

Contents

Preface IX

Abbreviations and Acronyms XI

Astronomical and Physical Constants XV

Color Plates XVII

1	The Observational Picture of AGN	1
1.1	From <i>Welteninseln</i> to AGN	1
1.2	Broad Lines, Narrow Lines, and the Big Blue Bump	3
1.3	Jets and Other Outflows	4
1.4	X-ray Observations: Probing the Innermost Regions	5
1.5	Up, Up and Away: from Gamma-Rays toward the TeV Range	7
2	Radiative Processes	11
2.1	Scattering of Photons	11
2.1.1	Thomson Scattering	11
2.1.2	Compton Scattering	12
2.1.3	Inverse Compton Scattering	15
2.1.4	Thermal Bremsstrahlung	17
2.1.5	Pair Production	20
2.2	Synchrotron Emission	21
2.2.1	Synchrotron Emission of a Particle Plasma	25
2.2.2	Polarization	27
2.2.3	Faraday Rotation	28
2.2.4	Synchrotron Self-Absorption	29
2.2.5	Synchrotron Self-Compton	32
3	The Central Engine	35
3.1	The Black Hole	35
3.1.1	Approaching a Black Hole	36
3.1.2	Evidence for Black Holes in AGN	37
3.1.3	Gravitational Field Near a Black Hole: the Schwarzschild Metric	42
3.1.4	Rotating Black Holes: the Kerr Metric	43
3.2	Accretion Processes	44

3.2.1	Accretion Basics: Bondi Accretion and the Eddington Limit	46
3.2.2	Accretion and Viscous Dissipation in a Thin Disk	48
3.2.3	Accretion in Thick Disks	51
3.2.4	Advection-Dominated Accretion Flows	52
3.3	Absorption Close to the Black Hole	54
3.3.1	The Torus Model	57
3.3.2	Mass Loss in AGN	59
3.4	Photoionization Modeling	63
3.5	Narrow and Broad-Line Regions	65
3.6	Reverberation Mapping: Probing the Scale of the BLR	73
3.7	AGN Jets: Emission, Dynamics and Morphologies	77
3.7.1	Raising the Jet	80
3.7.2	Shocks and Knots	84
3.7.3	Superluminal Motion	85
4	AGN Types and Unification	89
4.1	Seyfert Galaxies	89
4.1.1	Optical Classification	90
4.1.2	HII Regions	93
4.1.3	X-ray Classification	95
4.1.4	Narrow-Line Seyfert 1 Galaxies	96
4.2	Low-Luminosity AGN	99
4.3	Ultraluminous X-ray Sources	101
4.4	Ultraluminous Infrared Galaxies – ULIRGs	105
4.5	Radio Galaxies	106
4.6	Quasars	111
4.6.1	Radio-Quiet Quasars	113
4.6.2	Radio-Loud Quasars	115
4.7	Blazars	116
4.8	Unification of AGN	120
4.8.1	Absorbed versus Unabsorbed AGN	122
4.8.2	Radio-Loud versus Radio-Quiet	128
4.8.3	Breaking the Unification	132
4.8.4	Grand Unification of Black Holes in the Universe	136
5	AGN through the Electromagnetic Spectrum	141
5.1	Radio: Probing the Central Engine	141
5.2	Infrared: Dust Near and Far	145
5.3	Optical: Where It All Began	150
5.4	UV: The Obscured Inner Disk	156
5.5	X-rays: Absorption, Reflection, and Relativistically Altered Line Profiles	162
5.5.1	AGN in the X-ray from 1965 to the 1990s	162
5.5.2	Today and Future X-ray Missions	166
5.5.3	The X-ray Spectrum of AGN	169
5.6	Gamma Rays: the Blazar-Dominated Sky	177

5.7	VHE: the Evolving Domain	182
5.7.1	The High-Energy End of the Spectrum	188
5.8	The Whole Picture: the Spectral Energy Distribution	188
5.8.1	SED of Blazars: a Whole Different Story	191
5.8.1.1	The One-Zone Model	193
5.8.1.2	External Compton Scattering	197
5.8.2	The Spectral Energy Distribution of Nonbeamed Sources	200
5.8.2.1	The Synchrotron Branch	201
5.8.2.2	Dust in the SED	202
5.8.2.3	The Disk Component	203
5.8.2.4	The Inverse Compton Branch	205
6	AGN Variability	209
6.1	Variability in Radio-Quiet AGN	209
6.2	Analysis Methods for Variability Studies	212
6.3	Variability of Radio-Loud AGN	220
6.4	Quasiperiodic Oscillations in AGN	225
6.5	Rapid Variability	228
7	Environment	231
7.1	Host Galaxies of AGN	231
7.1.1	Are There Naked Black Holes?	232
7.1.2	Morphological Classification of Galaxies	232
7.1.3	Host Galaxy and Black Hole Mass	237
7.1.4	AGN-Host Galaxy Feedback	240
7.2	The AGN–Starburst Connection	242
7.2.1	Estimating the Star-Formation Rate	243
7.2.2	AGN–Starburst Feedback	244
7.3	Merging	247
7.4	AGN in Clusters of Galaxies	252
8	Quasars and Cosmology	259
8.1	The Universe We Live in	259
8.1.1	Geometry and Distances	260
8.1.2	Measuring Fluxes	265
8.1.3	The Three-Component Universe	267
8.1.4	From the Big Bang to the Cosmic Microwave Background	269
8.1.5	The Dark Matter Universe	271
8.2	AGN and the Distribution of Matter on Large Scales	272
9	Formation, Evolution and the Ultimate Fate of AGN	281
9.1	The First AGN: How Did They Form?	281
9.2	Tools to Study AGN Evolution	286
9.2.1	The Number-Flux Relation	286
9.2.2	The $V/V_{\max}$ Test	288
9.2.3	Luminosity Function	290
9.3	Luminosity Functions of AGN	294

9.4	AGN and the Cosmic X-ray Background	300
9.5	The Late Stages of an AGN's Life and Reignition SMBH	304
10	What We Don't Know (Yet)	307
10.1	The Central Engine	307
10.2	Environment, Interaction, and Feedback	311
10.3	Origin, Evolution, and Fate	312
10.4	Continuing the Quest	313
	References	315
	Index	347