GENESIS

SEARCH FOR ORIGINS

Semiannual Science Report to NASA

Nov. 2010

D. S Burnett and Genesis Science Team

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Introduction

The following 13 slides are a Genesis Misson overview, common to all Progress Reports.

What: Mission in a Nutshell

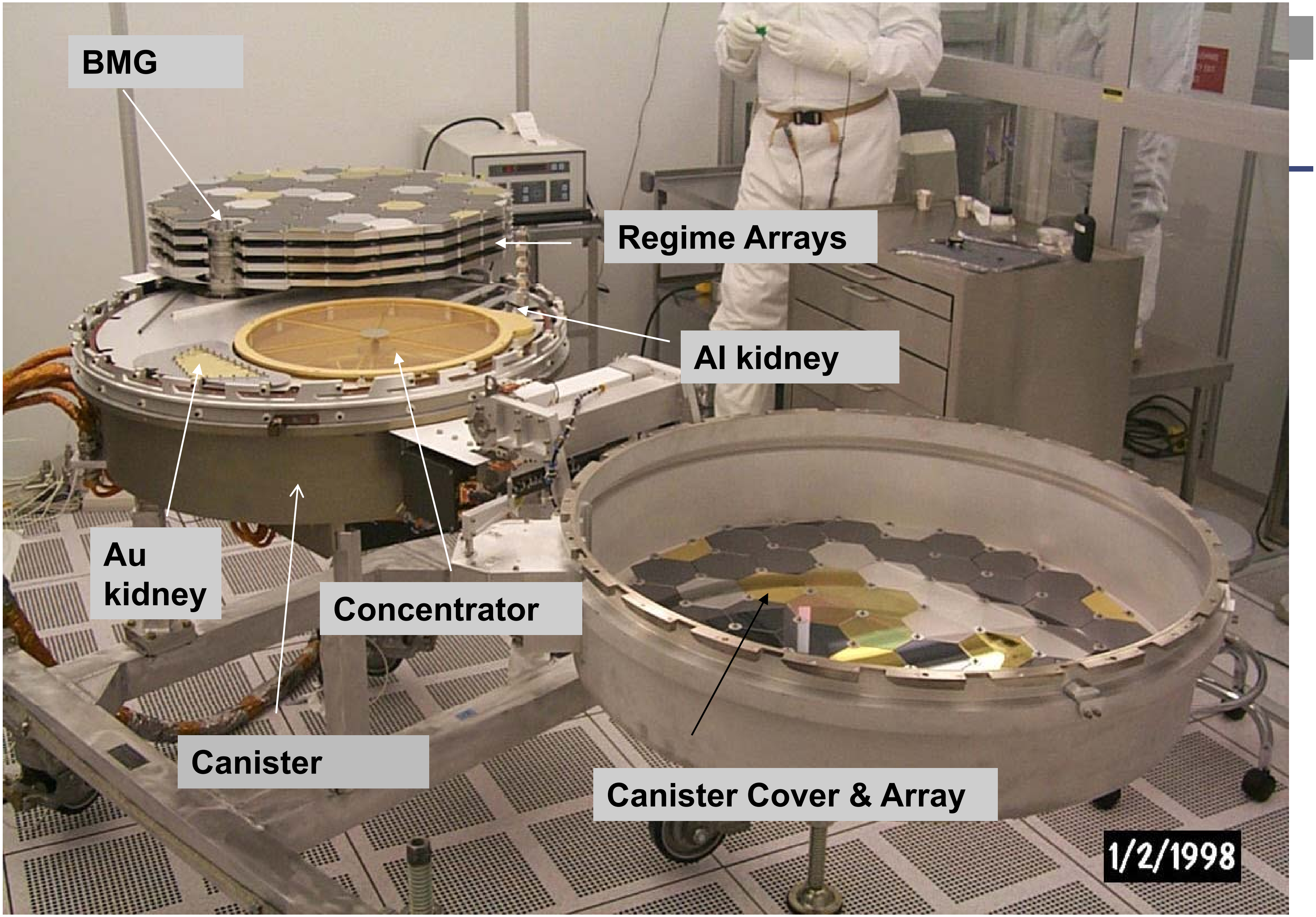
- Placed a spacecraft outside the terrestrial magnetosphere

- Exposed Materials
  - Solar wind ions (keV/amu) implant and stick
  - Exposed for 27 months
  - Fluences low, so materials must be ultrapure.

- Returned materials to Earth for analysis in terrestrial laboratories.

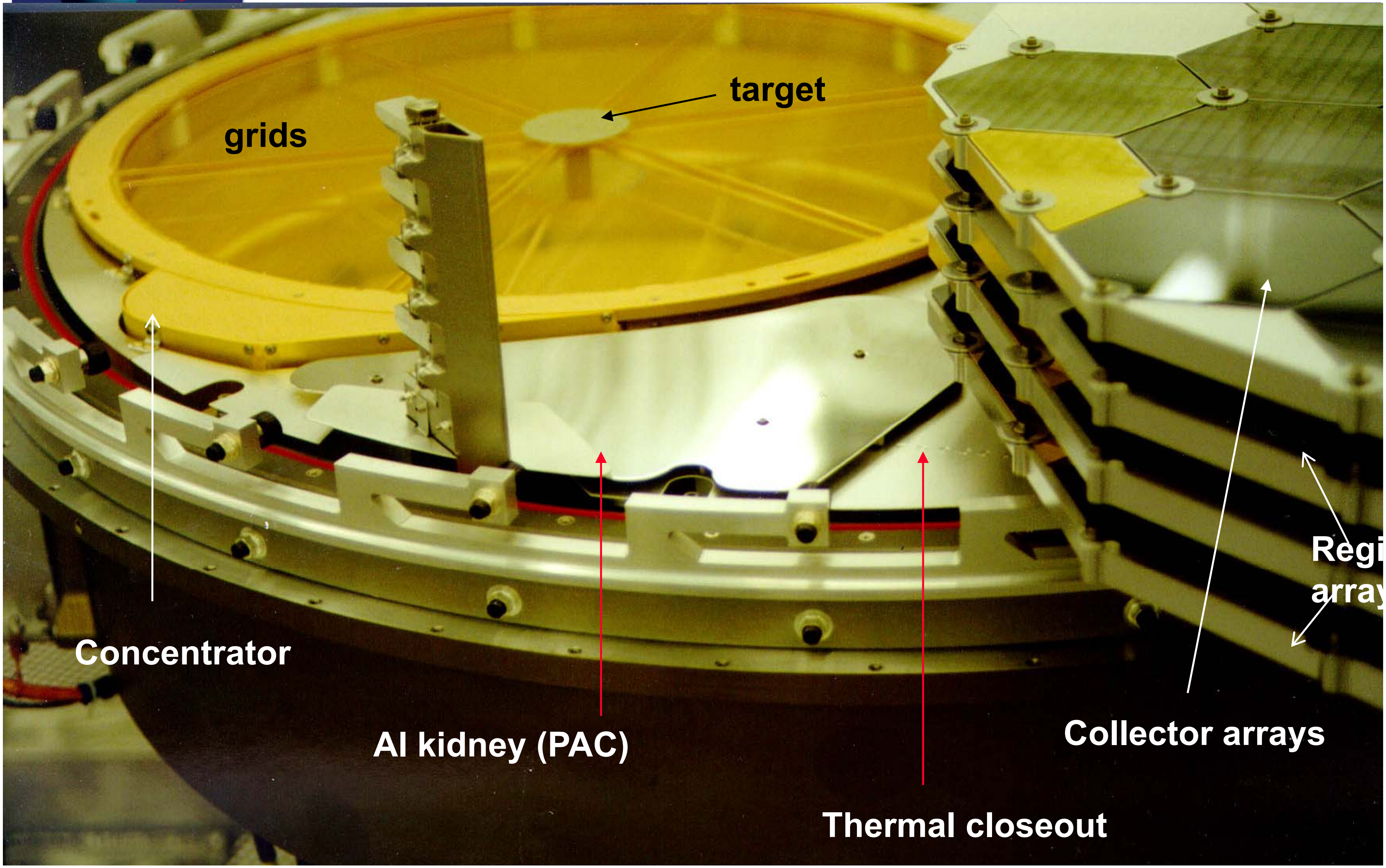
Why: Genesis Science Objectives

- Provide solar isotopic abundances to level of precision required for planetary science purposes.
- Provide greatly improved knowledge of solar elemental abundances.
- Provide a reservoir of solar matter to meet the needs of 21st century planetary science.
- Provide elemental and isotopic data for the 3 different types (“regimes”) of solar wind.



The Genesis Payload

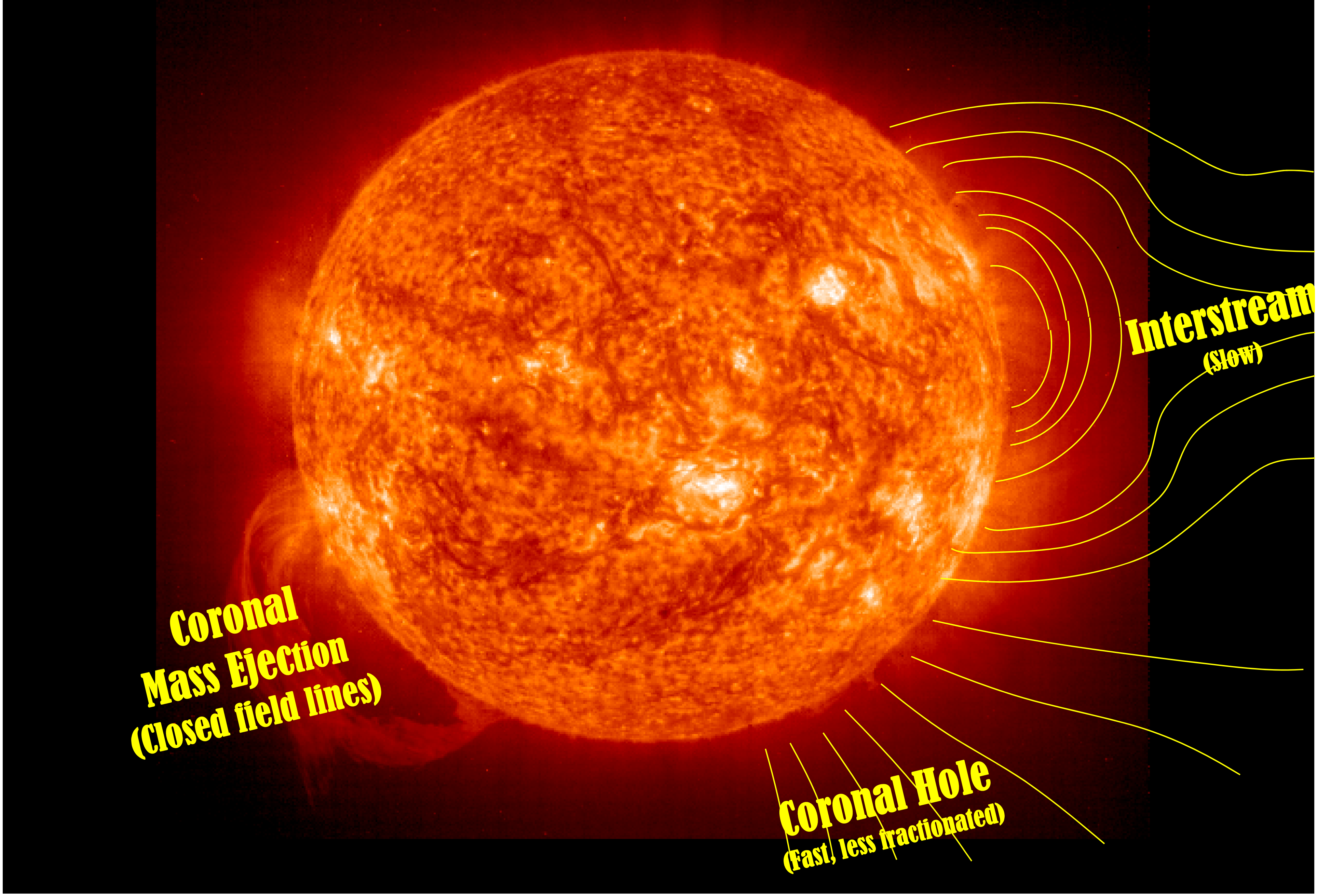
Canister and Collector Materials pre launch



Solar Wind Regimes

- Three different kinds (“regimes”) of solar wind:
  - High speed (coronal hole) Genesis H array
  - Low speed (“interstream”) Genesis L array
  - Coronal Mass Ejections Genesis E array.
- Genesis separately sampled each of 3 solar wind regimes as well as bulk solar wind:
  - Allows correction for differences in composition between sun and solar wind
  - Agreement in derived solar composition from different regimes validates correction procedures

Types of Solar Wind

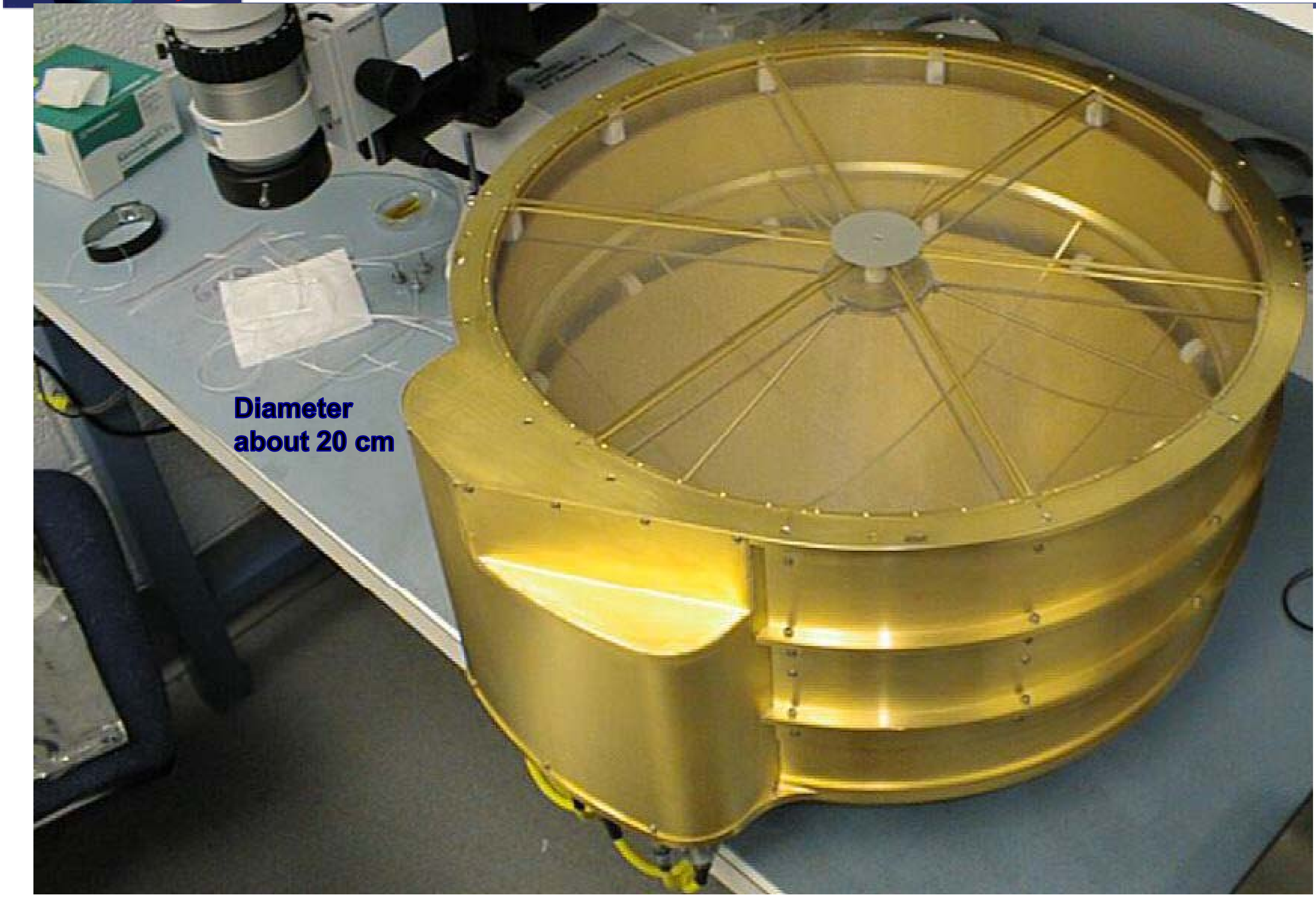


Interstream
(Slow)

Coronal
Mass Ejection
(Closed field lines)

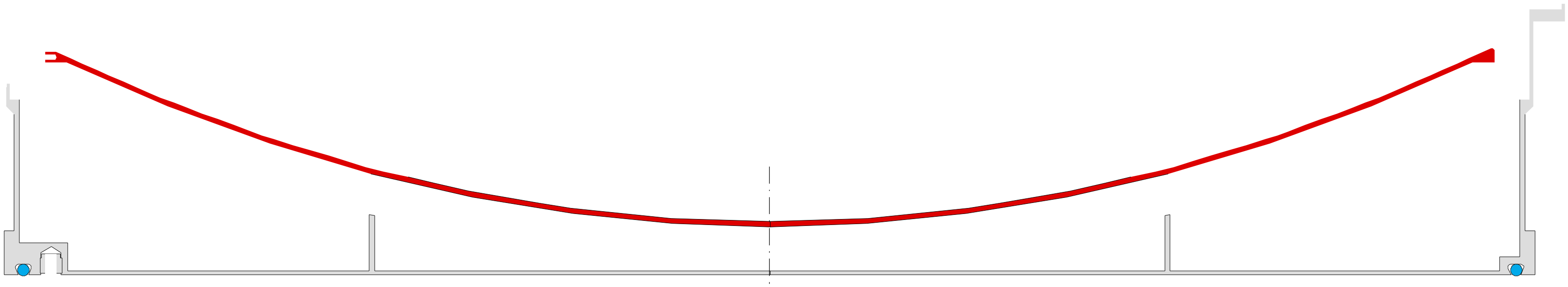
Coronal Hole
(Fast, less fractionated)

Concentrator: Focusing Ion Telescope



Diameter
about 20 cm

Concentrator Cross-section



Purpose of the Concentrator (LANL)

- Increase the Concentration of Solar Wind Ions Relative to the Background Contamination
  - Specifically for Oxygen and Nitrogen
  - Also for Any Other Elements < about 36 AMU
    - Mass range verified by post-recovery analysis
  - Four target 30mm radius quadrants.
  - C Excluded Due To Its Presence In Target Materials:
    - Silicon Carbide (O)
    - 13C CVD Diamond (O)
    - Amorphous Diamond-like-C Film on Si (N)
      - Small areas of bare Si: C isotope analyses may be possible.
  - Average Concentration of 20x Over Whole Target
  - Designed to Reject 93% of Protons to Avoid Radiation Damage
    - Limitations in flight rejection grid voltage lowered this to about 85%
- Mass fractionation can be well characterized to attain precise isotope ratios (see O isotope section).

Analysis Overview

- Genesis sample analysis is proceeding on a broad front in 26 laboratories worldwide.
- Rates vary, but progress is being made; 2009-2010 is a particularly good period.
- The goal of Genesis is quantitative data; great emphasis on getting numbers right.
- A major advantage of sample return missions is that important data can be verified, and in most cases, replicated with different techniques.
- A major effort has been to make accurate, replicated measurements of the fluences of Mg and Ne. Most techniques can analyze one of these elements, which will then constitute primary quantitative reference fluences for other elements.

Analysis Overview, con’t

Two distinct requirements:

- **Extract implanted solar wind from collector materials.**
- **Analyzed extracted solar wind.**

Can mix and match approaches for extraction and analysis.

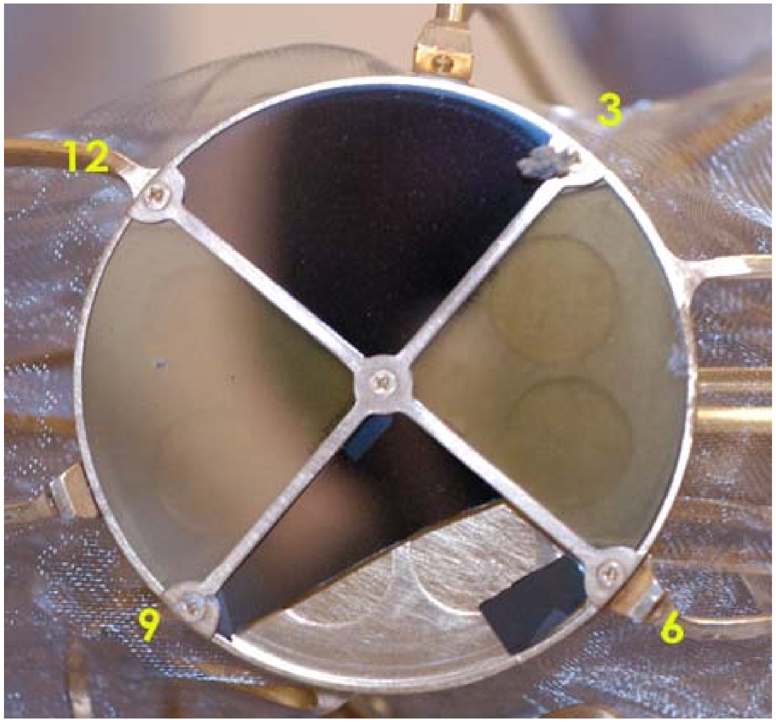
Mass spectrometry is the most widely-used analysis technique.

Science Team Analysis Methods

- Secondary Ion *Mass Spectrometry (SIMS)*
  - Solar wind extracted by ion beam sputtering
- Gas Source *Mass Spectrometry*
  - Extraction by laser ablation or chemical etching (HNO_3, Hg)
- Resonance Ionization *Mass Spectrometry (RIMS)*
  - Extraction by ion beam sputtering
- Total Reflection X-ray Fluorescence
  - *in-situ* analysis; unique in not requiring extraction.
  - essentially non-destructive.
- Inductively-coupled Plasma *Mass Spectrometry*
  - Extraction by differential chemical etching or laser ablation.
- Accelerator *Mass Spectrometry*
  - Extraction by differential chemical etching.
- Radiochemical Neutron Activation Analysis
  - Extraction by differential chemical etching.

Solar Wind O Isotopic Composition

- This is our highest priority science objective.
- Three of the four quadrants in the concentrator target were designed to support O isotopic analyses.
  - SiC (2)
  - 13C CVD diamond (1)
  - All of these quadrants were unbroken in crash.

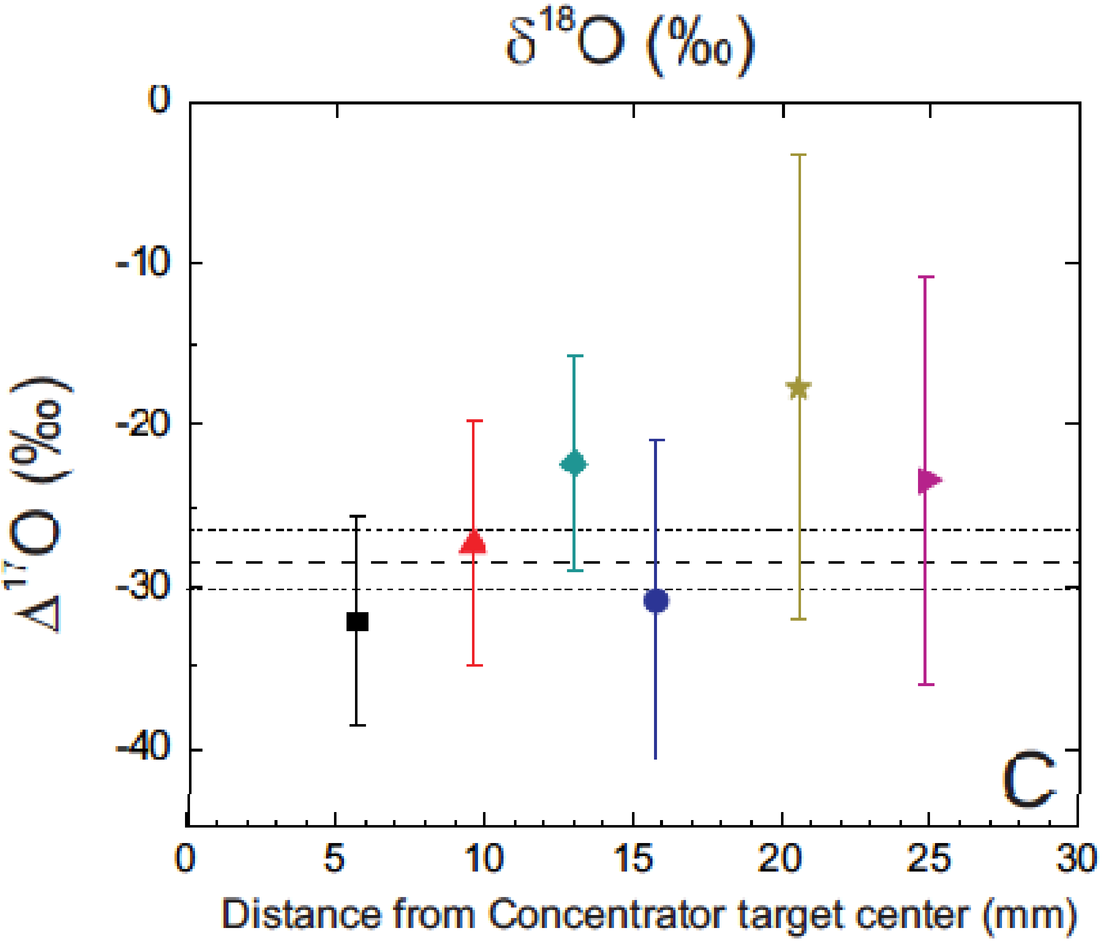


As recovered, concentrator target holder;
broken quadrant is diamond-like-carbon

GENESIS

O Isotopes. UCLA MegaSIMS

A paper describing these results will be the feature Research Article in the June 24 2011 issue of *Science.* (McKeegan et al.)



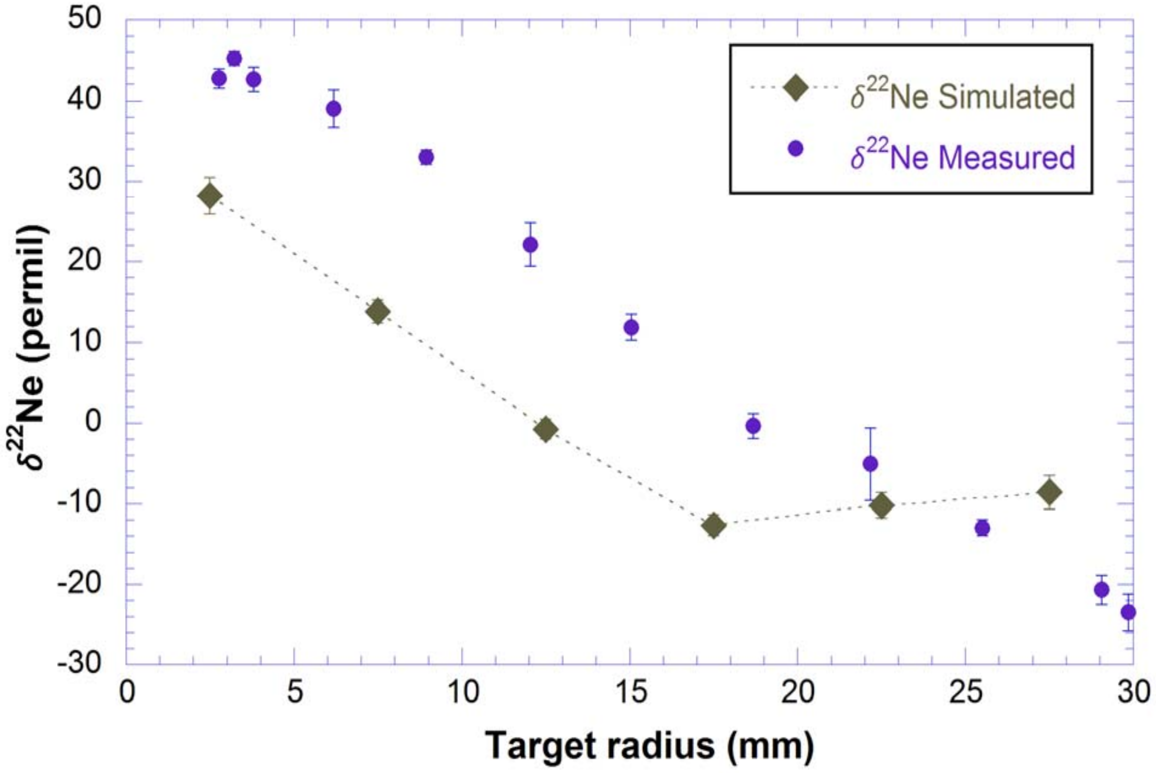
SiC quadrant 60001 was analyzed as a function of radius. The δ(18O) varies because of concentrator mass fractionation, but all analyses are consistent with Δ(17O) = -28.4 ± 1.8 permil.

The constant value of Δ(17O shows that, as expected, the concentrator isotopic fractionation is mass dependent in the traditional sense with variations in 18O/16O approximately twice those for 17O /16O.

O Isotopes. UCLA MegaSIMS

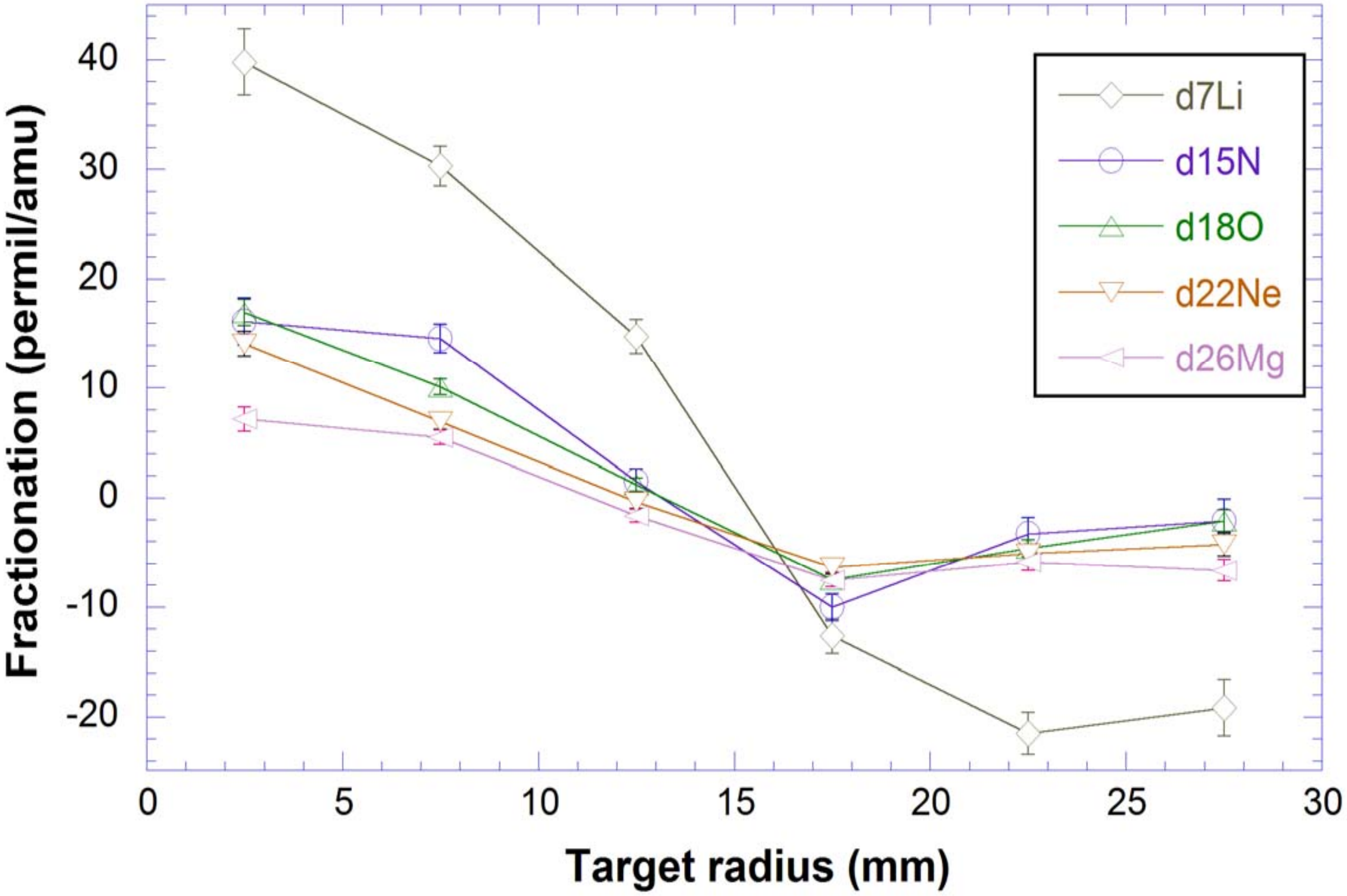
Concentrator mass fractionation corrections are based on analyses of Ne in 60001 (Heber et al., *Meteoritics and Planetary Science 46, 493-512,* 2011). Well defined profiles of Ne fluence and ^{20}Ne / ^{22}Ne (measured curve in figure below) were obtained.

Simulated Concentrator Ne fractionation (Wiens, LANL) similar to measured but some quantitative differences remain.

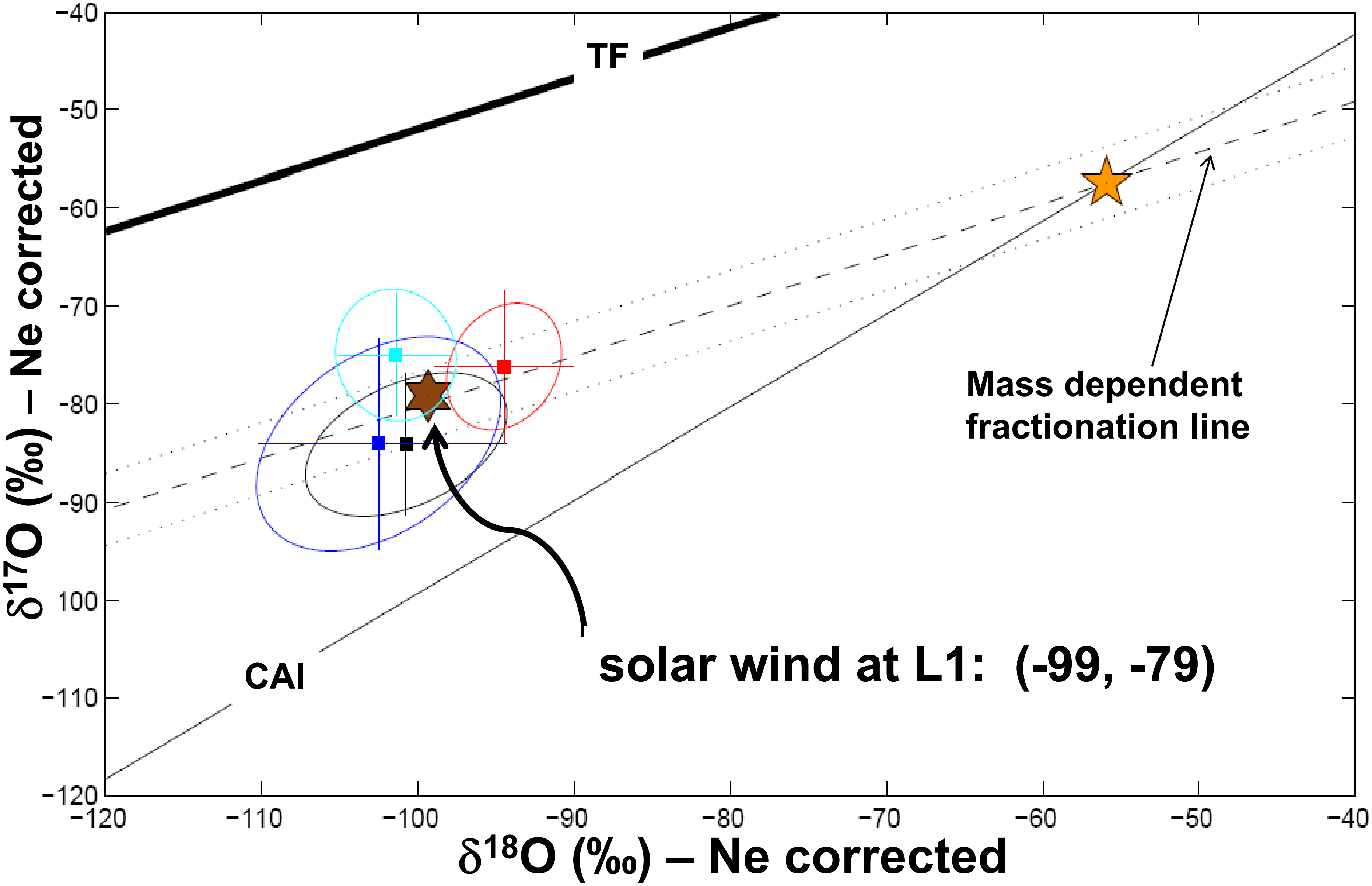


MegaSIMS O Isotopes: Mass Fractionation Correction

Simulations predict very similar fractionations for Ne and O, so adopt measured Ne fractionations to correct MegaSIMS O data.



60001 corrected for concentrator mass dependent fractionation



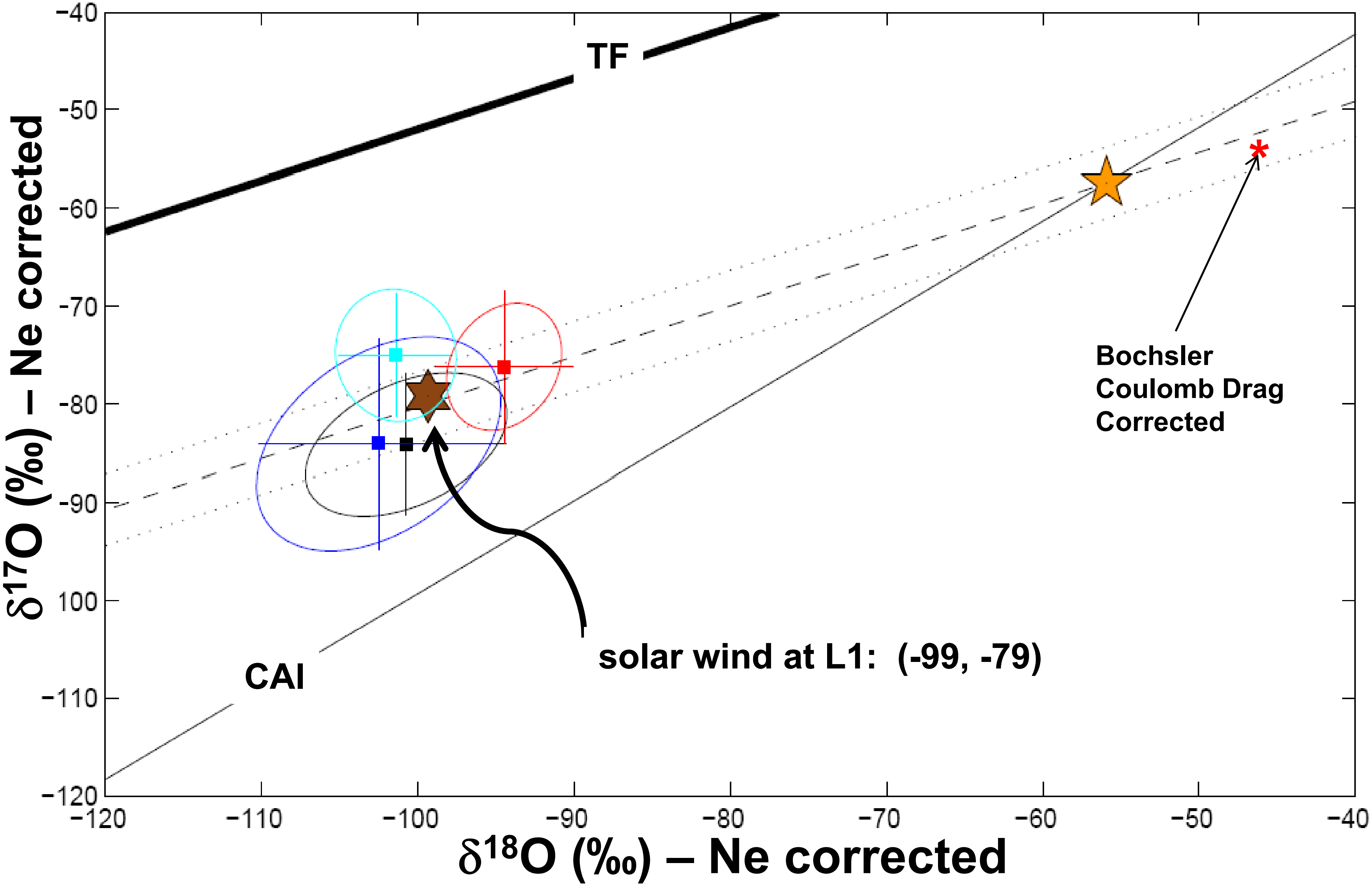
Mass dependent fractionation line

solar wind at L1: (-99, -79)

Isotopic Fractionation (Wiens et al., LPSC 2010)

- **Data:**
  - Mid 1990s: When GENESIS was proposed, there was no clear evidence for isotopic fractionation between Sun and solar wind.
  - 1998-2005: Slight evidence from in-situ spacecraft for fractionation, but error bars were very large.
  - 2007: Significant differences in solar-wind regimes for HeNeAr from GENESIS samples (see Heber et al LPSC 2008, abs 1779)
- **Theory:**
  - FIP-correlated elemental fractionation suggests no isotopic fractionation.
  - Large fractionations suggested by Bochsler (2000) Coulomb drag model (next slide).

60001 corrected for solar wind - Sun fractionation



solar wind at L1: (-99, -79)

Bochsler Coulomb Drag Corrected

O Isotope summary

- Sun-Solar Wind isotope fractionation moves measured Genesis solar wind point towards the CAI trend line.

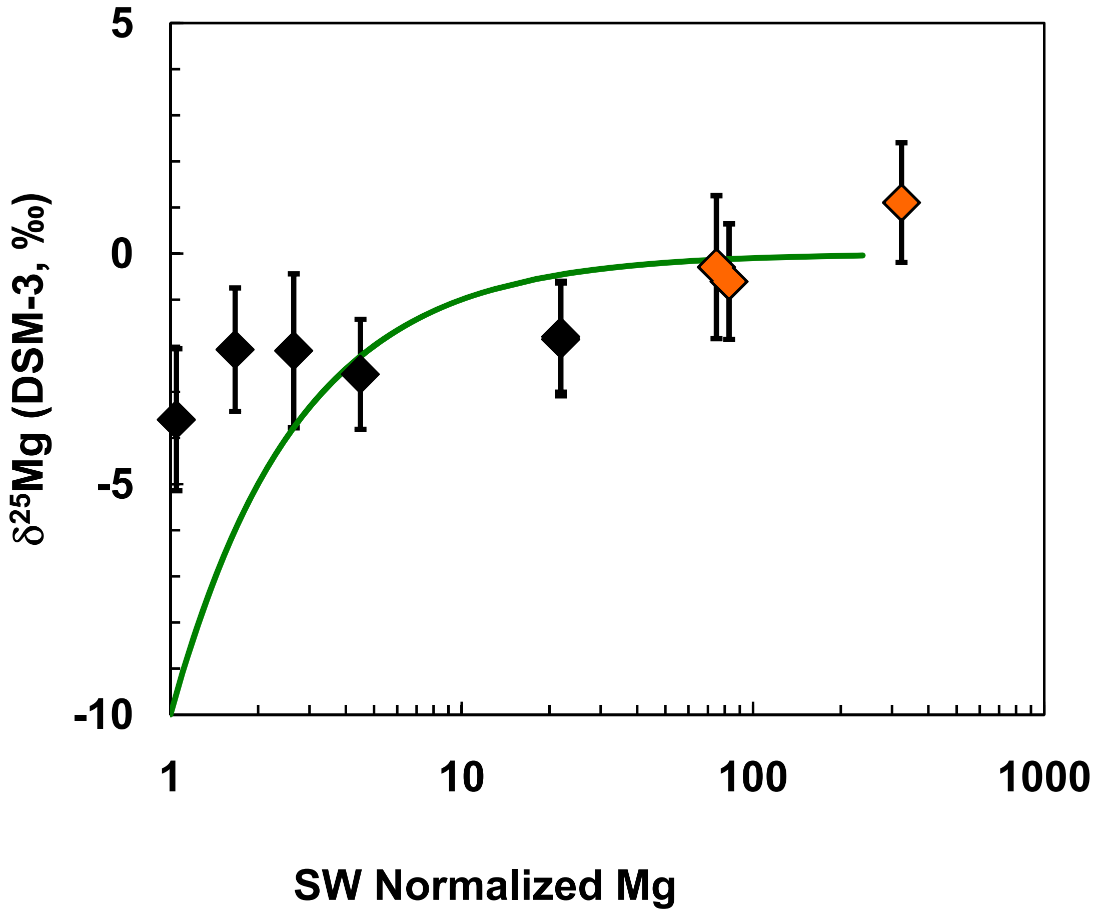
- Correction based on Bochsler Coulomb Drag (BCD) model puts Sun (solar nebula) to high del 18O sign of the CAI line.

- Regime HeNeAr data (Heber et al LPSC 2008, abs 1779) indicates that BCD model overcorrects (Heber and McKeegan, LPSC 2011; abstract 2789) . So, *plausible* that solar nebula lies on CAI line.

- Key test: Mg isotopes. BCD model predicts 8 permil/amu fractionation.
  - Except for some CAIs, mass dependent Mg isotopic variations in inner solar system material are less than 1 permil/amu.
  - So Terrestrial Mg isotopic composition should be equal to Sun, so solar wind – Earth Mg isotope fractionations equals Sun-solar wind differences.

- An 8 permil/amu fractionation should be measurable even with SIMS.

Preliminary ICPMS Mg isotope data. Humayun et al LPSC 2011 Abs 1211



Flight samples of Si-on-sapphire (SoS) were being cleaned with HF when the Si layer anomalously dissolved. Control SoS samples are unaffected by HF.

ICPMS 25Mg/24Mg analyses of the solutions were still possible (black points in figure) along with measurements of the amount of Mg dissolved, plotted here as a ratio of the measured to the expected amount of Mg, based on the known solar wind fluence. The orange points are analyses of the terrestrial contamination from the sample removed by aqua regia etching. The green curve represents mixing between terrestrial Mg and a solar wind Mg isotopic composition with -12 permil/amu fractionation as predicted by Bochsler.

The thickness of the Si layer in the SoS collectors is too thin. The calculated correction on δ^{25}Mg is +4 permil, making the SW and terrestrial Mg isotopic composition the same to within a few per mil, much less fractionated than predicted by Bochsler. Measurements are in progress to confirm these results.

Solar N Isotopic Composition

This is our #2 science objective.

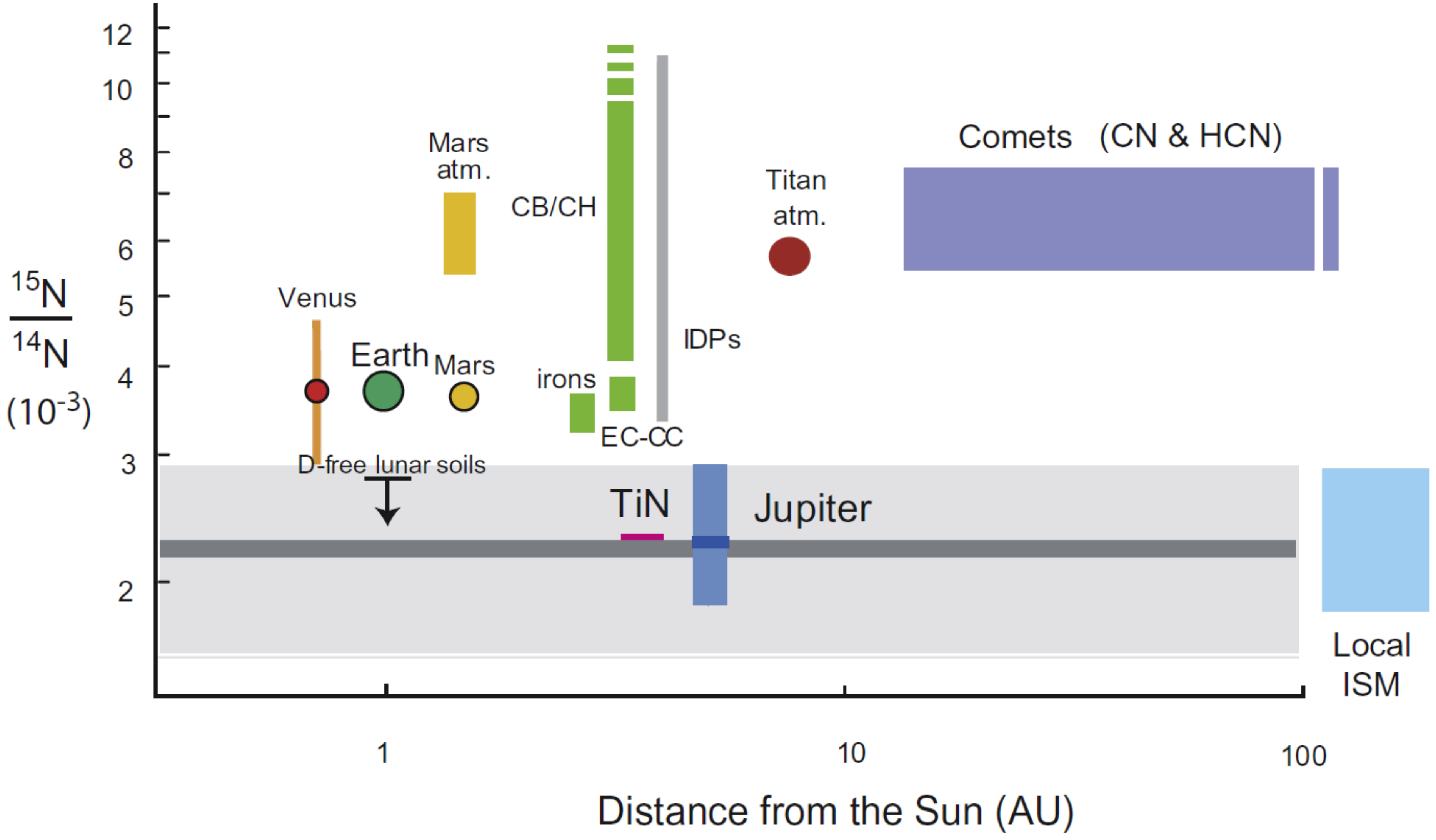
With the exception of one anomalous result (Pepin et al., LPSC 2009 abstract), preliminary Genesis sample data from five other laboratories have measured a solar wind ^{15}N / ^{14}N ratio much lower than the terrestrial ratio.

The most precise result to data is from a SIMS analysis of the 60001 SiC concentrator target used for the MegaSIMS O analysis.

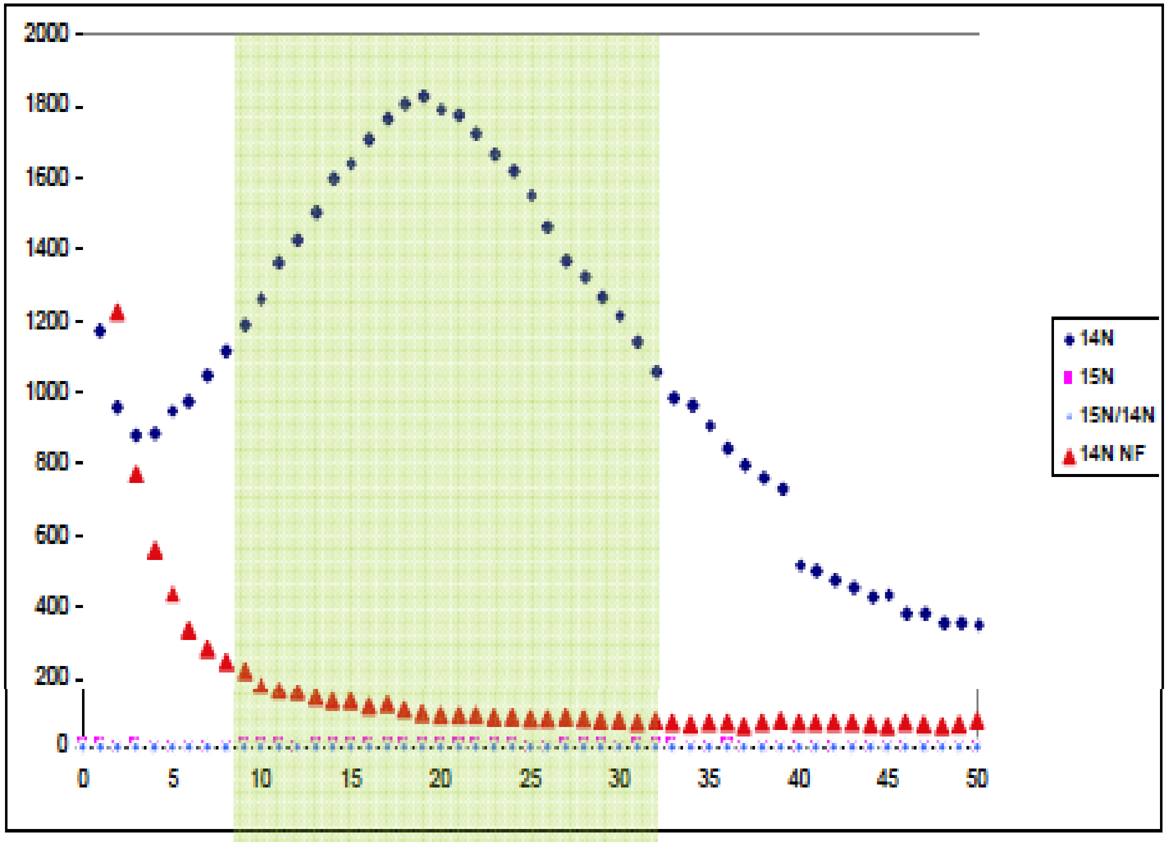
A paper on this result will appear as a feature article in the June 24 issue of *Science.*

$^{15}N/^{14}N$ in the solar system shows wide variations

(slide from Marty et al, 2010)



N Isotopes in 60001 SiC Concentrator Target. Marty, Chaussidon; Nancy SIMS analysis



Solar wind ^{14}N counting rate as a function of sputtering time (depth in sample) for 60001 (blue) compared with a flight spare control SiC (red)

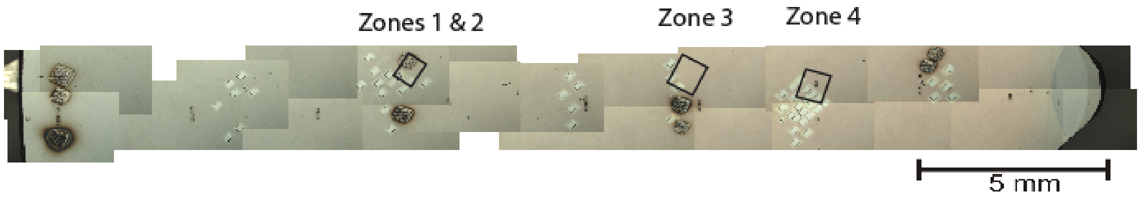
As for O with the MegaSIMS, a small amount of cleaning by sputtering with low E Cs leads to enhanced signal/noise with loss of only a small amount of surface.

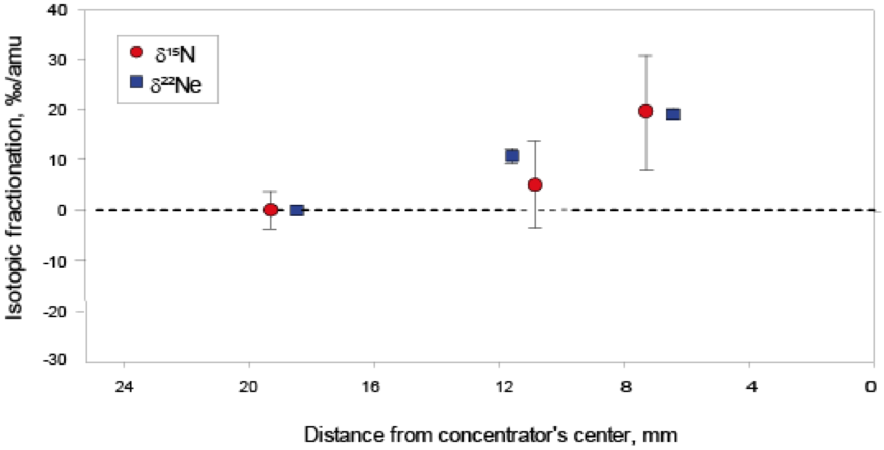
The depth of the solar wind 14N is close to that predicted for the Concentrator.

Synthesis : isotopes

Figure at the center : isotopic variations of Ne (Heber et al.) and N, expressed as deviations (‰ and per amu) *relative* to isotopic ratios measured at zone 1 & 2 (errors are 1 σ). These data support the concentrator modeling results (previous slides) that the isotopic fractionations for Ne and Ne (plus O) are very similar.

In the bottom table, the measured 15N/14N ratios are corrected for isotopic fractionation using the permil/amu fractionations from Ne The error-weighted average is then computed and the result is corrected for isotope discrimination of the ims 1280HR^2 using a SiC standard calibrated by laser ablation and gas source mass spec. The final value of -407 permil relative to the terrestrial atmosphere or 15N/15N = 2.18x10^{-3} is our best estimate for the SW N isotopic composition.

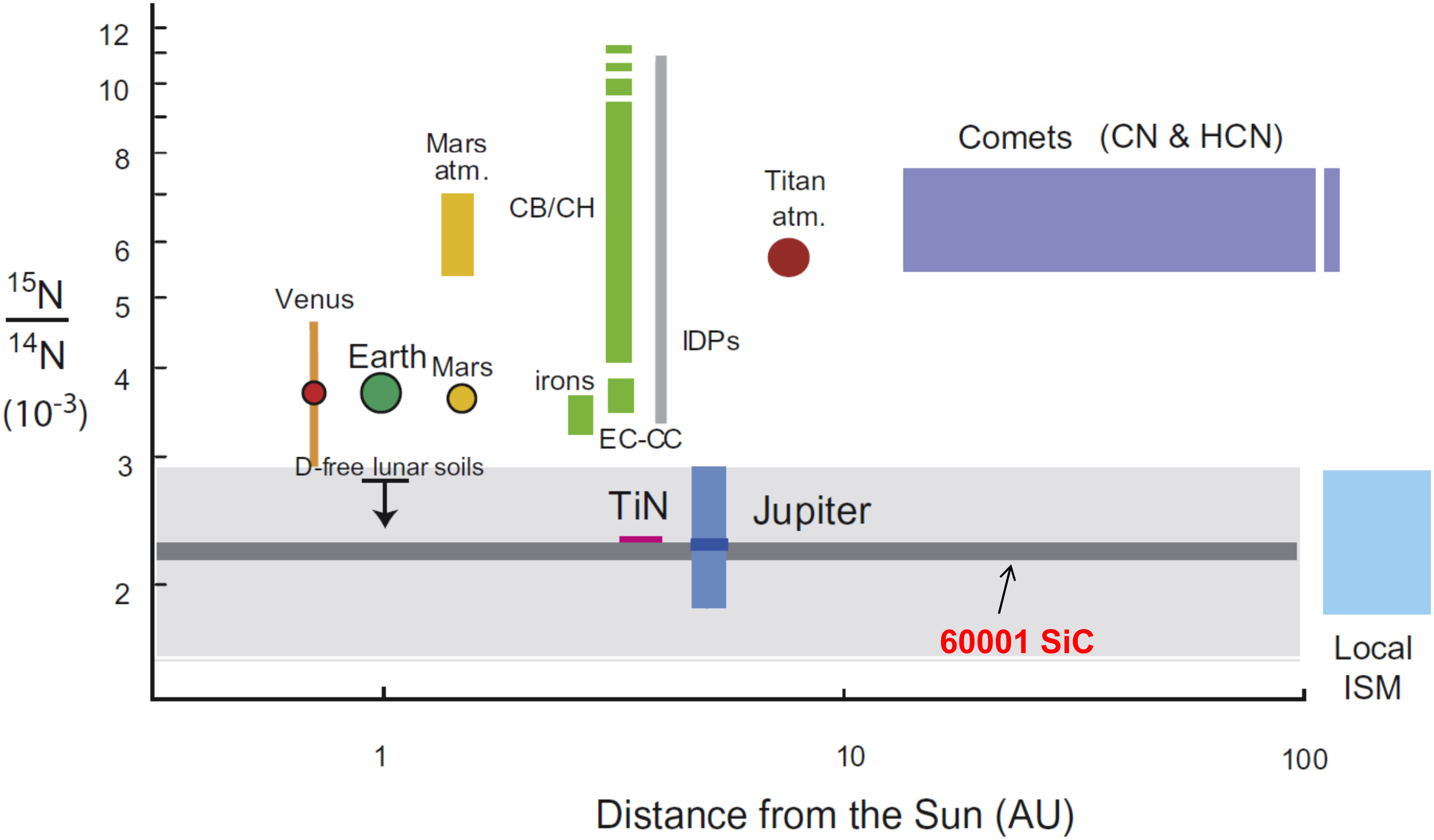




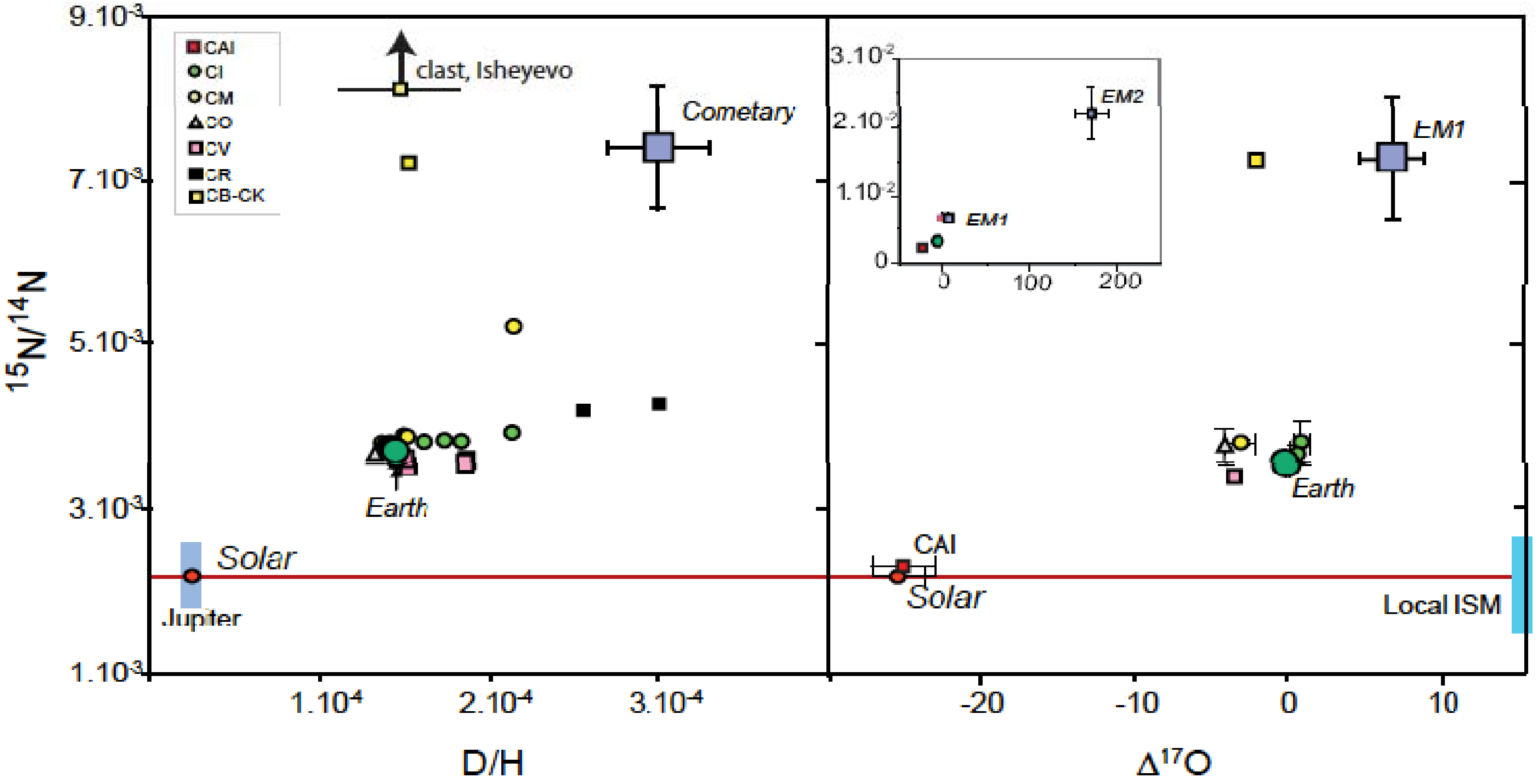
	dist/center mm	$^{15}N/^{14}N$ measured	2 σ	$(^{15}N/^{14}N)$ corr fract.	2 σ
Zone 1	19	2.143E-03	9.00E-05	2.143E-03	9.00E-05
Zone 2	19	2.116E-03	2.00E-05	2.116E-03	2.01E-05
Zone 3	11	2.126E-03	2.90E-05	2.103E-03	2.95E-05
Zone 4	7	2.158E-03	3.80E-05	2.117E-03	3.88E-05
			weight. average	2.114E-03	1.50E-05
			norm. Std	**2.178E-03**	**2.22E-05**
			$\delta^{15}N$	**-407**	**6**

$^{15}N/^{14}N$ in the solar system

(slide from Marty et al, 2010)



From Marty et al, 20111



Solar system materials show remarkable homogeneity in the isotopic compositions of elements relative to the large order of magnitude variations in isotopic compositions accompanying stellar nucleosynthesis. But, all elements are not the same; variations in H, N, and O are much larger (but not C?). The situation with noble gases is more complex. Possible isotopic correlations are explored in this diagram. EM1 and EM2 in the (O,N) plot are proposed end members by Marty et al. A strong case for coupling of the isotopic variations among the 3 elements is not obvious.

Conclusions

In agreement with previous Genesis results, the Nancy Cameca 1280 SIMS, the SiC concentrator sample 60001 gives solar $^{15}N/^{14}N$ within uncertainty of $^{15}N/^{14}N$ in Jupiter's atmosphere (and, inexplicably, TiN from a CAI). This has major implications for the relation between the inner and outer planets.

Nitrogen on Earth is heavy in same sense as Ne: additional evidence for significant early loss of terrestrial atmosphere?

#3 Measurement Objective: Noble Gas Elemental and Isotopic Analyses

Summary of work published or submitted.

Ne in Genesis Bulk Metallic Glass. SEP component doesn't exist. Solves long-standing lunar problem (ETH Zurich).

Grimberg et al. *Science* 314, 1133, 2006.

Proc. Symp. Comp. of Matter **symposium, 3 papers.**

Space Sci. Rev. vol 170, 2007.

Reisenfeld et al Solar Wind Conditions for Genesis samples, based on monitor data along with other spacecraft data for the same period.

Wiens et al Genesis Solar Wind Overview

Heber et al. Genesis Concentrator Performance Based on Ne Analysis of the Target Holder Gold Cross.

Ne and Ar isotopic composition of different regimes (Wash U), Meshik et al., *Science* 318, 443, 2007

This paper produced additional favorable technical summaries:

Science 318, 401, 2007

Nature News 17 Oct 2007

nature.com/news/2007/071018/full/news.2007.175.html\

Published work on noble gases, con’t

Solar wind noble gases in targets from the Genesis mission
PhD thesis, Ansgar Grimberg, ETH Zurich, 2007.

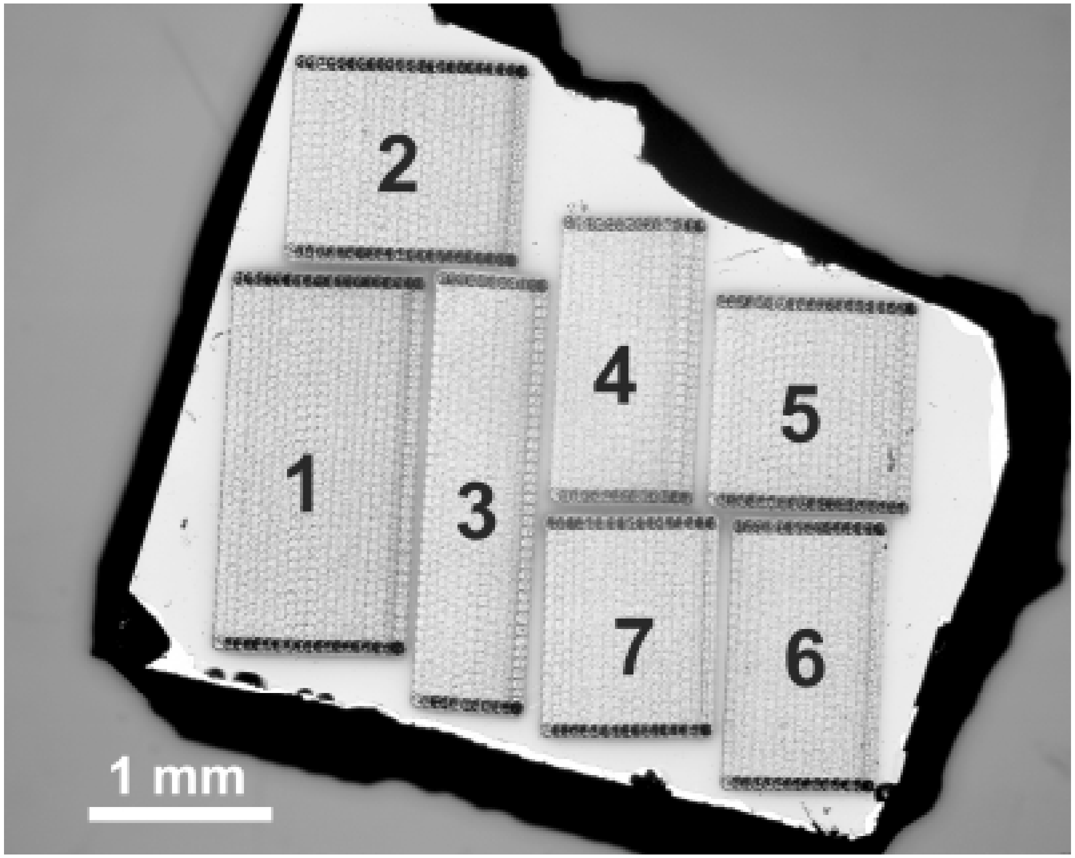
Wieler et al., Consequences of the non-existence of the SEP component for noble gas geo- and cosmochemistry. *Chemical Geology* 244, 382, 2007.

Grimberg et al. Solar wind He, Ne, and Ar isotopic and elemental composition. Data from the metallic glass flown on the NASA Genesis spacecraft. *Geochimica, Cosmochemica, Acta* 72, 626, 2008.

Heber et al. Noble gas composition of the solar wind as collected by the Genesis mission*.* *Geochimica, Cosmochimica, Acta 73, 7414, 2009.*

Heber et al. Isotopic and elemental fractionation of solar wind implanted in the Genesis concentrator target characterized and quantified by noble gases., Meteoritics and Planetary Science, *46, 493-512,* 2011.

From: Heber et al (2010). Noble Gas Isotopic and Elemental Composition in Bulk Solar Wind.



Samples (diamond-like-carbon shown here) are laser ablated to release HeNeArKrXe for mass spectrometric analysis.

Image shows pits from HeNeAr analyses. Those for KrXe are 3-7 times larger, given low fluences.

All noble gas laboratories analyzing Genesis samples extract using laser ablation. Mass spec techniques vary.

Xe isotopic composition
Crowther and Gilmour, U. Manchester

RELAX = refrigerator enhanced laser ablation mass spec analysis of Xe.

- Exceptional sensitivity: detection limit ~ 950 atoms ^{132}Xe
- Best blank ~ 1000 atoms ^{132}Xe
- Samples restricted to < ~ 10^6 atoms
  - Analyze large number of 3-4 mm CZ Si samples
  - Lots of these from crash.
- Xe extracted by uv laser step heating.
  - Large, unfocused laser beam
  - Cover 3-5 mm square sample
- Atoms from many pulses trapped at 80K; released in single IR laser pulse.
- Released atoms ionized with uv laser.

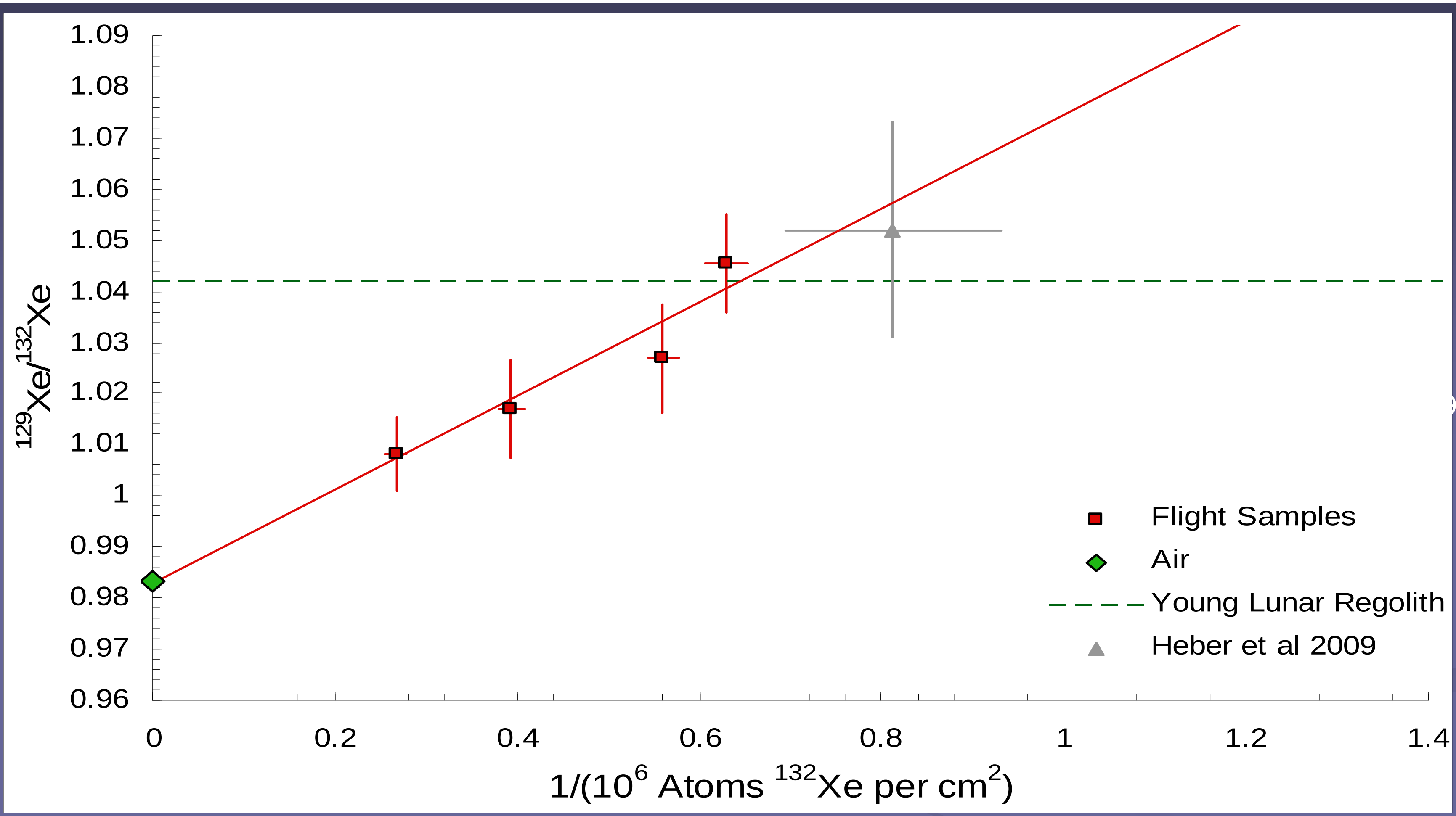
Relax Summary, con’t

UV laser ablation depth profiling offers better discrimination of solar wind Xe from Xe impurities in Si collectors and surface contamination Xe.

  - 1st pulse = surface contamination
  - Next 30 pulses mostly solar wind
  - Non flight samples give background Xe in Si.

- Observe variable concentrations of Xe in both flight and nonflight samples. Air bubbles in Si?
- Mixing line approach provides basis for deriving SW Xe isotopic composition.
  - Data consistent with mixture of atmospheric Xe and solar wind.
  - Plot isotope ratio vs (1/ ^{132}Xe)
  - Extrapolate to known solar wind ^{132}Xe, e.g. from Heber et al. (2010) to get solar wind isotopic composition (following slide).

Crowther and Gilmour LPSC 2011 Abstract 1969.



995)

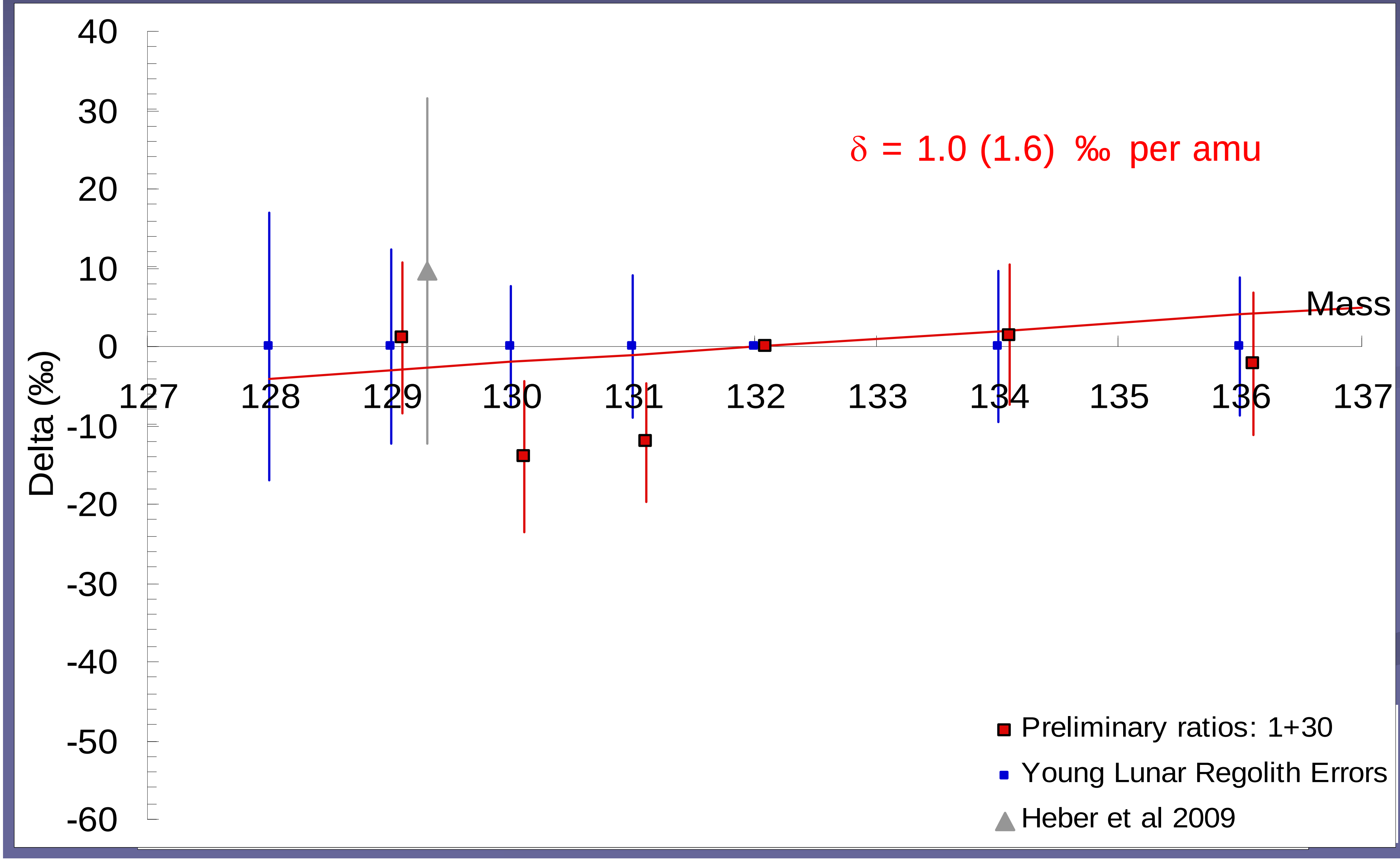
Genesis sample ratios correlate with $1/[^{132}Xe]$

- Uniform concentration implanted solar wind component mixing with variable concentration blank (non-flights)

- Need [SW] to determine composition
  - Precision of [SW] limits precision of ratios

Solar wind composition

- Delta relative to young lunar regolith. Consistent with no difference



LPSC 2011 Abs # 2703 Meshik et al. Wash U

Multi-collector analysis of Kr and Xe isotopes:

Comparing to standard MS:
8 individual Burle multipliers,
New pumping system (MagLev Turbo, ion pumps and more…), New cryogenic separation system,
266nm 7ns 15mJ @30Hz laser extraction system,
Low blank purification line + Calibration system,
Fast (10mm/s) heavy load (up to 15Kg) long range Newport stage with PID control,
LabView program control the stage rastering

Al on sapphire (AloS) and Polished Al collector (PAC)

Four experiments made: P-$\pi/4$, A-$\pi/4$, A-$\pi/2$, A-$\pi/8$

Number of analyses: 4 + 6 + 6 + 4 = 20

Data are binary mixture of Kr = SW + "trapped"

Trapped = adsorbed and bkg Kr in Al

$({}^{132}Xe/{}^{84}Kr)_{AIR} = 0.036$ & $({}^{132}Xe/{}^{84}Kr)_{SW} = 0.105$; very different

Trapped is fractionated air: $({}^{132}Xe/{}^{84}Kr)_{trap} \neq ({}^{132}Xe/{}^{84}Kr)_{AIR}$

KNOWN KNOWN KNOWN

$${}^{84}Kr_{SW.1} = {}^{84}Kr_{meas.1} \times [({}^{132}Xe/{}^{84}Kr)_{meas.1} - ({}^{132}Xe/{}^{84}Kr)_{trap}]/[({}^{132}Xe/{}^{84}Kr)_{trap} - ({}^{132}Xe/{}^{84}Kr)_{SW}]$$

$${}^{84}Kr_{SW.2} = {}^{84}Kr_{meas.2} \times [({}^{132}Xe/{}^{84}Kr)_{meas.2} - ({}^{132}Xe/{}^{84}Kr)_{trap}]/[({}^{132}Xe/{}^{84}Kr)_{trap} - ({}^{132}Xe/{}^{84}Kr)_{SW}]$$

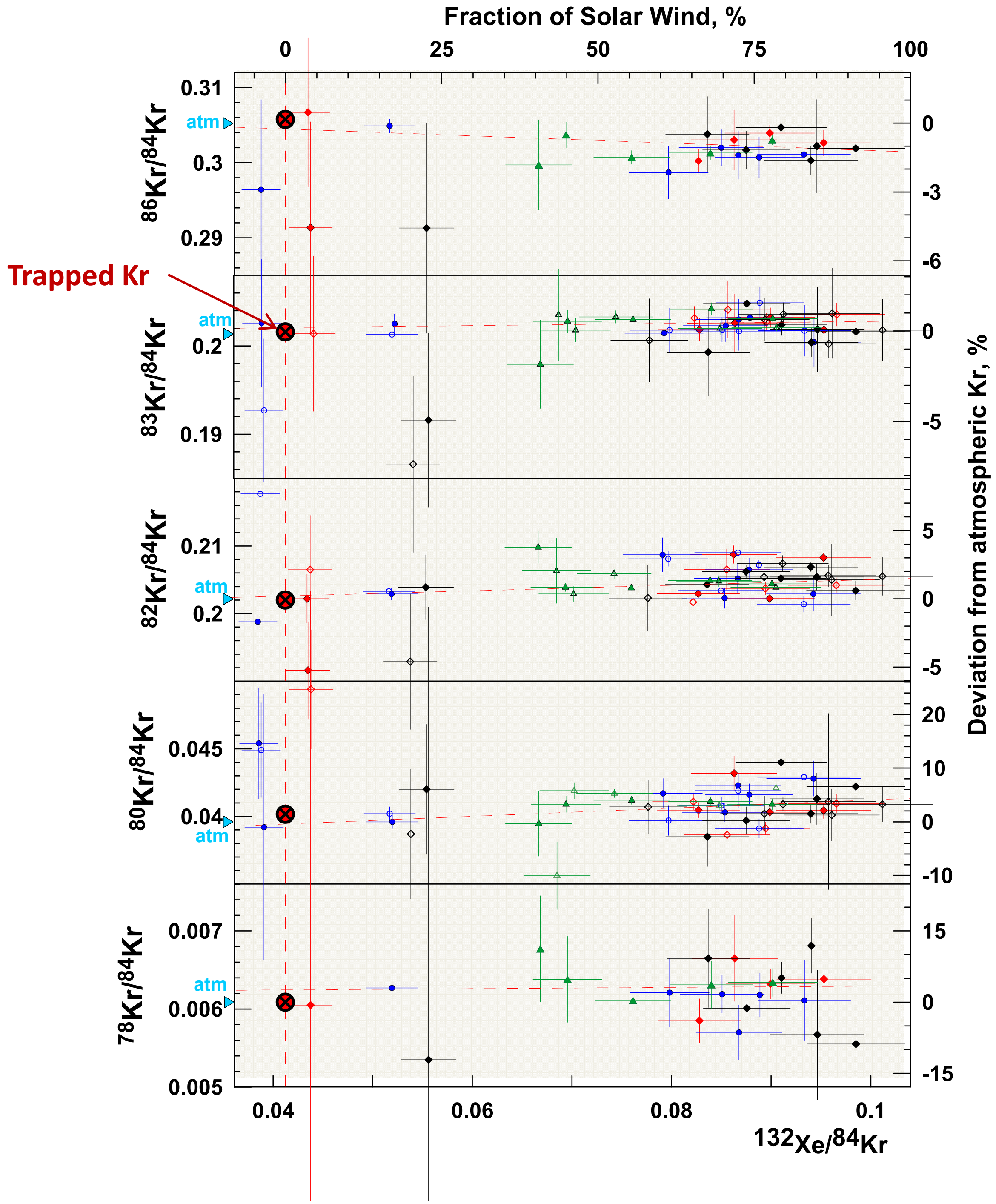
. . . .

$${}^{84}Kr_{SW.N} = {}^{84}Kr_{meas.N} \times [({}^{132}Xe/{}^{84}Kr)_{meas.N} - ({}^{132}Xe/{}^{84}Kr)_{trap}]/[({}^{132}Xe/{}^{84}Kr)_{trap} - ({}^{132}Xe/{}^{84}Kr)_{SW}]$$

To estimate the most likely value of $({}^{132}Xe/{}^{84}Kr)_{trap}$ we minimize StDev of SW-Kr fluences from 20 analyses:

${}^{132}Xe/{}^{84}Kr)_{trap} = 0.042$

Kr in AloS and PAC:



All experiments:

P-π/4,

A-π/4,

A-π/2,

A-π/8

agree

with each other.

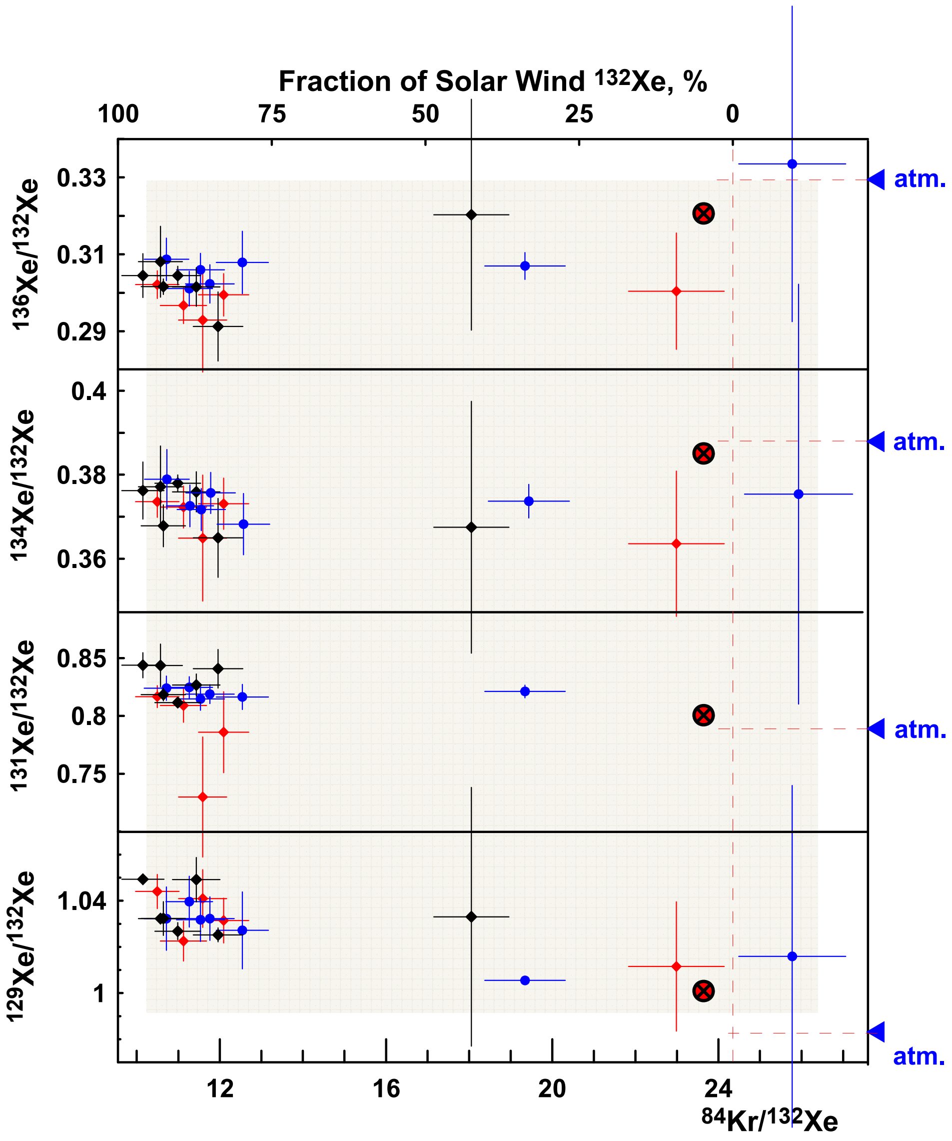
Small trapped correction

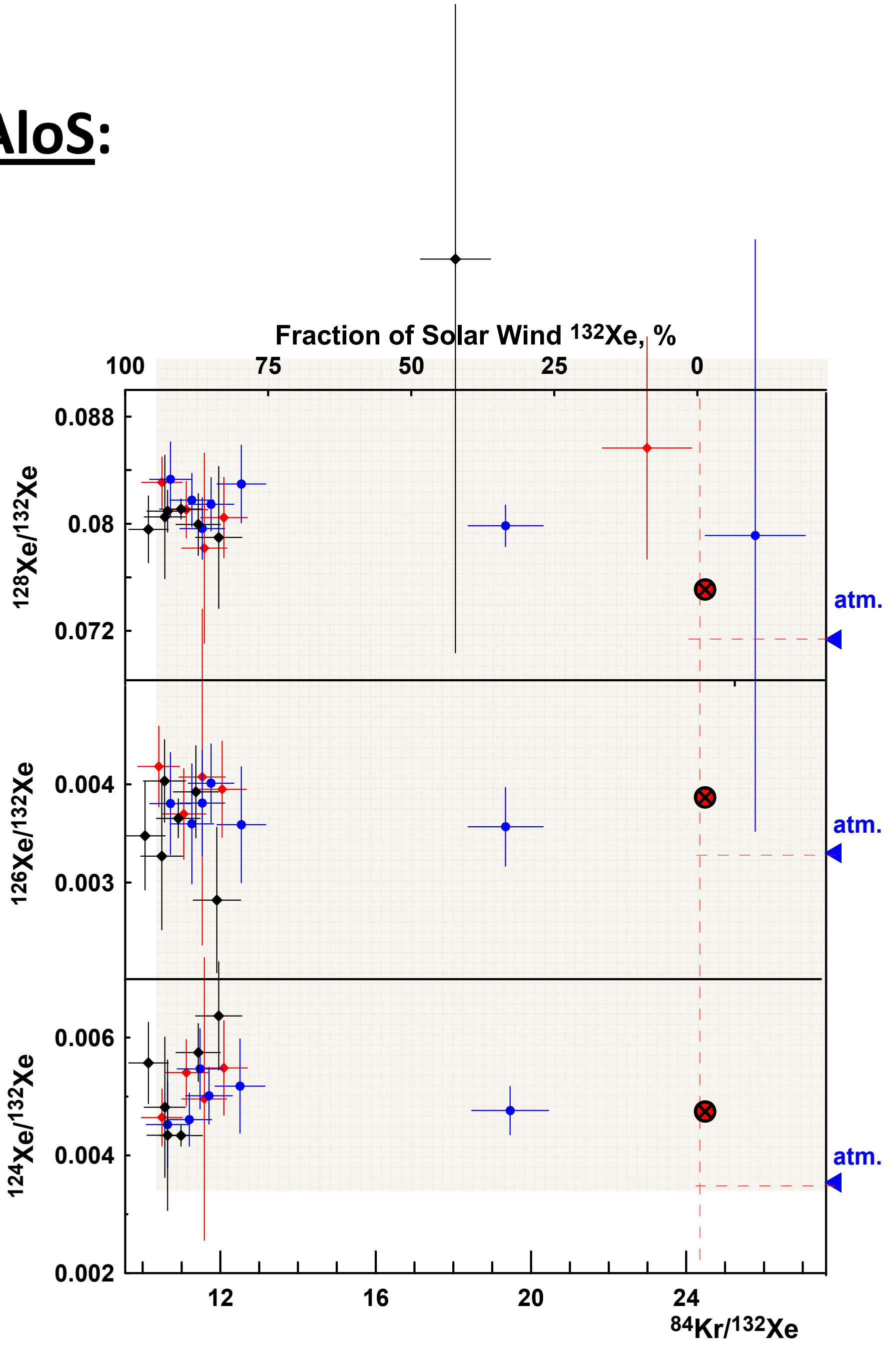
On average:

SW-Kr 75%

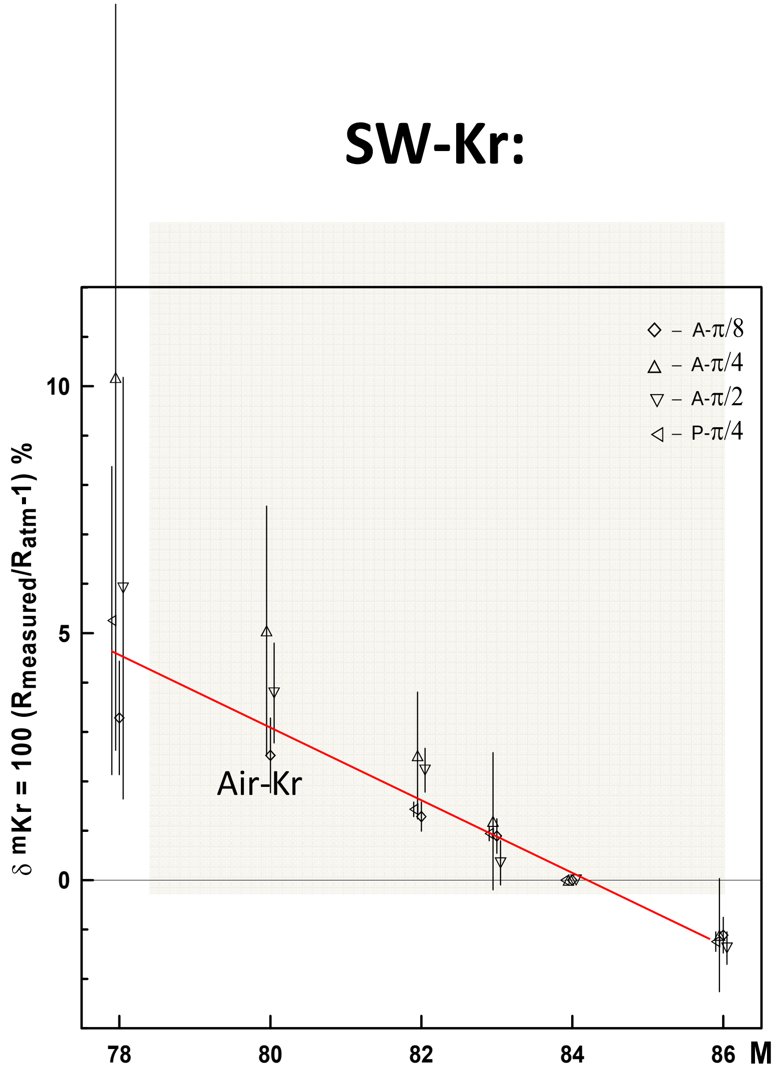
Correction for 25% trapped Kr using $^{132}Xe/^{84}Kr$ gives precise Kr isotope ratios.

Xe in AloS:


Fraction of Solar Wind ^{132}Xe, %
100
75
50
25
0
^{136}Xe/^{132}Xe
0.33
0.31
0.29
atm.
^{134}Xe/^{132}Xe
0.4
0.38
0.36
atm.
^{131}Xe/^{132}Xe
0.85
0.8
0.75
atm.
^{129}Xe/^{132}Xe
1.04
1
atm.
12
16
20
24
^{84}Kr/^{132}Xe


Fraction of Solar Wind ^{132}Xe, %
100
75
50
25
0
^{128}Xe/^{132}Xe
0.088
0.08
0.072
atm.
^{126}Xe/^{132}Xe
0.004
0.003
atm.
^{124}Xe/^{132}Xe
0.006
0.004
0.002
atm.
12
16
20
24
^{84}Kr/^{132}Xe

SW-Kr:



Lunar soil and gas-rich meteorites

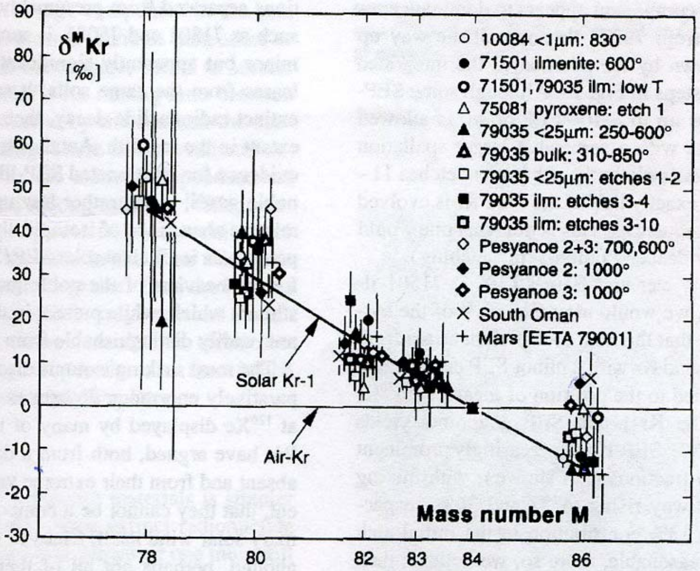
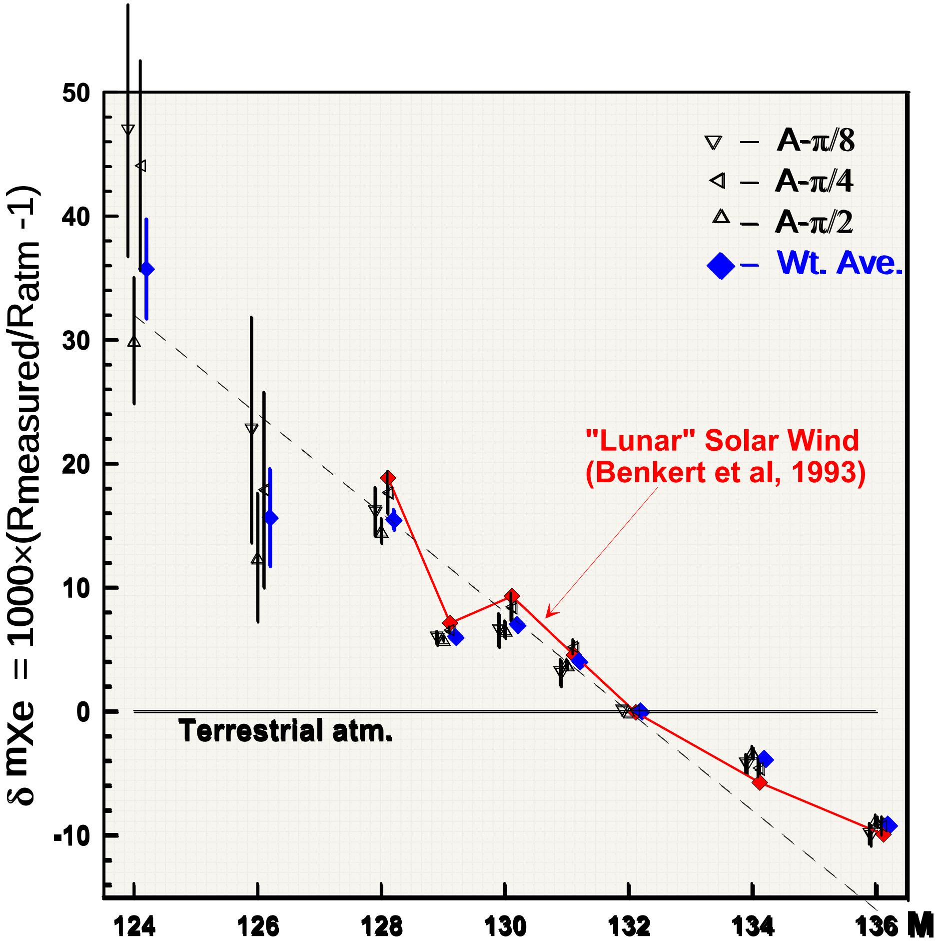


FIG. 13. As in Fig. 12, for total or fractional Kr releases from the listed samples. Data sources referenced in Table 4. Spallogenic Kr components are considered to be negligible in eight of these fourteen compositions, and small (except for etch fractions 3–4 and 3–10 from 79035 ilmenite) in the others. Plotted errors for this latter group do not include the generally minor effects of uncertainties in relative spallation yields (Table 4D).

(Pepin, Becker, Rider, GCA 1995)

Genesis SW-Kr agrees with Lunar regolith Kr
(except ^{86}Kr; fission Kr in lunar soils?)
Terrestrial atmosphere = fractionated Genesis solar wind Kr

SW-Xe:



For the first time we directly determined all SW-Kr and SW-Xe isotopes (including low abundant ^{124}Xe, ^{126}Xe, ^{78}Kr, ^{80}Kr) providing a better constrained slope of the fractionation lines.

In contract to SW-Kr, SW-Xe:

is fractionated stronger and not linearly relative to terrestrial air.

Excesses of ^{136}Xe, ^{134}Xe are not lunar fission xenon. Now we clearly see it in the SW.

^{129}Xe/^{132}Xe fell out from linear fractionation line in both Genesis and Lunar data.

Science Issue: Do Sun and solar wind have same *elemental* composition?

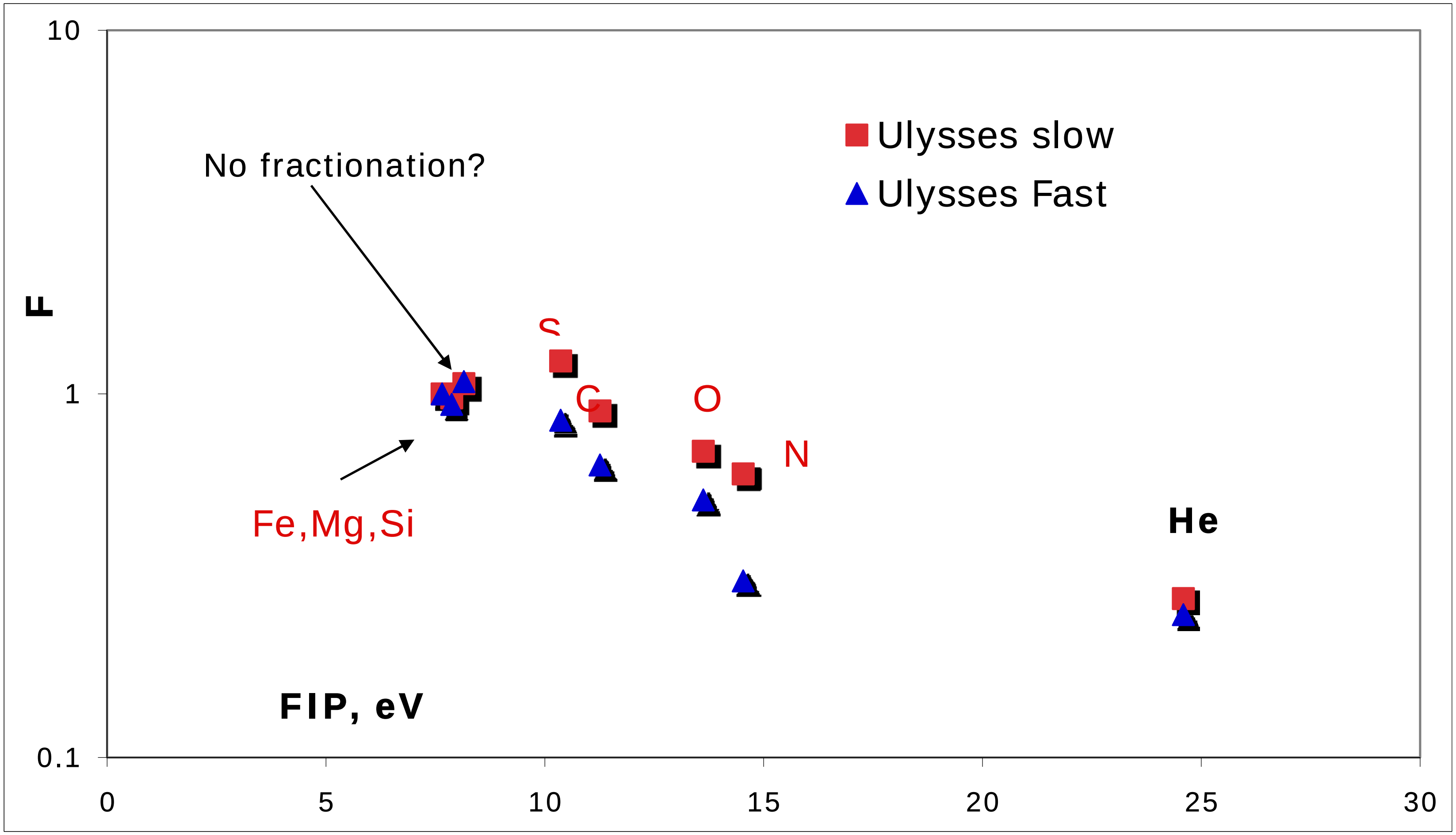
This and following four slides are background used in previous reports.

- **Spacecraft data have shown that high first ionization potential (FIP) elements, e.g. He, are depleted in solar wind compared to solar surface (photosphere).**
  - **e.g. He/Fe is lower in SW than in photosphere by factor of 2-3.**
- **Data for most easily-ionized elements (FIP < 9eV, e.g. Fe) appear unfractionated.**
  - **Most of elements in terrestrial planets have FIP<9eV**
- **Genesis will provide a better test, but never will escape need to know a few photospheric elemental ratios accurately.**
- **If fractionations due only to first ionization potential, solar wind and photosphere i*sotope* ratios expected to be same.**

Fractionation Factor

$$F = (X/Mg)_{SW} \,/\, (X/Mg)_{photosphere}$$

FIP Plot from spacecraft data

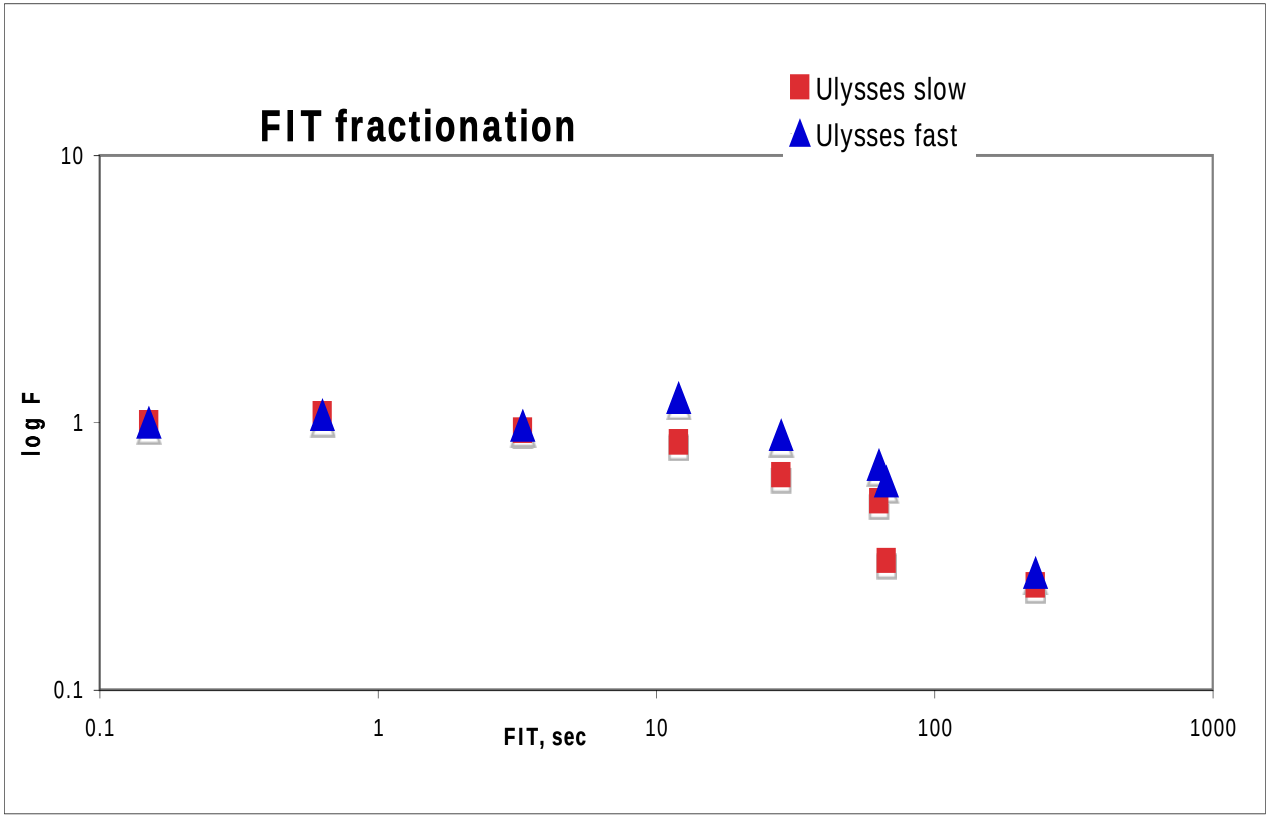


Parameters used to characterize solar wind-photosphere element fractionation. (Wiens et al., LPSC 2010)

- First ionization potential (FIP)s
  - High FIP elements depleted by ~2x relative to low FIP elements in interstream (L array) wind. Relatively little fractionation in coronal hole (H array) wind.
- First Ionization Time (FIT)
  - Time required to ionize an element under a given condition
  - Takes into account electron and UV photon impact rates as well as FIP
- Fractionation plots vs FIP or FIT similar but have significant differences.

FIT (first ionization time) plot from spacecraft data

FIT is more physical than FIP, but is model-dependent. Ulysses data plots using FIT are cleaner than those with FIP with the 9eV fractionation cutoff (translated to about 10- 20 sec ionization time) showing clear depletions of high FIP/FIT elements, but no evidence of fractionation among low FIP/FIT elements. Errors in SW abundances about 20%; errors in photosphere 10-20%. Note that Mg and Fe have same FIP but different FIT



Noble Gas Elemental Abundances

Fluences for bulk solar wind collectors published in Heber et al (2009) for all noble gases.

^{84}Kr and ^{132}Xe Bulk Solar Wind Fluences

	^{84}Kr (10^7 atoms/cm2)	^{132}Xe(10^6 atoms/cm2)
Heber et al (2009) CZ Si	1.23 ± 0.08	1.23 ± .18
Meshik et al LPSC 2011 #2703 AloS &PAC	1.06 ± 0.10	1.13 ± .08
Crowther & Gilmour LPSC 2011 #1969 CZ Si		1.20 ± 0.09

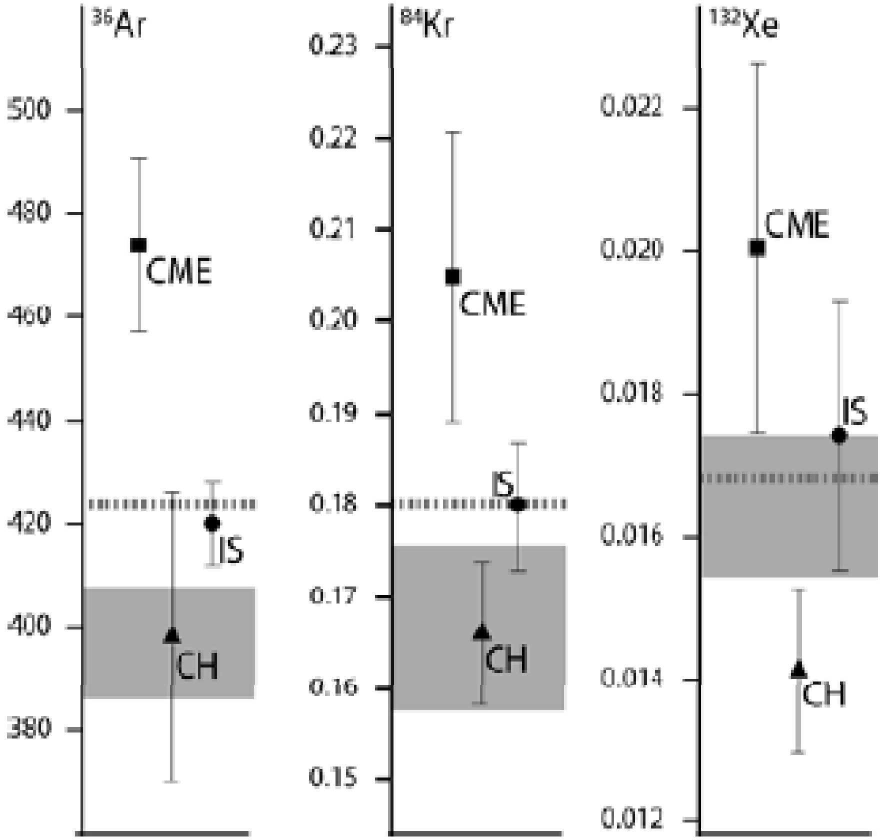
Errors are 1 sigma; agreement is good.

Noble Gas Data for Regime samples

Regime fluences and isotopic compositions for Ne and Ar in Meshik et al (2007)

Regime isotopic compositions for He, Ne, Ar in Heber et al LPSC 2008 Abs#1779.

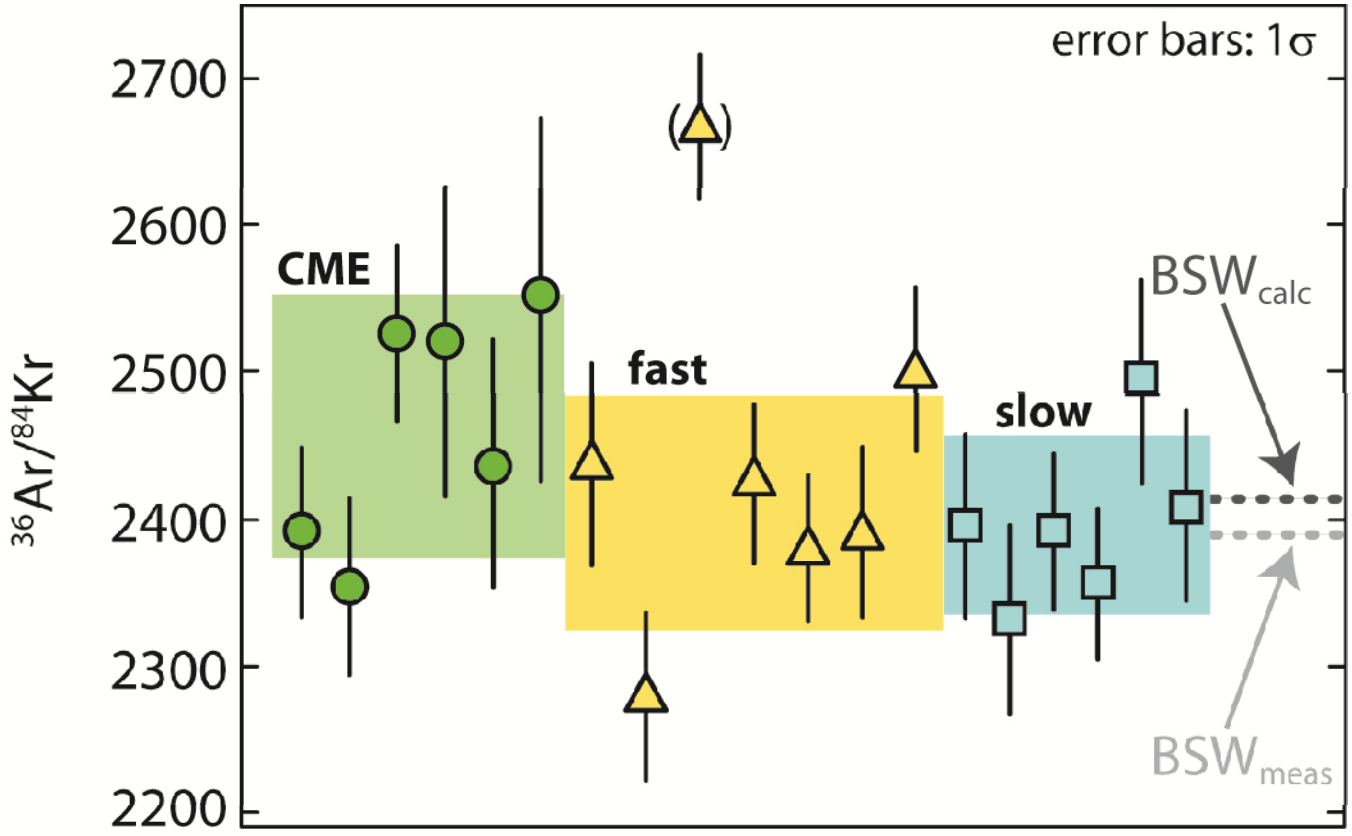
Preliminary Ar Ke Xe fluences for regimes
Vogel et al., LPSC 2011 Abs #1767



Fluxes of ^{36}Ar, ^{84}Kr, and ^{132}Xe in atoms/cm^{2}·sec in H (CH), L(interstream, IS), and E (CME) samples of CZ Si. The grey shaded areas represent the bulk solar wind fluxes from Heber et al., (2009). The time weighted averages (dashed lines) of the H, L, and E array fluxes, within errors, equals the measured bulk solar wind fluxes.

The ^{132}Xe flux is exceptionally low, corresponding to approximately only 1 atom per minute on a square cm area.

Regime element ratios $^{36}Ar/^{84}Kr$

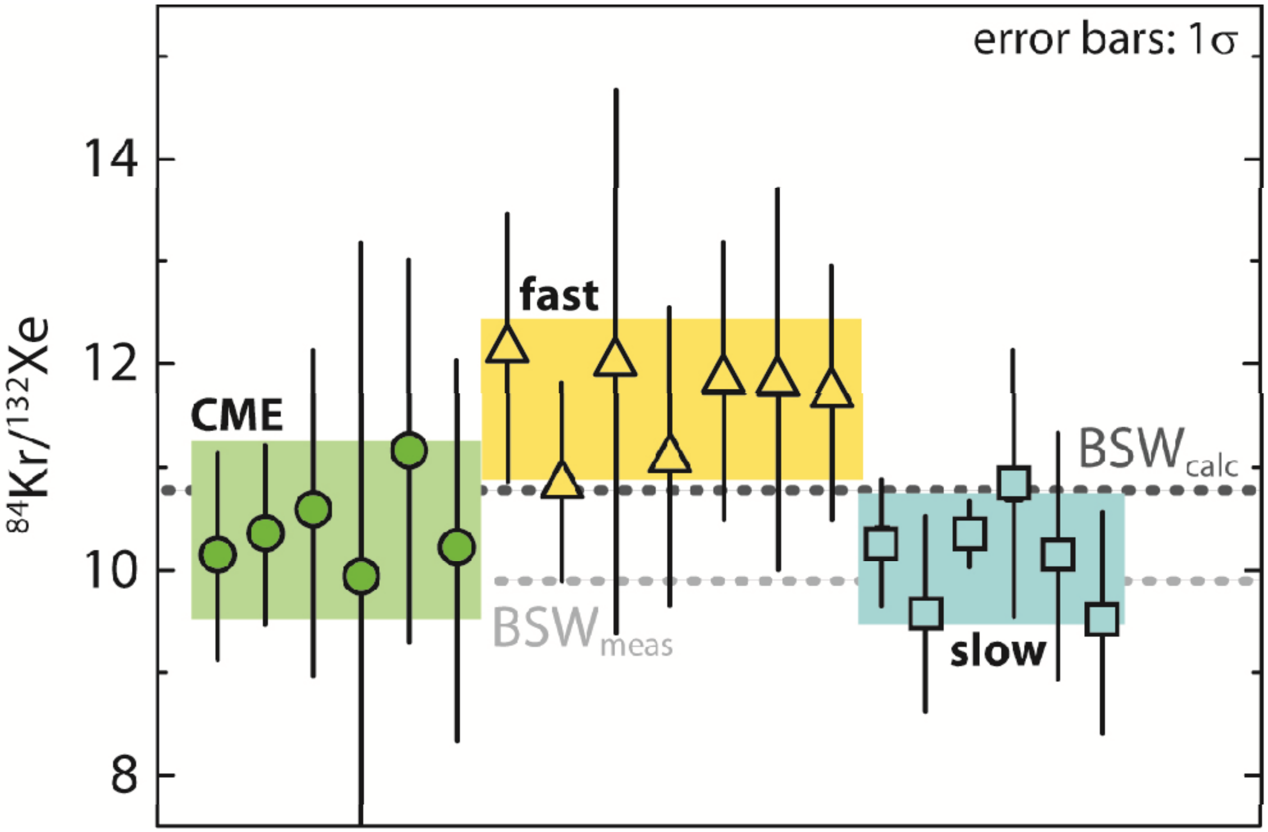


- Scatter of individual ratios within regimes
- Averages identical for all regimes.(CME possibly a bit higher)

→Different properties of SW regimes do not fractionate ^{36}Ar from ^{84}Kr

Relative contributions of slow, fast, CME SW: Reisenfeld et al. 2007; Measured bulk SW: Vogel et al. 2011; Lo: Lodders et al. 2009

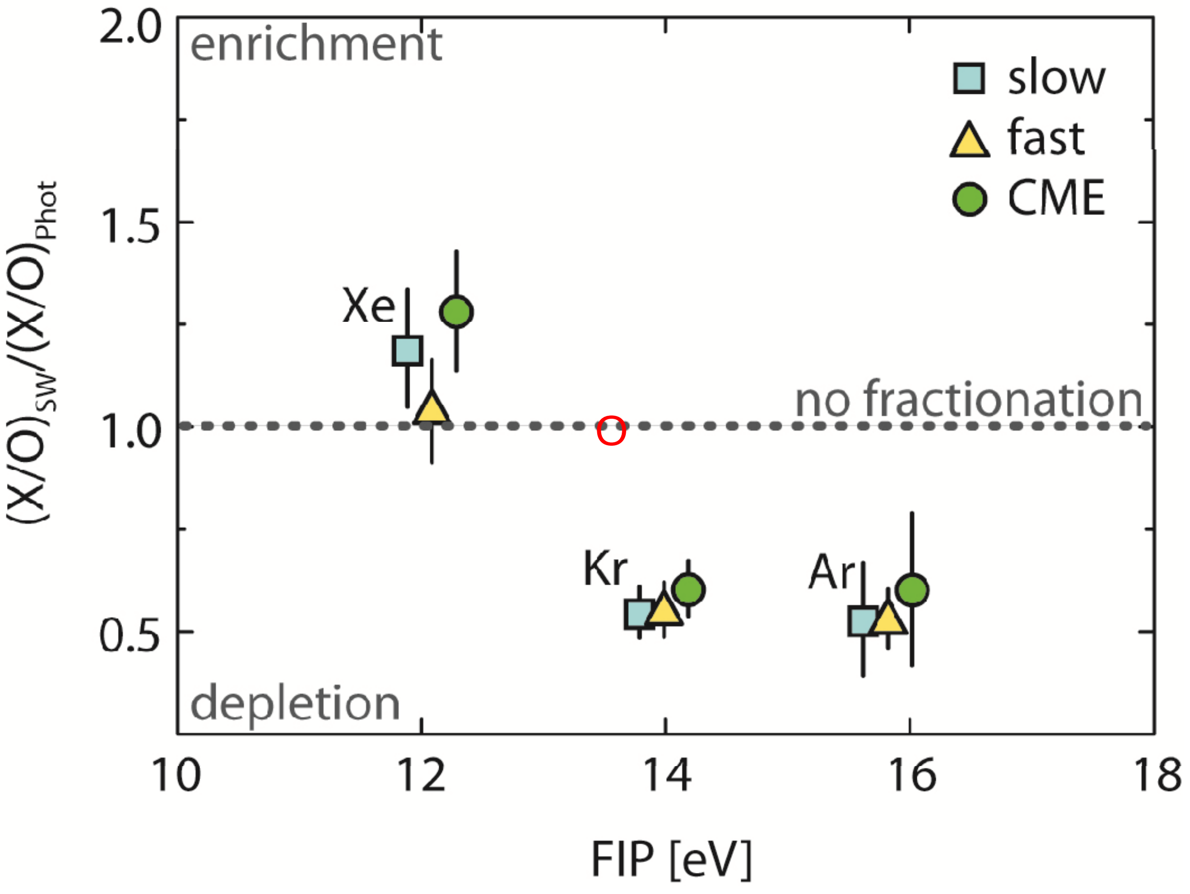
Regime element ratios ^{84}Kr/^{132}Xe



- Better clustering of individual data points for each regime than Kr
- Resolvable difference of the average ratios of fast and slow SW

Relative contributions of slow, fast, CME SW: Reisenfeld et al. 2007; Measured bulk SW: Vogel et al. 2011; Lo: Lodders et al. 2009

Vogel et al: O-normalized Heavy Noble Gas FIP Plot



Noble gases cannot be measured in the photosphere, so the denominator X/O ratio is model-dependent. A Genesis bulk solar wind Ar/O is known based on the O fluence of Heber et al (LPSC 2011 Abs# 2642). This agrees with the Ar/O ratio from spacecraft data for slow and fast (Bochsler, 2007). Slow and fast ratios for Xe/O and Kr/O are calculated using the measured Xe/Ar and Kr/Ar and the Genesis Ar/O. The CME and slow Ar/Kr and Kr/Xe ratios agree (previous slide) so it is assumed that the CME and IS Xe/O and Kr/O are also the same.

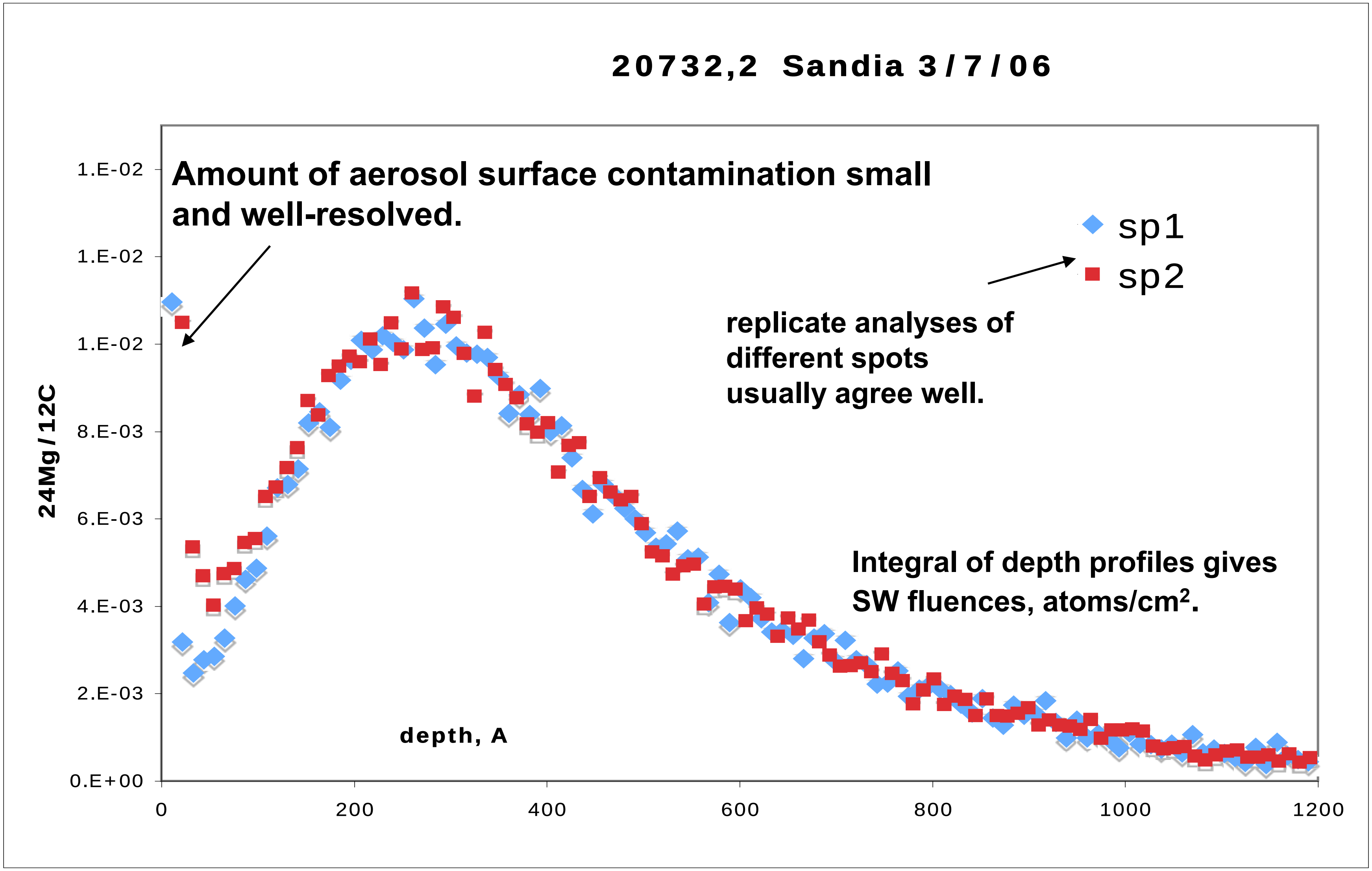
The red circle indicates the FIP for O. Taking the results at face value, a trend with a stepwise increased depletion of elements with FIP above O is indicated.

Genesis bulk SW O: Heber et al. 2011; In situ Ar/O: Bochsler 2007; bulk SW Ar: Vogel et al. 2011; Photosphere: Lodders et al. 2009

Secondary Ion Mass Spectrometry (SIMS) Essentials (e.g. Mg)

- Sample sputtered with O2+ ions, in presence of O_2 flood gas for Si collectors.
- Analyses at ASU (Jurewicz, Guan, Hervig), UCLA (McKeegan, Heber), CIW (Wang, Nittler), and Caltech (Heber, Guan, Jurewicz)
  - All SIMS instruments, but different design.
    - replicate analyses by different instruments; unique feature of sample return missions:
  - Mg+ ions produced and analyzed with mass spectrometer.
- Measure Mg relative to matrix ion:
  - Si or C from Amorphous diamond-like-carbon (Sandia).
  - Verify accuracy by replicating results on different materials
    - better quality data is a major feature of sample return missions.
- Data from 30-50 micron-size areas; particulate contamination avoided.
  - Many analyses possible even for small samples.
- Many depth profiles acquired in 5-10 minutes, (after hours of tuning).
- Quantitation simple in principle; relative to lab implant standard.

Beautiful depth profiles for Mg in Sandia diamond-like C and Si collector materials (Jurewicz et al, ASU)



Amount of aerosol surface contamination small and well-resolved.

replicate analyses of different spots usually agree well.

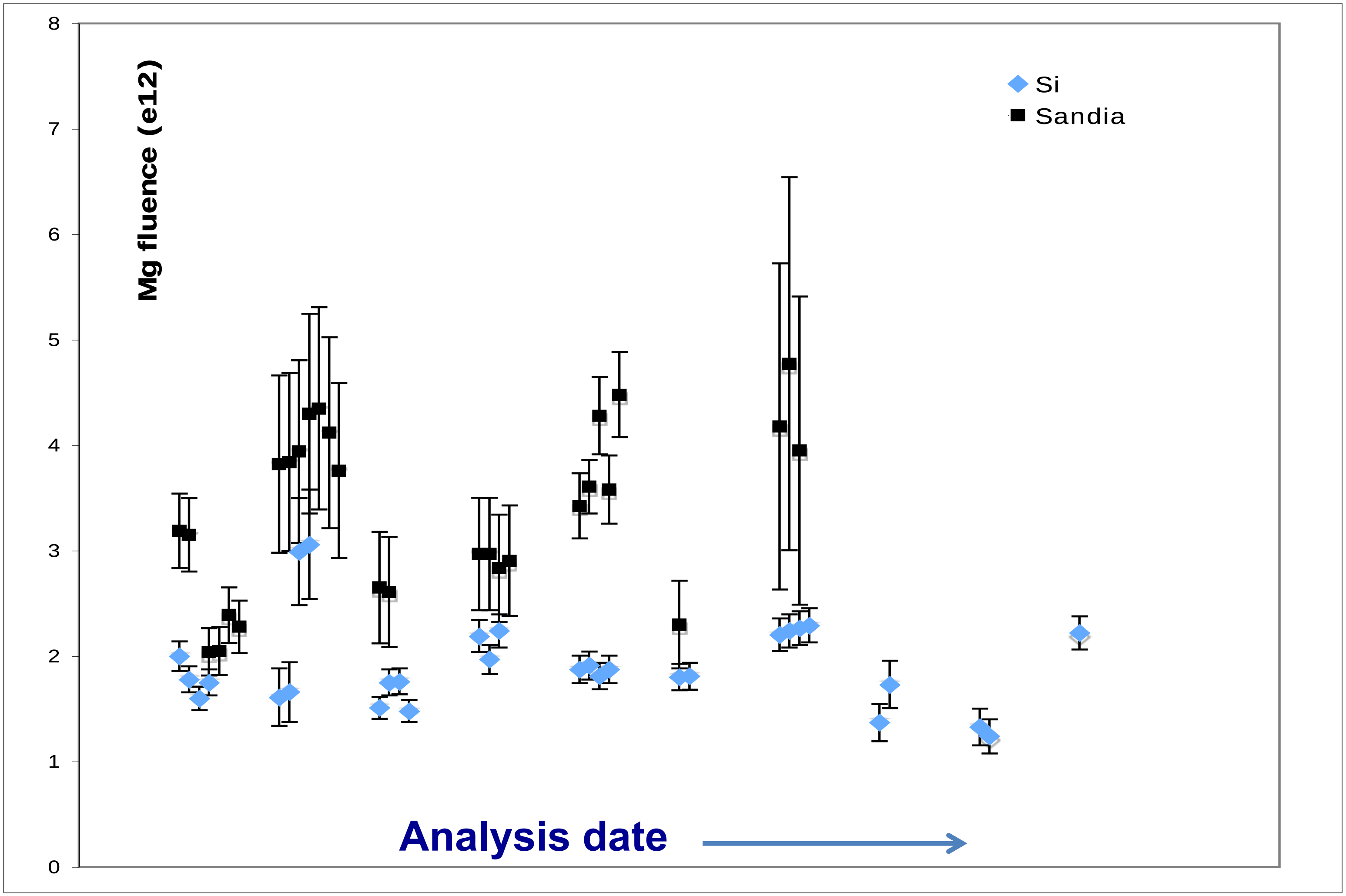
Integral of depth profiles gives SW fluences, atoms/cm^2.

Significance of Fe/Mg

- Genesis Fe, Mg fluences high and surface contamination relatively low.
- Possibly most accurate comparison with photospheric and CI ratios.
  - Tests possible metal-silicate fractionation in CI chondrite evolution.
- Mg fluence provides a reference for other techniques and elements. Should be accurate.

A huge effort has been made on Fe/Mg

Earlier Mg data based on external implant standards, i.e. consecutive analyses of separate implant and flight samples of same material.



Almost no overlap between Si and diamond-like-C (Sandia)!

Resolving the Discrepancy: Mg Flight Implants

- **Flight samples of Si and diamond-like-C were co-implanted with ^{25}Mg as internal standard.**

- **Fluence of ^{25}Mg controlled to be comparable to solar wind implanted ^{25}Mg fluence (1e12/cm^2).**

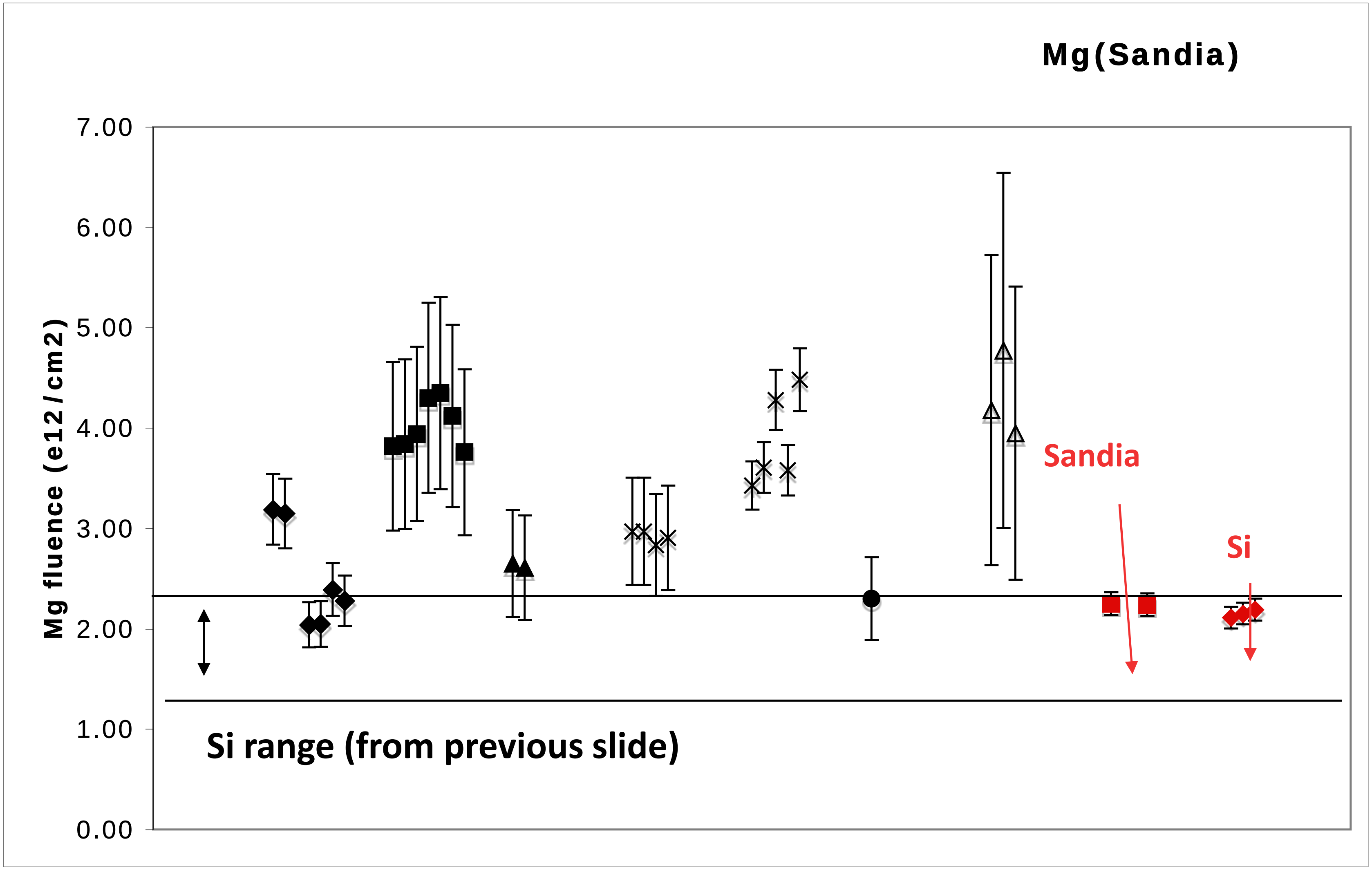
- **^{25}Mg implanted at deeper depth than most of solar wind to minimize isotopic interferences.**

- **Implant highly monoisotopic (^{25}Mg/^{24}Mg = 532). Negligible errors from isotopic interferences.**

- **Ratio of integrated solar wind ^{24}Mg to integrated ^{25}Mg scaled to known ^{25}Mg fluence to get solar wind ^{24}Mg fluence.**

Ultimate in accuracy: implant the samples you want to analyze

Mg fluences agree for all flight implant samples.



Jurewicz et al., LPSC 2011 Abs # 1917.

Fe Fleunces

Recent work has focused on Mg.

Unlike Mg, original Fe data appeared to give consistent results between Si and diamond like carbon (DLC) collectors.

It turns out that this agreement was fortuitous.

Review of Fe fluence data for Si collectors (Woolum) showed four additional small corrections required.

All four corrections had the same effect, lowering the Fe fluence for Si !

Jurewicz et al (2011) Fe fluence: 1.41 x 10^{12} atoms/cm^2 based on Si

Fe fluence from DLC: 1.36 ± 0.06 x 10^{12}

Revised Fe fluence in Si: 1.17 ± 0.05 x 10^{12}, 17% lower than Jurewicz et al.

Situation with Fe now similar to Mg with DLC fluence higher than Si, although effect is much smaller.

Solve Fe discepancy in same way as Mg:

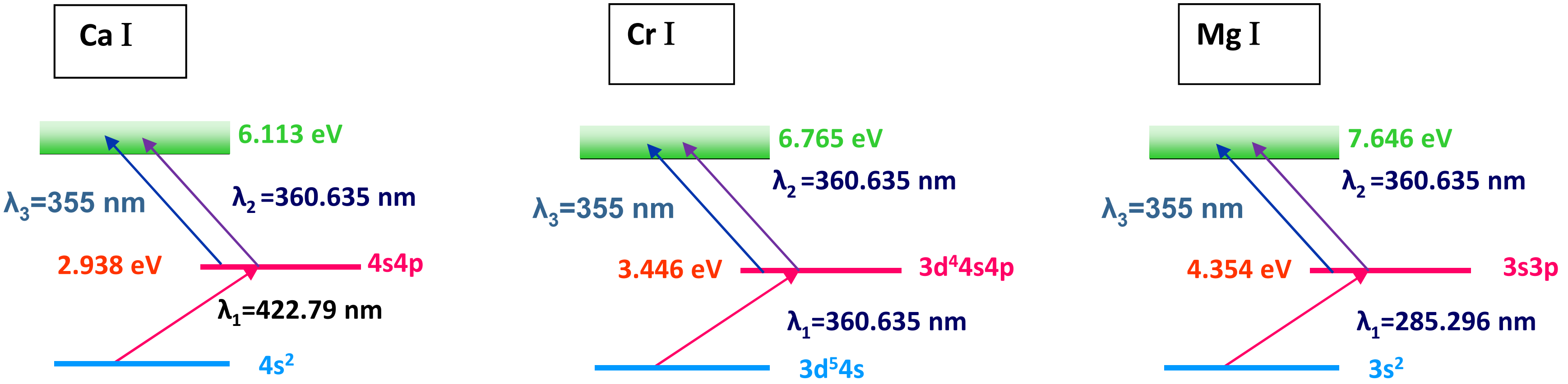
Implant flight samples with 54Fe as internal standard with 54Fe fluence calibrated against co-implanted NIST 617 glass with Fe content measured by ICPMS isotopic dilution (Humayun)

Measurements are in progress.

Resonance Ionization Mass Spectrometry (RIMS) essentials.
ANL Veryovkin et al.

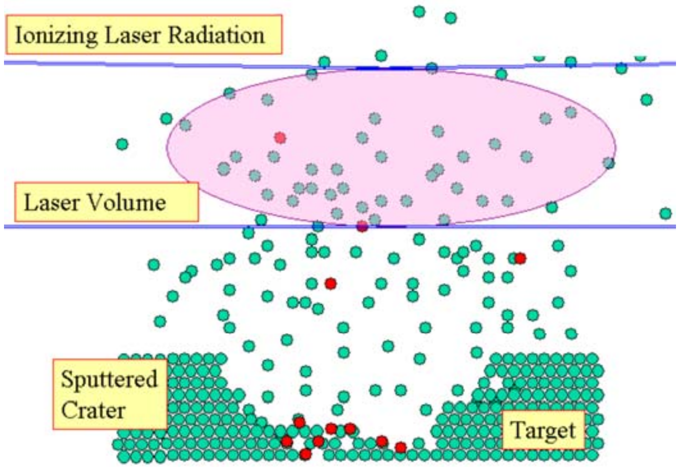
- RIMS analysis begins with sputtering with a primary ion beam, like SIMS.
  - However, only roughly 1/1000 of the atoms sputtered are the ions utilized by SIMS.
- RIMS ionizes the sputtered neutral species by timing ionizing laser pulses with an ion beam pulse with mass analysis by time-of-flight mass spectrometry.
  - Laser duty cycle limits acquisition time, presently 1 to 2 kHz
- A very large fraction (>1%) of the neutrals can be ionized and counted, producing very high sensitivity.
  - About 20% has been demonstrated for Mg.
- The photoionization takes place in two steps.
  - One laser frequency is highly tuned to excite the selected atom into an excited state. This provides high selectivity of the element being analyzed from any molecular ions of the same mass.
  - A second laser ionizes the excited atom which is detected by the time of flight mass spectrometer.
- A RIMS instrument designed specifically for Genesis samples is operating at ANL.
  - See Veryovkin et al., 2011 LPSC abstracts 2790, 2308.
- At present, both SIMS and RIMS are useful for Genesis samples, but eventually only RIMS will be able to analyze elements of low abundance.
  - Present detection limit is below 50 ppt.

Three element RIMS analysis:
422.79 nm, 369.635 nm and 285.296 nm light
Simultaneously detect Mg, Ca and Cr using only three tunable lasers



Excited atoms of all 3 elements ionized with 355 nm laser.

The 4 lasers intercept a cloud of ion sputtered neutral atomic species and convert them into ions for TOF MS analysis



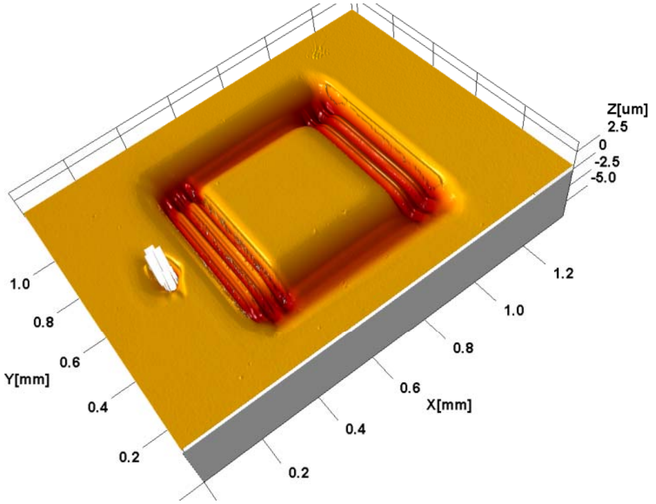
RIMS upgrades

A major instrument upgrade has been carried out to minimize effects of surface contamination by (1) better analytical depth resolution, (2) minimizing counts from surface contamination from regions outside analyzed spot, (3) SEM imaging of sample to avoid particles, and (4) improved preanalysis sample surface cleaning by CO_2 foam and acid cleaning, verified by TRXRF analyses (see later section).

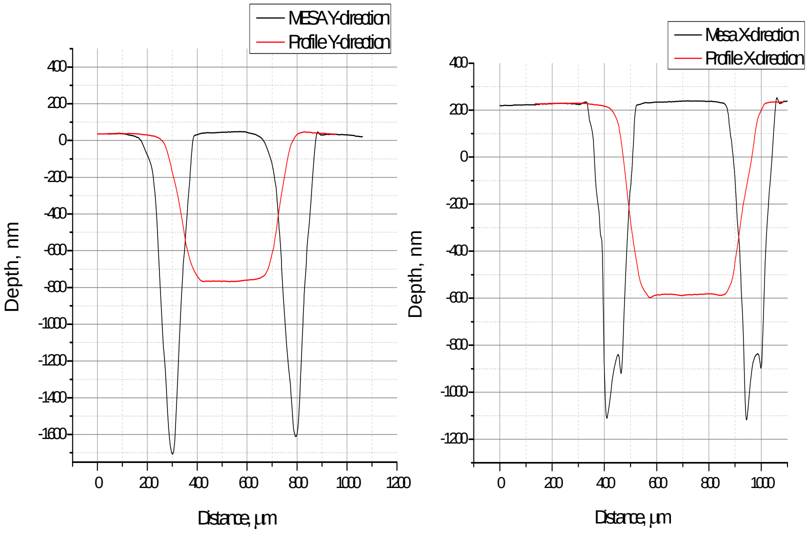
(1) At a given depth, a pulsed ion beam is used for the RIMS analysis. A DC ion beam is used to sputter to a deeper depth within the sample. Previously a single beam was used for both modes. Now a separate lower energy (500eV) DC ion beam will be used which will have much less ion beam mixing of surface contamination into the solar wind layers. The pulsed beam retains higher energy to provide adequate sputtering rate.

(2) Improved discrimination against surface contamination

A



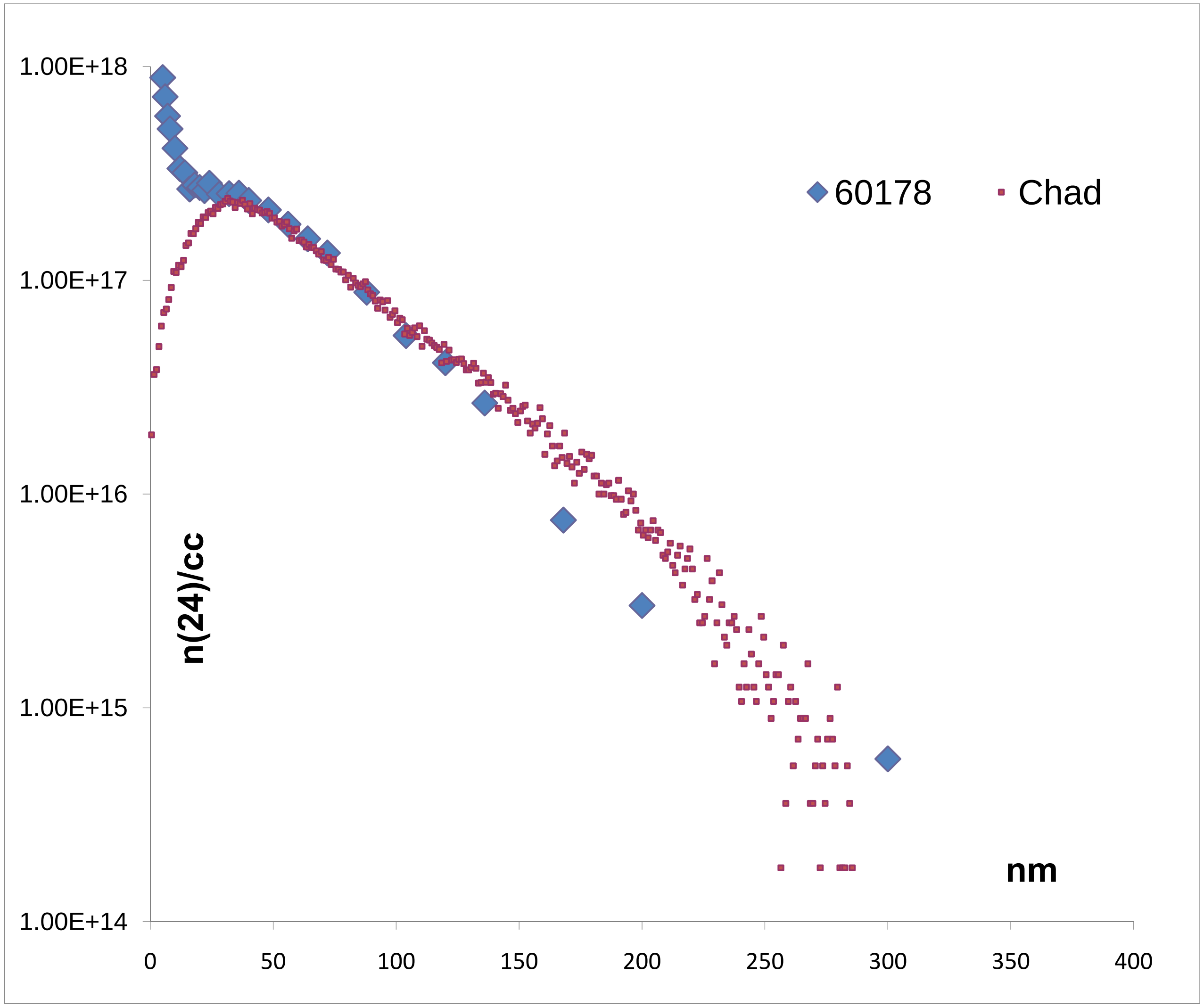
B



As shown in the figures, a focused ion beam is used to dig a trench around the area to be analyzed which occupies a "mesa" inside the trench (A and black curve in B). Surface contamination is removed from the trench, minimizing background from any stray ions reaching outside the area of the mesa. The red curve in B shows the crater analyzed in measuring a depth profile.

DC sputtering uniformly reduces the height of the mesa. The pulsed beam can be focused to the center of the mesa; alternatvely, improved spatial resolution can be achieved by rastering the pulsed beam, and accepting counts only near the center of the raster (gating).

Bulk SW Mg depth profile in 60178 Si; atoms ^{24}Mg/cc



Background correction based on observed signal beyond 300 nm.

Good agreement with theoretical depth profile (Chad) between 40 and 300 nm.

Some residual surface contamination below 30 nm

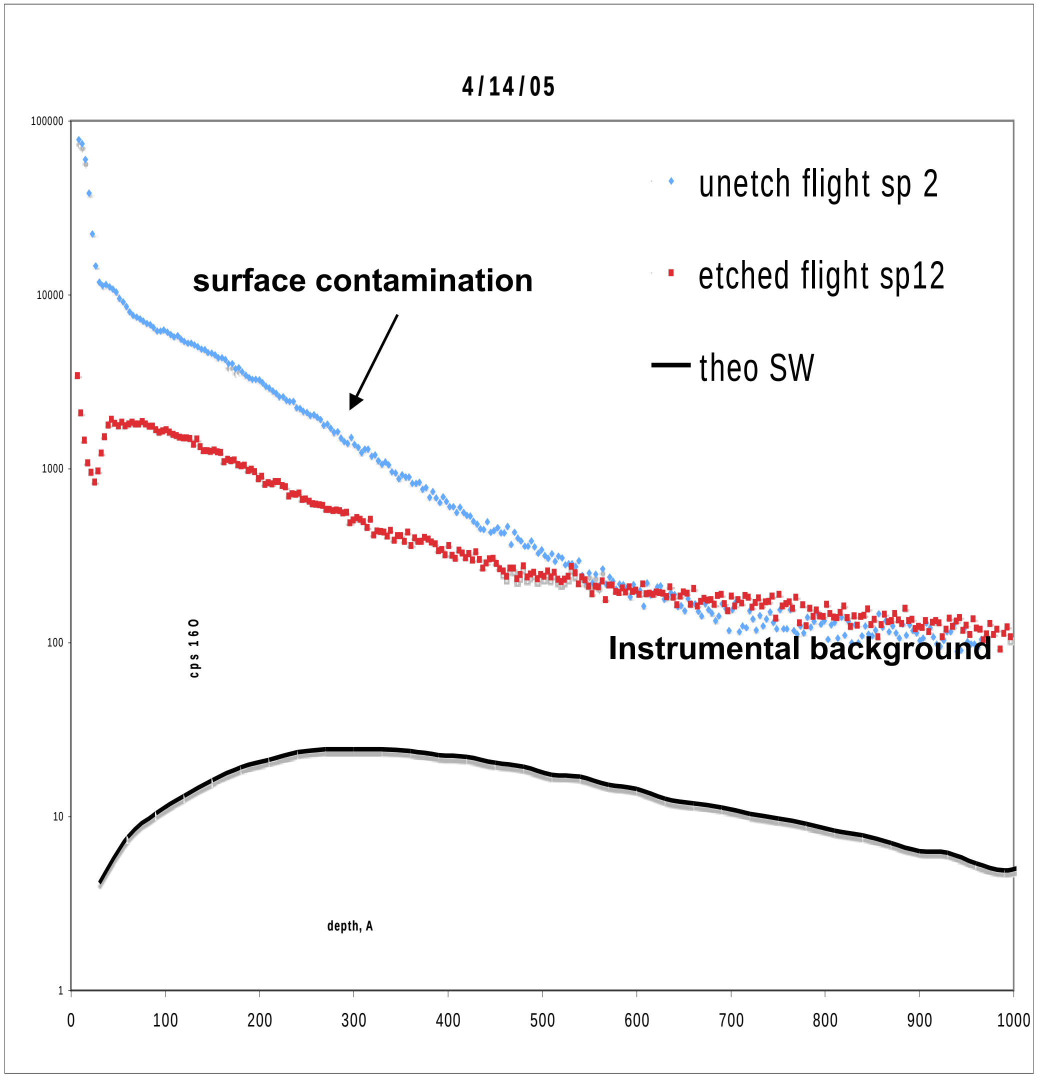
RIMS-SIMS fluence comparisons

Element	RIMS	SIMS	
Mg	2.24e12	2.15e12	ASU 6f
Ca	9.4e10	1.0e11	UCLA 1270
Cr	3.3e10	3.0e10	UCLA 1270

All data preliminary, but agreement good at this point.

Bulk solar wind O, C fluences

Heber, Woolum, S Smith(EAG), McKeegan, Kallio, Jurewicz, Guan



C and O are relatively easily measured by spacecraft instruments, but difficult for Genesis because of surface contamination and instrumental background problems. SIMS sensitivity is adequate.

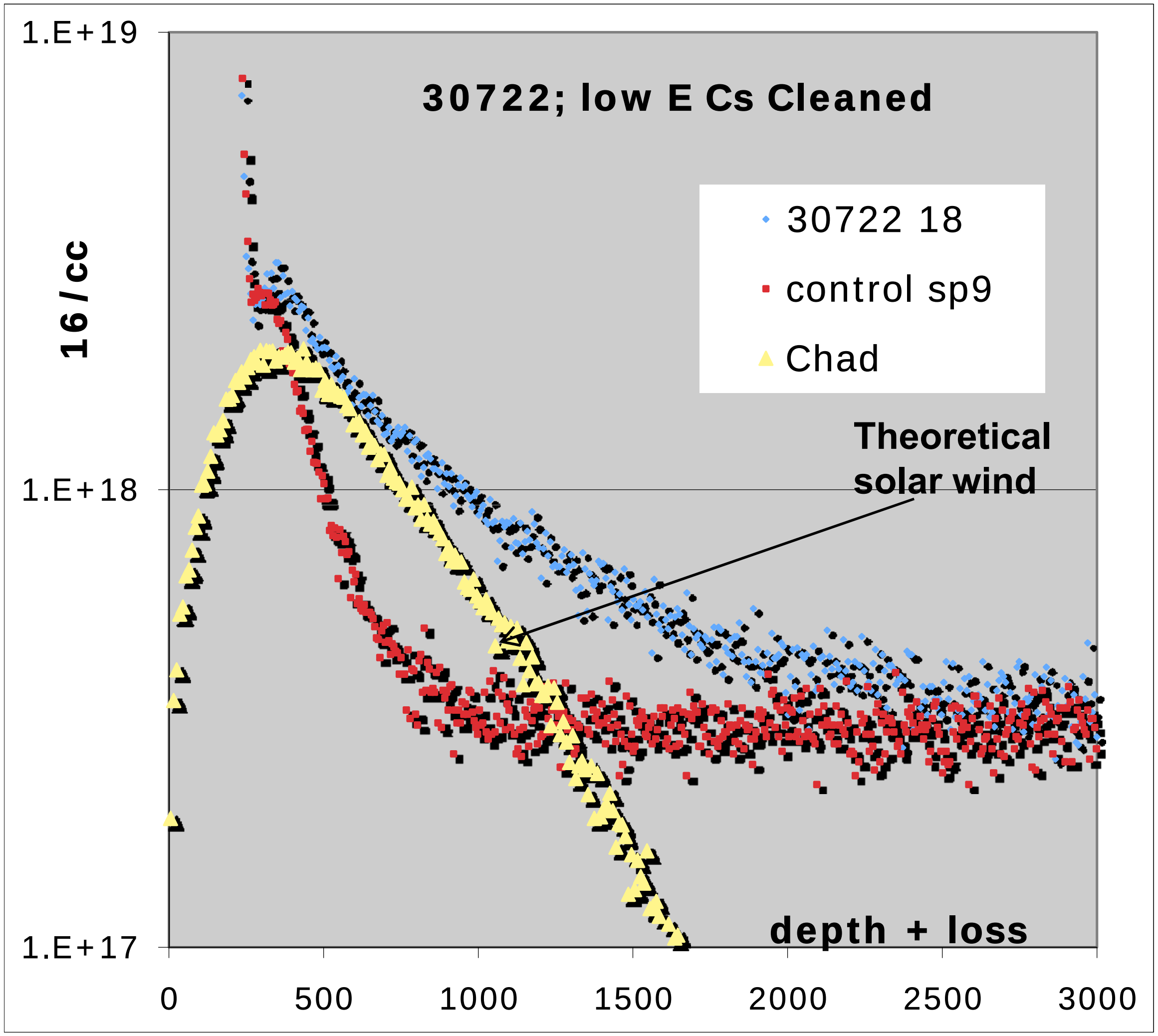
The figure (log scale) shows where we started in 2005.

The structure at small depths is due to transient sputtering effects. The deep tail reflects O from small (<100A) particles mixed to larger depths by the Cs primary ion beam with an exponential “gardening” profile.

In this experiment, chemical etching with $HF-H_2O_2$ reduced the surface contamination by about a factor of 3, but the residual signal was still two orders of magnitude higher than the expected solar wind levels.

At depths greater than 1000 A, the residual instrumental background, after sputtering away surface contamination, was still 10x the solar wind.

Fall 2009. Caltech 7f Major Improvements



Instrumental Background reduced by:

- **1e-10 Vacuum**
- **Many days of pumpdown**
- **Overnight Si sputtering.**

Surface Contamination reduced by:

Low E (5 keV) Cs surface cleaning.

Solar wind measured between 500 and 2000A, but surface bkg. still too high

Solution: Back Side Depth Profiling

Sample preparation (EAG)

- Epoxy up-side-down onto Si Substrate.
- Grind + polish to 0.4 – 2 microns thick
- B/C array Si fragments (5-8 mm)
- Fringes: sample is flat only in the center part

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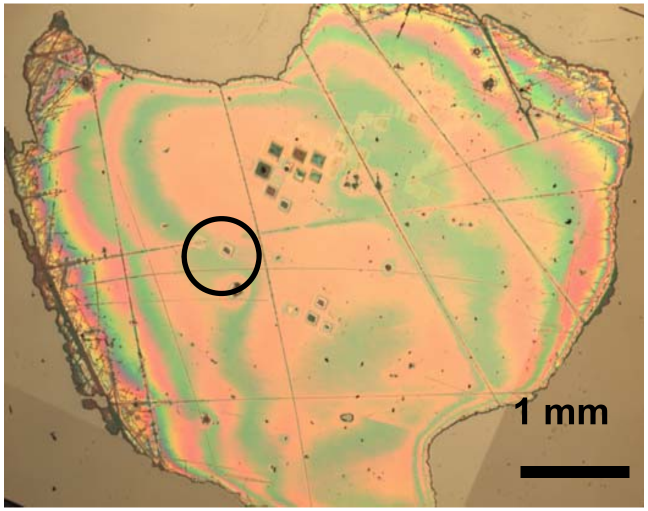


Depth profile: sputtering from the back side of the thinned sample.

- ➢ no gardened surface contamination
- ➢ good measurement of instrumental background
- ➢ analysis of almost complete SW profile
- ➢ no transient sputter effects during SW profile

See Heber et al LPSC11; abstract # 2642

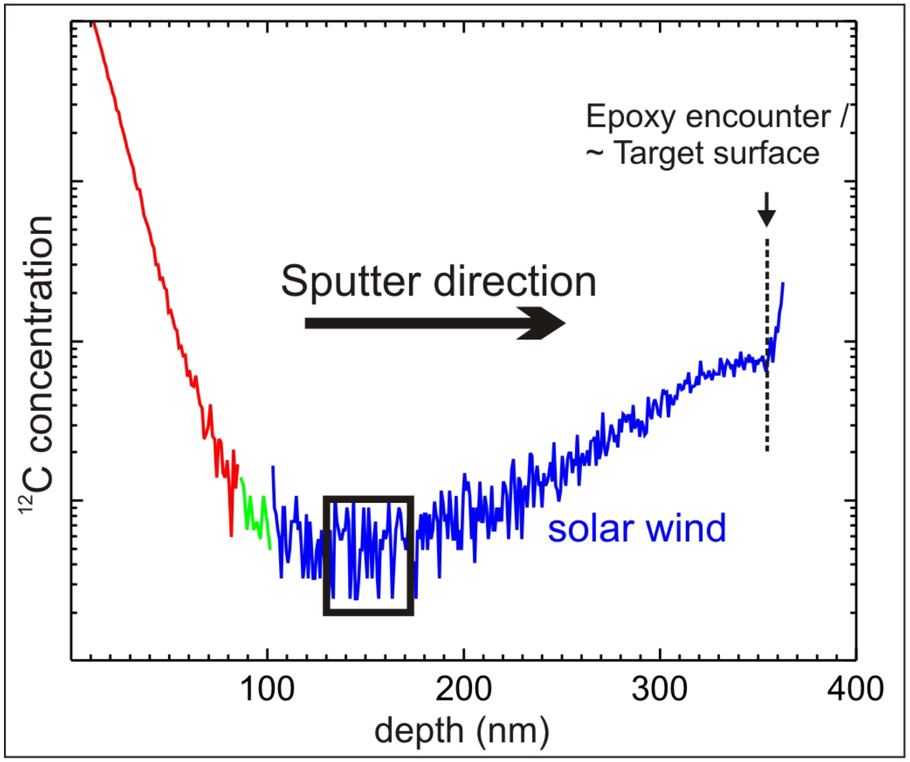
Genesis backside depth profiling analysis in 3 steps

(a) 125×125μm^2, 30nA beam→ remove surface contamination (^{12}C, ^{16}O, ^{28}Si)

(b) 100×100μm^2, 10nA beam → Si count rate, (^{12}C, ^{16}O, ^{28}Si)

(c) 100×100μm^2, 10nA beam → to increase data coverage for SW profile ^{12}C, and/or ^{16}O measured; Si count rate from (2) was assumed to be constant

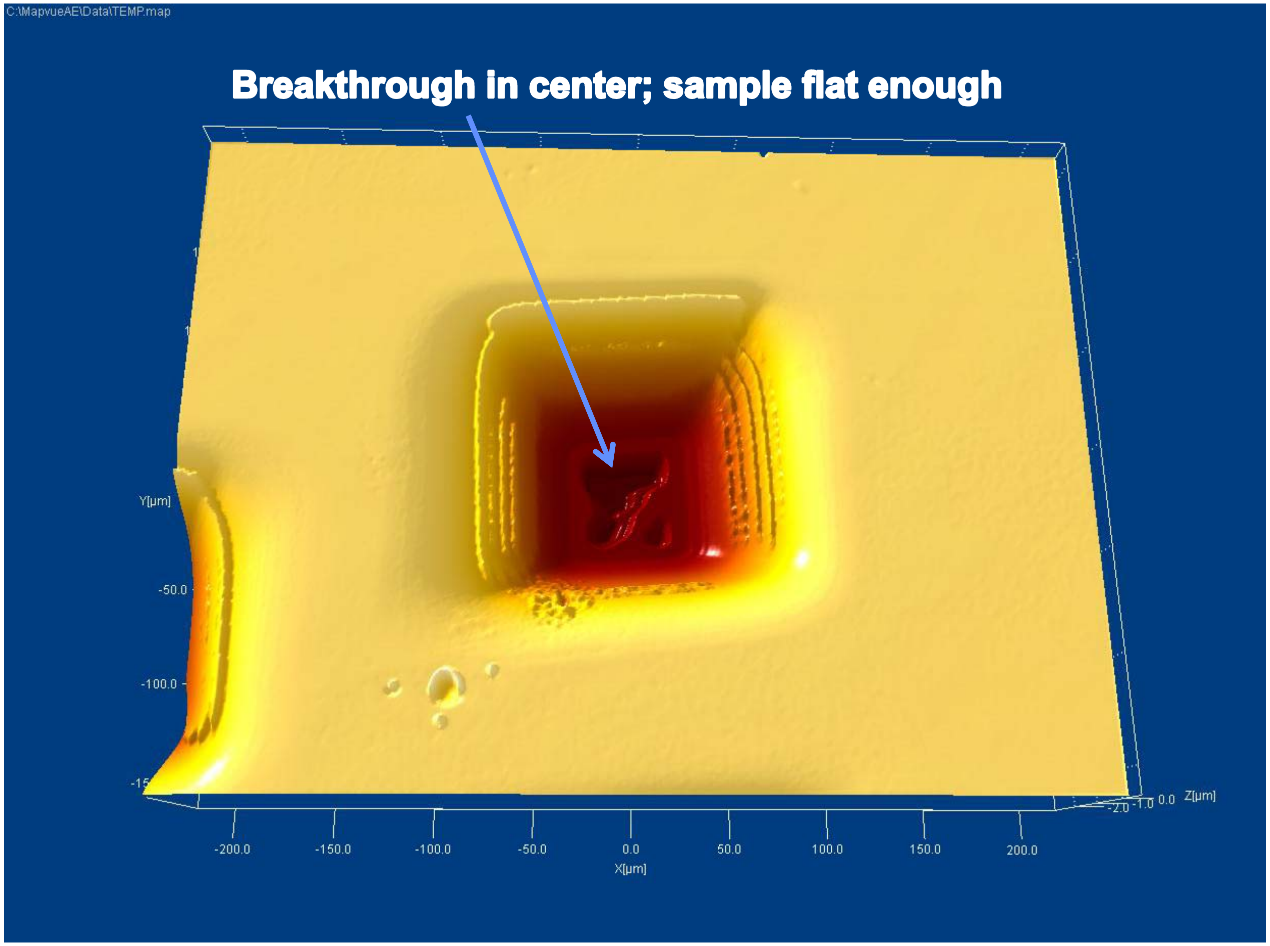
Back side



Front side

^{12}C depth profile for 60757

Optimize spatial, depth resolution to get as close to surface as possible



3D projection of interferometer profilometry (UCLA)

- 5 keV impact E
- Smallest field aperture: only analyze center of rastered beam.
- 30% gating
- Low sputtering rate
- Accept penalties in analysis time and counting rate.

Experimental - Data evaluation

- Fluences calibrated via ^{28}Si + implant standards
- No interferences on ^{16}O, ^{12}C; $^{14}N^{28}Si$ corrected for $^{12}C^{30}Si$, not for potential $^{12}C^{14}N^{16}O$ → preliminary N
- SIMS crater depths measured with optical interferometers

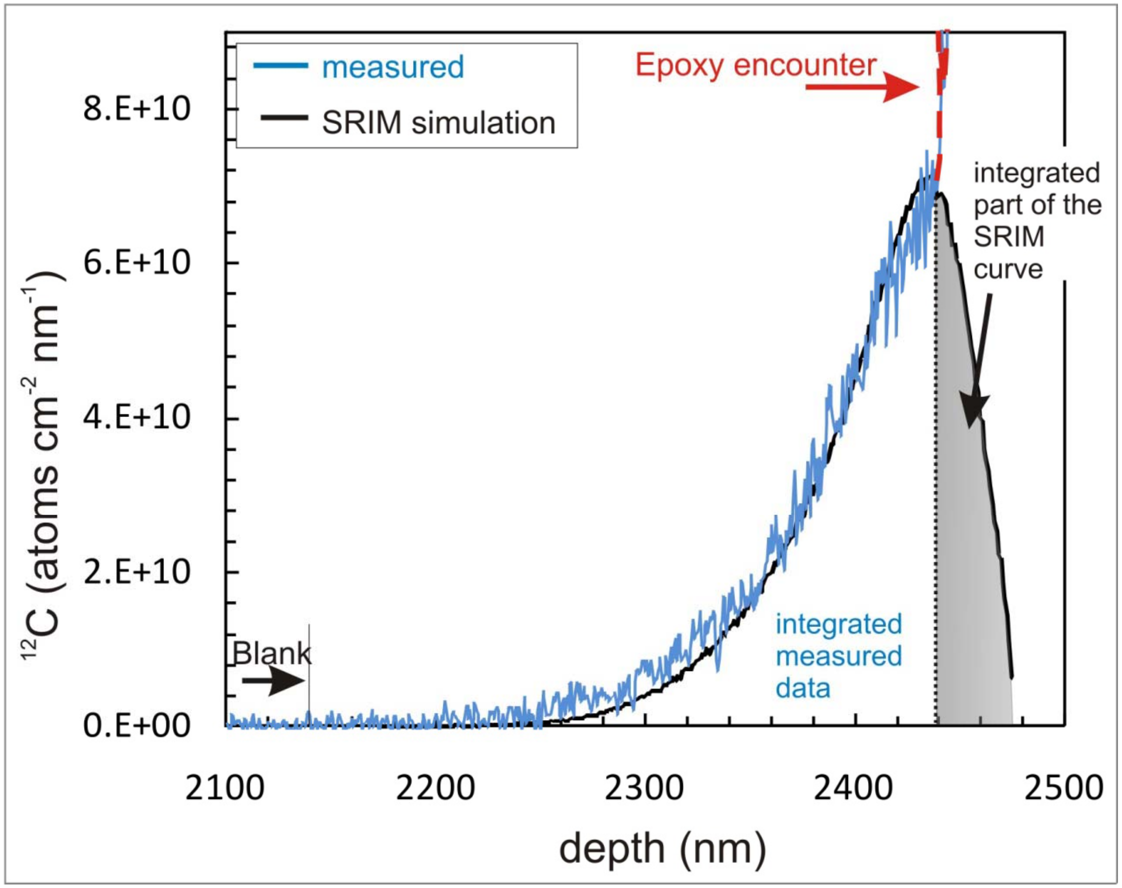
- After reaching SW implant peak, elevated C, N, O = epoxy encounter (previous slide)

no solar wind data from first 20-30 nm

- Profiles for C, N and O are similar

Fluences =

integral over all measured data **+** integral over SRIM curve for the missing data



Results

Solar wind C, N, O fluences and comparison with spacecraft data

	Genesis bulk SW fluences (× 10^{12} atoms/cm^2)	n analyses	
H	18400		GIM
^{12}C	5.96 ± 0.15	5	this work
^{14}N	1.2 ± 0.2*	3	this work
^{16}O	10.8 ± 0.7	2	this work
^{20}Ne	1.26 ±0.03		Heber et al. 2009

* preliminary

	Genesis	Ulysses (SWICS instrument)	
	Bulk	*slow*	*fast*
C/O	0.558±0.015	0.67±0.08	0.69±0.04
N/O	0.11±0.02	0.08±0.04	0.11±0.02
Ne/O	0.126±0.001	0.10±0.03*	0.083±0.013*

Ulysses: von Steiger et al. 2000 (*Ne abundances could be 30% higher (difficult to identify Ne in the data matrix) => in better agreement with our data.

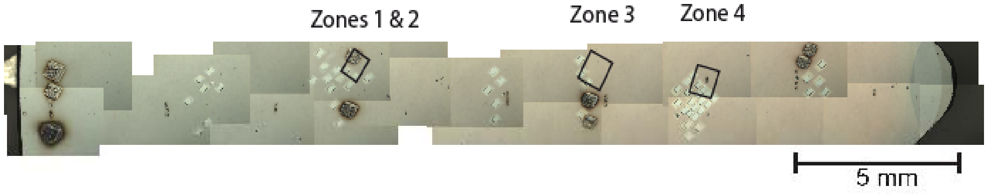
- First SW C, N, O fluences from Genesis
- N and Ne fluences (relative to O) of Genesis agree with SWICS/Ulysses data
- Genesis C/O is 16-20% lower than SWICS/Ulysses and SWICS/ACE *(Genesis science document)*- Real discrepancy in SW composition or an analytical artifact ?

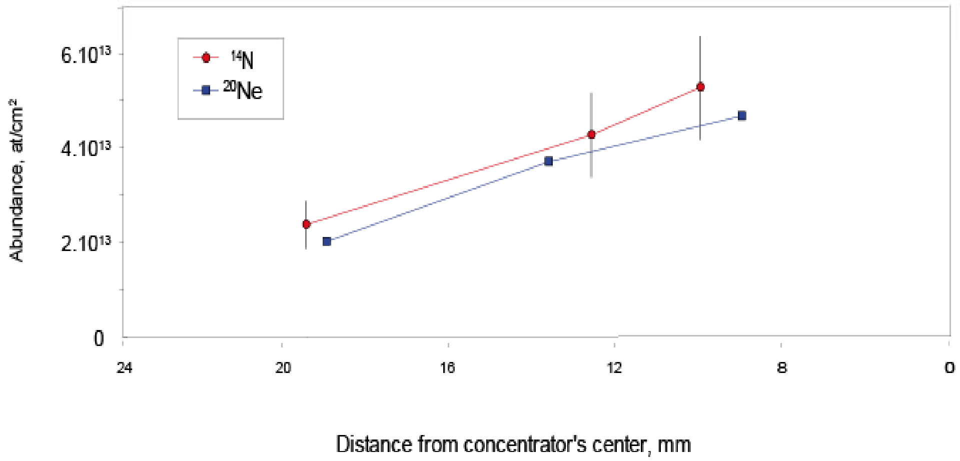
Solar Wind N fluence from 60001 Concentator SiC. (Marty et al., June 24 *Science, SOM)*)

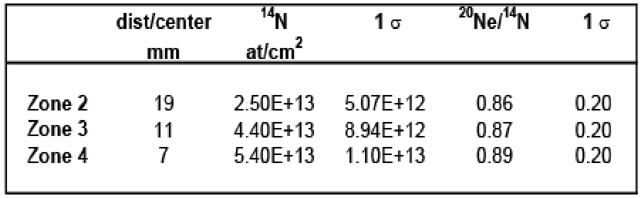
N fluences ('abundances' in figure) were computed based on an ^{15}N implant. Uncertainties were estimated from reproducibilities of standard SiC measurements. For Zones 1 & 2, a mean value of the two determinations was taken. The center figure shows that the N fluences increase as expected with distance and track the ^{20}Ne fluences of Heber et al., 2011. The table shows that N/Ne is constant, consistent with the concentrator models of Wiens. The mean ^{20}Ne/^{14}N ratio of all 3 zones is 0.88±0.01, similar within errors to the estimate of the (^{20}Ne/^{14}N)$_{SW}$ of 1.14±0.23 (Marty et al. 2010). The 0.01 error is reproducibility. Systematic errors in the 10-20% range are possible.

Using the accurate bulk solar wind fluence of 1.26x10^{12} (Heber et al., 2009), a bulk solar wind N fluence of 1.11x10^{12}/cm^2 ± 0.17 is obtained.

Synthesis : abundance







	dist/center mm	^{14}N at/cm^2	1 σ	^{20}Ne/^{14}N	1 σ
Zone 2	19	2.50E+13	5.07E+12	0.86	0.20
Zone 3	11	4.40E+13	8.94E+12	0.87	0.20
Zone 4	7	5.40E+13	1.10E+13	0.89	0.20

N Fluence from Collector Array DLC
G Huss; Hawaii, Cameca 1280 SIMS

- Paper submitted to Meteoritics and Planetary Science.
- Gardened surface contamination dominates solar wind for depths less than about 400 A.
- Instrumental background dominates solar wind for depths greater than about 1500 A.
- But region between 400 and 1500 A mostly solar wind for ^{14}N.
- Correct region below 400 and beyond 1500 using theoretical profile (C. Olinger, LANL)

N bulk solar wind fluence 1.41± 0.28 e12/cm^2, a bit higher than the Nancy result but errors overlap.

N Fluence Comparison

	N fluence ($10^{12}/cm^2$)	
Heber et al.	1.2 ± 0.2	SIMS backside depth profiling, Si
Huss et al.	1.41 ± 0.28	SIMS, DLC
Marty et al.	1.11 ± 0.17	SIMS Concentrator Target SiC

Results are in reasonable agreement; Heber et al result will be improved.

FIT plot from Genesis data

We can compile the heavy noble gas fluences (Crowther and Gilmour, 2011: Meshik et al, 2011; Vogel et al., 2011), Mg and Fe (Jurewicz et al., 2011), CaCr (Veryovkin et al., 2011) and CNO (Heber et al., 2011) to produce a preliminary FIT plot using only Genesis data.

Mg is used as normalizing element. Note that most literature FIP/FIT plots use O as the normalizing element. Errors in either the Genesis Mg fluence or the photospheric Mg abundance only affect the value of F for other elements. The pattern of points on the plot is unaffected.

Ne and Ar are not plotted, as there are no spectroscopic data for their photospheric abundances.

Kr and Xe are special cases. There are no spectroscopic photospheric abundances; however, CI abundance curves are sufficiently smooth in the Xe, and especially Kr, mass regions that interpolation gives relatively precise abundances subject to two assumptions:

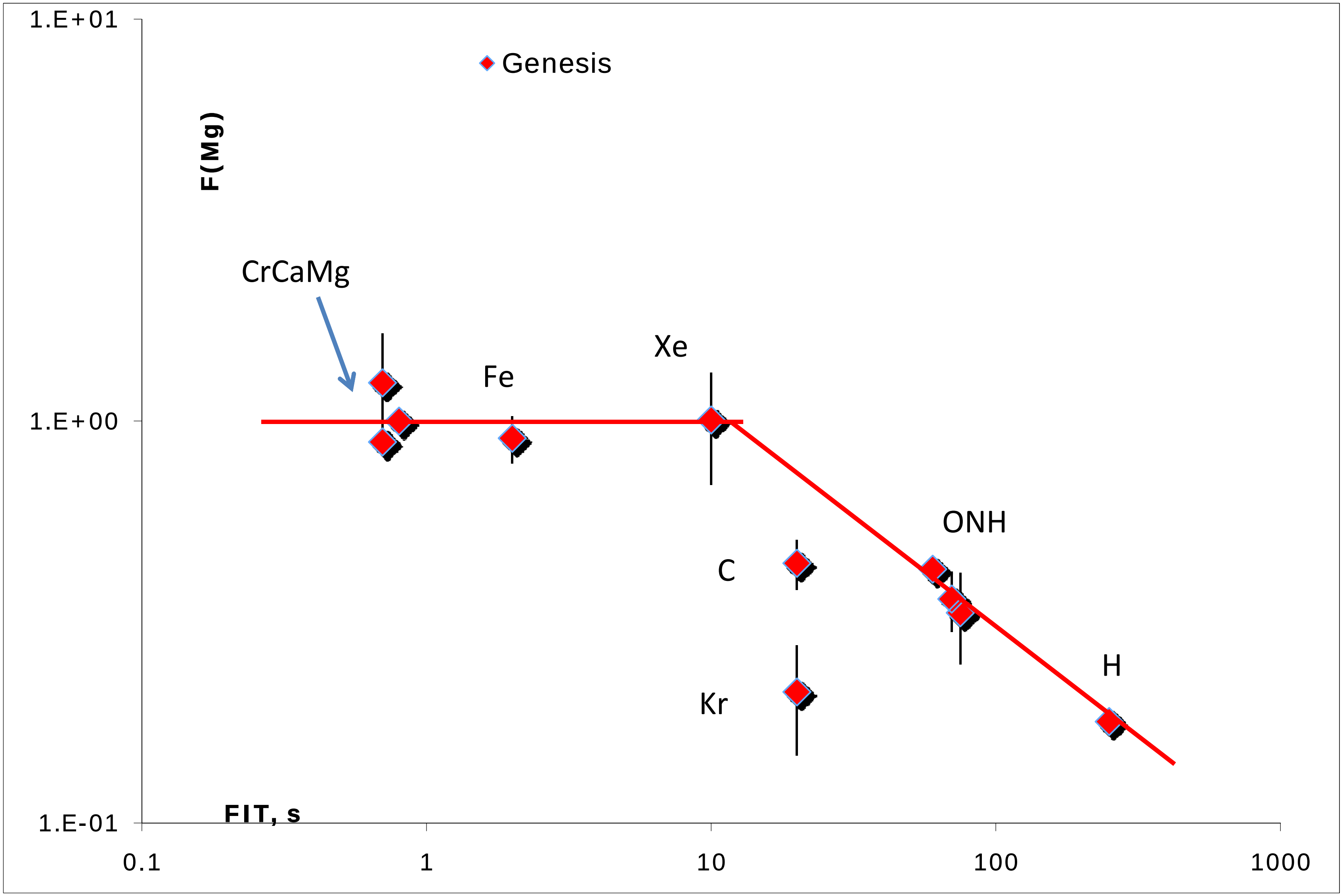
1) the overall validity of CI abundances.

2) the assumption that Kr and Xe, as volatile elements, are not depleted or enhanced relative to neighboring nonvolatile elements.

Genesis can eventually test both of these assumptions.

Light element photospheric abundances are too variable to interpolate abundances for Ne and Ar.

FIT plot with Genesis data.



Genesis FIT plot: interpretation

The red lines are obviously not a unique description of the data, but represent an interpretation commonly used for spacecraft data.

The genesis data indicate more complexity than the spacecraft model.

As more and better Genesis data are obtained, the true systematics of the data will be revealed.

As noted earlier by Vogel et al (LPSC 09), the solar wind Xe/Kr is significantly higher than the interpolated solar ratio. This is an issue deserving of further study.

Cleaning up to Recover Science after Crash

Three necessary steps to recovery of science objectives:

1. **Recover Collector Materials intact.** Done

   Expected 250 samples, have ~ 15,000 > 3mm; 1700 > 1 cm .

   Priority given to allocation, but catalogs at a high level of completion, see Genesis JSC web page.

2. **Remove surface contamination.**

   Required for essentially all analyses, especially from here on out.

3. **Learn to allocate and analyze smaller samples than planned.**

   Items 2 and 3 worked simultaneously.

Following 2 pages are background on sample cleaning included with all Progress Reports.

Brown Stain (slide unchanged from previous GPMCs)

Non-crash issue

- Polymerized organic contamination film (‘brown stain”)
  - Thicknesses measured by ellipsometry (JSC,) XPS (EAG, JPL), and FIB/TEM (LLNL).
  - Up to about 75 A thick, but
  - Highly variable; some samples appear essentially free of stain.

- If less than 100A: negligible SW attenuation (C. Olinger, LANL calculations).
- Brown stain must be removed for most, but not all, analyses:
- uv-ozone (demonstrated by Open U) most successful to date.
  - JSC unit is operational and demonstrated to remove C effectively
    - For some applications, greater amount of removal may be required.
  - good correlation between XPS and ellipsometery on same Si samples.

We have learned to work around Brown Stain.

Important Boundary Condition:

- Because amounts of contamination highly variable, cherry-picking ”good” (low brown stain) samples is an acceptable contamination control.

Particulate Contamination Overview.

Crash-related issue: Particulate contamination on all samples.

- Variety of wet cleaning techniques work to varying degrees:
  - Any solvent (e.g. ultra pure water) will take off 1/2-2/3 of particles and almost all big (>5 micron) ones.
  - For most samples, JSC Megasonic ultra-pure-H2O (UPW) in routine use for materials for which this possible.
    - Probably not applicable for AloS samples and must be done with care for AuoS

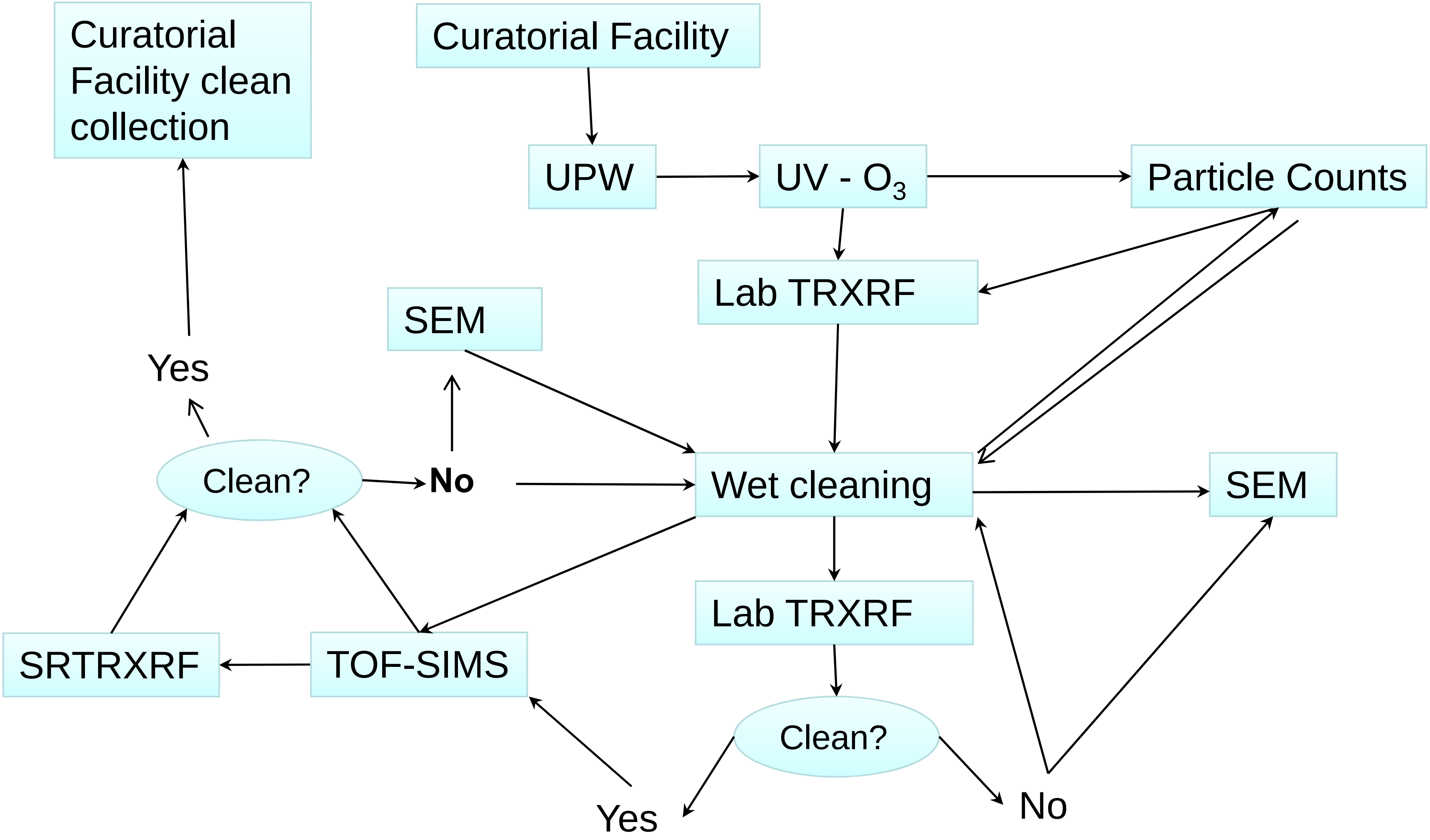
- *Particulate contamination is the major obstacle to completion of the Genesis science objectives*.
  - Our success so far has been with techniques such as SIMS or RIMS that can analyze areas of 50-200 micron size, can dodge micron-size particles, and can recognize, and afford to lose, a single particle-contaminated profile.
  - None of these benefits are available for large area analysis (> 1 cm size), for which in some cases a single contaminant particle can ruin the analysis.
  - Some of the science objectives require analysis of large areas.
- Some success with acid cleaning, but not good enough. Systematic approach needed.

Basic Approach, revised 2011:

- Contamination levels are highly variable.
- Cleanliness requirements vary for different analytical techniques.
  - No one-size-fits-all solution.
- Basic Curatorial cleaning services: UPW, uv-ozone, particle size distributions (latter is a new task).
- Previously, rest was left to PIs, but problem of cleaning samples to permit large surface area analysis so severe that a consortium has been established to produce a collection of “certified clean” samples in the curatorial collection:
    - Particle counting (JSC)
    - Lab total reflection X-ray fluorescence (TRXRF; Schmeling, Loyola, Chicago)
    - Acid cleaning (Caltech, FSU)
    - TOF-SIMS (Smithsonian, Washington)
    - SEM (Smithsonian, Kuhlman, Wisconsin)

Not all these will be used on all samples (see flow chart, next slide and subsequent slides).

Master Plan for Sample Cleaning



Master Cleaning Plan.

Full report at www.paque.com/genesis

- Although we know a lot about particulate surface contamination, we don’t know enough to routinely clean samples for large area analysis.
- We need approaches capable of efficient before-after measurements on samples subject to various wet cleaning techniques.
  - Analysis must be non-destructive; ideally quantitative but high accuracy not required.
  - Efficiency and access important because a lot of trial and error is required in wet cleaning tests.
  - We need to do a large number of analyses.
- XPS used prior to 2009 does not have adequate sensitivity for elements other than C or O.
  - But XPS remains our best technique to measure brown stain.
- Synchrotron radiation TRXRF (SRTRXRF) and TOFSIMS (Manchester; Lyon et al, LPSC 2011 abstract # 2528) have adequate sensitivity.
  - Genesis time for SRTRXRF at best only a few days per year. Need to emphasize solar wind analysis.
  - Access to Manchester TOFSIMS has been good, but not possible to process a large number of samples solely for cleaning studies.

Master Plan, con’t

Flow chart is primarily for “research” stage, i.e. trying to devise wet cleaning procedures to remove contamination at the lab TRXRF level.

- Research stage will use small 4-5 mm samples to be conservative, although only anticipated risk to samples is possibility of armoring resistance to acid by C coating from SEM analyses.

When feasible, some small-sample iterations with PI analysis labs desirable to know when sample is “clean enough” of element(s) to be analyzed.

In original 2009 plan, “success” was defined by research stage producing TRXRF-clean samples by the end of 2011. This has been accomplished.

- However, we also know that for some lab TRXRF samples, there is still too much residual contamination as shown by SRTRXRF and conventional static SIMS analyses.
- So, it is necessary that a sample be lab TRXRF clean, but this is probably not sufficient.
- Hence, we have added routine TOF-SIMS use into the 2011 Master Cleaning Plan.

Once we are confident that samples are not being damaged, we will go into “production” mode, generating a set of clean samples stored at JSC, available for future allocation.

Master Plan, JSC roles.

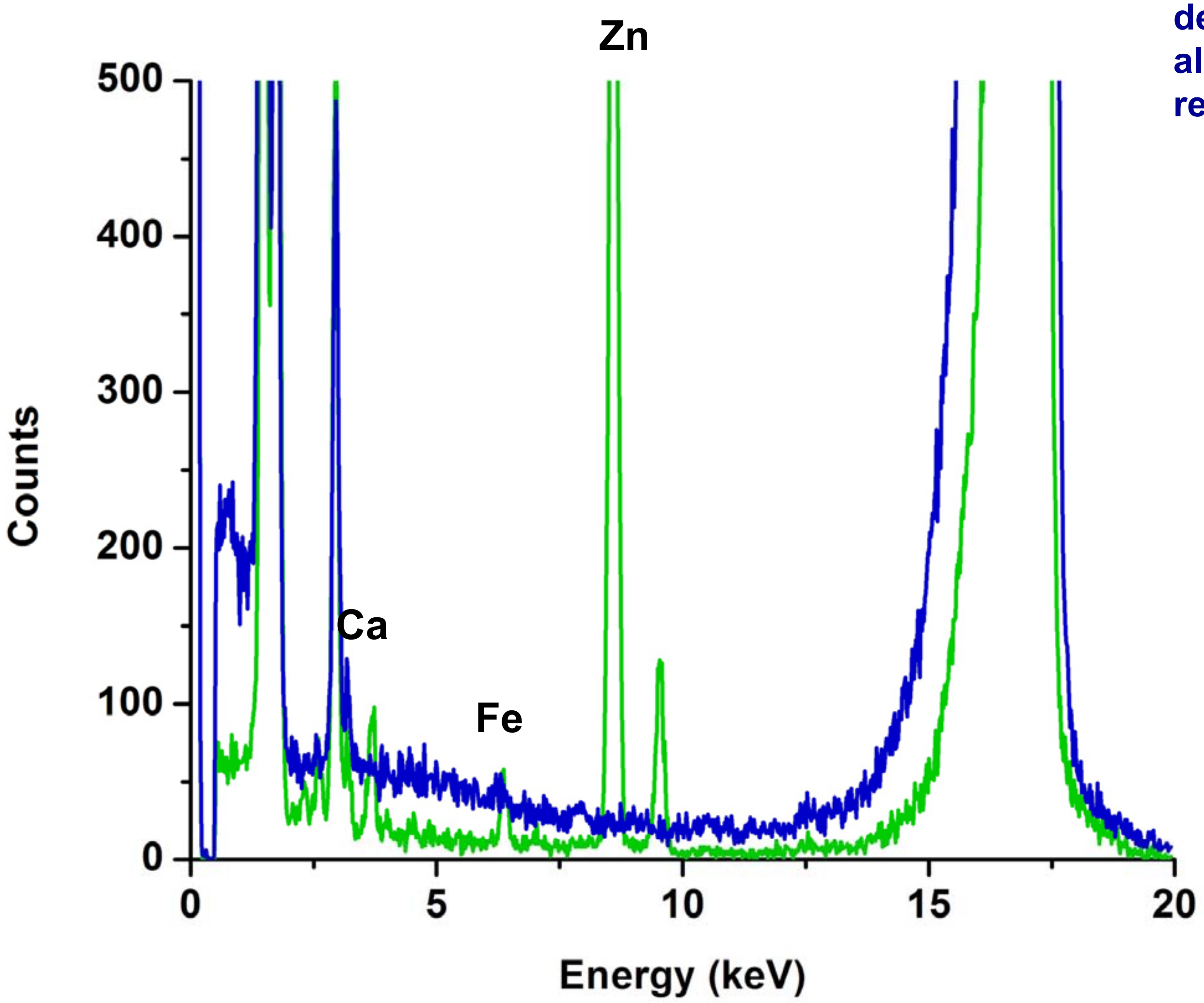
- Samples for cleaning studies selected by Curatorial Facility with concurrence of Allocation SubCommittee when large samples (> cm size) involved.
- Ultra-pure water (UPW) cleaning is routine for all collector materials except AloS and AuoS. Removes particles larger than 5 microns along with Utah salts.
- UV-ozone works for all materials, even Sandia diamond-like-C.
    - Pre-launch, only CZ Si documented to have clean surfaces for many elements at 10^{10} atom/cm^2 level.
    - Pre-launch surfaces of some materials, e.g. sapphire, now known to be relatively dirty.
    - Thus, brown stain is deposited on top of pre-launch surface contamination and must be removed. UV-ozone accomplishes this.
    - SiO_2 residue from silicone component in brown stain. Dilute HF will have to be the first step in all wet cleaning procedures. Possible for all but AloS collectors.
- JSC particle distribution mapping techniques being refined; hardware is available although unused for several years. Software updates required.
- Data base maintained for each sample in cleaning study.

Laboratory TRXRF (Schmeling et al, LPSC 2011 abs#2041)

- Use tube X-rays rather than synchrotron radiation (SRTRXRF); otherwise technique is same as described in previous semiannual reports and GPMCs on www.paque.com/genesis.
- XPS detection limits are ~ 10^{14} atoms/cm^2
- SRTRXRF has 10^9- 10^{10} atoms/cm^2 atoms/cm^2 detection limits.
- Lab TRXRF ~ 10^{11}- 10^{12} atoms/cm^2 detection limits achievable because of good signal/background and use of 10^4 - 10^5 sec counting times.
- Minimum sample handling; samples analyzed, as received, in air.
  - Samples handled in laminar flow benches.
  - Control Si samples are clean.
- TRXRF demonstrated to work on all collector materials (except diamond-like-C for unknown reasons).
- Not sensitive for elements lighter than Si; works best for 1st row transition elements (Ca-Ge), but samples clean of all these elements is way beyond where we are now.

Silicon coated Sapphire (SoS) Sample 60326

Green: no acid
Blue: 6M HCl



TRXRF spectra before (green) and after (blue) HCl cleaning of flight SoS sample. In this case acid cleaning removed contaminants to below detection levels. Many but not all samples show similar response to acid cleaning.

Master Plan: Wet Cleaning

Two labs (CalTech, FSU) are involved in the wet cleaning phase. Both use geochemical clean labs and high purity reagents.

The basic procedure will be for JSC-cleaned samples to be sent for Lab TRXRF. Analyzed locations (2-3 mm) recorded so that the same spot can be re-analyzed after wet cleaning. Typically 3 spots per sample.

Most collector materials are chemically inert, so cleaning trials to date have used acids, with recipes derived from the semiconductor literature.

As shown in previous slide, some success with HCl (CalTech). Improved SIMS analyses (Wang, Nittler) enabled with aqua regia.

Master Plan: SEM analyses.

- When a given cleaning cycle has not produced a lab TRXRF-clean sample, we can use SEM examination to determine the chemical/mineralogical form of the resistant element.
- Many collectors are conducting, allowing particles to be measured directly on the samples.
  - "Environmental" (low gas pressure) SEMs (Smithsonian) can be used for insulators (sapphire) or poorly conducting samples (SoS, AloS)
- Zn and Ga are ubiquitous contaminants from a white paint used for thermal control in the Sample Return Capsule The Zn and Ga in the white paint are in the form of $ZnGa_2O_4$ which is very insoluble. Analyzing Zn and Ga is not a high science objective of Genesis, but there may be other elements in the white paint. If necessary, these can be characterized on available paint coupons, starting with XPS.
- Somewhat surprisingly however, acid cleaning has been successful in removing Zn and Ga from sapphire and Si-on-sapphire (SoS) collectors.
- If acid-insoluble white paint removal becomes important, the acetate peel technique (Kuhlman) is the only approach we know of at present. Acetate peeling may also be the only technique available for AloS (Al on sapphire) collectors.
- Some dedicated tests will be made to check whether C-coating from SEM imaging armors particles from acid attack.

Master Plan: TOF-SIMS

Samples that are lab-TRXRF clean will be checked by TOF-SIMS at the Smithsonian Museum, Washington.

Modern TOF-SIMS instruments, such as at the Smithsonian, can image distributions of surface contaminant elements on scales as large as 250 x 250 microns. When necessary, micron scale distributions are possible, but Genesis emphasis is on sampling larger areas.

With a time-of-flight mass spectrometer, all elements can be analyzed, but with widely varying detection limits. In practice, the focus will be on Mg, Na, Al, Ca, Cr, and Fe, for which sensitivities are relatively high.

Quantitation is difficult, but goal is removal below detection limits.

Proof of success is actual analyzability of solar wind on cleaned sample.

TOF, Continued

Initially, some small test samples will be cycled between TOF-SIMS and acid cleaning:

- No complications during acid treatment, e.g. enhanced resistance to acid attack, are anticipated by the small amount of sputtering done in the TOF-SIMS analyses, but this can be checked with the test samples.

- The sputtered areas on the test samples will be examined by SEM to check for any unanticipated erosional effects.

- Control Si samples will be analyzed to check for handling contamination.

- Cross checks with samples cleaned with CO_2 snow (ANL) are possible.

Top Level Status Summary (unchanged)

- The bar has been raised considerably by crash, but not giving up on any of our measurement objectives.
- Particulate contamination remains our biggest challenge, but
- Optimism is justified by fact that contamination is *on* the surface,
- And solar wind is *below* the surface.
- The separation between dirt and signal is small (typically 100A).
- But, being a sample return mission, all of contemporary science and technology is available to clean the surfaces without disturbing the implanted solar wind.
- *With some luck,* major effect will be delay in results.

Specific Measurement Objectives (prioritized). Prelaunch.

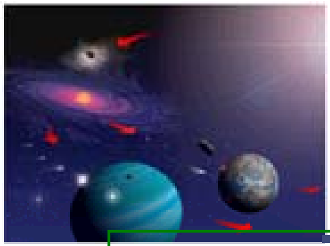
(1) O isotopes.
(2) N isotopes in bulk solar wind.
(3) Noble gas elements and isotopes.
(4) Noble gas elements and isotopes; regimes.
(5) C isotopes.
(6) C isotopes in different solar wind regimes.
(7) Mg,Ca,Ti,Cr,Ba isotopes.
(8) Key First Ionization Potential Elements
(9) Mass 80-100 and 120-140 elemental abundance patterns.
(10) Survey of solar-terrestrial isotopic differences.
(11) Noble gas and N, elements and isotopes for higher energy solar particles.
(12) Li/Be/B elemental and isotopic abundances.
(13) Radioactive nuclei in the solar wind.
(14) F abundance.
(15) Pt-group elemental abundances.
(16) Key s-process heavy elements.
(17) Heavy-light element comparisons.
(18) Solar rare earth elements abundance pattern.
(19) Comparison of solar and chondritic elemental abundances.

Measurement of bulk solar wind except when noted.

Color-coded Science Assessment; updated 5/10

- Measurement can definitely be made
- Should be Possible
- Challenging; many of these are large area analyses.
- Very Challenging; all of these are large area analyses.
- Not Possible

The number of green elements continues to grow. There is no red.



Specific Measurement Objectives

(prioritized)

(1) O isotopes.
(2) N Isotopes in bulk solar wind.
(3) Noble gas Elements and Isotopes. (He, Ne, Ar Kr, Xe)
(4) Noble gas Elements and Isotopes; regimes (He Ne Ar, Kr, Xe).

(5) C Isotopes
(6) C Isotopes in different solar wind regimes.
(7) Mg, Ca, Ti, Cr, Ba Isotopes.
(8) Key FIP Elements (Na, Mg, Fe, Si, Ca, Cr, Ni, Al, C, N, O Kr, Xe, etc)
(9) Mass 80-100 and 120-140 Elemental abundance patterns.
(10) Survey of solar-terrestrial Isotopic differences.
(11) Noble gas Elements and Isotopes: higher energy solar particles.
(12) Li/Be/B Elemental and Isotopic abundances.
(13) Radioactive nuclei in the solar wind.
(14) F abundance.
(15) Pt-group Elemental abundances.
(16) Key s-process heavy Elements.
(17) Heavy-light Element comparisons.
(18) Solar rare earth element abundance pattern.
(19) Comparison of solar and chondritic elemental abundances.

Summary (unchanged)

- The bar has been raised considerably, but nothing is red even after 6 years.
- The amount of green is growing. Good prospects remain for (Cr, Mn, Ni) from SRTRXRF. There is a significant amount of blue. We are optimistic that blue will turn to green.
- Significant progress since hitting bottom on 9/8/04, but pushing forward on a broad front.
- *With some luck,* the major effect will only be a delay in science.