CODEX: The Chemistry, Organics, and Dating Experiment. F.S. Anderson[1], T.J. Whitaker[1], J. Levine[2], and the CODEX team. [1]Southwest Research Institute (1050 Walnut St, Boulder CO; anderson@boulder.swri.edu), [2]Colgate University, Hamilton, NY 13346.

Introduction: The goals of CODEX are to search for evidence of past life on Mars, to reveal the history of habitability, and to ascertain how the local geology evolved. Scientists have been investigating Mars for decades [e.g. 1] as one of the most likely habitable sites in our solar system outside of Earth. Previous Mars missions have proven that habitable environments existed on Mars [e.g., 2]. The next step is to determine if—and when—life ever existed there. Key to addressing this complex question is the analysis of samples at fine spatial scales to establish whether habitable environments co-existed with potential biosignatures, and the determination of when such environments existed. CODEX is uniquely able to analyze the microscopic chemical and organic makeup of a sample, while simultaneously determining its age and historical context.

Method: CODEX analyzes drill cores provided by the rover coring system, which are transferred into the CODEX analysis chamber. Prior to analysis, locations on the sample are laser-ablated to remove surface contaminants. CODEX then interrogates hundreds of locations on the cylindrical surface of the core in a 2D grid using three modes: A) laser ablation mass spectrometry (LAMS) to measure chemistry, B) two-step laser desorption/ionization mass spectrometry (L2MS) to measure organics, and C) laser desorption resonance ionization mass spectrometry (LDRIMS) to measure rubidium-strontium geochronology (**Fig. 1**). CODEX produces images of the spatial distribution of chemical elements, compounds, and organics, and determines the isochron age of the sample. The images allow us to decipher the spatial relationships and geochemical setting of any detected potential biosignatures. This information is crucial to identification and prioritization of samples for caching and ultimate return to Earth.

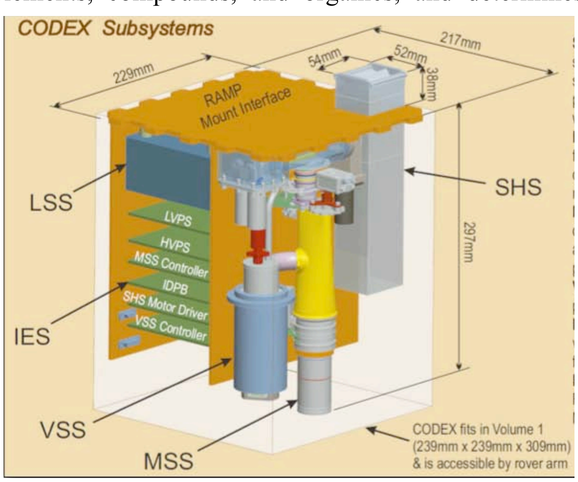

Figure 1: CODEX instrument. SHS = Sample Handling Subsystem; MSS = Mass Spectrometry Subsystem; VSS = Vacuum Subsystem; IES = Instrument Electronics Subsystem; LSS = Laser Subsystem.

Results: *Chemistry*. CODEX produces chemical maps of a sample core, revealing indicators of geologic context, history, and habitability. Importantly, because CODEX can place these observations in spatial context with organic signatures, and temporal context using its LDRIMS capability, the complex history of habitability can be determined and used to target the most important geologic localities in the search for life. CODEX uses LAMS to assess elemental, and molecular chemistry. LAMS utilizes laser ablation to directly create ions and survey elements and compounds. An image of the chemistry of the core surface is generated, without requiring a separate imager (**Fig. 2**), which enable several key geological observations, from the primary composition of the rocks to the secondary alteration processes and the record of habitability.

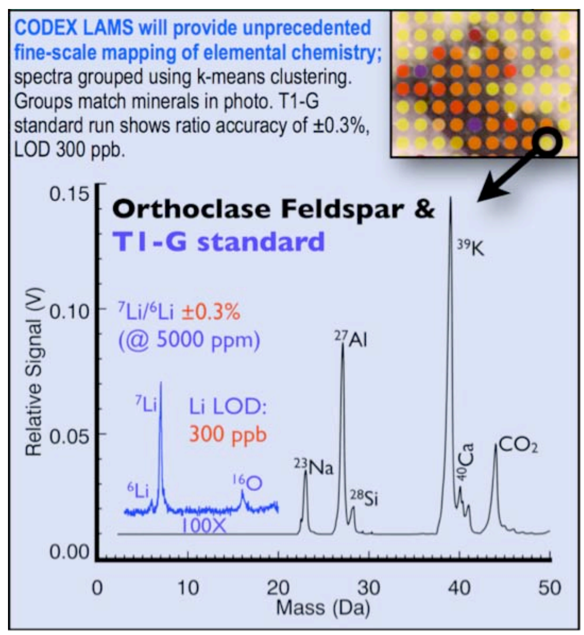

Figure 2: Example of a CODEX chemistry measurement.

Organics. CODEX addresses whether organics are a potential biosignature or are abiotic. The abiotic organic chemistry of the exogenous carbonaceous chondrite meteorites, like Murchison, consists of over 10,000 separate organic molecules present in almost every conceivable isomer; extant life, however, has a

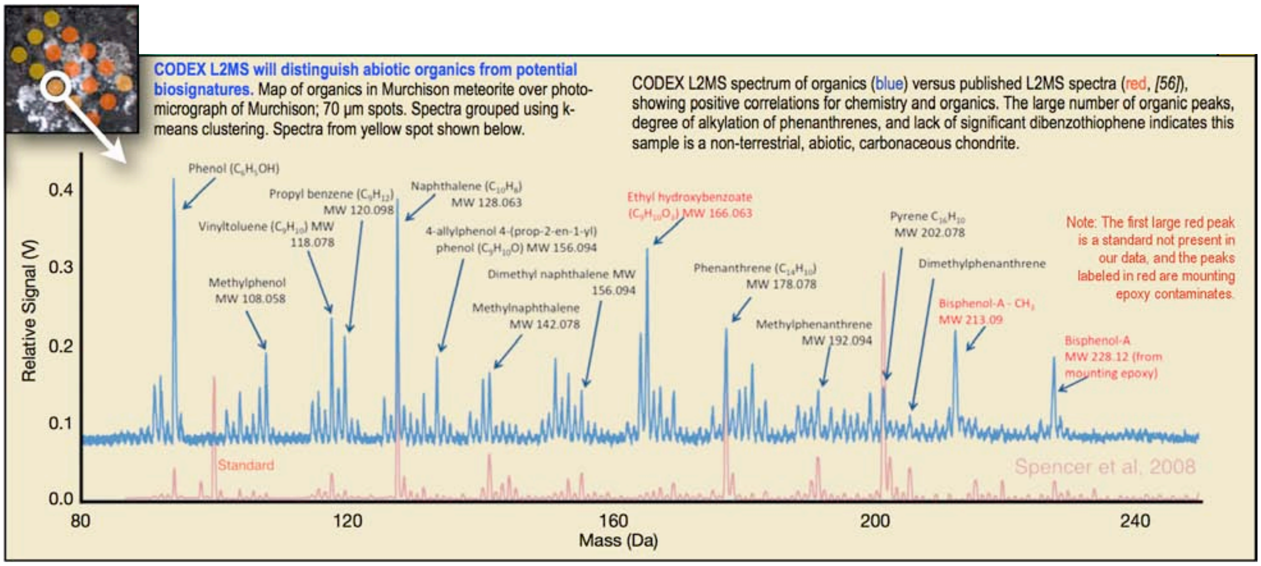

Figure 3: Example of a CODEX organics measurement.

tendency to concentrate only a few possible compounds, usually monomers (i.e. the 20 proteinaceous amino acids). CODEX uses L2MS to produce high sensitivity measurements of organic compounds at microscopic scales. In L2MS, atoms and molecules are gently removed from a sample surface by IR laser desorption, then photoionized using a UV laser. Using the portable CODEX prototype in L2MS mode, we have demonstrated the ability to determine organic parent masses and characteristic fragments in test samples such as organic dyes and meteorites like the carbonaceous chondrite Murchison (**Fig. 3**). Previous analyses have shown that the aromatic organics are present in Murchison at ~15-30 ppm, suggesting that our current sensitivity is ~0.6 ppm.

Dating. Understanding the rates of change for planetary processes (such as the history of water, climate, and potential biology) requires absolute ages. CODEX provides high-quality dates, establishing a local stratigraphic context, identifying the best locations for seeking biosignatures, and providing a foundation for understanding the history of Mars. CODEX uses LDRIMS-based Rb-Sr isotope analysis to determine isochron ages for samples. As a demonstration of the technique, the CODEX LDRIMS approach has been tested on the Martian meteorite Zagami [3], a basaltic shergottite composed of pyroxenes, maskelynite, and oxides with a Rb-Sr isochron age of 166±6 Ma [4]. In each analysis, we measured over 100 spots with a ~200 µm spacing and 70 µm diameter; the spots which yielded sufficient Rb and Sr for analysis are shown in an isochron diagram (**Fig. 4**), which implies an age 230 ± 170 Ma. This is consistent with the previously published age and with other analyses we have performed, and has precision exceeding NASA requirements (±200 Ma).

References: [1] Klein H.P. et al. (1976) *Science* 194, 99-105. [2] Grotzinger J.P. et al. (2014) *Science* 343, 1242777. [3] Anderson F.S, et al. (2014) *LPSC* 45, abstract 1665. [4] Borg L.E. et al. (2005) *Geochim. et Cosmochim. Acta 69*, 5819-5830.

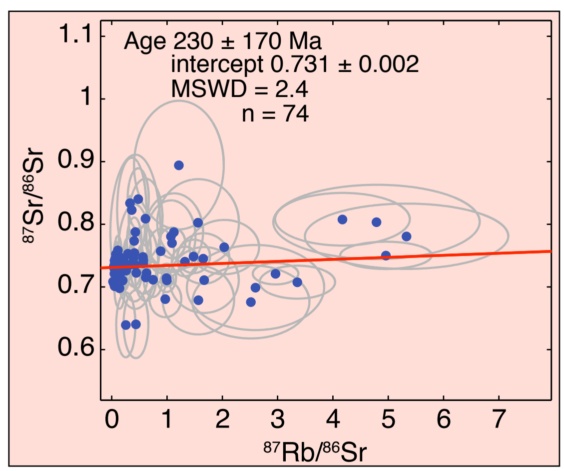

Figure 4: Example of a CODEX dating measurement, on Martian meteorite Zagami.