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TECHNICAL NOTE

D-488

RECENT DIRECT MEASUREMENTS BY SATELLITES OF COSMIC DUST IN THE VICINITY OF THE EARTH

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON September 1960

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by
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SUMMARY

Direct measurements of the space density of cosmic dust particles in the vicinity of the earth have been made from rockets, satellites, and space probes.

The largest data samples have been obtained from crystal transducer sensors that detect the impact-impulses occurring from the collision of dust particles on sensitive surfaces of space vehicles. Preliminary results from satellite 1959 Eta show: (1) over 1500 impacts and an area-time product greater than $10^{10}cm^2$-sec; and (2) a daily variation in the dust particle density near the earth.

The dust particle instrumentation of 1959 Eta and sensor calibration techniques are discussed in this paper. The results of direct measurements from space vehicles prior to 1959 Eta are summarized with respect to 1959 Eta information.

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INTRODUCTION

Extraterrestrial dust particles in the vicinity of the earth have been detected recently by satellites. Significant results have been obtained from two satellites that were planned and launched as part of the U. S. International Geophysical Year Program: 1958 Alpha (Explorer I), and 1959 Eta (Vanguard III). The complete results from 1958 Alpha are being reported in another paper (Reference 1). The major part of the present paper is concerned with preliminary data from 1959 Eta. This satellite was instrumented to measure magnetic fields, X-rays, and vehicle environmental conditions in space.

The data reported in this paper were obtained from one of several environmental sensors (References 2 and 3) on 1959 Eta. The environmental parameters measured were: (1) skin and package temperatures, (2) skin erosion and sputtering, and (3) micrometeorite impacts and damage.

The data from 1959 Eta are preliminary in nature, and concern only the environmental sensor measuring the micrometeorite impacts on the satellite. Data on skin erosion due to corpuscular and dust-particle bombardment, and the information on skin penetration due to single impacts or corpuscular erosion, are incomplete at this time.

COSMIC DUST INSTRUMENTATION OF SATELLITE 1959 ETA

Satellite 1959 Eta was launched on September 18, 1959 from Cape Canaveral, Florida. It carried a microphone impact counter system utilizing four piezoelectric transducers attached to the metallic skin of the satellite. A dust particle impact upon the satellite surface thus produced a piezoelectric signal from the microphone system. The microphone material, lead zirconate, was formed into 1-inch-diameter discs 1/8-inch thick. The curie point of the transducer used was 300°C. The outputs of four of these

*Originally presented at the First International Space Symposium sponsored by the Committee on Space Research (COSPAR), Nice, France, January 1960.

impact sensors were connected in parallel, and the electric pulse resulting from an impact was suitably amplified and stored in a three-digit counter. A block diagram of the micrometeorite counter system is shown in Figure 1.

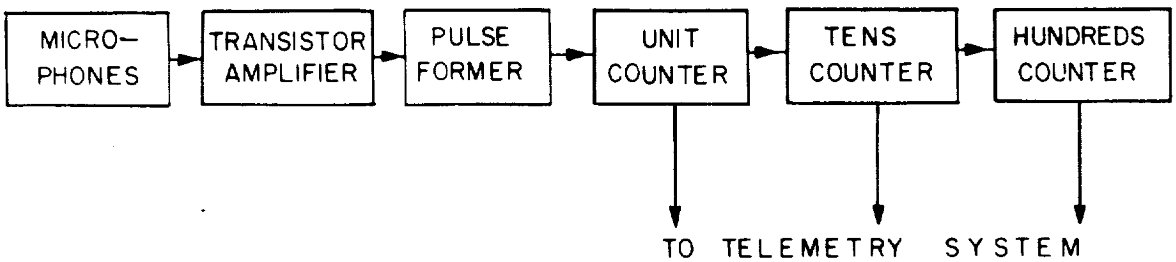

Figure 1 - Block diagram of micrometeorite counter

Magnetic cores constituted the basic elements of the pulse-former and counter circuits. The pulse former transformed the amplifier output from high-impedance pulses of a few microseconds duration each into low-impedance pulses of a millisecond duration each. These signals were then fed into the unit stage of the counter. This counter accepted nine pulses from the pulse former, increasing the frequency of an output oscillator in steps on application of each successive pulse. Upon receipt of the tenth pulse the oscillator output frequency returned to its initial value, and simultaneously the tens counter was pulsed to advance its output frequency one "digit." On its tenth count, the tens counter delivered a voltage pulse to advance the hundreds counter. Each decimal counter had as its most essential element a "rectangular loop" type of magnetic core (Reference 4) with a hole bored perpendicular to the coil axis; this configuration was named a "cyclops core." Rectangular-loop magnetic cores have the property of retaining any flux level to which they are set, after the current has ceased or diminished. Since the flux level of the cyclops cores was changed only by the incoming counts, continuous monitoring of the signal was not necessary to determine the total number of impacts.

The output of the telemetry system consisted of tone bursts separated by blank spaces. Information was contained in (1) the length of a tone burst, (2) the frequency of the burst, and (3) the length between it and the next burst. The counter information was presented in the second of these forms. The frequency of one tone burst was indicative of the units count, that of a second burst was indicative of the tens count, and a third frequency indicated the hundreds count. A typical calibration curve of telemetered frequency vs. digital counter state is shown in Figure 2.

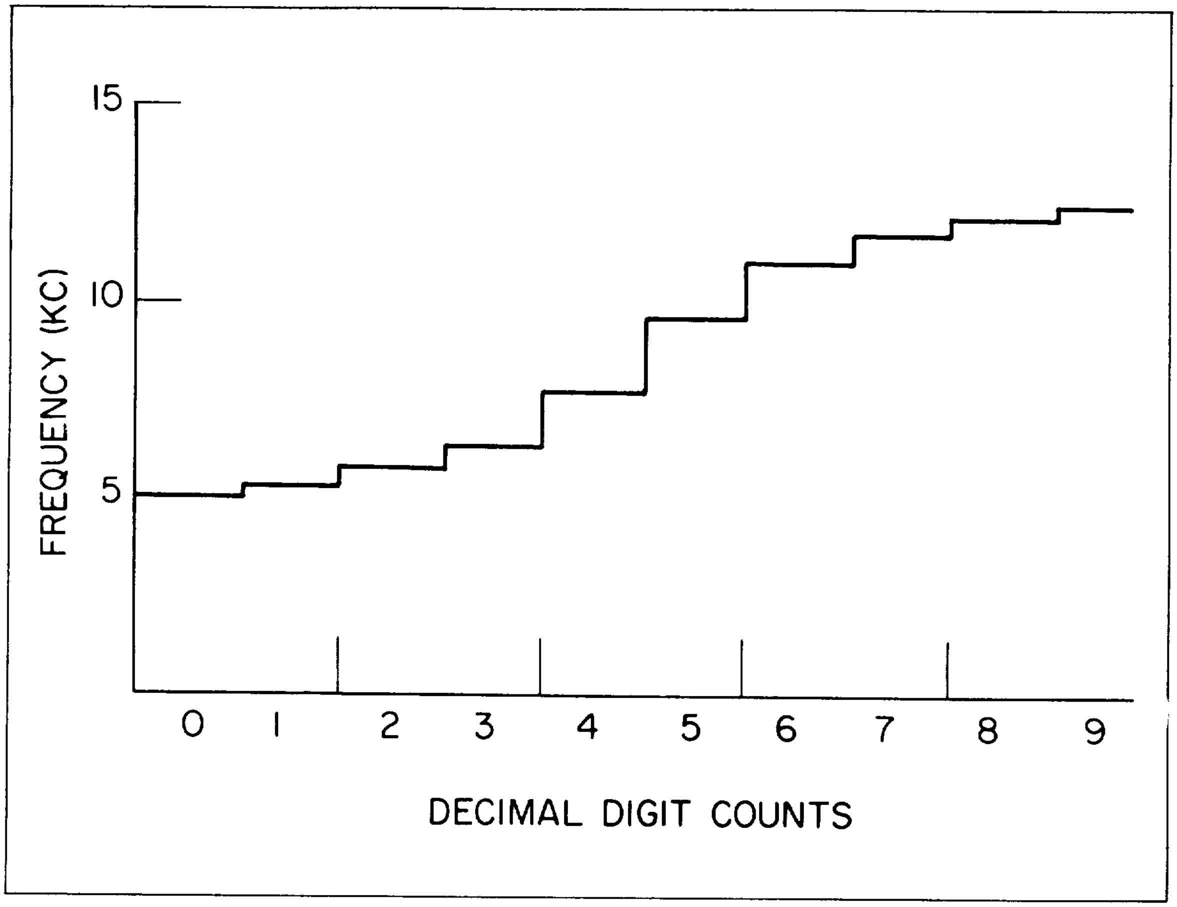

Figure 2 - Telemetering frequency vs counts, 1959 Eta

CALIBRATION OF SENSORS

Two major considerations were necessary to determine the calibration of the microphone impactor system:

(1) The physical parameter of the particle being measured by the sensor employed in the satellite, i.e., energy, magnitude of momentum, or mass of the impacting particle.

(2) The threshold of response of the sensor, and thus of the system, over the sensitized area of the satellite.

A number of experiments have been performed to ascertain the physical impact parameter being measured by the impactor sensor (References 5, 6, and 7). These laboratory measurements indicate that, in the impact velocity range from 20 cm/sec to 2×10^5 cm/sec, there exists a linear relation between the momentum of the particle before impact and the voltage output of the linear amplifier. Laboratory calibration measurements employing particles with meteor velocities have not yet been obtained. One theoretical consideration of hypervelocity impact phenomena indicates that the impulse measurement of the sensor is closely related to the momentum of the impacting particle. However, some experimenters state that the impulse measurement of the sensor is proportional to the kinetic energy of the meteor particle (Reference 8).

The 1959 Eta impactor sensors were calibrated as impulse measuring devices that measured a physical parameter closely related to the momentum of the impacting particle. As more knowledge is obtained concerning hypervelocity impact phenomena, the exactness of the calibration of acoustical devices used in dust particle sensors will be determined, and sensitivity threshold levels of reported results can be adjusted if necessary.

The threshold response of the sensors in 1959 Eta were determined by dropping very small glass spheres on the satellite surface. The mass of each bead was about 55 micrograms ±8 percent, and the velocity of the bead was known to an accuracy of ±5 percent. The locations of the sensors are shown in Figure 3. Except for an area of approximately 1 to 2 square inches centered over each microphone, the threshold sensitivity of the total sensitive surface (sections B and C in Figure 3) varied between 0.9×10^{-2} and 1.2×10^{-2} dyne-sec. A 1-inch-diameter circular disc was mounted over each microphone sensor; thus, for approximately 95% of sections B and C of the satellite skin, the threshold sensitivity was as determined. The physical dimensions of the surface sensitive to dust particle collisions was approximately 0.4 square meter.

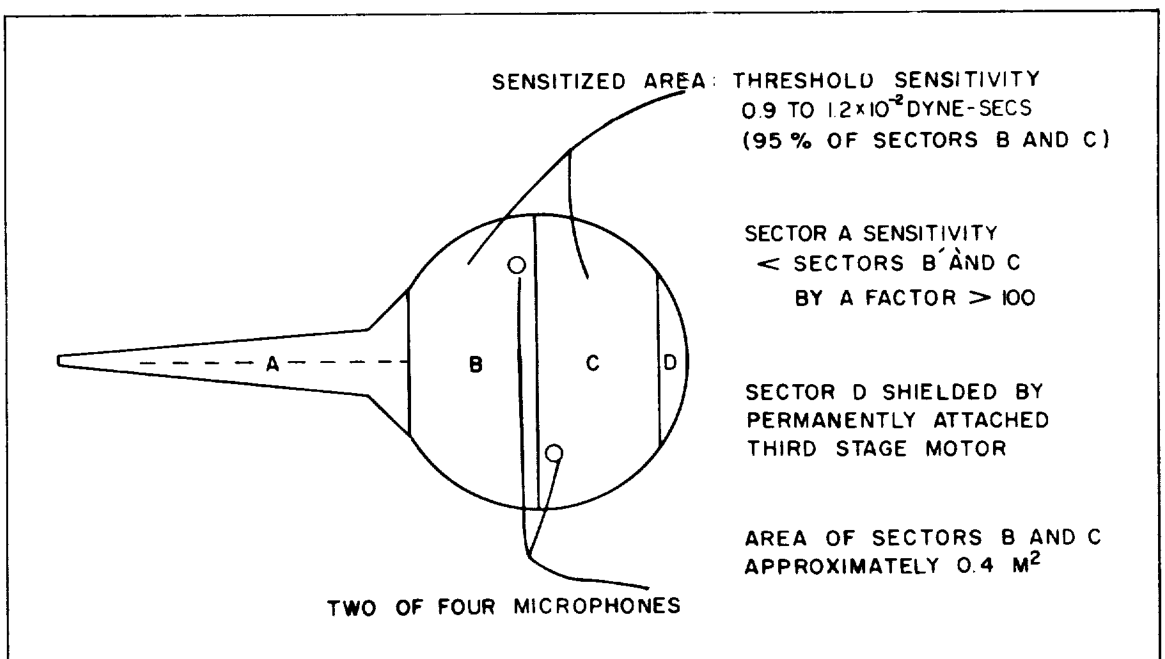

Figure 3 - Sensitive impact areas of satellite, 1959 Eta

RESULTS

The following preliminary results were obtained from the microphone sensor. The data which have been reduced primarily represent one counter reading per day.

There is an interaction between the magnetometer and the microphone instrumentation that requires a detailed study of all the telemetry records before the final analysis of the data is complete: The magnetic field experiment required a command function from the ground stations, and in some of the interrogations the command event added a count to the digital counter system. Most of the satellite interrogations occurred during a time when telemetered information was being received, and such false counts entering the counter were monitored and subtracted from the real counts. The average number of false counts per interrogation during the period covered by this paper was determined from the data reduced at this time. Since the total number of interrogations per day was known, the average rate of false pulses per day due to interrogations was determined and was subtracted from the total number of counts per day read from the counter. An additional check on the number of interrogation-caused pulses was obtained by having three periods during the lifetime of the satellite when no interrogations were made.

The total daily impact rate and the average daily number of false pulses due to the interrogations are shown in Figure 4 for the period of September 18, 1959 to October 9, 1959. Figure 5 shows the corrected impact rate (average daily interrogation pulses subtracted from the total daily count) and the influx rate in impacts per square meter per day for the same period. In computing the influx rate, an effective area for the impact section of the satellite had to be determined. Tentatively, the impact area is considered to be a 20-inch-diameter cylinder 10 inches high, tumbling in space and partially (approximately 25 percent) shielded by the earth. Over the 22-day period depicted in Figure 4, the maximum-minimum variation of any count rate recorded by the impact instrumentation for any 24-hour period is less than a factor of 10. One of the three periods when no interrogations of the magnetometer experiment occurred was on September 30, 1959. During this 24-hour period, 65 impacts on the sensitized area of the satellite were recorded. The average count per day for the 22-day period was 45, with interrogation counts subtracted. Thus, either the number of counts recorded during the interrogation-quiet period was higher than normal, or the average number of false pulses being used at this time is too high. However, the slight ambiguity present will be practically eliminated when the complete data records are available.

The influx rate of particles per square meter per day is shown in Figure 5. During the reported period the highest value of this quantity was 300 and the lowest 67. The daily count rate varied by a factor of approximately 4-1/2, as is shown in Figure 4. It is believed that the measurement definitely indicates an average influx rate of at least 150 impacts per square meter per day. The rate for the interrogation-quiet day was 210 impacts per square meter per day.

DISCUSSION OF RESULTS

A tentative estimate of the number and mass of interplanetary particles striking the earth per day can be made by using the data from 1959 Eta. This is done (1) in terms of the component of the interplanetary matter measured by 1959 Eta, and (2) in terms of the total mass of micrometeorites impinging on the earth per day by combining data from 1958 Alpha and 1959 Eta.

The mass of the threshold impacting particle may be computed by using a mean impact velocity of 30 km/sec, the calibration of the system having a threshold impact-impulse of 1×10^{-2} dyne-sec, and by assuming that a linear impact-impulse dependence at meteor velocities is valid. The threshold mass is 3.3×10^{-9} grams at a mean impact velocity of 30 km/sec. If the average figure is used for the influx rate over the 22-day period and it is assumed that, at the moment, a significant number of meteoric particles are not in orbit around the earth, the mass influx of this component of interplanetary matter on the earth is 6×10^{2} tons per day.

It is possible to obtain an estimate of the amount of interplanetary matter falling on the earth each day from two independent measurements, those of 1958 Alpha and 1959 Eta. Both the type of sensors and the calibration techniques employed in these two satellites were the same. The threshold impact-impulse sensitivity of 1958 Alpha was 2.5×10^{-3} dyne-sec. The corresponding threshold mass sensitivity was 8×10^{-10} grams at a mean impact velocity of 30 km/sec. If it is assumed that the two measurements are valid dust particle measurements, then by extending the mass distribution curve as defined by these two points (Figure 6), the influx rate on the earth of interplanetary particles of mass between 1.2×10^{-8} and 1.2×10^{-10} grams is approximately 10^{4} tons per day.

Two additional facts should be noted concerning the measurement of interplanetary dust particle influx from 1959 Eta. First, the number of actual events counted is the largest yet reported: The total count of impacts for the first 22 days is approximately 1000 with false pulses subtracted. Second, the area-time product for the lifetime of the satellite was greater than 3×10^{10} cm^2-sec. Data from 1958 Alpha contained 153 events and an area-time product of 1.8×10^{8} cm^2-sec.

The satellite 1958 Delta had impactor sensors for direct measurement of dust particle influx. No clear indication of the total number of events or the area-time product has been published to date. However, the average influx rate as of 1.7×10^{-3} impact per square meter per second, and a threshold sensitivity of 10^{-9} grams with a mean particle velocity assumed to be 40 km/sec, have been reported (Reference 9). Thus, considering the reported influx rates and the corresponding mass threshold sensitivities of the sensors, the findings from the three satellites indicate an influx rate between 1×10^{-3} and 8.4×10^{-3} impact per square meter per second for mass threshold sensitivities between 3.3×10^{-9} and 8×10^{-9} grams.

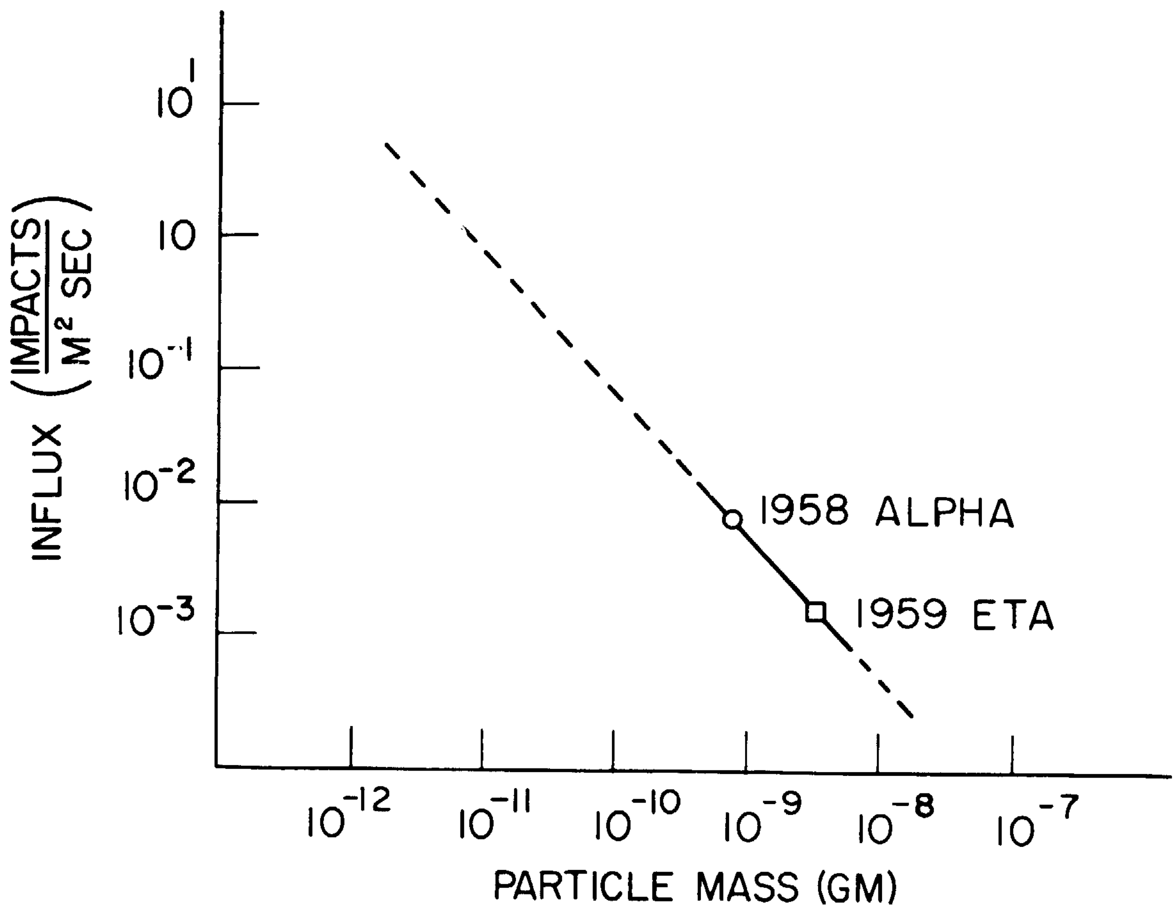

Figure 6 - Tentative mass distribution of micrometeorites as defined by results of 1958 Alpha and preliminary data from 1959 Eta

A brief comparison can be made of the influx rate obtained by direct measurement techniques on 1959 Eta with the data obtained from various indirect measurement methods. The indirect measurement methods can be classified in two main categories: (1) data obtained by visual and radar observations (References 10-12), and (2) data from considerations of zodiacal light (References 13-16). Data from the first category contain influx information on particles with masses as low as approximately 10^{-5} grams. Various zodiacal light computations consider particles with radii from 100 to 300 microns. The data from the various methods in category (1) are consistent with each other within one order of magnitude. By extrapolating the category (1) data to the mass threshold of 1959 Eta, the average influx rate as determined by 1959 Eta is found to be between two and three orders of magnitude greater than that of category (1). The different zodiacal light considerations are consistent with each other within approximately two orders of magnitude. In a comparison of these data with the 1959 Eta data, the resulting influx rate varies from a rate similar to the satellite findings to a rate two orders of magnitude less than the satellite findings.

ACKNOWLEDGMENTS

The authors wish especially to thank Mr. D. H. Schaefer, Mr. J. C. Schaffert, and Mr. R. W. Rochelle for their efforts in the design and construction of the instrumentation of the experiment; the members and their associates of the Vanguard Science Program for their vital work in planning, designing, fabricating, and testing the Magneray-Environmental Satellite; and the members of shops and scientific divisions of the U. S. Naval Research Laboratory who contributed to the design and fabrication of this satellite.

REFERENCES

1. Dubin, M., "Meteoritic Dust Measured from Explorer I," Planetary and Space Sciences 2(2/3):121-129, London, Pergamon Press, April 1960

2. LaGow, H. E., Secretan, L., and Giuliani, J., "Experiments for Satellite Environmental Measurements," paper presented at the CSAGI* Rockets and Satellite Conference, Washington, D. C., September 30 to October 5, 1957

3. LaGow, H. E., Schaefer, D. H., and Schaffert, J. C., "Micrometeorite Impact Measurements on a 20" Diameter Sphere at 700 to 2500 Kilometers Altitude," paper presented at the CSAGI * meeting of the IGY, Moscow, 1958

4. Matthews, W., Rochelle, R. W., and House, C. B., "Cyclops Cores Simplify Earth Satellite Circuits," Electronics 31(9):56-63, February 28, 1958

*Comité Speciale de l'Année Géophysique Internationale

5. Kells, M. C., et al., "Experimental Techniques Developed for Impact Studies of Microparticles," Proceedings of Third Symposium on Hypervelocity, Chicago, Armour Research Foundation of Illinois Institute of Technology, 7-9 October 1958, Vol. 1:361-384, February 1959

6. Cohen, H. A., Corman, A., and Dubin, M., "Calibration of Micrometeoritic Detectors Used in Satellites and Rockets," Proceedings of Third Symposium on Hypervelocity, Chicago, Armour Research Foundation of Illinois Institute of Technology, October 7-9, 1958, Vol. 1:405-424, February 1959

7. Alexander, W. M., et al., "Calibration of a Rocket-Borne Micrometeorite Detection System," Research Foundation Report, Oklahoma State Univ., April 1957, AF Contract No. 19(604)-1908

8. Isakovich, M. A. and Roy, N. A., "Acoustical Method for the Measurement of Mechanical Parameters of Meteorites," (Publication of the Academy of Sciences, USSR, Moscow, 1958) Jet Propulsion Laboratory Translation No. 2, Artificial Earth Satellites, pp. 150-153, September 1959

9. Komissarov, O. D., et al., "Investigation of Micrometeorites with Rockets and Satellites," (Publication of Academy of Sciences, USSR, Moscow, 1958) Jet Propulsion Laboratory Translation No. 2, pp. 99-108, September 1959

10. Watson, F. G., "Between the Planets," Cambridge, Harvard University Press, 1956

11. Bates, D. R., "The Earth and Its Atmosphere," New York, Basic Books, Inc., 1958

12. Manning, L. A. and Eshleman, V. R., "Meteors in the Ionosphere," Proc. IRE 47(2): 186-199, 1959

13. Van de Hulst, H. C., "Zodiacal Light in the Solar Corona," Astrophys. J. 105:471-488, May 1947

14. Takakubo, K., "Continuous Light of the Solar Corona," Publication of the Astronomical Society of Japan 2(1):14, 1950

15. Siedentopf, H., "Diffuse Matter in the Solar System," in Kaiser, T. R. ed., "Meteors," 145-146, New York, Pergamon Press, 1955

16. Elsässer, H., "Interplanetare Materie," Mitteilungen der Astronomischen Gesellschaft, 1957 II:61-88, Hamburg, 1958