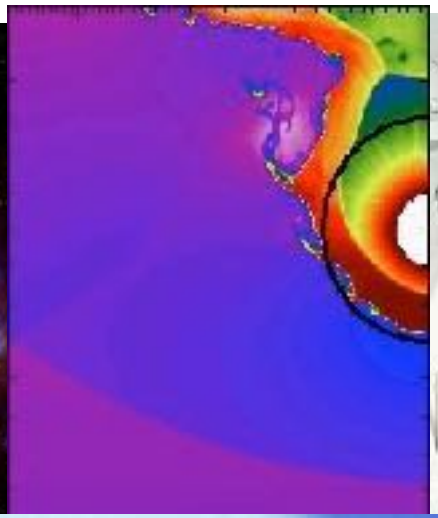
When Stars Attack!

Confirmation, Identification, and Localization of a Recent Near-Earth Supernova

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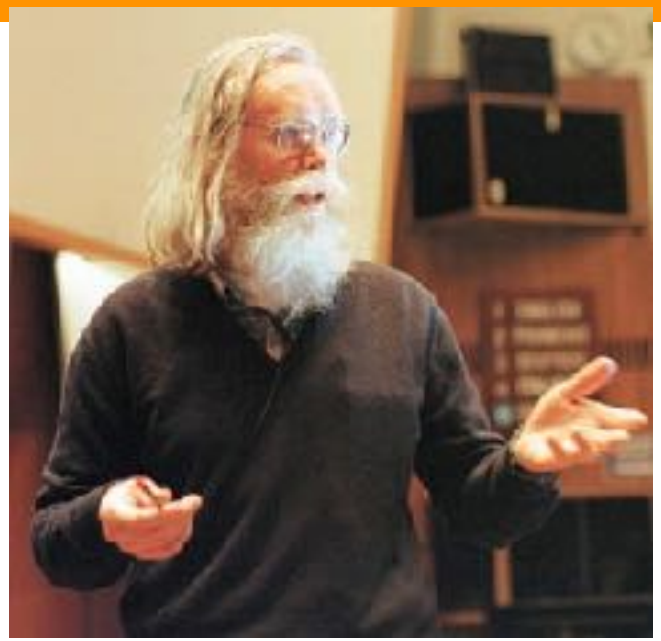
Team Nearby Supernova



John Ellis

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Kathrin Hochmuth

Scott Johnson

Themis Athanassiadou

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Conclusions

Supernovae are Radioactivity Factories

particularly core collapse

Nearby Supernovae are Inevitable

a unique laboratory…and a unique threat

The Smoking Gun

supernova radioactivities on Earth

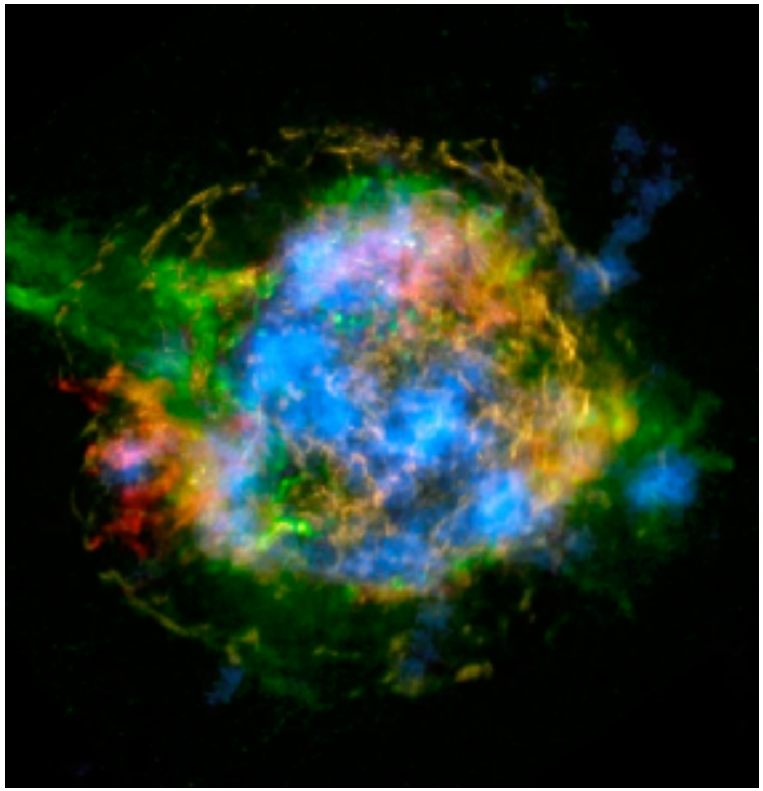
Widespread Evidence! Live ^{60}Fe

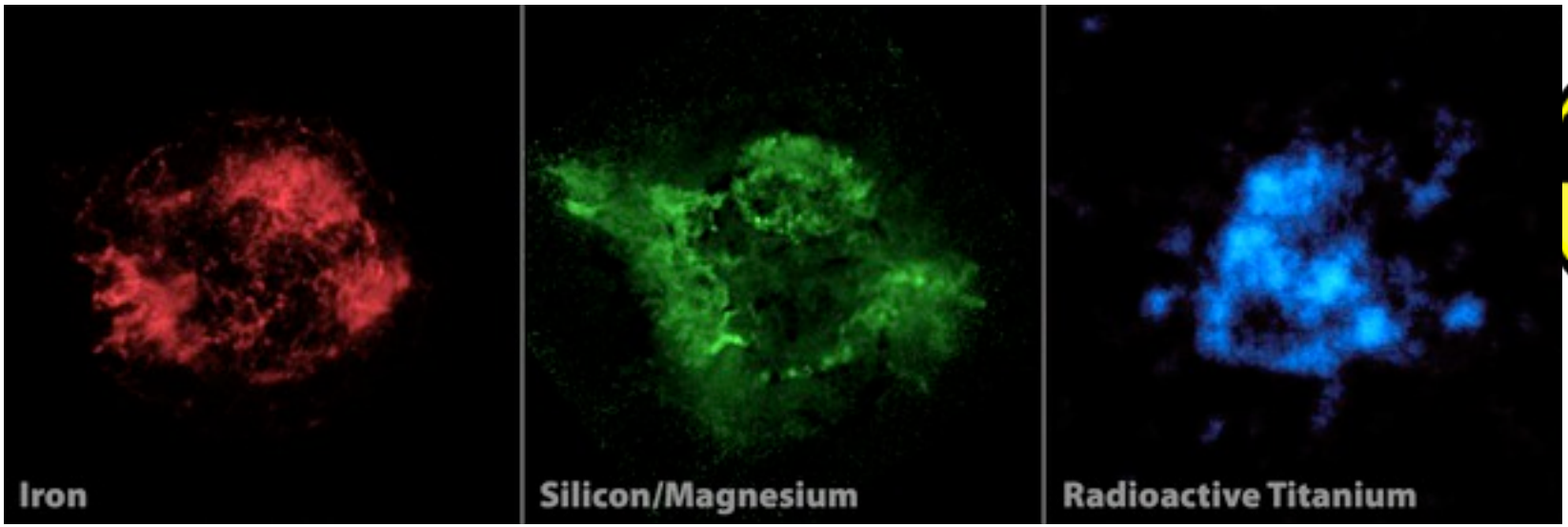
sea sediments and lunar cores as telescopes

Supernovae are Radioactivity Factories

Cas A: ~300 yr

Chandra & NuSTAR

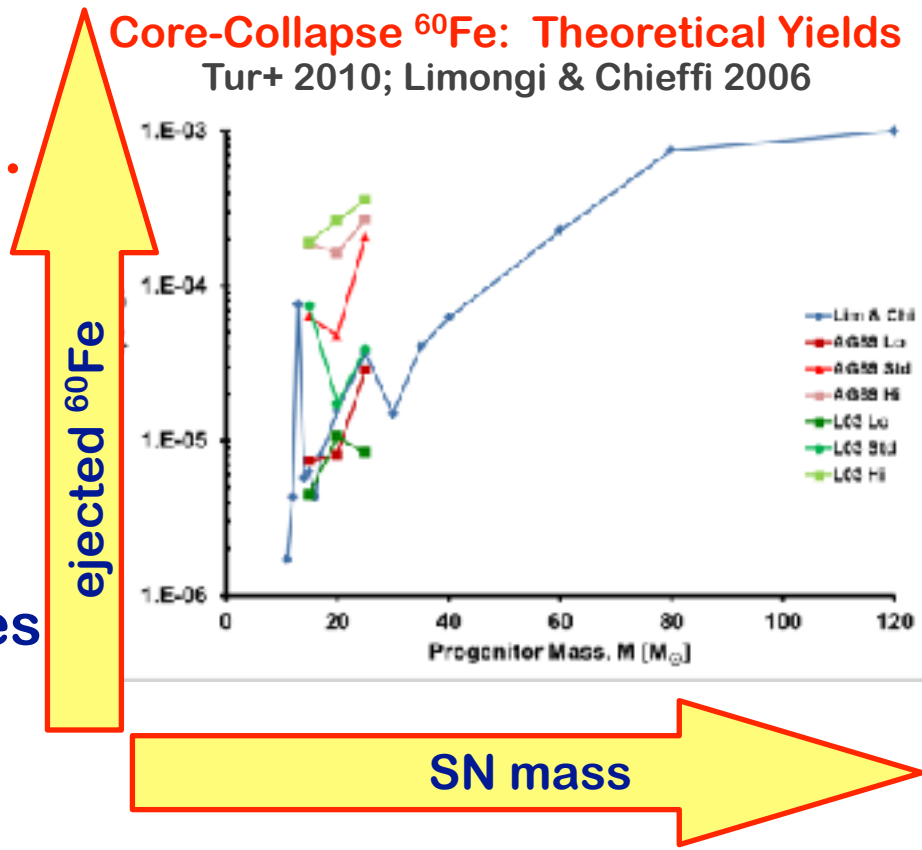




Supernova Radionucleosynthesis

Limongi, Hirschi, Martinez-Pinedo talks

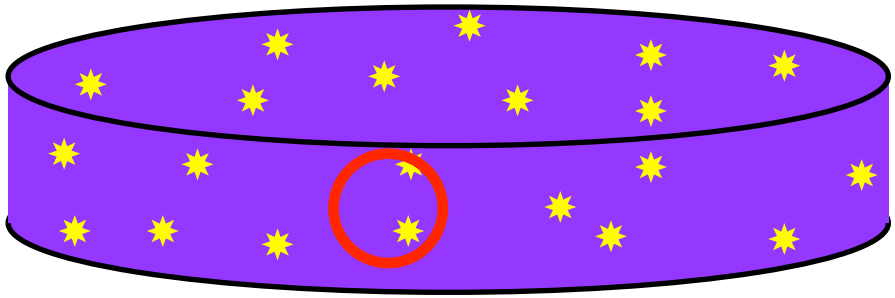
- long-ish lived radioactivities:
  ^{60}Fe, ^{26}Al, ^{41}Ca, ^{53}Mn, Tc, ^{146}Sm, …
- ^{60}Fe: made by neutron captures
  - "weak s-process"
    $$^{59}\mathrm{Fe}(n,\gamma)^{60}\mathrm{Fe}$$
  - large theoretical uncertainties in yield
  - sensitive to stellar evolution, nuke rates
  - accuracy ~order of magnitude
- r-process? ^{182}Hf, ^{244}Pu



Nearby SNe are Inevitable

Shklovskii 1968; BDF 2004

Rate of supernovae inside r



$$\text{SN Rate}(< r) \sim (10\ \text{Myr})^{-1} \left(\frac{r}{30\text{pc}} \right)^3$$

➡ multiple events < few pc in the last 4.5 Gyr!

Nachbarsternsupernovaexplosionsgefahr

or

Attack of the Death Star!

Brian Fields | NPA8@Catania

Nachbarsternsupernovaexplosionsgefahr

or

Attack of the Death Star!

Ill efects if a supernova too close

possible source of mass extinction

- Shklovskii; Russell & Tucker 71; Ruderman 74; Melott group

Ionizing radiation

- initial gamma, X, UV rays destroy stratospheric ozone

  Ruderman 74; Ellis & Schramm 94

- solar UV kills bottom of food chain

  Crutzen & Bruhl 96; Gehrels etal 03;

  Melott & Thomas groups; Smith, Sclao, & Wheeler 04

- cosmic rays arrive with blast, double whammy
- ionization damage, muon radiation

Neutrinos

- neutrino-nucleon elastic scatteri

  "linear energy transfer"

  ⇨ DNA damage

02

Nearby Supernovae Rain Ejecta on Earth

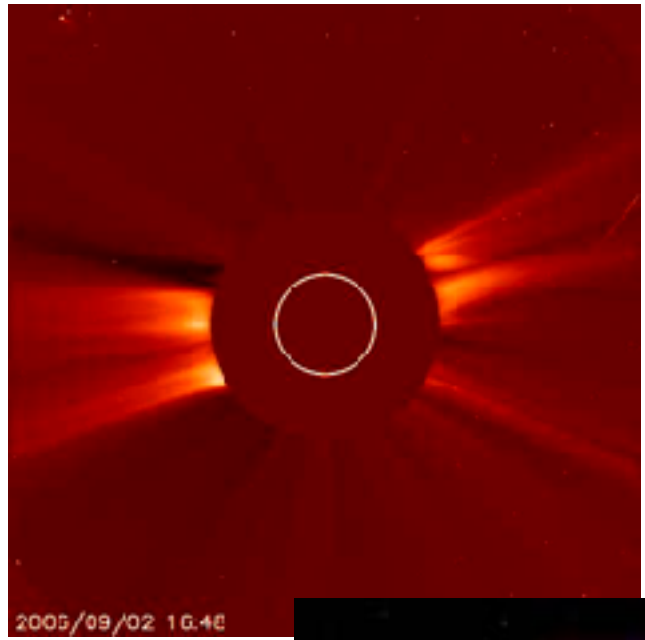
Ellis, BDF, & Schramm 1996; BDF, Athanassiadou, & Johnson 2008; Fry, BDF, Ellis 2015

SN eject plows thru interstellar matter

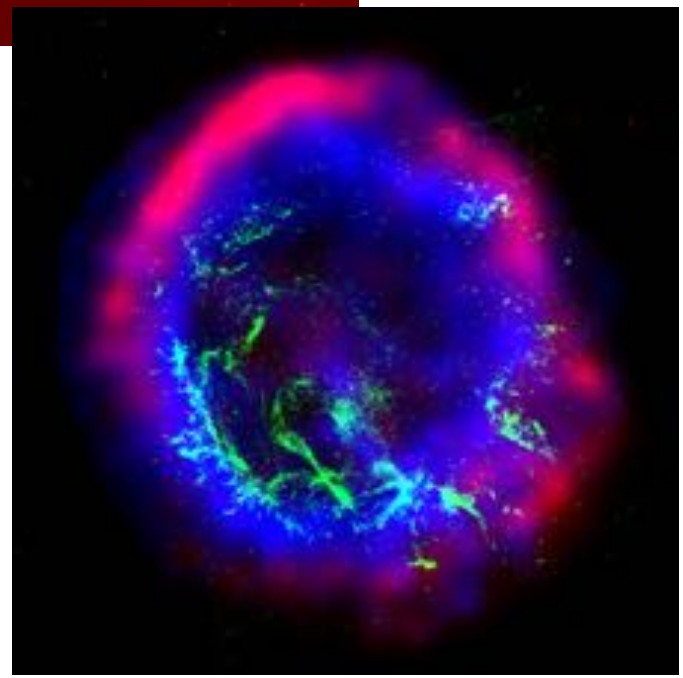
Earth shielded by solar wind

If blast close enough:

- plasma pushes to inner Solar System
- dust decouples, rains on Earth
- SN dust accumulates in deep ocean



SOHO



Chandra

Supernova Blast Impact on the Solar System

BDF, Athanassiadou, & Johnson 2006

Simulation:

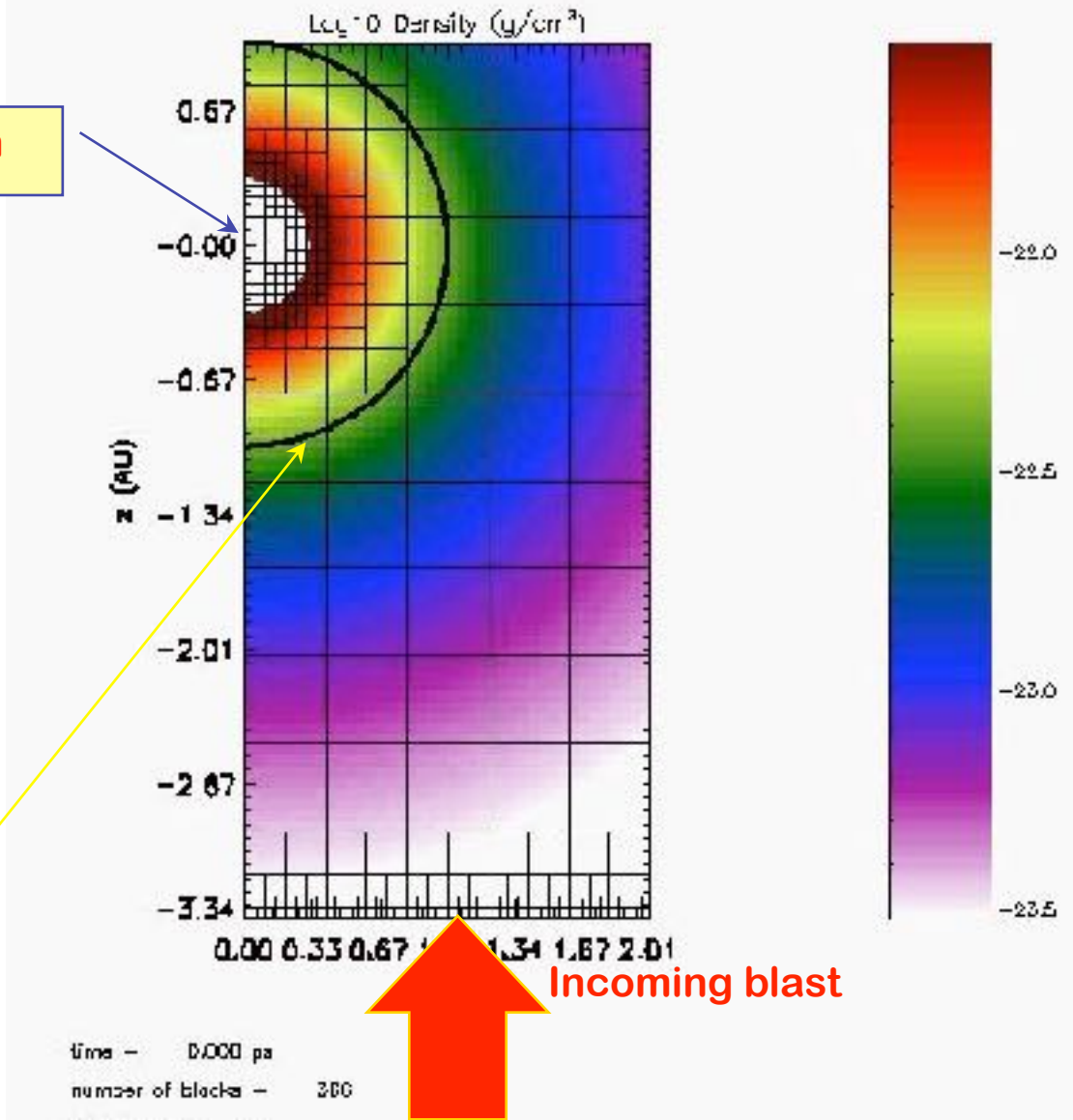
FLASH Fryxell et al 2000

Blast Properties:

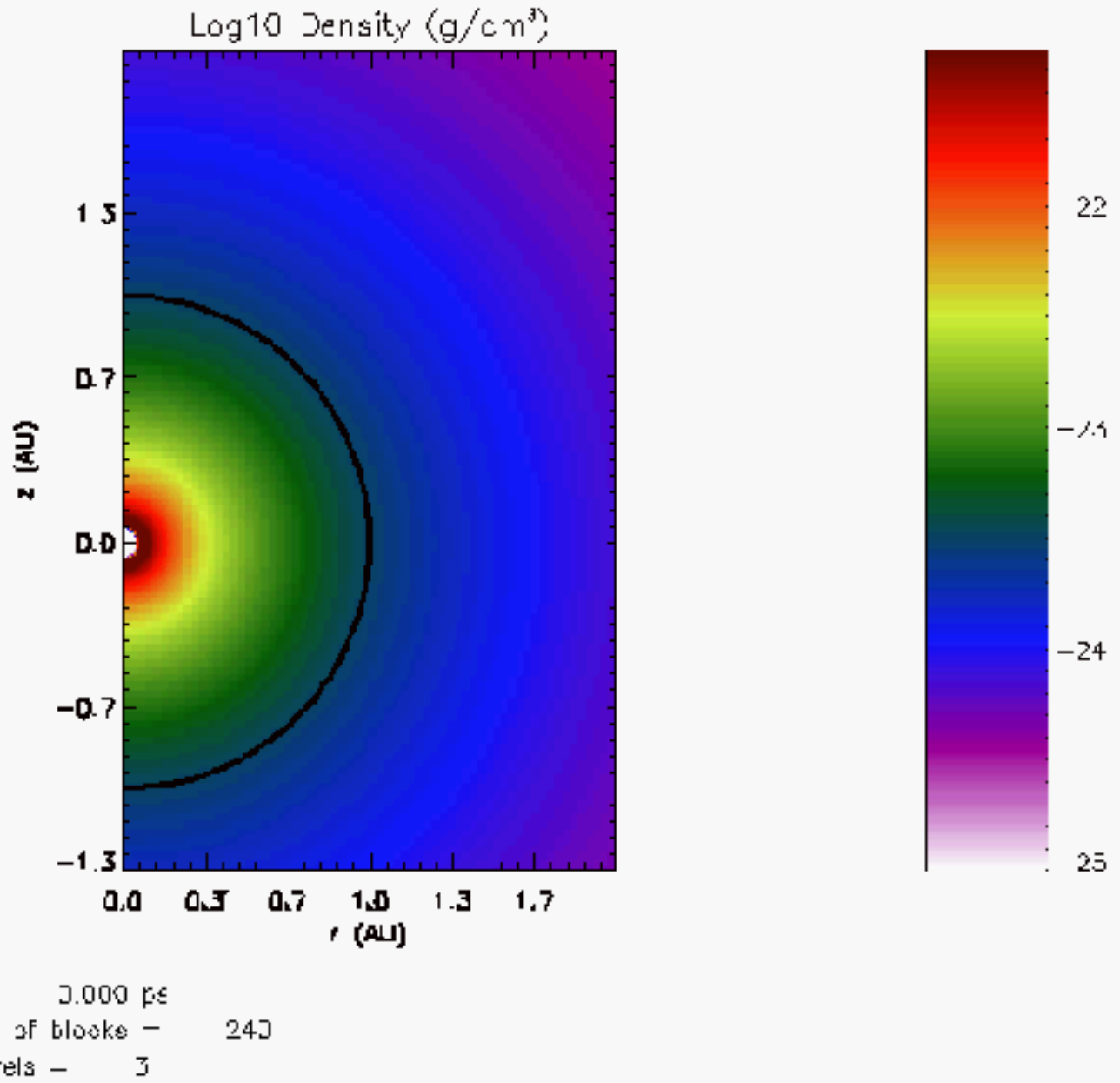
SN at 10 pc

Geometry:

Cylindrical



BDF, Athanassiadou, & Johnson 2008



The Smoking Gun: Radioactivity

Ellis, BDF, & Schramm 1996; BDF, Athanassiadou, & Johnson 2008; Fry, BDF, Ellis 2015

Q: How would we know?

Need observable SN "fingerprint"

⟹ Nuclear Signature

★Stable nuclides: don't know came from SN

★Live radioactive isotopes: none left on Earth

If found, must come from SN!

^{60}Fe $t_{1/2} = 2.6$ Myr

also, e.g., ^{26}Al, ^{97}Tc, ^{244}Pu?

Geological Signatures

Radioactivity Detection: ^{60}Fe

Knie et al (2004)

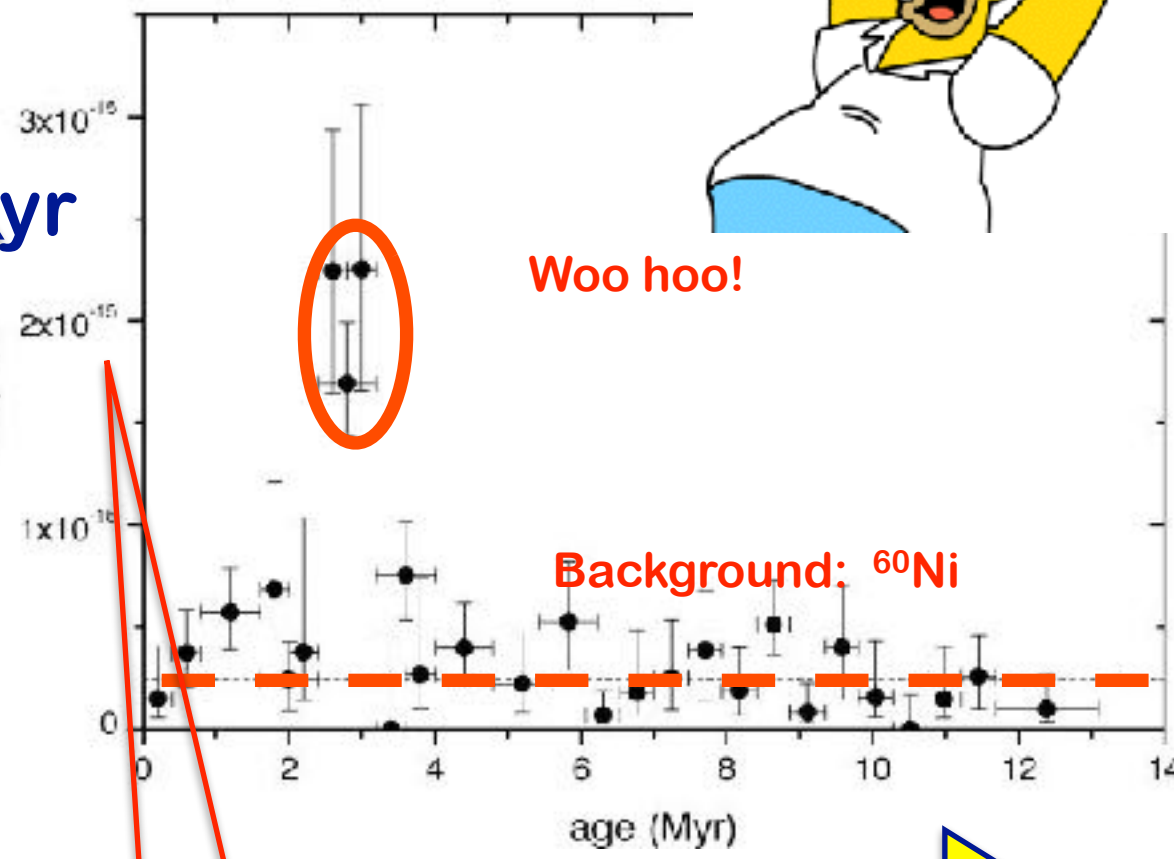
Ferromanganese crust

Pacific Ocean

- ✓ slow growth ~ 1 [illegible]yr
- ✓ accelerator mass spectrometry: live ^{60}Fe!

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

^{60}Fe abundance



Woo hoo!

Background: ^{60}Ni

time before present [Myr]

Note AMS sensitivity!

Whodunit?

Fry, BDF, & Ellis 2015

Turn the problem around:

$$N_{60,\mathrm{obs}} \sim \frac{M_{60,\mathrm{eject}}}{D^2}$$

$$D \sim \sqrt{M_{60,\mathrm{eject}} / N_{60,\mathrm{obs}}}$$

"radioactivity distance" from ^{60}Fe yield

What makes ^{60}Fe?

- core-collapse supernovae
- ~~Type Ia supernovae~~
- ~~AGB stars~~
- ~~kilonovae~~

SN distance:

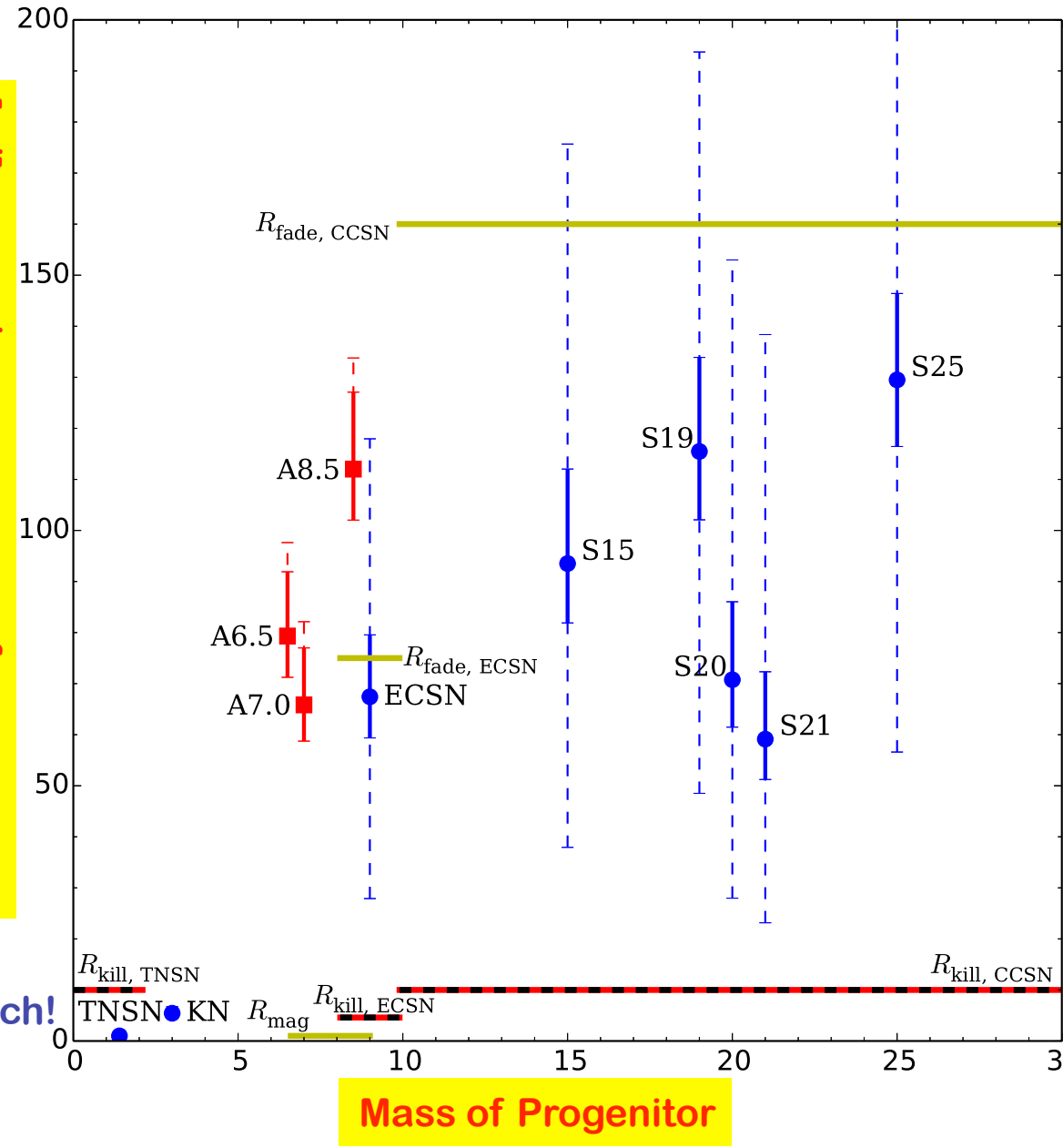
$$r_{\mathrm{SN}} \sim 20 - 150 \text{ pc}$$

Encouraging:

★astronomical distances not built in!

★nontrivial consistency vs rates, SN dust reach!

★also: not impactor(s).



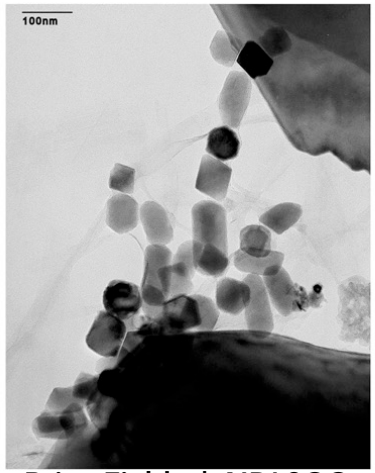

2016

New Data, New Probes, New Sites

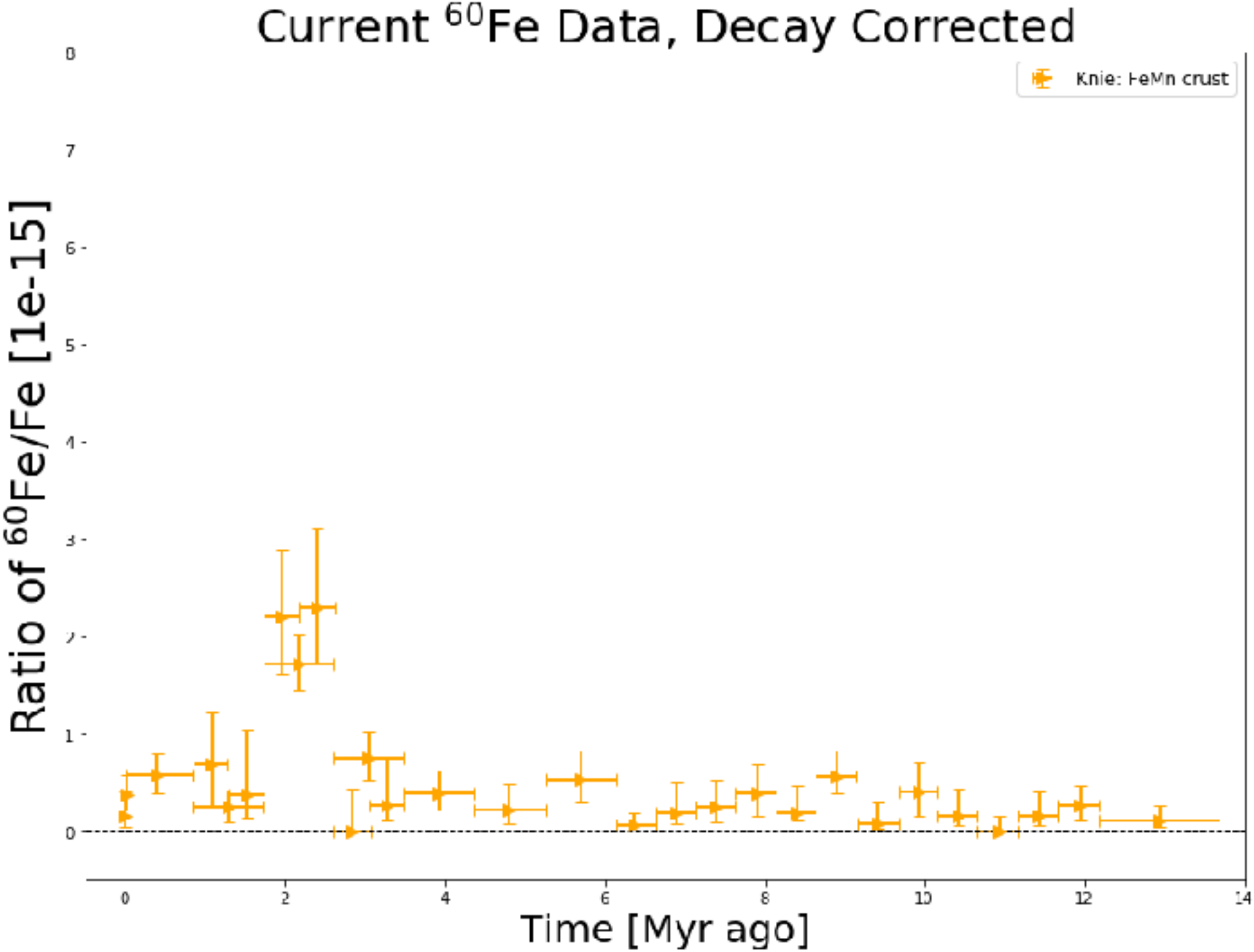
★ **New crust data** Wallner+ 2016
- consistency check

★ **Ocean sediment data** Ludwig+ 2016; Wallner+ 2016
- faster growth rate ~ 1 mm/kyr
- much improved time resolution
- magnetic microfossils!

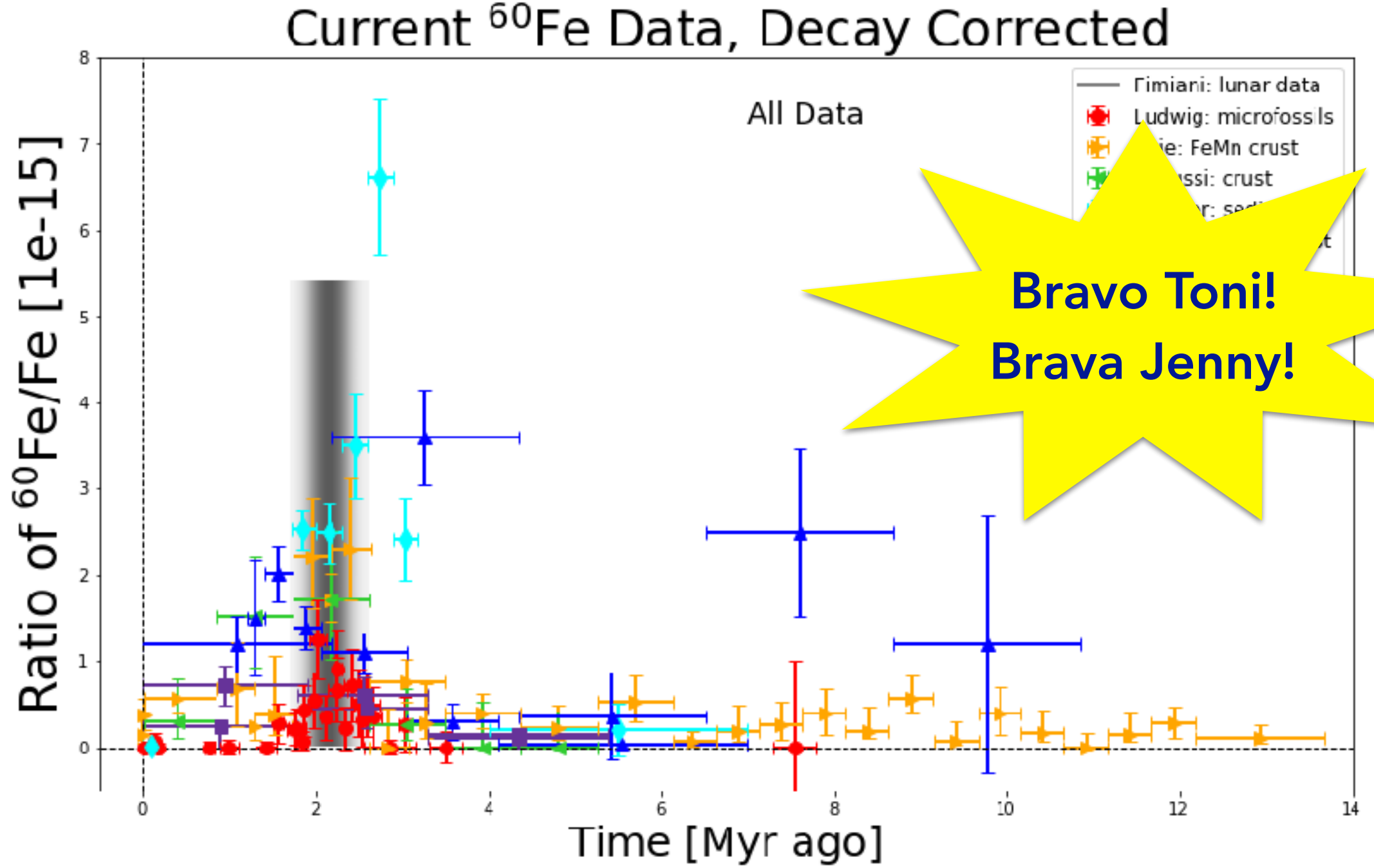
★ **Lunar cores!**
- ^{60}Fe excess over cosmic-ray production



BEFORE


Current ^{60}Fe Data, Decay Corrected
Knie: FeMn crust
Ratio of ^{60}Fe/Fe [1e-15]
Time [Myr ago]
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14

AFTER



Bravo Toni!

Brava Jenny!

★confirmation of ^{60}Fe crust signal at 2-3 Myr

★hint of another signal at ~8 Myr

Knie: FeMn crust
Fitoussi: crust
Wallner: FeMn crust
Wallner: nodules

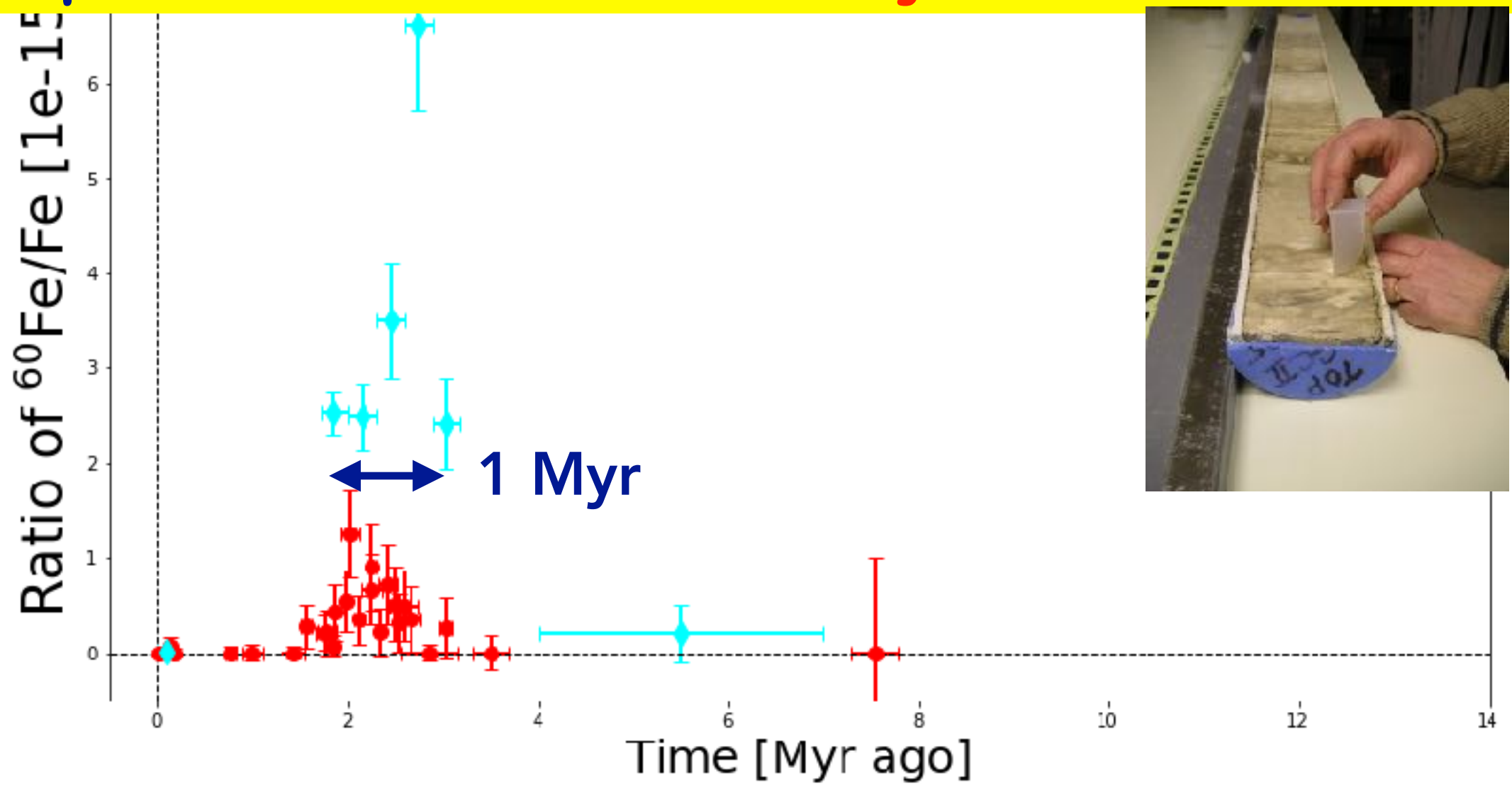
Ratio of ^{60}Fe/Fe [1e-15]

Time [Myr ago]

★^{60}Fe flux duration ~1 Myr

★far exceeds Sedov prediction!?! Fry+ 2015

★probes dust evolution & dynamics? Fry, Ertel + 2017



Plutonium-244

Waller talk; r-process sessions

★ **half-life** $t_{1/2}(^{244}\mathrm{Pu}) = 80\ \mathrm{Myr}$

- gateway to mass extinctions

★ **made in r-process** Kajino, Goriely, Surman talks

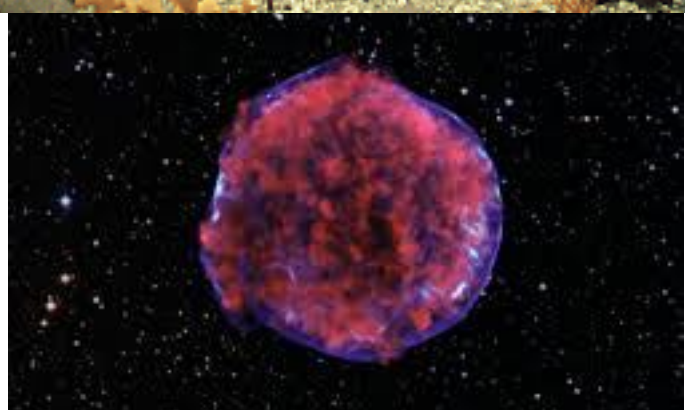
- core-collapse SN?
- binary NS mergers?

★ **detection would confirm:**

- (some) SNe are r-process factories!

★ **Results:**

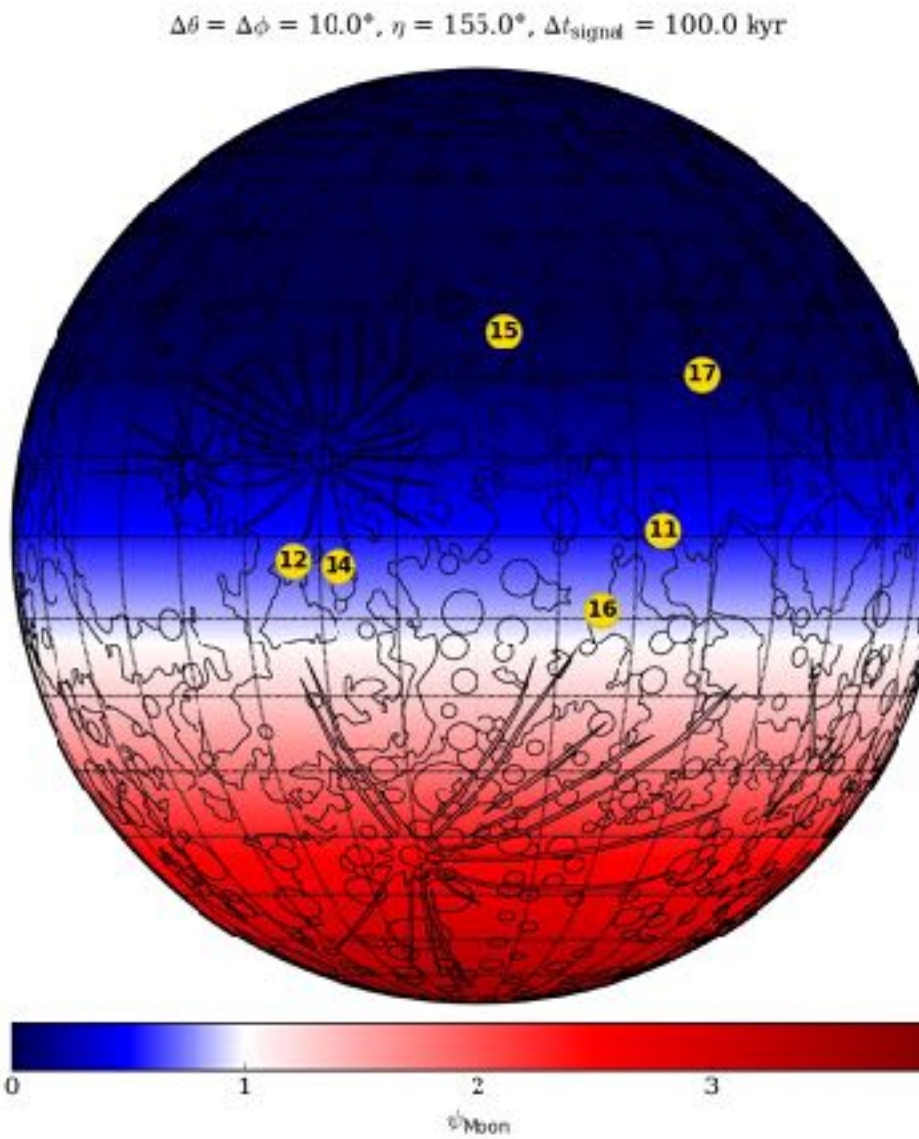
- see Wallner talk!



Whodunit?
The Moon as a Telescope

Fry, BDF, & Ellis (2016)

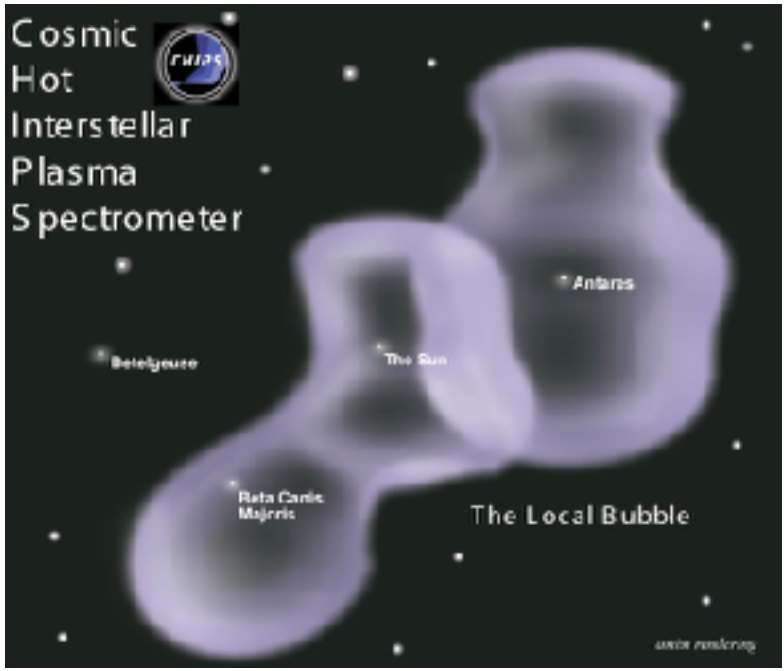
- ★ ^{60}Fe dust grains nearly undeflected in Solar Systen
- ★ Earth:
  - stratosphere scrambles
- ★ Moon is airless:
  - encodes direction!
  - ^{60}Fe pattern points to source!



Aftermath: The Local Bubble

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

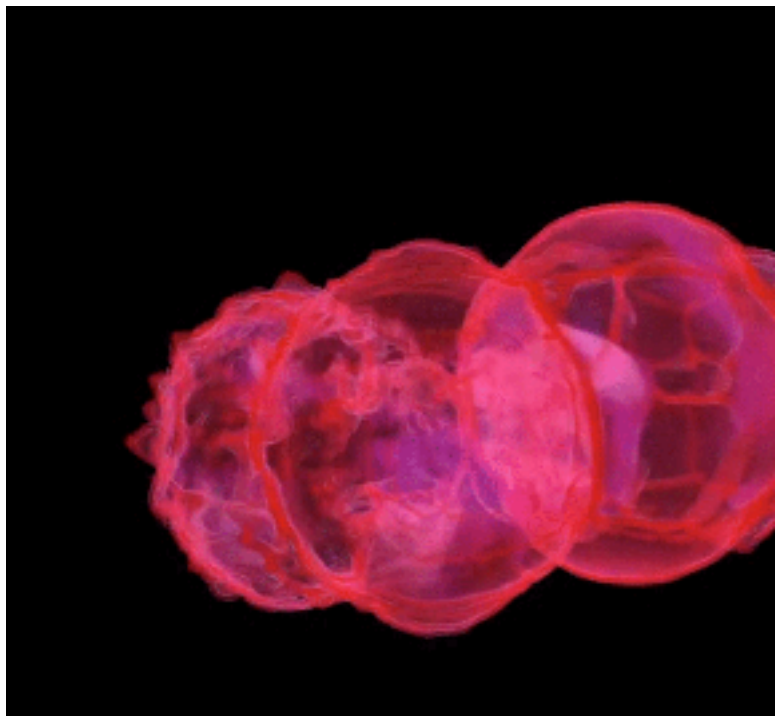
- The Local Bubble
- hot cavity ~50 pc ➪ huge



★ **Nearby SN needed**

- we live inside SN remains
- bubble requires >> 1 SN over 10 Myr
  Smith & Cox 01
- ^{60}Fe event from nearby star clusters? Benitez et al 02; Mamajek 2015

  Sco-Cen vs Tuc-Hor
- Bubble wall as source of ~1 Myr ^{60}Fe pulse width? Feige talk; Breitschwerdt+ 2016; 2017



CONCLUSION

THIS IS A THING

Nearby Supernova = New Tool for Nuclear Astrophysics

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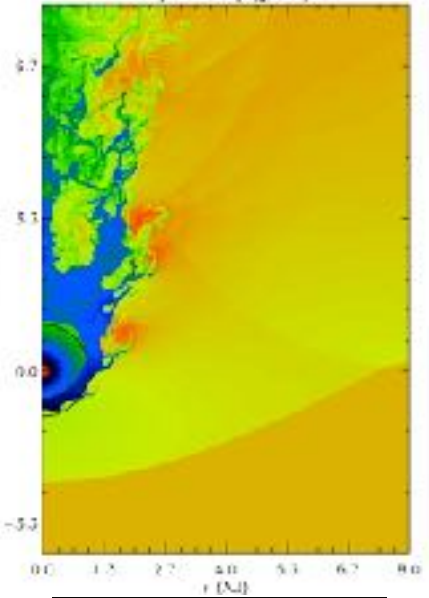
Outlook

Live ^{60}Fe seen globally and on the Moon

- ★ signal in deep ocean crusts, nodules, sediments find
- ★ confirmed pulse ~2-3 Myr ago
- ★ evidence for pulse at ~8 Myr
- ★ ^{60}Fe pulse duration ~1 Myr ?!? see Fry talk
- ★ evidence for lunar signal—directionality?
- ★ Source of Local Bubble?

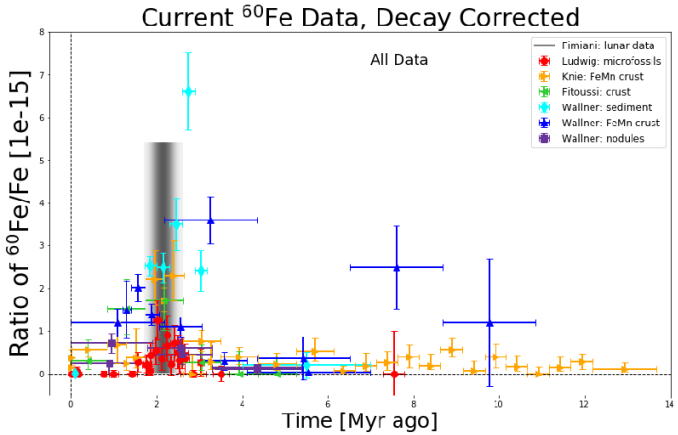


Birth of "Supernova Archaeology"

Implications across disciplines:
nucleosynthesis, cosmic dust, stellar evolution, bio evolution, astrobiology

Future Research

- Supernova(e) origin and direction
  - ★ lunar distribution
  - ★ cosmic-ray anisotropies, ^{60}Fe excess
  - ★ neutron star/pulsar correlation
  - ★ dust production, evolution, dynamics
- more, different samples:
  - ✓ other isotopes (reactions and nucleosynthesis!)
    - e.g., ^{26}Al, ^{41}Ca, ^{53}Mn, ^{97,98}Tc, ^{244}Pu
  - ✓ other media (fossil bacteria)
  - ✓ other sites: back to the Moon!
- other epochs? Mass extinction correlations?
- stay tuned…NPA9!



Sabbatical in Europe
AY 2017-18!