Contents

Preface ix
Acknowledgements xii

Part I Dynamic systems – general 1

1 Introduction to Part I 3

2 Astrophysical examples 8
2.1 Stellar population dynamics 8
2.2 One-zone model of a nonlinear stellar pulsator 12
2.3 Stellar orbits in a model galactic potential 21
2.4 One-element model of thermal convection 28
2.5 Patterns in a thermally unstable medium 32

3 Mathematical properties of dynamical systems 40
3.1 Local geometrical properties 42
3.2 Global attributes of dynamical systems 71
3.3 Elements of bifurcation theory 83
3.4 Dynamical systems near marginality 93
3.5 Fractal sets and dimensions 102

4 Properties of chaotic dynamics 112
4.1 Strange attractors 113
4.2 Sensitivity to initial conditions 118
4.3 Fractal properties of chaotic motion 125
4.4 Transition to chaos 128
4.5 Bifurcations of homoclinic and heteroclinic orbits 139
4.6 Theoretical predictive criteria of chaos 144

5 Analysis of time series 146
5.1 Time histories and Fourier spectra 148
5.2 The pseudo-state space and embedding 158
5.3 The embedding dimension and the time delay 162

6 Regular and irregular motion in Hamiltonian systems 168
6.1 Properties of Hamiltonian systems 169
6.2 Integrable systems 180
6.3 Nearly integrable systems and the KAM theorem 185
6.4 Chaos in Hamiltonian systems 191

7 Extended systems – instabilities and patterns 201
7.1 Linear instabilities 205
7.2 General qualitative properties of pattern-forming systems 209
7.3 Amplitude and envelope equations 212
7.4 Phase equations and coherent structures 221
7.5 Defects and spatio-temporal complexity in 1D systems 227
7.6 Defects in multidimensional systems 243
7.7 Coupled map lattices 251

Part II Astrophysical applications 255

8 Introduction to Part II 257

9 Planetary, stellar and galactic dynamics 260
9.1 The $n$-body problem – a historical note 262
9.2 Chaotic dynamics in the Solar System 267
9.3 Chaos and the evolution of tidal-capture binaries 299
9.4 The role of chaos in stellar and galactic dynamics 305

10 Irregularly variable astronomical point sources 317
10.1 Observed aperiodic astronomical signals 319
10.2 Nonlinear stellar pulsators – some specific models 328
10.3 A dynamical-system approach to stellar pulsation 332
10.4 Some models of accreting systems 340

11 Complex spatial patterns in astrophysics 347
11.1 Spatial structures in the interstellar medium 348
11.2 The large-scale structure of the Universe 370

12 Topics in astrophysical fluid dynamics 381
12.1 Basic concepts and equations 383
12.2 Special flows and their properties 392
12.3 Hydrodynamical stability 404
12.4 Thermal convection and the Lorentz model 422
12.5 Hamiltonian formulations and related topics 431

References 444
Index 451