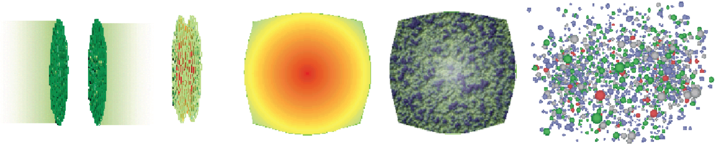
# Aleksi Kurkela

Helsinki 02-08, ETH Zurich 08-10, McGill (Montreal) 10-13, CERN 13-

Heavy-ion collisions well described by relativistic hydrodynamics:

- Hydro is an effective theory: expansion around local thermal eq.

$$T_{\mu\nu} = T_{\mu\nu}^{\mathrm{eq}} + \text{small corrections}$$

What are properties of (generic) quantum fields in equilibrium?

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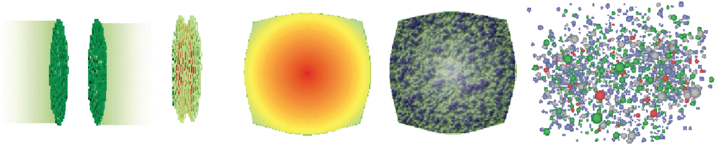

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- Hydro is an effective theory: expansion around local thermal eq.

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What are properties of (generic) quantum fields in equilibrium?

- ... but initial state far from thermal equlibrium

How do (generic) quantum fields relax towards equilibrium?

- Applications elsewhere: cosmological relics, reheating, cold atomic gases, neutron stars...

# Far-from-equilibrium dynamics

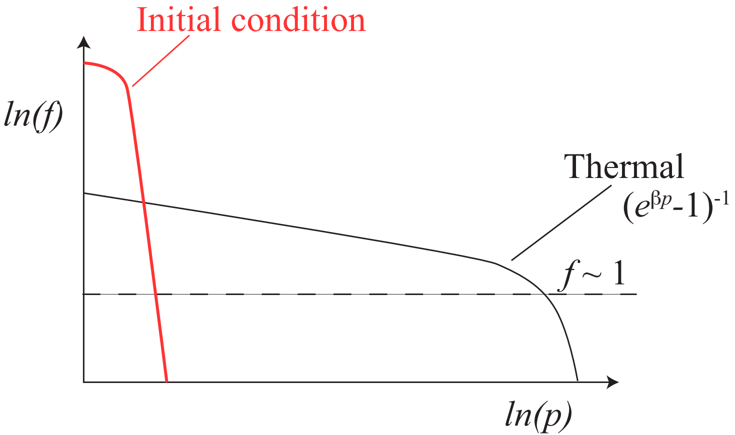
For generic theories, only weak coupling methods available:

- Mostly parametric estimates, not even LO results
- Even at weak coupling often non-perturbative: strong fields, secular divergences, instabilities...

- Weak coupling provides scale separations
- Case-by-case effective theories
  - Effective kinetic theory
  - Classical field theory
  - Hard loop effective theory/ Vlasov equations
  - ...

# Far-from-equilibrium dynamics

Simple example: what happens if you have too many soft gluons



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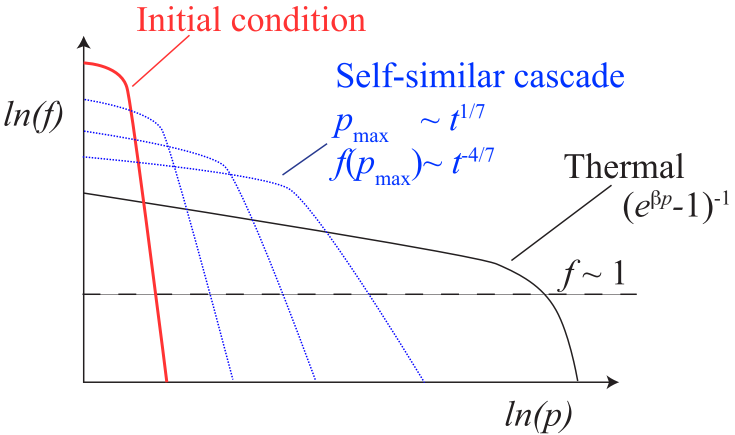

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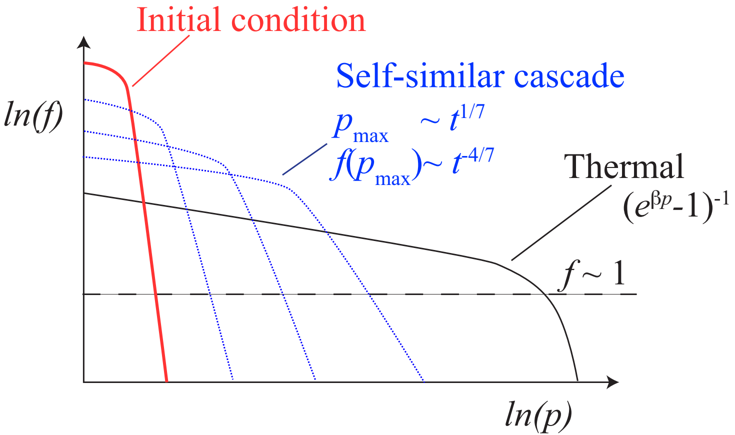



Quantitatively:

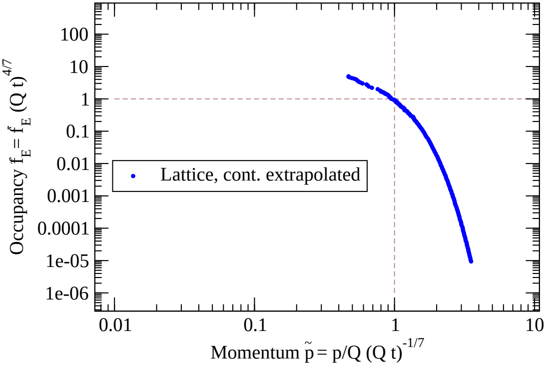
- Strong fields ($f \gg 1$): Classical (lat.) field theory
- But not too ($f \ll 1/\alpha$): Effective kinetic theory

# Shape of the self-similar cascade

On lattice, follow the evolution of gauge fields $(A_i, E_i)$:

$$\hat{H} = \sum_{\text{sites}} \mathrm{Tr}\left[E^2_{i,\hat{\mathbf{n}}}\right] + \sum_{\text{plaquettes}} 2\mathrm{Re}\mathrm{Tr}[1 - \Box],$$

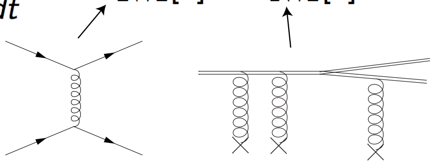
$$f(p) = |\mathbf{p}| \int d^3x e^{i\mathbf{p}\cdot\mathbf{x}} \langle E_a(x) E^a(0) \rangle_{\text{coulomb}}$$

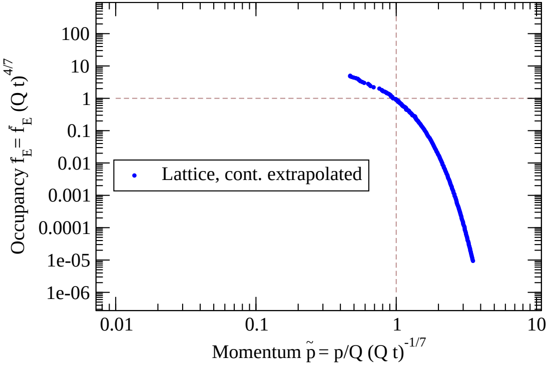


# Shape of the self-similar cascade

In kinetic theory, interactions through medium-corrected matrix-elements

$$\frac{df}{dt} = -C_{2\leftrightarrow 2}[f] - C_{1\leftrightarrow 2}[f]$$





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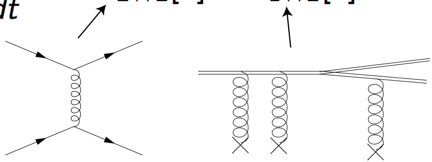
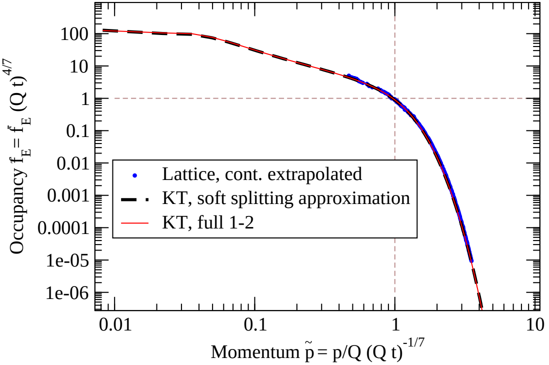
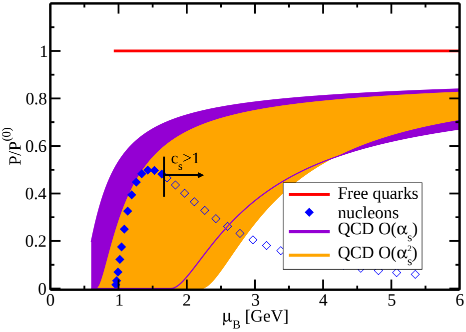
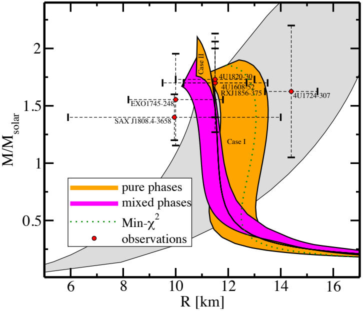




# Neutron star radii from perturbation theory: 1006.4062

NNLO Equation of state for $T = 0,\ \mu_B \neq 0,\ m_s \neq 0$:




Other stuff:

- Thermal photon production rate to NLO 1302.5970
- High-T eff. theories for thermodynamics: 0801.1566
- Overlap fermions with staggered kernel: 1202.1867
- Extra-dimensions on lattice: 1003.4643