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Siyao Xu

Study on Magnetohydrodynamic Turbulence and Its Astrophysical Applications

Doctoral Thesis accepted by
Peking University, Beijing, China

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Supervisor's Foreword

It is my great pleasure to write a foreword to this impressive dissertation book on magnetohydrodynamic (MHD) turbulence and its astrophysical applications, written by my former student and collaborator, Dr. Siyao Xu. Magnetic fields and turbulence are at the core of all astrophysical fluids. During six years of study at Peking University, China, Dr. Xu published ten first-author papers in leading astrophysical journals as a graduate student. These papers cover a wide range of subjects, from developing fundamental MHD turbulence theories to many applications of the theories to various astrophysical phenomena, including cosmic rays, molecular clouds, interstellar medium (ISM), radio pulsars, fast radio bursts (FRBs), and gamma-ray bursts. These publications contain original contributions to several different fields. The impact of these studies has been already felt by researchers in several different disciplines.

This book is a collection of the selected topics in the above list, with the focus on several projects finished during the last three years of her Ph.D. period. The first two chapters describe her major theoretical work on MHD turbulence in a partially ionized medium (Chap. 1) and small-scale turbulence dynamo (Chap. 2). Both are complicated subjects and previously have been tackled mostly numerically by researchers in the field. She developed innovative analytical tools to solve these problems. In particular, the analytical model of turbulent dynamo presents a major advance in the field. The theory solves a problem previously believed only solvable numerically and makes clear predictions that have been confirmed later by numerical simulations. The next three chapters are astrophysical applications of MHD turbulence theories in ISM (Chap. 3), radio pulsars (Chap. 4), and fast radio bursts (Chap. 5). In Chap. 3, she studied the structure function (SF) of the Faraday rotation measure (RM) of the ISM and developed a method of disentangling magnetic fluctuations from density fluctuations. She proposed a natural interpretation of a feature observed in the SF of ISM RM distribution as the transition from the global Kolmogorov turbulence to supersonic turbulence. Chapters 4 and 5 investigate scatter broadening of radio pulses in radio pulsars and FRBs. In the radio pulsar work, she interpreted a break in the observed dispersion measure—scatter broadening timescale also as due to the transition from the Kolmogorov turbulence to supersonic turbulence. In the FRB work, she interpreted the observed scattering tail of some FRBs as originating from the supersonic turbulence in the host galaxies of the FRBs, consistent with FRBs being born in star-forming galaxies. All three chapters address a self-consistent physical picture invoking supersonic turbulence.

In summary, this is a comprehensive dissertation with breadth, depth, rigor, consistency, and innovative ideas. It will be a good read for students and researchers working in the fields of MHD turbulence, ISM, pulsars, and FRBs. Enjoy!

Las Vegas, USA Prof. Bing Zhang
February 2019

Abstract

Turbulence and magnetic fields are ubiquitous in the universe. Their importance to astronomy cannot be overestimated. The theoretical advancements in magnetohydrodynamic (MHD) turbulence achieved during the past two decades have significantly influenced many fields of astronomy. Constructing predictive theories of the magnetic field amplification by turbulence and the dissipation of MHD turbulence in a partially ionized medium is the core of the thesis. These fundamental nonlinear problems were believed to be tractable only numerically. This thesis provided comprehensive analytical descriptions in quantitative agreement with existing numerics, as well as theoretical predictions in physical regimes still unreachable by simulations, and explanations of various related observations. The thesis further promoted the astrophysical applications of MHD turbulence theories, including interstellar density fluctuations and the effect on observations, e.g., Faraday rotation, scattering measurements of Galactic and extragalactic radio sources; evolution and importance of magnetic fields during the formation of the first stars and in molecular clouds; scattering and diffusion of cosmic rays. It demonstrates the key role of MHD turbulence in connecting diverse astrophysical processes and unraveling long-standing astrophysical problems, as foreseen by Chandrasekhar, a founder of modern astrophysics.

Keywords Magnetohydrodynamics · Turbulence · Turbulent dynamo · Interstellar medium

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