

# EXTREME ENVIRONMENT ASTROPHYSICS

<b>Introduction</b>	<b>9</b>
---------------------	----------

<b>Chapter 1 Accretion power</b>	<b>11</b>
----------------------------------	-----------

Introduction	11
1.1 Accretion as a source of energy	11
1.1.1 Accretion luminosity	11
1.1.2 Accretion discs	13
1.1.3 Accretion efficiency	15
1.2 Black hole accretors	15
1.2.1 Schwarzschild black holes	15
1.2.2 Rotating black holes	17
1.3 Accreting systems	18
1.3.1 Interacting binary stars	18
1.3.2 Active galactic nuclei	26
1.4 Radiation from accretion flows	30
1.4.1 Temperature of an accreting plasma	30
1.4.2 Continuum emission	31

<b>Chapter 2 Formation and evolution of accretion-powered binaries</b>	<b>40</b>
--	-----------

Introduction	40
2.1 Binary stars	40
2.2 The Roche-lobe radius	42
2.3 Steady-state mass transfer	45
2.4 Nuclear-driven mass transfer	50
2.5 Mass transfer driven by angular momentum losses	53
2.6 Mass transfer stability	55
2.7 Common envelope evolution	57
2.8 Neutron star and black hole formation	60
2.8.1 Neutron star binaries	60
2.8.2 Black hole binaries	62
2.9 Double degenerates and mergers	62

<b>Chapter 3 Steady-state accretion discs</b>	<b>68</b>
---	-----------

Introduction	68
3.1 A coordinate system for accretion discs	69
3.2 Viscosity and its causes	70
3.2.1 Stress, strain and viscosity	70
3.2.2 Viscous torque and dissipation	72

3.3	Conservation laws	76
3.3.1	Conservation of mass	77
3.3.2	Conservation of angular momentum	78
3.4	Radial structure of steady-state discs	79
3.4.1	The boundary layer	80
3.4.2	The steady-state surface density	81
3.4.3	The accretion disc luminosity	82
3.4.4	The accretion disc temperature profile	84
3.5	The vertical disc structure	85
3.6	Shakura–Sunyaev discs	88

## Chapter 4 Accretion disc outbursts 94

	Introduction	94
4.1	Viscous diffusion	95
4.2	Hierarchy of timescales	98
4.2.1	The dynamical time	98
4.2.2	The thermal time	99
4.2.3	The viscous time	100
4.2.4	Thermal instability	103
4.3	Disc instabilities	103
4.3.1	Viscous instability	103
4.3.2	Thermal–viscous instability	105
4.4	Dwarf novae and soft X-ray transients	106
4.5	Limit cycles and disc outbursts	109
4.5.1	Generating the S-curve	111
4.5.2	Local instability and limit cycle	113
4.5.3	Global instability	115
4.5.4	Link to observations	116

## Chapter 5 Indirect imaging of accreting systems 121

	Introduction	121
5.1	Compact binaries as laboratories to study accretion	121
5.1.1	CVs or X-ray binaries?	121
5.1.2	Continuum emission from accretion discs	122
5.1.3	Emission lines from accretion discs	123
5.2	Eclipse mapping	128
5.3	Doppler tomography	131
5.4	The broad-line region in AGN	137
5.4.1	The echo-mapping idea	140
5.4.2	Reverberation mapping applied to AGN	143

**Chapter 6 High-energy radiation from relativistic accretors** 147
*by Robin Barnard*

Introduction	147
6.1 An X-ray view of the Universe	147
6.2 The Eddington limit	150
6.3 Analyzing X-ray spectra	154
6.3.1 Thermal emission	155
6.3.2 Non-thermal emission	155
6.3.3 X-ray absorption	157
6.4 Time variability in accreting systems	159
6.4.1 Analyzing light curves	159
6.4.2 Frequency analysis of variations in the light curve	162
6.5 Observed X-ray variability	166
6.5.1 X-ray bursts	166
6.5.2 Periodic intensity dips	168
6.5.3 Stochastic variability: organized chaos	172
6.6 Ultraluminous X-ray sources	177
6.6.1 Intermediate-mass black holes	178
6.6.2 Are ULXs beamed like pulsars?	179
6.6.3 Extended emission	180
6.7 From X-ray binaries to AGN	180
6.7.1 Spectral and timing properties	181
6.7.2 Fluorescence: measuring the black hole spin	182

**Chapter 7 Relativistic outflows** 186
*by Hara Papathanassiou*

Introduction	186
7.1 Outflow conditions and types of outflow	186
7.1.1 Winds	187
7.1.2 Explosive outflows	187
7.1.3 Relativistic outflows	188
7.2 Relativistic effects	189
7.2.1 Lorentz transformations	189
7.2.2 Special relativistic effects on lengths and durations	191
7.2.3 Relativistic beaming	192
7.2.4 Superluminal motion	196
7.2.5 Doppler effect	197
7.2.6 Luminosity boosting	199

## Contents

7.3	Energy extraction and emission	200
7.3.1	Jet formation and collimation	200
7.3.2	Dissipation in the flow	200
7.3.3	Relativistic shocks	203
7.3.4	Non-thermal radiative processes	206
<b>Chapter 8    Gamma-ray bursts</b>		<b>215</b>
by Hara Papathanassiou		
	Introduction	215
8.1	Discovery and breakthroughs	215
8.2	Observed properties	216
8.2.1	Prompt emission	217
8.2.2	Afterglows	222
8.3	Constraints on GRB models	226
8.4	The fireball model	229
8.4.1	Relativistic expansion and transparency	229
8.4.2	Dissipation within the flow: prompt emission	232
8.4.3	Braking the fireball: afterglow	232
8.4.4	Jet effects and late evolution	235
8.5	The central engine	237
8.5.1	Progenitors	237
8.5.2	Energy extraction	240
8.6	Other signatures and applications	240
<b>References and further reading</b>		<b>246</b>
<b>Appendix</b>		<b>250</b>
<b>Solutions</b>		<b>252</b>
<b>Acknowledgements</b>		<b>279</b>
<b>Index</b>		<b>282</b>