1st RAON Users Workshop
April 3-5, 2019, IBS, Daejeon, Korea

Impact of RIB Science & υ Physics on Merger, Supernova and Big-Bang Nucleosynthesis

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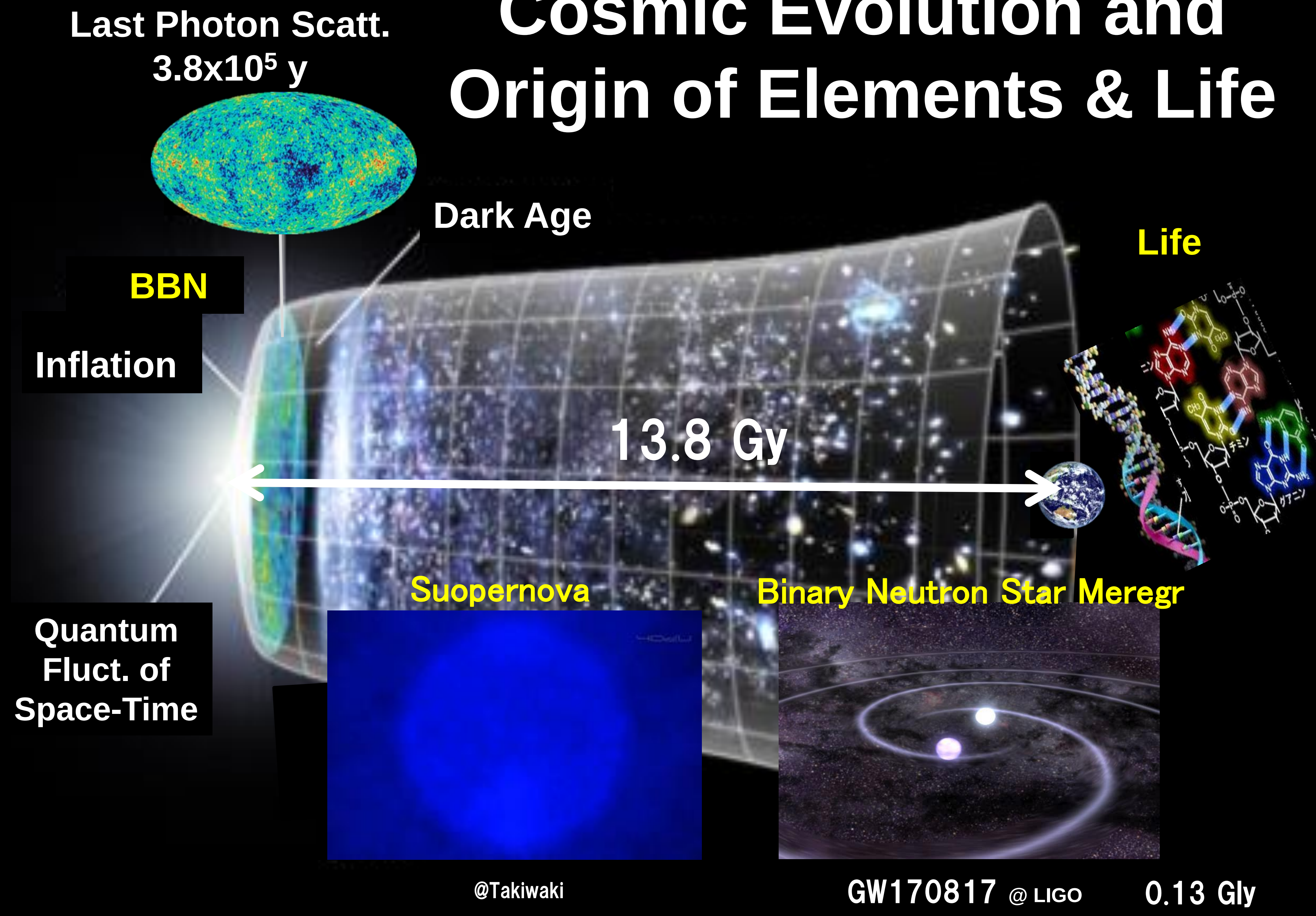
The University of Tokyo
Beihang University

Cosmic Evolution and Origin of Elements & Life



Content

1. Big-Bang Lithium Problem

Nuclear Reactions vs. New Physics ?

2. Cosmic Evolution & Origin of R-process

Neutron Star Merger vs. Supernova ?

3. Nucleosynthesis and ν Mass-Hierarchy

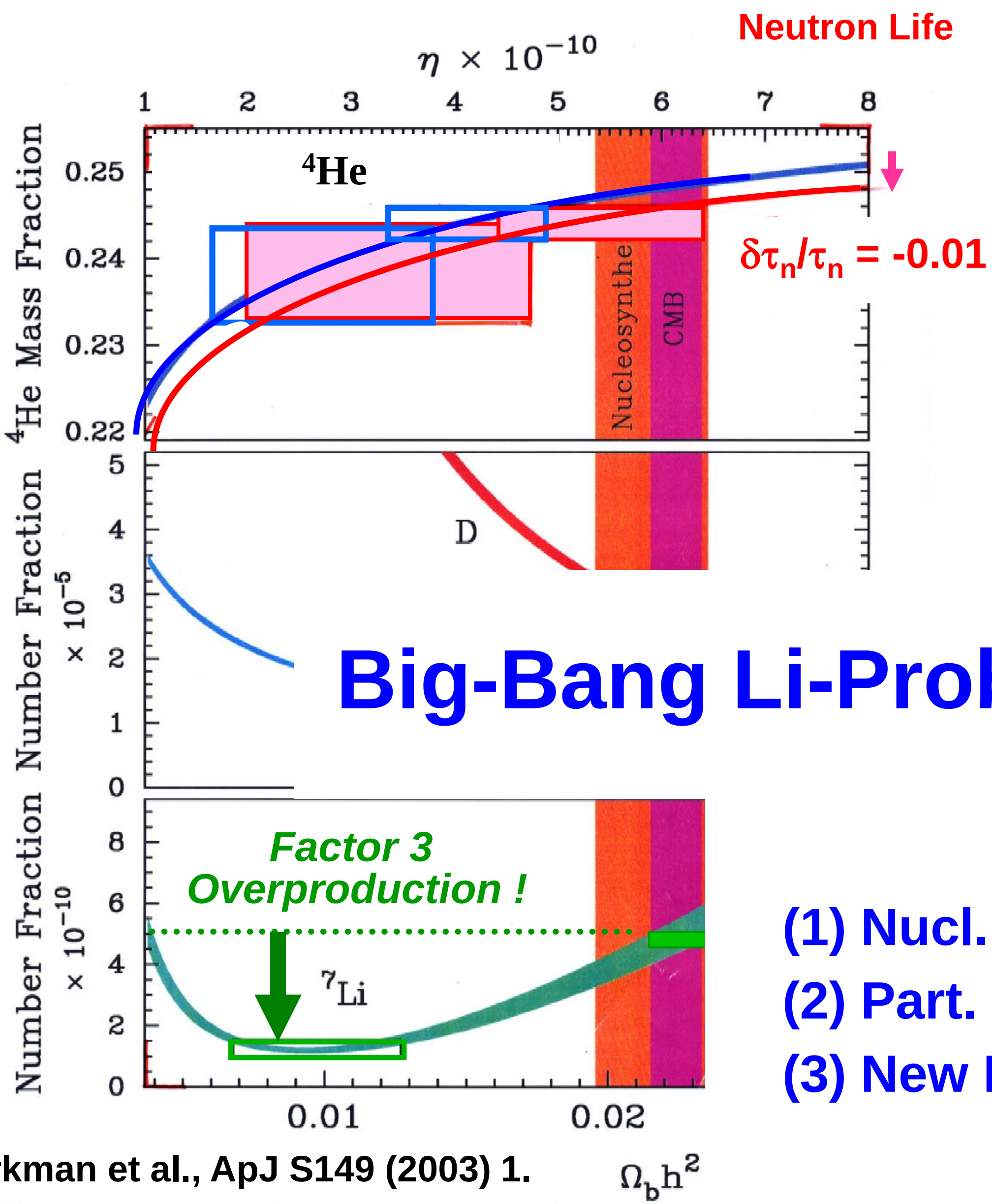
Collective Oscillation ?

Origin Amino Acid and Life

Chiral Selection vs. Neutrinos ?

Big-Bang Nucleosynthesis, Precise Science ~1%

Smith, Kawano & Malaney, ApJ S85(2003) 219; Mathews, Kajino & Shima, PRD71 (2005) 21302 (R).



Kirkman et al., ApJ S149 (2003) 1.

Big-Bang Li-Problem !

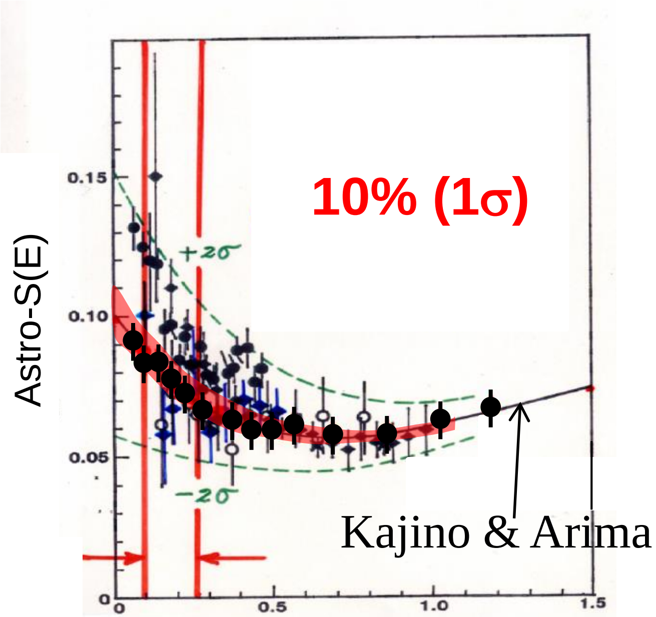
Solutions ?

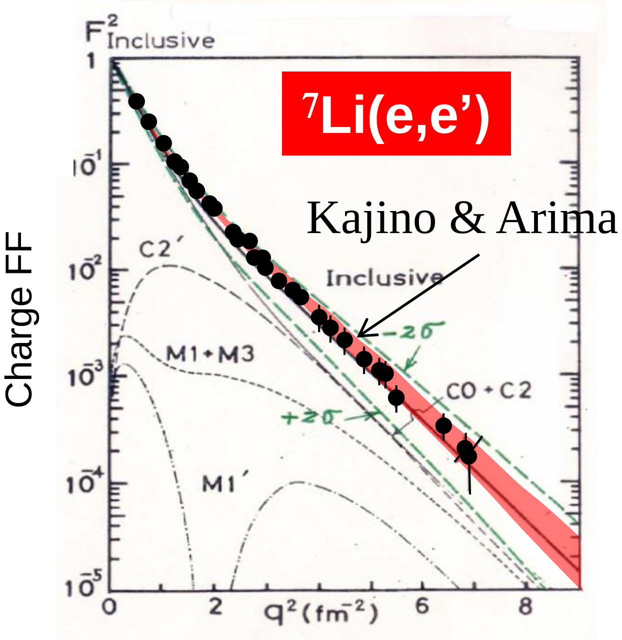
(1) Nucl. Phys.; Uncertain React. Rates

(2) Part. Phys. ; Relic DM Particles

(3) New Phys. ; ???

$^{4}He(^{3}H,\gamma)^{7}Li$ ⟷ **Mirror Conjugation** ⟷ $^{4}He(^{3}He,\gamma)^{7}Be$



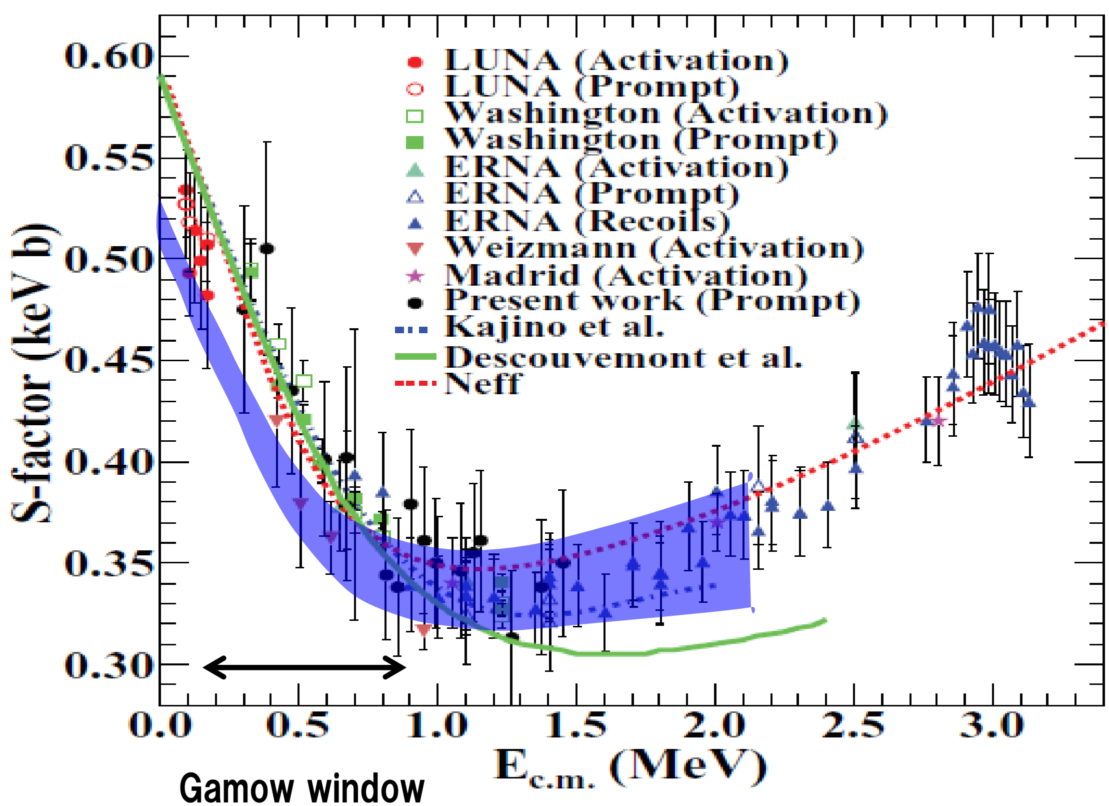


Adelberger, RMP 83 (2011),195.

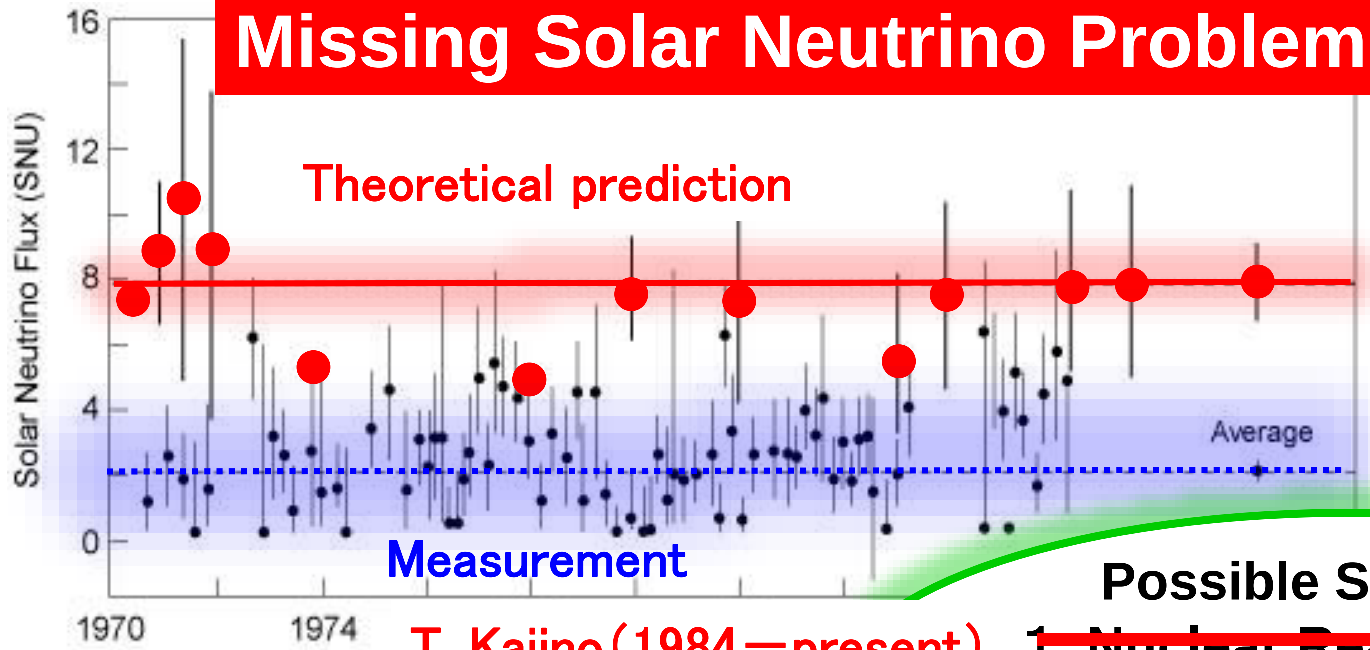
5% (1σ), uncertain !

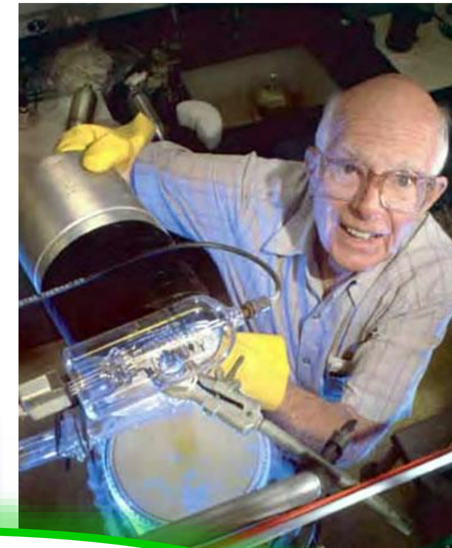
Kajino & Arima, PRL 52 (1984), 739; NP A413 (1084), 323; NP A460 (1986), 559; ApJ 319 (1987), 531, Neff, PRL 106 (2011), 042502, Dohet-Early et al., PL B757 (2016), 430.

$^{4}He(^{3}He,\gamma)^{7}Be$



Missing Solar Neutrino Problem

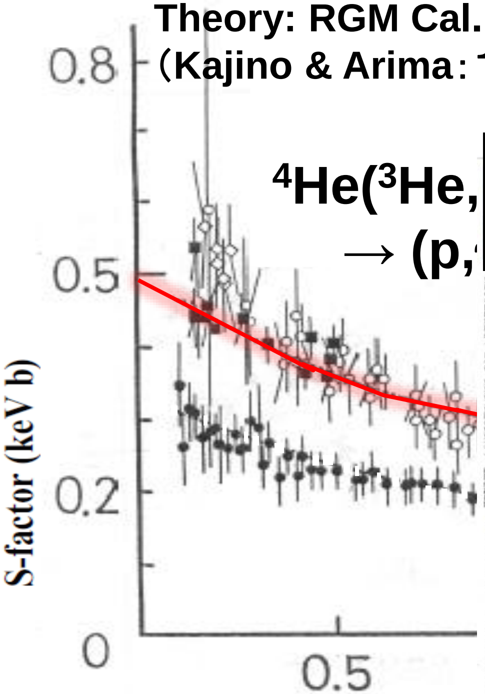




T. Kajino（1984－present）

J. Bahcall（1988）

Theory: RGM Cal. for Clus
(Kajino & Arima: 1984－



Possible Solution？

1. ~~Nuclear Reaction Rates~~

2. ~~Solar Model~~

3. Unknown Neutrino Nature

Nobel Prize to Kajita for ν-Oscillation

BBN Theory stands on precise nuclear physics.

Relevant nuclear reaction rates, ACCURATE enough within 10－25% ???

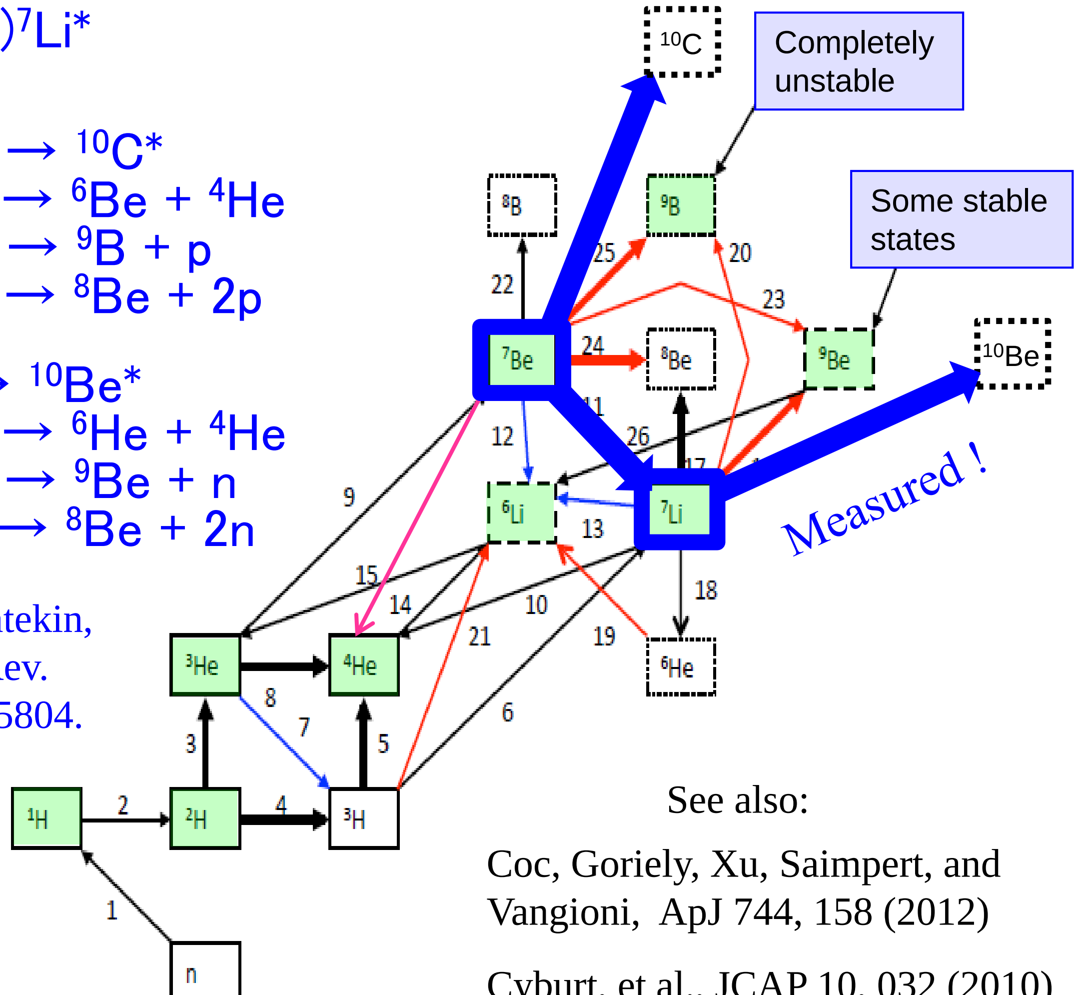
If YES ➡ **Uncertainty of nuclear reaction rate may not be the main source of Li discrepancy of factor 3-4 !**

$^{7}Be(n, p_1)^{7}Li^*$

$^{7}Be + ^{3}He \rightarrow ^{10}C^*$
$\rightarrow ^{6}Be + ^{4}He$
$\rightarrow ^{9}B + p$
$\rightarrow ^{8}Be + 2p$

$^{7}Li + ^{3}H \rightarrow ^{10}Be^*$
$\rightarrow ^{6}He + ^{4}He$
$\rightarrow ^{9}Be + n$
$\rightarrow ^{8}Be + 2n$

Famiano, Balantekin, Kajino, Phys. Rev. C93 (2016), 045804.



R. Boyd, C. Brune, G. Fuller, M. Smith, Phys. Rev. D82, 105005 (2010).

See also:

Coc, Goriely, Xu, Saimpert, and Vangioni, ApJ 744, 158 (2012)

Cyburt, et al., JCAP 10, 032 (2010)

Reaction Key	
$n \rightarrow {}^{1}H$	1
${}^{1}H(n,g){}^{2}H$	2
${}^{2}H({}^{2}H,n){}^{3}He$	3
${}^{2}H({}^{1}H,g){}^{3}He$	
${}^{2}H({}^{2}H,{}^{1}H){}^{3}H$	4
${}^{2}H(n,g){}^{3}H$	
${}^{3}H({}^{2}H,n){}^{4}He$	5
${}^{3}H({}^{1}H,g){}^{4}He$	
${}^{3}H({}^{4}He,g){}^{7}Li$	6
${}^{3}He(n,{}^{1}H){}^{3}H$	7
${}^{3}He({}^{2}H,{}^{1}H){}^{4}He$	8
${}^{3}He(n,g){}^{4}He$	
${}^{3}He({}^{4}He,g){}^{7}Be$	9
${}^{7}Li({}^{1}H,{}^{3}He){}^{4}He$	10
${}^{7}Be(n,{}^{1}H){}^{7}Li$	11
${}^{7}Be(n,{}^{2}H){}^{6}Li$	12
${}^{7}Li(n,2n){}^{6}Li$	13

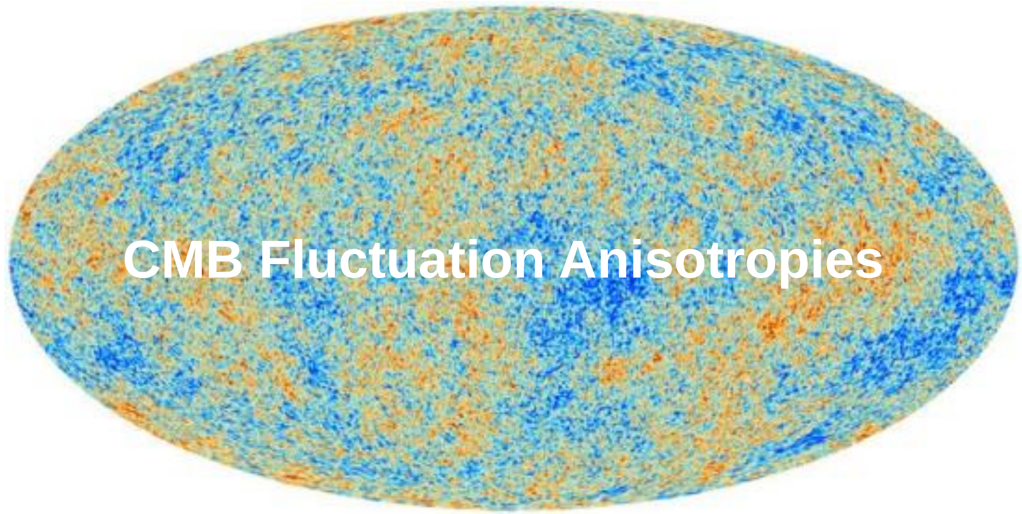
Reaction Key	
${}^{4}He({}^{2}H,g){}^{6}Li$	14
${}^{6}Li({}^{1}H,{}^{4}He){}^{3}He$	15
${}^{7}Li({}^{3}H,n){}^{9}Be$	16
${}^{7}Li({}^{3}He,{}^{1}H){}^{9}Be$	
${}^{7}Li({}^{2}H,n){}^{8}Be$	17
${}^{7}Li({}^{1}H,g){}^{8}Be$	
${}^{7}Li({}^{3}He,{}^{2}H){}^{8}Be$	
${}^{8}Be \rightarrow {}^{4}He+{}^{4}He$	
${}^{7}Li({}^{3}H,{}^{4}He){}^{6}He$	18
${}^{6}He \rightarrow {}^{6}Li$ or ${}^{4}He+{}^{2}H$	19
${}^{7}Li({}^{3}He,n){}^{9}B$	20
${}^{3}He({}^{3}H,g){}^{6}Li$	21
${}^{7}Be({}^{1}H,g){}^{8}B$	22
${}^{7}Be({}^{3}H,{}^{1}H){}^{9}Be$	23
${}^{7}Be({}^{2}H,{}^{1}H){}^{8}Be$	24
${}^{7}Be({}^{3}H,{}^{2}H){}^{8}Be$	
${}^{7}Be({}^{3}He,{}^{1}H){}^{9}B$	25
${}^{7}Be({}^{3}H,n){}^{9}B$	
${}^{9}Be({}^{1}H,{}^{4}He){}^{6}Li$	26

The Power of Quantum Mechanics and Relativity

Quantum Systems of Particles and Nuclei

$$n_i(p)dp = \frac{1}{2\pi^2} g_i \, p^2 \left[\exp\left(\frac{E_i(p) - \mu_i}{kT} \right) \pm 1 \right]^{-1} dp$$

- Elementary Particles; Relativistic
- Atomic Nuclei; Non-relativistic
- Fermi vs. Bose Statistics
  Planckian
  Maxwell-Boltzmann



Expansion Dynamics

- Einstein Eq.
- Fluid Dynamic. Eq.

$$H^2(t) = \left(\frac{1}{R} \frac{dR}{dt} \right)^2 = \frac{8\pi G}{3} \rho + \frac{\Lambda}{3} -$$

Numerical simulation for SNe etc

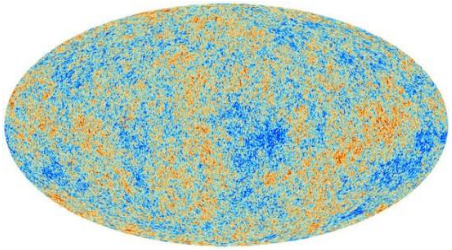
Flucuations ?

Reaction Network

$$dn_i/dt = \sum_{kl\,j} <\sigma_{kl \to ij}\, v> n_k n_l - \sum_{j\,kl} <\sigma_{ij \to kl}\, v> n_i n_j - n_i/\tau_i$$

- Nuclear (strong), Electro-magnetic, and Weak interactions

Primordial Magnetic Field (PMF) constrained from CMB



$$\rho_\lambda = \frac{\langle B^2 \rangle}{8\pi} = \frac{1}{8\pi}\int_{k_{[min]}}^{k_{[max]}} \frac{dk}{k}\frac{k^3}{2\pi^2} P_{[PMF]}(k)$$

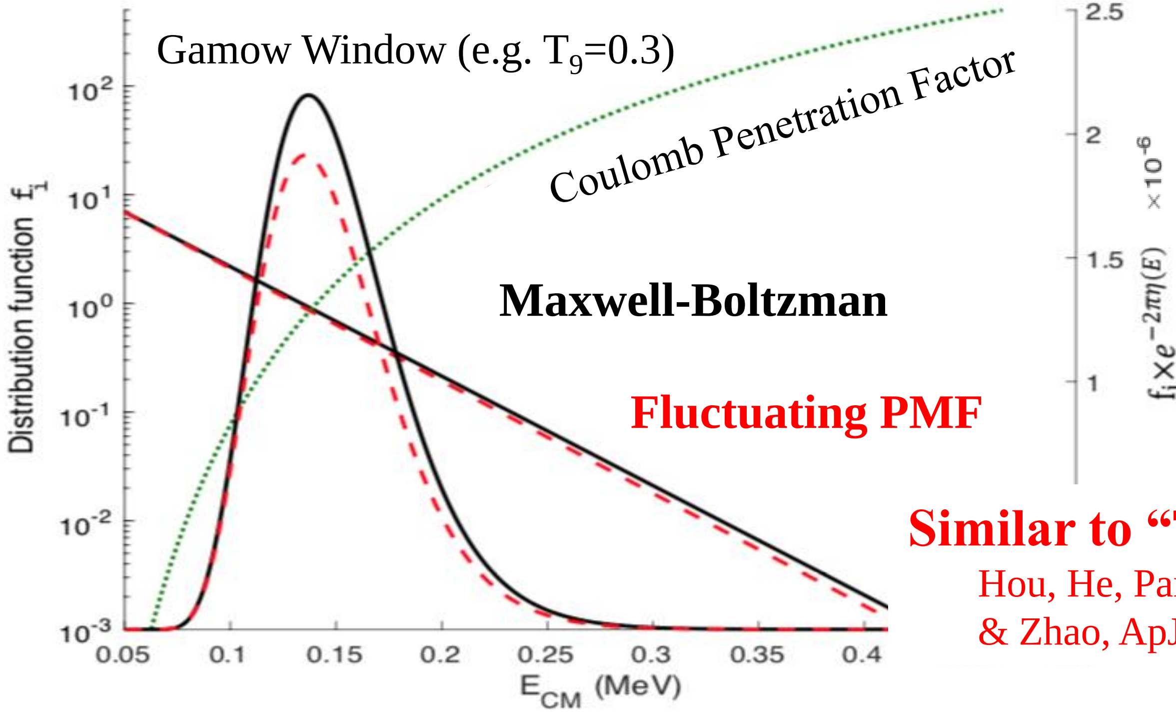
$$B^2 \propto P_{[PMF]} = Ak^{n_B}$$ *CMB power law spectrum*

Thermonuclear Reaction Rate: $$\langle \sigma v \rangle (T) = \left(\frac{\mu}{2\pi kT}\right)^{3/2} \int_0^\infty v \cdot \sigma(v) \cdot P(v) \cdot 4\pi v^2 dv$$

$$f(\beta) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(\frac{\pi g}{30}\cdot(T_{eff}^4 - \beta^{-4}) - \rho_\lambda)^2}{2\sigma^2}\right] \cdot \frac{2\pi g}{15}\beta^{-5}$$

$$P(v) = \int d\beta p(v|\beta) f(\beta)$$

Temp. Fluctuation
→ various $T=\beta^{-1}$



Yamazaki, Kajino, Mathews, Ichiki
Phys. Rep. 517 (2012), 141.

Luo, Kajino, Kusakabe, Mathews,
ApJ. 872 (2019), 172 (9pp).

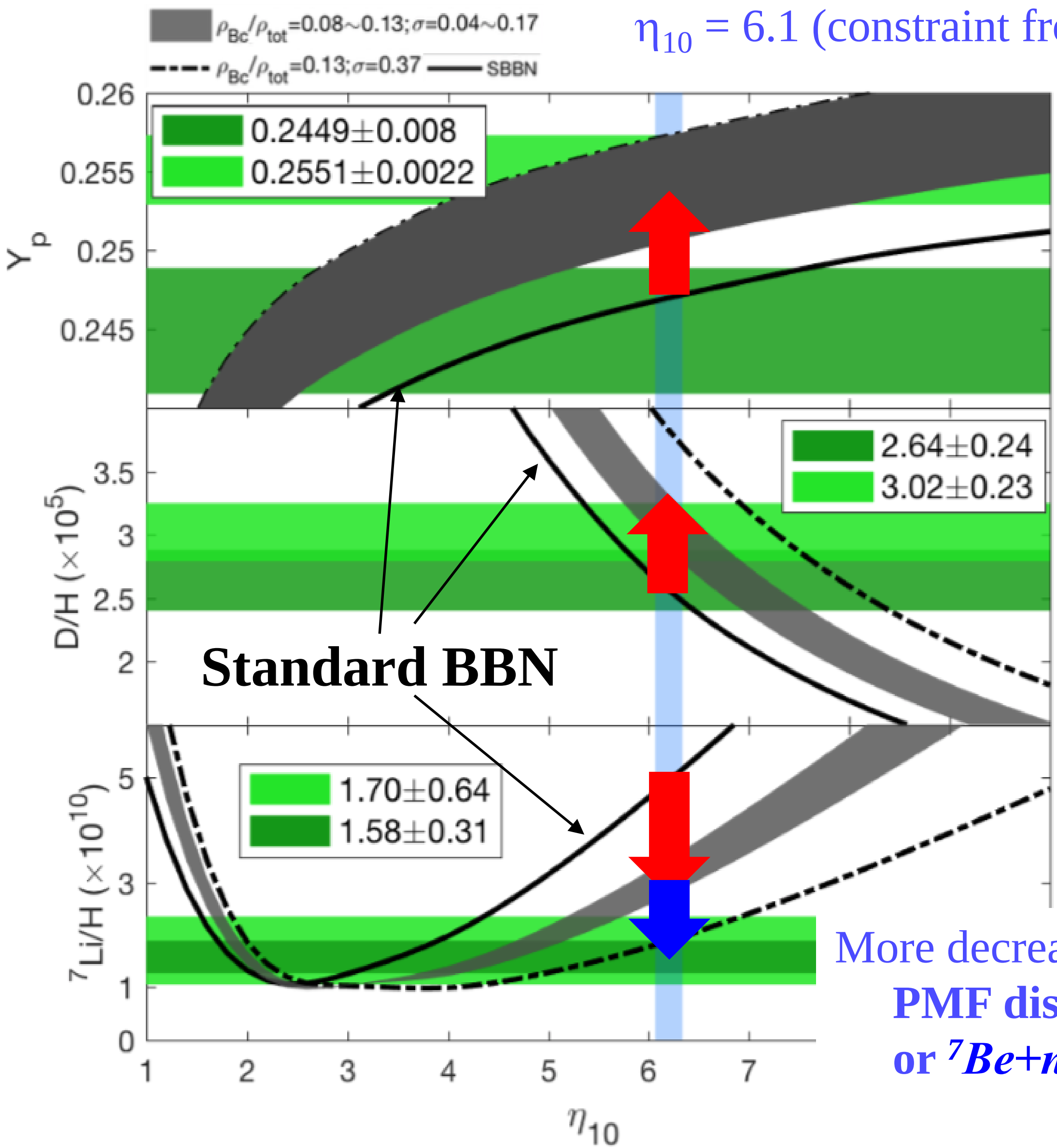
Similar to "Tsallis Distrib. (1<q)"

Hou, He, Parikh, Kahl, Bertulani, Kajino, Mathews
& Zhao, ApJ. 834 (2017), 165.

Fluctuating PMF: Non-MB distribution for BBN

Y.-D. Luo, T. Kajino, M. Kusakabe, and G. J. Mathews, ApJ. **872** (2019), 172 (9pp).

η_{10} = 6.1 (constraint from CMB)



Additional PMF accelerates cosmic expansion rate:

→ higher n/p ratio

→ higher ^4He

Destruction, quenched:

$^2H + ^2H \rightarrow p + ^3H$

$\rightarrow n + ^3He$

Production, quenched:

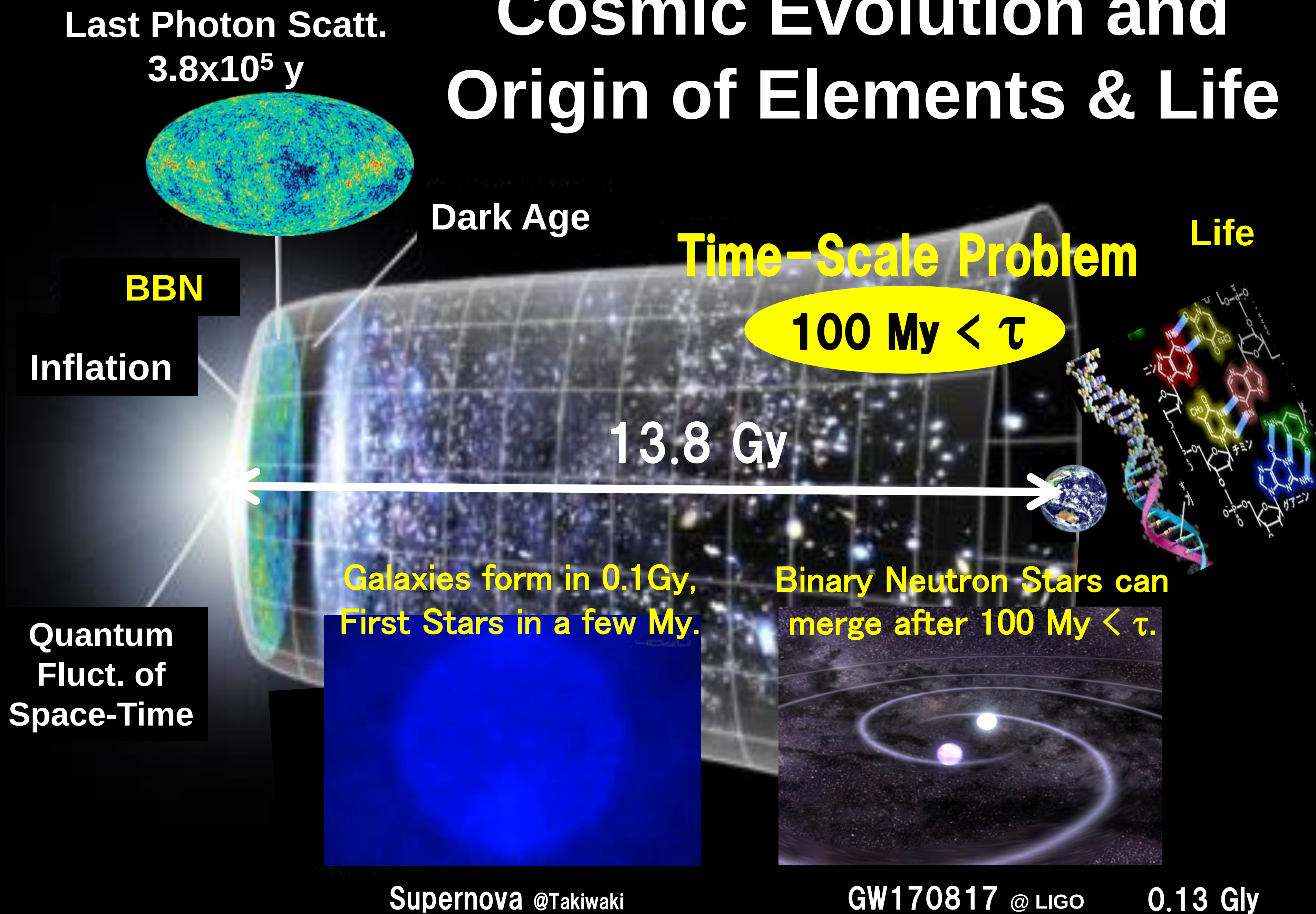
$^4He + ^3He \rightarrow ^7Be + \gamma$

More decrease of ^7Be may arise from:

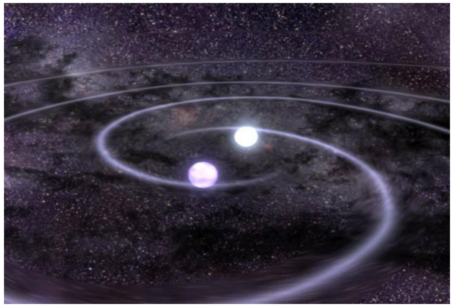
PMF dissipation, DM Particle decay,

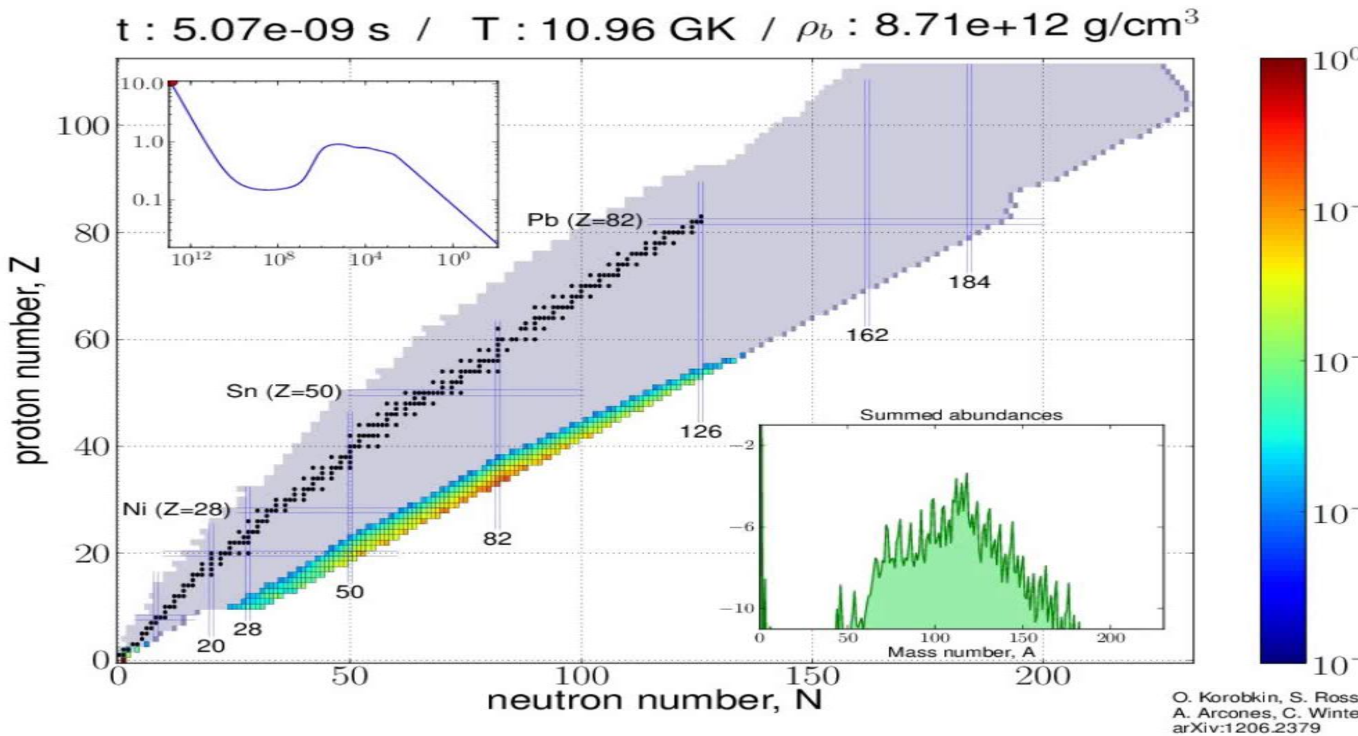
or $^7Be + n \rightarrow ^7Li^* + p_1$ & others ?

Cosmic Evolution and Origin of Elements & Life



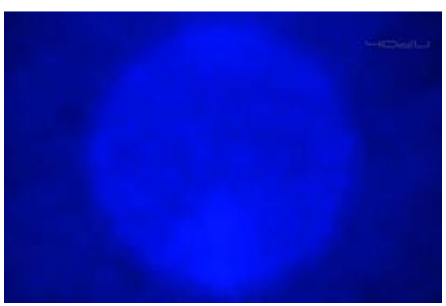
Neutron Star Merger

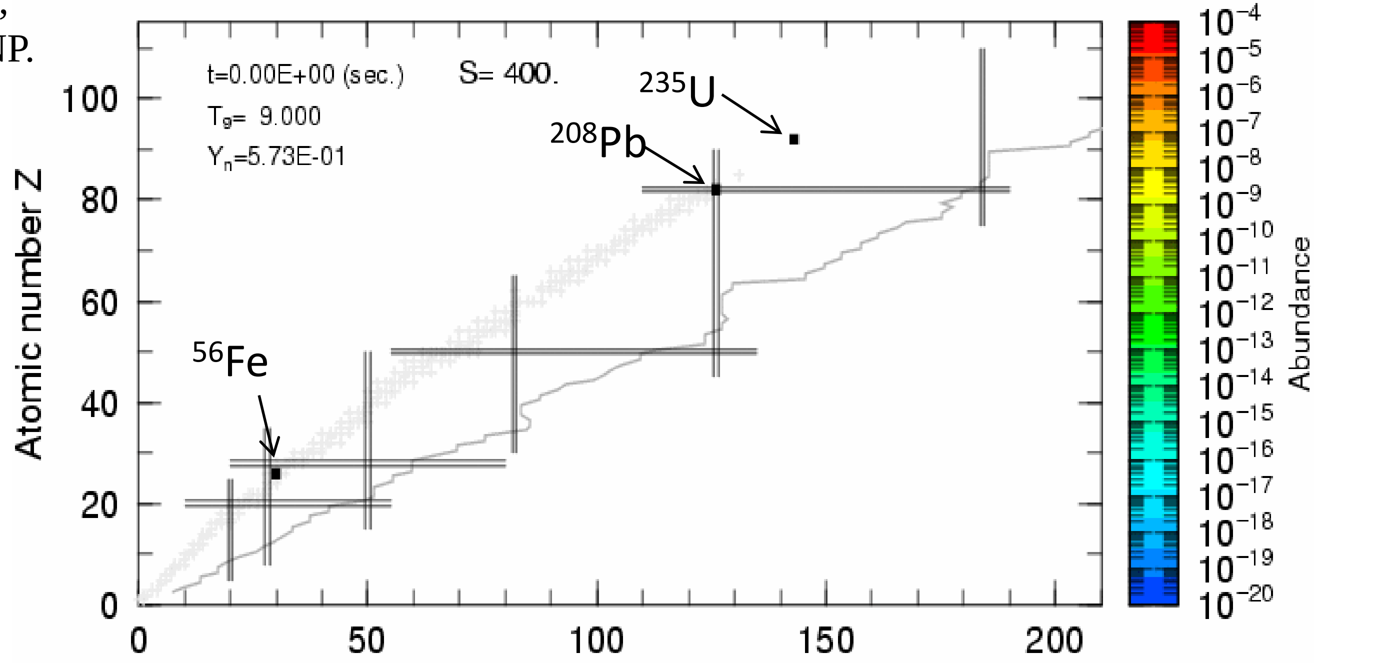


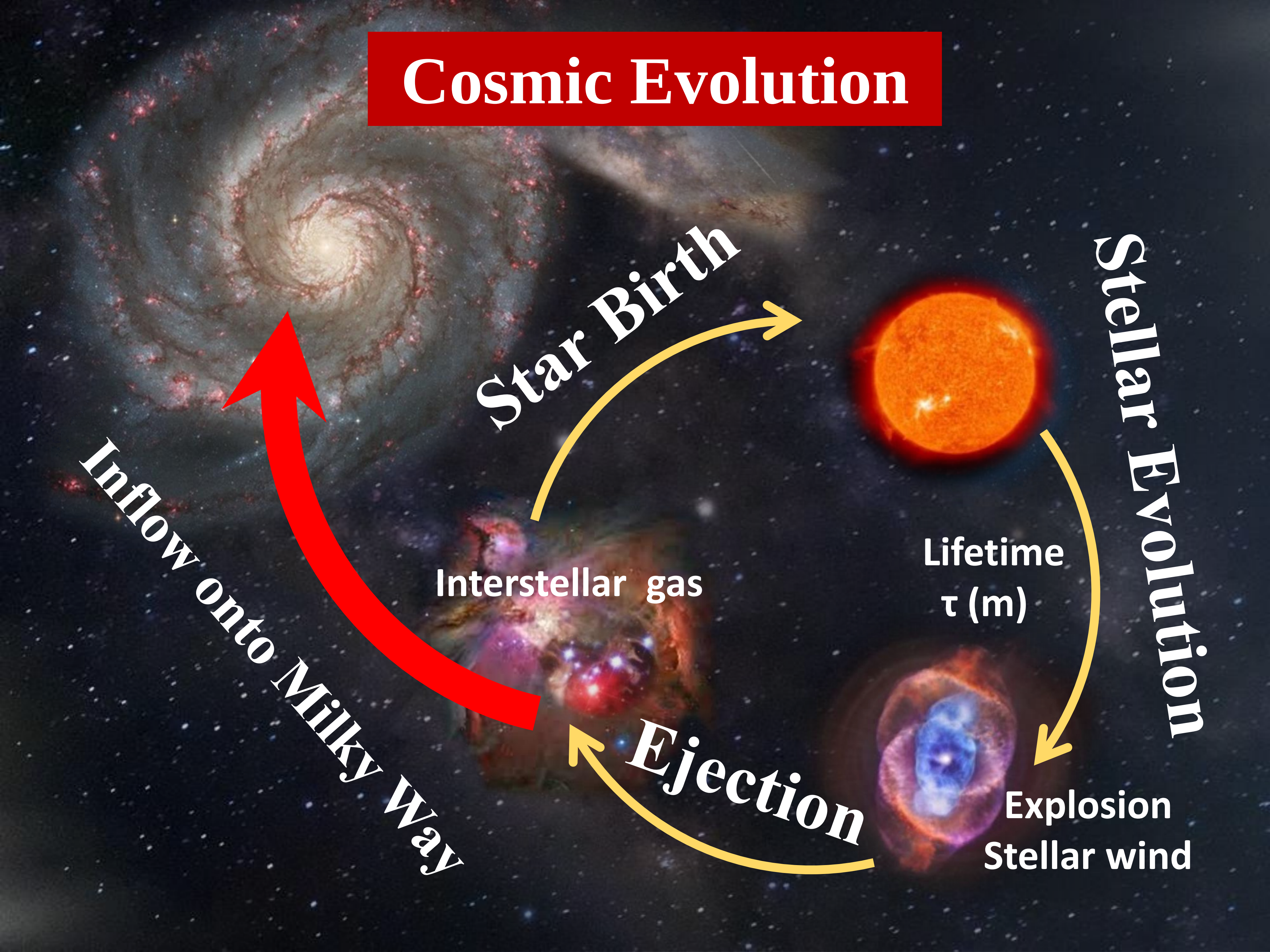


Shibagaki, Kajino, et al. (2016), ApJ 816, 79; Kajino & Mathews (2017), ROPP 80, 084901; Kajino, Aoki, Balantekin, Dihel, Famiano, Mathews (2019), PPNP.

Supernova (MHD Jet-SN)






Cosmic Evolution
Star Birth
Stellar Evolution
Lifetime
τ (m)
Explosion
Stellar wind
Ejection
Interstellar gas
Inflow onto Milky Way

Event Rate of SN & Merger

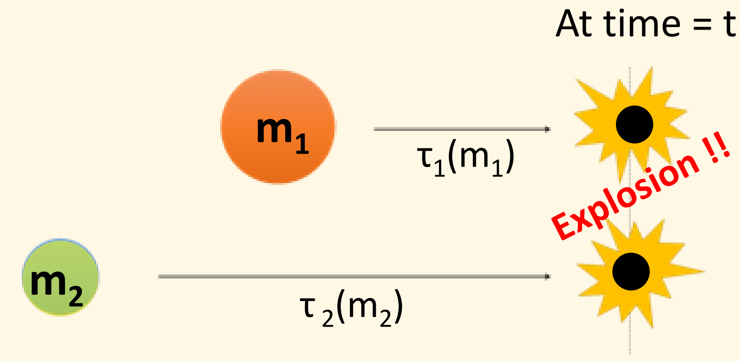
Supernova Rate :

$$R_{SNII} = \int_{m_l}^{m_h} \phi(m)\, B(t-\tau(m))\, dm$$

$\Phi(m)$: Initial mass function (Kroupa 2001, MNRAS)

$B(t)$: Star Formation Rate

1. Exp(-t) (Miller&Scalo 1979, ApJ)
2. Schmidt's law (Schmidt 1959, ApJ)



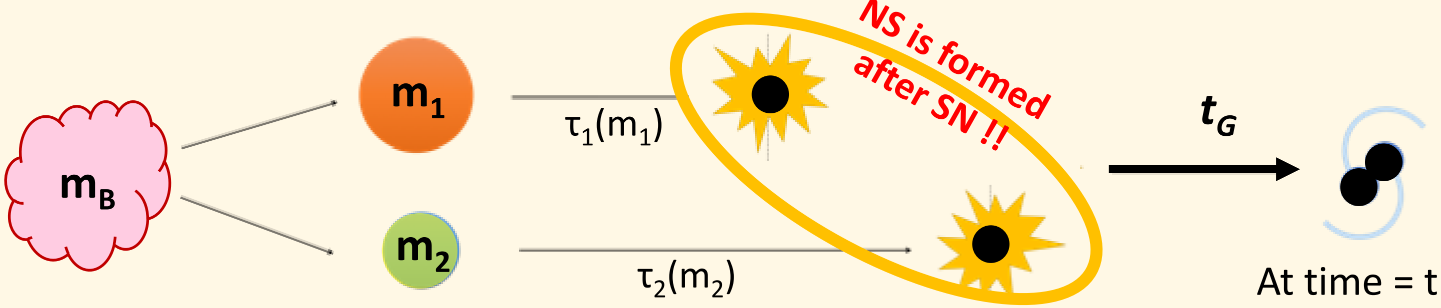
Neutron Star Merger Rate :

$$R_{NSM} = \epsilon_{NSM} \int_{m_l}^{m_h} dM_B\, \phi(M_B) \int_{q_l}^{1} dq\, f(q) \int_{a_l}^{a_h} da\, P(a)\, B(t-\tau(m_2)-t_G)$$

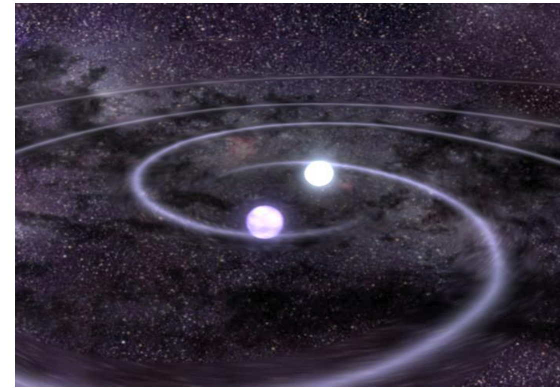
Coalescence time

f = m_2/m_1

a: separation of NS-binary

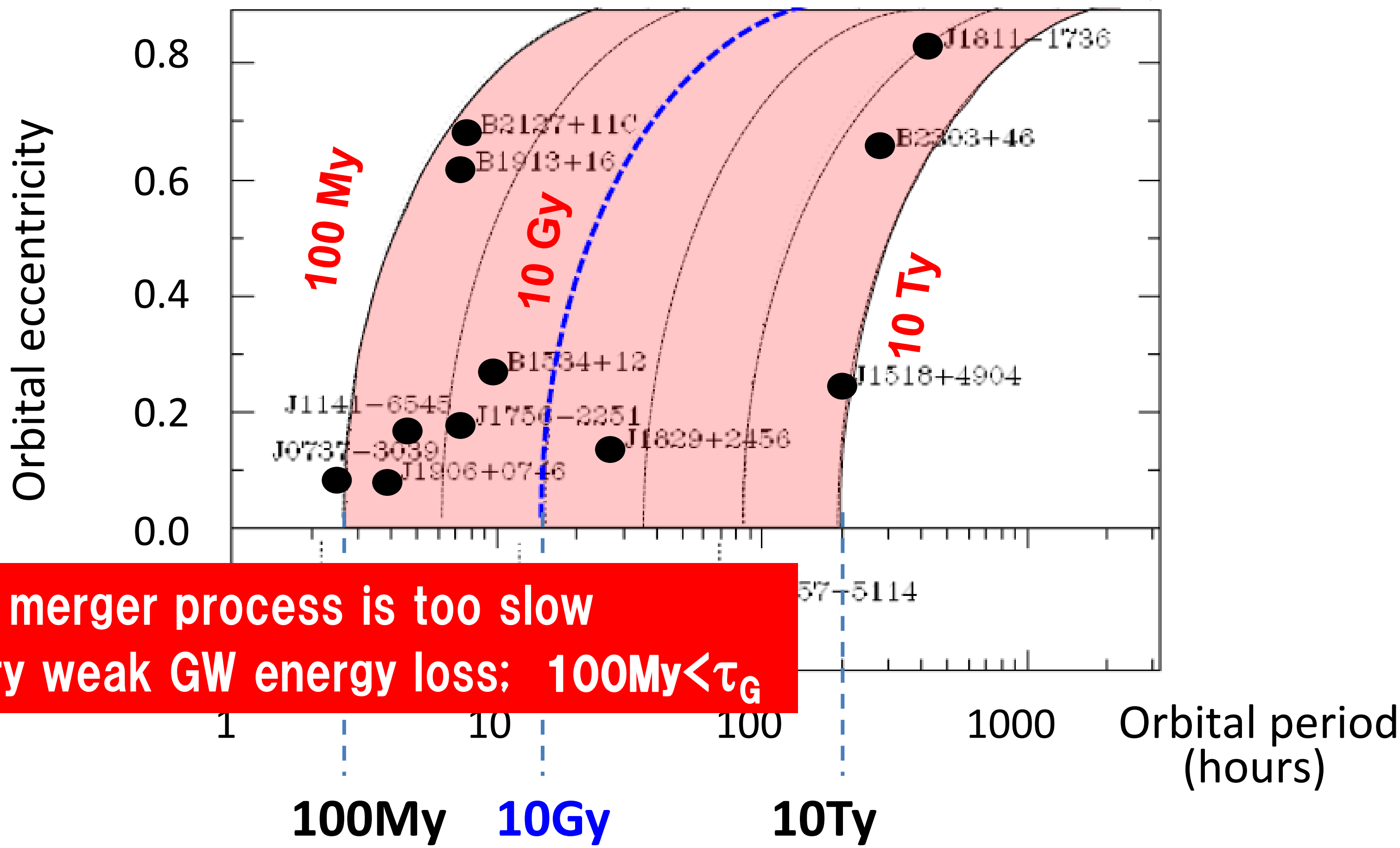


Merging Time Delay



$$\tau_G \simeq 9.83 \times 10^6 \text{ yr} \left(\frac{P_b}{\text{hr}}\right)^{8/3} \times \left(\frac{m_1 + m_2}{M_\odot}\right)^{-2/3} \left(\frac{\mu}{M_\odot}\right)^{-1} (1 - e^2)^{7/2}$$

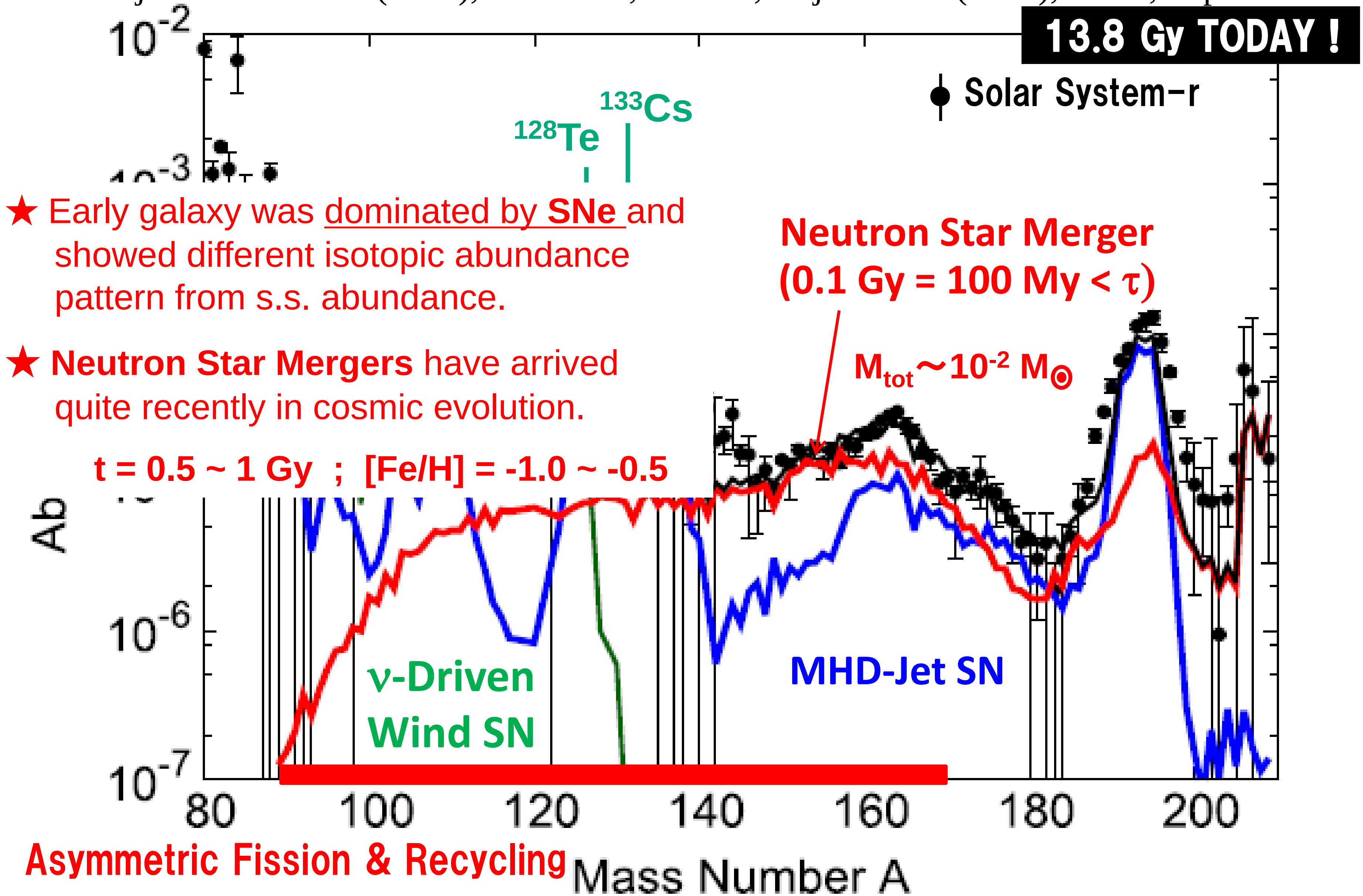
Lorimer, Living Rev. Rel. 11(2008), 8.



Binary merger process is too slow
for very weak GW energy loss: 100My<τ_G

Solar System r-Process Abundance

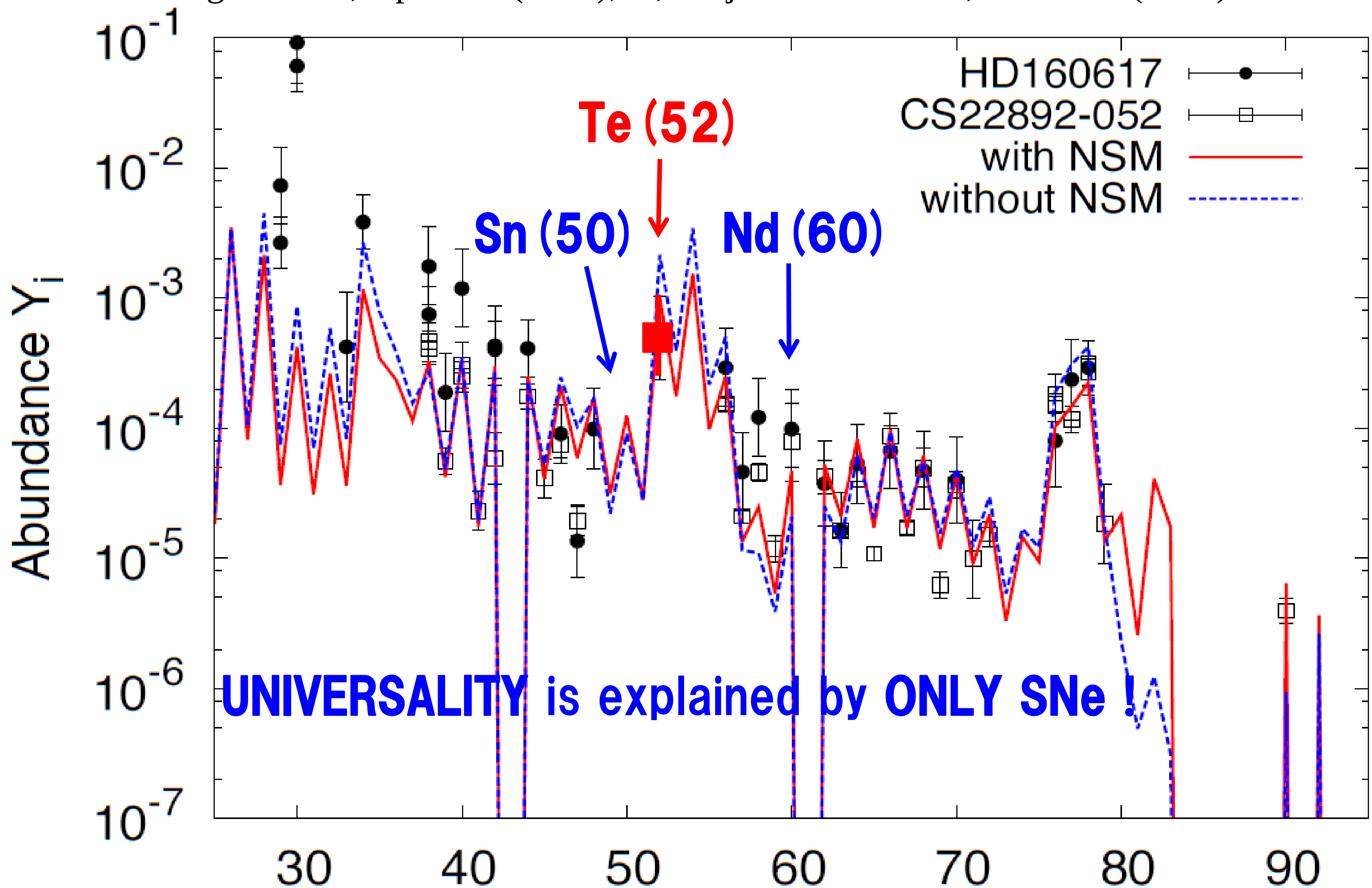
Shibagaki, Kajino, Chiba, Mathews, Nishimura & Lorusso (2016), ApJ 816, 79; ApJ (2018); Kajino & Mathews (2017), ROPP 80 , 084901; Kajino et al. (2019), PPNP, in press.



UNIVERSALITY !

Early Galaxy ⟺ TODAY

Shibagaki et al., ApJ. 816 (2016),79; Kajino & Mathews, ROPP **80** (2017) 08490.

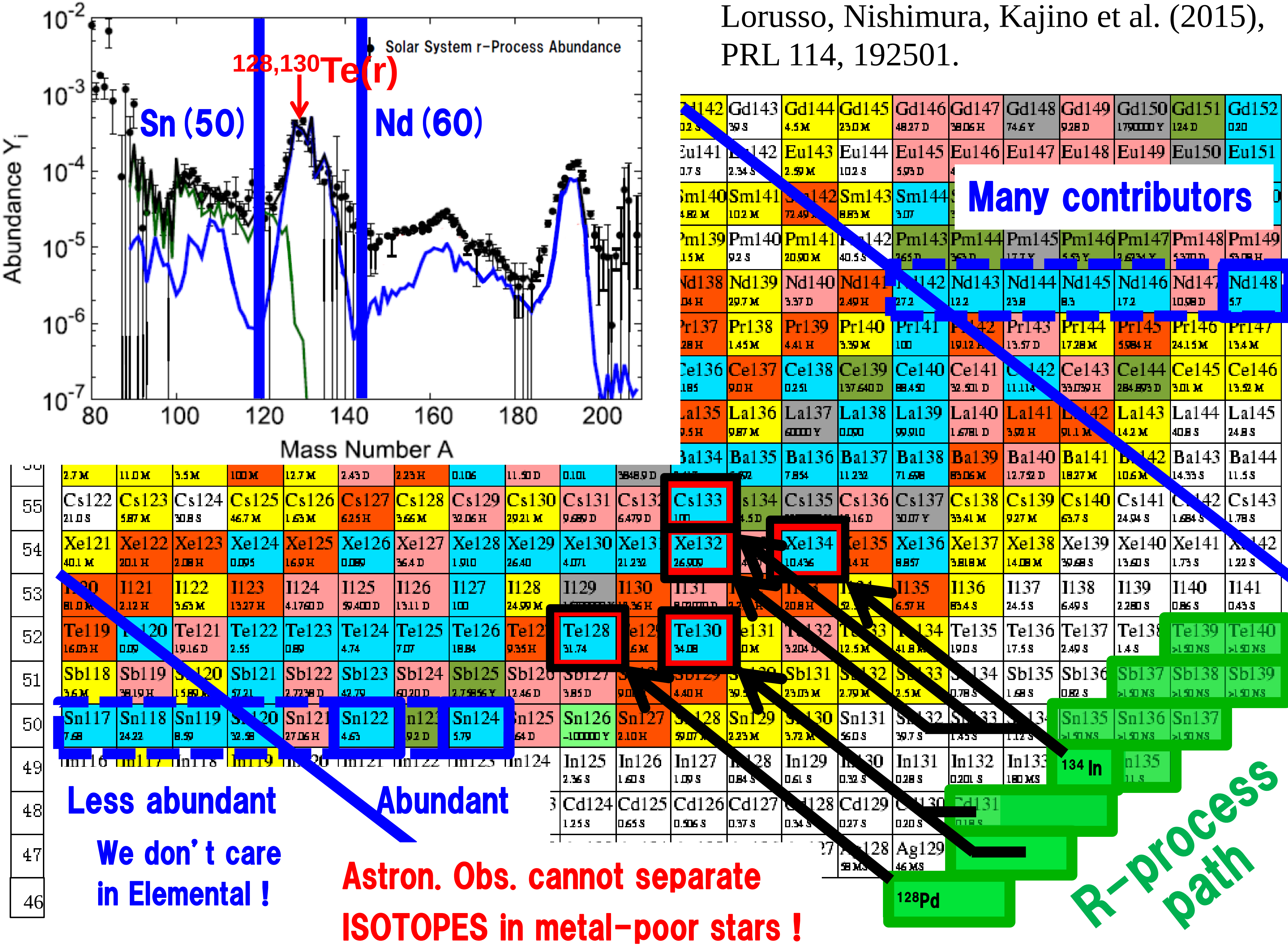


Astron. Obs. cannot separate ISOTOPES !

Atomic Number Z

ELEMENTAL (Z)

Lorusso, Nishimura, Kajino et al. (2015), PRL 114, 192501.



RIKEN-RIBF : Decay Spectroscopy around A = 100-145

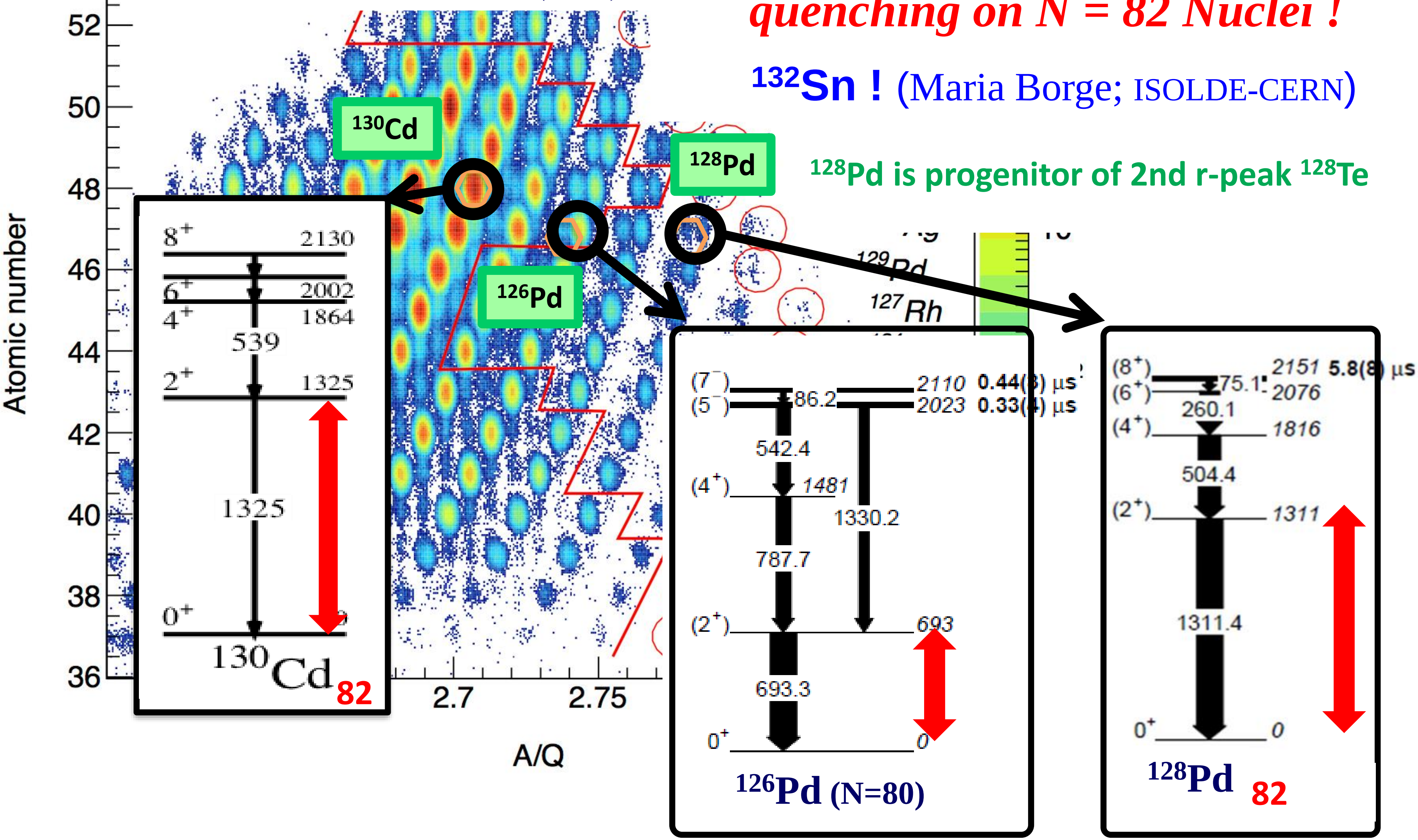
G. Lorusso et al., PRL 114 (2015), 192501.

A.Jungclaus, PRL99, (2007)
H. Watanabe et al., PRL111 (2013)

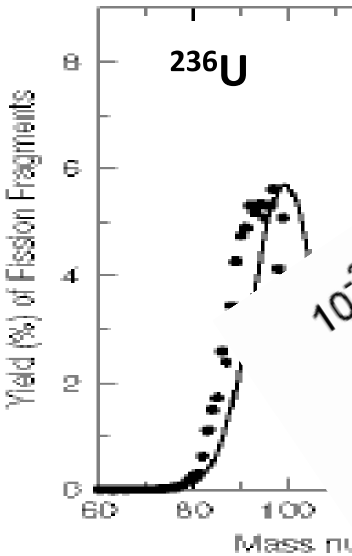
No clear evidence for shell quenching on N = 82 Nuclei !

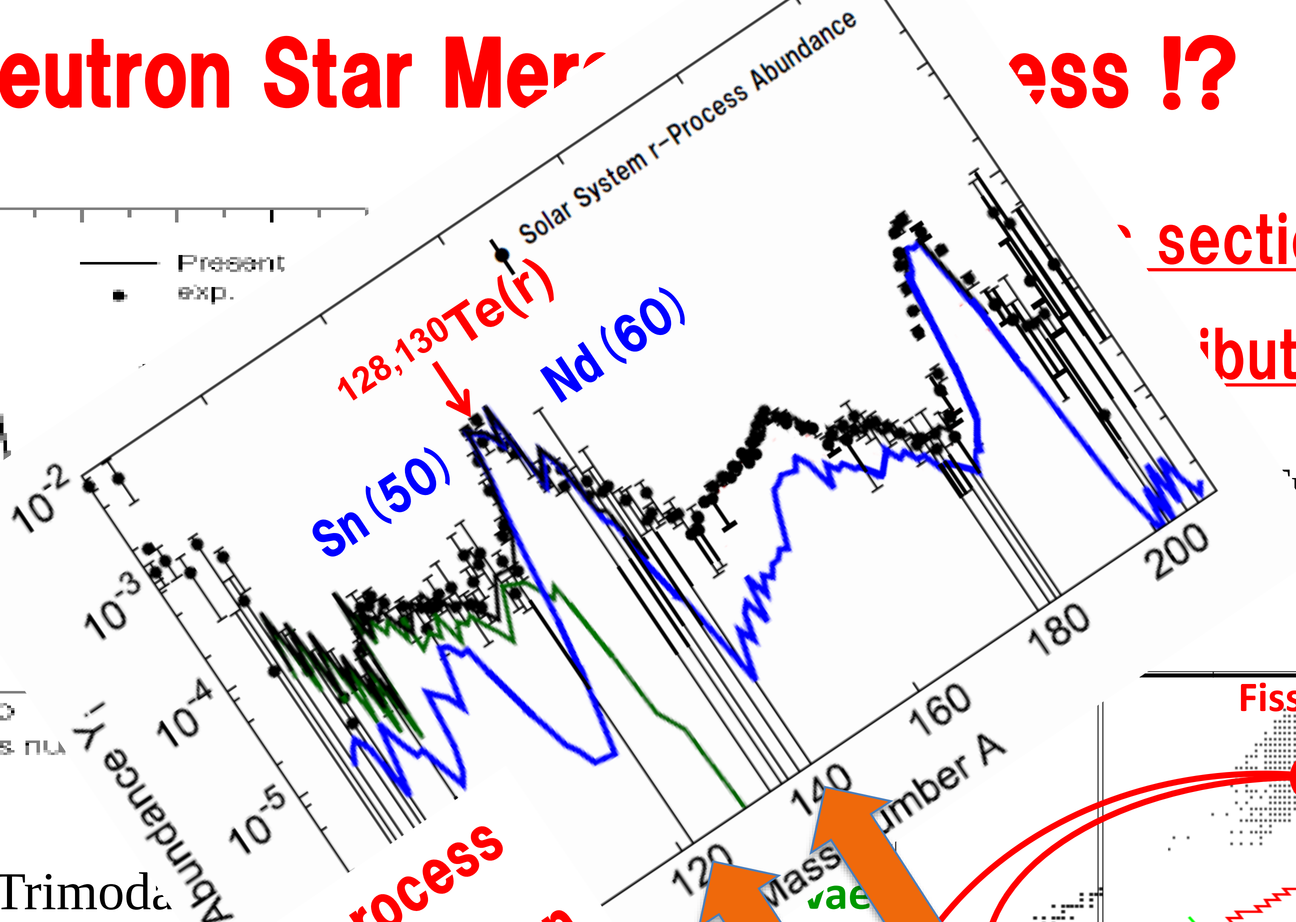
^{132}Sn ! (Maria Borge; ISOLDE-CERN)

^{128}Pd is progenitor of 2nd r-peak ^{128}Te



Neutron Star Mer… ess !?





… sections !

…ibution !

…rance, (2007)

Bimordial or Trimoda…

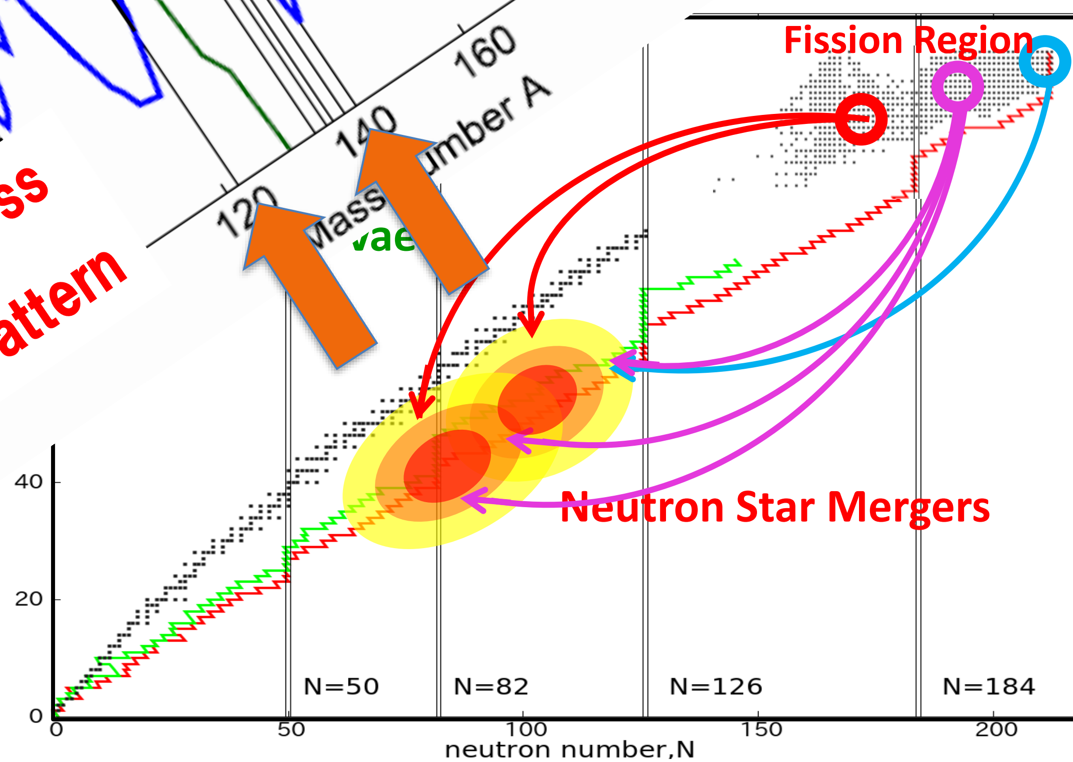
$$f(A, A_p) = \sum_{A_i} \frac{1}{\sqrt{2\pi\sigma}} W_i \exp \left(\ldots \right.$$

$$A_H = (1+\alpha)(\ldots$$

$$A_L = \ldots$$

$$A_M \ldots$$

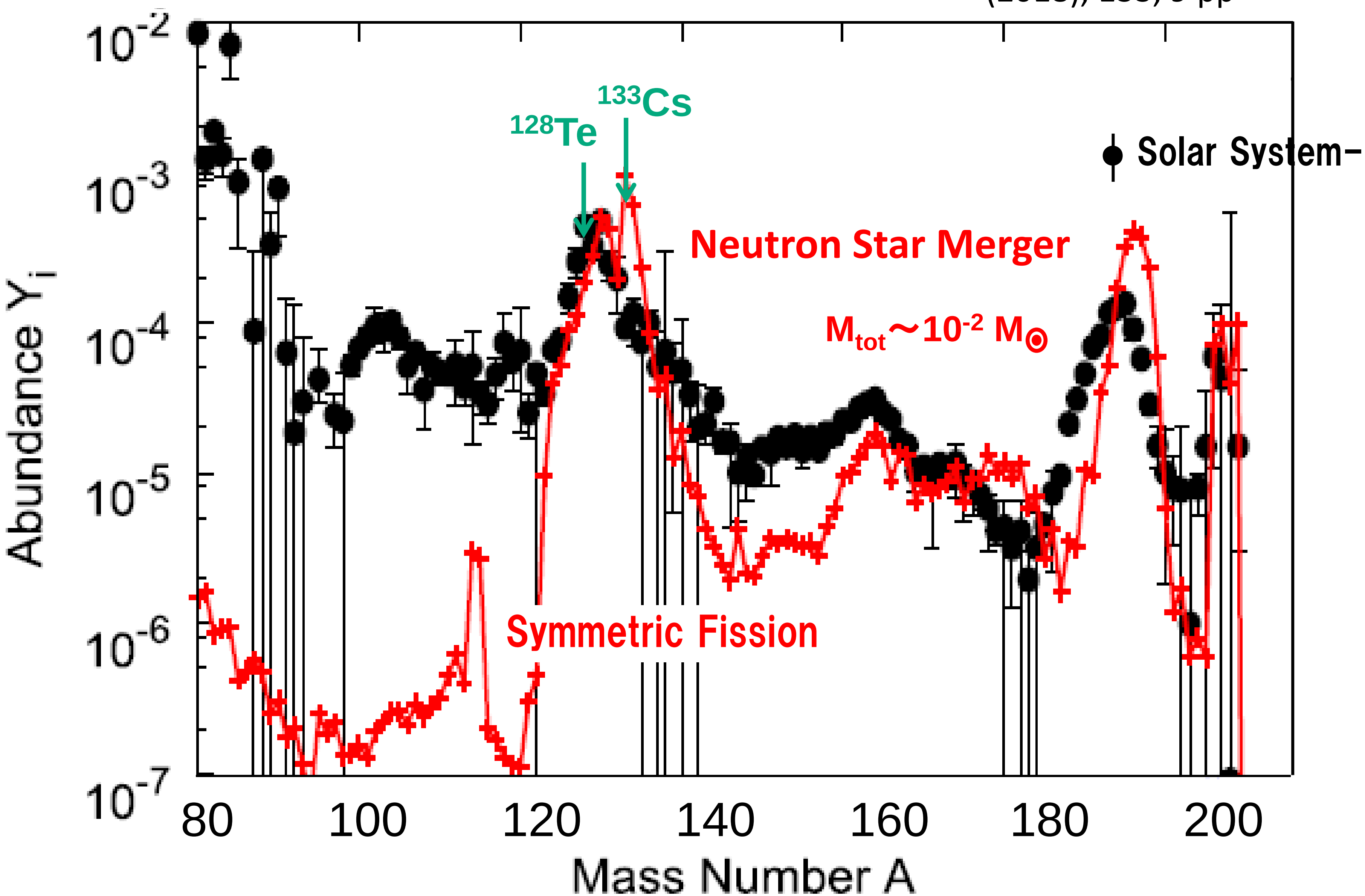
Fission recycling and r-process
(n, γ) & β-decay
for smoothing abundance pattern



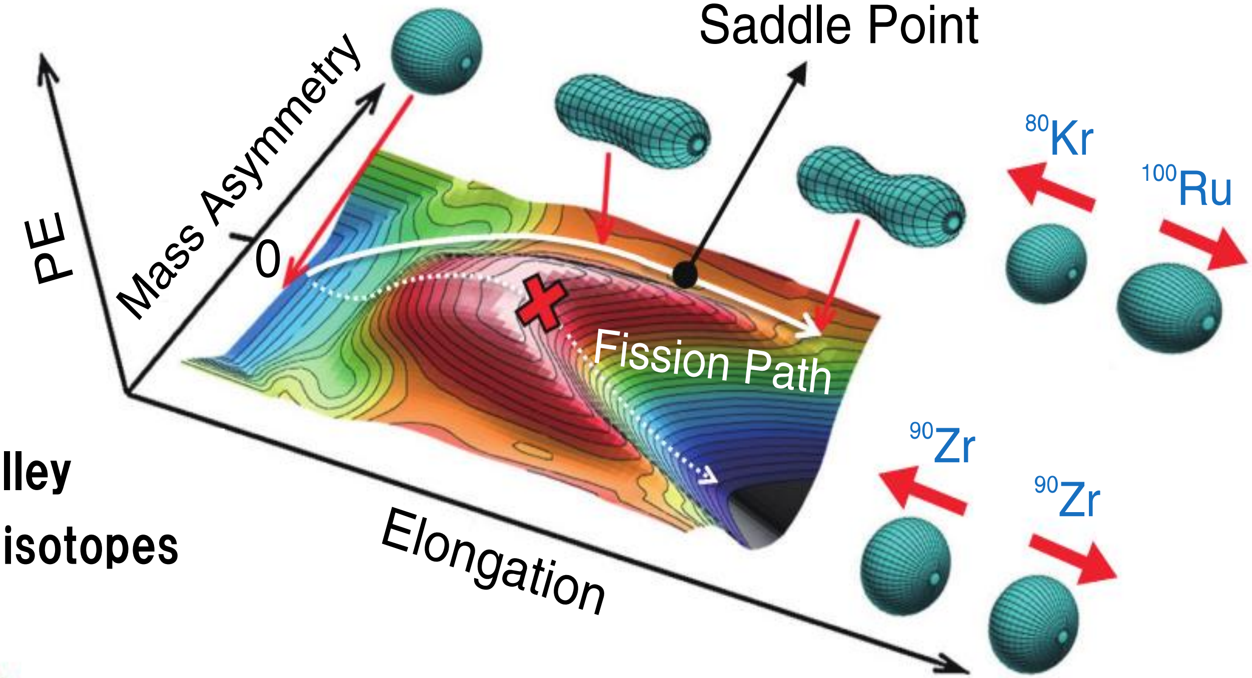
Challenge of Nucear Physics — Fission & Mass Formula

Mass Formula: FRDM (Moeller & Kratz)

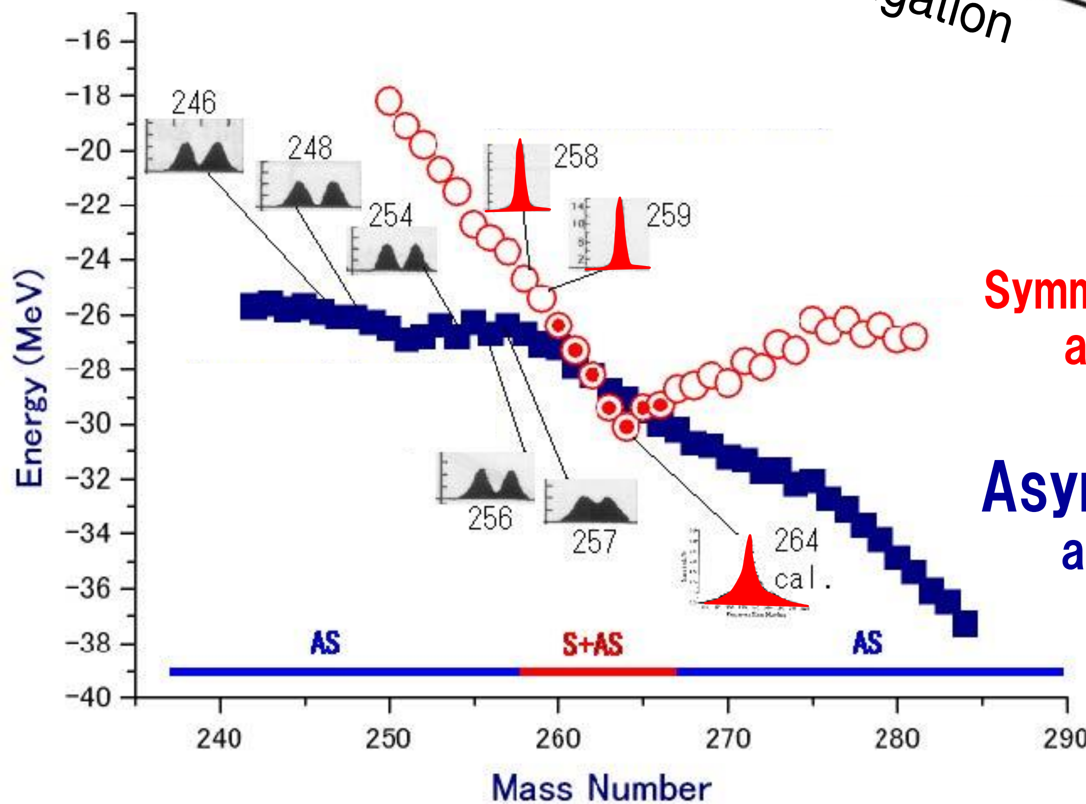
Suzuki, Kajino, et al., ApJ 859 (2018), 133, 9 pp



Fission Path of Mercury



Potential Depth of Fission Valley (near Scission Point) of Fm isotopes



Symmetric Valley around α=0, δ=0.05

Asymmetric Valley around α=0.15, δ=0.2

Fission is sensitive to Nuclear Models

RIKEN β-Decay Experiment:
S. Nishimura et al., PRL 106, 052502 (2011).

(Japanese) KTUY M… One of the Best Models!

Mass: Fission Barrier, Q_β

Koura, Tachibana, Uno, Yamada,
PTP 113, 305 (2005).

Reactions: αβ-decay, fission

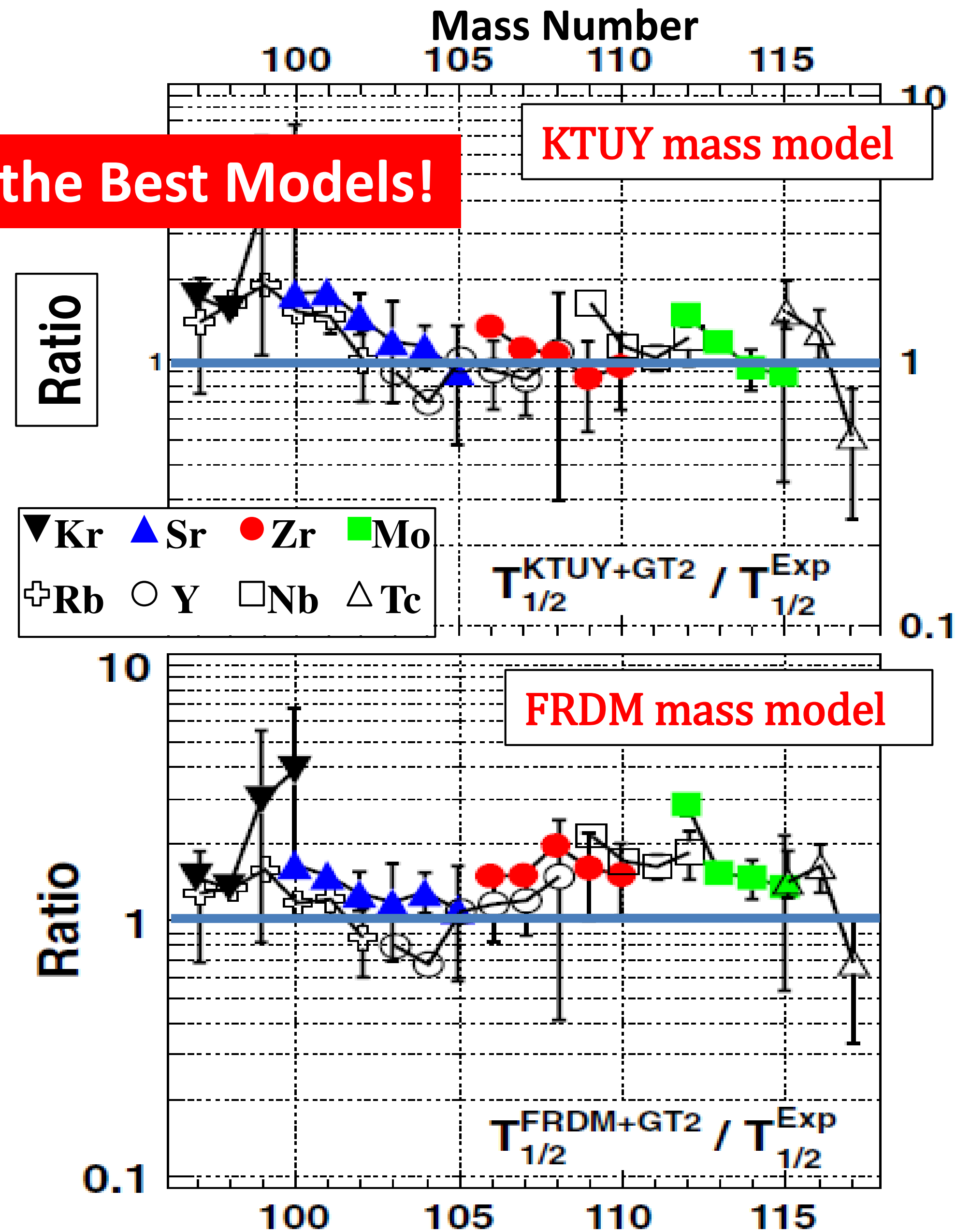
H. Koura, AIP Conf. Proc. 704, 60, (2004).

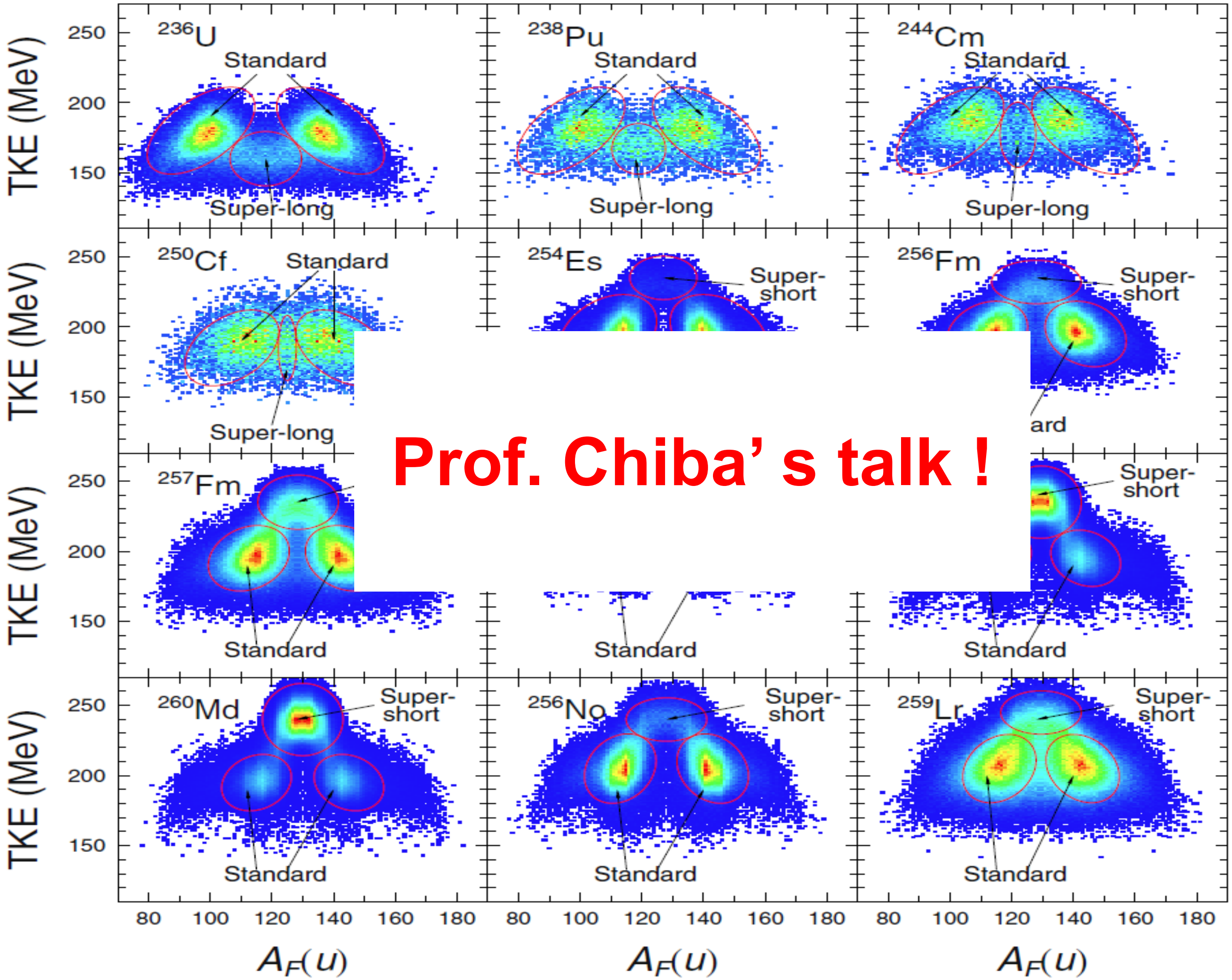
M. Ohta et al., Proc. Int. Conf. on Nucl. Data for Science and Technology, Nice, France, (2007).

FRDM Model

Möller, P., Myers, W. D., Sagawa, H., et al., PRL 108, 052501 (2012).

Möller, P., NIx, J. R., Myers, W. D., et al. ADNDT 59, 185 (1995).





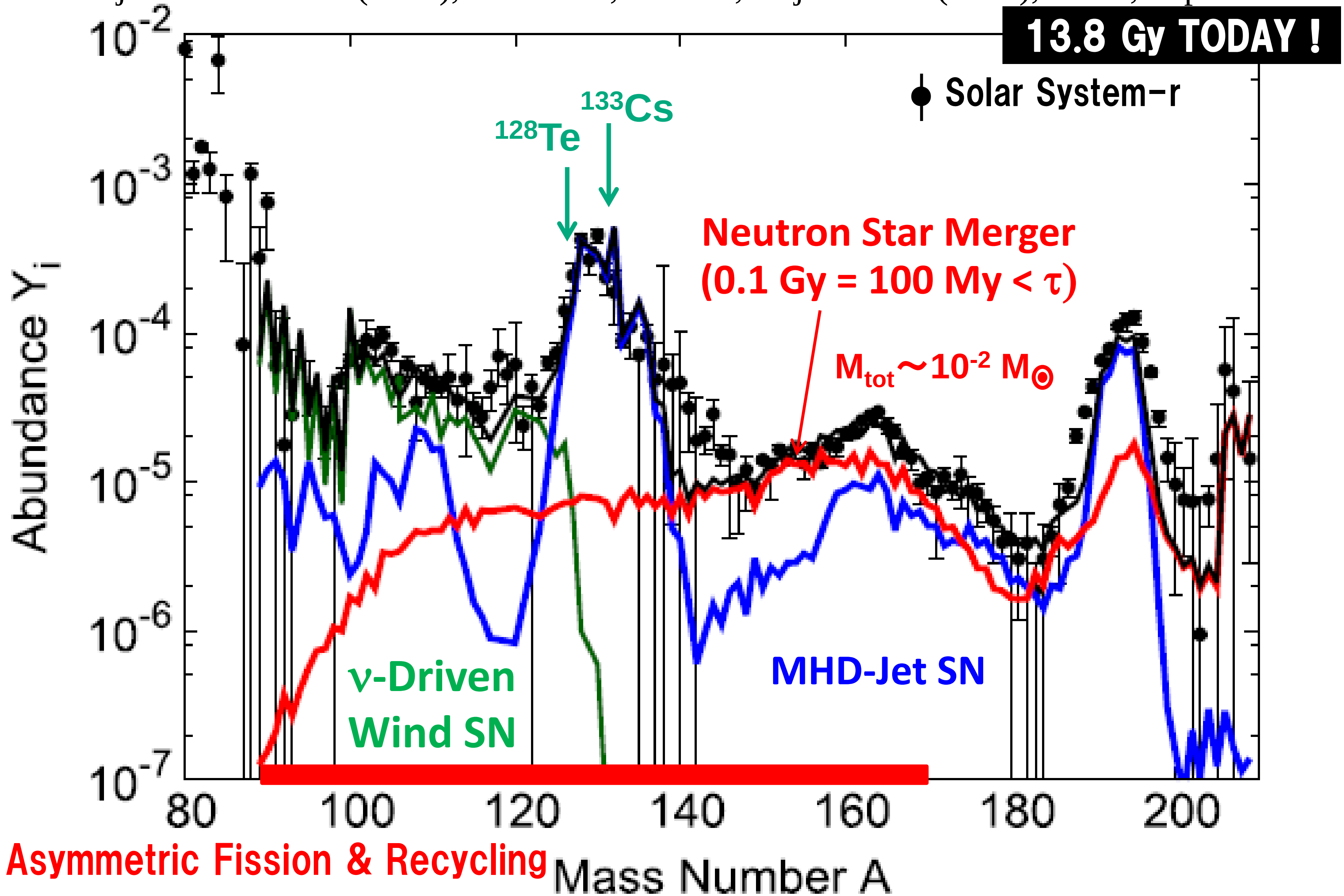
Correlation of mass number (horizontal axis) and total kinetic energy (vertical axis) of fission fragments from various fission nuclei calculated in 4D Langevin theory.

S. Okumura et al., J. Nucl. Sci. Tech. 55, 1009(2018).

M. D. Usang et al., Scientific Reports, 9, 1525(2019)

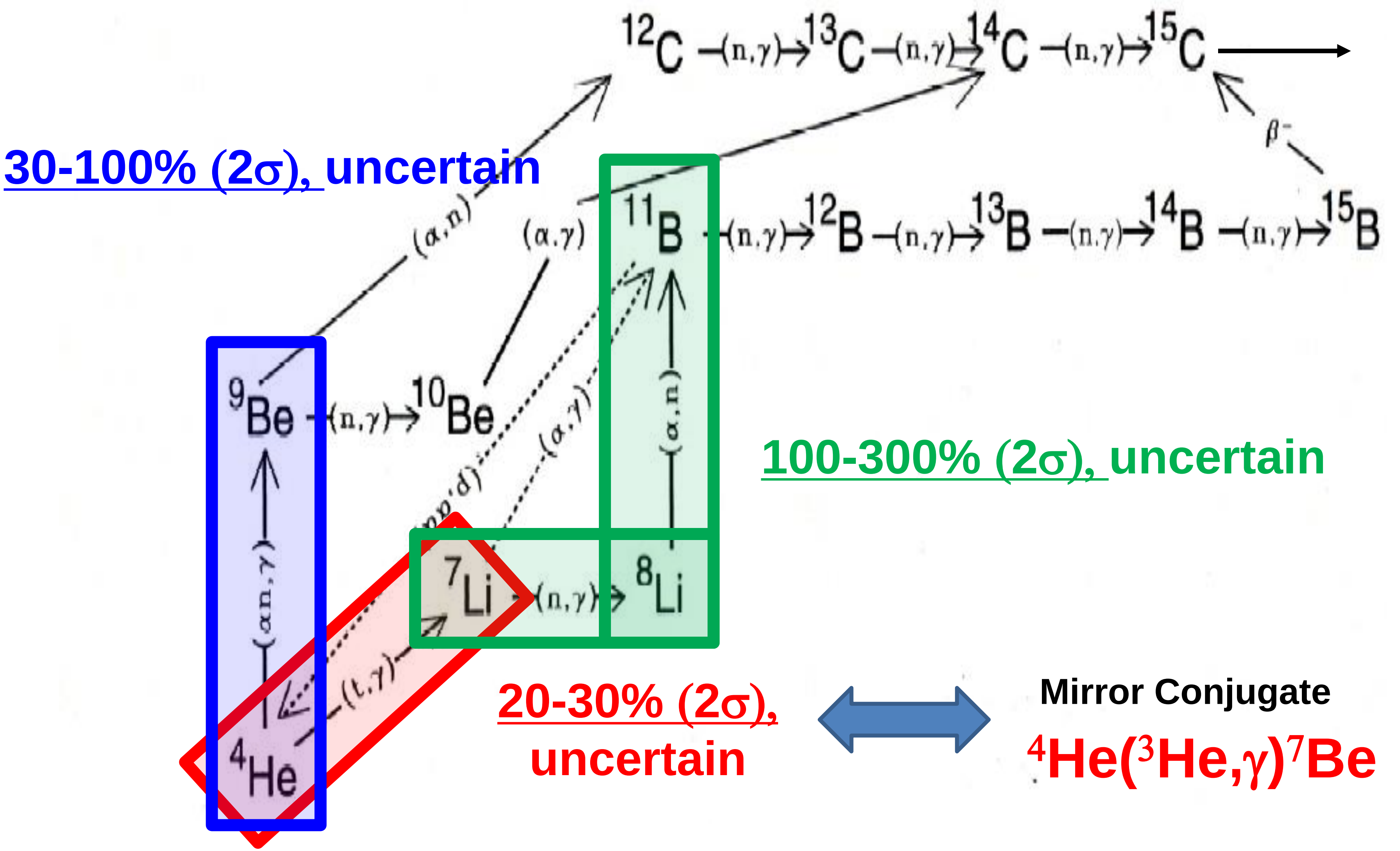
Solar System r-Process Abundance

Shibagaki, Kajino, Chiba, Mathews, Nishimura & Lorusso (2016), ApJ 816, 79; ApJ (2018); Kajino & Mathews (2017), ROPP 80 , 084901; Kajino et al. (2019), PPNP, in press.



SUPERNOVA R-Process: Important Reactions

Factor x2 change → Big difference in r-Process Peaks !

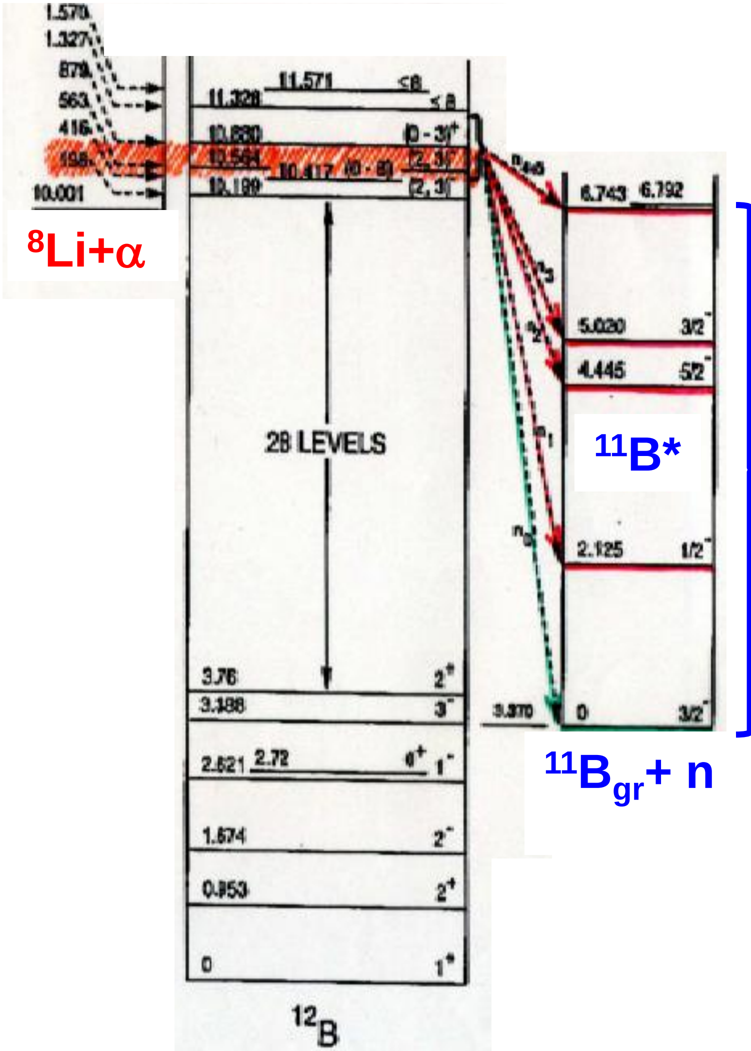


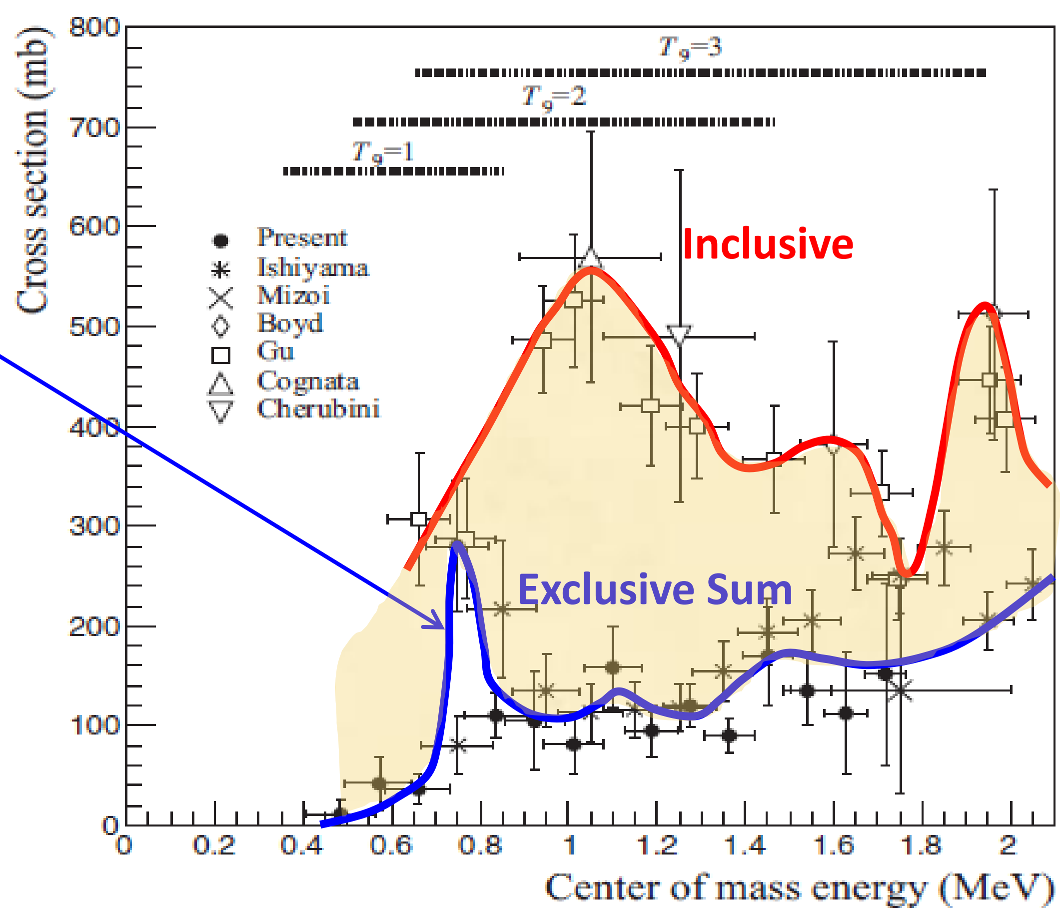
$^7Li(n,\gamma)^8Li(\alpha,n)^{11}B$

Discrepancy
Inclusive > Exclusive Sum ?

100-300% (2σ), uncertain !

◇ Boyd et al. Phys. Rev. Lett. 68 (1992), 1283.
△ LaCognata et al., Phys. Lett. B664 (2008), 157.
□ Gu et al., Phys. Lett. B343 (1995), 31.
✱ Ishiyama et al., Phys. Lett. B640 (2006), 82.
Hashimoto et al., Phys. Lett. B674 (2009), 276.
● Das, et al., Phys. Rev. C95 (2017), 055805.

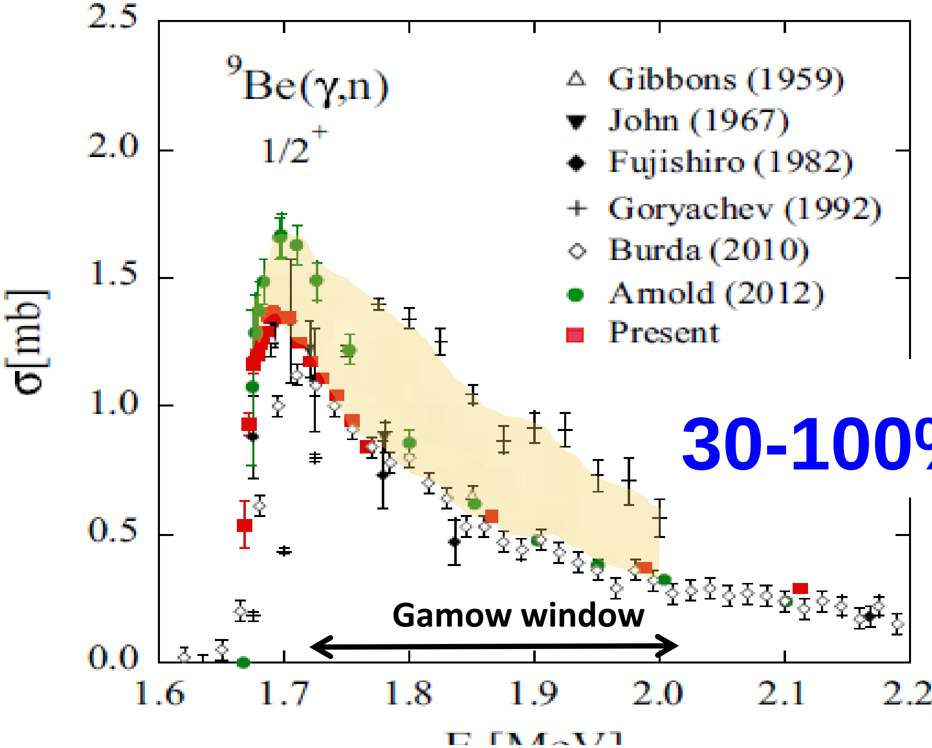




$\alpha(\alpha n, \gamma)^9Be$

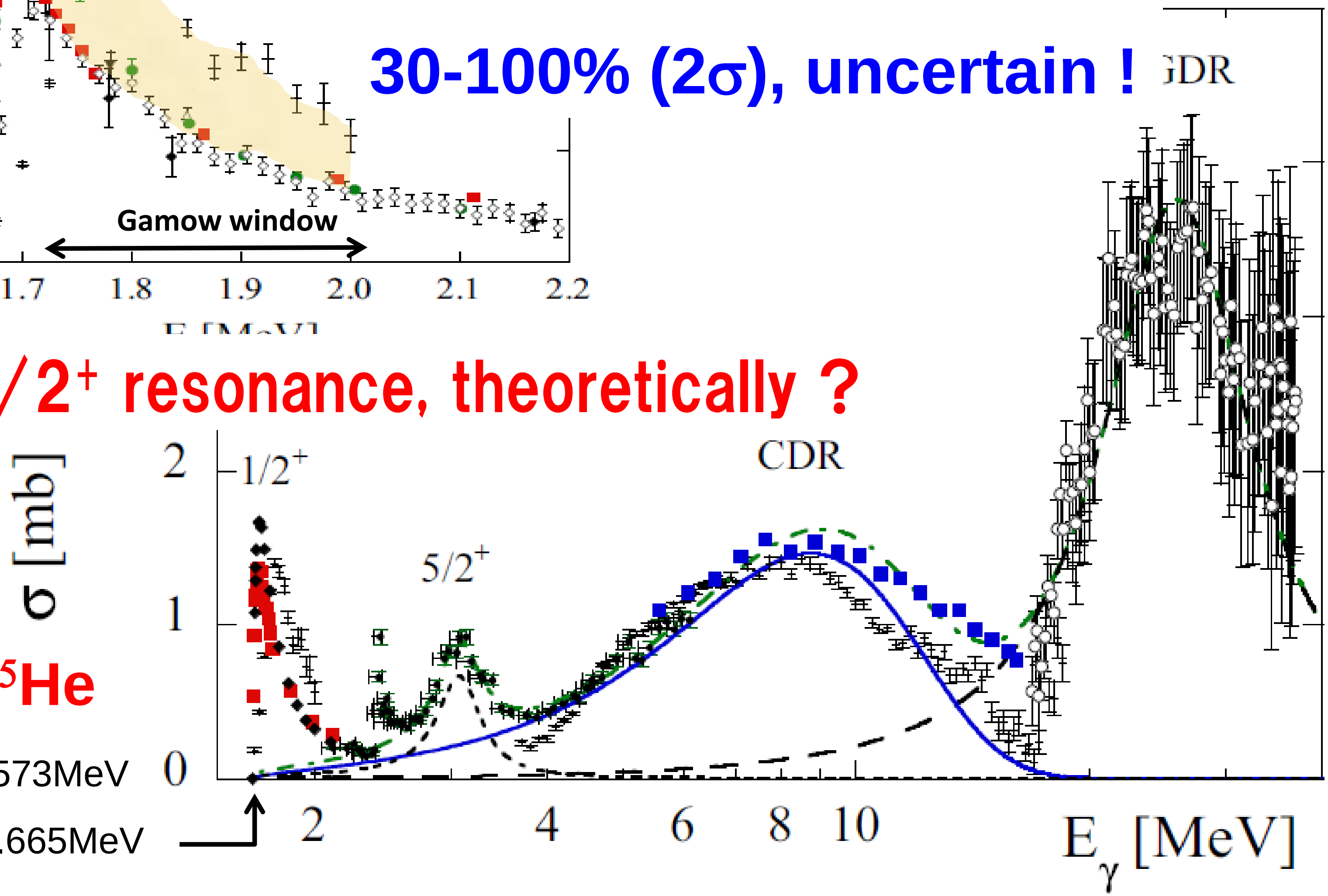
$^9Be + \gamma \rightarrow \alpha\ \alpha\ n$

Utsunomiya et al., PRC92 (2015), 064323.



30-100% (2σ), uncertain !

$1/2^+$ resonance, theoretically ?



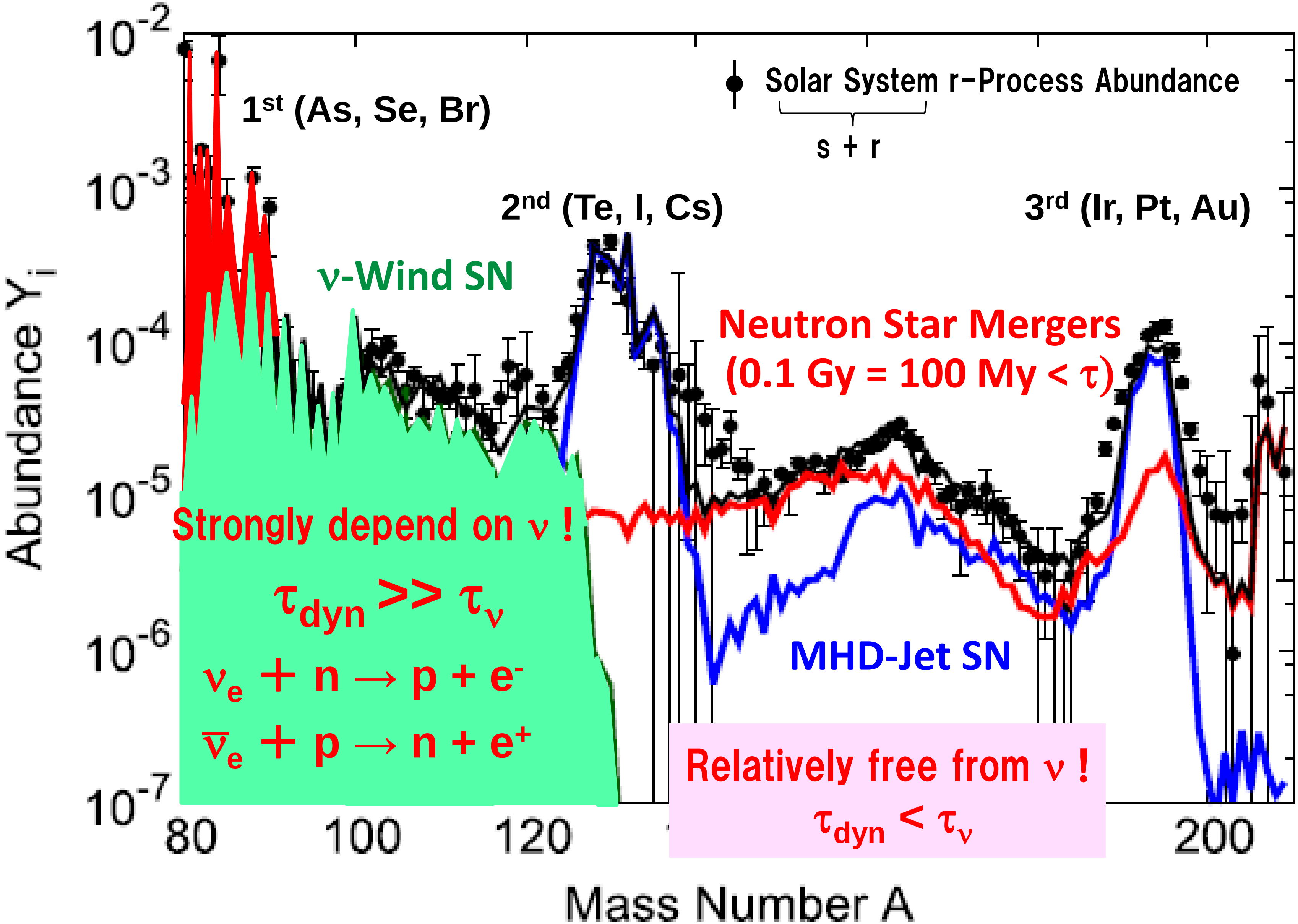
^8Be, ^5He

$E_{th}(n+2\alpha)=1.573MeV$

$E_{th}(n+^8Be)=1.665MeV$

Solar System r-Process Abundance Present Epoch: t = 13.8Gy

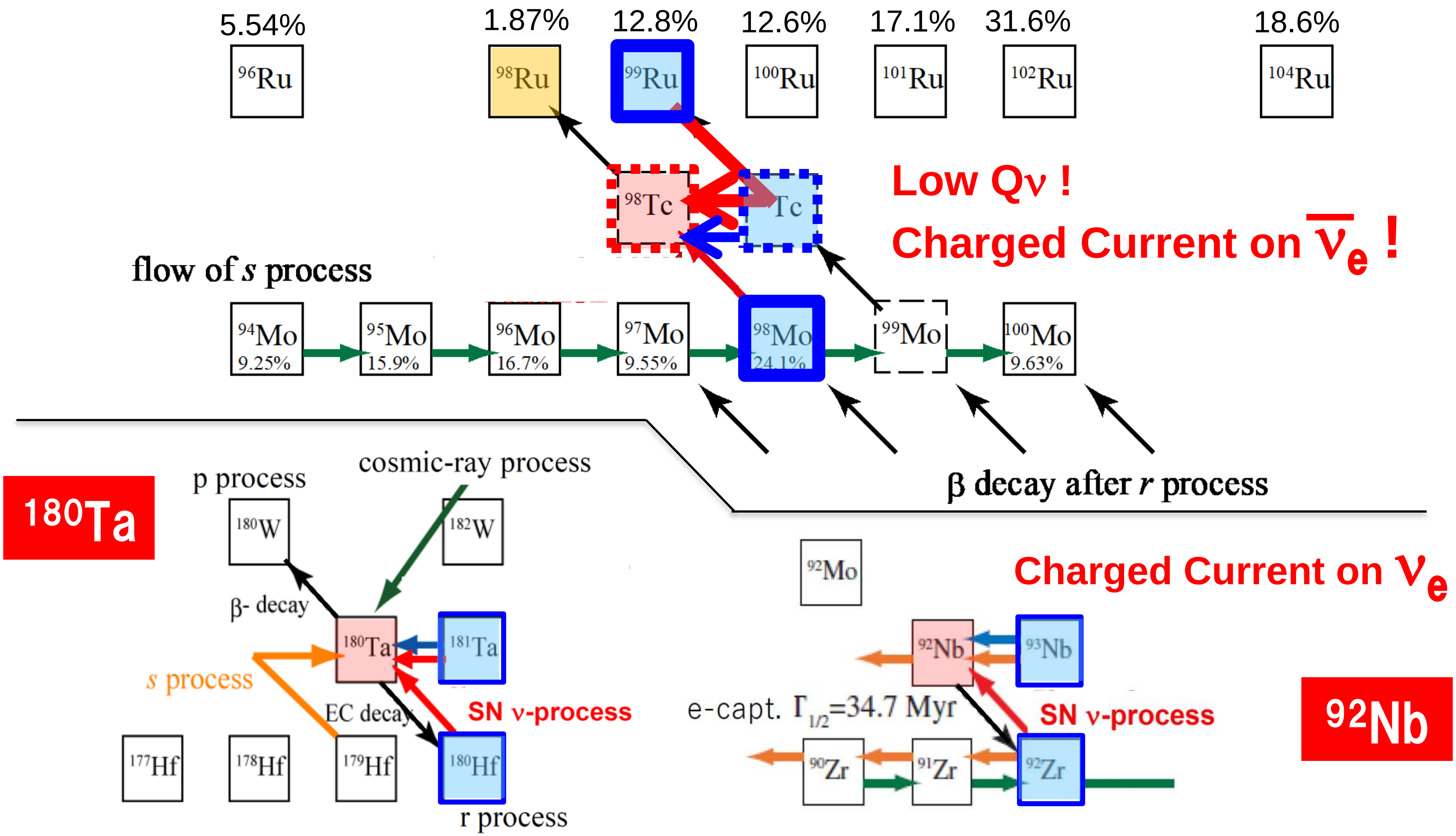
Shibagaki, Kajino, Chiba, Mathews, Nishimura & Lorusso (2016), ApJ 816, 79; ApJ (2018);
Kajino & Mathews (2017), ROPP 80 , 084901; Kajino et al. (2019), PPNP, in press.



^{98}Tc is sensitive to $\overline{\nu}_e$–spectrum !

Hayakawa, Kajino et al., PRL 121 (2018), 102701.

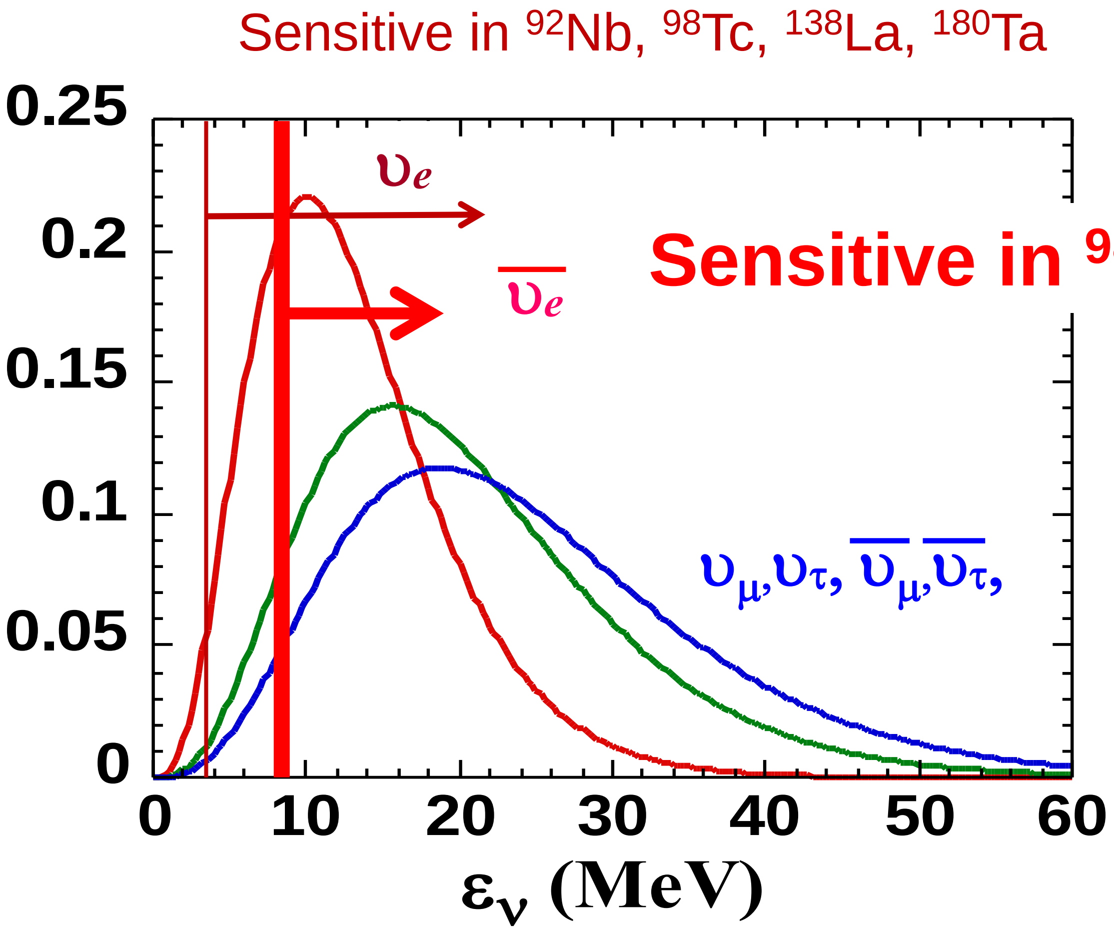
^{98}Tc decays to ^{98}Ru in 4.2×10^6 y, and meteoritic ^{98}Ru-isotope anomaly is expected.



Woosley, Hartmann, Hoffman, & Haxton, ApJ 356 (1990), 272; Heger et al., PL B606 (2005), 258; Hayakawa, Kajino et al., PR C81 (2010), 052801®; PR C82 (2010), 058801; ApJ L779 (2013), L1; Suzuki & Kajino, JoP G40 (2013), 083101; Kajino, Mathews & Hayakawa, JoP G41 (2014) 044007 ++

Sensitivity to Neutrino Energy Spectra

Hayakawa, Kajino et al., PRL 121 (2018), 102701.



$T(\nu_e) < T(\bar{\nu}_e) < T(\nu_x)$

$x = \nu_\mu, \bar{\nu}_\mu, \nu_\tau, \bar{\nu}_\tau$

$T(\nu_e) = 3.2$ MeV

$T(\bar{\nu}_e) = 5.0$ MeV

$T(\nu_{\mu,\tau}) = T(\bar{\nu}_{\mu,\tau}) = 6.0$ MeV

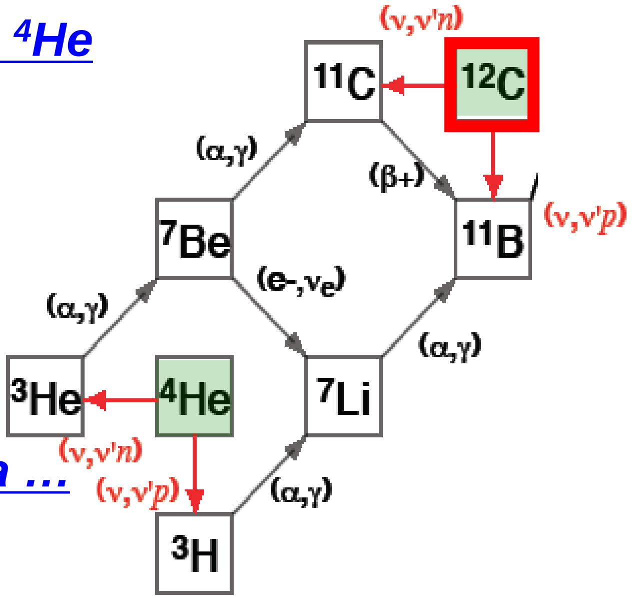
Theoretical Calculation for ν−Nucleus Cross Sections

New generation SM cal. with NEW Hamiltonian: ν-^{12}C, ^{4}He

Suzuki, Chiba, Yoshida, Kajino & Otsuka, PR C74 (2006), 034307;
Suzuki & Kajino, J. Phys. G40 (2013), 083101; +

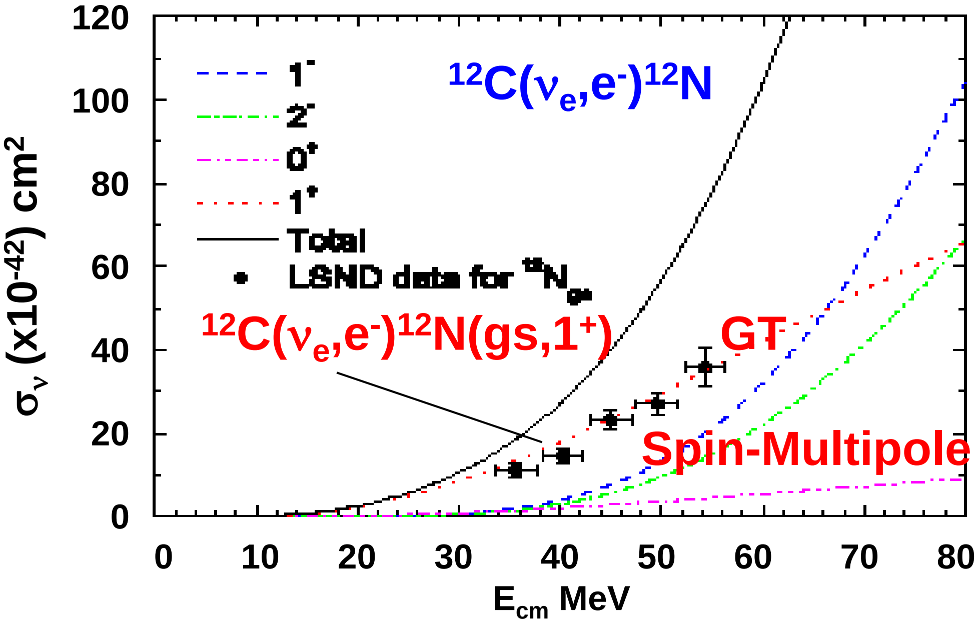
^{12}C: New Hamiltonian = Spin-isospin flip int. with tensor force to explain neutron-rich exotic nuclei.

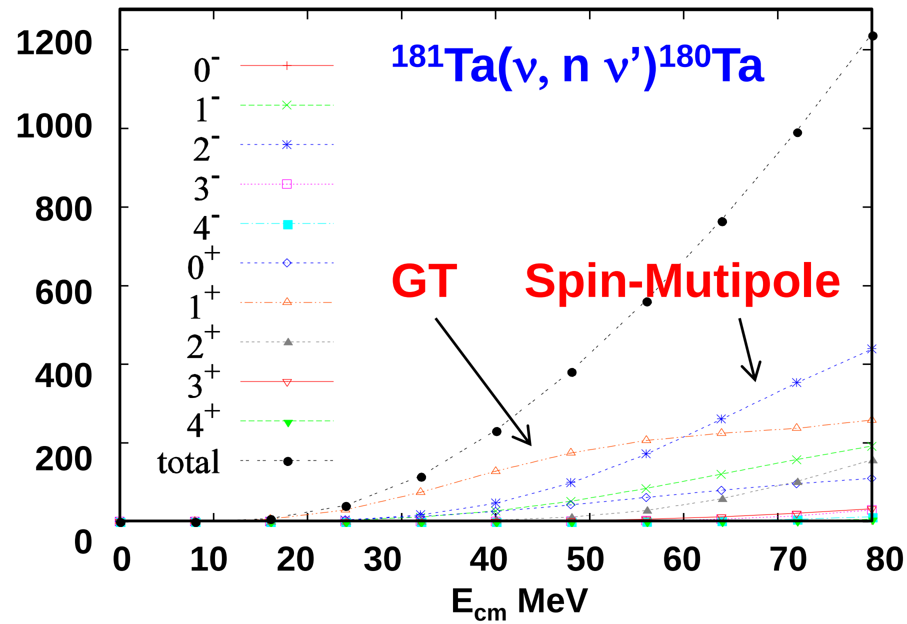
- μ-moments of p-shell nuclei
- GT strength for $^{12}C \rightarrow ^{12}N$, $^{14}C \rightarrow ^{14}N$, etc. (GT)
- DAR (ν,ν'), (ν,e-) cross sections



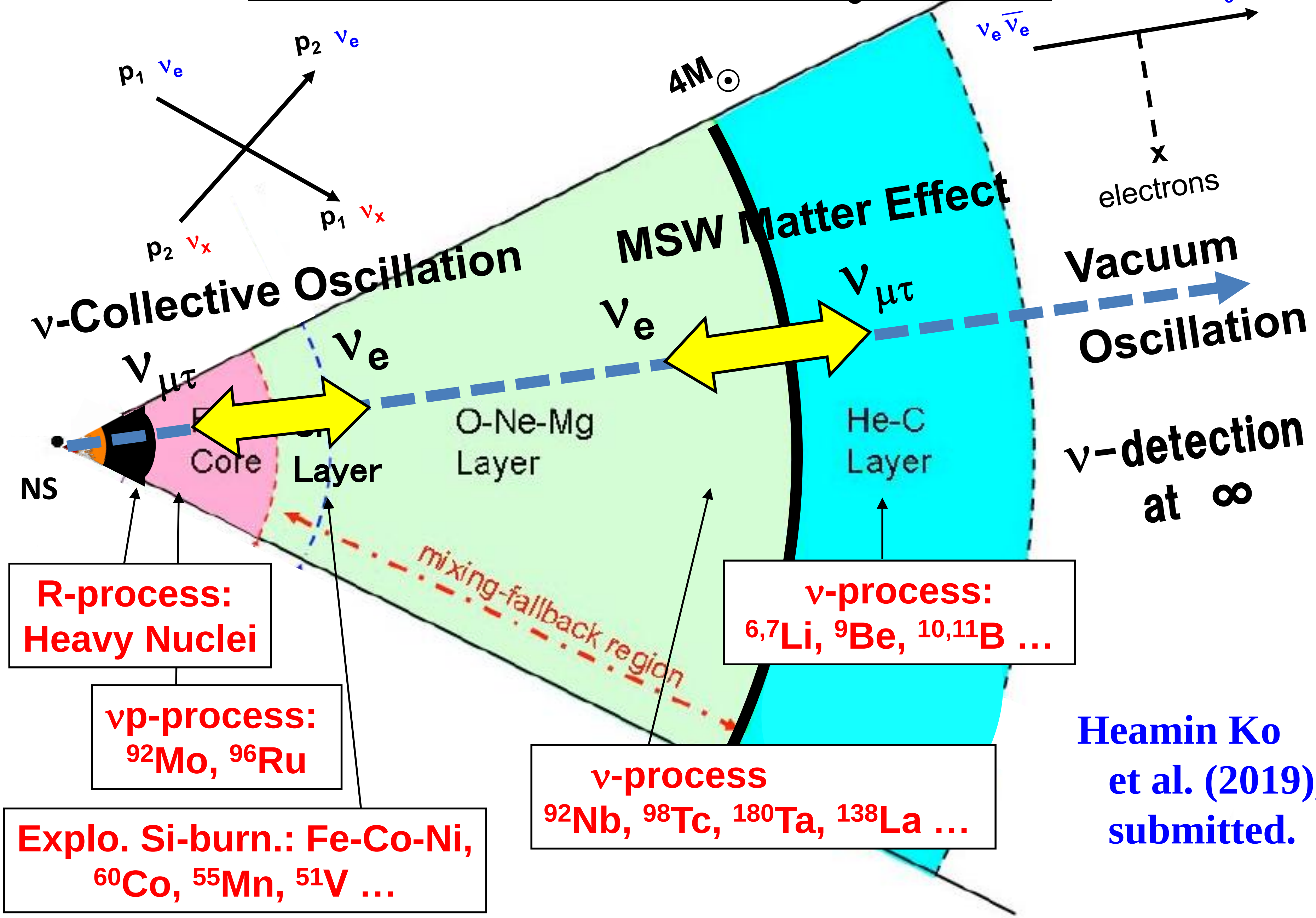
QRPA cal.: ν-^{4}He, ^{12}C, ^{40}Ar, ^{42}Ca, ^{98}Tc, ^{92}Nb, ^{138}La, ^{180}Ta …

Cheoun, et al., PRC81 (2010), 028501; PRC82 (2010), 035504:
J. Phys. G37 (2010), 055101; PRC 83 (2011), 028801; PRC 85 (2013), 065807; PLB 723 (2013), 464; J. Phys. G42 (2015), 045102; +





ν-Oscillation and Nucleosynthesis



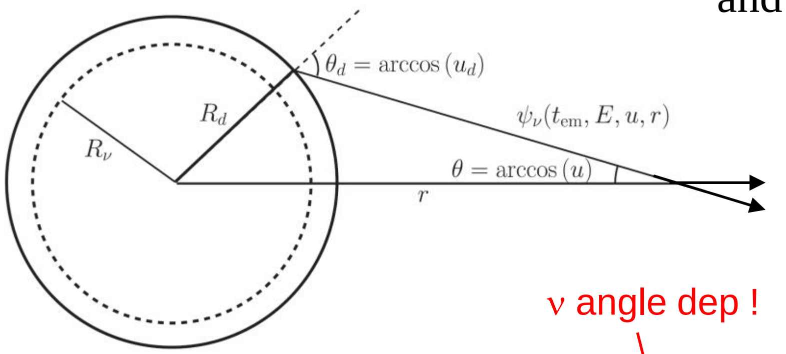
Heamin Ko et al. (2019), submitted.

Collective ν Oscillation — Many-Body Quantum Effect

Duan, Fuller, Carlson & Qian, PRL 97 (2006), 241101; Fogli, Lisi, Marrone & Mirizzi, JCAP 12 (2007) 010; Balantekin, Pehlivan & Kajino, PR D84 (2011), 065008; PR D90 (2014), 065011; PR D (2018), in press.

Sasaki, Kajino, Takiwaki, Hayakawa, Balantekin and Pehlivan, PR D96 (2017), 043013

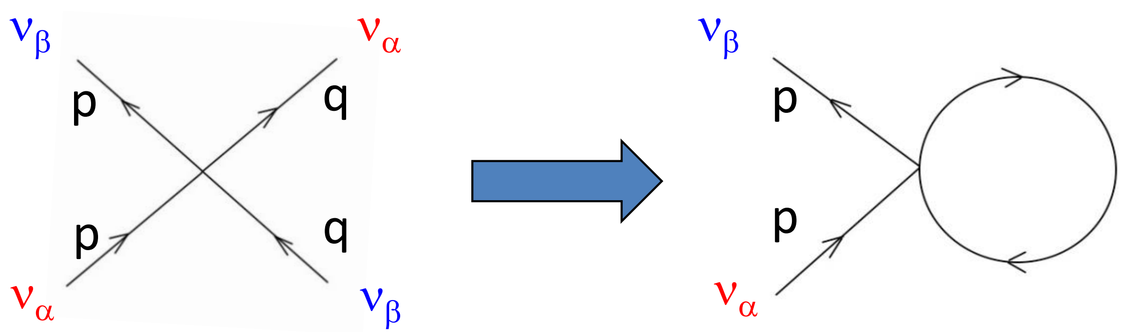
proto-neutron star (ν Sphere)



$$\begin{cases} i\dfrac{d\psi_\nu}{dt} = (H_v + H_e + H_\nu)\psi_\nu(t_{\rm em}, E, u, r), \\ H_v = U\dfrac{M^2}{2E}U^\dagger, \\ H_e = \sqrt{2}G_F n_e(r)\,{\rm diag}(1,0,0), \end{cases}$$

ν angle dep !

$$H_\nu = \sqrt{2}G_F \sum_\alpha \int dE' d\Omega' (1 - uu') \left[\frac{d^2 n_{\nu_\alpha}}{dE' d\Omega'} \rho_{\nu_\alpha}(t'_{\rm em}, E', u', r) - \frac{d^2 n_{\bar\nu_\alpha}}{dE' d\Omega'} \rho^*_{\bar\nu_\alpha}(t'_{\rm em}, E', u', r) \right].$$

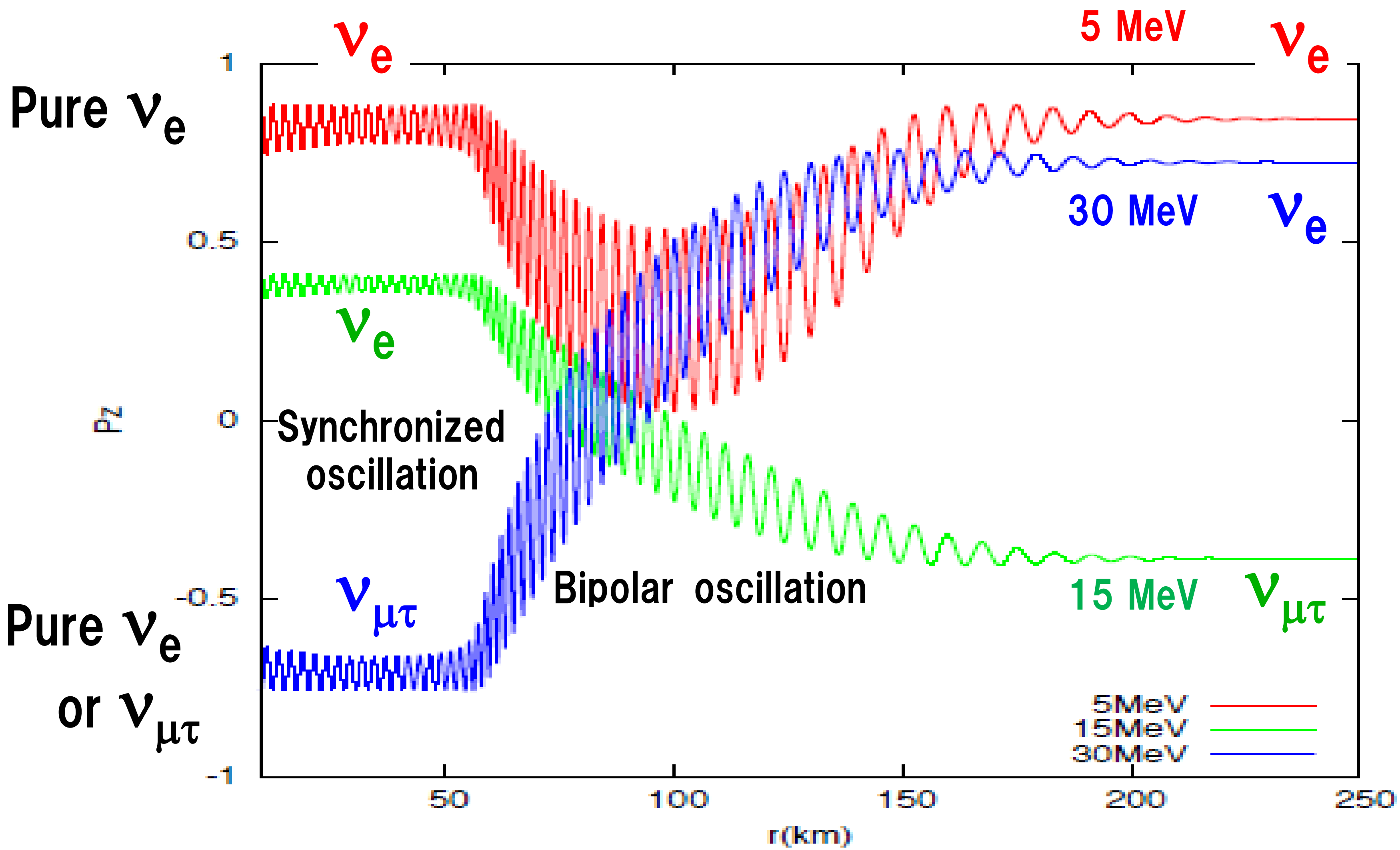


α, β = e, μ, τ

10^{48} ν's with 3-flavors & multi-angles ! → Mean Field Approx.

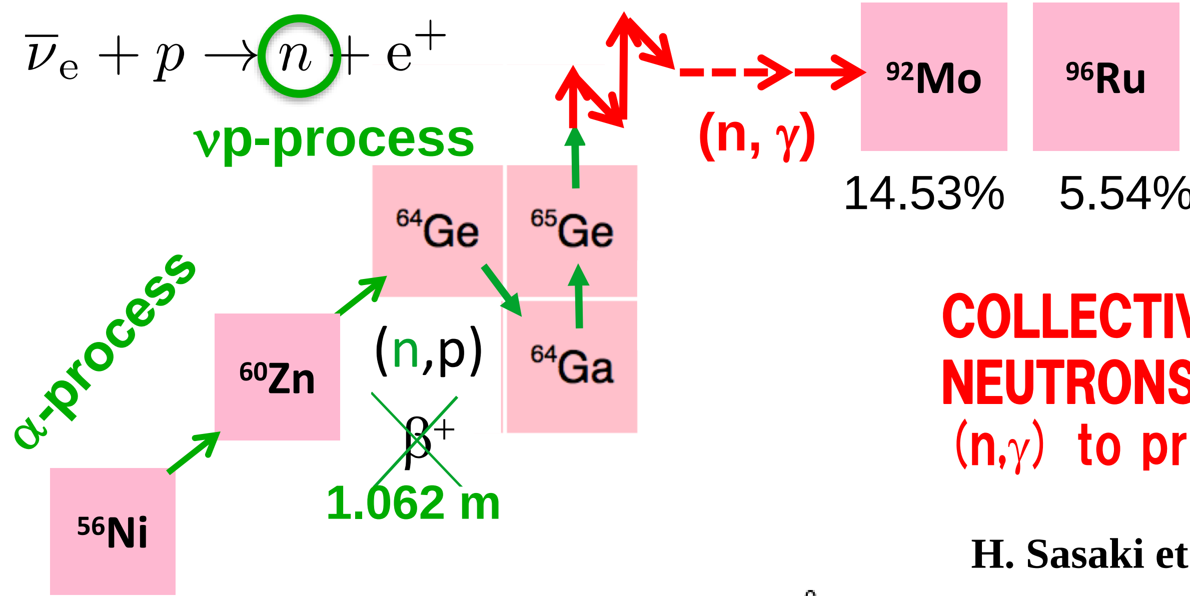
Calculated ν Flavor Oscillation

Energy spectra change !



Ordinary νp−process

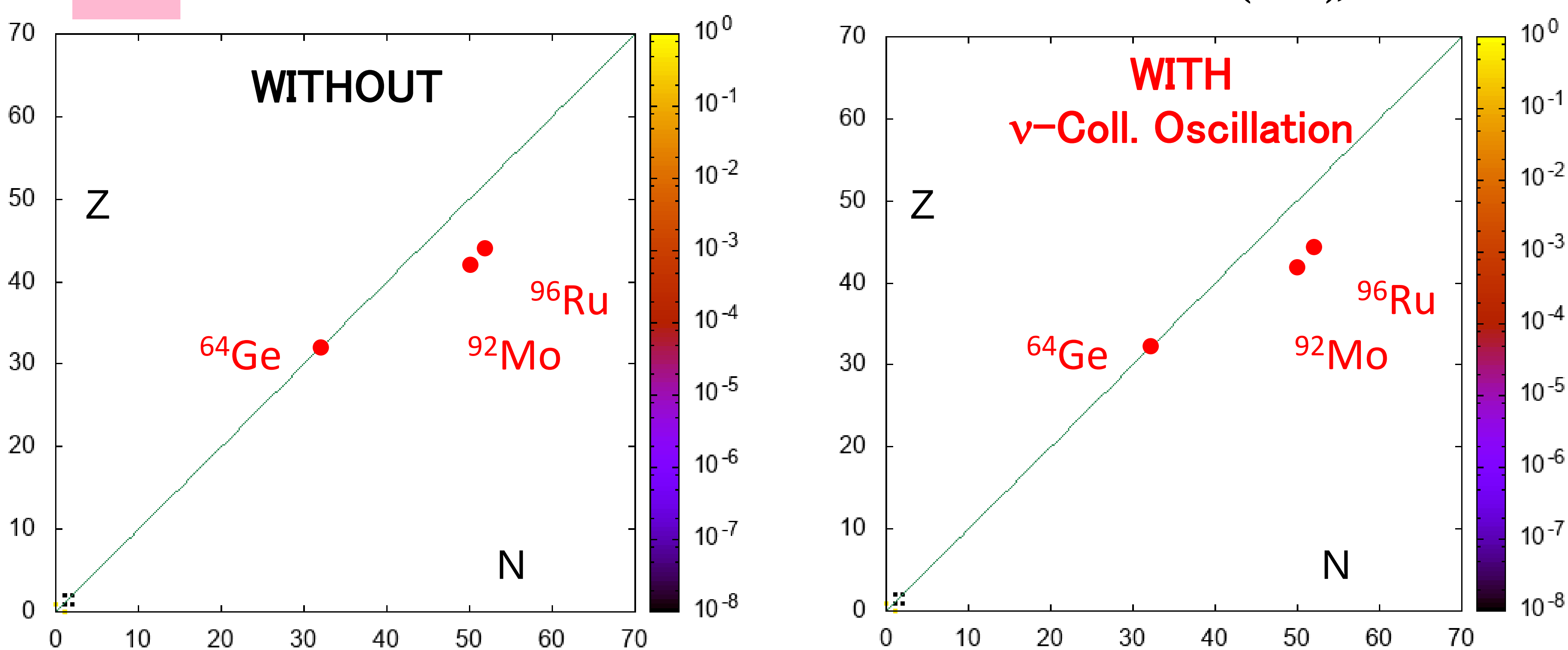
C. Freohlich, et al., PRL 96 (2006), 142502.



Isotopic ratio of p-nuclei ~ 0.1-1%

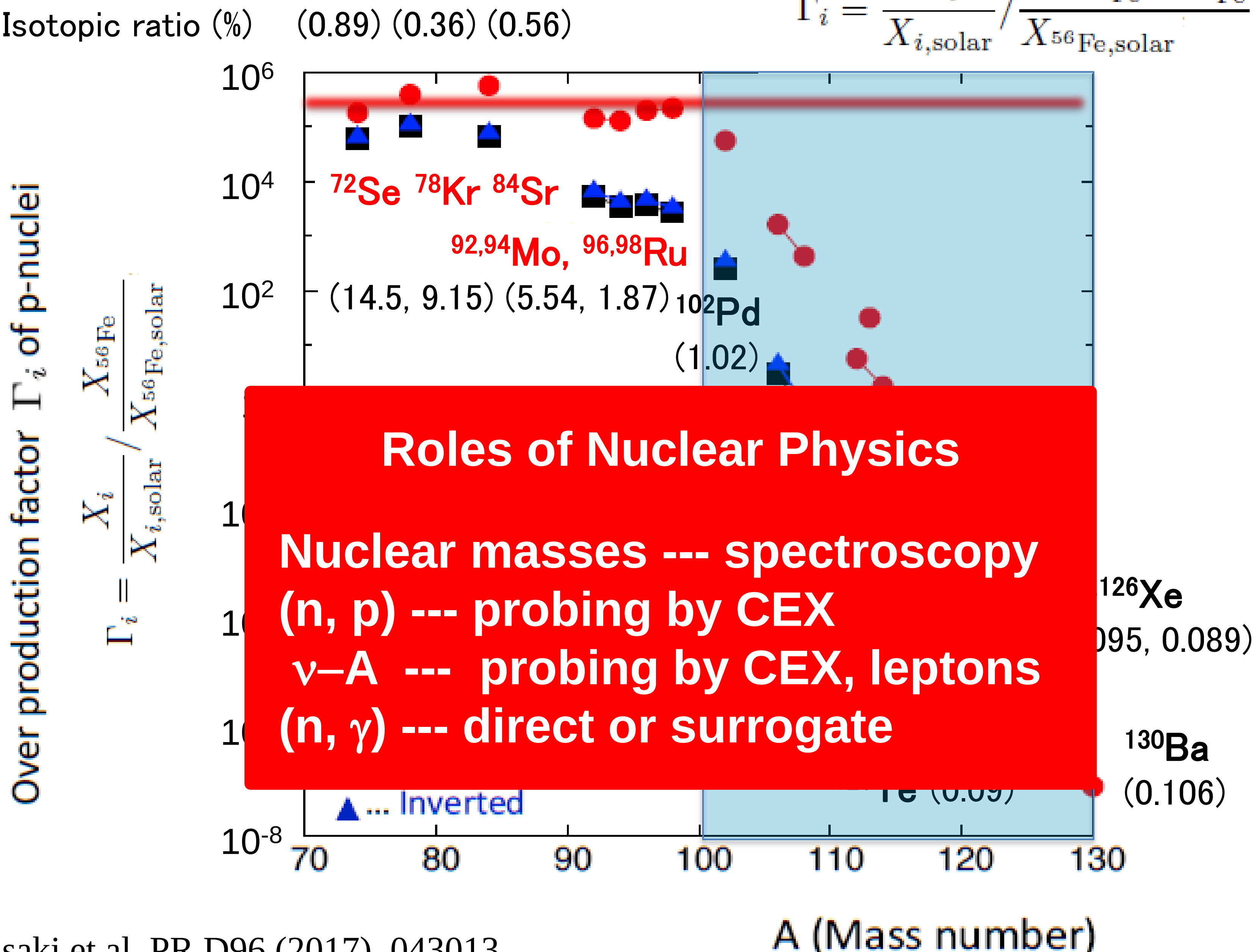
COLLECTIVE ν−OSC. supplies free NEUTRONS, followed by (n,p) and (n,γ) to produce ^{92,94}Mo, ^{96,98}Ru !

H. Sasaki et al. PR D96 (2017), 043013.



P−Nuclei

$$\Gamma_i = \frac{X_i}{X_{i,\mathrm{solar}}} \Big/ \frac{X_{^{56}\mathrm{Fe}} + X^{\text{Si-burn.}}_{^{56}\mathrm{Fe}}}{X_{^{56}\mathrm{Fe,solar}}}$$



Roles of Nuclear Physics

Nuclear masses --- spectroscopy
(n, p) --- probing by CEX
ν–A --- probing by CEX, leptons
(n, γ) --- direct or surrogate

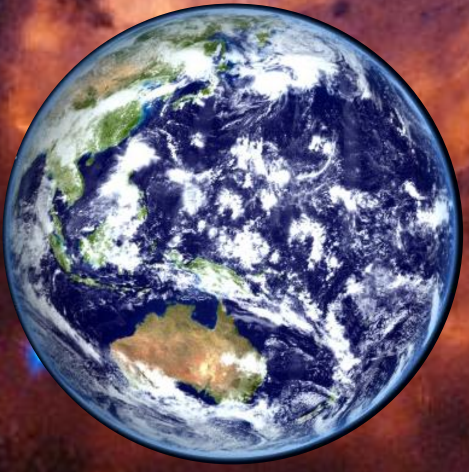
Sasaki et al. PR D96 (2017), 043013.

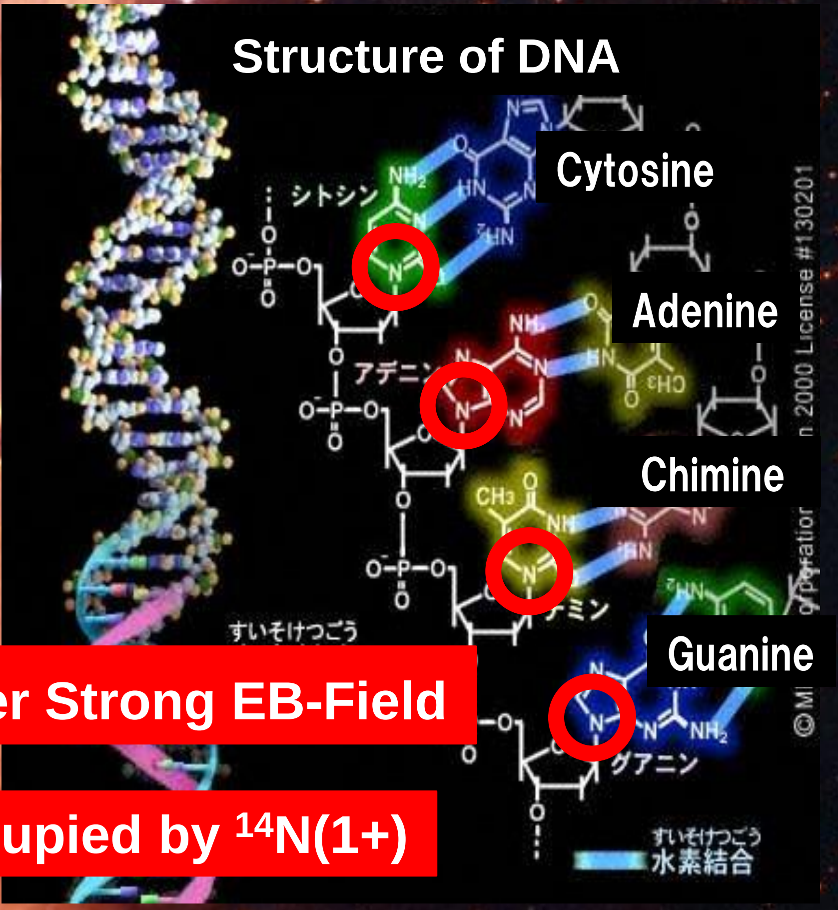
Origin of Life ?

— One Key is Selected Chrality. —
Why are All Amino-Acids Optically Left-Handed ?

Born in the Universe,
then brought into Earth ?

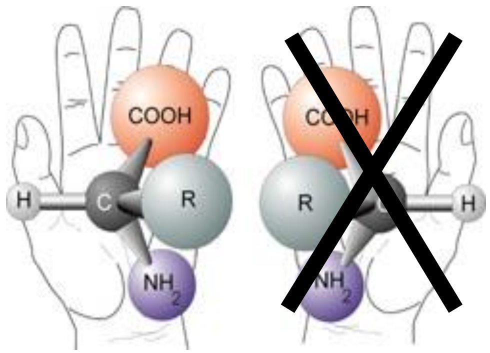
Born on the Earth, then evolved ?





ν-Interaction under Strong EB-Field

Connection is occupied by $^{14}N(1+)$



Origin of L-Chirality of Amino Acids — UNIVERSAL —

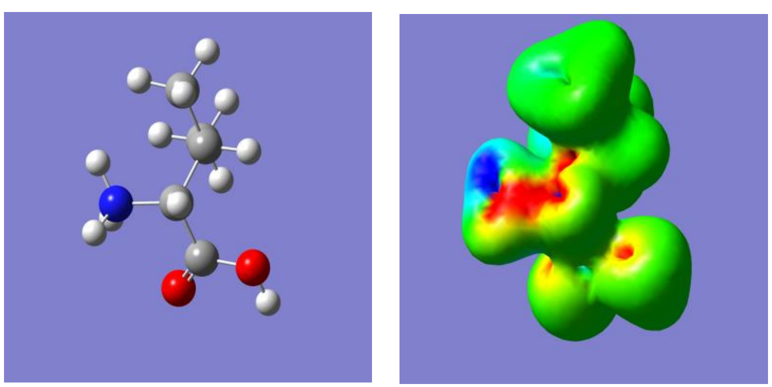
Boyd, Kajino, Onaka & Famiano, et al. Astrobio. 10 (2010), 561; Int. J. Mol. Sci. 12 (2011), 3432; Symmetry 6 (2014), 909; Astrobio. 18 (2018) 190; ApJ 856 (2018) 26(5pp); Sci. Rep. 8 (2018), 8833.

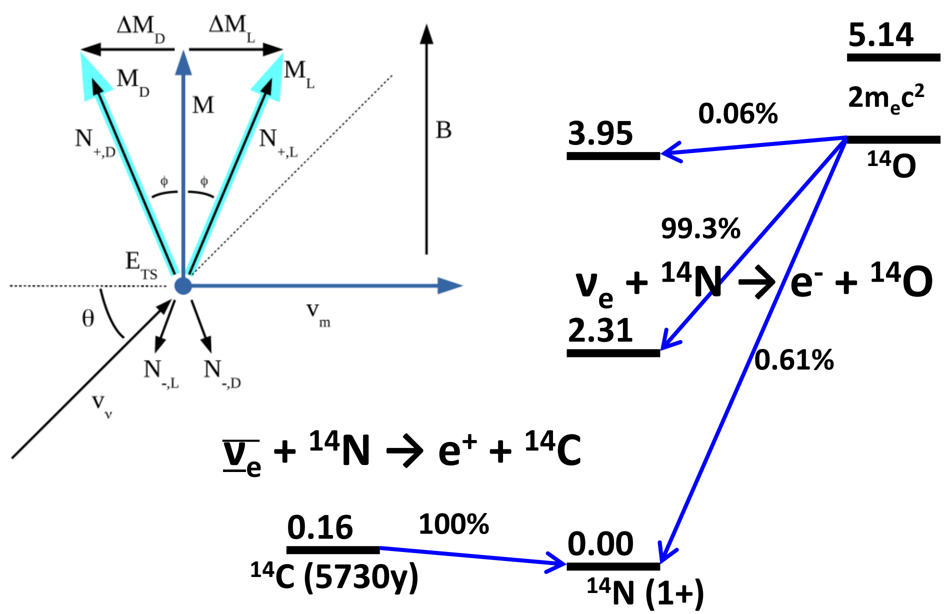
Coupling Nuclei to Molecules → Chiral Selection

- Magnetic B-field of NS, BH, NSM orients ^{14}N(s=1) via *nuclear* magnetic dipole moment.
- B-field + motion produces an effective Electric field in rest frame of grain, meteoroid, etc.
- E-field shifts the electrons, so affects the *molecular* electric dipole moment.

→ ***It's opposite for the two chiralities.***

Quantum molecular calculations for Valine



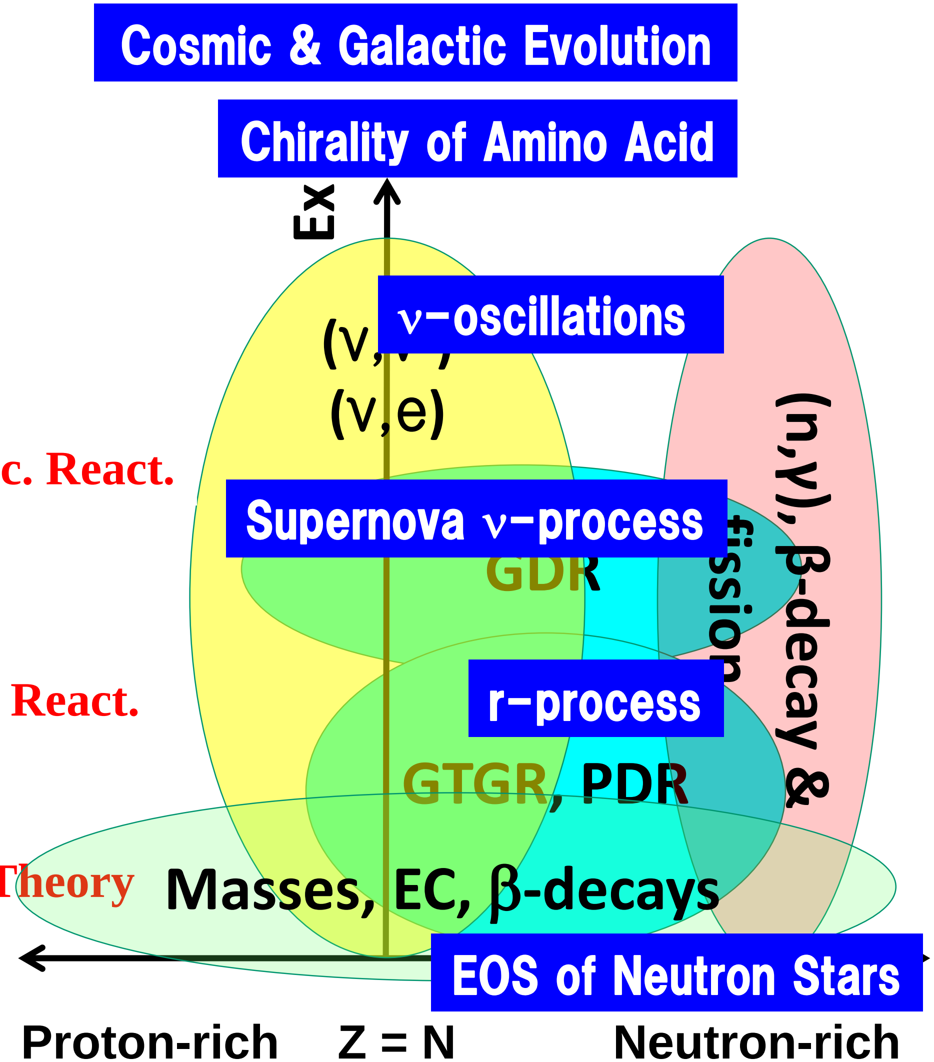


Quest for Nuclear Physics in Astrophysics

The developed HI & RIB technique
+ Intense RI-Beam at World RIFactories
+ High Precision Spectroscopy +

Probe any Energy on wide N-Z (Isospin)

Hadronic Charge-Exc. React.



Understanding of nuclear electro-weak response in astrophysical processes

Electro-Weak React.

→ **GT + first forbidden**
- SN explosion mechanism
- R-process, Th-U synthesis & cosmochronology

Reaction Theory

→ **Neutral & Charged currents**
- LiBeB synthesis & ν-oscillation
- Fe-Mn synthesis in 1st generations of star
- La, Ta, Nb synthesis & cosmic clock

→ **EC/beta-decays**
- SN II, SN Ia, X-ray bursts

Structure Theory of Exotic Nuclei, Fission

Sasano @ Uesaka Spin-Isospin Labo., RIKEN

Summary

◆ Big-Bang Lithium Problem

→ **Nuclear Physics + PMF Fluctuations (CMB) + DM Physics**

◆ R-process in the Early Galaxy was dominated by Supernovae, and Neutron Star Mergers have arrived later.

→ **Fission Recycling & Frag. Mass Distr. + masses, β-decay, (n, γ)**

◆ Supernova ν-Winds could produce A=90-100 p-Nuclei (^{92}Mo, ^{96}Ru etc.) in νp-process and Collective ν-Oscillations.

→ **ν-Mass Hierarchy, Nuclear Weak response of ^{98}Tc, ^{180}Ta, ^{138}La, ^{92}Nb, ^{7}Li, ^{11}B …**

◆ Chiral Selection of Amino Acids, Universal Origin.

→ **Symmetry breaking due to ν-molecular interactions**

Dawn of Multi-Messenger Astronomy & Nucl. Astrophysics

Neutron Star Meregrs
Supernovae ⇒ **GW, γ, ν, Elements**