Study of Observational Constraints on Dark Sector of the Universe

THESIS

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Chapter 6

Overall summary and future scope

This chapter summarizes the main findings of the research work presented in the previous three chapters 3, 4, and 5. It also includes the future scope and possible extensions of the research work presented in this thesis.

6.1 Summary

The cosmological models derived from Einstein's General Theory of Relativity are tested with various different observational data from different sources. The cleanest and powerful data come from the observations of CMB, the leftover radiation after Big Bang which is observed today in the microwave region of the spectrum. In this thesis, We have mainly used CMB data from the Planck experiment together with some other supplementary observations, including BAO, Hubble constant measurement from HST, and LSS data. We have investigated observational constraints on various physically realistic extensions of the standard ΛCDM model in order to shed the light on the behavior of DM and DE, and to look for the possible solutions to some potential issues with the standard model, in particular, the alleviation of the current tensions on H_0 and σ_8 parameters. These extensions include (i) a coupling between DM and photons where the DM decays into photons throughout the cosmic expansion history in the presence of a constant as well as a time-

varying DE; (ii) a time-varying EoS of DM and a constant non-zero sound speed of DM in the presence of a cosmological constant DE as well as a time-varying DE; and (iii) a possible interaction between dark sector components, namely DM and DE. We have constrained all the models with the above mentioned observational data sets in various combinations. The main results of this research work are summarized chapter-wise as follows:

- **Chapter 3:** The DM photon coupling scenario in the presence of constant DE has proved to be able to alleviate the tension on the Hubble constant. Due to the decay of DM into photons, we have found higher values of the Hubble parameter with all the data combinations consistent with the local measurement. In this scenario, a phantom behavior of DE is observed from two data combinations: CMB + BAO + LSS and CMB + BAO + HST + LSS, whereas in the other two cases it is consistent with the cosmological constant. This coupling scenario with a time-varying DE leads to lower values of σ_8 parameter with all data combinations in comparison to a constant DE. In this case, the coupling scenario favors the quintessence behavior of DE with all data combinations. Thus, we conclude that an alteration in the standard dynamics of the photons through the cosmic expansion can alleviate the tensions on the parameters of the standard model, and describes the physics beyond the standard model in light of observational data.

- **Chapter 4:** The DM with extended parameters: a time-varying EoS and a constant non-zero sound speed, in the presence of cosmological constant DE, provide larger values of Hubble constant and significantly lower values of σ_8 in comparison to the standard model. The constraints on all the extended parameters of DM are obtained very close to zero with all data combinations, and thus we observe no significant deviation from the standard CDM paradigm. In the study of extended DM parameters with a time-varying DE, we have not found any significant deviation in the constraints of extended DM parameters. On the other hand, the DE shows phantom as well as quintessence behavior. Thus, DE EoS parameter swings around the cos-

mological constant. We can conclude that the presence of extended DM parameters can diminish the H_0 and σ_8 tensions within the ΛCDM framework.

- **Chapter 5:** The coupling between dark sector components alleviates both the well-known tensions on the parameters H_0 and σ_8 of the standard model, simultaneously. We have found a non-null interaction between DM and DE up to 99% confidence limits. Thus, we conclude that a non-null interaction between DM and DE provides a viable remedy for the tensions between CMB and LSS measurements.

6.2 Future scope

We have shown that an alteration in the standard dynamics of photons provides a way to alleviate the well-known tensions in the parameters of the standard model. Likewise, it would be interesting to investigate the photon-curvature coupling scenario and to see its possible consequences with the recent observations. We have seen that the extended DM parameters significantly change the evolution of the standard model. So it would be interesting to investigate the DM extended properties that can induce the possible effect of shear viscosity, and find the observational bounds with recent and forthcoming data from various experiments such as gravitational-wave physics. The dark sector coupling scenario could be investigated with the recent measurements of the Hubble constant by using gravitational waves as standard sirens. This model-independent measurements of Hubble constant from more upcoming standard-siren measurements from future GWs sources like the KAGRA and LIGO-India would be helpful to place the statistical limits on the today's Hubble parameter.