The fundamental role of the metallicity in the nucleosynthesis of heavy elements

Oscar Straniero, Sergio Cristallo,
Luciano Piersanti & Roberto Gallino

INAF-Osservatorio AstronomicoTeramo

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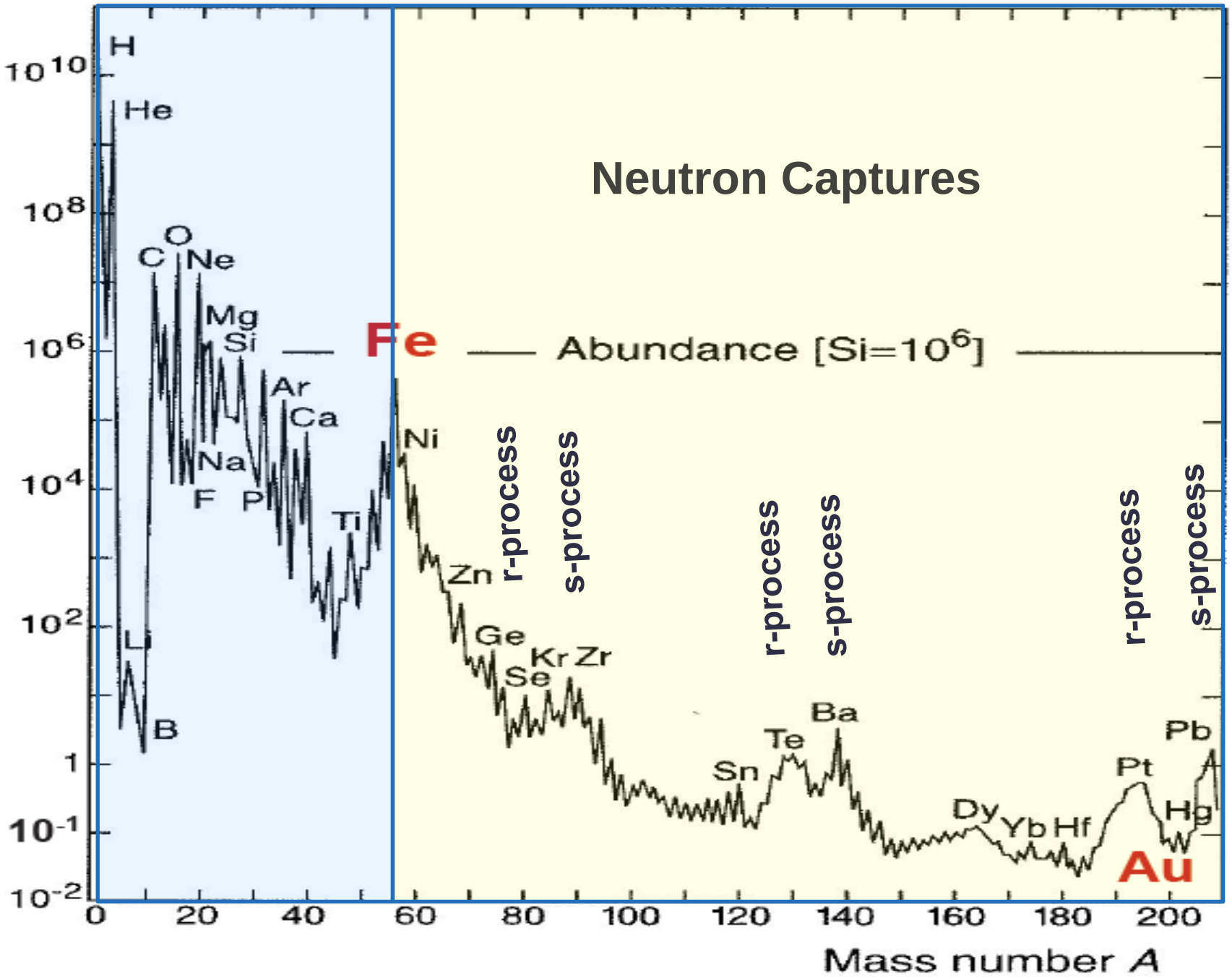
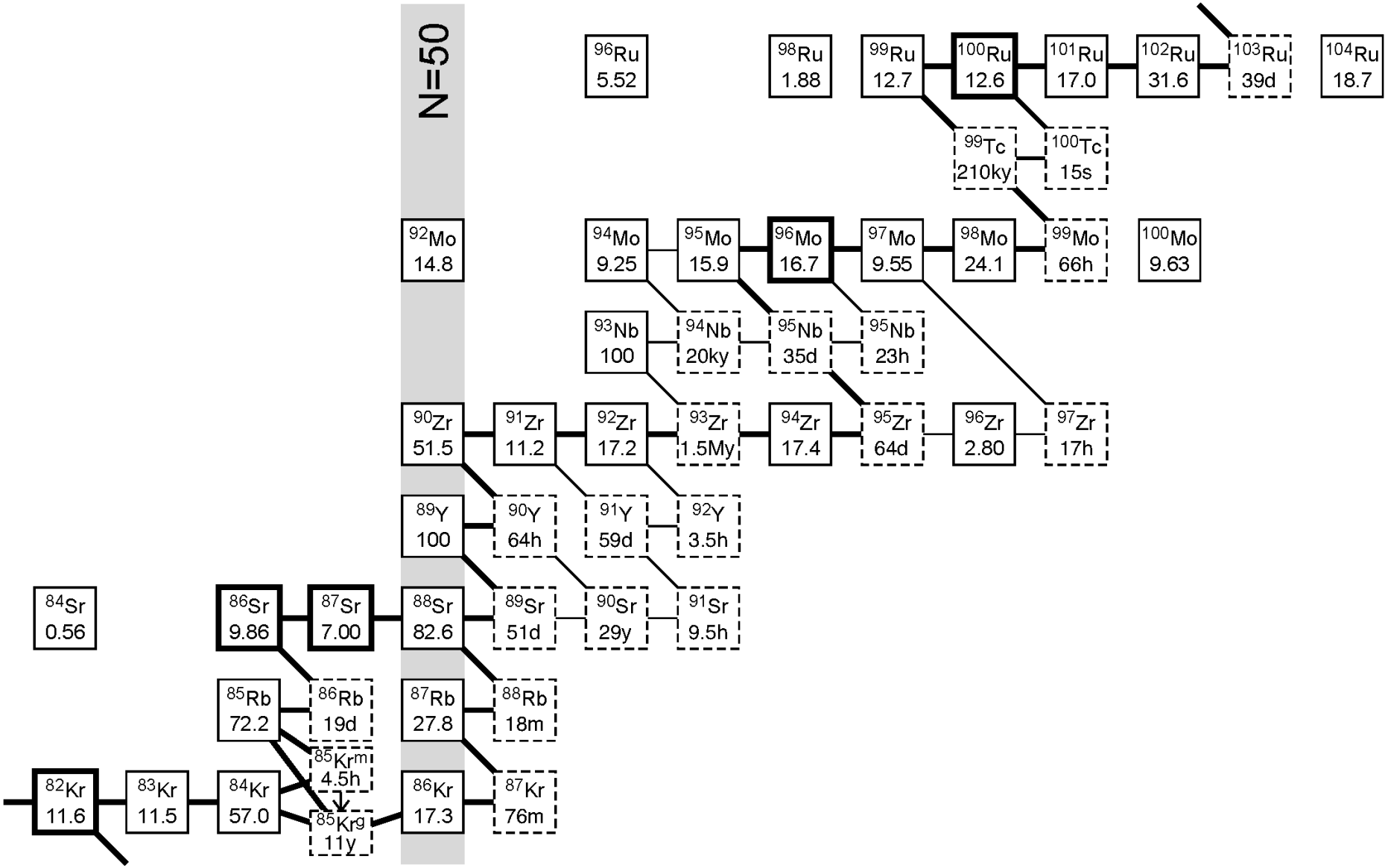

Neutron Captures
Abundance [Si=10^6]
Fe
H
He
C
O
Ne
Mg
Si
Na
F
P
Ar
Ca
Ti
Ni
Zn
Ge
Se
Kr
Zr
Sn
Te
Ba
Dy
Yb
Hf
Pt
Pb
Hg
Au
Li
B
r-process
s-process
r-process
s-process
r-process
s-process
10^10
10^8
10^6
10^4
10^2
1
10^-1
10^-2
0
20
40
60
80
100
120
140
160
180
200
Mass number A


N=50
96Ru 5.52
98Ru 1.88
99Ru 12.7
100Ru 12.6
101Ru 17.0
102Ru 31.6
103Ru 39d
104Ru 18.7
99Tc 210ky
100Tc 15s
92Mo 14.8
94Mo 9.25
95Mo 15.9
96Mo 16.7
97Mo 9.55
98Mo 24.1
99Mo 66h
100Mo 9.63
93Nb 100
94Nb 20ky
95Nb 35d
95Nb 23h
90Zr 51.5
91Zr 11.2
92Zr 17.2
93Zr 1.5My
94Zr 17.4
95Zr 64d
96Zr 2.80
97Zr 17h
89Y 100
90Y 64h
91Y 59d
92Y 3.5h
84Sr 0.56
86Sr 9.86
87Sr 7.00
88Sr 82.6
89Sr 51d
90Sr 29y
91Sr 9.5h
85Rb 72.2
86Rb 19d
87Rb 27.8
88Rb 18m
85Krm 4.5h
82Kr 11.6
83Kr 11.5
84Kr 57.0
85Krg 11y
86Kr 17.3
87Kr 76m

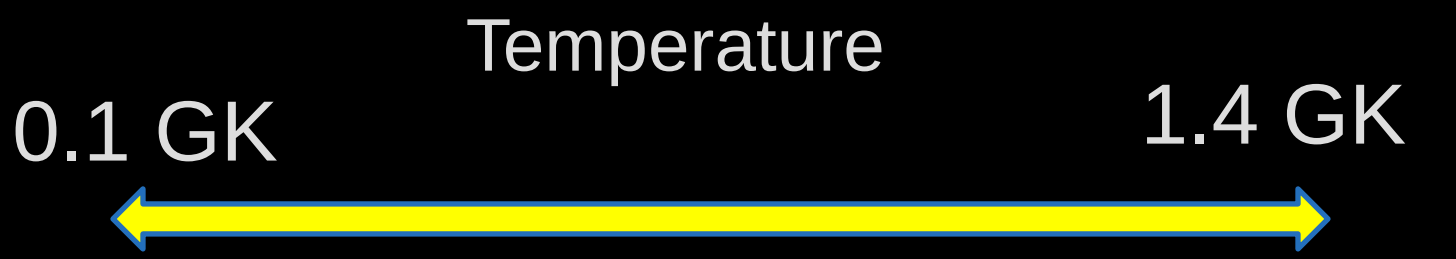
The s-process: Where:

- WEAK (A<90): MASSIVE STARS → shell-He burning (marginally), shell-C burning (mostly).

- MAIN (90<A<180): LOW MASS TP-AGB STARS → in a thin pocket close to the top of the He-rich intershell during the interpulse period (mostly). Also within the convective zone powered by a thermal pulse (marginally).

- STRONG (A>180): LOW MASS TP-AGB STARS (LOW Z) → as for the main component

Physical conditions



Low mass AGB

Low mass AGB

Massive AGB

Massive stars

Neutrons and neutron sources

WEAK : $^{22}Ne(\alpha,n)^{25}Mg$

$n=10^{6}$-10^{11} cm^{-3}

MAIN and STRONG: $^{13}C(\alpha,n)^{16}O$

$n=10^{6}$-10^{7} cm^{-3}

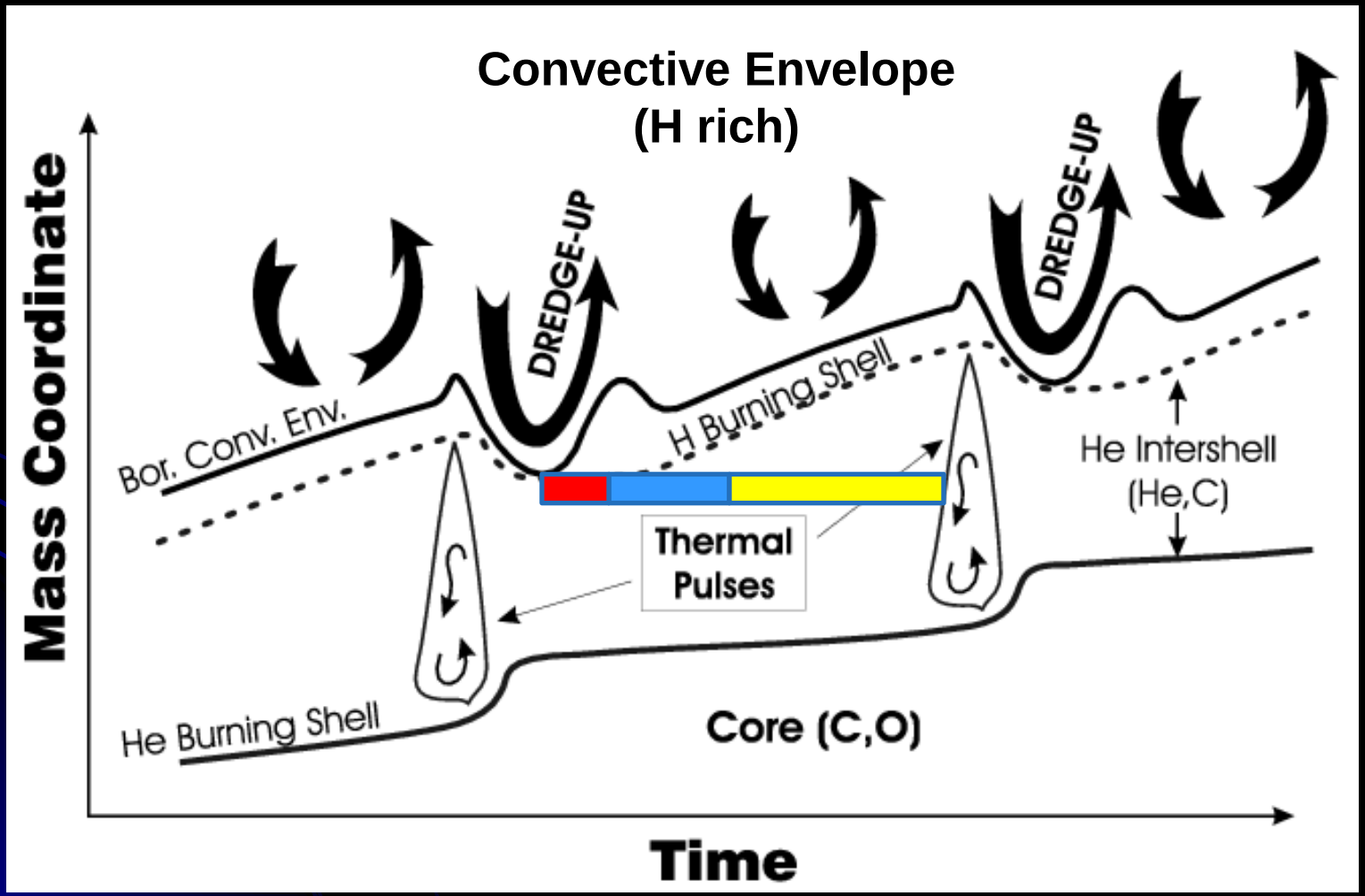
(marginal) $^{22}Ne(\alpha,n)^{25}Mg$

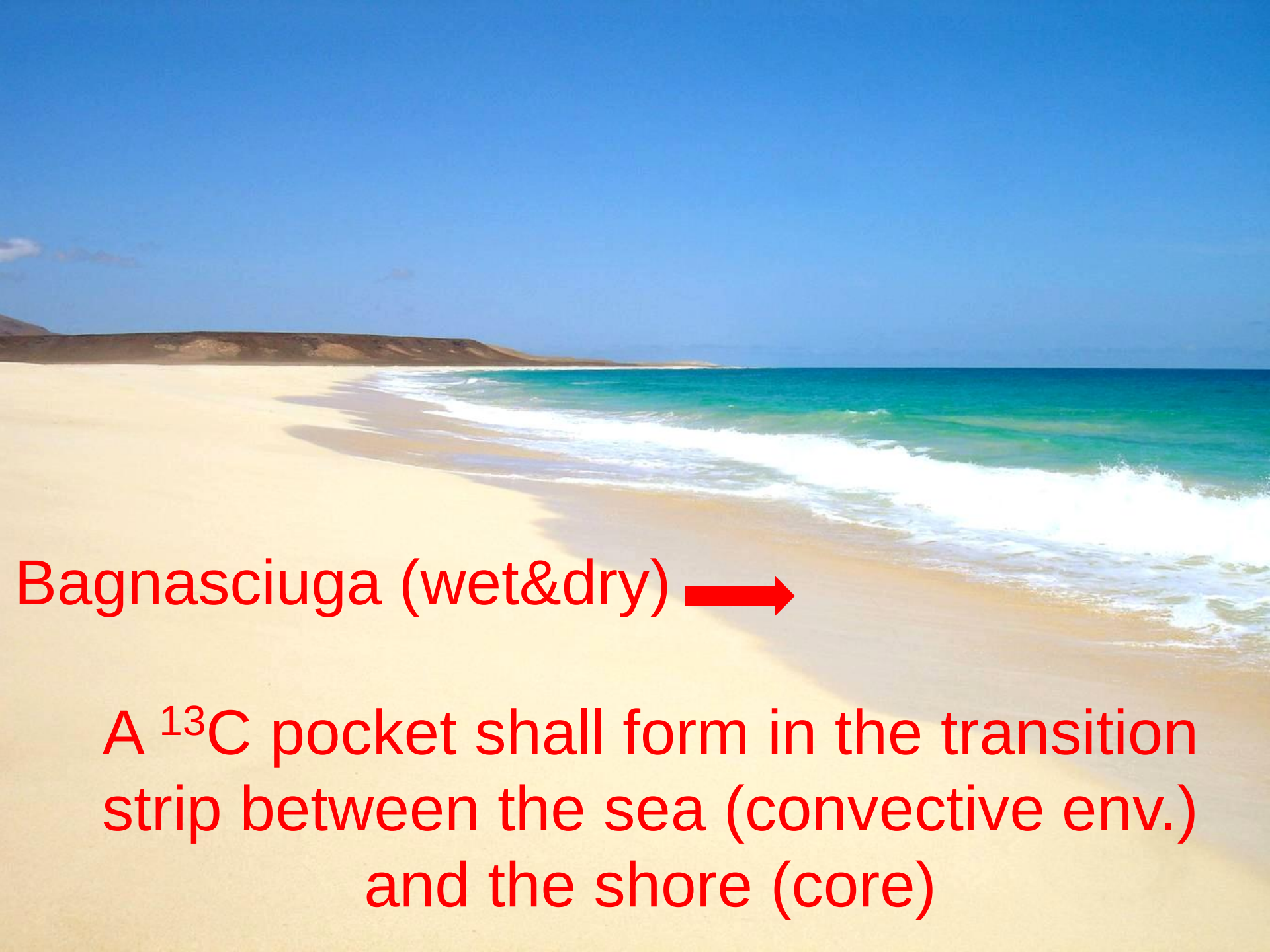
$n=10^{9}$-10^{10} cm^{-3}

Special cases: Proton Ingestions (CEMPs and Sakurai's objects) $^{13}C(\alpha,n)^{16}O$ with $n=10^{15}$ cm^{-3}

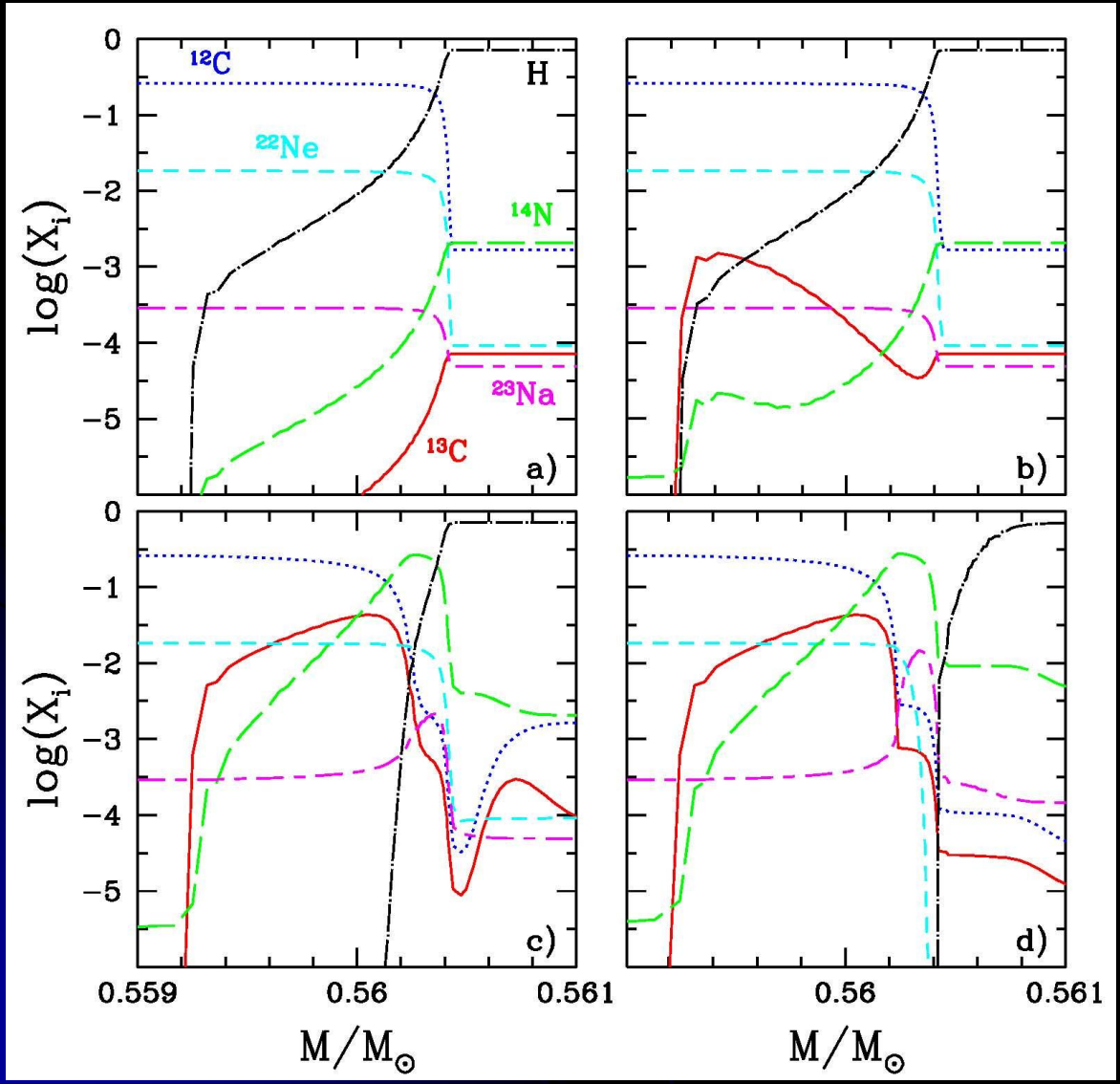
s-Proess paradigm for low-mass AGB (1-3 $M_{\odot}$)

Straniero et al. 1995 - Gallino et al. 1998




Bagnasciuga (wet&dry)
A ^{13}C pocket shall form in the transition strip between the sea (convective env.) and the shore (core)

The formation of the ^{13}C pocket in the wet&dry transition zone



$M=2M_{\odot}$ $Z=Z_{\odot}$

a) Maximum envelope penetration (TDU);

b) $^{12}C(p,\gamma)^{13}N(\beta^{-})^{13}C$ $^{13}C(p,\gamma)^{14}N$;

c) $^{22}Ne(p,\gamma)^{23}Na$;

d) The 3 pockets fully developed

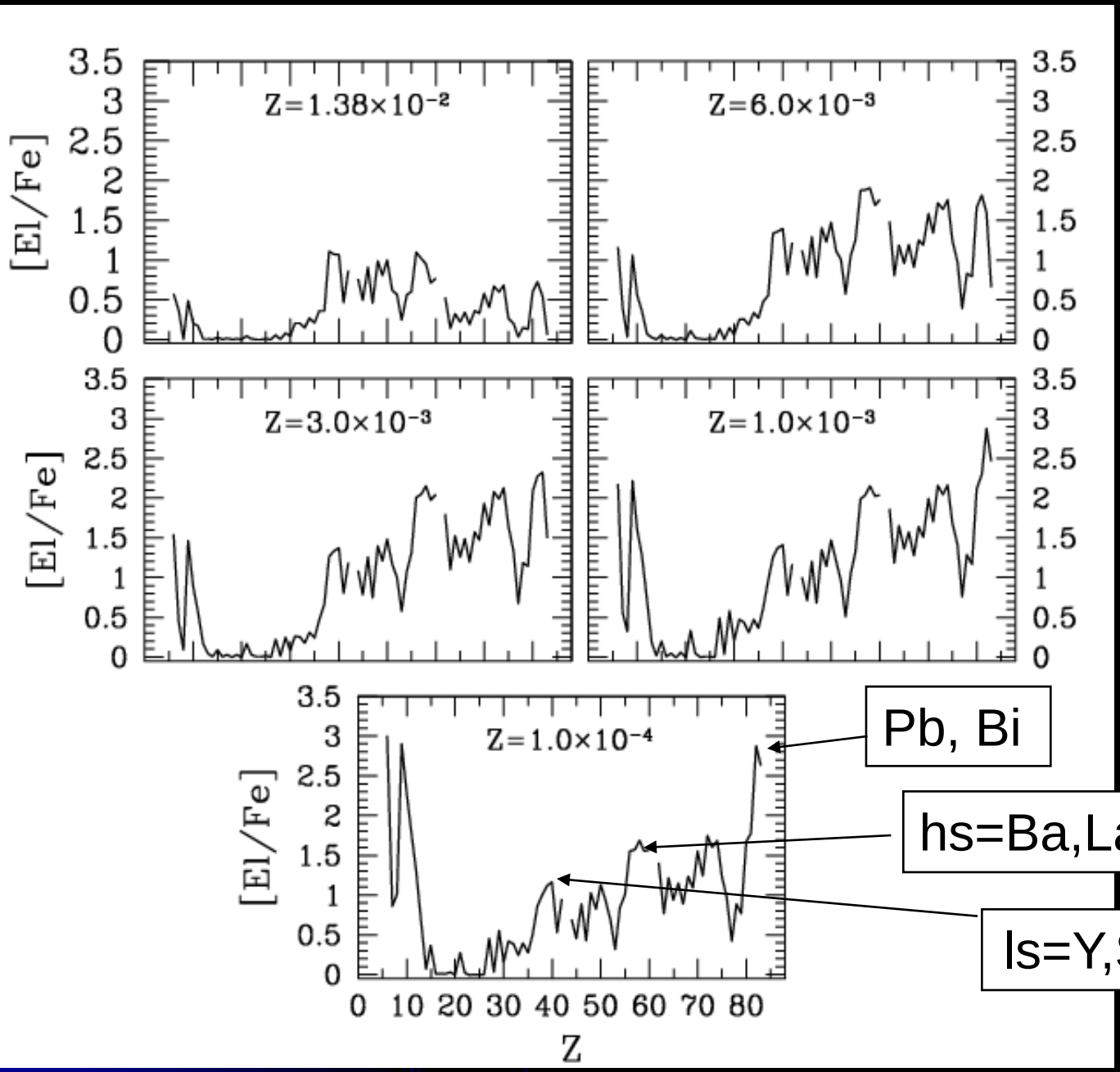
Later on, the $^{13}C(\alpha,n)^{16}O$ and the s-process

Full Network Stellar Evolution Models

- Full network (700 isotopes) coupled to stellar structure equations.
- Atomic & Molecular Opacity accounting for dredge up (C and N variations).
- Mass loss calibrated on pulsating AGB stars.

Straniero et al 2006 (Nucl. Phys. A)

Cristaòòp et al 2009, 2011 (ApJ)



Final AGB composition for $0.0001<Z<Z_{\odot}$

Varing the metallicity: theory versus observations

✓ AGB stars undergoing TPs and III TDU in the Galactic Disk or in nearby Galaxies (either O- and C-rich), like C(N type) stars. Tc detected (or low Nb).

✓ Post-AGB stars.

✓ s-rich stars, dwarfs or giants (no Tc), like Ba stars or CH stars (or CEMPs).

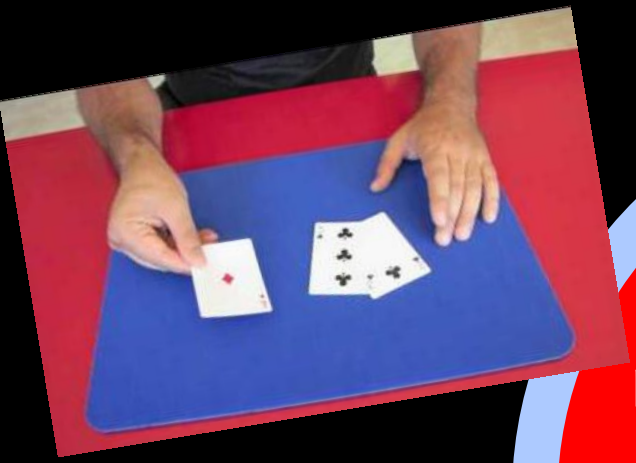
✓ AGB imprints in presolar grains (SIC or O-rich).

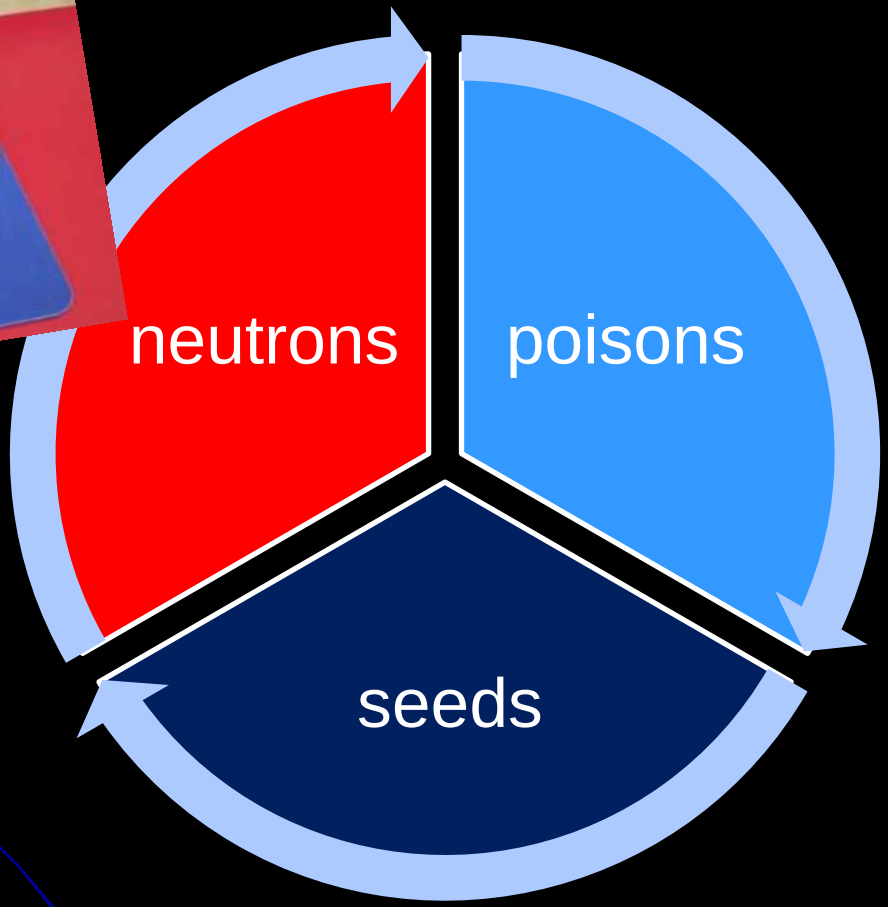
✓ AGB imprints in the Galactic Chemical Evolution.

Models Constraints

- hs/ls: is a measure of the neutrons/seeds ratio. It depends on the amount of neutrons (^{13}C), poisons (^{14}N) and seeds (Fe). Better than X/Fe, which is affected by several uncertain quantities, such as mass-loss rate, dredge-up ……
- Branching: Rb/Sr or $^{96}Zr/^{90}Zr$. They depends on the neutron density and, in turn, on the temperature of the stellar site where they are syntesized….
- AGB Luminosity Functions: depends on mass loss and dredge up

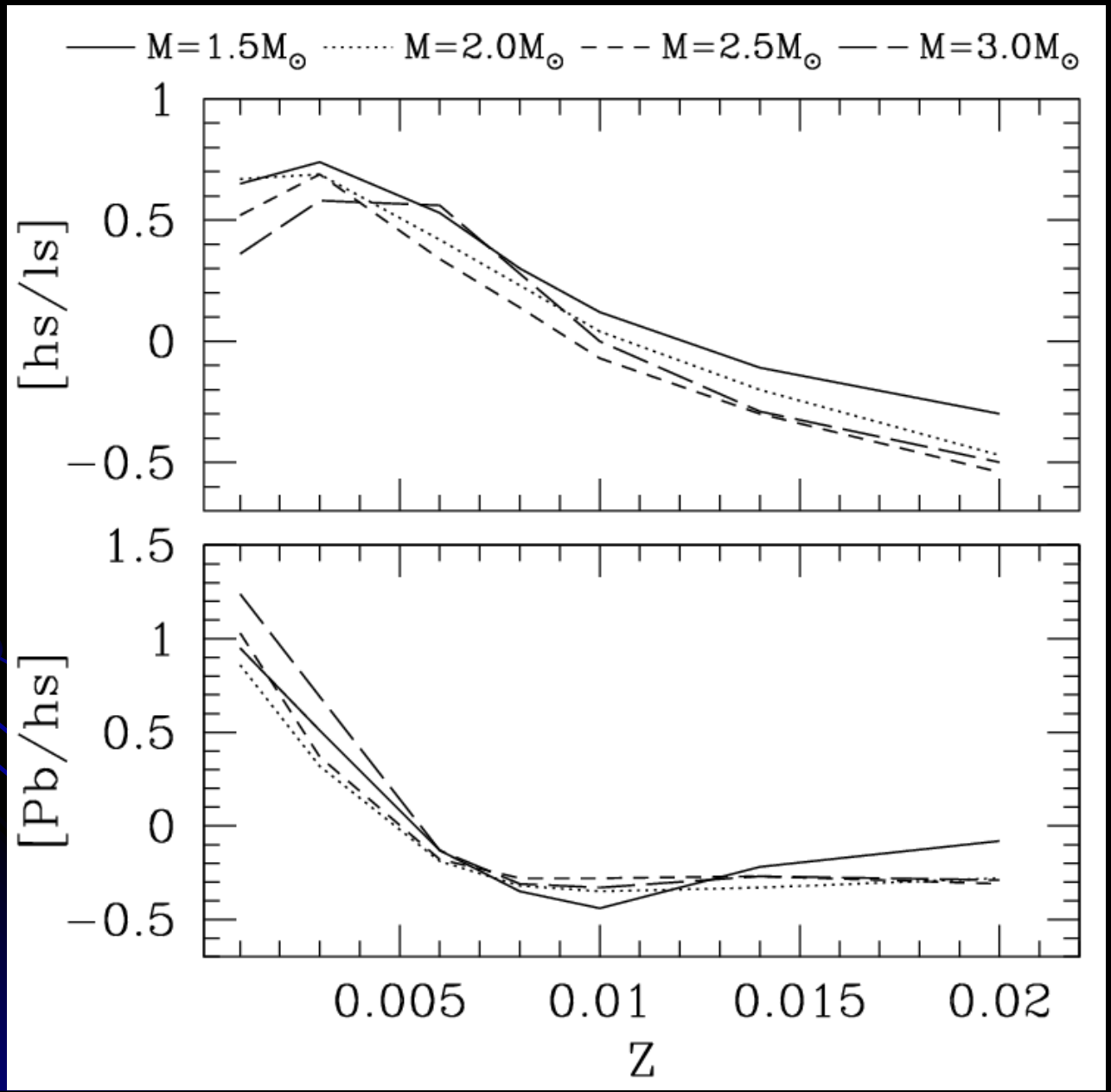
The hs/ls: a 3 cards game



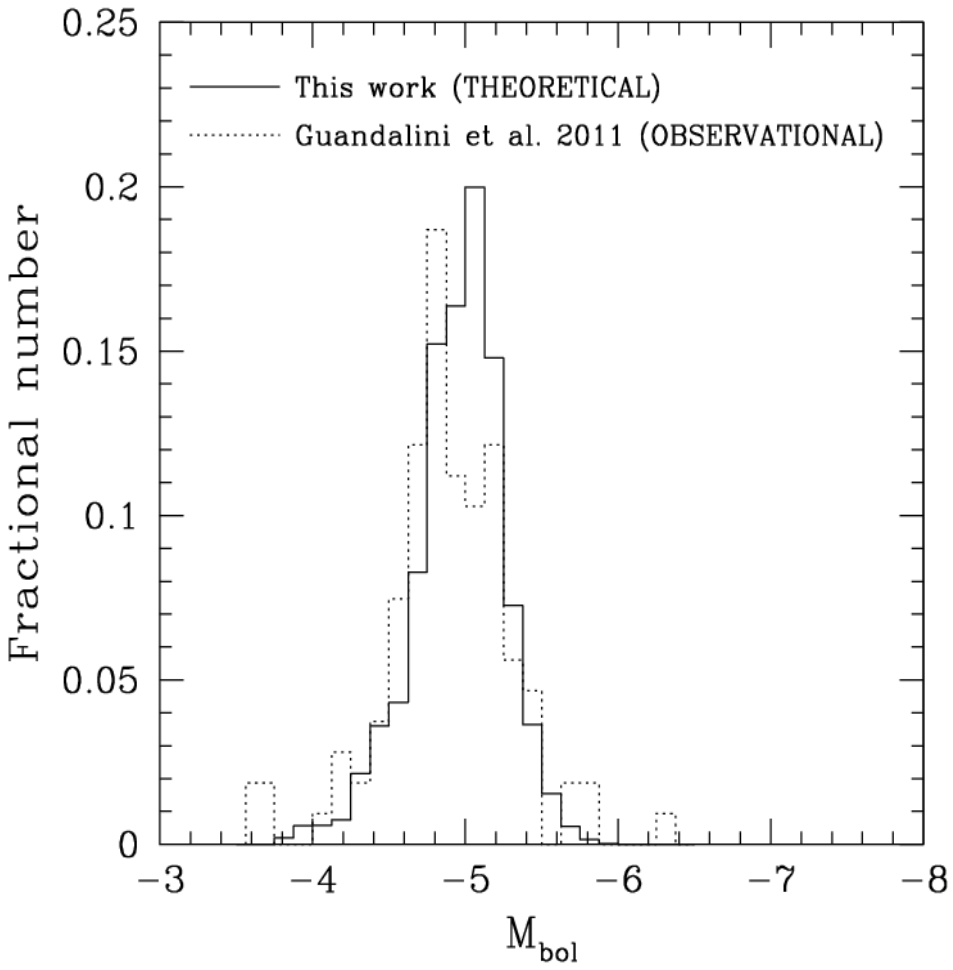


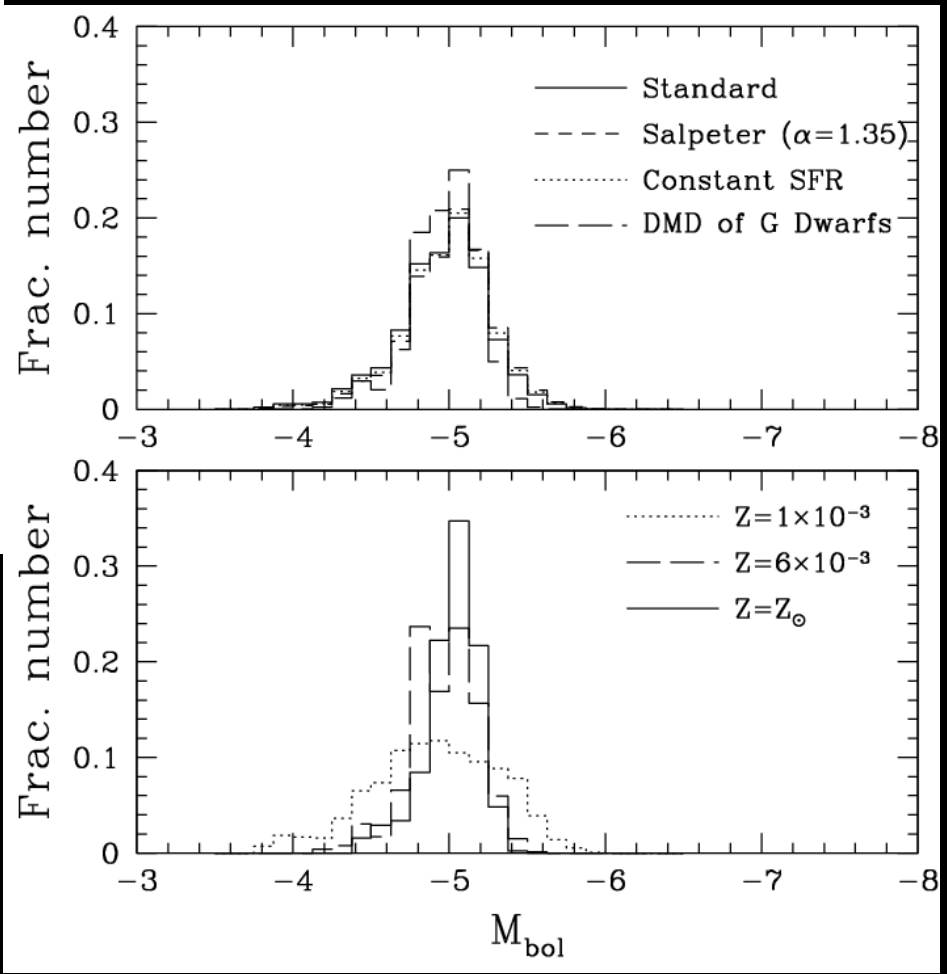
$$\frac{(\text{neutrons-poisons})}{\text{seeds}} \rightarrow \left[\frac{hs}{ls}\right]$$

Combining heavy-s and light-s



C-star LF Galactic Disk





Costraints for mass loss and dredge up

Mixing by rotation depends on ω_{rot}:

- Mixing limited to the ^{13}C pocket. In this case the ^{13}C spreads out, The total amount of neutrons is conserved, but ^{13}C/Fe is lower → lower neutrons/seeds and, in turn, lower hs/ls.

- Mixing extended up to the ^{14}N pocket. Partial or total overlap of ^{13}C and ^{14}N. This is equivalent to reduce the *effective* $^{13}C_{eff}=^{13}C-^{14}N$. The total number of neutron is lower → lower neutrons/seeds and lower hs/ls

s-process in a convective zone

- If the s-process takes place at the base of an extended convective zone, the seeds consumption is counterbalanced by the rapid mixing of fresh material from outside. This occurrence favors the light-s production.
- In massive AGB, we found an overproduction of ls, indeed, because the s process is dominated by the ^{22}Ne burning in the convective zones generated by the TPs. A similar result is found as a consequence of the proton ingestion in extremely-metal-poor AGBs.

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

(Franec Repository of Updated Isotopic Tables & Yields)

On-line DataBase v. 1.2.b

Select Data:

Mass ($M_\odot$)	Metallicity (Z)	Nuclides Properties	Multiple Table format (6)	Single Table format (7)
--	--	◉ Elements (1,2) Z: All	◉ All TDUs ○ Final Composition	○ Final Composition
		○ Isotopes (3) A: All Z: All		
		○ s-process (4) : [hs/ls], [Pb/hs], ...		
		○ Yields (5) A: All Z: All	○ Final	○ Final

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Physical quantities corresponding to the AGB models (.PDF file)

http://www.oa-teramo.inaf.it/fruity