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# Covariant Formulation of Semi-Classical Spin Hydrodynamics and Equilibration of Spin: Linear and Nonlinear Perspectives

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Spin hydrodynamics is the extension of standard relativistic hydrodynamics with the total angular momentum considered as an independent conserved charge, where the total angular momentum is often expressed as a surface integral of a rank-3 tensor.
This rank-3 tensor is then decomposed into orbital and spin parts, which, by using the definition of orbital angular momentum in Cartesian coordinates and the energy-momentum tensor conservation, leads to the equation of motion for the spin tensor.
This treatment is not covariant under coordinate transformations, even in flat spacetime.
We address this issue by redefining the orbital and total angular momentum in a covariant way, which can also be extended to curved spacetime in cases where the Belinfante and Hilbert definitions of the energy-momentum tensor are equivalent.
Then, we review the constitutive equations of semi-classical spin hydrodynamics developed from a systematic expansion in the reduced Planck constant, $\hbar$.
This formulation is inspired by, but not necessarily based on, quantum kinetic theory.
Up to the first order in $\hbar$, there is no back-reaction from the spin sector to fluid dynamics, and, therefore, solutions to standard hydrodynamics act as an input for the equations of motion for the spin tensor.
We consider three simple solutions to the fluid's equation of motion: hydrostatic, linearized hydrodynamics, and conformal Bjorken flow.
We demonstrate that, up to first-order in $\hbar$, the spin waves are not affected by the fluid waves, and therefore, the results from the hydrostatic case and linearized hydrodynamics are the same.
This shows that our results for the damping of spin waves are not modified by slight fluid perturbations.
For the case of conformal Bjorken flow, we first review the consequences of conformal invariance in spin hydrodynamics and, in particular, show that conformal invariance should be considered only in the limit where $\hbar$ vanishes.
Then, we use the attractor solution to find the evolution of the spin potential.
We show that the spin potential in this nonlinear regime is damped in a similar fashion to the linear regime.
These results strengthen our previous findings on the possible long equilibration time for spin, and support a dynamical treatment of spin degrees of freedom.

## Category

Theory

## Collaboration (if applicable)

**Authors:** CHIARINI, Annamaria; WAGNER, David (Florence University); RISCHKE, Dirk; SAMMET, Julia (Goethe Universität Frankfurt/ITP); SHOKRI, Masoud (Goethe University, ITP)

**Presenter:** SHOKRI, Masoud (Goethe University, ITP)

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