MASS LOADING OF THE EARTH'S MAGNETOSPHERE BY MICRON SIZE LUNAR EJECTA--
I: EJECTA PRODUCTION AND ORBITAL DYNAMICS IN CISLUNAR SPACE

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Investigations in progress have focused on particulate matter possessing lunar escape velocity which may be sufficiently perturbed to enhance the cislunar meteoroid flux. Extensive studies have been devoted to the examination of the interplanetary flux, while lunar ejecta created by the impact of this material on the lunar surface only now is being thoroughly examined. Of primary importance to this study is the production of ejecta at the lunar surface by hypervelocity impacts. Examination of the production mechanisms of lunar ejecta requires that one define the principal parameter of the hypervelocity impact event, i.e., the interplanetary meteoroid flux. To this end, two recently reported flux models /1, 2/ are employed to calculate the total mass impacting the lunar surface due to the sporadic meteor flux. However, when the moon intersects the orbit of shower meteoroids, additional matter will be injected into selenocentric space and consequently will increase the cislunar meteoroid flux. The increase is primarily due to an augmentation of lunar ejecta.

Hypervelocity meteoroid simulation experiments /3, 4, 5/ have provided ratios relating the mass of the impacting particle to the mass of ejecta produced. In order to discover that ratio, the effects of particle density as well as impact angle of incidence have been examined. Schneider /4/ has found that a 10 mg particle with a velocity of 4 km/s impacting at normal incidence would produce ejecta which represented 7.5×10^{-5} the mass of the incident particle and had a velocity greater than 3 km/s. Alexander /5/ has shown that under similar initial conditions the ejecta mass ratio, e, would be higher by an order of magnitude ($e = 5. \times 10^{-4}$). A recent study by Zook et al /6/ reported that oblique angle impacts would produce 200 to 300 times more microcraters (diameters = 7 μm) on ejecta measuring plates than would be produced by normal incidence impacts. Given that 7 μm diameter microcraters correspond to particles with $m \cong 10^{-12}$ g /7/ and that the impact velocity was 6.7 km/s, one may infer that the fraction of ejecta mass with lunar escape velocity would also increase by 200 to 300 times ($e = 1.5 \times 10^{-2}$). These three values for the "ejecta to incident particle mass" ratios will be employed to establish the total lunar ejecta mass after the interplanetary flux at 1 AU has been determined.

Two distinct dust flux models are used to carry out the calculations in this paper. The first model originates in McDonnell /8/ and then is updated in Alexander /1/; the second one is that of Grün et al /2/. Both interplanetary flux models rely exclusively upon the data gathered from in-situ experiments and thus will be represented by an empirical equation of the form

$$\Psi = \xi(m)\, m = A\, m^{1-\alpha}\, dm. \qquad (1)$$

Hughes /9/ reports that this equation describes the cumulative flux of particles on a surface (per unit area per unit time) having a mass greater than m. Table 1 presents the values for α in each regime of mass value for each model.

TABLE 1

	$m \leq 10^{-14}$(g)	10^{-14}(g) $\leq m \leq 10^{-9}$(g)	$m \geq 10^{-9}$(g)
McDonnell	0.33	0.303	1.22
Grün	0.85	0.36	1.34

Using equation (1) and the two models for interplanetary flux, the total mass flux of sporadic meteoroids impacting the lunar surface can be calculated. If one assumes the sporadic meteoroid flux is isotropic and impacts the lunar surface with an average speed of 20 km/s, then the spatial mass density near the lunar surface can also be calculated, using an equation from Grün et al /2/,

$$S\,(m) = \frac{k\Psi}{\bar{v}} \qquad (2)$$

where k = 4 for isotropic impacts and $\bar{v}$ is the average meteoroid impact velocity at the lunar surface.

TABLE 2

	Lunar Mass Flux (g/m^2 sec)	Total Mass Lunar Surface (tons/day)	Spatial Mass Density (g/m^3)
McDonnell	2.5×10^{-12}	8.72	5.0×10^{-16}
Grün	1.04×10^{-13}	0.74	2.1×10^{-17}

These two models determine the upper and lower bound for the sporadic meteoroid flux at the lunar surface.

There exist a few notable examples /10/ of experiments which have measured the physical and dynamic properties of the ejecta. However, only a few experiments /4,5/ have investigated the dynamics of that portion of the ejecta which has achieved lunar escape velocity (2.4 km/s). An additional ejecta parameter that is common to the studies /4, 5, 6/ is an estimate of the cumulative size distribution for high velocity micron size ejecta from which the important parameter α, the mass distribution index, can be determined. Such an index can be inferred from the information Schneider reported /4/. Table 3 gives the values for α for each reported instance.

Table 3
Mass Distribution Index

Schneider /4/	0.64
Alexander /5/	0.83
Zook, et al /6/	0.81

Given the total ejecta mass of interest (v = 2.4 km/s), the mass distribution index, and the ejecta mass ratio e for each study, one can determine the cumulative flux for the ejecta leaving the moon's sphere of influence.

Table 4 presents the Total Ejecta Mass Flux corresponding to each ejecta mass ratio for the two interplanetary flux models employed in this paper. (All values have the units g/m^2 sec.).

Table 4

	Ref /4/ (7.5×10^{-5})	Ref /5/ (5.0×10^{-4})	Ref /6/ (1.5×10^{-2})
McDonnell	1.9×10^{-16}	1.3×10^{-15}	3.8×10^{-14}
Grün	7.8×10^{-18}	5.2×10^{-17}	1.6×10^{-15}

The ejecta spatial density near the lunar surface is given in Table 5 for comparison with that of the interplanetary dust flux in Table 2. (All values have the units g/m^3).

TABLE 5

	Ref /4/	Ref /5/	Ref /6/
McDonnell	2.5×10^{-19}	1.7×10^{-18}	5.0×10^{-17}
Grün	1.04×10^{-20}	6.9×10^{-20}	2.1×10^{-18}

The above results show that the lunar ejecta spatial density near the lunar surface differs from the interplanetary dust spatial density by three orders of magnitude for Ref /4/, by two orders of magnitude for Ref /5/, and by one order of magnitude for Ref /6/. The variation between each spatial density value originates with the ejecta mass ratios which express the fraction of the incident particle mass with escape velocity. The lunar ejecta spatial density due to sporadic meteoroid flux at 1 AU remains essentially constant.

When the earth-moon system intersects the orbit of annual meteoroid showers, the interplanetary flux near these orbits significantly increases. Taking into account, the cumulative mass distribution and the energy of the meteoroids of the stream, one can calculate the cumulative mass flux of the particular shower. As the sporadic flux, one may then use the ejecta mass ratios to ascertain the lunar ejecta cumulative mass flux /11/. For two representative annual meteoroid streams, i.e., Quadrantids and Geminids, the lunar ejecta cumulative mass flux values are $4. \times 10^{-15}$ and $3. \times 10^{-15}$ (g/m^2 sec), or three times the upper bound value for the lunar ejecta mass flux created by the sporadic meteoroid flux in Table 4.

CONCLUSIONS

There is ample evidence to support the contention that the sporadic interplanetary meteoroid flux enhances the meteoroid flux of cislunar space through the creation of micron and submicron lunar ejecta with lunar escape velocity. During annual meteoroid showers there will be a significant increase in the lunar ejecta cumulative flux which will augment the cislunar meteoroid flux for the mass range $m \leq 10^{-9}$g by as much as an order of magnitude.

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