Modern Cosmology / Scott Dodelson

Contents

The Standard Model and Beyond p. 1
The Expanding Universe p. 1
The Hubble Diagram p. 7
Big Bang Nucleosynthesis p. 9
The Cosmic Microwave Background p. 13
Beyond the Standard Model p. 14
Summary p. 19
Exercises p. 21
The Smooth, Expanding Universe p. 23
General Relativity p. 23
The Metric p. 24
The Geodesic Equation p. 28
Einstein Equations p. 32
Distances p. 33
Evolution of Energy p. 37
Cosmic Inventory p. 40
Photons p. 40
Baryons p. 41
Matter p. 42
Neutrinos p. 44
Dark Energy p. 47
Epoch of Matter-Radiation Equality p. 50
Summary p. 51
Exercises p. 53
Beyond Equilibrium p. 58
Boltzmann Equation for Annihilation p. 59
Big Bang Nucleosynthesis p. 62
Neutron Abundance p. 65
Light Element Abundances p. 68
Recombination p. 70
Dark Matter p. 73
Summary p. 78
Exercises p. 80
The Boltzmann Equations p. 84
The Boltzmann Equation for the Harmonic Oscillator p. 85
The Collisionless Boltzmann Equation for Photons p. 87
Zero-Order Equation p. 93
First-Order Equation p. 94
Collision Terms: Compton Scattering p. 95
The Boltzmann Equation for Photons p. 100
The Boltzmann Equation for Cold Dark Matter p. 102
The Boltzmann Equation for Baryons p. 106
Summary p. 110
Exercises p. 113
Einstein Equations p. 117
The Perturbed Ricci Tensor and Scalar p. 117
Christoffel Symbols p. 118
Ricci Tensor p. 119
Two Components of the Einstein Equations p. 121
Tensor Perturbations p. 124
Christoffel Symbols for Tensor Perturbations p. 125
Ricci Tensor for Tensor Perturbations p. 127
Einstein Equations for Tensor Perturbations p. 129
The Decomposition Theorem p. 131
From Gauge to Gauge p. 132
Summary p. 135
Exercises p. 136
Initial Conditions p. 139
The Einstein-Boltzmann Equations at Early Times p. 139
The Horizon p. 142
Inflation p. 144
A Solution to the Horizon Problem p. 146
Negative Pressure p. 151
Implementation with a Scalar Field p. 151
Gravity Wave Production p. 155
Quantizing the Harmonic Oscillator p. 156
Tensor Perturbations p. 157
Scalar Perturbations p. 162
Scalar Field Perturbations around a Smooth Background p. 162
Super-Horizon Perturbations p. 164
Spatially Flat Slicing p. 169
Summary and Spectral Indices p. 170
Exercises p. 175
Inhomogeneities p. 180
Prelude p. 180
Three Stages of Evolution p. 182
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>185</td>
</tr>
<tr>
<td>Large Scales</td>
<td>189</td>
</tr>
<tr>
<td>Super-horizon Solution</td>
<td>189</td>
</tr>
<tr>
<td>Through Horizon Crossing</td>
<td>192</td>
</tr>
<tr>
<td>Small Scales</td>
<td>194</td>
</tr>
<tr>
<td>Horizon Crossing</td>
<td>195</td>
</tr>
<tr>
<td>Sub-horizon Evolution</td>
<td>199</td>
</tr>
<tr>
<td>Numerical Results and Fits</td>
<td>203</td>
</tr>
<tr>
<td>Growth Function</td>
<td>205</td>
</tr>
<tr>
<td>Beyond Cold Dark Matter</td>
<td>207</td>
</tr>
<tr>
<td>Baryons</td>
<td>208</td>
</tr>
<tr>
<td>Massive Neutrinos</td>
<td>209</td>
</tr>
<tr>
<td>Dark Energy</td>
<td>210</td>
</tr>
<tr>
<td>Exercises</td>
<td>212</td>
</tr>
<tr>
<td>Anisotropies</td>
<td>216</td>
</tr>
<tr>
<td>Overview</td>
<td>217</td>
</tr>
<tr>
<td>Large-Scale Anisotropies</td>
<td>223</td>
</tr>
<tr>
<td>Acoustic Oscillations</td>
<td>224</td>
</tr>
<tr>
<td>Tightly Coupled Limit of the Boltzmann Equations</td>
<td>224</td>
</tr>
<tr>
<td>Tightly Coupled Solutions</td>
<td>227</td>
</tr>
<tr>
<td>Diffusion Damping</td>
<td>230</td>
</tr>
<tr>
<td>Inhomogeneities to Anisotropies</td>
<td>234</td>
</tr>
<tr>
<td>Free Streaming</td>
<td>234</td>
</tr>
<tr>
<td>The $C_{l}$'s</td>
<td>239</td>
</tr>
<tr>
<td>The Anisotropy Spectrum Today</td>
<td>242</td>
</tr>
<tr>
<td>Sachs-Wolfe Effect</td>
<td>242</td>
</tr>
<tr>
<td>Small Scales</td>
<td>245</td>
</tr>
<tr>
<td>Cosmological Parameters</td>
<td>248</td>
</tr>
<tr>
<td>Curvature</td>
<td>249</td>
</tr>
<tr>
<td>Degenerate Parameters</td>
<td>251</td>
</tr>
<tr>
<td>Distinct Imprints</td>
<td>253</td>
</tr>
<tr>
<td>Exercises</td>
<td>256</td>
</tr>
<tr>
<td>Probes of Inhomogeneities</td>
<td>261</td>
</tr>
<tr>
<td>Angular Correlations</td>
<td>262</td>
</tr>
<tr>
<td>Peculiar Velocities</td>
<td>270</td>
</tr>
<tr>
<td>Direct Measurements of Peculiar Velocities</td>
<td>271</td>
</tr>
<tr>
<td>Redshift Space Distortions</td>
<td>275</td>
</tr>
<tr>
<td>Galaxy Clusters</td>
<td>282</td>
</tr>
<tr>
<td>Exercises</td>
<td>289</td>
</tr>
<tr>
<td>Weak Lensing and Polarization</td>
<td>292</td>
</tr>
</tbody>
</table>
Gravitational Distortion of Images p. 293
Geodesics and Shear p. 296
Ellipticity as an Estimator of Shear p. 300
Weak Lensing Power Spectrum p. 302
Polarization: The Quadrupole and the Q/U Decomposition p. 310
Polarization from a Single Plane Wave p. 313
Boltzmann Solution p. 320
Polarization Power Spectra p. 323
Detecting Gravity Waves p. 326
Exercises p. 331
Analysis p. 336
The Likelihood Function p. 337
Simple Example p. 337
CMB Likelihood p. 340
Galaxy Surveys p. 343
Signal Covariance Matrix p. 344
CMB Window Functions p. 345
Examples of CMB Window Functions p. 347
Window Functions for Galaxy Surveys p. 350
Summary p. 354
Estimating the Likelihood Function p. 356
Karhunen-Loeve Techniques p. 356
Optimal Quadratic Estimator p. 362
The Fisher Matrix: Limits and Applications p. 368
CMB p. 368
Galaxy Surveys p. 370
Forecasting p. 371
Mapmaking and Inversion p. 375
Systematics p. 378
Foregrounds p. 378
Mode Subtraction p. 384
Exercises p. 389
Solutions to Selected Problems p. 392
Numbers p. 415
Physical Constants p. 415
Cosmological Constants p. 416
Special Functions p. 418
Legendre Polynomials p. 418
Spherical Harmonics p. 418
Spherical Bessel Functions p. 419