Preface

It is well-known that the Sun is vital to the Earth and human beings because it supplies all the energy we need to survive. Another role that the Sun plays had escaped our attention until recent decades and the advent of space exploration. The Sun not only affects the terrestrial climate, but it also controls the conditions in space, the so-called "space weather", through solar activity. Solar flares, discovered in 1859, are one of the most spectacular phenomena of solar activity. They are natural accelerators that can boost particles to nearly the speed of light. These energetic particles, when arriving in near-earth space, can damage satellites and do harm to astronauts. Solar flares have thus stirred renewed interest of solar and space physicists. They provide a unique laboratory for studying particle acceleration mechanisms in general and investigating solar activity for space weather forecast purposes in particular. Understanding solar flares has other far-reaching implications, and can shed light on flares occurring elsewhere in the universe, such as those on other stars and accretion disks and near black holes.

A rich literature exists describing various aspects of solar flares. This includes several flare-dedicated books: *Solar Flares* by Švestka (1976), *The Physics of Solar Flares* by Tandberg-Hanssen & Emslie (1988), and *Particle Acceleration and Kinematics in Solar Flares* by Aschwanden (2002), and a few space mission motivated conference proceedings: *Solar Flares – A Monograph from Skylab Solar Workshop II* edited by Sturrock (1980), *Energetic Phenomena on the Sun – The Solar Maximum Mission Flare Workshop Proceedings* edited by Kundu & Woodgate (1986), and the upcoming *Solar Flares at High Energy – A RHESSI-inspired Monograph* edited by Dennis, Emslie, Hudson, & Lin (2008). The comprehensive textbook *Physics of the Solar Corona* by Aschwanden (2004) also includes extensive material on solar flares.

Advances in our knowledge of solar flares have been driven by multiwavelength observations obtained by space-borne and ground-based instruments over decades, particularly hard X-rays (HXRs) recorded by *Solar Maximum Mission* (*SMM*), *Hinotori*, *Yohkoh*, and *Compton Gamma Ray Observatory* (*CGRO*). In February 2002 NASA's *Reuven Ramaty High Energy Solar Spectroscopic Imager* (*RHESSI*) was launched. Unprecedented data poured in and new physics waited to be discovered. It was *RHESSI*'s scientific promise that motivated me to devote my PhD research to high-energy physics of solar flares. This led to the production of the materials presented in this work, which includes primarily my dissertation completed in late 2006 at Stanford University. In early 2008, after being approached by the German publisher Verlag Dr. Müller who proposed to publish my dissertation as a monograph, I made necessary revisions (Chapters 4 and 5) and additions (Appendices) based on my postdoctoral research at NASA Goddard Space Flight Center.

The main theme of this book is the investigation of the macro and micro physics of acceleration and transport of particles in solar flares, and their thermal and nonthermal radiative signatures. We have employed a two-pronged approach that relies on both data interpretation and numerical modeling, between which we attempt to bridge with physical concepts and first principles. With the goal to confirm or disprove theoretical models, we draw heavily on results from *RHESSI* HXR observations (Chapters 2–6), because HXRs provide the most useful information on the properties of accelerated electrons. This is complemented by combined Fokker-Planck and hydrodynamic simulations (Chapters 7–9) in an effort to improve our modeling capabilities and to explain new observations.

Our investigation started with a statistical study of limb flares with an emphasis on imaging spectroscopy of loop-top and footpoint X-ray sources (Chapter 2). This survey led to serendipitous discoveries of new physics in four individual flares: (1) the 2003 November 03 X3.9 flare showing correlated loop-top and footpoint source motions (Chapter 3), (2) the 2002 April 30 M1.4 flare exhibiting a rarely observed double coronal X-ray source as evidence of magnetic reconnection (Chapter 4), (3) the 2003 October 29 X10 flare with conjugate footpoints showing unshearing motions, various correlations, and asymmetric characteristics (Chapter 5), and (4) the 2003 November 13 M1.7 flare showing chromospheric evaporation signatures in HXRs (Chapter 6).

Motivated by these *RHESSI* observations, we devoted our modeling efforts to combining the Stanford stochastic acceleration (Fokker-Planck) model with the Naval Research Laboratory flux tube (hydrodynamic) model. As the first successful one of its kind, this combined model simulates, in a self-consistent manner, the interplay of the particle acceleration, transport, and radiation effects, and the atmospheric response to energy deposition by nonthermal electrons during the impulsive phase (Chapter 7). The empirical Neupert effect is tested with a more rigorous calculation of energy contents from this model than previous works (Chapter 8). We also examine the effects of suppression of conduction and/or heating in the presence of hydrodynamic flows during the decay phase (Chapter 9). We conclude this book by recapitulating our main findings, offering a prognosis for future investigation (Chapter 10), and providing a comprehensive description of *RHESSI* data analysis techniques used in this research and other technical details (Appendixes A–C).

This book therefore differs from others in existing literature in the sense that it provides a balanced treatment of observations and models. It is aimed at graduate students or early-career researchers who are acquainted with the basis physics, but need a jump start to grasp the latest development in high-energy aspects of solar flares. Younger readers are referred to the books of Tandberg-Hanssen & Emslie (1988), Aschwanden (2004), and others for an introduction to the required physical context.

Greenbelt, Maryland, May 2008 *Wei Liu*