Neutral networks and Nuclear Properties for the r-Process

Youngman Kim

CENS, IBS

Daejeon, Korea

in collaboration with:

T. Kajino, Kyungil Kim, Zhenyu He, Yudong Luo, I. Tanihata, Yong-Beom Choi, R. Diehl, submitted to ApJ

& Soonchul Choi: DNN in mass table for the r-process (e-Print: 2411.19470 [nucl-th], submitted to PRC

ibS 기초과학연구원 Institute for Basic Science

The 4th Workshop on Machine Learning in Nuclear Physics and Nuclear Data

2025/Oct/30-Nov/03 at the Yuelai Garden Hotel, Hengyang

CENS CENTER FOR EXOTIC NUCLEAR STUDIES


DCC1
DCC2
IBS

- Extrapolation Using Neural Networks in Ab Initio Nuclear Structure Theory

- Neural Networks in Density Functional Theory Applied to the r-Process

Ab initio nuclear structure theory

- **Ab initio NCSM**

  - Ab initio: nuclei from first principles using fundamental interactions without uncontrolled approximations.

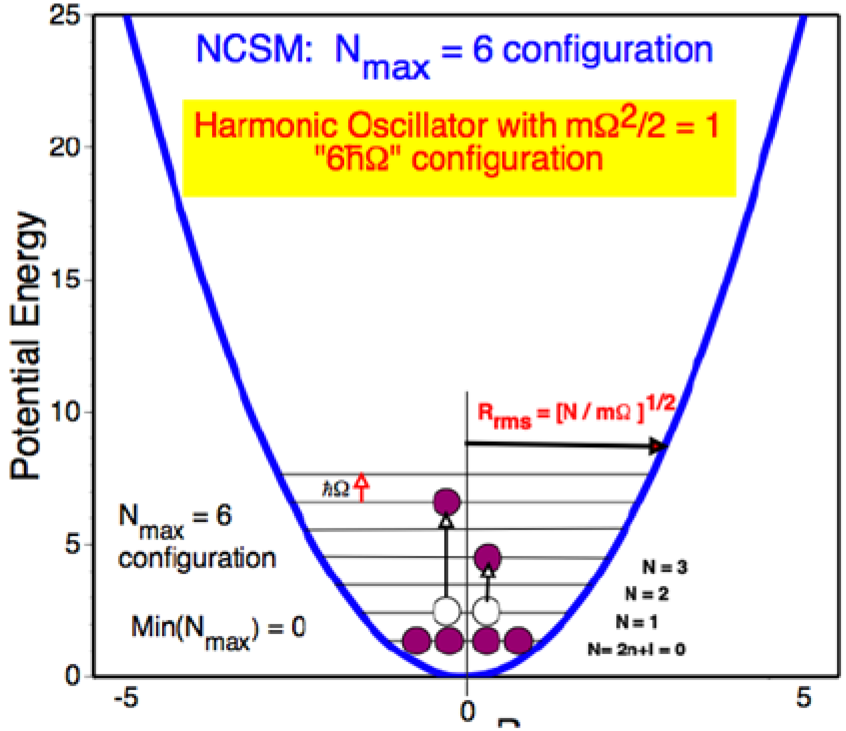
  - No core: all nucleons are active, no inert core.

  - Shell model: harmonic oscillator basis

  - Point nucleons

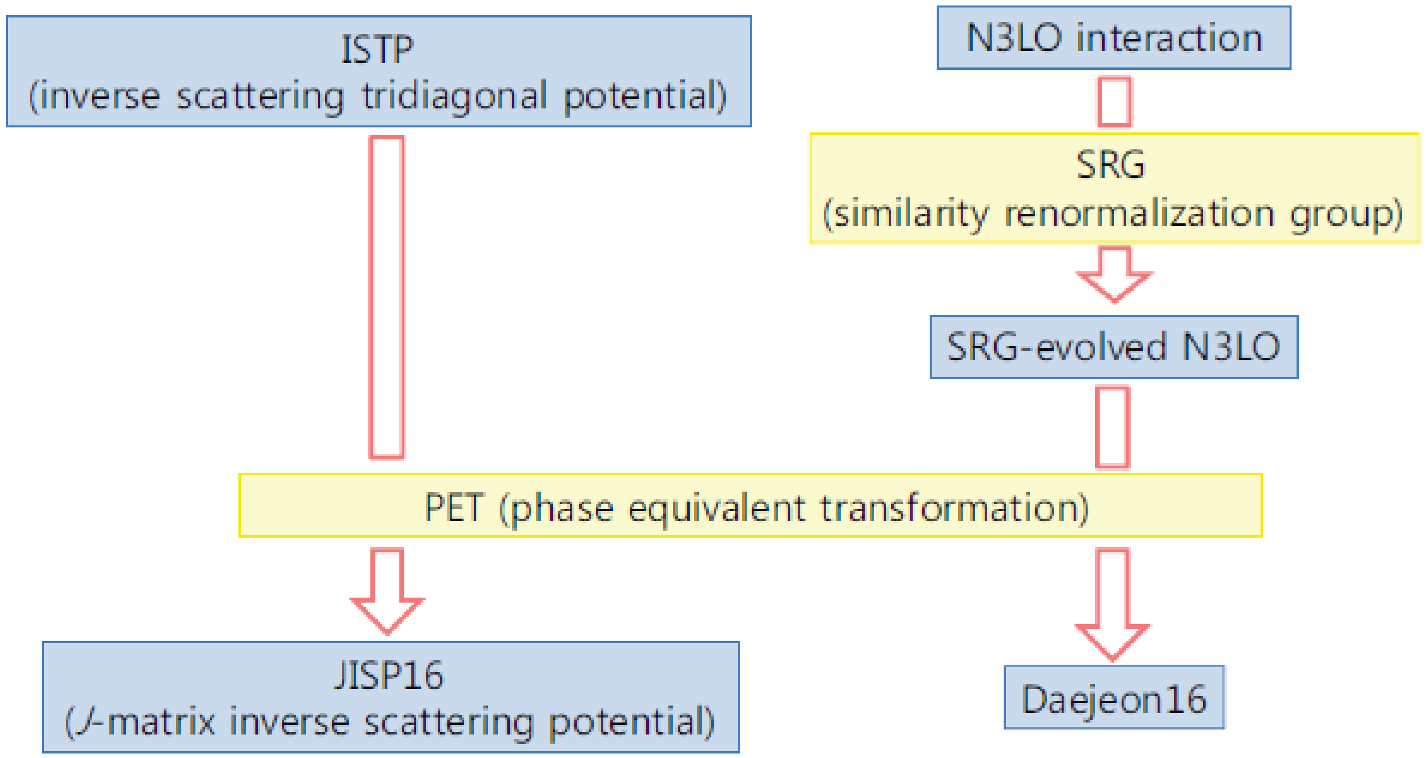
- single particle states ϕ
  for radial wave functions, harmonic oscillators are used

$$\Rightarrow \Phi_i \sim \phi_1^{(i)} \times \phi_2^{(i)} \times \cdots \times \phi_A^{(i)}$$



from the talk by J. Vary @ RISP, Mar. 2013

JISP16 vs Daejeon16



A sketch of the procedure to obtain Daejeon16 compared with JISP16.

A.M. Shirokov, I.J. Shin, YK, M. Sosonkina, P. Maris and J. P. Vary, *N3LO NN interaction adjusted to light nuclei in ab exitu approach*, Phys. Lett.B 761 (2016) 87

Deep learning: Extrapolation tool for ab initio nuclear theory

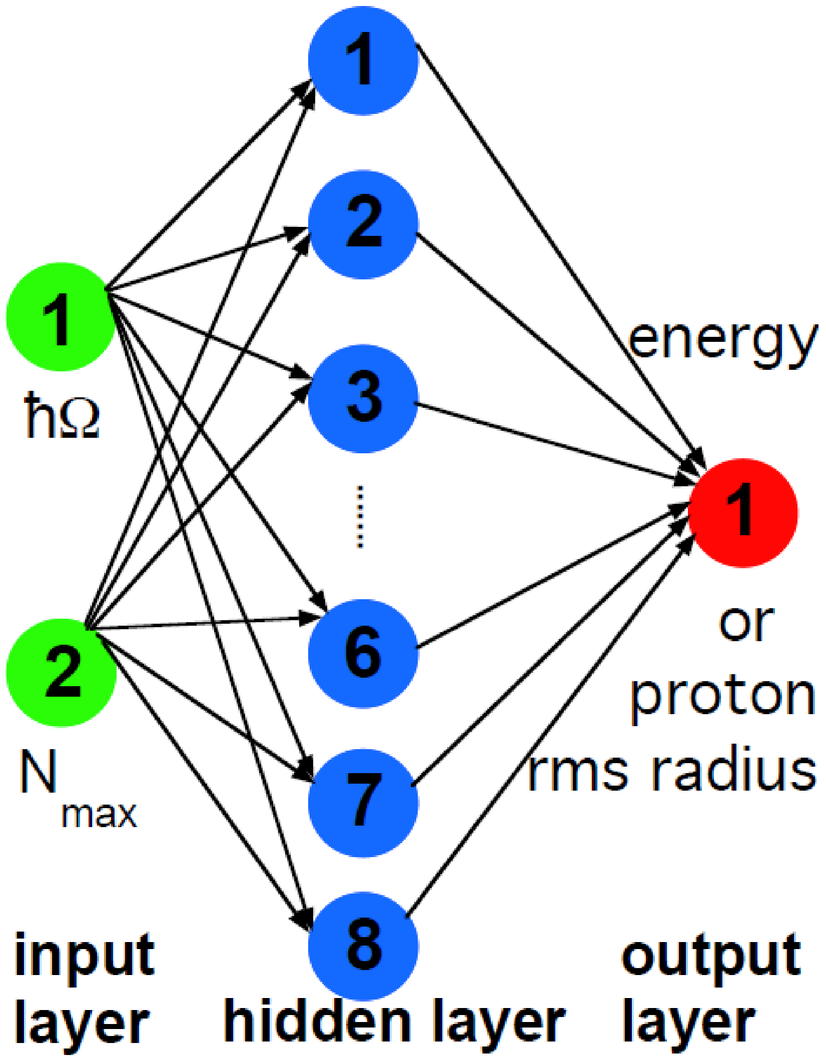


FIG. 1: Topological structure of the designed ANN.

N_{max}= 2, 4, …, 10 for ANN training and testing

Gianina Alina Negoita, et al., Phys. Rev. C99, 054308 (2019);
e-Print: 1803.03215 [physics.comp-ph]

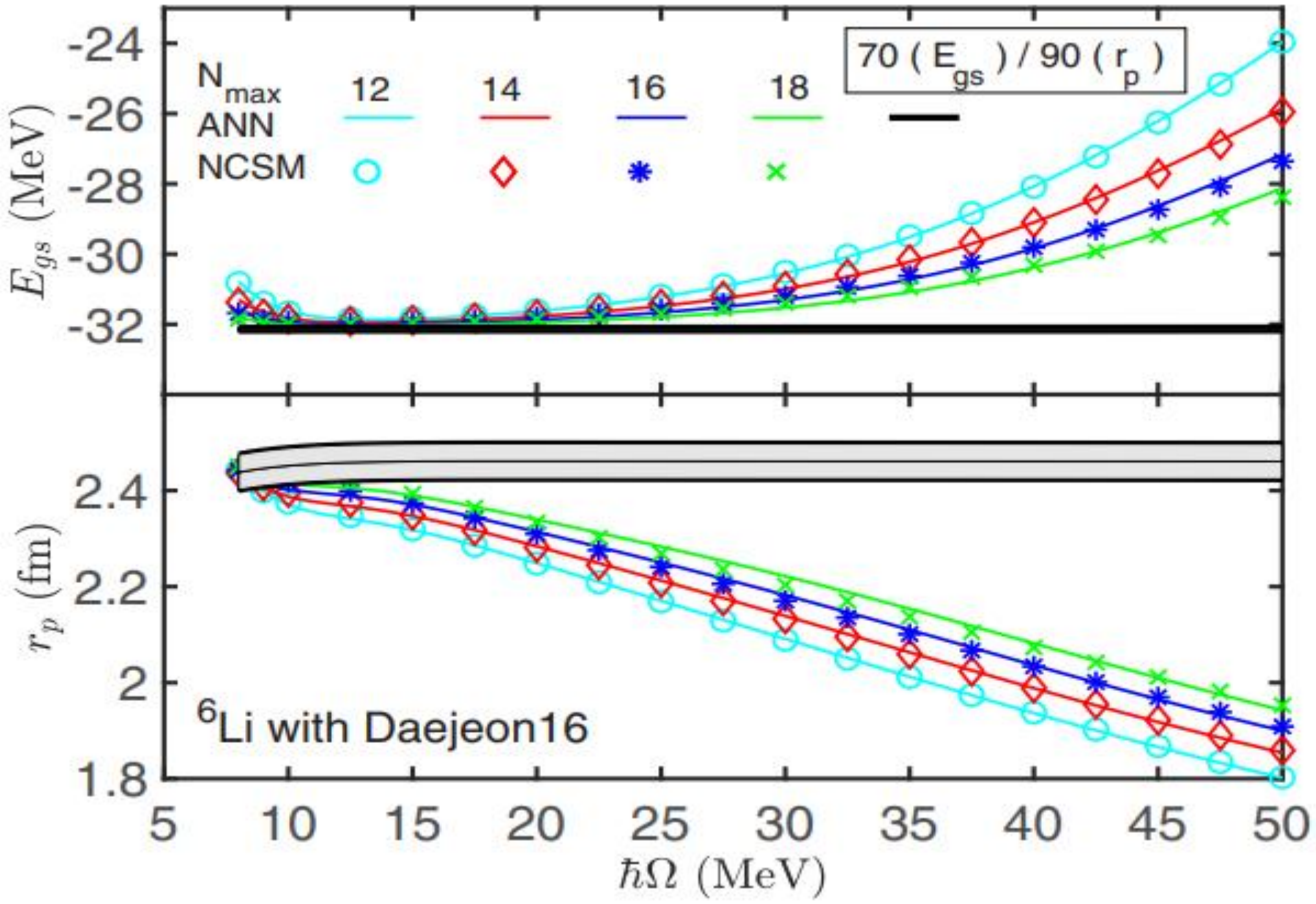


FIG. 6. Comparison of the best ANN predictions based on data set with $N_{max} \leqslant 10$ and the corresponding NCSM calculated GS energy and GS point-proton rms radius values of ^{6}Li as a function of $\hbar\Omega$ at $N_{max} = 12, 14, 16$, and 18. The shaded area corresponds to the ANN nearly converged result at $N_{max} = 70$ (GS energy) and $N_{max} = 90$ (GS point-proton rms radius) along with its uncertainty estimation quantified as described in the text.

For each value (ranging from 2 to 18), 19 different $\hbar\omega$ values were considered, using a total of approximately 170 data points.

G. A. Negoita, J. P. Vary, G. R. Luecke, P. Maris, A. M. Shirokov, I. J. Shin, Y. Kim, et al,
Deep learning: Extrapolation tool for ab initio nuclear theory,
Phys. Rev. C 99 (2019) 5, 054308

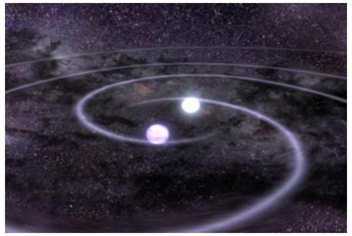
Neural Networks in Density Functional Theory Applied to the r-Process

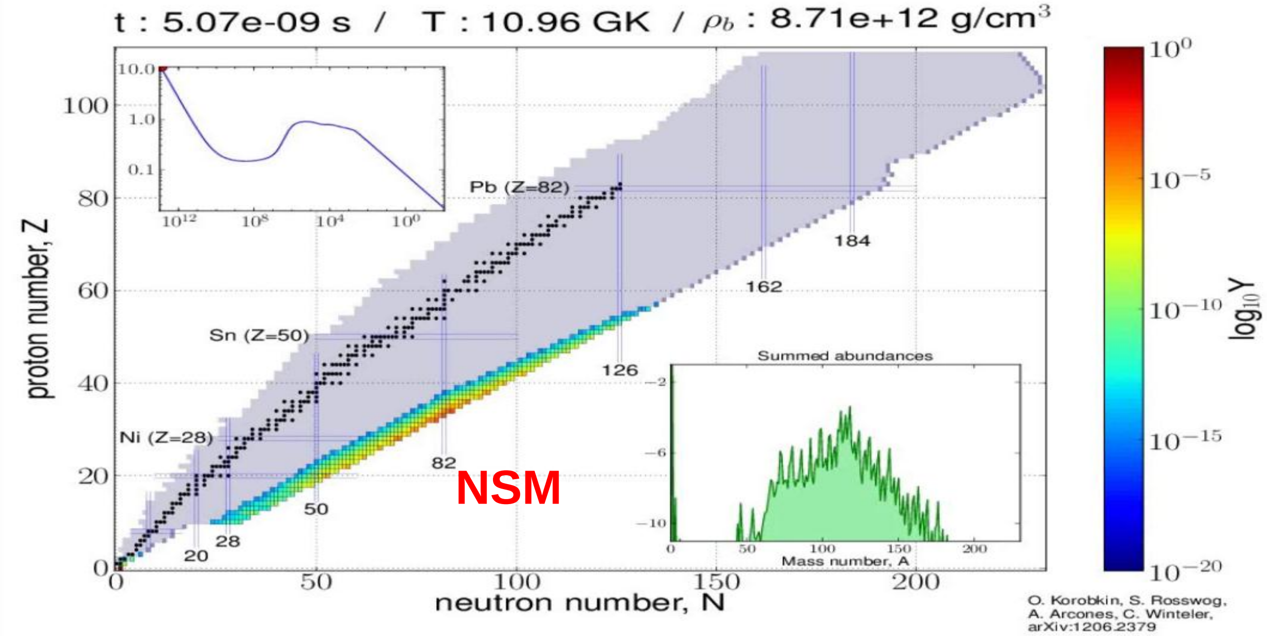
The production of the elements up to iron and about half of the elements heavier than iron is reasonably well explained by the Big Bang nucleosynthesis (BBN), slow-neutron capture process (s-process), etc. The other half of heavy elements in the universe is attributed to the rapid-neutron capture process (r-process).

The role of neutron dripline in the r-process (on-going)

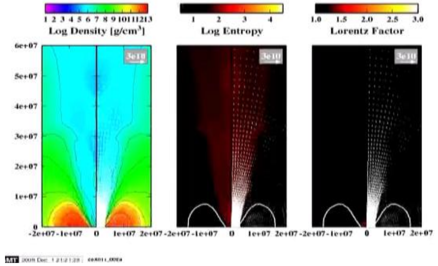
Kajino, Aoki, Balantekin,
Diehl, Famiano, Mathews,
Prog. Part. Nucl. Phys. 107 (2019) 109-166.

Neutron Star Merger

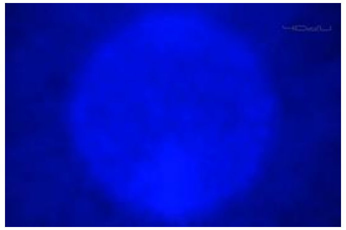


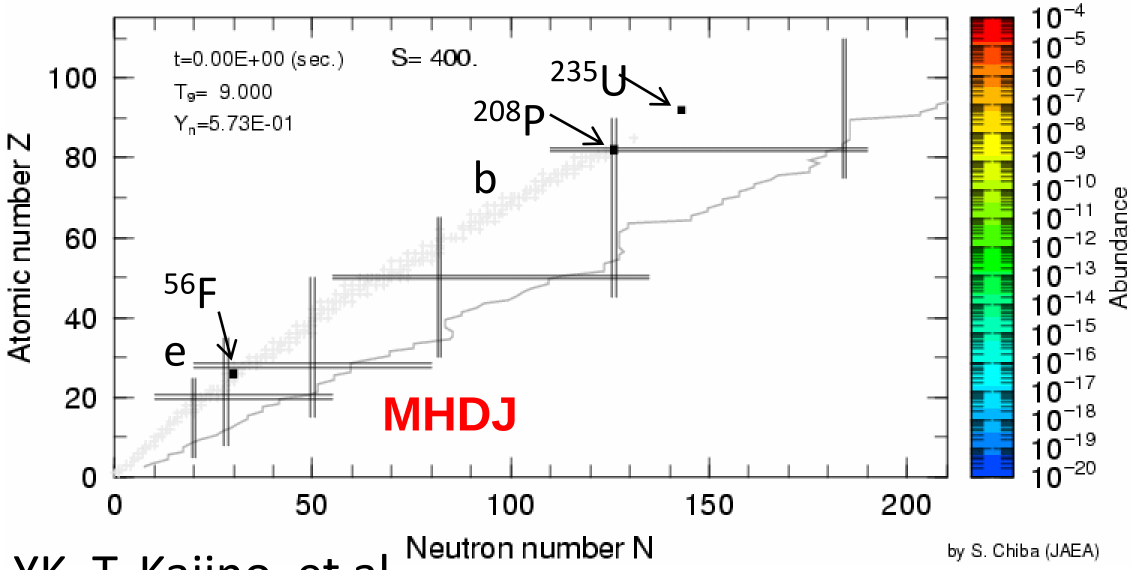


Collapsar Jet



MHD Jet/NSW SN



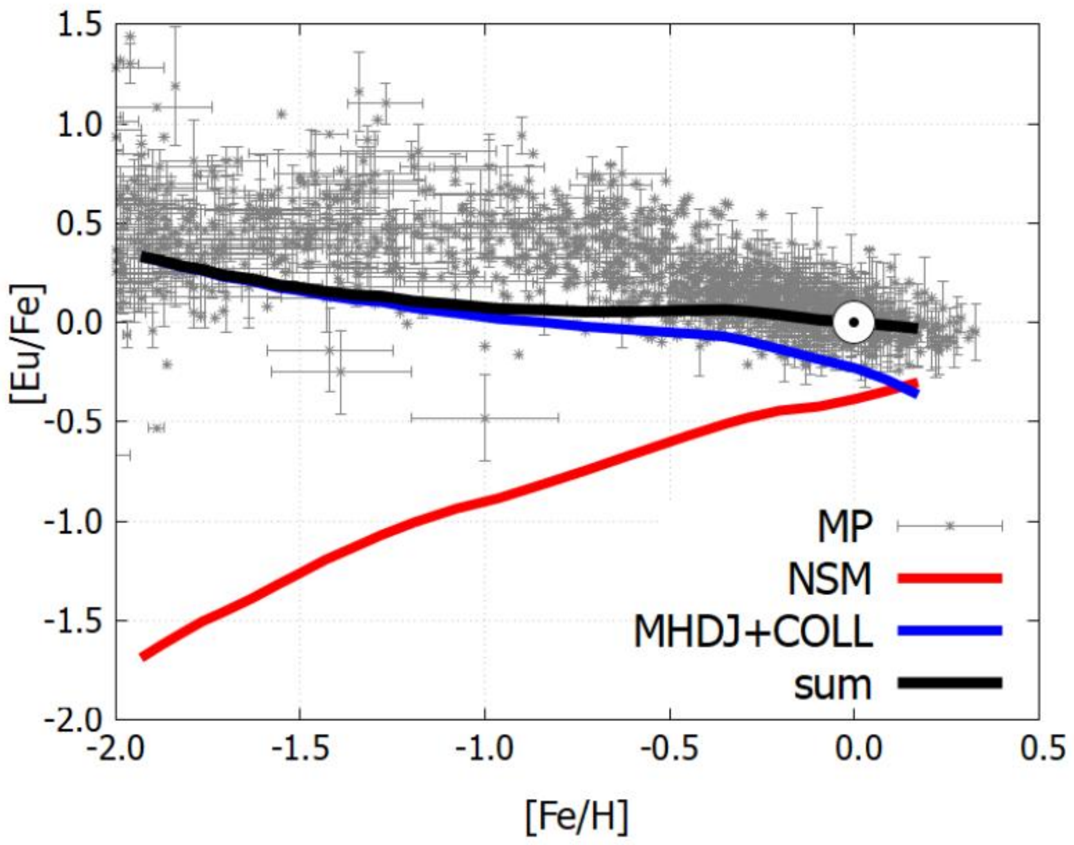


Yongbeom Choi (BUAA), Zhenyu He (BUAA), YK, T. Kajino, et al

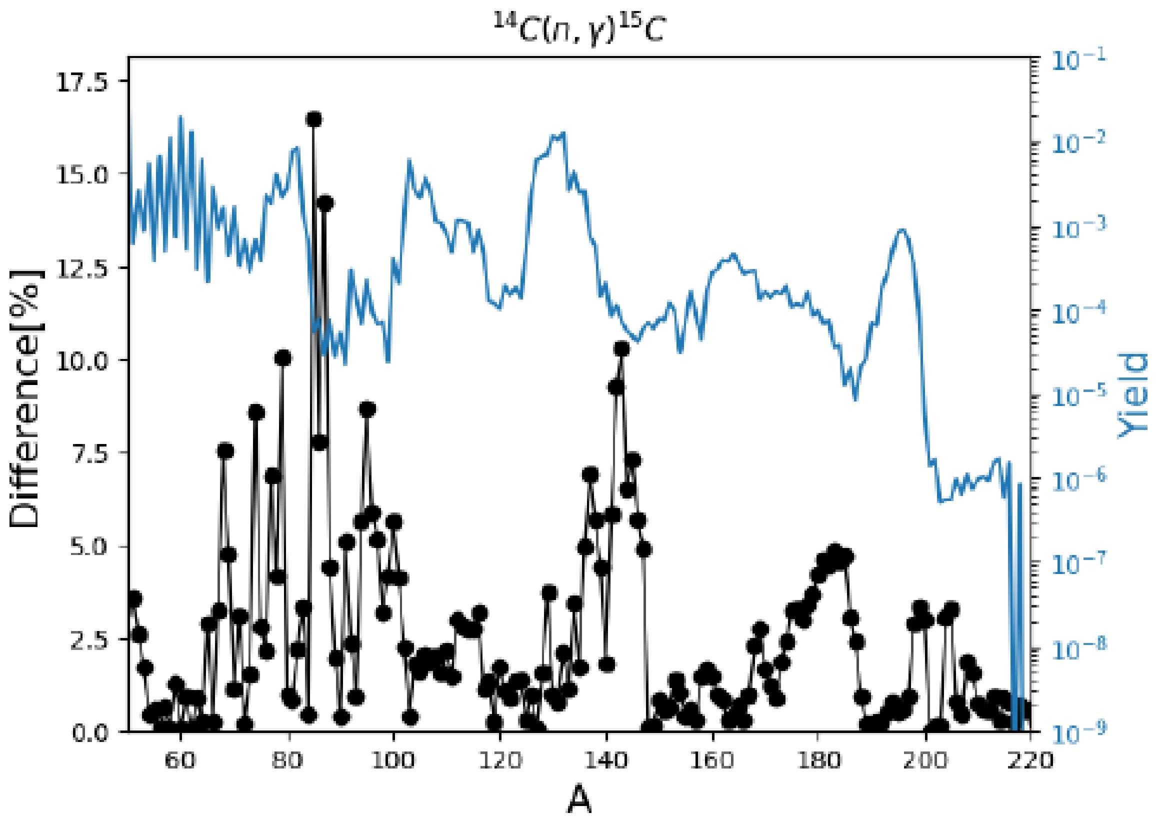
from T. Kajino

Astrophysical environments: MHD Jet Supernovae

- For our numerical simulations, we use the Libnucnet libraries for the reaction networks [B. S. Meyer, D. C. Adams, M&PSA, 42, 5215 (2007)] and take the thermonuclear reaction rate from JINA-REACLIB database.
- The collimated jets due to rapid rotation and strong magnetic fields could provide a favorable environment for a successful r-process; since nuclei are dissociated into free nucleons due to the high temperature, the initial composition of the elements consists of mainly protons and neutrons.
- We use the twenty three trajectories from the MHD jet model [S. Shibagaki, T. Kajino, G. J. Mathews, S. Chiba, S. Nishimura and G. Lorusso, Astrophys.J. 816, 79 (2016)]

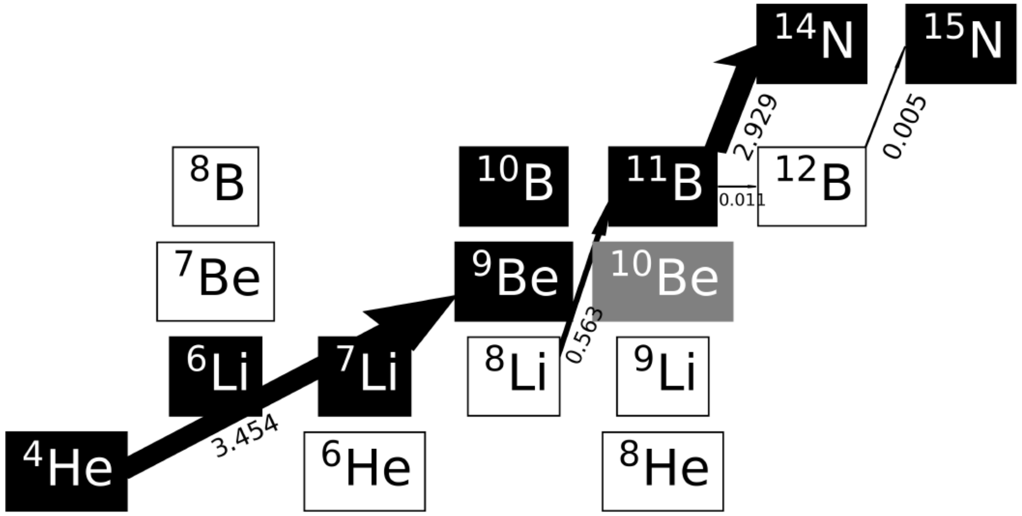


[Eu/Fe] as a function of metallicity [Fe/H].
Gray dots show the data from metal-poor halo stars

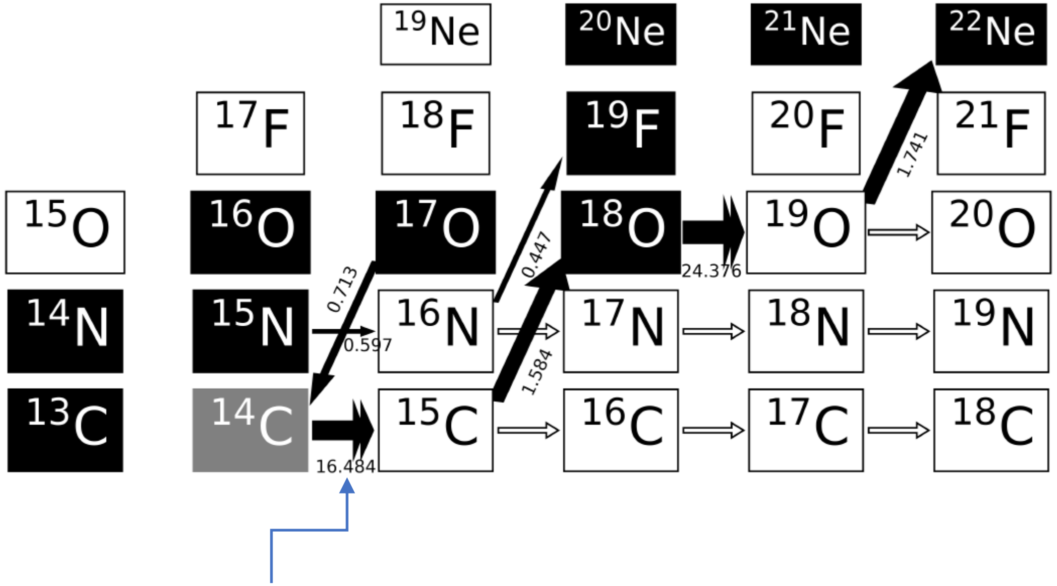


Observed sensitivities in MHD Jet Supernovae

Kyungil Kim, YK, Zhenyu He, Yudong Luo, T. Kajino, I. Tanihata, Yong-Beom Choi, R. Diehl (submitted to ApJ)



from He to B



from C to O

An interesting feature can be seen from the figures that the (n,γ) reaction of stable isotopes (^{15}N,^{18}O) or relatively stable one ^{14}C and their chain reactions (α,n) give a large sensitivity to the r-abundances.

- We observed an interesting feature in MHD model that the (n, gamma) reaction of stable isotopes (^{15}N,^{18}O) or relatively stable one ^{14}C and their chain reactions (alpha, n) show a high sensitivity to the r-abundances.
- The ^{14}C(n, gamma)^{15}C reaction has high sensitivity both in MHD jets and neutrino driven winds.
- In the collapsar model, neutron induced reactions, in general, have a high sensitivity.

Kyungil Kim, YK, Zhenyu He, Yudong Luo, T. Kajino, I. Tanihata, Yong-Beom Choi, R. Diehl (submitted to ApJ)

Systematic Investigations of Scandium, Titanium, and Vanadium in Galactic Chemical Evolution

Soonchul Choi*

Center for Exotic Nuclear Studies, Institute for Basic Science, Daejeon 34126, Korea

Eda Gjergo†

School of Astronomy and Space Science, Nanjing University, Nanjing 210093, China

Youngman Kim

Center for Exotic Nuclear Studies, Institute for Basic Science, Daejeon 34126, Korea

Toshitaka Kajino

School of Physics,
and International Research Center for Big-Bang cosmology and Element Genesis,
Beihang University, Beijing 100083, China
and
National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan

(Dated: October 22, 2025)

Scandium, titanium and vanadium can be synthesized primarily in core-collapse supernovae. However, galactic chemical evolution (GCE) models under-produce these elements at early epochs. Such GCE models have been validated against well-established element abundance patterns in the Milky Way. Which may well describe average patterns in the Galactic disc, but there is evidence of past variability. We present a systematic investigation of scandium and vanadium abundances using initial rotational velocity and the initial mass function as key parameters.

By incorporating these factors into a refined GCE framework, we address the discrepancies and improve the predictive power of theoretical models for these critical iron-peak elements. Our results indicate that combining rapid stellar rotation (IRV=300 km/s) with a non-canonical initial mass function ($\alpha_3 = 1.6$, and 2.3) can help reproduce not only the individual [X/Fe]–[Fe/H] trends for scandium, titanium, and vanadium, but also their observed cross-element correlations. In particular, these combined effects enable early-time enrichment that aligns with the abundance patterns seen in very metal-poor stars.

R-process mass (deformation) sensitivity study

1. Construction the neural network.
2. Training using AME2020+RCHB (even-even, even-odd) data and **compare the AME2020+RCHB whole data**.

   We expect that the machine might learn the odd information from AME2020 data.
3. Training using AME2020+DRHBc (even-even, even-odd) data and **predict the odd-even, odd-odd cases.**

Atomic Data and Nuclear Data Tables 121–122 (2018) 1–215

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/adt

The limits of the nuclear landscape explored by the relativistic continuum Hartree–Bogoliubov theory

X.W. Xia [a], Y. Lim [b,c], P.W. Zhao [d,e], H.Z. Liang [f], X.Y. Qu [a,g], Y. Chen [d,h], H. Liu [d], L.F. Zhang [d], S.Q. Zhang [d], Y. Kim [c], J. Meng [d,a,i,*]

[a] School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China
[b] Cyclotron Institute, Texas A&M University, College Station, TX 77843, USA
[c] Rare Isotope Science Project, Institute for Basic Science, Daejeon 305-811, Republic of Korea
[d] State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China
[e] Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA
[f] RIKEN Nishina Center, Wako 351-0198, Japan
[g] School of Mechatronics Engineering, Guizhou Minzu University, China
[h] Institute of materials, China Academy of Engineering Physics, Sichuan, 621907, China
[i] Department of Physics, University of Stellenbosch, Stellenbosch, South Africa

Deformation

X ⟷ O

RCHB — DRHBc

Spherical symmetry — Axial symmetry

Atomic Data and Nuclear Data Tables 144 (2022) 101488

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/adt

Nuclear mass table in deformed relativistic Hartree–Bogoliubov theory in continuum, I: Even–even nuclei

Kaiyuan Zhang [a], Myung-Ki Cheoun [b], Yong-Beom Choi [c], Pooi Seong Chong [d], Jianmin Dong [e,f], Zihao Dong [a], Xiaokai Du [a], Lisheng Geng [g,h], Eunja Ha [i], Xiao-Tao He [j], Chan Heo [d], Meng Chit Ho [d], Eun Jin In [k,l], Seonghyun Kim [b], Youngman Kim [m], Chang-Hwan Lee [c], Jenny Lee [d], Hexuan Li [a], Zhipan Li [n], Tianpeng Luo [a], Jie Meng [a,*], Myeong-Hwan Mun [b,o], Zhongming Niu [p], Cong Pan [a], Panagiota Papakonstantinou [m], Xinle Shang [e,f], Caiwan Shen [q], Guofang Shen [g], Wei Sun [n], Xiang-Xiang Sun [r,s], Chi Kin Tam [d], Thaivayongnou [g], Chen Wang [j], Xingzhi Wang [a], Sau Hei Wong [d], Jiawei Wu [j], Xinhui Wu [a], Xuewei Xia [t], Yijun Yan [e,f], Ryan Wai-Yen Yeung [d], To Chung Yiu [d], Shuangquan Zhang [a], Wei Zhang [h], Xiaoyan Zhang [p], Qiang Zhao [k,a], Shan-Gui Zhou [s,u,v,w], DRHBc Mass Table Collaboration

RCHB mass table project was initiated in 2013, mainly between IBS (YK) and Peking U. (Jie Meng).

Members of the DRHBc collaboration (2018 ~)

Up to now, there 31 universities and institutions from countries including China, South Korea, and Japan joining the DRHBc Mass Table Collaboration.

- Proton number Z,
- Neutron number N,
- Pairing indicator $\delta = [(-1)^Z + (-1)^N]/2$,
- Proton shell parameter P_p,
- Neutron shell parameter P_n.

The shell parameters are computed as the distance to the nearest magic numbers

RMSD (DRHBc, even Z)=1.433 MeV from the 1244 mass data

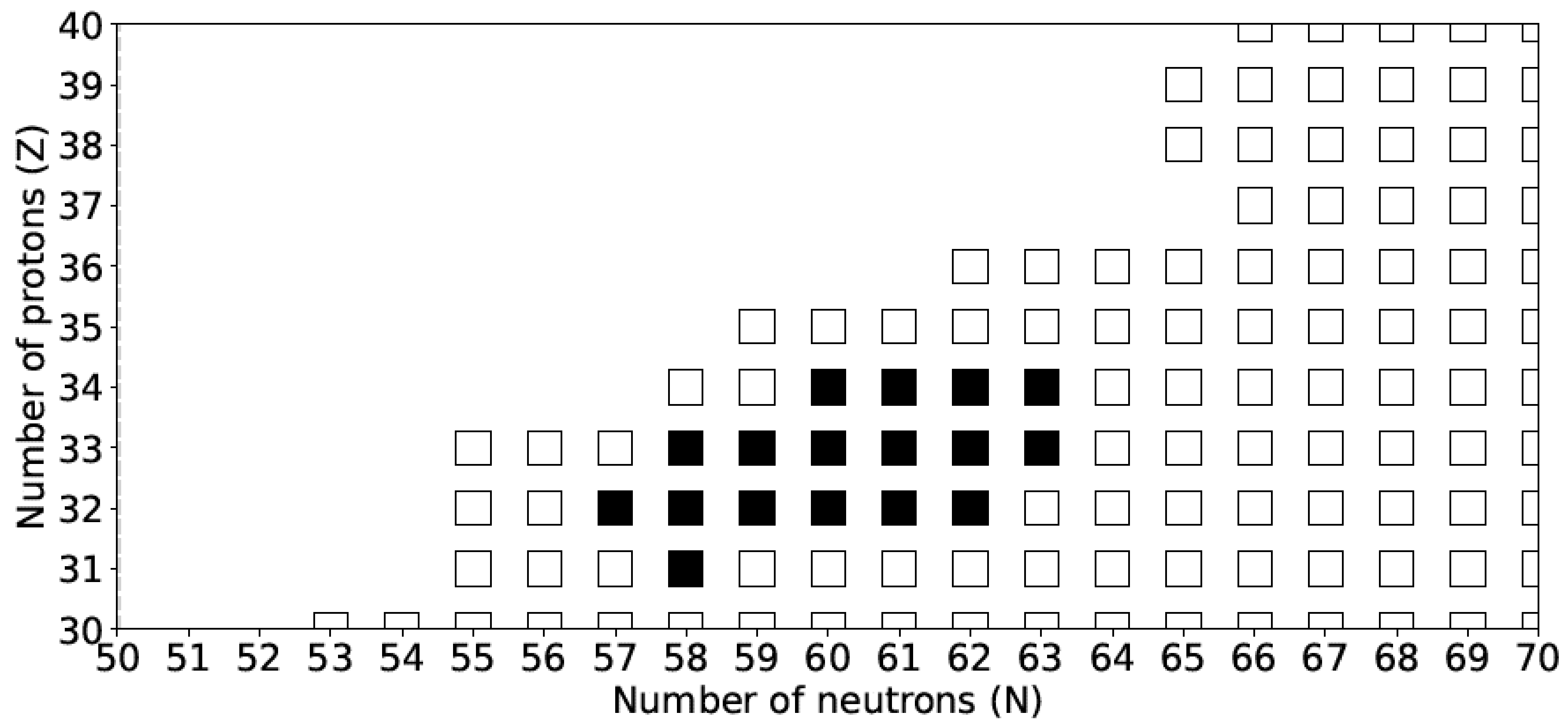
RMSD (RCHB)= 7.960 MeV from the 2284 mass data (either neutron or proton magic nuclei: RMSD= 2.157 MeV)

5-inputs DRHBc*

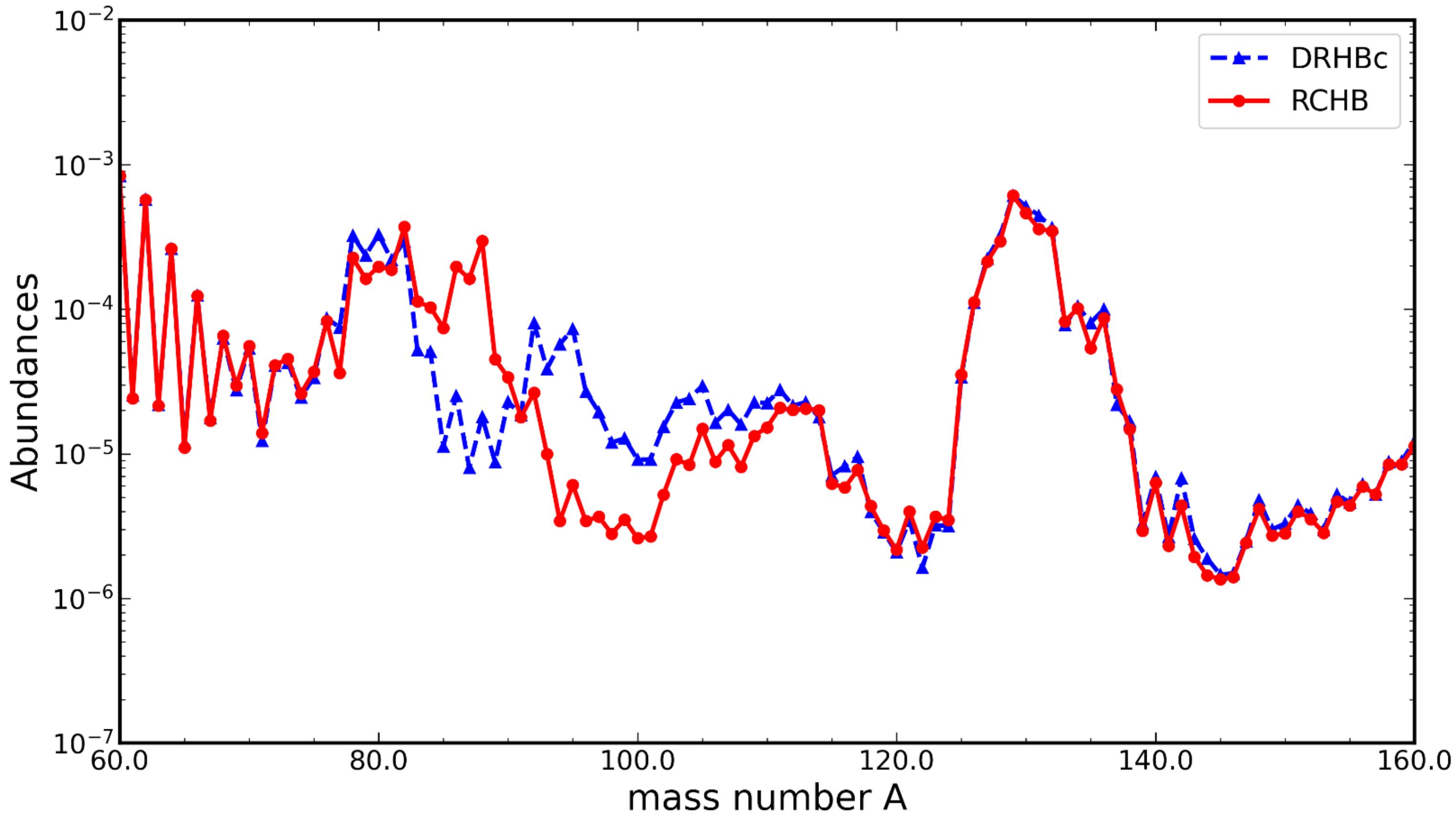
Layer-node	RMS deviation (AME+DRHBc)	RMS deviation (AME)
48-48-48	1.6629	0.8417
64-64	1.6500	1.2817

5-inputs RCHB*

Layer-node	RMS deviation (AME+RCHB)	RMS deviation (AME)
48-48-48	1.9567	1.8617
64-64	2.2422	1.7049



The isotopes with a mass difference greater than 5 MeV between DRHBc* and RCHB* for the five-inputs case.



Soon-Chul Choi, Kyungil Kim, YK and T. Kajino, e-Print: 2411.19470 [nucl-th] (submitted to PRC)

Summary

- (deep) Neural networks were applied to ab initio and microscopic nuclear structure theories

- We observed that deformation (mass) affects the r-abundances!