DETECTION OF A RADAR SIGNATURE OF THE UPRANGE PLUME IN FRESH OBLIQUE LUNAR CRATERS. S. W. Bell and P. H. Schultz, Department of Geological Sciences, Box 1846, Brown University, Providence, RI 02912 (samuel_bell@brown.edu)

Introduction: The oblique impact on the nucleus of comet 9P/Tempel-1 during the Deep Impact mission produced a collimated plume of ejecta uprange [1]. (The uprange direction is the direction the impactor came from, and the downrange direction is the direction the impactor was travelling towards.) This uprange plume has also been observed in laboratory impact experiments [1,2] and during the impact of comet Shoemaker-Levy 9 into Jupiter [3], but until now no geologic expression of the uprange plume has been identified in fresh lunar craters. (It has been identified on planets with atmospheres [4].) Utilizing newly available S-Band data from the Mini-RF imaging radar, we searched fresh oblique lunar craters for a signature of the uprange plume. Most of the craters examined did not preserve any related deposits. We did, however, identify six craters with uprange rays that we propose are deposits from the uprange ejecta ray (Table 1).

Mini-RF is a Synthetic Aperture Radar (SAR) on the Lunar Reconnaissance Orbiter (LRO) with a spatial resolution of 30 m and two wavelengths: 12.6 cm S-Band and 4.2 cm X-Band [5,6,7]. Because total radar backscatter measures the surface roughness on the scale of the wavelength of the radar, Mini-RF is capable of imaging blocky ejecta blankets that cannot be detected in optical images or are only visible under specific lighting conditions. This makes Mini-RF ideal for imaging the uprange ray, even if it is not obvious at visible wavelengths due to space weathering.

Results and Discussion: Oblique impacts at angles below ~30˚ produce a wedge-shaped "zone of avoidance" relatively clear of ejecta [8,1]. A ray extending into this zone can be readily distinguished from ordinary uprange rays. Figure 1 shows an example of a crater with a preserved uprange plume deposit. It is a fresh 1.7 km oblique crater on the western edge of Mare Nubium. Bifurcating the zone of avoidance, the uprange ray runs from the crater rim to the rim of nearby crater Kies C. High-resolution LROC NAC (Lunar Reconnaissance Orbiter Camera narrow-angle camera) images of the uprange ray near the crater rim show a blocky ray with several large blocks that range in size up to ~12 m (Figure 1b). The large blocks become less abundant with increasing distance from the crater (Figure 1c). The absence of trails behind the blocks indicates that they were probably not emplaced at low angles. The angle of the Deep Impact uprange plume increased during the excavation phase, evolving from an initial reverse plume to a late-stage high-angle plume [1].

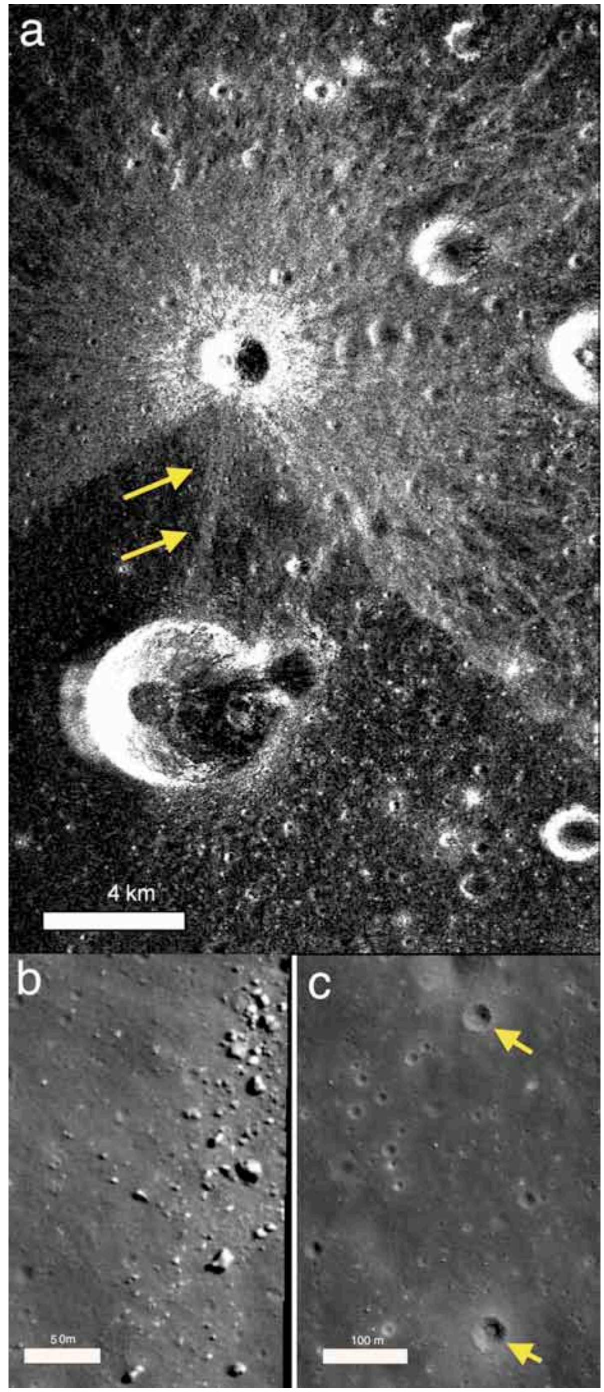

Figure 1: (a) Mini-RF S1 (total radar backscatter) image of a bright halo crater with a clear uprange ray (indicated by the yellow arrows) bifurcating the zone of avoidance. PDS tag: LSZ_01776_2S1_EKU_31S334_V1 (25.77˚S, 26.18˚W) (b) LROC NAC image of the uprange ray near the crater rim showing large boulders PDS tag: M111762882L (c) LROC NAC image of a more distal portion of the uprange ray, showing fewer blocks and two possible secondary craters (indicated with arrows)

The fresh oblique crater with an uprange ray shown in Figure 3a occurs in the southern portion of Mare Fecunditatis. Although it falls in the secondary field of Petavius B (a fresh crater that also has an uprange ray), its impact direction is inconsistent with it being a Petavius B secondary itself. A few blocks are visible along the crater rim in the LROC NAC image, but no individual blocks can be discerned along the uprange ray, and no optical signature of the ejecta can be discerned (Figure 2b). In the Mini-RF image, however, the ejecta blanket is visible. Extending out to ~5 crater radii in the radar, the ejecta show a clear zone of avoidance and uprange ray. The ejecta appear less fresh than the ejecta of the crater in Figure 1, which has ejecta extending out to ~12 crater radii and preserves the distinction between the bright inner "continuous" ejecta and the fainter outer "discontinuous" ejecta.

In the Deep Impact experiment, the uprange plume was a mixture of dust and vapor. On the Moon, the uprange ray incorporated large (~12 m) boulders along with it. For the uprange ray to be visible in 12.6 cm radar images in Figure 2, it must contain decimeter-scale blocks. These blocks may be buried a few decimeters below the surface or they all must be less than ~1 m in diameter--too small to be detected by the LROC NAC. The Deep Impact uprange plume was initially narrow during the penetration phase but became more diffuse by the latest stages of excavation. For the Moon, however, the large size of the blocks for the lunar uprange rays indicates that they could have come from rebound, back in the direction of impact.

Conclusion: Using newly available Mini-RF imagery of fresh oblique lunar craters, we have detected a geological expression of the uprange plume, previously known from Deep Impact, laboratory experiments, and Venus.

References: [1] Schultz, P. H. et al. (2007), *Icarus*, *190*, 295-333. [2] Schultz, P. H. et al. (2006), *Space Sci. Rev.*, *117*, 207-239. [3] Boslough, M. B. et al. (1994), *GRL*, *21*, 1555-1558. [4] Schultz, P. H. (1992), *J. Geophys. Res.*, *97*, No. E10, 16,183-16,248. [5] Raney, R. K. (2011), *Proc. of the IEEE*, *99*, 808-823 [6] Bussey, D. B. J. et al. (2011), *LPSC 42 Abstract #2086*. [7] Nozette, S. (2010), *Space Sci. Rev.*, *150*, 285-302. [8] Gault, D. E. and Wedekind, J. A., *Proced. of the 9th LPSC*, 3843-3875.

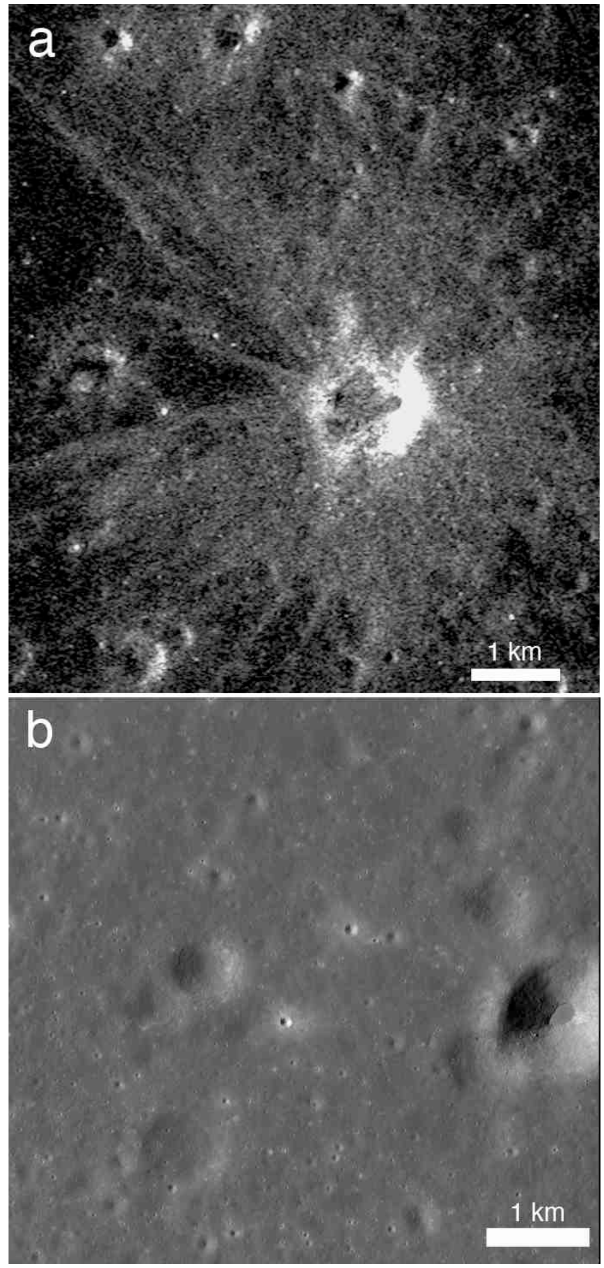

Figure 2: (a) A Mini-RF image of a moderately fresh crater with a visible uprange ray bifurcating the zone of avoidance. The ejecta blanket appears less fresh than the ejecta blanket of the crater in Figure 1. PDS tag: LSZ_02573_2S1_EKU_20S053_V1 (b) An LROC NAC image showing the location of the uprange ray. None of the ejecta are visible under these lighting conditions. PDS tag: M104169321R

	Diameter (km)	Latitude	Longitude	Location
1	6.5	9.6˚ S	153.3˚ W	In the highlands on the rim of Korolev.
2	1.0	13.3˚ N	10.4˚ E	On the ejecta of Manilius in eastern Mare Vaporum.
3	1.7	25.8˚ S	26.2˚ W	Western edge of Mare Nubium.
4	33	20.0˚ S	57.1˚ E	Southern edge of Mare Fecunditatis. Name: Petavius B.
5	0.37	32.2˚ S	15.6˚ W	In the highlands north of Wurzelbauer, on Tycho Ejecta.
6	1.2	16.9˚ S	53.1˚ E	Northwest of Petavius B. In southern Mare Fecunditatis.

Table 1: A table of craters with uprange rays identified in Mini-RF imagery.