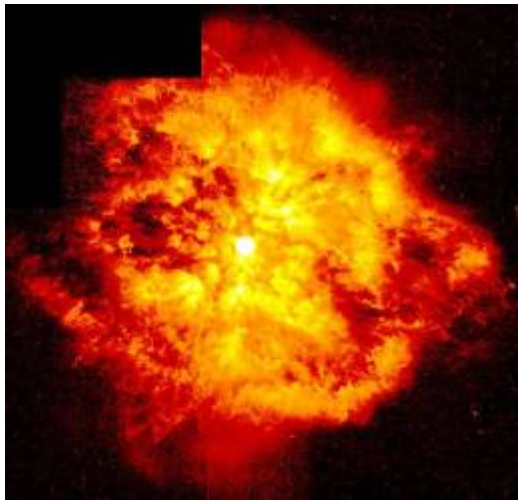
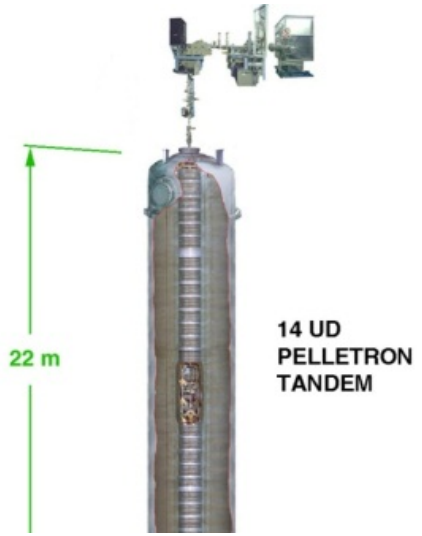
Interstellar Medium near Earth – mapped through live Fe--60 and Pu--244 on Earth



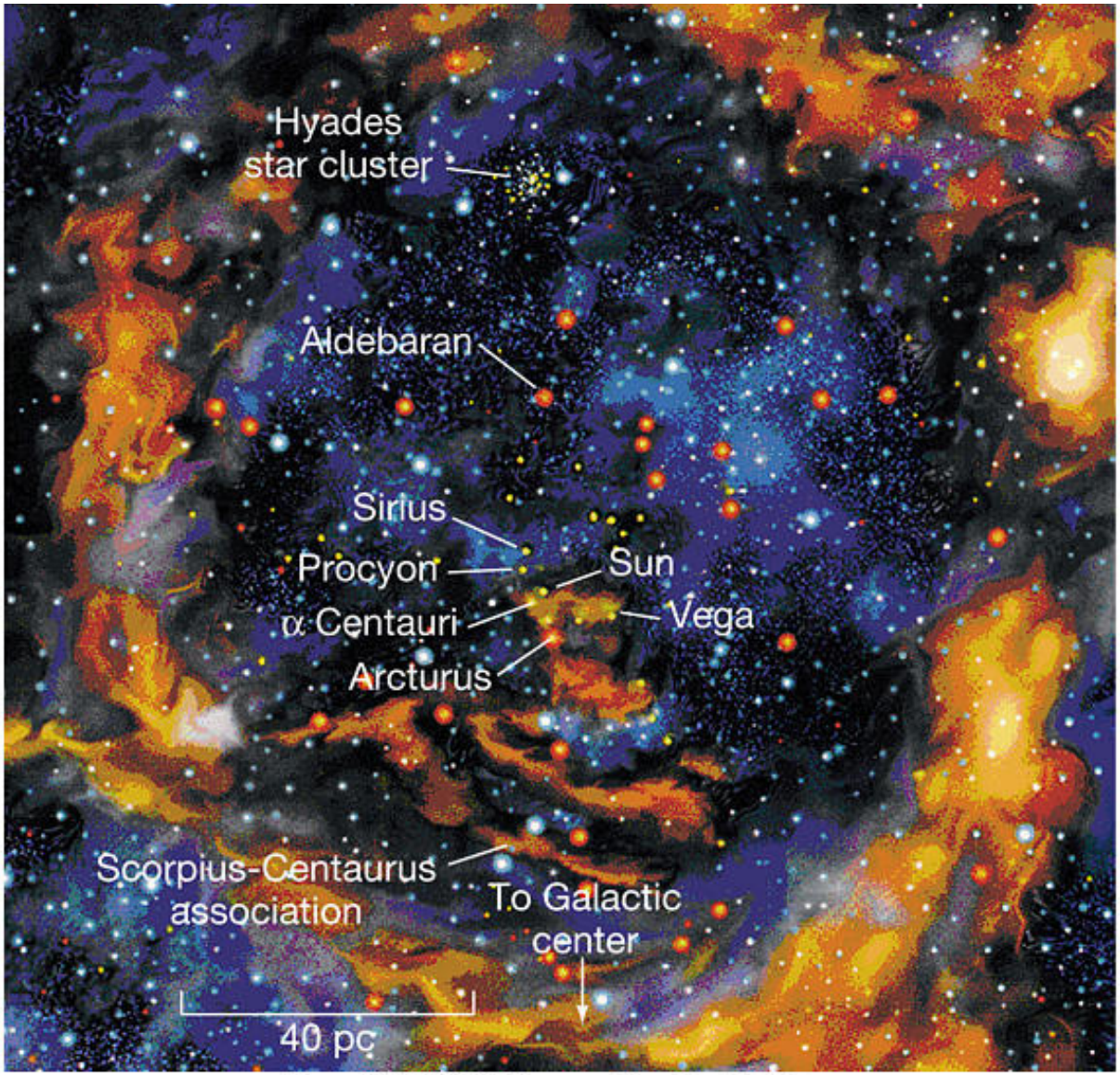
A. Wallner

The Australian National University (ANU)



Univ. of Vienna (AT):	J. Feige, R. Golser, W. Kutschera, G. Wallner, S. Winkler
Hebrew Univ. (Israel)	M. Paul
Nagoya/Tokyo (Japan)	N. Kinoshita
TU Munich (Germany):	T. Faestermann, G. Korschinek, K. Knie
TU Vienna (AT):	M. Bichler, J. Sterba
HZDR (Dresden, GER):	S. Merchel, S. Pavetich, G. Rugel
PSI (Villigen, CH):	D. Schumann
ANU (Canberra, AU):	L.K. Fifield, S. Tims, M. Froehlich (Srncik)

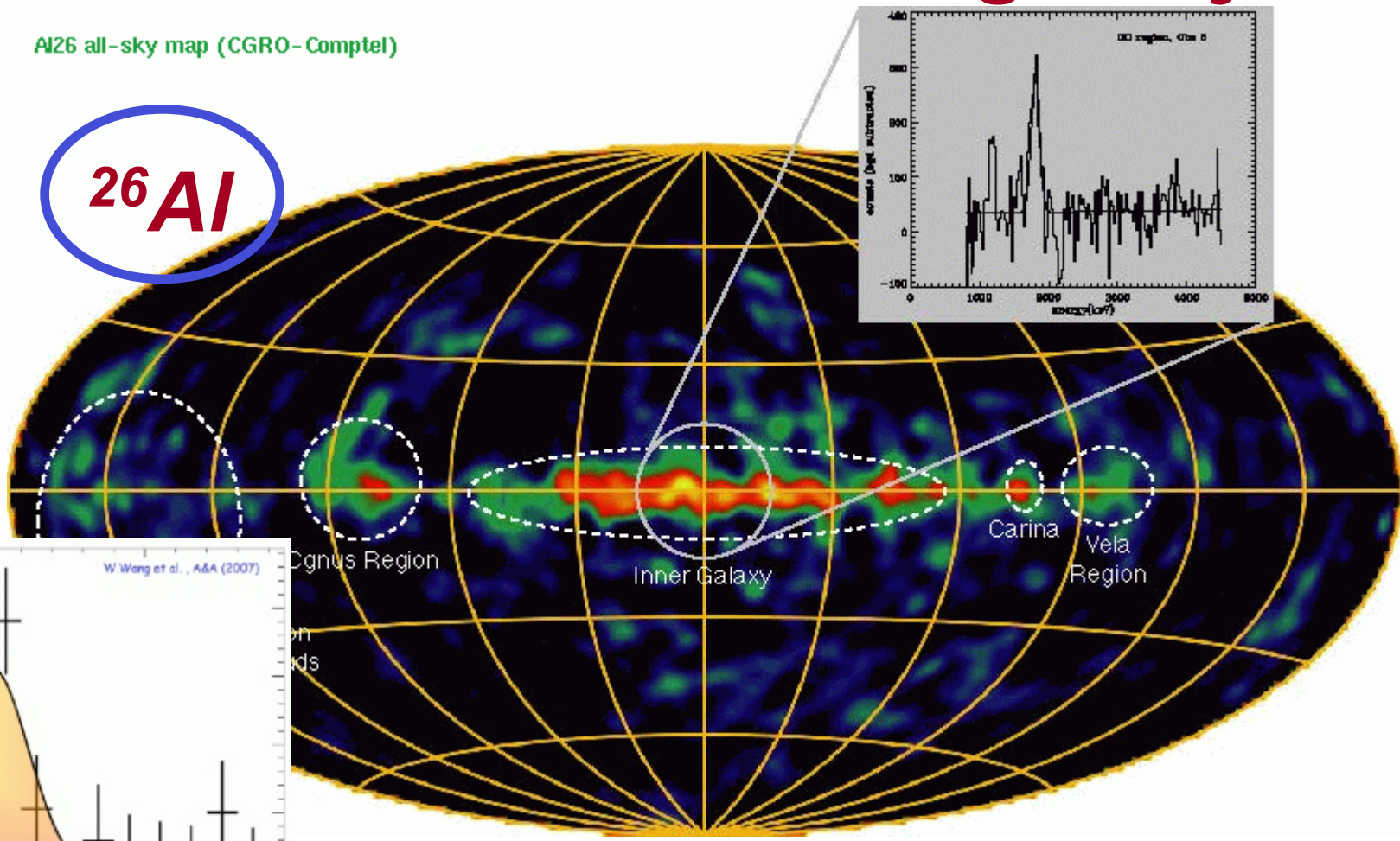
Extraterrestrial Radionuclides on Earth



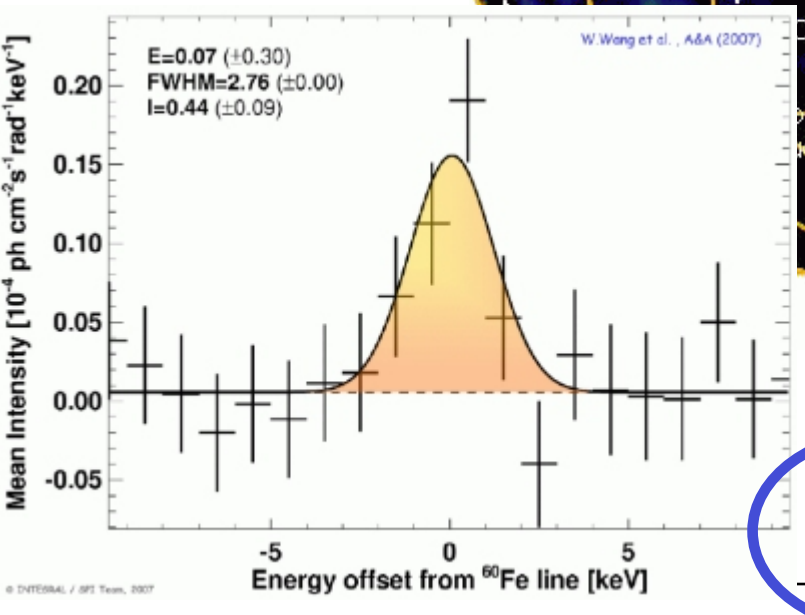
Can we find isotopic fingerprints of the ISM (interstellar medium) in terrestrial archives?

Radionuclides contain time information as they can serve as radioactive clocks!

Decay of radionuclides in the galaxy

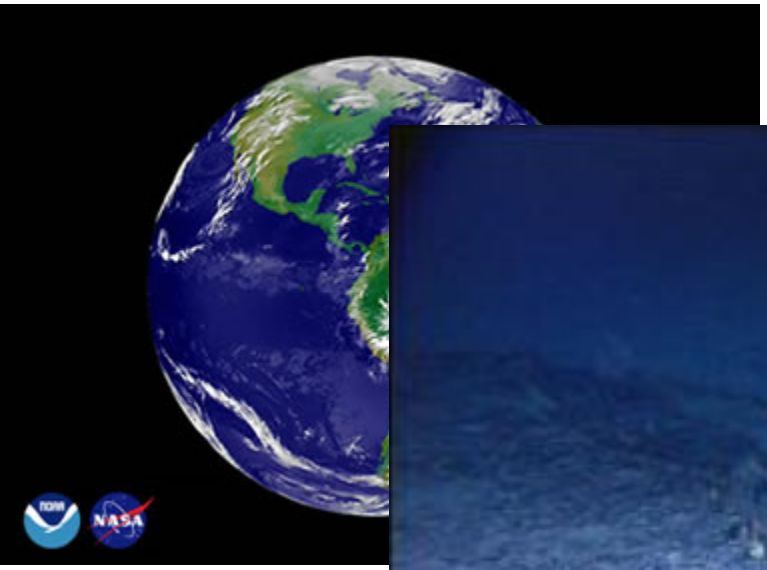


^{26}Al



^{60}Fe

Extraterrestrial Radionuclides on Earth



"recent" uptake into terrestrial archives

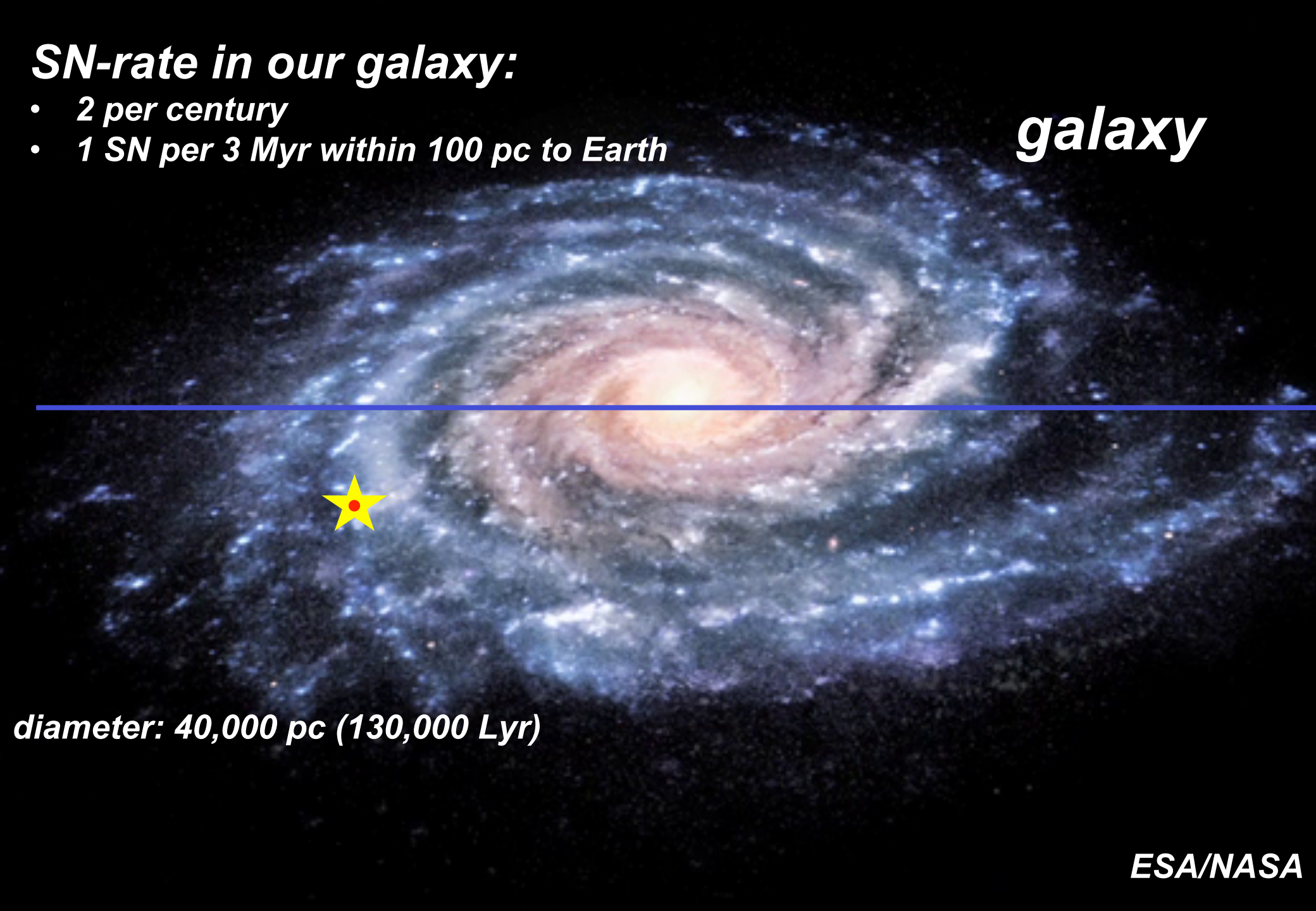
- extremely low growth rate (mm/Myr)
- integrate over tens of Myr
- efficiently enrich content of ocean water column
- remote locations – low terrestrial background

deep-sea mangenese crusts & sediments

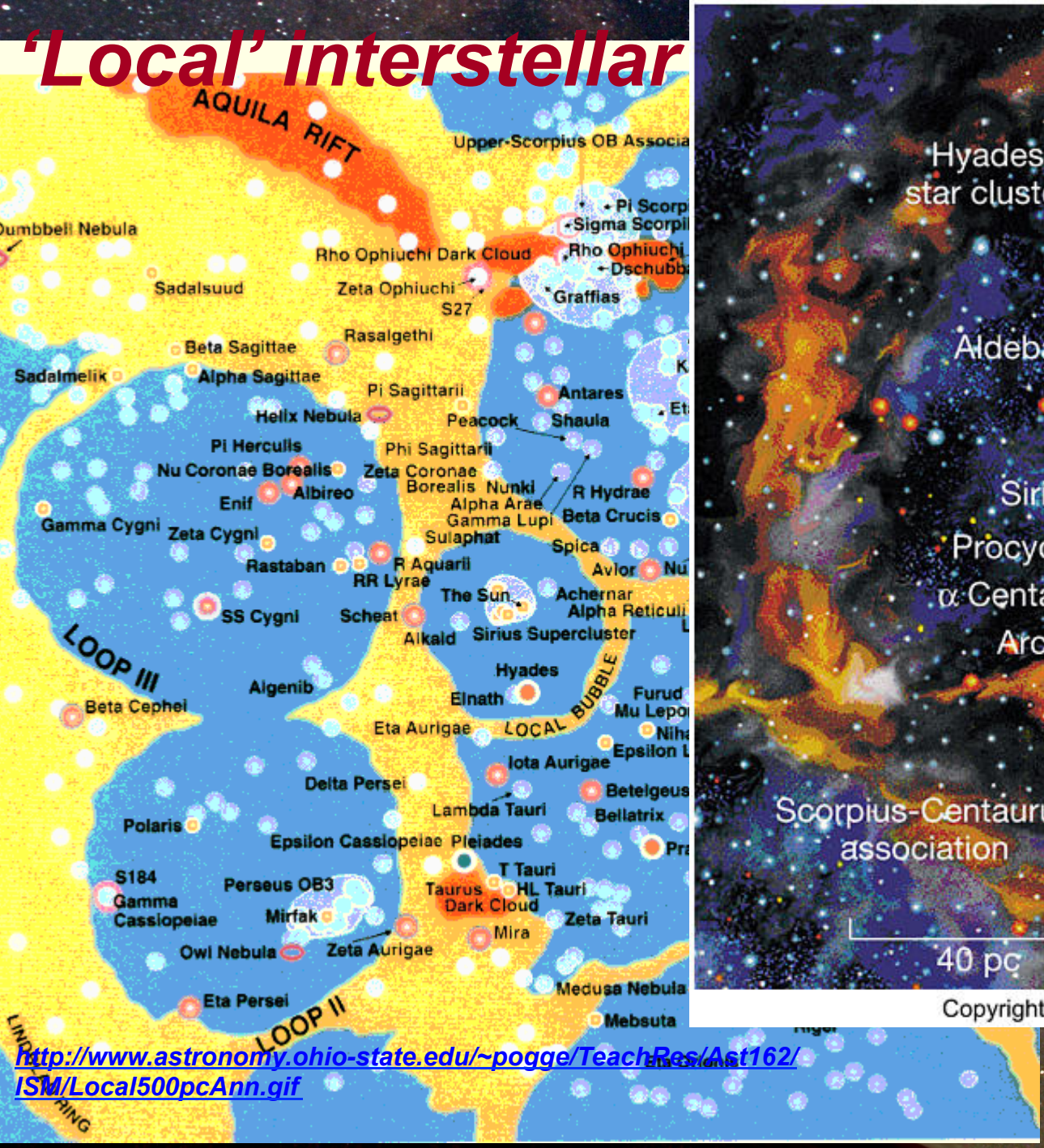
oceanexplorer.noaa.gov

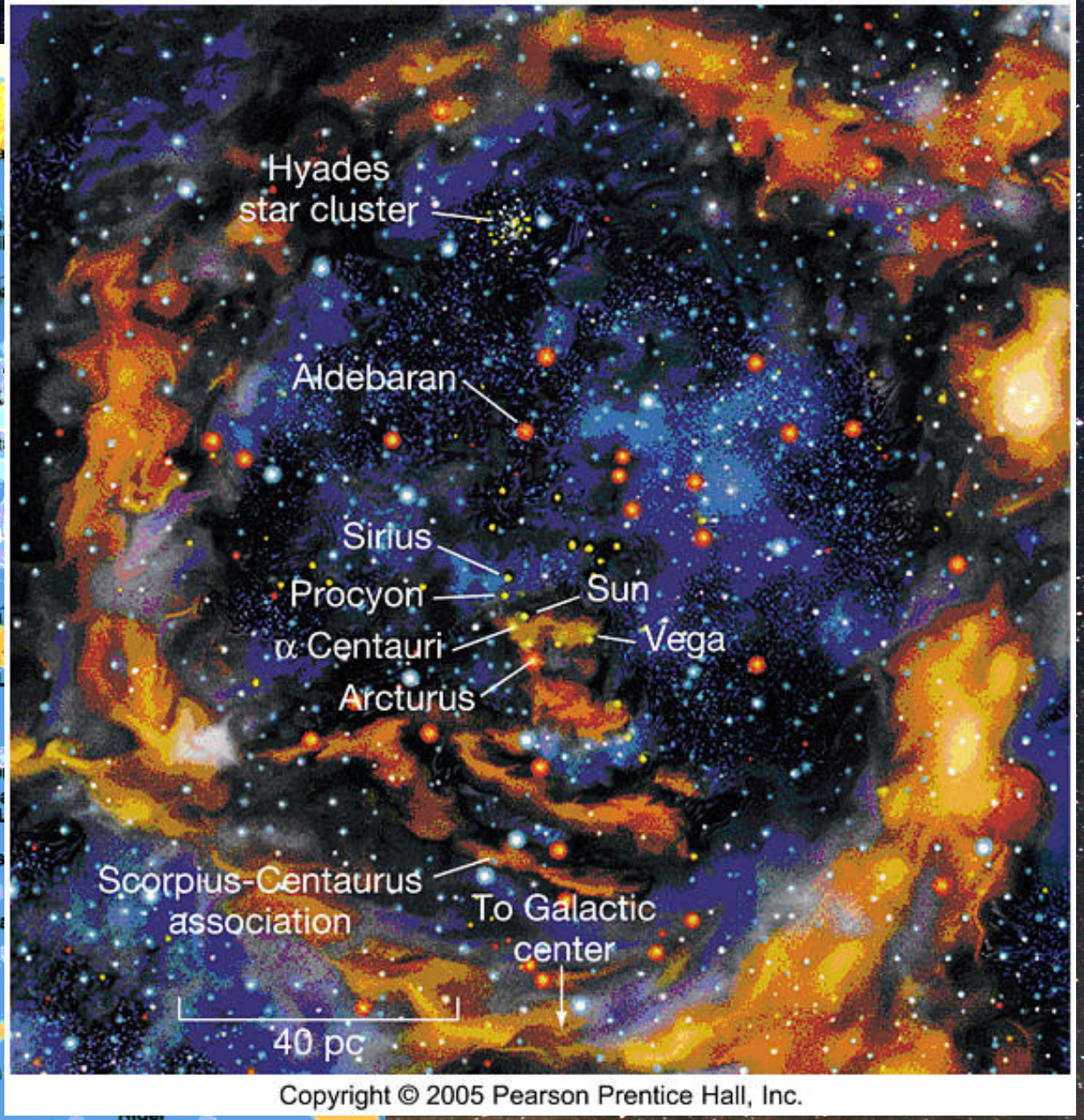
SN-rate in our galaxy:

- *2 per century*
- *1 SN per 3 Myr within 100 pc to Earth*



‘Local’ interstellar

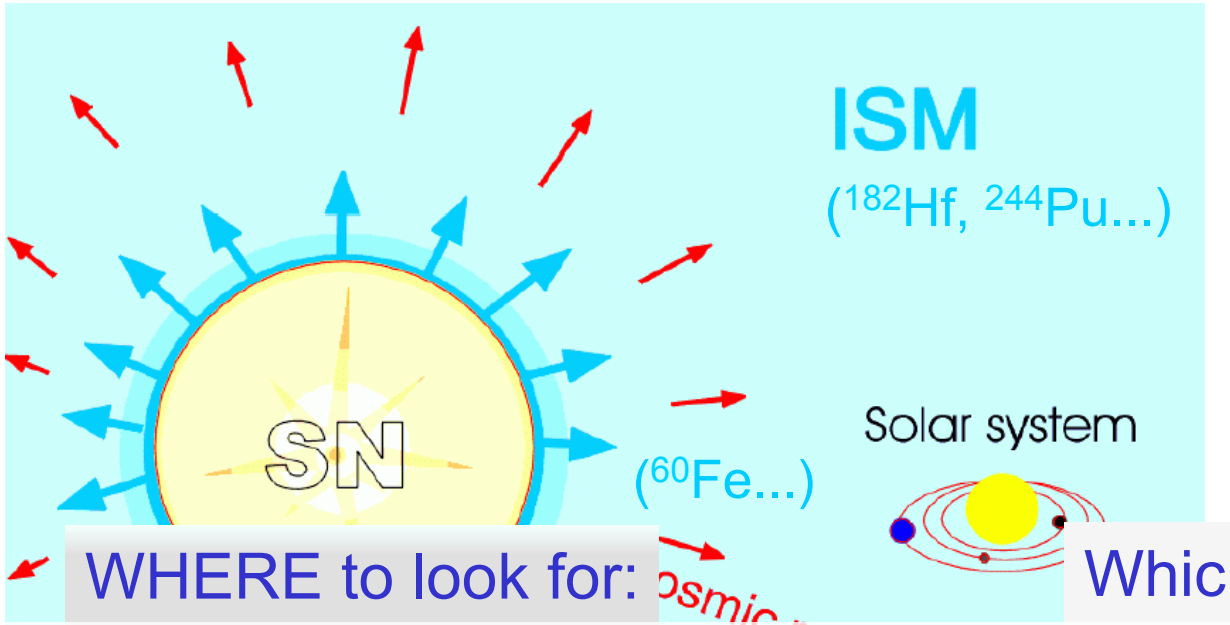




http://www.astronomy.ohio-state.edu/~pogge/TeachRes/Ast162/ISM/Local500pcAnn.gif

Supernova-produced radionuclides on Earth - Live!

nearby supernova: < 100 pc, rate ~ 0.3 -10 (Ma)$^{-1}$



WHERE to look for:

- ice core
- sediments
- deep sea crusts

Which isotopes:

- ^{26}Al, ^{53}Mn, ^{60}Fe, ^{146}Sm, (^{182}Hf, ^{244}Pu, ^{247}Cm)
- …

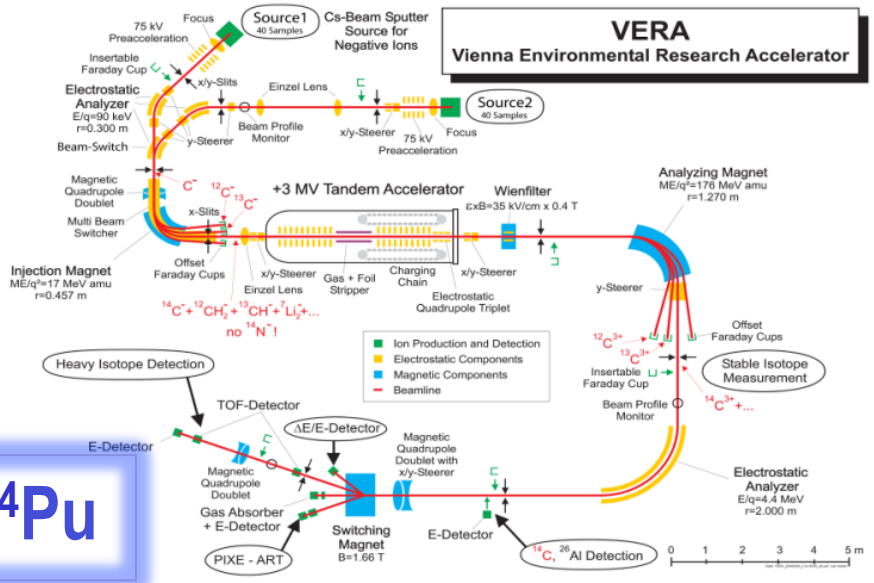
e.g. ^{60}Fe from SN: Korschinek, Knie et al., TU Munich

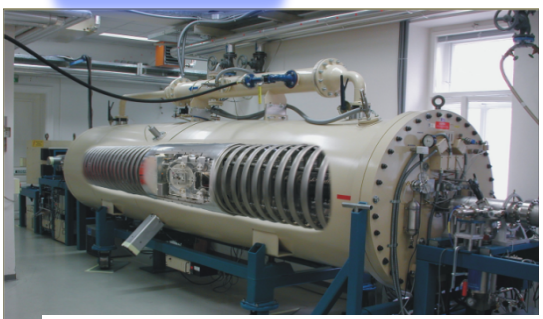
e.g. ^{244}Pu from SN: TU Munich, & M. Paul Hebrew Univ.

©TUM

ANU (15 MV) - Canberra

VERA (3 MV) - Vienna



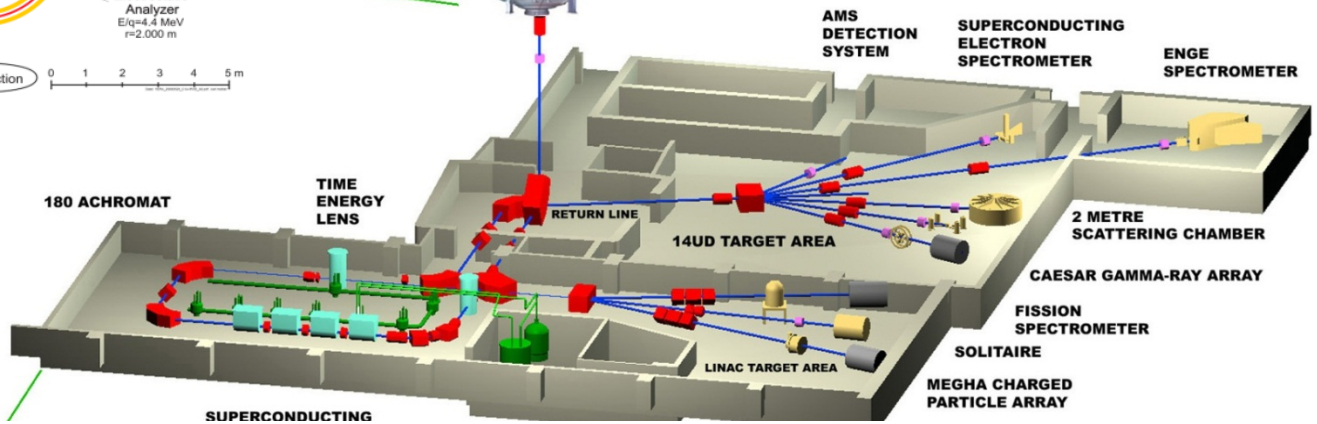


ANU HEAVY ION ACCELERATOR FACILITY

14 UD PELLETRON TANDEM

^{244}Pu

^{60}Fe

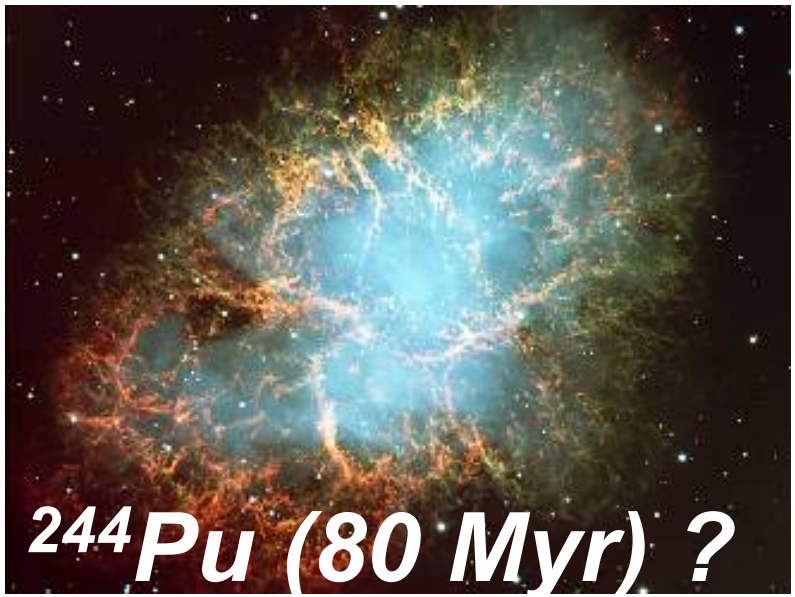


Accelerator Mass Spectrometry = AMS

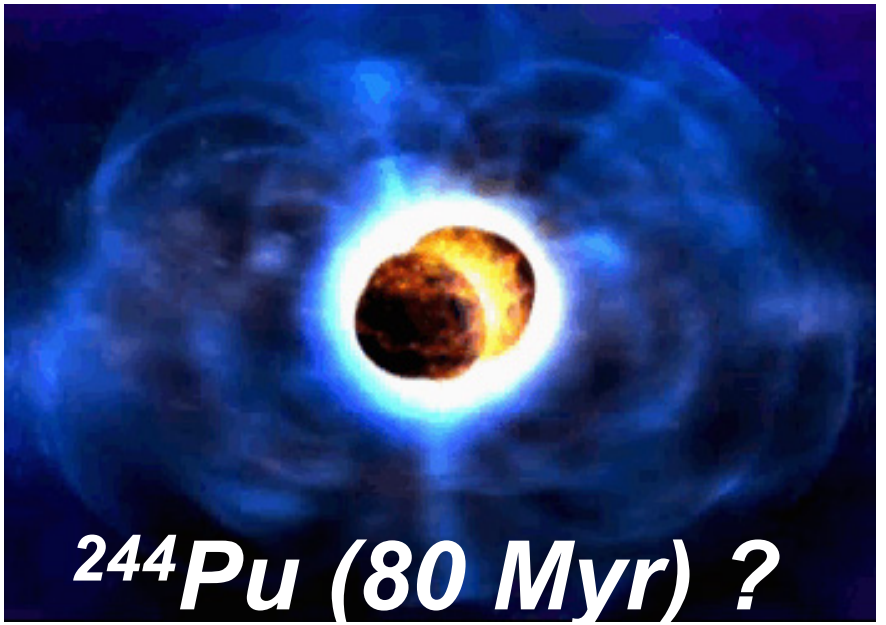
= single atom counting

Actinides – pure r process nuclides

r-process sites?

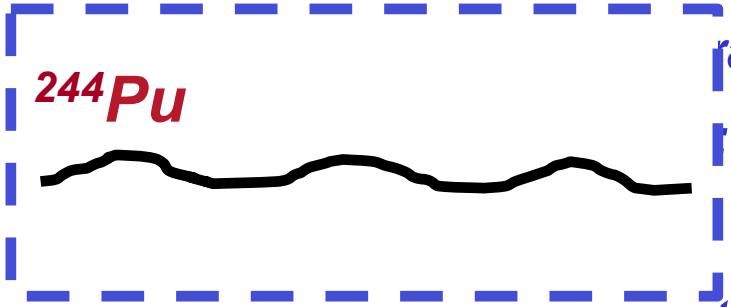


Hubble

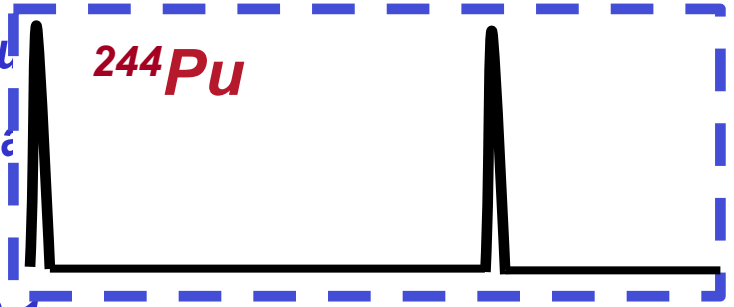


© NASA

core collapse supernova



neutron star mergers



rates:

~ 1000:1

rate ratio SN : NS-NS = 1000:1

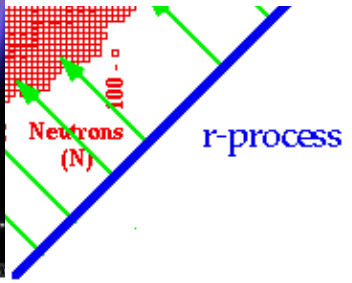
^{244}Pu: $t_{1/2}$ = 80 Myr - AMS at VERA / Vienna

Cm238 2.4 h 0+ EC,α	Cm239 2.9 h (7/2-) EC,α	Cm240 27 d 0+ EC,α,sf,...	Cm241 32.8 d 1/2+ EC,α	Cm242 162.8 d 0+ α,sf	Cm243 29.1 y 5/2+ EC,α,sf,...	Cm244 18.10 y 0+ * α,sf	Cm245 8500 y 7/2+ α,sf	Cm246 4730 y 0+ α,sf	Cm247 1.56E+7 y 9/2- α
Am237 73.0 m 5/2(-) EC,α	Am238 98 m 1+ EC,α	Am239 11.9 h (5/2)- EC,α	Am240 50.8 h (3-) EC,β-,α,...	Am241 432.2 y 5/2- α,sf	Am242 16.02 h 1- * EC,β-	Am243 7370 y 5/2- α,sf	Am244 10.1 h (6-) * β-	Am245 2.05 h (5/2)+ β-	Am246 39 m (7-) * β-
Pu236 2.858 y 0+ α,sf	Pu237 45.2 d 7/2- * EC,α	Pu238 87.7 y 0+ α,sf	Pu239 24110 y 1/2+ α,sf	Pu240 6563 y 0+	Pu241 14.35 y 5/2+	Pu242 3.733E+5 y 0+	Pu243 4.956 h 7/2+	Pu244 8.08E+7 y 0+	Pu245 10.5 h (9/2-)
Np235	Np236	Np237	N						

tion with

Korschinek, Knie

v.: M. Paul et al.



New crust sample for ^{244}Pu

25 cm^2 (110 g):
1 detector event
(TU Munich 2000)

now:

→250 cm^2 (1.8 kg): ??

- **Layer 1** (0-0.5 Myr), bomb test Pu
- **Layer 2a** (0.5-5 Myr)
- **Layer 2b** (5-12 Myr)
- **Layer 3** (12-25 Myr)
- **Layer 4**: hydro-thermal → blank ?

+ sediment – M. Paul 2003

SN-isotope ^{244}Pu- new results?

Possible „observatories" of ISM on Earth:

1. Deep-sea sediments :

2. Deep-sea nodules and crusts :

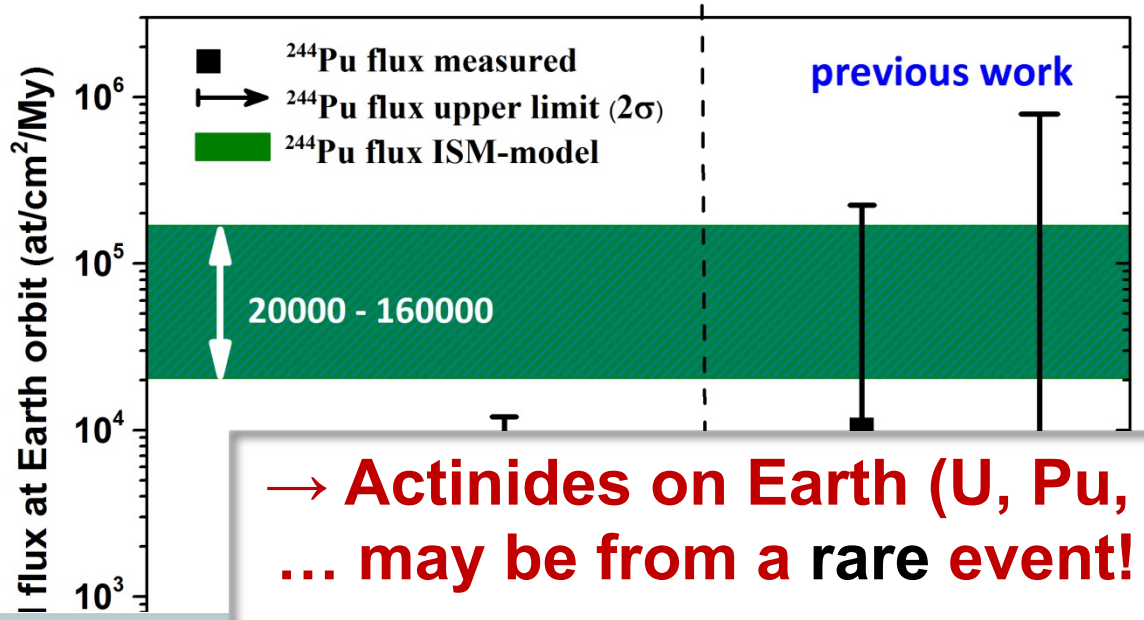
AMS results for ^{244}Pu-search:

TUM:	C. Wallner et al. 2000/03	Pacific ferromanganese nodules	1 ct
Rehovot:	M. Paul et al. 2003	Pacific sediment	1 ct*
new:	Rehovot / VERA	Pacific sediment	1 ct
new:	TUM / VERA	Pacific ferromanganese crust	0 & 1+1 ct

*fits to anthropogenic production

^{244}Pu ($t_{1/2}$=80 Myr)

100:1 estimated vs measured



^{244}Pu in terrestrial crust (+ AMS at Vienna):

- *crust: dust collection over 25 Myr*
- *^{244}Pu: time window - alive a few 100 Myr*
- *neutron star mergers or other rare process*

→ Actinides on Earth (U, Pu, … may be from a rare event!

Other planets:

x) Earth's core heating!

x) Nuclear technology

nature COMMUNICATI

ARTICLE

Received 30 Mar 2014 | Accepted 26 Nov 2014 | Published 20 Jan 2015

DOI: 10.1038/ncomms6956 OPEN

Abundance of live ^{244}Pu in deep-sea reservoirs on Earth points to rarity of actinide nucleosynthesis

A. Wallner[1,2], T. Faestermann[3], J. Feige[2], C. Feldstein[4], K. Knie[3,5], G. Korschinek[3], W. Kutschera[2], A. Ofan[4], M. Paul[4], F. Quinto[2,†], G. Rugel[3,†] & P. Steier[2]

LETTERS

PUBLISHED ONLINE: 1 DECEMBER 2015 | DOI: 10.1038/NPHYS3574

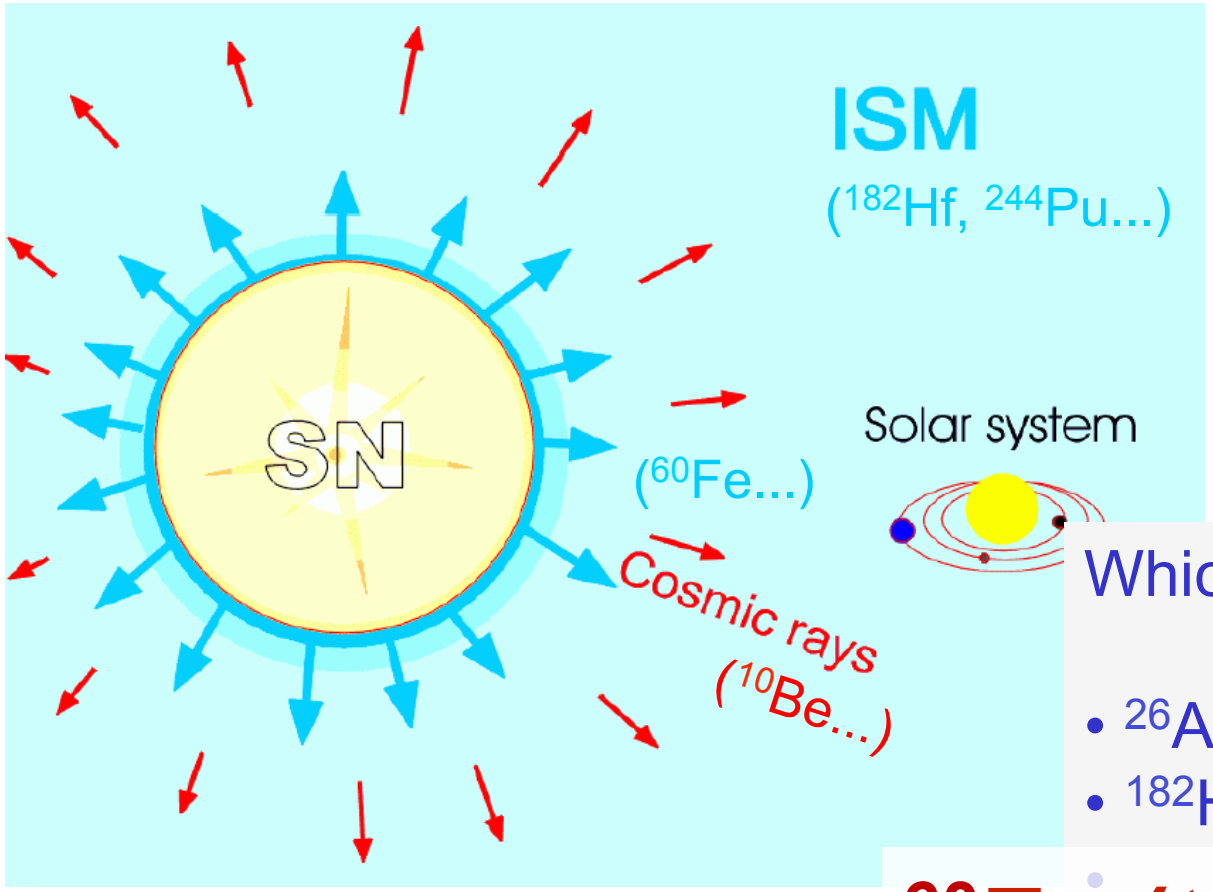
nature physics

Short-lived ^{244}Pu points to compact binary mergers as sites for heavy r-process nucleosynthesis

Kenta Hotokezaka*, Tsvi Piran* and Michael Paul

Supernova-produced radionuclides on Earth - Live!

nearby supernova: < 100 pc, rate ~ 0.3 -10 $(Ma)^{-1}$



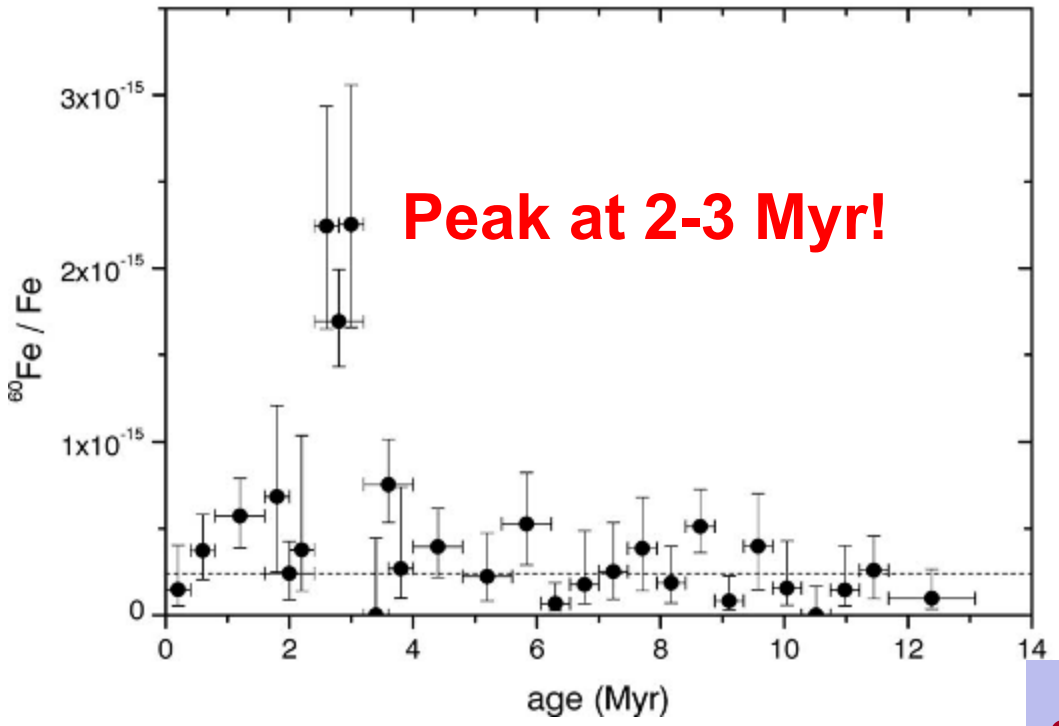
Which isotopes:

- ^{26}Al, ^{53}Mn, ^{60}Fe, ^{146}Sm,
- ^{182}Hf, ^{244}Pu, ^{247}Cm

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

©TUM

^{60}Fe-signal in a deep-sea crust AMS at Munich



AMS measurement of ^{60}Fe content of crust at TU Munich

← background level

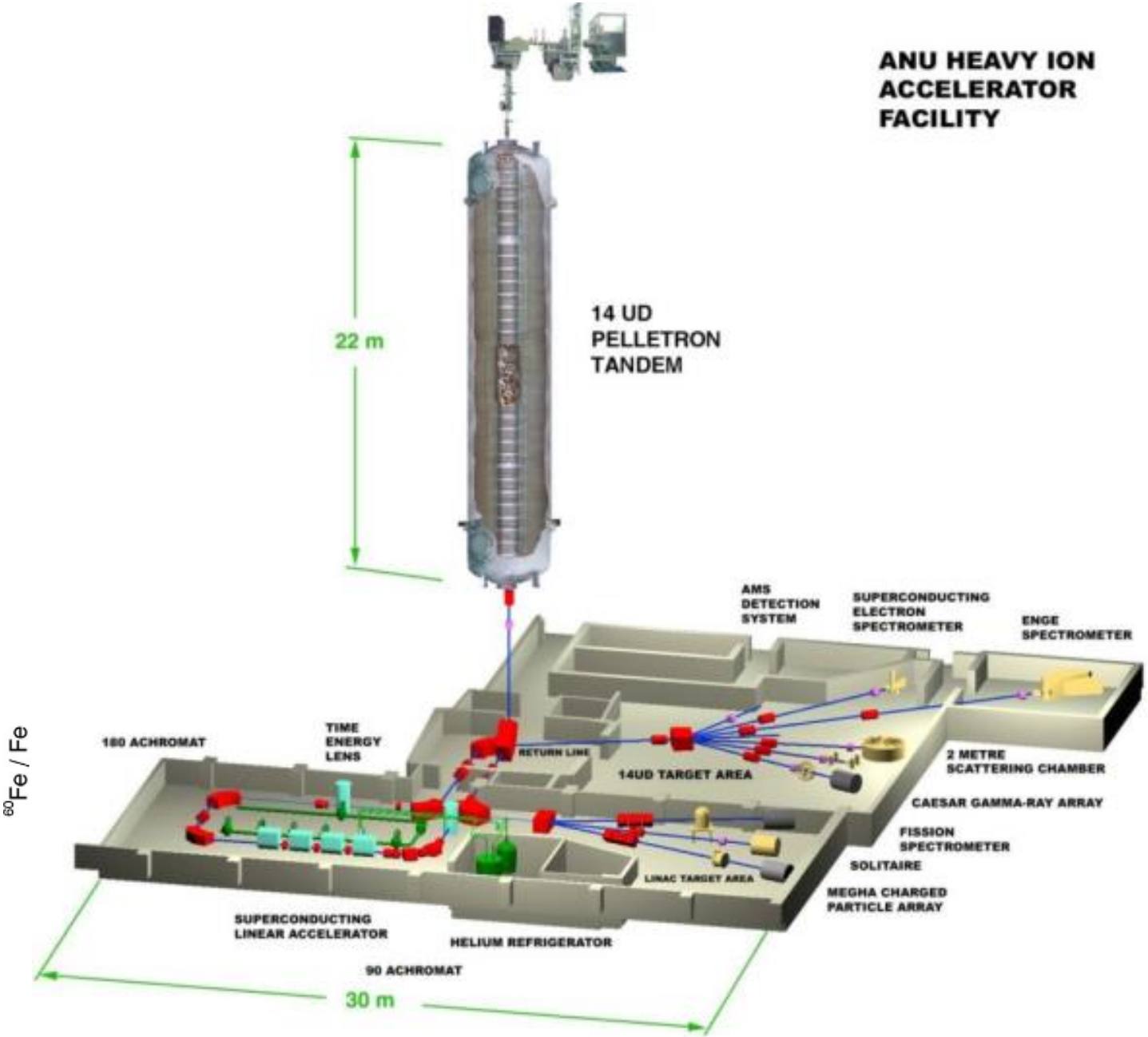
- ***the only lab yet !***

VOLUME 93, NUMBER 17 PHYSICAL REVIEW LETTERS week ending 22 OCTOBER 2004

^{60}Fe Anomaly in a Deep-Sea Manganese Crust and Implications for a Nearby Supernova Source

K. Knie,[1] G. Korschinek,[1,*] T. Faestermann,[1] E. A. Dorfi,[2] G. Rugel,[1,3] and A. Wallner[1,3]

^{60}Fe);

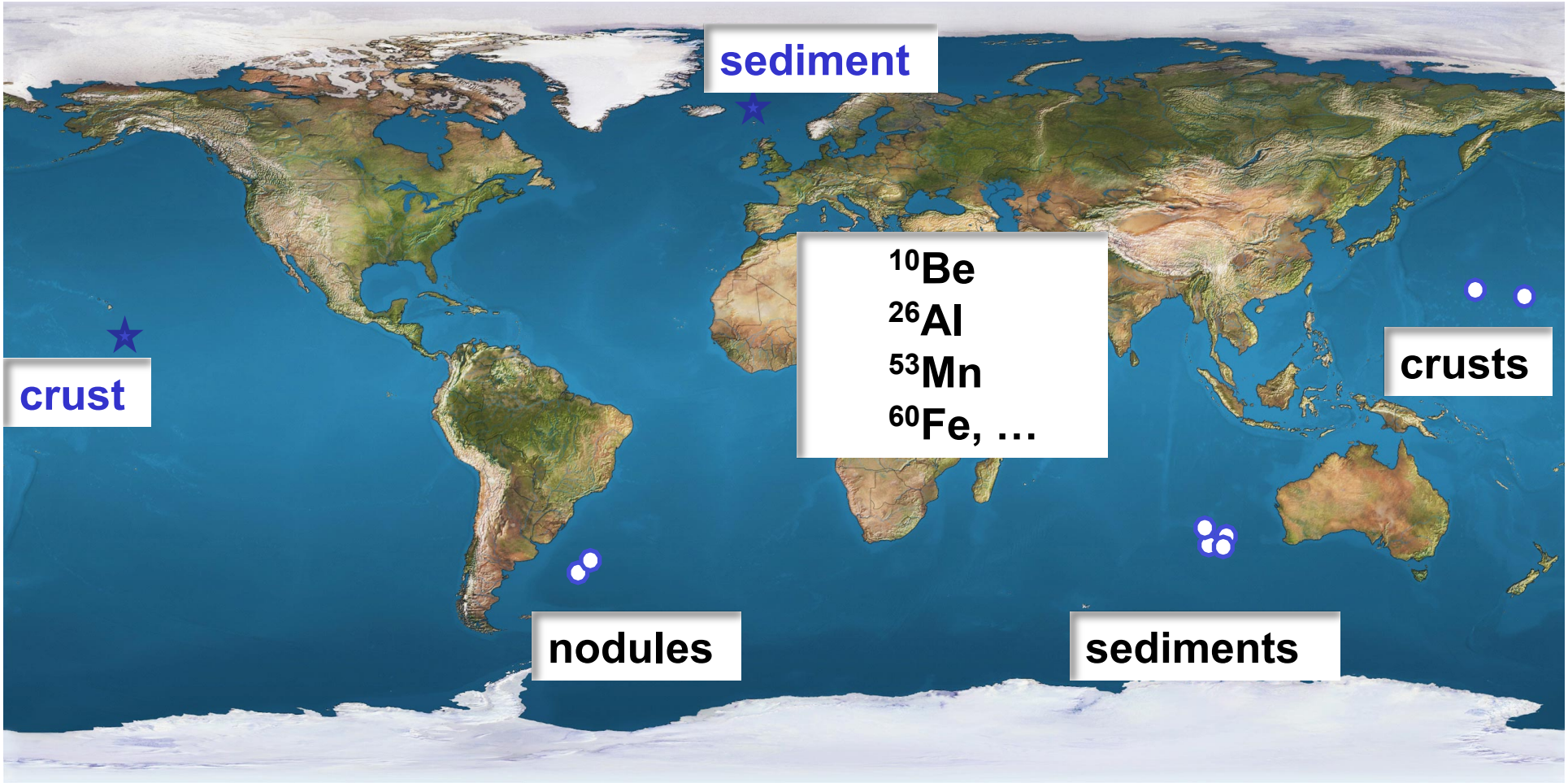


level: 4x10^{-17}

vents last 3 years)

$^{60}Fe / Fe$

Deep-sea archives for cosmic dust

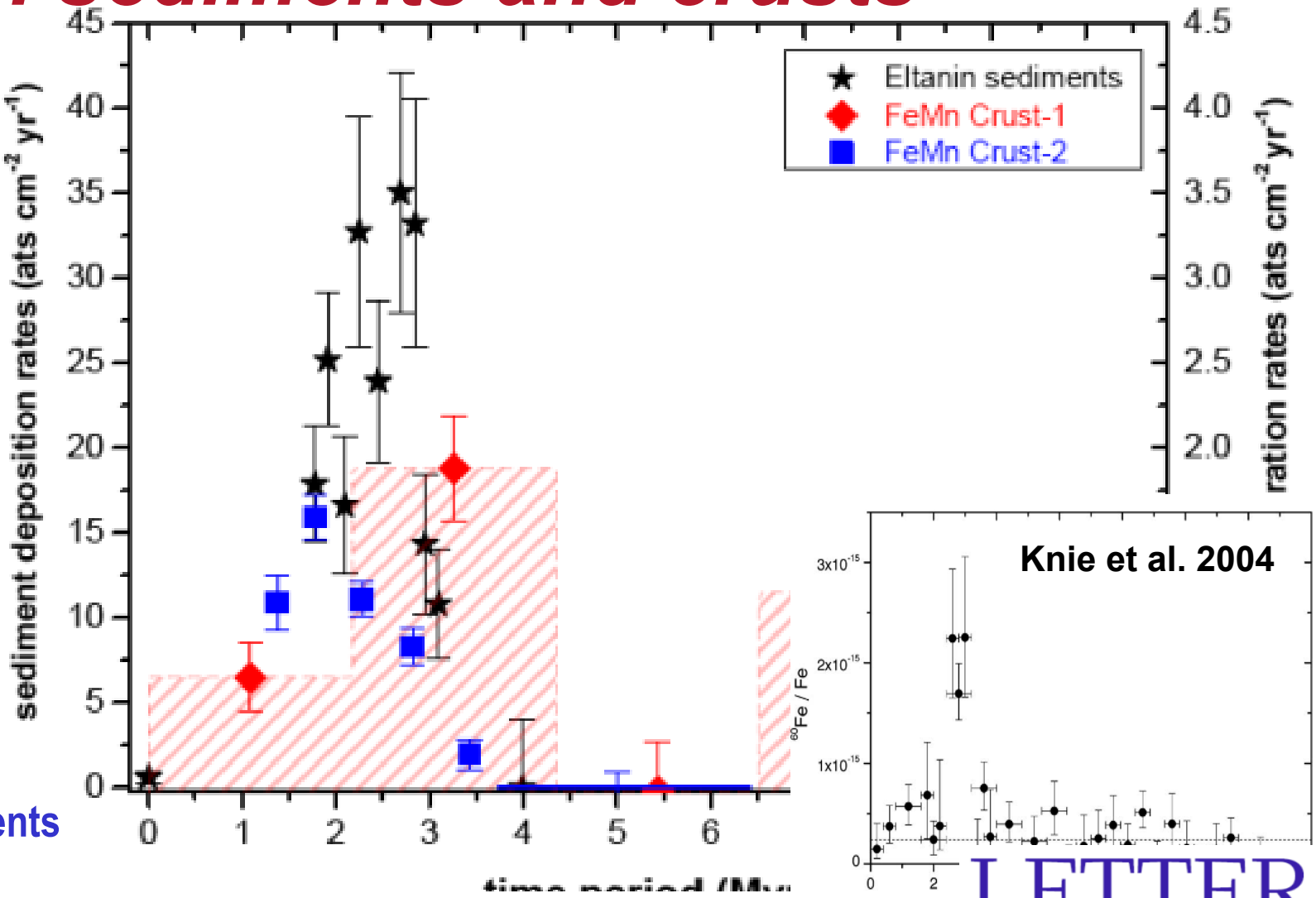


+ TU Munich: other sediment samples

+ TU Munich: lunar material

^{60}Fe from sediments and crusts

^{60}Fe flux



- Deep-sea sediments
- Deep-sea crusts

LETTER

Nature 2016

Recent near–Earth supernovae probed by global deposition of interstellar radioactive ^{60}Fe

A. Wallner[1], J. Feige[2]†, N. Kinoshita[3], M. Paul[4], L. K. Fifield[1], R. Golser[2], M. Honda[5], U. Linnemann[6], H. Matsuzaki[7], S. Merchel[8], G. Rugel[8], S. G. Tims[1], P. Steier[2], T. Yamagata[9] & S. R. Winkler[2]

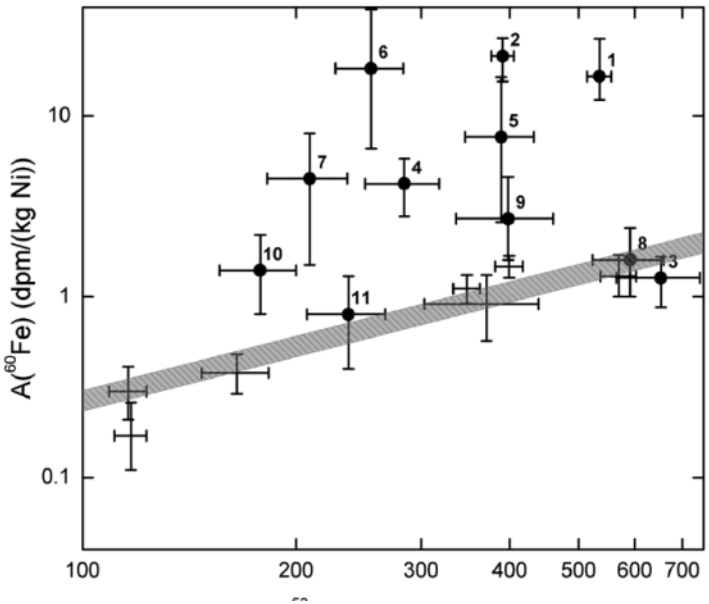
THE AUSTRALIAN NATIONAL UNIVERSITY

More ^{60}Fe data recently

PRL 116, 151104 (2016) PHYSICAL REVIEW LETTERS week ending 15 APRIL 2016

Interstellar ^{60}Fe

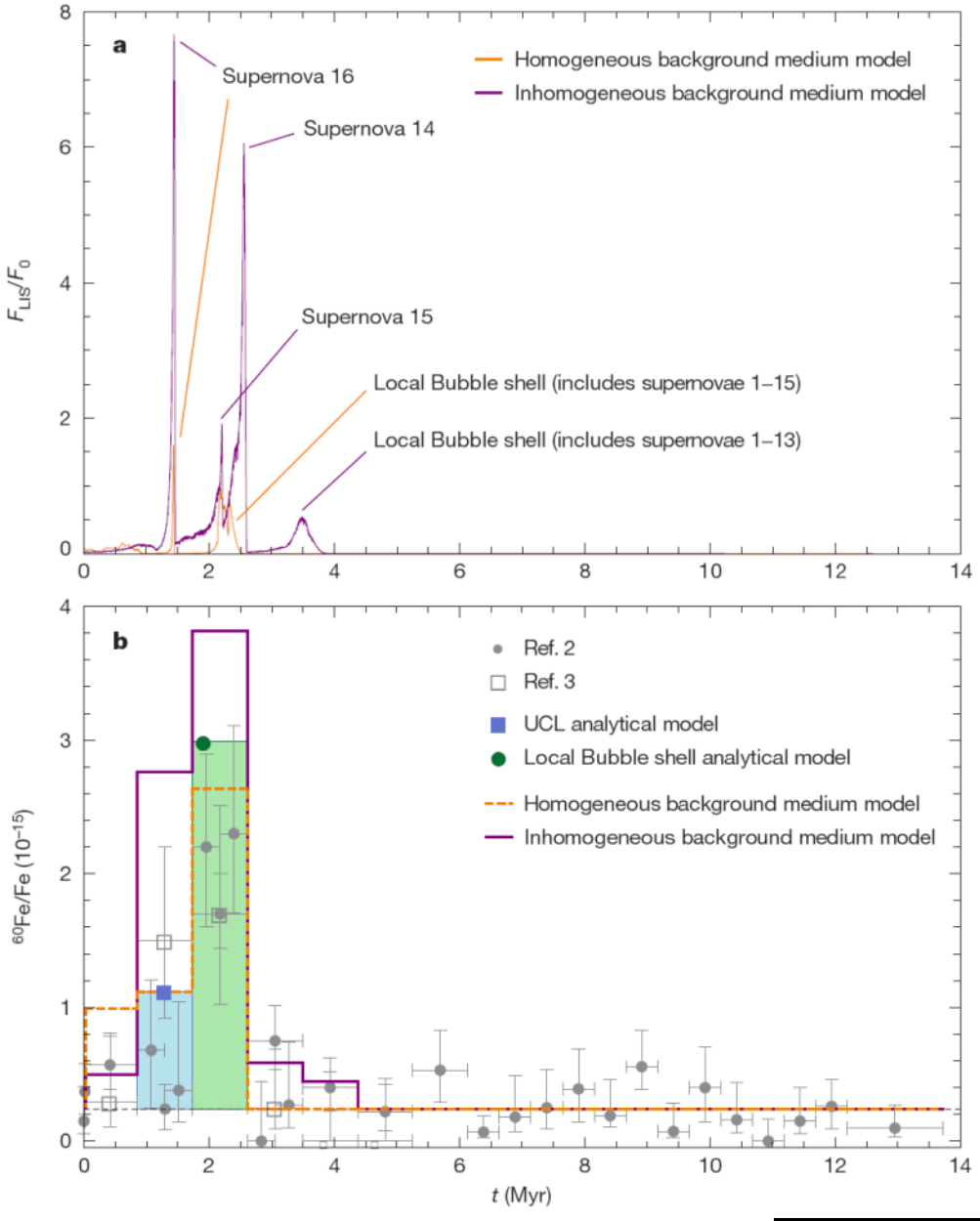
L. Fimiani,[1] D. L. Cook,[2,*] T. Faestermann,[1]
G. Korschinek,[1,‡] P. Ludwig



LETTER

The locations of recent supernova from modelling ^{60}Fe transport

D. Breitschwerdt[1], J. Feige[1], M. M. Schulreich[1], M. A. de. Avillez[1,2], C. Dettbarn[3] & B.



More recent work on ^{60}Fe

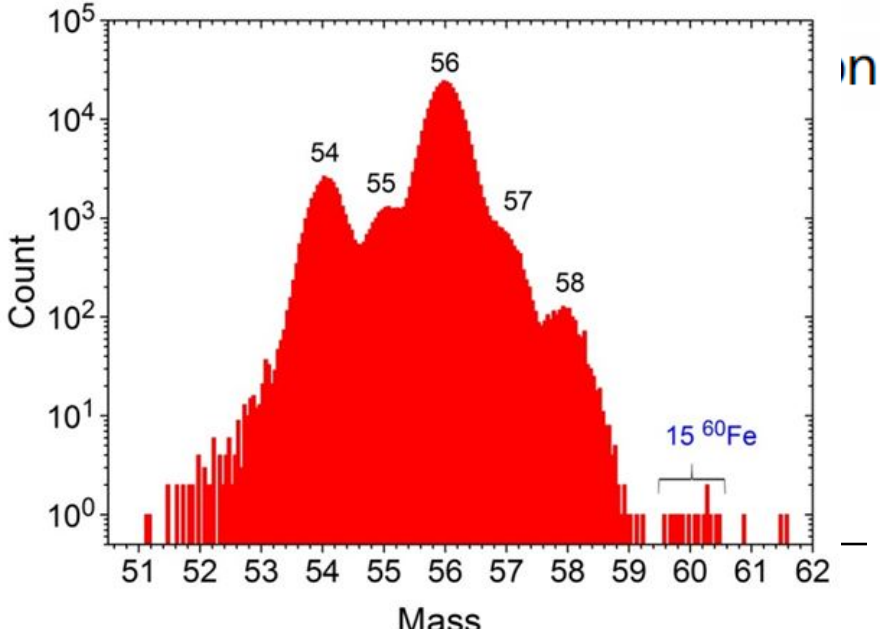
Signatures of a two million year old supernova in the spectra of cosmic ray protons, antiprotons and positrons

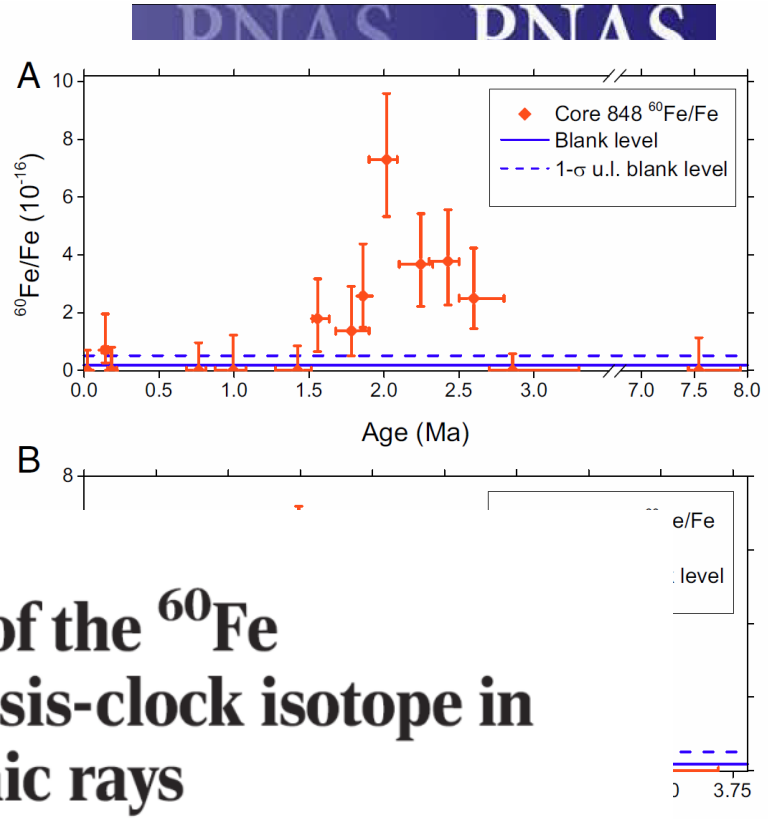
M. Kachelrieß[1], A. Neronov[2], and D. V. Semikoz[3]

Time-resolved 2-million-year-old discovered in Earth's microfossil

Peter Ludwig[a], Shawn Bishop[a,1], Ramon Egli[b], Valentyna Chernenko[a], B
Nicolai Famulok[a], Leticia Fimiani[a], José Manuel Gómez-Guzmán[a], Karin H
Silke Merchel[d], and Georg Rugel[d]

nas.1601040113





ASTROPARTICLE PHYSICS

Observation of the ^{60}Fe nucleosynthesis-clock isotope in galactic cosmic rays

W. R. Binns,[1*] M. H. Israel,[1*] E. R. Christian,[2] A. C. Cummings,[3] G. A. de Nolfo,[2] K. A. Lave,[1] R. A. Leske,[3] R. A. Mewaldt,[3] E. C. Stone,[3] T. T. von Rosenvinge,[2] M. E. Wiedenbeck[4]

SCIENCE sciencemag.org

A. Wallner

Summary

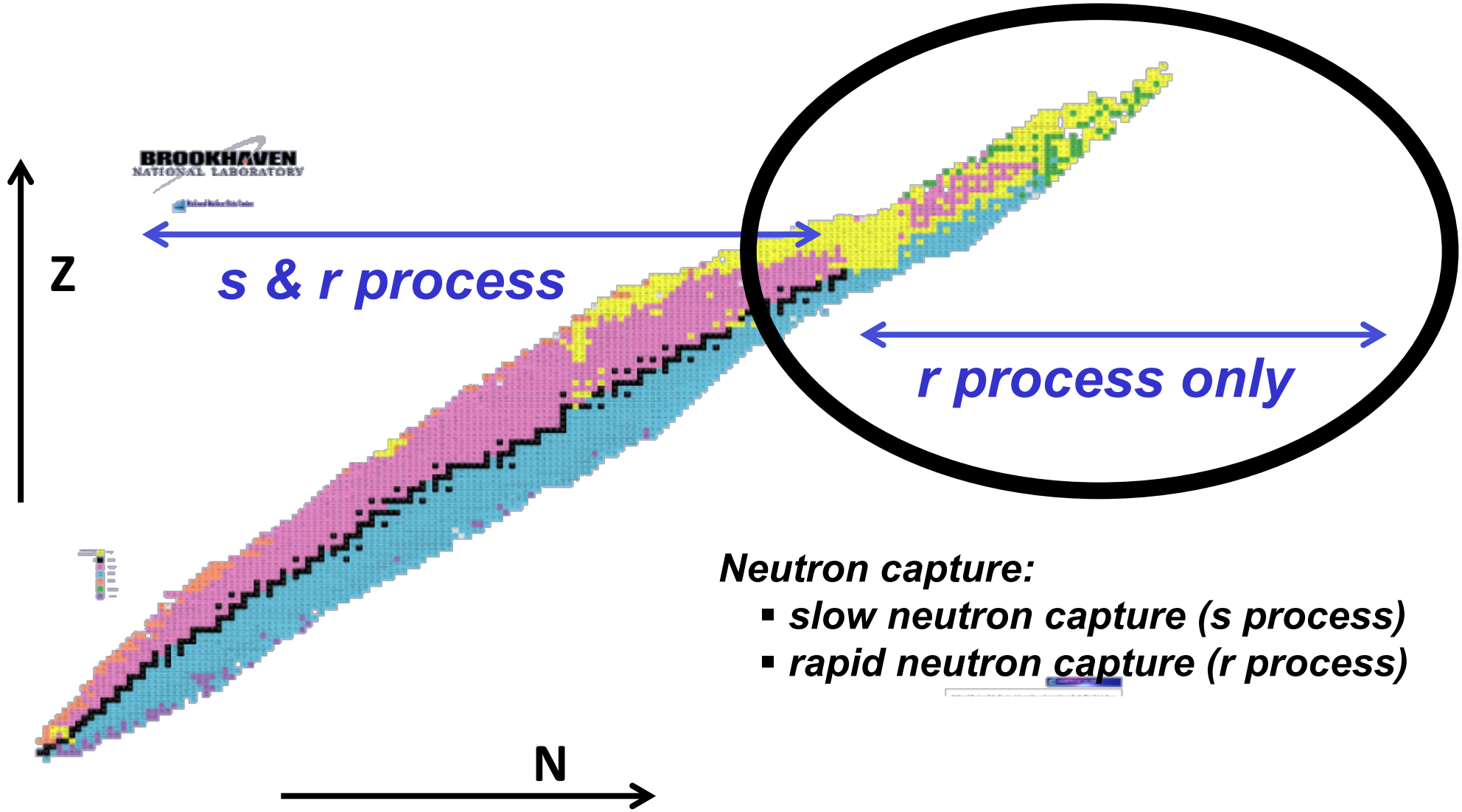
^{244}Pu – AMS at Univ. of Vienna:

- *100 times less abundant than expected*
- *rare production – neutron star mergers?*

^{60}Fe – AMS at the ANU:

- *new half-life confirmed*
- *clear extraterrestrial influx – points to recent SN activity close-by to Earth*
  - *multiple events!?*
  - *close-by (≤150 pc)*
  - *impact on Earth ? – climate, temperature, …*

The Chart of Nuclides

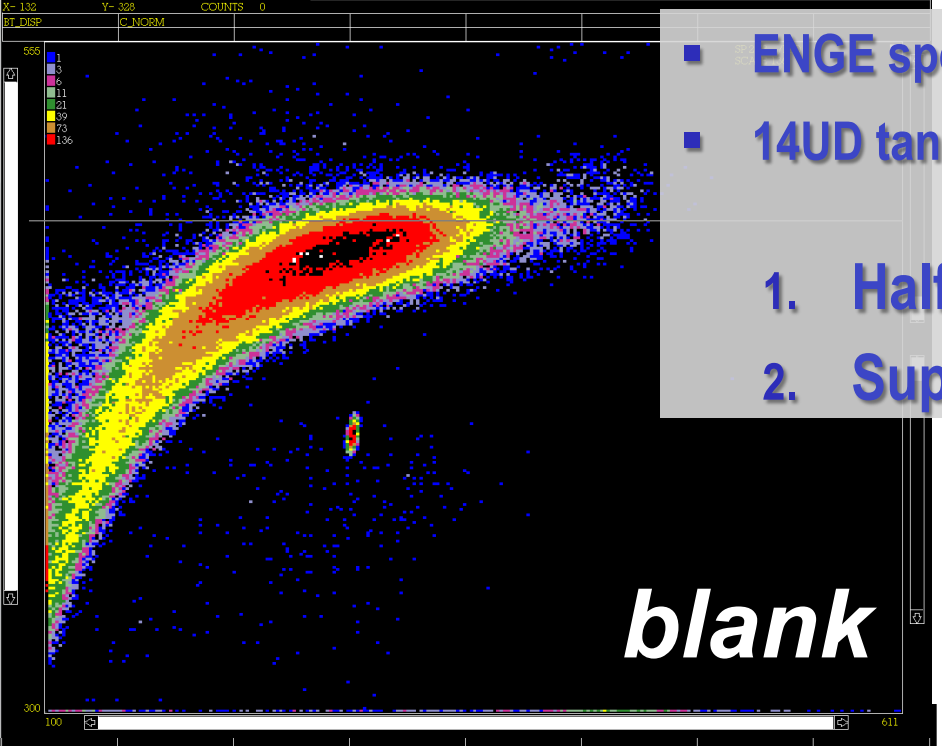


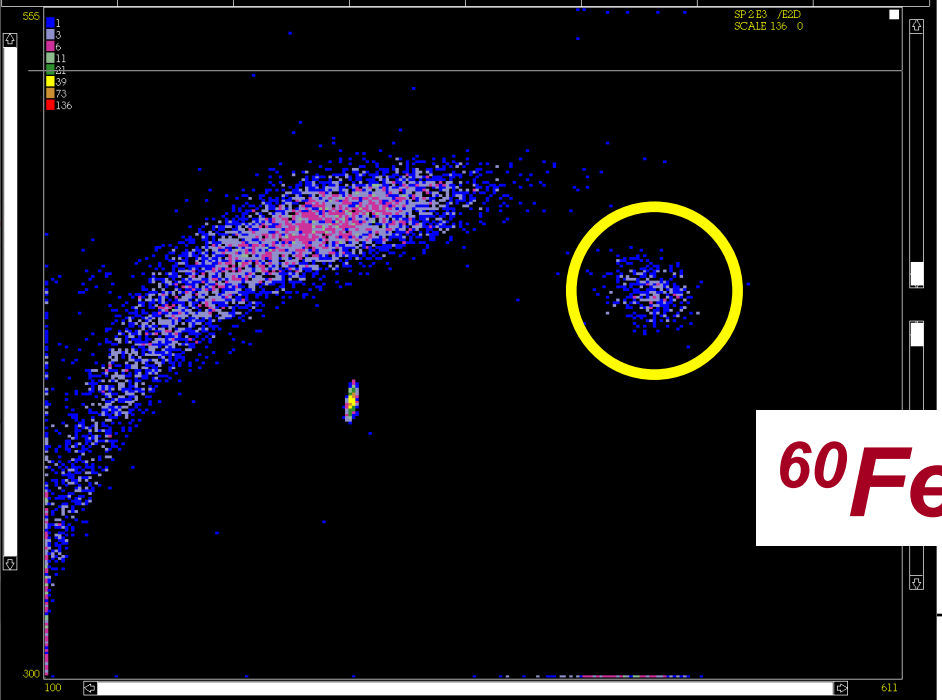
Neutron capture:

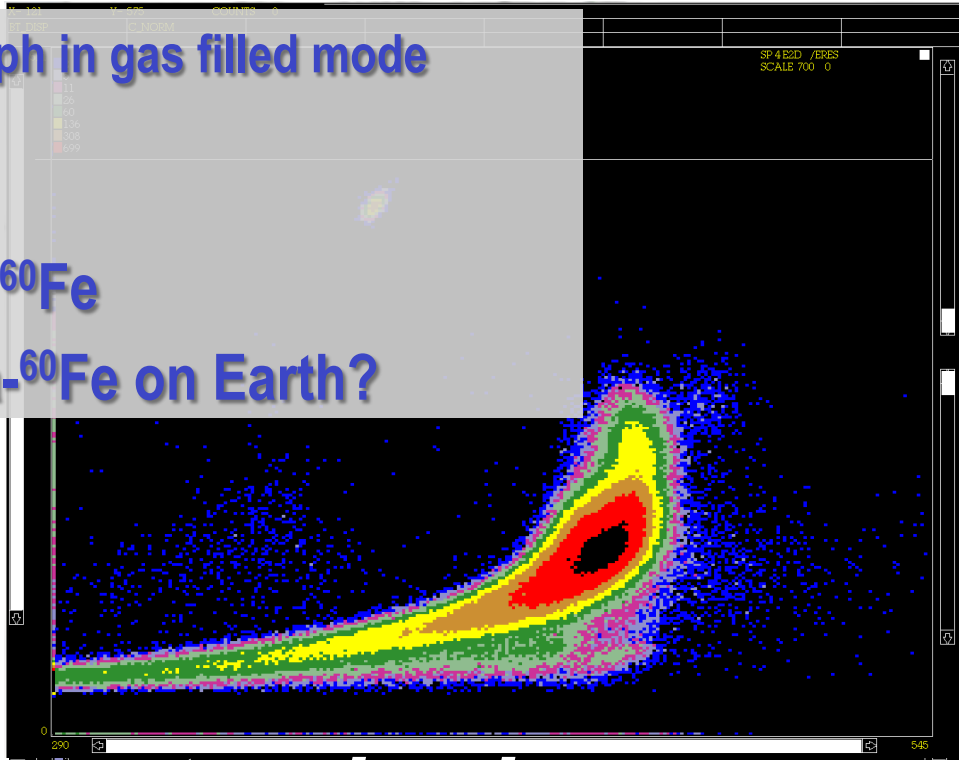
- ***slow neutron capture (s process)***
- ***rapid neutron capture (r process)***

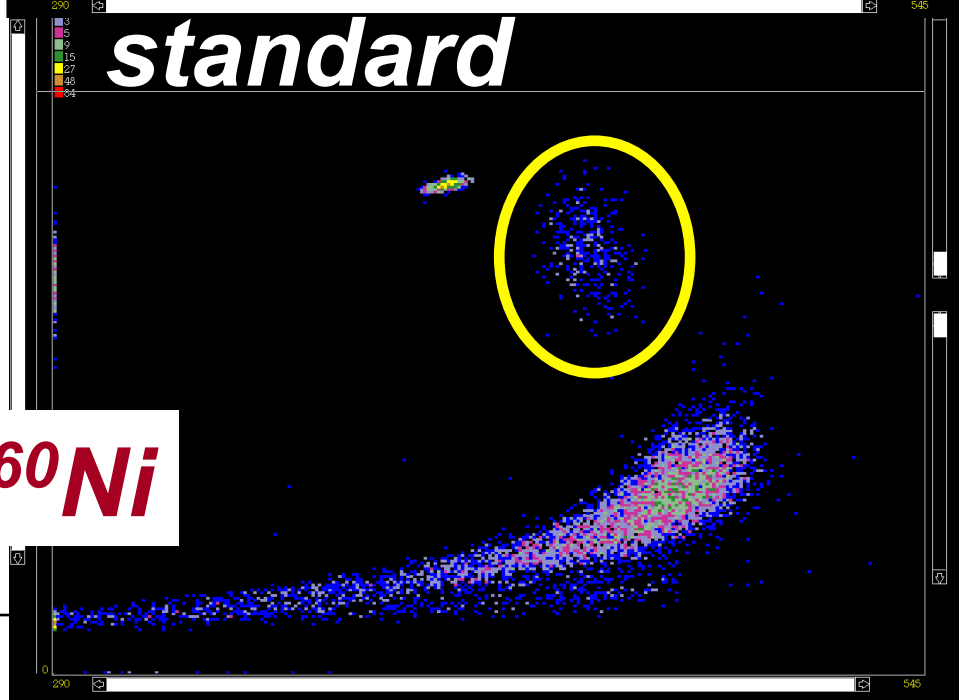
- ENGE spectrograph in gas filled mode
- 14UD tandem

1. Half life of ^{60}Fe
2. Supernova-^{60}Fe on Earth?





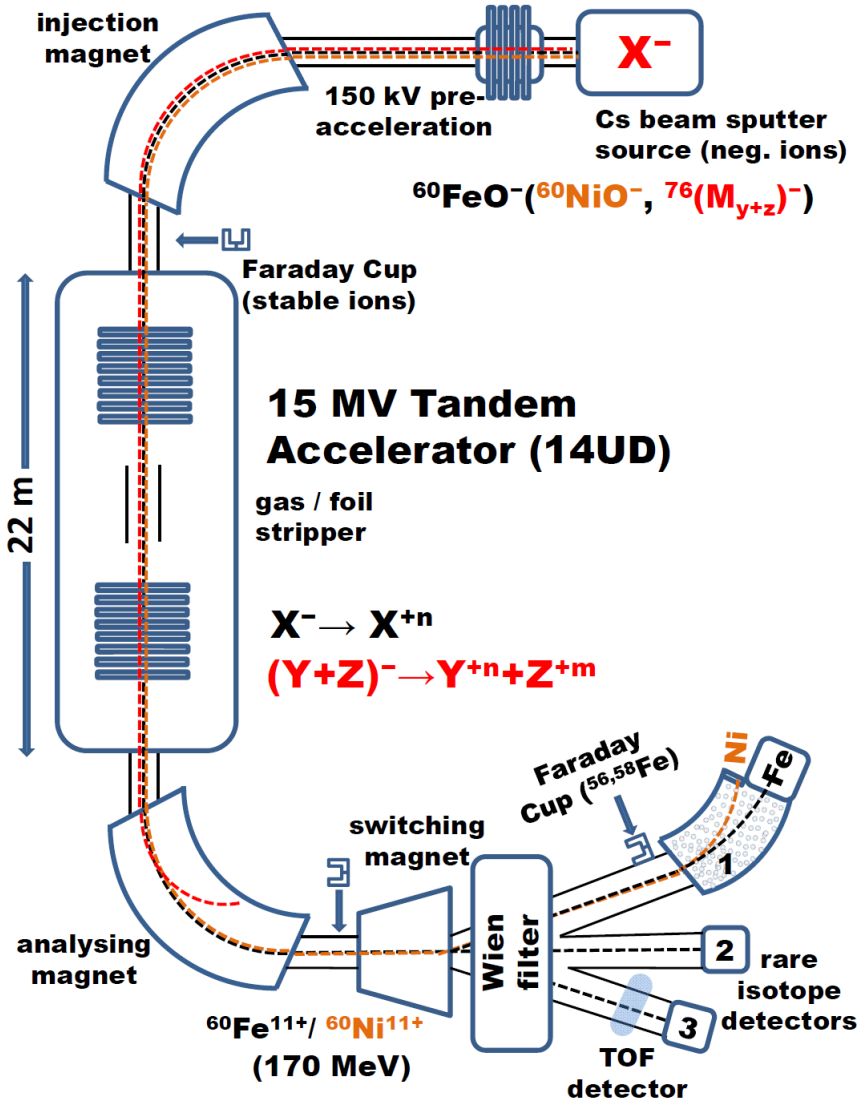




$^{60}Fe \leftrightarrow {}^{60}Ni$

ANU's HIAF - AMS facility

- *AMS determines isotope ratios – atom counting technique*
- *$^{14}C/^{12}C$ – radiocarbon dating*
- *highest sensitivity: 10^{-12} – 10^{-16}*
- *no isobaric background (<-> ICPMS) (molecules are completely destroyed)*
- *isotopic background clearly identified*



$^{14}C^- \leftrightarrow \cancel{^{14}N^-}$

but $^{60}Fe \leftrightarrow {}^{60}Ni$

11 Greatest Unanswered Questions in Physics

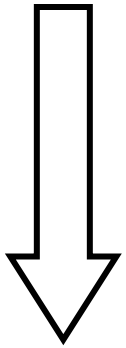
1. What is dark matter?
2. What is dark energy?
3. ***3. How were the heavy elements from iron to uranium made?***
4.
5.
6. pens at
7. Are there new states of matter at ultrahigh temperatures and densities?
8. Are protons unstable?
9. What is gravity?
10. Are there additional dimensions?
11. How did the universe begin?

Discover 2002; US National Research Council's board on physics and astronomy

Some radionuclides measured with AMS

^{55}Fe	2.7 years
^{3}H	12.3
^{44}Ti	60
^{63}Ni	100
^{32}Si	140
^{39}Ar	269
^{14}C	5 730
^{59}Ni	75 000
^{41}Ca	104 000
^{81}Kr	230 000
^{79}Se	280 000
^{36}Cl	301 000
^{26}Al	720 000
^{10}Be	1 388 000
^{60}Fe	2 600 000
^{53}Mn	3 600 000
^{182}Hf	8 900 000
^{129}I	17 000 000

fundamental physics



applied sciences

atom counting of radionuclides via isotope ratio measurements

...

Nucleosynthesis yields