Nishina Hall, RIKEN, October 17-19, 2012

1st NAOJ Visiting Fellow Workshop on

Element Genesis and Cosmic Chemical Evolution

R-Process Prespecive

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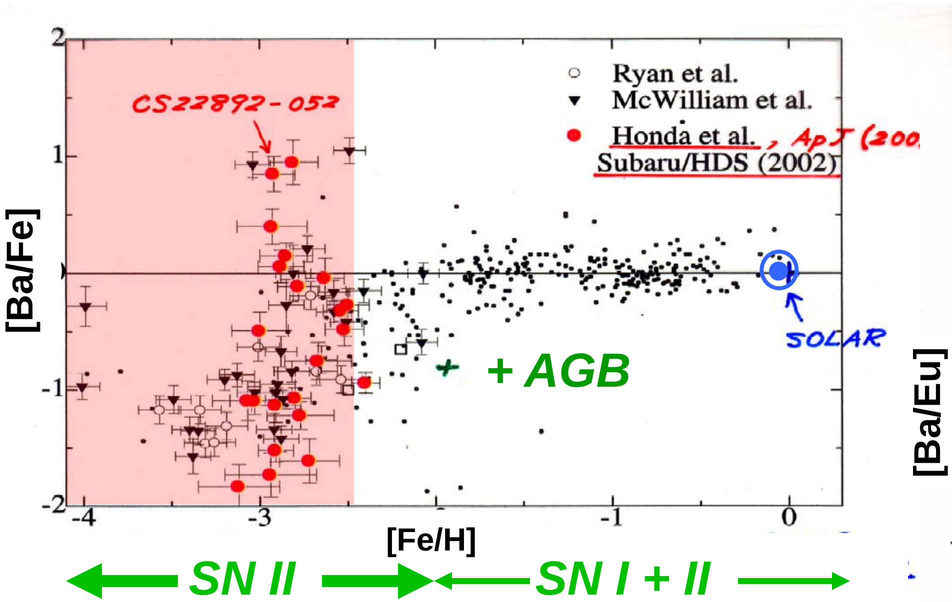
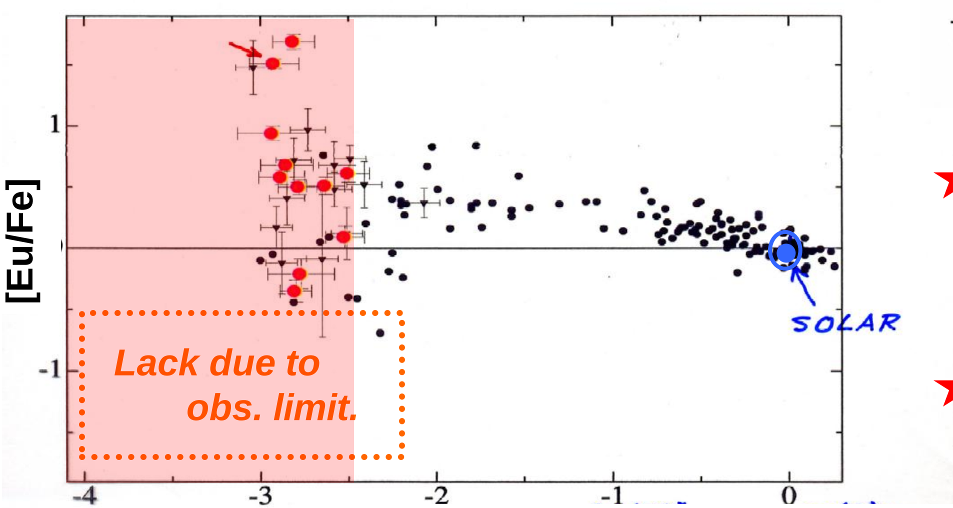
Organizers
Wako Aoki, Michael Famiano, Toshitaka Kajino (NAOJ)
Shunji Nishimura, Tohru Motobayashi, Shigeru Kubono (RIKEN)
Hidetoshi Yamaguchi (CNS), Hiroari Miyatake (KEK)

Host: NAOJ
Co-host: RIKEN NC
Sponsor: UT-CNS, KEK
Japan Forum of Nuclear Astrophysics

SUBARU Telescope HDS

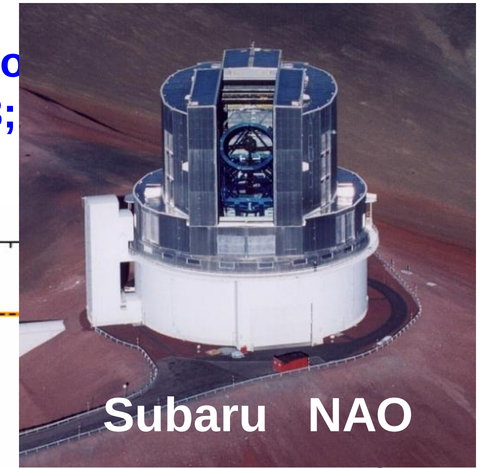


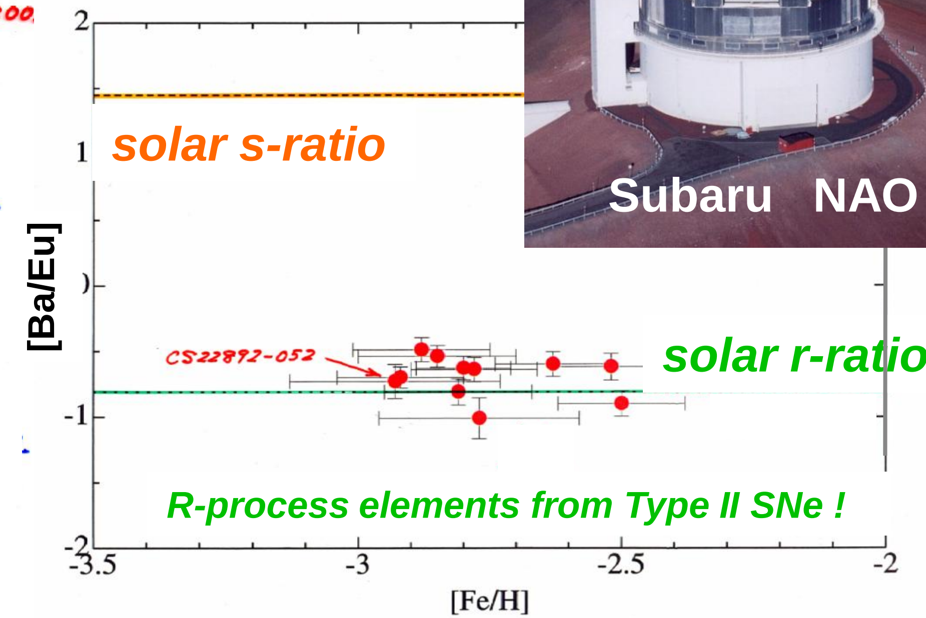


Early Universe

$[Fe/H] = \log(N_{Fe}/N_H)_{\star} - \log(N_{Fe}/N_H)_{\odot}$

Honda, Aoki et al.
(SUBARU/HDS Co
2004, ApJS 152, 113;
2004, ApJ 607, 474



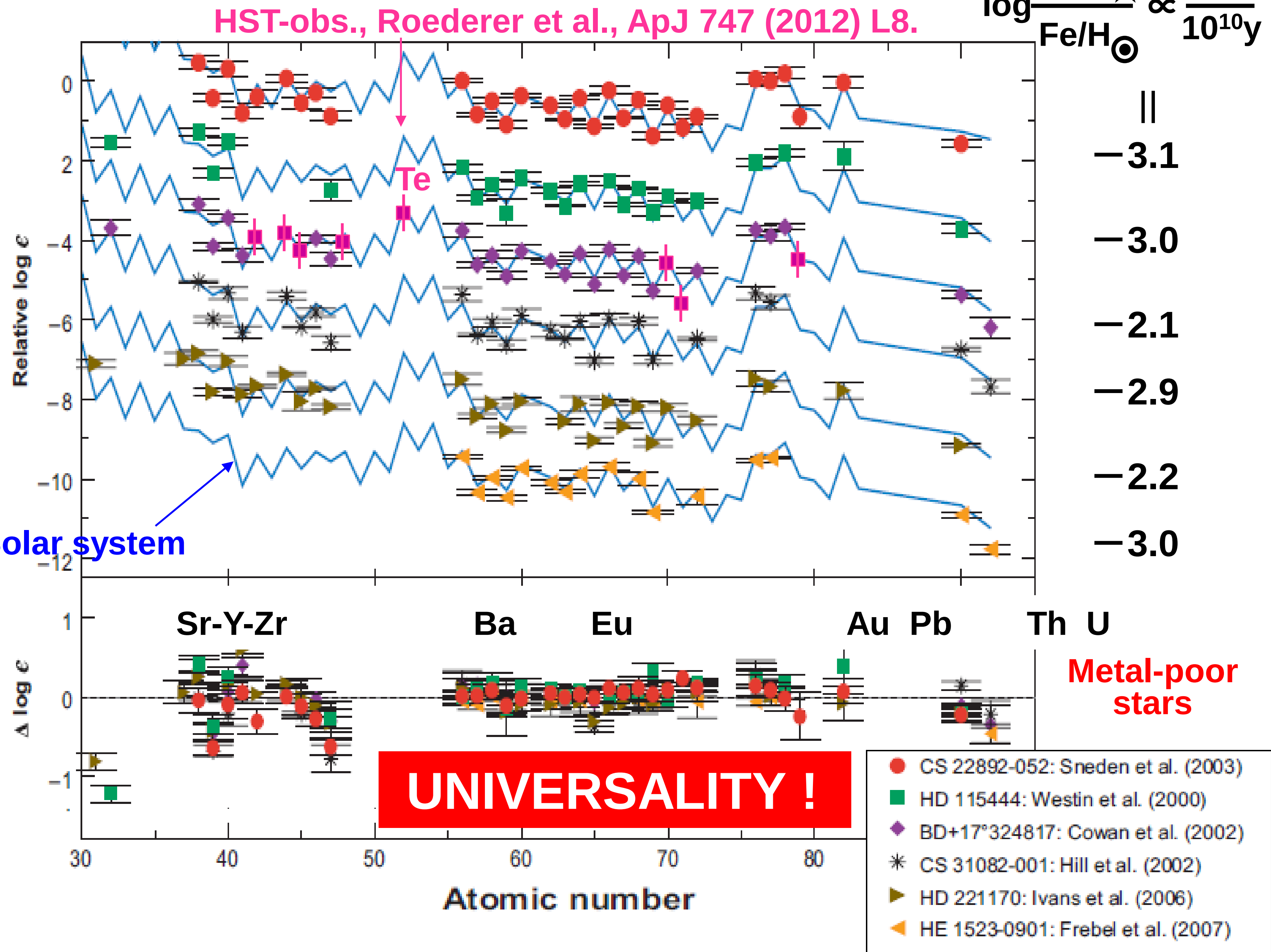


★ Large abundance scatter at [Fe/H]<-2 is an evidence for INDIVIDUAL supernova episode.

★ Only Core-Collapse TYPE II SUPER-NOVAE are the likely astrophysical sites of the R-Process !

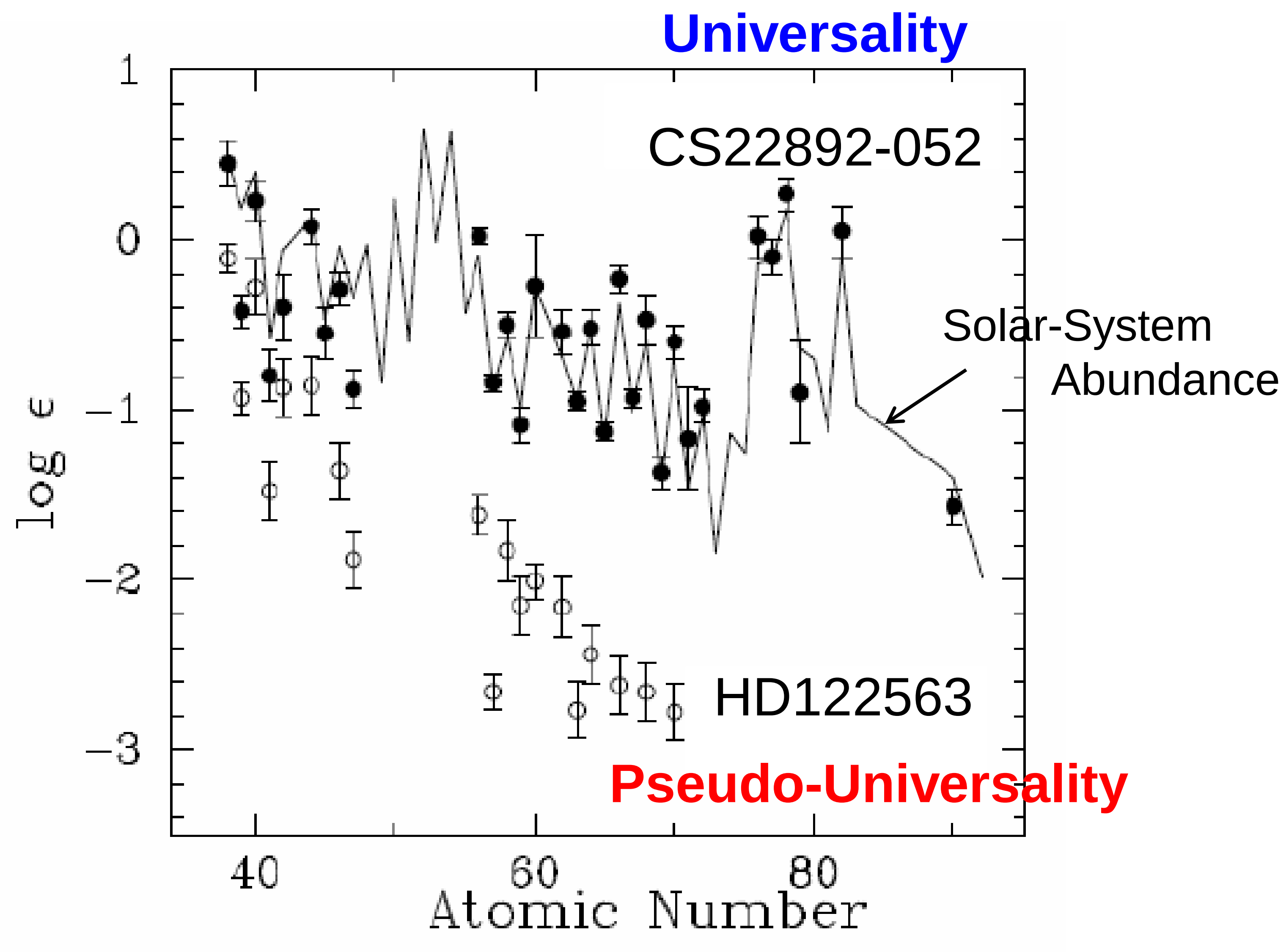
Sneden, Cowan, Gallino, ARAA 46 (2008) 241.

$$\log \frac{Fe/H_{\star}}{Fe/H_{\odot}} \propto \frac{t}{10^{10}y}$$



UNIVERSALITYの亜種の発見

（Honda, Aoki, + すばる望遠鏡HDSチーム）



Magic Number and Slow/Rapid Neutron-Capture Processes

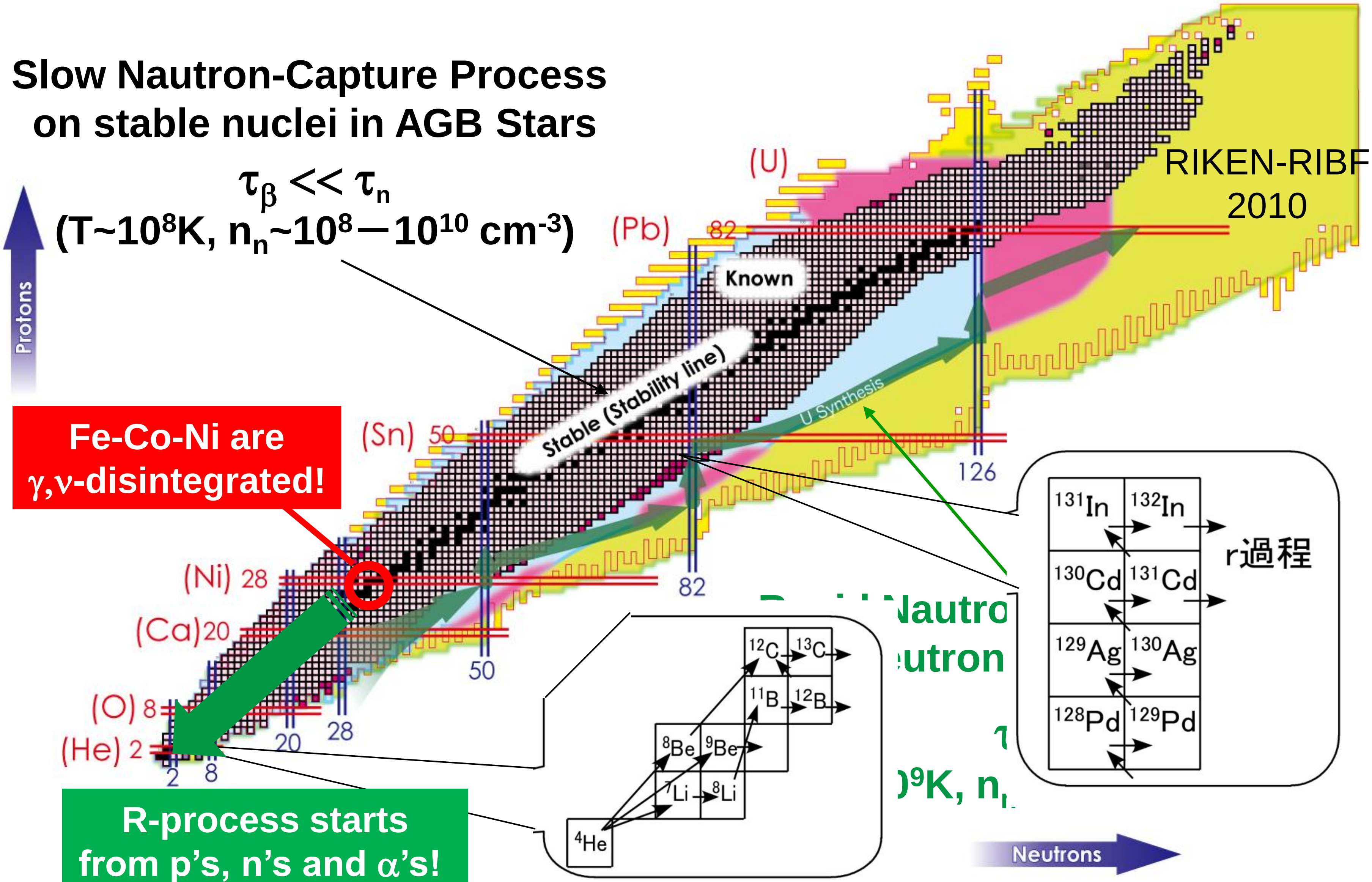
Slow Nautron-Capture Process on stable nuclei in AGB Stars

$\tau_\beta << \tau_n$

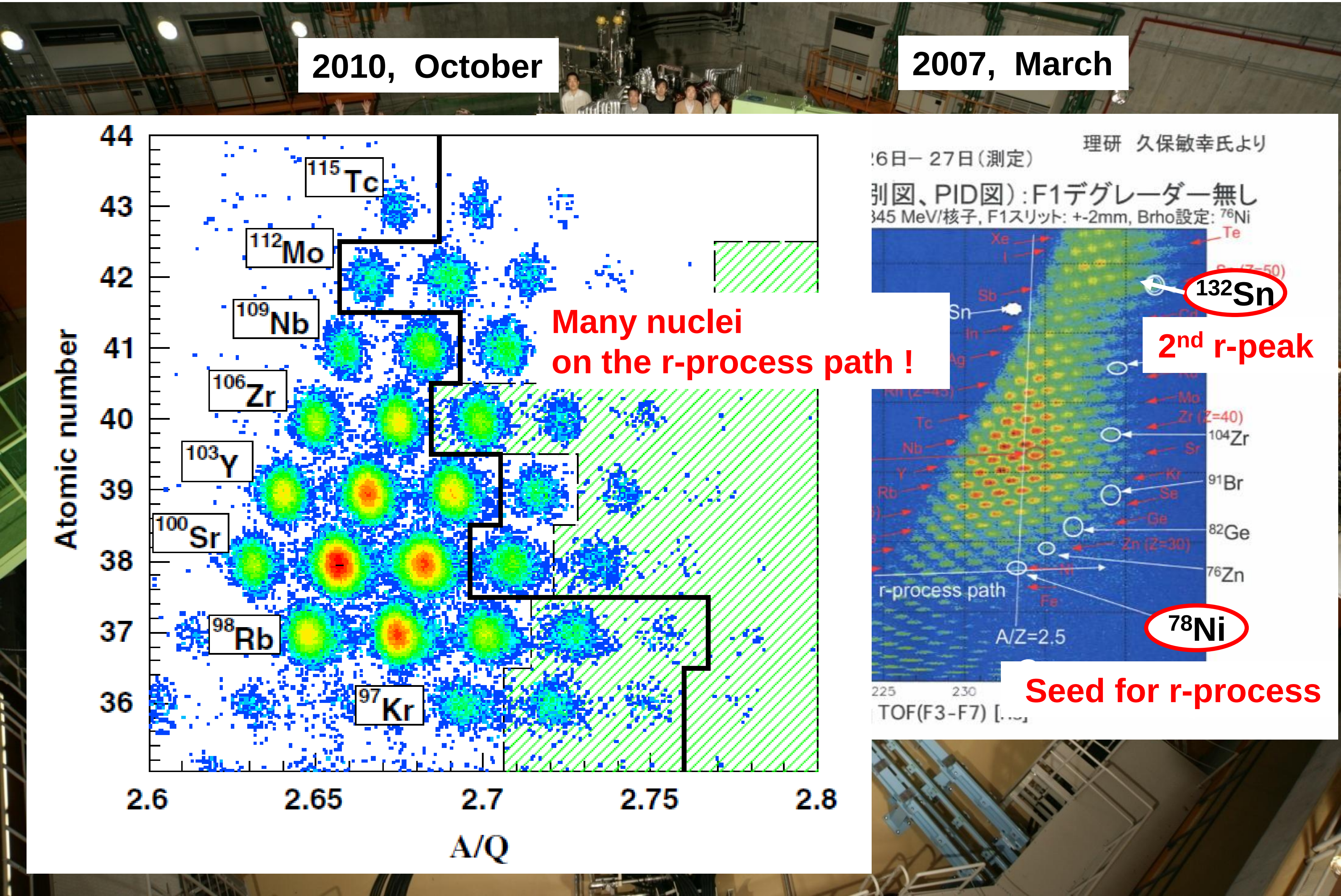
(T~10^8K, n_n~10^8—10^{10} cm^{-3})

Fe-Co-Ni are γ,ν-disintegrated!

R-process starts from p's, n's and α's!



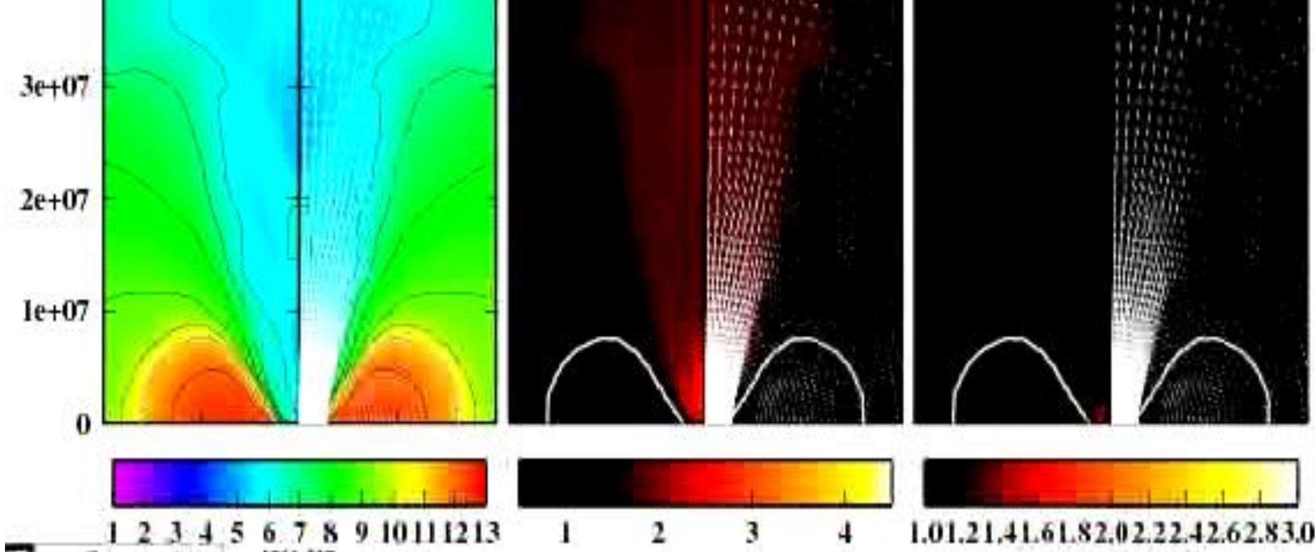
RIKEN-RIBF New Ring Cyclotron (since 2007)

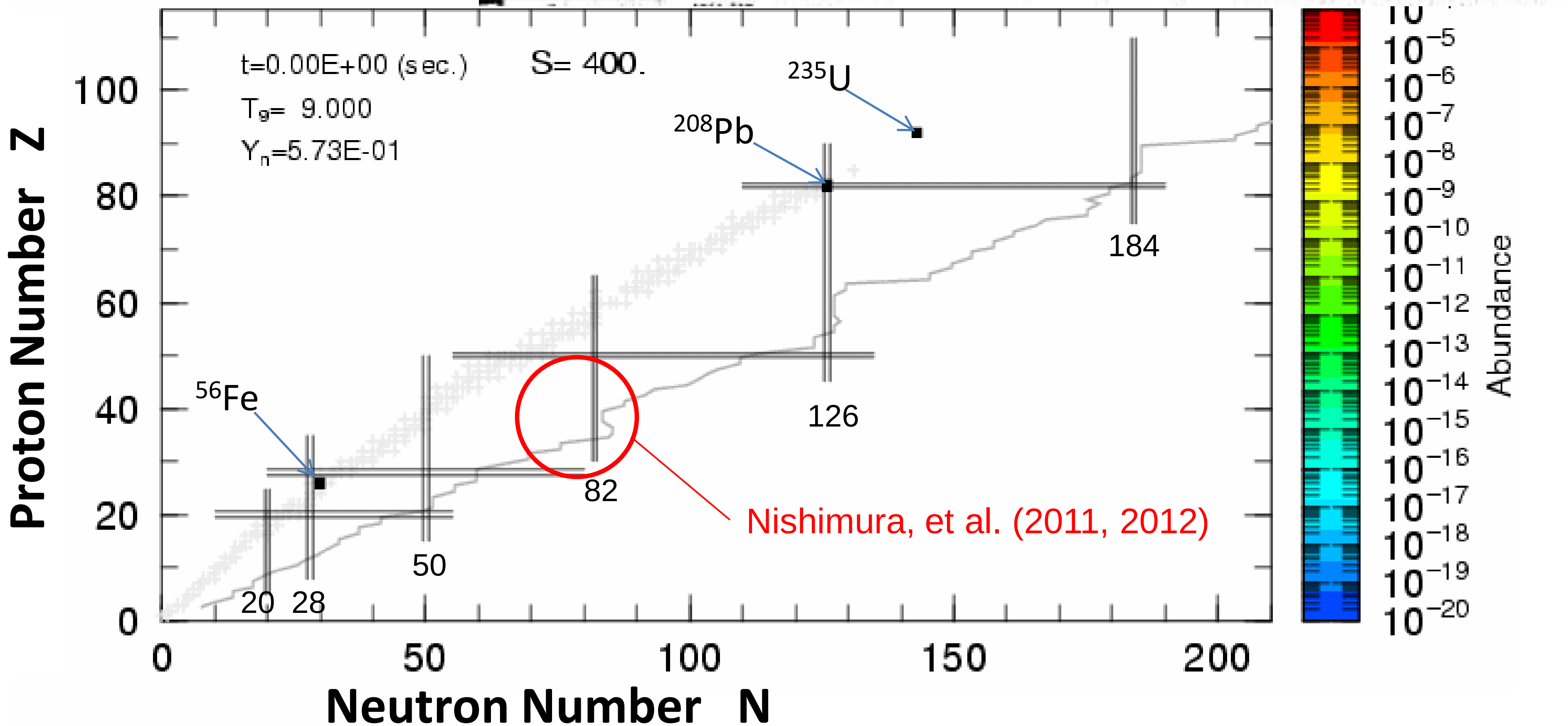


Supernova Nucleosynthesis Simulation

S. Chiba

ν-Pair Heated Collapsar Model
K. Nakamura, et al. ApJ (2012).





R–process Nucleosynthesis

K. Otsuki, H. Tagoshi, T. Kajino and S. Wanajo, ApJ 533 (2000), 424;
S. Wanajo, T. Kajino, and G. J. Mathews, and K. Otsuki, ApJ J. 554 (2001), 578.

$\nu_e + n \rightarrow p + e^-$
$\overline{\nu}_e + p \rightarrow n + e^+$

$T_{\nu e} = 3.2$ MeV $< T_{\overline{\nu e}} = 4$ MeV

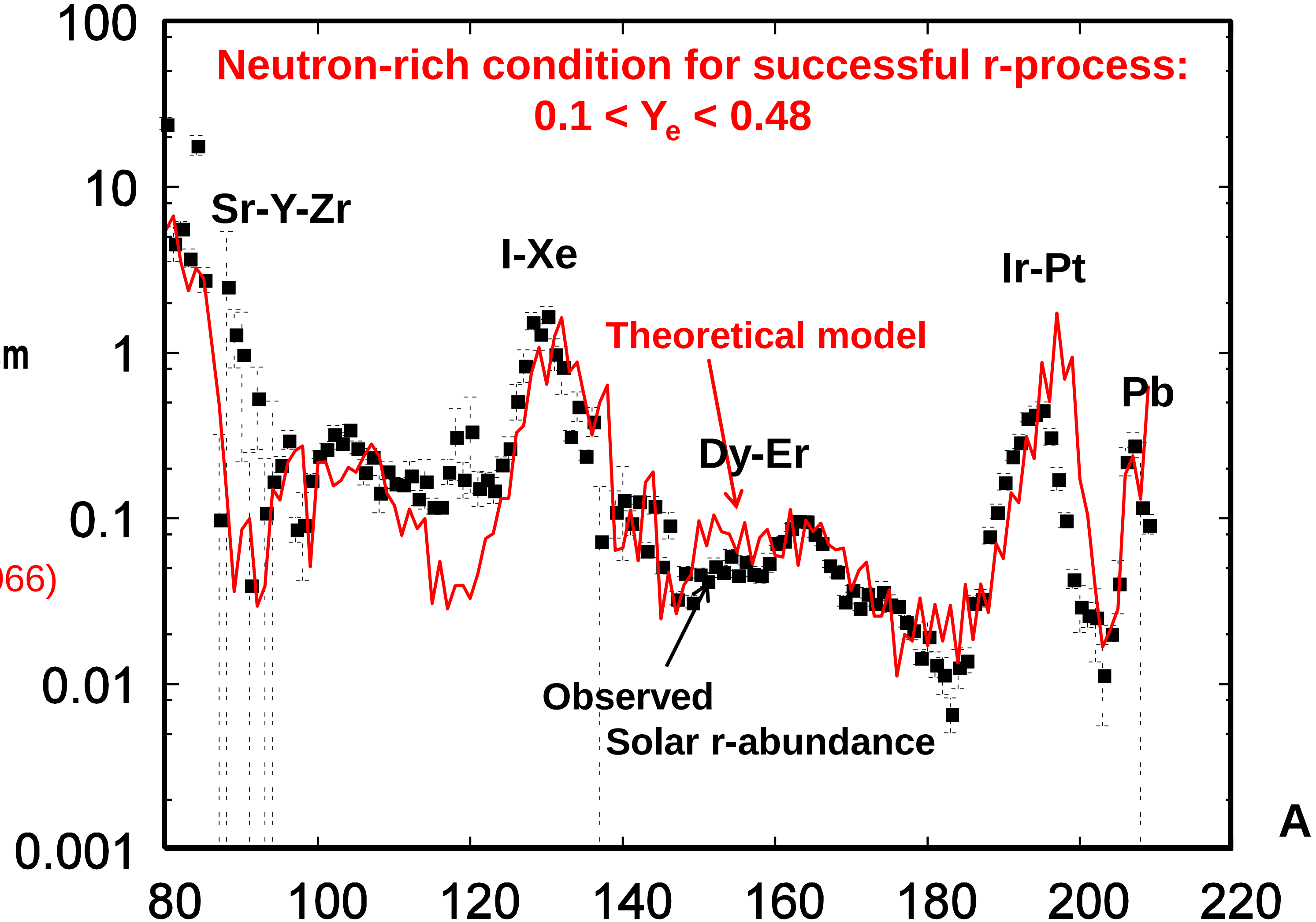
Challenge to identify astrophysical sites of the r-process:

- ν-wind SNe
- MHD jet SNe
- NS mergers
- GRBs

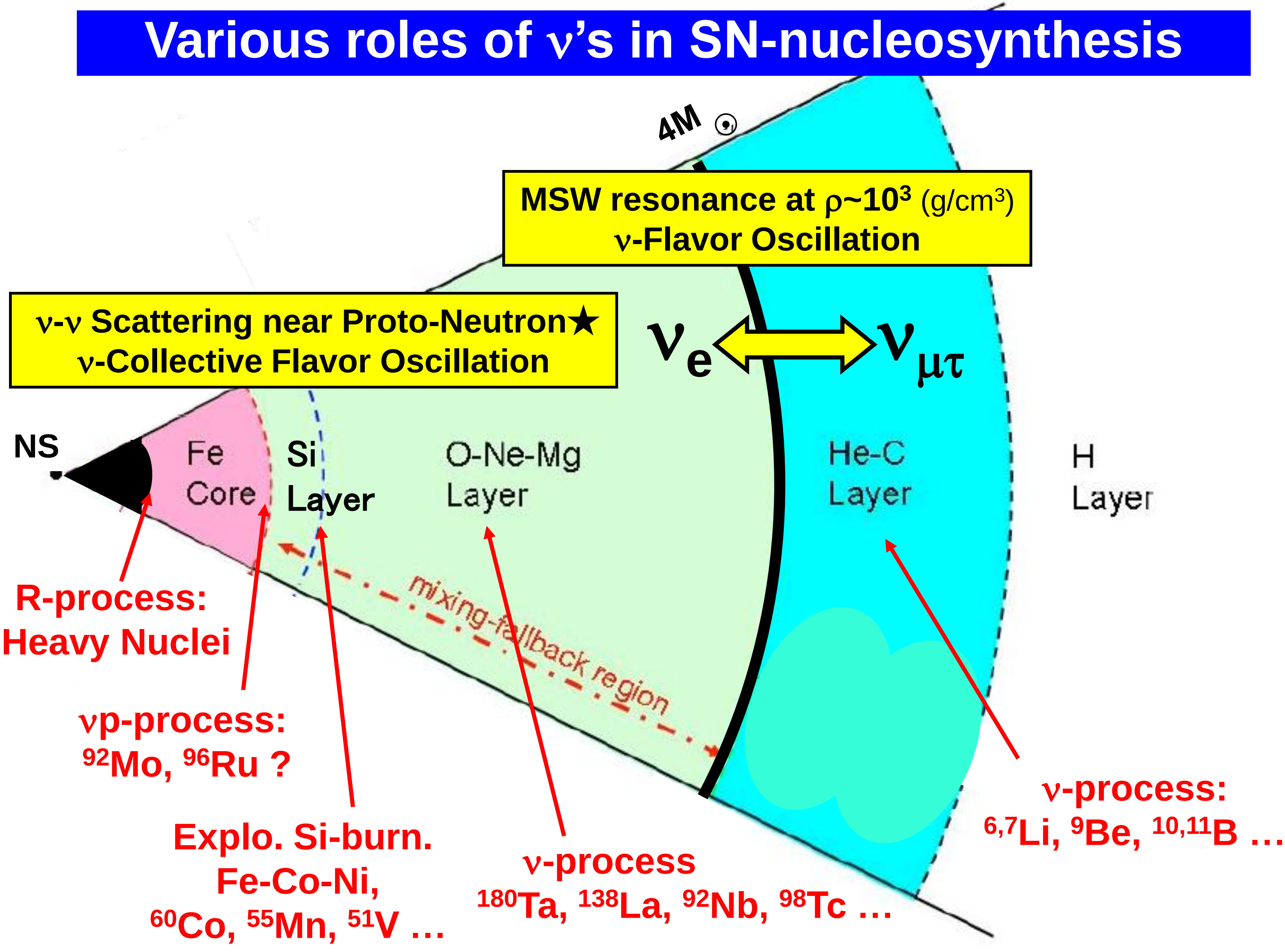
\+
Explosion mechanism

$Y_e > 0.5$?

Roberts, Reddy and Shen (arXiv1205.4066) pointed out
$Y_e < 0.5$
for nucleon pot. & Pauli blocking.



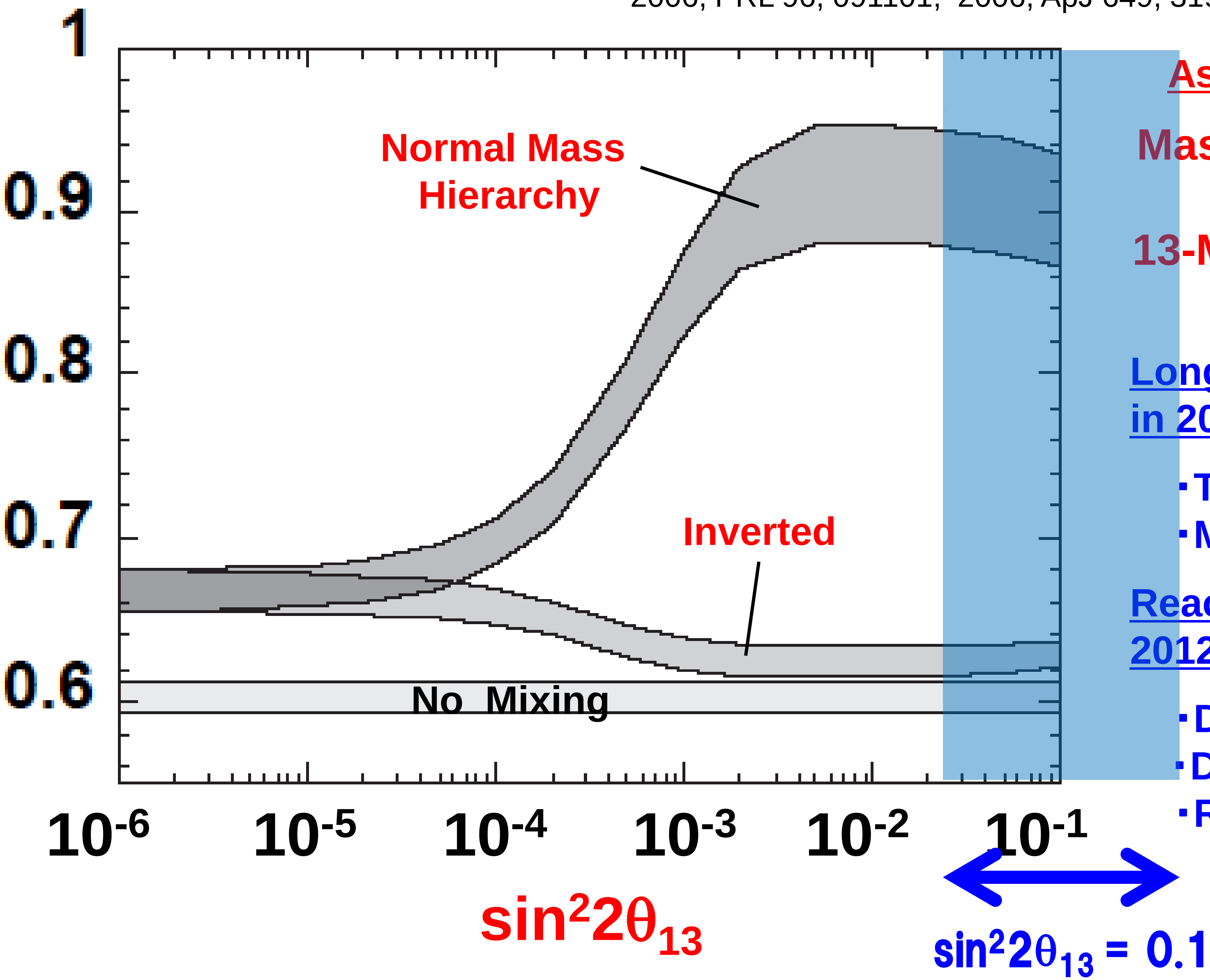
Various roles of ν's in SN-nucleosynthesis



MSW Effect & ν Mass Hierarchy

Predicted $^{7}Li/^{11}B$-Ratio

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



Astrophysics:

Mass Hierarchy
Δm_{13}^{2}
13-Mixing Angle
θ_{13}

Long BaselineExp. in 2011:

- T2K (Kamioka)
- MINOS

Reactor Exp. in 2012:

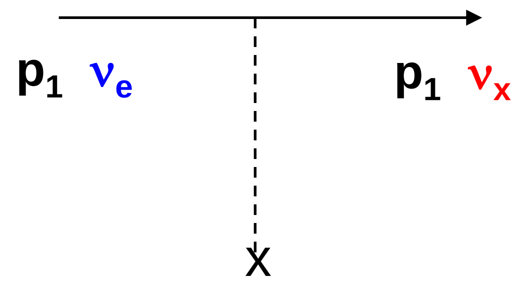
- Double CHOOZ
- Daya Bay
- RENO (KOREA)

ν-ν Scattering & Collective ν-scillation

H_ν = *Mixing and Interaction with Background Electrons*

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

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

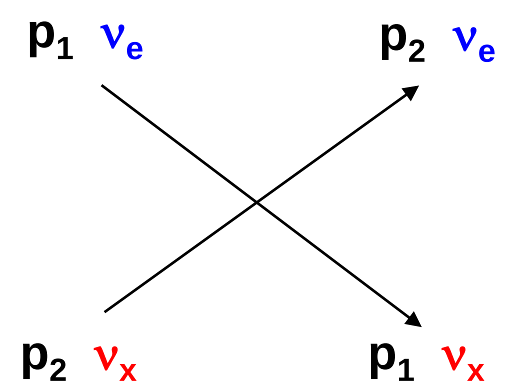


N_e = electron density

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

Self-Interaction

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



Quest for EXACT Many-Body SOLUTION !

"Invariants of collective neutrino oscillations"

Y. Pehlivan, A.B. Balantekin, T. Kajino & T. Yoshida

Phys. Rev. D84, 065008 (2011)

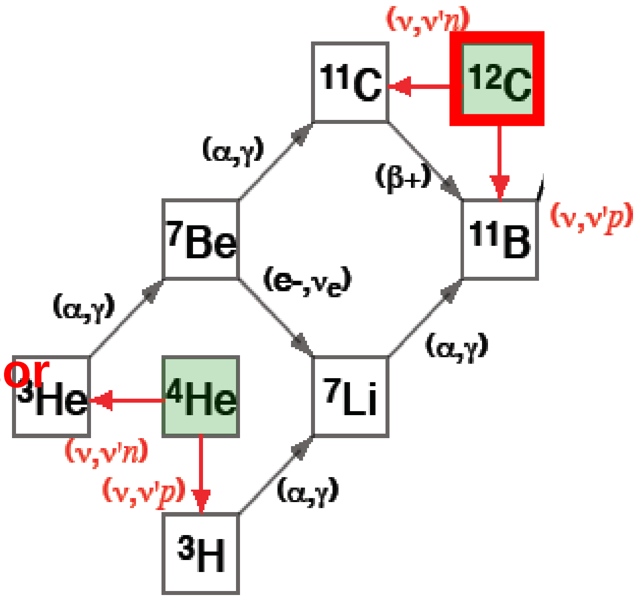
ν-A reaction cross sections?

Haxton's SM cal. (Woosley et al. ApJ. 356 (1990), 272)

Suzuki's new SM cal. with NEW Hamiltonian

Suzuki, Chiba, Yoshida, Kajino & Otsuka, PR C74 (2006), 034307.

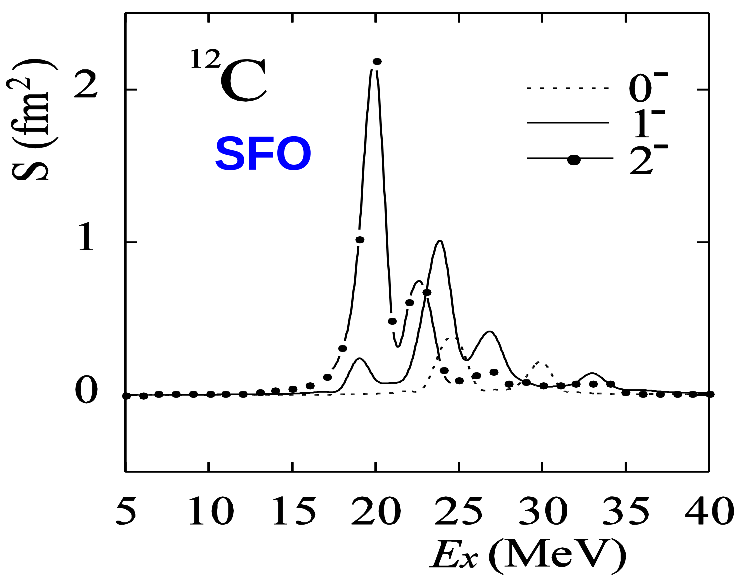
Suzuki, Fujimoto & Otsuka, PR C67, 044302 (2003) → SFO

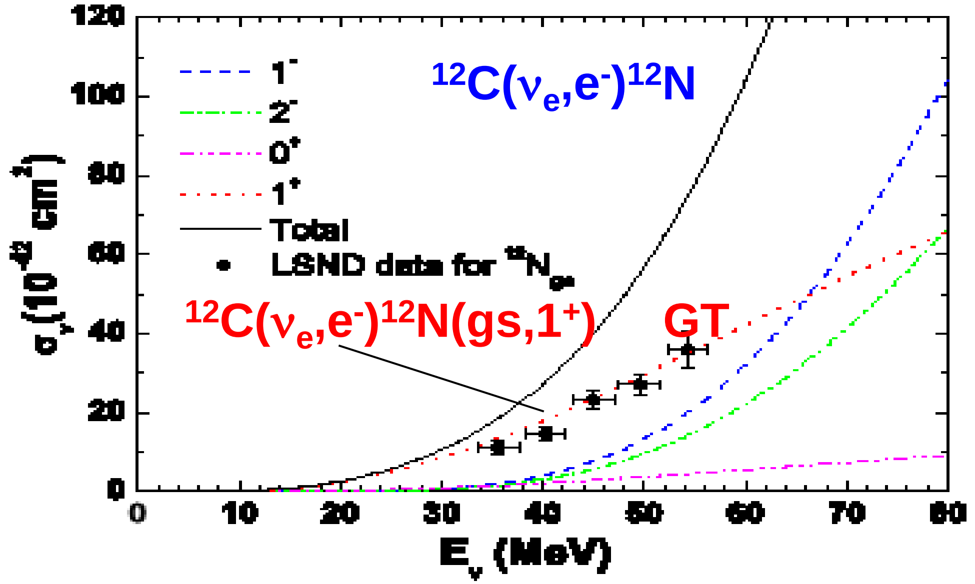


^{12}C: SFO Hamiltonian = Spin-isospin flip int. with tensor force to explain neutron-rich exotic nuclei.

- **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**

Cheoun et al., PRC81 (2010), 028501; J. Phys. G37 (2010) 055101: QRPA Cal.





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.

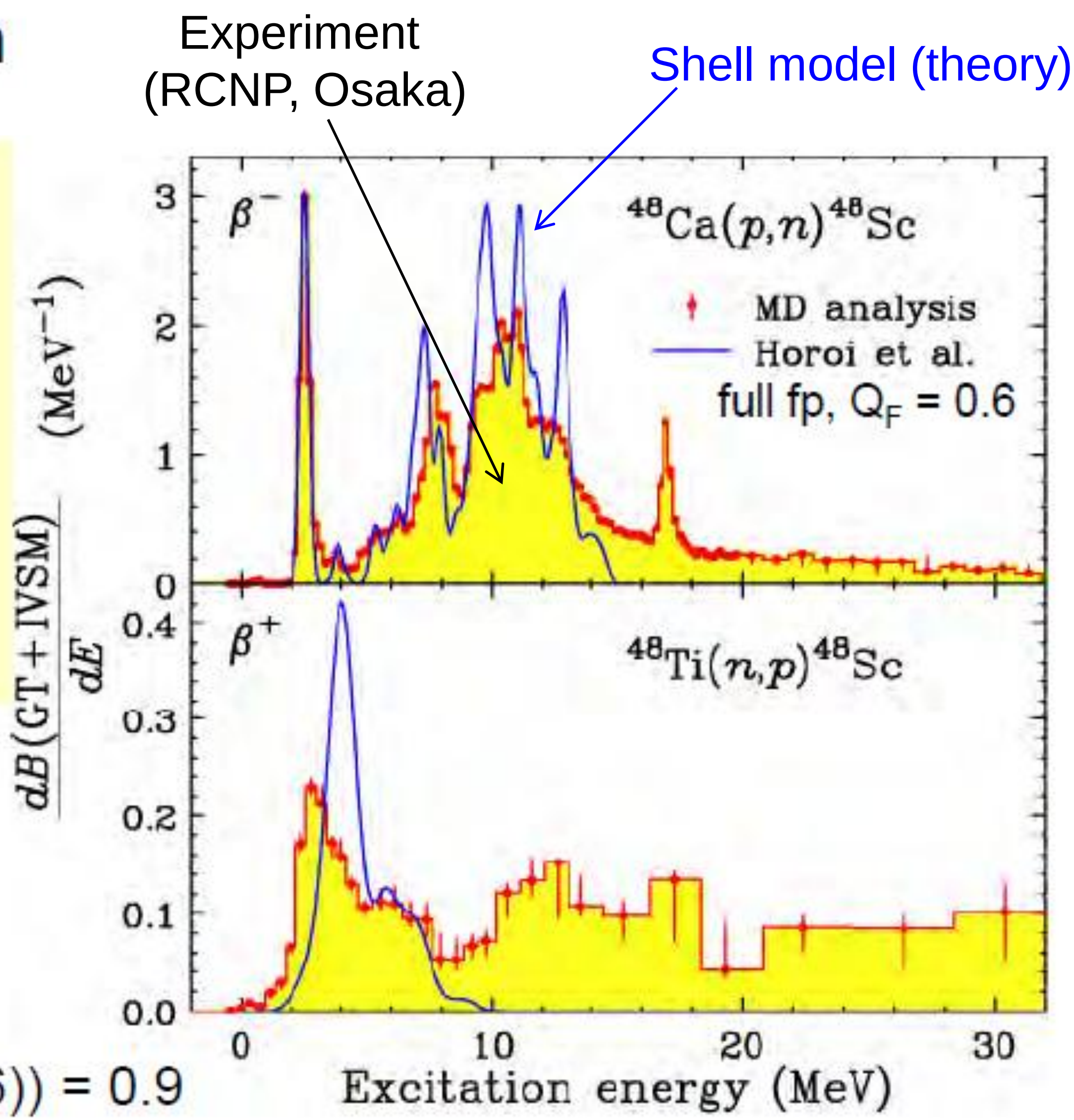
(n,p) channel :

ΣB(GT$^+$;exp) = 1.9±0.3…

(w subtraction of IVSM)

⬍

ΣB(GT$^+$;ShellModel(Q_F=0.6)) = 0.9



Nuclear Astrophysics Programs of Photon- & Lepton-Induced and Charge-Exchange Reactions for the Studies of Element Genesis

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

↓

Probe any Energy on wide N-Z (Isospin)

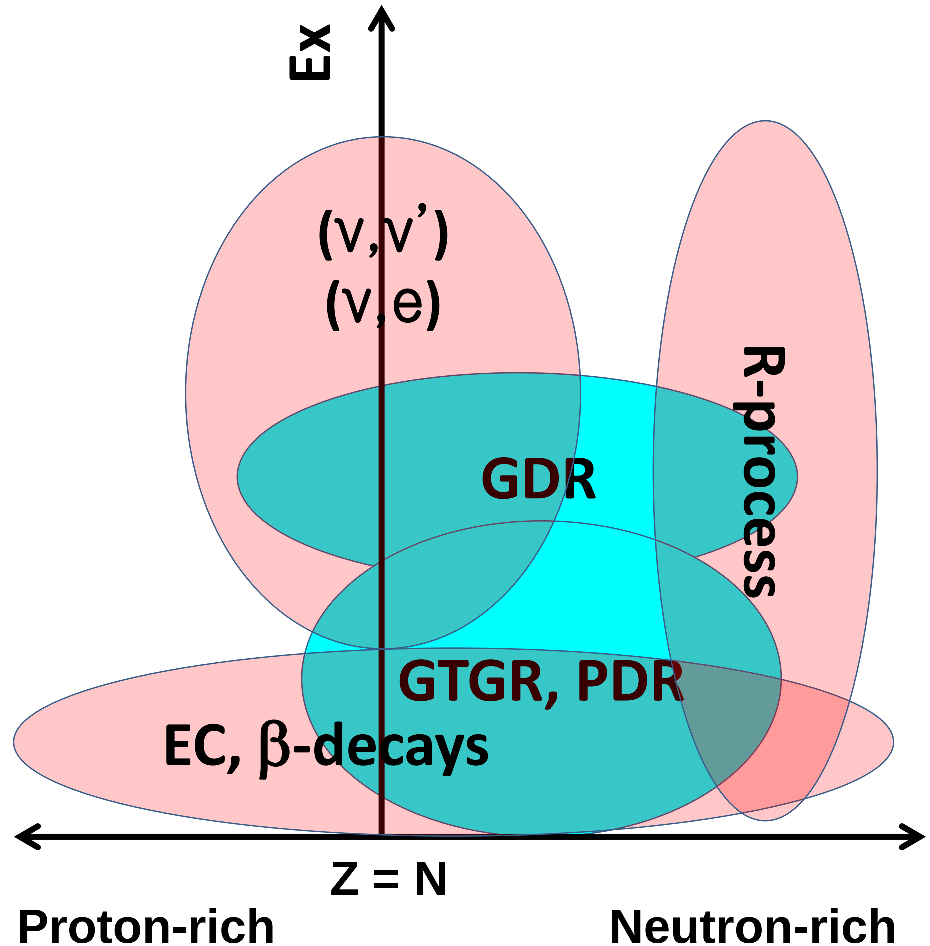
↓

Understanding of nuclear weak response in astrophysical processes

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

→ **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

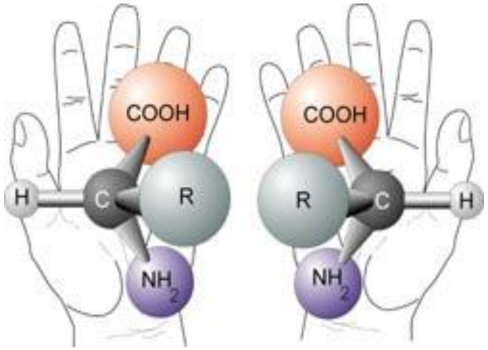


Sasano @ Uesaka Spin-Isospin Labo., RIKEN


SUZAKU Xγ-ray
Sattelite
ISAS
RIBF
RIKEN
Subaru NAO
Super
Kamiokande
ICRR, UT
Spring-8
NewSUBARU
New Subaru
RCNP
Osaka
J-PARC
J-PARC
Linac
3 GeV
Neutrino
Materials and Life
Science Facility
KEK-JAEA
Hadron Exp. Facility

All Amino Acids on the Earth, left-handed — Why?

Chitrality, Earth/Solar origin or Universal?

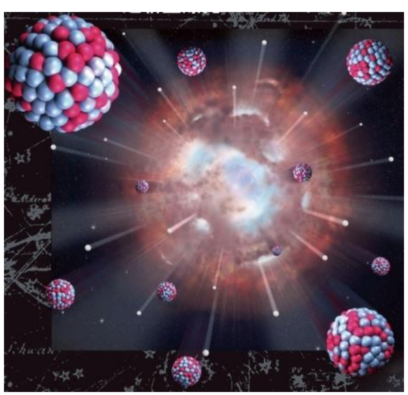


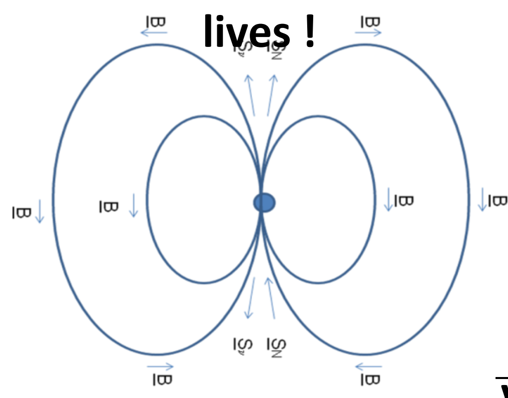
- ★ **Neutrinos are all left-handed!**
- ★ **Supernovae with strongly magnetized neutron star or BH emit intensive flux of neutrinos over 10^{10} yrs!**
- ★ **SN ejecta including ^{14}N interact with neutrino under strong magnetic field!**
- ★ **Neutrino-^{14}N coupling is asymmetric & chiral selective!**

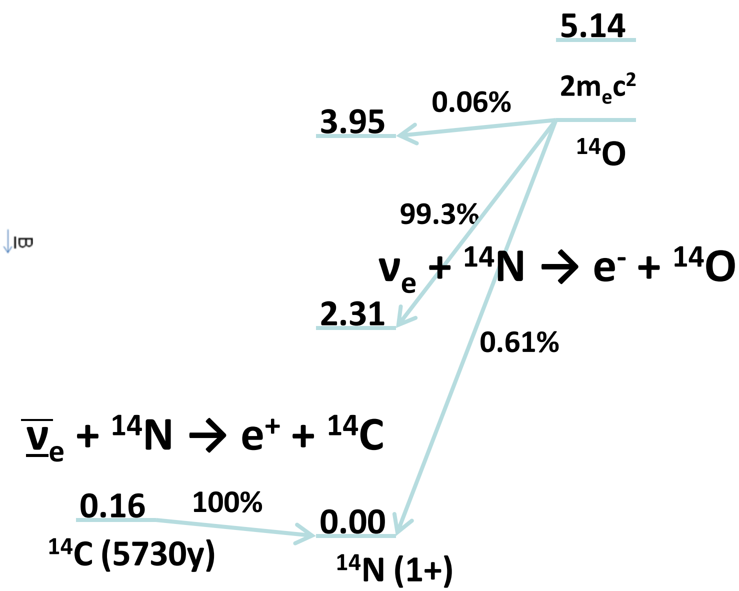
Boyd, Kajino, & Onaka (Astrobiology 10 (2010), 561-568)

L-handed chirality is UNIVERSAL !

Magnetized supernova



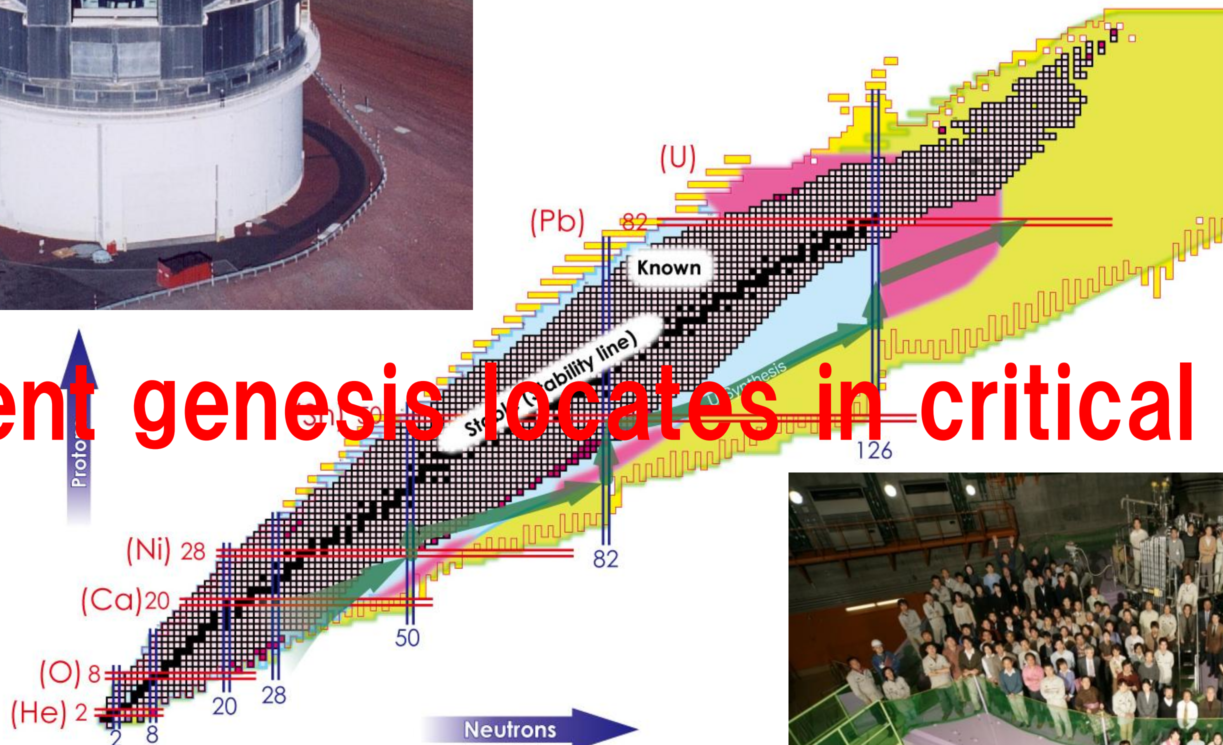




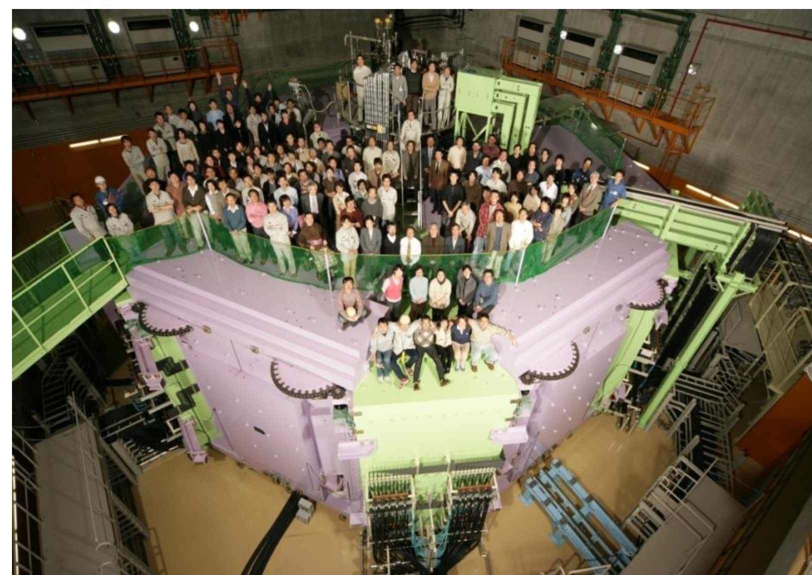
Mann and Primakoff (Origins of Life, 11 (1981), 255) suggested β-decay of 14C, but it's too SLOW!

Macro-Science

Astronomy & Astrophysics



Element genesis locates in critical position!



Micro-Science

Nuclear & Particle (ν) Physics