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

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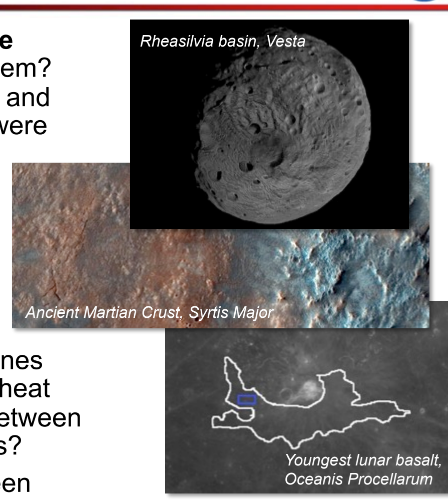
KArLE

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?



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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.)

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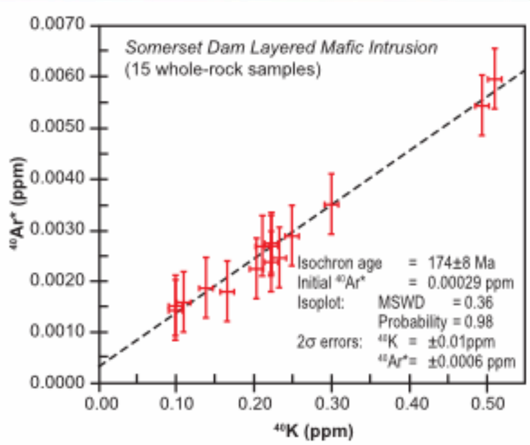
Whole-rock K-Ar isochron approach

- 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)



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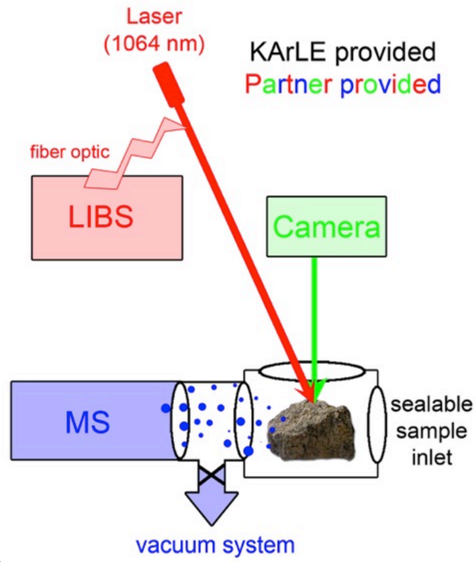
KArLE concept



- 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

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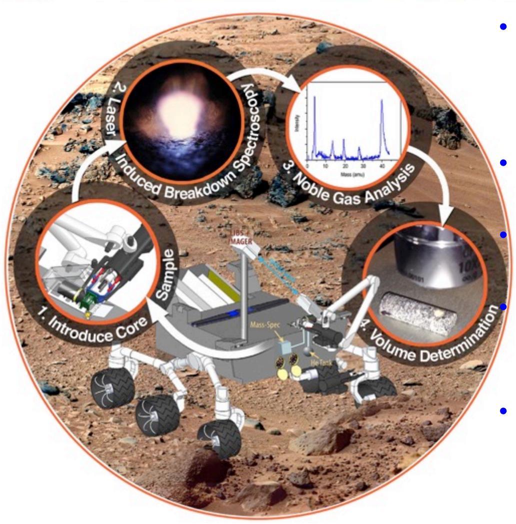

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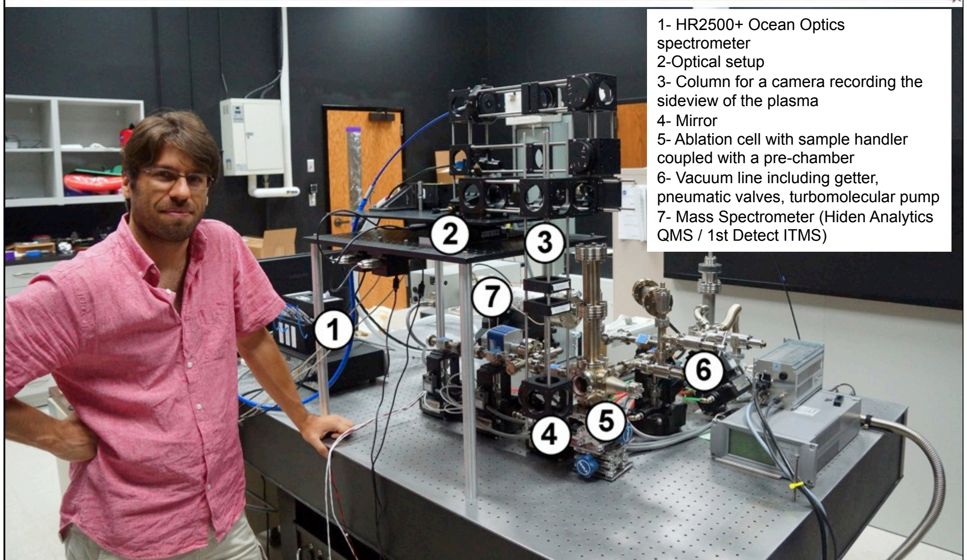
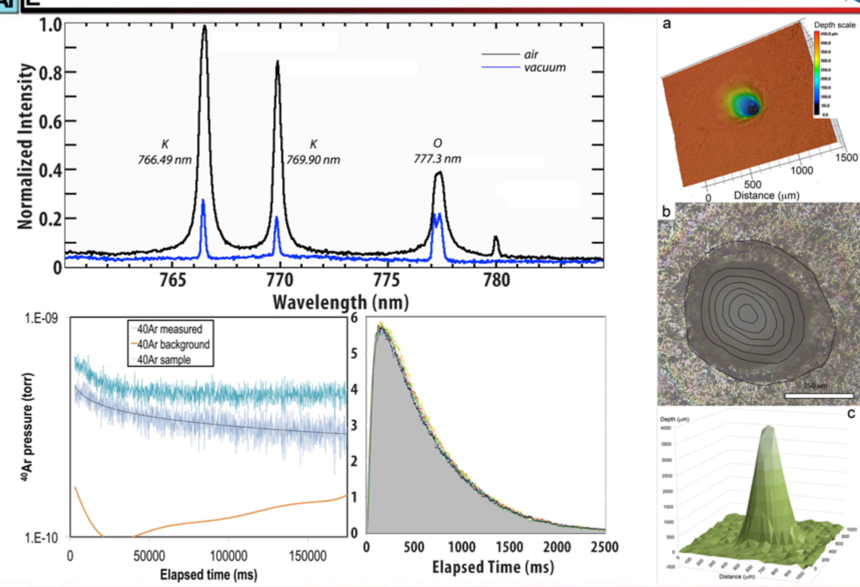
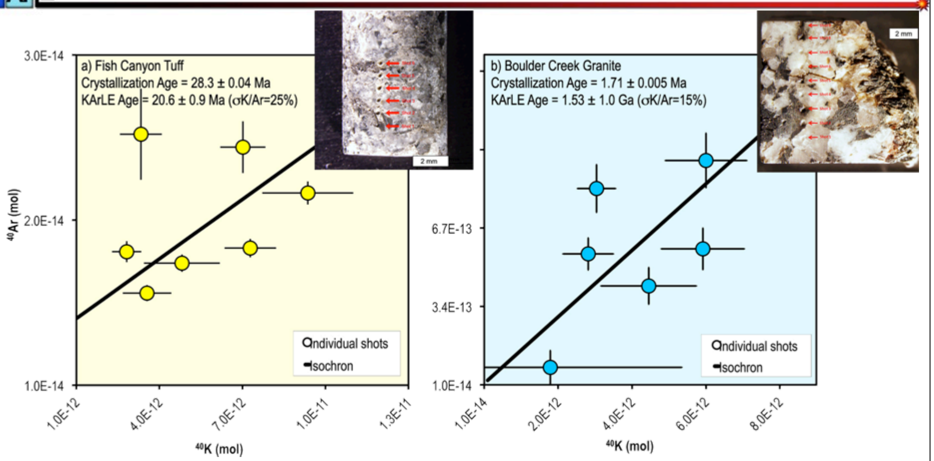
KArLE Breadboard (v2)



KArLE lab measurements

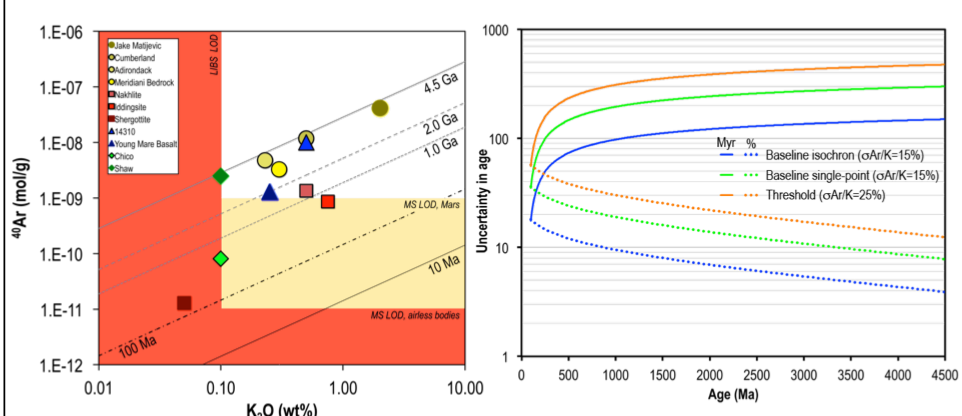


KArLE lab measurements



- 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

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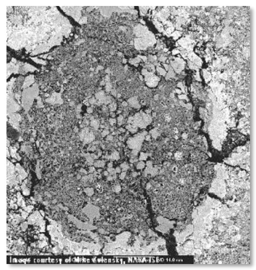
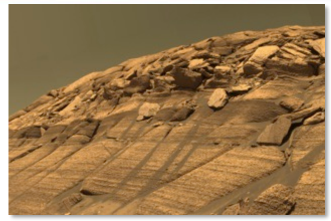
Materials suitable for K-Ar dating

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

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





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 ….)