

Contents

Modeling Physical Processes at Galactic Scales and Above	1
Nickolay Y. Gnedin	
1 In Lieu of Introduction	1
2 Physics of the IGM	2
2.1 Linear Hydrodynamics in the Expanding Universe	2
2.2 Lyman- α Forest	4
2.3 Modeling the IGM	13
2.4 What Observations Tell Us	15
3 From IGM to CGM	21
3.1 Large Scale Structure	21
3.2 How Gas Gets onto Galaxies	24
3.3 Cool Streams	25
3.4 Galactic Halos	27
3.5 Diversion: Cooling of Rarefied Gases	29
3.6 Back to Galactic Halos	35
4 ISM: Gas in Galaxies	38
4.1 Galaxy Formation Lite	38
4.2 Galactic Disks	40
4.3 Ionized, Atomic, and Molecular Gas in Galaxies	44
4.4 Molecular ISM	52
5 Star Formation	63
5.1 Kennicutt-Schmidt and All, All, All	63
5.2 Excursion Set Formalism in Star Formation	70
6 Stellar Feedback	72
6.1 What Escapes from Stars	73
6.2 Unconventional Marriage: Feedback and Star Formation	77
6.3 Toward the Future	80
7 Answers to Brain Teasers	80
References	82

Physical Processes in the Interstellar Medium	85
Ralf S. Klessen and Simon C.O. Glover	
1 Introduction	85
2 Composition of the ISM	88
2.1 Gas	88
2.2 Dust	91
2.3 Interstellar Radiation Field	93
2.4 Cosmic Rays	97
3 Heating and Cooling of Interstellar Gas	100
3.1 Optically-Thin Two-Level Atom	100
3.2 Effects of Line Opacity	105
3.3 Multi-level Systems	108
3.4 Atomic and Molecular Coolants in the ISM	110
3.5 Gas-Grain Energy Transfer	119
3.6 Computing the Dust Temperature	123
3.7 Photoelectric Heating	125
3.8 Other Processes Responsible for Heating	127
4 ISM Turbulence	132
4.1 Observations	132
4.2 Simple Theoretical Considerations	142
4.3 Scales of ISM Turbulence	148
4.4 Decay of ISM Turbulence	151
4.5 Sources of ISM Turbulence: Gravity and Rotation	153
4.6 Sources of ISM Turbulence: Stellar Feedback	158
5 Formation of Molecular Clouds	164
5.1 Transition from Atomic to Molecular Gas	164
5.2 Importance of Dust Shielding	175
5.3 Molecular Cloud Formation in a Galactic Context	178
6 Star Formation	183
6.1 Molecular Cloud Cores as Sites of Star Formation	183
6.2 Statistical Properties of Stars and Star Clusters	189
6.3 Gravoturbulent Star Formation	194
6.4 Theoretical Models for the Origin of the IMF	196
6.5 Massive Star Formation	209
6.6 Final Stages of Star and Planet Formation	211
7 Summary	214
References	218
 High Performance Computing and Numerical Modelling	251
Volker Springel	
1 Preamble	251
2 Collisionless N-Body Dynamics	252
2.1 The Hierarchy of Particle Distribution Functions	252
2.2 The Relaxation Time—When Is a System Collisionless?	255

2.3	N-Body Models and Gravitational Softening	257
2.4	N-Body Equations in Cosmology	258
2.5	Calculating the Dynamics of an N-Body System	259
3	Time Integration Techniques	260
3.1	Explicit and Implicit Euler Methods	261
3.2	Runge-Kutta Methods	262
3.3	The Leapfrog	263
3.4	Symplectic Integrators	264
4	Gravitational Force Calculation	267
4.1	Particle Mesh Technique	268
4.2	Fourier Techniques	276
4.3	Multigrid Techniques	283
4.4	Hierarchical Multipole Methods (“tree Codes”)	292
4.5	TreePM Schemes	296
5	Basic Gas Dynamics	298
5.1	Euler and Navier-Stokes Equations	298
5.2	Shocks	301
5.3	Fluid Instabilities	302
5.4	Turbulence	305
6	Eulerian Hydrodynamics	309
6.1	Solution Schemes for PDEs	309
6.2	Simple Advection	310
6.3	Riemann Problem	314
6.4	Finite Volume Discretization	317
6.5	Godunov’s Method and Riemann Solvers	319
6.6	Extensions to Multiple Dimensions	321
6.7	Extensions for High-Order Accuracy	323
7	Smoothed Particle Hydrodynamics	326
7.1	Kernel Interpolation	326
7.2	SPH Equations of Motion	329
7.3	Artificial Viscosity	332
7.4	New Trends in SPH	334
8	Moving-Mesh Techniques	336
8.1	Differences Between Eulerian and Lagrangian Techniques	336
8.2	Voronoi Tessellations	336
8.3	Finite Volume Hydrodynamics on a Moving-mesh	338
9	Parallelization Techniques and Current Computing Trends	341
9.1	Hardware Overview	341
9.2	Amdahl’s Law	346
9.3	Shared Memory Parallelization	347
9.4	Distributed Memory Parallelization with MPI	352
	References	355
	Index	359