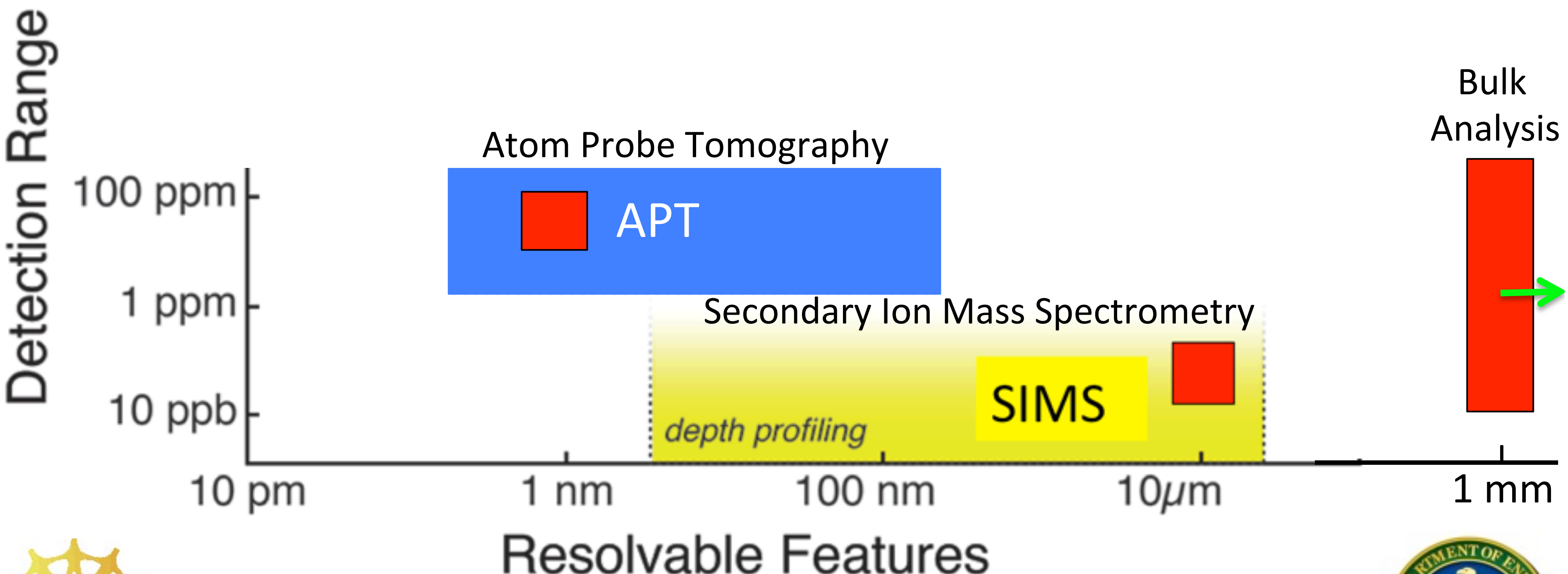
Go Small or Go Home

How Small is Too Small for Isotope Ratio Analysis?

John Valley

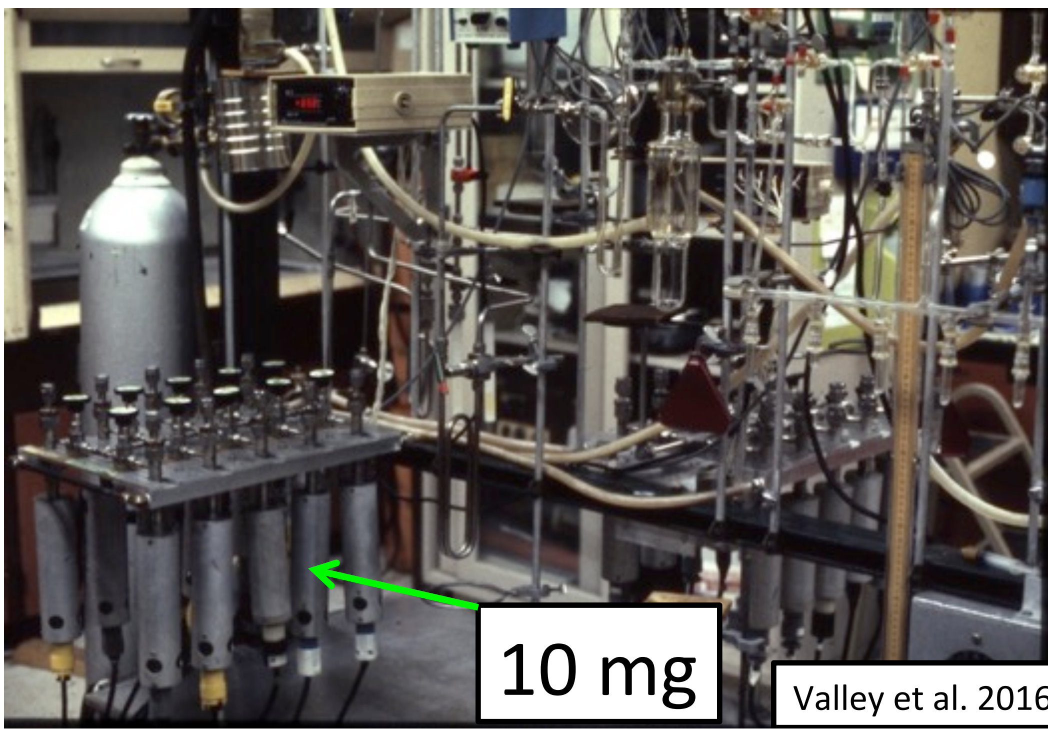
UW - Madison

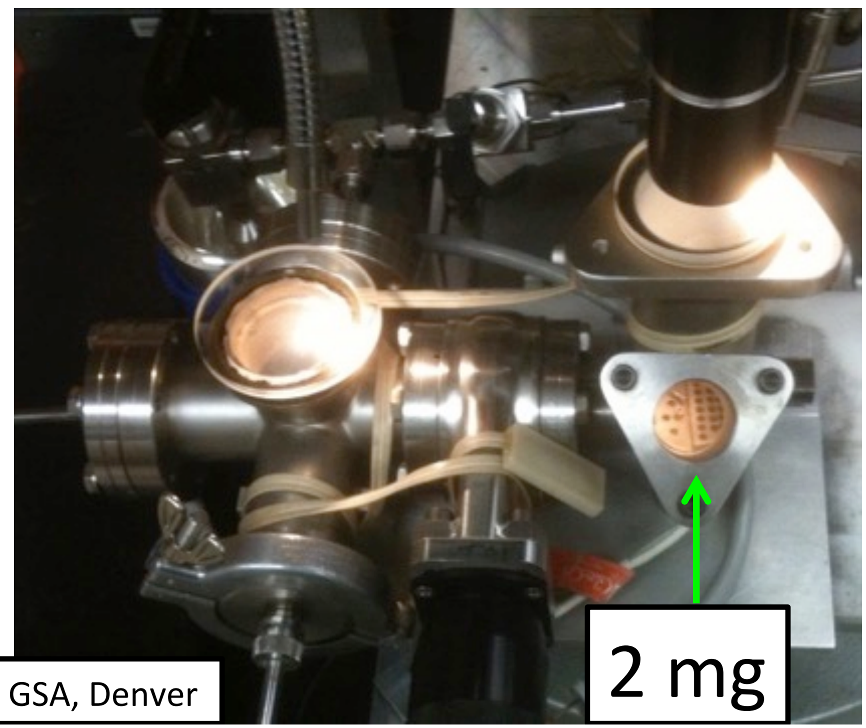
Tyler Blum, David Reinhard



Valley et al. 2016, GSA, Denver

Bulk Stable Isotope analysis



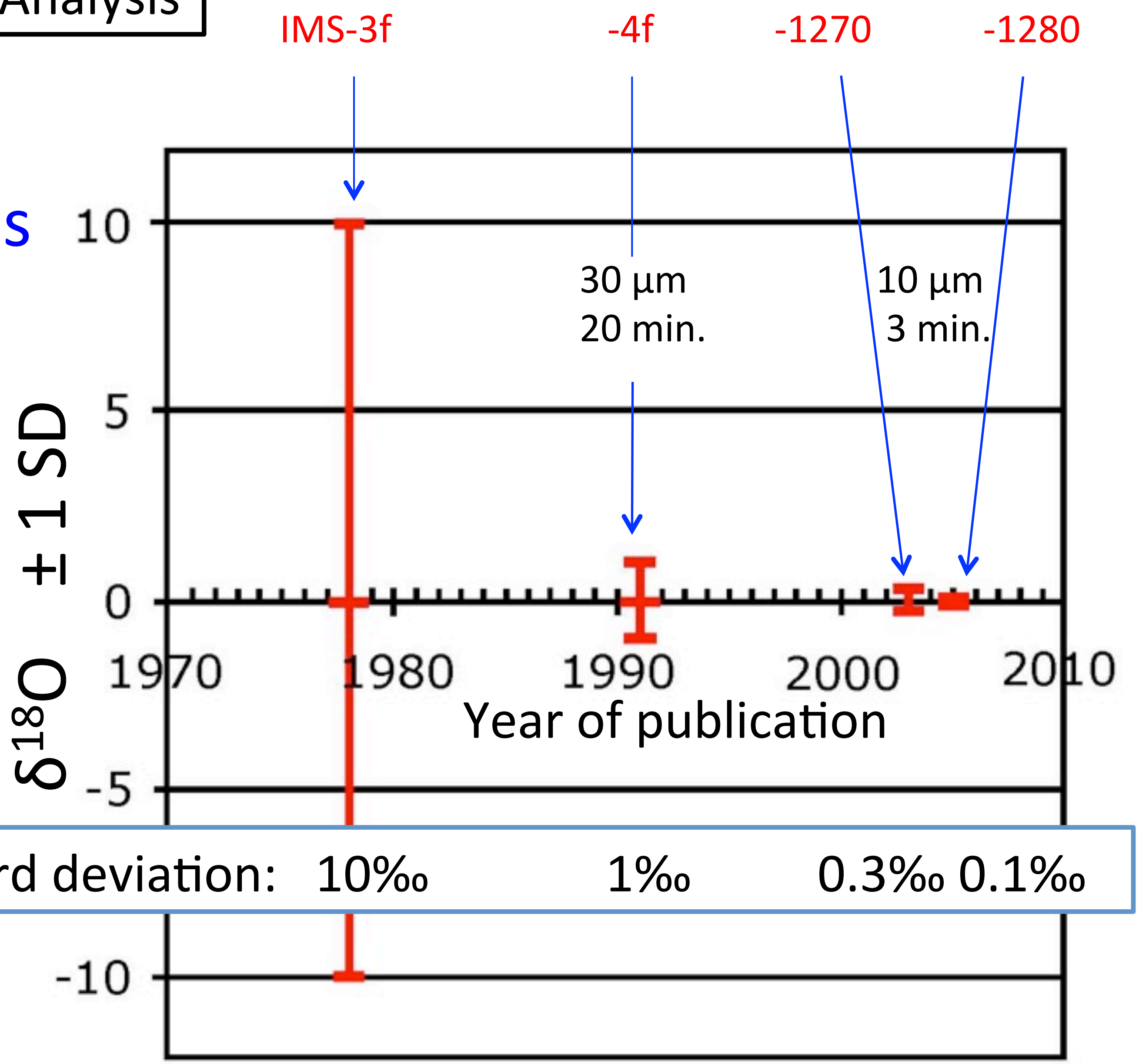


Valley et al. 2016, GSA, Denver

In situ Stable Isotope Analysis

SIMS
Oxygen Isotopes

Ion Microprobe
Analytical Precision
& Spot size
30 years of Improvement



Valley et al. 2016, GSA, Denver

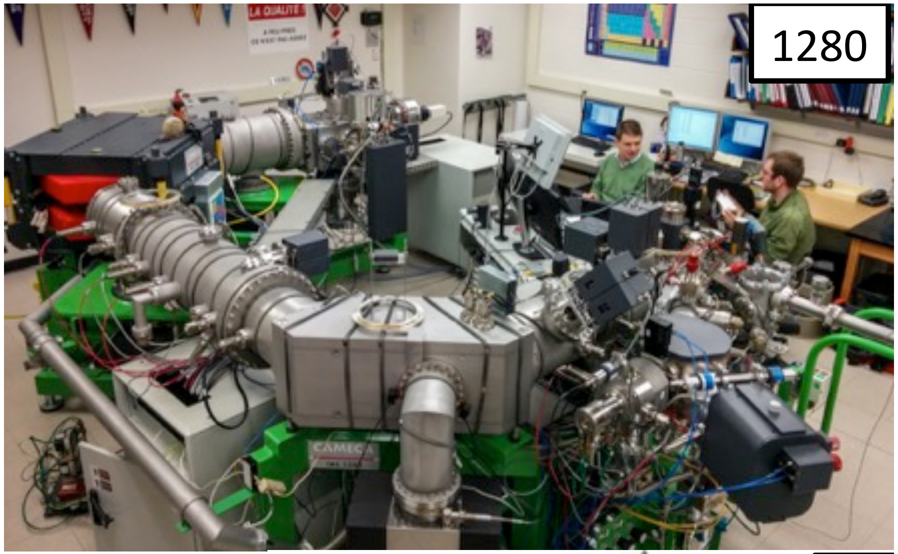
CAMECA

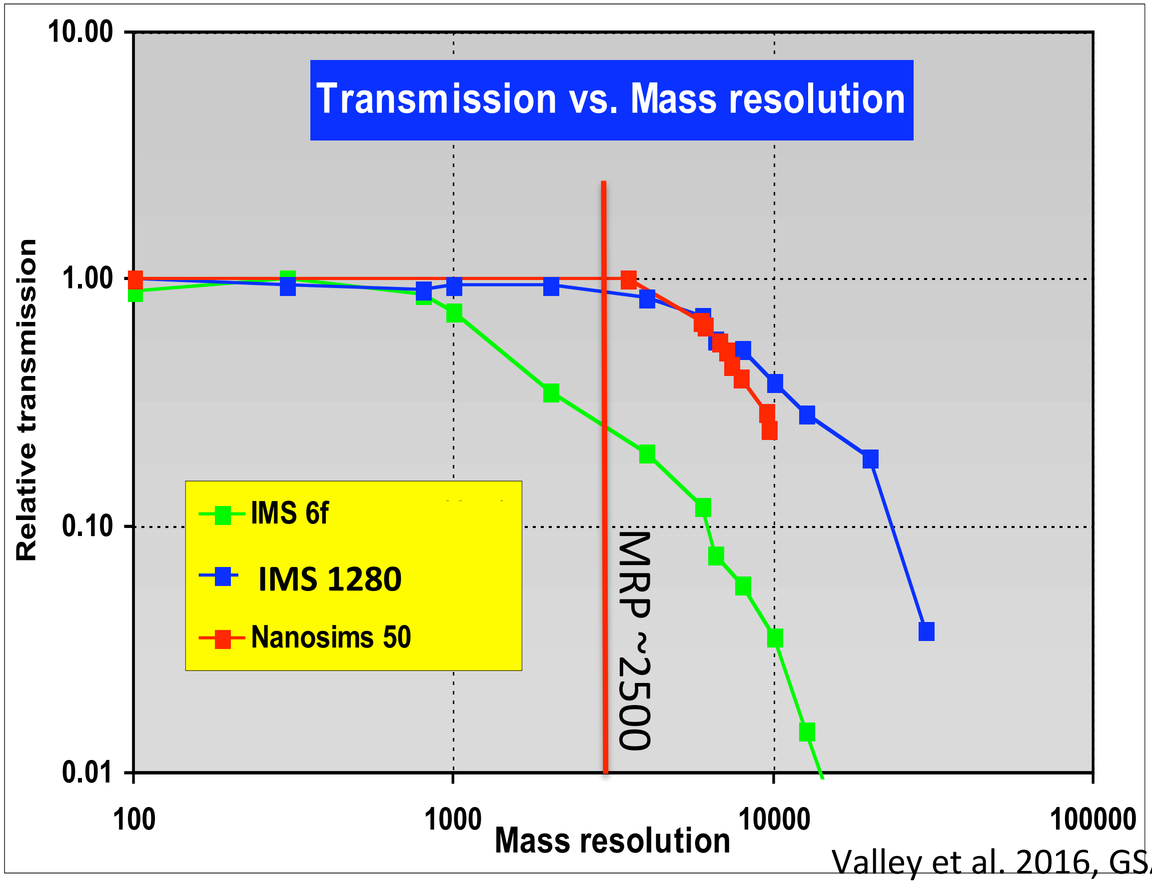
IMS- 3f, -7f

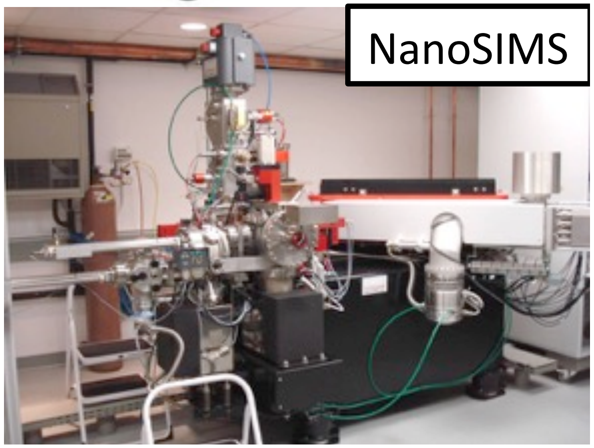
* IMS- 1270, -1300

NanoSIMS

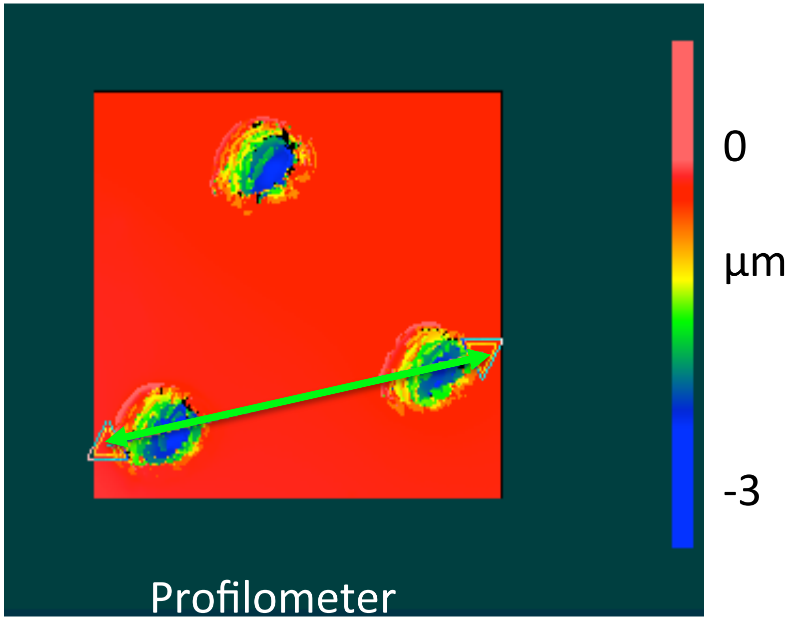
SHRIMP

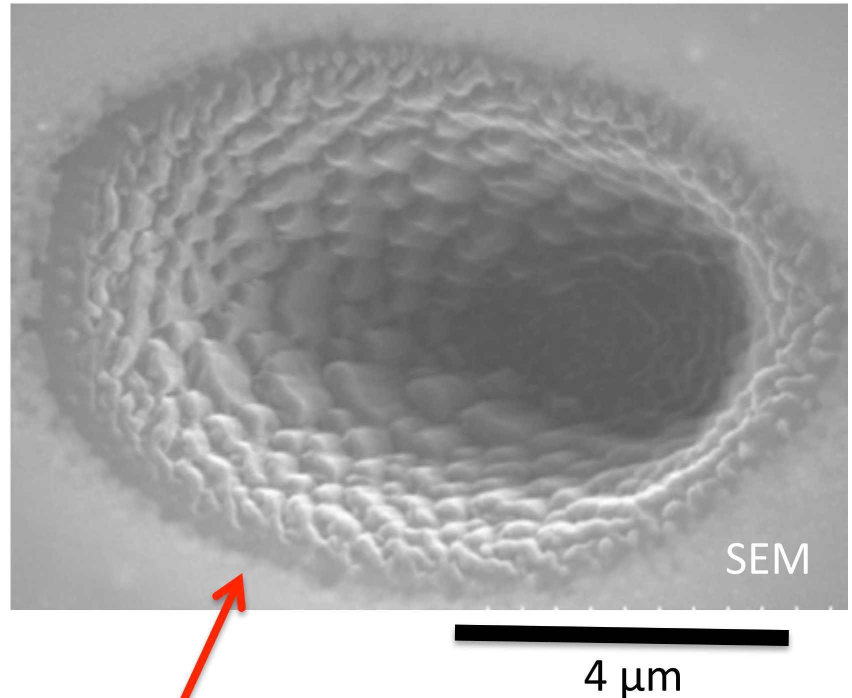




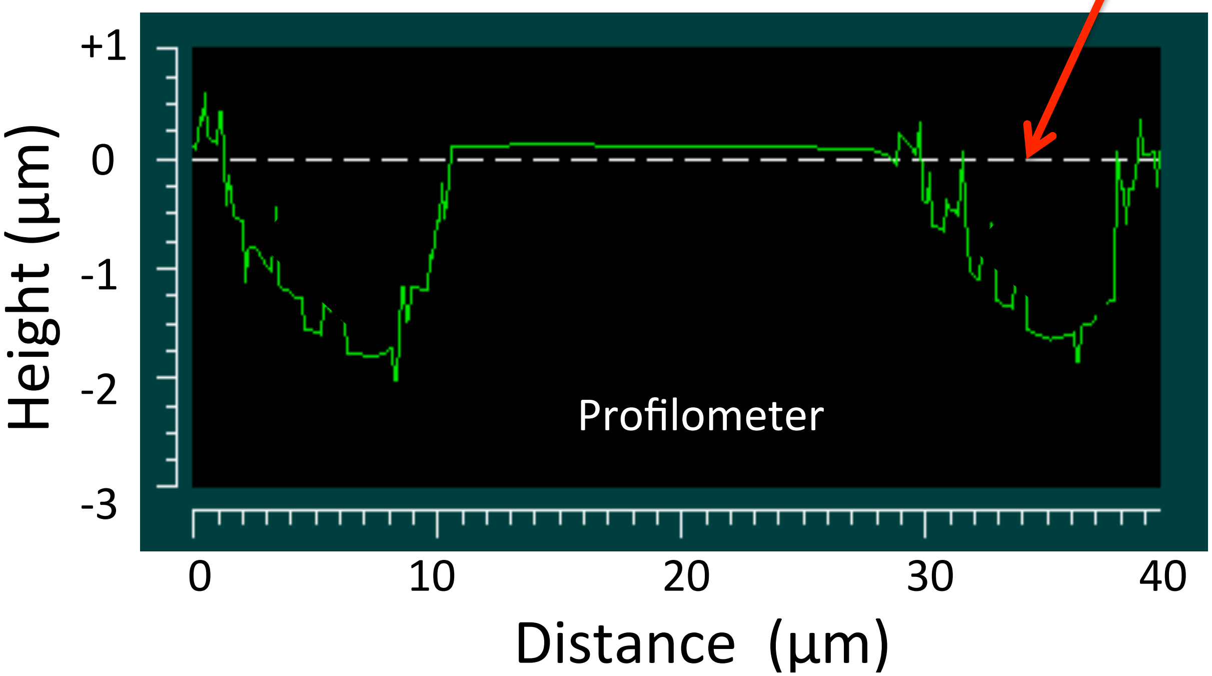


Valley et al. 2016, GSA, Denver





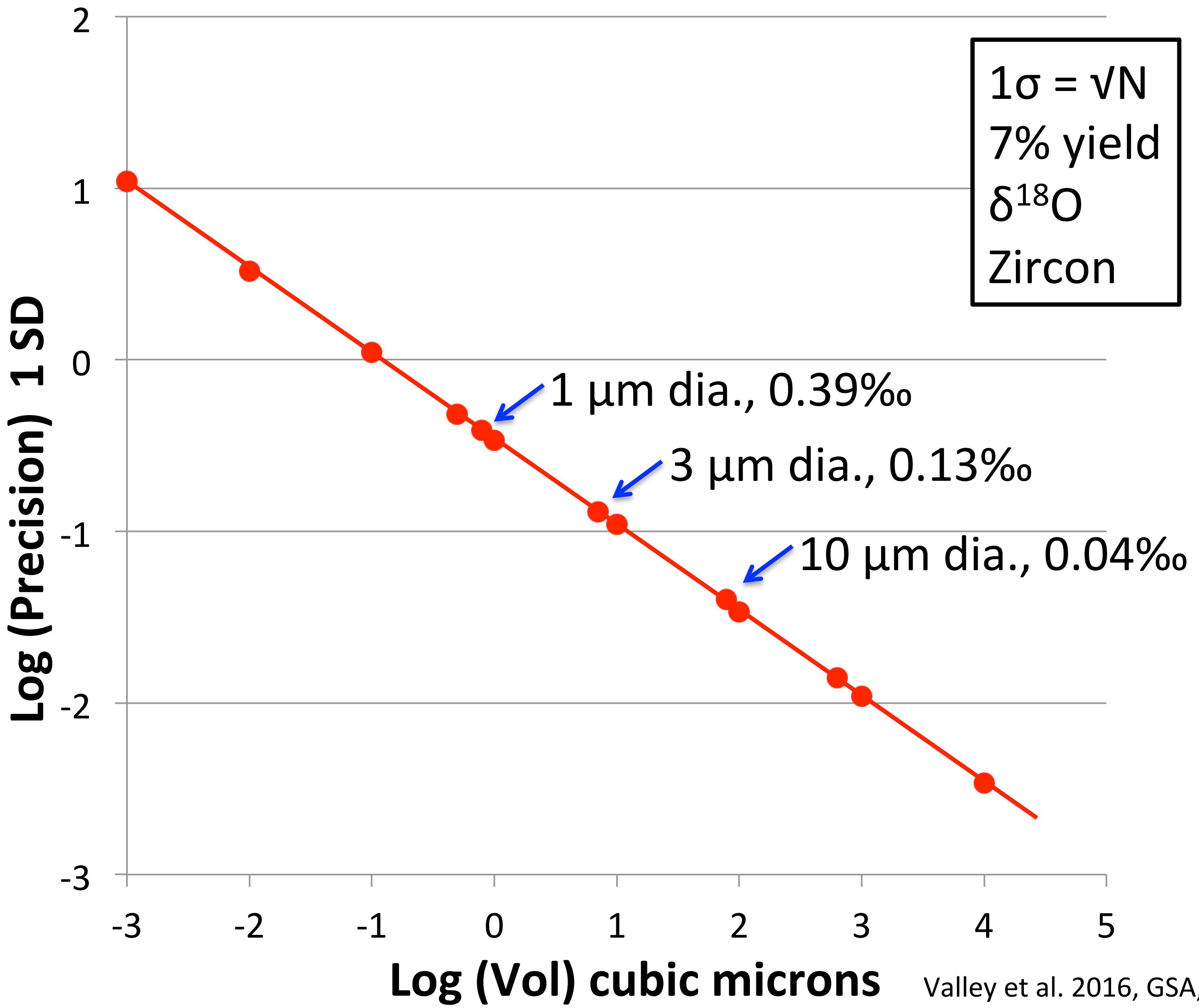
Volume = 75 µm^2



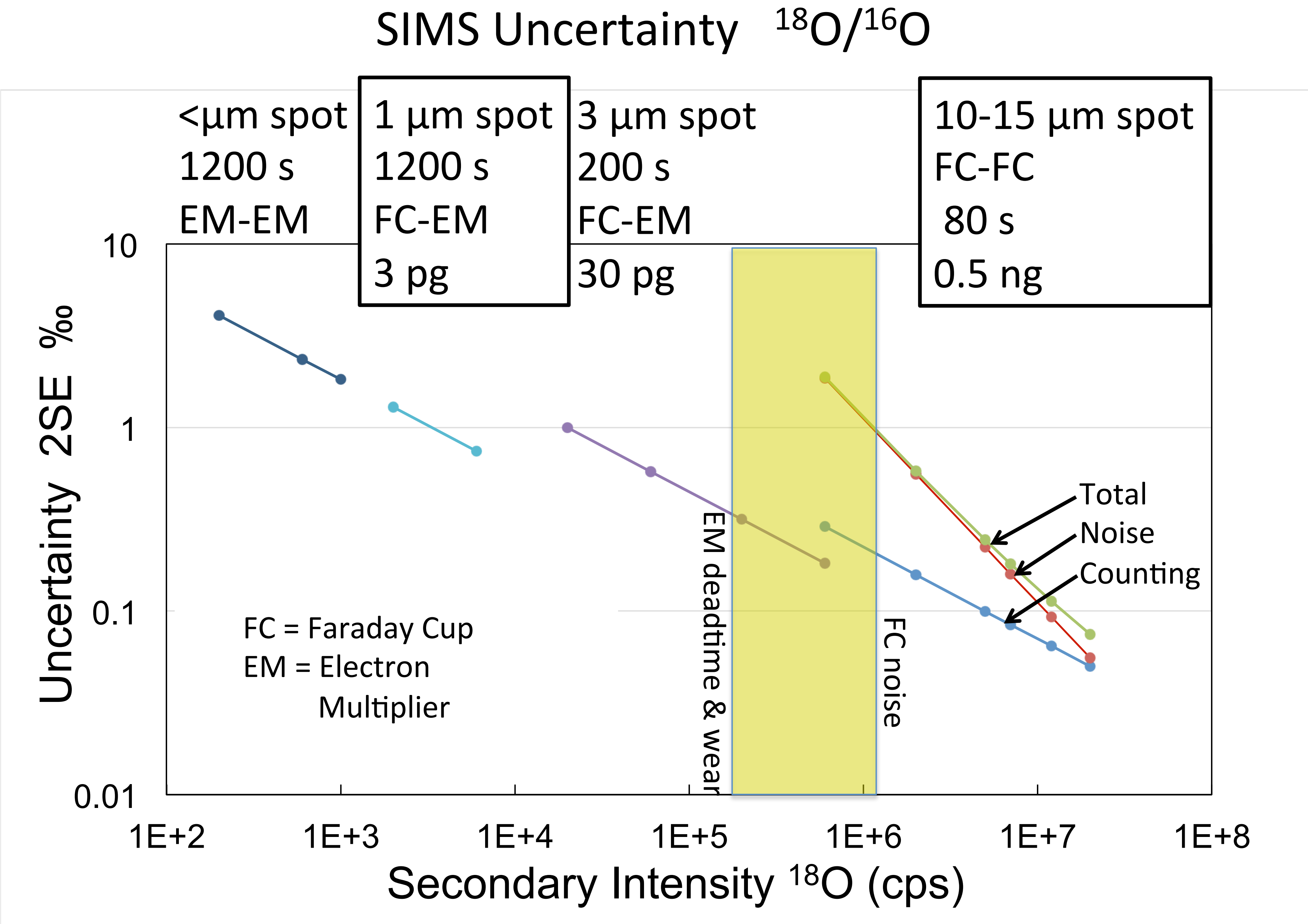
Useful ion yield
~7% for $\delta^{18}O$
IMS-1280
at WiscSIMS

Valley et al. 2016, GSA, Denver

Theoretical Limit: Precision vs. Pit Volume



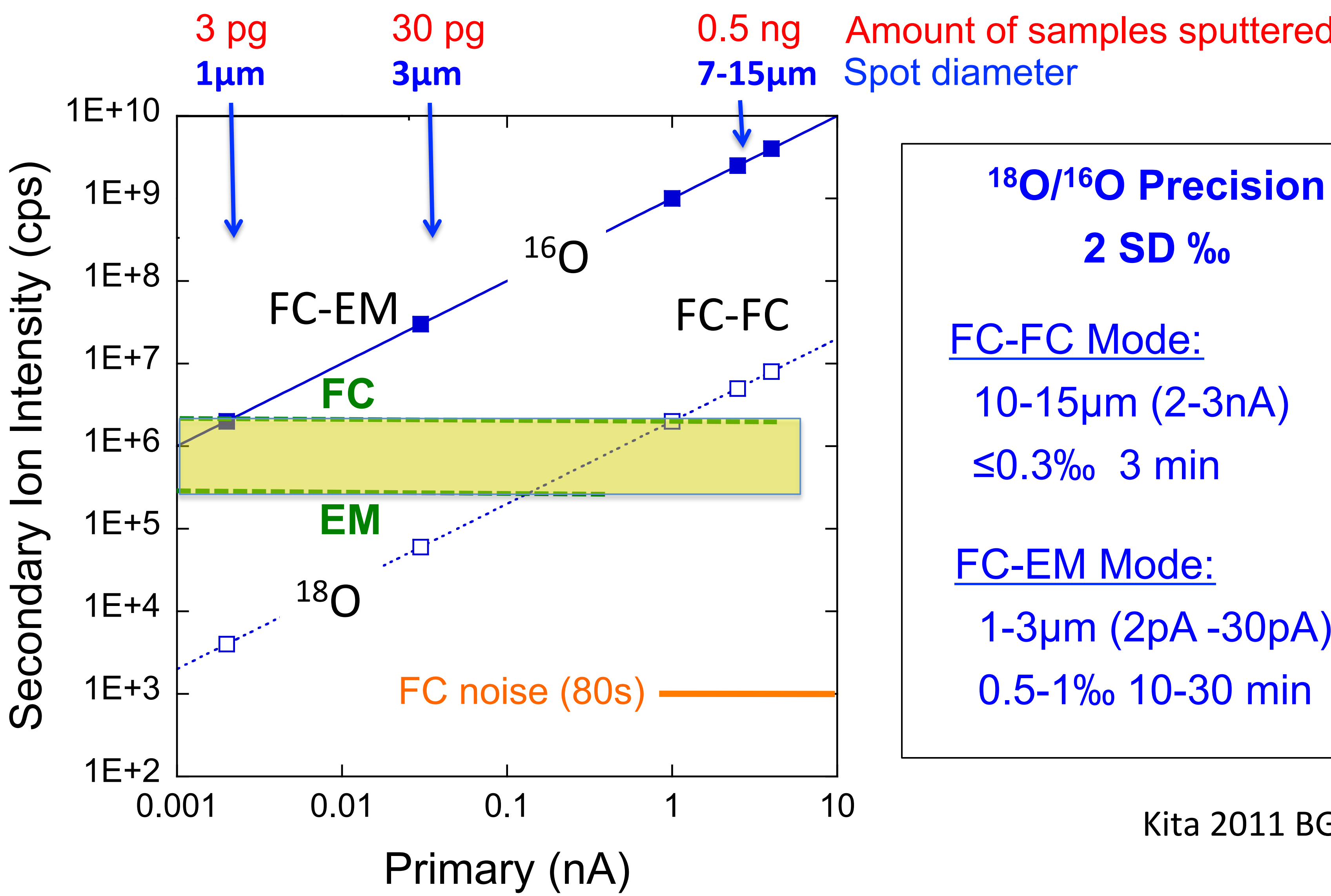
Valley et al. 2016, GSA, Denver



Additional factors: Deadtime, QSA, IMF

Valley et al. 2016, GSA, Denver

Precision of Analyses vs. Primary Beam Current



$^{18}O/^{16}O$ Precision

2 SD ‰

FC-FC Mode:

10-15μm (2-3nA)

≤0.3‰ 3 min

FC-EM Mode:

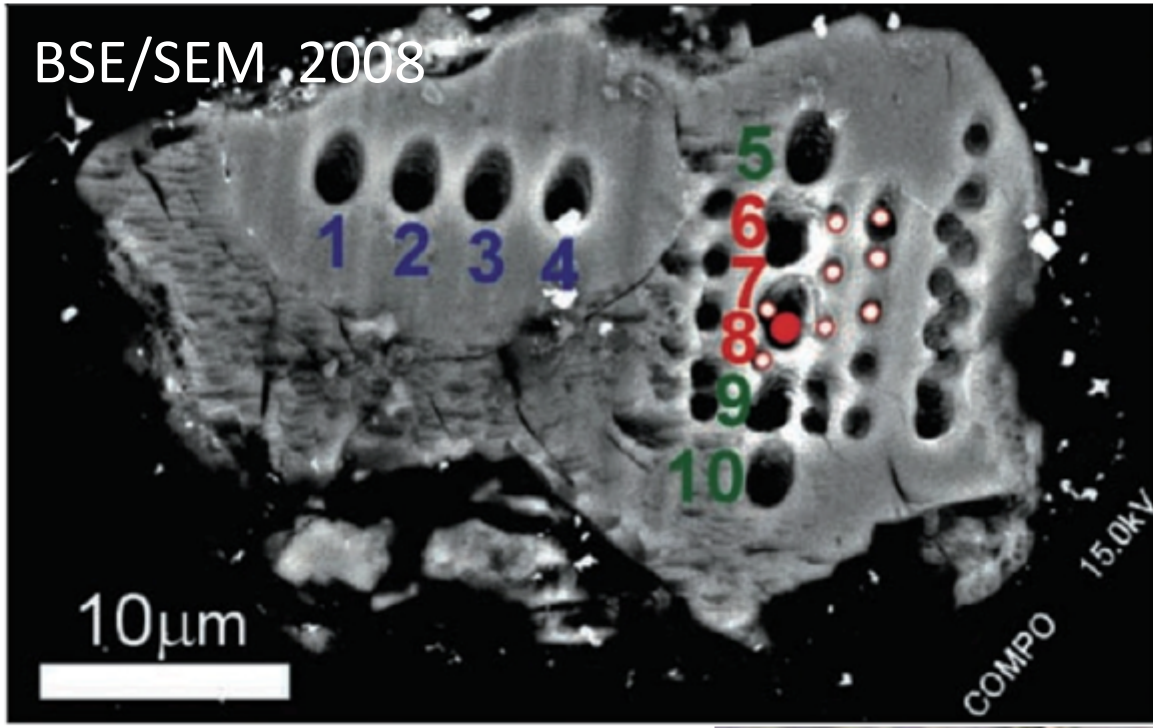
1-3μm (2pA -30pA)

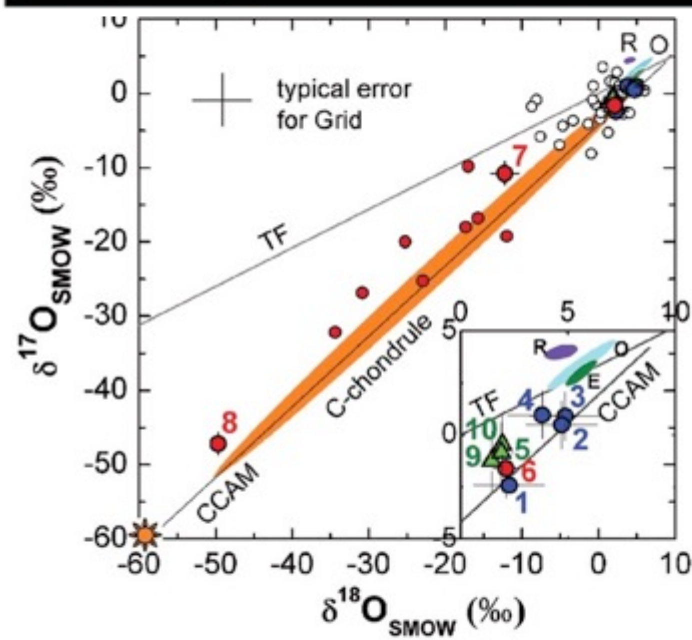
0.5-1‰ 10-30 min

Kita 2011 BGSW

Valley et al. 2016, GSA, Denver

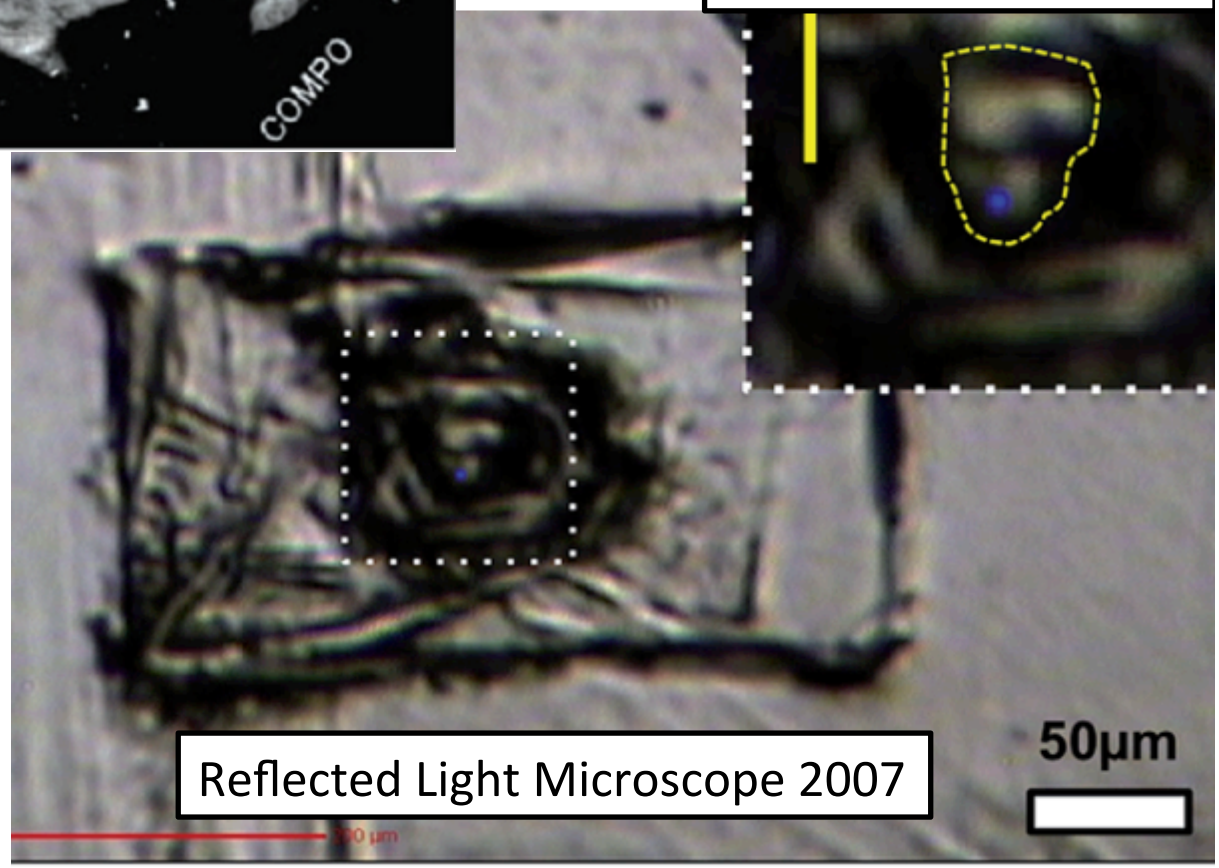
Comet Wild 2

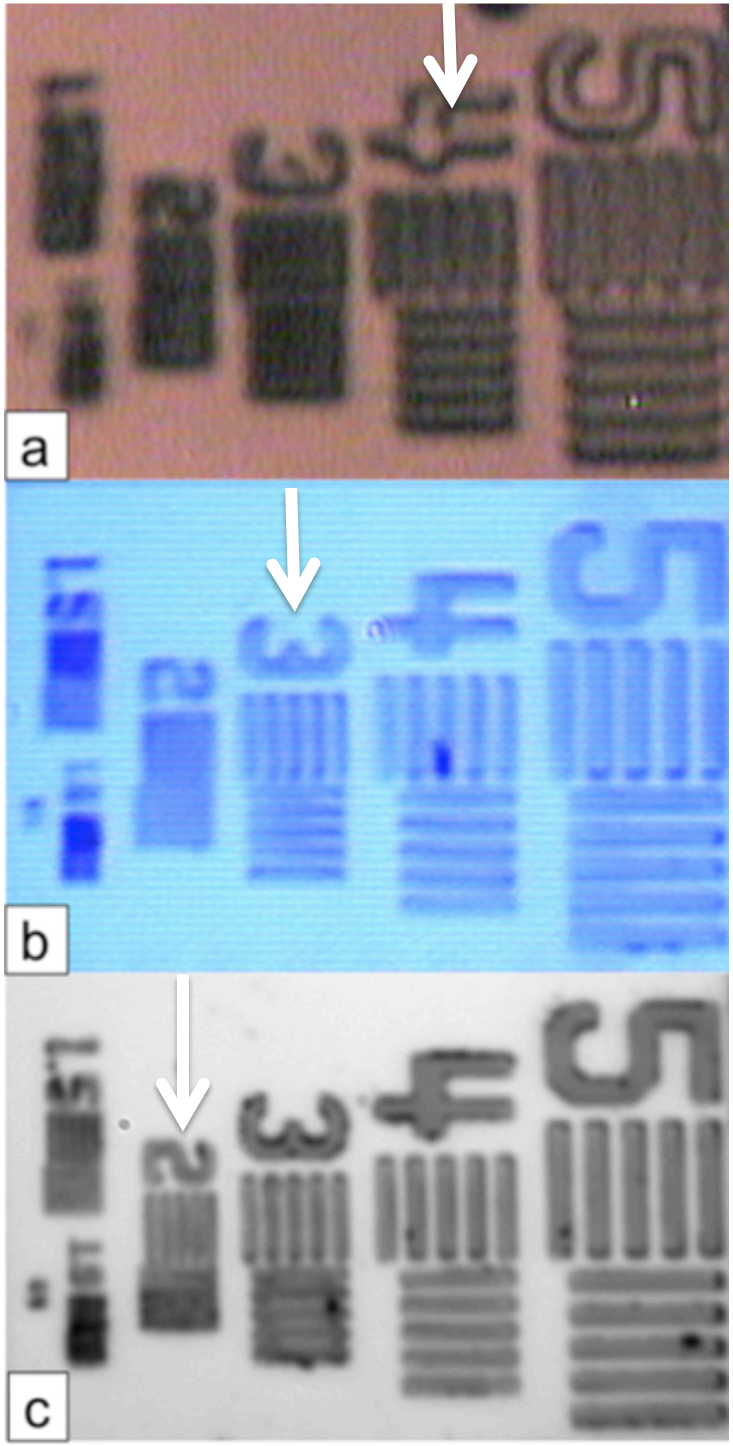




Nakamura et al. 2008, Science

Valley et al. 2016, GSA, Denver





White Light
λ = 400-700 nm
3.5 µm

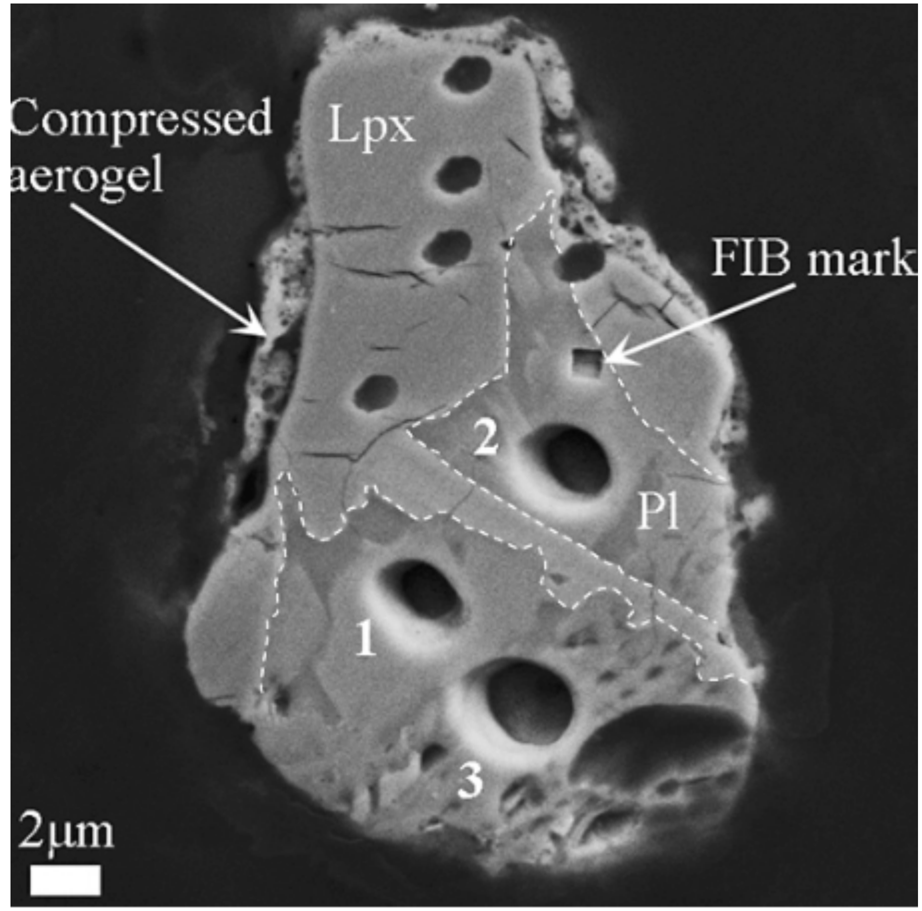
Blue LED
λ = 455 nm
2.2 µm

UV LED
λ= 365 nm
1.3 µm

Badgerscope software

Kita et al. 2015

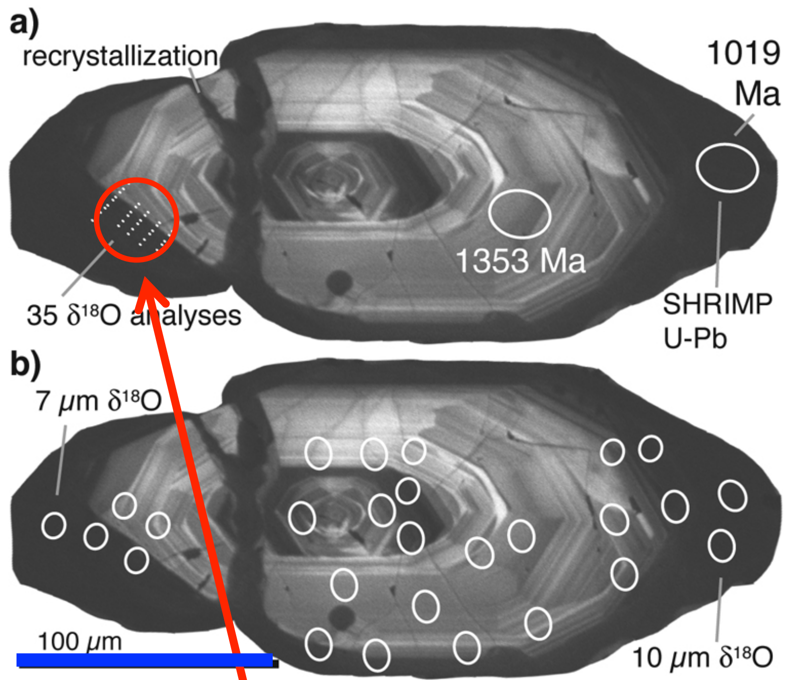
1 & 2 µm spots, 2015

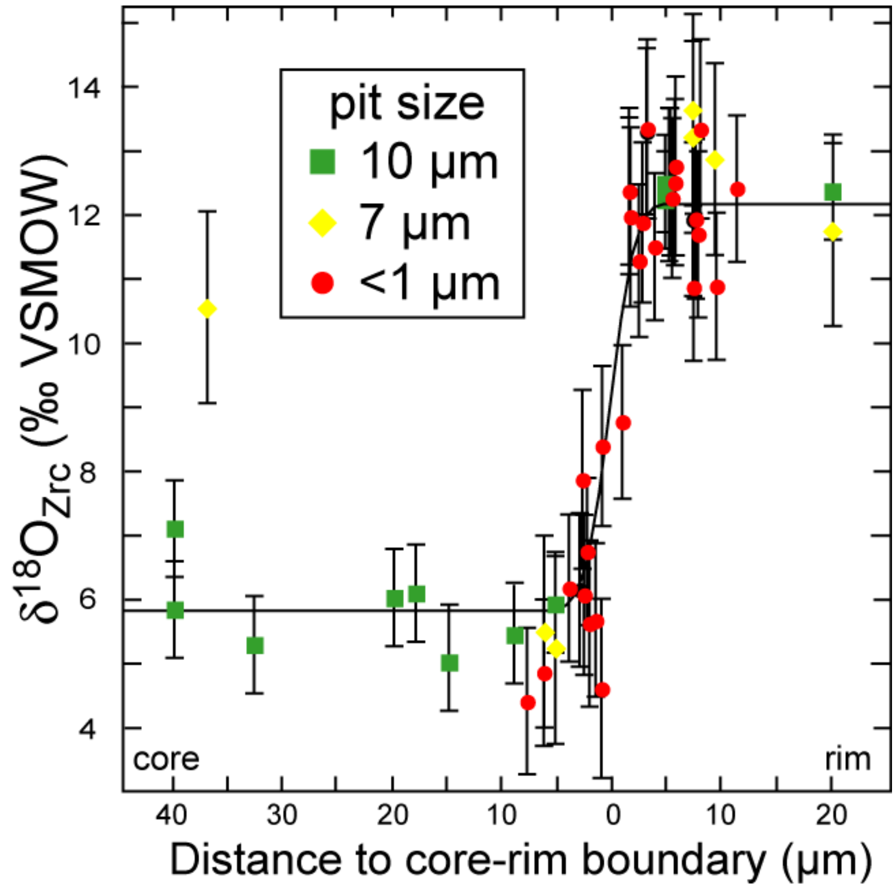


Nakashima et al. 2015

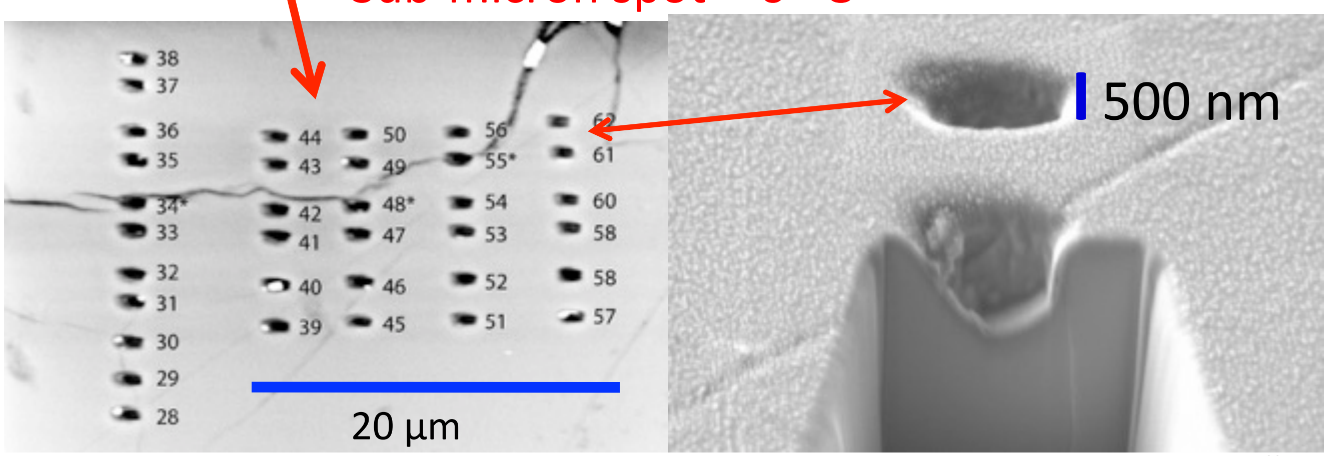
Valley et al. 2016, GSA, Denver

Oxygen diffusion in Zircon





Sub-micron spot - $\delta^{18}O$

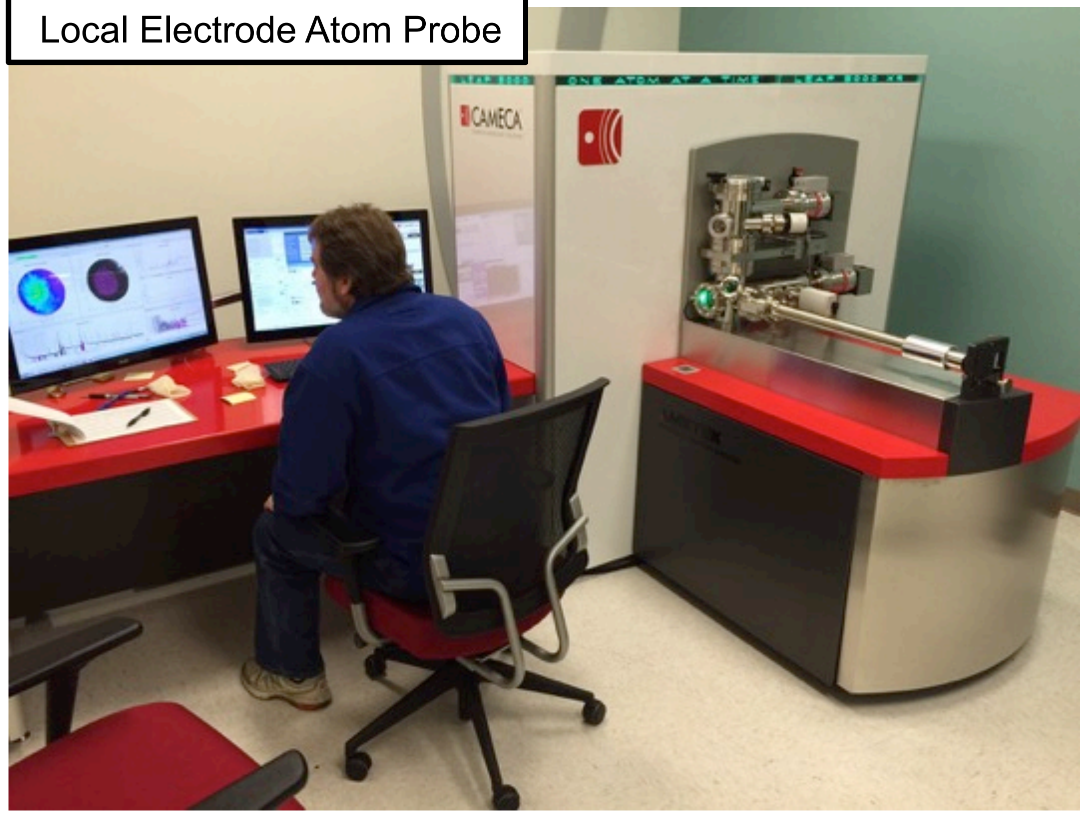


Page et al. 2007
Bowman et al. 2011

Valley et al. 2016, GSA, Denver

Valley et al. 2016, GSA, Denver

LEAP 5000
Local Electrode Atom Probe



Atom Probe Tomography

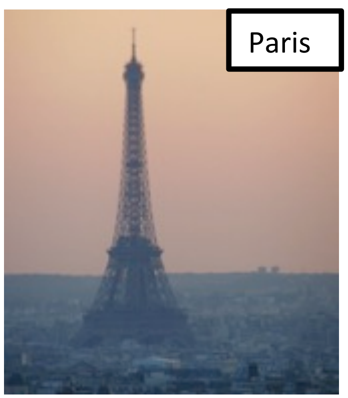
- Quantitative
- Spatially resolved, sub-nm
- Single-atom scale
- Mass-spectrometry

Nano-Geochronology
Evaluate Pb mobility
in zircon

LEAP 3000
LEAP 4000
LEAP 5000

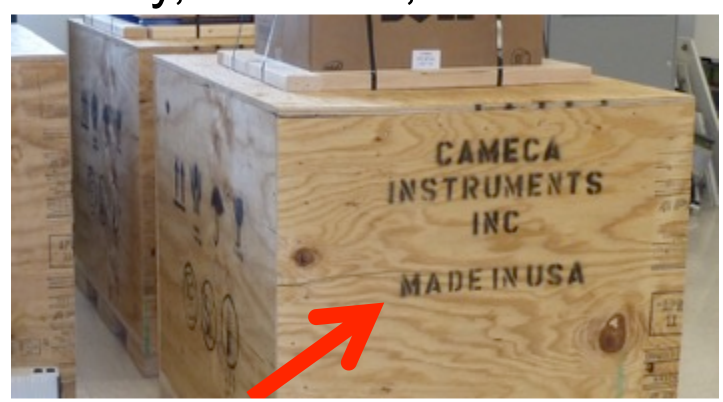
CAMECA®

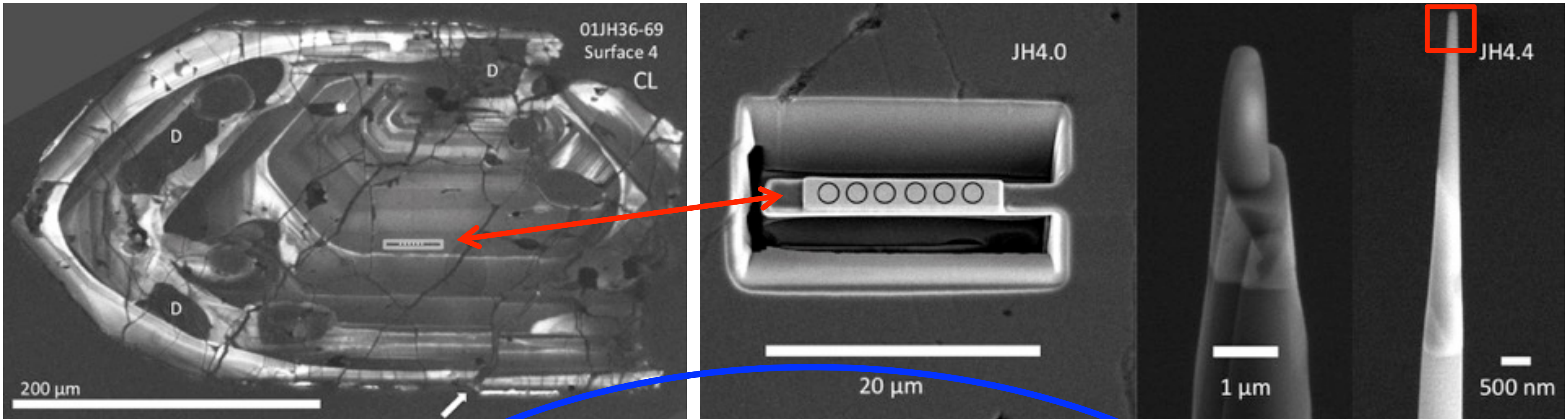
Paris

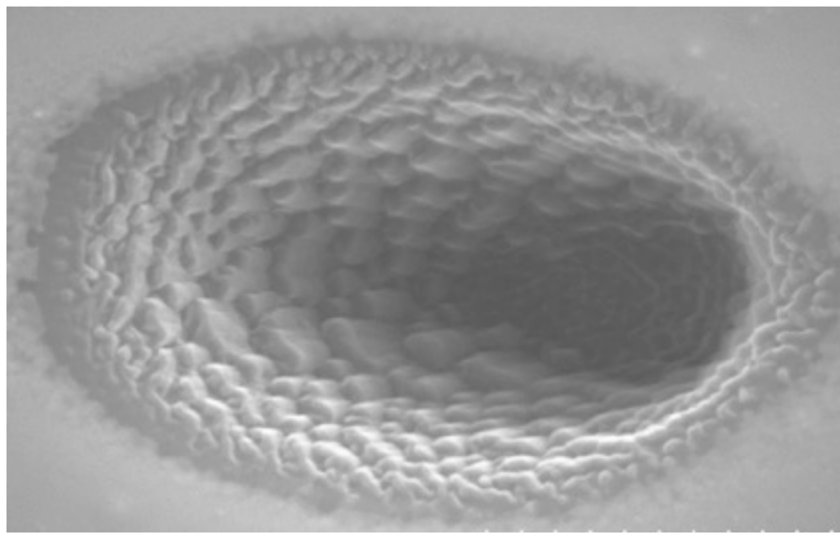


Madison

CAMECA Instruments
Factory, Madison, WI







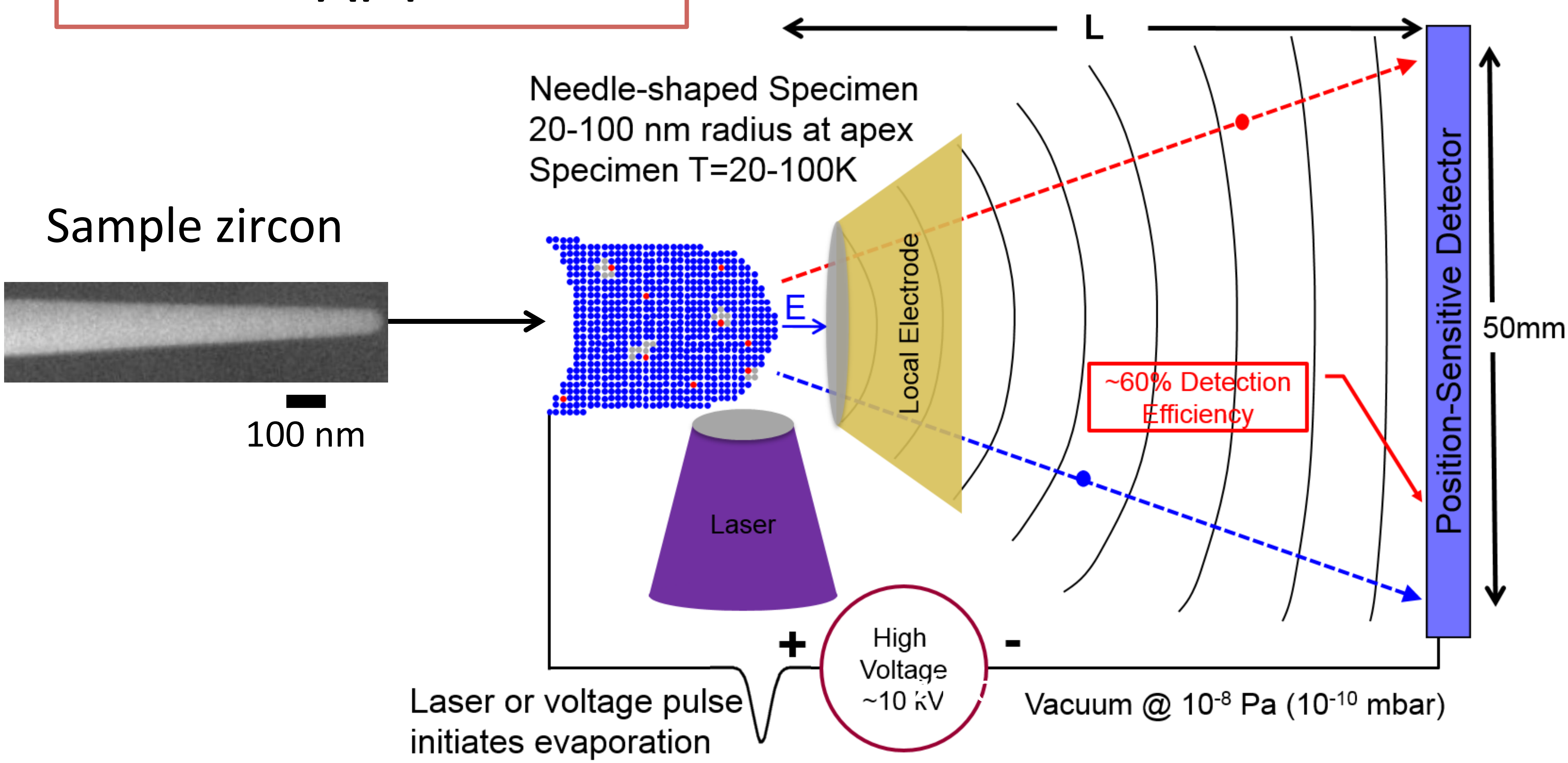
APT Specimen

10^5-10^6 smaller than SIMS

SIMS pit

Valley et al. 2016, GSA, Denver

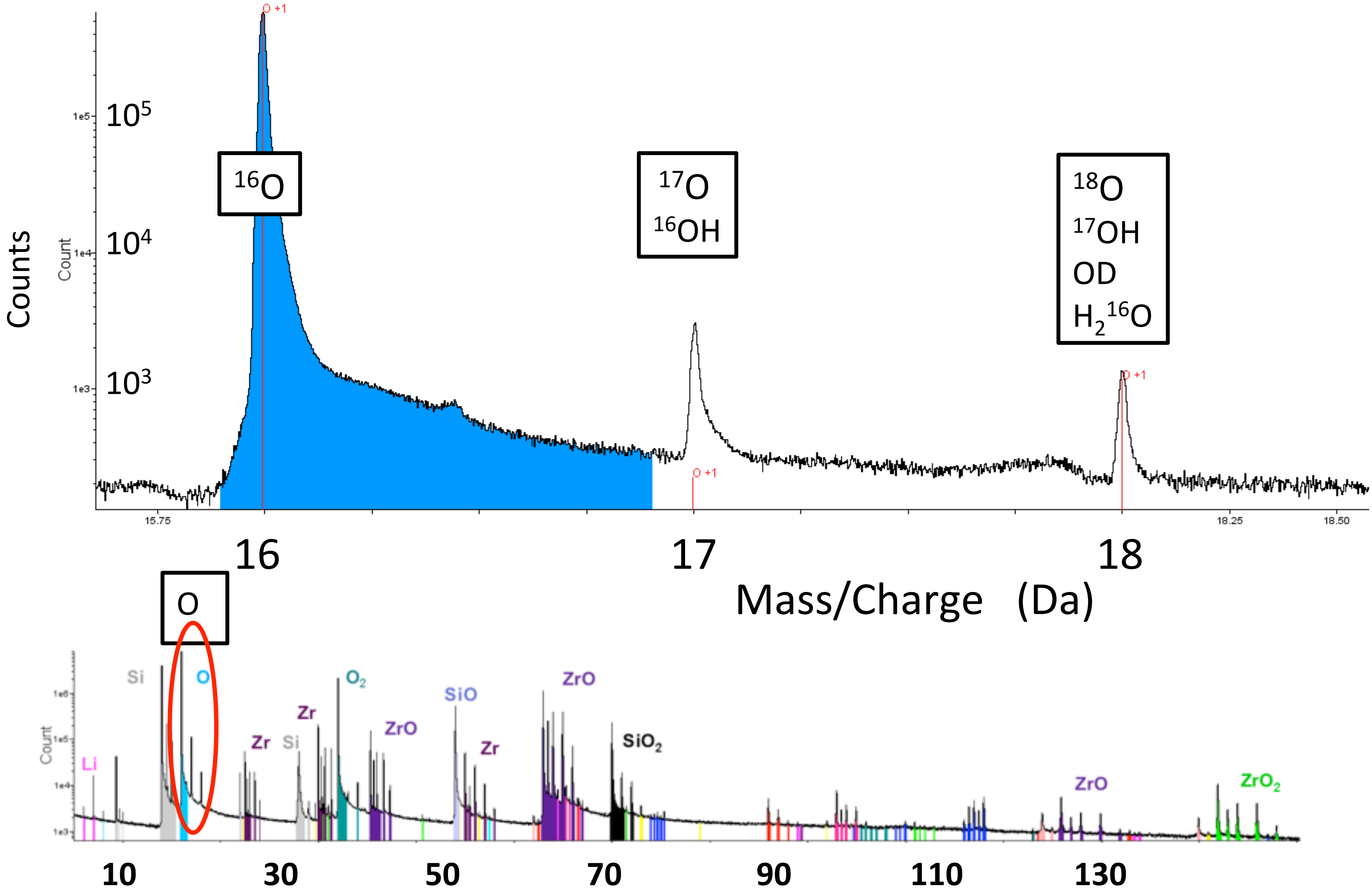
Atom Probe Tomography
APT



Valley et al. 2015 Am Min

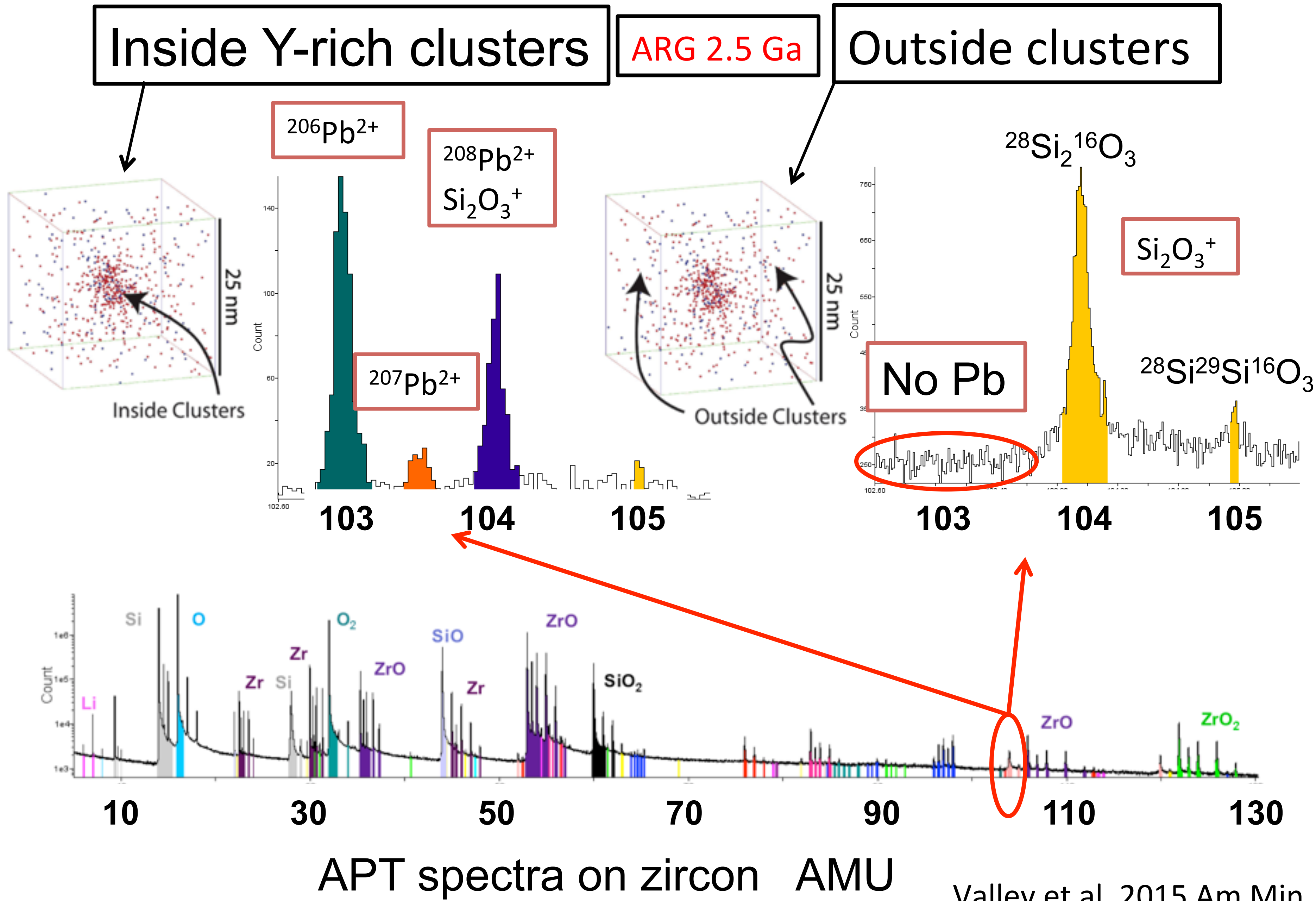
Valley et al. 2016, GSA, Denver

APT spectra on zircon



Valley et al. 2015 Am. Min.

(Da) CAMECA Valley et al. 2016, GSA, Denver

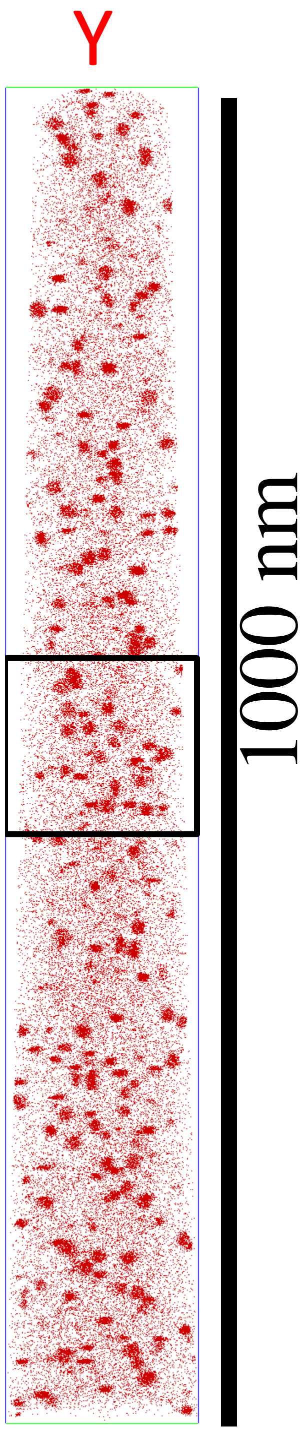


Valley et al. 2015 Am Min

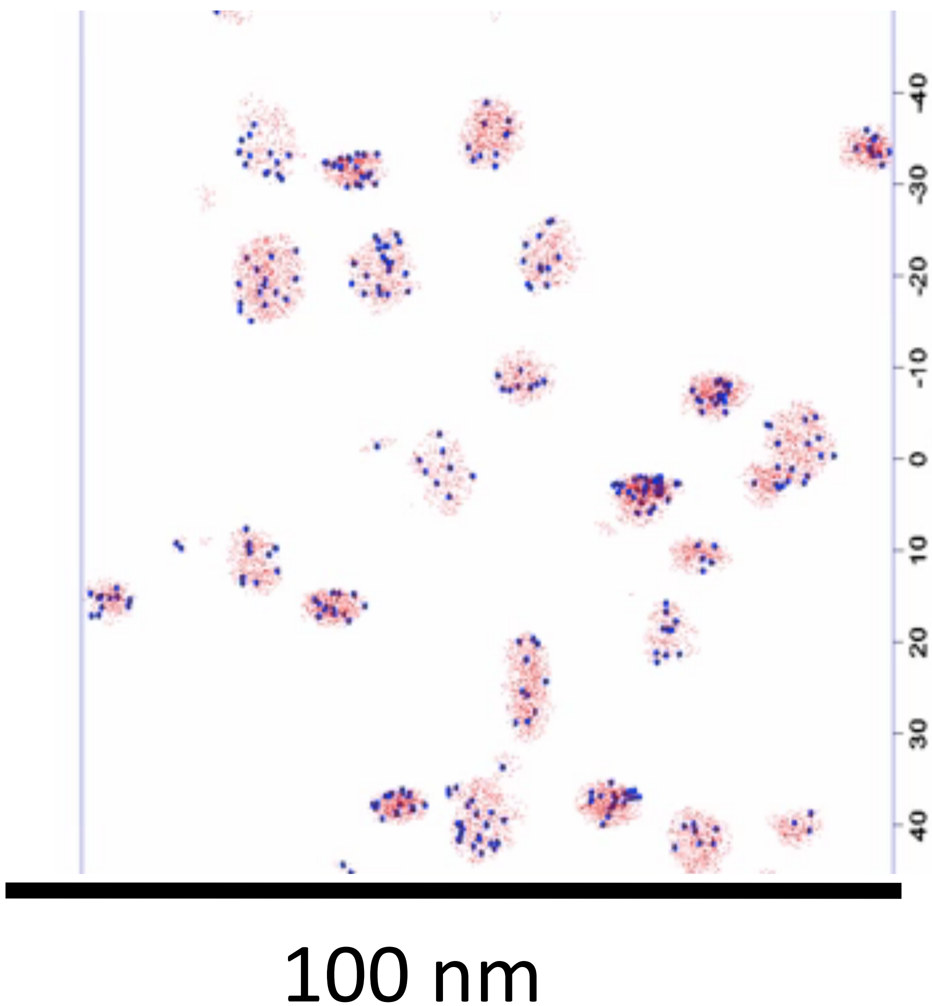
CAMECA

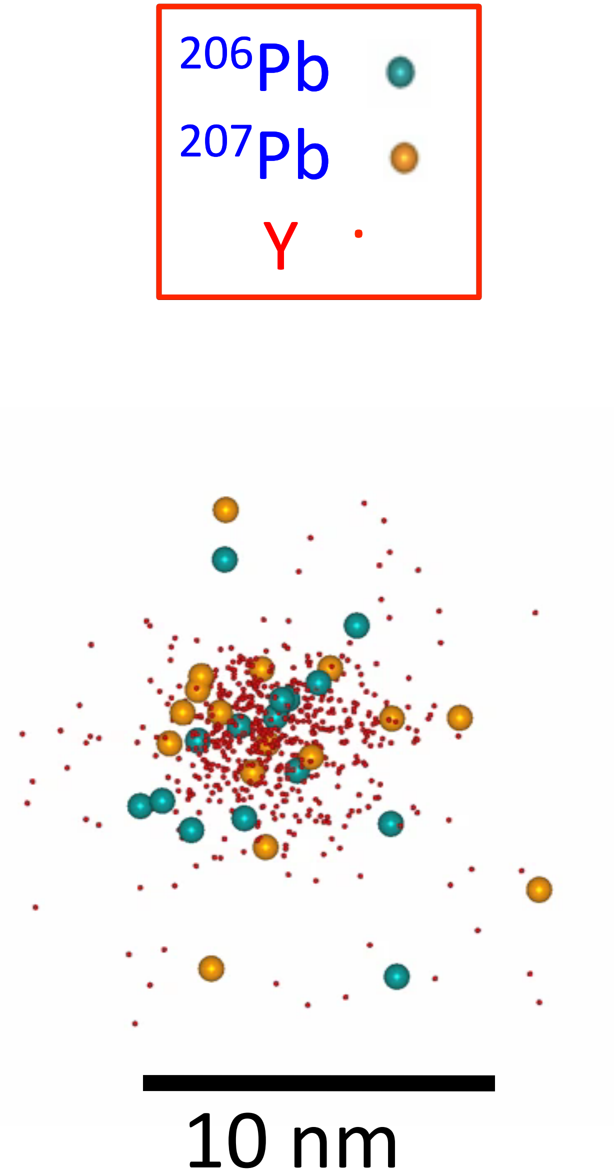
Valley et al. 2016, GSA, Denver

Clusters, 4.4 Ga



Y & Pb

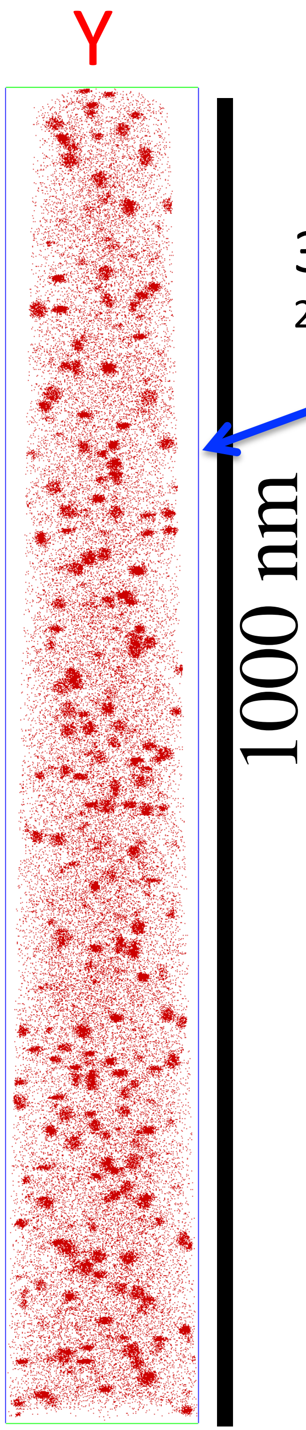




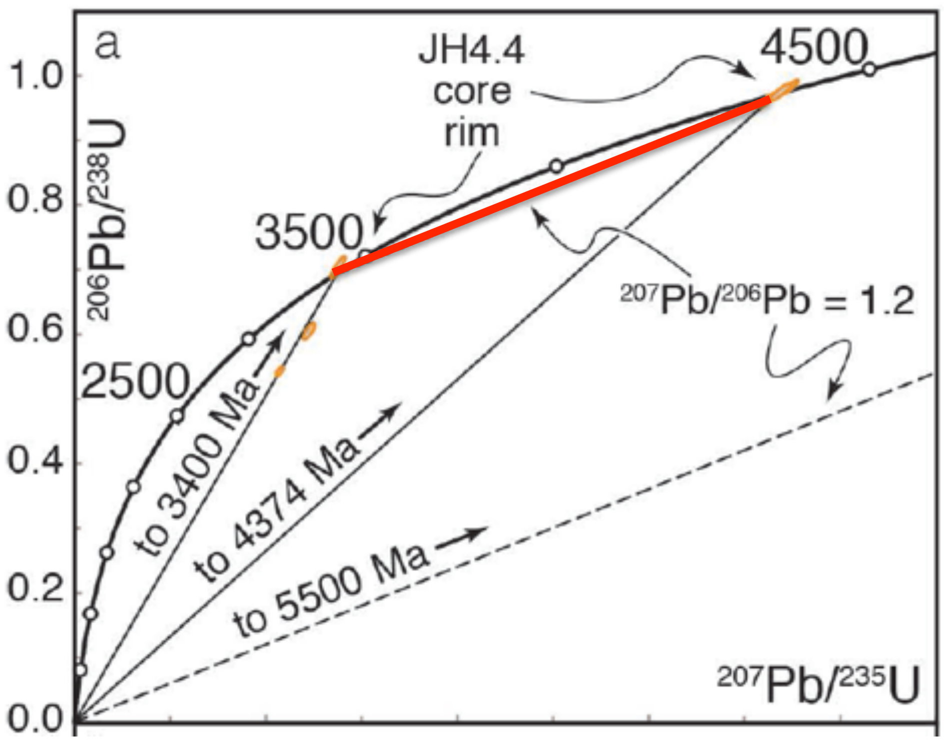
Valley et al. 2014 Nat. Geosci.
Valley et al. 2015 Am. Min.

Valley et al. 2016, GSA, Denver

Clusters, 4.4 Ga



391 clusters, 5,287 Pb atoms
$^{207}Pb/^{206}Pb = 1.2 \pm 0.05$



Valley et al. 2014 Nat. Geosci.
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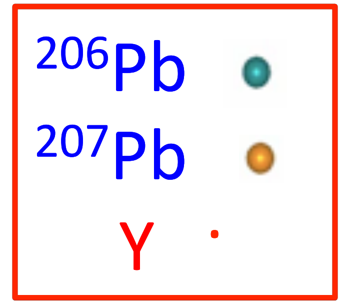
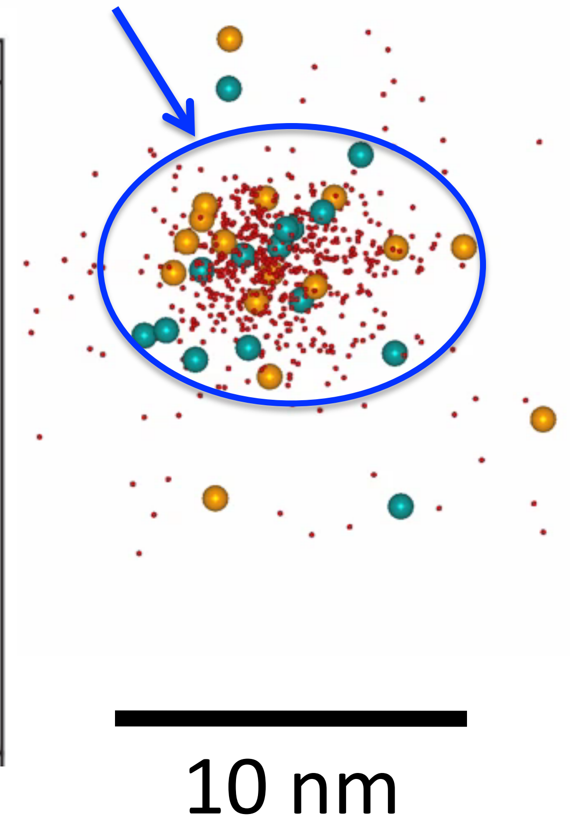


1 cluster, 25 Pb atoms
$^{207}Pb/^{206}Pb = 1.1$ (13/12)

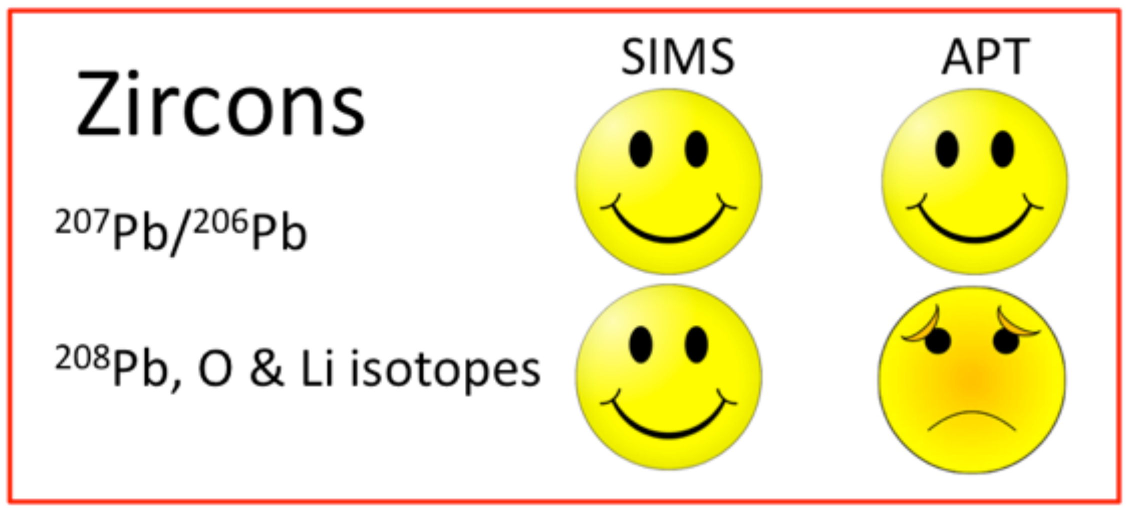


Valley et al. 2016, GSA, Denver

Small is always better...... until it isn't.

How Small is Too Small for Isotope Ratio Analysis?

Depends on the application:
- <≈ 0.5 µm for $\delta^{18}O$ at natural abundance
- <≈ 10 nm for $^{207}Pb/^{206}Pb$ in Archean clusters



Valley et al. 2016, GSA, Denver