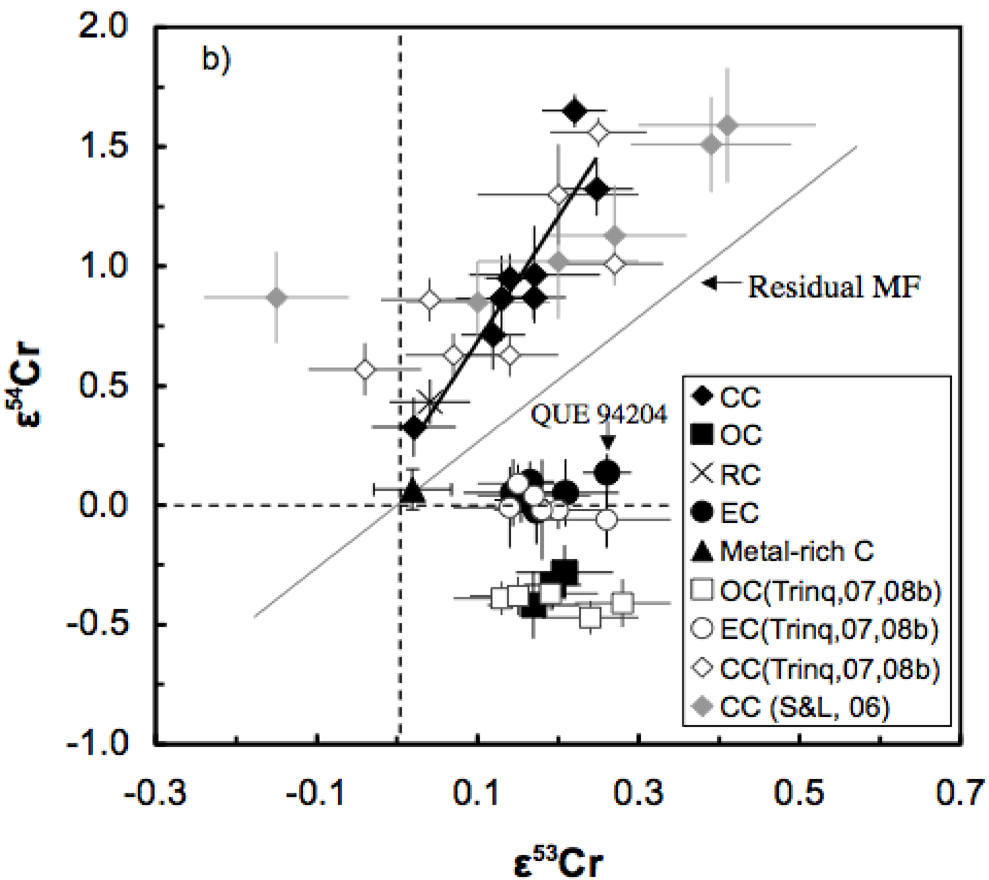
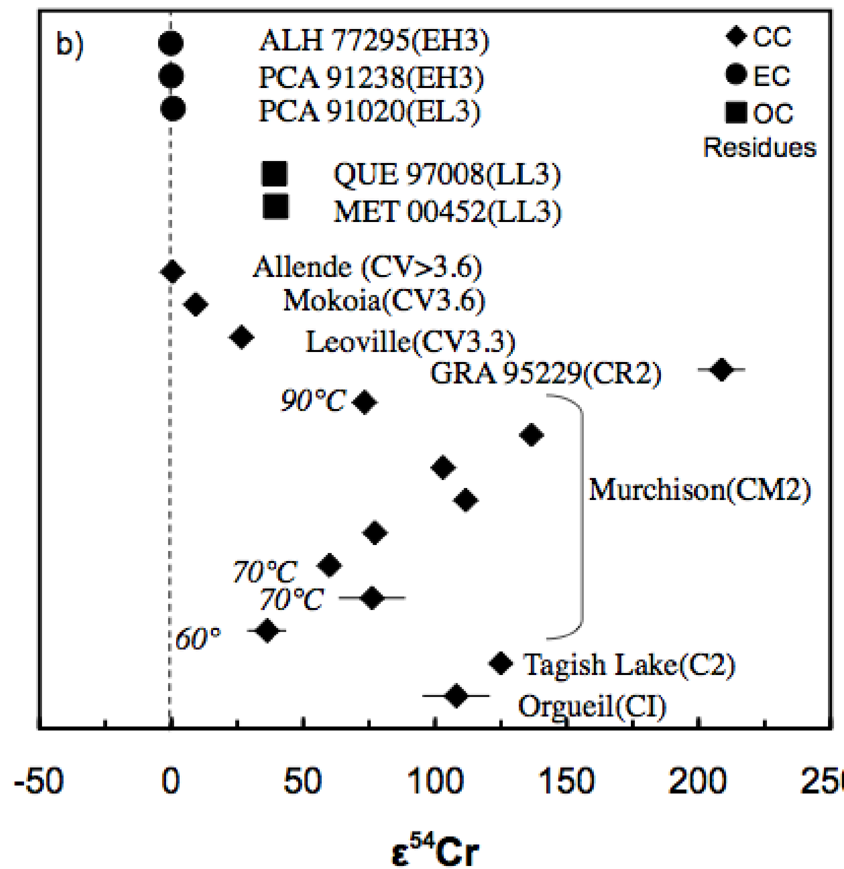
Extreme ^{54}Cr-rich oxide grains in meteorites: Evidence for a single late supernova injection into the Solar System

Larry Nittler, Liping Qin, Conel Alexander
Jianhua Wang, Rick Carlson
Carnegie Institution of Washington

Frank Stadermann
Washington University

Endemic Cr isotopic anomalies in the Solar System





Bulk Chondrites

Acid resistant residues

Qin et al., GCA, 2010 (see also Rotaru et al, 1992, Podosek et al. 1997, Trinquier et al 2007, etc)

ε=deviation in parts per 10^4

Origin of Cr isotopic heterogeneity?

- Cosmogenic?
  - Galactic cosmic ray-induced spallation of Fe in high Fe/Cr materials can produce correlated ^{54}Cr and ^{53}Cr excesses (Qin et al. GCA 2010)
- Nucleosynthetic?
  - ^{54}Cr made in low-entropy NSE in some SNIa; n-capture in SNII. Carried by presolar SN grains?

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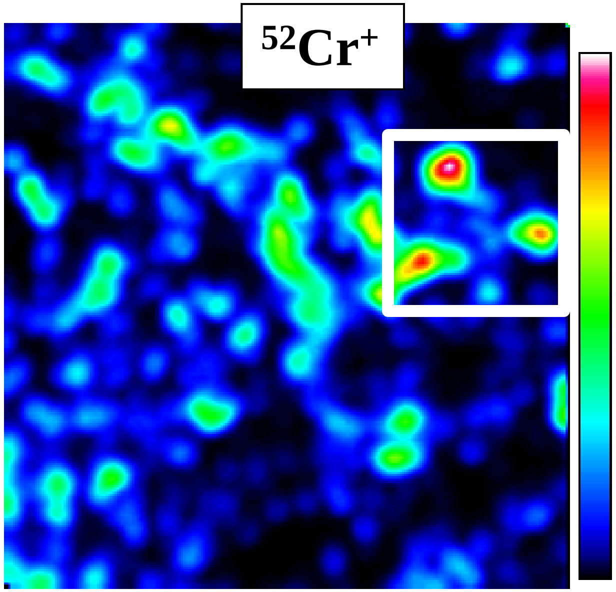
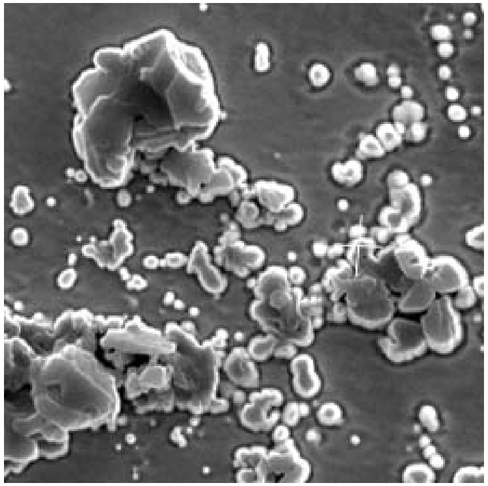
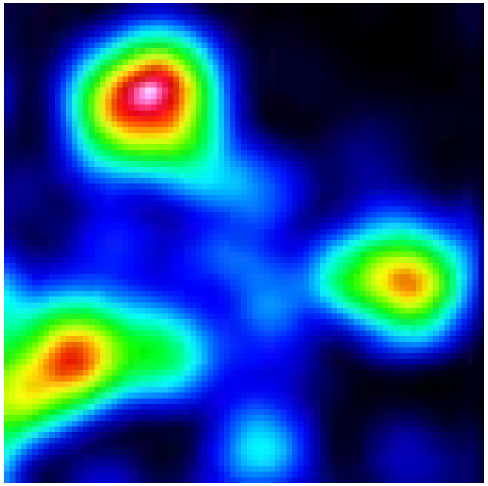
- Nucleosynthetic?
  - ^{54}Cr made in low-entropy NSE in some SNIa; n-capture in SNII. Carried by presolar SN grains?
  - YES, we have identified sub-μm Cr-oxide grains with extreme ^{54}Cr enrichments in acid residue of Orgueil meteorite (Qin *et al.*, submitted)
    - Most likely formed in Type II supernova(e)
    - Implications for formation of Solar System

Experimental

- Analyze acid-resistant residue of Orgueil CI meteorite
  - Very high density of grains on sample mount
  - Mostly sub-μm Cr-rich oxides and some SiC
- NanoSIMS imaging of Cr isotopes (+Ti, Fe)
  - 500-1000 nm O^- beam
  - "isotope dilution" significant problem!

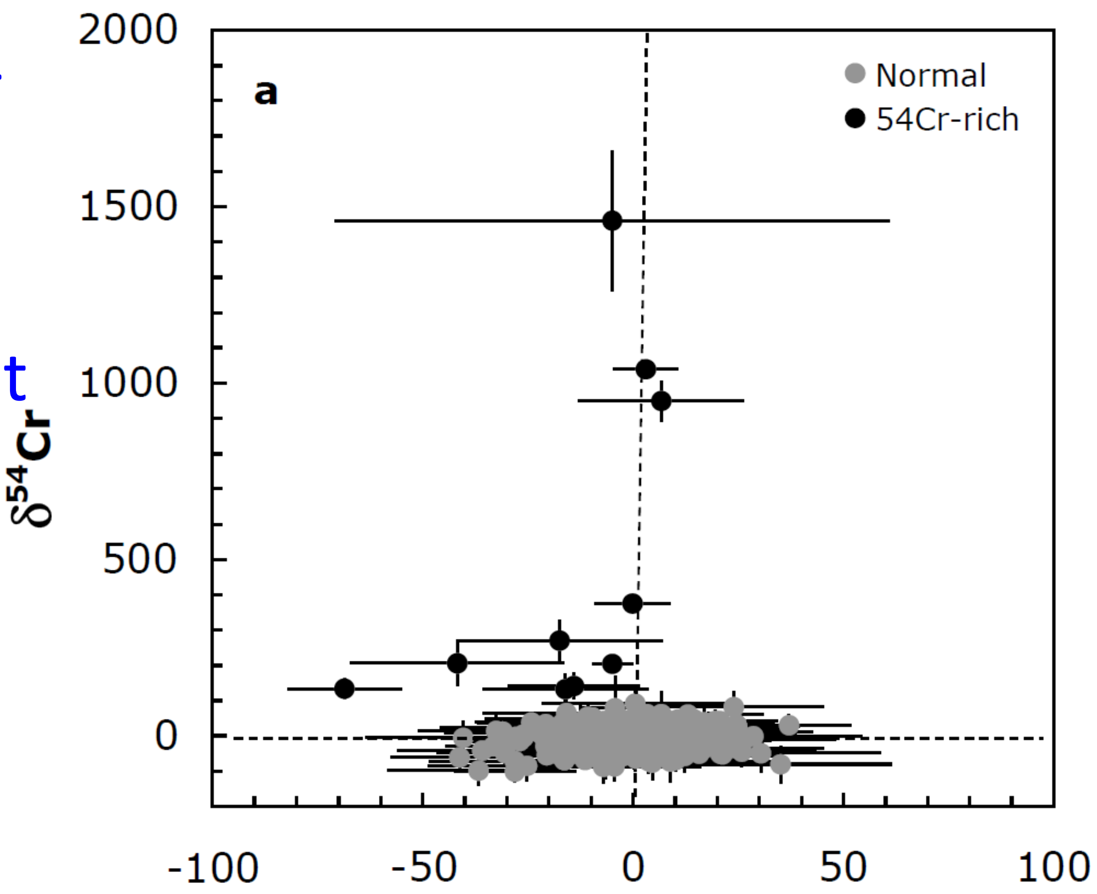






Cr Results

- Have identified 10 ^{54}Cr-enriched grains
- ^{50}Cr/^{52}Cr normal
- ^{53}Cr/^{52}Cr normal, except for slight depletion in one grain

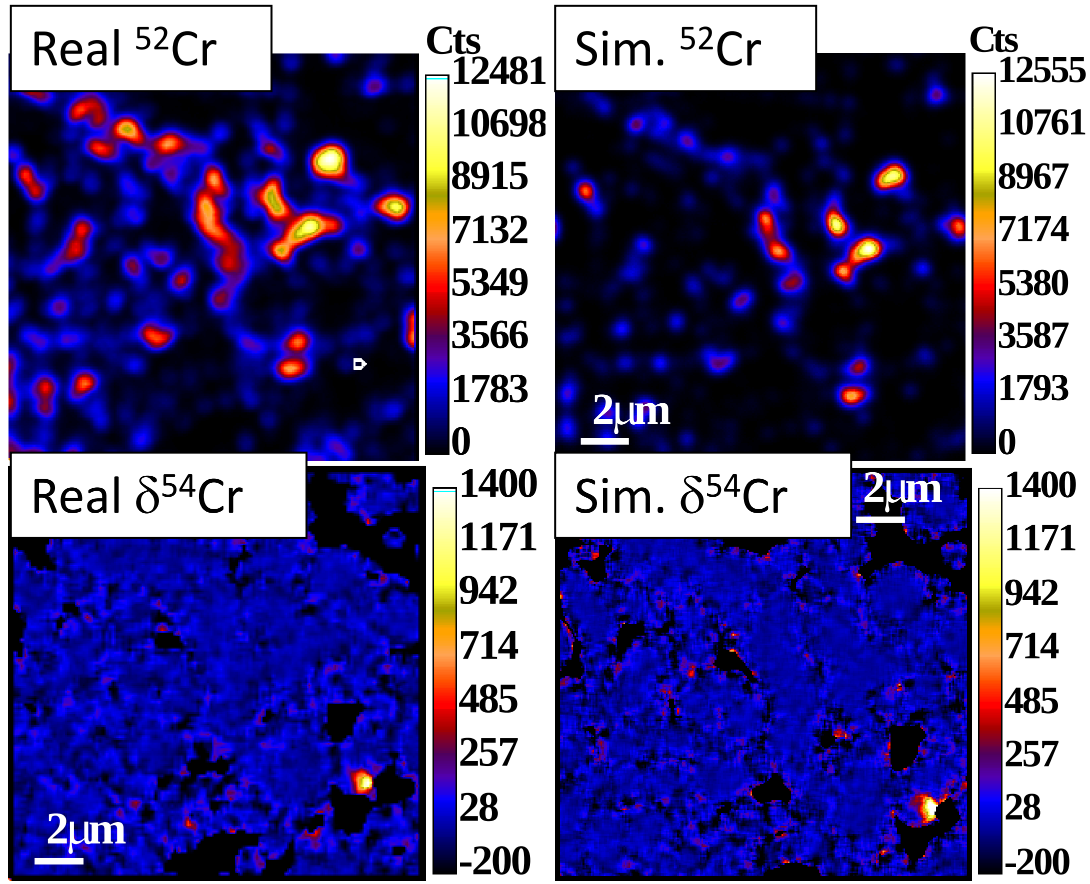


Degraded spatial resolution means anomalies are lower limits!

Dilution of Cr-Isotope Signatures

- Estimate true, un-diluted compositions of grains with simulated ion images based on high-res Cs^+ or SEM images
- Grain 7-10:
  - Excellent match with "true" $^{54}Cr/^{52}Cr \approx 54$ x Solar!
  - Same procedure on other grains also implies very high values

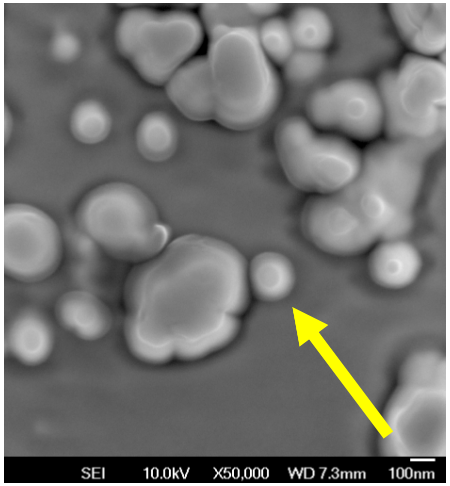
Grain 7-10



Extreme dilution means that many grains missed in surveys (higher abundance)

Mineralogy

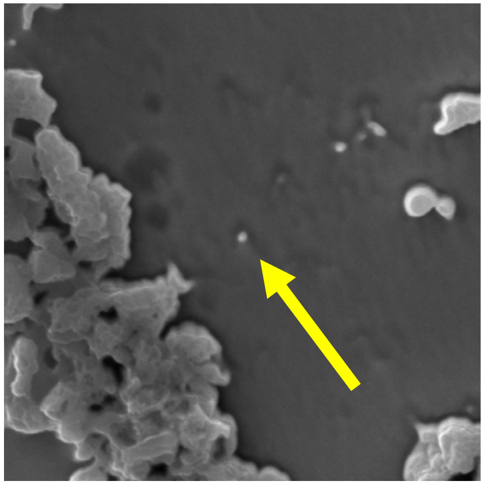
- Use scanning Auger spectroscopy and SIMS to infer grain chemical compositions



7-10 (100 nm)

δ^{54}Cr~53,000 ‰

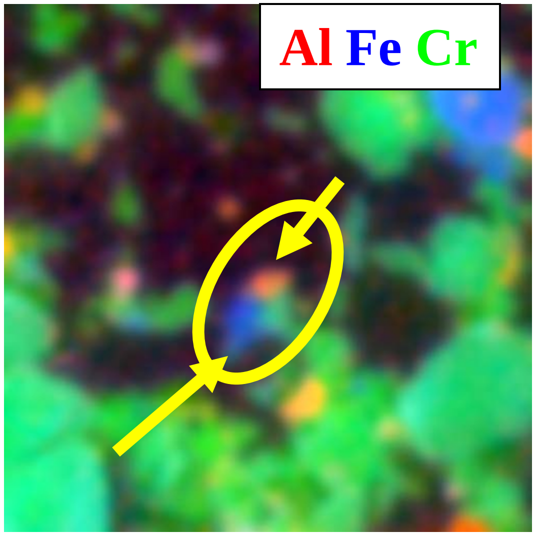
Cr, O, Al



8-3 (80 nm)

δ^{54}Cr> 20,000 ‰

Cr, O

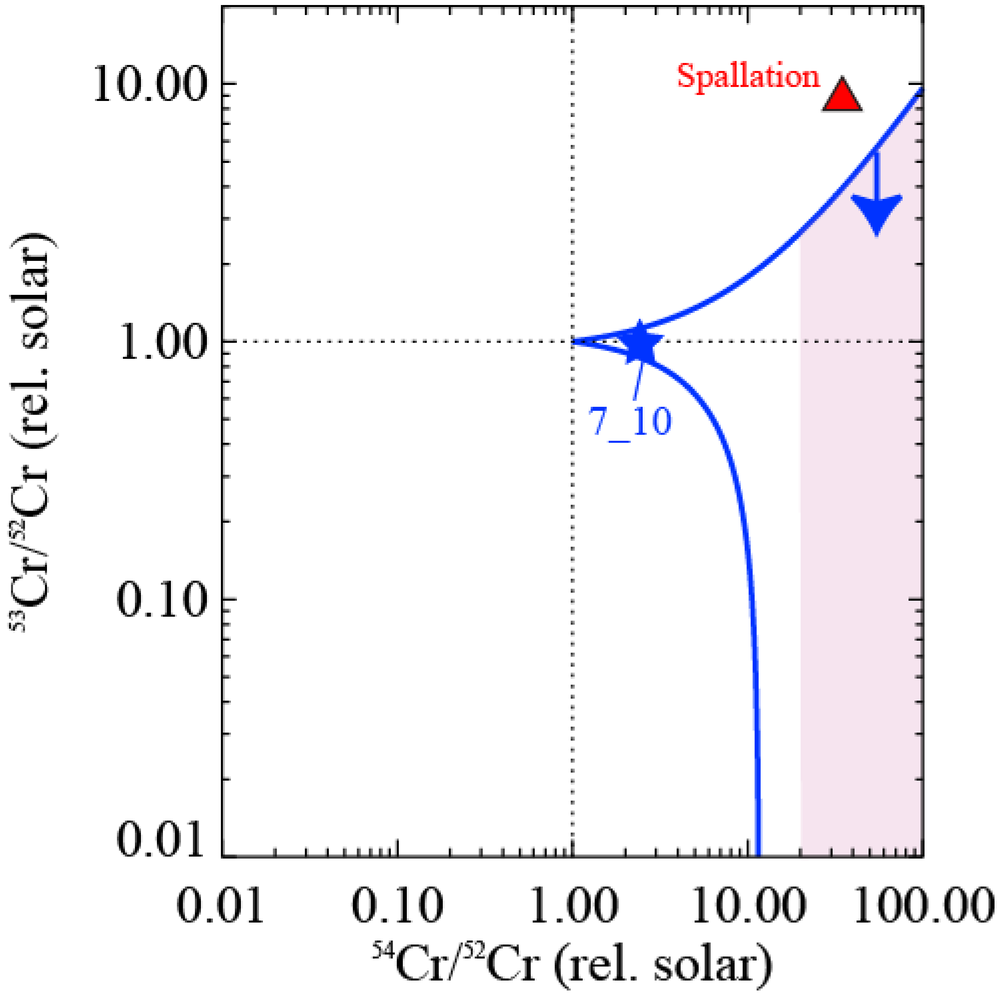


6-4 (multiple 100-400 nm Al- or Fe-rich Cr-oxides)

δ^{54}Cr> 11,000 ‰

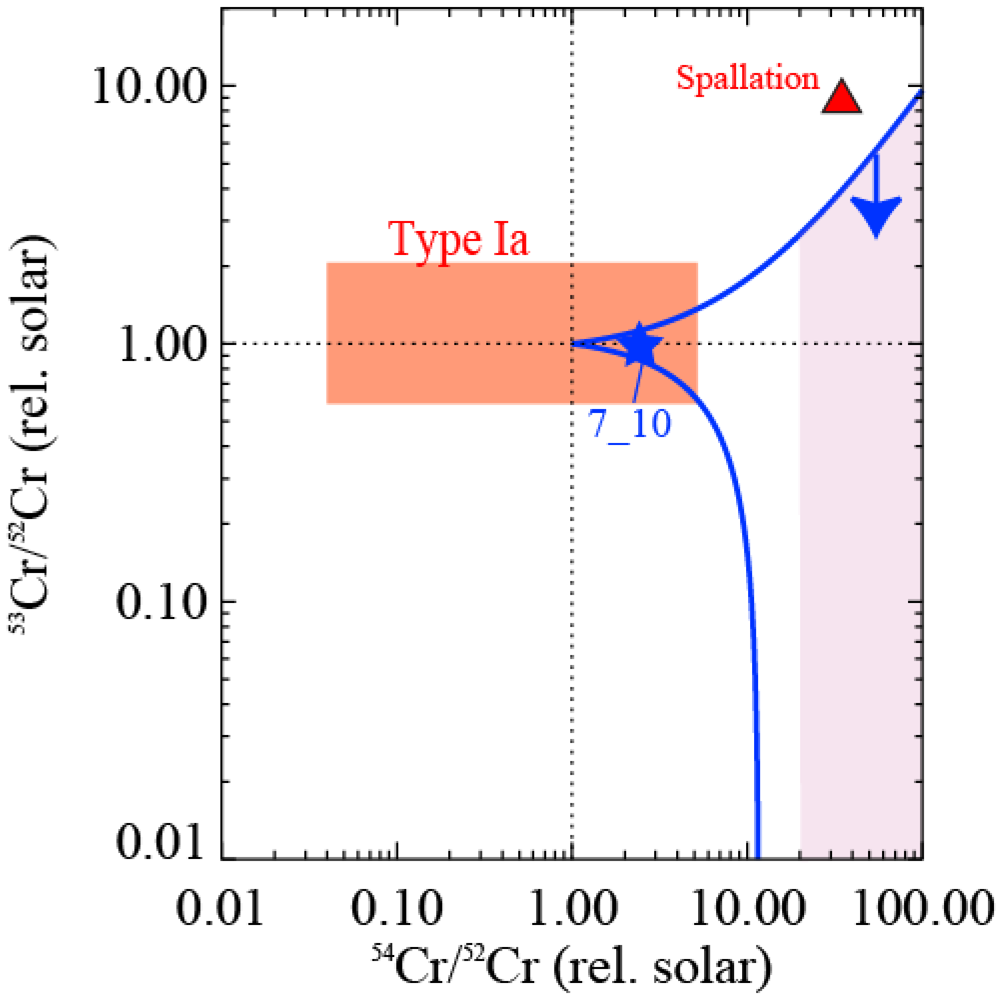
Origin of ^{54}Cr-rich Grains?

- Grain 7-10
  - Inferred $^{54}Cr/^{52}Cr = 54 \times \odot$
  - lower limit ~$20 \times \odot$
- Cannot be explained by AGB stars ($^{54}Cr/^{52}Cr < 2 \times \odot$) or spallation



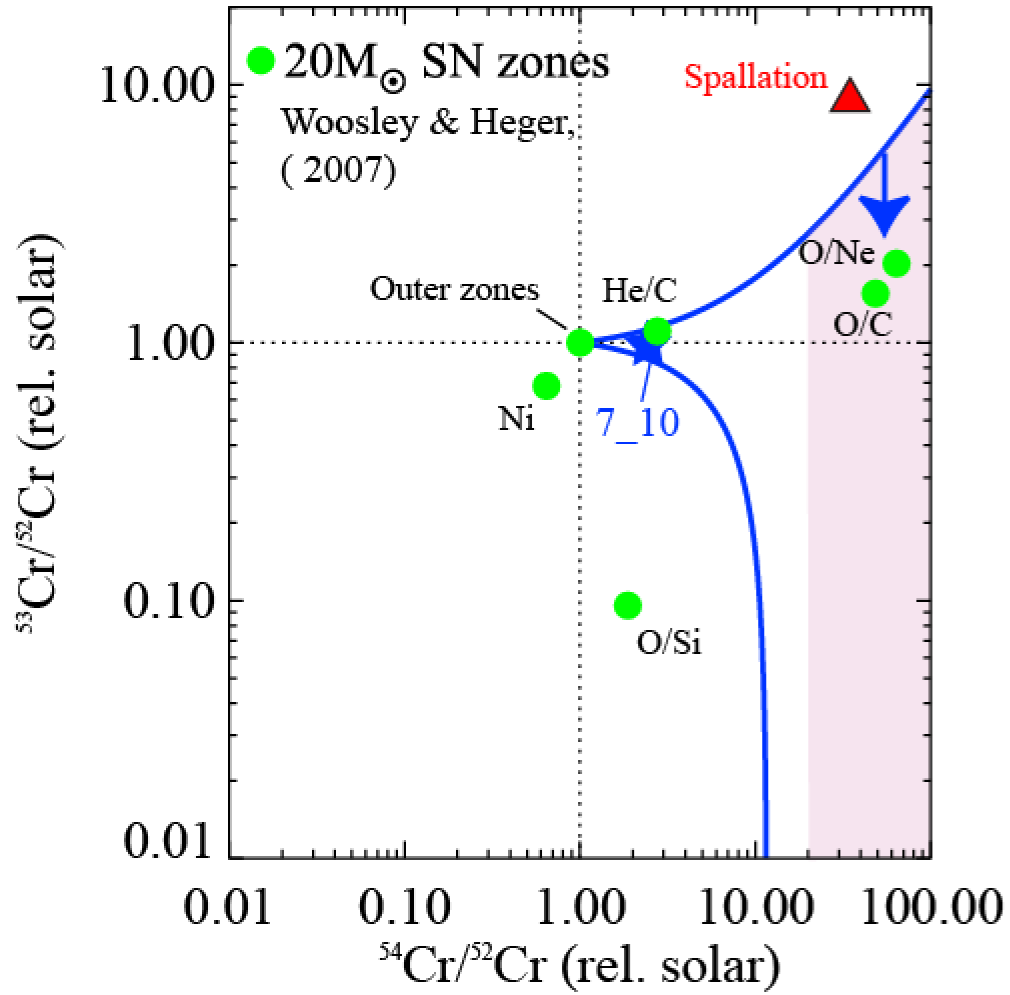
Origin of ^{54}Cr-rich Grains?

- Type Ia supernovae?
  - "Normal Ia": Max $^{54}Cr/^{52}Cr \sim 5 \times \odot$ (Iwamoto et al. 1999, Travaglio et al. 2004)
  - "C deflagration Ia": Much higher ^{54}Cr, but extremely unusual chemistry (unlikely to form oxides) [Meyer *et al.* 1996, Woosley 1997]



Origin of ^{54}Cr-rich Grains?

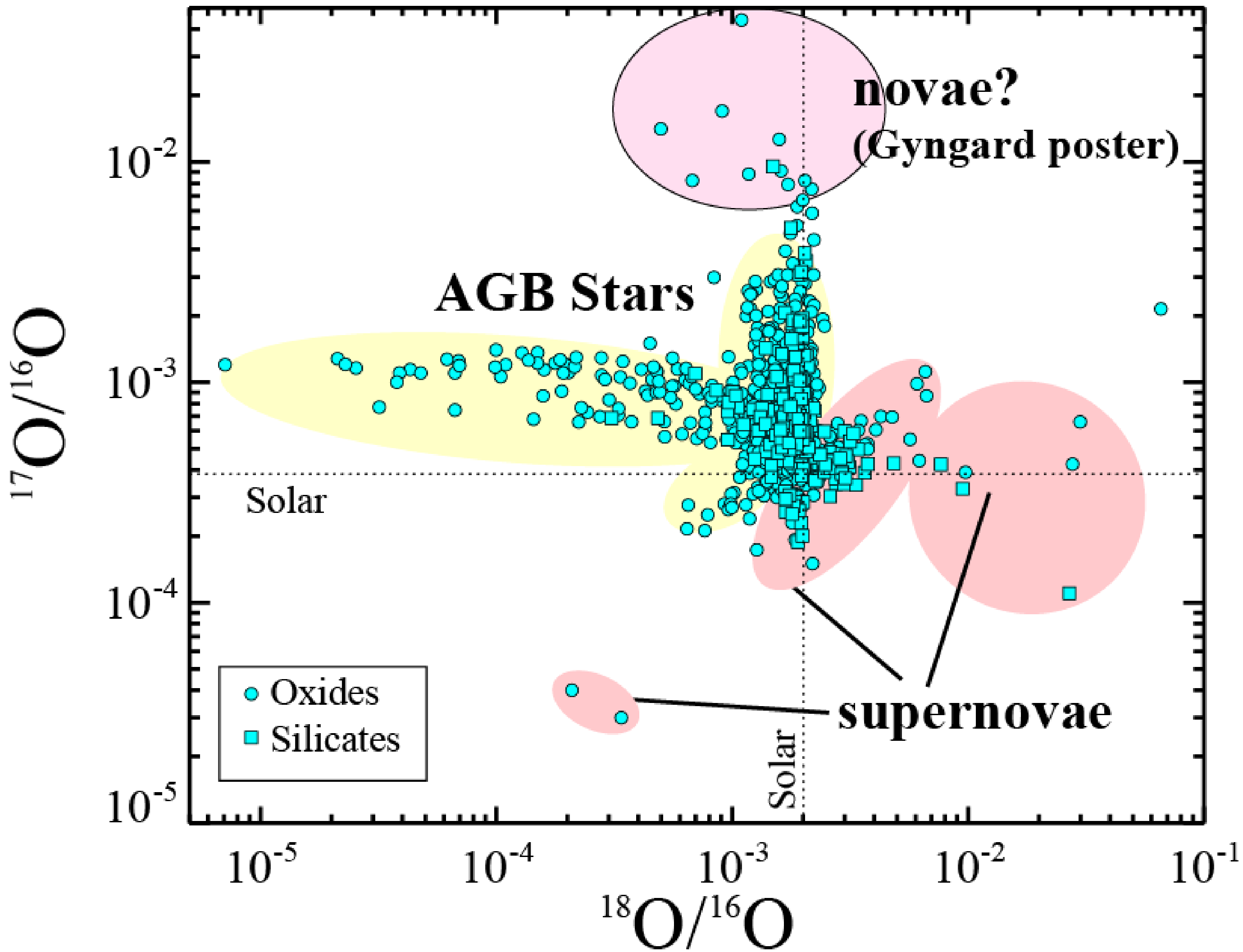
- Type II supernova?
  - 7-10 composition consistent with Type II SN ^{16}O-rich zones (*s*-process)
  - Extremely ^{16}O-rich (consistent with meas., but inconclusive)
  - Also ^{53}Cr-rich and ^{50}Cr-poor



New type of supernova presolar grain

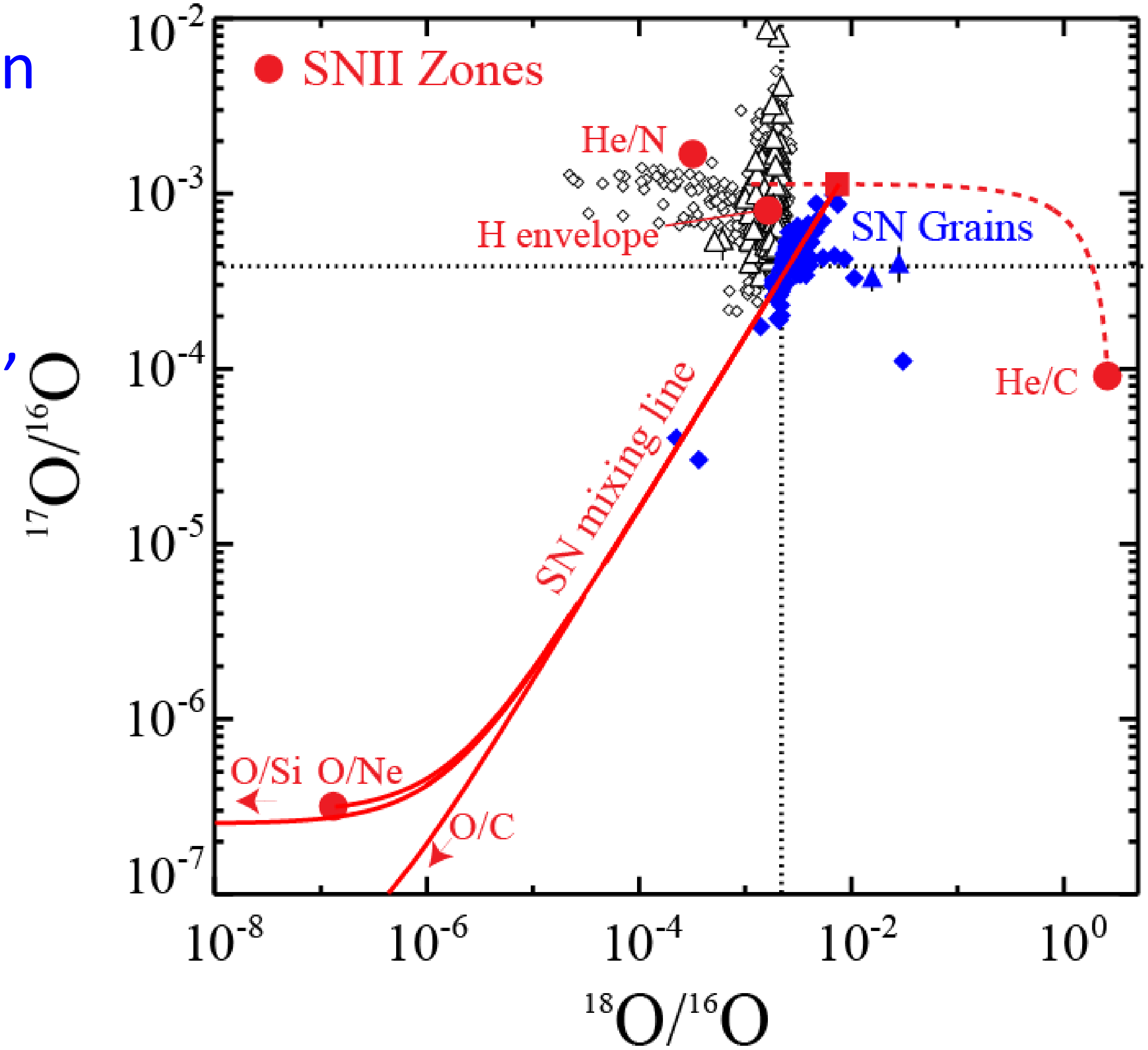
Supernova oxides/silicates

- ^{18}O- and/or ^{16}O-rich grains likely from SNe-II



Supernova oxides/silicates

- Majority of grains on single mixing line
  - Mixing in jets?
- SNe heterogeneous, single mixing line suggests *special* circumstances, probably a single supernova parent for most grains (Nittler *et al.* 2008)



Supernova oxides/silicates

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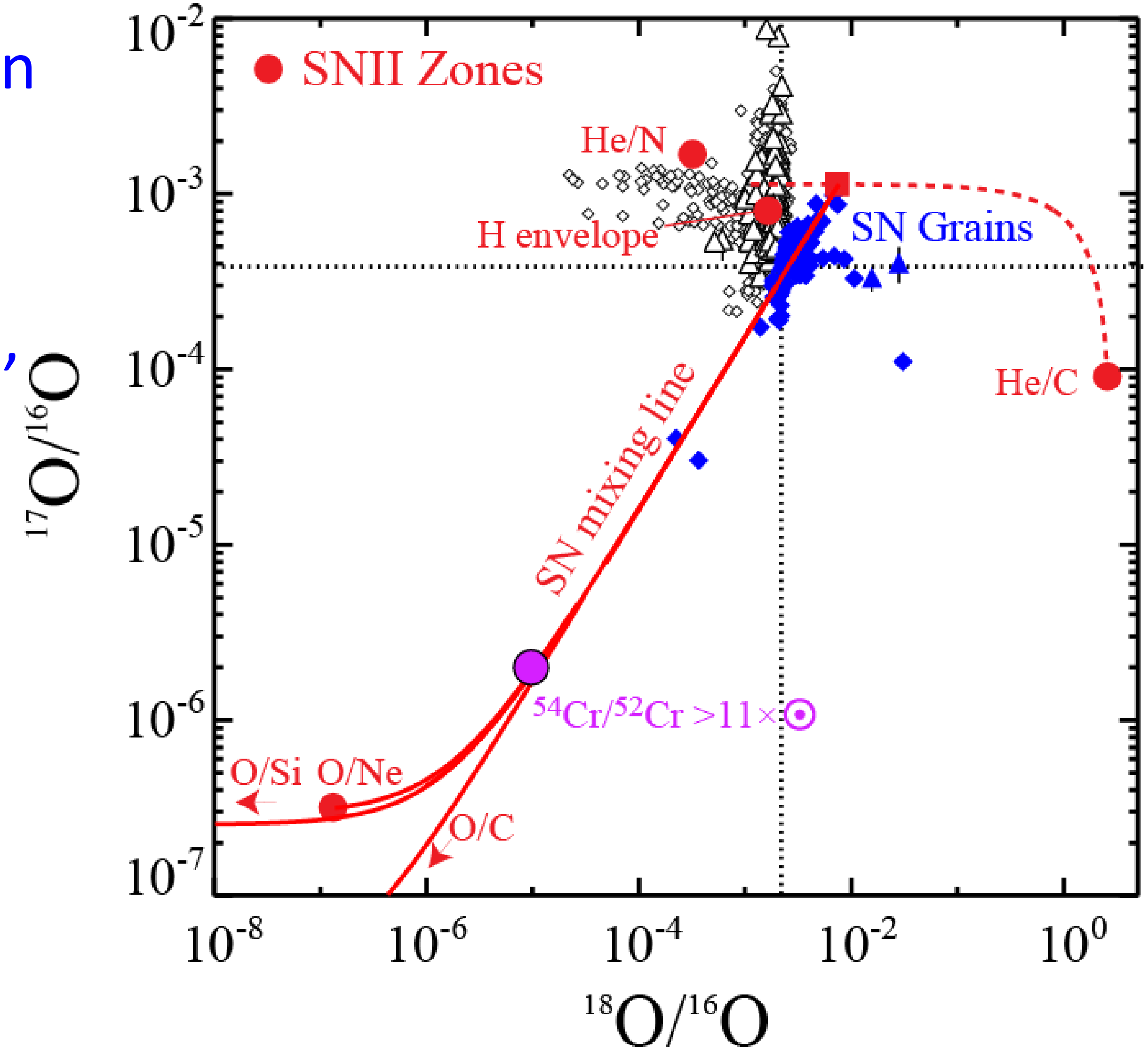
  - Mixing in jets?
- SNe heterogeneous, suggests special circumstances, probably a single supernova parent for most grains (Nittler *et al.* 2008)
  - ^{54}Cr rich grains should lie on same line



Implications for Solar System

- Heterogeneous distribution of SN grains in solar system?
  - Bulk variations in Cr isotopes in different meteorite classes explained by varying amounts of SN ^{54}Cr-rich grains
  - ^{18}O-rich (SN) presolar silicates more abundant in cometary (e.g. IDPs) than asteroidal samples (meteorites)

Supports direct injection of SN material into already-formed disk (Ouellette, Desch & Hester 2007, 2010)

Conclusions

- Orgueil acid residue rich in isotopically highly anomalous presolar oxide grains (^{54}Cr-rich as well as O-anomalous grains)
  - Isotopic measurements severely affected by poor spatial resolution
- ^{54}Cr-rich grains small (≤100nm) and inferred to have extreme enrichments (up to >50 x Solar)
- C, Ne, O burning zones of Type II SN most likely source
  - New type of presolar supernova grain
- Likely significant source of Cr isotope variations in bulk meteorites
  - Supports model of direct SN injection into early solar system.