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HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Combined Search for Live Stellar Fe-60 and r-Process Synthesized Pu-244 in Terrestrial Archives

Dominik Koll, M.Sc.

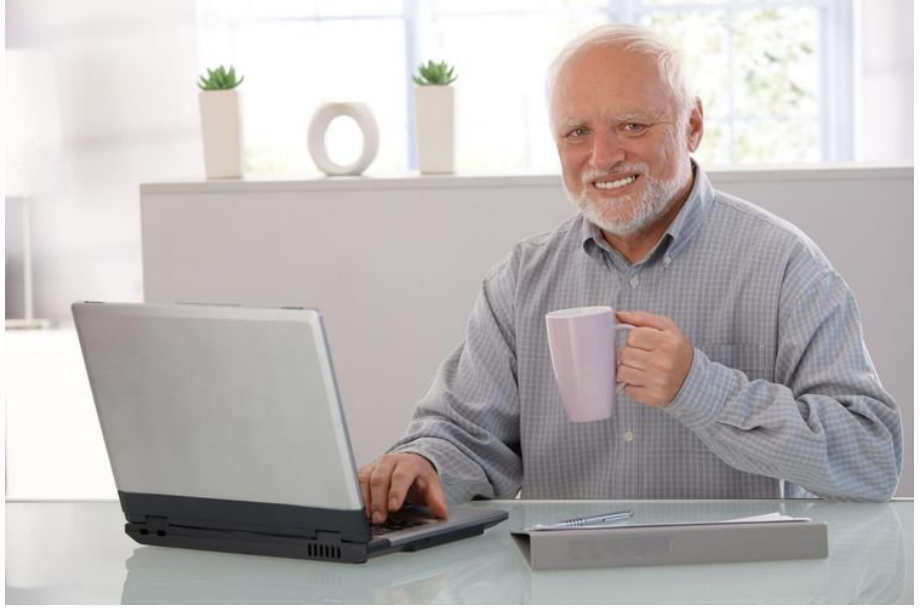
17th Rußbach School on Nuclear Astrophysics

13-19 March 2022


The Penguin and the Egg (NASA), my favorite pair of galaxies

Accelerator Mass Spectrometry and Isotope Research · Dominik Koll, M.Sc. · d.koll@hzdr.de · www.hzdr.de/fwir

Observational Astrophysics



Computational Astrophysics

Astrophysical Reactions

Observati hysics

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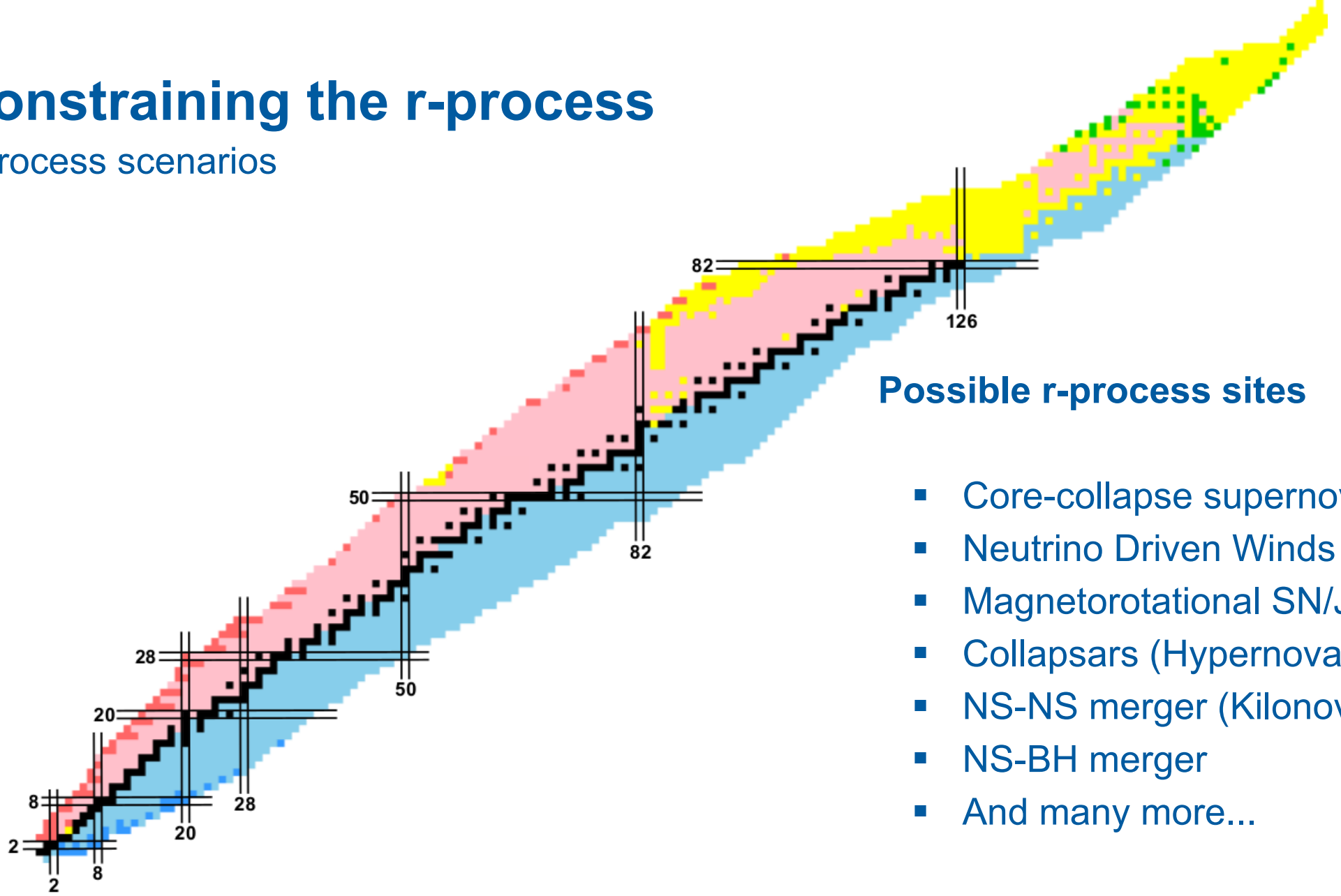
Constraining the r-process

r-process scenarios

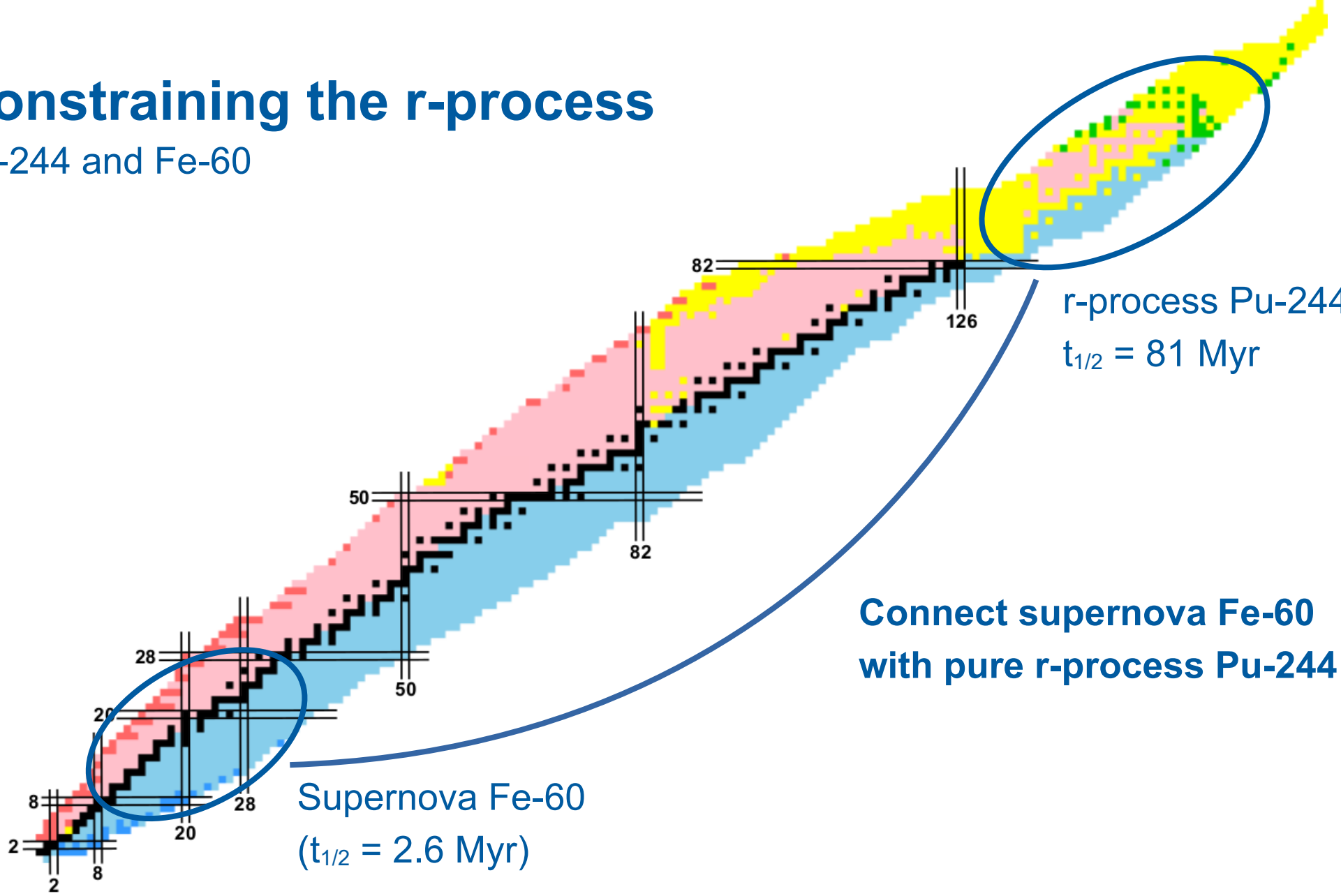


Possible r-process sites

- Core-collapse supernovae
- Neutrino Driven Winds in CCSN
- Magnetorotational SN/Jets
- Collapsars (Hypernova)
- NS-NS merger (Kilonova)
- NS-BH merger
- And many more...

Constraining the r-process

Pu-244 and Fe-60



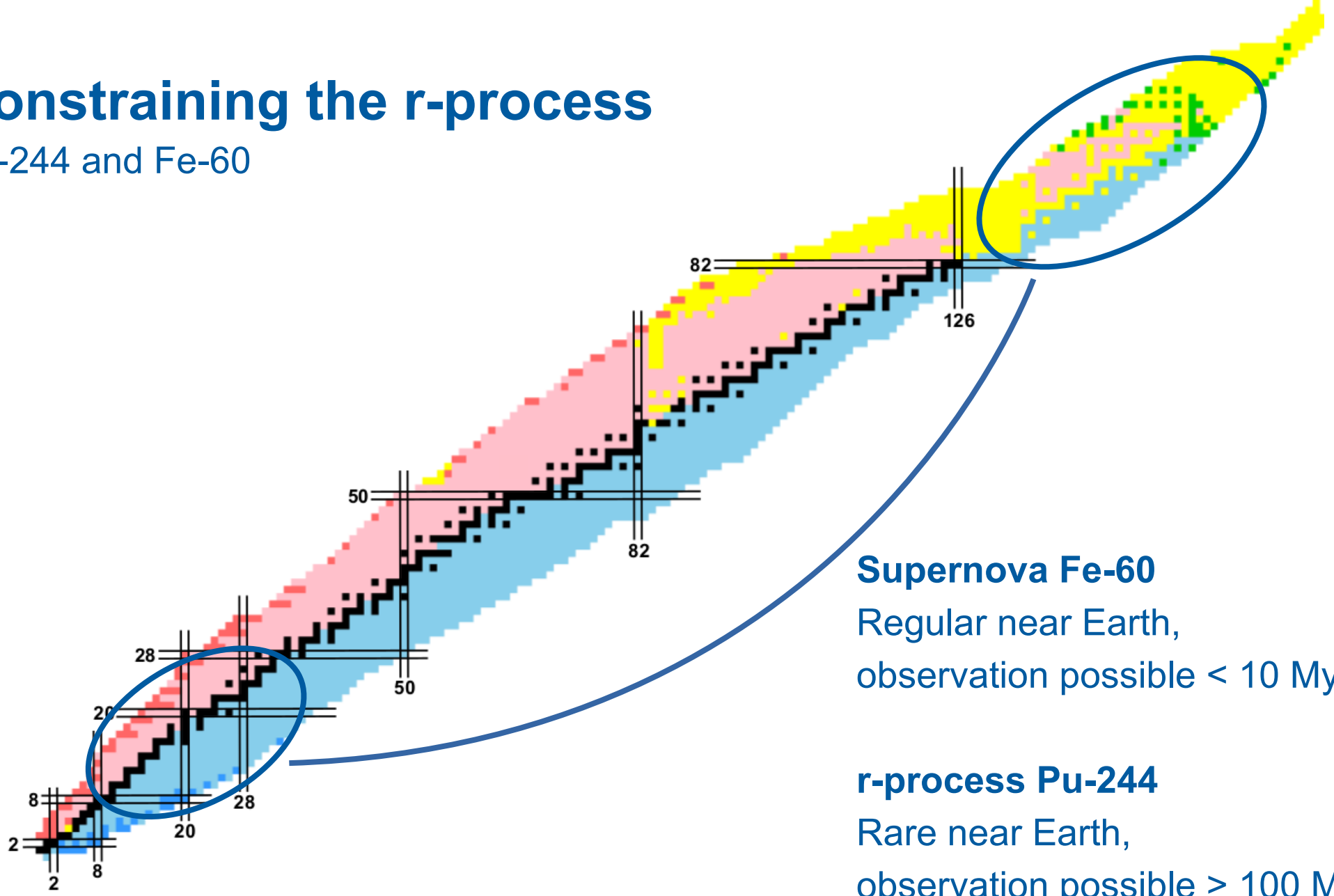
r-process Pu-244
$t_{1/2}$ = 81 Myr

Connect supernova Fe-60 with pure r-process Pu-244

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

Constraining the r-process

Pu-244 and Fe-60



Supernova Fe-60

Regular near Earth,
observation possible < 10 Myr

r-process Pu-244

Rare near Earth,
observation possible > 100 Myr

AMS
Accelerator Mass Spectrometry

Pioneering work

Supernova Fe-60 with AMS in Munich

1996: Fe-60 proposed to be an excellent tracer for the study of supernova traces on Earth (Korschinek et al, Ellis et al. 1996)

„The isotopes ^{26}Al, ^{41}Ca, ^{59}Ni and ^{60}Fe may be the most promising signatures of a nearby supernova“

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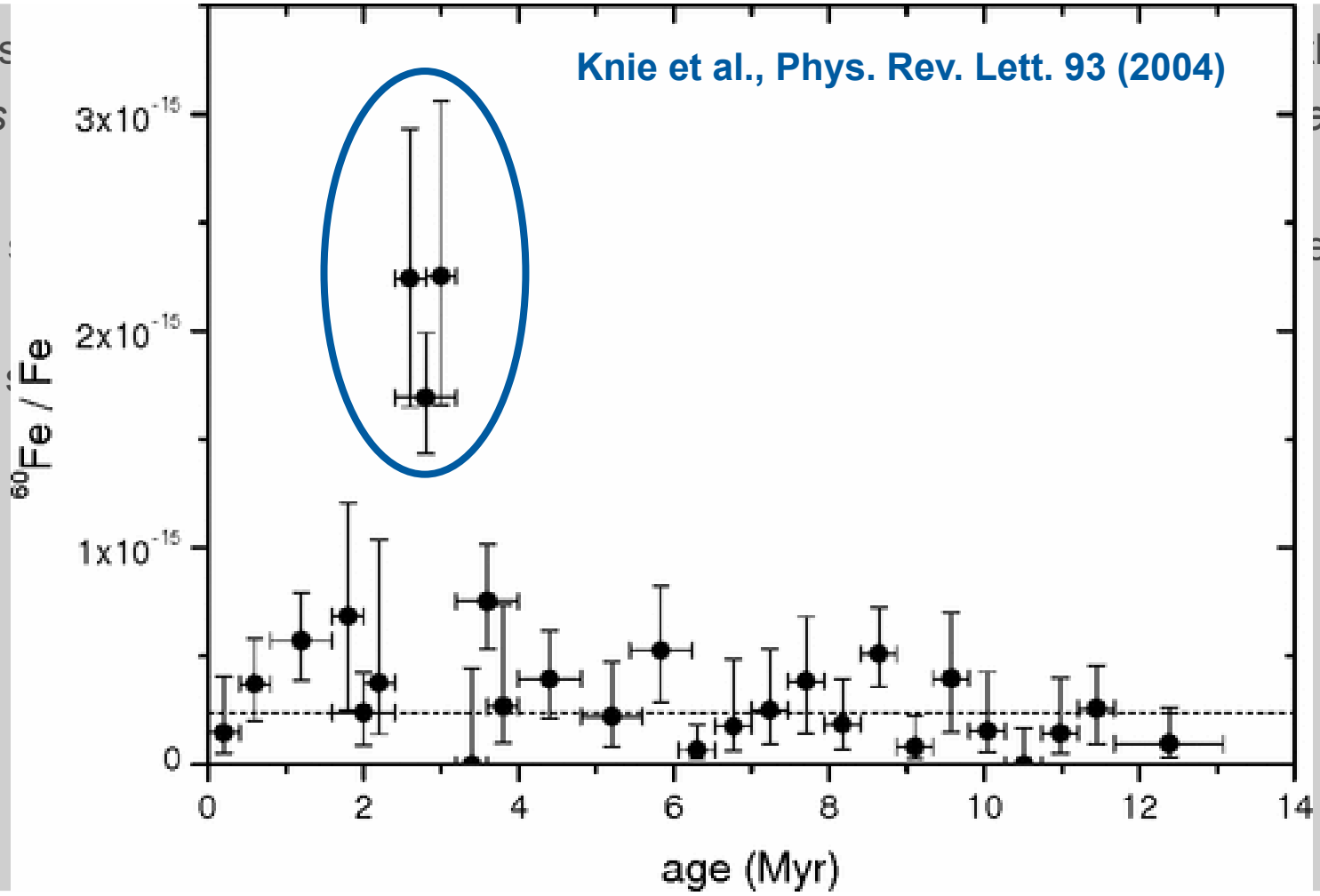

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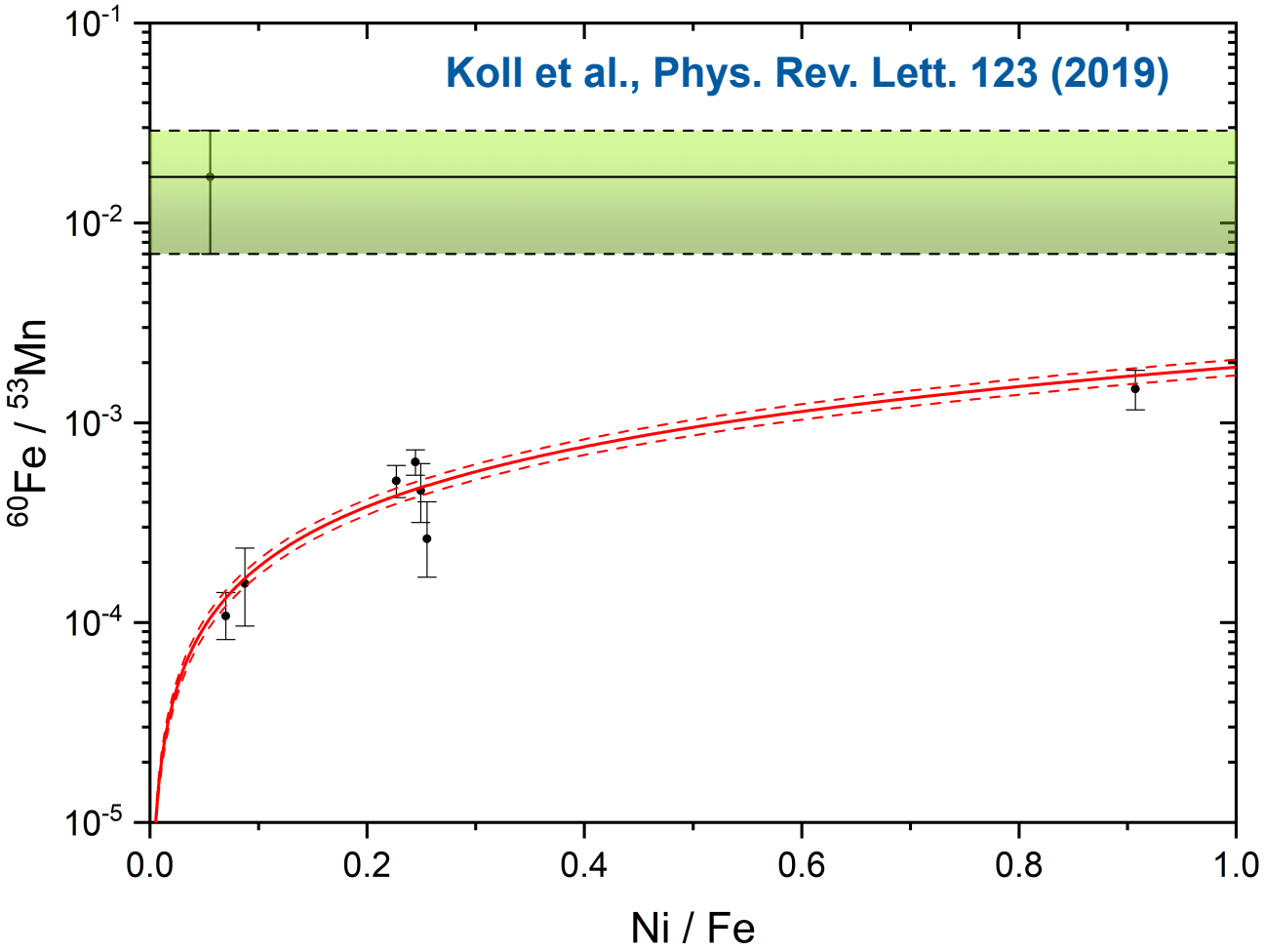

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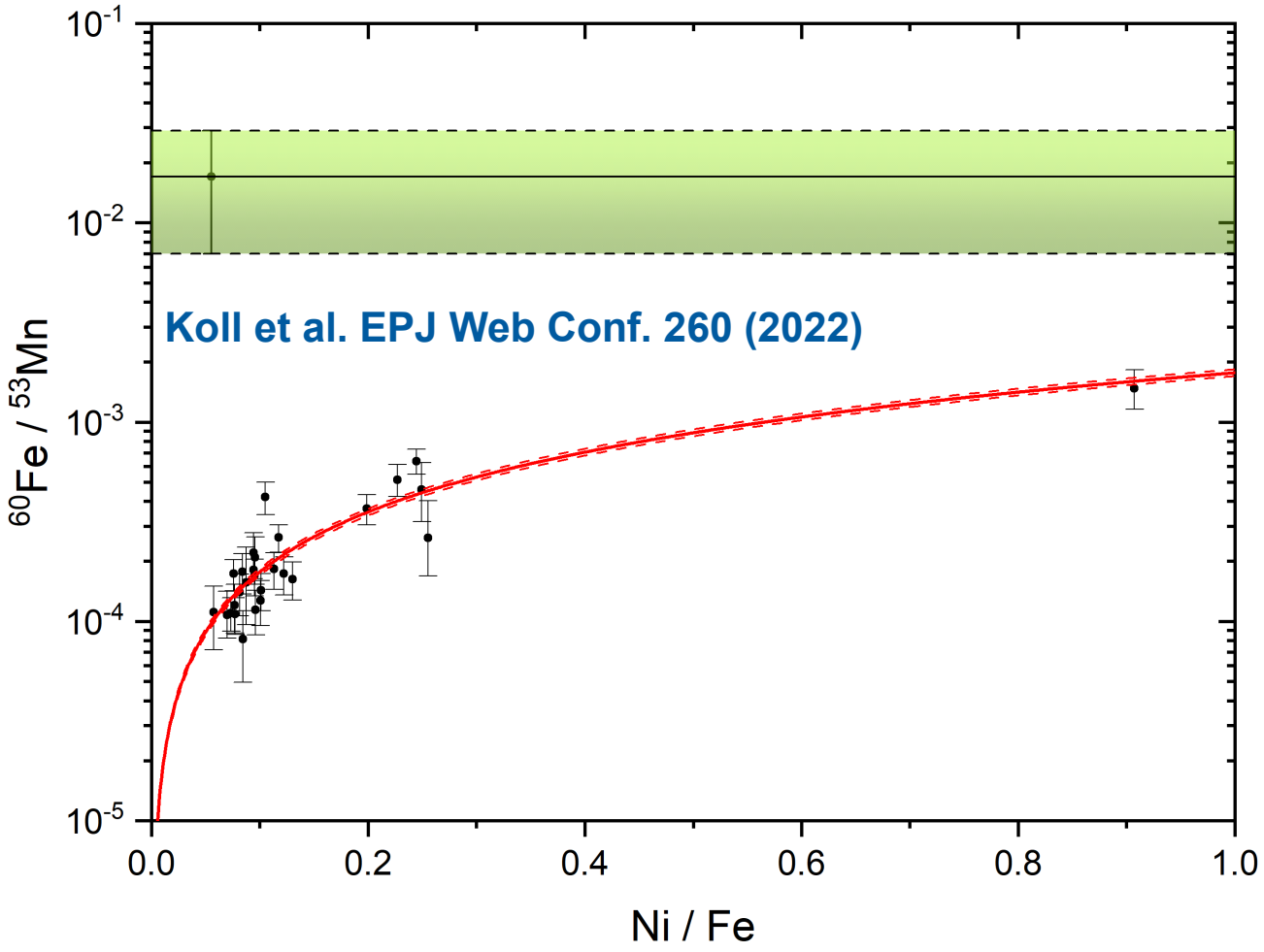

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2020: Confirmation of recent Fe-60 in deep-sea sediments (Wallner et al. 2020)

Pioneering work

r-process Pu-244 with AMS

2015: First large investigation with small AMS in Vienna, upper limit (Wallner et al. 2015)

- Time resolution only an integral over 25 Myr
- Sensitivity 1:10,000 atoms

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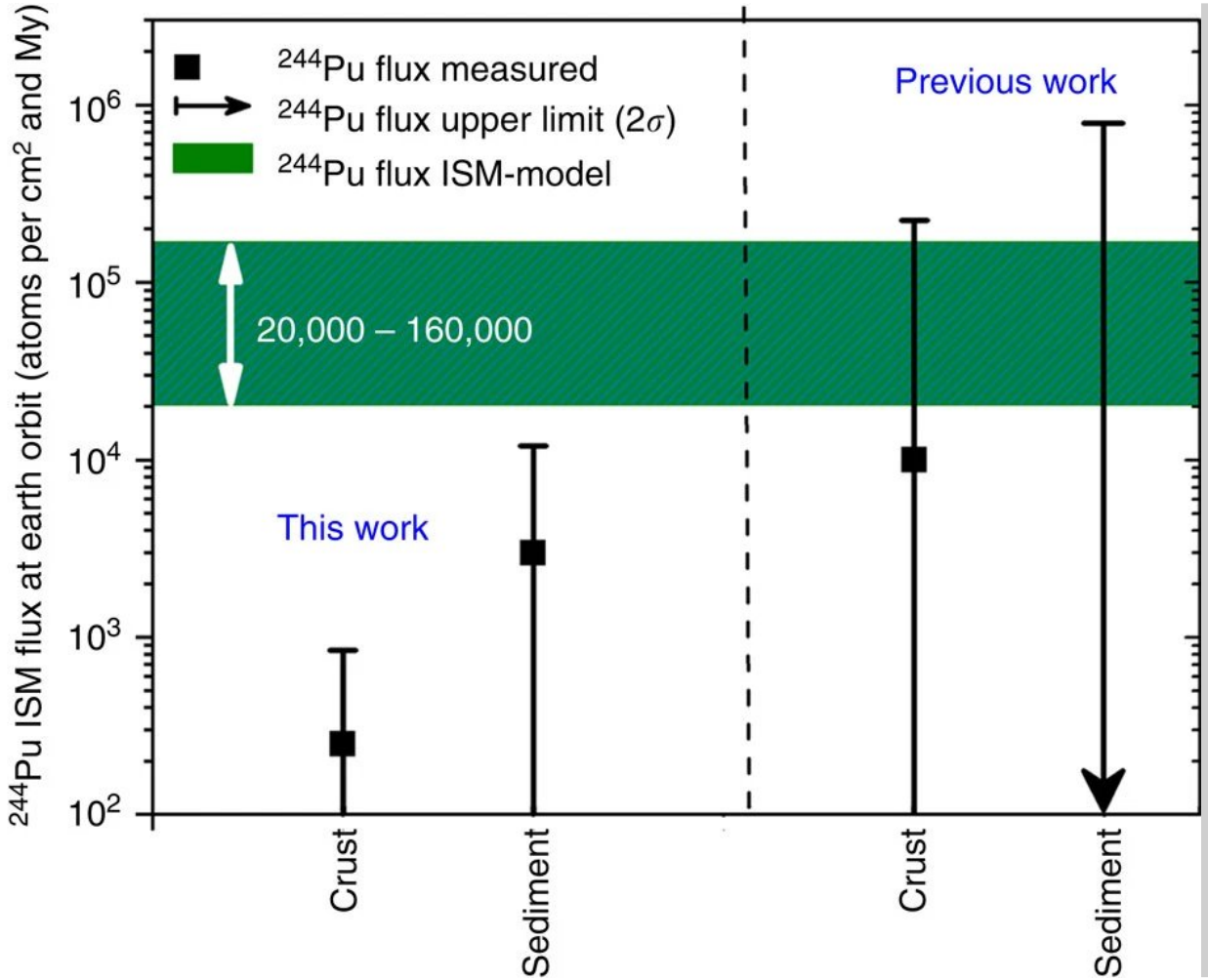
Wallner et al., Nat. Comm. 6 (2015)



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- Fe-60 influx between 6-7 Myr, previously 7-8 Myr, exact timing?

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2019:

2021:

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Detection efficiency 0.4x10^{-4}
= Sensitivity 1:25,000 atoms

Status report on AMS Measurements of Plutonium Isotopes using the 1MV Tandetron Accelerator at IFIN-HH

Iuliana Stanciu[1, 2], Doru Pacesila[1*], Shawn Bishop[2], Mihaela Enachescu[1], Alex Petre[1], Marian Virgolici[1], Andreea Serban[1, 3], Florin Albota[1], Ionuz Erhan[1], Viorel Fugaru[1], Decebal Iancu[1], Vasile Mosu[1]

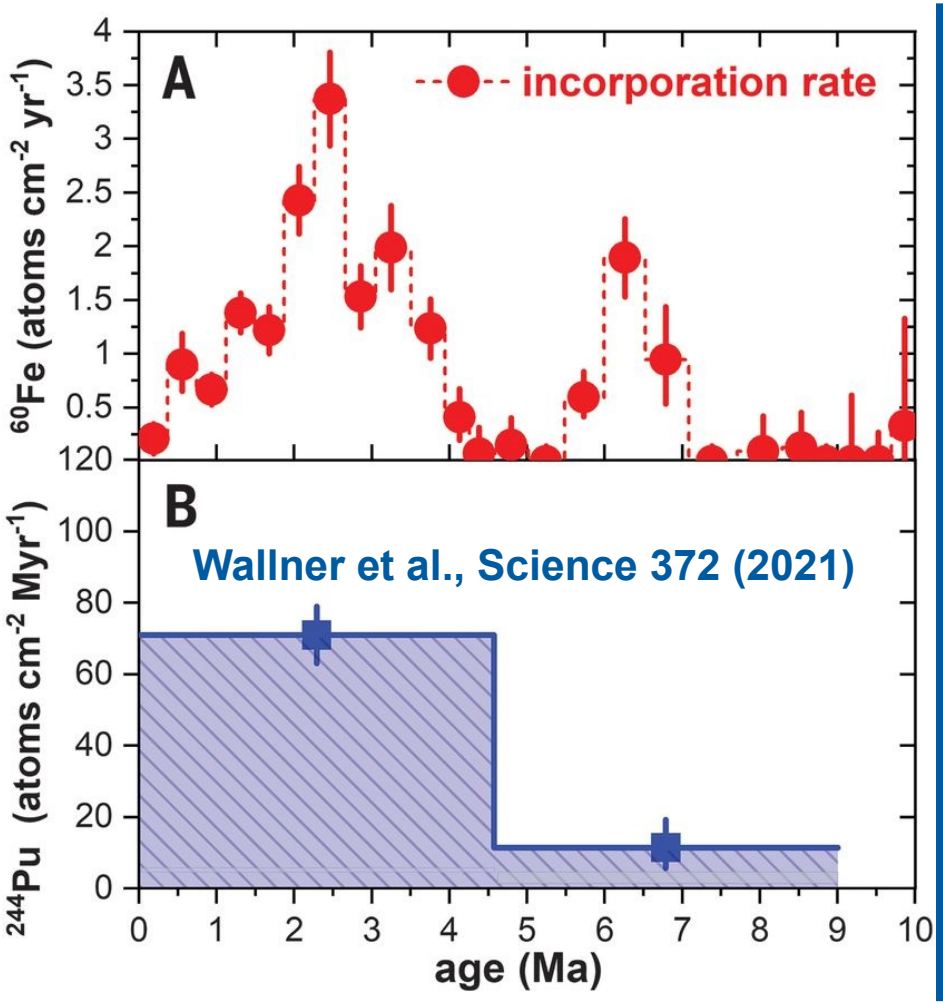
1. Horia-Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), Magurele, Romania,
2. 2. Physik Department E68, Technische Universität München, Garching, Germany
3. Faculty of Physics, University of Bucharest, Bucharest, Romania, *doru.pacesila@nipne.ro

The 15th International Conference on Accelerator Mass Spectrometry (AMS-15)
15 - 19 November 2021

^{x}Ac (U and Th particles)= $^{x}Ac^{3+}$ (A)·t (s)/3·e (C) e=1.602 x 10^{-19}C	*Transmission/Detection Efficiency Ion source - FC3 (Movable Faraday Cup) / GIC*
^{232}Th (averaged for 2 cathodes)	$1.43 \cdot 10^{-4} \pm 0.51 \cdot 10^{-4}$
^{238}U (averaged for 2 cathodes)	$0.32 \cdot 10^{-4} \pm 0.03 \cdot 10^{-4}$
^{242}Pu (averaged for 4 cathodes)	$0.41 \cdot 10^{-4} \pm 0.07 \cdot 10^{-4}$

Pioneering work

Interstellar radionuclides with AMS



- Two supernova Fe-60 influxes and recent influx
- Pu-244 detected, but only integral over Fe-60 influx
- AMS at ANU for Fe-60, only facility
- AMS at ANSTO for Pu-244

→ Large sample, characterization, high efficiency in chemistry and measurement
= Time resolved influx of Fe-60 and Pu-244

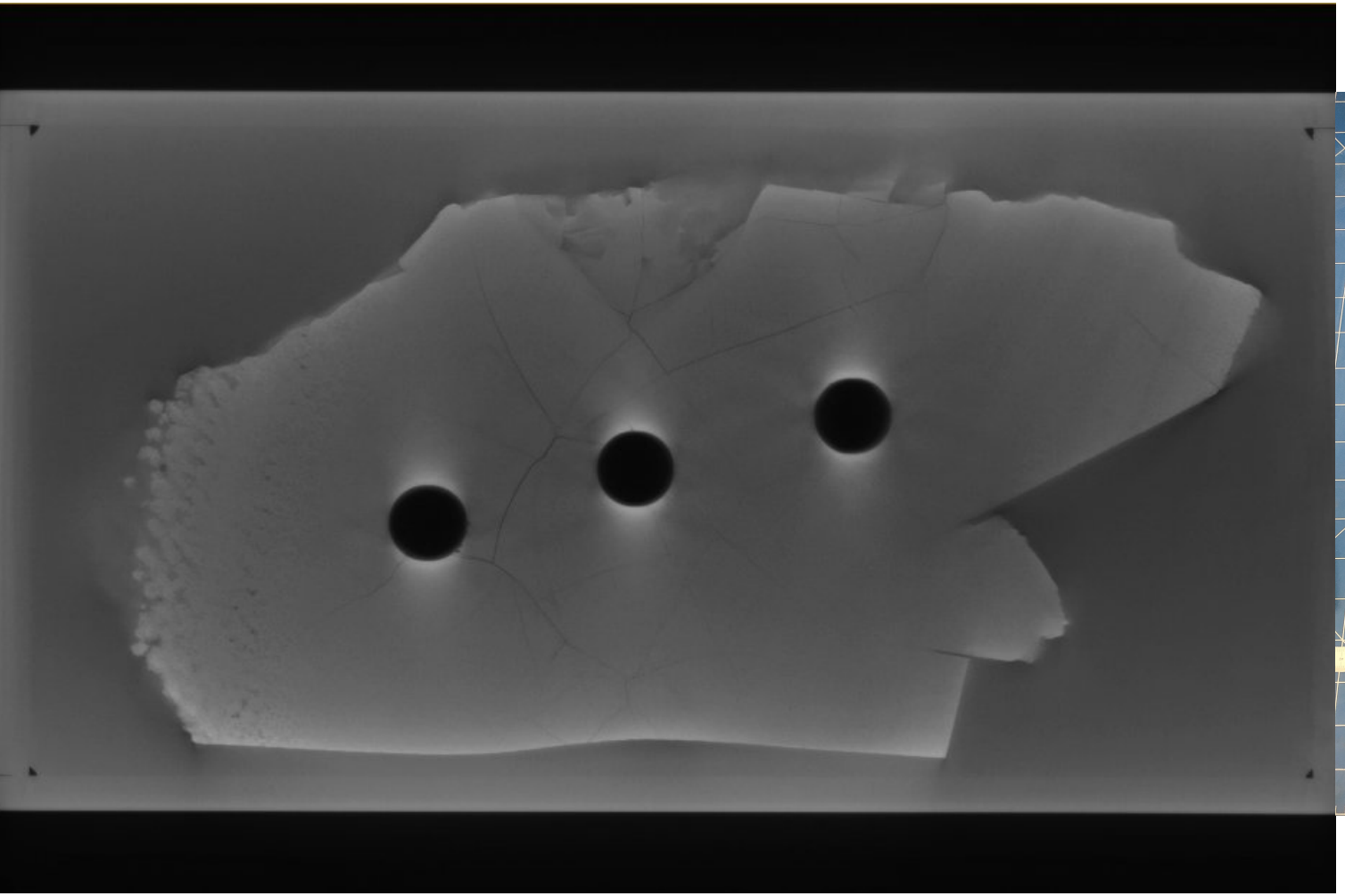
10 Myr time profile of Fe-60 and Pu-244

Characterization of the crust

- VA13-237KD
- 3.7 kg
- 2 drillcores for Be-10 dating
- 1 drillcore for Fe-60 profile
- Layers for Pu-244
- Characterization with
  3D optical scan
  3D x-ray scan
  3D CNC model and print

10 Myr time profile of Fe-60 and Pu-244

Characterization of the crust



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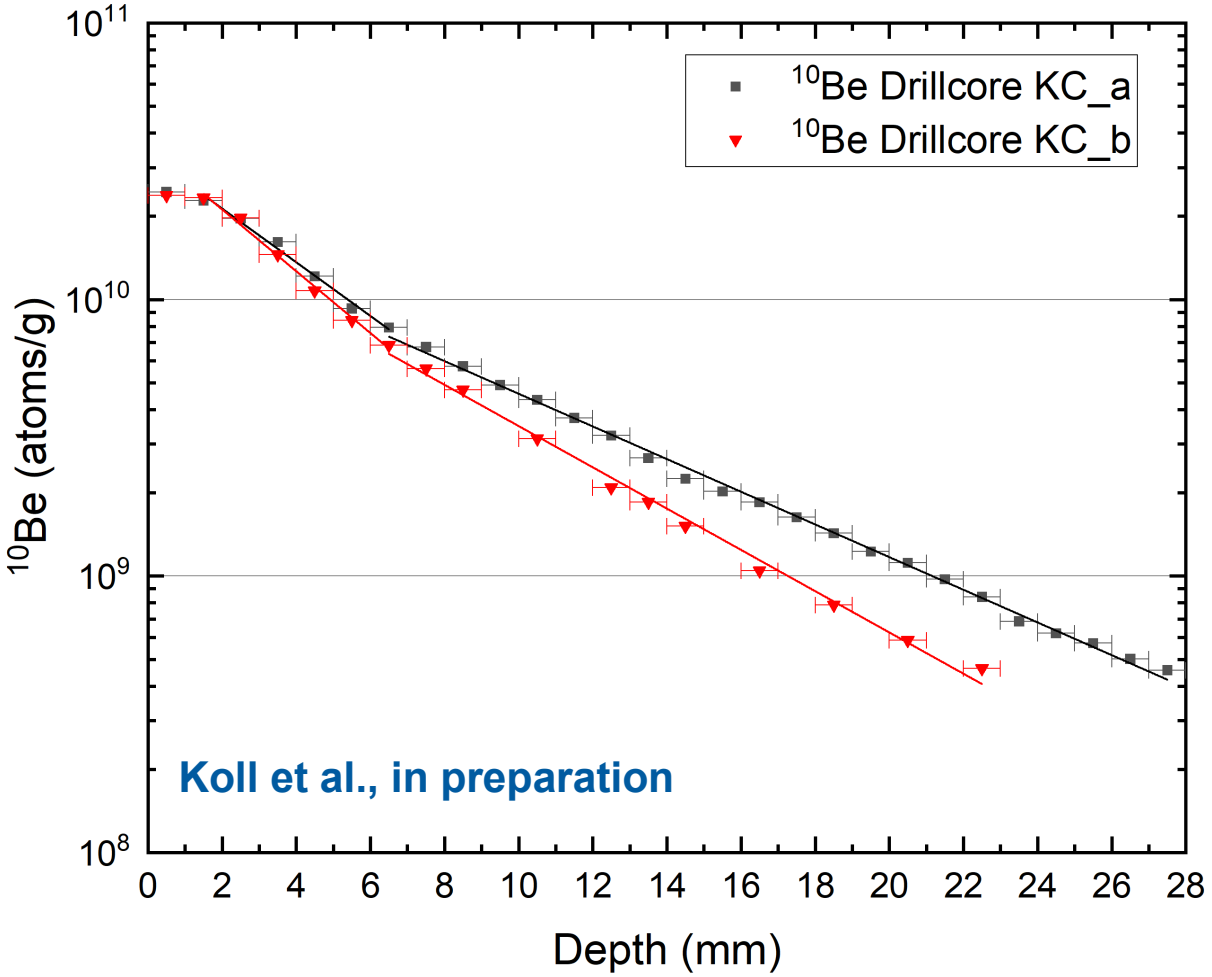
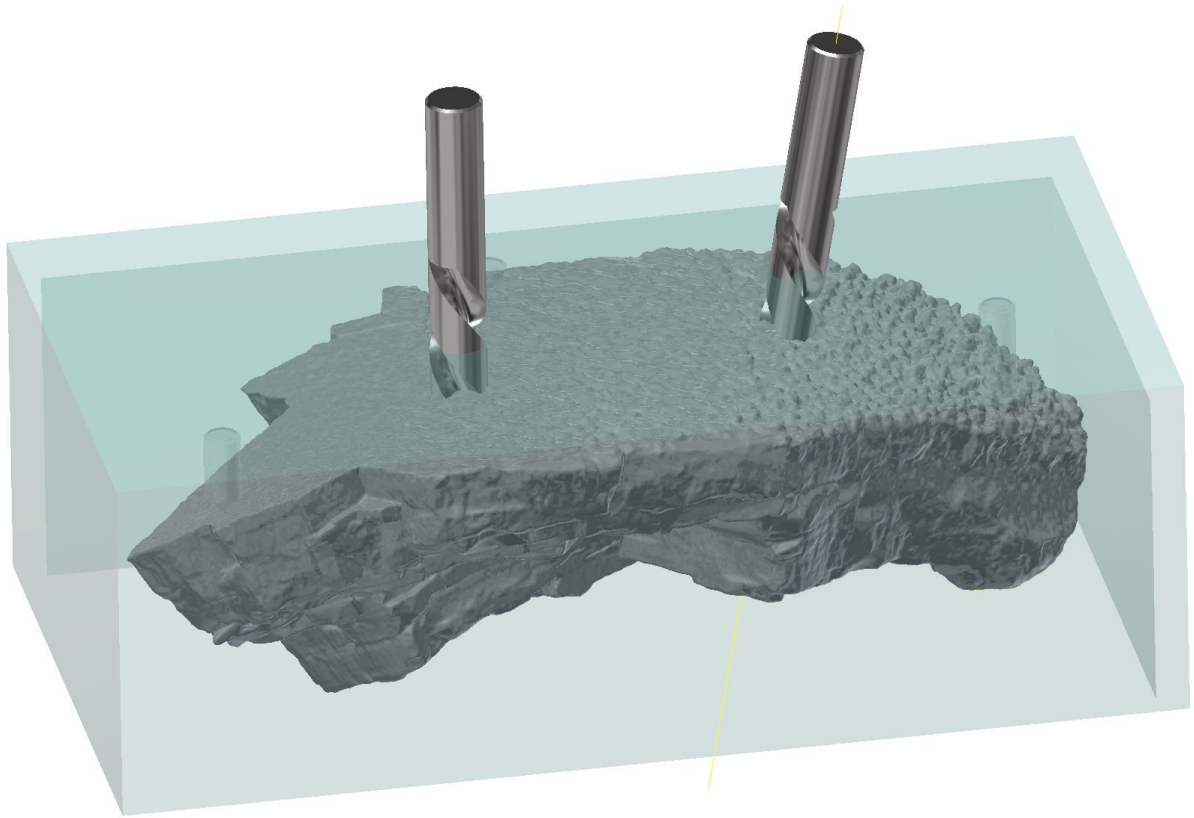
Characterization of the crust, Be-10 at HZDR





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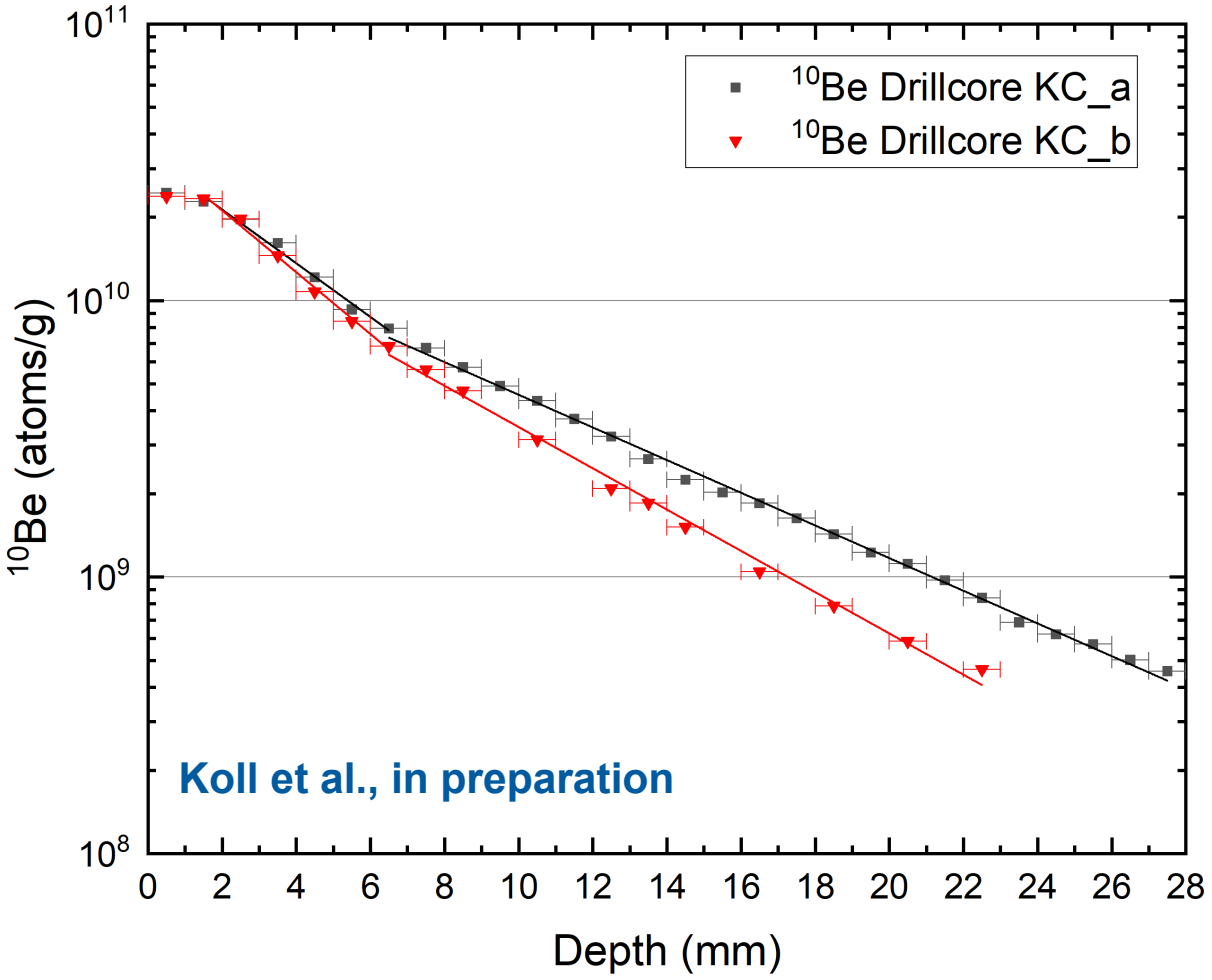

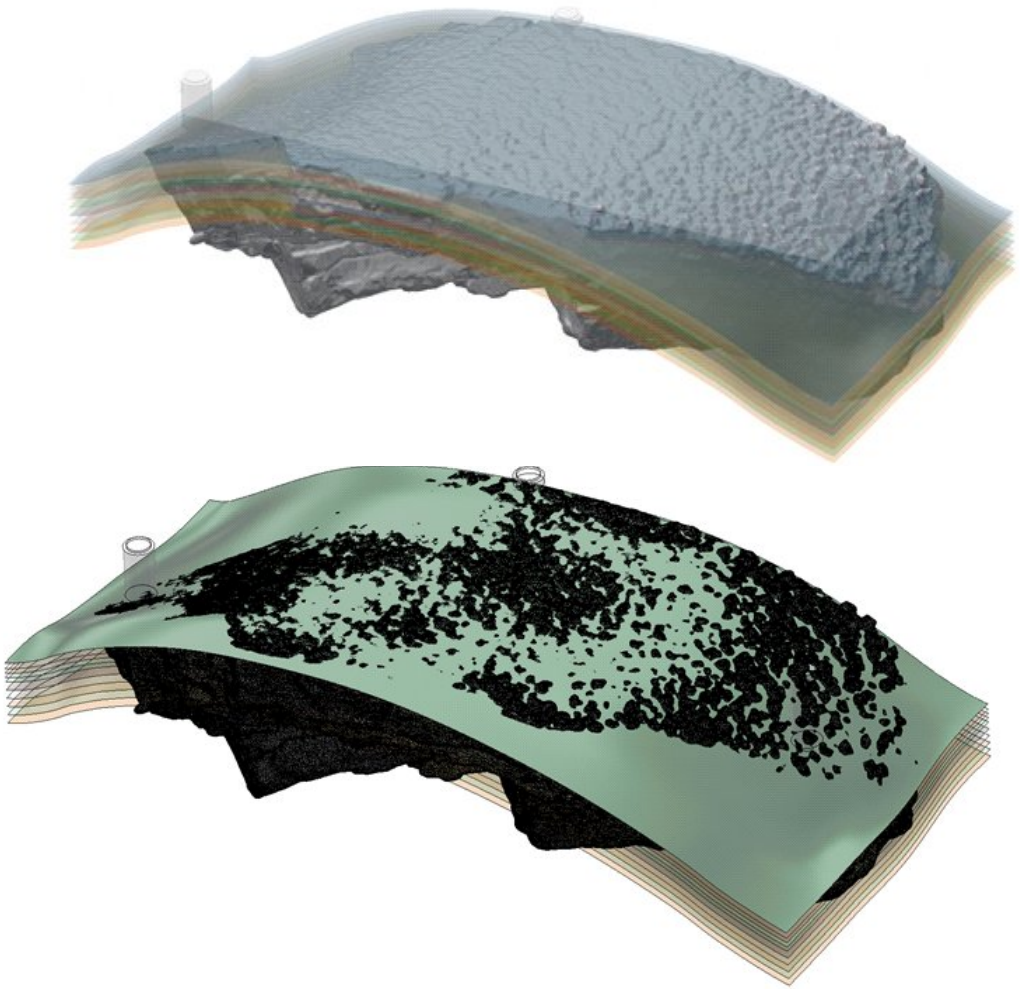

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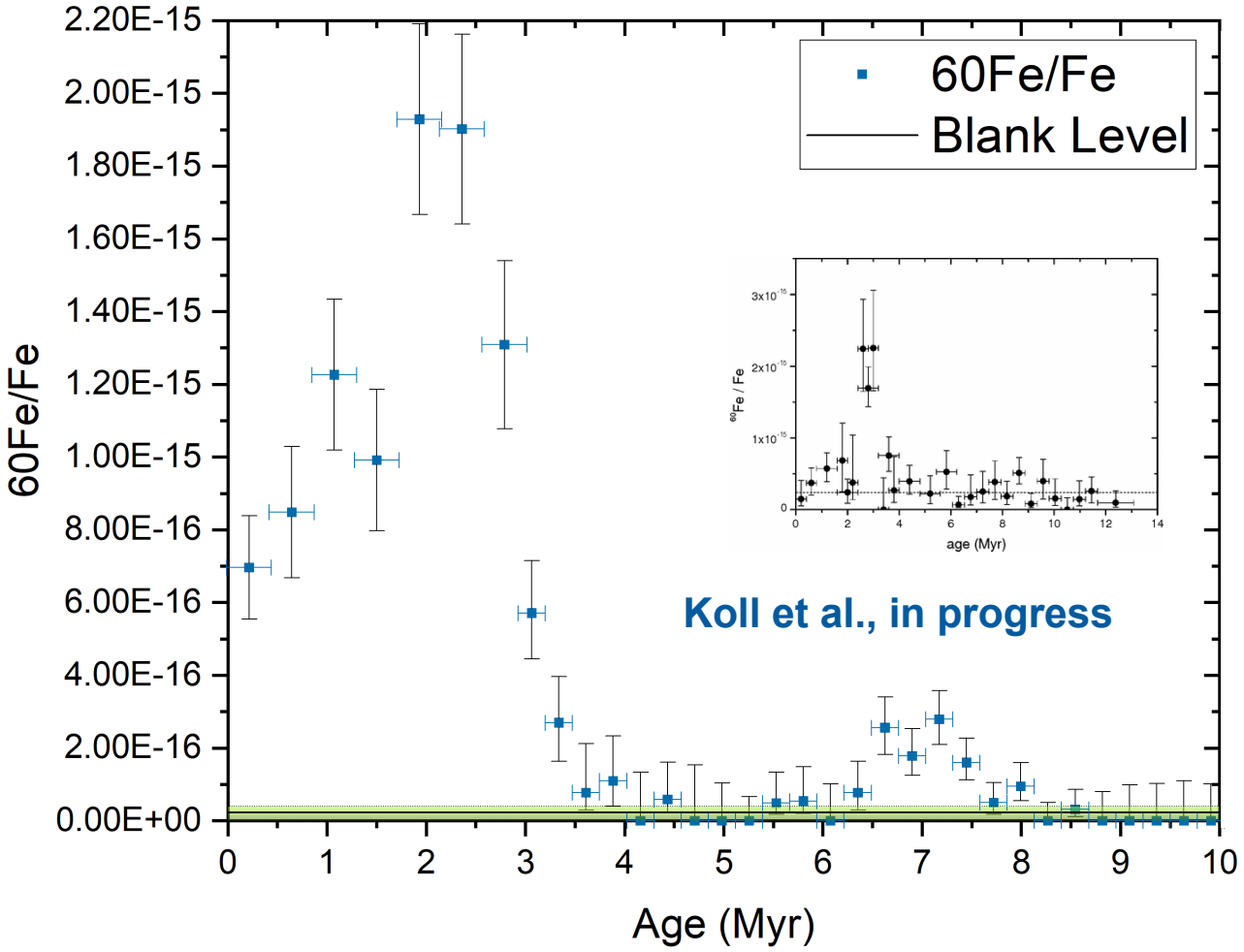
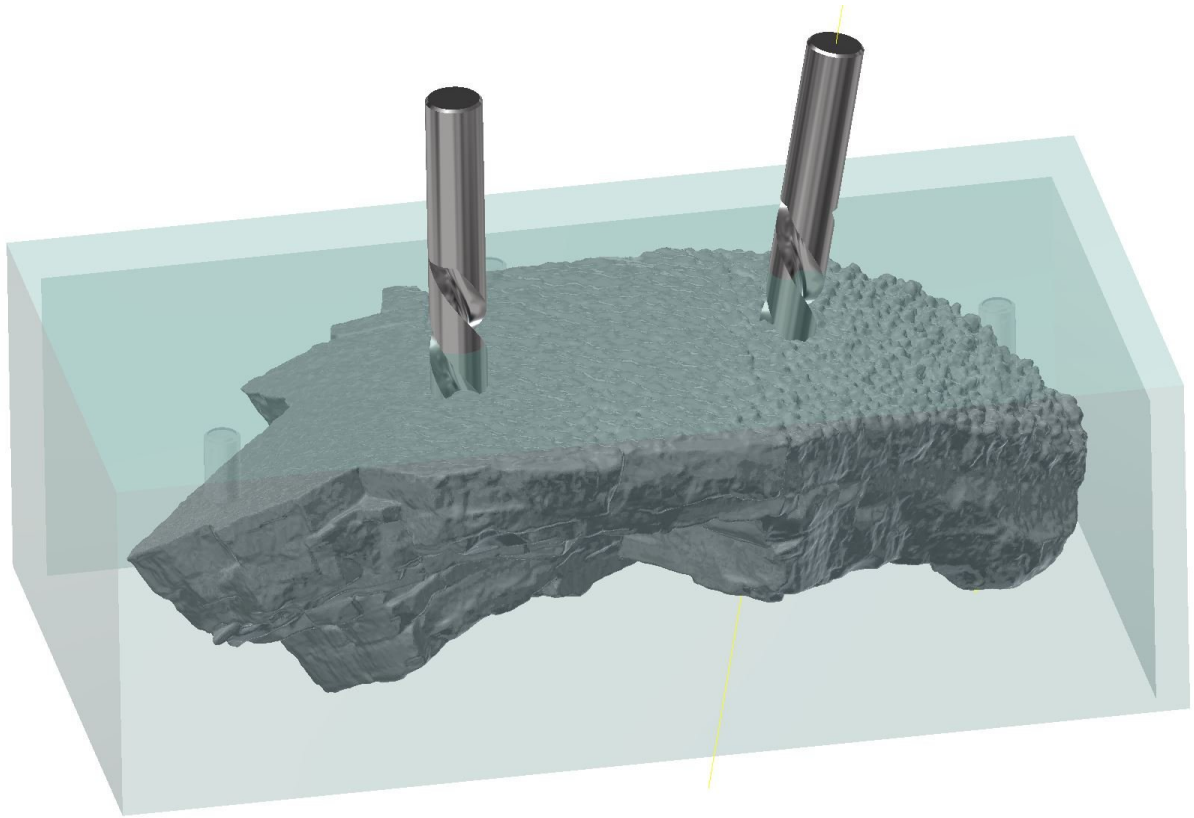
Fe-60 profile at ANU





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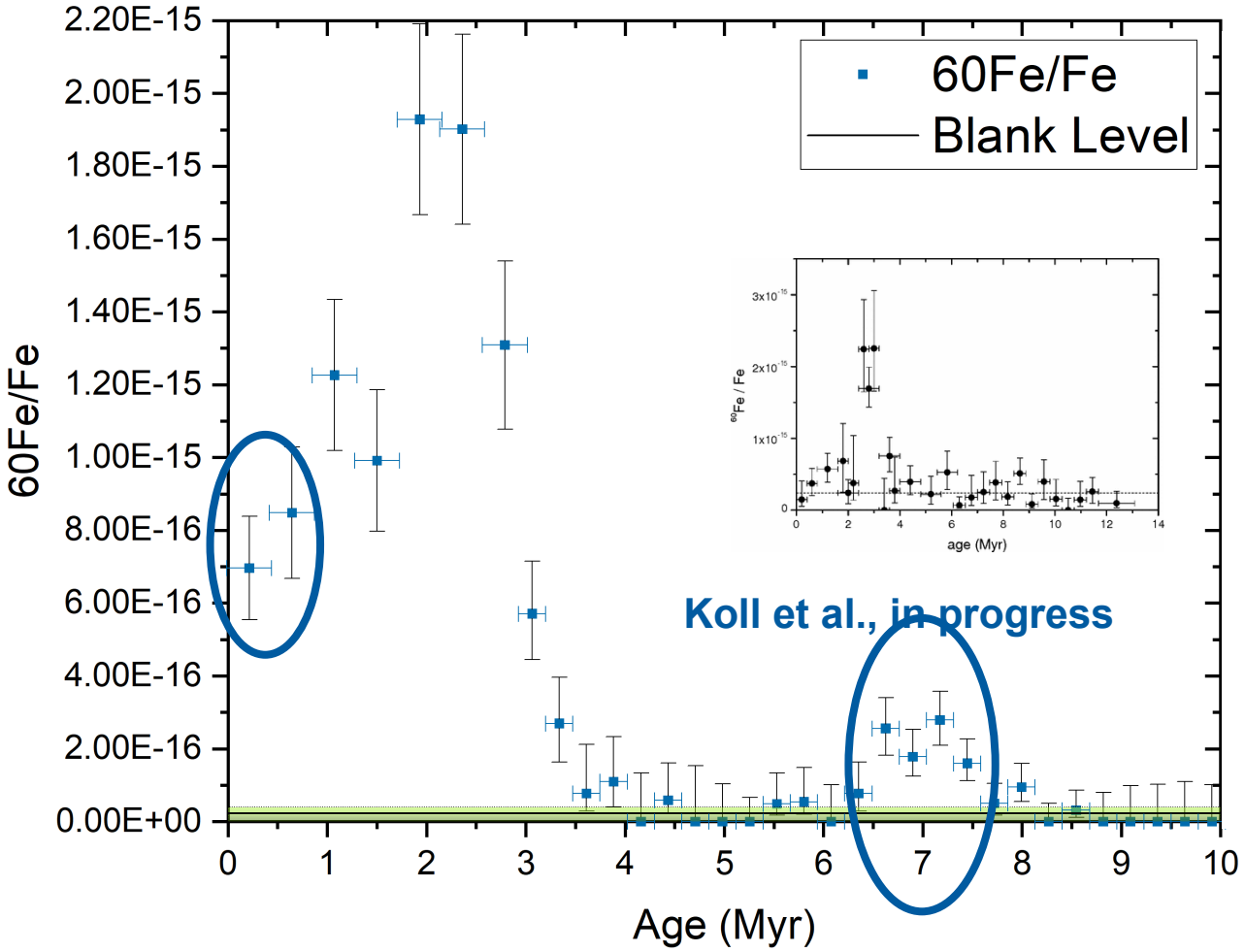

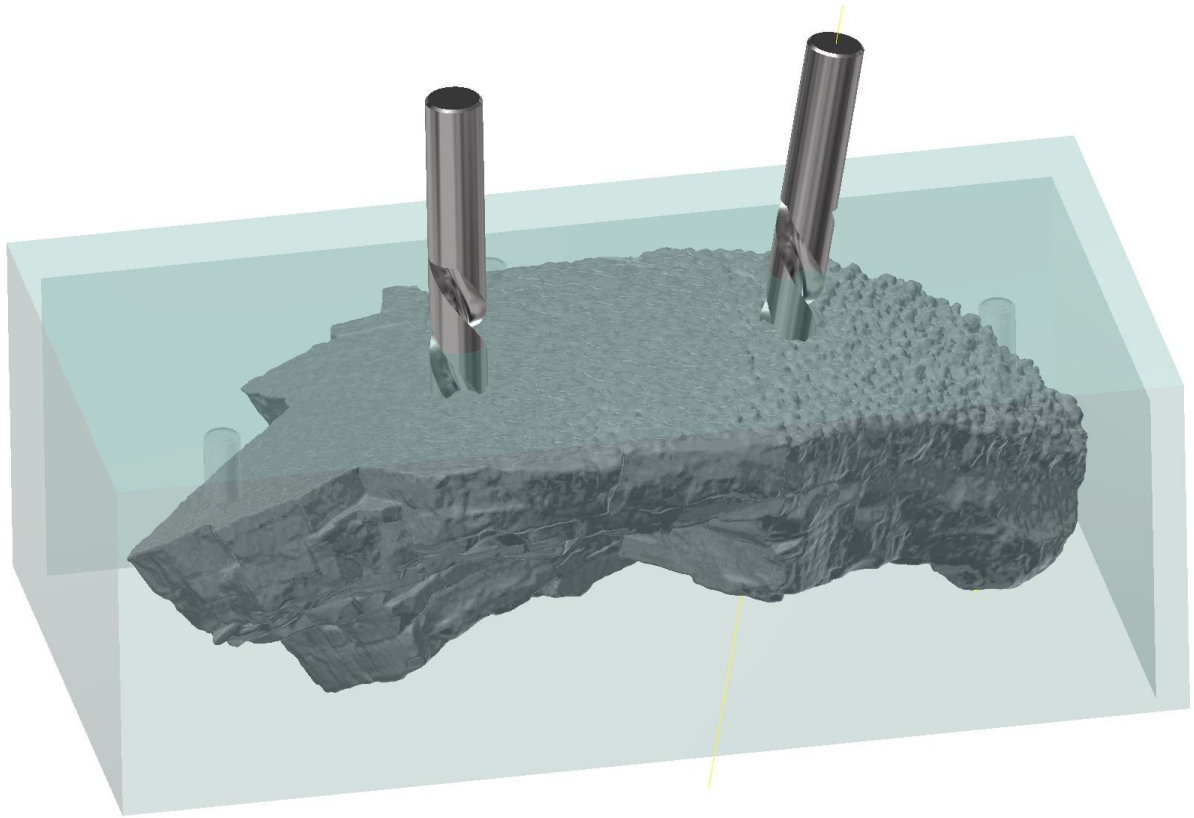

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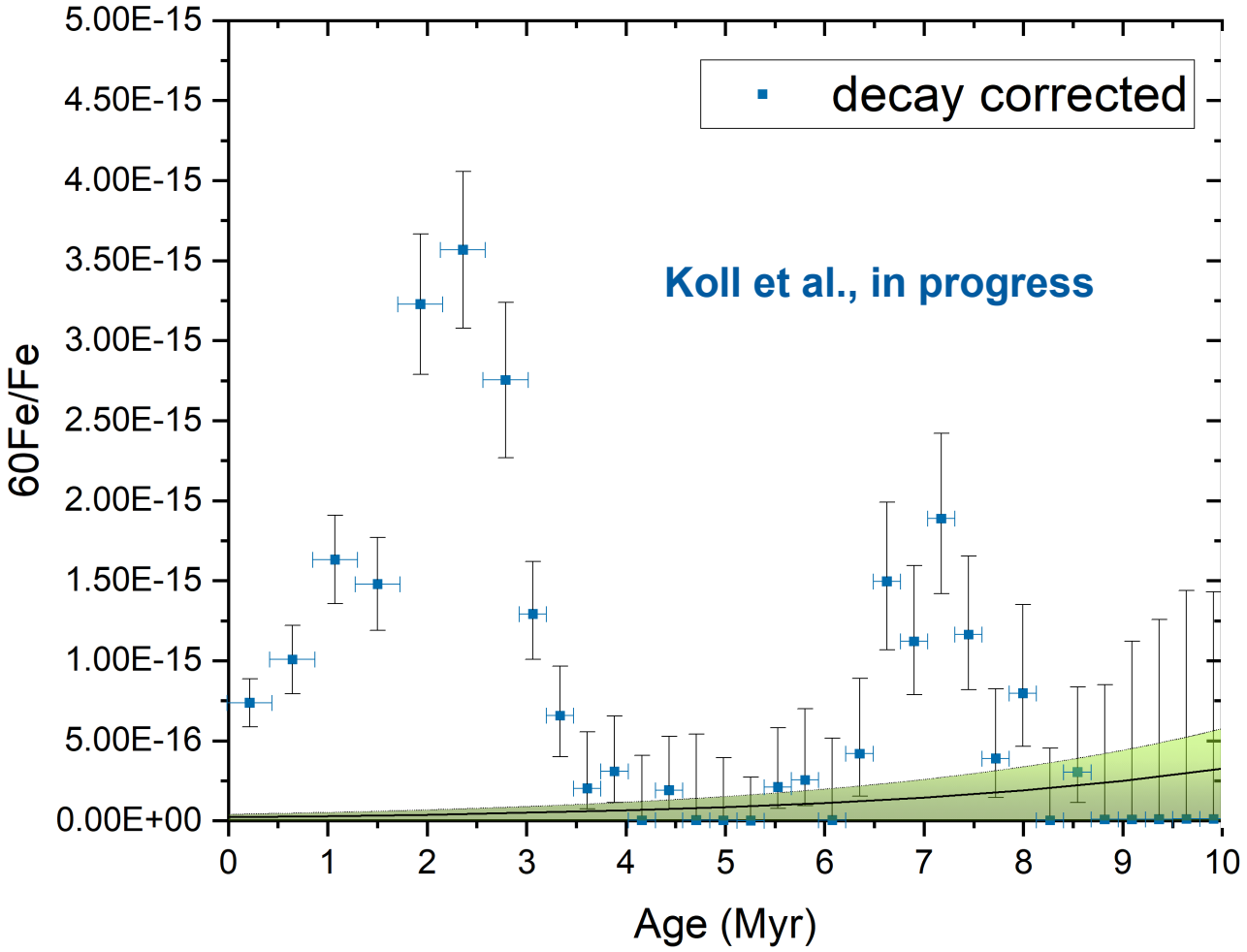

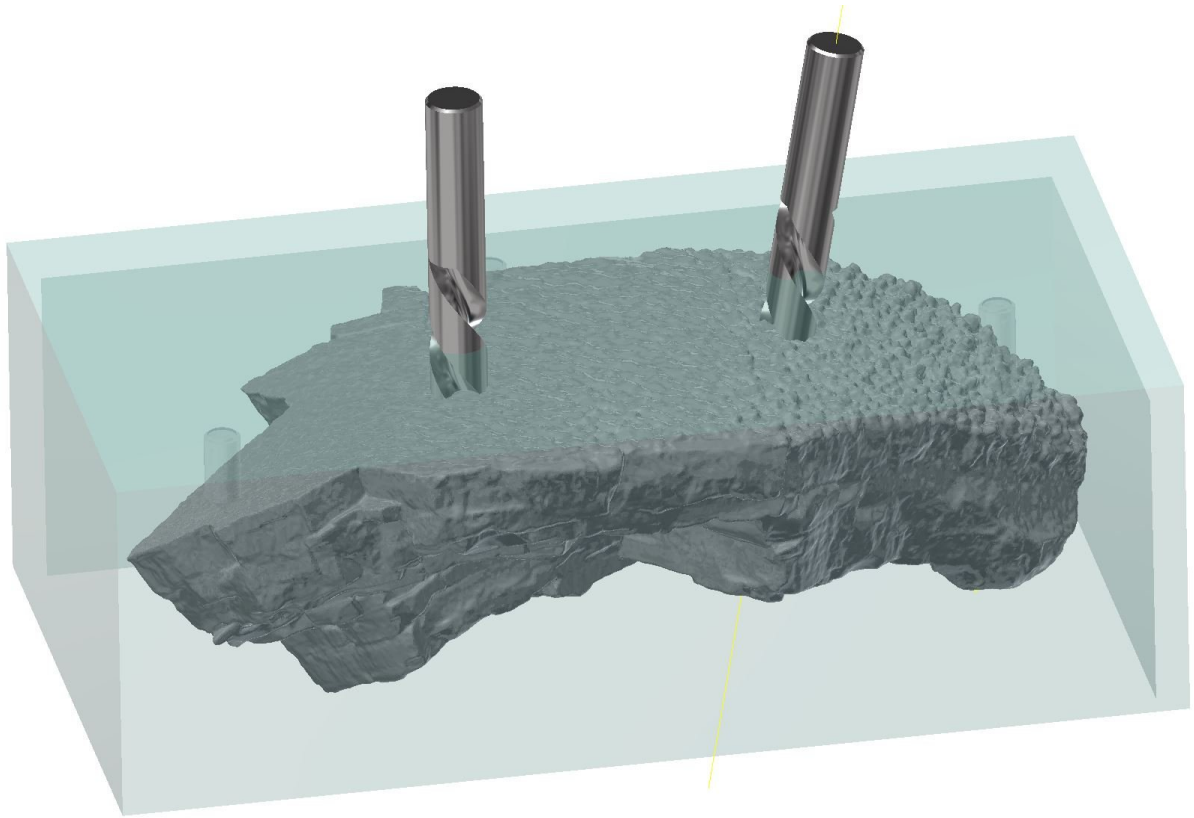

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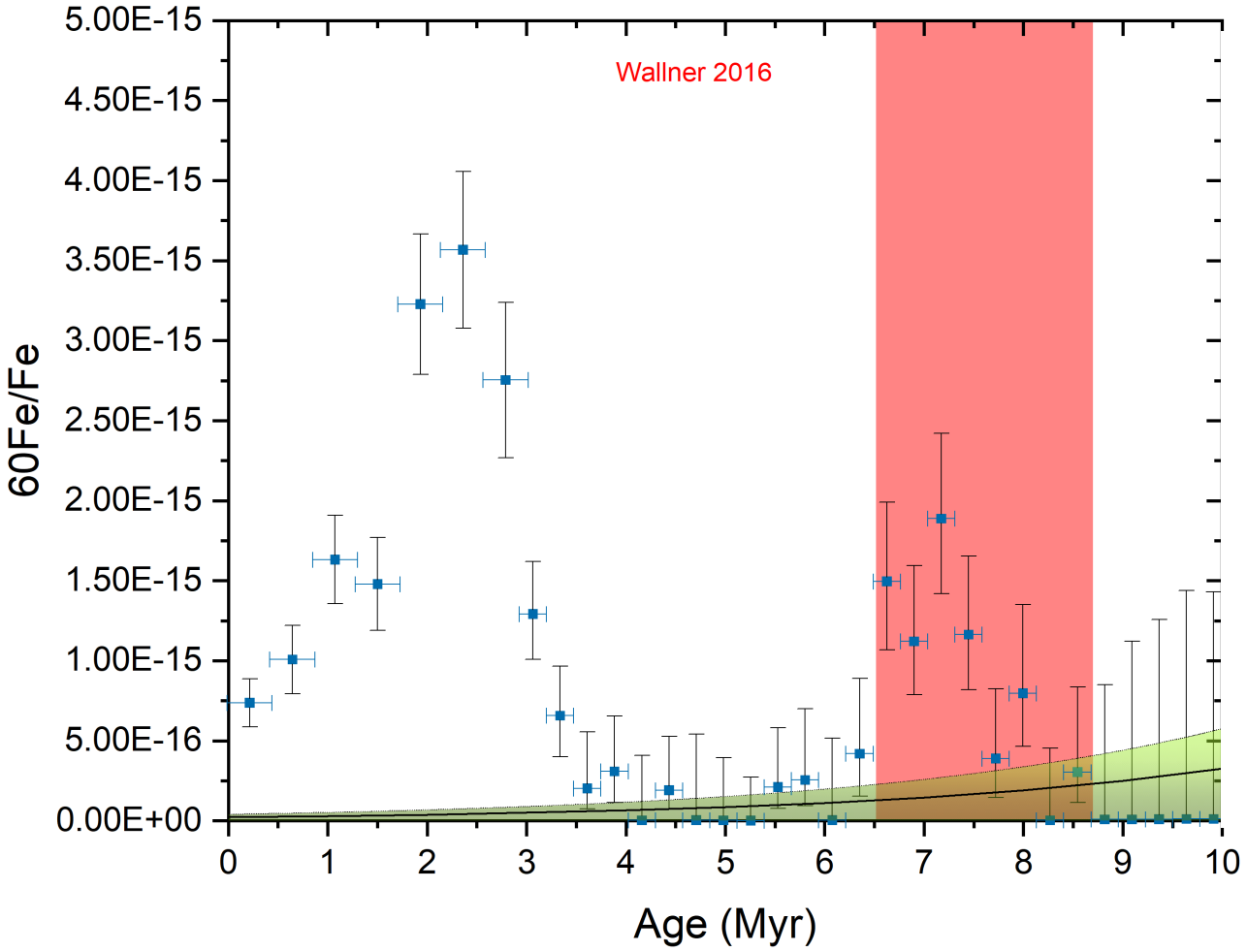
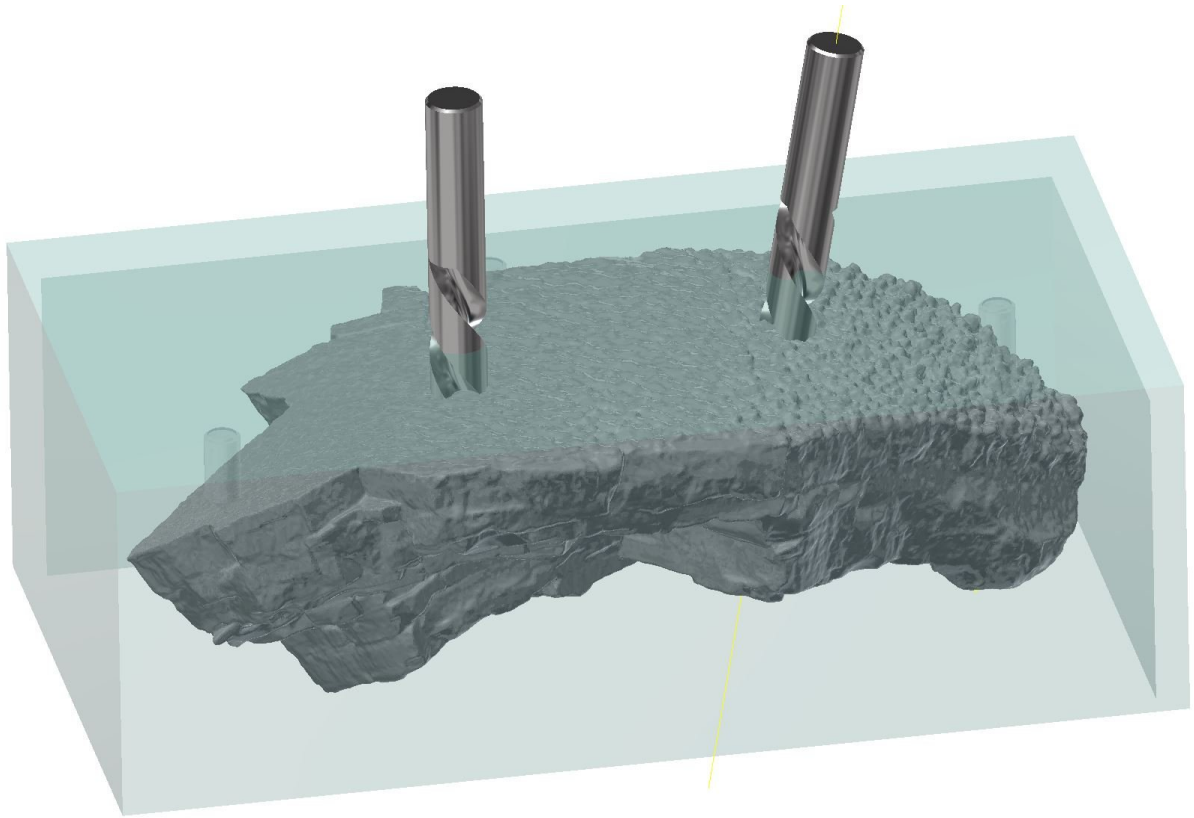
Fe-60 2nd peak





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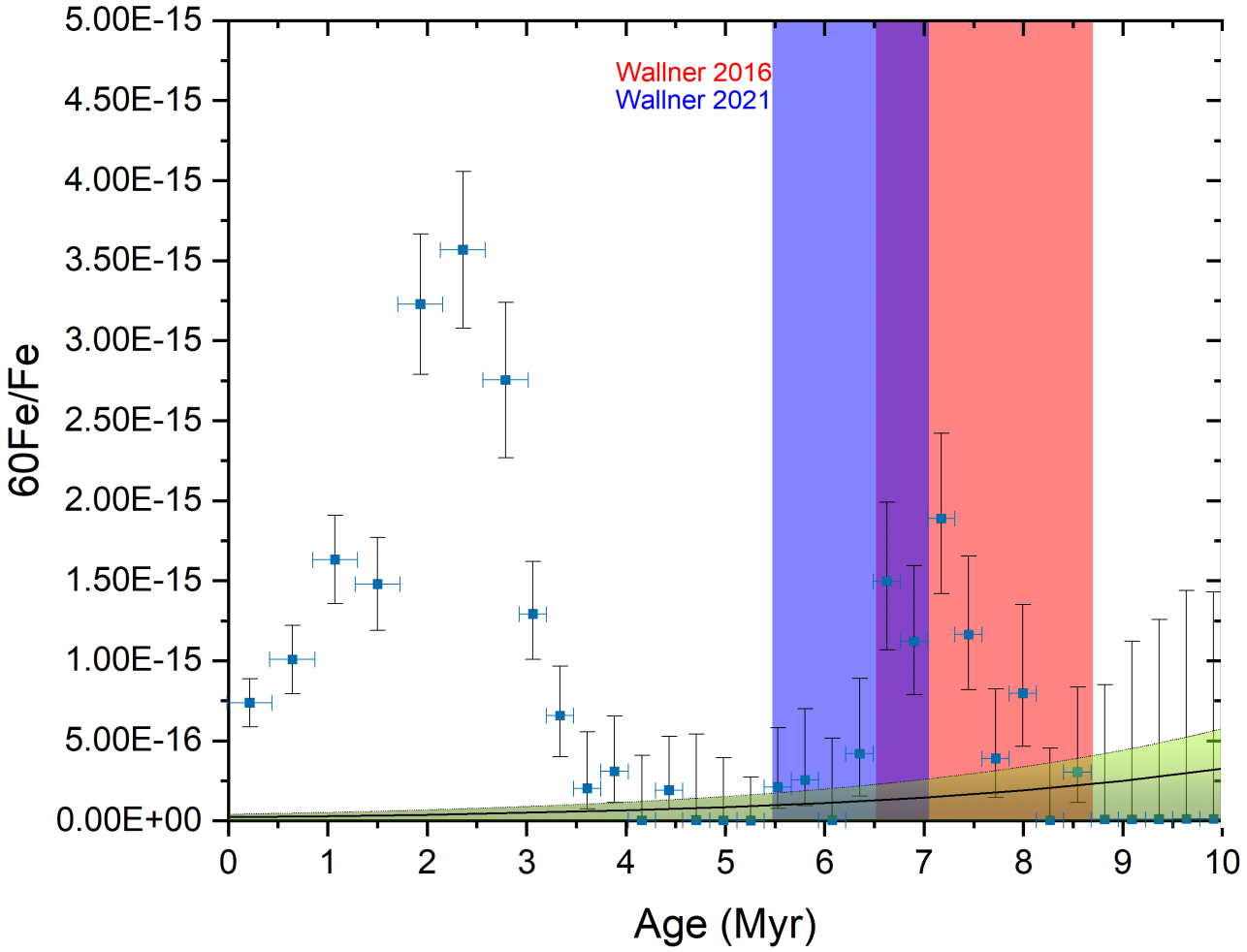

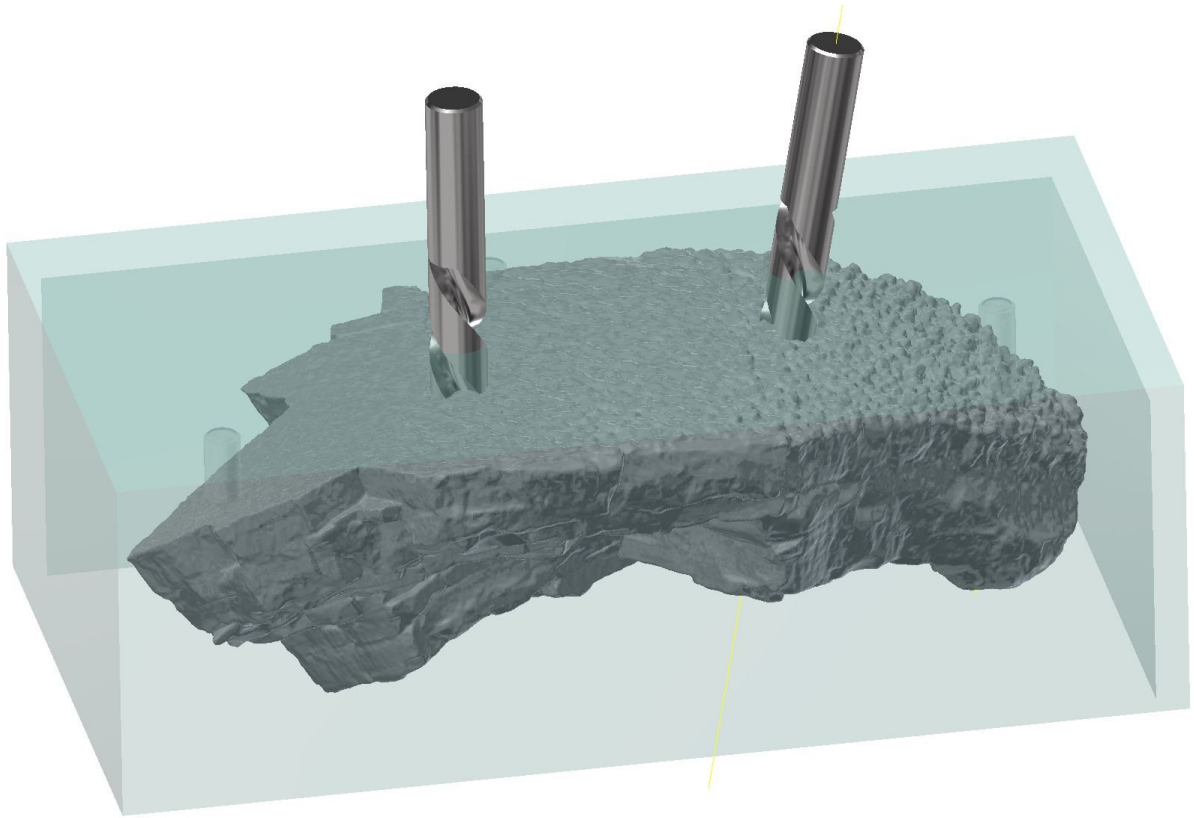

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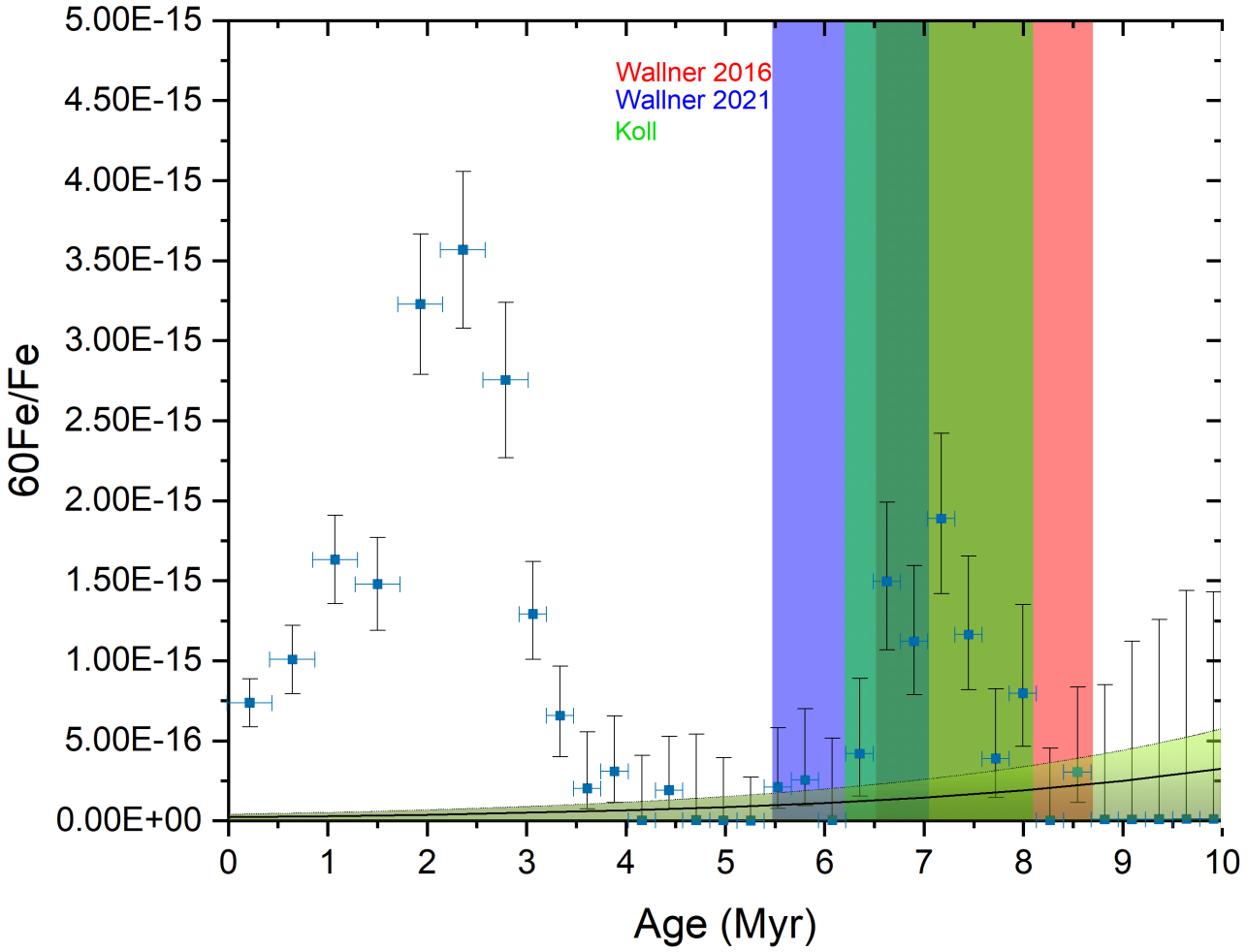
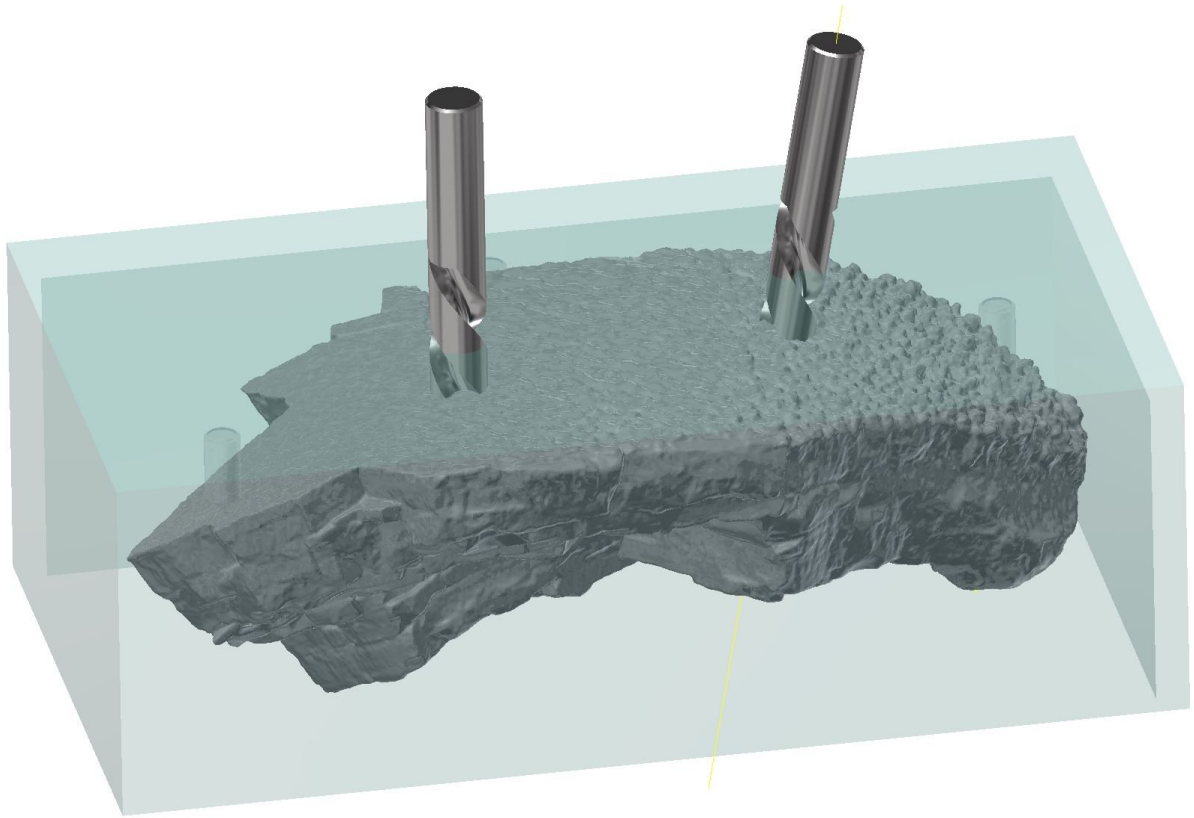


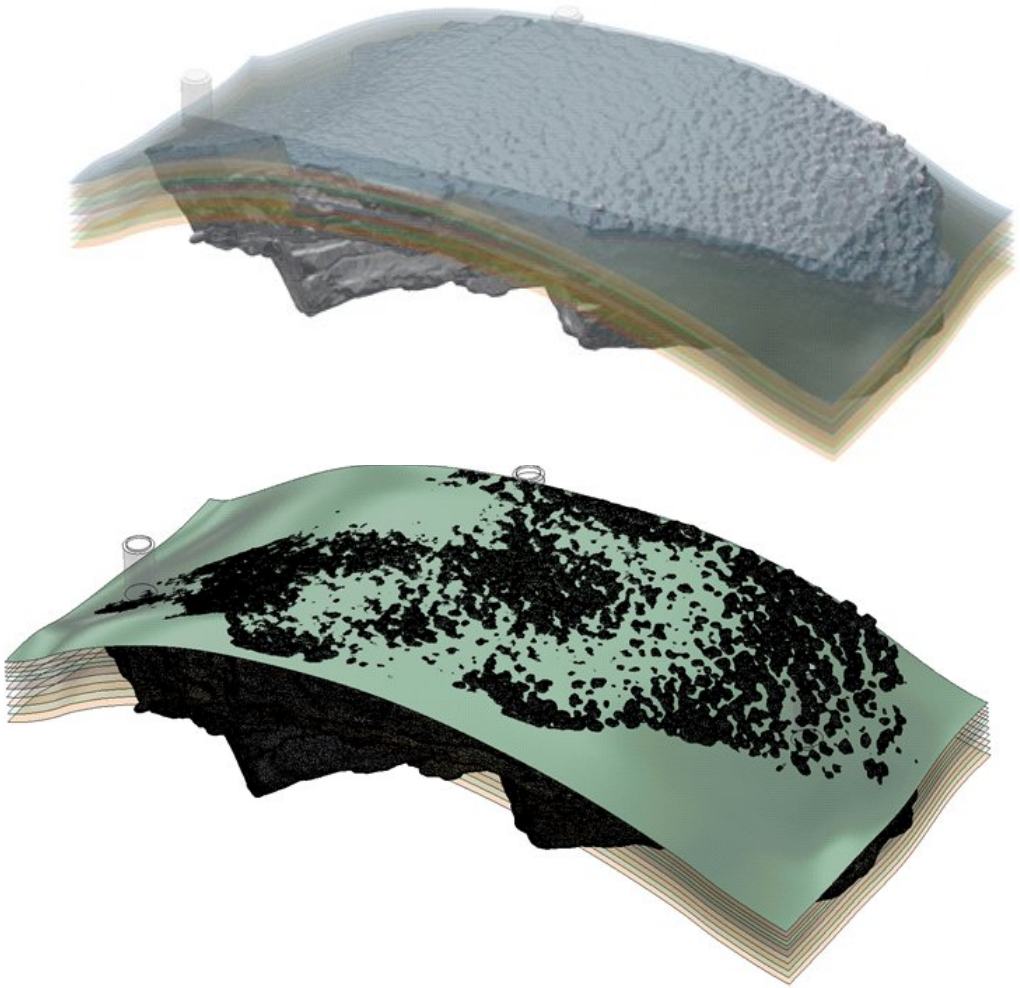


10 Myr time profile of Fe-60 and Pu-244

Pu-244 outlook

Measurements finished at VEGA

- **Time resolution 1 Myr**
- **ε_{Pu} = 1: 100 at**
- **Lower Pu-244 compared to Wallner 2021**
- **Confirm previous results, differences between samples**
- **PRELIMINARY:**
  Pu-244 follows Fe-60 for first peak
  BUT unexpected older influx pattern



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Outlook

- Analysis of Pu-244 data, measurements to confirm
- Further dating of drill cores into 10 Myr – 15 Myr region (up to 10 x $t_{1/2}$)
- Chemistry development for Cm-247 in same sample
- Chemistry development for Hf-182, lead by University of Vienna, ILIAMS
- New samples for Pu-244 investigations:
  Sediments/ice for less diffusion and full uptake, crusts for statistics, lunar for nuke free integral over more than 100 Myr

DRESDEN concept

Thanks to

A. Stuchbery, S. Battisson, M. Hartnett, L. K. Fifield, M. B. Fröhlich, S. Pavetich, Z. Slavkovska, S. G. Tims

A. Wallner, J. Lachner, S. Merchel, G. Rugel, R. Ziegenrücker

M. A. Hotchkis, D. Child

Australian National University

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ANSTO Science. Ingenuity. Sustainability.

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Wallner et al., Science 372 (2021)

AINSE

RADIATE

NCRIS National Research Infrastructure for Australia

AINSE Funding:
AINSE PGRA

ANSTO Proposals:
#AP12793
#AP12193

ARC Funding:
DP18100495
DP18100496

Radiate Proposals:
#21002421-ST
#20002142-ST