The electric potential at the Earth's quasi-parallel bow shock: Initial Cluster results

R. Behlke*, H. Kucharek†, S. D. Bale**, M. André* and E. A. Lucek‡

*Swedish Institute of Space Physics, Uppsala division, Box 537, 75121 Uppsala, Sweden
†Space Science Institute, University of New Hampshire, Durham, USA
**Space Science Laboratory, University of California, Berkeley, USA
‡Blackett Laboratory, Imperial College, London, UK

Abstract. We present multi-spacecraft measurements of a quasi-parallel shock crossing obtained by the Cluster satellites. Observations commonly show the presence of Short Large-Amplitude Magnetic Structures (SLAMS) at the Earth's quasi-parallel bow shock. These structures are thought to play an important role for decelerating, heating and deflecting the incident solar wind. We investigate the electric potential over SLAMS in the Normal Incidence Frame Φ_{NIF} as a possible means for achieving thermalisation in the foreshock region of the Earth's quasi-parallel bow shock. We show that SLAMS exhibit a substantial electric potential on the order of a few hundred Volt (V). Thus at the Earth's quasi-parallel bow shock, these structures may be important for dissipation that transforms the ram energy of the solar wind bulk flow into thermal energy. SLAMS might be responsible for returning particles, that have been reflected at the shock and whose guiding centre motion is pointing upstream, back to the shock.

Keywords: Quasi-parallel collisionless shock, electric cross-shock potential
PACS: 94.30.Va, 96.50.Fm, 96.50.Bh

INTRODUCTION

A major controlling factor for collisionless shocks is the angle θ_{Bn} between the upstream magnetic field and the shock normal. At quasi-perpendicular shocks ($\theta_{Bn} > 45°$), a significant part of the incoming solar wind ions is immediatly convected downstream after the first gyration where they are subsequently thermalised.

Under quasi-parallel conditions ($\theta_{Bn} < 45°$), the guiding centre motion of specularly reflected particles is pointed upstream and these particles may easily escape from the shock and propagate far upstream along magnetic field lines [1]. These specularly reflected particles cannot directly contribute to downstream thermalization in this shock geometry. Dissipation has to be achieved by other means, e.g., by waves that are generated by the backstreaming, reflected ions and shock-generated waves. These waves in their turn may point the guiding centre of reflected ions downstream again due to a slowly changing θ_{Bn}.

Incoming solar wind ions may interact with backstreaming, reflected ions. These interactions lead to the generation of low-frequency (ULF) waves [2] via an ion-ion beam instability. Some of the ULF waves steepen and form so-called Short Large-Amplitude Magnetic Structures (SLAMS) during their approach towards the shock [3]. A model of the quasi-parallel bow shock emerged in which the shock is considered a patchwork of SLAMS [4]. The shock is cyclically reforming as these structures are

CP 781, *The Physics of Collisionless Shocks,* edited by G. Li, G. P. Zank, and C. T. Russell

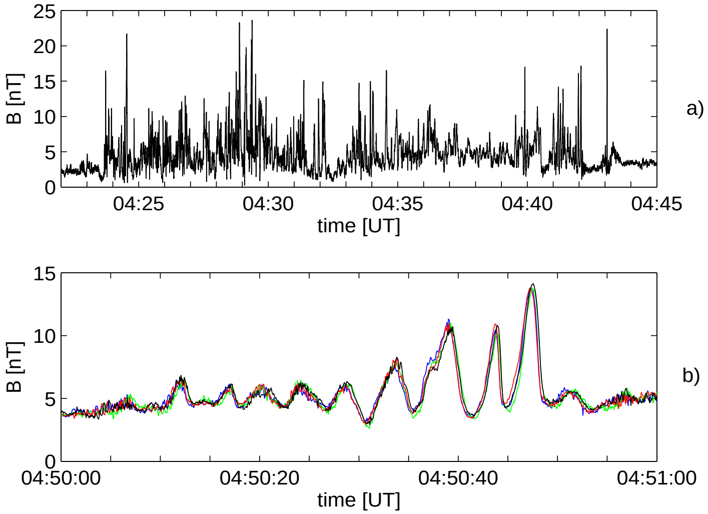

FIGURE 1. Cluster observations of a quasi-parallel shock crossing on February 3, 2002. Panel (a): The magnetic field amplitude *B* for a 23 minutes period (UT 04:22-04:45) obtained by Cluster 1 is shown. Panel (b) displays *B* for a 1 minute period (UT 04:50-04:51) for all four spacecraft. Note the Cluster colour notation: black, red, green, blue for spacecraft 1, 2, 3, 4, respectively.

convected into the shock by the solar wind. Note that SLAMS are produced far upstream in this scenario. However, some questions concerning the importance of SLAMS for pre-dissipation in the foreshock region of the quasi-parallel shock have not yet been investigated. The electric potential can, in combination with other mechanisms, be responsible for the dissipation of solar wind energy at SLAMS. It was thus an obvious question to investigate the electric potential over SLAMS.

INSTRUMENTATION

The data for this study are obtained by the Electric Field and Wave (EFW) instrument [5] onboard the four Cluster spacecraft [6]. It consists of two pairs of spherical probes on wire booms in the spin plane of each satellite. The separation between each probe pair is 88 m. For the data presented here, the electric field data are sampled at 25 Hz using a lowpass filter at 10 Hz. We also present data from the fluxgate magnetometer (FGM) instrument [7] in the analysis.

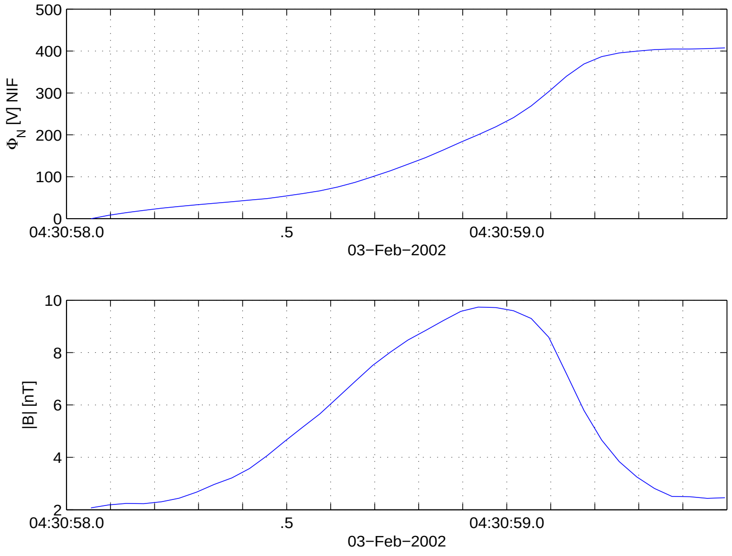

FIGURE 2. Cluster observations on February 3, 2002, UT 04:30:58.0 - 04:30:59.5. Panel (a) shows an example of the cross-SLAMS potential in the Normal Incidence Frame Φ_{NIF} for spacecraft 2. Panel (b) displays the corresponding magnetic field magnitude B.

OBSERVATIONS

Figure 1 shows magnetic field data during a supercritical, quasi-parallel shock crossing on February 3, 2002, as observed by the Cluster spacecraft. Note that the spacecraft separation during these observations was on the order of 100 km. The satellites were positioned at (11, 2, -8) R_E (R_E=Earth radii) in the GSE (Geocentric Solar Ecliptic) system. Panel (a) displays a 23 minutes interval within the shock crossing. It can clearly be seen that quasi-parallel shock crossings are characterised by an extented transition region consisting of magnetic pulsations. Panel (b) reveals that these pulsations are built up by ULF semicycles with periods of $T \sim 4$ sec and $B_{\mathrm{max}}/B_0 \sim 1$ and SLAMS with $T \sim 2$ sec and $B_{\mathrm{max}}/B_0 > 1$, where B_{max} is the peak magnetic field amplitude and B_0 the background magnetic field. The magnetic field enhancement is accompanied by a density enhancement, i.e., SLAMS are fast-mode structures [8]. Within SLAMS a change from the quasi-parallel to the quasi-perpendicular shock configuration is generally observed [9], i.e., whereas the inter-SLAMS regions are characterized by quasi-parallel conditions, a change to the quasi-perpendicular regime is observed in association with the leading edge. In association with the trailing edge, the magnetic field returns to quasi-parallel conditions. SLAMS generally have a direction of propagation that is quasi-parallel to the ambient magnetic field [10] and exhibit transverse scale lengths of the order of

1000 km [9]. Simulations revealed that SLAMS might change significantly on the order of seconds, i.e., the time it takes the SLAMS to move over the spacecraft [11]. Recent observations indicated indeed a growth rate of SLAMS of the order of 10% per second.

For a complete description of the methodology of the calculation of the electric potential in the Normal Incidence Frame, we refer to [13]. Figure 2 (a) displays the calculated cross-SLAMS potential Φ_{NIF} for a single SLAMS during this shock crossing. A net potential $\Phi_{\mathrm{NIF}} \sim 400$ V is calculated. Note that the potential is evenly divided between the trailing edge (left hand side) and leading, but more steepend, edge (right hand side) of the SLAMS. Panel (b) shows the corresponding magnetic field profile.

DISCUSSIONS AND CONCLUSIONS

We have shown that Short Large-Amplitude Magnetic Structures (SLAMS) are associated with a substantial electric potential of the order of a few hundred V. These structures are thought to play an essential role in quasi-parallel shock physics. Simulations have indeed shown that the potential over SLAMS is associated with a deceleration of the solar wind flow [14]. For supercritical shocks in general it is well-accepted that the velocity dispersion which results from ion reflection and subsequent transmission through the cross-shock potential accounts for a substantial part of effective dissipation [15]. The observed potential over SLAMS might, in combination with other processes, be responsible for deceleration, deflection and heating of the incident solar wind.

Future studies need to investigate the dependence of the cross-SLAMS potential on different parameters and its impact on particle distributions. Work in progress includes a statistical approach on the cross-SLAMS potential and associated ion distributions [13].

ACKNOWLEDGMENTS

The authors thank the Cluster software and engineering teams. We are thankful to the PI of the CIS-instrument, H. Remé and the PI of the FGM-instrument, A. Balogh, for making the data of their instruments available. RB thanks D. Burgess, B. Lembège, A. Vaivads, A.I. Eriksson and A. Tjulin for enlightening discussions, S.C. Buchert for help with FGM data and Y. Hobara for help with CIS data. RB is grateful for the hospitality at the SSL, UC Berkeley, at which this study was initiated during a visit.

REFERENCES

1. J. T. Gosling, M. F. Thomsen, S. J. Bame, and C. T. Russell, *J. Geophys. Res., 94*, 10027–10037 (1989).
2. M. T. Hoppe, and C. T. Russell, *J. Geophys. Res., 88*, 2021–2028 (1983).
3. S. J. Schwartz, D. Burgess, W. P. Wilkinson, R. L. Kessel, M. W. Dunlop, and H. Lühr, *J. Geophys. Res., 97*, 4209–4227 (1992).
4. S. J. Schwartz, and D. Burgess, *Geophys. Res. Lett., 18*, 373–376 (1991).
5. G. Gustafsson, R. Boström, B. Holback, G. Holmgren, A. Lundgren, K. Stasiewicz, L. Åhlen, F. S. Mozer, D. Pankow, P. Harvey, P. Berg, R. Ulrich, A. Pedersen, R. Schmidt, A. Butler, A. W. C. Fransen,

D. Klinge, M. Thomsen, C.-G. Fälthammar, P.-A. Lindqvist, S. Christenson, J. Holtet, B. Lybekk, T. A. Sten, P. Tanskanen, K. Lappalainen, and J. Wygant, *Space Sci. Rev., 79*, 137–156 (1997).
6. C. P. Escoubet, R. Schmidt, and M. L. Goldstein, *Space Sci. Rev., 79*, 11–32 (1997).
7. A. Balogh, C. M. Carr, M. H. Acũna, M. W. Dunlop, T. J. Beek, P. Brown, K.-H. Fornacon, E. Georgescu, K.-H. Glassmeier, J. Harris, G. Musmann, T. Oddy, and K. Schwingenschuh, *Ann. Geophys., 19*, 1207–1217 (2001).
8. R. Behlke, M. André, S. C. Buchert, A. Vaivads, A. I. Eriksson, E. A. Lucek, and A. Balogh, *Geophys. Res. Lett., 30*(4), 10.1029/2002GL015871 (2003).
9. E. A. Lucek, T. S. Horbury, M. W. Dunlop, P. J. Cargill, S. J. Schwartz, A. Balogh, P. Brown, P. Carr, K.-H. Fornacon, and E. Georgescu, *Ann. Geophys., 20,* 1699–1710 (2002).
10. G. Mann, H. Lühr, and W. Baumjohann, *J. Geophys. Res., 99*, 13315-13323 (1994).
11. K. Tsubouchi, and B. Lembége, *J. Geophys. Res., 109*, doi:10.1029/2003JA010014 (2004).
12. E. Lucek, et al., these proceedings, (2005).
13. R. Behlke, H. Kucharek, S. D. Bale, M. André, and E. A. Lucek, *Ann. Geophys.*, submitted (2005).
14. M. Scholer, H. Kucharek, and I. Shinohara, *J. Geophys. Res., 108*, doi:10.1029/2002JA009820 (2003).
15. D. Sherwell, and R. A. Cairns, *J. Plasma Phys., 17*, 265–279 (1977).