1. Introduction

1.1. Spin-polarization in HIC

- huge vorticity $\omega$ in magnetic field $B$ in non-central collisions
- spin-polarization by $\omega, B$
eq 0
- experimental evidence

1.2. Theoretical status of spin hydro

- Hydrodynamics is a powerful framework to describe QGP.
- It is far from complete for spin-polarized QGP.
- "hydro simulations" exist, but:
  - ordinary hydro (i.e., hydro w/o spin) is solved;
  - thermal vorticity $\gamma^{\mu\nu}$ is converted into spin via Cooper-Frye.
- Relativistic spin hydro is still under construction
  - established for non-relativistic case
  - some trials exist, but only at the "ideal" level (no dissipative corr.)
- controversy on the conservation of spin
  - some relativistic people claim spin is conserved, while it is established in non-relativistic spin hydro that spin must not be conserved.

Aim

1. Formulate relativistic spin hydro including 1st order dissipative corrections for the first time
2. Clarify that spin must be a dissipative quantity

2. Phenomenological formulation based on entropy-current analysis

2.1. Hydro without spin (review)

- Write down the conservation law
- Express $T^{\mu\nu}$ i.e. hydro variables (constitutive relation)
- Define hydro variables
- Write down all the possible tensor structures of $T^{\mu\nu}$
- Simplify the tensor structures with some assumptions
- symmetry
- power counting (gradient expansion)
- thermodynamics (entropic-current analysis)

2.2. Hydro with spin

- Write down the conservation laws
- Define hydro variables
- Write down all the possible tensor structures of $T^{\mu\nu}$
- Simplify the tensor structures with some assumptions
- symmetry
- power counting (gradient expansion)
- thermodynamics (entropic-current analysis)

3. Linear mode analysis

3.1. Setup

- Consider perturbations on top of a global static thermal equil. config.
- Expand hydro eqs. i.e. the pert. $\delta
\n3.2. Linearized hydro eq.

- $\omega^{\mu} = 0$ + $\delta \omega^{\mu}$
- $\omega^{\mu} = 0$ + $\delta \omega^{\mu}$

3.3. Eigenvalues of $M$

- $\omega = 4 \gamma^{\mu\nu} + 6 \delta \omega^{\mu}$

4. Summary

- Relativistic spin hydrodynamics with 1st order dissipative corrections is formulated for the first time
- Based on the phenomenological entropy-current analysis.
- Spin must be dissipative because of the mutual conversion b/w orbital angular momentum and spin.
- Linear mode analysis of the spin hydro equation found 6 new dissipative modes, which means that spin is dissipative, and time-scale of the dissipation is controlled by the new viscous constants $\gamma, \lambda$.

Outlook:
extension to 2nd order, Kubo formula, MHD, application to cond-mat, numerical simulations.