EARTH-MOON IMPACTS AT ~300 Ma and ~500 Ma AGO. N. E. B. Zellner[1,4], J. W. Delano[2], T. D. Swindle[3], F. Barra[3], E. Olsen[3], D. C. B. Whittet[4], and P. D. Spudis[5] [1]Lawrence Livermore National Laboratory, Livermore, CA 94550 zellner1@llnl.gov, [2]New York Center for Studies on the Origin of Life, Department of Earth and Atmospheric Sciences, University at Albany (SUNY), Albany, NY 12222, [3]University of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721, [4]New York Center for Studies on the Origin of Life, Rensselaer Polytechnic Institute, Troy, NY 12180, [5]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 20723.

Introduction: Impact events have played an important role in the evolution of planets and small bodies in the Solar System. Meteorites, lunar melt rocks, and lunar impact glasses provide important information about the geology of the parent body and the age of the impacting episodes. Over 2400 impact glasses from 4 Apollo regolith samples have been geochemically analyzed and a subset has been dated by the ^{40}Ar/^{39}Ar method. New results, consistent with 2 break-ups in the Asteroid Belt, are presented here.

Our previous study [1] reported that ^{40}Ar/^{39}Ar ages from 9 impact glasses showed that the Moon experienced significant impacts at ~800 Ma and at ~3800 Ma ago, somewhere in the vicinity of the Apollo 16 landing site. Additionally, [2] reported on Apollo 12 samples with ages around 800 Ma, together implying global bombardment events. New data on 7 glasses from regolith sample 66041,127 show that the Moon also experienced impact events at ~300 Ma and >500 Ma ago, which may coincide with the break-ups in the Asteroid Belt of the L- and H-chrondrite parent bodies [e.g. 3,4]. Since meteoritic evidence for these break-ups has been found on Earth, it follows that evidence should be found in lunar samples as well.

Lunar Impact Glasses: Lunar impact glasses are droplets of melt produced by energetic impact events that were quenched during ballistic flight. They possess the refractory element ratios of the original fused target materials at the site of impact [5]. Impact glasses offer the potential for providing information about local and regional units and terrains [5,6], and in this case, provide information about impacts in the Earth-Moon system as well.

Sample Analysis: Impact glasses were hand-picked from regolith sample 66041,127 and analyzed for Si, Ti, Al, Cr, Fe, Mn, Mg, Ca, Na, and K using a JEOL 733 electron microprobe in the Department of Earth and Environmental Sciences at Rensselaer. Five X-ray spectrometers were tuned and calibrated for each element analyzed in the glass sample. A 15 keV electron beam with a specimen current of 50 nAmps was used. Lunar working standards were used to assess analytical precision throughout the study. Count-times of 200 seconds were used for Na and K, while count-times of 40 seconds were used for the other elements. Backgrounds were collected for every element on every analysis. Uncertainties in the measurements were usually < 3% of the amount present.

Impact glasses were subsequently irradiated and analyzed in order to determine their ^{40}Ar/^{39}Ar ages. Samples were irradiated in the Phoenix Ford Reactor at the University of Michigan for about 300 hours, producing a J-factor of 0.05776 ± 0.00030. CaF_2 salts and MMhb-1 hornblende samples were irradiated simultaneously, the former to correct for reactor-produced interferences and the latter to determine the neutron fluence. Laser step-heating on these samples was carried out in the University of Arizona noble gas lab, using a continuous Ar-ion laser heating system. Heating steps were determined by passing a 5A beam over the sample. The amperage was then increased incrementally until ^{40}Ar counts from the sample peaked then decreased to no greater than background levels. In addition to system blank and interference corrections, Ar isotopes produced by cosmic ray spallation and by implantation from the solar wind were subtracted from each sample.

Results: Two groups of lunar impact glasses show ages that converge around 2 distinct time periods, 300 Ma and >500 Ma (Table 1, Figs. 1a and 1b). Previous analyses of meteorites show that the Asteroid Belt experienced break-ups of the L- and H- chondrite parent bodies during this same time period [e.g. 3,4]. Since meteorites from these break–ups have been found on Earth [e.g. 4], it would seem reasonable to find evidence in the lunar soil samples.

When comparing meteorite ages (Figure 2a) to lunar impact glass ages (Figure 2b), it is evident that impact events were occurring throughout the inner Solar System. Both the Asteroid Belt and the Moon experienced hits. Whether or not this occurred on Earth at the same time is an ongoing controversy [e.g. 7,8], at least in the case of the earlier event.

It is interesting to point out that the lunar impact glasses show no evidence of impacts on the Moon during the time interval 0.4-0.5 Ga ago, while the meteorites report that break-ups were occurring in the Asteroid Belt. Perhaps debris did not hit the Moon; perhaps this is solely an artifact of the binning.

Conclusions: The impact rate in the Earth-Moon system is being defined by impact ages associated with lunar glasses, lunar melt rocks, and meteorites. The impact flux can have local effects, both in space and time, affecting species, habitats and climates, as might be the case in the Permian (~250 Ma ago) [e.g. 7], and Late-Devonian (~364 Ma ago) [9] extinction episodes. Several of the glasses studied have ages coincident with these impact and/or (possible) extinction events (Table 1). Finally, while no impact glasses in our study show ages coincident with the Ordovician extinction episode (~480 Ma ago) [e.g. 10], they do have ages coincident with the Ordovician Period and may be further evidence of parent body break-ups in the Asteroid Belt.

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Table 1. Ages of Lunar Impact Glasses

Sample #	Age (Ma)	Uncertainty (1σ)	% ^{39}Ar released
438	253.6	5.4	90.2
542	274	11	100
427	361	4.7	84.5
493	385	29	76.1
443	511	20	86.7
469	556	32	67
421	583	21	92.7

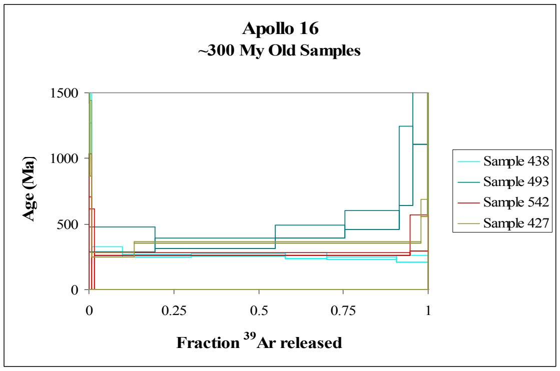

Figure 1a. Lunar impact glasses with ages ~300 Ma.

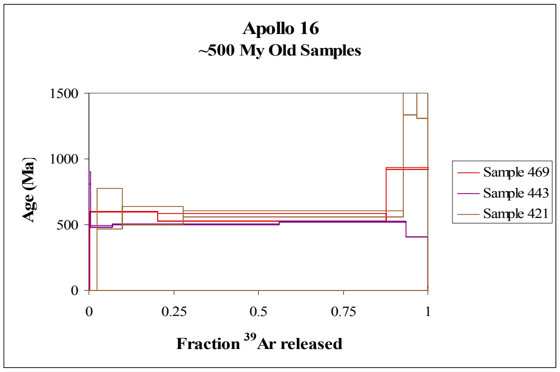

Figure 1b. Lunar impact glasses with ages ~500 Ma.

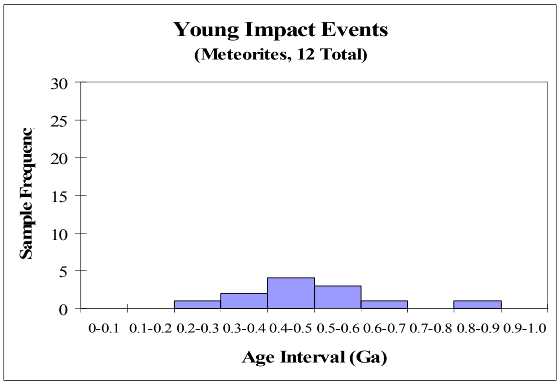

Figure 2a. Histogram of meteorites with young ages.

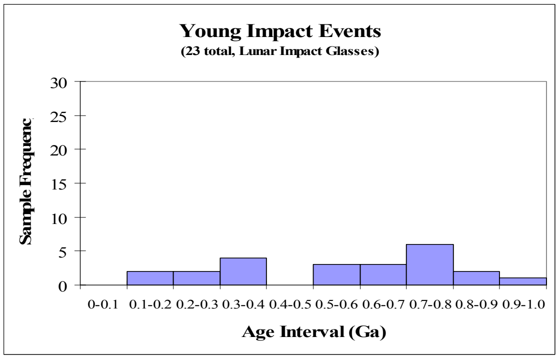

Figure 2b. Histogram of lunar impact glasses with young ages.