Is early isotropization in heavy ion collisions a necessary condition to describe HIC data?

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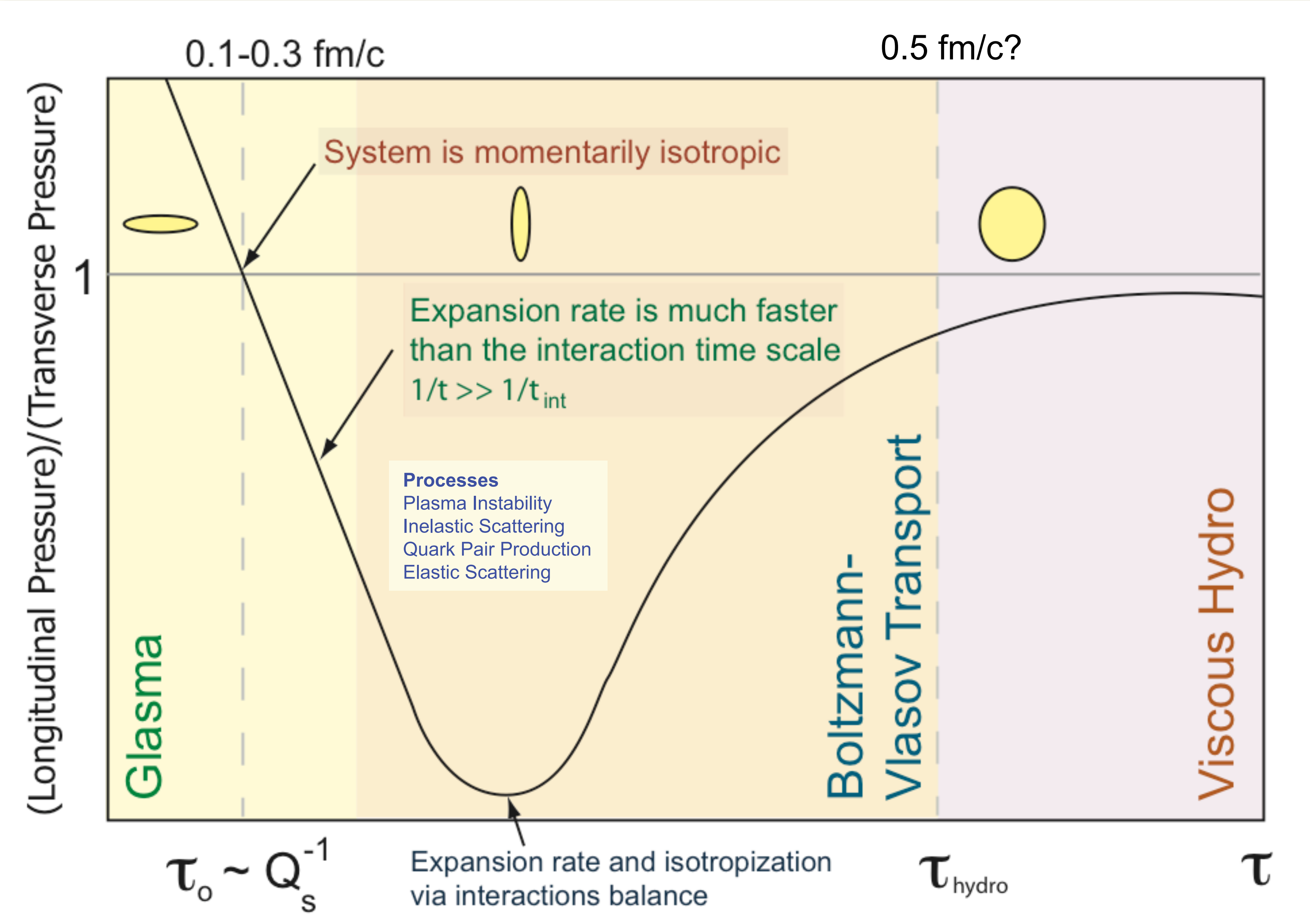
Gettysburg COLLEGE

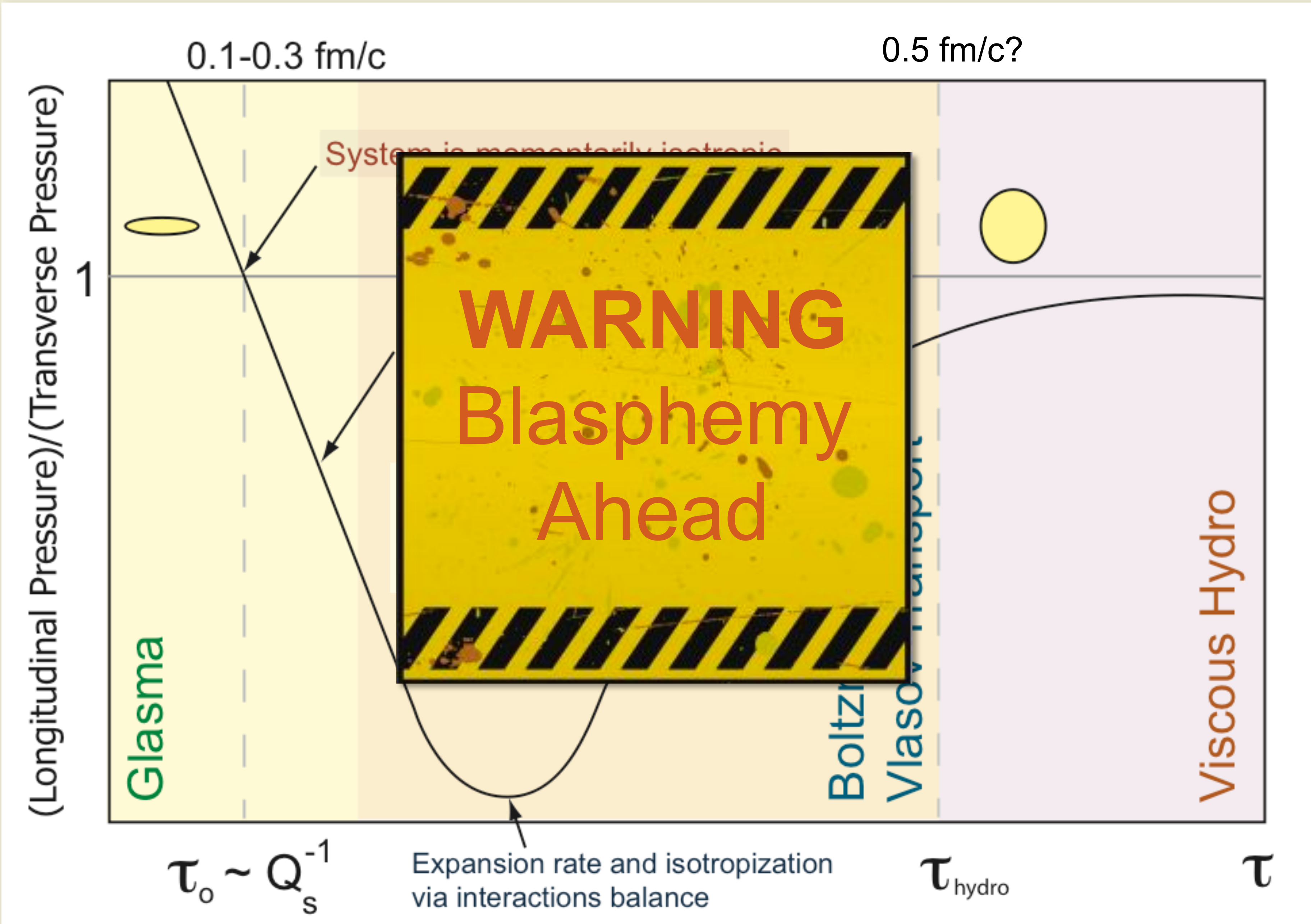
NSF

HIC for FAIR
Helmholtz International Center

QGP momentum anisotropy



QGP momentum anisotropy



Come ye of little faith …

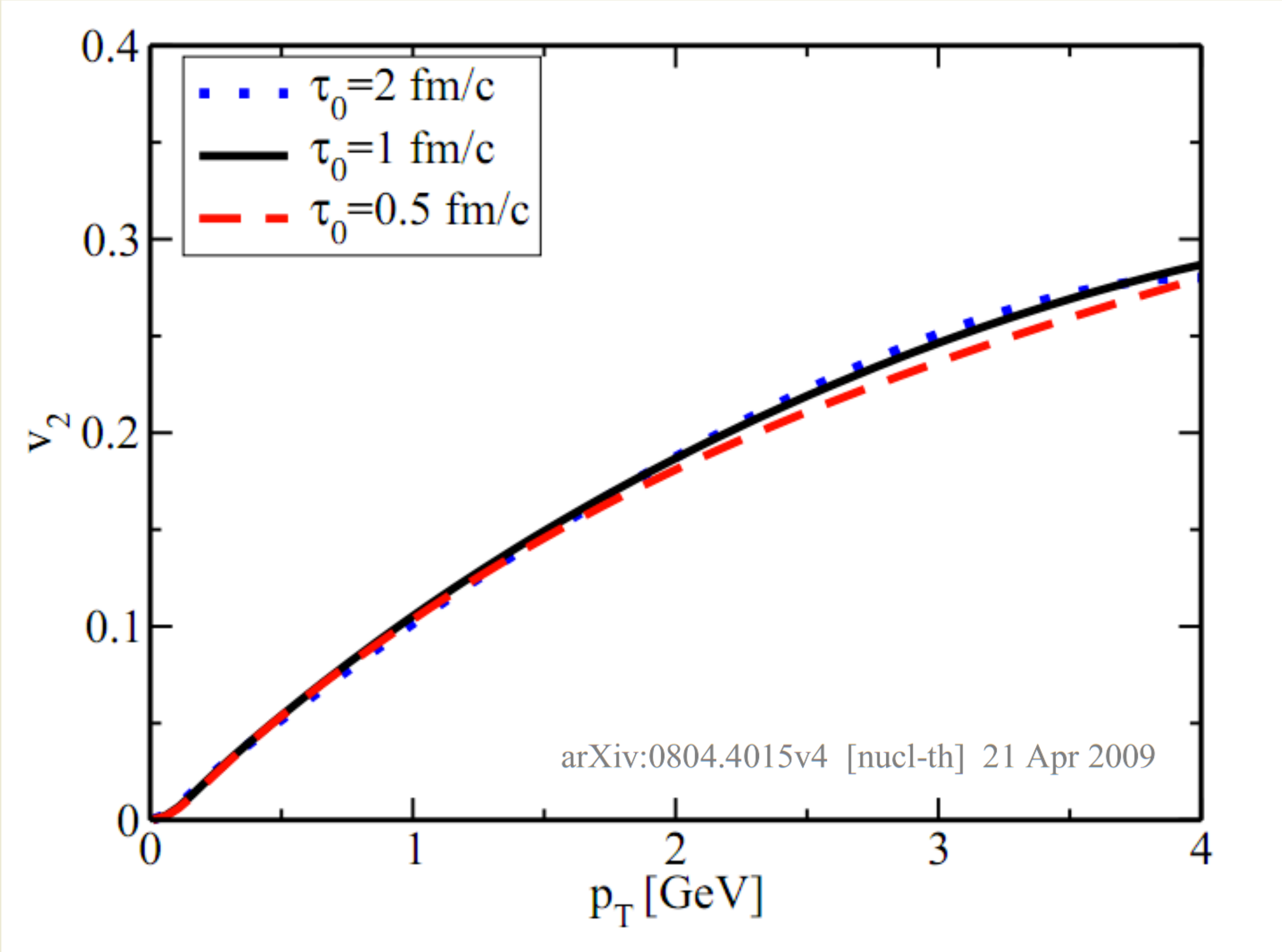
- It has been taken as gospel that agreement with experimental data for elliptic flow requires early isotropization/thermalization at times on the order of 0.5 fm/c.

- Is that true within viscous hydro?

- Let's ask some experts…

Conformal Relativistic Viscous Hydrodynamics: Applications to RHIC results at $\sqrt{s_{NN}} = 200$ GeV

Matthew Luzum[1] and Paul Romatschke[2]

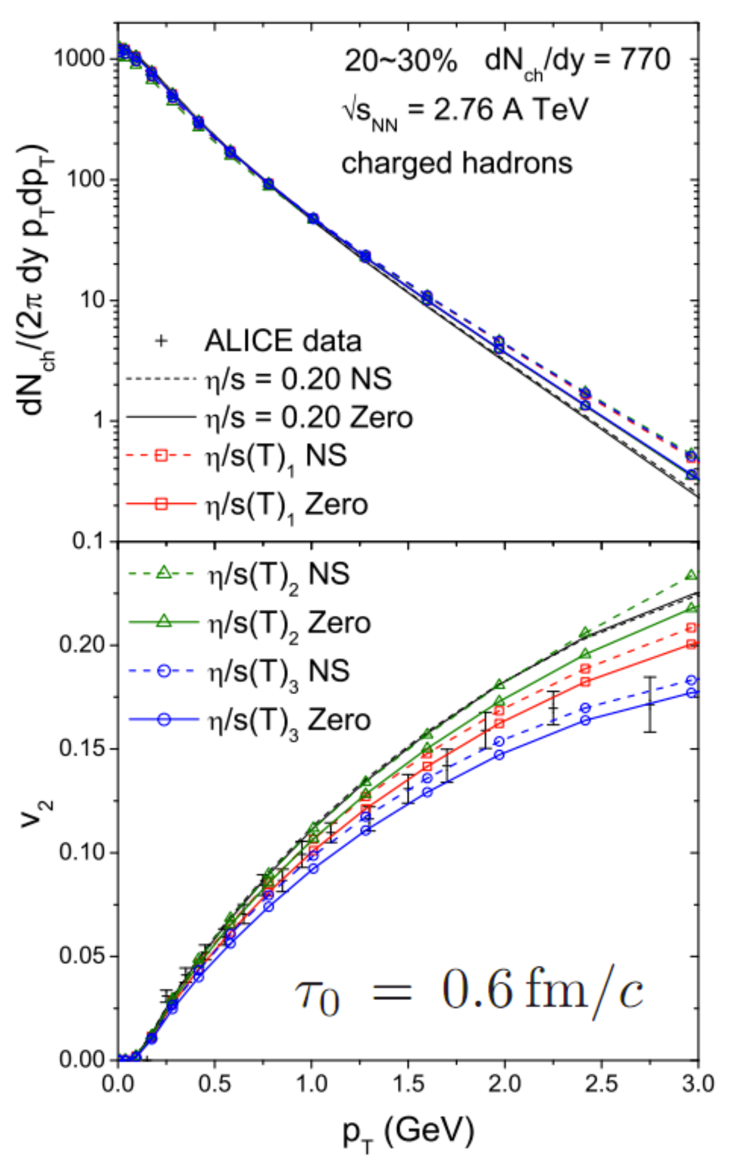


Simulation parameters were $T_i = 0.29$ GeV, $T_f = 0.14$ GeV for $\tau_0 = 2$ fm/c, $T_i = 0.36$ GeV, $T_f = 0.15$ GeV for $\tau_0 = 1$ fm/c, and $T_i = 0.43$ GeV, $T_f = 0.16$ GeV for $\tau_0 = 0.5$ fm/c.

Radial and elliptic flow in Pb+Pb collisions at the Large Hadron Collider from viscous hydrodynamics

Chun Shen,[1,*] Ulrich Heinz,[1,†] Pasi Huovinen,[2,‡] and Huichao Song[3,§]

arXiv:1105.3226v2 [nucl-th] 9 Sep 2011



η/s model	$\pi_0^{\mu\nu}$	s_0 (fm^{-3})	T_0 (MeV)
$\eta/s = 0.2$	0	191.6	427.9
	NS	172.4	413.9
$(\eta/s)_1(T)$	0	179.6	419.2
	NS	119.3	368.7
$(\eta/s)_2(T)$	0	179.6	419.2
	NS	115.6	365.1
$(\eta/s)_3(T)$	0	175.2	416.0
	NS	116.6	366.1

NS = Navier Stokes

$$\xi = \frac{\langle p_T^2 \rangle}{2\langle p_L^2 \rangle} - 1 \qquad \xi_{\rm NS} = \frac{10}{T\tau}\frac{\eta}{\mathcal{S}}$$

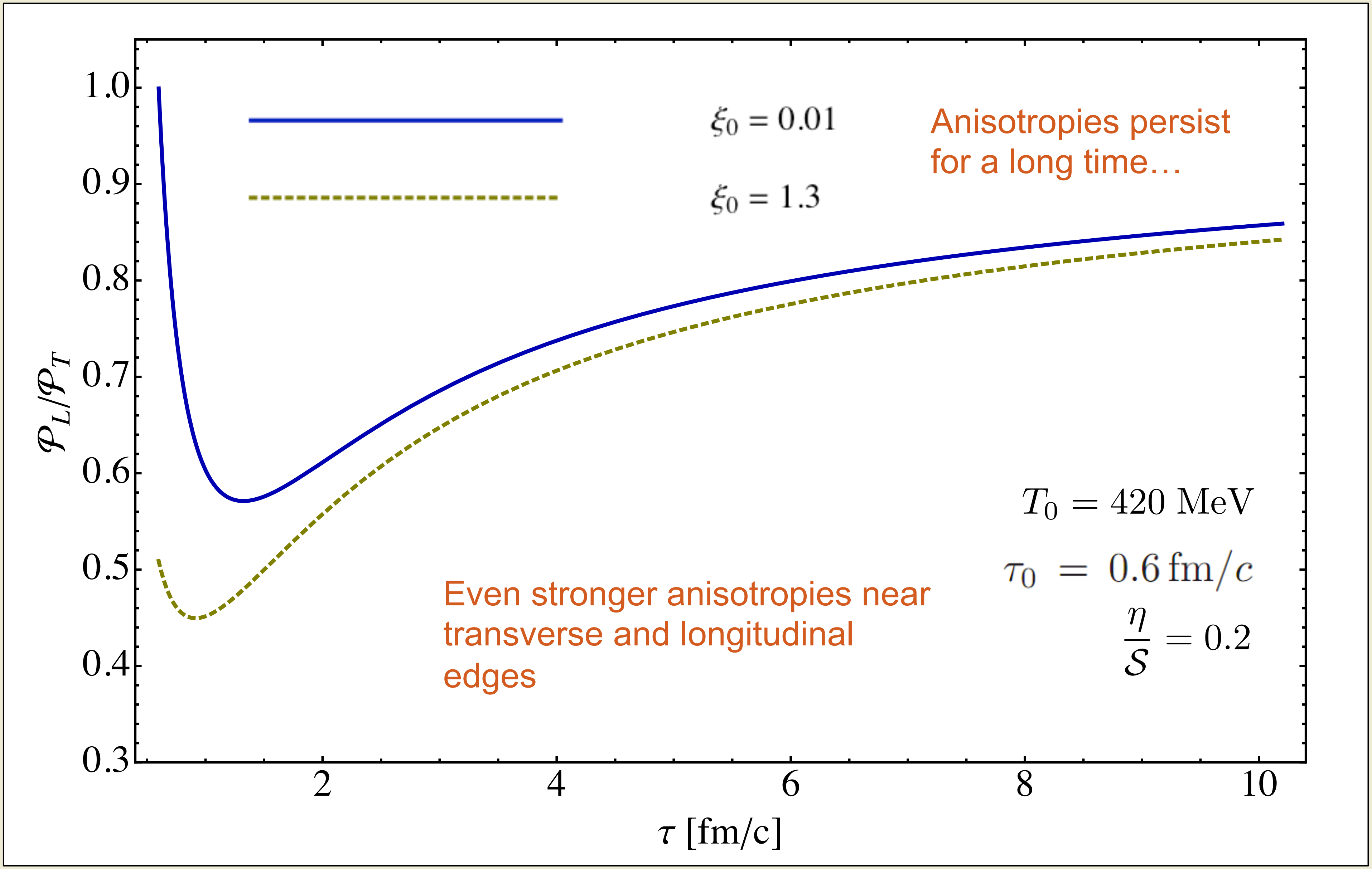
Using values from the paper I obtain

$$\xi_{0,\rm NS} \simeq 1.3$$

Which corresponds to

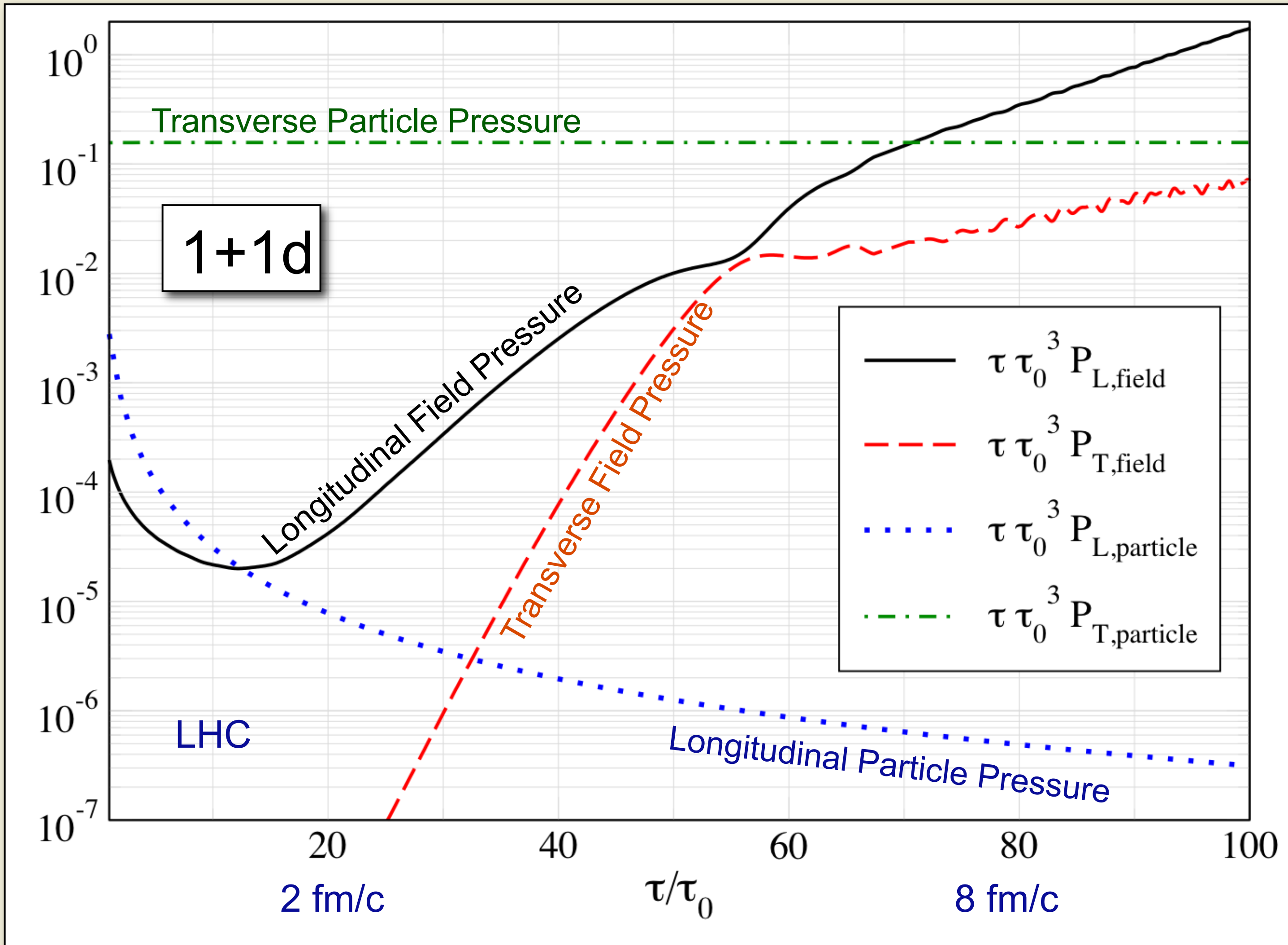
$$\mathcal{P}_L/\mathcal{P}_T \simeq 0.51$$

Pressure Anisotropy as a Function of Time



Hard loops in a free streaming background

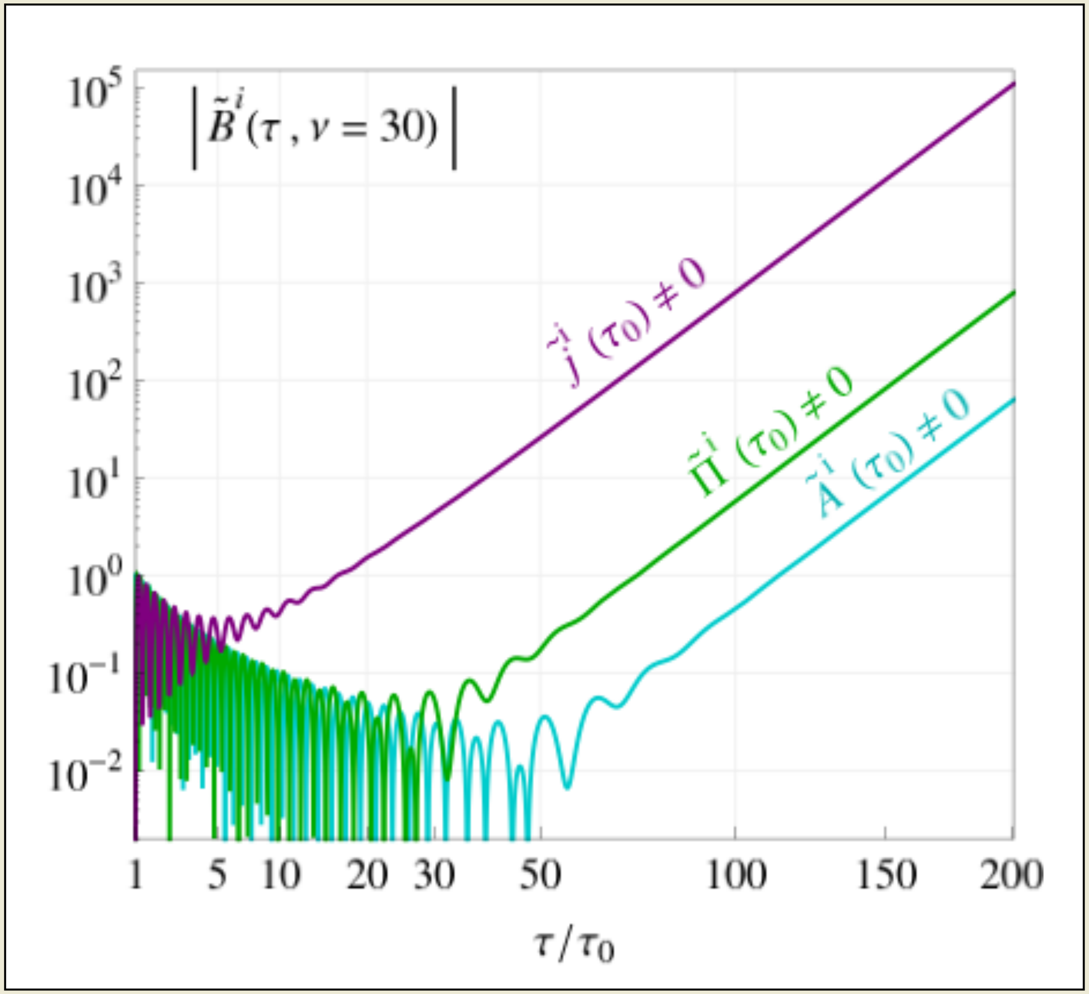
Particle and field pressures → Isotropization [Rebhan, Strickland, and Attems, 2008]



3+1d results forthcoming! [Attems, Rebhan, Strickland 2012] Requires 5d Lattice Calc ~> 96^5!

HEL - Different Initial Conditions

Rebhan and Steineder (2009) have shown the onset of unstable growth is accelerated dramatically if one has current fluctuations in the initial condition.



Start over from scratch

Viscous Hydrodynamics Expansion

$$f(\mathbf{x},\mathbf{p},\tau) = \underbrace{f_{\rm eq}(|\mathbf{p}|,T(\tau))}_{\text{Isotropic in momentum space}} + \delta f_1 + \delta f_2 + \cdots$$

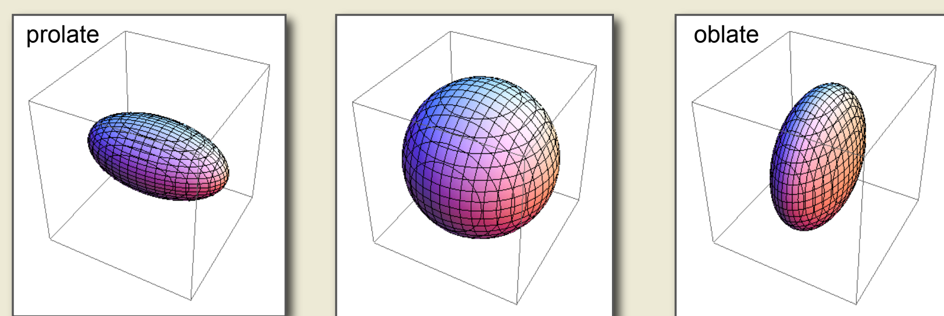
Anisotropic Hydrodynamics (AHYDRO) Expansion

$$f(\mathbf{x},\mathbf{p},\tau) = f_{\rm aniso}(\mathbf{p},p_{\rm hard}(\tau),\xi(\tau)) + \delta f_1' + \delta f_2' + \cdots$$

M. Martinez and MS, Nuclear Physics A 848, 183 (2010).

$$\xi = \frac{\langle p_T^2 \rangle}{2\langle p_L^2 \rangle} - 1$$

$$\begin{aligned} f(\tau,\mathbf{x},\mathbf{p}) &= f_{RS}(\mathbf{p},\xi(\tau),p_{\rm hard}(\tau)) \\ &= f_{\rm iso}\left([\mathbf{p^2} + \xi(\tau)p_z^2]/p_{\rm hard}^2(\tau)\right) \end{aligned}$$



$-1 < \xi < 0$ $\quad$ $\xi = 0$ $\quad$ $\xi > 0$

Using relaxation-time approximation scattering kernel gives in 1d

0th Moment of Boltzmann EQ

$$\partial_\alpha N^\alpha \neq 0$$

$$\frac{1}{1+\xi}\partial_\tau \xi - \frac{2}{\tau} - \frac{6}{p_{\rm hard}}\partial_\tau p_{\rm hard} = 2\Gamma\left[1 - \mathcal{R}^{3/4}(\xi)\sqrt{1+\xi}\right]$$

1st Moment of Boltzmann EQ

$$\partial_\alpha T^{\alpha\beta} = 0$$

$$\frac{\mathcal{R}'(\xi)}{\mathcal{R}(\xi)}\partial_\tau \xi + \frac{4}{p_{\rm hard}}\partial_\tau p_{\rm hard} = \frac{1}{\tau}\left[\frac{1}{\xi(1+\xi)\mathcal{R}(\xi)} - \frac{1}{\xi} - 1\right]$$

M. Martinez and MS, Nuclear Physics A 848, 183 (2010).

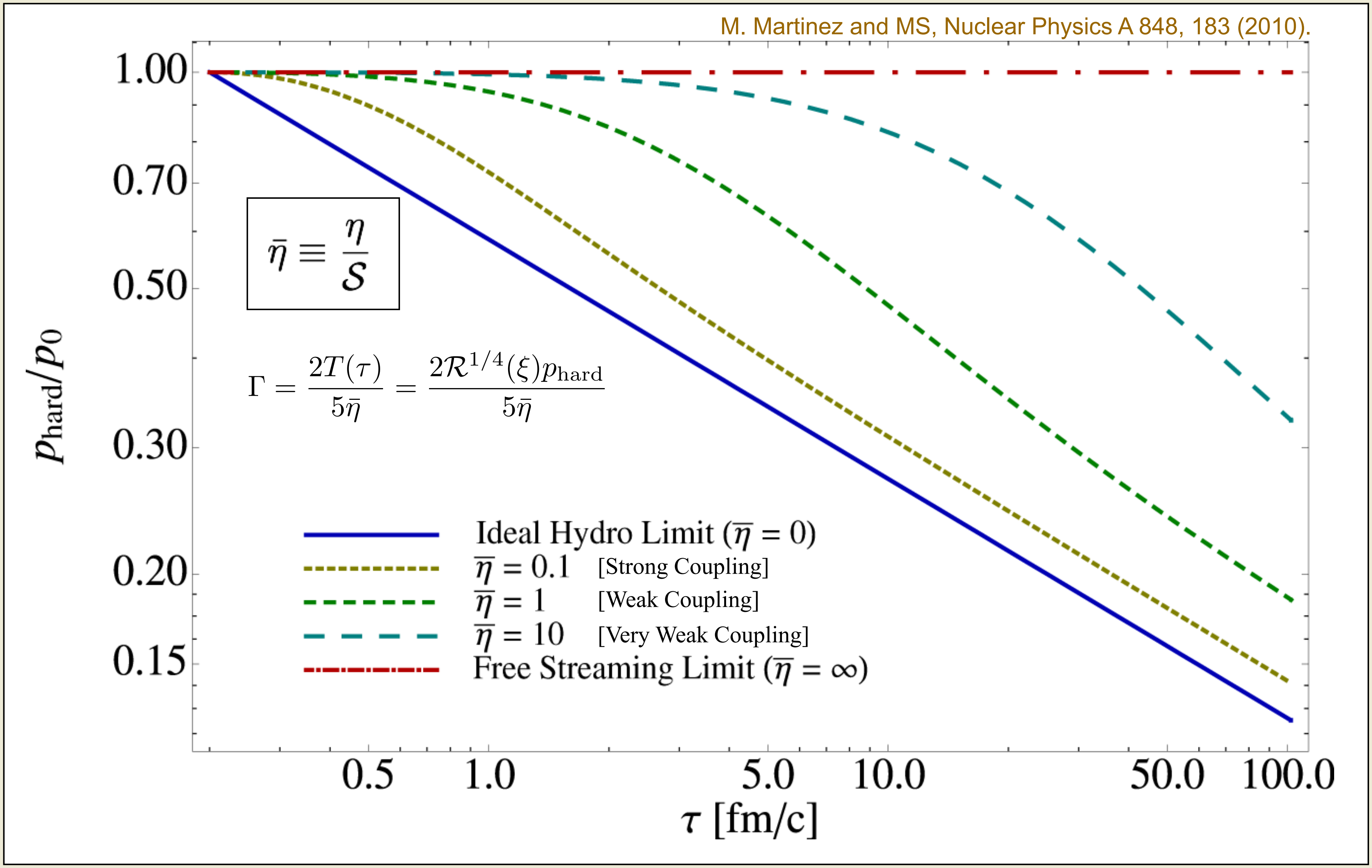
where

$$\mathcal{R}(\xi) \equiv \frac{1}{2}\left(\frac{1}{1+\xi} + \frac{\arctan\sqrt{\xi}}{\sqrt{\xi}}\right) \qquad \Gamma = \frac{2T(\tau)}{5\bar{\eta}} = \frac{2\mathcal{R}^{1/4}(\xi)p_{\rm hard}}{5\bar{\eta}}$$

Hard Momentum vs Time

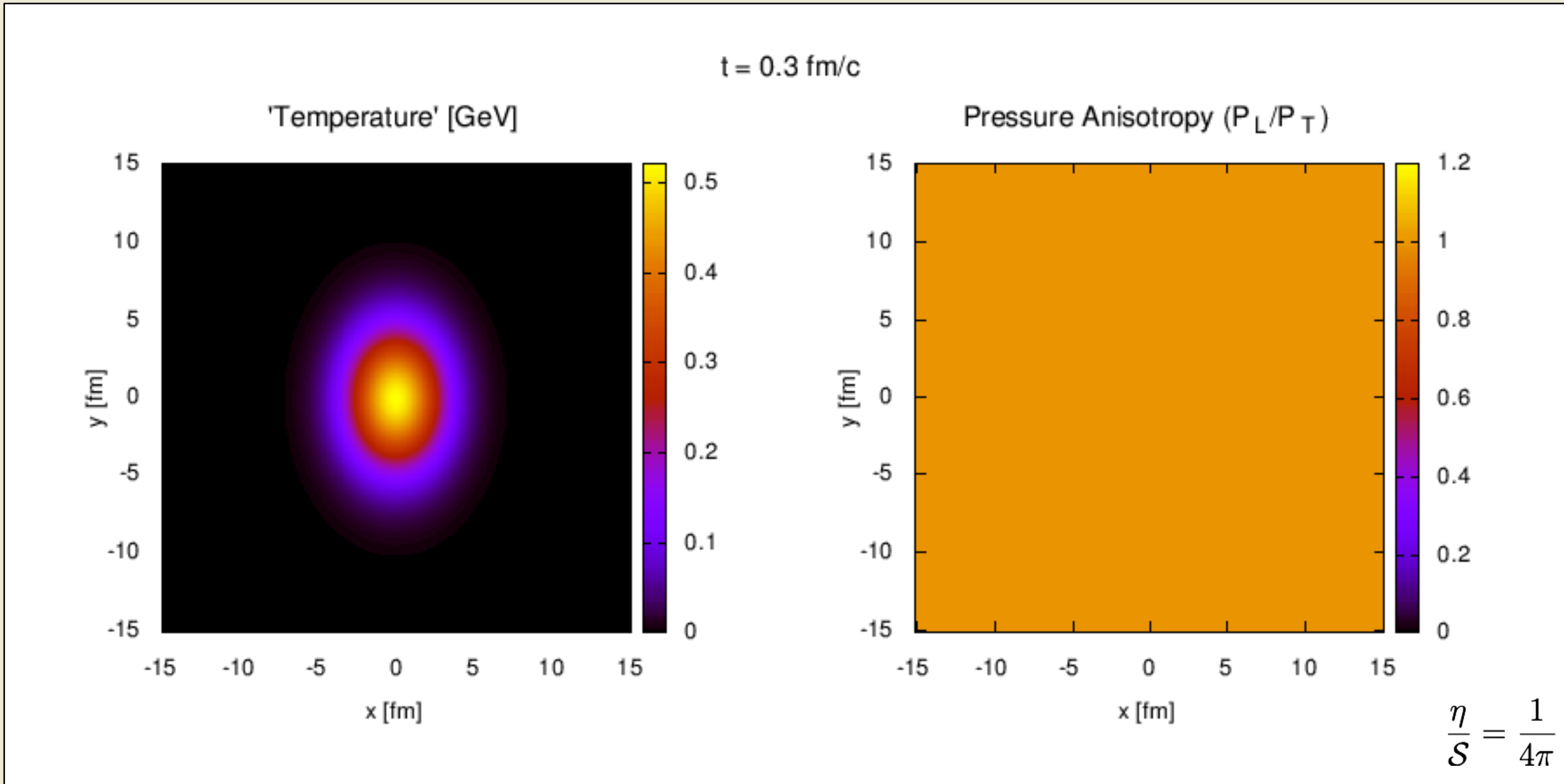
$$\frac{1}{1+\xi}\partial_\tau \xi - \frac{2}{\tau} - \frac{6}{p_{\rm hard}}\partial_\tau p_{\rm hard} = 2\Gamma\left[1 - \mathcal{R}^{3/4}(\xi)\sqrt{1+\xi}\right]$$

$$\frac{\mathcal{R}'(\xi)}{\mathcal{R}(\xi)}\partial_\tau \xi + \frac{4}{p_{\rm hard}}\partial_\tau p_{\rm hard} = \frac{1}{\tau}\left[\frac{1}{\xi(1+\xi)\mathcal{R}(\xi)} - \frac{1}{\xi} - 1\right]$$



Including Transverse Dynamics

W. Florkowski, M. Martinez, R. Ryblewski, and MS, forthcoming.



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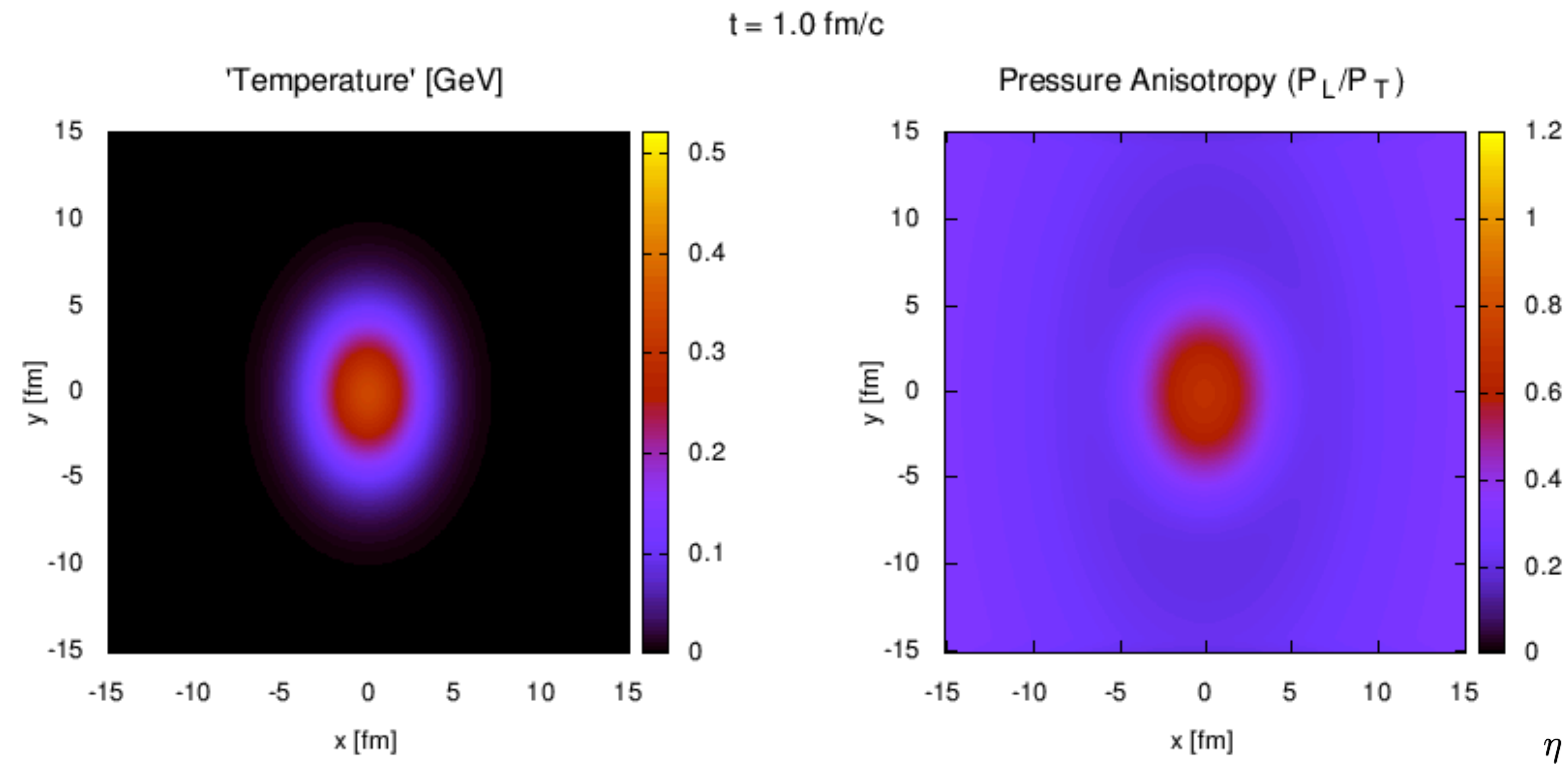

$$\frac{\eta}{\mathcal{S}} = \frac{1}{4\pi}$$

Conclusions

- Perhaps fast isotropization isn't required after all?
- Even in 2nd order viscous hydro local momentum-space anisotropies can be relatively large and persist for a long time
- New general class of codes which can be applied to highly anisotropic systems (trans/long edges, large shear viscosity) → aHYDRO
  Work in progress … stay tuned