Fission fragment distributions of neutron-rich nuclei based on Langevin calculations in the r-process region

Itoshi NISHIMURA(1), Nobuya NISHIMURA(2), Shoya TANAKA(3), Wataru MIYASAKAI(1), Shynya TAKAGI(1), Masahisa OHTA(4), and Yoshihiro ARITOMO(1)

(1)Graduate of Science and Engineering, Kindai University, Higashi-Osaka, Osaka, Japan
(2)Astrophysical Big Bang Laboratory, CPR, RIKEN, 2-1 Hirosawa, wako, Saitama 351-0198, Japan
(3)RIKEN Nishina Center, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
(4)Department of Physics, Konan University, Kobe, Hyogo 658-0198, Japan

1. Introduction

In 2017, the gravity wave in binary neutron star merger (GW170817) was observed. After that, kilonova was observed by follow-up observation with multi-wavelength electromagnetic waves. The energy source of kilonova is the decay heat of the r-process nucleosynthesis.

In this study, we focus on fission yields, which are the input data necessary for r-process network calculations. The nuclear fission of very neuron-rich nuclei is essential for the determination of the r-process flow on the nuclear chart and the determination of the final abundances. Nevertheless, most of the available fission data for neutron-rich nuclei are based on theory predictions mostly by phenomenological treatments. We calculate a series of nuclear fission distribution for neutron-rich nuclei away from the stability line. We are based on the dynamical fission model with the Langevin method. The obtained mass distributions are compared with the results of the GEF (General fission) code. The GEF model is based on novel theoretical concepts and ideas developed to model low energy nuclear fission.[1]

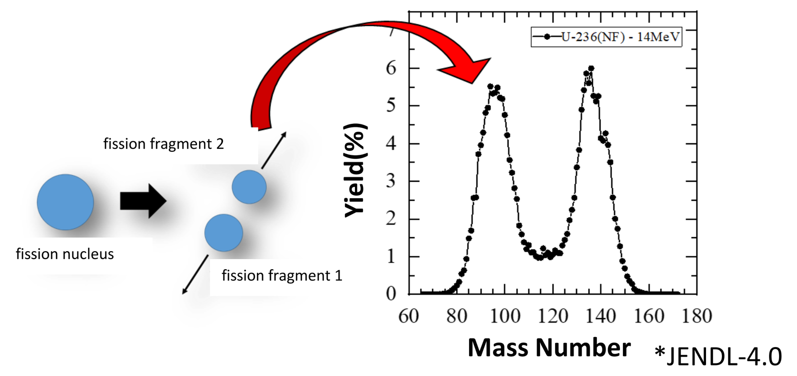

Fig1. Fission fragment mass yield

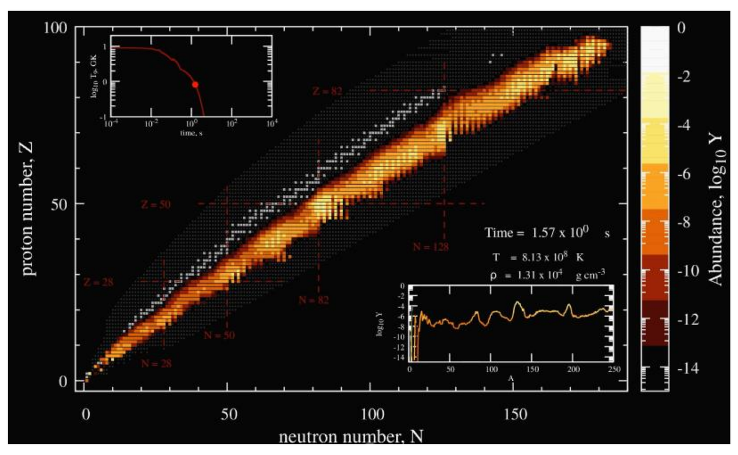

Fig2. r-process simulation

2.Fission Model

✓two center shell model[2]

$$q(z_0,\delta,\alpha)\begin{cases} z_0 = |c_1| + |c_2| \\ \delta = \dfrac{3(a-b)}{2a+b}\ (\delta_1 = \delta_2) \\ \alpha = \dfrac{A_1 - A_2}{A_1 + A_2} \end{cases}$$

z_0 :elongation
δ:deformation
α:mass asymmetry

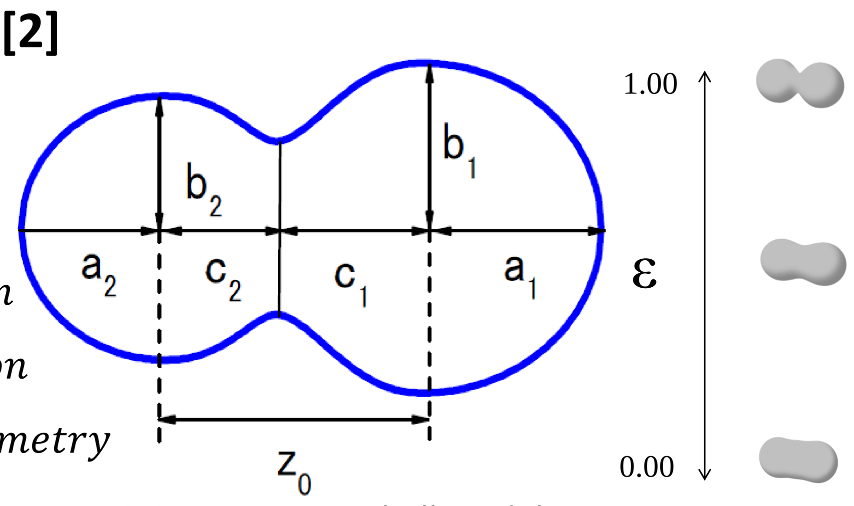

Fig3. Two center shell model

✓potential energy[3]

$$V(q,\ell,T) = V_{LDM}(q) + \frac{\hbar^2\ell(\ell+1)}{2I(q)} + V_{SH}(q,T)$$

$$V_{LDM}(q) = E_S(q) + E_C(q)$$

temperature-dependent term

$$V_{SH}(q,T) = E^0_{shell}(q)\Phi(T)$$

✓Langevin equation[4]

$$\frac{dq_i}{dt} = (m^{-1})_{ij}p_j$$

$$\frac{dp_i}{dt} = -\frac{\partial V}{\partial q_i} - \frac{1}{2}\frac{\partial}{\partial q_i}(m^{-1})_{jk}p_jp_k - \gamma_{ij}(m^{-1})_{jk}p_k + g_{ij}R_j(t)$$

$q_i(z,\delta,\alpha)$: defomation of nucleus
p_i : The conjugate momentum of q_i
V : potential energy
m_{ij} : inertial mass
γ_{ij} : friction coefficient

$$\gamma_{ij}T = \sum_k g_{ik}g_{kj}$$

3. Results

Different nuclides can be made one at a time.

asymmetric fission

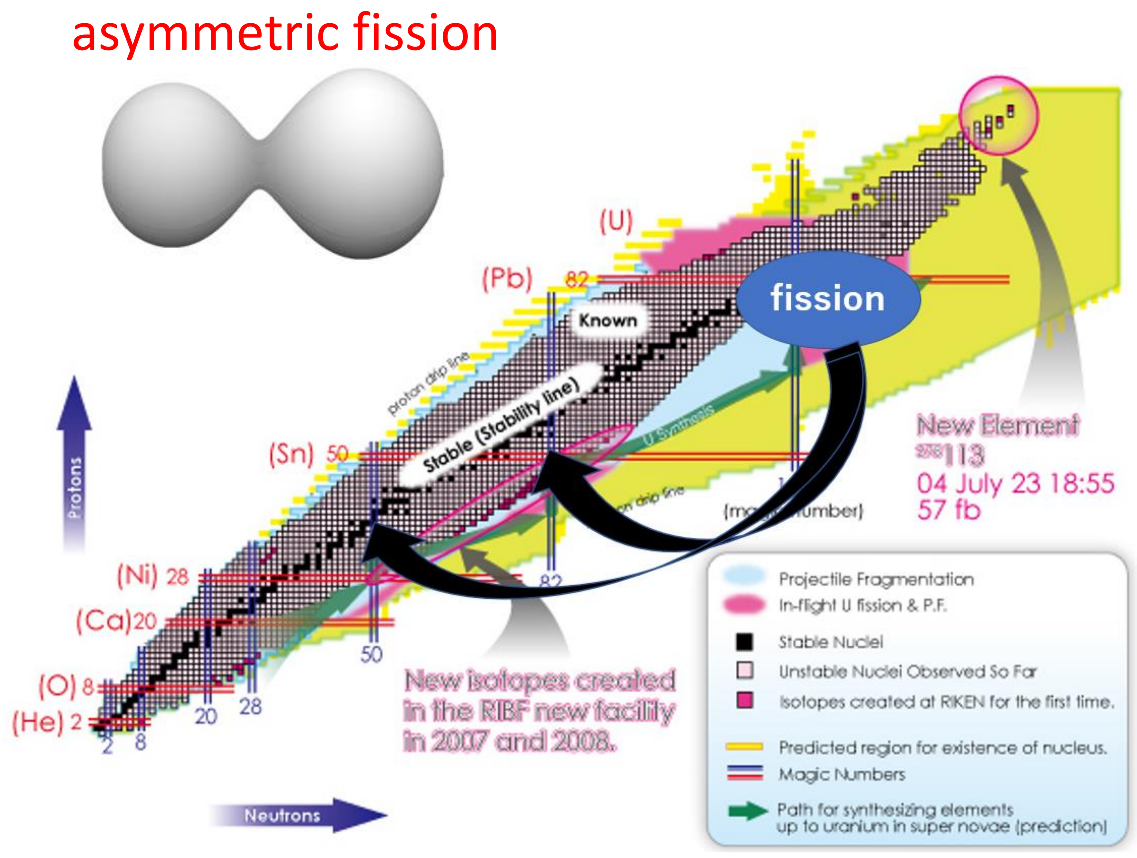

Fig4. Mass asymmetric fission

two identical nuclides can be made.

symmetric fission

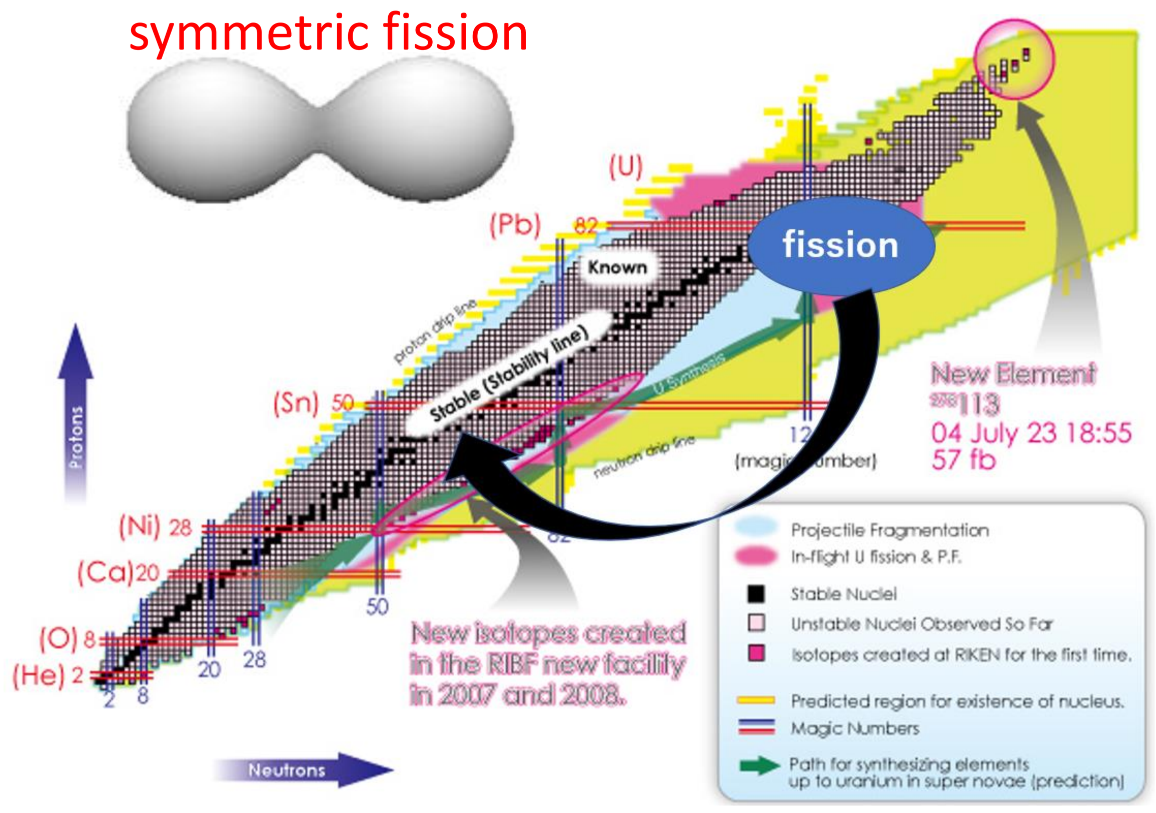

Fig5. Mass symmetric fission.

The Langevin model showed a transition from mass asymmetric to mass symmetric fission for all nuclides. While The GEF model showed almost mass asymmetric fission.

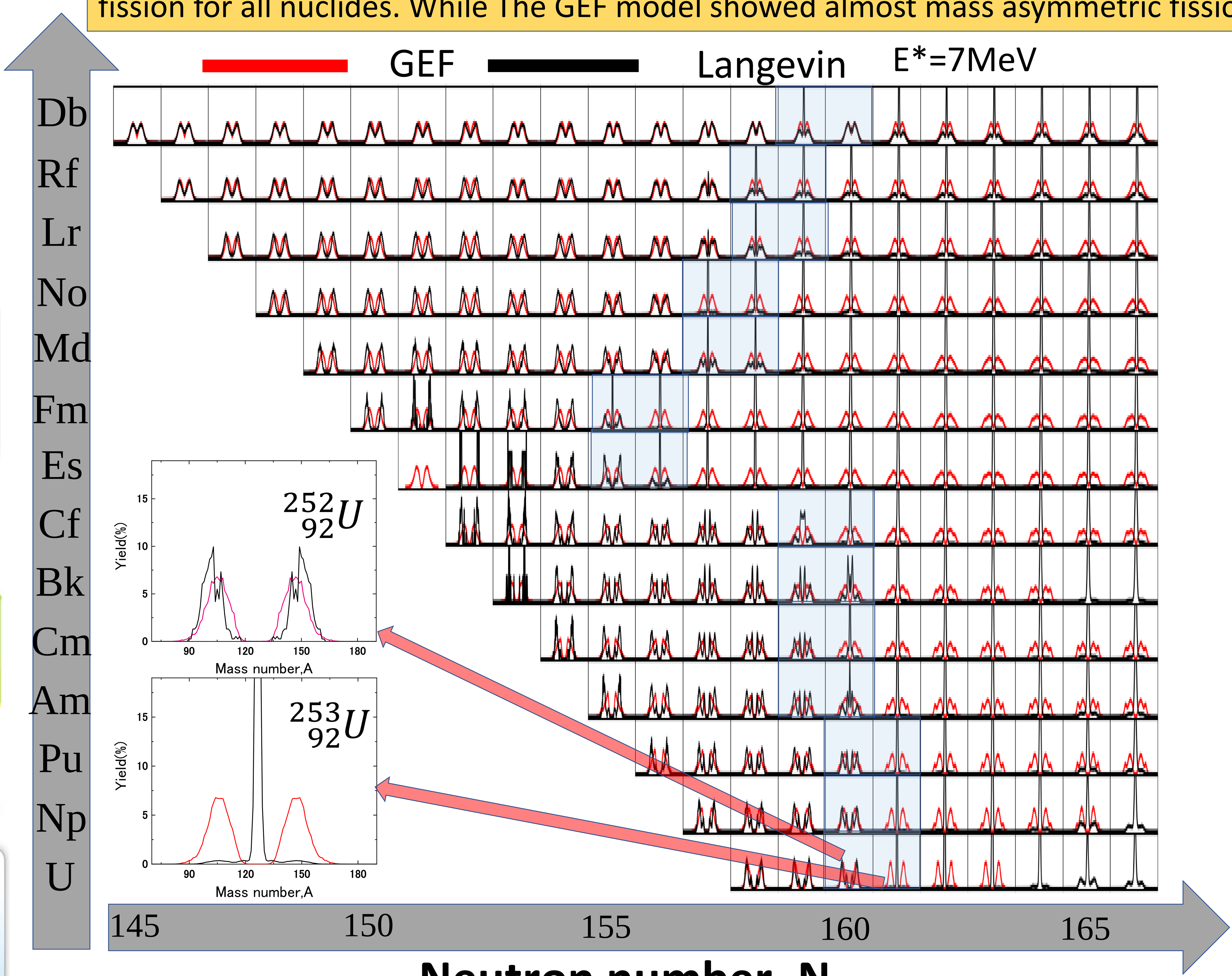

Fig6. A summary of calculation results

4. Conclusion

- We compared fission fragment mass distributions calculated by the Langevin model and the GEF code in neutron-rich and heavy-element-region for which no experimental data.
- In neutron rich region, each model shows different fission mode. It means that the difference between two models can affect the elemental abundance ratios of the universe.
- It is also necessary to see how the network calculation of the r-process is affected by comparing it with another model.
- Need to expand the region of computation to an even wider range

5. Reference

[1]K. Schmidt and B. Jurado, General description of fission observables. supplement to JEFF Report 24(2014)
[2] Maruhn and Greiner, Z. Phys. 251(1972) 431
[3]Y. Aritomo and S. Chiba, Phys. Rev C 88, 044614(2013)
[4]Y. Aritomo and M. Ohta, Nucl. Phys. A 744(2004)3-14