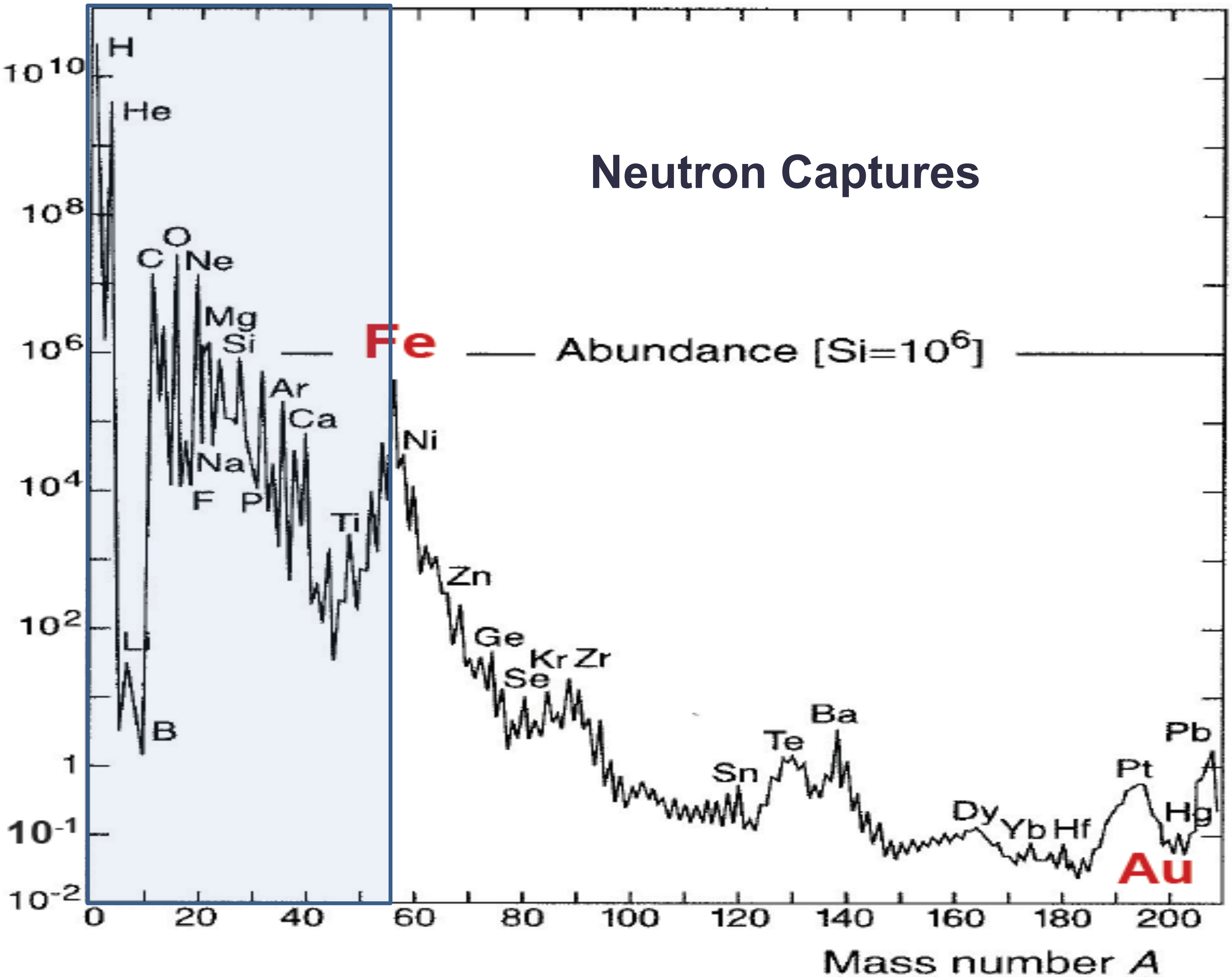
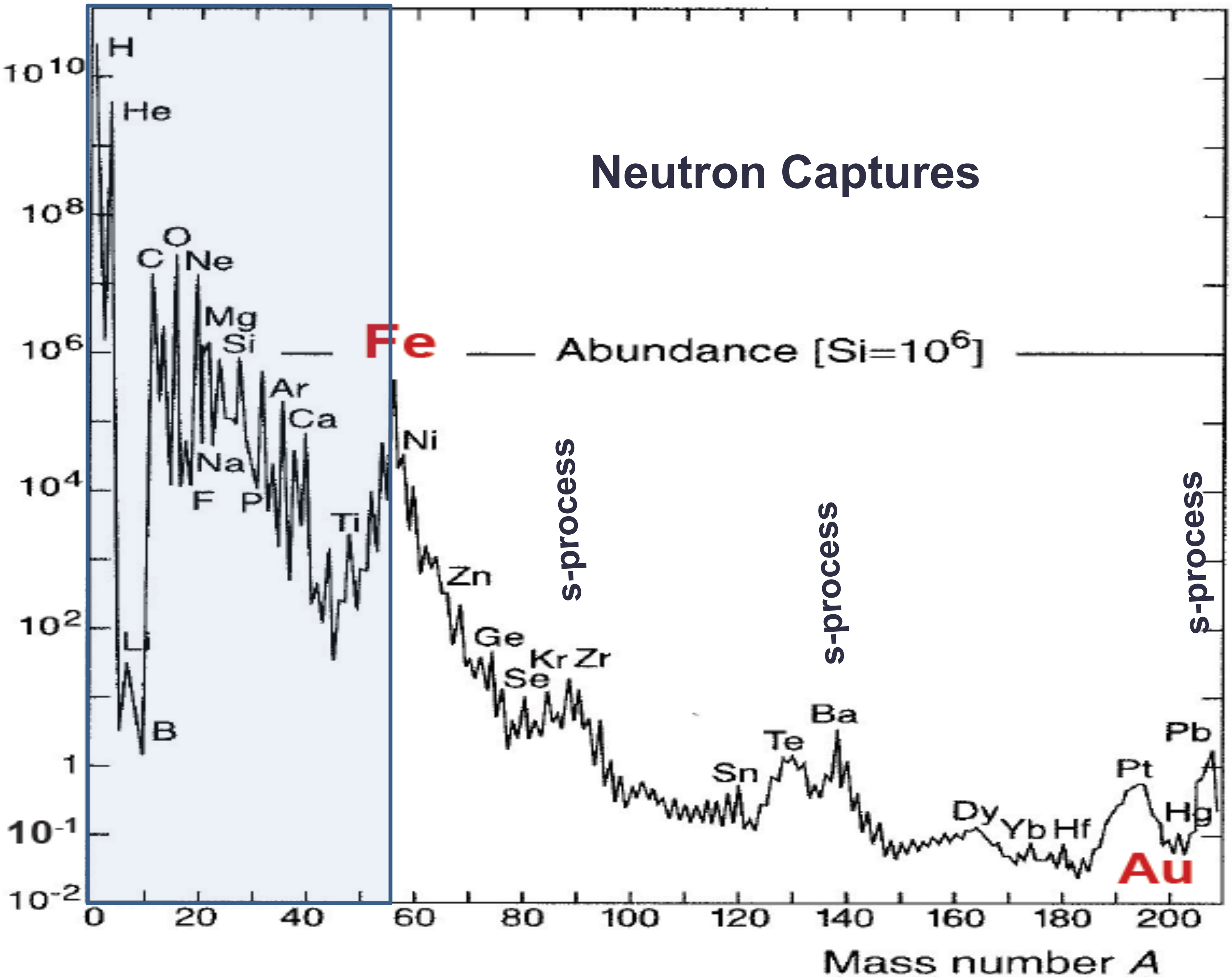
Stars and Stardust: Astrophysics at SPES

Oscar Straniero
INAF and INFN-LNGS

Caserta 12/13 Nov 2015



Neutron Captures
Abundance [Si=10^6]
Fe
Au
H
He
C
O
Ne
Mg
Si
Na
F
P
Ar
Ca
Ti
Ni
Zn
Ge
Se
Kr
Zr
Li
B
Sn
Te
Ba
Dy
Yb
Hf
Pt
Hg
Pb
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



Neutron Captures
Fe
Abundance [Si=10^6]
s-process
s-process
s-process
Au
H
He
C
O
Ne
Mg
Si
Ar
Ca
Na
F
P
Ti
Li
B
Ni
Zn
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Se
Kr
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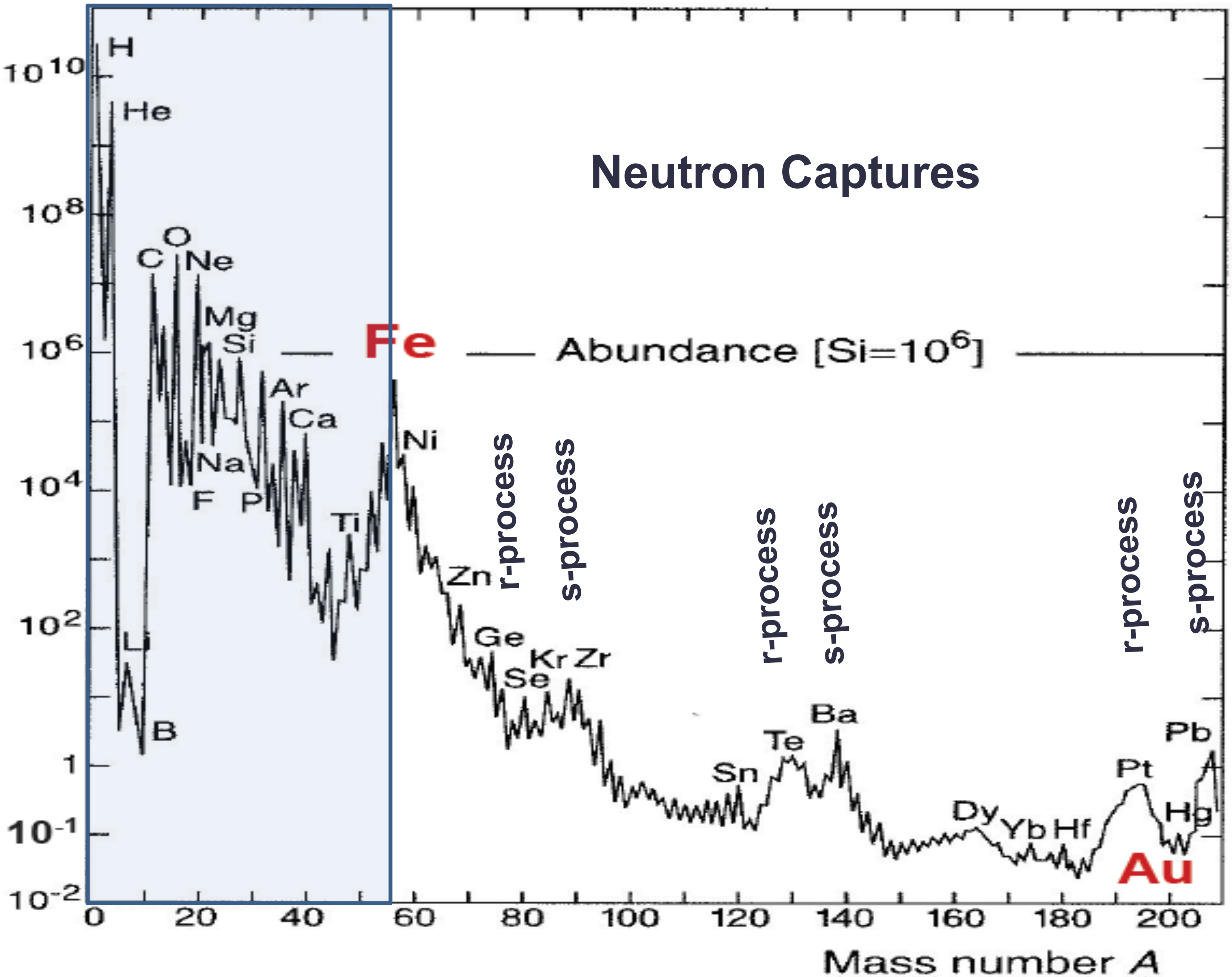
Neutron Captures
Abundance [Si=10^6]
Fe
Au
r-process
s-process
r-process
s-process
r-process
s-process
H
He
Li
B
C
O
Ne
Mg
Si
Na
F
P
Ar
Ca
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Ni
Zn
Ge
Se
Kr
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Sn
Te
Ba
Dy
Yb
Hf
Pt
Hg
Pb
Mass number A

The synthesis of heavy nuclei

- s process: Slow neutrons - $10^7 < n < 10^{11}$ cm^{-3} (low mass AGB !!!!, core-He and shell-C burnings of massive stars ?)

- r process: Rapid neutrons – $n > 10^{20}$ cm^{-3} (core collapse Sne, NS mergers ?)

- p process: photodissociations on s or r seeds (SNe ??????)

Intermediate process: $n \approx 10^{15}$ cm^{-3} ?
LEPP ?????

Chemical evolution: Observables

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- Sun: photospheres, solar corona, solar wind; and solar syste: meteorites, planets, minor bodies (asteroids and comets).

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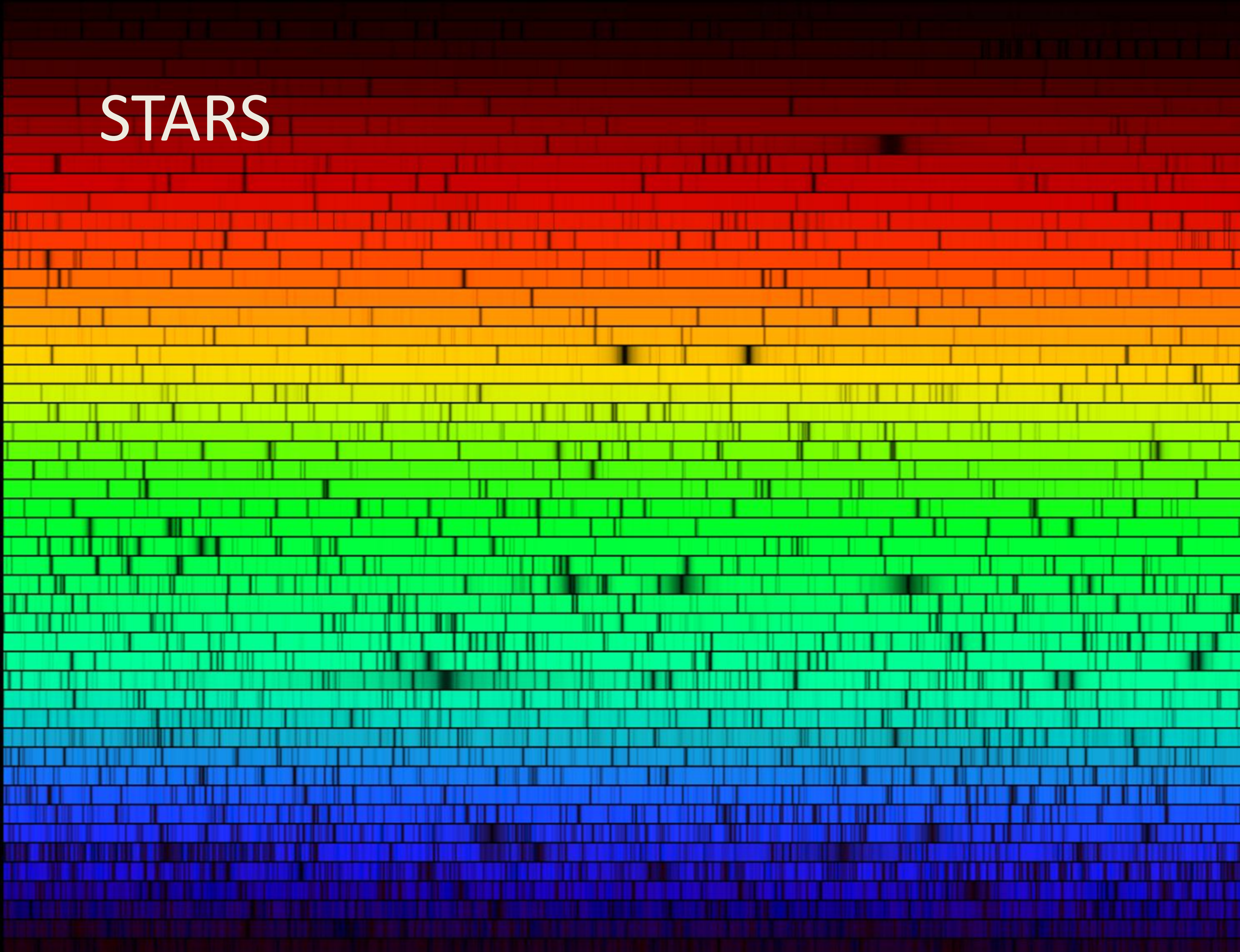
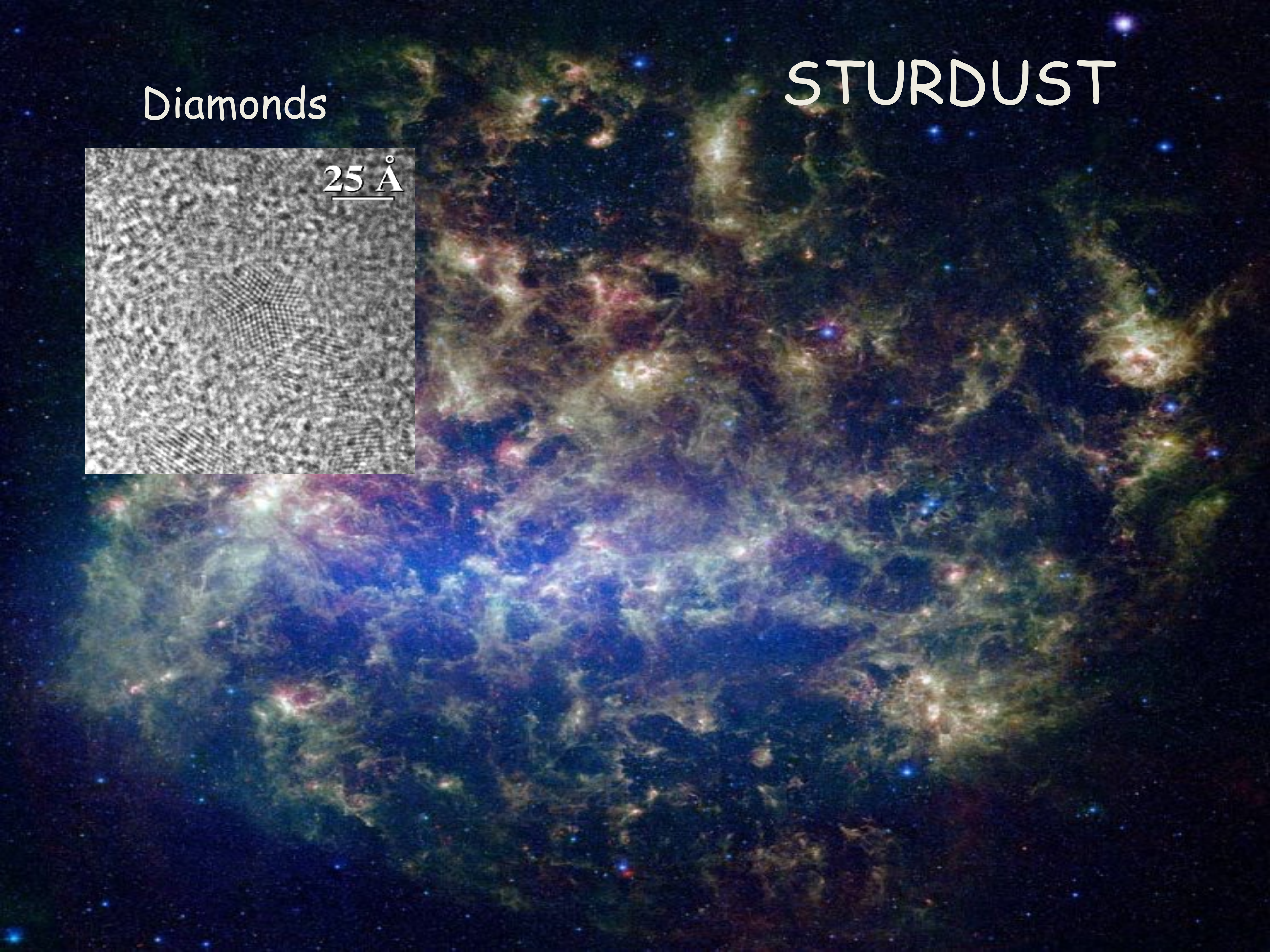
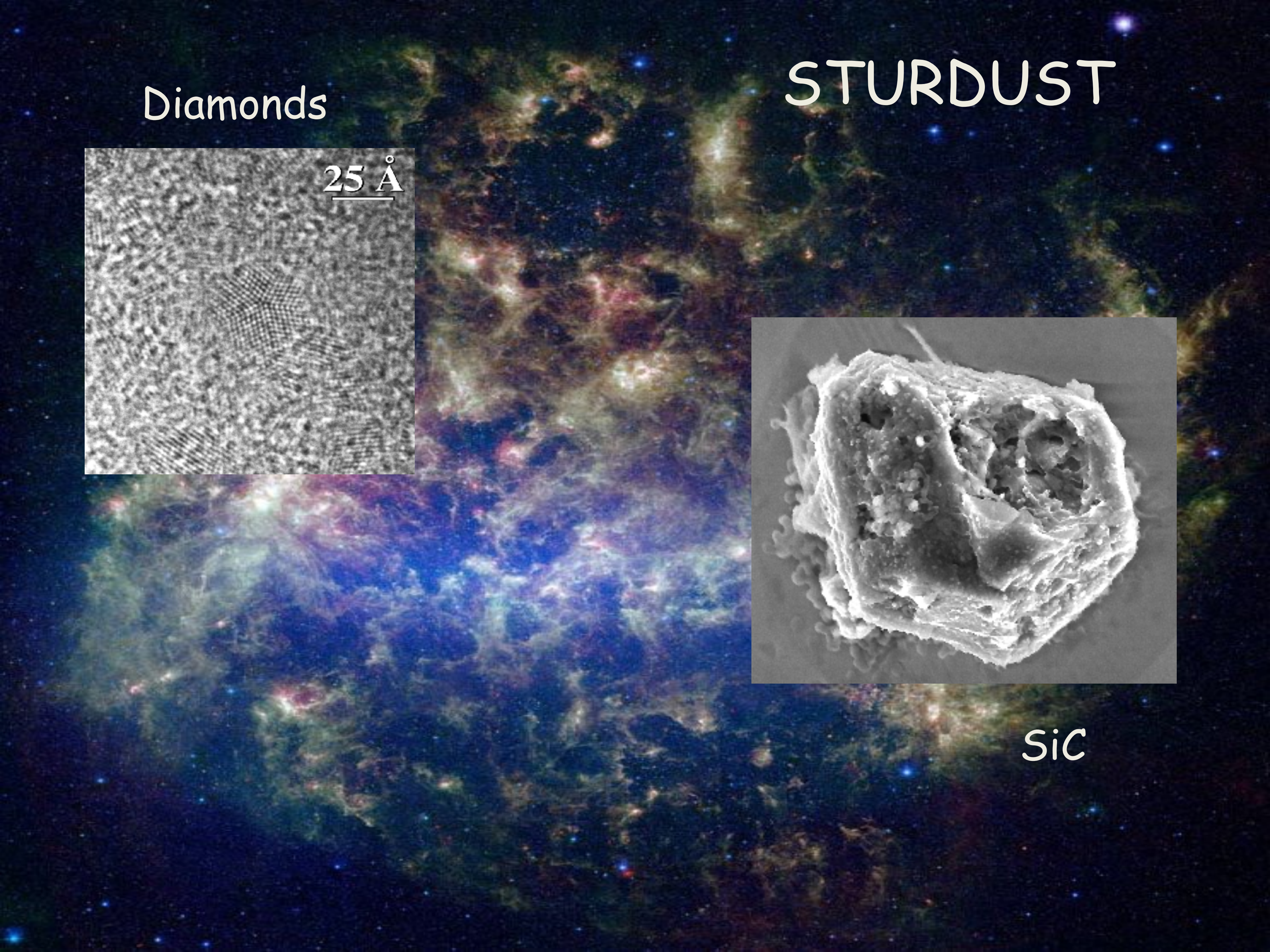
- Interstellar Medium (radio to UV, radioactive decays X and γ).
- Pre-solar grains found in meteorites.

STARS



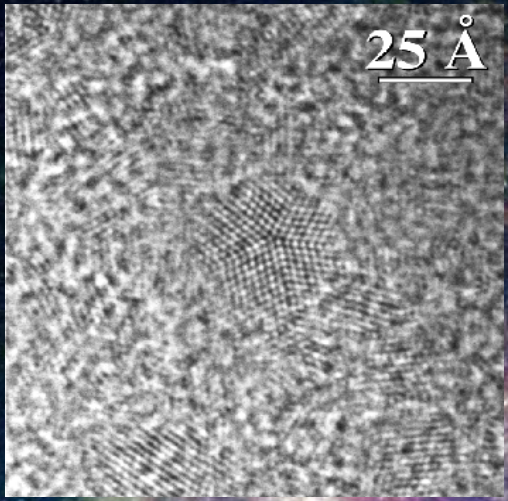

STURDUST

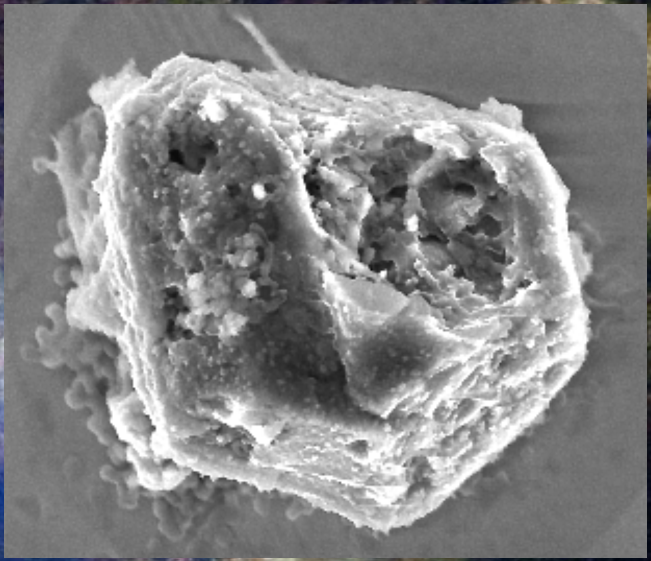

STURDUST
Diamonds
25 Å


STURDUST
Diamonds
25 Å
SiC

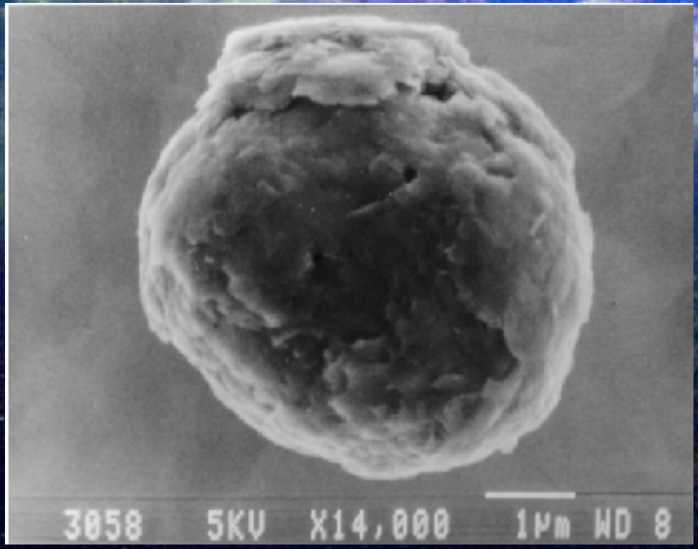
STURDUST

Diamonds





SiC



Graphite

r-process scenario

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Astrophysical sites not very well known, but associated to the final fate of massive stars .

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None of the proposed astro-sites has been confirmed yet by direct observations.

s-process standard paradigm

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- WEAK ($29<Z<40$). MASSIVE STARS $M>12\ M_{\heartsuit}$: Core-He burning (marginal) + Shell-C burning (dominant). $^{22}Ne(\alpha,n)^{25}Mg$ in both cases. It does not work at low Z, because of the lack of ^{22}Ne.

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- MAIN (37<Z<84). LOW MASS AGB STARS, 1.3-2.5 M❤: He/C rich layer, $^{13}C(\alpha,n)^{16}O$ (dominant), $^{22}Ne(\alpha,n)^{25}Mg$ (marginal).

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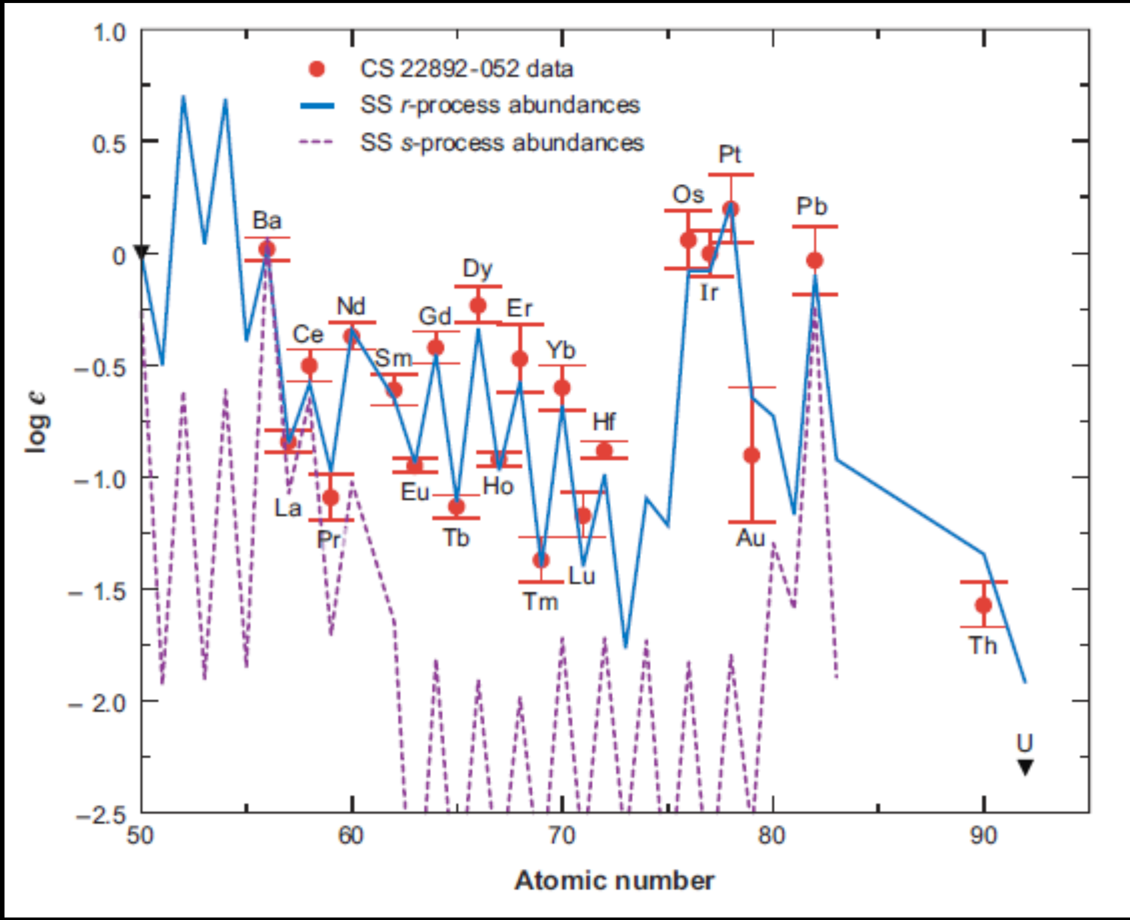
- STRONG (Pb/Bi). LOW-MASS LOW-Z AGB STARS .

Heavy elements in the Galactic Halo

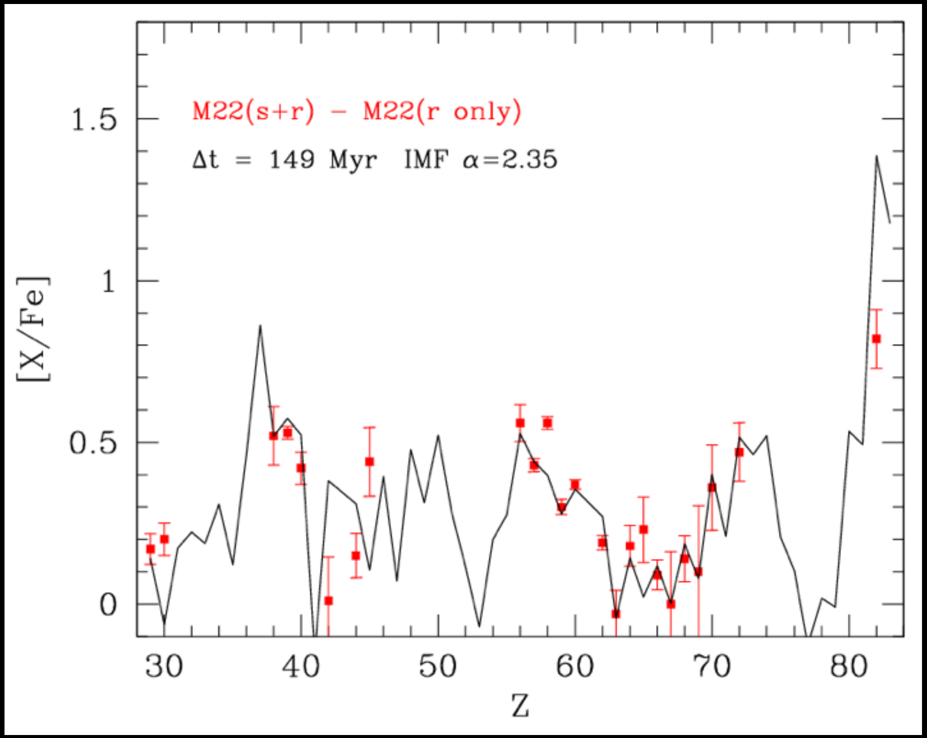
Only massive polluters, because the too short timescale. Heavy elements production dominated by the r-process. No weak s, because the lack of ^{22}Ne.

CS 22892-052

(from Sneden, Cowan, Gallino 2008)



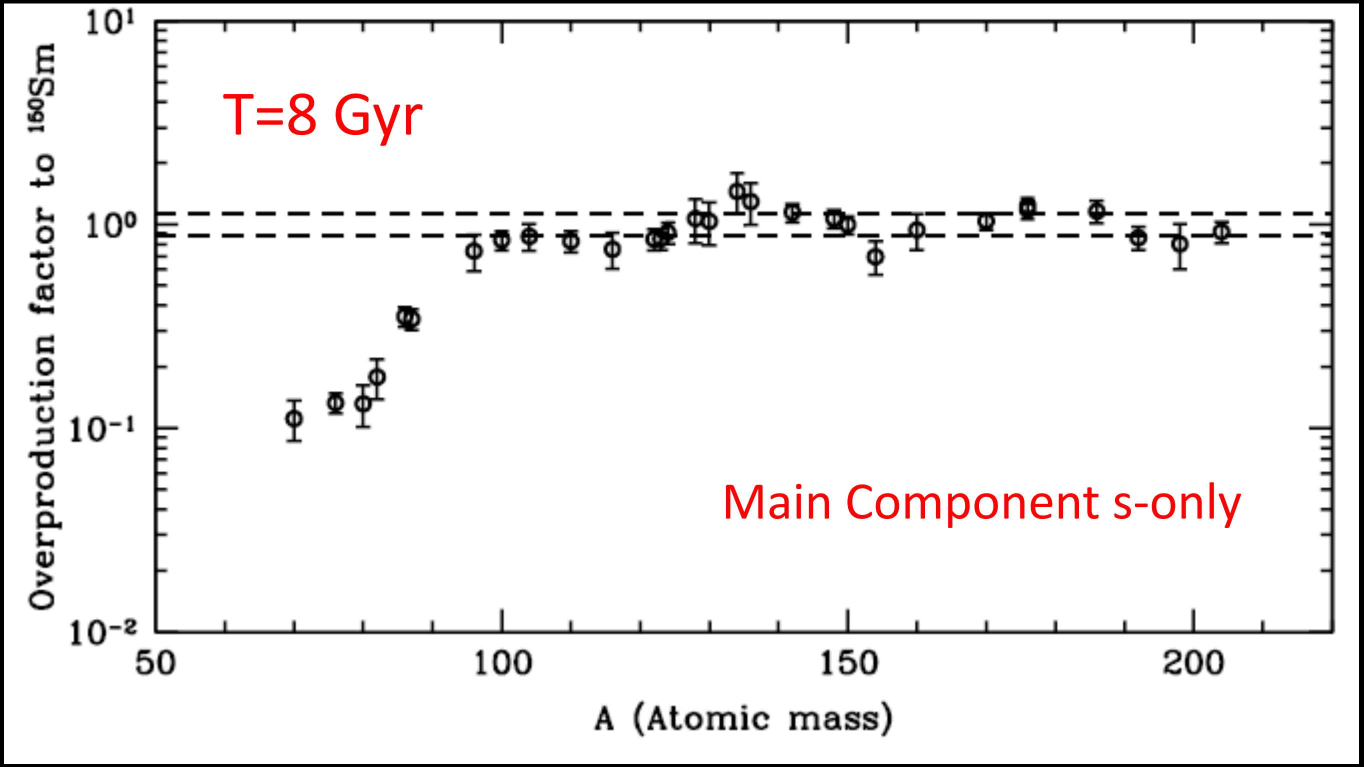
Globular Clusters: first evidence of s-process pollution (by massive AGB stars)



from Straniero Cristallo Piersanti 2014, ApJ

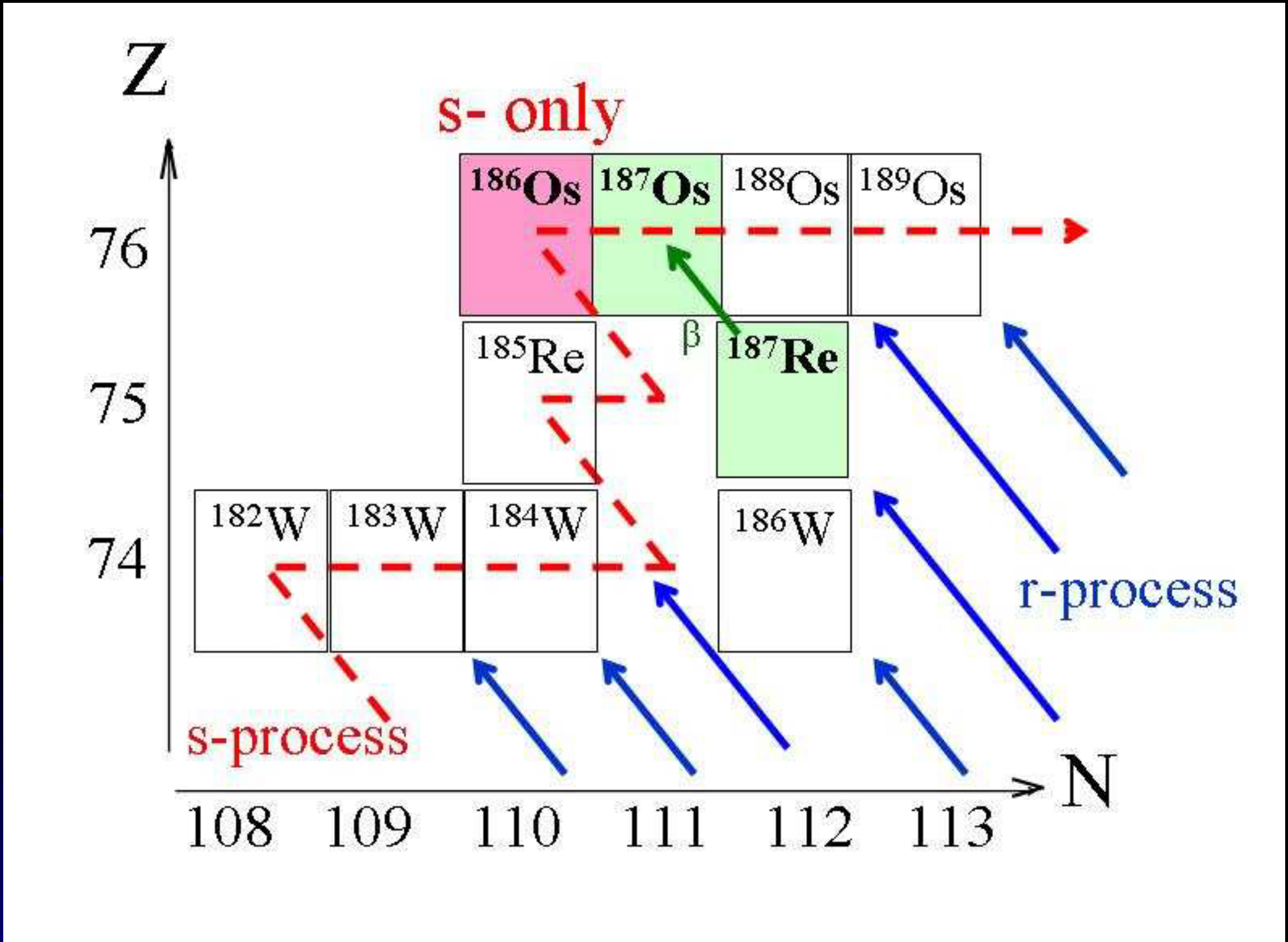
Second generation stars polluted by massive AGB

The bulk of the s process in the Galactic Disk



Chemcal evolution model (Cristallo et al. 2015).
Low-mass AGB pollution starts after about 1 Gyr

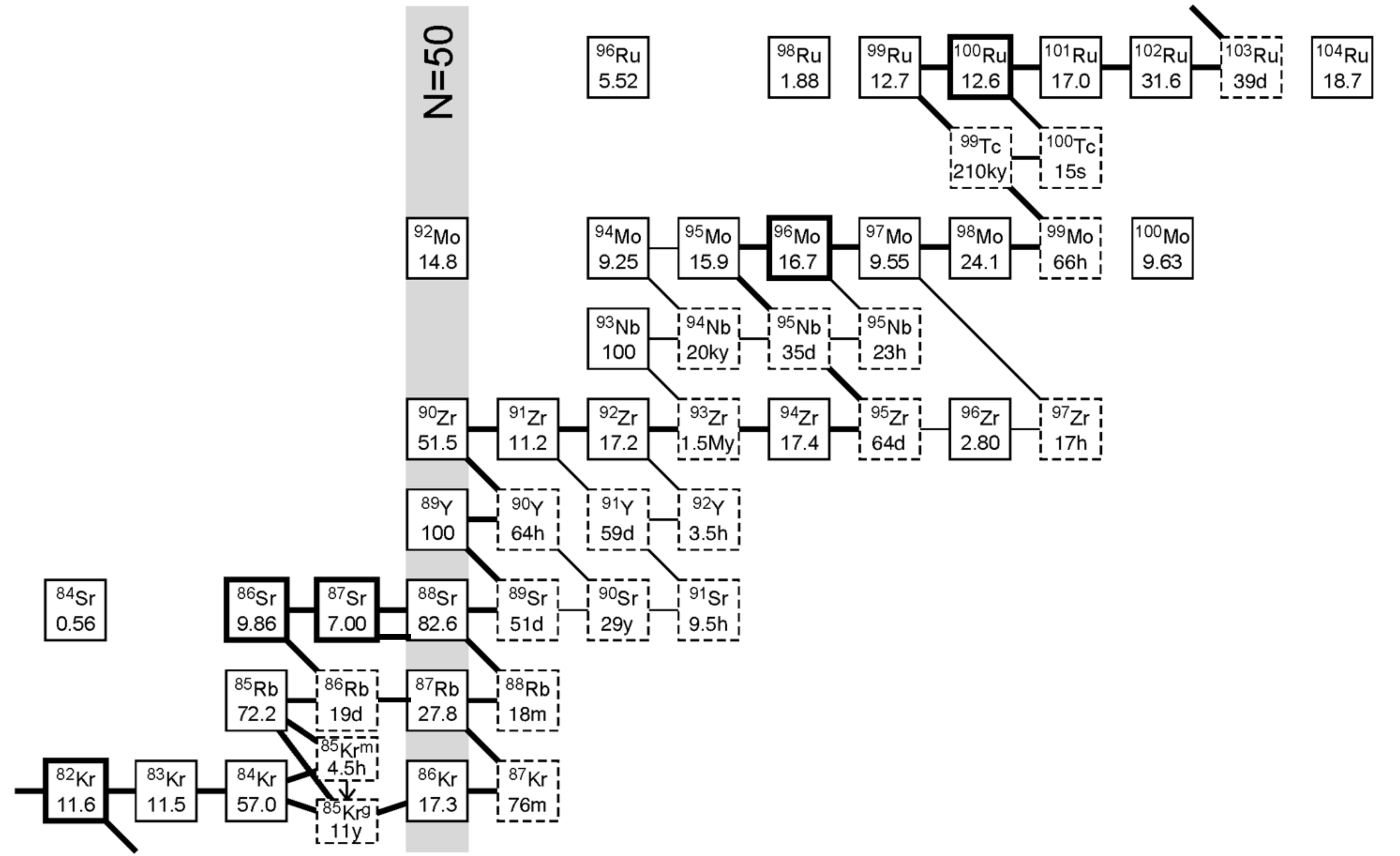
r versus s process



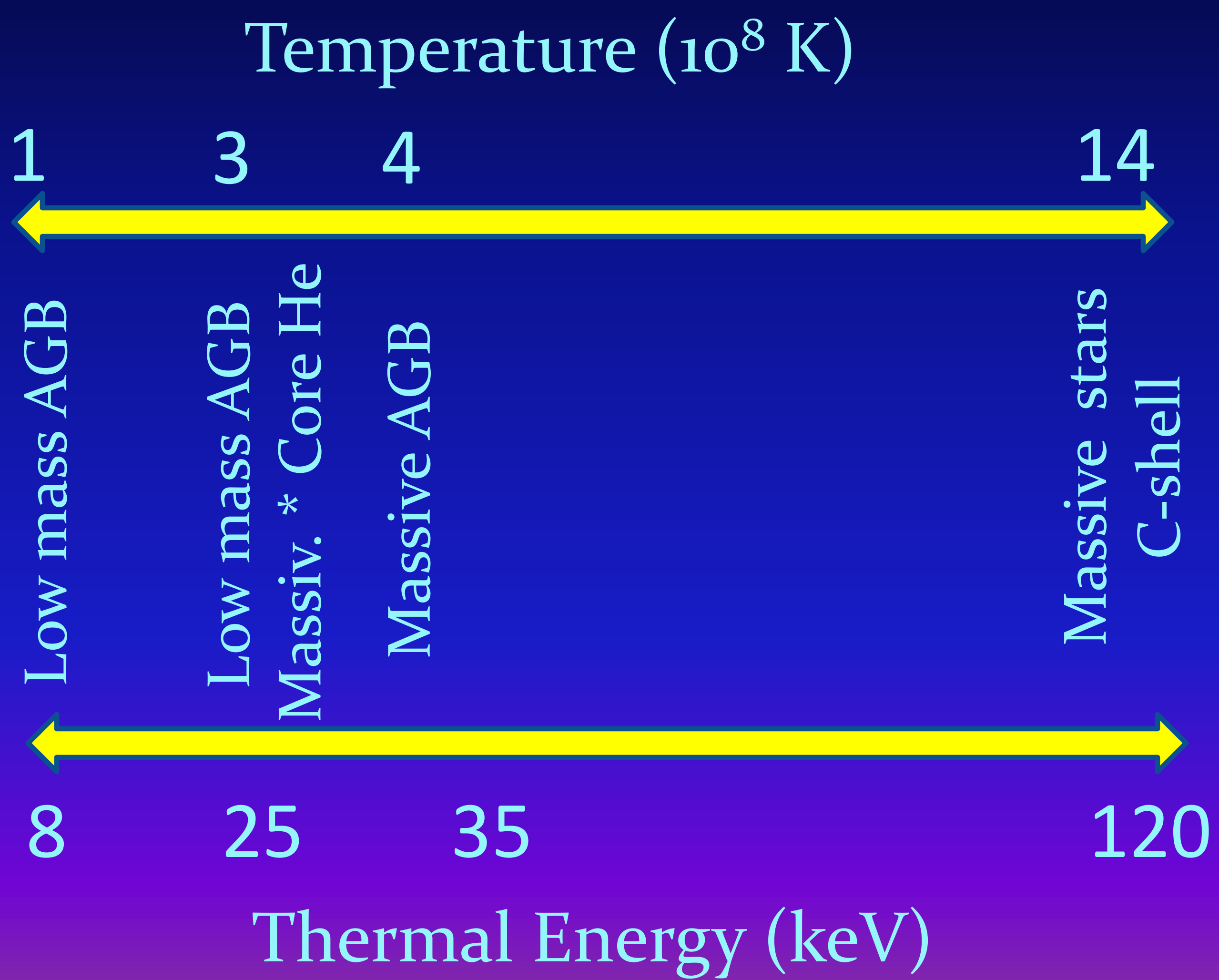
Nuclear physics inputs for neutron-capture nucleosynthesys

- Rates of the main neutron sources: $^{13}C(\alpha,n)^{16}O$, $^{22}Ne(\alpha,n)^{25}Mg$, ……………..at the relevant Gamow's peak energies
- Neutron capture rates on heavy (seeds) and light (poisons) isotopes (not only the stable ones) at the relevan thermal energies
- Decay rates at the relevant temperature

Branchings & neutron magics



Relevant temperature/energy



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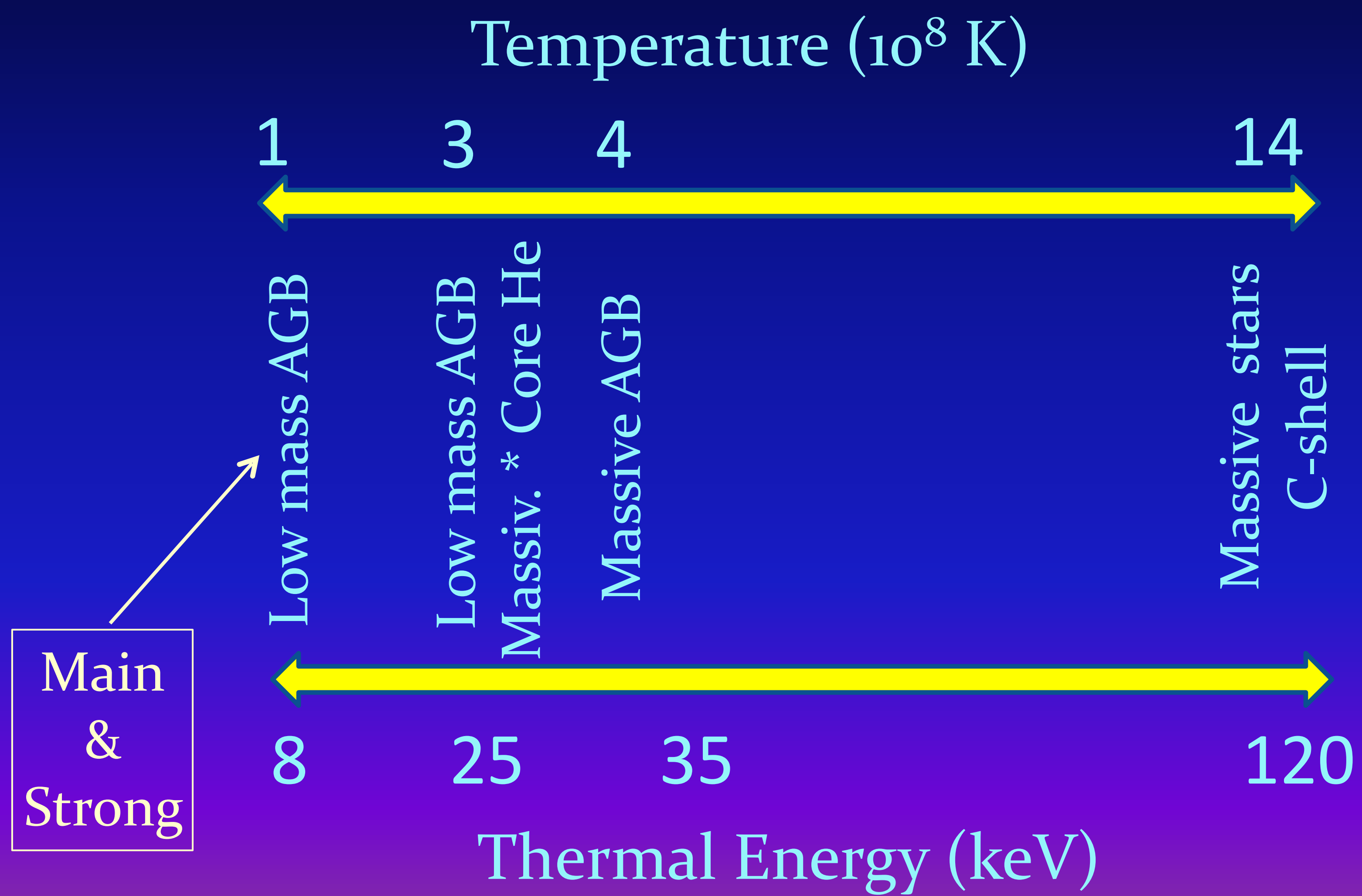

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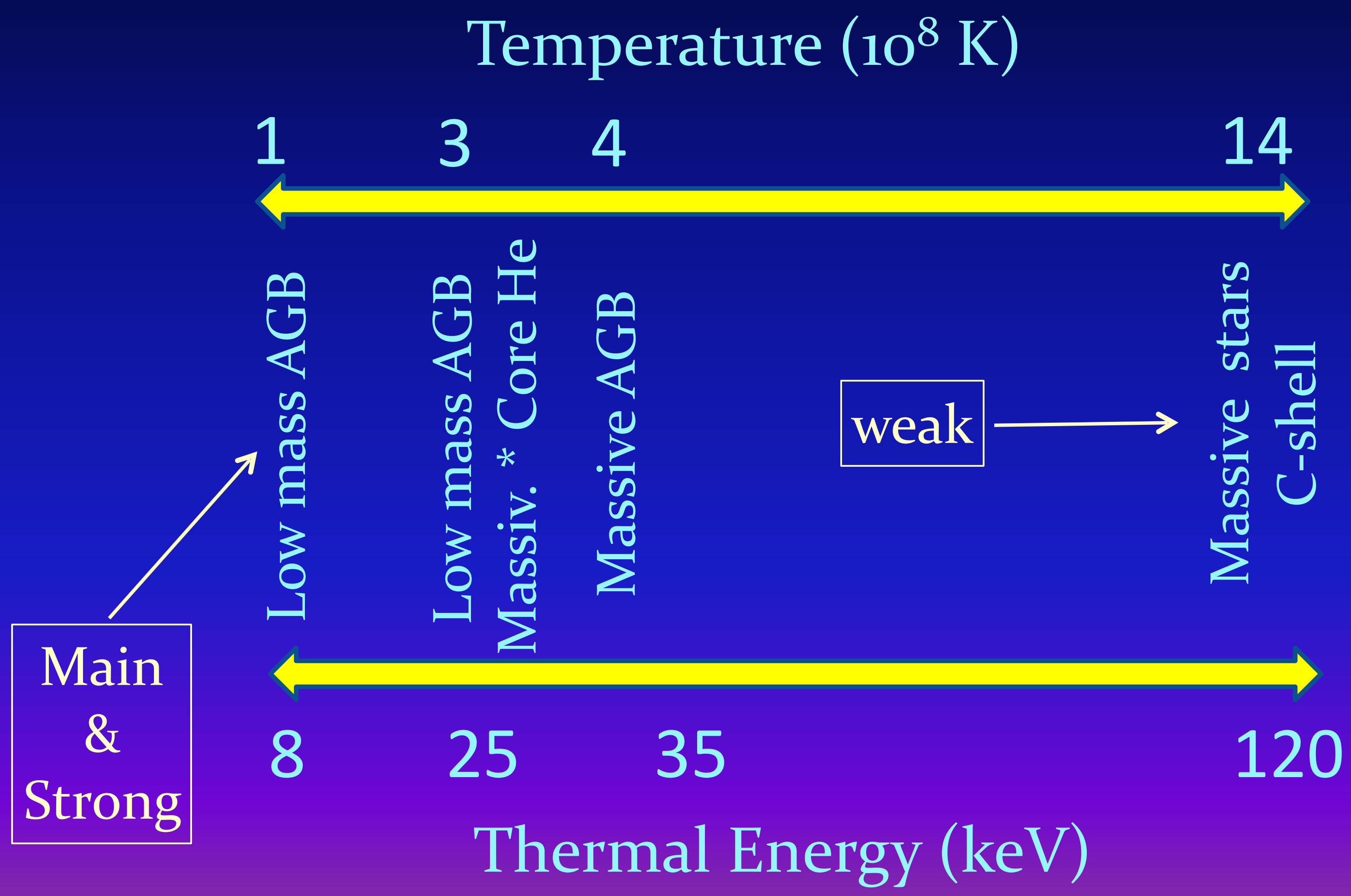
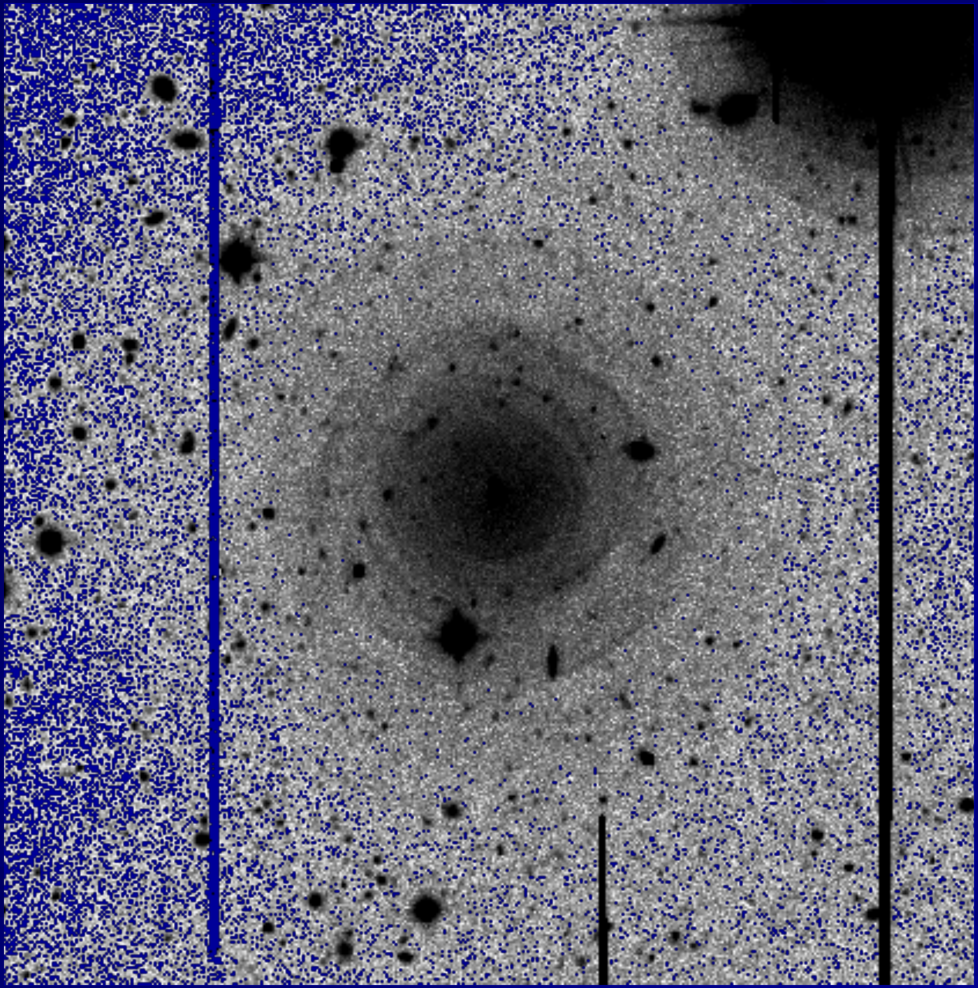
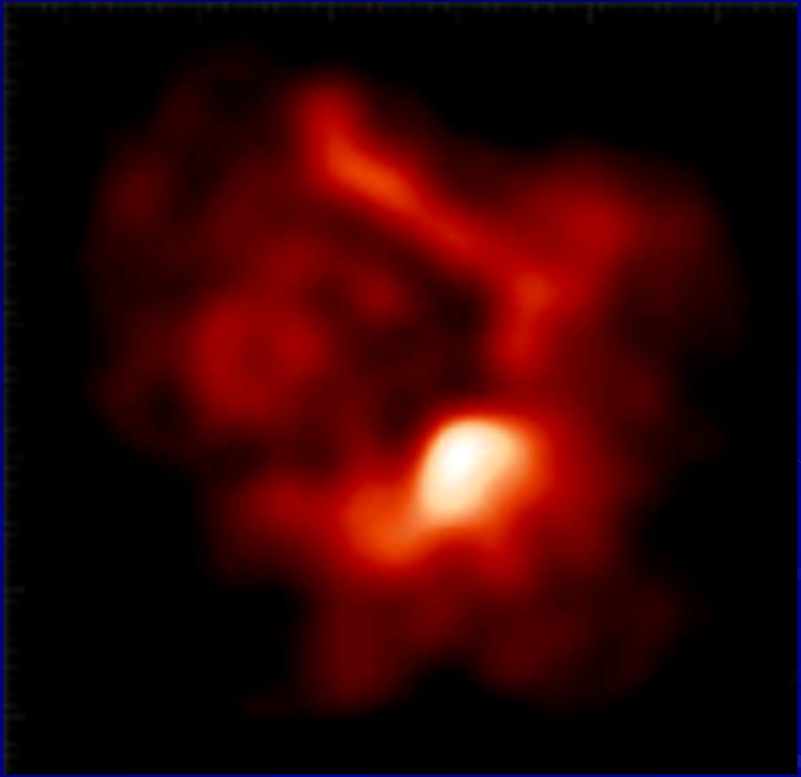


CW LEO. An example of C and s rich galactic AGB stars

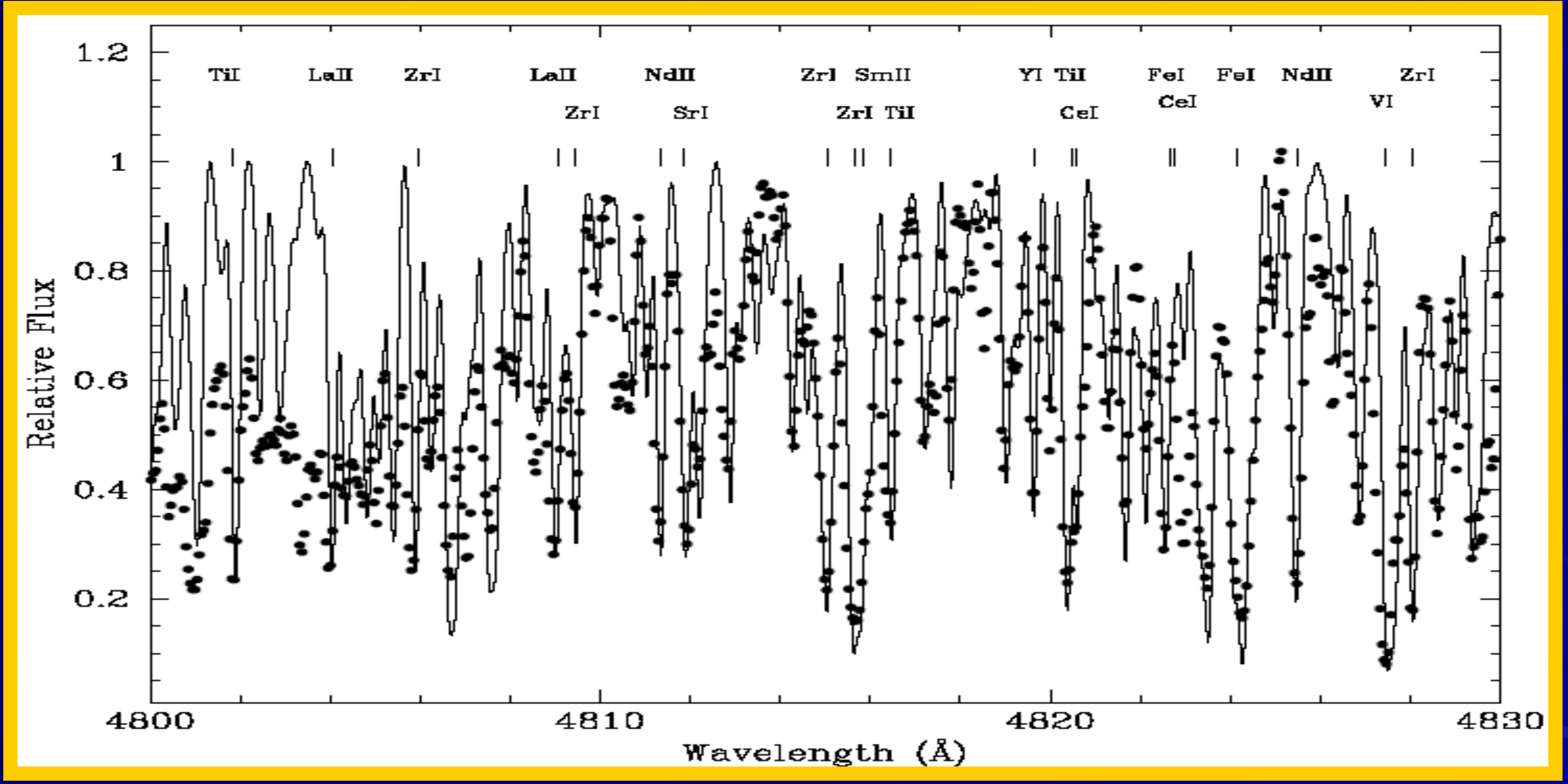


Light echoes (6000 A)



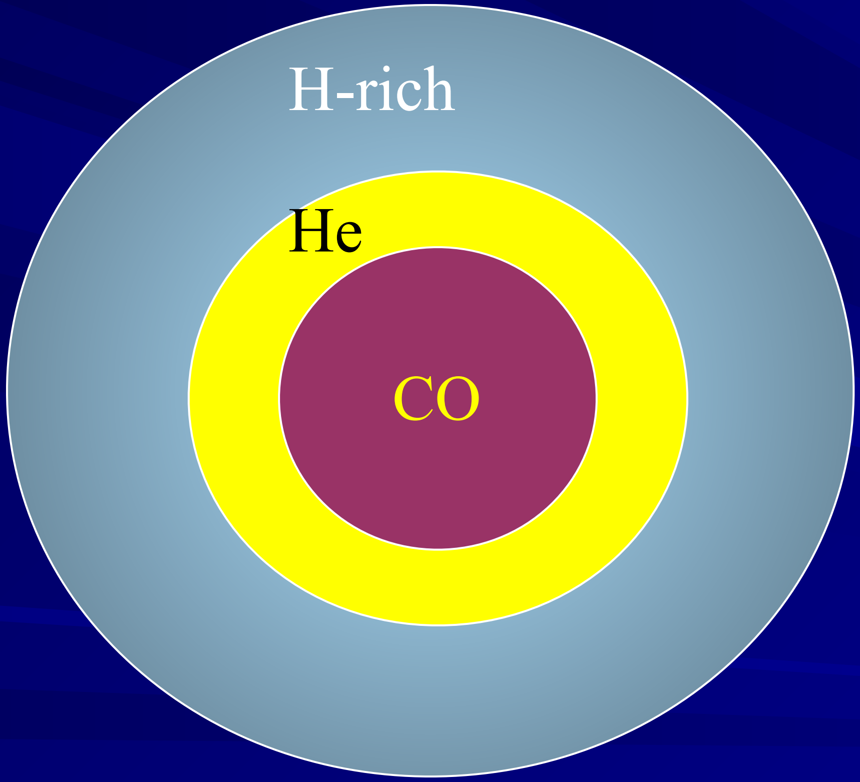
Irradiated IR light (10 μ)

Carbon Star Spectra



Abia et al. 2001

Beyond the core-He burning: the early-AGB



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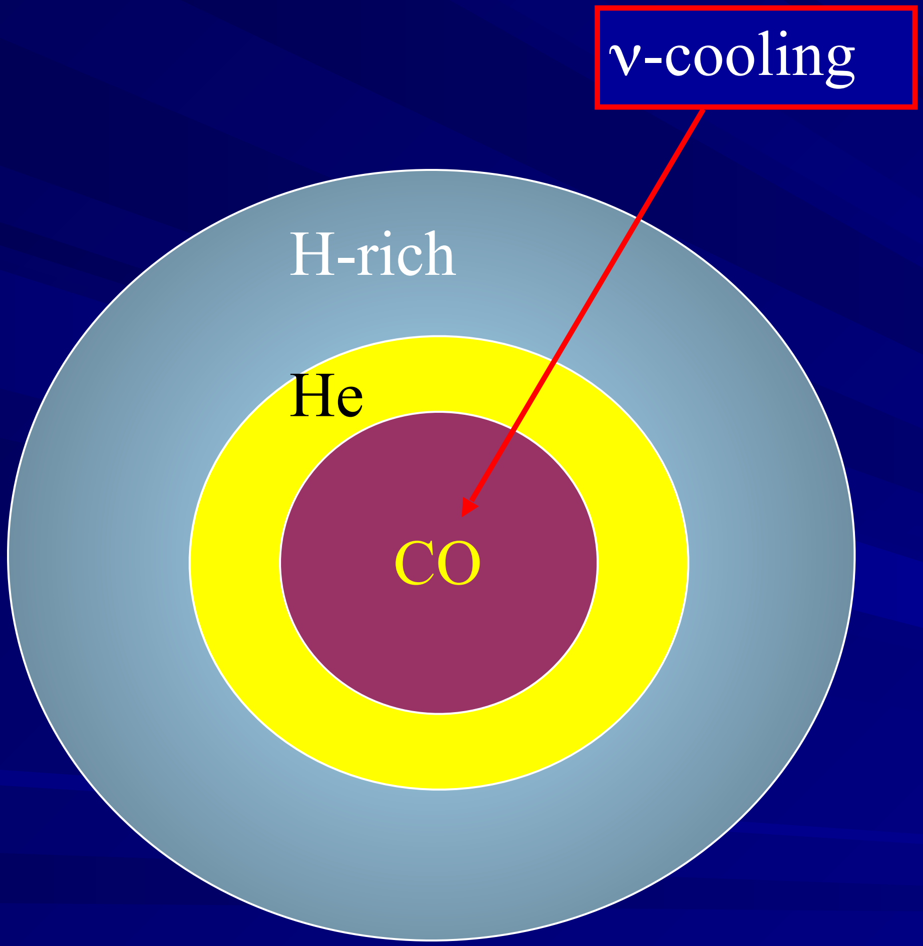

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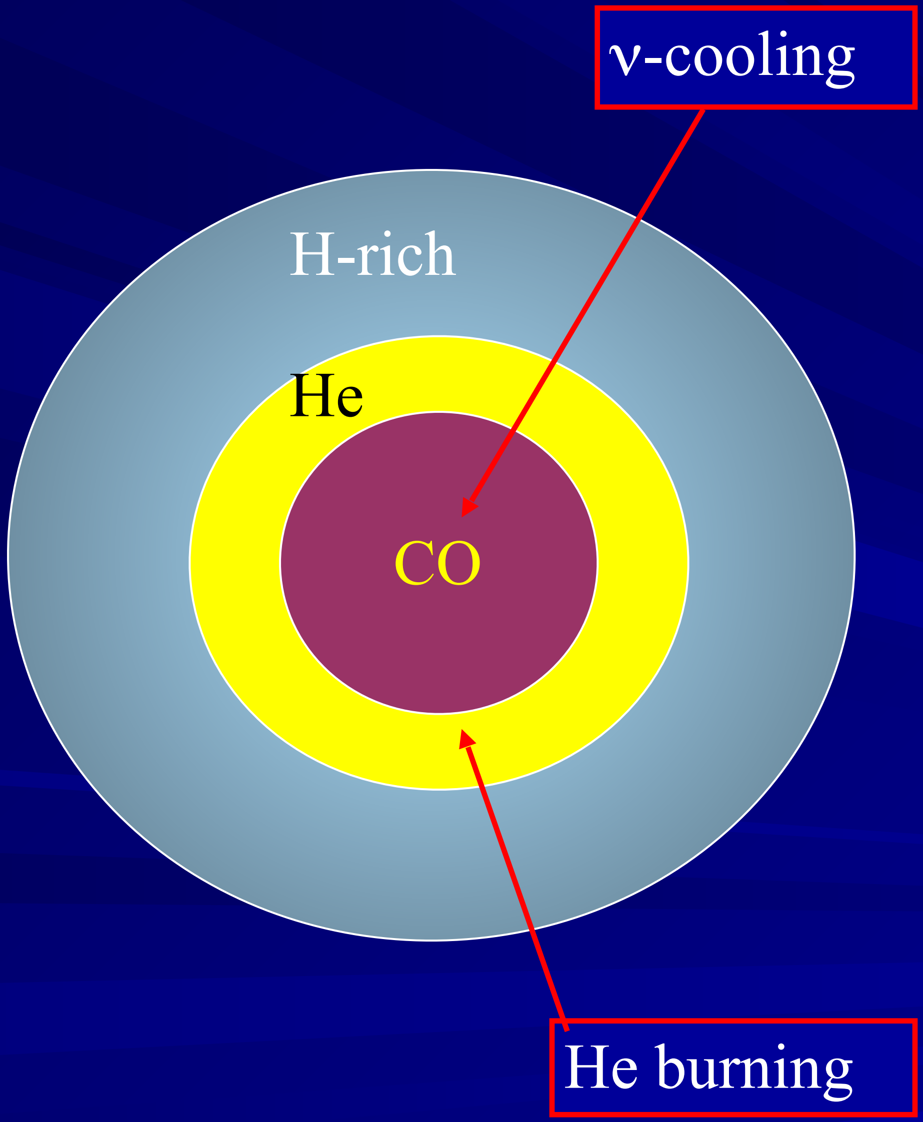

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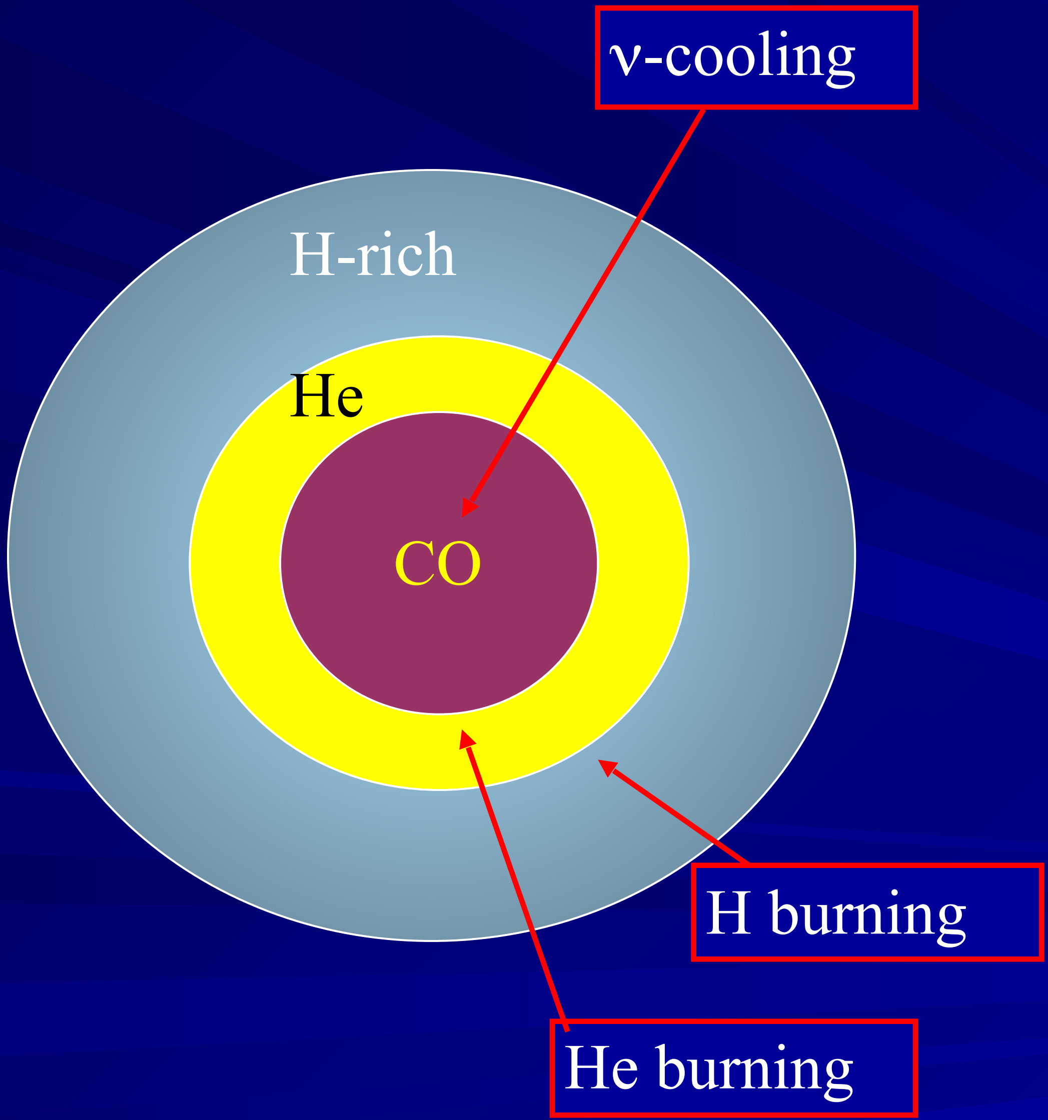

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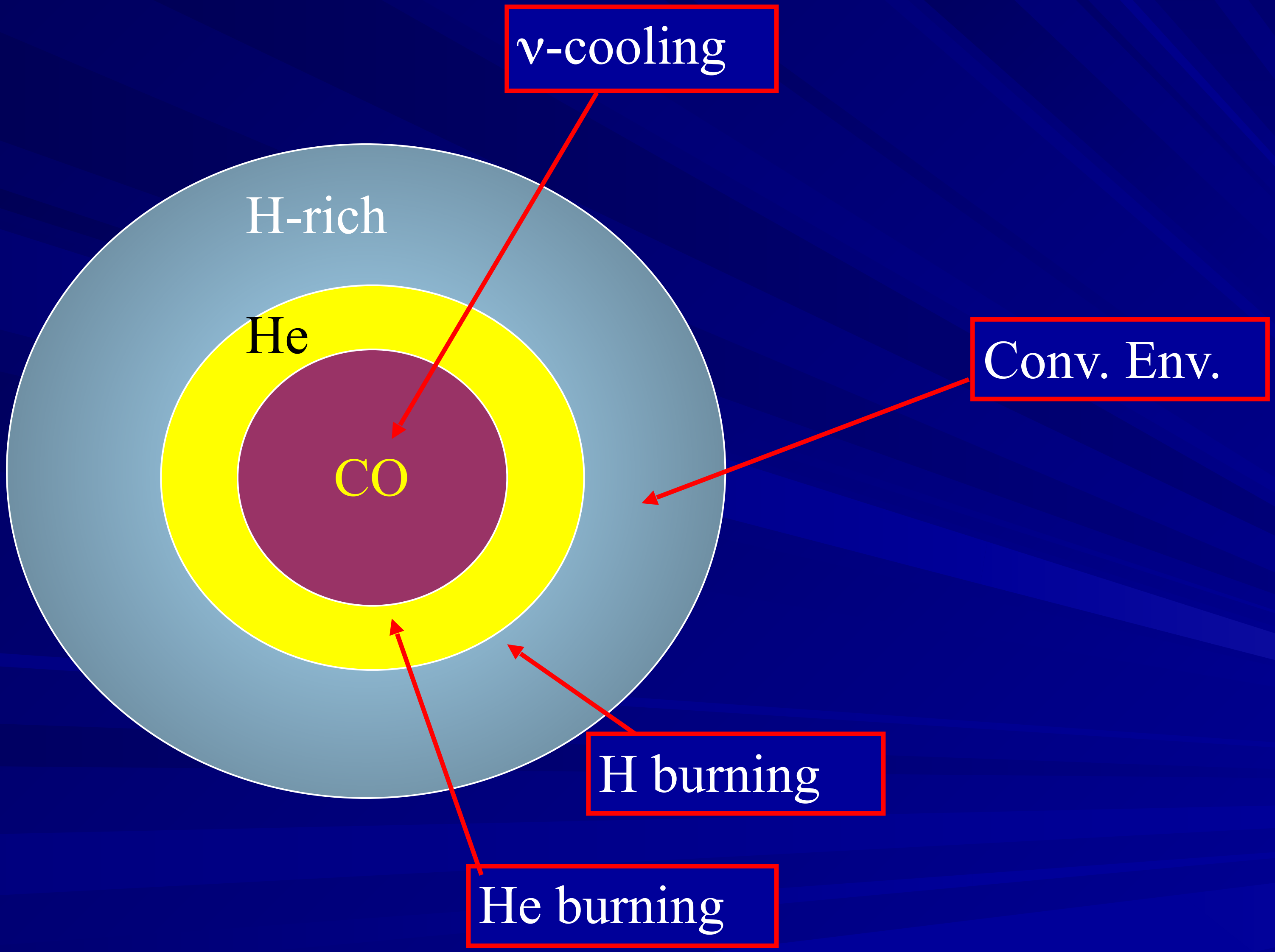
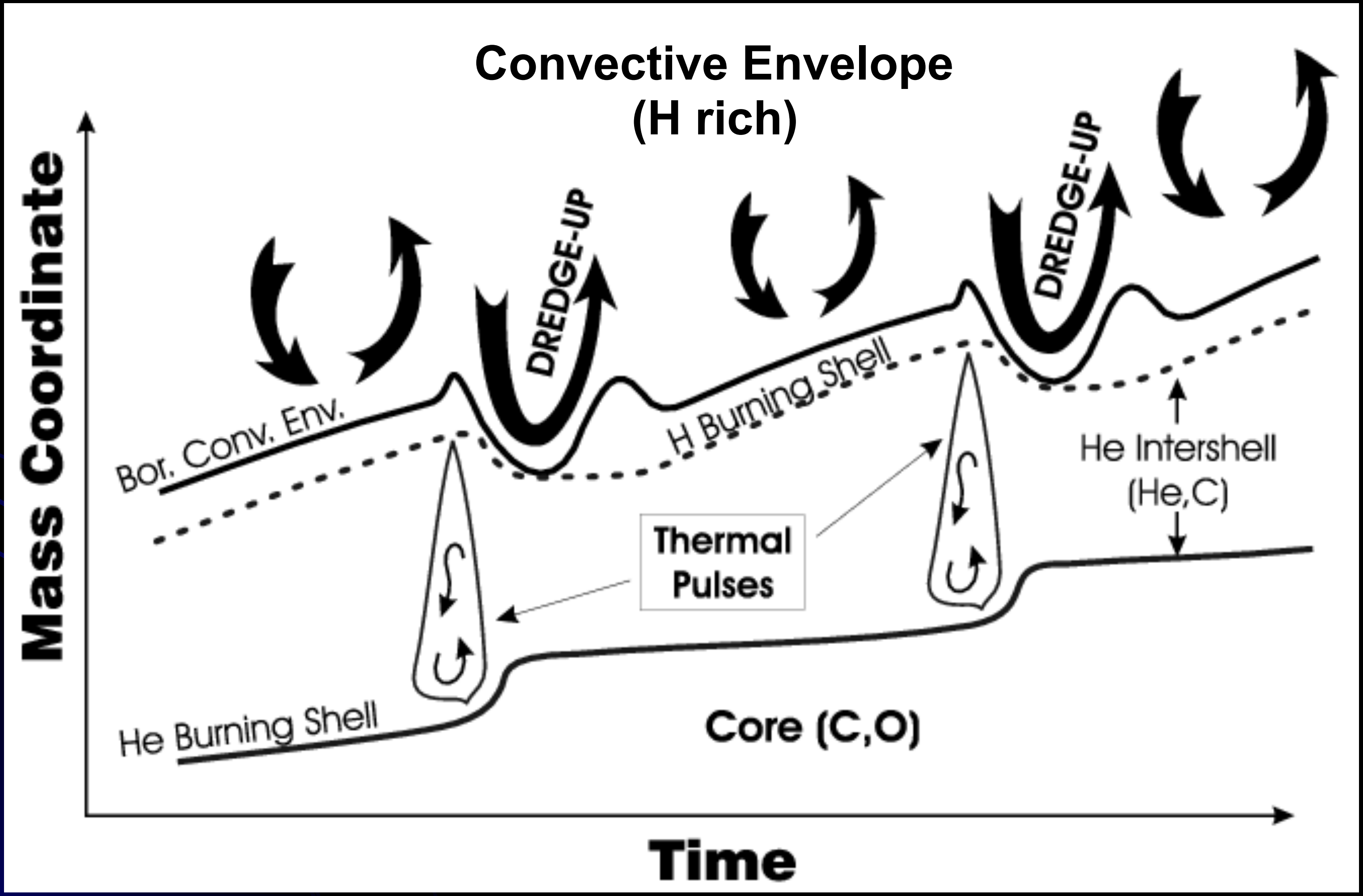


s-Proess paradigm for low-mass AGB (1.-3 $M_\odot$)

Straniero et al. 1995 – Gallino et al. 1998



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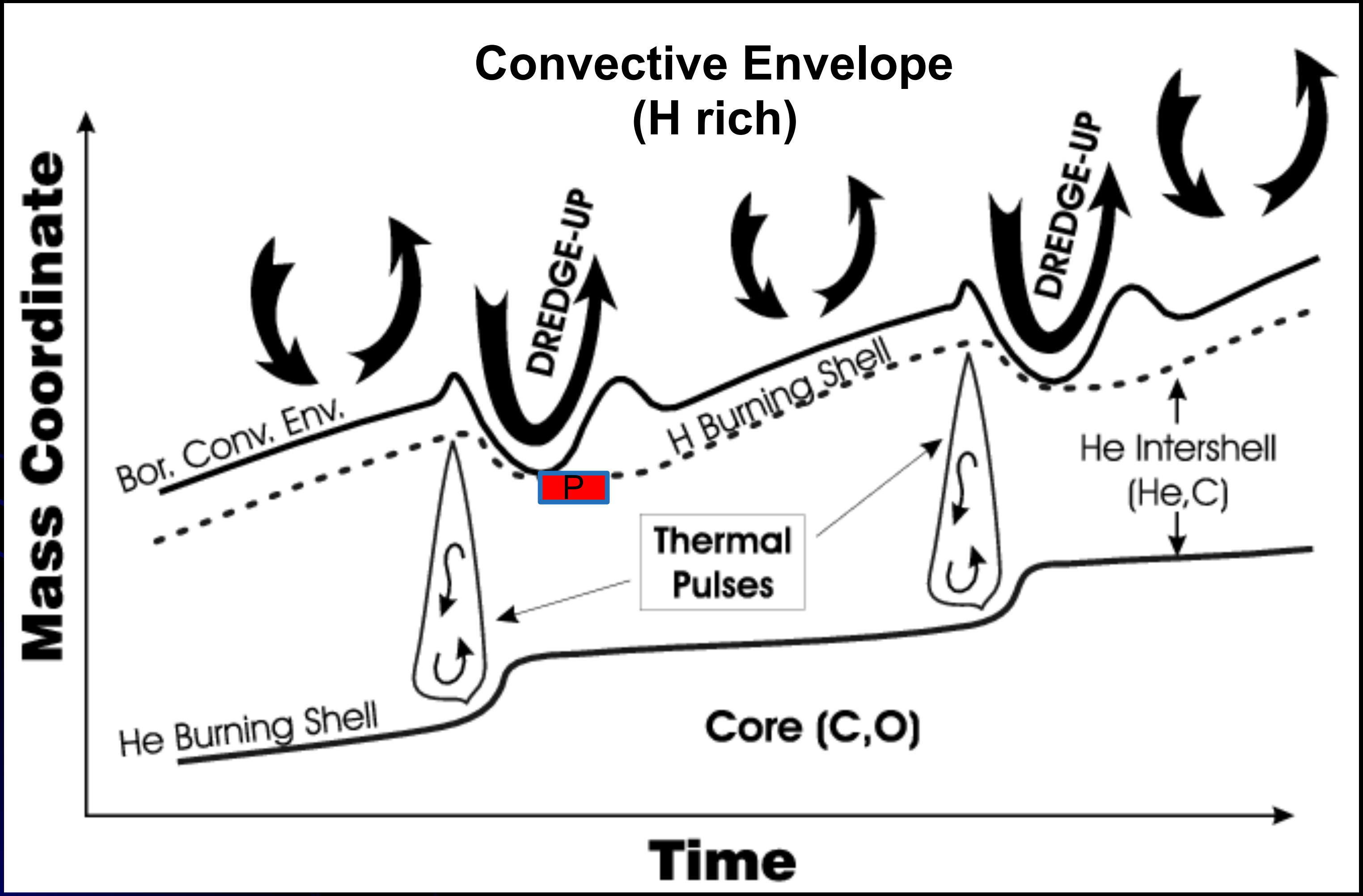

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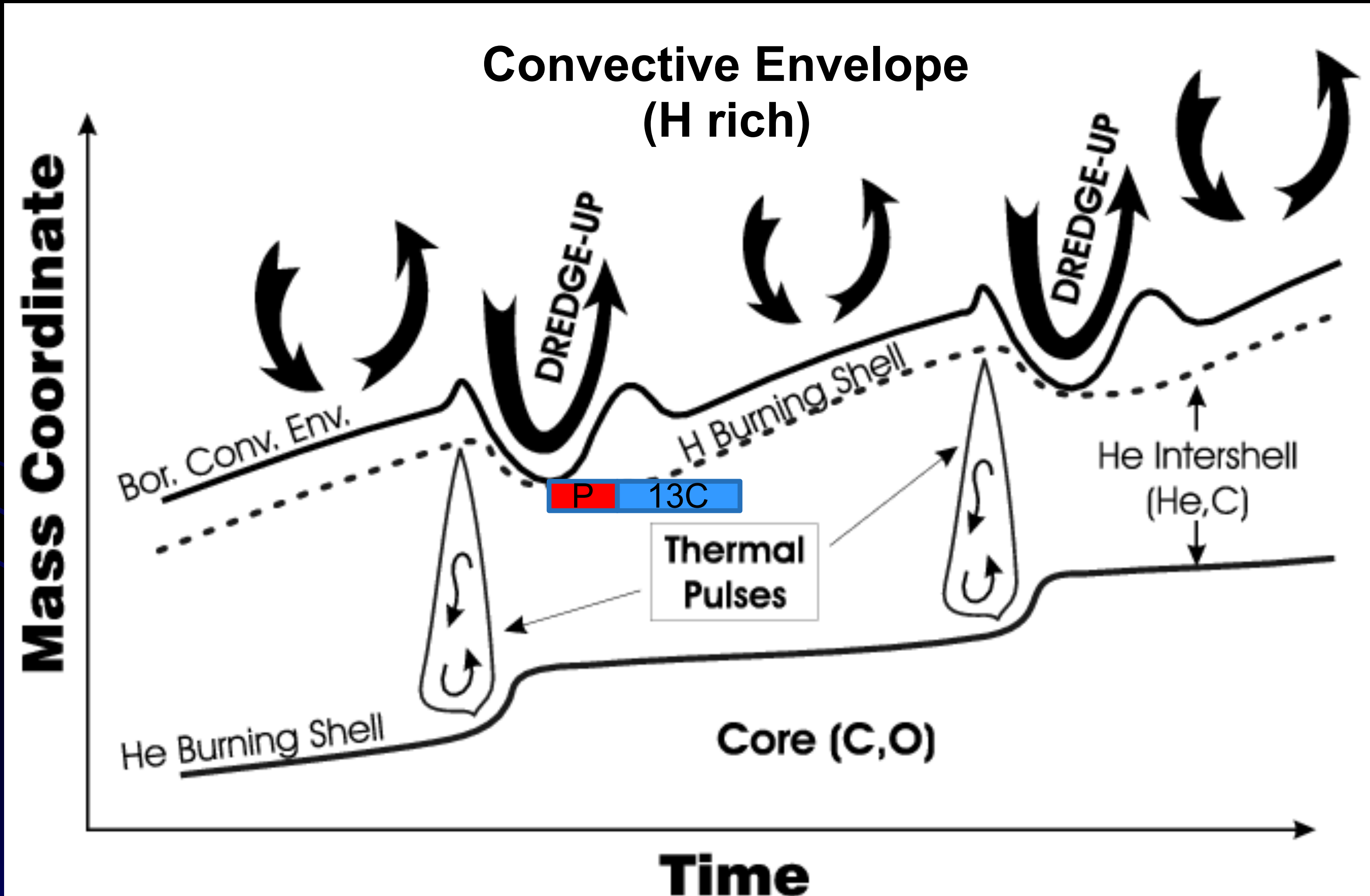

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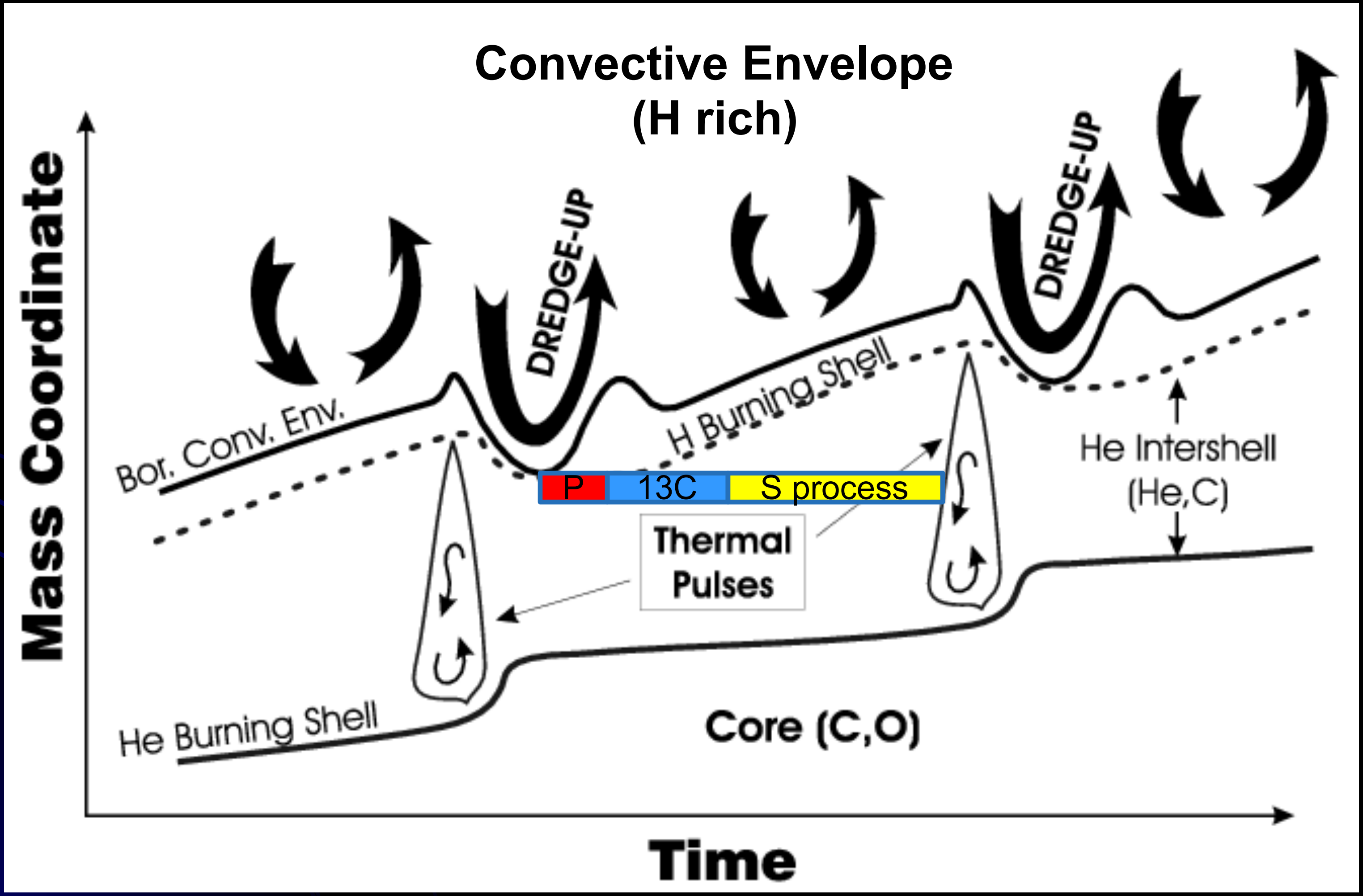
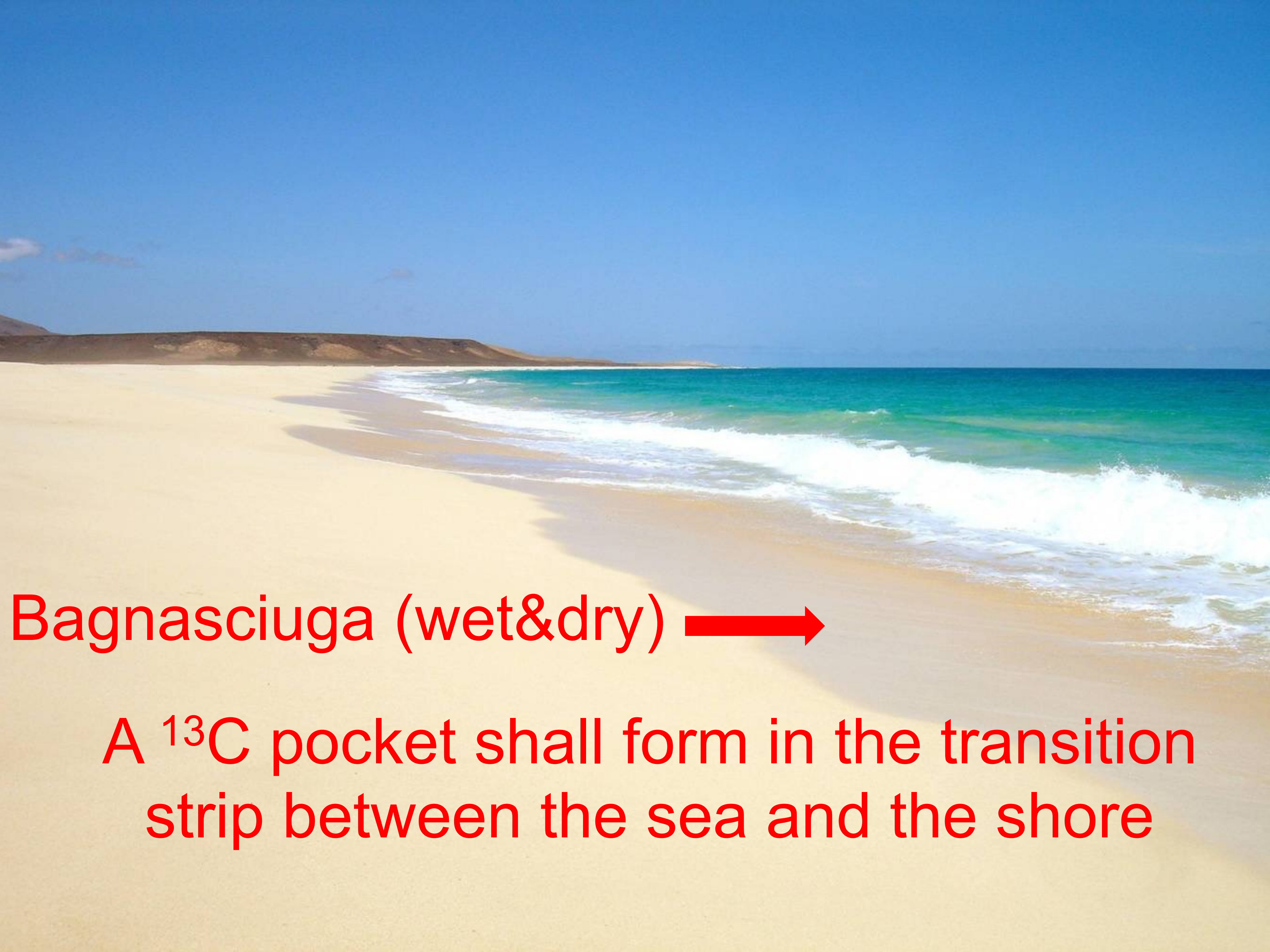



Bagnasciuga (wet&dry)


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

FUNS – FUll Network Stellar evolution (Straniero, Gallino, Cristallo NuPhys A 2006, Piersanti, Cristallo, Straniero ApJ 2013)

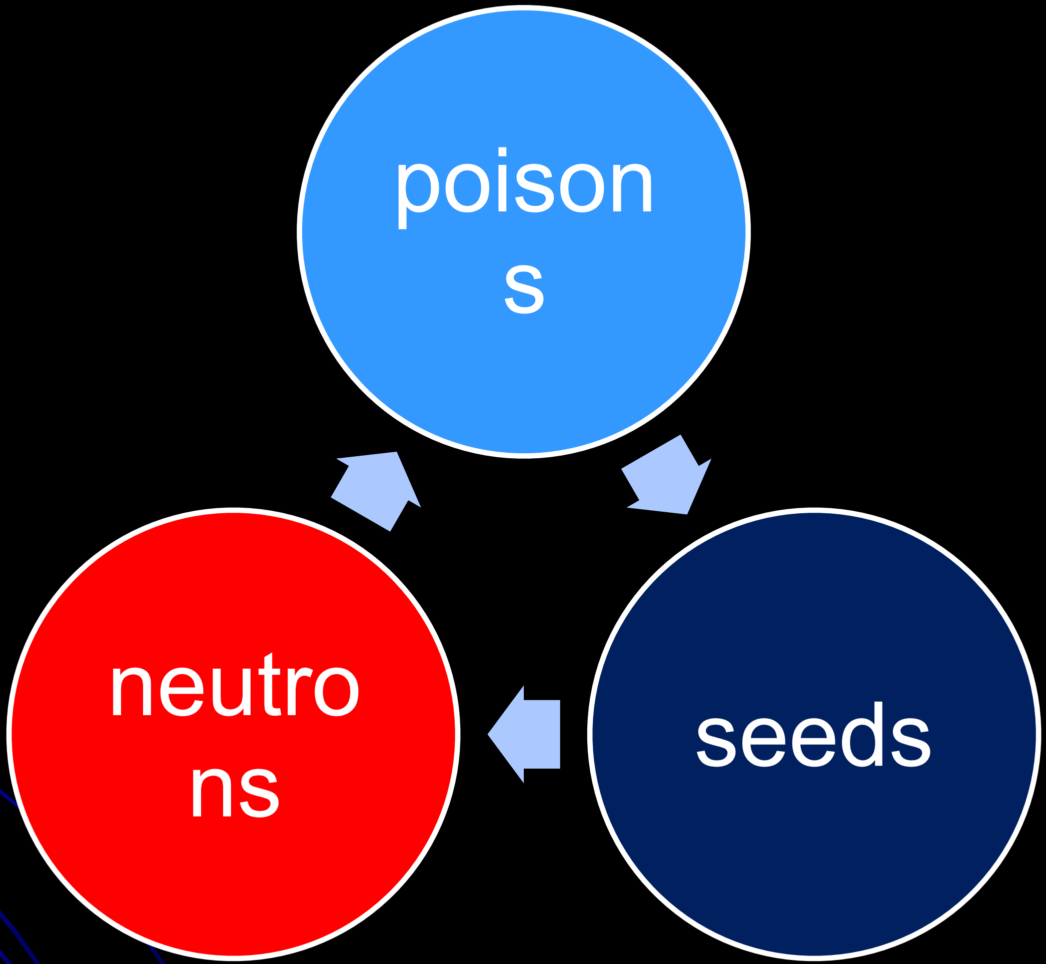
Id Stellar structure equations+500 isotopes (from H to U)

Detailed input physics: EOS (coulomb interactions +partial electron degeneracy+relativistic corrections), atomic and molecular opacity for C(N) rich material, continuously updated nuclear reaction database. Time dependent convection.

Rotation and related instabilities included.

(See also Cristallo et al. 2007, 2009, 2011 and the FRUITY database)

The 3 cards game



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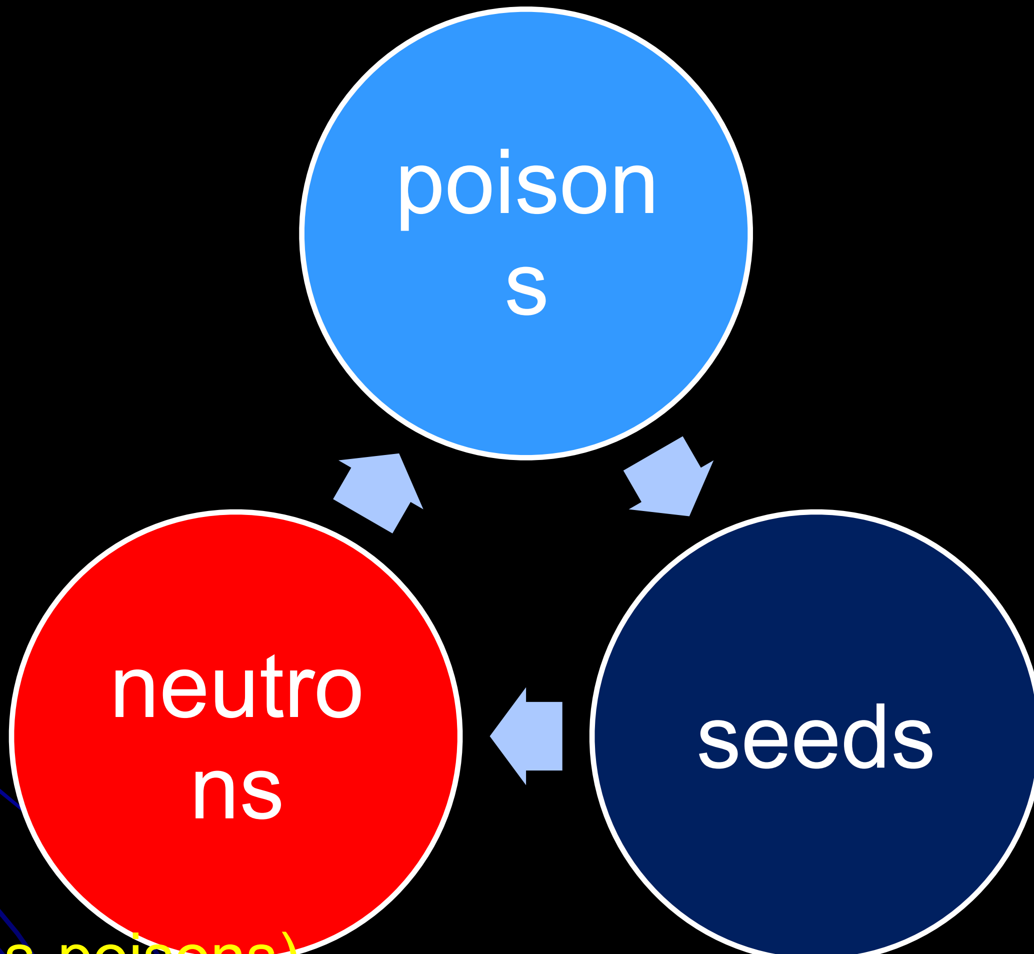
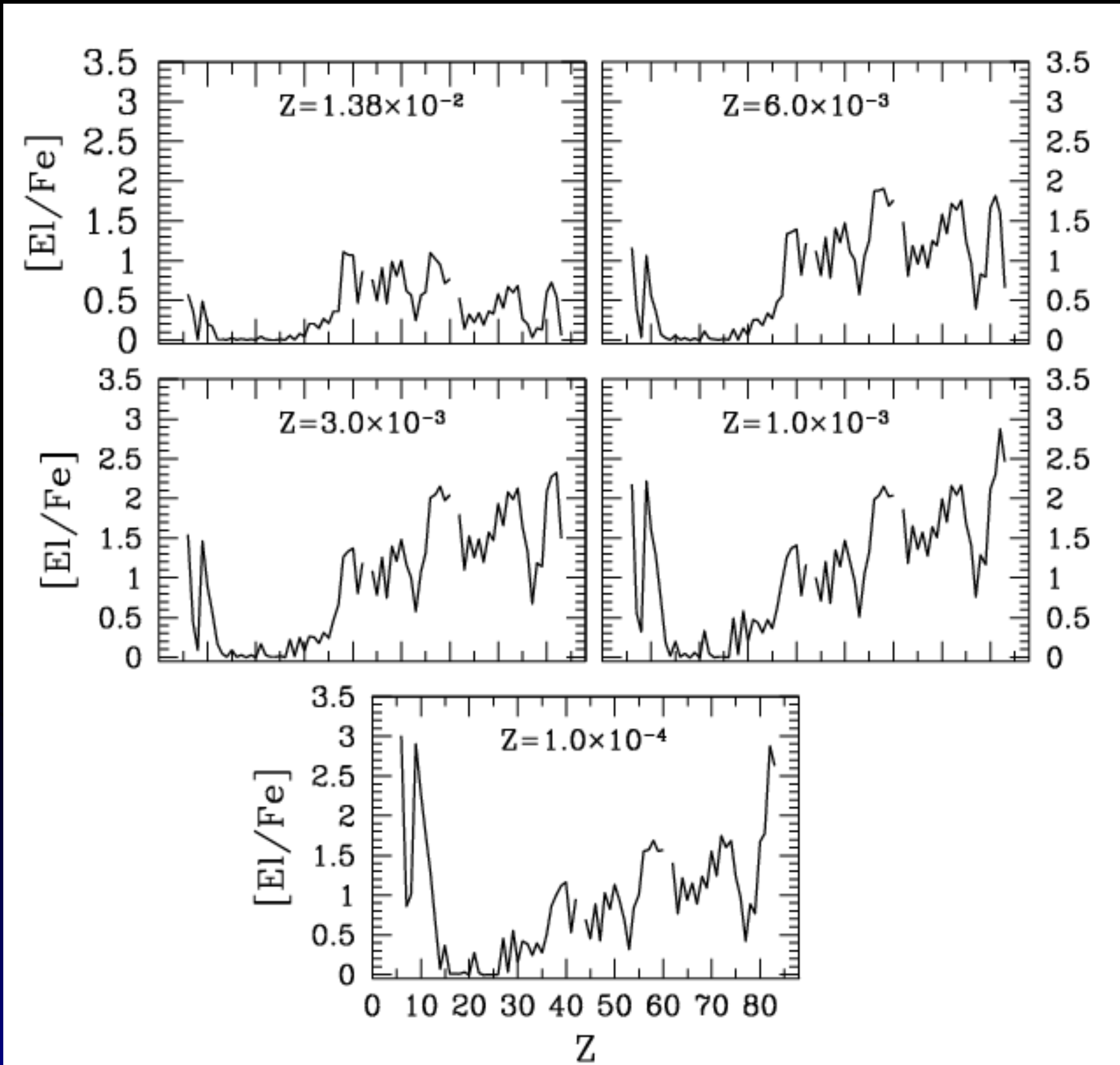


$$\frac{(\text{neutrons-poisons})}{\text{seeds}} \longrightarrow \left[\frac{hs}{ls}\right]$$



Final AGB composition for 0.0001<Z<Z☉

Cristallo et al. 2009, 2011, 2015

Final AGB composition for 0.0001<Z<Z☉

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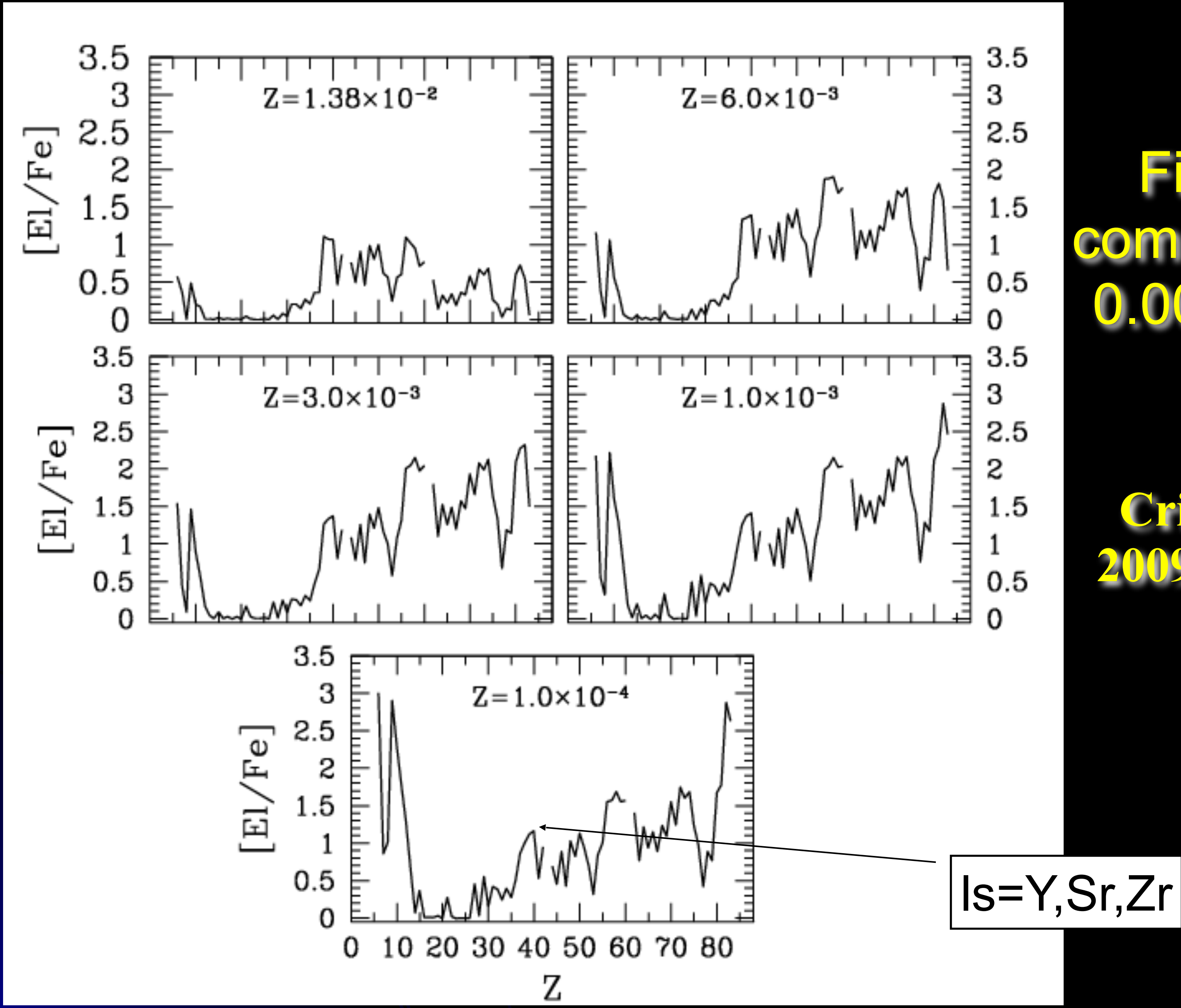
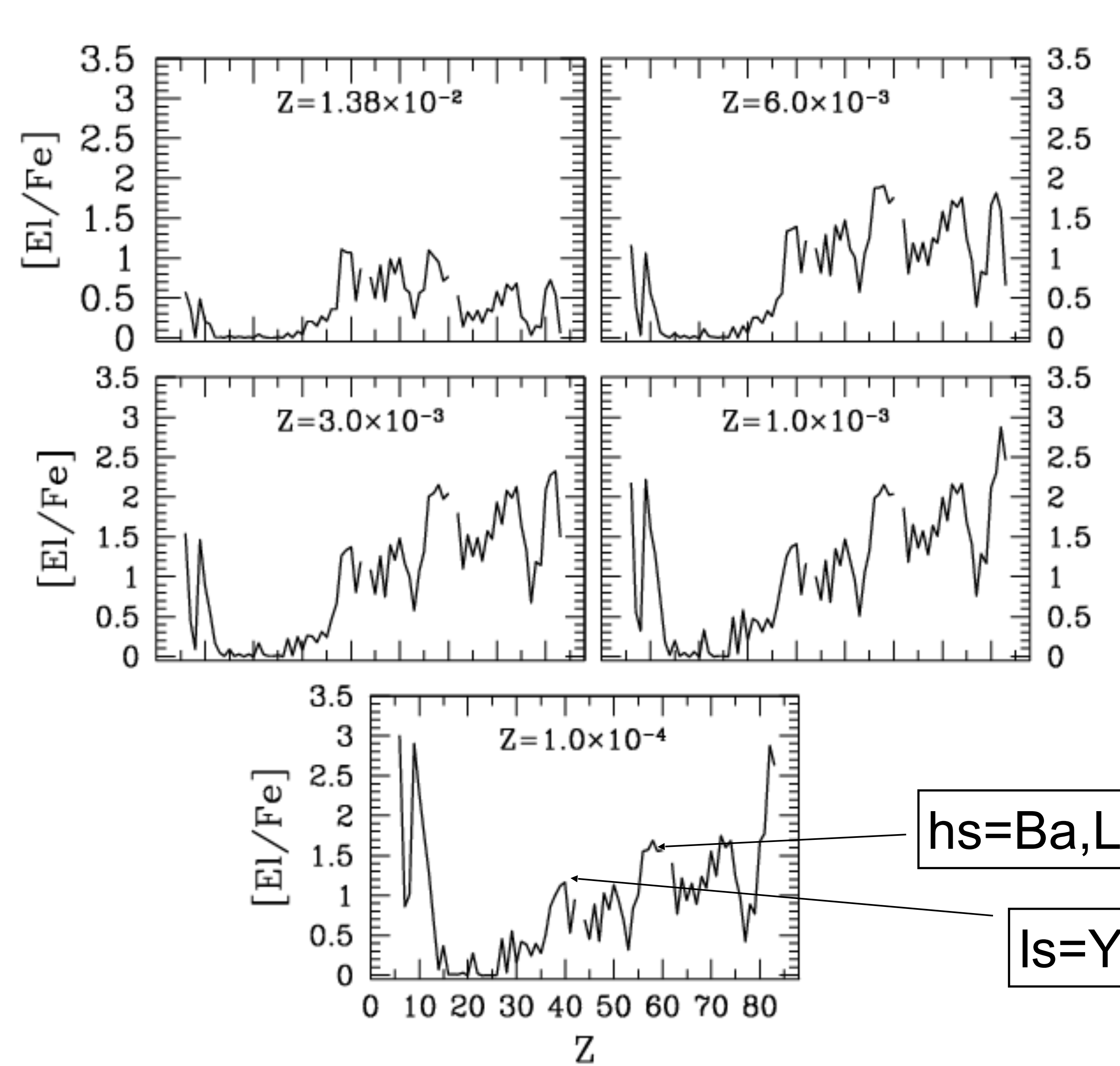


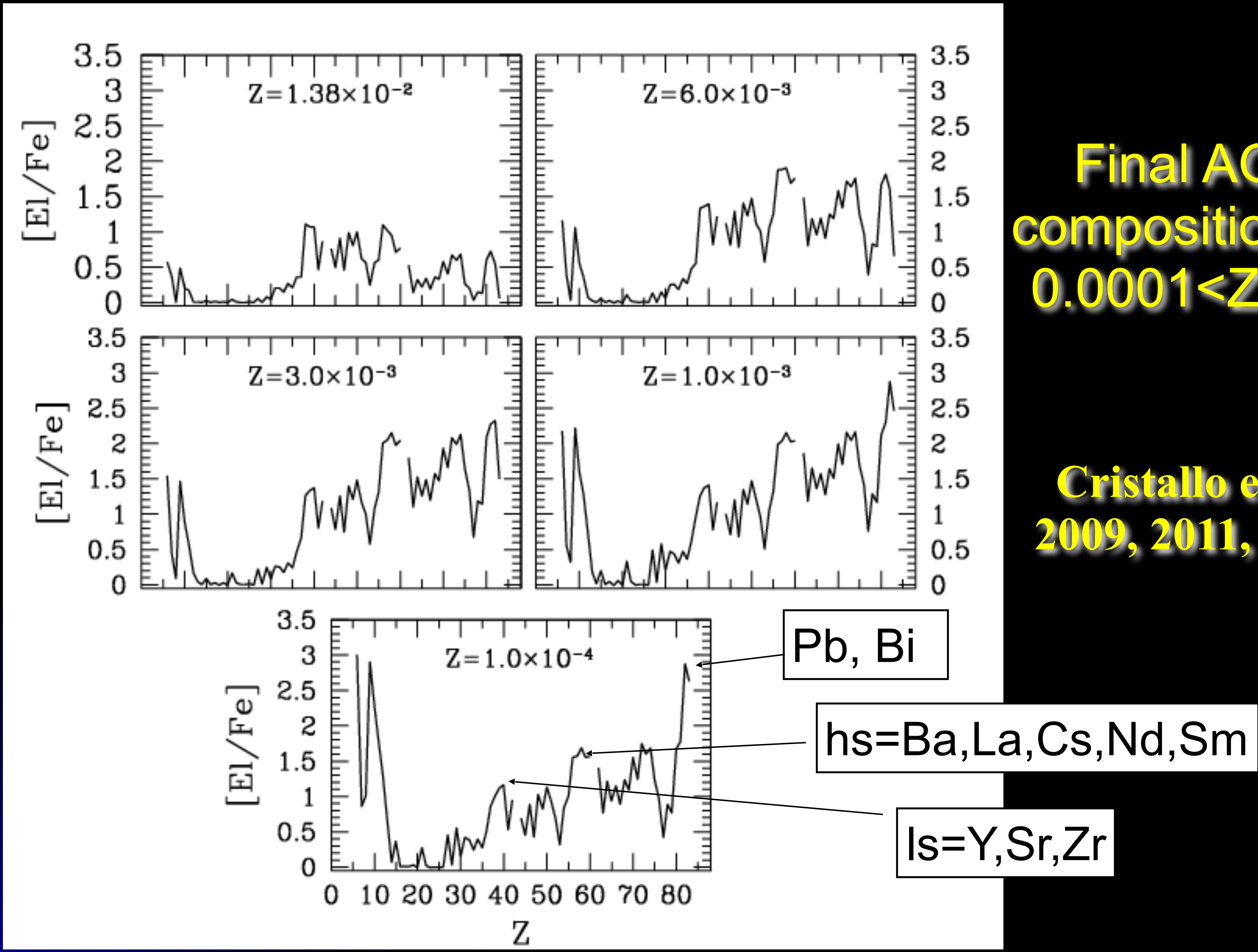
Final AGB composition for $0.0001<Z<Z_{\odot}$



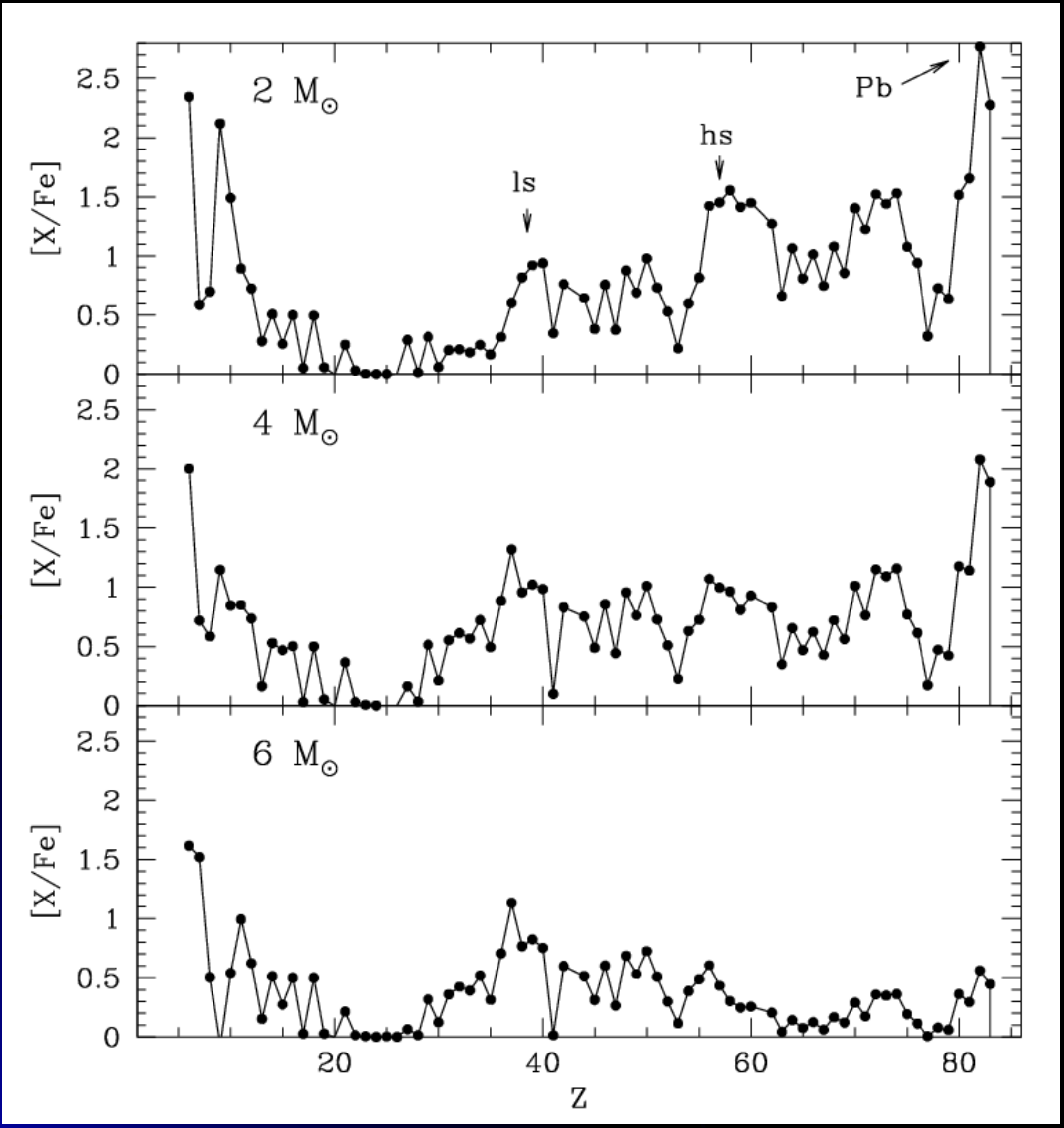
Cristallo et al. 2009, 2011, 2015

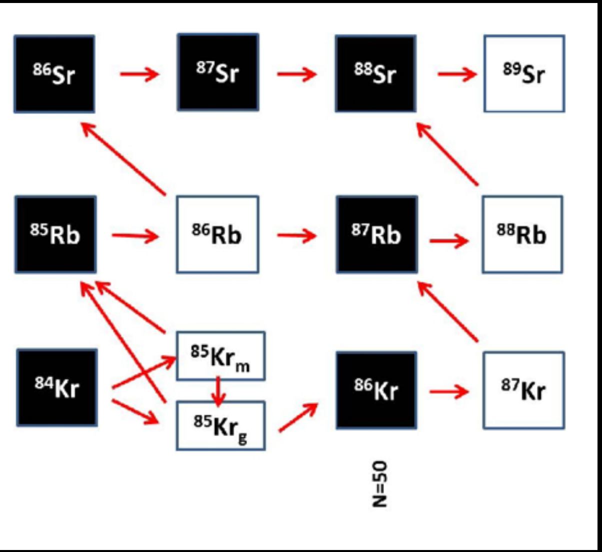
Final AGB composition for 0.0001<Z<Z☉

Cristallo et al. 2009, 2011, 2015



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





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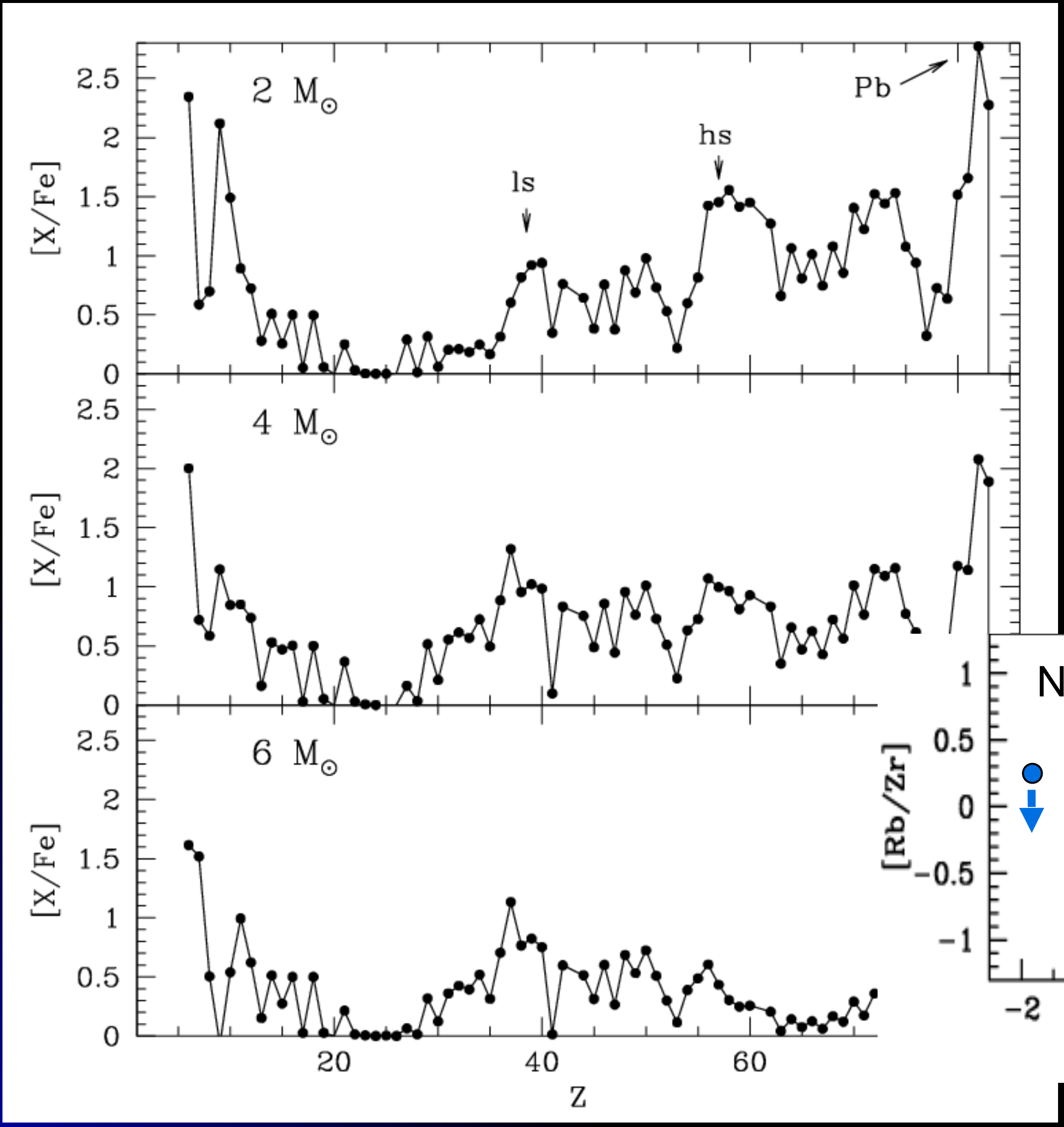
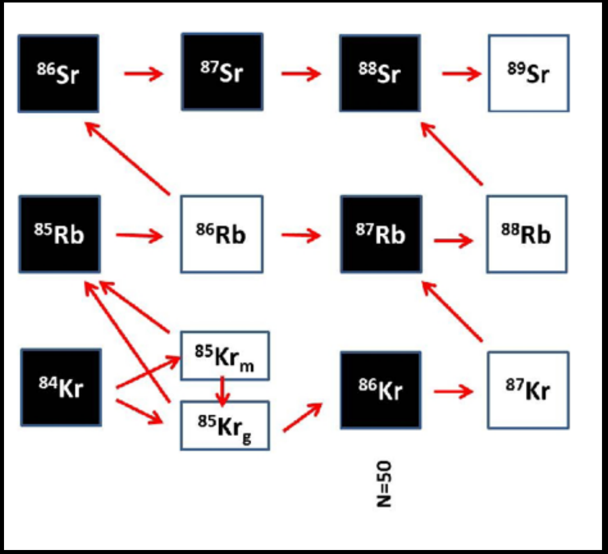
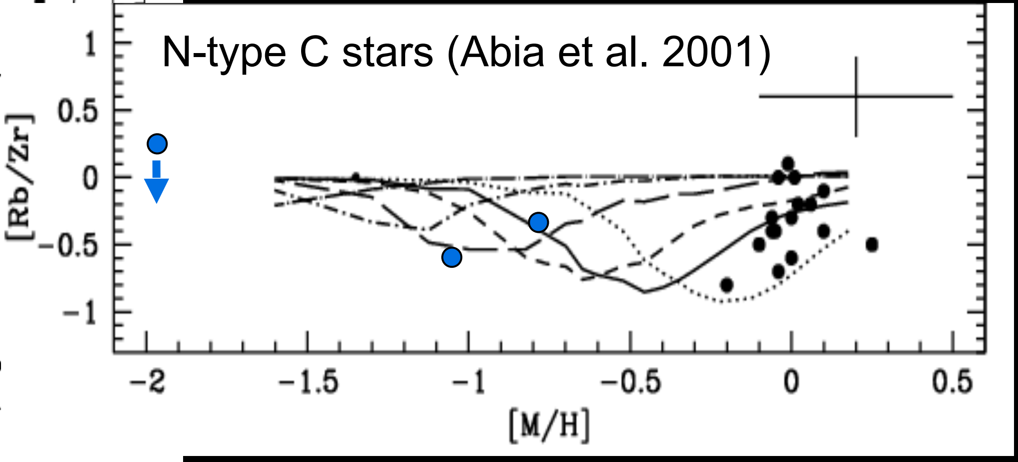
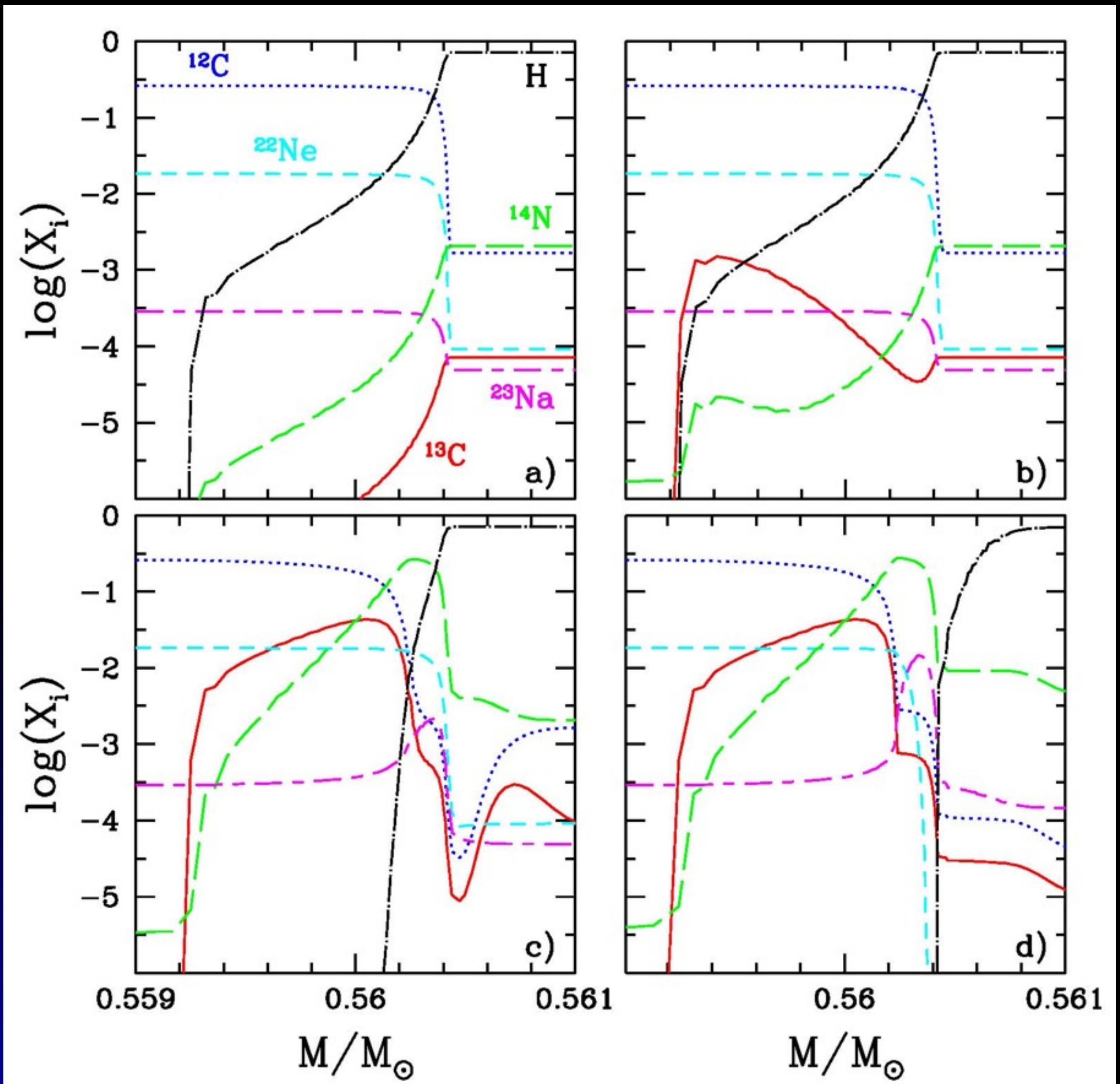






The formation of the ^{13}C pocket in the *bagnasciuga* transition zone



M=2*M*$_\odot$ *Z*=*Z*$_\odot$

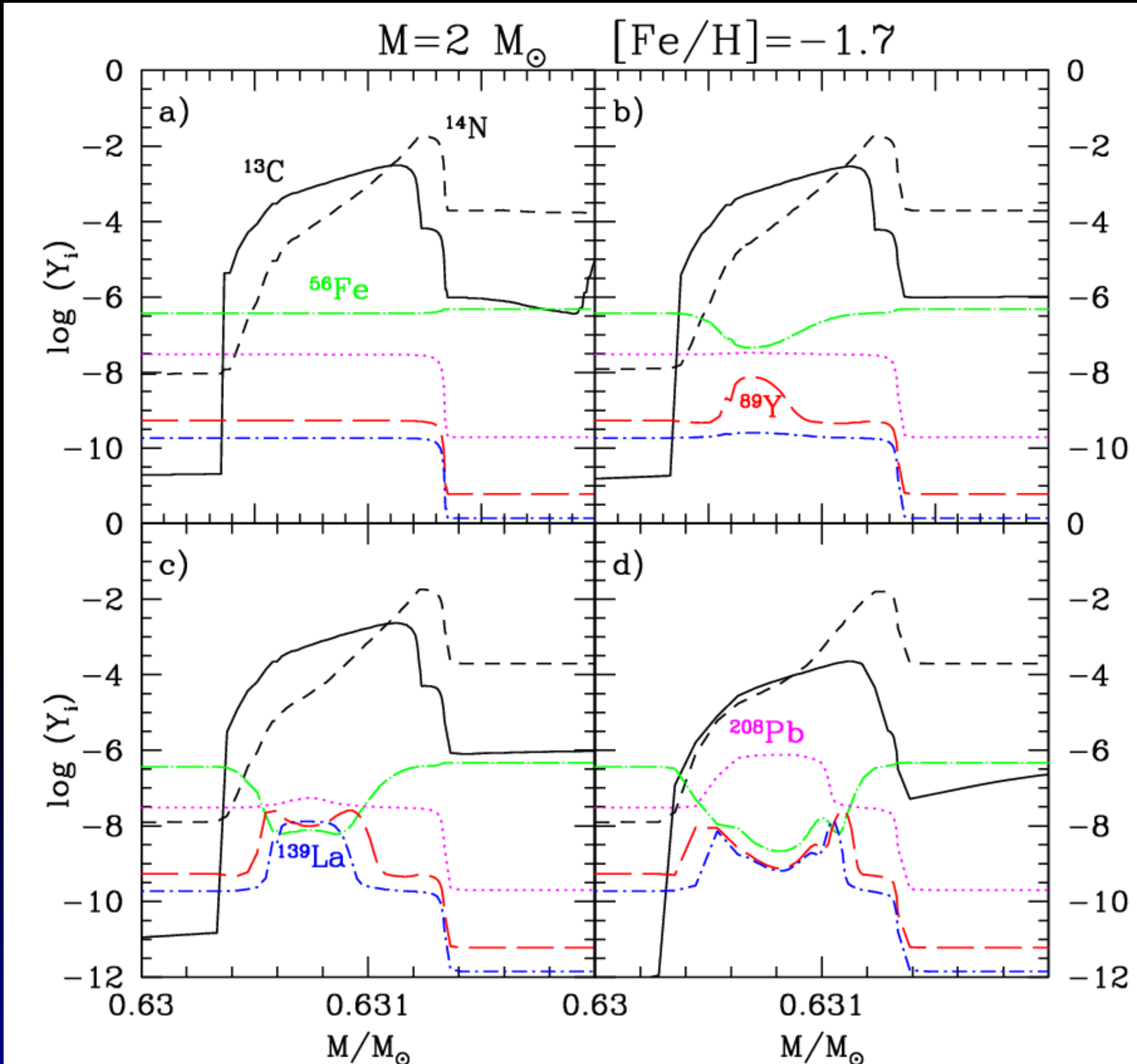
a) Maximum envelope penetration (TDU);

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

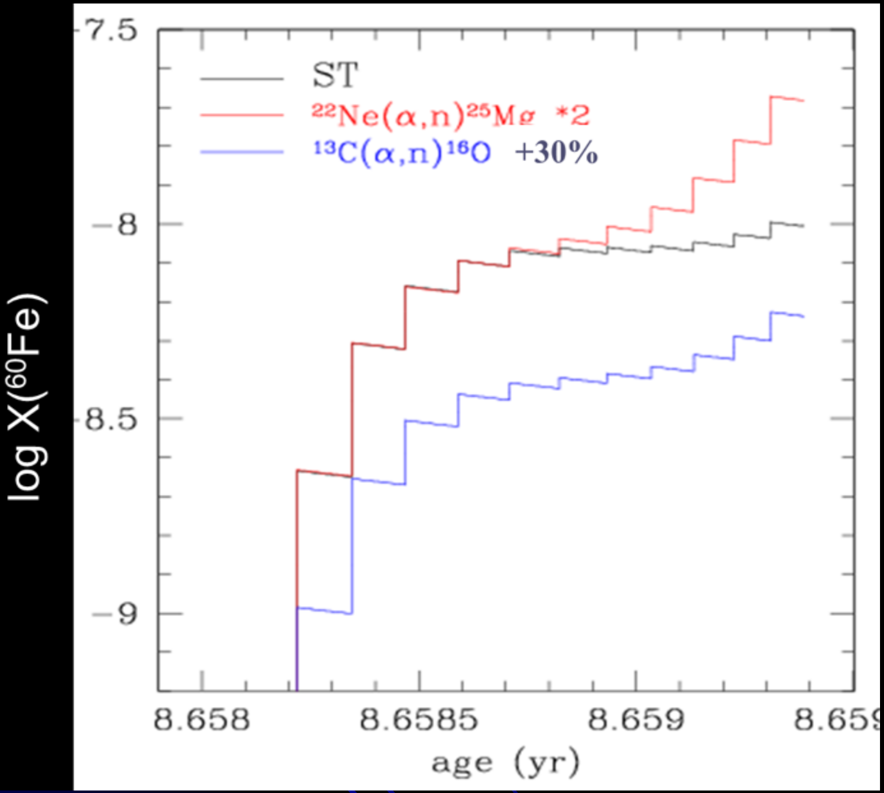
Later on, the $^{13}C(\alpha,n)^{16}O$ and the s-process

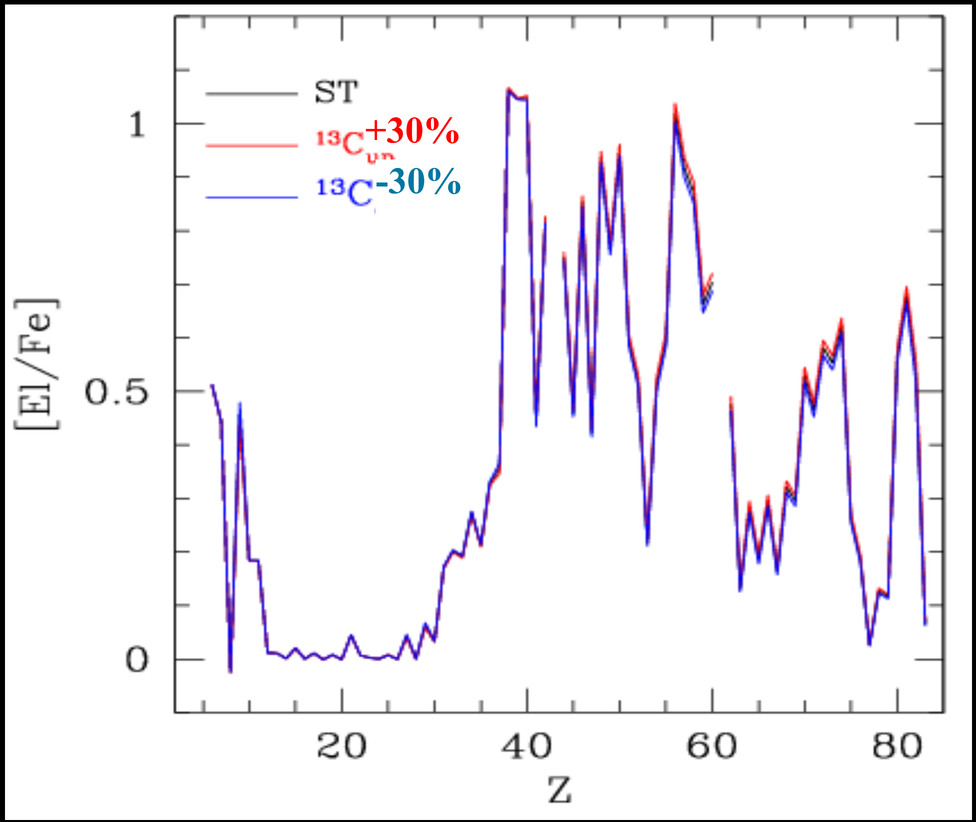


Low Z
high n/seeds
|
V
high Pb

Straniero et al. 2014
ApJ 785, 77

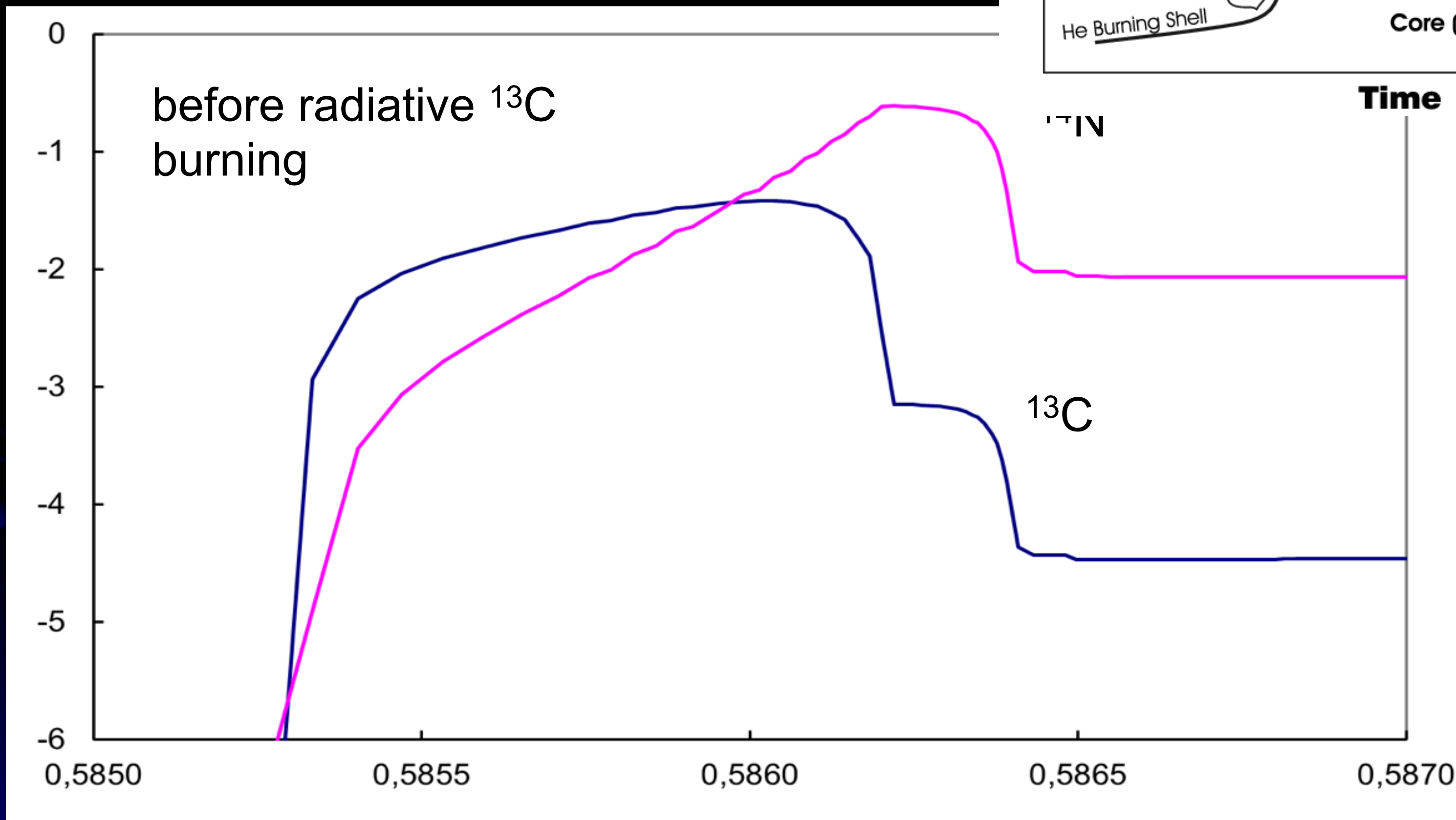
CONCLUSIONS:
Do we really need precise nuclear imputs?

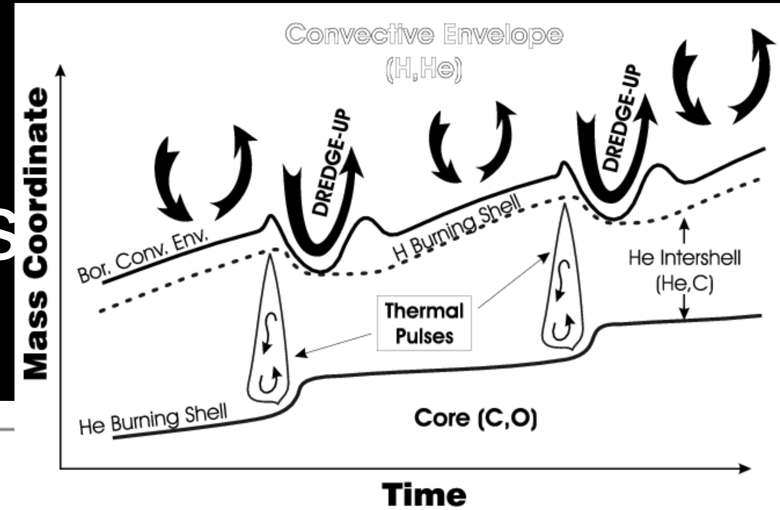




	Ni	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	Ni
	Co	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	Co	
Fe	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	Fe			

CONCLUSIONS:
Do we really need precis





Heil et al. 2008 (±30% at T_6=100)

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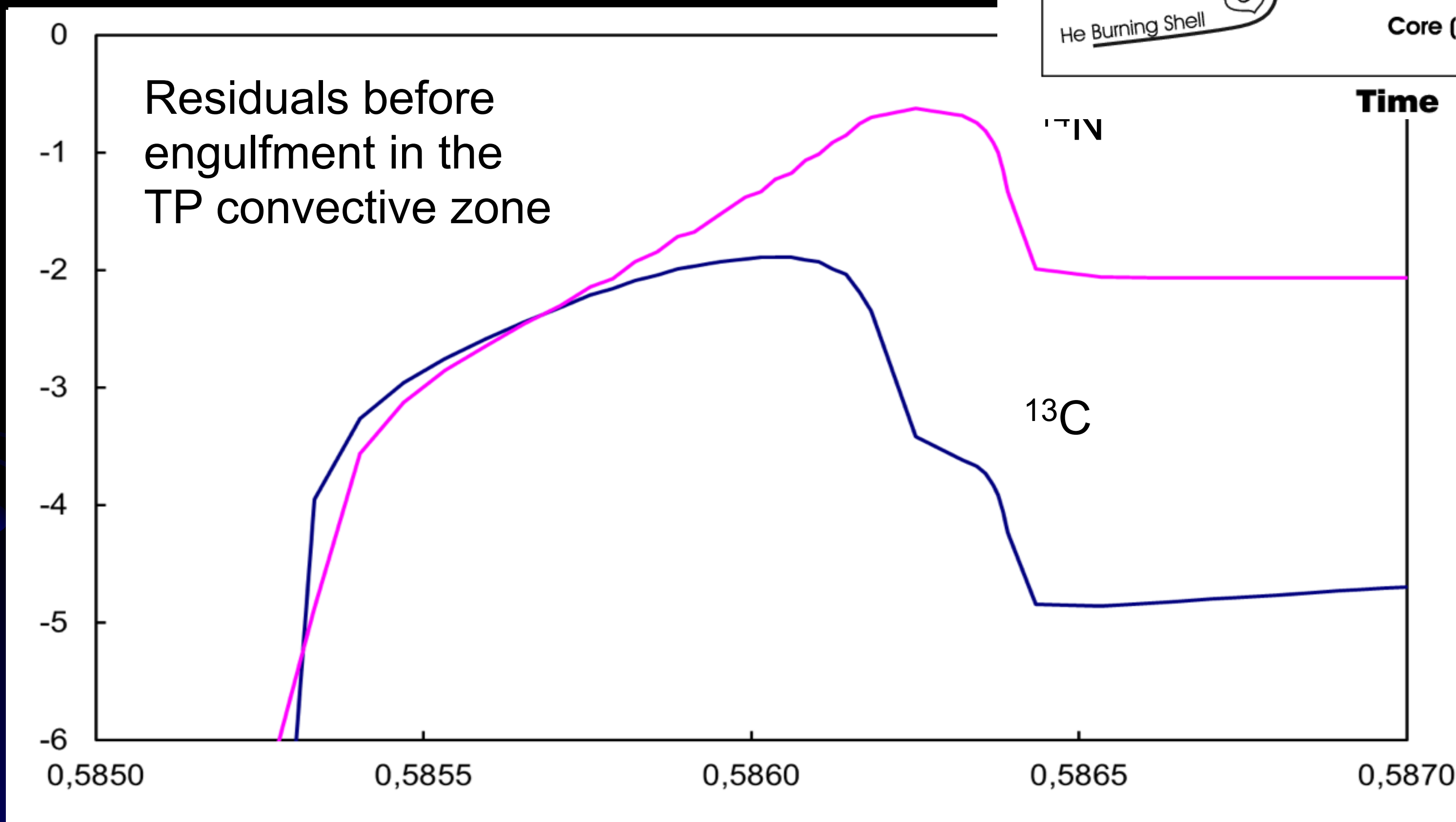
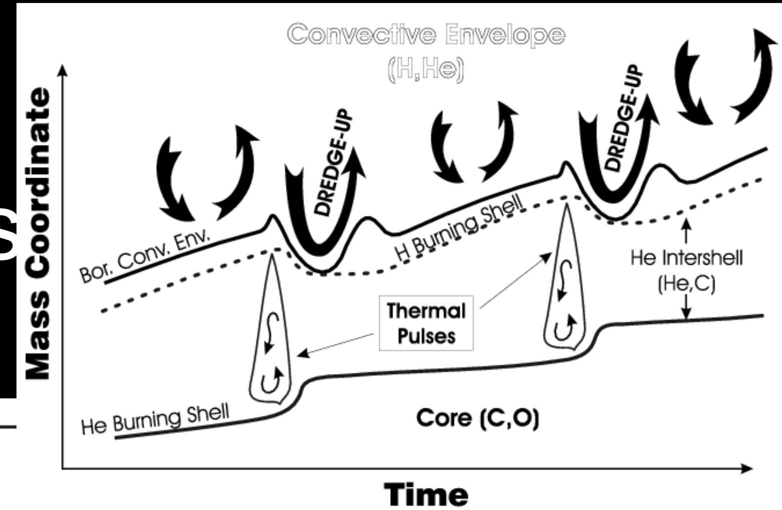
Do we really need precis





Heil et al. 2008 (±30% at T_6=100)

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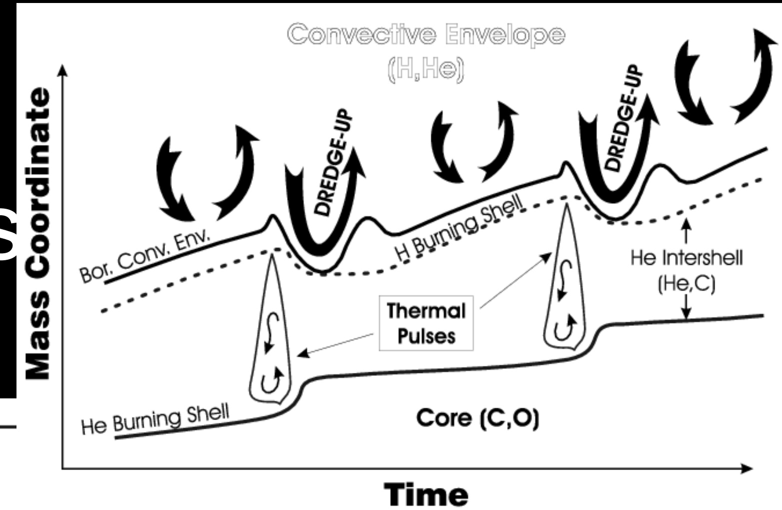

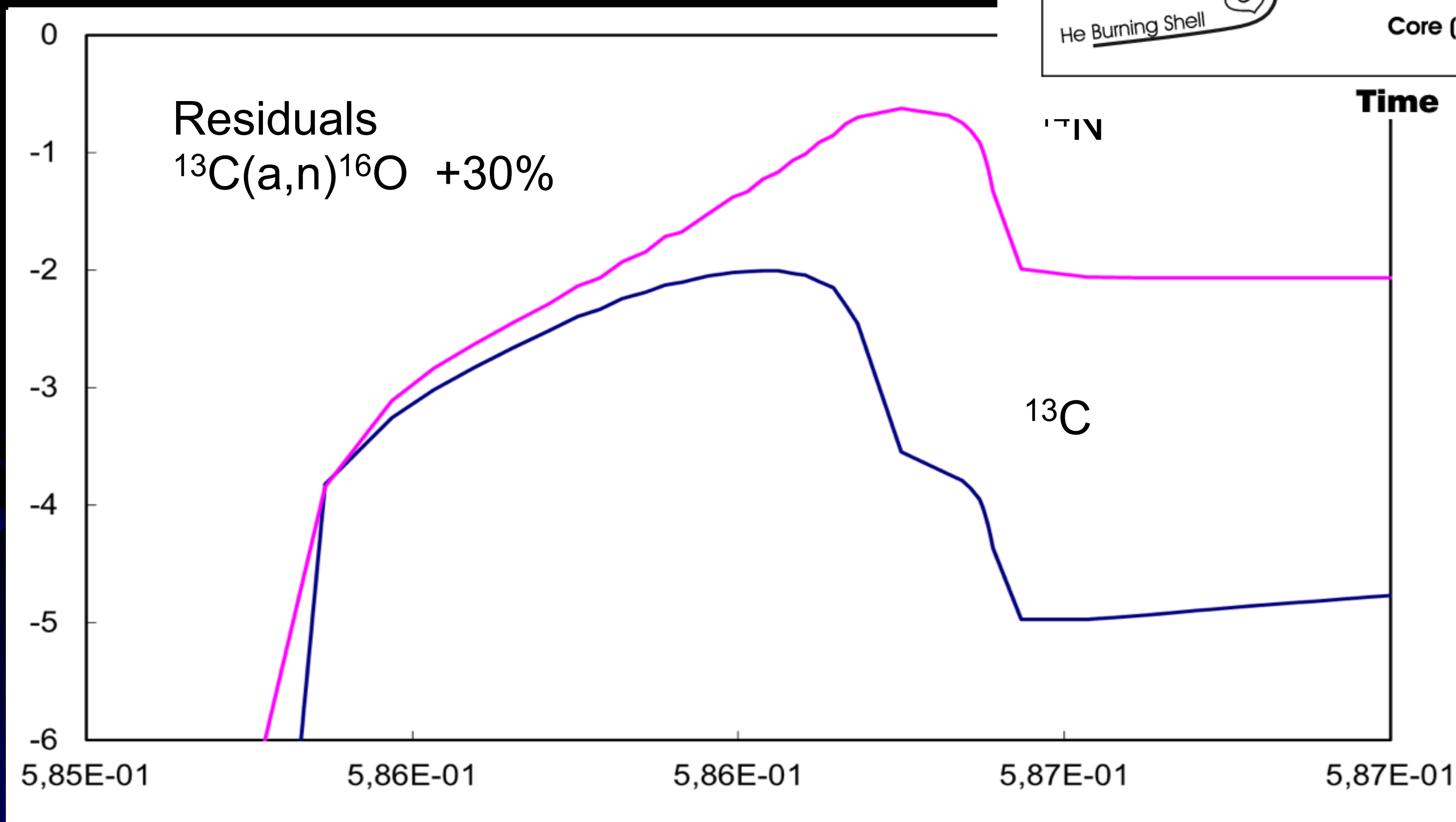

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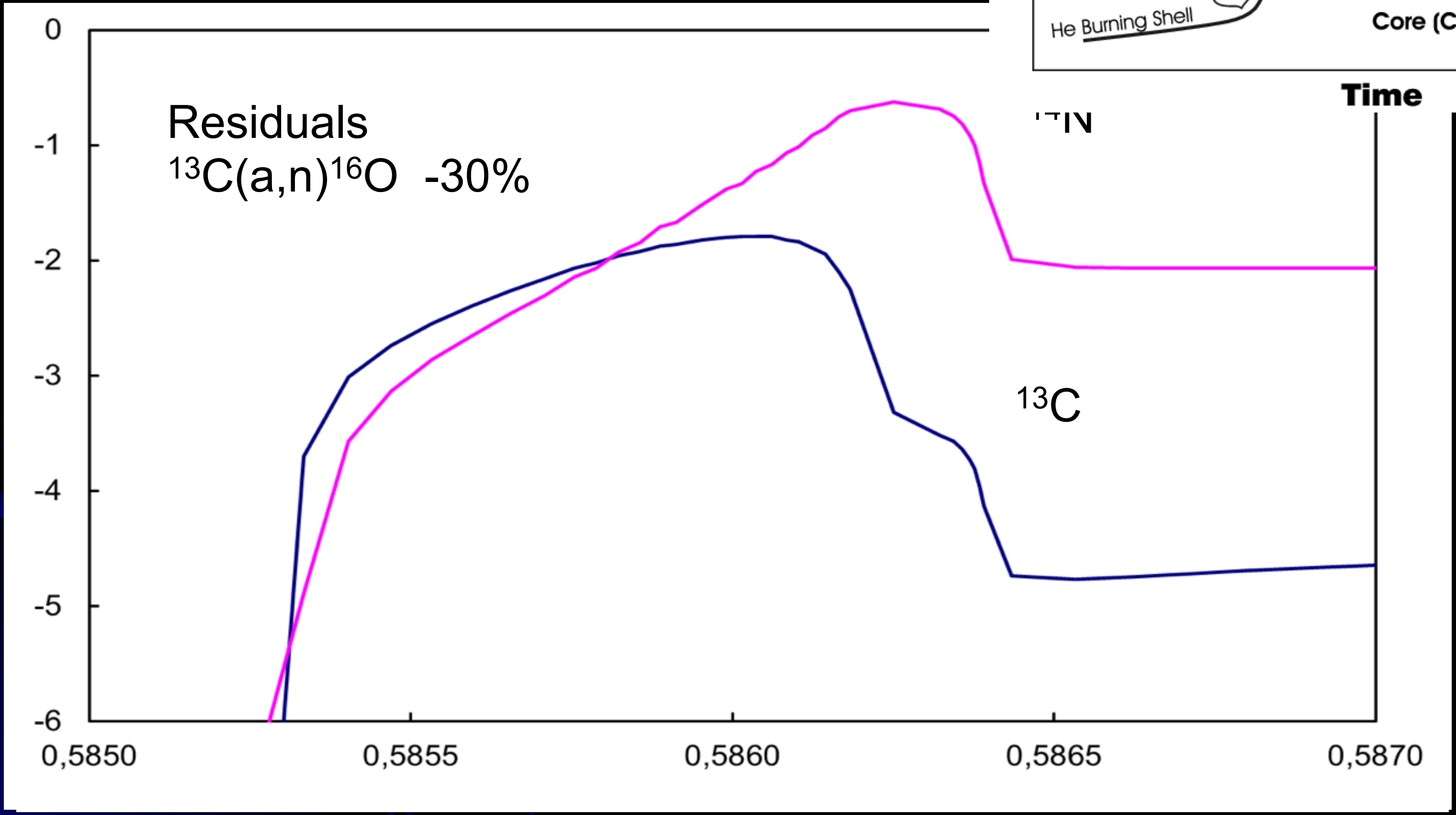

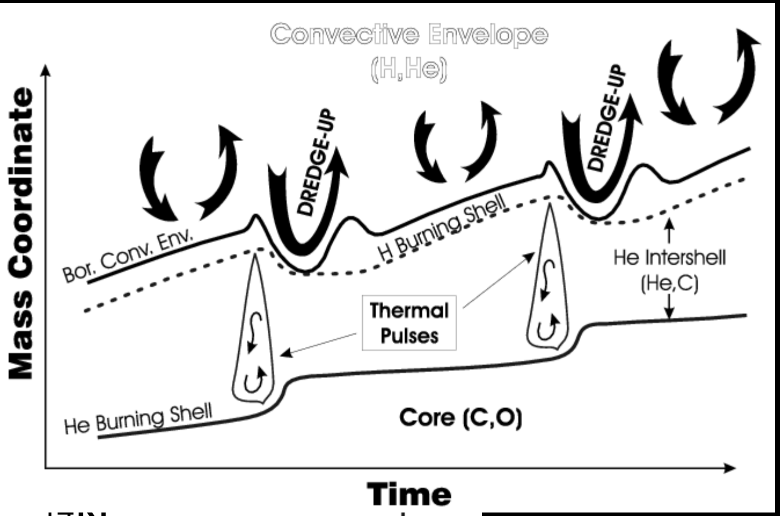

Heil et al. 2008 (±30% at T_6=100)