Conclusion and Outlook

The main goal of the thesis is the description of the behavior of strongly interacting matter via QCD inspired models under extreme conditions of temperature and/or density. We know in the low energy regime the strongly interacting matter is governed by hadronic degrees of freedom in which constituent quarks and gluons remain confined. Now if we increase the temperature and/or density, the hadronic system undergoes a phase transition where deconfined quarks and gluons are the main degrees of freedom. We have studied the strongly interacting matter using phenomenological models namely NJL and PNJL model both at finite temperature and density. The main drawback of NJL model is the absence of confinement property, which is further improved by the inclusion of Polyakov loop part in the Lagrangian. The advantage of these phenomenological models is that, compared to Lattice calculations they are not only cost effective but time saving too.

In chapter 2 we have investigated the Equation of state (EoS) and various thermodynamic properties i.e. specific heat, speed of sound, compressibility etc. of strongly interacting matter at high density. This type of matter is expected to exist in the core of massive astrophysical objects like neutron star. In fact it has been shown that inside the neutron stars, when the matter density exceeds about 5 times normal nuclear matter density the onset of hadron quark phase transition occurs. Initially hadrons convert to two flavor quark matter. However, two flavor quark matter is unstable. It was conjectured by Witten that strange quark matter is the stable ground state of strongly interacting matter. The unstable two flavor matter is eventually converted to stable strange quark matter. So we have considered 2+1 flavor quark matter system in our analysis. Since beta equilibrium and charge neutrality are two basic requirement for the matter inside neutron stars, we have performed our analysis considering beta equilibrium between the three quark chemical
potentials namely $\mu_u, \mu_d$ and $\mu_s$. Apart from the 2+1 flavor quark system we have considered free electrons with three different electron chemical potentials 0, 10 and 40 MeV. We have not imposed charge neutrality along with beta equilibrium, rather found charge neutral contours for the different electron chemical potentials. The whole study has been done using both NJL and PNJL model, and the results are compared. The QCD phase diagram for the beta equilibrated asymmetric matter was obtained using these models. We have also obtained the contours of constant baryon number density, constant strangeness fraction and constant entropy per baryons. The possible explanations of the behavior of such contours were described in the context of neutron star.

However, actually description of quark matter in neutron star scenario demands the consideration of diquark condensates at high density. Although at this moment we have not included this in our model, we plan to explore the neutron star evolution by incorporating diquark condensates.

The whole study in chapter 2 has been done keeping in mind that the u-d flavor asymmetry comes due to the difference in corresponding chemical potentials. For $\mu_e$ equals to zero, the matter is isospin symmetric. There is no significant qualitative difference in the behavior of the thermodynamic variables or phase diagrams when we move to isospin symmetric to asymmetric phase.

We decided to study the isospin asymmetry considering another possibility of isospin breaking i.e unequal masses for u and d flavors. Since the mass difference is very small, mass of u and d quark is considered to be same in all practical purposes. However, they are not equal in true sense. So in chapter 3 we have studied 1+1 flavor quark matter with $m_u \neq m_d$. Here we consider the average quark mass $m_1 = (m_u + m_d)/2$ fixed at 0.0055 GeV and study the effect of ISB with three representative values of $m_2 = (m_d - m_u)/2$. But it should be clarified properly that in this study the isospin chemical potential is strictly kept at zero, that means $\mu_u = \mu_d$ for this case. The asymmetry is entirely due to mass difference unlike the study in previous chapter. We have found that thermodynamic properties, i.e. pressure, energy density, specific heat, entropy do not show any significant changes. The striking results were found for the second and fourth order off diagonal susceptibilities in Baryon-Isospin sectors both in finite temperature and finite chemical potential directions. They show a critical behavior near $T_c$. They are not only sensitive with different values of $m_2$, but show almost a linear scaling with $m_2$. These findings help us to es-
timate the value of $m_2$ experimentally because the off diagonal susceptibilities give the correlation between the conserved charges that are experimentally measurable. It is worth to mention here that the diagonal susceptibilities do not show any dependences on $m_2$ unlike the off diagonal susceptibilities. The natural extension of this work is to explore all the quantities in 1+1+1 flavor case, which we plan to do in future.

The detailed understanding of the hadron–quark phase transition and the thermodynamics of quark gluon plasma, both at finite temperature and density, are of particular interest in the studies of relativistic heavy ion collisions. There are lots of theoretical studies where the existence of quark gluon plasma is suggested. In chapter 2 and 3 we have also shown the critical behavior of some thermodynamic quantities and correlations between conserved charges and pointed out that some of them are experimentally measurable, hence can be treated as QGP signatures also.

Production of photons and dileptons are longstanding classic probes for QGP formation as already mentioned in somewhat detail in chapter 1. So finally in chapter 4 we decided to explore dilepton production but with heavier mass ($\tau^+\tau^-$), which is relevant because of the availability of corresponding energy range at LHC. Another reason of considering this, is due to the heavy mass of the $\tau$ lepton, its production will not be affected by the overwhelming background production. Comparing the thermally generated $\tau$ with that produced in initial hard process (Drell-Yan), we have found that in the invariant mass window of 4 to 6 GeV, $\tau$ lepton can be treated as an excellent signature for the formation of quark gluon plasma.

For the first such case study we have considered tree level Feynmann diagrams. We plan to study the next to leading order diagrams and discuss the transverse momentum distribution of $\tau^+\tau^-$ pairs. As heavy quark production will be substantial at RHIC and LHC energies, $\tau$ production from heavy flavor decay is another important issue to be considered in future.