University of Ferrara

Heavy ions collision evolution modeling with ECHO-QGP

Valentina Rolando

May, 20th 2014

ECHO-QGP Collaboration

The ECHO-QGP collaboration involves the Universities of Ferrara, Firenze and Torino.

ECHO-QGP

L. Del Zanna, V. Chandra, G. Inghirami, V. Rolando, A. Beraudo, A. De Pace, G. Pagliara, and A. Drago, and F. Becattini.
Relativistic viscous hydrodynamics for heavy-ion collisions with ECHO-QGP.
Eur.Phys.J.,C73:2524, 2013. arXiv(nucl-th):1305.7052

Overwiew on ECHO-QGP

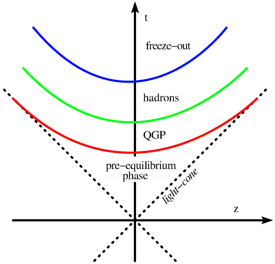
ECHO-QGP is a development of ECHO

ECHO

L. Del Zanna, O. Zanotti, N. Bucciantini, and P. Londrillo.
ECHO: an Eulerian Conservative High Order scheme for general relativistic magnetohydrodynamics and magnetodynamics
Astron.Astrophys., 473:11–30, 2007. arXiv(astro-ph):0704.3206

The original ECHO code can handle non-vanishing conserved-number currents as well as electromagnetic fields, which are essential for the astrophysical computations, in any (3+1)-D metric of General Relativity.

Setup



- Initial stage: Optical Glauber model (energy density/entropy density profile) or MC Glauber model
- Hydro stage:
  - the evolution can be purely ideal or viscous
  - can handle both Minkowski or Bjorken coordinates
  - it is designed to use any EoS, tabulated or Analytical
- Decoupling stage: Cooper-Frye prescription (mean spectrum and event generation)

ECHO-QGP Features

- ECHO-QGP has been originally conceived to be publicly released
  - user-friendly
  - exhaustive documentation and tutorials
- Designed to perform serial or parallel simulations
- Built-in standard tests initialization ($e.g.$ shock tube, Bjorken expansion, Gubser's solution . . .)
- Highly Customizable at runtime ($e.g.$ output, end criterion, grid, collision parameters, . . .)
- Several post-processing tools already included

The equations

$$g^{\mu\nu} = \begin{pmatrix} - & & & \\ & + & & \\ & & + & \\ & & & + \end{pmatrix}$$

Orthogonal projector

$$\Delta^{\mu\nu} \equiv g^{\mu\nu} + u^\mu u^\nu$$

Covariant derivative

$$d_\mu = \underbrace{-u_\mu D}_{D \equiv u^\alpha d_\alpha} + \underbrace{\nabla_\mu}_{\nabla_\mu \equiv \Delta_\mu^\alpha d_\alpha}$$

Set of equations

$$\begin{cases} d_\mu N^\mu = 0, \\ d_\mu T^{\mu\nu} = 0 \\ EoS \\ \pi^{\mu\nu} \text{ evolution} \\ \Pi \text{ evolution} \end{cases}$$

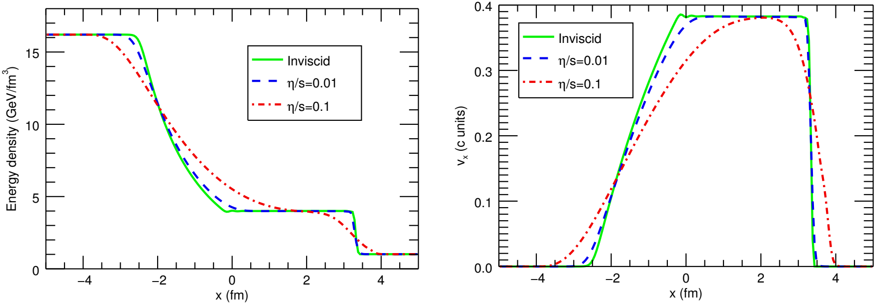
Conservative form

$$\partial_0 U + \partial_k F^k = S$$

$$N^\mu = n u^\mu + V^\mu$$

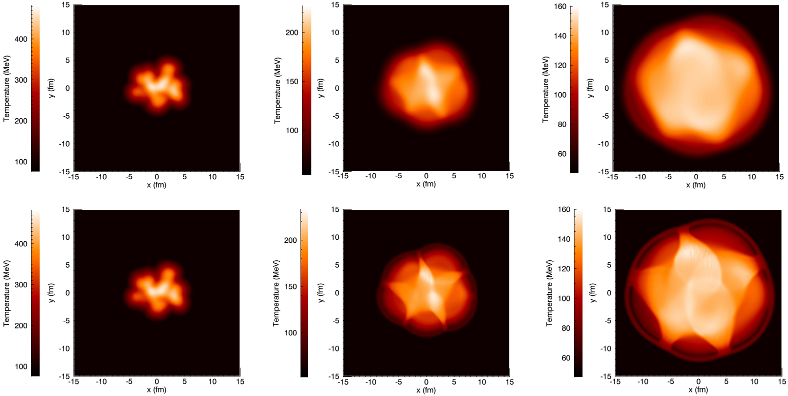
$$T^{\mu\nu} = e u^\mu u^\nu + (P + \Pi)\Delta^{\mu\nu} + \pi^{\mu\nu} + w^\mu u^\nu + w^\nu u^\mu$$

Test: (2+1)-D shock tubes



$T^L = 0.4$ GeV ($P^L = 5.40$ GeV/fm^3) and $T^R = 0.2$ GeV ($P = 0.34$ GeV/fm^3)
$\eta/s = 0, 0.01, 0.1$ at $t = 4$ fm/c.

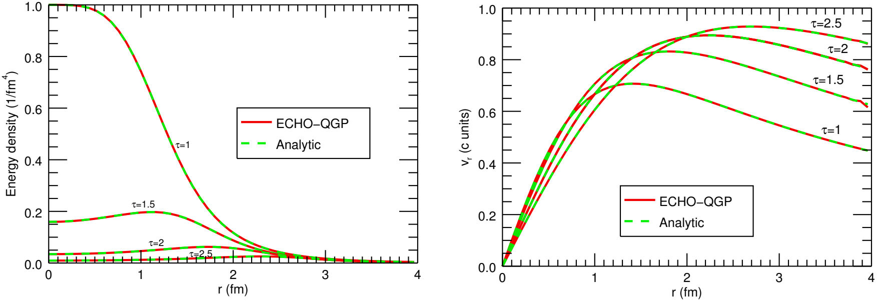
The effect of viscosity



Test:(2+1)-D with azimuthal symmetry

Ideal Gubser Test

Analytic solution from symmetry consideration [1]:

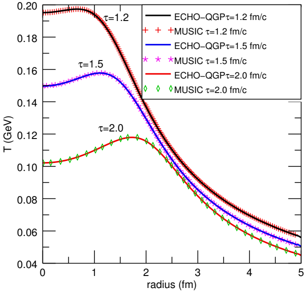


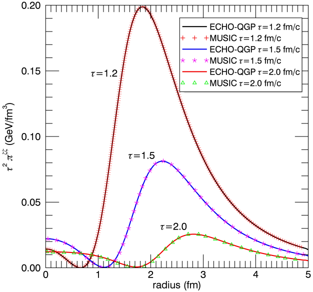
[1] S. S. Gubser. constraints on generalizations of Bjorken flow. *PRD*82:085027, 2010.

Test: (2+1)-D with azimuthal symmetry

Viscous Gubser Test

Analytic solution from symmetry consideration in for the Israel-Stewart frame[2]:





[2] H. Marrochio, et al. of Conformal Israel-Stewart Relativistic Viscous Fluid Dynamics. 2013.arXiv(nucl-th):1307.6130

Decoupling fluid to particles

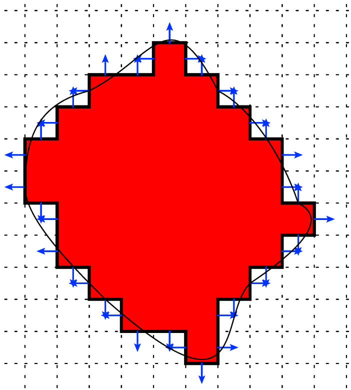
Isothermal hypersuface: our implementation

$$f_i(x,p) = \left[e^{-\frac{1}{T}(u^\nu p_\nu + \mu_i)} \pm 1\right]^{-1}$$

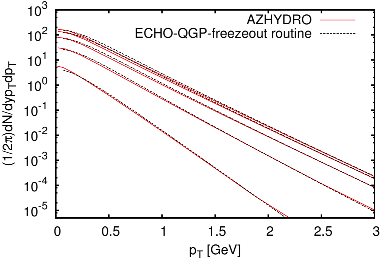
$$E\frac{\mathrm{d}^3 N_i}{\mathrm{d}p^3} = \frac{g_i}{(2\pi)^3}\int_\Sigma -f_i(x,p)p^\mu \mathrm{d}^3\Sigma_\mu$$

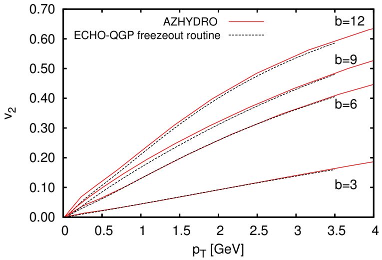
$$\mathrm{d}^3\Sigma_\mu = \begin{pmatrix} \mathrm{d}V^{\perp\tau} \\ \mathrm{d}V^{\perp x} \\ \mathrm{d}V^{\perp y} \\ \mathrm{d}V^{\perp\eta} \end{pmatrix} = \begin{pmatrix} \tau\,\Delta x \Delta y \Delta\eta_s\; s^\tau \\ \tau\,\Delta y \Delta\eta_s \Delta\tau\; s^x \\ \tau\,\Delta\eta_s \Delta\tau \Delta x\; s^y \\ \frac{1}{\tau}\,\Delta\tau \Delta x \Delta y\; s^\eta \end{pmatrix}$$

$$s^\mu = -\mathrm{sign}\left(\frac{\partial T}{\partial x^\mu}\right)$$



Freeze-out routine: tests with AZHYDRO[3]





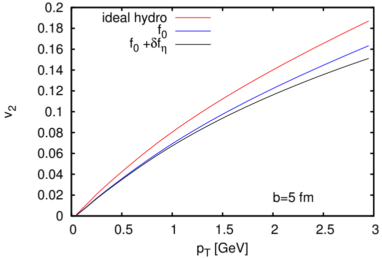
σ_{NN} mb	τ_0 fm	e_0 Gev fm^{-3}	α	b fm	μ_π GeV	T_{freeze} GeV
40	0.6	24.5	1	0,3,6,9,12	0.0622	0.120

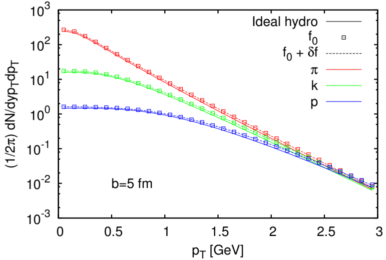
Table : The grid spacing here used is: $\Delta x = \Delta y = 0.4$ fm $\Delta\tau = 0.16$ fm.

[3] P. F. Kolb, J. Sollfrank and U. W. Heinz, transverse flow and the quark hadron phase transition *PRC* 62:054909, 2000

The effect of viscosity[4]

$$\delta f(x,p) = f_0(1 \pm f_0)\frac{p^\alpha p^\beta \pi_{\alpha\beta}}{2T^2(e+p)}$$





[4] D. Teaney. Effects of viscosity on spectra, elliptic flow, and HBT radii. *PRC* 68:034913, 2003.
R. Baier et al. Dissipative hydrodynamics and heavy ion collisions *PRC* 73:064903, 2006.

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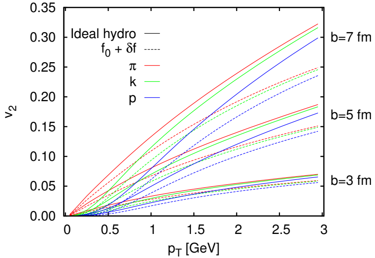

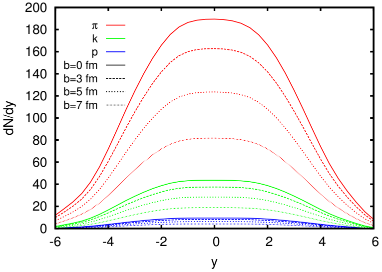

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Summary and Outlook

summary

- ECHO-QGP is a robust high-order shock-capturing code, solving either ideal or viscous (Israel-Stewart) hydrodynamics
- Modules for 1D, 2D, and 3D Minkowsky and Bjorken available
- ECHO-QGP reproduces the standard analytic solutions
- ECHO-QGP is consistent with AZHYDRO, UVH2, MUSIC
- ECHO-QGP will be made available soon . . . *stay tuned!*
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Summary and Outlook

outlook

- Recover of the original ECHO feature of evolving EM fields
- Inclusion of conserved currents

Thank you!

ECHO-QGP team is recruiting

P.S. If you feel like you have good skills in this subject and you are interested in working whithin the ECHO-QGP project please **contact us**!