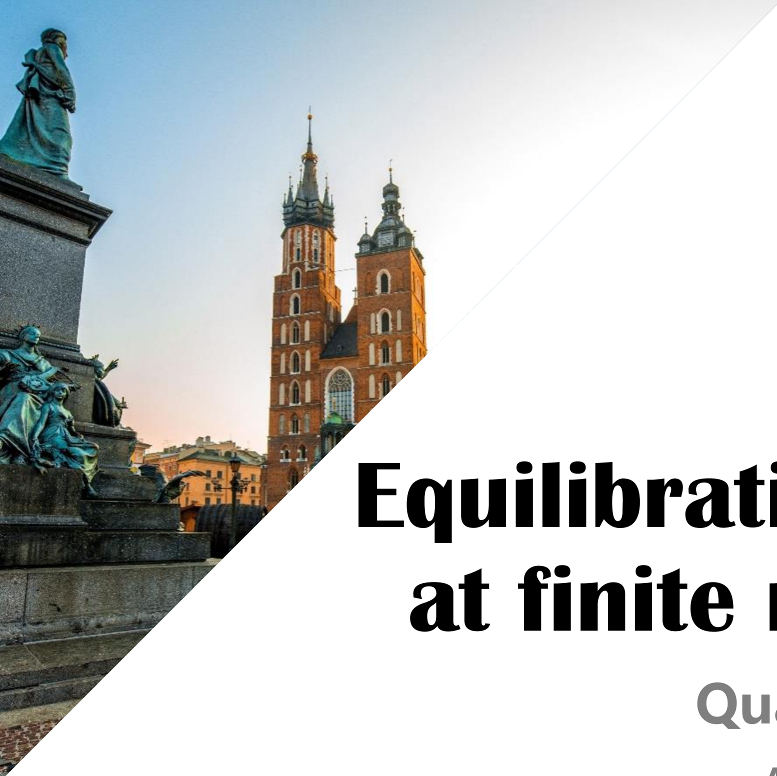


Equilibration of QCD plasmas at finite net-baryon density

Quark Matter 2022

April. 6th, 2022

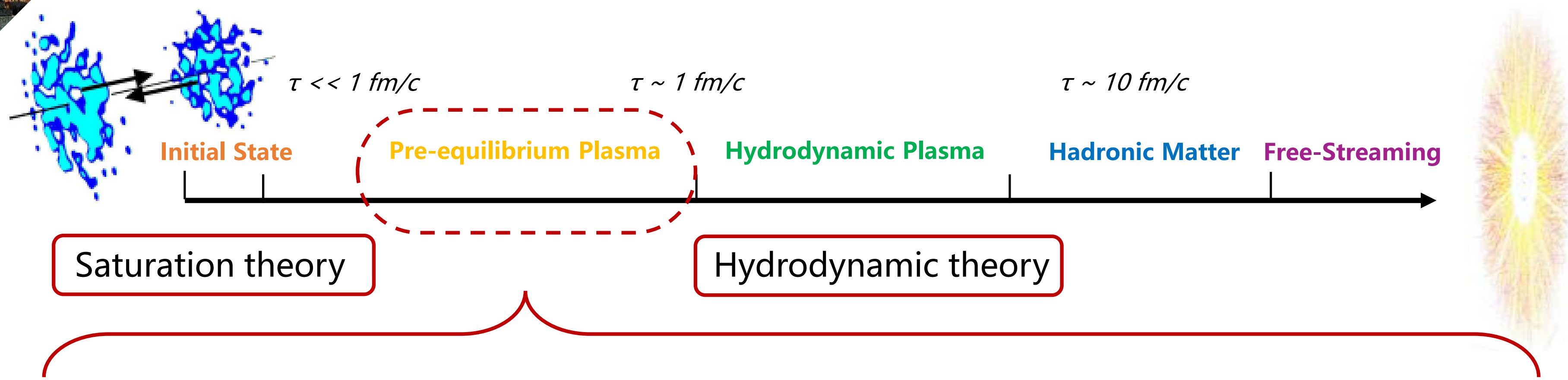
Kraków Poland + Cyberspace

Xiaojian Du | Bielefeld University

UNIVERSITÄT BIELEFELD

CRC–TR 211
Strong-interaction matter under extreme conditions

Initial stage in HICs



QGP equilibration in HICs

- Connects initial condition to equilibrium states
  - Off-thermal initial states into near-thermal hydrodynamic states
  - Gluon saturated fields into quark-gluon plasma

Kinetic Theory description of QGP equilibration

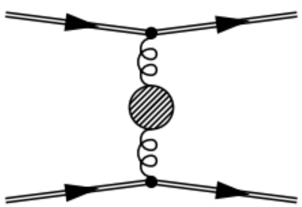
- Mechanism to thermalize states (kinetic equilibration)
- Include both gluon + quark degrees of freedom (chemical equilibration)

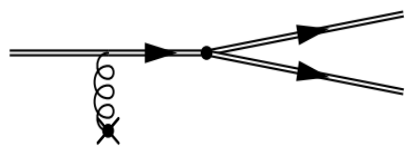
QCD Effective Kinetic Theory

First principle QCD Effective Kinetic Theory

$$\left(\frac{\partial}{\partial\tau} - \frac{p_\parallel}{\tau}\frac{\partial}{\partial p_\parallel}\right) f_a(\tau, p_T, p_\parallel) = -C_a^{2\leftrightarrow 2}[f](\tau, p_T, p_\parallel) - C_a^{1\leftrightarrow 2}[f](\tau, p_T, p_\parallel)$$

- Gluon + all light quark/antiquark (finite net-baryon density) $a = g, u, \bar{u}, d, \bar{d}, s, \bar{s}$
- LO 2↔2 elastic scatterings & 1↔2 inelastic scatterings





Arnold, Moore, Yaffe, JHEP01 (2003) 030
Arnold, Moore, Yaffe, JHEP0206 (2002) 030
Kurkela, Mazeliauskas, PRD99 (2019) 054018

Application to HICs

- Boost-invariant simulation with Bjorken flow at pre-equilibrium stage of HICs
- Color Glass Condensate inspired initial state (over-occupied & gluon saturated)

XD, Schlichting, PRD104(2021)054011
XD, Schlichting, PRL127(2021)122301

Hydrodynamization of QGP

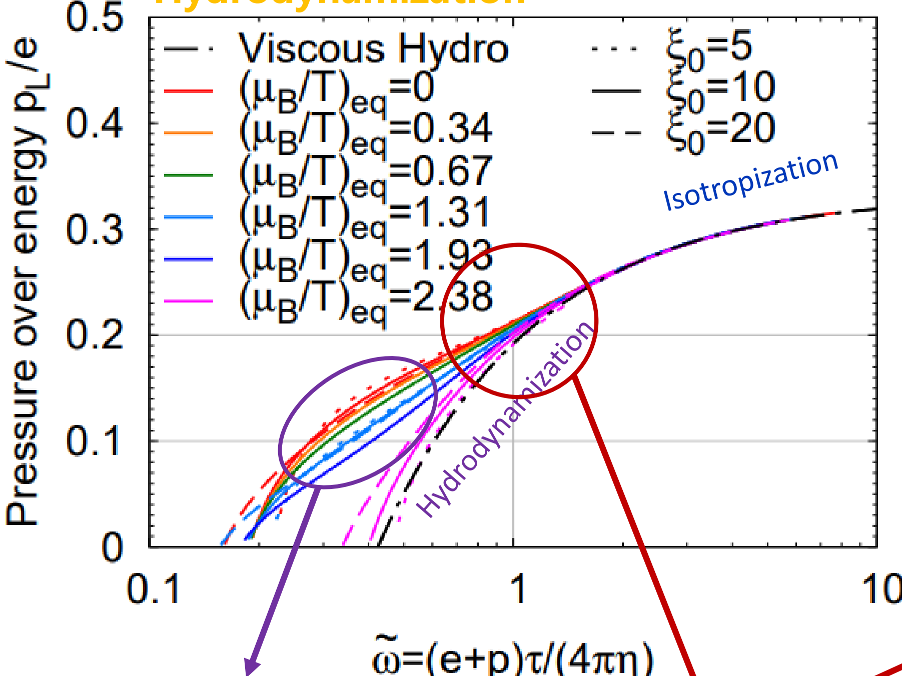
Kinetic equilibration

- First-order hydrodynamics

$$\frac{p_L}{e} = \frac{1}{3} - \frac{4}{9\pi\tilde{\omega}} \qquad \tilde{\omega} = \frac{(e+p)\tau}{4\pi\eta}$$

Universal time scale

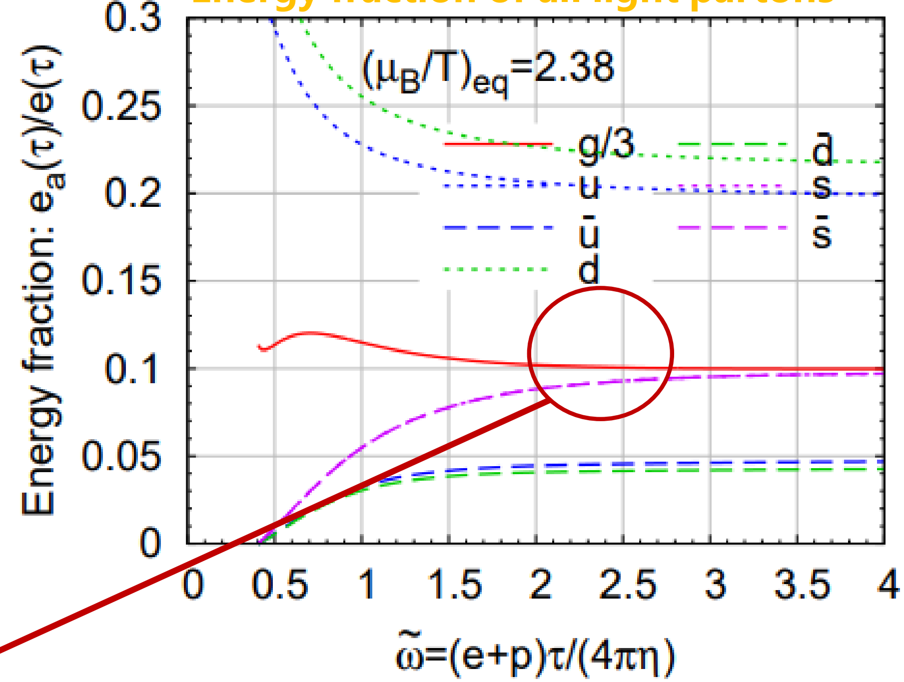
Hydrodynamization



Chemical equilibration

- Fractions of gluon/quark/antiquark evolve to equilibrium value

Energy fraction of all light partons



Quarks slow down equilibration

Chemical equilibration persists after kinetic equilibration (hydrodynamization)

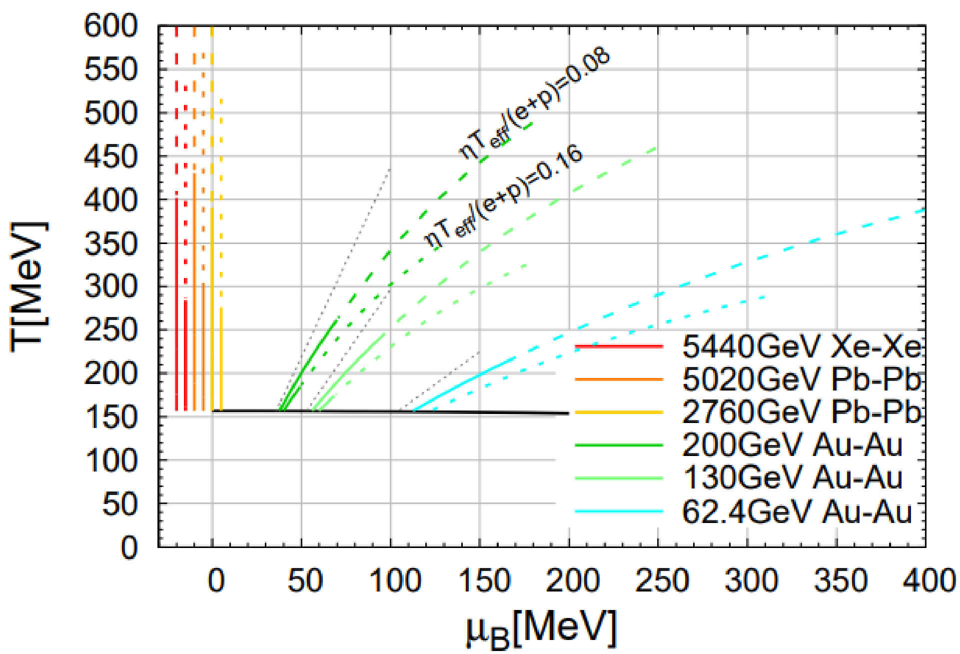
XD, Schlichting, PRL127(2021)122301

Pre-equilibrium QGP in HICs

Pre-equilibrium QGP evolution

- Pre-equilibrium description connects initial states to hydrodynamics in HICs

$$\left(\tau^{4/3}e\right)_{\tilde{\omega}} = \left(4\pi\frac{\eta T_{eff}}{e+p}\right)^{\frac{4}{9}}\left(\frac{\pi^2}{30}\nu_{eff}\right)^{\frac{1}{9}}(\tau e)_0^{\frac{8}{9}} C_\infty \mathcal{E}(\tilde{\omega}) \qquad \left(\tau\Delta n_f\right)_{\tilde{\omega}} = \left(\tau\Delta n_f\right)_0$$



QGP trajectory in QCD T-μ diagram

More phenomenology

- Chemical equilibration important

Quark production
before or even during hydro period

- Electromagnetic probes in pre-equilibrium stage, see

M. Coquet
Poster Session 2 T05 / T13 Apr 6

XD, Schlichting, PRL127(2021)122301

Conclusions & Outlook

Conclusions:

- We develop a QCD kinetic solver at finite net-baryon density
- We discuss both kinetic and chemical equilibration of QGP in HICs
- Chemical equilibration is essential to phenomenology in the early stage of HICs

Outlook:
Propagation of space-time perturbation

- Linearized Effective Kinetic Theory to calculate energy-momentum tensor

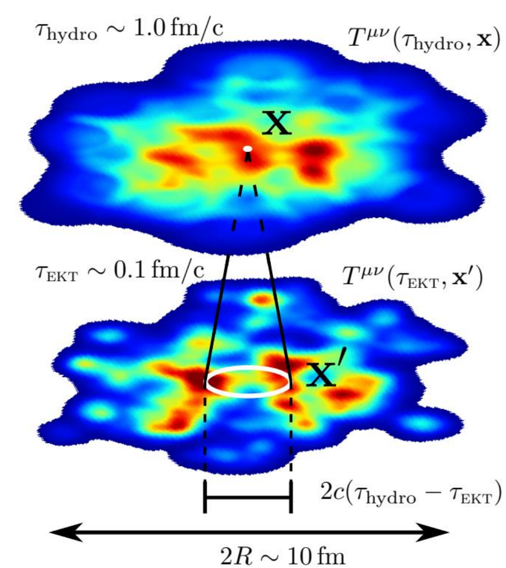
$$T^{\mu\nu}(\tau_{\mathrm{EKT}}, \mathbf{x}') = \boxed{\overline{T}^{\mu\nu}_{\mathbf{x}}(\tau_{\mathrm{EKT}})} + \boxed{\delta T^{\mu\nu}_{\mathbf{x}}(\tau_{\mathrm{EKT}}, \mathbf{x}')}$$

Background | Perturbation

EKT | Linearized EKT

- Charge fluctuation in QCD plasma

XD, Schlichting, in progress

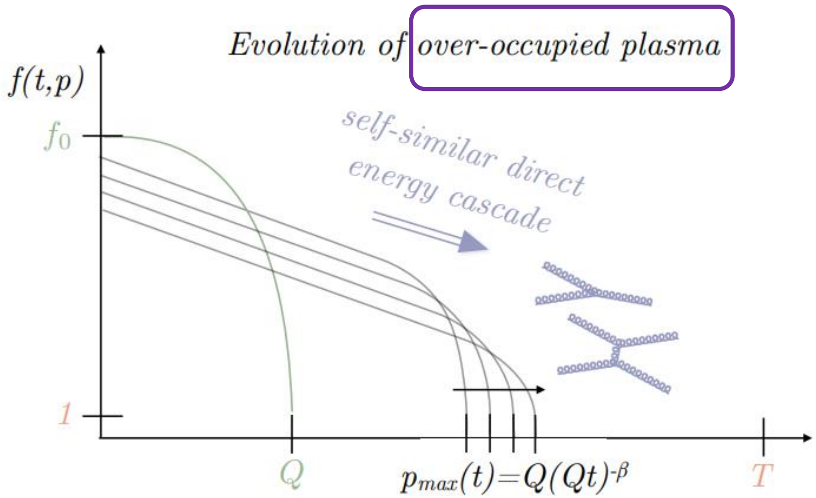


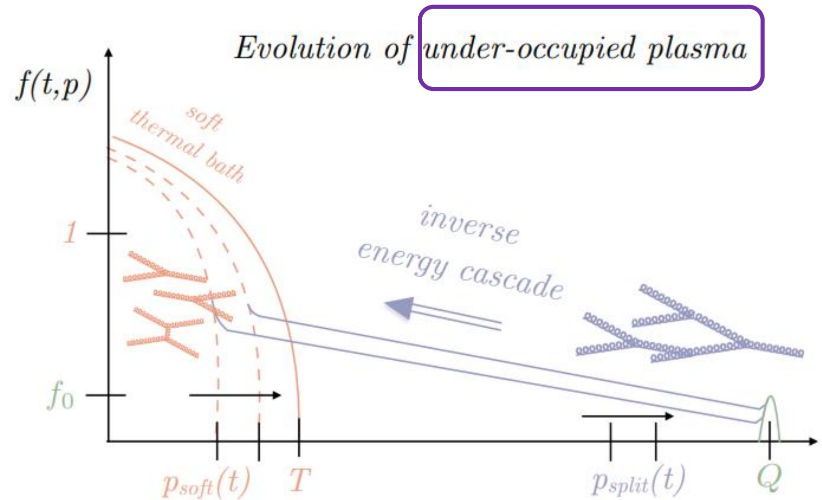
Supplementary slides

Turbulence

Equilibration of QCD plasmas

Two typical far-from-equilibrium systems





Over-occupied plasma

- Separation of scale

  $\langle p\rangle_0 \ll T$

- Direct energy cascade

  low → high momentum

- **Initial state in HICs**

Under-occupied plasma

- Separation of scale

  $\langle p\rangle_0 \gg T$

- Inverse energy cascade

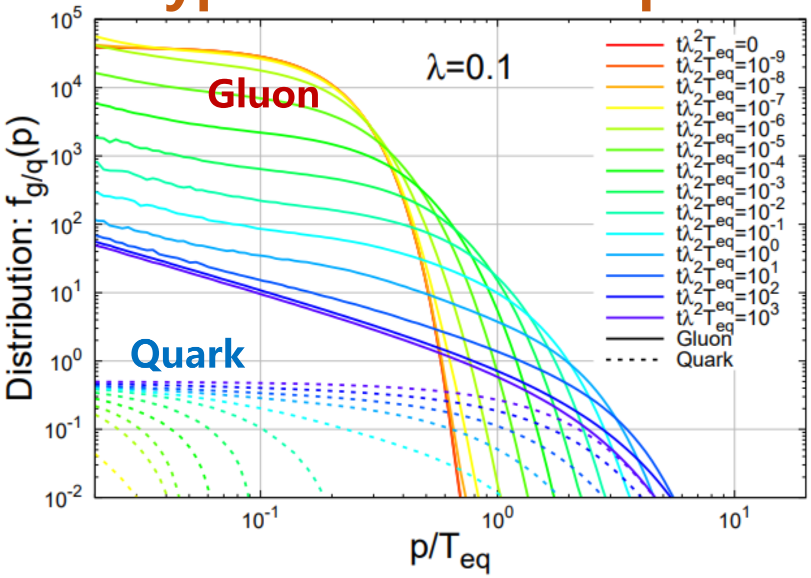
  high → low momentum

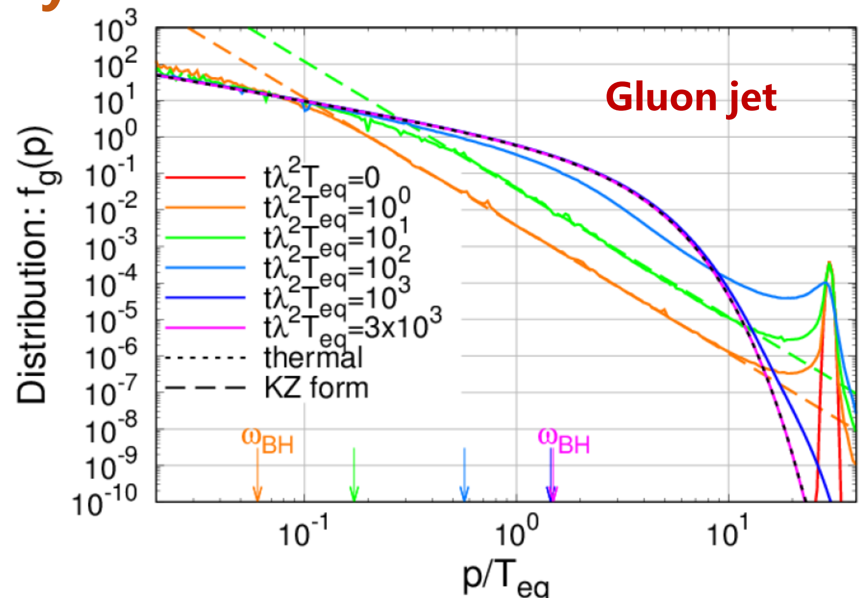
- **Jets in HICs**

Schlichting, Teaney, ARNPS 69 (2019) 447

Equilibration of QCD plasmas

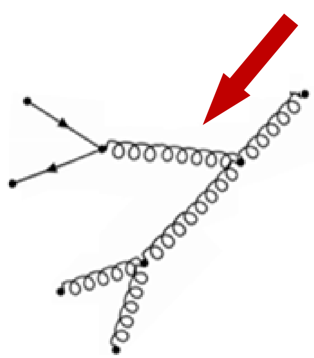
Two typical far-from-equilibrium systems





Over-occupied plasma

- Self-similar evolution of QCD plasma



Under-occupied plasma

- Kolmogorov-Zakharov spectrum (orange, green)
- Bottom-up thermalization

XD, Schlichting, PRD104(2021)054011