

Contents

1	Tides: A Tutorial	1
	Tadashi Tokieda	
1.1	What These Notes Do	1
1.2	Reference Data	2
1.3	Gravitation	3
1.3.1	Why $1/r^2$?	3
1.3.2	Attraction by a Spherical Shell	5
1.3.3	Attraction by a Solid Ball	8
1.3.4	Legendre Polynomials	9
1.3.5	Approximation Formulae for Bodies of Arbitrary Shape	10
1.4	Tides—Static Picture	12
1.4.1	Plan	12
1.4.2	Tidal Potential and Tidal Force	13
1.4.3	Shape of the Ocean	14
1.4.4	What About the Sun?	18
1.5	Tides—Dynamic Picture	18
1.5.1	Forced Oscillator	18
1.5.2	Free Oscillation of the Ocean	20
1.6	Astronomical Applications	22
1.6.1	Tidal Tearing	22
1.6.2	Tidal Locking	24
1.6.3	Tidal Dissipation	25
1.6.4	Visit to the Horizon	29
2	Investigations of Tides from the Antiquity to Laplace	31
	Vincent Deparis, Hilaire Legros, and Jean Souchay	
2.1	Introduction	31
2.2	Study of Tides in the Antiquity	32
2.3	Variety of Theories in the Middle Ages	35
2.4	Tides in the Renaissance and the 17th Century	37
2.4.1	Renaissance	37

2.4.2	Kepler's Views	38
2.4.3	Galileo: An Original Concept	39
2.5	Descartes and His Theory of Vortices	41
2.6	Newton and the Gravitational Attraction: A Giant Step	43
2.6.1	The Solar Perturbation on the Orbital Motion of the Moon	44
2.6.2	Ocean Tides	47
2.6.3	Assessment of Newton's Contribution	53
2.7	Theory of Tides and Analytical Calculations Around 1740	54
2.7.1	Prize of the Académie of 1740 for Bernoulli	55
2.7.2	Prize of Académie of 1740 for Euler	59
2.8	D'Alembert and His 'Reflexions sur la Cause Générale des Vents'	63
2.8.1	Mechanics of Surface Layer of Fluid	64
2.8.2	Self-gravity of the Fluid Surface Layer	65
2.9	Laplace's Masterpiece	66
2.9.1	Development of Analytical Mechanics	67
2.9.2	The Equations of 1775 and 1776	68
2.9.3	Conservation of Mass	70
2.9.4	Complementary Acceleration due to the Rotation of the Earth	71
2.9.5	A Decisive Innovation: Spherical Harmonics	71
2.9.6	Tidal Potential	72
2.9.7	Potential for Self-gravity	73
2.9.8	Dynamical Equations with Spherical Harmonics	73
2.9.9	Oscillation of the Fluid Layer in Case of a Static Earth	74
2.9.10	Hydrostatic Equilibrium	75
2.9.11	Three Species of Oscillation	76
2.10	Methodology, Organization, and Analysis of Observations	77
2.10.1	Semi-empirical Methods Based on Partial Flows	78
2.10.2	Determination of the Amplitudes and Phases of the Partial Flows	79
2.10.3	Determination of the Ratio of Lunar/Solar Tides	79
2.10.4	Laplace and Atmospheric Tides	79
2.11	Conclusion on Laplace's Work	80
2.12	Overall Conclusion	80
	References	81
3	Oceanic Tides	83
	Bernard Simon, Anne Lemaitre, and Jean Souchay	
3.1	Introduction	83
3.2	Basic Mathematical Tidal Theory	86
3.2.1	Tidal Potential	86
3.2.2	Tidal Force	88
3.3	Expression of the Tidal Potential for the Earth	89
3.3.1	Zonal Part of the Tidal Potential	89
3.3.2	Tesseral Part of the Tidal Potential	90
3.3.3	Sectorial Part of the Tidal Potential	91

3.3.4	Components of the Local Tidal Force	91
3.4	Doodson Expansion of the Tidal Potential	92
3.4.1	Previous Expansions of the Lunisolar Potential	92
3.4.2	Doodson’s Constant	93
3.4.3	Basic Principle	94
3.4.4	Six Fundamental Variables	94
3.4.5	Preliminary Expansions of Astronomical Trigonometric Functions	95
3.5	Tidal Spectrum	97
3.5.1	Characterization of the Semi-diurnal Waves	97
3.5.2	Characterization of the Diurnal Waves	98
3.5.3	Characterization of the Long Periodic Waves	99
3.5.4	Catalogue for the Lunisolar Potential	100
3.6	Tidal Behavior and Predictions Around the World	102
3.6.1	Global Characteristics	102
3.6.2	Tide Amplitudes in the Oceans	103
3.6.3	Tide Characterization	103
3.6.4	Amphidromic Points	104
3.6.5	Tidal Curves	105
3.6.6	Tidal Curves According to Tidal Types	107
3.6.7	Tides in Shallow Water	108
3.6.8	Spectral Characteristics of Tides	110
3.6.9	Tidal Currents	113
	References	114
4	Precession and Nutation of the Earth	115
	Jean Souchay and Nicole Capitaine	
4.1	Introduction	115
4.2	A Simple Geometric Explanation	117
4.2.1	Precession-Nutation due to the Sun	117
4.2.2	Precession-Nutation due to the Moon	121
4.2.3	Global Motion of the Pole of Rotation in Space	121
4.3	A Basic Mathematical Proof of the Precession-Nutation Phenomena	122
4.3.1	Reference Frames and Parametrization	122
4.3.2	Expression of the Tidal Torque	123
4.3.3	Expression of the Solar Torque	125
4.3.4	Expression for the Lunar Torque	126
4.3.5	Equations for the Rotational Motion of the Earth	127
4.4	Alternative Theories of Precession-Nutation for a Rigid Earth Model	132
4.4.1	Dynamical Equations of the Rotation of the Rigid Earth with Lagrangian Formalism	133
4.4.2	Dynamical Equations of the Rotation of the Rigid Earth with Hamiltonian Formalism	138
4.4.3	The Determination of the Disturbing Potential U	143

4.4.4	Generic Formula for the Expressions of the Nutations $\Delta\psi$ and $\Delta\varepsilon$	146
4.5	Modern Precession-Nutation Theories for a Rigid Earth Model	147
4.5.1	The Construction of a Highly Accurate Rigid Earth Precession-Nutation Model	148
4.6	Modern Nutation Theory for a Non-rigid Earth Model	153
4.6.1	Definition of Prograde and Retrograde Circular Nutations	153
4.6.2	Early Non-rigid Earth Nutation Theories	154
4.6.3	The Nutation Series of Wahr	155
4.6.4	Further Improvements	156
4.6.5	The Normal Modes of the Rotation of the Earth	156
4.7	The IAU 2006/2000 Precession Nutation	158
4.7.1	The IAU 2000 (MHB2000) Nutation	158
4.7.2	The MHB2000 Nutation Series	161
4.7.3	The IAU 2006 (P03) Precession	162
4.7.4	The Agreement of the IAU 2006/2000 Precession-Nutation with Highly Accurate VLBI Observations	163
	References	165
5	Tides on Satellites of Giant Planets	167
	Nicolas Rambaux and Julie Castillo-Rogez	
5.1	Introduction	167
5.2	Tidal Potential	171
5.3	Tidal Dynamics	175
5.3.1	Introduction	175
5.3.2	Transfer of Angular Momentum	176
5.3.3	Tides Raised on the Satellites	178
5.4	Static Tides and the Shape of the Moons	184
5.4.1	Introduction	184
5.4.2	Moments of Inertia	185
5.4.3	Satellite Shapes	187
5.4.4	Gravity and Shape Observations	188
5.5	Internal Stress	191
5.5.1	Introduction	191
5.5.2	Tidal Heating from Mechanical Energy Dissipation	192
5.5.3	A Hot Satellite: Io	193
5.5.4	Cryovolcanism	195
5.5.5	Tidally Driven Tectonics	196
5.6	Conclusion	196
	References	197
6	Recent Developments in Planet Migration Theory	201
	Clément Baruteau and Frédéric Masset	
6.1	Introduction	201
6.2	Physical Model and Notation	203
6.3	Migration of Low-Mass Embedded Planets: Type I Migration	205
6.3.1	Differential Lindblad Torque	205

- 6.3.2 Corotation Torque 210
- 6.3.3 Saturation Properties of the Horseshoe Drag 225
- 6.3.4 Type I Migration in Turbulent Discs 230
- 6.4 Migration of Gap-Opening Planets: Type II and III Migration . . . 232
 - 6.4.1 Shock Formation and Gap-Opening Criterion 232
 - 6.4.2 Partial Gap-Opening: Type III Migration in Massive Discs . . 234
 - 6.4.3 Deep Gap-Opening: Type II Migration 238
- 6.5 Planet Migration Theories and Observed Diversity of Exoplanets . 241
 - 6.5.1 Massive Planets at Large Orbital Separations 242
 - 6.5.2 Planet Population Syntheses 245
- 6.6 Conclusions 246
- References 247

- 7 Tides in Planetary Systems 255**
 Stéphane Mathis, Christophe Le Poncin-Lafitte, and Françoise Remus
 - 7.1 Introduction 256
 - 7.2 Advanced Tidal Dynamics 256
 - 7.2.1 Gravitational Potentials 257
 - 7.2.2 Equations of Motion 267
 - 7.3 Tidal Dissipation Mechanisms in Planetary Systems 279
 - 7.3.1 The Tidal Kinetic Energy Dissipation: The Driver of Systems Evolution 279
 - 7.3.2 Tidal Dissipation in Fluid Bodies 279
 - 7.3.3 Tidal Dissipation in Rocky or Icy Planetary Regions 293
 - 7.3.4 Boundary Conditions 294
 - 7.3.5 Hierarchy Between Dissipative Physical Processes and the Associated Obtained States 297
 - 7.4 Conclusion 297
 - References 298

- 8 Stellar Tides 301**
 Jean-Paul Zahn
 - 8.1 Introduction 301
 - 8.2 Equilibrium States 302
 - 8.3 The Equilibrium Tide 304
 - 8.3.1 A Crude Estimate of the Tidal Torque 304
 - 8.3.2 Turbulent Convection: The Most Powerful Mechanism for Tidal Dissipation 306
 - 8.3.3 Which Prescription for Fast Tides? 307
 - 8.3.4 The Quality Factor 309
 - 8.3.5 Beyond the Weak Friction Approximation 310
 - 8.4 Confronting the Theory of the Equilibrium Tide with the Observations 312
 - 8.4.1 Solar-Type Binaries on the Main Sequence 312
 - 8.4.2 Orbital Circularization During the Pre-Main-Sequence Phase 313

8.4.3	Circularization of Binaries Evolving off the Main-Sequence	314
8.5	The Dynamical Tide	316
8.5.1	Gravity Modes Excited by a Close Companion	316
8.5.2	Circularization of Massive Binaries	318
8.5.3	Resonance Locking in Early-Type Binaries	320
8.5.4	Resonance Locking in Late-Type Binaries	320
8.6	Tidal Damping Through Inertial Modes	321
8.7	Conclusion and Perspectives	322
	References	324
9	Tides in Colliding Galaxies	327
	Pierre-Alain Duc and Florent Renaud	
9.1	Preliminary Remarks	327
9.2	Historical Context	328
9.2.1	Discovery of Peculiarities	329
9.2.2	A Controversial Scenario	329
9.2.3	Tidal Origin	331
9.2.4	Forty Years of Numerical Simulations	332
9.3	Theory of the Tidal Tail Formation in Interacting Galaxies	336
9.3.1	Gravitational Potential and Tidal Tensor	337
9.3.2	Compressive Tides	338
9.3.3	Formation of Tidal Tails and Bridges	339
9.3.4	Gas Dynamics	341
9.3.5	Influence of the Internal and Orbital Parameters	342
9.3.6	Rings, Ripples, Shells, and Warps	344
9.3.7	Differences with Tides at Other Scales	345
9.4	Multi-wavelength Observations of Tidal Tails	345
9.4.1	Where the Mass Is: Atomic Hydrogen in Tidal Tails	346
9.4.2	When Components Are Missing: H I Without Optical Counterparts; Stellar Tails Without Gas	347
9.4.3	Sparse Components: Molecular Clouds, Dust, and Heavy Elements	350
9.5	Structure Formation in Tidal Tails	352
9.5.1	Star Formation	352
9.5.2	Star Cluster Formation	353
9.5.3	Formation of Tidal Dwarf Galaxies	354
9.6	Tidal Structures as Probes of Galaxy Evolution	355
9.6.1	Determining the Merger Rate Evolution with Tidal Tails	357
9.6.2	Determining the Mass Assembly History of Galaxies with Tidal Tails	359
9.6.3	Constraining the Distribution of Dark Matter with Tidal Tails	359
9.7	Conclusions	361
	References	362
	Index	371



<http://www.springer.com/978-3-642-32960-9>

Tides in Astronomy and Astrophysics

Souchay, J.; Mathis, S.; Tokieda, T. (Eds.)

2013, XII, 375 p. 138 illus., 60 illus. in color., Softcover

ISBN: 978-3-642-32960-9