# The Potassium–Argon Laser Experiment (KArLE): Design Concepts

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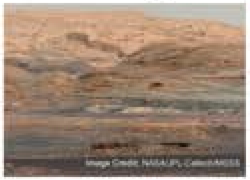
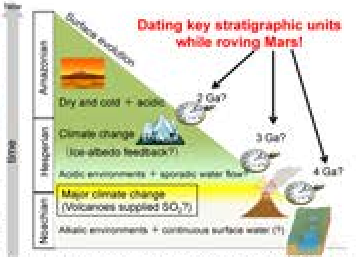
## 1. Background

◆When were they formed?

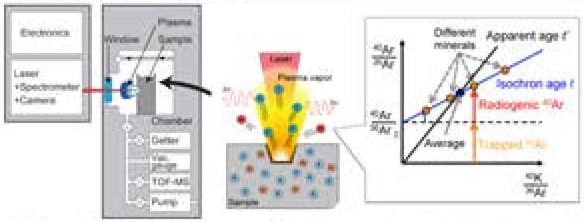



▲Beautiful stratigraphy observed by *Curiosity* on Mars. Nobody knows exactly when these layers were formed. Knowing their absolute ages is important to understand the processes that emplaced these deposits.




▲An important goal of the science community is to measure the age of various key geologic units to reconstruct Martian history and correlate it with other Solar System events.

## 2. In situ K–Ar dating




▲Schematics of KArLE measurements. Spot-by-spot analyses yield the isochron age of target rocks, enhancing the reliability and accuracy of the K–Ar age measurement.

◆ K–Ar dating with LIBS–MS approach

[Cho+ 2016, PSS; Cohen+ 2014, GGR; Devismes+ 2016, GGR]

K–Ar age $t = \frac{1}{\lambda}\ln\left(\frac{\lambda}{\lambda_e}\frac{[^{40}\mathrm{Ar}]_{\mathrm{rad}}}{[^{40}\mathrm{K}]}+1\right)$

1. Laser ablates a target rock in vacuum chamber
2. K contents measured with LIBS (e.g., ChemCam)
3. Released Ar measured using mass spectrometry (e.g., SAM)
4. K and Ar related by volume of the ablated pit using optical measurement (e.g., MAHLI)

◆ Use TRL 9 components to achieve new science

1. Payload synergy
2. Reasonable cost
3. Low risk
4. Near-term implementation

## 3. KArLE breadboards

▲KArLE breadboard at MSFC

1- HR2500+ Ocean Optics spectrometer
2- Optical setup
3- Column for a camera recording the sideview of the plasma
4- Mirror
5- Ablation cell with sample handler coupled with a pre-chamber
6- Vacuum line including getter, pneumatic valves, turbomolecular pump
7- Mass Spectrometer (Hiden Analytics QMS / 1st Detect ITMS)

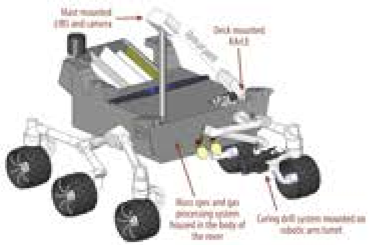
▲Breadboard in Japan / Field test at *Izu* island

1- MayaPro 2000 Ocean Optics spectrometer
2- Optical setup
3- KIGRE AO-1010 laser
4- Ablation cell with sample handler
5- Vacuum line including getter, manual valves, B-A gauge
6- Mass Spectrometer (Anelva QMS)

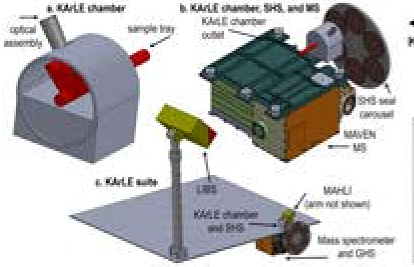
## 4. KArLE flight concepts (examples)

KArLE enables various configurations, because

- KArLE is a partner-provided instrument suite; agnostic to specific analysis providers
- KArLE allows for flexible implementation with multiple sample delivery systems (e.g., core, pebble, and slab)
- KArLE-specific hardware is mechanically simple sample handling system (SHS), which provides vacuum sealing and laser pits observation.

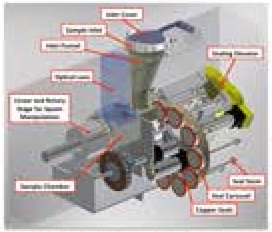


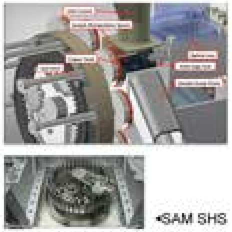

◂Curiosity-like configuration. The mast mounted LIBS measures the sample in the KArLE chamber. The chamber could be mounted on the deck or inside the rover body. The gas processing system and the mass spectrometer is stored in the rover body.




◂Point design for candidate KArLE flight configuration.

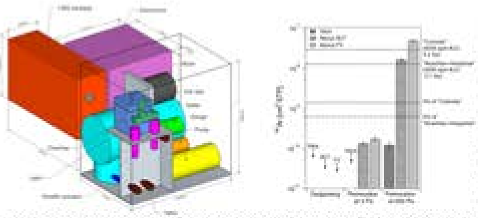
- LIBS+MS+camera payload ~15 kg; distributed volume; power = 10 – 66 W
- Chamber+sample handling ~variable but probably ~1-2 kg; low power (stepper motors, gasket preload)





◂SAM SHS

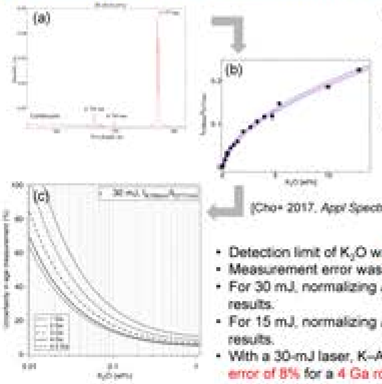
▲KArLE Sample Handling System (SHS). The SHS must be capable of ingesting a sample, achieving a vacuum seal, and enabling the measurements to be performed on the enclosed sample. A SAM-like elevator actuator seals the chamber. Samples are introduced into and ejected from the chamber by a spoon-like manipulator.



◂The amount of residual $^{40}Ar$ when different elastomeric O-rings are used under various ambient conditions. Viton O-rings can maintain low $^{40}Ar$ blank.

▲An alternative approach: Compact box configuration. Entire geochronology package is installed in the rover/lander body [Cho+ 2016b, *Trans. JSASS*]. Our experiments suggest that elastomeric O-rings would be useful for Ar analyses [Cho+ 2017, submitted to *ASR*].

## 5. Results of LIBS experiments

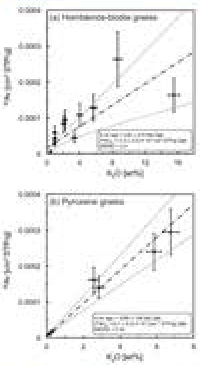



(a) Emission spectrum of a standard sample
(b) Calibration curve at the laser pulse energy of 30 mJ. Best-fit calibration curve and 1σ prediction bands are shown.
(c) Errors in K–Ar age measurement as a function of K contents. Error propagation was calculated assuming 10% error in $^{40}Ar$ measurements.

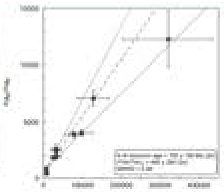
[Cho+ 2017, *Appl Spectrosc.*]

- Detection limit of $K_2O$ was 88 ppm.
- Measurement error was <20% when $K_2O$ >2400 ppm.
- For 30 mJ, normalizing $I_{K769nm}$ with $I_{O777nm}$ gave the best results.
- For 15 mJ, normalizing $I_{K769nm}$ with $I_{continuum}$ gave the best results.
- With a 30-mJ laser, K–Ar age can be measured with an error of 8% for a 4 Ga rock containing 3000 ppm $K_2O$.

## 6. Obtained Isochrons




Figures and images from [Cho+ 2016a, *PSS*]



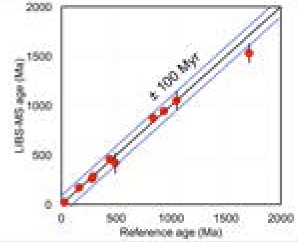
▲K–Ar isochron for the hornblende-biotite gneiss. The data points follow one regression line well, suggesting the viability of isochron measurements with the LIBS–MS approach. The slope and intercept yielded a K–Ar age of 700±190 Ma and an initial $^{40}Ar/^{36}Ar$ ratio of 440±280, respectively.

◂ $^{40}Ar$–K plot for (a) hornblende-biotite gneiss and (b) pyroxene gneiss samples. The "isochron" slopes agree with the K–Ar ages determined for biotite separates with conventional methods.

## 7. Performance of K–Ar dating

▸Compiled K–Ar dating results published from multiple labs. Results from multiple laboratories yield whole-rock ages within error of accepted ages and precision close to theoretical.

= TRL 4 (validation in the laboratory)




## 8. Work in progress

- Using the laboratory breadboard to measure Mars and Moon analog materials
- Characterizing and optimizing the performance of the components
- Pursuing funding for construction and test of the flight concepts

## References

- Cho, Y., Sugita, S., Miura, Y.N., Okazaki, R., Iwata, N., Morota, T., Kameda, S. An in-situ K-Ar isochron dating method for planetary landers using laser ablation technique. Planet. Space Sci. 128, 14-29, 2016a.
- Cho, Y., Kameda, S., Miura, Y.N., et al. Conceptual Design of an In Situ K-Ar Isochron Dating Instrument for Future Mars Rover Missions. Transactions of the Japan Society for Aeronautical and Space Sciences, Aerospace Technology Japan 14, Pk_89-Pk_94, 2016b.
- Cho, Y., Horiuchi, M., Shibasaki, K., Kameda, S., Sugita, S. Quantitative potassium measurements with laser-induced breakdown spectroscopy using low-energy lasers: application to in situ K-Ar geochronology for planetary exploration. Appl. Spectrosc., 2017, in press.
- Cho, Y., Kameda, S., Okuno, M., et al. Experimental characterization of elastomeric O-rings as reusable seals for mass spectrometric measurements: application to in situ K-Ar dating on Mars. Submitted to Advances in Space Research.
- Cohen, B.A., Miller, J.S., Li, Z.-H., Swindle, T.D., French, R.A. The Potassium-Argon Laser Experiment (KArLE): in situ geochronology for planetary robotic missions. Geostand. Geoanal. Res. 38, 421-39, 2014.
- Devismes, D., Gillot, P.-Y., Lefèvre, J.-C., Boukari, C., Rocard, F., Chiavassa, F. KArMars: A breadboard model for in situ absolute geochronology based on the K-Ar method using UV-laser induced breakdown spectroscopy and quadrupole mass spectrometry. Geostand. Geoanal. Res. 40, 517-32, 2016.
- Solé, J. In situ determination of K-Ar ages from minerals and rocks using simultaneous laser-induced plasma spectroscopy and noble gas mass spectrometry. Chem. Geol. 388, 9-22, 2014.