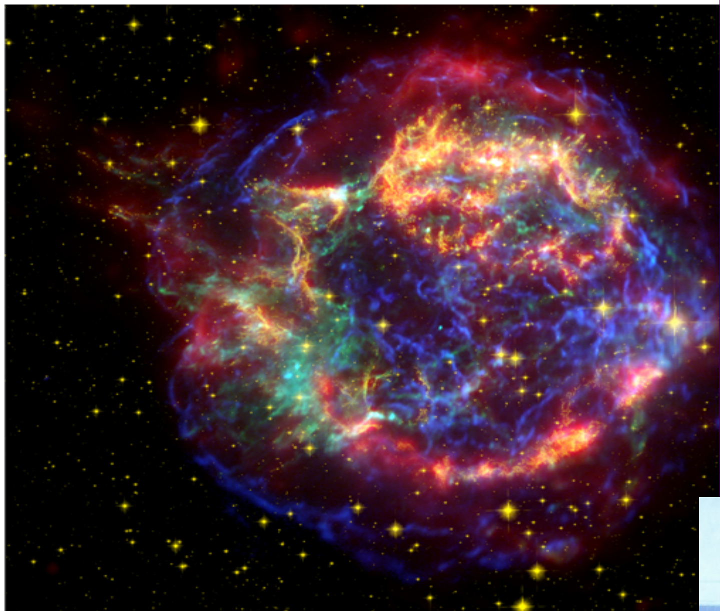
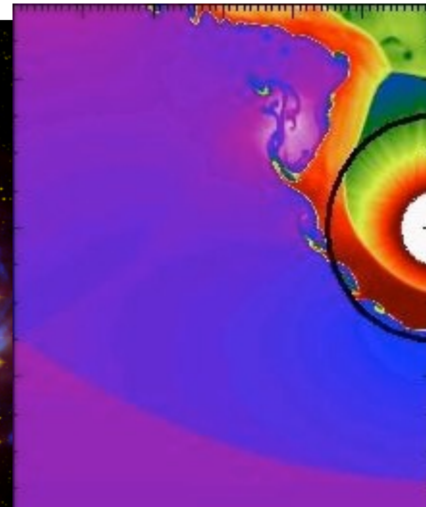
When Stars Attack!

Confirmation, Identification, and Localization of Recent Near-Earth Supernovae


Brian Fields

Astro & Physics, U Illinois

Midwest SN @ Chi. 26 Feb 2019


John Ellis
CERN

Brian Fry
Illinois

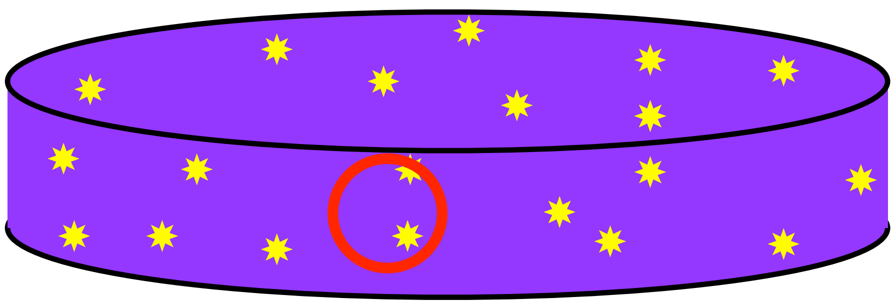
Ada Ertel
Illinois

Jesse Miller
Illinois

Nearby SNe are Inevitable

Shklovskii 1968; BDF 2004; Krishnan, Sovgut, Trauth, & BDF 2019 in prep

Rate of Supernovae inside **r**:

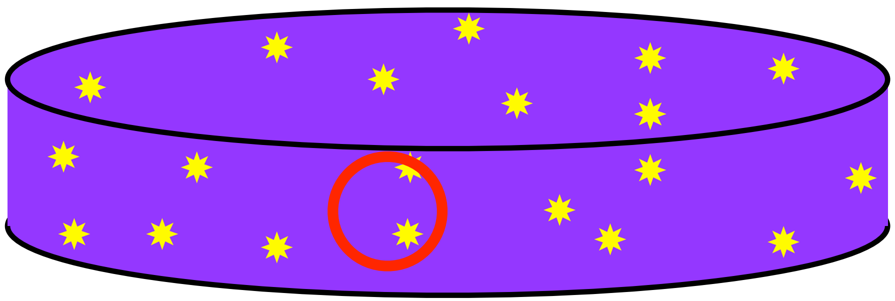


$$\mathrm{SN\ Rate}(< r) \sim (10\ \mathrm{Myr})^{-1} \left(\frac{r}{30\mathrm{pc}}\right)^3$$

Nearby SNe are Inevitable

Shklovskii 1968; BDF 2004; Krishnan, Sovgut, Trauth, & BDF 2019 in prep

Rate of Supernovae inside r:

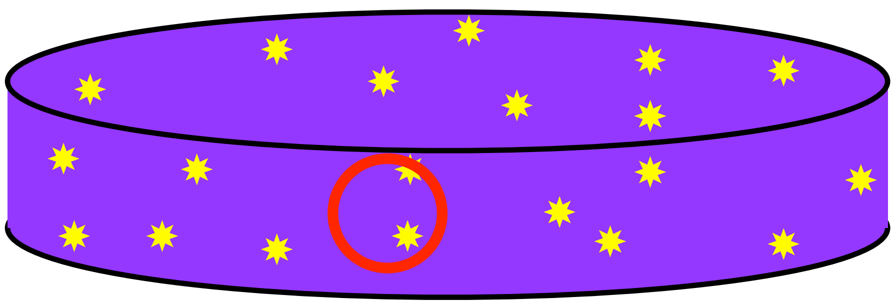


$$\mathrm{SN\ Rate}(< r) \sim (10\ \mathrm{Myr})^{-1} \left(\frac{r}{30\mathrm{pc}} \right)^{3}$$

Nearby SNe are Inevitable

Shklovskii 1968; BDF 2004; Krishnan, Sovgut, Trauth, & BDF 2019 in prep

Rate of Supernovae inside r:



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

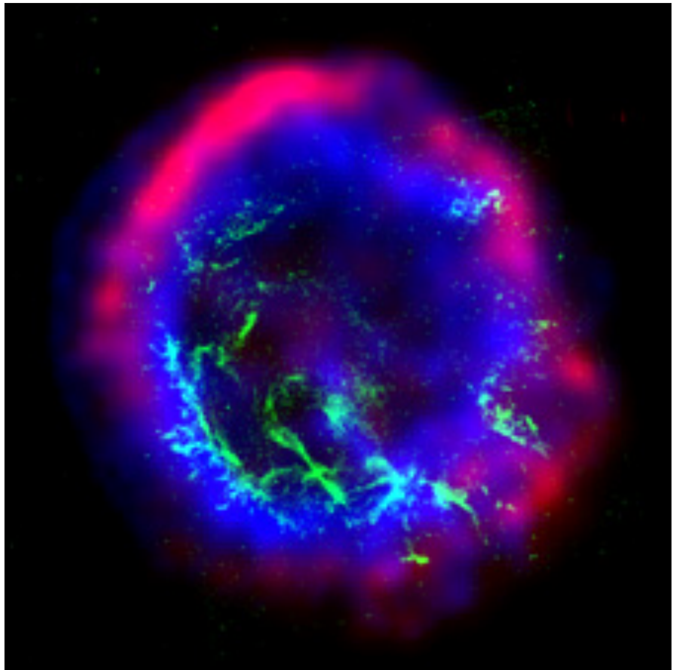
- multiple events < few pc in the last 4.5 Gyr!
- biological impact can be severe if < 10 pc!

Thomas, Melott, Overholt group; Gehrels 2003

Nearby Supernovae Rain Ejecta on Earth

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

Chandra

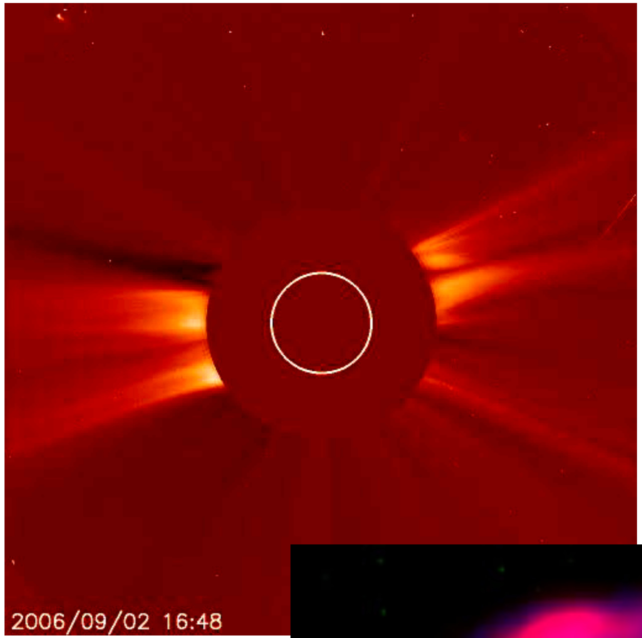


Nearby Supernovae Rain Ejecta on Earth

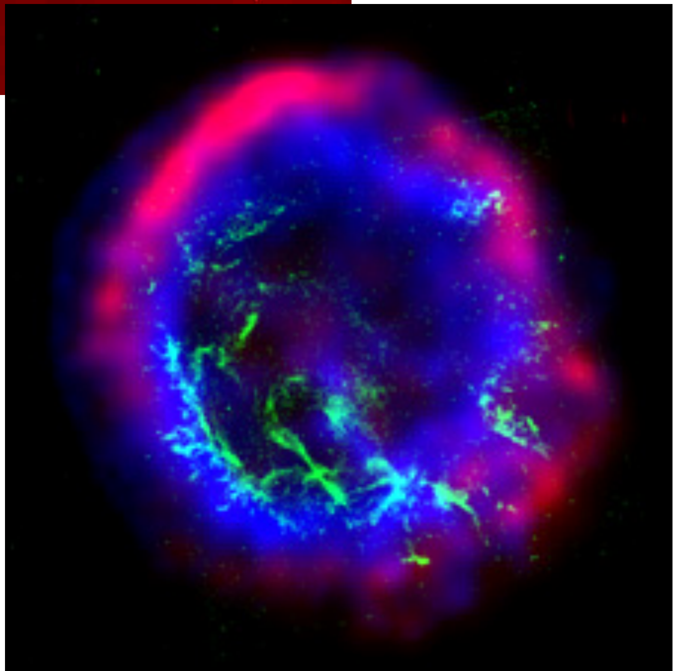
Ellis, BDF, & Schramm 1996;   BDF, Athanassiadou, & Johnson 2008;   Fry, BDF, Ellis 2015

SN eject plows thru interstellar matter

Earth shielded by solar wind



SOHO



Chandra

Nearby Supernovae Rain Ejecta on Earth

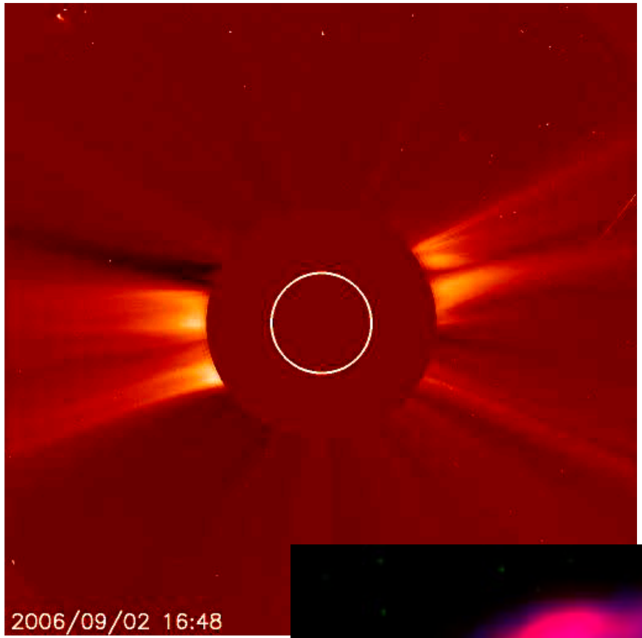
Ellis, BDF, & Schramm 1996; BDF, Athanassiadou, & Johnson 2008; Fry, BDF, Ellis 2015

SN eject plows thru interstellar matter

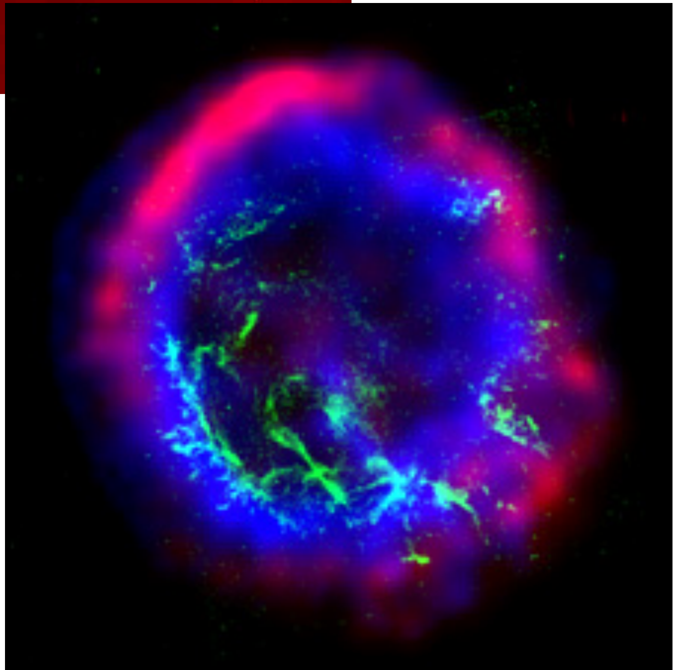
Earth shielded by solar wind

If blast close enough:

- plasma pushes to inner Solar System



SOHO



Chandra

Nearby Supernovae Rain Ejecta on Earth

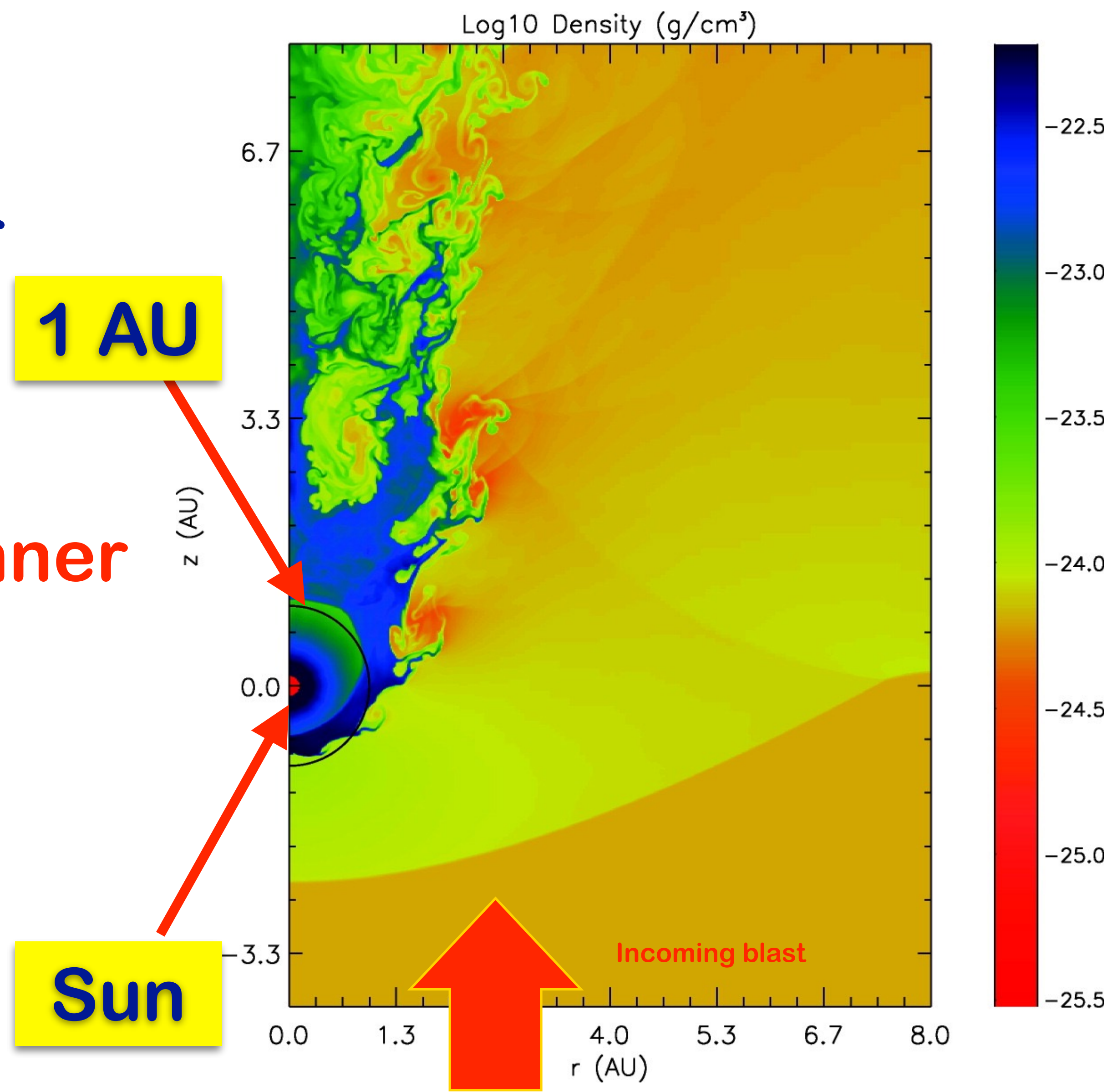
Ellis, BDF, & Schramm 1996; BDF, Athanassiadou, & Johnson 2008; Fry, BDF, Ellis 2015

SN eject plows thru interstellar matter

Earth shielded by solar wind

If blast close enough:

- plasma pushes to inner Solar System



Nearby Supernovae Rain Ejecta on Earth

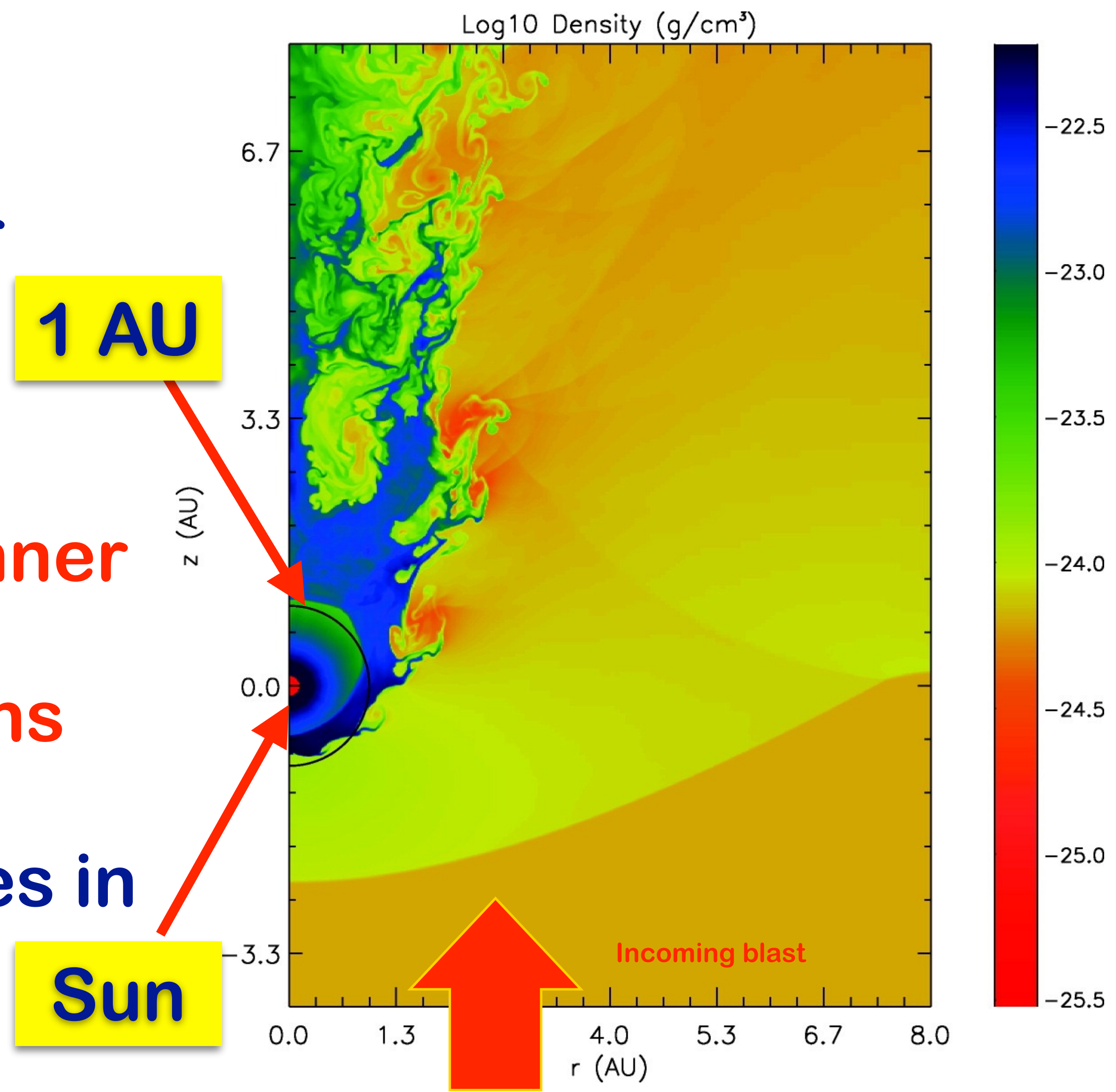
Ellis, BDF, & Schramm 1996; BDF, Athanassiadou, & Johnson 2008; Fry, BDF, Ellis 2015

SN eject plows thru interstellar matter

Earth shielded by solar wind

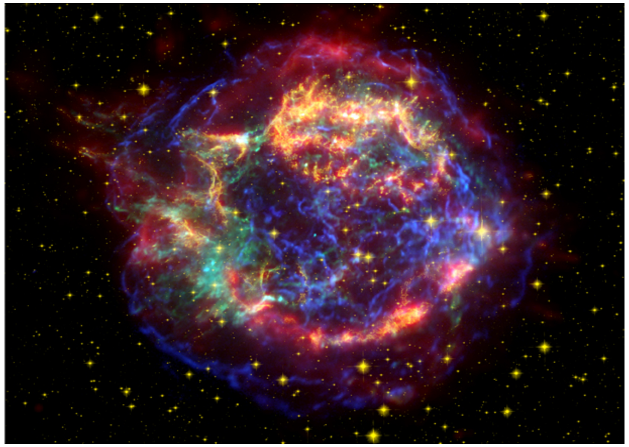
If blast close enough:

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



The Smoking Gun: Radioactivity

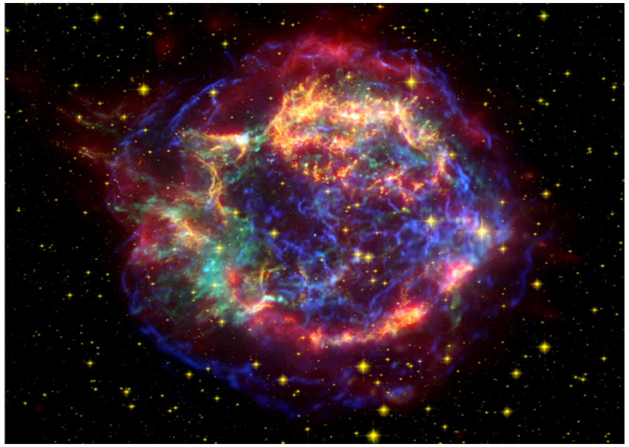
Ellis, BDF, & Schramm 1996;   BDF, Athanassiadou, & Johnson 2008;   Fry, BDF, Ellis 2015



Q: How would we know?

The Smoking Gun: Radioactivity

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

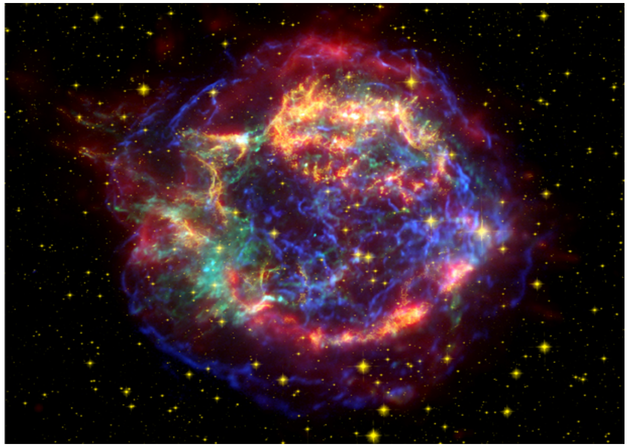


Q: How would we know?

Need observable SN "fingerprint"
→ Nuclear Signature

The Smoking Gun: Radioactivity

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



Q: How would we know?

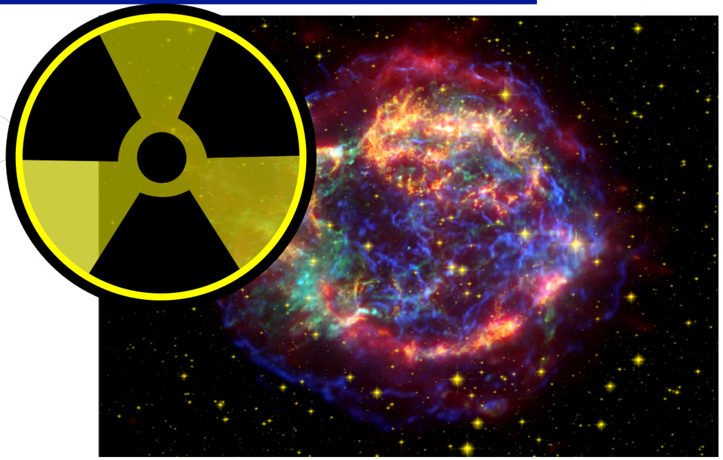
Need observable SN "fingerprint"

⇨ Nuclear Signature

★ Stable nuclides: don't know came from SN

The Smoking Gun: Radioactivity

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



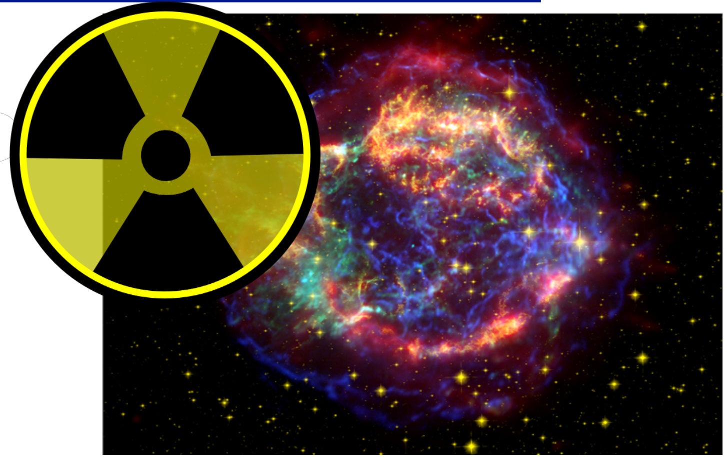
Q: How would we know?

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!

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!

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

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

Radioactivity Detection: ^{60}Fe
Knie et al (2004)

Radioactivity Detection: ^{60}Fe
Knie et al (2004)

Ferromanganese crust

Pacific Ocean

✓ slow growth ~ 1 mm/Myr

✓ accelerator mass spectrometry: live ^{60}Fe!

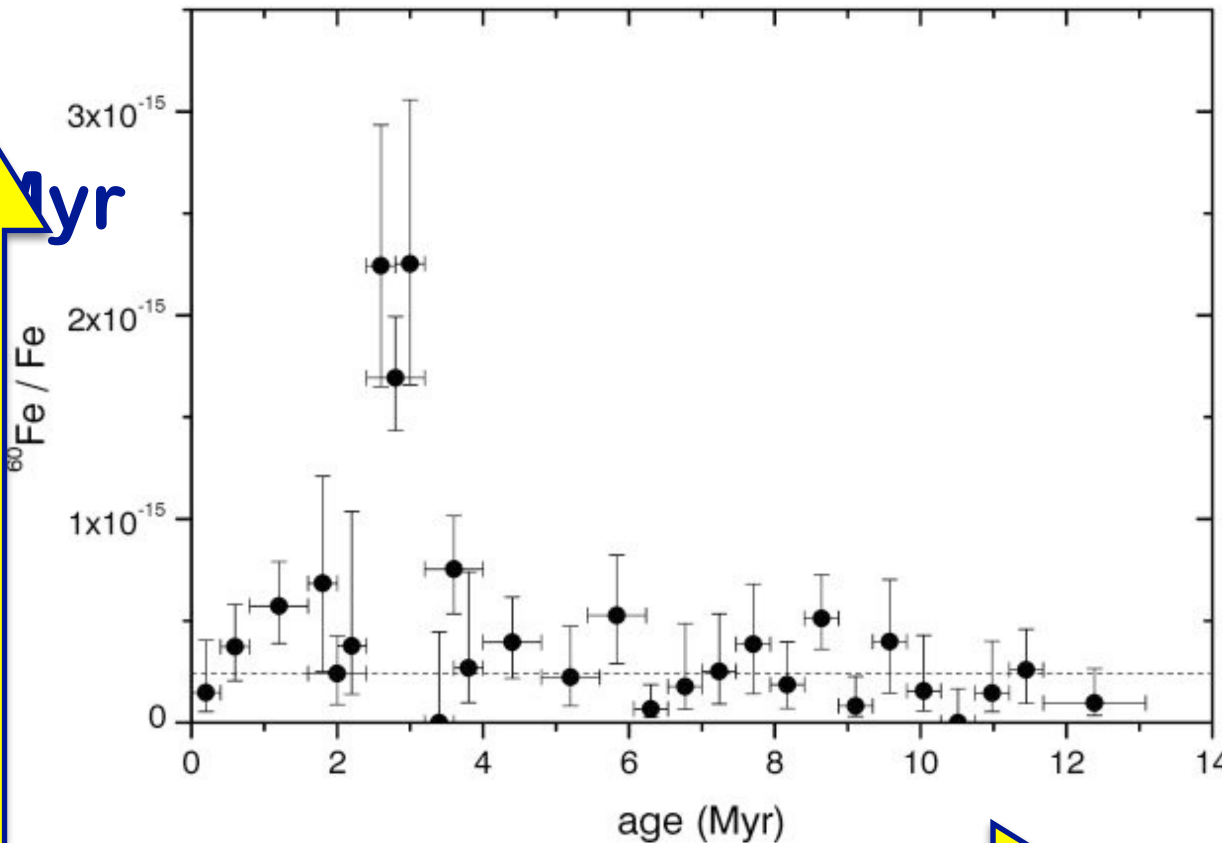
Radioactivity Detection: ^{60}Fe

Knie et al (2004)

Ferromanganese crust

Pacific Ocean

- ✓ slow growth ~ 1 … Myr
- ✓ accelerator mas… spectrometry: live ^{60}Fe!



^{60}Fe abundance

time before present [Myr]

Radioactivity Detection: ^{60}Fe

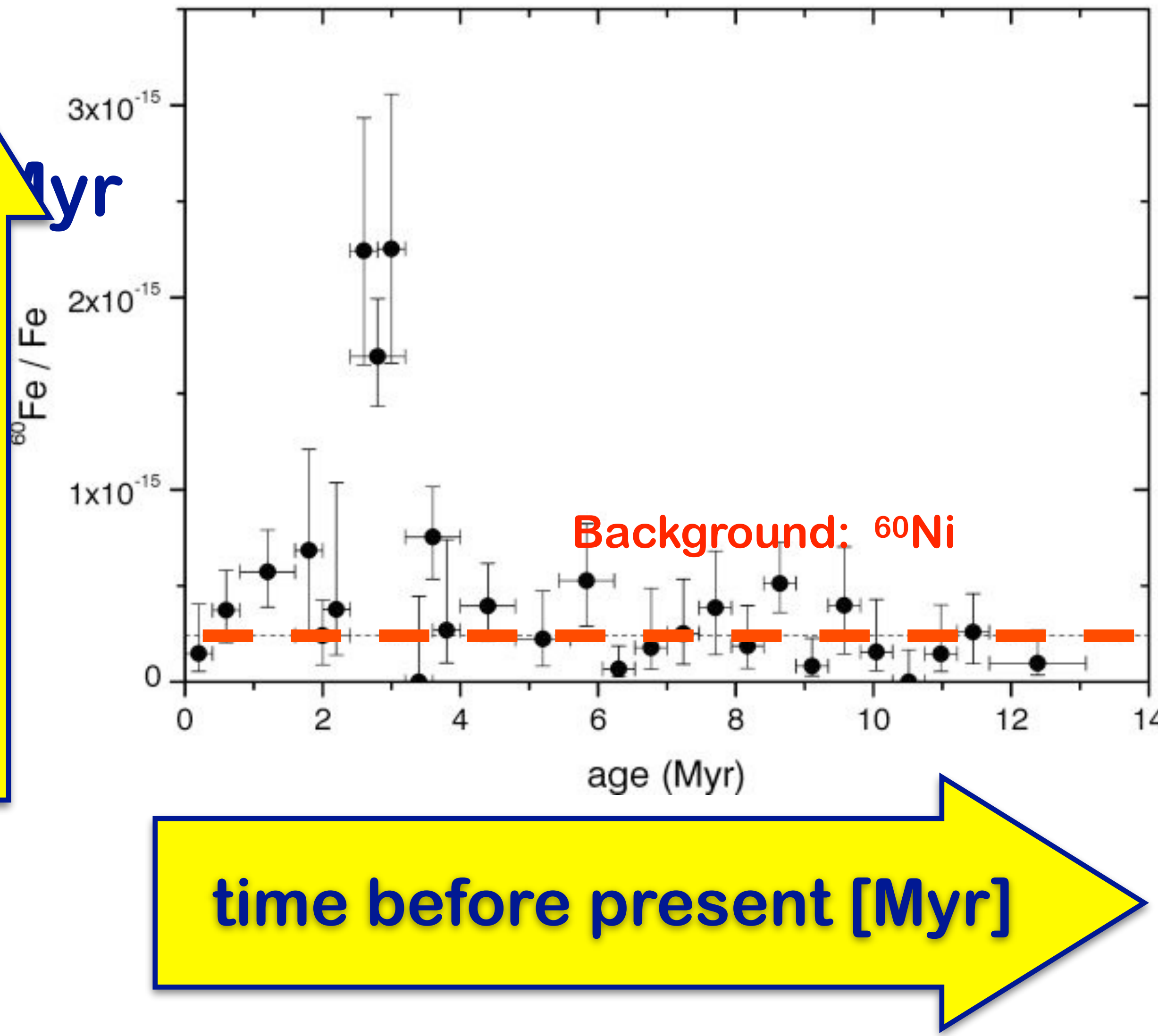
Knie et al (2004)

Ferromanganese crust

Pacific Ocean

- ✓ slow growth ~ 1 ... Myr
- ✓ accelerator mas... spectrometry: live ^{60}Fe!

^{60}Fe abundance



Radioactivity Detection: ^{60}Fe

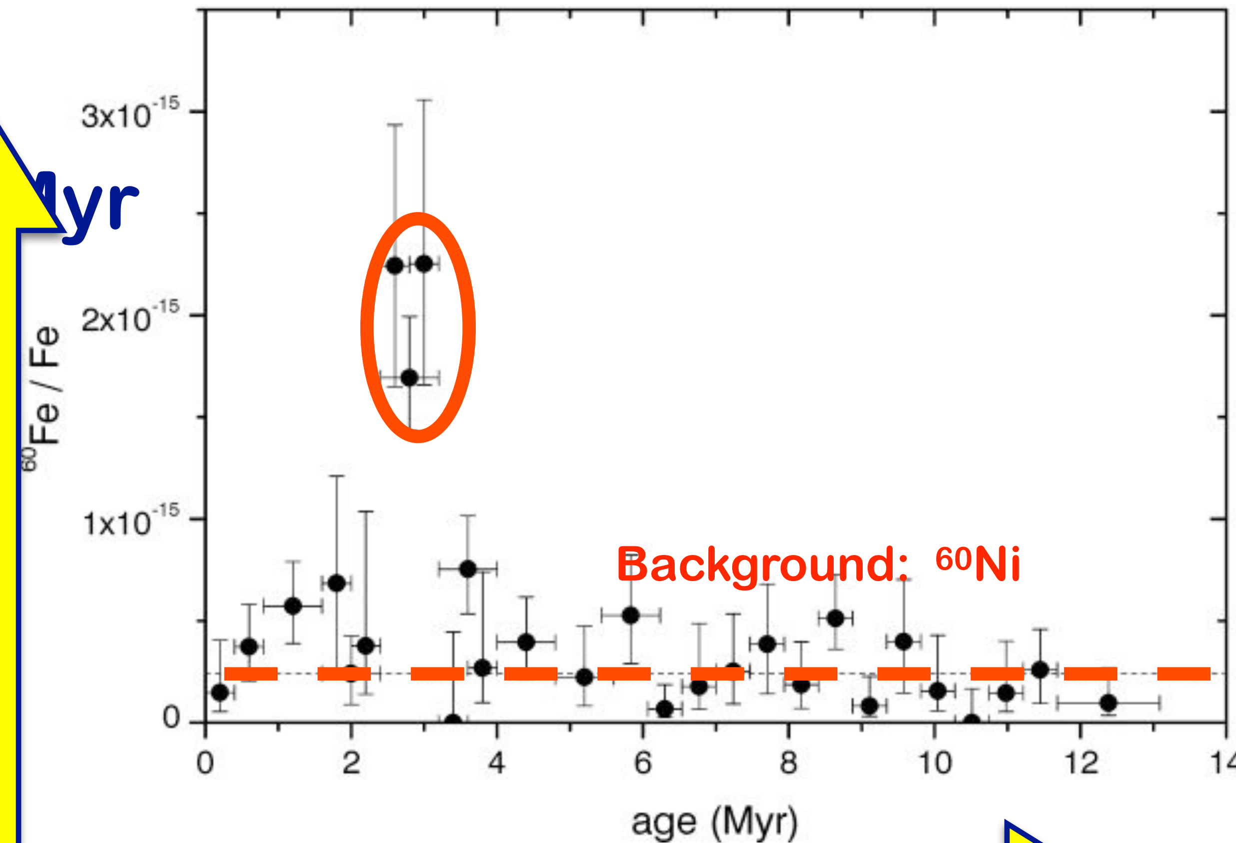
Knie et al (2004)

Ferromanganese crust

Pacific Ocean

- ✓ slow growth ~ 1 Myr
- ✓ accelerator mas spectrometry: live ^{60}Fe!

^{60}Fe abundance



time before present [Myr]

Radioactivity Detection: ^{60}Fe

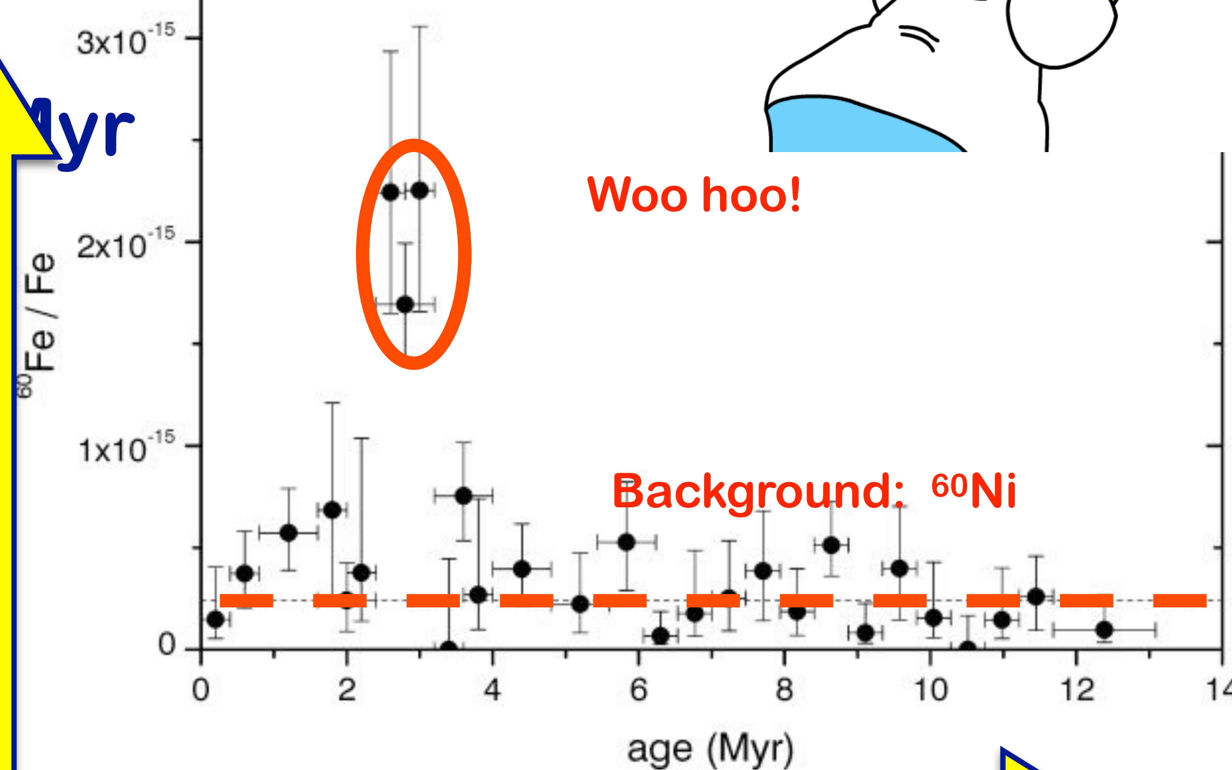
Knie et al (2004)

Ferromanganese crust

Pacific Ocean

- ✓ slow growth ~ 1 mm/Myr
- ✓ accelerator mass spectrometry: live ^{60}Fe!

^{60}Fe abundance



time before present [Myr]

Radioactivity Detection: ^{60}Fe

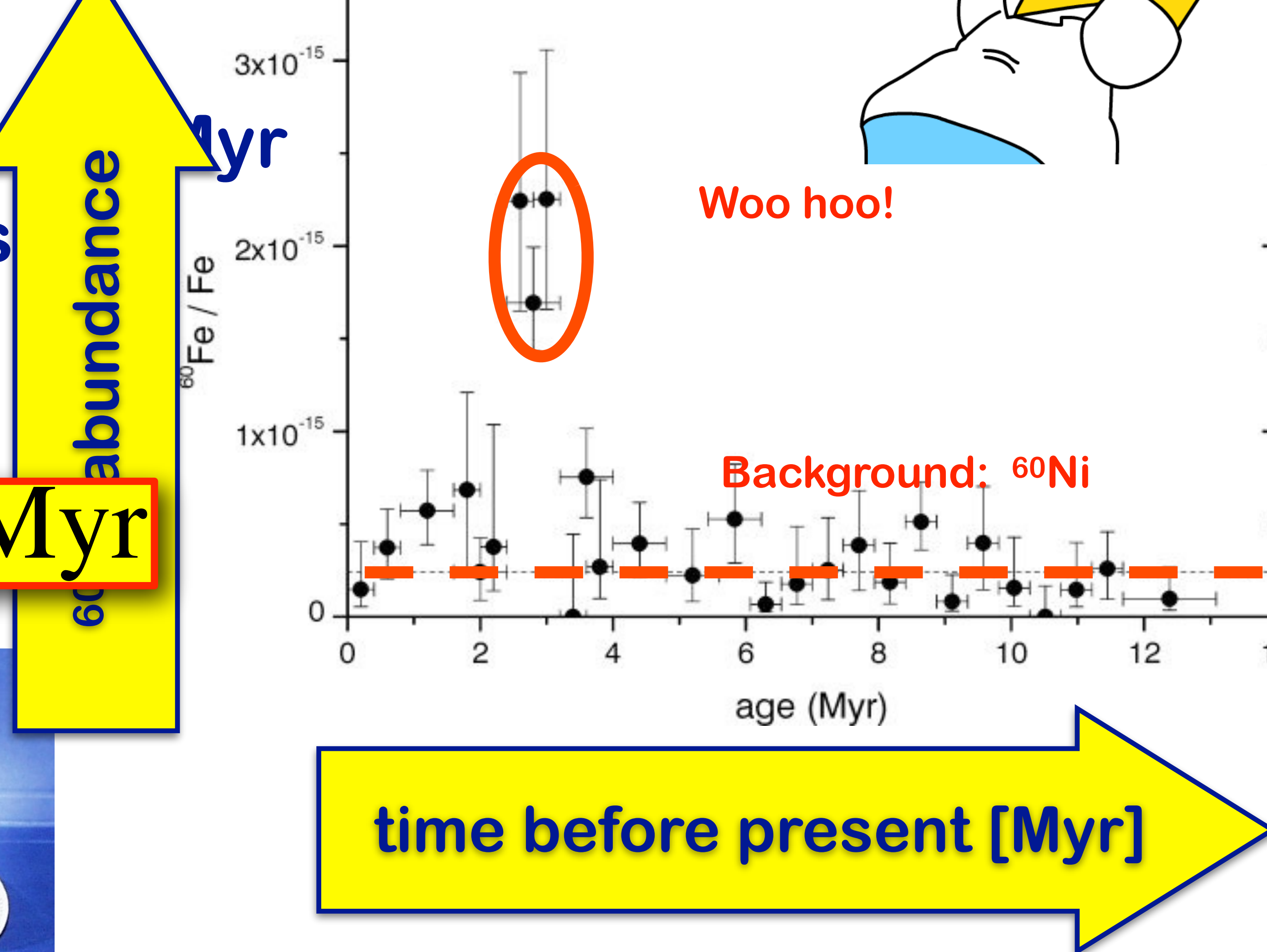
Knie et al (2004)

Ferromanganese crust

Pacific Ocean

- ✓ slow growth ~ 1… Myr
- ✓ accelerator mas… spectrometry: live ^{60}Fe!

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



Radioactivity Detection: ^{60}Fe

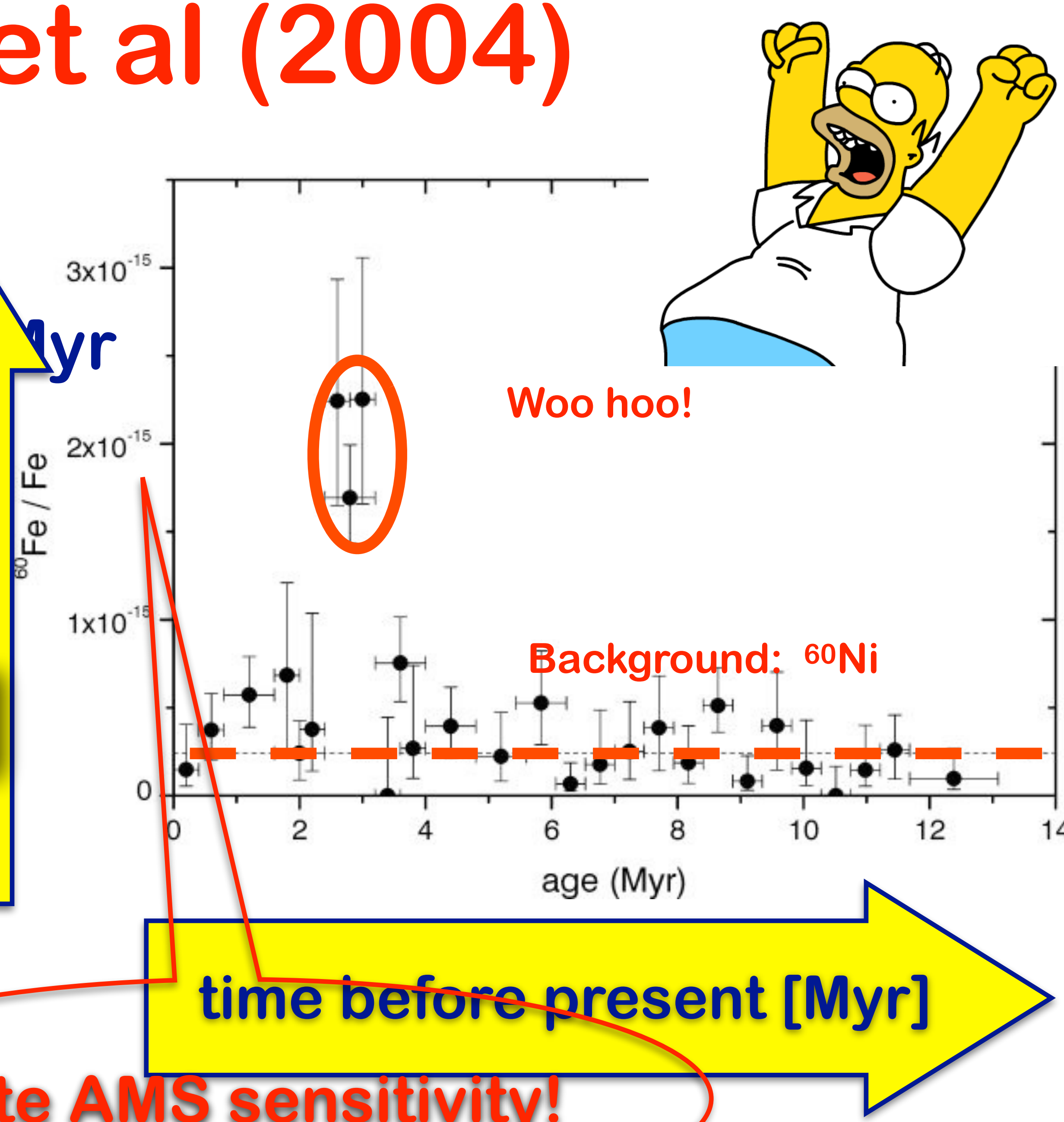
Knie et al (2004)

Ferromanganese crust

Pacific Ocean

- ✓ slow growth ~ 1 … Myr
- ✓ accelerator mas… spectrometry: live ^{60}Fe!

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



Note AMS sensitivity!

Explosion Distance

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ellis 2005; Fry, BDF, & Ellis 2015

Observable: surface density/fluence:

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

Explosion Distance

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ellis 2005; Fry, BDF, & Ellis 2015

Observable: surface density/fluence:

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

Turn the problem around:

"radioactivity distance" from ^{60}Fe yield

Explosion Distance

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ellis 2005; Fry, BDF, & Ellis 2015

Observable: surface density/fluence:

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

Turn the problem around:

"radioactivity distance" from ^{60}Fe yield

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

Explosion Distance

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ellis 2005; Fry, BDF, & Ellis 2015

Observable: surface density/fluence:

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

Turn the problem around:

"radioactivity distance" from ^{60}Fe yield

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

^{60}Fe Suspects:

Explosion Distance

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ellis 2005; Fry, BDF, & Ellis 2015

Observable: surface density/fluence:

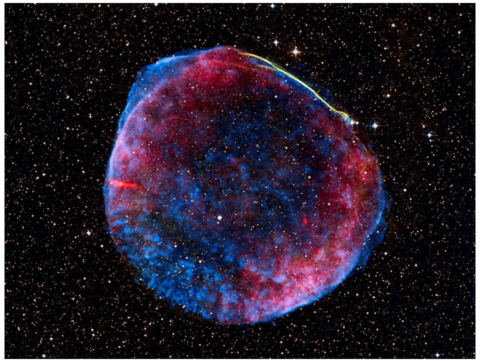
$$N_{60,\mathrm{obs}} \sim \frac{M_{60,\mathrm{eject}}}{D^2}$$

Turn the problem around:

"radioactivity distance" from ^{60}Fe yield

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

^{60}Fe Suspects:



core-collapse supernova

Explosion Distance

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ellis 2005; Fry, BDF, & Ellis 2015

Observable: surface density/fluence:

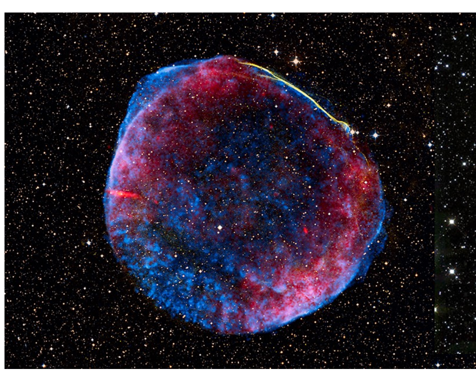
$$N_{60,\mathrm{obs}} \sim \frac{M_{60,\mathrm{eject}}}{D^2}$$

Turn the problem around:

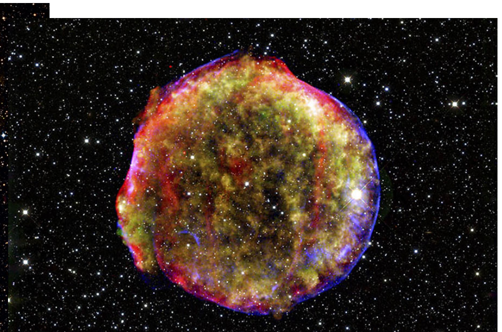
"radioactivity distance" from ^{60}Fe yield

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

^{60}Fe Suspects:



core-collapse supernova



Type Ia supernova

Explosion Distance

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ellis 2005; Fry, BDF, & Ellis 2015

Observable: surface density/fluence:

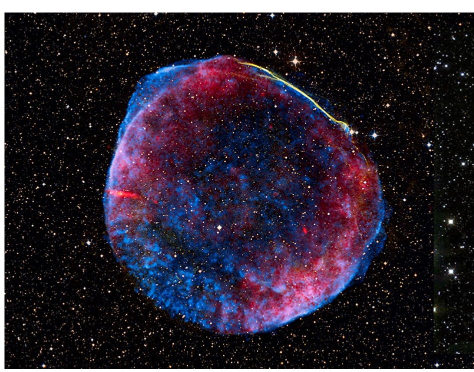
$$N_{60,\mathrm{obs}} \sim \frac{M_{60,\mathrm{eject}}}{D^2}$$

Turn the problem around:

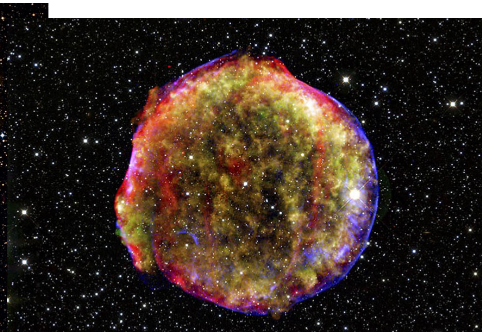
"radioactivity distance" from ^{60}Fe yield

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

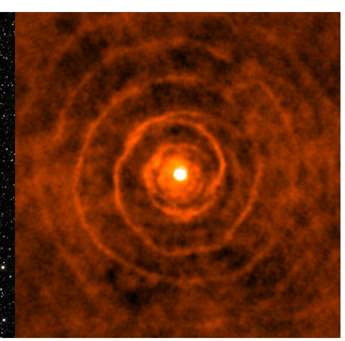
^{60}Fe Suspects:



core-collapse supernova



Type Ia supernova



AGB star

Explosion Distance

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ellis 2005; Fry, BDF, & Ellis 2015

Observable: surface density/fluence:

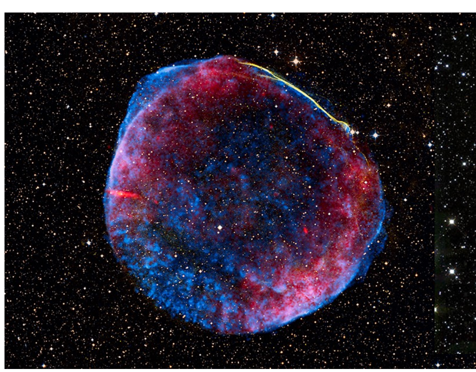
$$N_{60,\mathrm{obs}} \sim \frac{M_{60,\mathrm{eject}}}{D^2}$$

Turn the problem around:

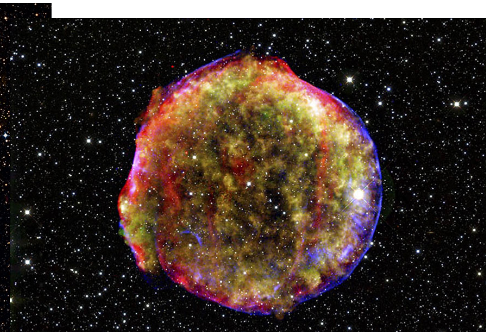
"radioactivity distance" from ^{60}Fe yield

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

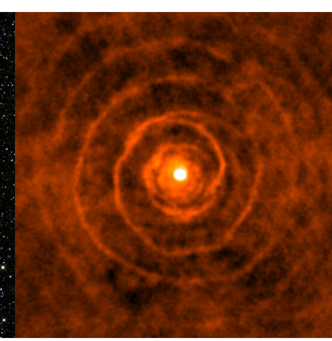
^{60}Fe Suspects:



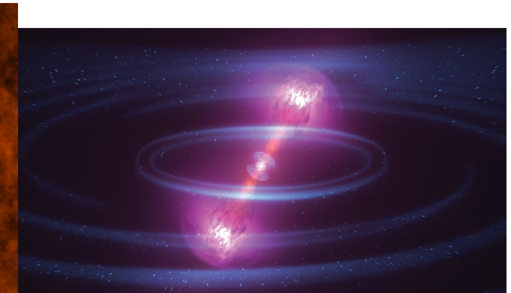
core-collapse supernova



Type Ia supernova



AGB star



NS merger

Explosion Distance

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ellis 2005; Fry, BDF, & Ellis 2015

Observable: surface density/fluence:

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

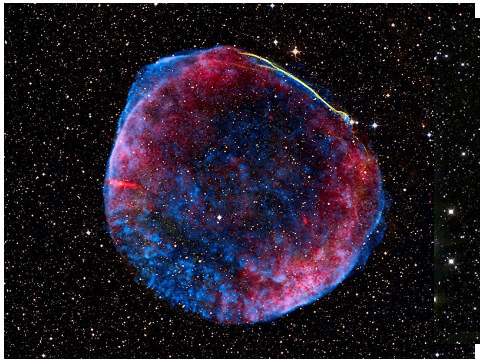
Turn the problem around:

"radioactivity distance" from ^{60}Fe yield

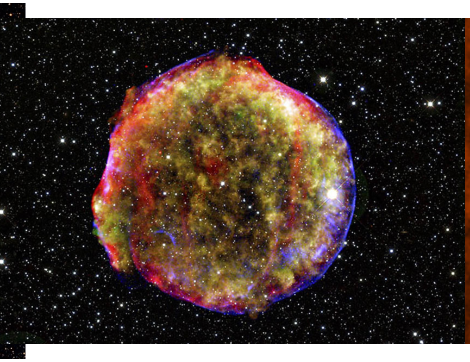
$$D \sim \sqrt{M_{60,\mathrm{eject}} / N_{60,\mathrm{obs}}}$$

Jesse Miller

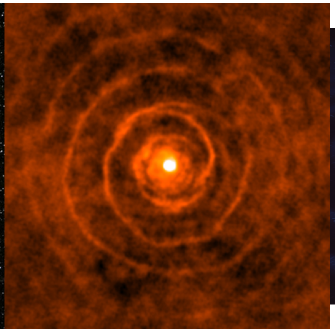
^{60}Fe Suspects:



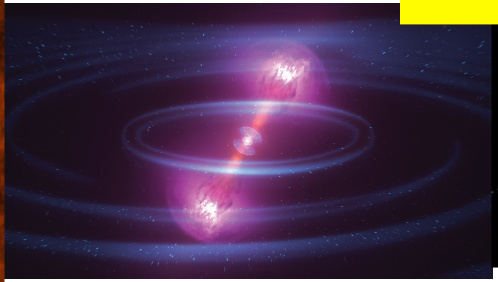
core-collapse supernova



Type Ia supernova



AGB star



NS merger

impactor

Explosion Distar

Ellis, BDF, Schramm 1996; BDF & Ellis 1999; BDF, Hochmut & Ell

Verdict:
Core Collapse
~30-150 pc

Observable: surface density/fluence:

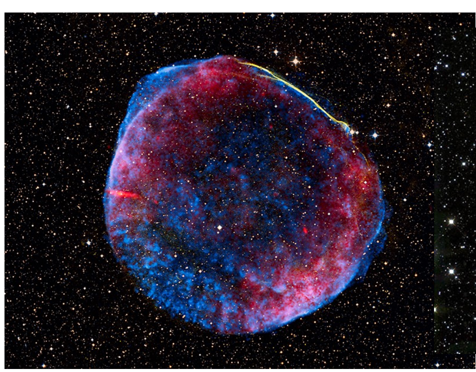
$$N_{60,\mathrm{obs}} \sim \frac{M_{60,\mathrm{eject}}}{D^2}$$

Turn the problem around:
"radioactivity distance" from ^{60}Fe yield

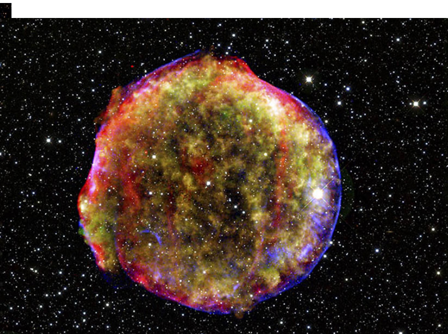
$$D \sim \sqrt{M_{60,\mathrm{eject}} / N_{60,\mathrm{obs}}}$$

Jesse Miller

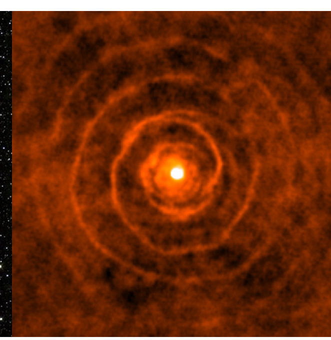
^{60}Fe Suspects:



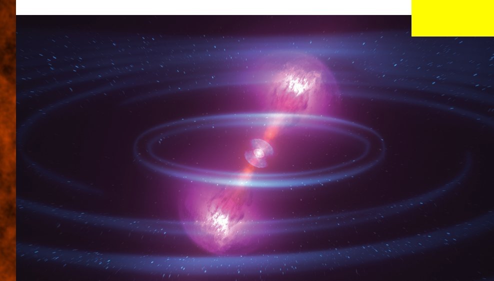
core-collapse supernova



Type Ia supernova



AGB star



NS merger

impactor

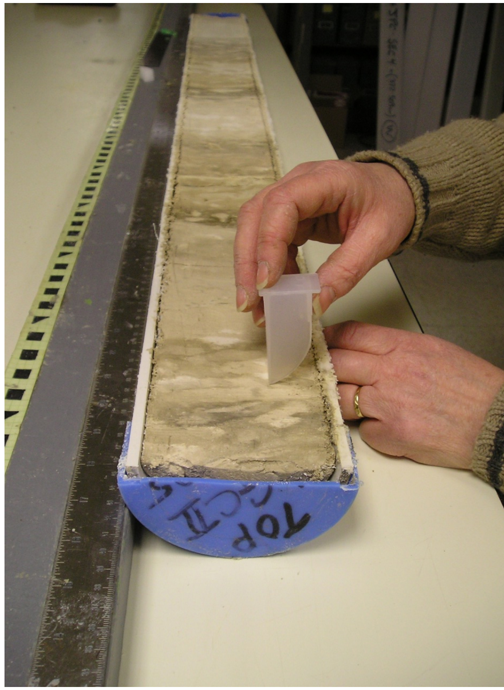

2016

New Data, New Probes, New Sites

New Data, New Probes, New Sites

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

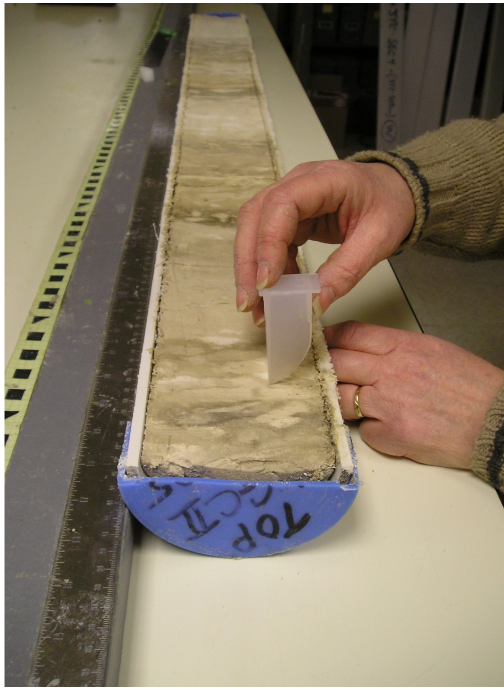
New Data, New Probes, New Sites

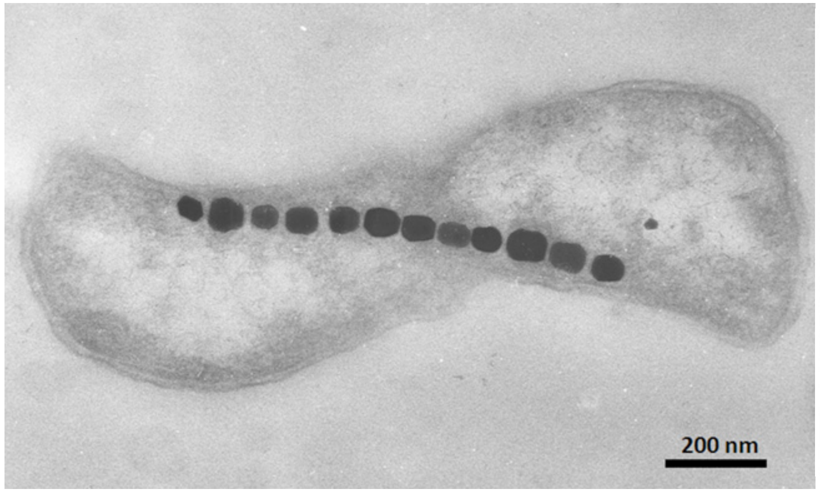


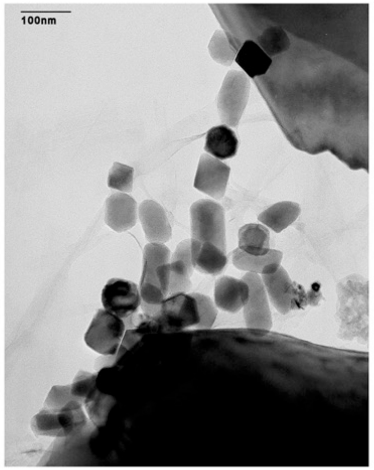
- ★ **New crust data** Wallner+ 2016
  - consistency check
- ★ **Ocean sediment data** Ludwig+ 2016; Wallner+ 2016
  - faster growth rate ~ 1 mm/kyr
  - much improved time resolution
  - magnetic microfossils!

New Data, New Probes, New Sites

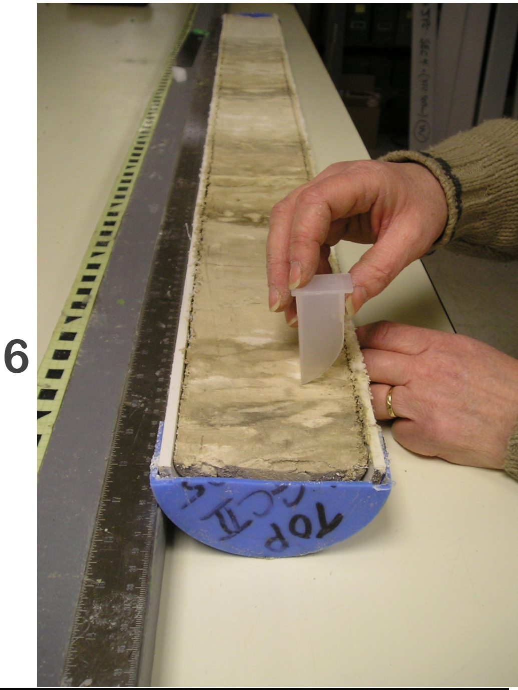
- ★ **New crust data** Wallner+ 2016
  - consistency check
- ★ **Ocean sediment data** Ludwig+ 2016; Wallner+ 2016
  - faster growth rate ~ 1 mm/kyr
  - much improved time resolution
  - magnetic microfossils!



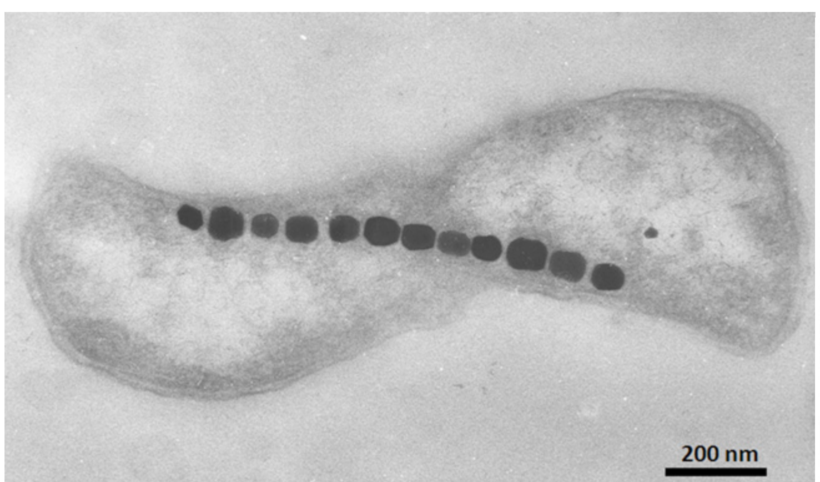


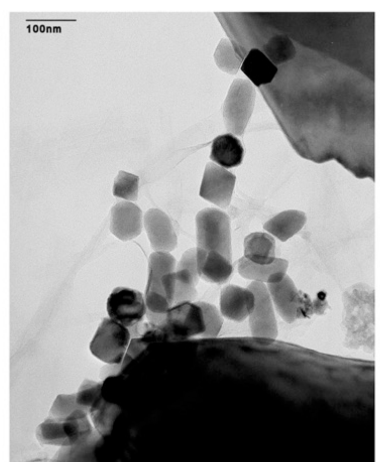


New Data, New Probes, New Sites

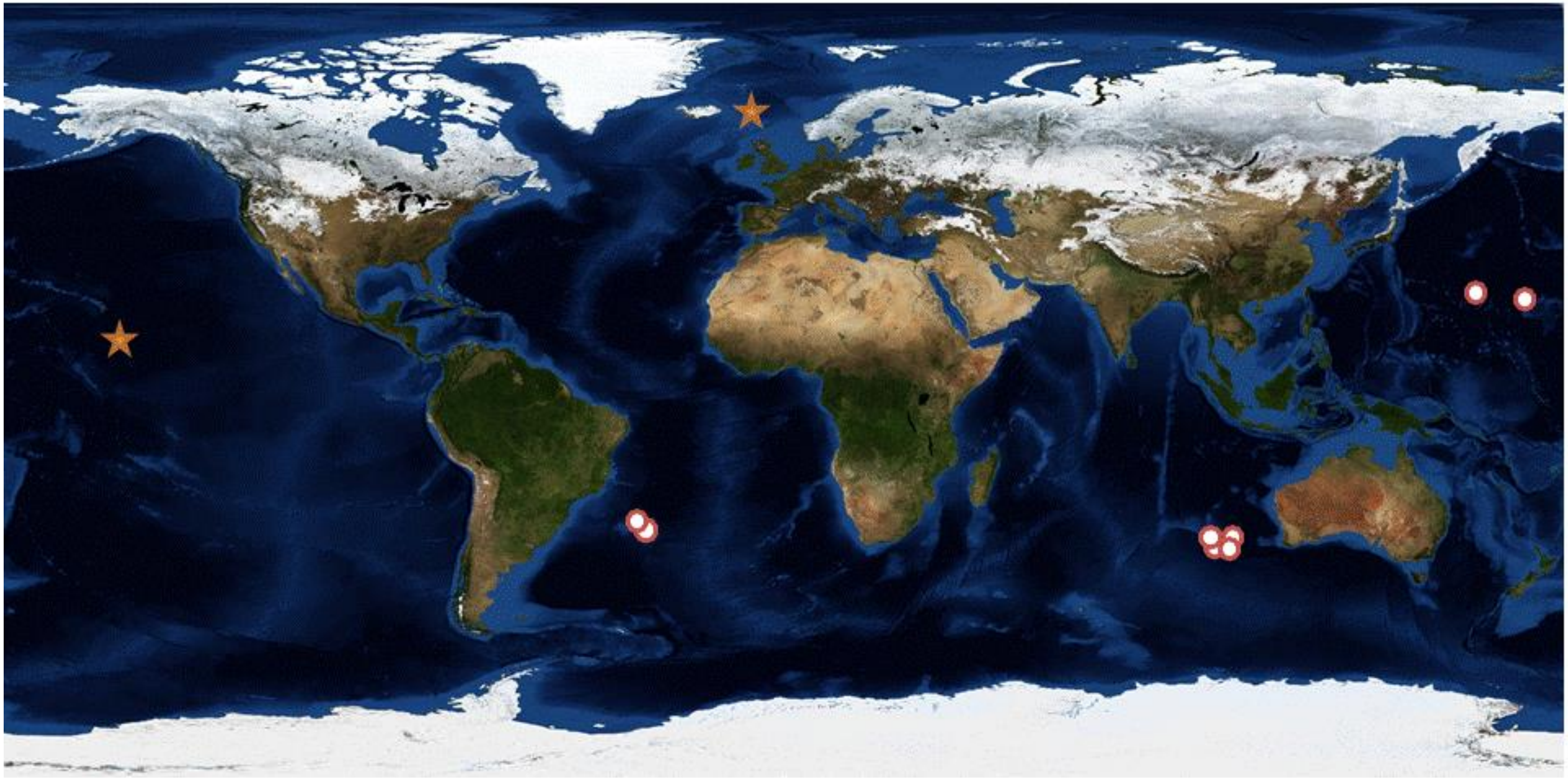


- ★ **New crust data** Wallner+ 2016
  - consistency check
- ★ **Ocean sediment data** Ludwig+ 2016; Wallner+ 2016
  - faster growth rate ~ 1 mm/kyr
  - much improved time resolution
  - magnetic microfossils!
- ★ **Lunar cores!**
  - ^{60}Fe excess over cosmic-ray production

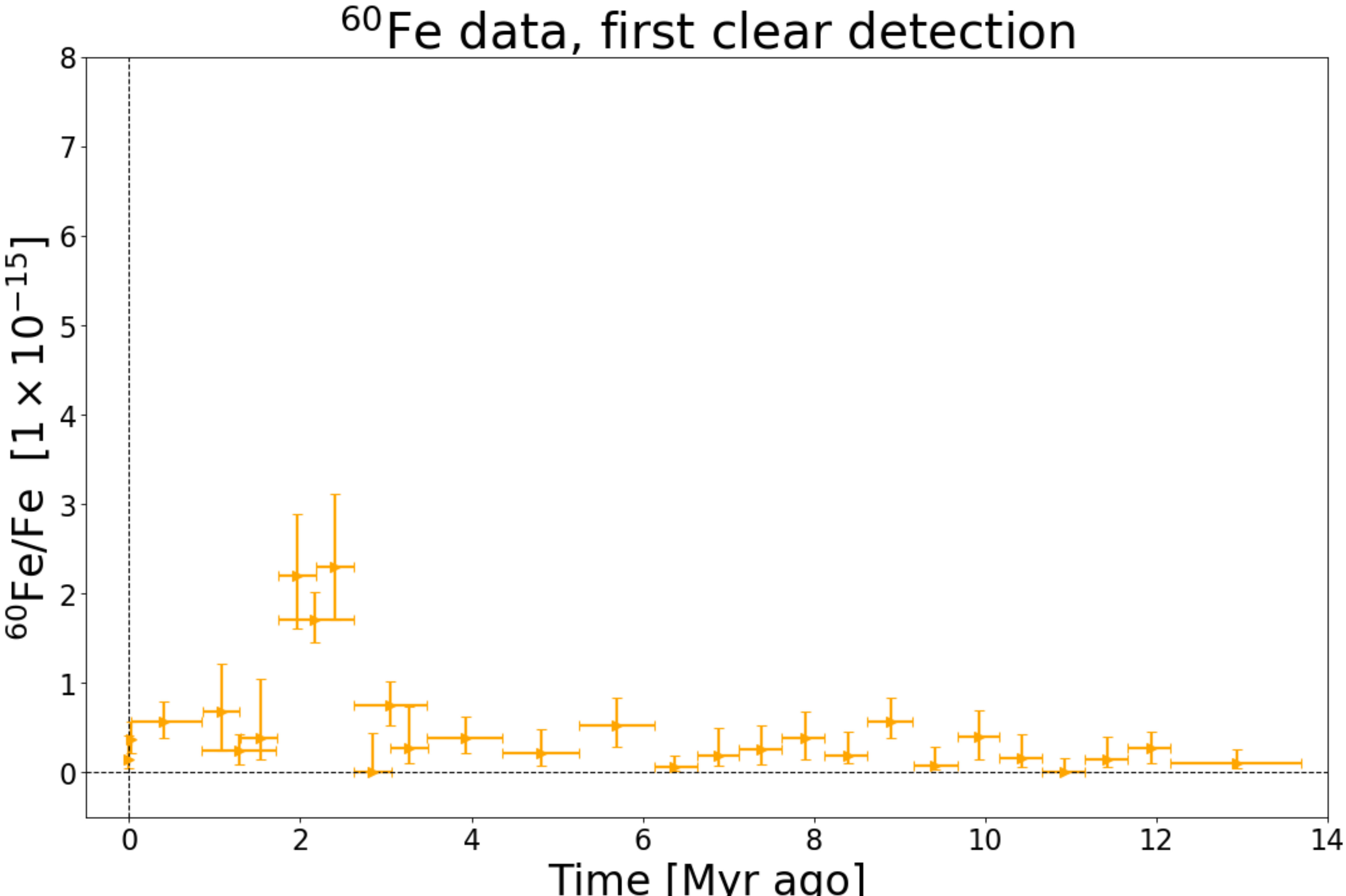




^{60}Fe Sample Sites

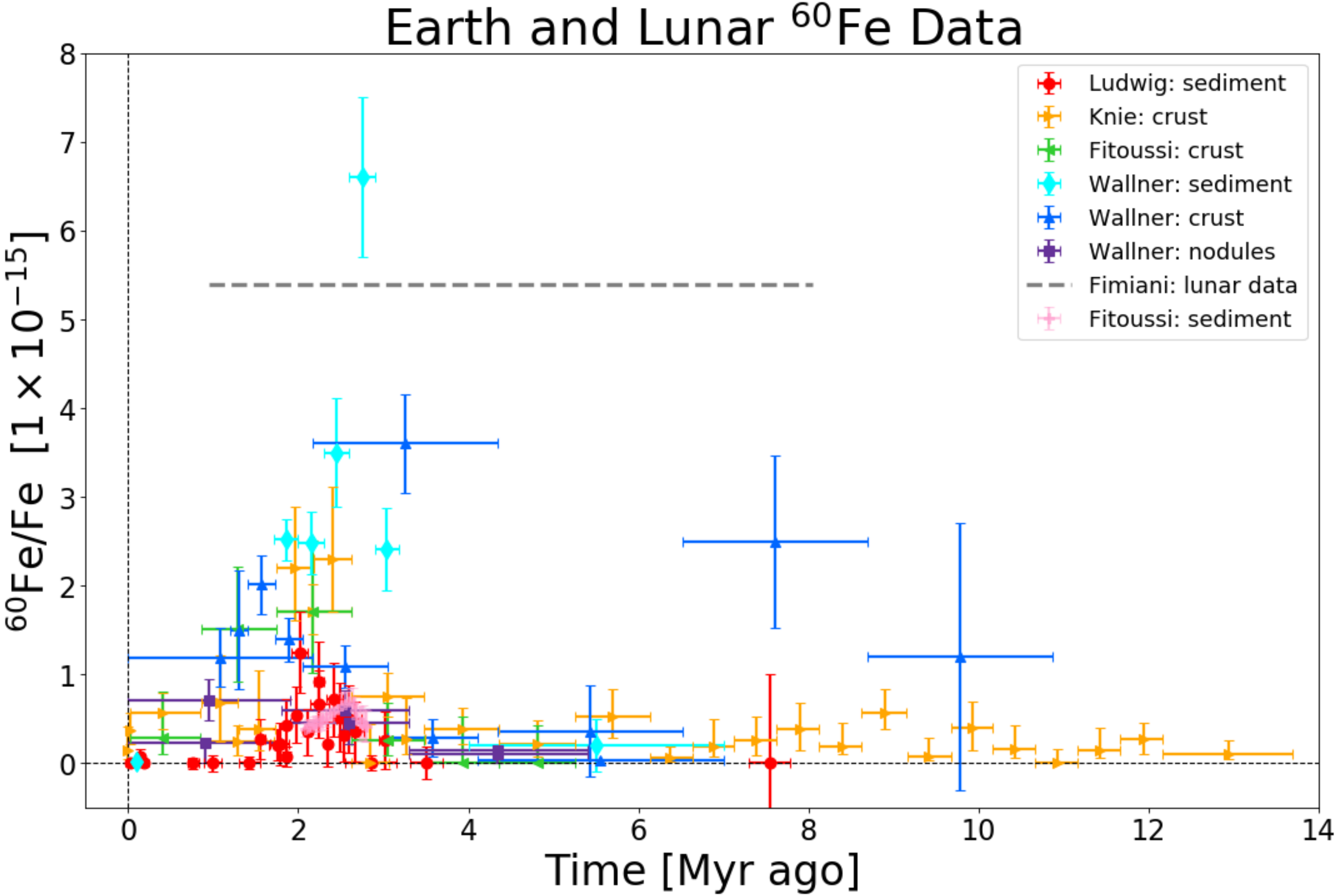


BEFORE



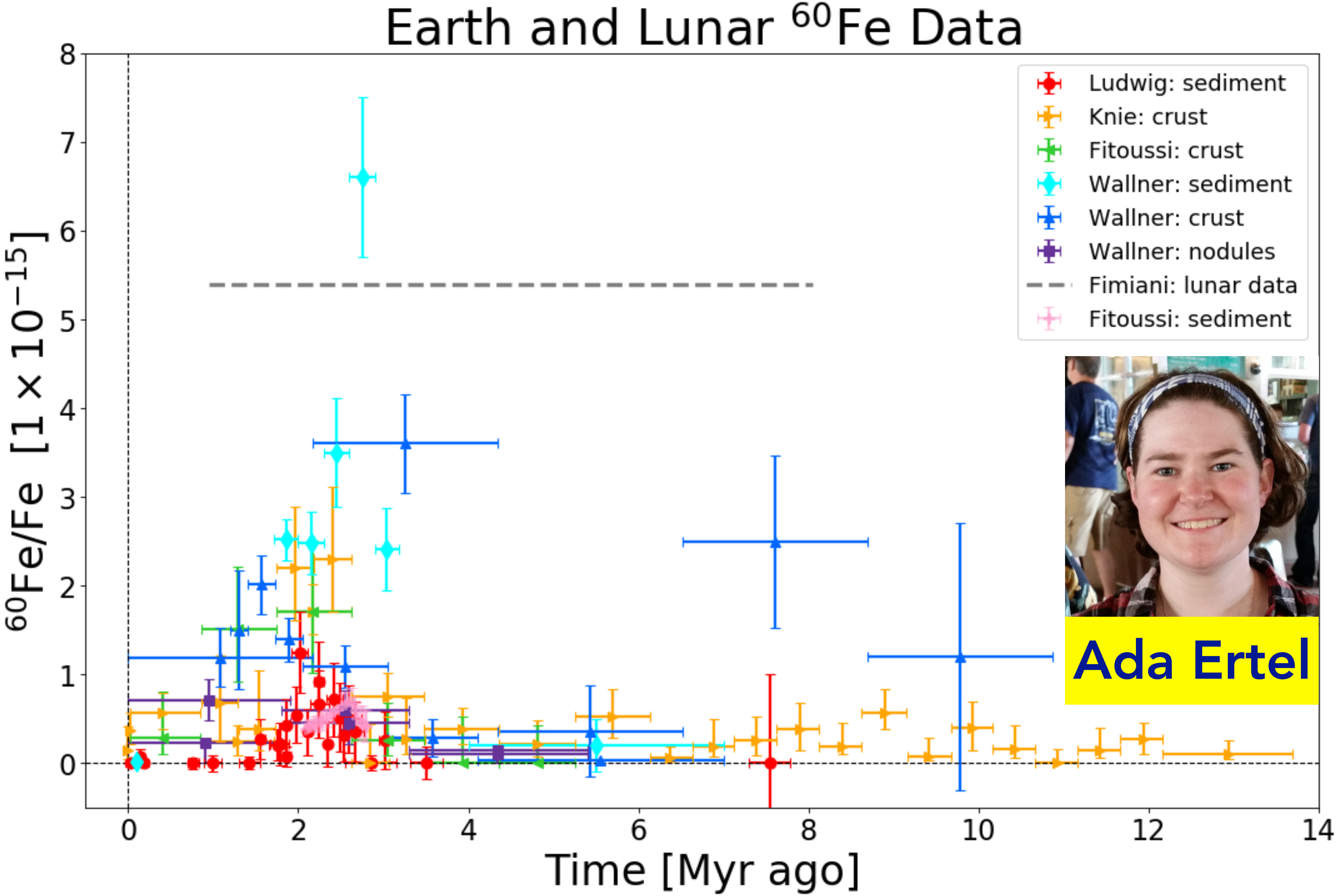
^{60}Fe data, first clear detection
^{60}Fe/Fe [1×10^{-15}]
8
7
6
5
4
3
2
1
0
0
2
4
6
8
10
12
14
Time [Myr ago]

AFTER

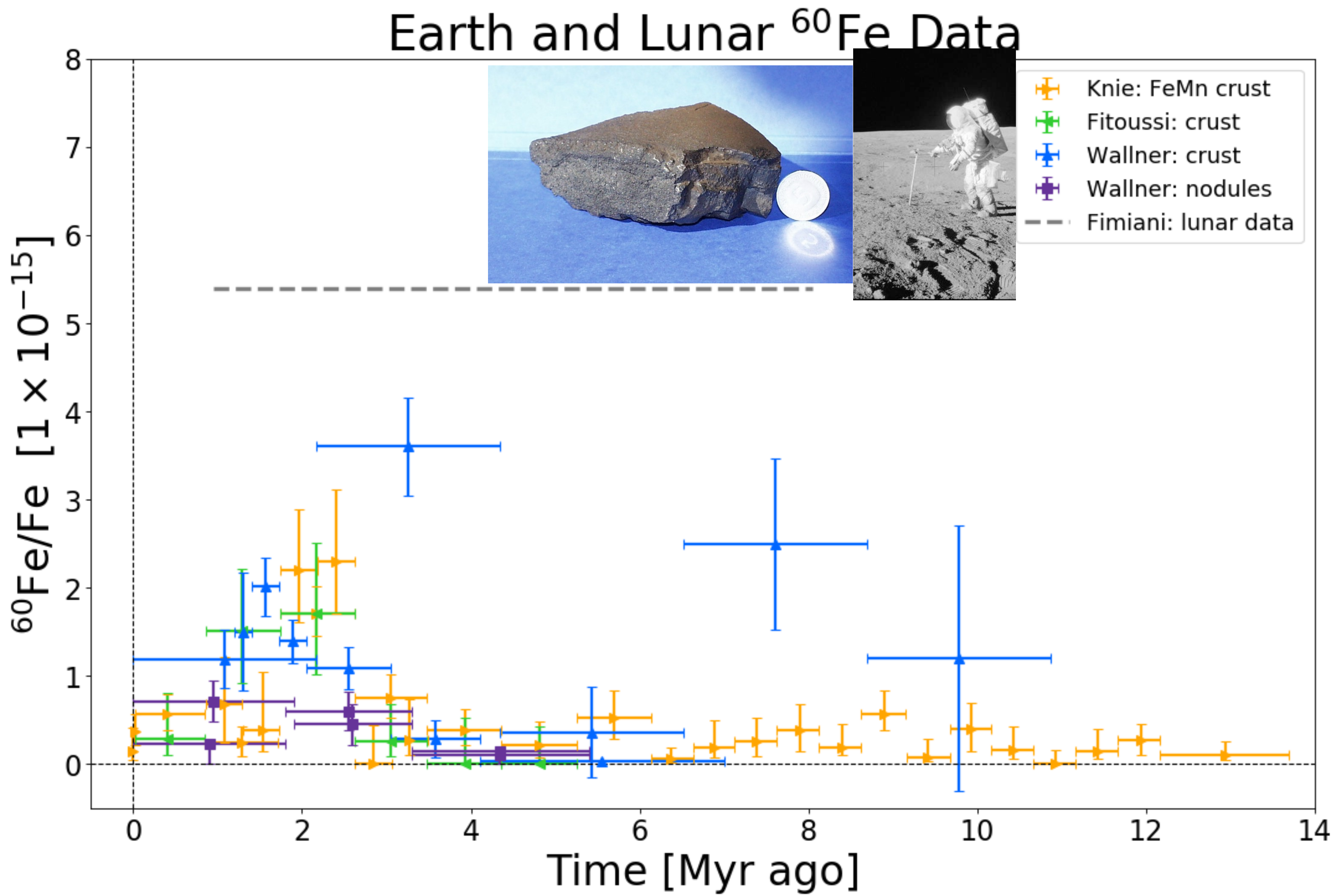


Earth and Lunar ^{60}Fe Data
^{60}Fe/Fe [1×10^{-15}]
Time [Myr ago]
Ludwig: sediment
Knie: crust
Fitoussi: crust
Wallner: sediment
Wallner: crust
Wallner: nodules
Fimiani: lunar data
Fitoussi: sediment
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14

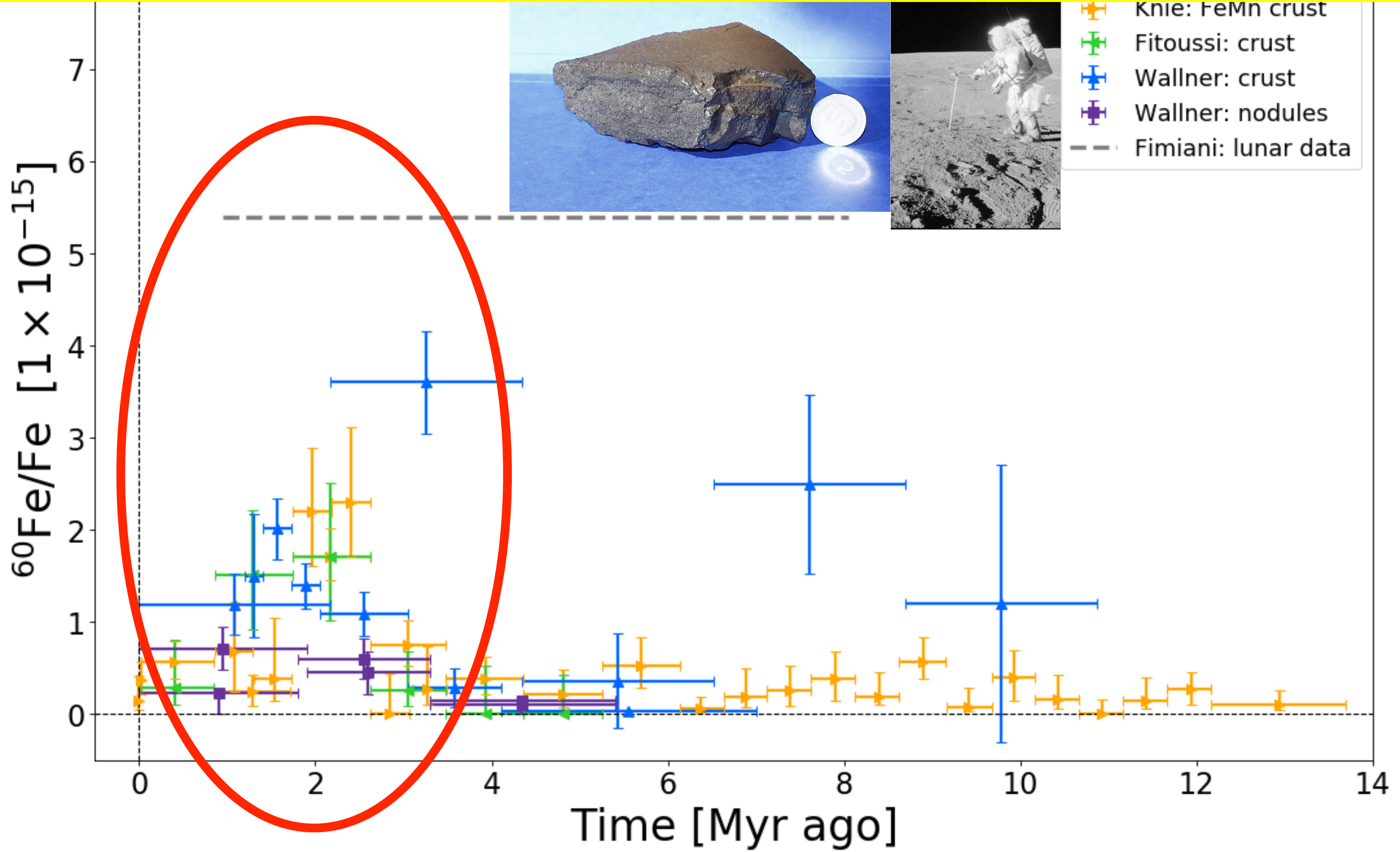
AFTER



Ada Ertel

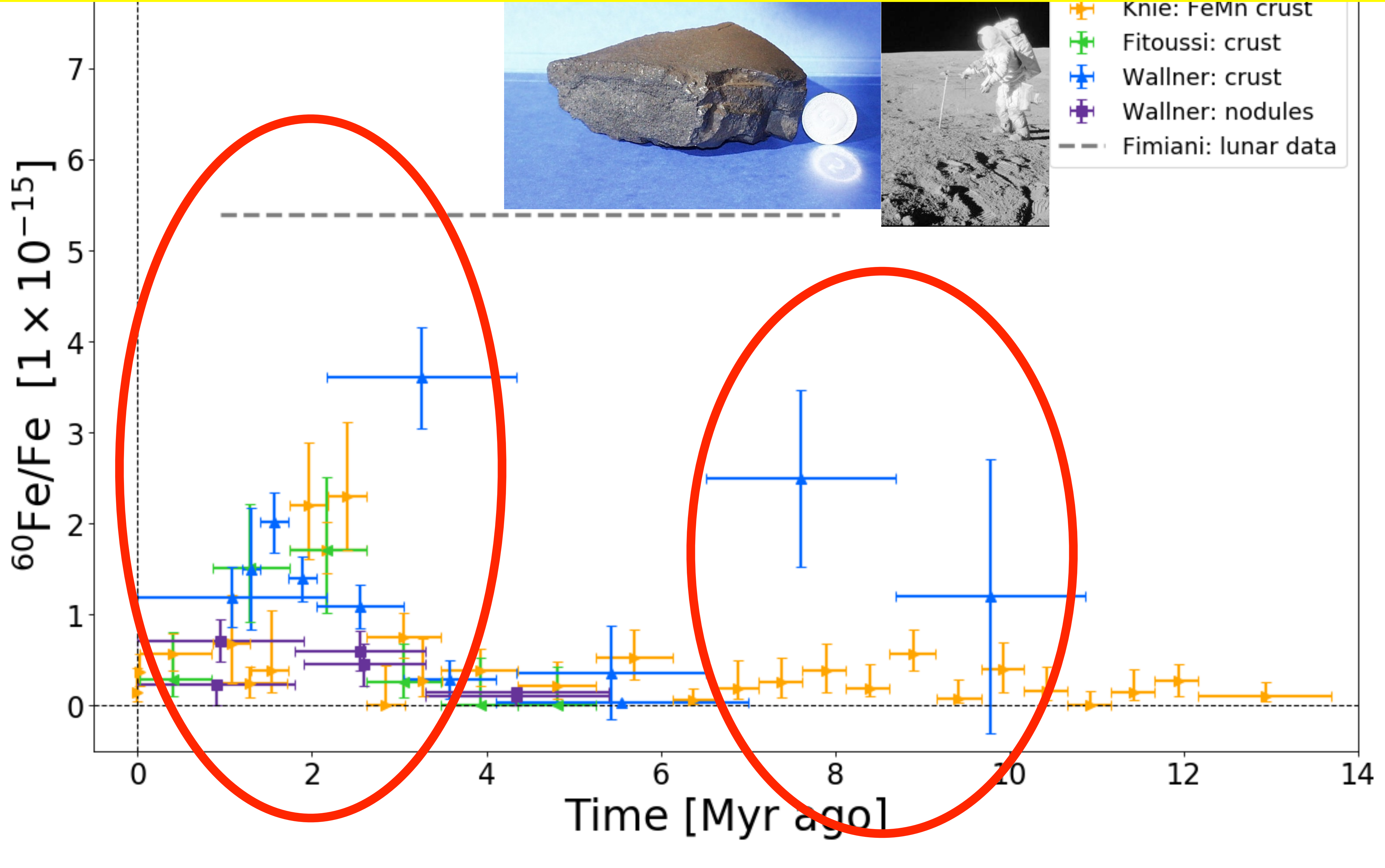

Earth and Lunar ^{60}Fe Data
Knie: FeMn crust
Fitoussi: crust
Wallner: crust
Wallner: nodules
Fimiani: lunar data
^{60}Fe/Fe [1×10^{-15}]
Time [Myr ago]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14

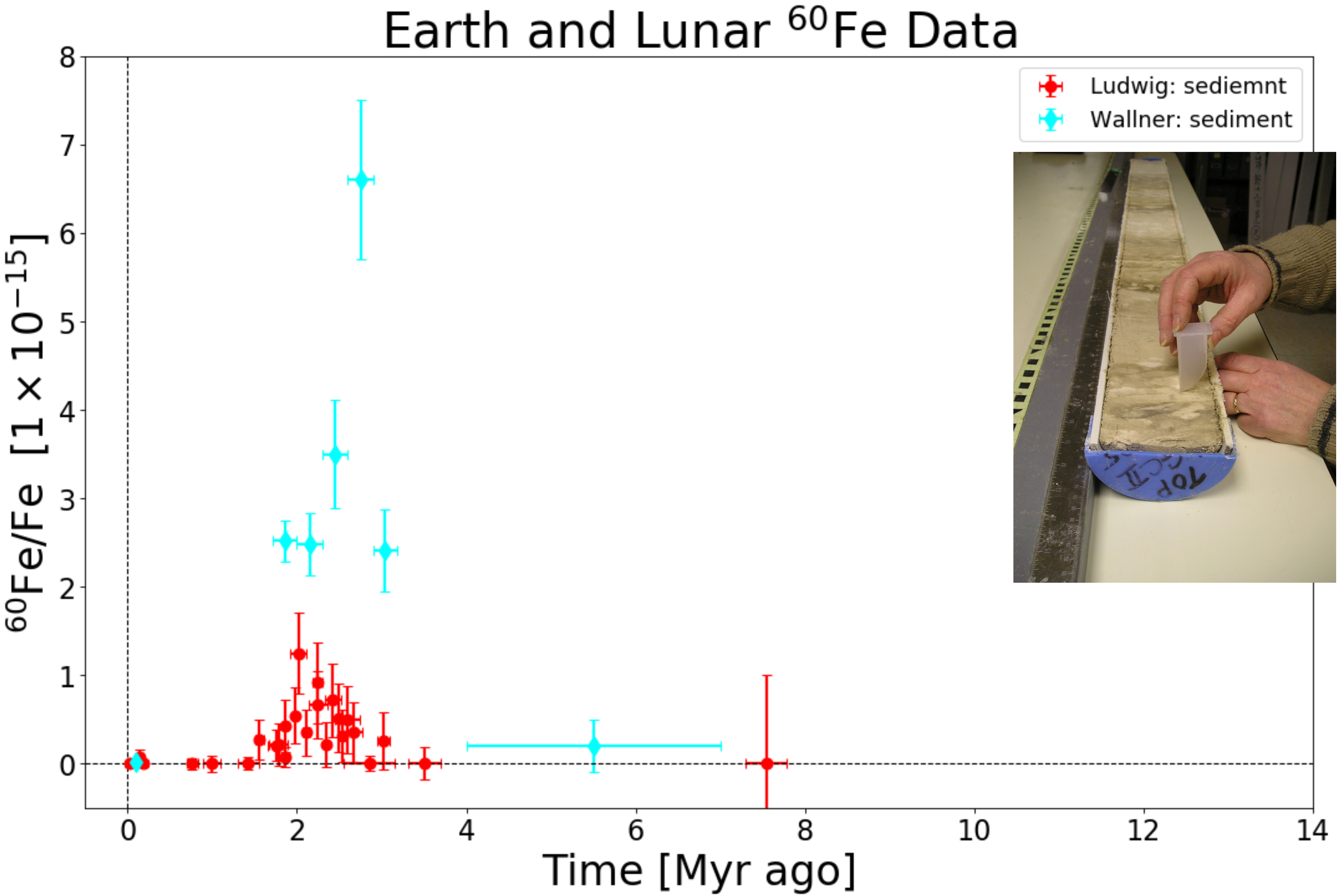
★confirmation of ^{60}Fe crust signal at 2-3 Myr



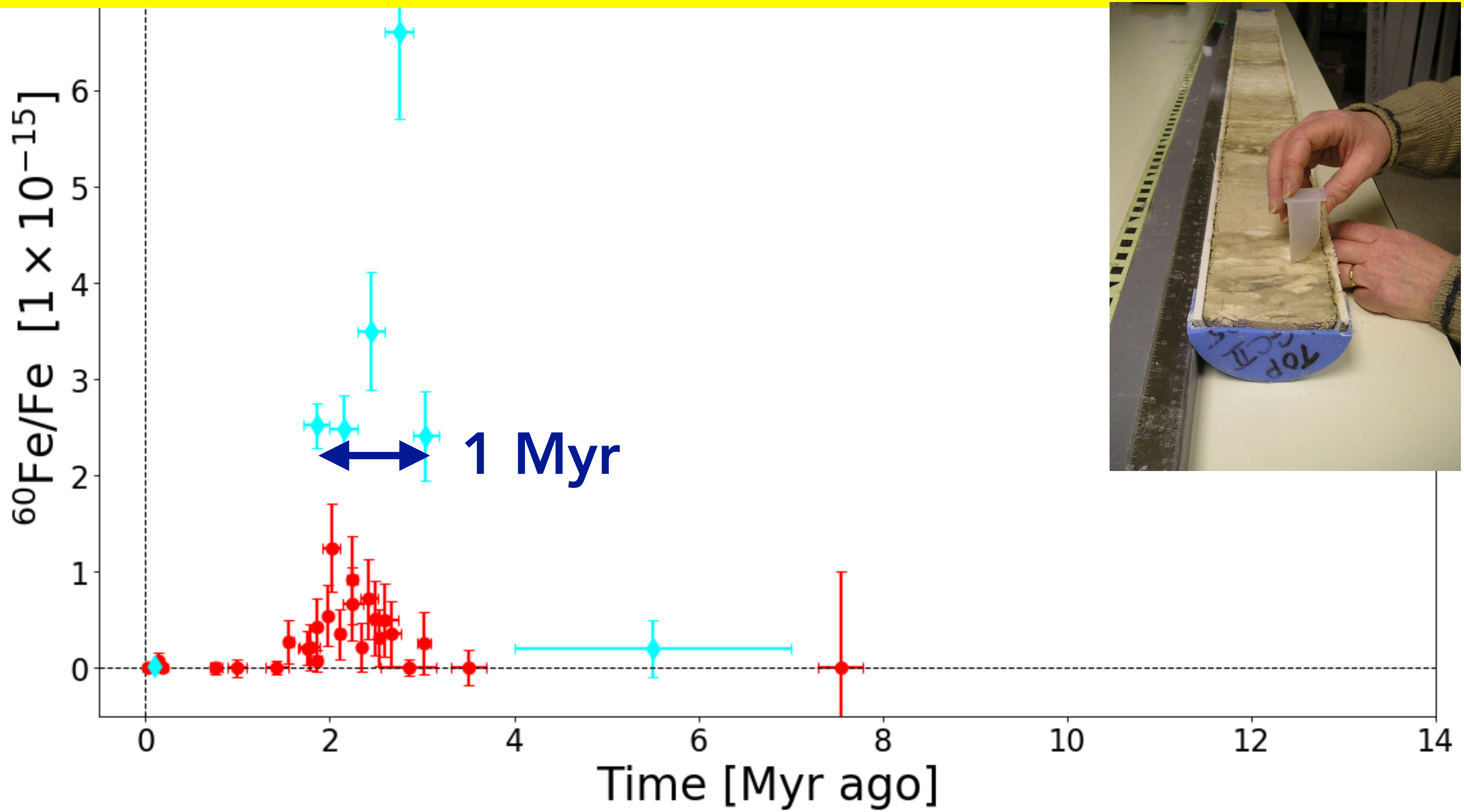
★confirmation of ^{60}Fe crust signal at 2-3 Myr

★another signal at ~8 Myr? ...now confirmed



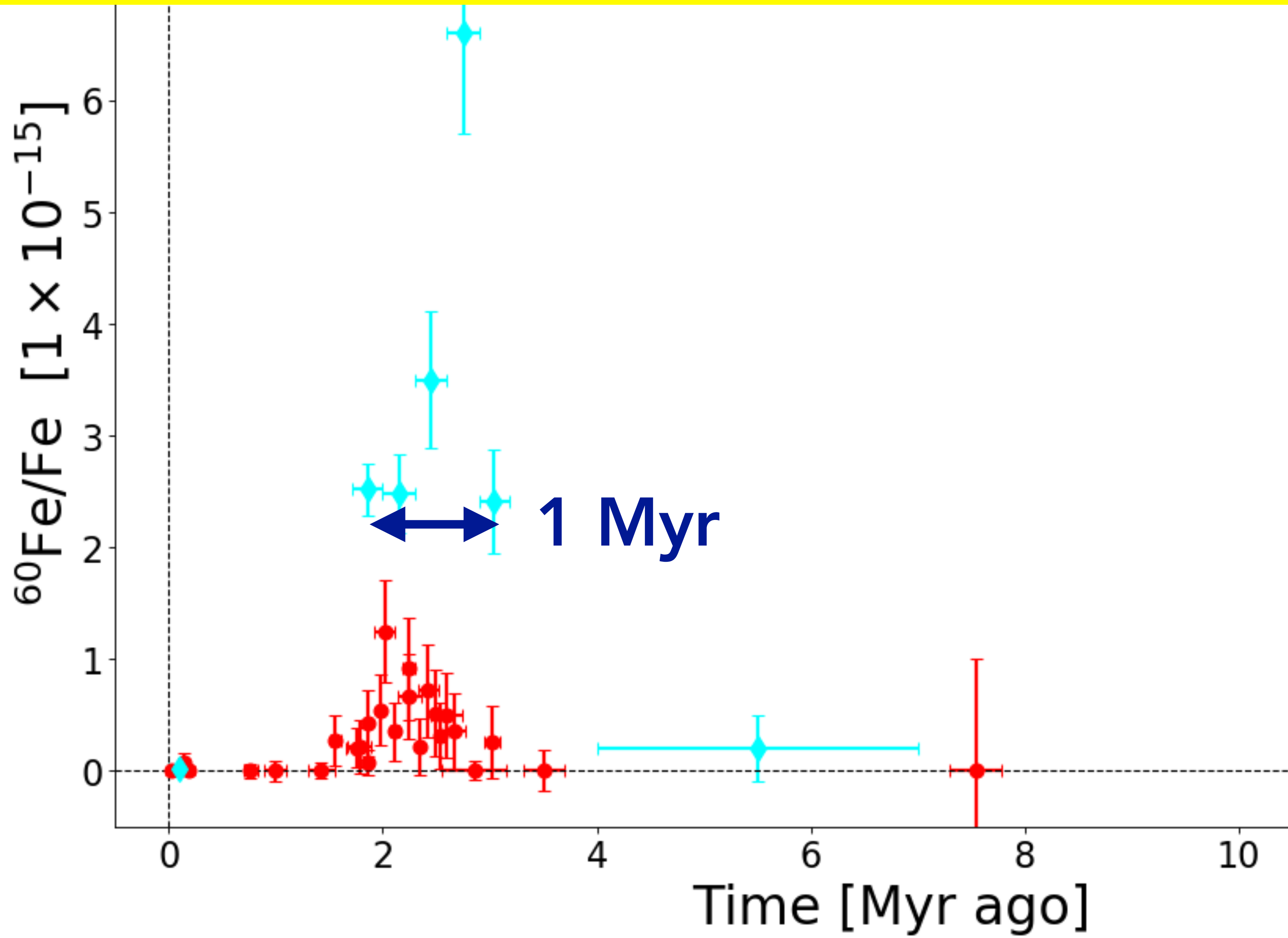

Earth and Lunar ^{60}Fe Data
^{60}Fe/Fe [1×10^{-15}]
Time [Myr ago]
Ludwig: sediemnt
Wallner: sediment
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14

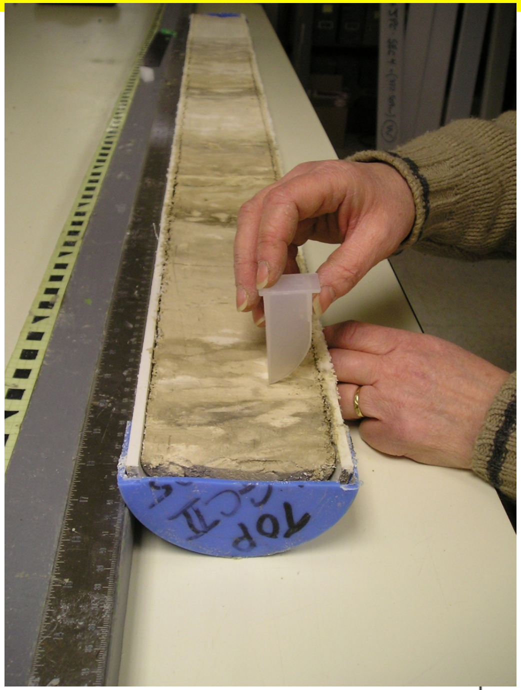
★^{60}Fe flux duration ~1 Myr



★^{60}Fe flux duration ~1 Myr

★far exceeds Sedov prediction!?! Fry+ 2015

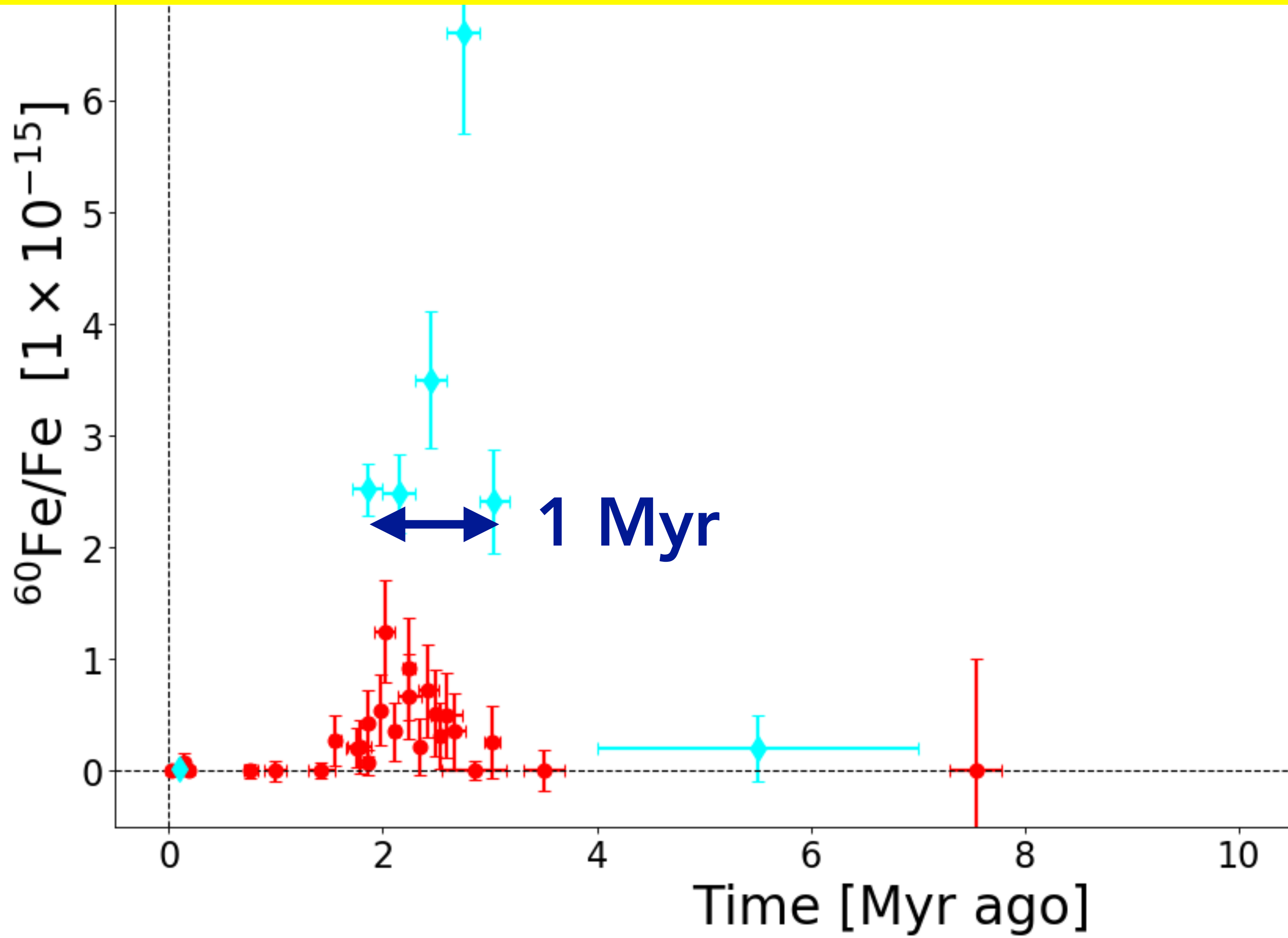


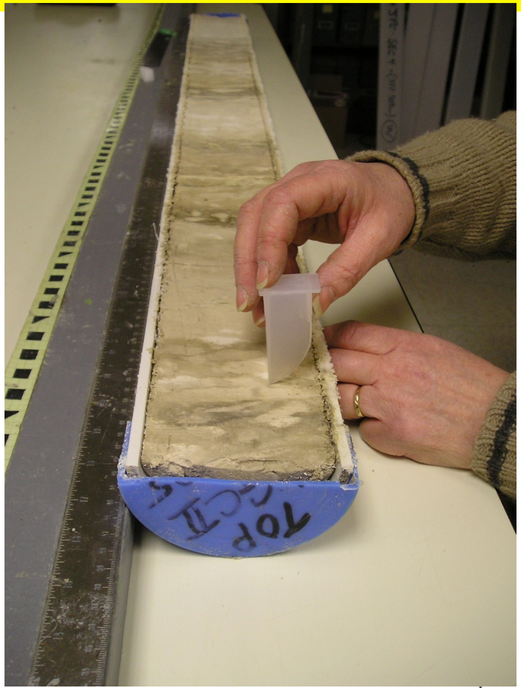


★^{60}Fe flux duration ~1 Myr

★far exceeds Sedov prediction!?! Fry+ 2015

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





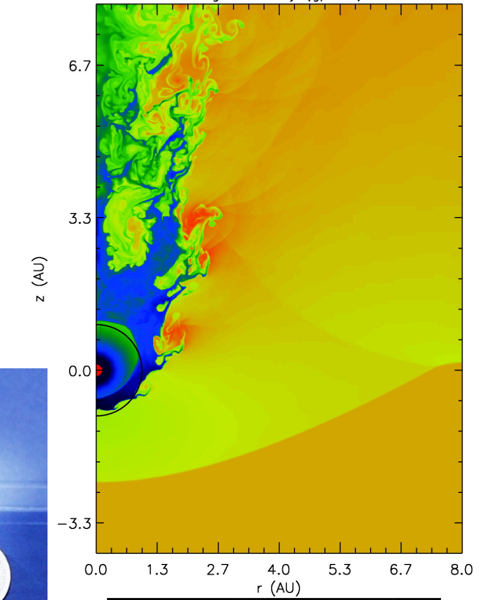
CONCLUSION

CONCLUSION

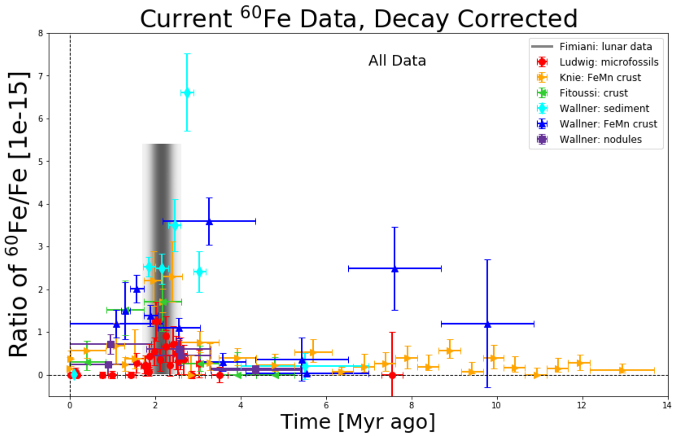
THIS IS A THING

new probe for astronomy, astrophysics, geology, biology…

Outlook



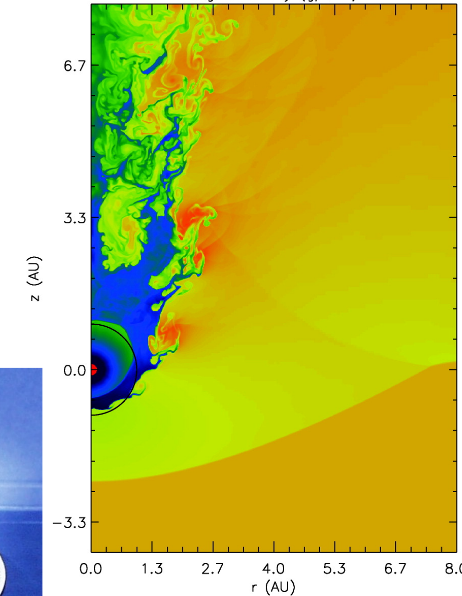
6.7
3.3
0.0
−3.3
z (AU)
0.0 1.3 2.7 4.0 5.3 6.7 8.0
r (AU)

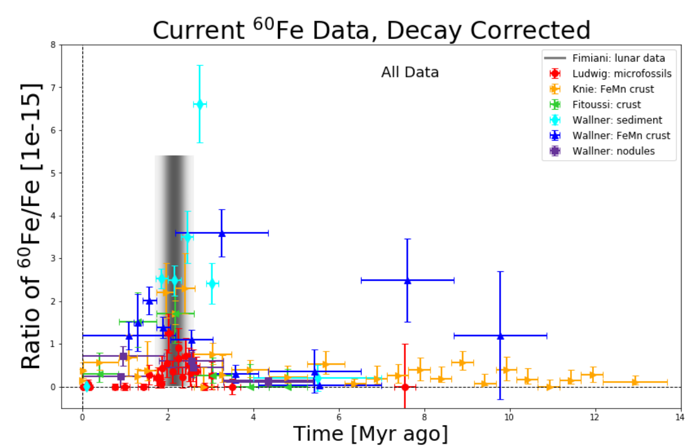


Current ^{60}Fe Data, Decay Corrected
All Data
Fimiani: lunar data
Ludwig: microfossils
Knie: FeMn crust
Fitoussi: crust
Wallner: sediment
Wallner: FeMn crust
Wallner: nodules
Ratio of ^{60}Fe/Fe [1e-15]
Time [Myr ago]

Outlook

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

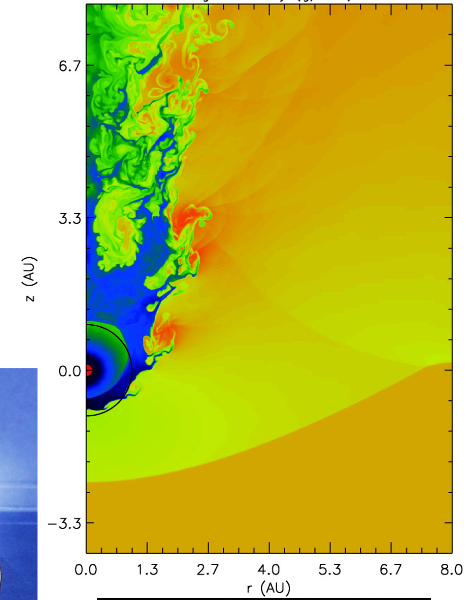


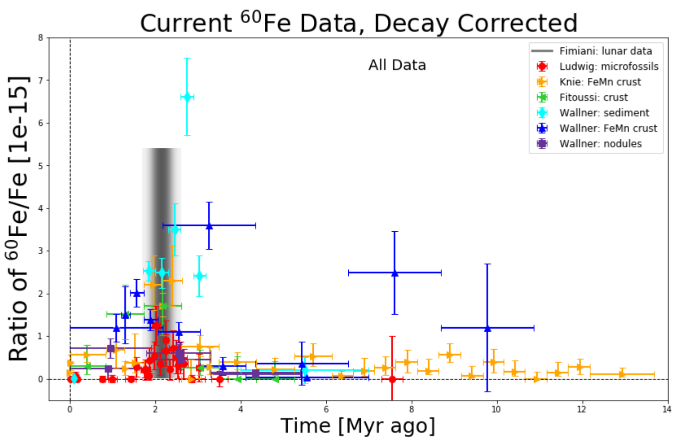


Outlook

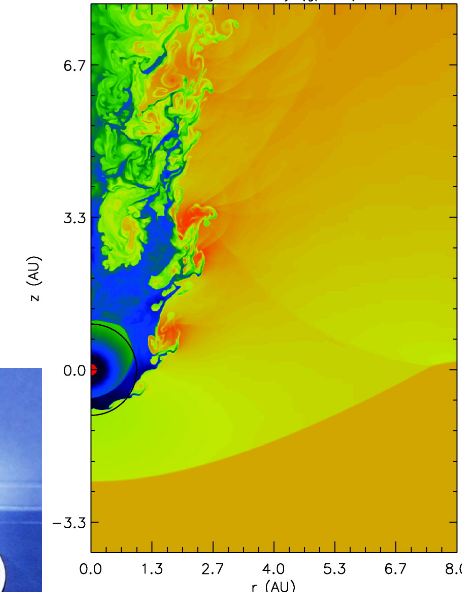
Live ^{60}Fe seen globally and on the Moon

- ★ 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 ?!?
- ★ evidence for lunar signal—directionality?
- ★ Source of Local Bubble?





Outlook



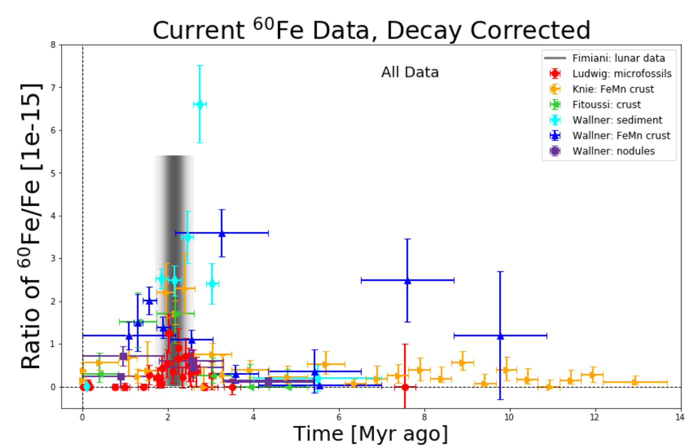
Live ^{60}Fe seen globally and on the Moon

- ★ 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 ?!?
- ★ evidence for lunar signal—directionality?
- ★ Source of Local Bubble?

Birth of “Supernova Archaeology"

Implications across disciplines:

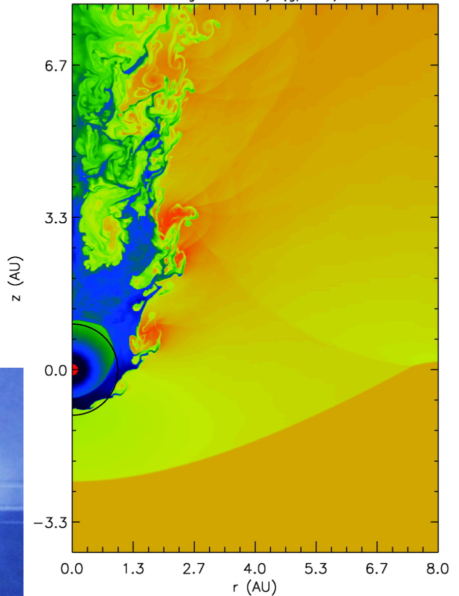
nucleosynthesis, cosmic dust, stellar evolution, bio evolution, astrobiology



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 ?!?
- ★ evidence for lunar signal—directionality?
- ★ Source of Local Bubble?



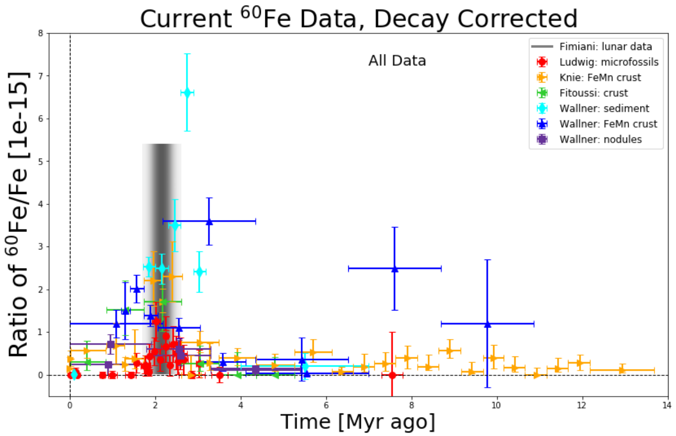
Birth of "Supernova Archaeology"

Implications across disciplines:

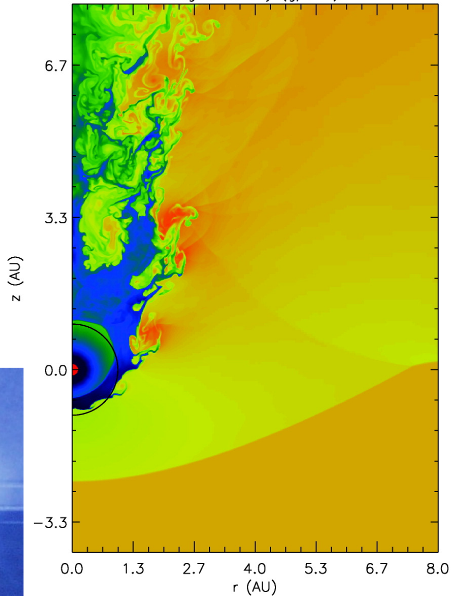
nucleosynthesis, cosmic dust, stellar evolution, bio evolution, astrobiology

Future Research

- Supernova(e) origin and direction
  - ★ lunar distribution
  - ★ cosmic-ray anisotropies, ^{60}Fe excess
  - ★ neutron star/pulsar correlation
  - ★ dust production, evolution, dynamics



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 ?!?
- ★ evidence for lunar signal—directionality?
- ★ Source of Local Bubble?

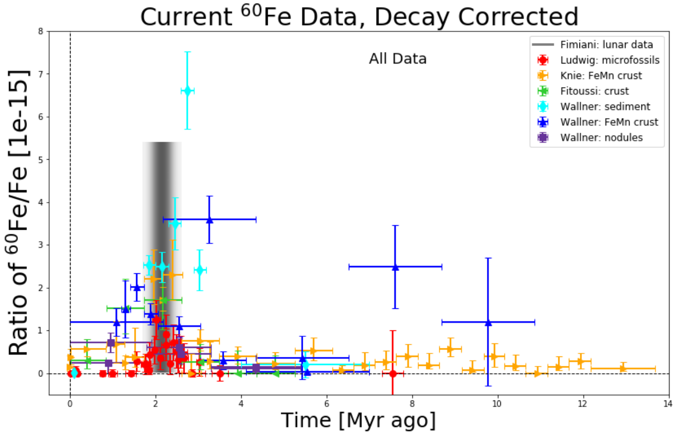
Birth of "Supernova Archaeology"

Implications across disciplines:

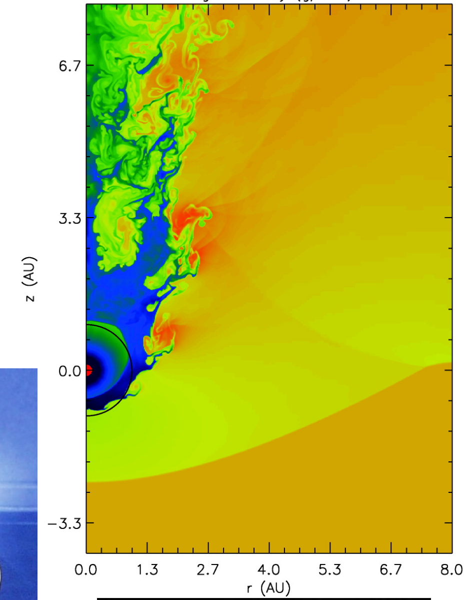
nucleosynthesis, cosmic dust, stellar evolution, bio evolution, astrobiology

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
  - ✓ other media (fossil bacteria)
  - ✓ other sites: back to the Moon!



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 ?!?
- ★ evidence for lunar signal—directionality?
- ★ Source of Local Bubble?

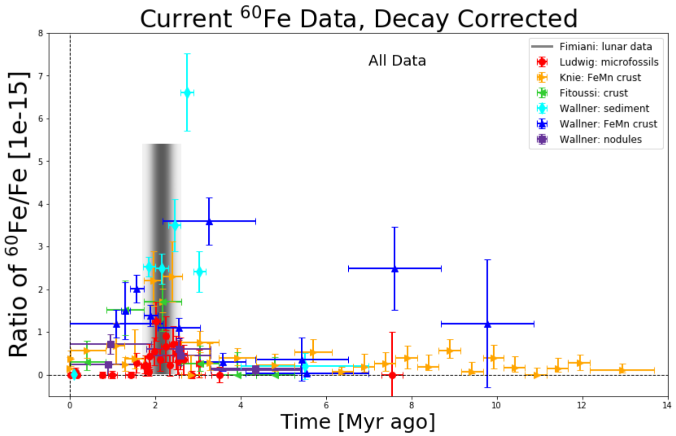
Birth of “Supernova Archaeology"

Implications across disciplines:

nucleosynthesis, cosmic dust, stellar evolution, bio evolution, astrobiology

Future Research

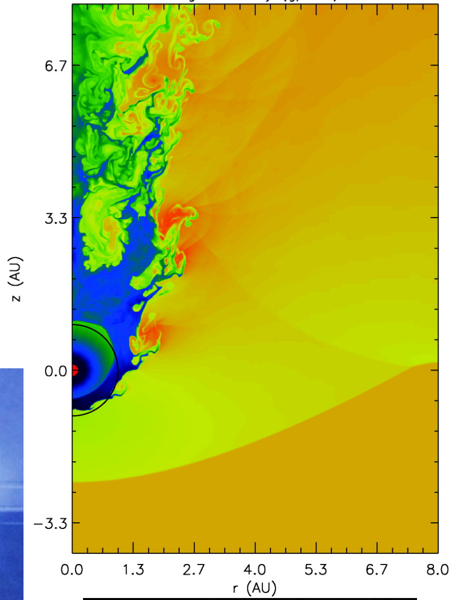
- Supernova(e) origin and direction
  - ★ lunar distribution
  - ★ cosmic-ray anisotropies, ^{60}Fe excess
  - ★ neutron star/pulsar correlation
  - ★ dust production, evolution, dynamics
- more, different samples:
  - ✓ other isotopes
  - ✓ other media (fossil bacteria)
  - ✓ other sites: back to the Moon!
- other epochs? Mass extinction correlations?



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 ?!?
- ★ evidence for lunar signal—directionality?
- ★ Source of Local Bubble?



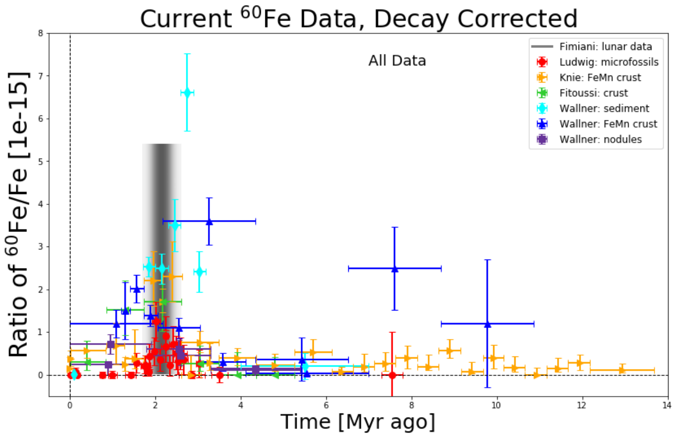
Birth of "Supernova Archaeology"

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
  - ✓ other media (fossil bacteria)
  - ✓ other sites: back to the Moon!
- other epochs? Mass extinction correlations?
- stay tuned…Midwest SN 202x!



Whodunit?
The Moon as a Telescope

Fry, BDF, & Ellis (2016)

- ★ ^{60}Fe dust grains nearly undeflected in Solar System

Whodunit?
The Moon as a Telescope

Fry, BDF, & Ellis (2016)

- ^{60}Fe dust grains nearly undeflected in Solar System
- Earth:

Whodunit?
The Moon as a Telescope

Fry, BDF, & Ellis (2016)

- ★ ^{60}Fe dust grains nearly undeflected in Solar System
- ★ Earth:
  - stratosphere scrambles

Whodunit?
The Moon as a Telescope

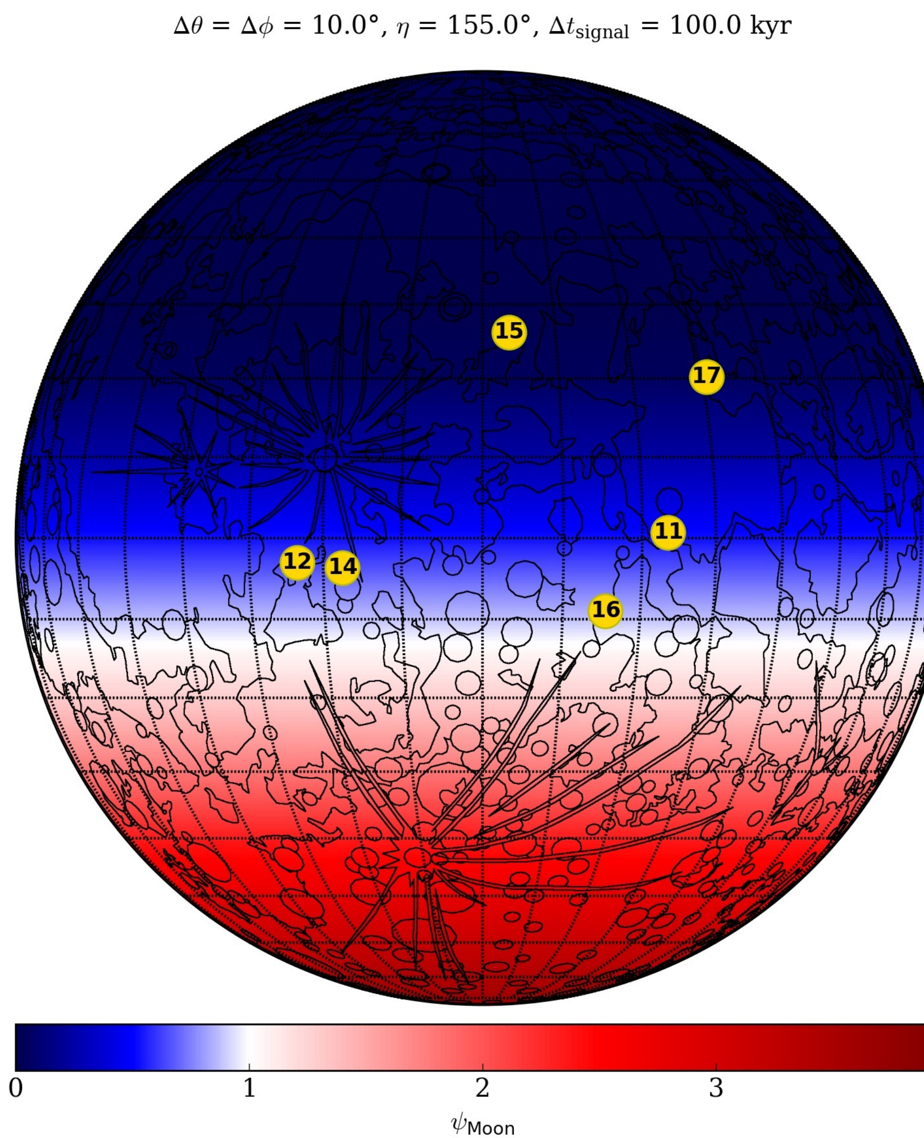
Fry, BDF, & Ellis (2016)

- ★ ^{60}Fe dust grains nearly undeflected in Solar System
- ★ Earth:
  - – stratosphere scrambles
- ★ Moon is airless:

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!



Whodunit?

Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

Whodunit?

Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- Type Ia supernovae
- AGB stars
- kilonovae
- impactor Wallner+ 16; Miller & BDF 18

Whodunit?

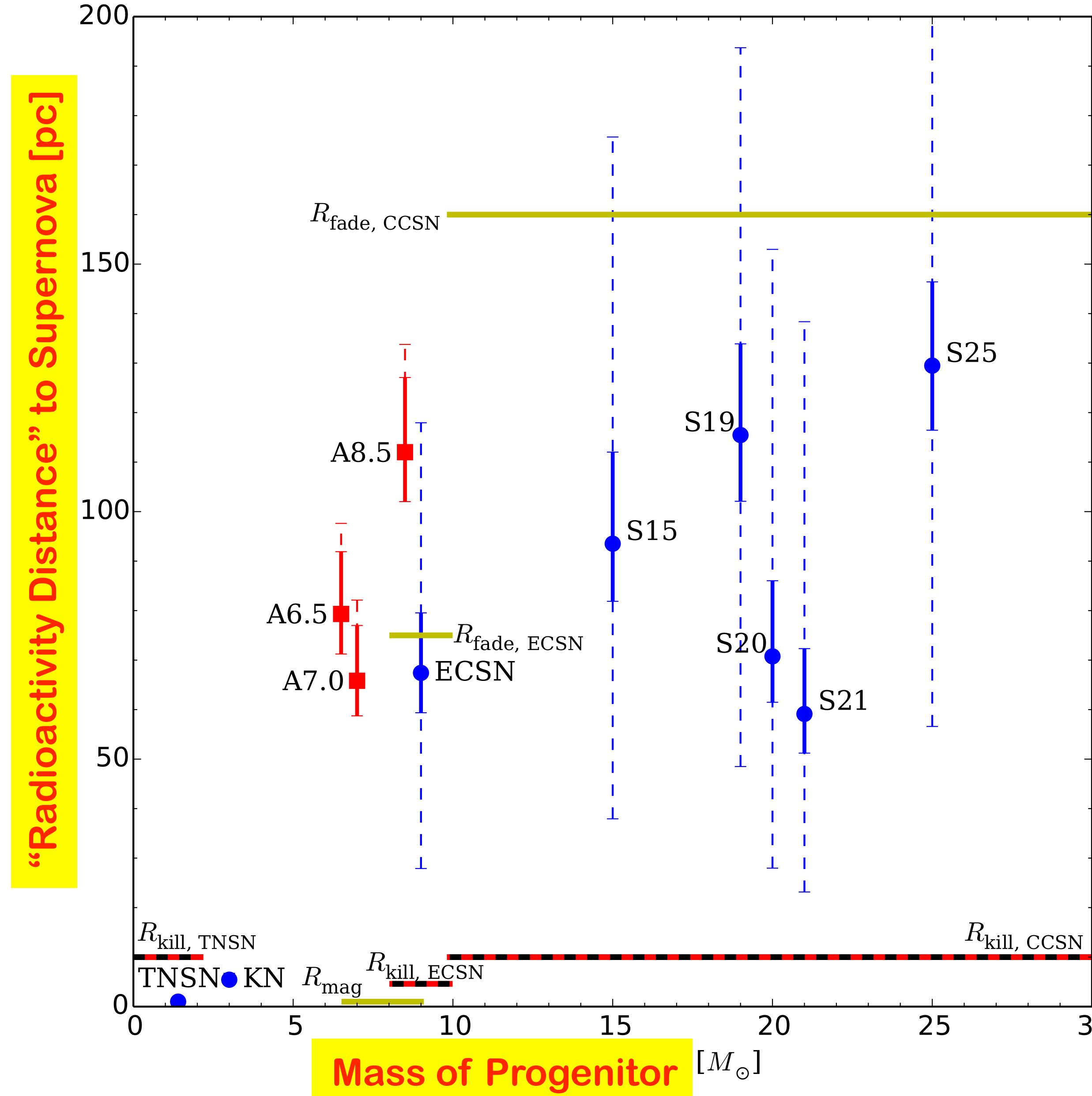
Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- Type Ia supernovae
- AGB stars
- kilonovae
- impactor Wallner+ 16; Miller & BDF 18



Whodunit?

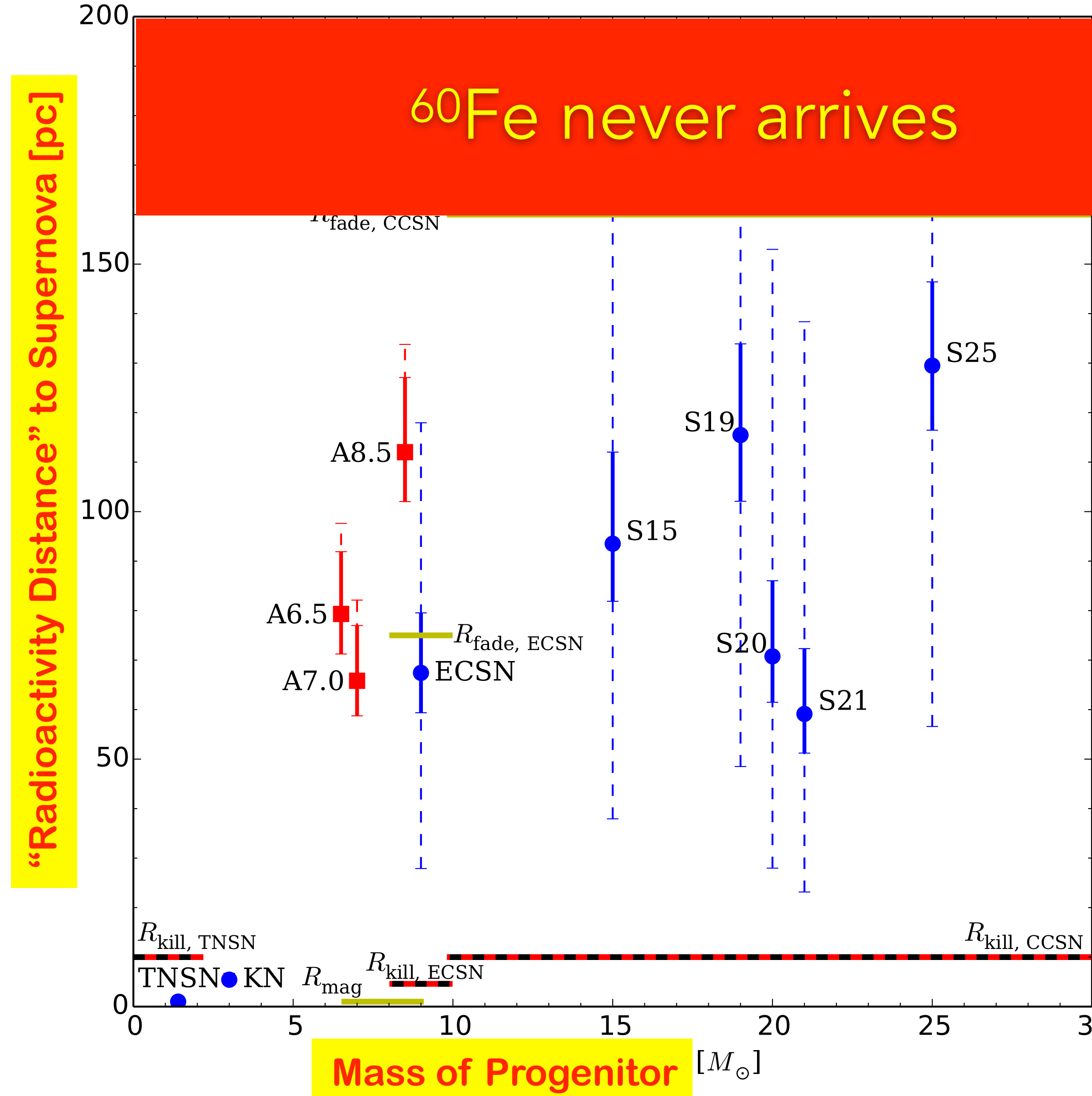
Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- Type Ia supernovae
- AGB stars
- kilonovae
- impactor Wallner+ 16; Miller & BDF 18



Whodunit?

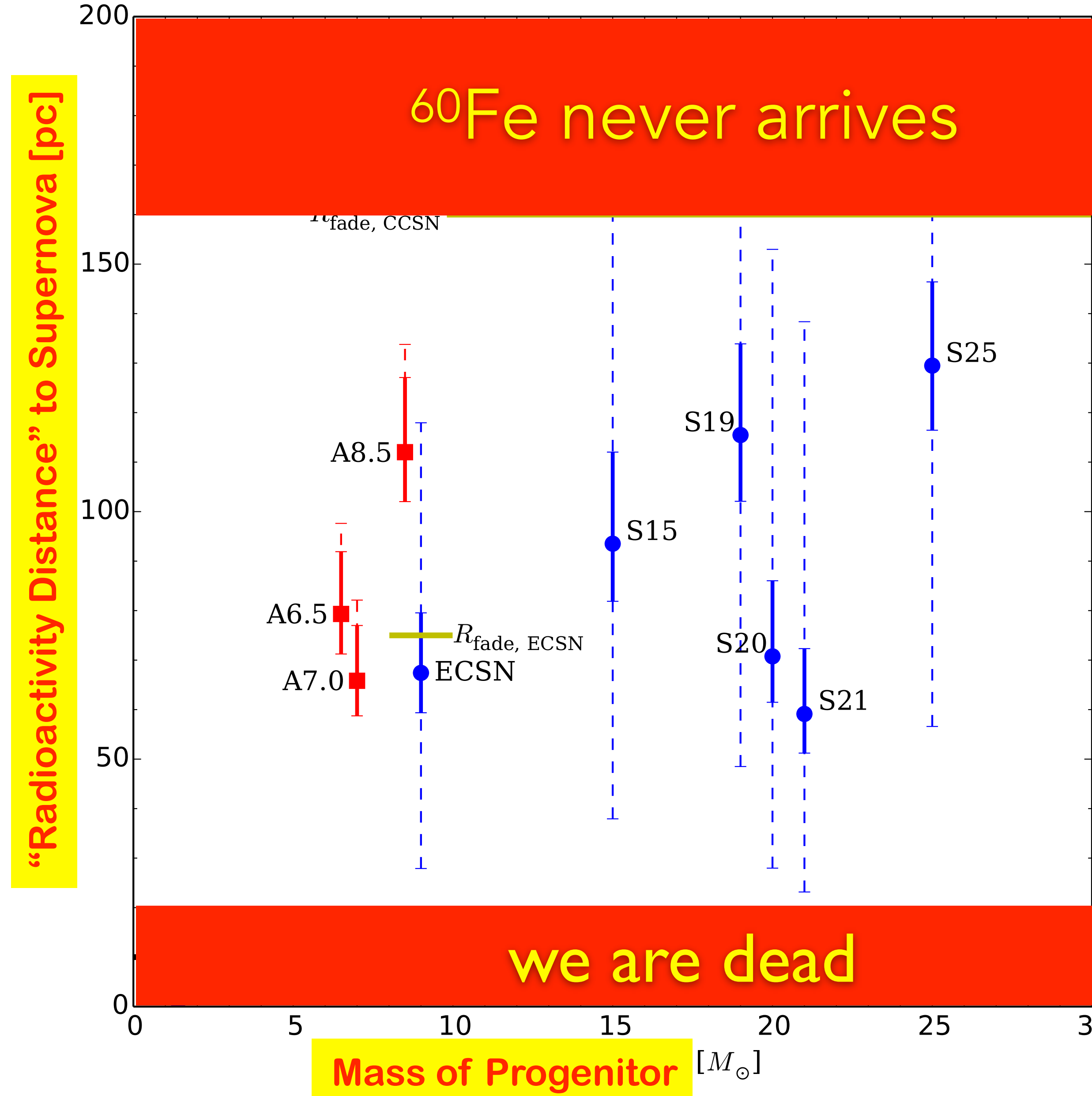
Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- Type Ia supernovae
- AGB stars
- kilonovae
- impactor Wallner+ 16; Miller & BDF 18



Whodunit?

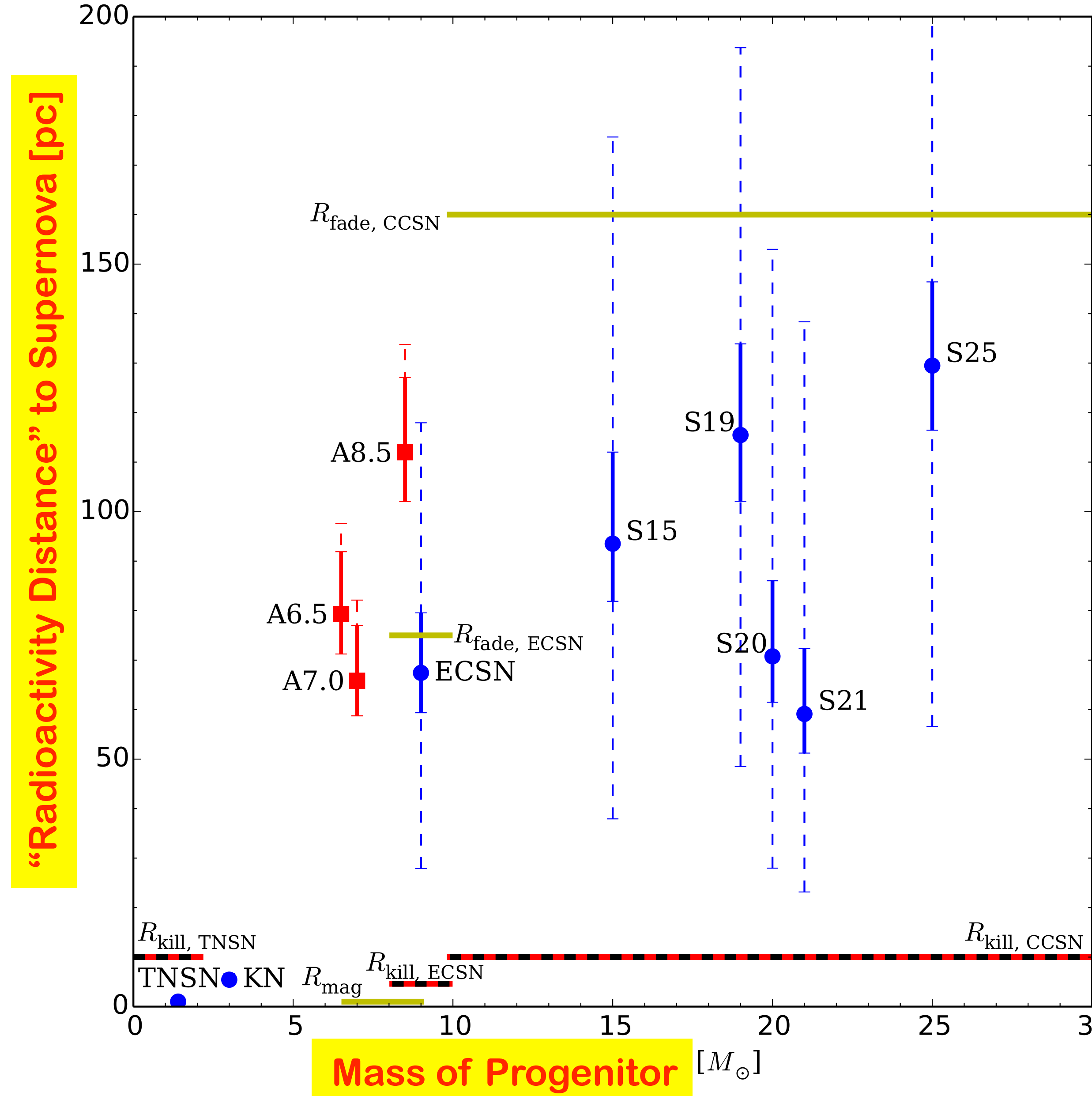
Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- Type Ia supernovae
- AGB stars
- kilonovae
- impactor Wallner+ 16; Miller & BDF 18



Whodunit?

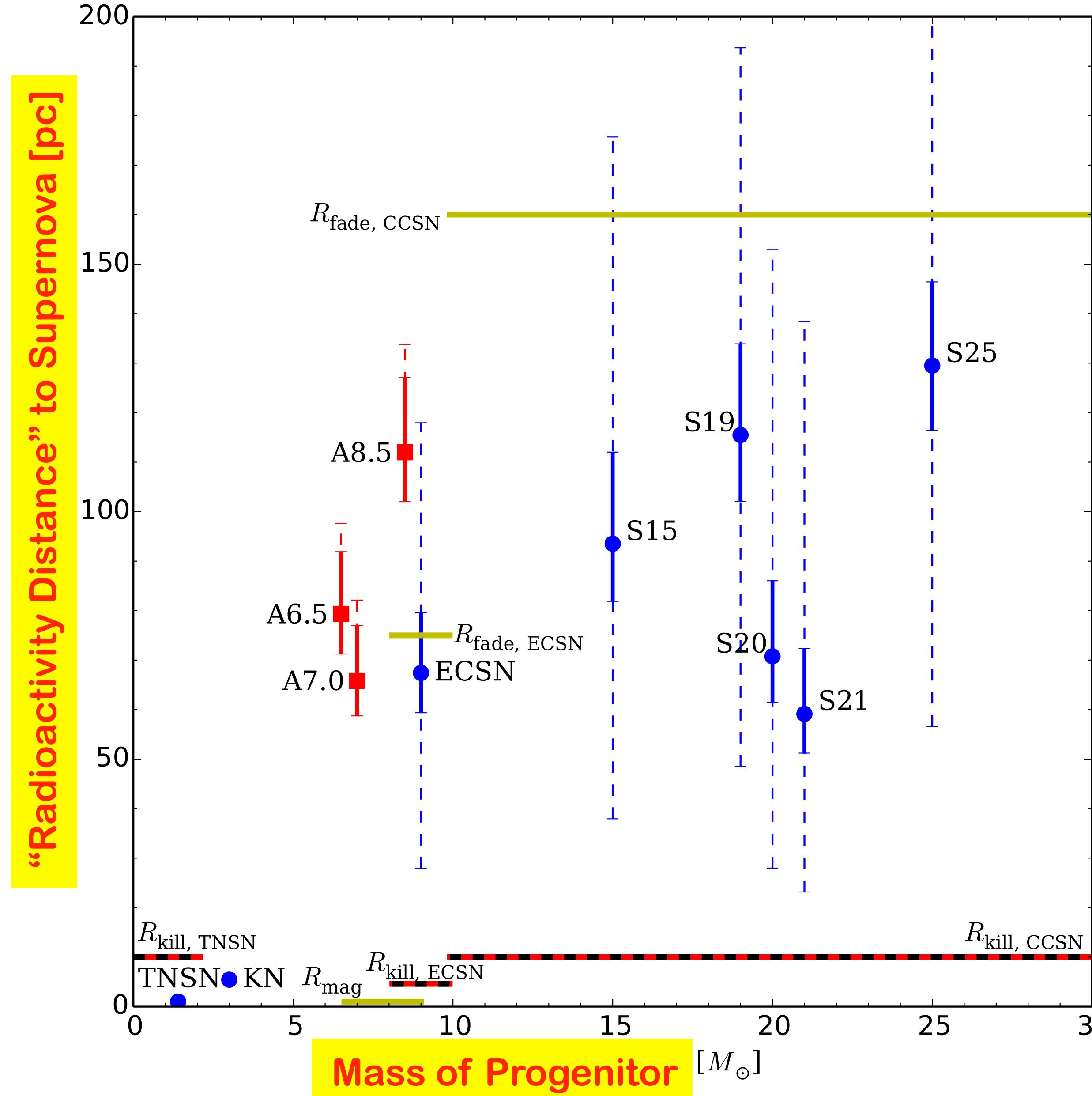
Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- ~~Type Ia supernovae~~
- AGB stars
- kilonovae
- impactor Wallner+ 16; Miller & BDF 18



Whodunit?

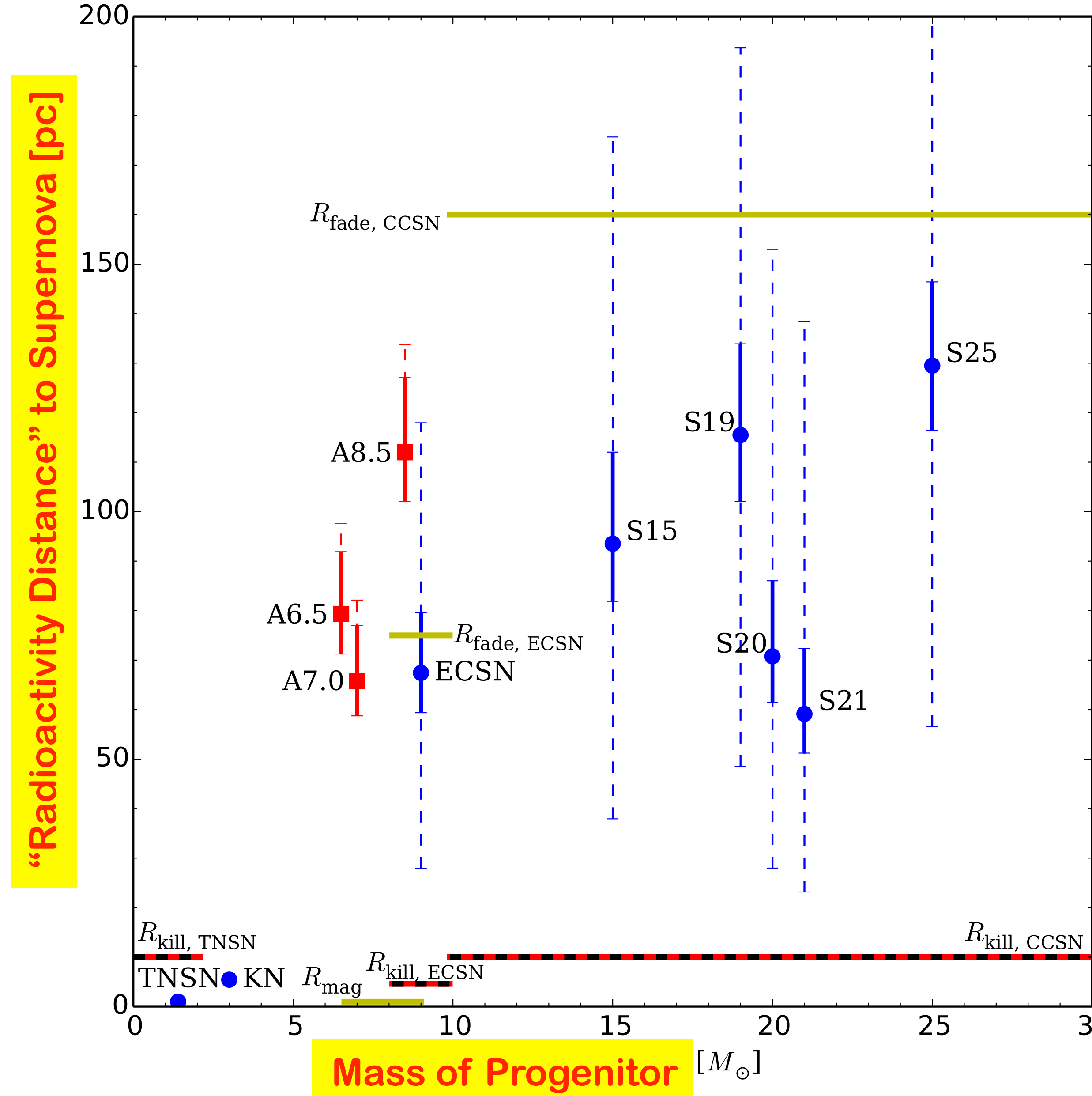
Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- ~~Type Ia supernovae~~
- AGB stars
- ~~kilonovae~~
- impactor Wallner+ 16; Miller & BDF 18



Whodunit?

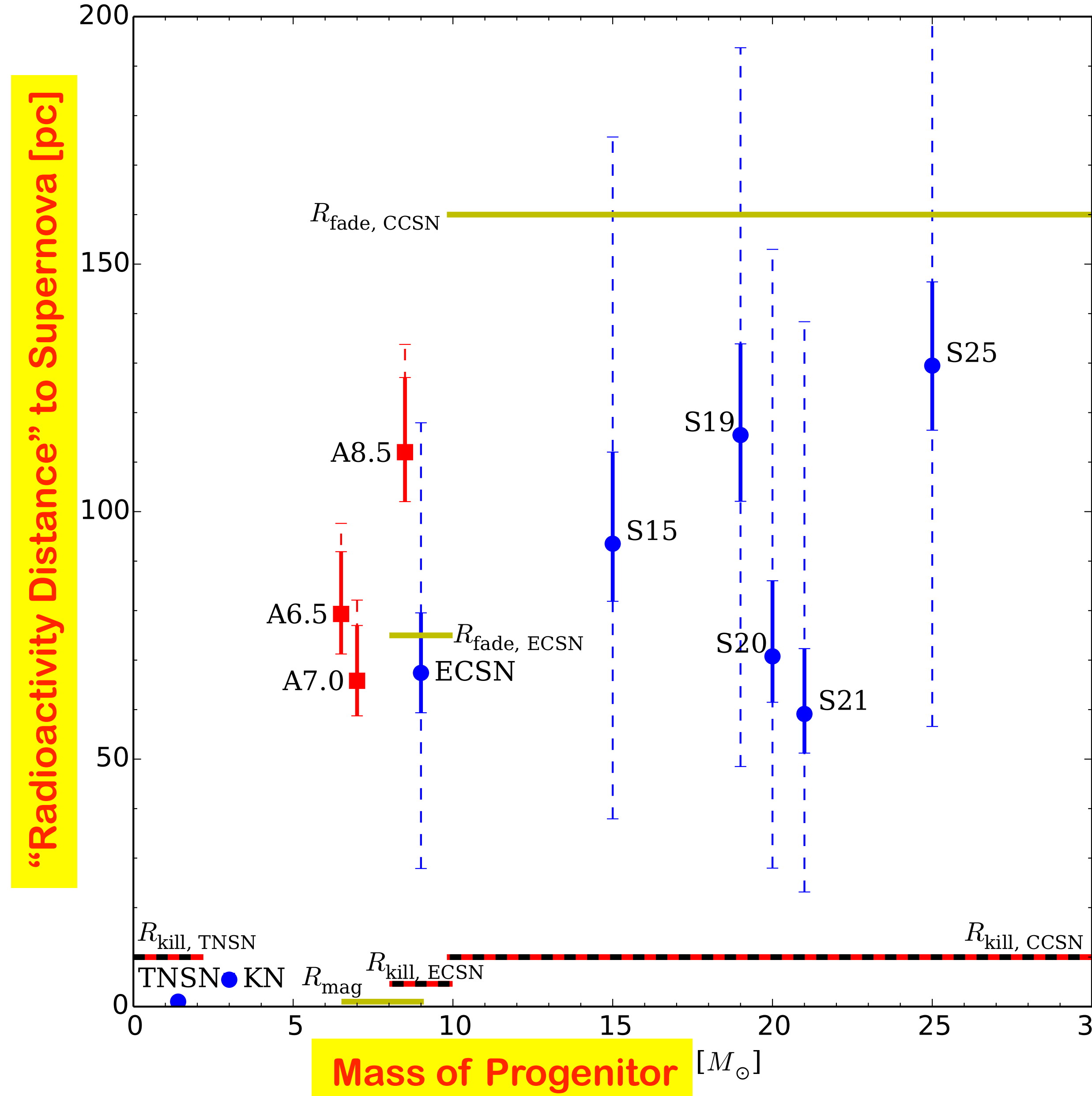
Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- ~~Type Ia supernovae~~
- ~~AGB stars~~
- ~~kilonovae~~
- impactor Wallner+ 16; Miller & BDF 18



Whodunit?

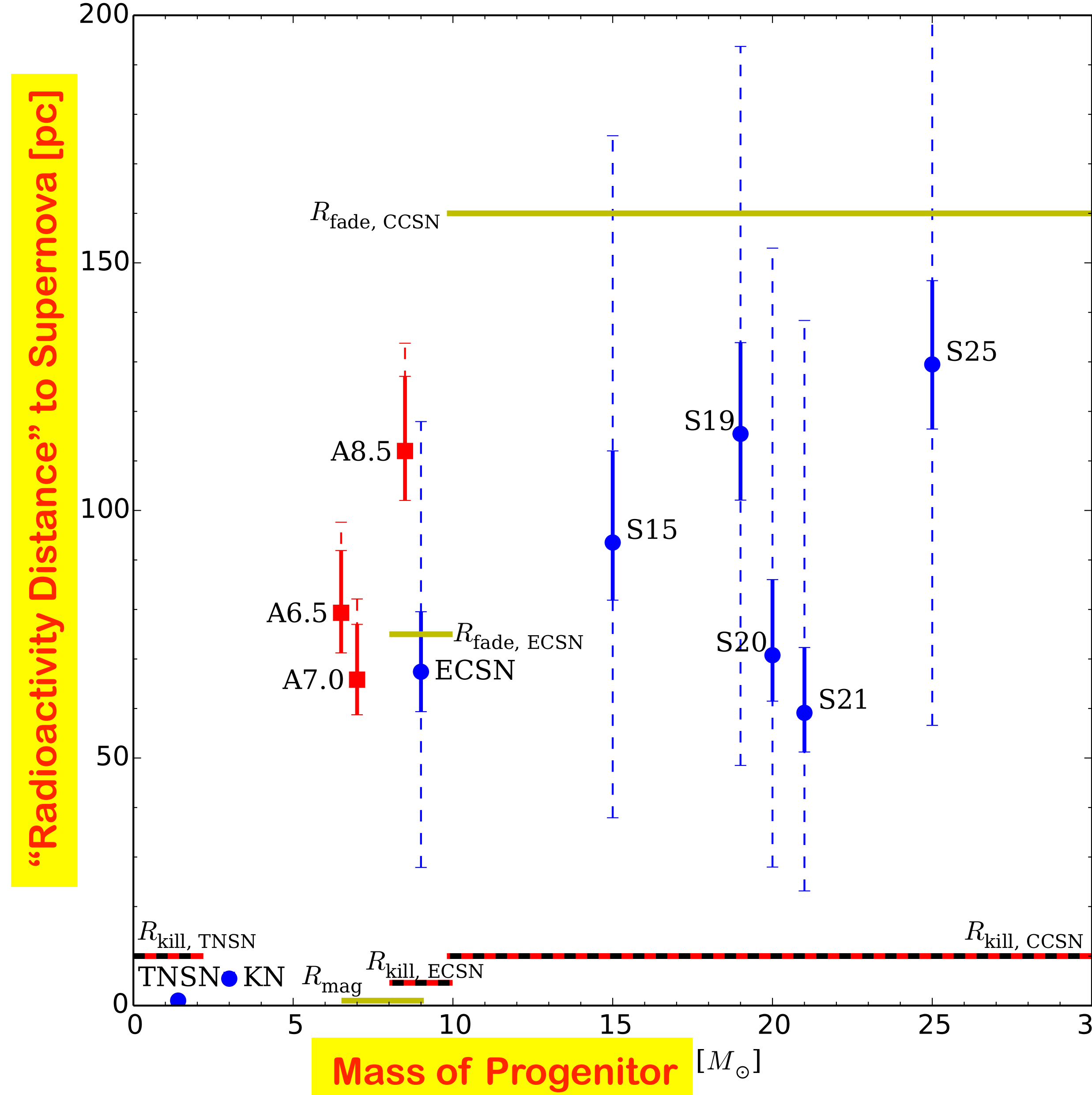
Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- ~~Type Ia supernovae~~
- ~~AGB stars~~
- ~~kilonovae~~
- ~~impactor~~ Wallner+ 16; Miller & BDF 18



Whodunit?

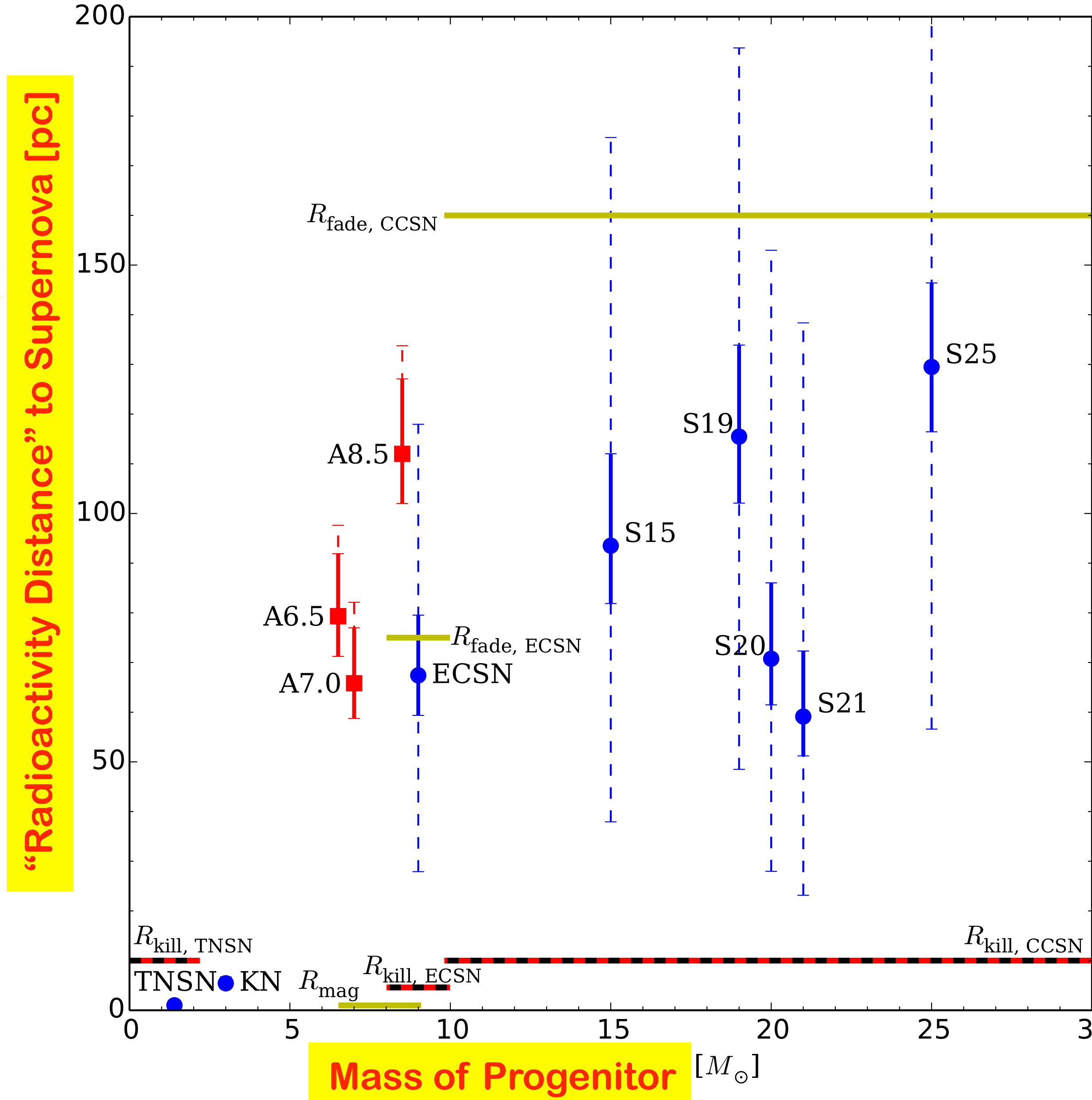
Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- ~~Type Ia supernovae~~
- ~~AGB stars~~
- ~~kilonovae~~
- ~~impactor~~ Wallner+ 16; Miller & BDF 18



Whodunit?

Fry, BDF, & Ellis 2015

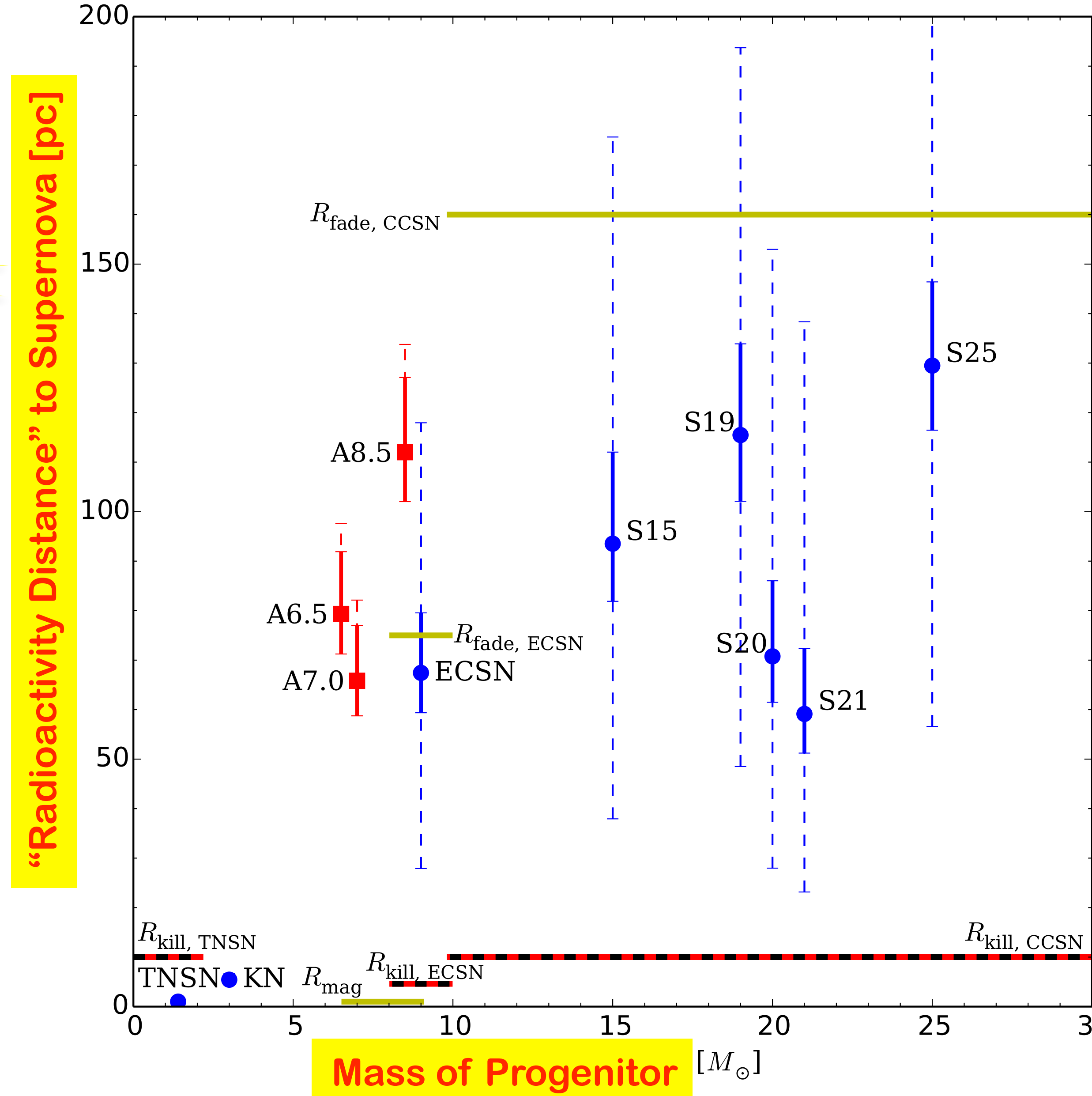
"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- ~~Type Ia supernovae~~
- ~~AGB stars~~
- ~~kilonovae~~
- ~~impactor~~ Wallner+ 16; Miller & BDF 18

SN distance:



Whodunit?

Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

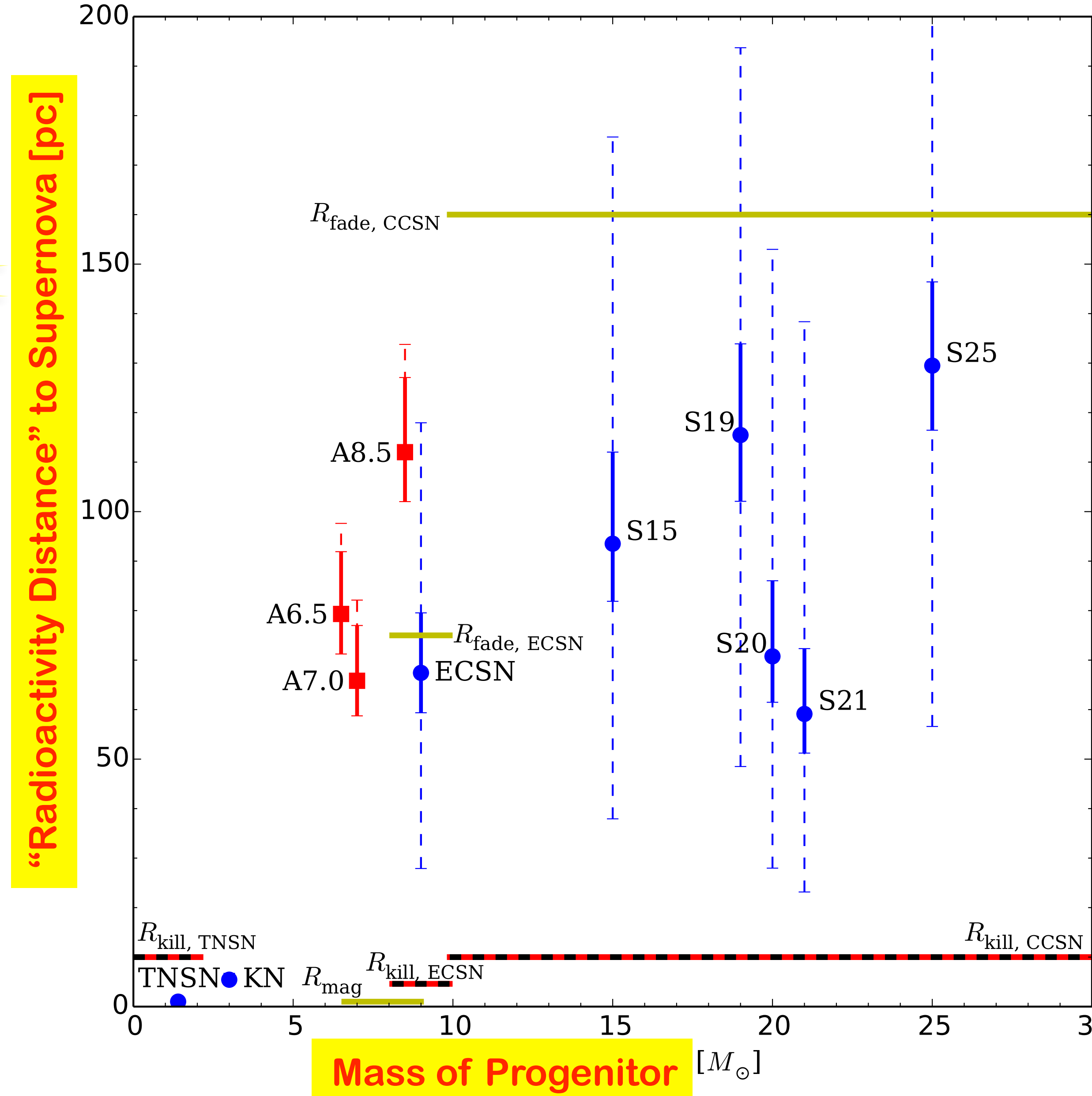
What makes ^{60}Fe?

core-collapse supernovae

- ~~Type Ia supernovae~~
- ~~AGB stars~~
- ~~kilonovae~~
- ~~impactor~~ Wallner+ 16; Miller & BDF 18

SN distance:

$$d(^{60}\mathrm{Fe}) \sim 30 - 150 \text{ pc}$$



Whodunit?

Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

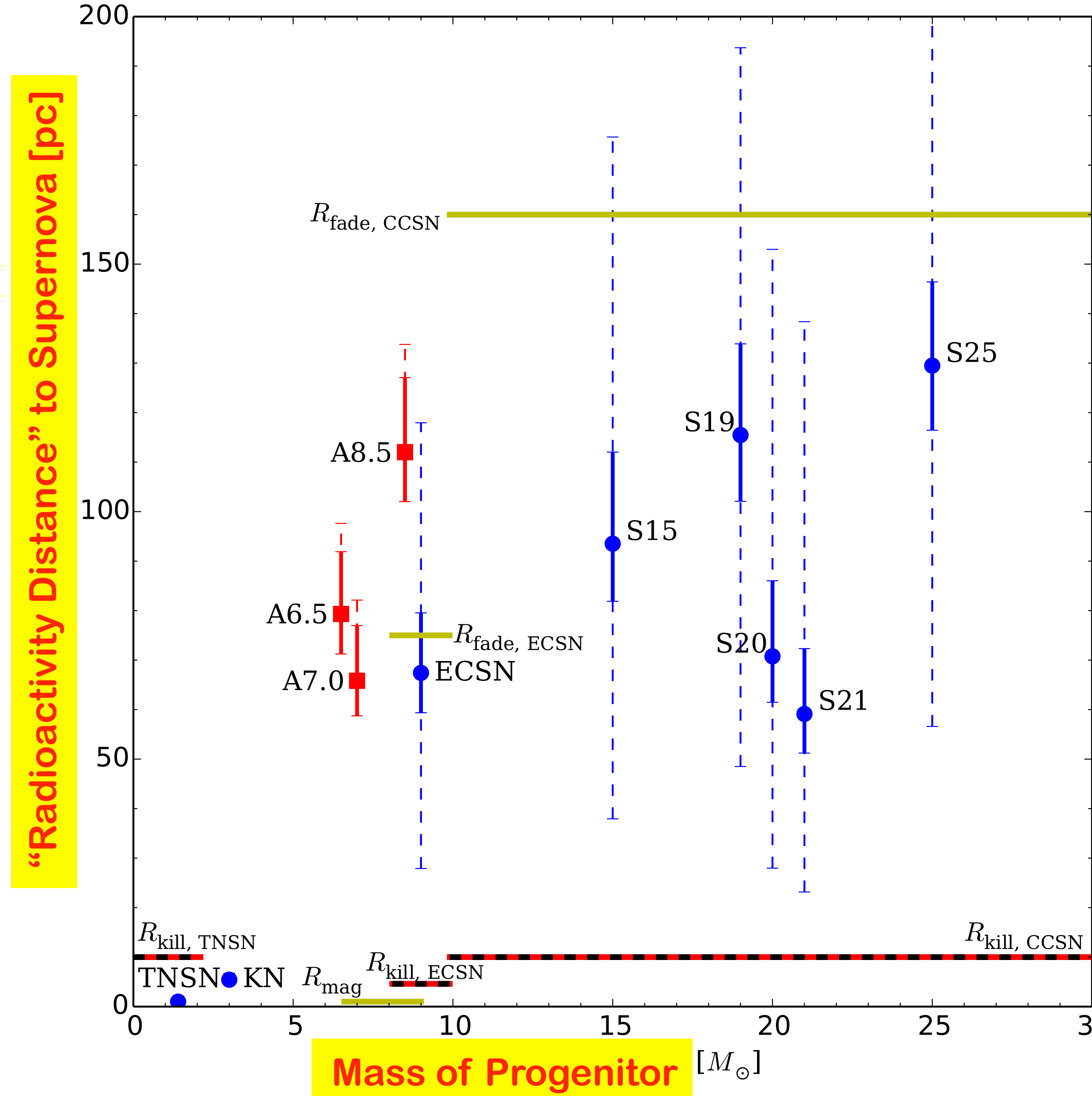
What makes ^{60}Fe?

- core-collapse supernovae
- ~~Type Ia supernovae~~
- ~~AGB stars~~
- ~~kilonovae~~
- ~~impactor~~ Wallner+ 16; Miller & BDF 18

SN distance:

$$d(^{60}\mathrm{Fe}) \sim 30 - 150 \text{ pc}$$

Encouraging:



Whodunit?

Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

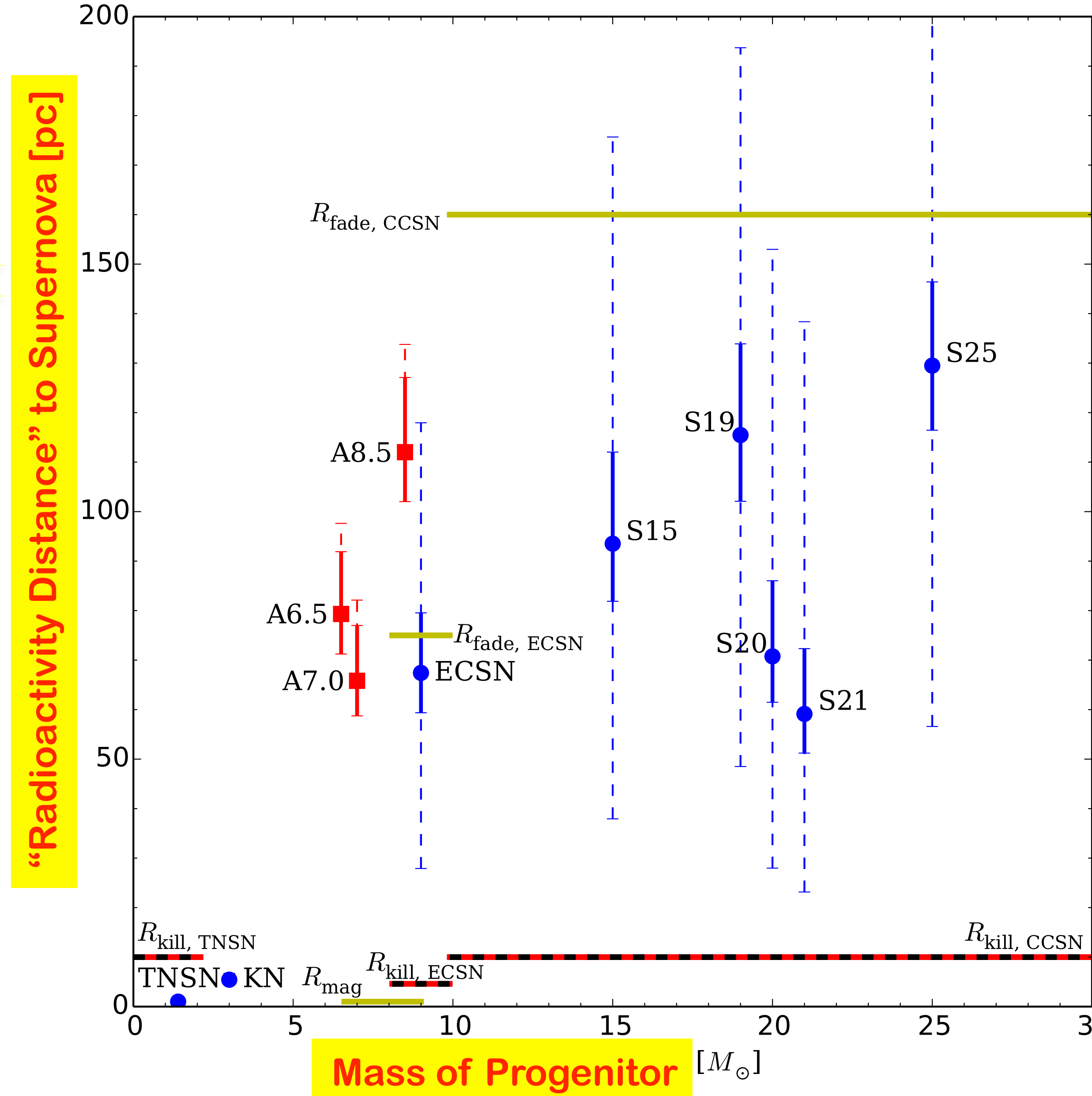
- core-collapse supernovae
- ~~Type Ia supernovae~~
- ~~AGB stars~~
- ~~kilonovae~~
- ~~impactor~~ Wallner+ 16; Miller & BDF 18

SN distance:

$$d(^{60}\mathrm{Fe}) \sim 30 - 150 \text{ pc}$$

Encouraging:

★astronomical distances not built in!



Whodunit?

Fry, BDF, & Ellis 2015

"radioactivity distance" from ^{60}Fe yield

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

What makes ^{60}Fe?

- core-collapse supernovae
- ~~Type Ia supernovae~~
- ~~AGB stars~~
- ~~kilonovae~~
- ~~impactor~~ Wallner+ 16; Miller & BDF 18

SN distance:

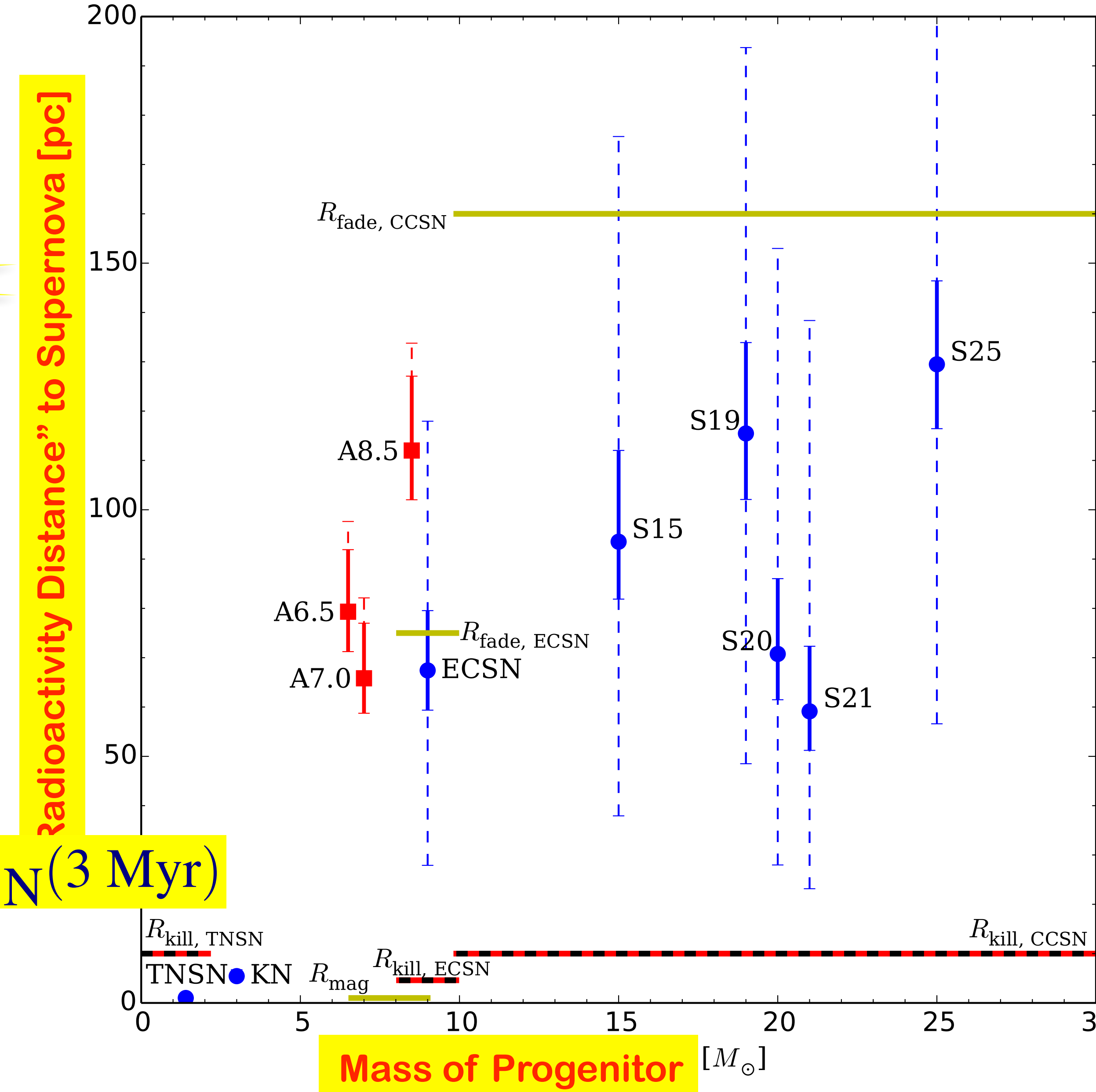
$$d(^{60}\mathrm{Fe}) \sim 30 - 150 \text{ pc}$$

Encouraging:

★ astronomical distances not built in!

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

⇨ nontrivial consistency!



Nachbarsternsupernovaexplosionsgefahr

or

Attack of the Death Star!

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

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

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 scattering:

  "linear energy transfer"

  ⇨ DNA damage

  Collar 96, but see Karam 02

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 scatterin

  “linear energy transfer”

  ⇨ DNA damage

  02

Minimum safe distance: ~8 pc