

# AN INTRODUCTION TO ACTIVE GALACTIC NUCLEI

BRADLEY M. PETERSON

*Department of Astronomy, The Ohio State University*



# Contents

<i>Preface</i>	xi
<i>Acknowledgements</i>	xv
<b>1 Basic Properties and a Brief Historical Perspective</b>	1
1.1 Seyfert Galaxies	1
1.2 Radio Surveys and Quasars	5
1.3 Properties of Quasars	8
1.3.1 Radio Properties of Quasars	10
1.3.2 Variability	13
1.3.3 Ultraviolet Fluxes	14
1.3.4 Broad Emission Lines	14
1.3.5 Quasar Redshifts	16
1.4 Radio-Quiet Quasars	18
<b>2 Taxonomy of Active Galactic Nuclei</b>	21
2.1 Seyfert Galaxies	21
2.2 Quasars	23
2.3 Radio Galaxies	24
2.4 LINERs	24
2.5 BL Lac Objects and Optically Violent Variables	27
2.6 Narrow-Line X-Ray Galaxies	28
2.7 Related Phenomenology	28
2.7.1 Starburst Galaxies	28
2.7.2 Markarian Galaxies	28
2.7.3 Zwicky Galaxies and N Galaxies	29
2.7.4 Ultraluminous Far-Infrared Galaxies	29
2.8 The Relationship Between Seyferts and Quasars	29
<b>3 The Black-Hole Paradigm</b>	32
3.1 Mass of the Central Object	32
3.2 Fueling Quasars	34
3.3 Accretion-Disk Structure	36
3.4 Alternatives to Black Holes	38

<b>4 Continuum Emission</b>	40
4.1 Ultraviolet–Optical Continuum	43
4.2 High-Energy Spectra	49
4.3 Infrared Continuum	56
4.4 Radio Continuum	57
4.4.1 Compact Radio Sources	58
4.4.2 Superluminal Motion	59
4.5 Blazar Spectra	63
<b>5 The Broad-Line Region</b>	67
5.1 Broad-Line Spectra	67
5.2 Basic Parameters	70
5.3 Photoionization of the BLR	75
5.4 Broad-Line Profiles	78
5.4.1 Logarithmic Profiles	78
5.4.2 Line Asymmetries and Wavelength Shifts	81
5.5 Reverberation Mapping	82
5.6 The BLR Velocity Field	87
5.7 Cloud Properties	88
5.8 Line–Continuum Correlations	90
5.8.1 The Balmer Lines	90
5.8.2 The Baldwin Effect	91
<b>6 The Narrow-Line Region</b>	93
6.1 Narrow-Line Spectra	93
6.2 Physical Conditions in Low-Density Gases	95
6.2.1 Electron Densities	95
6.2.2 Electron Temperatures	99
6.3 Basic Parameters	101
6.4 Narrow-Line Profiles	103
6.5 Morphology of the Narrow-Line Region	106
<b>7 Unified Models of AGNs</b>	110
7.1 Unification Ideas and Principles	111
7.2 Evidence for Unification in Seyferts	112
7.3 Statistical Tests for Unification	118
7.4 Results of Unification Studies	120
7.4.1 Radio-Quiet Objects	120
7.4.2 Radio-Loud Objects	121
7.4.3 ‘Grand Unification’ and the Relationship Between Radio-Quiet and Radio-Loud AGNs	123
<b>8 The Environment of AGNs</b>	126
8.1 Host Galaxies	126

8.1.1 Host-Galaxy Morphology	126
8.1.2 Surface-Brightness Profiles and Luminosities	128
8.1.3 Relationships Between AGNs and Their Hosts	129
8.2 Nearby Companions	133
8.3 Galaxy Mergers and Starbursts	134
<b>9 The Geometry of the Expanding Universe</b>	135
9.1 The Metric	135
9.1.1 The Cosmological Redshift	137
9.1.2 The Expansion Parameter	139
9.1.3 Distance Measures	140
9.2 The Friedmann–Lemaître Equations	141
9.3 Time Dependence of Cosmological Parameters	145
9.4 Transformations Between Reference Frames	152
9.4.1 Redshifted Spectra	152
9.4.2 Geometrical Effects	154
<b>10 Quasar Surveys</b>	157
10.1 Basic Principles of QSO Surveys	159
10.1.1 Expected Number Counts	159
10.1.2 Problems with Flux-Limited Samples	161
10.1.3 The Eddington Bias	162
10.1.4 Survey Selection Functions	164
10.2 Color Selection	165
10.2.1 $K$ -Corrections	165
10.2.2 Color-Induced Biases	167
10.2.3 Color-Selected QSOs	169
10.3 Slitless Spectroscopy	171
10.4 Other Selection Methods	173
10.5 The Surface Density of QSOs	174
<b>11 The Quasar Luminosity Function and Evolution</b>	175
11.1 Simple Tests for Evolution	175
11.1.1 The Log $N$ – Log $S$ Test in a Non-Euclidean Universe	175
11.1.2 Results of the Log $N$ – Log $S$ Test	178
11.1.3 The Luminosity–Volume Test	179
11.1.4 Results of the Luminosity–Volume Test	182
11.2 The QSO Luminosity Function	183
11.3 QSO Evolution	186
11.3.1 Mass Accretion on Cosmological Time Scales	186
11.3.2 Evolution of the AGN Population	189
<b>12 Quasar Absorption Lines</b>	194
12.1 Absorption-Line Physics	195

12.2 Basic Characteristics	200
12.3 Broad Absorption-Line QSOs	204
12.4 Absorption-Line Statistics	206
12.4.1 The Comoving Number Density of Absorbers	206
12.4.2 Characteristics of the Absorbers	209
12.5 Galaxies as Absorbers	210
12.6 The Intergalactic Medium	212
12.6.1 The Gunn-Peterson Test	212
12.6.2 Ionization of the Intergalactic Medium	214
<i>References</i>	217
<i>Bibliography</i>	229
<i>Index</i>	232