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

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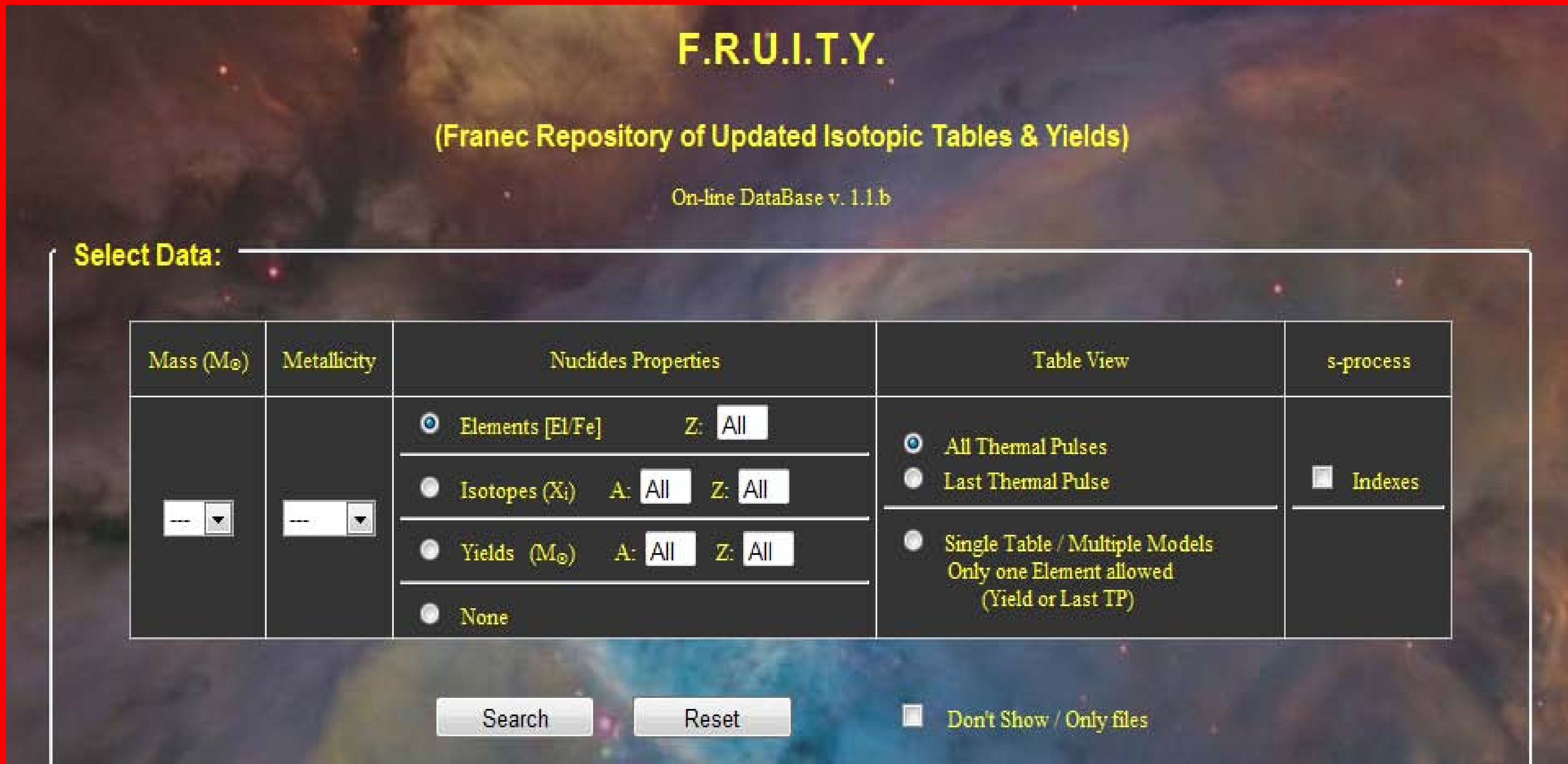
The FRANEC Code

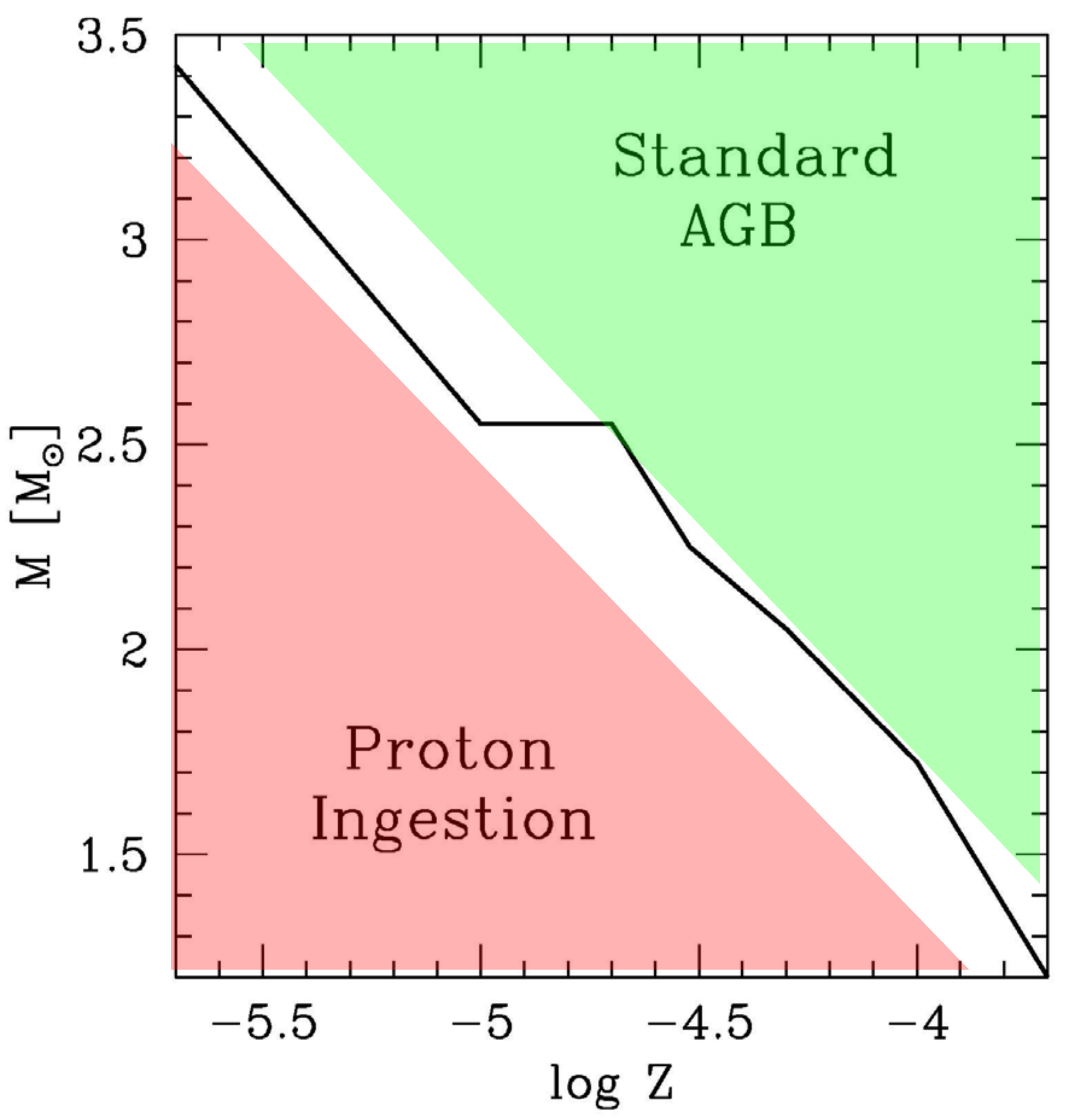
(Frascati RAppson-Newton Evolutionary Code)



Soon available on-line at FRUITY Database Web Pages

(Franec Repository of Updated Isotopic Tables & Yields)

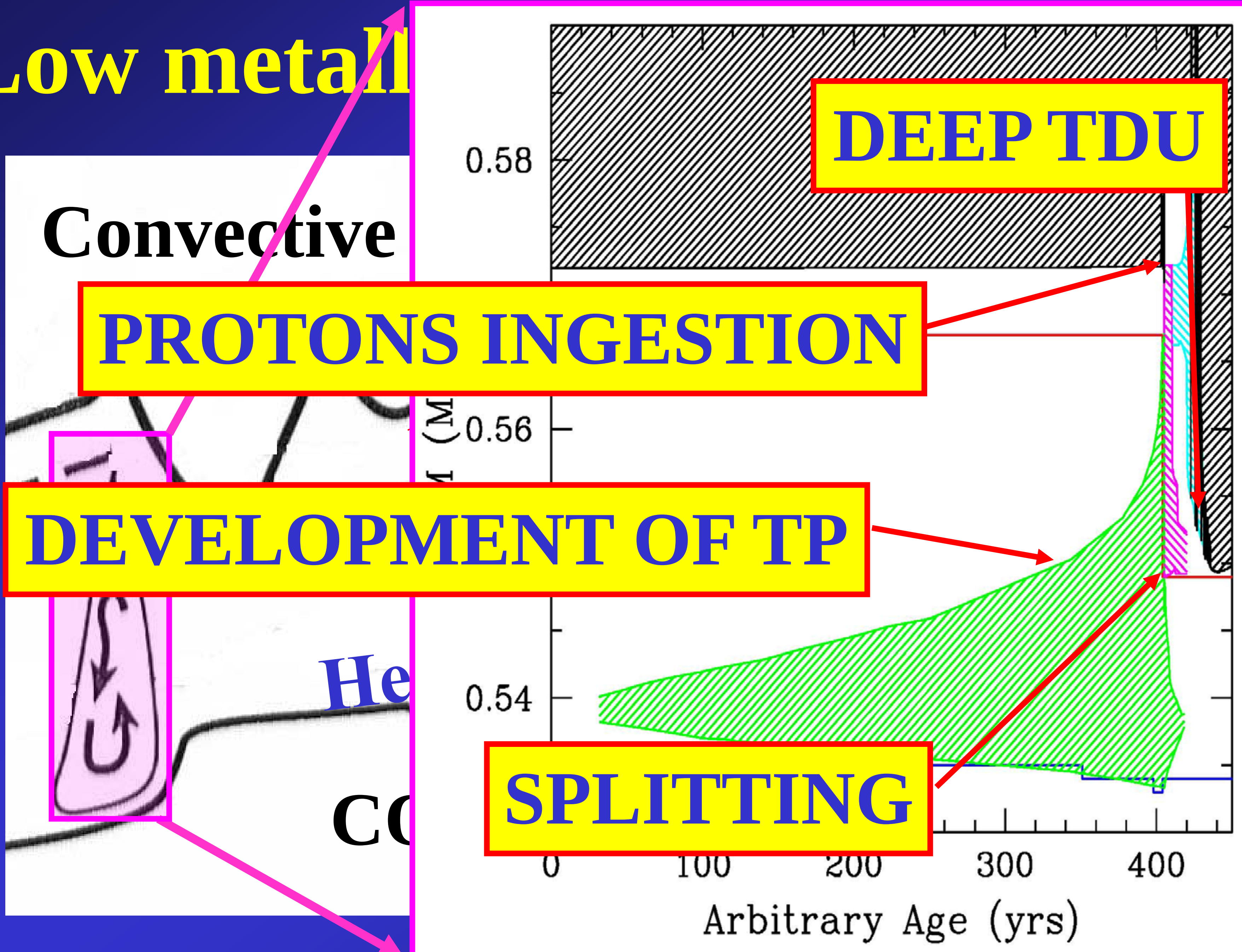
What happens at very low metallicities:



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)

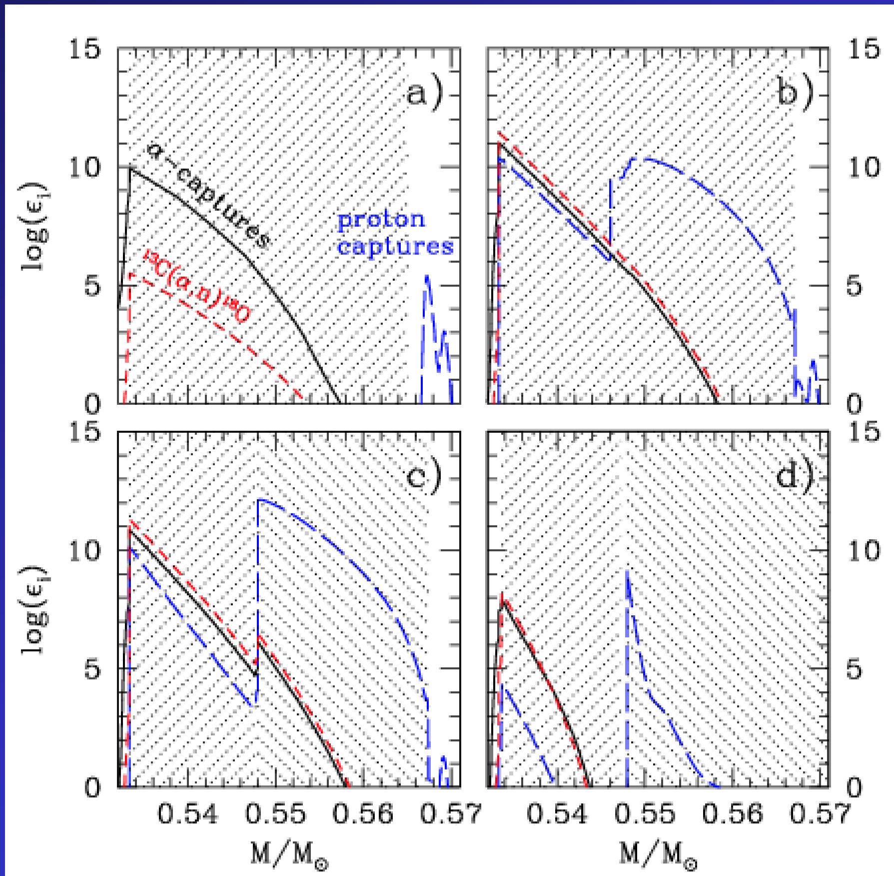
Cristallo et al. (2007), ApJ 667 489

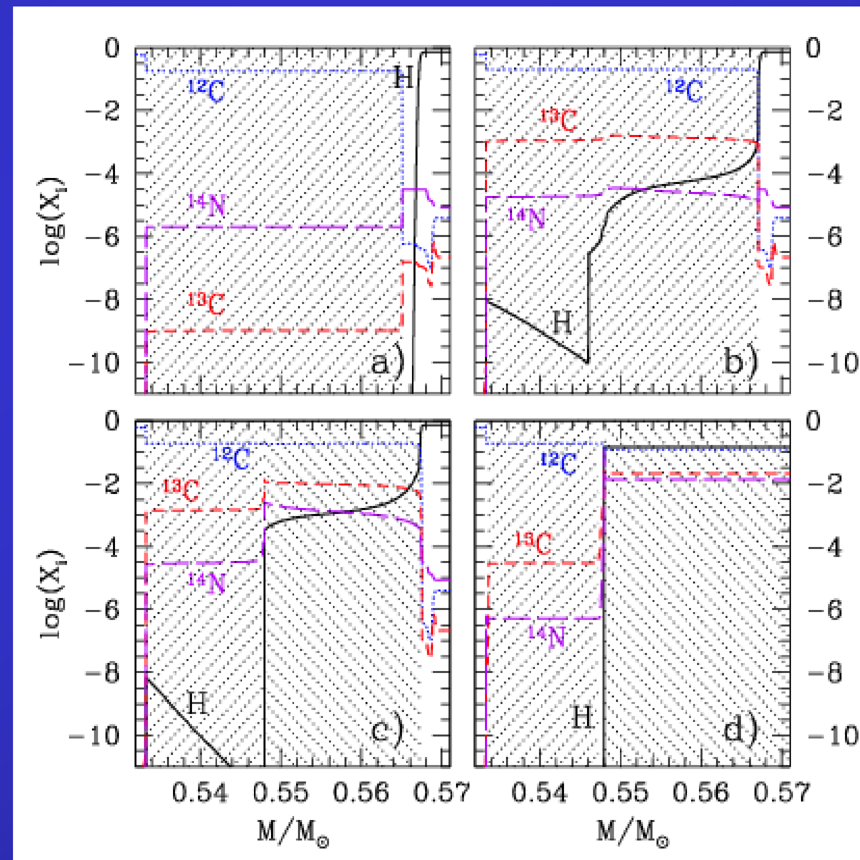
Low metall


Convective
PROTONS INGESTION
DEVELOPMENT OF TP
He
CO
DEEP TDU
SPLITTING
0.58
0.56
0.54
0
100
200
300
400
Arbitrary Age (yrs)

Energy

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

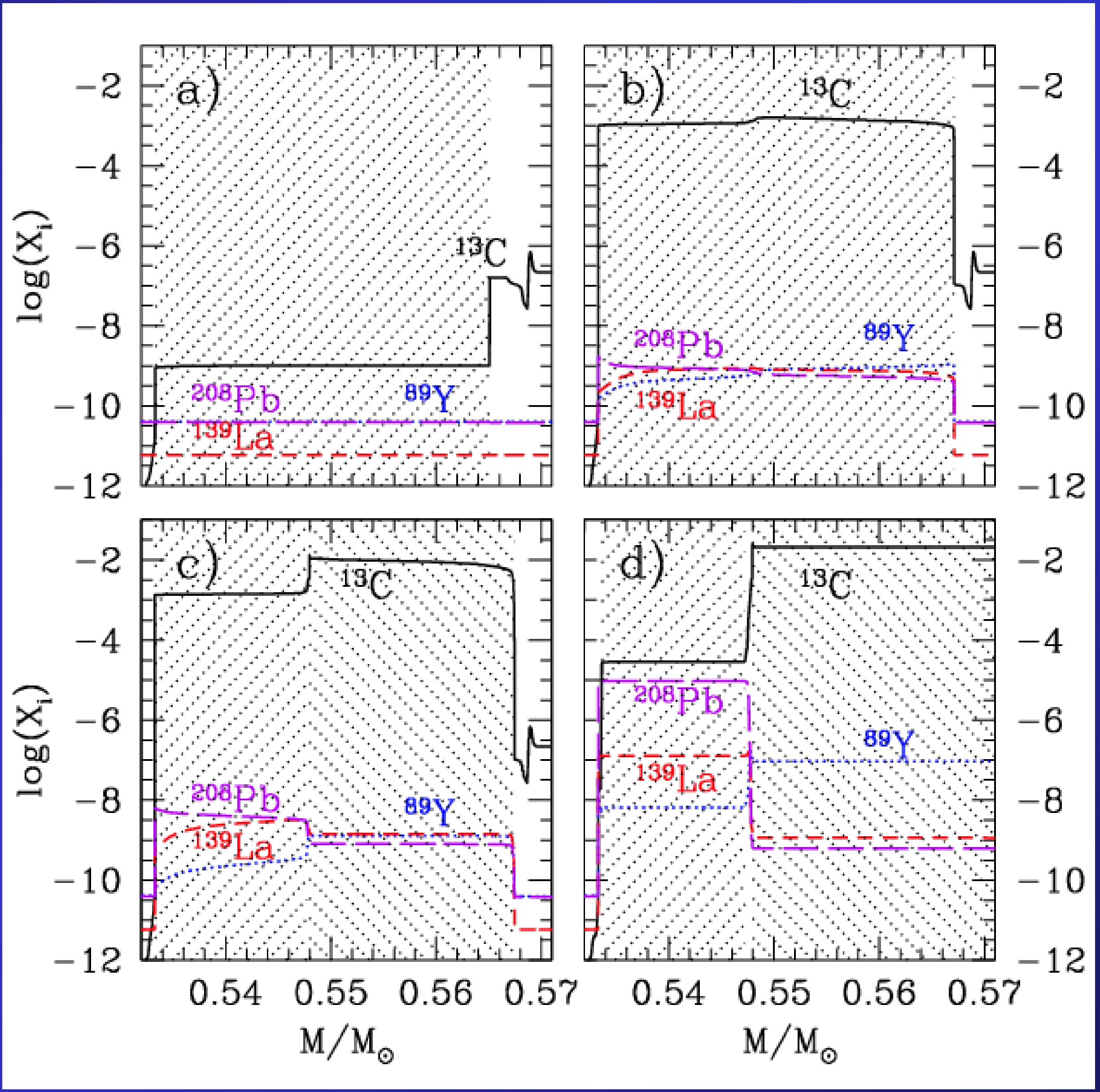




M= 1.5 $M_{\odot}$, [Fe/H]= -2.45

Light elements

Heavy elements



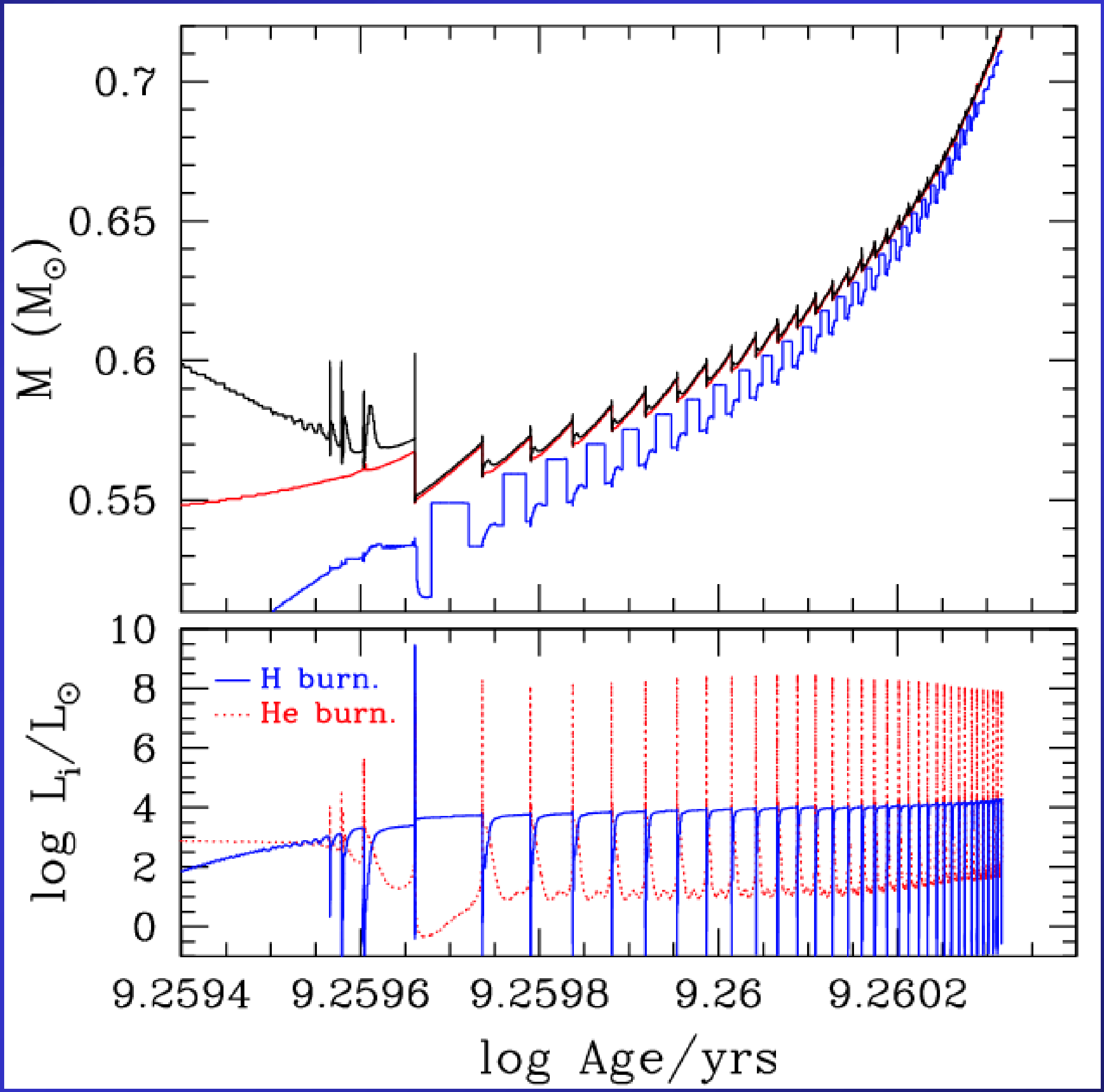
M= 1.5 $M_\odot$
[Fe/H]= -2.45

Nuclear Network of 700 isotopes coupled with the physics

***M*= 1.5 *M*$_\odot$**

[Fe/H]= -2.45

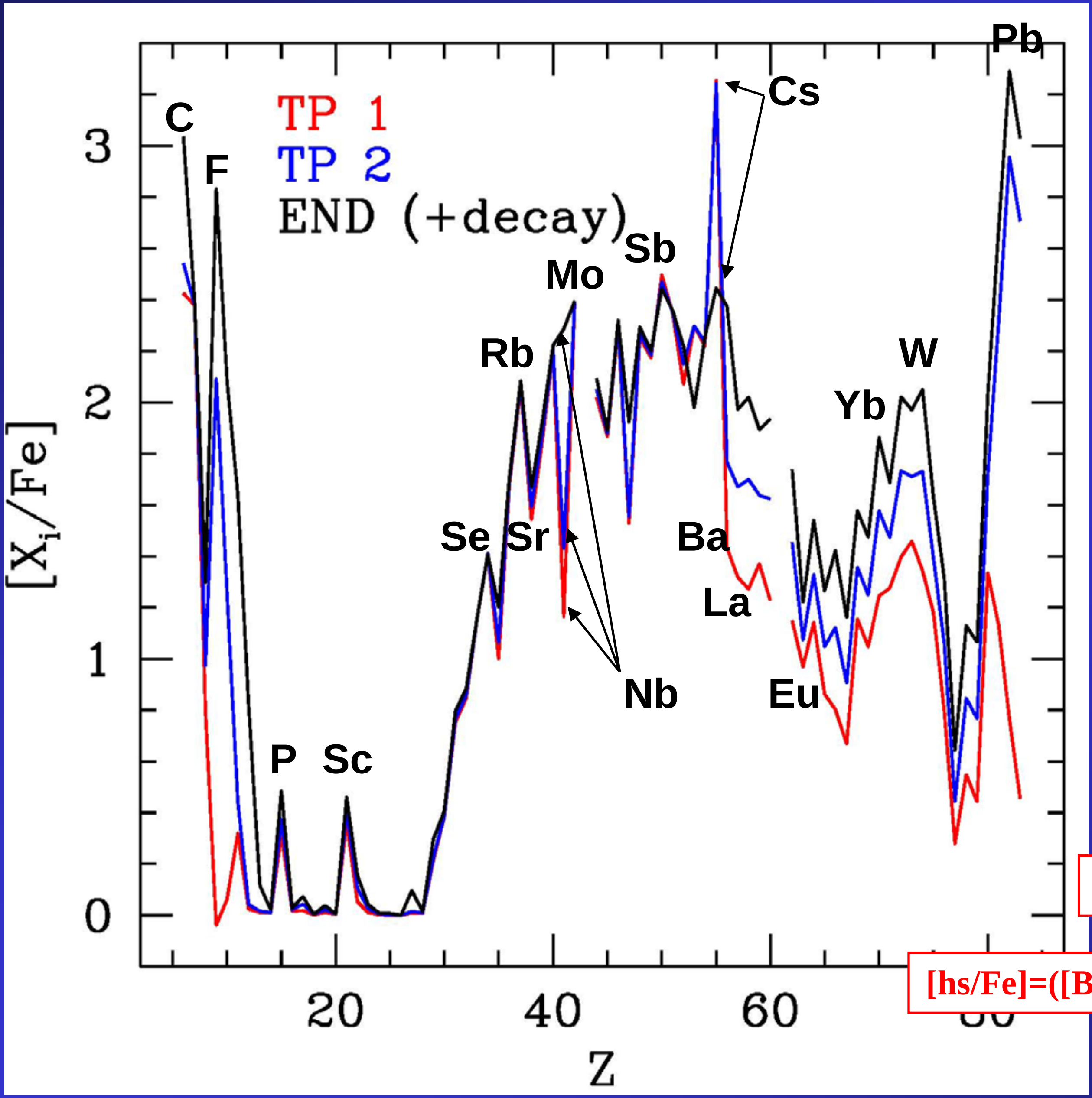
(*Z*= 5.0x10^{-5})



Cristallo et al. 2009, PASA, 26, 139

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

Surface distribution



TDU	$^{12}C/^{13}C$
1	5.7
2	9.2
26	75

TDU	hs/ls
1	-1.3
2	0.2
26	0.6

[ls/Fe]=([Sr/Fe]+[Y/Fe]+[Zr/Fe])/3

[hs/Fe]=([Ba/Fe]+[La/Fe]+[Nd/Fe]+[Sm/Fe])/4

[hs/ls]= [hs/Fe]-[ls/Fe]

The importance of nuclear cross sections

Normal s-process (main path)

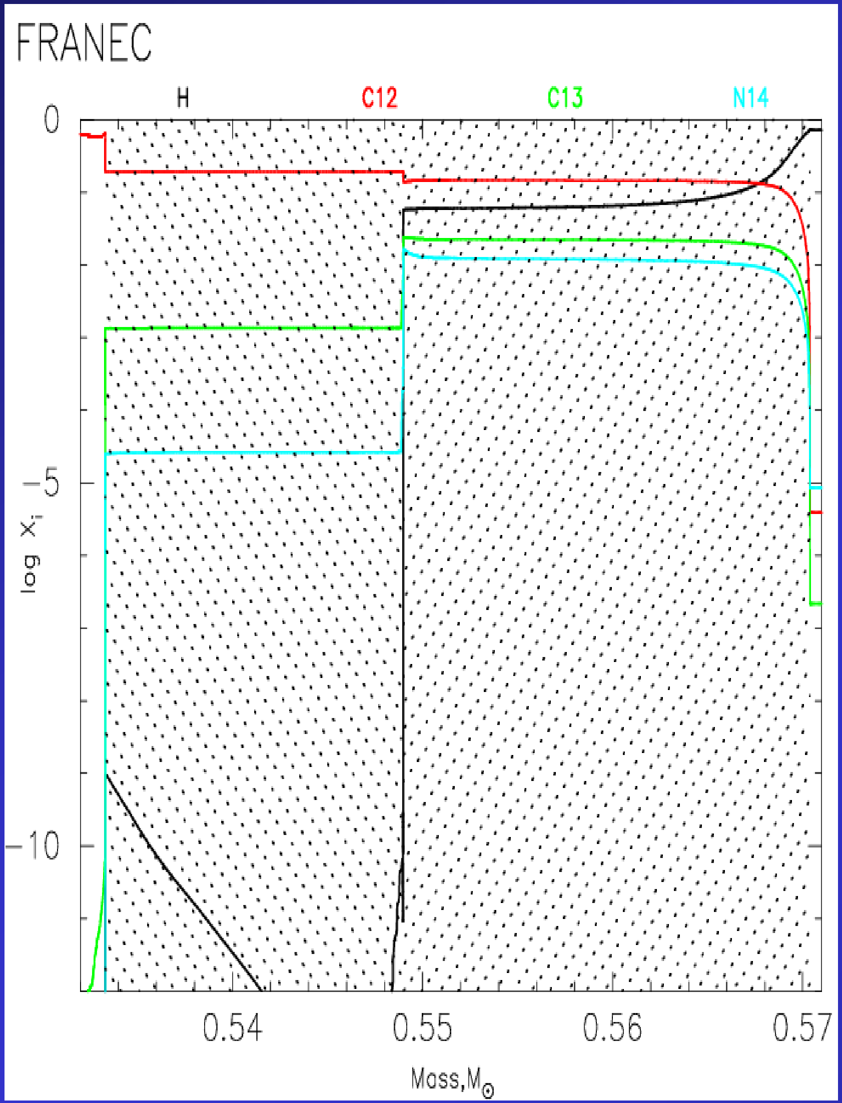
Proton ingestion

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

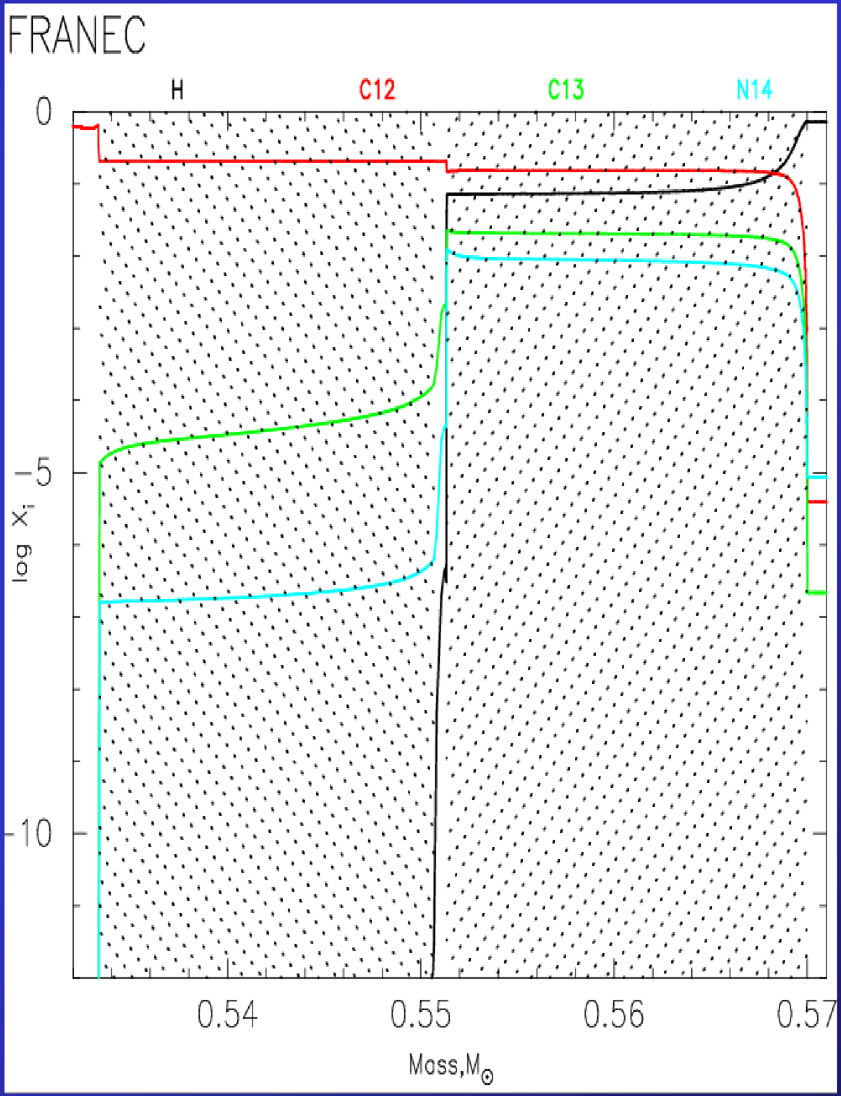
$\sigma(^{135}I)_{30\ Kev} \sim 1/20\ \sigma(^{138}Ba)_{30\ Kev}$

from Rauscher&Thielemann 2000

The importance of the network

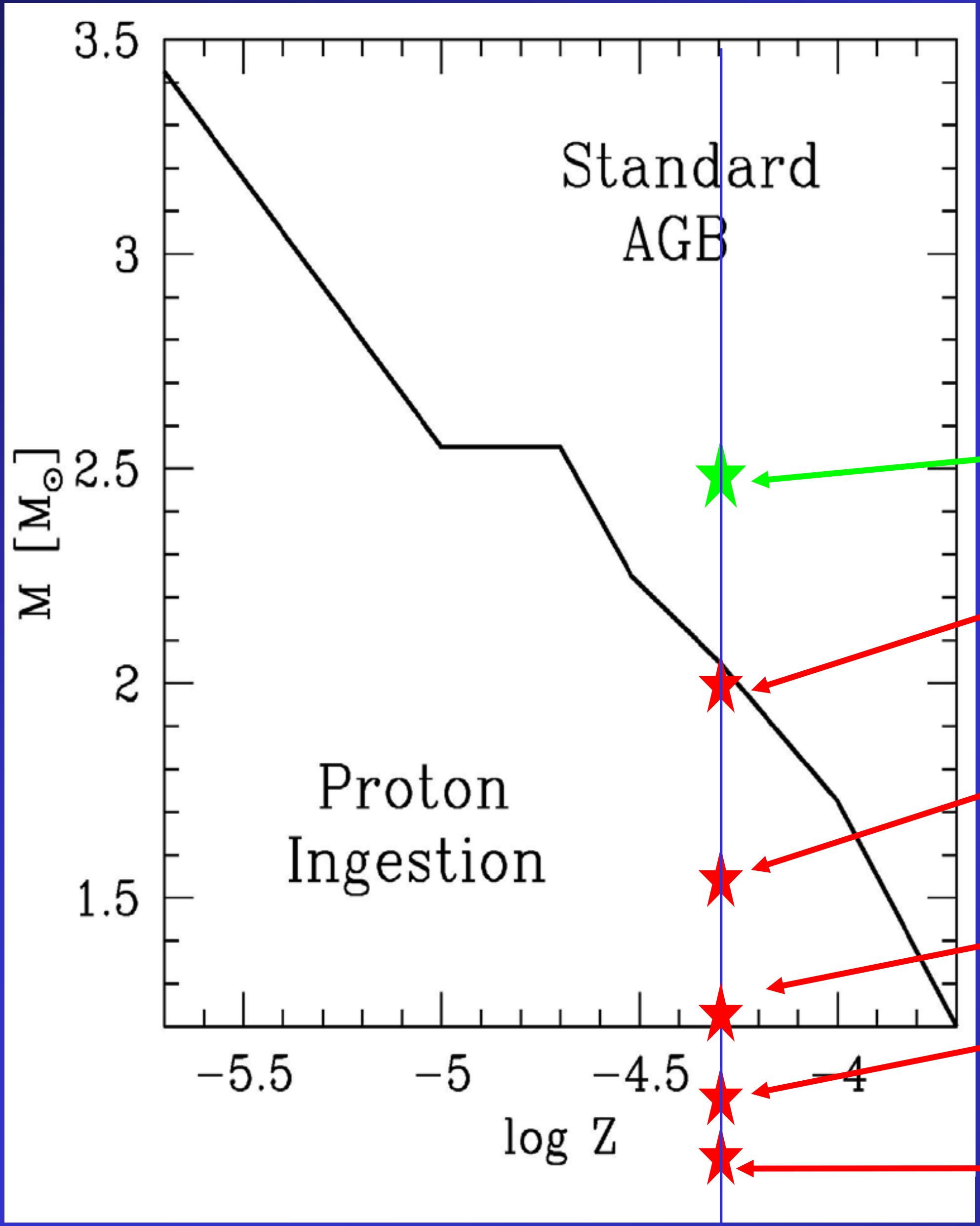


Complete network



Reduced network

Solar scaled Models



[Fe/H]=-2.45

$Z_{tot}=5x10^{-5}$

M=2.5 *M*⊙

M=2.0 *M*⊙

M=1.5 *M*⊙

M=1.2 *M*⊙

M=1.0 *M*⊙

M=0.85 *M*⊙

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	D+1	3.8	0.8	11.9	2.9	3.2	0.3
1.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.1
1.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.7
1.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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

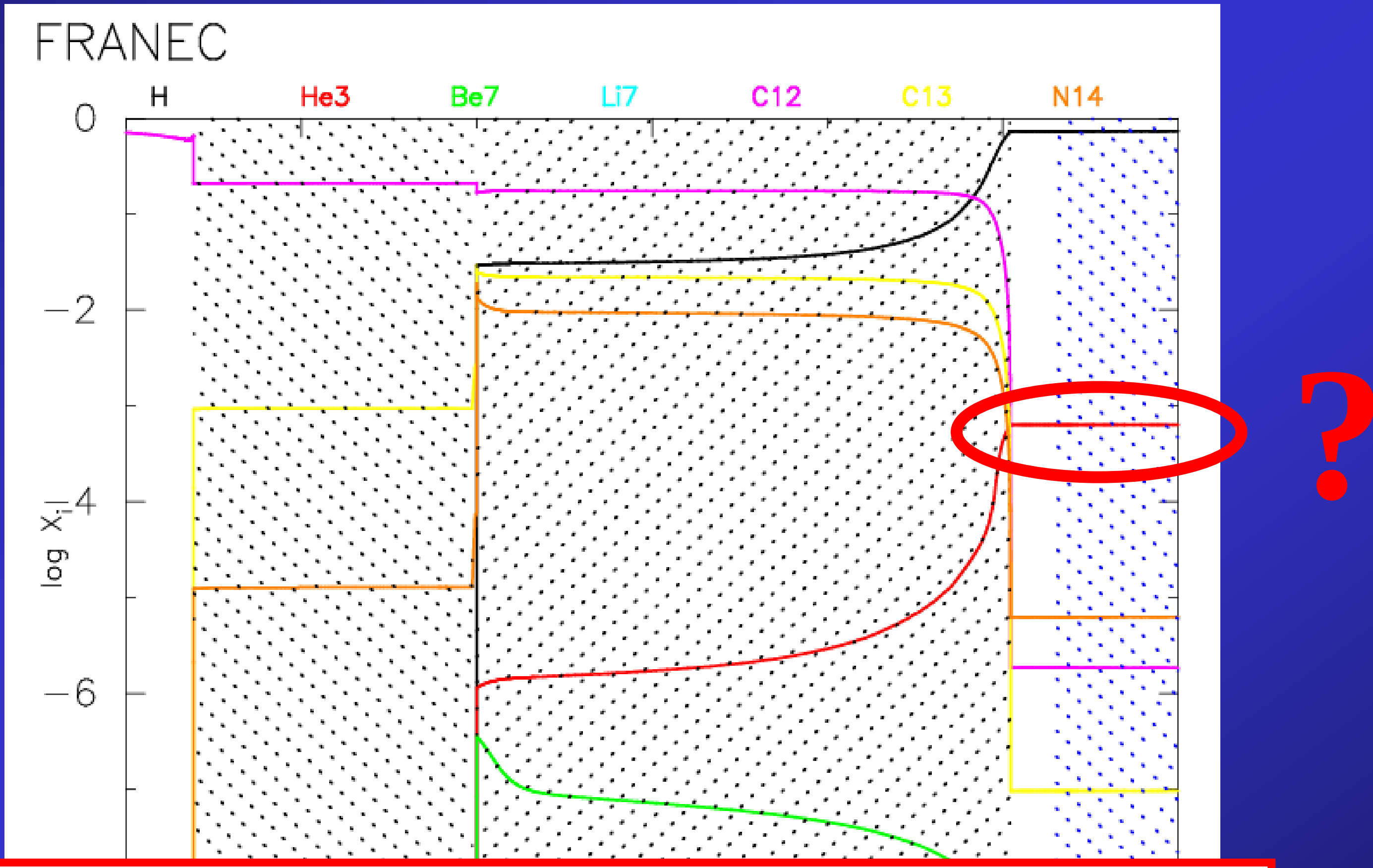
EXTRAMIXING PROCESSES DURING THE RGB & AGB

See PALMERINI's Poster (n.049)

See ANGELOU's Poster (n.306)

D: Deep Dredge Up (following PIE)

^{7}Li production



Have a second look to PALMERINI's & ANGELOU's Posters

See also

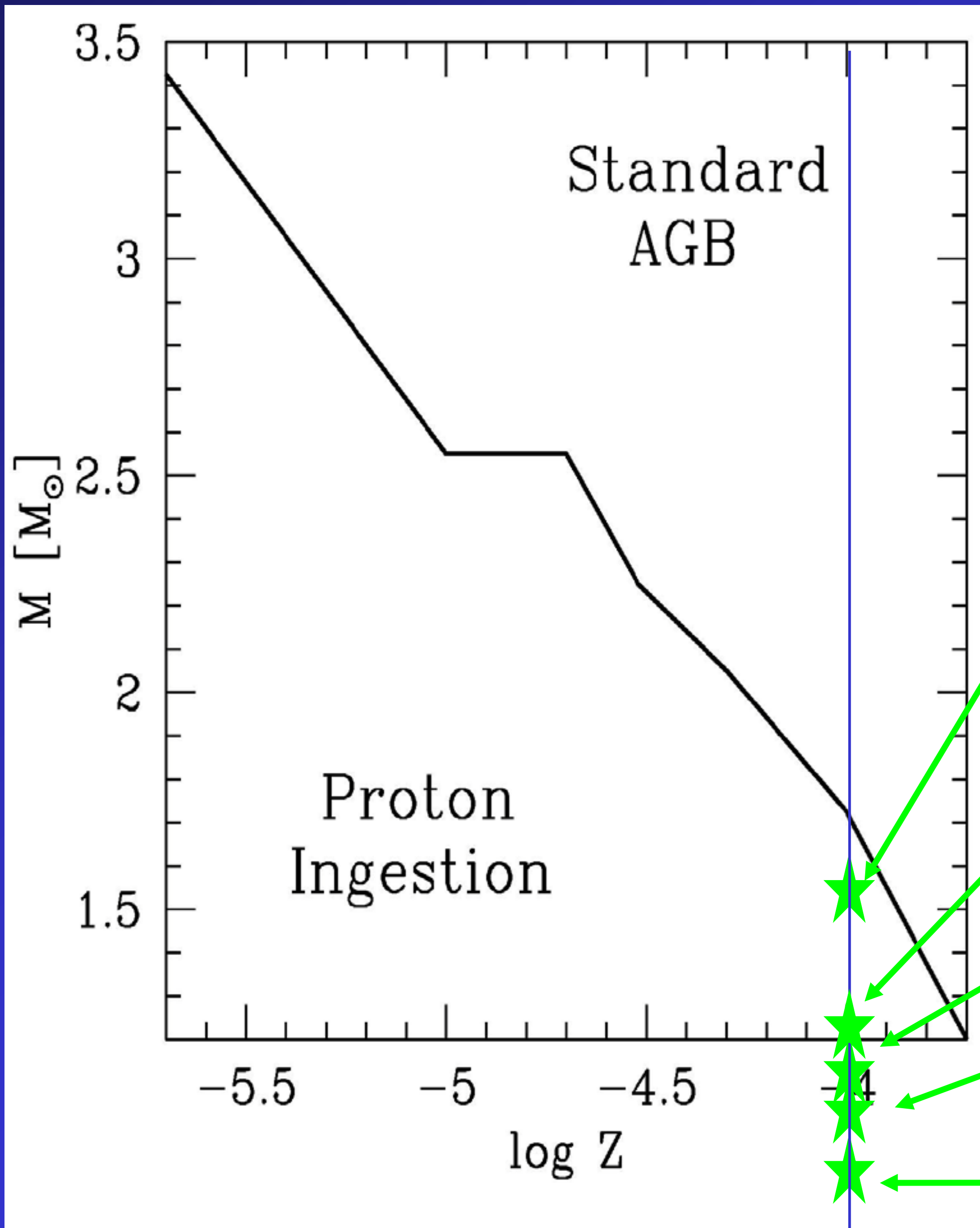
α-enhanced Models

[Fe/H]=-2.45

O_{enh}=0.55

α_{enh}=0.4

Z_{tot}~10^{-4}



***M*=1.5 *M*⊙**

***M*=1.2 *M*⊙**

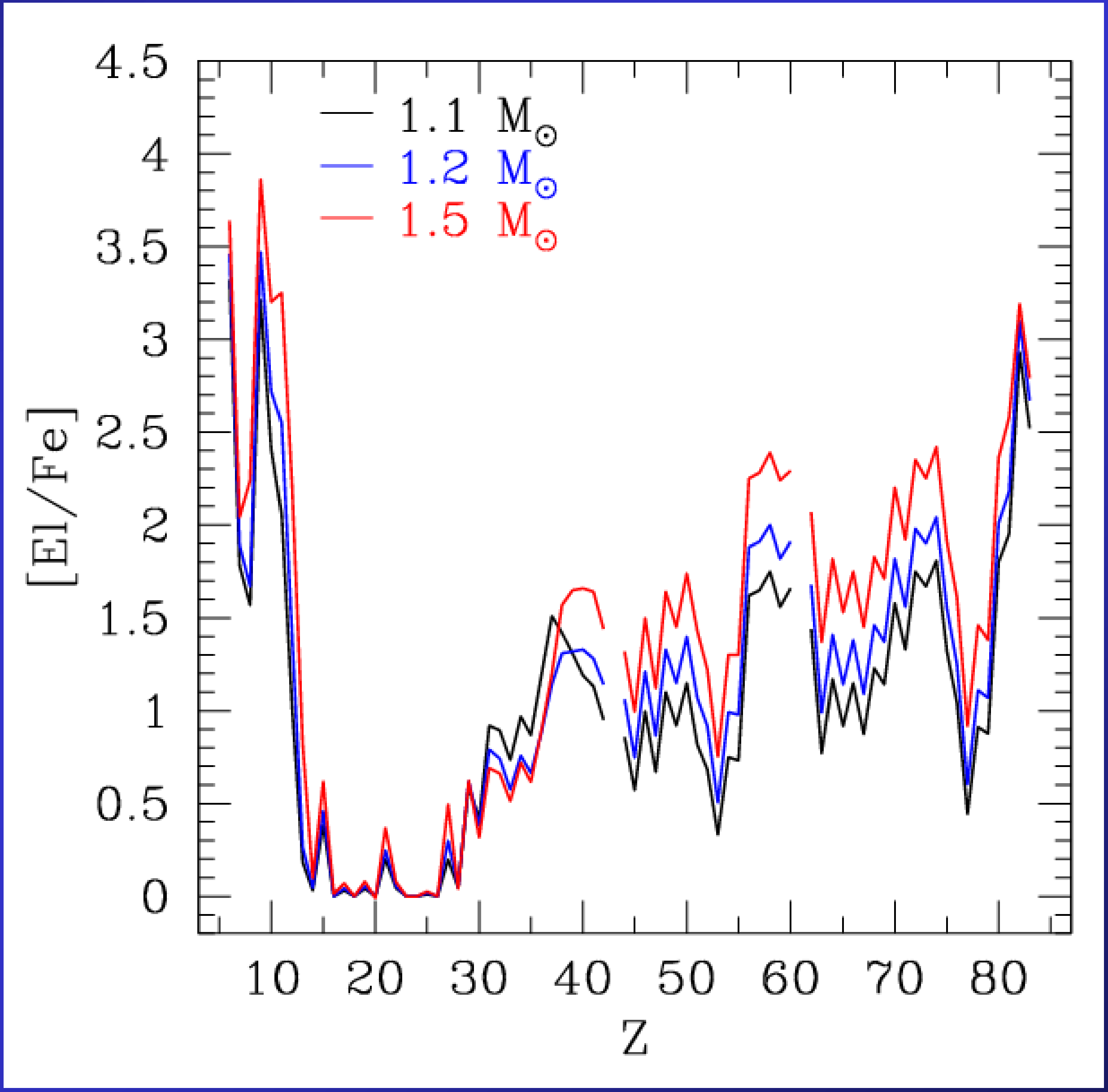
***M*=1.1 *M*⊙**

***M*=1.0 *M*⊙** In progress

***M*=0.85 *M*⊙** NO TDU

Final surface distributions of α-enhanced models

[Fe/H]=-2.45



These models show $^{12}C/^{13}C$>5000

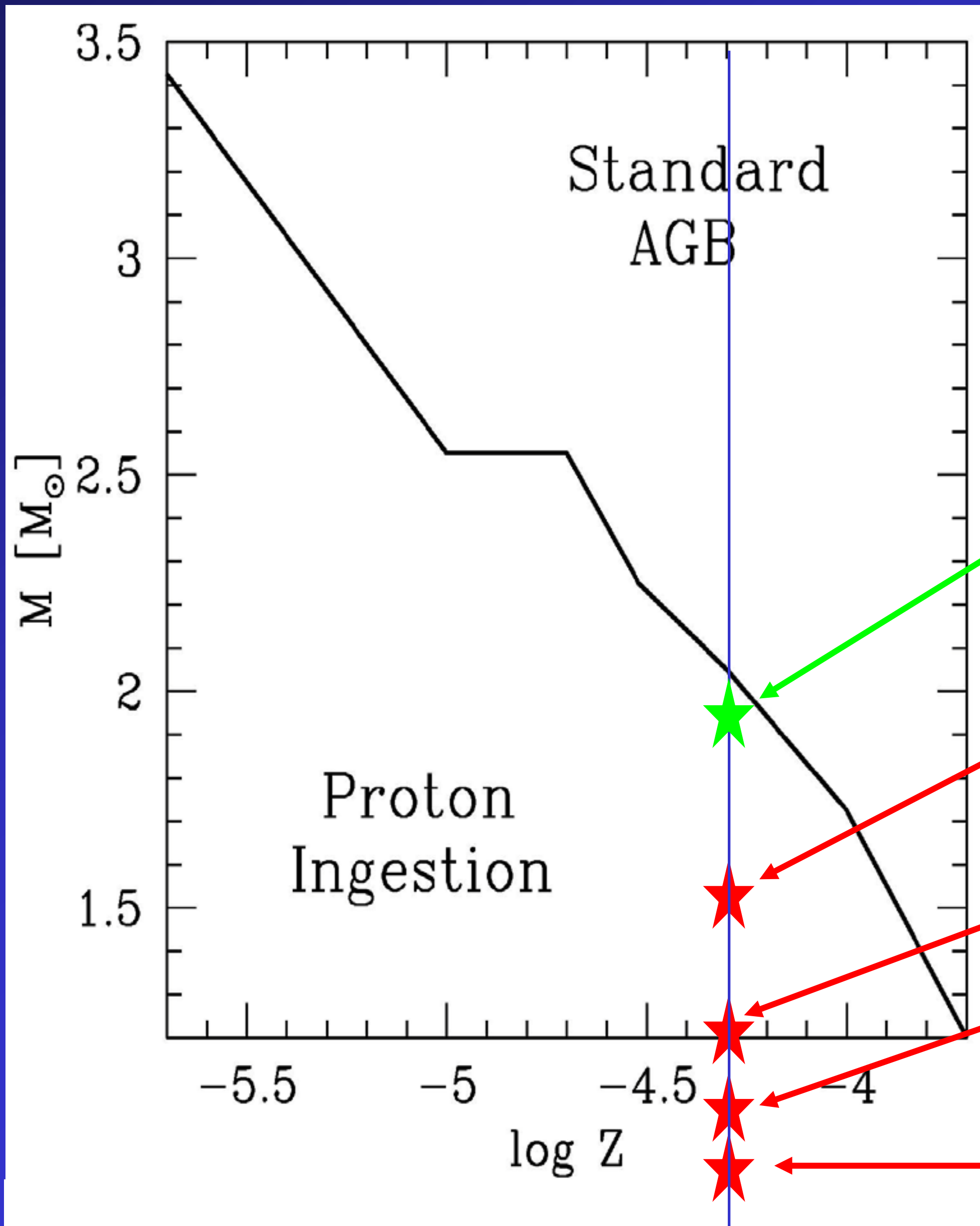
α-enhanced Models

[Fe/H]=-2.85

O_{enh}=0.55

α_{enh}=0.4

Z_{tot}~5x10^{-5}



***M*=2.0 *M*⊙** In progress

***M*=1.5 *M*⊙**

***M*=1.2 *M*⊙**

***M*=1.0 *M*⊙**

***M*=0.85 *M*⊙**

Final surface distributions of α-enhanced models

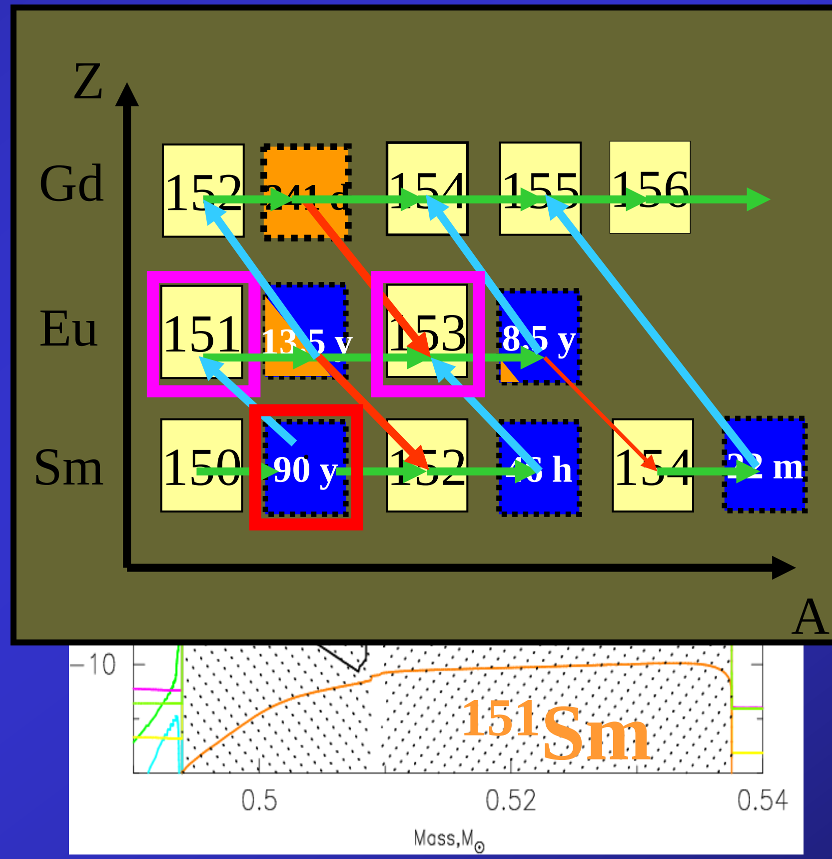
$M/M_{\odot}$	n. TDU	[C/Fe]	[C/N]	$^{12}C/^{13}C$	[ls/Fe]	[hs/Fe]	[hs/ls]
0.85	D+1	4.2	0.7	8.9	2.9	3.1	0.2
1.0	D+1	3.5	0.6	7.9	2.0	2.2	0.2
1.2	D+10	3.8	0.9	16.3	2.4	2.8	0.4
1.5	D+29	4.1	1.2	100	2.0	2.7	0.7

D: Deep Dredge Up (following PIE)

Production of ^{151}Eu

$M/M_\odot$	[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

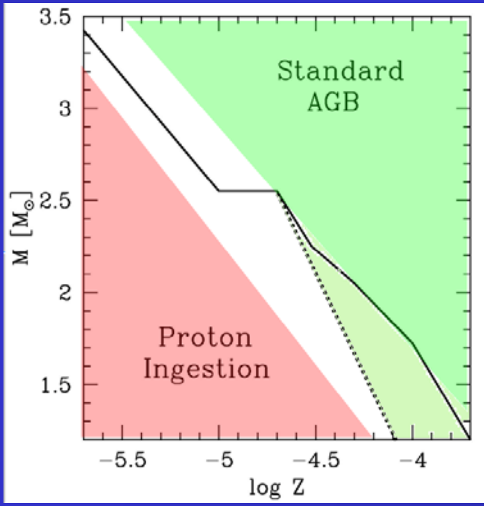
Standard s-process nucleosynthesis



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 $Z \sim 10^{-4}$;
2. Strong influence of the α-enhancement on the occurrence of PIE;
3. Importance of the adopted network;
4. Chemically enriched envelopes in very low mass stars;
5. PIE characteristics:
   - Low $^{12}C/^{13}C$ and [C/N] ratios;
   - Large amount of ^{7}Li (depending on the ^{3}He content!!);
   - Large amount of ls elements (very low [hs/ls] ratios);
   - Larger $^{151}Eu/^{153}Eu$ ratios with respect to a standard s-process nucleosynthesis.

IN THE FUTURE

Test the PIE in other stellar phases:

1. **Very Late Thermal Pulse Scenario**

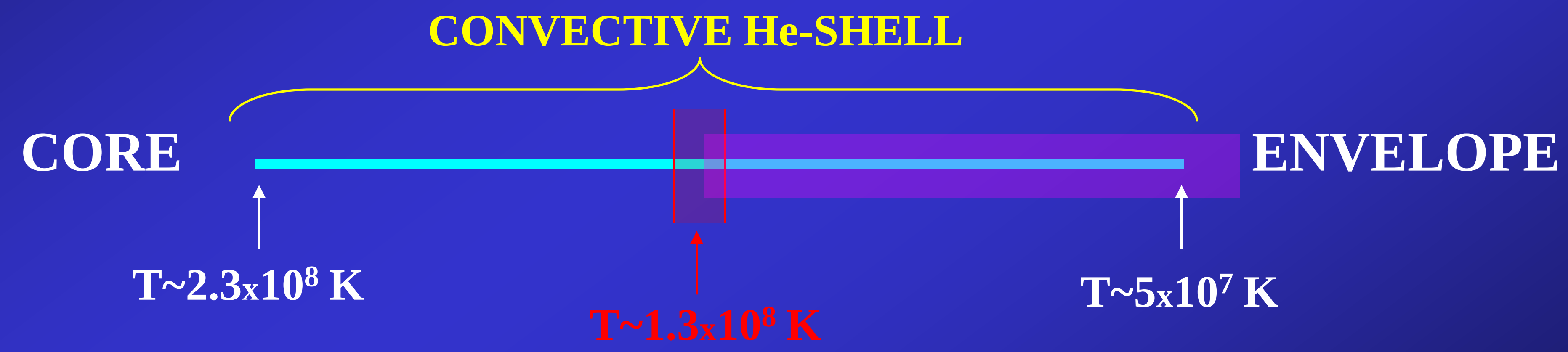
   see HERWIG&HIRSCHI's (n. 224) & PIGNATARI's (n.255) Posters

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 →Coupling between phisical and chemical evolution
- Large neutron densities (n_n>10^{14} cm^{-3}) →700 isotopes & 1000 reactions



We limit proton ingestion up to the mesh where τ_{CNO}=1/3 Δt

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