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The first confirmed Perseid lunar impact flash

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Abstract

The first confirmed lunar impact flash due to a non-Leonid meteoroid is reported. The observed Perseid meteoroid impact occurred at $18^{\mathrm{h}}28^{\mathrm{m}}27^{\mathrm{s}}$ on August 11, 2004 (UT). The selenographic coordinates of the lunar impact flash are $48 \pm 1°$ N and $72 \pm 2°$ E, and the flash had a visual magnitude of ca. 9.5 with duration of about $1/30$ s. The mass of the impactor is estimated to have been 12 g based on a nominal model with conversion efficiency from kinetic to optical energy of 2×10^{-3}. Extrapolation of a power law size-frequency distribution fitting the sub-centimeter Perseid meteoric particles to large meteoroids suggests that several flashes should have been observed at this optical efficiency. The detection of only one flash may indicate that the optical efficiency for Perseid lunar impact is much lower, or that the slope of the size distribution differs between large meteoroids and typical sub-centimeter meteoric particles.

Keywords: Impact processes; Meteoroids; Meteors; Moon, surface

1. Introduction

Meteoroids collide not only with the terrestrial atmosphere, resulting in meteoric phenomena, but also with the lunar surface, where impact velocities exceed several kilometers per second. These high-velocity impacts with the lunar surface generate a hot vapor cloud that radiates briefly in the optical spectrum. Laboratory measurements suggest that the optical efficiency for such impacts, that is, the portion of the projectile's kinetic energy transferred to optical energy, is typically less than 10^{-4} at impact velocities of several $\mathrm{km\,s^{-1}}$ (Eichhorn, 1976; Kadono and Fujiwara, 1996). However, theoretical work by Artemieva et al. (2000) and analyses of Leonid lunar impact flashes by Bellot Rubio et al. (2000a, 2000b) indicate that the optical efficiencies may be as high as 10^{-3} for meteoroidal impacts at velocities of several tens of $\mathrm{km\,s^{-1}}$. This would suggest, for example, that the impact flash of a 1 kg meteoroid traveling at 59 $\mathrm{km\,s^{-1}}$ upon impact (impact velocity of the Perseids) could be observed on Earth with a magnitude of 6, assuming that the optical energy were released within $1/60$th of a second (one half-frame exposure time of a video camera). The observation of lunar impact flashes over a large target section of the Moon may provide useful information with respect to the near-Earth flux of large meteoroids. Furthermore, lunar impacts provide novel insights into high-velocity impact phenomena, since lunar impact velocities far exceed those achievable by laboratory experiments.

On November 18, 1999 (UT), for the first time, more than 10 lunar flashes were successfully observed on the night side of a 10 day-old Moon from locations in the United States, Mexico, and Japan (Dunham et al., 2000; Ortiz et al., 2000; Yanagisawa and Kisaichi, 2002). The magnitude of the flashes ranged from 3 to 7. Most of the flashes were less than 0.1 s in duration, and all occurred during the period of the Leonid me-

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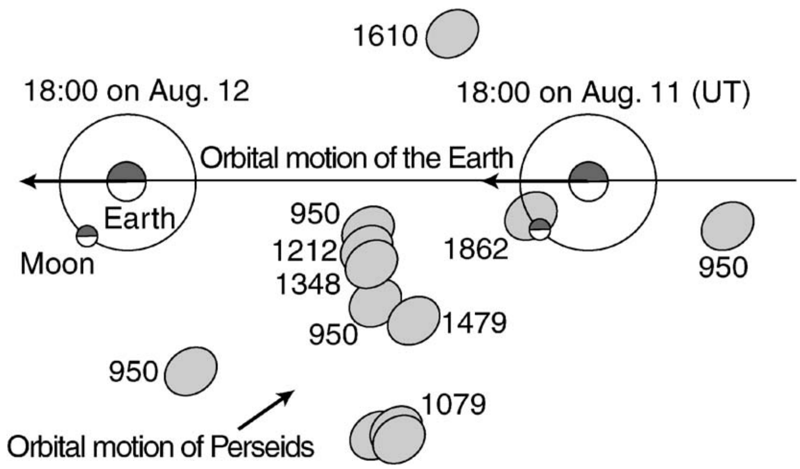

Fig. 1. Cross sections of Perseids dust trails on the ecliptic plane (calculated by I. Sato; personal communication). Number for each cross section shows the year when particles were ejected from the Comet 109P/Swift–Tuttle. The shape and size of the cross sections are arbitrary. The Sun is located far below the figure. The arrow shows the projection of the Perseid velocity vector on the ecliptic plane. The velocity is 41 $\mathrm{km\,s^{-1}}$ and the vector is southward making an angle of 62° with the plane. The orbital motion of the Earth–Moon system (30 $\mathrm{km\,s^{-1}}$) must be considered in order to obtain the Perseid velocity vector relative to the Moon.

teor shower. The observers concluded that these were, indeed, Leonid lunar impact flashes. The lunar phase was again favorable for observing the Leonid impact flashes on November 18, 2001, and Ortiz et al. (2002) observed 4 lunar flashes in that period. Observations from three widely separated stations in the United States confirmed 2 flashes of approximately magnitude 4 on November 18 and 19, 2001 (http://iota.jhuapl.ed/leo01n26.htm). It should be noted that electric noise, cosmic ray hits on charge-coupled device (CCD) detectors, and glints from artificial satellites or space debris could be misinterpreted as lunar flashes. The flashes described above were, however, either simultaneously recorded on videotape by observers in at least 2 different locations, or confirmed as flashes after an exhaustive search that eliminated any possible noise and glints from artificial space objects.

It is interesting to note that the confirmed or carefully checked flashes were only observed during the Leonids. This raises the question as to whether the Leonid meteoroids possess special characteristics that could possibly increase the probability of lunar impact flashes. Some possibilities for this phenomena include the high impact velocity of Leonids (70 $\mathrm{km\,s^{-1}}$), the possible dependence of the optical efficiency on the impact velocity, the unique chemical and physical properties of the meteoroids causing high optical efficiency, or exceptionally high meteoroidal flux during Leonid activity, in particular, when the Moon crosses some of the dust trails in the Leonid stream. Finally, the possibility of a selection effect, since most observations tend to be conducted during the Leonid meteor shower, cannot be discarded. To answer these questions, it is necessary to organize a campaign to monitor the night side of the Moon during the other annual meteor shower periods.

2. Observations and results

2.1. Campaign to search for Perseid lunar impact flashes

The closest approach of the Earth to the dust trail originating from the 1862 cometary activity of the 109P/Swift–Tuttle comet was predicted to occur at about 21:00 on August 11, 2004 (UT) (Lyytinen and Van Flandern, 2004). We found that the Moon encountered the trail at about 18:00 on that day (Fig. 1).

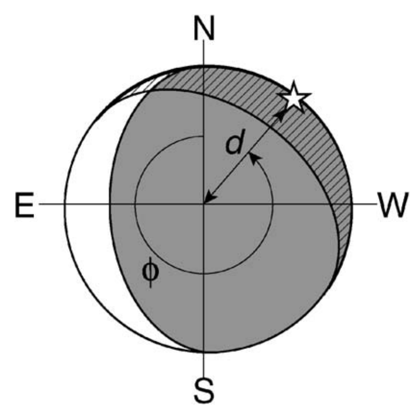

Fig. 2. Lunar disk on August 11, 2004 (UT). White indicates the area illuminated by the Sun, and hatching denotes that area in which Perseids could impact. A flash was observed at the star symbol. The definitions of angular distance d and position angle ϕ are also shown.

Perseid meteoroids mainly hit the far side of the Moon, and the area of the near side exposed to the meteoroids was not large (Fig. 2). The calculated ejection velocity from the comet of particles in the dust trail was 23 $\mathrm{m\,s^{-1}}$ (I. Sato, M. Sato; personal communication). Only small particles could have been captured and accelerated to the required velocity by gas outflow from the nucleus. Large meteoroids were therefore not expected in the trail. These facts decrease the detection probability of lunar impact flashes.

On the other hand, the 25 day-old Moon was not very bright, and the exposed area was far from the sunlit portion. This situation greatly facilitated detection of faint flashes from relatively small meteoroids. A search for lunar impact flashes using video cameras attached to telescopes was organized in Japan for the period 17:00–19:00 on August 11 (UT) by M.Y. and K.O.