

Radioactive Nuclei from Recent Near-Earth Supernovae as Telltale Signatures for our Solar System History

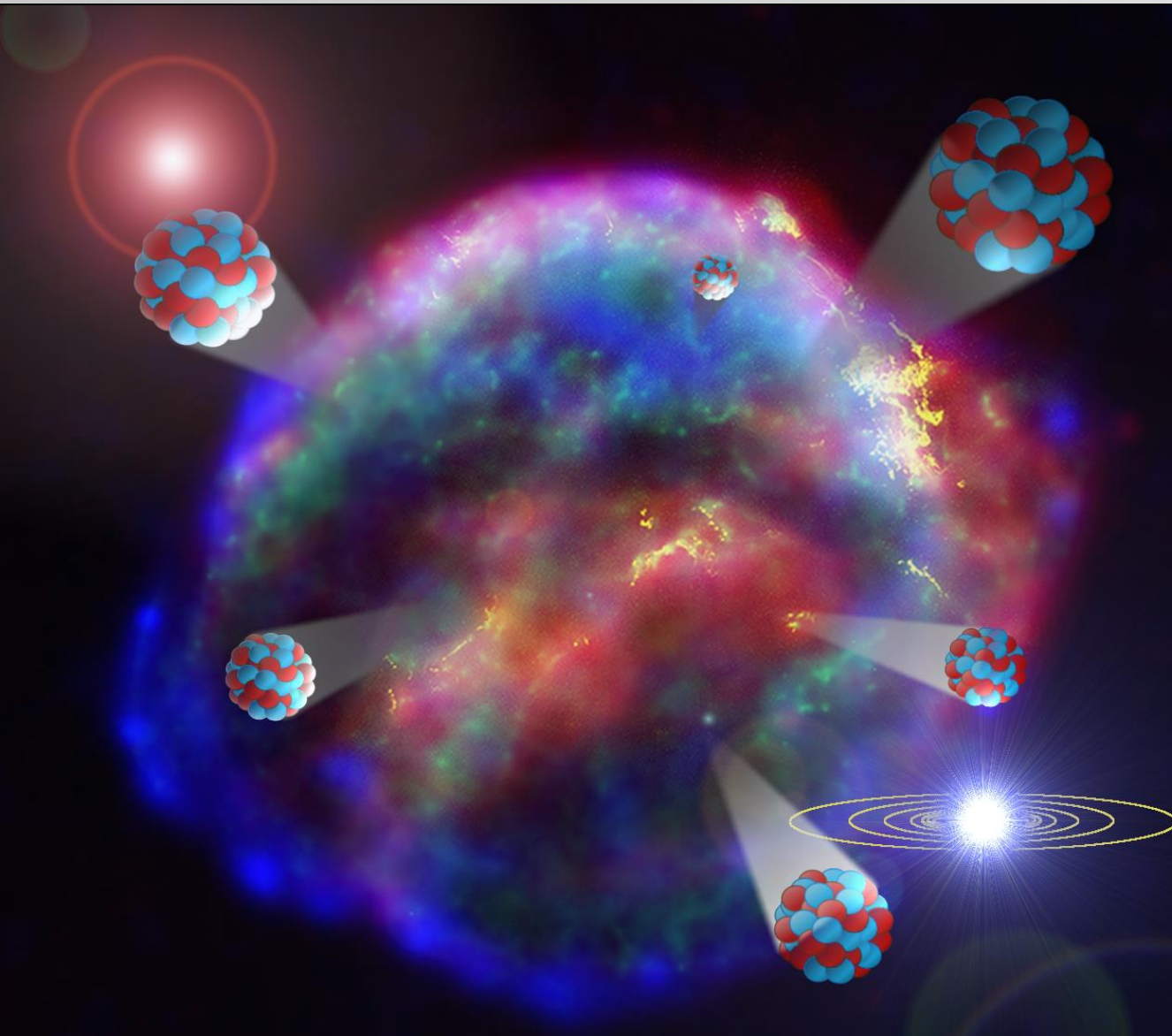
Jenny Feige

Technische Universität Berlin, Germany

09.09.2022

Nuclear Physics in Astrophysics - X

Outline



Radioactive Nuclei from Recent Near-Earth Supernovae as Telltale Signatures for our Solar System History

- Introduction
- Data
- Models
- Conclusions

The Solar Environment

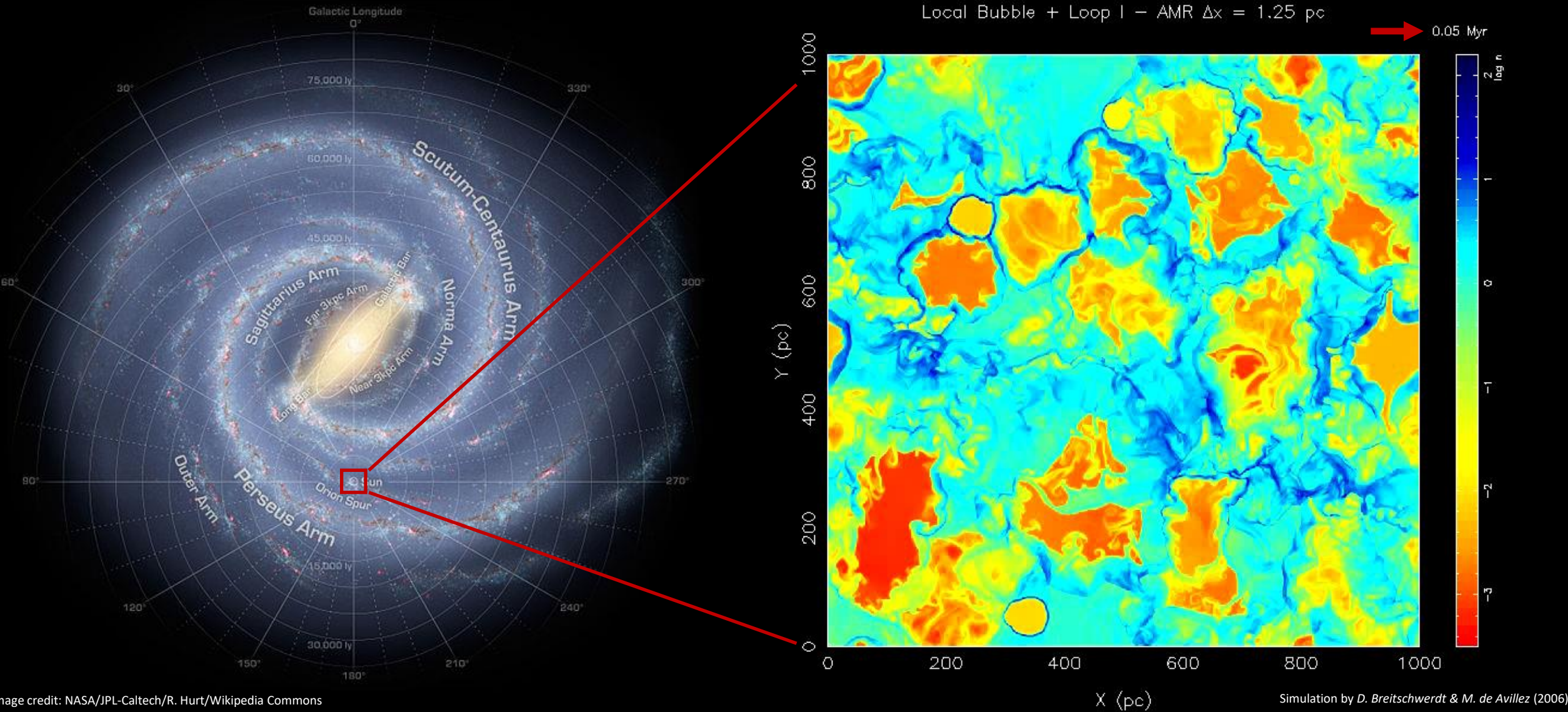


Image credit: NASA/JPL-Caltech/R. Hurt/Wikipedia Commons

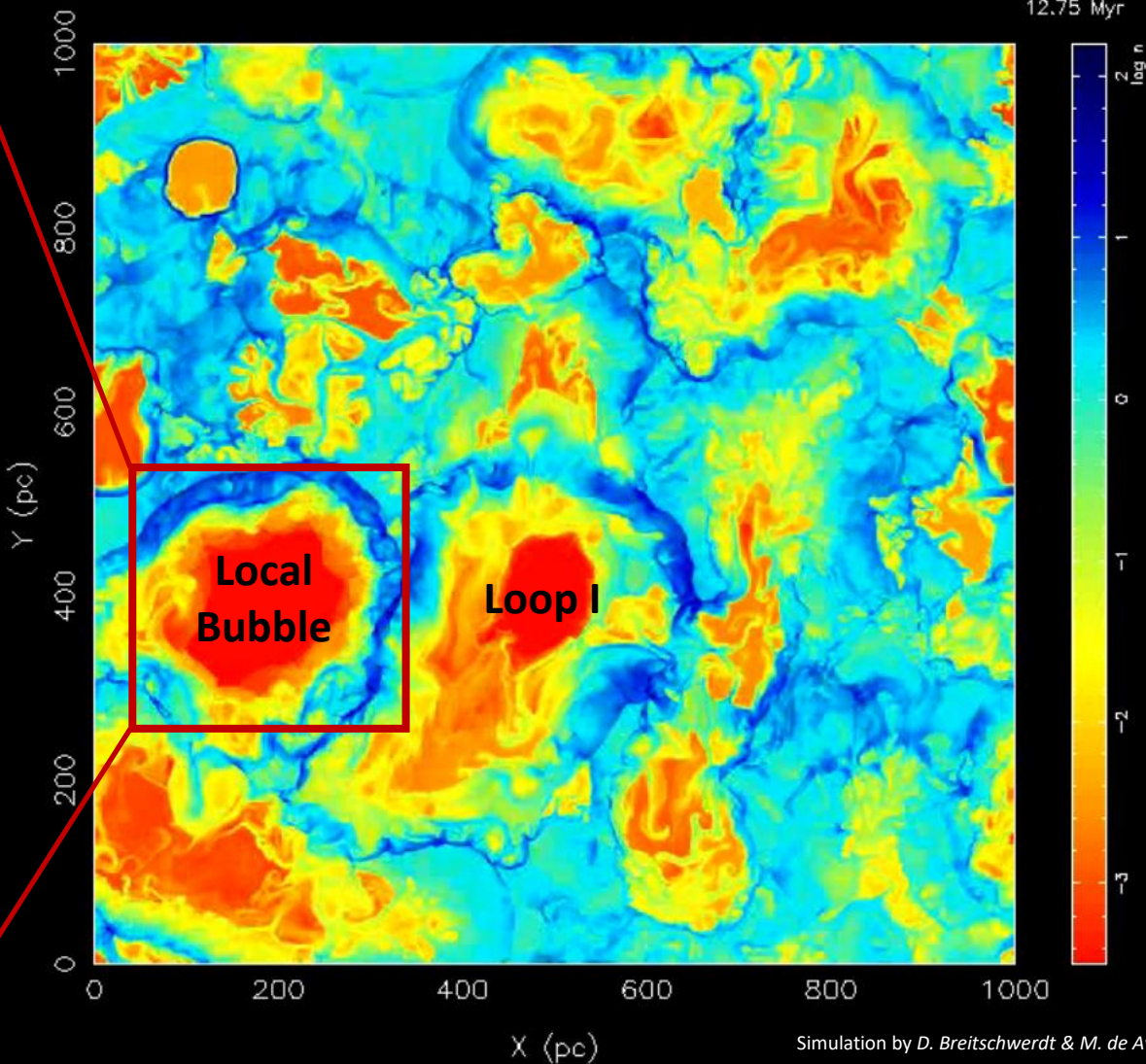
The Solar Environment

Age: 14 Myr
Origin: 14-20 SNe
 $T = 10^6$ K
 $n = 5 \times 10^{-3}$ atoms cm^{-3}
 $V = 200^2 \times 600$ pc^3

Sun ☉

Local Bubble

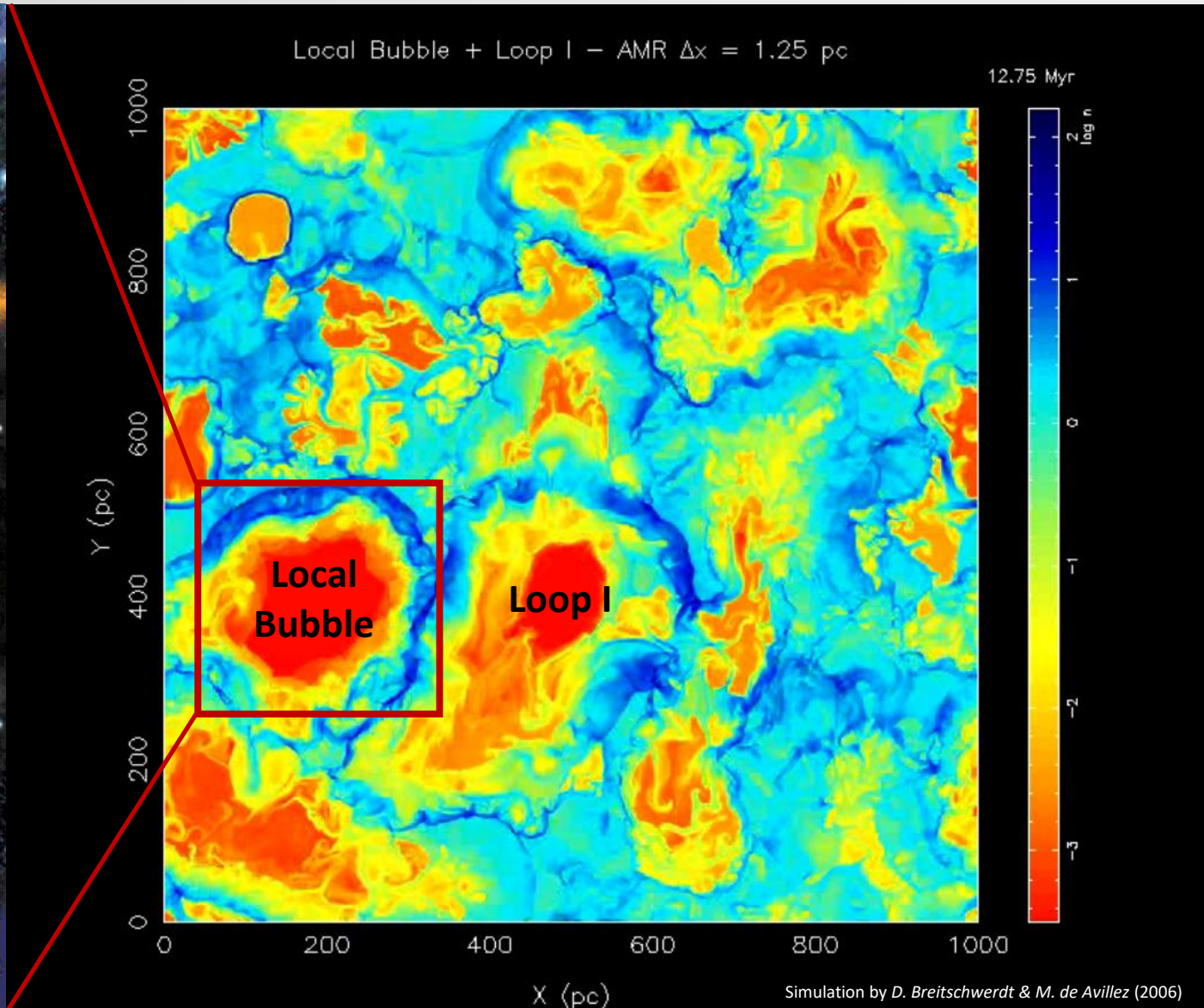
Local Bubble + Loop I - AMR $\Delta x = 1.25$ pc



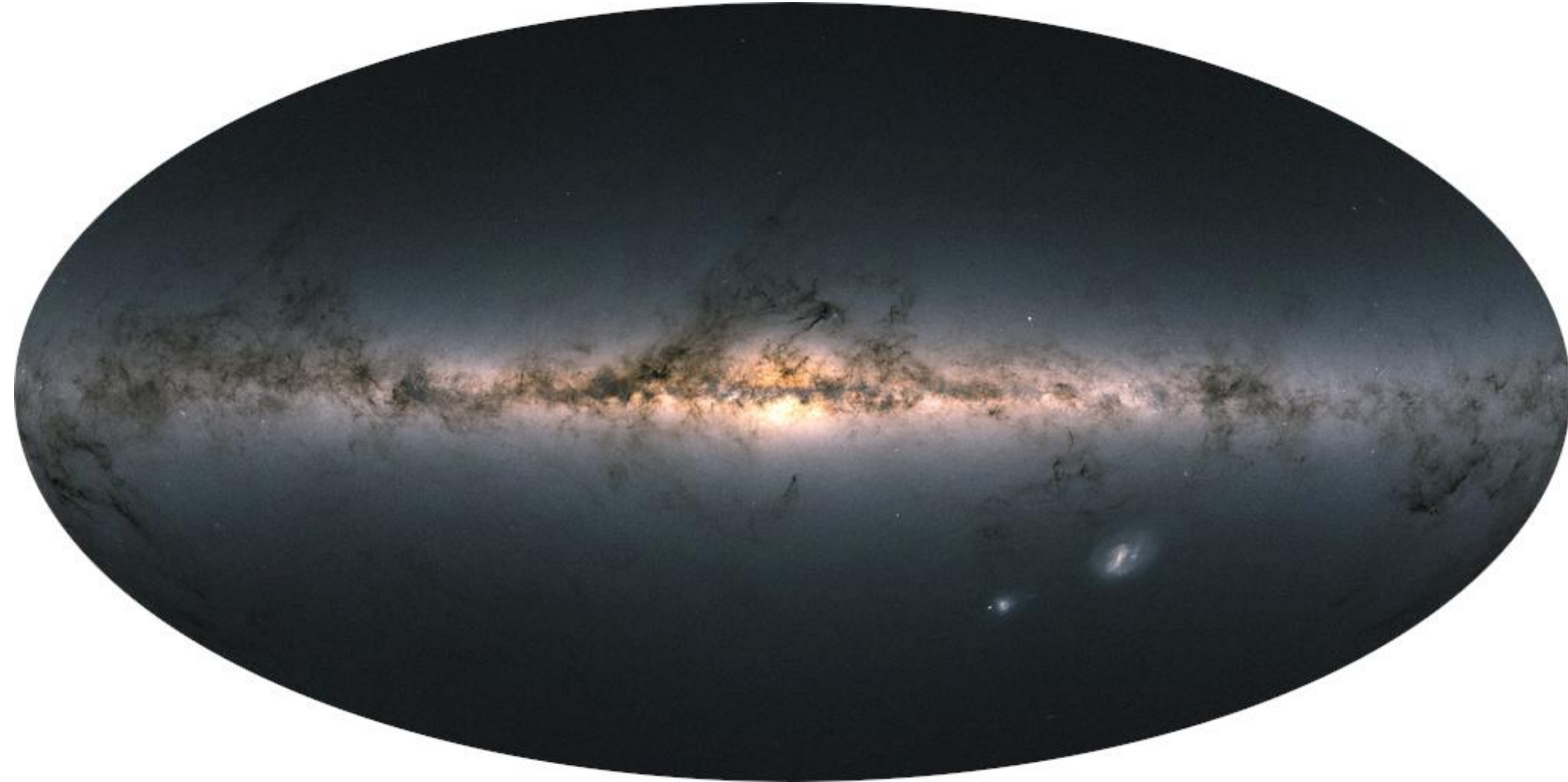
Simulation by D. Breitschwerdt & M. de Avillez (2006)

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The Solar Environment



Radioactivity in our Milky Way

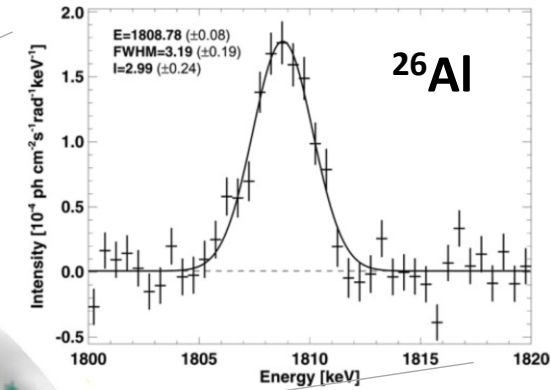
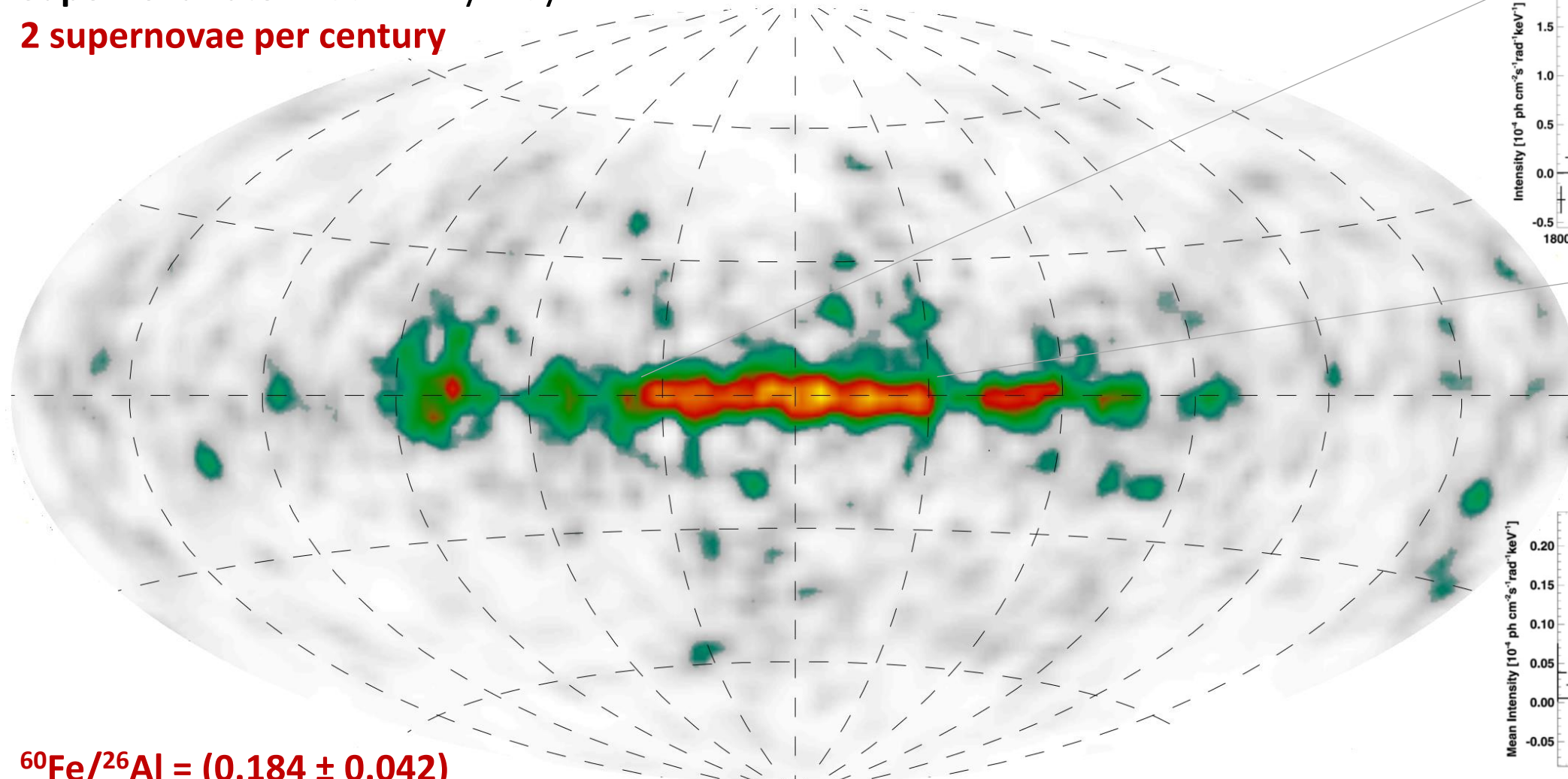


www.dlr.de/content/en/images/2020/4/gaia-milky-way.html

Radioactivity in our Milky Way

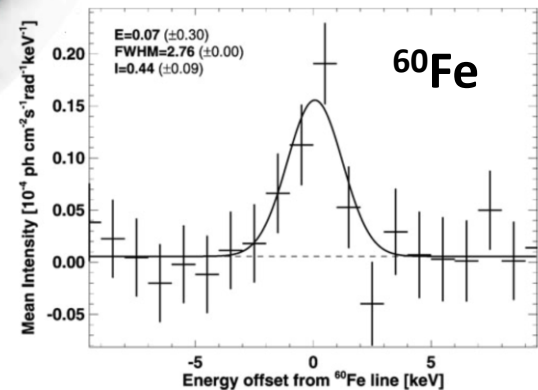
Supernova-rate in our Milky Way

2 supernovae per century



^{26}Al , $t_{1/2} = 0.7$ Myr

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

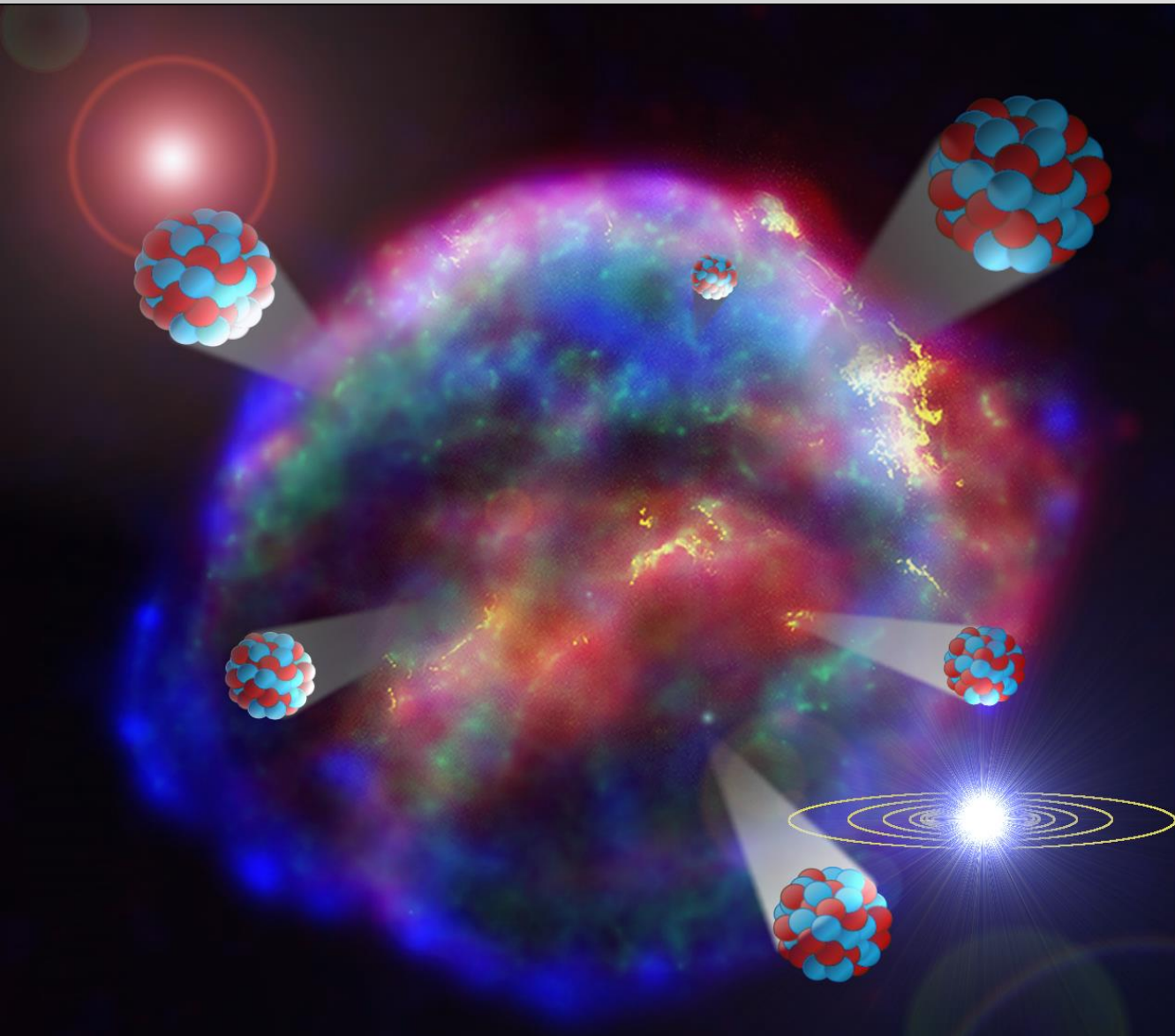


$^{60}\text{Fe}/^{26}\text{Al} = (0.184 \pm 0.042)$

Plüschke et al., ESA Sp. Publ. 459, 55 (2001); Diehl et al., Nature 439, 45 (2006)

Plüschke et al., ESA Sp. Publ. 459, 55 (2001); Diehl et al., Nature 439, 45 (2006); Wang et al., A&A 469, 1005 (2007); Wang et al., APJ 889, 169 (2020)

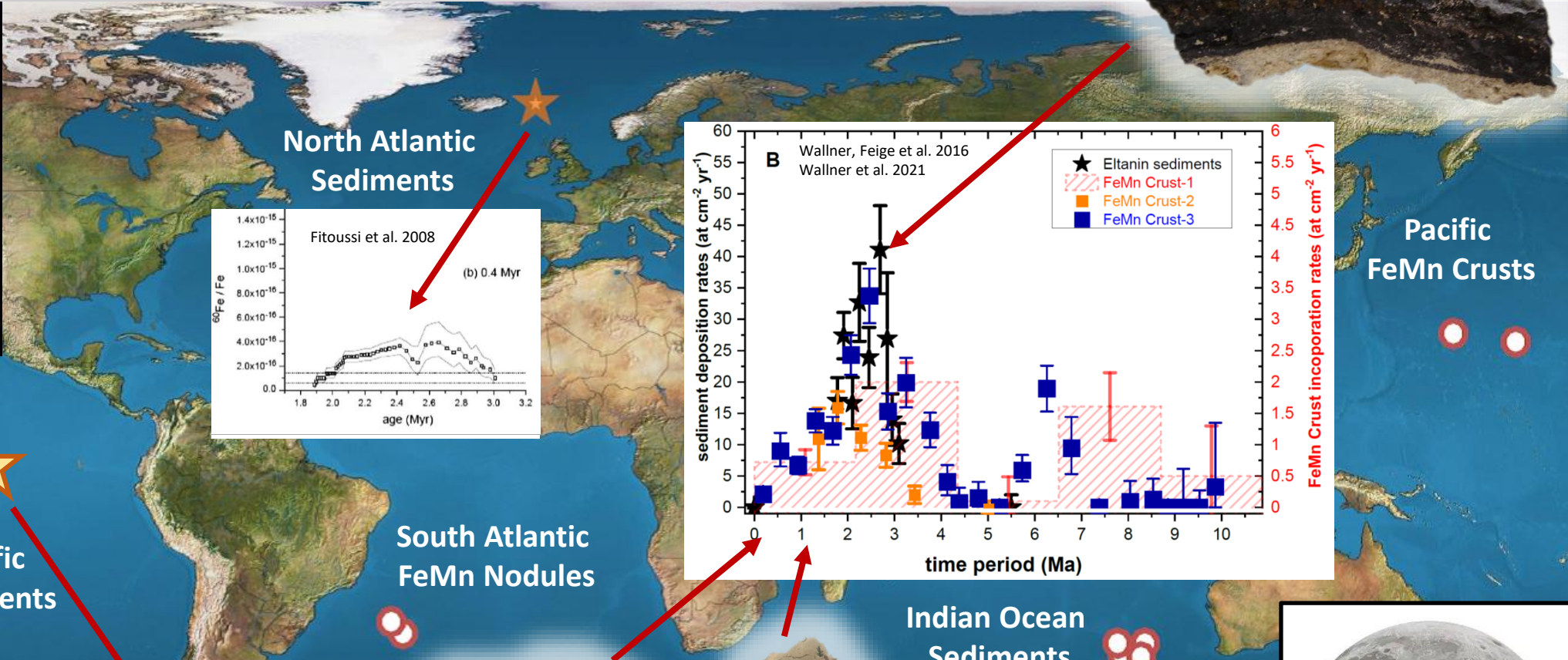
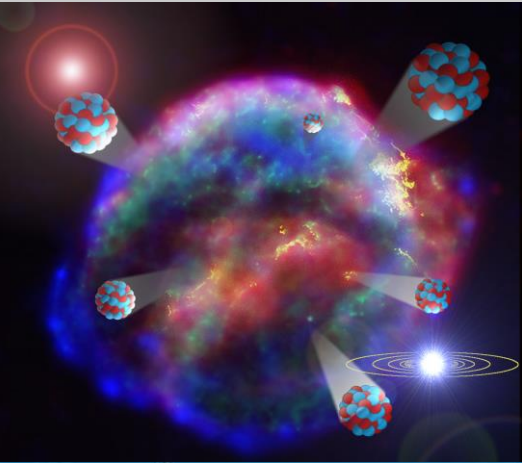
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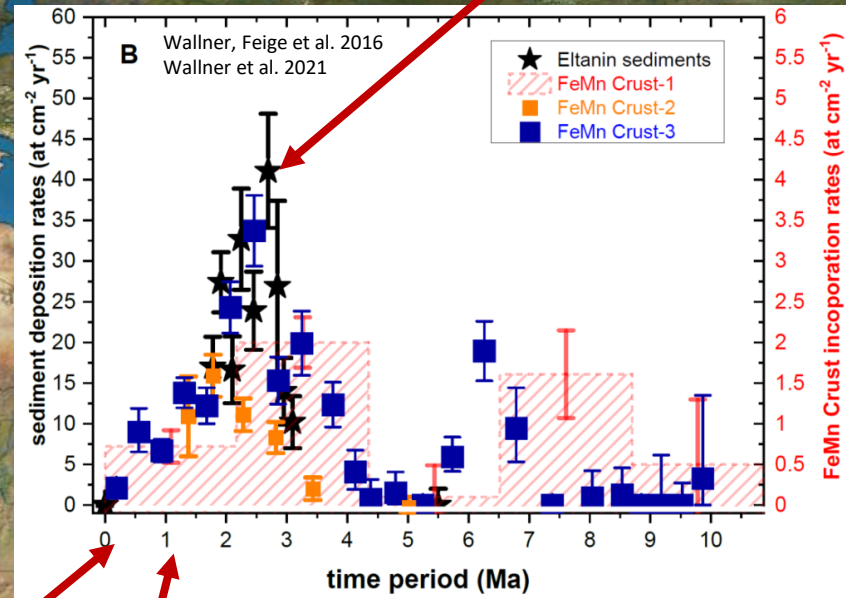
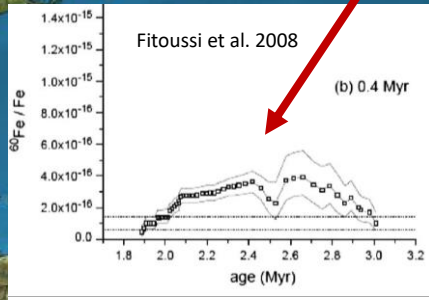
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Global ^{60}Fe signatures



North Atlantic Sediments



Pacific FeMn Crusts

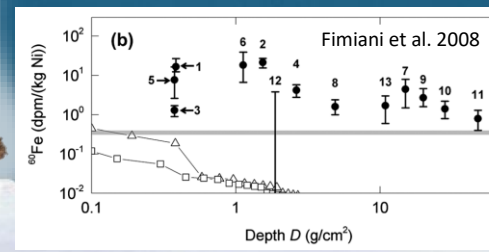
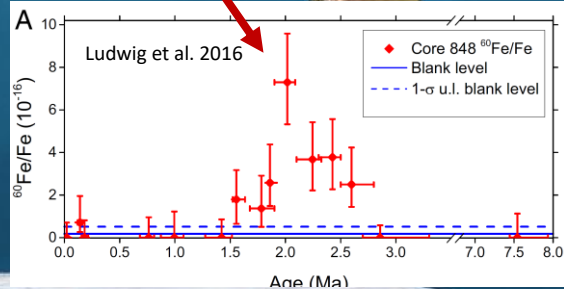
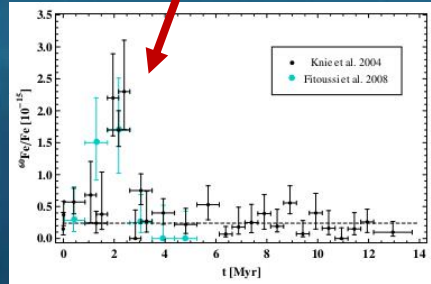
Pacific Crust 237 KD



Pacific Sediments

South Atlantic FeMn Nodules

Indian Ocean Sediments



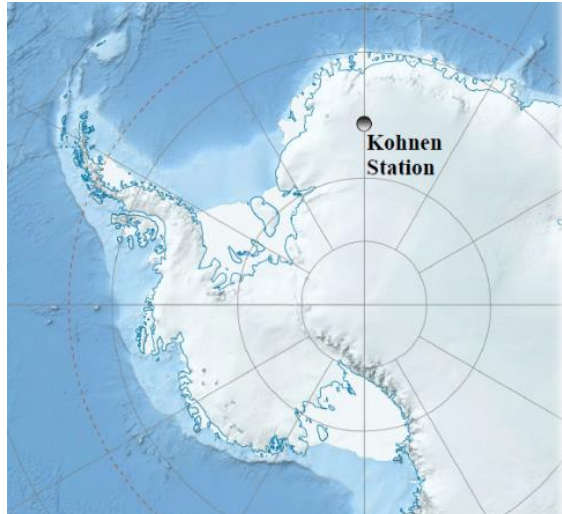
Recent Supernova Influx

PHYSICAL REVIEW LETTERS 123, 072701 (2019)

Editors' Suggestion Featured in Physics

Interstellar ^{60}Fe in Antarctica

Dominik Koll,^{1,4} Gunther Korschinek,^{1,2} Thomas Faestermann,^{1,2} J. M. Gómez-Guzmán,¹ Sepp Kipfstuhl,³ Silke Merchel,⁴ and Jan M. Welch⁵



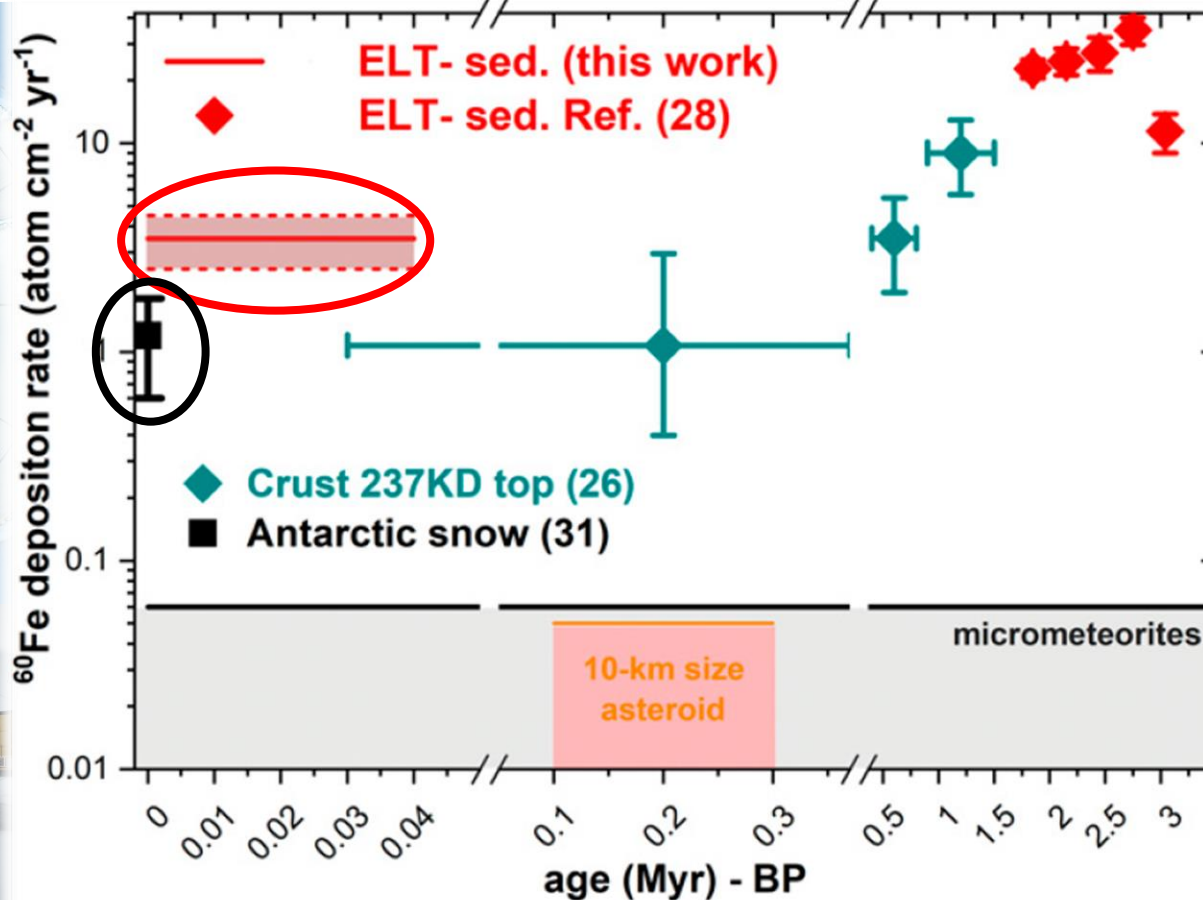
500 kg of Antarctic snow
Age: <20 years



Martin Leonhardt / Alfred-Wegener-Institut (AWI)

^{60}Fe Flux today
1/10 of peak flux

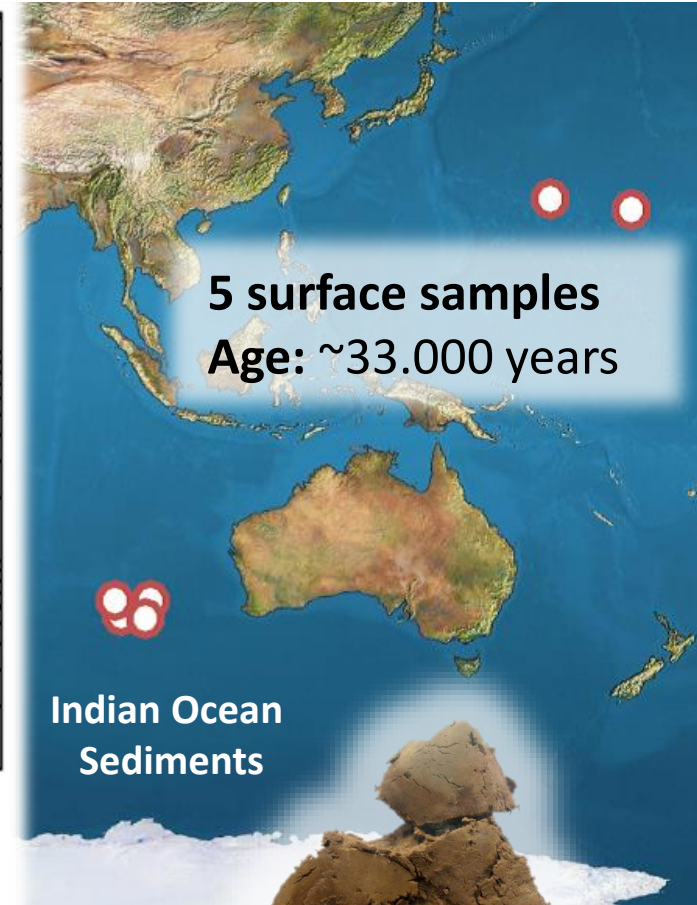
Peak-flux:
 $\sim 30 \text{ ats/yr/cm}^2$



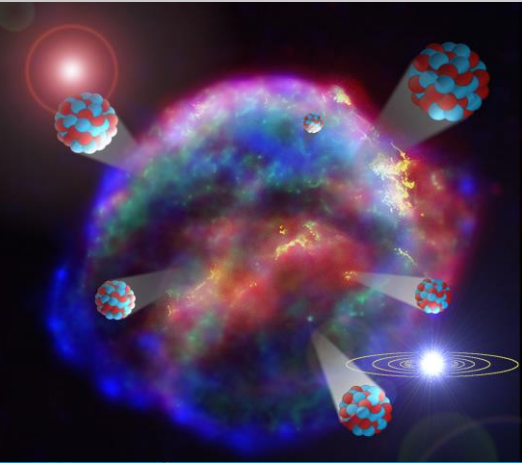
PNAS PNAS

^{60}Fe deposition during the late Pleistocene and the Holocene echoes past supernova activity

A. Wallner^{a,b,1}, J. Feige^{c,d}, L. K. Fifield^a, M. B. Froehlich^e, R. Golser^f, M. A. C. Hotchkiss^g, D. Koll^h, G. Leckenby^g, M. Martschini^{h,c}, S. Merchel^h, S. Panjkov^g, S. Pavetich^g, G. Rugel^h, and S. G. Tims^g



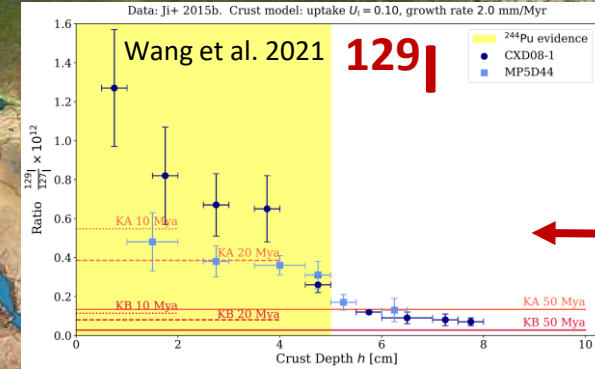
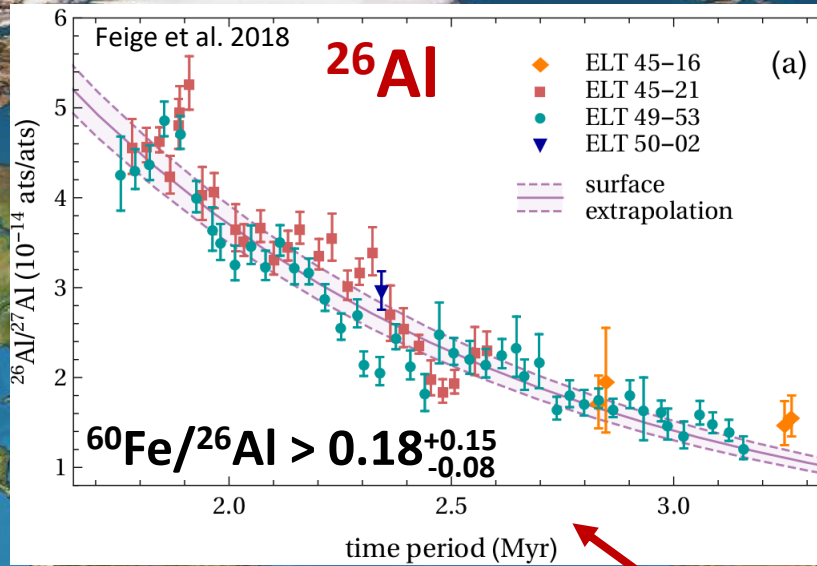
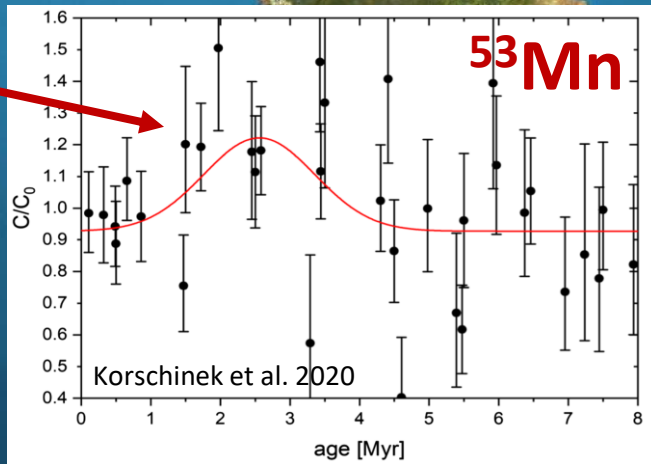
Signals from other radioactive nuclei



Pacific Crust 237 KD

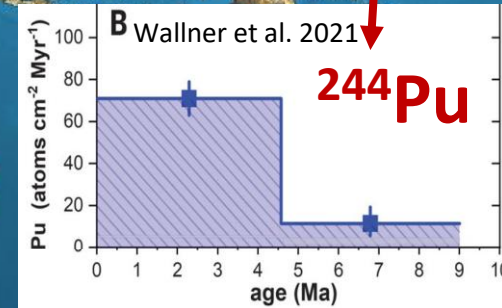


$^{53}\text{Mn}/^{60}\text{Fe} \sim 14$

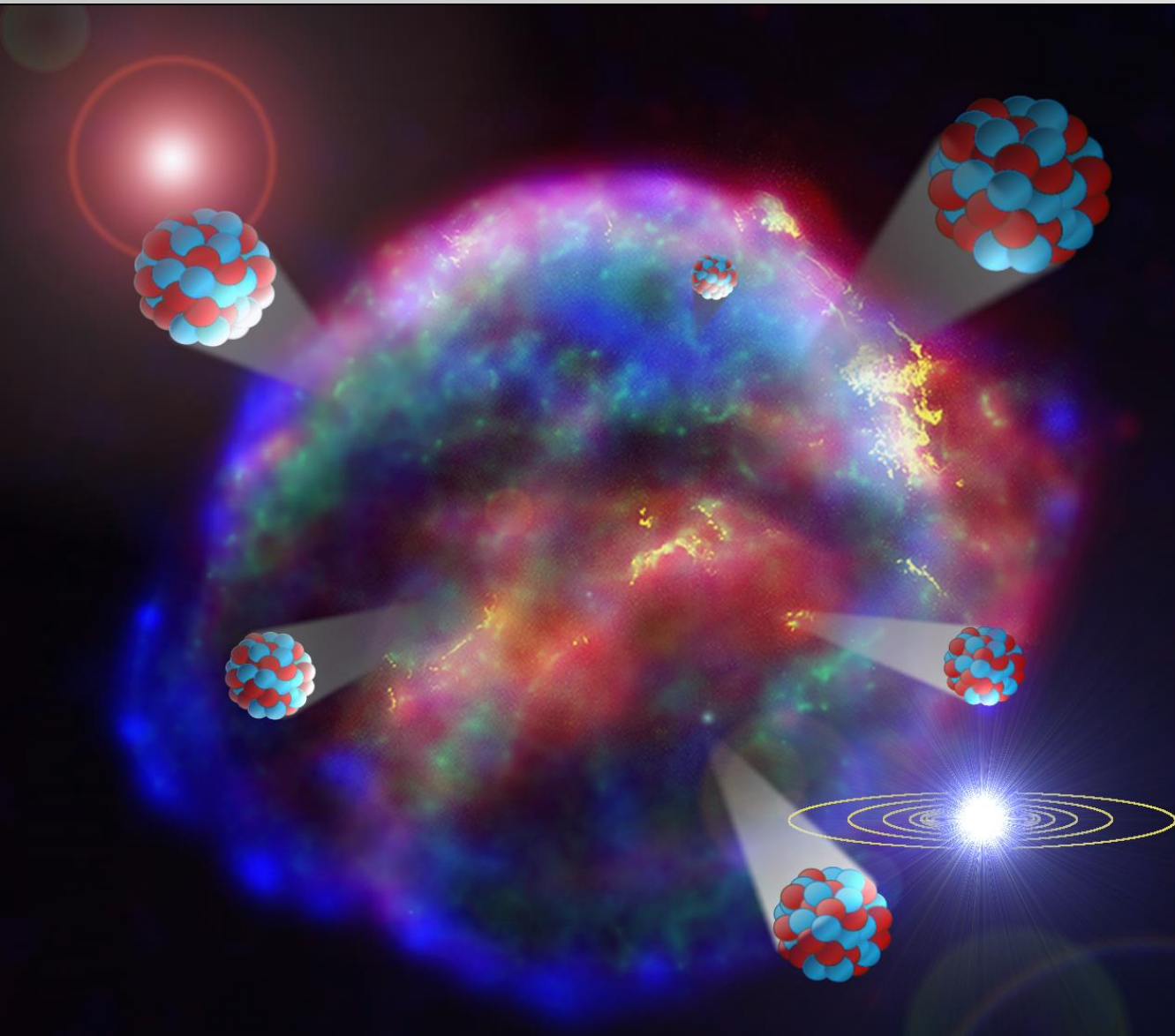


Pacific FeMn Crusts

Indian Ocean Sediments



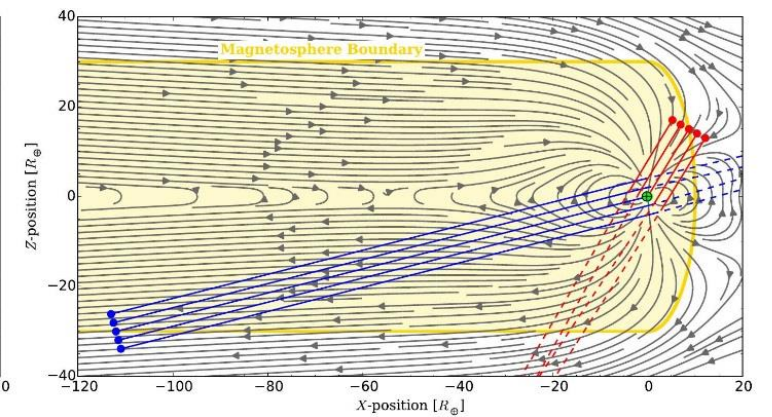
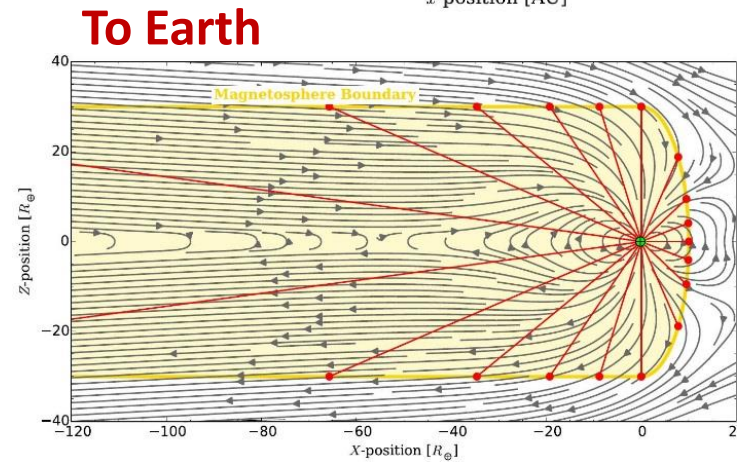
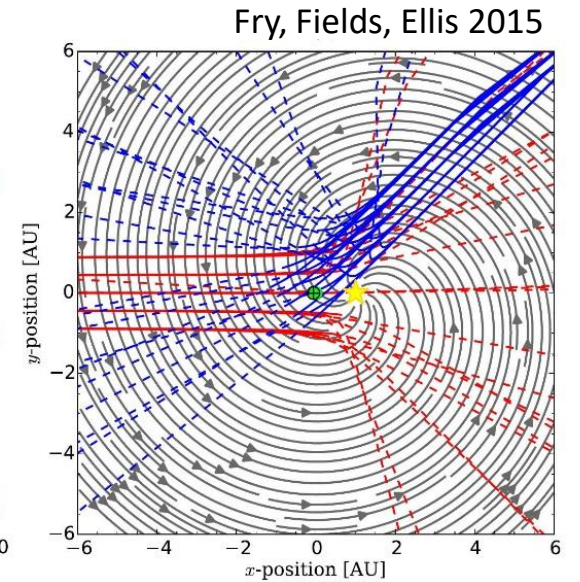
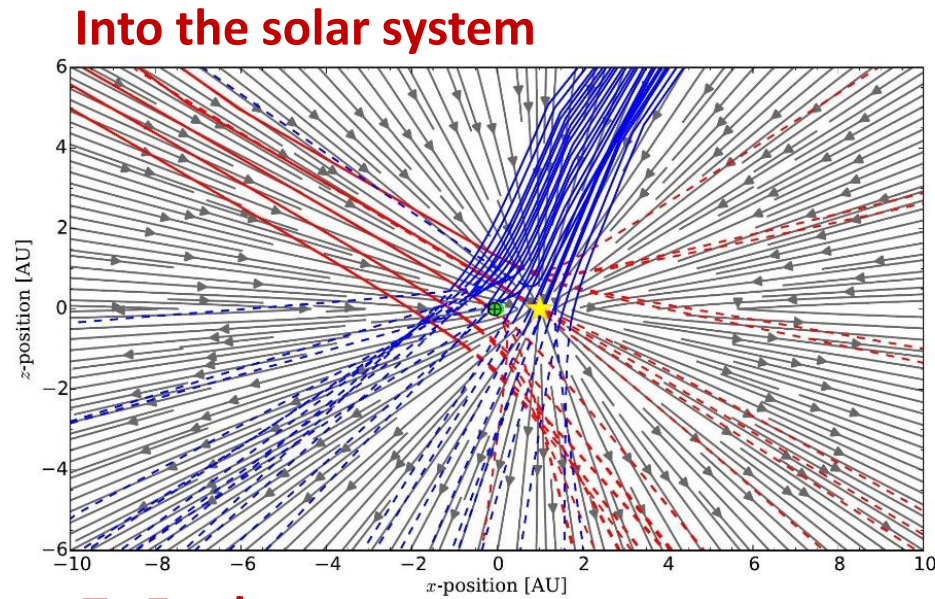
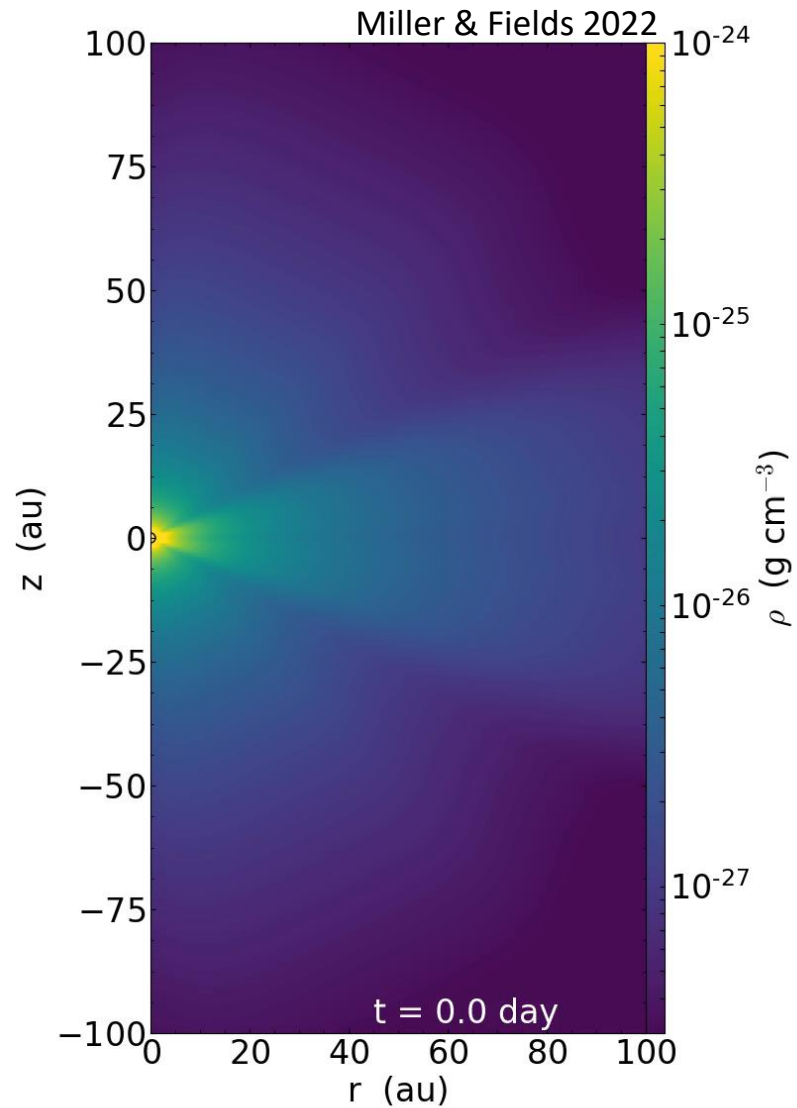
Outline



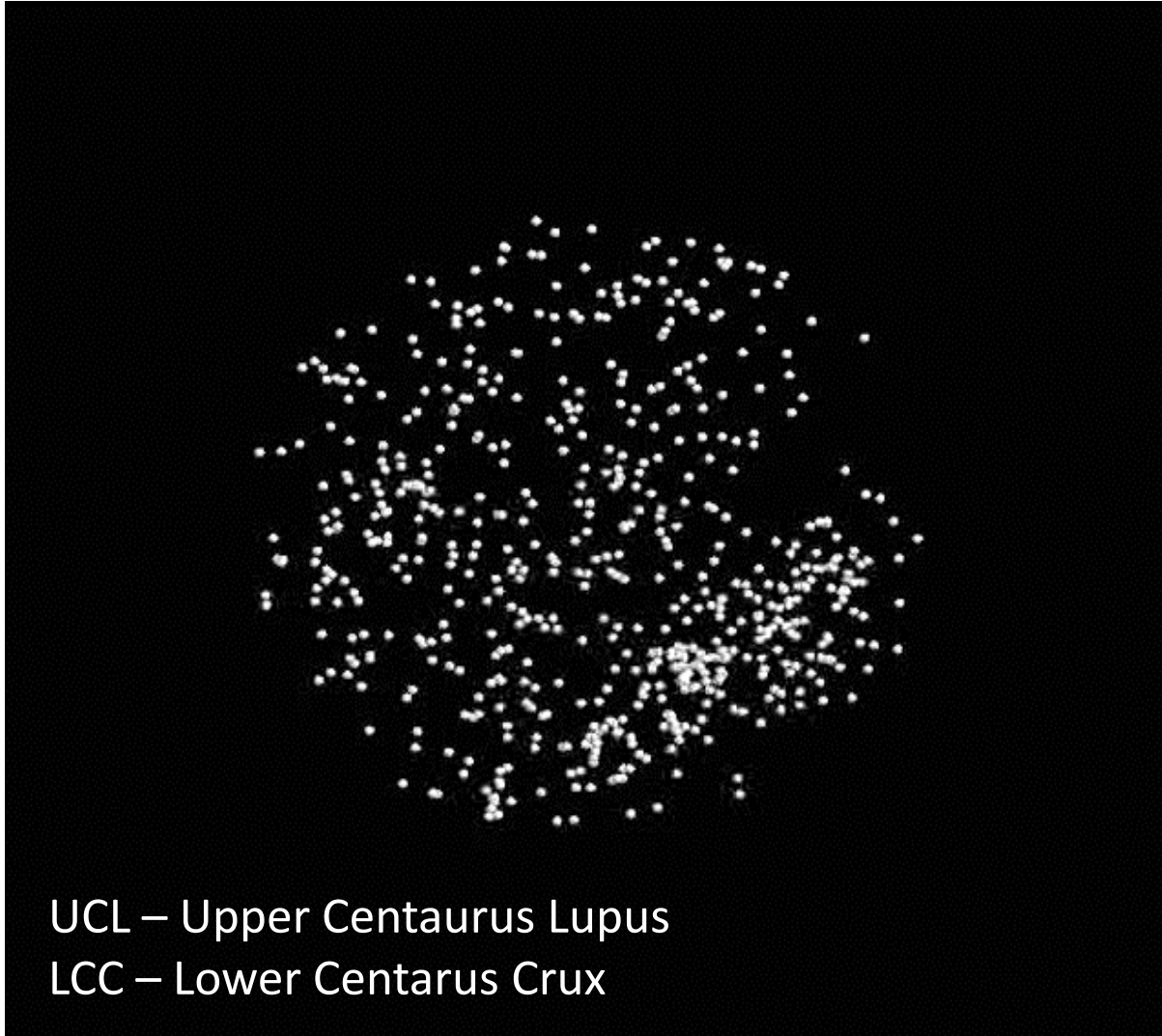
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Supernova Dust Transport to Earth



Nearby Stellar Moving Groups



Mon. Not. R. Astron. Soc. **373**, 993–1003 (2006)

doi:10.1111/j.1365-2966.2006.11044.x

The search for the origin of the Local Bubble redivivus

B. Fuchs,^{1*} D. Breitschwerdt,² M. A. de Avillez,^{2,3} C. Dettbarn¹ and C. Flynn⁴

Solar environment ($r = 200$ pc) was searched for **suspicious stars**.

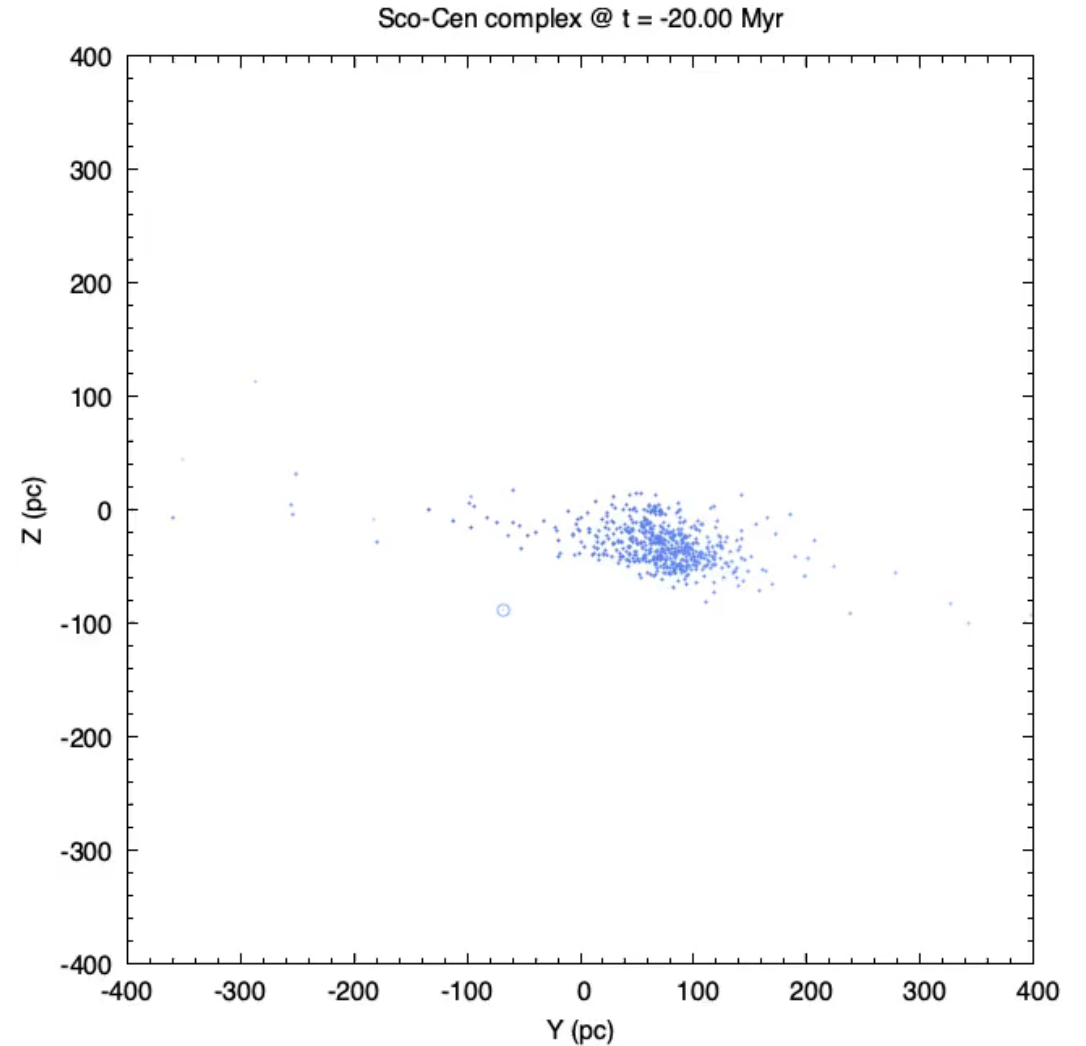
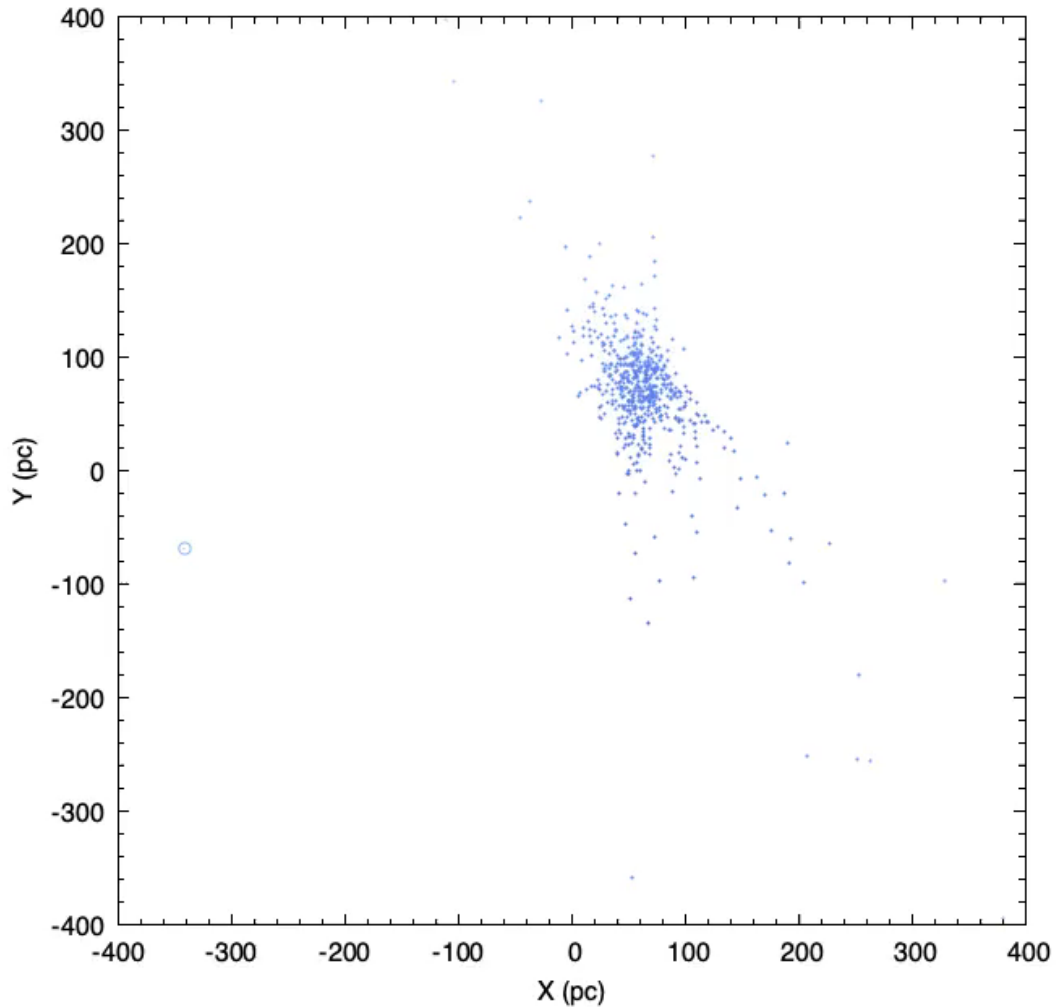
Subgroups of the **Scorpius-Centaurus association!**

Ages: ~20 Myr

IMF: universal distribution of stellar numbers over masses at formation

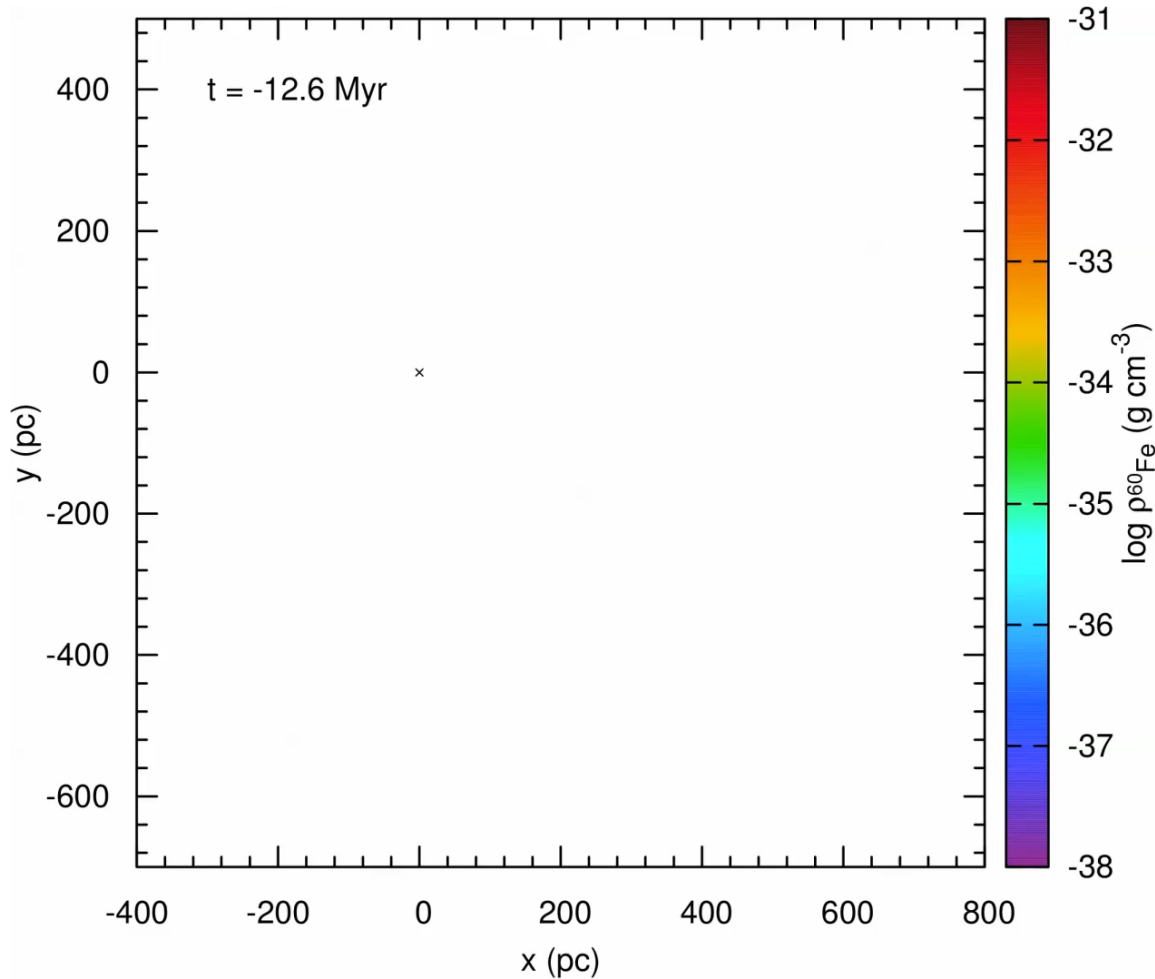
Most massive stars explode first!

Nearby Stellar Moving Groups



Schulreich, Feige, Breitschwerdt in prep.

Modelling the ^{60}Fe Signal and the Local Bubble



Homogeneous ambient medium ($0.3 \text{ atoms cm}^{-3}$)

Resolution: 0.7 pc

Number of Supernovae: 16

Local Bubble shell crosses Solar System 2.2 Myr ago!

Distance of SNe: ~100 pc

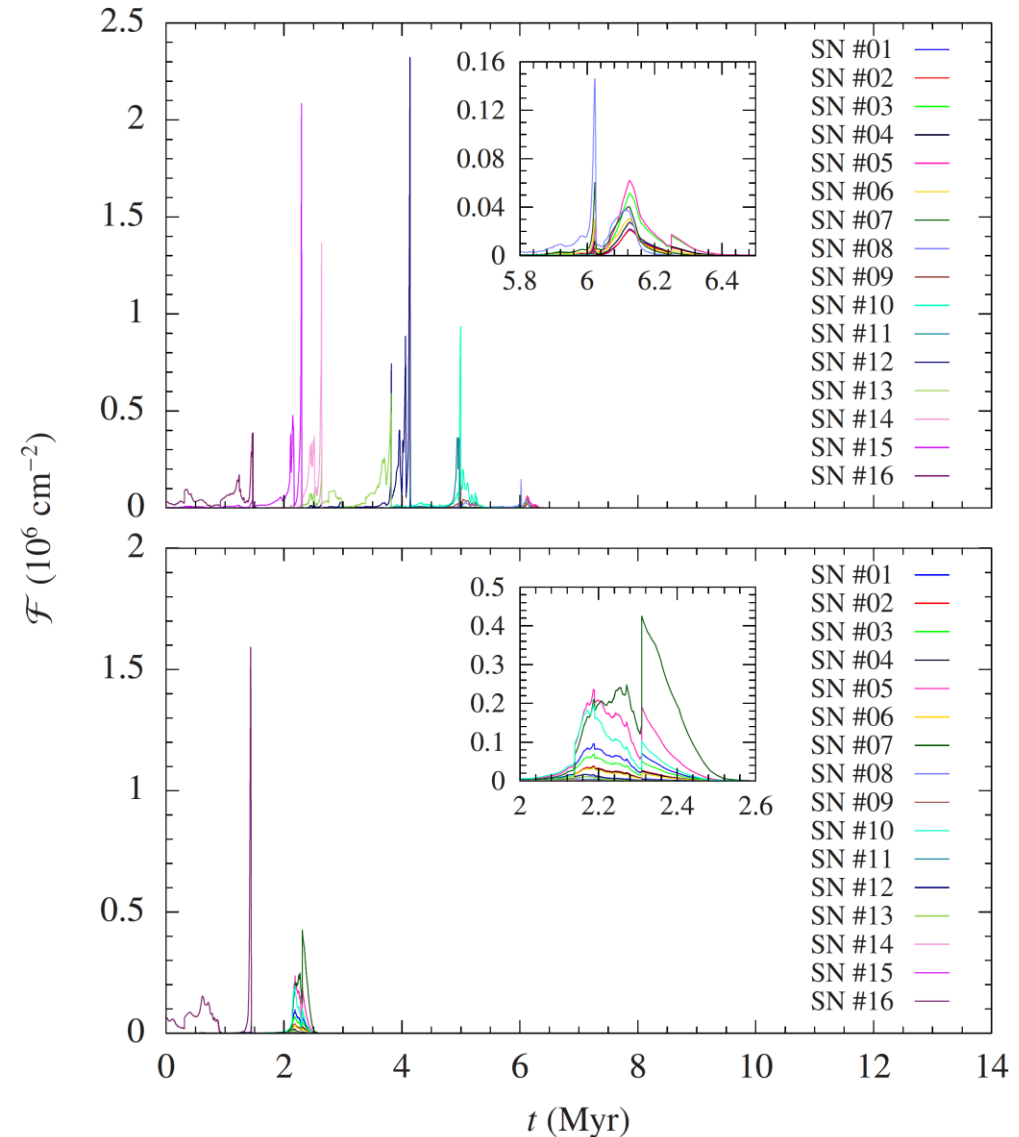
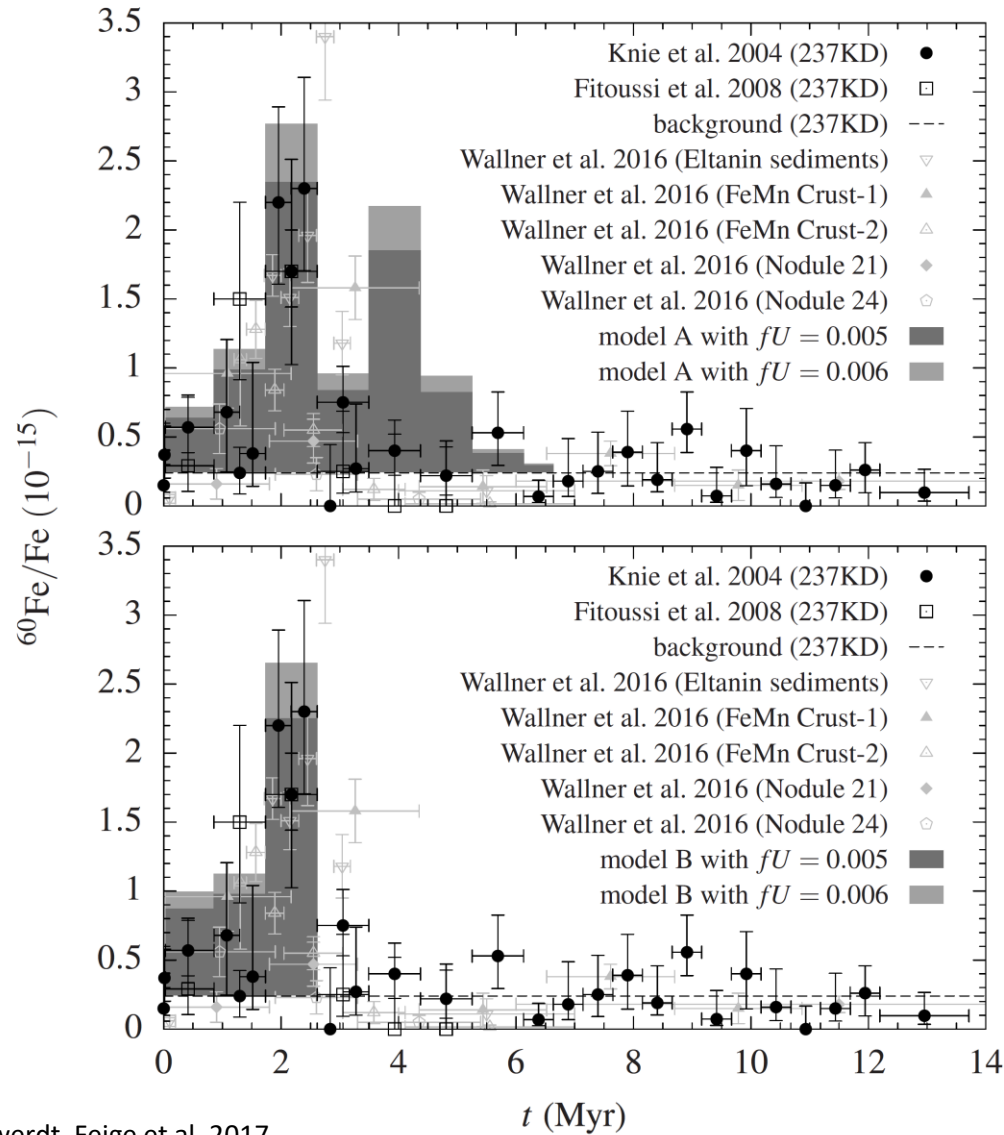
Fluence:

- Number of atoms that reach the Earth per cm^2

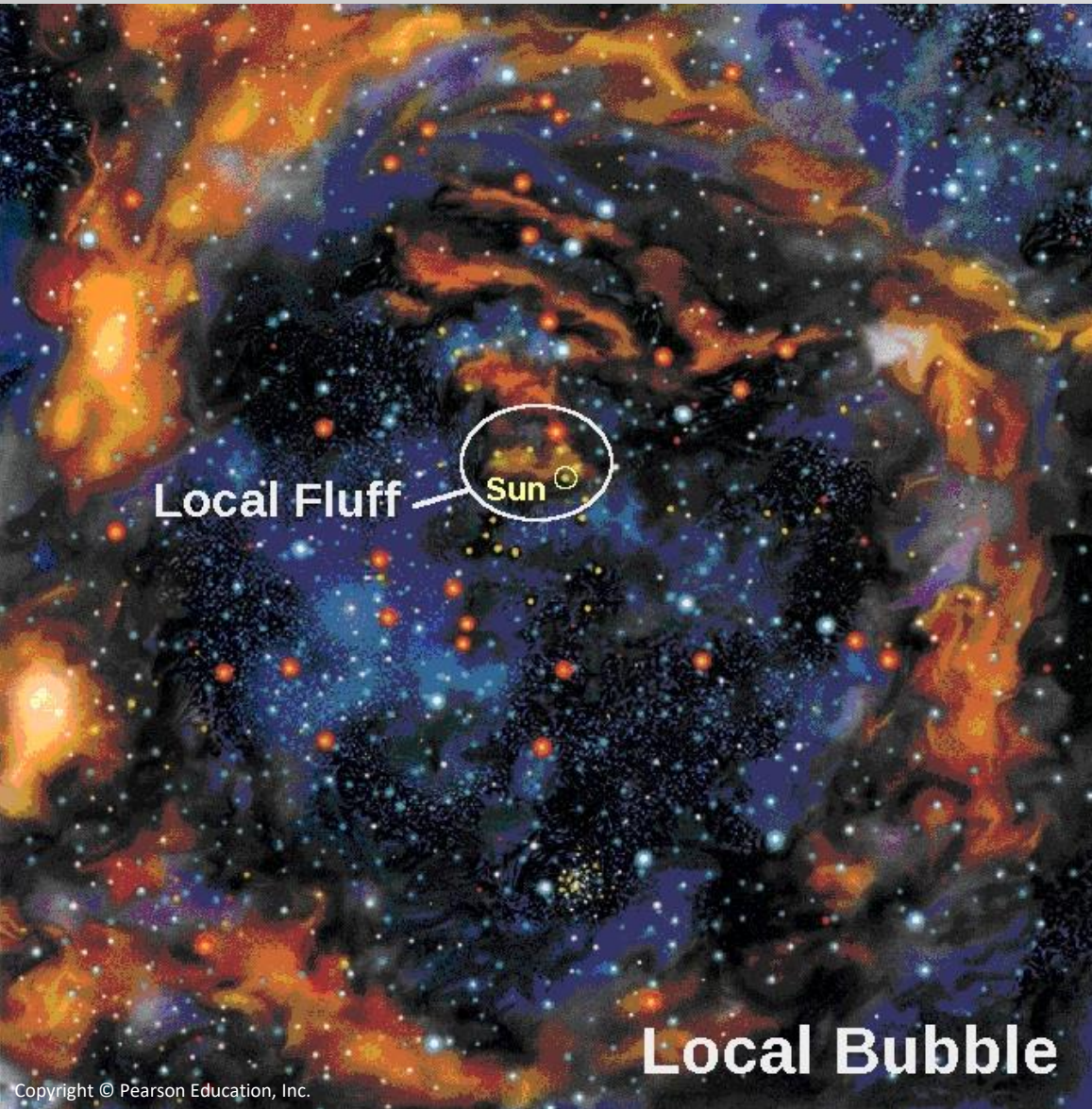
$$F = \frac{U}{4} \frac{M_{\text{ej}}}{4\pi r^2 A m_p} e^{-t/\tau}$$

t time since explosion
 M_{ej} ... ejected ^{60}Fe mass
 r distance of the explosion site
 A mass number
 m_p proton mass
 τ ^{60}Fe mean lifetime
 U uptake factor

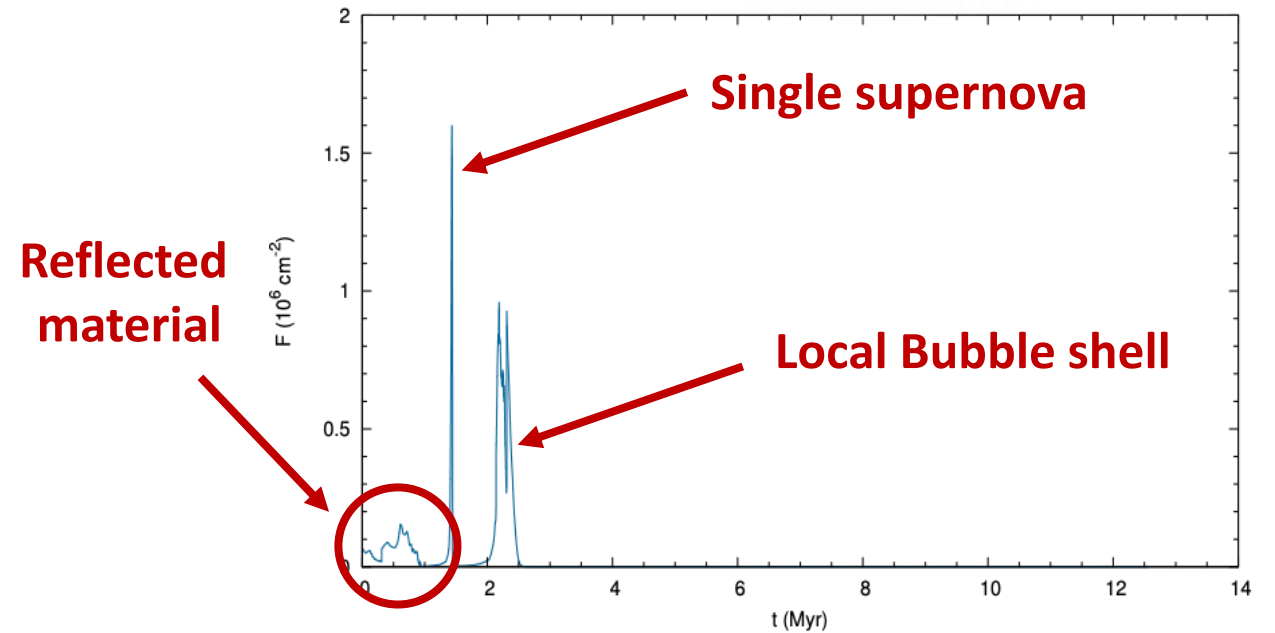
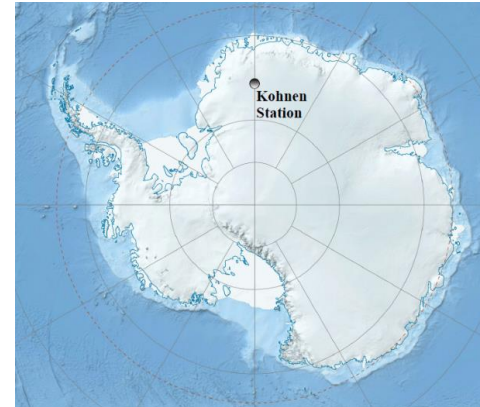
Modelling the ^{60}Fe Signal and the Local Bubble



Recent Supernova Influx

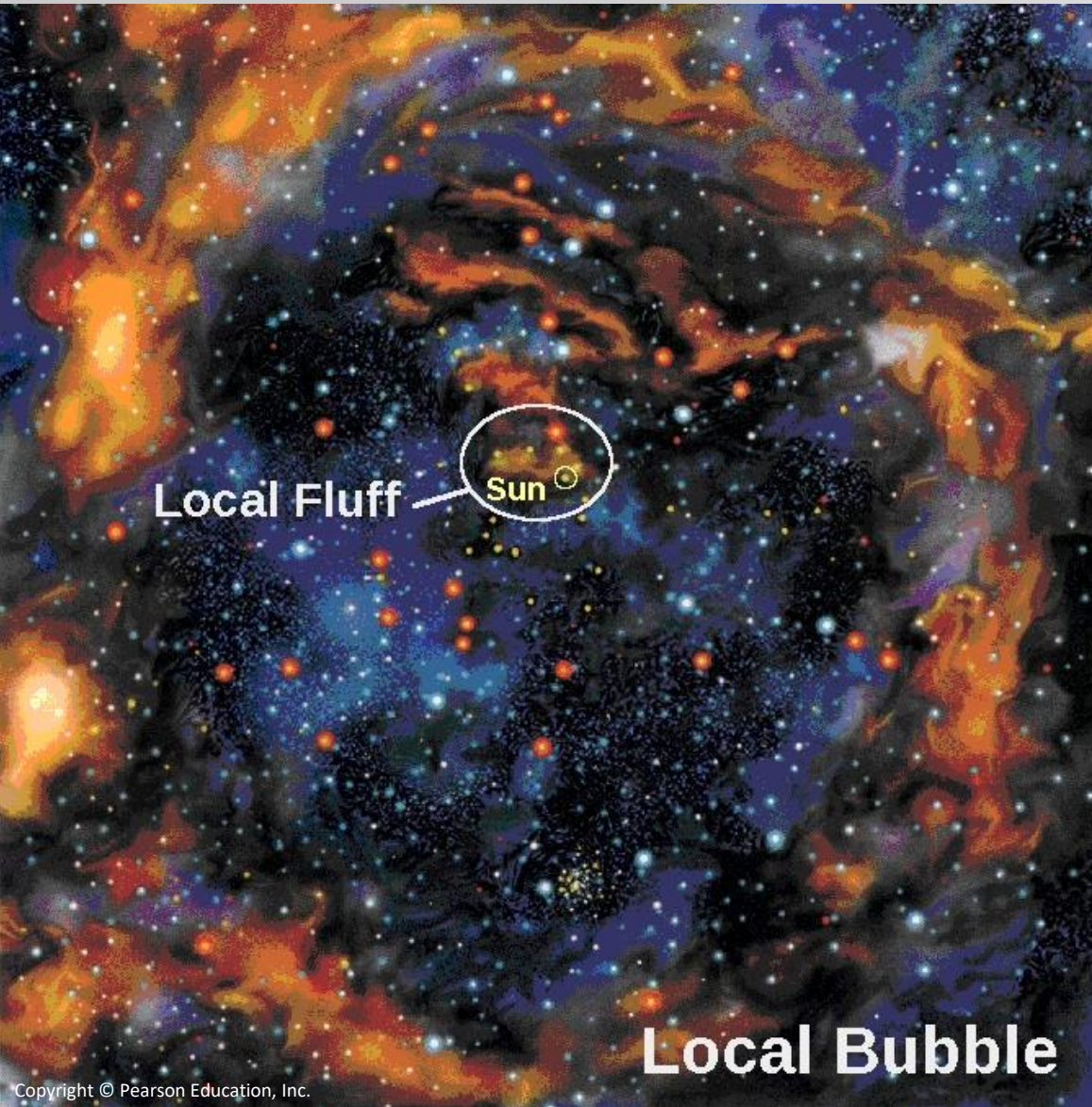


Koll et al., PRL 123, 072701 (2019), Wallner et al., PNAS 117 (36) 21873 (2020)

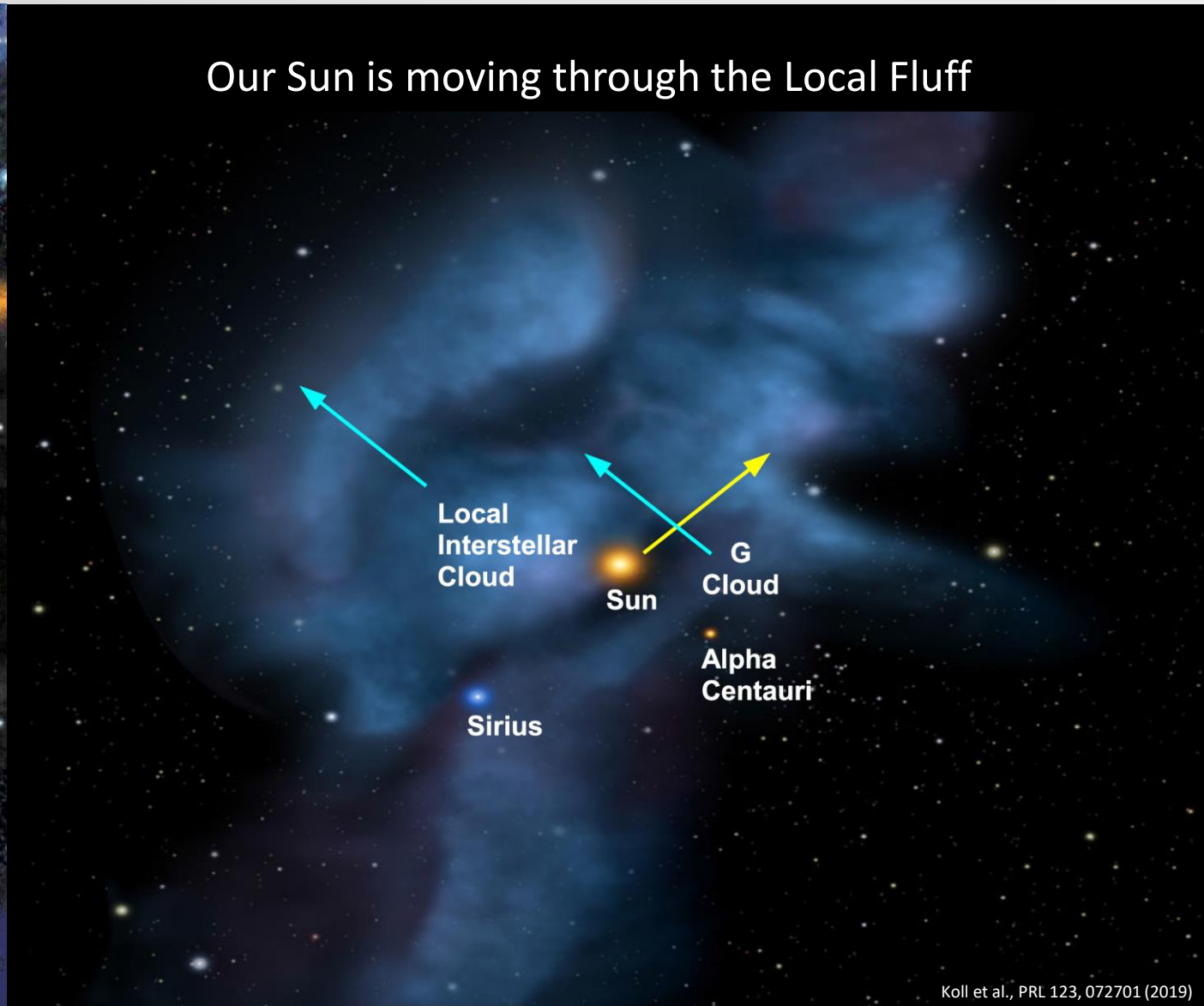


Schulreich, Breitschwerdt, Feige et al. 2017

Recent Supernova Influx



Our Sun is moving through the Local Fluff

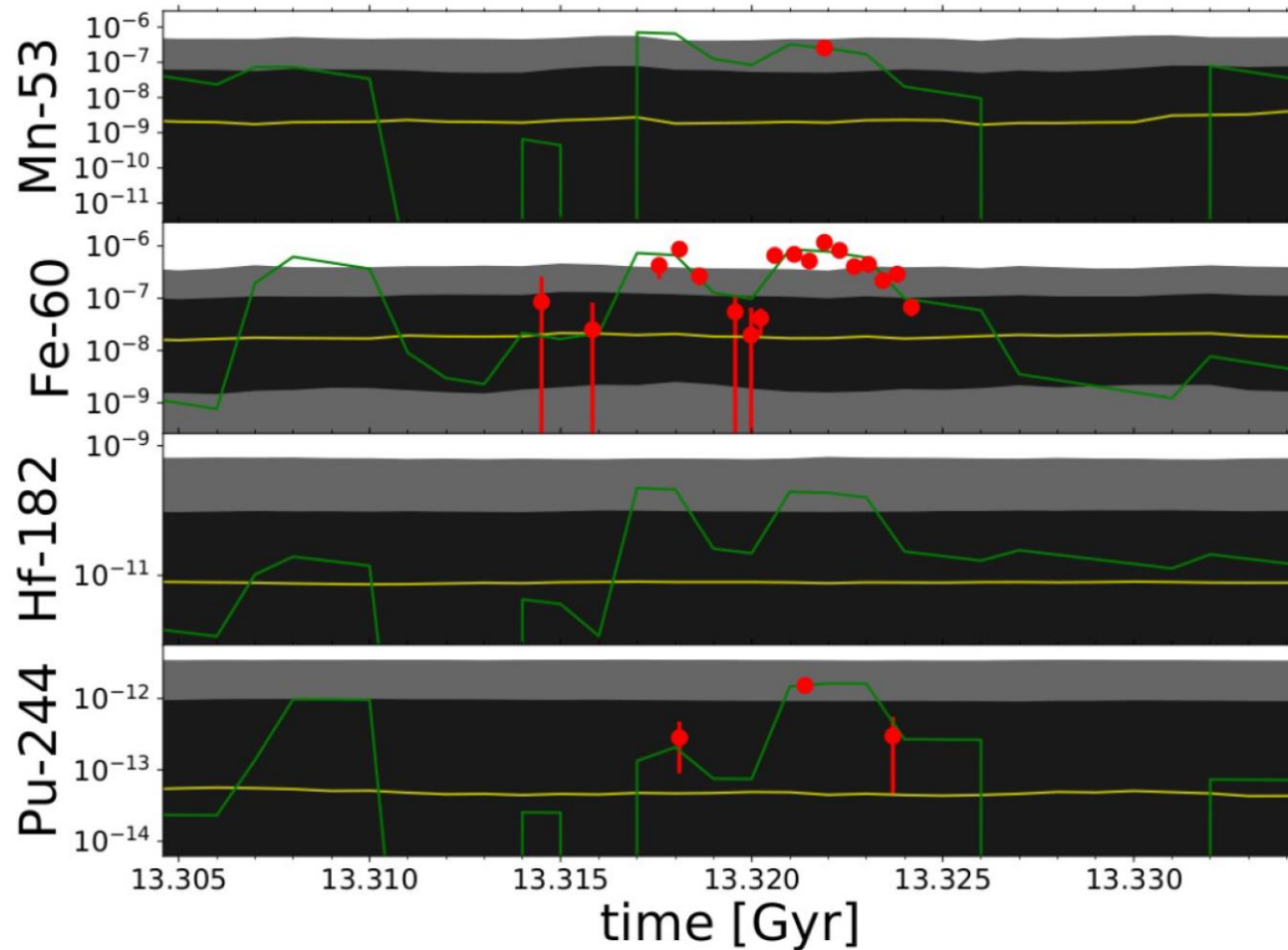


Koll et al., PRL 123, 072701 (2019)

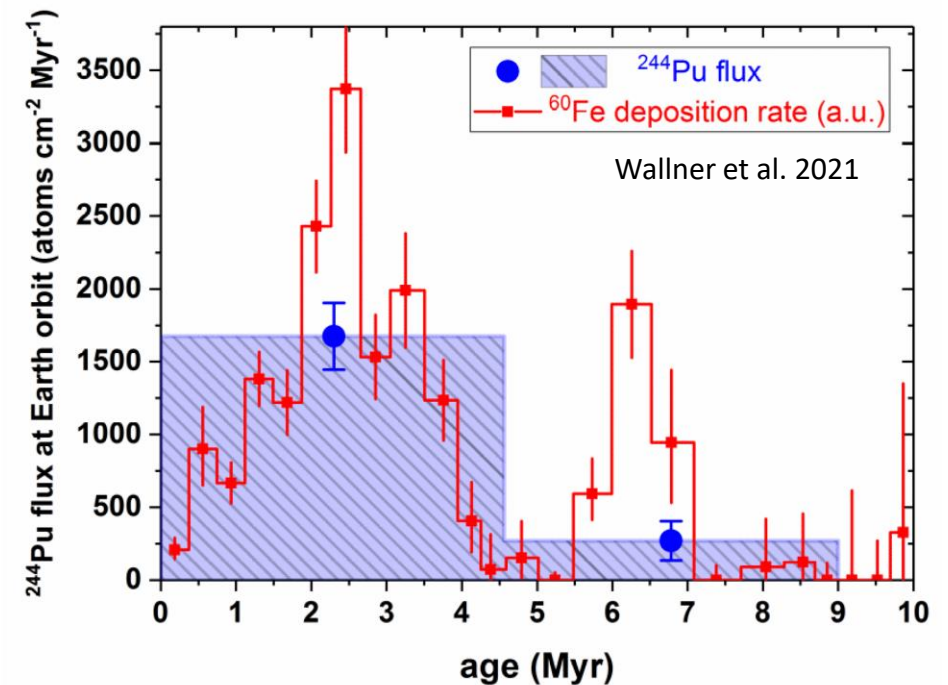
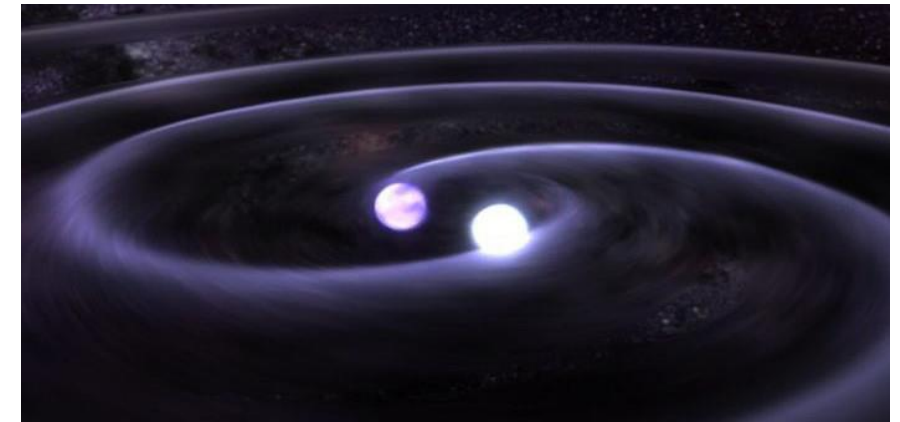
Transport of r-process radioactive nuclei through the ISM

Wehmeyer et al., NPA-X

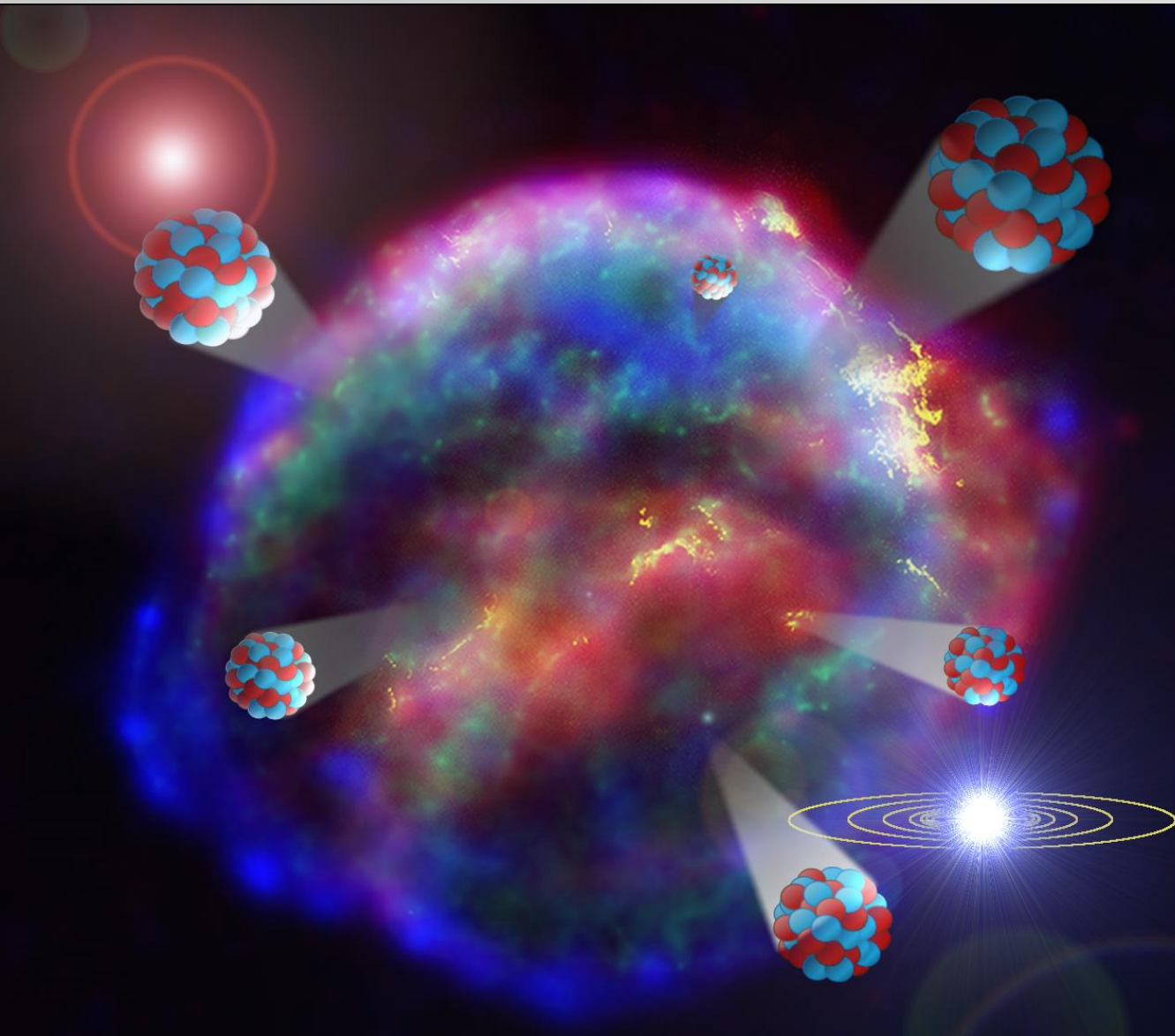
Compare 3D model to deep-sea detection values



Fe-60, Pu-244 from Wallner+, Mn-53 from Korschinek+, time shifted



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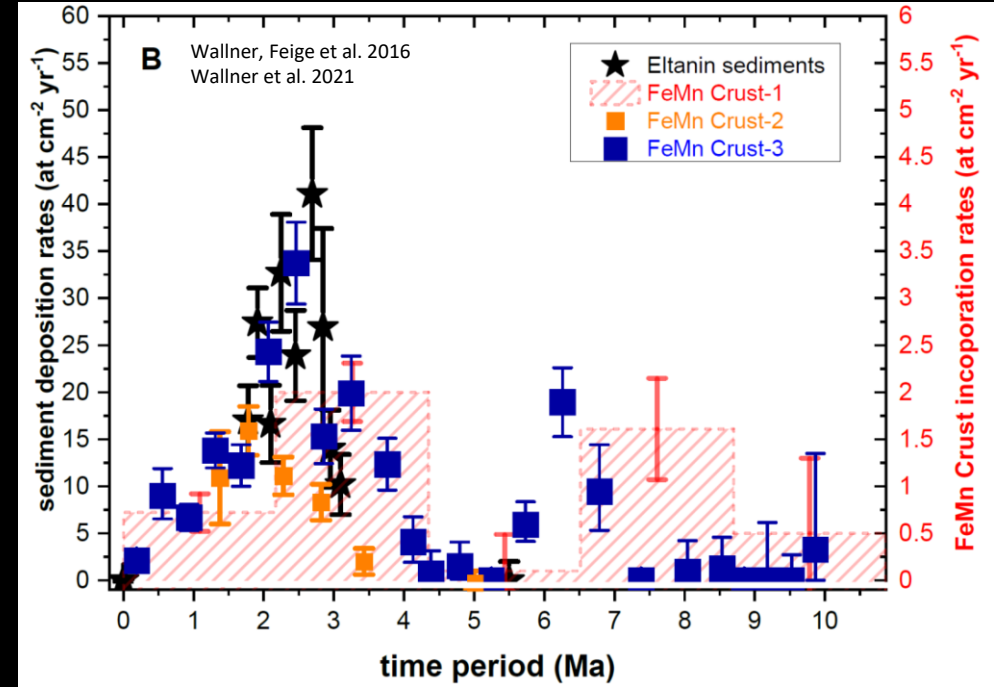
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Our Solar System History

14 13 12

MILLION YEARS AGO

Zucker et al. 2022



Thank you for your attention!

