

Contents

<i>Preface</i>	<i>page</i> xi
1 Introduction	
1.1 Rudimentary definitions and concepts	1
1.2 Jet presence and function	4
1.3 Early history	5
1.4 Surprising discoveries	8
1.5 Overview and points of view	10
1.6 Summary	15
2 Detection and measurement	
2.1 Synchrotron radiation	17
2.2 Self-absorption and polarisation	20
2.3 Compton processes	22
2.4 Electrons: free-free and bremsstrahlung processes	23
2.5 Atomic processes	23
2.6 Molecular processes	25
2.7 Maser beams	26
2.8 Power and size	27
2.9 Summary	28
3 The dynamical toolbox	
3.1 The inviscid hydrodynamic equations	29
3.2 Viscosity	31
3.3 Magnetohydrodynamics	32
3.4 Steady jets as potential flows	34
3.5 Streamlines: rotating MHD flow	35
3.6 Special relativistic flow	37
3.7 Shock waves	40
3.7.1 Relativistic shock waves	41
3.7.2 Non-relativistic shock waves	43
3.7.3 Radiative shock waves	45
3.8 Non-ideal MHD and non-MHD	47
3.9 Summary	49
	vii

viii **Contents**

4	Observations of extragalactic jets	50
4.1	The morphological classes of radio galaxies	51
4.1.1	Edge-brightened and edge-darkened	51
4.1.2	Wide-angled tails	56
4.1.3	Narrow-angled tails	59
4.1.4	Classical doubles	61
4.1.5	Lobe-dominated quasars	62
4.1.6	Relaxed doubles	63
4.2	Detailed structure and multiwavelength features	65
4.2.1	X-ray cavities and relics	65
4.2.2	Hot spots	66
4.2.3	Optical and X-ray jets	67
4.3	Host galaxies and triggering jets	68
4.4	Summary	69
5	Jets in galactic nuclei	70
5.1	Individual blazar jets	71
5.1.1	3C 279	71
5.1.2	3C 273	74
5.1.3	M 87	78
5.2	Speed and Doppler boosting	82
5.3	The class of blazar jets	84
5.4	Variability and temperature	85
5.5	The Lorentz factor crisis	88
5.6	Polarisation	89
5.7	Summary	89
6	Jets from young stars and protostars	91
6.1	Optical jets	92
6.1.1	The HH 30 jets	94
6.1.2	The RW Aur jet	96
6.1.3	The DG Tau jet	98
6.1.4	Optical jets: general results	101
6.2	Embedded protostellar jets	103
6.2.1	HH 34 and HH 111	105
6.2.2	Deeply embedded jets: HH 211 and HH 212	110
6.3	Termination: Herbig–Haro and molecular hydrogen objects	114
6.4	Bipolar outflows	117
6.5	Small-scale jets: radio and masers	118
6.6	Summary	119
7	Jets associated with evolved stars	121
7.1	Planetary nebulae	121
7.2	Symbiotic systems	124
7.3	Supersoft X-ray sources	129
7.4	Cataclysmic variables	131
7.5	Microquasars: XRB jet systems	131

Contents

ix

7.5.1	Low-mass X-ray binaries	132
7.5.2	High-mass X-ray binaries	133
7.5.3	Microquasars	135
7.5.4	SS 433	136
7.6	Pulsar jets	138
7.7	Gamma-ray bursts	140
7.8	Summary	143
8	Jets within the solar system	144
8.1	Cometary jets, pre-2000	144
8.2	Cometary jets, post-2000	146
8.3	Moon jets	151
8.4	Solar jets	153
8.5	Summary	156
9	Jet launching	157
9.1	Hydrodynamic methods	158
9.1.1	Hydrodynamic methods: nozzles	158
9.1.2	Hydrodynamic methods: discs	162
9.1.3	Hydrodynamic methods: vents	163
9.2	Jets via magnetic reconnection	168
9.2.1	Spicules	169
9.2.2	Coronal jets	171
9.3	Magnetic field methods	172
9.3.1	Hydromagnetic driving from rotating discs	172
9.3.2	Magnetocentrifugal quantities	174
9.3.3	X-winds	176
9.3.4	Spinning black holes	179
9.3.5	Poynting jets	180
9.4	Alternative models and mechanisms	182
9.4.1	MHD simulations	182
9.4.2	Magnetic towers and funnels	182
9.4.3	ADAF jets: ion-supported flows	183
9.4.4	The disc–jet connection	183
9.4.5	Radiation-driven jets	184
9.5	Summary	184
10	Jet propagation	186
10.1	Components and structure	186
10.2	Jet shapes	190
10.3	Jet disruption	193
10.4	Jet flares and knots	195
10.5	Instability	197
10.6	Changing direction	200
10.6.1	Precession and wiggling	200
10.6.2	Bending	201
10.7	Summary	202

x ***Contents***

11	The astrophysical jet	203
11.1	Composition	203
11.2	Regulation	205
11.3	Feedback	206
11.4	Unification	206
11.5	The future	207
 <i>References</i>		209
<i>Index</i>		224