NUCLEOSYNTHESYS IN VERY LOW METALLICITIES AGB STARS: TRACES FROM PROTON INGESTION EPISODES

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DSSERVATORIO ASTRONOMICO DI TERAMO



The FRANEC Code (Frascati RAppson-Newton Evolutionary Code)

F.R.U.I.T.Y.

(Franec Repository of Updated Isotopic Tables & Yields)

On-line DataBase v. 1.1.b

Mass (M⊚)	Metallicity	Nuclides Properties	Table View	s-process
		O Elements [El/Fe] Z: All	All Thermal Pulses	
		Isotopes (Xi) A: All Z: All	Last Thermal Pulse	Indexes
		O Yields (M _☉) A: All Z: All	Single Table / Multiple Models Only one Element allowed	
		None	(Yield or Last TP)	

Soon available on-line at FRUITY Database Web Pages (Franec Repository of Updated Isotopic Tables & Yields)

What happens at very low metallicities:



Hollowell et al. (1990) Fujimoto et al. (2000) Iwamoto et al. (2004) Suda et al. (2004) Campbell et al. (2007) Cristallo et al. (2009b) SUDA's Poster (n.202)

Cristallo et al. (2007), ApJ 667 489



Energy



a) Δt=0 b) Δt=1.6457 yrs c) Δt=1.6468 yrs d) Δt=2.1843 yrs



 $M = 1.5 M_{\odot}$ [Fe/H] = -2.45

Light elements

Heavy elements



$M=1.5 M_{\odot}$ [Fe/H]= -2.45 (Z= 5.0x10⁻⁵)



Cristallo et al. 2009, PASA, 26, 139

 $M = 1.5 M_{\odot}$ [Fe/H] = -2.45

Surface distribution



The importance of nuclear cross sections

La 130 8,7 m	La 131 59 m	La 132 24.3 m 4.8 h	La 133 3,91 h	La 134 6,67 m	La 135 19,4 h	La 136 9,9 m	La 137 6 · 10 ⁴ a	La 138 0,0902	La 139 99,9098	a 140 40,272 h	La 141 3,93 h	La 142 92,5 m
β* γ357: 551, 544: 908	β* 1,4; 1,9 γ 108; 418, 365; 286; g	A* 1465, 1465, 567 (162), 285, 1910,	y 279: 302; 290, 633; 618 9	β* 2.7 γ 605; (1555)	γ 481; (875; 588) 9	β* 1,9 γ819: (761: 1323)	no y g	4_5"0.3 7 1436;760 # 57	or 9,0	γ 1596; 487; 816; 329 σ 2,7	β 2,4 γ 1355	β ⁺ 2,1; 4,5 γ 641; 2398; 2543
Ba 129 2,13 h 2,20 h	Ba 130 0,106	Ba 131	Ba 132 0,101	Ba 133 38,9 h 10,5 a	Ba 134 2,417	Ba 135 28,7 h 6,592	Ba 136 7,854	Ba 137 2,55 m 11,23	Ba 138 71,70	Ba 139 83,06 m	Ba 140 12,75 d	Ba 141 18,3 m
* 182, 1,214, 1459; 221, 202, 129,	w 1,0 + 5,5	hy 108. 1596. 79 124. a ⁻ 216	10,4 + 4,6	12 + 358, 81; y (\$33) 333	ur0,16+1.8	h 268 8° +≤8	o 0,010 + 0,44	h 162	#0,45	β ⁻ 2,4 γ 166; (1421) σ 5	γ 537; 30; 163; 305 σ 1,6	β ⁼ 2,8; 3,0 γ 190; 304; 277; 344
Cs 128 3,8 m	Cs 129 32,06 h	Cs 130 3,46 m 29,21 m	Cs 131 9,69 d	Cs 132 6,47 d	Cs 133 100	Cs 134 2,95 h 2,06 a	Cs 135	Cs 136	Cs 137 30,17 a	Cs 138	Cs 139 9,3 m	Cs 140 63,7 s
p* 2.9 y 443; 527	β+ γ 372; 411; 549; g	h 80. 51: 5*20. 148. 5*0.4 • 7.3%	no st no y g	¢; β [*] β [*] 0.8 γ 668; 465; 630	o 2.5 + 26.5	7 505; e ⁺ a 140	+ 781: 640. # £.9	0.7 h#1.3	m; g m; g m; 25	p ⁺ 3.0. 3.9 + 1436: + 1436: 460: 463; 192. 1010	β [−] 4,2 у 1283; 627; 1421	β 5,6; 6,2 γ 602; 909; 1201
Xe 127 70 s 36,4 d	Xe 128 1,91	Xe 129 8,89 d 26,4	Xe 130 4,1	Xe 131	Xe 132 26,9	Xe 133 2,194 5,25 d	Xe 134 10,4	Xe 135	Xe 136 8,9	Xe 137 3,83 m	Xe 138 14,1 m	Xe 139 39,7 s
hr 125. 172. 173 371	#0,48+<7,5	197 197 17 H 22	ii 0,45 + 6	in 164 e ⁺ er 107	ır 0,05 + 0,40	h 233	rr 0.003 + 0.2	11527 100 1787) 808 9 1285 15	ii:0,26	β 4,1 γ 456; (849)	β 0,8; 2,8, γ 258; 434; 1768; 2016 g	β 5,0 γ 219; 297; 175
l 126 13,11 d	127 100	l 128 25.0 m	l 129 1,57 · 10 ⁷ a	I 130 9,0 m 12,35 h	l 131 8,02 d	132 83,6 m 2,30 h	133 9s 20,8 h	134 3.1 m 52.0 m	l 135 6,61 h	136 45s 84s	137 24,2 s	l 138 6,4 s
е; µ 0,9; 1,3 р 1,1 у 389; 666 σ - 10000	a 6,15	y 443; 527 o 22	B ^{-0,2} 0 ⁻⁷ , g a 20,7 + 10,3	1, 1231 1 8 6" 7 536 6"2.5 660; 738 7 536 7 18	β ⁻ 0,6; 0,8, 284; g σ - 0,7	1 668. 773. 773: 600; 455; 175. 523.	Hy 913, 647, 73 g	β ⁺ 2.5 γ 847, γ 97 884, 234 884	β [−] 1,5; 2,3, 1678: 1458 0: 0	β ⁺ β ⁺ 4;1; γ 1312; 5.4 381; γ 1313; 197 1321	β 5,0 γ 1218; 601 βn 0,37; 0,48	β γ 589; 875; 2262; 484 βn
Te 125 57,4 d 7,139	Te 126 18,95	Te 127	Te 128 31.69	Te 129 33,6 d 69,6 m	Te 130 33,80	Te 131 30 h 25,0 m	Te 132 76,3 h	Te 133 55,4 m 12,5 m	Te 134 41,8 m	Te 135 18,6 s	Te 136 17,5 s	Te 137 2,5 s
h (35)	or 0, 12 + 0,8	17 (00) 10" 0.7 2 (58) B 0.7 17 418	7,2 - 10 ²⁴ a	by 11069 p= 1.5. b.7.1.6. 400, y 806. 487.	2,7 + 10 ²¹ a a 0,03 + 0,20	р 0.5 2.5 852. у 150. Ут 182 452.	β 0,2 γ220, 30 9	9 0/7 9 2.2 3.3 2.7 645 9 400 9 304 1333 9	β ⁺ 6.9; 0,7 7767; 10; 276; 79; 566 9	β 6.0 γ 604; 267; 670; 1133	в 2.5; 4,9 у 2078; 334; 579; 2569; 3235 βn 0,43; g	β ⁺⁻ 6,3; 6,8, γ 243; 554; 469 βn

Normal s-process (main path)

$$n_n^{max} > 10^{14} \text{ cm}^{-3}$$

Proton ingestion

 $\sigma(^{135}I)_{30 \text{ Kev}} \sim 1/20 \sigma(^{138}Ba)_{30 \text{ Kev}}$

from Rauscher&Thielemann 2000

The importance of the network



Complete network

Reduced network

Solar scaled Models



Final surface distributions of solar scaled models									
M/M_{\odot}	n. '	TDU	[C/Fe]	[C/N]	¹² C/ ¹³ C	[ls/Fe]	[hs/Fe]	[hs/ls]	
0.85	Γ) +1	-1 3.8 0.8 11.9 2.9 3.2						
1.0	Ι	E		IIXIN C THI	G PRO	CESSI & ACE	ES .	-0.1	
1.2	D							0.7	
1.5	D	See See	PALMI ANGEI	ERINI LOU's	Poster	er (n.04 (<mark>n.306</mark>)	.9)	0.5	
2.0	D	+38	3.7	2.1	293	1.9	2.6	0.7	
2.5		13	3	2.1	390	0.9	1.2	0.3	

D: Deep Dredge Up (following PIE)

⁷Li production



Posters

See also



Final surface distributions of α-enhanced models



These models show ¹²C/¹³C>5000





Final surface distributions of α-enhanced models

M/M_{\odot}	n. TDU	[C/Fe]	[C/N]	¹² C/ ¹³ C	[ls/Fe]	[hs/Fe]	[hs/ls]
0.85	D+1	4.2	0.7	8.9	2.9	3.1	0.2
1.0	D+1	3.5	0.6	7.9	2.0	2.2	0.2
1.2	D+10	3.8	0.9	16.3	2.4	2.8	0.4
1.5	D+29	4.1	1.2	100	2.0	2.7	0.7

D: Deep Dredge Up (following PIE)

Production of ¹⁵¹Eu

M/M _o	[Fe/H]	$\frac{^{151}Eu}{(^{151}Eu+^{153}Eu)}$
0.85	-2.85	0.61
1.2	-2.85	0.55
0.85	-2.45	0.59
1.0	-2.45	0.56
1.5	-2.45	.0.46

Standard s-process nucleosynthesis



Observations

LP 625-44 ([Fe/H]=-2.72) → 0.60 CS 31062-050 ([Fe/H]=-2.30) → 0.55 (Aoki et al. 2003)

Conclusions

- 1. Revision of the relationship presented in 2007 at Z~10⁻⁴;
- 2. Strong influence of the <u> α -enhancement</u> on the occurrence of PIE;



- 3. Importance of the <u>adopted network;</u>
- 4. Chemically enriched envelopes in very low mass stars;
- 5. PIE characteristics:
 - Low ¹²C/¹³C and [C/N] ratios;
 - Large amount of ⁷Li (depending on the ³He content!!);
 - Large amount of ls elements (very low [hs/ls] ratios);
 - <u>Larger</u> ¹⁵¹Eu/¹⁵³Eu ratios with respect to a standard sprocess nucleosynthesis.

IN THE FUTURE

Test the PIE in other stellar phases:

1. Very Late Thermal Pulse Scenario see HERWIG&HIRSCHI's (n. 224) & PIGNATARI's (n. 255) Posters

2. H accretion on White Dwarfs

see TRAVAGLIO's talk on Thursday

Proton Ingestion Episode (PIE)

- Low time steps → Time dependent mixing
- Rapid structure reaction \rightarrow Coupling between phisical and chemical evolution
- Large neutron densities $(n_n > 10^{14} \text{ cm}^{-3}) \rightarrow 700$ isotopes & 1000 reactions



We limit proton ingestion up to the mesh where $\tau_{CNO} = 1/3 \Delta t$

Temporal step of the model (Δt) is limited to 1/2 τ_{mix}