

CONTENTS

A	Cosmology and the dynamics of the Universe	1
A.1	Physics on cosmological scales	1
A.2	Newtonian gravity	2
A.3	Newtonian cosmology	5
B	Gravity and concepts of relativity	7
B.1	Metric structure of spacetime	7
B.2	Metric and inner products	8
B.3	Vectors and covariant derivatives	9
B.4	Geodesics and autoparallelity	12
B.5	Spacetime curvature	14
B.6	Covariant divergence	16
B.7	Geodesic deviation: experiencing curvature	17
B.8	Curvature invariants and curvature tensors	18
B.9	Raychaudhuri-equation	19
B.10	Energy-momentum tensor	22
B.11	Equation of state for ideal fluids	23
B.12	Relativistic fluid mechanics	24
C	FLRW-cosmologies	27
C.1	Dynamics of spacetime	27
C.2	Light propagation on a FLRW-spacetime and redshift	28
C.3	Evolution of the Hubble-expansion with time	30
C.4	Field equation: coupling gravity to matter	31
C.5	FLRW-spacetimes and their dynamics	31
C.6	Gravitating fluids and their associated dynamics	33
C.7	Redshift and the Hubble-expansion	33
C.8	Continuity equation and general relativity	35
C.9	Construction of FLRW-universes for ideal fluids	36
C.10	Cosmological distance measures	37
C.11	Age of FLRW-universes	39
C.12	Causal structure of FLRW-spacetimes and cosmological horizons	40
D	Observations of FLRW-dynamics	43
D.1	Hubble-Lemaître constant H_0	43
D.2	Spatial curvature Ω_K	43
D.3	Supernova measurements and acceleration q	43
D.4	(Finite) age of the Universe t_0	44
E	Thermodynamics and cosmology	47
E.1	Temperature evolution and FLRW-dynamics	47
E.2	Cosmic microwave background	48
E.3	Into and out of equilibrium	50
E.4	Photon background as a thermodynamical ensemble	52
E.5	Quantum-statistics and classical statistics	56
E.6	Radiation backgrounds	57
E.7	Particle cosmology	58
E.7.1	Baryogenesis	59
E.7.2	Big bang nucleosynthesis	59

F	Early universe and cosmic inflation	63
F.1	Need for inflation and scales	63
F.2	Why is accelerated expansion (and stopping it) so difficult?	64
F.3	Quintessence and dynamic dark energy	66
F.4	Gravity of the quintessence field	68
F.5	Slow-roll approximation	71
F.6	Accelerated expansion in the late Universe	73
F.7	Seeding of cosmic structures in inflation	73
G	Fluid mechanics	75
G.1	fluid mechanics as a continuum theory	75
G.2	From relativistic to non-relativistic fluid mechanics	75
G.3	Continuity	77
G.4	Navier-Stokes equation	77
G.5	Ideal versus viscous fluid mechanics	78
G.5.1	Bulk and shear viscosity	79
G.5.2	Viscous fluid mechanics	80
G.6	Fluid mechanical similarity and scaling relations	81
G.7	Gravity and the Poisson-equation	82
G.8	Wave-type solutions and the Jeans-scale	82
G.9	Vorticity equation	84
G.10	Effective processes in collisionless systems	85
H	Cosmic structure formation	87
H.1	Structure formation equations	87
H.2	Linearised equations on an expanding background	88
H.3	Peculiar velocity field	89
H.4	Linear structure formation	90
H.5	Nonlinear structure formation	92
H.6	Eulerian perturbation theory	93
H.7	Dark matter in astrophysical systems	95
H.7.1	Rotation curves of galaxies	95
H.7.2	Virial equilibria of clusters of galaxies	96
H.7.3	Gravitational lensing	97
H.8	Properties of dark matter	100
H.9	Spherical collapse of dark matter haloes	100
H.10	Mass function of dark matter haloes	102
I	Statistics in cosmology	105
I.1	Statistical description of structure and random fields	105
I.2	Fluctuations on the sky and Limber-projections	108
I.3	Cosmic microwave background anisotropies	111
I.4	Secondary anisotropies in the cosmic microwave background	111
I.4.1	Gravitational lensing of the CMB	111
I.4.2	Thermal and kinetic Sunyaev-Zel'dovich effect	115
I.4.3	Integrated Sachs-Wolfe effect	116
I.5	Weak gravitational lensing by the large-scale structure	117
I.6	Bayes-inference in cosmology	120