GEOCHEMICAL MEASUREMENT OF THE HALF-LIFE OF THE DOUBLE-BETA DECAY OF ^{96}Zr

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NSERC CRSNG

TRIUMF

- Studying the ββ-decay of $^{96}Zr \rightarrow {}^{96}Mo$
  - Valuable system to study neutrinos
- We are studying two properties:
  - Q value ***(done and published)***
  - Half-life

^{96}Zr Decay

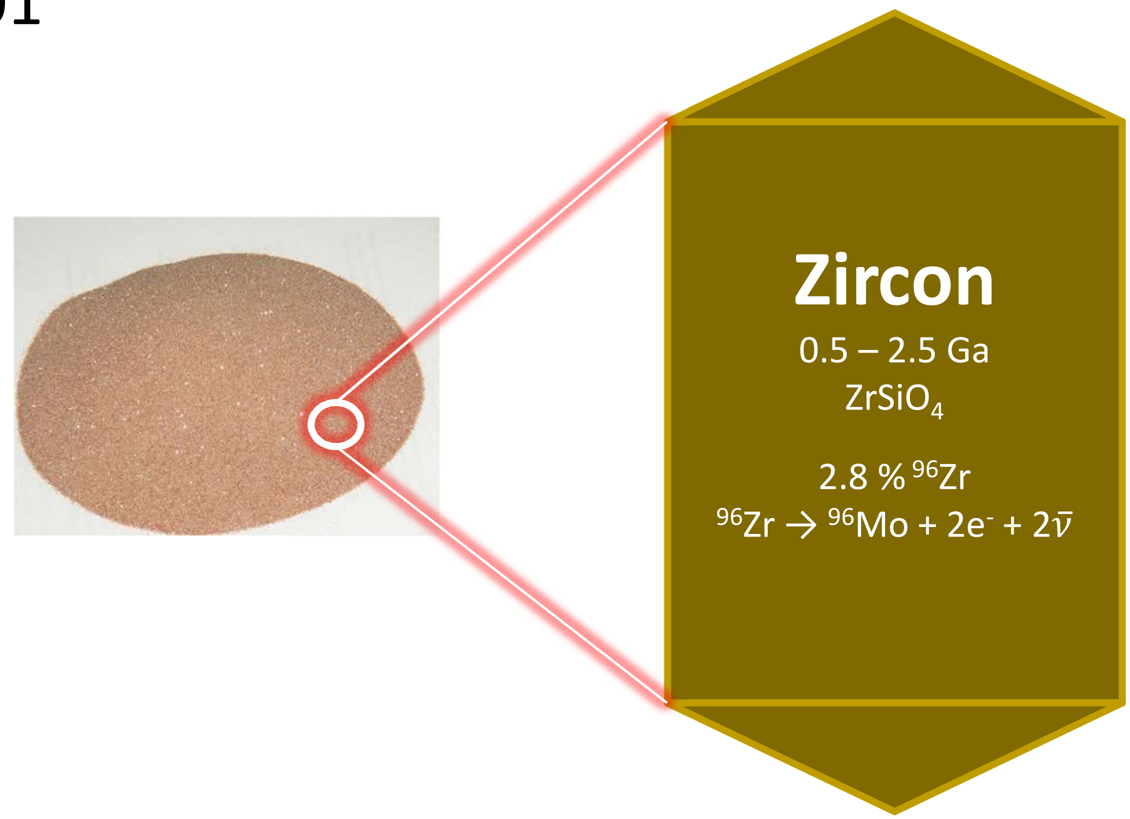
- ^{96}Zr is of particular interest:
  - One of the largest Q values and shortest half-lives
  - Unstable against single β-decay (4th order forbidden)
- Two previous measurements of half-life did not agree:
  - Geochemical measurement: $0.94(32) \times 10^{19}$ a
  - Direct count-rate measurement: $2.35(30) \times 10^{19}$ a

Zircons

- Zircon, or $ZrSiO_4$, is a highly stable mineral inclusion found in many types of host rocks
- Remain a closed system over billions of years
  - Evidenced by accurate U-Pb ages
- Large amount of zirconium (~50 wt%)
- Very little molybdenum (~ ppm)

Double-beta decay half-life by stable isotope geochemistry

- Re-examine measurements by Wieser and DeLaeter in 2001



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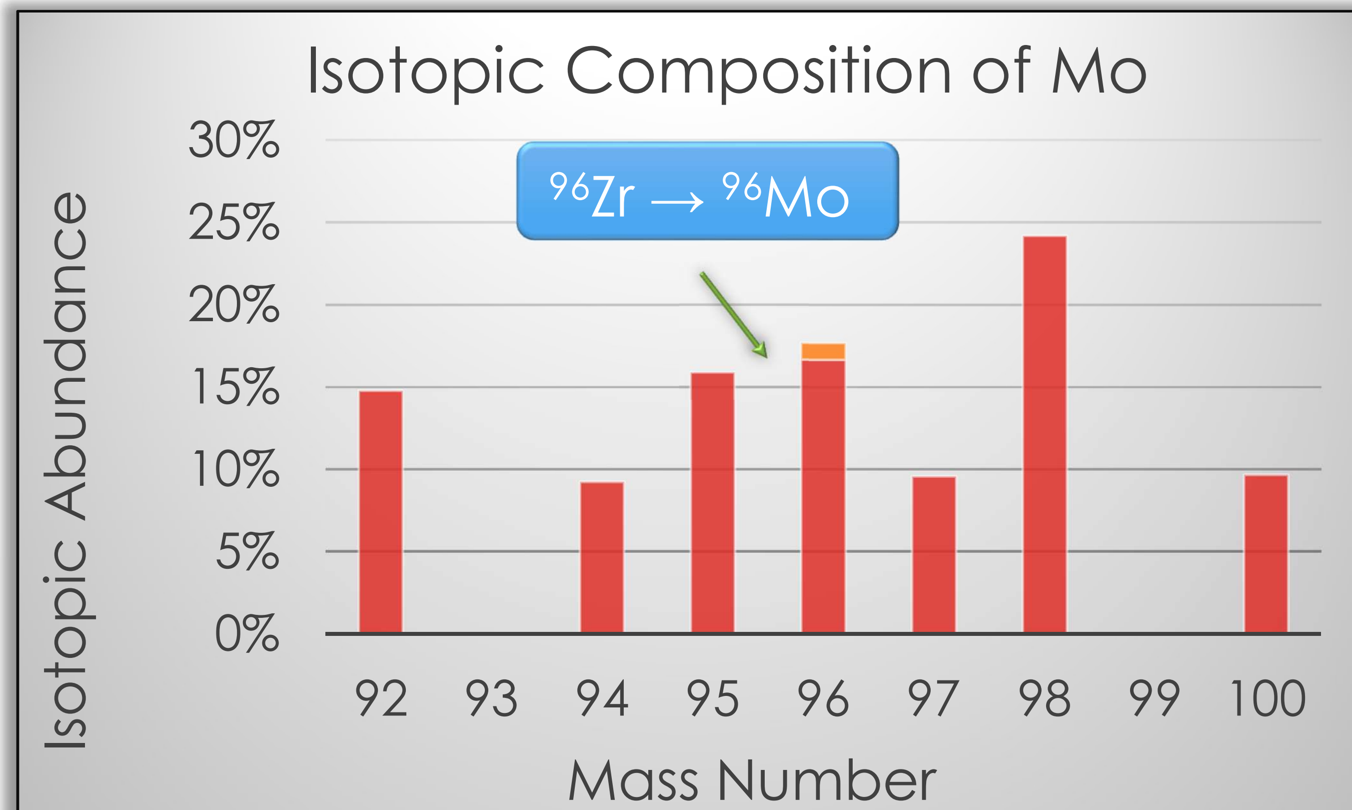


Zircon

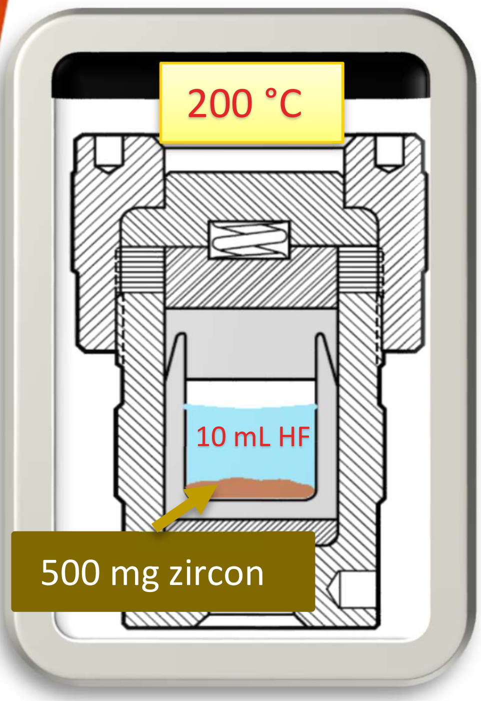
0.5 – 2.5 Ga

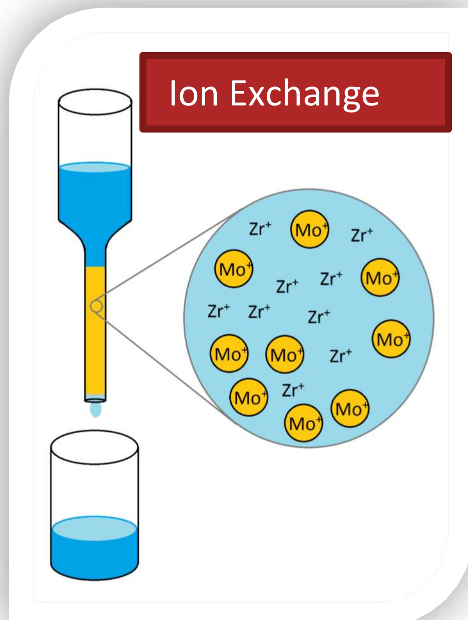
$ZrSiO_4$

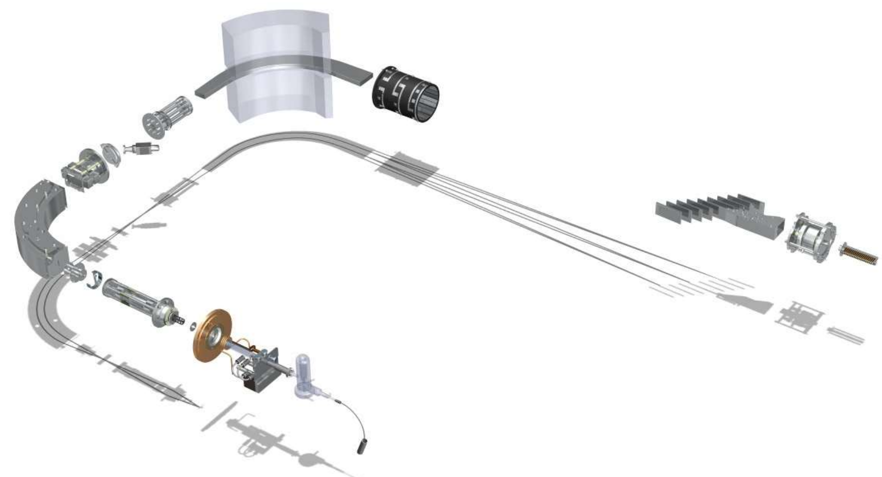
2.8 % ^{96}Zr

$^{96}Zr \rightarrow {}^{96}Mo + 2e^- + 2\bar{\nu}$

Zircon sample prep and analysis







Thermo Scientific Neptune:
Multi-collector inductively coupled plasma mass spectrometer

How will we improve over the previous measurement?

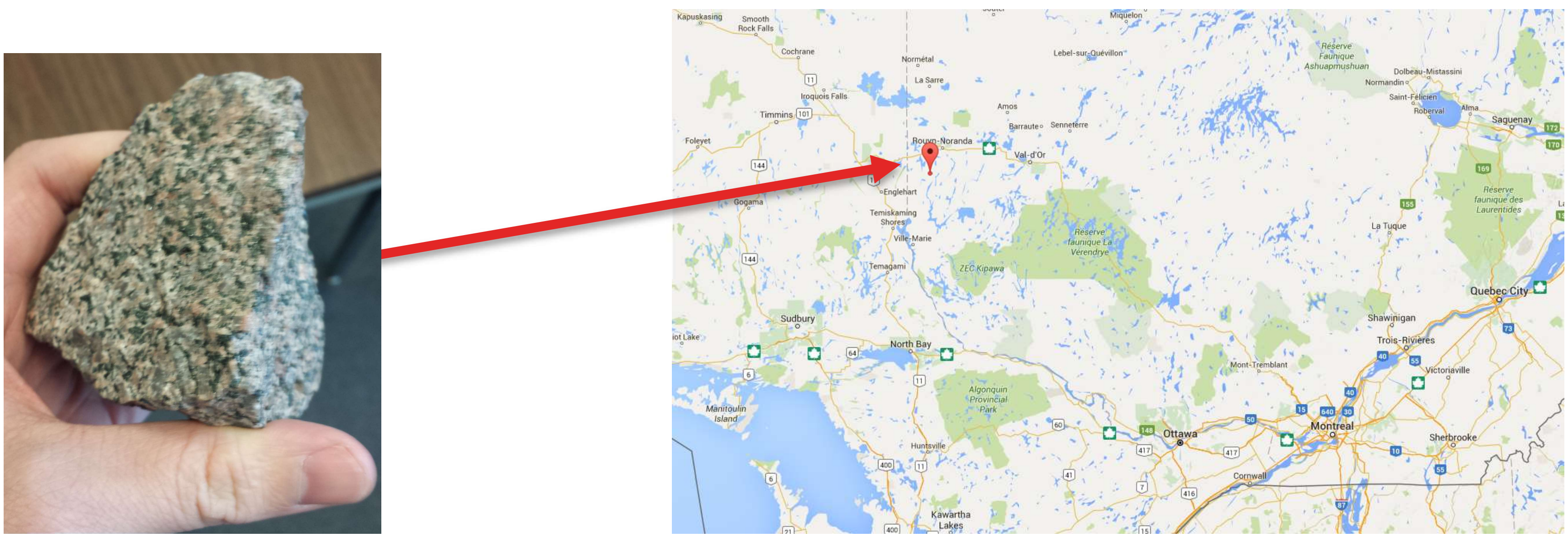
- 2001 measurements performed with Thermal Ionization MS

	Previous (TIMS)	New (MC-ICP-MS)
Sensitivity	100 ng Mo	10 ng Mo
Chemistry blank	10 ng Mo	1 ng Mo
Precision	1.0 ‰	<0.1 ‰

- All related measurements performed in house
- Zircons with a wide range of ages, from 500 Ma to 2.5 Ga

Zircon samples

- Repeat previous measurement with same samples, from Capel sands in Western Australia:
  - 3 samples with ages from 900 – 1000 Ma
- Further, we will add at least 2 more data points:
  - TEMORA-2 reference (Australia): 417 Ma
  - 1242 reference: 2679 Ma



$$t_{1/2} = \frac{-t \ln(2)}{\ln(1 - n_d/n_0)}$$

n_d daughter product: $n_d(^{96}\mathrm{Mo}) = \frac{m_{\mathrm{Mo}}\, N_A}{A_W(\mathrm{Mo})}\ \mathrm{C}(^{96}\mathrm{Mo})\ \delta(^{96}\mathrm{Mo})$

n_0 parent: $n_0(^{96}\mathrm{Zr}) \cong \frac{m_{\mathrm{Zr}} N_A}{A_W(\mathrm{Zr})}\ \mathrm{C}(^{96}\mathrm{Zr})$

Half-life calculation

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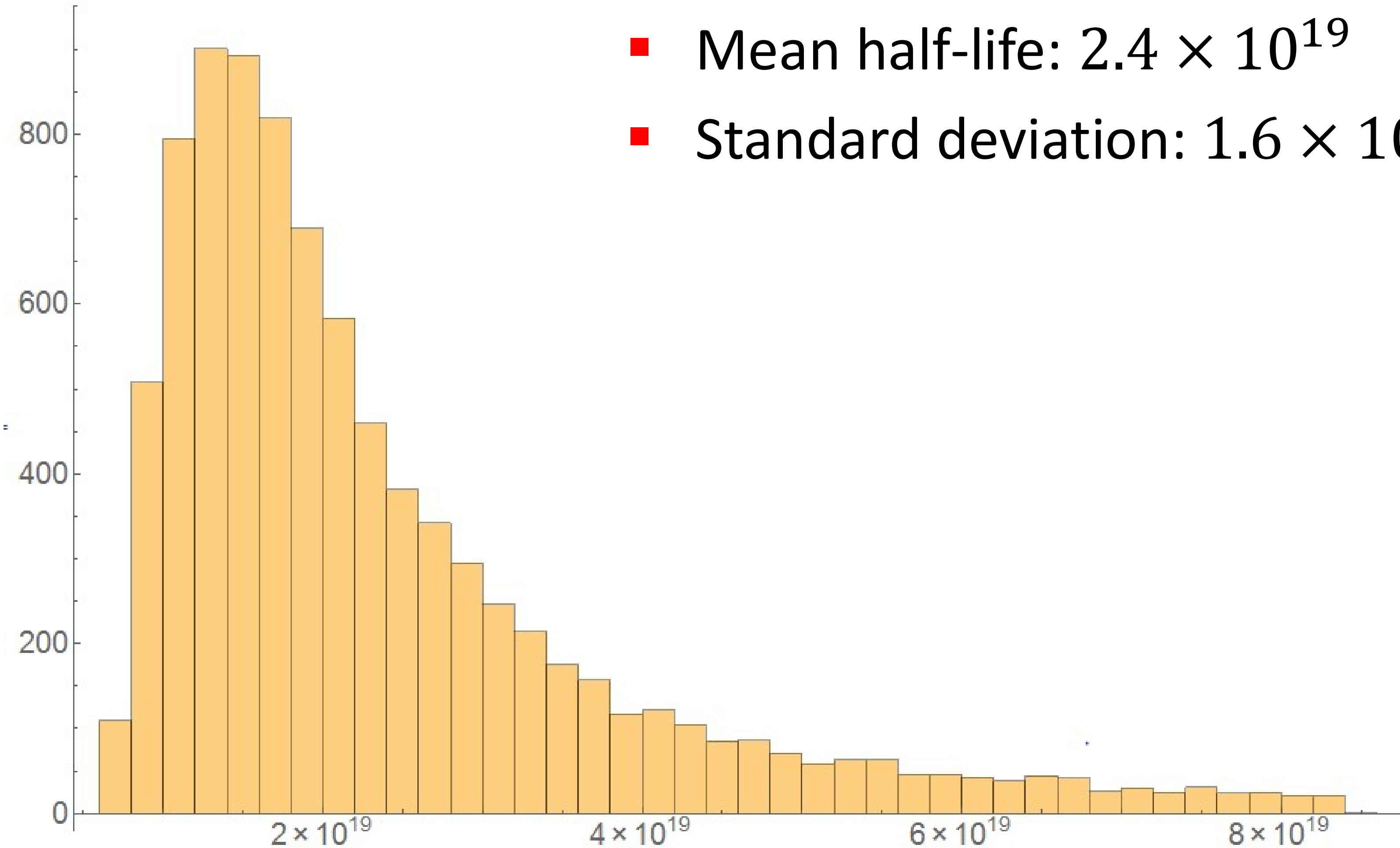
$$\frac{n_d}{n_0} = \frac{m_{\mathrm{Mo}}}{m_{\mathrm{Zr}}}\,\frac{A_W(\mathrm{Zr})}{A_W(\mathrm{Mo})}\,\frac{\mathrm{C}(^{96}\mathrm{Mo})}{\mathrm{C}(^{96}\mathrm{Zr})}\,\delta(^{96}\mathrm{Mo})$$

Simulate results: Input parameters

	Value	**Uncertainty**
AwZr	91.224	0.002
AwMo	95.95	0.01
c96Zr	0.0280	0.0009
c96Mo	0.16673	0.00003
mZr (g)	0.250	0.010
mMo (pg)	250	50
Age (Ga)	2.68	0.05
δ96* (permil)	0.016	0.010

**δ96* predicted based on half-life:* 2×10^{19} *a*

Simulation Results



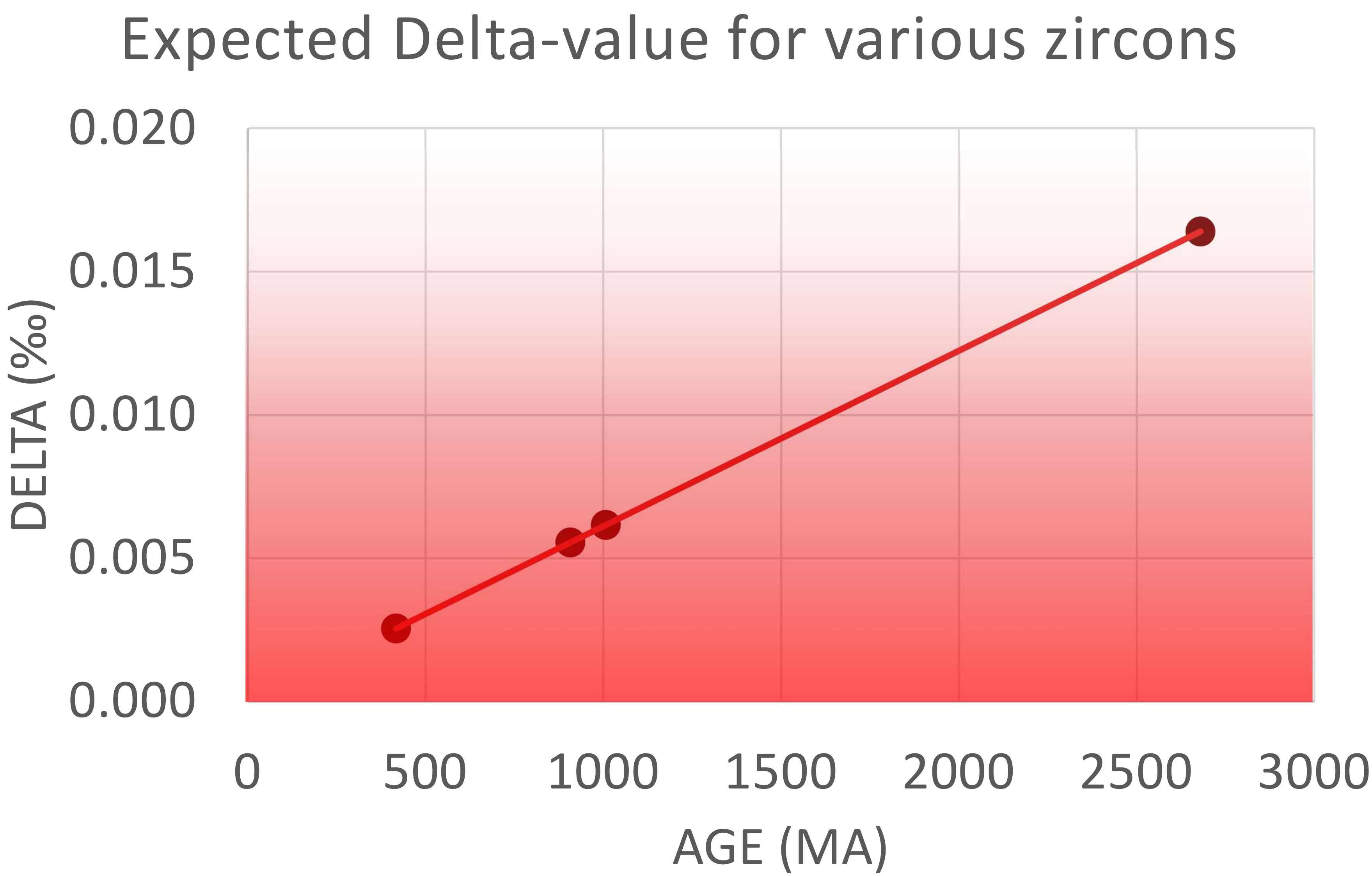
- Mean half-life: 2.4×10^{19}
- Standard deviation: 1.6×10^{19} a

Determine contributions to uncertainty

- By varying one parameter at a time, we can see the individual contributions to the uncertainty.
- The total uncertainty is: $\sqrt{\sum_i {\sigma_i}^2}$
- The relative contribution is: $\frac{{\sigma_i}^2}{\sum_i {\sigma_i}^2}$

Variable	Contribution (%)
AwZr	7.0E-11
AwMo	1.6E-09
c96Zr	1.6E-04
c96Mo	4.5E-09
mZr	2.3E-04
mMo	8.0E-03
Age	1.4E-07
delta96	99.99

Various ages of zircons



So where did the previous result come from?

- Wieser and DeLaeter did not compare the decay product directly to the parent
- They instead compared to the parallel fission decay of ^{238}U
  - [^{238}U] = 200 ppm
  - $t_{1/2} = 4.47 \times 10^{9}$ a
  - $\mathrm{SF} = 5.45 \times 10^{-5}$ %
  - $^{97\text{-}100}Mo$ fission yield: ~ 6 %

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  - Back of the envelope "partial half-life" for $^{238}U \rightarrow {}^{97}Mo$: $\mathbf{2 \times 10^{19}}$ **a** (adjusted for U-concentration relative to ^{96}Zr)

- So long as the excess seen in the U fission decay products is similar to the ^{96}Mo excess, the determined half-life would be the right order of magnitude…

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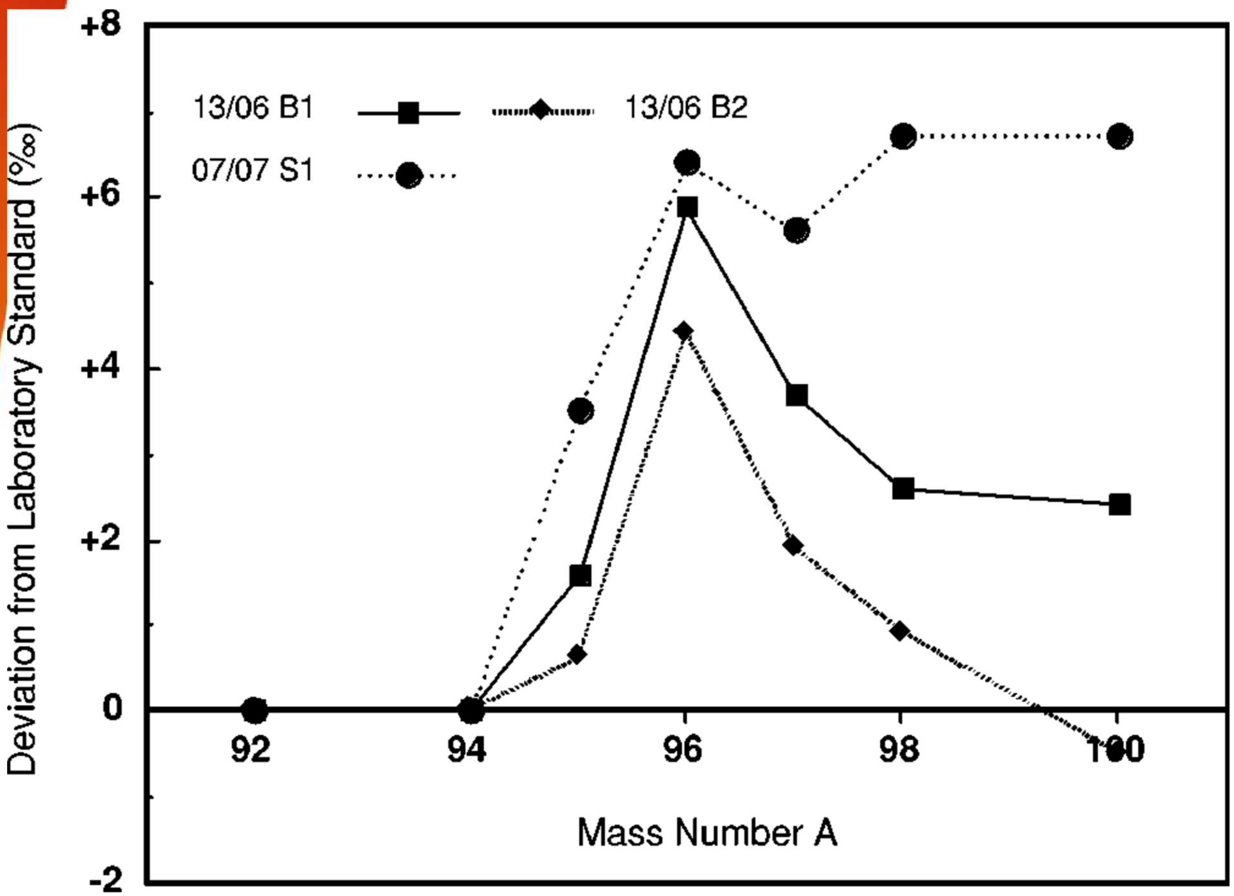

Wieser and DeLaeter 2001 – PRC 46

- ^{238}U decay products are inconsistent, especially ^{100}Mo
- These delta-values only possible if Zr:Mo is around 370M:1
- I've measured Zr:Mo in several samples to be around 1M:1
- Therefore delta values should be 370x smaller (unresolvable)

- Previous measurements had significant errors contributing to the measurement
- I still aim to prove this conclusively by significantly improving the precision of the measurements
- If possible, I will try to achieve a more direct geochemical half-life measurement using the 2.7 Ga zircons
  - At the limit of what can be measured using this technique