Constraining the Ratio of Micrometeoroids From Short- and Long-Period Comets at 1 AU From LADEE Observations of the Lunar Dust Cloud

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Abstract We interpret recent observations of the secondary dust ejecta cloud around the Moon from the Lunar Dust Experiment (LDEX) on board the NASA Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft with help from dynamical models of meteoroids. Results suggest that in order to match the spatial structure of observed ejecta profiles, the flux of meteoroids on the Moon must be primarily provided by short-period comets with an excess ratio of at least 1.3:1 compared to long-period comets. This ratio increases significantly if the dependence of the ejecta yield on impactor velocity is stronger than generally believed. The model accounts for the orbital geometry of LADEE and shows no indication of a large asymmetry in the meteoroid flux impacting from the Helion and Anti-Helion directions.

Plain Language Summary Because of the lack of atmosphere, small meteoroids impact the Moon surface at high speeds. The impacts release plumes of dust from the surface termed the secondary dust ejecta cloud. The Lunar Atmosphere and Dust Environment (LADEE) was a NASA satellite launched in 2013 with several scientific objectives, one of which was to measure and characterize these ejecta. LADEE showed several surprising temporal features of this cloud. In this manuscript we utilized sophisticated models to follow the life of meteoroids from the moment they are released from their parent comet to the moment they impact the Moon, a process that takes thousands to millions of years. These models use several families of comets characterized by their period (P), that is, how long it takes to orbit around the Sun. We found that in order to produce an ejecta cloud similar to that observed by LADEE, short-period comets (P lower or equal than 20 years) provide 1.3 times more meteoroids that long-period comets (P much greater than 20 years). However, since the meteoroids produced by long-period comets impact the Moon at much higher velocities than short-period comets, they are responsible for producing most of the ejecta.

1. Introduction

The Micrometeoroid Input Function (MIF) on the lunar surface (hereafter referred as LuMIF) is expected to vary spatially and temporally similar to the micrometeoroid environment at Earth. However, unlike at Earth, this variability has a more direct effect on the Moon. At Earth, the MIF produces layers of atomic metals from meteoroid ablation in the mesosphere (Janches et al., 2009; Plane et al., 2015), and any direct link between the neutral atoms and the MIF is mostly removed by atmospheric chemical and dynamical processes (Marsh et al., 2013) by the time they are observed. In contrast, meteoroid impacts on the Moon produce secondary ejecta and ionized and neutral vapor clouds whose characteristics are expected to be more directly linked to the LuMIF, with the Moon’s surface acting as an amplifier for the complex mass, angle, and velocity function of the meteoroid environment.

The Lunar Dust Experiment (LDEX) on board NASA’s Lunar Atmosphere and Dust Environment Explorer (LADEE) mission observed the Moon’s secondary dust ejecta cloud as a permanently present, asymmetric dust cloud engulfing the Moon (Horányi et al., 2015). LDEX observations showed that this cloud is most dense...
at 5–8 h of lunar local time, with a peak density tilted somewhat sunward of the dawn terminator. Initial results reported by Szalay and Horányi (2015) (hereafter referred as SH15) found that the ejecta cloud in the Moon’s equatorial plane is primarily produced by impacts from a combination of the three known sporadic meteoroid sources (Helion, Anti-Helion, and Apex). Furthermore, the cloud density is modulated by both the Moon’s orbital motion about the Earth and about the Sun. The tilting of the ejecta cloud toward the Sun was more pronounced earlier in the LADEE mission (November 2013), while the LDEX signal became more centered around the dawn terminator toward the end of the mission (April 2014). From these data features SH15 inferred a variable relative strength between the Apex (Ap), Helion (H), and Anti-Helion (AH) sources to account for the change in the structure of the ejecta cloud throughout the mission.

Our work reports initial results aiming to promote the understanding of these observations, specifically (1) to improve estimates of the relative importance of each dust population with a physical model and (2) to differentiate between variability caused by the meteoroid environment, the physical processes related with the regolith response to meteoroid impacts, and by observational biases. The main improvements introduced by our model are the accurate determination of arrival directions of micrometeoroids at the Moon and their velocity distribution functions, which are important because the ejecta yield is a function of incident velocity. We demonstrate that LDEX observations of the secondary dust ejecta can be approximately modeled with a combination of meteoroids produced by short-period, Jupiter Family Comets (JFCs) and long-period comets—such as Halley-type (HTC) and Oort Cloud Comets (OCC)—with a contributed total mass ratio of 1.3:1 ($\pm$0.2) assuming the same ejecta yield utilized by SH15. Asteroidal meteoroids were not considered in this model because their much lower impact velocities make a negligible contribution to the ejecta cloud. We find no evidence from previous observations and this model that indicates that the flux of H meteoroids impacting the lunar surface could be twice as strong as their AH counterpart as suggested by SH15 from the local time dependence of LDEX ejecta counts. We suggest that additional physical and/or measurement-specific processes may introduce a slight asymmetry in the response of the dayside and nightside surface to incoming micrometeoroids.

2. Models
2.1. JFC Model
The model used here follows Nesvorný et al. (2010; Nesvorný, Janches, et al., 2011), who argued that JFC particles represent 85–95% of the total meteoroid budget (in terms of number of particles) in the inner solar system. Once released from the comets, JFC meteoroids drift toward the inner solar system under the influence of Poynting-Robertson (P-R) drag and provide a continuous input of extraterrestrial material to Earth from the direction of the H and AH apparent sporadic sources (Jones & Brown, 1993; Nesvorný et al., 2010).

To simulate the distribution of JFC meteoroids throughout the solar system, our model uses the initial distribution of orbital elements for JFCs proposed by Levison and Duncan (1997), where the number of comets as a function of their distance from perihelion, $q$, is given by

$$dN(q) \propto q^{\gamma_{JFC}} dq$$

(1)

where $\gamma_{JFC}$ is a free parameter ($\gamma_{JFC} = 0$ in this work). The continuous size frequency distribution (SFD) of meteoroids produced by these comets is given by a power law

$$dN(D) \propto D^{-\alpha} dD,$$

(2)

where $D$ is the meteoroid diameter and $\alpha = 3$ is the slope index. The model is normalized such that it results in a total meteoroid mass input on Earth of $32 \pm 1.5$ t d$^{-1}$ from JFC meteoroids, and efforts to calibrate this quantity using various spaceborne and ground-based techniques are ongoing (Carrillo-Sánchez et al., 2016; Janches et al., 2017; Nesvorný, Janches, et al., 2011). More recently, Pokorný et al. (2017) used 100 $\mu$m JFC and HTC particles from this model to explore the meteoroid environment at Mercury and its role in shaping the morphology of the planet’s exosphere. Here the model is applied to the Moon by using the position and velocity vector from this model to explore the meteoroid environment at Mercury and its role in shaping the morphology of the planet’s exosphere.

Mutual collisions of meteoroids of all populations considered in this work and the Zodiacal cloud are following estimates from Pokorný et al. (2014) who adopted a formalism of Steel and Elford (1986). The authors found...
that the nominal collisional lifetime is too short to explain the observed distribution of meteors in the north toroidal source unless the collisional lifetime is assumed to be 20 times longer than originally suggested by Steel and Elford (1986). Note that the collisional lifetime is calibrated with the recent reinvestigation of the Long Duration Exposure Facility (LDEF) measurements (Cremonese et al., 2012; Love & Brownlee, 1993).

The JFC model (as well as the HTC and OCC models introduced later) provides an estimate of \( F_{\text{Moon}}(D, V_s, \lambda, \beta) \), which is the number of particles with diameter \( D \) and selenocentric velocity \( V_s \) originating from a radiant with Sun-centered ecliptic coordinates \((\lambda, \beta)\) and crossing the Moon’s cross-section disk. Our model allows us to calculate \( F_{\text{Moon}}(D, V_s, \lambda, \beta) \) covering 12 bins ranging from \( D = 10 \) to \( 2,000 \) \( \mu m \), \( V_s \) ranging from \( \sim 2 \) to \( 70 \) \( \text{km s}^{-1} \) with \( 1 \) \( \text{km s}^{-1} \) bin size, and \( \lambda \) and \( \beta \) binned every \( 2^\circ \). \( F_{\text{Moon}}(D, V_s, \lambda, \beta) \) is calculated every \( 12 \) \( \text{h} \) for an entire year from \( 1 \) July 2013, 12:00:00 UTC, to \( 30 \) June 2014, 12:00:00 UTC, covering the period of LADEE science operations. The meteoroid mass input was assumed to be constant throughout the year and by dividing the year from 1 July 2013, 12:00:00 UTC, to 30 June 2014, 12:00:00 UTC, covering the period of LADEE science operations which is the number of particles with diameter

\[
\text{median inclination value of } \sim 70^\circ.
\]

In addition, their semimajor axes are close to 1 \( \text{AU} \), but with a long tail to larger values, and have a broad distribution of eccentricities with a maximum at \( \sim 0.2 \) (see Figure 13 in Janches et al., 2015). The model tracks the dynamical evolution of thousands of dust particles released from a synthetic population of HTCs for millions of years until particles reach the end of their life, either by being scattered from the solar system by giant planets (mostly Jupiter), or by encountering one of the terrestrial planets, or by evolving too close to the Sun. The model adopts the HTC orbital architecture proposed by Levison et al. (2006) based on an observed inclination distribution of HTCs, which contains preferentially prograde orbits with a median inclination value of \( \sim 55^\circ \) and only a small fraction of comets on retrograde orbits. The prograde portion of HTC populates mostly the toroidal sources with a characteristic velocity distribution, which peaks at \( \sim 25 \) \( \text{km s}^{-1} \). The model shows also that the Ap source is formed in part also by HTC-released particles, with a velocity distribution which peaks at \( \sim 55 \) \( \text{km s}^{-1} \). These are predominantly retrograde or high eccentricity orbits representing a minority (\( \sim 11\% \)) of cases among the HTCs yet, together with OCCs, probably dominate impact ejecta production at the Moon.

### 2.2.2. OCC Model

For meteoroids released from OCCs, we adapted the model developed by Nesvorný et al. (2011), who investigated the effects of radiation pressure on particles released from the highly eccentric OCC orbits, and their dynamical evolution under gravitational perturbations from planets and P-R drag to determine if at least a fraction of the near-Earth meteoroid environment is produced by the contribution of dust released from these bodies. For small perihelion distances \( q \), the model follows the orbital distribution reported by Francis (2005). For larger perihelion distances, the authors assumed an increasing distribution with \( q \), opposed to the flat and/or declining distribution proposed by Francis (2005), given by

\[
dN(q) \propto \begin{cases} 
(1 + \sqrt{q}) dq & \text{if } q < 2 \text{AU} \\
2.41(q)^{1.36} dq & \text{if } q > 2 \text{AU}.
\end{cases}
\]

where \( 0 \leq \gamma_{\text{OCC}} \leq 1 \) and \( q \) is uniformly distributed between \( 0 \) \( \text{AU} \leq q \leq 5 \) \( \text{AU} \), thus assuming that particles with \( q > 5 \) \( \text{AU} \) will never reach Earth. In this work, we use \( \gamma_{\text{OCC}} = 0 \) since the authors found that the effect of changing this parameter was insignificant.
Nesvorný et al. (2011) found that OCC particles cannot provide a significant contribution to the overall meteoroid budget of the inner zodiacal cloud. Most of the small particles (i.e., \( D \sim 10 \mu m \)) are blown out of the solar system by radiation pressure, while millimeter-sized meteoroids get scattered by planets and their orbits never decouple from Jupiter, and thus, the collision probability of these meteoroids with Earth is negligible. The authors concluded that only meteoroids with diameters between \( \sim 100 \) and \( 300 \mu m \) can evolve in orbits decoupled from Jupiter and effectively populate the Ap source with preferentially retrograde meteoroids observed impacting the Earth with speeds around \( 55–60 \text{ km s}^{-1} \); yet, they may dominate the ejecta production at the Moon due to their large impact velocities.

2.3. Secondary Ejecta Model

Since in this work we focus on the meteoroid environment, for comparison purposes we adopt the same treatment of the regolith response than previous work. Thus, following SH15, the mass production of ejecta per unit surface can be estimated as

\[
M^+ = n_{\text{Moon}} (D, V_S, \lambda, \beta, \alpha(t)) \cos \alpha(t) mY, \tag{5}
\]

where the yield, \( Y \), is the ratio between the total mass of ejected material to the mass of the impacting particle in kilograms (\( m \), calculated from its diameter \( D \) assuming spherical particles of density \( 2 \text{ g cm}^{-3} \)). \( Y \) is given by

\[
Y \approx C m^3 V_S^2 \cos^2 \alpha(t), \tag{6}
\]

where \( C = 30 \) for a silicate surface, \( \chi = 0.2 \), and \( \delta = 2.5 \) (Koschny & Grün, 2001; Krivov et al., 2003).

3. Ejecta Cloud From JFCs

Figure 1a displays contour plots of the resulting sporadic radiant distributions of modeled JFC meteoroids in the near-Earth environment. The radiants are displayed in the Sun-centered ecliptic coordinates as a function of \( \lambda - \lambda_0 \), where \( \lambda \) is the ecliptic longitude of the radiant and \( \lambda_0 \) is the true longitude of the Sun. This effectively removes the motion of the Earth relative to the Sun, allowing to display the position of each radiant fixed in ecliptic coordinates throughout the year (e.g., the Earth’s apex is always at 270°). Both H and AH meteoroid apparent sources are well defined in this map, and their directionality implies that the incoming flux at the Moon should exhibit large spatial variability. The directional arrival of the sporadic meteoroid background has been extensively studied on Earth (Campbell-Brown & Wiepert, 2009; Fentzke et al., 2009; Pifko et al., 2013; Schult et al., 2017) and recently modeled at Mercury for the first time (Pokorný et al., 2017).

The remaining panels in Figure 1 show in more detail the expected variability of the secondary ejecta cloud from JFC meteoroids reaching the surface of the Moon. Each panel represents the normalized ejecta rate, \( M^+ \), calculated using equation (5) and accumulated during each lunar month of LADEE’s mission lifetime. Specifically, the contour plots show \( M^+ \) as a function of lunar latitude and local time produced by all masses, velocities and zenith angles resulting from the model. Two hot spots of ejecta centered at the equator are apparent, one centered at \(-01:30 \text{ LT} \) and a second peak centered at \(-10:30 \text{ LT} \), which are produced by AH and H meteoroids, respectively. The peak of the activity by JFC meteoroids is confined within \( \pm 20° \) of the lunar equator.

The model of JFC impacts predicts an asymmetric ejecta cloud around the dawn terminator (sunrise) where the degree of asymmetry changes from month to month. During the first month of the mission, the model predicts a stronger secondary ejecta cloud to be produced by H meteoroids because the Earth itself moves toward perihelion. However, as the Earth-Moon system moves away from the Sun into the spring equinox, the situation reverses and by the end of the mission the hot spot produced by AH meteoroids is predicted to be \( \sim 20\% \) stronger. In summary, the ejecta cloud produced by low-velocity particles from JFCs is significantly affected by the Moon’s motion with respect to the Sun both within a month and over a year (i.e., causes both synodic and annual variation), favoring the H source when the Moon moves toward the Sun and the AH source when the Moon moves away from the Sun.

If the ejecta yield is only a function of impactor velocity, our model of JFCs can reproduce only small variations of ejecta rates from the Helion and Anti-Helion directions over a year. This result is not an explicit assumption of the model; the equivalence of the H and AH sources simply follows from the trajectory elements of JFC particles. By fitting the LDEX ejecta measurements to an empirical model of the AH, H, and Ap sources, SH15 suggested that the H source must dominate over the AH source by a factor of 2.5 consistently throughout the LADEE mission to explain the measurements, with a decrease to a factor of 1.5 during the last month of the mission. The surprisingly high LDEX-derived H-to-AH ratio is in discord not only with our model but also...
Figure 1. (a) Sporadic radiant distributions of modeled JFC meteoroids in the near-Earth environment displayed in a Sun-centered frame of reference. (b–f) Normalized ejecta rate, \( M^+ \), calculated using equation (5) and accumulated during each lunar month of LADEE’s mission lifetime. The red curves in these panels show the local time versus selenocentric latitude covered by LADEE during each period.

with decades of meteor radar observations, which have shown that these two sources have similar strengths, with the AH source always being slightly stronger than the H source (~10 to 20%, depending on the survey, see, e.g., Table 3 in Janches et al., 2015). Similar results were reported more recently using the more sensitive MAARSY radar in northern Scandinavia (Schult et al., 2017). The higher sensitivity of this instrument indicates that, according to Earth-based observations, the H and AH sources have similar strengths down to micron-sized particles. Furthermore, our model shows that there is no dynamical justification to suggest that the meteoroid environment near the Moon is significantly different than that observed at Earth.
4. Effects of LADEE’s Inclination on the Observations

In order to account for potential LDEX observational biases, we investigate first the effects introduced by the satellite’s orbit. The maximum and minimum selenocentric latitude covered by LADEE as a function of local time for each lunar month are shown in Figures 1b–1f as red curves. It is immediately clear that the LADEE trajectory favors the detection of ejecta from the H source. Figure 2 displays in further detail the variability of the ejecta cloud produced by these sources with lunar phase and time of the year and how it is observed by LDEX. Figure 2a shows the modeled $M^+$ with the maximum normalized to unity as a function of LT and day of the year (DOY). For a given LT and DOY, the values represent an integration over all selenocentric latitudes. The model predicts a small synodic (monthly) modulation of the ejecta cloud produced by JFCs meteoroids, as well as a more pronounced annual variation. Within a lunar day the H and AH sources of ejecta peak at different times of the month, and thus, their ratio changes with lunar phase, where the H source produces more ejecta from Full Moon to New Moon, a period when the Moon is moving toward the Sun. In the course of a year the ejecta from these two sources show $\sim 15\%$ variation because of Earth’s eccentricity. On average the secondary ejecta cloud produced by H meteoroids is predicted to be more dominant from mid-July to January, while the AH source dominates the first half of the year. This effect is even more pronounced at Mercury due to its higher eccentricity (Pokorny et al., 2017).

Figure 2b shows the normalized $M^+$ predicted to be observed by LDEX given the satellite’s orbital characteristics, which introduce a bias favoring the H source. The quantification of this bias effect is shown in Figure 2c. The blue curve in this panel represents the modeled H-to-AH ratio, while the red curve is the predicted observed ratio when orbital biases are not considered. The nearly straight lines across the curves are average values obtained by applying a 30 day moving window average to remove the synodic variability. For comparisons the results reported by SH15 are also shown in this figure. Overall, the orbital bias introduces only a $\sim 20–30\%$ increase on the H source with respect to the AH source indicating that this is not the main explanation for the conclusions in SH15.
Figure 3. Modeled normalized $M^+$ produced by (a) HTCs and (b) OCCs meteoroids as a function of local time and day of the year during the duration of LADEE's mission (November to mid-April). Normalized $M^+$ predicted to be observed by LDEX given the satellite's orbital characteristics from (c) HTCs and (d) OCCs meteoroids.

5. Effects of Long-Period Comets on the Morphology of the Ejecta Cloud

The input from long-period comets must be included to the results presented in the previous sections in order to provide the full picture of LuMIF. Even though these particles are thought to be less dominant in total mass influx than JFCs (Carrillo-Sánchez et al., 2016; Fenztke et al., 2009), their higher selenocentric impact velocities make them the principal producer of the secondary dust ejecta cloud (Szalay & Horányi, 2015). As a consequence, LDEX results cannot be accurately modeled and interpreted without considering their contribution.

As in Figure 2 for JFC meteoroids, Figures 3a and 3b show the normalized modeled $M^+$ produced by HTC and OCC meteoroids on the Moon's surface as a function of LT and DOY, while Figures 3c and 3d show how they would be observed by LDEX. HTC particles produce a broader cloud with an extent similar to that produced by JFCs. OCC particles, on the other hand, produce a narrower cloud in local time. In both cases, the predicted observations show a bias toward the beginning of the mission, when the satellite's orbit crosses the Apex point closer to the Moon's equator than toward the end of the mission (see Figure 1).

From a comparison between LDEX observations and our modeled results, we can obtain constraints on the relative importance of long- and short-period comets at 1 AU. Each panel in Figure 4 represents an average over each lunar cycle during the mission, while the color curves are the modeled results for various examples of JFC to LPC ratios. The latitudinal coverage of the LADEE measurements is so limited to the equatorial region that we have no constraints from the observations to distinguish between the effects produced by HTCs and OCCs; thus, we constrained their sum. The average LDEX $M^+$ shown in each panel is calculated by determining the average dust density at the surface over a time range of 29.5 days (lunar synodic period) centered on the fifteenth of each month in 1.5 h LT bins and normalized to unity. Since the LADEE spacecraft deorbited...
Figure 4. Comparison between observed normalized $M^+$ and those predicted by our model using four different relative contribution ratios of short- and long-period comets. The LDEX points show 29.5 day averages centered on the fifteenth day of each month. Bars indicate the extent of local times that were binned together. The modeled data are provided as supporting information.

on 18 April 2014, the April panel shows LDEX data centered on 2 April 2014. This calculation follows existing methods to remove the altitude dependence from the LDEX measurements (Szalay & Horányi, 2016). The uncertainty of each data point is calculated using $\sqrt{N}$ statistics for each LT bin on the total number of counts per bin. We assume that LPC meteoroids are composed from equal contributions from HTC and OCC meteoroids with regard to their total mass influx on the Earth; that is, our calibration is done with respect to the Earth and then projected to the Moon. Furthermore, for comparison purposes between model and observations and given reasonable assumptions on the impact ejecta plume geometry, LDEX is able to detect changes very local to its location, on the order of the LADEE altitude squared.
Figure 4 presents a comparison between LDEX results and the model output for various JFC to LPC ratios. Performing a least squares fit, best agreement is found between model and observations when JFCs contribute about 1.3 ± 0.2 times as much total meteoric mass than that contributed by LPCs. Note that this required ratio is somewhat smaller, by a factor of 4 to 5, than those suggested by other Earth-based methods. For example, Carrillo-Sánchez et al. (2016) required a ratio of ~6 to simultaneously reproduce lidar observations of the vertical Na and Fe fluxes above 87.5 km and the measured cosmic spherule accretion rate at South Pole. As seen in Figure 4, higher contributions of JFC as compared to LPCs will overestimate the produced secondary dust ejecta, specifically during the peak activity periods of the H and AH sources. If the JFC contribution is, in fact, higher than our results suggest, this may indicate that the response of the soil as a function of impact velocity may be stronger than expected. In fact, Koschny and Grün (2001) specifically stated that their results should be applied mainly to ice-rich targets with impactor velocities between 1 and 12 km/s. This is significantly different than the high-velocity impacts on the lunar regolith discussed in this work, which questions the validity of using $\delta = 2.5$. For example, increasing $\delta$ in equation (6) from 2.5 to 3.5 results in similar agreement between observations and model but yields a ratio of JFCs to LPCs equal to 6.2 ± 0.8 (green dashed line in Figure 4), similar to Carrillo-Sánchez et al. (2016). We note that the $M^*$ inferred by LDEX on the duskside was larger during some months than predicted from the empirical three source model utilized by SH15. This is most likely due to a small contribution of impact ejecta from the weak antapex source (Janches et al., 2000) and has been included in recent LDEX analyses (Szalay & Horányi, 2016). The omission of this weak source is not expected to appreciably affect the results of this study.

6. Conclusions

We find that cometary meteoroids produce a variable cloud in both selenocentric latitude and local time, with a mild annual variation as well as a synodic modulation of the ejecta cloud. In particular, for meteoroids originating from JFC our model predicts more ejecta from the H source during the first part of the mission (October–December 2013), while the production of ejecta by the AH meteoroids is larger later in LADEE's mission (February–April 2014). Our predictions of a variable day-night asymmetry on the Moon's dust cloud from JFCs changing from month to month support findings from LADEE (Horányi et al., 2015; Szalay & Horányi, 2015).

A 1.3:1 (±0.2) ratio of short-period comets to long-period comets reproduces the degree of dawn-dusk asymmetry suggested by the shape of the near-dawn-centered peak in the ejecta cloud recorded by LDEX. However, this ratio is somewhat smaller than that suggested by, for example, the Earth-based method reported by Carrillo-Sánchez et al. (2016). This discrepancy might indicate that the ejecta yield might be more sensitive to the impactor's velocity than originally believed. Clearly, experimental measurements are needed of the velocity power dependence ($\delta$ in equation (6)) for collisions simulating the lunar surface rather than ice. The model presented here is only one realization from a broad spectrum of models allowed by uncertainties in free parameters discussed in section 2. The effect on ejecta calculations of our assumptions regarding the size frequency distribution, the distribution of initial orbits of cometary meteoroids, and the collisional lifetime of the meteoroid populations will be the subject of a future investigation.

One important discrepancy between the meteoroid populations included in our model and LDEX observations was the magnitude of the H source dominance over the AH source. In our model the H and AH sources are approximately equal in terms of the total mass influx on the lunar surface, with small variations during the year due to the Moon's motion. Accounting for the orbital inclination of LADEE did not favor the Helion source sufficiently to explain why in some months the ejecta peak was found to be significantly displaced from dawn. The dust ejecta observed by LDEX combines two main functions: (1) LuMIF that provides the dynamical characteristics of the impactors on the lunar surface and (2) the regolith response to those impactors governed mostly by the assumptions regarding the yield $Y$. We conclude in this work that the meteoroid environment is not the main source of the H/AH imbalance in the LDEX observations reported by Szalay and Horányi (2015). Such an argument is supported by long-term Earth-based observations and advanced models as the one presented here. Instead, the LDEX observed imbalance could be due to as of yet unrecognized effects on the instrument or, more likely, on $Y$, including surface temperature, UV, and solar wind exposure, for example, possibly responsible for the increased production of ejecta on the lunar dayside. As such, this effect should be referred to as a daytime-nighttime ratio rather than H/AH ratio, as it seems to be the result of a broader set of processes than originally suggested.
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