

Observation of universal dynamics in a spinor Bose gas far from equilibrium

Maximilian Prüfer



UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386



STRUCTURES
CLUSTER OF
EXCELLENCE

Synthetic
Quantum
Systems

@SynQS Heidelberg



Bosonic Quantum Gases



Maximilian
Prüfer



Philipp
Kunkel



Stefan
Lannig



Alexis
Bonnin



Helmut
Strobel



Markus
Oberthaler

Theory

1PI



Torsten
Zache



Jürgen
Berges

Scaling

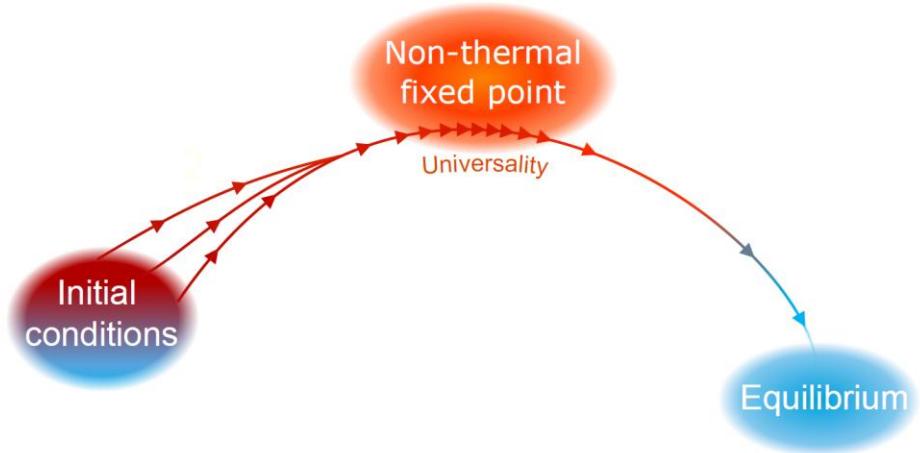


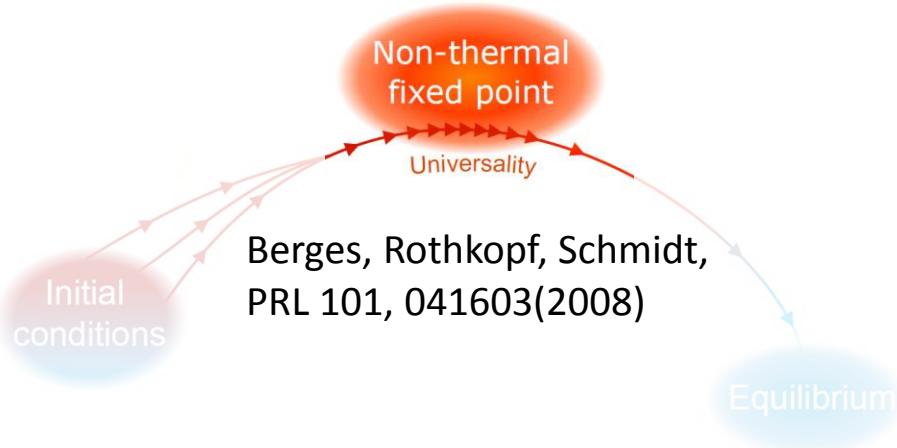
Christian-Marcel
Schmied

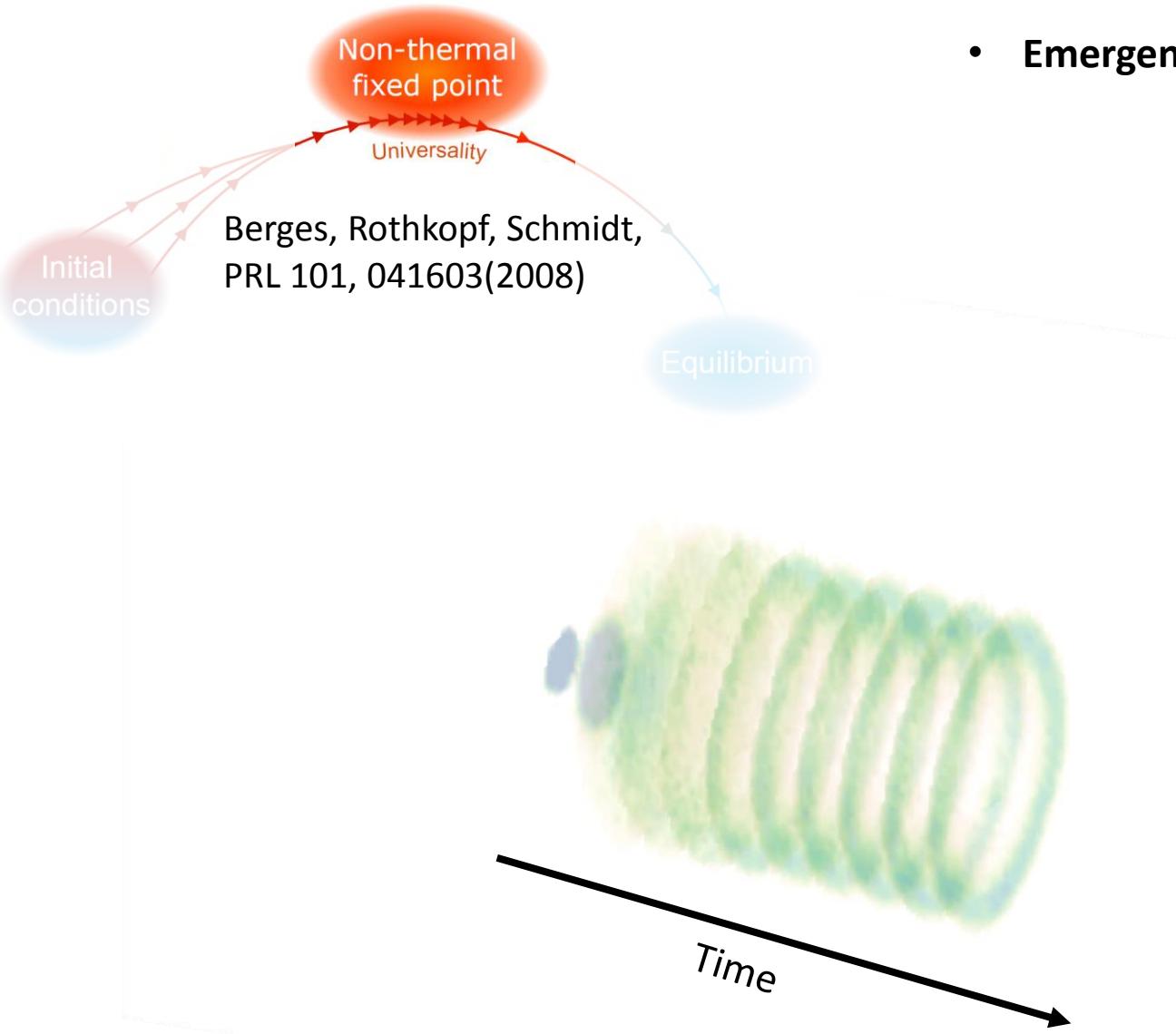


Thomas
Gasenzer

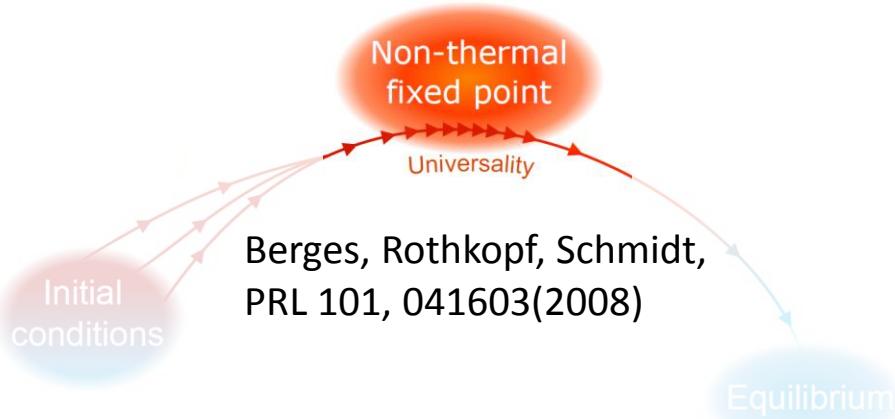






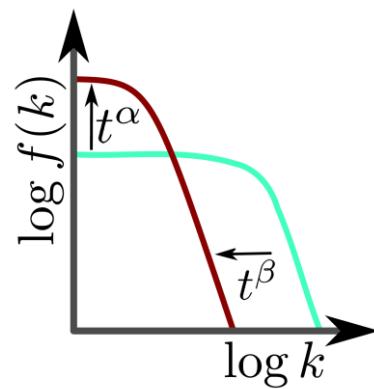


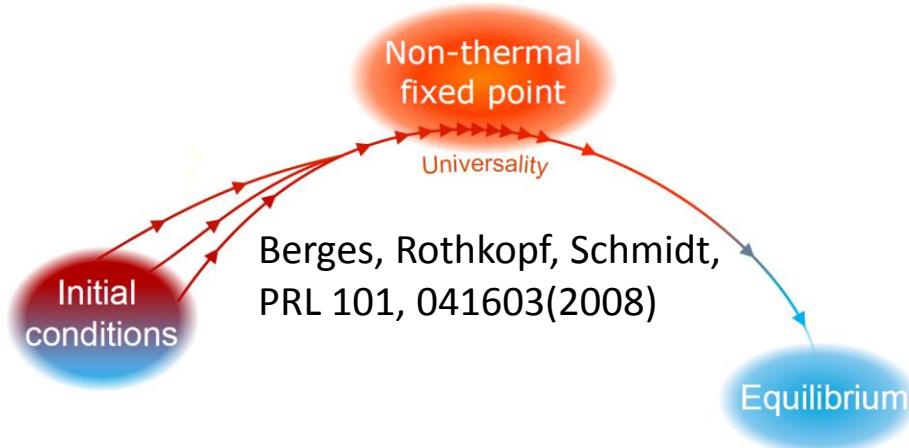
- **Emergent** degree of freedom



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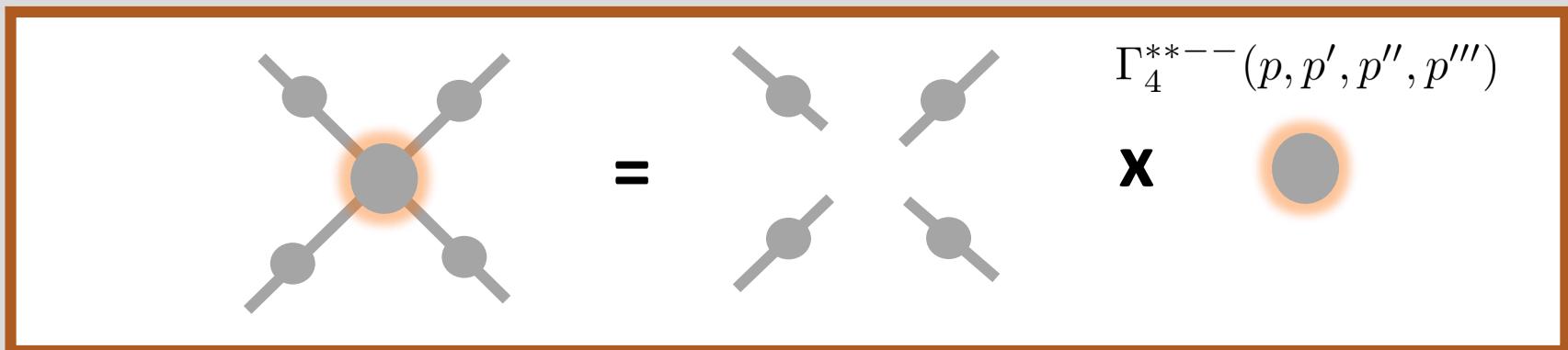
$$f_\theta(k, t) = t^\alpha f_S(t^\beta k)$$





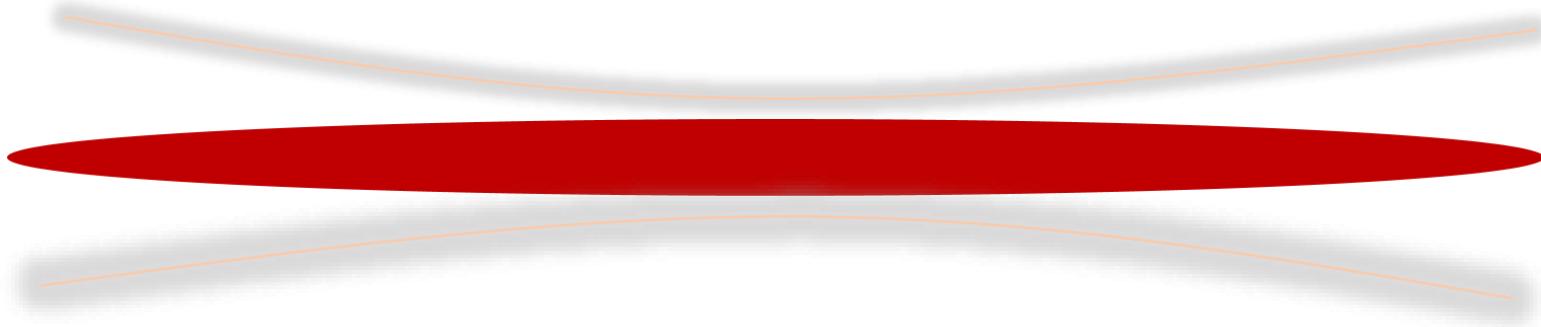
- **Emergent** degree of freedom
- **Universal dynamics** close to Non-thermal fixed point
- Interaction „constants“ of **effective field theory** can become momentum dependent

1 particle irreducible correlations



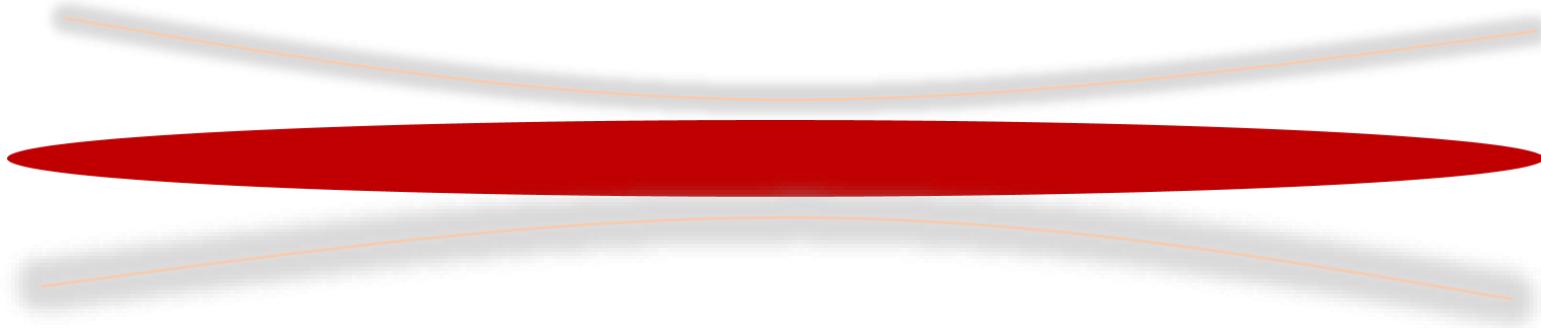
^{87}Rb

$\sim 100\,000$ atoms



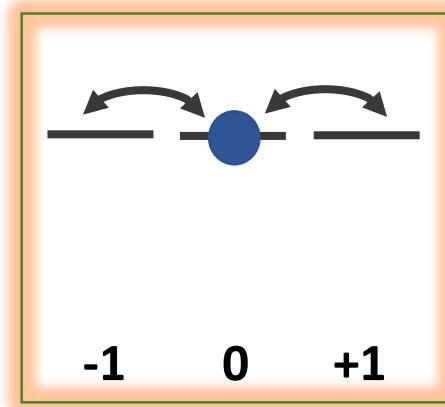
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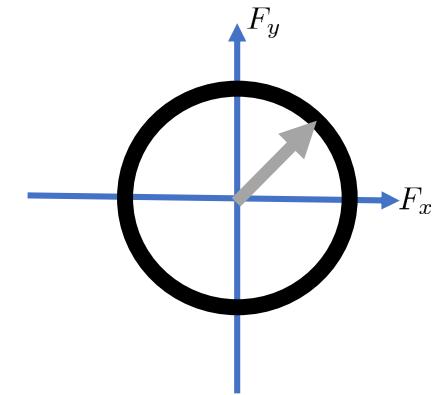


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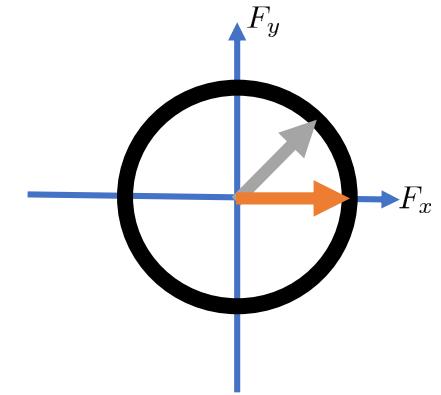
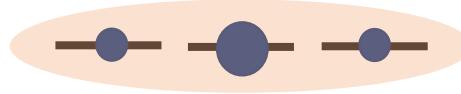
$F = 1$



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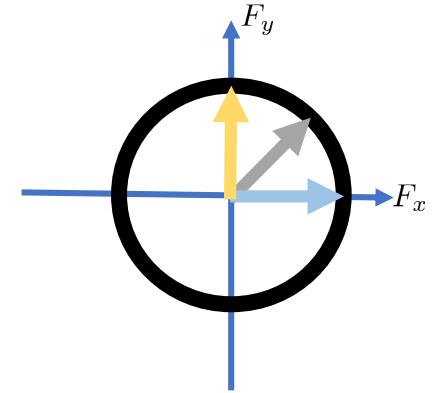
Kunkel, P. et al., PRL **123**, 063603

$F = 2$

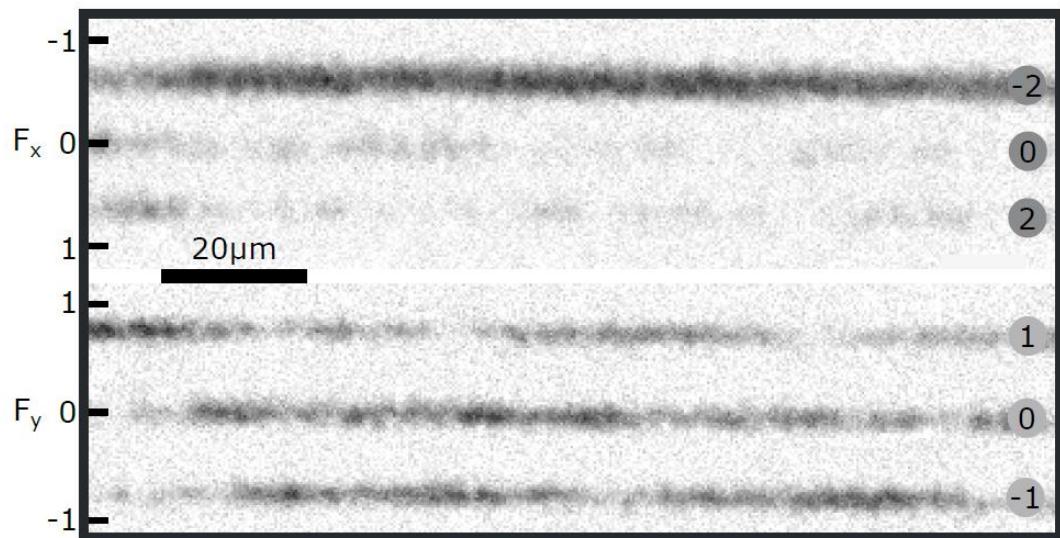
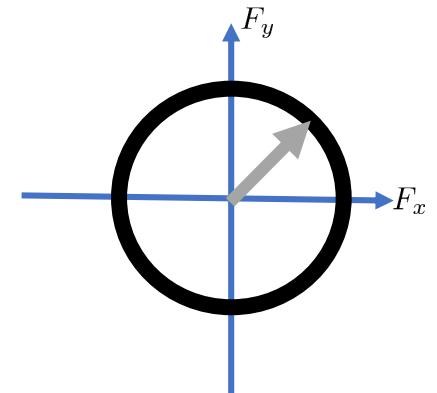
$F = 1$

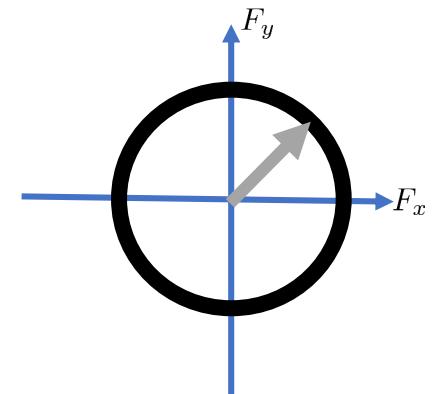


**Microwave
6.8 GHz**

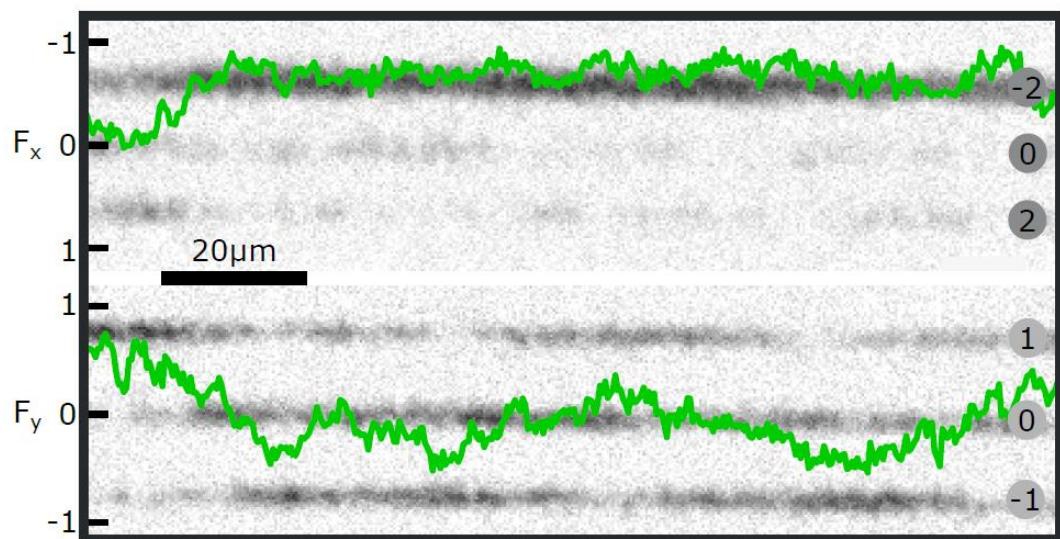


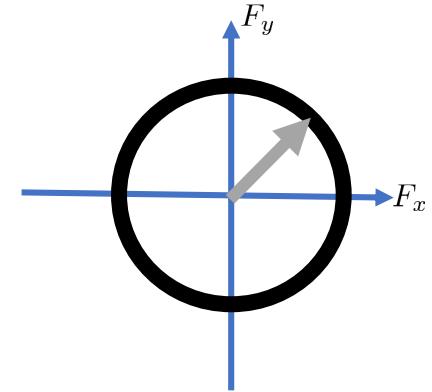
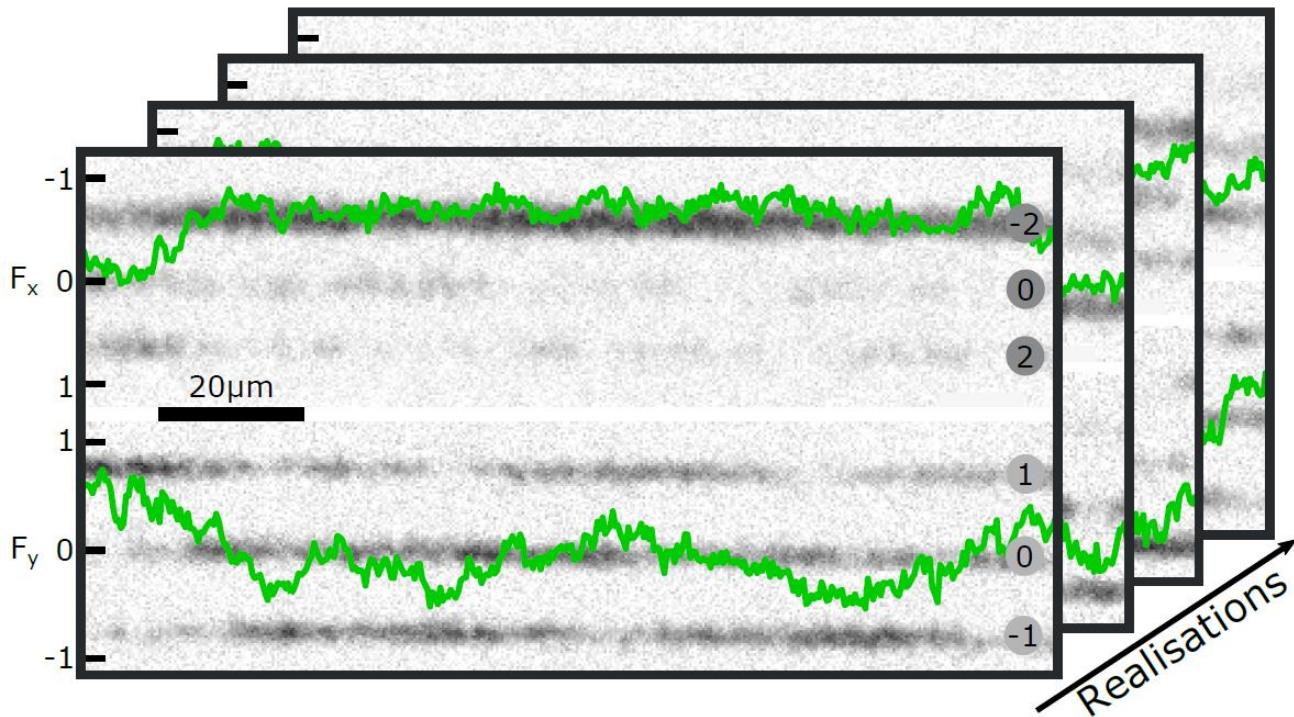
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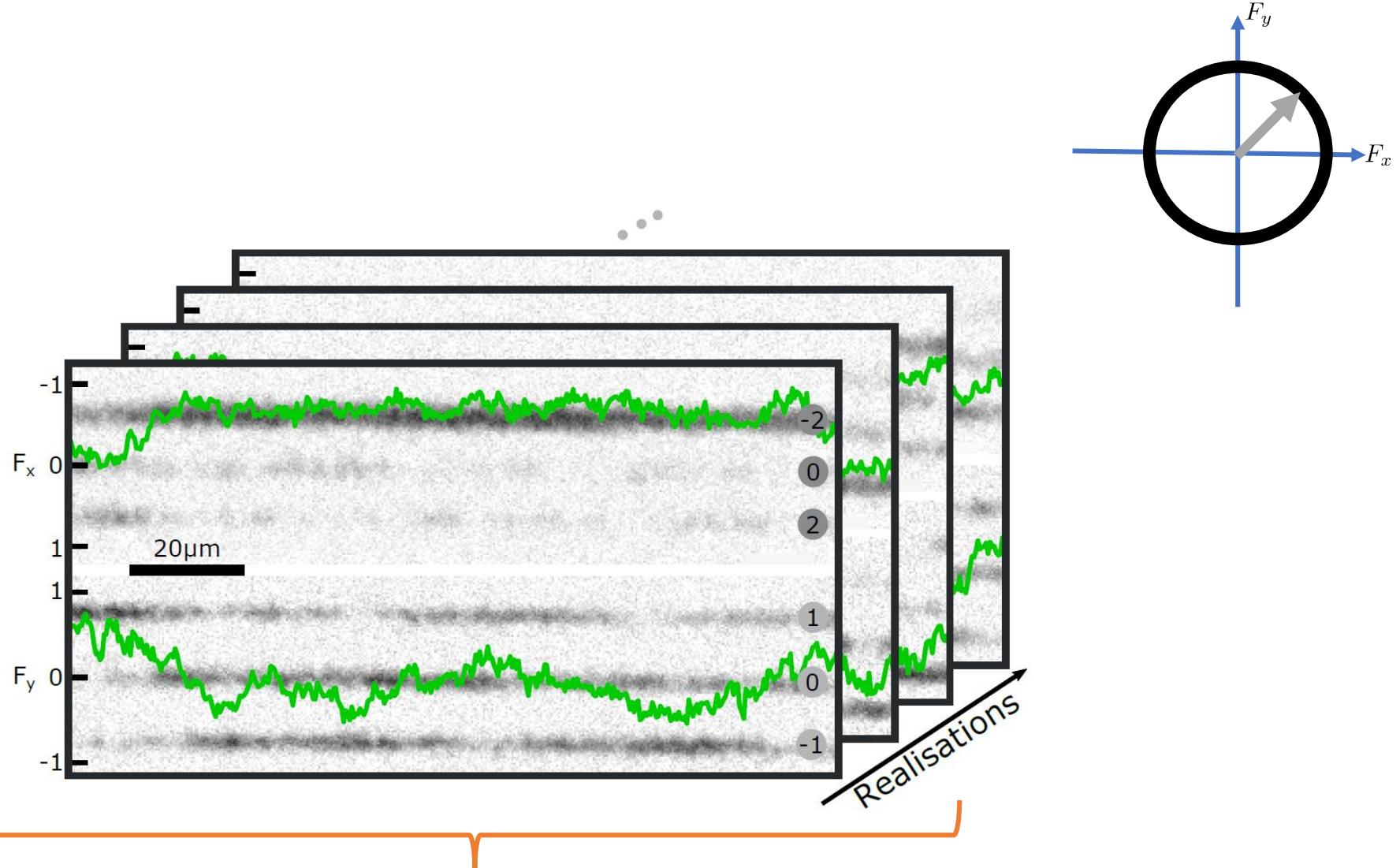




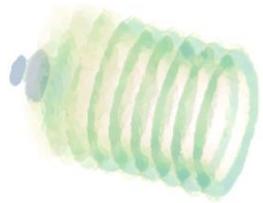
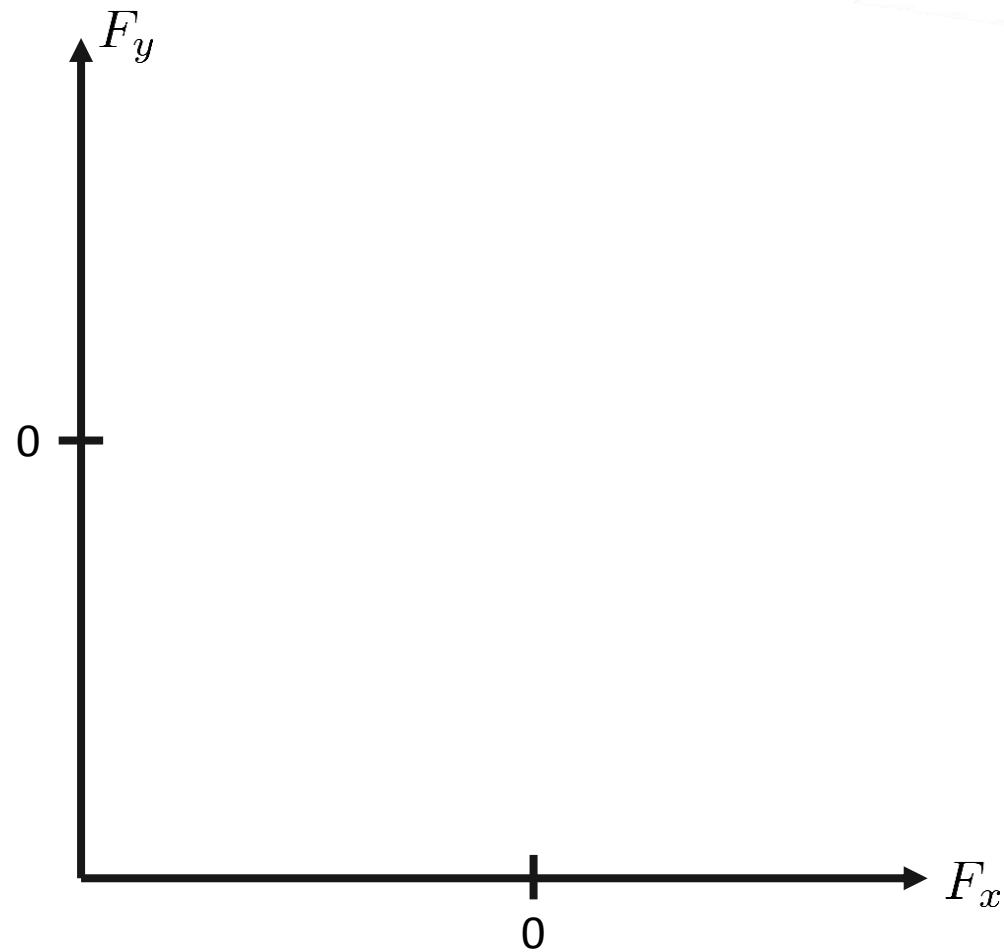
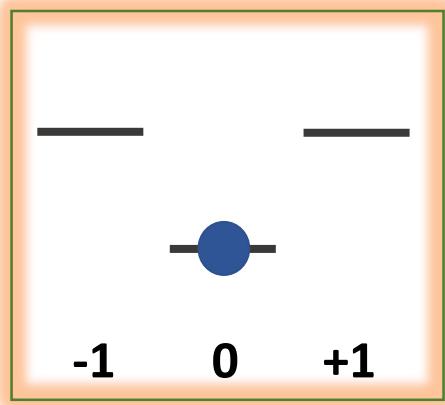
$$F_{\perp} = F_x + iF_y$$

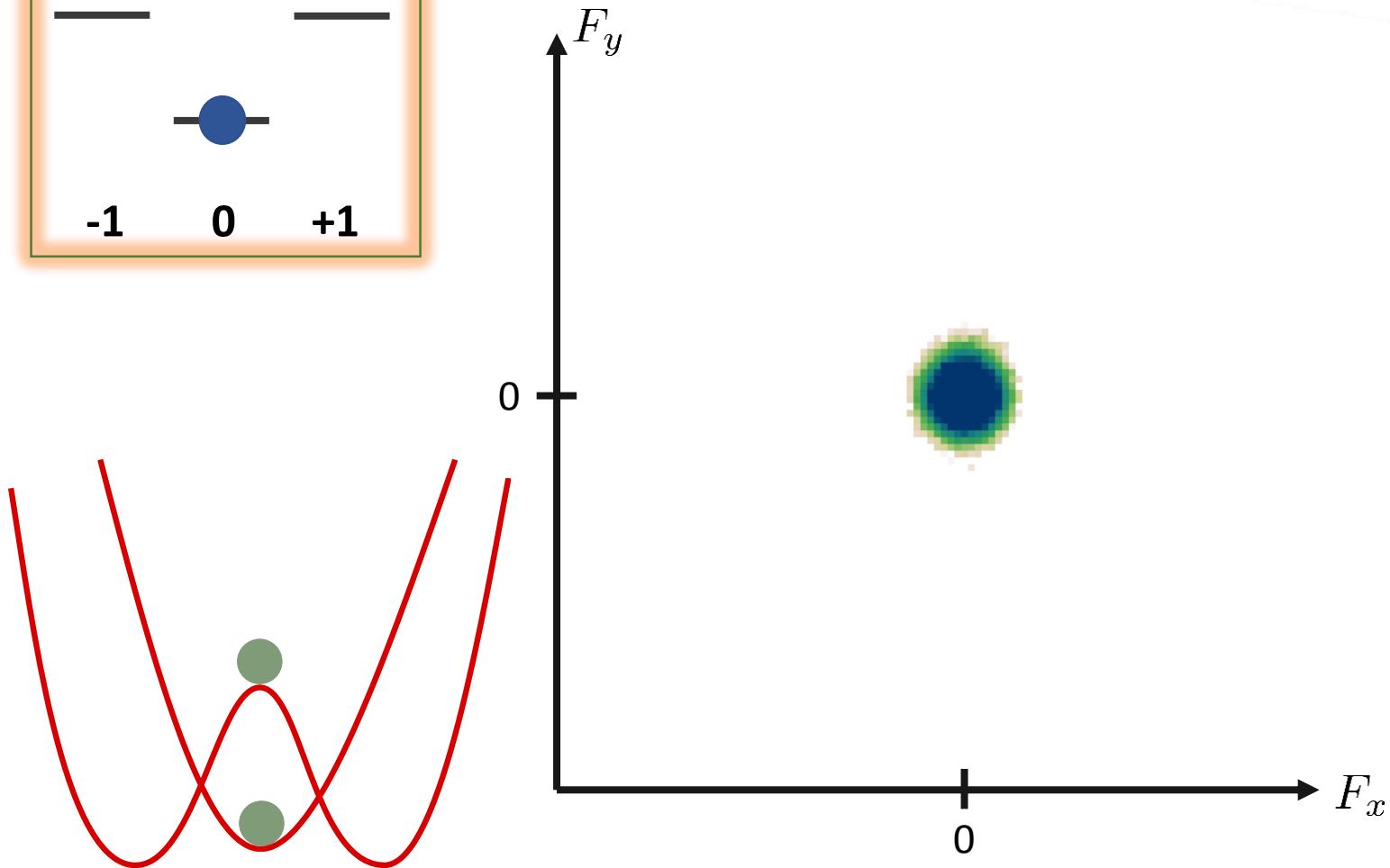
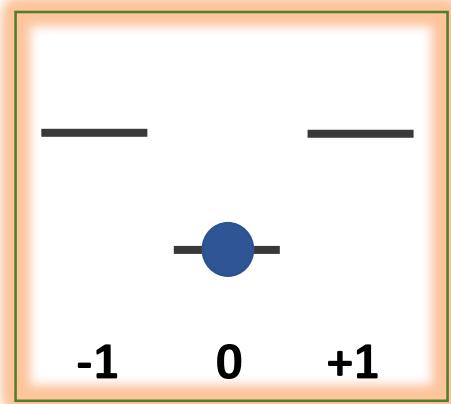
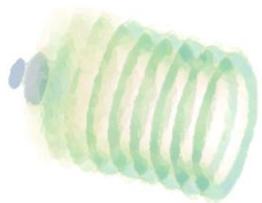


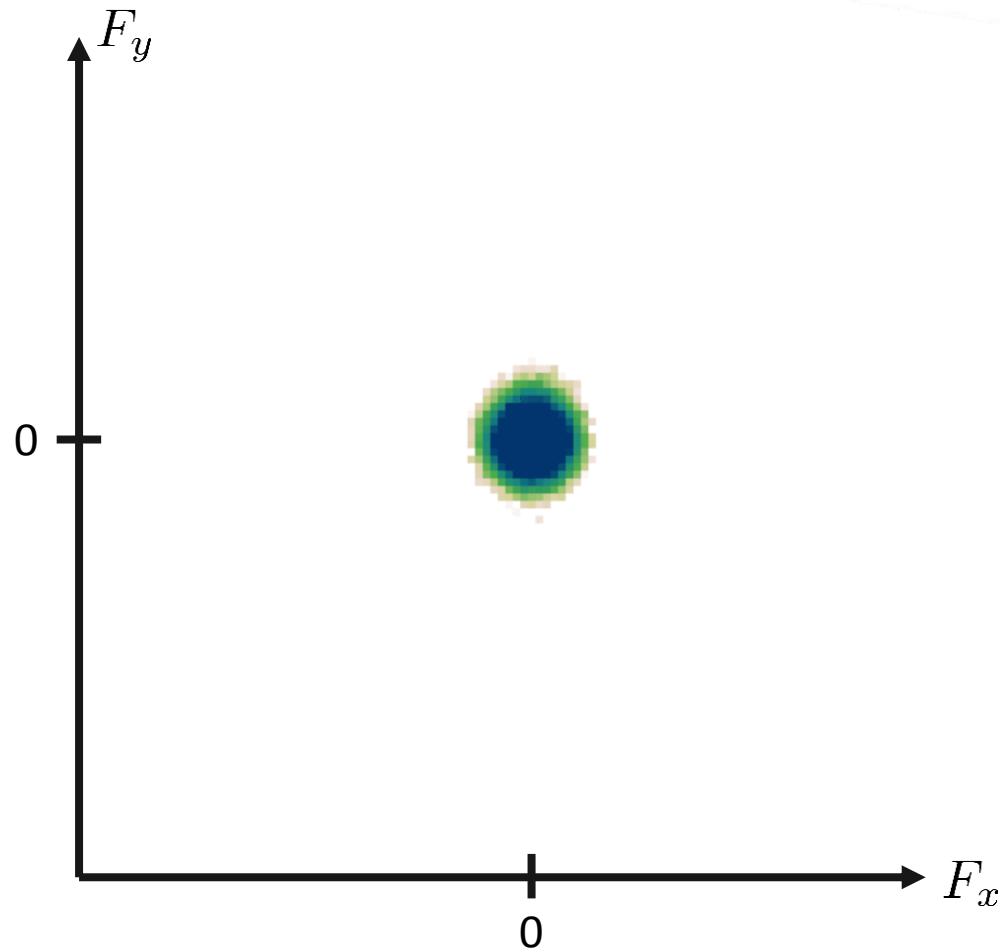


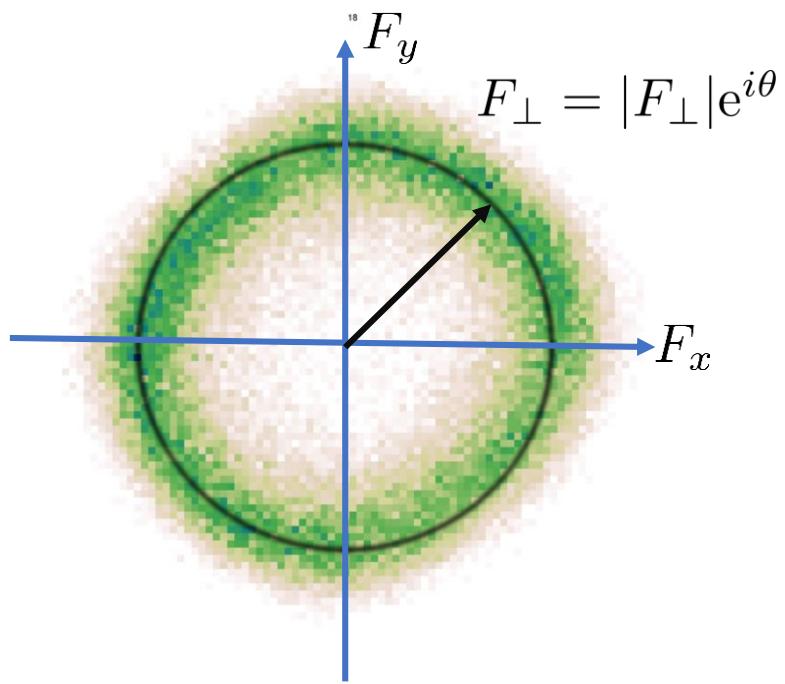


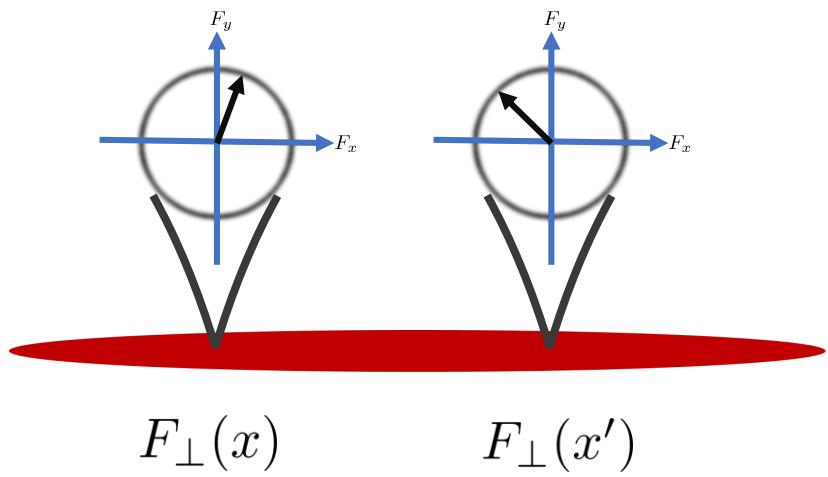
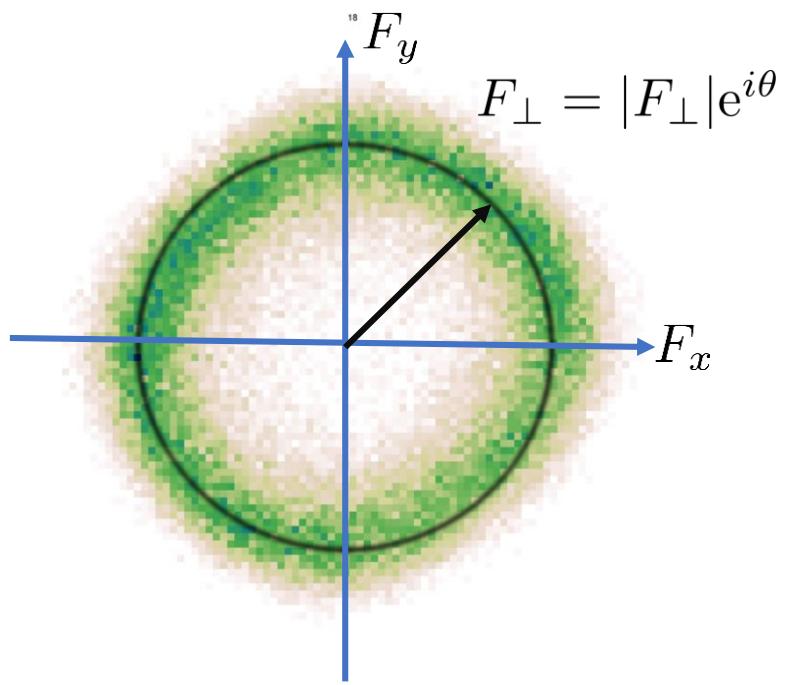
Ensemble averaged transversal spin
distribution function

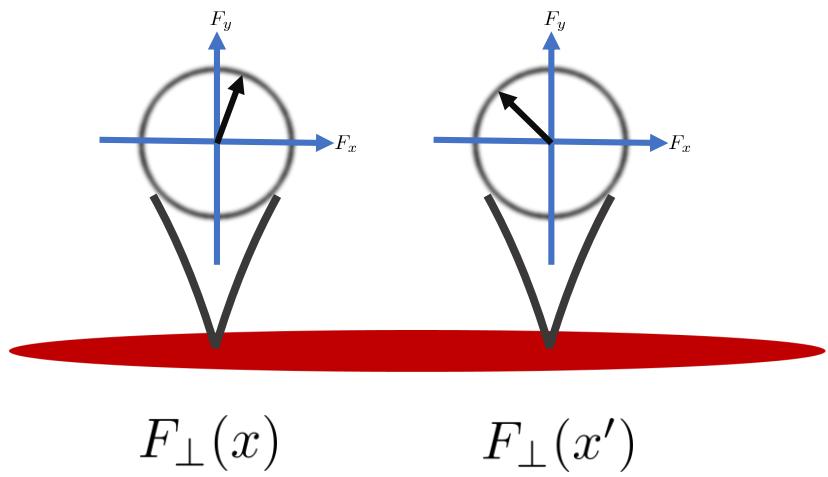
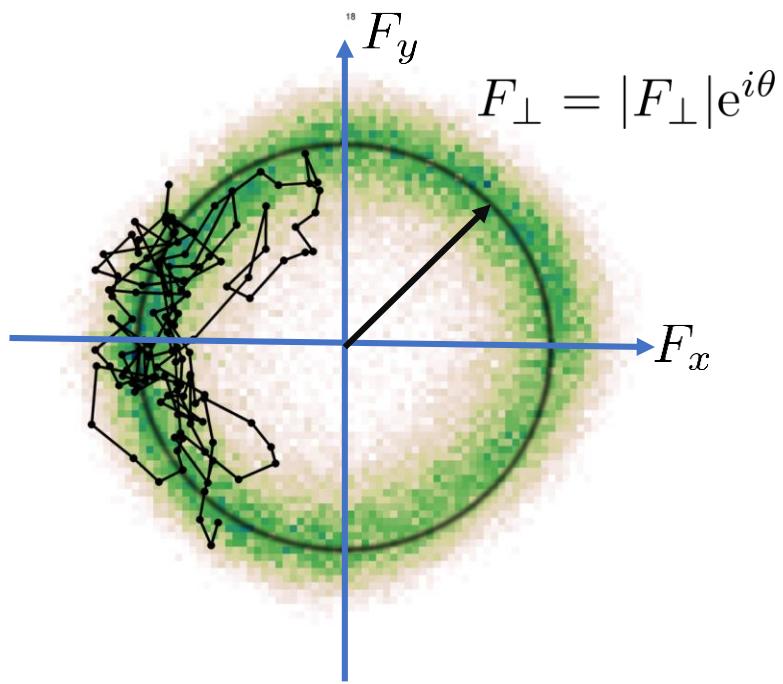


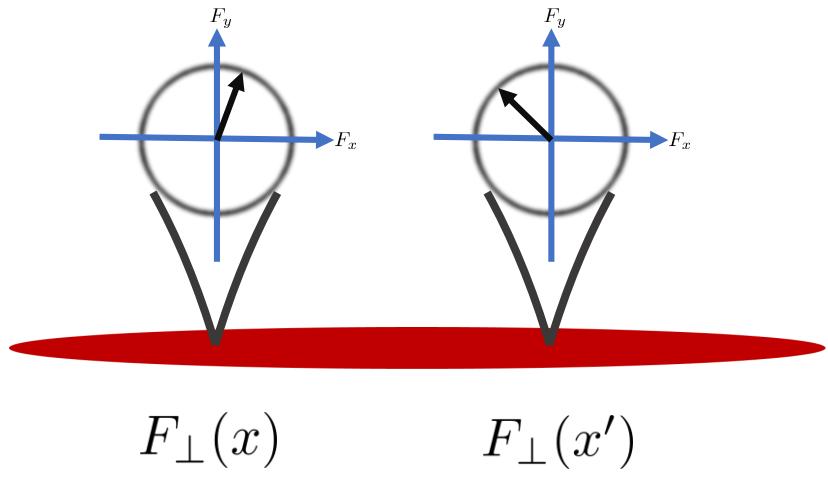






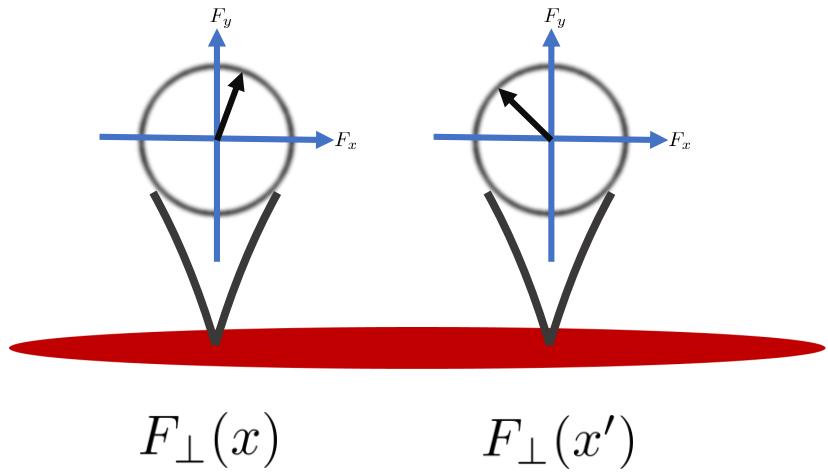






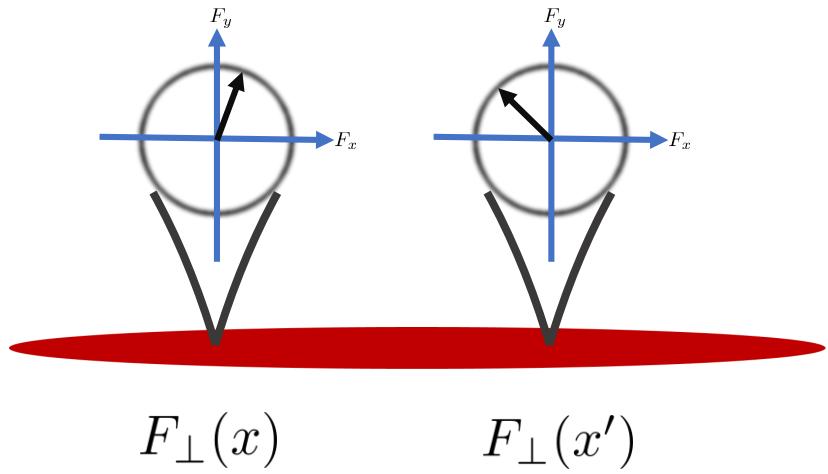
Correlation functions

$$C_2^{*-}(x, x') = \langle F_{\perp}^*(x) F_{\perp}(x') \rangle$$



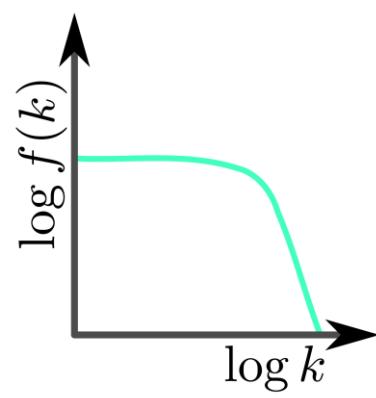
Correlation functions

$$C_2^{*-}(p, p') = \mathcal{FT} (C_2^{*-}(x, x'))$$



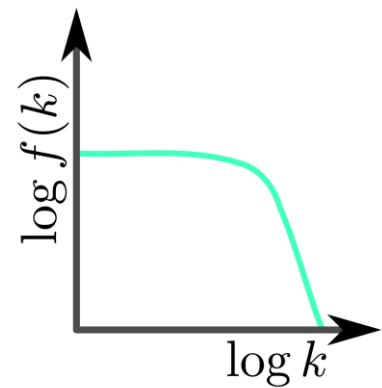
Observation of universal dynamics in a spinor Bose gas far from equilibrium

Prüfer, M. et al., Nature **563**, 217-220 (2018)



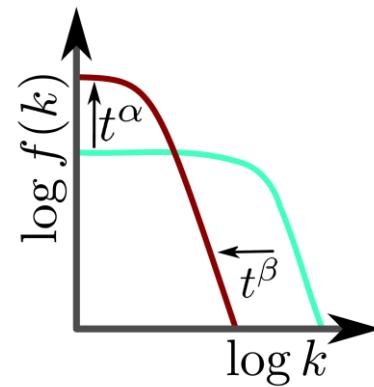
Dynamics is described by:

1. Scaling exponents α, β
2. Scaling function f_S

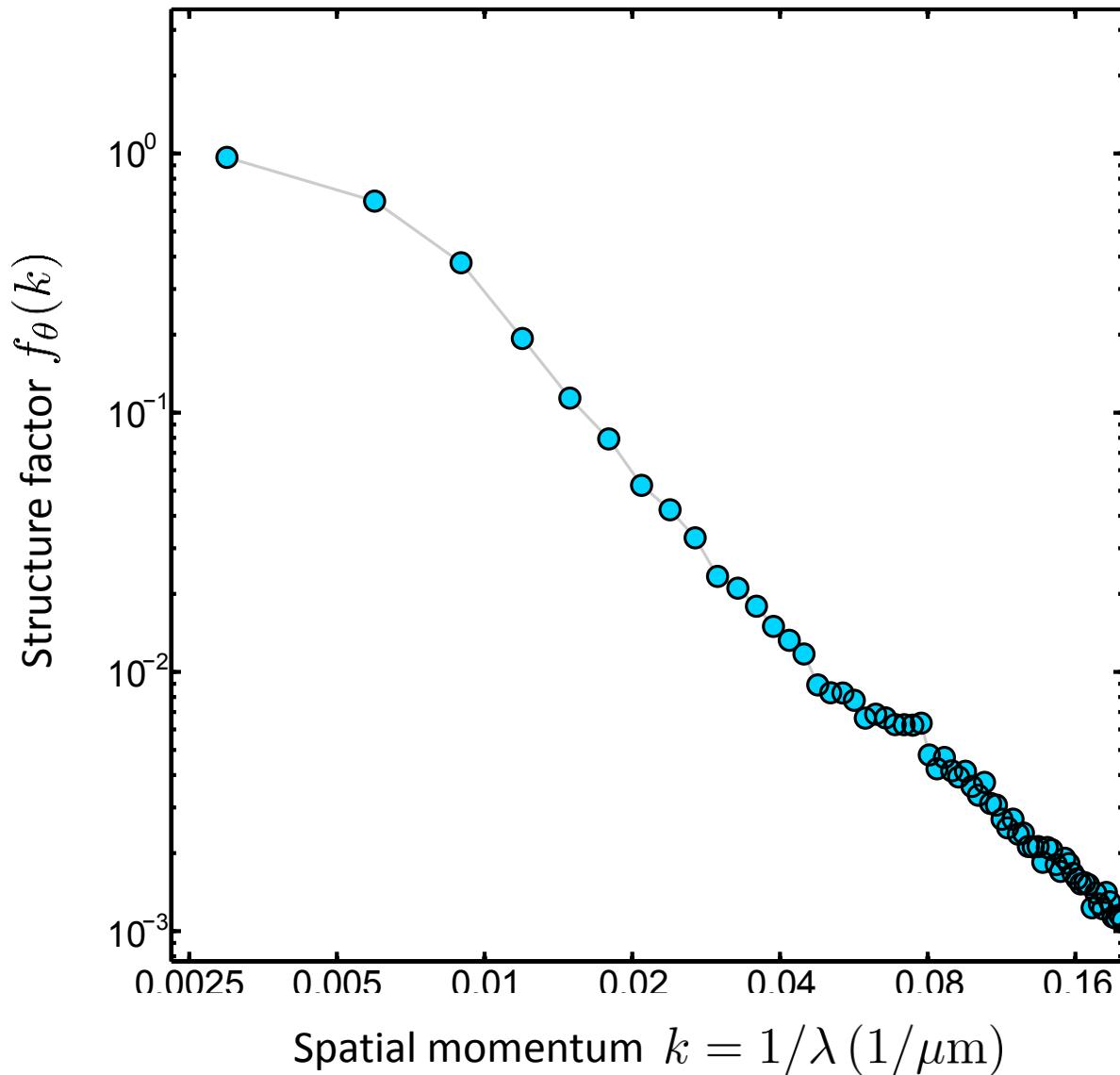


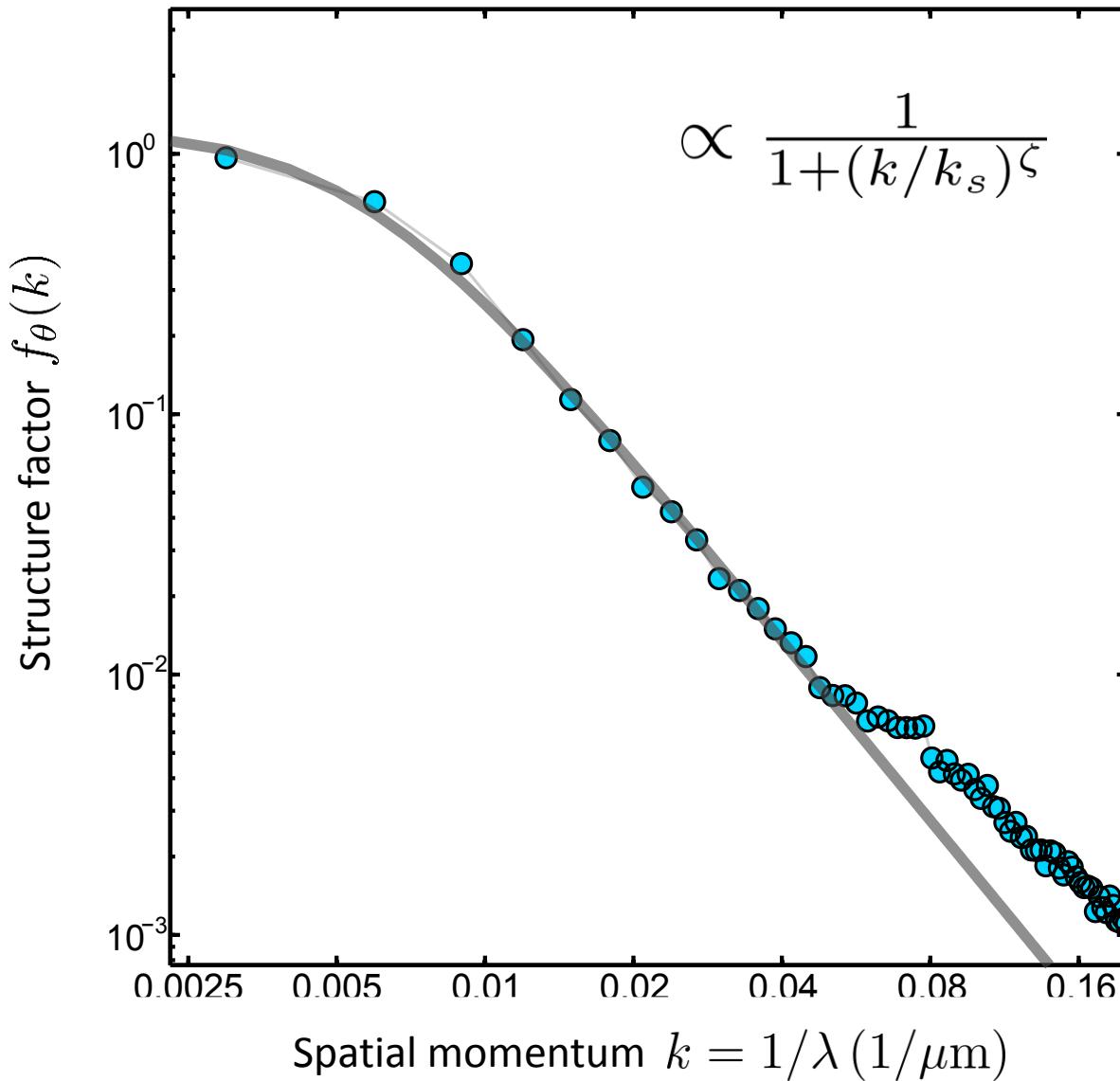
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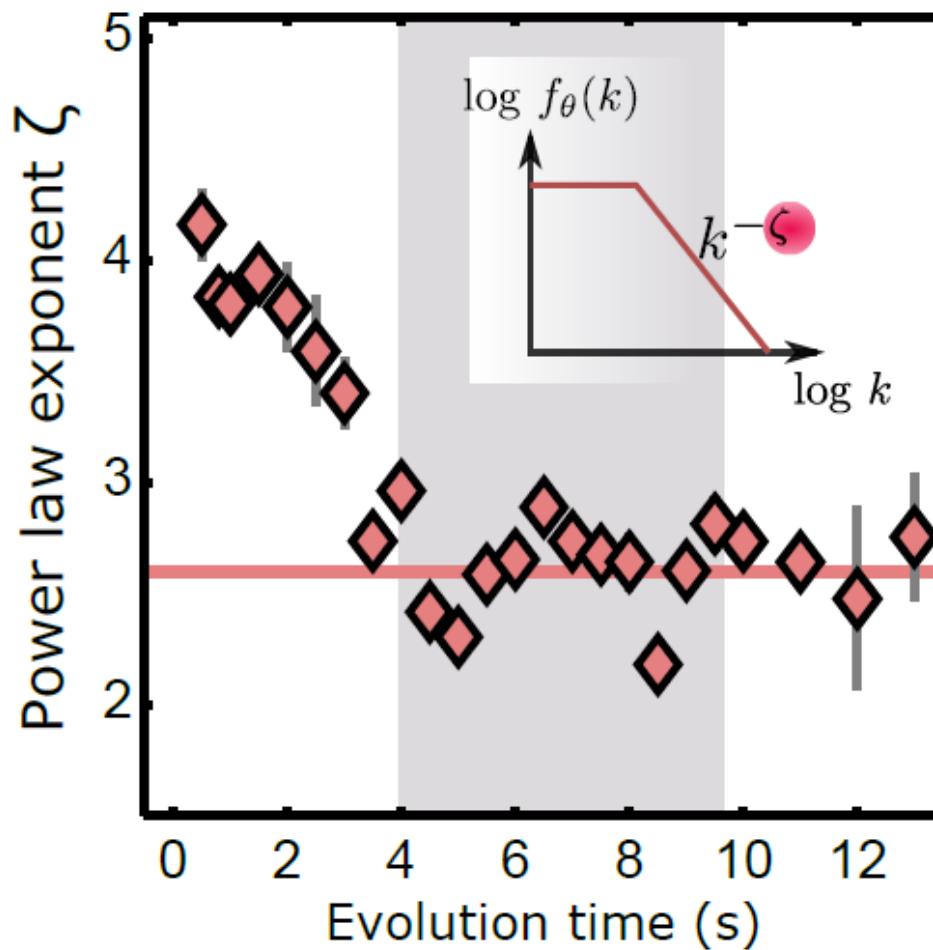
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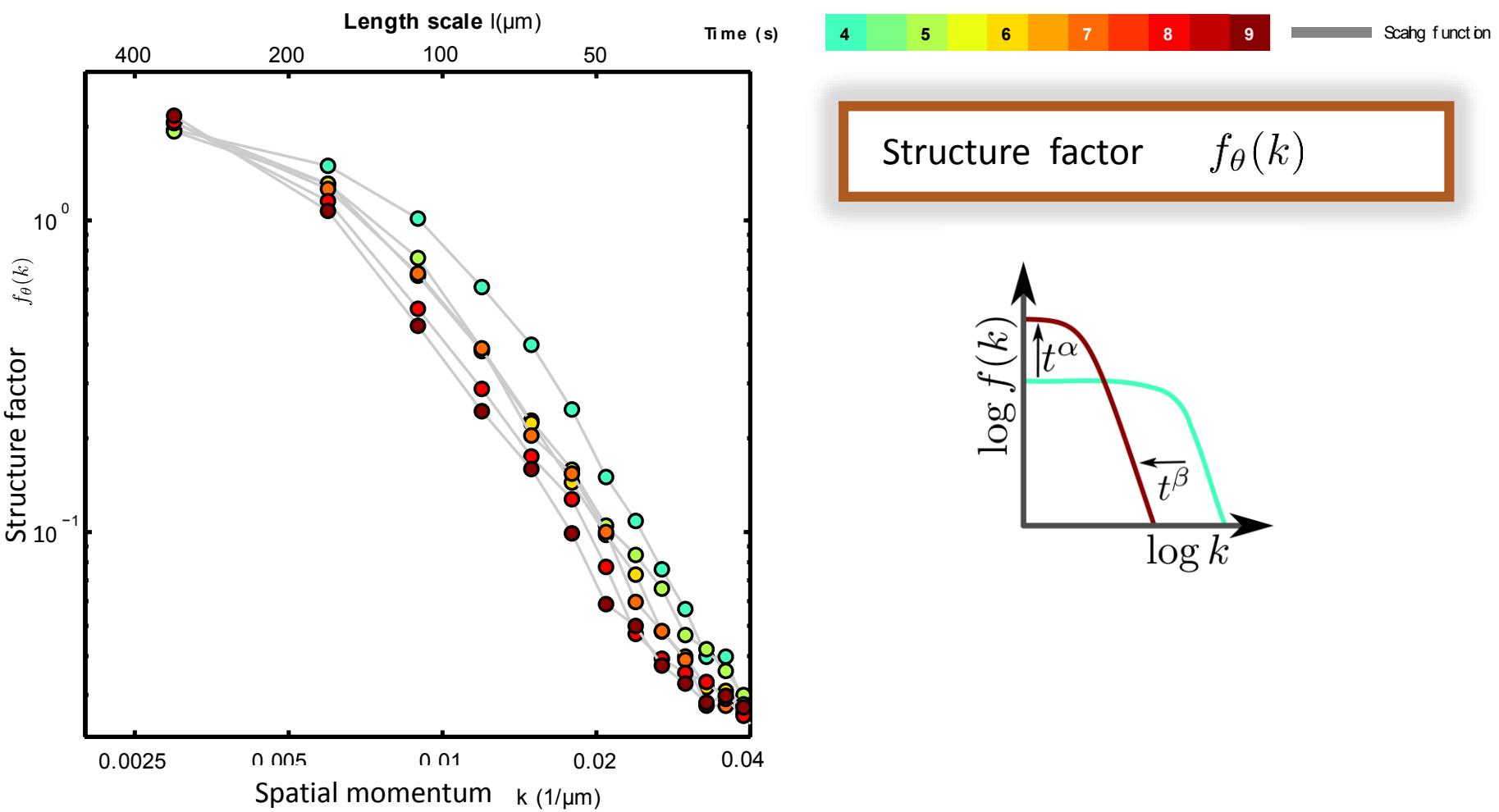


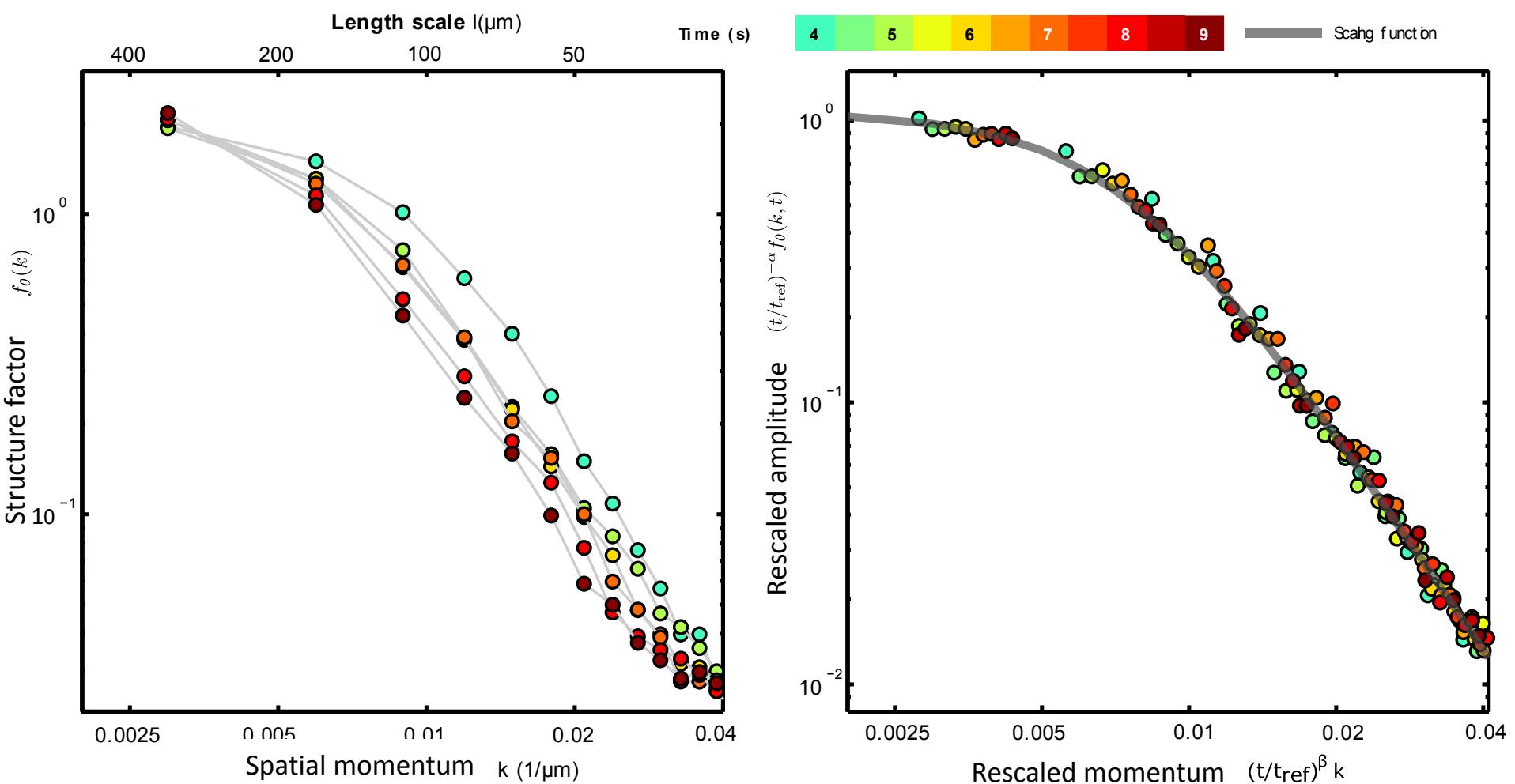
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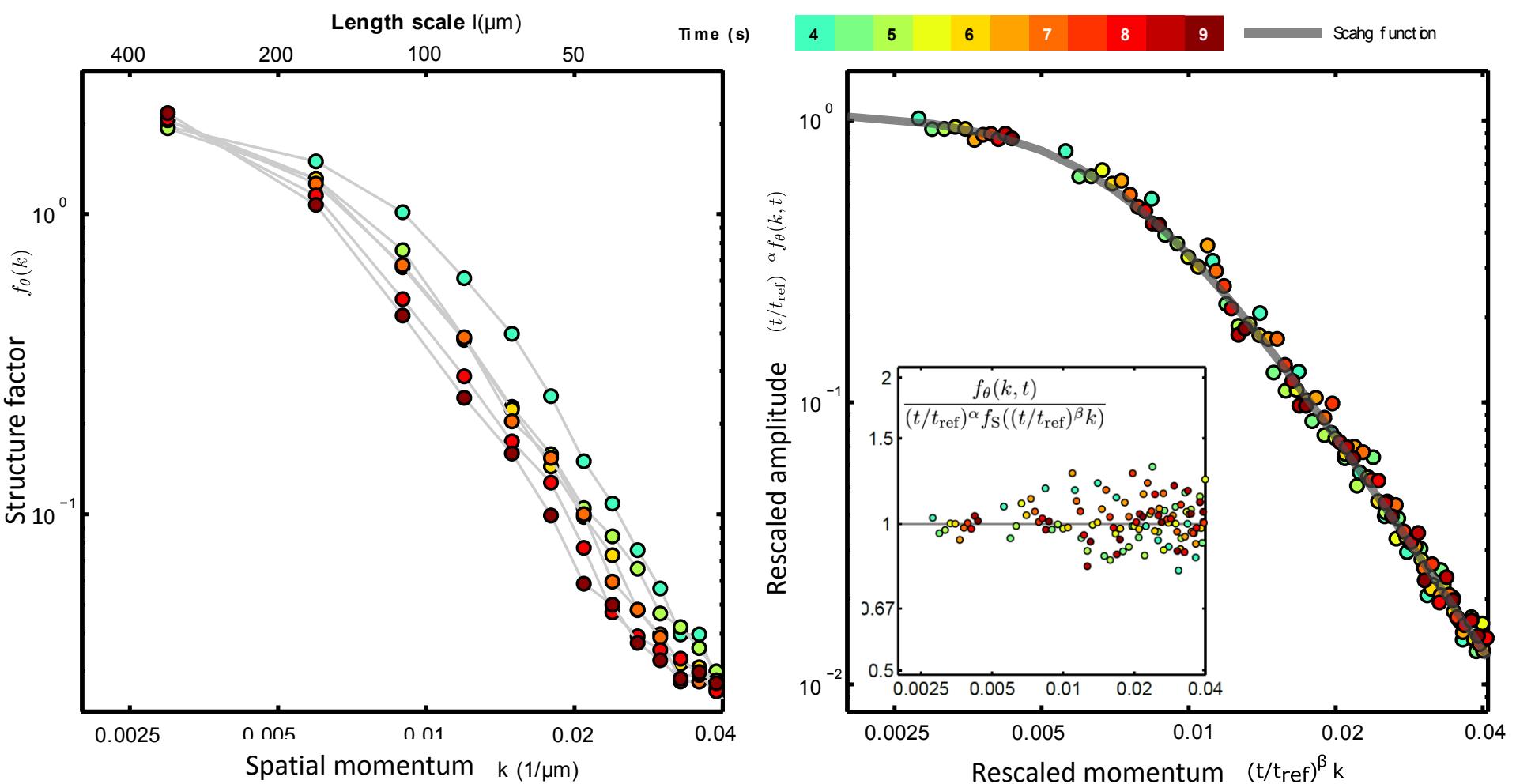


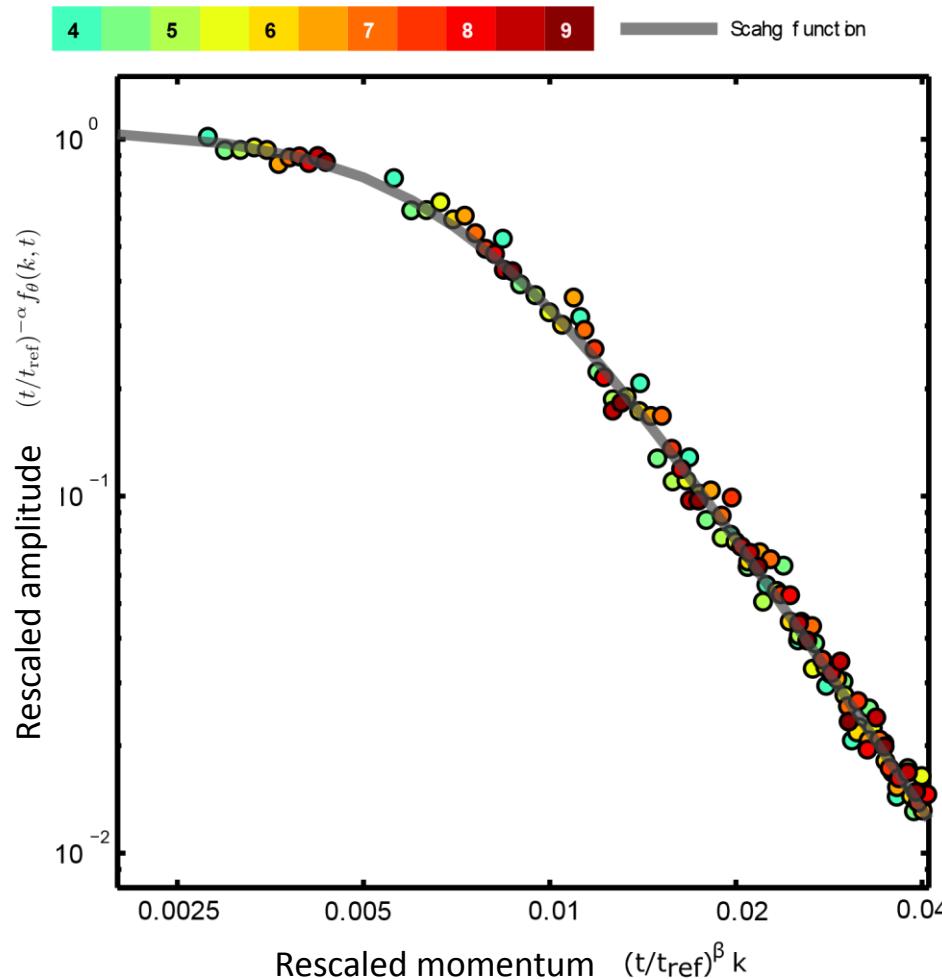








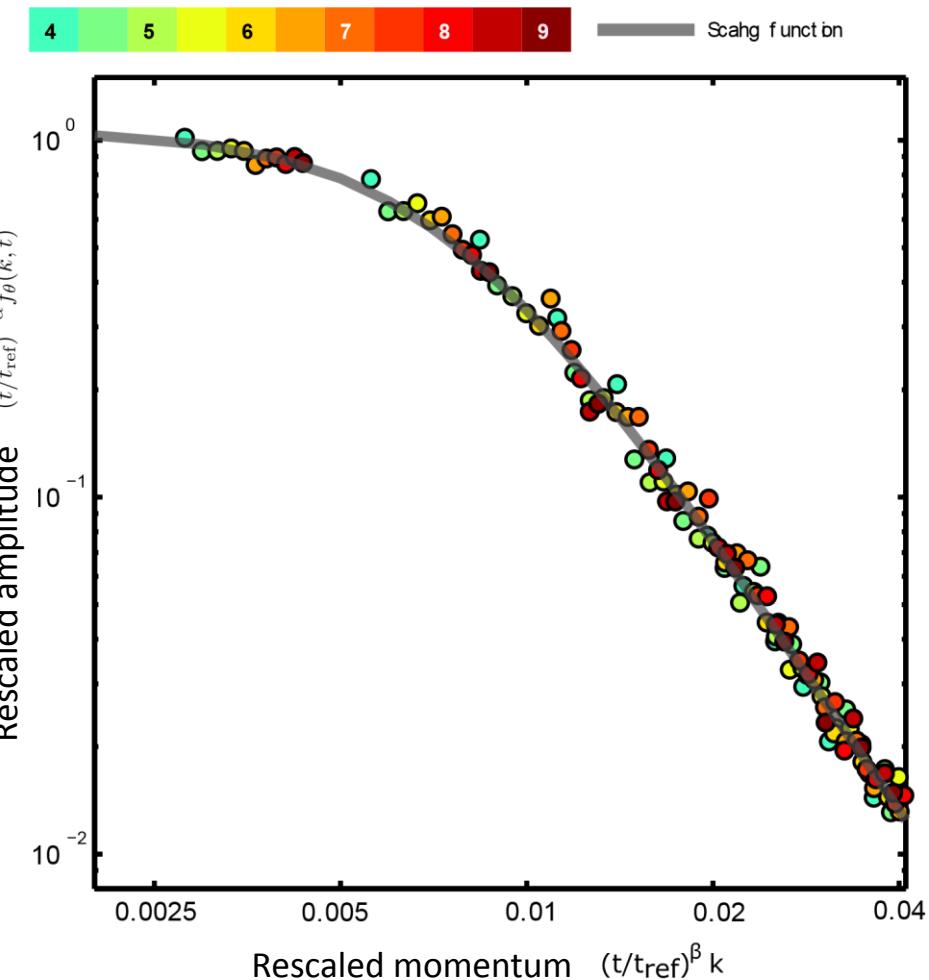




This work:

$$\beta \approx 0.55$$

Prüfer, M. et al., Nature 563, 217-220 (2018)



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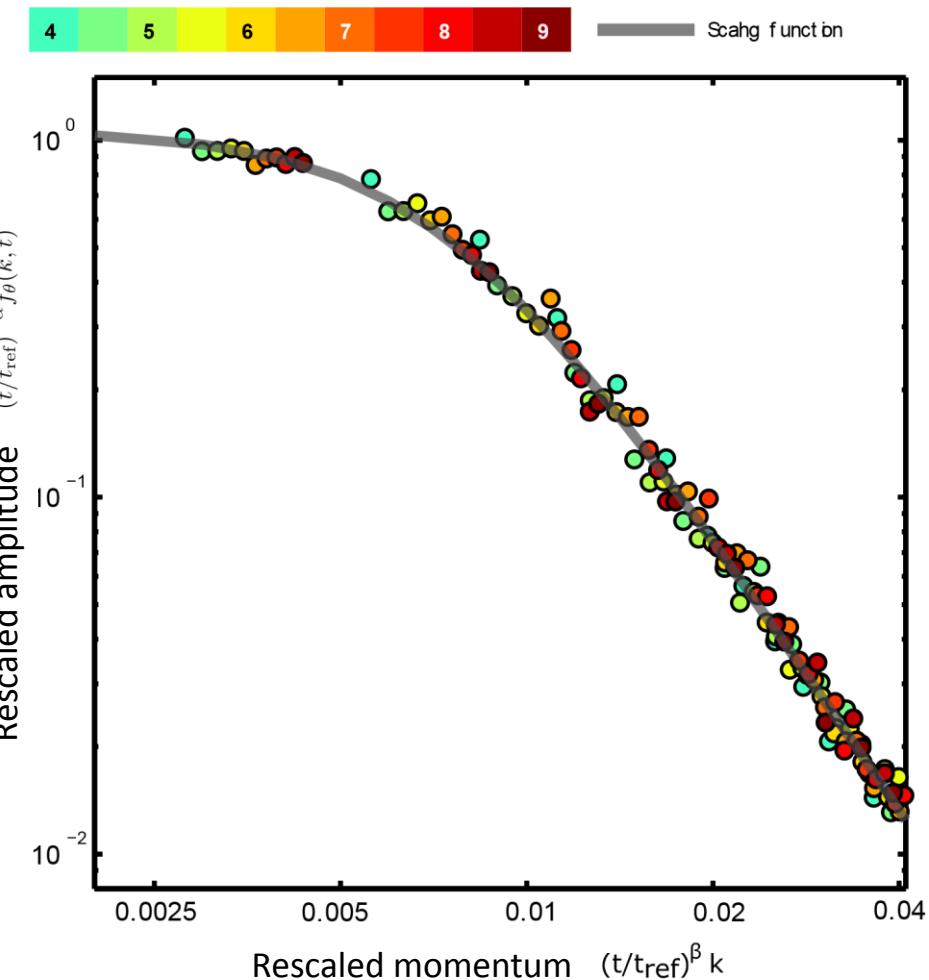
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Experiment Vienna:

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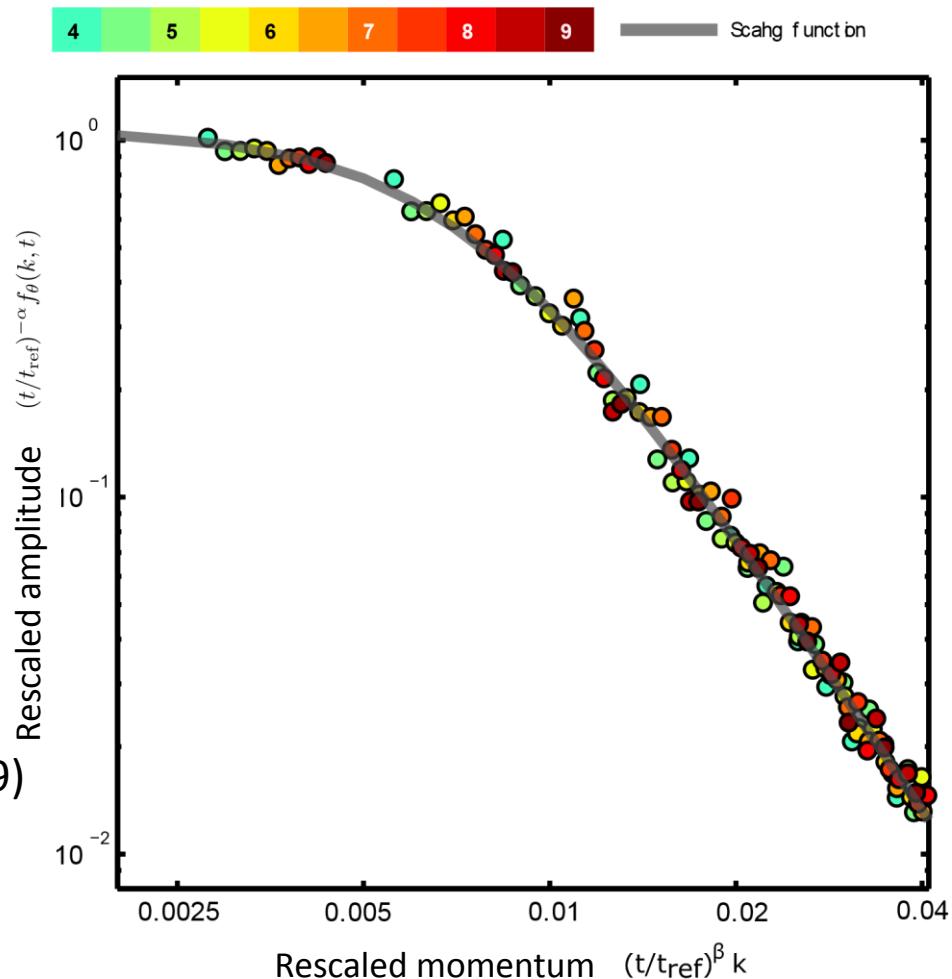
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Numerics:

$$O(1)/O(3) \text{ 3D: } \beta \approx 0.5$$

Orioli, A. et al., PRD **92**, 025041 (2015)

Schmied, C.-M. et al., PRL **122**, 170404 (2019)



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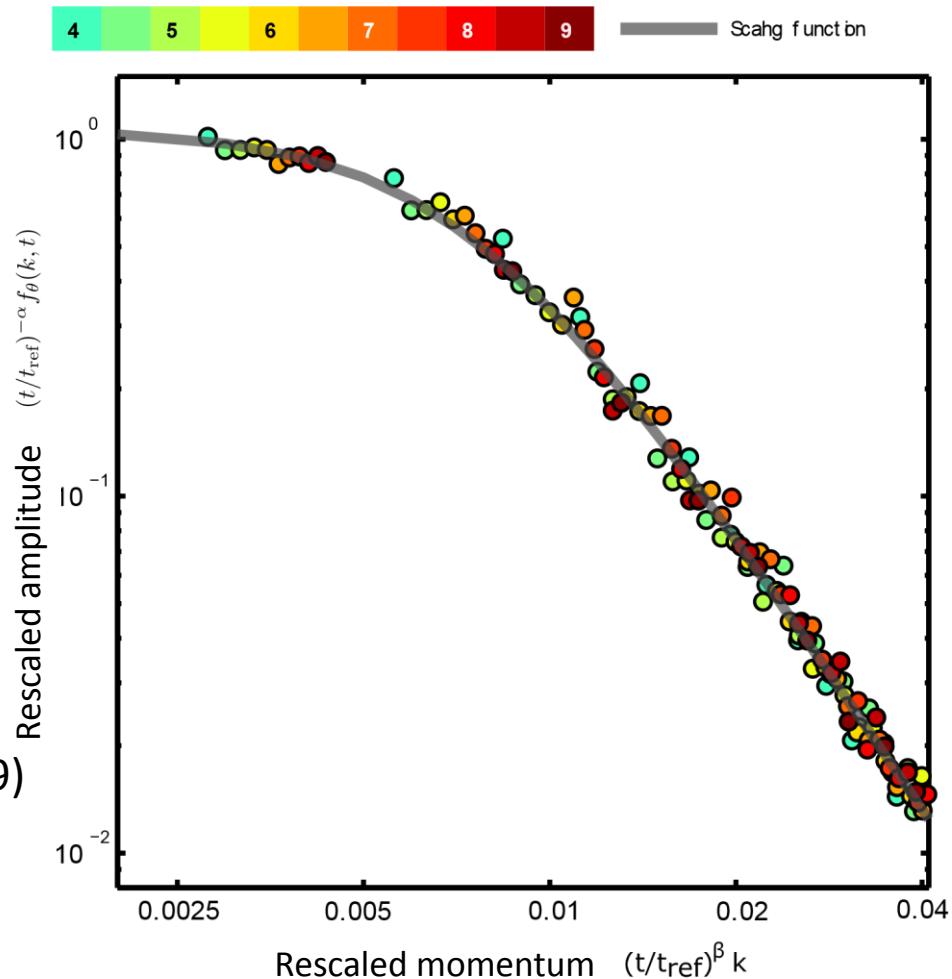
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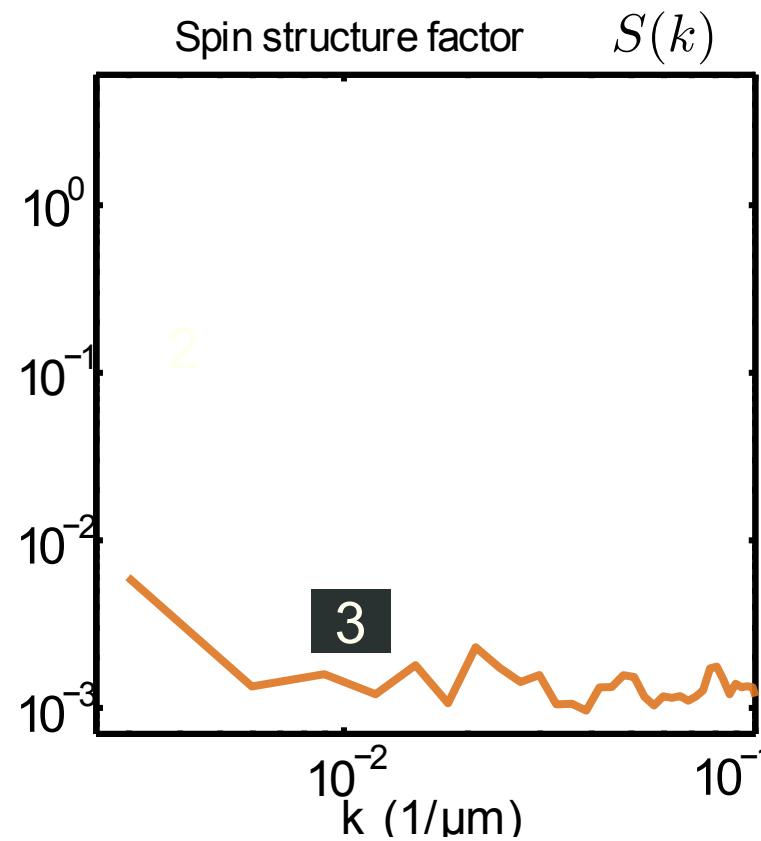
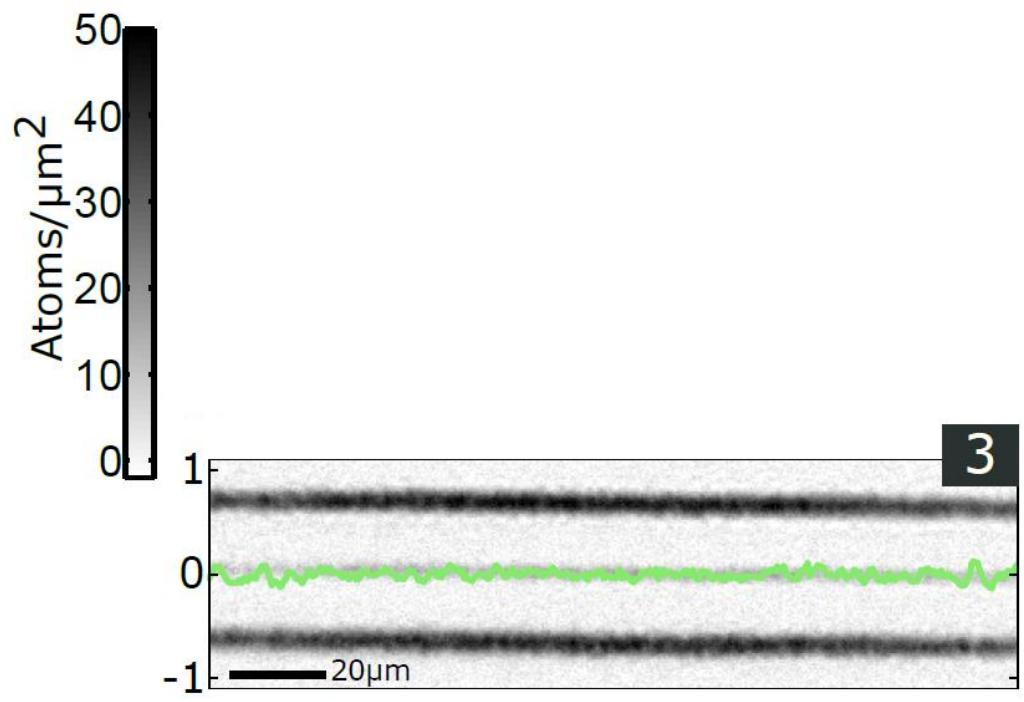
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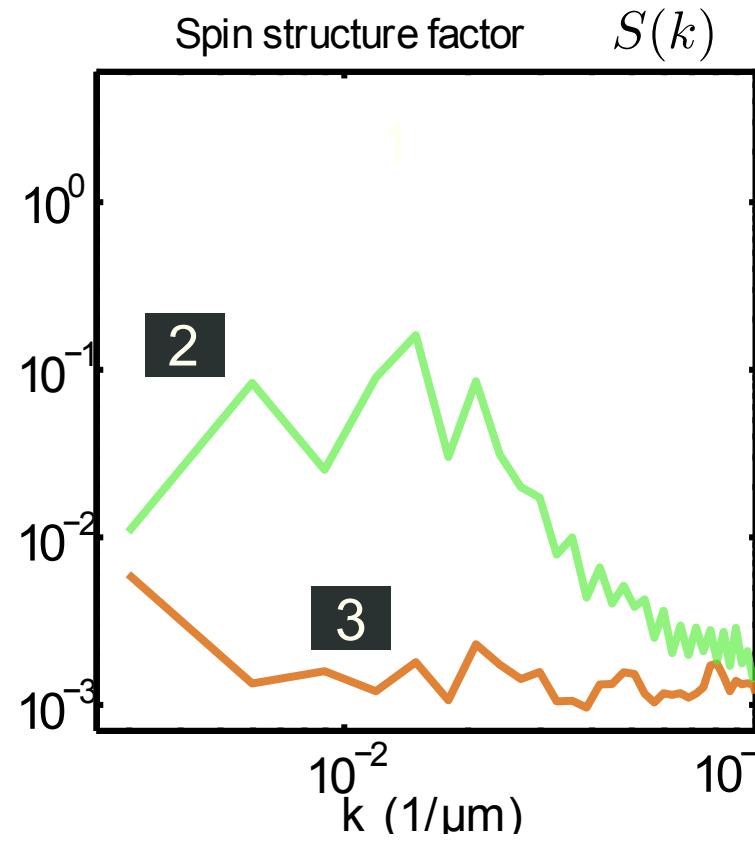
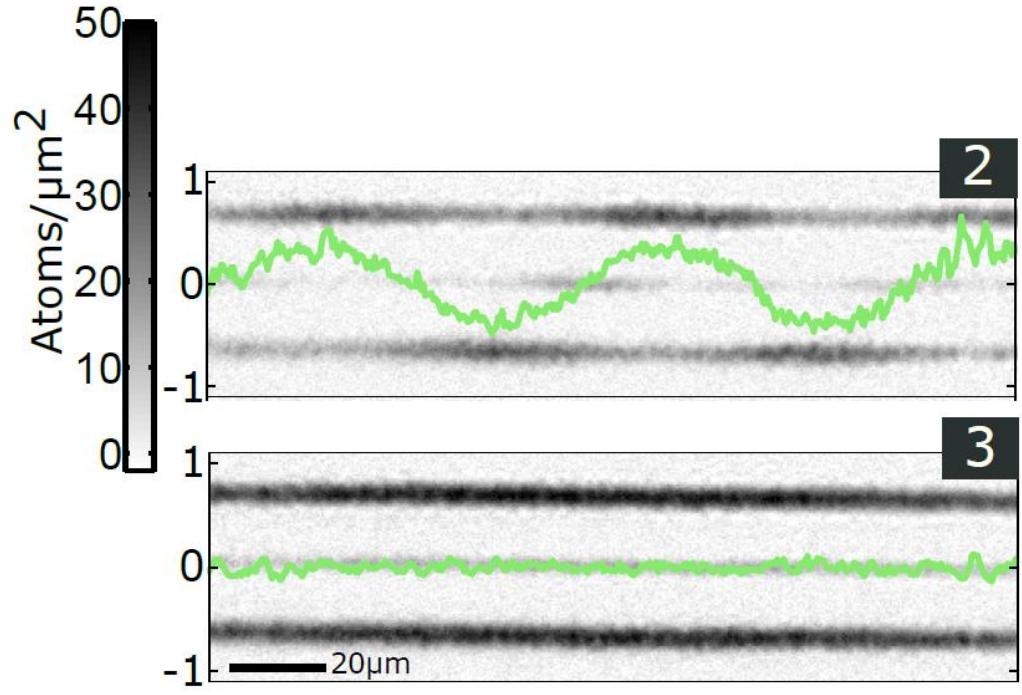
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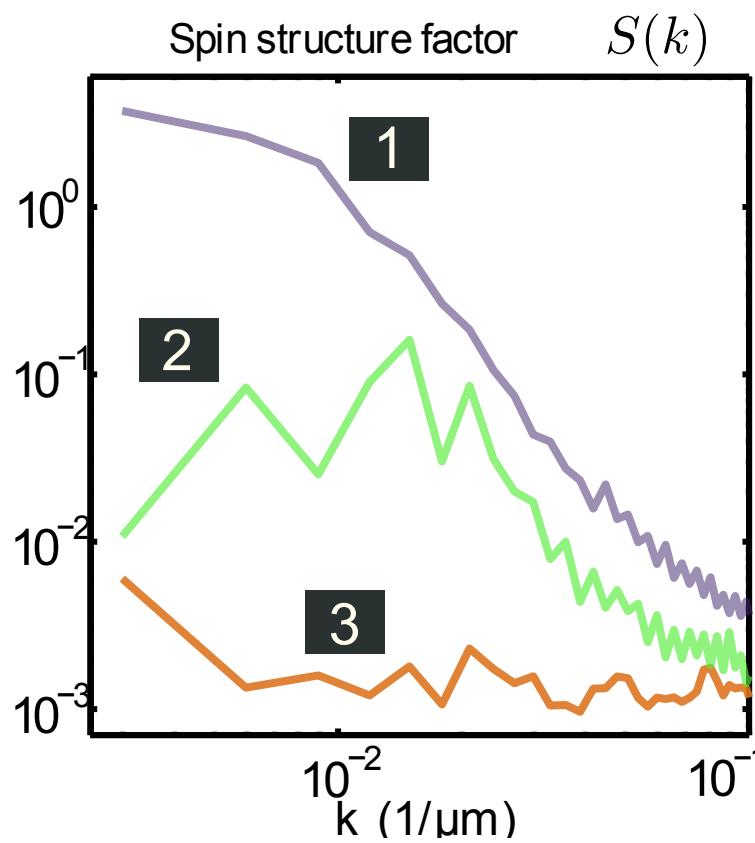
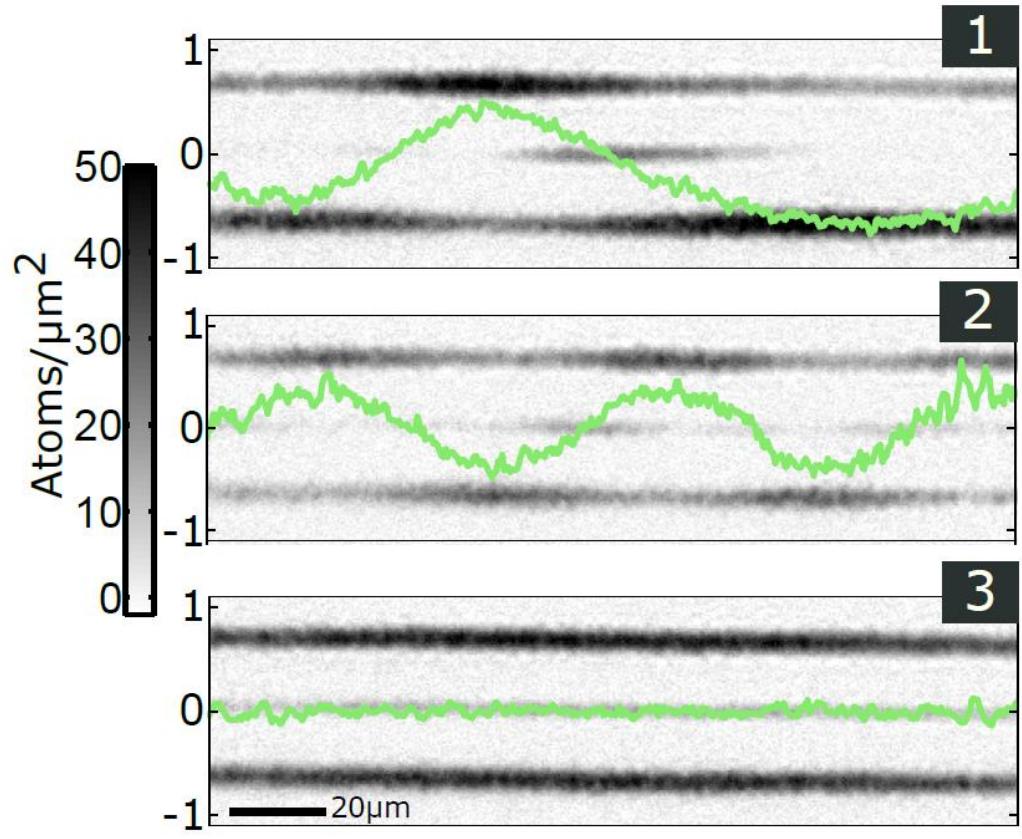
Spin-1 1D: $\beta \approx 0.25$

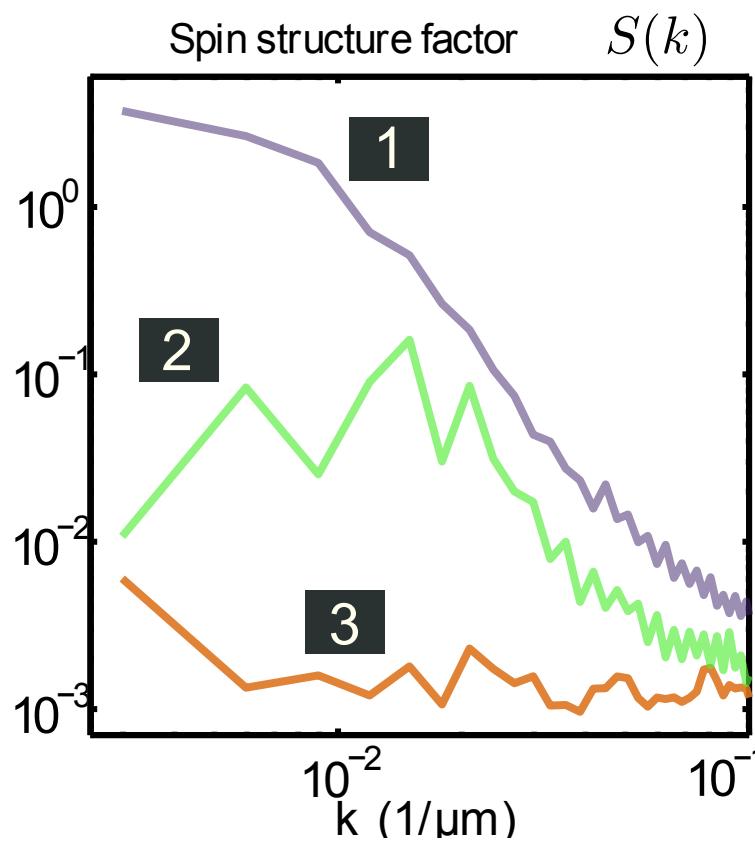
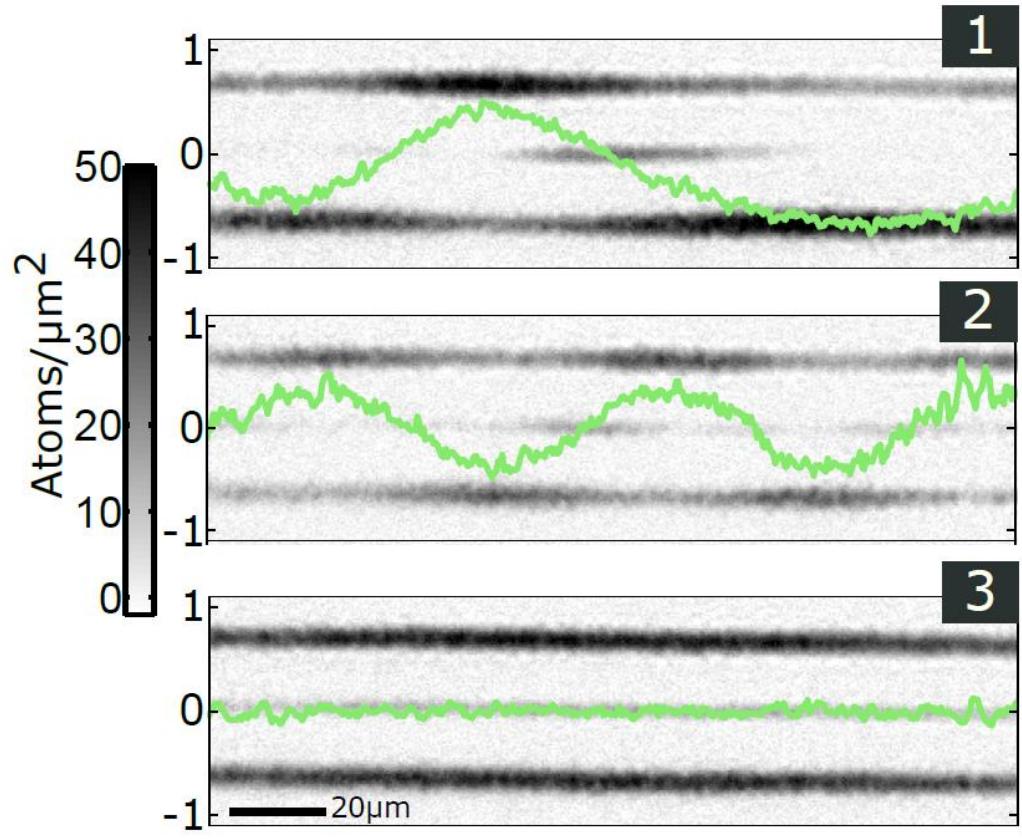
Schmied, C.-M. et al., PRA **99**, 03361 (2019)

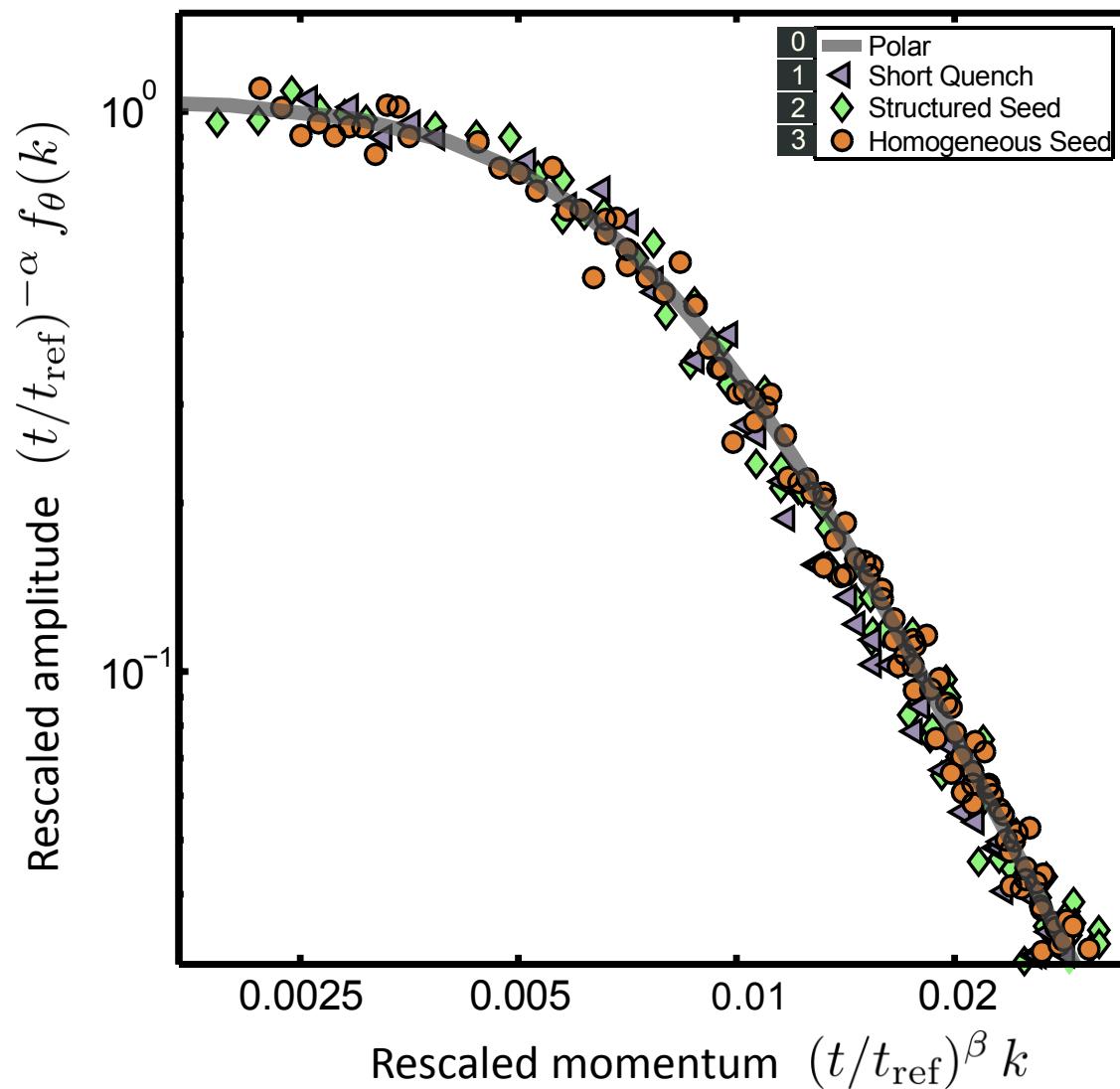


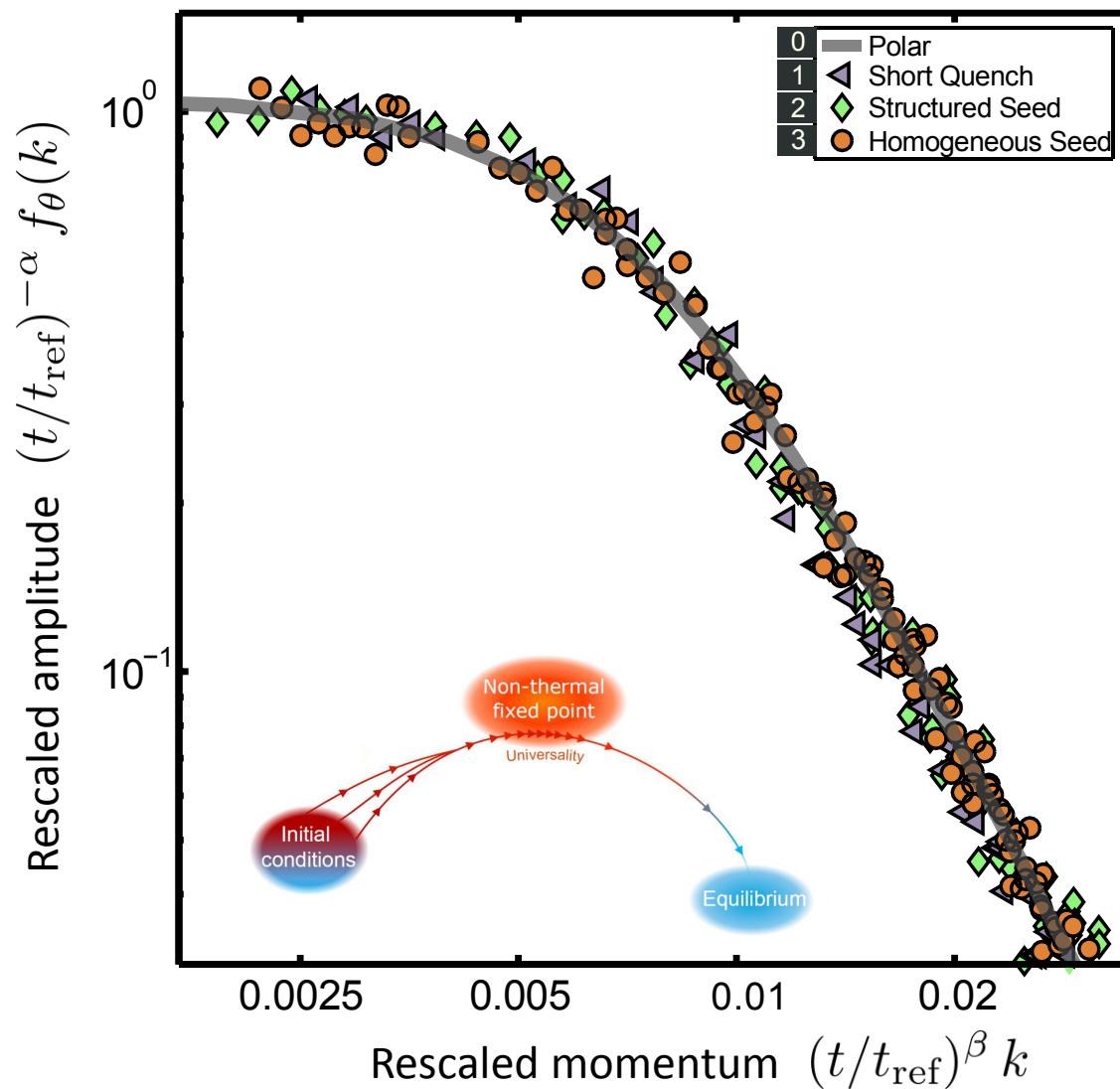












Correlation functions

$$C_2^{*-}(p, p') = \mathcal{FT} (C_2^{*-}(x, x'))$$

Correlation functions

$$C_2^{*-}(p, p') = \langle F_{\perp}^*(p) F_{\perp}(p') \rangle_C$$

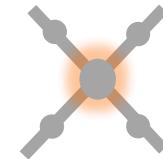


Correlation functions

$$C_2^{*-}(p, p') = \langle F_\perp^*(p) F_\perp(p') \rangle_C$$



$$C_4^{**--}(p, p', p'', p''') = \langle F_\perp^*(p) F_\perp^*(p') F_\perp(p'') F_\perp(p''') \rangle_C$$

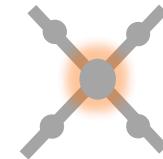


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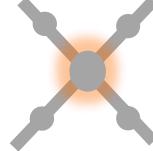


$$\Gamma_4^{**--}(p, p', p'', p''')$$



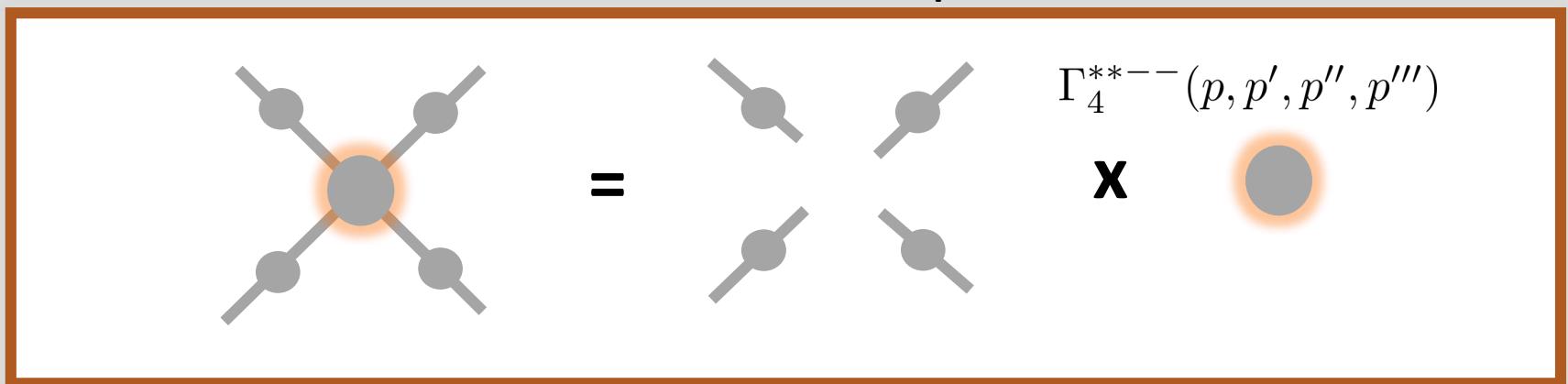
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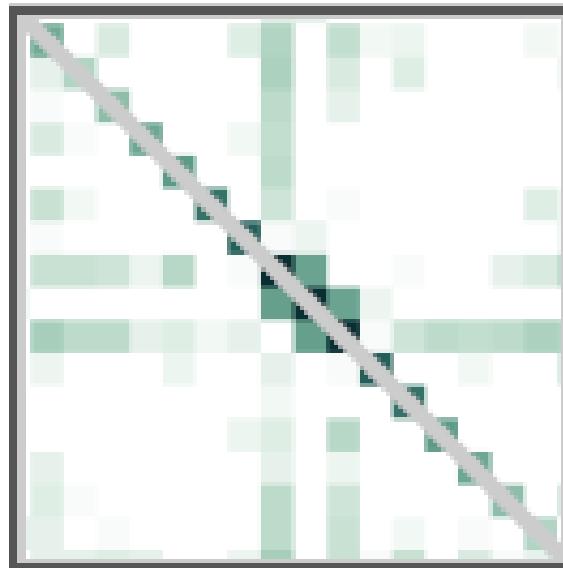
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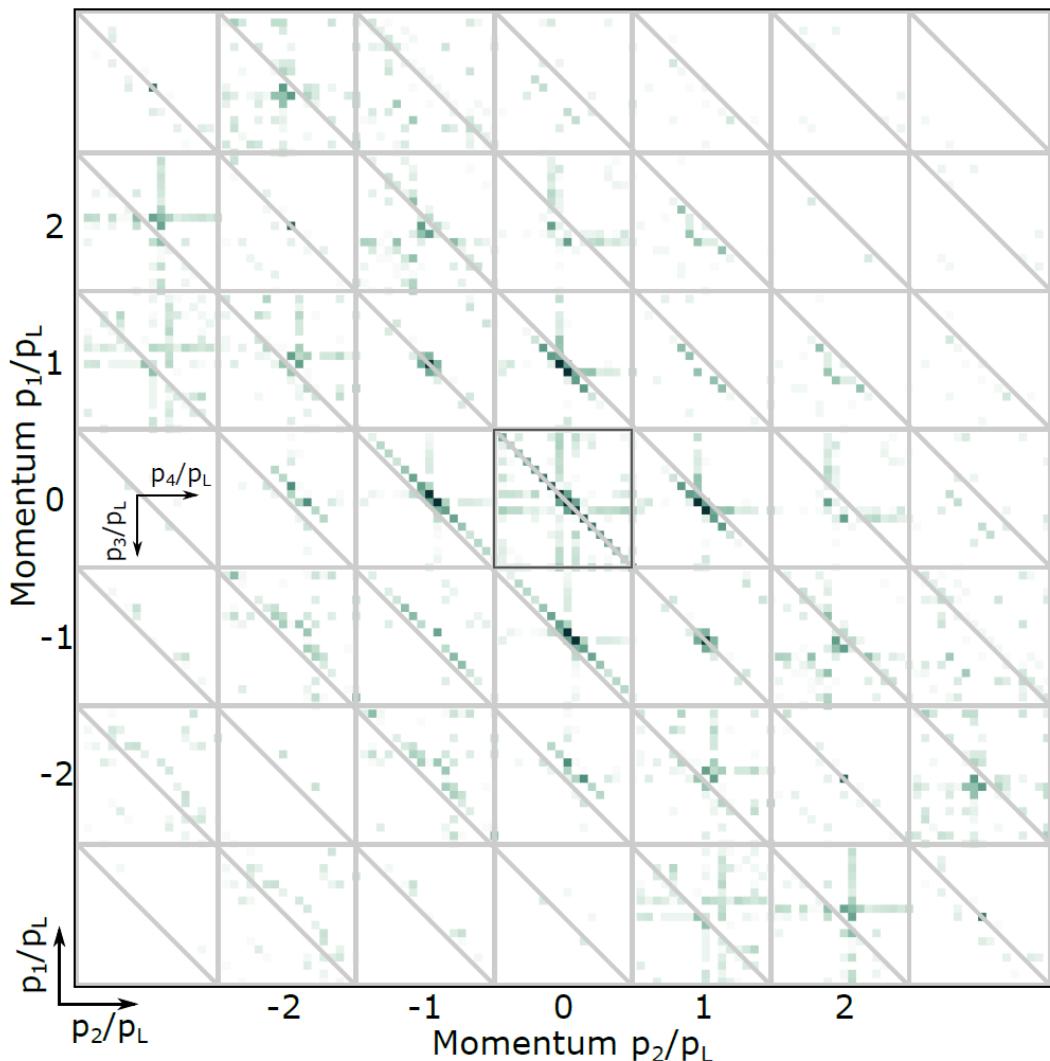

1 particle irreducible correlations

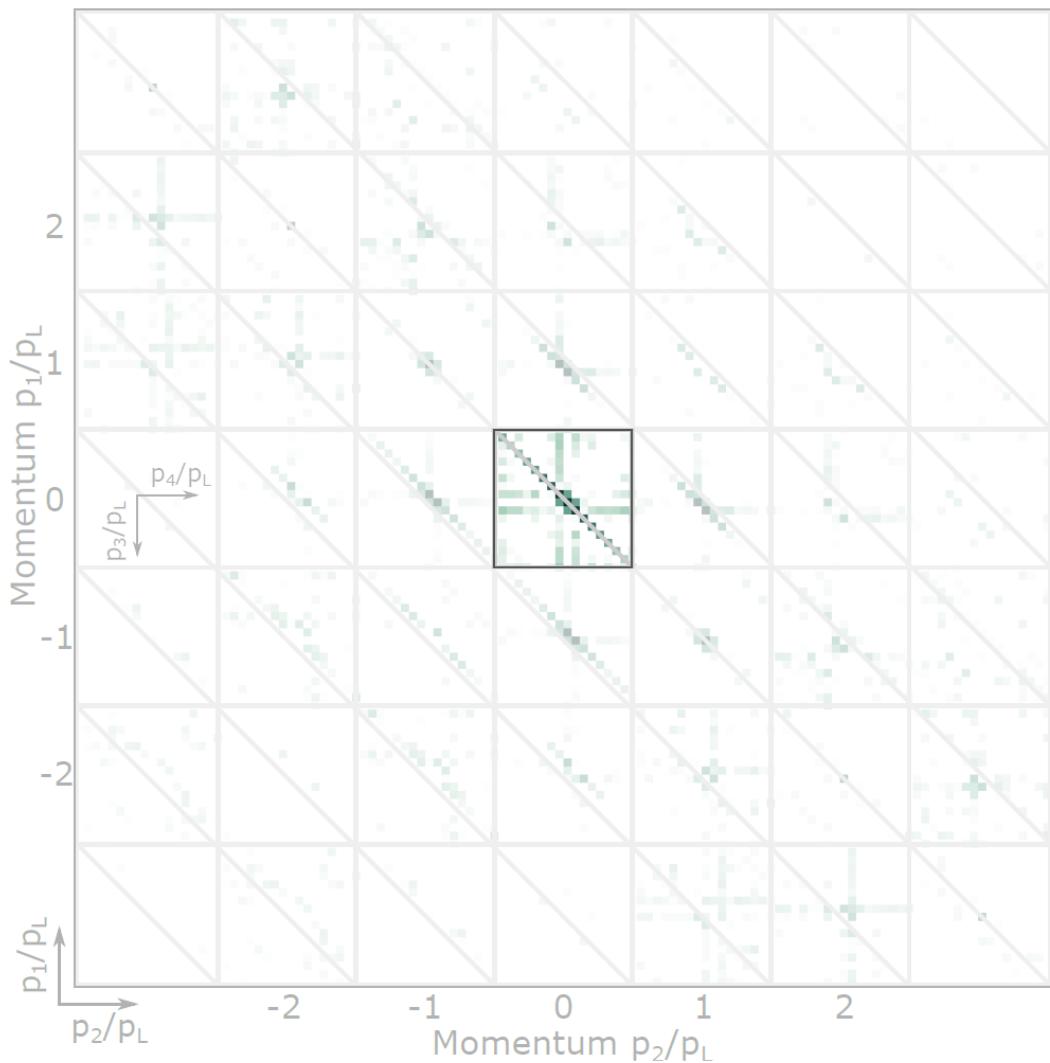
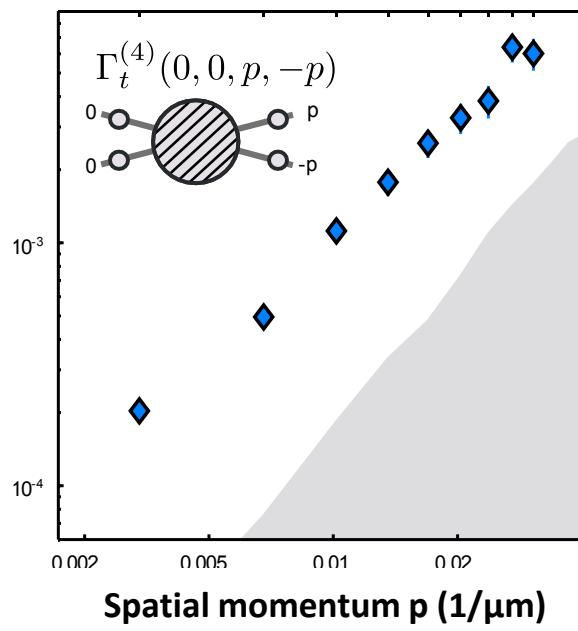


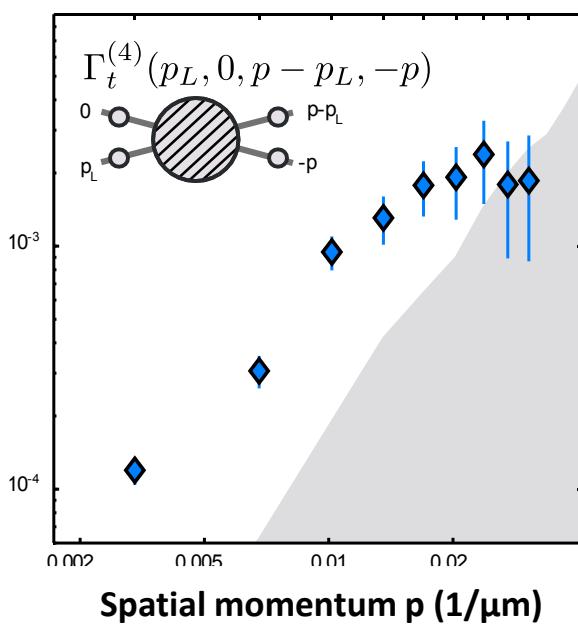
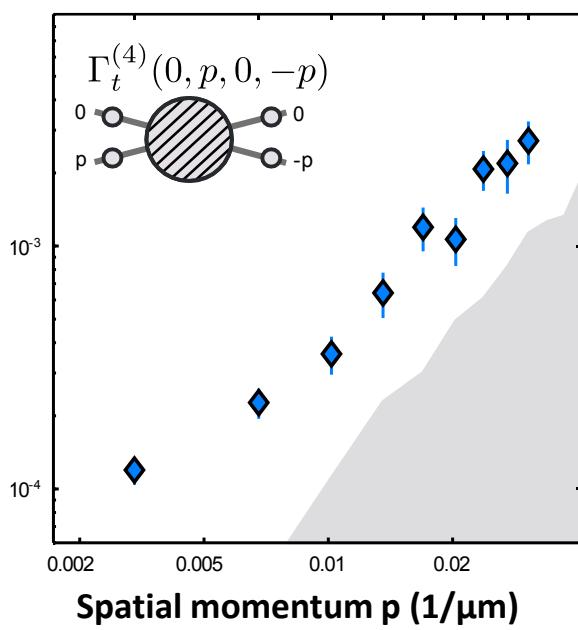
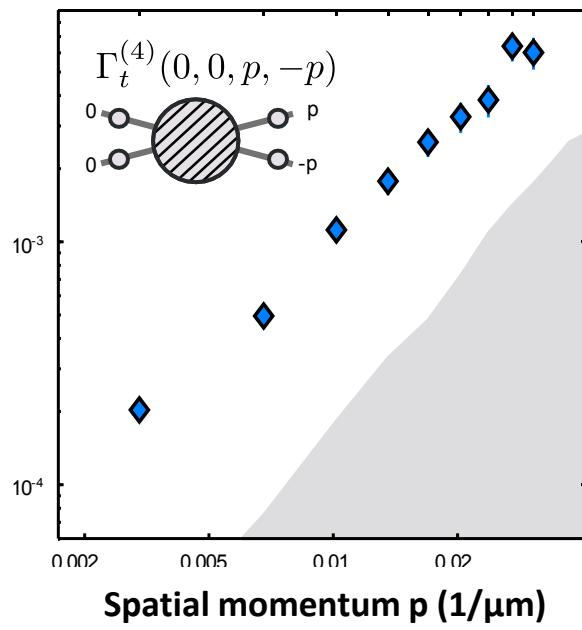
$$\Gamma_4^{* * --}(p, p', p'', p''')$$

$$\Gamma_4^{**--}(0,0,p'',p''')$$



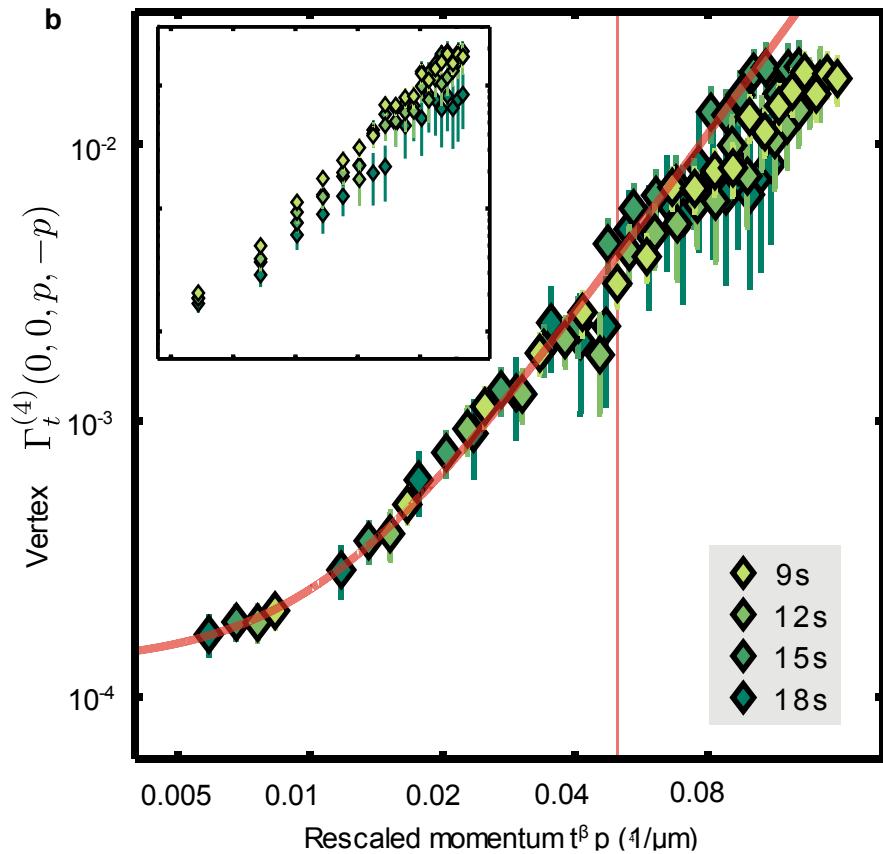
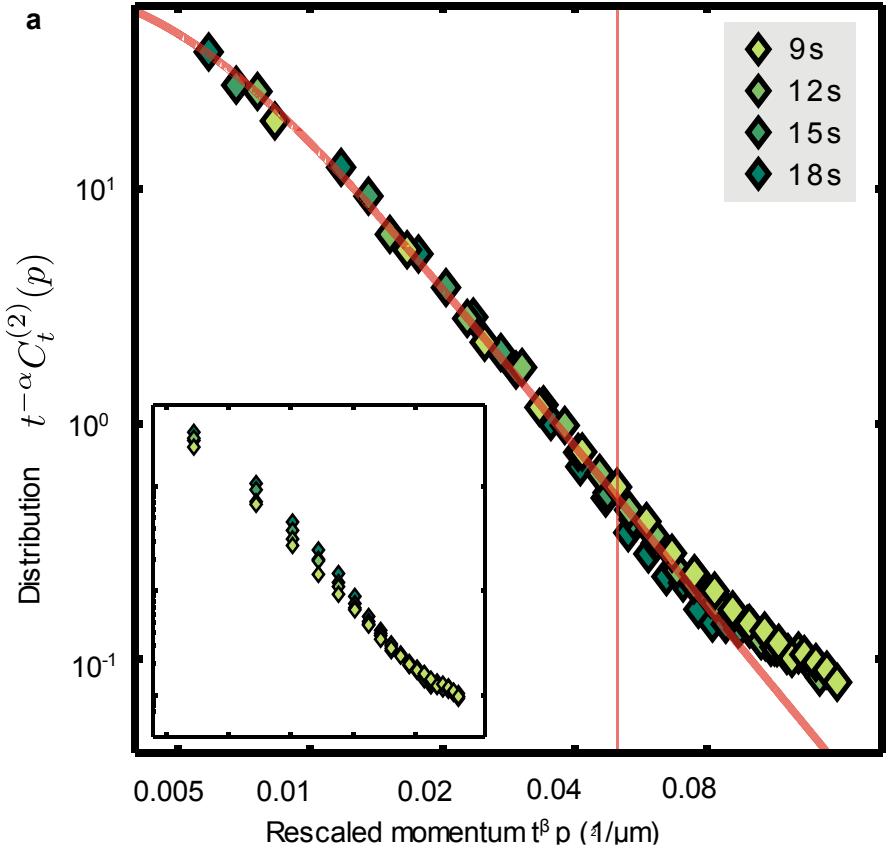


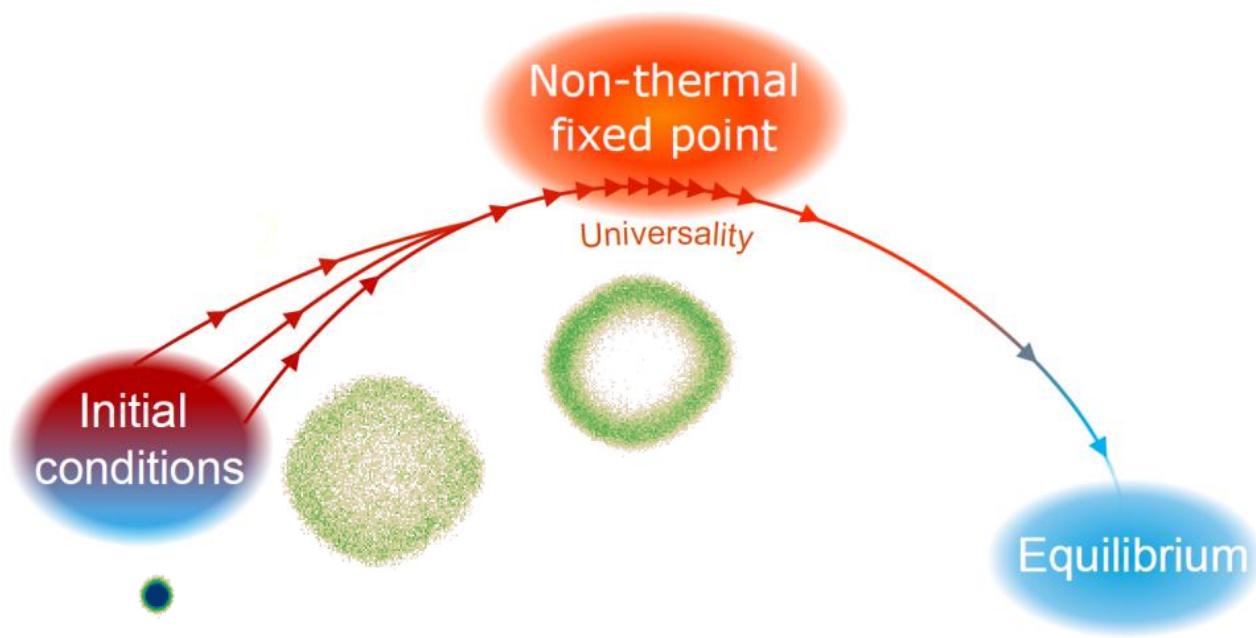


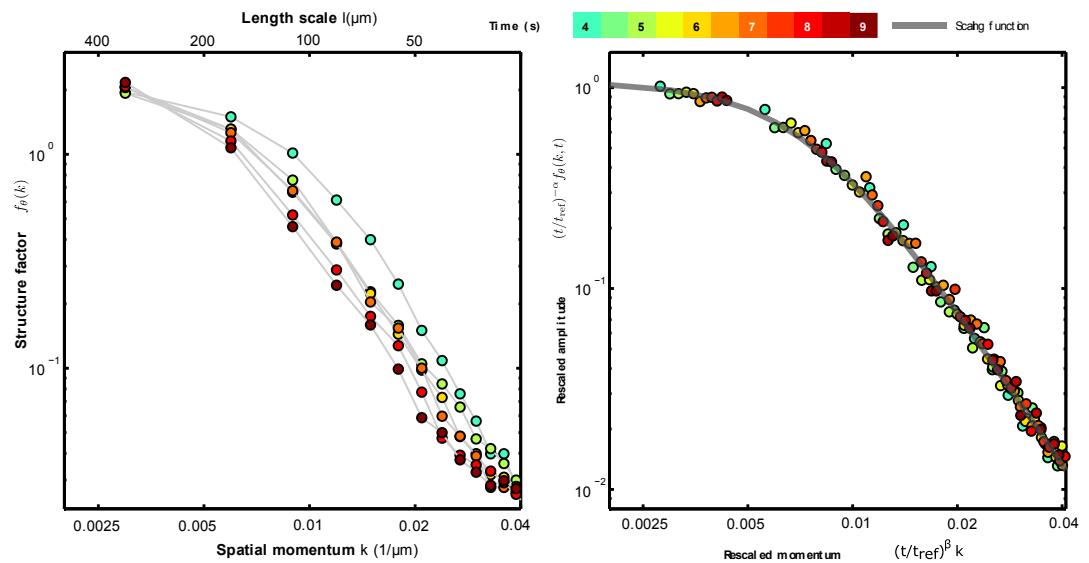


Prüfer et al., arXiv 1909.05120

What about time evolution?

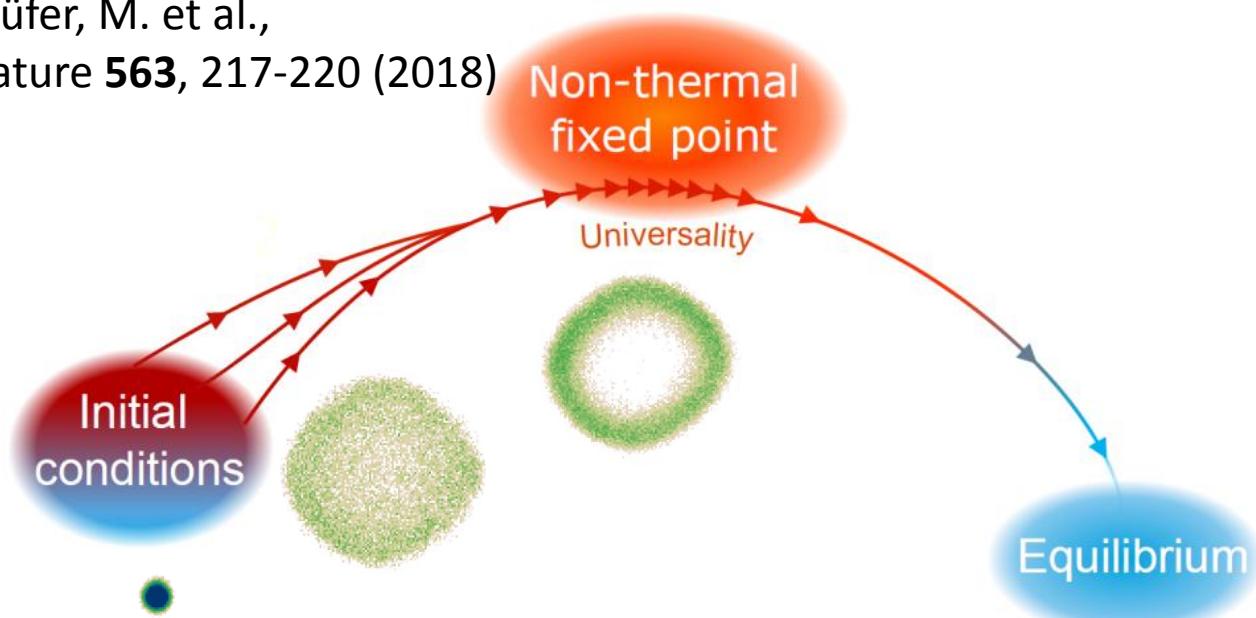


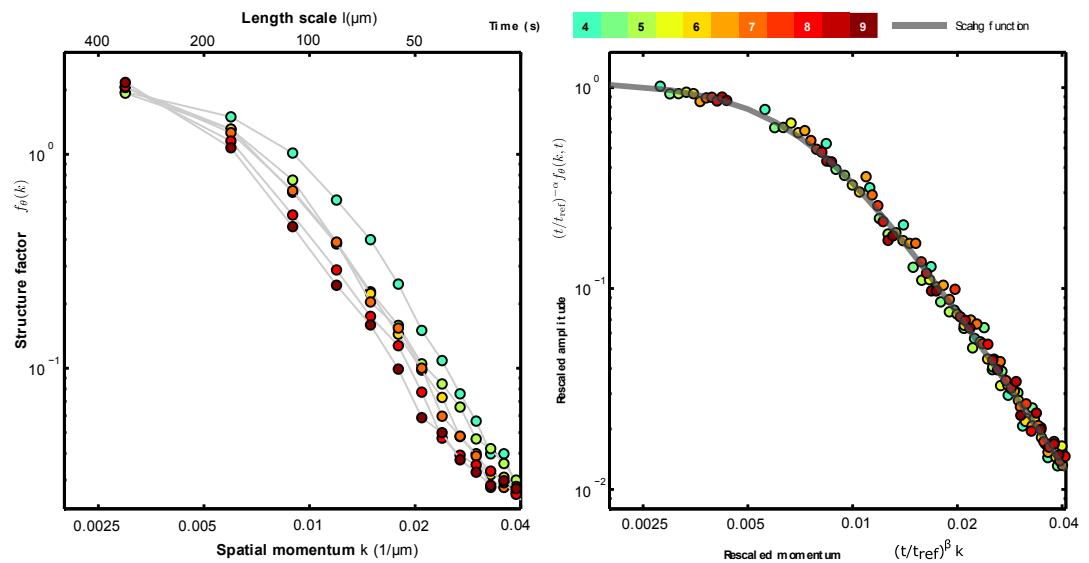




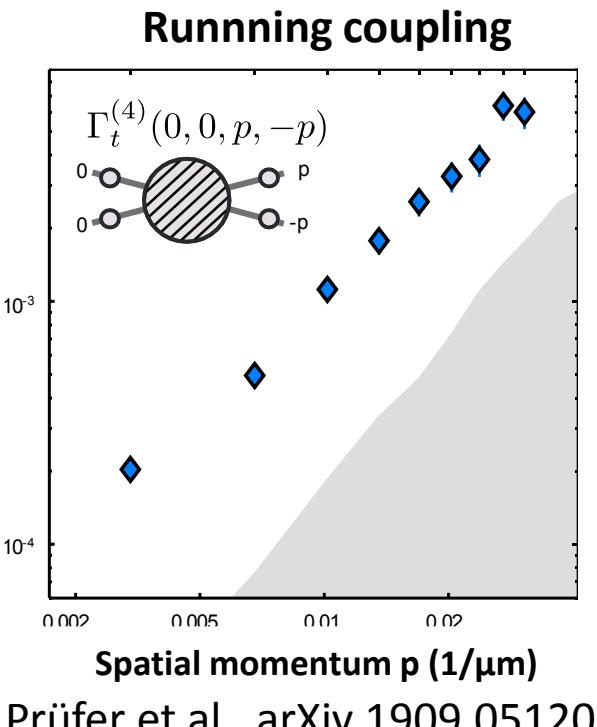
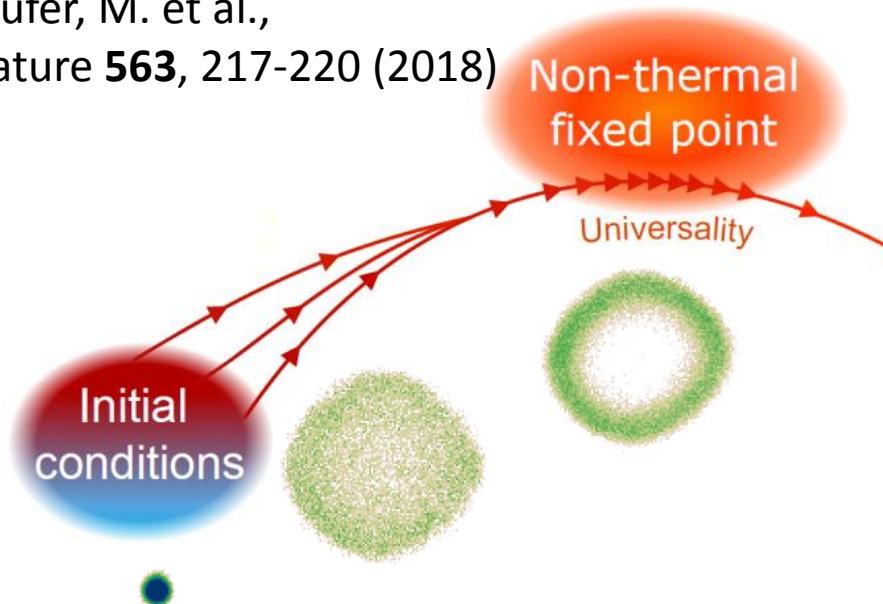
Prüfer, M. et al.,

Nature 563, 217-220 (2018)

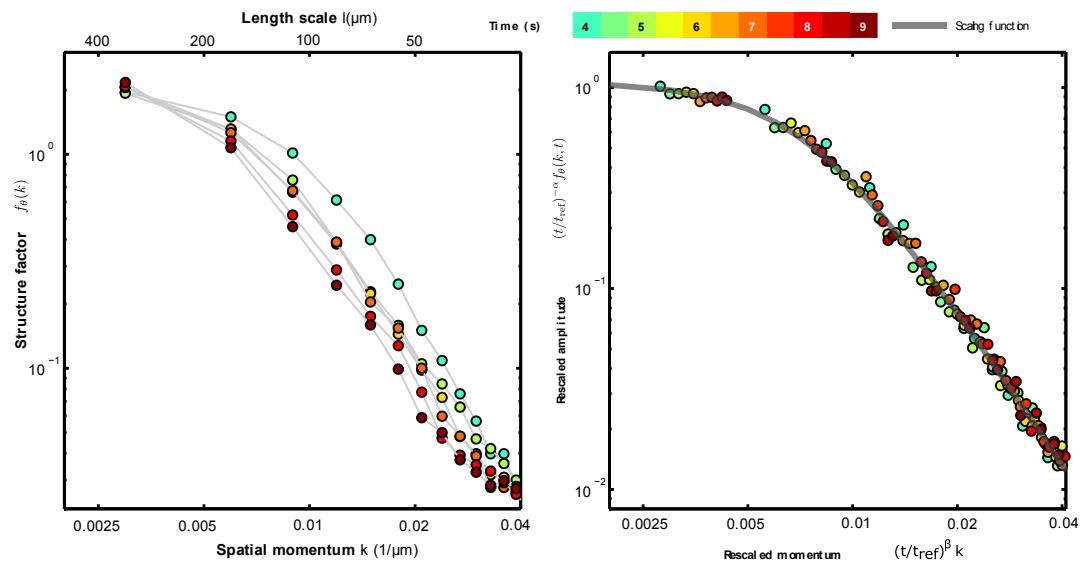




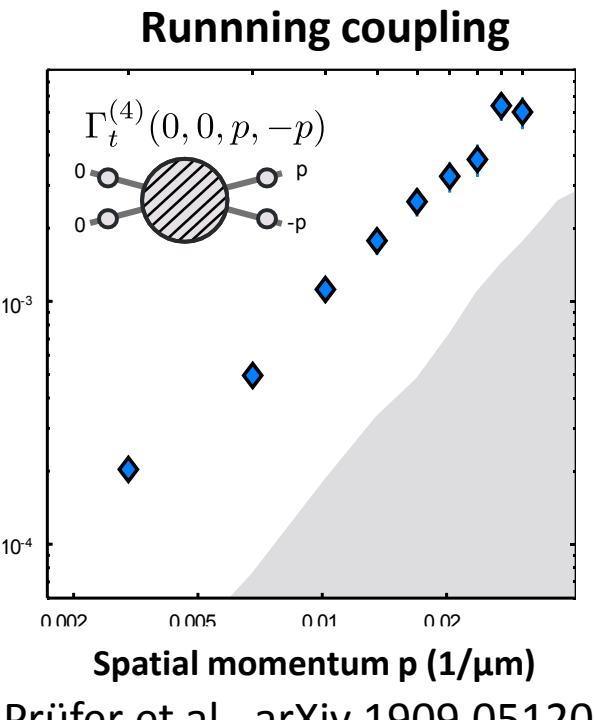
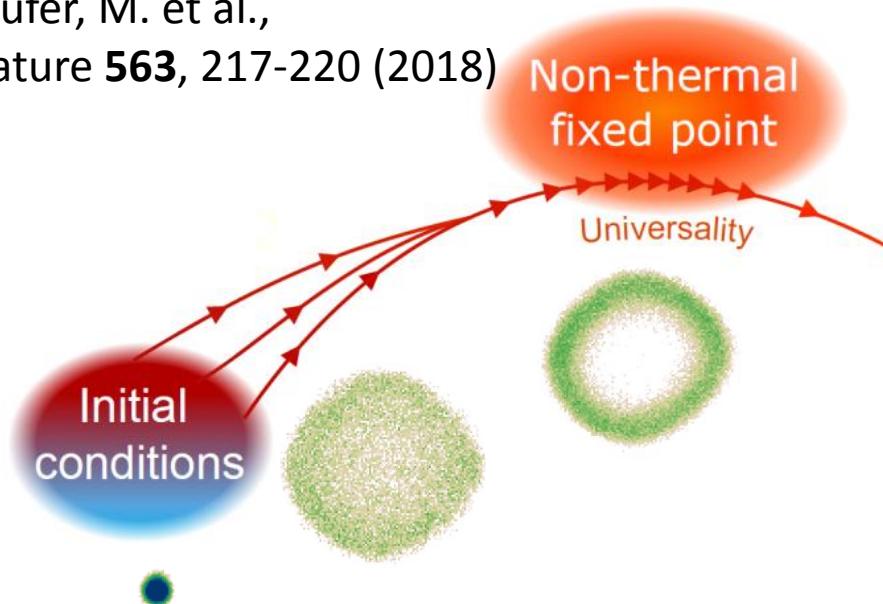
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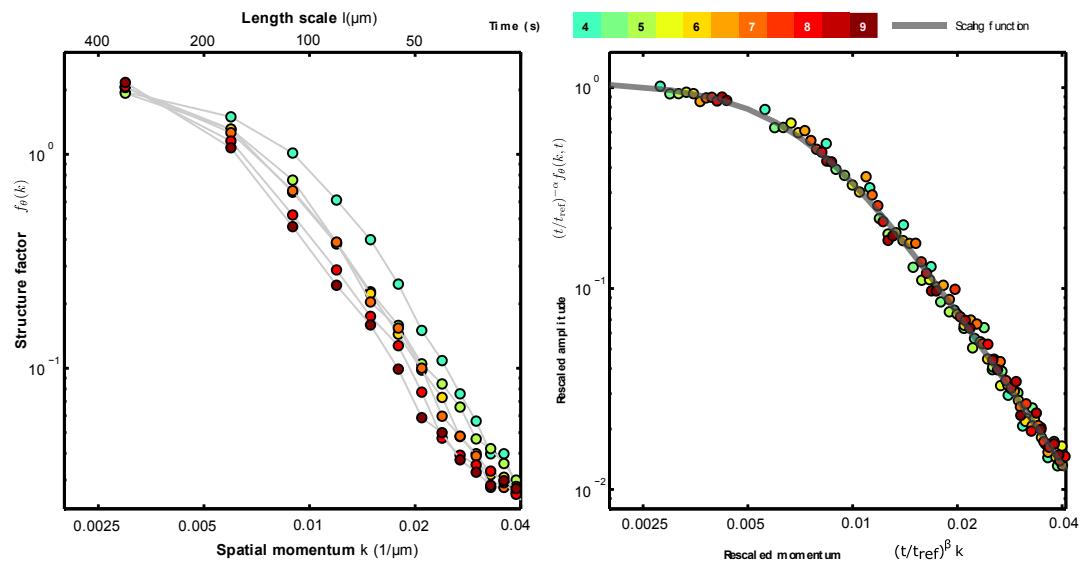
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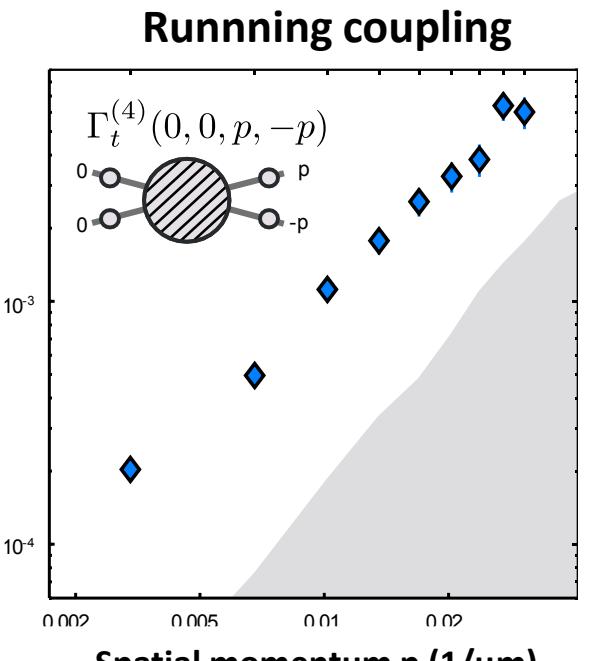
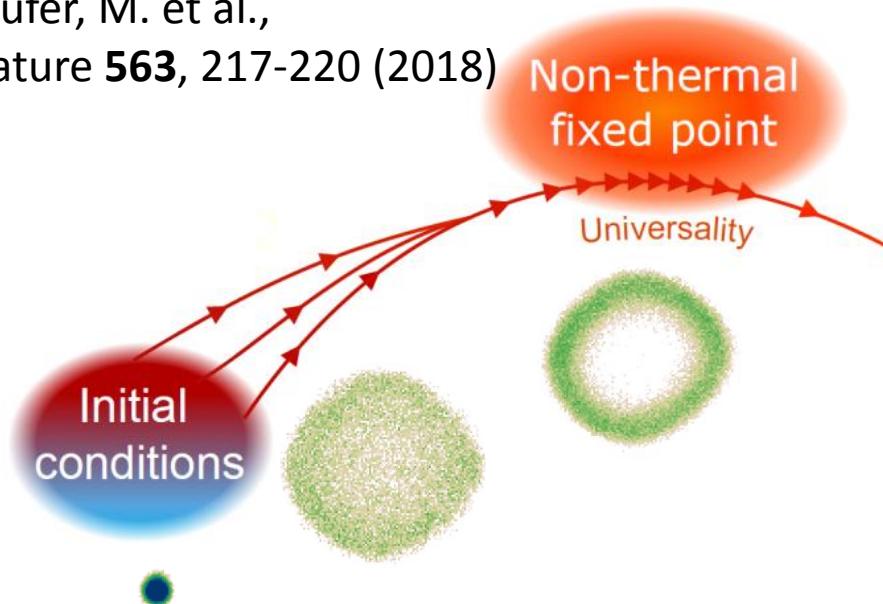
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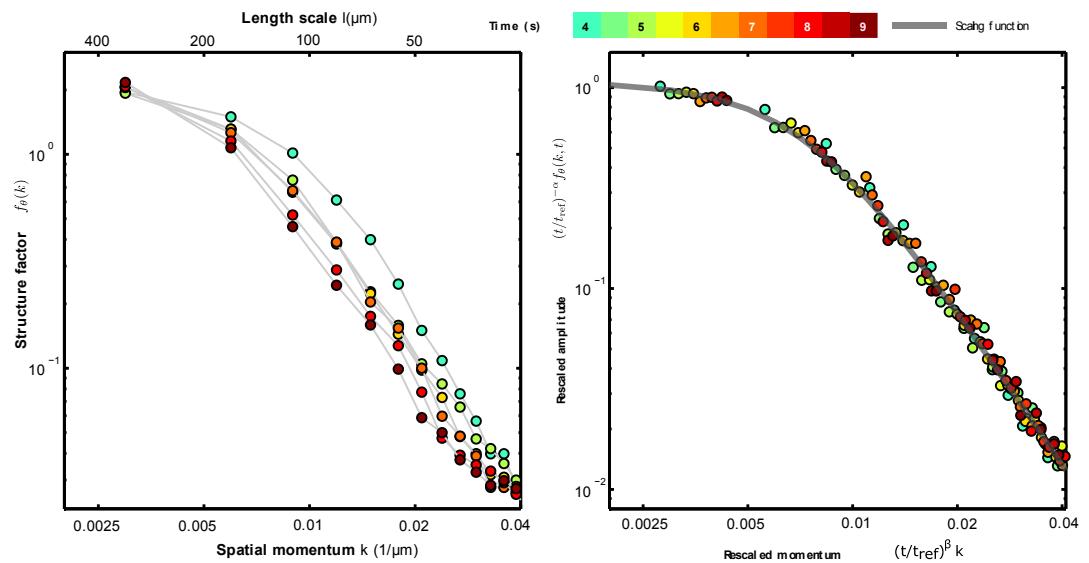
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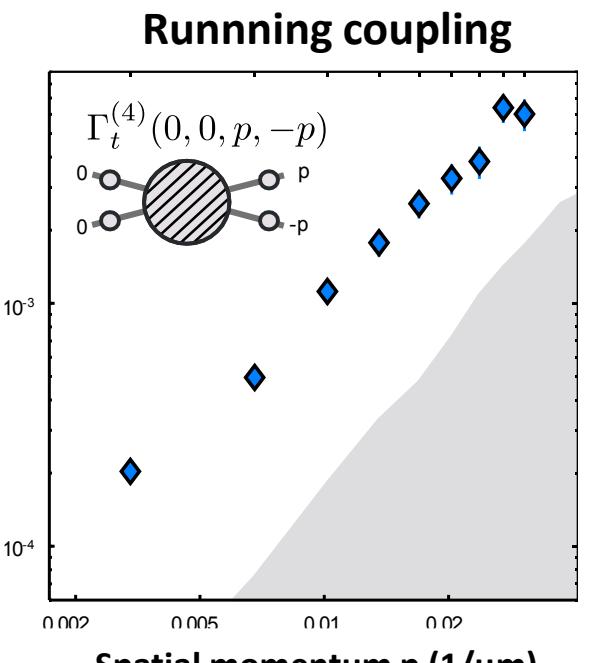
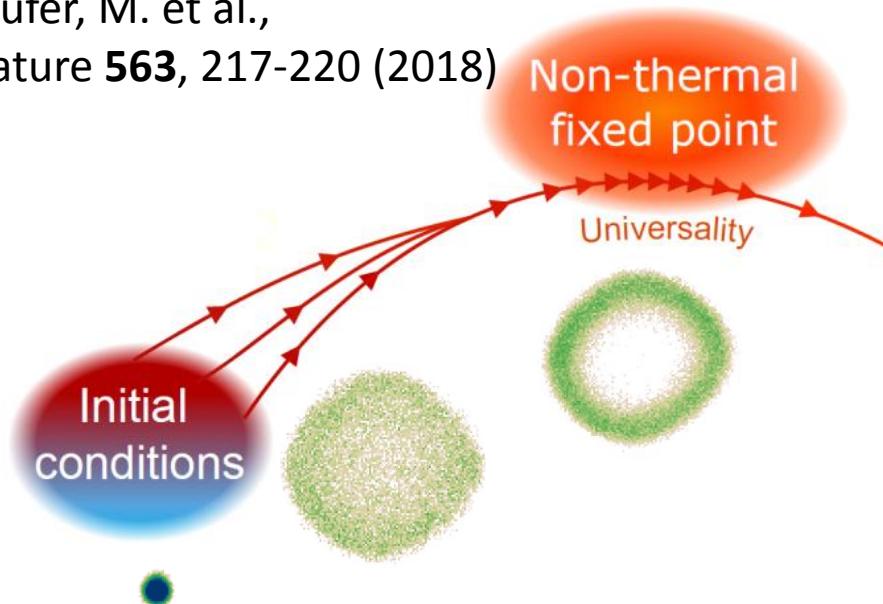
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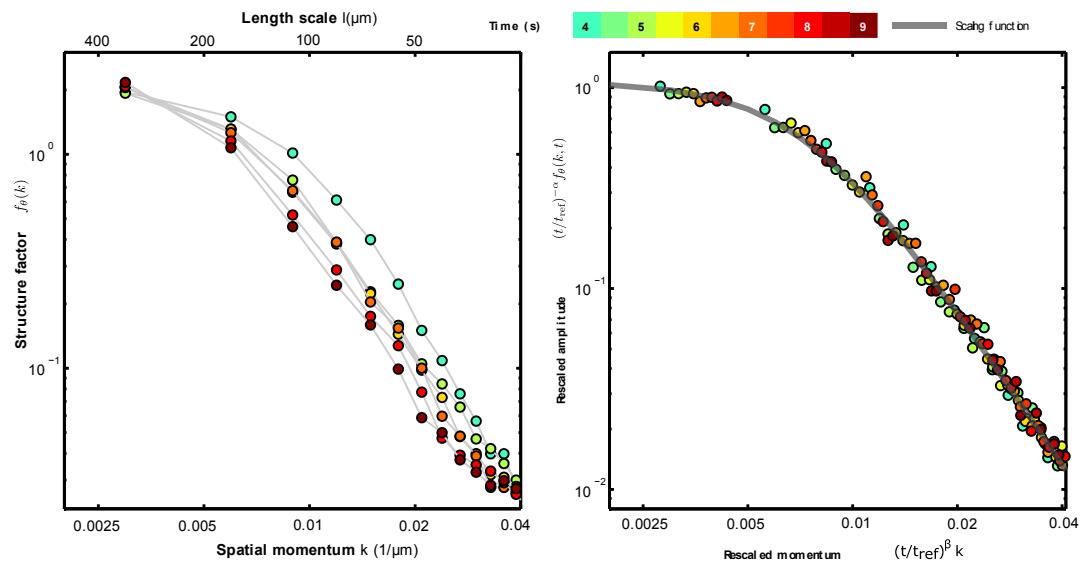
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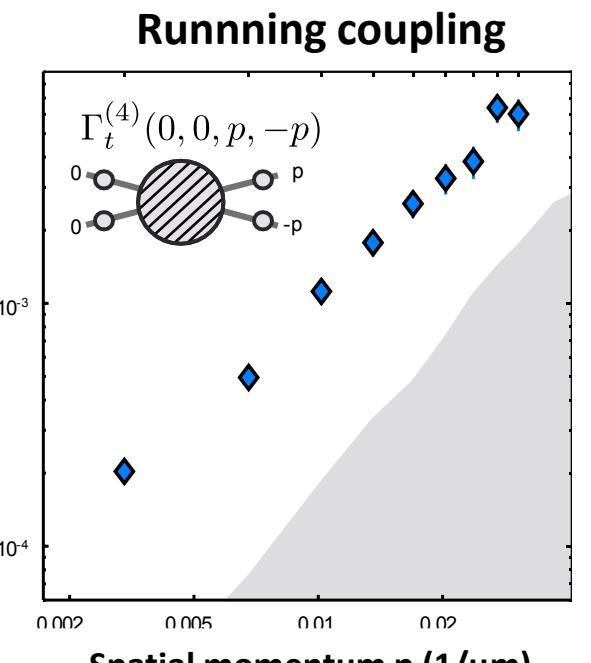
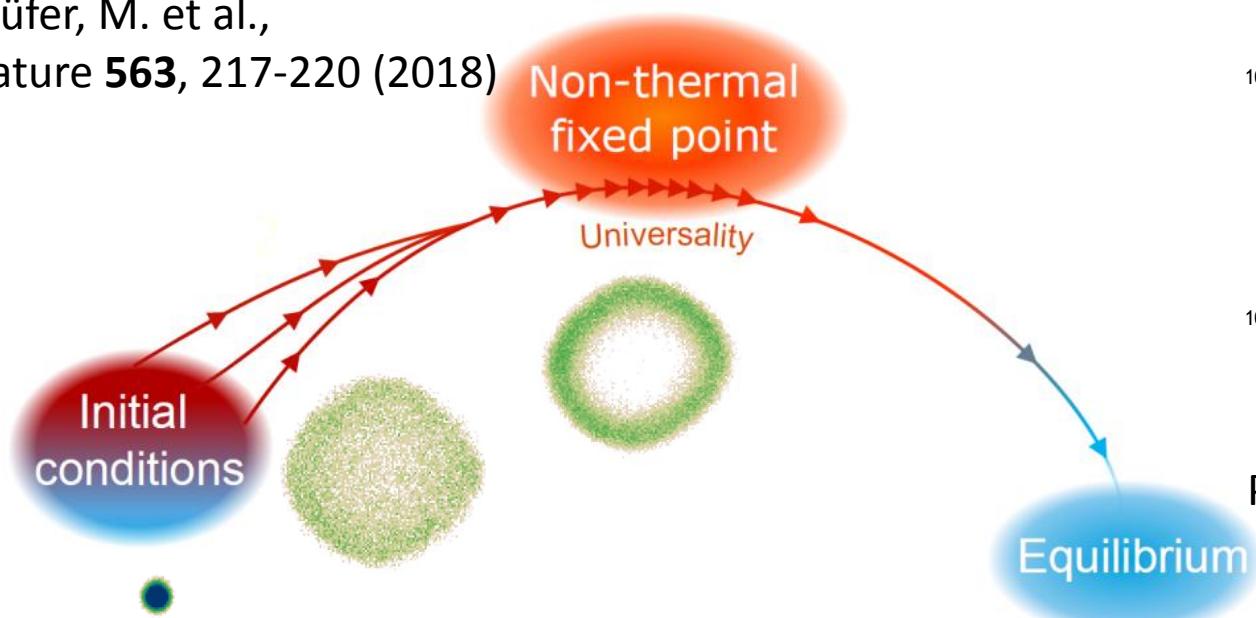
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