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# Modeling the detection of impact ejecta on the lunar surface

Yanwei Li [a,b,1], Ralf Srama [b,c], Yiyong Wu [a], Eberhard Grün [d,e]

[a] Harbin Institute of Technology, Xidazhi Street 92, 150001 Harbin, China
[b] Institut für Raumfahrtsysteme, Universität Stuttgart, Pfaffenwaldring 29, 70569 Stuttgart, Germany
[c] Baylor University, Waco, TX 76706, USA
[d] Max Plank Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
[e] LASP, University of Colorado, Boulder, Colorado 80309, USA

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ABSTRACT

The lunar surface is continuously exposed to the micrometeoroid environment. Hypervelocity impacts of interplanetary dust particles with speeds around 17 km s$^{-1}$ generate secondary ejecta on the lunar surface. A dust detector placed on the moon is capable of characterizing the secondary ejecta population. The purpose of this paper is to study the speed and trajectory information of ejecta by impact simulations and its implications for the location of a dust sensor on the surface. AUTODYN15.0/2D software was used to simulate the velocity and angular distributions of ejecta created by the primary impacts of interplanetary dust particles. We considered projectiles with sizes of 10 μm spheres in diameter with speeds of 17 km s$^{-1}$. We used impact angles of 15°, 30°, 45°, 60°, 75°, and 90° with respect to the surface. A significant percentage of the impact ejecta are created in the early-time stage of the impact process. This population can be captured by a sensor placed on the lunar surface (e.g. Lunar Ejecta and Meteorites (LEAM) experiment) or by a sensor mounted directly on a lander (e.g. Lunar Dust eXplorer (LDX)). The secondary ejecta population above the lunar surface is considered to explain the results of the LEAM experiment. A sensor directly placed on the surface like LEAM is not very well suited to measure the high-speed ejecta component – a sensor located at a few meters height (e.g. on top of a lunar lander) would measure higher fluxes.



## 1. Introduction

One of the highest-priority issues for a future human or robotic lunar exploration is the lunar dust (Crawford et al., 2012). This problem should be studied in depth in order to develop a dust environment model for a future lunar exploration. Secondary ejecta of impacting interplanetary meteoroids are the major source mechanism for the production of fine regolith particles (Colwell et al., 2007). The bombardment of planetary surfaces of atmosphere-less bodies like asteroids or the moon is a basic process in our planetary system. Fast impact ejecta transport material and compositional information over many kilometers and their study informs about surface compositional variations or dust–plasma interactions (Postberg et al., 2011).

The study of impact ejecta on the lunar surface will extend our knowledge about the evolution of the lunar regolith, the lunar dust cloud and the parent interplanetary dust particles of the Earth–Moon environment. A dust detector placed on the lunar surface provides a direct method to measure the characteristics of the impact ejecta such as velocity or trajectory information.

### 1.1. The lunar impact ejecta environment

Each year, the moon is bombarded by about $10^6$ kg of interplanetary dust of cometary and asteroidal origin. Most of these projectiles range from 10 nm to about 1 mm in size and impact the moon with speed between 10 and 72 km s$^{-1}$ speed which corresponds to an average speed of 17 km s$^{-1}$ (Grün et al., 2011). They may excavate lunar soil of up to 1000 times their own mass (Grün et al., 2011). Such impacts leave a crater record on the surface from which the micrometeoroid size distribution has been deciphered (Hörz et al., 1975). An impact crater is more than a mere hole in the ground. The material excavated from the crater and deposited on the surrounding terrain is called ejecta. The impact ejecta impact phenomenon is a fundamental process for the evolution of the lunar surface. The impact phenomenon of fast secondary ejecta impacting on the surface is a fundamental process for the evolution of the lunar surface. Grün et al. (1985) compared the in-situ spacecraft measurements, optical observations and the

*E-mail address:* li@irs.uni-stuttgart.de (Y. Li).
[1] Tel.: +49 6221 516 557.

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hypervelocity impact experiments. The observed size distribution of lunar micro-craters usually do not agree with the flux of interplanetary dust particles with masses of less than $10^{-10}$ g. These micron sized craters are probably created by the secondary ejecta impacts. Based on the experimental results from Zook et al. (1984), the number of secondary impact pits from oblique impact angles is more than two orders of magnitude higher than from primary impacts. This underlines the important of impact ejecta impacts on the surface.

The impact process can be described by a two-stage process. In the early-time stage of the impact process, the projectile is still coupling its energy and momentum to the target leading to different ejecta dynamics in comparison to the main-stage (Hernalyn and Schultz, 2013). The pressures are highest in the impact point zone, and the materials ejected near the impact point are therefore dominated by small fragments with high speeds and relatively small ejecta angles to the lunar surface. The high speed ejecta created during the early-time stage are one of the sources for the lunar dust cloud, which can be observed by a dust sensor nearby the impact location (Berg et al., 1975; Li et al., 2014). Hoerth et al. (2013) studied the porous sandstone using experimental methods. They found that the ejecta cone angles range from 44° to 60° with respect to the target surface for vertical impacts during the early-time stage of the ejecta cone evolution process. As the process continues, ejecta with larger sizes, slower velocities and lower ejection angles with respect to the target surface launch from the crater zone.

The distance that ejecta can travel on a ballistic trajectory depends on both the velocity vectors at which the material is ejected, and on the gravity field. Ejecta grains with velocities exceeding the escape velocity of the moon (2.4 km $s^{-1}$) become interplanetary dust particles, which takes an important role for the determination of the dust density and flux near earth (Artemieva and Shuvalov, 2008; Whipple, 1961). However, most of the excavated mass returns to the lunar surface and blankets the lunar crust with a highly pulverized layer (Grün et al., 2011).

### 1.2. Detection of impact ejecta

All airless planetary bodies are expected to be surrounded by dust clouds, which were firstly detected by the dust detector onboard the Galileo spacecraft during the close flybys of icy moons of Jupiter (Krüger et al., 2000). Based on the latest data, the Lunar Dust EXperiment (LDEX) sensor onboard lunar orbiter Lunar Atmosphere and Dust Environment Explorer (LADEE) already identified the existence of a dust cloud around the lunar surface down to 5 km (Horányi et al., 2015). The ejecta created by the impacts of interplanetary meteoroids are thought to be one of the main components of the dust cloud. There are several outstanding issues which must be addressed to ensure acceptable cost and risk for sustained human lunar programs. Arguably, one of the highest-priority issues to be addressed is that of the lunar dust (Crawford et al., 2012).

The most well known dust sensor placed on the lunar surface is the LEAM experiment of the Apollo 17 mission. The objectives of LEAM were to detect impact ejecta created by the hypervelocity impacts of interplanetary dust particles on the lunar surface and to detect the interplanetary dust grains themselves (Berg and Richardson, 1973). The experiment has three sensors facing in the West, East and Up directions. We therefore call the three sensors West sensor, East sensor and Up sensor. The sensors were multi-layered arrays designed to identify the velocity, trajectory and kinetic energy of incident dust grains. A basic sensor (West or East sensor) consists of a front film-grid sensor array and a rear film-grid sensor array (see Fig. 1), while the Up sensor just has a rear film-grid array. The performance of the sensors depend on two basic measurable phenomena that occur when a hypervelocity particle impacts on a surface: the formation of an impact plasma and a transfer of momentum. When a low energy particle enters the front sensor, it deposits all its kinetic energy at the front film. A pulse-height analysis is performed on the positive output signals as a measure for the kinetic energy of the particle. A relatively high speed particle may pass through the front film sensor and deposits some of its kinetic energy by the generation of an impact plasma. As the particle continues its path, it deposits its remaining energy at the rear sensor film with a secondary amount of impact charges. However, the obtained LEAM data were rich in noise events and its interpretation is discussed contradictively in O'Brien (2011) and Grün and Horányi (2013).

Today, new sensors are available for the detector of submicron and micron sized particles. The Lunar Dust eXplorer (LDX) is a newly developed dust trajectory sensor for lunar lander missions (Li et al., 2014). It consists of an electron reflector and of three planes of charge sensitive electrodes. High speed particles can also be measured by an impact ionization target. Each grid electrode is connected to a single charge sensitive amplifier (CSA) in order to measure the particle primary charge and the particle velocity vector. The three electrode planes of LDX have in total 18 electrodes (Fig. 2). The size of the instrument is about 25 cm × 21 cm × 21 cm with an open area of approximately 400 $cm^2$. The used

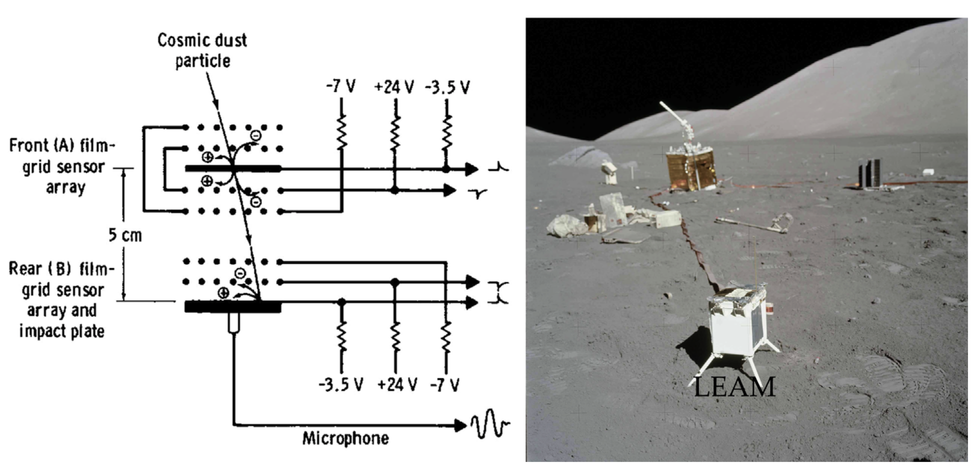


**Fig. 1.** The schematic diagram of the West and East sensor (left side) of LEAM (Berg and Richardson, 1973). The front film consists of a 0.3 μm thick aluminized pargyline film. The instrument was deployed to the lunar surface during the Apollo 17 mission (right side, NASA Apollo 17 photograph). Here, the sensors are still protected with a dust cover and the West sensor is hidden in this view.