CORRESPONDENCE

To the Editors of 'The Observatory'

Lunar Dust Clouds and Space Missions

The high accident rate of space probes, when attempting to land on the lunar surface, is still a surprising phenomenon. Thus, in the period 2019–2023 the following landers were lost at low (<15 km) altitudes: *Beresheet*, *Vikram 1*, *OMOTENASHI*, *Hakuto-R Mission 1*, and *Luna 25*. The 'successful' lander *SLIM* had losses of an engine nozzle and communication with the Earth during descent. It had landed at a 90-degree angle. The next lunar module to have 'survived', *Odysseus IN-1*, tipped over during landing. Perhaps such incidents are partly a manifestation of an unaccounted risk factor.

In this regard, the problem of levitating lunar dust deserves attention[1]. Apparently, the effects of absorption and scattering of light by lunar dust clouds were first noticed during the occultation of Saturn on 1762 June 17[2]. Despite numerous reports[3] of Earth-based observations of similar effects, dust clouds on the Moon were recognized by the planetary community only after they were recorded *in situ* as a lunar horizon glow by the *Surveyors 5–7* and *Apollo 10, 15, 17* missions[4,5]. Although the later *Clementine* and *LRO* missions found that the concentration of lunar dust above the lunar surface appears 10^4 times lower than that suggested by the *Apollo* estimates, a specialized lunar mission, *LADEE*, registered five dust clouds which had a density comparable to the estimates based on *Apollo* data[6]. Hence, the dust concentration varies greatly and its *in-situ* measurement over a limited space-mission time span is unrepresentative. At the same time, the information on lunar dust clouds, provided by Earth-based monitoring, is apparently forgotten. It makes sense to fill this gap in data analysis.

Really, ground-based observations of lunar horizon glow (*i.e.*, the forward scattering of sunlight by electrostatically levitating dust particles) are described in astronomical literature[3] (21 cases) in the form of light strips along the dark limb of the crescent Moon, or as light ledges near cusps of the solar crescent during an eclipse[7,8]. Sometimes (23 events), the lunar horns' prolongations close the crescent, and turn it into a ring[9–11]. The images of such an annular Moon can be found in ancient artifacts[12] as well as in modern Earth-based photos[13]. Moreover, the dust clouds were manifested sometimes in the form of a dark band of light extinction parallel to the lunar limb on the discs of Jupiter[14], Saturn[2], and Mars[15] during their occultations. There is a photo of such a dark stripe[16], which was parallel to the lunar limb but perpendicular to the Jovian cloud bands. The analysis of all nine such anomalous planetary occultations shows that the dust clouds extended from the lunar surface up to the height of between 4 and 66 km.

In the Lunar Occultation Archive (cdsarc.cds.unistra.fr/viz-bin/cat/VI/132C), among 849 occultations during the period 1967–2022, in which the duration, τ, of a star's appearance/disappearance was measured, in 419 cases (49%) the event duration was anomalously long ($0 \cdot 1 \leq \Delta t \leq 8 \cdot 6$ s). These values are significantly longer then the predicted timescale $\Delta t \approx 0 \cdot 05$ s of stellar occultations. Obviously, binary systems cannot explain the gradual fading of a star as reported by observers[3]. However, the anomalous duration of occultation, converted into the space-scale $0 \cdot 1 < \Delta t \, V_M < 8 \cdot 4$ km (here $V_M = 1 \cdot 02$ km/s is the average orbital speed of the Moon), is comparable with the scale height $5 < H < 20$ km of lunar levitating dust according to *Apollo*[17] data.

The effective light extinction during an anomalous occultation means the sufficient optical thickness of a dust cloud: $\tau = N_d\sigma \sim 1$. Here N_d is the dust column density, and $\sigma = \pi r_d^2$ is the cross section of a dust particle of r_d radius. For rough estimates, one can use the cloud model in the form of a homogeneous layer of thickness H. The path length of the starlight ray inside the dust layer is $L = 2\ [(R+H)^2 - R^2]^{1/2}$, where R is the lunar radius. Hence, $N_d = n_d L$, where n_d is the average dust concentration in the layer, which could be estimated using the condition $\tau \sim 1$: $n_d \sim (\pi L r_d^2)^{-1}$. Assuming realistic[17] values of $H = 10$ km and $r_d = 1$ μm, one can estimate $n_d \sim 10^6$ m^{-3} and the mass of a dust particle $m_d = \rho(4/3)\pi\, r_d^3 = 1{\cdot}26\times10^{-14}$ kg for the lunar density $\rho = 3\times10^3$ kg m^{-3}. Now let's estimate the time, T_c, during which a spacecraft with a mass $M_{sc} = 100$ kg and cross-section $S = 1$ m^2, flying at a circular orbit of altitude $Z_o \le 10$ km with velocity $V \approx 1{\cdot}68$ km/s inside a circumlunar dust cloud, would crash on the Moon. The spacecraft's energy-loss rate due to collisions with the dust is $\varepsilon = (0{\cdot}5\, m_d\, V^2)\ (n_d SV) \approx 30$ W. The work needed for vehicle descent is $\Delta E = g\, M_{sc}\, Z_o \le 1{\cdot}6\times10^6$ J, where $g = 1{\cdot}622$ m s^{-2} is the lunar surface gravity. Hence, the time-scale of the fall is $T_c \sim \Delta E/\varepsilon \le 15$ hours. Note that this estimate is on the order of the orbital period ($2\pi R/V = 1{\cdot}8$ h). By adding the factor $(S/1\text{ m}^2)^{1/2}$, one can transform the resulting T_c to the case of a different cross-section. Correspondingly, a femtosatellite ($S < 0{\cdot}01$ m^2) could drop during one orbit. Analogously, the factor 1 μm/r_d transforms the model value T_c to the case of a different dust size. Hence, the case of $r_d \ge 10$ μm is fatal for small satellites.

The estimates obtained demonstrate the danger of the dust factor, which needs to be taken into account, especially when planning manned flights to the Moon.

Yours faithfully,
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On the Value of Conference Proceedings

Upon returning from some recent travel, I found the April issue of *The Observatory* in my letterbox. In a book review[1], the question was raised as to the on-going value of printed books of conference proceedings in light of the fact that many contributions had been published in journals before the proceedings, or even before the conference. Another question was whether printed books are needed with many journals becoming on-line-only. The second question is really unrelated; also, the arguments for and against conventional printed and on-line-only versions of journals and conference proceedings are essentially the same. The third question was whether anyone still seeks them out and searches them for new work*. I know for a fact that some people still seek them out for *old* work. Most of my recent travel was to the Moriond cosmology conference[2], and during that conference I got a message from a colleague saying that he had recently looked up a reference from a 1981 Moriond conference, praising the fact that each contribution had a photo of the author (a tradition which still continues to this day). Sometimes something needs to be cited but there is no journal reference; for example, I've cited a conference proceeding for the source redshift of the gravitational-lens system 0218+357[3].

In the old days, there were three main reasons to go to conferences: to hear about the latest results, to get an overview of work outside of one's own field, and to meet old and new friends and colleagues. Electronic communication has made the first obsolete to some extent (thus leaving more time for the other two), though not entirely. Sometimes results, especially involving strong claims, take a while to be refereed, and will appear long after the conference, perhaps even after the publication of the proceedings — or they might not appear at all if found wanting. Those are exactly the type of results which should be checked and confirmed or refuted, and the conference proceedings might be the only source one can cite, at least initially.

While it might just be possible to keep up with the literature in one's own field, it is impossible to do so in all fields. One might hear an interesting talk in a field different from one's own; the proceedings provide a starting point for looking up further references. I tend to present topics at conferences before submitting them to journals, in order to get feedback. But even if the work has appeared elsewhere before the conference, the conference proceeding is usually shorter and more digestible, and there can be value in a collection of such contributions on a common theme, especially if the proceedings are well produced (examples are reviewed in refs. 4 and 5).

Conference proceedings are also useful for historians of science. I'm writing this while reading a book[6,7] which mentions the 1927 Solvay conference. As with the 1957 Chapel Hill conference on the role of gravitation in physics, we should be grateful that there is a written record. Even if the written record differs somewhat from what was actually said (as in Bohr's contribution to the 1927 Solvay conference), that in itself can be interesting. When I was younger it was much more common for proceedings to include the questions and answers after the talk. That is a tradition which should be revived, as perhaps even more so than the contributions themselves they indicate what people were thinking at

*"Does anyone seek them out and search them for new work anymore...." It is not clear to me whether it is the new work which is being sought out in the proceedings, or whether proceedings are being sought out in order to be cited in some other new work.