

Contents

Preface *XI*

1	Historical Overview	1
1.1	Discovery of the First Pulsating Variable Stars	1
1.1.1	Nomenclature	5
1.2	The Recognition of Pulsation as a Cause of Variability	8
2	Fundamentals of Stellar Variability Observations	11
2.1	Definitions	11
2.1.1	Time and Julian Dates	11
2.1.2	Light Curves	14
2.2	Photometric Bandpasses	16
2.3	Period Determination	16
2.4	Common Observational Techniques	20
2.4.1	Visual Methods	20
2.4.2	Photographic Methods	22
2.4.3	Photoelectric Methods	24
2.4.4	CCD Surveys	25
2.5	Space-Based Versus Ground Observations	27
3	Classification of Variable Stars	29
3.1	Regular, Semi-Regular, and Irregular Variables	29
3.2	Variability: Intrinsic and/or Extrinsic	30
3.3	Extrinsic Variables	30
3.3.1	Algol-Type Eclipsing Binaries (EAs)	30
3.3.2	β Lyrae-Type Eclipsing Binaries (EBs)	32
3.3.3	W UMa-Type Eclipsing Binaries (EWs)	32
3.3.4	R-Type Binaries	32
3.3.5	Planetary Transits and Asteroid Occultations	33
3.4	Intrinsic Variables	34
3.4.1	Rotational Variables	34
3.4.1.1	Ap Stars (α^2 CVn Stars)	34
3.4.1.2	Spotted W UMa, β Lyr, and Algol Systems	36

3.4.1.3	RS Canum Venaticorum Stars	36
3.4.1.4	BY Dra Stars	37
3.4.1.5	FK Com Stars	38
3.4.1.6	Ellipsoidal Variables	38
3.4.2	Eruptive Variables	39
3.4.2.1	UV Ceti Stars	39
3.4.2.2	FU Orionis (FUor) Stars	39
3.4.2.3	EX Lupi (EXor) Stars	40
3.4.2.4	T Tauri Stars	40
3.4.2.5	Herbig Ae/Be Stars	40
3.4.2.6	Luminous Blue Variables	41
3.4.2.7	Wolf–Rayet Stars	41
3.4.2.8	R Coronae Borealis (R CrB) Variables	42
3.4.2.9	γ Cassiopeiae (Be) Stars	43
3.4.3	Explosive and Novalike Variables	44
3.4.3.1	Cataclysmic Variables	44
3.4.3.2	Symbiotic Stars	47
3.4.3.3	Supernovae	48
3.4.4	Pulsating Variables and the Scope of this Book	50
4	Stellar Structure and Evolution Theory	53
4.1	The Basic Equations of Stellar Structure and Evolution	53
4.2	The Evolution of Low-Mass Stars	57
4.3	The Evolution of Intermediate-Mass Stars	66
4.4	The Evolution of High-Mass Stars	70
5	Stellar Pulsation Theory	73
5.1	Timescales	73
5.2	Ritter's (Period–Mean Density) Relation	76
5.3	Basic Equations of (Radial) Stellar Pulsation Theory	78
5.3.1	Generalization of the Energy Conservation Equation	78
5.3.2	Summary	81
5.4	Linearization of the Stellar Pulsation Equations	81
5.4.1	Perturbation Theory	82
5.4.2	The Continuity Equation	83
5.4.3	The Conservation of Momentum Equation	84
5.4.4	The Energy Conservation Equation	85
5.4.5	The Energy Transfer Equation	86
5.4.6	Constitutive Equations	86
5.5	Linear Adiabatic Oscillations: The LAWE	87
5.5.1	Justification of the Adiabatic Approximation	88
5.5.2	The LAWE	90
5.5.3	Boundary Conditions	92
5.6	Eigenvalues and Eigenfunctions of the LAWE	95
5.6.1	Examples	98

5.6.1.1	The Homologous Case	99
5.6.1.2	The Polytropic Case	99
5.6.1.3	An Actual RR Lyrae Model	102
5.7	Non-Adiabatic Theory: Conditions for Stability	105
5.8	The Linear Non-Adiabatic Wave Equation	109
5.9	Driving Mechanisms	113
5.9.1	The ϵ Mechanism	114
5.9.2	The κ and γ Mechanisms	117
5.9.3	The “Opacity Bump” Mechanism	120
5.10	Stability Conditions and Instability Strip Edges	123
5.10.1	Other Instability Mechanisms	124
5.10.1.1	Convective Blocking Mechanism	124
5.10.1.2	Convective Driving (δ Mechanism)	124
5.10.1.3	Stochastically Excited Pulsations	125
5.10.1.4	Tidally Excited Pulsations	129
5.10.1.5	Gravitational Waves	129
5.10.1.6	Stellar Mergers	130
5.10.1.7	Sunquakes and Starquakes: Flare-Driven Oscillations	130
5.11	Non-Radial Pulsations	130
5.11.1	Theoretical Framework; Helio- and Asteroseismological Applications	131
5.12	Nonlinear Effects	153
6	RR Lyrae Stars	157
6.1	RR Lyrae Stars as a Class of Pulsating Variable Star	157
6.2	RR Lyrae Stars as Standard Candles	164
6.3	Evolution of RR Lyrae Stars	167
6.4	Pulsation	168
6.5	The Blazhko Effect	169
6.6	RR Lyrae Stars in Globular Clusters	172
6.7	The Oosterhoff Groups	173
6.8	Period Changes	177
6.9	RR Lyrae Stars beyond the Milky Way	181
7	Cepheid and Related Variable Stars	183
7.1	Classical Cepheids	183
7.1.1	Cepheid Light Curves	185
7.1.2	The Period Luminosity Relation: Leavitt’s Law	189
7.1.3	Evolution and Period Changes	192
7.1.4	Polaris	195
7.2	Type II Cepheids	196
7.2.1	Light Curves	200
7.2.2	Spectra and Chemical Composition	203
7.2.3	Period–Luminosity Relation	204
7.2.4	Evolution and Period Changes	206

7.3	BL Boo Stars or Anomalous Cepheids	208
7.4	RV Tauri Stars	211
8	Red Variable Stars	215
8.1	Convection and Pulsation	217
8.2	Mira and Related Long-Period Variables	219
8.3	Semi-Regular Variables	229
8.4	Irregular Variables	231
9	Pulsating Stars Close to the Lower Main Sequence in the H-R Diagram	233
9.1	δ Scuti and SX Phoenicis Stars	233
9.2	γ Doradus Stars	240
9.3	roAp Stars	242
10	Pulsating Stars Close to the Upper Main Sequence in the H-R Diagram	245
10.1	β Cephei Stars	248
10.2	SPB (53 Per) Stars	251
11	Pulsating Supergiant Stars	253
11.1	SPBsg Variables	253
11.2	PV Telescopii, V652 Herculis, and R CrB Stars	256
11.3	α Cygni, S Dor, and Wolf-Rayet Stars	258
12	Hot Subdwarf Pulsators	263
12.1	EC 14026 (V361 Hya, sdBV, sdBV _p , sdBV _r) Variables	268
12.2	PG 1716+426 (V1093 Her, “Betsy,” sdBV _g , sdBV _s) Variables	269
12.3	sdOV (V499 Ser) Variables	270
12.4	He-sdBV Stars	272
13	Pulsating Degenerate Stars	275
13.1	GW Vir Stars	285
13.2	DBV (V777 Her) Stars	287
13.3	DQV Stars	290
13.4	DAV Stars	292
13.4.1	ELM-DAV Stars	294
13.4.2	Hot DAV Stars	296
13.5	ELM-HeV Stars	298
13.6	GW Librae Stars: Accreting WD Pulsators	300
13.7	Pulsations in Neutron Stars and Black Holes	302
	Glossary	305
	References	311
	Index	411