

## **Report on the MITP scientific program JPTCCE, 28 July 2014 -- 8 August 2014**

**The main idea of the program** was to discuss the computational frameworks and methods used in thermal field theory, both in the context of heavy-ion collisions and in cosmology. In this way participants of one field could learn about the important issues in the other field and possibly carry over useful methods to their field. Some of the participants have made important contributions to both fields. Throughout the meeting there were two morning talks, nominally 45 minutes but with questions and discussion generally expanding to 75 minutes, and an afternoon discussion with two discussion leaders, generally lasting 60 to 70 minutes. Each day had a specific topic but the topics were mixed day-by-day to emphasize overlap and common issues between topics.

### **Some of the discussion titles were**

- ``What are outstanding issues in Leptogenesis? in Electroweak Baryogenesis?``,
- ``What problems in cosmology require new techniques?``,
- ``Thoughts on tools for far from equilibrium systems``,
- ``Relation between cosmology/heavy ion physics``,
- ``Energy-loss in a medium beyond leading order``,
- ``What can lattice teach us about heavy quarks? about transport?``.

### **Far from equilibrium in cosmology:**

The earliest epoch of the Universe was discussed along with processes that could lead to potentially observable phenomena today such as gravitational waves (talk by D. Figueroa) or dark matter (talk by F. Steffen). D. Figueroa addressed gravitational waves originating from particle production during reheating involving the Standard Model Higgs, and from primordial phase transitions leading to cosmic defects. The latter of which can give rise to scale invariant gravitational waves. The first of which requires improvements to include effects of gauge bosons which may lead to more promising observational prospects. F. Steffen presented particle candidates for dark matter such as the axion, the gravitino and the axino and their production mechanisms in the early Universe. Systematic and reliable treatments of those mechanisms are required.

They are relevant for our understanding of the origin of dark matter and for the gravitino problem of leptogenesis.

### **Leptogenesis:**

The various allowed parameter regions and their possible signature in low energy experiments were discussed, both for high scale (talk by P. Di Bari) and for TeV scale leptogenesis (talk by B. Garbrecht). Another aspect was computational questions, both for the non-resonant (talk by M. Garny) and the resonant regimes (talk by A. Kartavtsev). Various systematic approaches were discussed, some are based on closed time techniques for non-equilibrium problems, others on effective rate equations with coefficients determined by matching to thermal field theory (S. Biondini). For the resonant approach the subtleties of the required resummation were discussed in detail.

**The approach to equilibration in heavy-ion collisions:**

(at weak coupling: talks by S. Schlichting and G. Moore; at strong coupling: talks by A. Vuorinen and L. Yaffe) The passage from infinite coupling to finite coupling was discussed by A. Vuorinen, in particular for the quasi-normal modes in the shear and vector channels. High-quality numerics of the collision of two sheets calculated in AdS/CFT were shown by L. Yaffe. The applicability of hydrodynamics was discussed. It appears that viscous hydrodynamics works at surprisingly early times, even when the viscous corrections are not small compared to the ideal hydrodynamic expressions.

**Heavy particles in a thermal bath:**

(talks by A. Vairo, M. Escobedo, J. Soto) An effective field theory formulation of the physics of heavy quark and heavy quark bound states in a hot medium was presented. The different regimes where the Debye screening length is larger or lower than the size of the quarkonium quasibound state have been analyzed, and the effect of the quarkonium moving in the plasma has been quantified.

**Jets:**

(talks by S. Caron-Huot and M. Benzke) The treatment of jets via effective field theories was discussed. A possible path to a NNLO and NNLL calculation was sketched by S. Caron-Huot and M. Benzke. A further approach to dealing with jets in a medium is using an effective kinetic theory. The extension to NLO was discussed by J. Ghiglieri.

**Dilepton production:**

(talk by M. Laine) The newest NLO calculations allow one to estimate the scale sensitivity of the perturbative results. Second, a matching with the LPM resummed results was performed recently at small frequencies.

**Electroweak baryogenesis:**

(talks by St. Huber, Th. Konstandin) The viable mechanisms, as well as the potential upcoming constraints from electric dipole moment measurements, were reviewed. Detailed numerical simulations of gravity waves arising from nucleating bubbles were presented by St. Huber.

**Lattice QCD calculations:**

Two talks presented the status of lattice QCD calculations, for static quantities and heavy-quark observables (P. Petreczky) and for a few dynamical quantities (H. Meyer). The static quantities appear to be broadly consistent with a hadron resonance gas at low-temperature and a quark-gluon plasma at high temperatures. It was discussed to what extent our limited knowledge about dynamical properties support this picture.