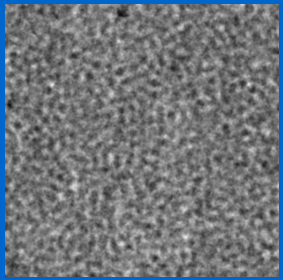
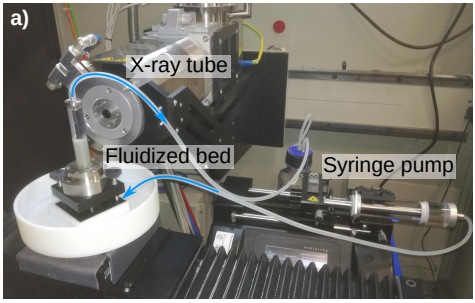
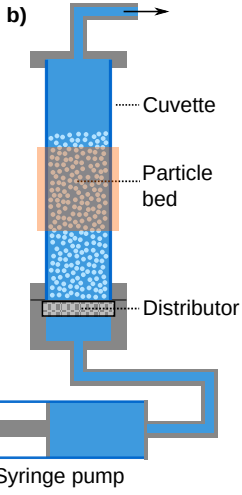
Measuring granular dynamics with X-ray Digital Fourier Analysis (X-DFA)



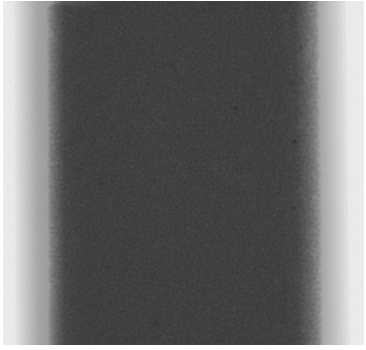
In collaboration with M. Escobedo & S. Egelhaaf, University of Düsseldorf

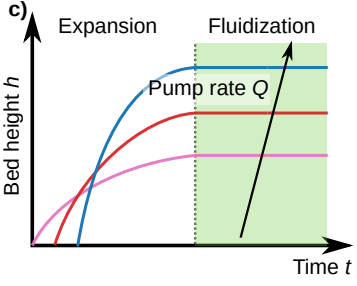
The system: A liquid fluidized bed





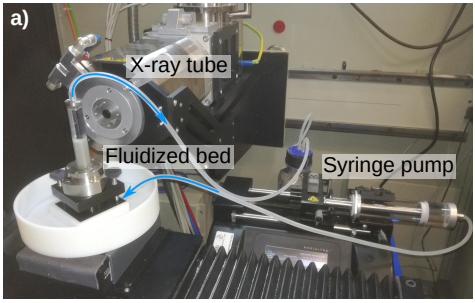
Radiogram

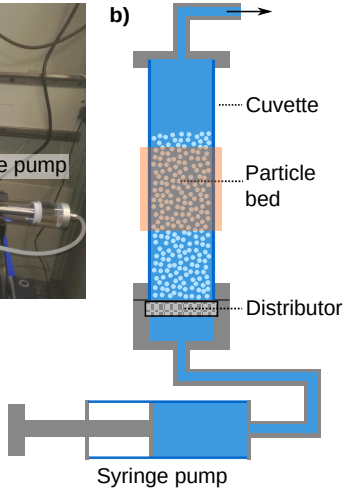


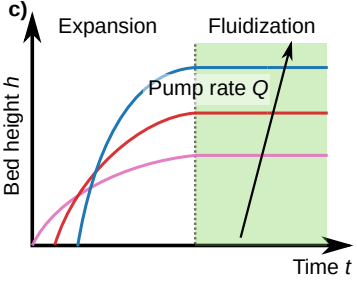


$0.45 < \Phi < 0.56$

The system: A liquid fluidized bed

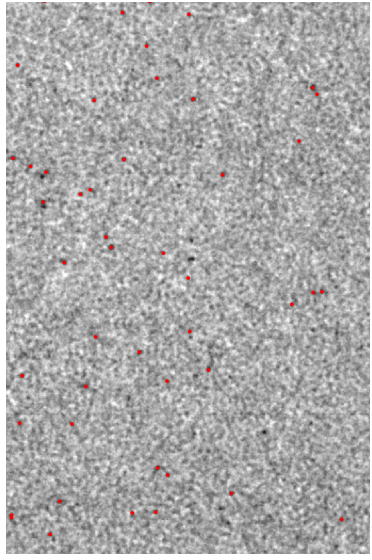




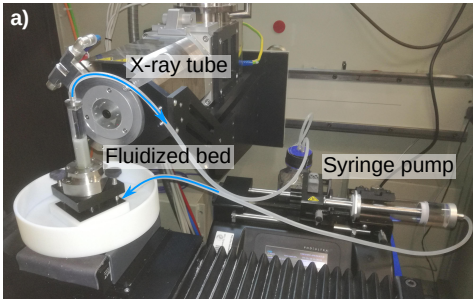


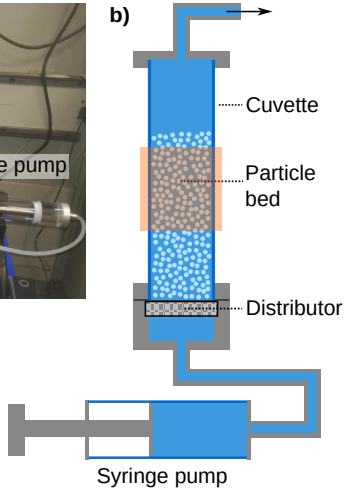
$0.45 < \Phi < 0.56$

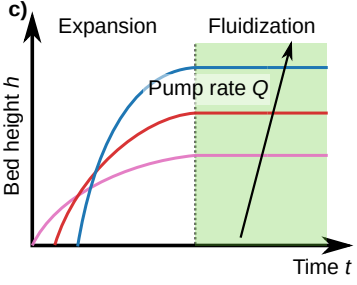
Particle tracking



The system: A liquid fluidized bed

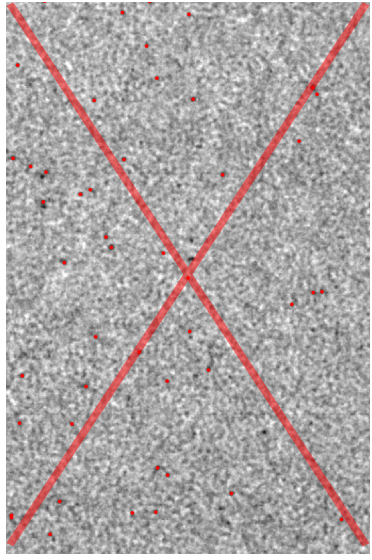




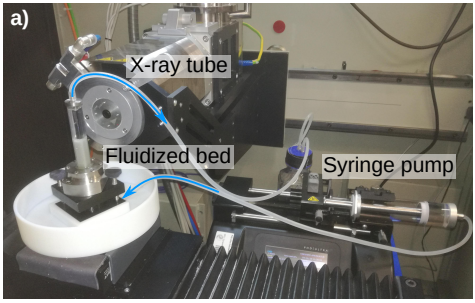


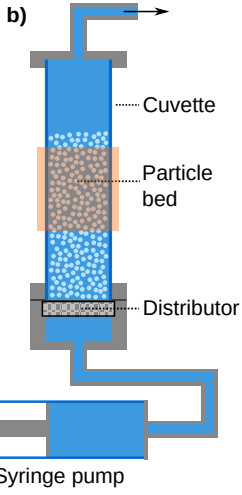
$0.45 < \Phi < 0.56$

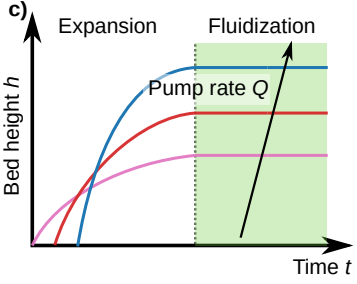
Particle tracking



Experiments: A liquid fluidized bed

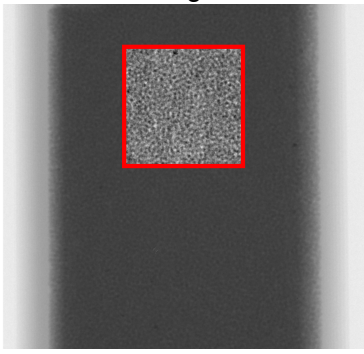


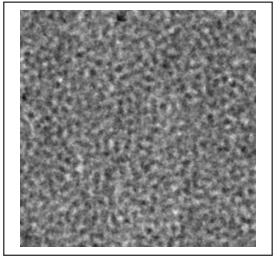




$0.45 < \Phi < 0.56$

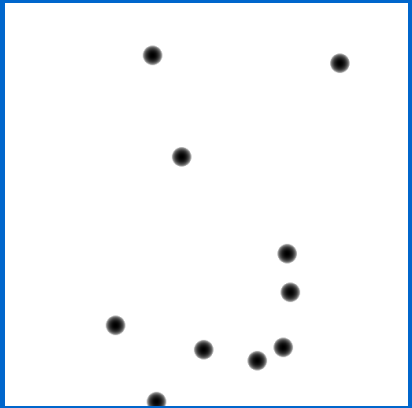
Radiogram



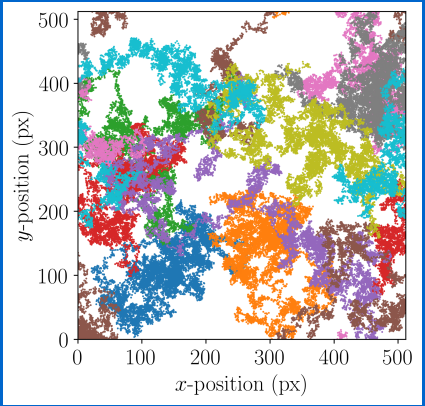


Introduction to Differential Dynamic Microscopy (DDM)

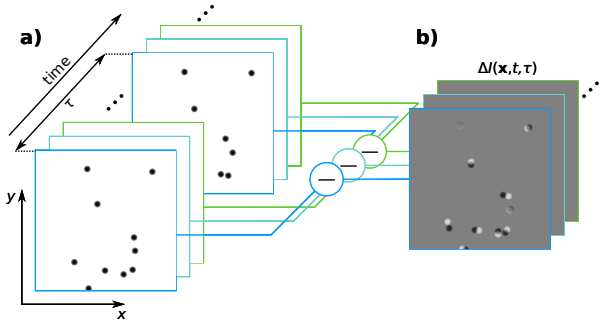
Synthetic radiograms



Particle trajectory

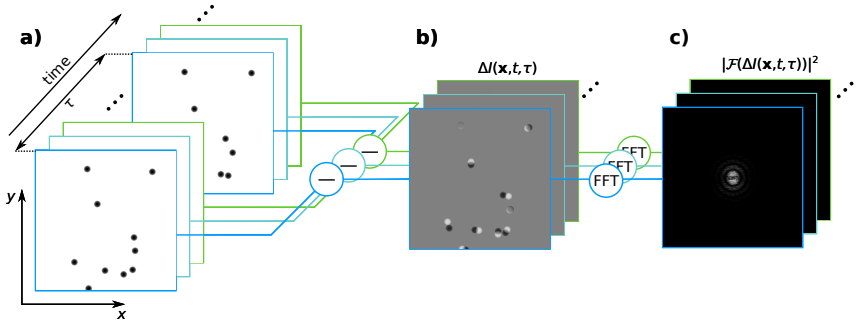


The image structure function $D(\mathbf{q}, \tau)$



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

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



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

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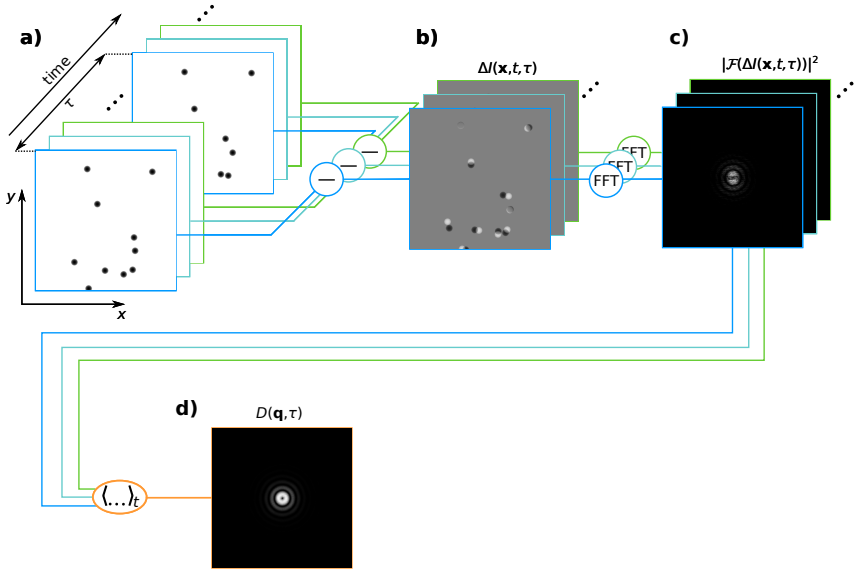

Giavazzi *et al*, PRE **80**, 031403 (2009)

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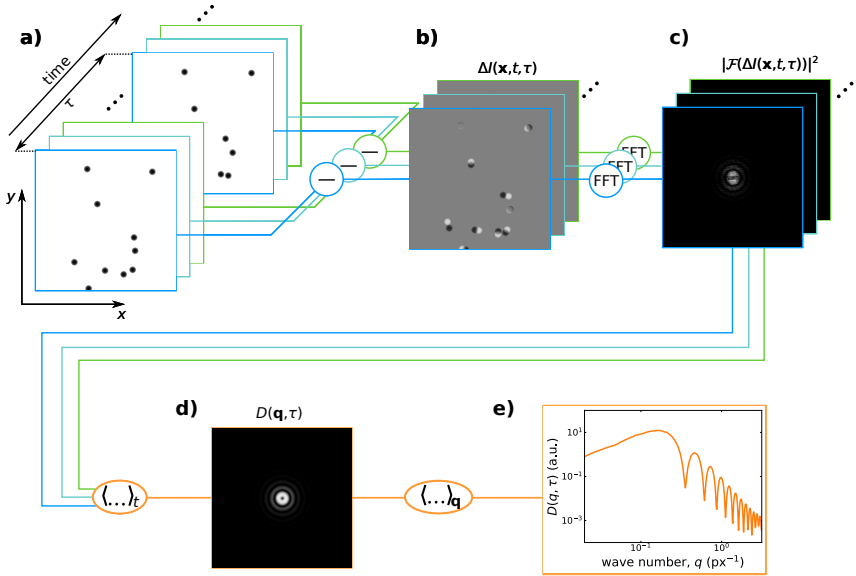

Giavazzi *et al*, PRE **80**, 031403 (2009)

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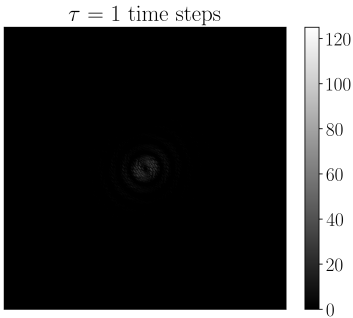
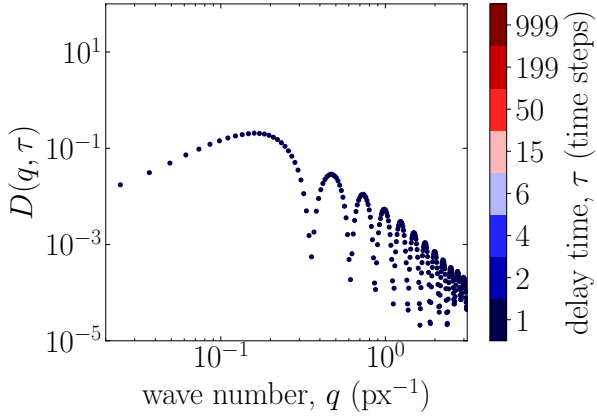


Time averaging: $D(\mathbf{q}, \tau) = \langle |\mathscr{F}(\Delta I)|^2 \rangle_t$

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



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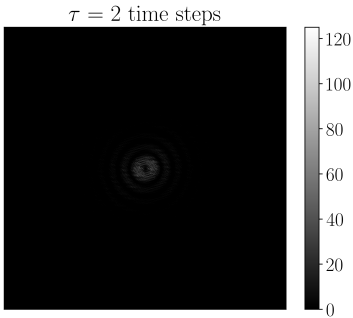

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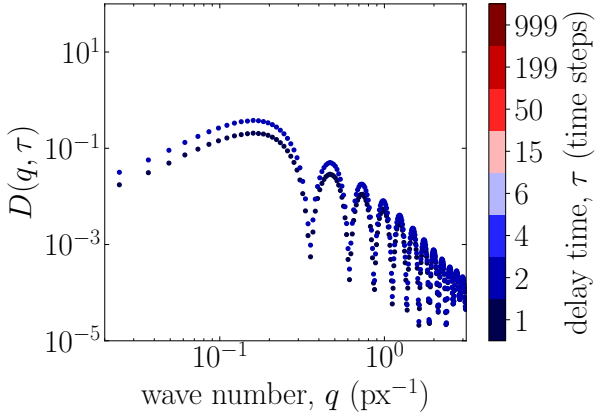

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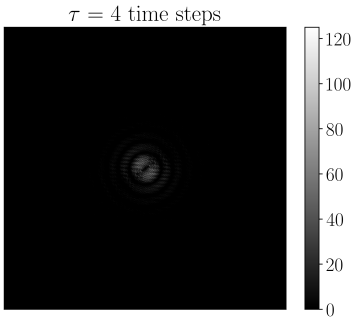

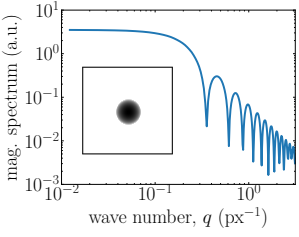

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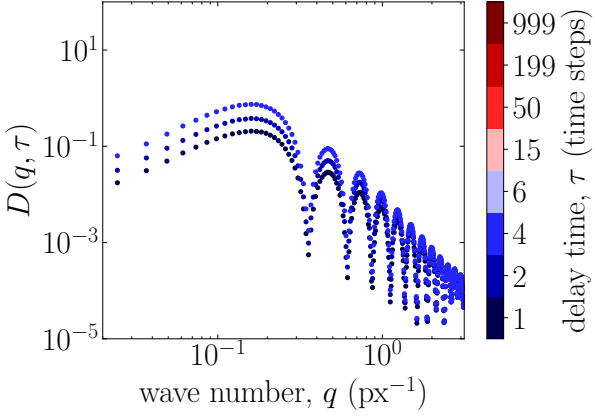

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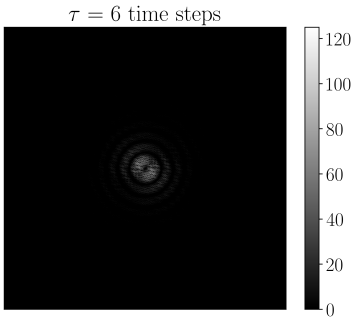

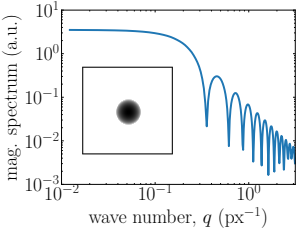

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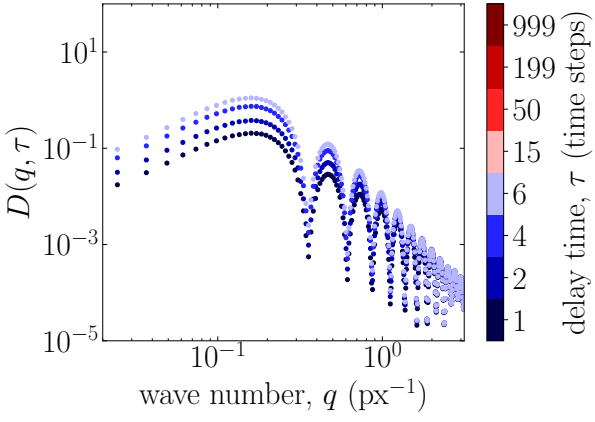

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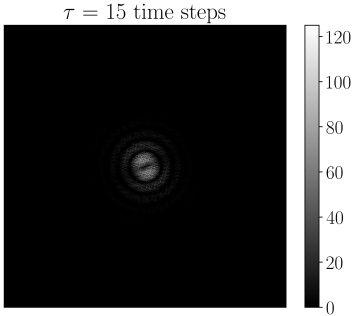

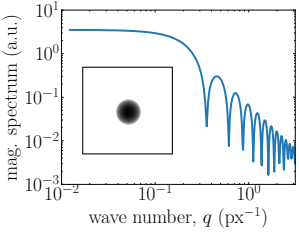

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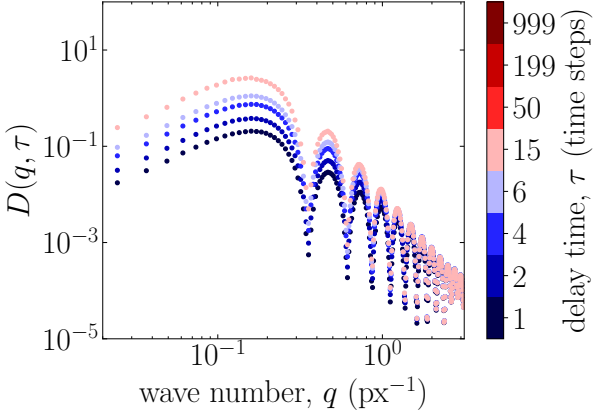

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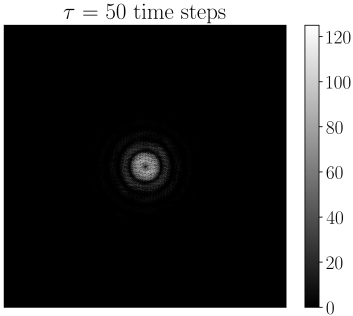

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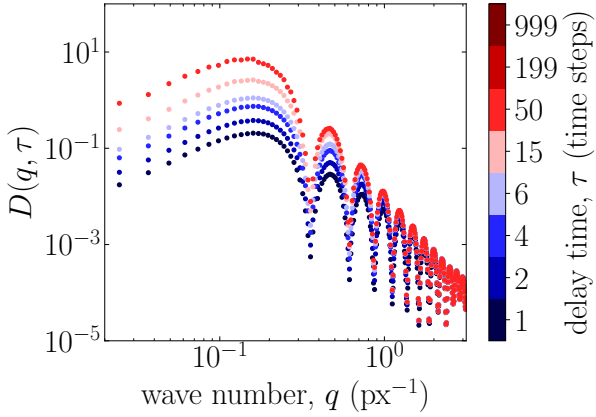
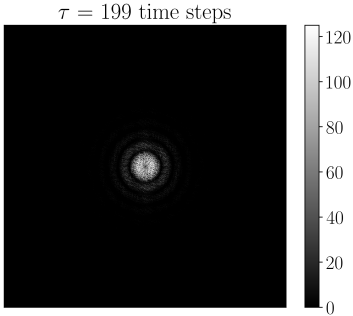


The image structure function $D(q, \tau)$



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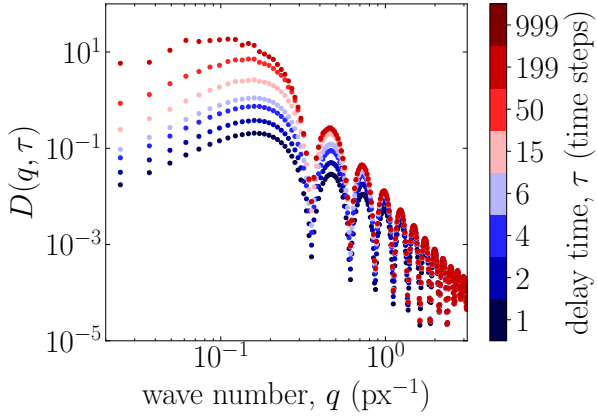

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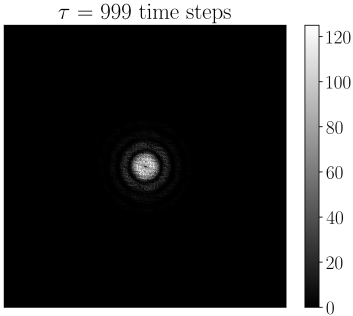

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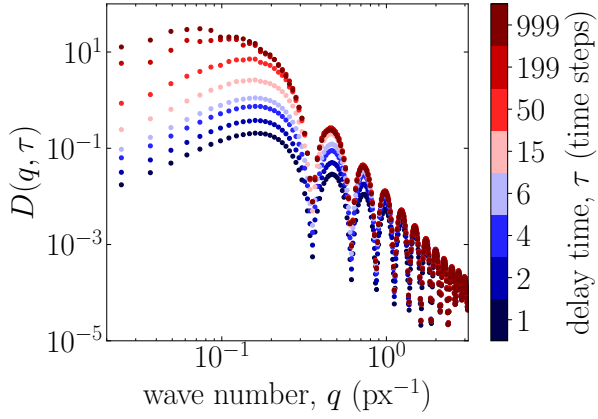

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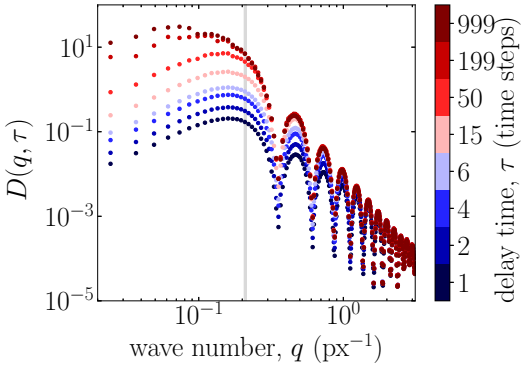

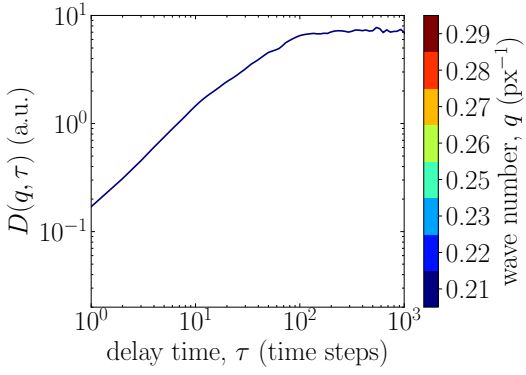

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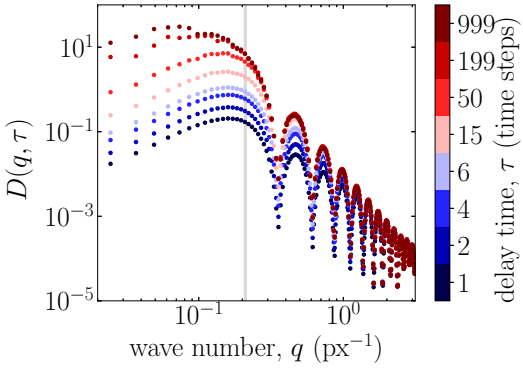
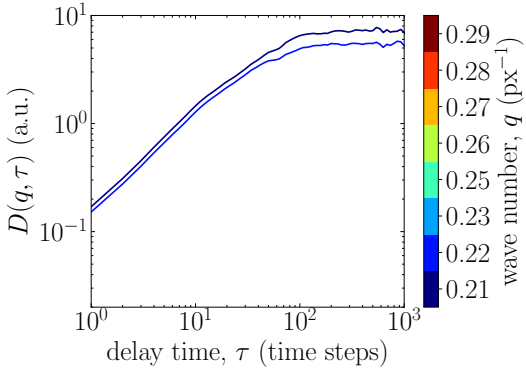
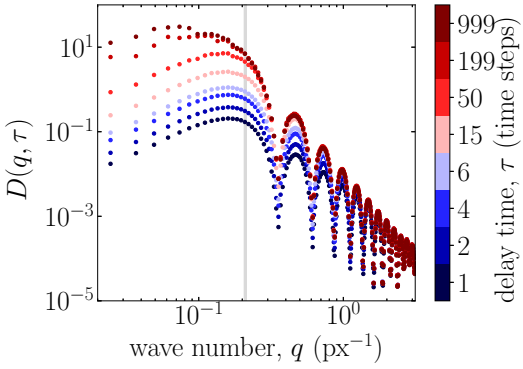
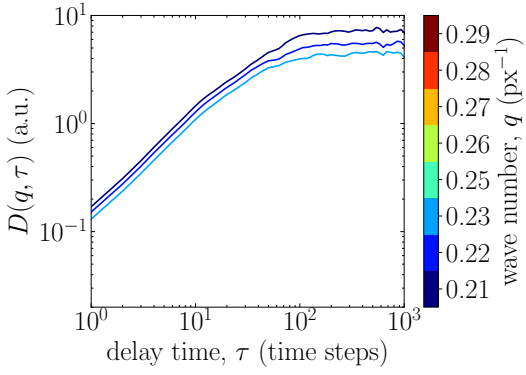




The image structure function $D(q, \tau)$





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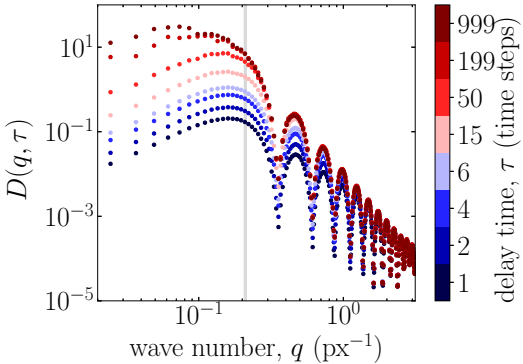

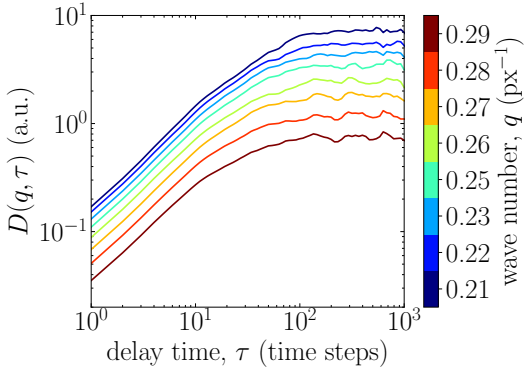

$$D(q,\tau) = \left\langle |I(q,t+\tau) - I(q,t)|^2 \right\rangle_t$$

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

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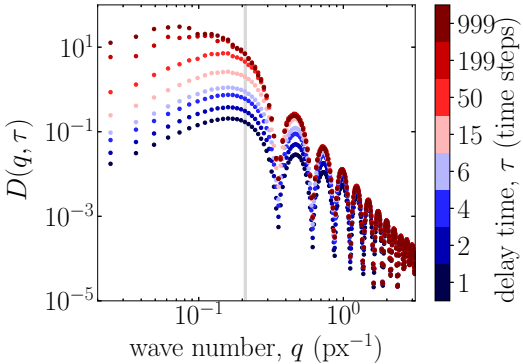

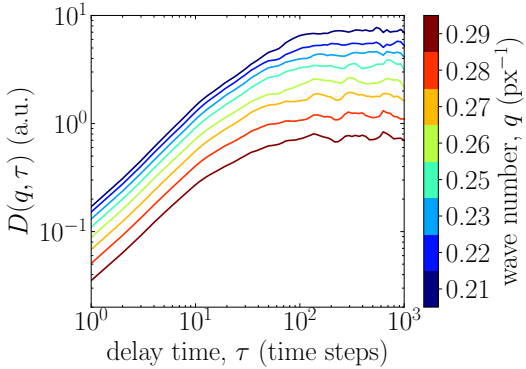

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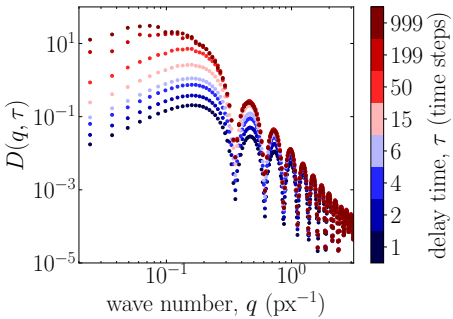
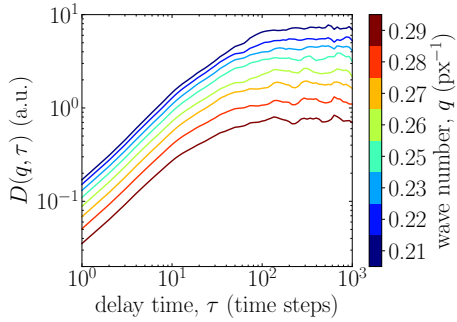
Image correlation function





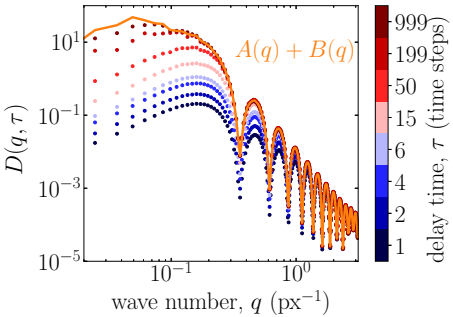
$$D(q,\tau) = \left\langle |I(q,t+\tau) - I(q,t)|^2 \right\rangle_t$$

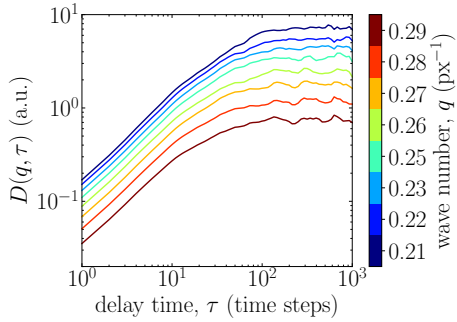
$$= A(q)\left[1 - \underbrace{\frac{\left\langle I^*(q,t)I(q,t+\tau)\right\rangle_t}{\left\langle |I(q,t)|^2\right\rangle_t}}_{\text{Image correlation function}}\right] + B(q)$$

Linear space invariant imaging

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

Intermediate scattering function





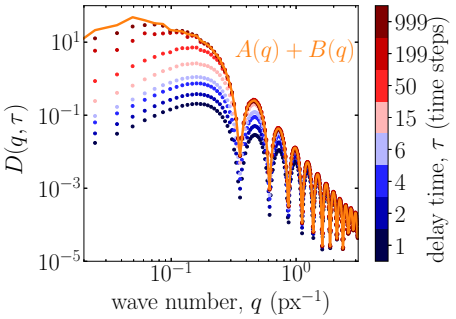
$$D(q,\tau) = \left\langle |I(q,t+\tau) - I(q,t)|^2 \right\rangle_t$$
$$= A(q)\left[1 - \frac{\left\langle I^*(q,t) I(q,t+\tau) \right\rangle_t}{\left\langle |I(q,t)|^2 \right\rangle_t}\right] + B(q)$$

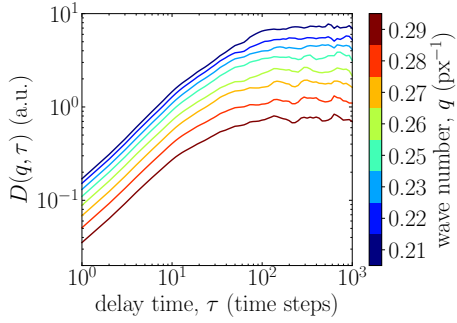
- $D(q, \tau \to 0) = B(q) = 0$
- $D(q, \tau \to \infty) = A(q) + B(q)$

Linear space invariant imaging

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

Intermediate scattering function





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

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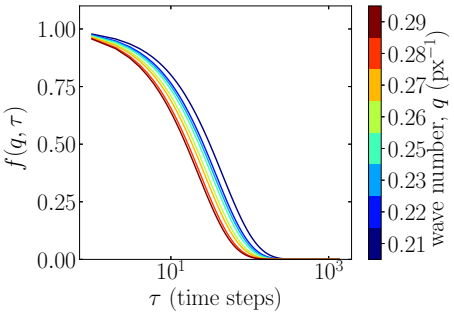
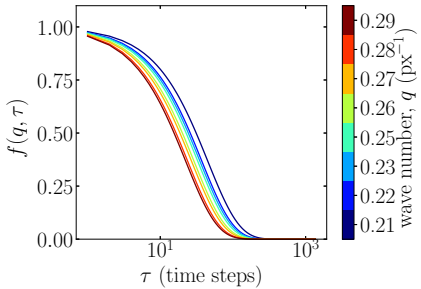
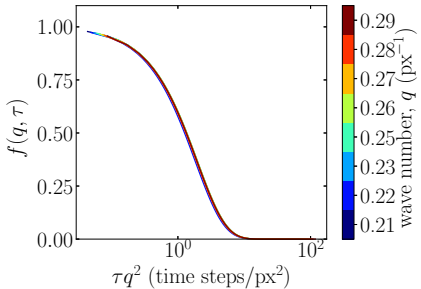


Intermediate scattering function $f(q, \tau)$

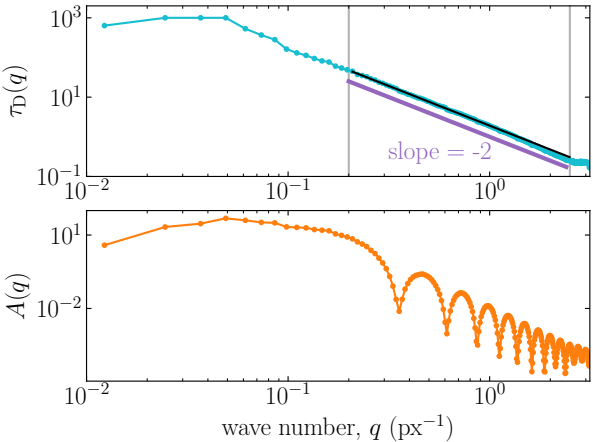




Brownian motion:

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

Accuracy: 2% - 6%



Differential Dynamic Microscopy (DDM)

	up to now	**this work**
system	dispersion, gels	fluidized bed
particles	colloids	granulate
part. diameter	< 1 μm	≈ 200 μm
volume fraction	$\Phi \leq 0.33$	$0.45 < \Phi < 0.56$
imaging	light microscope	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	granulate
part. diameter	< 1 μm	≈ 200 μm
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imaging	light microscope	x-ray radiography
dynamics	Brownian motion, caging, glassy, collective motion	

Digital Fourier Analysis of X-Ray Radiograms (X-DFA)

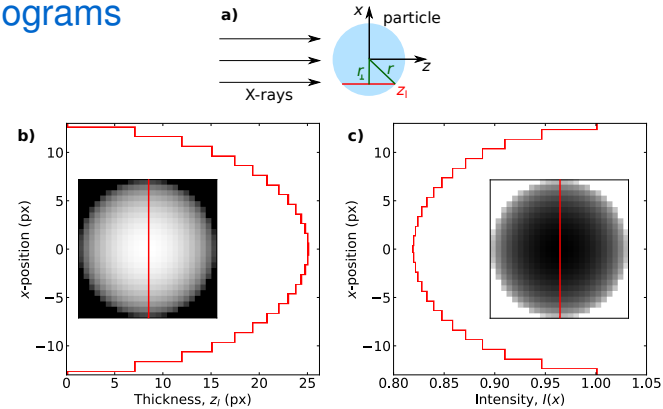
Giavazzi *et al*, PRE **80**, 031403 (2009)

extra slide with videos of 10, 1000, 100000 particles + accuracy, next slide is *Extending DDM to X-DFA*

state that tracking and PIV not possible, but X-DFA gives reasonable results.

backup slides from here on

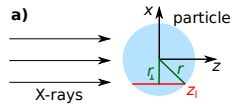
Synthetic radiograms

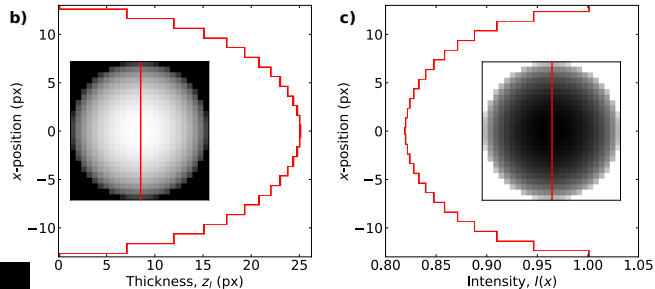


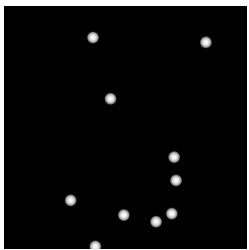
Beer-Lambert

$$I(z_l) = I_0 \exp(-\mu z)$$

Synthetic radiograms







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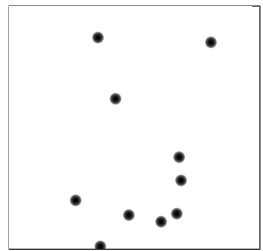

Linear space invariant imaging

Image correlation function

$$g(\mathbf{q}, \tau) = \frac{\langle I^*(\mathbf{q}, t) I(\mathbf{q}, t + \tau) \rangle_t}{\langle |I(\mathbf{q}, t)|^2 \rangle_t}$$

Linear space invariant imaging

Image correlation function

$$g(\mathbf{q},\tau) = \frac{\langle I^*(\mathbf{q},t) I(\mathbf{q},t+\tau)\rangle_t}{\langle |I(\mathbf{q},t)|^2\rangle_t}$$

Intermediate scattering function

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

Linear space-invariant imaging:

$$I(\mathbf{r},t) = I_0 + \int \mathrm{d}\mathbf{r}'\, \mathrm{d}z'\, T(\mathbf{r}-\mathbf{r}', -z')\, c(\mathbf{r}', z', t)$$