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Non-Equilibrium Dynamics in the Early Universe

I will first briefly review the current state-of-the-art in calculating non-equilibrium processes in the early Universe, particularly in the context of baryogenesis and dark matter production. I will then focus on dark matter freeze-in, where various semi-classical Boltzmann approaches are employed in the literature and require careful scrutiny. I will present our recent calculation of freeze-in production for a real scalar dark matter candidate, based on the closed time path (CTP) formalism, deriving the non-equilibrium dynamics in the thermal plasma from first principles. I will show that the sensitivity of the freeze-in mechanism to the vacuum mass of the parent particle requires a treatment beyond the Hard-Thermal-Loop (HTL) approximation. To this end, I will present our calculation based on the leading-order contribution in the loop expansion of the 2PI effective action, using 1PI-resummed propagators. To include all leading-order contributions to the interaction rate in the ultra-relativistic regime, I will also present our extended calculation that effectively incorporates the Landau-Pomeranchuk-Migdal (LPM) effect, providing the new state-of-the-art calculation. Finally, I will compare these results with those obtained from the HTL approximation and various semi-classical Boltzmann approaches, quantifying their associated uncertainties.

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