Nonthermal fixed points and superfluid turbulence

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EMMI

Center for Quantum Dynamics

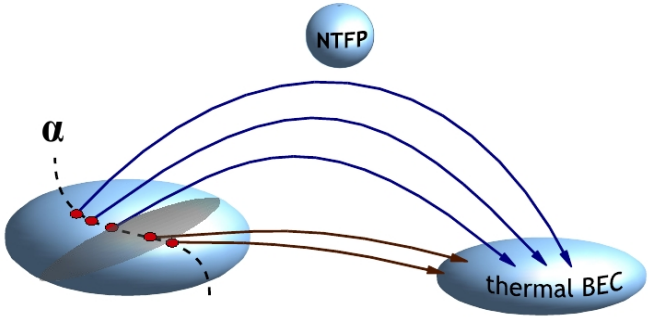
Nonequilibrium Dynamics



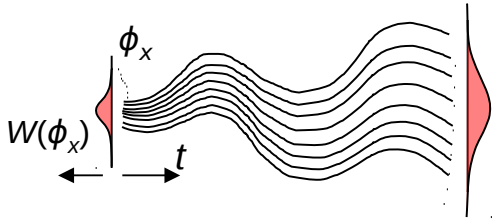
Initial state:
Far from equilibrium

Transient state:
e.g. Turbulence
(Nonthermal fixed point)

Final state:
Thermal equilibrium



Semi-classical simulations



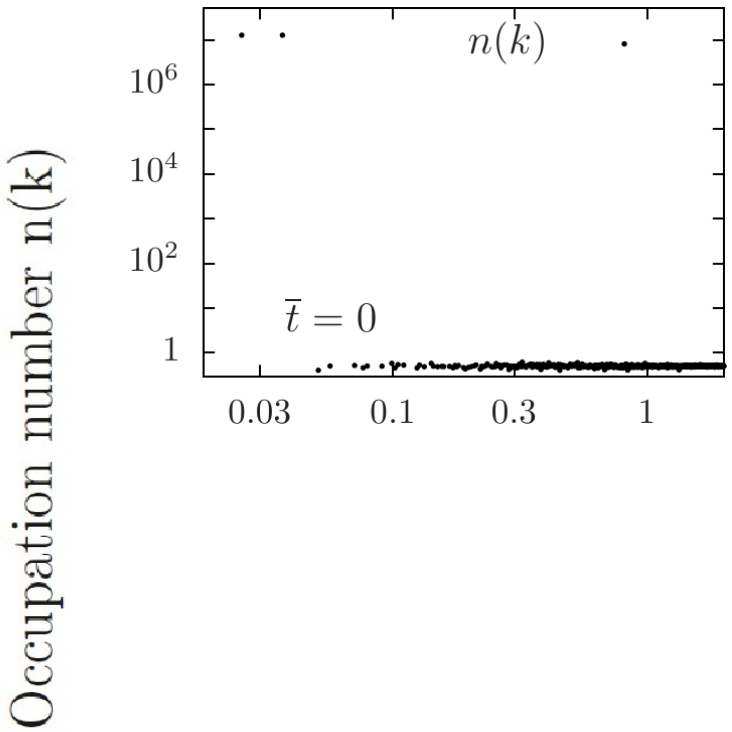
Classical field equation for ϕ(x,t):

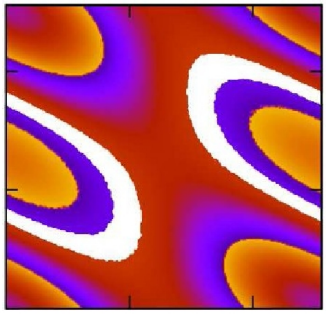
$$\mathrm{i}\partial_t \phi(\mathbf{x},t) = \left[-\frac{\nabla^2}{2m} + g|\phi(\mathbf{x},t)|^2\right]\phi(\mathbf{x},t)$$

Observables: e. g. Momentum distribution

$$n(k) = \int \mathrm{d}^{d-1}\Omega_k \, \langle \phi^*(\mathbf{k})\phi(\mathbf{k})\rangle_{\mathrm{ensemble}}$$

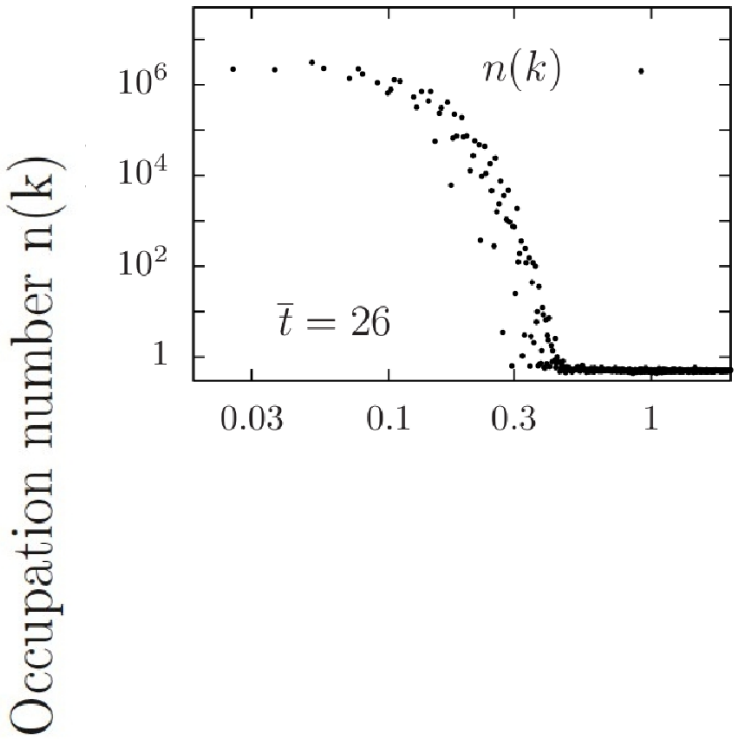
2D: Quench dynamics

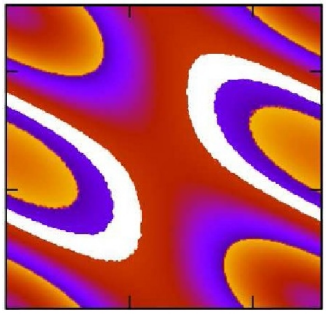




BN, D. Sexty, T. Gasenzer PRB 84(R) (2011), BN, J. Schole, D. Sexty, T. Gasenzer PRA 85 (2012)

2D: Quench dynamics





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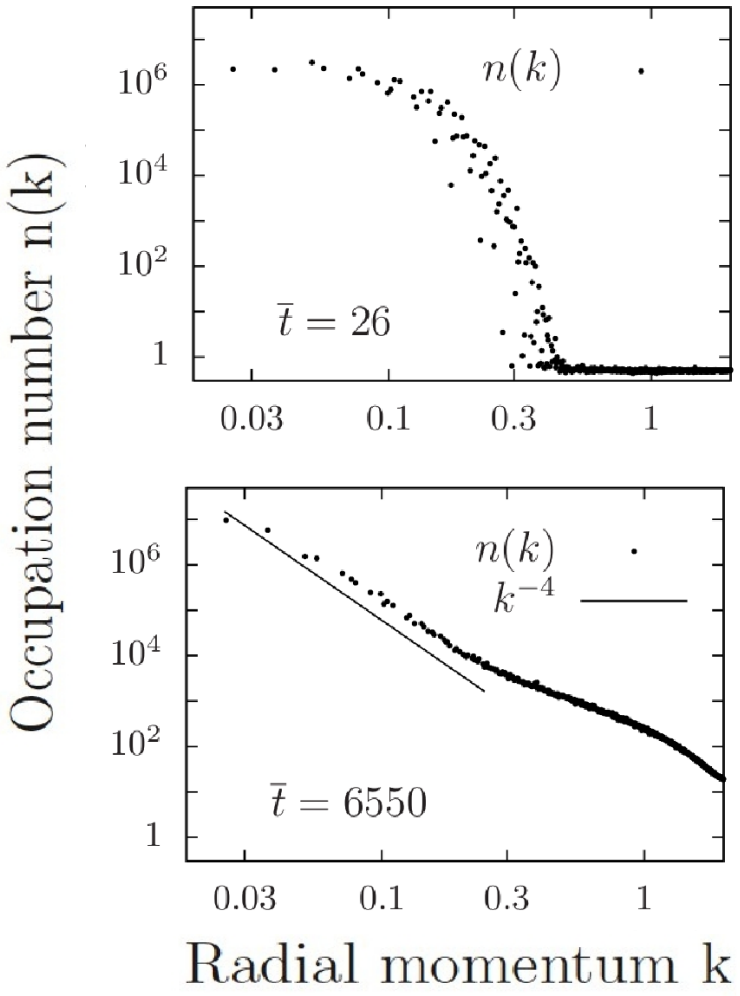

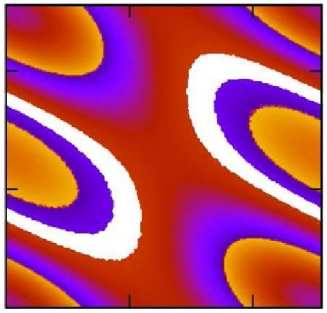

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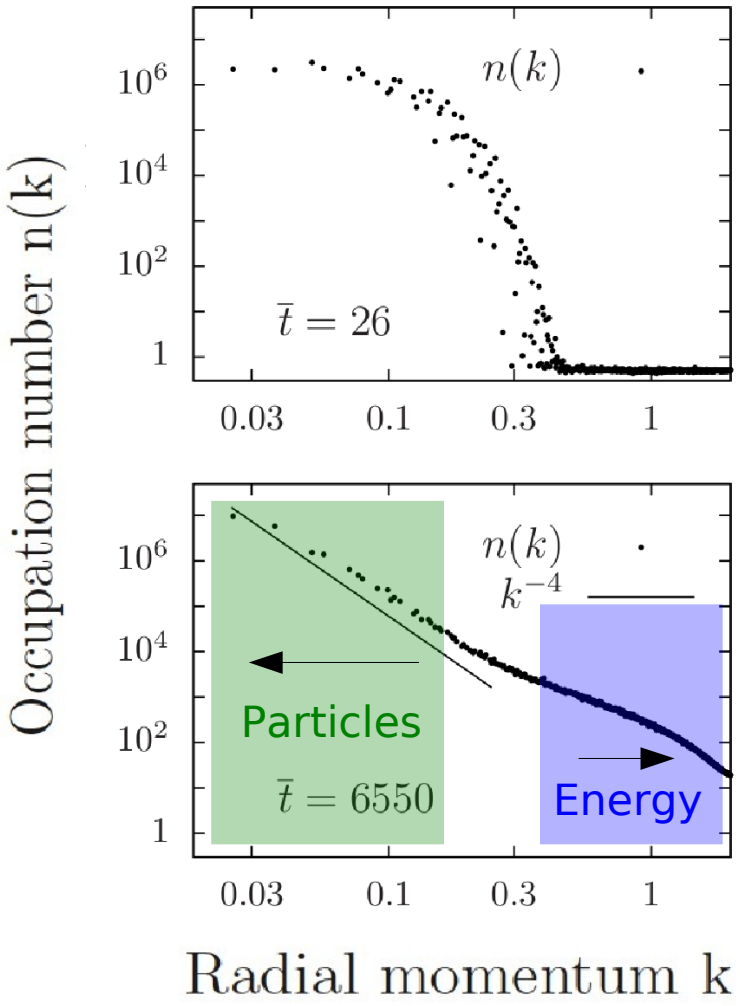

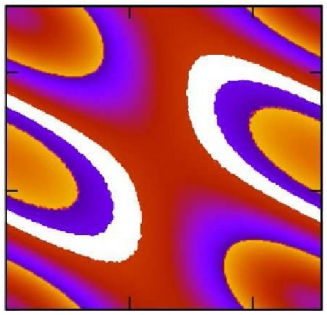

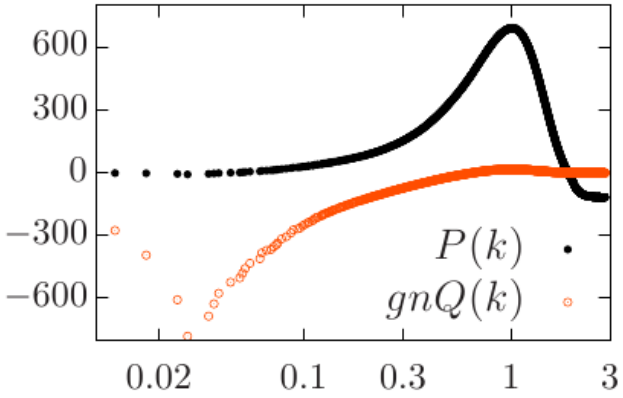

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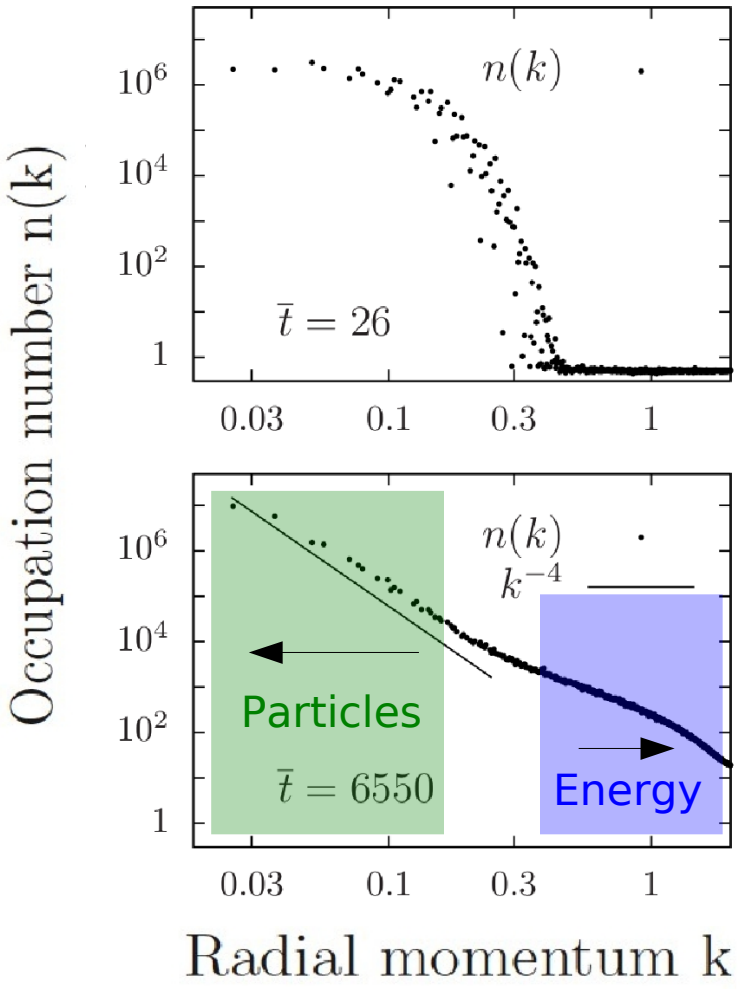

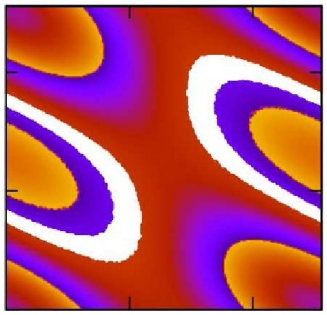

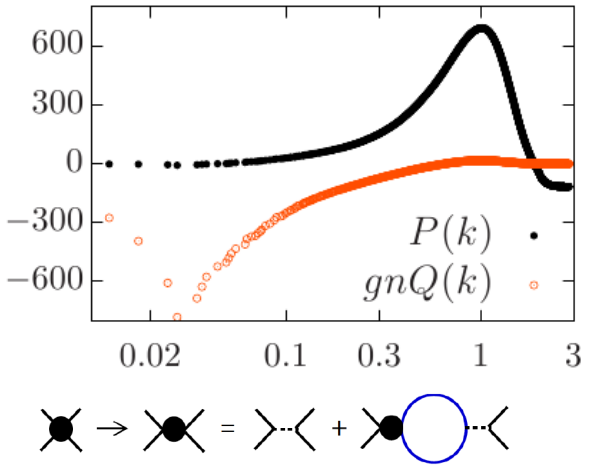

J. Berges, A. Rothkopf, J. Schmidt PRL (2008)
C. Scheppach, J. Berges, T. Gasenzer, PRA (2010)

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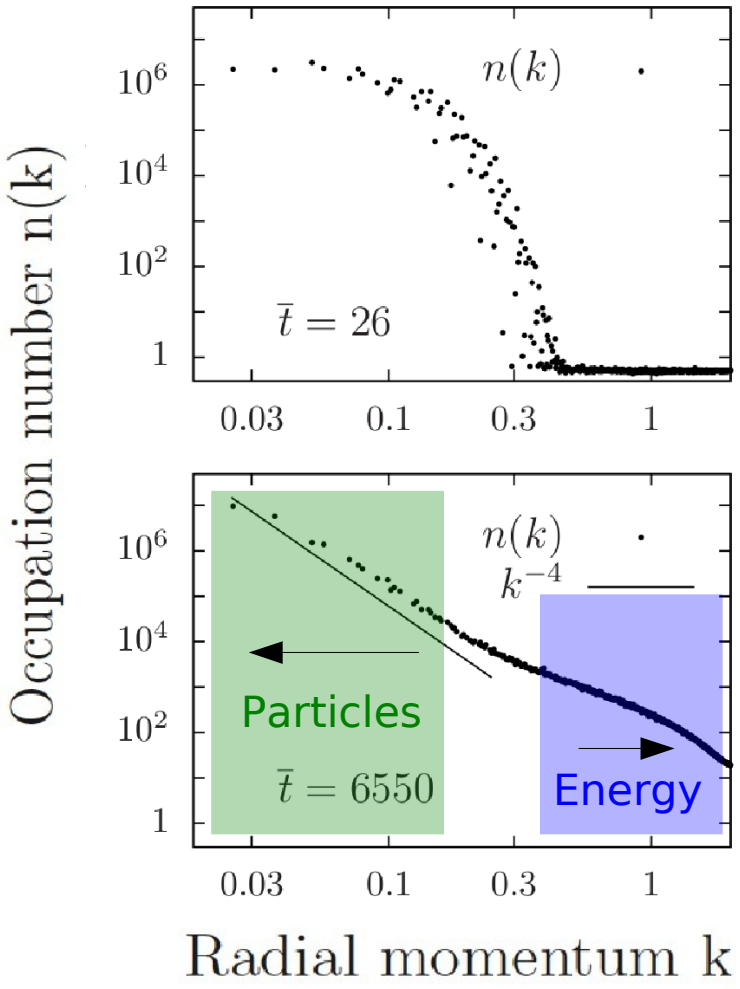
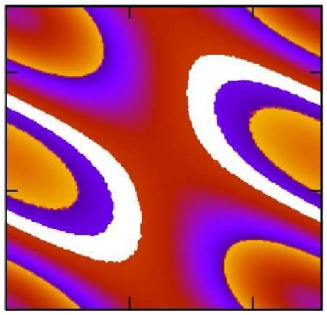
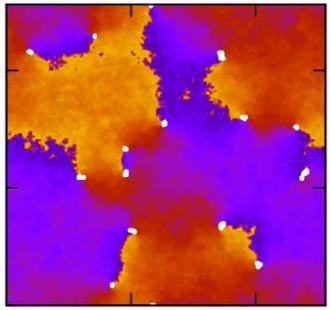
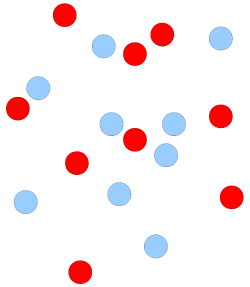






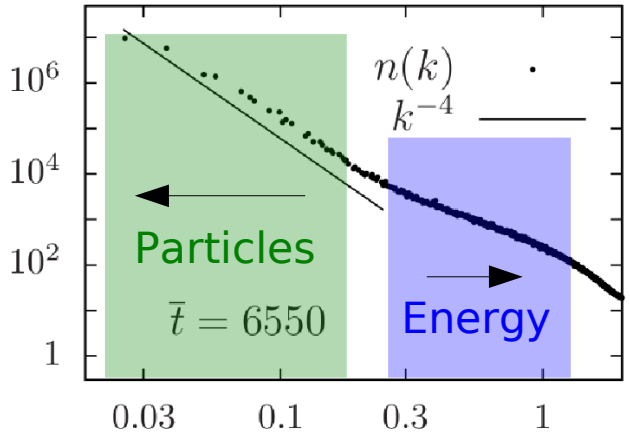


$n_k \sim k^{-4}$

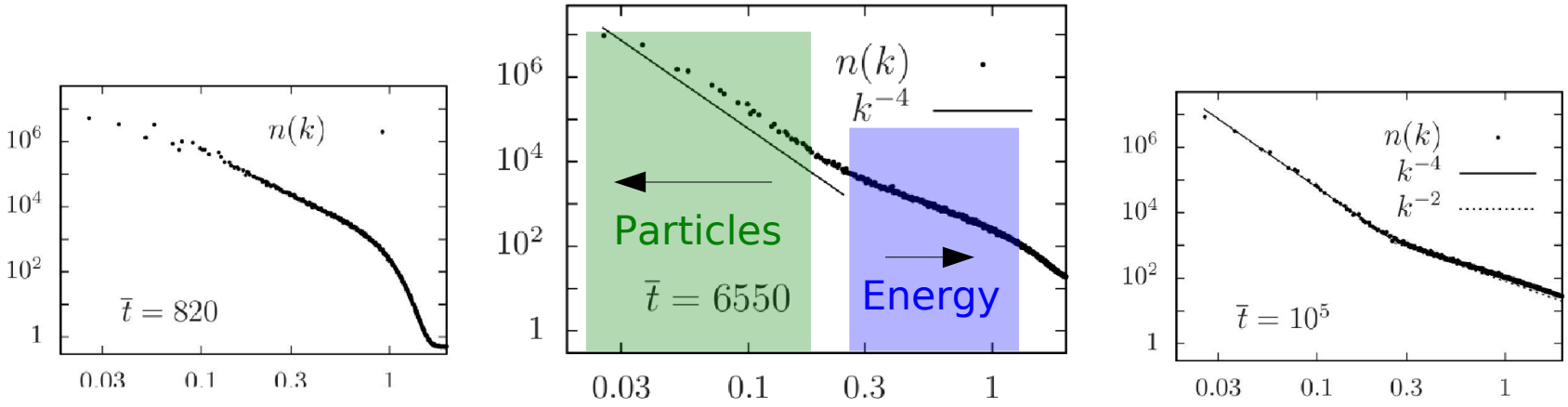
$E_k \sim k^{-1}$

BN, D. Sexty, T. Gasenzer PRB 84(R) (2011), BN, J. Schole, D. Sexty, T. Gasenzer PRA 85 (2012)

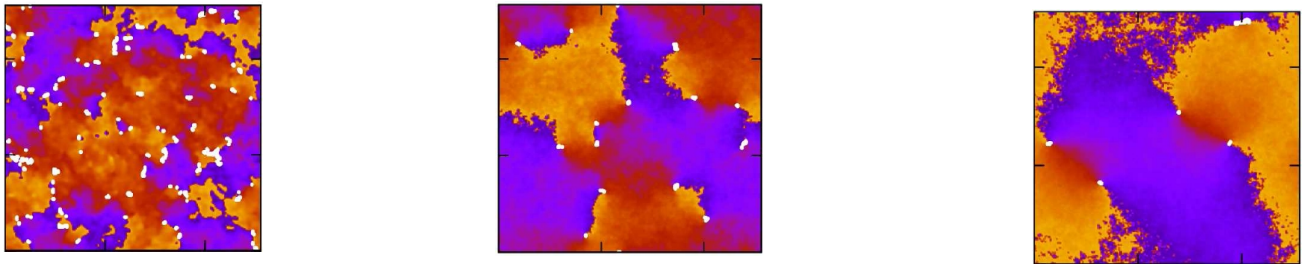
2D: Phase ordering dynamics



2D: Phase ordering dynamics



Time



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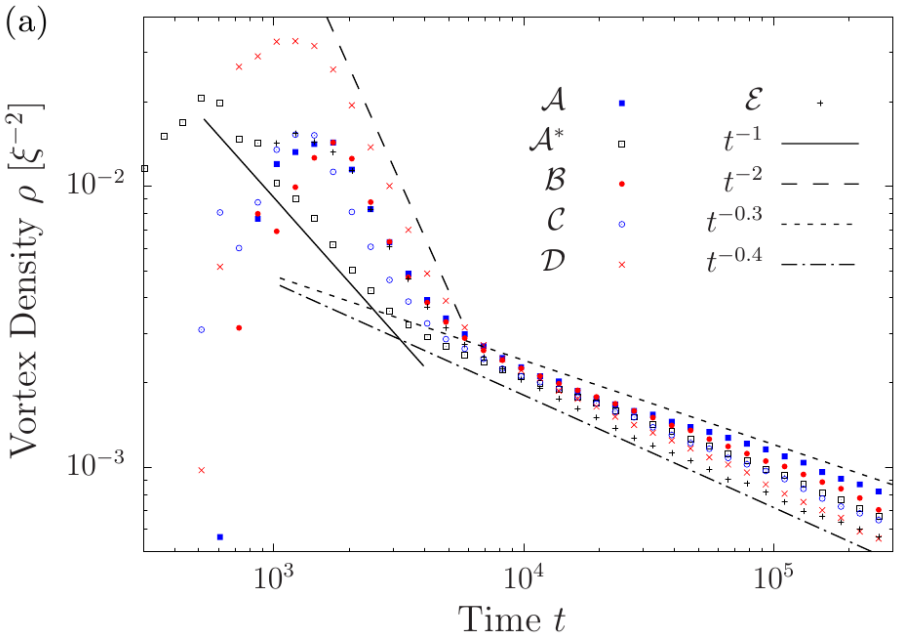
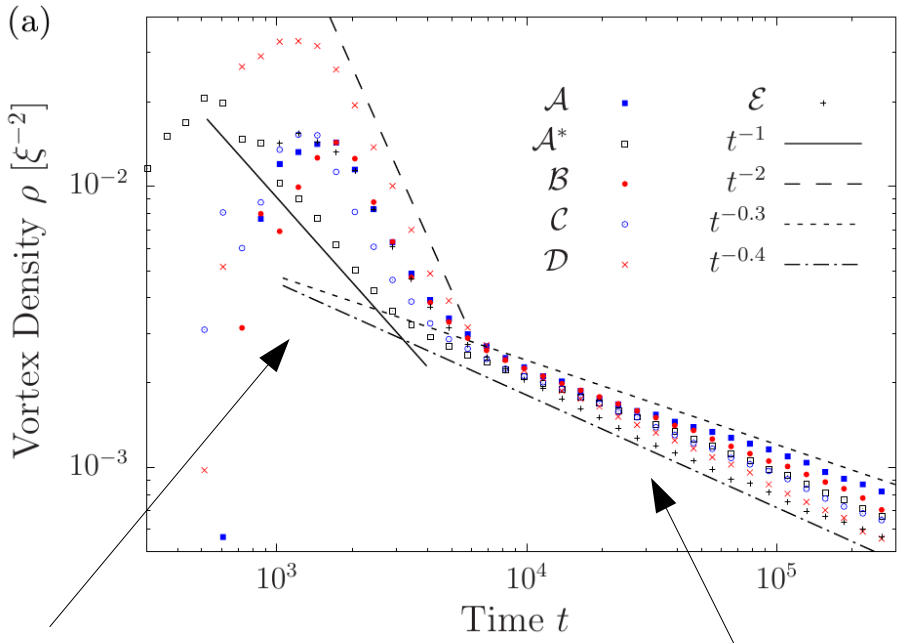


J. Schole, BN, T. Gasenzer, arXiv:1204.2487

2D: Phase ordering dynamics

Scaling needs vortex unbinding

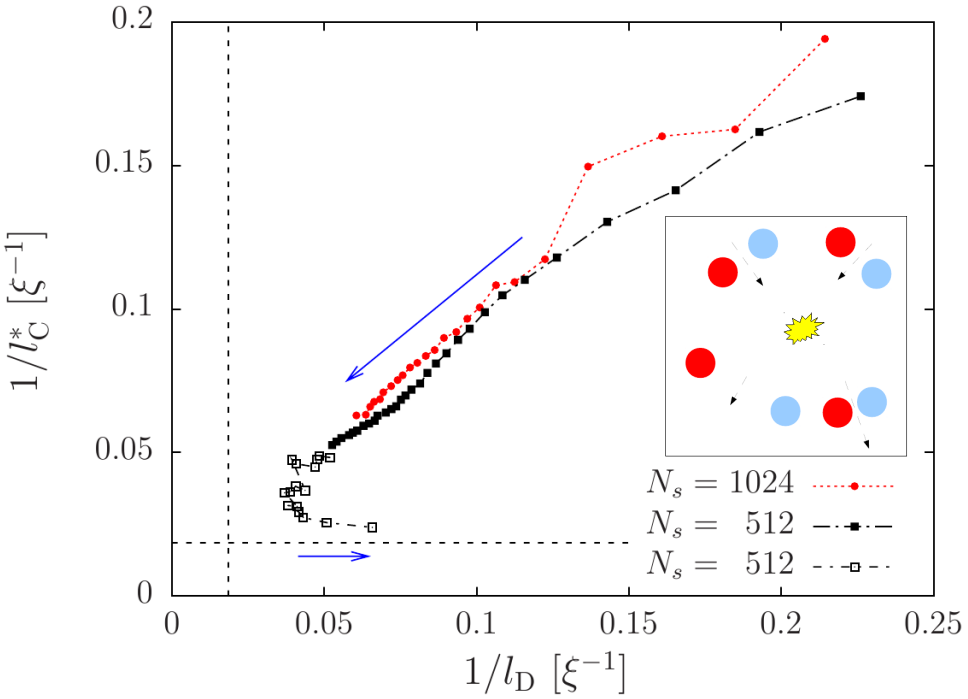


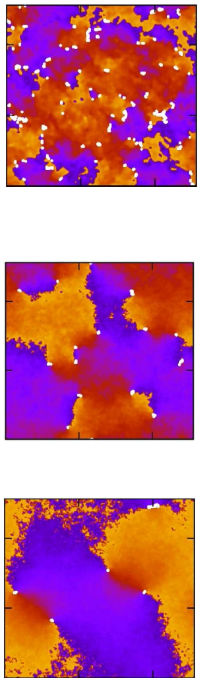
Non-universal decay law
(Initial vortex distribution dependent)
Kinetic gas theory for dipoles

Universal decay regime
Strongly correlated, dilute vortex gas
Scaling $n(k) \sim k^{-4}$

J. Schole, BN, T. Gasenzer, arXiv:1204.2487

Correlations near the NTFP



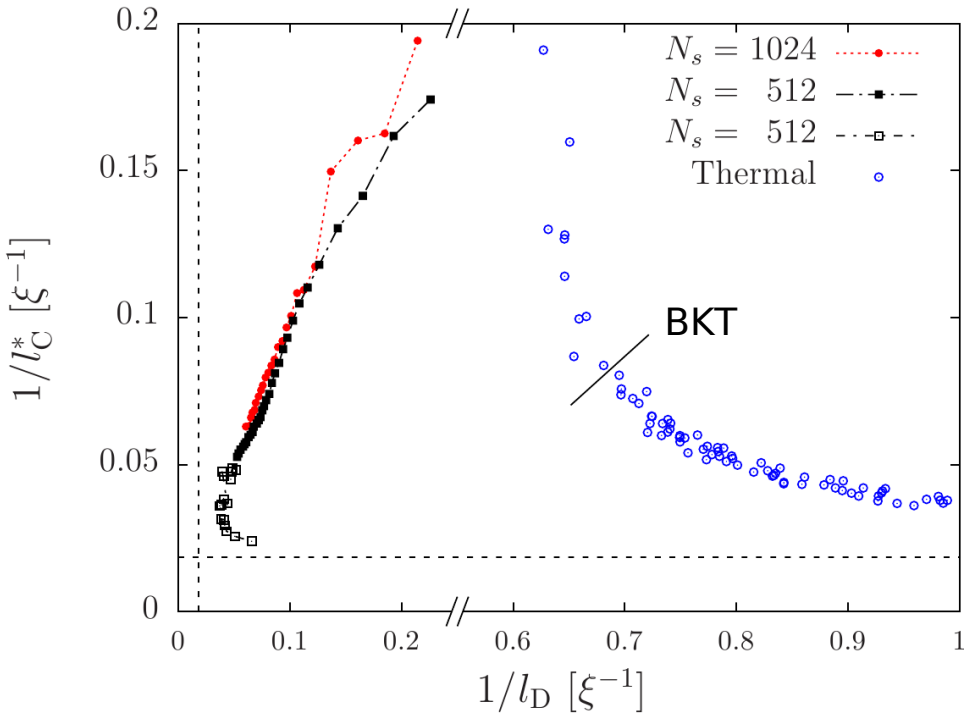


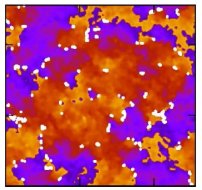
$l_C^\star$ Phase coherence length

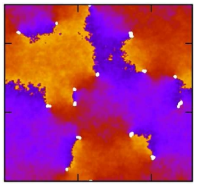
l_D Vortex-antivortex pair distance

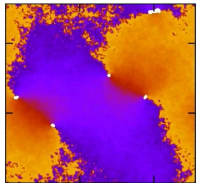
J. Schole, BN, T. Gasenzer, arXiv:1204.2487

Correlations near the NTFP









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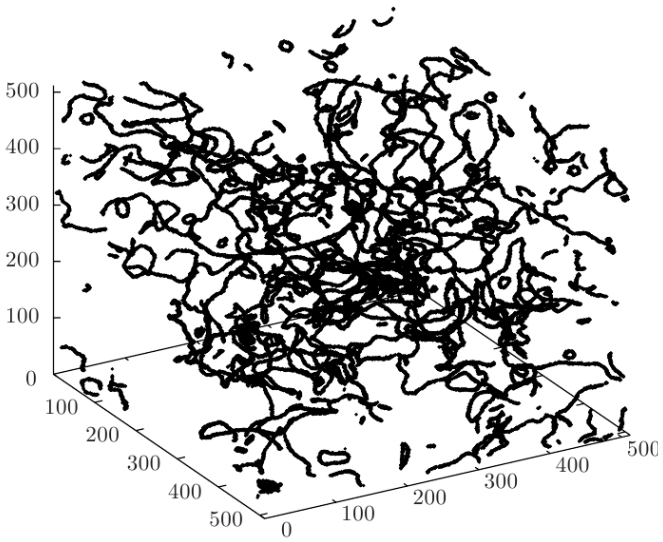
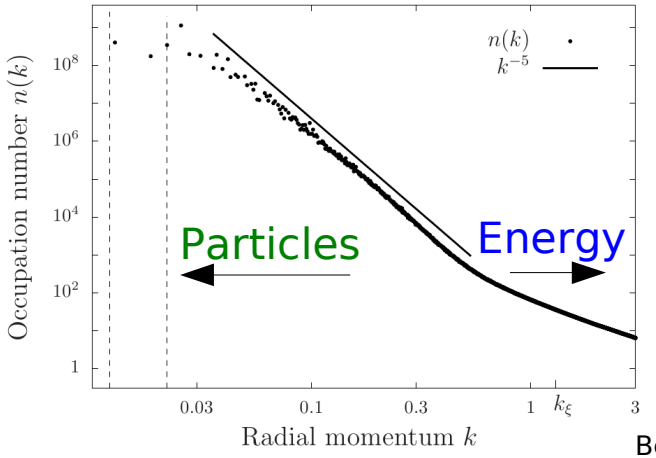
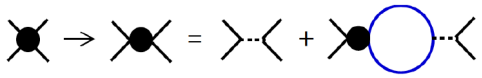
3D Nonthermal fixed point





IR: $\varsigma = d+2$
UV: $\varsigma = d$



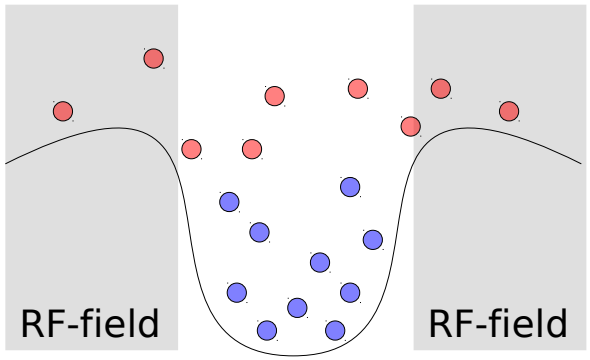
Berges, Rothkopf, Schmidt PRL (2008)
Scheppach, Berges, Gasenzer PRA (2010)

Vortices ⟵ Spectrum n(k) ⟶ QFT

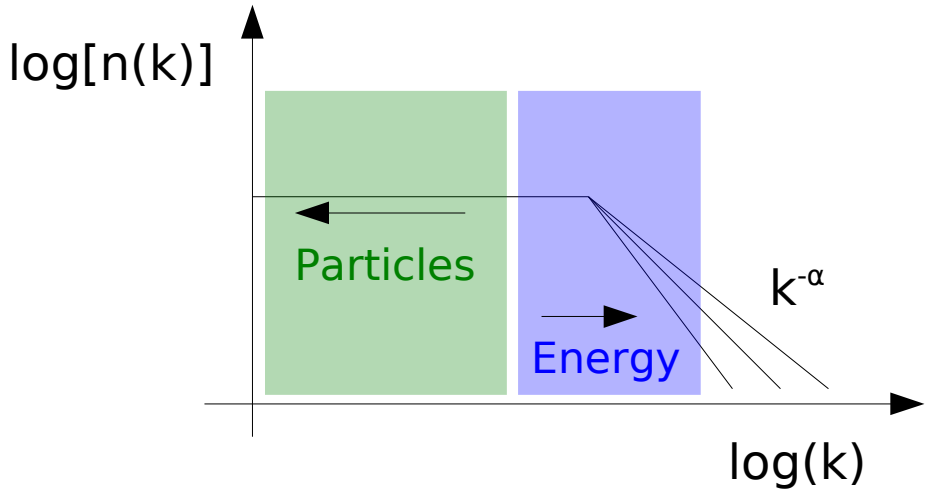
Condensation dynamics: Kagan, Svistunov, Shlyapnikov ('90s), Semikoz, Tkachev (1995), Berloff (2002), Anderson, Davis (2008), Blaizot, McLerran(2012), Berges, Sexty (2012)

BN, D. Sexty, T. Gasenzer PRB (2011), BN, J. Schole, D. Sexty, T. Gasenzer PRA (2012)

3D: Bose condensation



Evaporative cooling



Experiments: Hänsch, Esslinger (2002), Esslinger (2007), Hadzibabic (2012)

Condensation dynamics: Kagan, Svistunov, Shlyapnikov ('90s), Semikoz, Tkachev (1995), Berloff (2002), Anderson, Davis (2008), Blaizot, McLerran(2012), Berges, Sexty (2012)

BN., T. Gasenzer arxiv: 1206.3181

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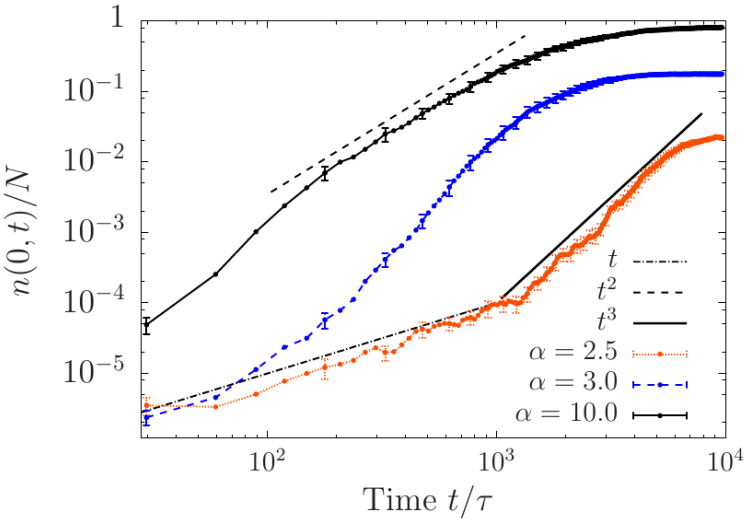

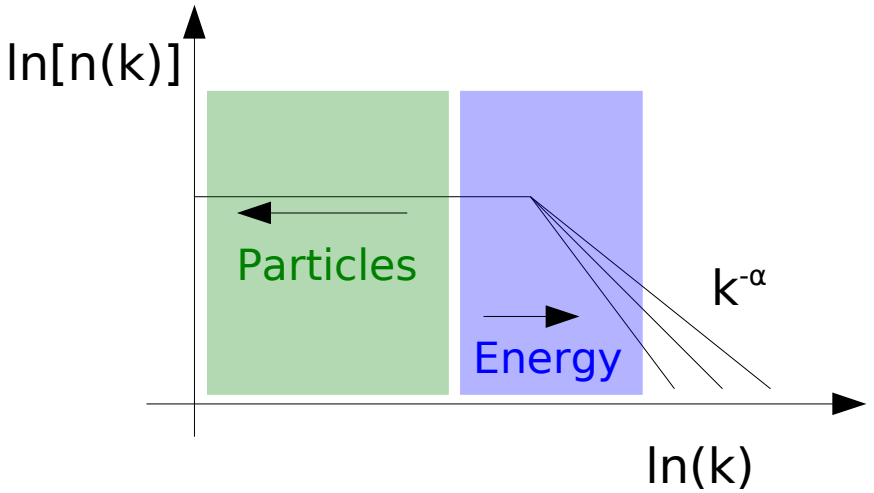

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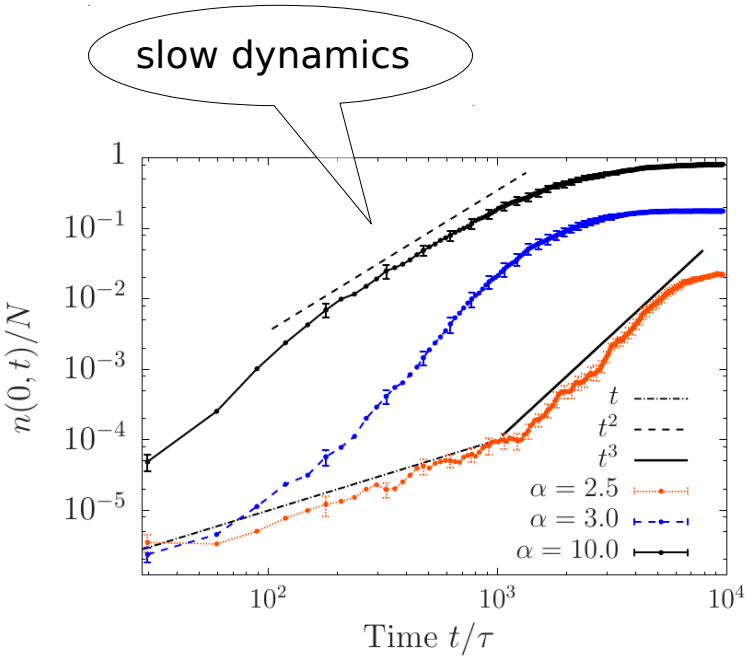

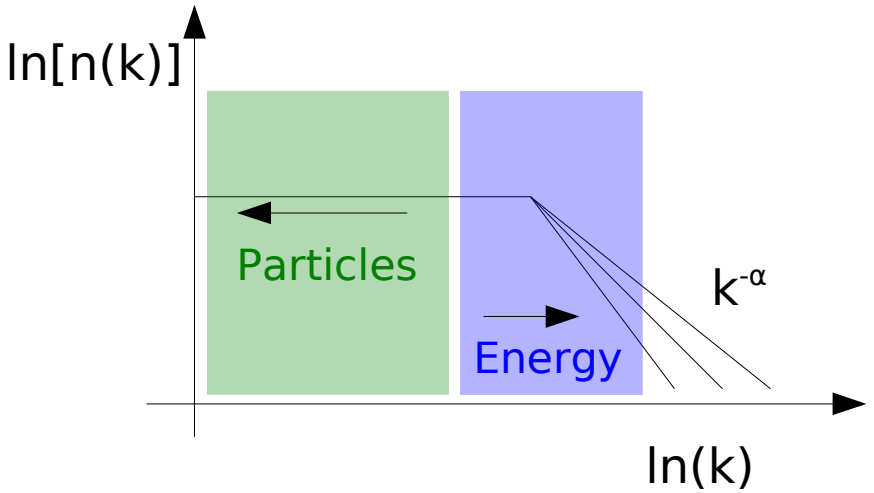

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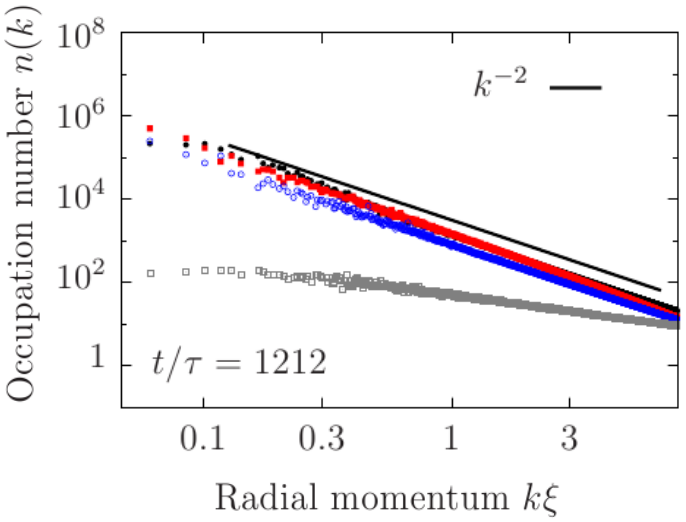
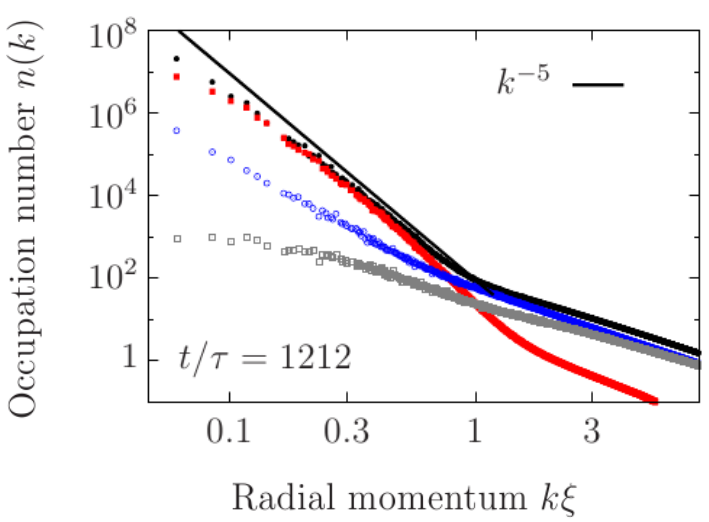
3D: Bose condensation

α=2.5



α=10



BN., T. Gasenzer arxiv: 1206.3181

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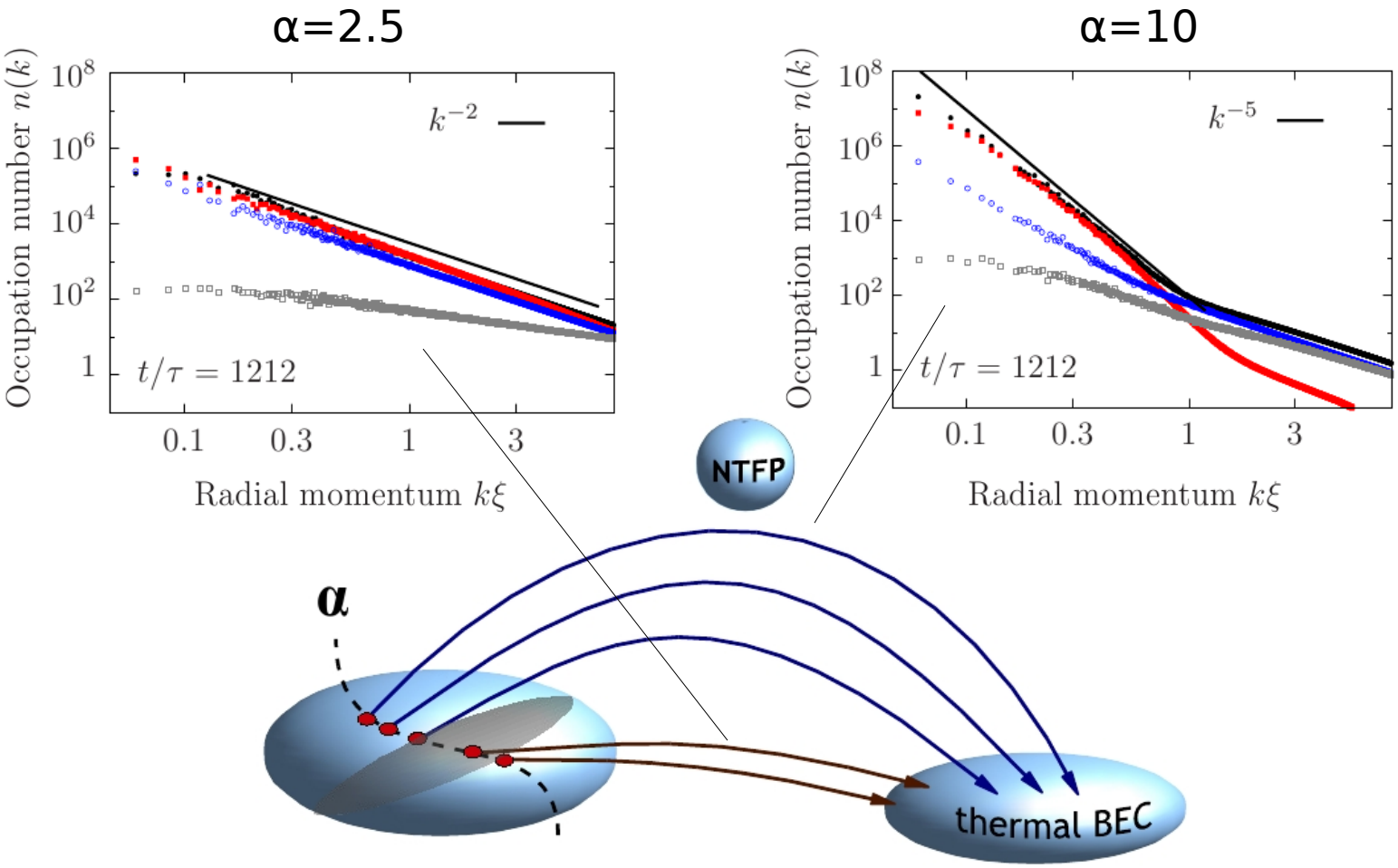

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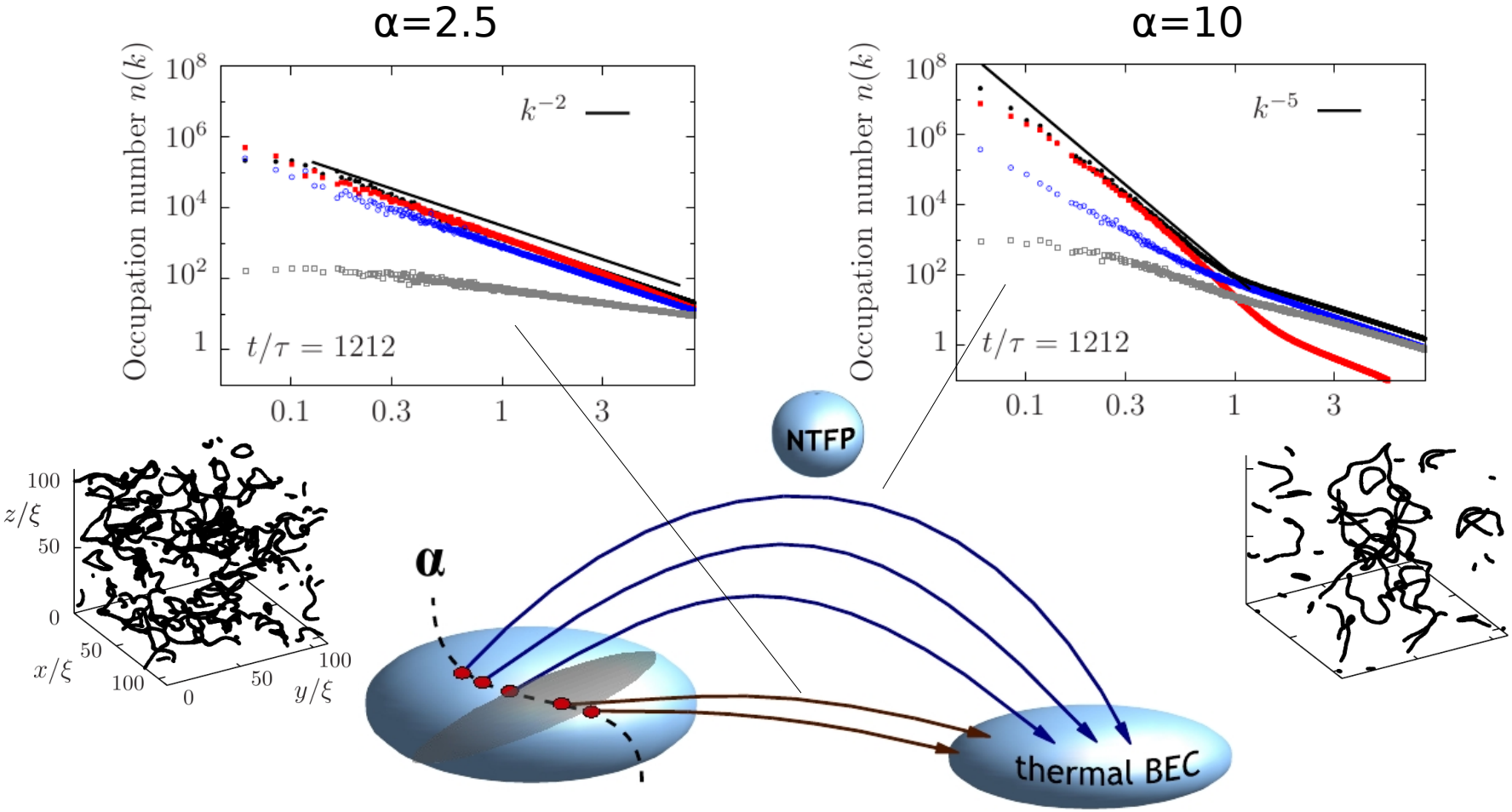
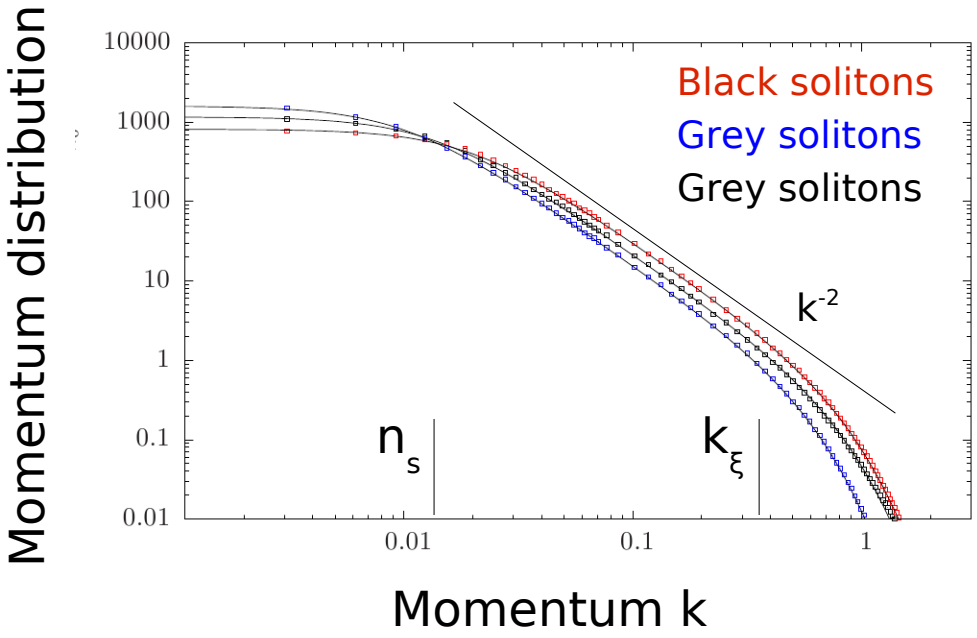


BN., T. Gasenzer arxiv: 1206.3181

1D: Momentum distribution

- Random soliton model for black/grey solitons (in a trap):

e. g. $$n(k)|_{\nu=0} = \frac{4n_s n}{4n_s^2 + k^2} \frac{(\pi k\xi)^2/2}{\sinh^2\left(\pi k\xi/\sqrt{2}\right)}$$ (Black Solitons)

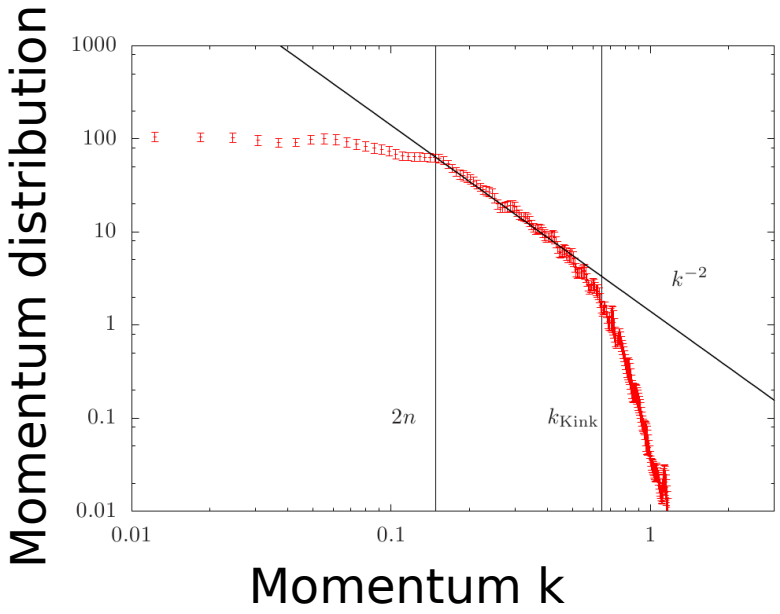


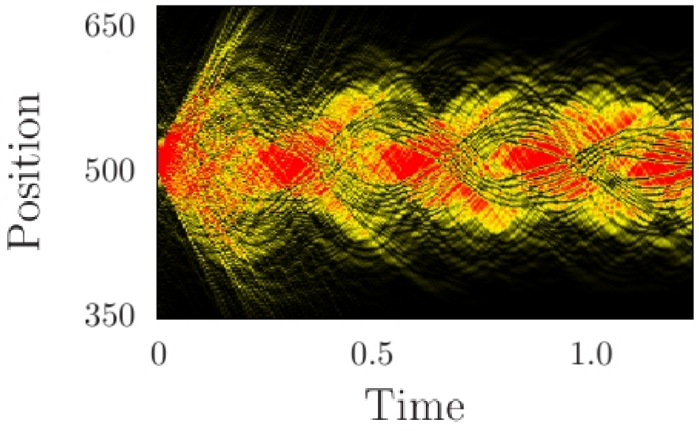
M. Schmidt, S. Erne, BN, D. Sexty, T. Gasenzer NJP (2012), to appear

1D: Quench dynamics

Features:

- Quasi-stationary profile
- Scaling



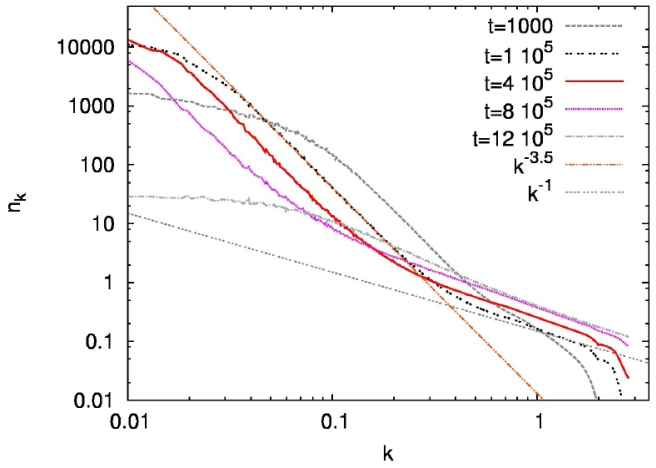


M. Schmidt, S. Erne, BN, D. Sexty, T. Gasenzer NJP (2012), to appear

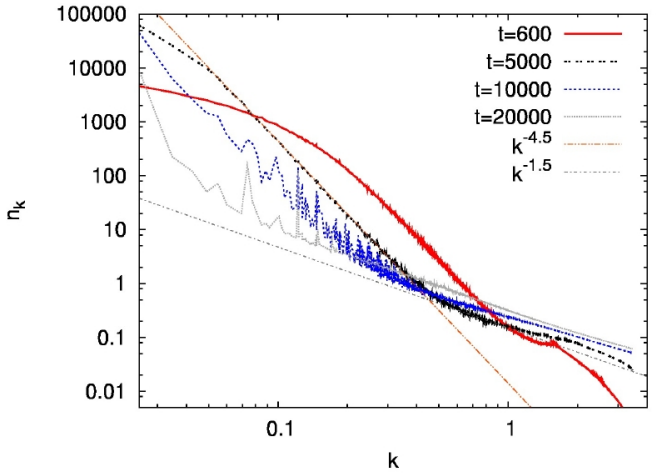
Relativistic simulations

Classical field equation: $\left[\partial_t^2 - \Delta + \Phi^2\right]\Phi_a = 0$

d=2



d=3



T. Gasenzer, BN, D. Sexty PL (2012)

S. Khlebnikov, I. Tkachev PRL (1996)
J. Berges, A. Rothkopf, J. Schmidt PRL(2008)
J. Berges, D. Sexty PRD (2011)

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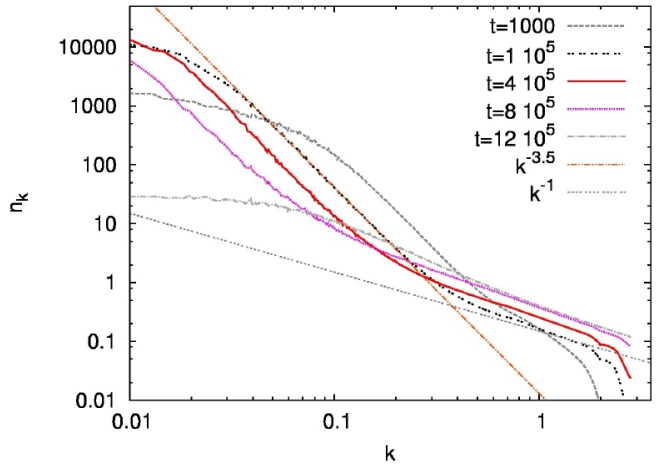
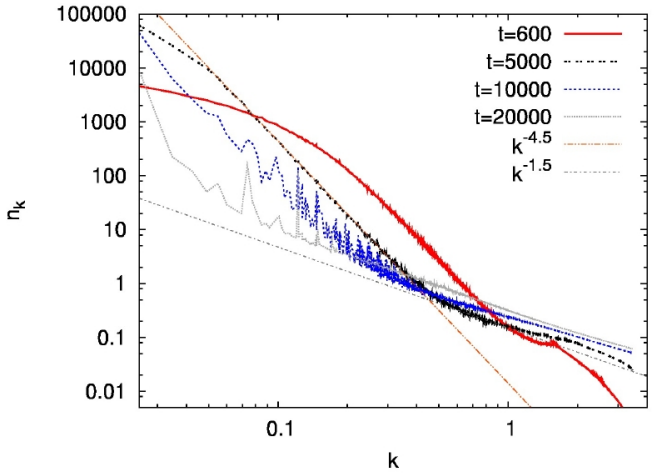
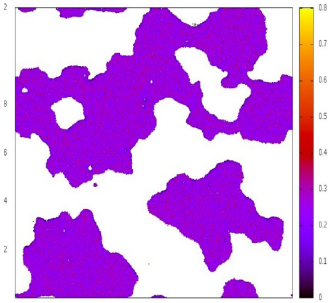
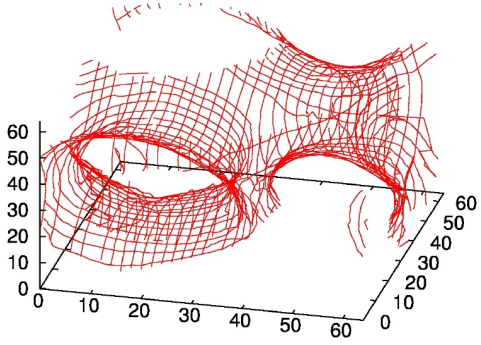


d=3





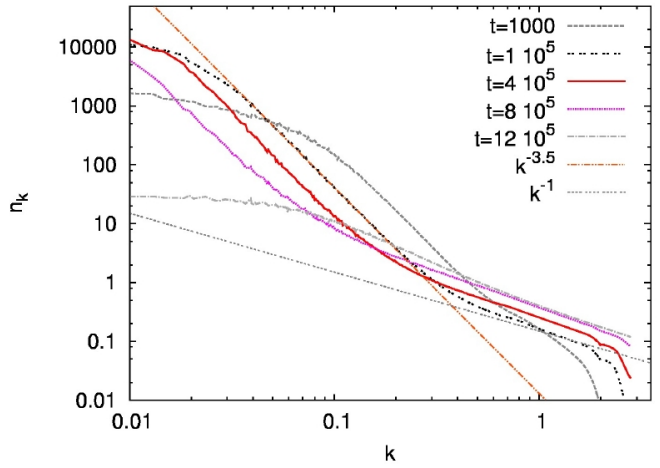


T. Gasenzer, BN, D. Sexty PL (2012)

Relativistic simulations

Classical field equation: $\left[\partial_t^2 - \Delta + \Phi^2\right]\Phi_a = 0$

d=2



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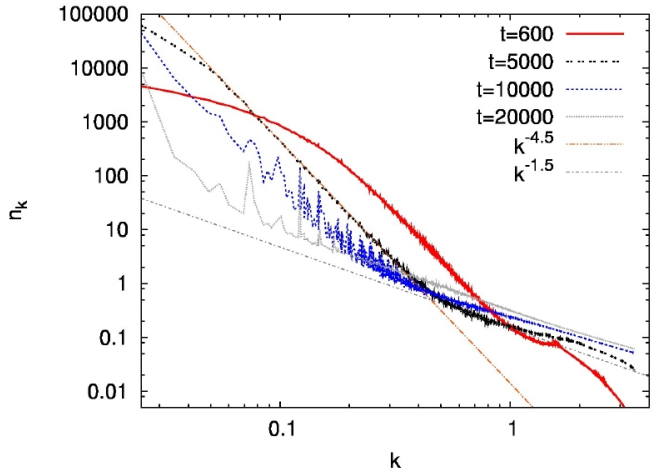
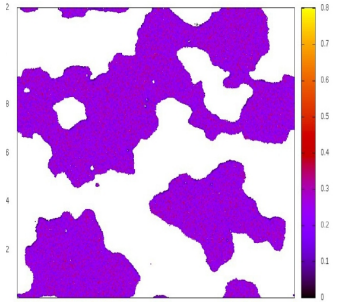
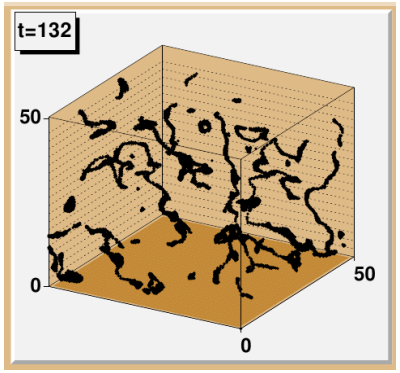
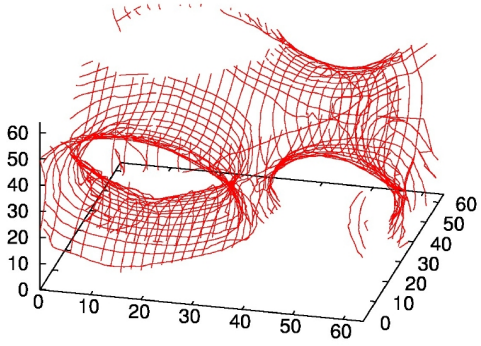


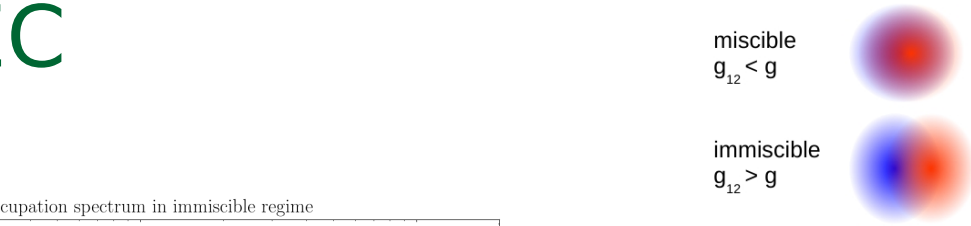


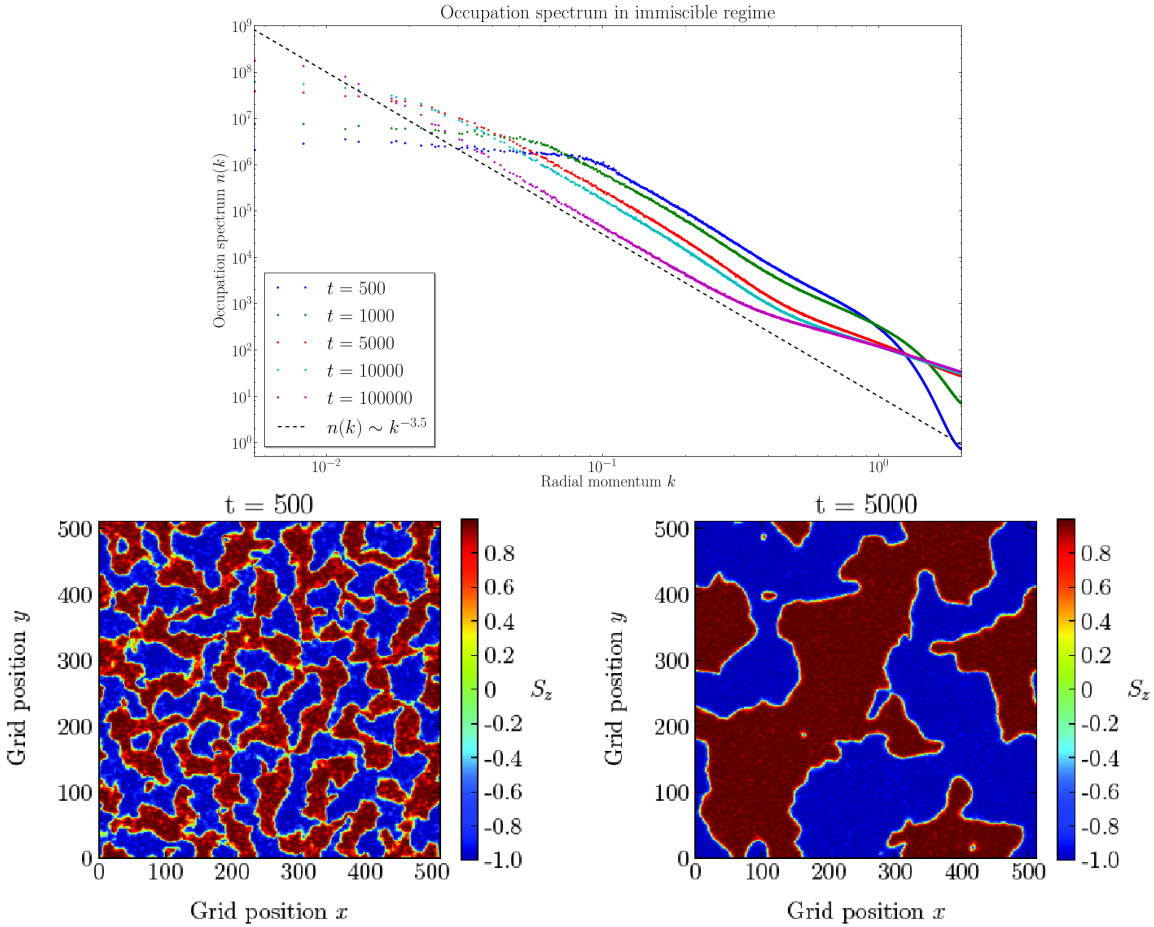




T. Gasenzer, BN, D. Sexty PL (2012) I. Tkachev, S. Khlebnikov, L. Kofman, A. Linde PL (1998)

2-component BEC

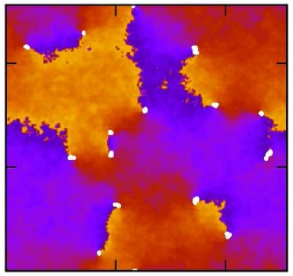


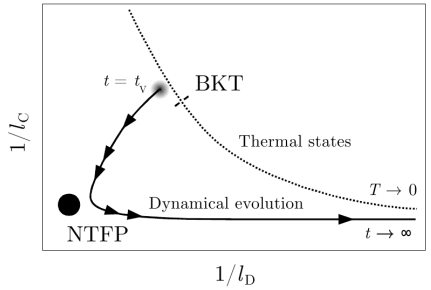


Summary

Nonthermal fixed points (NTFP)

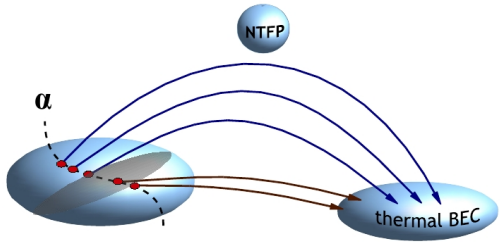
Superfluid turbulence in 2D

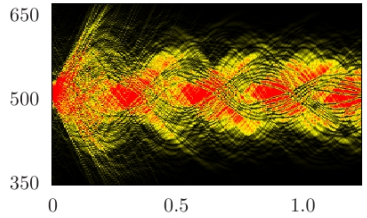




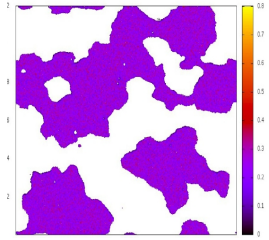
Dynamics near the NTFP in 2D

Dynamic Bose condensation in 3D





Solitonic state as a NTFP



Charge Separation/Domain Walls