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ScienceDirect
Planetary and Space Science 55 (2007) 2049–2062
Planetary and Space Science
www.elsevier.com/locate/pss

Review

Comparative studies of meteoroid-planet interaction in the inner solar system

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Received 7 June 2006; received in revised form 28 March 2007; accepted 2 May 2007
Available online 22 May 2007

Abstract

We review the current state of studies in planet–meteoroid interactions, a relatively new discipline in planetary science. Recent observations of phenomena such as meteor trails in the atmosphere of Mars and impact flashes on the Moon have prompted new theoretical work in the field. However, our ability to test these new models and advance our understanding of the processes involved is being inhibited by the lack of systematic long-term observations with instruments dedicated to the task. Here we consider the different types of meteoroid effects on a planetary environment. The current state of knowledge leads us to expect signatures detectable by existing instrumentation, either serendipitously or, in a more targeted fashion, by employing such apparatus in innovative ways and making use of already available model predictions. These will result in near-term advances in the field, to be used towards incorporating meteoroid-effect-detecting capabilities explicitly into future planetary instrumentation or building dedicated instruments.

Keywords: Meteoroids; Meteors; Terrestrial planets; Moon

Contents

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0032-0633/$ - see front matter
doi:10.1016/j.pss.2007.05.001

1. Introduction

A meteoroid, officially defined by the IAU as "a celestial body considerably larger than a molecule and considerably smaller than an asteroid" (Millman, 1961), can be thought of, in more practical terms, as any celestial body ranging in size between 100 μm and 10 m (Beech and Steel, 1995). Depending on composition and structure, the mass of meteoroids can range from 10^{-10} kg (for a 100 μm low-density fluffy aggregate) to 10^{7} kg (for a solid 10 m iron–nickel body). The bulk of the meteoroid population originates either from comets, carried away from the nucleus within a gaseous medium as the former approaches the Sun and its ices begin to sublimate (Whipple, 1950), or from asteroids through collisional ejection. Some meteoroids represent material from planetary bodies, for example the Moon or Mars, but these constitute a small fraction of the total population.

Meteoroids recently ejected from comets form *streams* with orbits similar to those of the respective parent comets (Kirkwood, 1861). These streams are the main contributor to the annual *number* influx to the Earth over *sporadics*, that is, meteoroids on randomised orbits that make up the general background flux (Whipple, 1967; Hughes, 1975). Large members of the sporadic background provide the bulk of the *mass* influx (Ceplecha and Borovička, 1992). Streams play a crucial role in meteor observations as, here, parent bodies are—sometimes—known and accurate predictions can now be made on opportunities of observing meteor rates orders of magnitude higher than the sporadic background rate (Kondrateva and Reznikov, 1985; McNaught and Asher, 1999; Lyytinen and Van Flandern, 2000).

When meteoroids encounter a planet, they transfer their mass and kinetic energy to the planetary environment through a variety of mechanisms depending, on one hand, on meteoroid characteristics such as mass, composition and velocity and, on the other, on the properties of the target medium which can vary a great deal between the two boundary conditions of an airless surface and a thick atmosphere.

If there is a significant atmosphere present, then the following mechanisms are relevant (Fig. 1): (i) the emission of electromagnetic energy—light—giving rise to the meteor phenomenon; (ii) the shedding of meteoric material though ablation either in neutral or ionised form; (iii) the ionisation of atmospheric species along the entry path; (iv) the generation of acoustic or infrasonic waves. If the meteoroid or part thereof reaches the surface intact then to the above-mentioned mechanisms we can add the impact plume, seismic shaking and crater excavation and the effect on the average composition and density of the exosphere (Fig. 2). Each one of these mechanisms can be exploited by the appropriate instrumentation to yield information on the meteoroid.

Although some of these effects have been studied intensively for the case of the Earth, these processes should also occur at other planetary bodies, in particular the Moon and the Terrestrial planets. For example, predictions

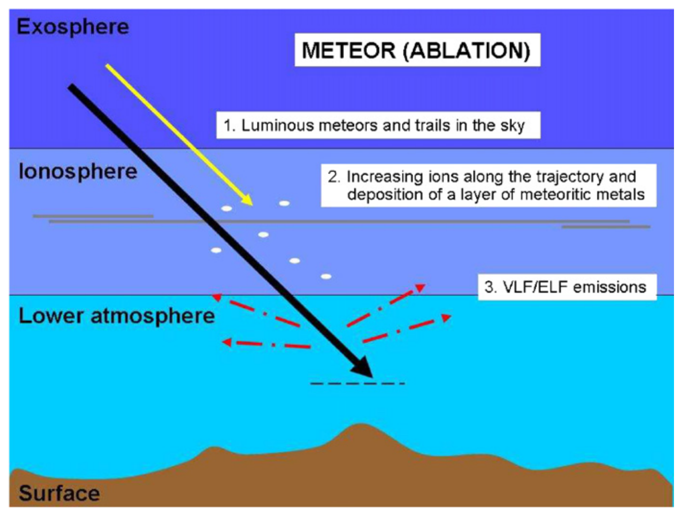

Fig. 1. Depiction of the interaction of a meteoroid with the different layers of an atmosphere. Apart from the emission of electromagnetic energy in the form of light and very-low-frequency radiation, the ablation process deposits electrons and metallic ions in the ionosphere.

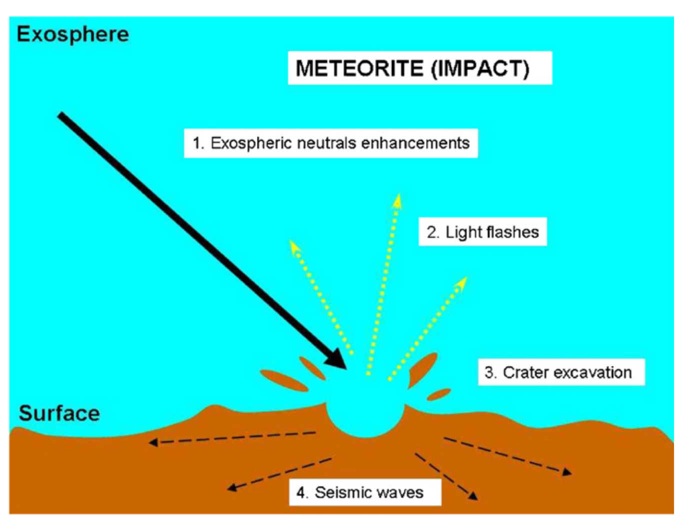

Fig. 2. Depiction of the different manifestations of a meteoroid impact on a planetary surface: the impact flash; seismic waves; crater excavation; and enrichment of the exosphere with meteoric species.