A PROBABLE TAURID IMPACT ON THE MOON. W.J. Cooke[1], R.M. Suggs,[1] and W.R. Swift[2], [1]Meteoroid Environment Office, EV13, Marshall Space Flight Center, AL 35812 william.j.cooke@nasa.gov, [2]Raytheon, Huntsville, AL, 35812 wesley.swift@nasa.gov.

Introduction: On November 7, 2005, at 23:41:52 UT, observers located at the Marshall Space Flight Center captured the flash produced by a kilogram-size meteoroid striking the lunar surface. Photometric analysis of the event video, combined with the plausible assumptions of a luminous efficiency of $2x10^{-3}$ and that the meteoroid was a member of the Taurid meteoroid stream, yield a striking power of approximately 640 lbs of TNT and a mass of approximately 3.8 kg.

Even though no confirming independent observations are known to exist, there is high confidence in the impact origin of the flash; reasonable attempts have been made to eliminate other possibilities, such as cosmic ray hits on the CCD and glints from satellites that may have crossed the lunar disk near the impact time.

Equipment Setup: The instrument used in making the observations was an Orion Atlas 25.4 cm f/4.7 Newtonian reflecting telescope, to which an AstroVid StellaCam EX CCD camera was attached. The StellaCam has an imaging array of 795x496 pixels and was operated in the standard NTSC video mode (30 frames per second, interlaced). This telescope/camera combination allowed for the monitoring of approximately one half of the dark portion of the nearly 1st Quarter Moon. The output of the camera was fed into a Sony digital tape deck, which sent a digital video stream to a computer via a firewire connection.

After using a handheld GPS unit to establish the position of the telescope (86° 40' 16".7 W, 34° 38' 56".7 N), two hours of video were recorded to disk. Even though the camera output was also displayed on a video monitor, no flash was noted; it was discovered during the analysis, which occurred during the following week.

Analysis: The impact flash was discovered in the process of manually reviewing the video using custom IDL software developed for astronomical video analysis. Once identified, the frames containing the flash were extracted and subjected to photometric analysis. This was greatly facilitated by the presence of several faint stars (7th to 9th magnitude) in the field of view. The flash light curve (in arbitrary instrument units) is presented in figure 1; the peak intensity corresponds to a visual magnitude of ~7.3. Integration of the light curve yields an at Earth energy per unit area of $1.5x10^{-12}$ J m^{-2}, which translates to an impact energy of $1.39x10^{9}$ J if the luminous efficiency is assumed to be 0.002.

The observations were conducted in an attempt to determine the proper equipment combination necessary to observe lunar impacts – it was not thought that such an impact would actually be observed during the short time of video data collection. As such, a precise time for the start of the video was not recorded, requiring the use of some timable events on the video to establish the time of the impact. This was accomplished by noting the frame numbers of three occultations of known stars by the Moon and using the IOTA Occult program to establish the absolute times of these events. The derived impact time, 23:41:52 UT, is probably not in error by much more than 1 second.

It was also possible to determine the impact location by using commercial software to co-add and stretch the video frames to the point where lunar features were visible by virtue of the Earthshine. A comparison to electronic lunar atlases resulted in an impact point at 39.5° W, 31.9° N, just to the south of the crater Gruithuisen.

Elimination of Other Causes: The lack of an independent confirmation necessitated that a fair amount of time be spent in the consideration of three other possible causes of the flash: 1) a cosmic ray hit on the detector, 2) a glint from a solar array or some other component of a satellite passing between the observer and the Moon, and 3) a meteor in Earth's atmosphere moving parallel to the optical axis of the telescope.

A cosmic ray hit was eliminated by noting that the flash persisted in 5 frames (see figure 2); cosmic rays are typically present in only one frame. Persistent cosmic ray flashes have been noted in some detector types; however, the CCD used in the StellaCam is not one of these. None of the numerous cosmic ray induced flashes we have seen with this camera have ever lasted longer than a single video frame.

Satellite glints were eliminated by using Satellite Toolkit and the publicly available satellite catalog to compute the positions of all unclassified satellites and trackable debris at the impact time. None were calculated to be near the impact position. Of course, there remains the possibility that a classified satellite could have produced the flash; however, the shape of the light curve is not what would be expected from such a cause. Indeed, the sharp rise and exponential decay is very similar to the light curves of the Leonid impact flashes observed by Yanagisawa and Kisaichi [1].

A further bit of evidence against a satellite cause is the fact that the impact flash remains motionless in the video; the system used would be able to detect a motion as small as 1.5 arc seconds over the 5 frames the flash was visible; such a small rate would eliminate all but geostationary satellites.

The light curve shape can also be used to eliminate the third possibility, as it does not conform to what one would expect to see from a point meteor.

Taurid Identification: The meteoroid observed to strike the Moon on November 7 has been tentatively identified as belonging to the Taurid stream, based on the following:

1) The 2005 Taurids were rich in large meteoroids, as evidenced by the numerous fireballs observed here on Earth during the last week of October and the first week of November.
2) The Taurid radiants were at altitudes of 53° and 42° above the lunar horizon at the impact point.

If the meteoroid was a Taurid, its impact speed would have been approximately 27 km s^{-1}; combining this with the impact energy estimate results in an impactor mass of approximately 3.8 kg.

References:

[1] Yanagisawa, M. and Kisaichi, N. (2002), *Icarus, 159*, 31-38.

[2] Ortiz et al. (2002), *ApJ, 576*, 567-573.

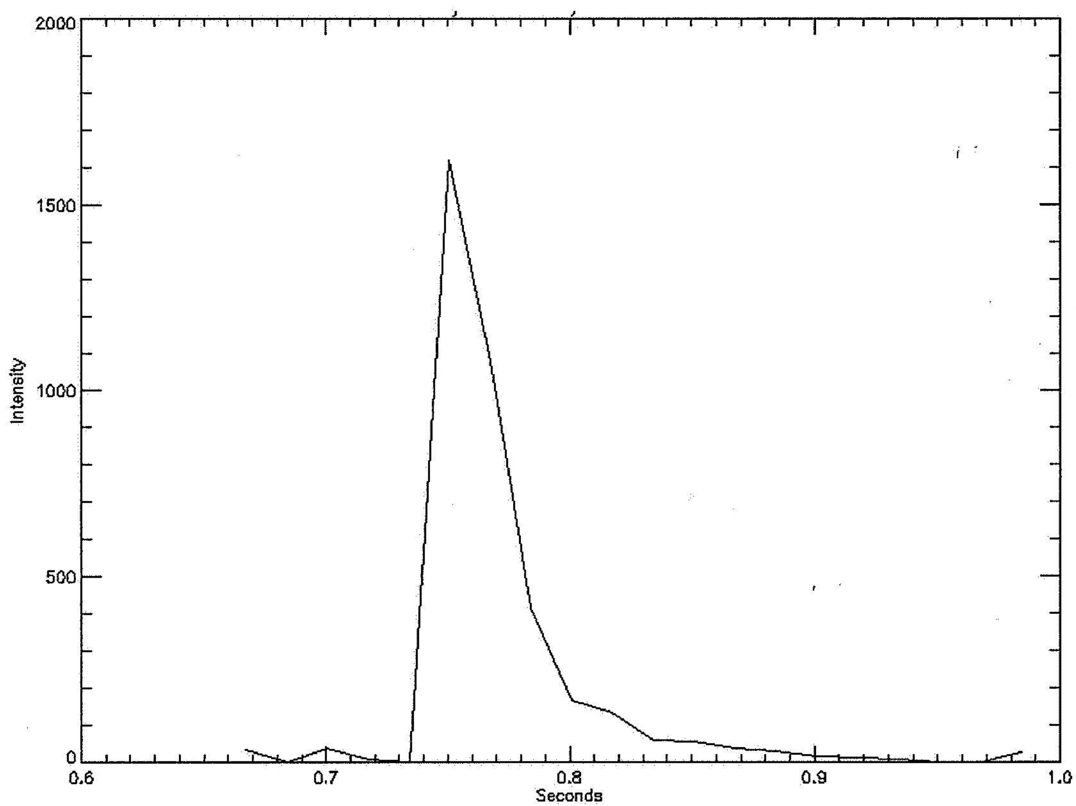

Figure 1. Light curve of flash observed on November 7, 2005 at 23:41:52 UT. Background subtracted total intensity is measured in arbitrary instrumental units on a field by field basis.

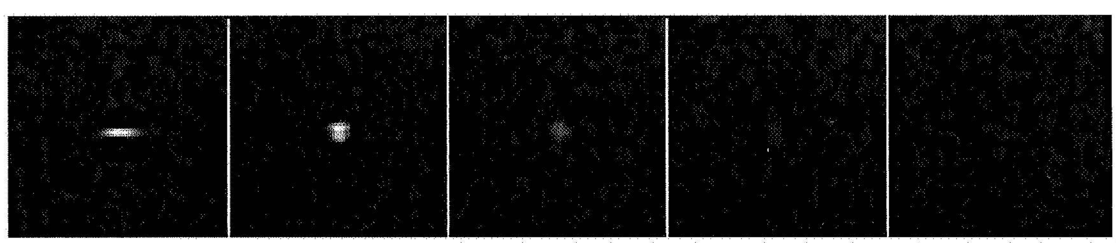

Figure 2. 5 frame sequence showing the evolution of the flash with time. The first frame has the flash only in its second field so it appears to have only half the exposure. Although dimmer, the second frame appears brighter since both fields are exposed.