

THE POTASSIUM-ARGON LASER EXPERIMENT (KArLE): IN SITU GEOCHRONOLOGY FOR PLANETARY MISSIONS. B. A. Cohen, NASA Marshall Space Flight Center, Huntsville AL 35812 (Barbara.A.Cohen@nasa.gov).

Introduction: Isotopic dating is an essential tool to establish an absolute chronology for geological events. It enables a planet's crystallization history, magmatic evolution, and alteration to be placed into the framework of solar system history. The capability for in situ geochronology will open up the ability for this crucial measurement to be accomplished as part of lander or rover complement. An in situ geochronology package can also complement sample return missions by identifying the most interesting rocks to cache or return to Earth. Appropriate application of in situ dating will enable geochronology on more terrains than can be reached with sample-return missions to the Moon, Mars, asteroids, outer planetary satellites, and other bodies that contain rocky components.

The capability of flight instruments to conduct in situ geochronology is called out in the NASA Planetary Science Decadal Survey and the NASA Technology Roadmap as needing development to serve the community's needs. Beagle 2 is the only mission launched to date with the explicit aim to perform in situ K-Ar isotopic dating [1], but it failed to communicate and was lost. The first in situ K-Ar date on Mars, using SAM and APXS measurements on the Cumberland mudstone [2], yielded an age of 4.21 ± 0.35 Ga and validated the idea of K-Ar dating on other planets, though the Curiosity

method is not purpose-built for dating and requires many assumptions that degrade its precision. To get more precise and meaningful ages, multiple groups are developing dedicated in situ dating instruments [3-8].

KArLE methodology: KArLE uses currently available, flight-proven instruments to measure the age of a planetary sample, in addition to providing the original analyses of the instrument. KArLE is a science experiment whose implementation yields geochronology data and improvement in mission data quality and functionality enhancement to existing on-board instruments. KArLE measures K using laser-induced breakdown spectroscopy (LIBS), measures the Ar liberated by the laser ablation using mass spectrometry (MS) and relates K and Ar by measuring the volume of the ablated pit using optical imaging (Fig. 1). We have previously reported experimental results confirming the KArLE methodology [5]. Here, we describe requirements for KArLE flight hardware that would be reliable, reconfigurable and adaptable to multiple instruments and mission architectures.

KArLE Point Design: We used the GSFC Instrument Development Laboratory (IDL) to create a KArLE point design integrated into a notional lunar or martian lander or rover. We adopted a mission configuration from the Curiosity platform, assuming a mast unit, interior volumes, and a sample acquisition system (arm) as mission design elements. We used the more extreme lunar environment to further drive mission design elements such as lifetime, thermal environment, and sample type (regolith rather than hard rock).

The KArLE designs for all candidate missions have elements in common (Fig. 1). KArLE relies on measurement of the ^{40}Ar liberated by the LIBS laser ablation;

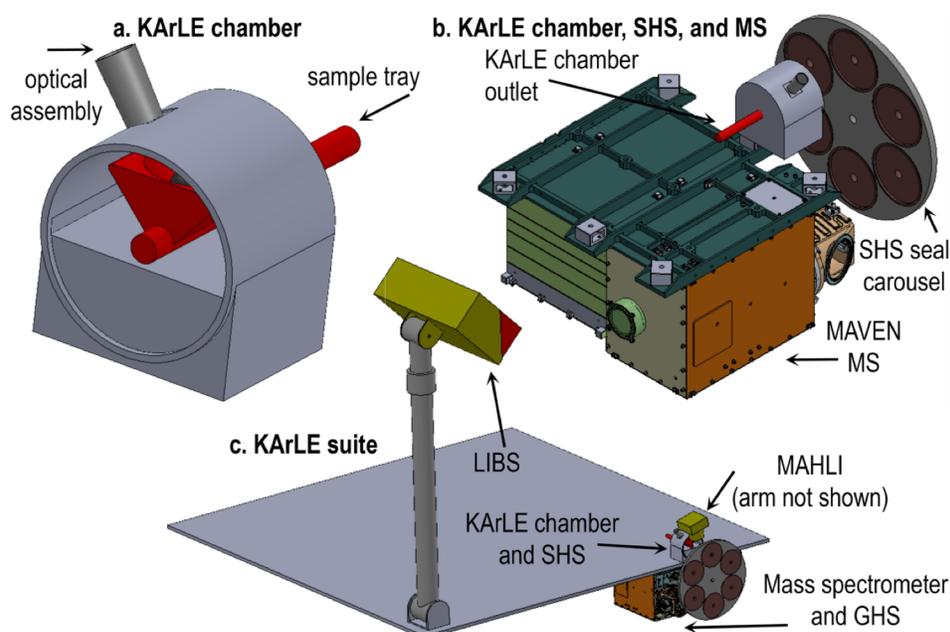


Figure 1. Point design for candidate KArLE flight configuration. Mass and volume estimates were derived for the MS from the MAVEN design, for LIBS from ChemCam, and for imaging from MAHLI, all currently aboard Curiosity.

therefore, the ablation needs to take place within an enclosed chamber that does not allow sample gases to escape (or atmosphere to enter). A sample handling system must be able to introduce a rock sample for multiple KArLE laser spot analyses. The KArLE experiment is flexible to the exact sampling system; some examples might be a rough, natural sample such as a pebble, a prepared sample such as a cut face, or a core sample from a drill. While not a requirement, the ability to examine candidate samples outside the KArLE chamber and choose the appropriate ones for analysis prior to sample introduction is desired.

The KArLE sample handling system (SHS) is the hardware that meets these functional requirements. The KArLE SHS is physically mounted either to the spacecraft deck or internal volume. The sample chamber assembly has a resealable sample inlet port, an optical port to allow the LIBS instrument to operate on the sample, and a gas transfer line to allow the vaporized sample to expand to the MS for ^{40}Ar measurements. A calibration target composed of natural or synthetic rock resides inside the SHS, available to the LIBS and camera. An external housing or cover may be added to protect the optics from dust contamination during landing and/or extended inactivity.

The optical interface to the KArLE chamber permits the laser wavelength to enter and the visible light to be collected by the spectrometer. In addition, the laser must focus at the sample and must be able to impinge on multiple spots on the sample in serial. These two functions may be performed in multiple ways. For example, it is possible to package the LIBS instrument so that it is optimized for analysis in a chamber inside the spacecraft body [9], but the more synergistic situation would be to take advantage of a mast-mounted LIBS and body-mounted mass spectrometer that would be able to independently interrogate the environment.

The Curiosity mast has a pointing accuracy of 0.3 mrad relative to elements on the rover deck, allowing it to accurately point at the ChemCam calibration target set. This pointing accuracy implies that successive spots of 1 mm separation could be achieved on the sample with the mast pointing through a window. However, at 2 m distance, the spot diameter is ~ 0.035 cm, giving a peak intensity of ~ 13 GW/cm², exceeding the sapphire damage threshold. To mitigate window damage, the beam is focused at infinity (collimated) coming from the mast, and focused on the sample using a short focal length optic embedded into the SHS window. This window may be placed at a distance from the sample to minimize deposition onto it from the LIBS ablation process by mounting it in a “snout” protruding from the SHS.

After LIBS ablation, evolved gas is sent to the mass spectrometer via a gas handling system consisting of a

getter to remove active gases (and enrich the noble gases), pumps, a calibration gas tank, and microvalves, connected by capillary tubing. There is no requirement on how far the mass spectrometer can be from the KArLE chamber; although, increased distance increases the dilution volume and equilibration time.

The KArLE measurements themselves are made via the KArLE suite instruments: mass spectrometer, LIBS, and camera. These instruments have full and independent functionality outside of the KArLE experiment, and do not need to be re-designed or re-qualified. However, there are several KArLE-specific parts that will need to be monitored and/or controlled, including stage motors, environmental sensors, dust covers, and any decision-making algorithms that trigger the experiment to begin or end. The KArLE-specific electronics are assumed to be able to be kept within a thermal range common to electronics (-10°C to $+40^{\circ}\text{C}$) via thermally coupling to a spacecraft thermal loop or radiator. Thermal-insulating blankets or a passive housing as a shield may also need to be added to protect the chamber from sunlight, depending on the spacecraft configuration.

A KArLE operations sequence consists of multiple sub-sequences, including sample acquisition, placement in the KArLE SHS, evacuation, blanks, backgrounds and standards, sample interrogation (LIBS, MS, and imaging) and sample removal. Built-in checkpoints may be included throughout the combined sequence; for example, a preload confirmation or a threshold MS background level.

Because several of the KArLE components are already flight-proven under similar conditions, they do not need to be requalified for flight. However, we have proposed to build a test article to qualify elements of the KArLE experiment under relevant environments by subjecting it to thermal vacuum (TVAC), vibration, and field tests. With this activity, we hope to show that the KArLE approach is a low-risk, synergistic way to implement a first attempt at in situ geochronology.

References: [1] Talboys, et al. (2009) *Planetary and Space Science* 57, 1237-1245, doi:10.1016/j.pss.2009.02.012. [2] Farley, et al. (2014) *Science* 343, doi:10.1126/science.1247166. [3] Anderson, et al. (2015) *Rapid Comm. Mass Spec.* 29, 191-204, doi:10.1002/rcm.7095. [4] Solé (2014) *Chem. Geo.* doi:10.1016/j.chemgeo.2014.08.027. [5] Cohen, et al. (2014) *Geostand. Geoanal. Res.* 38, 421-439, doi:10.1111/j.1751-908X.2014.00319.x. [6] Farley, et al. (2013) *Geochim. Cosmochim. Acta* 110, 1-12, doi:10.1016/j.gca.2013.02.010. [7] Cho, et al. (2016) *Planet. Space Sci.* 128, 14-29. [8] Devismes, et al. (2016) *Geostand. Geoanal. Res.* doi:10.1111/ggr.12118. [9] Cho et al. (2015) *Int. Symp. Space Tech. Sci.* 30, #2015-k-2042.