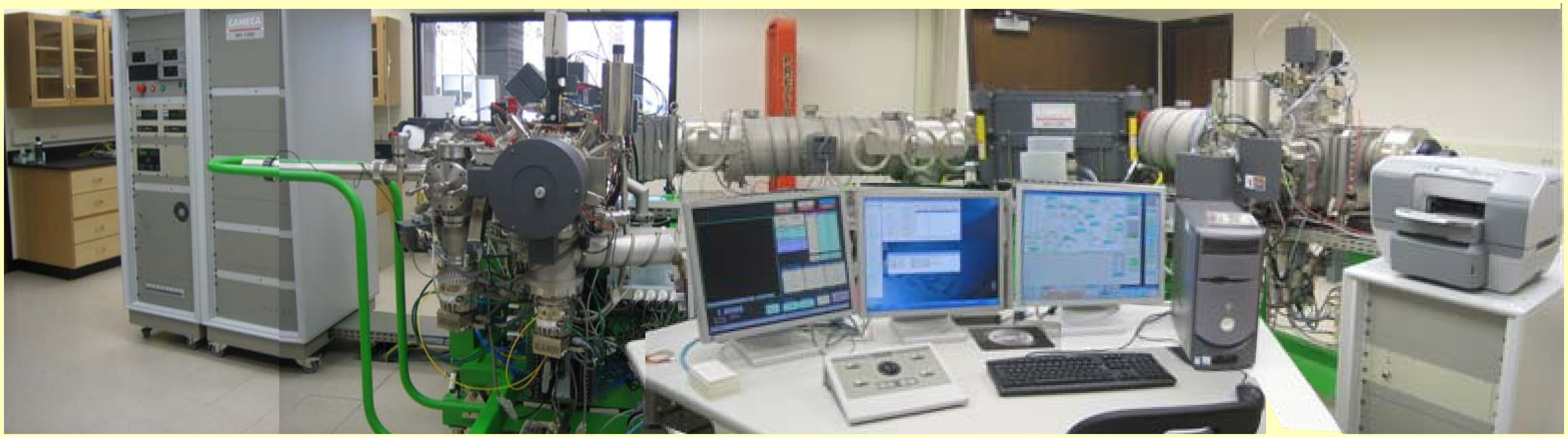
Cosmochemical application of High Precision Multi-collector SIMS



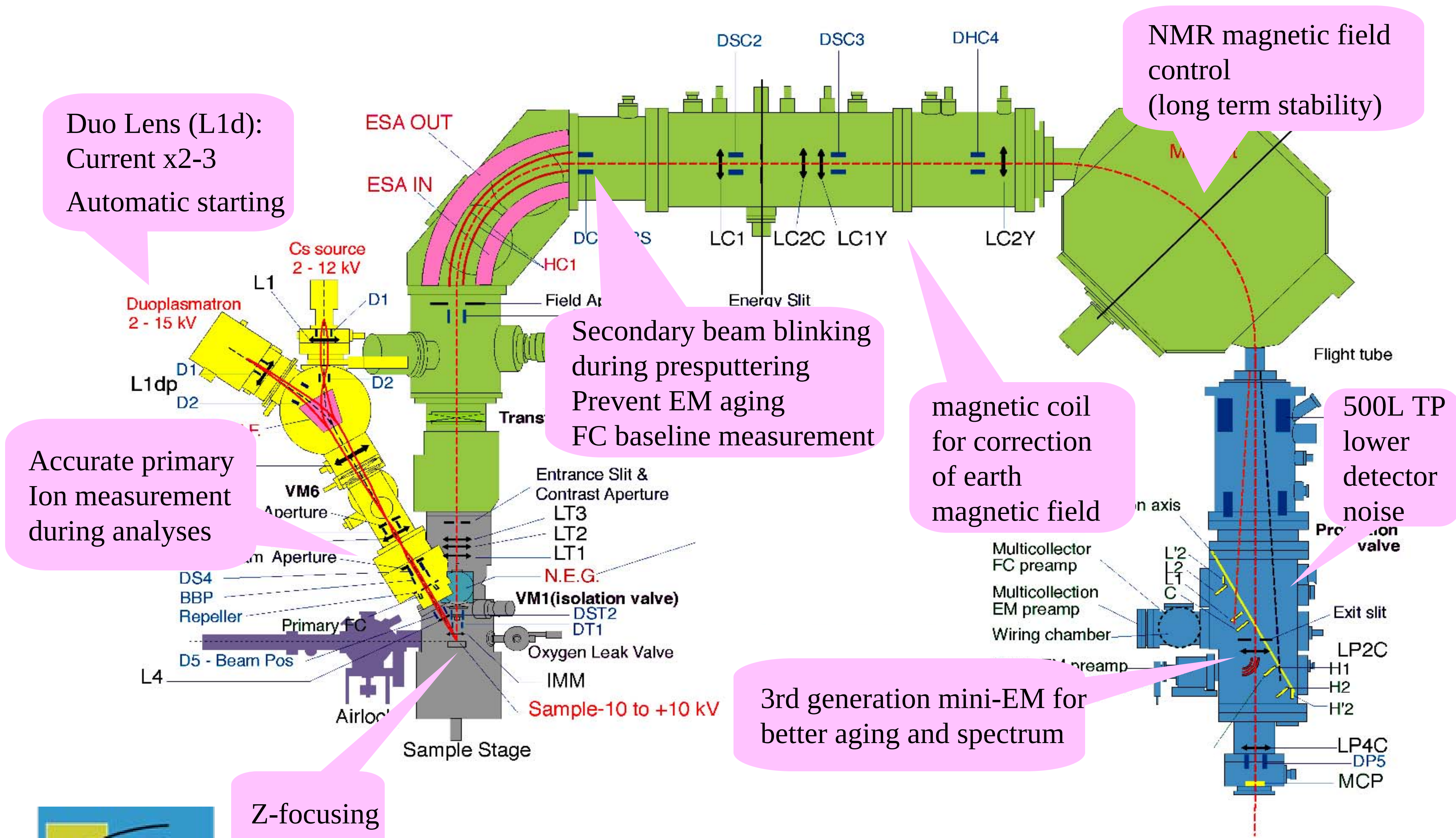
- Oxygen Three Isotopes in Chondrules
- Early Solar System Chronology of Refractory Inclusions

Noriko Kita

Wisc-SIMS Laboratory, University of Wisconsin-Madison

Taka Ushikubo, John Valley, John Fournell
Hiroko Nagahara, Shogo Tachibana, Makoto Kimura, Tomoki Nakamura
Andrew M. Davis, Frank Richter, Kim Knight, Ruslan Mendybaev

CAMECA IMS-1280: New Generation Large Radius Sector SIMS



Multi-collection System: 4 Faraday Cups (FC)

3 small Electron Multipliers (EM)

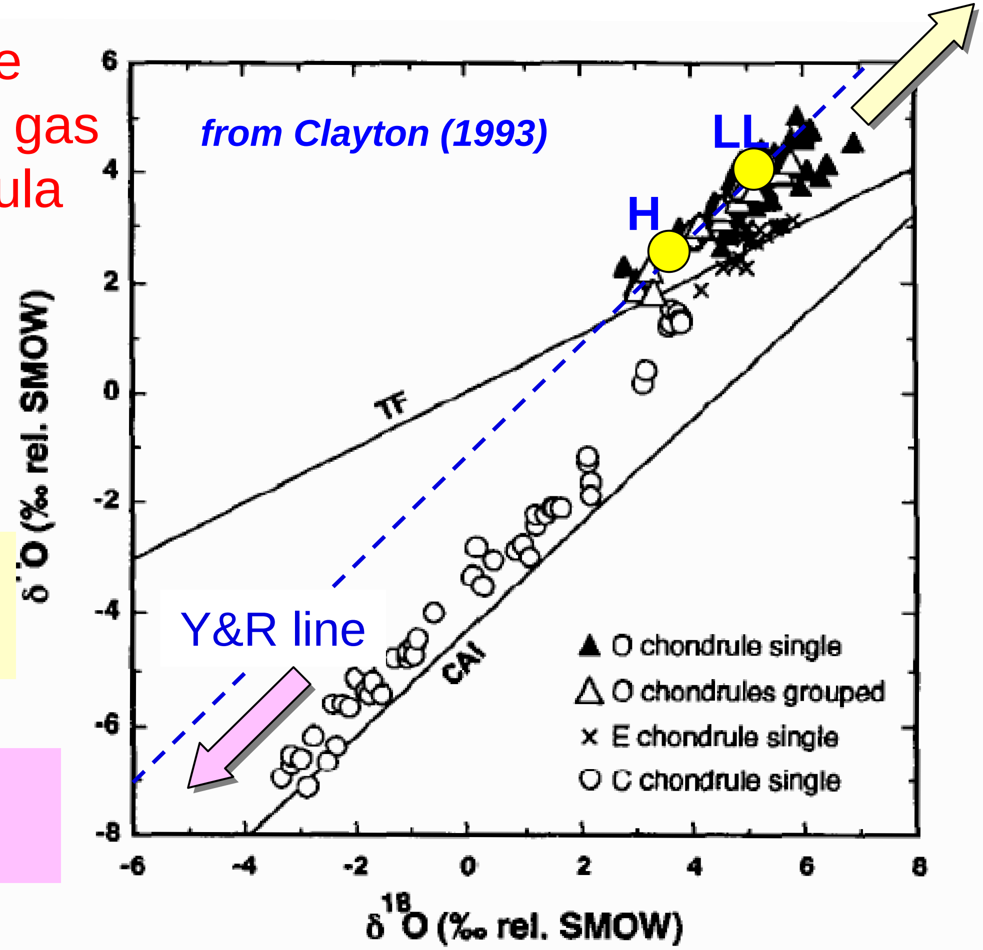
Mono-collector (Axial) : 2 FCs and 1 normal size EM

Oxygen Isotopes in Chondrules from Ordinary Chondrites

Process of oxygen isotope exchange between ^{16}O-rich solid and ^{16}O-poor gas at high temperature in the solar nebula

Clayton et al. (1991): bulk

- scatter along bulk H-L-LL
- no relation to host chondrite
- no relation to chondrule types



Bridges et al. (1998; 1999):
feldspar and glass show high $\Delta^{17}O$

Russell et al. (2000): Ion Microprobe
Al-rich chondrules are more ^{16}O rich

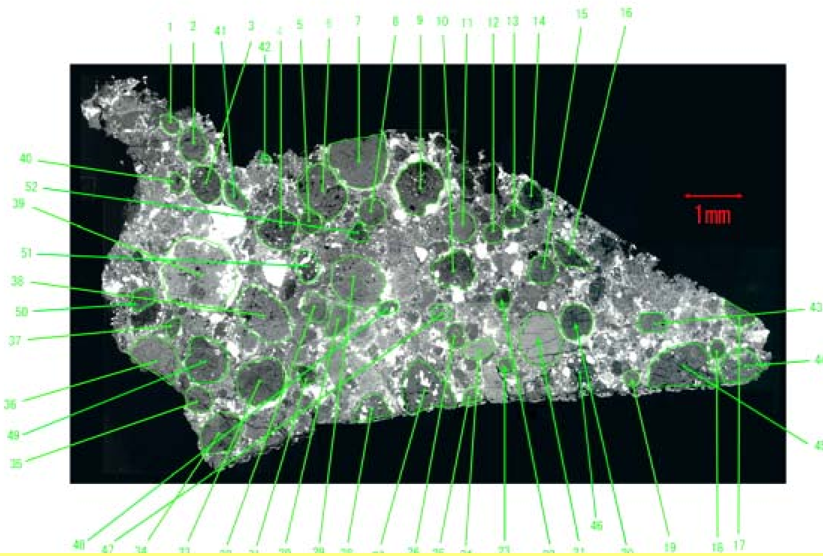
No detailed SIMS study in the past:
Variations among normal chondrules were too small for previous SIMS analytical uncertainty

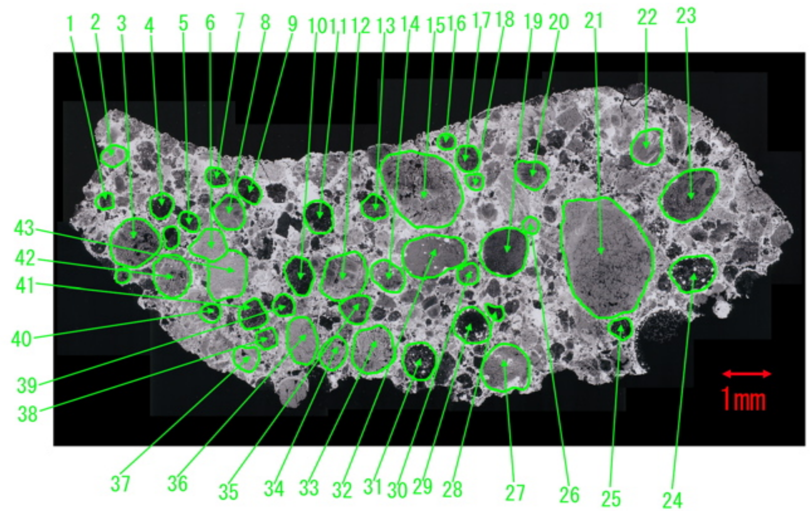
Systematic Survey of Chondrules from LL3.0-3.1

The least equilibrated ordinary chondrites:
Semarkona (LL3.0), **Bishunpur** and **Krymka** (LL3.1)

Al-Mg chronology and bulk chemical compositions: Kita et al. (2000); Mostefaoui et al. (2002); Tachibana et al. (2003); Kita et al. (2005)

Tomomura et al. (2004): Bulk compositions of ~70 randomly selected chondrules





This Work: In-situ oxygen isotope analyses of 36 chondrules from Semarkona (N=12), Bishunpur (N=17), and Krymka (N=7) that cover entire range of chondrule types.

Oxygen Three Isotope Analyses (Multi-FC Mode)

Cs+ **5 nA focused beam (15μm)** no raster

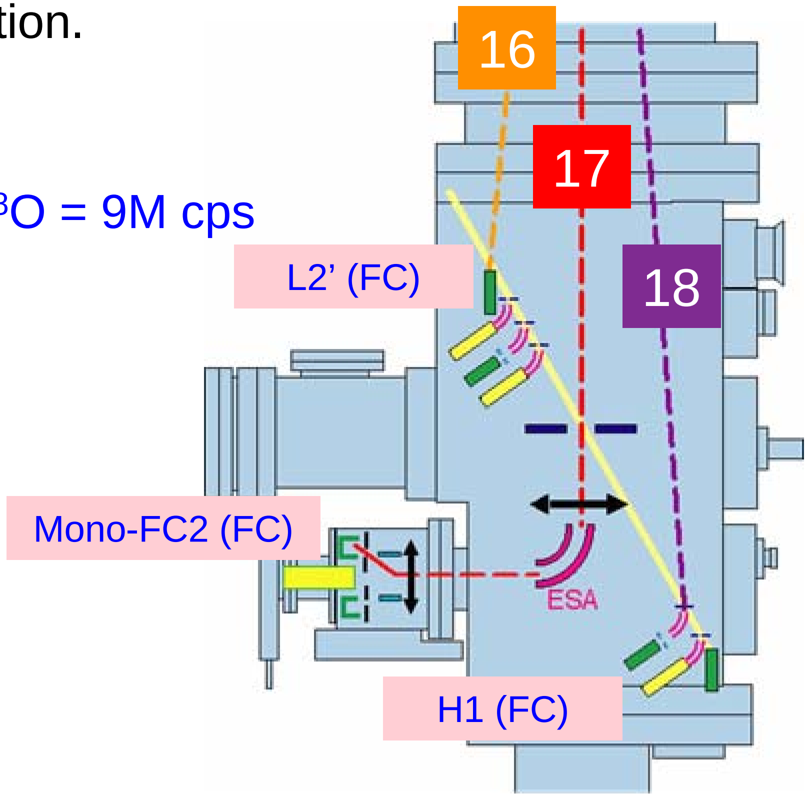
Electron gun is used for charge compensation.

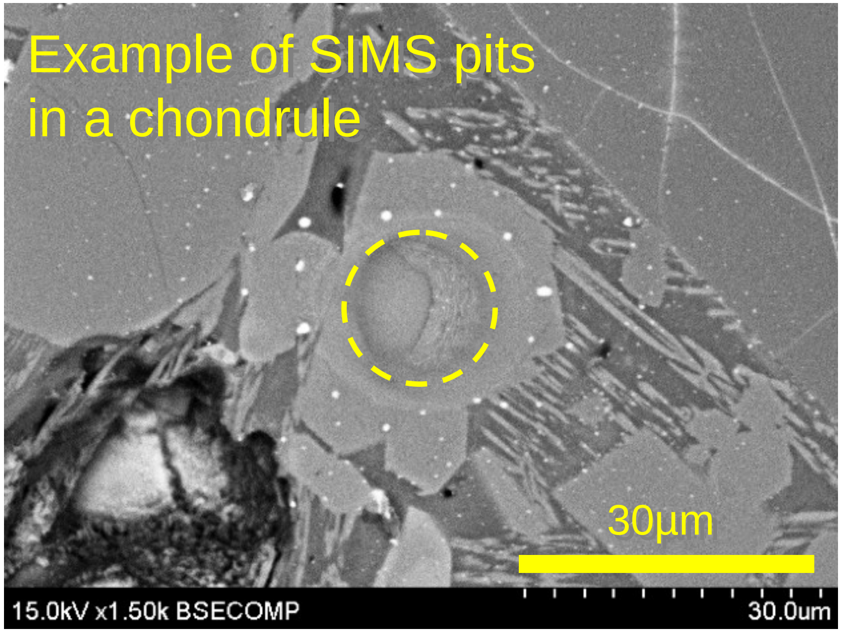
MRP =2500 for Multi-collector

MRP =4500 for Mono-collector

Secondary Ions: ^{16}O = 4.5G, ^{17}O = 1.7M, ^{18}O = 9M cps

Integration time: **200s** (=10s x 20 cycles)

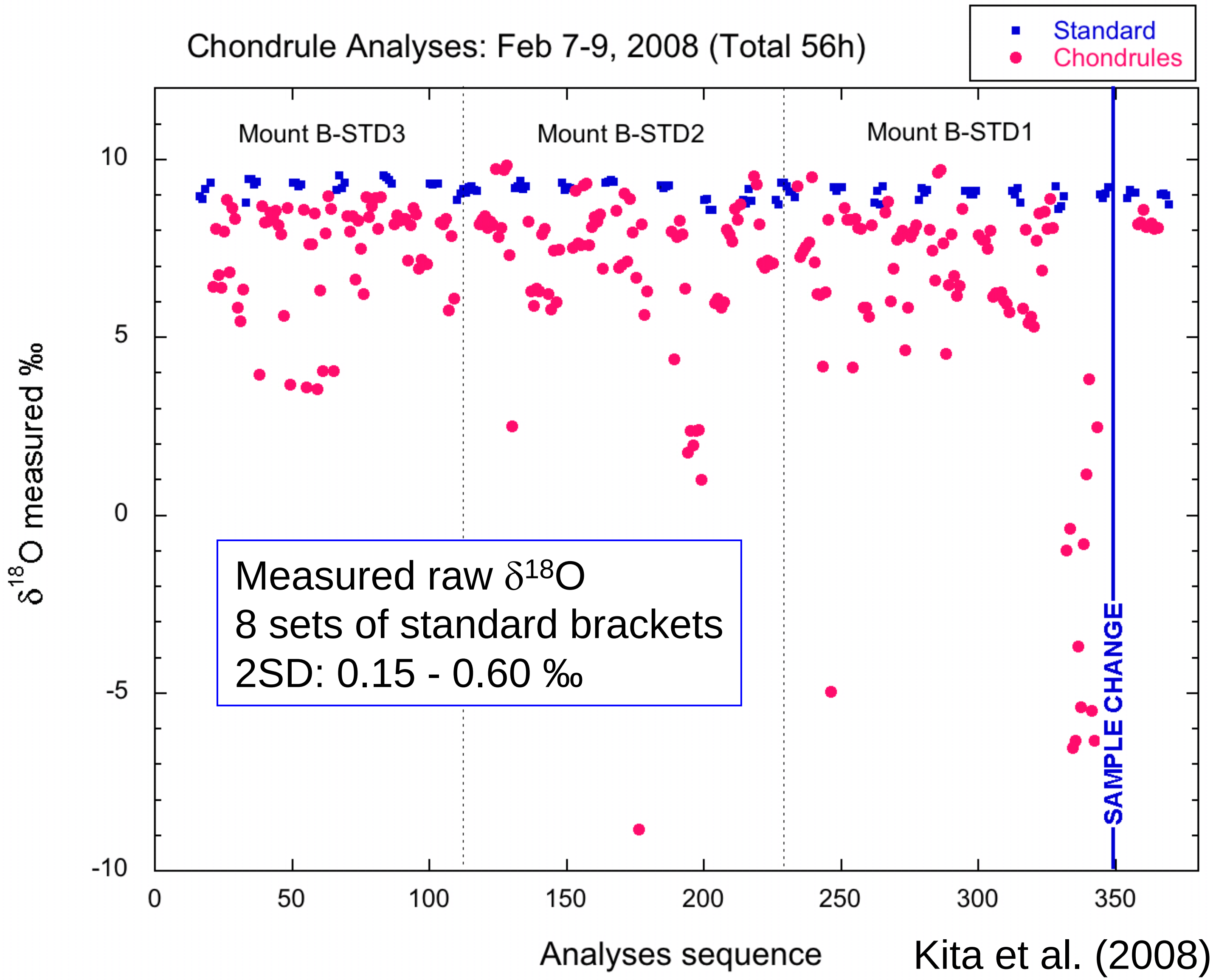




8min/spot

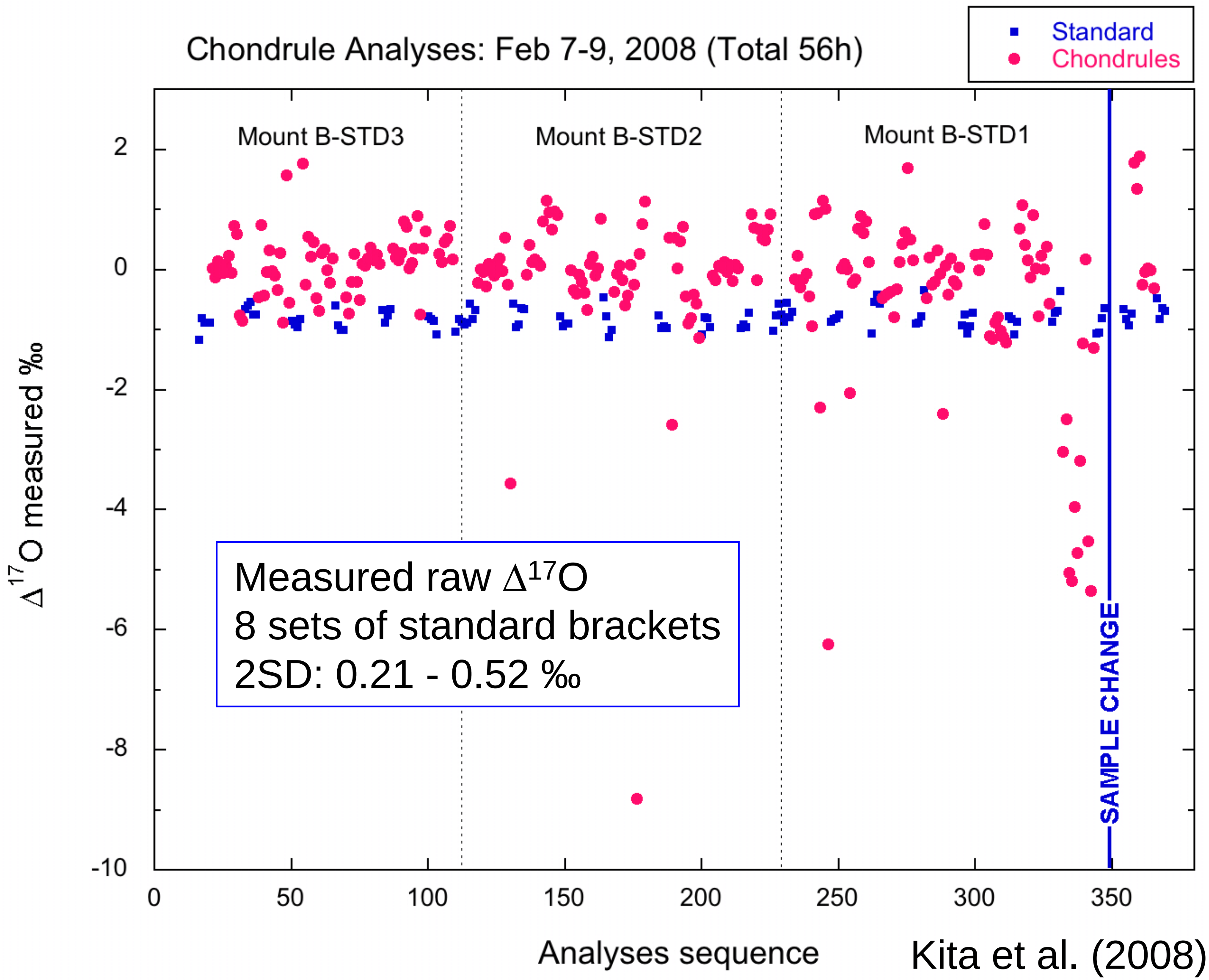
Typical Reproducibility 0.3-0.4‰ (2SD)

Reproducibility of Standards ($\delta^{18}O$)



Kita et al. (2008)

Reproducibility of Standards ($\Delta^{17}O = \delta^{17}O - 0.52 \times \delta^{18}O$)

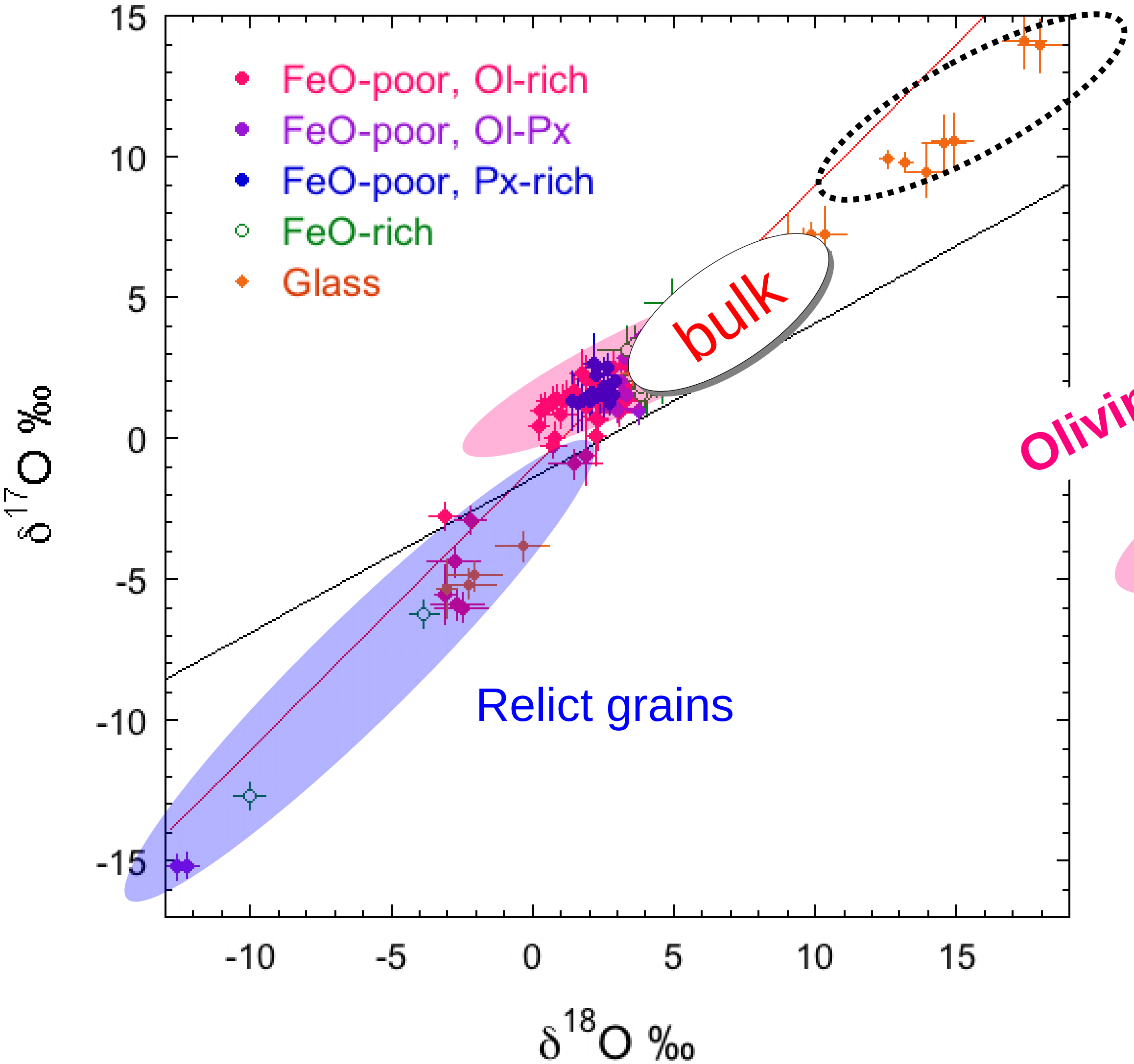


Kita et al. (2008)

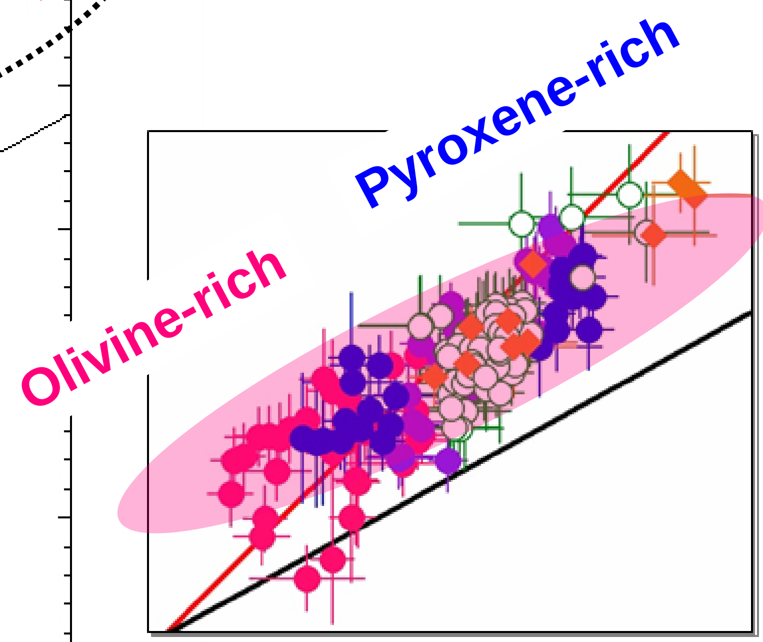
Chondrules from Ordinary Chondrites (LL3.0-3.1)

(Kita et al., LPSC 2006; 2007)

209 spots from 36 chondrule



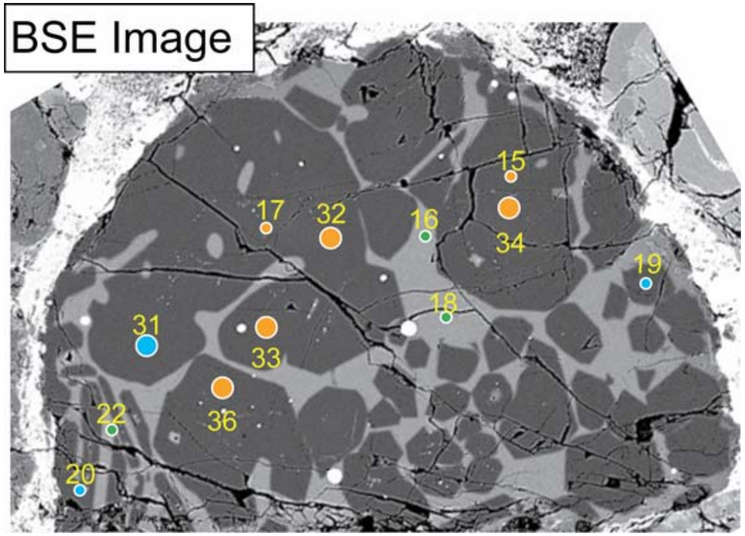
Alteration of glass

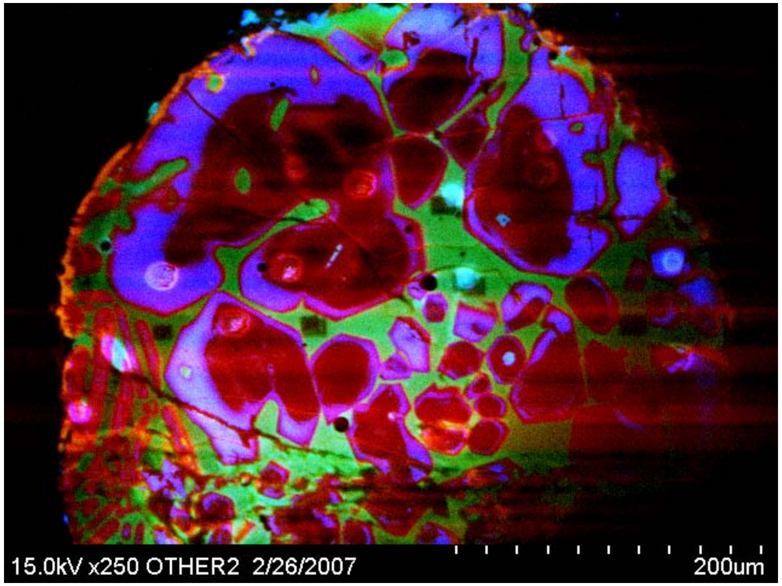


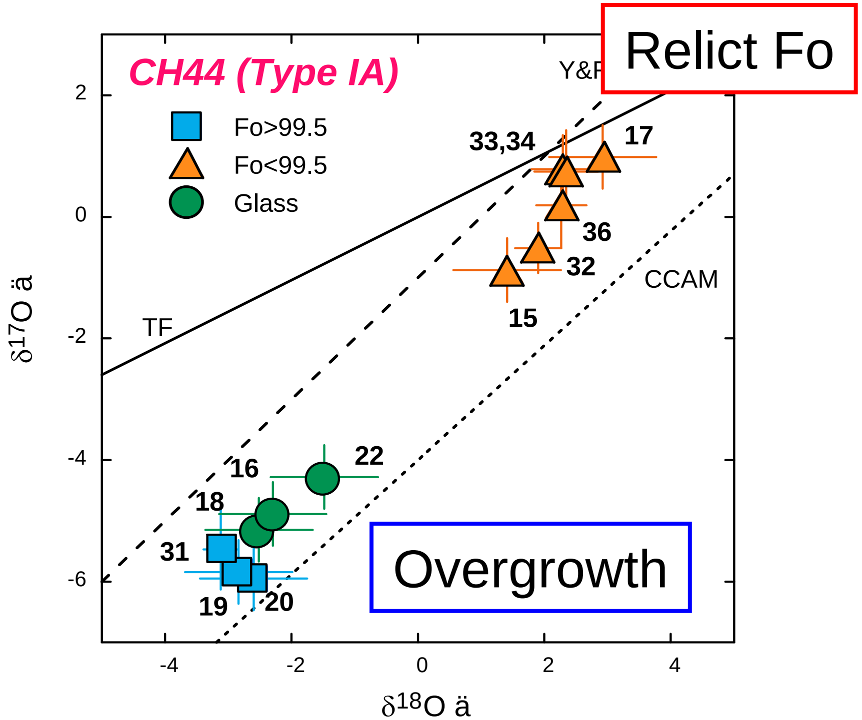
Evaporation and Condensation during Chondrule formation

Relict ^{16}O-poor Fo in ^{16}O-rich melt-grown olivine

(Kita et al., LPSC 2007)







^{16}O-poor forsterite

^{16}O-rich refractory forsterite (Ca, Al-rich)

^{16}O-rich Al, Ca-rich Glass normal

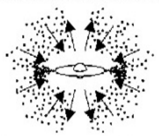
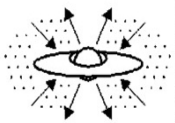
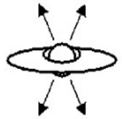
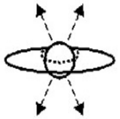
No evidence of isotope exchange between ^{16}O-poor gas and melt

^{26}Al-^{26}Mg (0.73Ma) Chronology of Ca, Al-rich Inclusions (CAIs)

Initial Ratios of (^{26}Al/^{27}Al) in CAIs ~5×10^{-5} (MacPherson et al., 1995)

Supra-Canonical Value? $(6\text{-}7)\times10^{-5}$ using ICP-MS and SIMS
(Young et al., 2005; Thrane et al., 2006; Cosarinsky et al., 2007)

Protostar: 0.01-0.1 Myr

PROPERTIES	*Infalling Protostar*	*Evolved Protostar*	*Classical T Tauri Star*	*Weak-lined T Tauri Star*	*Main Sequence Star*
SKETCH					
AGE (YEARS)	10^4	10^5	$10^6 - 10^7$	$10^6 - 10^7$	$> 10^7$
mm/INFRARED CLASS	Class 0	Class I	Class II	Class III	(Class III)

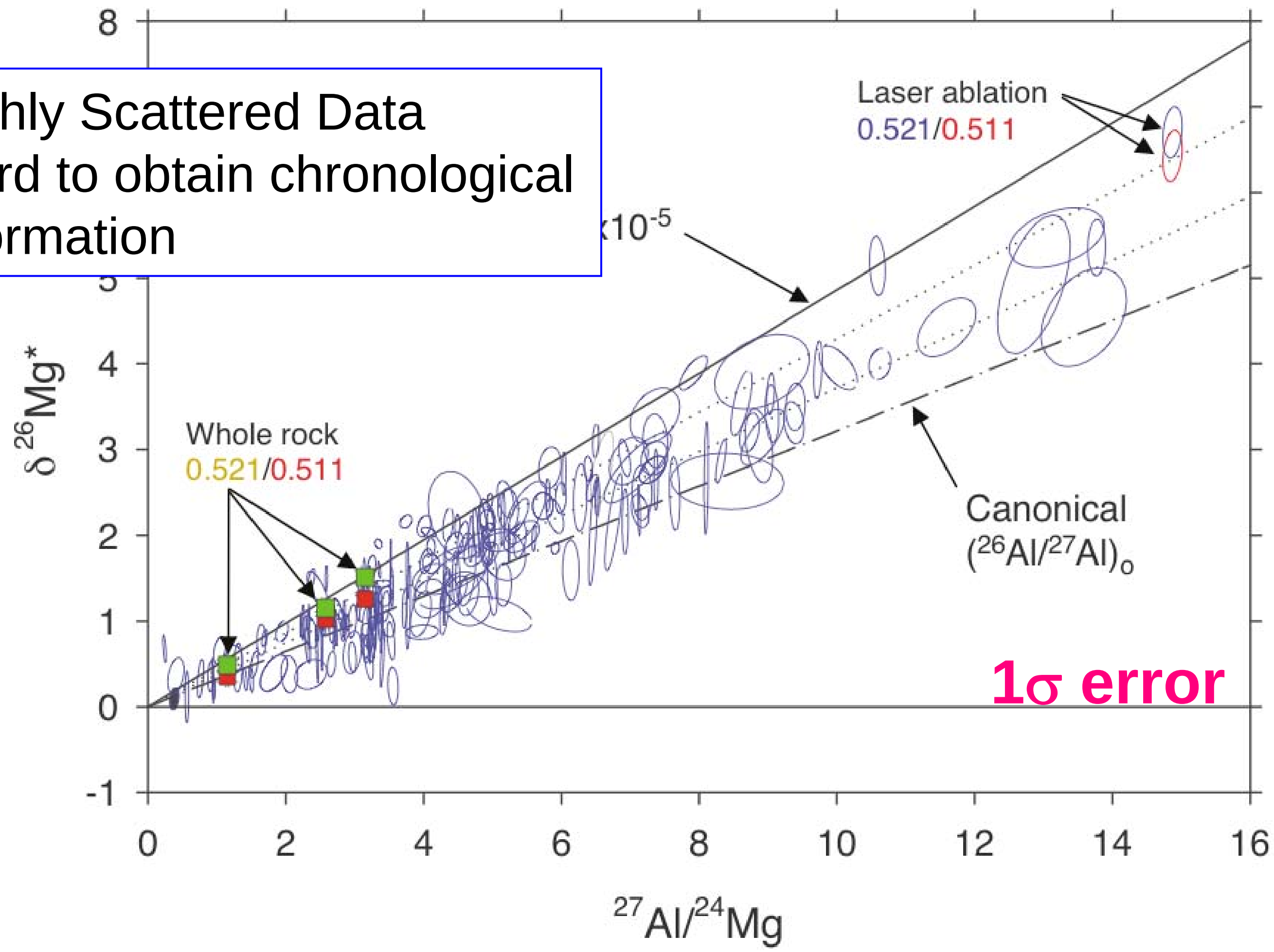
CAI formation could be
- as short as 0.02 Myr ?
- as long as 0.4 Myr ?

Time Scale of proto-planetary disk evolution (Feigelson and Montmerle, 1999)

Variation of $^{26}Al/^{27}Al$ ratios in CAIs (Canonical or Supra-Canonical?)

Young et al. (2005): (4-7)e-5, Laser ICP-MS internal isochrons

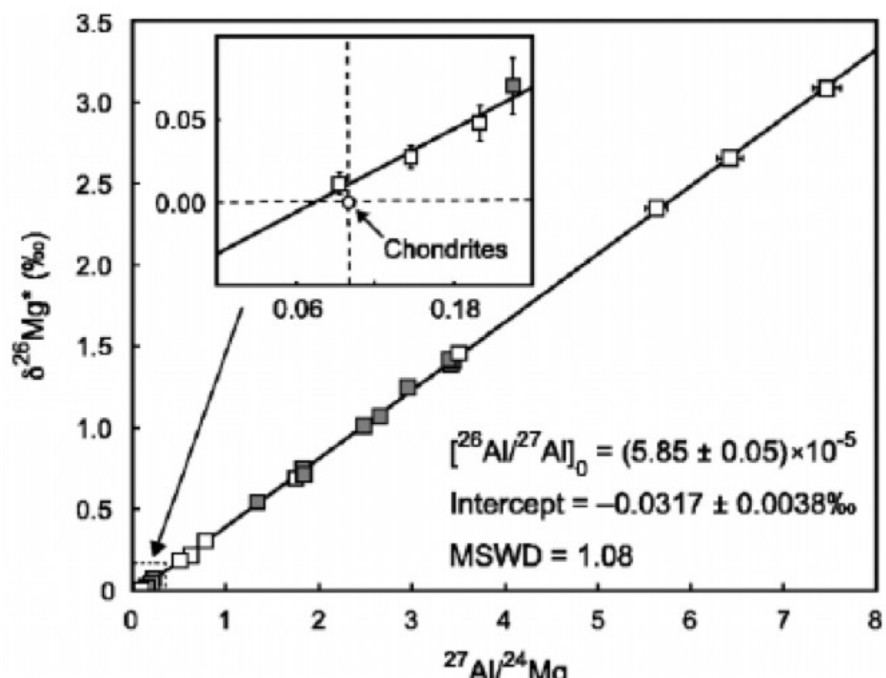
Highly Scattered Data
-hard to obtain chronological information



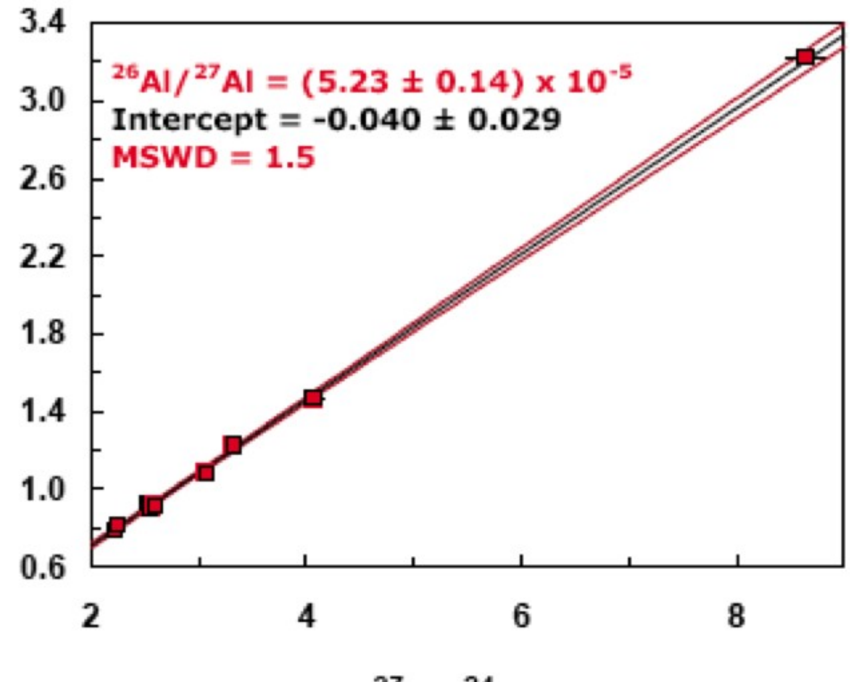
Variation of $^{26}Al/^{27}Al$ ratios in CAIs (Canonical or Supra-Canonical?)

ICP-MS bulk isochrons: Two data differ by 10%, 0.1 Myr

Thrane et al. (2006): (5.85±0.05)e-5



Jacobsen et a;. (2008): (5.23±0.13)e-5



Goal: High Time Resolution Chronology (≤ 20kyr)

by In-situ SIMS analyses of Al-rich phase

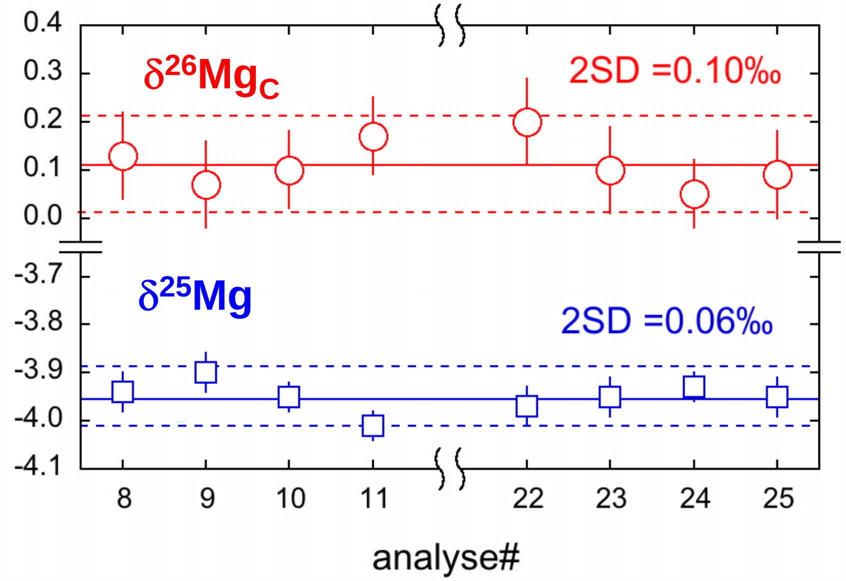
Melilite (Ca_2AlSiO_7-$Ca_2MgSi_2O_7$), Anorthite ($CaAl_2Si_2O_8$)

Reproducibility of Mg isotope analyses

Synthetic Melilite standard (Åk100, Åk20-70, Åk67Glass)

20µm spots
Multi-collector Farady Cups (8min/spot)
$^{24}Mg = (0.5\text{-}2)\times10^8$ cps, 300s integration
Mass fractionation correction factor: 0.514

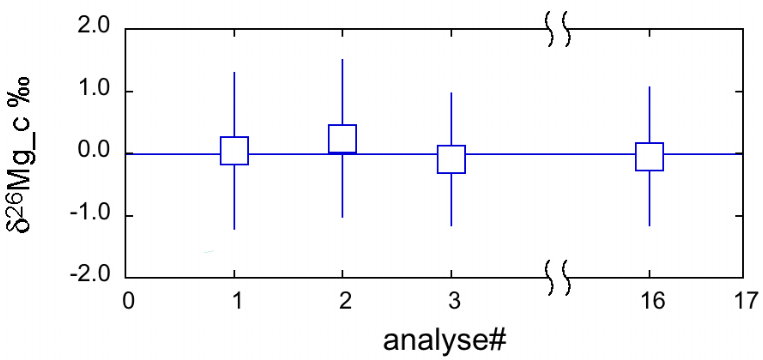
Reproducibility of Ak67 Glass
$^{27}Al/^{24}Mg \ll 1\%$; $\delta^{26}Mg < 0.1‰$



Plagioclase standard (Natural crystal and synthetic glass)

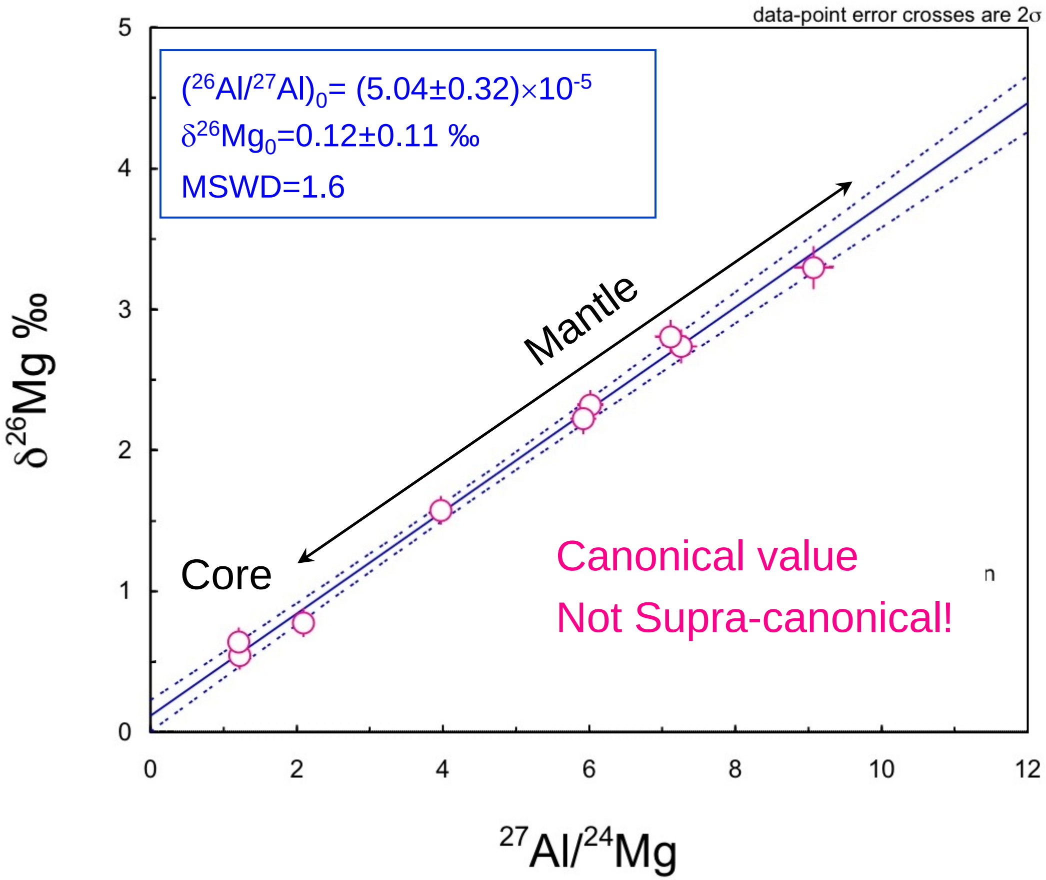
8µm spots
Single collector EM ($^{24, 25, 26}Mg$) + multi-FC(^{27}Al)
$^{24}Mg \sim 2\times10^5$ cps for 0.1% MgO (30s x 50 cycles))

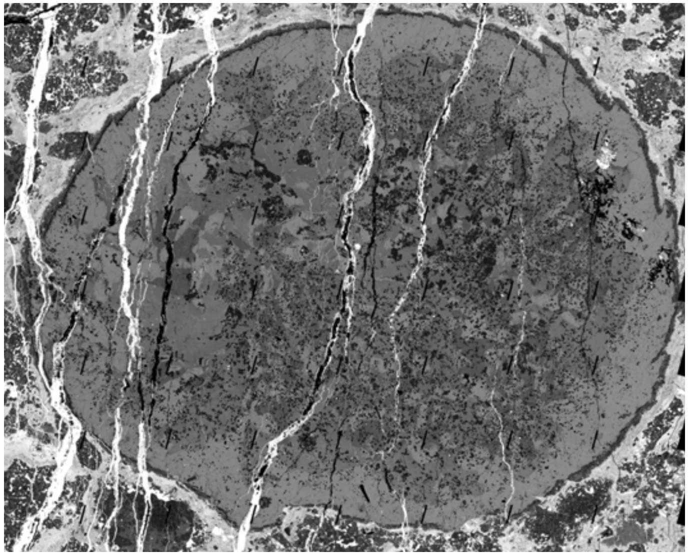
Reproducibility of An60 standard
$^{27}Al/^{24}Mg < 1\%$; $\delta^{26}Mg < 1‰$

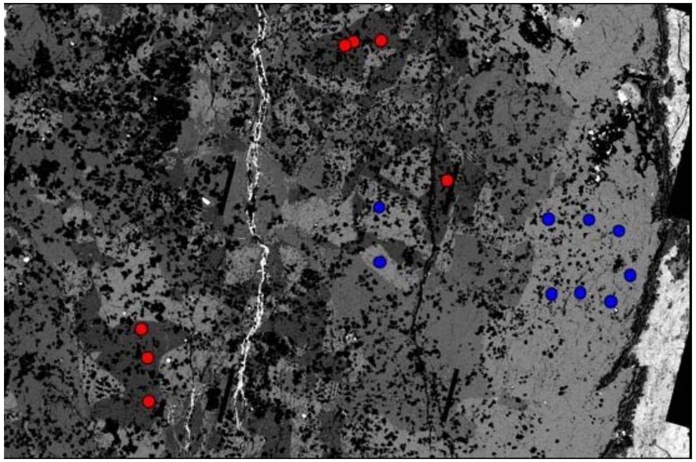


➡ **Corresponding isochron error as small as 2-3% (=30Ky)**

Melilite Isochron (20µm spot)



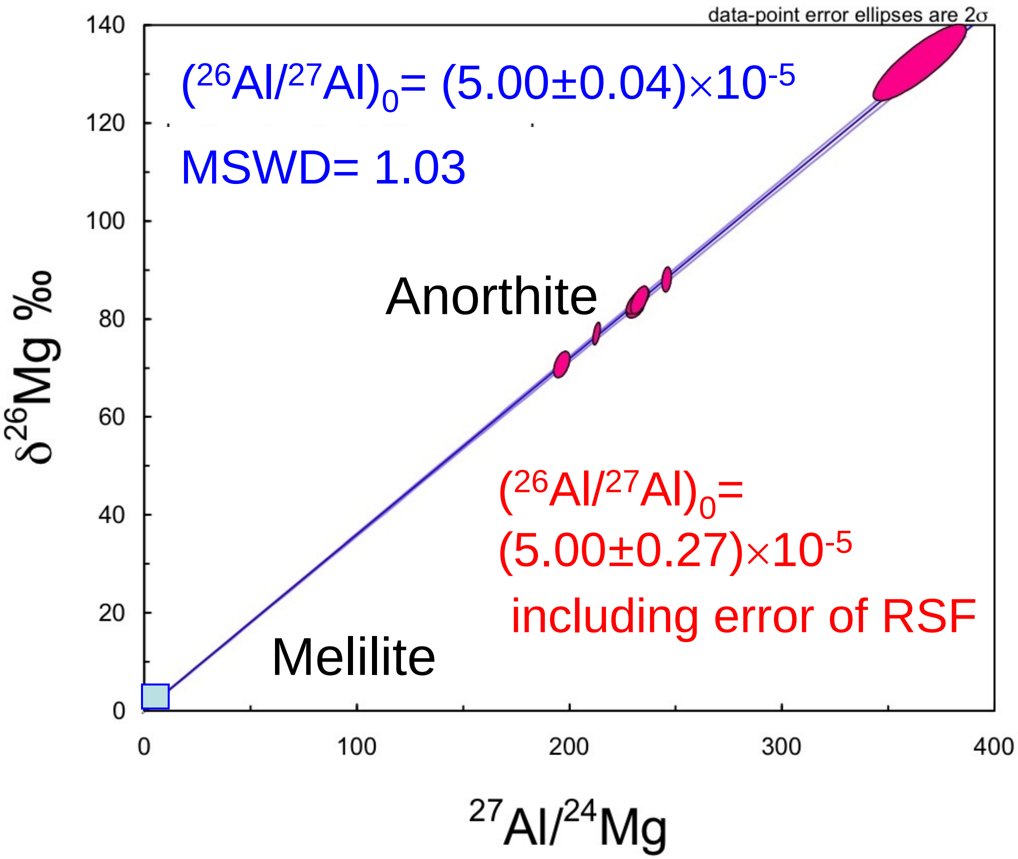


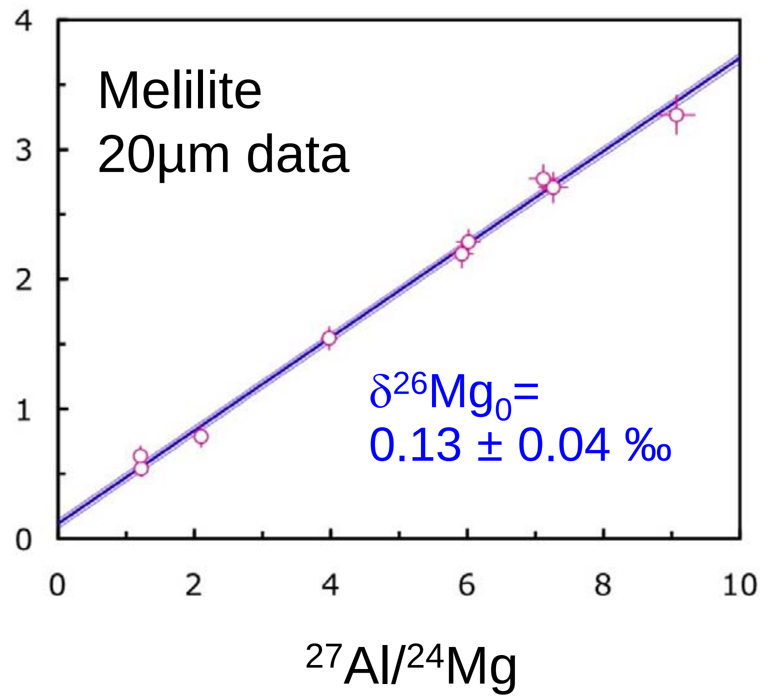


The same CAI was studied for Mg isotope fractionation in zoned melilite (Richter et a., 2007; Knight et al., 2008)

Anorthite melilt e

Melilite+Anorthite Combined Data

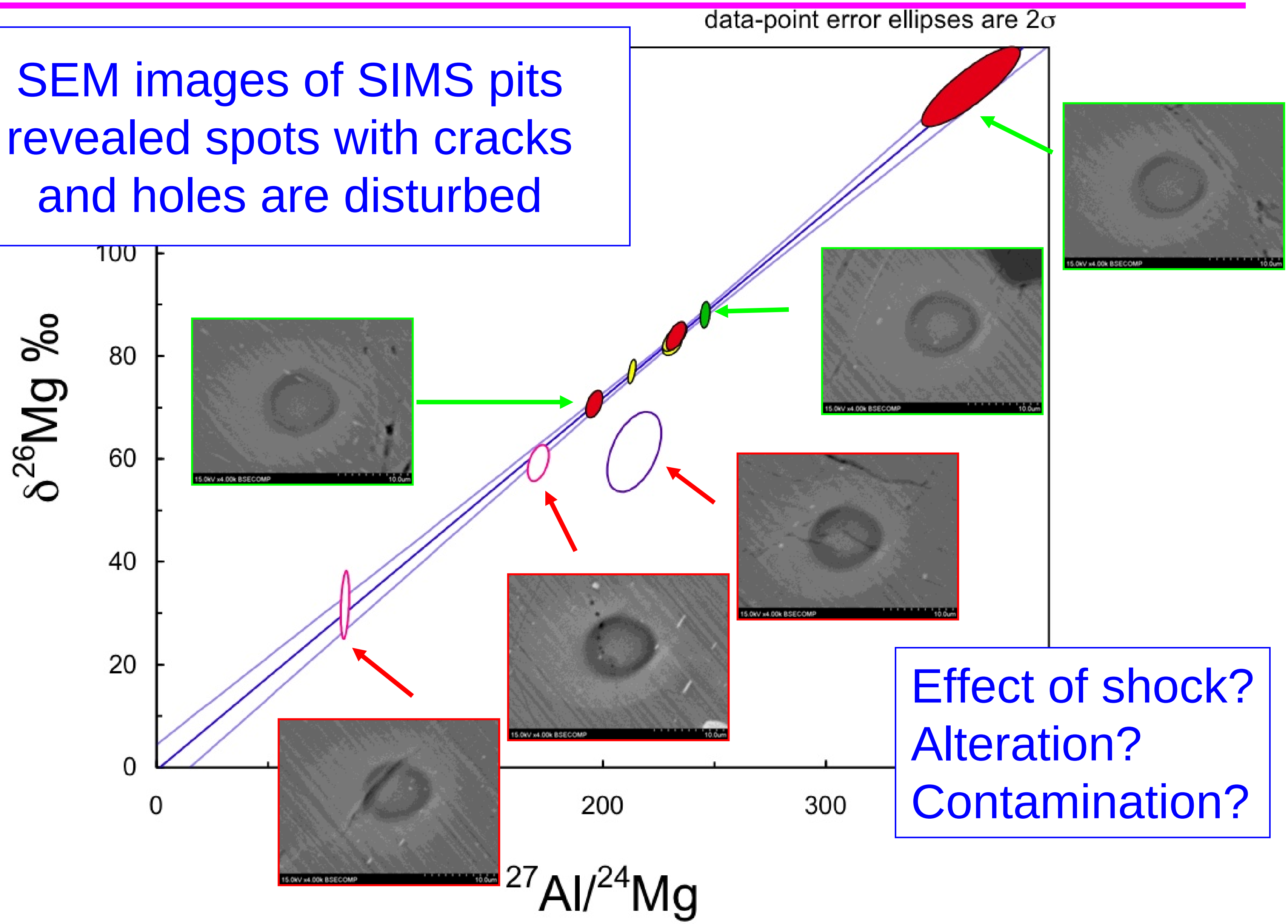




- Consistent with Canonical initial (Jacobsen et al., 2008).
- Well-defined isochron with age error ~8ky.
- Slightly elevated initial $\delta^{26}Mg$; remelting of refractory precursor?

A few An spots did not plot on the isochron: After SIMS SEM Evaluation

SEM images of SIMS pits revealed spots with cracks and holes are disturbed



Effect of shock?
Alteration?
Contamination?

Concluding Remarks

High Precision SIMS analyses provide us new set of information that was not available before

Oxygen Isotopes in chondrules

- Evidence for evaporation and condensation
- mixing of different precursors

Oxygen Isotopes in Stardust returned samples

- Heterogeneous oxygen isotope within a few µm scale

Al-Mg chronology of CAIs

- High time resolution <10kyr
- Evaluation of isotope closure since the formation