Final Report

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Time-dependent Ionization in Solar Eruptions

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Abstract
We propose to supply time-dependent ionization modules that can be with magnetohydrodynamics MHD) simulations of solar eruptions. They can be used to compute the ionization states of several elements for comparison with the ionization states measured in space and for computation of the intensities of EUV emission lines observable from Earth-orbiting spacecraft.

Report:

This Grant covered the efforts of Drs. John Raymond and Chengcai Shen in support of NASA LWS grant "Investigating the Origin and Evolution of Magnetic Flux Ropes in the Heliosphere" (Mark Linton, PI). Our original intent was to develop computer code to efficiently compute the time-dependent ionization state and resulting Extreme Ultraviolet emission from large MHD simulations of solar eruptions in post-processing. We accomplished that and went a step farther, developing a module for in-line computations.

Our post-processing code is based on the eigenvalue method, and it uses atomic rates from the CHIANTI database. It is presented in Shen et al. (2015) and is available on github. We tested it with MHD models from the MAS code for models of a steady-flow corona (Shen et al. 2017) and solar flare current sheets (Shen et al. 2013, 2018). It predicts the emission in narrowband images from AIA and UV spectral lines. We showed that time-dependent ionization is very important for the correct interpretation of UV and EUV observations of the Sun.

More recently, we developed an module for in-line calculation of time-dependent ionization and EUV emission and incorporated it into the MAS and Athena MHD codes. This module uses enough computer memory that it requires a modest reduction in grid size, but it has the advantages that it does not require saving frequent snapshots of the simulation and that it permits self-consistent calculation of radiative cooling. So far it has only been presented in an AGU talk (Lionello 2017).

In addition, we have participated in other efforts of the collaboration (Nieves-Chincilla et al. 2018) and in other simulations of solar eruptions and reconnection current sheets (Ye et al. 2019)

In connection with this project, Drs. Raymond or Shen or both attended team meetings in Washington, DC, Ann Arbor, MI, Bozeman, MT, Boston, MA and St. Andrews, UK.

Publications:

"Non-equilibrium Ionization Modeling of the Current Sheet in a Simulated Solar Eruption" Shen, C., Reeves, K.K., Raymond, J.C., Murphy, N.A., Ko, Y.-K., Lin, J., Mikic, Z. & Linker, J.A. 2013, ApJ, 773, 110

"Time-dependent Ionization in a Steady Flow in an MHD Model of the Solar Corona and Wind" Shen, C., Raymond, J.C., Mikic, Z., Linker, J.A., Reeves, K.K. & Murphy, N.A. 2017, ApJ, 850, 26

"Understanding the Internal Magnetic Field Configurations of ICMEs Using More than 20 Years of Wind Observations" Nieves-Chinchilla, T.; Vourlidas, A.; Raymond, J. C.; Linton, M. G.; Al-haddad, N.; Savani, N. P.; Szabo, A.; Hidalgo, M. A. 2018, Sol. Phys., 293, 25

"The Dynamical Behavior of Reconnection-driven Termination Shocks in Solar Flares: Magnetohydrodynamic Simulations", C. Shen, X. Kong, F. Guo, J.C. Raymond \& B. Chen 2018, ApJ, in press

"Numerical study of the cascading energy conversion of the reconnection current sheet in solar eruptions," Ye, J.; Shen, C.; Raymond, J.C.; Lin, J.; Ziegler, U., 2019, MNRAS, 482, 588

Conference Presentations:

Murphy, N. A.; Shen, C.; Rimple, R.; Raymond, J. C. 2016, AGUFMSH31B2584M, "Plasma Heating During Coronal Mass Ejections"

Ye, J.; Lin, J.; Raymond, J. C.; Shen, C. 2017, AGUFMSH11B2436Y, "Numerical Study of the Cascading Energy Conversion of the Reconnecting Current Sheet in Solar Eruptions"

Lionello, R.; Riley, P.; Torok, T.; Linker, J.; Mikic, Z.; Raymond, J. C.; Shen, C. 2017, AGUFMSH11B2438L, "Ion Charge States in the July 14, 2000 CME: MHD Simulations"

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14. ABSTRACT
We propose to supply time-dependent ionization modules that can be with magnetohydrodynamics (MHD) simulations of solar eruptions. They can be used to compute the ionization states of several elements for comparison with the ionization states measured in space and for computation of the intensities of EUV emission lines observable from Earth-orbiting spacecraft. The key observational signatures for the state of the plasma in flux ropes ejected during solar eruptions are the ionization state at 1 AU and the UV and EUV intensities observed close to the Sun. The plasma ionization state is far from equilibrium, so the time-dependent ionization state must be computed in order to make predictions based on MHD models.

15. SUBJECT TERMS
Time-dependent ionization, Solar eruptions, Magnetohydrodynamics (MHD) simulations, Plasma.

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