University of Ferrara

Heavy ions collision evolution modeling with ECHO-QGP

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

ECHO-QGP

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Relativistic viscous hydrodynamics for heavy-ion collisions with ECHO-QGP.

Overview on ECHO-QGP

ECHO-QGP is a development of ECHO

ECHO

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

\[ g^{\mu \nu} = \left( \begin{array}{cccc} - & + & + & + \\ \end{array} \right) \]

Orthogonal projector

\[ \Delta^{\mu \nu} \equiv g^{\mu \nu} + u^\mu u^\nu \]

Covariant derivative

\[ d_\mu = -u_\mu D + \nabla_\mu \]

\[ D \equiv u^\alpha d_\alpha \quad \nabla_\mu \equiv \Delta_\alpha^\mu d_\alpha \]

Set of equations

\[
\begin{aligned}
d_\mu N^\mu &= 0, \\
d_\mu T^{\mu \nu} &= 0 \\
EoS \\
\pi^{\mu \nu} \text{ evolution} \\
\Pi \text{ evolution}
\end{aligned}
\]

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

\[ T^L = 0.4 \text{ GeV} \left( P^L = 5.40 \text{ GeV/fm}^3 \right) \text{ and } T^R = 0.2 \text{ GeV} \left( P = 0.34 \text{ GeV/fm}^3 \right) \]
\[ \eta/s = 0, 0.01, 0.1 \text{ at } t = 4 \text{ fm/c}. \]
The effect of viscosity
Test: (2+1)-D with azimuthal symmetry

Ideal Gubser Test

Analytic solution from symmetry consideration $^1$:

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

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

\( \tau = 1.2 \)
\( \tau = 1.5 \)
\( \tau = 2.0 \)

Decoupling fluid to particles

Isothermal hypersurface: our implementation

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

\[ E \frac{d^3 N_i}{dp^3} = \frac{g_i}{(2\pi)^3} \int_{\sum} -f_i(x, p)p^\mu d^3\Sigma_\mu \]

\[ d^3\Sigma_\mu = \begin{pmatrix} dV^\perp_\tau \\ dV^\perp_x \\ dV^\perp_y \\ dV^\perp_\eta \end{pmatrix} = \begin{pmatrix} \tau \Delta x \Delta y \Delta \eta_s \ s^\tau \\ \tau \Delta y \Delta \eta_s \Delta \tau \ s^x \\ \tau \Delta \eta_s \Delta \tau \Delta x \ s^y \\ \frac{1}{\tau} \Delta \tau \Delta x \Delta y \ s^\eta \end{pmatrix} \]

\[ s^\mu = -\text{sign} \left( \frac{\partial T}{\partial x^\mu} \right) \]
Freeze-out routine: tests with AZHYDRO\(^3\)

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

The effect of viscosity

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

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Summary and Outlook

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!
- More ongoing physics studies (vorticity, fluctuation propagations ...)

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Summary and 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 within the ECHO-QGP project please contact us!