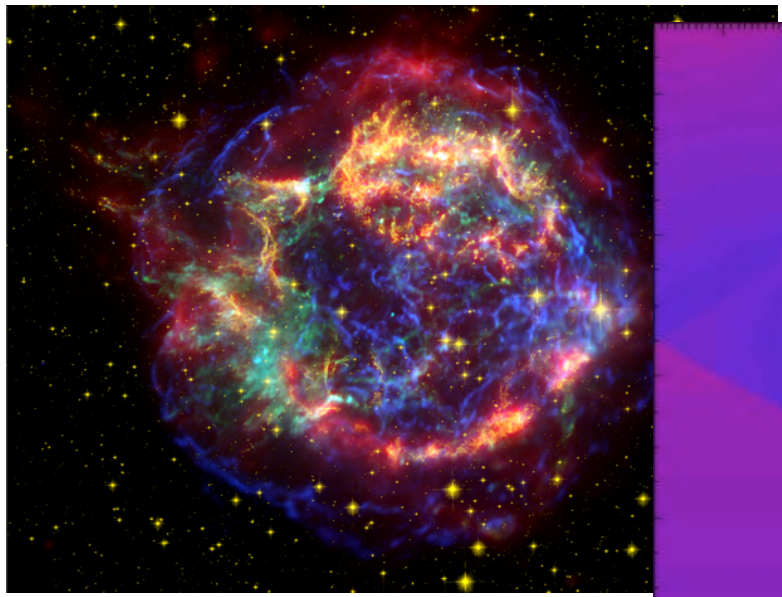
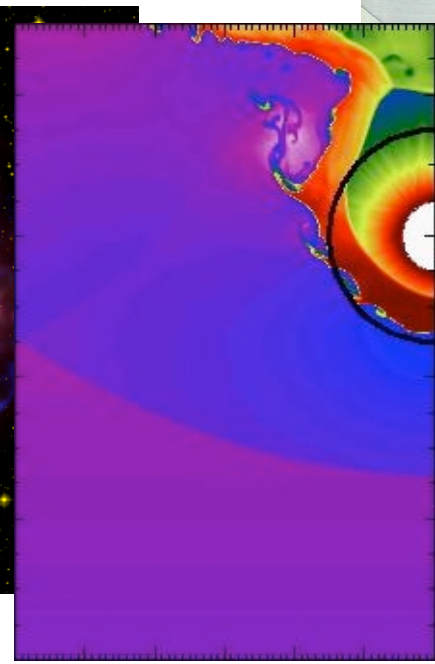
Cosmic Wiplash
From
There and Then
to
Here and Now

When Stars Attack!

Supernova Nucleosynthesis Products in the Laboratory





Brian Fields

Astronomy & Physics, U Illinois

JINA Building Virtual Galaxies Workshop

April 29, 2010

Themis Athanassiadou Arizona State

John Ellis CERN

Leslie Looney Illinois

John Tobin U Michigan

When Stars Attack!

Live Radioactivities as Signatures of Near-Earth Supernova Explosions

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Live Radioactivities as Signatures of Near-Earth Supernova Explosions

★ **Nearby Supernovae**

a unique laboratory…and a unique threat

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★ **Geological Signatures**

sea sediments as telescopes

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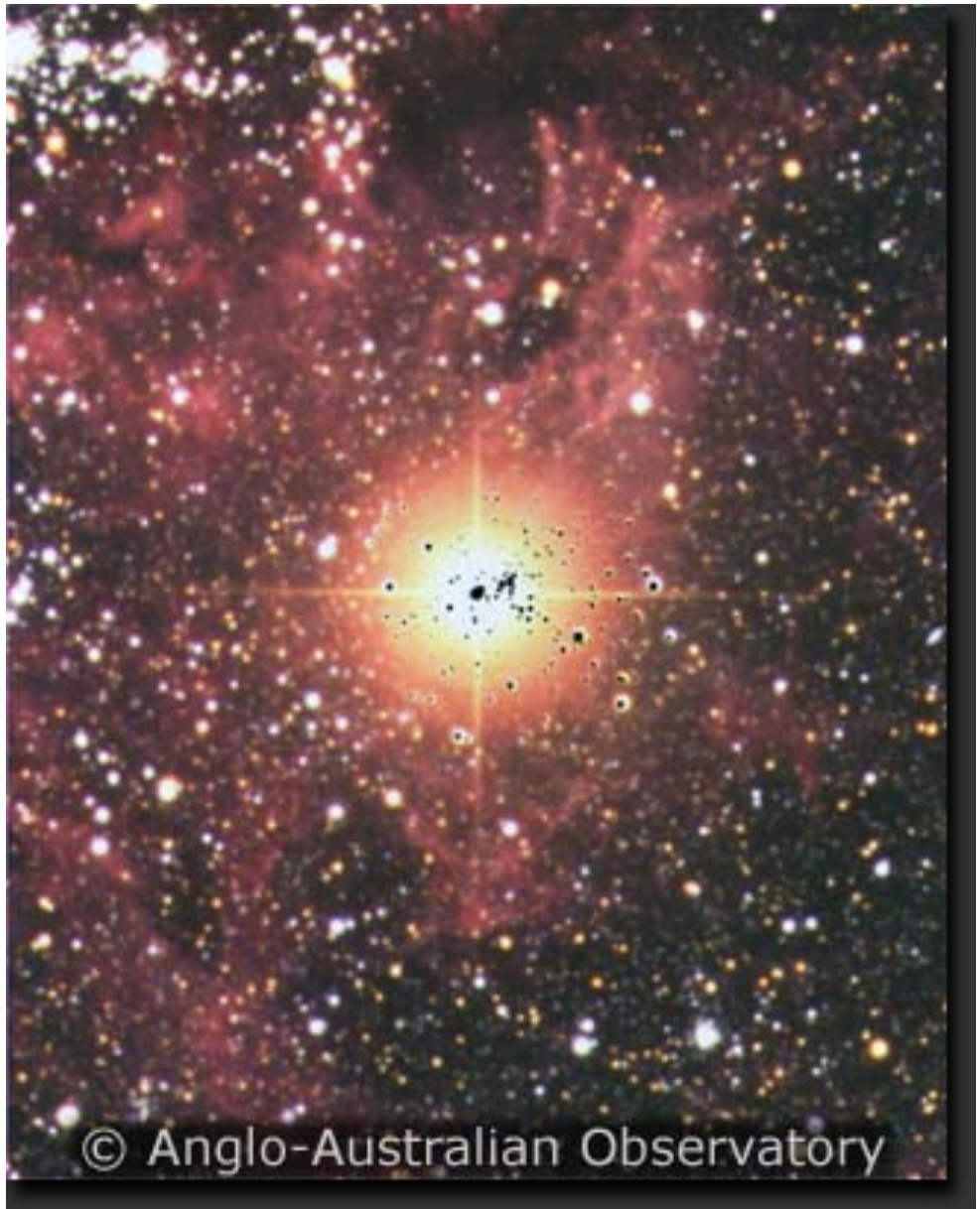
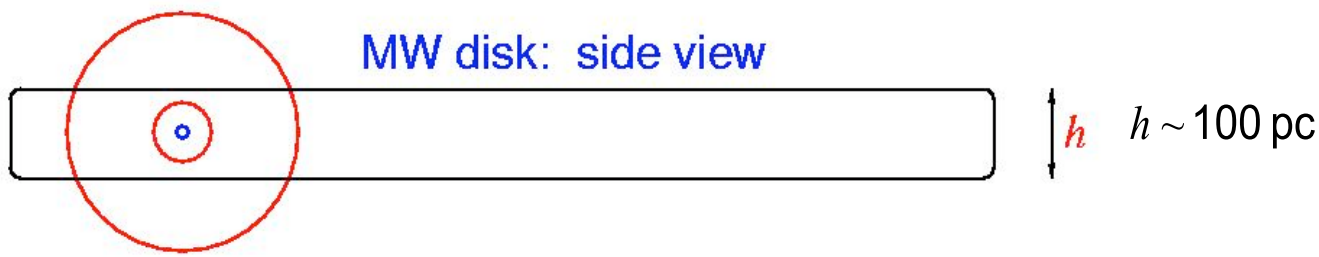


Cosmic WMD: Rates

★ **How often? Depends on how far!** Shklovskii 68

★ **Rate of Supernovae inside d:**

- Galactic supernova rate today: $\mathcal{R}_{\rm SN}$
- in homog. disk, scale height



$$\lambda(<d) = \frac{V_{\rm disk}(<d)}{V_{\rm disk,total}} \mathcal{R}_{\rm SN} = (10\ {\rm Myr})^{-1} \left(\frac{d}{30{\rm pc}}\right)^3$$

- corrections: spiral arms, molecular clouds, exponential disk... Talbot & Newman 77
- multiple events < few pc in the last 4.5 Gyr!

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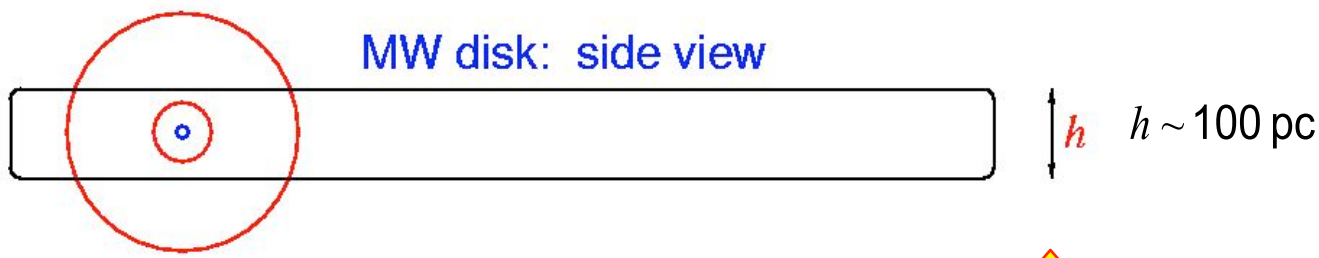

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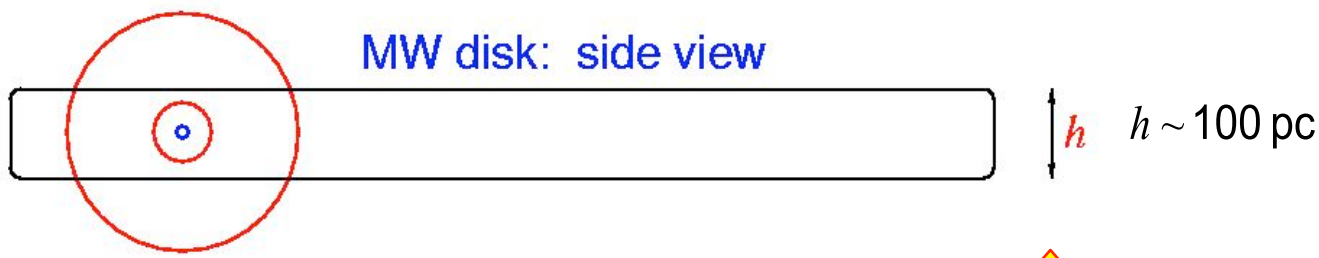

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Nachbarsternsupernovaexplosionsgefahr

or

Attack of the Death Star!

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Ill efects of a supernova too close

possible source of mass extinction

- Shklovskii; Russell & Tucker 71; Ruderman 74

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- initial gamma, X, UV rays
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- destroy ozone in atmosphere
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- solar UV kills bottom of food chain
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- neutrino-nucleon elastic scattering:
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  ⇨ DNA damage
  Collar 96, but see Karam 02

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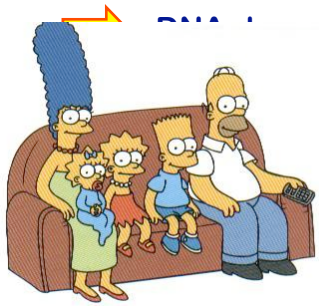

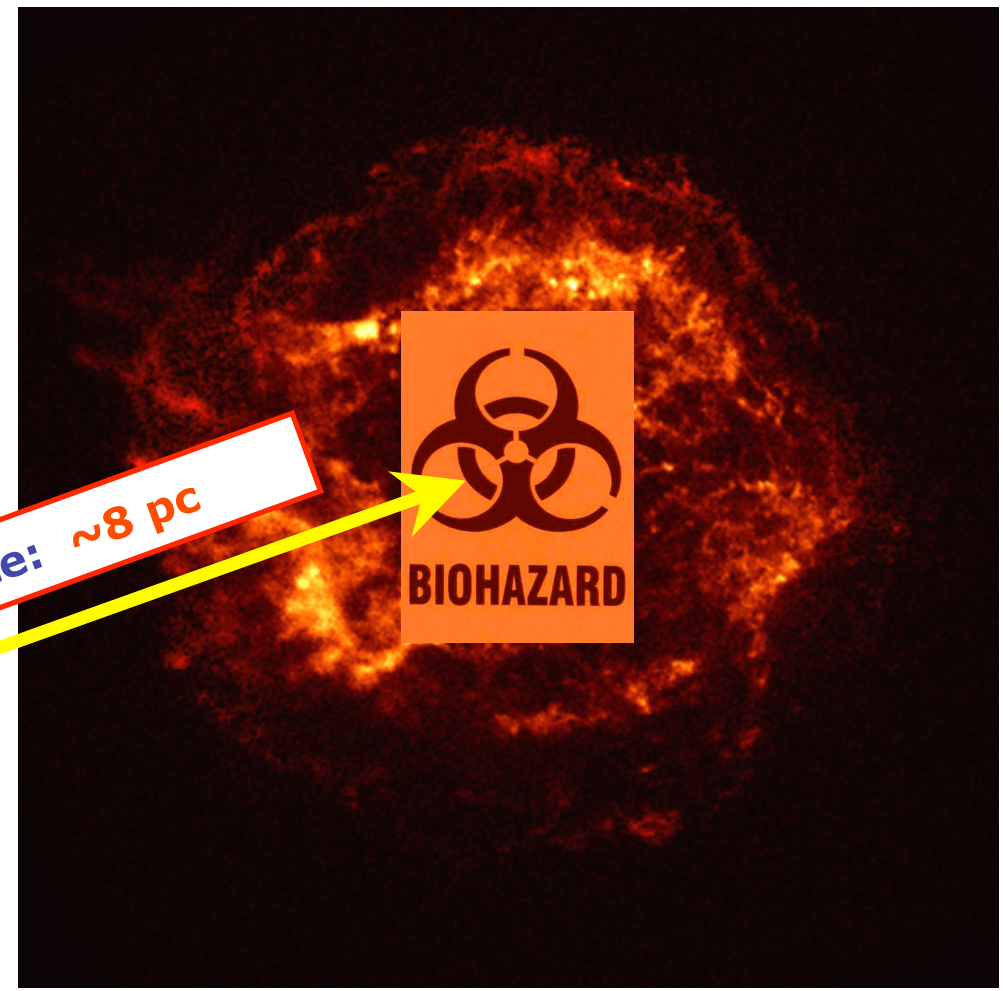

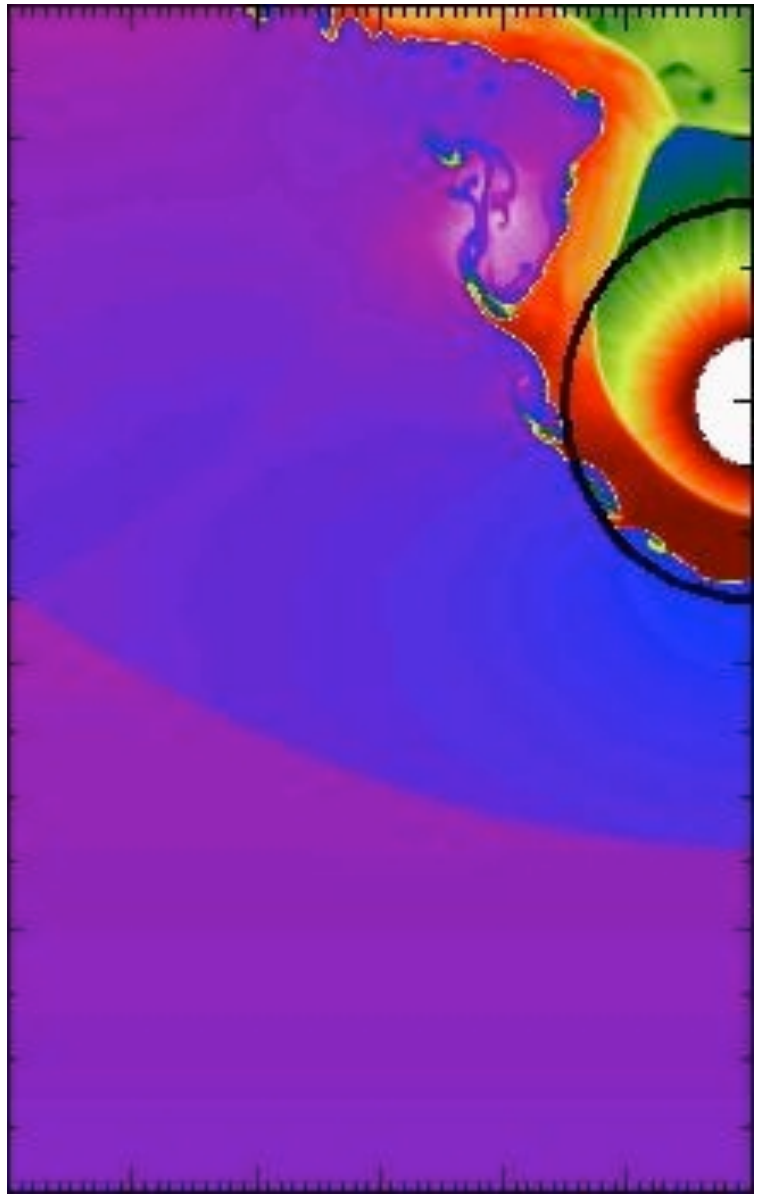

The Smoking Gun

The Smoking Gun: Supernova Debris on the Earth

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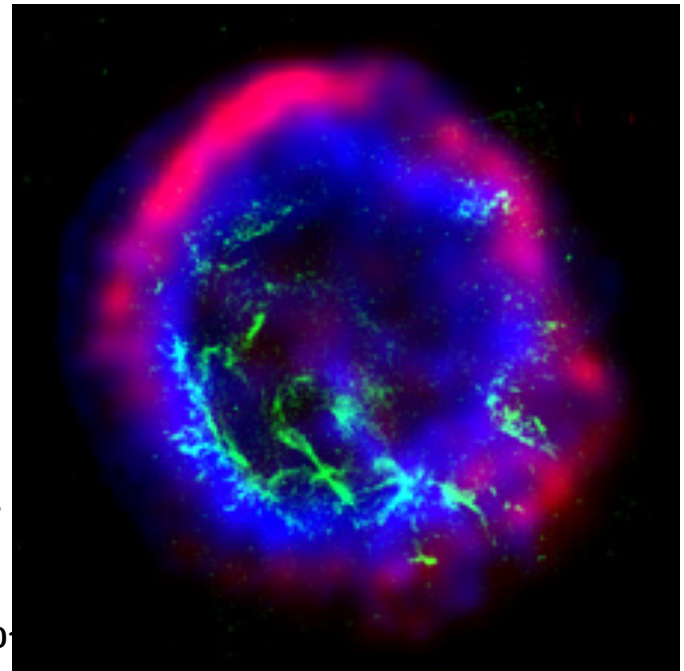

Chandra

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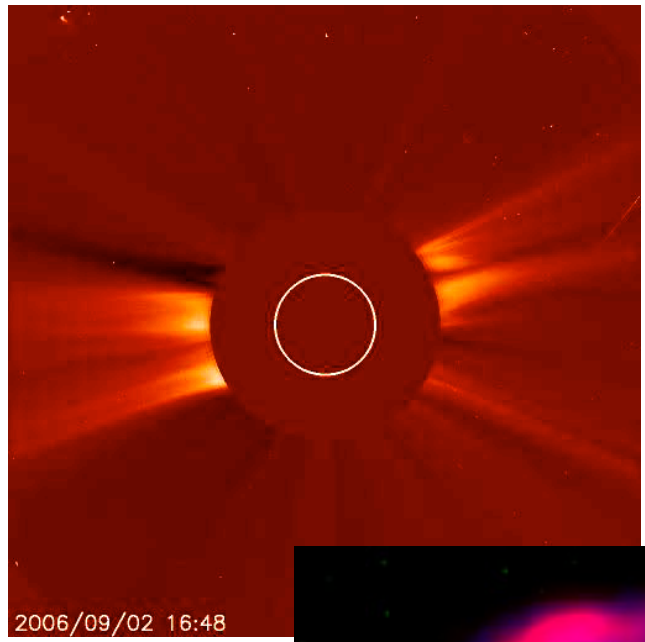
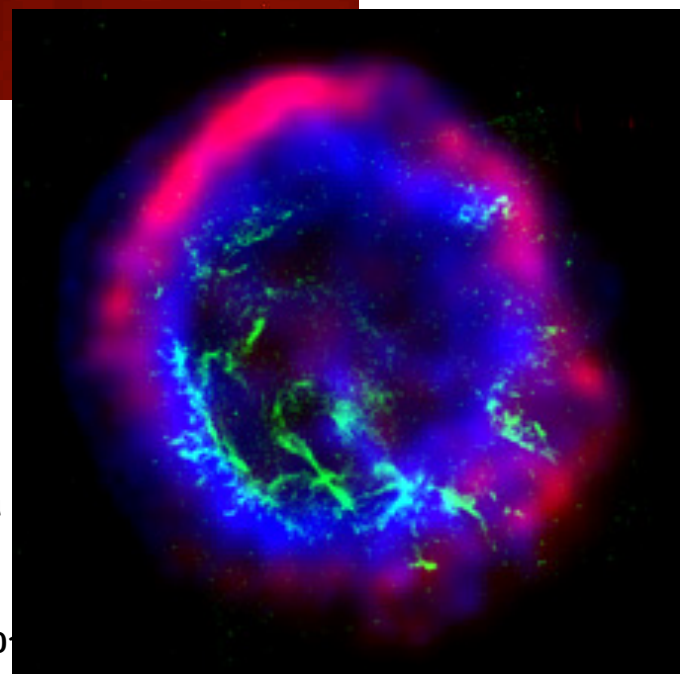


SOHO



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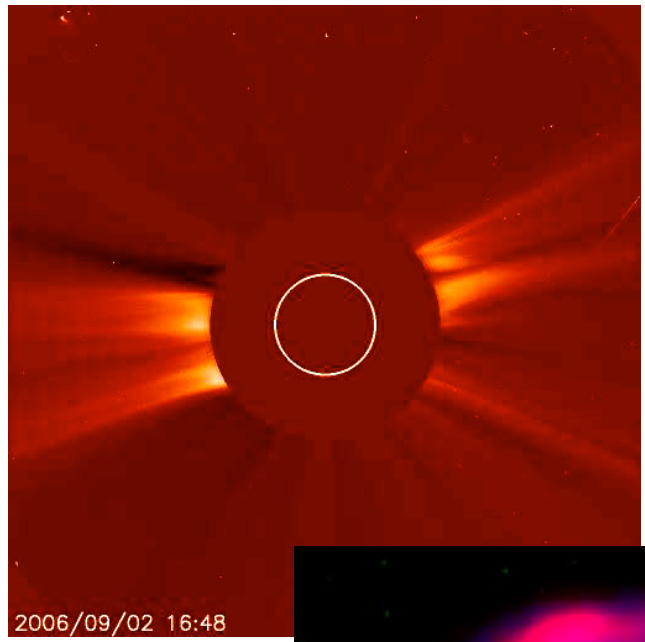

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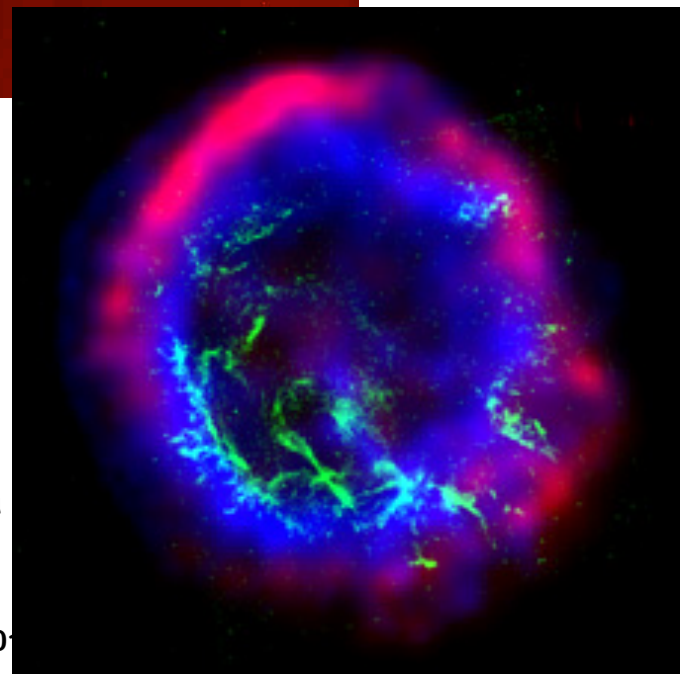

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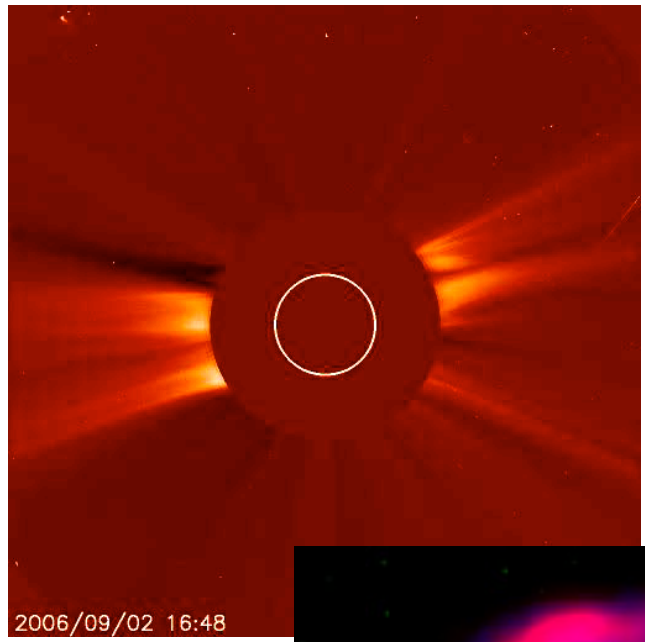

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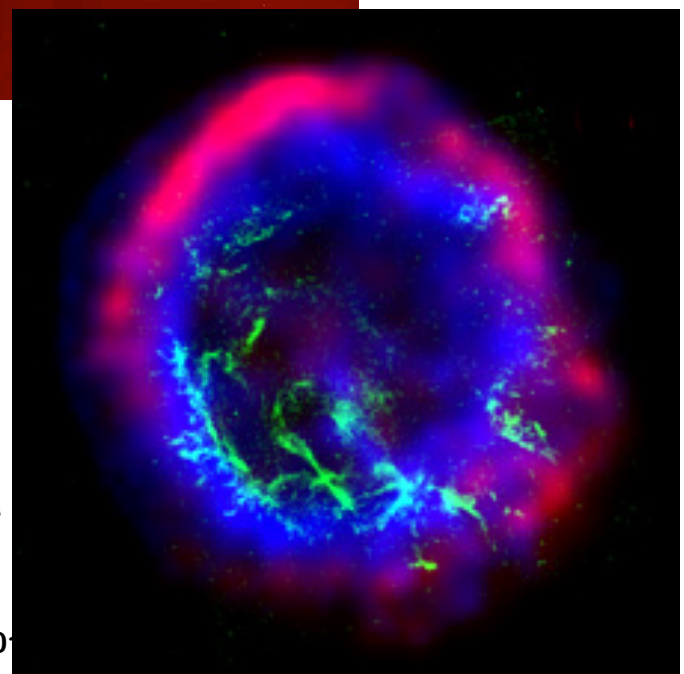

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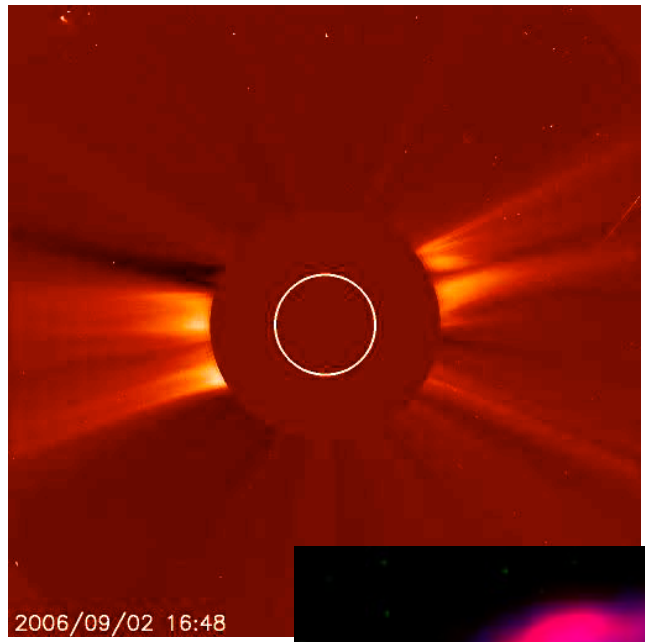

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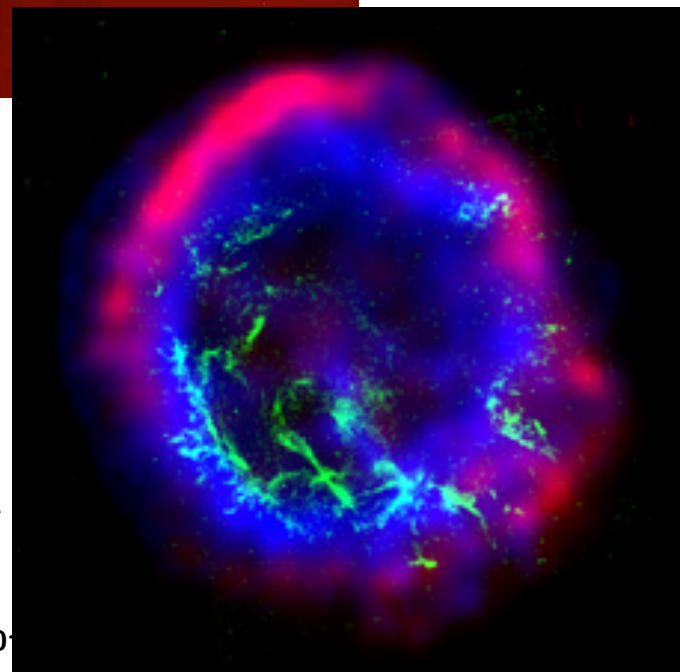

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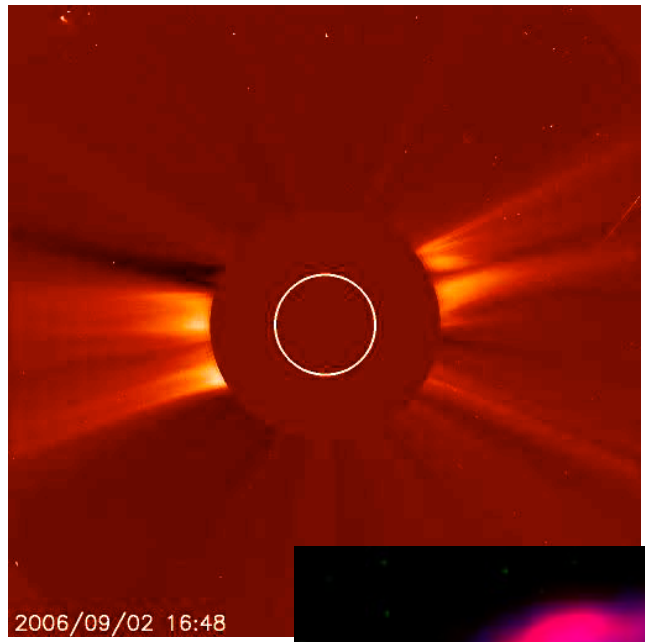

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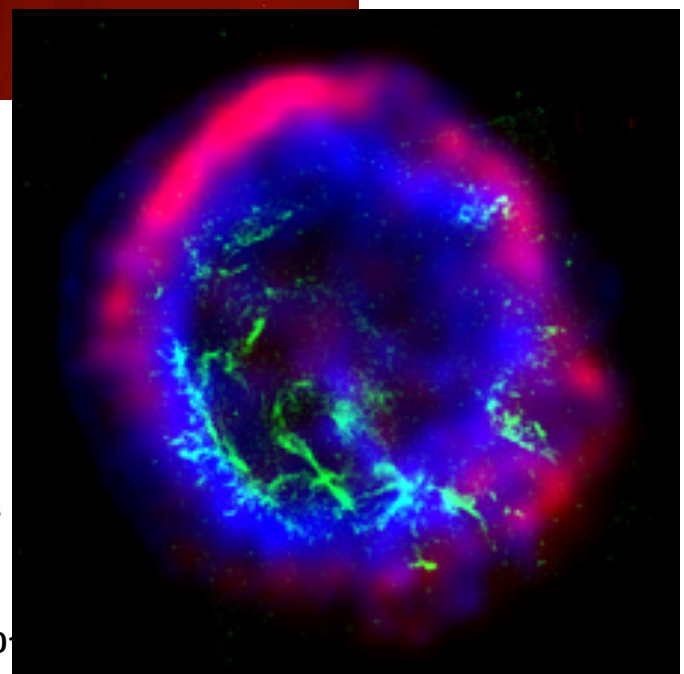

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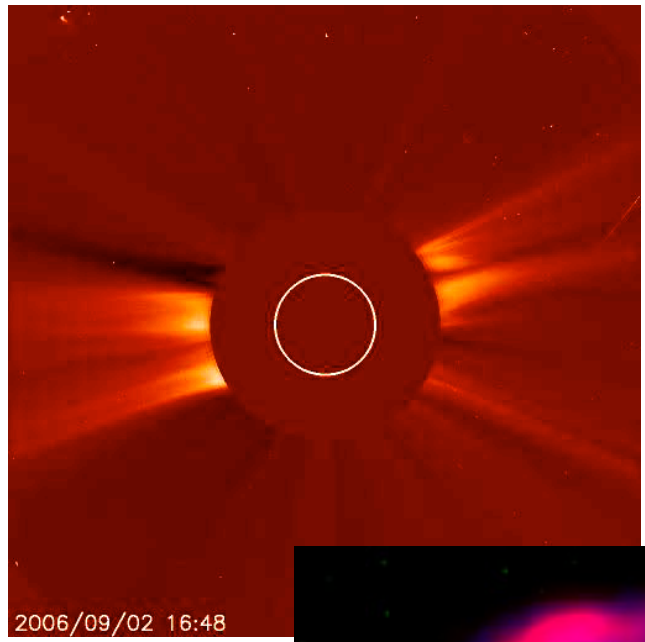

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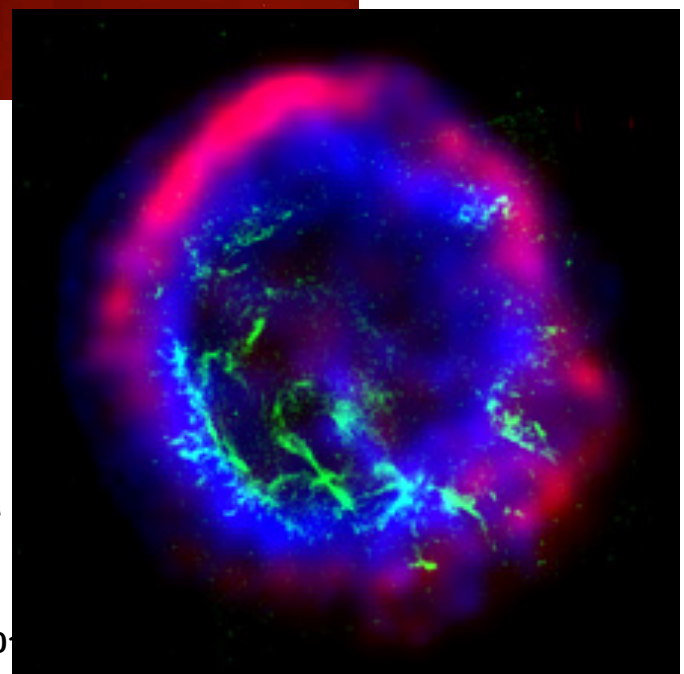

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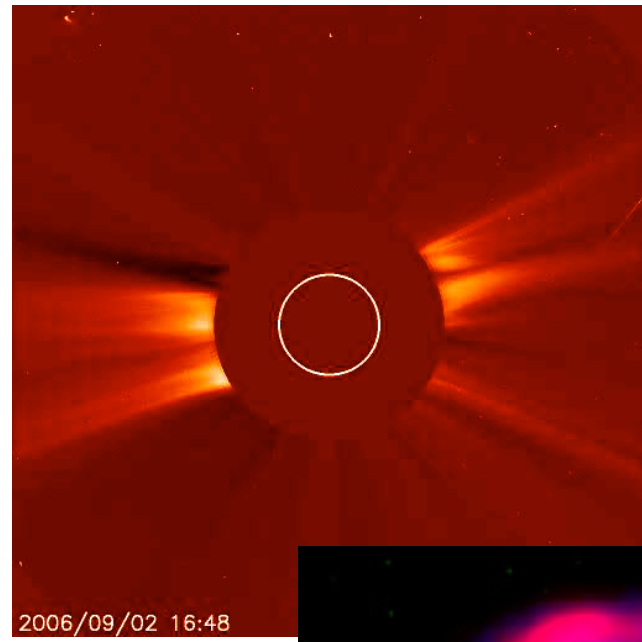
- ✓ Live radioactive isotopes: none left on Earth
  If found, must come from SN!



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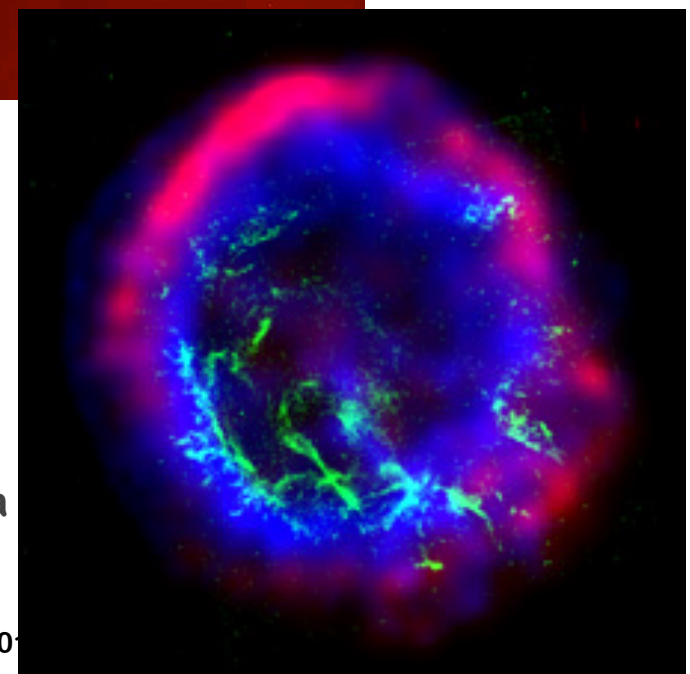

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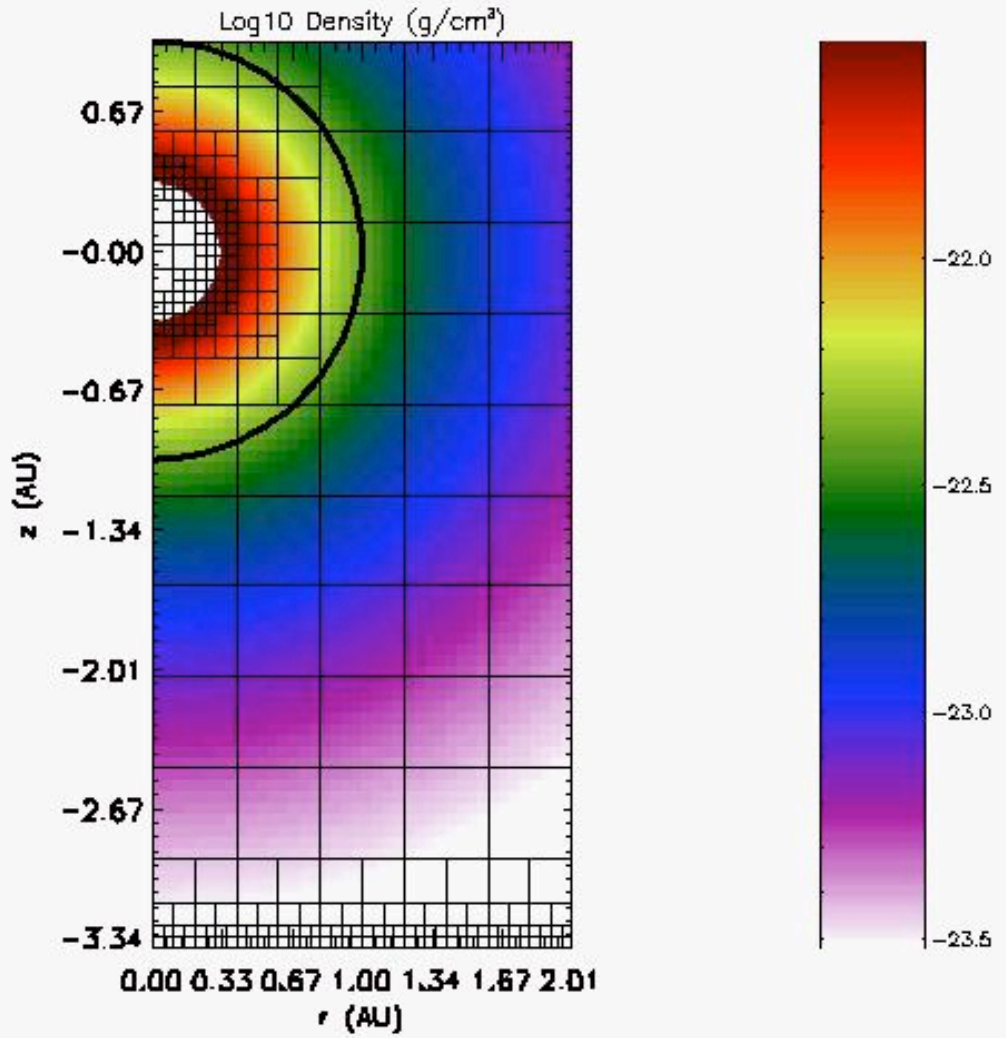
Supernova Blast Impact on the Solar System

BDF, Athanassiadou, & Johnson 2006



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Simulation:

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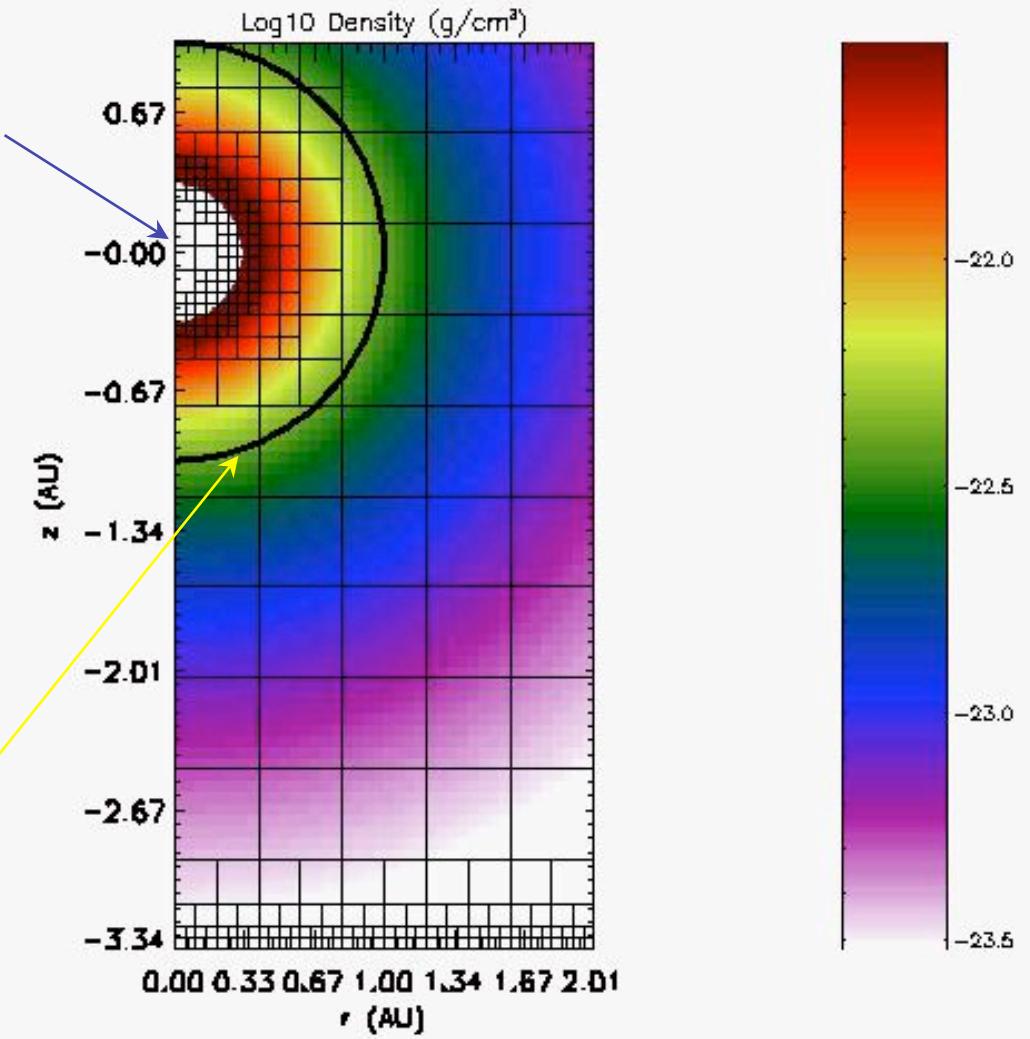
Blast Properties:

SN at 10 pc

Geometry:

Cylindrical



1 AU =
Earth's orbit

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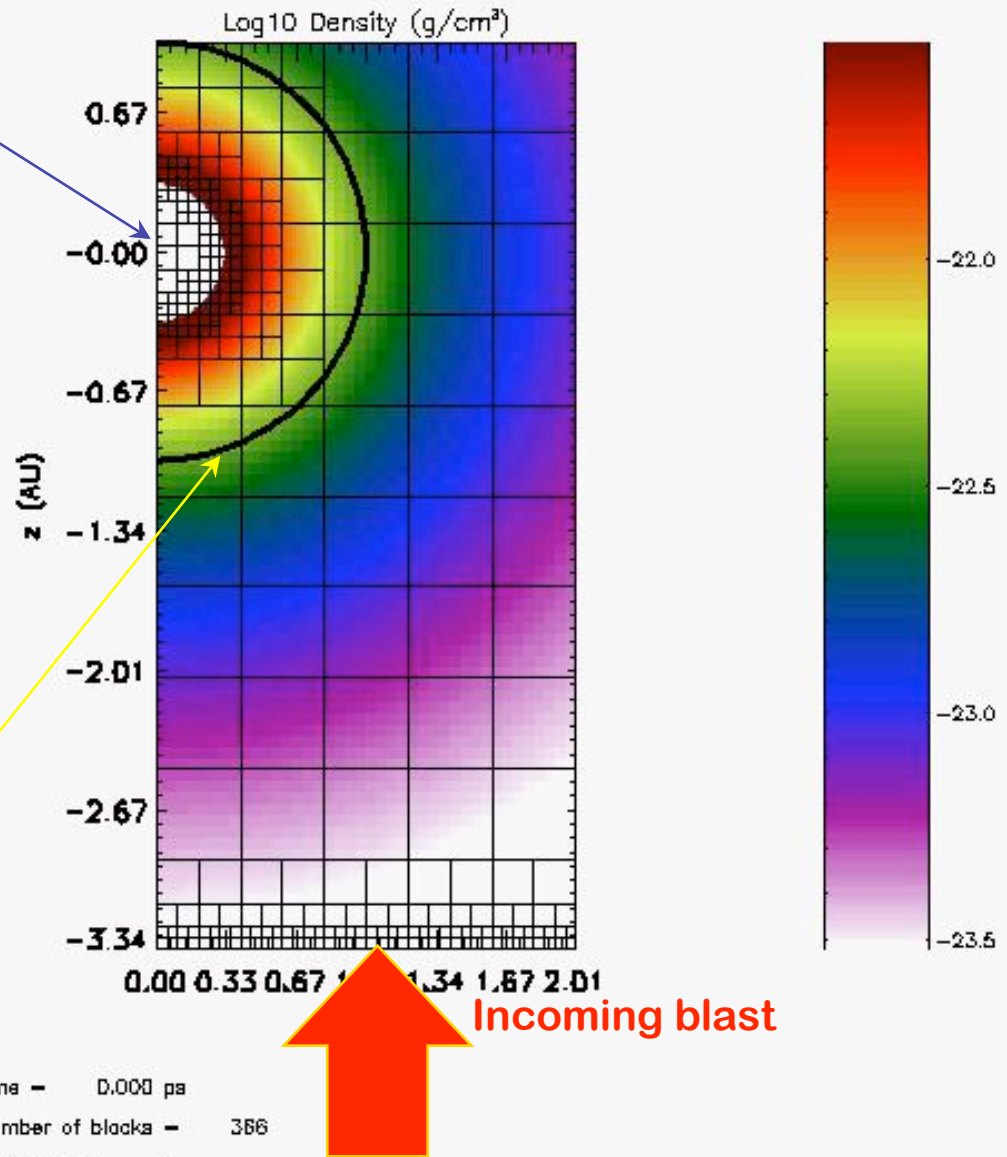

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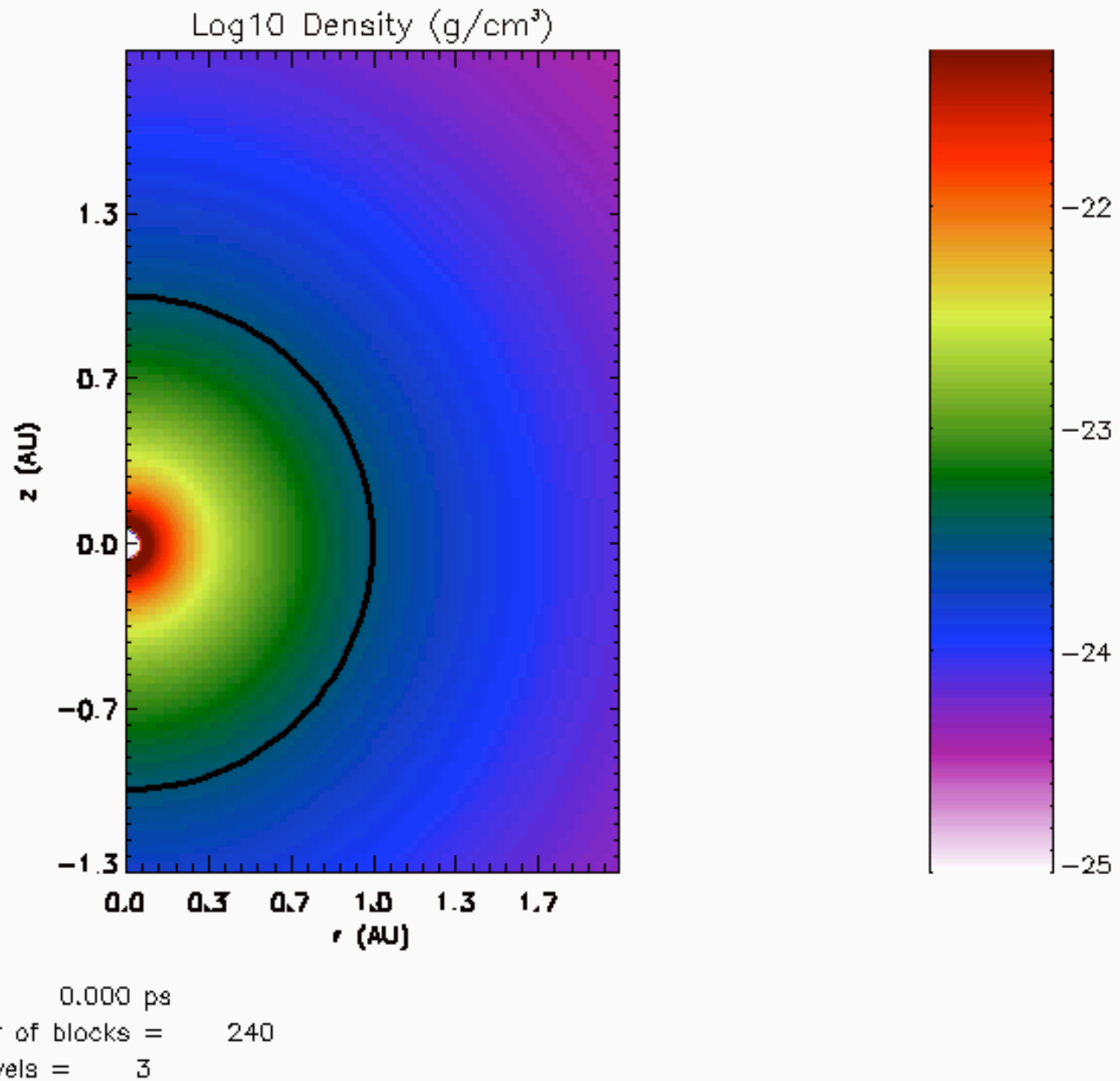

Geological Signatures

Deep Ocean Crust

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Knie et al. (1999,2004)
ferromanganese (FeMn) crust

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growth: ~ 1 mm/Myr

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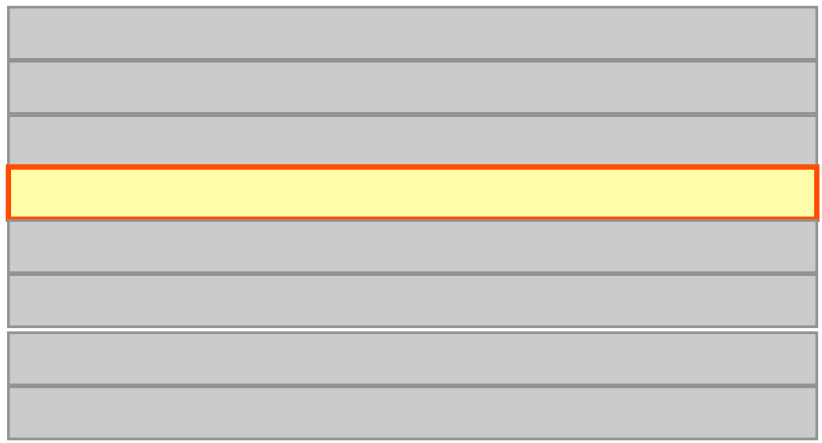

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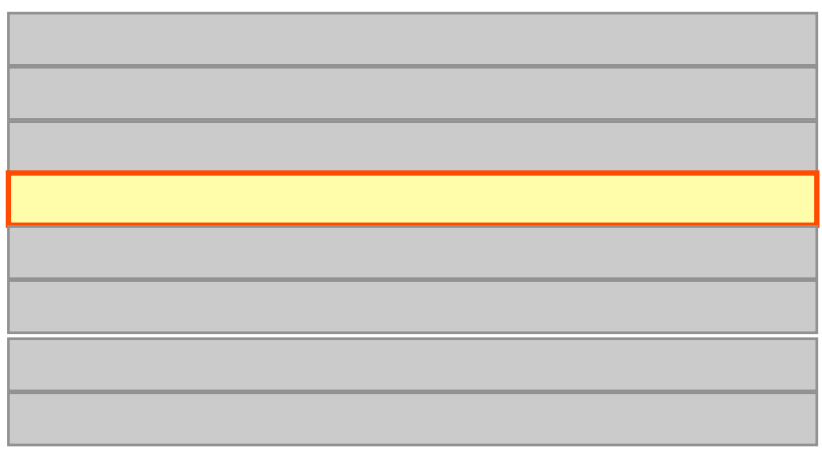

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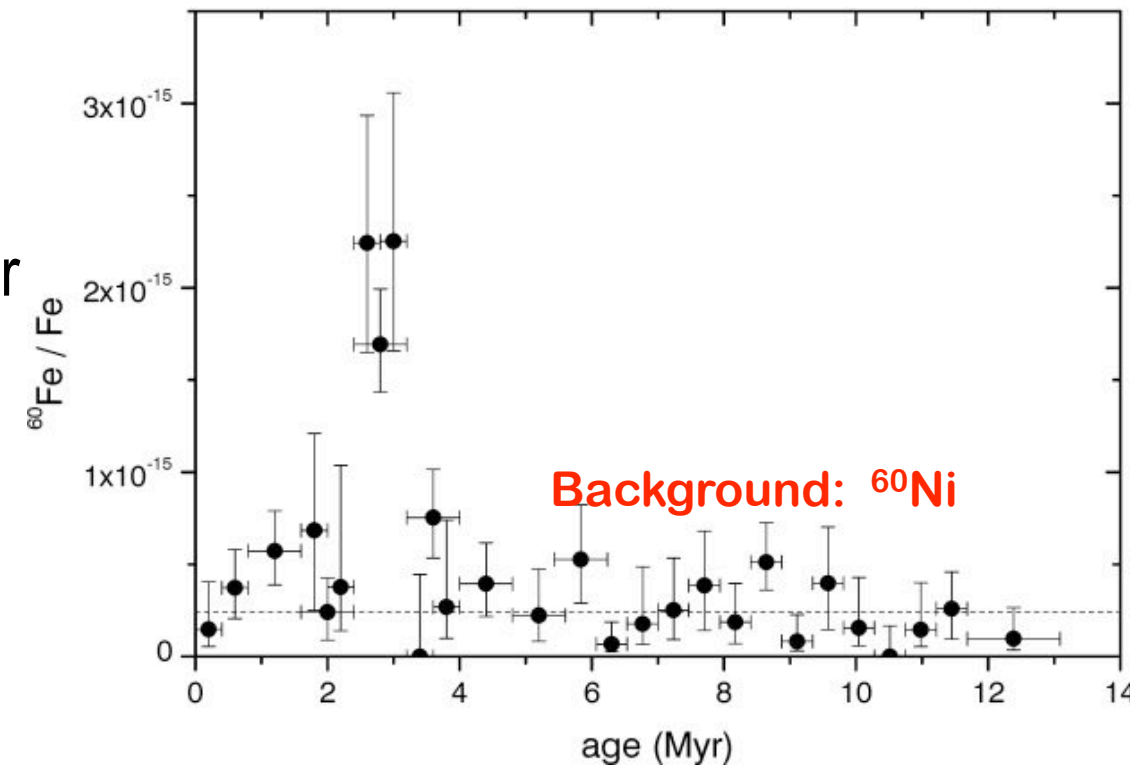

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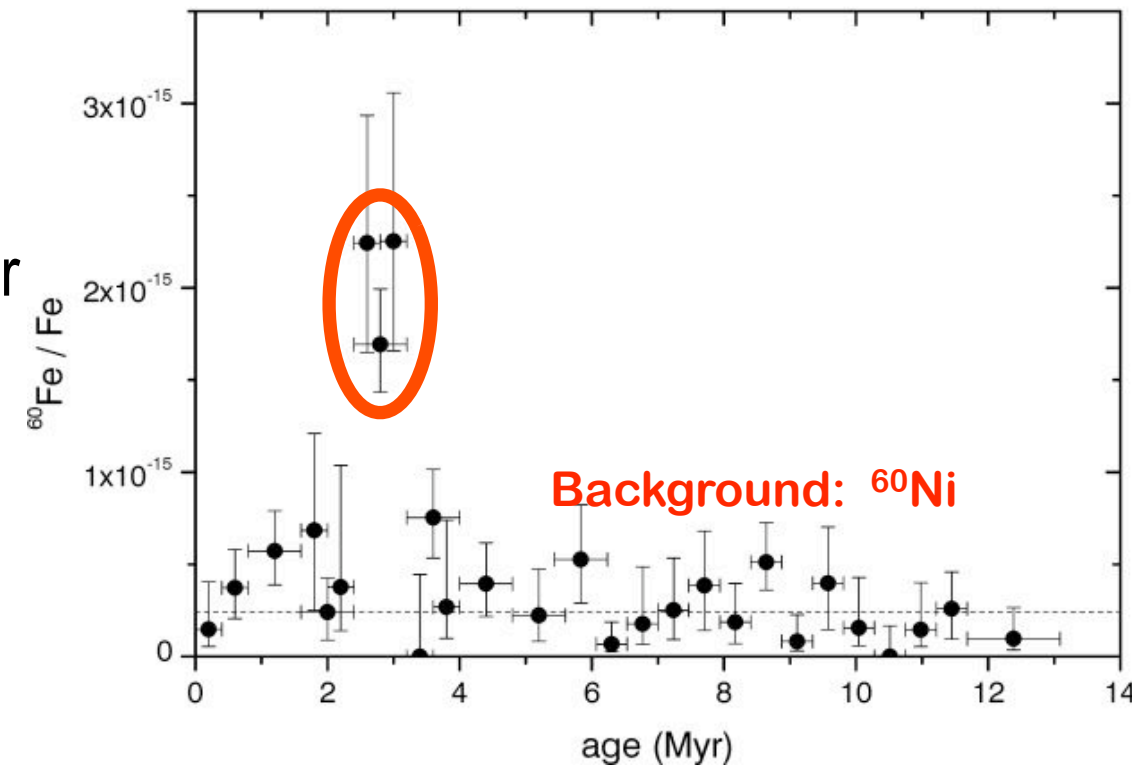

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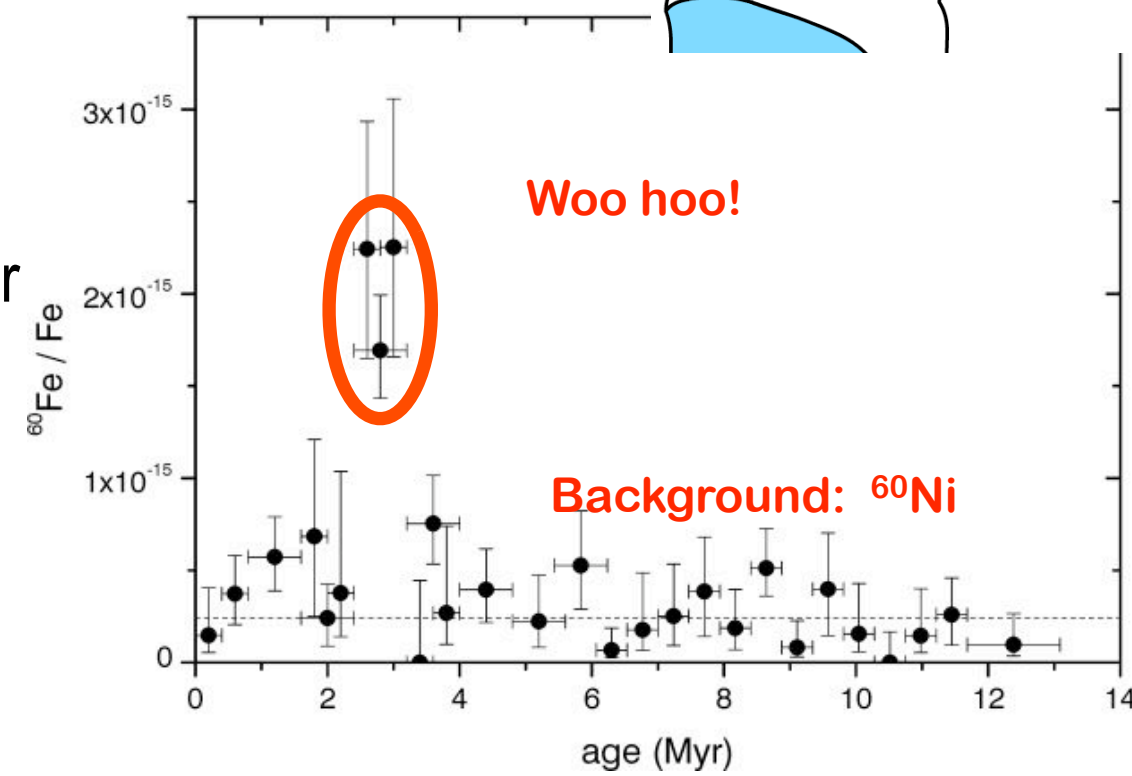

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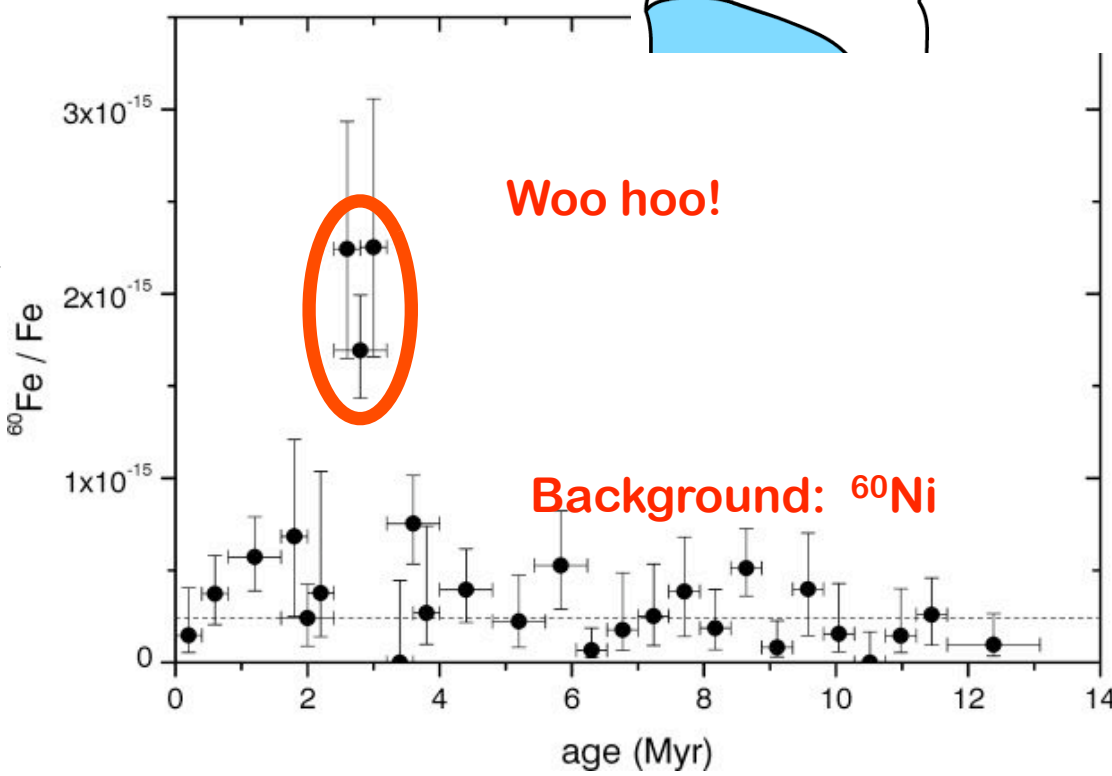
$$t = 2.8 \pm 0.4 \text{ Myr}$$

A Landmark Result

- Isolated pulse identified
- Epoch quantified



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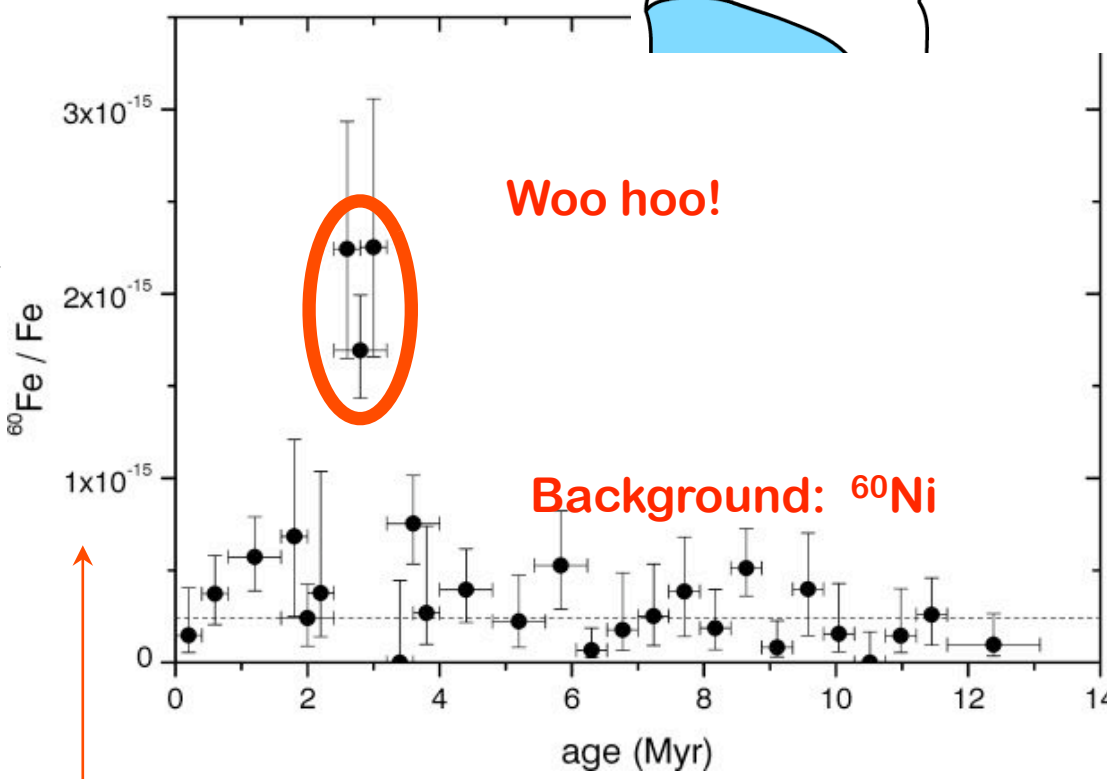

Note fantastic AMS sensitivity!

Implications: SN Distance

Turn the problem around:

$$N_{60,\mathrm{obs}} \sim M_{\mathrm{ej},60} e^{-t/\tau} / d^2$$

$$d \sim \sqrt{\frac{N_{\mathrm{obs}}}{M_{60}(M_{\mathrm{SN}})}}$$

In principle:

- Multiple isotopes ⇨ SN mass

In practice:

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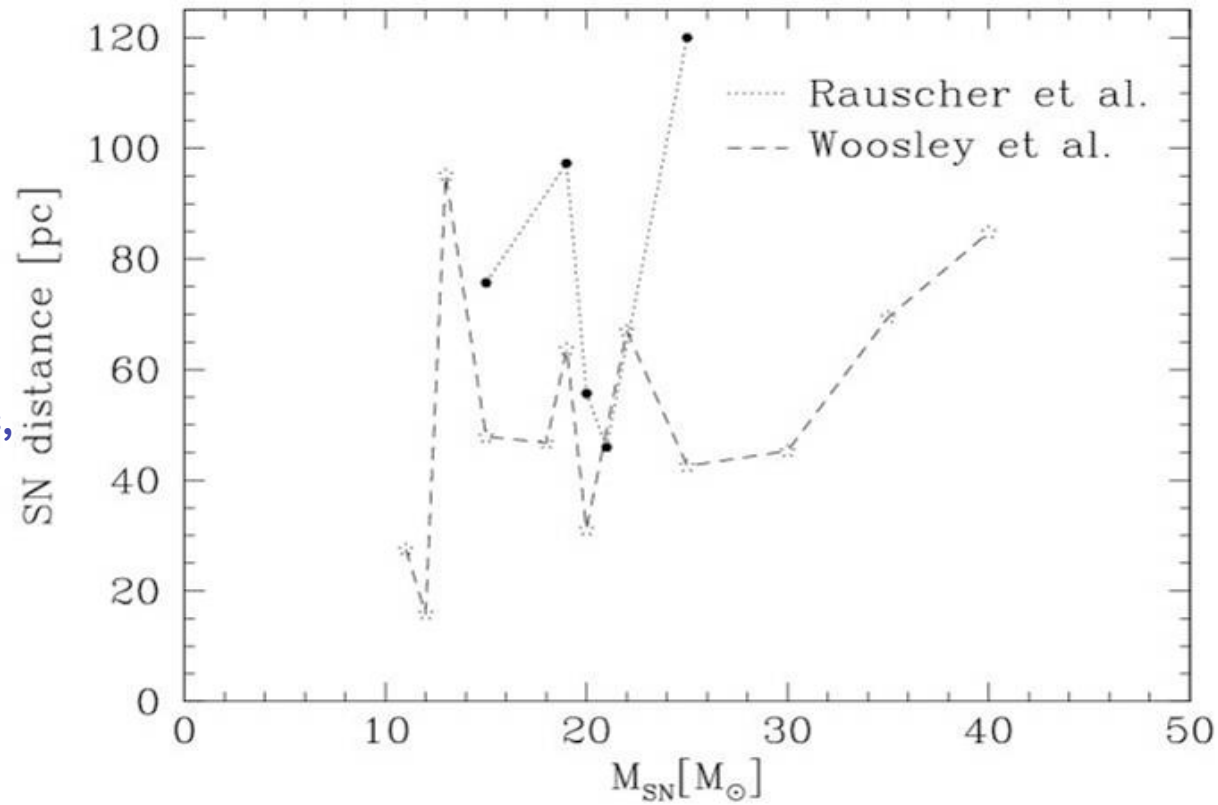
- Need other isotopes

For now

$$d(\mathrm{SN}) \sim 20 - 100 \ \mathrm{pc}$$



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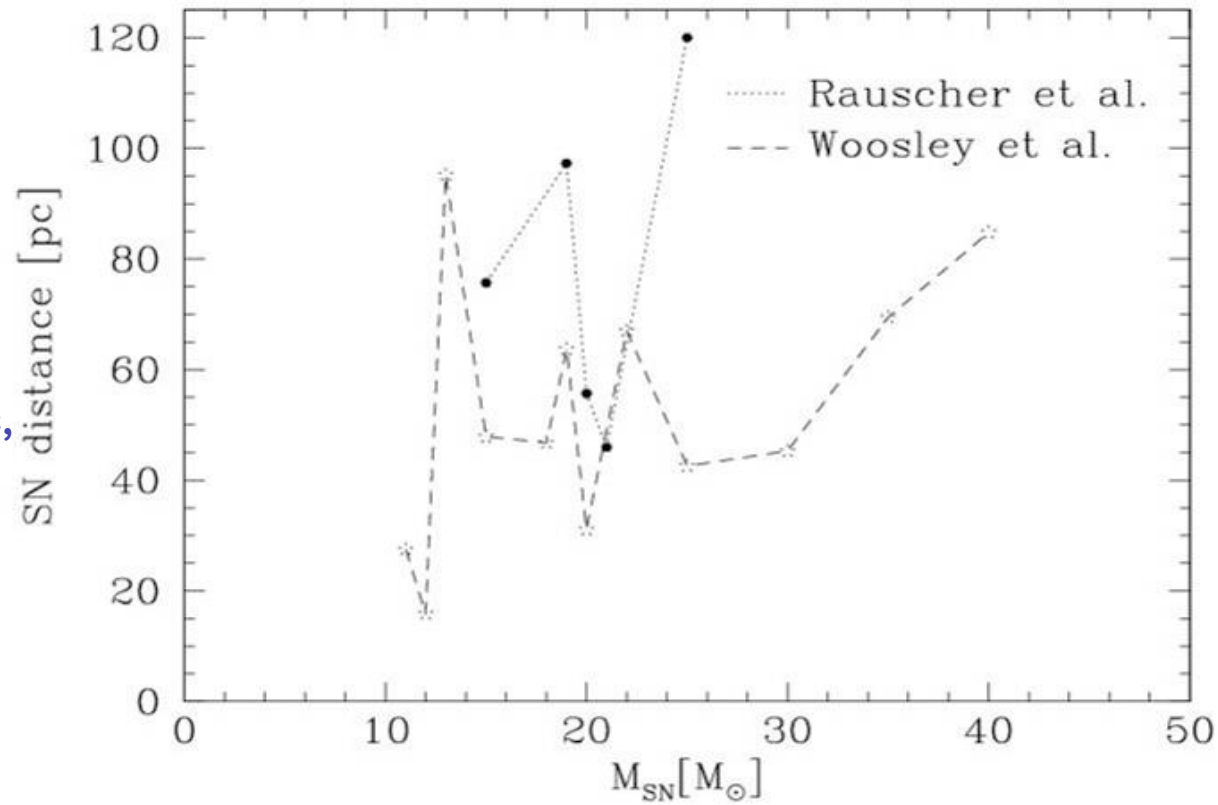

Implications: SN Distance

Turn the problem around:

$$N_{60,\mathrm{obs}} \sim M_{\mathrm{ej},60} e^{-t/\tau} / d^2$$

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- Multiple isotopes ⇨ SN mass

In practice:

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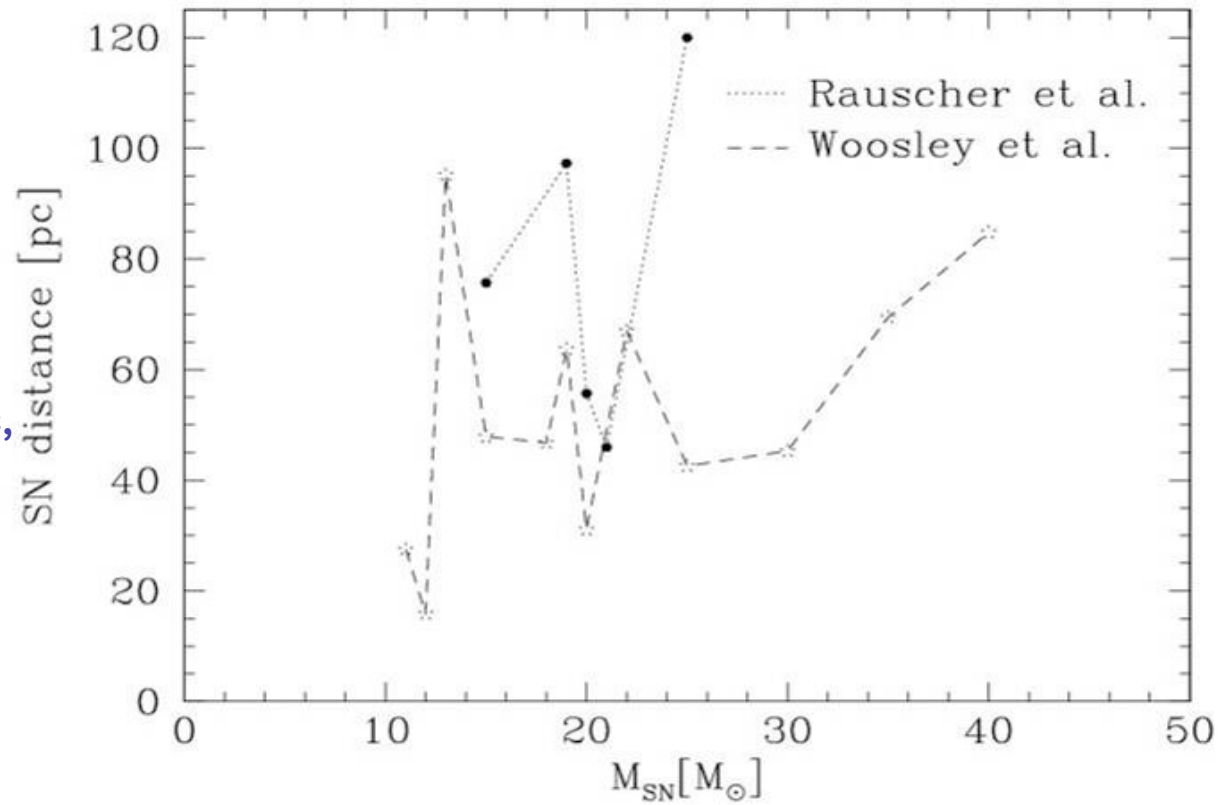

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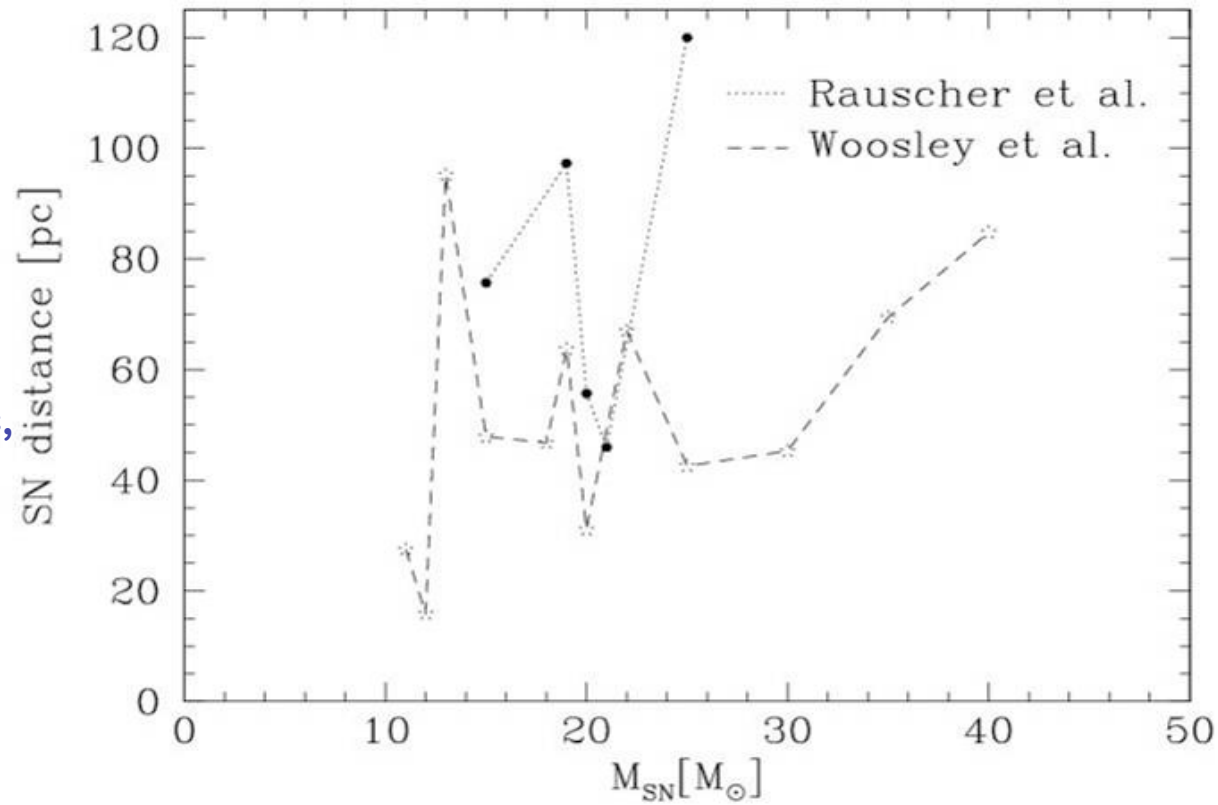

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★astronomical distances not built in!

★ $d(^{60}\mathrm{Fe}) \approx d(\mathrm{SN} \rightarrow \mathrm{Earth}) \approx d_{\mathrm{SN}}(3\ \mathrm{Myr})$

⇨ nontrivial consistency!

Sea Sludge as a Telescope

Given ^{60}Fe:

Other isotopes fixed by SN mass

Indep of SN distance!

$$N_i = \frac{M_{\mathrm{ej},i}(M_{\mathrm{SN}})/A_i}{M_{\mathrm{ej},60}(M_{\mathrm{SN}})/60} N_{60}$$

Probes SN mass, nucleosynthesis

Expect observable signals:

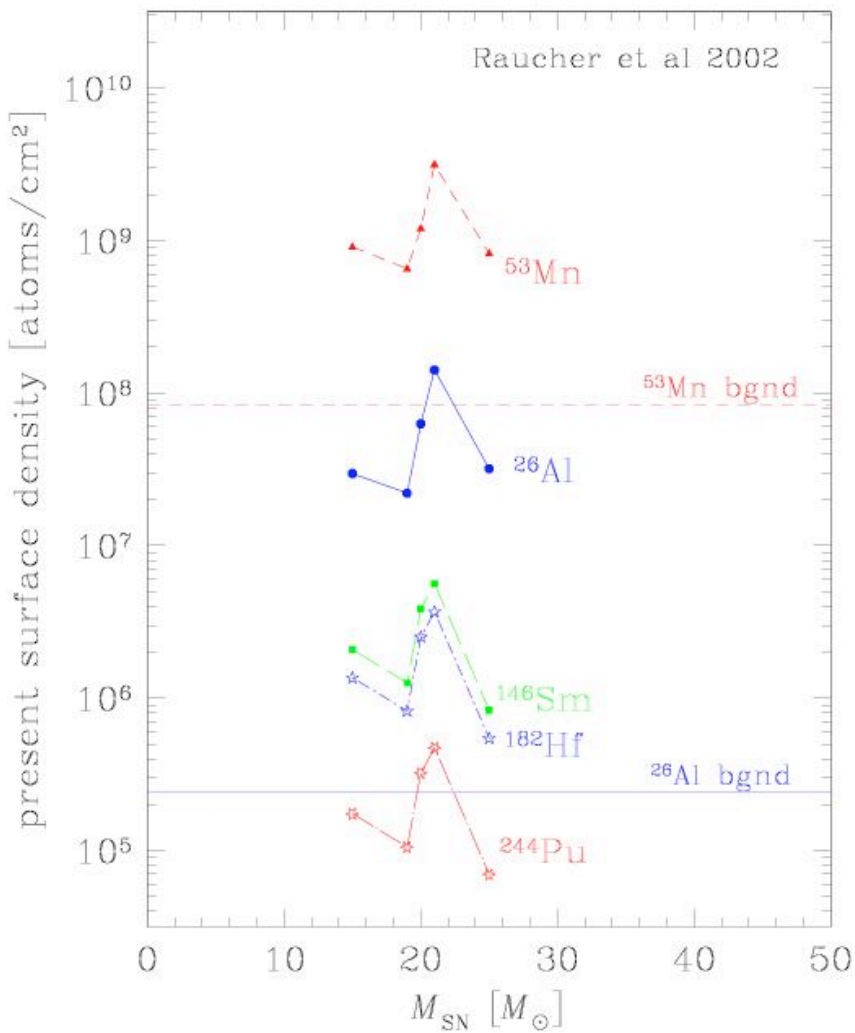
^{10}Be, ^{26}Al, ^{53}Mn

If r-process made:

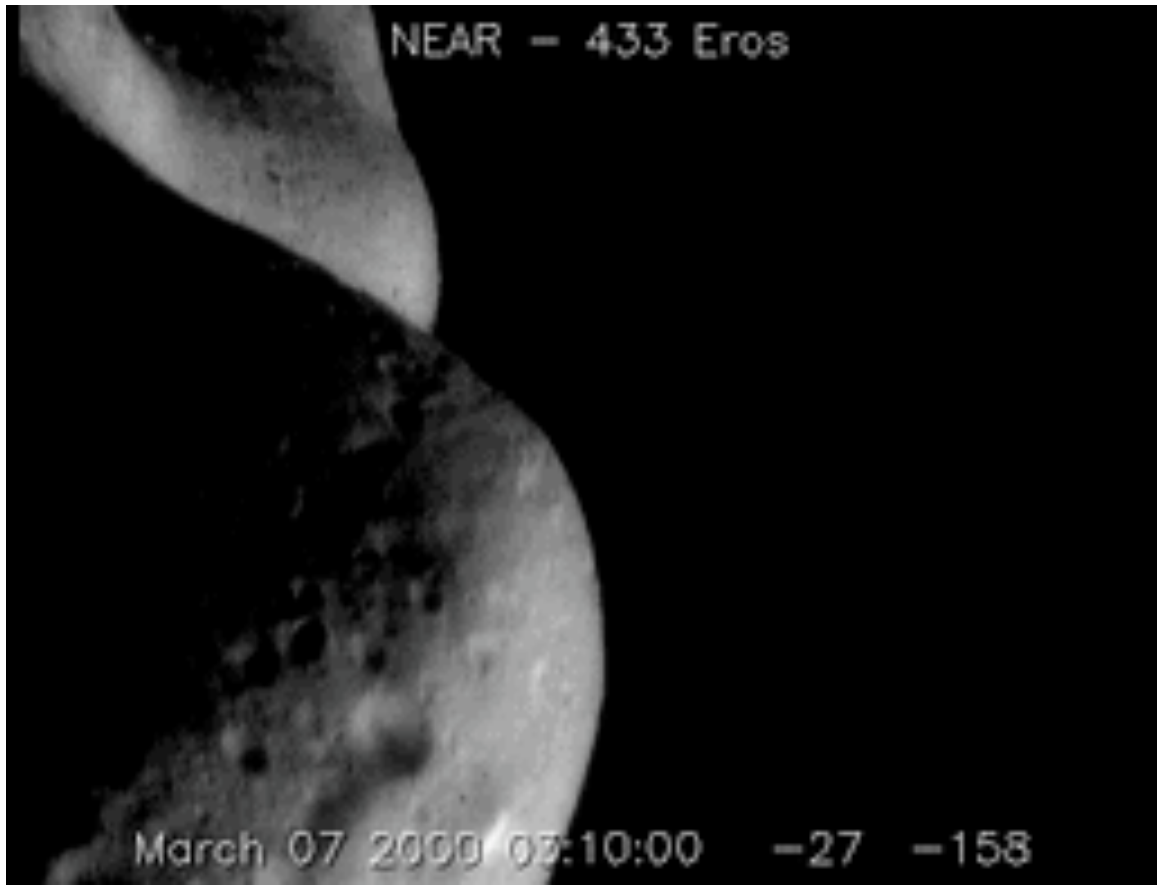
^{182}Hf, ^{244}Pu

Wallner et al 2002: single ^{244}Pu atom(!)

If real: SN are r-process site!



Meteoritic Forensics of the Pre-Solar Supernova



fuggedaboutit

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    - abundance: inverse square law = yardstick

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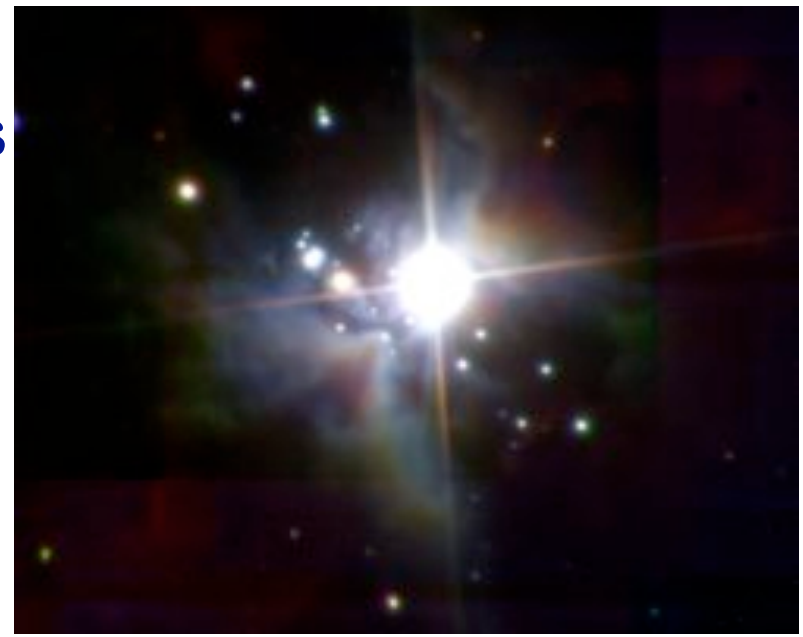

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Live ^{60}Fe seen in several deep-ocean crusts

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JINA and the Future

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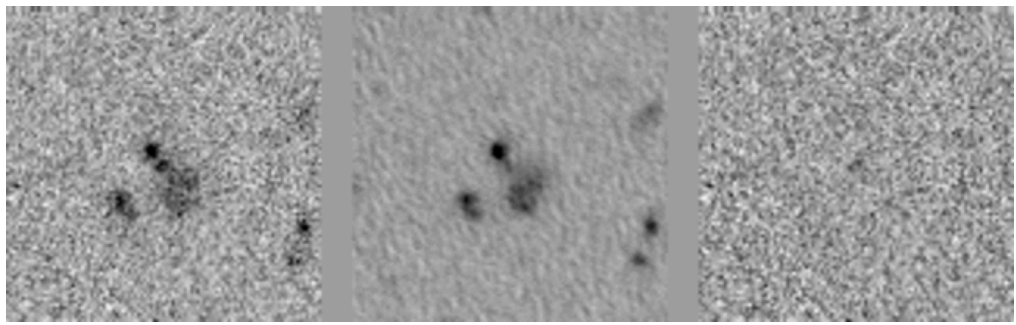
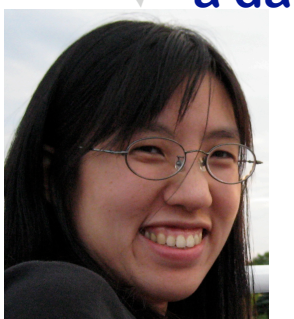
SN Legacy Survey ~4 month scan

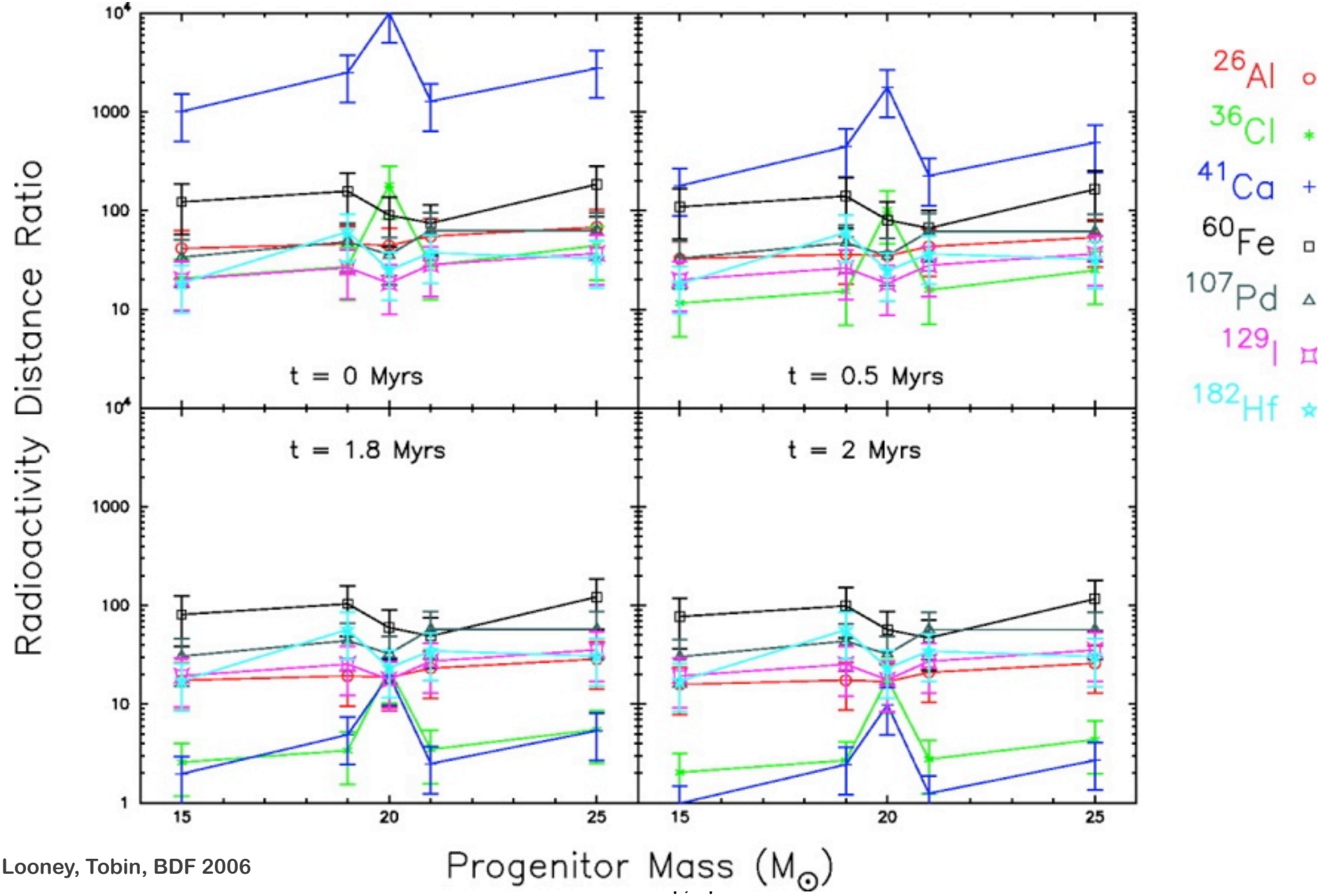


Epoch - Reference = Difference



Amy Lien 連雅琳

Radioactive Supernova Tracking



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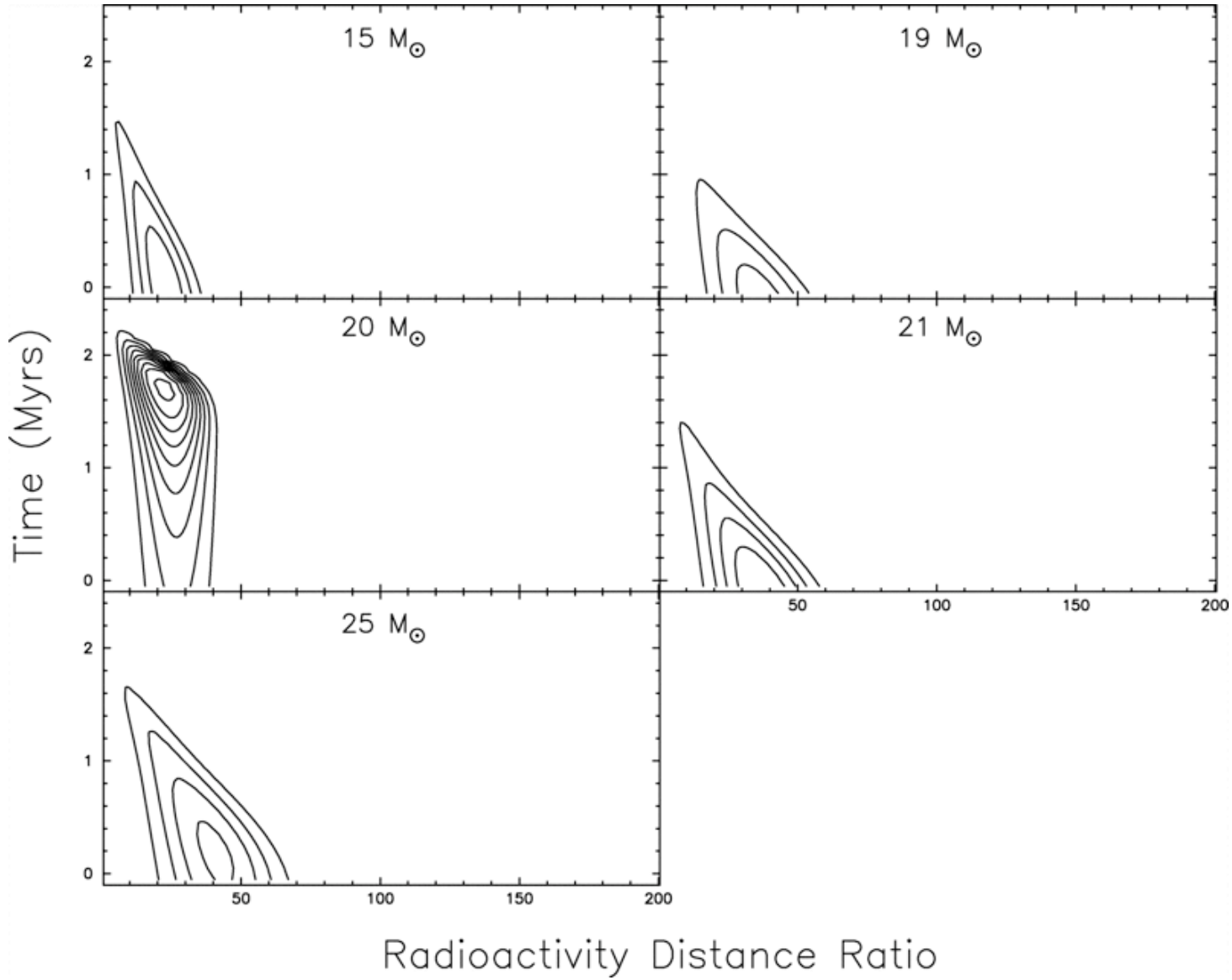

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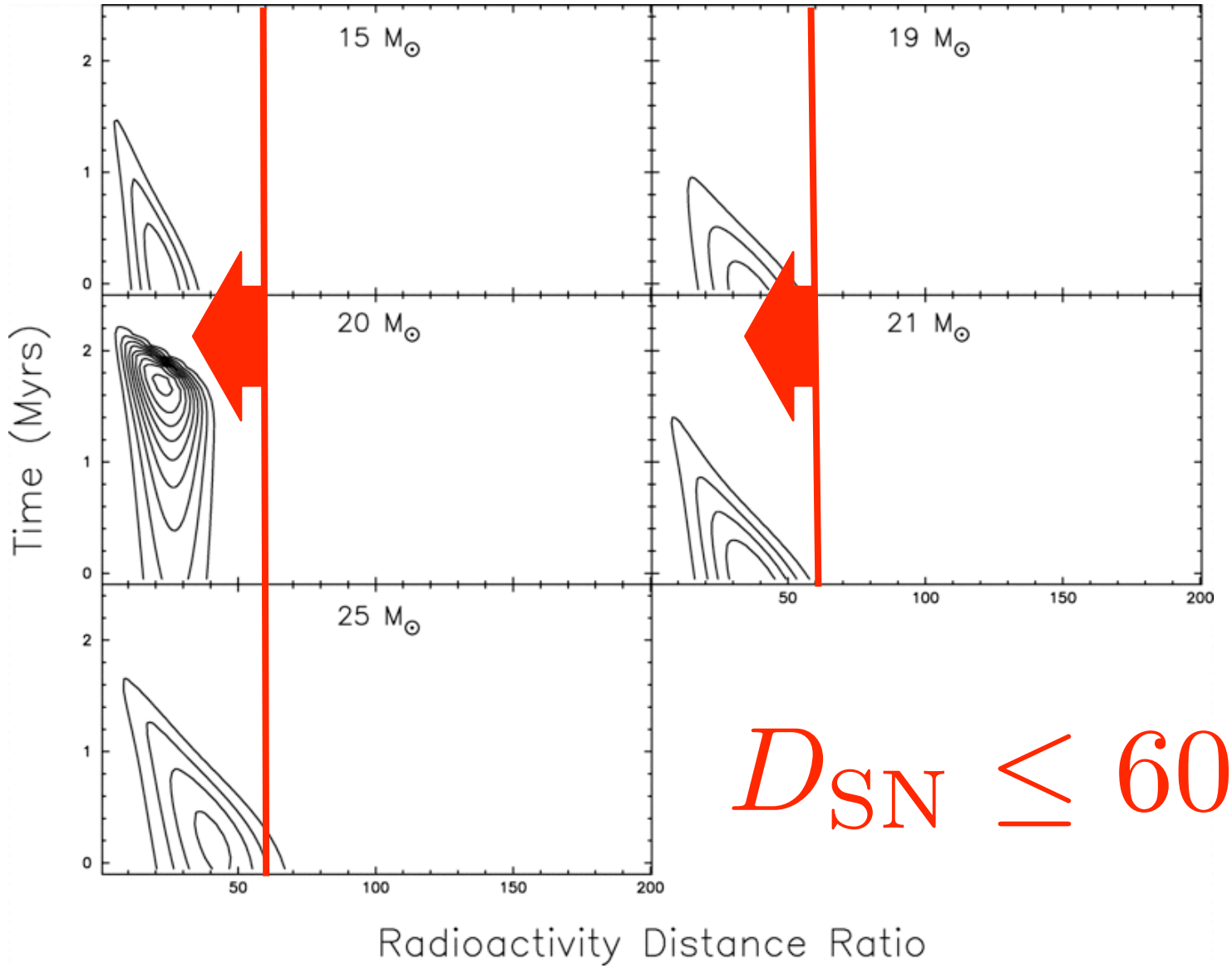

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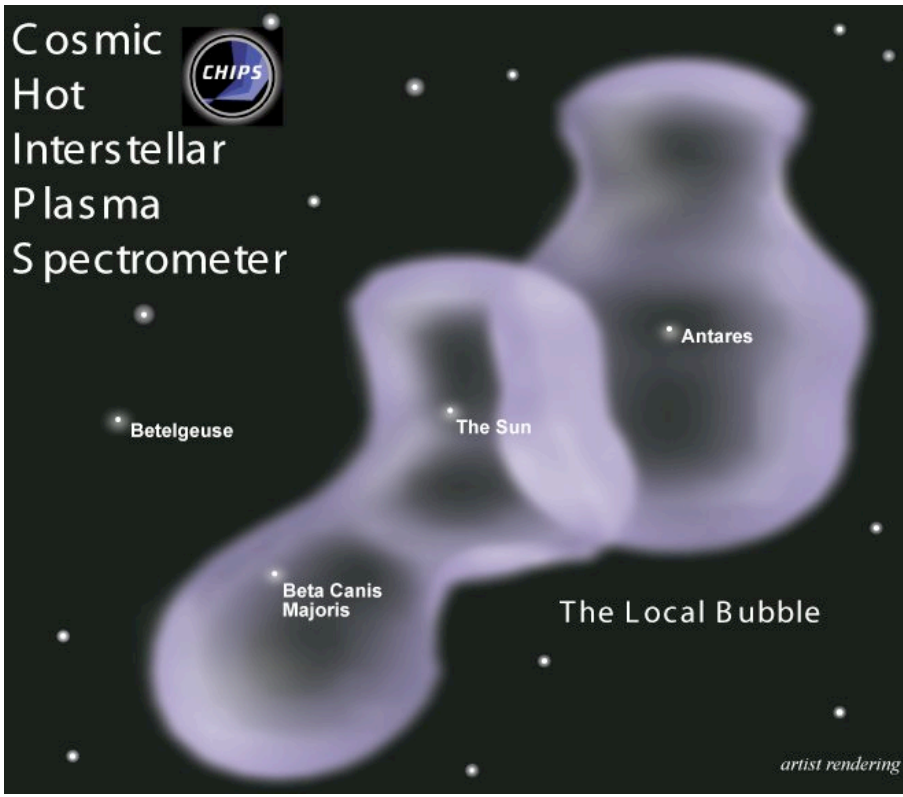
For today:

- **Take seriously possibility of SN ejecta** ➡ **Earth**
- **Look for observable consequence**

Aftermath: The Local Bubble?

- ★ The Sun lives in region of hot, rarefied gas



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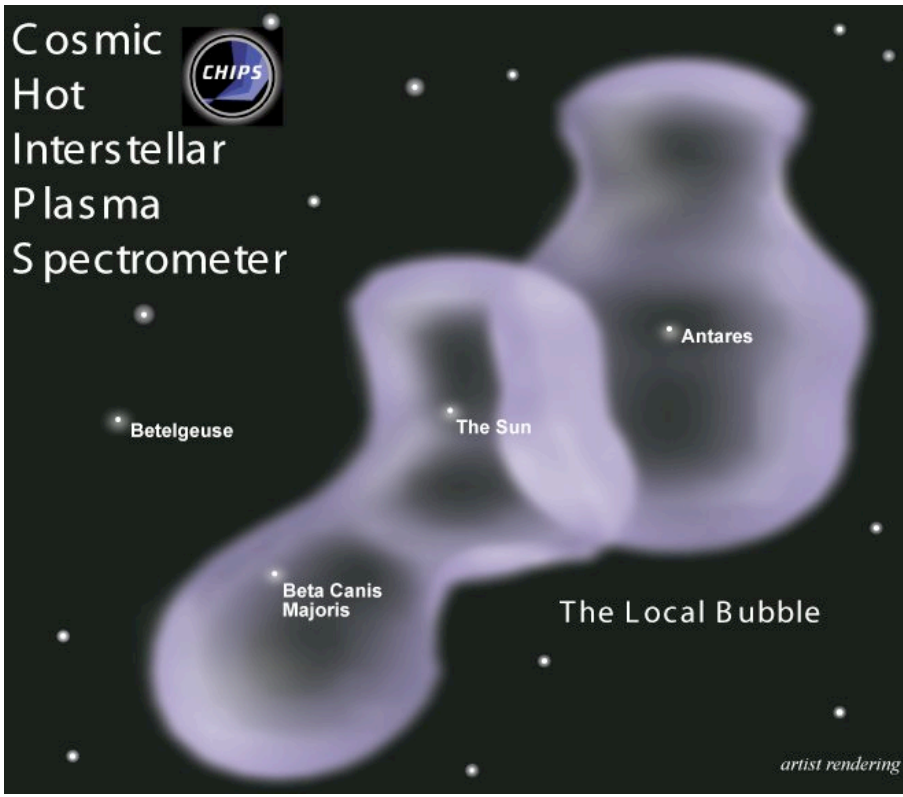

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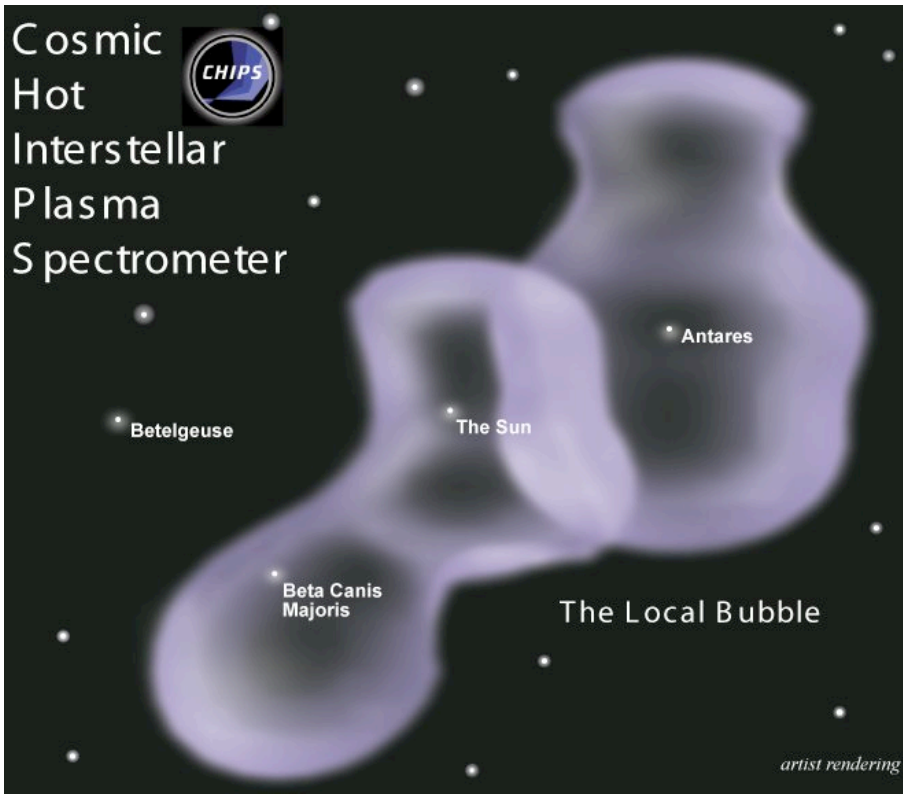
- ★ **Nearby SN needed**
  - we live inside SN remains
  - bubble models require >> 1 SN in past 10 Myr Smith & Cox 01
  - ^{60}Fe event from nearest massive star cluster? Benitez et al 00



A Near Miss?

$d > d_{\text{kill}} \sim 10$ pc ...but barely:
"near miss"

- ¿ cosmic ray winter?
- ¿ bump in extinctions?

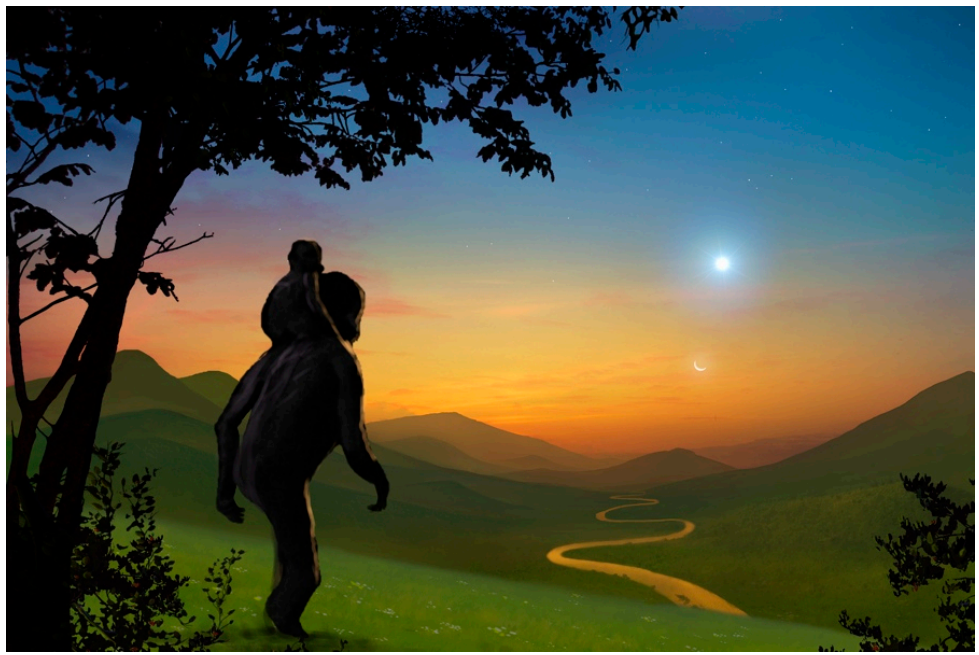


Image: Mark Garlick
www.markgarlick.com

If true:
implications for astrobiology
tightens Galactic habitable zone

Debris Delivery via Dust

Athanassiadou & BDF 08

What if $d_{\rm SN} > 10$ pc ⇨ $r_{\rm shock} > 1$ AU **?**

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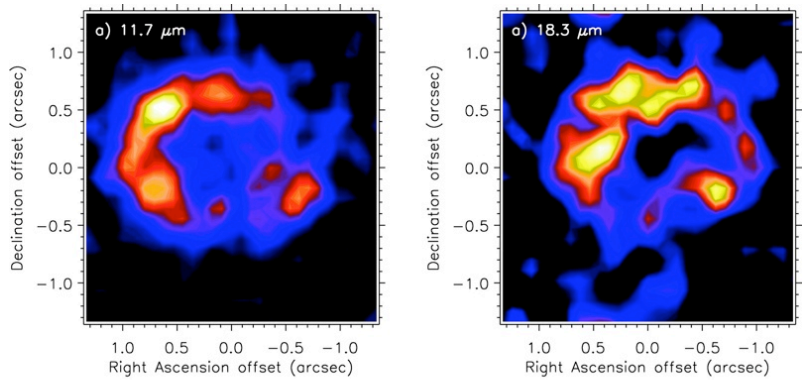

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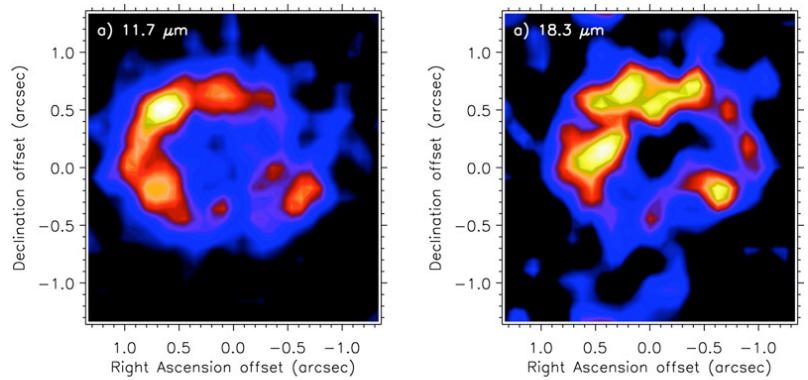
SN dust penetrates to 1 AU even if gas does not

- for $v_{\rm dust} > 100$ km s$^{-1} \gg v_{\rm esc}$ nearly ballistic trajectory
- radioisotope delivery efficiency set by dust survival fraction



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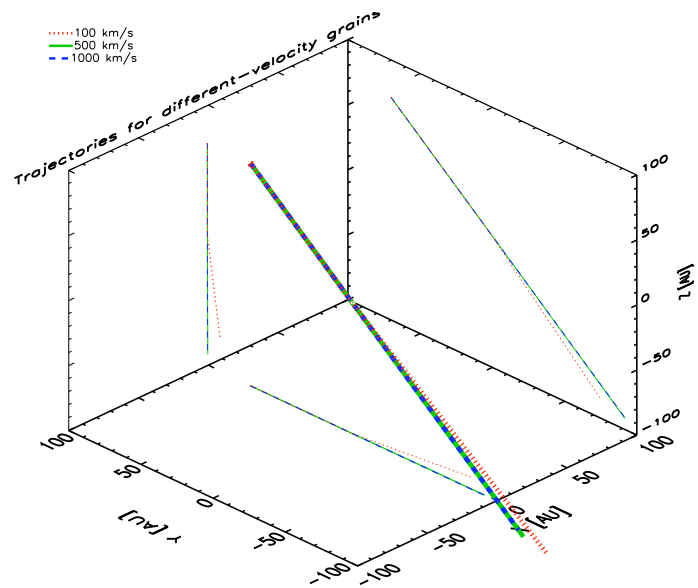

Terrestrial Signatures of Nearby SNe

Ellis, BDF, Schramm 96

Observables

- Signature: Isotope Anomalies
- Medium: Gelogical Sediments “Natural Archives”
  - Ice Cores
  - Sea Sediments
- Measure: Specific concentration

$$\frac{n_i}{\rho_{\rm sed}} \sim \frac{M_{{\rm SNeject},i}/d^2}{({\rm sed\ rate})\Delta t_{\rm dep}}$$

$$= 5\times 10^7\ {\rm atoms\ g^{-1}} \left(\frac{X_{ej,i}}{10^{-5}}\right)\left(\frac{1\ {\rm kyr}}{\Delta t_{\rm dep}}\right)\left(\frac{10\ {\rm pc}}{d}\right)^2$$

The Future:
Supernova Tsunami

Lien & BDF

- By LSST: **~1,000,000 core-collapse events** *each year!*
- Cosmic Supernova Rate by ***direct counting***
  - rate measured to 10% out to **z~1**
    - tradeoff: redshift range (scan depth) vs SN counts (sky coverage)
  - largest uncertainty: dust obscuration
- ***Core-collapse come for free!***
  - survey characteristics tuned to SN Ia
  - automatically well-suited for SN II