Contents

Certificate . . . iii

Acknowledgements . . . vii

Abstract . . . ix

List of Abbreviations . . . xiv

List of Tables . . . xvi

List of Figures . . . xxi

1 Introduction **1**

1.1 Background Cosmology . . . 2

1.1.1 Homogeneity and isotropy (cosmological principle) . . . 2

1.1.2 Expanding Universe: Hubble's law . . . 2

1.1.3 The story of hot Big Bang . . . 6

1.1.4 Accelerated expansion of the Universe . . . 8

1.1.5 Energy components of the Universe . . . 9

1.1.6 Background equations and cosmological parameters . . . 14

1.2 Linear perturbation theory . . . 22

1.2.1 Classification of perturbations . . . 22

1.2.2 Gauges . . . 24

1.3 Research work in the thesis . . . 28

1.3.1 Origin of the research work . . . 28

1.3.2 Issues with the standard model . . . 29

1.3.3 Tension on the Hubble constant . . . 30

1.3.4 Tension on matter density perturbation 31

2 Bayesian statistics, data sets and methodology 35

2.1 Bayesian statistics 36

2.1.1 Estimation of parameters 36

2.1.2 Monte Carlo Markov Chain technique 38

2.1.3 Bayesian model selection 40

2.1.4 Akaike information criterion 40

2.2 Observational data analysis 41

2.2.1 CMB anisotropy measurement 41

2.2.2 Planck mission and data release 43

2.2.3 CMB power spectrum 44

2.2.4 Matter power spectrum 48

2.2.5 Baryonic acoustic oscillations measurements 50

2.2.6 Hubble space telescope measurement 52

2.2.7 Large scale structure probes 52

2.3 Methodology 54

2.3.1 CLASS and Monte Python 55

2.3.2 Minimal parameter set of the ΛCDM model 56

3 Cosmological bounds on dark matter-photon coupling 59

3.1 Introduction 60

3.2 Background and perturbation equations of the model 61

3.3 DM-photon coupling with constant dark energy 64

3.3.1 Effects CMB temperature (TT) and matter power spectra 66

3.3.2 Results and discussion 66

3.4 DM-photon model with time-varying dark energy 72

3.4.1 Effects on matter and CMB TT power spectra 74

3.4.2 Results and discussion 76

3.5 Bayesian model comparison . . . 81
3.6 Concluding remarks . . . 81

4 Testing the warmness of dark matter 83
4.1 Introduction . . . 84
4.2 Model with extended properties of dark matter . . . 86
4.2.1 Results and discussion . . . 88
4.2.2 Estimating the warmness . . . 94
4.2.3 Comparison with previous studies . . . 96
4.2.4 Effects on CMB TT and matter power spectra . . . 99
4.2.5 Bayesian model comparison . . . 100
4.2.6 Constraints on the extended DM properties with variable dark energy . . . 101
4.3 Concluding remarks . . . 106

5 Dark sector interaction: a remedy for CMB and LSS tensions 109
5.1 Introduction . . . 110
5.2 Interacting model of dark sector . . . 111
5.2.1 Results and discussion . . . 113
5.2.2 Bayesian model comparison . . . 117
5.3 Concluding remarks . . . 118

6 Overall summary and future scope 119
6.1 Summary . . . 119
6.2 Future scope . . . 121
Bibliography . . . 122
List of research publications . . . 147
Brief biography of the supervisor . . . 150
Brief biography of the candidate . . . 152