RATE AND DISTRIBUTION OF KILOGRAM LUNAR IMPACTORS.

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Introduction: Since the November, 2005 discovery of a flash attributed to a Taurid meteoroid striking the lunar surface [1], the NASA Meteoroid Environment Office and Marshall Space Flight Center's Space Environments Team have been regularly monitoring the Moon during crescent phases for similar events. During this time, improvements have been made to the observational equipment and the analysi software, resulting in an increase in the number of faint detections (8th magnitude and dimmer).

Equipment and Software Setup: The Orion Atlas 25.4 cm f/4.7 Newtonian reflecting telescope involved in the Taurid discovery has been replaced by two 35.5 cm f/8 Ritchey-Chretien telescopes. While observing the Moon, these systems are fitted with f/0.33 focal reducers, resulting in an effective field of view of approximately 24 arc minutes. The cameras used in the observations continue to be AstroVid StellaCam EX CCD cameras, which are operated in the standard NTSC video mode (29.97 frames per second, 720x480, interlaced). This telescope/camera combination allows for the monitoring of approximately one half of the dark portion of the nearly 1st Quarter Moon. The output of the camera is fed into a Sony digital tape deck, which sends a digital video stream to a computer via a Firewire connection. Time information from a KIWI-OSD GPS time encoder is stored on the video, which also has time from radio station WWV on the audio track for redundancy.

The original reduction software, written in IDL, has been replaced by a new development, compiled from C source code. The new program, LunarScan, is much faster, produces fewer false alarms, and has a slightly better flash detection algorithm. Re-analysis of the video data with LunarScan has resulted in the fainter flash discoveries, and we anticipate new finds as new data is analyzed and the reprocessing of older video continues.

To date, approximately 20 potential lunar impacts have been observed (Table 1); of these, 10 appear to be sporadics and 9 shower meteoroids. One, candidate #17, has a significant chance of being a glint from a non-functioning Strela communcations satellite, Kosmos 647; we list it in the table in the hopes of receiving a confirming observation.

Elimination of Other Causes: Requiring that a flash be simultaneously visible in both telescopes precludes a cosmic ray origin. "Point" meteors - a meteor in Earth's atmosphere moving parallel to the optical axis of the telescope – can easily be eliminated through parallax, as the 20 m separation of the instruments would result in a shift in the flash location of approximately 20 pixels. Unfortunately, this instrument separation is not sufficient to use parallax to eliminate satellite reflections ("glints") as a possible flash cause. The current procedure rejects any flash that shows obvious elongation due to motion, and a satellite propagator tied to the complete public satellite catalog is used to identify satellite passages across the lunar disk during the observation periods. Any flash coincident with one of these passages is labeled as suspect, e.g. flash candidate #17. However, there are classified objects not in the catalog, and, as Kessler [2] has pointed out, the extension of our flash detectability to 9th magnitude has now raised the possibility of the fainter flashes being caused by specular reflections from low Earth orbit debris objects as small as 1 cm in size. This is well below the catalog threshold of approximately 10 cm. A set of experiments is underway to achieve some statistical understanding of how many flashes from debris would be observed in a typical observation session. If significant, then the only means of removing such events from the data would be to separate the instruments by a distance of some 10 km.

Results: The observed distribution of the sporadic candidates matches well with the observed geometry; impacts observed during waxing phases being due to apex and anti-helion meteoroids and those during waning phases coming only from the antihelion source. Anti-helion meteoroids, which account for most of the flux, would show a preference for the limb rather than towards the center of the disk.

Our analyses to date give 10 probable sporadic impactors in approximately 107 hours of observation, corresponding to an impact rate of 1 kg-class sporadic meteoroid every 11 hours. Active meteor showers produce much higher rates: ~1 per hour in the case of the Geminids on the night of the peak. Two Leonids were also detected on the night of November 17, the traditionl shower peak. Area determination and limiting magnitude algorithms are being developed for flux determinations, and an hypervelocity test program has been started to permit better determination of the impact luminous efficiency as a function of speed.

References:

[1] Cooke, W., Suggs, R., and Swift, W. (2006), *LPSC XXXVII*, Abstract #1731

[2] Kessler, D. (2007), *personal communication*.

#	UT Date	UT Time	Video Frames (1/30 s)	Approx. Magnitude	Probable Type	Telescopes
1	07 Nov 05	23:41:52	5	7.3	Taurid	10”
2	02 May 06	02:34:40	14	6.9	Sporadic	10”
3	04 June 06	04:48:35	1.5	7.9	Sporadic	10”
4	21 June 06	08:57:17	2.5	8.3	Sporadic	10” & 14”
5	19 July 06	10:14:44	2	8.4	Sporadic	10” & 14”
6	03 Aug 06	01:43:19	3.5	6.7	Sporadic	14”
7	03 Aug 06	01:46:11	1.5	9.1	Sporadic	14”
8	04 Aug 06	02:24:57	2	7.1	Sporadic	10” & 14”
9	04 Aug 06	02:50:14	2	8.9	Sporadic	10” & 14”
10	16 Sep 06	09:52:53	1	8.7	Sporadic	two 14”
13	30 Oct 06	00:24:27	1.5	7.6	Sporadic	two 14”
12	17 Nov 06	10:46:27	1	9.4	Leonid	two 14”
11	17 Nov 06	10:56:34	1	8.2	Leonid	two 14”
14	14 Dec 06	08:12:40	1	9.4	Geminid	two 14”
15	14 Dec 06	08:50:36	1	8.5	Geminid	two 14”
16	14 Dec 06	08:56:43	0.5	8.6	Geminid	two 14”
17	14 Dec 06	09:00:22	1	8.5	Satellite?	two 14”
18	14 Dec 06	09:03:33	0.5	10	Geminid	two 14”
19	14 Dec 06	10:56:42	1	8.7	Geminid	two 14”
20	14 Dec 06	11:28:08	2.5	7.5	Geminid	two 14”

Table 1. Lunar impact candidates. Flash ID numbers are indicative of order of discovery, not chronological order. The origins of the fainter flashes (9^{th} magnitude and dimmer) are still the subject of debate (see text).

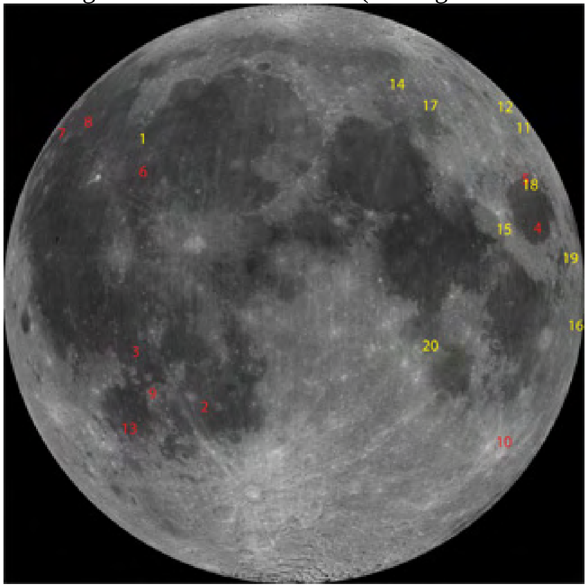

Figure 1. Flash locations. Yellow indicates a potential shower meteoroid and red indicates a potential sporadic.

Figure 2. Impact Flash occurring on May 2, 2006 at 2:34:40 UT. Note the visibility of lunar features illuminated by Earthshine.