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Submoon

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Figure 1 shows a photograph of a submoon, that is a halo exactly like a subsun, but generated by moonlight rather than by sunlight. This phenomenon, whether submoon or subsun, is the simplest among all halos and, in terms of halo-to-light-source ratio, the brightest. Observing it requires a position above the ice crystals. For air travellers, the subsun (see e.g. Anderson, 2012) is the most common halo; the submoon is the most frequent halo among the moonlight-generated halos witnessed by air travellers at night.

Figure 1. The submoon, photographed during a night flight from Canada to Europe on 29 September 2012, one day before Full Moon. The horizontal field of view of the picture is 58°. Exposure time 1/8s, ISO 6400 and aperture f/2.4. (Photograph by G. P. Können.)

Submoon/subsun formation requires the presence, below the observer, of moonlit/sunlit ice crystals of sufficient size (larger than ~20 μm) having at least one of their crystal faces horizontally oriented. The light path that contributes most to the radiance of the submoon or subsun is a simple external reflection at a horizontally-oriented face located at the top of the crystals (Tape, 1994; Können, 2004; Cowley, 2012). Usually the reflecting face is a basal face of a plate crystal; this light path is depicted in Figure 2. For celestial objects, the set of horizontally-oriented crystal faces acts as a giant horizontal mirror in which, below the horizon, the image of the moon or sun may appear. Because of imperfection in the horizontal orientations of the faces, the image is usually somewhat elongated (see Figure 1).

The submoon belongs to the class of reflection halos, that is halos that emerge without net refraction; in contrast to refraction halos, reflection halos do not show any colouring. Due to the dominant role of the light path depicted in Figure 2 in submoon/

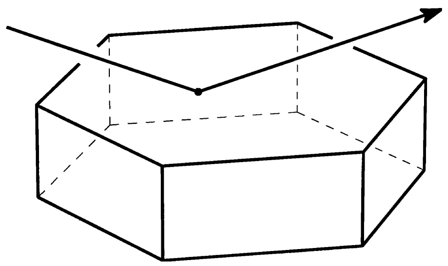

Figure 2. The main light path that generates the submoon/subsun (from Tape, 1994). All reflecting ice crystals have assumed the same orientation, with a horizontally-oriented reflecting face.

subsun formation, their light is strongly polarized; this remarkable property can easily be verified with a simple polarizer.

The frequent occurrence and brightness relative to other halos from the same source makes the submoon/subsun or its equivalent from other light sources a logical target in searches for halo occurrence in marginal situations. This applies, for example, to searches for sunlight-generated halos in the atmospheres of other planets (Können, 2006) or searches for terrestrial halos due to faint celestial light sources.

The submoon depicted in Figure 1 appeared at 0237 UTC on 29 September 2012 during a flight from Vancouver to Amsterdam. The readings of the in-flight Aircraft Condition Monitoring System (an extended version of Flight Data Recording) reveal that the aircraft's position was 67°55´N, 76°40´W, which means that it was over Prince Charles Island in northeast Canada. The height was 10.7km and the direction of flight was towards 73.5°; the aircraft's heading was at 69.2°. The moon was bright and almost full (Full Moon was at 0319 UTC on 30 September) and 87° to the right of the aircraft, at azimuth 155.9°; the lunar elevation was 21.5°. Directly below the moon, at 21.5° below the true horizon, was the submoon; its bright inner centre (Figure 1) measures 1.4° × 0.7°.

The submoon appeared in a polar cirrus deck, apparently consisting of plate crystals. The 0000 UTC readings from the nearest radiosonde station (Hall Beach, station 71081, 200km northwest of Prince Charles Island) indicate a cirrus deck having its top at 6.8km above the Earth's surface: the temperature at that level was – 35°C. Above the cirrus top the air was clear. Given the eastward-component in the atmospheric flow at that level, and the mutual consistency with the 0000 UTC radiosonde data at Coral Harbor (station 71915, 400km SW of Prince Charles Island), the data about the cirrus collected at Hall Beach can be considered to be representative for the submoon-generating cirrus below the aircraft.

A search in the international bibliographical databank of Schmidt (2012) revealed eight earlier published reports of visual observations of submoons. Three of these were from meteorological stations located on high mountains in the Alps and Ore Mountains (Rossmann, 1934; Küttner and Model, 1948; Hinz, 2001), and five were as a by-product of the routine upper-air observations from planes organized by the German Meteorological Service in the late 1930s (Reichsamt für Wetterdienst, 1936 and 1938). Remarkably, all eight reports were found in German, rather than English, literature. Pictures of the submoon are rare, although an early, and maybe first-ever, submoon picture was published as early as the 1930s (Rossmann, 1934): it was taken from a Swiss mountain station. A recent picture of a nearby submoon in a cold climate was published on the web by Riikonen (2010).

As the Full Moon is a million times less bright than the sun, a picture of its submoon requires at least a million times longer exposure time than for the subsun. Figure 1, maybe the first submoon picture ever taken from a moving platform, has only been made possible by virtue of the current availability of very sensitive digital cameras.

Although the submoon and subsun are basically the same phenomenon, the submoon is the more rarely seen. The reason is not the intrinsic weakness of moonlight-generated halos compared to solar halos, as is sometimes claimed (see, e.g., Meyer, 1929, p. 3). Instead of the absolute brightness, the governing factor for the visibility of halos is the signal-to-background ratio. In the absence of other light sources, this ratio is independent of the brightness of the celestial halo-generating light source – which could be the sun, the moon or whatever. This independence is elegantly illustrated by a historical visual report of a subjupiter (Küttner and Model, 1948), a situation where the light source (Jupiter) and subjupiter are 10 000 times weaker than for the moon and submoon during Full Moon.

A fundamental reason for the relative rarity of the submoon is that on most days the moon is above the horizon for only part of the night. Obviously, in that respect, the situation is most favourable near Full Moon, when the moon is above the horizon all night. The brightness of moon and submoon at this lunar phase could have some beneficiary effect on the signal-to-background ratio, as it outshines background light from sources other than the moon. A second reason for the rarity of submoon reports is that at night fewer people are above the clouds than by day, and the high mountains are even more sparsely populated during the night than during daytime: only professional meteorologists or astronomers at mountain stations watch the sky all night. The prospects of observing submoons from aircraft might seem better than from mountains, but in practice the number of such observations is lower than it could be – perhaps because during night flights the cabin crew often advise the few passengers awake to close their window blinds.

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