Chapter 9

Concluding remark and Future plan of work

General theory of Relativity (in short, GTR) is the basis for understanding the dynamics of the universe. However, it has been realized today that the GTR is not enough for understanding the universe as a whole. Therefore in theoretical cosmology the evolution and composition of the universe are studied as a system by constructing cosmological models in the framework of GTR, or in a modified theory of GTR confronting them with experiments and observations. Cosmology at the present time deals to a large extent with statistical predictions and measurements of its different parameters. In recent years, advances in experiments and computational techniques along with several astronomical and cosmological missions have made it possible to consider cosmology as an experimental science. It is predicted from cosmological observations that the universe might have originated from Big Bang in the past. Some of the relics of the Big Bang namely, CMBR, abundances of Helium etc., are the evidences in favour of Big Bang model. Although the standard Big Bang model is successful in many aspects yet it fails to predict the observed universe both in the early and in the late era. If the early universe be probed in Big Bang model some of the conceptual issues in cosmology namely, horizon problem, flatness problem and singularity problem emerged which do not have solution in the perfect fluid assumptions. In order to address those issues, the concept of inflation was introduced in cosmology in 1981 by Guth [3]. A handful of inflationary models have been proposed in the literature in the last 30 years to realize early inflation ([3]-[48]). Inflationary scenario is attractive as it solves some of the outstanding problems of cosmology and particle physics satisfactorily. It also opens up new avenues in the interface of particle physics and cosmology. In modern cosmology [245, 246, 247] inflation is therefore considered as one of the essential ingredient to build a viable cosmological model. It may be pointed out here that inflation can be realized if matter is described in terms of quantum fields. The homogeneous scalar field of standard model in GTR gives rise to an inflationary phase when the potential energy of the field dominates over the kinetic energy. Although there is a progress in realizing early universe, it remains to be understood when and how the universe entered into the phase. Thus, early inflation in cosmology is still an open area of research.

In recent times cosmological observations, such as high redshift surveys of SNe Ia [49, 50, 51, 104], CMBR ([105]-[109]), WMAP ([110]-[114]) discovered another interesting phenomena that the present universe is passing through a phase of accelerated expansion. This is a new area in theoretical physics. It is known that the standard model of particle physics with GTR cannot provide a satisfactory explanation of this new predictions. Thus, a new form of energy is needed to realize the late acceleration in cosmology which is termed as dark energy, it is different from that of dark matter. It has now become a challenge in theoretical physics to address the recent observational issues. However, in the literature following proposals: (i) a modification of the matter sector, (ii) a modification of the gravitational sector of the Einstein-Hilbert action or both may be considered. Modification of the matter sector of the Einstein gravity with exotic matter having negative pressure namely, phantoms [118, 119, 120], tachyons [121, 122, 123], quintessence [124, 125, 126], K-essence [127, 128, 129], Chaplygin gas etc. are considered widely.

A number of modified gravity with a polynomial in Lagrangian with scalar curvature R have also been considered in the literature ([76]-[80]). Another modified gravity proposed by Horava and Lifshitz known as HL gravity is also considered in recent times because of its successes ([207]-[217]) in condensed matter physics. Emergent universe model [68] obtained in GTR with a non-linear EoS provided an interesting area of cosmology to explore. EU model permits a universe with a composition of three different types of fluids which can be realized by a non-linear EoS. Emergent universe scenario is ever existing without an initial singularity and which accommodates a late accelerating phase satisfactorily. If this is tuned efficiently it can produce the late accelerating phase as well. The EoS for EU model contains two free parameters which are constrained using the observed data in Ref. [248, 249]. The constituents of this universe may vary as the value of the parameter B varied. For a given value of B parameter, it can accommodate dark energy as one of its constituents. The dark energy with negative pressure responsible for the present acceleration, is found to exist in the EoS required for EU model in all cases.

In Chapter 2, a general model of EU scenario of Mukherjee *et al.* is considered. The EoS parameters are constrained employing the $(H(z) - z)$ data (OHD) [99], BAO peak parameter and CMB shift parameters using *Chi-square* minimization technique. The best-fit values of the model along with the range for the EoS parameters are estimated. Variation of deceleration parameter, density parameter are also studied here. The viability of the model is tested by plotting μ-z curves.

In Chapter 3, best-fit values of one of the EoS parameters and an integration constant of the models are determined for $B = -\frac{1}{3}, 0, \frac{1}{3}, 1$. Thereafter, the range of values of the corresponding parameters at different confidence levels are determined using χ^2 minimization technique. Viability of the models is further tested by comparing μ-z plot of the model and that of union compilation supernovae data.

In Chapter 4, MCG is chosen as a candidate of dark energy in standard gravity model. In this scenario EoS parameters are constrained with the age constancy of the universe and $(H(z) - z)$ data ([130]). Best-fit values and range of values are thereby determined by numerical analysis. Viability of the model is tested through the distance modulus μ *vs*. z plot.

In Chapter 5, MCG is chosen as a candidate of dark energy which is used to analyze in the context of the structure formation of the universe. Growth data set which is related to the structure formation through initial density perturbation of the universe is used here to explore dynamical aspects of the universe. Also *r.m.s* mass fluctuation σ_8 data obtained from various source such as Lyman-α data is used here along with $(H(z) - z)$ (Stern) data (OHD) [99]. Thereafter, MCG model parameters obtained from the observational data analysis are then compared with that of GCG and ΛCDM model parameters.

In Chapter 6, holographic dark energy (in short, HDE) model of the universe is considered with a scalar field equivalent to MCG. Holographic dark energy field and its potential are determined for a non flat universe. Inclusion of a barotropic fluid (which is MCG) does not alter the form of potential and evolution of the holographic dark energy field. Holographic dark energy contributes more for ($B \neq 0$) compared to the case $B = 0$. It is found that the holographic dark energy is stable for a restricted domain of the values of Ω_Λ in a closed model of the universe.

In Chapter 7, HL gravity model in the detailed balance scenario is considered. In this framework MCG is used to obtain late time accelerating scenario and determine the EoS parameters for a viable cosmology. Best-fit values for EoS parameters of GCG are determined and have been compared with that of MCG.

In Chapter 8, HL gravity model in the beyond detailed balance scenario is considered. Here the effect of the dark radiation on the matter parameters have been considered in details. The best-fit values of the parameters along with their range of values have been calculated and compared with that of detailed balance scenario.

In the above analysis it is found that the EoS parameters of the different models considered here permit late accelerating phase satisfactorily. In the general EU model EoS parameters A, B and the other parameter K are found very small, whereas, for the particular EU models with $B = 0, \frac{1}{3}, 1$ the parameters A, K may pick up considerably higher values. In both the types, the model parameters allow accelerating universe, at late time.

The EoS parameters for MCG are determined in GTR considering $(H-z)$ data [130] and dimensionless age parameter for CDM and UDME model which are presented in Chapter 4. In Chapter 5, $(H-z)$ data (OHD) [99], growth data and $r.m.s$ mass fluctuation data for the numerical analysis are used. It is noted that the parameters determined in Chapter 4 are higher than that obtained in Chapter 5, where growth data are considered. In alternative gravity for example HL gravity with detailed balance scenario the best-fit values and the range of values for MCG in closed and in open universe are evaluated and it is found that the values of A_s, B are much much less than that obtained from GTR framework. In the case of beyond detailed balance scenario the range of A_s, B values are almost same as that obtained with detailed balance condition. It is also noted that in HL gravity values of A_s, B are smaller compared to that of GTR.

9.1 Future plan of work:

The numerical analysis adopted here in EU scenario involves kinematics only and it is also interesting to analyze cosmological model to determine the model constraints using the dynamical aspects like structure formation etc. A more stringent constraint on the EU model may be obtained for a viable candidate in cosmology. The recent Planck data [250] may be useful to probe the cosmologies in addition to WMAP 7 data.

HL gravity with MCG is considered to study the evolution of the universe and in the process it determines various physical parameters of the universe which are supported by observations. However, the present analysis does not enlighten the conceptual issues in HL gravity. A number of issues *e.g.*, why the value of neutrino parameter is small in HL gravity with MCG remains to be explored. In GTR, MCG is analyzed using the OHD, BAO data, CMB data, growth data and $r.m.s$ mass fluctuation data. The Planck data along with the predictions will be useful to figure out the suitability of cosmological models in future. The analysis adopted here may be extended for this purpose as future activity.