WHO LAUNCHED LUNAR METEORITE OUED AWLITIS 001? Axel Wittmann[1], Randy L. Korotev[2], Bradley L. Jolliff[2], Michael Zanetti[3], Kunihiko Nishiizumi[4]; A. J. Timothy Jull[5]; Marc W. Caffee[6] and Anthony J. Irving[7]; [1]LeRoy Eyring Center for Solid State Science, Arizona State University, Tempe, AZ 85287, USA, axel.wittmann@asu.edu; [2]Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130, USA; [3]Department of Earth Sciences, University of Western Ontario, London, Ontario, Canada; [4]Space Sciences Laboratory, University of California Berkeley, CA 94720; [5]Department of Geosciences, University of Arizona, Tucson, AZ 85721; [6]Department of Physics and Astronomy, Purdue University, West Lafayette, IN 47907, USA; [7]Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195, USA.

Introduction: Oued Awlitis (OA) 001 is a highly feldspathic lunar meteorite that was recovered in 2014. Its petrography suggests it is a clast-rich poikilitic impact melt rock that records a shock metamorphic overprint of the bulk rock on the order of 24 GPa [1], which could relate to its ejection from the Moon. The cosmogenic nuclide inventory of Oued Awlitis 001 suggests an ejection from the Moon 0.3 Ma ago from a depth >4 m and little mass loss due to ablation during its passage through Earth's atmosphere [2]. We use Lunar Reconnaissance Orbiter Camera (LROC) images to speculate about the origin of OA 001 on the Moon.

Launch Constraints: To excavate OA 001 from a minimum depth of 50 m, which would be the center of a 100 m thick impact melt volume that is deemed necessary for crystallizing poikilitic impact melt rocks such as OA 001, an impact is required that produces a >0.5 km Ø crater [3]. For an average excavation depth of 50 m on the Moon, [4] assumes a 1 km Ø impact crater. Thus, it is possible that OA 001 was excavated and subsequently incorporated into an ejecta blanket on the Moon, where it was deposited at a depth >4 m before being launched into an Earth-crossing orbit by a third impact. However, the impact that produced the ~20 GPa pressure pulse in OA 001 and corresponding petrographic features does not appear to be overprinted by another shock event. While we cannot rule out that OA 001 was launched from a deeper location in the lunar regolith where it could have been deposited after impact-excavation from its host impact melt rock, we explore a launch of OA 001 from the Moon by the event that excavated it from where it crystallized.

While excavation of material from a depth of 50 to 100 m on the Moon can be accomplished by small (1 to 3 km Ø) impacts that occur at a frequency of a several dozen per Ma [4], in order to accelerate ejecta to the average escape velocity of 2.38 km/s from the Moon, the meteoritic material must have been part of a spall zone. This "shock wave interference zone" is expected to be on the order of 50 m thick for a 10 km Ø crater on the Moon [4]. In addition, CRE data indicates the crater that ejected OA 001 from the Moon formed 0.3 Ma ago [2]. Because a 10 km Ø crater on the Moon has a statistical recurrence of every 1 to 4 Ma, and a ~20 km Ø crater only has a probability to form every 4 to 15 Ma [4], we expect a very limited number of such candidate launch sites on the Moon for OA 001.

Candidate Launch Sites: The four youngest lunar craters ≥18 km in diameter are 37 km Ø Necho, 18 km Ø Byrgius A, 24 km Ø Moore F, and 22 km Ø Giordano Bruno crater [5]. They have model ages from cumulative size-frequency distributions of craters counted on their continuous ejecta blankets of 80, 48, 41, and 4 Ma, respectively [6]. This suggests that only Giordano Bruno crater is a viable candidate in this size group for the launch site of OA 001.

Giordano Bruno. Further constraints for the age of Giordano Bruno of 5 to 10 Ma have been based on presumed secondary craters at the Luna 24 landing site [7]. However, [8] suggested Giordano Bruno could be much younger, even historical, because self-secondary craters may yield artificially old crater-counting ages with discrepancies between counts on the ejecta blanket and impact melt surfaces. Crater counting ages for Giordano Bruno that take self-secondary craters into account find ages as low as 0.61 Ma [9], which agrees with estimates for an age of ~1 Ma based on optical roughness imagery [10]. This could indicate that Giordano Bruno is not conclusively older than CRE age constraints for OA 001.

Giordano Bruno is located just outside the SE' rim of 337 km Ø Harkhebi crater, and within one crater radius of 122 km Ø Szilard crater that lies to the SE (Fig. 1A). Topography data for Giordano Bruno produced from LRO's high resolution Narrow-Angle Camera reveals steep walls with slopes close to the angle of repose (Fig. 1B). While all crater walls have a relief greater than 2 km, the NW' wall displays ~2.8 km steep walls with angles of 40°, suggesting competent rocks near the surface. This could indicate ponded impact melt near the crater rim of Harkhebi. Although such ponded impact melt deposits are known from many smaller lunar craters where they are typically up to a few decameters thick [11–12], it seems plausible that they could reach a thickness of ~100 m at the rim of Harkhebi crater.

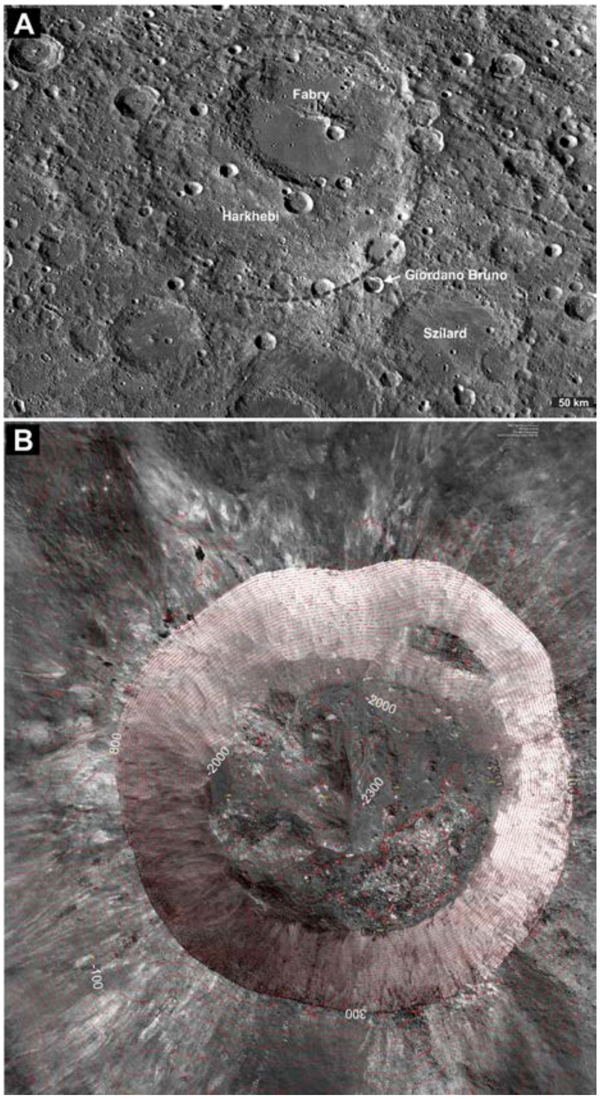

Fig. 1. Giordano Bruno crater.

A - Regional context for Giordano Bruno crater from the NASA/GSFC/ASU-ACT-REACT QuickMap.

B - LROC NAC mosaic with contour lines generated from stereo observations (NASA/GSFC/ASU).

Goddard A. Another "very young", rayed Copernican impact crater is 11 km Ø Goddard A [13]. Goddard A lies on a patch of highlands terrain near the rim of 93 km Ø Goddard crater on the Moon's nearside close to the edge of Mare Marginis and inside the outer ring of pre-Nectarian, 878 km Ø Smythii basin [14].

The prominence of poikilitic rocks on the rims of the lunar impact basins Imbrium and Serenitatis has been demonstrated with the samples collected by Apollo 15 and Apollo 17. These poikilitic impact melt rocks have been interpreted as fragments of thick impact melt deposits on the rims of these basins [e.g., 15–16].

Implications of Candidate Launch Sites: While both Goddard A and Giordano Bruno could have launched poikilitic melt rocks from ponded poikilitic impact melt near the rims of ancient lunar basins, Goddard A's location in the Moon's Eastern Basin Terrane contrasts with the location of Giordano Bruno in the western Feldspathic Highlands Terrane [17]. The present day crustal thicknesses in the Eastern Basin Terrane near Goddard A is ~35 km, while it is ~45 km near Giordano Bruno [18]. Moreover, the Spectral Profiler instrument onboard the Selenological and Engineering Explorer (SELENE) spacecraft detected highly feldspathic "purest anorthosite" near Giordano Bruno but not in the vicinity of Goddard A [19]. The proximity of Goddard A to Smythii basin and Goddard crater requires consideration of the compositions of impact melt rocks generated by these impacts. Smythii basin should have incorporated a significant proportion of mafic lower crust and mantle in its melt zone; evidence for crustal thinning in its center is indicated in recent gravity maps [14; 19]. In contrast, 93 km Ø Goddard crater could have produced highly feldspathic, poikilitic impact melts akin to OA 001 from an intermediate depth in the pre-Nectarian lunar crust that could have been launched by Goddard A.

If Giordano Bruno launched OA 001 along with $\sim 10^{12}$ kg lunar rocks, current and future lunar meteorites that reach Earth would be dominated by ejecta from this impact [20] and feldspathic lunar meteorites with CRE ages of ~0.3 Ma would be prevalent.

Goddard A launched a much smaller mass of high-velocity ejecta than Giordano Bruno that would contain more mingled breccia components of feldspathic and basaltic rocks that may be more representative of the types of currently known lunar meteorites.

References: [1] Wittmann A. et al. (2014) *Met. Soc. 77,* Abstract #5352. [2] Nishiizumi K. et al. (2016) *LPS 47,* Abstract #1669. [3] Wittmann A. et al. (2015) *LPS 46,* Abstract #1141. [4] Warren P. H. (1994) *Icarus 111,* 338–363. [5] Grier J. A. et al. (1991) *JGR 106*, 32847–32862. [6] Morota T. et al. (2009) *MAPS 44*, 1115–1120. [7] Basilevsky A. T. and Head J. W. (2012) *PSS 73*, 302–309. [8] Plescia J. B. et al. (2010) *LPS 41,* Abstract #2038. [9] Williams J.-P. et al. (2011), *LPS 42*, Abstract #2882. [10] Shkuratov Y. et al. (2012) *Icarus 218*, 525–533. [11] Denevi B. W., et al. (2012) *Icarus 219*, 665–675. [12] Öhman T. and Kring D. A. (2012) *JGR 117*, E00H08. [13] Wilhelms D. E. (1987) *USGS Prof. Pap. 1348*, 329 pp. [14] Neumann G. A. et al. (2015) *Sci. Adv. 1*, 10 pp. [15] Dalrymple G. B. and Ryder G. (1993) *JGR 98*, 13,085–13,095. [16] Dalrymple G. B. and Ryder G. (1996) *JGR 101*, 26069–26084. [17] Jolliff B. L. et al. (2000) *JGR 105*, 4197–4216. [18] Wieczorek M. et al. (2013) *Science 339*, 671–675. [19] Yamamoto S. et al. (2012) *GRL 39*, L13201. [20] Fritz, J. (2012) *Icarus 221*, 1183–1186.