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Sunrise-driven movements of dust on the Moon: Apollo 12 Ground-truth measurements

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ABSTRACT

The first sunrise after Apollo 12 astronauts left the Moon caused dust storms across the site where rocket exhausts had disrupted about 2000 kg of smooth fine dust. The next few sunrises started progressively weaker dust storms, and the Eastern horizon brightened, adding to direct sunlight for half an hour. These Ground truth measurements were made 100 cm above the surface by the 270 g Apollo 12 Dust Detector Experiment we invented in 1966. Dust deposited on the horizontal solar cell during two lunar days after the first sunrise was almost 30% of the total it then measured over 6 years. The vertical east-facing solar cell measured horizon brightening on 14 of the first 17 lunations, with none detected on the following 61 Lunar Days. Based on over 2 million such measurements we propose a new qualitative model of sunrise-driven transport of individual dust particles freed by Apollo 12 activities from strong particle-to-particle cohesive forces. Each sunrise caused sudden surface charging which, during the first few hours, freshly mobilised and lofted the dust remaining free, microscopically smoothing the disrupted local areas. Evidence of reliability of measurements includes consistency among all 6 sensors in measurements throughout an eclipse. We caution Google Lunar XPrize competitors and others planning missions to the Moon and large airless asteroids that, after a spacecraft lands, dust hazards may occur after each of the first few sunrises. Mechanical problems in its first such period stranded Chinese lunar rover Yutu in 2014, although we would not claim yet that the causes were dust. On the other hand, sunrise-driven microscopic smoothing of disturbed areas may offer regular natural mitigations of dust consequences of mining lunar resources and reduce fears that many expeditions might cause excessive fine dust globally around the Moon.

1. Introduction

Before Apollo, it was agreed that dusty lunar surfaces in mare areas are smooth (Gold, 1962, 1966; Shoemaker, 1966), implying that surface dust is transported not only by myriad meteoritic impacts but by daytime surface charging of dust by solar ultraviolet radiation. During Apollo, although lunar dust movements begun by human activities caused severe operational problems for astronauts and deployed scientific observatories (Gaier, 2005; Schmitt, 2005; Beattie, 2001), comparatively few measurements of dust were made on the Moon (O'Brien et al., 1970; O'Brien, 2015). After Apollo, interest in naturally-occurring transport of lunar dust was extended by laboratory experiments (Colwell et al., 2007; Marshall et al., 2011). After outputs of Apollo 17 Lunar Ejecta and Meteoroids Experiment (LEAM) on the lunar surface were interpreted as caused by slow-moving heavily-charged levitated lunar dust (Berg et al., 1976), research priorities shifted to hypothetical vertical transport or levitation of very fine dust to a suspended position. Such interpretations of LEAM data became a major rationale for theoretical models of vertical transport of dust to kilometre heights above the Moon (Colwell et al., 2007; Stubbs et al., 2006; 2014). Horizon Glow, a brightening above the lunar sunset horizon photographed by Surveyors in 1967–8 (Rennilson and Criswell, 1974) was considered a manifestation of very fine levitated dust. However, evidence was published that an alternative explanation of LEAM data was electronic noise (O'Brien, 2011), while far-ultraviolet spectroscopy by LRO/LAMP reduced the upper limit of concentrations of such high-altitude dust by four orders of magnitude (Feldmann et al., 2014). Recent direct measurements by Dust Detector Experiment LDEX on the lunar-orbiting LADEE spacecraft found no evidence of a major mission objective, very fine electrostatically lofted dust at 3–250 km above the lunar terminator in high densities predicted from Apollo observations and thought to be linked with Horizon Glow (Horanyi, 2013, 2014; Szalay and Horanyi, 2015; Horanyi et al., 2015).

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Dust movements caused by human activities have been studied in video analyses by Metzger and his teams (Lane and Metzger, 2015 and references therein) and by direct measurements by the minimalist 270 g Dust Detector Experiment (DDE) deployed on Apollo 11 and 12 (O'Brien et al., 1970; O'Brien, 2009, 2011). Hollick and O'Brien (2013) analysed long-term accumulation on horizontal solar cells of Apollo 12, 14 and 15 DDEs. However, missing until now have been direct measurements of sunrise effects on dust on the surface of the Moon, when common sense suggests sunrise could be the most powerful impulsive and periodic natural force on dust provided that particles were freed from natural cohesive forces discovered by Gold (1971).

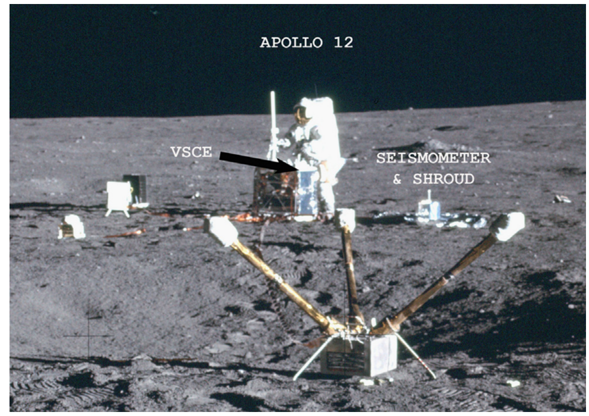

Fig. 2. Apollo 12 DDE 100 cm above the lunar surface (black arrow). The Seismometer is 3 m from the VSCE to the Southeast. (Source: NASA Image AS12-47-6921).

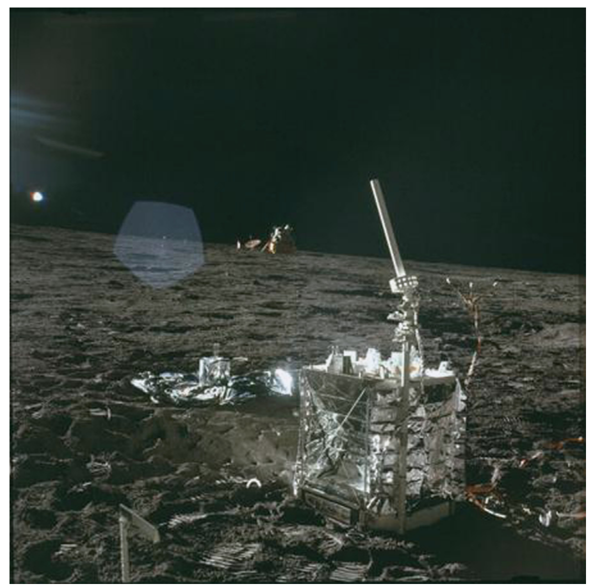

Fig. 3. Southeast dawn field of view of VSCE, mounted on opposite corner to the antenna. (Source: NASA AS12-47-6928).

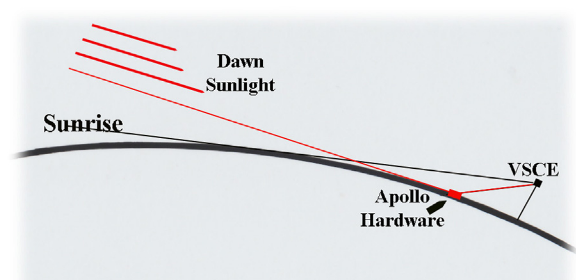

Fig. 4. Sketch of VSCE sources of brightness. Angle of dawn sunlight hitting VSCE is much exaggerated in the sketch. Sunlight strikes the Mylar sheet, some 2–3 m from VSCE, before the Sun is 1 solar disc high above the horizon viewed by VSCE.

2. Methods

Only the Apollo 12 Dust Detector Experiment (DDE) has the original orthogonal design using 3 shielded conventional space-qualified solar cells, with a vertical cell facing East (VSCE) to measure brightness of the dawn on the surface of the Moon (Figs. 1 and 2) (O'Brien, 1966, 2009, 2015; Bendix, 1969), and a horizontal cell (HSC) to measure dust deposition (Hollick et al., 2013). Percentage change in output of HSC is fungible for various dusts and simulants, with a nominal 0.5 mg cm^{-2} of simulated dust MLS-1 causing a 10% reduction in output. Deployed about 100 cm above the surface of the Moon in early lunar morning of 19 November, 1969, Lunar Day 1 (LD1) (NASA, 1974; O'Brien, 2009), its first sunrise was on LD2 a month later. Here we use some 2 million measurements at 54.34 s intervals by VSCE of the combined brightness of the Sun and the Eastern moonscape (Figs. 1–3) which includes dust and Apollo hardware as photographed in Fig. 2 and sketched in Fig. 4. The major purpose is to find and study anomalies of brightness which may be caused by movements of dust on or above the moonscape and possibly the cell itself. Further details are given in Supplementary S2Methods. The Apollo 12 DDE also has a vertical solar cell facing West (VSCW). However, light into VSCW is contaminated by nearby hardware (see Fig. 1 and Apollo Image AS12-47-6926) reflecting morning sunlight and shadowing afternoon sunlight (O'Brien, 2009; Hollings and O'Brien, 2013). Accordingly we cannot rigorously use VSCW to attempt to measure Horizon Glow in the western sunset Moonscape.

Fig. 1 (close-up of NASA AS12-47-6927) shows the face of VSCE together with thin dusting of collateral lunar dust within about 10 cm. Fig. 2 (close-up of NASA AS12-47-6921) shows the VSCE face of the DDE (black arrow) and a northern view of the early morning sunlit Moonscape. Figs. 2 and 3 and measurements in Fig. 5 show that VSCE-measured dawn brightness profiles are dominated to about 95% by direct sunlight. Additional brightness comes from light forward scattered or reflected from the Moonscape surface and several Apollo artifacts (Figs. 2 and 4), particularly the Apollo 12 Passive Seismometer and its aluminized Mylar thermal shroud (Figs. 2 and 3 and Latham et al., (1969); Bates et al., 1979, Figs. 1 and 2; Supplementary Figures S3A and S3B here). The assembly of photos also shows that the Passive Seismometer could not shadow VSCE.

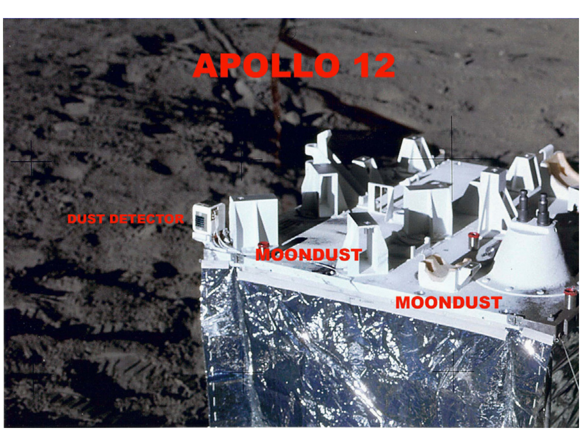

Fig. 1. Close-up of VSCE and collateral dust. (Source: NASA Image AS12-47-6927).