POTENTIALS OF ASTEROID SPACE MISSIONS

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There is an important relation between the development of solar electric spacecraft and the possible inclusion within the space program of new missions devoted primarily to asteroid investigations. The notion that space missions to asteroids have a high potential to return critically needed data will be illustrated in some detail.

One might wonder why there is so much material on solar electric spacecraft at an asteroid colloquium. For 2 yr, independent teams have been working on feasibility studies and preliminary plans for solar electric spacecraft. For the studies to be realistic, it is necessary to consider the missions on which these hypothetical spacecraft might be flown, and this is discussed, for example, in the previous papers in this session. In addition to missions, the scientific objectives must also be considered to bring into evidence the varieties of data to be acquired and thereby define the science instrument payload in some detail.

All this activity has produced several kinds of results. We now have an understanding of technique and possible science return for several kinds of asteroid missions. The space science planners find a growing awareness that the asteroid exploration may provide a rich storehouse of clues as to the origin of the solar system. There is now a real possibility that some of these missions will become a reality.

The present studies represent the final stage in the 10 yr technological development of solar electric spacecraft. (See Stuhlinger, in this volume.[1]) The next step, if this 10 yr history, representing a sizable investment in technology, is to continue, is to put this technical knowledge into practice. If this happens, and if at the same time interest within what might be called the asteroid sector of the scientific community is sufficiently high, solar electric spacecraft will be built and asteroid missions will be among those on which they will be flown.

In spite of the vast amount of facts known, it is not hard to find critically important knowledge gaps, weaknesses, and ambiguities that seriously hinder theoretical progress. The following is a partial list of knowledge gaps and

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[1] See p. 489.

insecure facts that could be cleared up by a multiple asteroid flyby mission, such as that discussed by Brooks and Hampshire:[2]

(1) Asteroid size, shape, albedo, distribution of surface reflectance, phase function for angles up to 90°, surface composition by reflectance spectroscopy (McCord, Adams, and Johnson, 1970; Chapman, Johnson, and McCord[3]) for selected bodies down to absolute magnitude 14.5, surface temperature (in support of the work of Allen[4]), and mass of larger asteroids (Anderson[5])

(2) The existence and nature of the small-body population, down to micrometeoroids, including orbital characteristics, cumulative space density including possible fine structures such as jetstreams (many papers on this latter subject are presented in this colloquium), the population index, and possibly the particle mass density and composition

(3) Facts relating to the space distribution of the particles giving rise to the zodiacal light

I should note that Pioneers F and G, bound for Jupiter in 1972 and 1973, will be the first spacecraft to gather data in the asteroid belt.

I should like now to go into more detail regarding how the objectives previously mentioned might be achieved, illustrating this particularly with the use of television. I have made no attempt to optimize television equipment; I am merely examining what the planned Mariner Venus-Mercury television system could accomplish on an asteroid mission. Figure 1 is a composite of two graphs. The inner rectangle has been adapted from a portion of figure 6 in the report of the Palomar-Leiden survey of faint minor planets (van Houten et al., 1970). In the plot of the log of the number per half-magnitude interval against absolute magnitude of the asteroids in the distance group 2.6 to 3.0 AU, the circles are the Palomar-Leiden results and the x's are the older McDonald survey results. Note particularly the break in the curve from about 11 to a little over 12 in magnitude. The outer rectangle is miss distance b versus diameter d, both in kilometers. The abscissa of the two graphs are matched, assuming an asteroid albedo of 0.16. The symbol appearing in the lower center is not the letter L, but is an indicator of how far the inner graph would move to the right and the diagonal lines would move upward if the albedo were 0.10, a more favorable situation. The diagonals represent lines of constant angular disk size corresponding to asteroid diameters and miss distance. The camera and optics chosen for this discussion have a field of view of 1°.1 by 1°.4, and the format is a frame with 700 by 832 pixel, or image, elements. A reasonable accuracy requires 10 pixel elements. In the number pairs on the diagonal lines, the first

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[2] See p. 527.
[3] See p. 51.
[4] See p. 41.
[5] See p. 577.

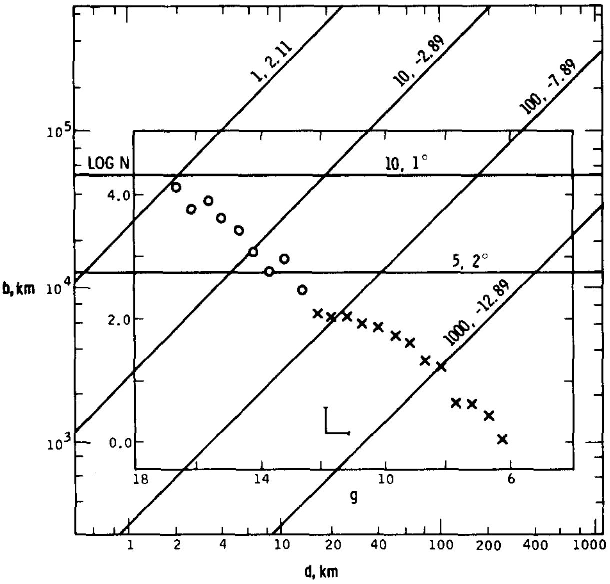

Figure 1.—Relations governing applicability of television to asteroid flyby missions.

is the number of pixel elements across the diameter, and the second is the apparent magnitude as seen by the camera. Thus, the practical limit of 10 pixel elements corresponds to an apparent magnitude of −2.89. The horizontal lines concern the passage of the asteroid past the spacecraft: The first number in the number pair is the velocity in kilometers per second and the second number is the angular rate in degrees per minute. The television camera and other equipment can be mounted on a scan platform that is controlled by a star tracker. The practical upper limit for the scan rate of the platform and cameras for accurate pointing lies somewhere between these two lines.

A study of figure 1 shows that it is possible to make adequate disk measurements of asteroids lying on both sides of the interesting break in the distribution curve. Judging by the magnitudes in this range of usefulness, it seems entirely possible to obtain reflectance spectra of the type that Chapman and McCord get for asteroids in this range. The same is true of other optical measurements, including infrared radiometry and zodiacal light photopolarimetry. The small-particle sensors are discussed by Kinard and O'Neal[6] and Soberman, Neste, and Petty[7] for Pioneers F and G. On an asteroid mission, these may be considerably enlarged. There are also other types of small-particle sensors such as the one described by Berg and Richardson (1969), which is an impact detector to determine velocity, energy, and direction. There are

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[6] See p. 607.
[7] See p. 617.

promising instruments, in the breadboard stage of development, to determine composition by time-of-flight mass spectroscopy (Grün, 1970; Roy and Becker, 1970).

The small-particle population can provide diagnostic evidence for phenomena currently going on in the asteroid belt, as well as data on hazards to spacecraft. To facilitate this discussion, figure 2 represents a model synthesized by Kessler (1970, and in this volume[8]). It is assumed here that the small particles and subvisual asteroid population can be represented by a power-law spectrum in mass in which N is the cumulative space density per cubic meter and the exponent is 0.84. The curve at the high-mass end represents the contribution of visual asteroids and the low-mass cutoff is at 10^{-9} g. Also shown is Kessler's model of the cometary meteoroid population. The horizontal bars represent the range of practical applicability of various instruments and techniques.

The power-law exponent can provide clues to the collisional and possibly accretive processes currently taking place (Dohnanyi, 1969, and in this volume;[9] Hellyer, 1970; Piotrowski, 1953). The small-particle cutoff yields information on the interaction of particles to radiation, presumably the Poynting-Robertson effect. It is evident that the sensors have a capability of determining both the small-particle cutoff and the power-law exponent, if a particle population of this nature exists. Moreover, data may be obtained regarding jetstreams, the subject appearing in several titles in this colloquium.

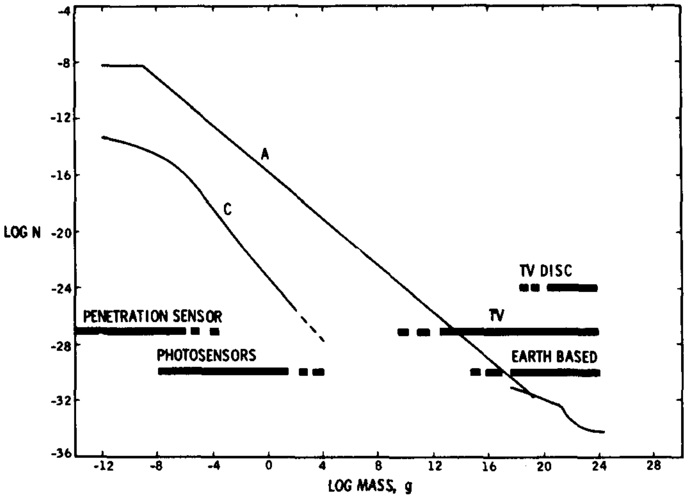

Figure 2.—Kessler model. Cumulative space density in ecliptic plane at 2.5 AU. Curve *A*, asteroid population; curve *C*, cometary population.

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[8] See p. 595.

[9] See p. 263.

Of course, cometary meteor streams are well known, and these are also accessible to the sensors.

The curves in figure 2 apply to points in space in the ecliptic plane at the solar distance of 2.5 AU. To obtain similar curves at other points, the Kessler model provides radial and latitude functions by which the curves are simply multiplied. This, of course, assumes that the curves are functionally separable from each other and from possible mass dependence. Kessler's radial curves are particularly interesting in their own right (fig. 3). The asteroid curve *A* is obtained by computer calculation, employing the orbital elements of all numbered asteroids, with correction for observational selection, and represents the sum of the contributions of each asteroid to the local space density. The effect of Jupiter is to concentrate the perihelia close to Jupiter's perihelion. The location of perihelia and aphelia of Earth, Mars, and Eros are shown. Off scale to the right would be Jupiter at 4.95 and 5.25 AU. The effect of the planets in depressing the local space density is noticeable. (See also Williams.[10]) The cometary curve, of course, is not so well known; but to the extent it can be believed, it represents a young population with moderate to large eccentricities, whereas the asteroid curve represents an old population with small eccentricities (Marsden, 1970).

From the point of view of mission analysis, Eros is a prime target for rendezvous, landing, or even sample-return missions (Bender and Bourke;[11] Mascy and Niehoff;[12] Meissinger and Greenstadt[13]) because of its orbital

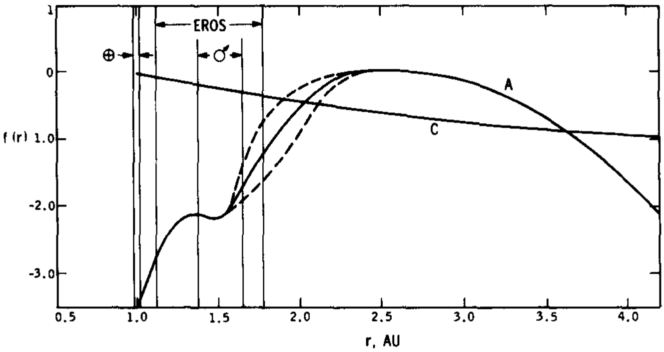

Figure 3.–Kessler model. Asteroid and cometary radial functions. Also shown are regions swept out by Earth, Mars, and Eros. *f*(*r*) is the log of the ratio of the asteroid spatial density at distance *r* to the spatial density at the center of the asteroid belt. Broken lines show the asymmetry of distribution in heliocentric longitude: upper and lower curves correspond to longitudes of Jupiter's perihelion and aphelion, respectively.

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[10] See p. 177.
[11] See p. 503.
[12] See p. 513.
[13] See p. 543.

characteristics and low gravity. There is great scientific interest in Eros. Does its shape imply that it is a fragment of a larger parent body? Is it solid iron (Anders, 1964)? Is it a potential source of stony meteorites, in the sense that eventually it will be scattered by Mars into Earth-crossing orbit (Wetherill and Williams, 1968)? Is it, despite its shape, a defunct cometary nucleus with possibly an associated non-Earth-crossing meteoroid stream (Marsden, 1970)? Is it, as Alfvén and Arrhenius suggest (1970*a,b,* and in this volume[14]), a very ancient body and a possible source of primordial grains and gently treated meteoroidal material?

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[14] See p. 473.