

## S E M I N A R

# Relativistic Langevin equation as a microscopic route to relativistic viscosity for QCD matter

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Friday, 22 May 2026 @ 14h00-15h00 SAST

**Venues:** NITheCS Seminar Room, Stellenbosch University; and Online

### ABSTRACT:

Our understanding of ordinary liquid matter is based on the statistical physics of Brownian motion and self-diffusion, described by Einstein and Langevin. The Langevin equation as a stochastic equation of motion which comprises all physical effects of atomic motion in liquids (from conservative interactions to dissipation) is used ubiquitously to predict the macroscopic properties of matter based on microscopic dynamics and interactions. In nuclear physics, the viscosity is a key quantity which plays a pivotal role in various high-energy processes, from fusion-fission nuclear reactions [1] to heavy-ion collisions and the quark-gluon plasma [2]. Apart from numerical simulations, the viscosity of liquid matter cannot be predicted as an expansion around the gaseous state (e.g. Boltzmann equation plus Chapman-Enskog closure) due to the high packing density of the microscopic building blocks [3]. The only alternative is, thus, the Green-Kubo relation. This is a macroscopic description that heavily relies on numerics.

I will first show how the non-relativistic Langevin equation can provide a fully microscopic derivation of Maxwell-type viscoelasticity and of viscosity of ordinary liquids, leading to microscopic expressions in terms of the energy (phonon) spectrum of the system [4,5]. I will then show how a relativistic Langevin equation can be derived from a microscopic relativistic particle-bath (Caldeira-Leggett) Lagrangian [6].

Contrary to previous approaches to the relativistic Langevin equation, which were not based on a first-principles derivation, this treatment reveals the intrinsically non-Markovian nature of the dynamics, as a result of the relativistic locality principle. The corresponding fluctuation-dissipation theorem is therefore also non-Markovian, implying that the white noise assumption is, generally, incompatible with special relativity and with causality [6]. This result calls for a fundamental revisiting of previous approaches in high-energy theory and QCD matter, such as the Parisi-Wu quantisation.

Finally, I will show how the relativistic Langevin equation can be a starting point for a microscopic derivation of the viscosity of dense strongly-correlated high-energy liquids, where it predicts the cubic scaling of viscosity with temperature [7] observed in quark-gluon plasma [8]. The same theory can recover the non-relativistic formula for the viscosity of gases by taking the dilute limit [9], hence providing a relativistic theory of the viscosity of fluids valid across the energy and density spectrum.

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*Alessio Zaccone received his PhD at ETH Zurich in 2010. He was subsequently a Swiss National Science Foundation Fellow and Oppenheimer Research Fellow at the Cavendish Laboratory, University of Cambridge. After serving as a W2 Professor of Physics at the Technical University of Munich and a Lecturer in Chemical Engineering at the University of Cambridge, he was appointed Associate Professor and, since 2022, a Full Professor and Chair in the Department of Physics at the University of Milano. His awards include the ETH Silver Medal, 2020 Gauss Professorship of the Göttingen Academy of Sciences, Fellowship of Queens' College Cambridge, 2017 Influential Researcher Award from Industrial & Engineering Chemistry Research, IoP Journal of Physics Emerging Leader Award, and ERC Consolidator Grant ('Multimech'). He authored Theory of Disordered Solids (Springer, 2023). His research interests include amorphous solids, complex fluids, superconductivity, non-equilibrium statistical physics, open quantum systems, and relativistic fluids.*

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