news and views

Even small meteoroids are fluffy

EVER since the enormous advances made in radar during the Second World War, scientists have been using radar techniques to study meteors. Most of the pioneer work was carried out at Jodrell Bank, but nowadays the world is dotted with radar research stations busily analysing the echoes returned from the columns of ionisation left behind by ablating meteoroids and relating these echoes to the physical parameters of the particles.

In an important article in a recent edition of the *Journal of Geophysical Research* (**78**, 8429; 1973), Verniani of the Instituto di Fisica dell'Atmosfera del Consiglio Nazionale delle Richerche, Bologna, Italy analyses the physical parameters of 5,759 faint radio meteors recorded at Havana, Illinois in 1962 under the Harvard Radio Meteor Project. A system of six radar stations has been operated at Long Branch, Havana at a frequency of 40.92 MHz with a peak transmitted power of around 2 MW. Trains of pulses transmitted from the double trough antenna at the main site were reflected from the electron columns produced by meteoroids in the upper atmosphere (at heights of around 90 km) and observed at a series of five remote sites. These remote sites were connected to the main site by microwave links, the echoes being displayed on oscilloscopes and recorded on film.

The Fresnel pattern produced as the incident meteoroid moves through the antenna beam is used to determine the meteoroid velocity, and the measurement of the echo amplitude yields the electron line density (the number of electrons per unit length along the train). Each of the Fresnel patterns received at the different stations furnishes a value of velocity and line density at a particular time. Velocity can be measured to ±5 km s^{-1}. Deceleration can be obtained from the variation of velocity with time and, by fitting a parabola to the values of line density, the maximum line density and the total number of electrons in the train can be calculated. Measurements of the zenith angle of the apparent radiant and the altitude of the echo points can be used to find the height of the reflection point from the echo range. The deduced ionisation curve gives the beginning and end height of the meteor train. The use of a few assumptions allows the computation of the original mass of the meteoroid when it was outside the Earth's atmosphere, the radio magnitude, the meteoroid density and the ablation coefficient (this coefficient relates the rate of mass loss to the deceleration; it is a function of the heat of fusion of the meteoroid material and the degree of fragmentation. Measurement of the coefficient gives a vital clue to the chemical composition and the physical structure of the meteoroid). It is this multiplicity of data about individual meteors that makes the observations taken at Havana and this work of Verniani's so important in extending knowledge and understanding of these meteoroid particles.

Verniani finds that the 5,759 radio meteors analysed (mean mass of 1.6×10^{-4}g, and radio magnitude +8.2) have a mean geocentric velocity of 36 km s^{-1} and decelerate at the rate of 13 km s^{-2} on hitting the atmosphere. These meteoroids produce electron trains of length 11 km containing around 2×10^{16} electrons, the electron line density maximuning at a value of 3×10^{10} cm^{-1}. This maximum ionisation occurs at a height of 92 km, the beginning height being 95 km and the end height of the train 88 km.

How do these observations tie in with other work on meteors? First, the mean density of the meteoroids is found to be 0.8 g cm^{-3}, and even more important this density is independent of mass in the range 10^{-6} to 10^{-3}g, suggesting that meteoroids have a porous, loosely conglomerate structure similar to that found for photographic and visual meteoroids having masses 10^6 times greater (see Verniani, *Space Sci. Rev.*, **10**, 230; 1969). This favours a cometary origin for these particles as opposed to an origin as asteroidal collision debris, a process which would produce particles of much higher density. Verniani also finds that sporadic and shower meteors are very similar, indicating that the cometary origin of most meteoroids extends right down to 10^{-6}g.

Does the low value for the meteoroid density provide an indication of the structure of comets? The 'gravel bank' model of Lyttleton (*Comets and their Origin*; Cambridge University Press, 1953) has comets consisting of a cloud of widely spaced, small, rocky particles whereas Whipple (*Astrophys. J.*, **111**, 375; 1950) postulates that comets have nuclei, these being a conglomerate of dust particles bound together by solid ices. Solar heating leads to the formation of a porous dust crust surrounding a central dirty iceball; this crust then breaks up irregularly to produce meteoroids, the low densities of the meteoroid being caused by their spongy texture, the holes in the sponge having been filled with ice when they were in the cometary nucleus. So the low density can be easily accounted for by Whipple's model; with the 'gravel bank' one would have to postulate that the gravel was itself in a low density form and this would have repercussions on the ease with which comet tails are formed. These particles, however, could be easily produced if comets are accreted from interstellar clouds by gravitational focusing. The constancy of density with mass indicates that micrometeoroids, particles of masses less than 10^{-6} g which by radiating away their heat energy float to ground and do not ablate, could be 'fluffy' and of low density whereas previously these particles were thought to have densities around 3.5 g cm^{-3}, the larger radio and visual meteoroids simply being made up of collections of these micrometeoroids.

The low density value for radio meteors is further supported by the results obtained by Verniani for the train length. The mean train length of 11 km is much shorter than was theoretically expected when meteoroids were thought to be solid, compact, stone or iron particles which simply dissipated the energy obtained from the impacts of individual air molecules by surface vapourisation of the meteoric material. The short train values lead Verniani to the conclusion that these small radio meteors often fragment, this being the same conclusion that Jacchia drew from his observations of faint photographic meteors and that Jones and Hawkes (*Nature*, in the press) draw from their work on very faint (8th magnitude) "image intensifier plus television" meteors observed at the University of Western Ontario. It seems that all meteoroids between the mass limits of 100g and 10^{-6}g are porous, fragile, crumbly objects made up of loosely conglomerate spongelike material; they all originate in comets and it is to be expected that the mean velocity of the meteoroids is independent of mass, a fact which unfortunately cannot be checked with data from radio meteors because of the height–ceiling selection effect inherent in the technique.

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