Statement of Research

Matthew R. Argall

My research focuses on two broad but interrelated energy-conversion processes within the solar and terrestrial magnetospheres: magnetic reconnection and wave-particle interactions. During magnetic reconnection, the reconnection electric field draws plasma and magnetic field lines inward, supplying new energy to the region. As they convect inward, first ions and then electrons decouple from the magnetic field. This allows the reconnection electric field to freely accelerate the plasma as magnetic field lines "break" and release their energy. Electrons are accelerated in the electron diffusion region, or EDR, and often become energized in such a way that electromagnetic waves grow and resonate with the plasma, spurring additional energization. My goal is to study energization and wave-particle interactions within and around the EDR in order to identify fundamental processes that allow magnetic energy release to produce highly energetic particles. To investigate these phenomena, I make use of laboratory experiments from the Magnetic Reconnection eXperiment (MRX), 2D and 3D particle-in-cell (PIC) simulations, and satellites, including those from the Cluster, Van Allen Probes (VAP), and Magnetospheric Multiscale (MMS) missions. I have also been deeply involved in the design, construction, calibration, and data processing for several instruments, both ground- and space-based.

Past Research: Prior to the MMS mission, in-situ observations of the EDR were rare, primarily because of the lack of small-scale multi-point measurements that could separate temporal from spatial variations. Our knowledge of the EDR, therefore, was lead by laboratory experiments and computer simulations. My thesis[1] combined data from MRX, several PIC simulations, and the Cluster satellites to provide a means of locating the EDR with data from a single spacecraft. This method increased the potential for Cluster and other missions to locate and study magnetic reconnection. It also helped prepare scientists to meet the mission goals of MMS, which include studying EDRs to better understand the energy conversion mechanisms of reconnection.

The first EDR discovered by MMS[2] exhibited all of the features described in my thesis[3]. It further exhibited large amounts of energy dissipation[4] and electron bunching around the magnetic field[2], or “agyrotropy”. I was able to show that electrons that have been accelerated up to 500eV exhibit agyrotropy and that if analyzed as a function of energy, agyrotropy can serve as an additional indicator of proximity to the EDR. Additionally, I looked at the substructure of the electron dynamics that results in agyrotropy and showed electron flux oscillations coincident with oscillations in the electric field, indicative of wave-particle interactions. Similar waves were visible whenever agyrotropy was observed, suggesting wave activity may play an important role in the energy conversion process[5].

Present Research: Simultaneous observations of agyrotropy and modulated electric fields within the EDR raise the question of the role electron whistler waves play during magnetic reconnection. Currently, I am examining an electron whistler wave event detected in the reconnection outflow region, downstream from the EDR[6]. Electrons that were previously accelerated within the EDR become narrowly focused perpendicular to the magnetic field, leading to wave growth. Concurrent with these waves are bursts of high-energy electrons near 1keV. It is possible, therefore, that wave-particle interactions downstream of the EDR may provide an additional acceleration mechanism.

These studies are not possible without the Electron Drift Instrument[7] (EDI) on MMS, and will be aided by the fluxgate-searchcoil-merged (FSM) data product[8]. As part of the FIELDS team on MMS, I aid in the calibration and cross-calibration of the electric field double probes (EDP), fluxgate magnetometer (FGM), search coil magnetometer (SCM), and EDI. With EDI, I am also responsible for data processing and provide input to science operations planning to help meet the overall mission objectives. To create FSM data, I designed a digital filter that takes into account the in-situ noise floor and signal response of both the FGM and SCM instruments. I then apply the filter to the two datasets to create a full-spectrum (0 - 4098 Hz) data product with an improved noise floor. The EDI and FSM datasets then provide high time resolution measurements of particle flux and currents, respectively, that I use to study EDR encounters.

Future Research: My future work will continue to focus on identifying dissipation mechanisms related to magnetic reconnection. My analysis of agyrotropy as a function of energy is important in identifying whether agyrotropy forms as a result of demagnetized, freely accelerating electrons, or of highly magnetized electrons experiencing a diamagnetic drift due to a local pressure gradient. If the latter case is true, then there is no energy dissipation associated with agyrotropy and the waves I identified previously take on a more important role. If the former case is true, then waves may be responsible for breaking up large current sheets into small-scale turbulent structures. To realize my goal, I will analyze the 32 EDRs that MMS encountered during its day-side reconnection phases[9]. Data will be paired with the wave dispersion relation solver WHAMP to calculate growth rates and determine wave stability. Particle-in-cell simulations can then be used to model the results and probe scale sizes inaccessible to MMS. This research provides the framework for a proposal to NASA's MMS Guest Investigator program.

Continuing my instrumentation work, I am advising an electrical engineering student in the design of a Faraday Rotation Ammeter[10] (FRA) as a means of providing direct measurements of currents in space. An advantage of the FRA over other instruments is that it can directly measure local currents due to cold plasma flow. This is of particular interest because the currents containing hot, accelerated plasma generated by reconnection result in ionospheric return currents consisting of cold plasma. The details of current closure can be illuminated by the FRA. My goal is to develop an instrument prototype and computer model and apply to the Advanced Component Technology grant from NASA. I can then propose sounding rocket missions through NASA's Heliophysics Technology and Instrument Development opportunity to explore ionospheric current structures with the FRA during active auroral displays.

My analysis of energy conversion within EDRs and wave-particle interactions using high time resolution measurements of particles and fields data has several broad applications. At small scales probed by MMS, 3D effects produce turbulent structures with filamentary EDR-like regions. I am collaborating with the University of Colorado at Boulder on another MMS Guest Investigator proposal to NASA to study turbulence in the context of reconnection. In addition, electron whistler waves are often observed within another type of wave structure called mirror modes. I am leading a proposal through NSF's Geophysical Environmental Modelling section to study the transport of energy from ion to electron scales within mirror mode structures. Finally, the Faraday rotation ammeter promises a whole new set of measurements in the auroral region that will improve our understanding of magnetosphere-ionosphere coupling and meso-scale energy transport.

References

[1]**Argall, M. R.** (2014), Estimating Proximity to the Asymmetric Reconnection X-line, University of New Hampshire, Ph.D. thesis.

[2]Burch, J. L., Torbert, R. B., Phan, T. D., Chen, L.-J., Moore, T. E., Ergun, R. E., Eastwood, J. P., Gershman, D. J., Cassak, P. A., **Argall, M. R.**, Wang, S., Hesse, M., Pollock, C. J., Giles, B. L., Nakamura, R., Mauk, B. H., Fuselier, S. A., Russell, C. T., Strangeway, R. J., Drake, J. F., Shay, M. A., Khotyaintsev, Yu. V., Lindqvist P.-A., Marklund, G., Wilder, F. D., Young, D. T., Torkar, K., Goldstein, J., Dorelli, J. C., Avanov, L. A., Oka, M., Baker, D. N., Jaynes, A. N., Goodrich, K. A., Cohen, I. J., Turner, D. L., Fennell, J. F., Blake, J. B., Clemmons, J., Goldman, M., Newman, D., Petrinec, S. M., Trattner, K. J., Lavraud, B., Reiff, P. H., Baumjohann, W., Magnes, W., Steller, M., Lewis, W., Saito, Y., Coffey, V., Chandler, M. (2016), Electron-scale measurements of magnetic reconnection in space, *Science (80-.).*, *352*(6290), doi:10.1126/science.aaf2939.

[3]**Argall, M. R.**, Yoo, J., Chen, L.-J., Torbert, R. B., (in-prep), Estimating proximity to the asymmetric reconnection X-line, *J. Geophys. Res. Sp. Phys.*

[4]Torbert, R. B., Burch, J. L., Giles, B. L., Gershman, D., Pollock, C. J., Dorelli, J., Avanov, L., **Argall, M. R.**, Shuster, J., Strangeway, R. J., Russell, C. T., Ergun, R. E., Wilder, F. D., Goodrich, K., Faith, H. A., Farrugia, C. J., Lindqvist, P.-A., Phan, T., Khotyaintsev, Y., Moore, T. E., Marklund, G., Daughton, W., Magnes, W., Kletzing, C. A., Bounds, S., (2016), Estimates of terms in Ohm's law during an encounter with an electron diffusion region, *Geophys. Res. Lett.*, *43*(12), 5918–5925, doi:10.1002/2016GL069553.

[5]**Argall, M. R.**, Paulson, K., Alm, L., Torbert, R. B. (submitted), Electron dynamics within the electron diffusion region of asymmetric reconnection, *J. Geophys. Res. Sp. Phys.*

[6]**Argall, M. R.**, Paulson, K., Ahmadi, N., Matsui, H., Alm, L., Torbert, R. B. (in-prep), Wave-particle interactions in the flux pile-up region of magnetic reconnection, *J. Geophys. Res. Sp. Phys.*

[7]Torbert, R. B., Vaith, H., Granoff, M., Widholm, M., Gaidos, J. A., Briggs, B. H., Dors, I. G., Chutter, M. W., Macri, J., **Argall, M.**, Bodet, D., Needell, J., Steller, M. B., Baumjohann, W.,

Nakamura, R., Plaschke, F., Ottacher, H., Hasiba, J., Hofmann, K., Kletzing, C. A., Bounds, S. R., Dvorsky, R. T., Sigsbee, K., Kooi, V. (2015), The Electron Drift Instrument for MMS, *Space Sci. Rev.*, *199*(1), 283–305, doi:10.1007/s11214-015-0182-7.

[8]**Argall, M. R.**, Le Contel, O., Fischer, D., Torbert, R. B. (in-prep), The fluxgate-searchcoil merged (FSM) data product for MMS, *Space Sci. Rev.*

[9]Webster, J. M., Burch, J. L., Reiff, P. H., Graham, D. B., Torbert, R. B., Ergun, R. E., Daou, A, G., Sazykin, S. Y., Marshall, A., Chen, L.-J., Wang, S., Phan, T. D., Genestreti, K. J., Giles, B. L., Moore, T. E., Fuselier, S. A., Cozzani, G., Russell, C. T., Erickson, S., Rager, A. C., Broll, J. M., Goodrich, K., Wilder, F. (submitted) Magnetospheric Multiscale Dayside Reconnection Electron Diffusion Region Events, *J. Geophys. Res. Sp. Phys.*

[10]Saxena, I., and R. B. Torbert (1990), Compact Optical Fiber Faraday Ring Ammeter, *Proc. SPIE*, *1166*, 454–460, doi:10.1117/12.962916.