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Investigation on the formation of lunar swirls based on Chang'E-1 IIM data

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Abstract

The formation of lunar swirls remains a mystery for many years. One leading hypothesis for the origin of lunar swirls was solar wind deflection model which explains its formation as the mass fraction difference of submicroscopic iron (SMFe) between on- and off-swirl regions. In this study, an empirical method was used to estimate mass fraction of SMFe of lunar swirls based on Change'E-1 IIM data. Results indicate that solar wind model is a validate hypothesis for the formation of lunar swirls.

1. Introduction

Lunar swirls are bright curvilinear marking on the lunar surface. They are optically immature than the surrounding areas and coincident with regions possessing high magnetic field strength, but not associated with distinct topography [1]. Elucidating the origin of lunar swirls is central to understanding the relative importance of solar wind implantation and micrometeorite bombardment on space weathering, and the origin of lunar surface magnetic field. One leading hypothesis for the formation of lunar swirls is solar wind deflection model. This model states that because of the deflection effect of lunar magnetic anomalies, a less amount of SMFe is generated in on-swirl regions due to a reduced solar wind flux, resulting in higher albedo of the lunar on-swirl regions than off-swirl regions to which solar wind ions are deflected to and a higher amount of SMFe is accumulated [2].

In this study, an empirical approach described in [3] was applied to estimate mass fraction of SMFe in on- and off- swirl regions using Chang'E-1 IIM data. We aimed to test whether on-swirl regions are indeed deficient in mass fraction of SMFe relative to off-swirl regions and whether solar wind deflection model is a valid hypothesis for the formation of lunar swirls.

2. Study Areas and Dataset

Three lunar swirls including Reiner Gamma, Firsov and a portion of Ingenii were investigated in this study. Their geological settings, magnetic field strength, and locations are shown in Table 1. Three sub-images of Chang'E-1IIM Level 2C radiance data were used in this study. They cover the central portion of these three swirl regions, and have been normalized to a standard geometry ($i=g=30^{o}$, $e=0^{o}$).

3. Method

Through conducting correlation analysis to the lunar soil samples from Lunar Soil Characterization Consortium (LSCC), Liu and Li (2015) [3] found that the ratio of 540 nm/810 nm single scattering albedo (SSA) of lunar soils is highly correlated with the mass fraction of SMFe. A simple exponential function can be used to describe this correlation as indicated in Fig.1. This exponential function was used in this work to estimate the mass fraction of SMFe in on- and off-swirl regions.

The radiance data of the three sub-images were first converted to reflectance by: $R=(I/Istd)*Rstd$, where Rstd is lab measured reflectance of lunar soil sample 62231, Istd is the corresponding radiance data of Apollo 16 landing site extracted from Chang'E-1 IIM 2C data, and I is the radiance data of sub-images covering the three swirl regions. Then, the reflectance data were converted to SSA using Hapke's radiative transfer model. The closest bands of Chang'E-1 IIM data to 540 nm and 810 nm used in the exponential function are 541 nm and 818 nm, respectively. However, 841 nm band of Chang'E-1 IIM data was selected rather than 818 nm band because of its high noise. At last, the ratio of 541 nm SSA/841 nm SSA was used in the exponential function to estimate the mass fraction of SMFe in Reiner Gamma, Firsov and Ingenii.

4. Results and Discussion

Shown in Fig. 2b is the mass fraction of SMFe of Ingenii. Off-swirl regions evidently possess higher mass fraction of SMFe than on-swirl regions. The derived mass fraction of SMFe ranges from 0% to 0.60% consistent with the measured data of lunar soils (0~0.5%) [4]. Similar trend was also found for swirl Reiner Gamma and Firsov.

Off-swirl regions are indeed enriched in SMFe as postulated by the solar wind deflection model. Because of the shielding effect of magnetic field, fewer solar wind ions, especially H^+ could penetrate into on-swirl regions and thus fewer Fe^{2+} could be reduced and sputtered to form SMFe. In contrast, implanted H^+ could be deflected onto off-swirl regions, resulting in higher amount of SMFe accumulated in off-swirl regions than in on-swirl regions.

5. Conclusions

Results from this work imply that solar wind deflection model is a validate hypothesis for the formation of lunar swirls. Moreover, this study indicates that solar wind ion implantation could be the major mechanism of space weathering rather than micrometeoroid impacts. Otherwise, the mass fraction difference of SMFe between on- and off-swirl regions would be absent.

References

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Table 1: Lunar swirls investigated in this study

Swirls	Locations	Geological Setting	Magnetic Anomaly Strength (nT)
Reiner Gamma	7.5°N, 302.5°E	Mare	22 - Strong
Firsov	10.5°S, 16.5°E	Highland	11- Moderate
Ingenii	33.5°S, 160°E	Highland	20 - Strong

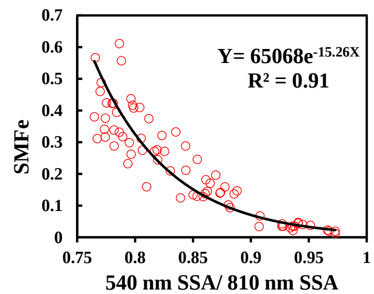

Figure 1: Correlation between the ratio of 540 nm SSA/810 nm SSA and SMFe for LSCC soil samples

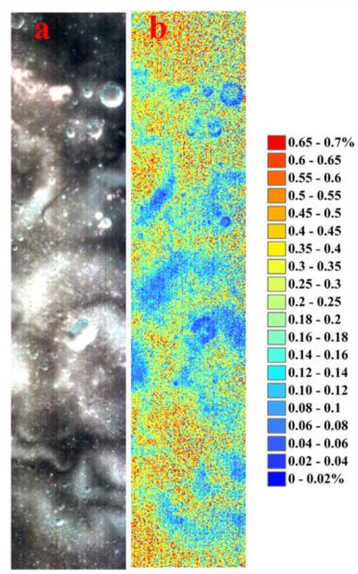

Figure 2: (a) Chang'E-1 IIM false color composite (R = 865 nm, G = 645 nm, B = 550 nm) for a portion of Ingenii. (b) Mass fraction of SMFe.