IMPLEMENTING LUNAR IN SITU DATING WITH THE DIMPLE PAYLOAD. F. S. Anderson[1], E. B. Bierhaus[2], S. E. Braden[3], A. L. Fagan[4], R. G. Fausch[5], J. W. Head III[6], K. H. Joy[7], J. Levine[8], S. Osterman[1], J. Pernet-Fisher[7], R. Tartèse[7], P. Wurz[5], M. Yant[2] [1]Southwest Research Institute, Boulder, CO 80302 USA, [2]Lockheed Martin Space, Littleton, CO 80127 USA, [3]Lunar Scholar Services LLC, Aurora, CO 80247 USA, [4]Western Carolina University, Cullowhee, NC 28723 USA, [5]Universität Bern, CH-3012 Bern, CH, [6]Brown University, Providence, RI 02912 USA, [7]The University of Manchester, Manchester M13 9PL, UK, [8]Colgate University, Hamilton, NY 13346 USA.

Introduction: The Dating an Irregular Mare Patch with a Lunar Explorer (DIMPLE) payload, selected for flight in 2023, will determine the age and origin of the potentially young (33 ± 2 Ma [1]) irregular mare patch Ina. Mounted on a lander and rover sourced from a CLPS provider, DIMPLE will image the geologic context of Ina, collect rock samples, and determine their age and composition.

DIMPLE has four payload elements: a) the Chemistry, Organics, and Dating EXperiment (CODEX), which is comprised of a laser subsystem and a mass spectrometer (in this lunar context, the organics capability of CODEX will not be exploited); b) a sample handling system for gripping rocks from the lunar surface, creating smoothed rock faces, and presenting those smoothed faces, in turn, to a lander-mounted camera and to CODEX; c) the Payload Control Unit (PCU) which receives data from the CODEX instrument and operates the sample-handling system; and d) a scooping rake to be mounted to a CLPS-provided rover, for collecting samples along traverses and carrying them to the lander. The sample-handling system and rake are designed by Lockheed Martin.

Threshold, baseline, and enhanced mission: The DIMPLE threshold mission consists of landing at Ina on the smooth mound Mons Agnes [2], acquiring a single sample at the foot of the lander, and measuring the sample's age and composition [3]. The baseline mission builds on the threshold mission by using a fetch-rover to acquire ≥2 additional samples from ejecta of nearby small impact craters, fragments of boulders, or the rough terrain surrounding Agnes. The baseline mission samples enhance measurement representativeness, and allow rover-based imaging of site geology and the contact between the local Ina rough and smooth units. In addition, the fetch rover provides contingency against the possibility that no samples are available adjacent to the lander, or that they are not representative of Ina, by providing the ability to drive to new sampling locations. In the enhanced mission scenario, the payload analyzes over six samples from various locations on and around Mons Agnes, in a single lunar day.

CODEX: CODEX uses a time-of-flight mass spectrometer to analyze ions ablated from a series of small spots over a rock surface [4]. It uses pulsed 266 nm laser ablation [5] to vaporize 35 μm spots, generating plumes of ions and neutral atoms. In resonance-ionization mode, CODEX selectively ionizes neutral Rb or Sr atoms from the ablated plume and analyzes those ions. CODEX also operates as a conventional laser-ablation mass spectrometer to analyze the ions in the plume, which may be of any element.

For Rb, selective ionization is achieved by shining a pulse of 778 nm laser [6] light through the plume, which resonantly excites ground-state neutral Rb atoms by two-photon absorption, along with 1064 nm light to ionize the excited atoms. On alternating shots, a 459 nm laser [7] substitutes for the 778 nm laser, to selectively excite Sr atoms by an analogous process. Rb and Sr isotope analyses are used for radioisotropic dating by the ^{87}Rb-^{87}Sr isochron method, which has been employed for a range of terrestrial and planetary samples, including lunar and martian meteorites [8].

CODEX typically analyzes ~400 locations on a sample in a raster pattern, ablating spots >80 μm apart, and thus sampling a range of different minerals for Rb-Sr isotope abundances. At each spot, we clean the sample surface with 1000 ablation shots. Next, we acquire four cycles of (1) 1000 shots alternating between resonantly ionizing Rb and Sr, and (2) 1000 shots for which the 459 nm laser is detuned from the Sr resonance by 0.4 nm to analyze backgrounds. After every four sample spot analyses, we analyze a well-characterized standard such as USGS glasses T1-G, GSD-1G, or BHVO-2 [9-11] in the same manner, totaling 100 standard spots during the analysis of each sample.

The precision of the date obtained is primarily a function of Rb concentration and the number of analysis spots where we find high Rb/Sr ratios. We conservatively estimate the dating precision for samples from Ina as ±375 Myr. Using our laboratory breadboard version of CODEX we measured lunar meteorite LaPaz Icefield 02205 with ±300 Myr statistical precision (Fig. 1), using a resonance ionization scheme that we have found to yield 25% better relative precision than the two-photon absorption approach used for DIMPLE.

In tandem with its resonance-ionization analyses of Rb and Sr isotopes, CODEX also uses laser-ablation mass spectrometry to acquire complete mass spectra of

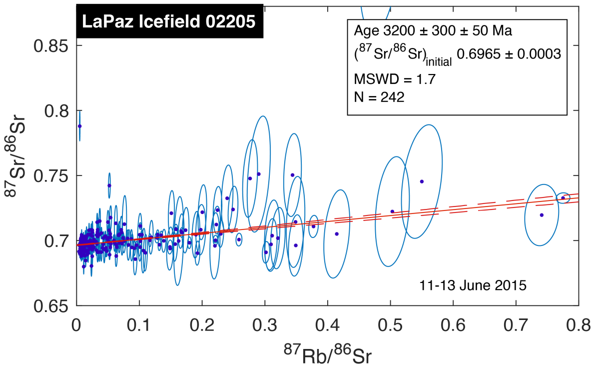

Fig. 1: 2600 ± 300 Ma isochron for lunar meteorite LAP 02205, demonstrating sufficient precision to meaningfully date lunar rocks.

all elements in the sample from the same analysis spots. The flight design uses the same mass spectrometer as employed by Luna-Resurs [12]. With an earlier design [13] quantitatively measured 19 major and minor elements in the matrix of the Allende carbonaceous chondrite meteorite, and [14] analyzed the KREEP-rich lunar meteorite Sayh al Uhaymir 169. Frey et al. [14] made 100-300 spot analyses on the matrix, which sufficed to determine the atomic abundances of the major rock-forming elements Na, Mg, Al, Si, K, Ca, and Fe, with all absolute uncertainties <0.4%. Neuland et al. [13] also detected the lower-abundance elements Li, C, P, S, Sc, V, Mn, and Co with 10-20% relative precision. These or other ppm-level abundance elements could provide additional constraints on the evolution of the magma that formed Ina. For DIMPLE, we incorporated a contingency factor of ~2 orders of magnitude into the precision estimate for major element abundances. This conservative precision is sufficient to classify DIMPLE samples on the total alkali silica diagram, and to locate their oxide compositions in chemical abundance space relative to common Apollo rock types. The elemental abundances at each spot will also aid in the interpretation of the geochronological data obtained by resonance ionization mass spectrometry. CODEX analyses will be assembled into maps using images from the lander-mounted camera to identify and measure vesicles and mineral grains to help determine sample type.

Sample-handing system and rake: The sample-handling system has capabilities similar to the components described by [4], though the design has evolved for more efficient performance. The rake takes advantage of a CLPS-provided mobility service to gather rock samples from a much wider area than is accessible to the lander-mounted arm, and it is able to exhume rocks from the upper ~2 cm of the lunar surface. Our surface operations plan calls for each collected sample to be brought to the lander for CODEX analysis.

Sampling opportunities: Mons Agnes has multiple sites that are sufficiently smooth (no visible boulder hazards) and flat (slopes ≤6°) to permit a safe landing. To augment the population of rocks found at the landing site itself, we have identified a series of rover traverses that would permit acquisition of samples from nearby boulders and fresh craters visible from orbit. A final rover traverse would visit the rough terrain below Mons Anges and return a sample to the lander if possible. The total round-trip distance of all rover traverses is <2 km.

All surface operations are to be completed within a single lunar day of ~348 hours, of which 8 are budgeted for instrument commissioning. The two main factors that limit the number of samples we can analyze are the time for a CODEX analysis and the data downlink rate to Earth. Each CODEX analysis, including 400 analysis spots on the sample and 100 on the calibration standard, can be completed in <12 hours, including a 50% duty cycle we may need to adopt near solar noon. In such a case, we could potentially analyze 28 rocks over the course of the experiment. However, if for the sake of precision, we analyze 2000 spots on the sample (and 500 on the standard), then it could take up to 57 hours to analyze each rock, leaving time only for 6 samples to be analyzed. In either case, the bit rate for downlink is likely to limit CODEX to ≤12 rock analyses.

Summary: Together the components of the PRISM DIMPLE experiment are designed to resolve a fundamental problem in lunar thermal evolution: the absolute age of the cessation of lunar mare volcanism.

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