ON THE ASTEROIDAL CONDUCTIVITIES AS INFERRED FROM METEORITES

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Abstract. Solar wind interactions with planetary bodies without intrinsic magnetic fields depend to a large extent on the electrical conductivities of the objects in question. If the combined (i.e., ionospheric and interior) electrical conductivities are large, as in the case of Venus, the solar wind interaction is strong due to the generation of a large electrical current flow. It is suggested here that a similar interaction may occur at some asteroids, if their interior conductivity can be approximated by the conductivities of carbonaceous or iron-bearing meteorites. This interaction, in turn, can be used as a tool for remote sensing of the asteroidal interior properties in a spacecraft mission to asteroids.

Asteroids belong to the class of small bodies of primitive nature which are generally believed to contain important information on the processes of condensation and formation of the solar system. In opposite to the planetary objects of large sizes, the asteroids with diameters ranging from a thousand km to a few km might not have suffered too much geological activities to obliterate the information once stored there. One major goal of spacecraft missions to such bodies in planning, therefore, is to extract data of the surface and internal structures and compositions of different types of asteroids to facilitate the reconstruction of the history of the solar system.

While the surfaces of these small bodies may be investigated by imaging and different kinds of remote sensing techniques during close-flyby or rendezvous observations, probing of the interiors is not as straightforward. Mass determination and hence estimate of the average density is one practice usually employed to infer the internal chemical compositions, for example, of the icy satellites of Saturn. In this connection, it must be pointed out that the meteorites collected on the ground might have already given us a partial sampling of the composition types to be expected for asteroids. So far, ground-based spectroscopic observations have been useful in classifying many asteroids into several main groups with surface mineral signatures characteristics of different types of meteorites (Chapman, 1976; Zellner, 1976; Bowell *et al.*, 1978). Whether such a correlation is valid or not is still under debate. However, if it is assumed that the surface spectroscopic signatures are indeed diagnostic of the compositions of the asteroidal interiors, then some interesting points may be made concerning the solar wind interaction with the asteroids.

In Figure 1 is a listing of representative planetary materials arranged according to

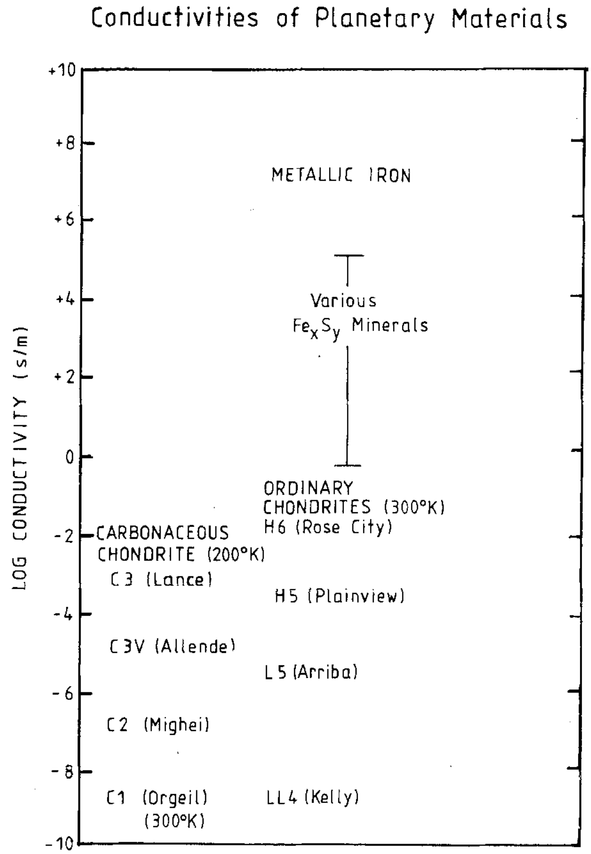

Fig. 1. Diagram showing relative electrical conductivities of representative planetary materials.

electrical conductivity. Note that the electrical conductivities given for carbonaceous chondrites and other chondritic material (Brecher *et al.*, 1975) are sufficiently larger than that measured for the silicates (Huebner *et al.*, 1979) at low temperatures, as are, of course, the conductivities of the iron materials (Parkhomenko, 1967). The interesting point, thus, is that the C-type asteroids which might have compositions similar to the carbonaceous chondrites could be reasonably good conductors even at typical asteroidal surface temperatures. Such a statement might also be true of the *S*-type and *U*-type objects. Some asteroids like the *M*-type objects may be even metal-rich, and if so are almost certainly good conductors. As the possibility that some of them are in fact partially, if not completely, composed of nickel-iron akin to the iron meteorites cannot be readily ruled out at this point, the effective conductivities of some of these *M*-type asteroids may be the highest among the planetary bodies without an atmosphere.

Thus the asteroids could have large electrical conductivities if their compositions are similar to the different types of meteorites examined so far. In this event, the unipolar dynamo action of the solar wind plasma will be effective in generating current flows through the asteroids, large and small.

It should be emphasized that the crucial site of electrical current control in the planetary surface. Most rocky materials have very low electrical conductivity at the environmental temperatures found outside of the earth's orbit. Such materials, when they dominate the surface composition of a planet, prevent significant electrical currents from flowing through the interior. This is the situation in the case of the Earth's Moon, in spite of a presumably hot and therefore electrically conductive interior. But highly conductive materials – similar to carbonaceous chondrite, say – covering a planetary surface to many kilometers' depth would allow large currents to flow.

More specifically, the convection electric field

$$\mathbf{E}_c = -\mathbf{V}_{sw} \times \mathbf{B} \tag{1}$$

would induce a current given by

$$\mathbf{J} = \sigma \mathbf{E}_c, \tag{2}$$

where σ is the effective interior conductivity. A magnetic field loop will be generated by this induced current, the net effect is to pile up the interplanetary magnetic field just ahead of the asteroid but to reduce the field strength in the wake region (Gold, 1966; Sonett and Colburn, 1967; Dessler, 1968) as schematically illustrated in Figure 2b. To what degree that ambient field may be modified in the vicinity of these objects would depend on their corresponding values of the electrical currents.

For example, using the surface of the asteroidal object of radius R_a as the reference point, the magnitude of the induced magnetic field can be approximated as

$$B_i \sim \frac{\mu_0 I}{2\pi R_a}, \tag{3}$$

where I is the total current given as

$$I \sim \pi R_a^2 J. \tag{4}$$

For $R_a \sim 50\,\mathrm{km}$ and $\sigma_c \sim 10^{-4}\,\mathrm{mho\,m^{-1}}$, the induced surface field (B_i) could reach a value comparable to that of the interplanetary magnetic field. Clearly this value is within reach of the carbonaceous chondrites, and therefore perhaps the *C*-type asteroids also. As a result, sizable magnetospheres may be built up in the near-environment of the asteroids. For the *M*-type asteroids, the electrodynamic process could be even more dramatic as a result of their large electrical conductivities if their interiors are indeed metallic.

There are limitations to the above scenario. First of all, such unipolar current may be in fact self-limiting in the sense that enhancement of the magnetic field upstream of the conducting bodies would tend to deflect the solar wind plasma, at least partially, around them and hence reduce the magnitude of the convection electric field (Dessler, 1968; Sonett *et al.*, 1968). The total current thus would be adjusted in such a way that a

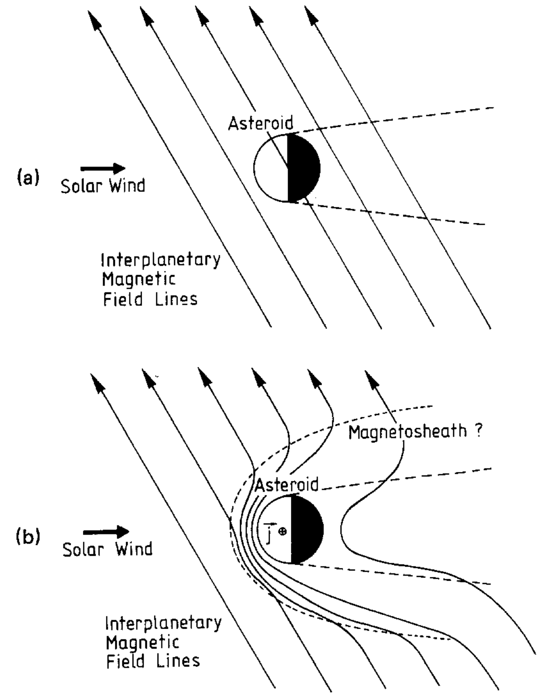

Fig. 2. (a) Solar wind interaction of an asteroid with low electrical conductivity. As a result of direct impinging of the solar wind onto the dayside surface a plasma void is formed within the region defined by the dotted lines. Details of the process could change as a function of the asteroidal size. (b) Solar wind interaction with a highly conducting asteroid. Unipolar dynamo action by the solar wind would generate a current system flowing across the asteroidal body. The magnetic fields so induced lead to the pile-up of the interplanetary magnetic field ahead of the asteroid and the formation of a magnetotail downstream in the wake region.

balance between the solar wind unipolar dynamo action and the resulting diversion effect can be reached. This is a complicated issue especially in view of the small sizes of the asteroids. Along the same line, the hydrodynamic description for a continuum flow loses its validity in picturing the asteroid-solar wind interaction because of the small sizes of the asteroids (few have radii larger than 100 km) in comparison with the gyroradius of the solar wind protons ($r_g \sim 500$ km). For one thing, the large gyroradius would allow the solar wind protons to hit the asteroids rather freely even if there is appreciable magnetic field pileup. Physical effects like bow shock formation are dubious in this circumstance. Kinetic approach as employed by Dryer (1968) and Wu and Dryer (1973) as well as laboratory simulation might be important in shedding light on this problem.

In summary, then, if the electrical conductivities of the asteroids could be inferred from those of the meteorites, the possibility of unipolar induction in the asteroid-solar wind interaction cannot be ruled out at this point. By the same token, it is perhaps feasible to probe the interiors of asteroids in a flyby or rendezvous mission via particles-and-fields instruments. The investigation of the Io flux tube by Voyager 1 (Ness *et al.*, 1979) and the mapping of the lunar magnetic fields by using magnetometers and electron deflection techniques (Sonett *et al.*, 1972; Herbert, 1980; Lin *et al.*, 1976) are pertinent examples. The experimental data would be a constraint on the global properties of the asteroidal interior complementary to the mass determination.

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