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REMOTE VISUAL DETECTION OF IMPACTS ON THE LUNAR SURFACE:

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Collisions of small meteoroids or comets with the terrestrial planets and their satellites are an important factor in the evolution of the Solar System [1]. Moderate size impacts on the Earth may even present a hazard to human civilization. Further information about the composition and size-velocity distribution of such objects is thus of great interest. We propose a novel method of remotely observing impacts on the airless Moon that may extend the present data base on meteoroids down to 1 m in diameter. Meteorites or comets of radius $r_0 \sim 1$-100 m are burnt away or dispersed in the atmospheres of the Earth and Venus. However, when such objects strike the Moon they deposit their energy in a small initial volume, forming a plasma plume whose visible and infrared radiation may be visible from the Earth.

We consider impacts of model SiO_2 projectiles on the surface of an SiO_2 model Moon (these compositions are chosen for simplicity, because the equation of state of SiO_2 is well known: more sophisticated analysis may be performed with more realistic compositions). Figure 1 shows the shock hugoniot and release adiabats in temperature-density coordinates for various impact velocities. These curves were computed following [2]. At velocities larger than 20 km/s initial shock temperatures reach 1-10 eV (1eV = 11,640 K). At such temperatures the radiation flux is an important part of the energy balance in the expanding plume.

The electromagnetic flux density from a hot volume is more than σT_*^4 while its temperature is more than T_*, the transparency temperature [3], which is equal to 0.5 eV for SiO_2. Here σ is Stefan-Boltzman constant.

Figure 1 shows that the transparancy temperature is reached when the density of the expanding plume plume declines to $\rho = 10^{-3}$ g/cm^3. The plume achieves this density after its volume has increased by 10^3-10^4 times. In other words, the temperature decreases to T_* when the size of the plume is equal to 10-15 r_0. The radiation flux from the impact can thus be estimated as $Q_{min} \approx 5 \times 10^2 r_0^2 \sigma T_*^4$. This relation gives the minimum value of Q, which is attained when $\rho V^3 < \sigma T^4$, where V is the impact velocity.

Using this estimate, we can evaluate the size r_c of the smallest projectile whose impact can be detected from the Earth. The sensitivity of modern photomultipliers is of the order of $Q_c \approx 10^{-6}$ W. If the radius of the telescope mirror (in the focus of which the detector is placed), R_T, is equal to 1 m, the radiation flux density must be more than $Q_c/\pi R_T^2$. Finally, the value of r_c can be estimated from the relation

$$\frac{Q_c}{\pi R_T^2} = \frac{5 \times 10^2 \, r_c^2 \, \sigma \, T_*^4}{2 \, \pi \, R_{ME}^2}$$

where $R_{ME} \approx 3.5 \times 10^8$ m is the distance between the Moon and the Earth. The result is $r_c \approx 1$ m.

This simple estimate shows that the radiation from small impacts on the Moon may be detected from the Earth with a modest telescope. The peak of the blackbody spectrum of this radiation is in the visible, since T_* is comparable to the surface temperature of the Sun. The duration of the resulting "flash" is brief: only a few milliseconds, but recording such flashes is well within the capability of modern instrumentation.

However, to go further and determine the composition of an impactor by such observations one must consider the physics of radiation emission in more detail. We have thus performed numerical simulations of the impact of SiO_2 bodies on the surface of an SiO_2 Moon using one-dimensional and two-dimensional gasdynamic codes. Detailed data on the optical properties of SiO_2 were used to describe the radiative transfer. These data were placed at our disposal by G. S. Romanov and his group (Institute of Heat and Mass Transfer, Minsk, Belarus). Figure 2 shows the time dependence of the radiation flux Q, in GW, within a unit solid angle for the case of $r_0 = 1$ m, velocity $V = 50$ km/s (cometary debris). The dashed line corresponds to the flux Q_E of radiation that reaches the surface of the earth (photons with energies $\varepsilon < 4$ eV).

Observations by equipment placed on satellites orbiting the Moon would allow detection of impacts of objects much smaller than 1 m. The spectrum and power of the radiation pulse may be used to determine the composition of the body and surface material as well as impactor's size and velocity.

Our investigation also shows that the radiative effects of impacts on the Moon are different from those on planets having atmospheres. In spite of high initial temperatures, the emitted radiative energy in lunar impacts is lower than the kinetic energy of the projectile due to the large initial optical thickness of plasma plume. By the time that the plume it is rarefied enough for the radiation to escape, most of the its thermal energy is converted into kinetic energy. On planets with atmospheres, however, the plume's kinetic energy is converted back into thermal energy of the atmospheric gases.

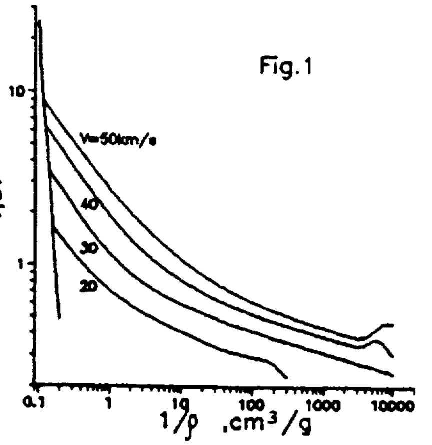
Fig.1

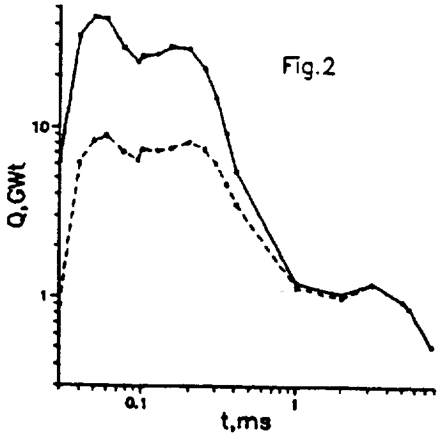
Fig.2

References: [1] Melosh, H. J. (1989) *Impact Cratering: A Geologic Process*, Oxford. [2] Vickery, A. M., J. Geophys. Res. **91**, 14,139-14,160. [3] Zeldovich, Ya. B. and Raizer, Yu. P., (1967) *Physics of shock waves and high temperature hydrodynamic phenomena*, Academic Press.