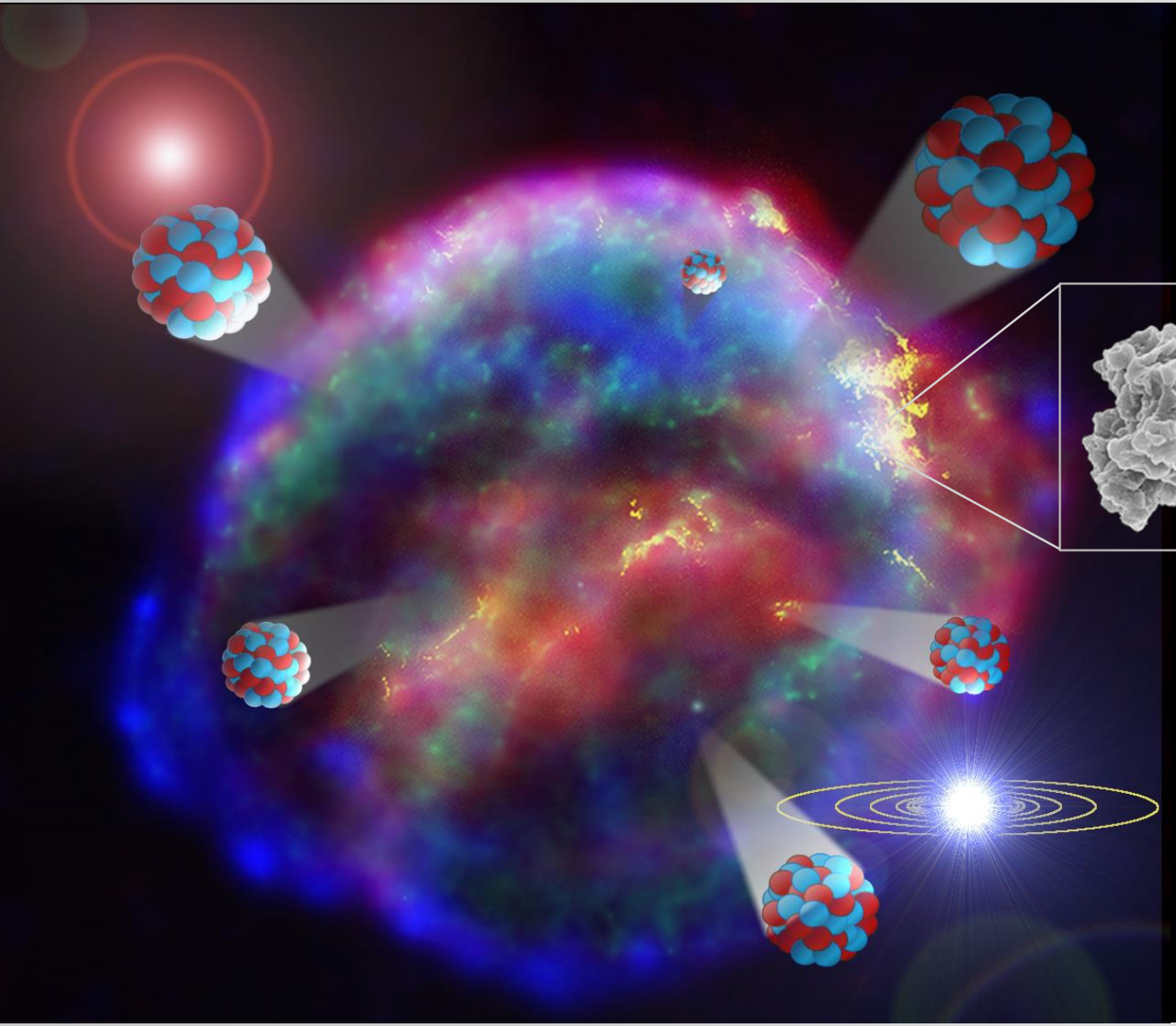
Jenny Feige
Technische Universität Berlin, Germany
17.03.2023

Supernova Dust on Earth

- Introduction
- Data
- Models
- Outlook



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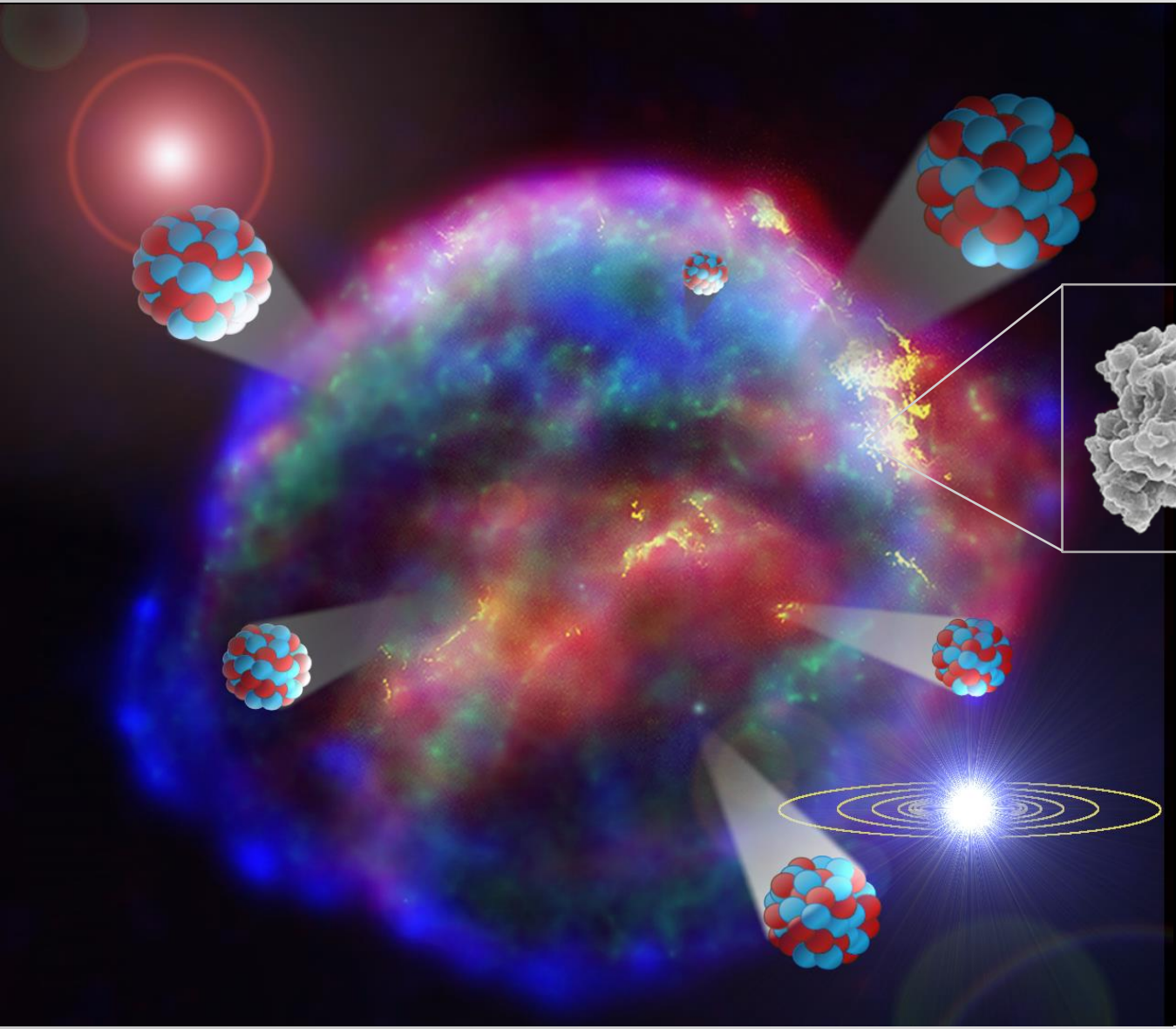
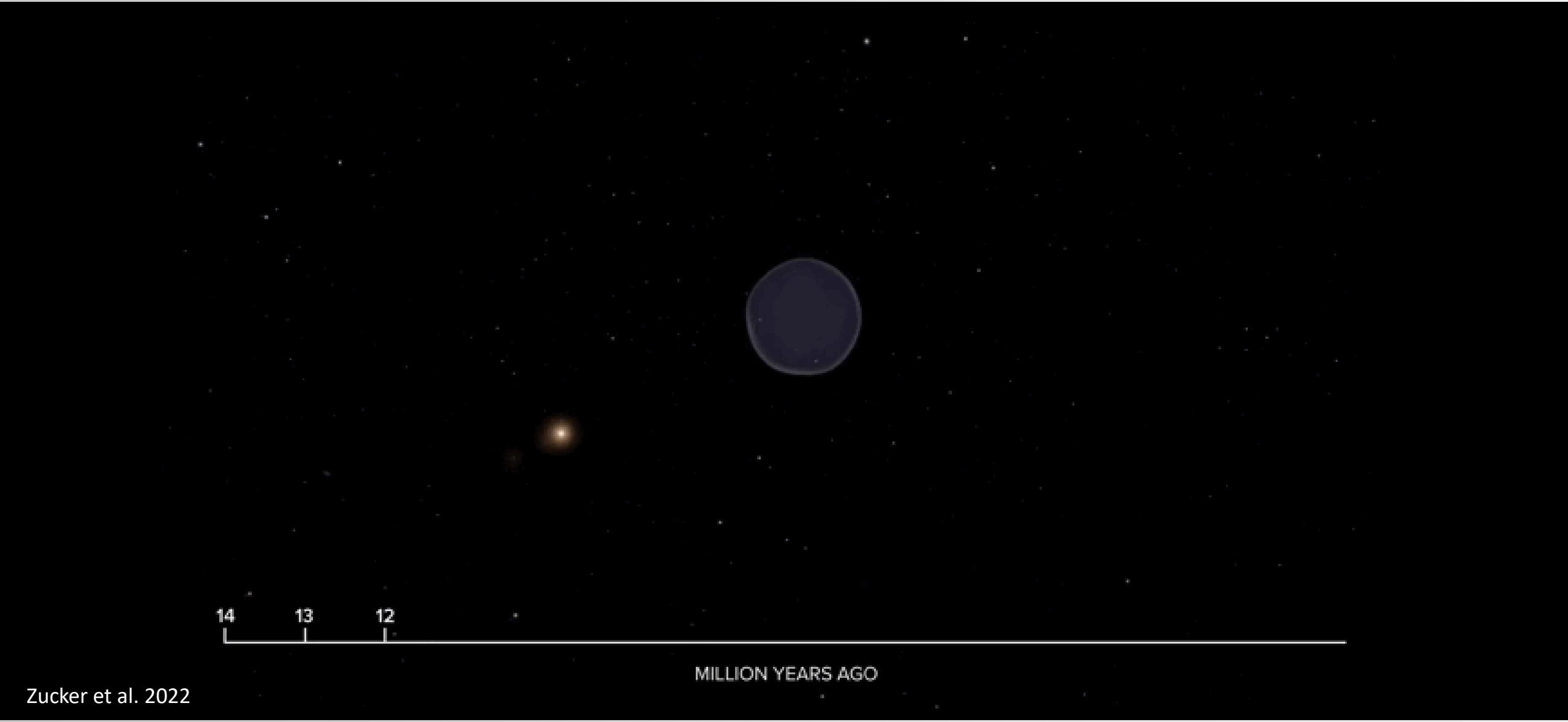


Our Solar System History



Zucker et al. 2022

The Solar Environment

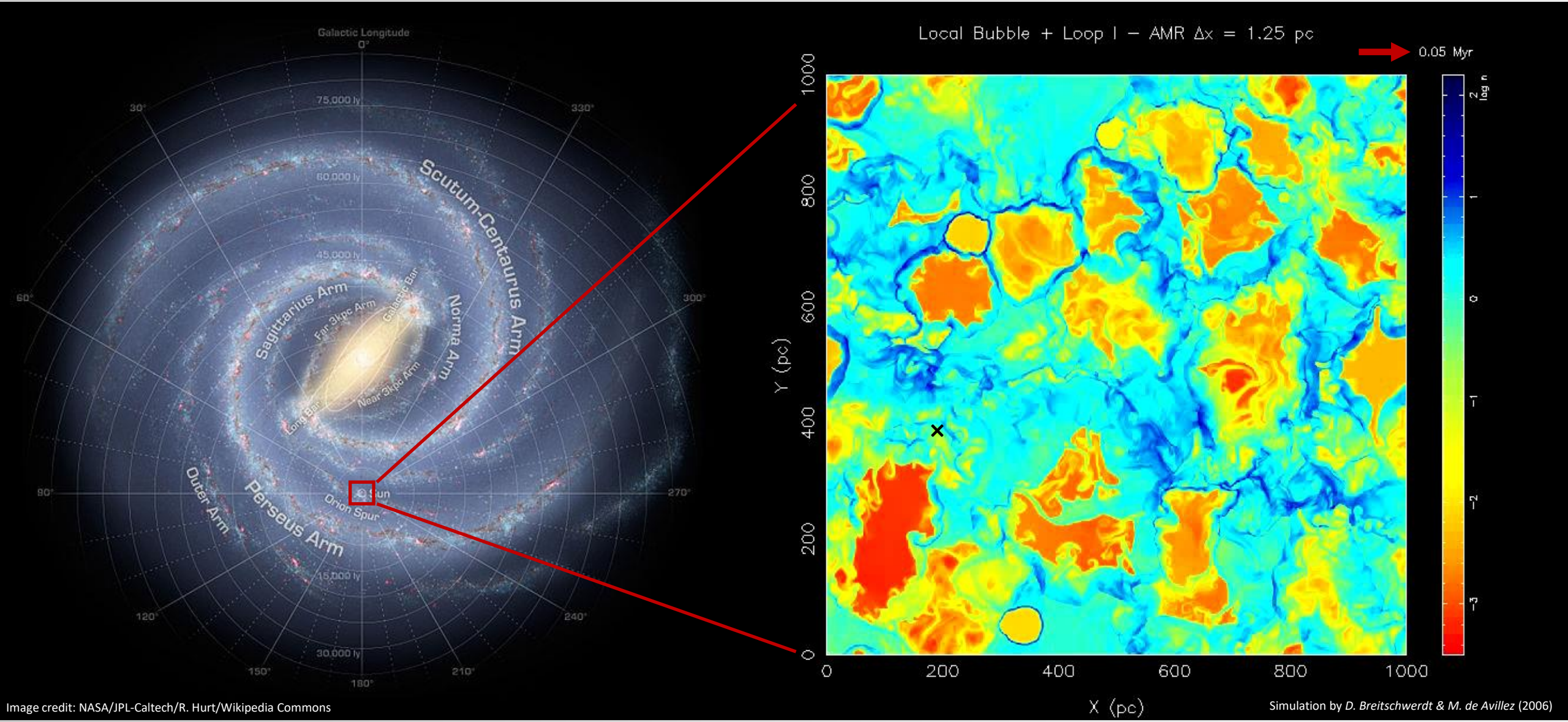
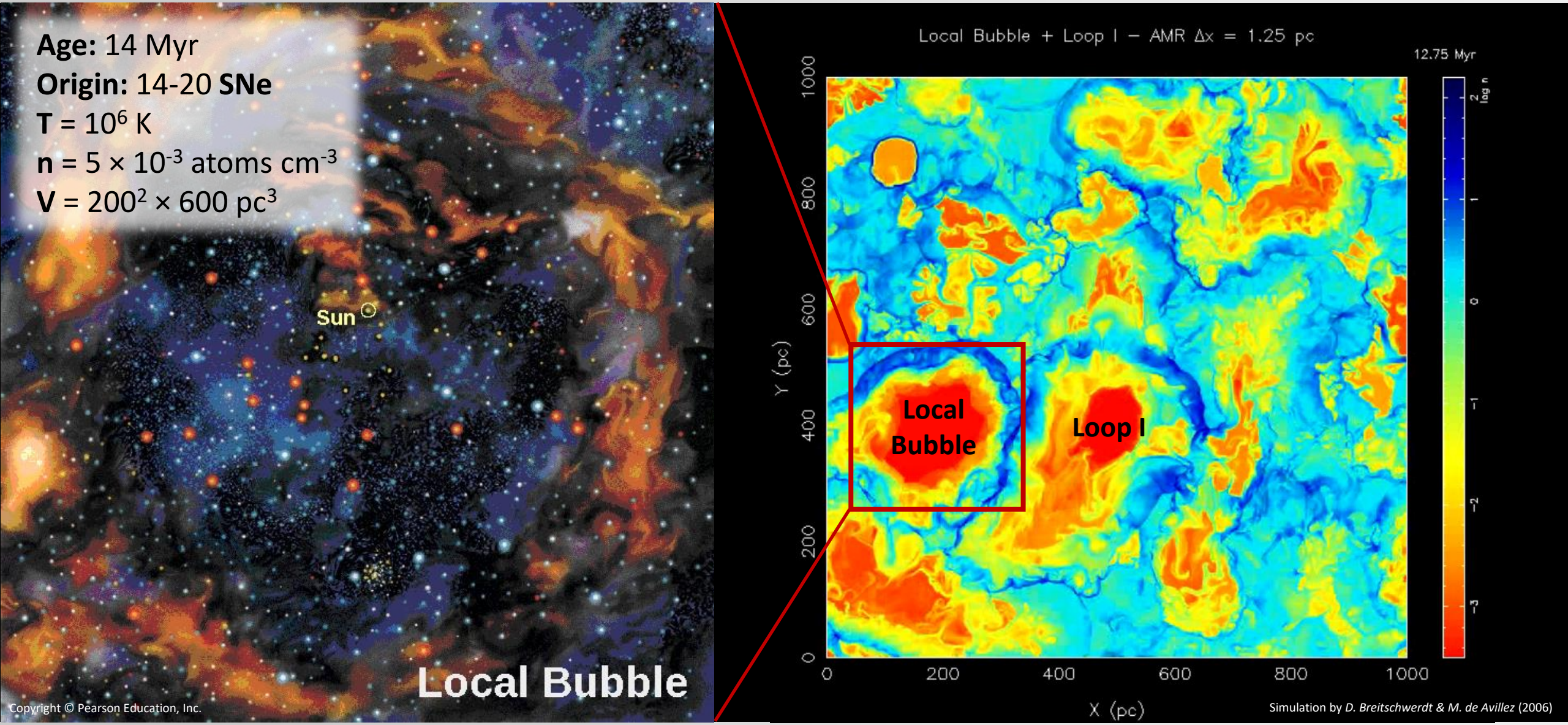


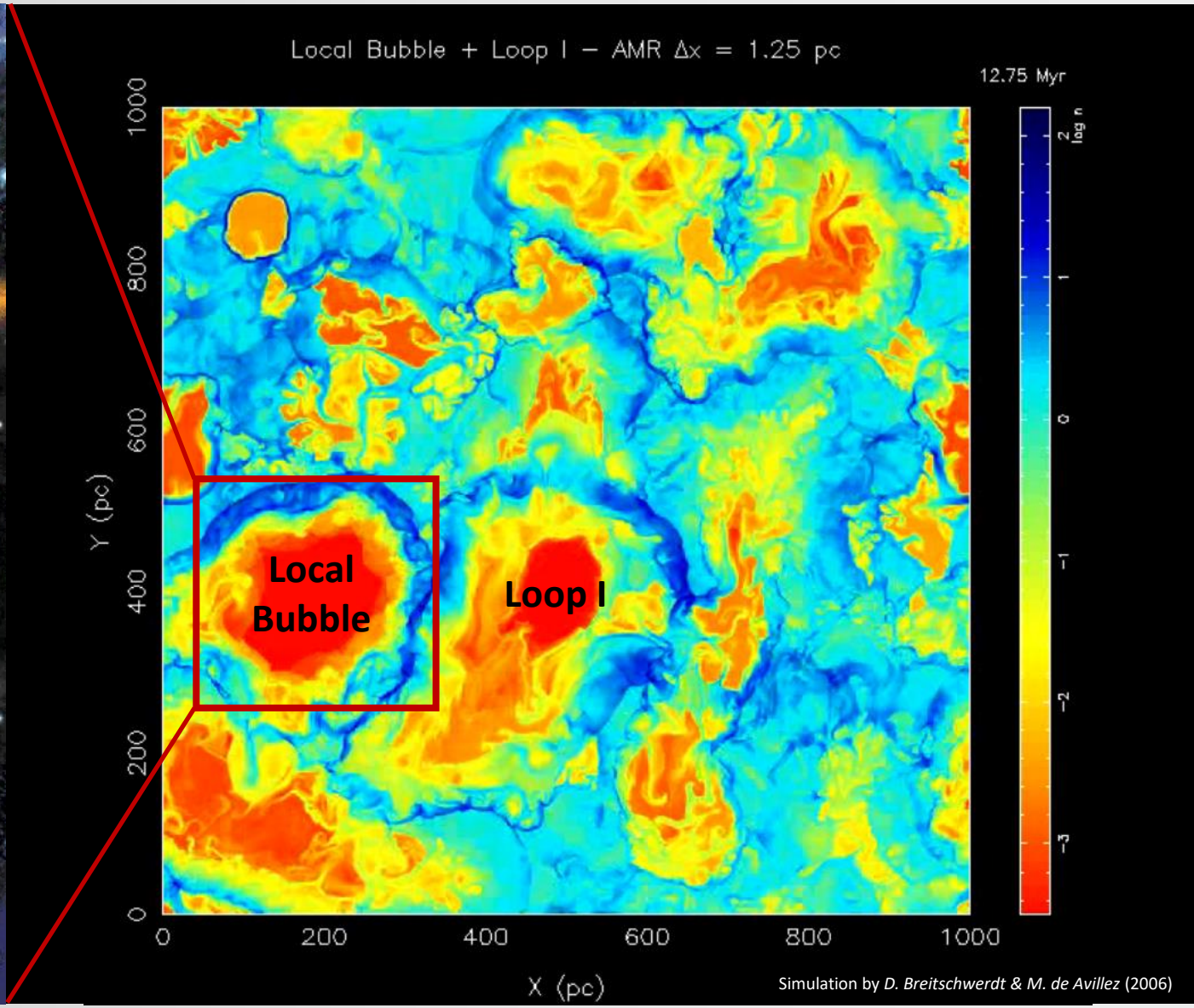
Image credit: NASA/JPL-Caltech/R. Hurt/Wikipedia Commons

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

The Solar Environment



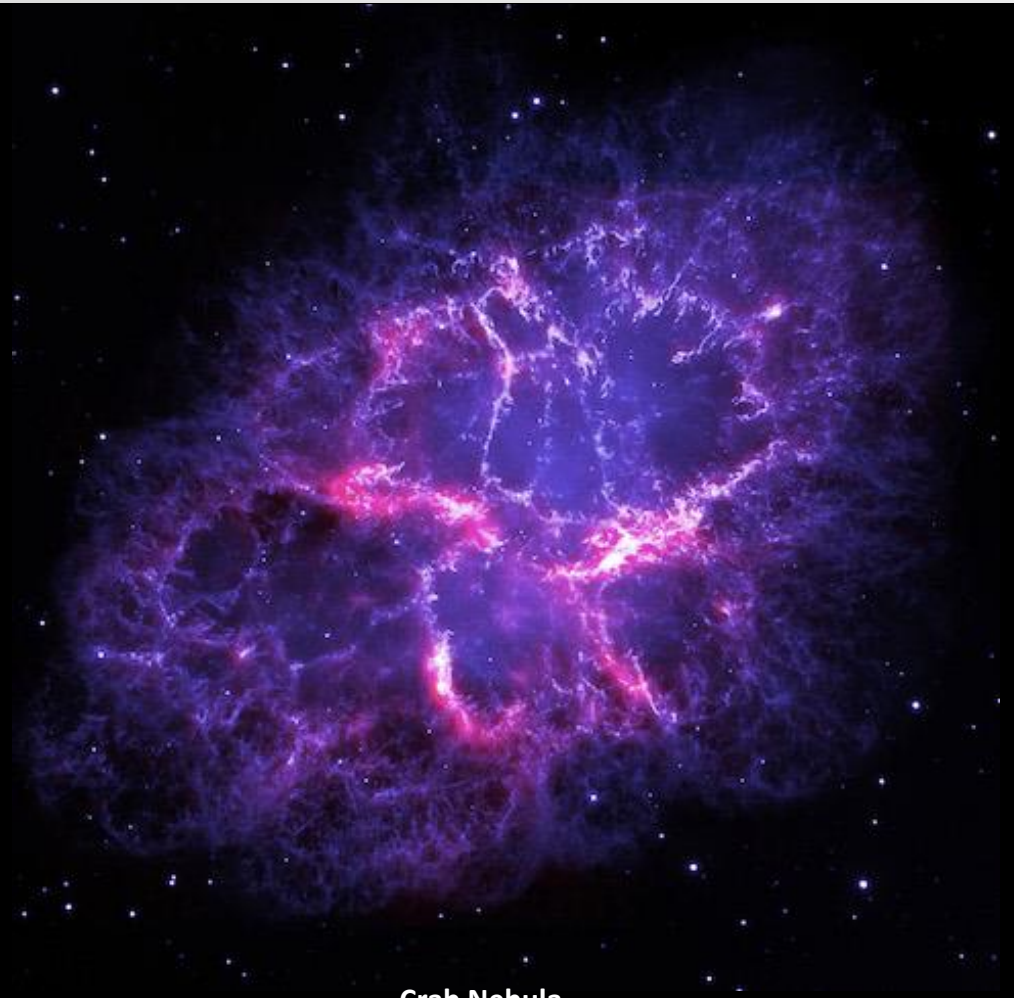
The Solar Environment



Supernovae are radioactive element factories

Supernova Remnant SNR 0509–67.5
HST/ACS/WFC3 • *CXO*/ACIS

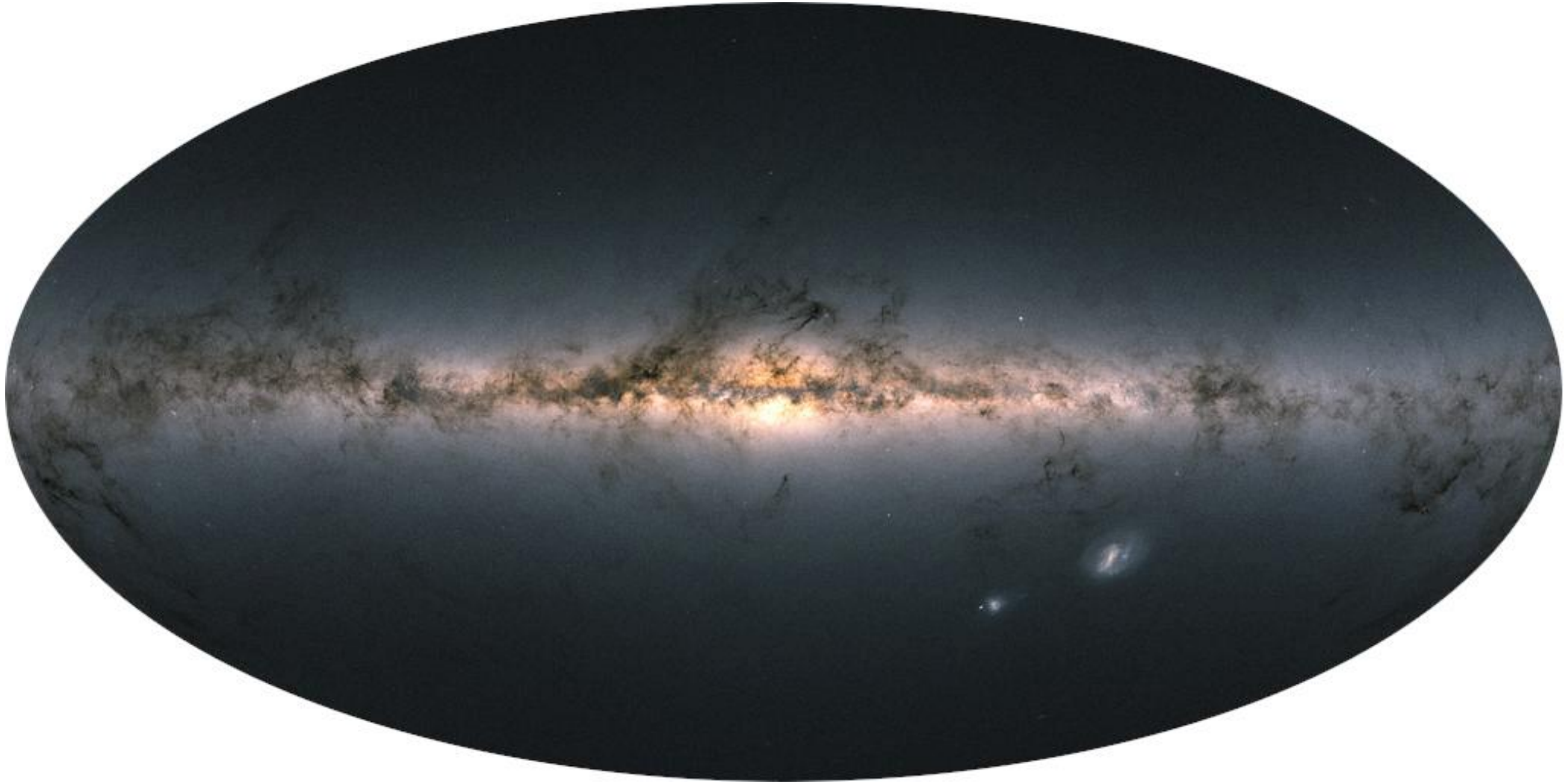
NASA, ESA, CXC, SAO, B. Schaefer and A. Pagnotta (Louisiana State University, Baton Rouge), the Hubble Heritage Team (STScI/AURA), and J. Hughes (Rutgers University) STScI-PRC12-06a



Crab Nebula
Herschel (red) and Hubble (blue) composite

Credit: ESA/Herschel/PACS/MESS Key Programme Supernova Remnant Team; NASA, ESA and Allison Loll/Jeff Hester (Arizona State University).

Radioactivity in our Milky Way

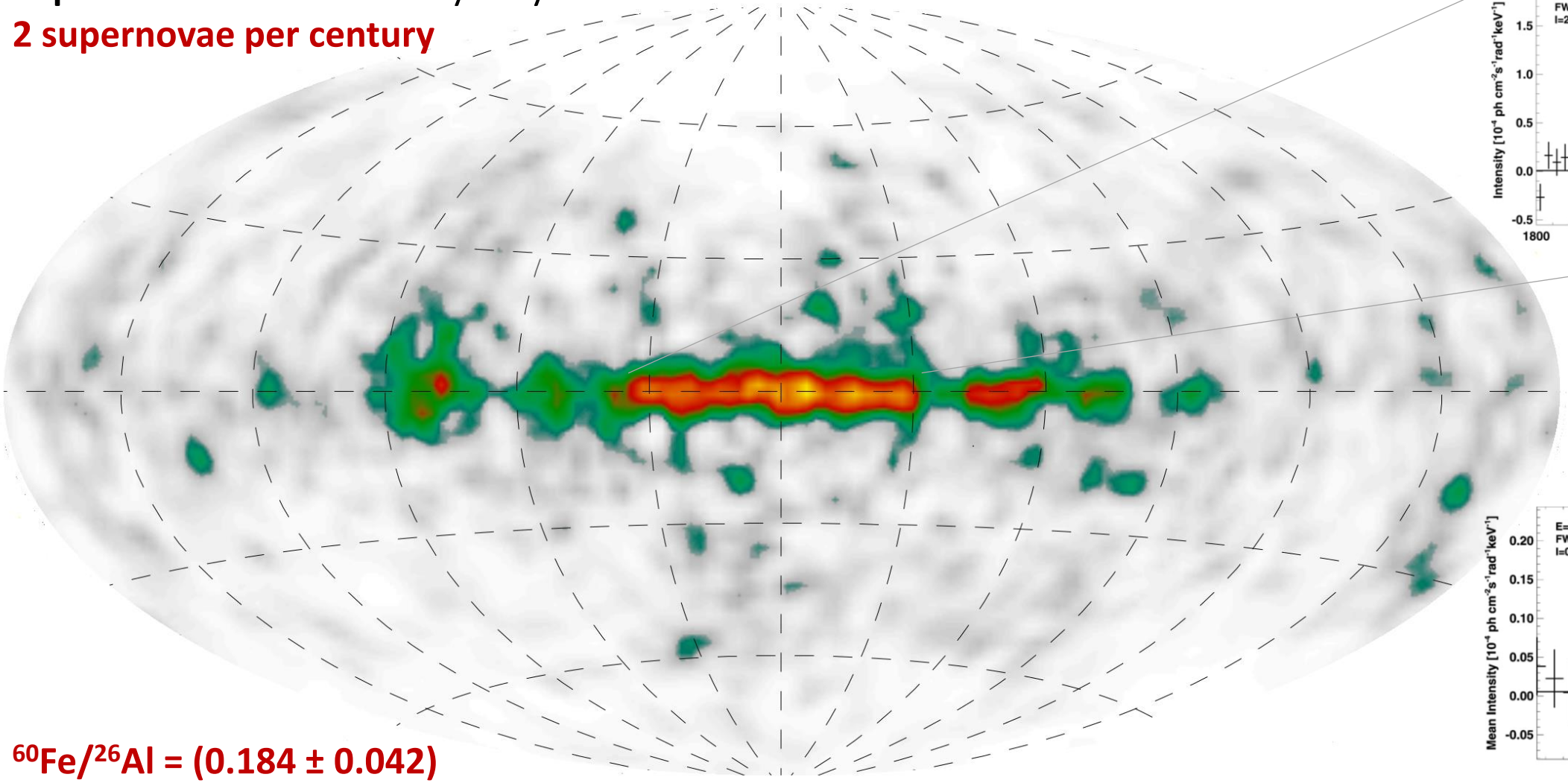


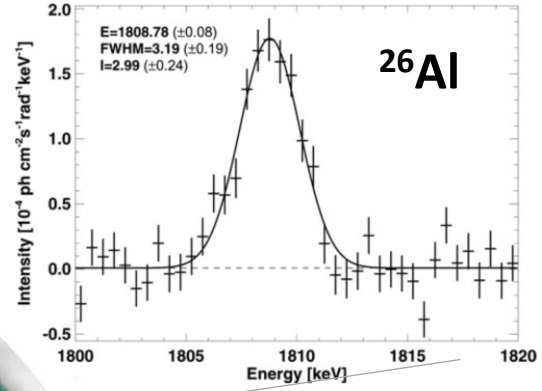
www.dlr.de/content/en/images/2020/4/gaia-milky-way.html

Radioactivity in our Milky Way

Supernova-rate in our Milky Way

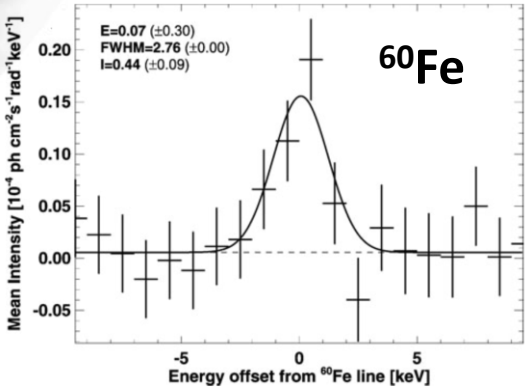
2 supernovae per century





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

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



^{60}Fe/^{26}Al = (0.184 ± 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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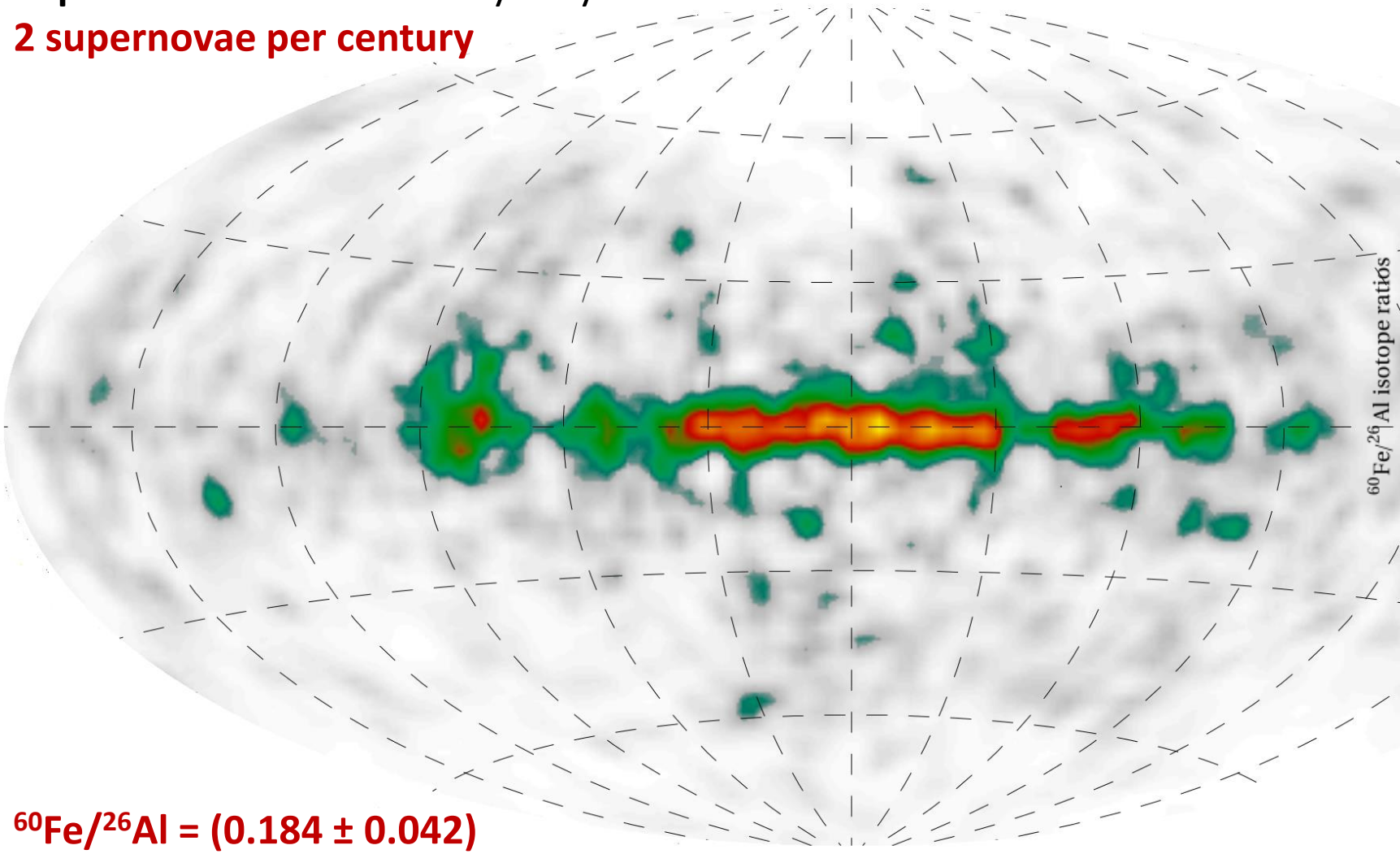

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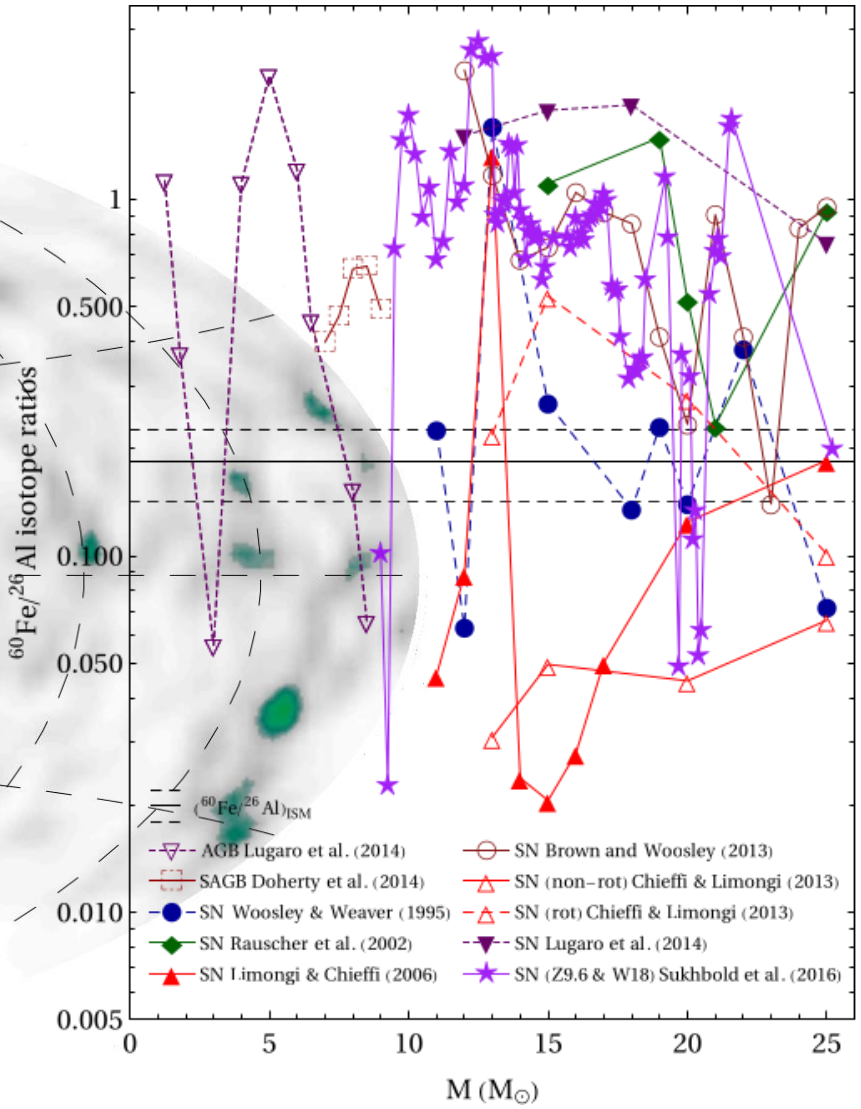

Modified from Feige et al., PRL 121, 221103 (2018)

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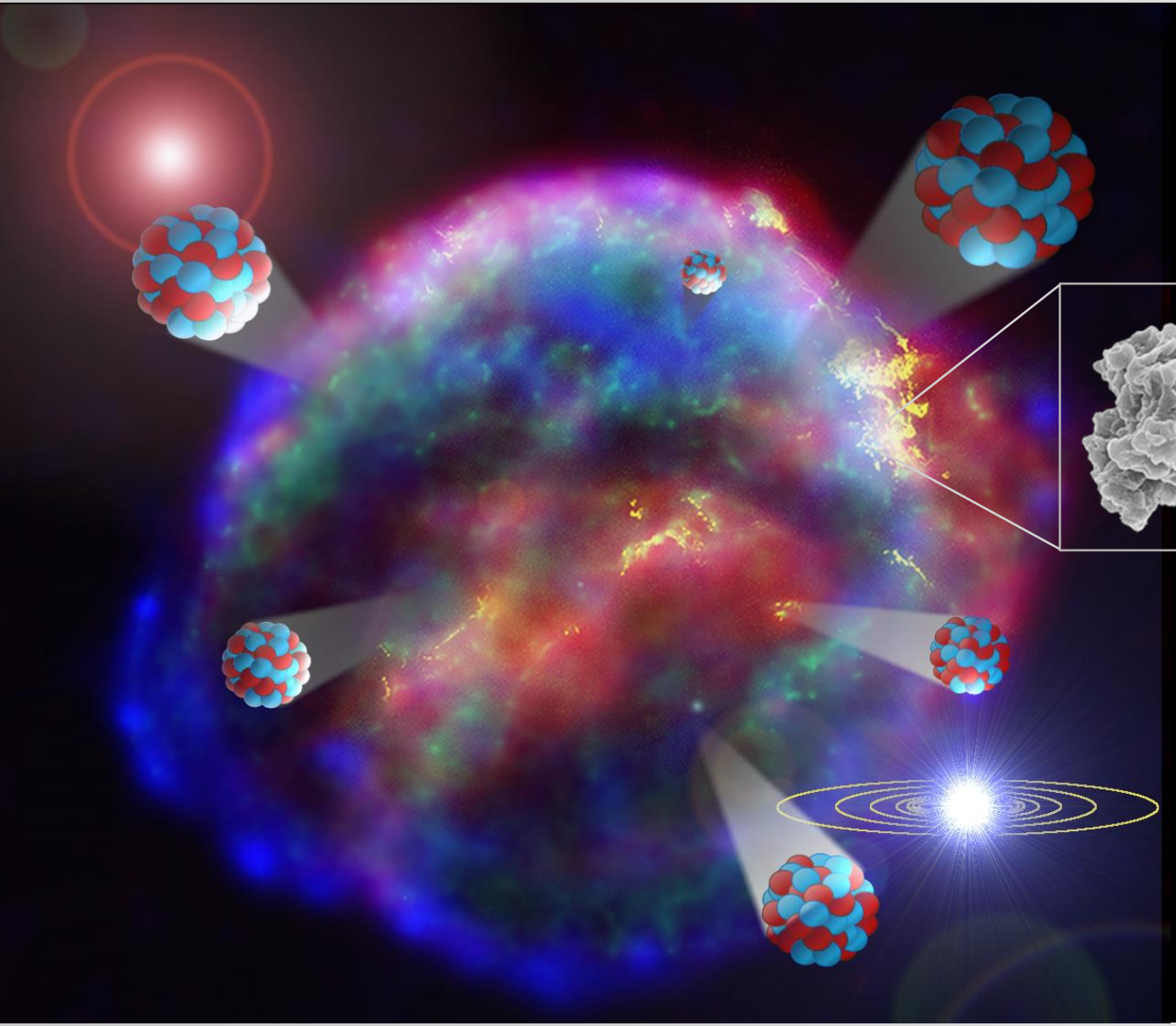
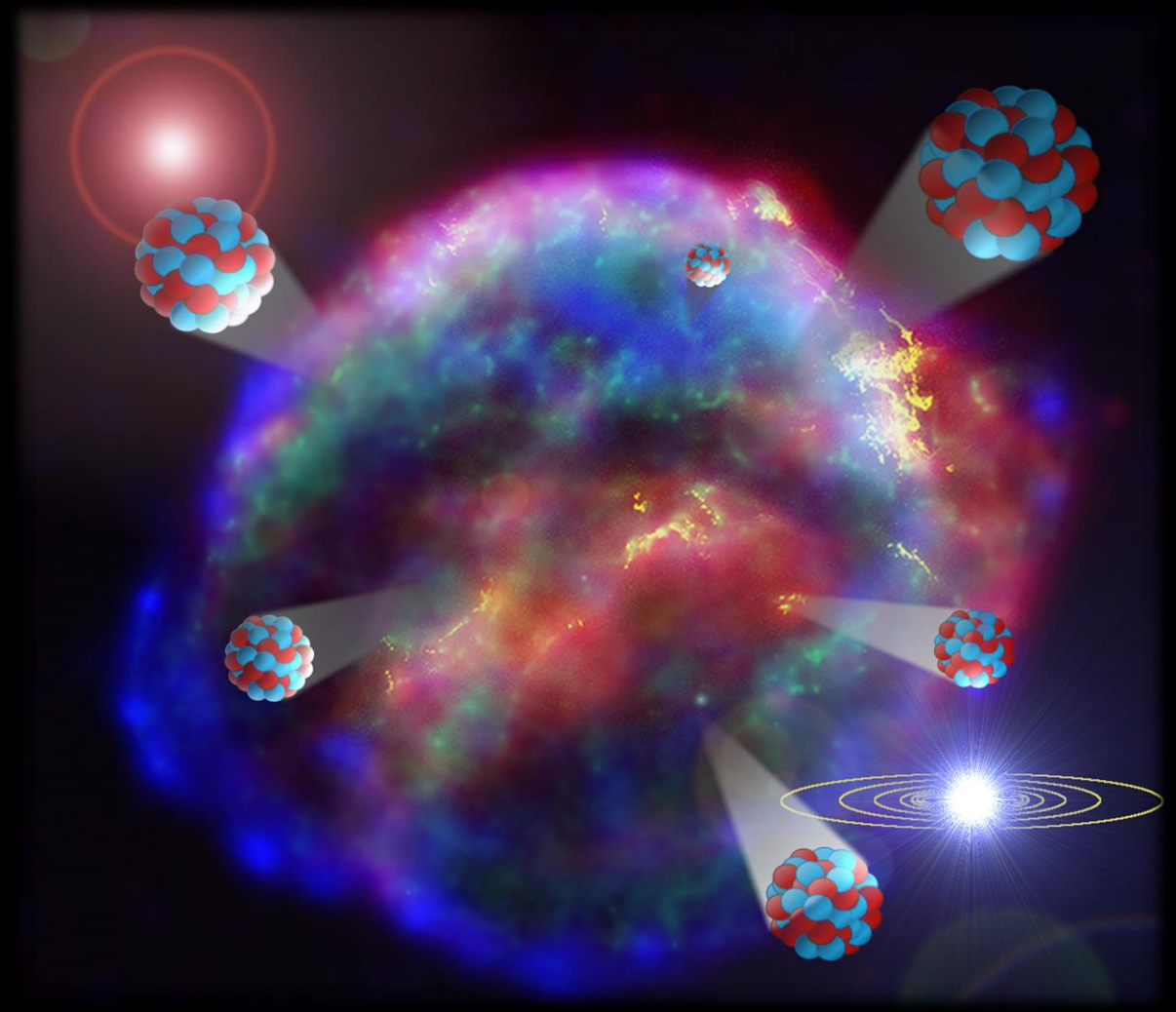


Radioactive Supernova Traces

r >10 pc

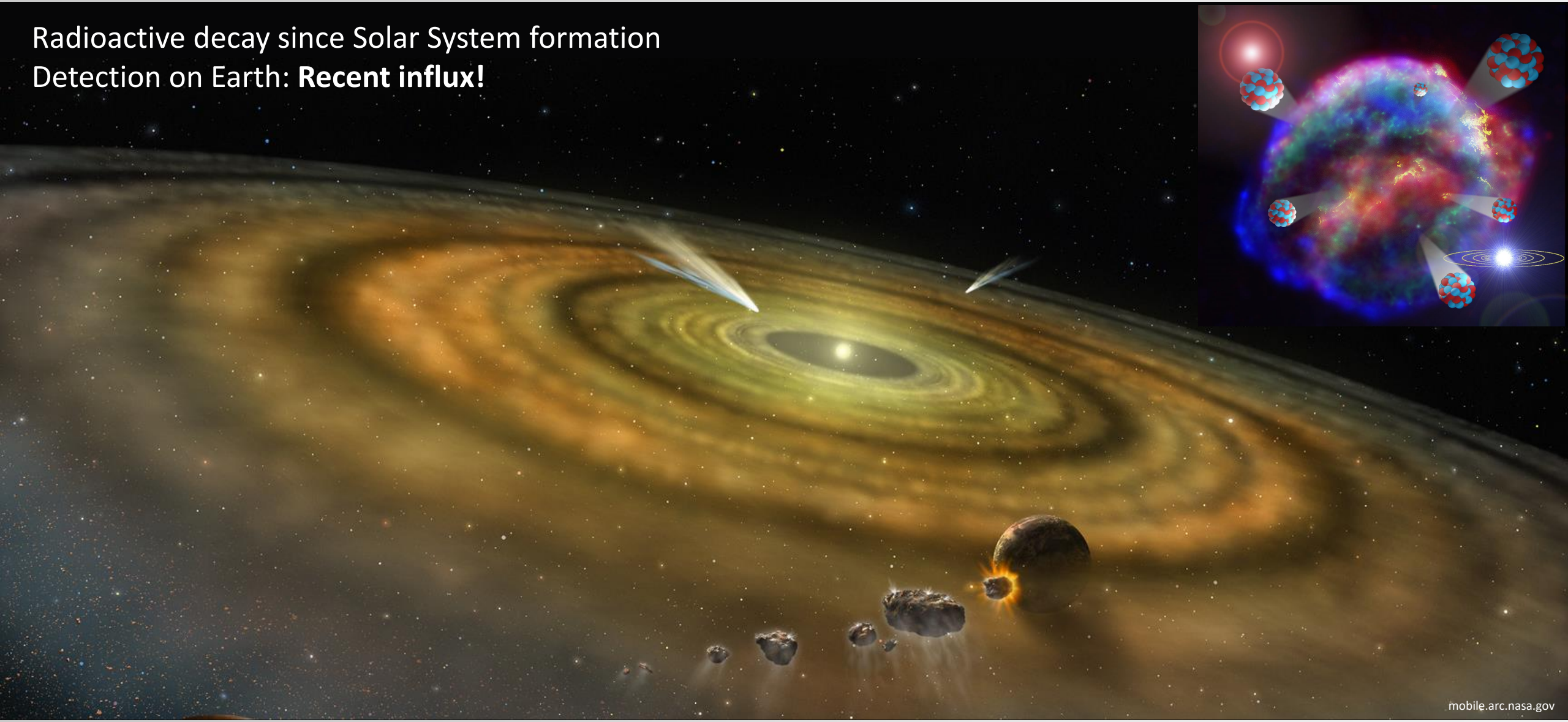


Observable Supernova fingerprints:

- **Radioactive isotopes, e.g., ^{26}Al, ^{53}Mn, ^{60}Fe, ^{244}Pu**
- **Half-lives** in the order of **0.7-80 million years!**

Solar System Formation 4.57 Gyr ago

Radioactive decay since Solar System formation
Detection on Earth: **Recent influx!**



Supernova Traces on Earth

Deep-sea sediments

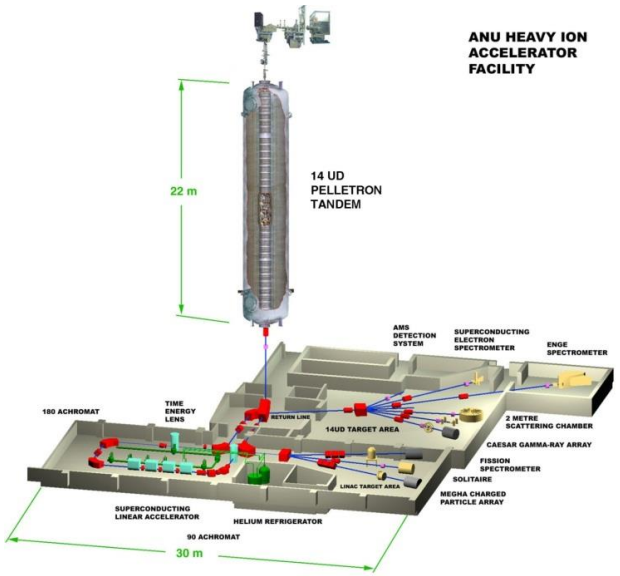
- Accumulation rate: **mm/kyr**
- Ideal for resolving SN events!!!

Deep-sea crusts and nodules

- Growth rate: **mm/Myr**
  - Rough time estimation
- Cover a large time range

Undisturbed archives
with a long-term memory!

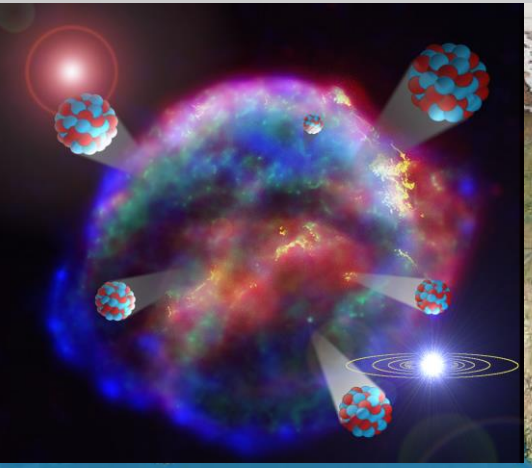
Searching for Global Supernova Traces



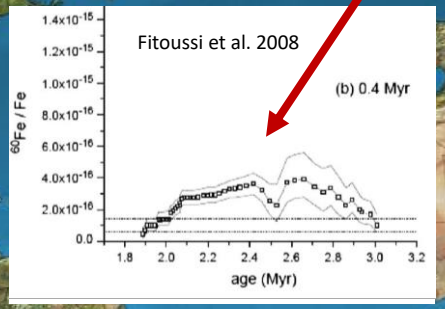
ANU
Canberra
Australia

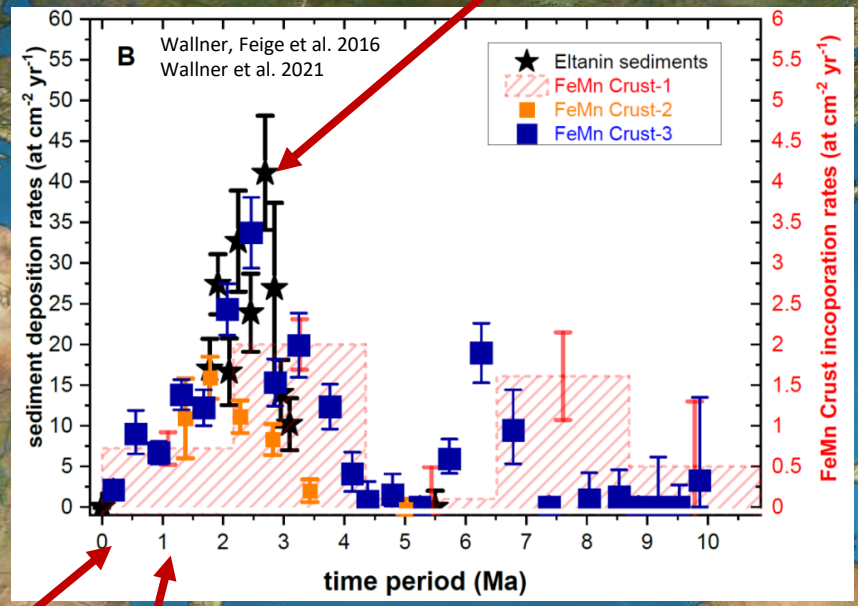
Less than
10 ^{60}Fe atoms
in a 3 g sediment sample!

Global ^{60}Fe signatures



North Atlantic Sediments



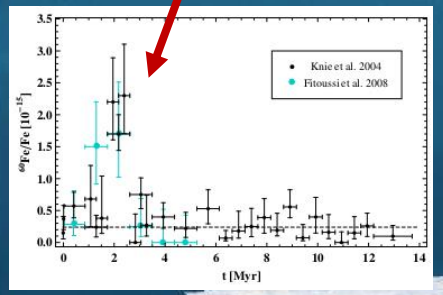


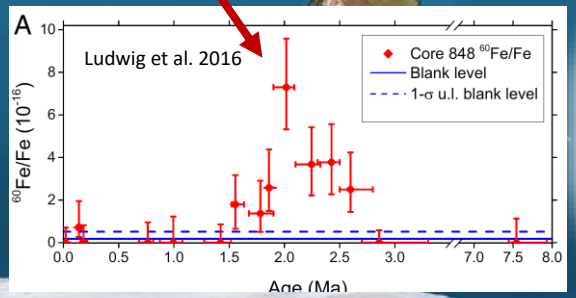
Pacific FeMn Crusts

Pacific Crust 237 KD

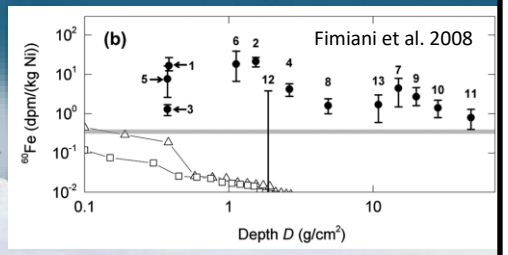
Pacific Sediments

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,*] Gunther Korschinek,[1,2] Thomas Faestermann,[1,2] J. M. Gómez-Guzmán,[1] Sepp Kipfstuhl,[3] Silke Merchel,[4] and Jan M. Welch[5]

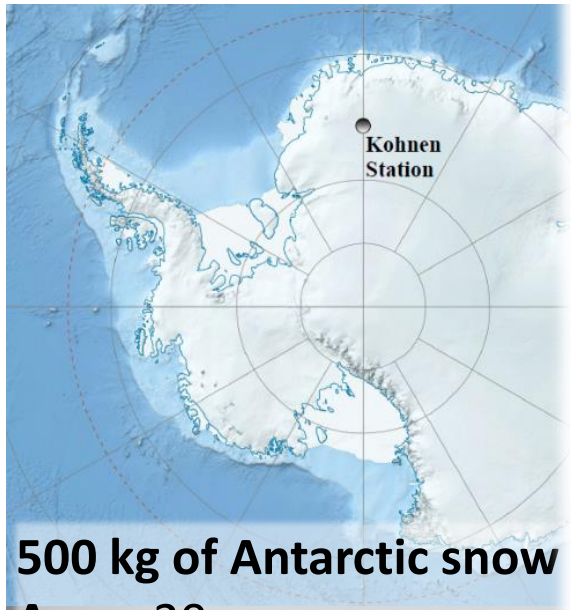
^{60}Fe Flux today
1/10 of peak flux

Peak-flux:
~30 ats/yr/cm²

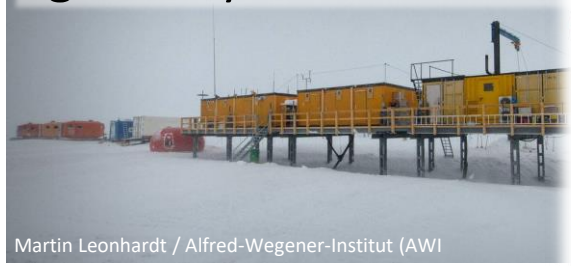
PNAS PNAS

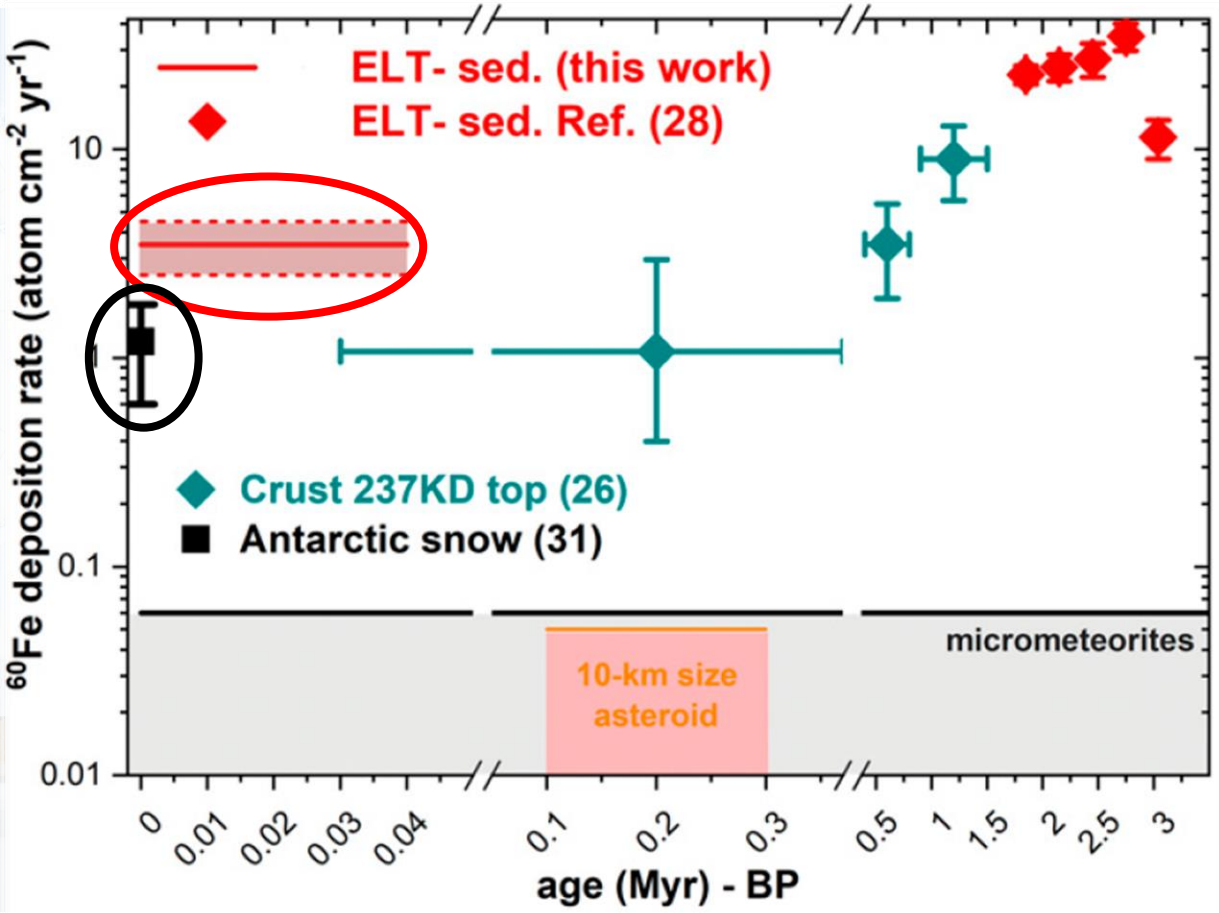
^{60}Fe deposition during the late Pleistocene and the Holocene echoes past supernova activity

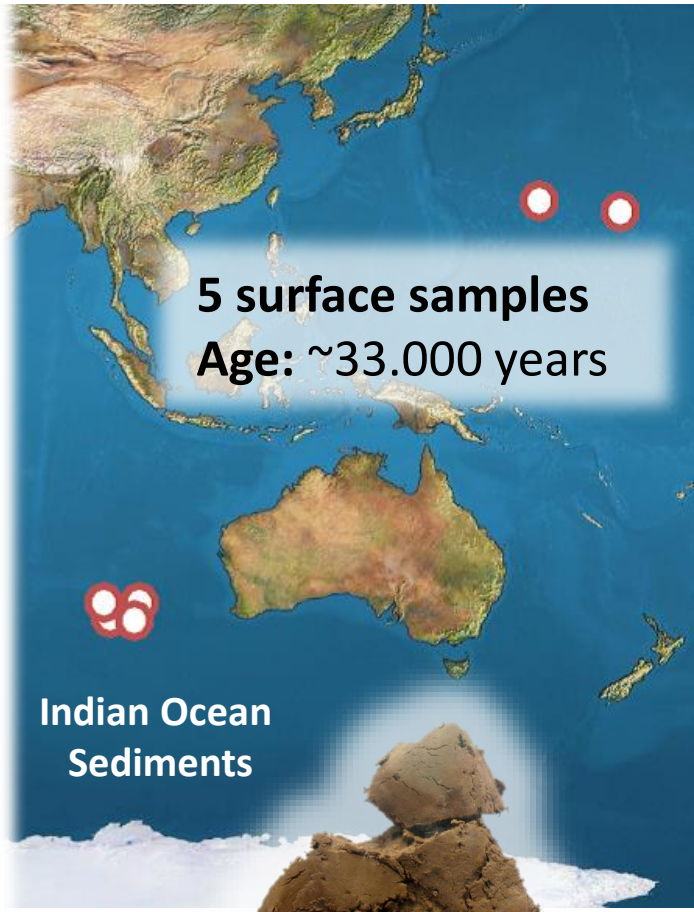
A. Wallner[a,b,1], J. Feige[c,d], L. K. Fifield[a], M. B. Froehlich[a], R. Golser[c], M. A. C. Hotchkis[e], D. Koll[a], G. Leckenby[a], M. Martschini[a,c], S. Merchel[b], S. Panjkov[a], S. Pavetich[a], G. Rugel[b], and S. G. Tims[a]



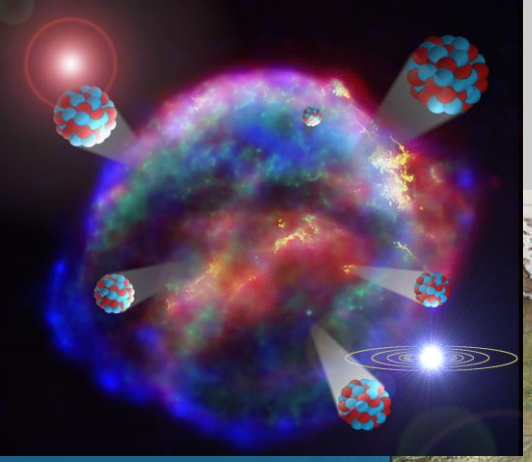
500 kg of Antarctic snow
Age: <20 years

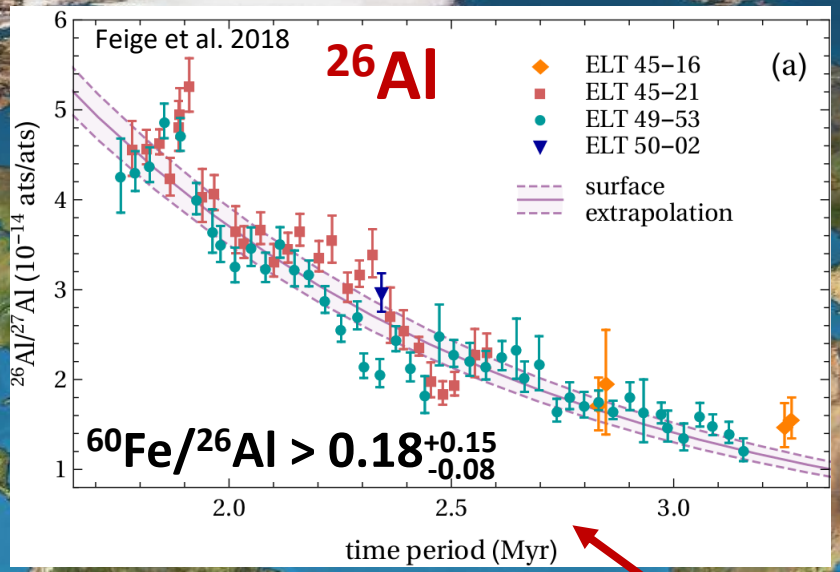


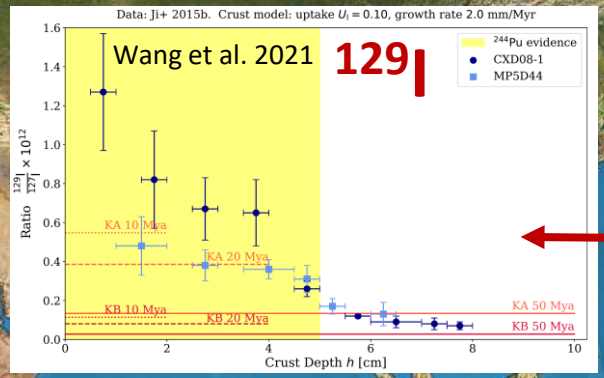




Signals from other radioactive nuclei

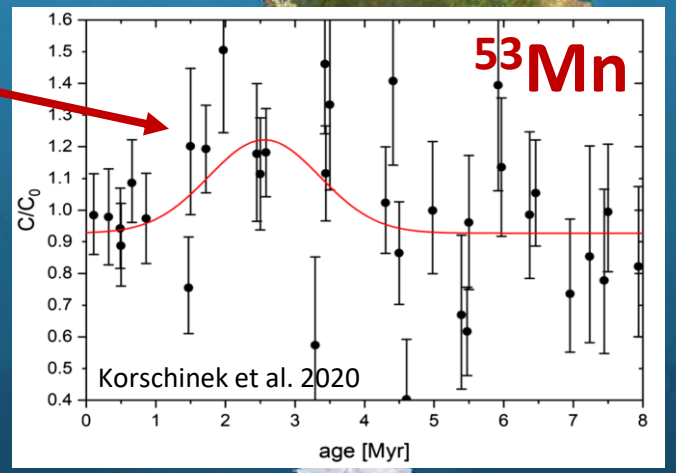






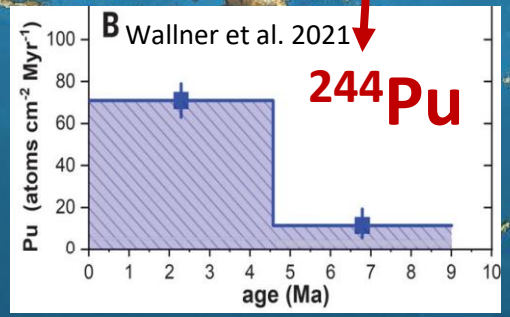
Pacific
FeMn Crusts

Pacific
Crust 237 KD



^{53}Mn/^{60}Fe ~ 14

Indian Ocean
Sediments



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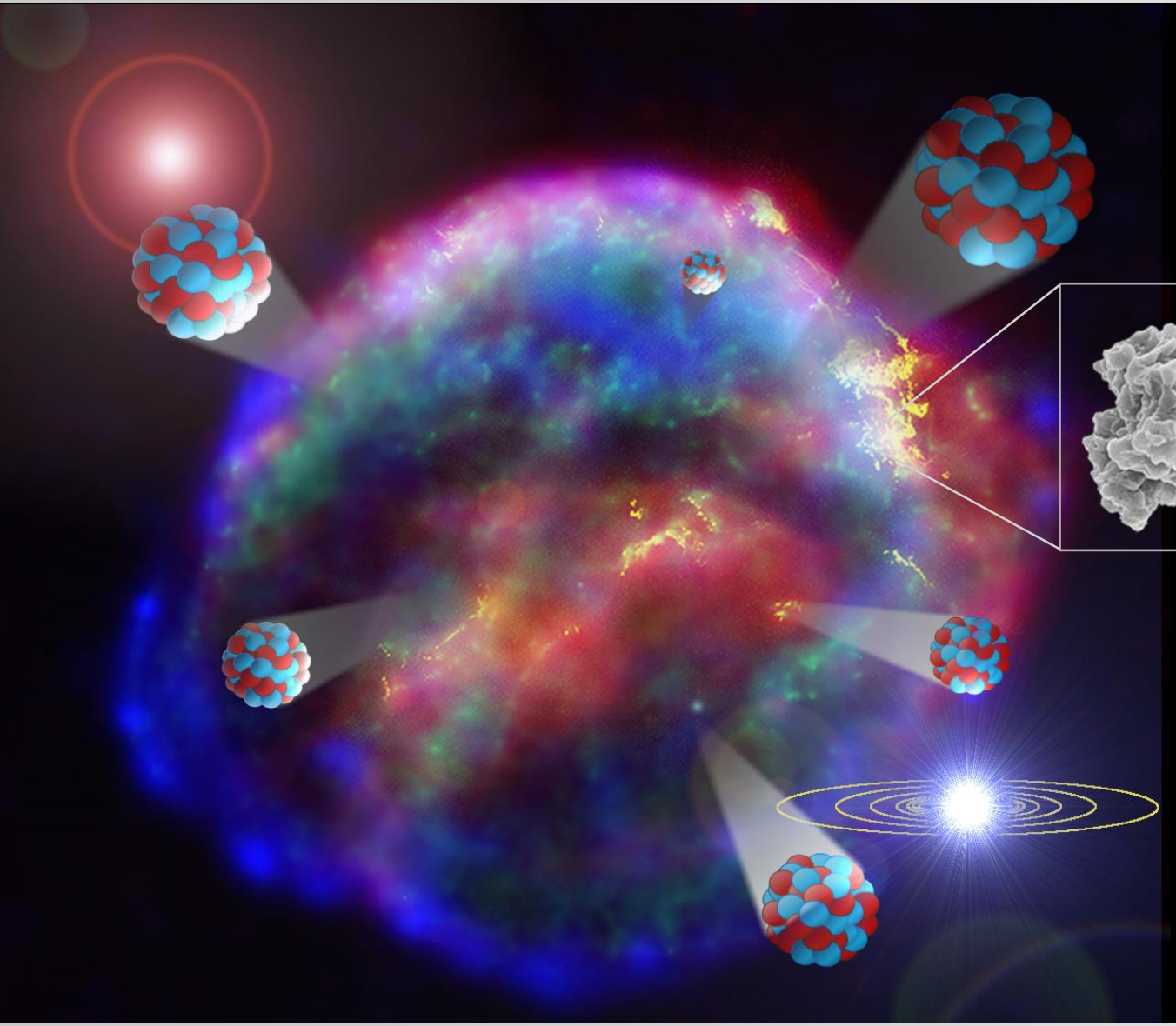
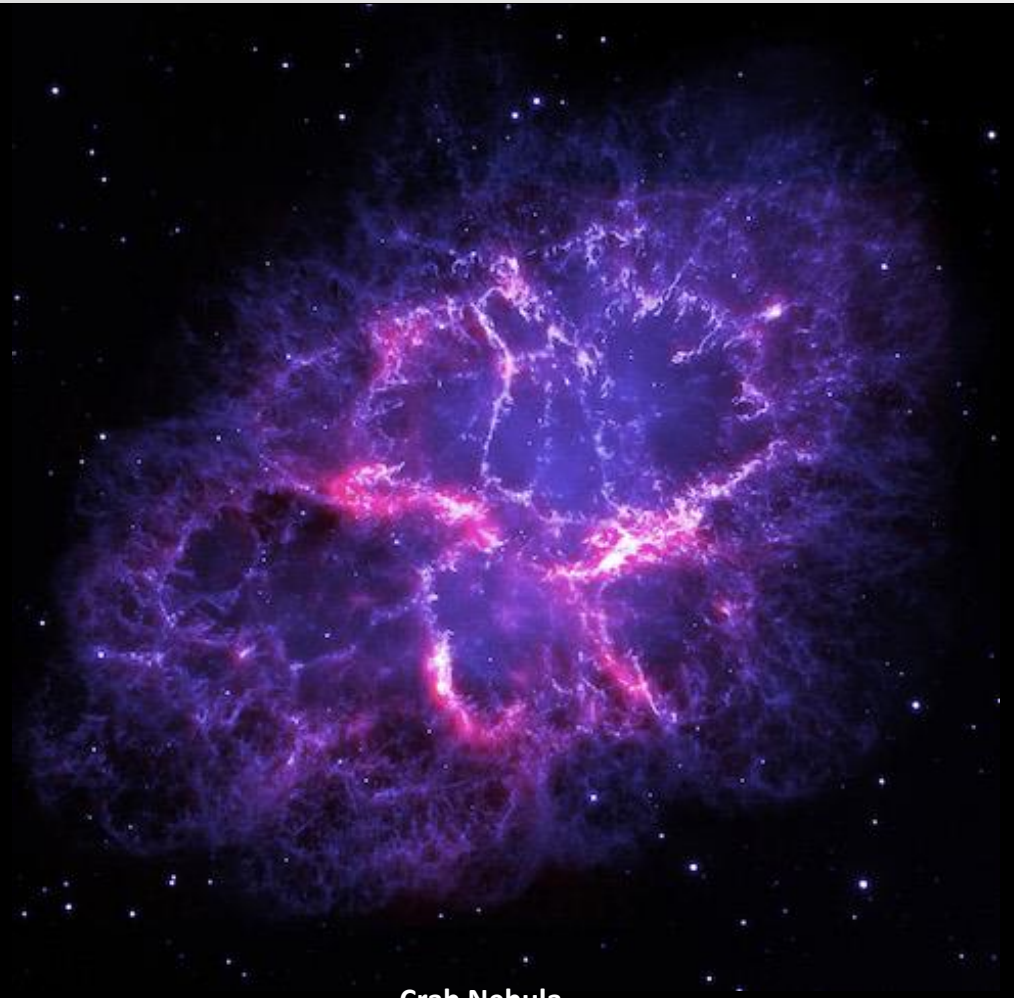


Supernovae are dust factories

Supernova Remnant SNR 0509–67.5
HST/ACS/WFC3 • *CXO*/ACIS

NASA, ESA, CXC, SAO, B. Schaefer and A. Pagnotta (Louisiana State University, Baton Rouge), the Hubble Heritage Team (STScI/AURA), and J. Hughes (Rutgers University) STScI-PRC12-06a

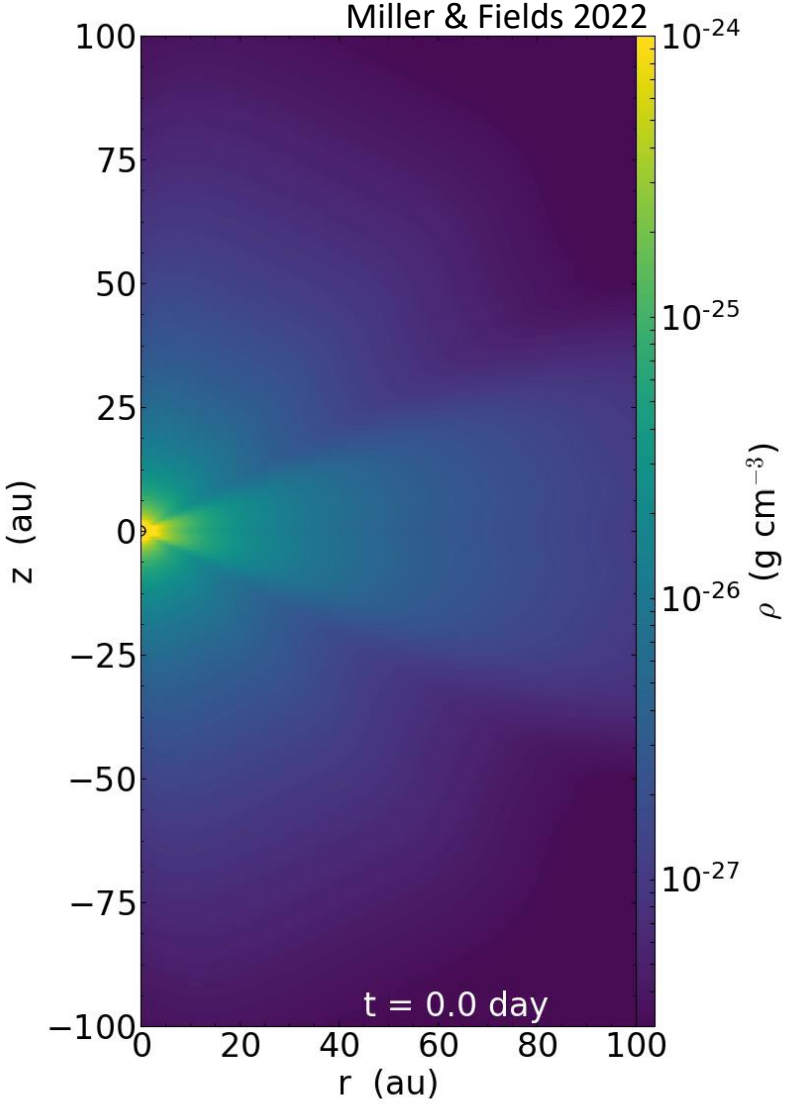


Crab Nebula
Herschel (red) and Hubble (blue) composite

Credit: ESA/Herschel/PACS/MESS Key Programme Supernova Remnant Team; NASA, ESA and Allison Loll/Jeff Hester (Arizona State University).

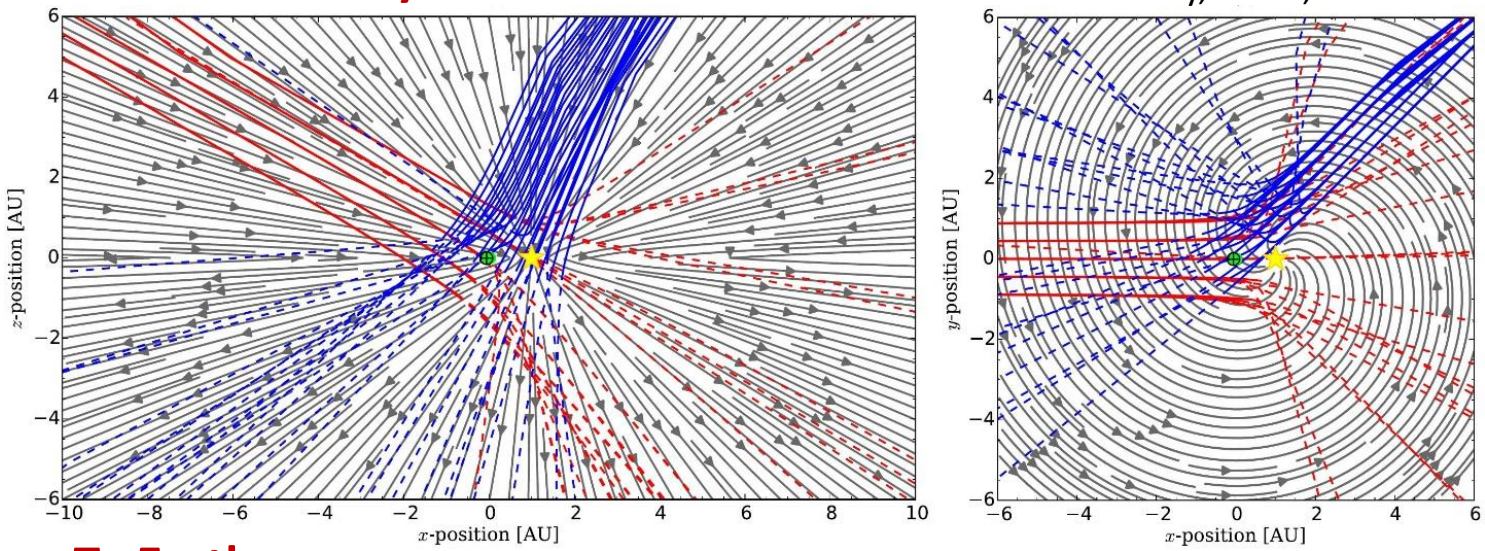
Supernova Dust Transport to Earth

Miller & Fields 2022

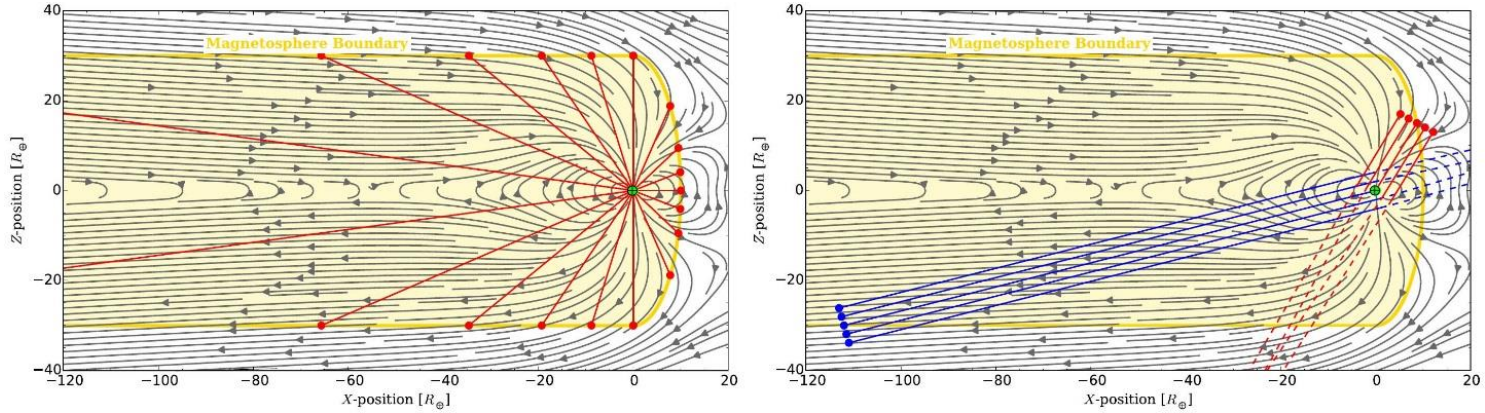


Into the solar system

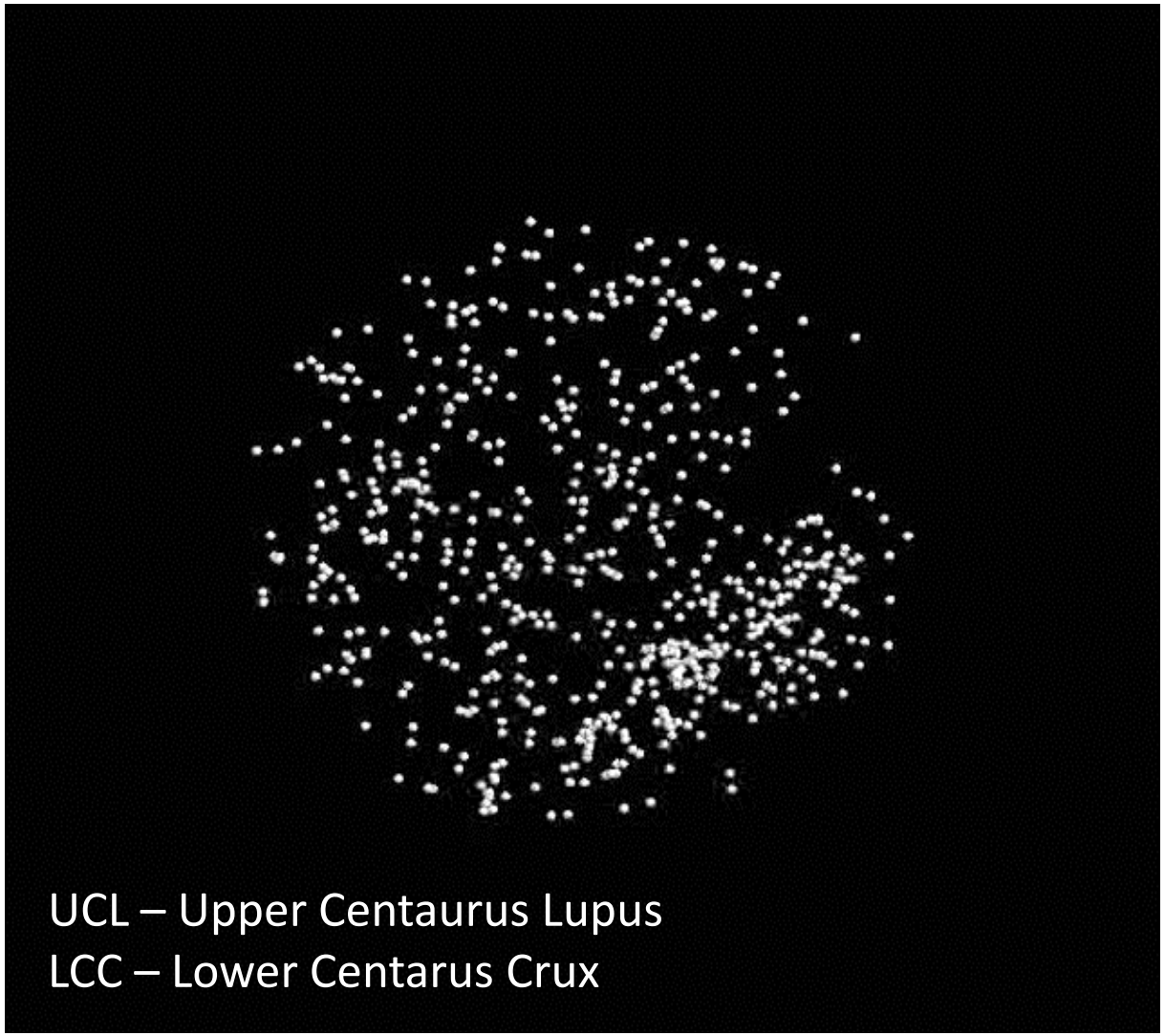
Fry, Fields, Ellis 2015



To Earth



Nearby Stellar Moving Groups



UCL – Upper Centaurus Lupus
LCC – Lower Centarus Crux

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. Dettbarn[1] and C. Flynn[4]

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

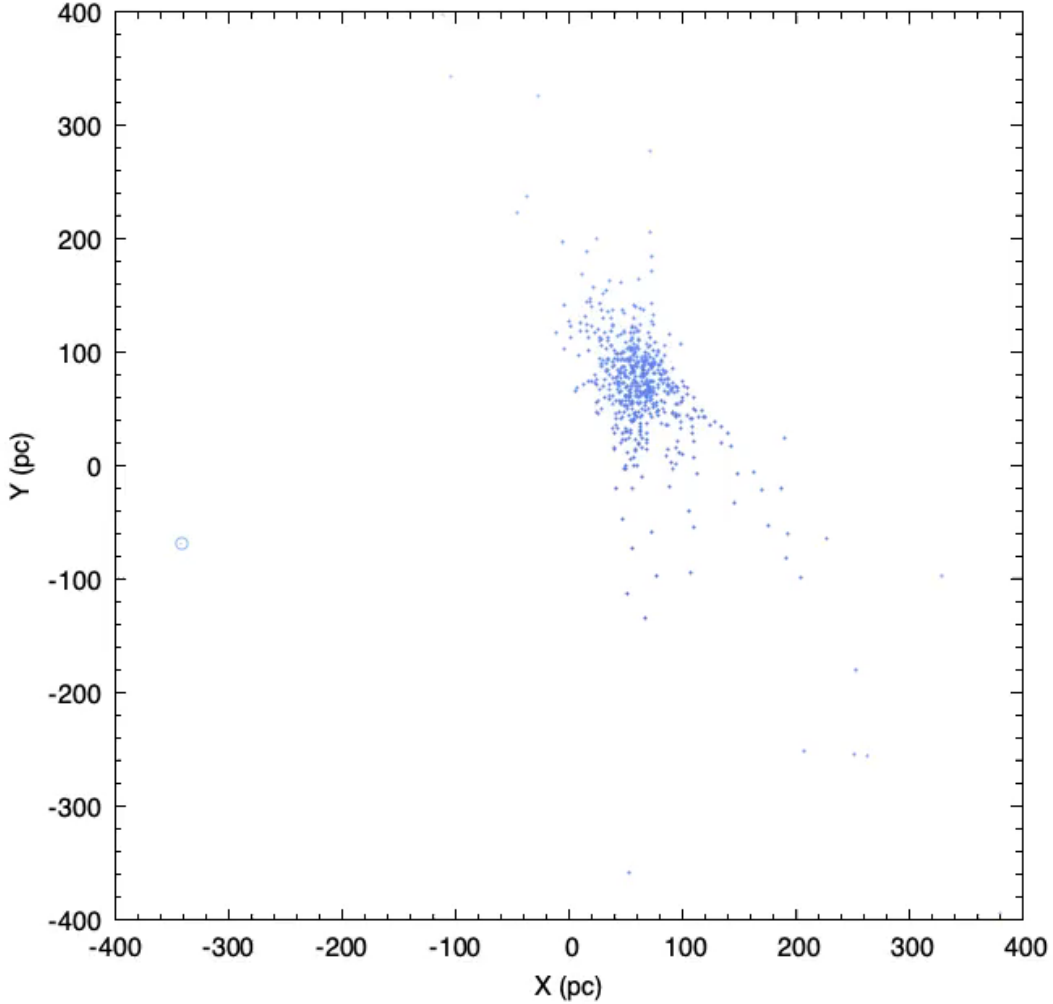
Subgroups of the **Scorpius-Centaurus association**!

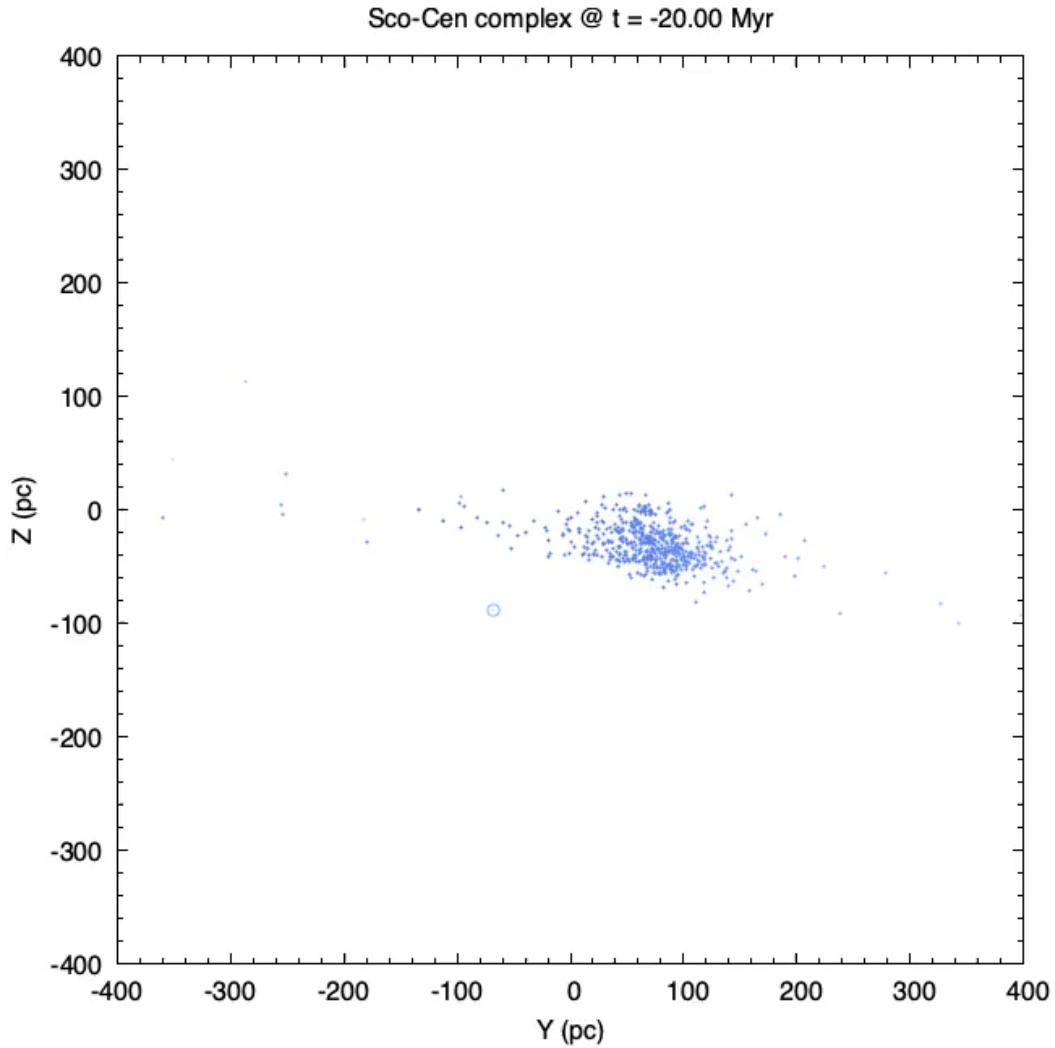
Ages: ~20 Myr

IMF: universal distribution of stellar numbers over masses at formation

Most massive stars explode first!

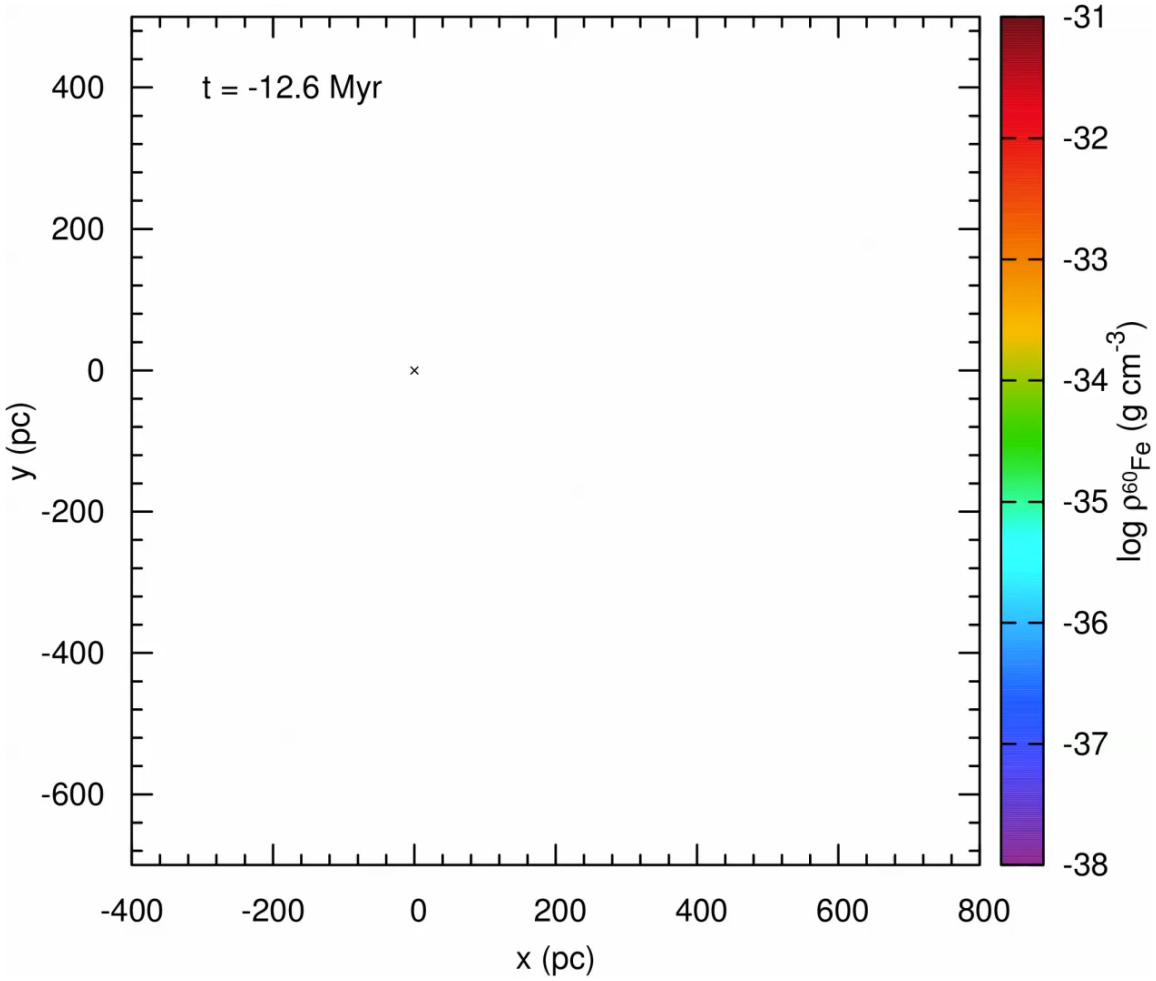
Nearby Stellar Moving Groups





Schulreich, Feige, Breitschwerdt in prep.

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



Homogeneous ambient medium (0.3 ats 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:

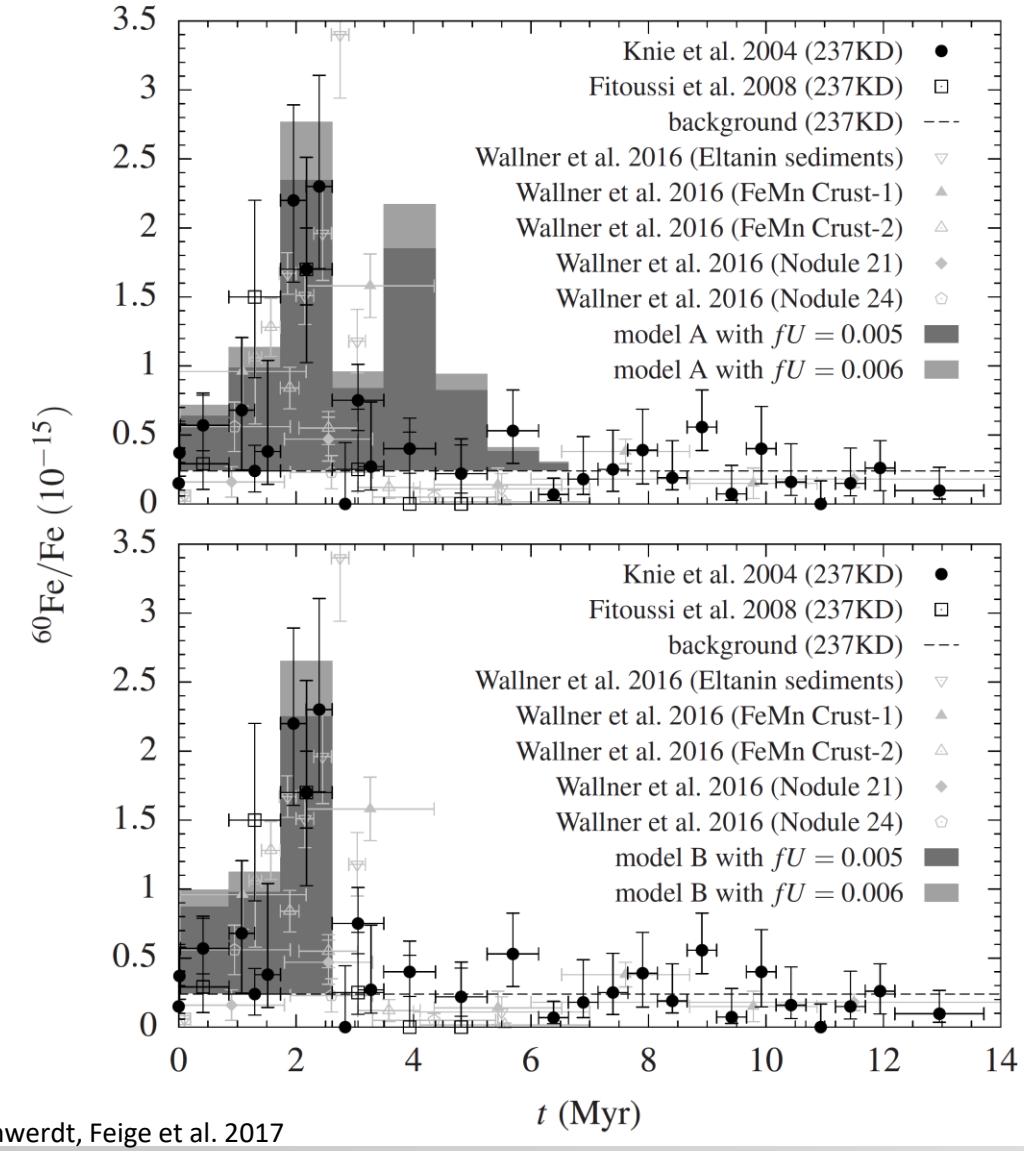
- Number of atoms that reach the Earth per cm^2

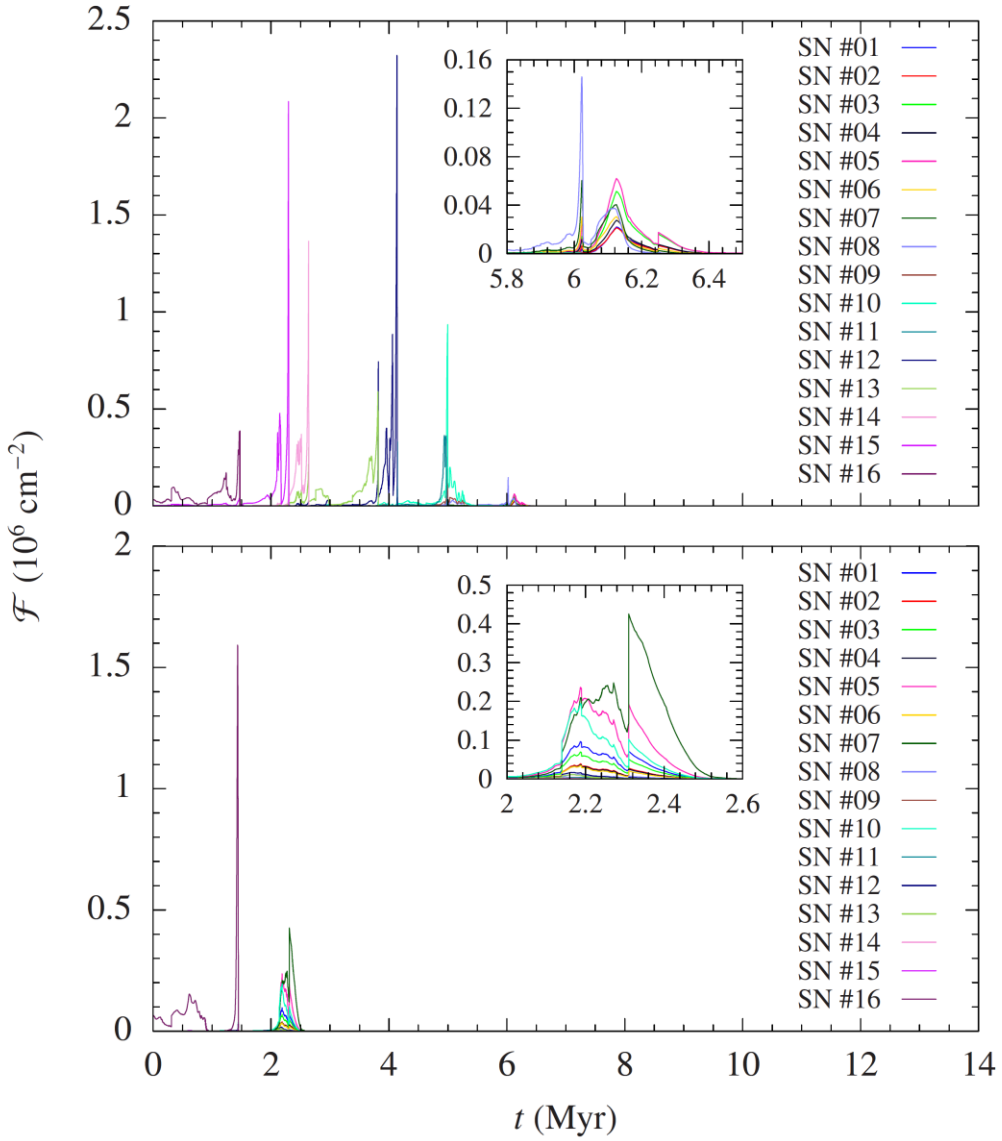
$$F = \frac{U}{4} \frac{M_{ej}}{4\pi r^2 A m_p} e^{-t/\tau}$$

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

Breitschwerdt, Feige, Schulreich et al., Nature 532, 73 (2016)

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

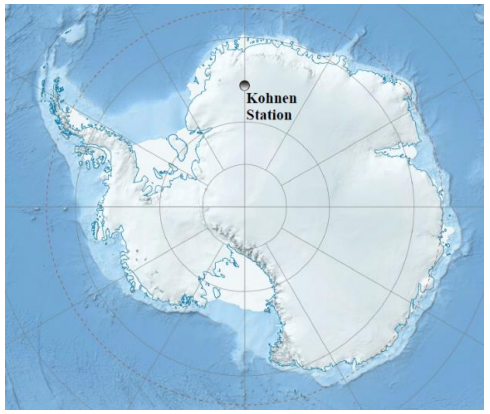


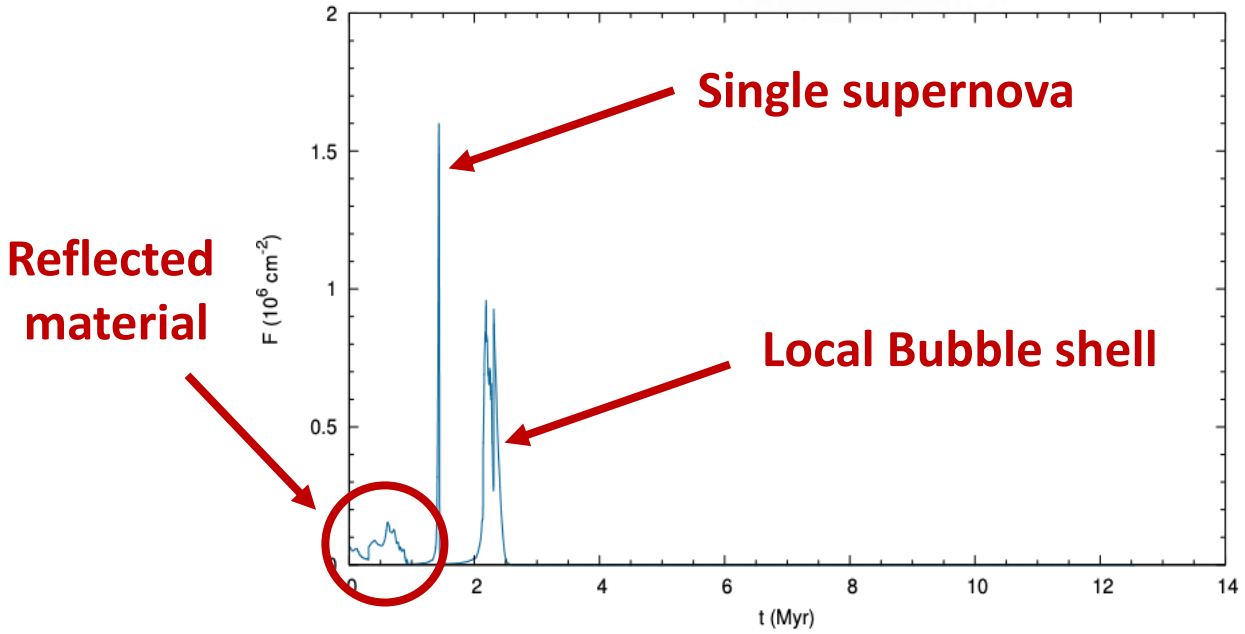


Schulreich, Breitschwerdt, Feige et al. 2017

Recent Supernova Influx

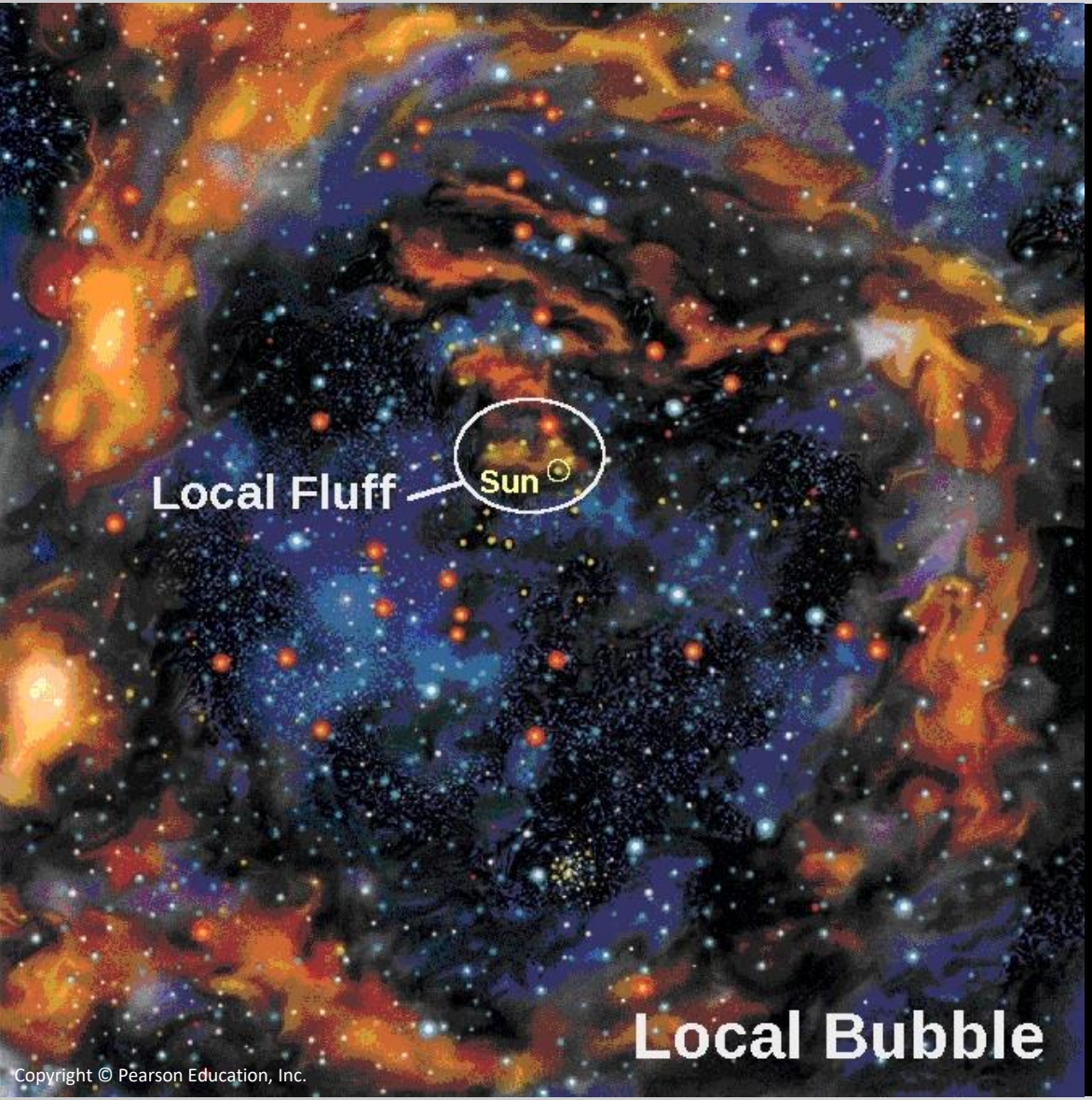
Koll et al., PRL 123, 072701 (2019), Wallner et al., PNAS 117 (36) 21873 (2020)

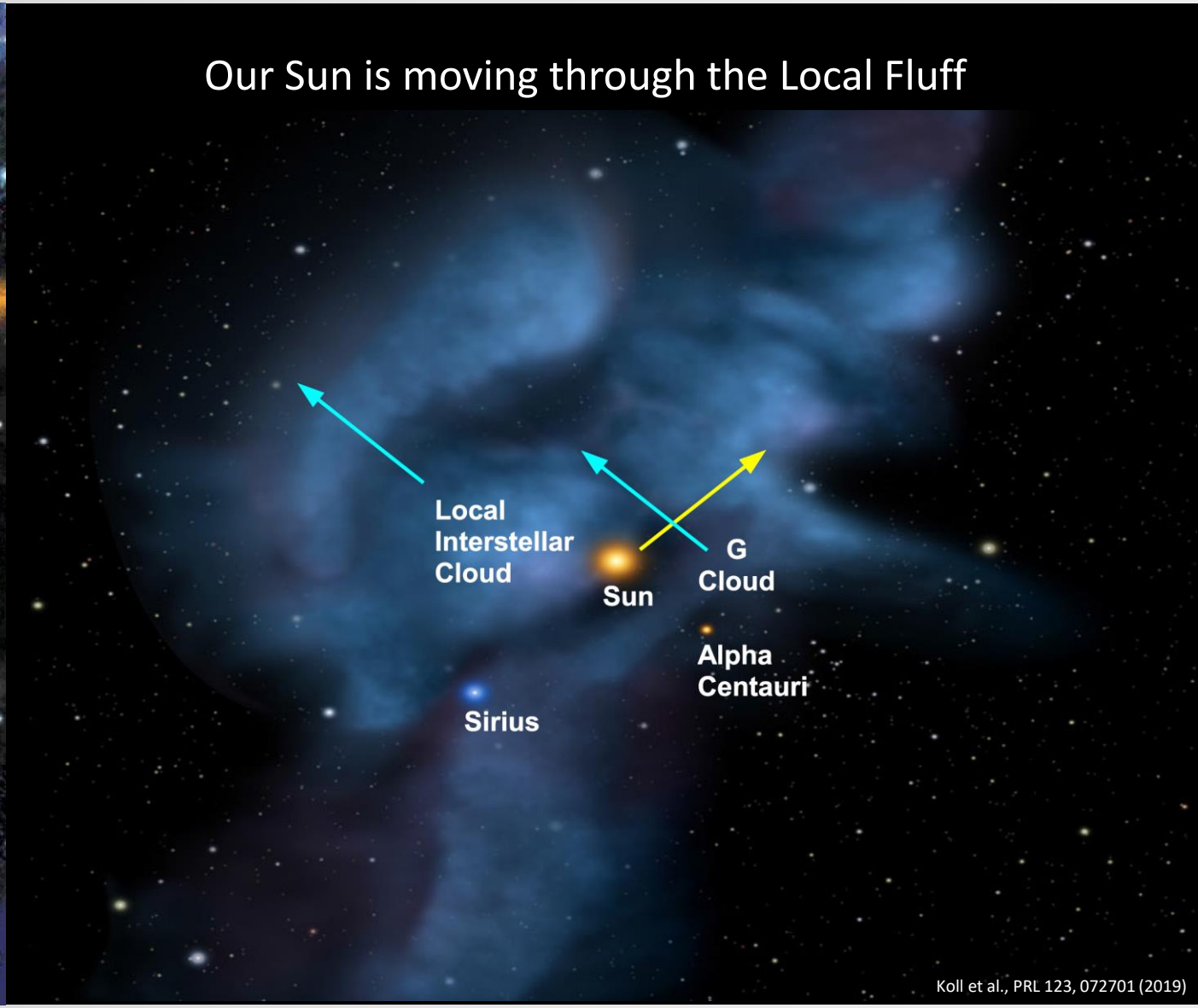




Schulreich, Breitschwerdt, Feige et al. 2017

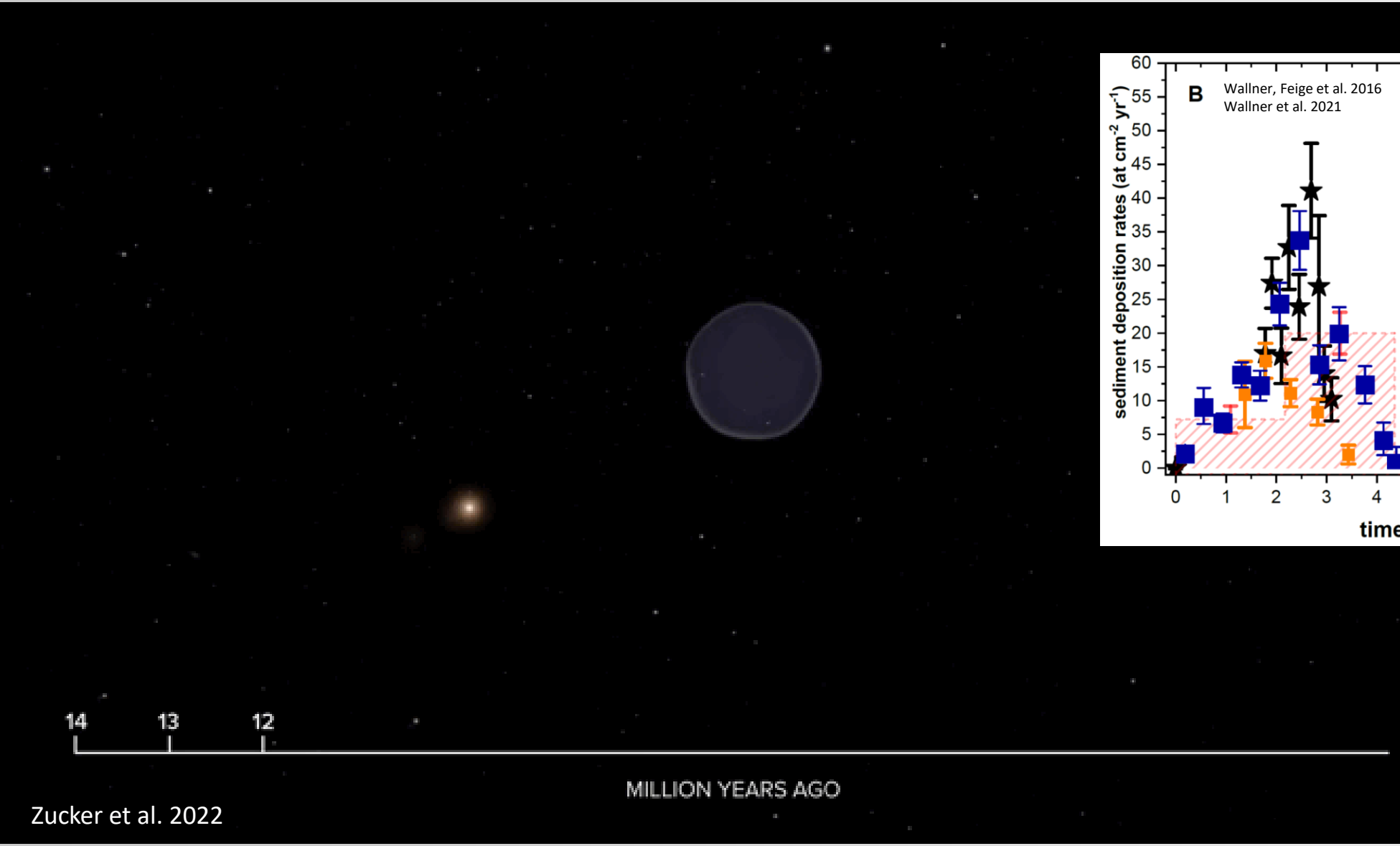
Recent Supernova Influx



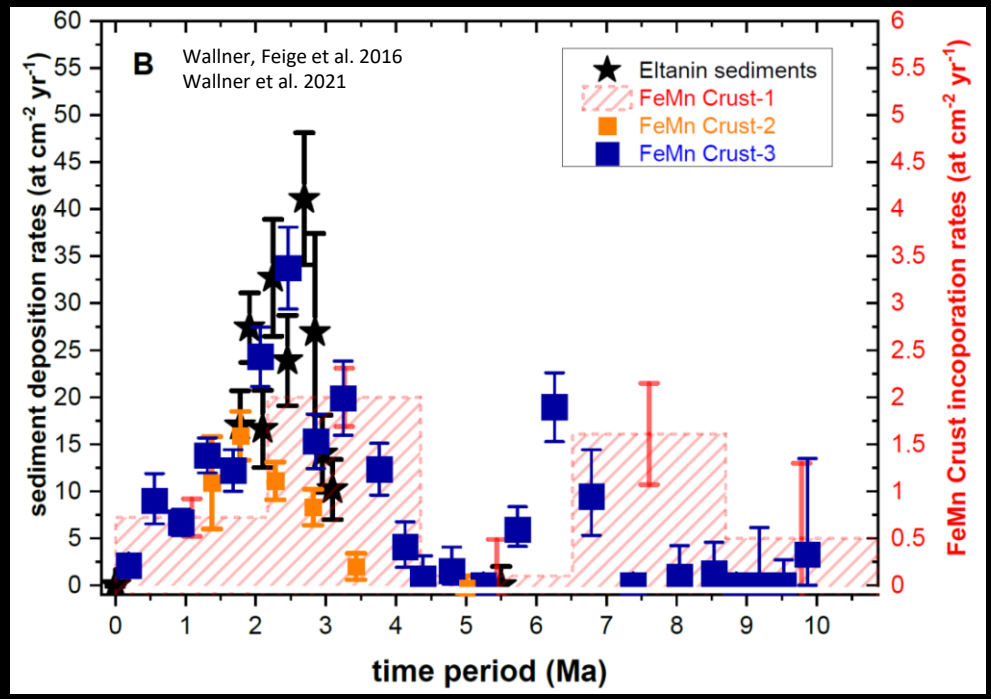


Koll et al., PRL 123, 072701 (2019)

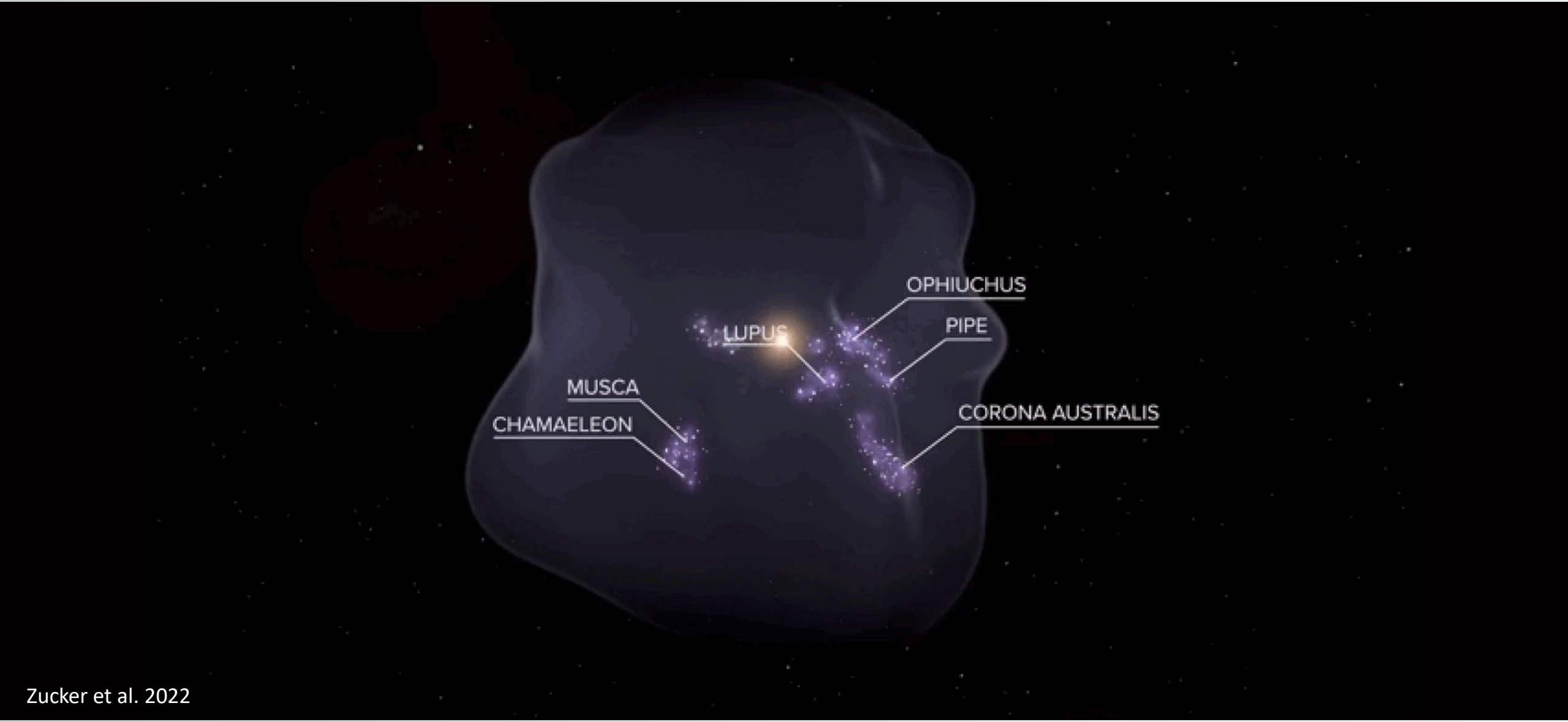
Our Solar System History



Zucker et al. 2022



Triggered star formation



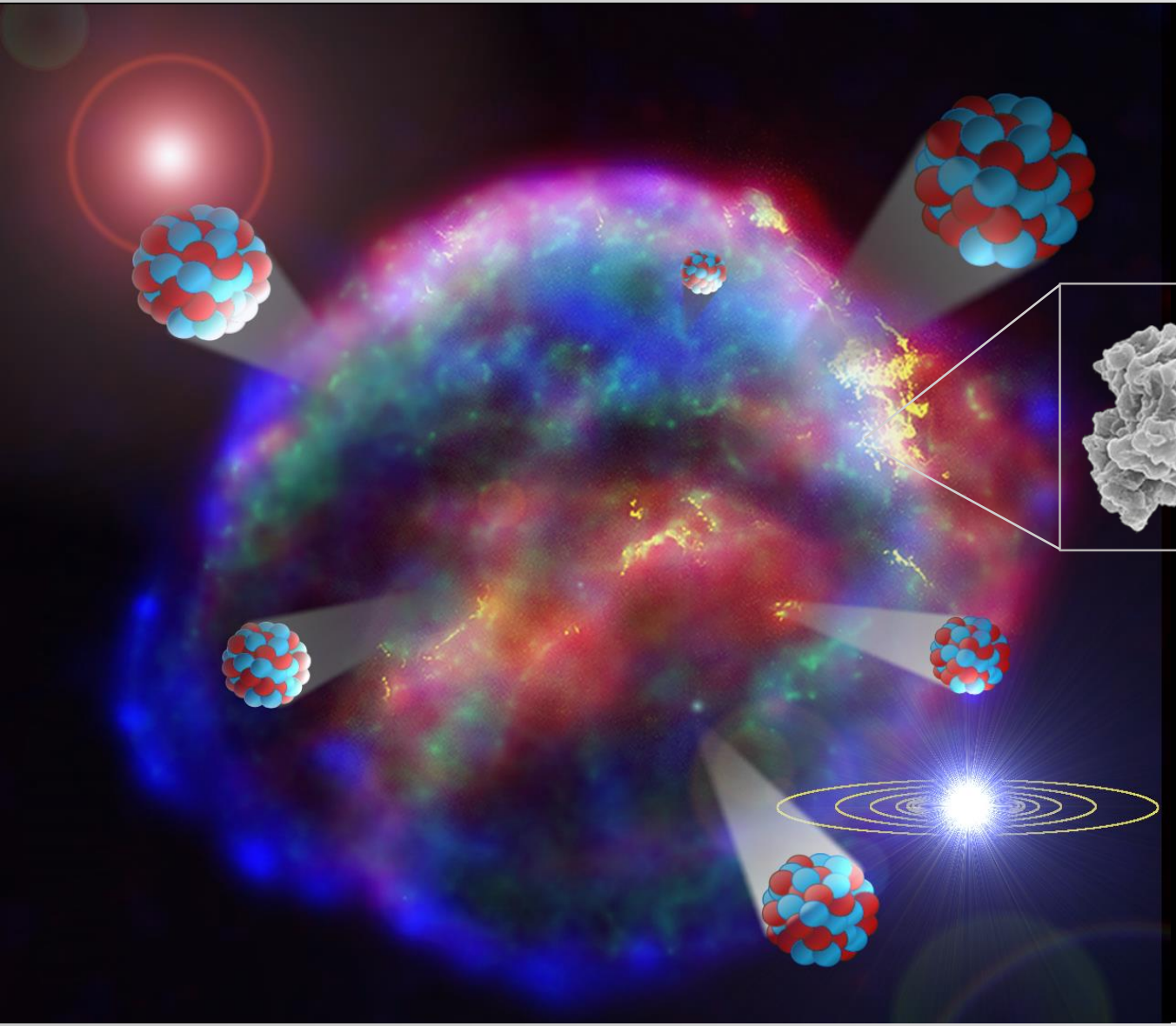
Zucker et al. 2022

Impact on humanity

Jenny Feige
Technische Universität Berlin, Germany
17.03.2023

Supernova Dust on Earth

- Introduction
- Data
- Models
- Outlook



From the Deep-Sea to the Desert

Unique to the Atacama Desert, Chile:

- Hyperarid conditions
- Extremely low sedimentation rates (1 m Myr^{-1})
- Up to ~10 Myr old

Cosmic dust in time-resolved Atacama Desert records

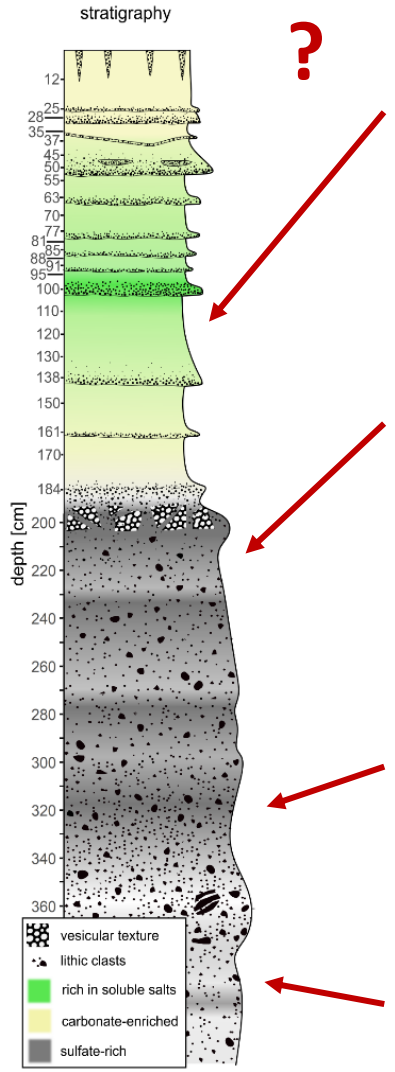
surface

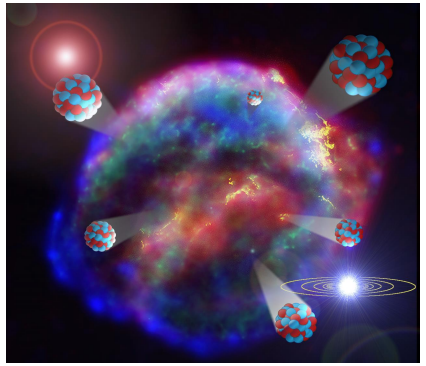
9,000 yr

19,000 yr

2.2 Myr

3.5 Myr





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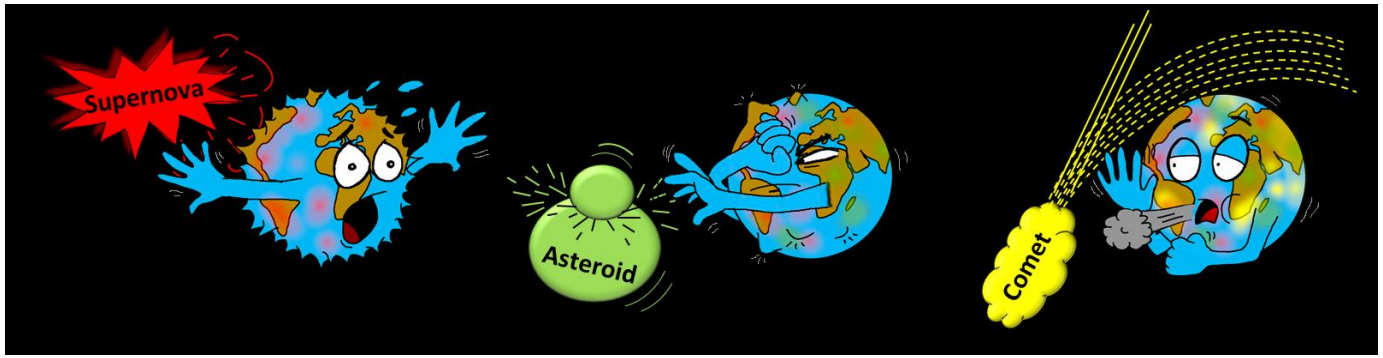
erc Starting Grants



Novel perspectives on our **S**olar System **H**istory recorded in the **A**tacama **DE**sert

What was the **quantity, timing, location, and type of supernovae** having occured in our solar neighbourhood?

Which were the major **dust-producing events and processes** having taken place in our Solar System?

Take-Home Messages

Million-year-old remnants of Supernovae can leave traces on Earth if close enough

- Suitable geological archives: **Deep-sea records**
- Suitable isotopes: **Long-lived radionuclides**

Million-year-old Supernova traces have been detected in

- Deep-sea crusts, nodules and sediments all over the world
- Fossil magnetotactic bacteria
- Lunar samples

Our Sun is located in a region with turbulent history: **The Local Bubble!**

- Subgroups of the **Sco-Cen association** are most prominent for producing the 2-3 Myr old ^{60}Fe signal as well as our Local Bubble!

We are able to decipher the Solar System history from signals recorded on Earth!