THE STATUS OF LUNAR METEOR RESEARCH (AND APPLICATIONS TO THE REST OF THE SOLAR SYSTEM). B. M. Cudnik[1], [1]Department of Physics, Prairie View A&M University (P.O. Box 519, MS 2230, Prairie View, TX, 77446; bmcudnik@pvamu.edu)

Introduction: Since the first confirmed video recordings of meteoroids impacting the lunar surface in 1999, the field of hypervelocity impact research has greatly expanded. Astronomers, both professional and amateur, have been scrutinizing the moon for the past seven years and have added to our findings concerning the rate and nature of impacts. Old data are being re-examined in a new light as we learn more about the frequency and physics of such impact events. Now a team from NASA-Marshall Space Flight Center has systematically monitored the moon and found that impact events are more common than once thought.

These new findings have implications for the establishment of a manned lunar outpost as NASA makes plans to return humans to the moon by 2020.

A Summary of Campaigns: Work by [1], [2], [3], and efforts from amateur groups such as the Association of Lunar and Planetary Observers have scrutinized the moon for the telltale point flashes of meteoritic impact and have succeeded in recording these events. The ALPO / Lunar Meteoritic Impact Search group have documented two independently confirmed Leonid meteor impacts during the storms of November 2001. [3] reported a single confirmed Perseid impact flash, the first confirmed non-Leonid impact event. [2] have made regular observations from November 2005 and have documented nearly 20 impacts from annual shower objects and sporadic meteoroids.

[1] suggested using the lunar surface as an impact counter to derive the impact rates of large meteoroids. The advantage is the large collecting area presented to observers, much larger than a ground- or satellite-based survey of terrestrial fireballs. This team carried out a systematic survey from 2001 to 2004 and have observed 3 good impact candidates, all derived from sporadic meteoroids, and has made the conclusion that 80,000 objects with masses 1kg and greater collide with the Earth. If one assumes that the Earth's impact rate is 35 times more than that of the Moon, it follows that 1kg objects (which are large enough to produce an impact flash detectable from the Earth) should strike the moon about 2,300 times per year. If one reduces this by 75% (50% due to only one hemisphere at a time being visible from Earth, and 25% being the average area in sunlight, hiding most meteor impacts), it follows that up to 575 impact events on average could be potentially observed from ground-based instrumentation per year. The actual numbers are far less due to viewing geometry, weather, instrumentation problems, the moon being lost to the glare of dawn / dusk for part of the month, etc.

Implications for the Future: In addition to the implications provided by the results of the work summarized above, more of the big picture of interplanetary debris emerges when other impact targets are taken into account. In addition to this, the numerous reports of so-called Lunar Transient Phenomena need to be looked at again, since the likelihood of at least some of the reports being genuine impact events has greatly increased with the results summarized here. Each of these implications is briefly considered.

Risk Assessment for the Return of Manned Missions to the Moon and Beyond. With at least one group conducting a regular survey of the Moon on a monthly basis, more information should be made available in the coming years concerning the frequency of lunar meteor impacts. In addition to providing a measure of the flux of intermediate-sized objects in our part of the solar system, a systematic campaign also provides risk assessment as NASA plans to send astronauts back to the moon by 2020 and to establish a permanently-staffed lunar base by 2024. Risks to astronauts, habitation units, and equipment need to be weighed prior to sending people to the moon.

Impact Research on Other Worlds. Other groups such as [4], [5], and [6], have considered the study of meteoroid impacts on other worlds (to even include Saturn's rings). The most famous of these to date is the Shoemaker-Levy 9 impact with Jupiter in July 1994. Events such as these provide an opportunity to observe not only the physical processes involved in the impact itself, but also to obtain information on the composition of both the impactor and the target. [7] provides insight into the potential of a special camera, the Smart Panoramic Optical Sensor Head (SPOSH) that can be mounted aboard spacecraft placed in orbit around other worlds to monitor the dark side of that world for flashes from meteor impacts, lightning, and other temporal phenomena. If such instrumentation could be mounted on spacecraft bound for other planets and satellites, the combined dataset from each of these would expand our knowledge of the size spectrum and object type of previously unobservable objects to other parts of the solar system. The implications of having direct observations of meteoric influx on other bodies of the solar system are outlined in [5].

Validation of Lunar Transient phenomena Observations. Over the centuries, numerous reports of change occurring on the lunar surface have been catalogued. This change, referred to as Lunar Transient Phenomena or LTP, has been a controversial topic in planetary research. Nonetheless, with the increasing number of positive observations of lunar meteor impact flashes, one needs to consider at least some of these observations in a new light. Many LTP's have been reported by highly skilled and reputable observers, making these difficult to dismiss. Also, ALPO gets reports, at least several times per year, of people serendipitously observing apparent impact events.

As a database of events is logged, one has a set of standards to compare previous LTP observations with. Once can potentially select the best LTP observations resembling impact events (most commonly manifested as very brief point flashes of light) and use these to add to the statistics of lunar meteor phenomena.

Conclusions: Lunar Meteoritic Phenomena, once regarded with much skepticism, is now becoming a commonly-observed type of celestial event. Table 1 provides information about the best impact events to date. The data were acquired from several sources and consist of 48 events ranging in magnitude from 3 to 9.5. Nearly all the flashes had durations of less than 0.25 second (0.02 to 0.05 second is typical) but one had a duration of 0.47 seconds. Over half of these (27) are most likely Leonids, 13 are sporadic, 6 are Geminids, one is a Perseid, and one is a Taurid. The quality of these events range from confirmed to probable (but each is very likely an actual impact event).

With plans to release automated impact detection software to professional and amateur astronomers in the coming year [10], it seems quite likely that observers from both groups will participate in a more complete, comprehensive monitoring of the moon during favorable times. This participation will not only greatly increase the number of catalogued events, but will provide further insight into the near-Earth meteoroid environment and the physics of hypervelocity collisions.

References: [1] Ortiz J. L. et al. (2006) *Icarus, 184*, 319–326. [2] Cooke W. J. et al. (2006) *LPS XXXVII,* Abstract #1731. [3] Yanagisawa M. et al. (2006) *Icarus, 182*,489–495. [4] Korycanksy D. G. and Zahnle K. J. (2004) *Icarus*, *169*, 287-299. [5] Pesnell W. D. et al. (2004) *Icarus*, *169*, 482-491. [6] Chambers L. S. et al. (2005) *Bull. Amer. Ast. Soc., 37*, 771. [7] Koschny D. (2003) *Pimo. Conf.*64-69. [8] Cudnik B. M. et al. (2003) *EM&P* **93** 145-161. [9] NASA / MSFC Lunar Impact Monitoring Website http://www.nasa.gov/centers/marshall/news/lunar/index.html . [10] www.spaceweather.com for 4 January 2007.

Table 1-the 48 best impact candidates reported in the literature.

UT Date	UT Time	Mag	TYPE	Ref.
18 Nov 99	1:46:09.7	6.7	Leonid	[8]
18 Nov 99	2:52:20.0	8.3	Leonid	[8]
18 Nov 99	3:05:45.0	6.2	Leonid	[8]
18 Nov 99	3:49:40.4	4.9	Leonid	[8]
18 Nov 99	4:08:04.1	5.8	Leonid	[8]
18 Nov 99	4:12:27.8	5.5	Leonid	[8]
18 Nov 99	4:32:50.8	4	Leonid	[8]
18 Nov 99	4:34:49.5	7	Leonid	[8]
18 Nov 99	4:40:26.7	6.3	Leonid	[8]
18 Nov 99	4:46:15.5	5.1	Leonid	[8]
18 Nov 99	4:51:24.9	6.3	Leonid	[8]
18 Nov 99	5:14:12.9	6.2	Leonid	[8]
18 Nov 99	5:15:20.2	5.3	Leonid	[8]
18 Nov 99	5:26:43.25	5.3	Leonid	[8]
18 Nov 99	11:07:46.2	6	Leonid	[8]
18 Nov 99	11:18:05.9	7	Leonid	[8]
18 Nov 99	12:11:45.5	7	Leonid	[8]
18 Nov 99	13:54:26.0	4?	Leonid	[8]
18 Nov 99	14:14:31.0	3?	Leonid	[8]
18 Nov 01	18:27:46	5.2	Leonid	[8]
18 Nov 01	18:10:36	7.5	Leonid	[8]
18 Nov 01	18:12:21	7.9	Leonid	[8]
18 Nov 01	18:19:55	8.2	Leonid	[8]
18 Nov 01	23:19:15.2	6.4	Leonid	[8]
19 Nov 01	0:18:58.2	5.0	Leonid	[8]
19 Feb 02	19:40:04	7.6	Sporadic	[1]
05 Feb 03	19:24:43	8.3	Sporadic	[1]
26 Dec 03	17:36:38	7.1	Sporadic	[1]
11 Aug 04	18:28:27	9.5	Perseid	[3]
07 Nov 05	23:41:52	7.3	Taurid	[9]
02 May 06	02:34:40	6.9	Sporadic	[9]
04 June 06	04:48:35	7.9	Sporadic	[9]
21 June 06	08:57:17	8.3	Sporadic	[9]
19 July 06	10:14:44	tbd	Sporadic	[9]
03 Aug 06	01:43:19	6.7	Sporadic	[9]
03 Aug 06	01:46:11	9.1	Sporadic	[9]
04 Aug 06	02:24:57	7.1	Sporadic	[9]
04 Aug 06	02:50:14	8.9	Sporadic	[9]
16 Sep 06	09:52:53	8.7	Sporadic	[9]
30 Oct 06	00:24:27	tbd	Sporadic	[9]
17 Nov 06	10:46:27	9.4	Leonid	[9]
17 Nov 06	10:56:34	8.2	Leonid	[9]
14 Dec 06	08:12:40	tbd	Geminid	[9]
14 Dec 06	08:50:36	8.5	Geminid	[9]
14 Dec 06	08:56:43	tbd	Geminid	[9]
14 Dec 06	09:03:33	tbd	Geminid	[9]
14 Dec 06	10:56:42	8.7	Geminid	[9]
14 Dec 06	11:28:08	7.5	Geminid	[9]