Measurements of Presolar Grains

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Outline

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SiC
Oxides
Advances
Summary

- Introduction
  - Stardust in meteorites & IDPs
  - Astrophysical information
- Presolar Silicon Carbide
  - C, N, & Si isotope systematics
  - Heavy elements
- Presolar Oxides & Silicates
  - Identification of silicates
  - O isotope systematics
- Recent Advances
  - SiC SN grains
  - Oxide SN grains
- Summary

Introduction (I)

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- Primitive meteorites contain small quantities (ppb-ppm) of refractory dust grains with highly anomalous isotopic compositions
- First hints on the presence of meteoritic minerals with highly anomalous isotopic compositions in the 1960s
- Separation of SiC as carrier of anomalous noble gas components in the 1980s

  → Presolar origin
  → Stardust

Introduction (II)

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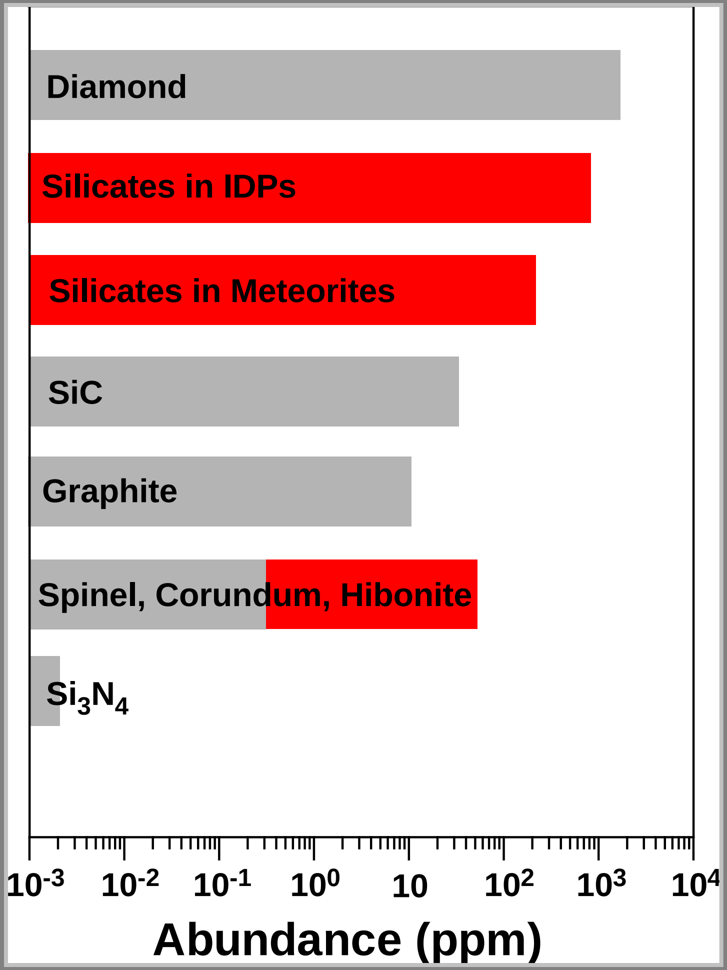
Presolar Minerals



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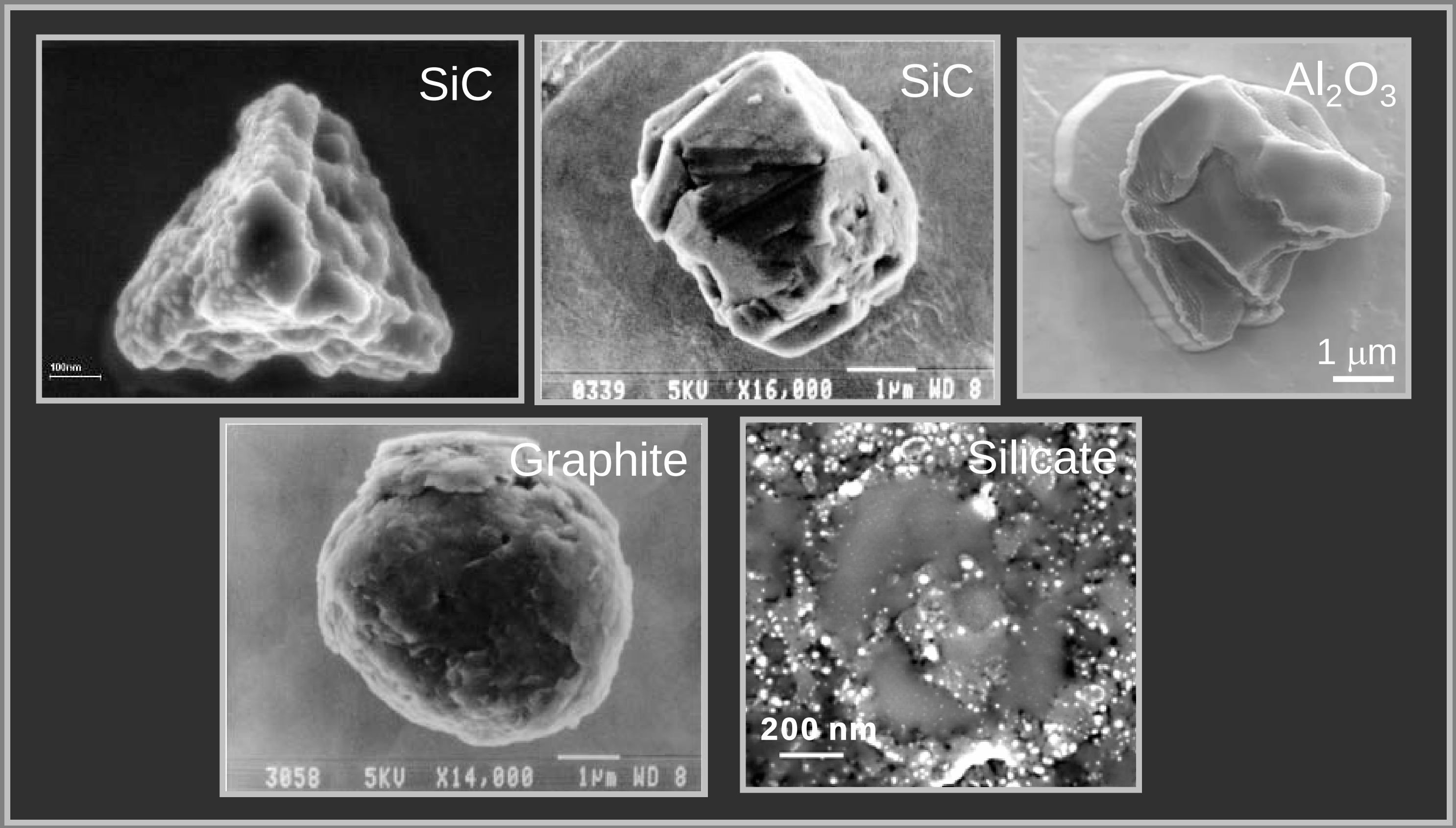
Introduction (III)

Presolar Grains



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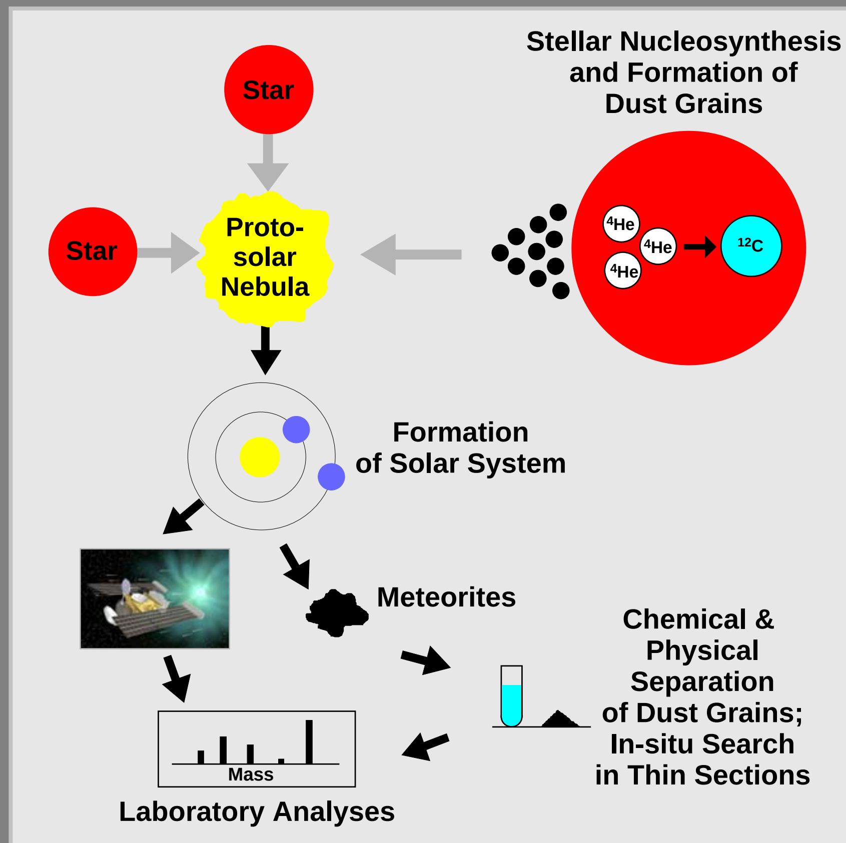
Introduction (IV)

From Circumstellar to Interstellar to Presolar Grains



Introduction (V)

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Astrophysical Information

- Stellar nucleosynthesis and evolution
- Galactic chemical evolution
- Grain formation in stellar environments
- Chemistry in the ISM
- Types of stars that contributed dust to the Solar System
- Solar System formation

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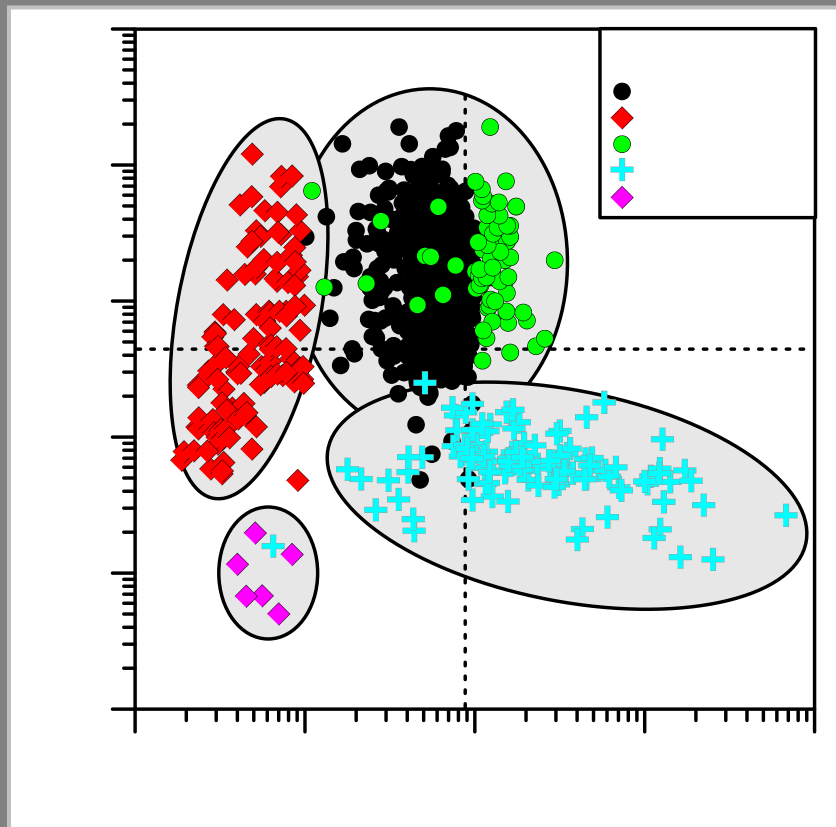
Silicon Carbide (I)

C and N Isotopes



(Data sources: WU St. Louis, MPI Mainz, Carnegie Inst.)

- Mainstream (90%):
  1.5-3 $M_\odot$ AGB stars, solar metallicity
- Type Y&Z (a few %):
  1.5-3 $M_\odot$ AGB stars, sub-solar metallicity
- Type X (1%):
  Type II supernovae
- Nova (0.1%)
- Type A&B (a few %):
  J-type C stars?
  Born-again AGB stars?

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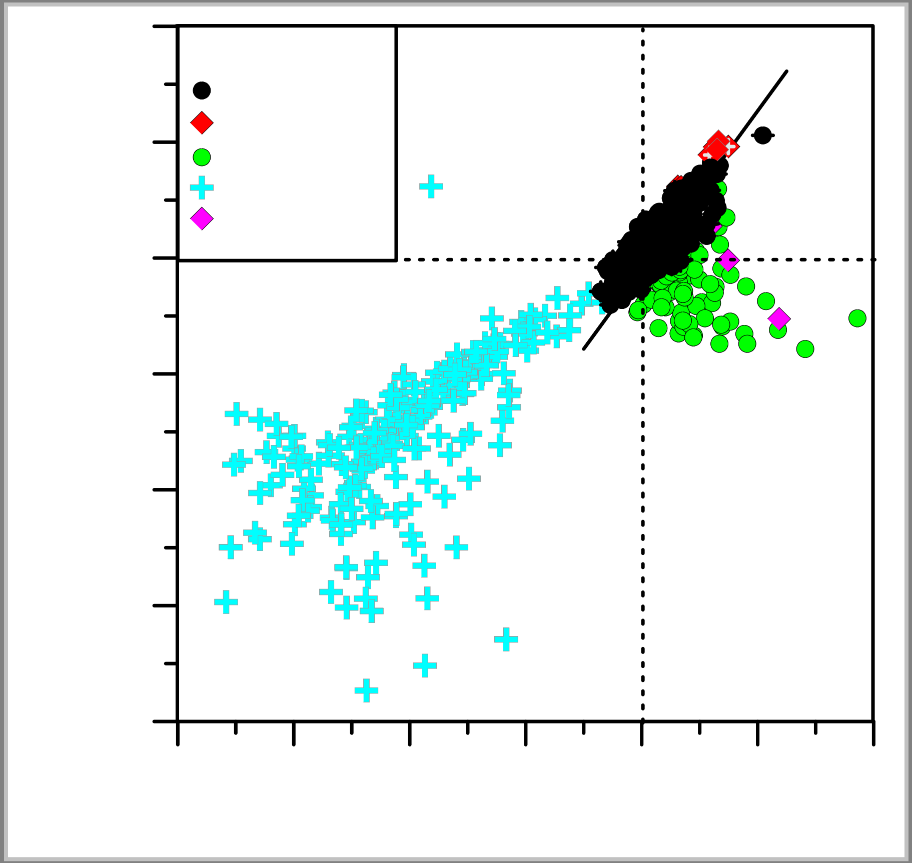
Silicon Carbide (II)

Si Isotopes



(Data sources: WU St. Louis, MPI Mainz, Carnegie Inst.)

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Silicon Carbide (III)

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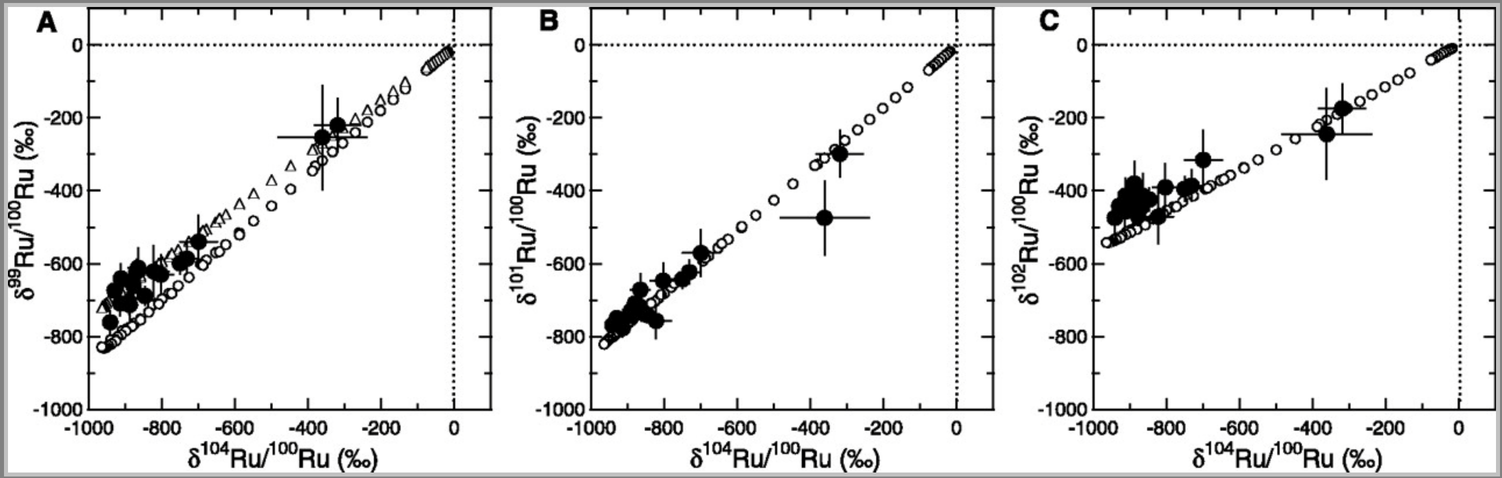
^{99}Tc and *s*-Process Isotopic Signatures in MS Grains



(Savina et al., 2004)

- Heavy elements in MS grains show s-process isotopic signatures
- Strong support for origin from 1-3 $M_{\odot}$ AGB stars

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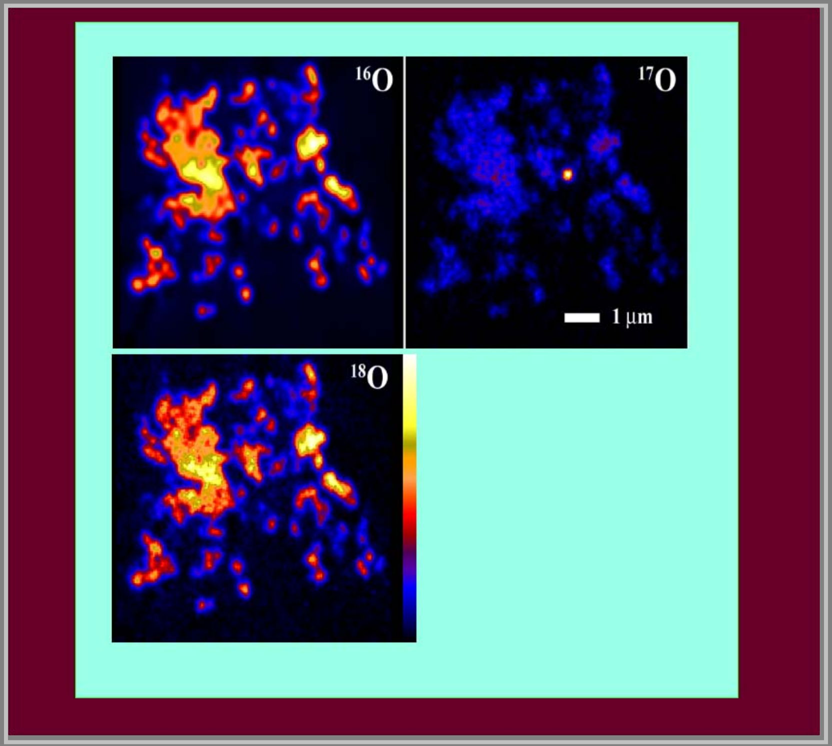
Oxides & Silicates (I)

Identification of Presolar Silicates



(Messenger et al., 2003)

- Most presolar minerals can be separated by harsh chemical treatments from meteorites
- Does not hold for silicates
- Silicates are major constituent of O-rich dust around stars
- First silicates discovered in an IDP in 2002
- O isotope mapping with 100 nm resolution

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Oxides & Silicates (I)

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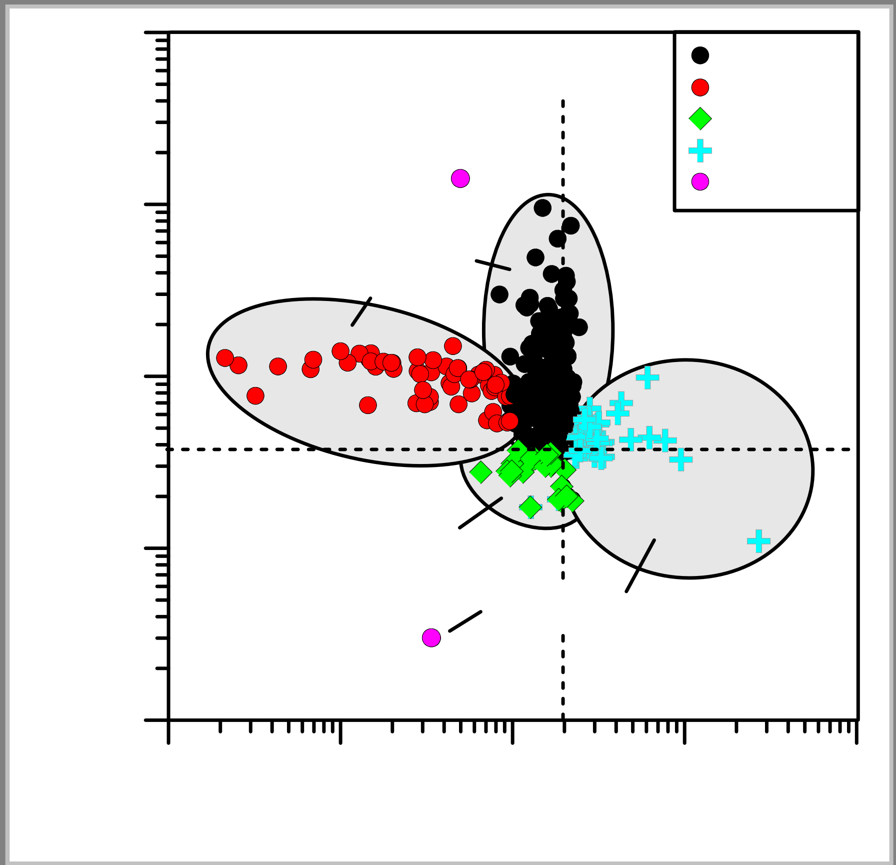
O Isotopes



(Data sources: WU St. Louis, Carnegie Inst., JSC, Caltec, MPI Mainz)

- Group 1 (70%):
  1.2-2.2 $M_{\odot}$ AGB stars, solar metallicity
- Group 2 (15%):
  <2 $M_{\odot}$ AGB stars, CBP
- Group 3 (5%):
  Low-mass, low-met. AGB stars?
  Type II supernovae?
- Group 4 (10%):
  Type II supernovae

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Oxides & Silicates (III)

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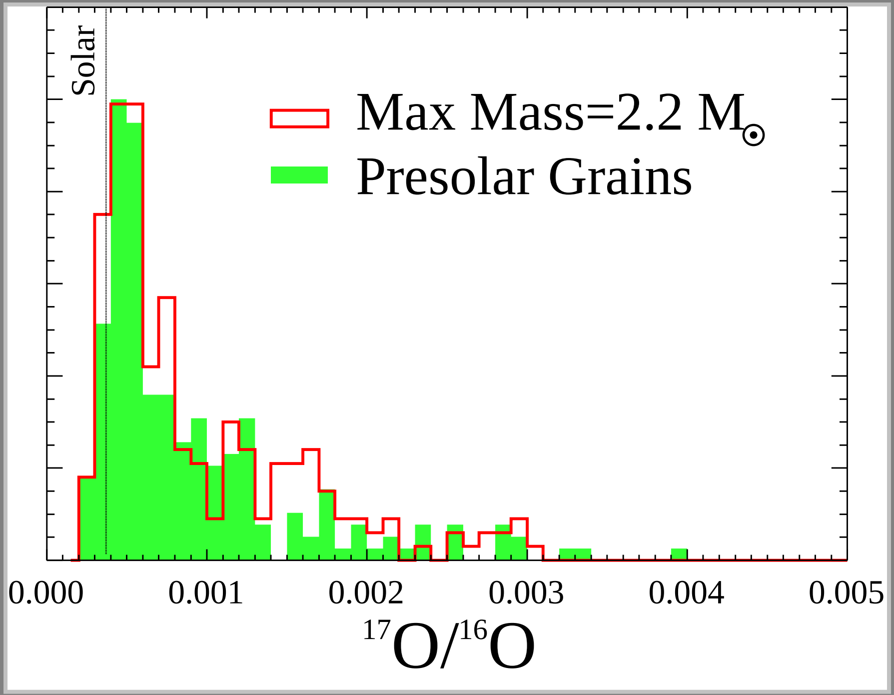
$^{17}O/^{16}O$ in Presolar Grains and Red Giant Stars



(Nittler, 2009)

- $^{17}O/^{16}O$ in RG stars depends mainly on stellar mass
- Distribution of $^{17}O/^{16}O$ in AGB grains is sensitive measure of mass distribution of parent stars
- Upper mass limit of AGB parent stars inferred from Monte Carlo simulation
- Best match for a mass limit of 2.2 $M_\odot$

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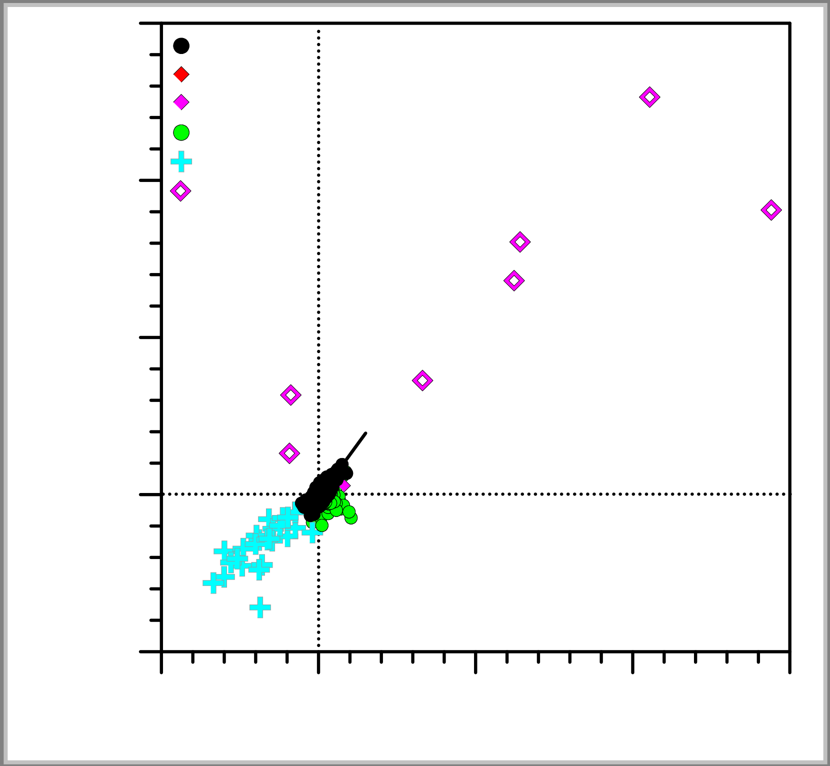
Recent Advances (I)

Submicrometer-sized Presolar SiC



(Gyngard et al., 2010; Hoppe et al., 2010; Zinner et al., 2010)

- Grains with strong enrichments in $^{29,30}Si$ very rare among larger grains
- Origin:
  - Outside range of AGB grains
  - $^{12}C/^{13}C$ incompatible with nova predictions
  - Outside range of common SN grains
  - But: large range of Si compositions in SNII ejecta possible

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Recent Advances (II)

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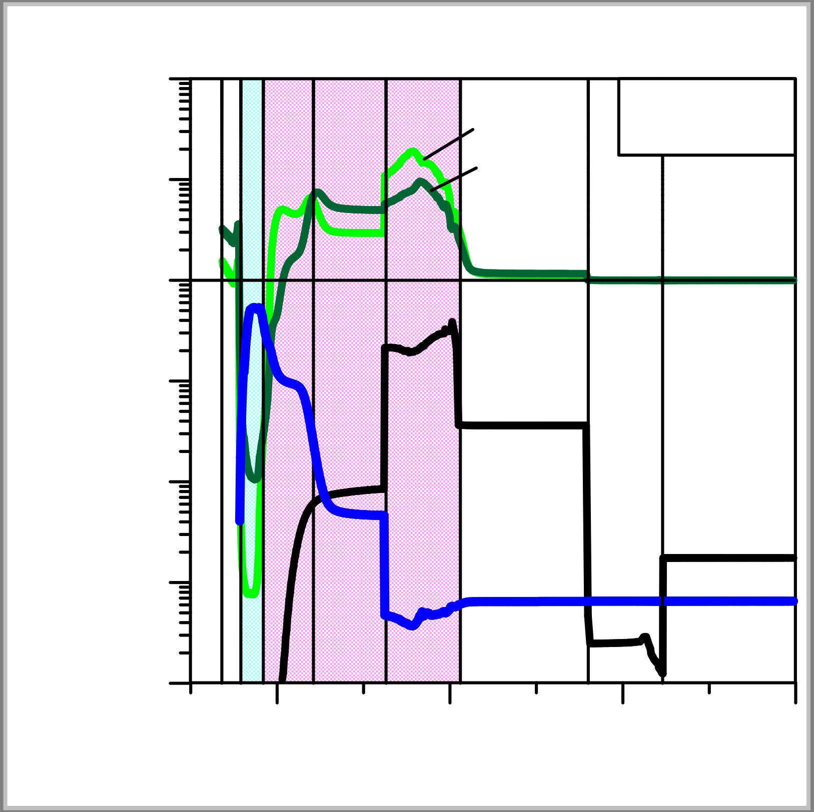
Si in Type II SNe



(Rauscher et al. 2002)

- Mixing of matter from different SN layers can produce a wide range of Si-isotopic compositions
- Grain B has $^{29}Si/^{30}Si$ of ~2x solar
  - Implies relative large contributions from O/Ne zone
  - Provides opportunity to make test of Travaglio et al. hypothesis (2x higher ^{29}Si yield in O/Si and O/Ne)

Recent Advances (III)

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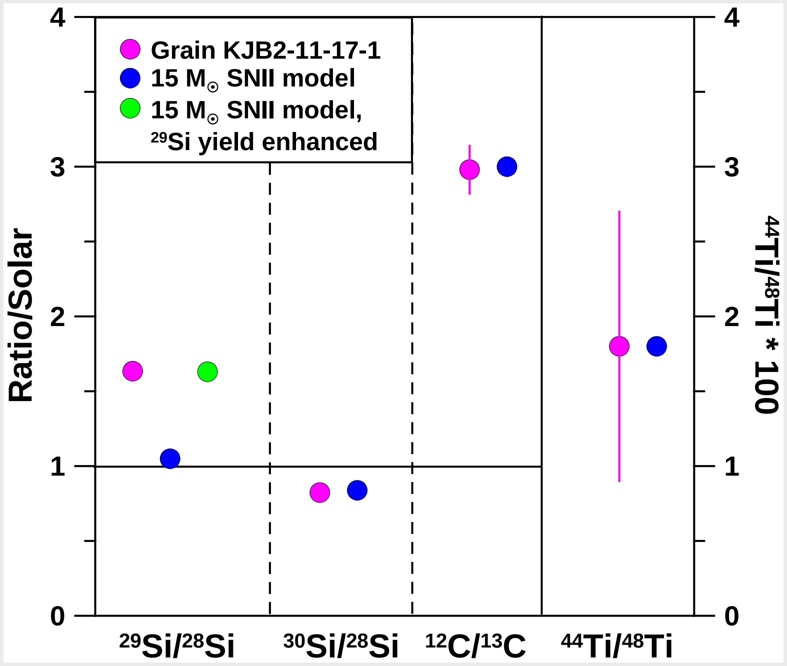
Mixing of 15 $M_\odot$ SNII Ejecta



Hoppe et al. (2009)

- Very good match except for $^{29}Si/^{28}Si$
- Doubling the ^{29}Si yield in the O/Ne zone:
  - Perfect match for $^{29}Si/^{28}Si$
  - Supports idea of under-estimated ^{29}Si production
  - 3x higher $^{26}Mg(\alpha,n)^{29}Si$ increases ^{29}Si yield by 2x
- GCE models predict way too little ^{29}Si
  - 1.8-1.9x more ^{29}Si in SNeII
  - Good match to solar ^{29}Si

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Recent Advances (IV)

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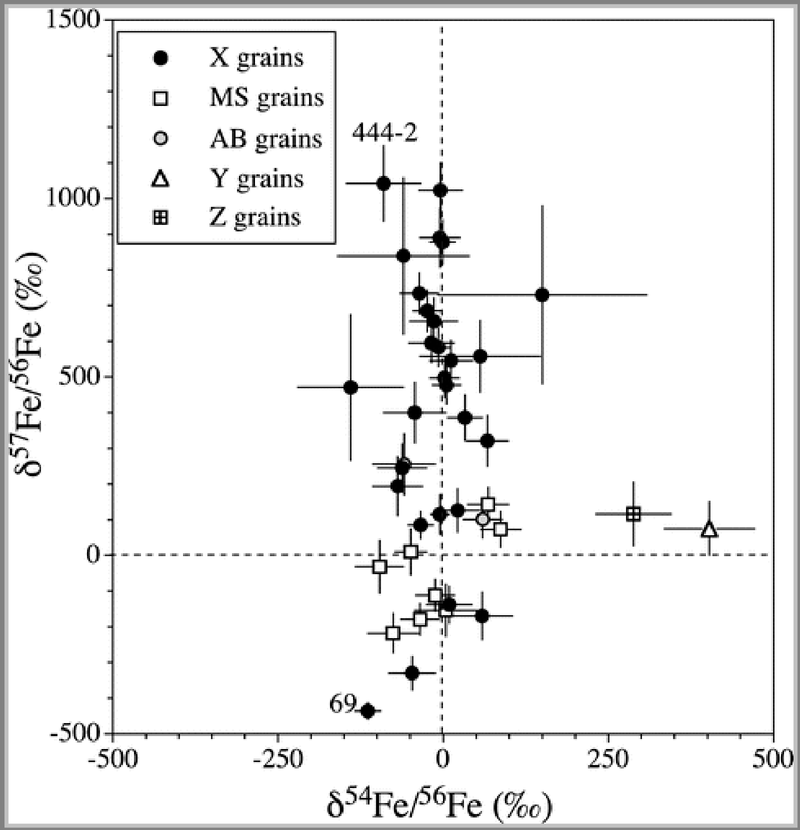
Fe in SiC SN X grains



(Marhas et al. 2008)

- SiC X grains contain up to 0.5 wt% Fe
- ^{57}Fe enrichments in most X grains with ^{57}Fe/^{56}Fe up to 2x solar
- ^{54}Fe/^{56}Fe are essentially normal

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Recent Advances (V)

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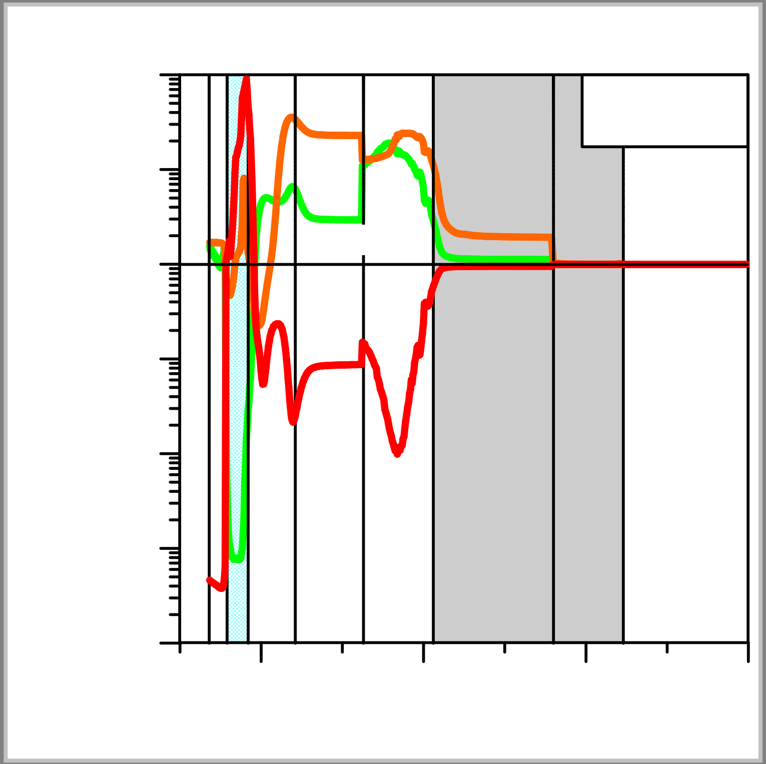
Fe in Type II SNe



(Rauscher et al. 2002)

- $^{57}Fe/^{56}Fe$ and Si can be explained by mixing matter from He/N, He/C, and Si/S zones
- Normal $^{54}Fe/^{56}Fe$ puzzeling:
  - Si/S zone is very rich in ^{54}Fe
  - Preferential trapping of Fe from outer zones?
  - Element fractionation by molecule chemistry?
  - S isotope anomalies in two SN grains with heavy Si support this idea

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Recent Advances (VI)

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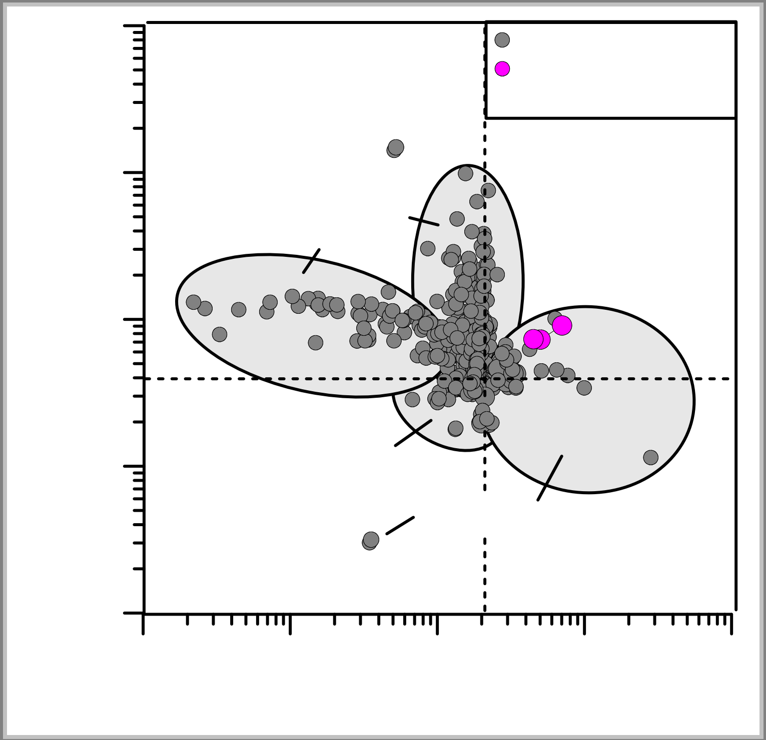
Origin of Group 4 Oxide/Silicate Grains



(Nittler et al. 2008)

- Origin of Group 4 grains:
  - Type II SNe
  - High-metallicity AGB stars
- Multi-element isotope data:
  - Isotope data for O, Mg, and/or Ca from three Group 4 oxide grains
  - Comparison with SNII mixing models

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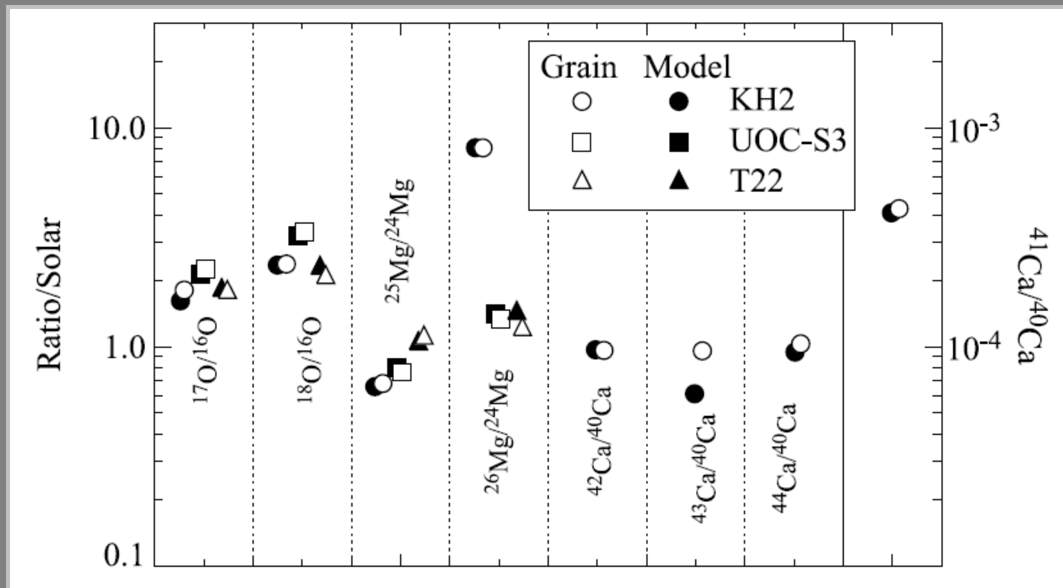
Recent Advances (VII)

Origin of Group 4 Oxide/Silicate Grains

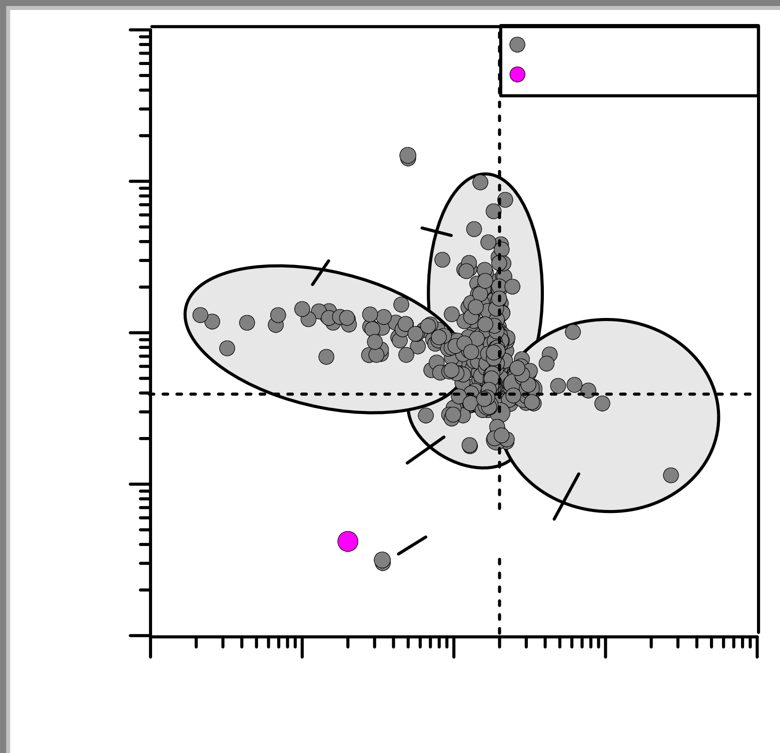


(Nittler et al. 2008)

- Isotope data are well explained by 15 $M_\odot$ SNII mixing models
  - Most matter from H and He/N zones
  - ^{18}O enrichments due to admixture of He/C zone matter
- Strong support for SN origin of Group 4 grains
- Additional evidence from Mg & Si data of silicate grains

Recent Advances (VIII)

^{44}Ti in a SN Spinel



(Gyngard et al. 2010)

- ^{16}O-rich SN grains are extremely rare
- ^{16}O-rich spinel with radiogenic ^{44}Ca found
  - ^{17,18}O/^{16}O ~ 0.1x solar
  - ^{44}Ca/^{40}Ca ~ 60x solar
  - ^{44}Ti/^{48}Ti = 0.004
  - Strong support for SN origin
  - Multi-element isotope data can be reproduced by SN mixing (15 $M_{\odot}$ model of Woosley & Heger 2007)

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Recent Advances (IX)

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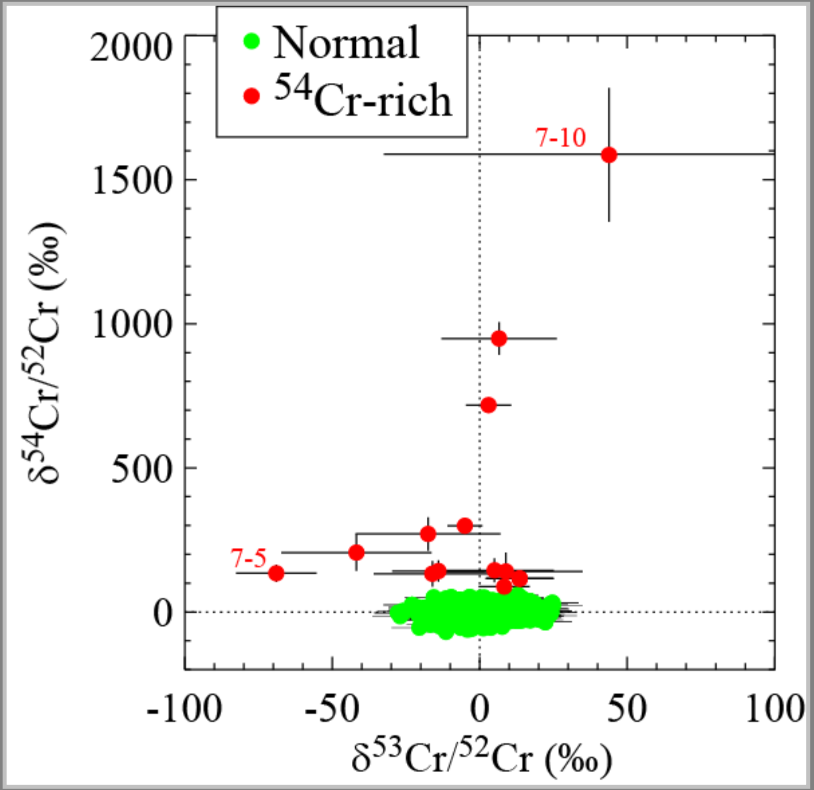
^{54}Cr Excesses in Oxide Grains



(Nittler et al. 2010)

- Bulk meteorites show ^{54}Cr variations
- Identification of oxide grains with large ^{54}Cr excesses but no O isotope anomalies
- Origin of ^{54}Cr anomaly:
  - Oxidation (ISM, Solar System) of SN metal grains
  - Cr oxides from SNeII
  - GCR irradiation of Fe-rich grains

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Summary

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- Primitive meteorites and IDPs contain presolar dust grains that provide a wealth of astrophysical information
- The majority of presolar grains formed in 1-3 $M_\odot$ AGB stars, a few % in SNeII, and << 1% in novae
- (Some) existing problems/shortcomings:
  - For the most abundant presolar mineral, the silicates, only limited information on isotopic compositions exists
  - Why are there no apparent contributions from >4 $M_\odot$ AGB stars?
  - The role of CBP in the parent stars of presolar grains from AGB stars
  - Why so few SN grains with ^{16}O excesses?
  - The comparison of SN grain data with model predictions is based on ad-hoc mixing calculations; more realistic models desired (physics of mixing, molecule chemistry)