

Contents

Preface XI

1	The Dark Energy Problem	1
1.1	Evidence for Cosmic Acceleration	1
1.1.1	The Basic Cosmological Picture	1
1.1.2	First Direct Observational Evidence for Cosmic Acceleration	4
1.1.3	Current Observational Evidence for Cosmic Acceleration	8
1.2	Fundamental Questions about Cosmic Acceleration	10
2	The Basic Theoretical Framework	15
2.1	Einstein's Equation	15
2.2	Cosmological Background Evolution	16
2.3	Cosmological Perturbations	18
2.3.1	Cosmological Perturbations: Nonrelativistic Case	18
2.3.2	Cosmological Perturbations: Generalized Case	22
2.4	Framework for Interpreting Data	31
2.4.1	Model-Independent Constraints	31
2.4.2	Using the Fisher Matrix to Forecast Future Constraints	32
2.4.3	Using the Markov Chain Monte Carlo Method in a Likelihood Analysis	32
2.4.4	Self-Consistent Inclusion of Cosmic Microwave Background Anisotropy Data	33
3	Models to Explain Cosmic Acceleration	35
3.1	Dark Energy Models	35
3.1.1	Quintessence, Phantom Field, and Chaplygin Gas	36
3.1.2	Worked Example: PNGB Quintessence	39
3.1.3	Worked Example: The Doomsday Model	40
3.2	Modified Gravity Models	44
3.2.1	$f(R)$ Gravity Models	44
3.2.2	DPG Gravity Model	45
3.2.3	The Cardassian Model	46
3.3	A Cosmological Constant	47
4	Observational Method I: Type Ia Supernovae as Dark Energy Probe	51
4.1	Type Ia Supernovae as Distance Indicators	51

4.2	Possible Causes of Observational Diversity in SNe Ia	56
4.3	Supernova Rate	57
4.4	Systematic Effects	61
4.4.1	Extinction	62
4.4.2	K-Correction	64
4.4.3	Weak Lensing	66
4.4.4	Other Systematic Uncertainties of SNe Ia	71
4.5	Data Analysis Techniques	73
4.5.1	Light Curve Fitting	73
4.5.2	Flux-Averaging Analysis of SNe Ia	76
4.5.3	Uncorrelated Estimate of $H(z)$	79
4.6	Forecast for Future SN Ia Surveys	83
4.7	Optimized Observations of SNe Ia	86
5	Observational Method II: Galaxy Redshift Surveys as Dark Energy Probe	91
5.1	Baryon Acoustic Oscillations as Standard Ruler	91
5.2	BAO Observational Results	93
5.3	BAO Systematic Effects	97
5.3.1	Nonlinear Effects	98
5.3.2	Redshift-Space Distortions	99
5.3.3	Scale-Dependent Bias	101
5.4	BAO Data Analysis Techniques	103
5.4.1	Using the Galaxy Power Spectrum to Probe BAO	104
5.4.2	Using Two-Point Correlation Functions to Probe BAO	114
5.5	Future Prospects for BAO Measurements	119
5.6	Probing the Cosmic Growth Rate Using Redshift-Space Distortions	124
5.6.1	Measuring Redshift-Space Distortion Parameter β	124
5.6.2	Measuring the Bias Factor	128
5.6.3	Using $f_g(z)$ and $H(z)$ to Test Gravity	132
5.7	The Alcock–Paczynski Test	134
6	Observational Method III: Weak Lensing as Dark Energy Probe	135
6.1	Weak Gravitational Lensing	135
6.2	Weak Lensing Observational Results	142
6.3	Systematics of Weak Lensing	147
6.3.1	Point Spread Function Correction	148
6.3.2	Other Systematic Uncertainties	154
6.4	Future Prospects for the Weak Lensing Method	157
6.5	The Geometric Weak Lensing Method	159
6.5.1	Linear Scaling and Off-Linear Scaling	160
6.5.2	Implementation of the Linear Scaling Geometric Method	161
7	Observational Method IV: Clusters as Dark Energy Probe	163
7.1	Clusters and Cosmology	163
7.2	Cluster Abundance as a Dark Energy Probe	164

7.2.1	Theoretical Cluster Mass Function	164
7.2.2	Cluster Mass Estimates	166
7.2.3	Cluster Abundance Estimation	172
7.2.4	Cosmological Parameters Constraints	175
7.3	X-Ray Gas Mass Fraction as a Dark Energy Probe	179
7.4	Systematic Uncertainties and Their Mitigation	182
8	Other Observational Methods for Probing Dark Energy	185
8.1	Gamma Ray Bursts as Cosmological Probe	185
8.1.1	Calibration of GRBs	185
8.1.2	Model-Independent Distance Measurements from GRBs	190
8.1.3	Impact of GRBs on Dark Energy Constraints	193
8.1.4	Systematic Uncertainties	195
8.2	Cosmic Expansion History Derived from Old Passive Galaxies	196
8.3	Radio Galaxies as Cosmological Probe	198
8.4	Solar System Tests of General Relativity	202
9	Basic Instrumentation for Dark Energy Experiments	205
9.1	Telescope	205
9.2	NIR Detectors	210
9.3	Multiple-Object Spectroscopic Masks	213
10	Future Prospects for Probing Dark Energy	219
10.1	Designing the Optimal Dark Energy Experiment	219
10.2	Evaluating Dark Energy Experiments	222
10.3	Current Status and Future Prospects	225
References		229
Index		239

