# INTERACTION OF LUNAR EJECTA AND THE MAGNETOSPHERE OF THE EARTH

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## ABSTRACT

A significant flux of ejecta from lunar impacts of interplanetary dust particles leaves selenocentric space and enters the magnetosphere of the earth. During favorable lunar phases, 80% of the ejecta enter the magnetosphere, where their orbits are determined by electrodynamic as well as gravitational forces. Initial study of the orbital characteristics and perturbations of these magnetosphere ejecta is presented and its implications are discussed.

## RECAP OF PERTINENT SATELLITE MEASUREMENTS IN THE VICINITY OF THE EARTH

The 1959 Eta (Vanguard III) satellite was in orbit in near earth space between September 18 and December 1, 1959. The dust particle experiment detected an unusual number of events during the 10-day period between the 10th and 20th of November. This time period coincided very closely with the time of the Leonid shower. Alexander et al.[1], reported these data and pointed out that the impact rate was far too high to be considered a part of the sporadic background, while at the same time it was extremely unlikely that micron size particles could exist as continuing members of a meteor stream such as the Leonids. The possibility of lunar ejecta associated with the Leonids was considered, but investigation of orbital characteristics of these particles was not carried out at that time. The other possibility considered then and later was that the events recorded could have been noise events probably associated with thermal cycling of the satellite during each orbit. Bohn and Alexander [2] presented the results of an extensive investigation of the possibility of thermally caused events in the 1959 Eta dust particle experiment and found that it was not possible to show that these events were thermally caused noise. However, the impact rate was so high during the Leonid period, at least two orders of magnitude enhancement, that a question has always remained concerning the nature of these events.

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The most significant determination of dust particle flux in the vicinity of the earth came from the measurements conducted by the dust particle experiments on Explorers XIII and XV, as reported by D'Aiutolo [3], and Pegasus, as reported by Naumann [4]. These data were for particle sizes larger than those projected for the magnetosphere ejecta.

It was not until the HEOS dust particle experiment [5] that measurements were made of particle fluxes near the earth in the micron and submicron size range. Hoffman et al. [5] have reported findings from HEOS that show particle "swarms" in regions near the earth. A study was made of a possible ejecta source for these particles [5] with a positive, though not exclusive, result. The size of the HEOS particles was in the range of interest and always occurred in the magnetospheric region of interest.

The 1959 Eta and HEOS results do not, in any way, represent conclusive measurements of ejecta in the magnetosphere. However, they may be indicative of such, especially the more recent HEOS measurement. It is not believed that the other satellites mentioned would have detected these ejecta, and there are no other in-situ measurements. The following sections present the initial results of a study which gives (1) a mass magnitude of the pulse of lunar material into the magnetosphere and (2) a preliminary look at the dynamics of these particles in near-earth space.

## MASS OF EJECTA PULSE INJECTED INTO THE MAGNETOSPHERE

The mass of ejecta injected into the magnetosphere during each pulse is very significant to any investigation of interactions between the ejecta and the atmosphere of the earth. Recent studies of the mass of ejecta leaving the moon have been reported [6, 7]. The ejecta mass index parameters used in these investigations were obtained from laboratory studies of micron and submicron ejecta resulting from hypervelocity impacts of simulated meteoroids on basalt-type rocks [6,7]. In addition to these studies, Gault [8] found the cumulative ejecta mass below a nanogram to be $2 \times 10^{-7}$ g/cm$^{-2}$ yr$^{-1}$. The recent laboratory experiments above support this figure.

From all of the above information, the total mass of ejecta less than a nanogram leaving the moon and selenocentric space is $2.1 \times 10^5$ kg/day. While this is a small fraction of the total mass of sporadic meteoroids, it is comparable to the sporadic meteoroid background for the same size range. In addition, particles with radii less than 0.5 um will not, in general, be a part of the sporadic dust cloud at 1 AU because of the radiation pressure force. However, ejecta with radii less than 0.05 um are found in the lunar ejecta flux and will enter the magnetosphere. Therefore, the moon is the primary source for all particulates in the magnetosphere with radii less than 0.5 um.

Over a lunar phase angle of 70 to 165° [9], an average of 50% of the ejecta enter the magnetosphere. This lunar phase angle translates into about 8 days with the mass of ejecta entering the magnetosphere being about 8 x $10^5$ kg.

## DYNAMICS OF EJECTA IN THE MAGNETOSPHERE

Over the window of the lunar phase angle [9] ,the moon is well outside the earth's magnetosphere, and an ejectum leaving the lunar sphere of influence finds itself in an environment in which the equilibrium charge is determined by photoelectrons and solar wind only and is limited to about +7 V [10]. When the ejectum enters the magnetosphere, however, accretion of electrons predominates as the charge-causing mechanism, the sign of the charge on an ejectum reverses [10, 11], and the potential on the ejectum may reach -1000 V [11].

Is it possible, then, for the ejectum to become magnetically trapped? Table 1 gives the cyclotron radii of various sized particles all at a potential of -500 V in various uniform magnetic fields. The strength of each magnetic field is the strength of the earth's magnetic field in the magnetic equatorial plane under a simple magnetic dipole approximation. An ejectum density of 3 g-$cm^{-3}$ is assumed. The speed of each ejectum is taken to be the speed an object would attain in freely falling from a distance equal to the mean lunar orbit radius to the earth's surface, 11.1 km-$sec^{-1}$.

Table 1. Cyclotron radii for -500 V ejecta in uniform magnetic fields of the same magnitude as fields found at various distances from the earth. Above each solid line the variation in the real magnetic field over a distance equal to the cyclotron radius is less than the percentage labeling that line.

| Distance in earth radii | Ejecta size | | | |
|---|---|---|---|---|
| | 0.05 um | 0.10 um | 0.30 um | 0.60 um |
| 1.25 | 1.31 km | 5.24 km | 47.4 km | 189 km |
| 1.50 | 2.27 | 9.05 | 81.9 | 327 |
| 1.75 | 3.60 | 14.4 | 130 | 520 |
| 2.00 | 5.38 | 21.5 | 194 | 776 |
| 2.25 | 7.65 | 30.6 | 276 | 1100 |
| 2.50 | 10.5 | 41.9 | 379 | 1510 |
| 2.75 | 14.0 | 55.8 | 505 | 2020 |
| 3.00 | 18.1 | 72.4 | 655 | 2620 |
| 3.25 | 23.0 | 92.3 | 832 | 3330 |
| 3.50 | 28.8 | 115 | 1040 | 4160 |
| 3.75 | 35.4 | 142 | 1280 | 5120 |
| 4.00 | 42.9 | 172 | 1550 | 6210 |
| 4.25 | 51.5 | 206 | 1860 | 7450 |
| 4.50 | 61.1 | 245 | 2210 | 8840 |
| 4.75 | 71.9 | 288 | 2600 | 10400 |
| 5.00 | 83.8 | 336 | 3030 | 12100 |

1% 3% 10% 20%

At the magnetopause a particle would not have attained this velocity by gravitational forces alone, but in the sun-earth-moon configurations under consideration, it would have been accelerated by solar radiation pressure. The solid lines in the table indicate limits above which the variation in the earth's magnetic field do not exceed some percentage over a change in geocentric distance equal to the cyclotron radius of the particle. Variations in the equilibrium charge of an ejectum due to spatial variation in Van Allen electron flux are expected to be comparable in magnitude.

## CONCLUSION

Clearly, magnetospheric trapping of "sufficiently small" particles can take place, and the quantification of "sufficiently small" appears to lie within the range of particle sizes considered by Chamberlain et al. [9]. More detailed analysis of the dynamics of ejecta entering the magnetosphere is presently underway in order to quantify further the nature of trapped ejecta.

## REFERENCES

1. Alexander, W. M., McCracken, C. W., and LaGow, H. E.: 1961, J. Geophys. Res. *66*, pp. 3970-3973.
2. Bohn, J. L., Alexander, W. M., and Simmons, W. F.: 1968, Space Res. VIII, pp. 588-595.
3. D'Aiutolo, C. T.: 1964, Space Res. IV, pp. 858-870.
4. Naumann, R. J.: 1965, NASA TM X-1192.
5. Hoffman, H. J., Fechtig, H., Grün, E., and Kissel, J.: 1974, Space Res. XIV, pp. 363-369.
6. Alexander, W. M.: 1975, Ph.D. Dissertation, Univ. of Heidelberg.
7. Richards, M.: 1975, M.S. Thesis, Baylor University.
8. Gault, D. E., Horz, F., and Hartung, J. B.: 1972, Proc. of 3rd Lunar Conf. *3*, ed. D.R. Criswell, pp/ 2713-2730.
9. Chamberlain, J. D., Alexander, W. M., and Corbin, J. D: 1980 (this volume).
10. Singer, S. F.: 1979, private communication, IAU Sym. No. 90.
11. Morfill, G. E.: 1979, private communication, IAU Sym. No. 90.

## DISCUSSION

*Morfill*: Dust particle charge is an important parameter with changes in different plasma regimes. What did you use? The potential may be as high as 1 kV in some regions of the magnetosphere.
*Alexander*: 500 volts.

*Singer*: In the outer magnetosphere the charge changes from positive to negative, a feature which may enhance residence time and increase flux. Co-rotation should also be taken into account.
*Alexander*: Co-rotation and charge change will be used in extended studies.