Derek Everett
Ulrich Heinz
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3+1D Free Streaming for Pre-equilibrium Evolution

Overview

- Initial Conditions for Hydro
- Free streaming approx.
- Formalism
- First results
- Future prospects

Hydro for Heavy Ion Collisions

- Viscous Hydro evolves conserved currents .
- Applied to heavy ions, yields good agreement; e.g. particle spectra, flow harmonics, …

$$\nabla_\mu T^{\mu\nu} = 0$$

$$\nabla_\mu J_i^\mu = 0$$

Hydro requires initial conditions

$$T^{\mu\nu} = \epsilon u^\mu u^\nu - (p + \Pi)\Delta^{\mu\nu} + \pi^{\mu\nu}$$

- We have initialized hydro ad hoc when using MC Glb, TRENTO,...
- Initial flow velocity set to zero; shear stress, bulk pressure zero or N.S. values

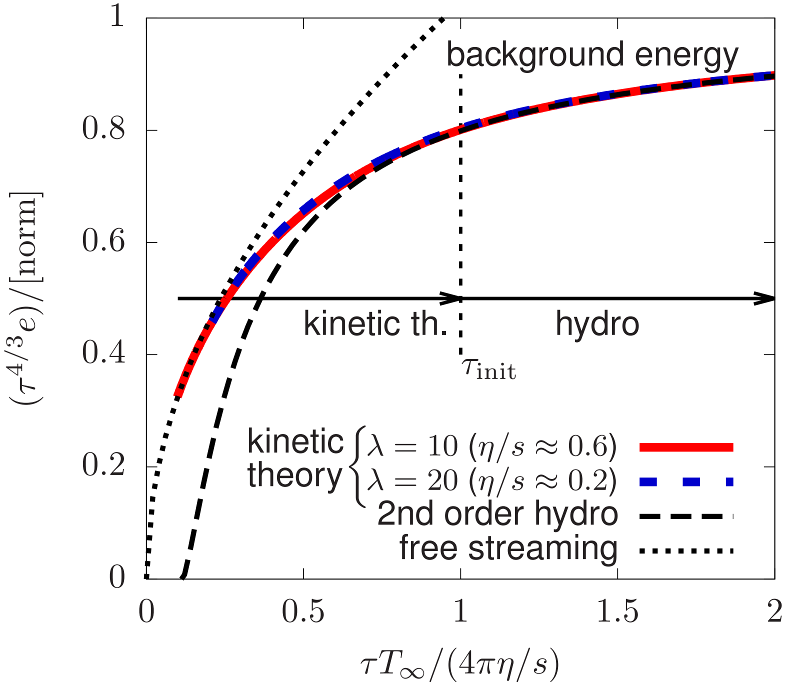
$$u_s^\mu = ?$$

$$\pi_s^{\mu\nu} = ?$$

$$\Pi_s = ?$$

Pre-equilibrium Dynamics

- Using EKT, Kurkela et al showed early dynamics ~ free streaming.
- Approximate pre-equilibrium dynamics by free streaming; then Landau match to hydro at τ_s.



*arXiv:1704.05242v1

Free Streaming Formalism

- Collisionless Boltzmann Eqn. evolves $f(\tau, \boldsymbol{x}; p)$.
- Evolve $T^{\mu\nu}$, J^{μ} w/o knowing $f(\tau_0, \boldsymbol{x}; p)$, given initial energy, baryon densities from initial state model (MC Glb, TRENTO, …)
- Possible given assumptions:
  - Massless particles
  - $f(\tau_0, \boldsymbol{x}; p)$ isotropic in $\boldsymbol{p}_T$
  - Assume dependence of $f(\tau_0, \boldsymbol{x}; p)$ on rapidity ξ

$$f(\tau_0, x, y, \eta; p_T, \xi) = \exp(\frac{(\eta - \xi)^2}{2\sigma^2}) \cdot \tilde{f}(\tau_0, x, y, \eta; p_T)$$

Free Streaming Formalism

$$T_0^{\mu\nu} \to T_s^{\mu\nu}$$

- Define a momentum dependent function $G^{\mu\nu}(x; \phi_p, \xi)$:

$$G^{\mu\nu}(x; \phi_p, \xi) \equiv \int dp_T p_T p^\mu p^\nu f(x; p)$$

$$\implies \quad T^{\mu\nu} = \frac{g}{(2\pi)^3} \int d\xi d\phi_p G^{\mu\nu}(x; \phi_p, \xi)$$

(Can define similar function for J^μ)

Free Streaming Formalism

- Solution of collisionless Boltzmann Eqn.

$$f(\tau, \mathbf{x}_T, \eta; p) =$$

$$f(\tau_0, \mathbf{x}_T - \frac{\mathbf{p}_T}{p_T}[\tau \cosh(\xi - \eta) - \tau_0 \cosh(\xi - \eta_0)], \sinh^{-1}[\frac{\tau \sinh(\eta_0 - \xi)}{\tau_0}] + \xi; p)$$

- Free stream function $G^{\mu\nu}$, then integrate out momenta to find $T^{\mu\nu}(\tau, \boldsymbol{x})$.

$$G^{\mu\nu}(\tau, \mathbf{x}_T, \eta; p) =$$

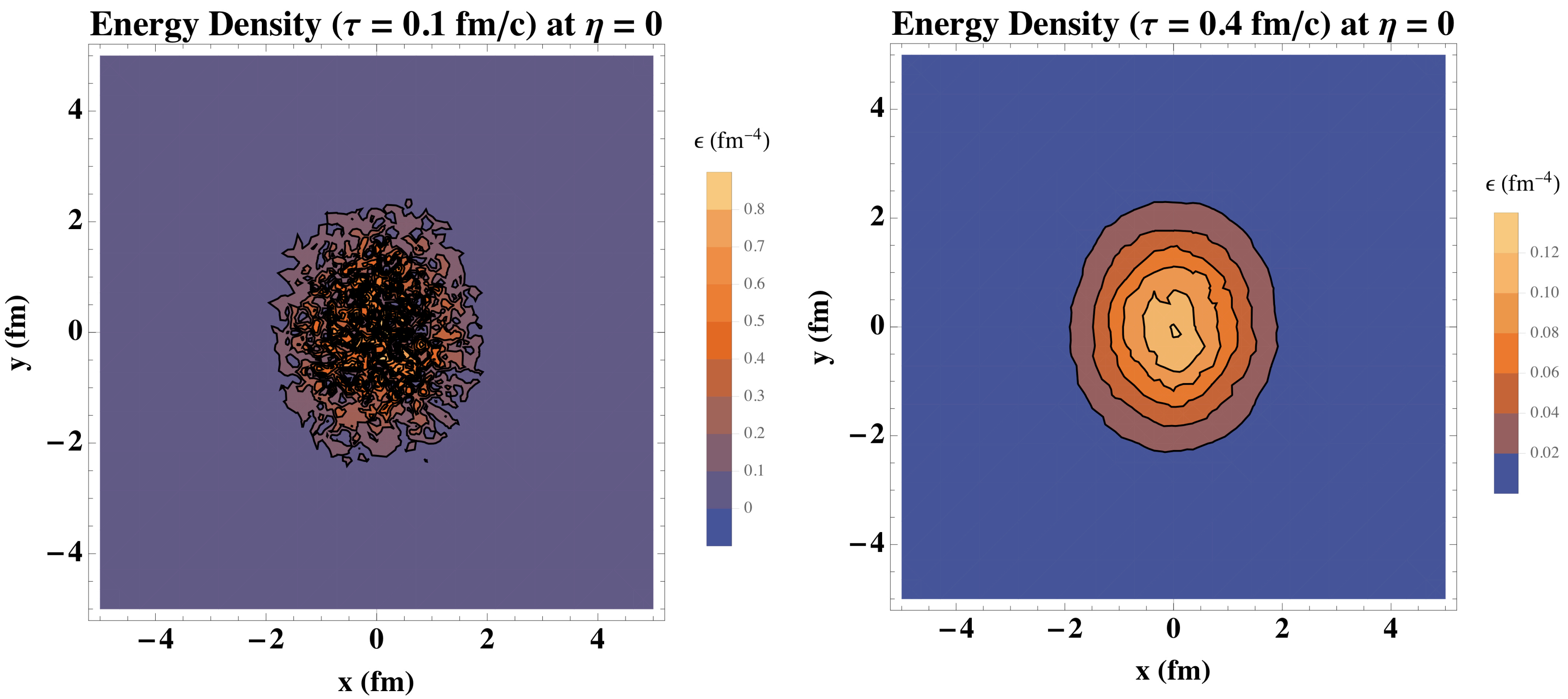
$$G^{\mu\nu}(\tau_0, \mathbf{x}_T - \frac{\mathbf{p}_T}{p_T}[\tau \cosh(\xi - \eta) - \tau_0 \cosh(\xi - \eta_0)], \sinh^{-1}[\frac{\tau \sinh(\eta_0 - \xi)}{\tau_0}] + \xi; p)$$

Landau Matching at τ_s

- Solve eig. problem $$T^{\mu}{}_{\nu} u^{\nu} = \epsilon u^{\mu}$$
- Use E.o.S. $$p = p(\epsilon)$$
- Find bulk, shear stress

$$T^{\mu\nu} = \epsilon u^{\mu} u^{\nu} - (p + \Pi)\Delta^{\mu\nu} + \pi^{\mu\nu}$$

Results of 3+1D free streaming



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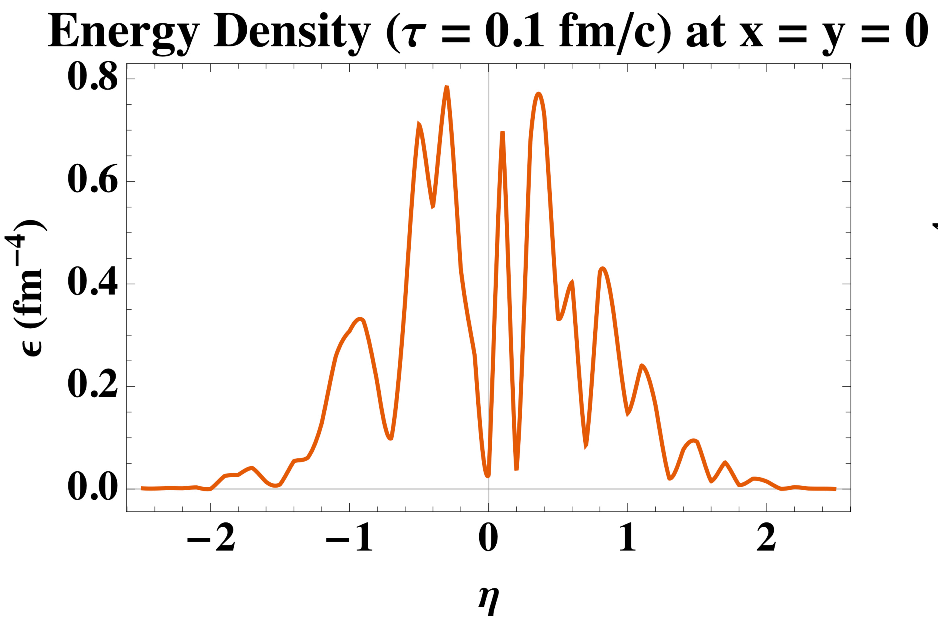

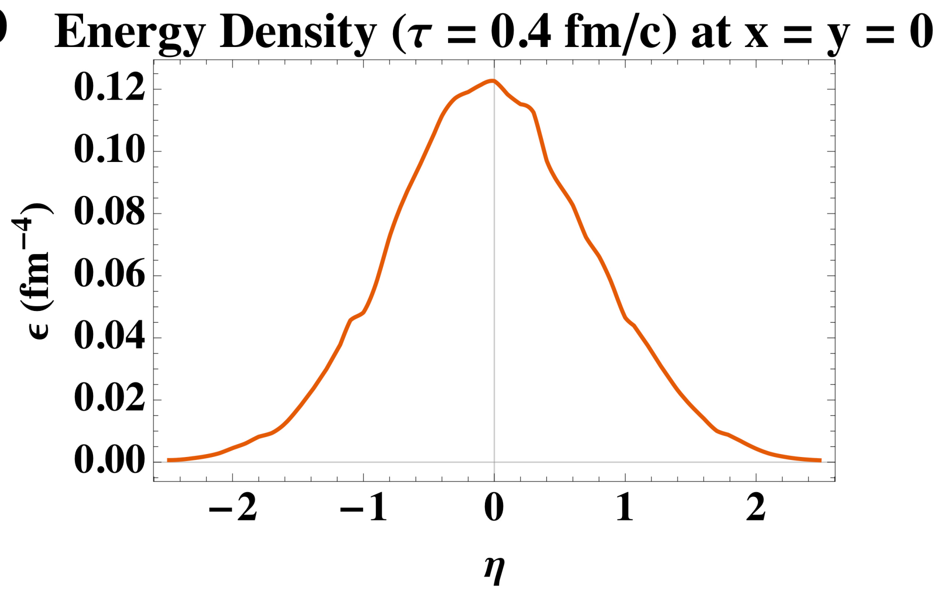

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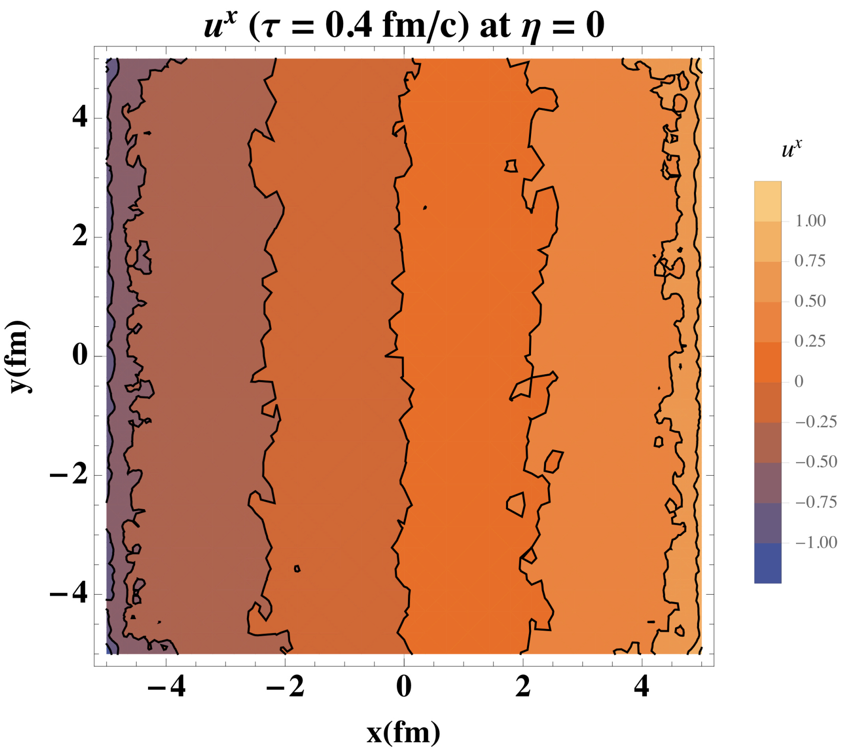

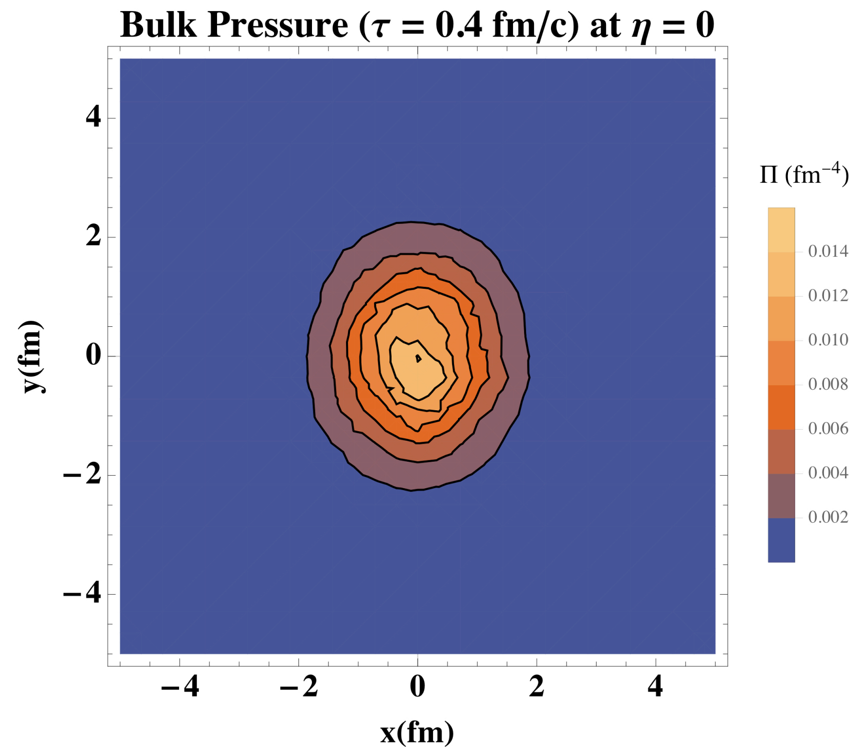

Coming soon

- 3+1D OSU Hydro (with F.O. and Cooper Frye) on CPU/GPU
- Effects of 3D Free Streaming on Hydro/Spectra

Thank You

More Results