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NONEQUILIBRIUM IN PRIMORDIAL QUARK-GLUON PLASMA

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Non-stationary breaking of thermal equilibrium is the dynamic pre-requirement for baryogenesis in primordial Universe – the other two Sakharov conditions are: existence of baryon conservation violating processes, and CP breaking allowing matter to grow more rapidly in abundance compared to antimatter. If there is quark-gluon plasma (QGP) nonequilibrium, a nonstationary behavior arises due to time dependence of the nonequilibrium properties. These arise naturally both, in an expending time dependent Universe, as well as in the laboratory formed exploding fireball of QGP. In the study of nonstationary condition we distinguish between two possible nonequilibrium features inherent to primordial quark-gluon plasma (QGP): i) The abundance (chemical) nonequilibrium and; ii) the momentum distribution (kinetic) nonequilibrium.

The Universe following on electroweak transformation at a temperature $T \simeq 125$ GeV was dominated during the following $25\mu s$ by strongly interacting quarks and gluons forming a new state of matter, the color deconfined Quark-Gluon Plasma (QGP), hadronization at $T > 150$ MeV formed material particles we are familiar with. In the laboratory environment QGP is formed in highly relativistic collisions of heaviest nuclei, with laboratory temperatures $T \simeq 0.5$ GeV. For the strong QCD force the thermal reaction rates in QGP have been studied in depth in consideration of explosive disintegration of the dense matter fireball with QCD scale lifespan
$calO(10^{-22}$\,s). The following recent research builds upon our study of strangeness abundance nonequilibrium in laboratory formed QGP and the lecture will review this matter in preparation of the more complex situation of interest to baryogenesis.

The expansion of the Universe is described by the Hubble parameter H which is many ({\it e.g.\/} 15-18) orders of magnitude slower compared to the microscopic reaction rates. Even so, we find that nonequilibrium of physical significance arises in the early Universe, similar to the laboratory formed QGP environment. Specifically, we show bottom quark abundance nonequilibrium near to hadronization of QGP. There is competition between strong force forming bottom pairs in fusion of gluons and lighter quarks, and weak interaction driving decay of bottom flavor. These two processes have nearly similar picosecond scale rate at$T \simeq 0.25$\,GeV, {\it i.e.} just above hadronization of the Universe.

The Higgs particle is in abundance nonequilibrium across the entire QGP domain: This is due to decay proceeding in a significant manner by a kinematically forbidden path $h(125\,\text{GeV}) \to W^*W(2\cdot 80.4\,\text{GeV}), Z^*Z(2\cdot 91.2\,\text{GeV})$ (25.7 ± 2.5\% and 2.8 ± 0.3\% partial widths of $\Gamma_h = 3.7{+}1.9{-}1.4$\,MeV). Such decay is irreversible in a thermal bath, detailed balance is thus broken. This is so since collisions of real on-mass-shell gauge bosons cannot form Higgs and multiparticle back reaction occurs for each collision channel incoherently, while the decay of W^* and Z^* into a large multitude of physical channels is a coherent process assuring these virtual particles materialize with unit probability. We also discover that at $T < 25$\,GeV the Higgs momentum distribution is nonthermal. In this temperature range the abundance of 'heavy' particles Higgs couples to strongly via minimal Yukava coupling has diminished to be irrelevant while Higgs is too weakly coupled to light particles so once produced in $2 \to 1$ process it cannot scatter ($2 \to 2$ process). Hence the momentum distribution is what {\it e.g.\/} bottom pair fusion $b + \bar{b} \to h$ creates.

Primary author: RAFELSKI, Johann (The University of Arizona)

Presenter: RAFELSKI, Johann (The University of Arizona)