DATING THE IRREGULAR MARE PATCH INA: A DIMPLE UPDATE. 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 (scott.anderson@swri.org), [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, Switzerland, [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 DIMPLE (Dating an Irregular Mare Patch with a Lunar Explorer) payload [1,2] was selected under the NASA PRISM program to fly in 2028 to the irregular mare patch (IMP) Ina [3-6]. One of the most striking features of Ina and other large IMPs is that they have very few impact craters, consistent with the hypothesis that they are very young, ~18-66 Ma [4]. This relative youth begs the question how lunar volcanism, thought to have largely ended more than 3 billion years ago, could have remained active into the geologically recent past, and what that means for the geochemical and geothermal history of the Moon. An alternative hypothesis contends that IMPs are in fact ancient, but are comprised of materials that cannot sustain crater-forms over geologic time, such as a volcanic foam or highly vesicular lava [7]. The DIMPLE payload will land on Ina, the largest IMP, a 3-km wide volcanic caldera located near the summit of a lunar shield volcano in Lacus Felicitatus. Its goal is to determine whether the surface materials at Ina are young (~33 Myr) or ancient (~3.7 Gyr), and assess the geologic context and nature of the regolith.

DIMPLE (**Fig. 1**) will distinguish between these hypotheses by landing on a high-standing smooth mound called Mons Agnes within the ~50-m deep Ina caldera, and use an instrument called CODEX [8] to measure the elemental composition and Rb-Sr age of local rocks. CODEX uses laser-ablation mass spectrometry to assess composition and adds a resonance-ionization stage to provide isobar-free Rb and Sr isotope measurements. Ablation is accomplished with a 266 nm, 100 µJ, 10 ns pulsed laser. Rb resonance ionization is achieved with 778 & 1064 nm, ~100 µJ, 6 ns laser pulses, and Sr with 459 & 1064 nm, ~100 uJ, 6-ns laser pulses. To enhance the limited efficiency of one color resonance ionization, CODEX bounces the blue and red lasers through the ablated neutral atoms using a multi-pass optical cell.

DIMPLE will acquire a baseline of three ~1.9-3.8 cm unbrecciated basaltic rocks from: a) the foot of the lander using a robotic arm, b) nearby craters and boulders on the mound using a rover, and c) the nearby rough terrains below the plateau rim (**Fig. 2**). To prepare each rock for measurement by CODEX, the arm will pass it over a saw that cuts a smooth, flat surface. CODEX measurements will be supported by cameras

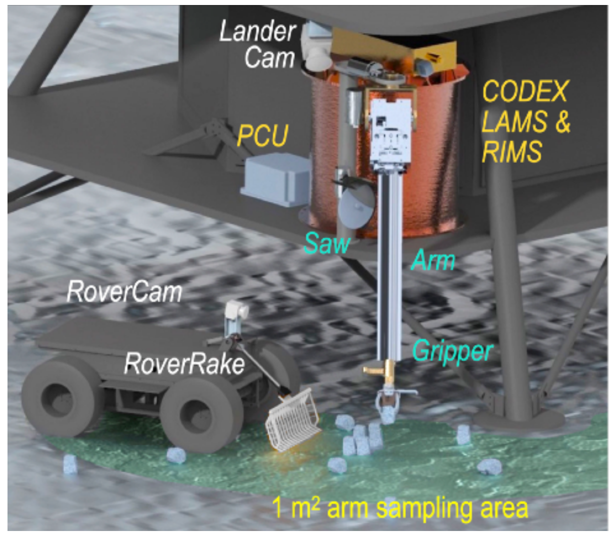

Figure 1: The DIMPLE payload shown with a notional CLPS lander and rover to be selected in 2026.

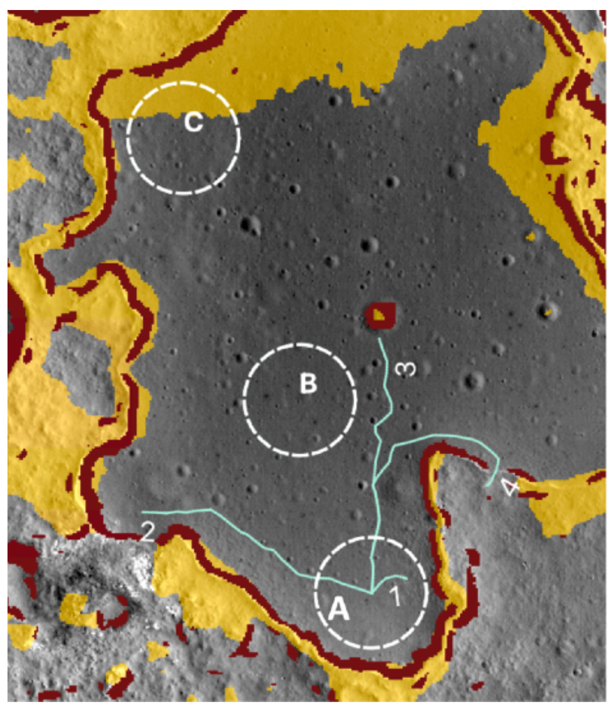

Figure 2: DIMPLE plans to acquire samples on 4 traverses by the CLPS rover totaling 1.6 km.

on the lander and rover, which provide geological context, as well as close-up imaging of the analyzed rock surfaces [9].

DIMPLE demonstrates that high-priority decadal-survey science can be carried out under small but aggressive programs like NASA's Payloads and Research Investigations on the Surface of the Moon (PRISM). Using instruments like CODEX on payloads like DIMPLE, we can obtain new scientific results for well-posed scientific problems at a high cadence, while also driving the scientific need for new sample returns by identifying exciting samples in advance. In addition to ensuring the most interesting samples are returned through triage, in-situ measurements reduce the risk of sample return during the return flight.

Status: DIMPLE was fully funded in early 2024, and a tremendous amount of progress has been made on the science, hardware, and program:

DIMPLE Science. In preparation for the flight to Ina, the DIMPLE science team has been planning for the observations we will make, and the science interpretations that will result. DIMPLE planning has stimulated a suite of abstracts submitted to this meeting, and others in recent months, including:

1) The Enigmatic Ina Irregular Mare Patch (Imp): Theories Of Origin And Tests Of Hypotheses (Gao et al, LPSC 2025);
2) Identifying Vesicularity On The Lunar Surface To Determine Origin Of Lunar Irregular Mare Patch, Ina (Fagan et al, LPSC 2025);
3) Ina Small Shield Volcano And Summit Pit Crater: Stages In Formation And Predictions For The Nature Of Deposits (Head and Wilson, LPSC 2025);
4) How Well Can CODEX Date Lunar Rocks? (Levine et al, LPSC 2025);
5) New Topographic Data Products For Ina Irregular Mare Patch And Hadley–Apennine Region, Moon (Boatwright and Head, LPSC 2025);
6) Lockheed Martin Sample Handling and Acquisition Capabilities (Yant et al, AGU 2024);
7) Lunar Large Irregular Mare Patches (Ina, Cauchy 5, Sosigenes) (Type 1 Imps): Comparative Analysis Of Geologic Settings, Morphology, And Modes Of Origin (Kuehr et al, LPSC 2025);
8) In-situ Petrologic And Regolith Clues: Assessing Irregular Mare Patch Hypotheses Through Lander And Rover Cameras On Dimple (Fagan et al, GSA 2024);
9) Ina Irregular Mare Patch (Imp): Utilizing Perspective Views To Optimize Mission Planning And Science Success (Buchanan et al, LPSC 2025);
10) Ina Irregular Mare Patch (IMP): Comparing Three Hypotheses For Its Formation And Evolution (Shkuratov et al, LPSC 2025);

DIMPLE hardware and program. The flight hardware for DIMPLE is rapidly advancing, with engineering development unit (EDU) designs under construction for the mass spectrometer (MS), mass spectrometer electronics, and the optical interface deck between the lasers and MS. The MS door EDU has been completed and tested, and the EDU laser system, developed under MatISSE and DALI, tested and modified for DIMPLE use. Delivery of the MS and integration with the EDU components will be underway by July 2025, which will be followed by a test campaign using terrestrial analogs and Apollo basaltic samples. In addition, the flight data analysis software development is underway, the CONOPS defined in detail, and the plan for the science operations center formulated.

There have been two major changes to the DIMPLE program, including the transfer of the DIMPLE rover rake sample acquisition system to CLPS, and the modification of one the lasers to produce a second wavelength of light. The transfer of the rake was requested by NASA to simplify the assembly, integration, and test with the CLPS rover, which will be delivered significantly after the delivery of DIMPLE. The second change modifies the laser system to produce 405 & 778 nm laser light with a common laser amplifier. This permits the use of efficient two color resonance ionization schemes (405 and 461-nm) while keeping mass as low as possible, and is possible because CODEX alternates between Rb and Sr analyses.

Overall, the DIMPLE program has passed it's initial Systems Requirements Review (SRR), and is expecting to have it's Preliminary Design Review (PDR) before June 2025. Strong relationships have been built between PMPO, CLPS, and the DIMPLE PRISM team, allowing for efficient integrated planning.

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References: [1] Anderson et al. (2024) LPSC Abs #2336. [2] Anderson et al. (2024) LPSC Abs #2547. [3] Strain and El-Baz (1980) *LPSC* 2437-244. [4] Braden et al. (2014) *Nature Geosci. 7*, 787. [5] Garry et al. (2012) *JGR*, *117*, E00H31. [6] Schultz et al. (2006) *Nature, 444*, 7116. [7] Qiao et al. (2019) J. Geophys. Res.-Planets, 124, 1100-1140 [8] Levine et al. (2023) *Planet. Sci. J.* **4**, 92. Fagan et al. (2024) GSA 218-7.