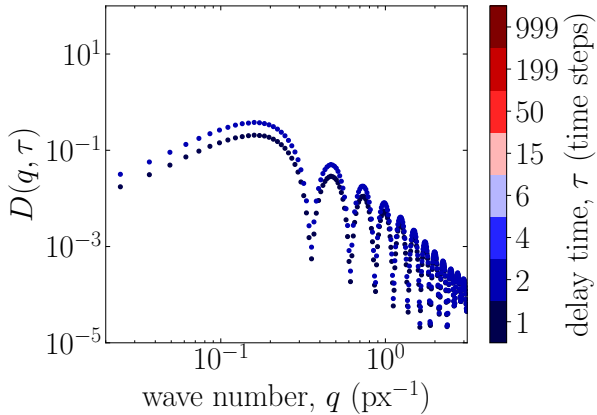

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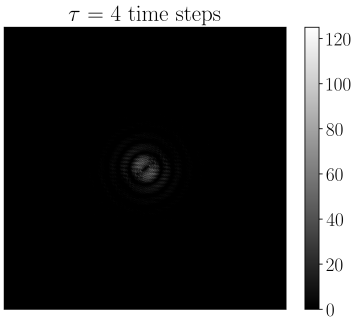

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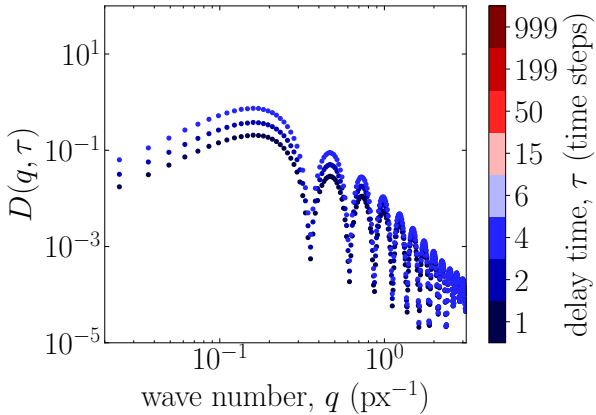

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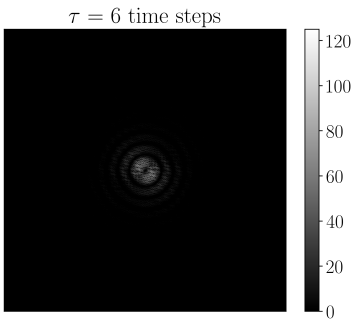

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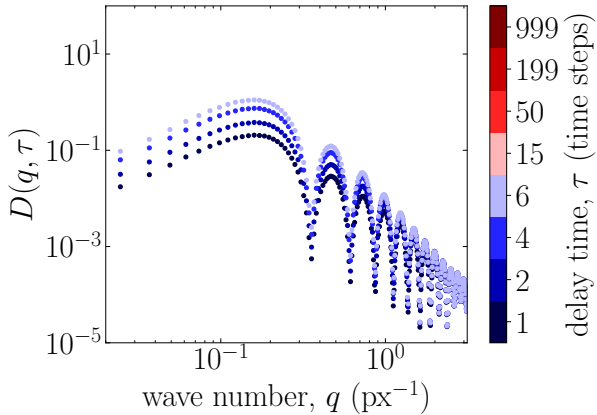

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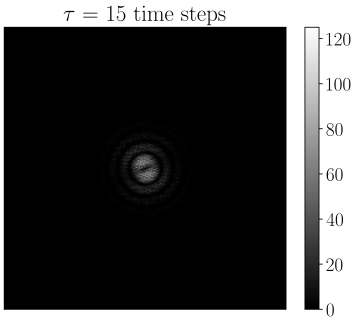

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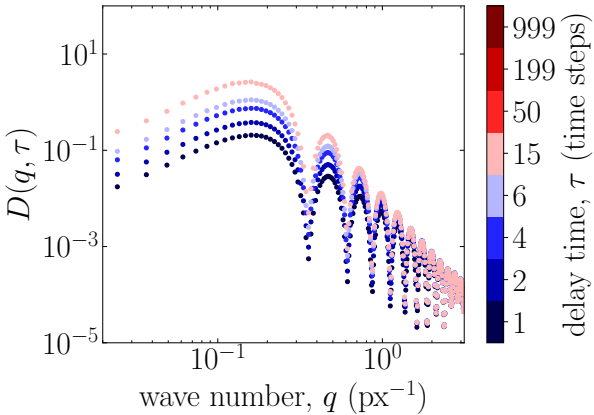

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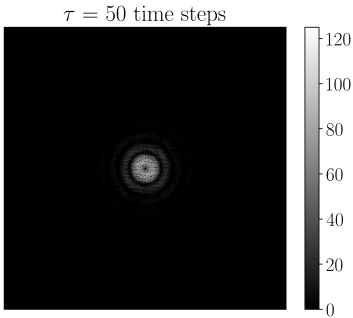

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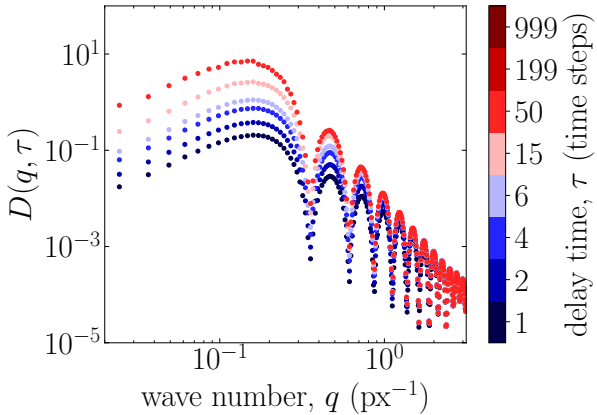

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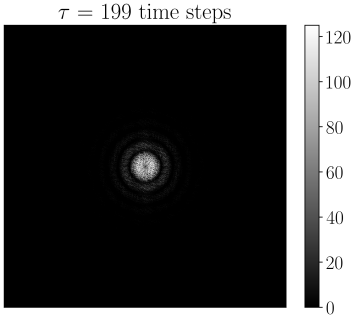

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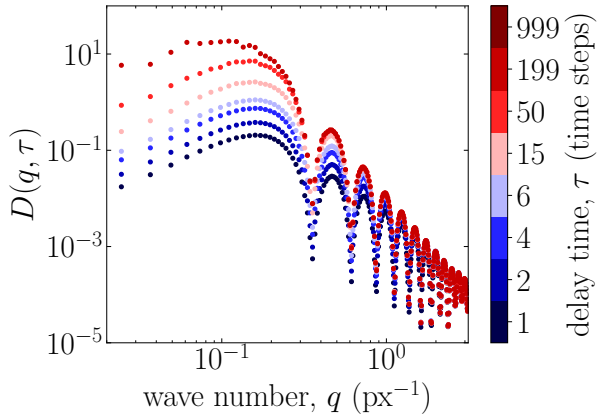

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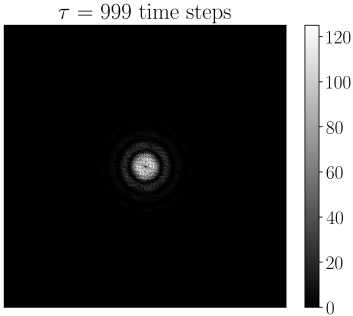

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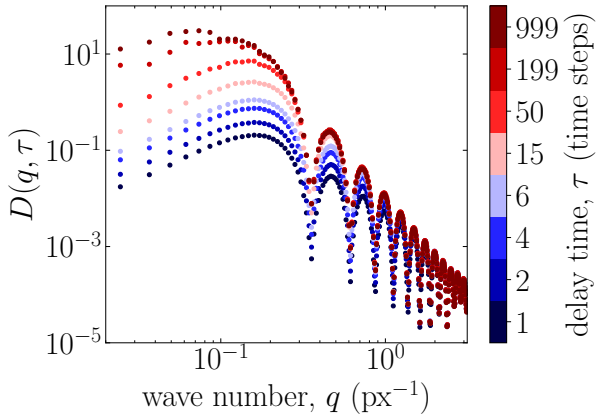

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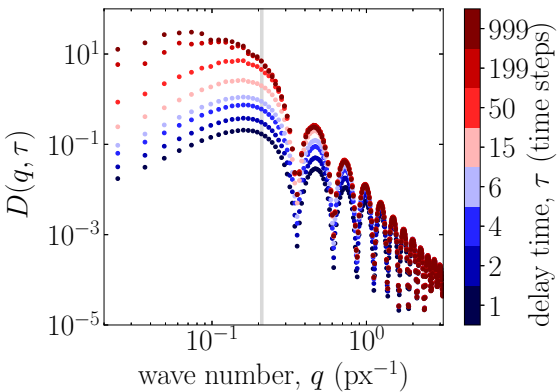

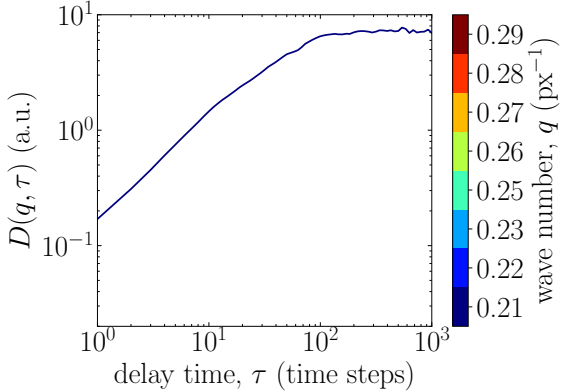

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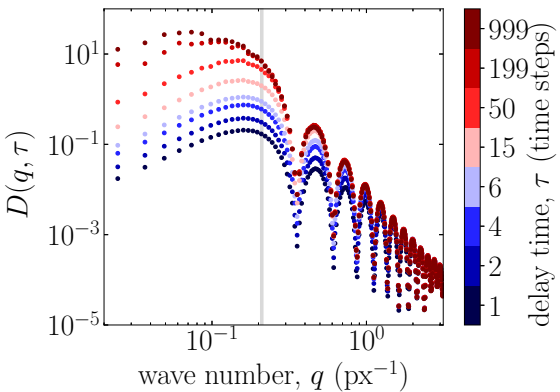

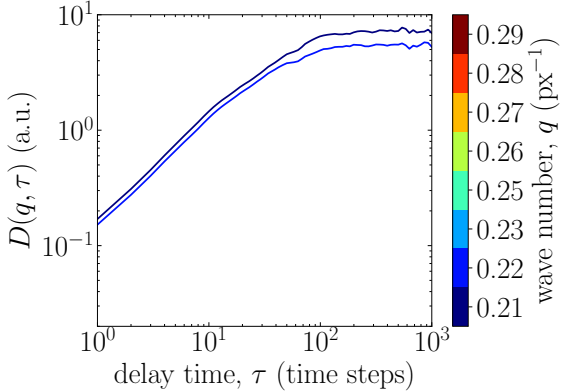

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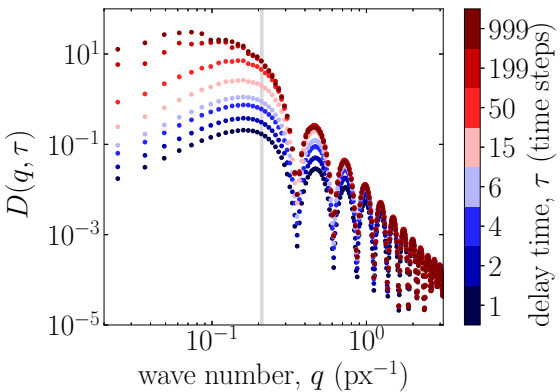

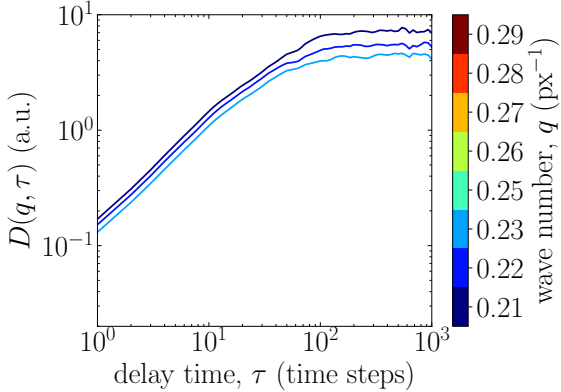

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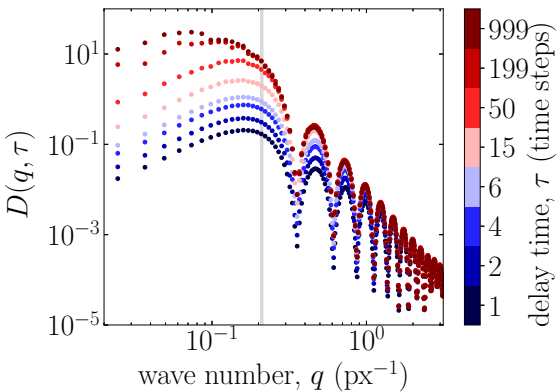

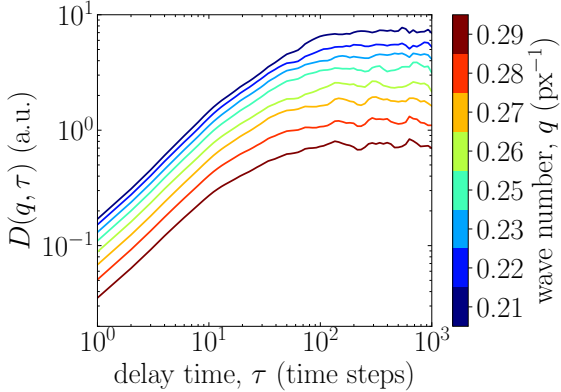

Linear space invariant imaging

$$D(q,\tau) = \left\langle |I(q,t+\tau) - I(q,t)|^2 \right\rangle_t$$

Linear space invariant imaging

$$
\begin{aligned}
D(q,\tau) &= \left\langle |I(q,t+\tau) - I(q,t)|^2 \right\rangle_t \\
&= A(q)\left[1 - \frac{\left\langle I^*(q,t) I(q,t+\tau) \right\rangle_t}{\left\langle |I(q,t)|^2 \right\rangle_t}\right] + B(q)
\end{aligned}
$$

Linear space invariant imaging

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$$= A(q)\left[1 - \underbrace{\frac{\left\langle I^*(q,t)I(q,t+\tau)\right\rangle_t}{\left\langle |I(q,t)|^2\right\rangle_t}}\right] + B(q)$$

Image correlation function

Linear space invariant imaging

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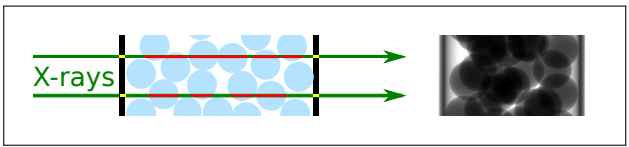
Image correlation function



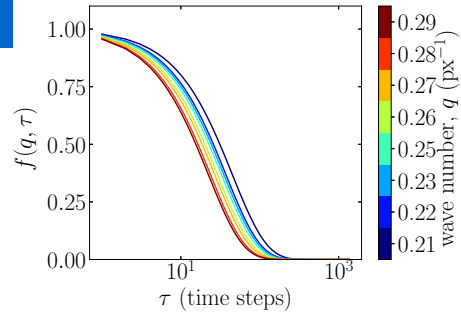
Intermediate scattering function

$$f(q,\tau) = \frac{\langle \rho^*(q,t)\rho(q,t+\tau)\rangle_t}{\langle |\rho(q,t)|^2\rangle_t}$$

Intermediate scattering function $f(q, \tau)$

Brownian motion:

$$f(q, \tau) = \exp(-q^2 \tau / \tau_D)$$



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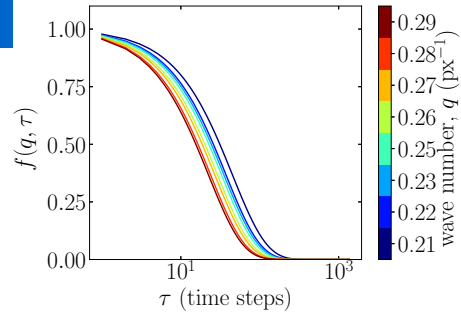

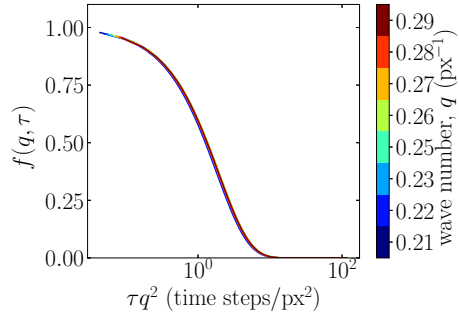

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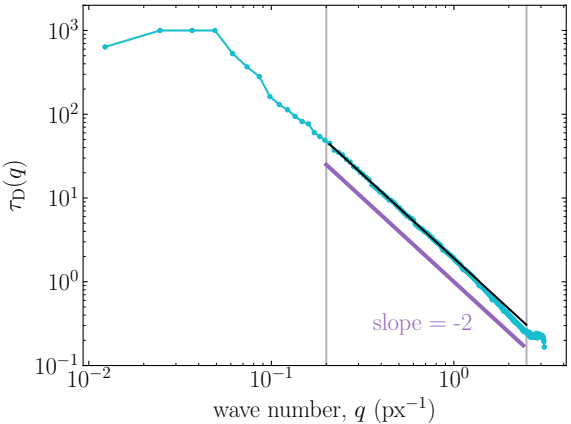
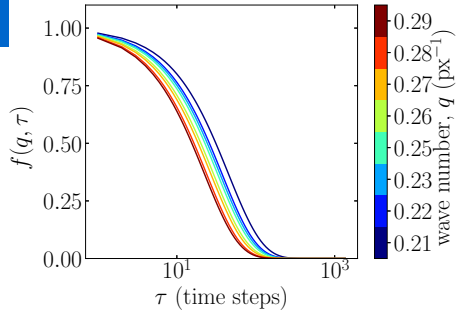
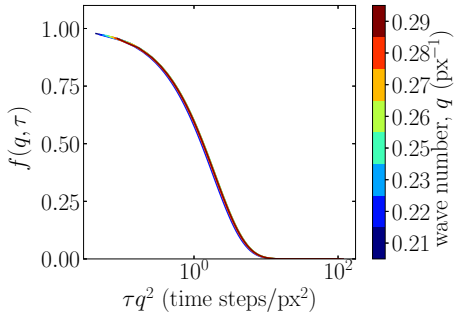
$$f(q, \tau) = \exp(-q^2 \tau / \tau_D)$$

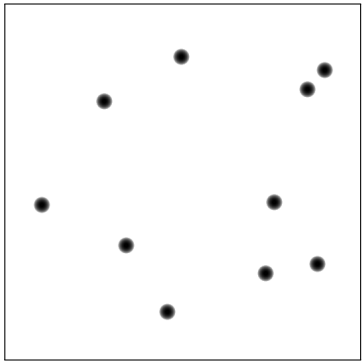




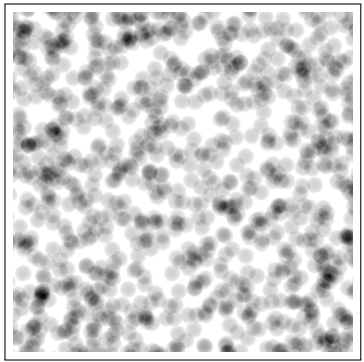


Accuracy of X-DFA: Varying the number of particles

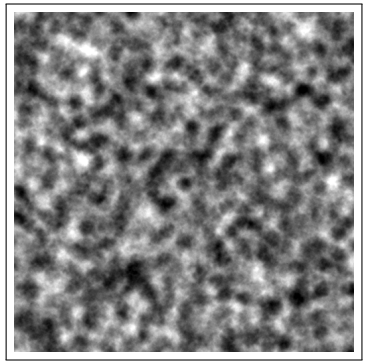
10 particles



1000 particles



100 000 particles



Deviation from the simulation input:

6%

2%

2%

PIV off by ≈ 650%