Nonthermal fixed points in turbulent Bose gases

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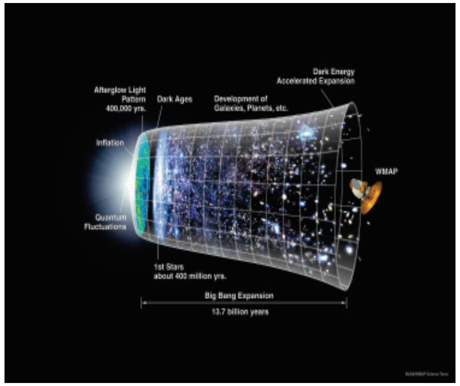
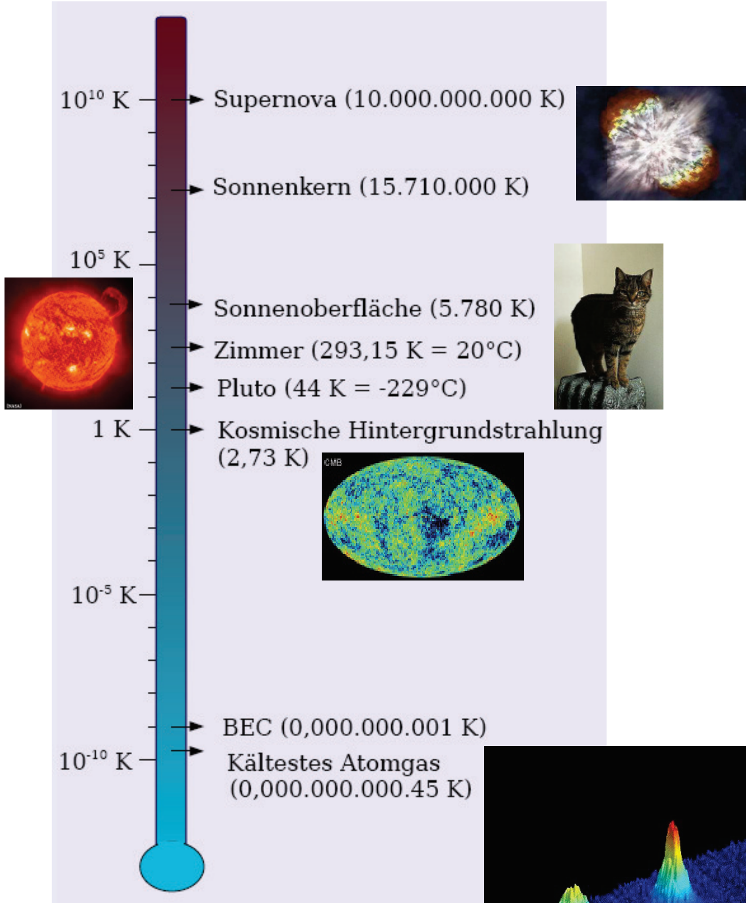
EMMI

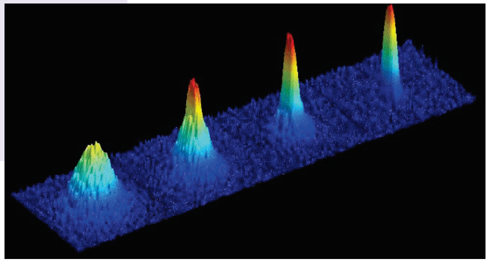
Center for Quantum Dynamics

Nonequilibrium Quantum Gases

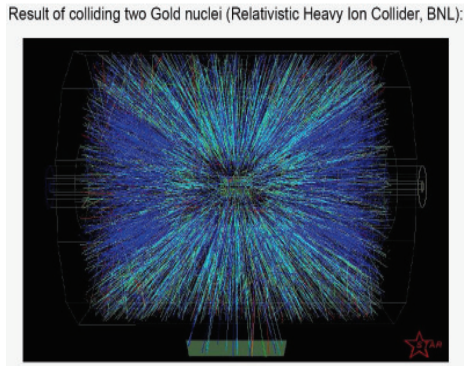


Early universe





Ultracold gases



Heavy-ion collisions

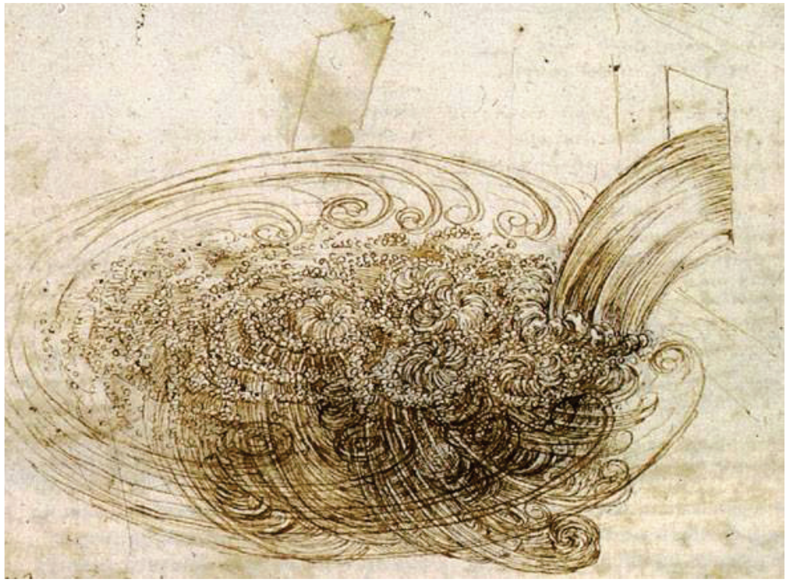
Nonequilibrium Dynamics

Initial state:
Far from equilibrium

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

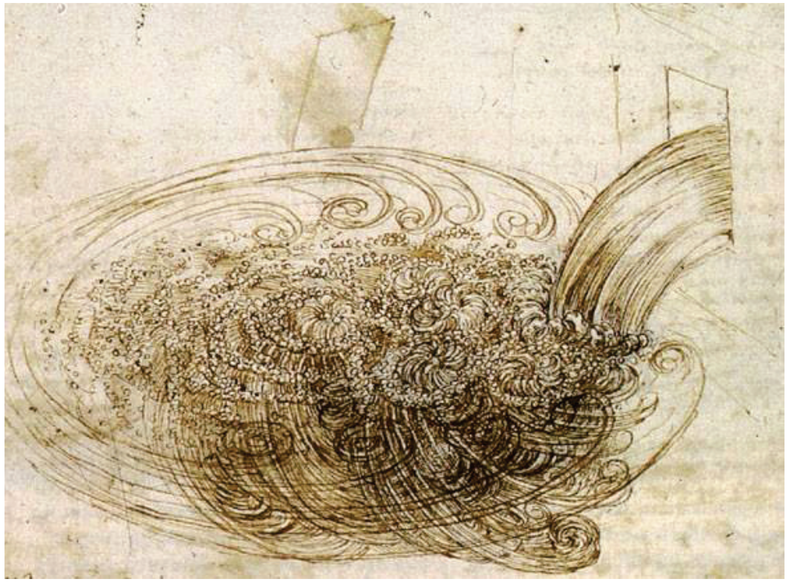
Final state:
Thermal equilibrium

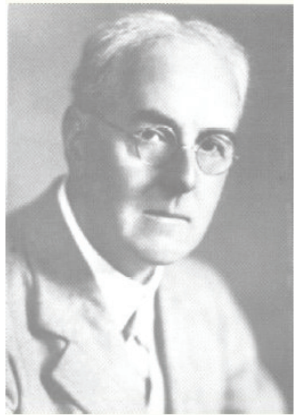
Classical Turbulence



Leonardo da Vinci
(1452 – 1519)

Richardson cascade



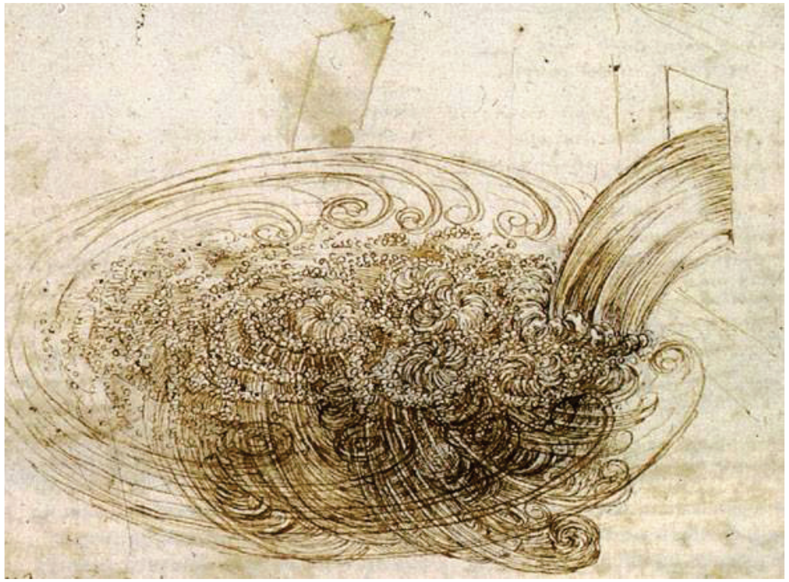


Lewis F. Richardson
(1881-1953)

Kinetic energy cascade:

large scales (source) → small scales (sink)

Kolmogorov theory



Andrey N. Kolmogorov
(1903-1987)

Kinetic energy cascade:

large scales (source) $\rightarrow$ small scales (sink)

Kolmogorov (1941): $E(k) \sim k^{-5/3}$

...Turbulence as dynamical critical phenomenon...

Turbulent ultracold Bose gas

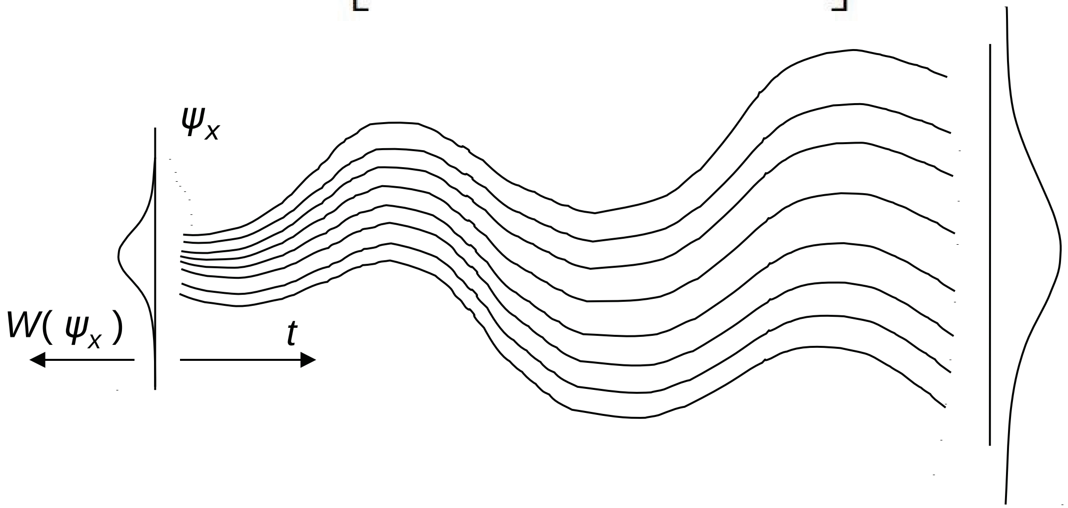
B. N., D. Sexty, T Gasenzer: Phys. Rev. B, Rapid Comm. (2011)

B. N., J. Schole, D. Sexty, T. Gasenzer: in preparation

Semiclassical simulations

Classical field equation for a nonrelativistic complex scalar field:

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



Radial occupation number:

n(k) = <Ψ*(**k**)Ψ(**k**)> + path average
+ angle average

e.g. P. B. Blakie et al.: Adv Phys. (2008)

Movie 1

Phase Evolution in 2D
(single run)

$$\psi(\mathbf{x},t) \;=\; \sqrt{n(\mathbf{x},t)}\,\exp\{i\phi(\mathbf{x},t)\}$$

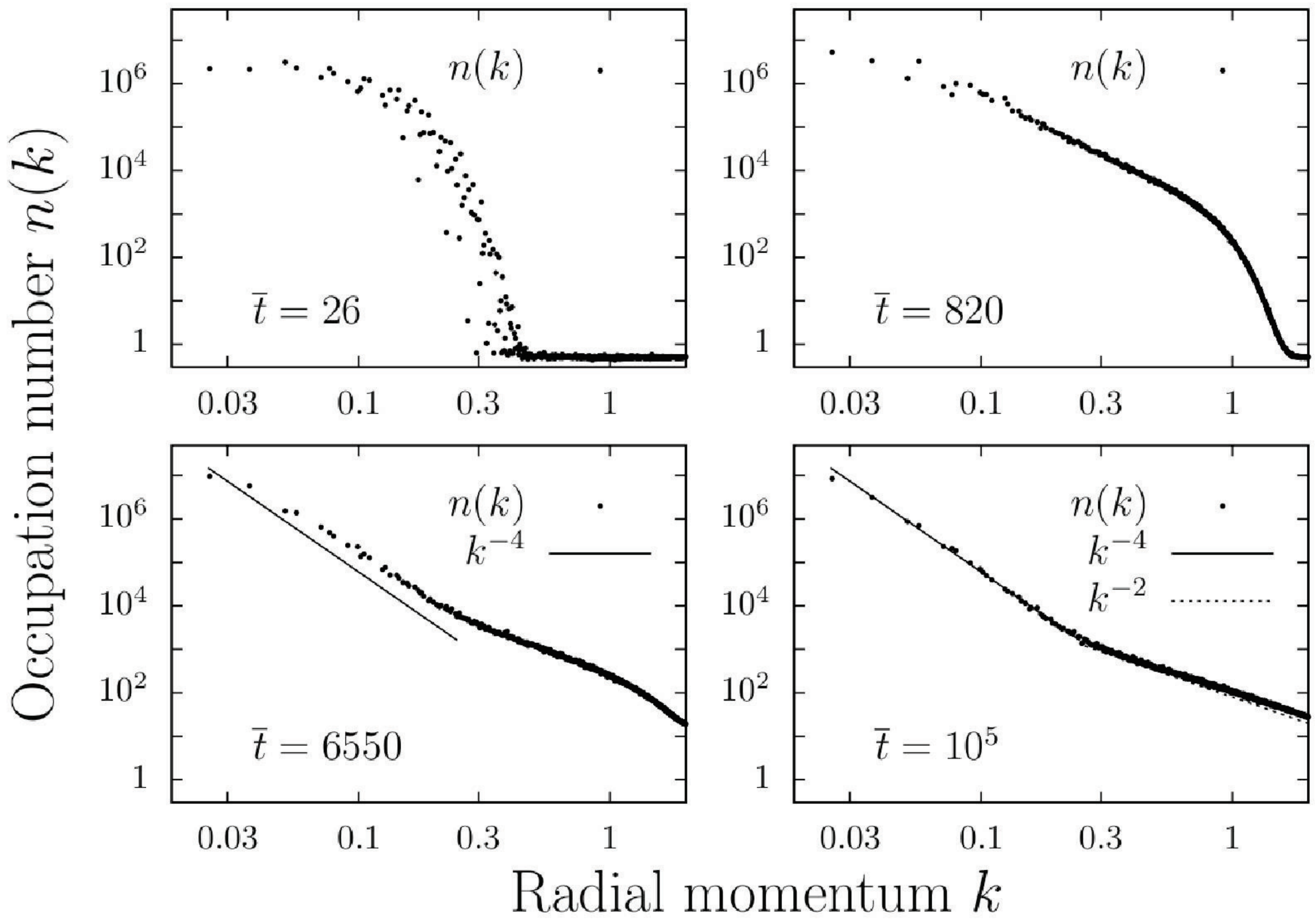
Movie 2

Vortex dynamics and spectrum in 2D
(single run)

Radial occupation number:

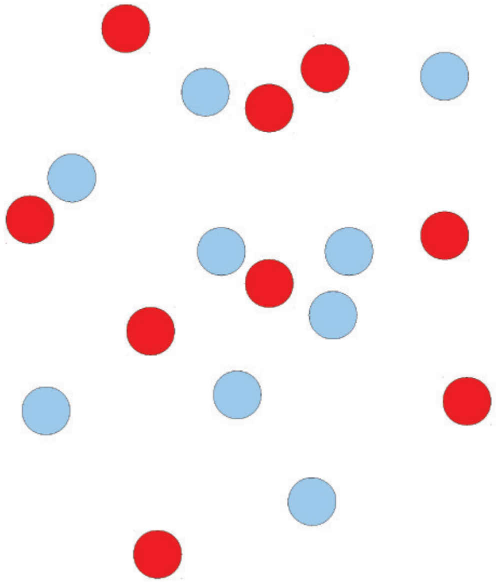
$n(k) = \quad \langle \Psi^*(\mathbf{k})\Psi(\mathbf{k}) \rangle$ (+ path average)
+ angle average

2D simulations

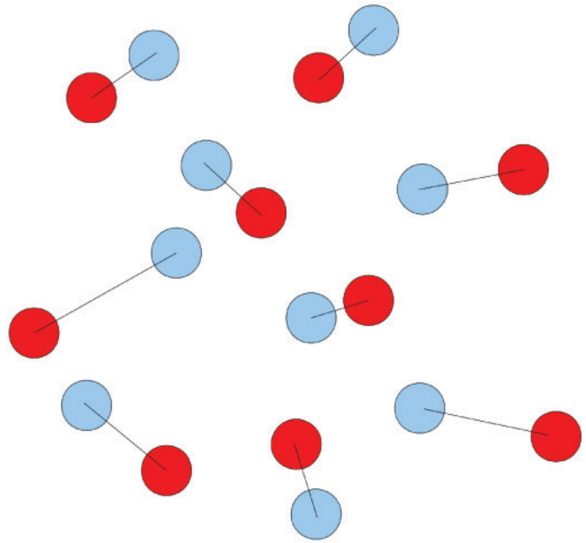


B. N., D. Sexty, T Gasenzer: Phys. Rev. B, Rapid Comm. (2011)

2D statistics of vortices



$n_k \sim k^{-4}$

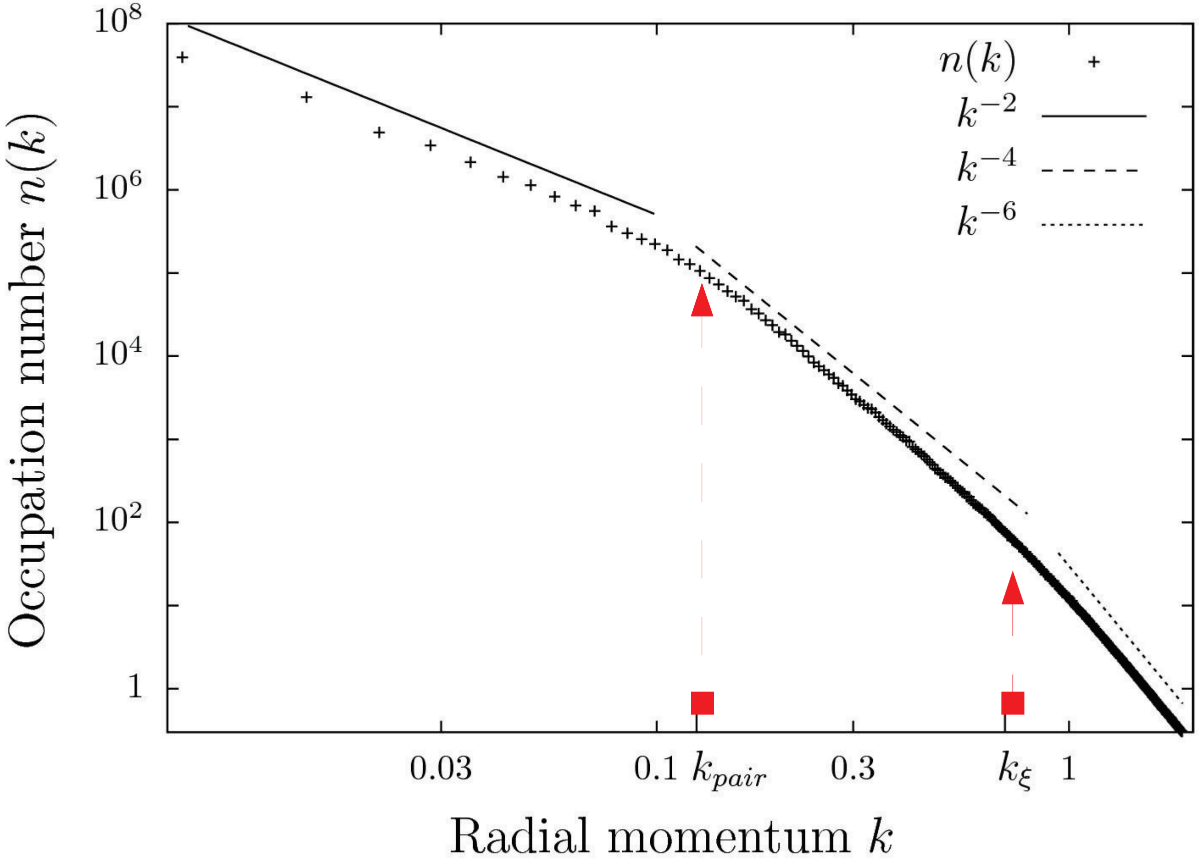


$n_k \sim k^{-2} \quad k < k_{pair}$

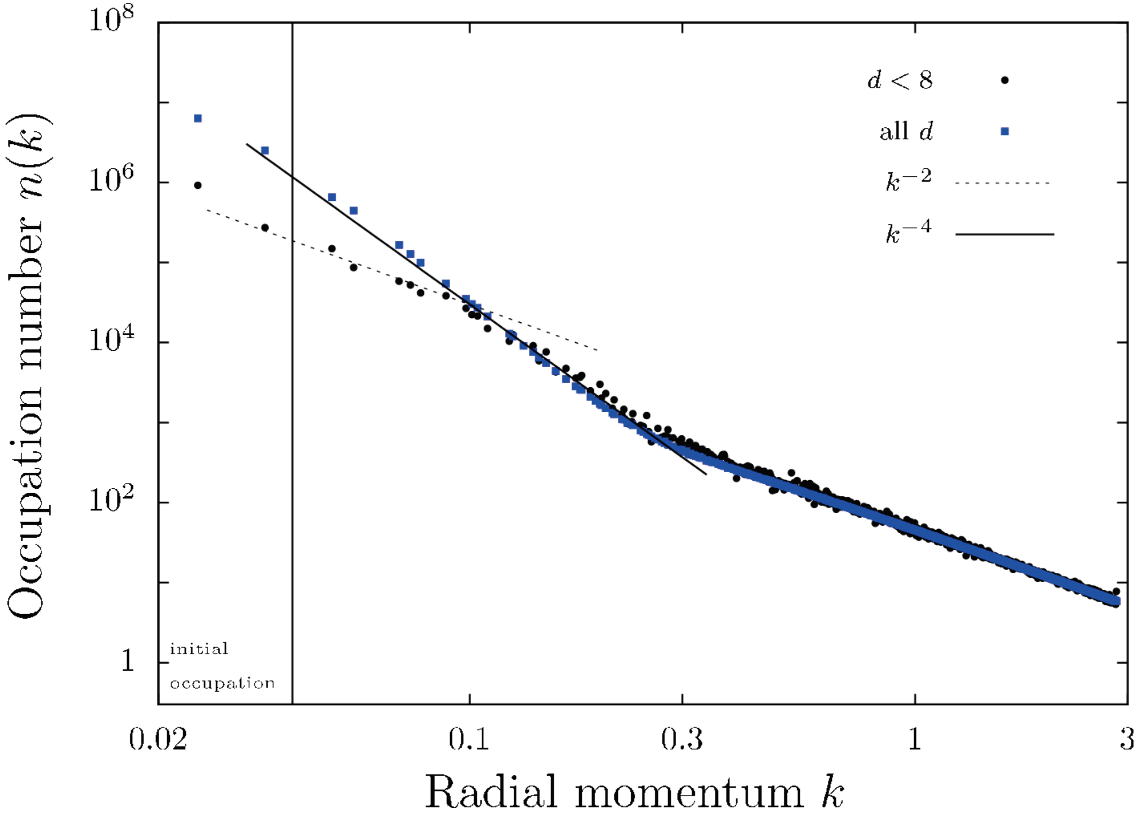
$n_k \sim k^{-4} \quad k > k_{pair}$

B. N., J. Schole, D. Sexty, T. Gasenzer: in preparation

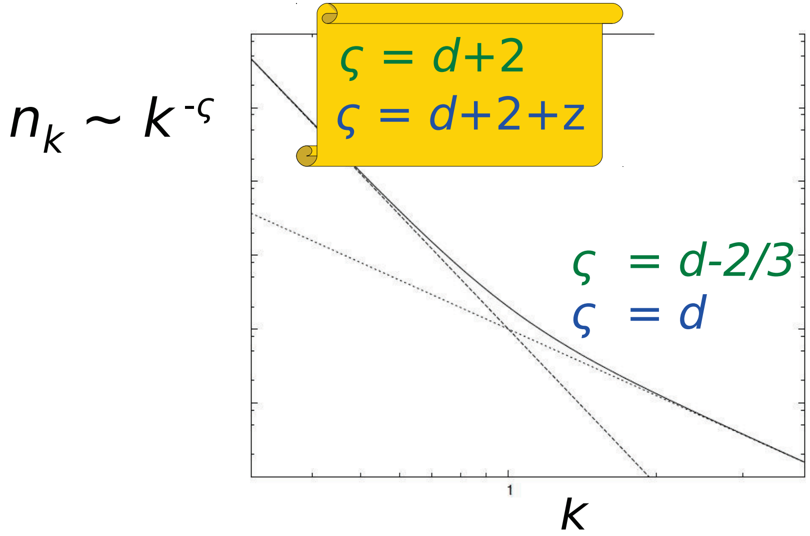
Scaling transition in 2D
- pairing and vortex core size



Pair-scaling in simulations



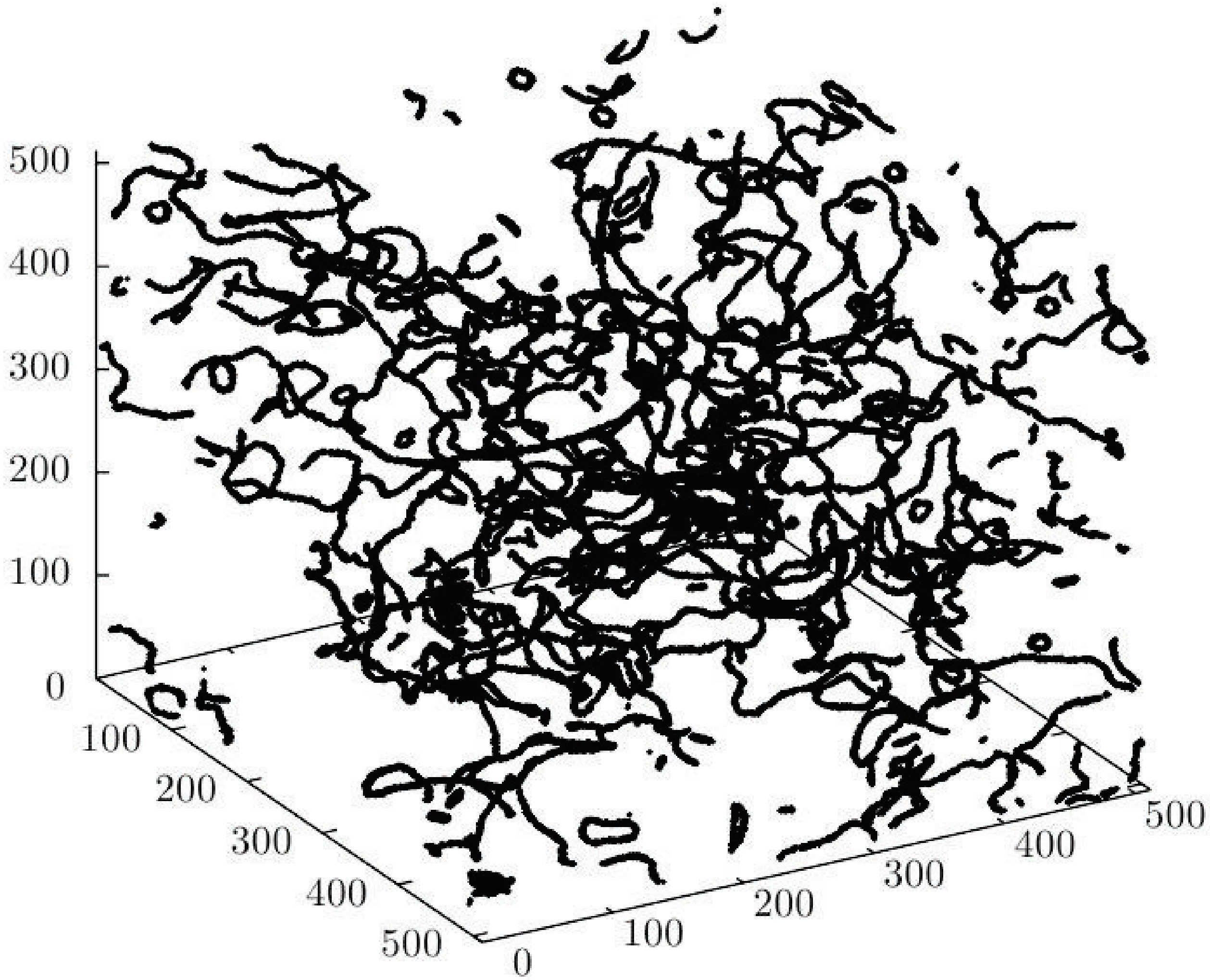
Nonthermal fixed points



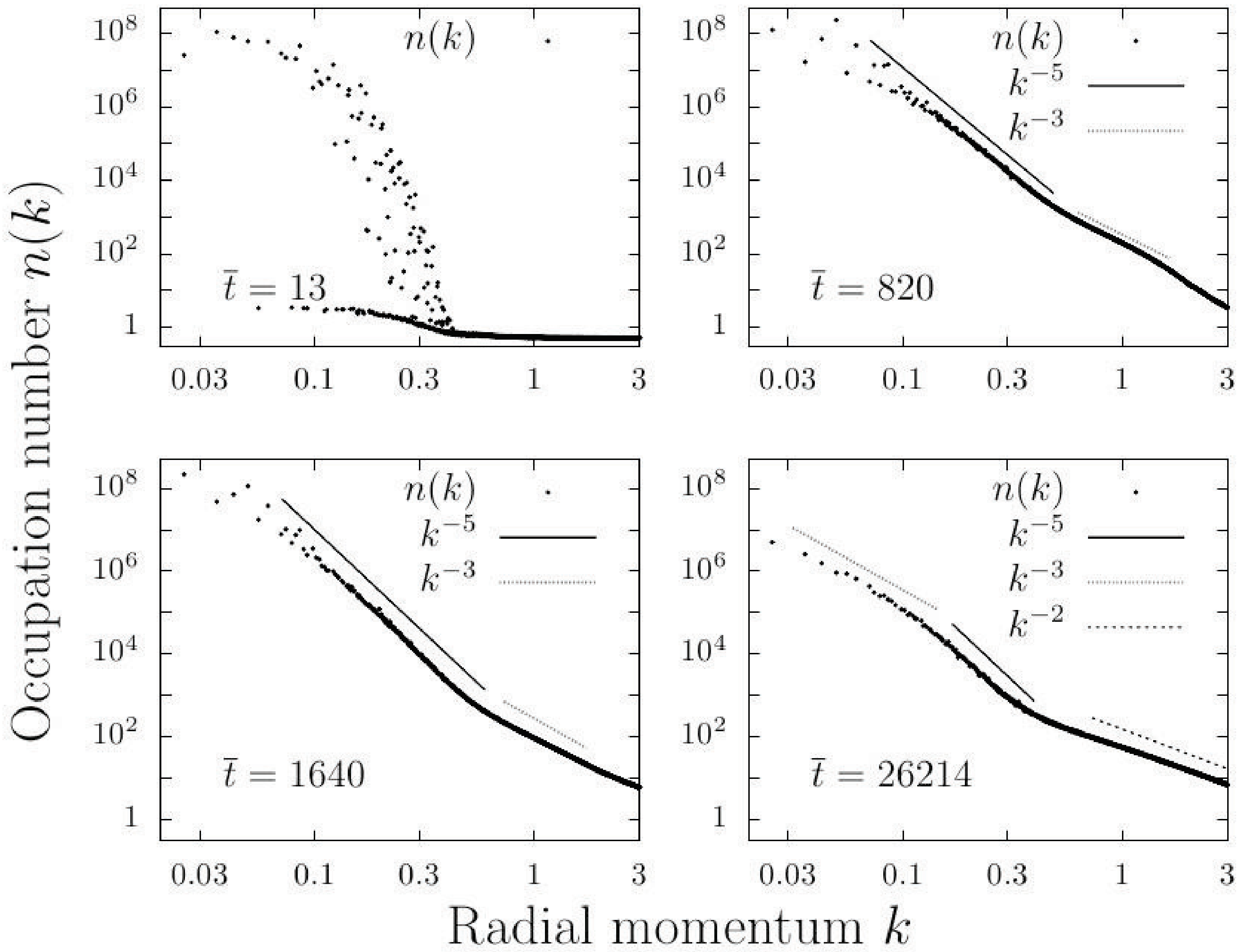
J. Berges, A. Rothkopf, J. Schmidt, PRL (2008)

C. Scheppach, J. Berges, T. Gasenzer, PRA (2010)

3D simulations

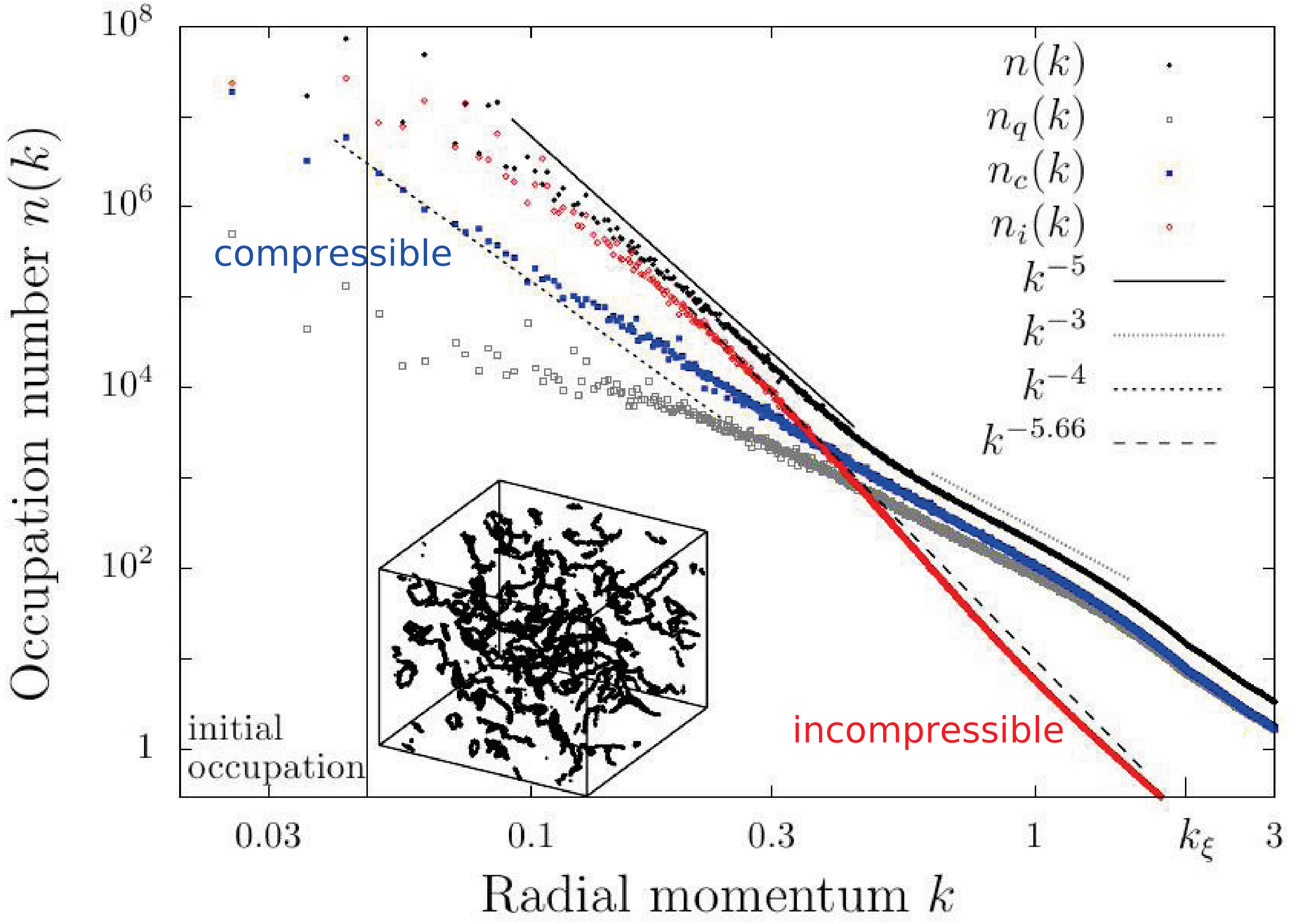


3D simulations



Scaling in 3D

$E(k) = \omega(k)k^{d-1}n(k)$



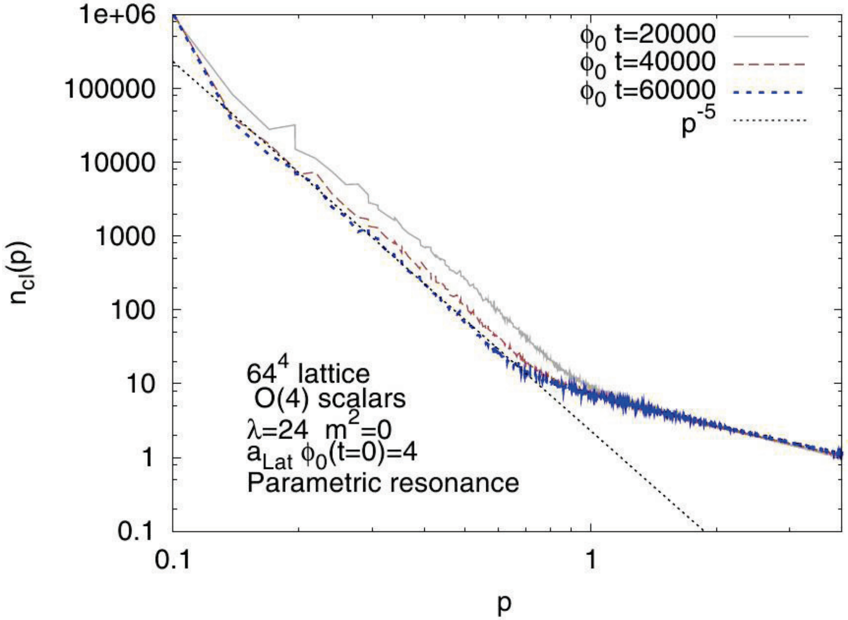
Turbulent relativistic Bose gas

D. Sexty, B. N., T. Gasenzer: arXiv: 1108.0541 [hep-ph]

Relativistic simulations O(N)
in d+1 dim.

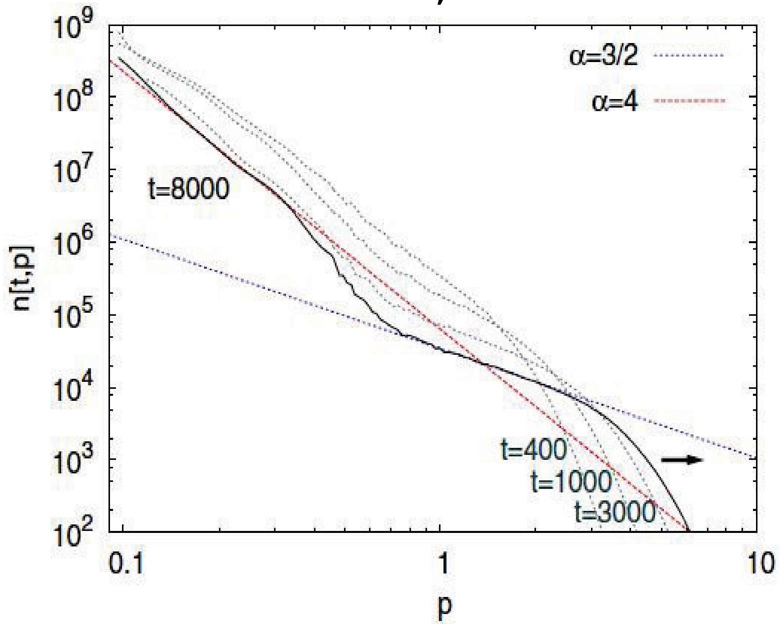
Classical field equation: $\left[\partial_t^2 - \Delta + \Phi^2\right]\Phi_a = 0$

d=4, N=4



J. Berges, D. Sexty: PRB (2011)

d=3, N=4

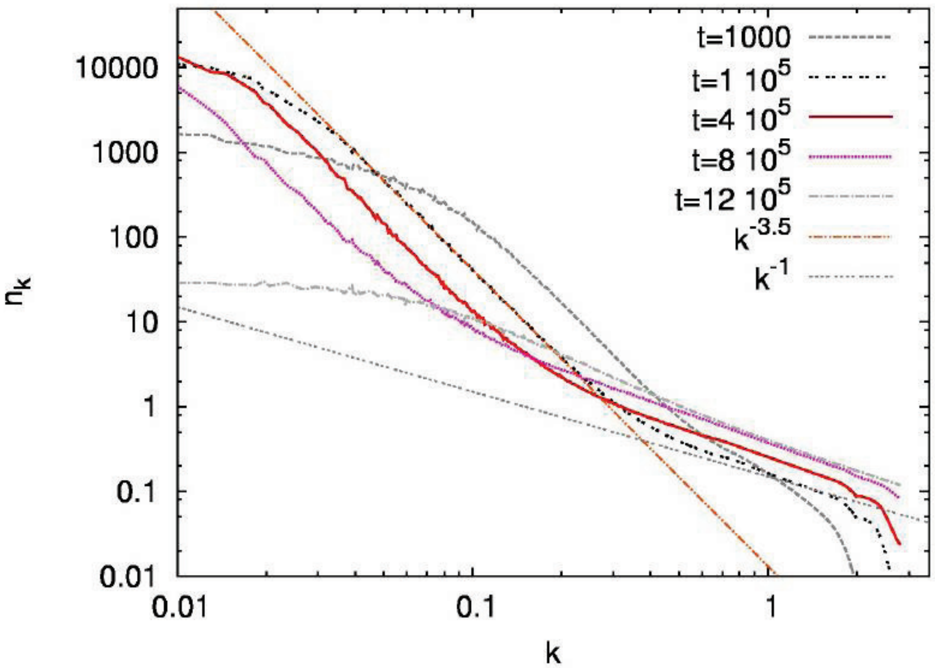


J. Berges, A. Rothkopf, J. Schmidt: PRL (2008)

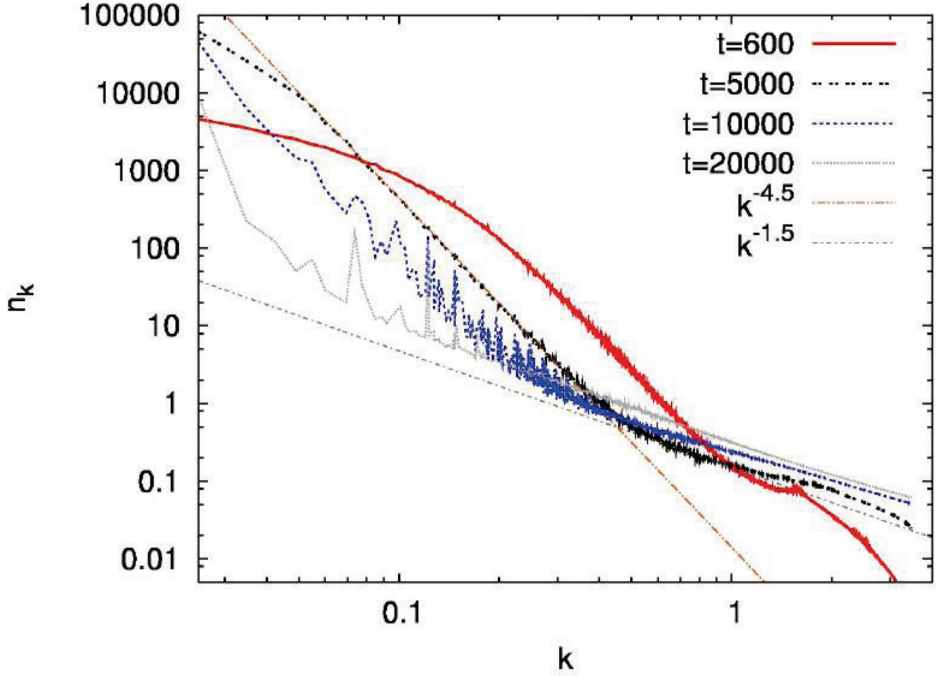
Relativistic simulations O(N)

in d+1 dim.

d=2, N=2



d=3, N=2



D. Sexty, B. N., T. Gasenzer: arXiv: 1108.0541 [hep-ph]

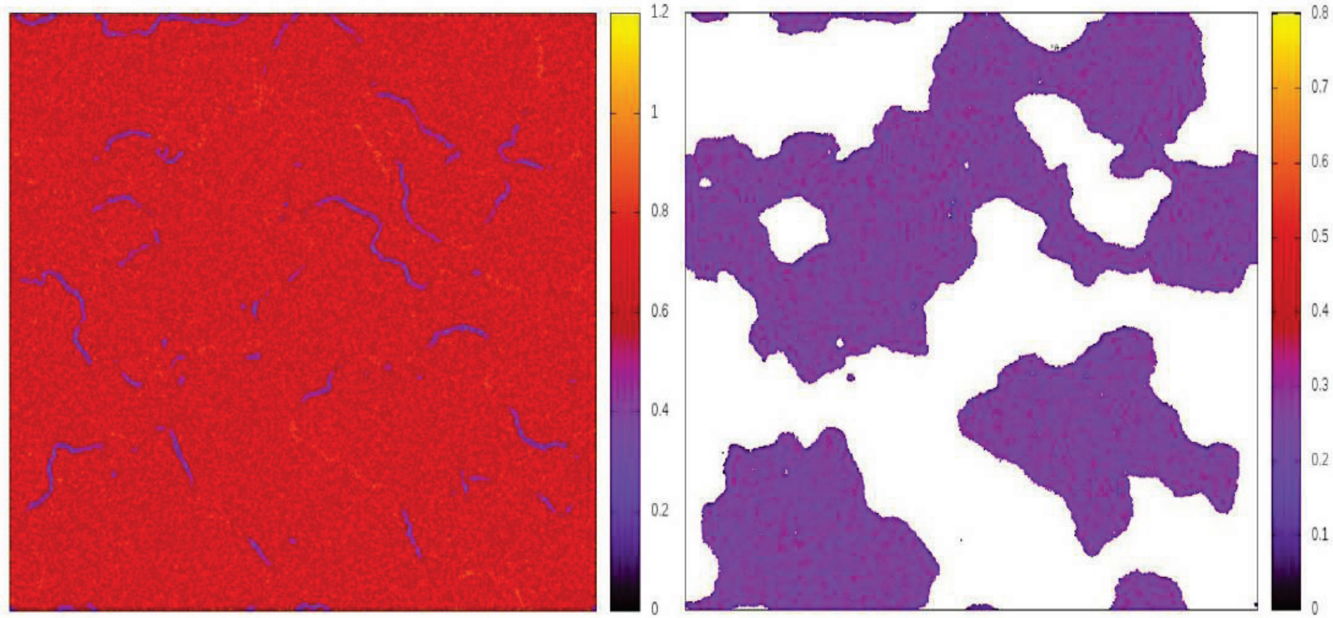
Movie 3

Early Universe:
Relativistic scalar field in 2D
(single run)

$|\Psi(x,t)|$

Charge Separation

Modulus of complex field $|\varphi|$ vs. mean charge distribution



$$j_\mu(x) = \Phi_1(x)\partial_\mu\Phi_2(x) - \Phi_2(x)\partial_\mu\Phi_1(x).$$

Charge Separation