

# Contents

Preface	ix
Acknowledgements	xi
<b>1 Introduction</b>	<b>1</b>
1.1 Solar Flare Observations and Models . . . . .	1
1.2 Stochastic Particle Acceleration Model . . . . .	2
1.3 Hard X-ray Observations and <i>RHESSI</i> Instruments . . . . .	4
1.4 Introduction to This Book . . . . .	5
1.4.1 <i>RHESSI</i> Observations . . . . .	5
1.4.2 Combining the Fokker-Planck and Hydrodynamic Codes . . . . .	6
<b>2 Statistical Study of <i>RHESSI</i> Limb Flares</b>	<b>8</b>
2.1 Introduction . . . . .	8
2.2 Data Reduction and Analysis . . . . .	9
2.2.1 Sample Selection Criteria . . . . .	9
2.2.2 Imaging . . . . .	11
2.2.3 Imaging Spectra and Light Curves . . . . .	11
2.3 Case Study Results . . . . .	12
2.3.1 Single Loop Flares . . . . .	12
2.3.2 Multiple Loop Flares . . . . .	14
2.3.3 Miscellaneous Types . . . . .	15
2.4 Statistical Results . . . . .	18
2.4.1 Imaging Spectroscopy . . . . .	18
2.4.2 Statistics of the Relative Fluxes: FPs vs. LTs . . . . .	20
2.5 Flare Statistics and Selection Biases . . . . .	20
2.6 Summary and Discussion . . . . .	22
<b>3 Flare Reconnection Model: 2003-11-03 X3.9 Flare</b>	<b>23</b>
3.1 Introduction . . . . .	23
3.2 Observations and Data Analysis . . . . .	24
3.2.1 Source Structure and Motion . . . . .	25
3.2.2 Imaging Spectroscopy . . . . .	27
3.3 Summary and Discussion . . . . .	30

<b>4 Double Coronal Source: 2002-04-30 M1.4 Flare</b>	<b>33</b>
4.1 Introduction . . . . .	33
4.2 Observations and Data Analysis . . . . .	35
4.2.1 Source Structure: Energy Dependence . . . . .	37
4.2.2 Source Structure: Temporal Evolution . . . . .	39
4.2.3 Spectral Evolution . . . . .	42
4.3 Interpretation and Discussion . . . . .	46
4.3.1 Energy Dependence of Source Structure . . . . .	46
4.3.2 Temporal Evolution of Source Structure . . . . .	48
4.3.3 Spectral Characteristics . . . . .	49
4.4 Summary and Discussion . . . . .	50
<b>5 Conjugate HXR Footpoints: 2003-10-29 X10 Flare</b>	<b>53</b>
5.1 Introduction . . . . .	53
5.2 Observations and Data Analysis . . . . .	55
5.2.1 <i>RHESSI</i> Light Curves and Images . . . . .	56
5.2.2 Imaging Spectroscopy of Footpoint and Loop-top Sources . . . . .	59
5.2.3 Multiwavelength Images . . . . .	62
5.3 Two-phase Unshearing Motions of HXR Footpoints . . . . .	62
5.4 Temporal Correlations of Conjugate Footpoints . . . . .	66
5.4.1 Spectral Correlations . . . . .	66
5.4.2 Spatial Correlations . . . . .	70
5.4.3 Magnetic Field Correlation . . . . .	70
5.4.4 Correlations Among Spectral, Spatial, and Magnetic Field Parameters	71
5.4.5 Implications of Various Correlations . . . . .	72
5.5 HXR Footpoint Asymmetries . . . . .	73
5.5.1 Magnetic Mirroring . . . . .	74
5.5.2 Column Density . . . . .	75
5.5.3 Magnetic Mirroring and Column Density Combined . . . . .	78
5.5.4 Other Transport Effects and FP Asymmetries . . . . .	79
5.5.5 Acceleration-induced Asymmetry . . . . .	80
5.6 Summary and Discussion . . . . .	82
<b>6 Chromospheric Evaporation: 2003-11-13 M1.7 Flare</b>	<b>85</b>
6.1 Introduction . . . . .	85
6.2 Observations and Data Analyses . . . . .	86
6.2.1 Source Structure and Evolution . . . . .	89
6.2.2 Spectral Analysis . . . . .	97
6.2.3 The Neupert Effect . . . . .	98
6.3 Loop Density Derivation . . . . .	104
6.4 Summary and Discussion . . . . .	107

<b>7 Modeling Impulsive Phase Solar Flares</b>	<b>109</b>
7.1 Introduction . . . . .	109
7.2 Simulation Models . . . . .	111
7.2.1 Stochastic Acceleration Model . . . . .	111
7.2.2 Particle Transport and Radiation Model . . . . .	115
7.2.3 NRL Hydrodynamic Model . . . . .	117
7.2.4 Combining the Particle and Hydrodynamic Codes . . . . .	118
7.3 Simulation Result . . . . .	122
7.3.1 Case R: Reference Calculation . . . . .	123
7.3.2 Case A: Fiducial Run with SA Model . . . . .	125
7.3.3 Case B: Variable Electron Spectrum . . . . .	134
7.3.4 Case C: Harder Electron Spectrum . . . . .	139
7.3.5 Case D: Smaller Normalization . . . . .	139
7.3.6 Comparing The Cases: A Summary . . . . .	145
7.4 Summary and Discussion . . . . .	147
<b>8 Testing the Neupert Effect</b>	<b>149</b>
8.1 Energy Budget and the Neupert Effect . . . . .	149
8.2 Case R: Reference Calculation . . . . .	151
8.2.1 History of Energy Budget . . . . .	151
8.2.2 Neupert Effect Test . . . . .	153
8.3 Cases A-D: Combined HD & Particle Calculation . . . . .	157
8.3.1 Case A: Fiducial Run with SA Model . . . . .	157
8.3.2 Case B: Variable Electron Spectrum . . . . .	159
8.3.3 Case C: Harder Electron Spectrum . . . . .	160
8.3.4 Case D: Smaller Normalization . . . . .	160
8.4 Summary and Discussion . . . . .	163
<b>9 Hydrodynamic Simulation of the Decay Phase</b>	<b>166</b>
9.1 Introduction . . . . .	166
9.2 Model of Suppression of Conduction and Plasma Heating . . . . .	167
9.3 Numerical Results . . . . .	168
9.3.1 Case A: No Heating or Suppression of Conduction . . . . .	170
9.3.2 Case B: Heating Only . . . . .	172
9.3.3 Case C: Suppression of Conduction Only . . . . .	173
9.3.4 Case D: Heating and Suppression of Conduction . . . . .	174
9.3.5 Comparing Cases A-D . . . . .	176
9.4 Summary and Discussion . . . . .	179
<b>10 Concluding Remarks</b>	<b>180</b>
10.1 Summary and Conclusions . . . . .	180
10.1.1 Hard X-ray Observations . . . . .	180
10.1.2 Combined Fokker-Planck and Hydrodynamic Modeling . . . . .	183
10.2 Future Work . . . . .	184
<b>Appendices</b>	<b>187</b>

<b>A RHESSI Data Analysis Tools</b>	<b>187</b>
A.1 Imaging Spectroscopy Flow Chart . . . . .	187
A.2 Notes for Imaging Spectroscopy . . . . .	190
A.3 Spectral Analysis for 2002-04-30 M1.4 Flare . . . . .	192
A.3.1 Spatially Integrated Spectra . . . . .	192
A.3.2 Spatially Resolved (Imaged) Spectra . . . . .	195
A.4 Effects of Pulse Pileup . . . . .	196
A.4.1 Pileup Effects for 2003-11-13 M1.7 Flare . . . . .	197
A.4.2 Pileup Effects on Imaging Spectroscopy for 2003-10-29 X10 Flare . . . . .	198
A.5 RHESSI Simulation Tool and Its Applications . . . . .	200
<b>B Notes for Analyzing 2003-10-29 X10 Flare</b>	<b>202</b>
B.1 Coalignment of Images from Different Instruments . . . . .	202
B.2 Derivation of Footpoint Fluxes from Asymmetric Column Densities . . . . .	204
B.3 Estimation of Column Densities in Loop Legs . . . . .	205
<b>C Coulomb Loss and Diffusion in Warm Plasmas</b>	<b>208</b>
C.1 Coulomb Loss in Warm Plasmas . . . . .	208
C.2 Coulomb Diffusion in Warm Plasmas . . . . .	210
C.3 Implementation of Coulomb Loss and Diffusion . . . . .	211
C.4 Thermalization Test of Injected Distribution . . . . .	214
<b>List of</b>	<b>215</b>
Tables . . . . .	215
Figures . . . . .	216
<b>Bibliography</b>	<b>219</b>
<b>Index</b>	<b>227</b>
Author Index . . . . .	227
Subject Index . . . . .	229