Hydrodynamics for Relativistic Heavy-Ion Collisions

DEPARTMENT OF PHYSICS

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Collaboration

11th Korean Nuclear Physics School
June 24-28, 2013

References:

arXiv:nucl-th/0305084 (Kolb, UH)
arXiv:hep-ph/0407360 (UH)
arXiv:nucl-th/0512049 (UH)
PRC 73 (2006) 034904 (UH, Song, Chaudhuri)
PLB 658 (2008) 278 (Song, UH)
PRC 77 (2008) 064901 (Song, UH)
PRC 78 (2008) 024902 (Song, UH)
arXiv:0901.4355 (UH)
PRC 81 (2009) 024905 (Song, UH)
PRL 106 (2011) 192301 (Song, Bass, UH, Hirano, Shen)
PRC 83 (2011) 024912 (Song, Bass, UH)
arXiv:1108.5323 (UH, Shen, Song)
arXiv:1204.1473 (Martinez, Ryblewski, Strickland)
arXiv:1301.2826 (UH, Snellings)

Motivation

- Relativistic viscous hydrodynamics is the backbone of dynamical modeling for heavy ion collisions at RHIC and LHC
- Needed to describe the space time evolution of the matter produced in a heavy ion collision
- Application is justified a priori by the smallness of the shear viscosity of the plasma as measured in RHIC and LHC experiments
- Canonical viscous hydrodynamics relies on a linearization around an isotropic equilibrium state
- Anisotropic viscous hydrodynamics generalizes this to a linear expansion around a spheroidally deformed (anisotropic) local momentum distribution

Three Lecture Plan

Lecture 1

- Motivation and Introduction
- Kinetic Theory vs. Hydrodynamics
- Ideal Fluid Dynamics
- Ideal Fluid Equations of Motion
- 0+1d Boost-Invariant Transversely Homogeneous Systems (Bjorken Solution)

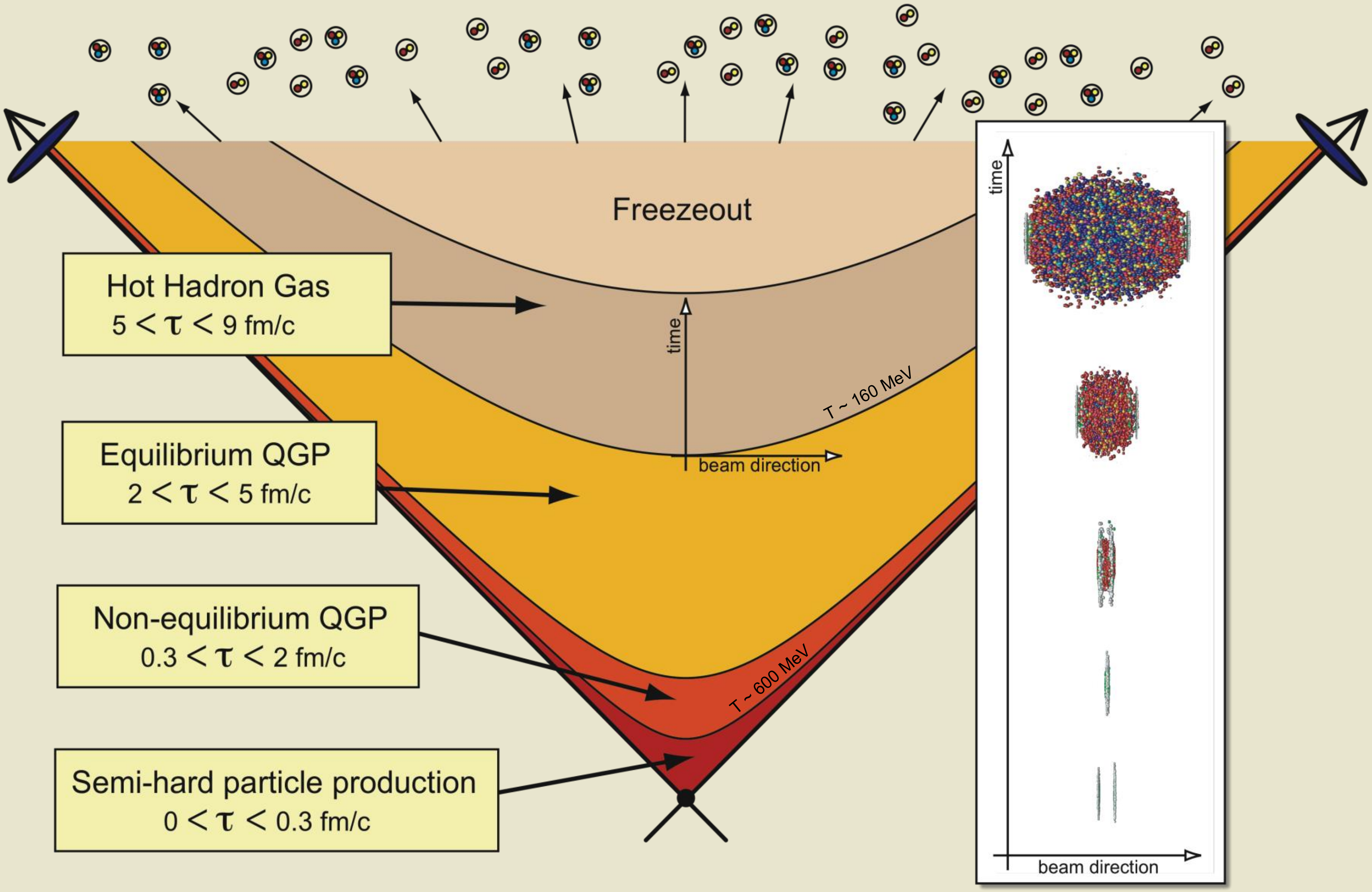
Lecture 3

- Results

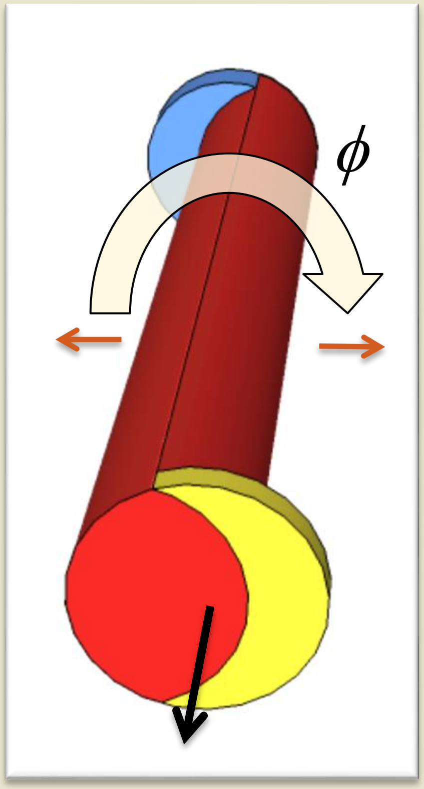
Lecture 2

- 1^{st} and 2^{nd} Order Viscous Hydro
- Limitations of Viscous Hydro
- Spheroidal Distribution
- Anisotropic $T^{\mu\nu}$
- Anisotropic Dynamics Equations
- 0+1d Limit
  → Connection to Viscous Hydro

Heavy Ion Collision Timescales



Hydro for collective flow



- During non-central collisions overlap region breaks azimuthal symmetry

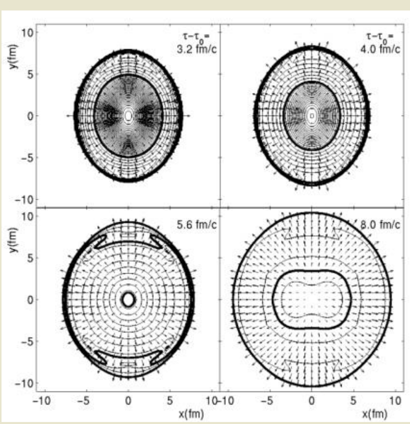
$$\frac{dN}{d\phi} = \frac{1}{2\pi}(v_0 + 2v_1\cos\phi + 2v_2\cos 2\phi + 2v_3\cos 3\phi + \ldots)$$

Directed Flow

Elliptic Flow

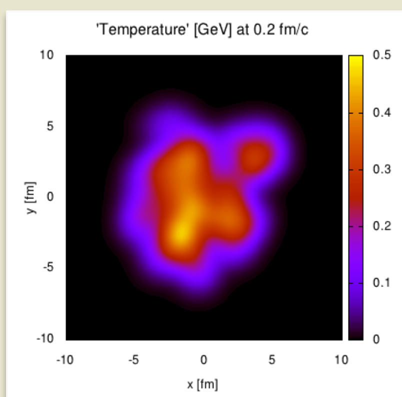
Triangular Flow

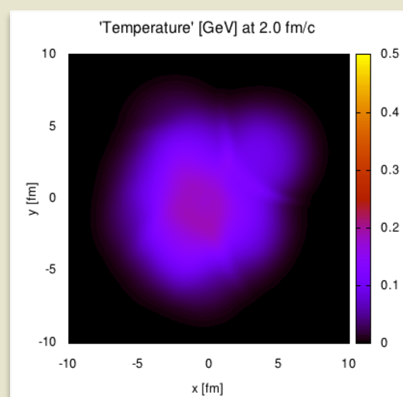
"Average" analysis

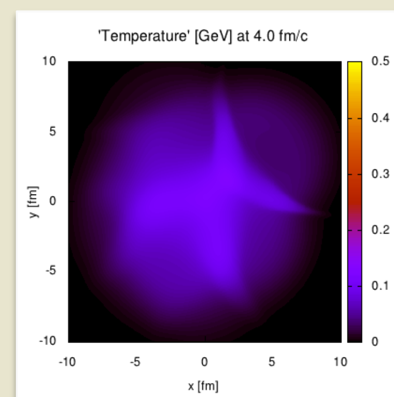


Kolb, Sollfrank, Heinz, Phys. Rev. C 62, 054909 (2000).

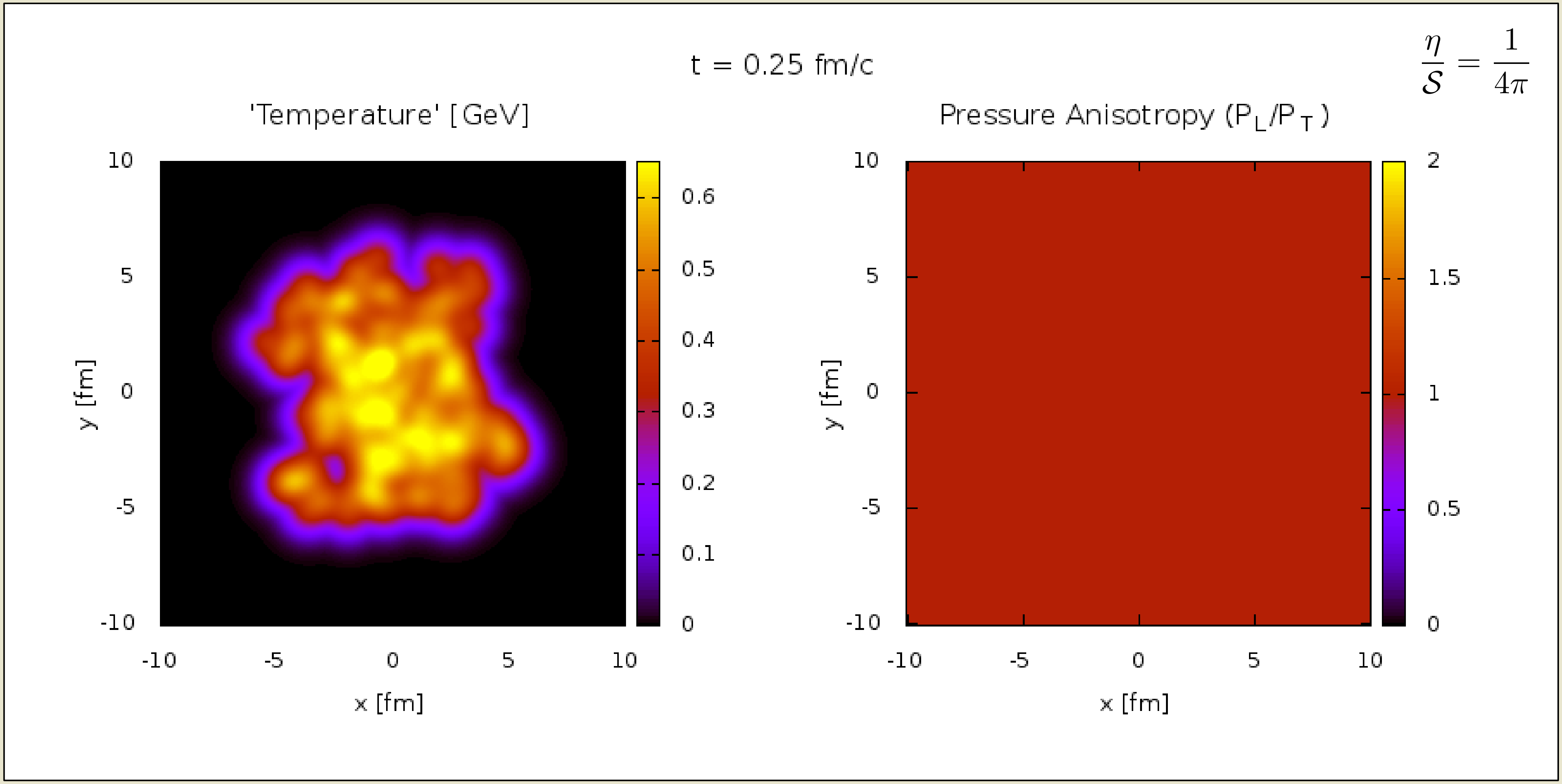
Event-by-Event analysis





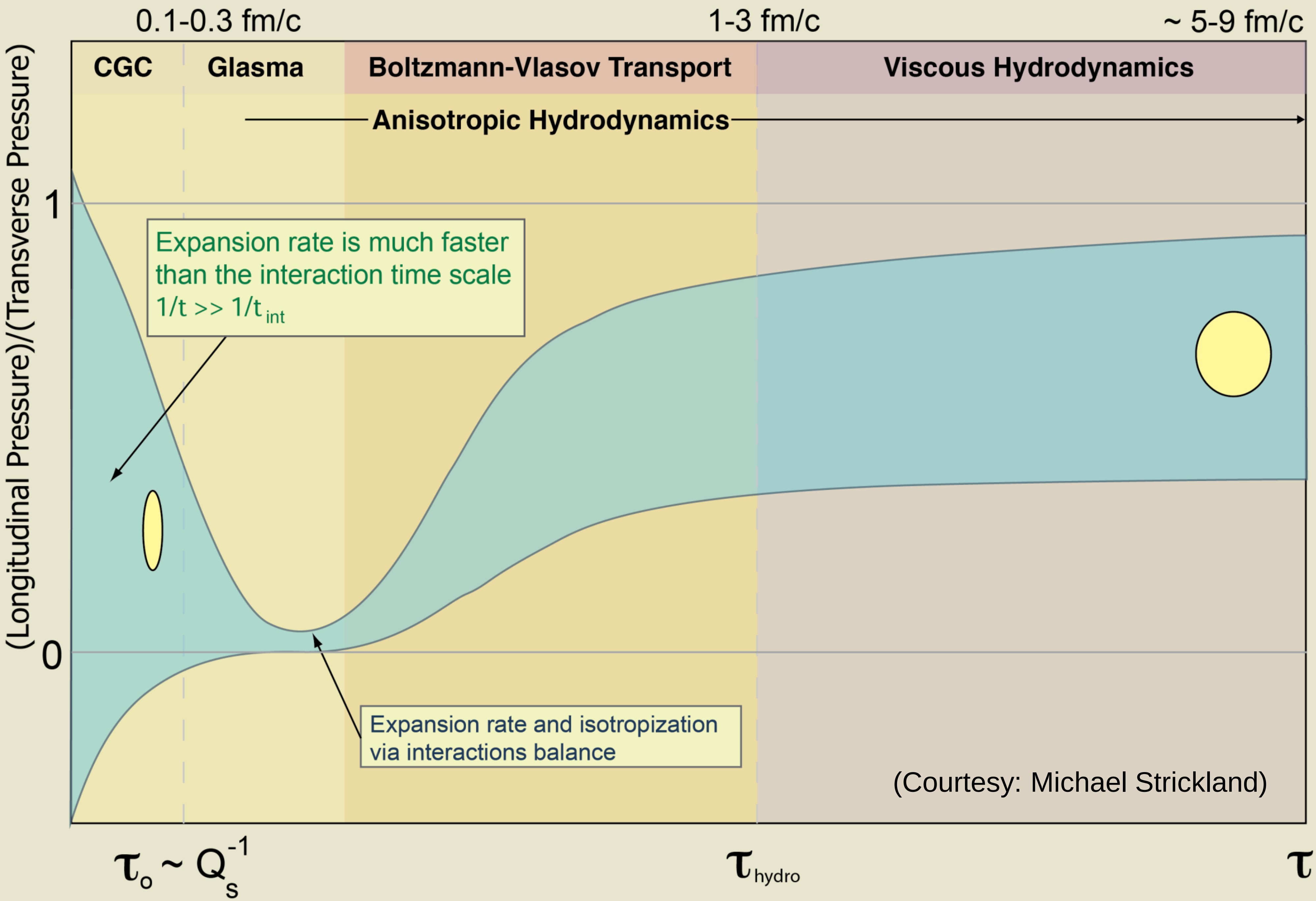


Spatiotemporal Evolution



- Pb-Pb, b = 7 fm collision with Monte-Carlo Glauber initial conditions T_0 = 600 MeV @ τ_0 = 0.25 fm/c
- Left panel shows temperature and right shows pressure anisotropy

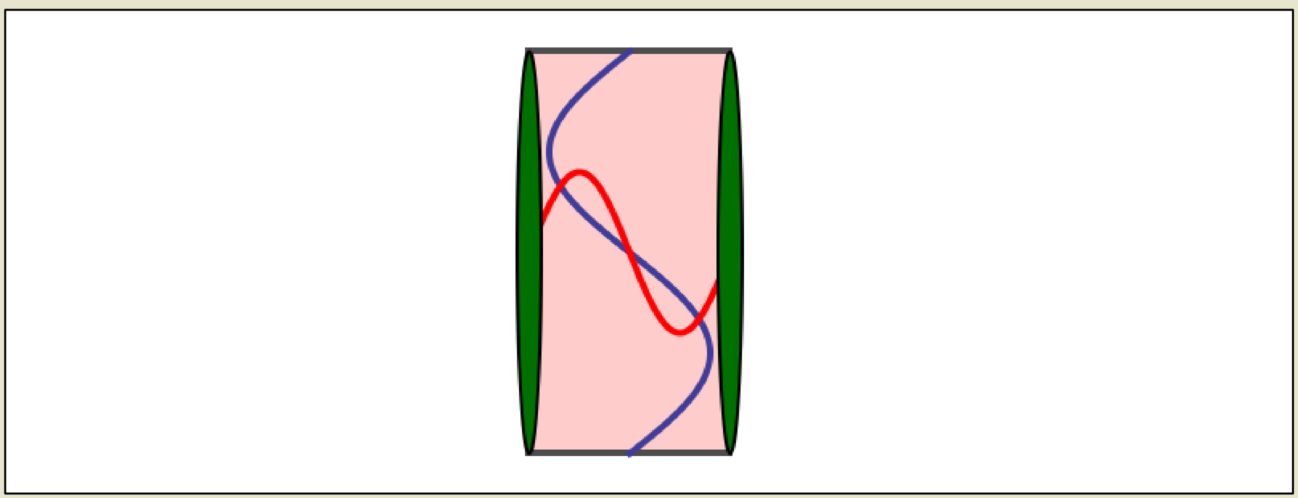
QGP momentum anisotropy



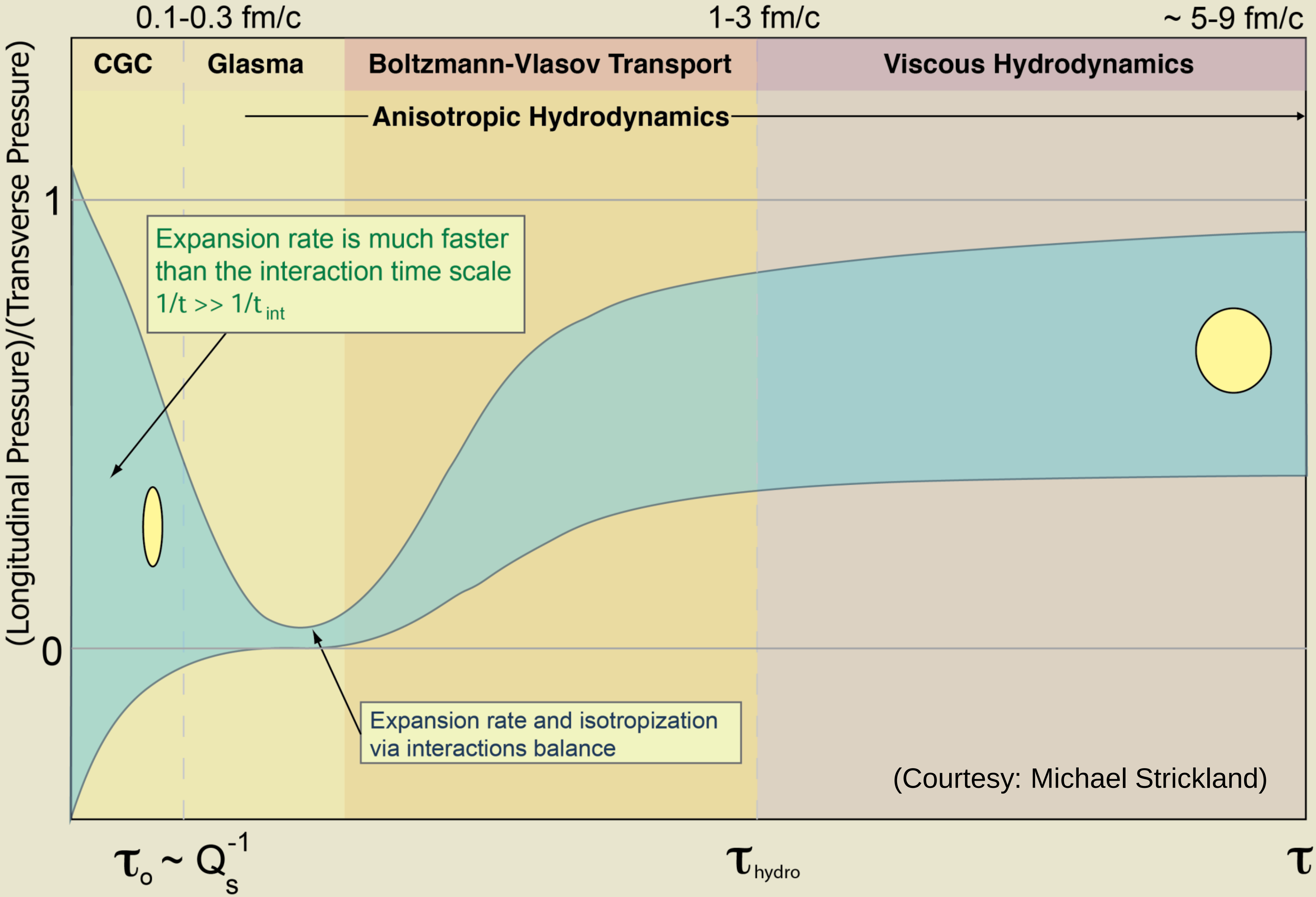
Longitudinal Expansion

- The nearly speed of light expansion of the quark gluon plasma along the beamline direction causes “longitudinal cooling” of the plasma during the first few fm/c of the plasma’s lifetime.

- One can think of the system as a tiny one-dimensionally expanding universe in which momenta are red-shifted along the beamline direction.



QGP momentum anisotropy



- Hydro From Transport -