Chromium Isotopes in Presolar Silicon Carbide Grains

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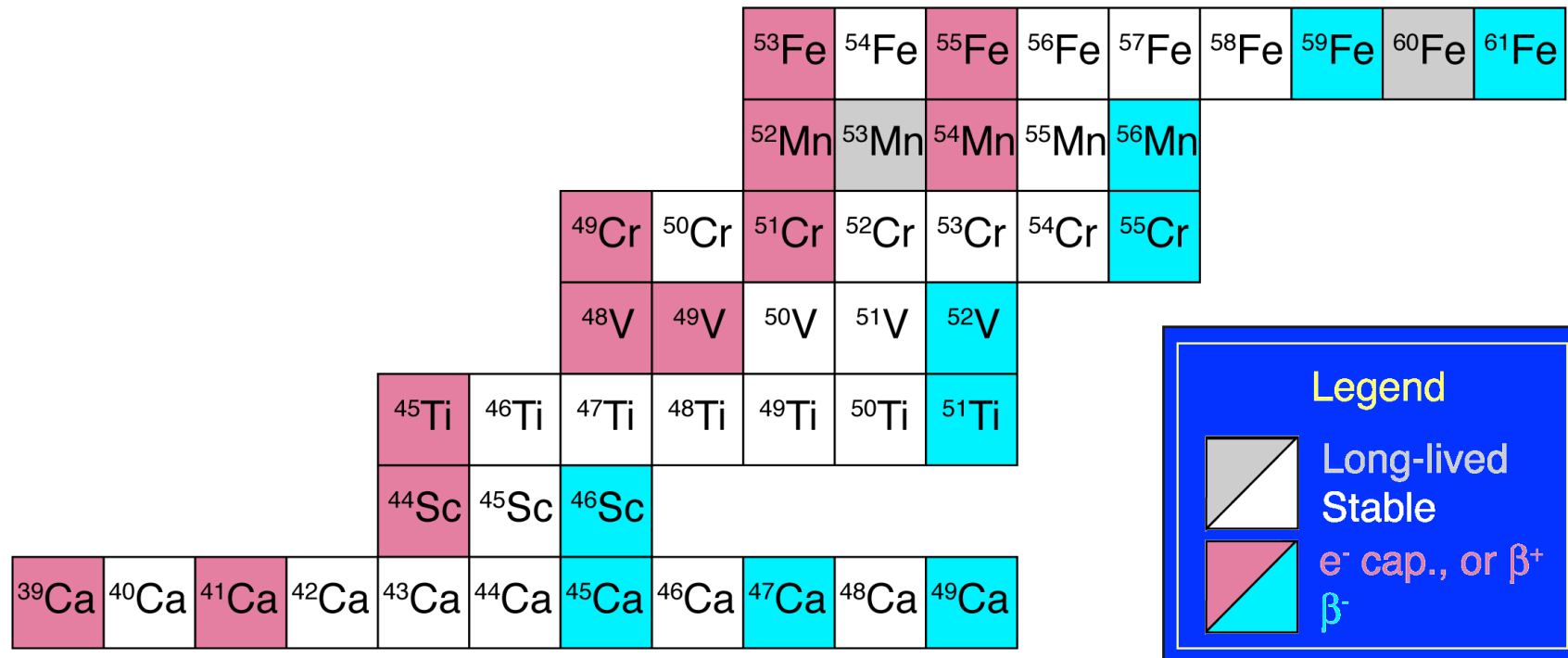[5]Enrico Fermi Institute, The University of Chicago
[6]Physical and Life Sciences Division, Lawrence Livermore National Laboratory
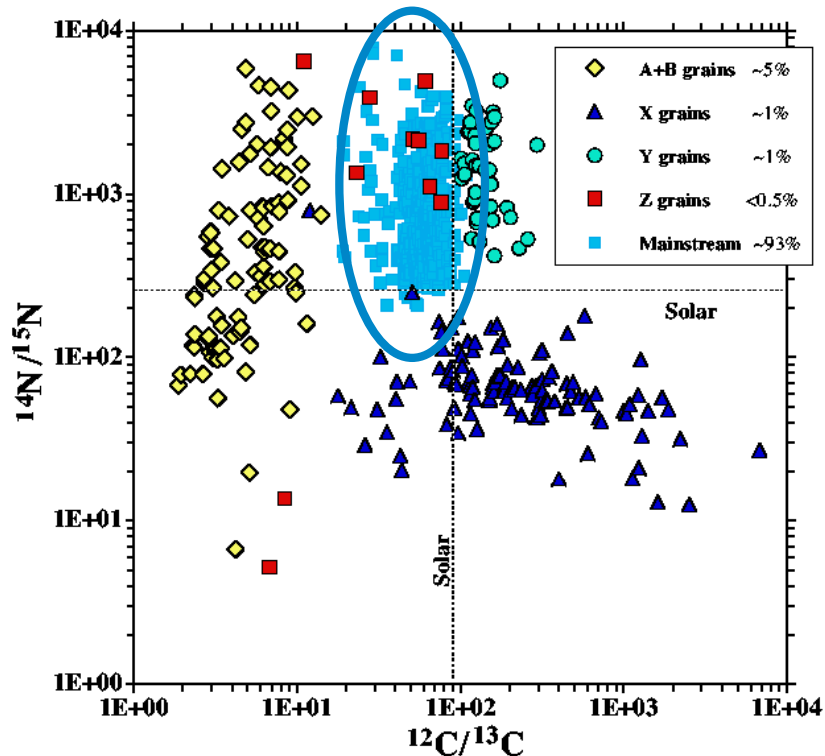
Nuclei in the Cosmos XI July 2010

Chromium in presolar SiC

- Test models of stellar nucleosynthesis in iron peak.
- Infer the chemical state of the galaxy >4.5 Ga ago.

SiC stardust grain isotopic classifications

Zinner E. *Annu. Rev. Earth Planet. Sci.* **(1998)**

Legend:
- A+B grains ~5%
- X grains ~1%
- Y grains ~1%
- Z grains <0.5%
- Mainstream ~93%

Axes: $^{14}N/^{15}N$ (vertical), $^{12}C/^{13}C$ (horizontal)

Mainstream SiC grains:
- well-studied & well understood
- produced by low mass AGB stars (~1.5 - 3 $M_\odot$)
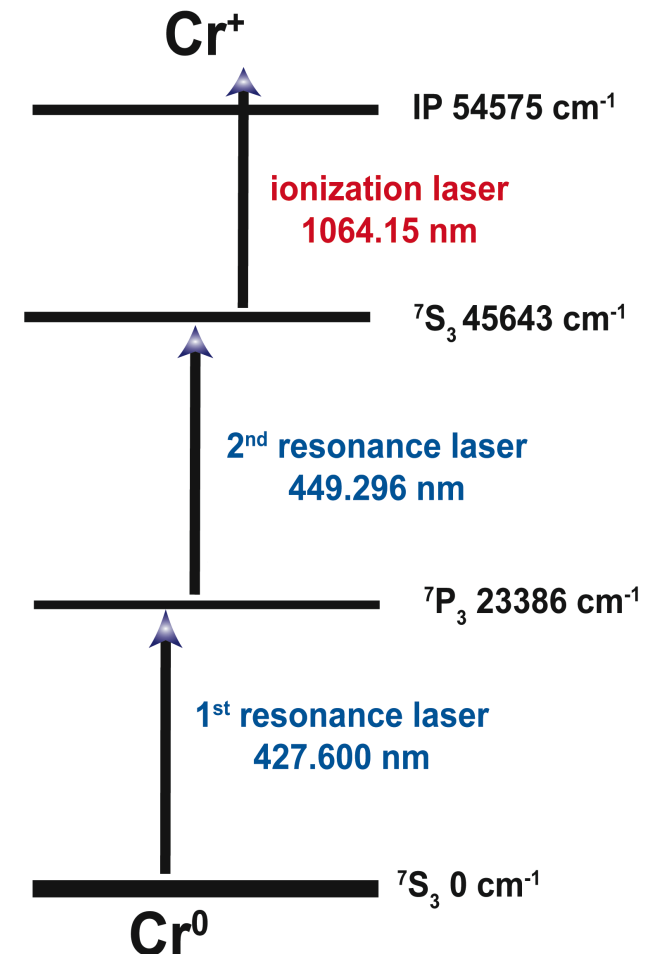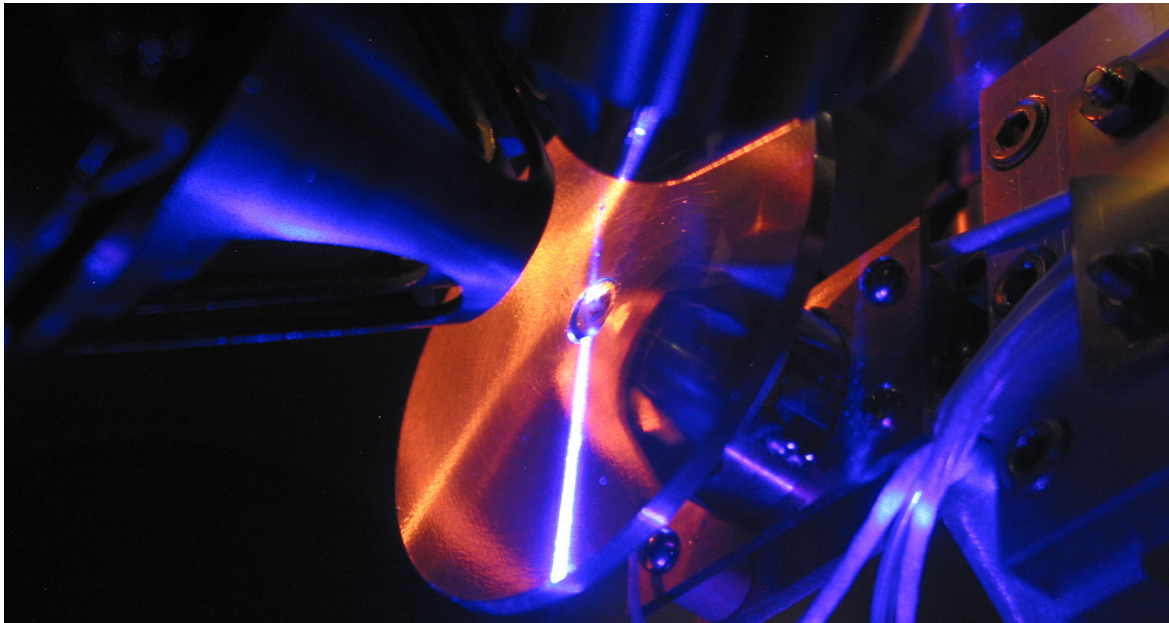- show strong *s*-process signatures

- *Different classes of grains represent different classes of stars.*
- *Each grain contains an isotopic record of nucleosynthesis in a particular star.*
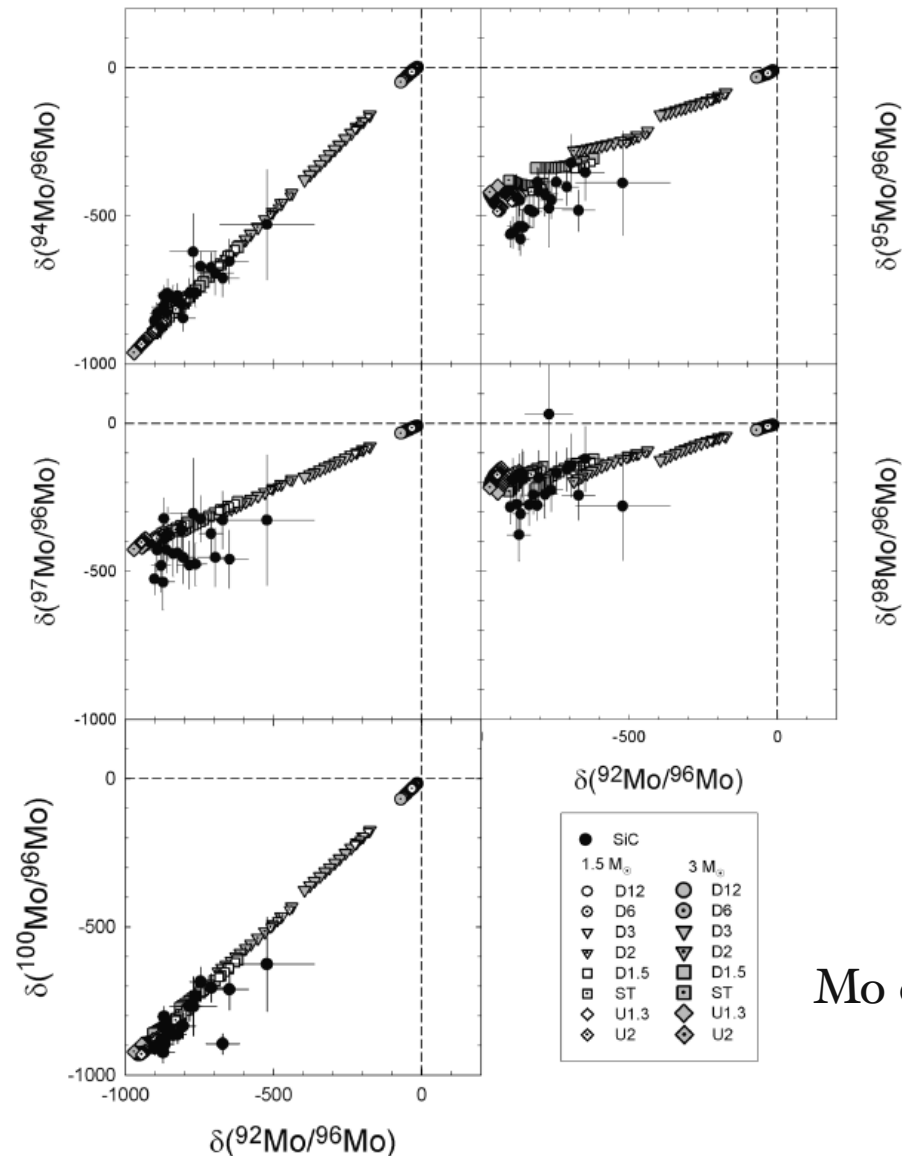
Resonance Ionization Mass Spectrometry

CHARISMA:

CHicago-**A**rgonne **R**esonance **I**onization **S**pectrometer for **M**icro-**A**nalysis

Cr⁺

IP 54575 cm⁻¹

ionization laser
1064.15 nm

⁷S₃ 45643 cm⁻¹

2ⁿᵈ resonance laser
449.296 nm

⁷P₃ 23386 cm⁻¹

1ˢᵗ resonance laser
427.600 nm

⁷S₃ 0 cm⁻¹
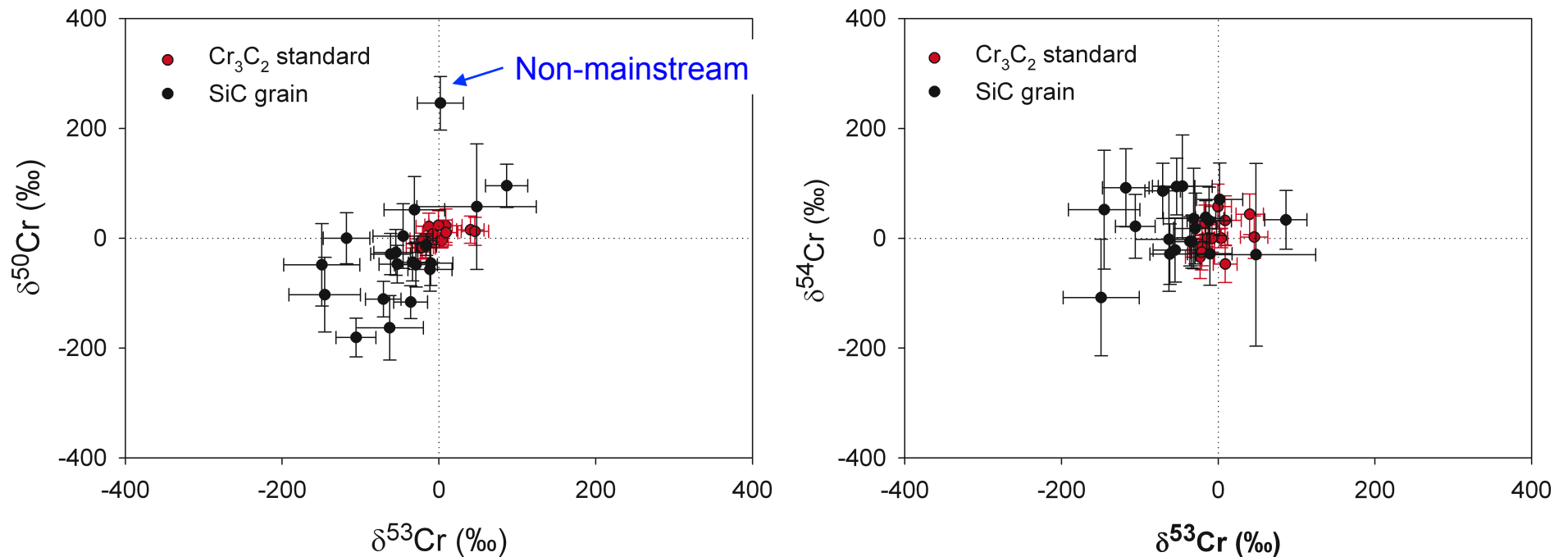
Cr⁰

s-Process signature in mainstream grains

- Mo isotopes show strong s-processing
- Excellent agreement with AGB models from Gallino *et al.*
- Similar results for Zr, Ba, Sr, Ru (Lugaro, 2003)

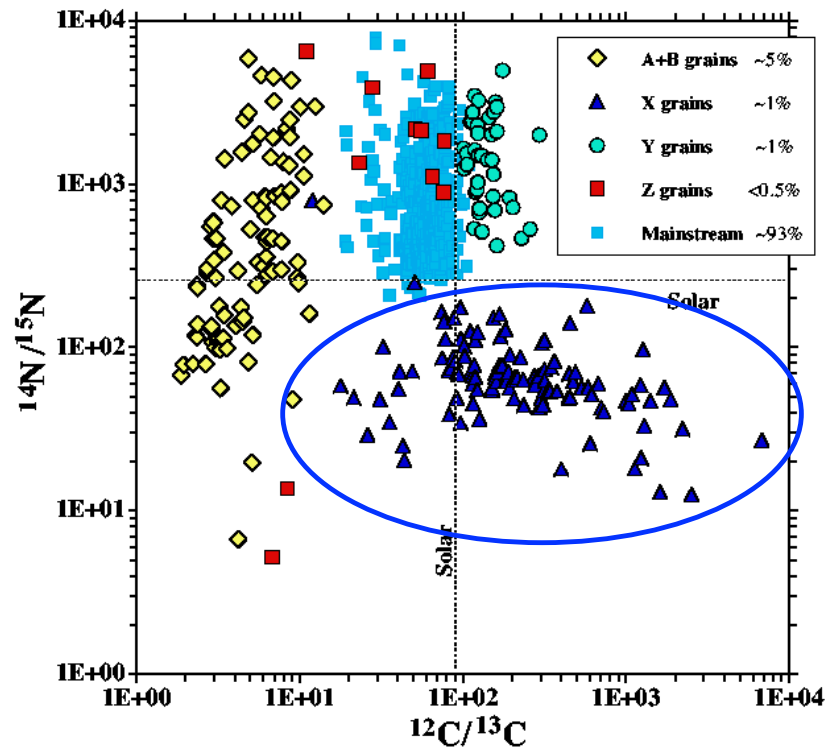Mo data from Barzyk, 2007

Chromium 3-isotope plots

Isotopic anomalies much smaller than in heavier elements

- *One anomalous grain ($^{50}Cr/^{52}Cr$)*
- *Small deficits in ^{50}Cr & ^{53}Cr in most grains*
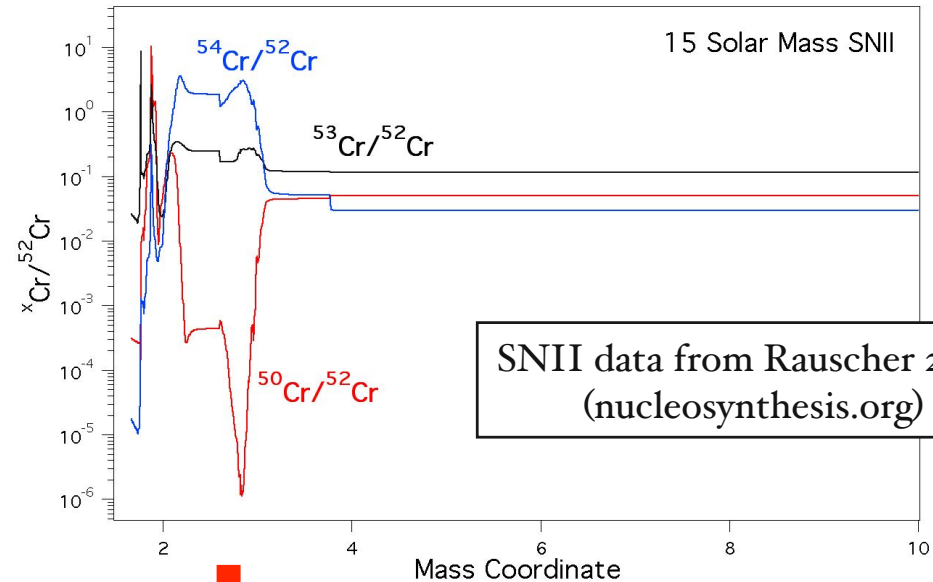- *^{54}Cr is normal or perhaps slightly enhanced*
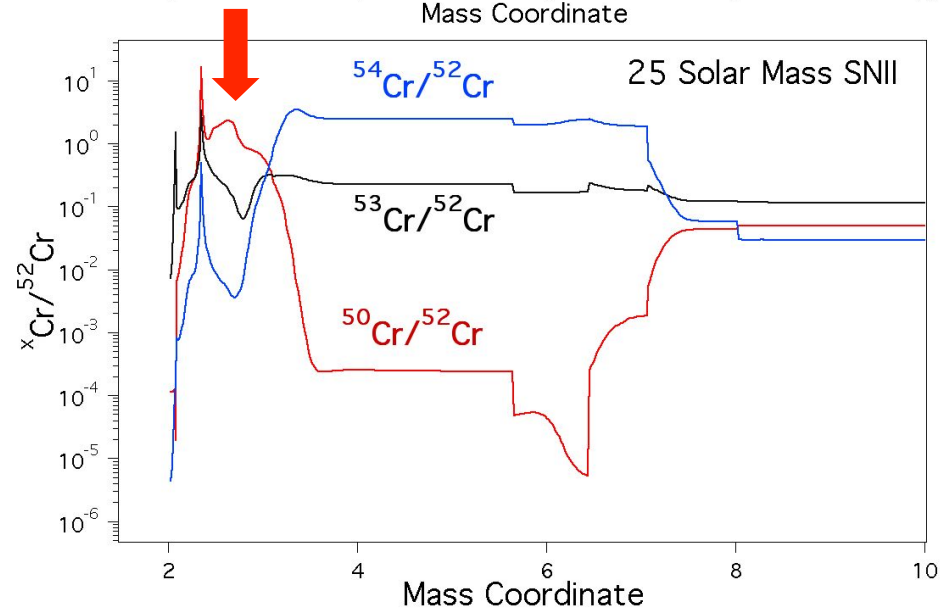
Anomalous (non-mainstream) grain

Zinner E. *Annu. Rev. Earth Planet. Sci.* **(1998)**

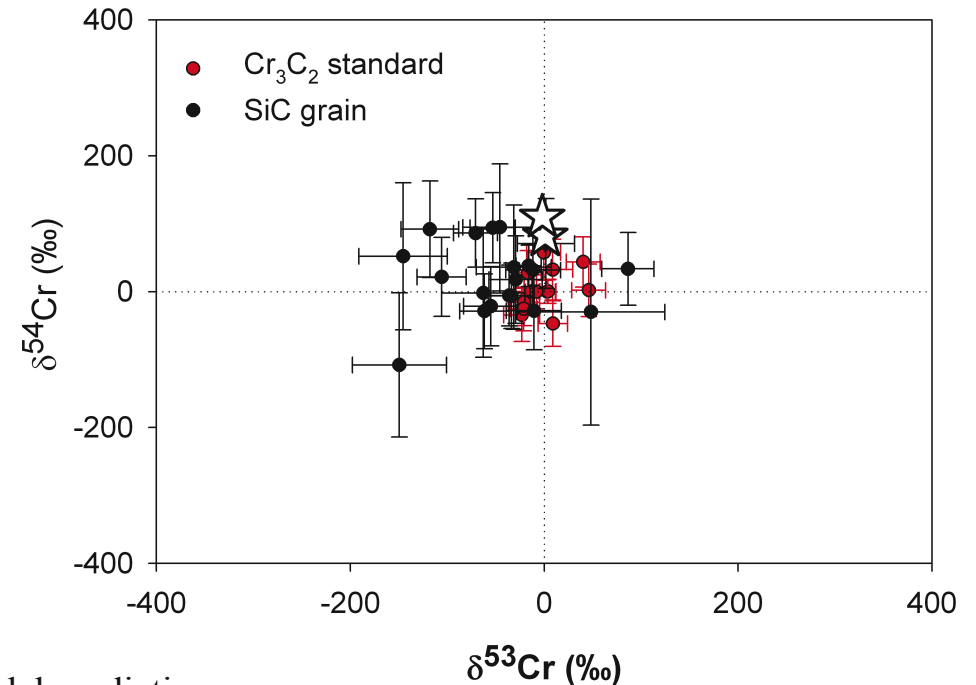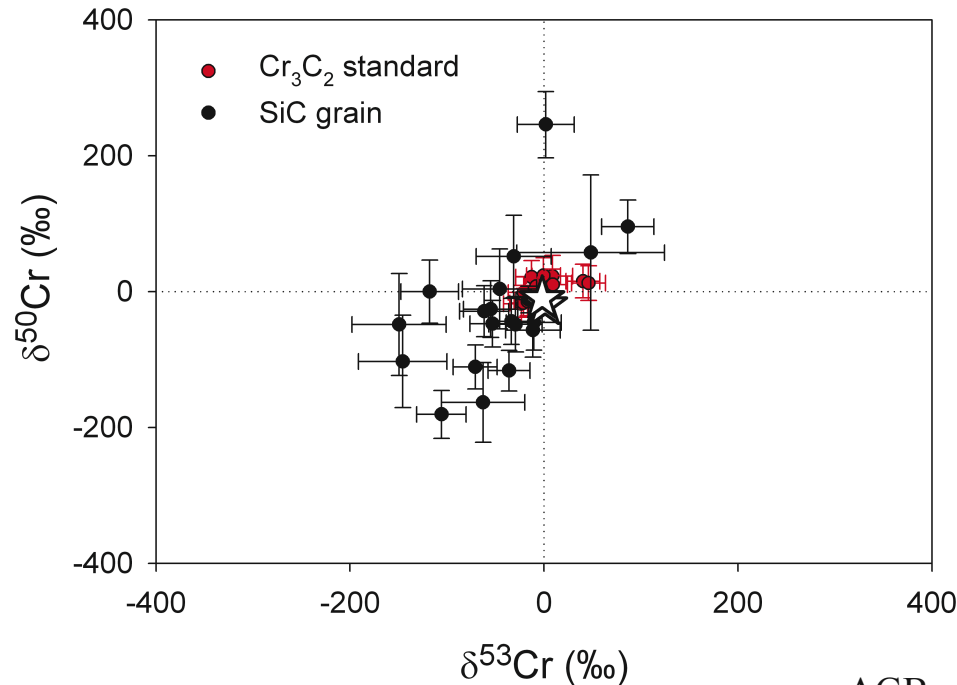- *However, it is difficult to explain the lack of anomalies in other isotopes*

  ⟹ *Need C, N & Si isotopes*

SNII data from Rauscher 2002
(nucleosynthesis.org)

Mainstream grains & AGB models

AGB model predictions:
$\delta^{50}Cr = -20‰$
$\delta^{53}Cr \sim 0‰$
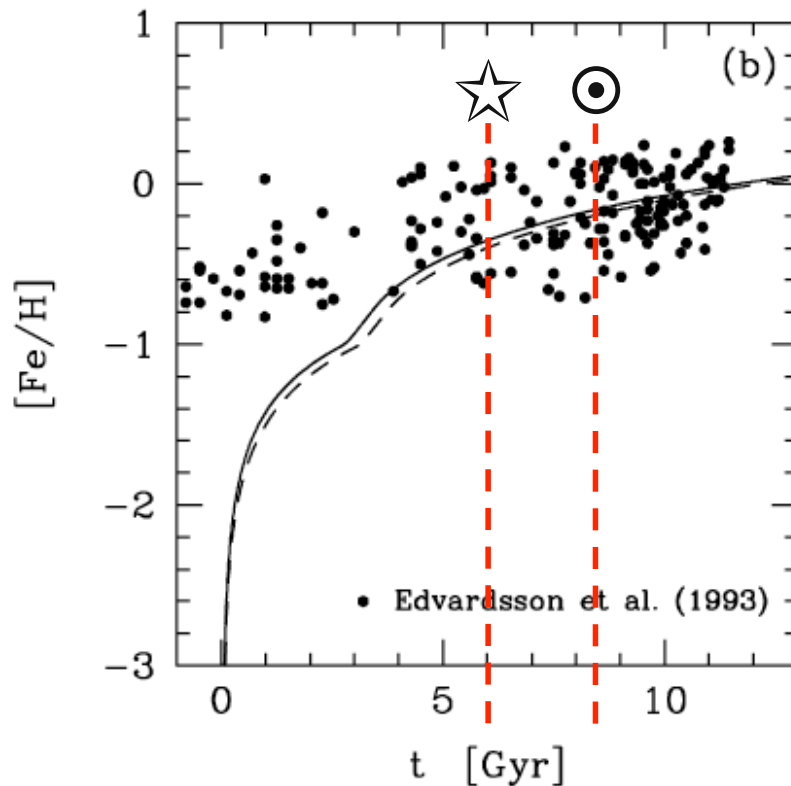$\delta^{54}Cr = +110‰$

Mainstream SiC grains largely preserve the Cr isotopes present in the protostellar nebulae of the parent stars, especially ^{50}Cr and ^{53}Cr (Davis et al. 2009)

$\Rightarrow$ The ISM was slightly richer in ^{52}Cr at the time these stars formed

Galactic Chemical Evolution of Cr
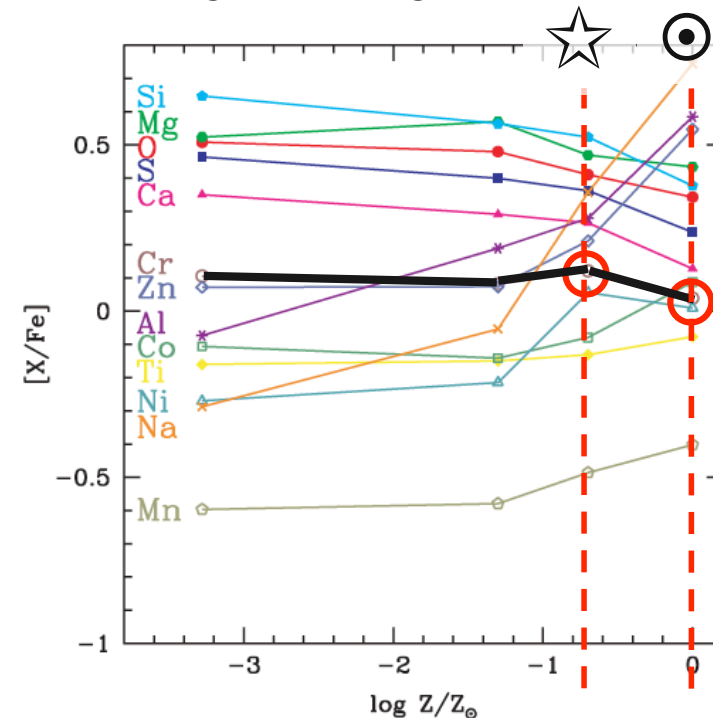
Cr abundance evolution:
IMF-weighted averages of SNII + HN

FIG. 5.—IMF-weighted abundance ratios as a function of metallicity of progenitors, where the HN fraction $\epsilon_{HN} = 0.5$ is adopted. The $Z = 0$ results are plotted at $\log Z = -5$.

Kobayashi *et al.* (2006)

SNII + HN Cr production is not a strong function of metallicity...

Galactic Chemical Evolution of Cr

Cr isotopic evolution:
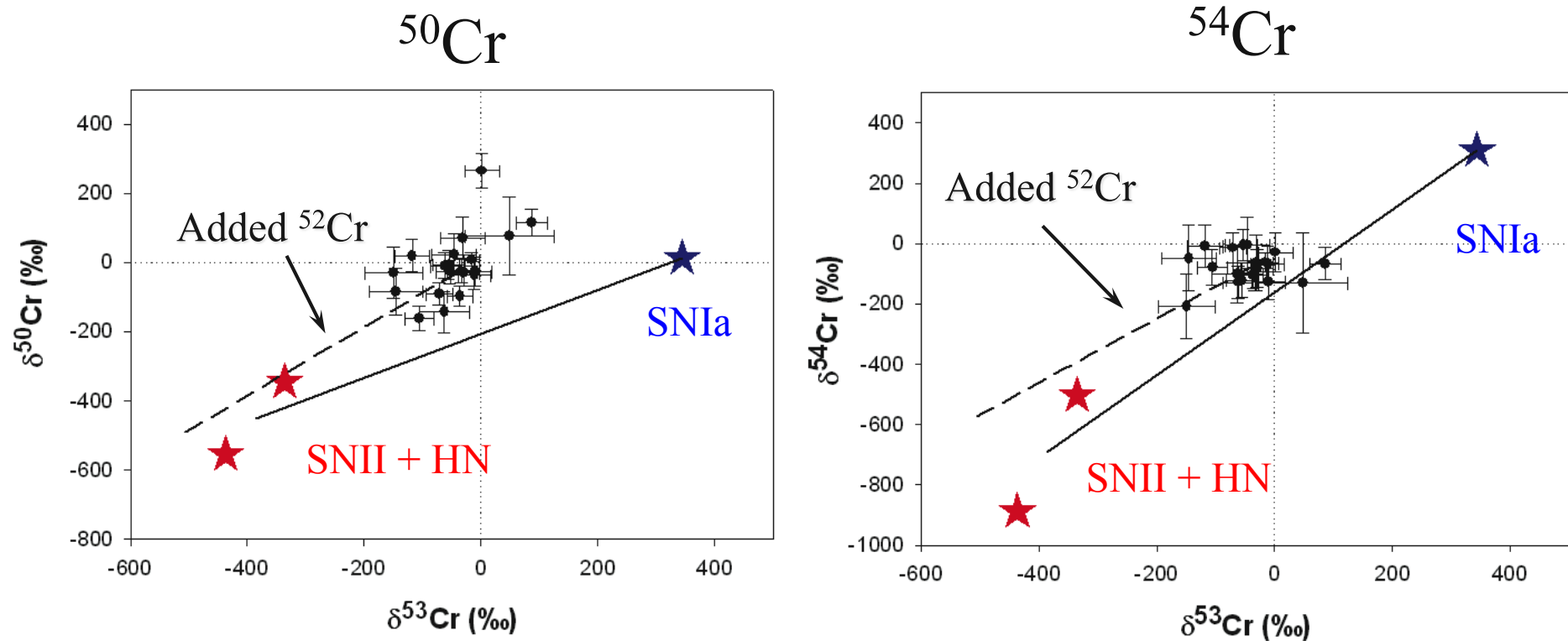IMF-weighted averages of SNII + HN
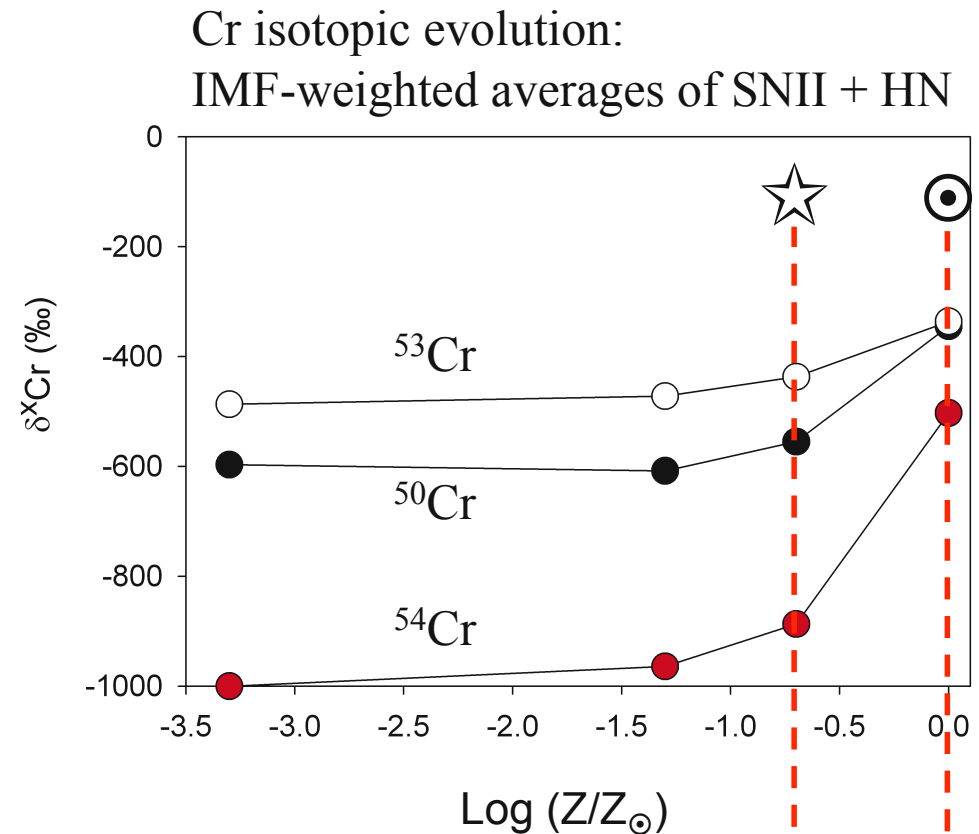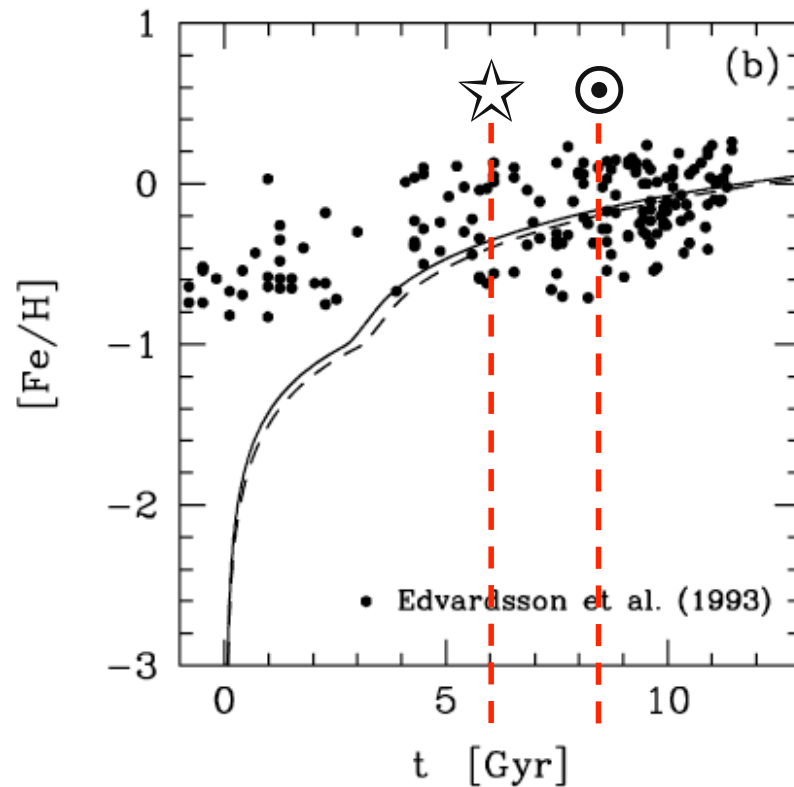
From Kobayashi *et al.* (2006)

SNII + HN Cr production is not a strong function of metallicity...
...but Cr isotopic composition is

Mainstream SiC grains + mixing models

^{50}Cr

^{54}Cr

- AGB component removed from grain data
- SN models from Kobayashi *et al.* (2006):
    Salpeter IMF, M = 0.07 - 50 M$_\odot$, log(Z/Z$_\odot$) = 0 & -0.7

Summary & Conclusions

- Presolar SiC grains show slight deficits in ^{50}Cr & ^{53}Cr and normal or perhaps slightly enhanced ^{54}Cr

  ⇒ The ISM was slightly richer in ^{52}Cr when these stars formed

- Best candidate for our non-mainstream grain is the inner region of a 25 M$_\odot$ SNII, though more data is needed

- Deviation from simple SN mixing line requires adjustments to more than one isotope
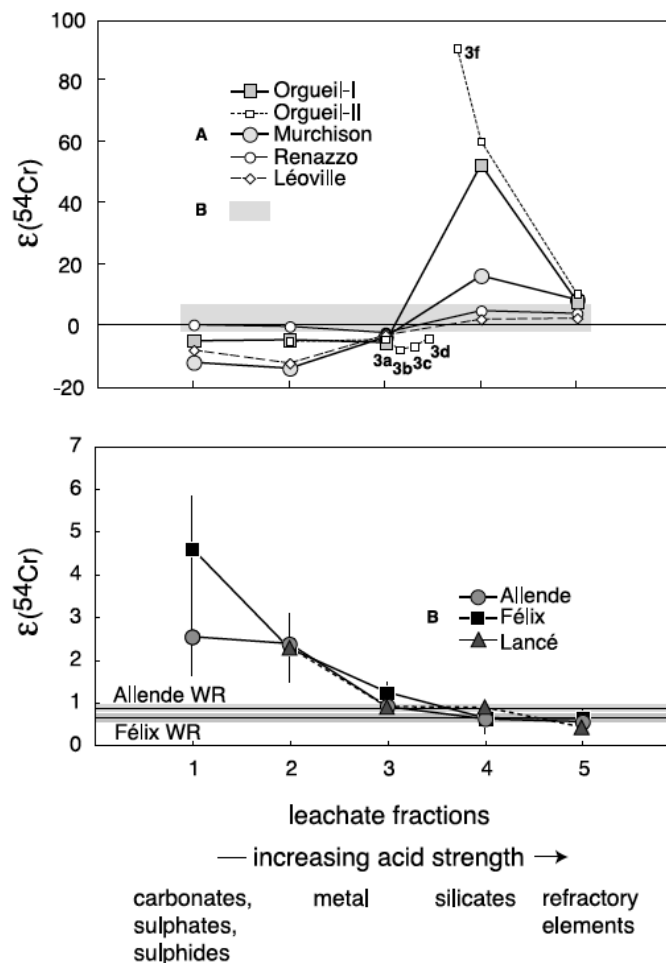
The ^{54}Cr anomaly in meteorites

FIG. 1.—The ϵ^{54}Cr heterogeneity among sequentially dissolved fractions of bulk carbonaceous chondrites measured in this study. Procedure I (Rotaru et al.
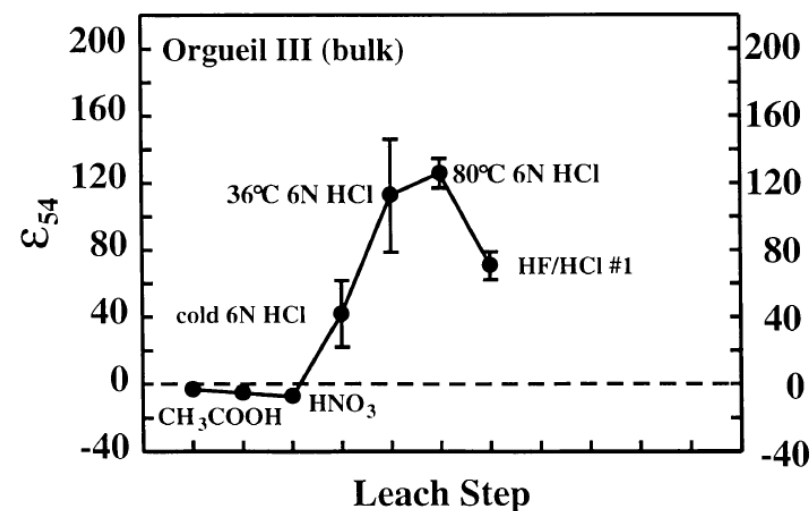
Trinquier *et al.* (2007)

FIG. 2. Display of ^{54}Cr anomalies plotted against sample number (sequence of progressive leach/dissolution steps) for whole rock Orgueil samples O-I (top) and O-III (bottom). Data from Table 2.
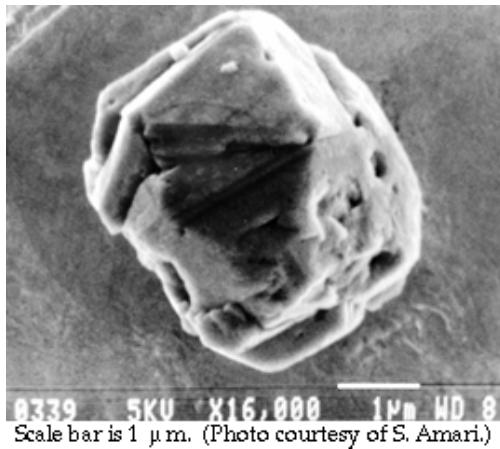
Podosek *et al.* (1997)

SiC is not dissolved in these procedures, the pattern could reflect the inverse of the SiC composition
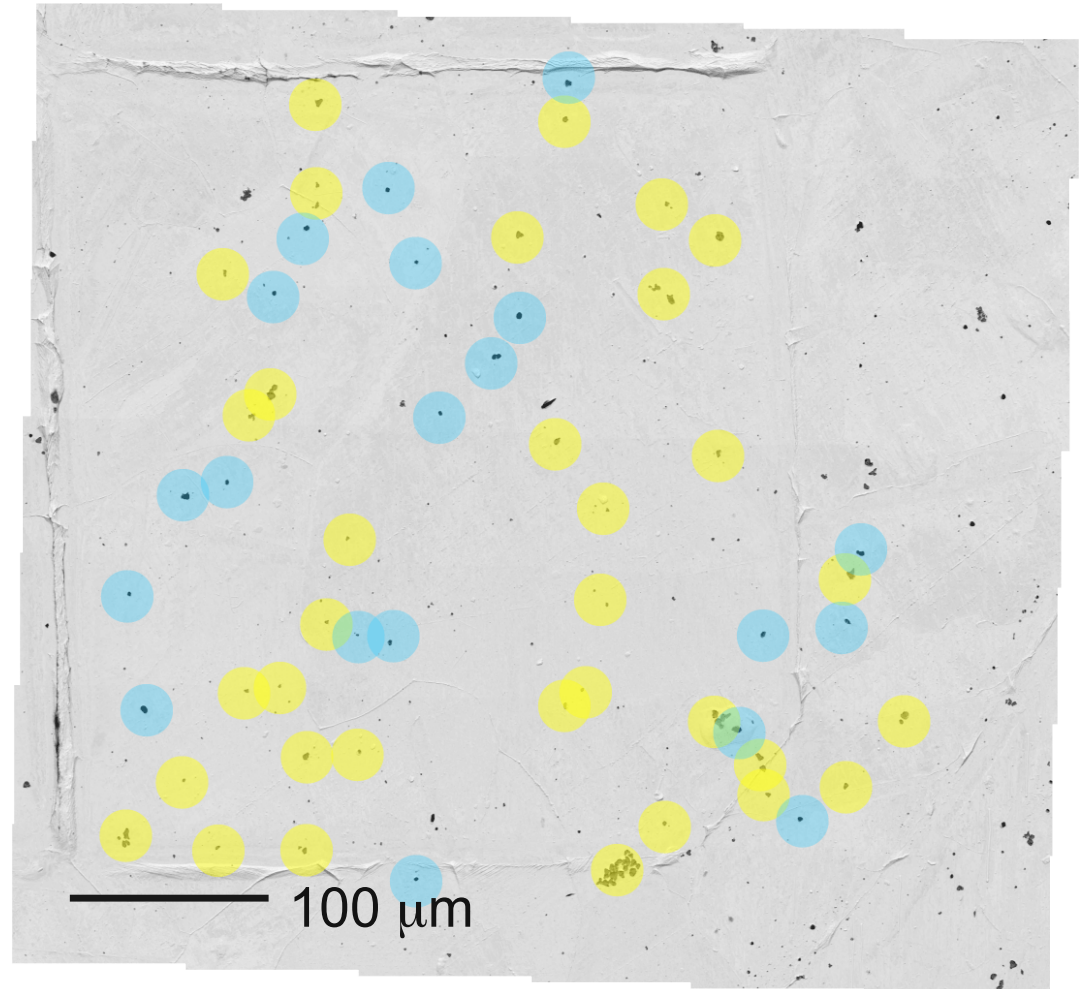
Sample mount with standards

Murchison presolar SiC grain mount RWB6-1

0339   5KV   X16,000   1μm WD 8
Scale bar is 1 μm. (Photo courtesy of S. Amari.)

Presolar SiC grains ●

Synthetic Cr_3C_2 grains ●

100 μm

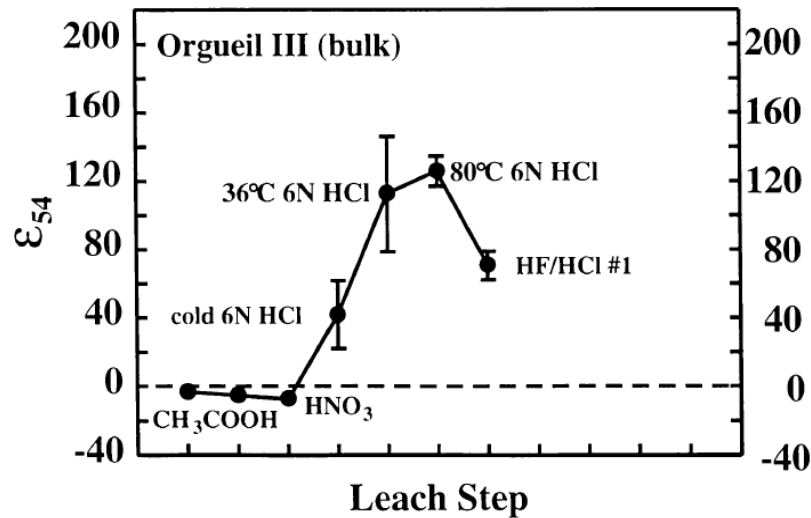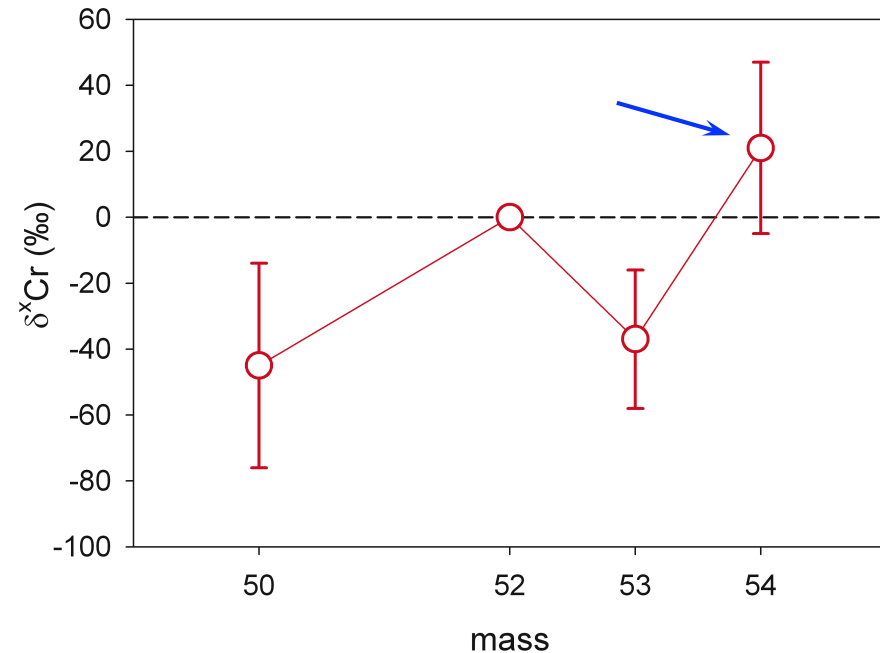# SiC does not carry the ^{54}Cr anomaly in meteorites

FIG. 2. Display of ^{54}Cr anomalies plotted against sample number (sequence of progressive leach/dissolution steps) for whole rock Orgueil samples O-I (top) and O-III (bottom). Data from Table 2.
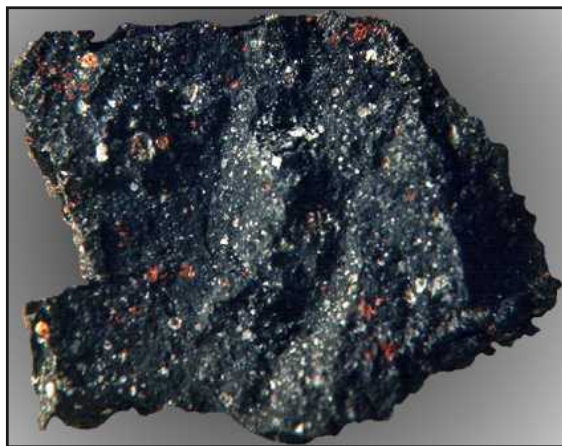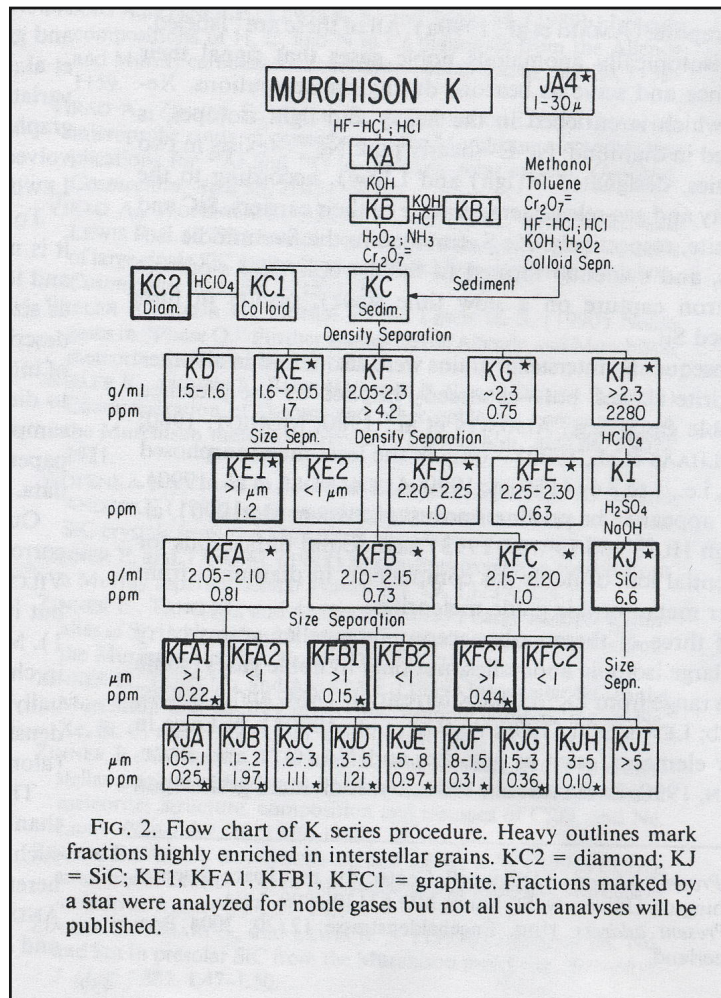
Podosek *et al.* (1997)

This work: weighted averages of 20 grains

- *^{54}Cr in SiC is normal or perhaps slightly positive - would have to be strongly negative to account for the anomaly*

How to find stardust

The Murchison meteorite

FIG. 2. Flow chart of K series procedure. Heavy outlines mark fractions highly enriched in interstellar grains. KC2 = diamond; KJ = SiC; KE1, KFA1, KFB1, KFC1 = graphite. Fractions marked by a star were analyzed for noble gases but not all such analyses will be published.

Amari S., Lewis R. S., and Anders E. (1994)
Geochim. Cosmochim. Acta **58**, 459-470.
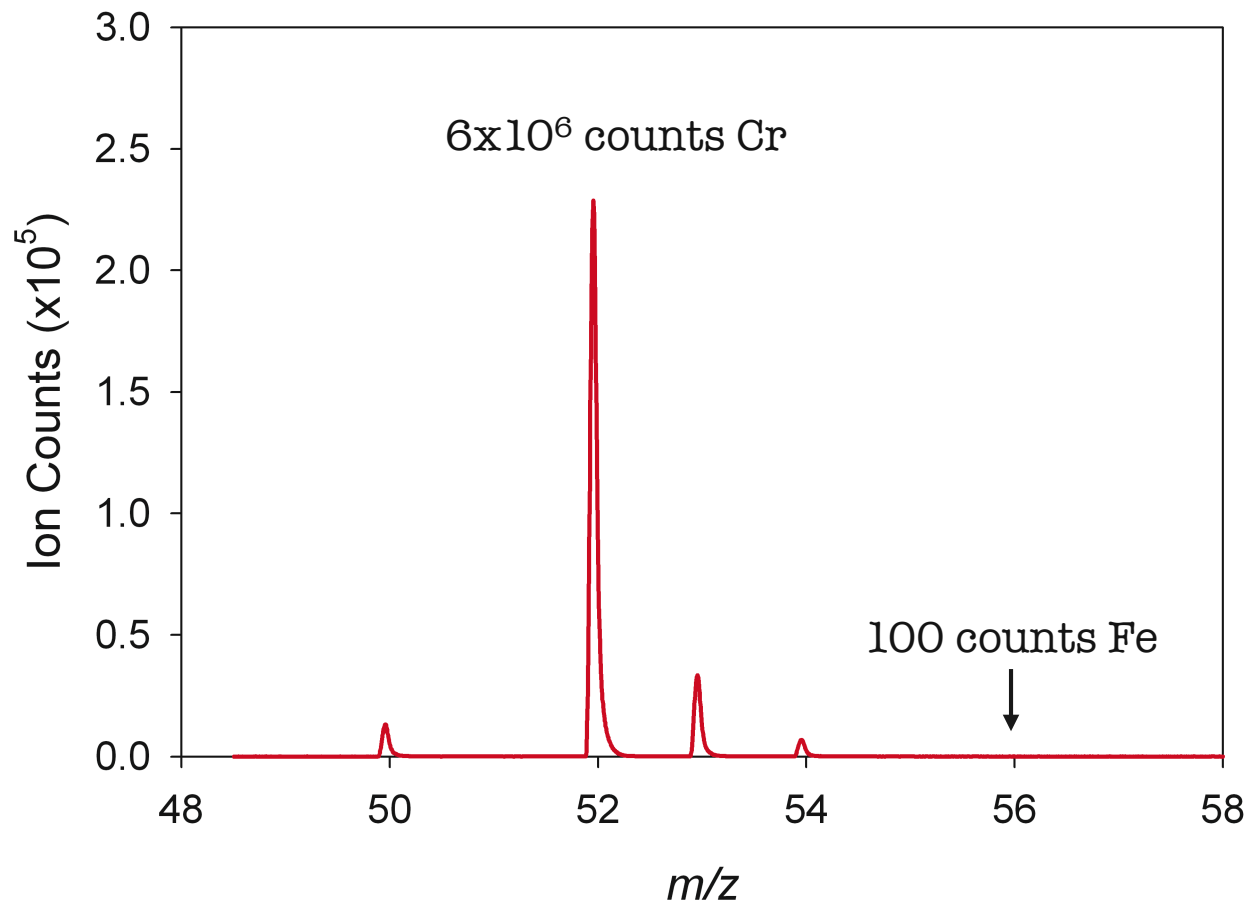

Stardust fraction isolated from the rocky matrix

SiC

Cr/Fe discrimination

NIST SRM 1246a: 660 ppm Cr / 980,000 ppm Fe

6×10^6 counts Cr

100 counts Fe

Ion Counts ($\times 10^5$)

m/z

Cr/Fe discrimination:
~10^8