Table of contents

List of Participants 5

Preface 11

Double-diffusive processes in stellar astrophysics 13
Pascale Garaud

1 Introduction 13
2 Linear instability of double-diffusive systems 15
2.1 Model setup 15
2.2 Linear stability properties of homogeneous double-diffusive systems 17
2.3 Where is fingering convection likely to occur in stars? 22
2.4 Where is ODDC/semiconvection likely to occur is stars? 22
2.5 Beyond linear theory 24
3 Mixing by fingering convection 25
3.1 Traditional models of "thermohaline" mixing 25
3.2 Numerical simulations of small-scale fingering convection 26
3.3 The Brown et al. 2013 model for small-scale fingering convection 29
3.4 Large-scale instabilities? 31
3.5 Conclusions for now 35
3.6 Applications to stellar astrophysics 36
4 Oscillatory double-diffusive convection and layered convection 38
4.1 Traditional models of mixing by ODDC 38
4.2 Numerical simulations of ODDC 41
4.3 Transport in non-layered ODDC 42
4.4 Criterion for layer formation 44
4.5 Mixing in layered convection 47
4.6 Conclusions for now 48
4.7 Applications to stellar astrophysics 49
5 What next? 50
5.1 Model limitations 51
5.2 More realism 52
References 57

Thermo-compositional adiabatic and diabatic convection 61
Pascal Tremblin

1 Introduction 61
2 Linear stability analysis of adiabatic and diabatic convection 61
2.1 Adiabatic case 61
2.2 Diabatic case 62
3 Non-linear regime and temperature-gradient reduction 62
References 63

Fully compressible time implicit hydrodynamics simulations for stellar interiors 65
Isabelle Baraffe

1 The MUSIC code 65
2 An example of application: convective penetration 66
References 67

Thermal Convection in Stars and in Their Atmosphere 69
Friedrich Kupka

1 Introduction 69
2 Convection in astrophysics and the basic physics of convection 70
2.1 The physics of convection 70
2.2 Examples from astrophysics and geophysics 71
2.3 Astrophysical implications 72
2.4 Local stability analysis for the case of convection 73
2.5 Conservation laws 74
2.6 The challenge of scales 76
3 Modelling of convection 77
3.1 MLT and phenomenological models 77
3.2 Ensemble and volume averages 80
3.3 Reynolds stress approach 81
3.4 Two-scale mass flux models 84
3.5 Comparisons 87
4 Challenges and pitfalls in numerical modelling 88
4.1 General remarks 88
4.2 Uniqueness of numerical solutions 89
4.3 Initial conditions and relaxation 90
4.4 Boundary conditions 91
4.5 Criteria for modelling replacing the quest for parameter freeness 92
4.6 Computability 93
4.7 A comparison 95
5 Applications: overshooting 96
5.1 Overshooting 96
5.2 Modelling non-locality 98
5.3 The DA white dwarfs 99
5.4 3D simulations of overshooting 99
5.5 The role of the Péclet number 101
5.6 Previous research and a deep DA WD simulation 103
5.7 Conclusions 104
6 Summary 105
References 105

Turbulence in stably stratified radiative zone 111
François Lignières

1 Introduction 111
2 Stability of parallel shear flows in radiative atmosphere 112
2.1 Unstratified shear flows 113
2.2 Stably stratified shear flows 115
2.3 Stably stratified shear flows in highly diffusive atmosphere 118
3 Turbulent transport 122

3.1 The eddy diffusion hypothesis 123
3.2 Vertical eddy diffusion in stably stratified turbulence at Pr ~ 1 125
3.3 Vertical eddy diffusion due to radial shear in radiative zone 130
3.4 Vertical eddy diffusion in strongly stably stratified turbulence with high thermal diffusivity 136
4 Conclusion 137
References 138

An extremely short course on stellar rotation and magnetism 141
Matthew K. Browning

Preface 141
Lecture 1: An introduction to stellar rotation and magnetism 142
A breezy tour of observational techniques 143
Some observational punchlines and motivating puzzles 144
Some order-of-magnitude estimates about stars 146
Summary of the first lecture 149
Lecture 2: Descriptive MHD, and some limiting cases in fluid mechanics 149
The only equations we will solve 149
Dimensionless numbers and the momentum equation 151
Dimensionless numbers and the induction equation 153
Equations for a thin layer, and geostrophic balance 154
Descriptive MHD 155
Example: shaking of coronal loops 156
Example: magnetospheres and accretion onto a magnetized star 157
Lecture 3: an introduction to dynamo theory 159
The minimum Rm for growth 159
Stretching and amplification 160
Is stretching enough? A brief survey of anti-dynamo theorems 161
Qualitative building blocks of dynamo action 162
Mean-field dynamo theory and the link to helicity 164
Closing remarks: simulations, open issues, and a biased summary 166
References 168

Stellar magnetism: bridging dynamos and winds 171
Allan Sacha Brun and Antoine Strugarek

1 Introduction 171
2 A brief summary of what is a star 172
3 Mean-field model of stellar dynamo and nonlinear aspects 172
4 Stellar wind: extensions of the Parker model 177
5 Coupling dynamo and stellar wind on dynamical and secular timescales: a perspective 183
6 Conclusion 186
References 187
7 Solutions of the exercises 189

Multi-dimensional asteroseismology 195
Daniel Roy Reese

1 Introduction 195
2 Impact of rotation on stellar structure and evolution 196
2.1 Structural changes 196
2.2 Baroclinic effects 197
3 Calculating pulsations 198
3.1 The non-rotating case 198
3.2 The rotating case 199
4 The effects of rotation on pulsations 200
4.1 Gravito-inertial modes 201
4.2 Acoustic modes 202
5 Asteroseismology 204
5.1 Frequency patterns 204
5.2 Mode identification techniques 205
5.3 Observed stars 206
6 Conclusion 207
References 208

Multi-dimensional physics of core-collapse supernovae 213
Jérôme Guilet

1 Introduction 213
2 Hydrodynamic instabilities 214
2.1 Ledoux convection inside the protoneutron star 214
2.2 Double diffusive convection? 215
2.3 Neutrino-driven convection in the post-shock layer 216
2.4 Standing accretion shock instability (SASI) 217
2.5 Corotation instability (aka low-T/W instability) 219
2.6 g-mode excitation 220
3 Magnetic field origin and impact 220
3.1 Slow-rotating standard supernovae 221
3.2 Fast-rotating (extreme?) supernovae 221
4 Conclusion 224
References 224