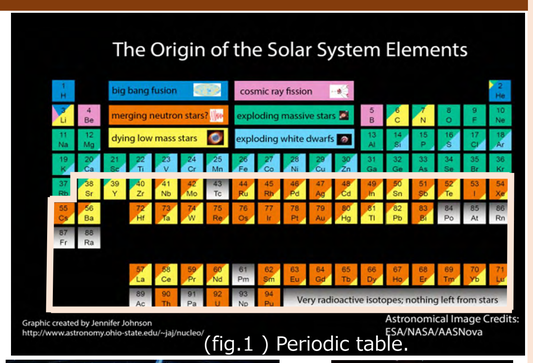
High-dispersion spectroscopic observations of stellar heavy elements, including Europium and Thorium

Kurumi Furutsuka, Satoshi Honda (University of Hyogo)
e-mail: furutsuka@nhao.jp

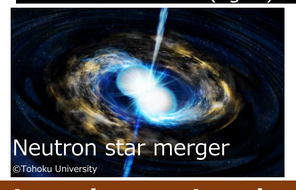
The origin of the r-process is a major matter of debate. We can discuss the origin of elements by observing stars of various metallicities and investigating their chemical abundances. We obtained the spectra of stars with -2 < [Fe/H] using Nayuta/MALLS, Gunma/GAOES, and Subaru/HDS (archived data; SMOKA), and estimated the Europium and Thorium abundances. In -2 < [Fe/H] < 0, there are a few actinide boost stars and [Th/Eu] scatter is less than [Fe/H] < -2. The actinide boost event might be rare or likely to occur in a metal-poor region.

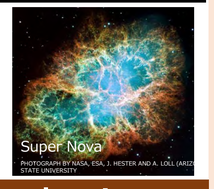
Origin of the elements

The origin of the **r-process**, which synthesizes elements with atomic numbers greater than **iron**, is a major matter of debate.
The detection of gravitational waves, along with photometric and spectroscopic observations, suggested neutron star merger synthesis of heavy elements (e.g., Tanaka et al., 2017).
On the other hand, the existence of other origins remains a subject of debate (e.g., Nishimura et al., 2015).



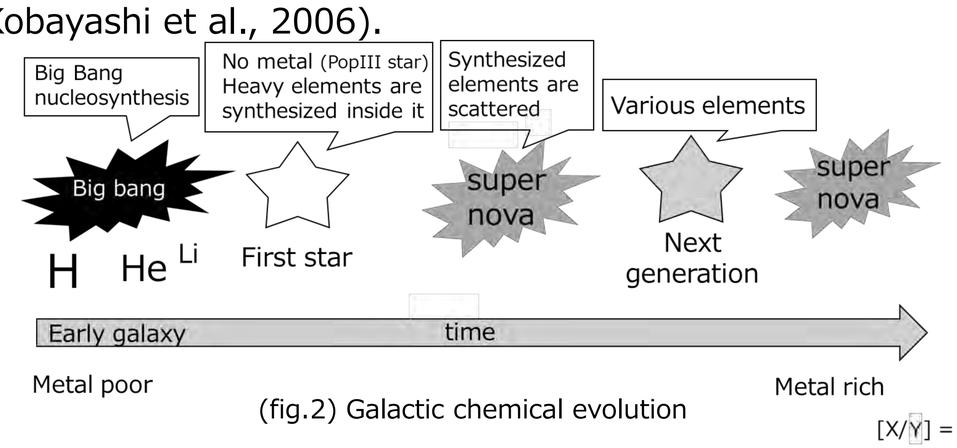
(fig.1) Periodic table.





Stellar abundances and galactic chemical evolution

To estimate the origin of elements, we investigate stellar abundances (e.g., Kobayashi et al., 2006).

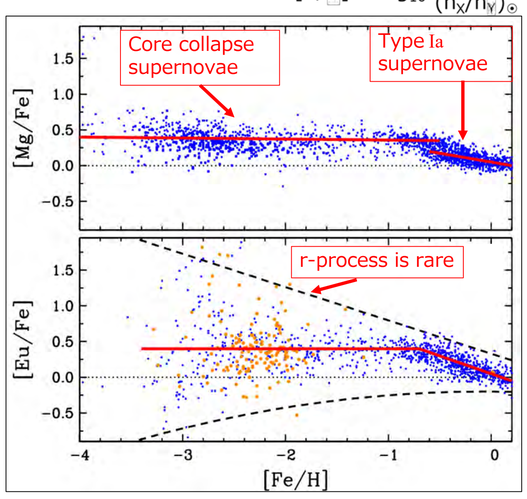


(fig.2) Galactic chemical evolution

$$[X/Y] = \log_{10}\frac{(n_X/n_Y)_{star}}{(n_X/n_Y)_{\odot}}$$

Top panel
[Fe/H] ≲ -1
Massive stars with short lifetimes cause CCSNe, which synthesize Fe, Mg.
-1 ≲ [Fe/H]
Low mass stars in a binary star system with long lifetimes cause Type Ia SNe, which increases Fe.

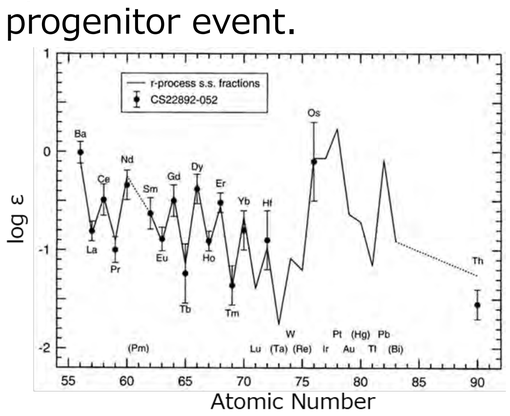
Bottom panel
[Fe/H] ~ -3
The r-process is a rare event in the universe.



(fig. 3) Observation of (a)Mg, (b)Eu in stellar atmosphere (Cowan et al., 2021).

r-process abundances in metal-poor stars

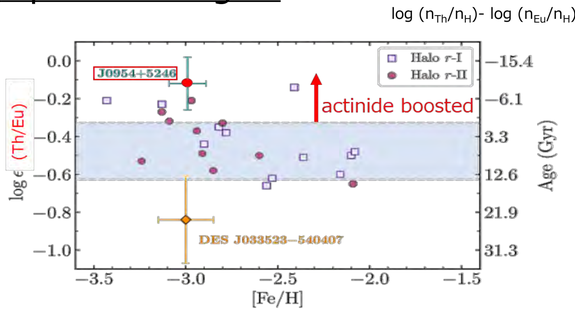
r-process universality
The abundance pattern is the same in Sun and CS22892-052 ([Fe/H]=-3.1).
It indicates that r-process elements are synthesized with the same ratio in the progenitor event.



(fig. 4) abundance pattern of Sun and CS22892-052 (Sneden et al.,1996).

The actinide-boost star
About 30 % of metal-poor r-process-rich stars, high [Th/Eu] stars have been found (e.g., Holmbeck et al., 2018).
These stars suggest diversity in r-process origins.

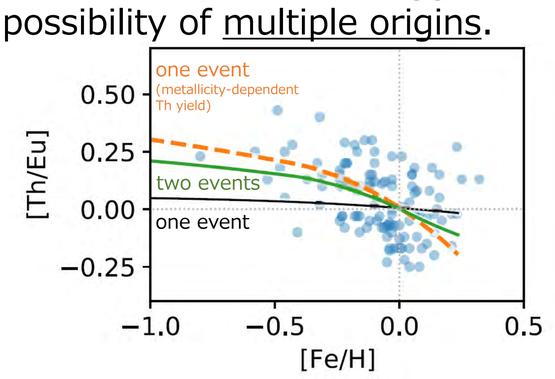
$$\log \varepsilon(Th/Eu) = \log (n_{Th}/n_H) - \log (n_{Eu}/n_H)$$



(fig. 5) log ε(Th/Eu) as a function of [Fe/H] (Holmbeck et al., 2018).

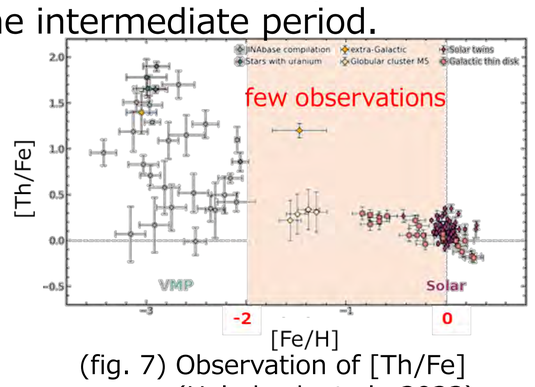
Thorium abundance in metal-rich region

In main-sequence (metal-rich) stars, [Th/Eu] shows a decrease as a function of [Fe/H]. It suggests the possibility of multiple origins.



(fig. 6) Observation of [Th/Eu] (Mishenina et al., 2022)

There are a few observations in -2 ≲ [Fe/H] ≲ 0. This region is the key to the diversity and chemical enrichment of the r-process during the intermediate period.



(fig. 7) Observation of [Th/Fe] (Holmbeck et al., 2023)

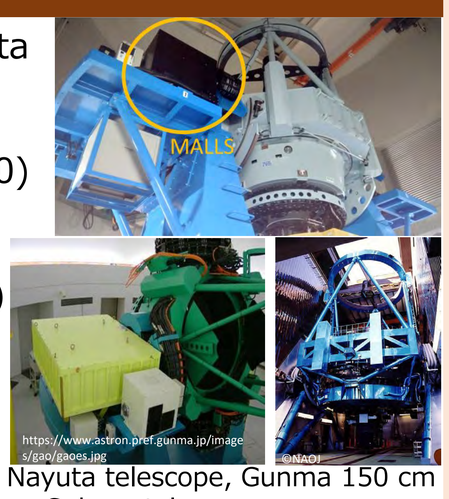
To approach the origin of the r-process, we aim to detect Th in -2 < [Fe/H] stars.

Observations

We obtained high dispersion spectroscopic data of 45 red giant stars in -2 < [Fe/H] with

- 2 m Nayuta telescope and MALLS (R~35000)
- 150 cm telescope/Gunma and GAOES (R~70000)
- Archived data of Subaru telescope (SMOKA) and HDS (R~70000)

S/N is 100 – 200, wavelength is 5000 - 7000 Å.



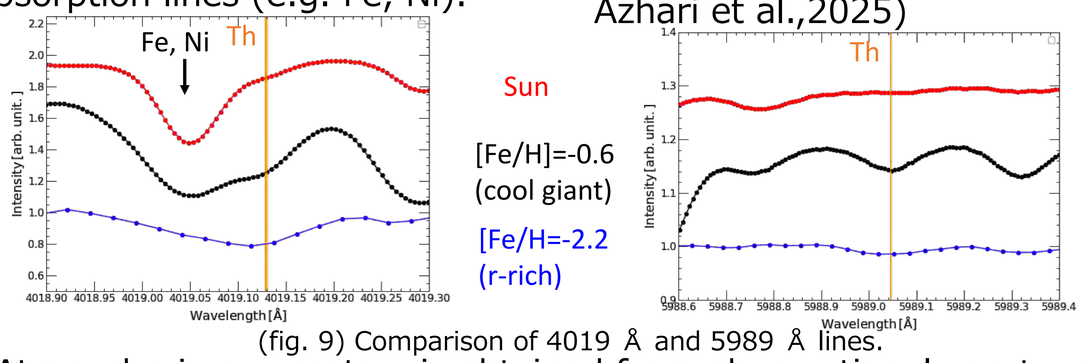
(fig. 8) Nayuta telescope, Gunma 150 cm telescope, Subaru telescope.

Analysis

Th absorption lines

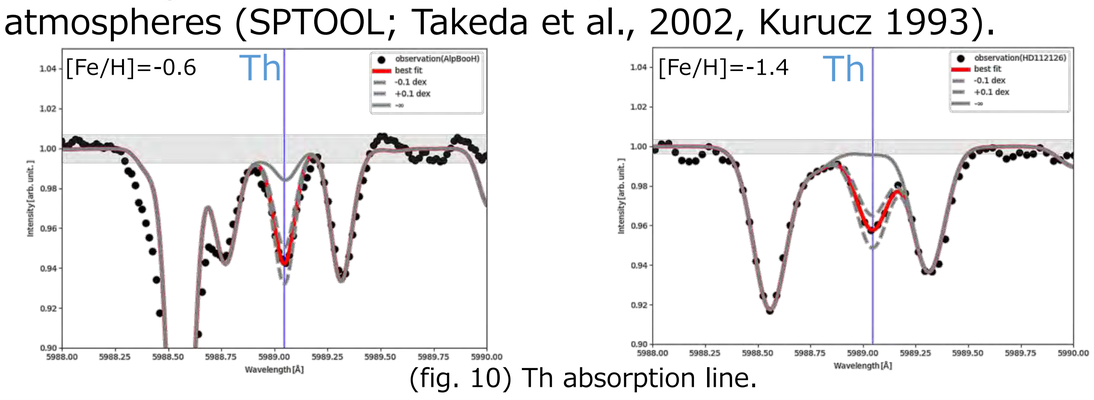
4019 Å
This line has been used so far.
The line **blends** with other absorption lines (e.g. Fe, Ni).

5989 Å
This line will not blend any other absorption lines. It is useful for detecting Th in -2 ≲ [Fe/H] (c.f., Azhari et al.,2025)



(fig. 9) Comparison of 4019 Å and 5989 Å lines.

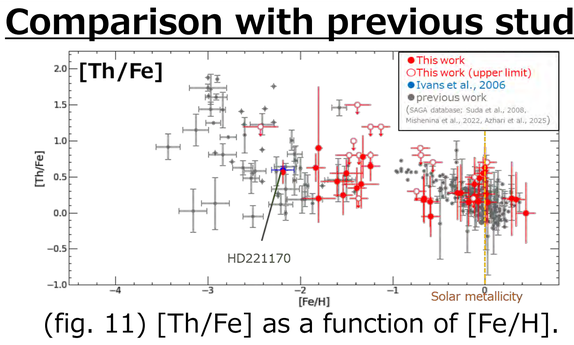
Atmospheric parameters is obtained from observational spectrum (TGVIT; Takeda et al., 2005). Abundances were estimated by comparing observed spectra with synthetic spectra from model atmospheres (SPTOOL; Takeda et al., 2002, Kurucz 1993).



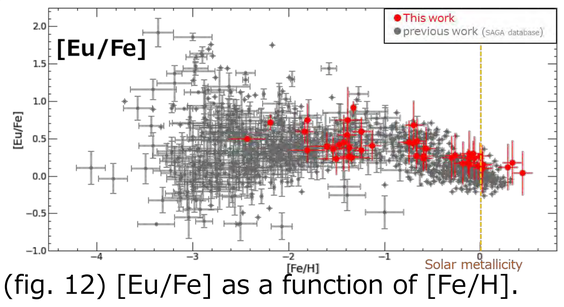
(fig. 10) Th absorption line.

Result and discussion

Comparison with previous studies



(fig. 11) [Th/Fe] as a function of [Fe/H].



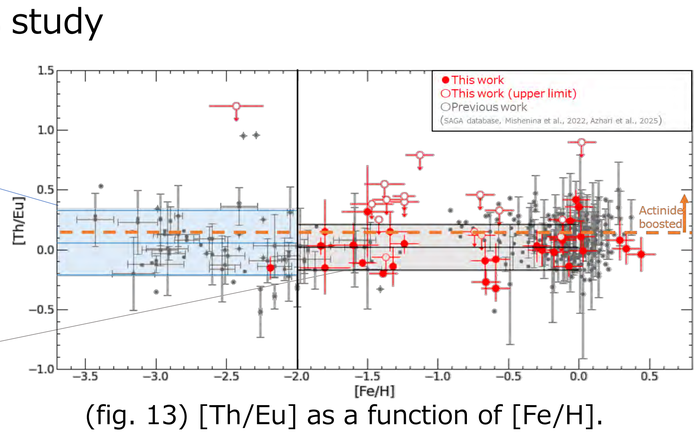
(fig. 12) [Eu/Fe] as a function of [Fe/H].

We detected Th in 29 stars.
[Th/Fe] values are smaller than the previous studies in [Fe/H] ~ -0.7. and larger than the previous study in [Fe/H]~0 stars.

[Eu/Fe] trend is consistent with previous studies.

[Fe/H] < -2
Average: 0.058
Standard deviation: 0.27

-2 < [Fe/H] < 0
Average: 0.020
Standard deviation: 0.19



(fig. 13) [Th/Eu] as a function of [Fe/H].

There are a few actinide boost stars, and the scatter is less than [Fe/H] < -2. It indicates that the actinide boost event is rare or likely to occur in a metal-poor region.

Summary
Investigated stellar Th abundances in -2 < [Fe/H] with 5989 Å line. There are a few actinide boost stars, and [Th/Eu] scatter is less than [Fe/H] < -2. The actinide boost event might be rare or likely to occur in a metal-poor region.