INITIAL RESULTS FROM THE ACTIVE SPACECRAFT POTENTIAL CONTROL (ASPOC) ONBOARD MAGNETOSPHERIC MULTISCALE (MMS)

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ABSTRACT

NASA's Magnetospheric Multiscale (MMS) Mission was successfully launched in March, 2015. The scientific objectives of MMS are to explore and understand fundamental plasma physics processes in the Earth's magnetosphere: magnetic reconnection, particle acceleration and turbulence. The region of scientific interest of MMS is in a tenuous plasma environment where the positive spacecraft potential may reach an equilibrium as high as several tens of Volts. The Active Spacecraft Potential Control (ASPOC) instrument neutralizes the spacecraft potential by releasing positive charge produced by indium ion emitters. While the method has been successfully applied on other spacecraft such as Cluster and Double Star, new developments in the design of the emitters and the electronics are enabling lower spacecraft potentials and higher reliability compared to previous missions. In this presentation we report the initial results from the tests of ASPOC performances during the commissioning phase and discuss the different effects on the particle and field instruments observed at different plasma environments in the magnetosphere.

1. INTRODUCTION

NASA's MMS mission (Magnetospheric Multiscale) (Burch et al., 2014) will explore the dynamics of the Earth's magnetosphere and its underlying energy transfer processes. Four identically equipped spacecraft are to carry out three-dimensional measurements in the Earth's magnetosphere. After the successful launch on March 12, 2015, MMS was in the commissioning phase until end of August, followed by the official start of the first scientific phase on 1st of September 2015. The Active Spacecraft Potential Control (ASPOC) neutralizes the spacecraft potential by releasing positive charge produced by indium and thereby controlling the spacecraft potential. ASPOC enables accurate plasma measurements also in sparse plasma environments, essential to study properties of reconnection, which is the main scientific object of MMS. In this presentation, we report the ASPOC performance in orbit, highlight initial results using ASPOC data and discuss the effects of ASPOC on plasma and field observations.

2. ASPOC INSTRUMENTS

ASPOC was built by a consortium led by the Institut für Weltraumforschung (IWF) for NASA's four spacecraft Magnetospheric Multiscale (MMS) mission. Each ASPOC instrument unit (Figure 1) contains four ion emitters, whereby one emitter per instrument is planned to be operated at a time. Compared to the previous missions, MMS ASPOC includes new developments in the design of emitters and the electronics and is equipped with a more capable control software.

Figure 1. ASPOC instrument.

Furthermore, unlike the previous missions, for which one ASPOC unit was installed, each MMS spacecraft carries two ASPOC units so that the emitted beams are oppositely directed in the spin-plane (Figure 2). A more detailed description of the MMS ASPOC instrumentation is given in [1].

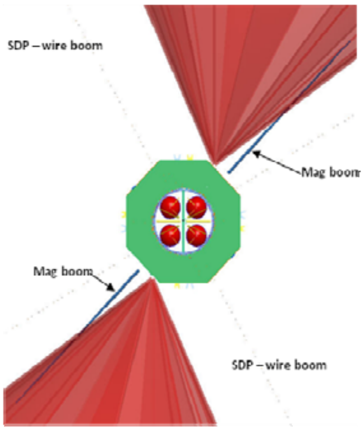

Figure 2. Drawing of the ASPOC ion beams on MMS.

3. EMITTER TESTS DURING THE COMMISSIONING PHASE

After launch ASPOC participated in commissioning activities, when all the 32 emitter units were switched on and used for different tests. There were nine emitter-test activities including low/high voltage tests, single/dual beam basic/extended tests and cross-instrument checkouts. It has been shown already in the early commissioning phase that ASPOC controls the spacecraft potential below 4V, in consistence with the science requirement of MMS.

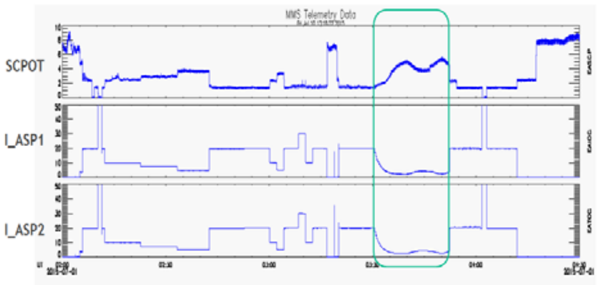

Figure 3. Spacecraft potential, ion currents from ASPOC 1 and ASPOC 2 from MMS2 on July 15, 2015.

Figure 3 shows some results from the extended dual beam test on MMS2 performed on July 15, 2015. The spacecraft potential data transferred onboard from the spin-plane double probe (SDP) measurements [2], ion currents emitted from ASPOC 1 and ASPOC 2 are shown from top to bottom. During the extended tests, different current levels and different operation modes are tested. The nominal operation of ASPOC is performed by setting a constant current level for each of the ASPOC unit. ASPOC, however, can be also operated in a way that a target spacecraft potential level is set so that the ASPOC current level will be changed by referring to the spacecraft potential level onboard. This mode is called the feed-back mode and was successfully tested during the time interval as given in the interval bounded by the green lines in the figure.

The commissioning activities were completed by the end of August. Since then ASPOC is operating in nominal mode and is participating in the science phase activities. All the ASPOC level 2 science data products are publicly available from the Science Data Center (https://lasp.colorado.edu/mms/sdc/public/).

4. EFFECTS OF ASPOC ON PLASMA MEASUREMENTS

In sparse plasma regions the spacecraft is positively charged exceeding several tens of Volts and the low-energy electron observations are contaminated by photoelectrons originating from the spacecraft surface.

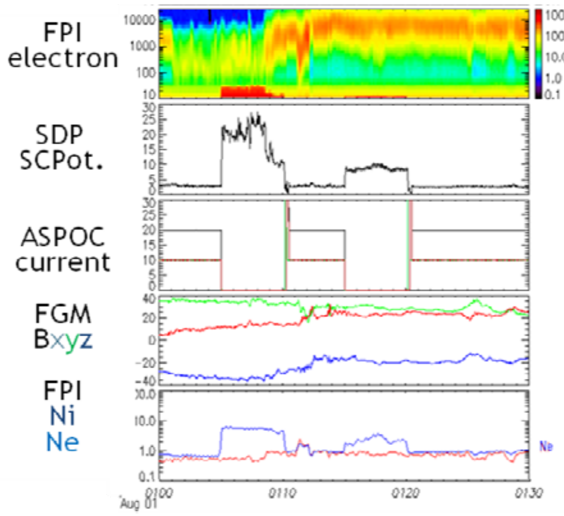

Figure 4. Electron energy spectra, spacecraft potential, ASPOC ion currents, magnetic field, and plasma density on August 1, 2015.

Figure 4 shows an example of such observations, during which ASPOC was turned off for two short intervals in the lobe and plasma sheet regions. The electron measurements (top panel) are from the fast plasma instrument (FPI) [3] and showing intense photoelectrons during the time interval when the spacecraft potential (second panel) exceeds 10 V and is associated with the turn-off of the ASPOC emitters, as can be seen in the ASPOC ion current (third panel). The magnetic field data from the flux gate magnetometer (FGM: [4]) in the fourth panel show that MMS was in the magnetotail lobe entering the plasma sheet, where denser and hotter plasma is observed. The first ASPOC-off interval is from the magnetotail lobe and the second from the plasma sheet. It can be seen that the effect of turning-off the ASPOC emitter is more prominent in the magnetotail where the plasma density (bottom panel) is low.

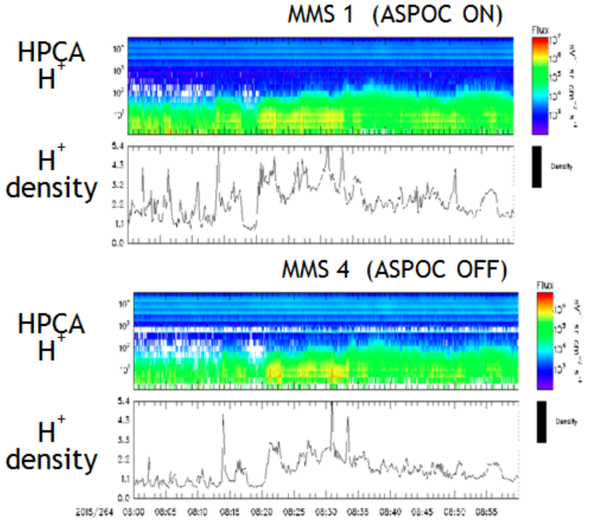

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Figure 5. Proton energy spectra and proton density from MMS1 (upper two panels) and from MMS4 (bottom two panels).

The positively charged spacecraft also affects measurements of low energy ions. Namely, when the level of the spacecraft potential exceeds the energy of the ions, they cannot be measured due to the potential barrier. Figure 5 shows an example of such a case observed by the hot plasma composition analyzer (HPCA: [5] Young et al., 2014) in the dayside magnetosphere. Here the top two panels show proton measurements from MMS1, where ASPOC emitters were turned on, while the bottom two panels are from MMS4, where the emitters were turned off so that the low energy protons were not observable. Accordingly, the densities derived by the two spacecraft show different profiles, demonstrating the importance of keeping the spacecraft potential at low values constantly.

5. PLASMA DENSITY DERIVATION USING ASPOC CURRENT AND SPACECRAFT POTENTIAL

Following methods established in previous studies [6, 7], we can recover uncontrolled spacecraft potential data from controlled ones and use those to derive plasma density estimations. According to those methods, we combine simultaneous measurements of the ASPOC ion current and spacecraft potential from at least two spacecraft, one with active spacecraft potential control and one without and assuming that those are in the same magnetospheric environment we can estimate the photoelectron emission during that period and use that information together with the ASPOC ion current to reconstruct the spacecraft potential to values we would get if ASPOC was off. Finally, using the derived curve, we provide plasma density estimates using spacecraft potential observations from spacecraft with or without spacecraft control.

During the MMS commissioning phase, March-August 2015, we performed spacecraft potential reconstructions and plasma density estimates during several time intervals with at least one of the spacecraft having ASPOC on. We also tried to establish criteria when such reconstructions are possible. It was concluded that for ASPOC currents up to 30 μA spacecraft potential reconstructions are largely successful (at least for periods when the spacecraft are not traversing very tenuous regions).

In Figure 6 we show an example of plasma density estimates in the magnetotail, during the time interval of 20:00 July 15 to 02:00 July 16 2015. The third and fourth panels shows plasma density estimates for a spacecraft with ASPOC on, MMS1, and one with ASPOC off, MMS4, respectively, while the second panel shows the electron density observations from FPI. Comparison of FPI observations with our estimates are in a very good agreement. For more details about the reconstructions and density estimates using the MMS observations see [8].

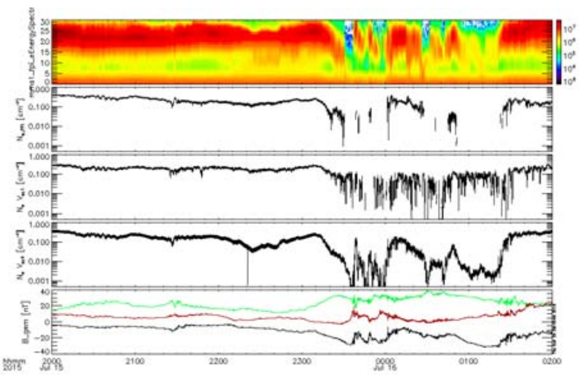


Figure 6. Estimates of the electron density during the time interval of 20:00 July 15 to 02:00 July 16 2015. The first panel depicts the electron energy channel spectrogram and the second panel the electron density from the FPI instrument. The third and fourth panel show the plasma density estimates using spacecraft potential measurements of the spacecraft under active control, MMS1, and with no active control, MMS4, respectively. The fifth panel shows magnetic field observations in gsm coordinates (B_x in black, B_y in green, B_z in red).

6. EFFECTS OF ASPOC ON ELECTRIC FIELD MEASUREMENTS

The Electric Field Double Probes (EDP) consist of four probes in the spin plane (SDP) located at the end of 60 m wires and of two axial probes (ADP) mounted on coiled booms and separated by ~29.2 m effective length. The two ASPOC ion beams point at half-angle between the SPD probes 1 and 3, respectively probes 2 and 4 (see sketch in Fig. 7 showing the location of the beams and spin plane booms including the magnetometer booms (5 m length). Baffles limit the width of the beams to stay off the probes.

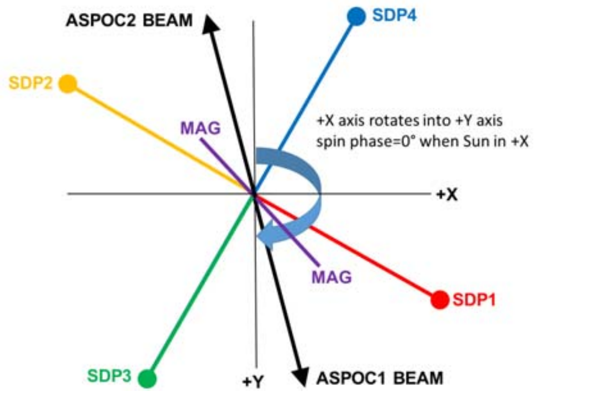
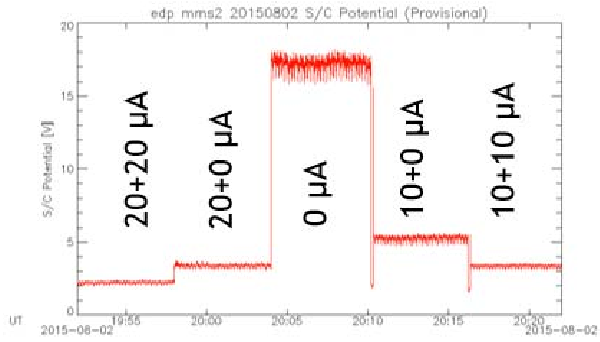


Figure 7. The location of the ASPOC beams and the booms.

In spite of the symmetric position of the ion beams with respect to SDP the initial data reveal some residual effects which require further analysis and eventually further dedicated calibration of the SDP data when ASPOC is active. It is difficult to disentangle any instrumental effects from natural variations of the electric field, but general trends can be seen, as illustrated by the example in Fig. 8. In this period of ~25 minutes the ion beams have been set in five configurations as indicated in the figure. The top panel shows the preliminary spacecraft potential. The value of ~17 V with ASPOC off suggests an ambient plasma density below 1 cm^{-3}. The lower panel shows the electric field components measured between probes 1 and 2, and 3 and 4, respectively, in the spinning spacecraft system. The amplitude, indicating the magnitude of the ambient electric field, is highest with ASPOC off, but the amplitude at 2 x 20 µA is higher than for 2 x 10 µA, which contradicts a direct proportionality between beam current and electric field effect.
The two intervals with just one active beam cause additional offsets between the two electric field components.



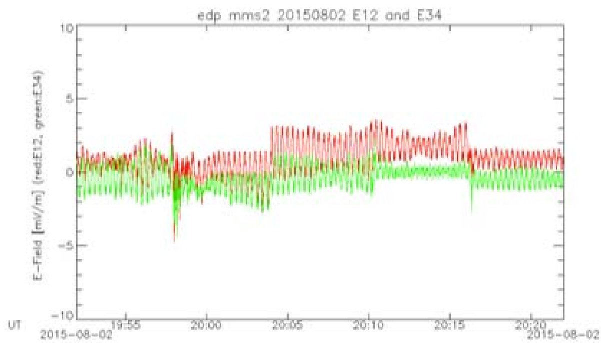


Figure 8. ASPOC ion beam current (top) and the electric fields (bottom).

The derivation of plasma density from the small variations of the spacecraft potential when ASPOC is active still works, as described in Section 5. Additional considerations are necessary, however, in the presence of strong electric fields, when the gradient of the plasma potential across the conductive - and therefore equipotential - spacecraft-boom structure becomes measurable.

To study these various effects of the ASPOC beams in different plasma environment, PIC simulation studies are ongoing to support the interpretation of these measurements (see [9] for details).

7. SUMMARY

- ASPOC on MMS is successfully operating since early 2015 during commissioning and science phase.
- ASPOC allowed to reduce the effects from photo-electrons and to measure cold ions in different regions of magnetosphere.
- Estimation of plasma density using ASPOC current and spacecraft potential works under certain conditions of plasmas and ASPOC current level.

- Investigation on the effect of asymmetric spacecraft potential caused by the ASPOC beam is ongoing by also comparing with modeling results.

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