40. Possible Interaction of Interstellar Particles With the Solar and Terrestrial Environment

J. Mayo Greenberg

State University of New York at Albany and Dudley Observatory
Albany, New York

The possibility for detection of interstellar particles in the Earth's environment is considered on the basis of the passage of the solar system through the interstellar medium. Among the forces which inhibit interstellar particle penetration, the deflection by the solar magnetic field and the repulsive force due to the radiation from the Sun are by far the most important.

IT IS VARIOUSLY ESTIMATED that the number density of small particles in the solar system at one AU is of the order of 10^{-12} cm^{-3}. If we use an average interstellar extinction per unit distance in the solar neighborhood as 1 mag/kpc we obtain an average number density for 0.1μ radius interstellar particles of $N_{IP} \cong 10^{-12}$ cm^{-3} which is the same order of magnitude.

While it is true that the interstellar particles are generally smaller than the interplanetary particles, nevertheless the small particle component of the interplanetary space which contributes particularly to the polarization of the zodiacal light is suggestively similar in typical size (Giese and Dziembowski, 1967, Aller et al., 1967). It is therefore not unreasonable to examine further the question of the interstellar component of the interplanetary particle distribution (Greenberg, 1969, 1970). We must consider first the chance for passage of the Sun through an interstellar cloud and further we must consider the effects of repulsive forces exerted by the solar system on the incoming interstellar particles.

PASSAGE OF THE SUN THROUGH AN INTERSTELLAR CLOUD

The space between the stars appears to consist mainly of cool neutral hydrogen clouds imbedded in a hot neutral hydrogen medium of quite low density. The cool clouds vary in size typically between 1 pc and 10 pc in radius. We picture a spherical shape for illustrative purposes only. The larger clouds may have a hydrogen number density of $N_H = 10$ cm^{-3} and the smaller ones may have a density of $N_H = 10^3$ cm^{-3} or higher. Neither the distribution of cloud size nor the appropriate densities is firmly established. For our purposes it will be useful to make some crude assumptions to get order of magnitude estimations of the probability that the Sun may be passing through some cloud. It should be noted that with the hydrogen densities chosen above the respective particle densities in small and large clouds would be the order of 4000×10^{-12} cm^{-3} and 40×10^{-12} cm^{-3} which are larger than the number density of small zodiacal light particles.

If all the clouds are of 10 pc radius, the number density of such clouds would be 6×10^3 kpc^{-3} and if all are 1 pc radius clouds the number density would be 6×10^4 kpc^{-3}. Using random cloud velocities of 10 km/sec (10 pc in one million years) we see that the time of passage through the large and small clouds are 10^6 and 10^5 years respectively. Based on the cloud number densities the time spent between the clouds is, for the former, 5×10^6 yrs. and, for the latter, 2.5×10^6 yrs. Thus the fraction of time spent inside a cloud

is bracketed between $\frac{1}{5}$ and $\frac{1}{25}$. Neither of these probabilities—certainly not the former—is sufficiently small to exclude the chance that some of the interplanetary particles are of interstellar origin. It should be pointed out on the other hand that there is apparently no convincing evidence that we are now passing through a cloud.

DUST REPELLING MECHANISMS

Three obvious mechanisms for repelling the interstellar dust from entering the solar system are magnetic fields, the solar wind and solar radiation pressure. The first is applicable only if the dust particles are charged. The effects of the second are stronger if the dust particles are charged but exists even when the grains are uncharged.

Solar Wind

Let us estimate the distance over which an interstellar grain will penetrate the solar system under the assumption that it meets the solar wind head-on. We assume that the solar wind consists of 3 protons cm^{-3} moving with a speed of 400 km sec^{-1}. The penetration distance d is obtained by requiring that the total energy imparted to the grain by the colliding protons equal the initial grain kinetic energy. We may write this condition approximately as $\frac{1}{2}m_g V^2 = m_H v_H^2 n_H \pi a^2 \, d$. Using grain density $s=1$ and radius $a=10^{-5}$ cm we find that $d \approx 50$ AU if the speed of passage of the solar system through the cloud is 10 km/sec. This is so large insofar as the solar wind is concerned that the interstellar grains should pass through unaffected. In view of the fact that we have assumed a constant solar wind intensity throughout the solar system in this simplified calculation, we have greatly overestimated the solar wind effect. Even taking into account the fact that a charged grain would have a greater collision cross section, the average rate of momentum transfer for the distant collisions is not sufficient to change our conclusions.

Magnetic Field

As an illustration we consider the effect on a "typical sized" $a=0.1\mu$ grain. Larger grains would

be less deflected than smaller grains so the criticality derived is an upper limit insofar as larger grains are concerned.

Rather than calculating the radius of curvature of a typical entering grain we calculate its deflection. The calculation is simplified by assuming the net effect will not be large. The final result will indicate the consistency of this assumption.

Consider the worst possible case that the grain enters normal to the magnetic field in the solar system. The field will be represented by its transverse component B_t, (Ness, 1968) having a field strength of the order of 6×10^{-5} gauss at 1 AU.

The force on the grains is qVB and the acceleration is $a_\perp = qVB_t/m_g$ where $B_t = B_0(1 \text{ AU}/R)$ and $B_0 = 6 \times 10^{-5}$ gauss. The deflection may be calculated simply by assuming a very large radius of curvature. We get the lateral deflection as

$$\Delta = \int_0^t a_\perp t \, dt$$

We let $t = x/V$ where x is measured from some outer point in the solar system. We shall choose this outer point as $R_0 = 10$ AU. Then:

$$\Delta = \frac{qVB_0(1 \text{ AU})^2}{m_g V^2} \int_{R_1}^{R_0} \frac{(R_0 - R) \, dR}{R}$$

where R_1 is chosen as the distance from the Sun where the deflection is defined. If we let $R_1 = 1$ AU and let the charge on the grain be such as to give it a one volt potential we get $\Delta \approx 10^3$ AU for $V = 20$ km/s! This is enormous. It is only for grains with potentials $\leq 10^{-3}$ volts that the angle of deflection becomes moderate. For $a = 10^{-5}$ cm this implies less than one electron charge. We note that, for fixed potential, $\Delta \sim a^{-2}$ so that interstellar grains in the one micron size range might sweep through.

Radiation Pressure

The criterion we use here is whether the net repulsive force is such that an incoming grain at 10 km/sec turns around at 1 AU. We therefore equate the initial kinetic and final potential energy where the latter is defined in terms of an effective repulsive gravitational constant ϵG. Thus $\epsilon \equiv (\frac{1}{2}V^2)/(GM_0/R_1)$. This gives $\epsilon \approx 0.05$, i.e., the radiation force need be only slightly greater than

the gravitational force. For a 6000 K blackbody the radiation force on a 0.1μ dirty ice grain is $\approx 10^{-10}$ dynes. The gravitational force is equivalently 4.3×10^{-10} dynes. Thus a 0.1μ ice grain should penetrate. It can be shown that somewhat smaller grains will also penetrate. However it is clear that the dominant factor in preventing the penetration of dust particles from interstellar space is the radiation of the Sun.

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List of Participants

Albers, H., Vassar College

Alvarez, J. M., NASA Langley Research Center

Blanchard, M. B., NASA Ames Research Center

Brecher, A., University of California at San Diego

Brett, P. R., NASA Manned Spacecraft Center

Brownlee, D., University of Washington, Seattle

Cameron, A. G. W., Yeshiva University

Ceplecha, Z., Ondřejov Observatory, Czechoslovakia

Collins, J. G., University of Western Ontario

Cook, A. F., Harvard College Observatory and Smithsonian Astrophysical Observatory

Di Benedetto, F., University of Rome, Italy

Dohnanyi, J. S., Bellcomm, Inc.,

Dubin, M., NASA, Washington, D.C.

Fechtig, H., Max-Planck Institut, Heidelberg

Fleischer, R. L., General Electric Co. Research and Development Center, Schenectady

Forti, G., Harvard College Observatory and Smithsonian Astrophysical Observatory

Früchtenicht, J., TRW Systems, Redondo Beach, Calif.

Giese, R. H., Ruhr-Universität, Bochum

Gill, J. R., NASA, Washington, D.C.

Greenberg, J. M., State University of New York at Albany and Dudley Observatory

Hallgren, D. S., Dudley Observatory

Halliday, I., National Research Council of Canada

Hanner, M. S., Dudley Observatory

Hartung, J. B., NASA Manned Spacecraft Center

Harvey, G. A., NASA Langley Research Center

Hemenway, C. L., Dudley Observatory and State University of New York at Albany

Hindley, B., Vanderbilt University

Jones, J. V., University of Western Ontario

Kresák, L., Astronomical Institute, Bratislava, Czechoslovakia

Leinert, C., Landessternwarte Heidelberg

Lindblad, B. A., Lunds Universitet

Millman, P. M., National Research Council of Canada

McCrosky, R. E., Harvard College Observatory and Smithsonian Astrophysical Observatory

McIntosh, B. A., National Research Council of Canada

Naumann, R. J., NASA Marshall Space Flight Center

Patashnick, H., Dudley Observatory

Peterson, A. W., University of New Mexico, Albuquerque

Richardson, M. B., State University of New York at Albany

Roosen, R. G., NASA Goddard Space Flight Center

Roy, N. L., TRW Systems, Redondo Beach, Calif.

Russell, J. A., University of Southern California, Los Angeles

Savage, H. F., NASA Ames Research Center

Schmalberger, D. C., State University of New York at Albany and Dudley Observatory

Sekanina, Z., Harvard College Observatory and Smithsonian Astrophysical Observatory

Shao, C. Y., Harvard College Observatory and Smithsonian Astrophysical Observatory

Soberman, R. K., General Electric Co. Space Sciences Laboratory, Philadelphia

Southworth, R. B., Harvard College Observatory and Smithsonian Astrophysical Observatory

Swider, A. L., State University of New York at Albany

Theisinger, P., Jet Propulsion Laboratory, California Institute of Technology

Utech, K., Gesellschaft für Weltraumforschung, Bad Godesberg

Weinberg, J. L., Dudley Observatory

Wetherill, G. W., University of California, Los Angeles

Whipple, F. L., Harvard College Observatory and Smithsonian Astrophysical Observatory

Wilson, L., University of Lancaster

Wright, F. W., Harvard College Observatory and Smithsonian Astrophysical Observatory

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