A New Approach to In-Situ K-Ar Geochronology

Better than 10% precision on K/Ar ages with a single analytical instrument, easily accessible Ar extraction temperatures, and no mass determination required

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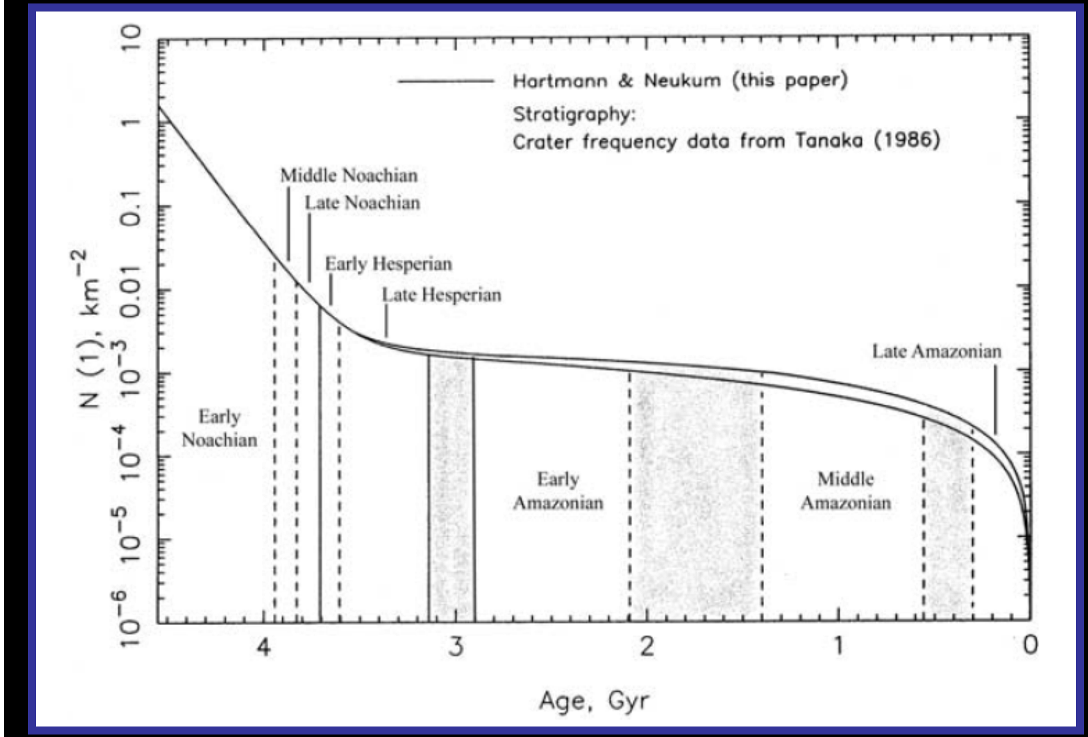
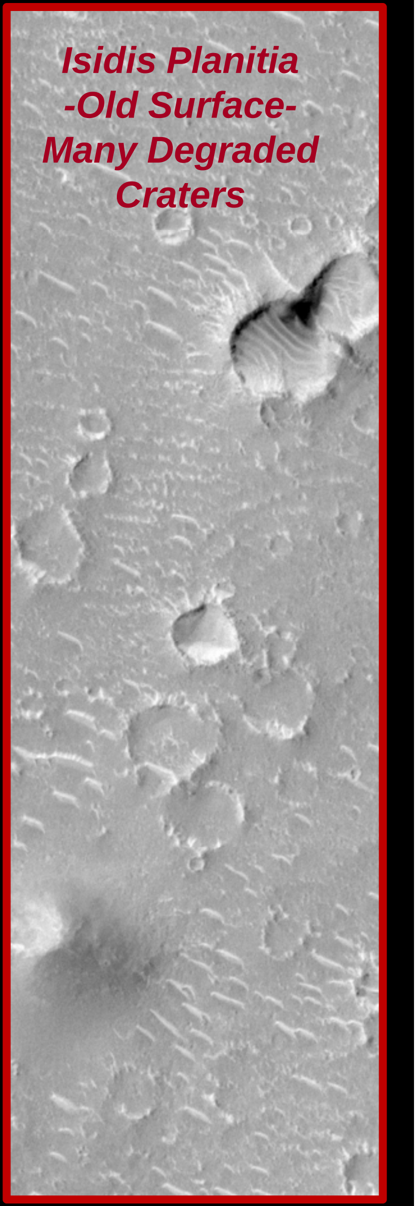
Crater Counting Chronology




Amazonis Planitia
-Young Surface-
No Craters


Isidis Planitia
-Old Surface-
Many Degraded
Craters

The Two Major Assumptions (weaknesses):

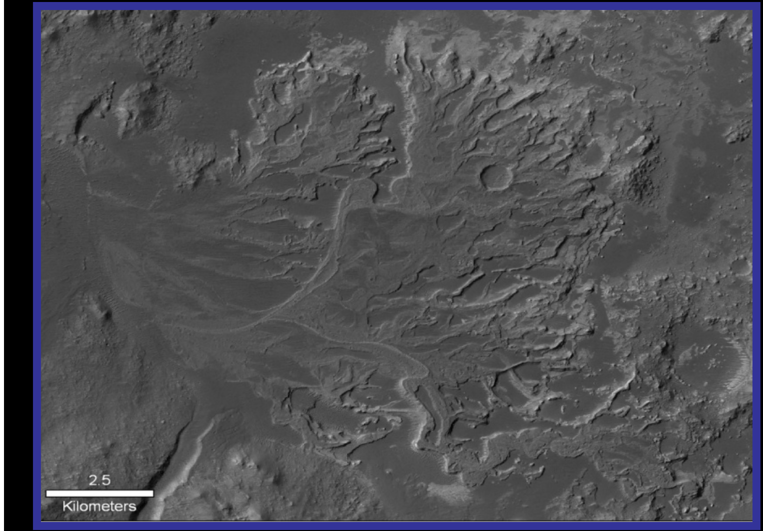
1. The lunar cratering rate can be scaled to an appropriate value for Mars

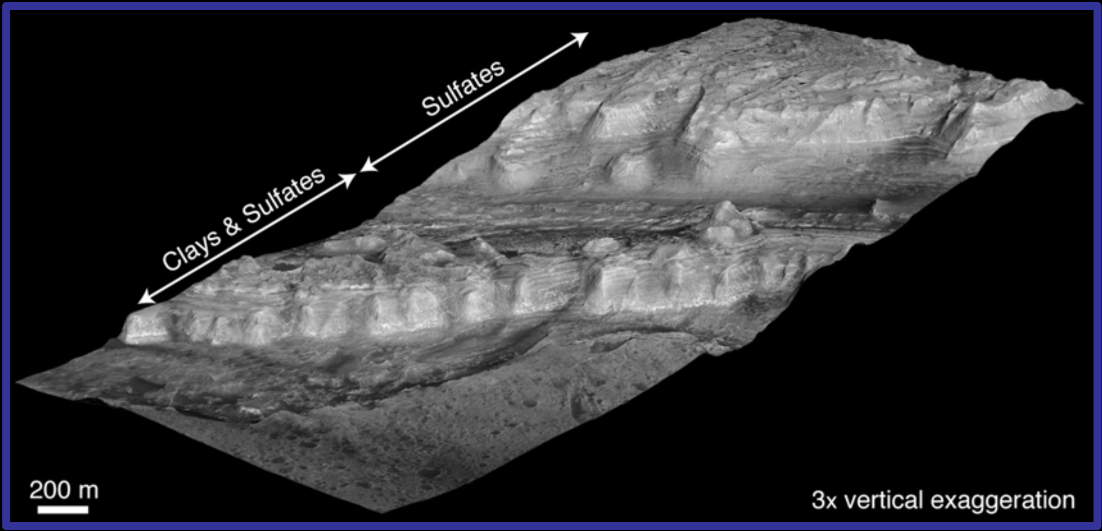
2. The geologically active surface of Mars (which erases and modifies craters in ways not experienced on the Moon) can be properly accounted for

Why in-situ Geochronology?

Important Questions:

1) *When did aqueous activity occur on the Martian surface?*
2) *When did the Martian surface environment undergo major changes?*
3) *Does Mars record evidence of a late heavy bombardment?*
4) *Did Mars harbor a biosphere, and if so, exactly when?*





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These are fundamentally questions of timing.
Our understanding of absolute time on Mars is
currently subject to the limitations of crater counting.

K-Ar Geochronology

What?

- $^{40}K \rightarrow {}^{40}Ar$, $t_{1/2} = 1.3 \times 10^9$ years

Why?

- Applicable to basalt and K-bearing alteration phases including jarosite and alunite
- Useful over a wide range of age (10’s of Ma to many Ga)
- Involves K, a major element (rather than trace elements, e.g., Rb-Sr, Sm-Nd, U-Pb)
- Martian targets of interest are likely to be old, and accordingly, have high Ar-concentration

How are K-Ar Ages Measured on Earth?

1. Measure K-concentration by conventional techniques
2. Place a second weighed aliquot of sample into an MS
3. Heat sample to melting point (~1200°C$^+$ for basalts)
4. Measure isotopic composition and amount of Ar
5. Calculate K-Ar age using K/Ar concentration ratio

Weighing small aliquots of sample
+
Heating them above 1000°C
=
Some of the hardest things to do with spacecraft instrumentation.

How do we surmount these problems?

A work around to designing a space-qualified high temperature oven

= FLUX ASSISTED MELTING

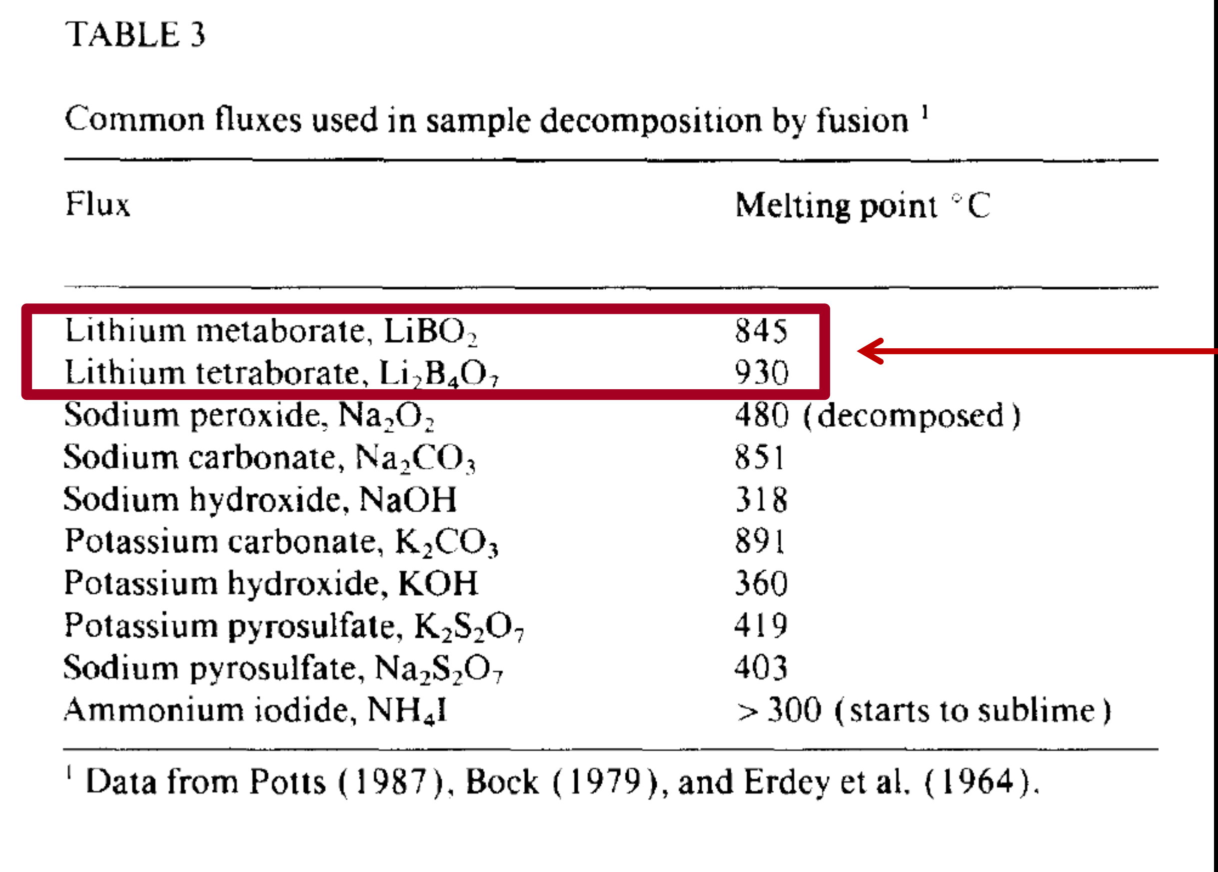


TABLE 3

Common fluxes used in sample decomposition by fusion [1]

Flux	Melting point °C
Lithium metaborate, $LiBO_2$	845
Lithium tetraborate, $Li_2B_4O_7$	930
Sodium peroxide, Na_2O_2	480 (decomposed)
Sodium carbonate, Na_2CO_3	851
Sodium hydroxide, NaOH	318
Potassium carbonate, K_2CO_3	891
Potassium hydroxide, KOH	360
Potassium pyrosulfate, $K_2S_2O_7$	419
Sodium pyrosulfate, $Na_2S_2O_7$	403
Ammonium iodide, NH_4I	> 300 (starts to sublime)

[1] Data from Potts (1987), Bock (1979), and Erdey et al. (1964).

SAM Pyrolysis oven can achieve 1000-1100°C

How do we surmount these problems?

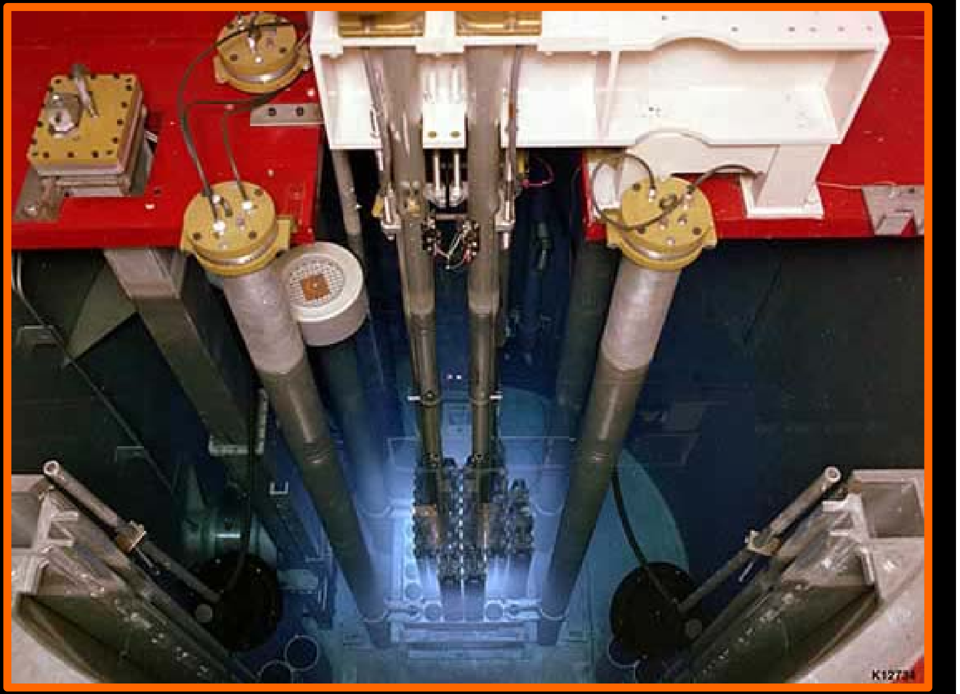
A work around to designing a space-qualified
high precision analytical balance
= DOUBLE ISOTOPE DILUTION

- Isotope dilution is the "gold standard" for laboratory measurements, yielding typical precisions of ~1%
- We employ a double-isotope spike containing ^{41}K and ^{39}Ar
- Here's how we cancel out the mass measurement:

$$\frac{^{40}Ar*}{^{40}K} = c * \frac{\left(\frac{^{40}Ar*}{^{39}Ar}\right)_{measured}}{\left(\frac{^{39}K}{^{41}K}\right)_{measured}} * \left(\frac{^{41}K}{^{39}Ar}\right)_{spike}$$

Spike Synthesis

Caltech Petrology Lab

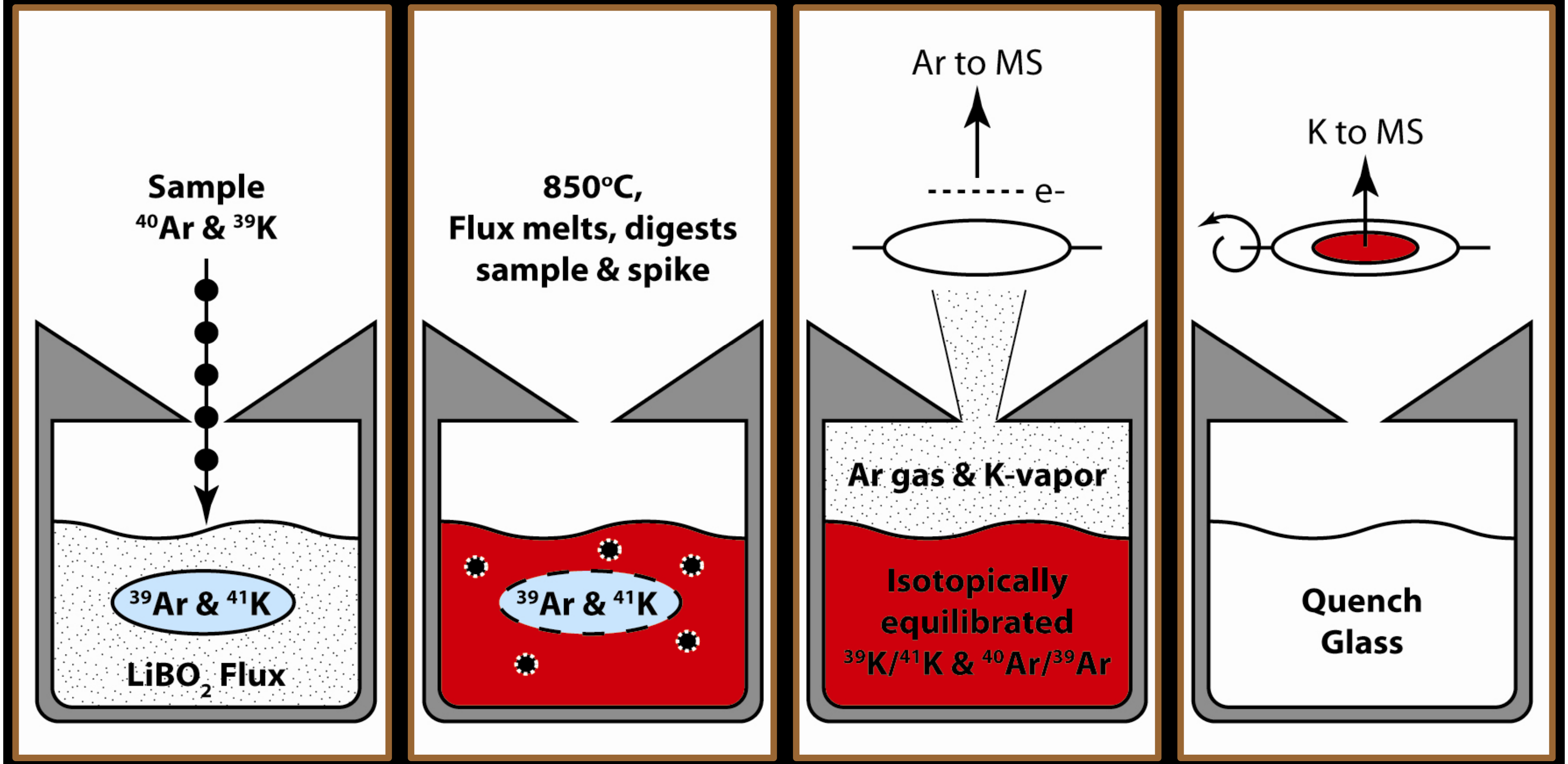


Oregon State University's TRIGA Reactor

Synthesized a glass containing known amounts of ^{41}K & ^{39}Ar:

- We did this by combining synthetic albite glass ($NaAlSi_3O_8$) with isotopically-enriched ^{41}KCl and melting them in a controlled atmosphere.
- This glass was irradiated, producing ^{39}Ar from the trace (~1%) ^{39}K present in the isotopically enriched ^{41}KCl.

How might we employ our technique on another planet?



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Our First Age Measurement

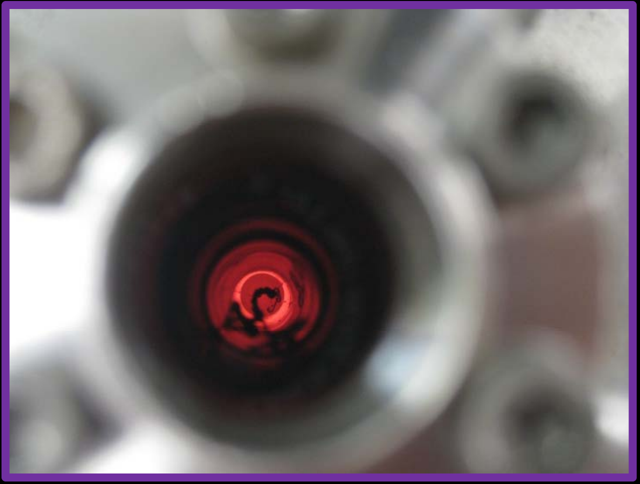
At present = no single instrument for both Ar & K measurement…

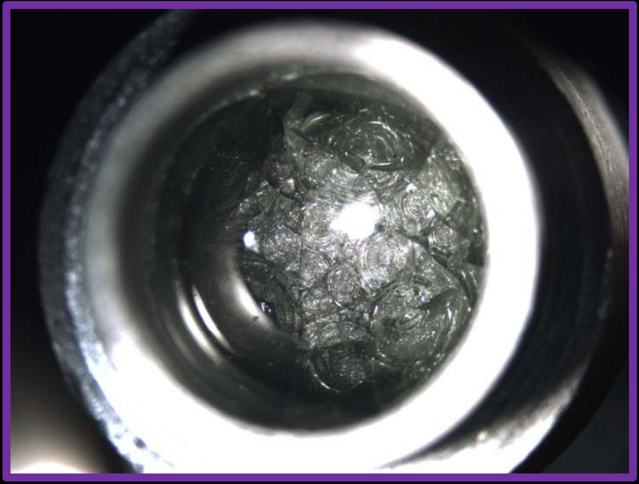
➔ We are using 2 steps to perform this analysis using a basalt sample from the Viluy traps, Siberia (0.8 wt% K_2O).

AIM: Measure an age of 354±2Ma

Step 1:

Combine flux (150mg) + basalt (15mg) + spike glass (1.5mg), in a crucible. Melt at 950^{o}C, measure Ar-isotopic composition on Ken Farley’s noble gas mass spectrometer at Caltech.



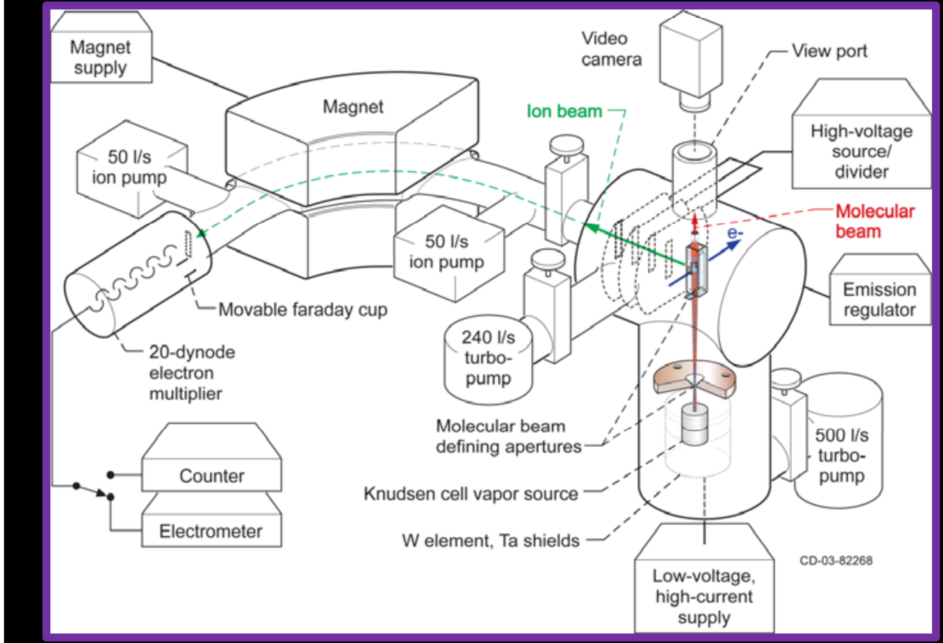


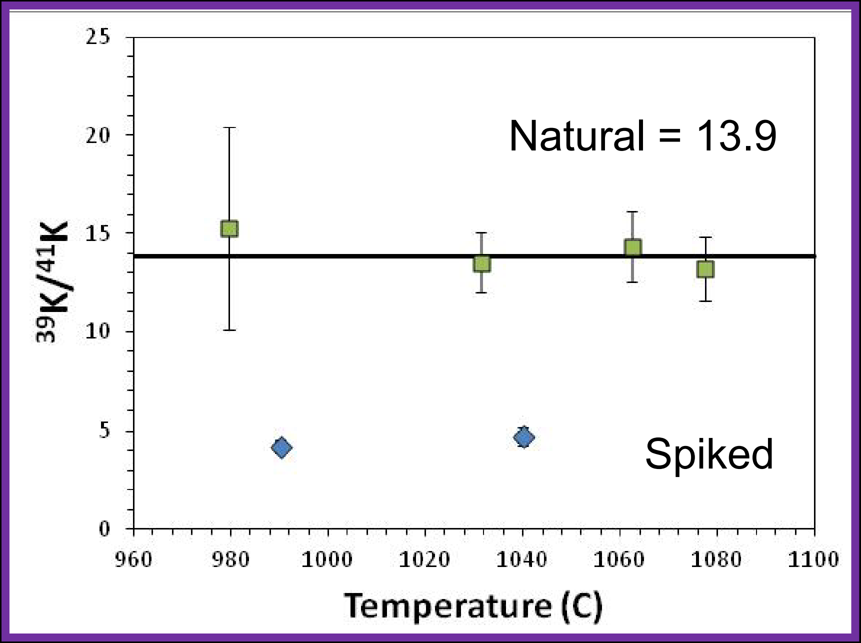
Our First Age Measurement

Step 2:

FedEx the cell to NASA Glenn Research Center, measure K isotopic composition on Nate Jacobson's Knudsen Effusion Mass Spectrometer.

AIM: Measure an age of 354±2Ma





RESULT: We calculate a preliminary age of 337 ± 30 Ma

Conclusions

1. Developed and verified a technique that can be implemented for a flight instrument system. Basically consists of an oven and a mass spectrometer

   → Uses a mixture of basic geochemical practices developed in the mid-20th century, including K-Ar, flux digestion & isotope dilution

2. No mass measurement is required, high temperatures are not required, MS only has to measure isotope ratios, and no new technology development is required.

3. This double isotope dilution technique should yield in-situ whole rock ages with precision better than 10%.