# Preface

Turbulence has emerged as an important research topic in several areas of astrophysics, ranging from stellar astrophysics to cosmology. In contrast to terrestrial turbulence, astrophysical turbulence encompasses regimes that are hardly accessible by laboratory measurements. Although pure turbulent dynamics is a scale invariant process, invariance is broken by gravity and thermal processes in astrophysical systems. The situation is further complicated by interactions with magnetic fields, chemical processes, and a diversity of different mechanisms of energy injection. Even for the most idealized systems, supersonic flow introduces severe technical and theoretical difficulties. As a consequence, supercomputer simulations became an essential tool to investigate the properties of astrophysical turbulence.

This book focuses on fundamental statistical properties of hydrodynamical turbulence and numerical methods to perform simulations, from which these properties can be inferred. Computational astrophysics has been particularly active in devising such methods in the last decade. Moreover, the advancement of massively parallel computers made compressible turbulence simulations of sufficient numerical resolution feasible. Thereby, a wealth of data was obtained. Although the interpretation of the data is still not settled, many useful insights have been gained. Basically, there are two schools of thought. One school takes it for granted that statistically stationary and homogeneous turbulence must have universal scaling properties, even in the highly compressible regime. Finding universal statistics is a matter of asking the right question in a numerical experiment. Any deviation from non-universality must be due to resolution effects or other external factors that distort the pure nonlinear dynamics of turbulence. The opposing school of thought emphasizes the complexity of astrophysical turbulence. From this point of view, compressible turbulence is a multiparameter system with at least two parameters (the Mach number and the mixture of solenoidal and compressive large-scale modes). Depending on the system parameters, different statistical properties and scaling laws are observed (both in the literal sense and in the sense of analyzing numerical data). With the material included in this book, I make an attempt to ponder both points of views. Possibly, they convey different aspects of the same thing. I decided to restrict the discussion to the context of supersonic isothermal turbulence in star-forming clouds, which is the simplest form of compressible turbulence. In galaxies such as our Milky Way, stars form in molecular clouds, in which the gas is very cold because it cannot cool further. Consequently, the Mach numbers are high. Since the temperature is close to its minimum, it can be assumed to be nearly constant. The importance of magnetic fields in molecular clouds is undisputed, but the numerical treatment of magnetohydrodynamical turbulence introduces many difficulties, which were fully tackled only at recent time. Notwithstanding their astrophysical shortcomings, simulations of purely hydrodynamical turbulence played a substantial role in fundamental studies of supersonic turbulence. The guided tour through theoretical, numerical, and astrophysical topics in this book considers selected examples. By far not all important works are covered or even mentioned. It is up to reader to draw conclusions and to further follow this endeavor. More realistic numerical models will doubtlessly play a central role in future research. This means that an ever increasing number of astrophysical processes are going to be incorporated with great detail into numerical simulations. Hopefully, this will bring us closer to turbulent flow conditions in astrophysical systems, without obscuring the underlying physics by overly complex models. In any case, numerical techniques have to pay tribute to this development by utilizing adaptive methods for self-gravitating and turbulent gas, subgrid scale models for small-scale physics below the resolution limit, and sophisticated solvers for hydrodynamics and magnetohydrodynamics under extreme conditions.

The research presented in this book covers parts of my Habilitation Thesis at the Universities of Würzburg and Göttingen. I am indebted to Jens Niemeyer, who graciously supported my work and encouraged me to follow new ideas, rather than sticking to opinions. I thank my former Ph.D. Supervisor, Wolfgang Hillebrandt, for initiating this publication. I also express my gratefulness to Christian Klingenberg and Karl Mannheim, who accompanied my habilitation with all kind of advice. Many thanks to the Ph.D. students, postdocs, and collaborators, who helped me with countless contributions. In particular, I thank Christoph Federrath and Ralf Klessen for doing a great job in unraveling the mysteries of turbulence in star-forming clouds and trying to make sense of them. For several years now, Alexei Kritsuk has been someone to make me aware of the subtleties of numerics and turbulence theory. This is something of high value. I acknowledge the permissions from Christoph Federrath and Alexei Kritsuk to reuse figures from their articles. Another important partner for discussions has been Patrick Hennebelle. And I met Dave Collins just at the right time to learn more about the relationship between turbulence and gravity, by using his simulation suite. Without naming them, I finally thank all the other colleagues and friends, whose influence is so important to do good research.

Göttingen, May 2013 Wolfram Schmidt

http://www.springer.com/978-3-319-01474-6

Numerical Modelling of Astrophysical Turbulence
Schmidt, W.
2014, VIII, 90 p. 50 illus., 22 illus. in color., Softcover
ISBN: 978-3-319-01474-6