The Potassium-Argon Laser Experiment (KArLE): In Situ Geochronology for Planetary Robotic Missions

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Geochronology: An essential tool

- What are the constraints on the time evolution of the dynamic solar system? When did the outer planets migrate and the asteroid belt lose mass? What were the effects on the other planets?
- When was Mars warm and wet?
- How much time did organisms have to thrive in this environment?
- What was going on elsewhere in the solar system at this time?
- How long were planetary heat engines active? What are the differences in heat dissipation and magma formation between the Moon, Mars, and large asteroids?
- How long have current surfaces been exposed to (and possibly changed by) the space environment?
History of in situ geochronology

Several in situ instruments to measure rock ages have been proposed and developed, but none have yet flown, because
- Isotopic measurements with sufficient resolution are challenging
- Correct interpretation of results as an age (rather than a numeric ratio) is challenging

- **K-Ar**
  - Beagle 2 (Talboys et al. 2009)
  - Curiosity (Farley et al. 2013)
  - AGE (Swindle et al.)
  - ID-KArD (Farley et al.)
  - LIBS-MS (Cho et al. 2014; Devismes et al. 2013; Solé et al. 2014)

- **Rb-Sr**
  - CODEX (Anderson et al.)

Whole-rock K-Ar isochron approach

An age is the interpretation of a geologic event
- remote sensing for geologic setting
- microimaging for petrology
- chemical and mineralogic composition and variation

Multiple measurements to ensure validity of fundamental assumptions
- Isochron helps age precision
- Variation shows whether the sample components are cogenetic
- Intercept shows whether the system has been closed to addition/loss ("trapped" / disturbed)

![Isochron diagram](image)
• Sample introduced by the spacecraft as a core, a pebble, etc. - no special sample preparation required
• K measured using laser-induced breakdown spectroscopy (LIBS)
• Liberated Ar measured using mass spectrometry (MS)
• K and Ar related by volume of the ablated pit using optical measurement (Camera)
• Similar to laser (U–Th)/He dating technique in use in terrestrial laboratories
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)

KArLE lab measurements
**Karle lab measurements**

- Each point represents 200-500 simultaneous LIBS, MS, and volume measurements.
- Error bars set by the uncertainties in determination of K and Ar for each measurement, which have variable abundances, blanks, and backgrounds.
- Results yield whole-rock ages within error of the accepted ages.

**Range and Precision**

- Level of detection and achievable precision suitable for answering many (but not all) important planetary science questions.
Materials suitable for K-Ar dating

**Phyllosilicates**
- Identified on Mars and asteroids
- Indicator of neutral, habitable environment
- May hold biosignatures
- K-rich phyllosilicates common in alteration assemblages

**Igneous rocks**
- Crustal base of every rocky body
- Impact-melt rocks
- K-rich accessory minerals to give wide spread of parent/daughter
- Well-studied $^{40}$Ar-$^{39}$Ar ages and diffusion characteristics

**Sulfates**
- Widespread identification on Mars
- Indicator of acidic, generally uninhabitable environment
- K-rich jarosite common in terrestrial sulfate assemblages
- Well-studied $^{40}$Ar-$^{39}$Ar ages and diffusion characteristics

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**Summary**
- **In situ** dating does not replace sample return - however, we can’t get samples from everywhere in the solar system
- KArLE can determine the age of geologic samples with 10-15% precision, sufficient to address a wide range of fundamental questions in planetary science
- We achieve this using flight-proven components with no consumables or inherently limiting steps, enabling thousands of measurements
- KArLE-specific hardware is a simple, low-cost, value-added addition to a synergistic payload that achieves analyses common to most planetary surface missions (elemental and volatile analysis, microimaging)
- Flight heritage of components ensures they will fit (mass, volume, power) on future landers or rovers to the Moon, Mars, Asteroids (Phobos, Vesta, Ganymede ….)