K-Ar
(and noble gas cosmic ray exposure age)
(and U/Th-He)

Dating

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Why consider in-situ dating for 2020 when there will be a 2022 sample return?

Planning for Mars Sample Return

Years until Mars sample return launch vs Year

- Mars Rover Sample Return
- Pre-Accident 1999
- Faster, better, cheaper
- 2013 launch
- 2016 launch

All data from Aviation Week & Space Technology

Last updated 2005, but ...
K-Ar dating

Radioactive decay

$^{40}K \rightarrow ^{40}Ar \ (T_{1/2} = 1.3 \times 10^9 \text{ yrs})$

Measure abundance of $K$, $^{40}Ar$; Calculate time since last thermal event

Cosmic ray exposure dating

Cosmic ray protons

Nuclear reactions produce

$^3He$, $^{20,21,22}Ne$, $^{36,36}Ar$

Surface rock with O, Si, Mg, Ca, Fe, etc.

Measure abundances of O, Si, Mg, Ca, Fe, etc., $^3He$, $^{20,21,22}Ne$, $^{36,36}Ar$; Calculate time within ~1m of surface
Advantages of noble gas geochronology

- Multiple techniques with single system
  - Complementary
    - Measure different identifiable conditions, may be same event
- Intrinsically simple – using techniques that were used 50 years ago in terrestrial labs
Requirements for in situ noble gas geochronology system

- Measure noble gases
  - Mass spectrometer
    - MSL SAM, Beagle2, many others

- Measure major elements plus K
  - XRS (many flown)
  - LIBS
    - MSL ChemCam

This sounds easy!
- What’s needed to make those measurements?
The tough requirements

- Acquire sample (10 mg)
- Heat sample
  - For CRE, many terrestrial labs use 1600°C
  - SAM, Phoenix TEGA 900-1100°C
- Weigh sample
  - XRF, LIBS give fractional abundance; mass spectrometers give absolute
- Interpret the results
Heating a sample

- Conduction (Phoenix TEGA)
- Radiative (MIDP AGE)
- In both cases, fighting
  - Radiative losses ($\sigma T^4$)
  - Heating surrounding material
    - Outgassing, stressing materials
- Best alternative – diode lasers
  - Labs often use lasers, but not efficient enough for S/C
  - Until recently, efficient lasers were low-power (mW)
  - Diodes spec ~40% efficiency, 10s of W (~20W needed)
Weighing a sample

- Knife-edge balances unlikely to like vibe
- Calculate from volume of powder
  - Packing fraction?
- Melt & measure volume, calculate density
  - 7% relative uncertainty (1σ) for MIDP AGE
  - Requires melting
- Piezoelectrics?
- Vibration frequency?

"Calibration factor" (factor $\rho V$ has to be multiplied by to get the correct mass) for two basalts, a chondritic meteorite, and three peridotites. The calibration factor is necessary because the molten sample develops a meniscus. From Fennema et al. (LPSC XXXVIII, #1772).
Interpretation

- **Trapped atmosphere?**
  - Adsorption?
    - 1% of $P_{\text{Earth}}$, but lower temperatures
  - Shock-implanted atmosphere unlikely to be problem
    - Heavily shocked rocks likely to be uncommon

- **Partially reset ages?**
  - Less likely to be problem than Earth (no plate tectonics, impacts not very effective at resetting)

Martian meteorite Elephant Moraine 79001, with its shock-produced glasses (dark patches) full of Martian atmospheric gases.
Interpretation (continued)

- Magmatic gases incorporated?
  - Could be problem for $^{40}\text{Ar}$, particularly for young samples
    - Bogard – Shergottites incorporate ~constant amount of $^{40}\text{Ar}$, not constant $^{40}\text{Ar}/^{36}\text{Ar}$ ratio
    - For very young samples, CRE age could be more accurate
  - Need multiple samples

Bogard (2008) LPSC XXXIX, #1100
The bottom line

- In situ noble gas geochronology is promising, but there are tough (not insurmountable) problems to solve
  - Sample heating (10 mg to 1500°C)
  - Weighing a 10 mg sample

- Problems aren’t unique to noble gas systems