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# Solar wind proton deceleration at higher altitude above lunar magnetic anomalies

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## Abstract

We study interaction between the solar wind (SW) flow and lunar magnetic anomalies. Our recent study showed that incident SW protons are decelerated at low altitude (say, ~25 km) above strong magnetic anomalies, and that SW protons are less or not affected by the magnetic anomalies at higher altitude (~100 km). Here we report that SW protons are strongly decelerated above strong and wide magnetic anomaly region even at the higher altitude under specific SW conditions of high density and strong interplanetary magnetic field (IMF). The SW proton deceleration at higher altitude is accompanied by a strong enhancement in local magnetic field, which suggests that pile-up of the IMF is more effective under the conditions.

## 1. Introduction

The Moon does not have an intrinsic magnetic field, while it has remnant magnetic field near its surface, which is called magnetic anomaly. It has been known that lunar magnetic anomalies are distributed in a wide region of the lunar surface, including both the near-side and far-side hemispheres [1]. Above all, a wide area (more than several hundred km) around South-Pole Aitken (SPA) basin on the farside has been known to possess strong magnetic field, and it can interact with the incident SW particles when it is on the dayside [2].

Recently, a Japanese lunar orbiter SELENE (Kaguya) performed comprehensive measurements of the plasma and electromagnetic environment around the Moon at ~100 km and much lower altitude in polar orbits with a 2 hour period [3]. The SELENE measurement revealed (1) that more than 50 percent of the incident SW protons are reflected (or scattered) around the strongest magnetic anomalies [4], and (2) that the incident SW protons are decelerated at lower altitude (typically, 10 to 25 km) above the strong magnetic anomalies around the SPA basin [5]. The proton deceleration was accompanied by magnetic enhancement and upward electron acceleration, which shows the existence of upward electric field that is originated from the difference between the proton and electron motions. In addition, the solar zenith angle (SZA) of the area where the SW proton deceleration was apparent ranged from small (~ 20 deg) to large angle (>50 deg).

Meanwhile, the proton deceleration is apparent at the lower altitude, while deceleration (or modulation) of incident SW protons at higher altitude (~100 km) was thought to be less effective. Actually the SW protons at the higher altitude show no modulation even above the strongest magnetic anomalies. However, we have found that under some specific conditions the incident SW protons are strongly decelerated above the SPA basin. We will show the latest data of strong SW proton deceleration observed above the SPA basin and discuss physical meaning of the phenomena.

## 2. New observations

Under the typical SW condition, the incident SW protons are hardly affected at 100 km altitude even above the strongest and widest magnetic anomalies. However, we have detected several cases of SW proton deceleration under the stronger IMF and higher density conditions.

### 2.1 SW protons around SPA under unusual condition

We have found that the incident SW protons are at times decelerated around the strong magnetic anomalies even at the 100 km altitude. The SW deceleration occurs when the SW density is relatively high (> 10 /cc) and the IMF is strong (> 10 nT). (These conditions are typical for a passage of corotational interaction region (CIR) in the SW.) Most of these events occurred at relatively large SZA (>50 deg) and in somewhat downstream area of the strongest magnetic field with respect to the SW flow, and deceleration was in relation to an enhancement of the local magnetic field (say, an increase from 15 nT of upstream IMF strength to 30 nT) at 100 km altitude.

One might imagine that the high dynamic pressure of the SW flow compresses the magnetic anomalies on the lunar dayside to make them less effective at higher altitude. However, what was observed at the high altitude under the higher SW dynamic pressure is magnetic enhancement that is at times accompanied by the deceleration in the incident SW protons. This suggests that the high dynamic pressure of the SW flow makes the pile-up of the IMF more effective.

However, in some cases with similar SW conditions, the SW proton deceleration was not apparent so much. Although we have not caught an answer to the question, the difference between decelerated and non-decelerated cases seems to be the IMF direction. That is, the IMF direction may change the effectiveness of pile-up of the IMF above the strongest magnetic anomalies, possibly depending on the field direction of the magnetic anomalies.

## 6. Summary and Conclusions

We have newly detected SW proton deceleration at higher altitude orbit above strongest magnetic anomalies. We have found that SW protons are strongly decelerated above the SPA basin even at the higher altitude under the high SW density and strong IMF. The SW proton deceleration at higher altitude is accompanied by a strong enhancement in local magnetic field, which suggests that pile-up of the IMF is more effective under the conditions.

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