ECT* Workshop on Neutron-Capture Reactions for Astrophysical Processes

Measurement on the reaction rate on Fe59(n,g) in RIBLL

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Trento， Italy

Outline

1, r-process
  -CEJSNe scenario

2, measurement of $^{59}Fe(n,\gamma)$ reaction
  -facility & detector
  -reaction rate

3, $^{60}Fe/^{26}Al$
  -observation
  -model calculation

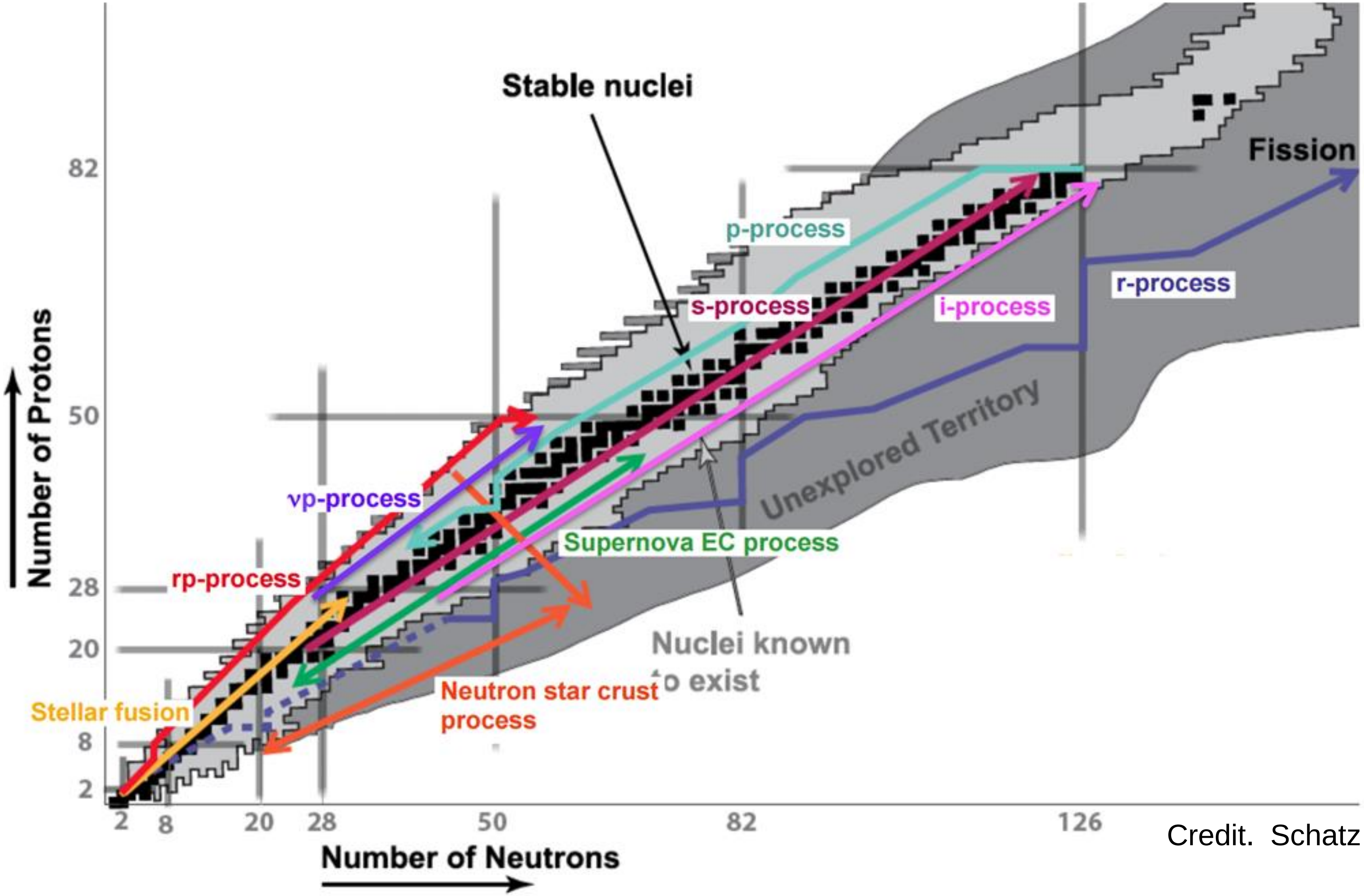
Nucleosynthesis process

N-deficient side:

- rp-process
- P-process aka γ process
  - p-nuclide ^{74}Se-^{196}Hg
- ν p-process:
  - ^{92,94}Mo ^{96,98}Ru

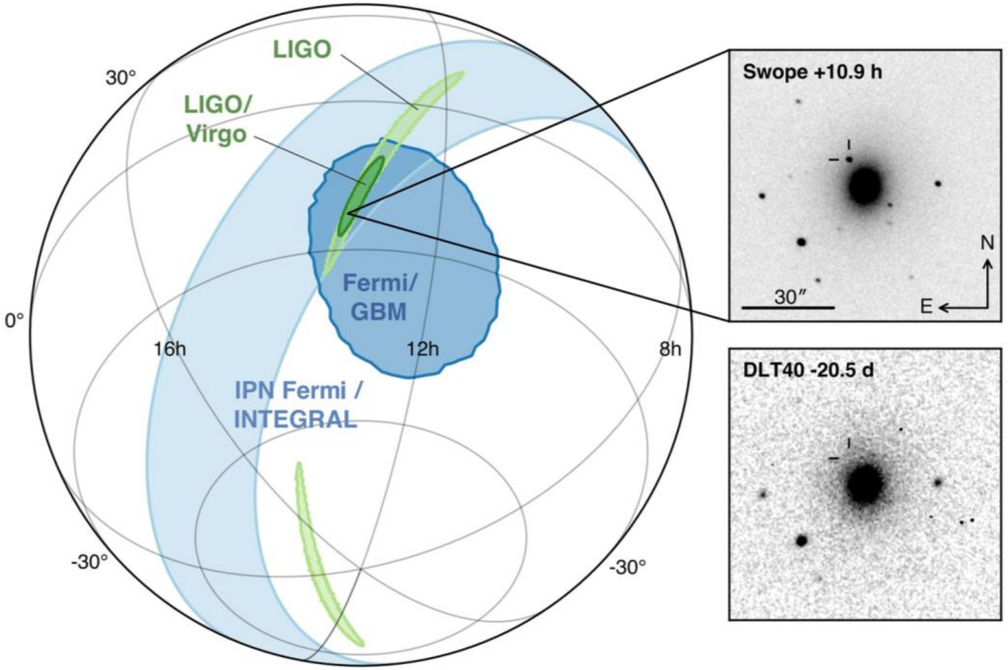
N-rich side:

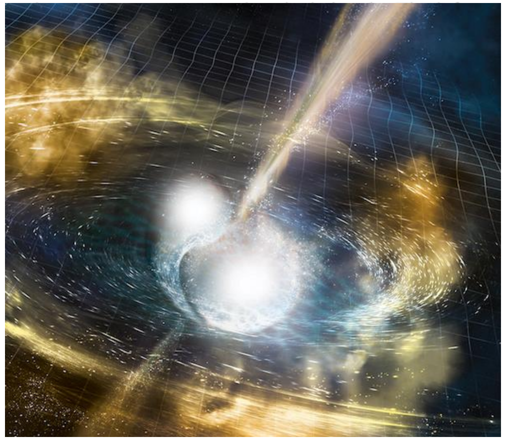
- s-process:
  - -slow (n,g) fast β decay
  - -AGB
  - -weak, strong/main
  - -half, stable valley
- r-process:
  - -fast (n,g) slow β decay
  - -sites?
  - -weak, strong/main
  - -half drip line
- i-process
  - -CEMP r/s



Credit. Schatz

r-process





Neutron Star Merger
GW170817
2017/8/17

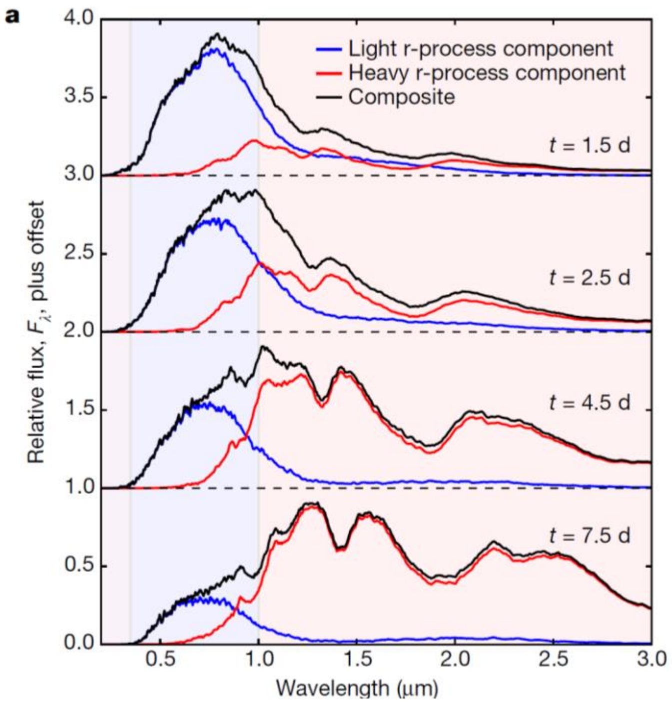
-GW LIGO/VIRGO
Abbot et al,2017

-Afterglow AT 2017gfo
Arcavi et al,2017

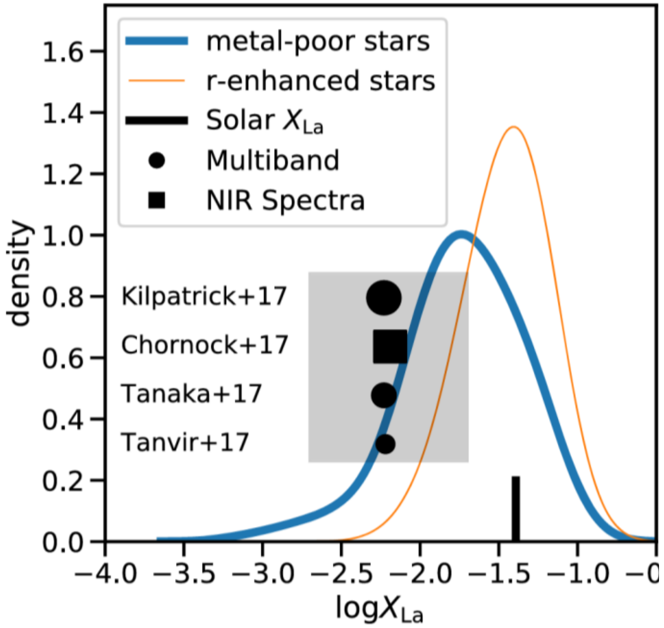
-Lanthanides
Kasen et al. 2017

-Sr
Watson et al. 2019

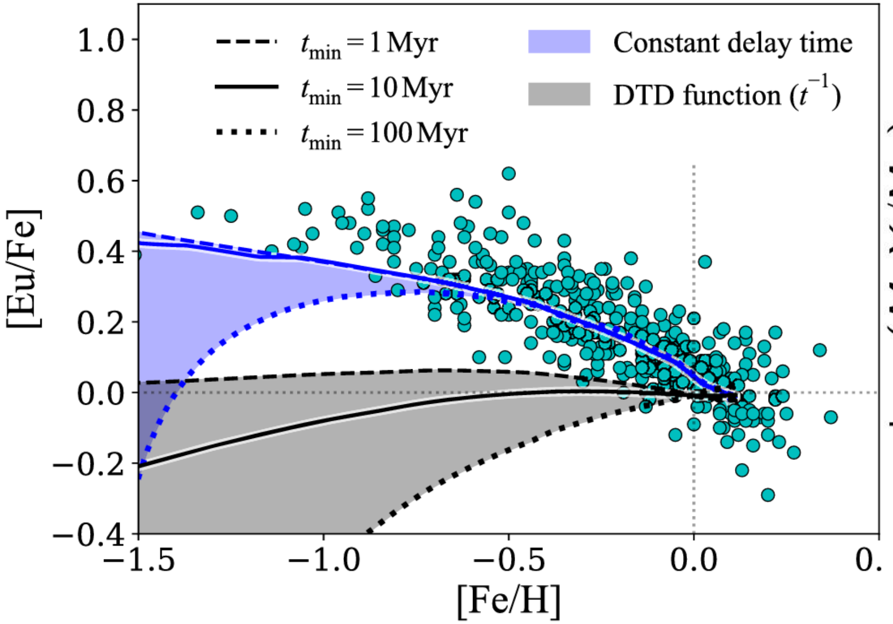
-^{191}Os, ^{234}Th 74days later
Kasliwal et al. 2019



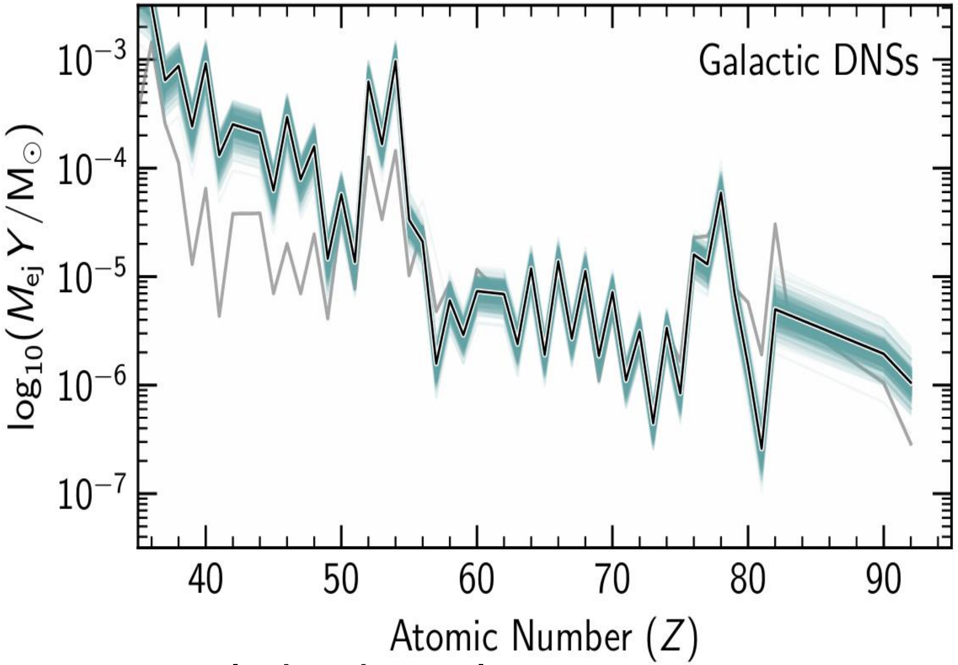
r-process



Ji et al. 2019
insufficient La

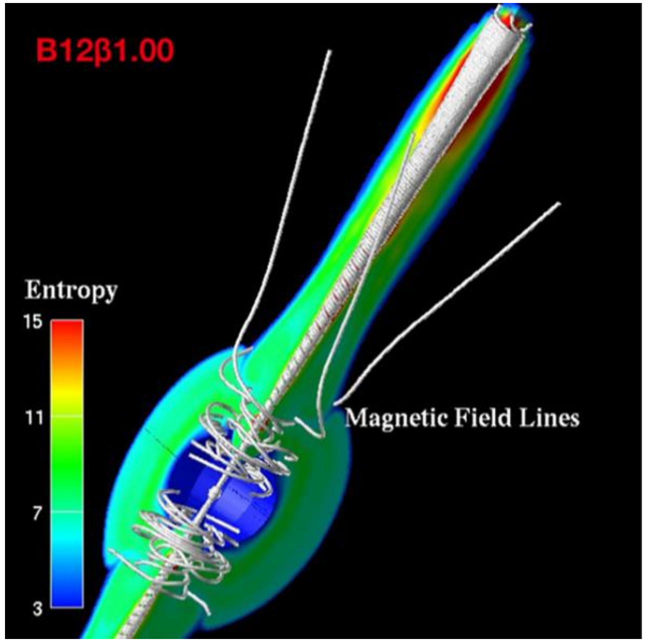


Côté et al. 2019
Inconsistent with [Eu/Fe]

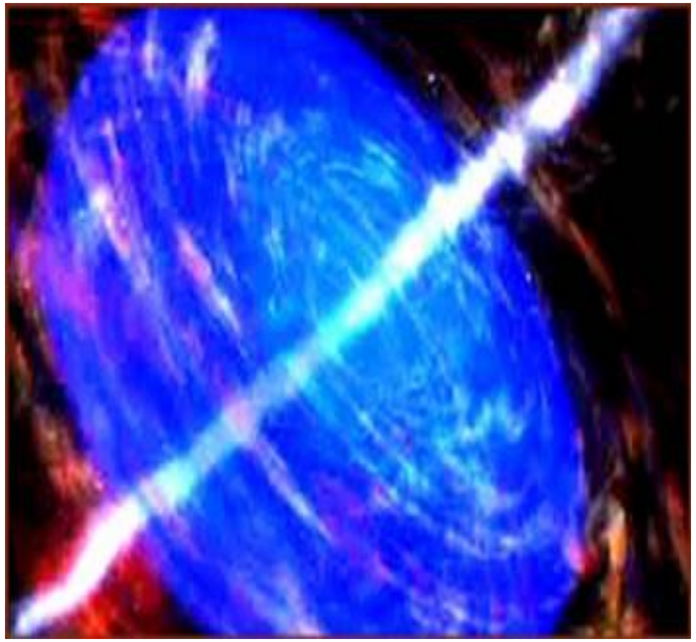


Holmbeck et al. 2023
Data of DNS, weaker than solar

r-process



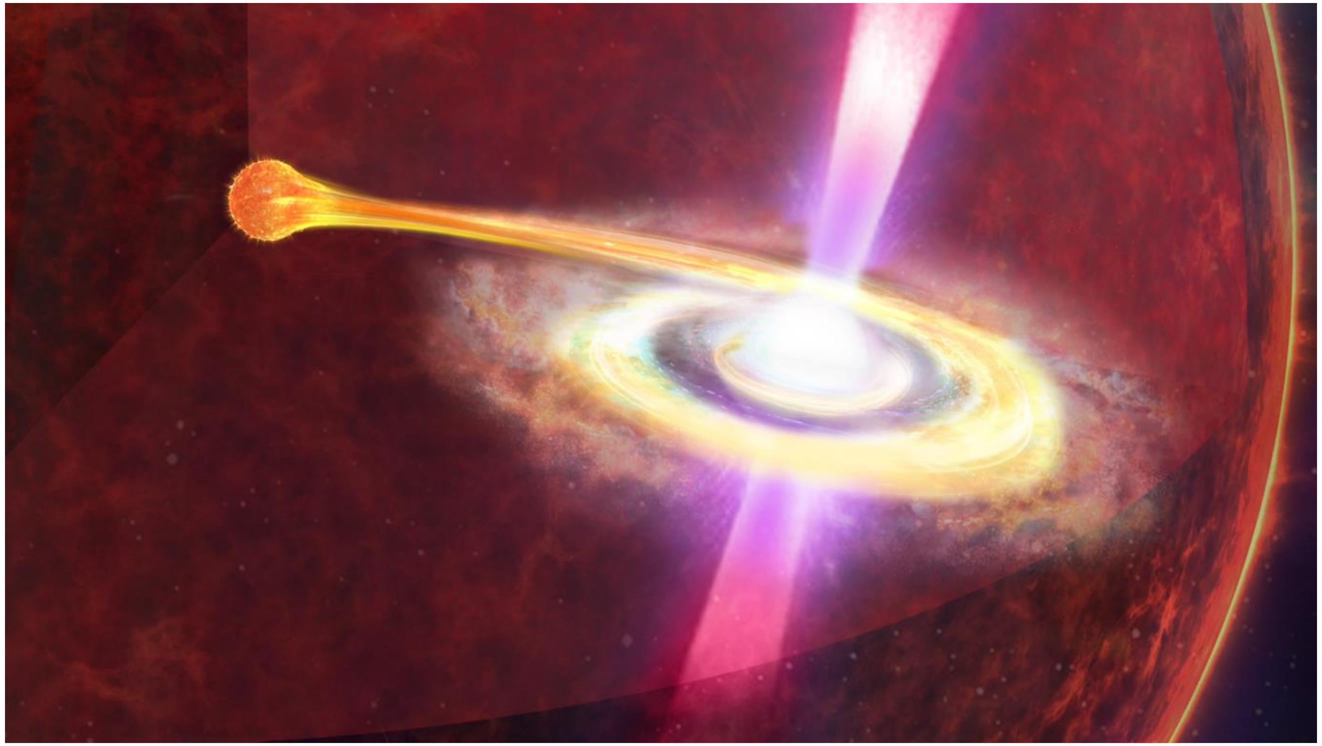
Magneto HydroDynamics Supernovae



Collapsar

The sites of r-process remain open

Common Envelop Jet Supernova ➡



Common Envelope Jet Supernovae

-death of two stars

-RSG and NS

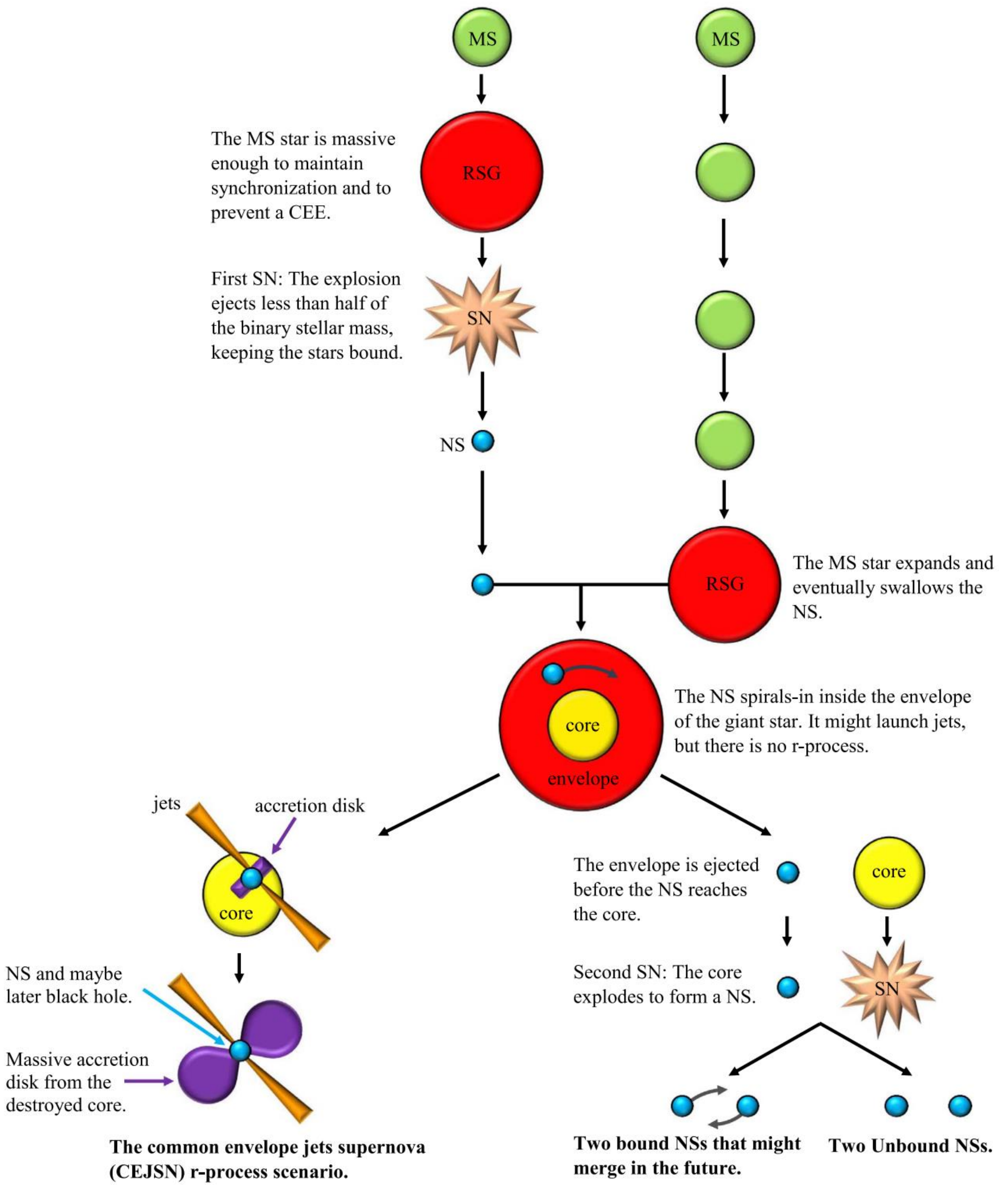
-RSG swallows NS

-Ns spirals in core

-accretion disk formed

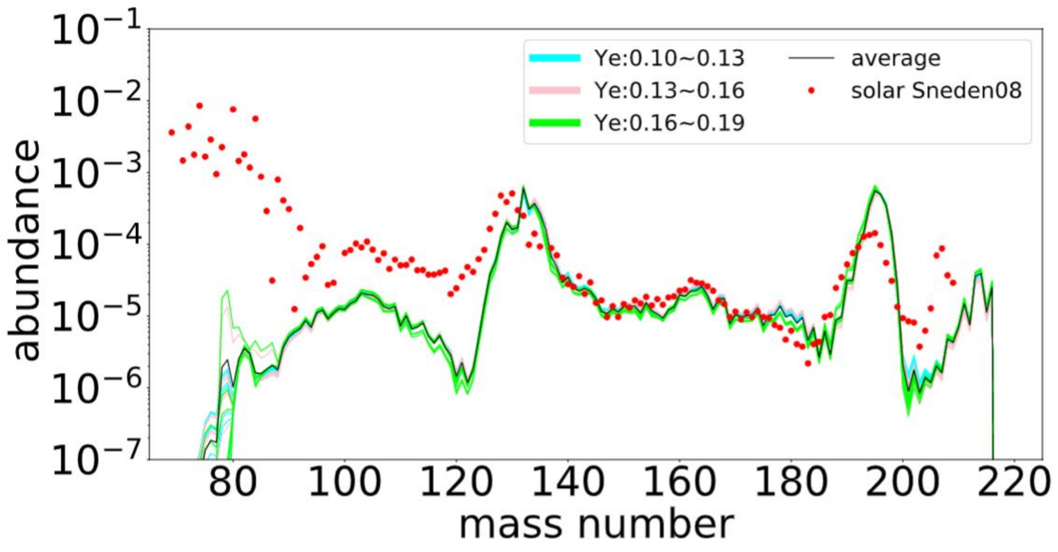
-core destroried

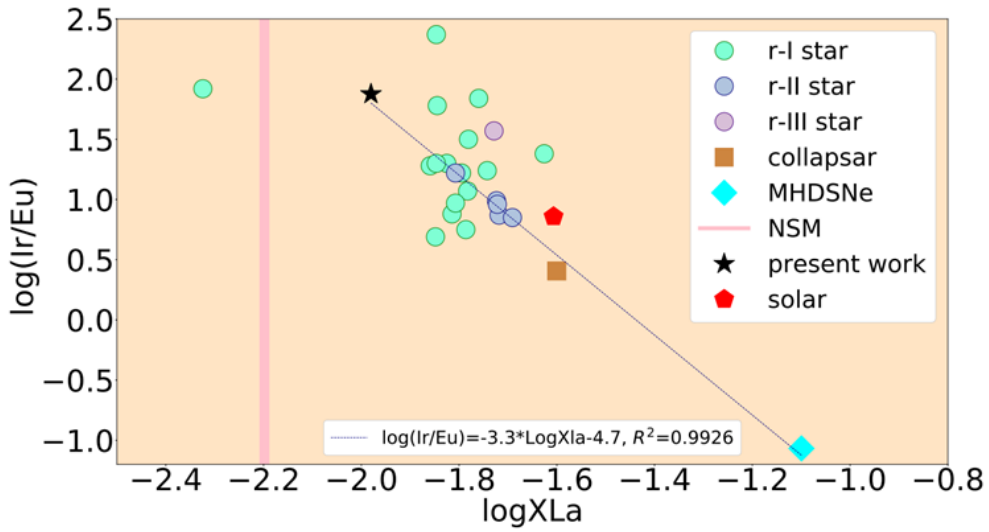
-bipolar jet



Credit by Soker

CEJ-SNe



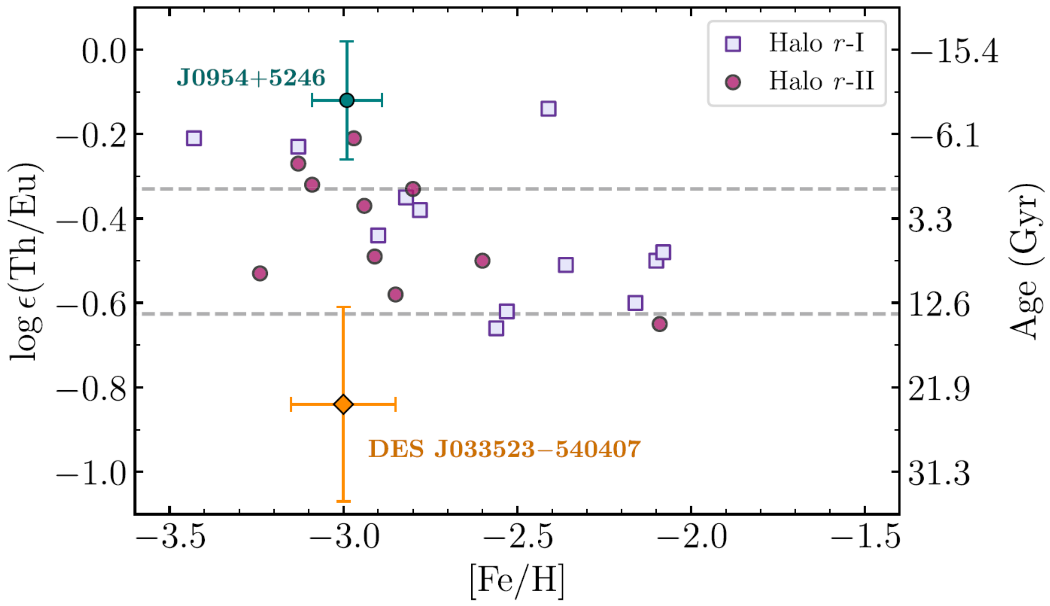


- New density function
- Favor A>140
- Agreement with La
- Strong 3rd peak

- Define log(Ir/Eu) VS La
- Explain r-enhanced stars
- Anti-correlation of Lanthanides and the third peak

JIN & Soker, ApJ, 971(2024)189

The Astrophysical Journal Letters, 859:L24 (6pp), 2018 June 1



$$\tau = 46.7 \times [\log(\mathrm{Th/Eu})_0 - \log(\mathrm{Th/Eu})_*] \text{ Gyr},$$

Using the production ratios from Schatz et al. (2002), the Th/U age is 13.0 ± 4.7 Gyr, commensurate with its low metallicity. Uncertainties on the age contain only the measured abundance uncertainty and do not include those on the production ratios. The $\boxed{\text{Th/Eu}}$ and U/Eu ages are $\boxed{-9.5 \text{ Gyr}}$ and 5.8 Gyr, respectively. These ages can be made to agree with the Th/U age of 13.0 Gyr by boosting the initial production ratios of thorium and uranium by a factor of 3.1.

Age by CEJSNe: 11.09Gyr

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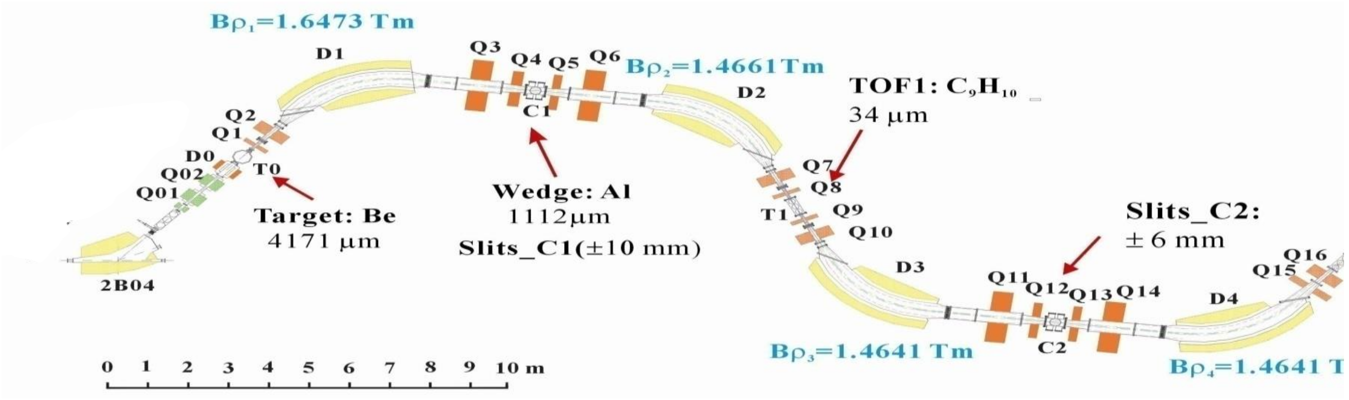
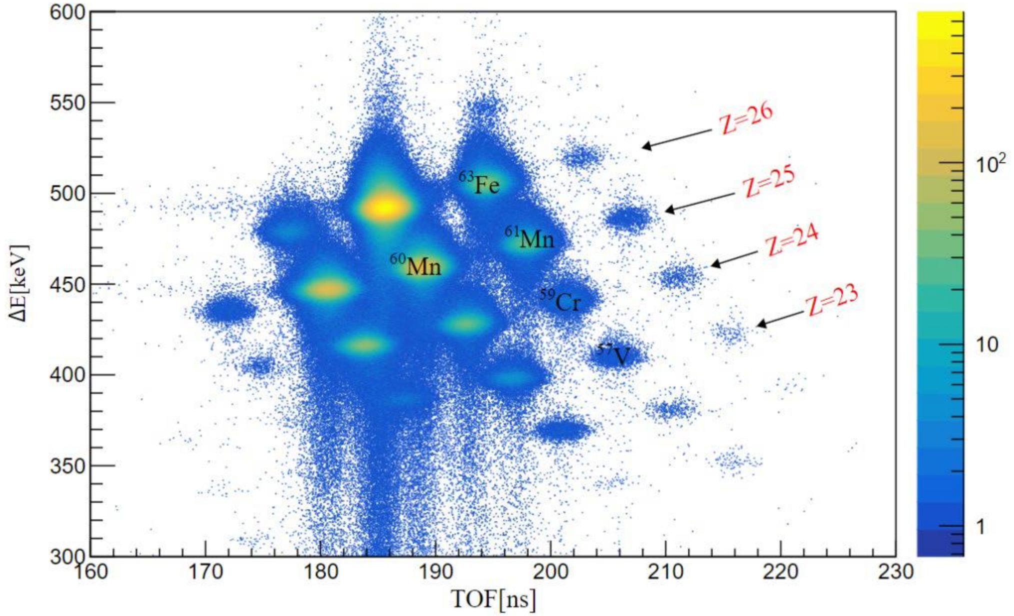
Heavy Ion Research Facility in Lanzhou (HIRFL)

^{59}Fe(n,γ): Experimental setup

Radioactive Ion Beam Line in Lanzhou (RIBLL)



- Primary Beam: ^{64}Ni@60MeV/u
- Fast Beam(PF): ^{60}Mn
  ^{60}Mn $\xrightarrow{\beta decay}$ ^{60}Fe (NLD&γSF)
- Intensity: ~1.2pps
- Purity: ~11%
- Beam time: ~200 hr

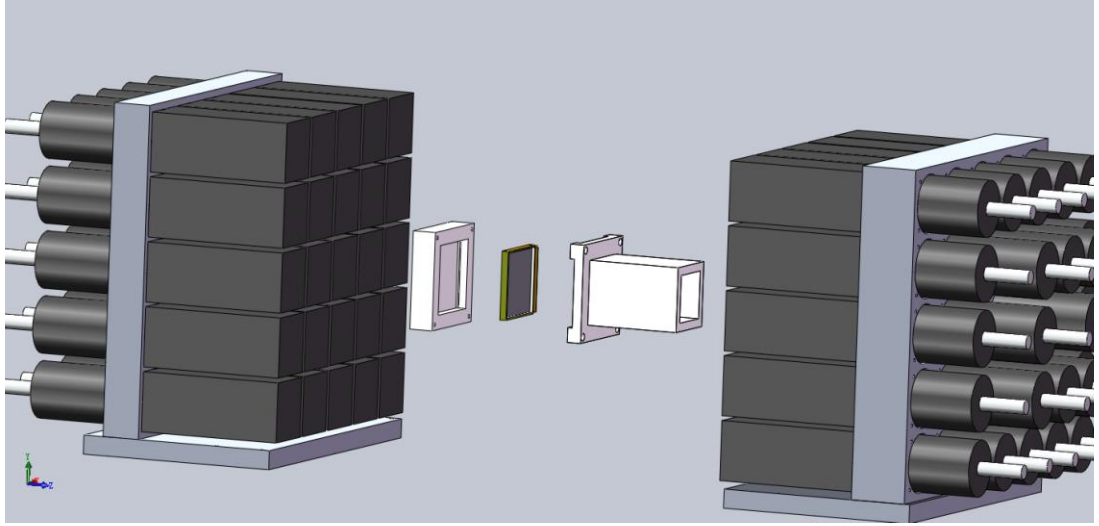


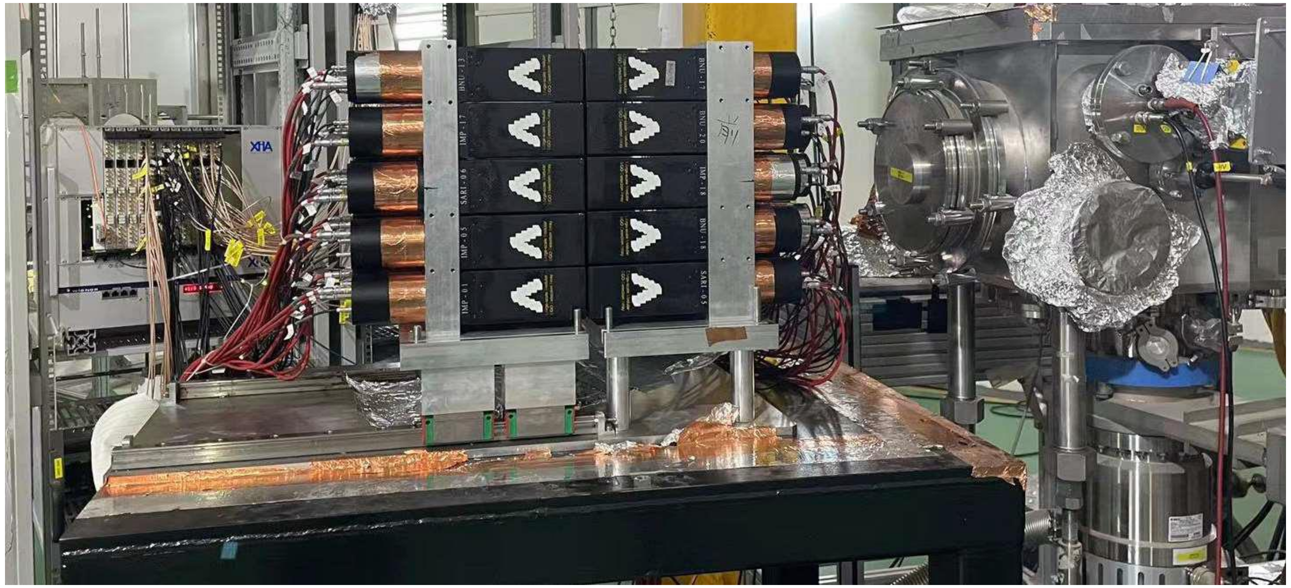
$^{59}Fe(n,\gamma)$: LAMBDA Detector

LAMBDA (LArge-scale Modular BGO Detector Array)

49 BGO modules

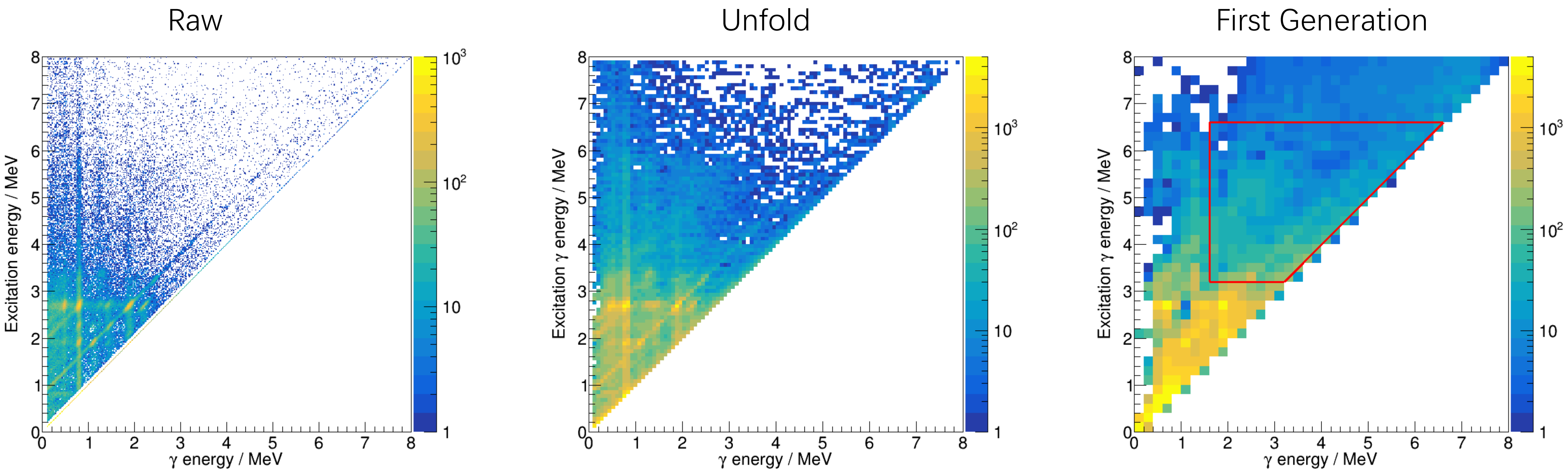
-Size:6cm×6cm×12cm
-Energy resolution: <9.7%@662keV
-Total efficiency: 90%@1MeV 80%@10MeV





$^{59}Fe(n,\gamma)$: data analysis

Summing γ VS individual γ

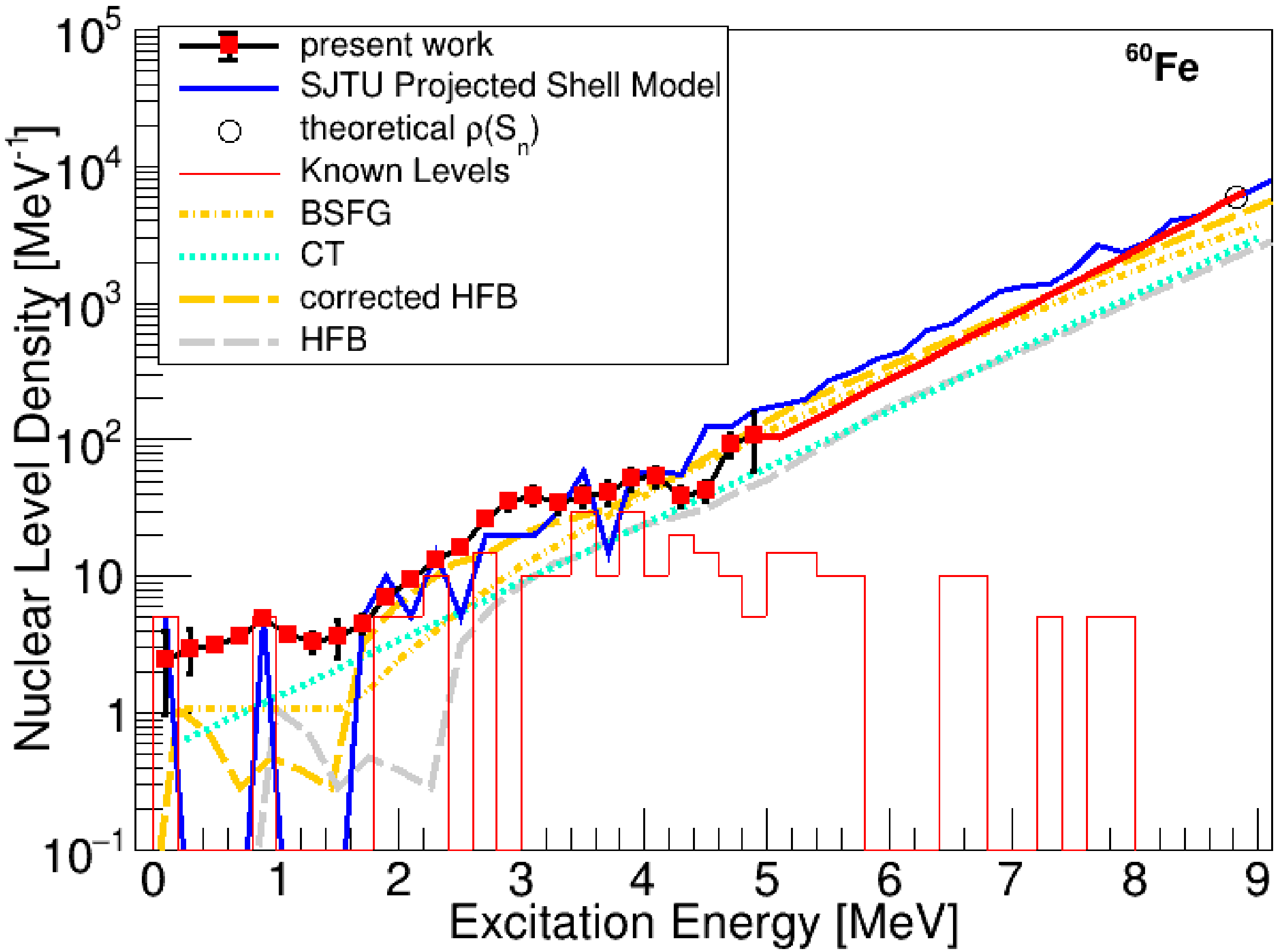


Response function

γ source: ^{60}Co, ^{133}Ba, ^{152}Eu

6.793MeV γ from $^{14}N(p,\gamma)^{15}O$ experiment

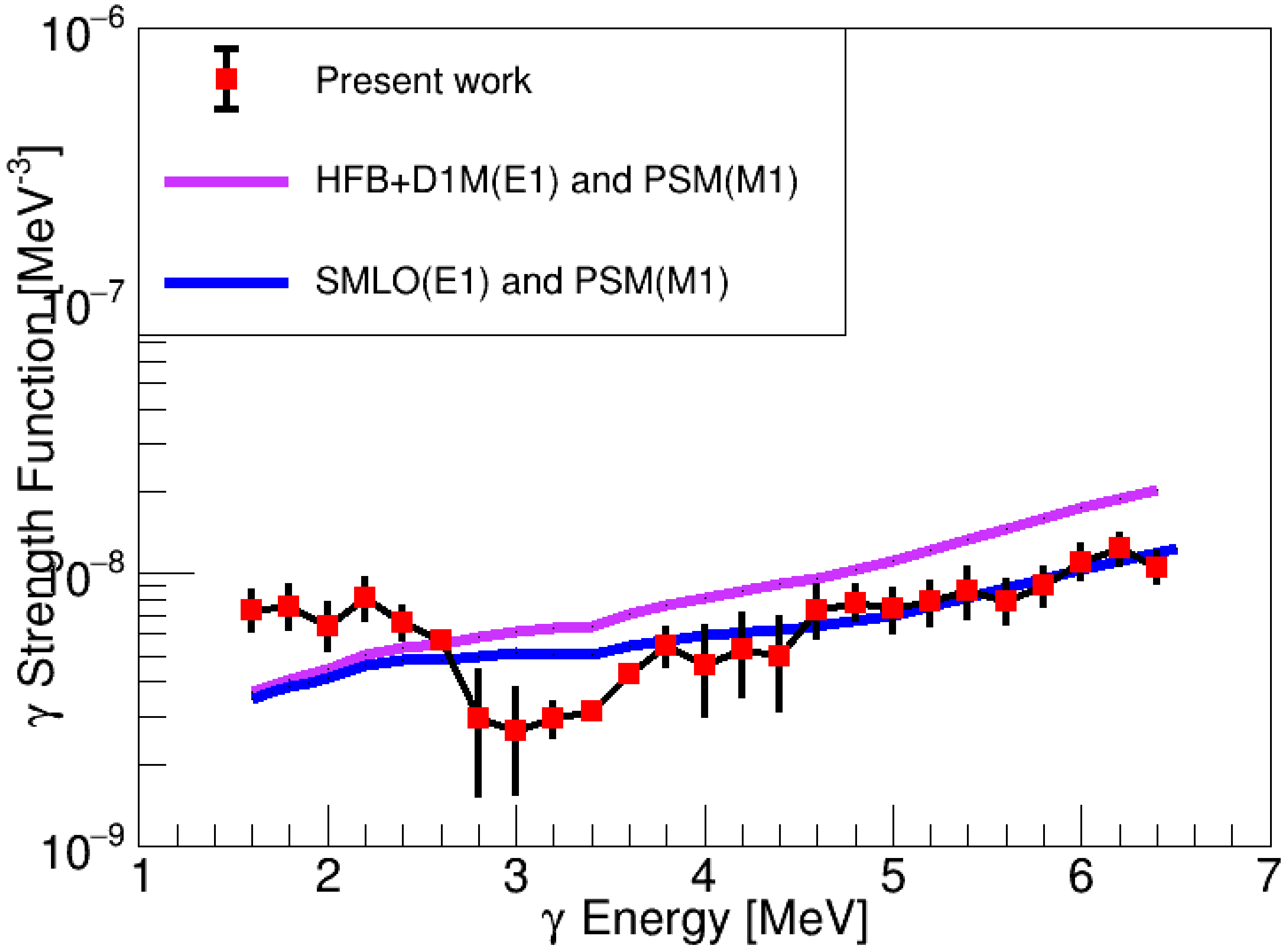
$^{59}Fe(n,\gamma)$: nuclear level density



Sn from Projected Shell Model: detail in Sun's talk

code ompy

$^{59}Fe(n,\gamma)$: gamma strength function



E1: HFB+D1m & SMLO
M1:Projected Shell Model
Chen's talk

code ompy

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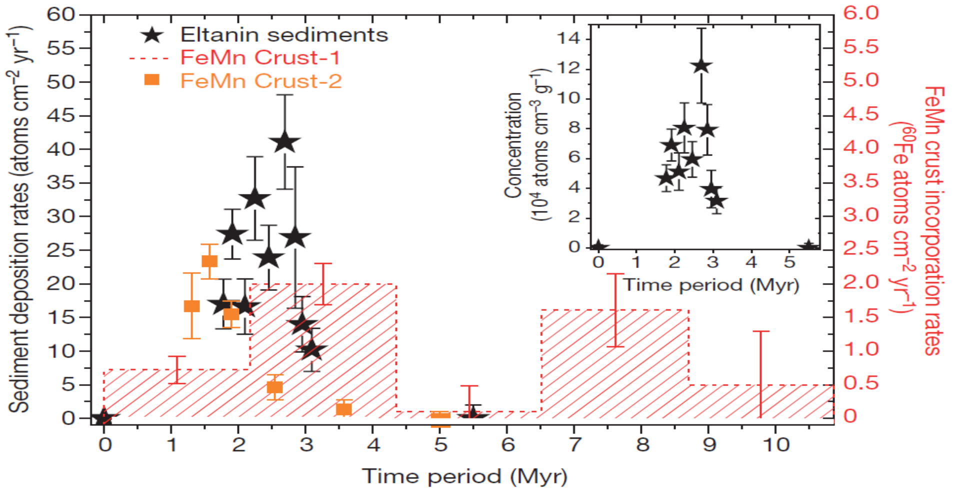
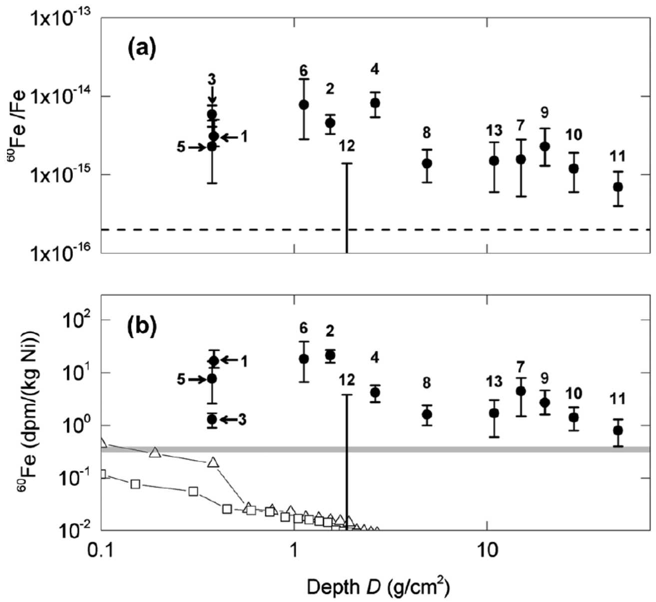
$^{60}Fe/^{26}Al$: observation

^{60}Fe $T_{1/2}$: 2.6My ^{26}Al $T_{1/2}$: 0.7My

Records of recent nucleosynthesis



^{60}Fe found in sediments from Indian Ocean, Nature,71



^{60}Fe found in Moon from Apollo 16, PRL,151104

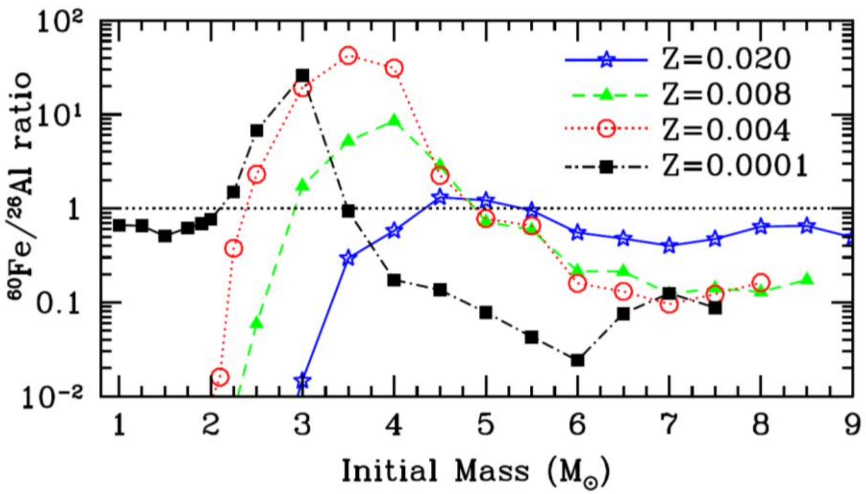
several observations have been made on $^{60}Fe/^{26}Al$

- -gamma-ray emission in our galaxy: 18.4%±4.2%, Wang+ ApJ, 2020
- -sediments from Indian Ocean: 18%(+15%,-10%), Feige+ PRL, 2018

$^{60}Fe/^{26}Al$: models

Two scenarios can produce 60Fe and 26Al at same time:

1, low and intermediate-mass AGB stars
  -highly depends on models
  -4 orders of magnitude



2, massive stars' core-collapse supernovae
  -both of them can be ejected in NDW
  -models over-predict such ratio by about a factor 3 to 10 (1Dmodel)

them in the Galaxy. Most massive star models over-predict such ratio by about a factor 3 to 10, (see, e.g. Woosley & Heger 2007; Sukhbold et al. 2016; Austin, West, & Heger 2017). However, there

due to less neutrons from the ^{22}Ne source, which would preferably capture protons than α particles. More investigations are needed, also comparing these 1D model results to current 3D supernova modelling.

PASA, 38, 602

$^{60}Fe/^{26}Al$: in nucleosynthesis

Run the evolution to obtain 60Fe/Al26

1 in CEJSNe
- -Al26 is not able to produce···

2 in 3D model of CCSNe
- -slightly neutron rich
- -ongoing

Summary

1, r-process

-Common Envelop Jet Supernova is significant scenario

2, measurement of $^{59}Fe(n,\gamma)$

-first experiment in China

-new rate less than REACLIB

3, $^{60}Fe/^{26}Al$

-in progress

New Facility-HIAF

-neutron rich unstable isotopes

-first beam commissioning on 10/28/25

-only spent one day for ion injection, acceleration and extraction

Acknowledgement

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