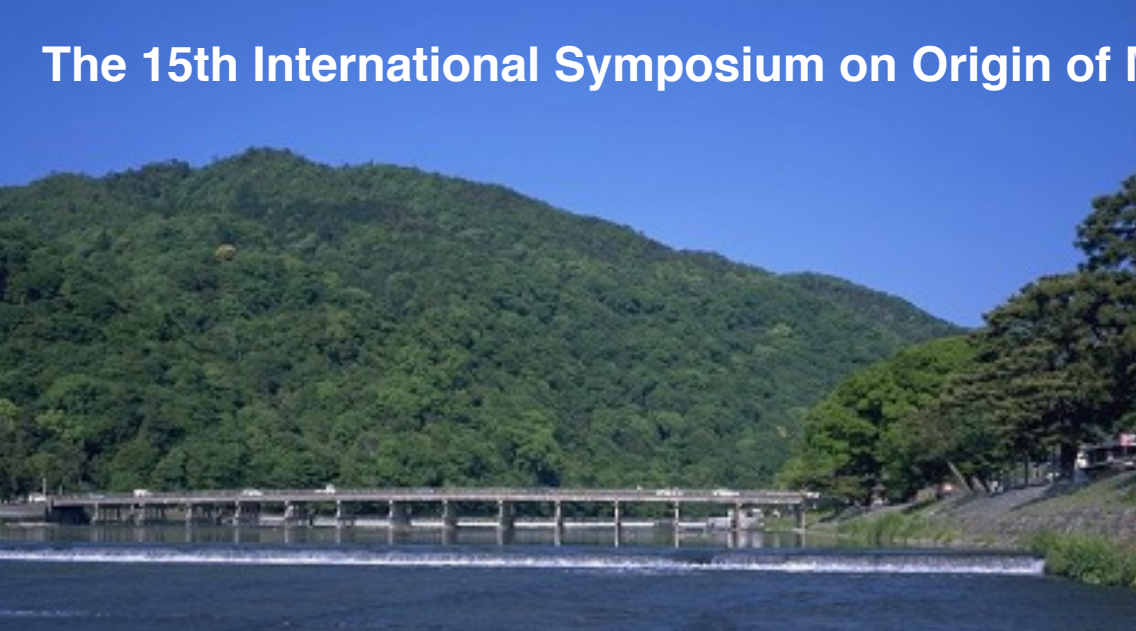


# The 15th International Symposium on Origin of Matter and Evolution of Galaxies



## Concluding Remarks

T. Motobayashi (RIKEN Nishina Center)

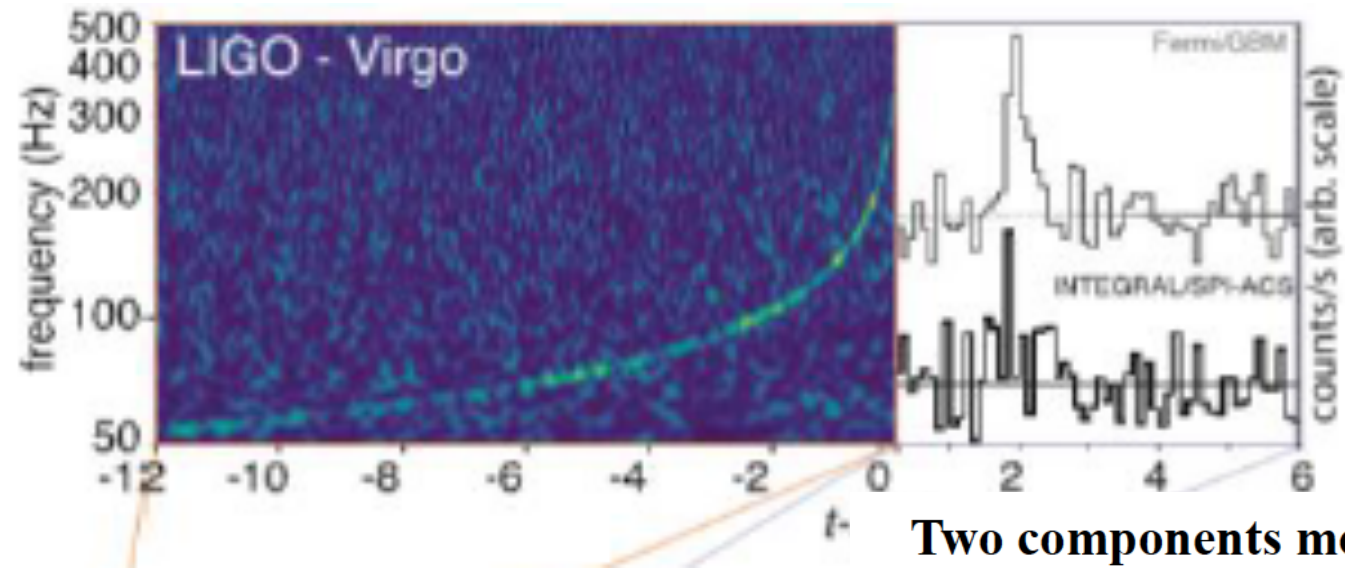
1<sup>st</sup> in 1988

from 1996 (4<sup>th</sup>) “Origin of Matter and Evolution of Galaxies”  
always in Japan until 2013 (12<sup>th</sup>)

Beijing (China) – Daejeon (Korea) – Kyoto

The “engines” of the Japan series: Kubono and Kajino

# Gravitational waves – a highlight BH-BH (2016-), NS-NS (2017-)

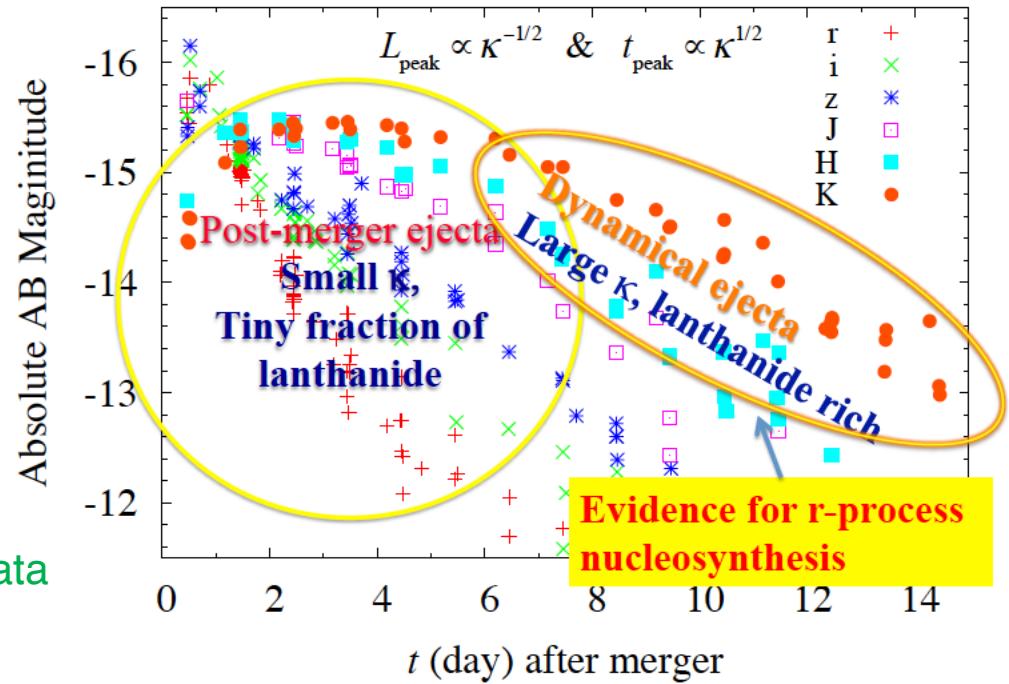


“kilonova”

EM **observed** just after the NS-NS merger

Ando

## Two components model for GW170817



Shibata

long lived red light  
 → heavy elements synthesized  
 (r-process)

Various organized observations  
 New researches triggered (prepared)

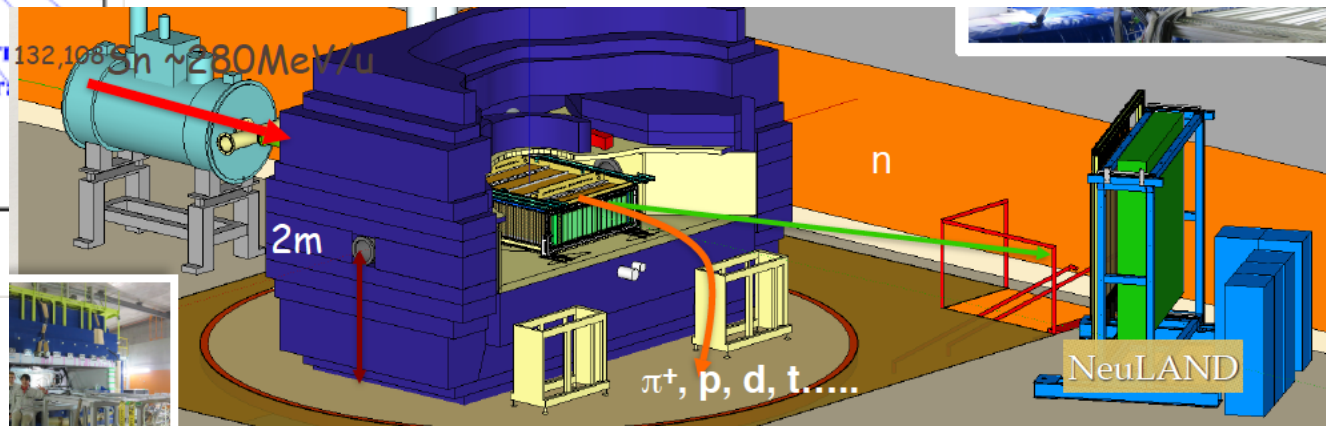
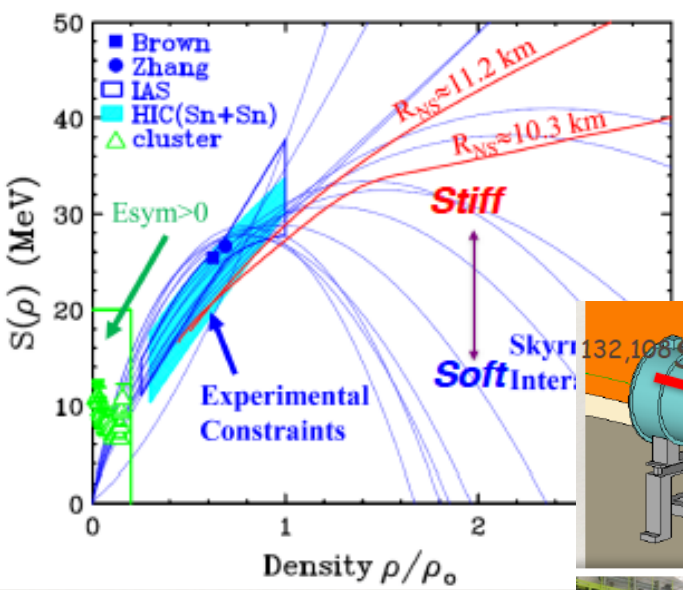
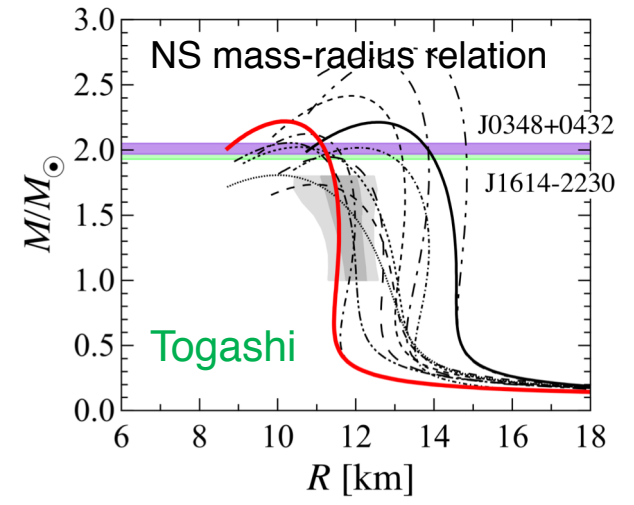
**However we still have  
 only one event:**

# EOS - neutron star / supernova (p-n asymmetric ..)

Gravitational wave Ando  
 wave from  $\rightarrow$  tidal deformability  $\rightarrow$  softness of EOS

Theoretical EOS Lattimer, Togashi  
 realistic nuclear forces ...

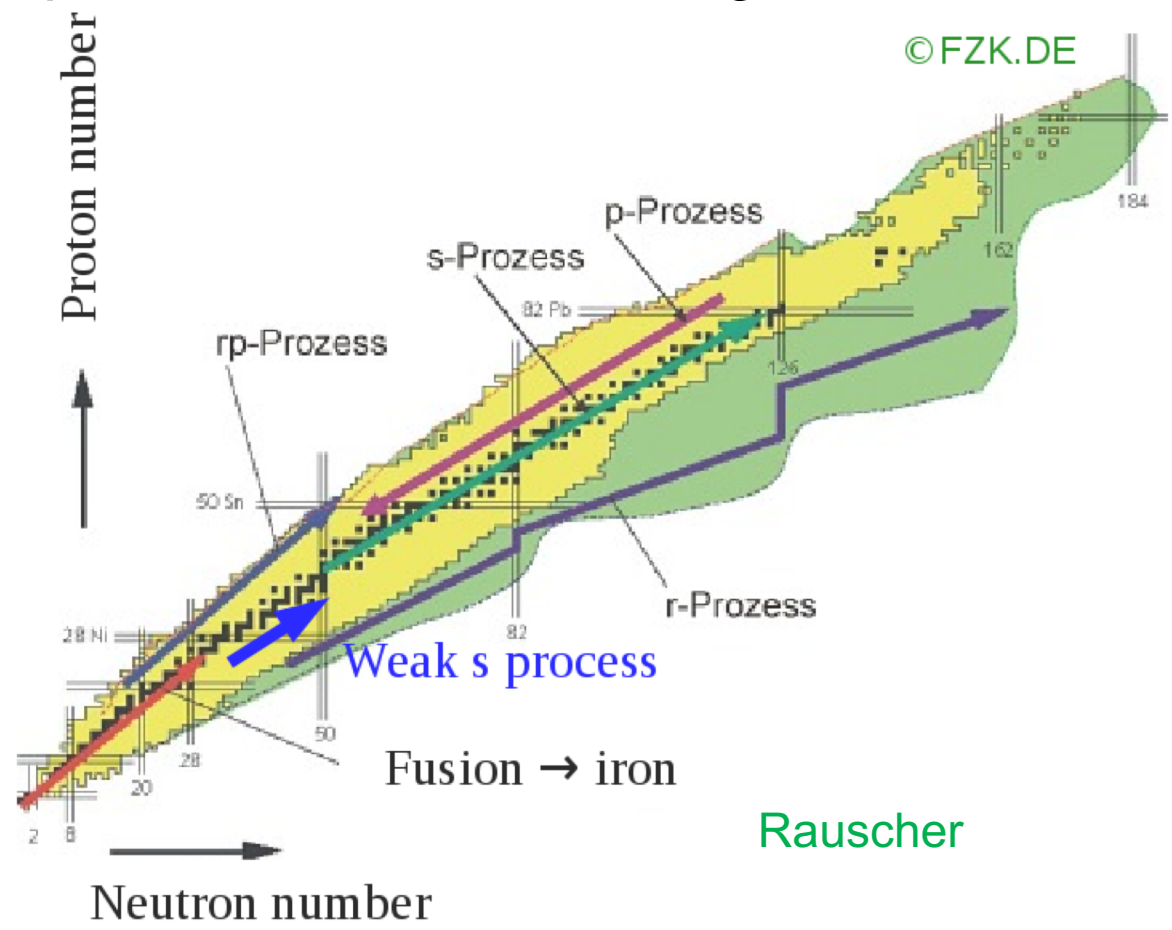
Nuclear experiment (HI collisions) Kurata-Nishimura  
 n-rich radioactive isotope beams at RIKEN RIBF  
 alpha-cluster?



July 2019

# Nucleosynthesis - Origin of Matter

various processes (chains) recognized



# Nucleosynthesis - Origin of Matter

What I learned:

various processes (chains) recognized

pp, CNO, ... , s, r, rp, p,  $\gamma$ , vp, ...

nuclear processes?  $\Leftarrow$  experiment, theory  
reactions, decays, mass (Q), fission, ..

sites ?  $\Leftarrow$  simulation (theory) on stellar (chemical) evolution  
BigBang, Stars, AGB, NS merger, SNs, ...

(element, isotope) abundance  $\Leftarrow$  observation, material analysis\*

# They are all related. *c.f.* Error impact analysis by [Rauscher](#).

\* including meteorites (even lab. exp. [Takigawa](#))

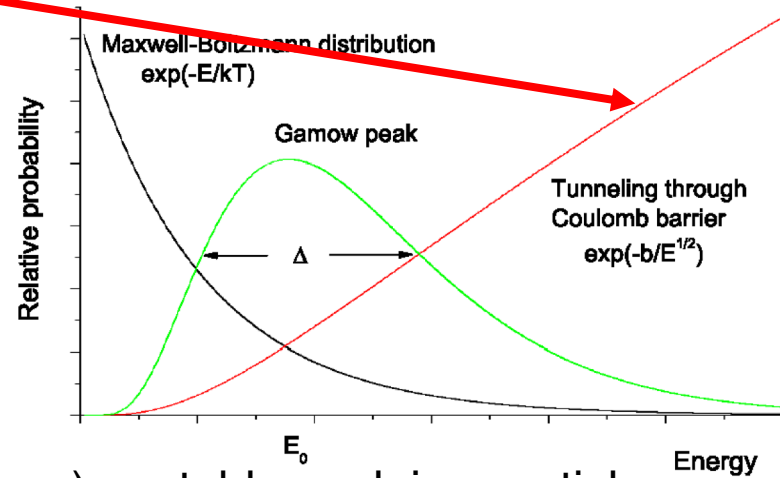
# Nucleosynthesis - nuclear reactions

microphysics

$$P_{12} = \rho_1 \rho_2 \langle \sigma v \rangle$$

$$\langle \sigma v \rangle = \left( \frac{8}{\pi \mu_{12} (kT)^3} \right)^{1/2} \int dE \sigma(E) E \exp\left[-\frac{E}{kT}\right]$$

$\rho, T \leftarrow$  environment



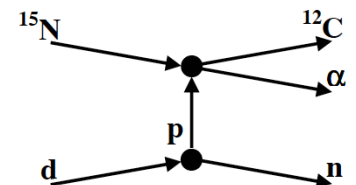
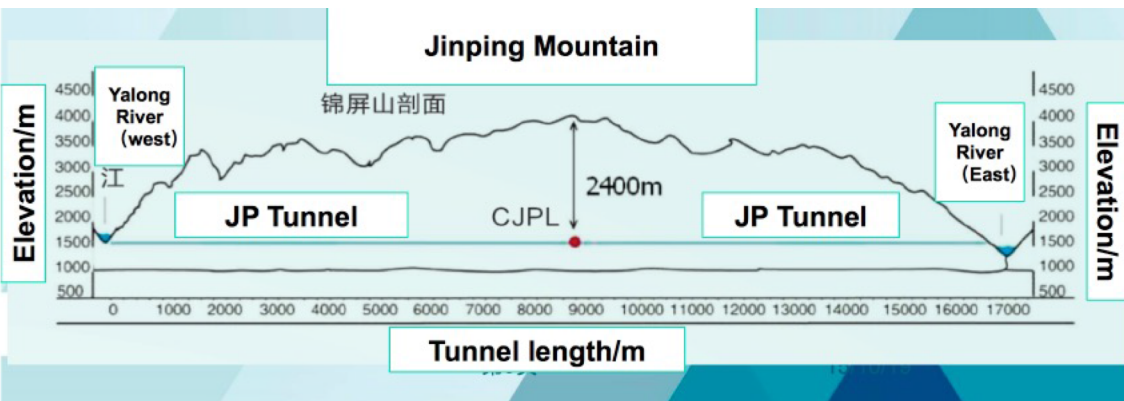
small **cross sections**, involving (sometimes) unstable nuclei or particles

underground experiments JUNA Liu

smart methods THM Cherubini, Pizzone, Surrogate Imai

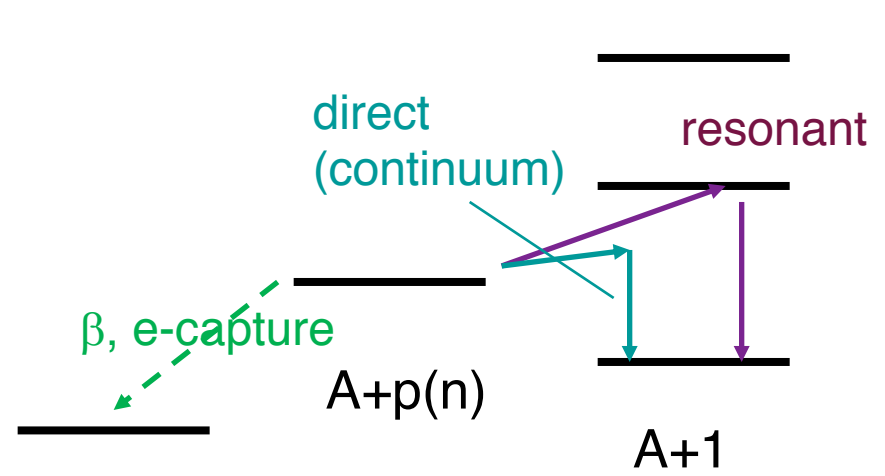
$\gamma$ -decay without measuring  $\gamma$  Kawabata

RI beam facilities RIBF, HIAF, RAON, FRIB, ... , GSI in-ring Glorius

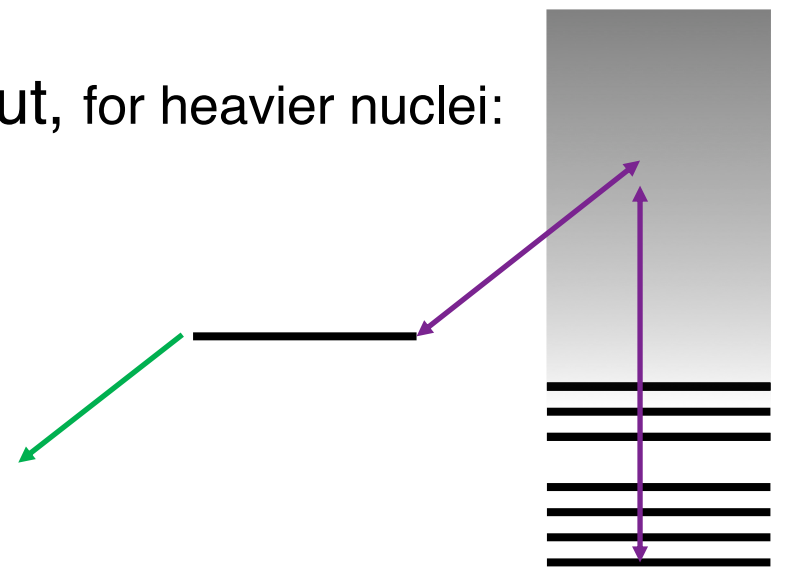


# Nucleosynthesis - nuclear reactions - 2

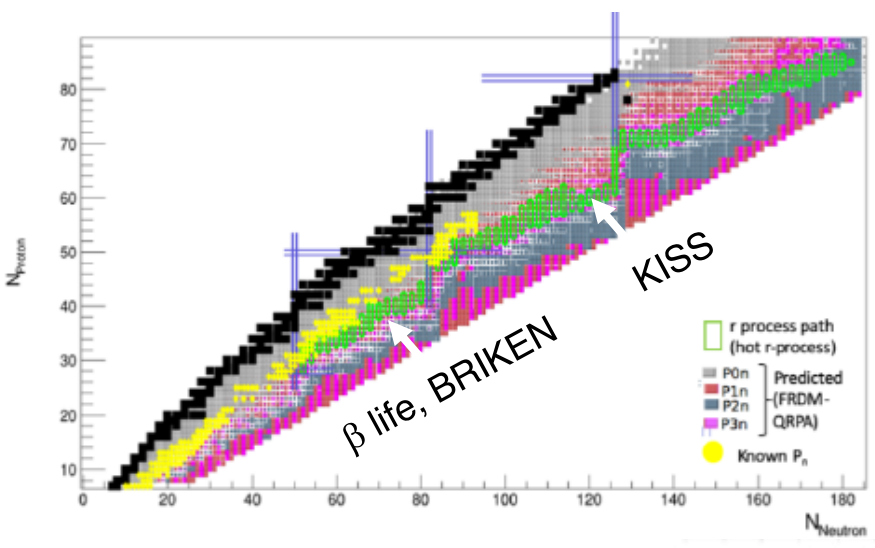
“Typically”...



But, for heavier nuclei:



Forward-backward equilibrium for explosive cases (e.g. r-process)  
 →  $Q$  or mass,  $\beta$ ,  $\beta$ -delayed n  
 BRIKEN Phong, KISS Miyatake  
 IMP Tang



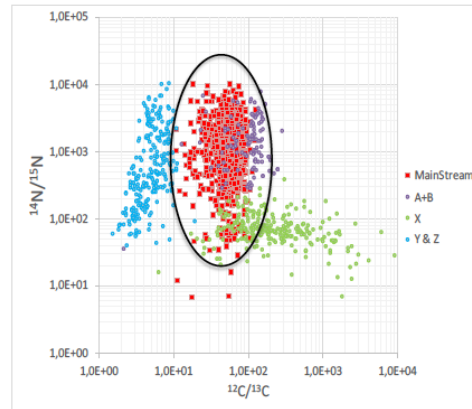
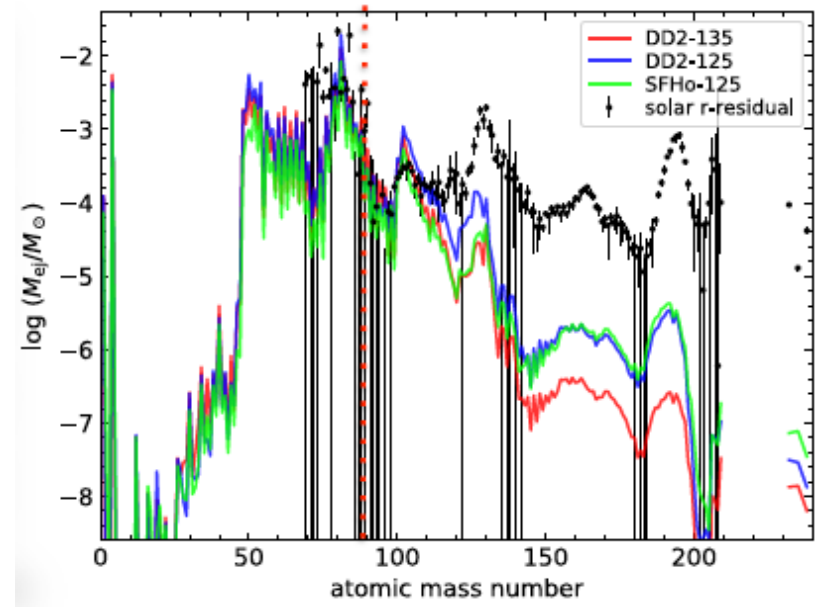
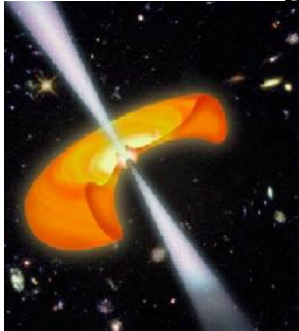
# Nucleosynthesis - sites

r process

Kilonova (NS-NS merger)

Simulations produce only few heavy r-nuclei **Wanajo**

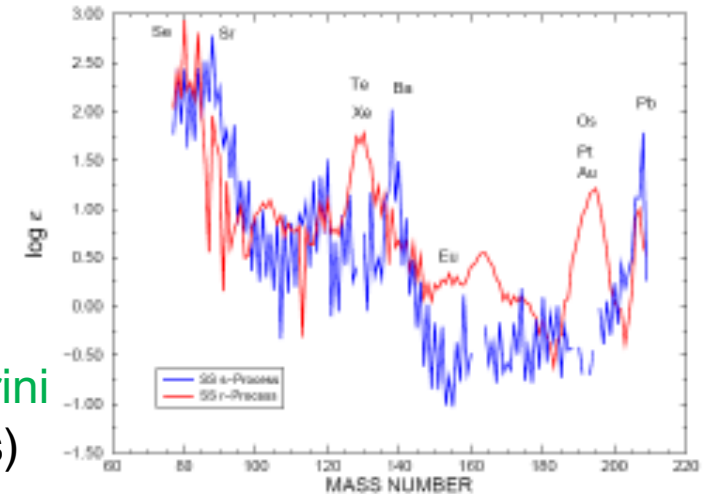
Magneto-rotational supernovae may produce heavy r-nuclei **Nishimura**



s process

presolar grains from AGBs **Palmerini**  
(**isotope** separation for meteorites)

Solar System Abundances  
s-Process and r-Process

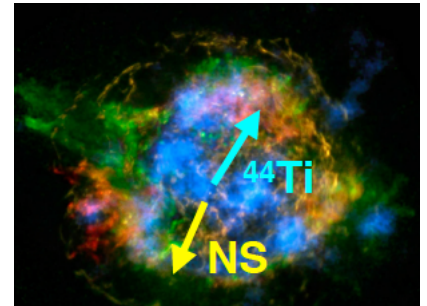




# Super novae

Nuclear astronomy (line  $\gamma$ -rays from  $^{56}\text{Ni}$ ,  $^{44}\text{Ti}$ ,  $^{26}\text{Al}$  and ...) [Diehl](#)

X,  $\gamma$ - (w. red shift) images v.s. nature of core collapse SN explosion [Yamaguchi](#)



State-of-art 3D simulation of core collapse SN  
still needs refinements for strong explosion [Takiwaki](#)

Peculiar 1987A could be a binary merger\*? [Ono](#)

\* followed by core collapse



# Tough questions exist.

*e.g.*

${}^7\text{Li}$  production in BigBang nucleosynthesis - inconsistent with other products

Cosmological solutions? **Mathews**

Search for destruction processes (toward high precision network)

**Coc, Hayakawa, Ishihkawa**

Non standard physics (time dependent quark mass) **Mori**

The **problem** not firmly resolved.

of course

dark matter (energy)

and more ...

# This field ...

There exist some good blocks (sub-fields), and recent development is rather remarkable, but

Our knowledge is still quite limited  
to build an entire view of **Origin of Matter and Evolution of Galaxies.**

→ a lot of room for new ideas to connect them.



→ ...

Let's enjoy!  
We shall meet and discuss again.

July 2019

Kyoto