Impact of Neutron Star Merger & Supernova on R-Process and Neutrino Physics

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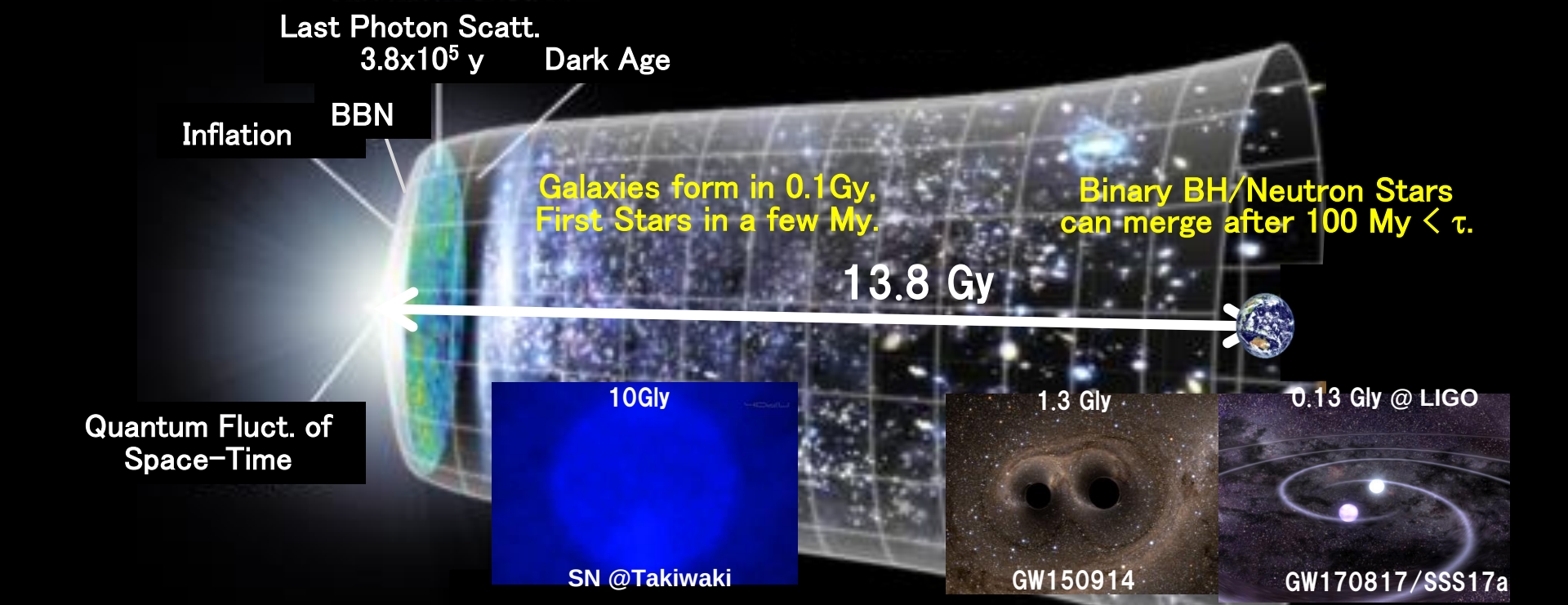


Hirai, Ishimaru, Saitoh, Fujii, Hidaka and Kajino,
ApJ 814 (2015), 41; MNRAS 466 (2017), 2474.

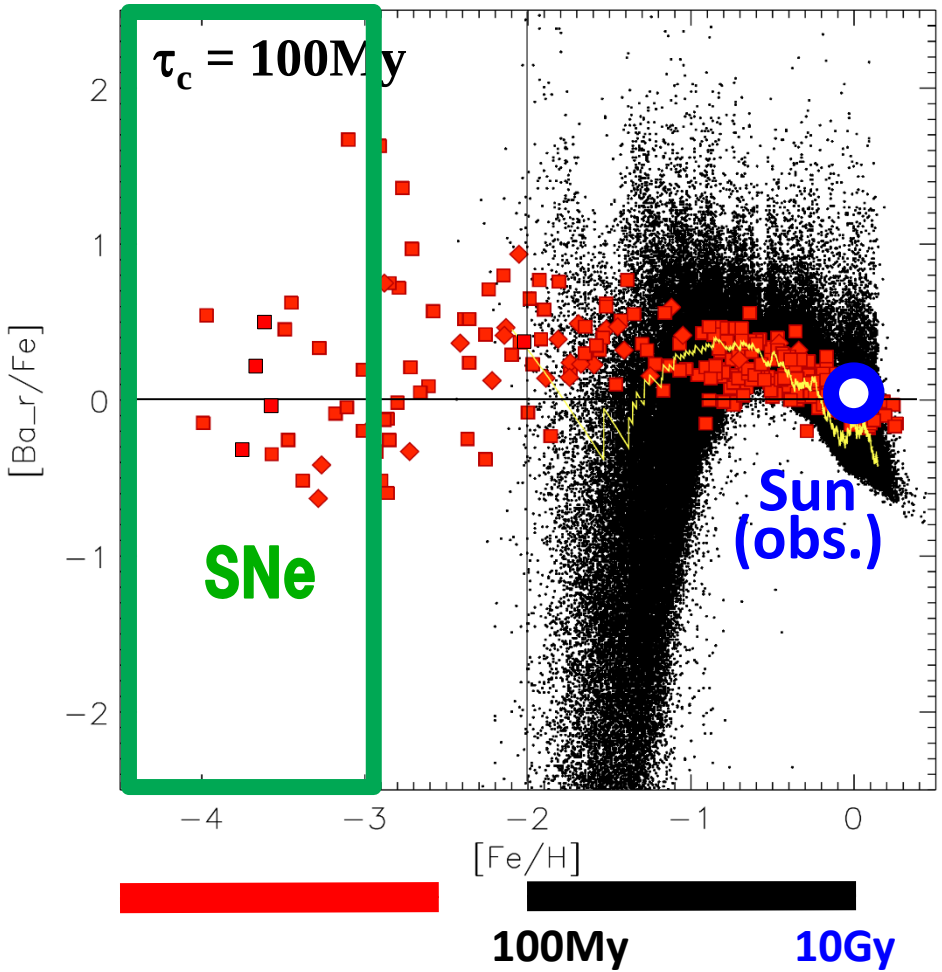
100 My < τ

SPH Supercomputing Simulation of Galactic Chemo-Dynamical Evolution of Dwarf Galaxies ("Building Blocks" of MW Halo)

Time Scale Problem

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

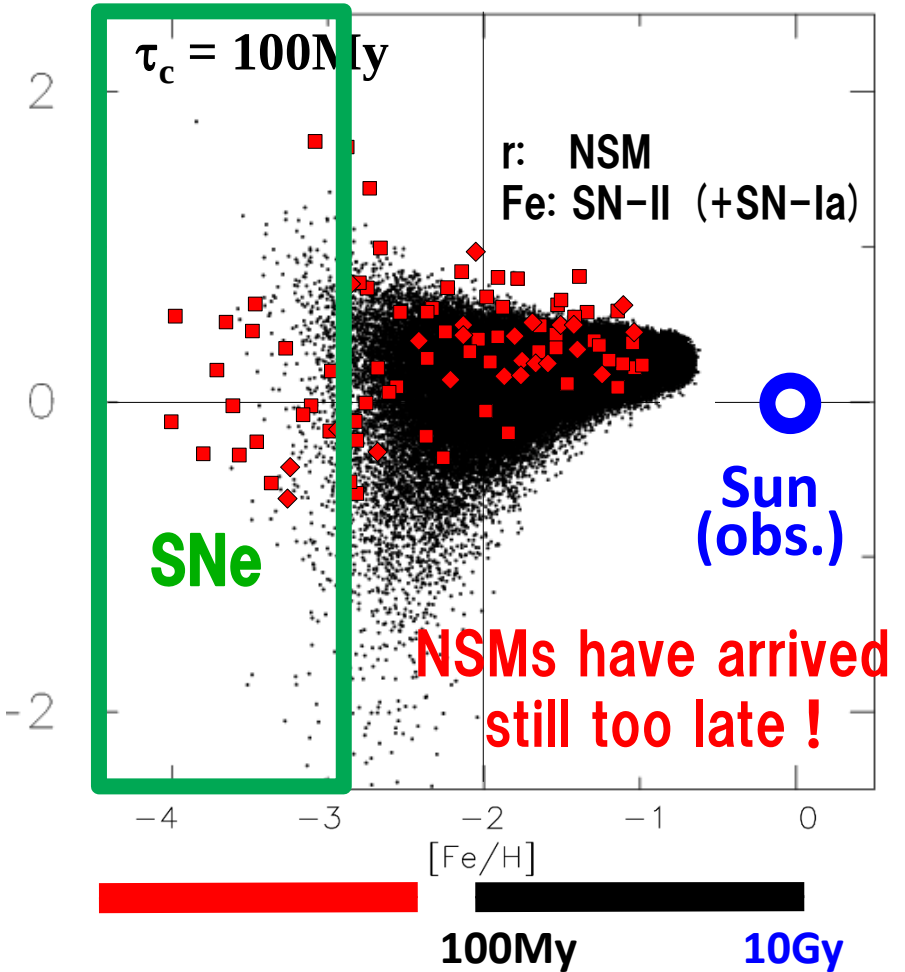
GCE W/O Dynamics & Gas mix.



Hirai, Ishimaru, Saitoh, Fujii, Hidaka and Kajino, ApJ 814 (2015), 41; MNRAS 466 (2017), 2474.

3 Comp. (DMs, Gas, Stars),
Star forms: $T<10^4$K, $v<0$, $n_H>100$ cm^{-3} → 100pc

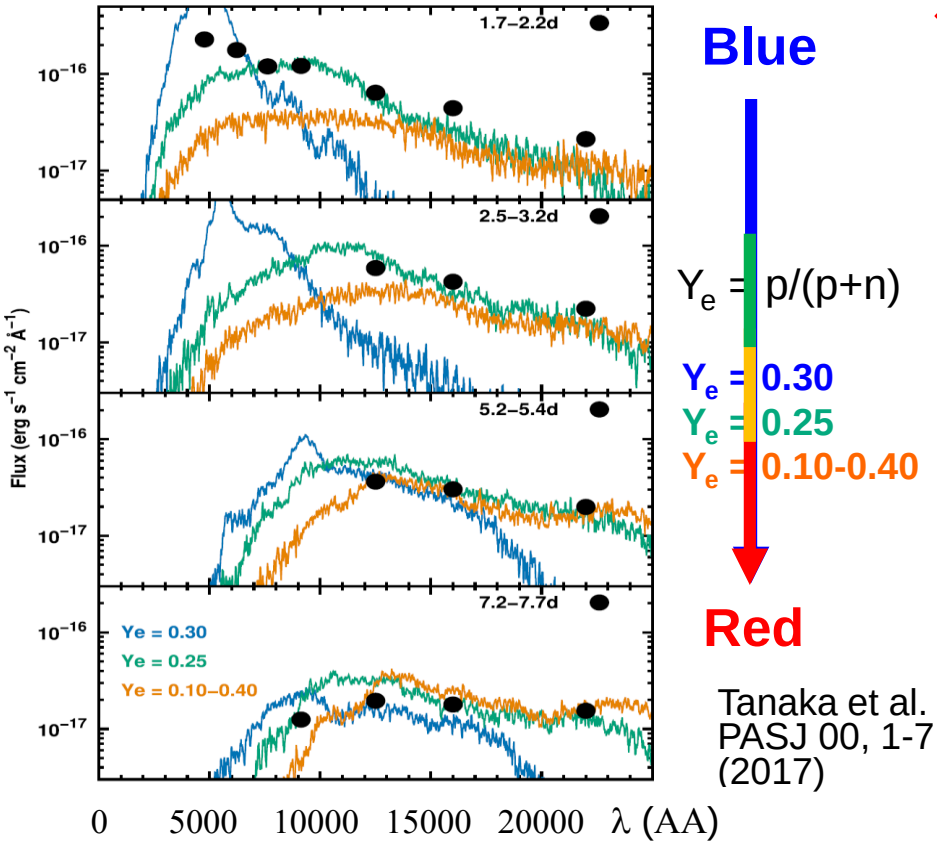
With Dynamics, Gas mix. & Inhomogeneity



GW170817/SSS17a

Abbott et al. (LIGO-Virgo), PRL 119, 16101 (2017)

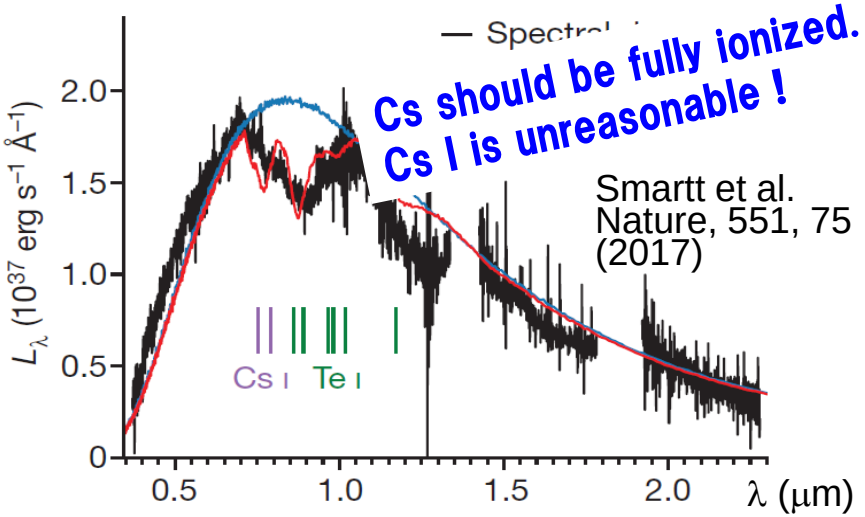
1. GW170817 (LIGO-Virgo) : $0.86<M/M_{\odot}<2.26$ → EoS
2. GRB170817A (Fermi-GBM) : 1.7 s → Central Enginge
3. No ν–Signal: 10^{-6} weaker than SN1987A (0.16 Mly)
4. X-rays & Radio waves : Remnant NS or BH, not identified.
5. **Optical and Near-infrared : SSS17a (over 70 Telescopes)**



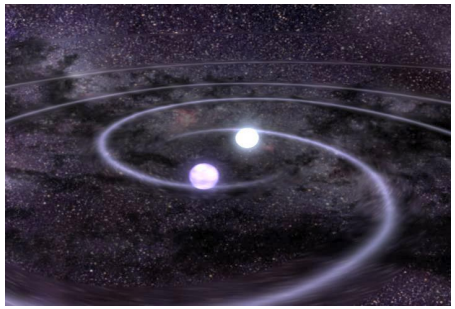
Tanaka et al. PASJ 00, 1-7 (2017)

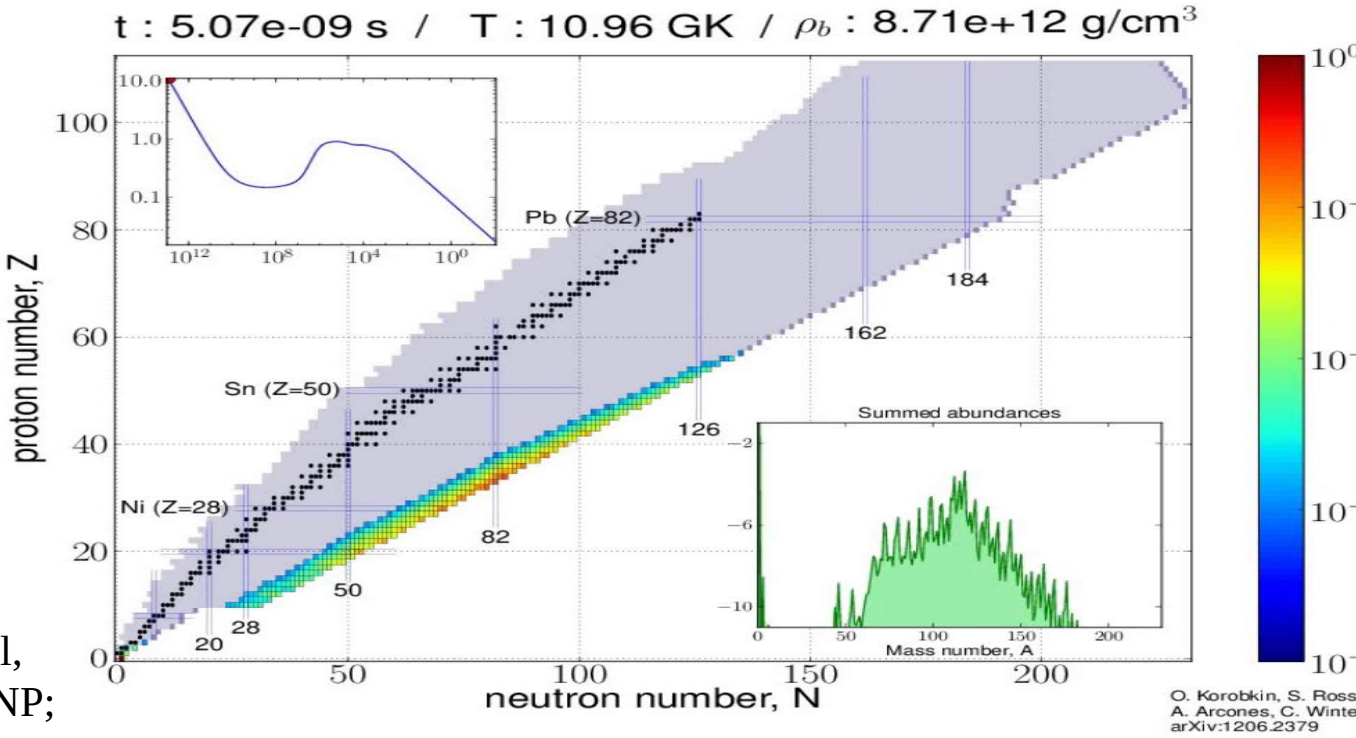
◆ **Emission Energy, seems consistent with radioactive decay of r-elements ! (Probably Lanthanoids)**

◆ ***No r-element, identified !?***



Neutron Star Merger

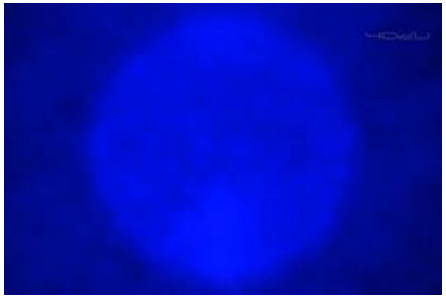


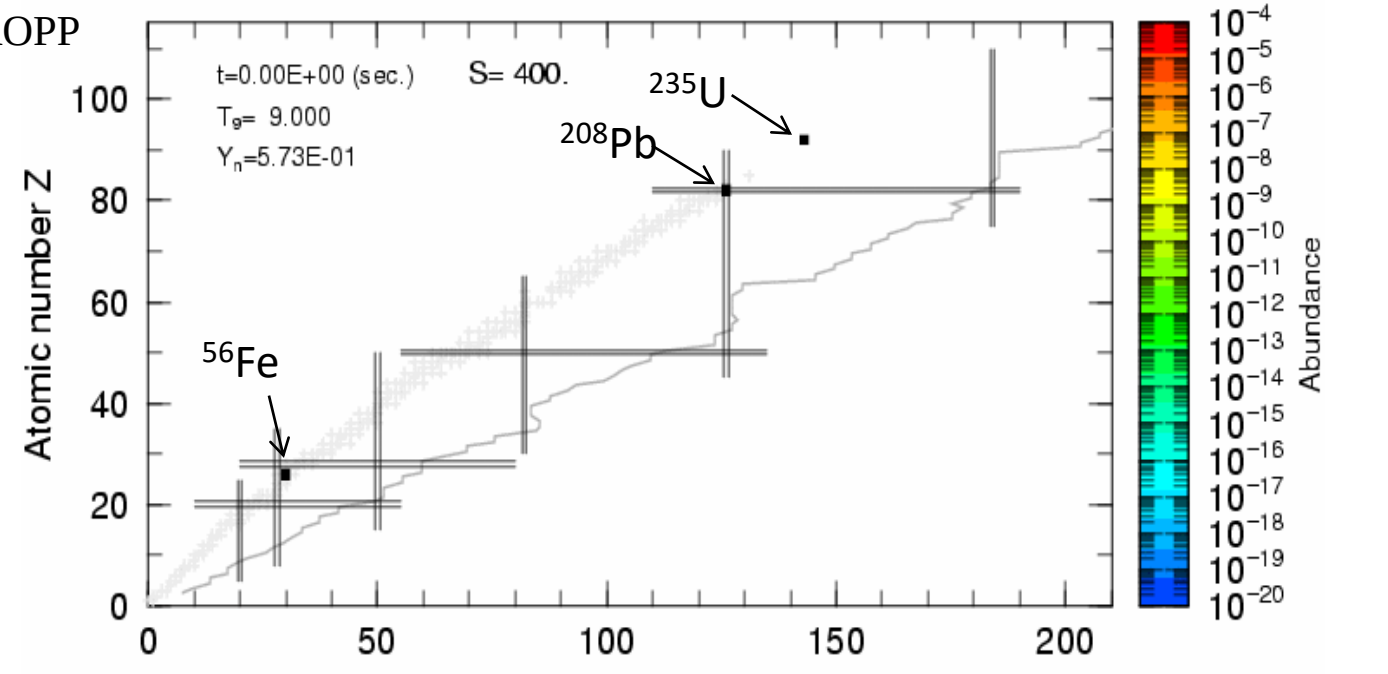


Kajino, Aoki, Balantekin, Dihel, Famiano, Mathews (2018), PPNP;

Kajino & Mathews (2017), ROPP 80, 084901.

Supernova (MHD Jet)

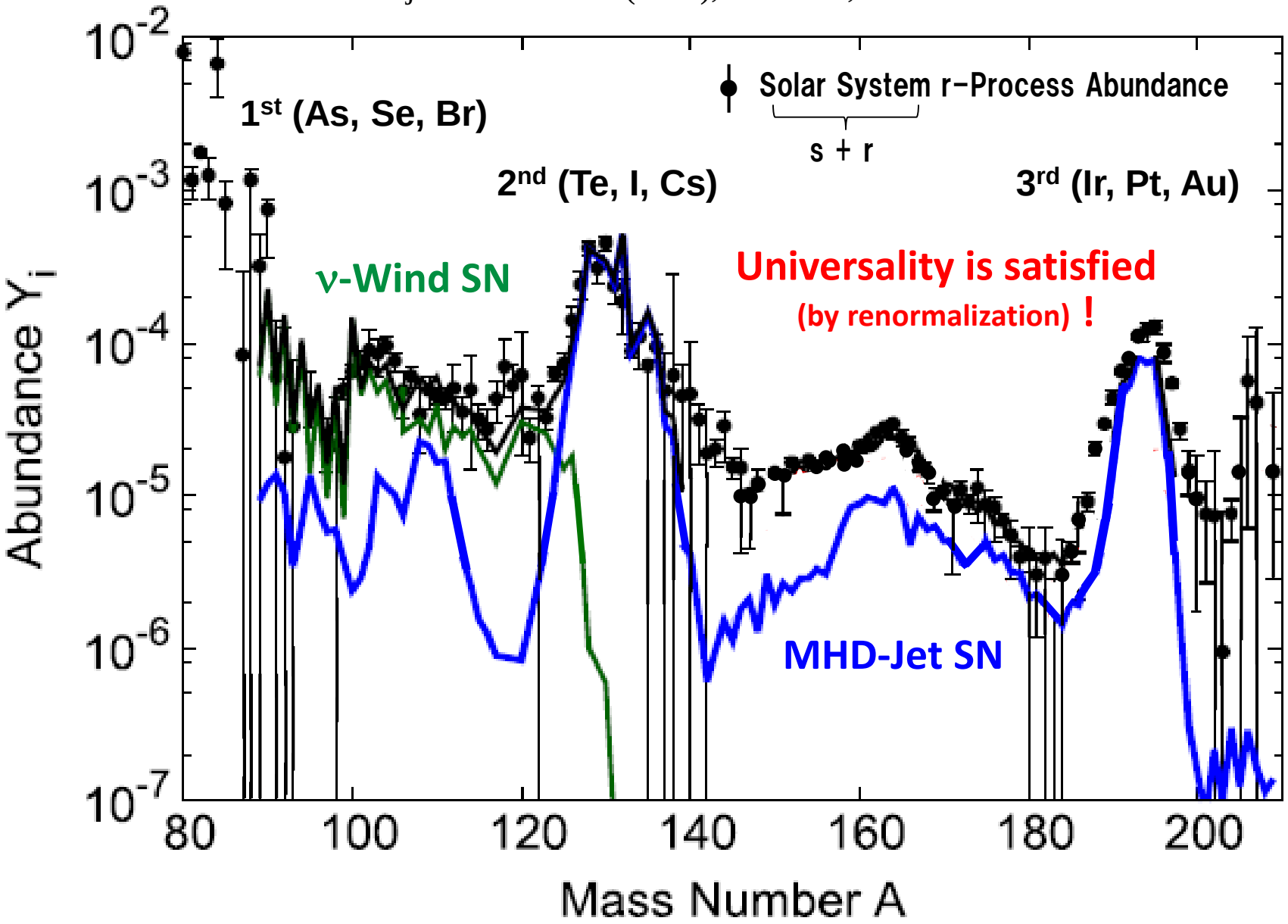




Solar System r-Process Abundance

Very Early Galaxy

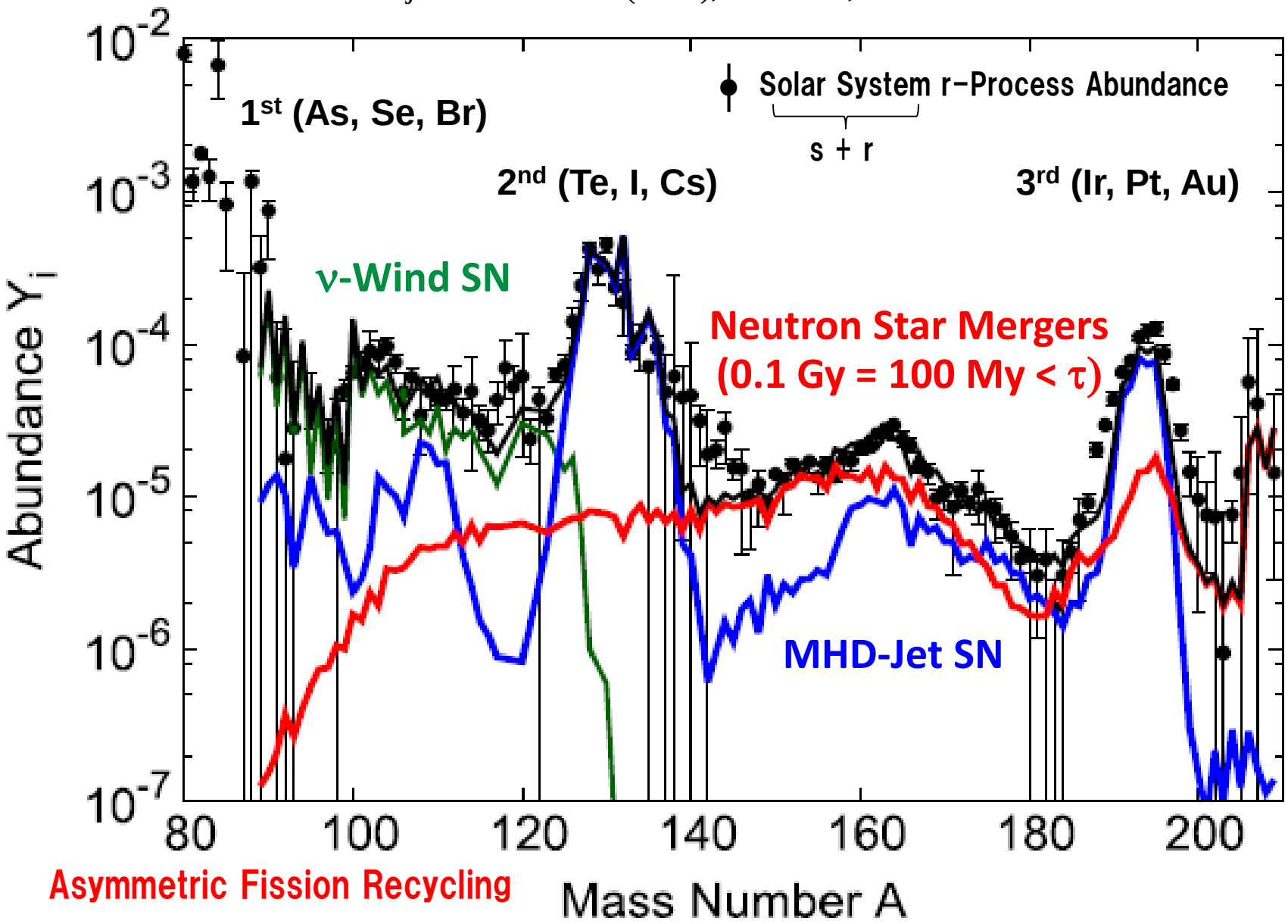
Shibagaki, Kajino, Chiba, Mathews, Nishimura & Lorusso (2016), ApJ 816, 79; ApJ (2017); Kajino & Mathews (2017), ROPP 80, 084901.



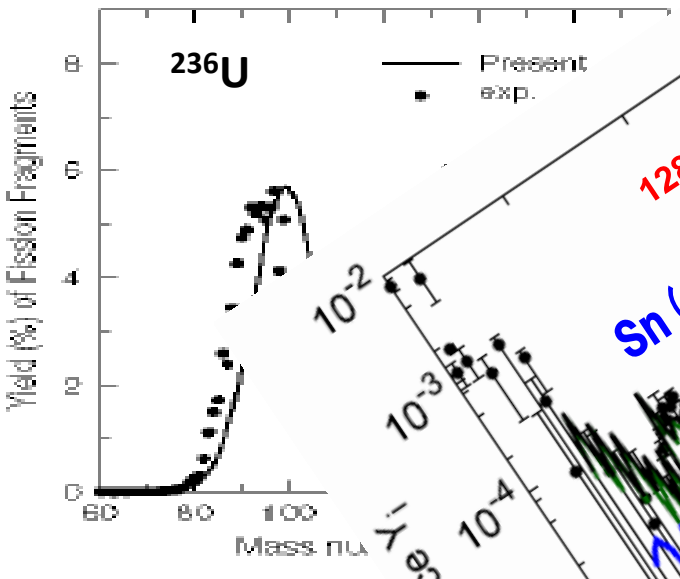
Solar System r-Process Abundance

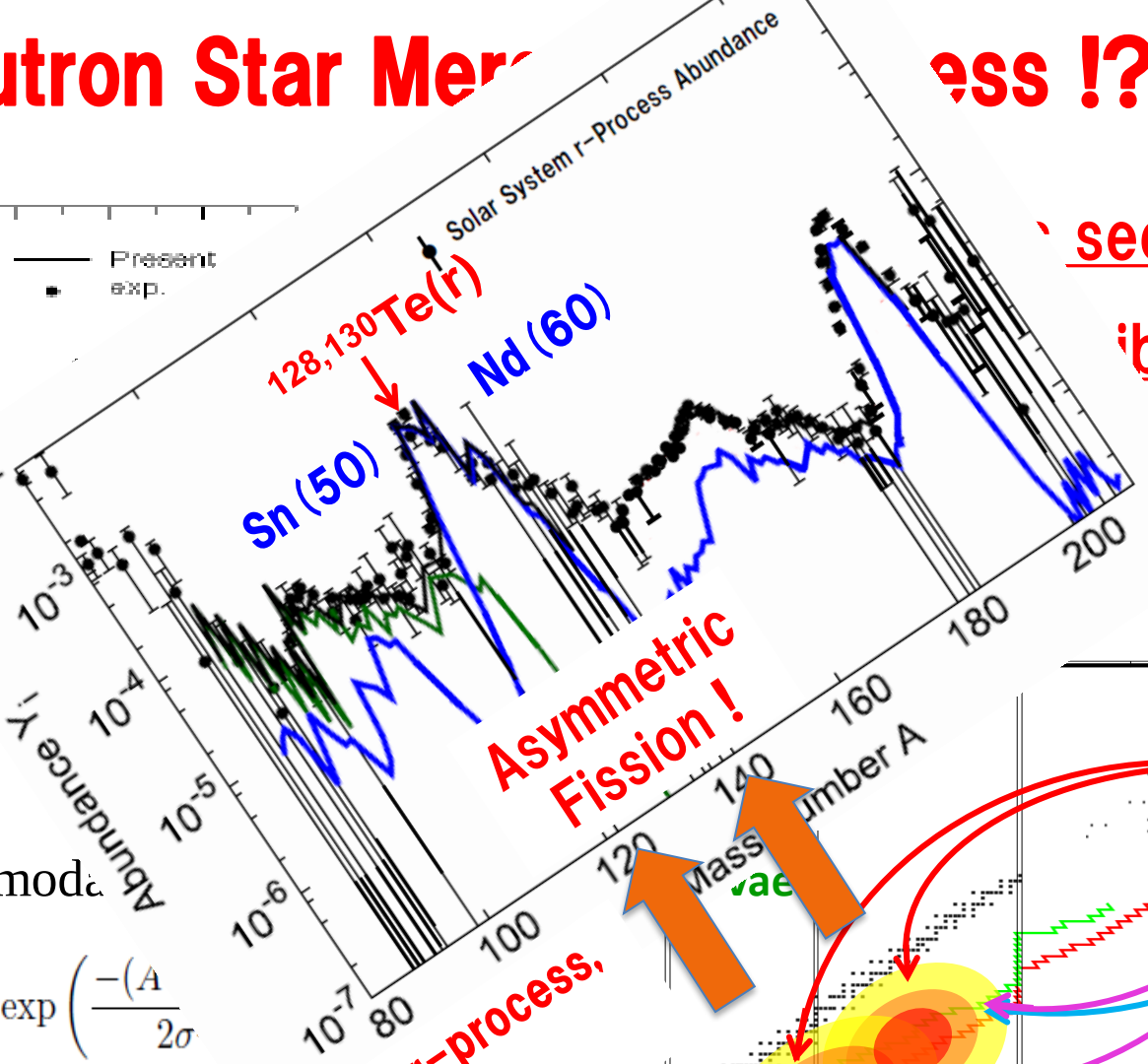
Present time: t = 13.8Gy

Shibagaki, Kajino, Chiba, Mathews, Nishimura & Lorusso (2016), ApJ 816, 79; ApJ (2017);
Kajino & Mathews (2017), ROPP 80, 084901.



Neutron Star Mer ess !?





sections !

bution !

rance, (2007)

Bimordial or Trimoda

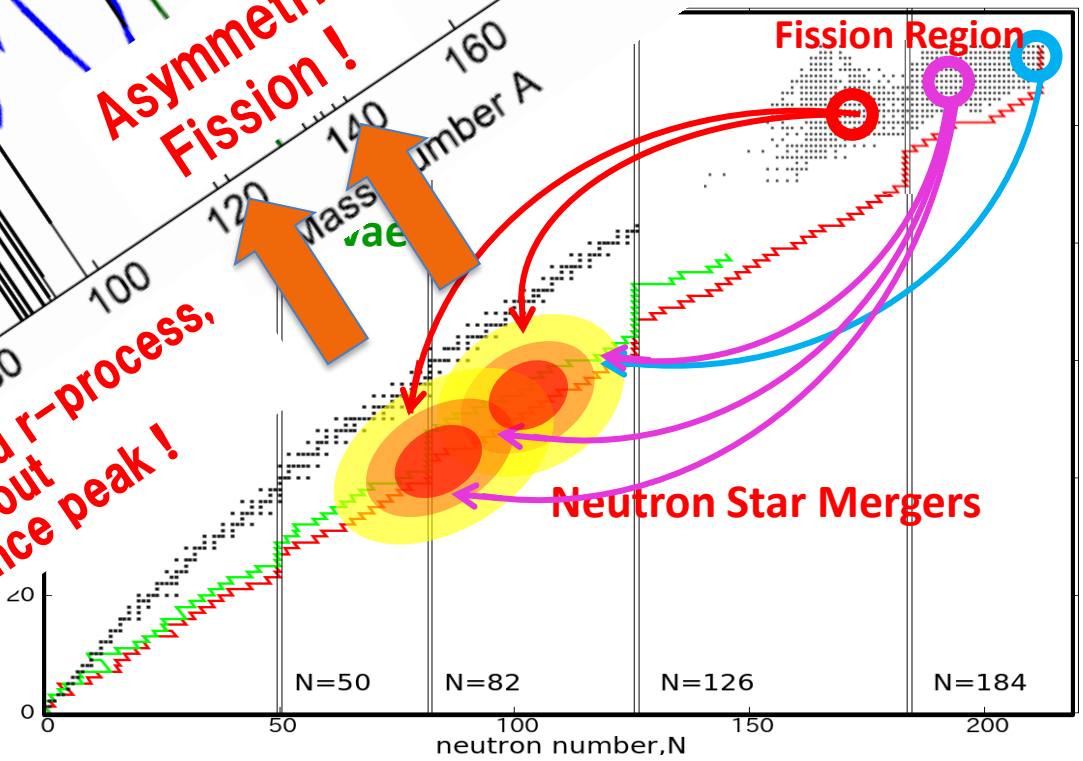
$$f(A,A_p)=\sum_{A_i}\frac{1}{\sqrt{2\pi}\sigma}W_i\exp\left(\frac{-(A$$

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

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

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

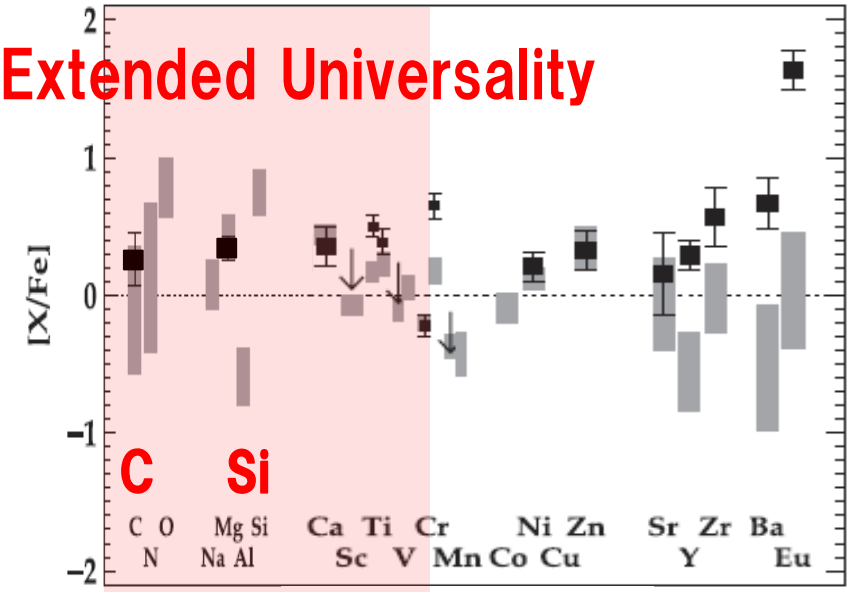
Fission recycling and r-process, smooth out 2nd abundance peak !



Ultra-Faint Dwarf Galaxy: Ret. II

Astron. Observation

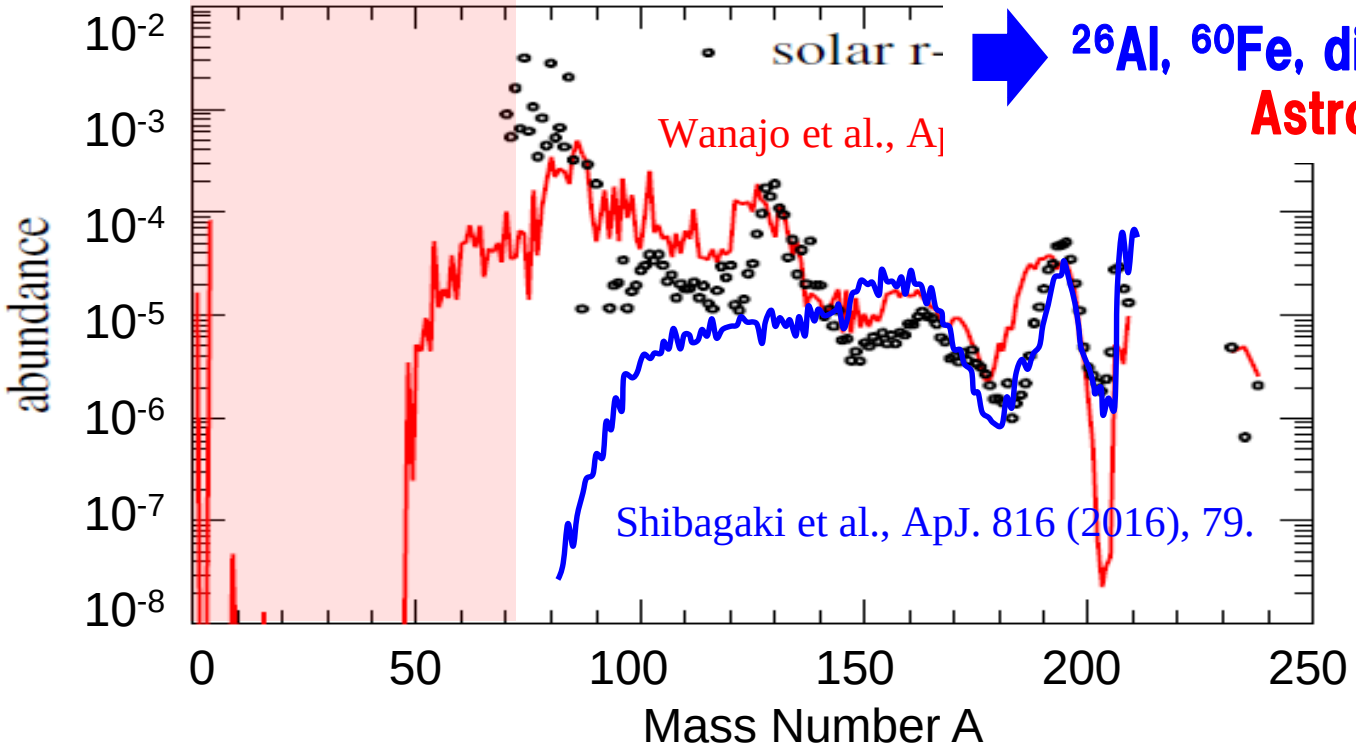
Ian U. Roederer et al., ApJ. 151 (2016), 82;
P. Ji Alexander, Anna Frebel, Anirudh Chiti, Joshua D. Simon, Nature 531 (2016), 610.



NSM, difficult to produce A<70 !

➡ **Dust formation, difficult !**
Cosmo-Chemistry (meteorite) ?

➡ **^{26}Al, ^{60}Fe, difficult !**
Astronomy ?

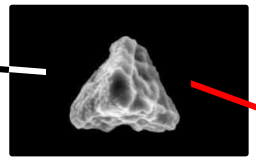


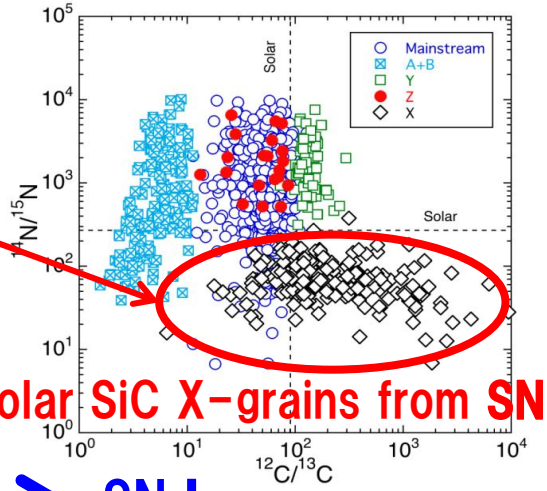
Goriely, et al., ApJ 738, L32 (2011); Korobkin, et al., MNRAS 426, 1940 (2012); Bauswein, et al., ApJ 773, 78 (2013); Rosswog, et al., MNRAS 430, 2585 (2013); Goriely, et al., PRL 111, 242502 (2013), (2015): Piran, et al., MNRAS 430, 2121 (2013).

How to prove SN/NSM R-process ?

◎ Cosmo-Chemistry: Supernova Grains, e.g. Murchison Meteorite

SiC X-grains





- Enhanced ^{12}C ($^{12}C/^{13}C$ > Solar) & ^{28}Si
- Deficient ^{14}N ($^{14}N/^{15}N$ < Solar)
- Decay of ^{26}Al ($t_{1/2}$=7x10^{5}yr), ^{44}Ti ($t_{1/2}$=60yr)

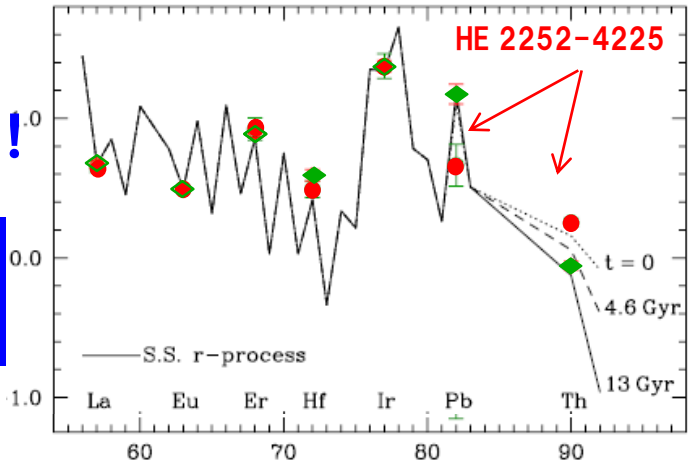
Presolar SiC X-grains from SN EJECTA.

- SiC X-grain including r-elements → SN !
- Radioact.: ^{26}Al, ^{60}Fe, ^{244}Pu → SN/NSM !

} NSM/SN event rates

◎ Astron. & Astrophys.: Spectr. Obs., e.g. Actinide-Boost Stars

- Actinide boost → NSM !
- Extended universality → both NSM & SN !



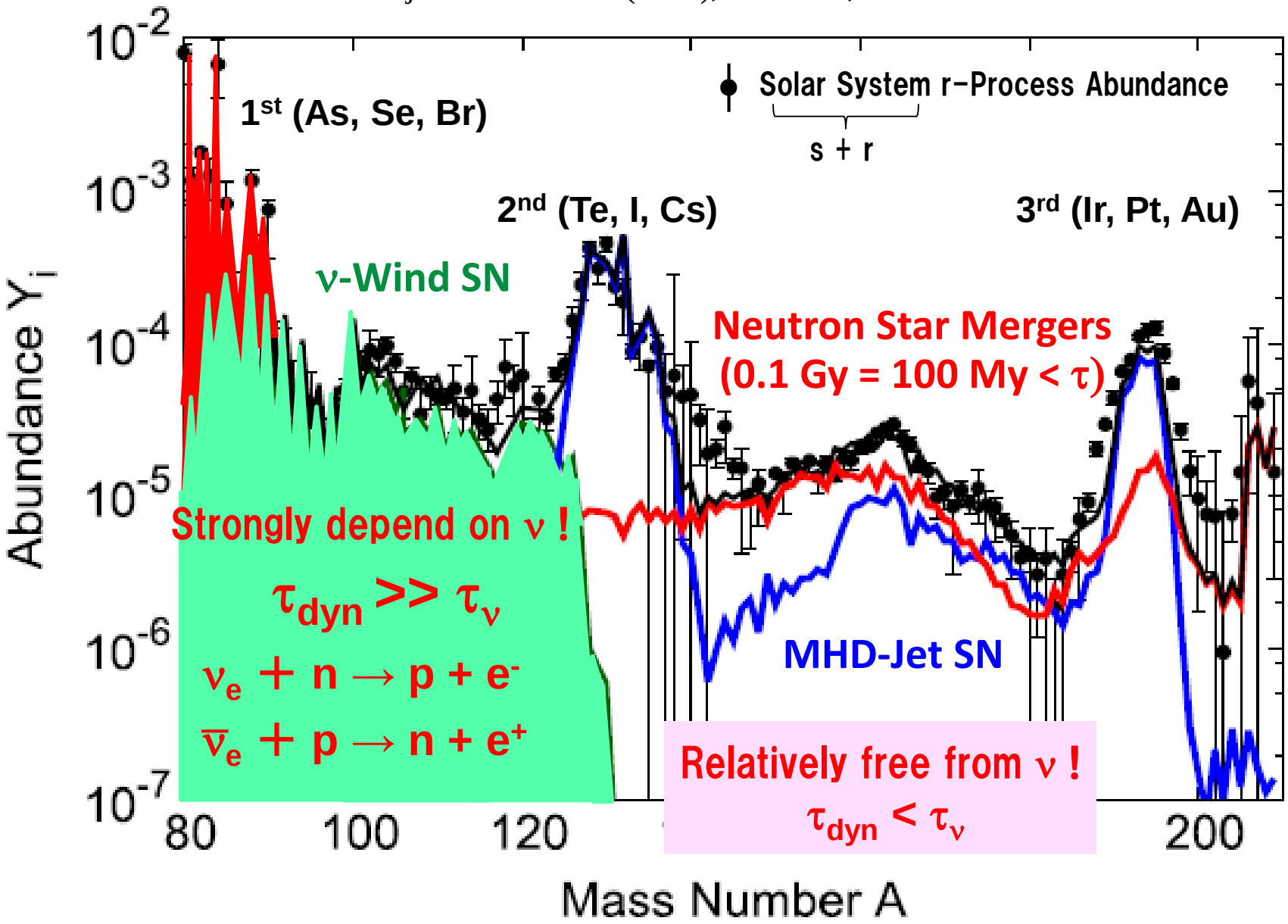
Simultaneous detection of C, Si, ^{26}Al, ^{60}Fe, ^{244}Pu and r-elements is highly desirable !

Mashonkina et al. A&A 569, A43 (2014)

Solar System r-Process Abundance

Present time: t = 13.8Gy

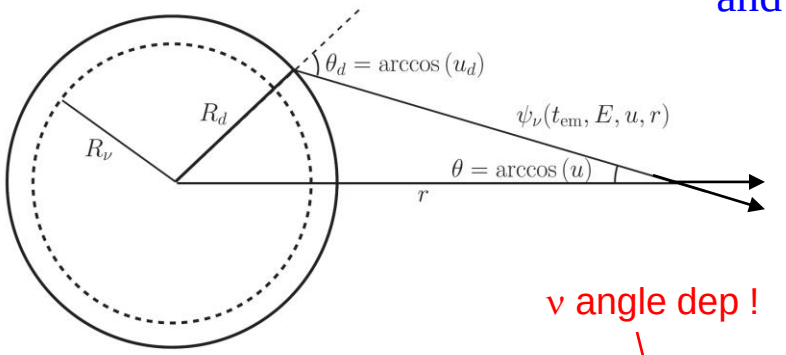
Shibagaki, Kajino, Chiba, Mathews, Nishimura & Lorusso (2016), ApJ 816, 79; ApJ (2017); Kajino & Mathews (2017), ROPP 80, 084901.



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.

proto-neutron star (ν Sphere)



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

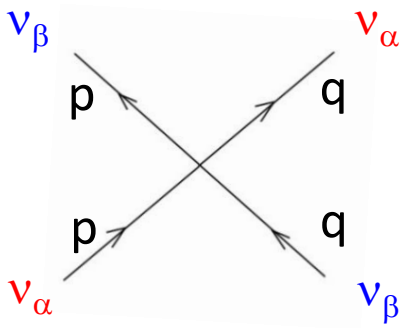
$$i\frac{d\psi_\nu}{dt} = (H_{\rm V} + H_e + H_\nu)\psi_\nu(t_{\rm em}, E, u, r),$$

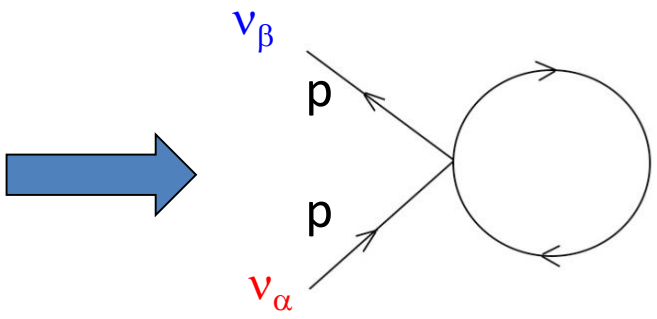
$$H_{\rm V} = U\frac{M^2}{2E}U^+$$

$$H_e = \sqrt{2}\,G_F n_e(r)\ \mathrm{diag}(1,0,0)$$

ν angle dep !

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



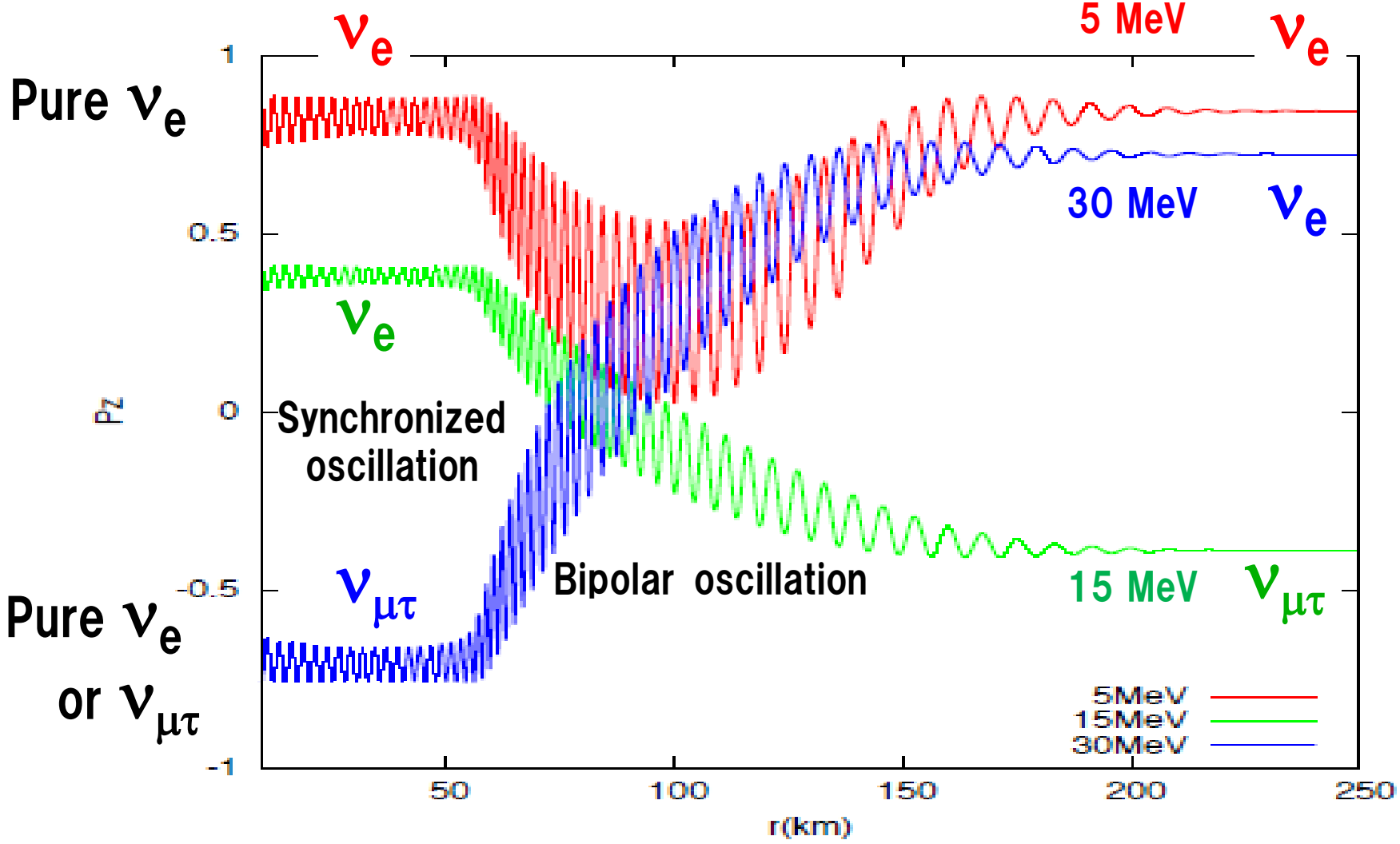


α, β = e, μ, τ

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

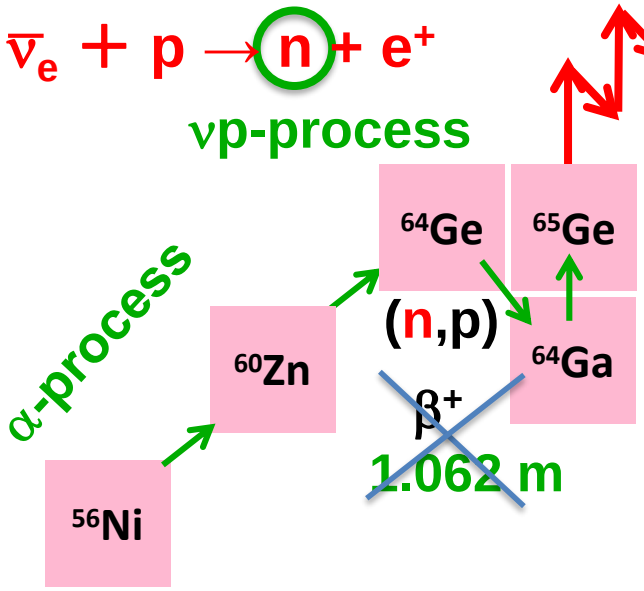
Calculated ν Flavor Oscillation

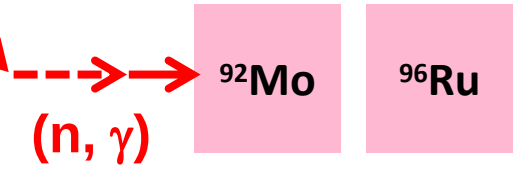
Energy spectra swap!



Ordinary νp-process

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





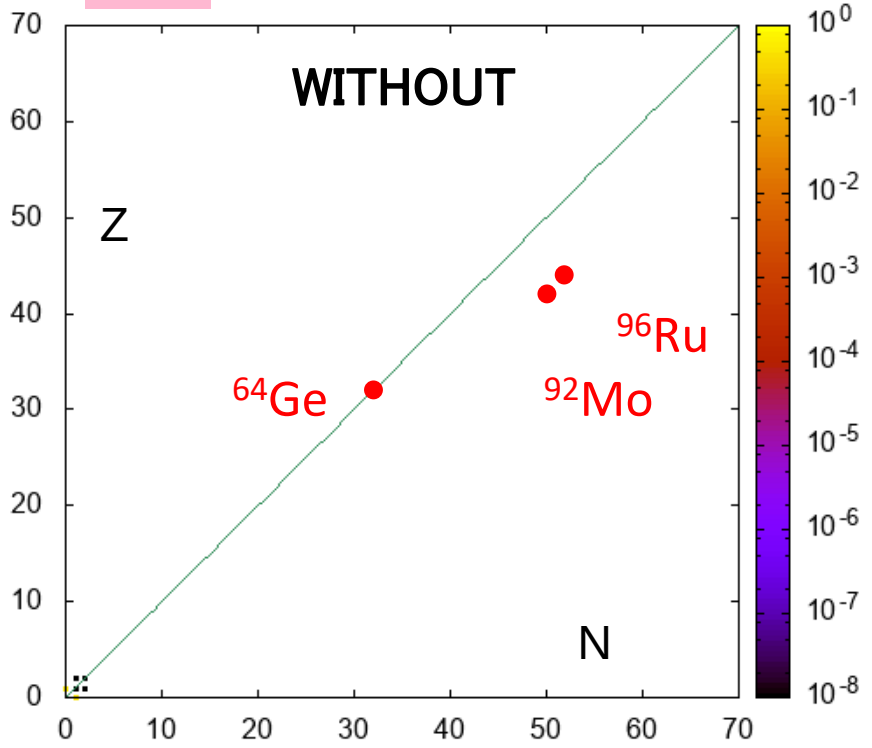
14.53% 5.54%

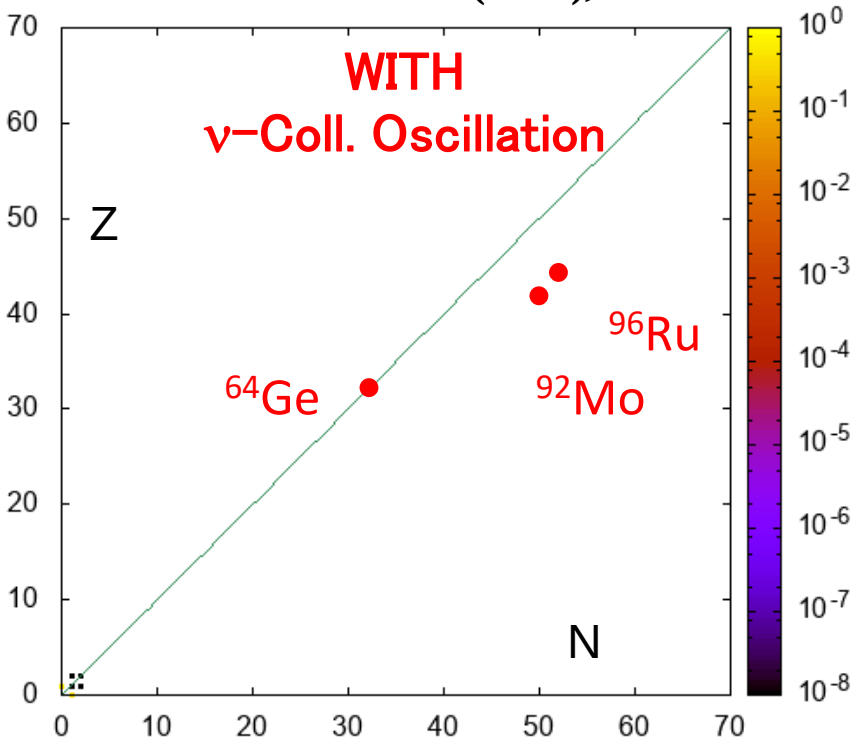
HIGH isotopic ratio!

(c.f. isotopic ratio of p-nuclei ~ 0.1-1%)

Neutrons are supplied continuously by Collective ν–Oscill., followed by (n, γ)' s to reach ^{92,94}Mo, ^{96,98}Ru!

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

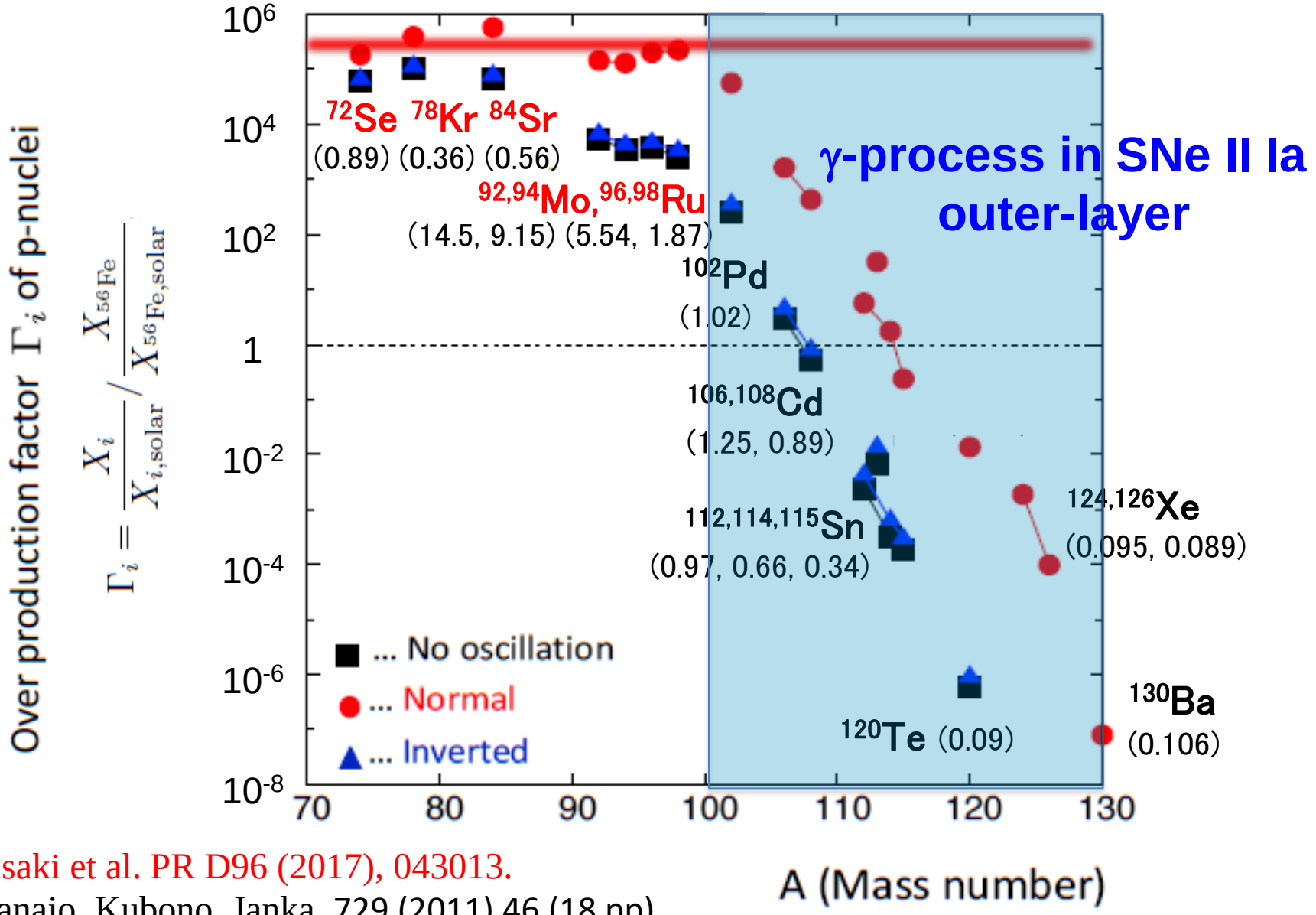




P–Nuclei (Isotopic ratio %)

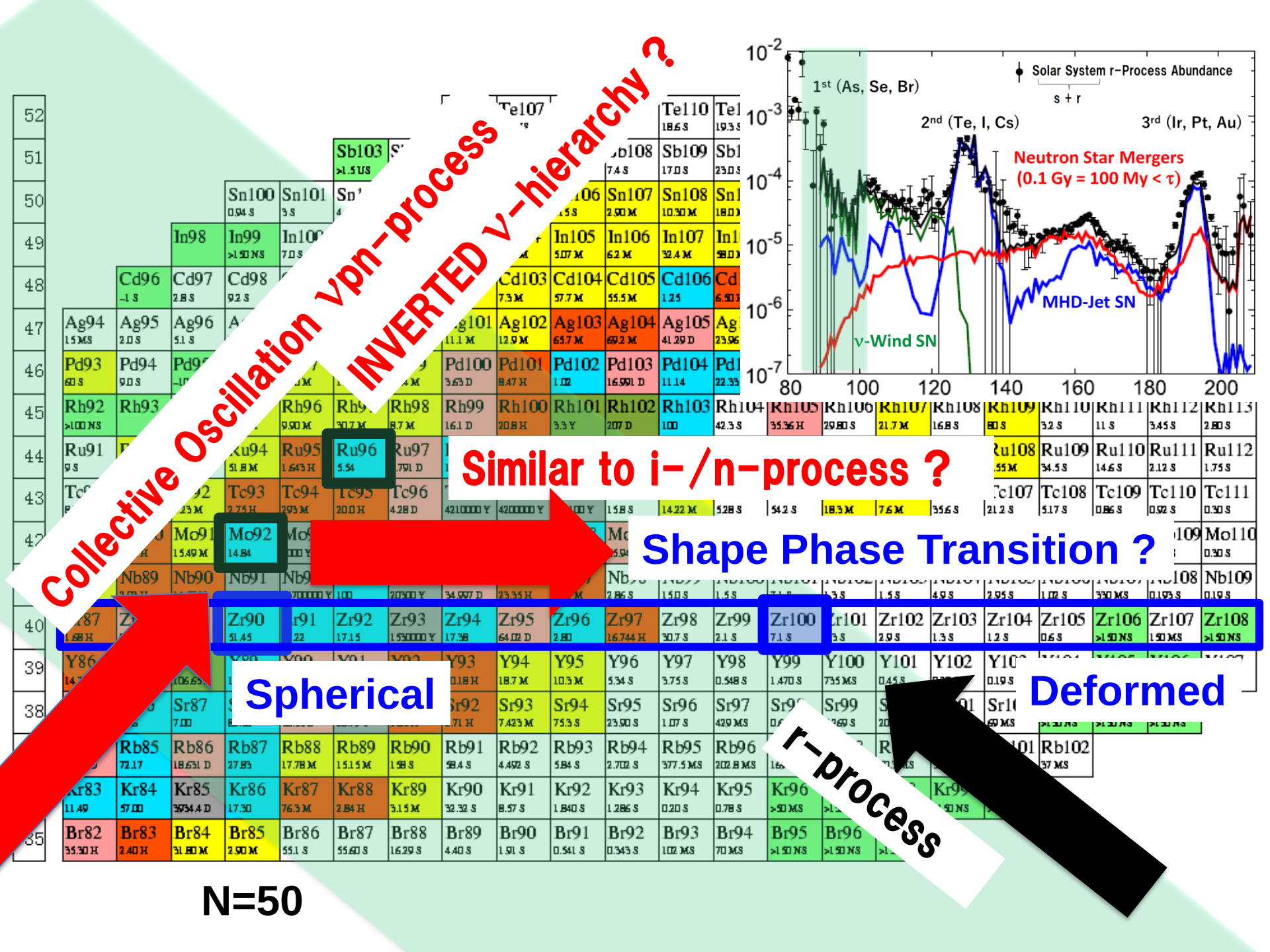
$$\Gamma_i = \frac{X_i}{X_{i,\mathrm{solar}}} \Big/ \frac{X_{^{56}\mathrm{Fe}} + X_{^{56}\mathrm{Fe}}}{X_{^{56}\mathrm{Fe,solar}}}$$

Si-burn.



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

Wanajo, Kubono, Janka, 729 (2011) 46 (18 pp).


Collective Oscillation νpn-process
INVERTED ν-hierarchy ?
Similar to i-/n-process ?
Shape Phase Transition ?
Spherical
Deformed
r-process
N=50
Solar System r-Process Abundance
s + r
1st (As, Se, Br)
2nd (Te, I, Cs)
3rd (Ir, Pt, Au)
Neutron Star Mergers
(0.1 Gy = 100 My < τ)
MHD-Jet SN
ν-Wind SN

SUMMARY

Origin of R-Process:

- The Early Galaxies, dominated by SNe (MHD-Jet & ν-wind) .——Universality
- Neutron Star Mergers have arrived later. ———— Actinide Boost Stars
- S.S. material consists of both. ———— SiC X-grains, ^{26}Al, ^{60}Fe, ^{244}Pu in sedim

Supernova-ν Process:

- Good Probe for ν-Collective Oscillations & MSW Effect.———— ^{92}Mo, ^{96}Ru
- Constrain ν-MASS HIERARCHY and θ_{13} simultaneously.
  ———— ^{7}Li, ^{11}B, ^{92}Nb, ^{98}Tc, ^{138}La, ^{180}Ta

⇒ Quest for Astronomy & Cosmochemistry

⇒ Quest for Synergy with Nuclear Astrophysics

:- is to look for ISOTOPIC abundances of ν-, r-, p-nuclei from the early Galaxy to the solar system including isotopic ANOMALIES of presolar SiC X-grains.