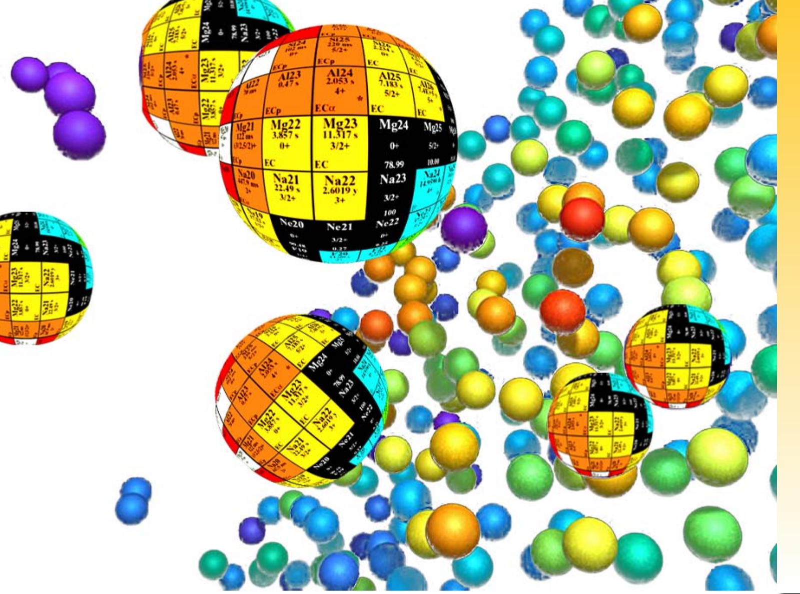
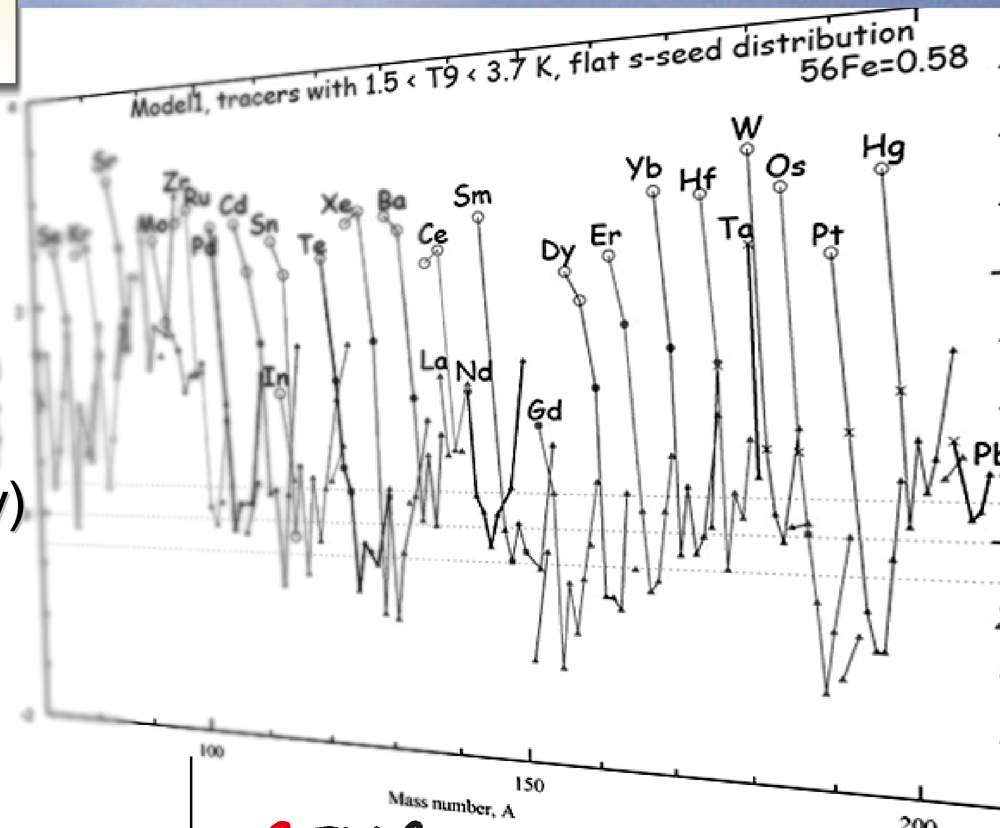


p-process in SNIa: new perspectives

The 6th European Summer School on Experimental Nuclear Astrophysics



R. Gallino
University Turin (Italy)
Observatory Teramo-INAF

B2FH Ricerca per l'Astrofisica Nucleare

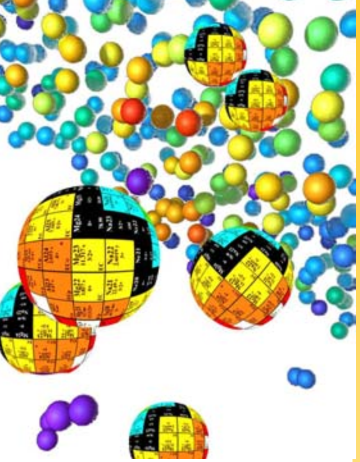
C. Travaglio
Observatory Turin – INAF (Italy)

F. Roepke, W. Hillebrandt
MPA Munich (Germany)

Computer resources

cilea CONSORZIO INTERUNIVERSITARIO CALCOLO ALTE PRESTAZIONI TECNOLOGIE DELL'INFORMAZIONE E DELLA COMUNICAZIONE

B2FH Ricerca per l'Astrofisica Nucleare



The results presented here, have just been published

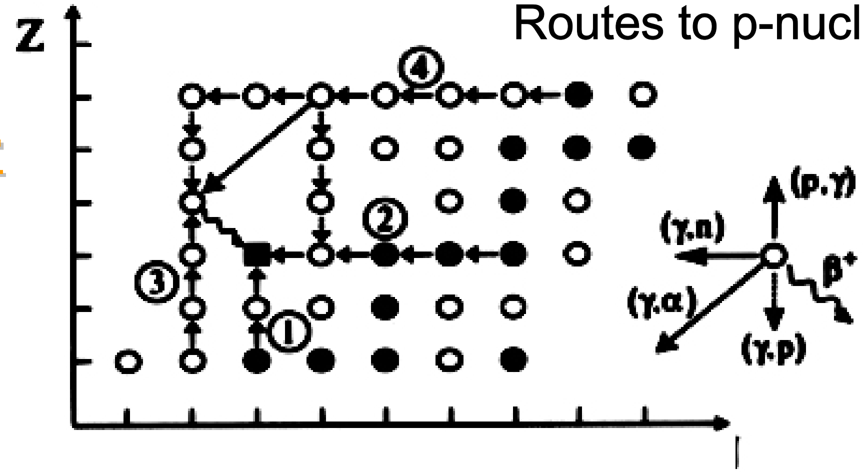
TITLE: Type Ia Supernovae as Sites of p-process: Two-Dimensional Models Coupled to Nucleosynthesis

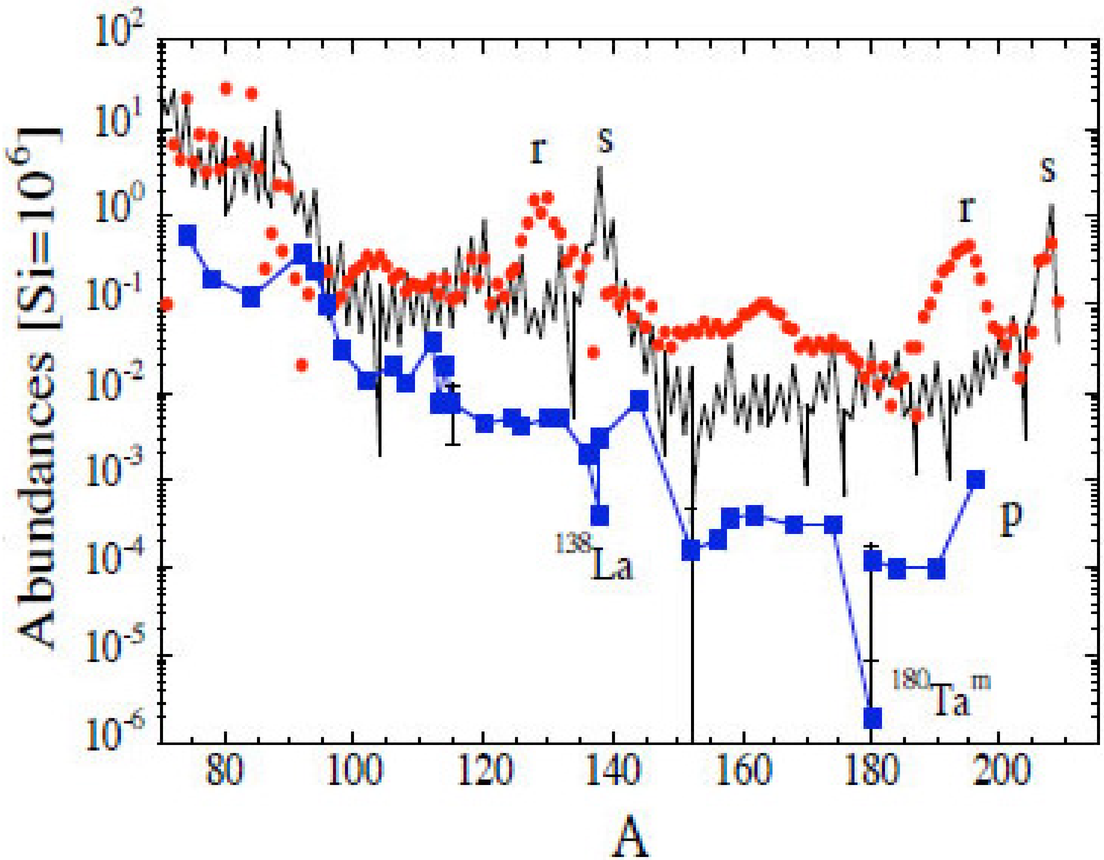
AUTHORS: Travaglio, C., Gallino, R., Roepke, F., Hillebrandt, W.

ApJ, 739, 93

Production channels of p-nuclei. Are there 35 p-nuclei ?

Routes to p-nuclei

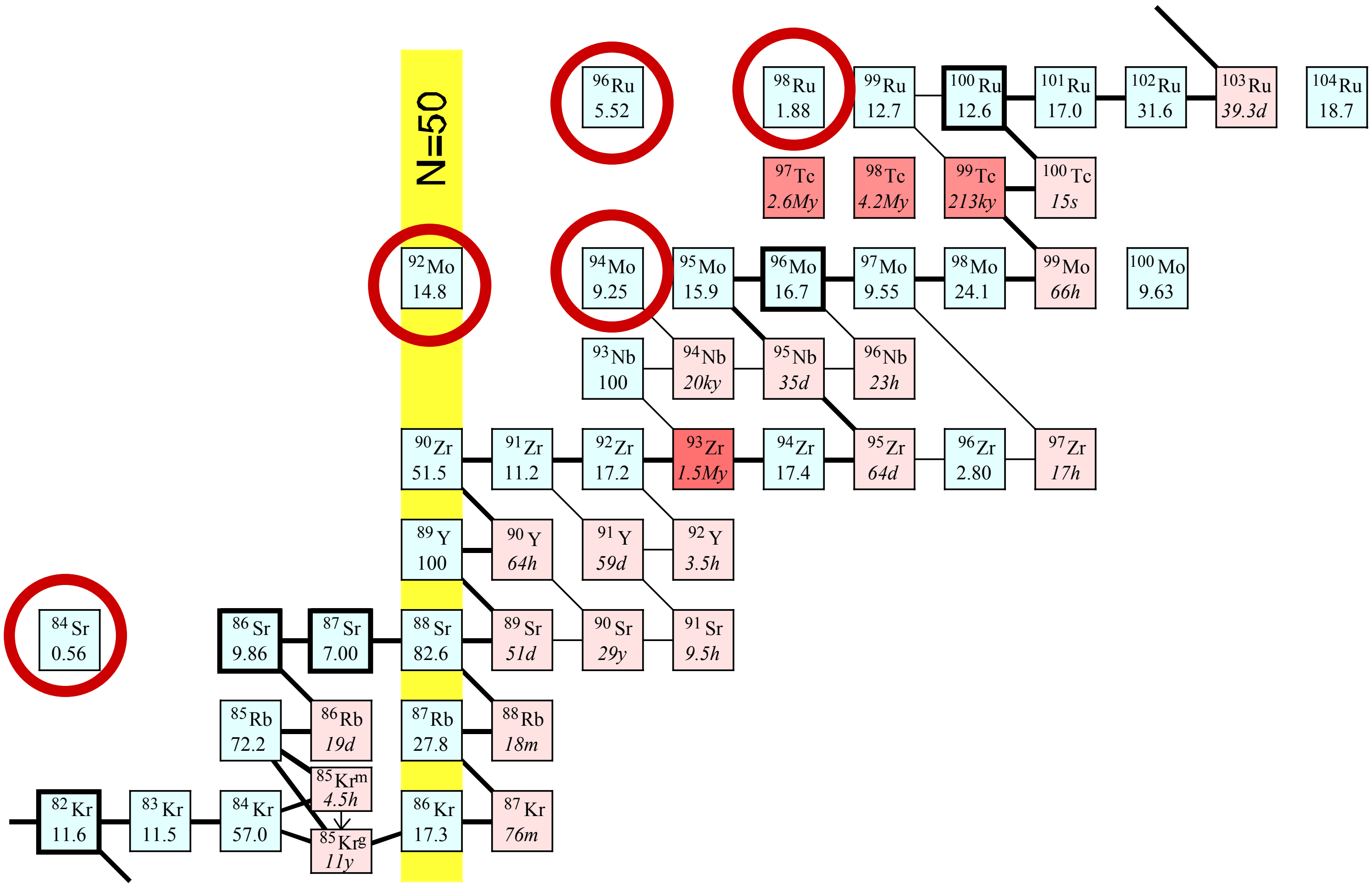


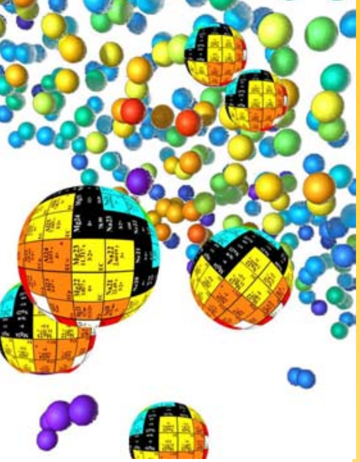


p-nuclei in the Solar System

^{164}Er missing

P-only nuclei in the region Sr to Ru.
They are indicated with a red circle



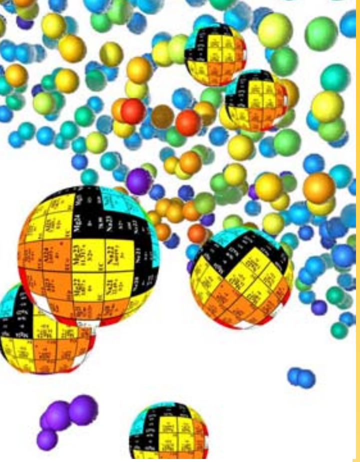


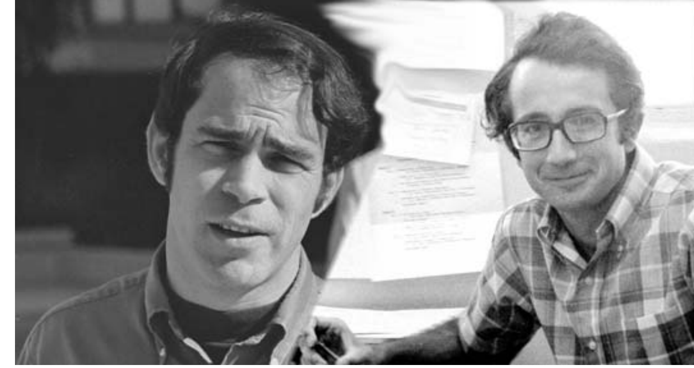
B^{2}FH RMP 29, 547 (1957)

+Cameron A.G.W.
Pasp, 69, 201 (1957)

H-rich layers of SNII
(p,γ) and (γ,n) reactions operating on preexisting *s*- and *r*-seed nuclei
Because of the dominant role of played by proton reactions, named these 'p-process' nuclei
They suggested temperature of about 2.5 10^9 K, and timescale of 10-100 s

(Cameron called them '*excluded isotopes*')





Audouze & Truran

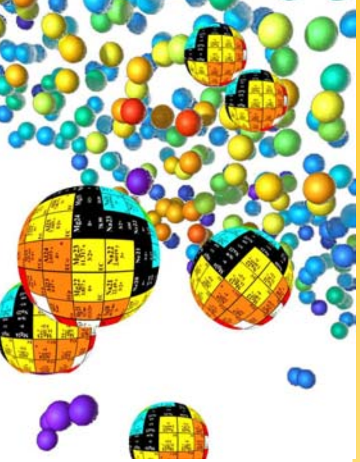
ApJ 202, 204 (1975)

T and ρ optimum conditions for the synthesis of p-nuclei in SNII explosions: 1-2 10^9 K

H-rich matter in postshock supernova envelope following the passage of the shock wave, and realized that required T are not acquired there

Another possible site, novae associated with binary systems. In the accreted material T and ρ optimum conditions can be reached.

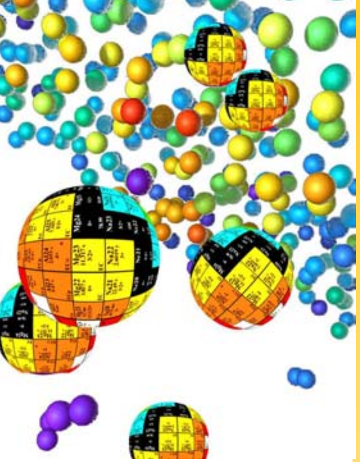
s-process enhancement is needed, but not sufficient in SN II.



Arnould (1976)

Synthesis of p-nuclei during hydrostatic oxygen burning

A large enhancement of heavy elements, presumably by prior *s*-processing is required. Only *s*-seed nuclei should be enhanced and not *r*-process seeds (recognized to be not important seeds).



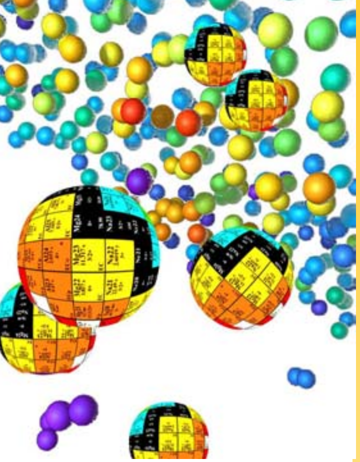
Woosley & Howard ApJS 36, 285 (1978)

They found that the (p,g) chain may require physical conditions that cannot be easily realized in nature.

Alternately, they proposed a “gamma-process”. A distribution of heavy elements subjected to a ‘hot photon bath’ ((g,n), (g,p), (g,a)) will be transformed on a timescale of 1s into a distribution close to the solar distribution of p-nuclei.

Tempertaure optimum conditions for the synthesis of p-nuclei in explosive events:

2 to 3.2 10^9 K



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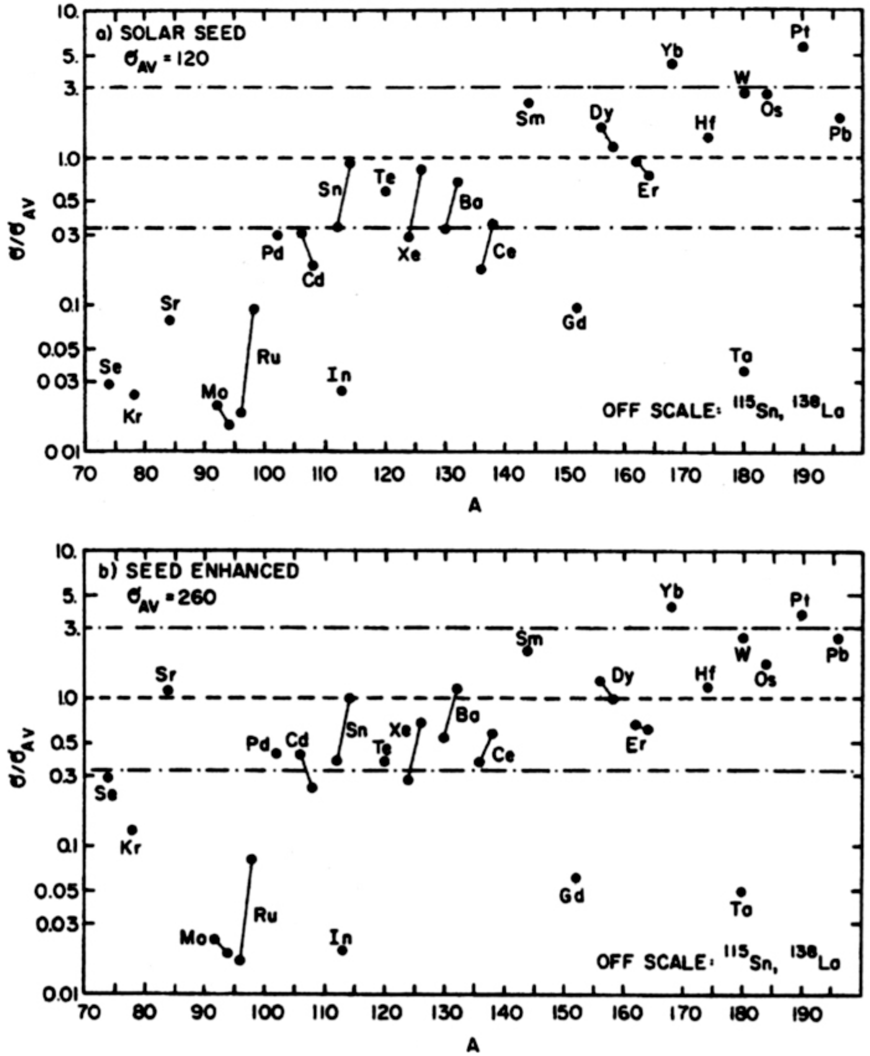
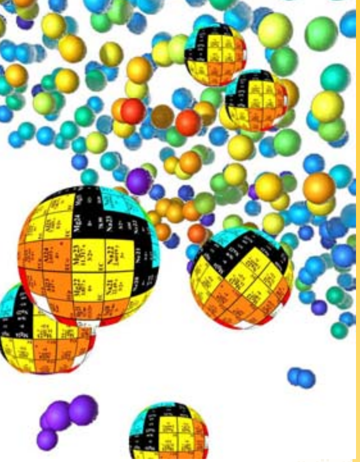
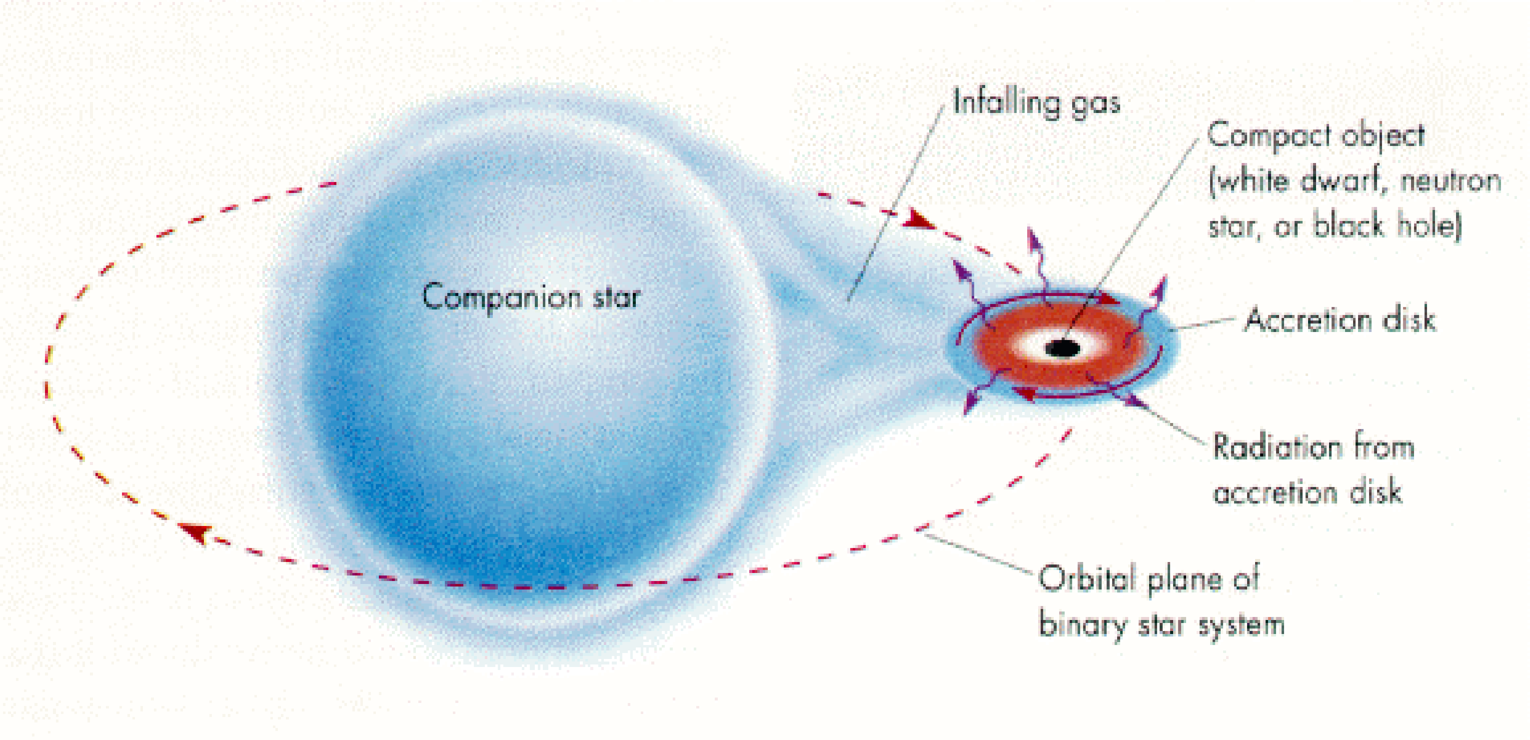
Woosley & Howard ApJS 36, 285 (1978)



“One must still contend with disappointingly small synthesis of species like 92Mo, 94Mo, 96Ru, 98Ru”



p-nuclei in SNIa



"Accreting white dwarfs as an alternate or additional source of s-process isotopes" (Iben, ApJ 243, 1981)

Howard, Meyer & Woosley

ApJ, 373, L5 (1991)

A new site for the gamma-process:

Type Ia supernovae.

(A CO-WD exploding by deflagration or detonation)

They investigated chains to produce the light-p, and found that

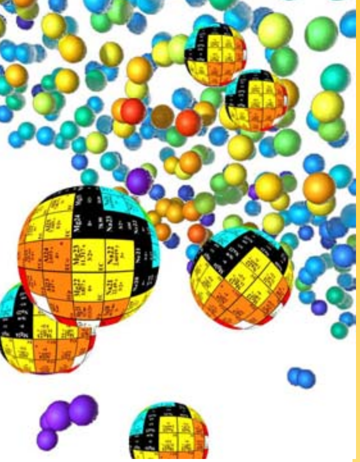
^{86}Kr(p,γ) … ^{90}Zr(p,γ)^{91}Nb(p,γ)^{92}Mo

is responsible for half of ^{92}Mo (and important for ^{90}Zr as well) and (p,γ) reactions produce also ^{96}Ru. The other half of ^{92}Mo, and ^{94}Mo, come from (γ,n) reaction sequence

+Howard & Meyer (Proceed. Nuclei in the Cosmos 1992, Eds. F. Kaeppeler and K. Wisshak, IOP 1993, p. 575-580

Used s-process seeds enhanced by a factor 6,000

Still small synthesis of 92Mo, 94Mo, 96Ru, 98Ru



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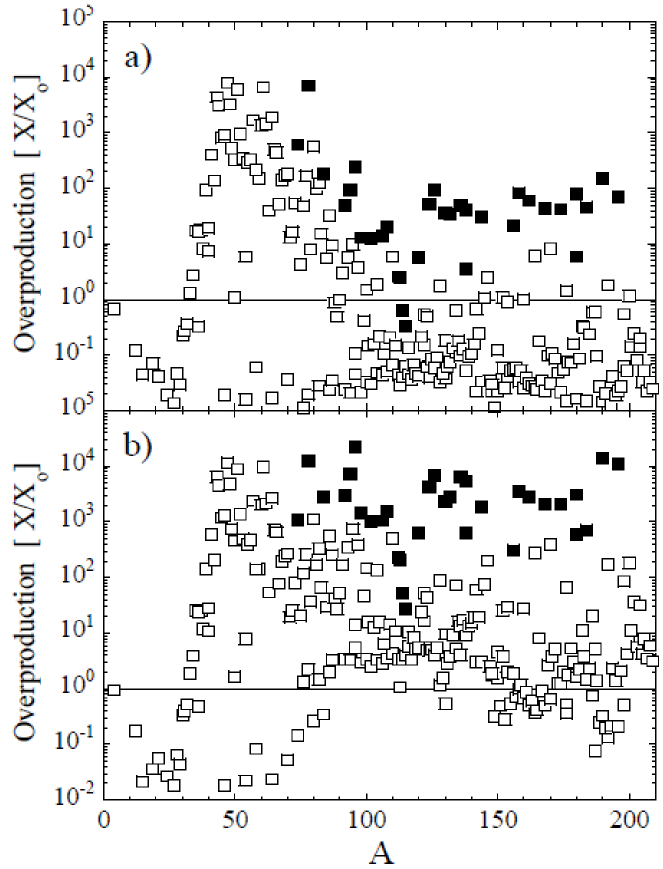
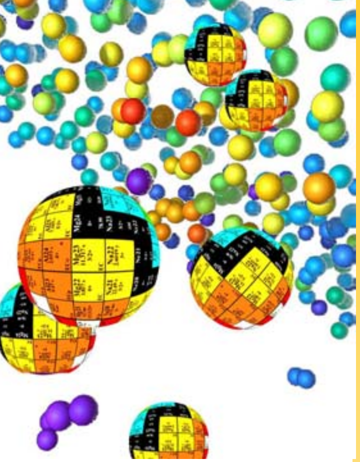
Goriely et al. (A&A 2002; A&A 2005)

He accreting WD with sub-Chandrasekhar mass
p-process are produced in the accreting He-layers
Using a solar system initial abundance, they found that most of the p-nuclei are underproduced (except ^{78}Kr) with respect to Fe (panel a).

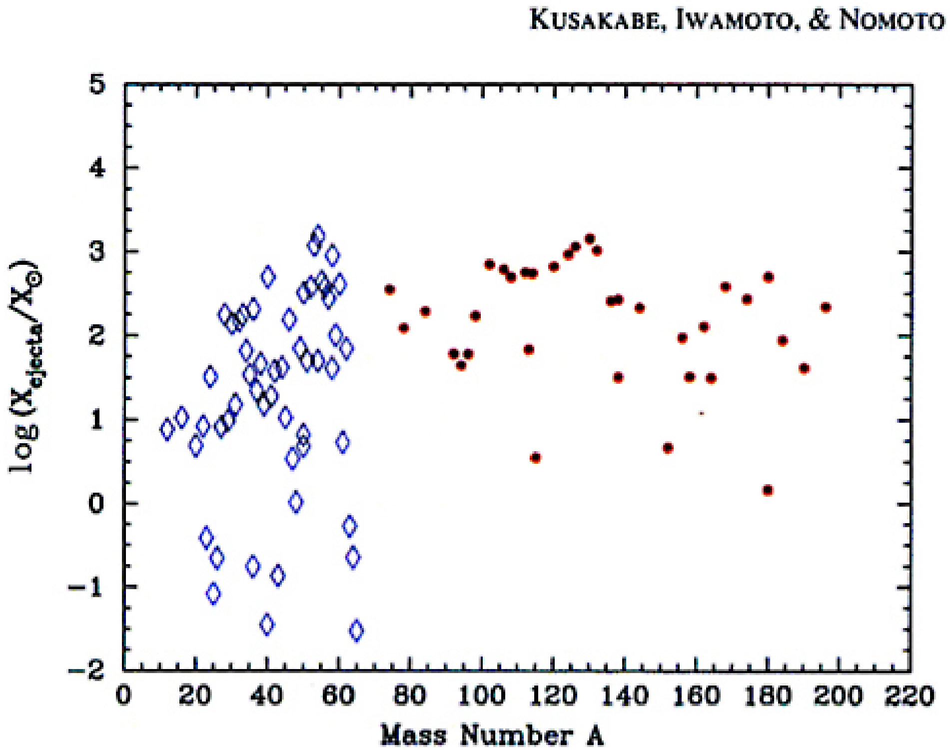
Then they tested an initial s-seed enhancement of 100xsolar (panel b)



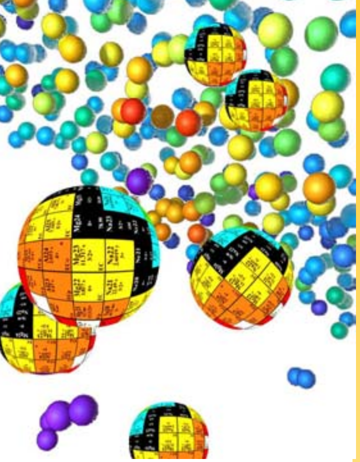


Kusakabe, Iwamoto & Nomoto ApJ, 727,10(2011)

- They used as SNIa model the W7 (Nomoto et al.'84), pure deflagration
- They also examine the impact of different s-seed distributions



Results obtained using s-seeds enhanced by a factor 6,000



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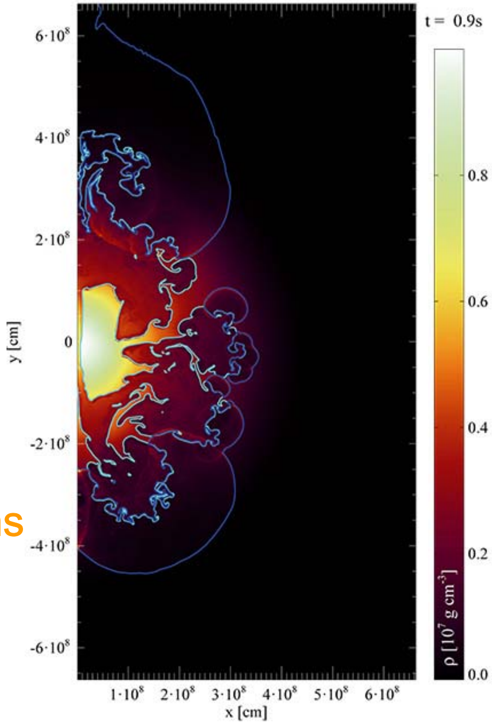
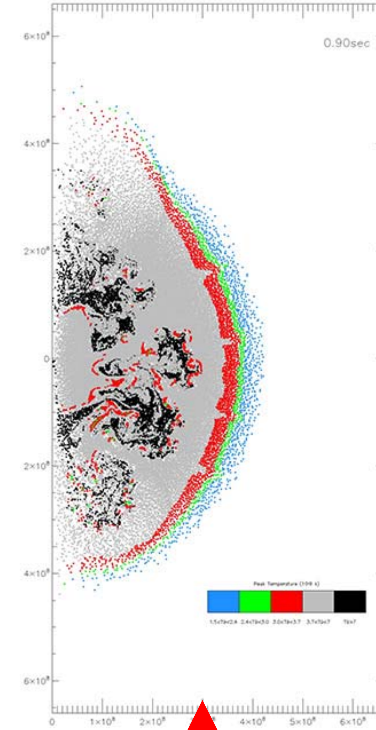
Travaglio et al.

(2011,ApJ 739, 93)

F. Roepke & W.Hillebtandt

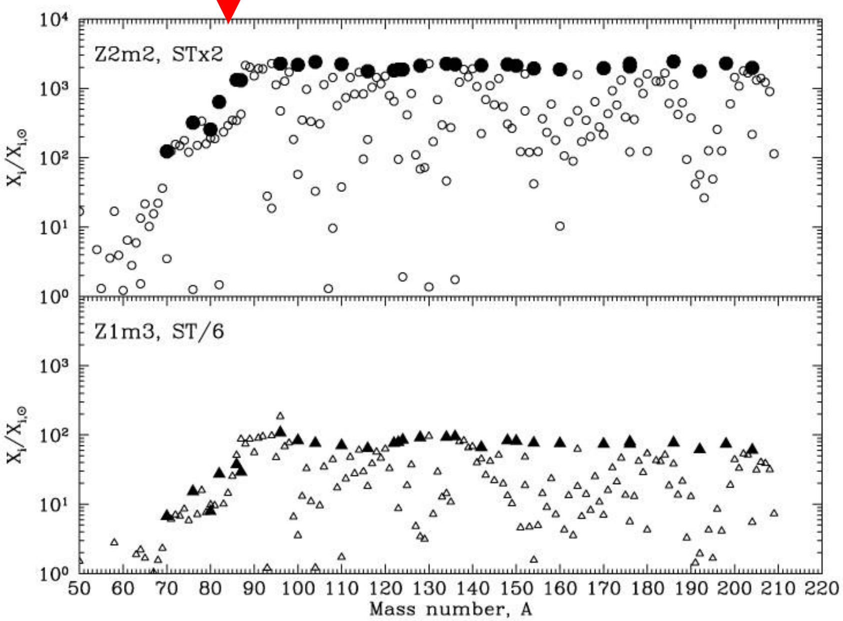
SNIa models





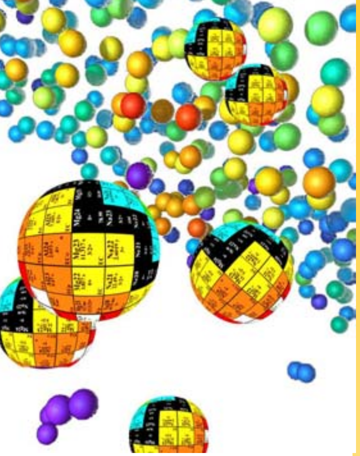
R. Gallino s-process calculations

Flat s-seeds enhancement (production factor 2,000 upper panel)



C. Travaglio

p-process nucleosynthesis

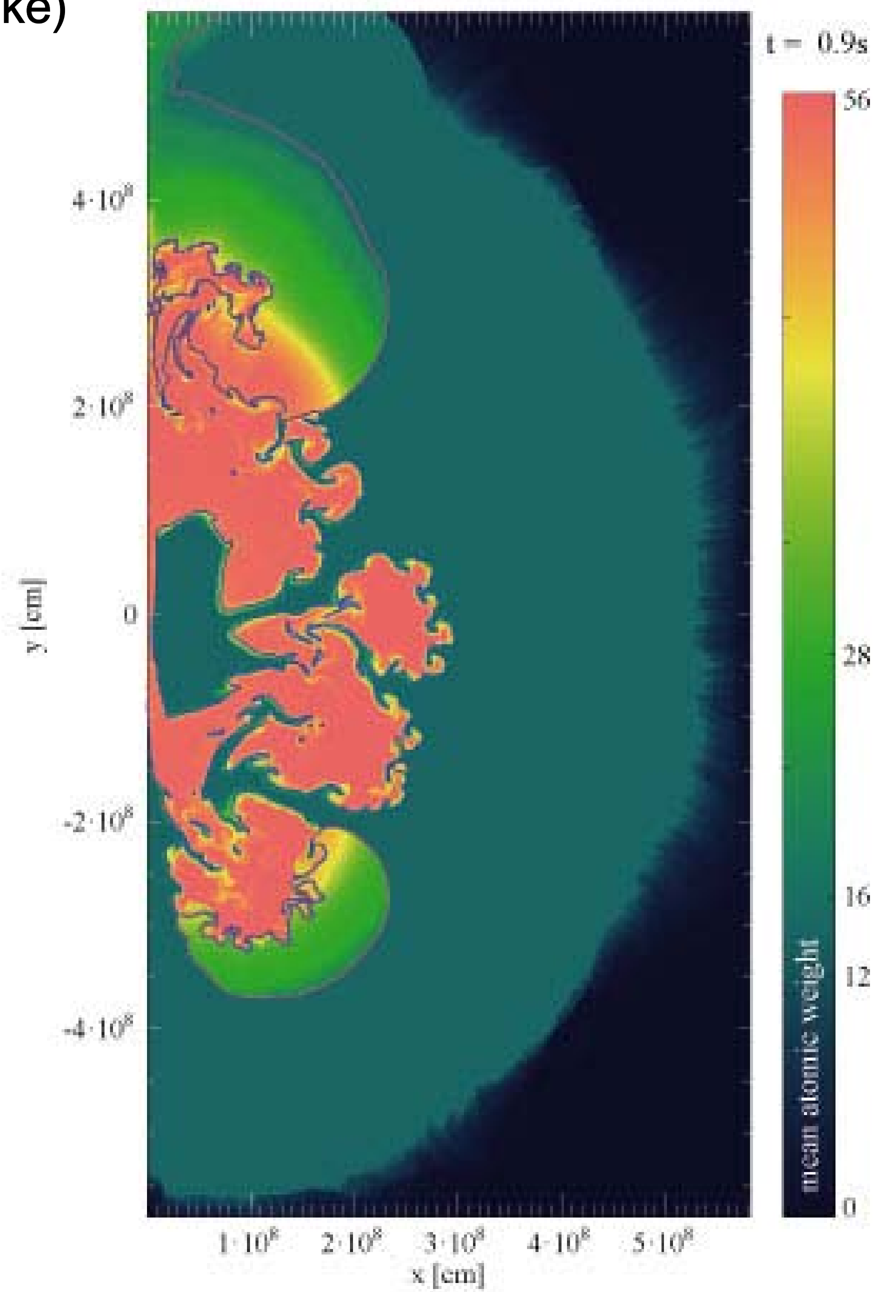


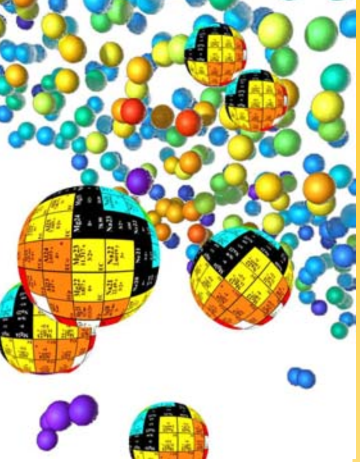
Type Ia models: 2D

(simulation done by F. Roepke)

We tested different SNIa models:

- pure deflagration
- delayed detonation with different strenghts

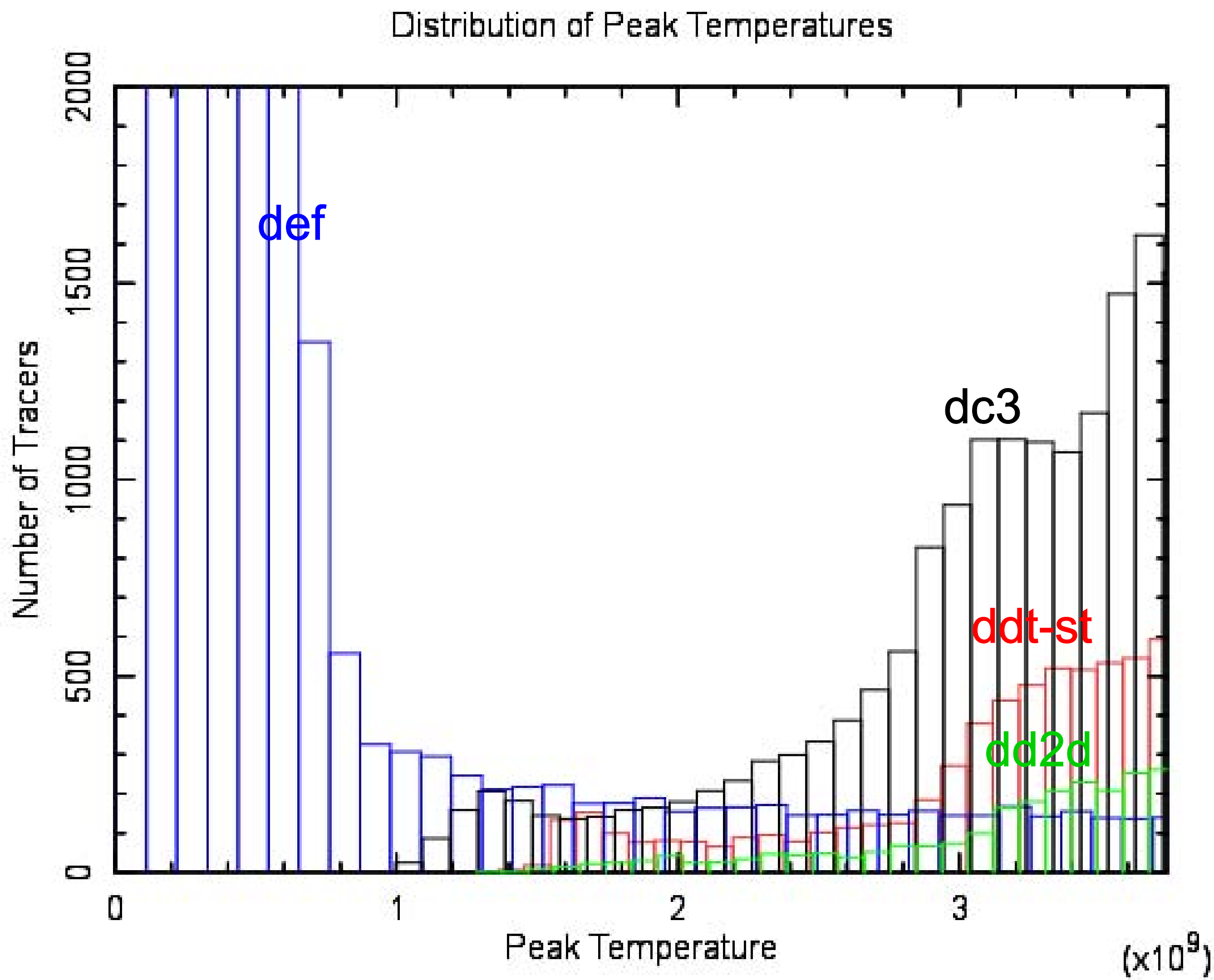




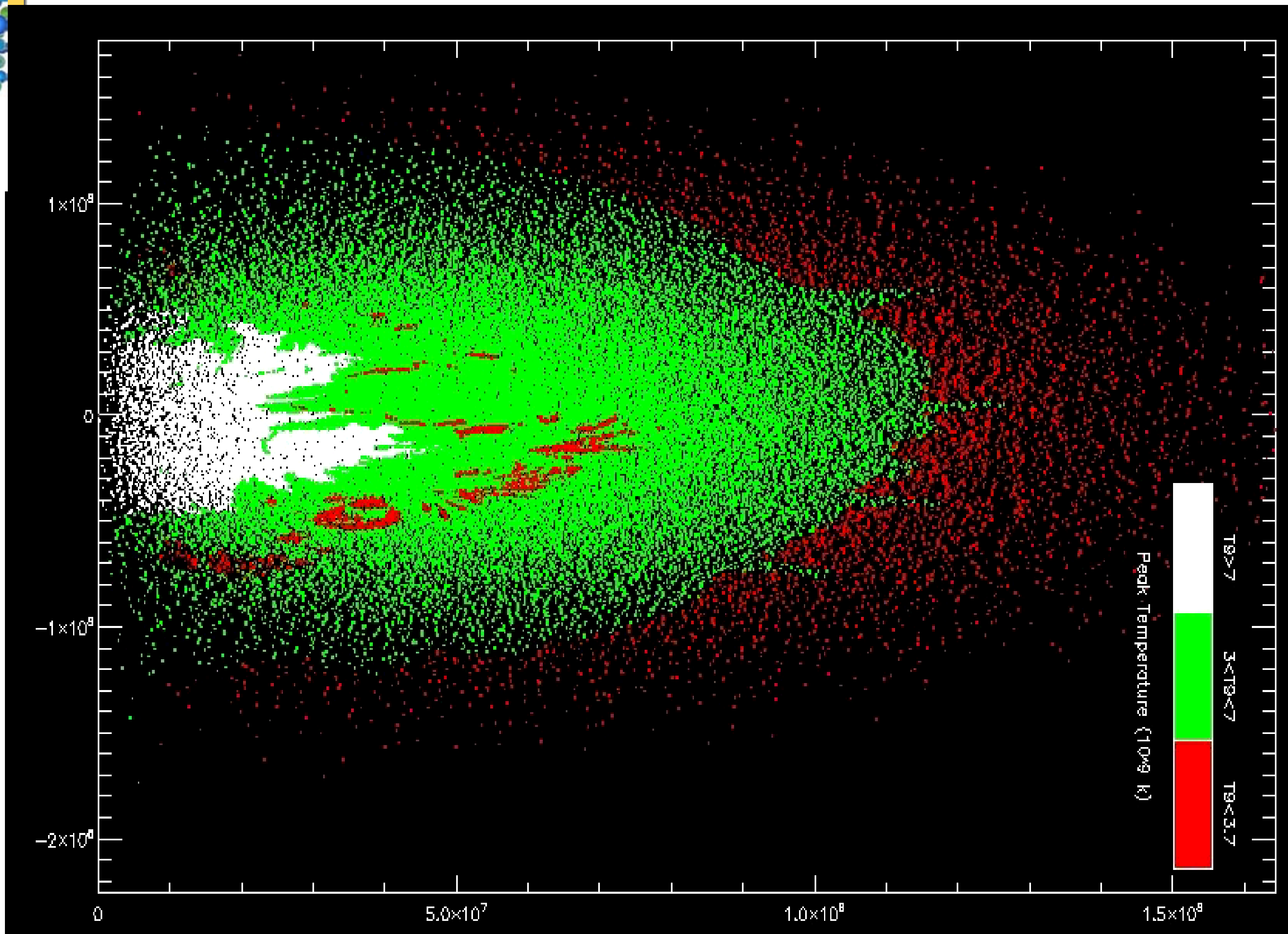
Distribution of tracers

def = deflagration
ddt-st = standard del. det.

dc3 = weaker del. det.
dd2d = stronger del. det.



Tracer particles in SNIa models



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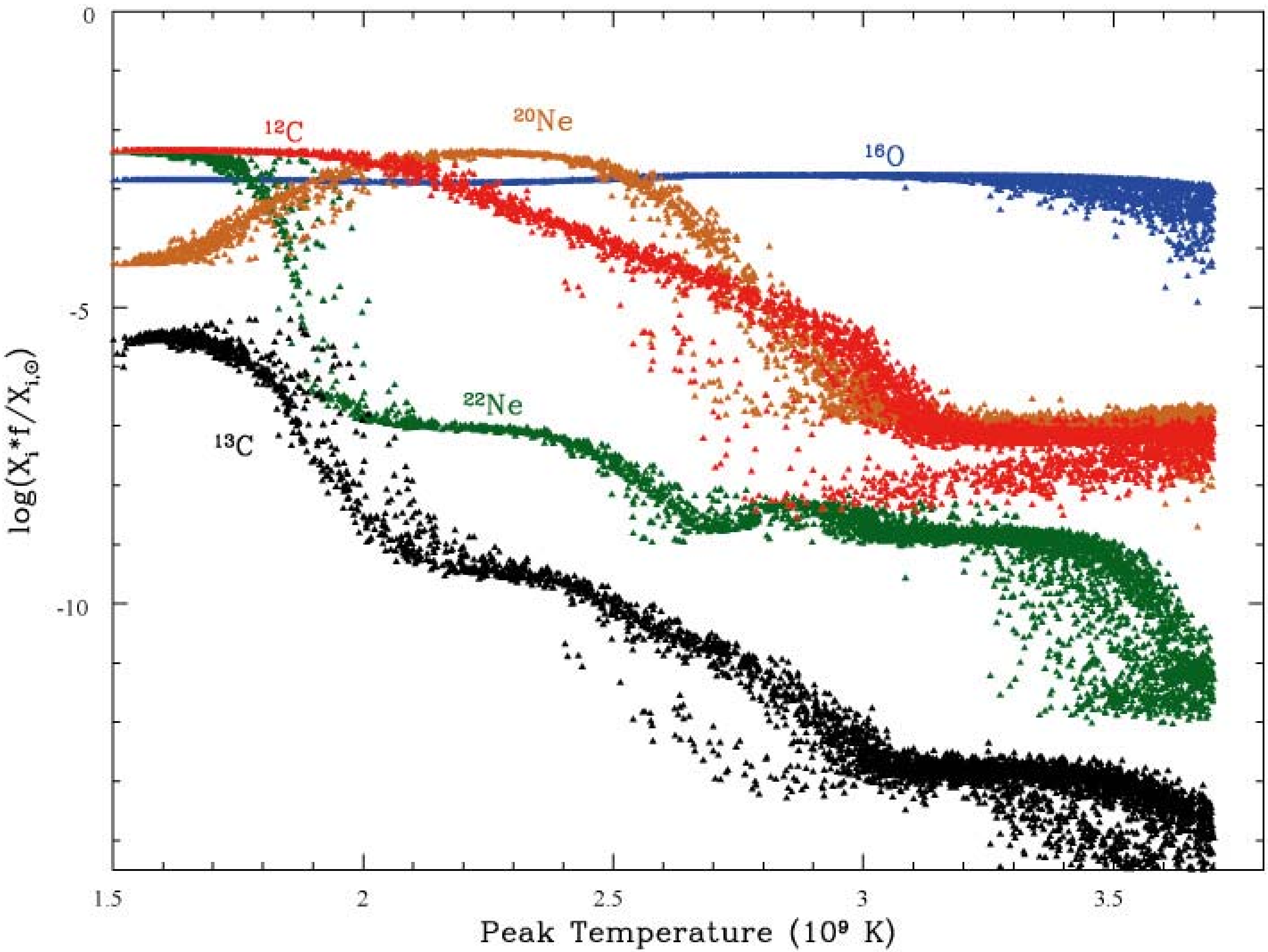
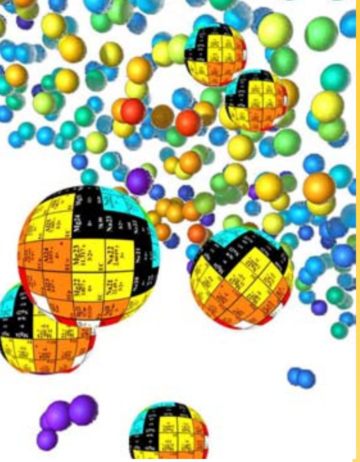
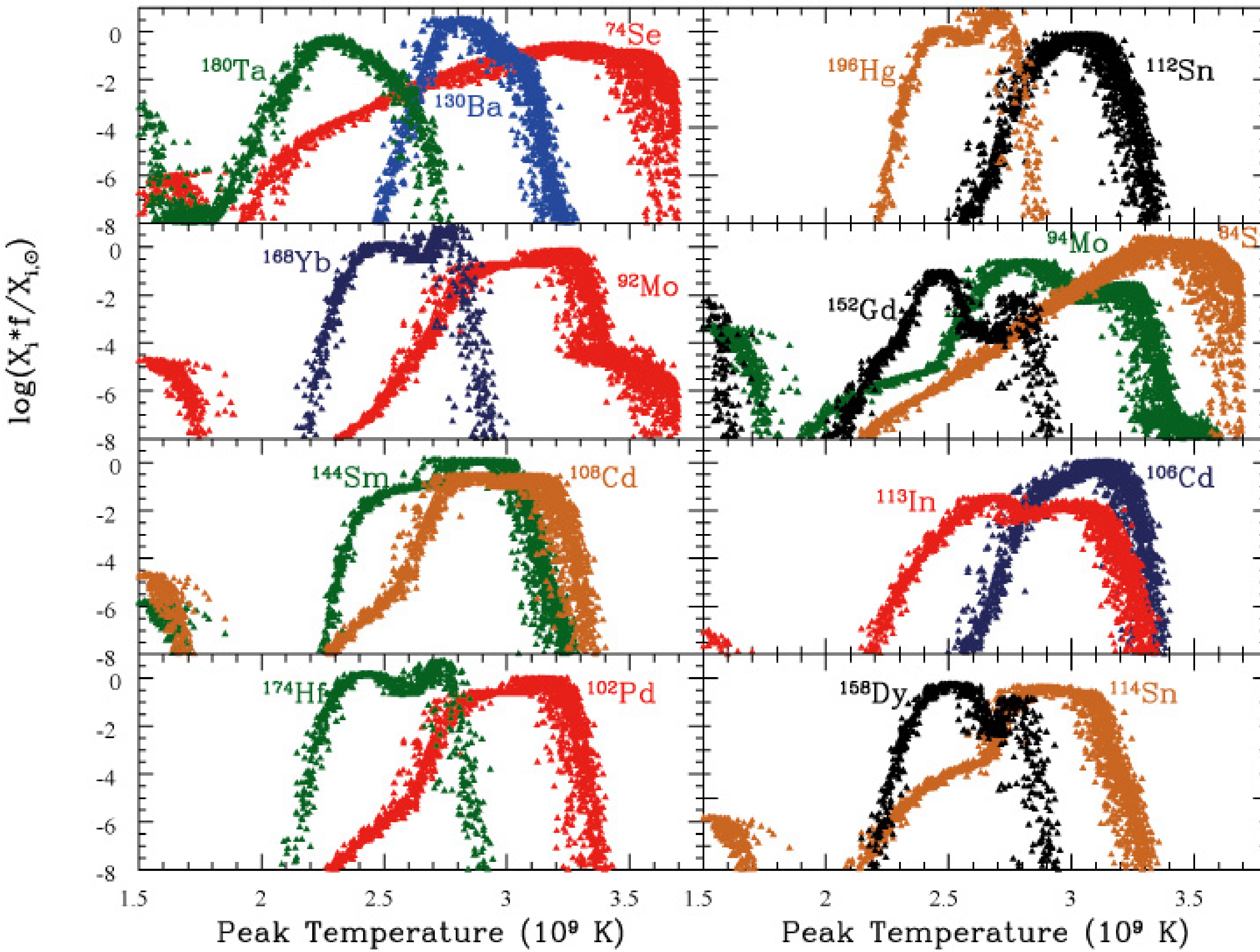
SNIa
Major burning in outer regions

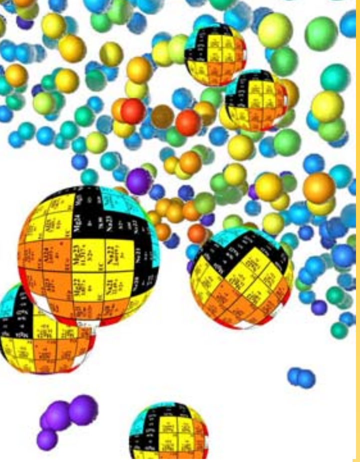


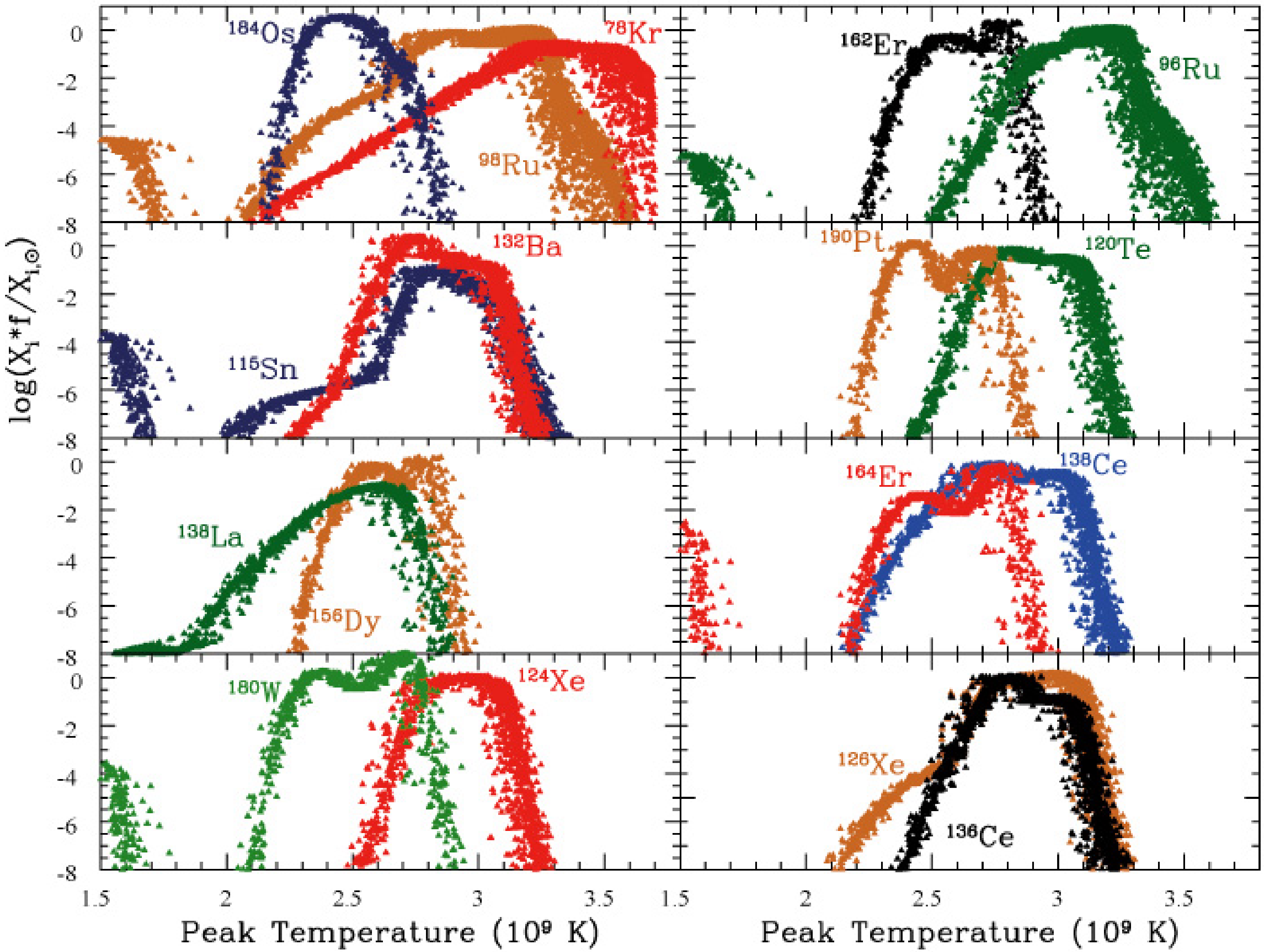


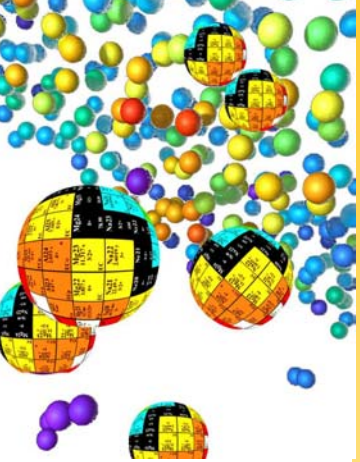
p-nuclei versus peak T (1)



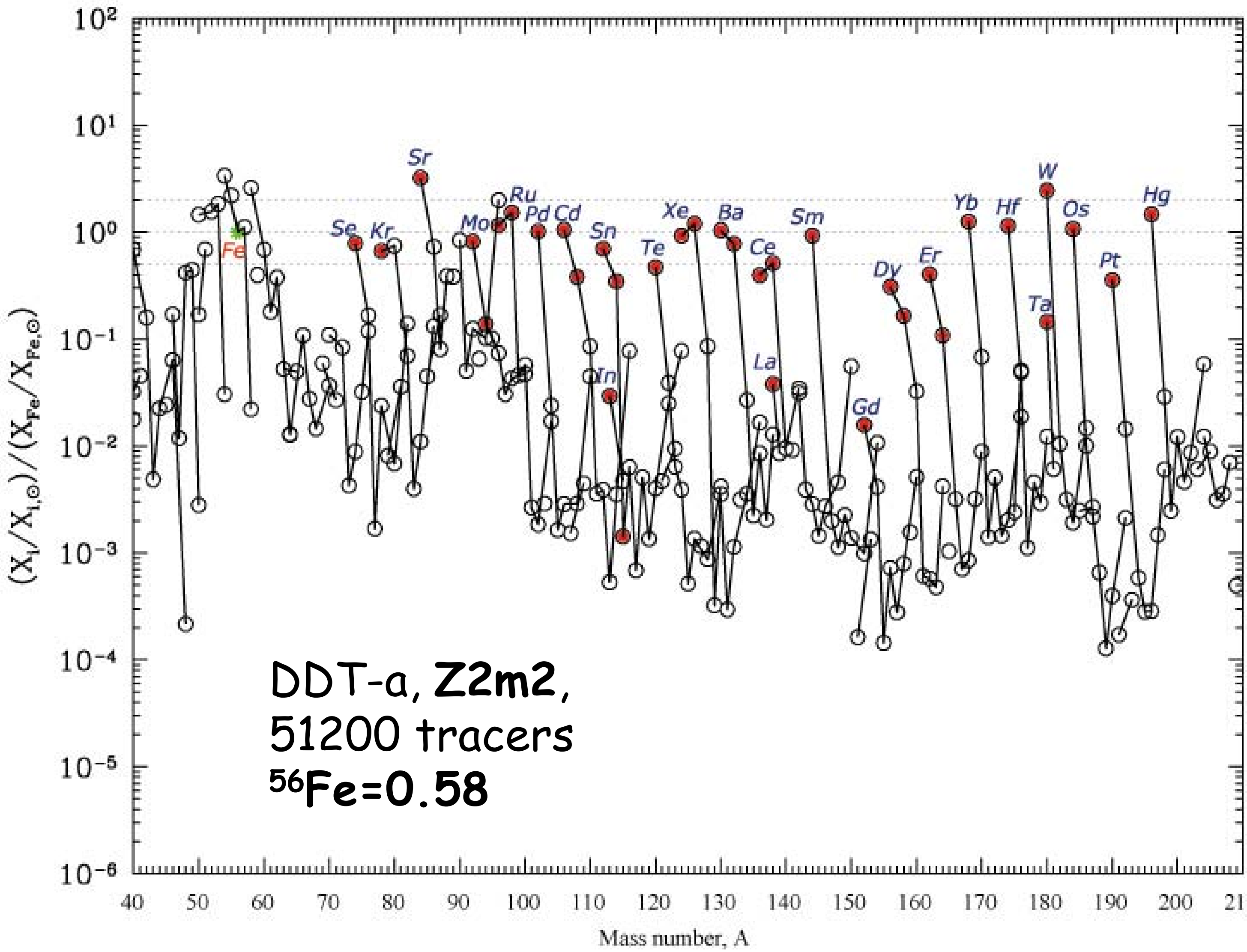
p-nuclei versus peak T (2)





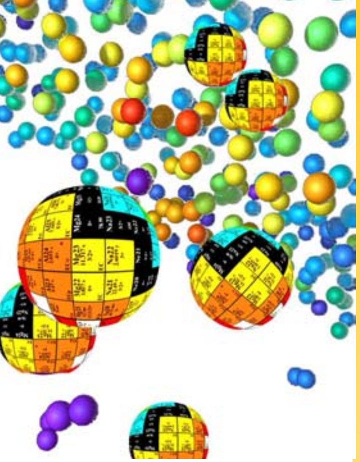


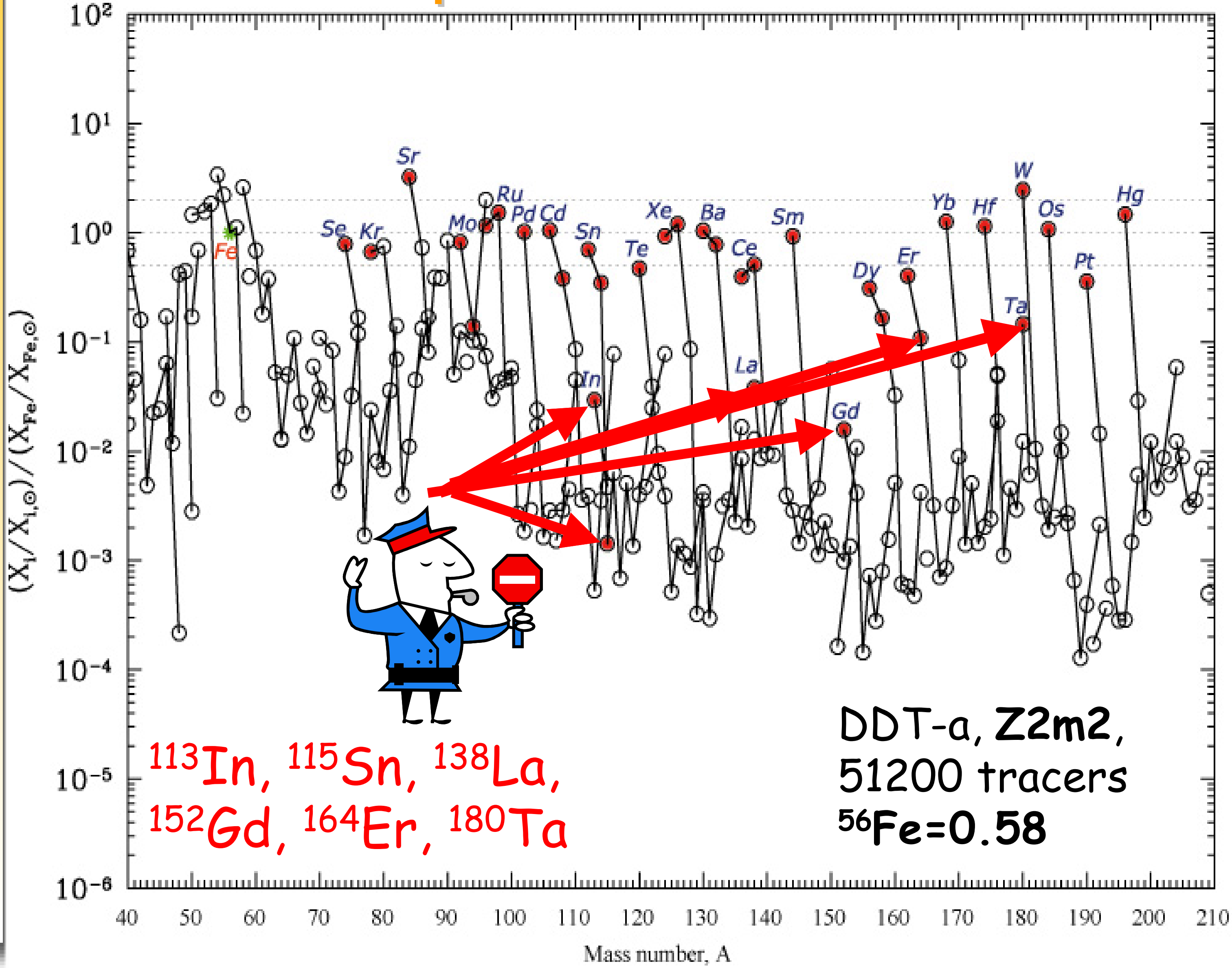
Results: solar metallicity



Looking deeper into p-nuclei

29 p nuclei !





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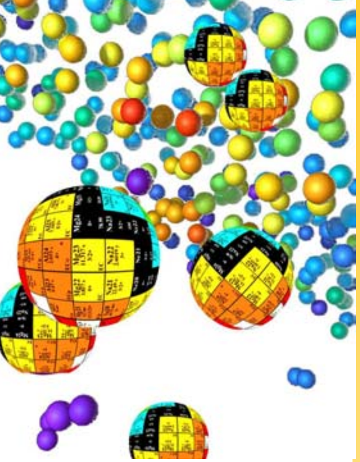


Looking deeper into p-nuclei

^{113}In, ^{115}Sn are p-only isotopes?

r-process contribution *(Dillmann et al. 2008, Nemeth et al. 1994)?*

^{138}La and ^{180}Ta produced by neutrino-Nuclei interactions (Woosley et al. 1990)

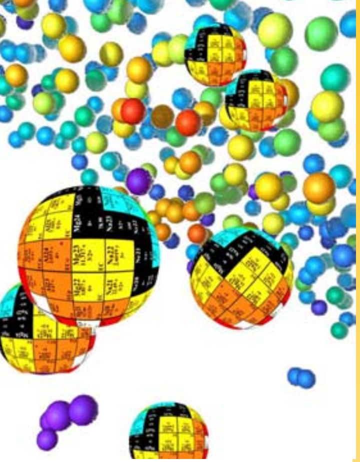
Note: ^{180}Ta

Also produced substantially by the s-process

^{152}Gd large s-process contribution

75% at solar composition, with 11% of errorbar

(Arlandini et al. 1999, Kaeppeler et al. 2011)



Long-lived p-nuclei

(Dauphas et al. 2002)

$^{92}Nb/^{92}Mo$

$2.8 \pm 0.5 \times 10^{-5}$ meteorite

$1.5 \pm 0.6 \times 10^{-3}$ production in SNe

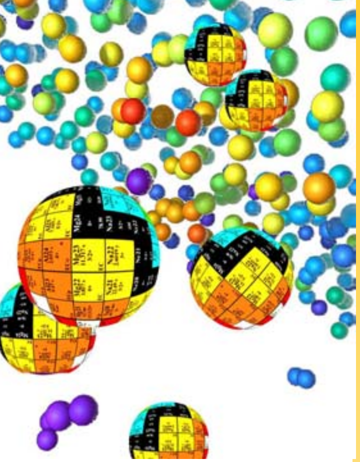
1.3×10^{-3} our model

$^{146}Sm/^{144}Sm$

$7.6 \pm 1.3 \times 10^{-3}$ meteorite

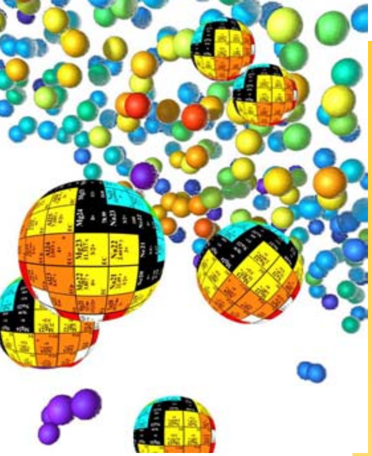
$1.8 \pm 0.6 \times 10^{-1}$ production in SN

3.2×10^{-1} our model



Main channels to the light p-nuclei

Nuclear reaction channel	Produced isotope final abundance contribution
^{91}Zr(γ,n)^{90}Zr	73%
^{91}Nb(γ,p)^{90}Zr	27%
^{99}Ru(γ,n)^{98}Ru	69%
^{99}Rh(γ,p)^{98}Ru	31%
^{75}Se(γ,n)^{74}Se	100%
^{97}Ru(γ,n)^{96}Ru	93%
^{100}Pd(γ,α)^{96}Ru	7%
^{95}Mo(γ,n)^{94}Mo	100%
^{85}Sr(γ,n)^{84}Sr	100%
^{79}Kr(γ,n)^{78}Kr	100%
^{93}Mo(γ,n)^{92}Mo	76%
^{96}Ru(γ,α)^{94}Mo	24%



p-process

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Table 4. s-nuclides with p-contribution

Isotope	% Isotopic abundance (a)	Note	$(X_i/X_{i,\odot})/(^{144}Sm/^{144}Sm_{\odot})$ (b)
^{80}Kr	11.7	1	0.808
^{86}Kr	27.0	2	0.142
^{86}Sr	47.0	1	0.786
^{87}Rb	35.3	2	0.181
^{88}Sr	92.3	2	0.418
^{89}Y	92.0	2	0.412
^{90}Zr	72.2	3	0.905
^{96}Zr	55.0	4	2.142

(a) – Arlandini et al. (1999)

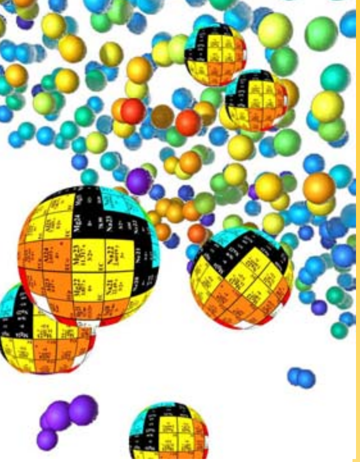
(1) – ^{80}Kr and ^{86}Sr, s-only isotopes. In this work we find an important contribution from p-process.

(2) – ^{86}Kr, ^{87}Rb, ^{88}Sr, and ^{89}Y are relics of the s-process seeds.

(3) – ^{90}Zr is a neutron magic nucleus at $N=50$. In this work we find an important contribution from p-process.

(4) – ^{96}Zr in our SN Ia models gets an important contribution by neutron capture during ^{22}Ne-burning.

(b) – Synthesized mass in DDT-a model normalized to ^{144}Sm. For the results of this column, see Section 6.2.



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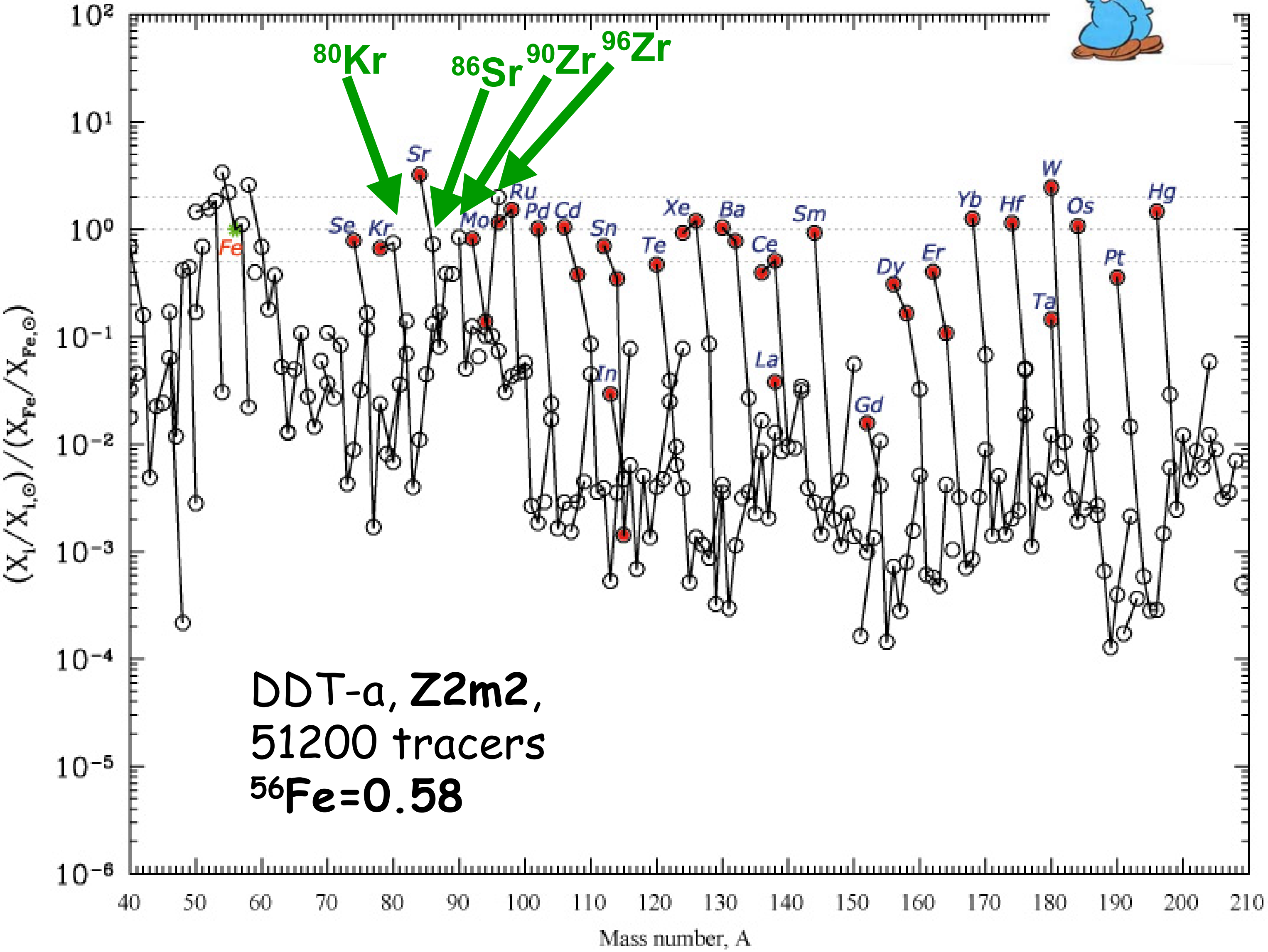
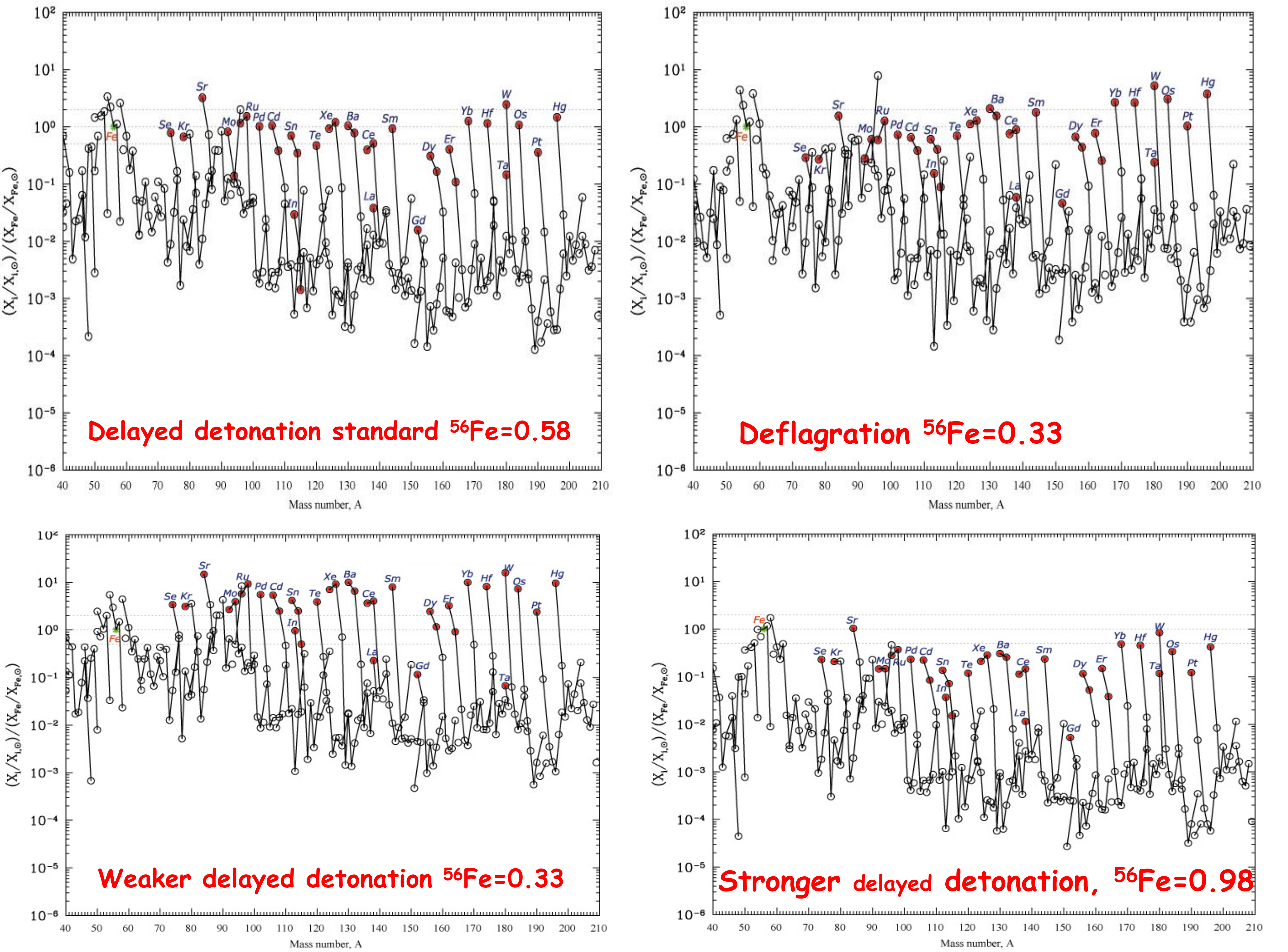
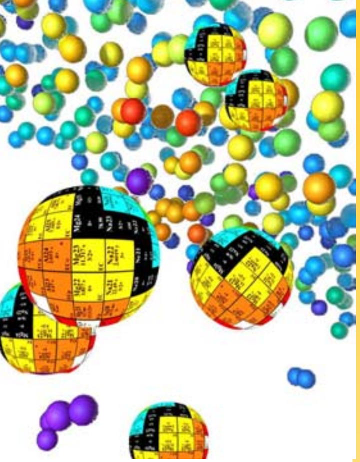
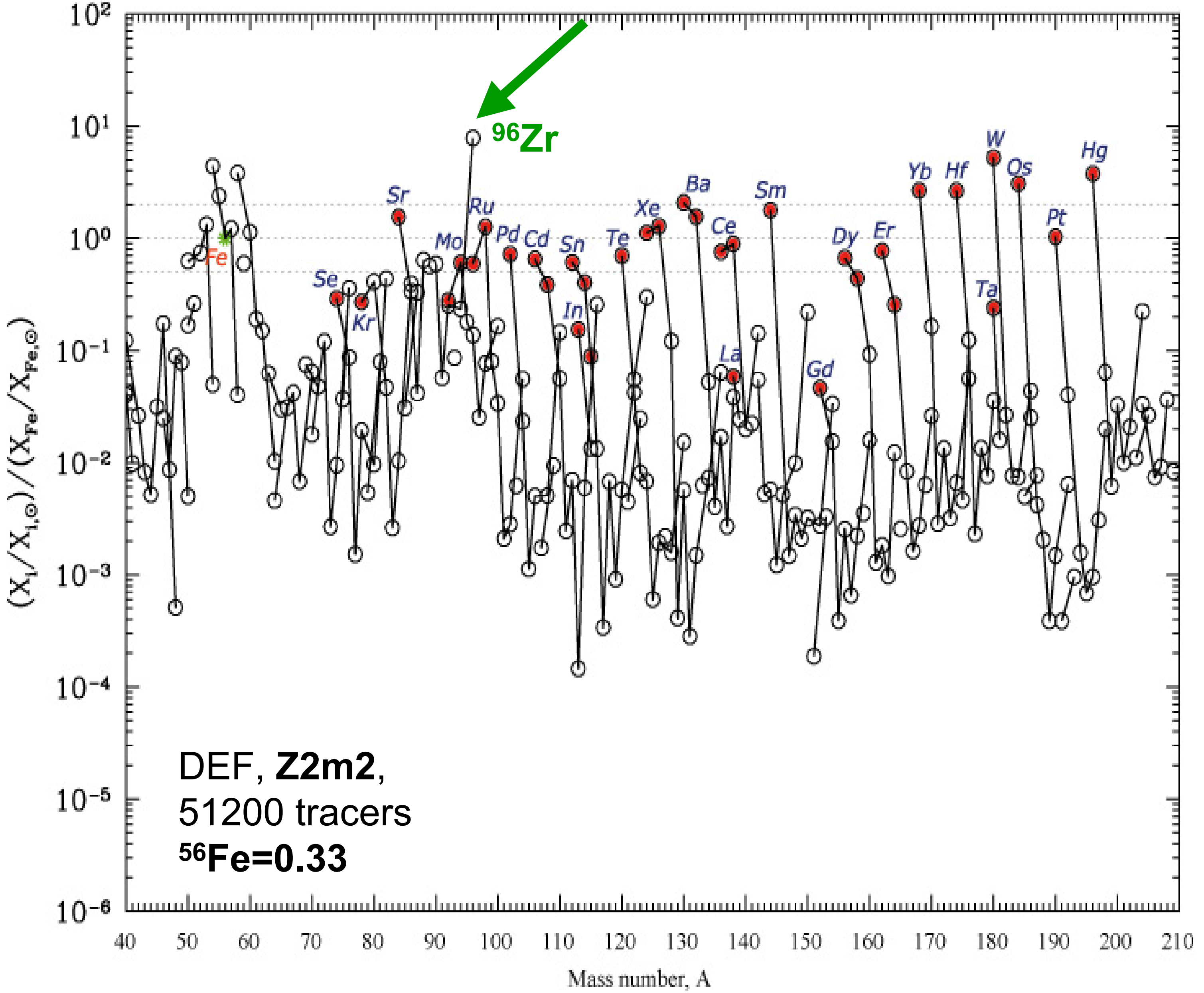




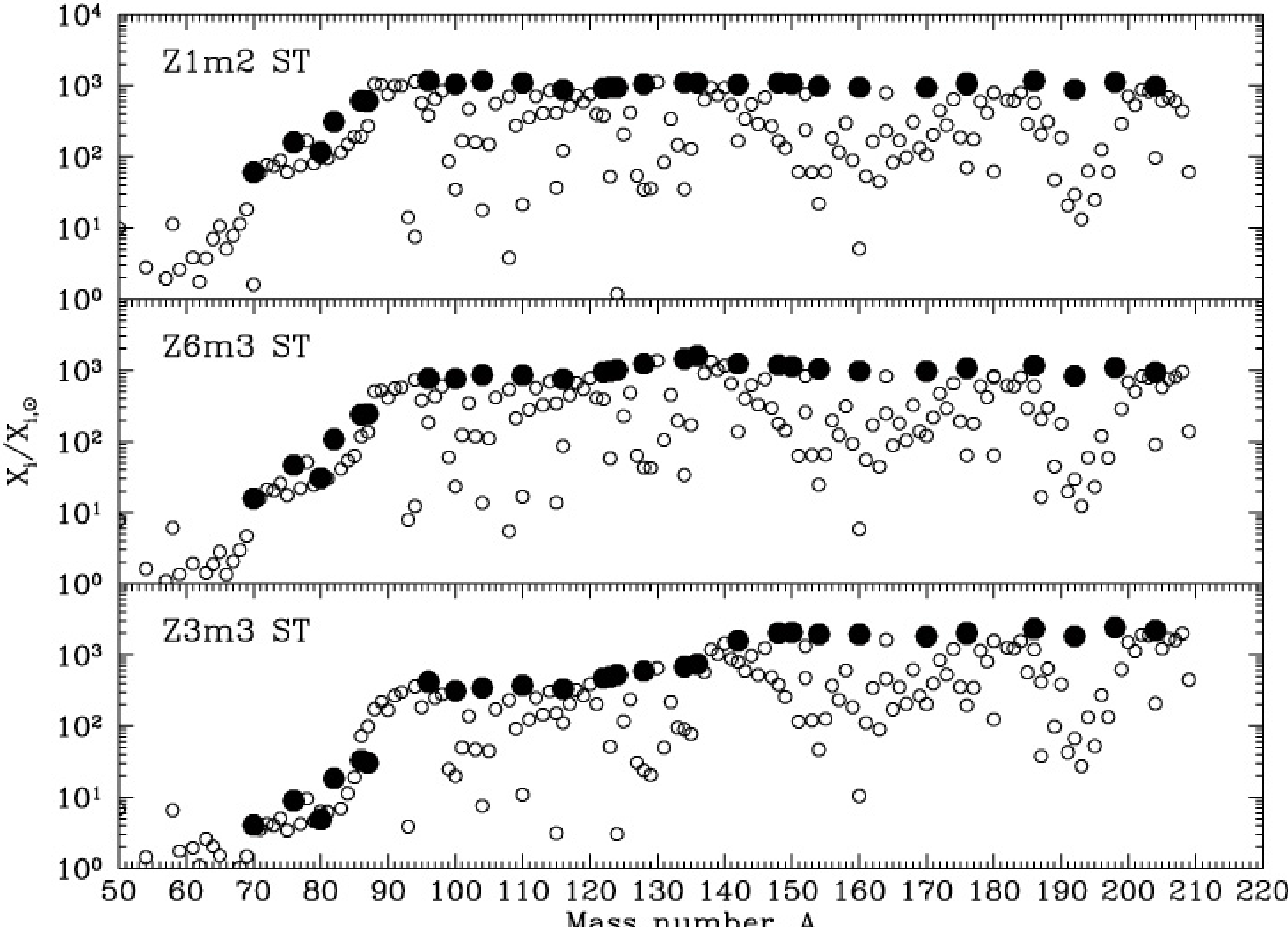
Delayed detonation standard ^{56}Fe=0.58
Deflagration ^{56}Fe=0.33
Weaker delayed detonation ^{56}Fe=0.33
Stronger delayed detonation, ^{56}Fe=0.98
$(X_i/X_{i,\odot})/(X_{Fe}/X_{Fe,\odot})$
Mass number, A
Fe
Se
Kr
Sr
Mo
Ru
Pd
Cd
Sn
In
Te
Xe
Ba
Ce
La
Sm
Gd
Dy
Er
Yb
Hf
Ta
W
Os
Pt
Hg



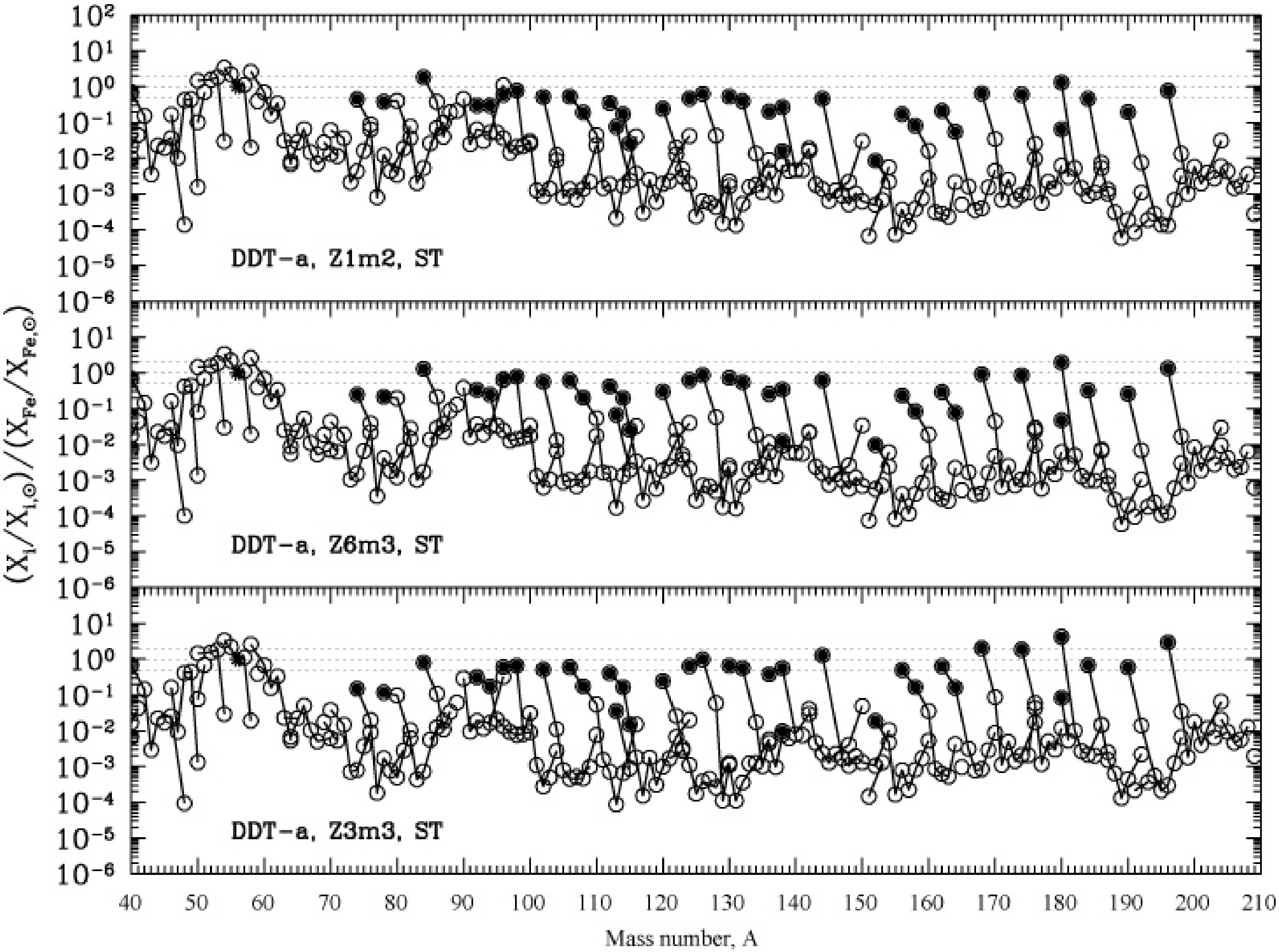

^{96}Zr
DEF, **Z2m2**,
51200 tracers
^{56}Fe=0.33
$(X_i/X_{i,\odot})/(X_{Fe}/X_{Fe,\odot})$
Mass number, A
Fe
Se
Kr
Sr
Mo
Ru
Pd
Cd
In
Sn
Te
Xe
Ba
La
Ce
Sm
Gd
Dy
Er
Yb
Hf
Ta
W
Os
Pt
Hg

How do p-nuclei and s-parents behave with metallicity?

(Travaglio et al., in prep.)



Taking a fixed choice of the ^{13}C-pocket at different *Z*, we may infer that the $(p/^{56}Fe)/(p/^{56}Fe)_{sun}$ ratio is always constant. This suggests a <u>primary</u> nature of p-process (Travaglio et al., in prep.)



Chemical evolution

From the hypothesis that SNIa are responsible for 2/3 of the solar ^{56}Fe, and assuming that our DDT-a model represents the typical SNIa with a frequency of 70% (Li et al. 2010), we conclude that they can be responsible for about 50% of the all p-nuclei.

If we take an average between DDTw-a and DDTs-a models, considering that they represent 10% of all SNIa, they account for 75% of all p-nuclei.

WKP

p-process at various metallicities and chemical evolution
(Travaglio et al. in prep.)

Nucleosynthesis in accreted mass
(tbd)

SNIa in 3D and sub-Chandrasekhar models
(Roepke et al. at MPA)