Double Beta Decays in Nucleosynthesis

Tatsushi Shima
Research Center for Nuclear Physics, Osaka University

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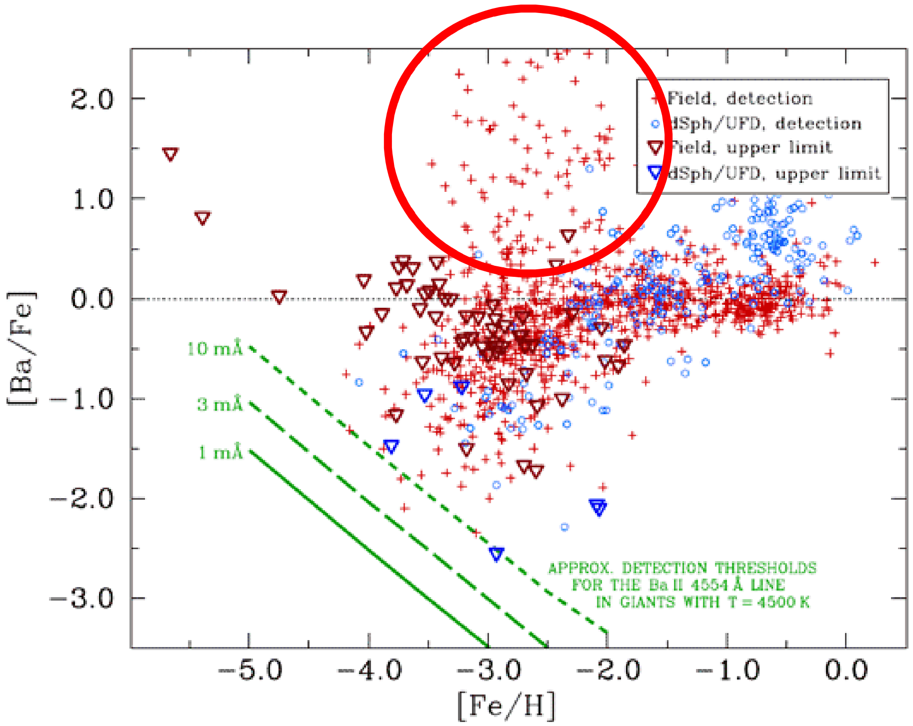
Barium is a typical s-element in solar-system, but is expected to be dominated by r-process in metal-poor (MP) stars.



I.U. Roederer, 2012

$$f_{odd} = \frac{N\left({}^{135}Ba\right) + N\left({}^{137}Ba\right)}{N\left(Ba\right)}$$

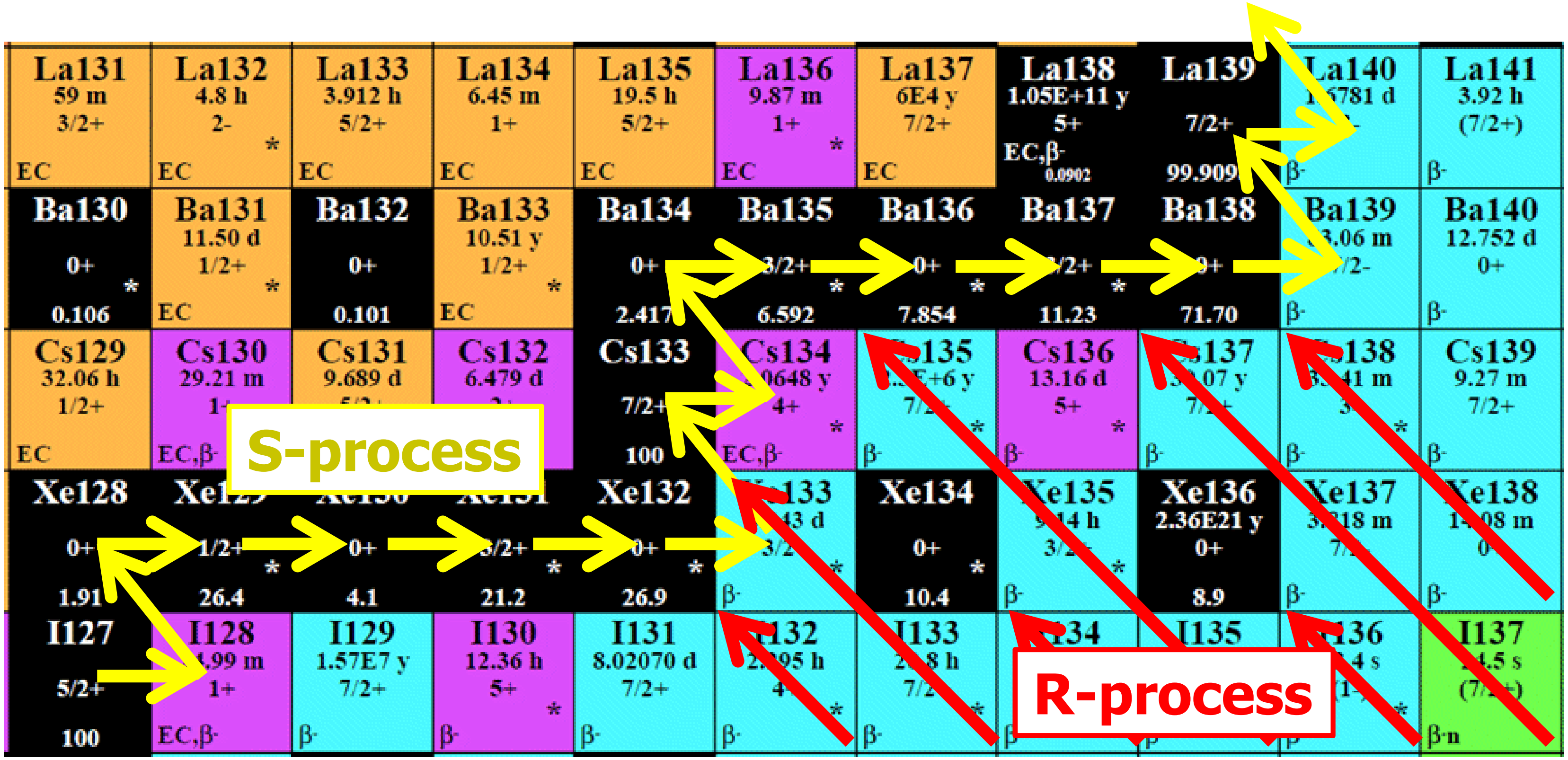
$= 0.11 \pm 0.01$ for s-only

0.46 ± 0.06 for r-only

0.17 in solar system

(Anders & Grevesse 1989)

Stellar s- and r-process paths



Note. f_{odd} becomes large for r-process, because ^{134}Ba and ^{136}Ba are shielded by ^{134}Xe and ^{136}Xe, respectively.

Slow neutron-capture processes

	Main process	Weak process
Atomic mass region	A>90	56<A<90
Neutron density [cm^{-3}]	10^7~10^{10}	10^6~10^7
Duration [y]	~20000 /pulse	10^5~10^6
Astrophysical site	He-shell burning in Low-mass AGB* (M=1.5~3$M_{\odot}$)	Core He-burning in Massive star (M >10$M_{\odot}$)

* Asymptotic Giant Branch

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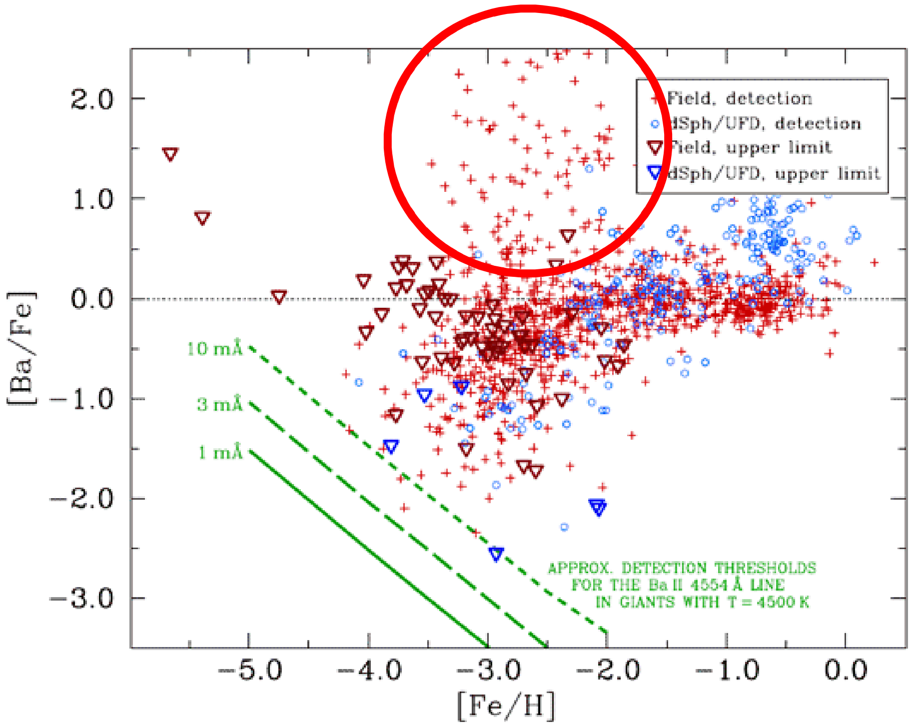

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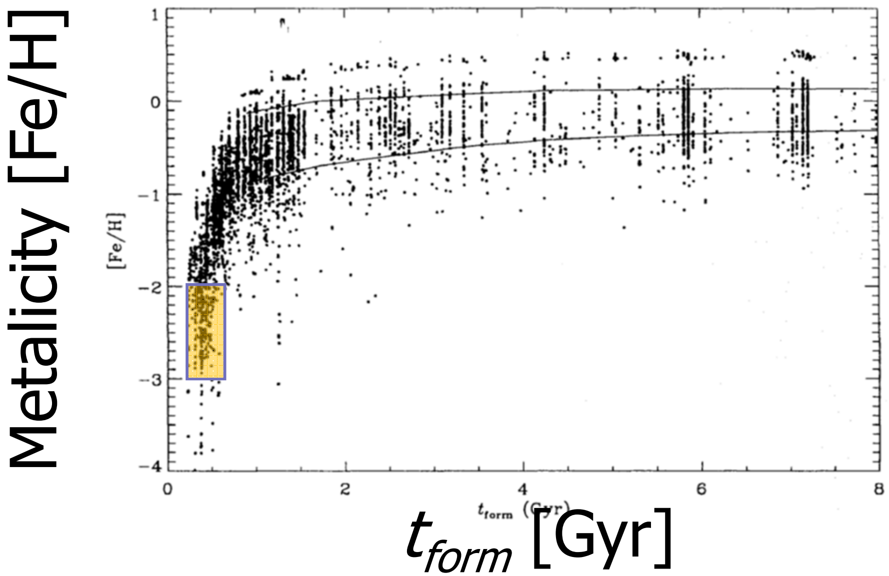
MP:

- **0.18 ± 0.08**
  Gallagher, Aoki, Honda et al. 2012
- **0.15 ± 0.12**
  Collet, Asplund, Nissen 2009

★ Age-metalicity relation

C.M. Raiteri et al., A&A 315, 105-115 (1996)



[Fe/H]= -2.15 ~ -3.07
Gallagher, Aoki, Honda et al. 2012

[Fe/H]= -2.50
Collet, Asplund, Nissen 2009

➡ t_{form} = 0.3~0.6 Gyr

★ Lifetime of stars;

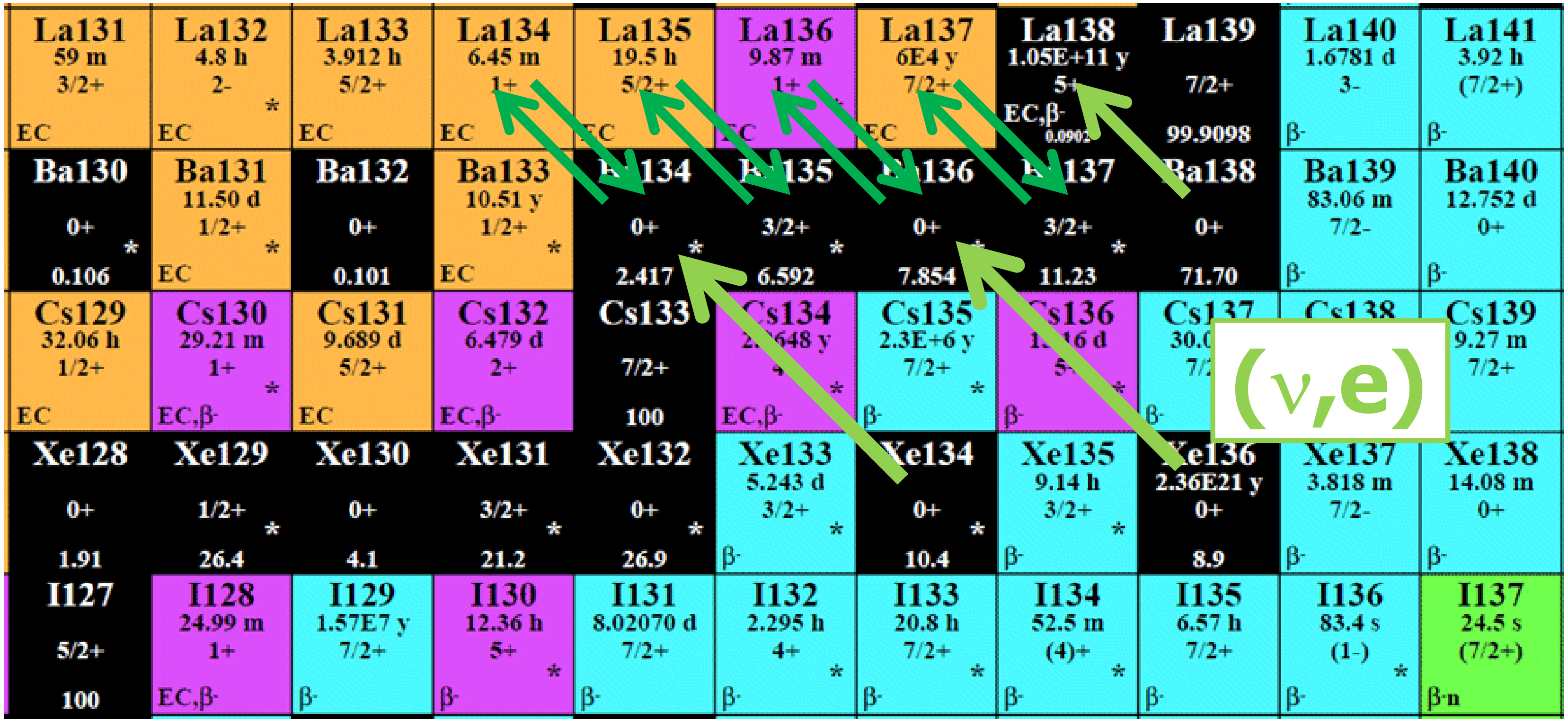
$$\tau_{MS} = 7\times 10^{9}\left[\frac{M}{M_{\odot}}\right]^{-3} \quad [\mathrm{yr}]$$

➡ τ_{MS} = 0.26~2.1 Gyr for M= 1.5~3$M_{\odot}$

- Observation discovered old stars with enhanced abundances of ^{134}Ba and ^{136}Ba.
- ^{134}Ba and ^{136}Ba are produced mainly by main s-process.
- Main s-process occurs in AGB phase of low-mass stars, which take long time to enter He-burning stage.

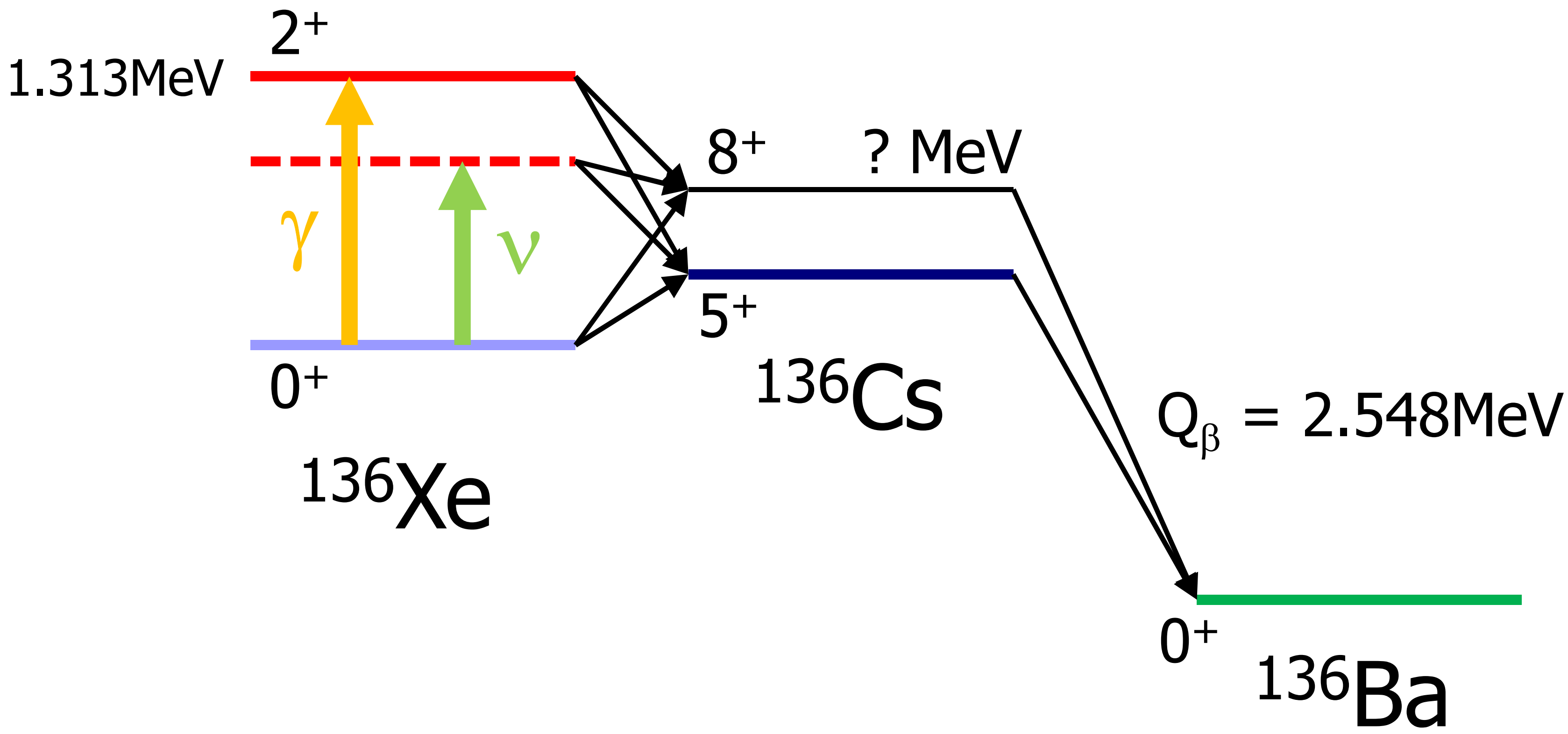
Is there any unknown type of s-process ?
Is there any unknown effect in r-process ?

Neutrino-induced ββ decay

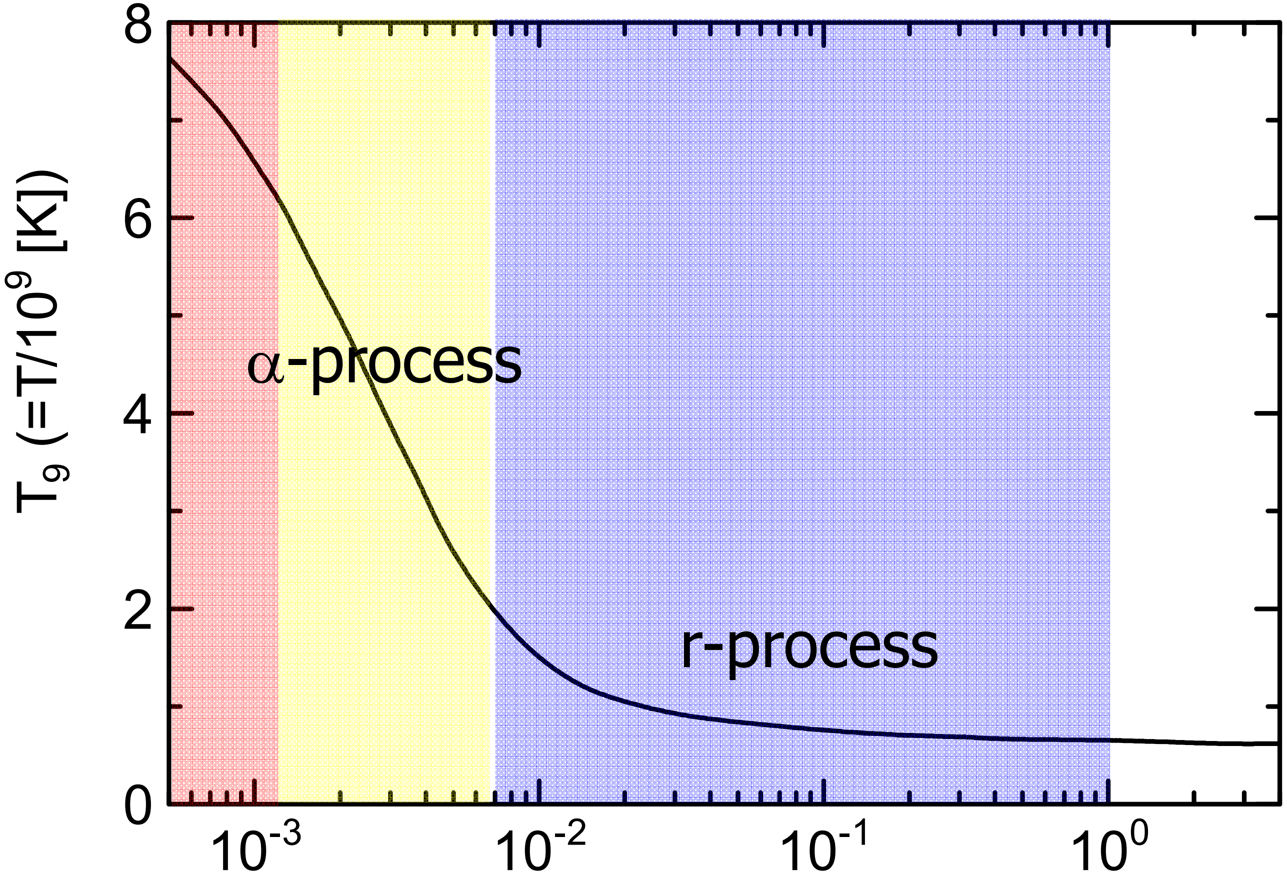


Neutrino-induced double-beta decays of $^{134,136}Xe$ may play crucial roles in production of $^{134,136}Ba$ in r-process.

ν-induced $\beta\beta$ v.s. $\beta\beta$ from excited states

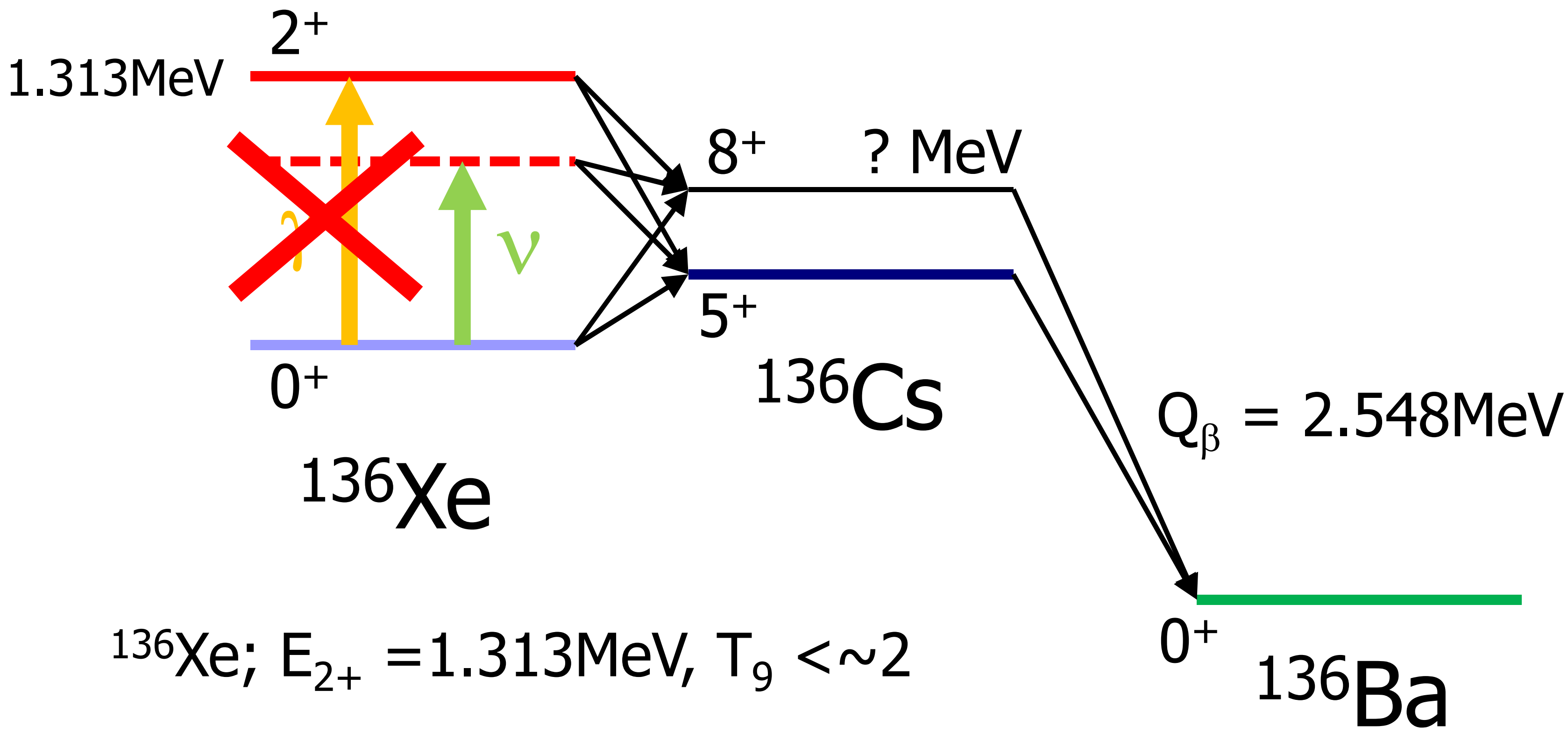


Temperature (Matter)



n,p,^{4}He
NSE

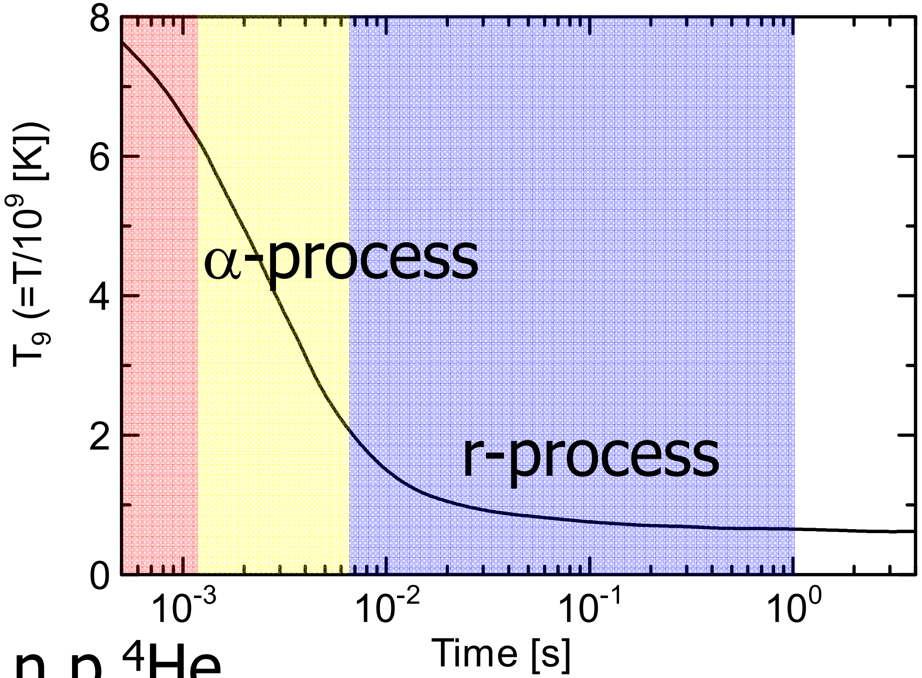
ν-induced ββ v.s. ββ from excited states



^{136}Xe; E_{2+} =1.313MeV, T_9 <~2

→ $P(2^+) < 5 \times 10^{-4}$

Temperature (Matter)



n,p,^{4}He
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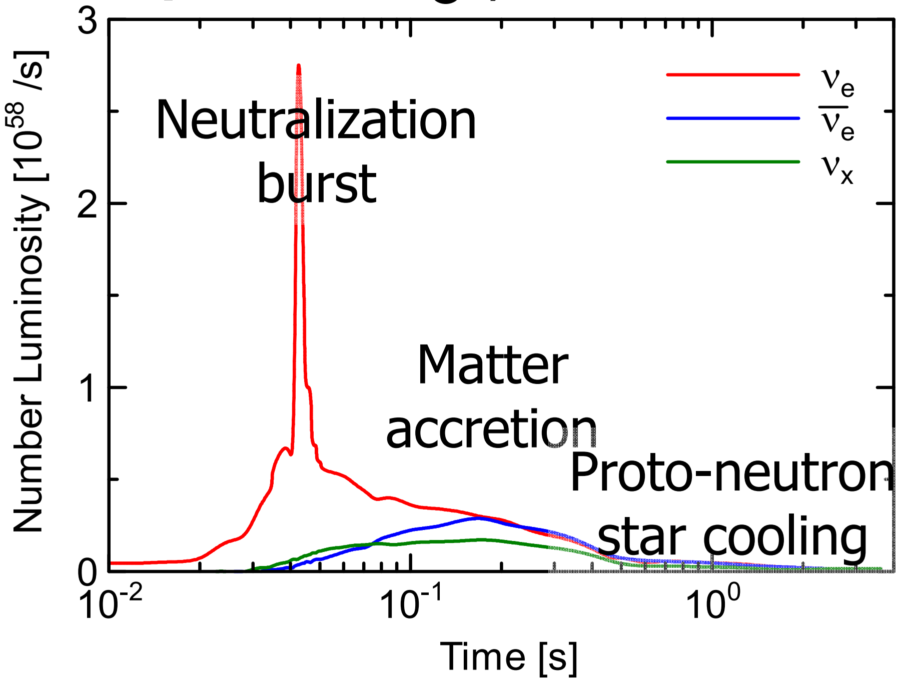
Neutrino Luminosity ($M=20M_\odot$)



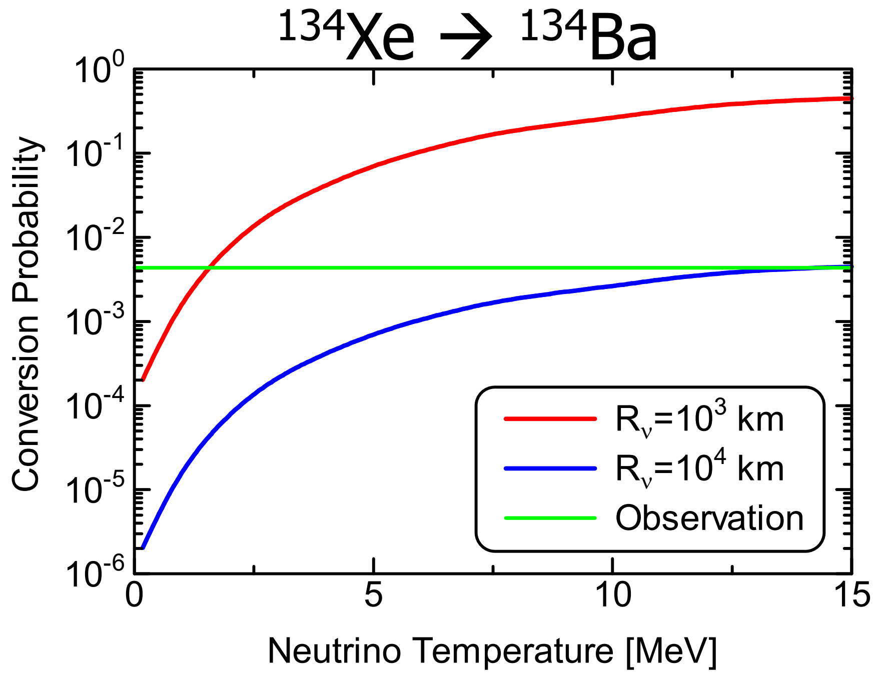
$\langle E_{\nu e}\rangle \sim 10$MeV $\langle E_{\bar{\nu} e}\rangle \sim 15$MeV

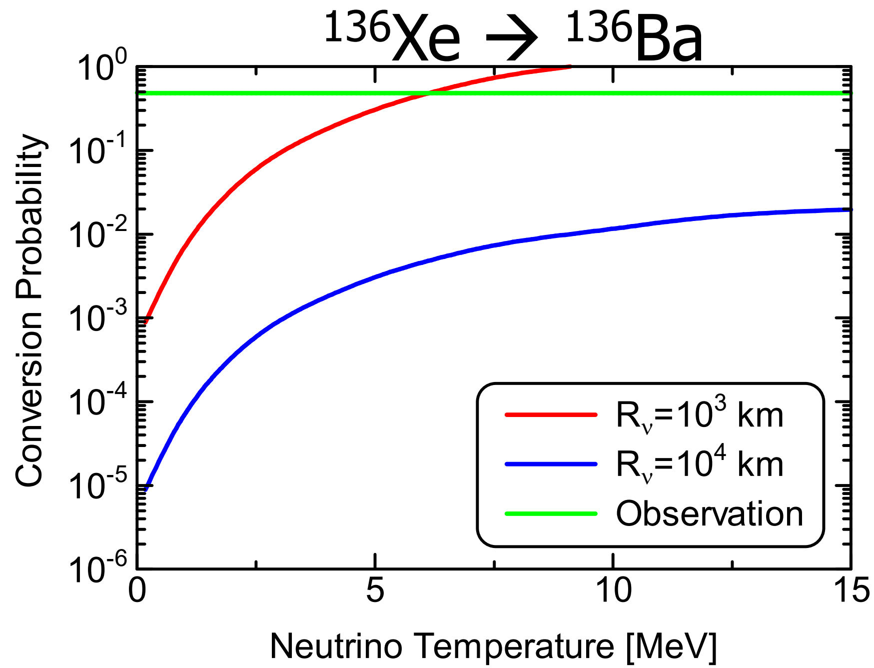
$\langle E_{\nu x}\rangle \sim 23$MeV

T. Totani, K. Sato, H.E.Dalhed, J.R.Wilson, ApJ 496, 216-225 (1998)

Probability of ^{134,136}Ba production via ν-ββ process

Assuming total energy of emitted neutrinos to be 3.5×10^{53} erg, ν_e will have total energy of $\sim 6 \times 10^{52}$ erg or $\sim 3.7 \times 10^{58}$ MeV.





Given realistic reaction rates, temperature and radius of ν-ββ region can be constrained.

Summary

- Some metal-poor stars indicate large enhancement in even-even Ba isotopes.
- Heavier (~$3M_{\odot}$) component of low-mass AGB stars may contribute. Another possibility will be ββ-decays of $^{134,136}Xe$ induced by absorptions of neutrinos or photons.
- γ-induced ββ-decays of $^{134,136}Xe$ are unlikely due to too small population of 1st excited states at r-process temperature; $T_9 < 2$.
- On the other hand, ν-induced ββ-decay is still possible.
- Since b-decay lifetimes of ^{134}I and ^{136}I are much longer than r-process duration, ν-ββ process cannot occur in single r-process episode.
- For quantitative analysis, reliable calculation for ν-ββ rate is necessary.