A new assessment of the Solar s- and r-process components

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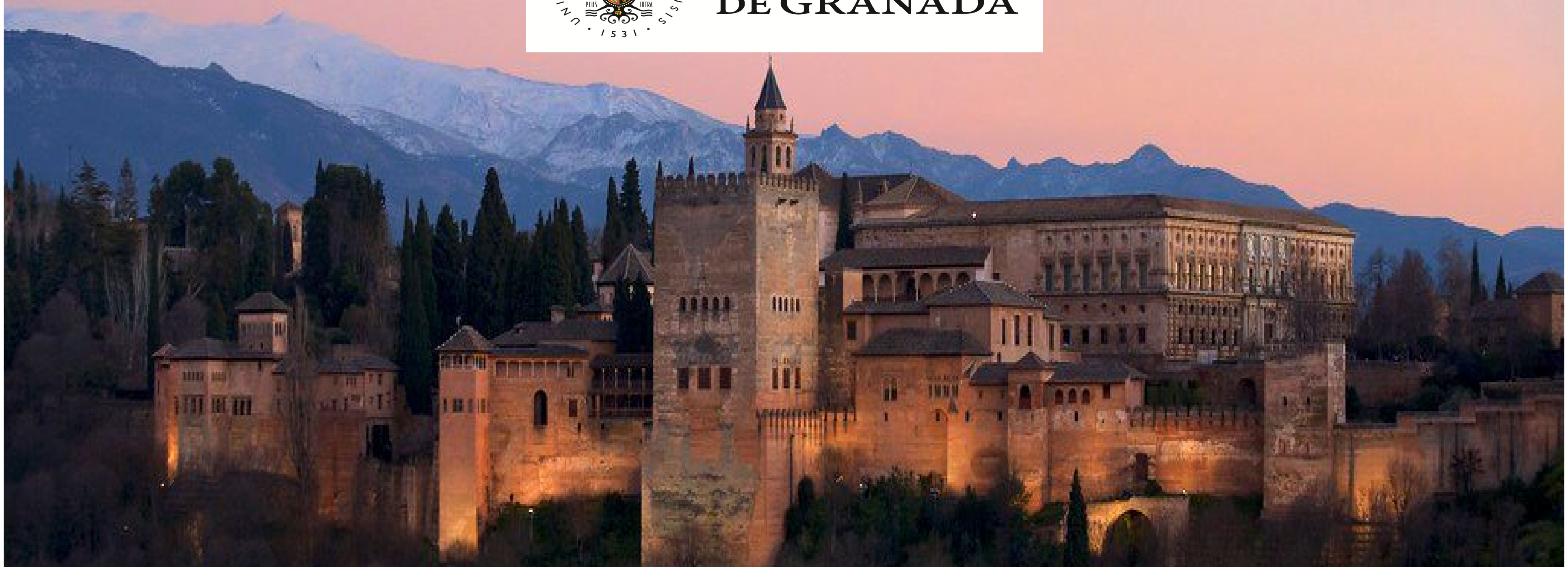
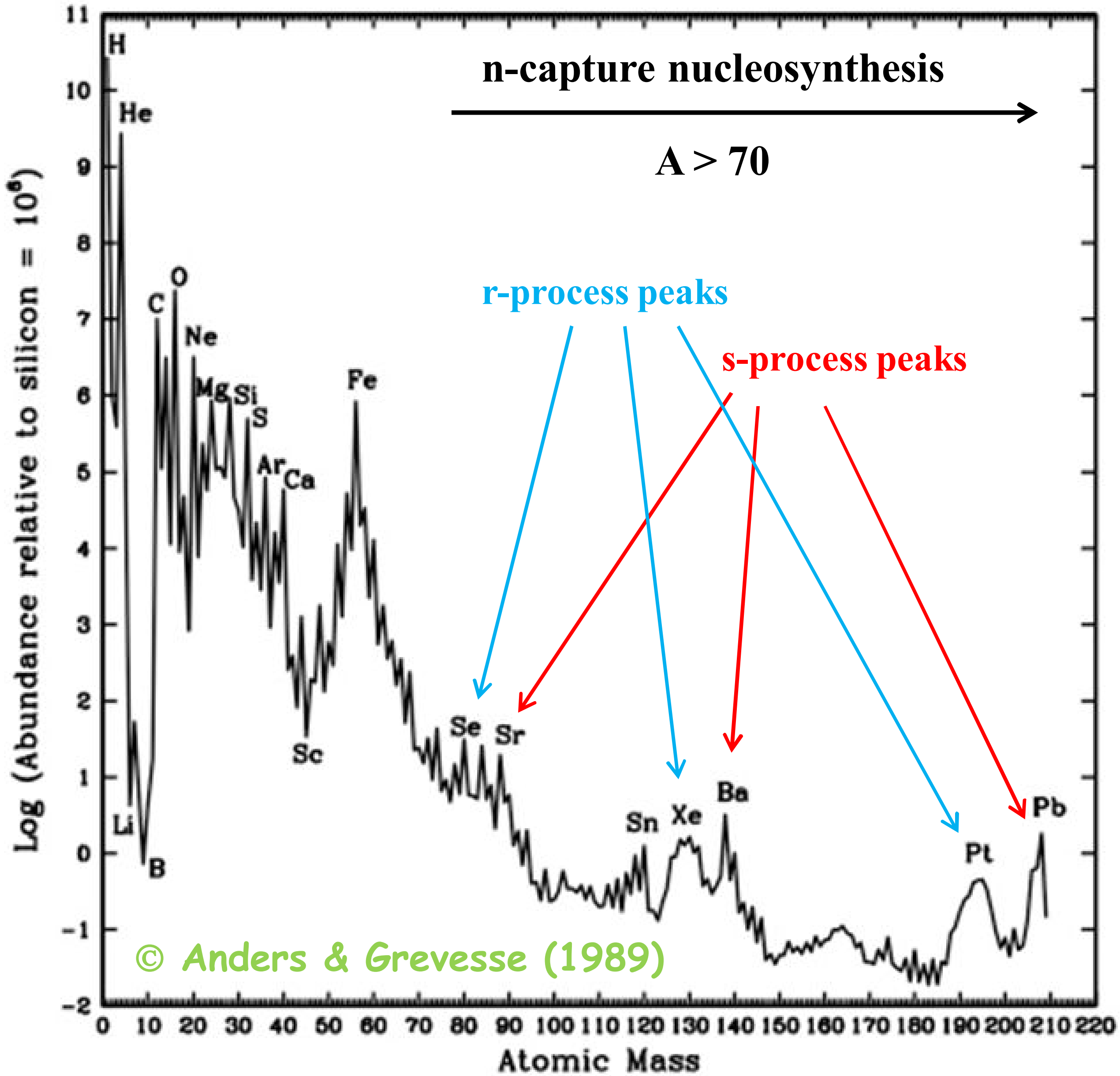


in collaboration with

N. Prantzos (IAP), S. Cristallo (OAT), A. Chieffi (IAS), M. Limongi (OAMP)

Solvay Workshop, 25-27 November, Brussels

The Solar System abundances



The astrophysical sites

➢ **S-process: hydrostatic He- & C-burning (N_n~10^{6-8} cm^{-3})**

Käppeler et al. (2011)

- **Asymptotic Giant Branch stars ($1 \leq M/M_\odot \leq 8$)**

  $90 \leq A \leq 210$ main component

  $^{13}C(\alpha,n)^{16}O$, $^{22}Ne(\alpha,n)^{25}Mg$ neutron sources

- **Massive stars (> 8 $M_\odot$)**

  $70 \leq A \leq 90$ weak component $^{22}Ne(\alpha,n)^{25}Mg$

➢ **R-process: ? (N_n > 10^{23} cm^{-3})**

$A \geq 70$ components?

- Core collapse SNe
- NS + NS, NS + BH mergers
- Collapsars
- ....

Arnould et al. (2007)
Thielemann et al. (2018)

Methods: ...first compute the s-contribution, then

$$N_r = N_{SS} - N_s$$

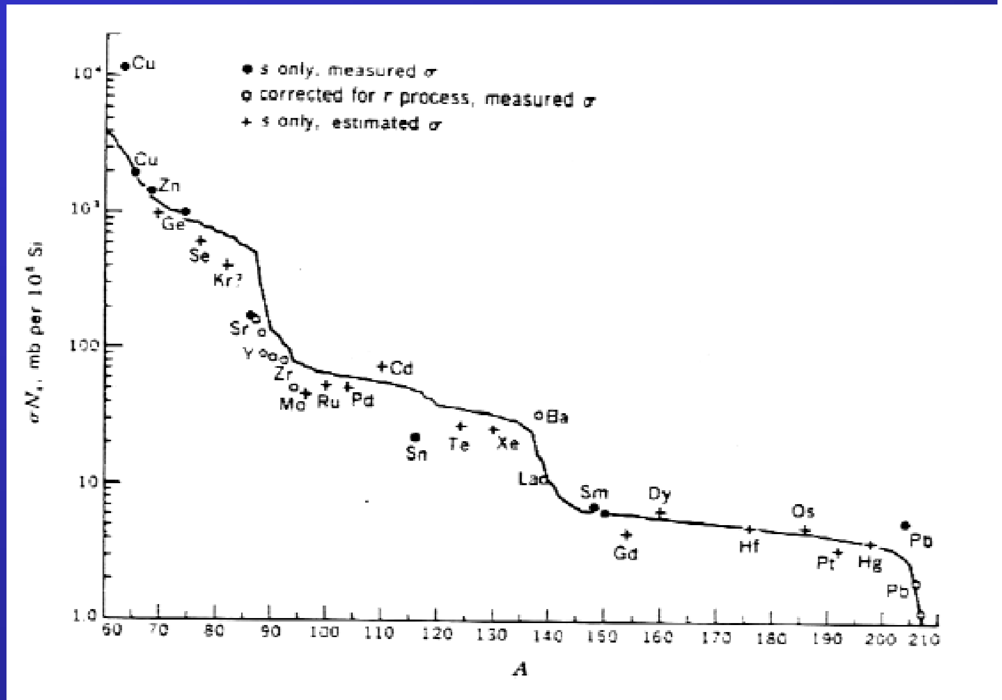
✓ **Classical method** (Clayton 1968)

τ_o (N_n, T), Fe/n

$N_s \, \sigma_n \approx$ const   for s-nuclei

- Multi-event approach (Goriely 1999)

ΔN_n, ΔT, N_e, $Z_\odot$



✓ **Stellar method** (Arlandini et al. 1999)

Fit to the SS s-only abundances from a post-processing calculation using a range (M, Z) stellar structure AGB models

✓ Galactic Chemical Evolution (GCE) models

Travaglio et al. (2004)

The SS abundance distribution must be calculated considering the interplay between the SFR history, stellar evolution, ISM ...integrated over the galactic life-time.

Detailed GCE models including ACCURATE s-process yields provide a reference to r-process calculations

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **476,** 3432–3459 (2018) doi:10.1093/mnras/sty316
Advance Access publication 2018 February 6

Chemical evolution with rotating massive star yields – I. The solar neighbourhood and the s-process elements

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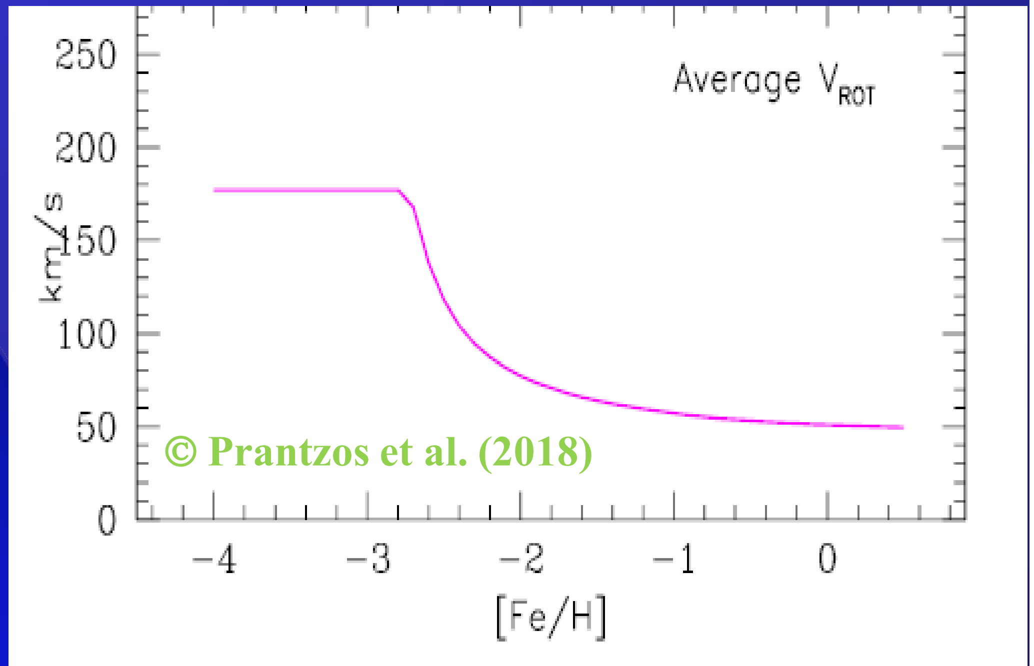
Effect of rotation on stellar yields

- Mixes protons into He-burning regions and products of H- & He-burning
- Boosting production of CNO, F, ^{22}Ne..and s-process
- Turns “secondary” elements in “quasi primary” ones



Adopted rotational profile vs. [Fe/H] to fit the observed [N/Fe] vs. [Fe/H]

https://fruity.oa-abruzzo.inaf.it/

https://orfeo.iaps.inaf.it/

Results from Paper I

Calculated SS abundance distribution

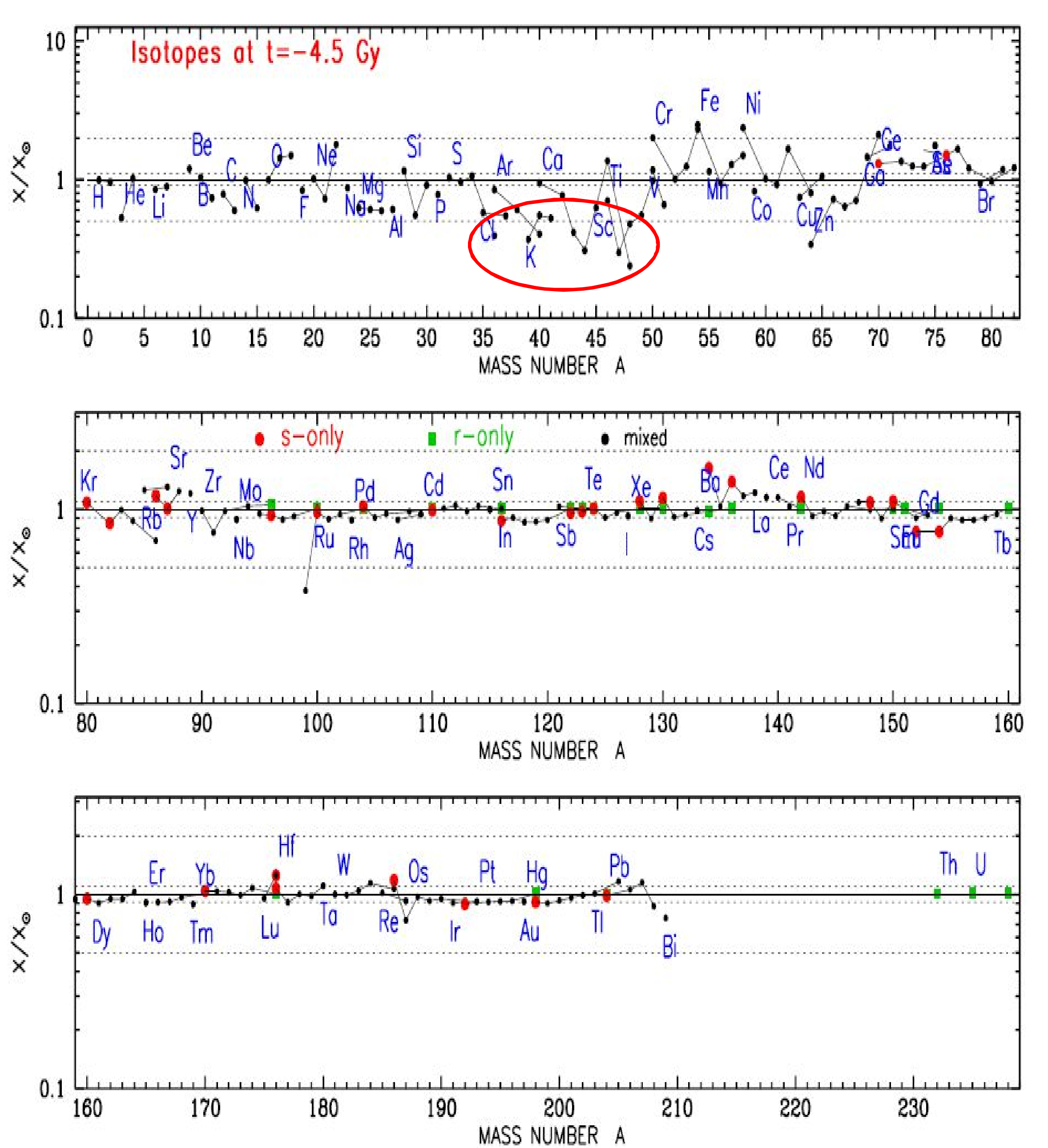
- better than a factor 2

- s-only nuclei better than 40%

- r-nuclei: yields from r-residuals by Sneden et al. (2008) scaled to α-elements and fixed to match Solar abundances of pure-r (Th, U)

$$Y_{r,i}(M,Z) = Y_{^{16}\mathrm{O}}(M,Z)\,\frac{X_{r,\odot}}{X_{^{16}\mathrm{O},\odot}}\,f_{r,i},$$

Solar r-fractions
(Sneden et al. 2008)



New “*bootstrap*” method

Step 0: GCE model ONLY with s-component by removing from the yields the initial r-component:

$$y_i(M,Z) = y_{i,0}(M,Z) - f_{r,i,0}\, X_{i,\odot}\, Z\, M_{ej}(M,Z)$$

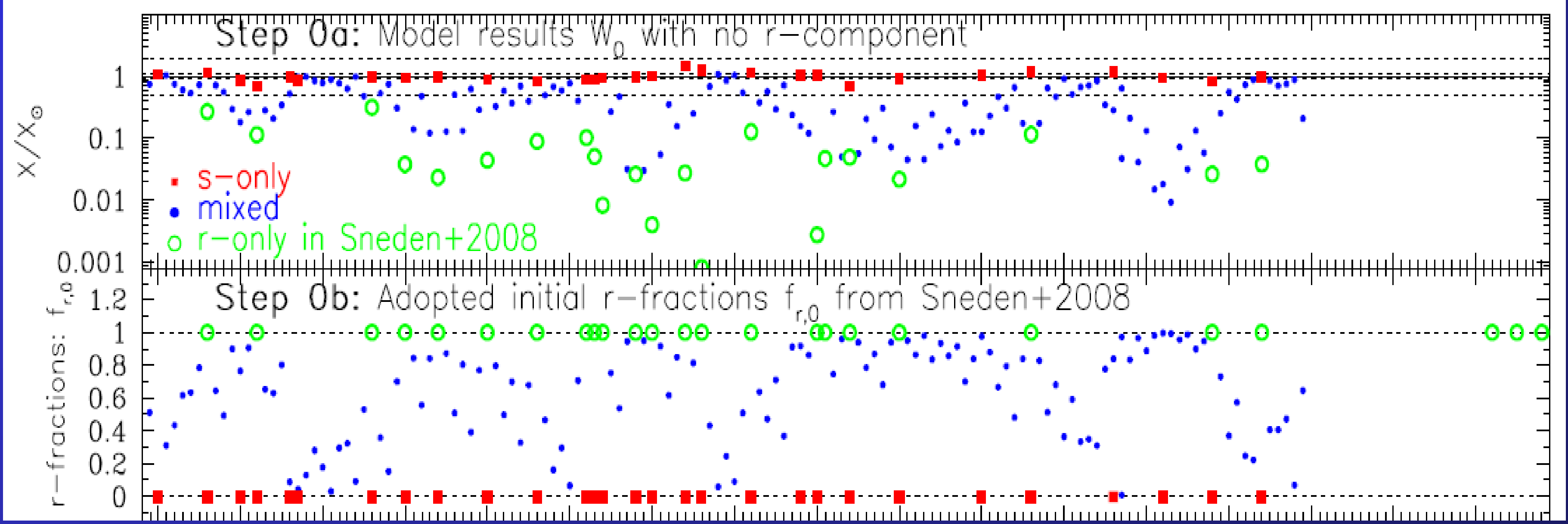
original yield

total ejected mass

Solar r-fractions (Sneden et al. 2008; Goriely 1999)

Then, each isotope is normalized to Lodders (2009):

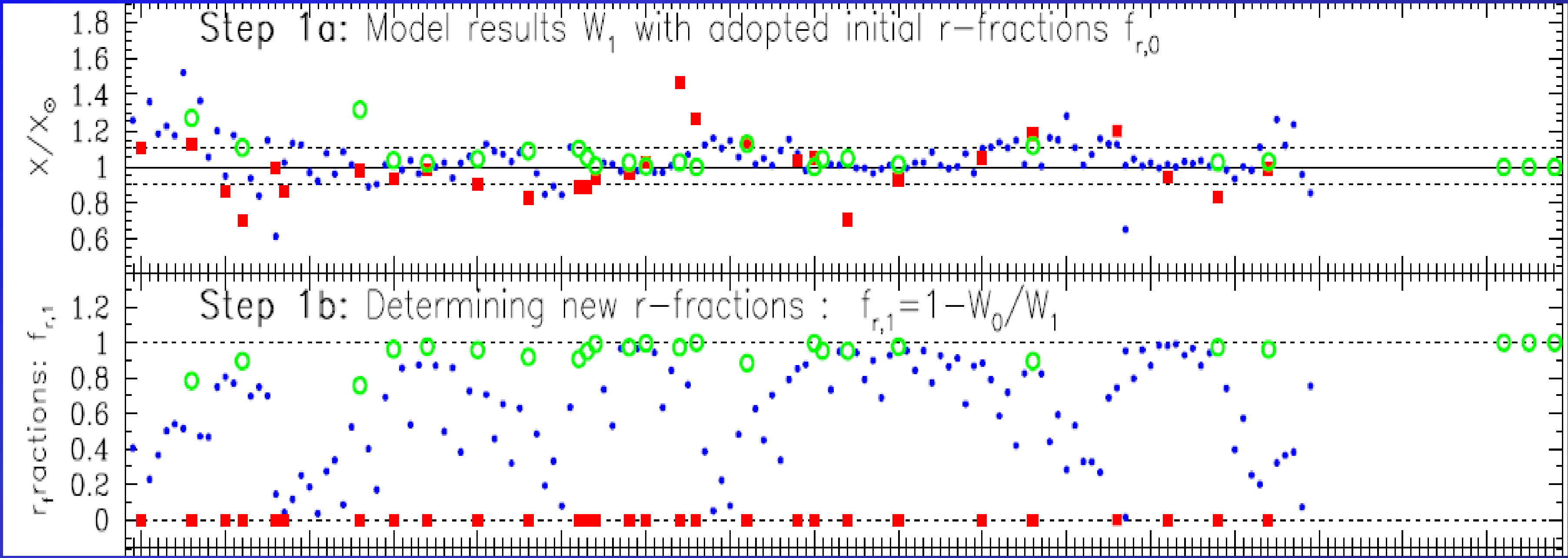
$$W_{i,0} = X_{i,0}/X_{i,\odot}$$



Atomic mass (A)

Step 1: **Run a GCE model with original yields and introducing the r-component of each isotope scaled to an alpha-element**

$$y_{i,1}(M,Z) = y_{i,0}(M,Z) + f_{r,i,0}\, y_{^{16}\mathrm{O}}(M,Z)\, X_{i,\odot}/X_{^{16}\mathrm{O},\odot}$$



Atomic mass (A)

From Step 0 $W_{i,0} = X_{i,0}/X_{i,\odot}$

From Step 1 $W_{i,1} = X_{i,1}/X_{i,\odot}$

→

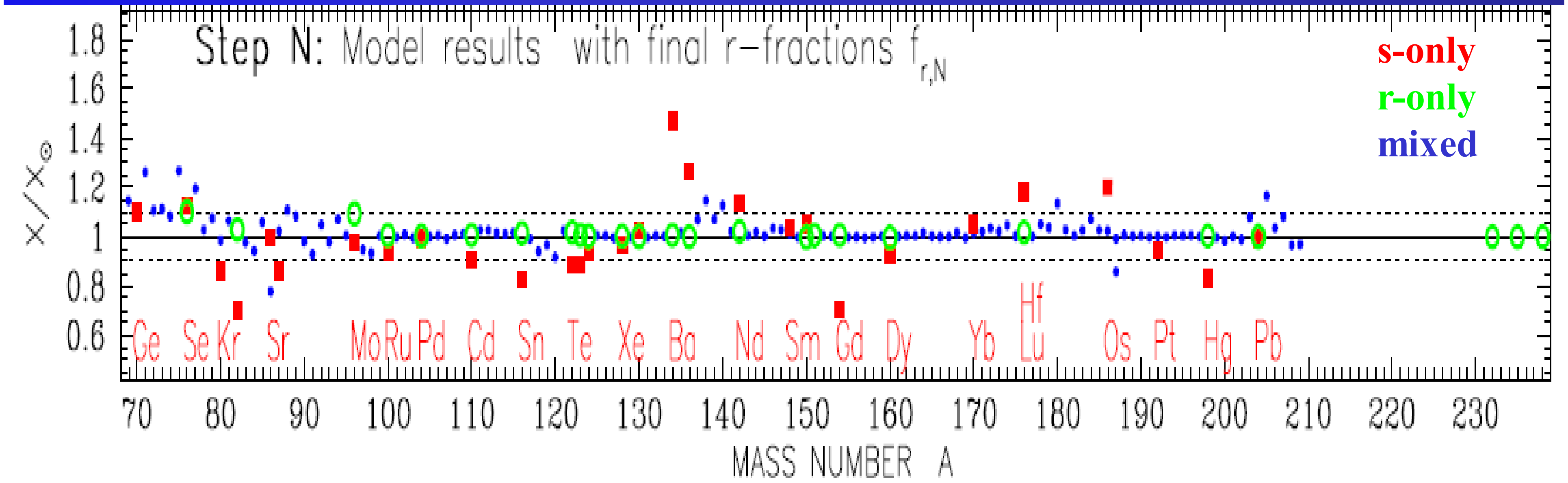
$f_{s,i,1} = W_{i,0}/W_{i,1}$ **new s-fraction**

$f_{r,i,1} = 1 - f_{s,i,1}$ **new r-fraction**

Step 2....N: we re-inject the obtained r-fractions in

$$y_{i,1}(M,Z) = y_{i,0}(M,Z) + f_{r,i,0}\, y_{^{16}O}(M,Z)\, X_{i,\odot}/X_{^{16}O,\odot}$$

Run it N times... untill convergence (~15-20 times, χ^2 test < 0.01)

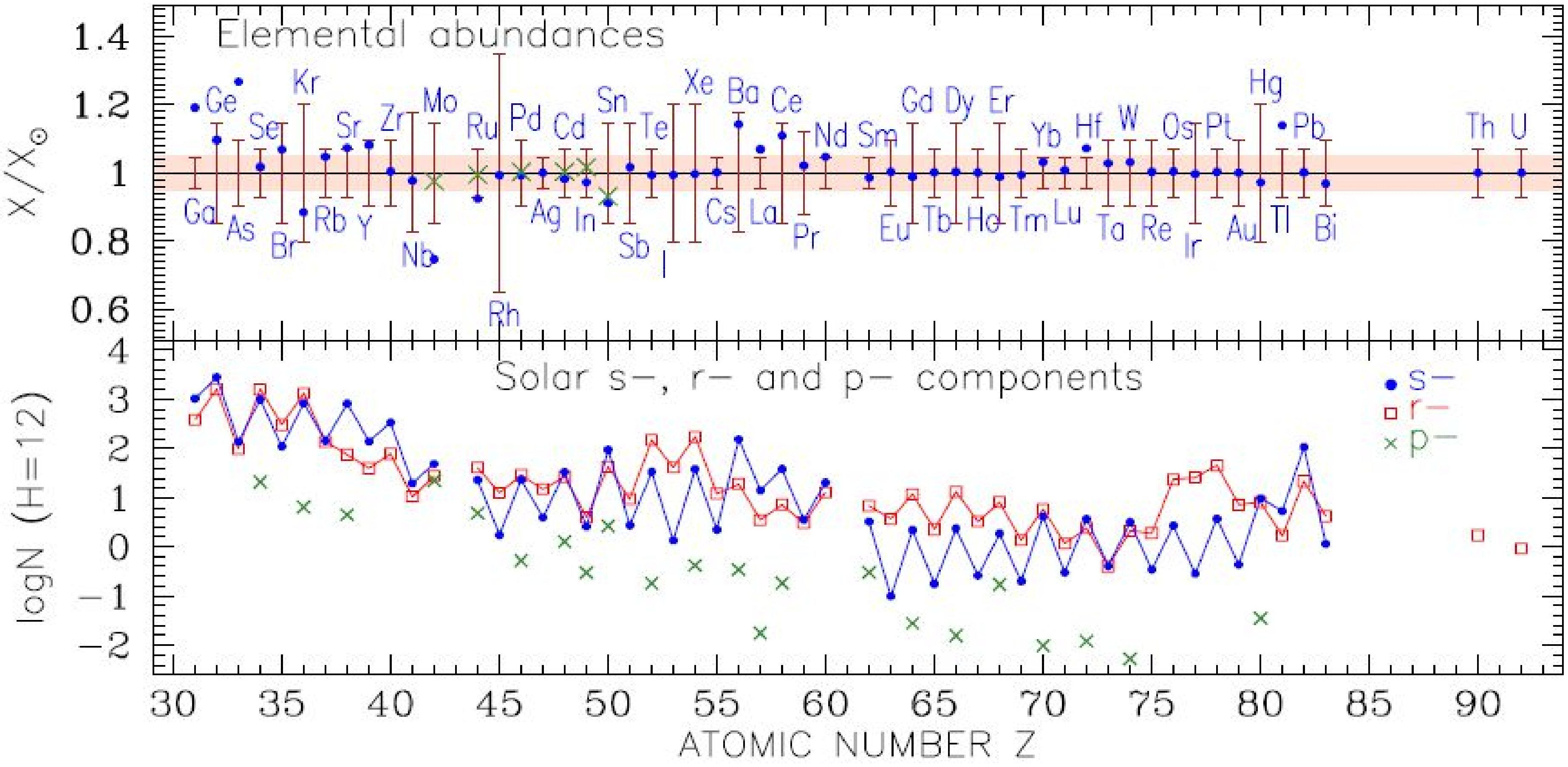


Results ONLY depend on:

- ✓ the adopted stellar s-isotope yields (GCE)
- ✓ the goodness to the fit of the pure-r isotopes Th & U

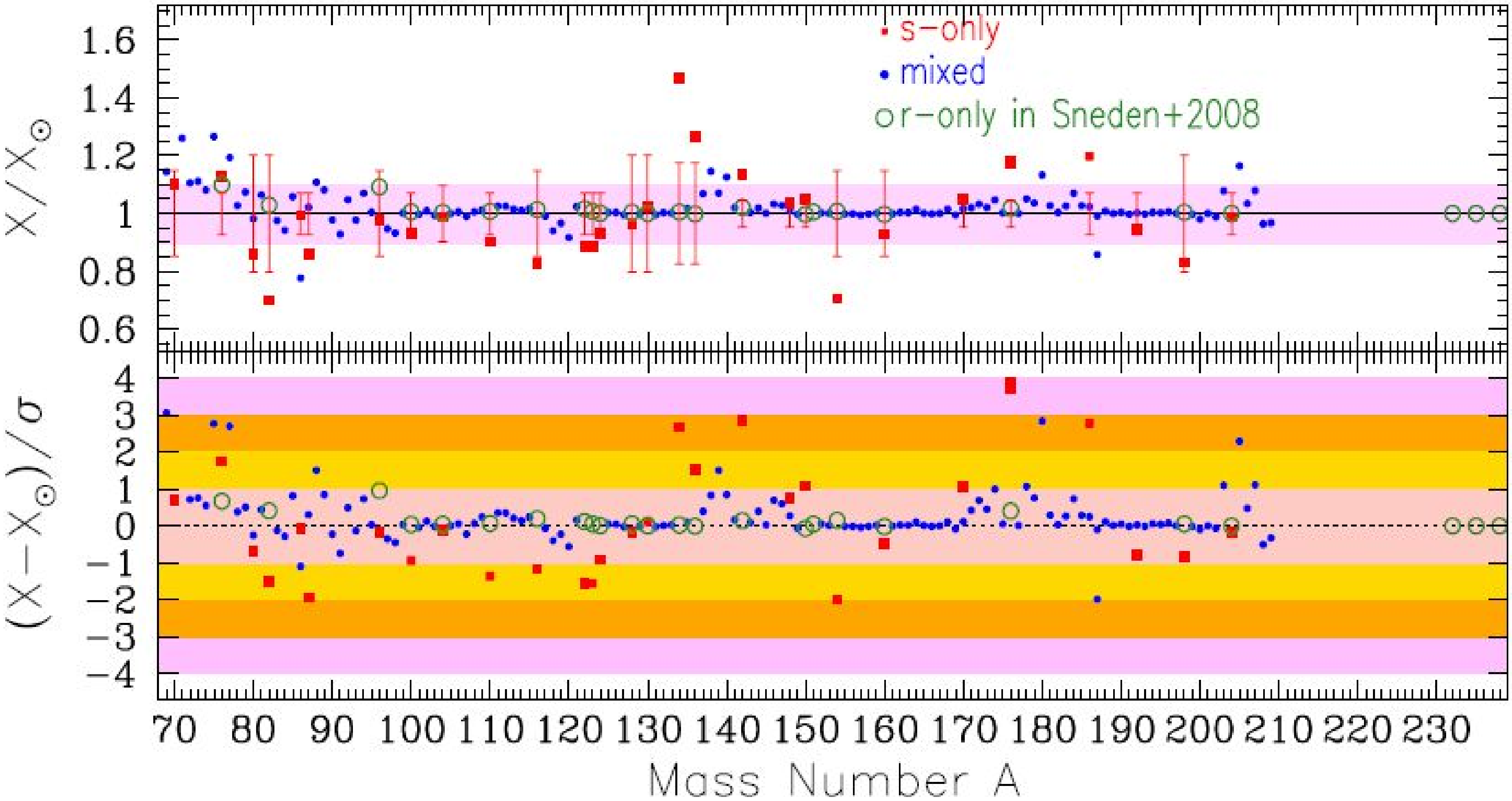
independently of the initial choice $f_{r,i,0}$!!

Comparison to Solar system: elements



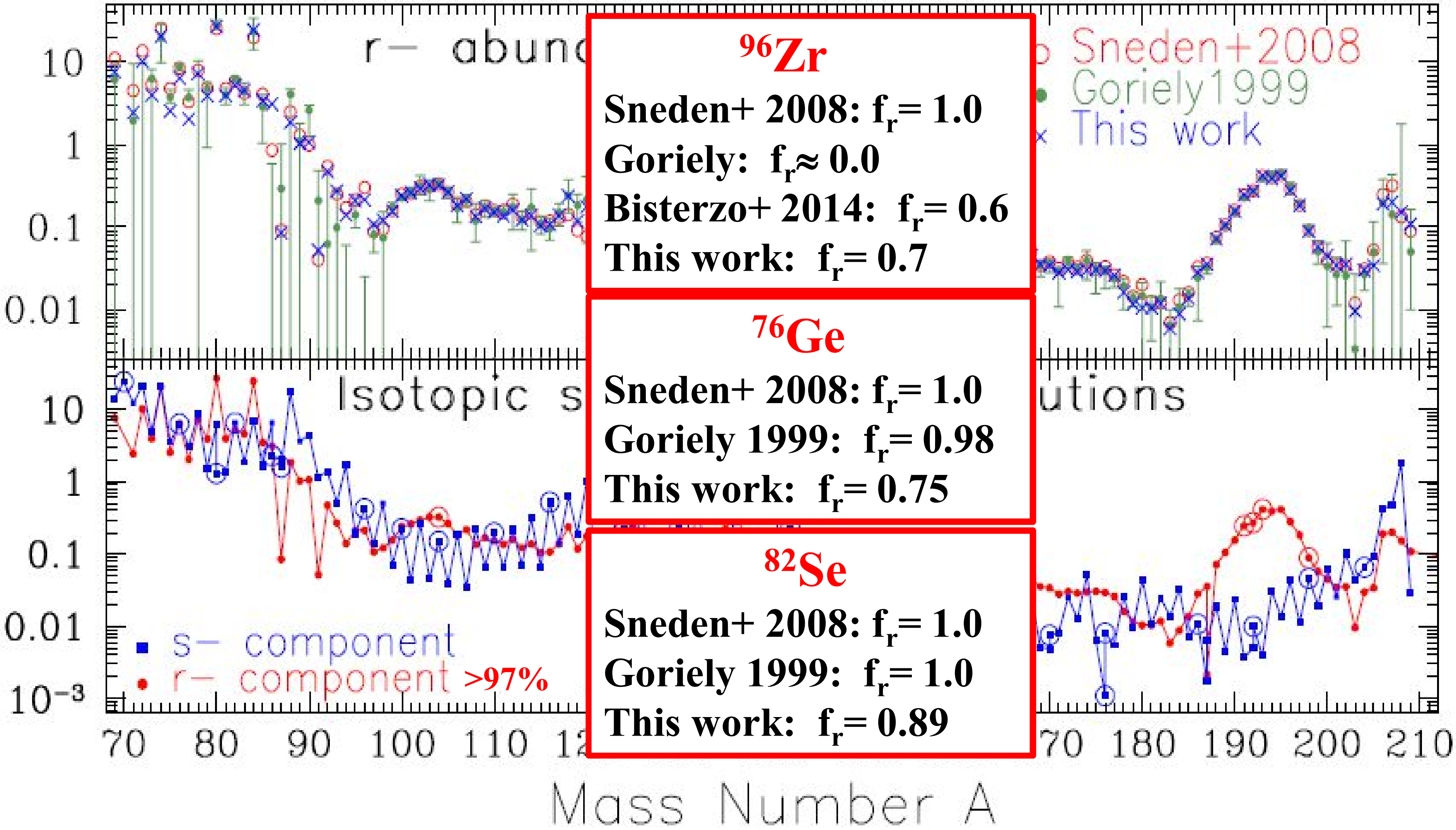
38 elements out 53 within ± 5% (Th and U imposed)...
...with contribution from p-process: 41 out 53

Comparison to Solar system: isotopes



120 isotopes within ± 10%
96 isotopes within ± 5%

Comparison to previous works



^{96}Zr

Sneden+ 2008: f_r= 1.0
Goriely: $f_r \approx$ 0.0
Bisterzo+ 2014: f_r= 0.6
This work: f_r= 0.7

^{76}Ge

Sneden+ 2008: f_r= 1.0
Goriely 1999: f_r= 0.98
This work: f_r= 0.75

^{82}Se

Sneden+ 2008: f_r= 1.0
Goriely 1999: f_r= 1.0
This work: f_r= 0.89

Largest differences found for lightest isotopes & s-dominated elements

Our tribute to the 150th anniversary of the Mendeleiev's Periodic Table

57	La	138	139								
56	Ba	130	132	134	135	136	137	138			
55	Cs	133									
54	Xe	124	126	128	129	130	131	132	134	136	
53	I	127									
52	Te	120	122	123	124	125	126	128	130		
51	Sb	121	123								
50	Sn	112	114	115	116	117	118	119	120	122	124
49	In	113	115								
48	Cd	106	108	110	111	112	113	114	116		
47	Ag	107	109								
46	Pd	102	104	105	106	108	110				
45	Rh	103									
44	Ru	96	98	99	100	101	102	104			
42	Mo	92	94	95	96	97	98	100			
41	Nb	93									
40	Zr	90	91	92	94	96					
39	Y	89									
38	Sr	84	86	87	88						
37	Rb	85	87								
36	Kr	78	80	82	83	84	86				
35	Br	79	81								
34	Se	74	76	77	78	80	82				
33	As	75									
32	Ge	70	72	73	74	76					
31	Ga	69	71								

s

r

p

83	Bi	209						
82	Pb	204	206	207	208			
81	Tl	203	205					
80	Hg	196	198	199	200	201	202	204
79	Au	197						
78	Pt	190	192	194	195	196	198	
77	Ir	191	193					
76	Os	184	186	187	188	189	190	192
75	Re	185	187					
74	W	180	182	183	184	186		
73	Ta	180	181					
72	Hf	174	176	177	178	179	180	
71	Lu	175	176					
70	Yb	168	170	171	172	173	174	176
69	Tm	169						
68	Er	162	164	166	167	168	170	
67	Ho	165						
66	Dy	156	158	160	161	162	163	164
65	Tb	159						
64	Gd	152	154	155	156	157	158	160
63	Eu	151	153					
62	Sm	144	147	148	149	150	152	154
60	Nd	142	143	144	145	146	148	150
59	Pr	141						
58	Ce	136	138	140	142			

MNRAS 000, 1–20 (2019) Preprint 18 October 2019 Compiled using MNRAS LaTEX style file v3.0

arXiv-1911.02545

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Thanks for your attention !!