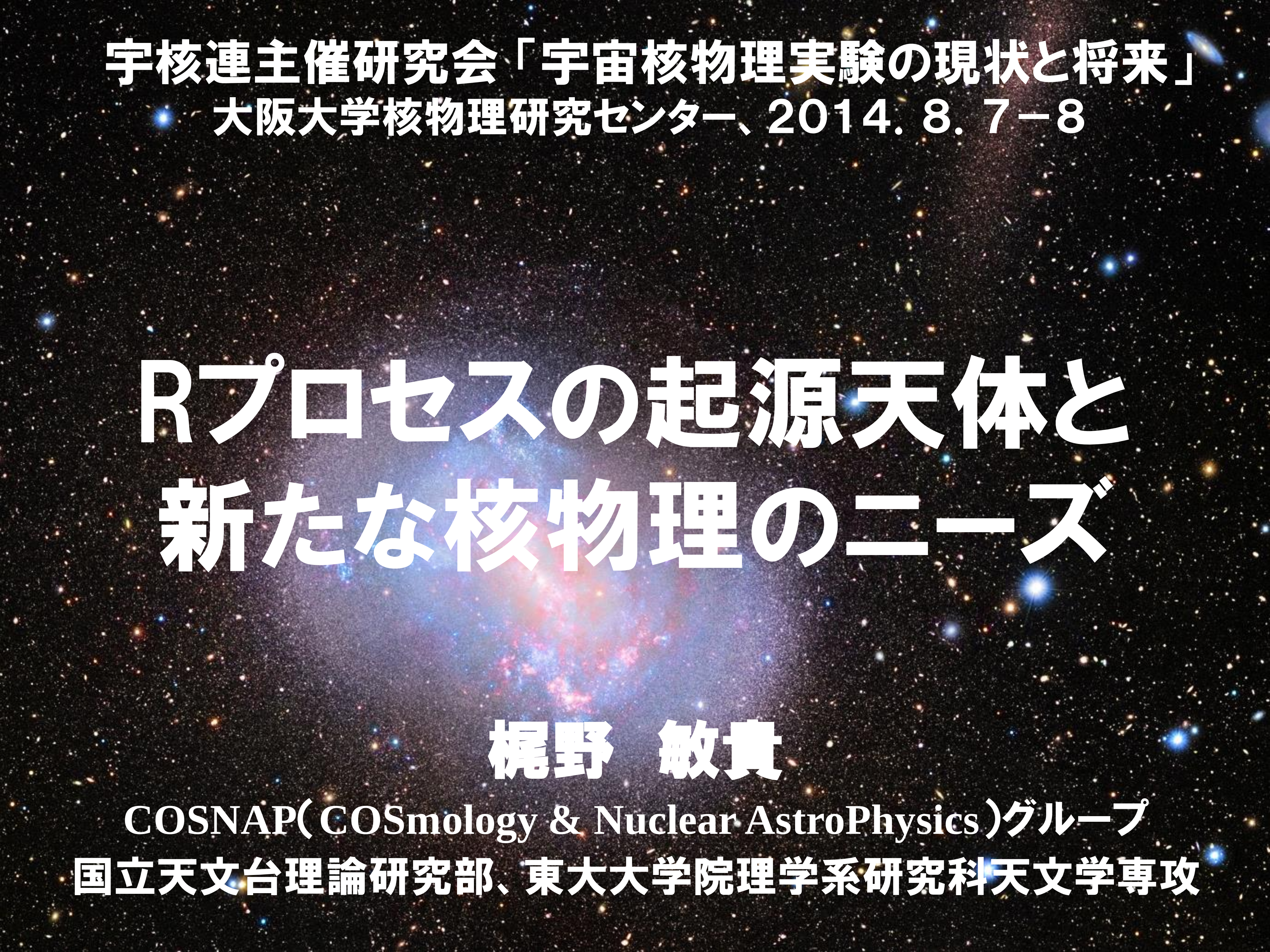


宇核連主催研究会「宇宙核物理実験の現状と将来」
大阪大学核物理研究センター、２０１４．８．７－８

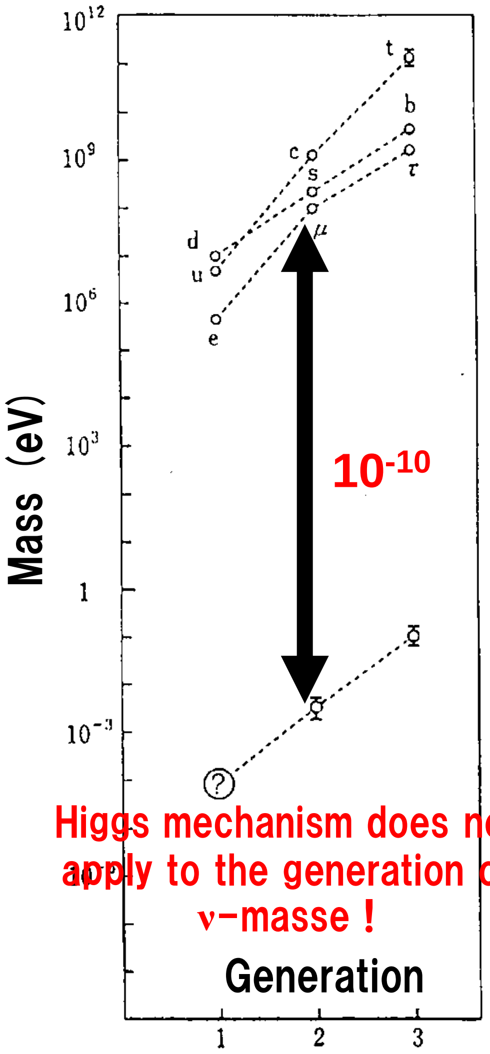
Rプロセスの起源天体と新たな核物理のニーズ

梶野　敏貴

COSNAP（COSmology & Nuclear AstroPhysics）グループ
国立天文台理論研究部、東大大学院理学系研究科天文学専攻

Challenge of the Century

Higgs (standard model) produces 1% of Quark Masses.



Higgs mechanism does not apply to the generation of ν-masse !

Universe is flat and expanded acceleratingly.

$$\Omega_B + \Omega_{CDM} + \Omega_\Lambda = 1$$

- **What is CDM (Ω_{CDM} = 0.27) and DE (Ω_Λ = 0.68) ?**

  CMB & LSS including absolute ν-mass

- **Is BARYON sector (Ω_B = 0.05) well understood ?**

  BBN ^{7}Li-Problem with DMs (Axion, SUSY …)

  SUSY-DM ⇒ beyond the Standard Model ⇒ $m_\nu \neq 0$, unique signal

Key Physics with $m_\nu \neq 0$ beyond the Standard Model :

- Unification, CP & L- & B-genesis, Dirac or Majorana ?
- Dark Matter & Big Bang Nucleosynthesis ?
- Explosion Mechanism of CC-SNe & Nucleosynthesis ?

Today's Purpose

is to elucidate the significance of ASTRO-NUCLEAR PHYSICS in the studies of element genesis in the Universe.

^{6}Li はビッグバン起源か？ ⇒ ビッグバン宇宙論の危機？

Shima et al. Phys. Rev. C72 (2005) 044004.
Kusakabe, Kajino, Yoshida, Shima, Nagai, and Kii, PRD 79 (2009), 123513.
Kusakabe, Kajino, Cheoun, Kino, Mathews, ApJ Suppl. (2014), in press.

#1: Leptonic SUSY, stau (NLSP)

$^4He_X(d,X^-)^6Li$

$^7Be_X(p,\gamma)^8B_X, {}^7Be^*_X(p,\gamma)^8B_X, {}^7Be_X(p,\gamma)^8B^*_X$

#2: Decaying massive relic DM
#3: Axion BEC + SUSY

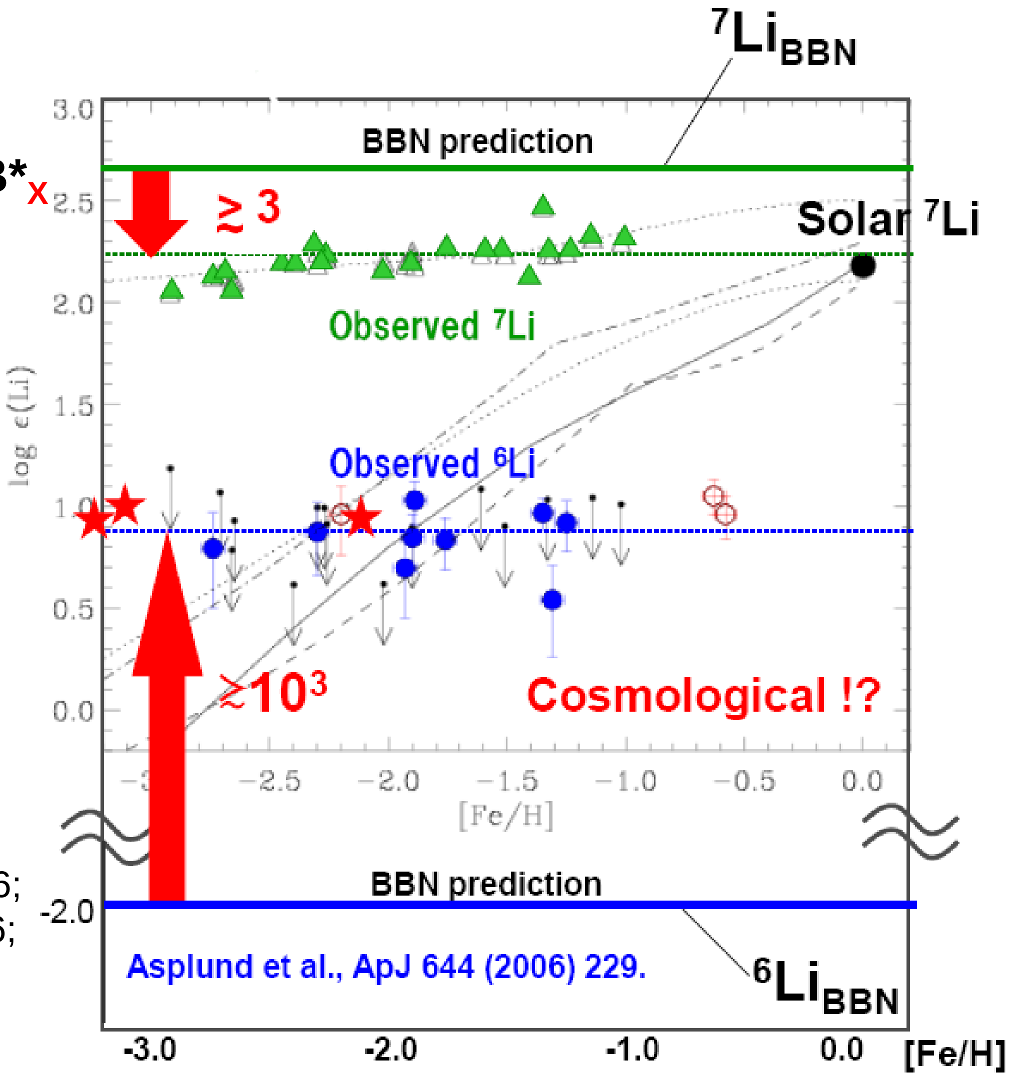
$^4He(\gamma_{NT},n)^3He(^4He,p)^6Li$

$^4He(\gamma_{NT},p)^3H(^4He,n)^6Li$

光核 (→ 弱電) 反応

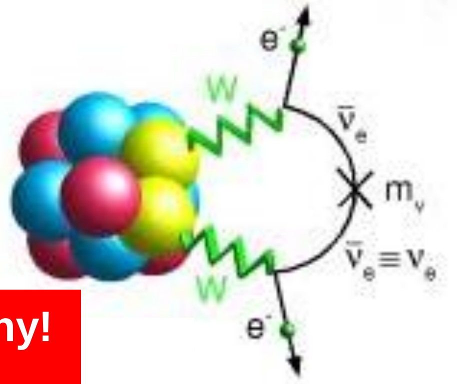
Pospelov (2007)
Hamaguchi et al. (2007)
Bird et al. (2008)

Kusakabe, Kajino, et al., PRD74 (2006), 023526; PRD76 (2007), 121302(R); ApJ 680 (2008), 846; PRD79 (2009) 123513; PRD80 (2009), 103501; PRD81 (2010), 083521; PL 718 (2013), 704; PR D87 (2013), 085045.



Asplund et al., ApJ 644 (2006) 229.

Total ν−Mass, constrained from Nuclear Physics and Cosmology



Neutrinoless ββ

- **0νββ in COUORE, NEMO3, EXO, KamLAND Zen**

→ 0.05〜0.1 eV in the future

$|\sum U^2_{e\beta} m_\beta| < 0.3$ eV: COUORE, NEMO3, EXO, KamLAND Zen (2012)

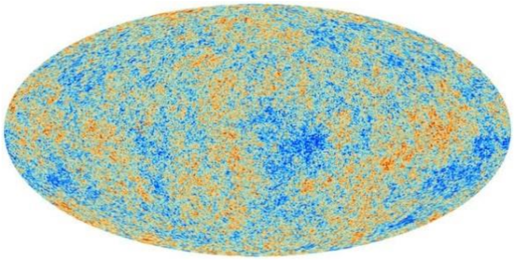
Strongly constrains mass hierarchy!
→ 0.1 eV in the future

- **CMB Anisotropies + LSS**

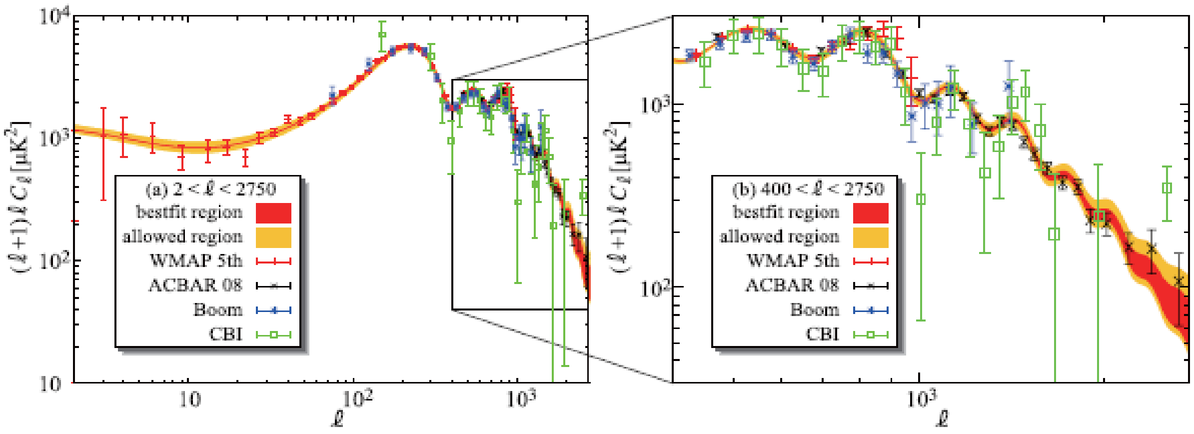
$\sum m_\nu < 0.36$ eV (95%C.L.): WMAP-7yr + HST + CMASS (Putter et al. arXiv:1201.1909)

CMB Anisotropies & Polarization including Cosmic Magnetic Field

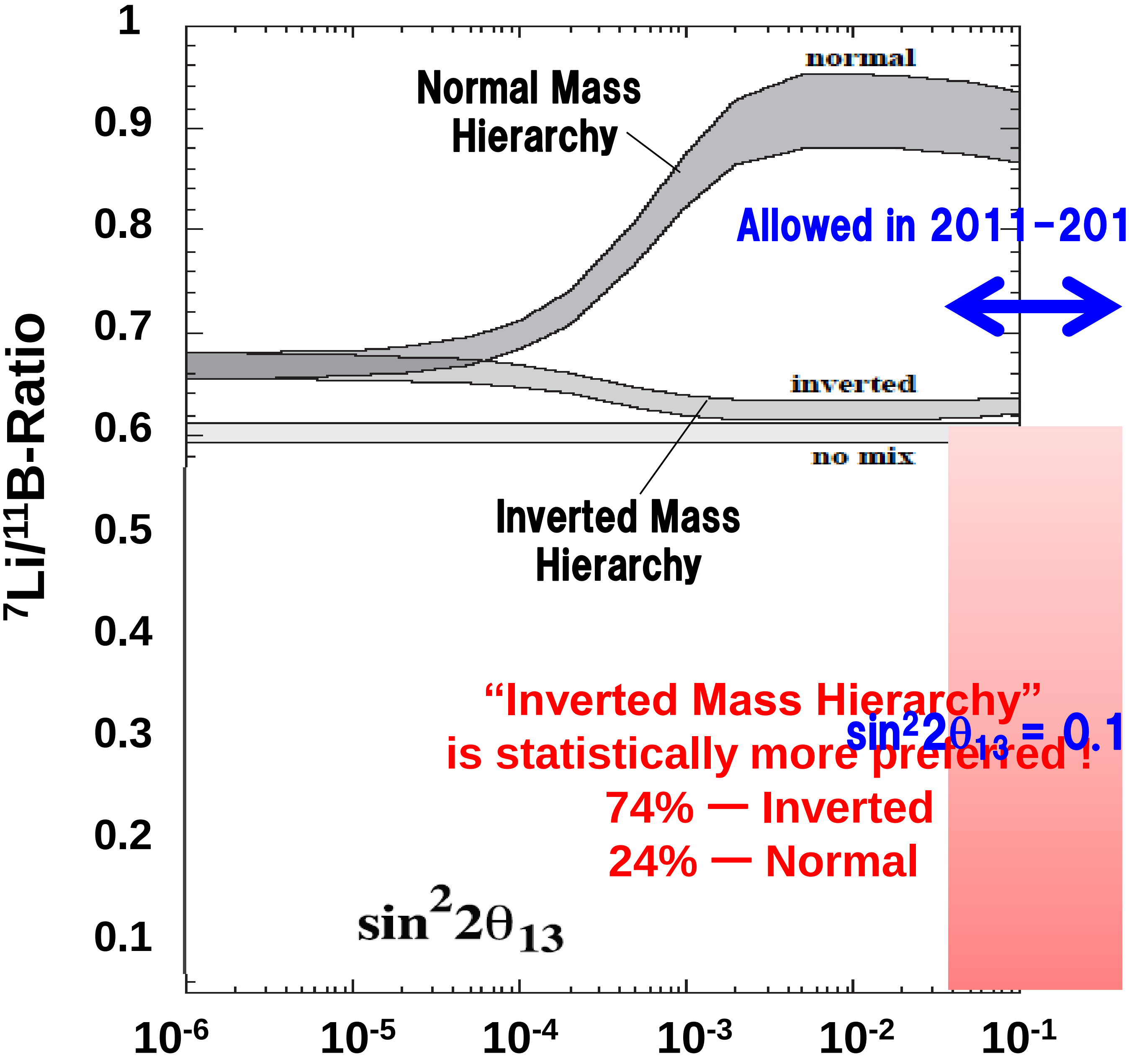
$\sum m_\nu < 0.2$ eV (2σ, $B_\lambda < 2$nG): with Magnetic Field; Ymazaki, Kajino, Mathews & Ichiki, Phys. Rep. 517 (2012), 141; Phys. Rev. D81 (2010), 103519.



www.esa.int/Our_Activities/Space_Science/Planck/Planck_reveals_an_almost_perfect_Universe



混合角 θ$_{13}$ と質量階層を同時に決定する核物理の方法



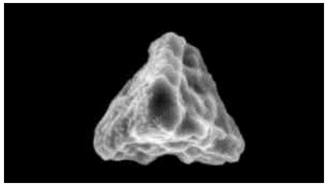
"Inverted Mass Hierarchy"
is statistically more preferred !
74% — Inverted
24% — Normal

Yoshida, Kajino et al.
2005, PRL94, 231101;
2006, PRL 96, 091101;
2006, ApJ 649, 319;
2008, ApJ 686, 448.

Mathews, Kajino, Aoki & Fujiya, PR D85, 105023 (2012).

Suzuki and Kajino, J. Phys. G40 (2013), 083101.

First Detection of ^{7}Li/^{11}B in SN-grains



W. Fujiya, P. Hoppe, & U. Ott, ApJ 730, L7 (2011).

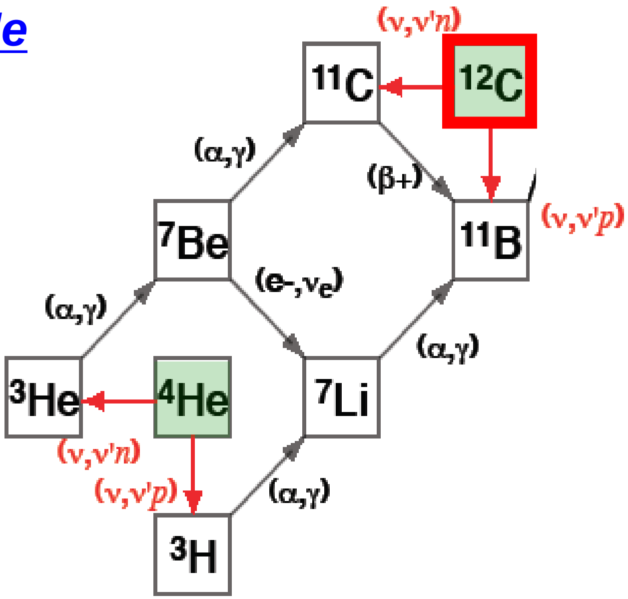
理論予測に必要なニュートリノ・原子核反応率の理論計算

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

Suzuki, Chiba, Yoshida, Kajino & Otsuka, PR C74 (2006), 034307.
Suzuki, Fujimoto & Otsuka, PR C67, 044302 (2003)

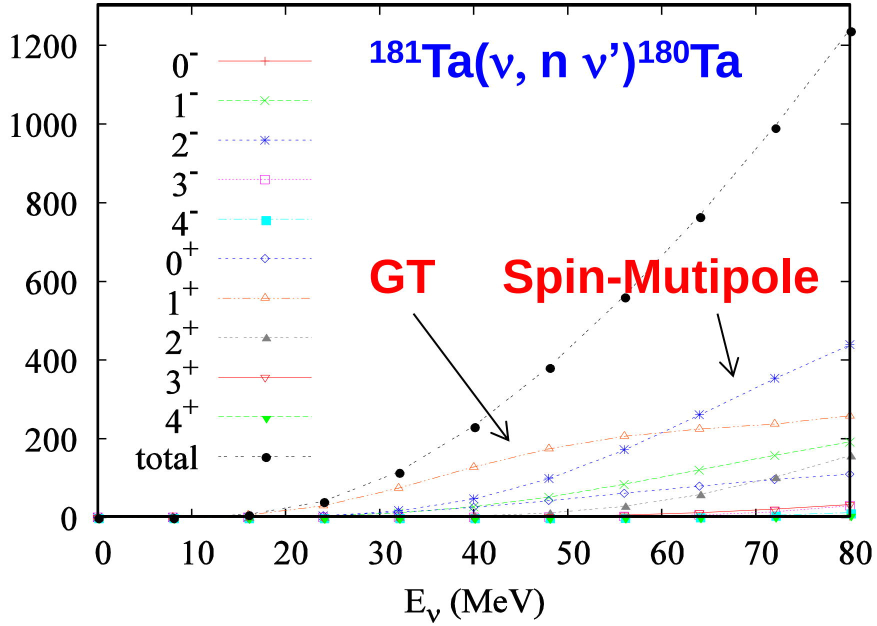
^{12}C: New Hamiltonian = Spin-isospin flip int. with tensor force to explain neutron-rich exotic nuclei.

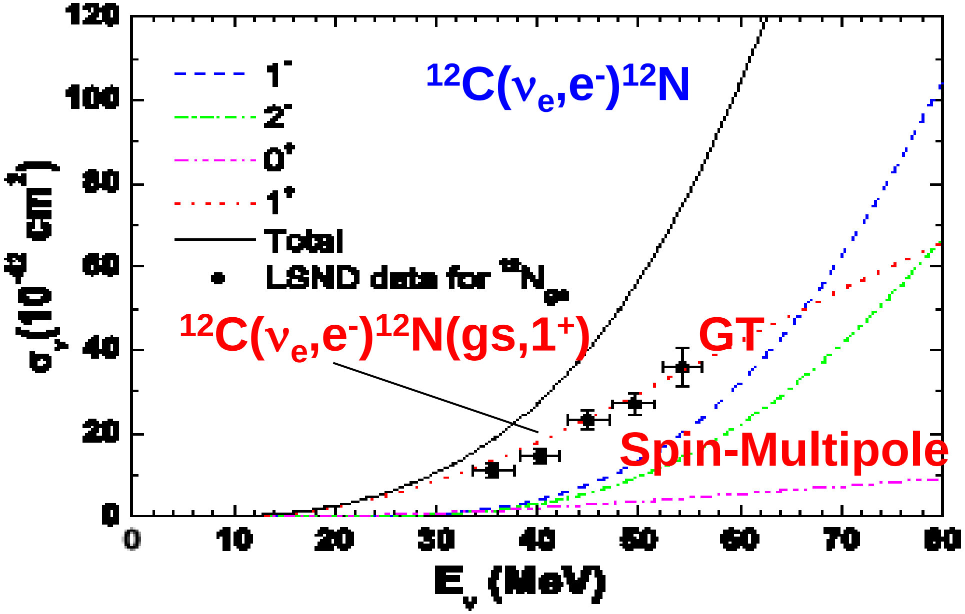
- μ-moments of p-shell nuclei
- GT strength for $^{12}C \rightarrow {}^{12}N$, $^{14}C \rightarrow {}^{14}N$, etc. (GT)
- DAR (ν,ν'), (ν,e^-) cross sections



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

Cheoun, et al., PRC81 (2010), 028501; PRC82 (2010), 035504:
J. Phys. G37 (2010), 055101; PRC 83 (2011), 028801





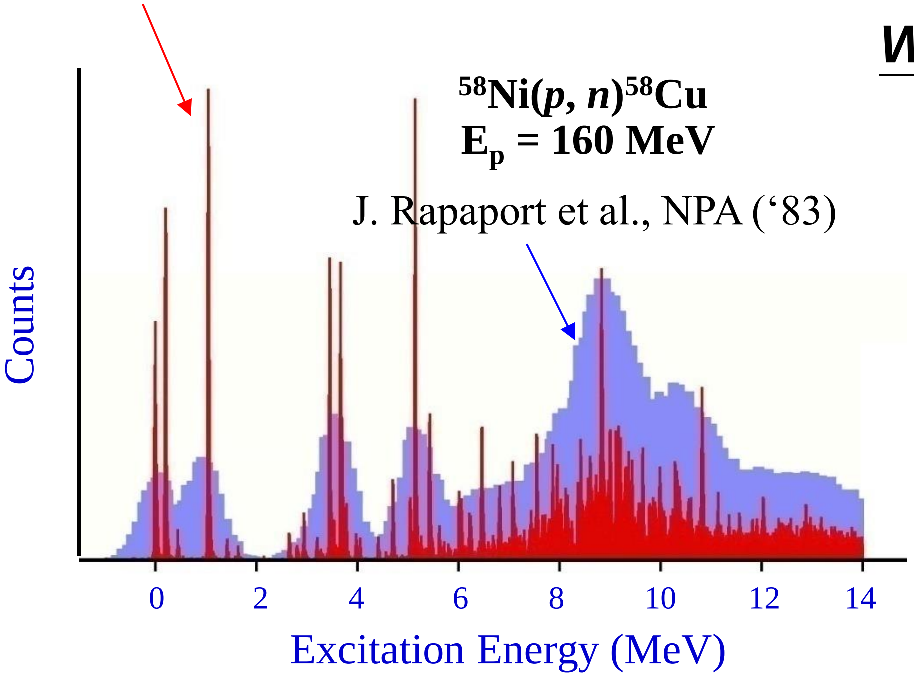
ν-BEAM は未だ実現していない量子ビーム！

We can use EM- & Hadronic (CEX) PROBE !

Similarity between Electro-Magnetic & Weak Interactions

^{58}Ni(^{3}He, *t*)^{58}Cu
E = 140 MeV/u

Y. Fujita et al., EPJ A 13 ('02) 411.
Y. Fujita et al., PRC 75 ('07)



^{58}Ni(*p*, *n*)^{58}Cu
E_p = 160 MeV

J. Rapaport et al., NPA ('83)

EM-current = $\vec{V}$, Weak-current = $\vec{V}$ - $\vec{A}$

$$\vec{V} \approx g_V^{IV} \frac{i}{2m} \vec{\sigma} \times \vec{q} + \frac{g_V}{2m} (\vec{p} + \vec{p}\,')$$

$$\vec{A} \approx g_A \vec{\sigma}$$

Weak operator in non-relativistic limit

Gamow-Tellar operator = $\vec{\sigma}\tau_{\pm}$

Spin-Multipole operator = $[\vec{\sigma} \times Y^{(L)}]^{J} \tau_{\pm}$

荷電交換反応

光核 (→ 弱電) 反応

Double β decay – ν mass – Astro-Cosmology Connection

K. Yako et al., PRL 103 (2009) 012503.

B(GT$^{+/-}$) distribution

Shell model …

with quenched operator

Spectra agree qualitatively up to …

(p,n) : E_x = 15 MeV

(n,p) : 8 MeV

Strengths beyond … underestimated.

(n,p) channel :

ΣB(GT$^+$;exp) = 1.9±0.3…

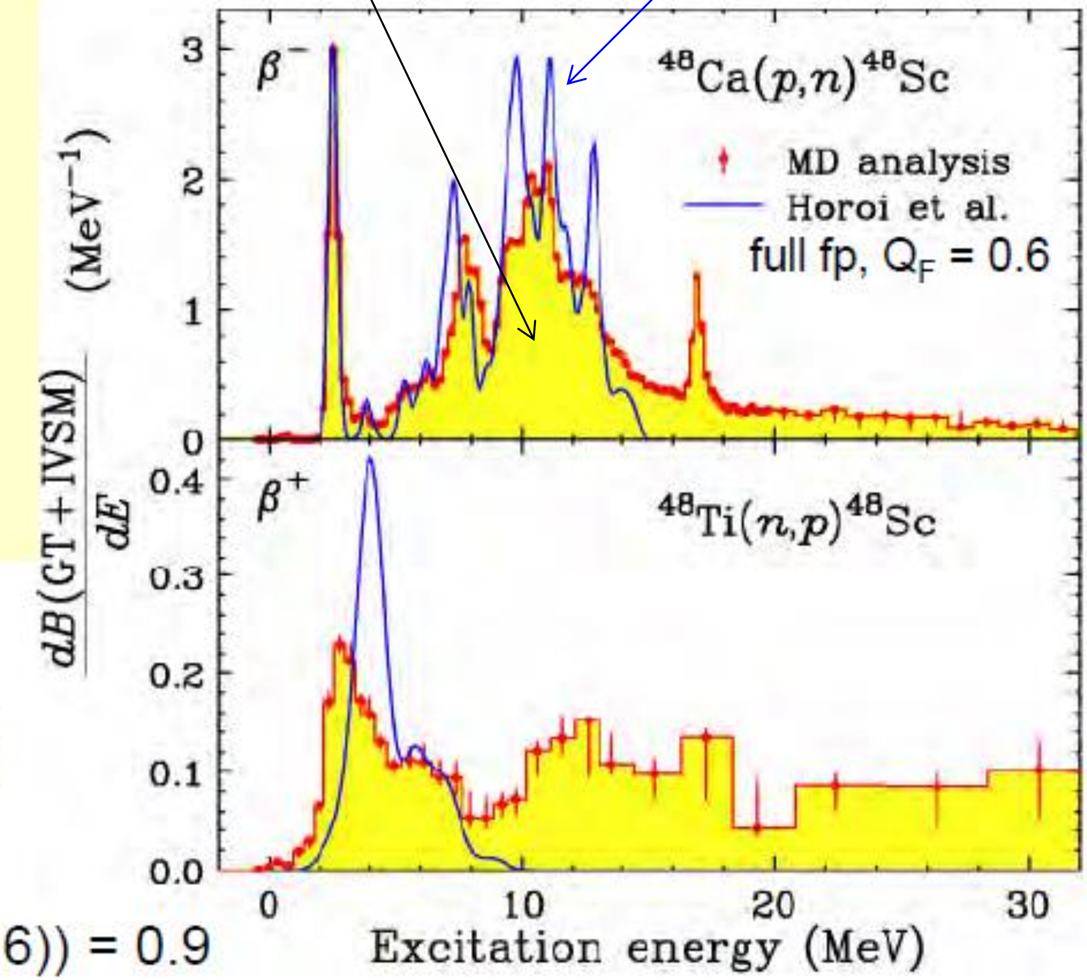
(w subtraction of IVSM)

↕

ΣB(GT$^+$;ShellModel(Q_F=0.6)) = 0.9

Experiment (RCNP, Osaka)

Shell model (theory)

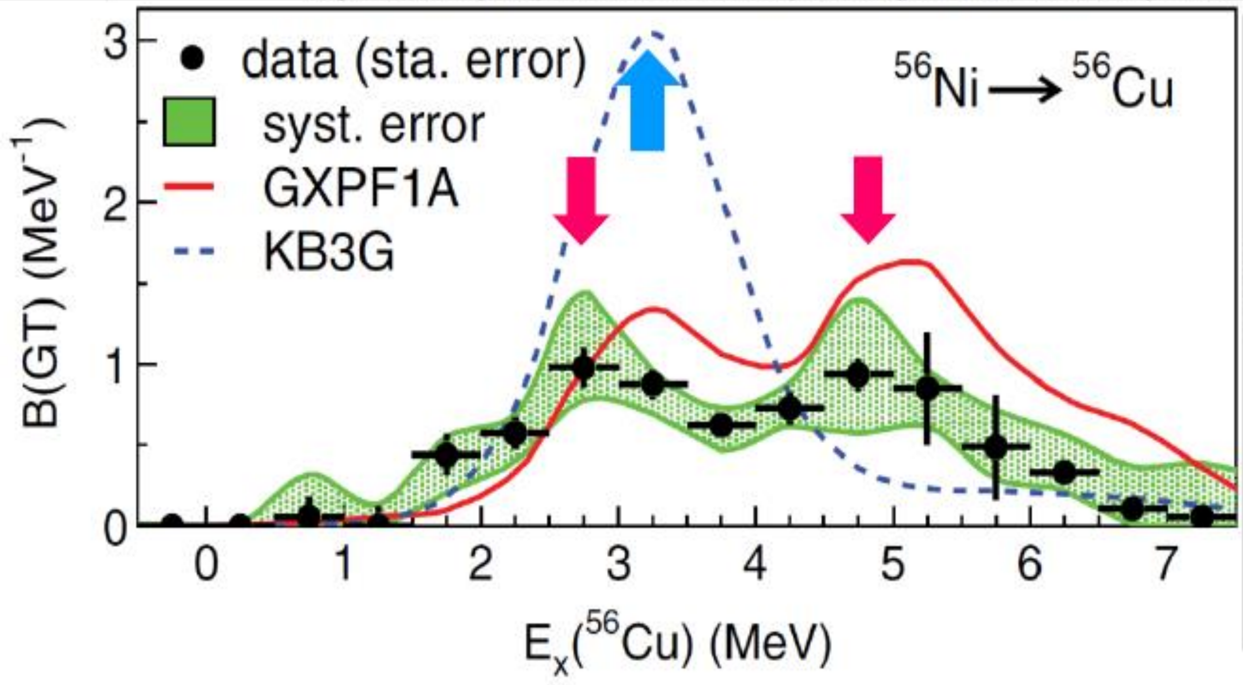


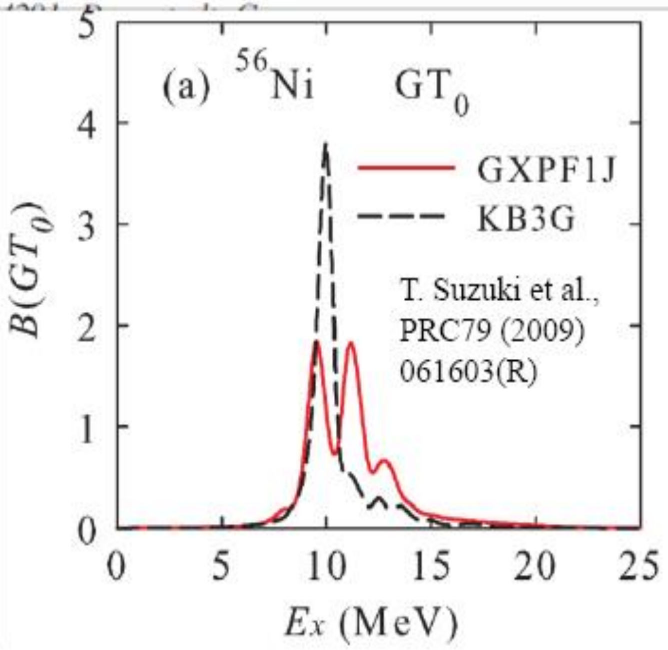
Selected for a Viewpoint in *Physics*
PRL **107,** 202501 (2011) PHYSICAL REVIEW LETTERS week ending 11 NOVEMBER 2011

Gamow-Teller Transition Strengths from ^{56}Ni

M. Sasano,[1,2] G. Perdikakis,[1,2] R. G. T. Zegers,[1,2,3] Sam M. Austin,[1,2] D. Bazin,[1] B. A. Brown,[1,2,3] C. Caesar,[4] A. L. Cole,[5] J. M. Deaven,[1,2,3] N. Ferrante,[6] C. J. Guess,[7,2] G. W. Hitt,[8] R. Meharchand,[1,2,3] F. Montes,[1,2] J. Palardy,[6] A. Prinke,[1,2,3] L. A. Riley,[6] H. Sakai,[9] M. Scott,[1,2,3] A. Stolz,[1] L. Valdez,[1,2,3] and K. Yako[10]

[1]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*
[2]*Joint Institute for Nuclear Astrophysics, Michigan State University, East Lansing, Michigan 48824, USA*
[3]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*





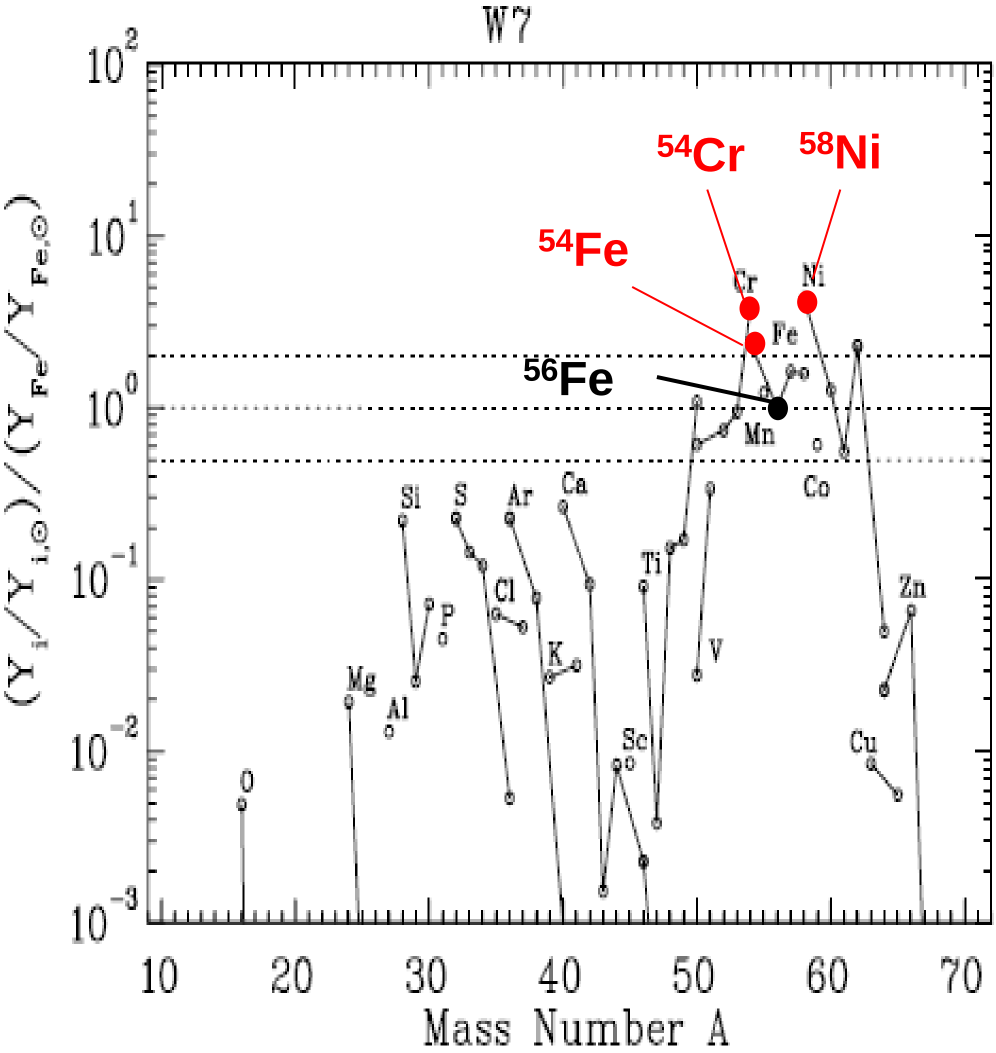
T. Suzuki et al., PRC79 (2009) 061603(R)

Quenching factor = 0.74

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 125:439–462, (1999)

NUCLEOSYNTHESIS IN CHANDRASEKHAR MASS MODELS FOR TYPE Ia SUPERNOVAE AND CONSTRAINTS ON PROGENITOR SYSTEMS AND BURNING-FRONT PROPAGATION

KOICHI IWAMOTO,[1,2,3] FRANZISKA BRACHWITZ,[4] KEN'ICHI NOMOTO,[1,2,3] NOBUHIRO KISHIMOTO,[1]
HIDEYUKI UMEDA,[2,3] W. RAPHAEL HIX,[3,5] AND FRIEDRICH-KARL THIELEMANN[3,4,5]



Ia型超新星元素合成:

^{54}Cr, ^{54}Fe, ^{58}Ni / ^{56}Fe

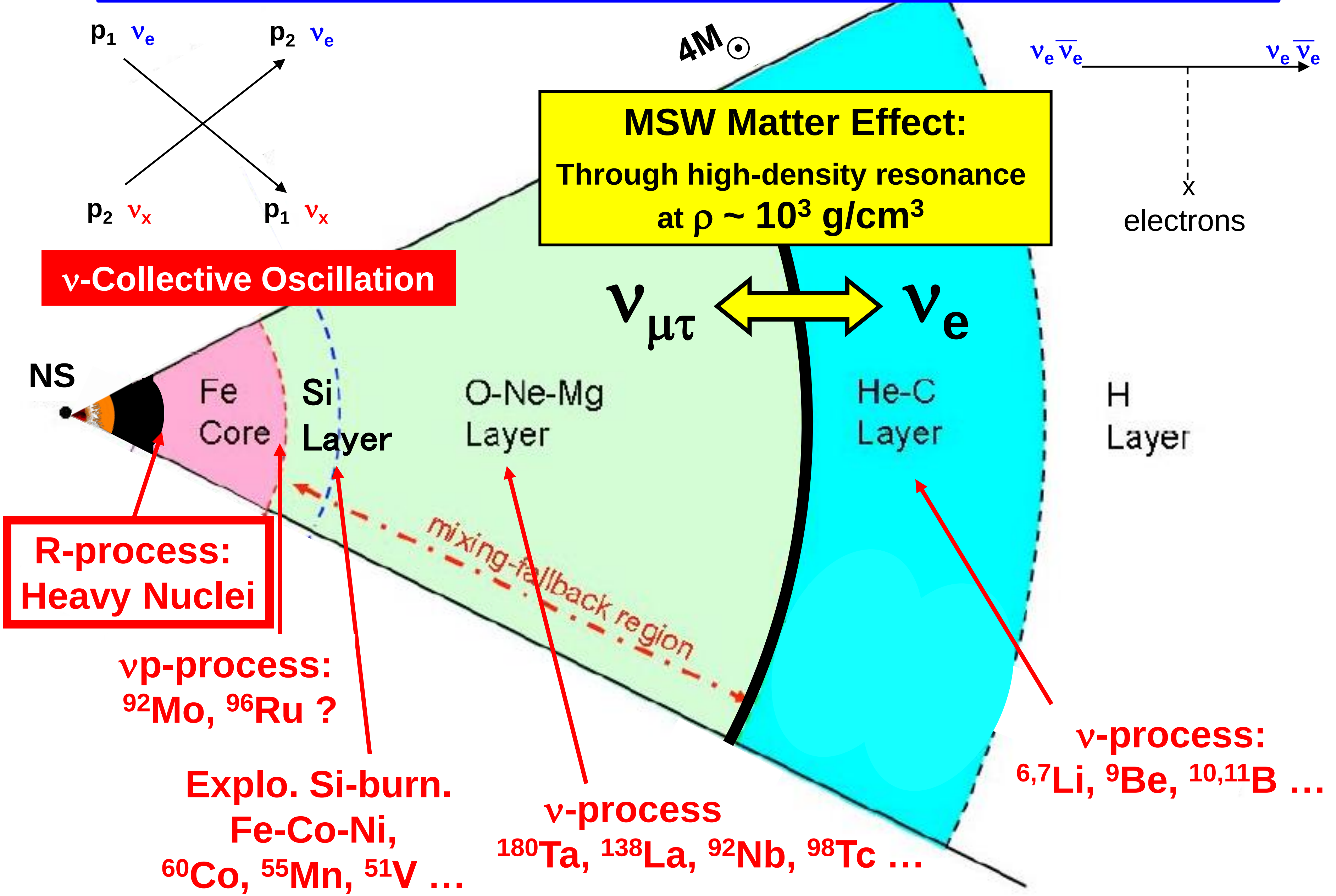
（中性子過多の原子核）

過剰生成問題

- **Detonation vs. Defragration ?**
  → NOT a solution !
- **中性子過剰性, known correctly?**
  → 電子捕獲 is a KEY !

Suzuki, Otsuka, Kajino, Hidaka et al.
(2014)

Neutrino Oscillation and SN-Nucleosynthesis



ν-Collective Oscillation

MSW Matter Effect:

Through high-density resonance at $\rho \sim 10^3$ g/cm^3

R-process: Heavy Nuclei

νp-process:
^{92}Mo, ^{96}Ru ?

Explo. Si-burn.
Fe-Co-Ni,
^{60}Co, ^{55}Mn, ^{51}V …

ν-process
^{180}Ta, ^{138}La, ^{92}Nb, ^{98}Tc …

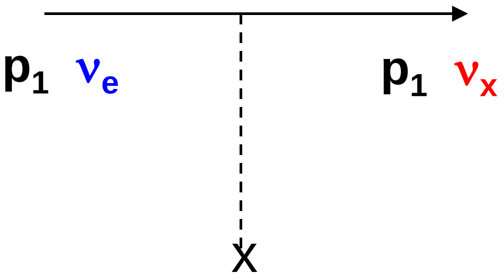
ν-process:
^{6,7}Li, ^{9}Be, ^{10,11}B …

Neutrino Hamiltonian: $H_{tot} = H_{\nu} + H_{\nu\nu}$

H_{ν} = *Mixing and Interaction with Background Electrons*

MSW (Matter) Effect: Mikeheev-Smirnov-Wolfebstein (1978, 1985)

$$H_\nu = \frac{1}{2}\int \mathrm{d}^3p \left(\frac{\delta m^2}{2p}\cos 2\theta - \sqrt{2}G_F N_e\right)\left(a_x^\dagger(p)a_x(p) - a_e^\dagger(p)a_e(p)\right)$$
$$+\frac{1}{2}\int \mathrm{d}^3p \frac{\delta m^2}{2p}\sin 2\theta\left(a_x^\dagger(p)a_e(p) + a_e^\dagger(p)a_x(p)\right).$$

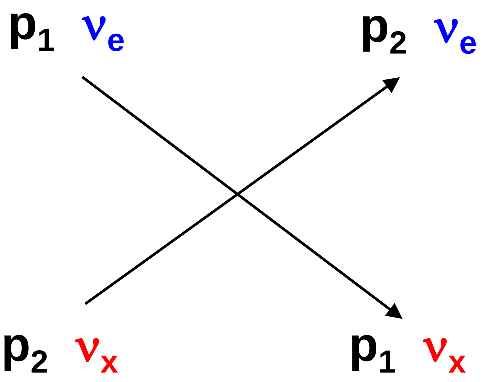


N_e = electron density

$H_{\nu\nu}$ = *Self-Interaction*

Self-Interaction

$$H_{\nu\nu} = \frac{G_F}{\sqrt{2}V}\int \mathrm{d}^3p\,\mathrm{d}^3q\, R_{pq}\left[a_e^\dagger(p)a_e(p)a_e^\dagger(q)a_e(q) + a_x^\dagger(p)a_x(p)a_x^\dagger(q)a_x(q)\right.$$
$$\left. + a_x^\dagger(p)a_e(p)a_e^\dagger(q)a_x(q) + a_e^\dagger(p)a_x(p)a_x^\dagger(q)a_e(q)\right],$$



Quest for both EXACT &
APPROXIMATE many-body SOLUTION !

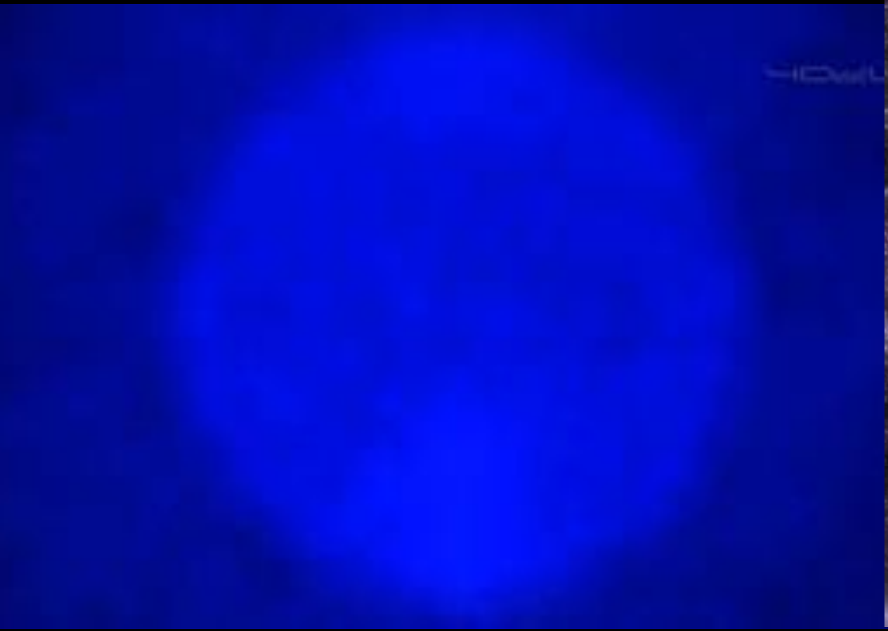
"Invariants of collective neutrino oscillations"

Y. Pehlivan, A.B. Balantekin, T. Kajino & T. Yoshida, Phys. Rev. D84, 065008 (2011),
Y. Pehlivan, A.B. Balantekin, & T. Kajino, Phys. Rev. D (2014), in press.

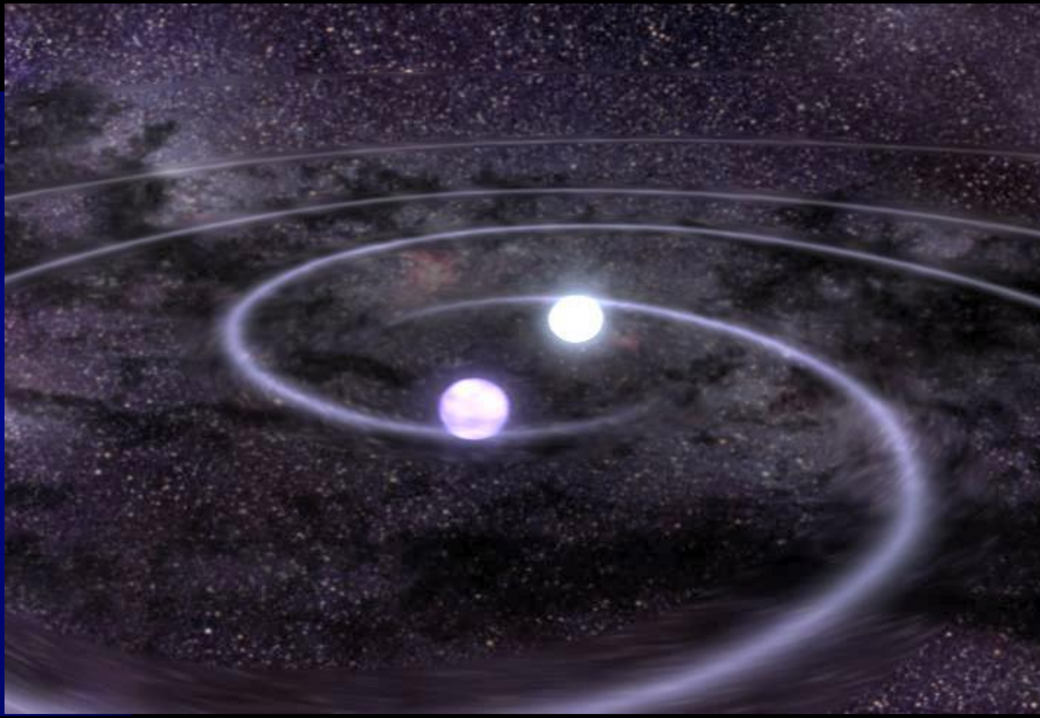
Where is the r-process astrophysical site?

Supernovae or Binary Neutron-Star Merger ?

3D ν-driven CC-Supernova （11.2 Msun)
Takiwaki, Kotake, Suwa, ApJ 786 （2014）, 83.



Binary Neutron Star Merger
(Credit-NASA)



Candidate Astrophysical Sites for R-Process in Metal-Poor Stars

	Physical Conditions			Expected Event Rate	Evaluation
	S/k	Ye	$\dot{M}_r/(SN)$		
Supernovae					
ν-Driven Wind	100	0.45	$10^{-5}M_\odot$	10^{-2}/yr/gal*	○ Solar∼Metal poor stars ○ Universality → Weak-r ? △ Explosion model Too high Y_e ?
MHD Jet	10	0.1-0.4	$10^{-3}M_\odot$	10^{-4}	○ Solar∼Metal poor stars X Universality, broken △ Explosion model Special cond. ?
Gamma-ray Burst					
(S) Binary Neutron Star Merger	1	0.1	$10^{-2}M_\odot$	10^{-5}	X Universality, broken ? τ>1Gy, too late for [Fe/H]<-3? △ Explosion model Special cond. ?
(L) Collapsar	1-10^4	0.1	$10^{-1}M_\odot$	10^{-5}	○ Solar∼Metal poor stars X Universality, broken △ Explosion model Mechanism ?

*Solar-System r-abundance = $10^3 M_\odot$ ← $10^{-5}M_\odot \times 10^{-2} \times 10^{10} = 10^3 M_\odot$

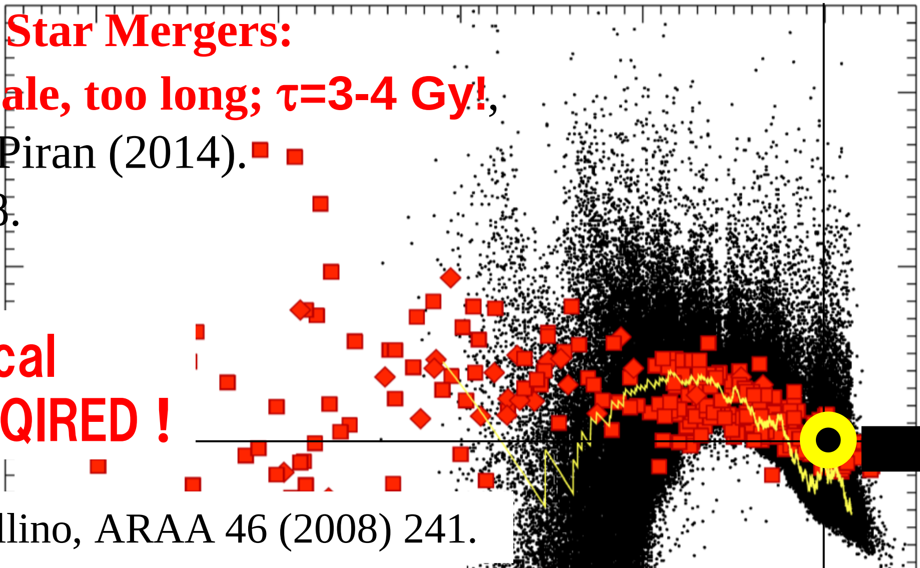
Consistent with observed SN frequency

Cosmic age

Binary Neutron Star Mergers:

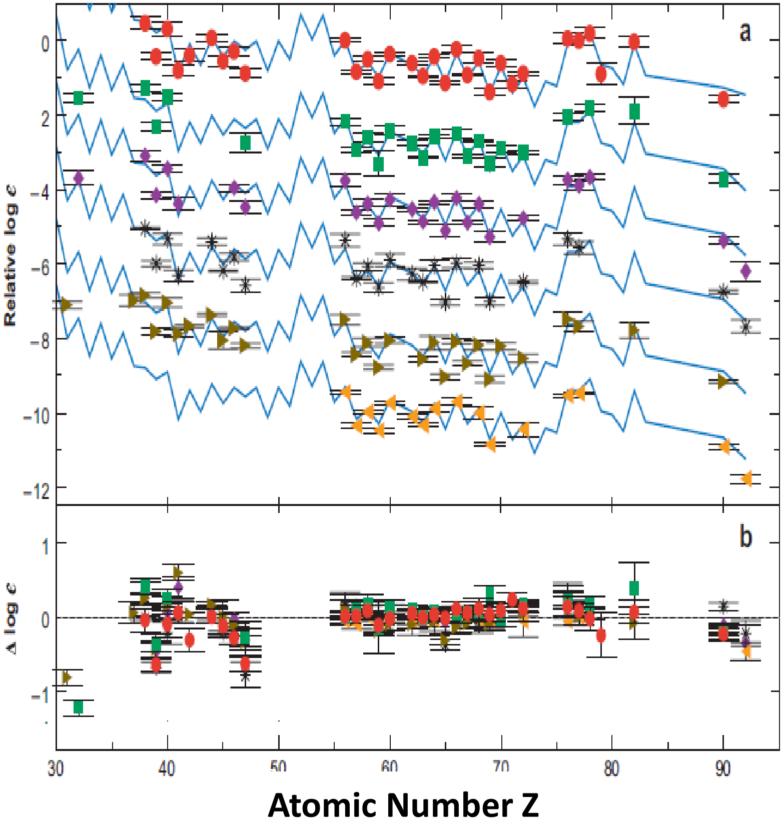
Merging time scale, too long; τ=3-4 Gy!, Wanderman and Piran (2014). arXiv: 1405.5878.

Argast, Samland, Thielemann, Qian, A&A 416 (2004), 997.

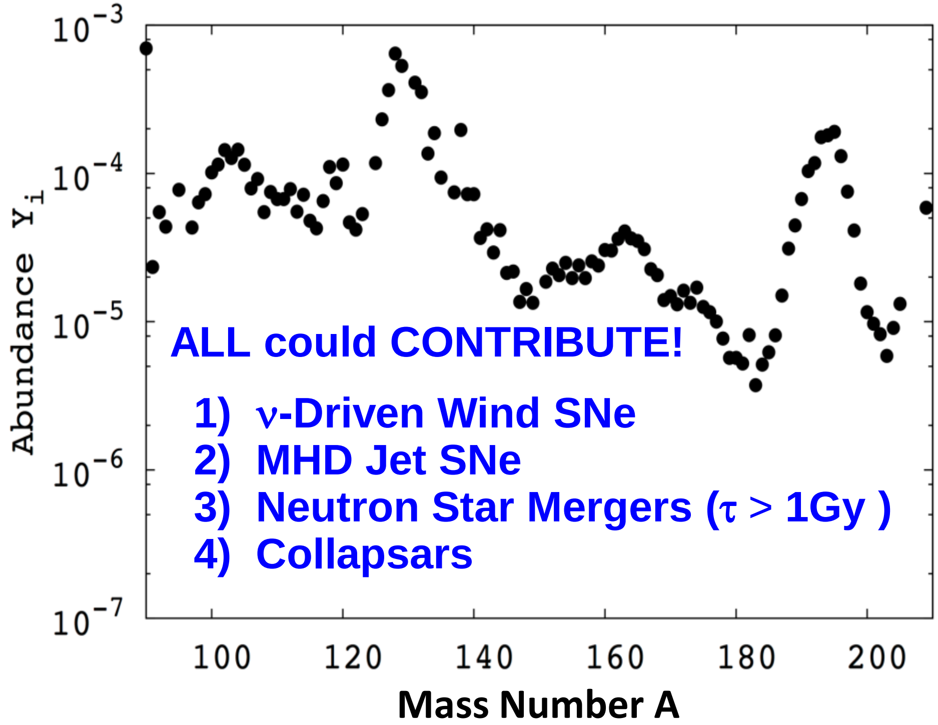


More Theoretical Studies, REQIRED !

Sneden, Cowan, Gallino, ARAA 46 (2008) 241.



Solar System Abund.



ALL could CONTRIBUTE!

1) **ν-Driven Wind SNe**
2) **MHD Jet SNe**
3) **Neutron Star Mergers (τ > 1Gy)**
4) **Collapsars**

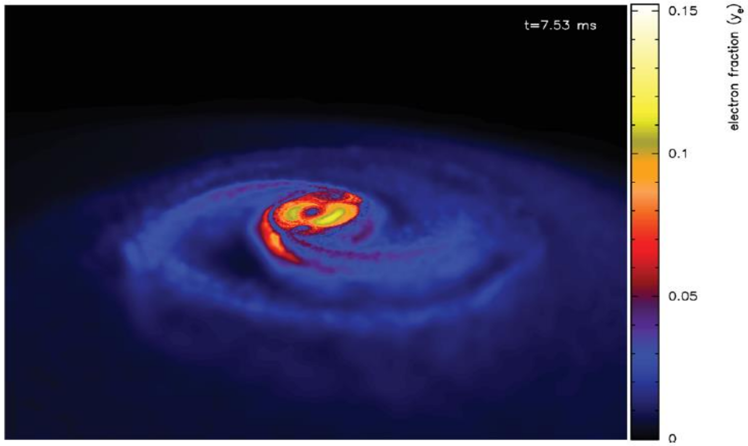
Fluid-Dynamical Data for Neutron Star Merger

Binary Neutron Star Merger:

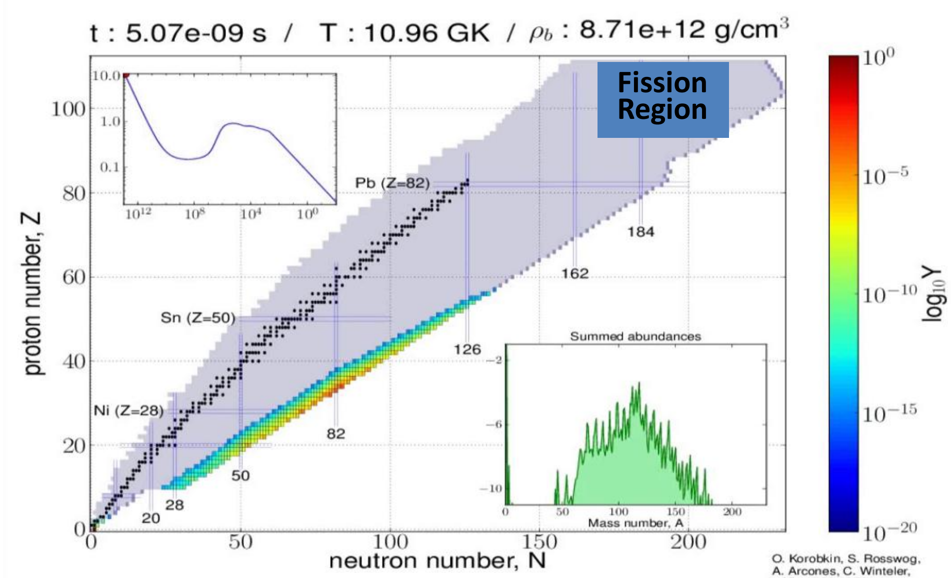
Korobkin et al., MNRAS 426 (2012), 1940,
Piran et al., MNRAS 430 (2013), 2121,
Rosswog et al., MNRAS 430 (2013), 2585.

SPH simulation:

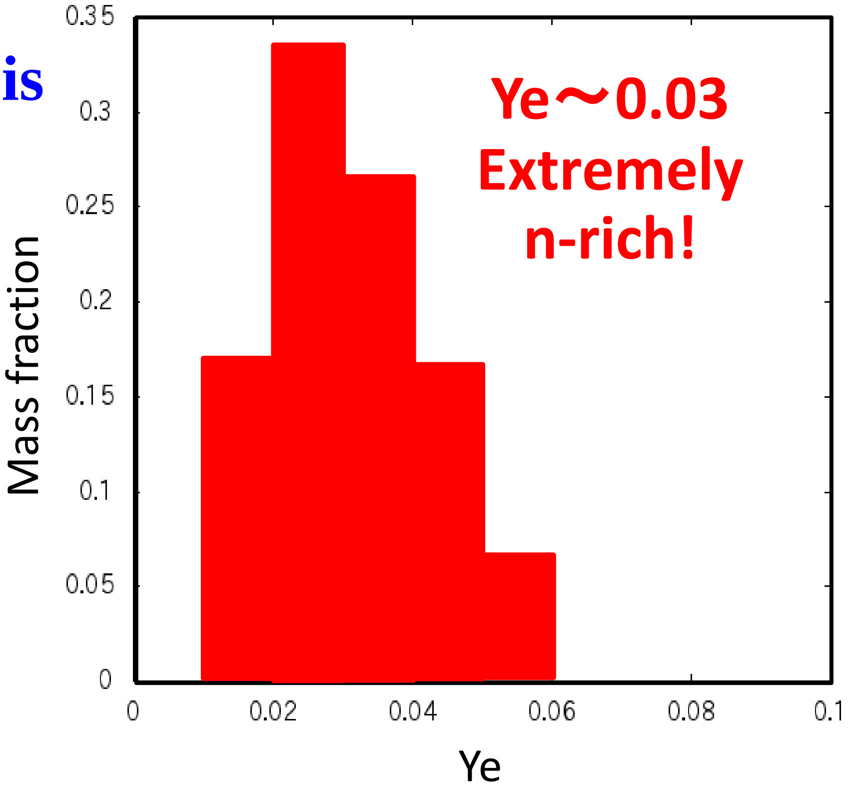
Newtonian gravity
Neutrino Leakage scheme



Apply to R-Process Nucleosynthesis



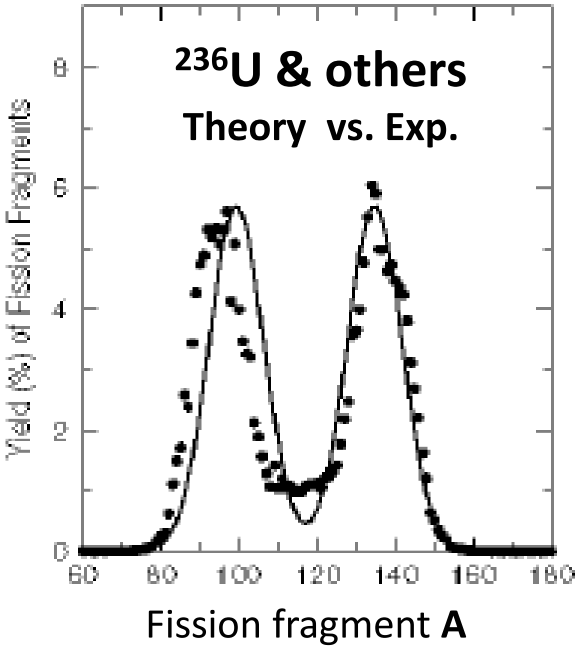
O. Korobkin, S. Rosswog,
A. Arcones, C. Winteler,
arXiv:1206.2379

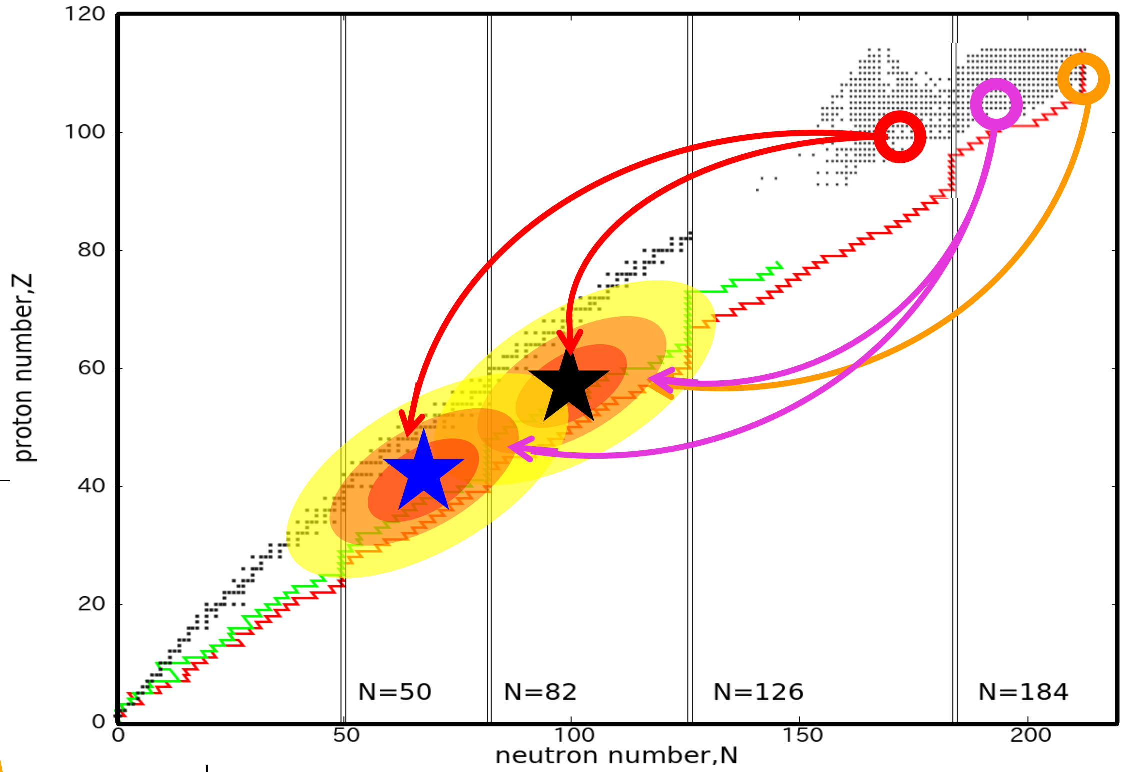


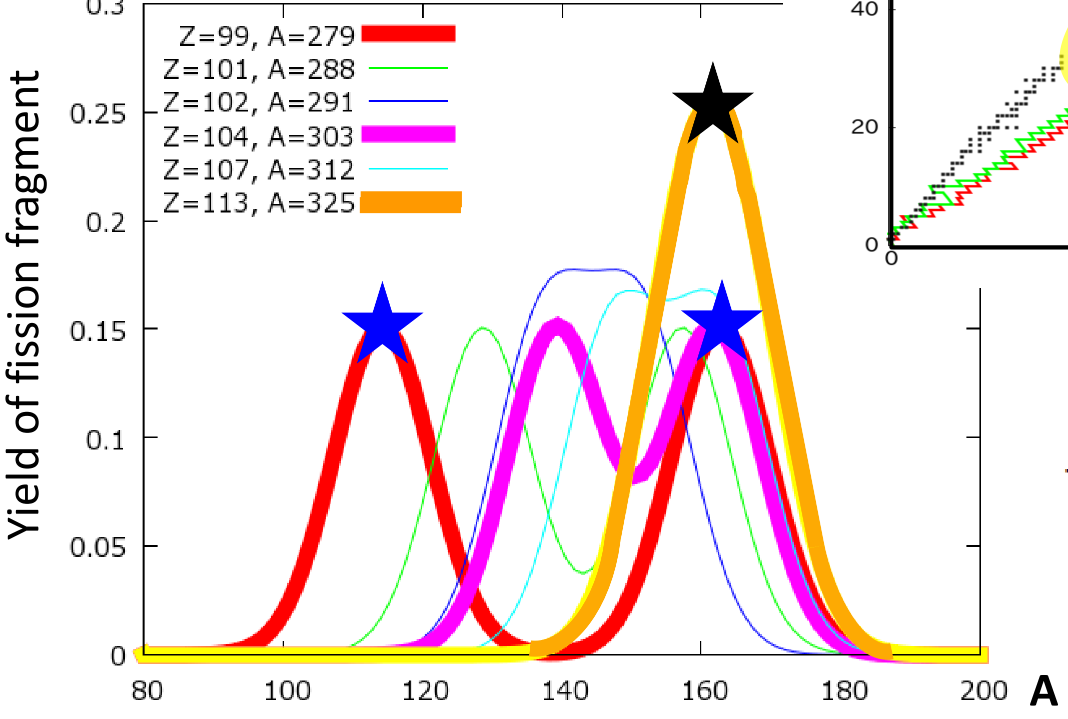
Ye～0.03
Extremely
n-rich!

Fission Fragment Mass Distribution

M. Ohta et al., Proc. Int. Conf. on NDST, Nice, France, (2007)
S. Chiba et al., AIP Conf. Proc. 1016, 162 (2008).







Bimordial or Trimodal FFD:

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

$$A_H=(1+\alpha)(A_p-N_{loss})/2$$

$$A_L=(1-\alpha)(A_p-N_{loss})/2$$

$$A_M=(A_H+A_L)/2.$$

Nuclear Models
— sensitive to Fission —

One of the Best Models !

Nuclear Mass Model:

KTUY Model

Fission Barrier, Q_{β}, (n,γ)

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

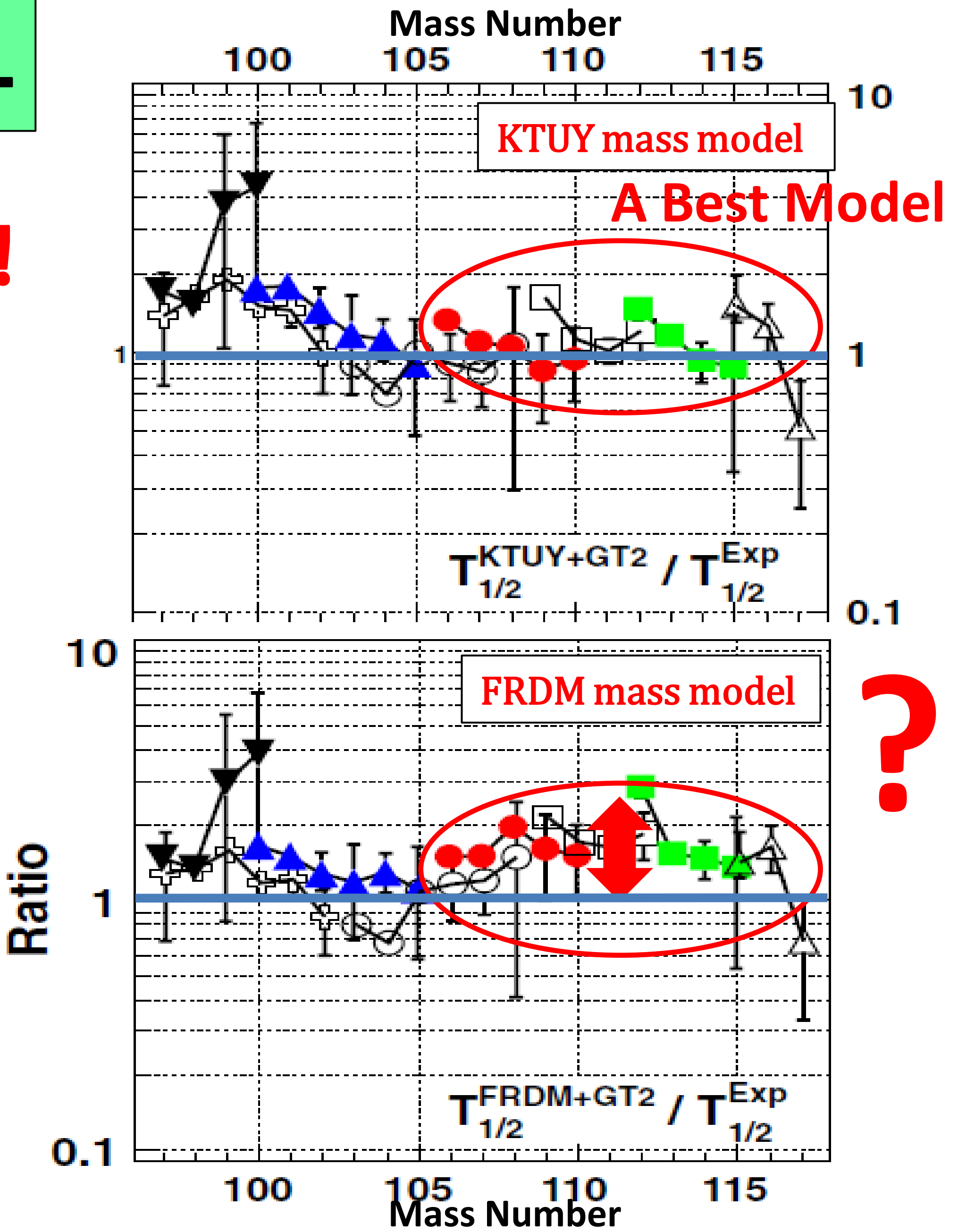
Reaction Rates:

α-decay, β-decay, fission

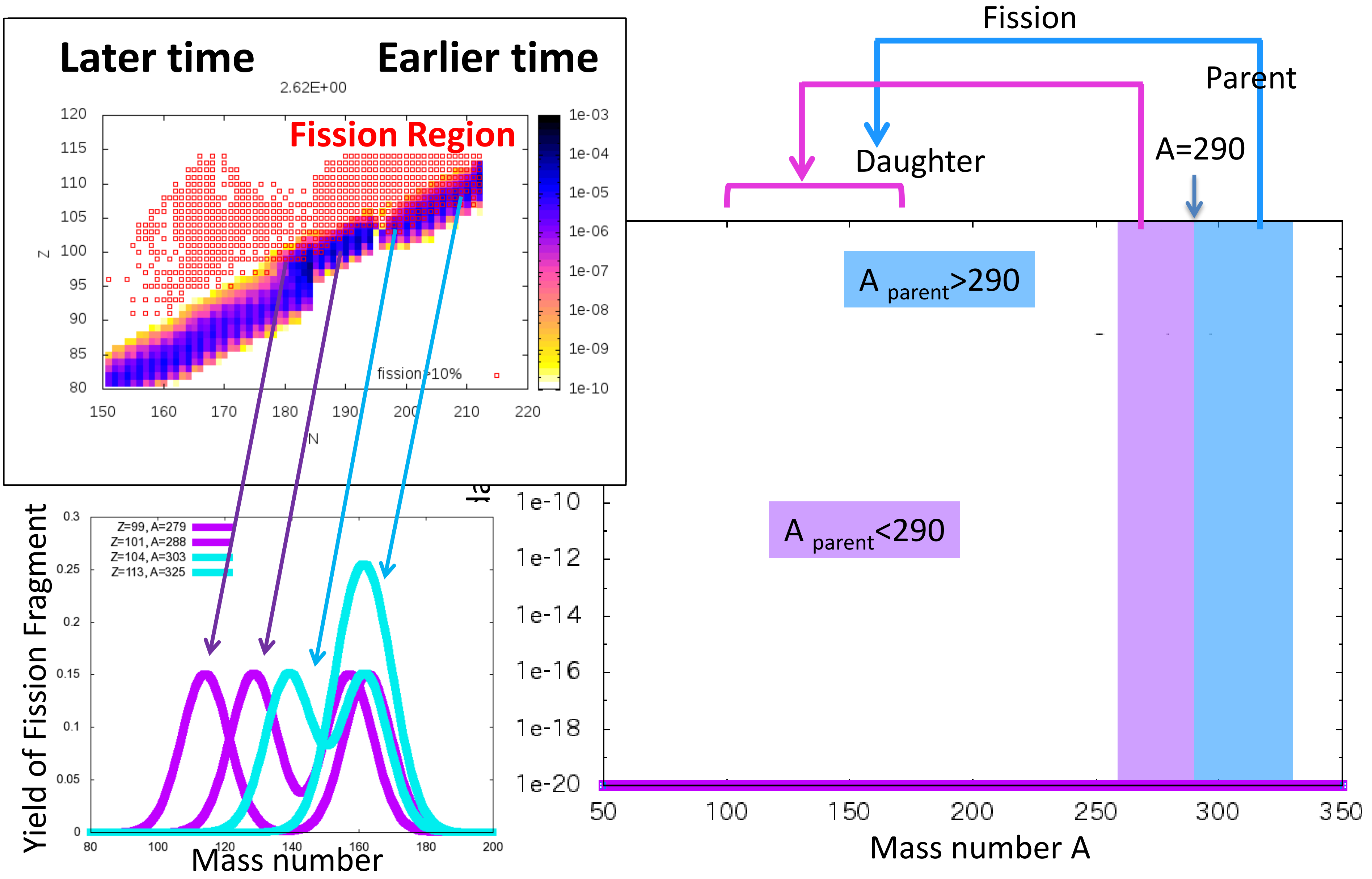
H. Koura, AIP Conf. Proc. 704, 60, (2004).

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

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



Abundance Evolution of Neutron Star Merger (MOVIE)

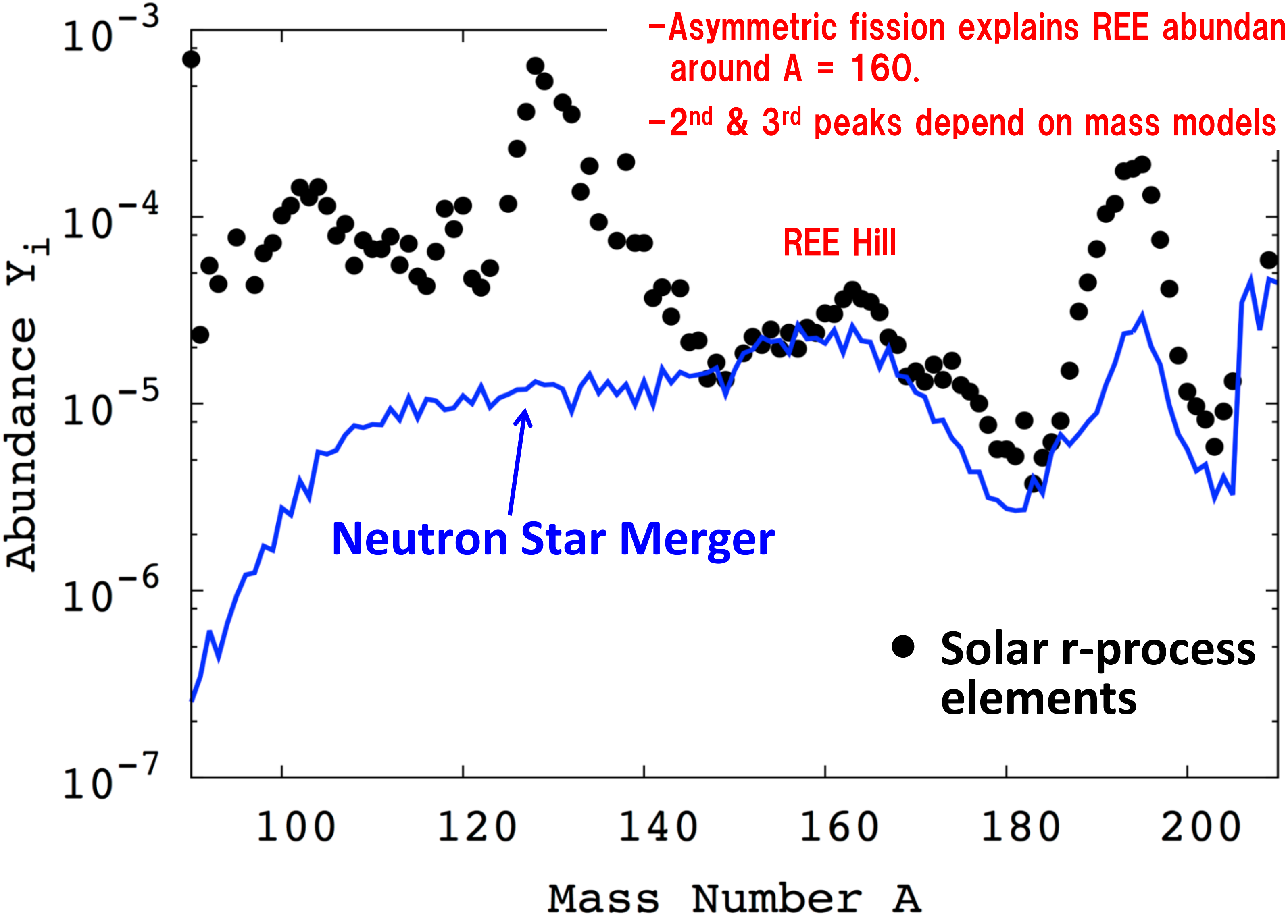


Contribution from Neutron Star Merger

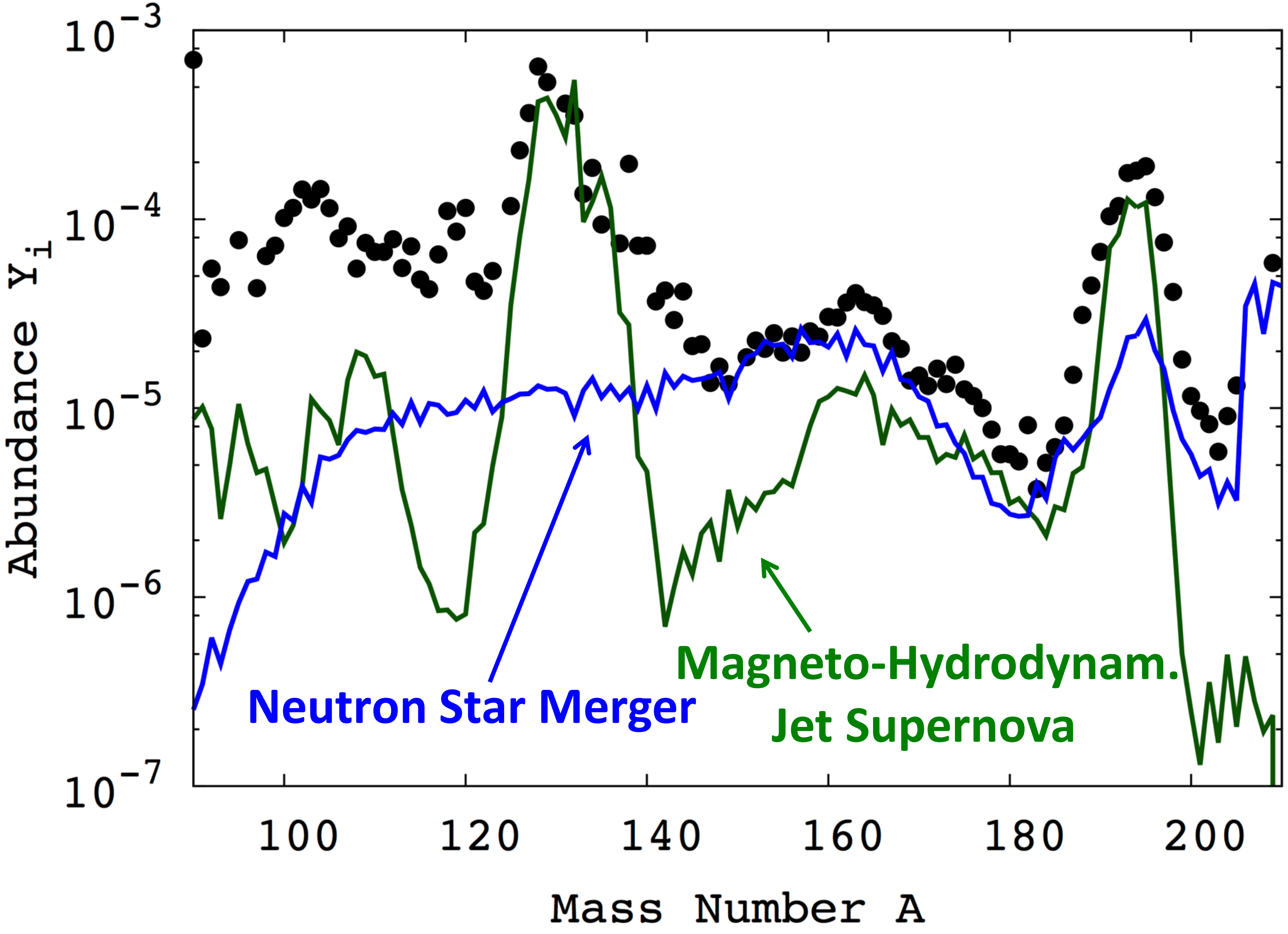
Shibagaki, Kajino, Chiba, Mathews,
Nishimura & Lorusso, submitted (2014)

S. Goriely et al., PRL 111, 242502 (2013)
M. Eichler, talk in this Conf. (7/11/2014)

- Asymmetric fission explains REE abundance hill around A = 160.
- 2nd & 3rd peaks depend on mass models & FFD.

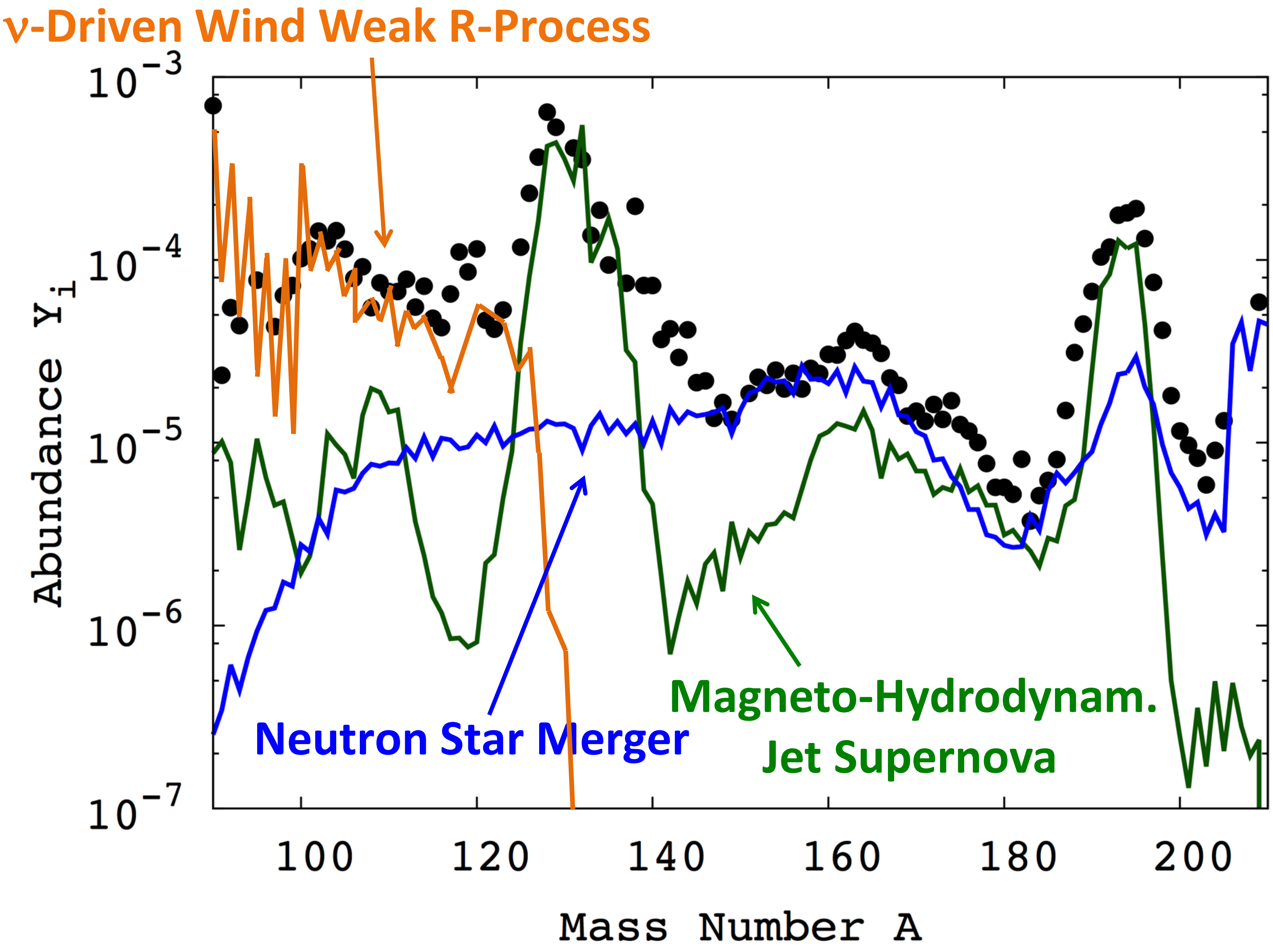


Contribution from Supernova（MHD Jet）



Contribution from ν-driven Winds (Weak-r)

S. Wanajo, ApJL, L22 (2013)



ν-Driven Wind Weak R-Process

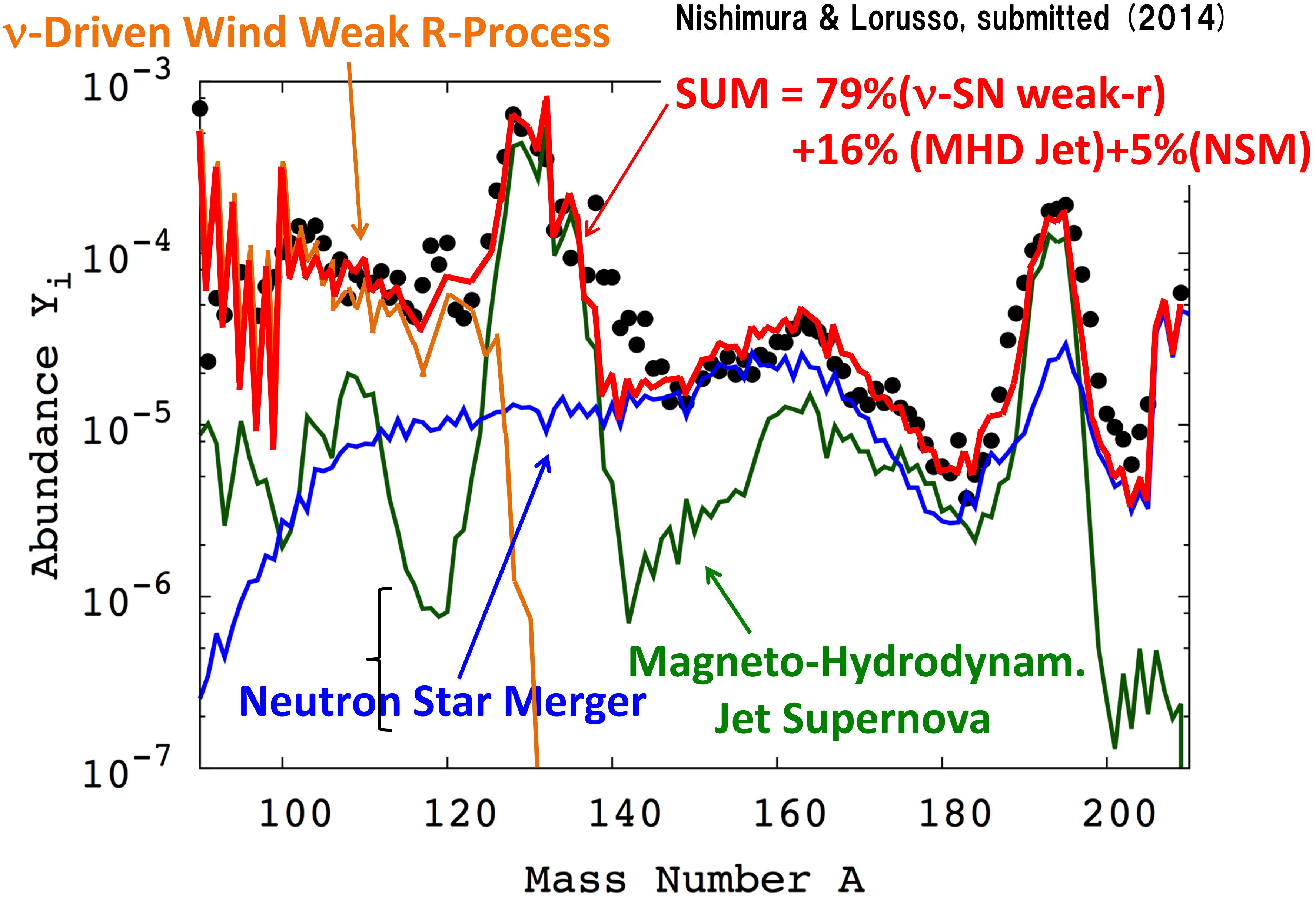
Neutron Star Merger

Magneto-Hydrodynam. Jet Supernova

Recipe to reproduce solar r-elements

S. Wanajo, ApJL, L22 (2013)

Shibagaki, Kajino, Chiba, Mathews,
Nishimura & Lorusso, submitted（2014）



ν-Driven Wind Weak R-Process

SUM = 79%(ν-SN weak-r)
+16% (MHD Jet)+5%(NSM)

Neutron Star Merger

Magneto-Hydrodynam.
Jet Supernova

Recipe to reproduce solar r-elements

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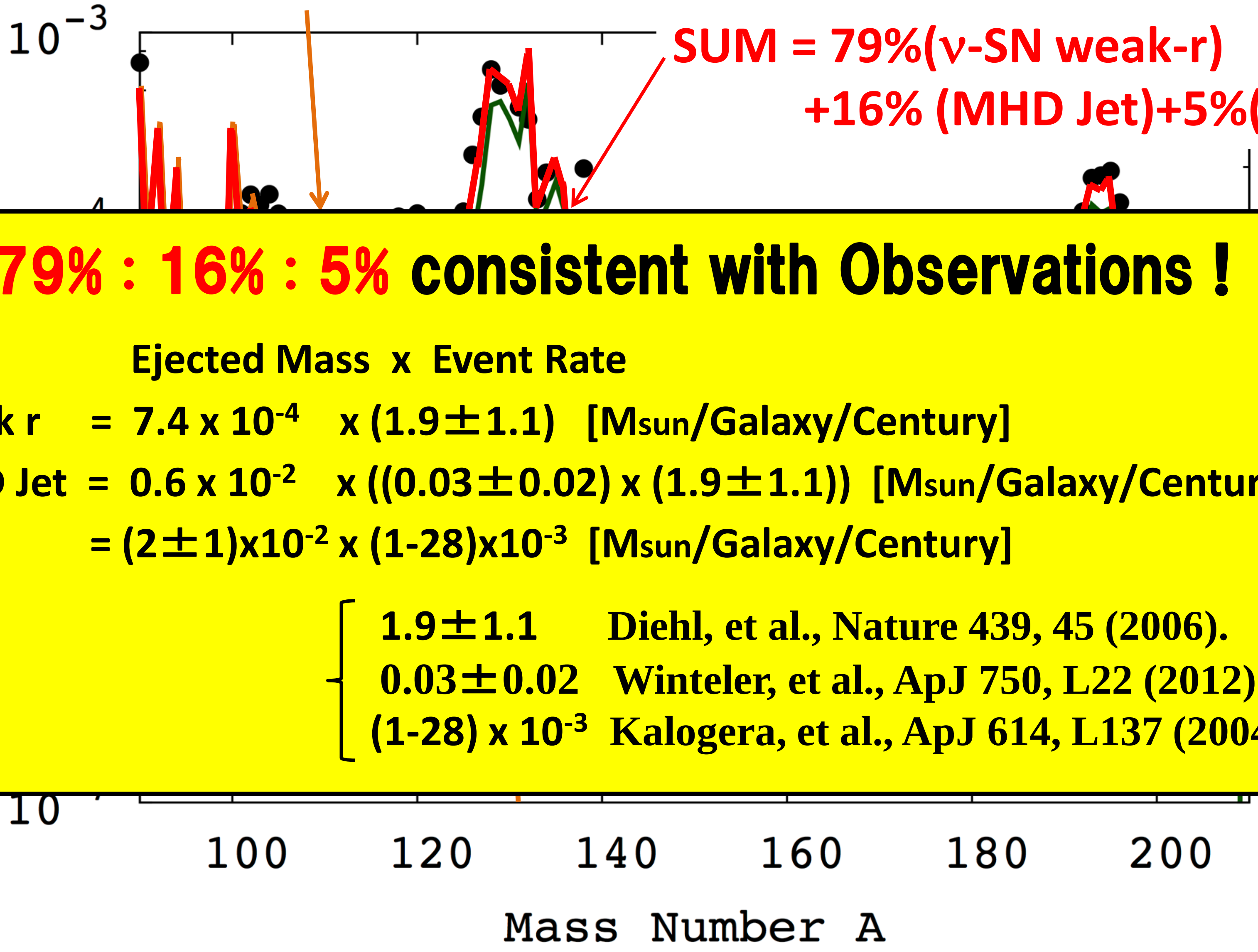


ν-Driven Wind Weak R-Process

SUM = 79%(ν-SN weak-r)
+16% (MHD Jet)+5%(NSM)

79% : 16% : 5% consistent with Observations !

Ejected Mass x Event Rate

Weak r = 7.4×10^{-4} x (1.9±1.1) [Msun/Galaxy/Century]

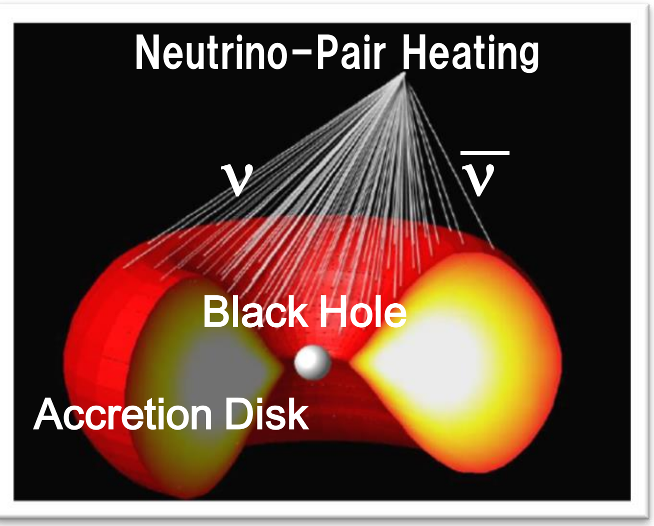
MHD Jet = 0.6×10^{-2} x ((0.03±0.02) x (1.9±1.1)) [Msun/Galaxy/Century]

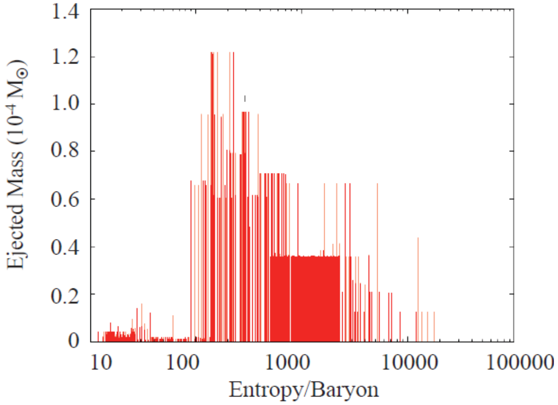
NSM = (2±1)x10^{-2} x (1-28)x10^{-3} [Msun/Galaxy/Century]

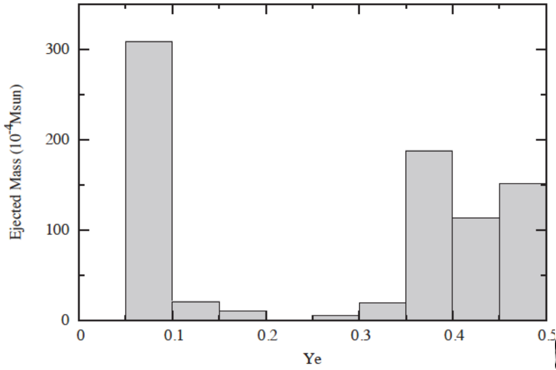
1.9±1.1	**Diehl, et al., Nature 439, 45 (2006).**
0.03±0.02	**Winteler, et al., ApJ 750, L22 (2012).**
(1-28) x 10^{-3}	**Kalogera, et al., ApJ 614, L137 (2004).**

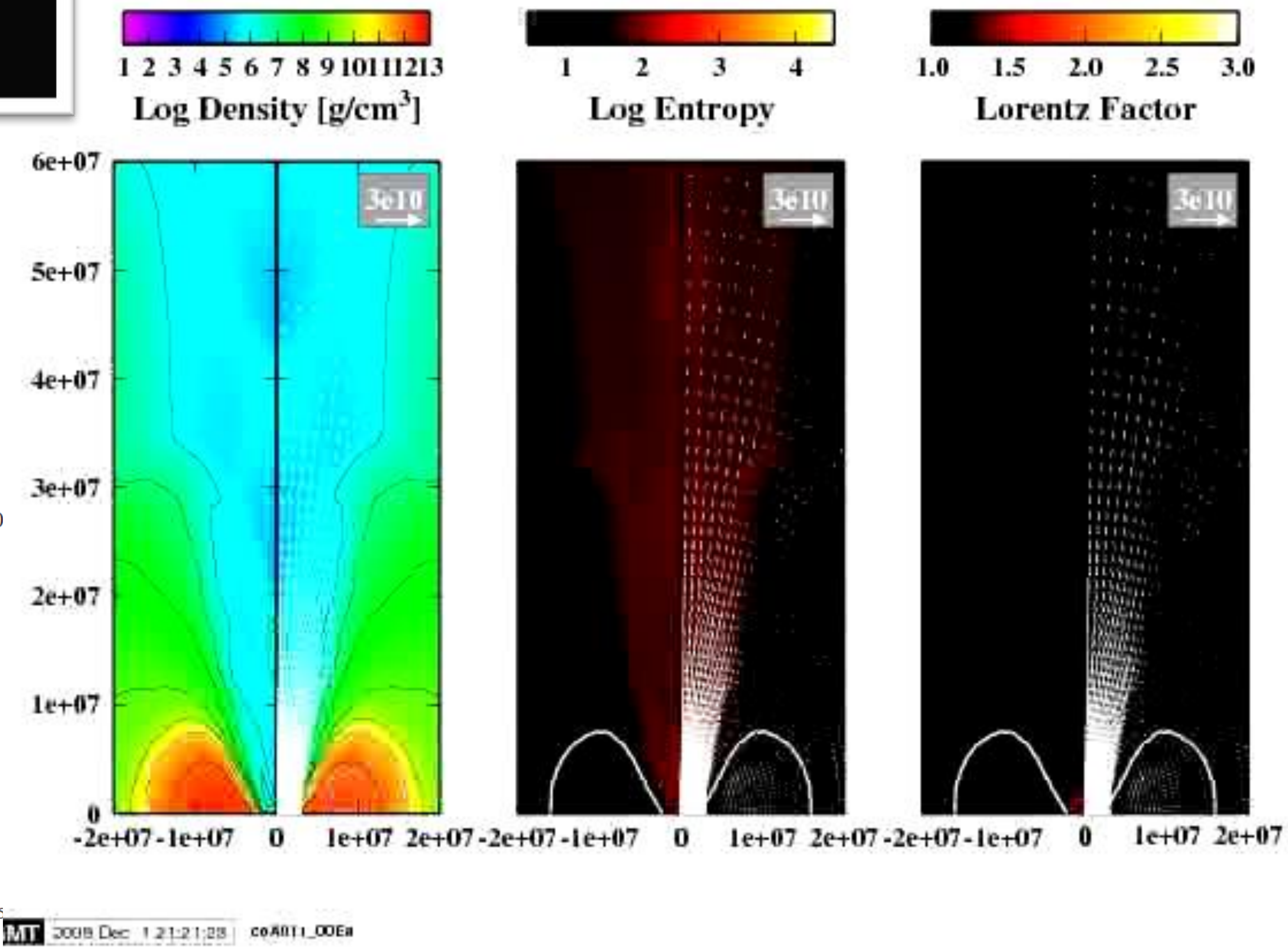
Collapsar Model for Long Gamma-Ray Bursts

Harikae et al., ApJ 704 (2009), 354; 713 (2010) 304.
Nakamura, Kajino, Mathews, Sato & Harikae, IJMP 22 (2013), 1330022.



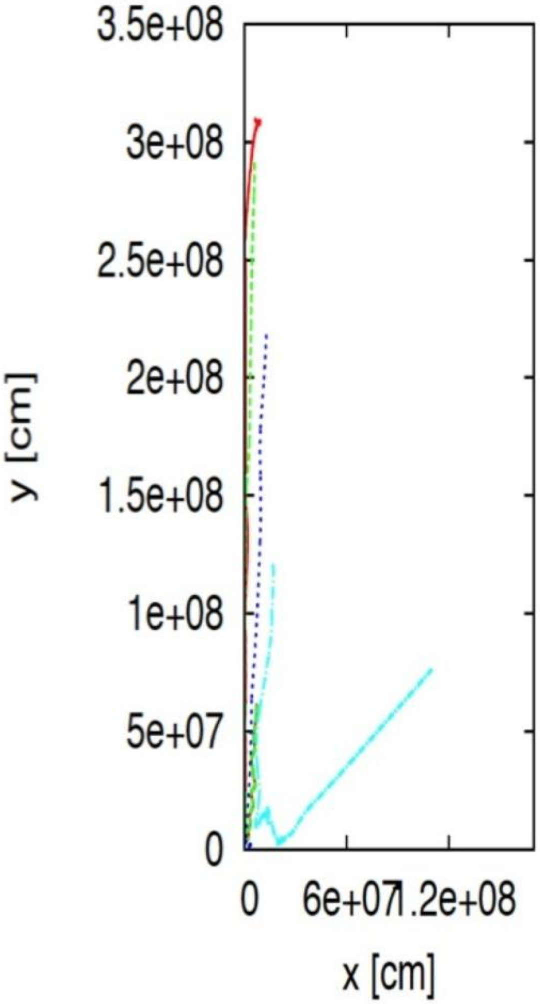






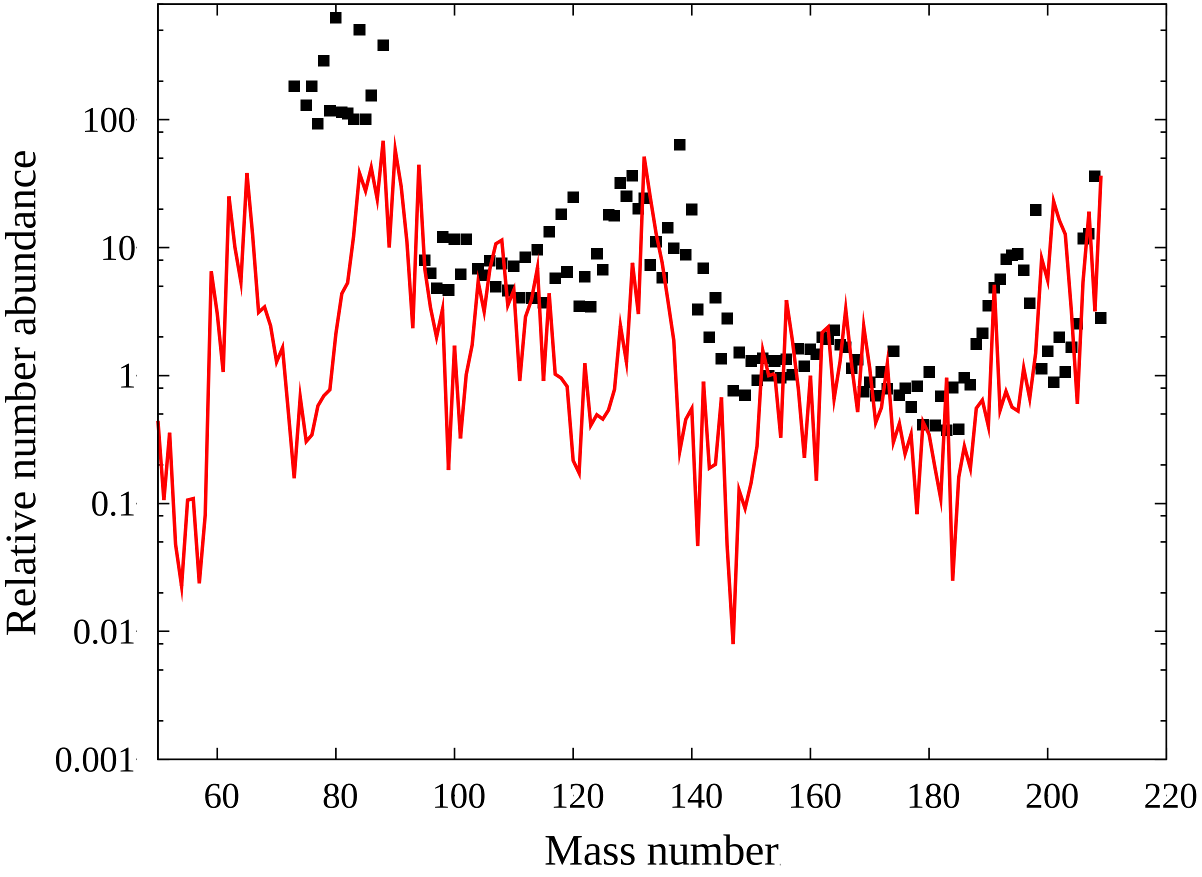
R-Process in the collapsar jet ?

Nakamura, Kajino, Mathews, Sato & Harikae, Int. J. Mod. Phys. 22 (2013), 1330022.



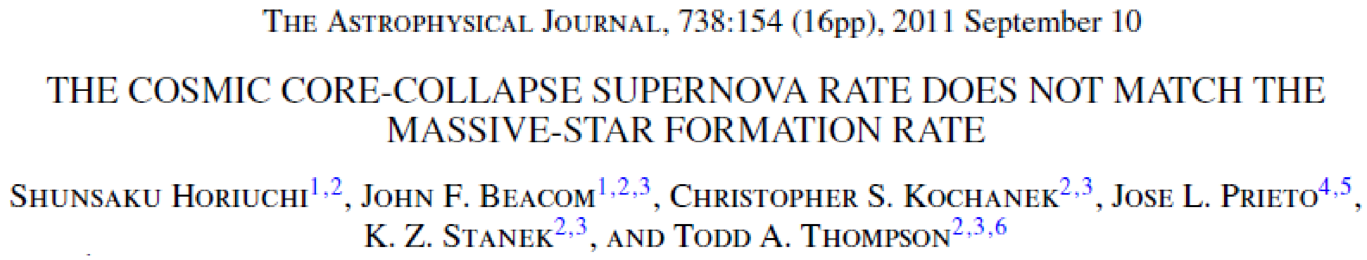
Final abundances:

Sum of 1208 ejected tracer particles



A New Method to constrain EOS from Relic SN-ν

G.J. Mathews, J. Hidaka, T. Kajino & J. Suzuki, ApJ（2014）,in press.



THE ASTROPHYSICAL JOURNAL, 738:154 (16pp), 2011 September 10

THE COSMIC CORE-COLLAPSE SUPERNOVA RATE DOES NOT MATCH THE MASSIVE-STAR FORMATION RATE

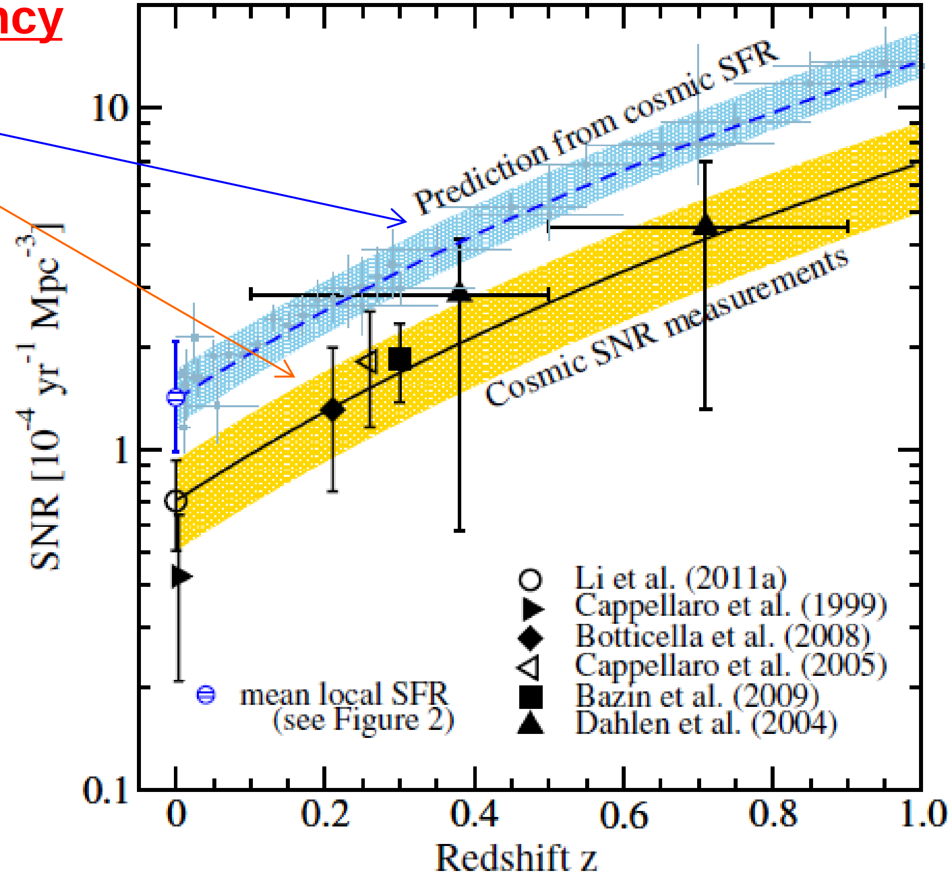
SHUNSAKU HORIUCHI[1,2], JOHN F. BEACOM[1,2,3], CHRISTOPHER S. KOCHANEK[2,3], JOSE L. PRIETO[4,5],
K. Z. STANEK[2,3], AND TODD A. THOMPSON[2,3,6]

Supernova Rate Problem/Discrepancy

SFR of Massive Stars at birth

SNR: Supernova Explosions at death !

50% Massive Stars, missing !



Expected Reasons:

Half was evolved into too dark SNe to detect!

1. Failed SNe (<25M⊙ BH formation)
2. Faint ONeMg-SNe (8-10 M⊙)

or the mass function changed!

ν-driven wind weak-r **MHD-Jet SNe** **NEW** **Long GRB**

Electron-capture SNe (Faint SnNe)	Normal CC-SNe (Neutron Star fromation)	Failed SNe (Black Hole formation)	Pair-ν heated SNe (BH + Acc. Disk)

detail	ONeMg SN	CC-SN	fSN(SH EOS)	fSN(LS EOS)	GRB
mass($M_\odot$)	(8 ~ 10)	8 ~ 25(10~25)	25 ~ 125 (99.96%)	25 ~ 125 (99.96%)	25 ~ 125 (0.04%)
Remnant	Neutron Star	Neutron Star	Black Hole	Black Hole	Black Hole
Phenomenon	Supernova	Supernova	Failed Supernova	Failed Supernova	Gamma-Ray Burst
T_{ν_e} (MeV)	3.0	3.2	5.5	7.9	3.2
$T_{\bar{\nu}_e}$ (MeV)	3.6	5.0	5.6	8.0	5.3
T_{ν_x} (MeV)	3.6	6.0	6.5	11.3	4.4
$E^{total}_{\nu_e}$ (erg)	3.3×10^{52}	5.0×10^{52}	5.5×10^{52}	8.4×10^{52}	1.7×10^{53}
$E^{total}_{\bar{\nu}_e}$ (erg)	2.7×10^{52}	5.0×10^{52}	4.7×10^{52}	7.5×10^{52}	3.2×10^{53}
$E^{total}_{\nu_x}$ (erg)	1.1×10^{53}	5.0×10^{52}	2.3×10^{52}	2.7×10^{52}	1.9×10^{52}
$\triangle$ t	few s	few s	$\sim 0.5s$	$\sim 0.5s$	$\sim 10s$

- **CC-SNe:** Yoshida, et al., ApJ **686** (2008), 448;
  Suzuki & Kajino, J. Phys. **G40** (2013) 83101.

- **fSN (failed SNe):** Sumiyoshi, et al., ApJ **688** (2008) 1176.

  * **Shen-EOS:** Shen et al. Nucl. Phys. **A637** (1998) 435.
  * **LS-EOS:** Lattimer & Swesty, Nucl. Phys. **A535** (1991) 331.

- **ONeMg SNe:** Hudepohl, et al., PRL 104 (2010).

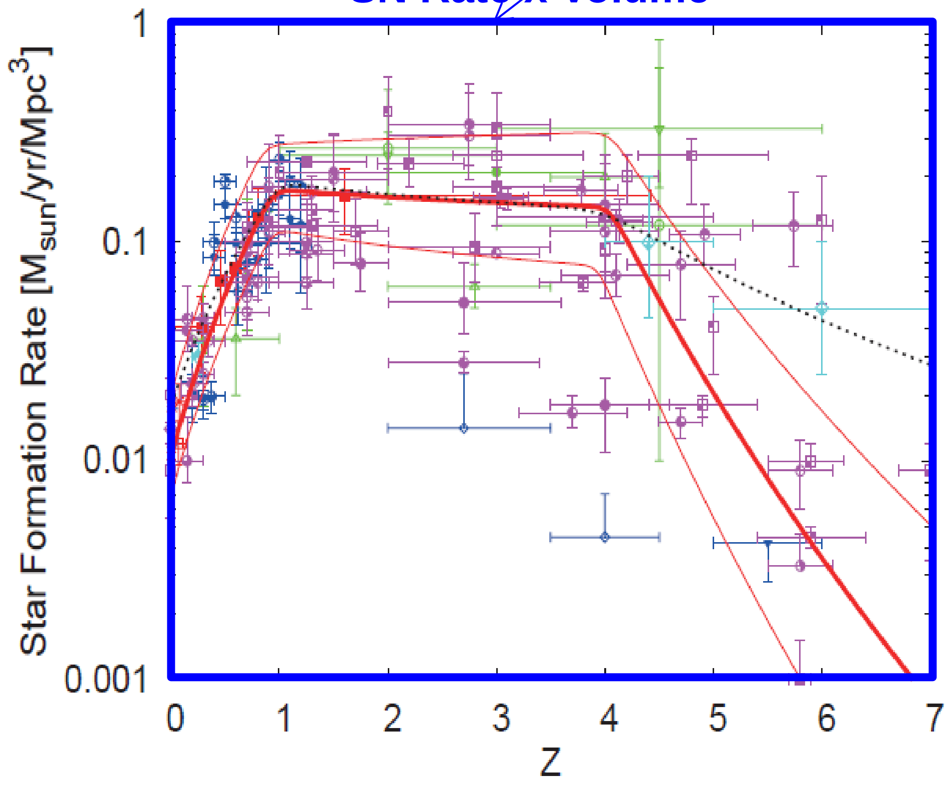
- **GRBs:** Nakamura, Kajino, Mathews, Sato & Harikae, *Int. J. Mod. Phys*. **E22** (2013) 1330022; Kajino, Mathews & Hayakawa, J. Phys. **G41** (2014) 044007.

Spectrum of Relic Supernova Neutrinos (RSNs)

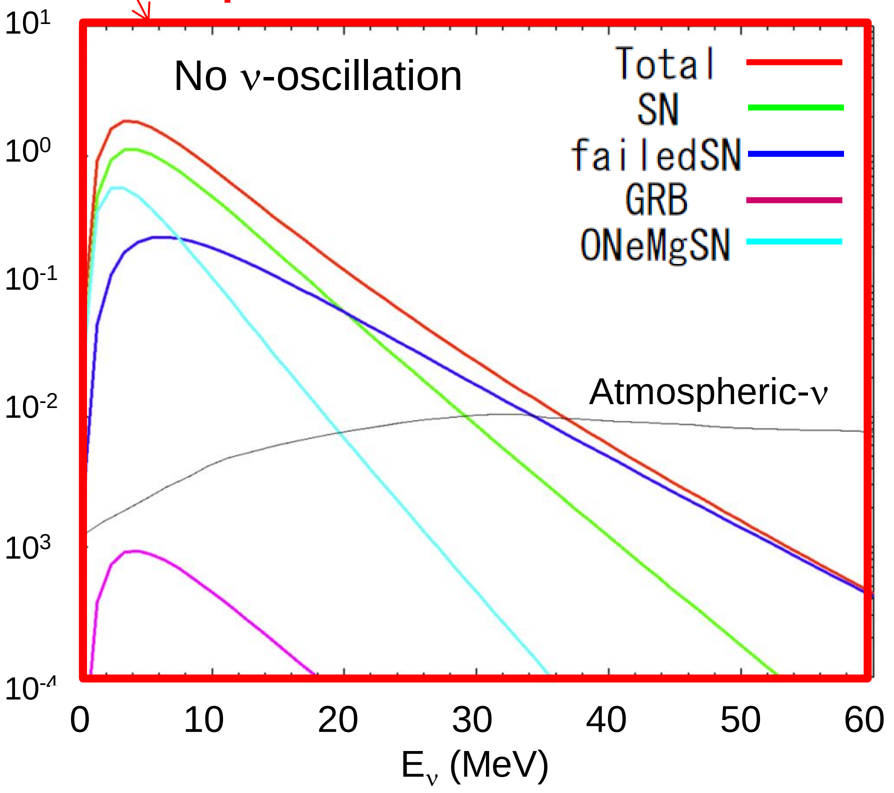
for Hyper-Kamiokande (Mega-ton): Water Cherenkov $\bar{\nu}_e + p \rightarrow e^+ + n$

$$\frac{dN_\nu}{dE_\nu} = \frac{c}{H_0}\int_0^{z_{max}} \boxed{R_{SN}(z)}\boxed{\frac{dN_\nu(E'_\nu)}{dE'_\nu}} \times \boxed{\frac{dz}{\sqrt{(\Omega_m)(1+z)^3+\Omega_\Lambda}}}$$

SN Rate x Volume



ν-spectrum at Various SNe & GRB



Relic Supernova Neutrinos (RSNs)

Hyper-Kamiokande (Mega-ton, 10y), Gd-loaded Water Cherenkov Detector

$\bar{\nu}_e + p \rightarrow e^+ + n$

G. J. Mathews, J. Hidaka, T. Kajino, and 2014), 115.

Assuming 2 x failed SNe for BH formation!

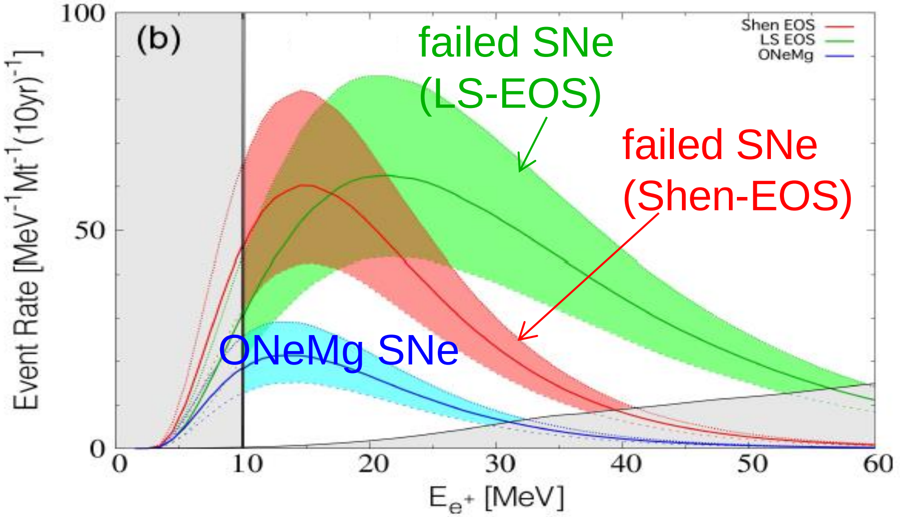
SN rate problem is resolved!!

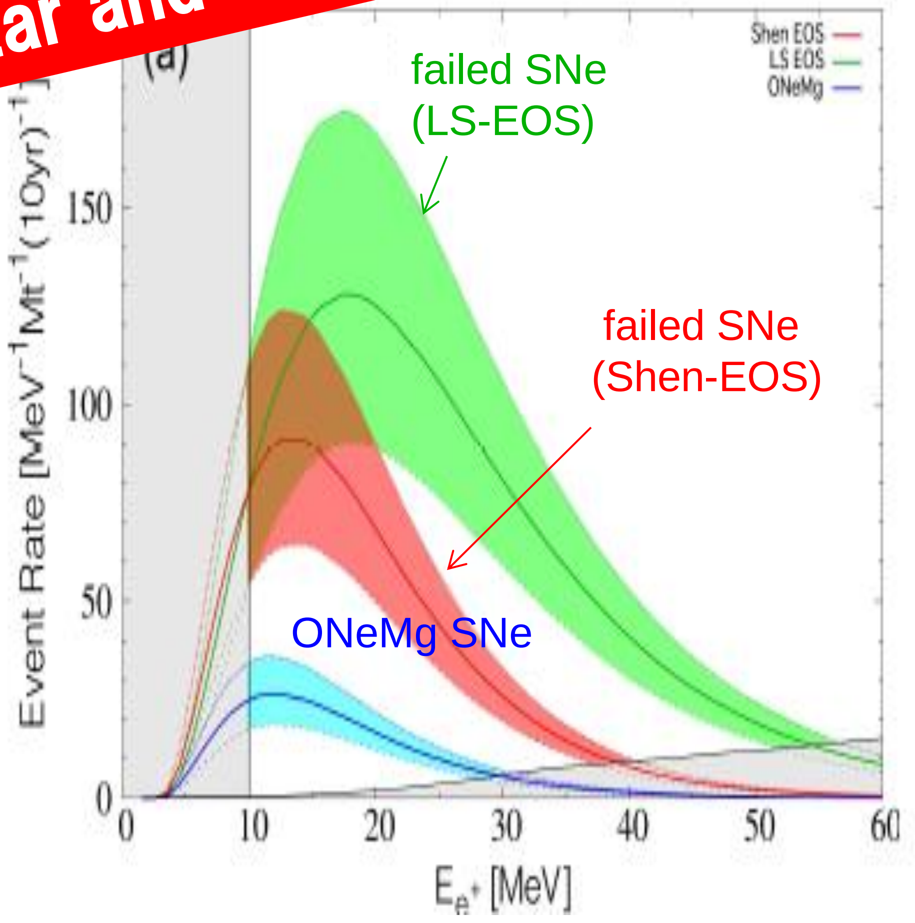
Oscillation

Same

RSN-ν is a sensitive probe of the EoS of the Proto-Neutron Star and ν-oscillation !

Adiabatic MSW Oscillation





元素に見る宇宙進化の研究と
核物理の役割

The developed HI & RIB technique
+ Intense RI-Beam at RIKEN
+ High Precision Spectrometer at RCNP

Probe any Energy on wide N-Z (Isospin)

荷電交換反応

Understanding of nuclear electro-weak response in astrophysical processes

弱電核反応

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

→ **Neutral & Charged currents**

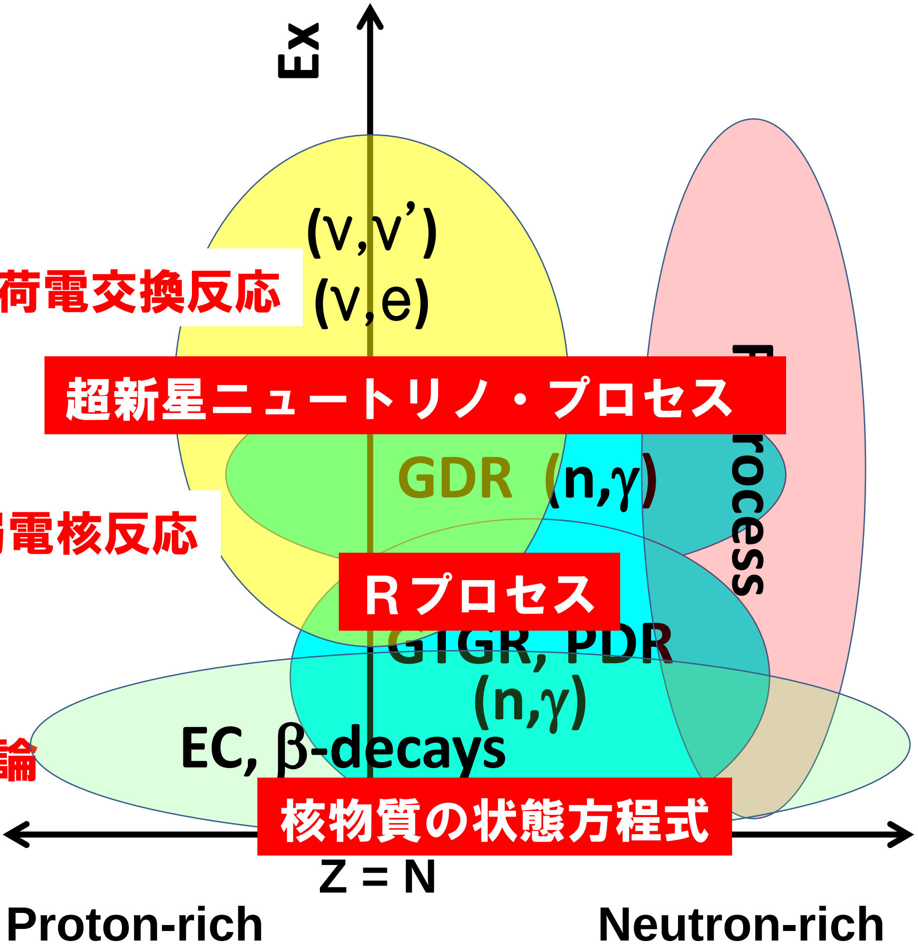
核反応理論

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

→ **EC/beta-decays**

エキゾチック核構造理論

- SN II, SN Ia, X-ray bursts



宇宙・銀河の化学動力学進化

Sasano @ Uesaka Spin-Isospin Labo., RIKEN