THE ROLE OF LOW AND INTERMEDIATE MASS STARS IN GALACTIC CHEMICAL EVOLUTION

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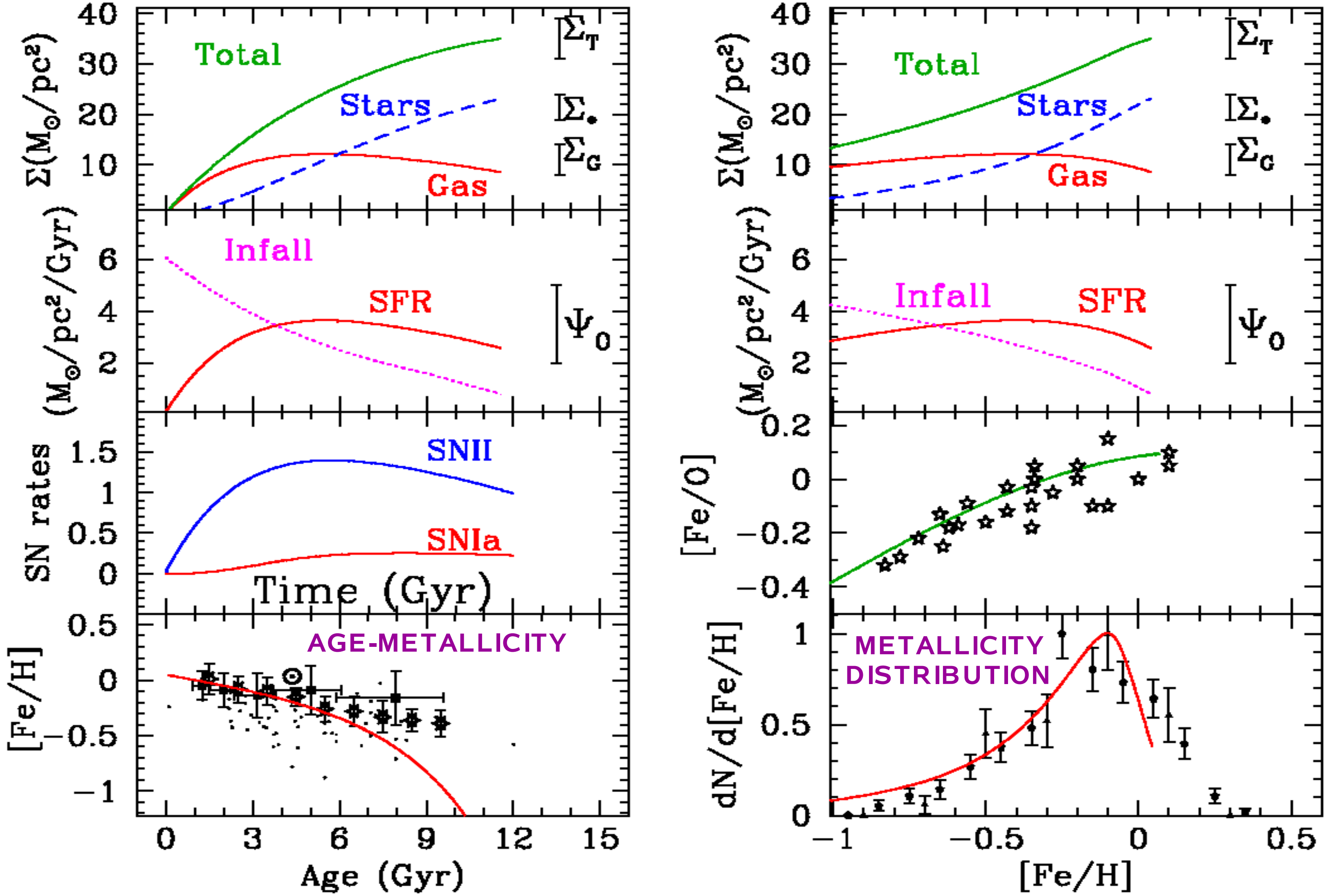
IAP

Chemical evolution of the Solar Neighborhood

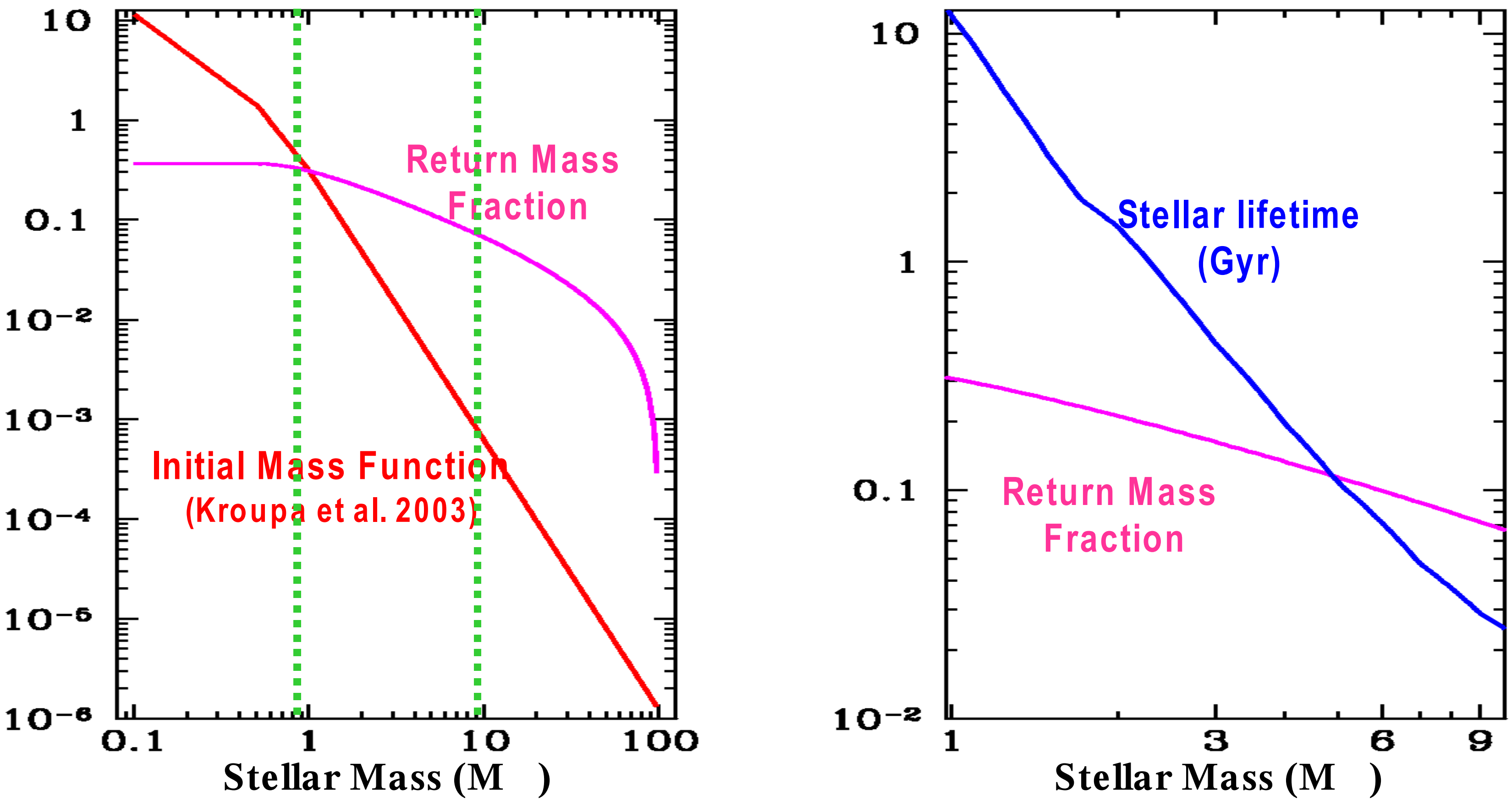


SLOW INFALL (τ = 7 Gyr) to fix G-dwarf problem,

SNIa to account for [Fe/O] evolution

PREDICTIONS: evolution of abundances (depends on yields)

Low and Intermediate Mass stars (0.8 – 9 M)



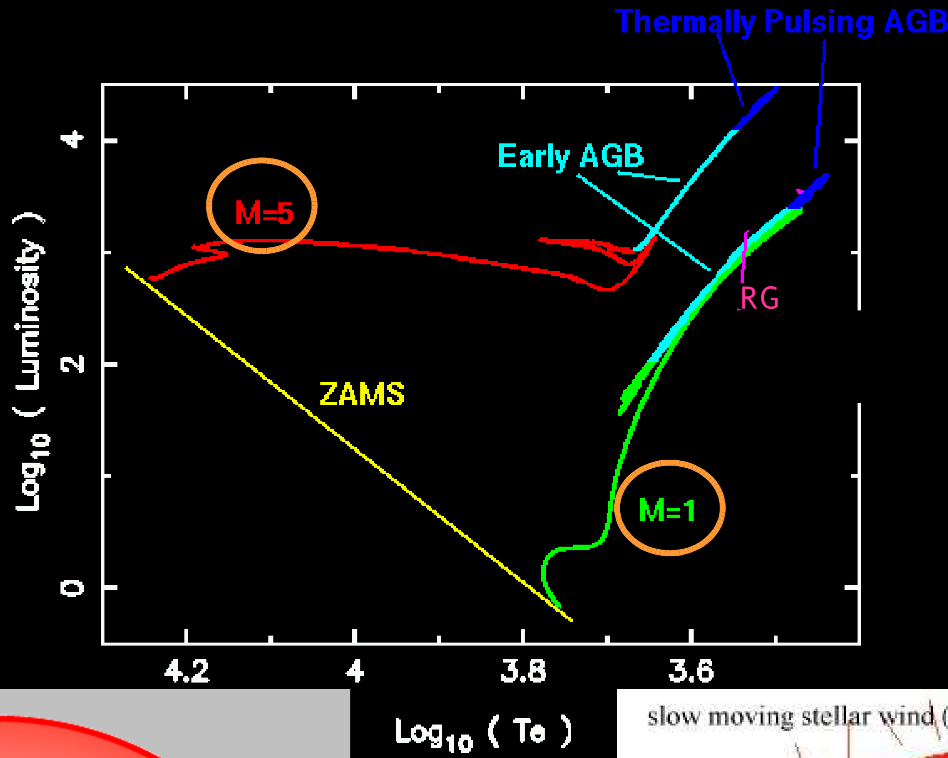
LIMS eject ~75-80 % of the mass returned by a stellar generation

Stars in the mass range of 1-2, 2-4 and 4-9 M
contribute each ~1/3 of that amount

Stars of Mass <1.6-2 M have lifetimes >1-2 Gyr and cannot
have affected the chemical evolution of the Milky Way's halo (T<1-2 Gyr)

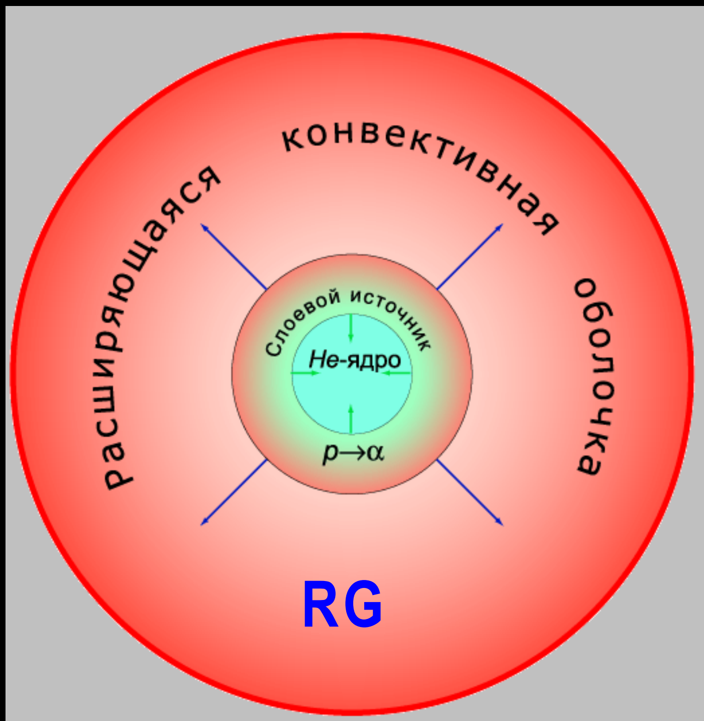
Low and IMS stars contribute to Nucleosynthesis either in the RGB

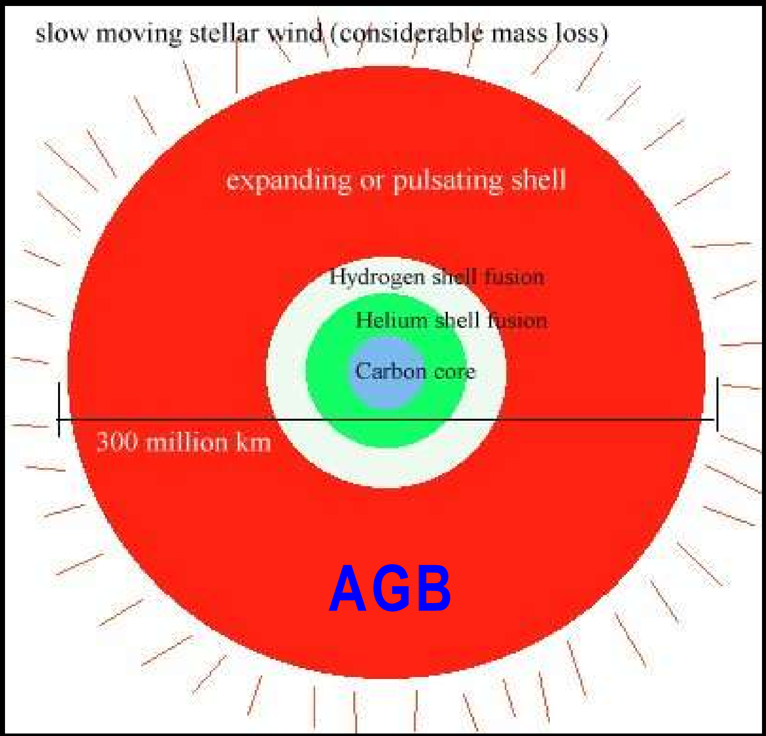
(products of H-burn : He-3, secondary N-14, C-13 Li from CBP ?)



.. or in the AGB

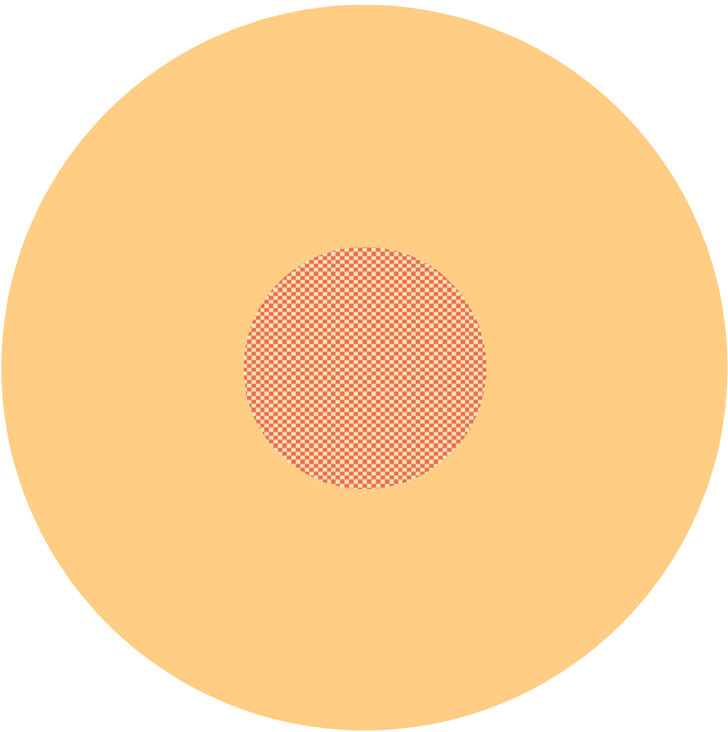
(products of H- and He- burn : He-3 ? primary N-14, C-13 ? C-12 ? Li from HBB ? F-19 ? Mg isotopes ? S-elements)

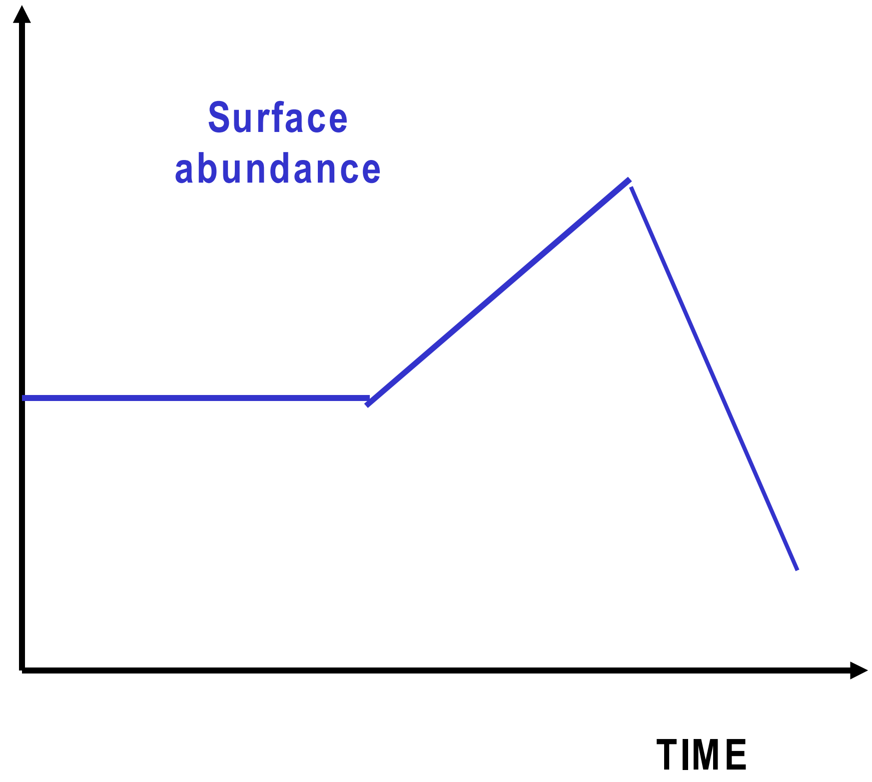




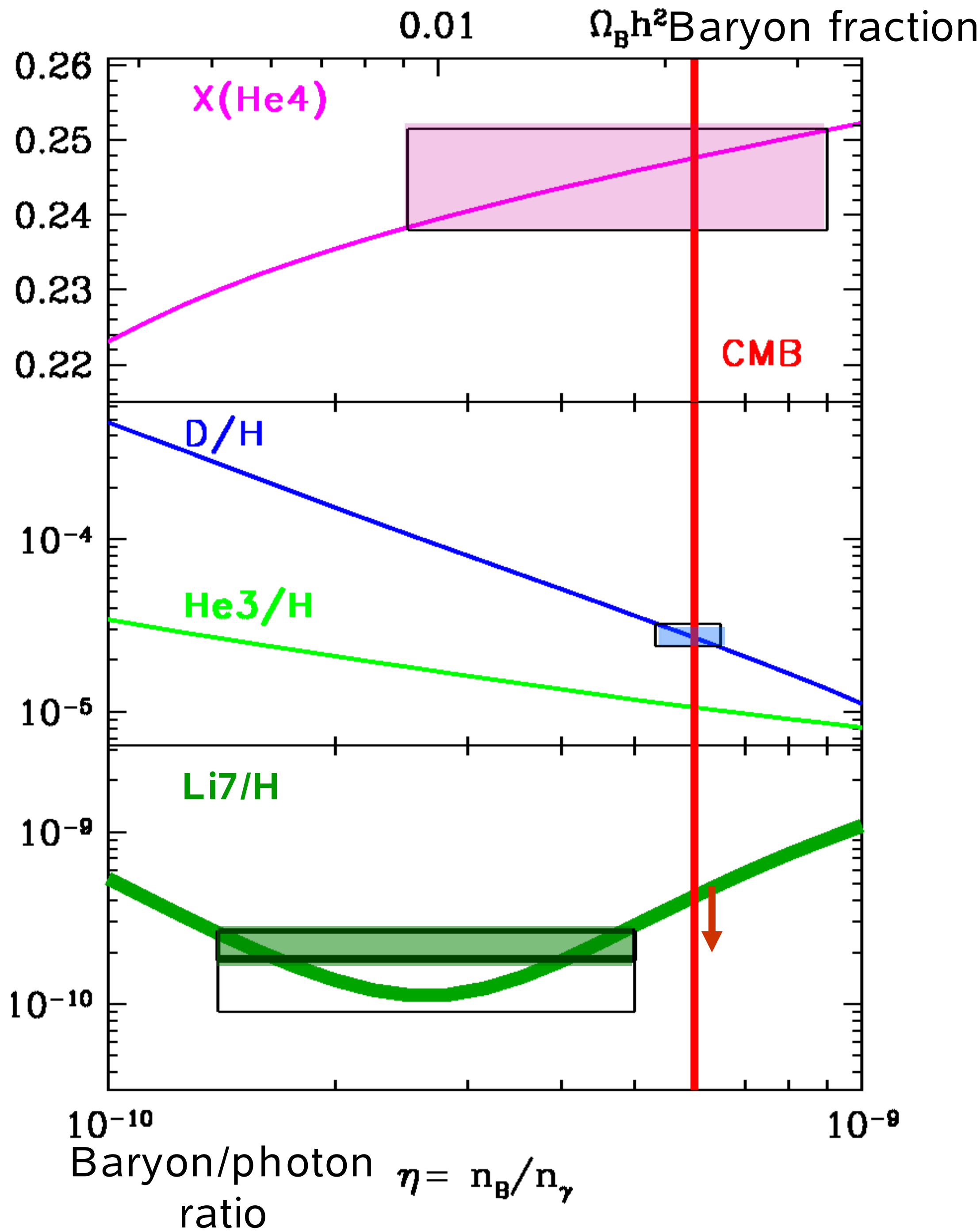
How to be sure that a given star is net contributor
to the abundance of a given element ?

Observationally : difficult !





Models (constrained by observations)



Calculations of
primordial nucleosynthesis
and determination
of baryonic density
by WMAP measurements of
Cosmic Microwave Background

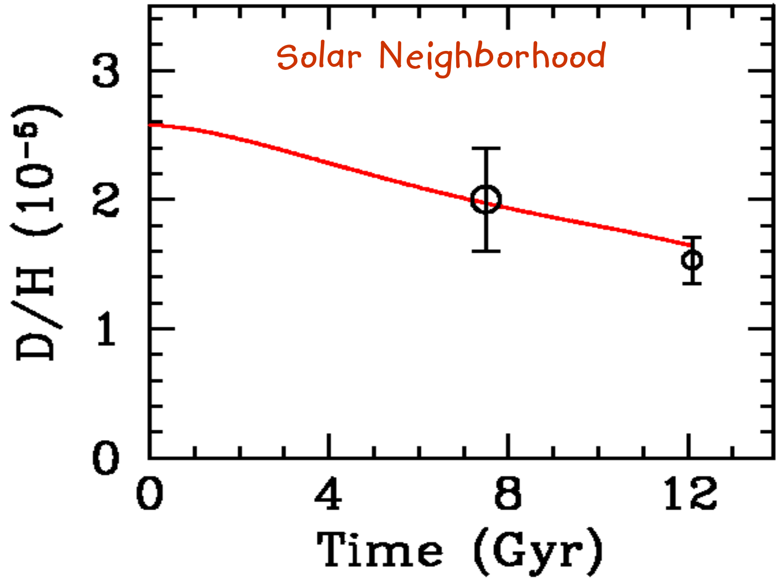
-are consistent with
observed "primordial" D
$D/H \sim 2.6 \ 10^{-5}$
in high redshift gas clouds

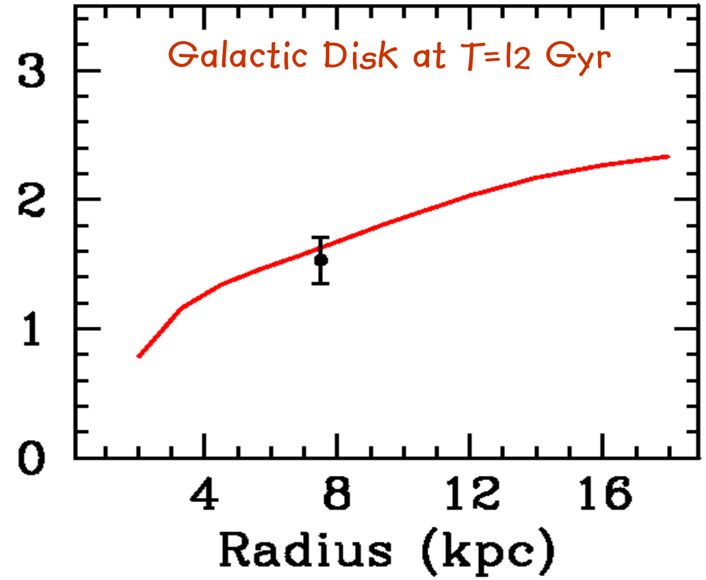
- correspond to
primordial He3/H $\sim 10^{-5}$

-suggest a value of
primordial Li7
~2 times higher
than the observed
"plateau" in halo stars

Perhaps Li7 destruction is
underestimated in standard BBN
(Coc et al. 2004)

Astration of Deuterium

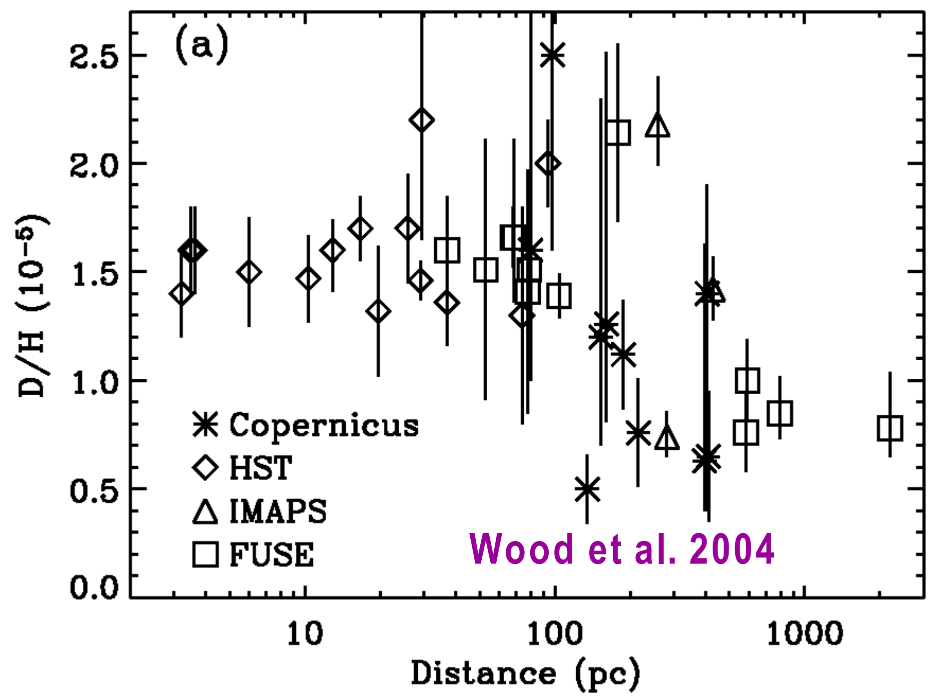




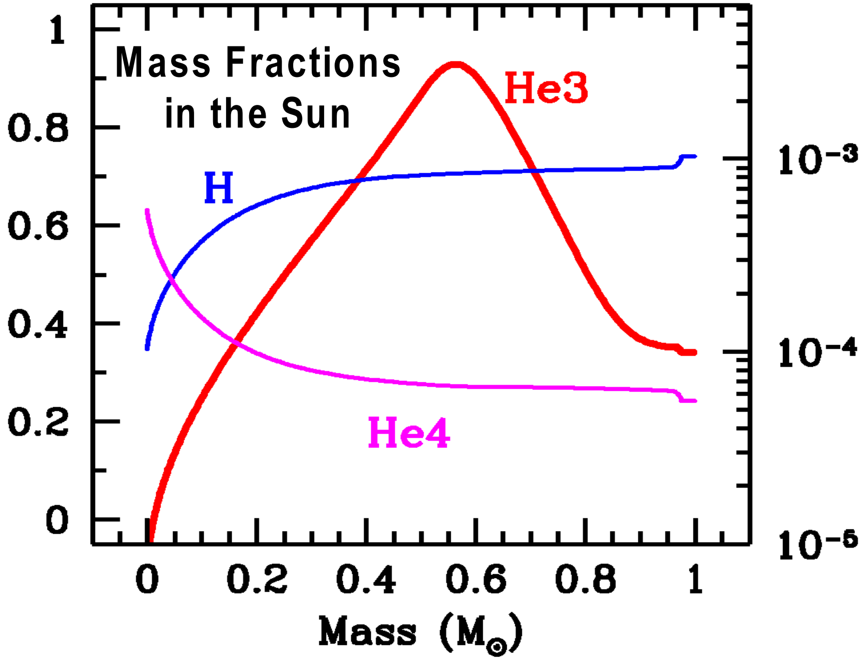
Standard GCE models (with standard IMF and slow infall of primodial composition) predict small D astration in the solar neighborhood (mostly by Low and IM stars)

$D_{PRIMORDIAL}/D_{TODAY} < 2$

But: what is the value of $(D/H)_{TODAY}$?



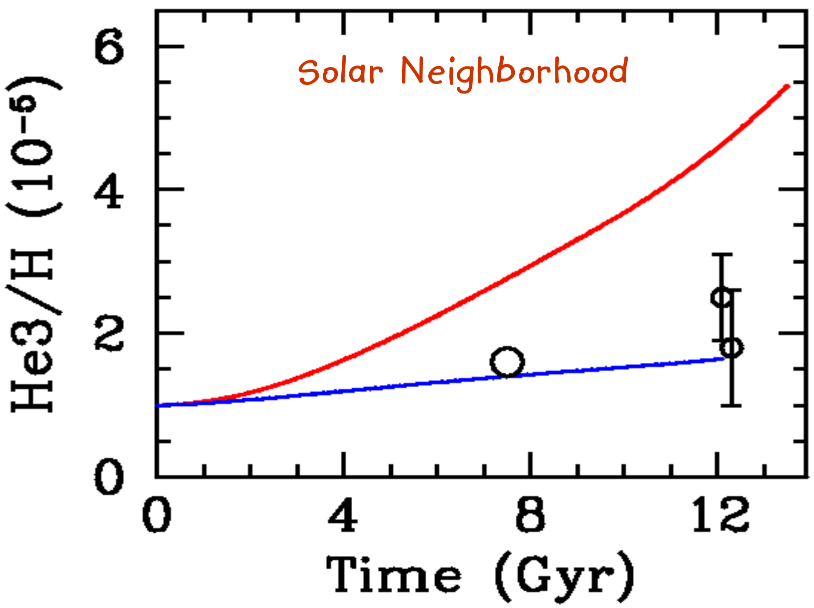
Production of He-3 in LIMS ; more than we need ?



He-3 is an unavoidable product of H-burning, through the p-p chains, ultimately ejected in RGB and AGB

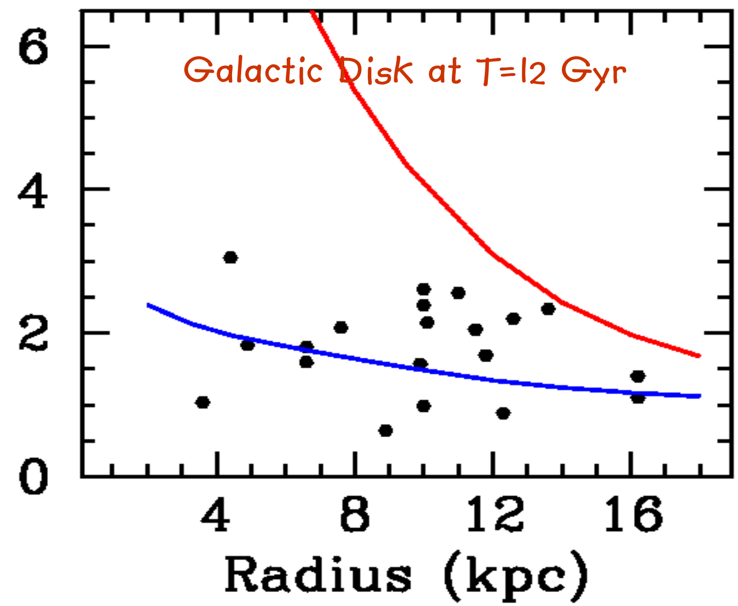
"Standard" yields and Chemical evolution models suggest an oveproduction of He-3, locally and across the Milky Way disk

Important He-3 destruction required, at some point after the Main Sequence



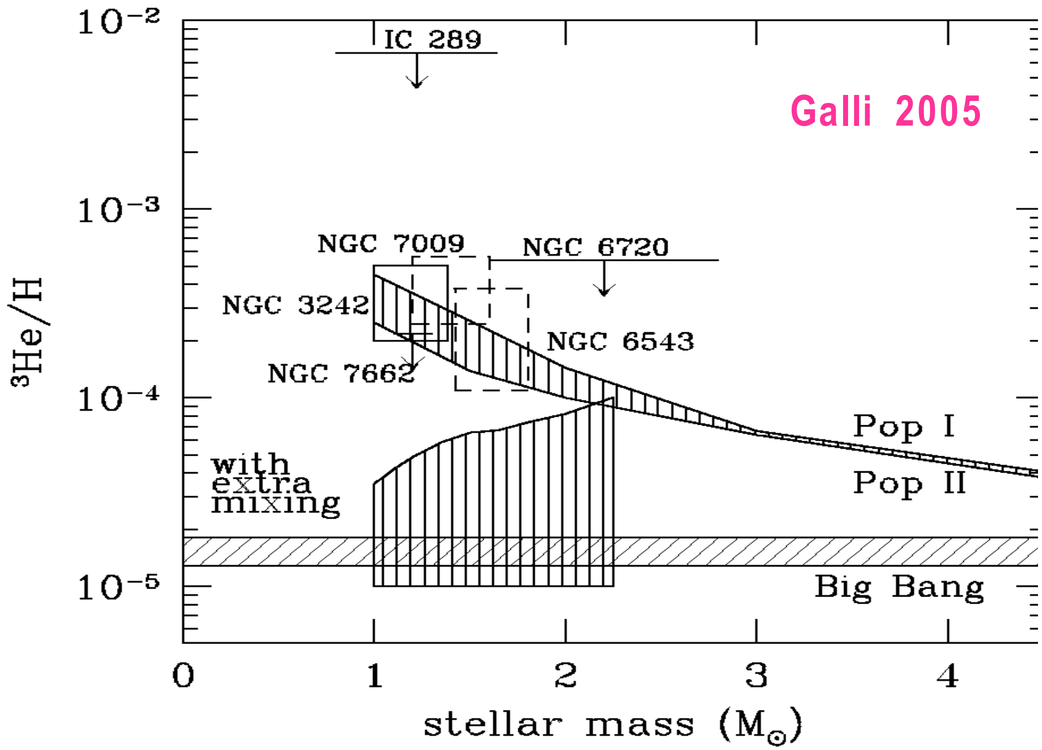
Standard Yields

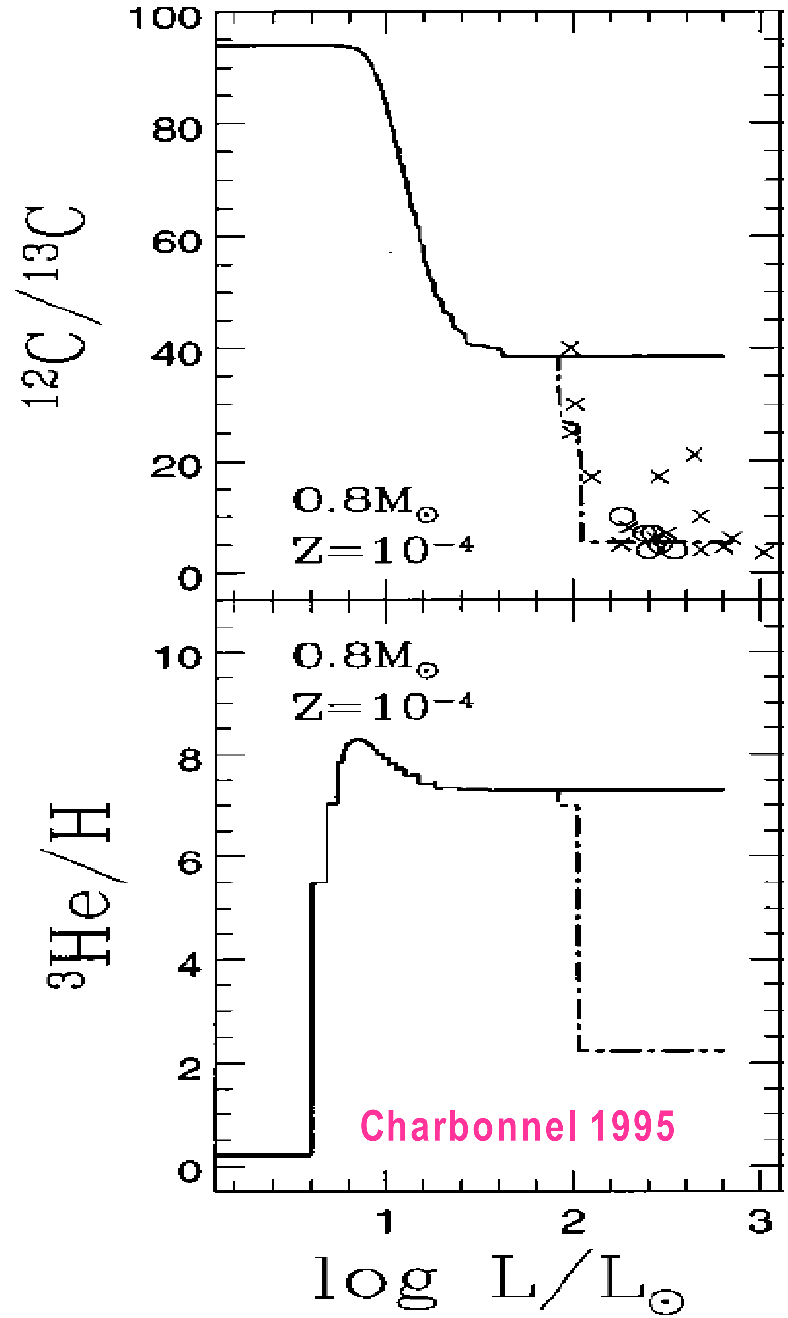
Yields reduced by 95% in stars of 1-2 M



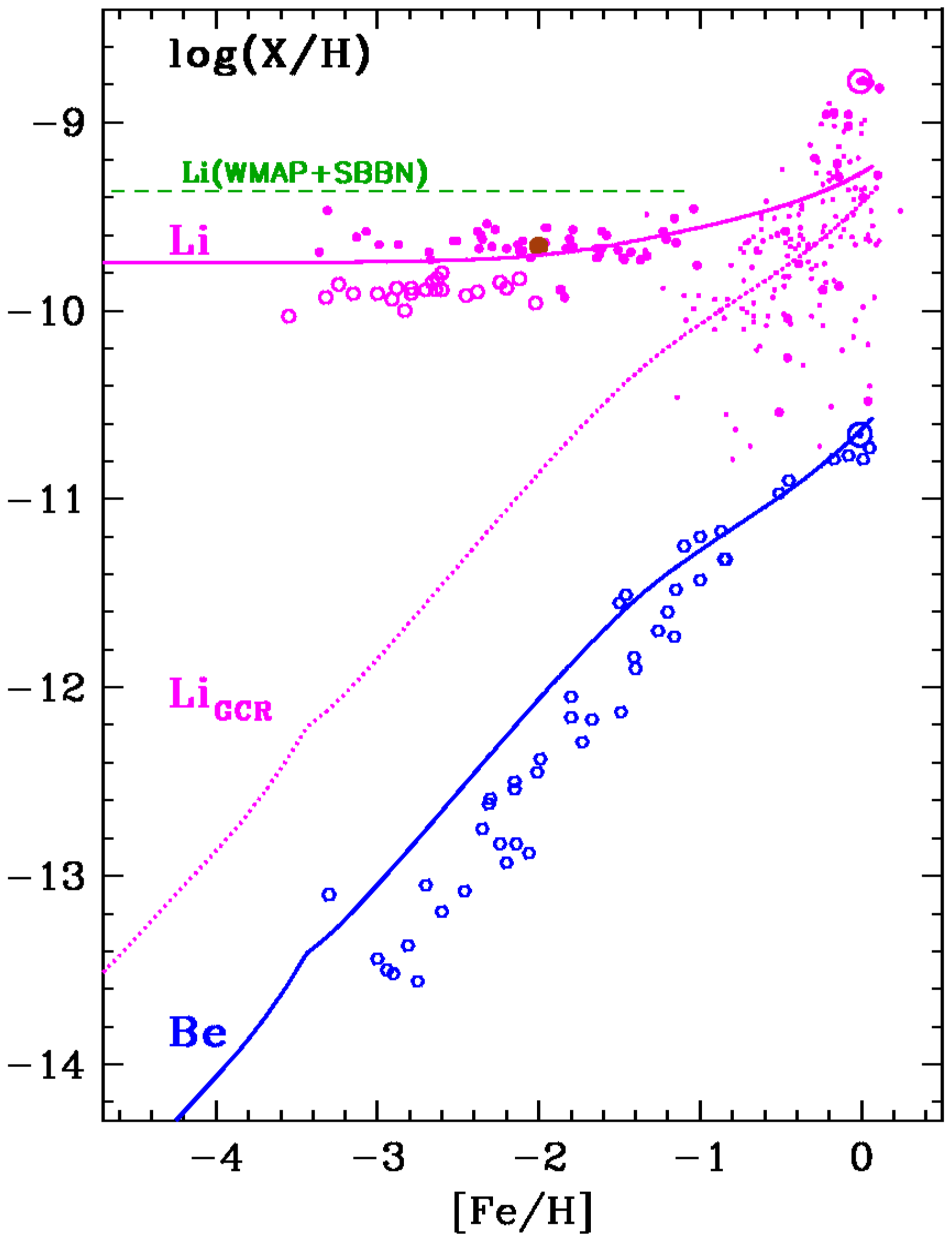
Such destruction may occur in the RGB, and help explain the observed low C12/C13 ratio in RGBs (Hogan 1995, Charbonnel 1995)

However, available observations of He3/H in Planetary Nebulae are in excellent agreement with "Standard" (non-mixed) models...





What is the origin of pre-solar (meteoritic) Li ?



After its primordial (Spite plateau) value in halo stars, Li increases by a factor ~10 until the formation of the Sun

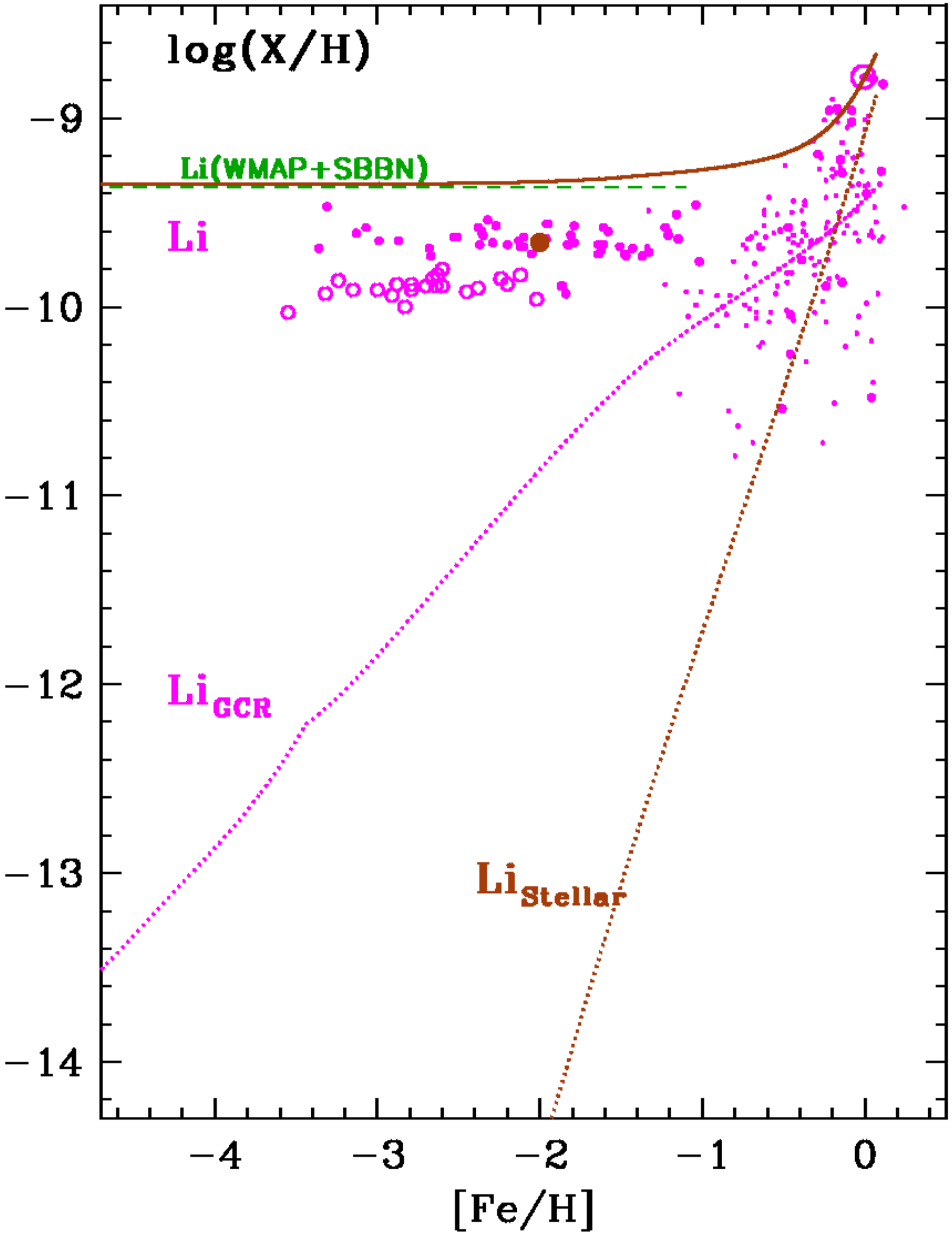
What is the source ?

Li is produced by Cosmic Rays, along with Be

By matching the observed Be evolution, one may evaluate the Li contribution of CR

CR produce about 25 % of pre-solar Li

What is the origin of pre-solar (meteoritic) Li ?



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What is the source ?

Li is produced by Cosmic Rays, along with Be

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CR produce about 25 % of pre-solar Li

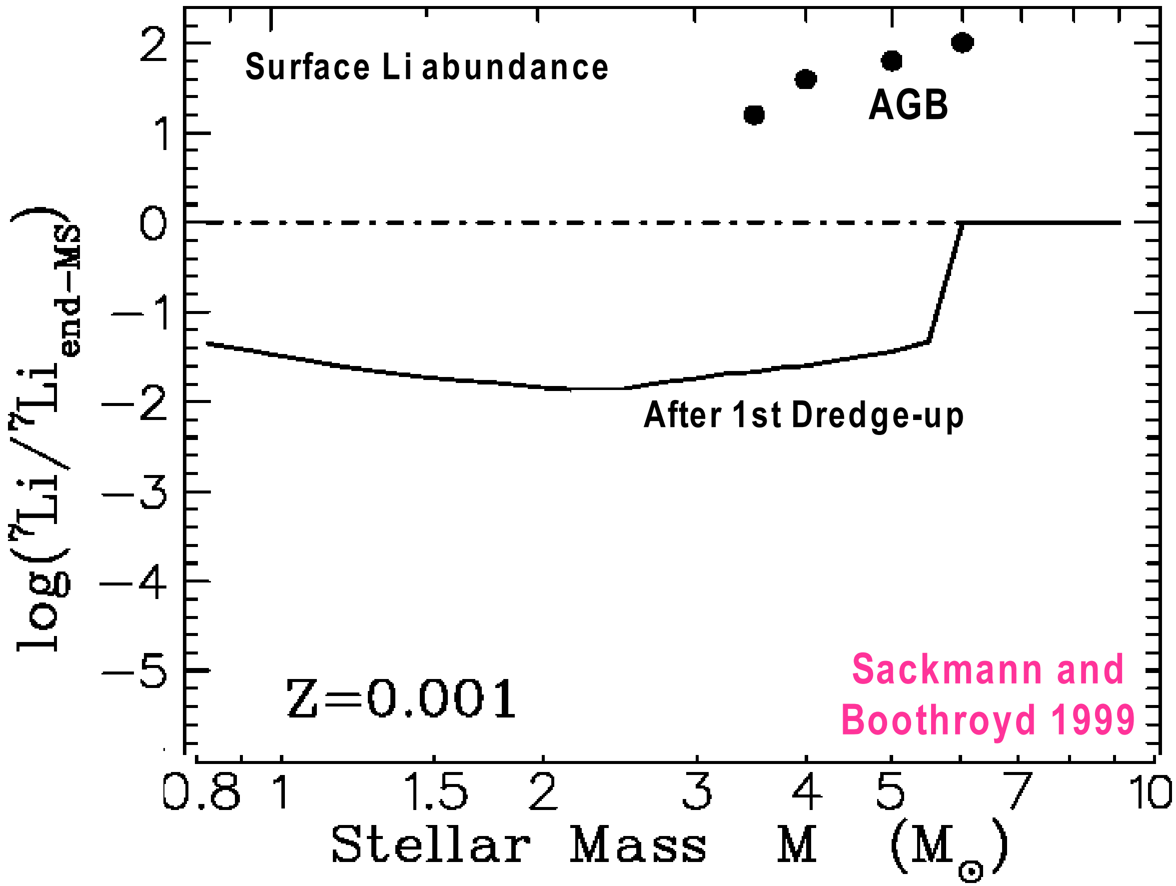
Whatever remains from

Li_{OBS}(upper envelope) – $Li_{PRIMORDIAL}$ – Li_{CR}

is the stellar contribution to Li (SNII, LIMS, novae ?)

That contribution and its evolution depend on the assumed value of $Li_{PRIMORDIAL}$

Can AGB stars produce Li-7 ?



Perhaps... through the Cameron-Fowler mechanism

(He-3 + He-4 ⇒ Be-7 in Hot Bottom Burning,

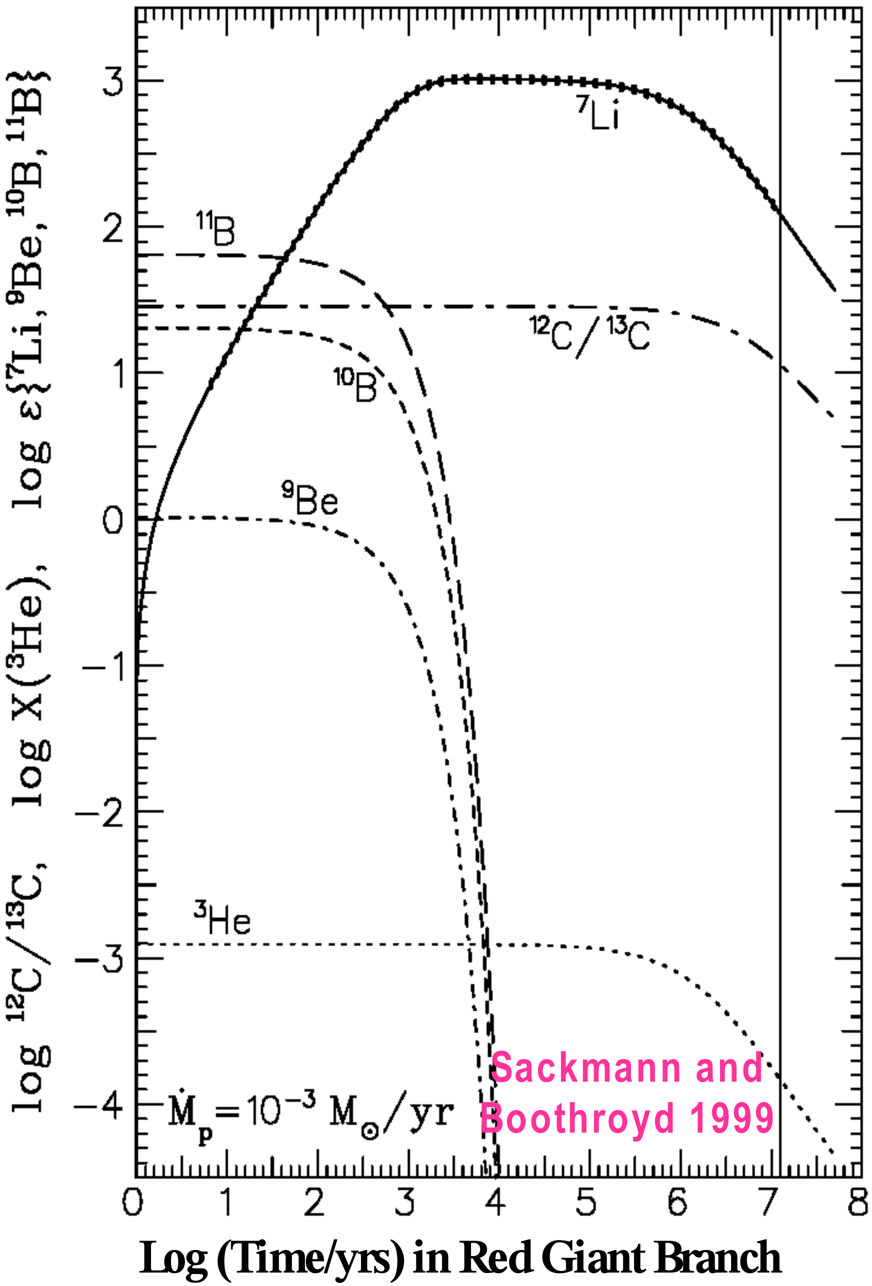
and convective transport of Be-7 in the outer envelope

to escape destruction and decay to Li-7)

BUT, only the most massive
(and short-lived) AGBs can do so...
Their contribution comes early and
would destroy the Spite plateau...

...Unless their Li production
is strongly suppressed
at low metallicities...
(but why ?)

Can Red Giants produce Li-7 ?

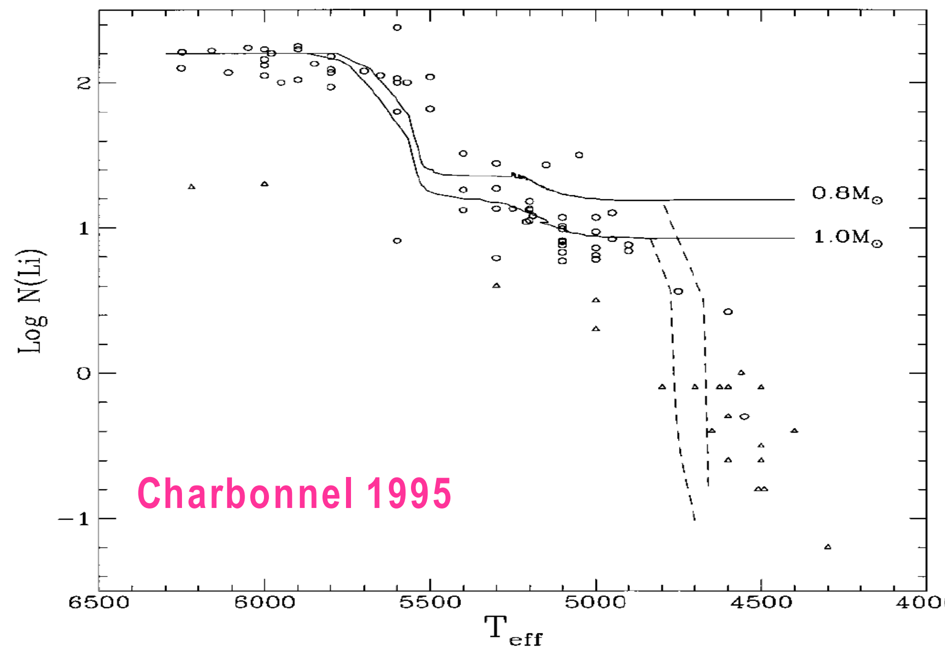


Some super Li-rich RG observed
(e.g. de la Reza et al. 1997)

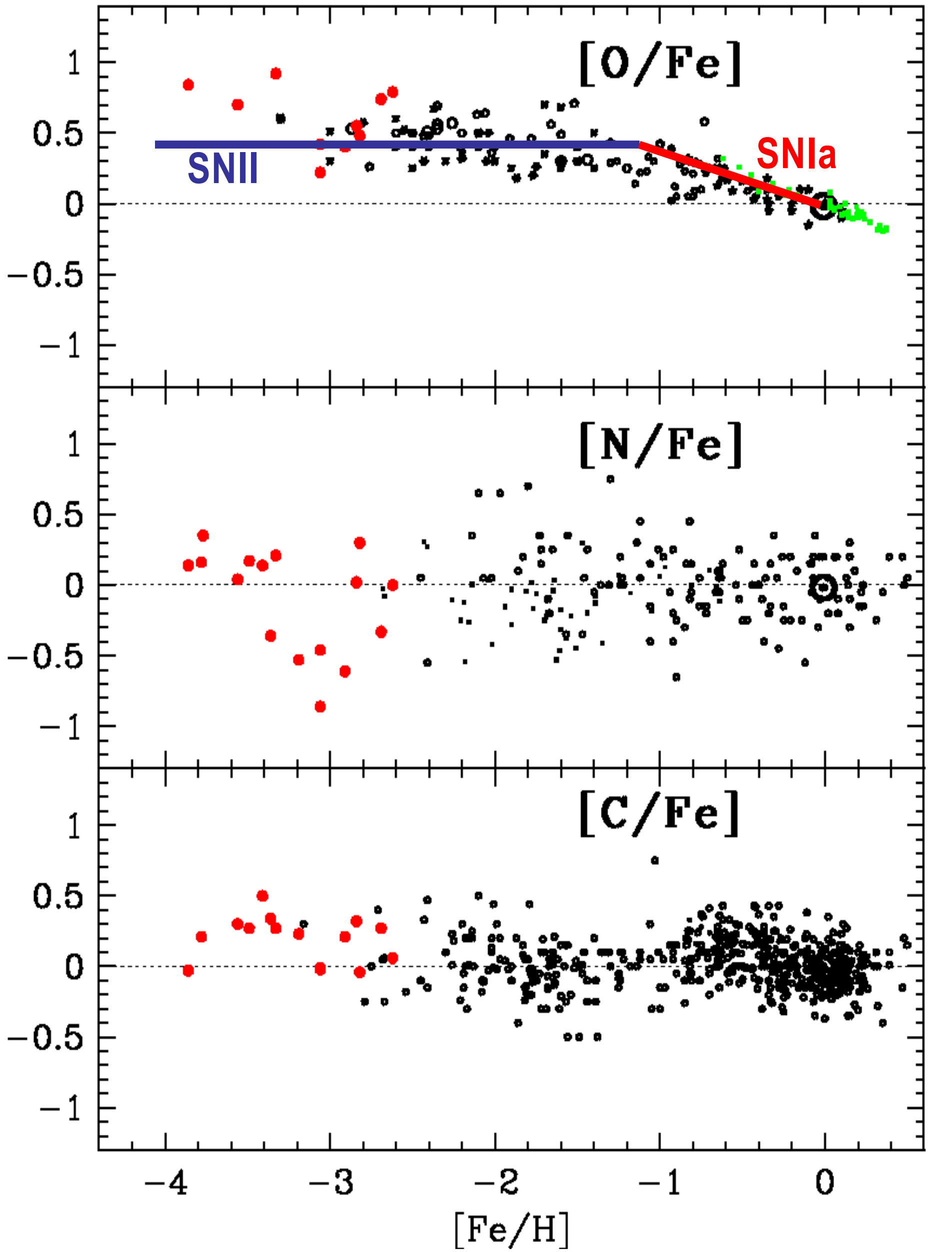
In "Cool Bottom Processing" (CBP)
Li-7 is made in the H-burning shell and
transported to the RG envelope
Sackmann and Boothroyd (1999)

In the "Li-flash"
(Palacios et al. 2001)

BUT..., how much could be ejected before
destruction, which is required to explain
observations of C12/C13 in RG ?



Evolution of CNO in Solar neighborhood



C and N abundances
always follow Fe
PRIMARIES ?

But: ~2/3 of Fe in disk
come late from SNIa

~2/3 of C and N in disk
come from a late source

(not operating in halo)

Could late N-14 and C-12
come from LMS
(long-lived) stars ?

Or, perhaps,
metallicity-dependent yields
from massive, mass losing, stars?

Primary N in early halo:
Which source?

CNO yields of AGB stars

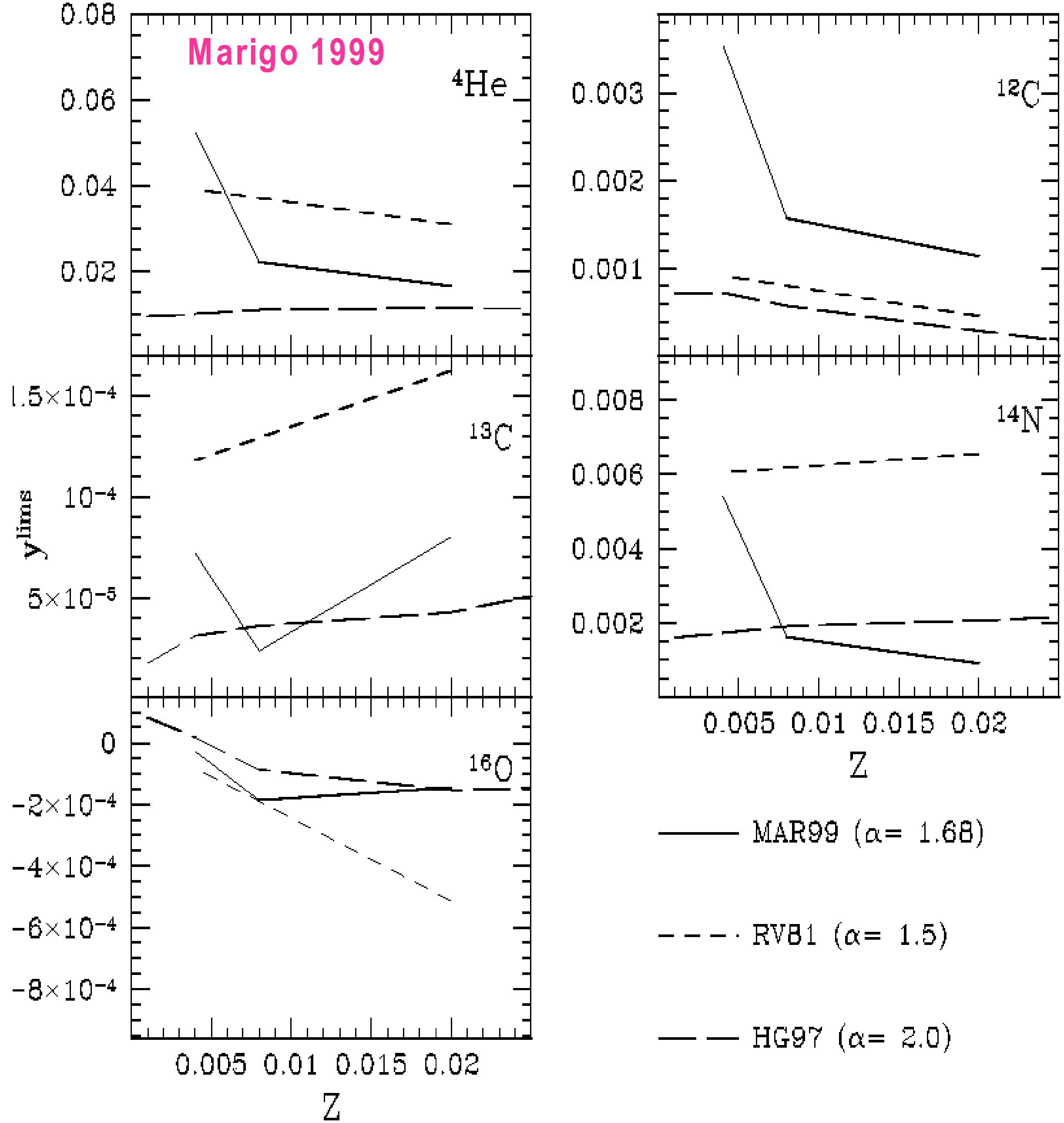
They depend a lot
on assumptions
about
AGB mass loss and
mixing processes
(+ nuclear uncertainties)

Just from first principles,

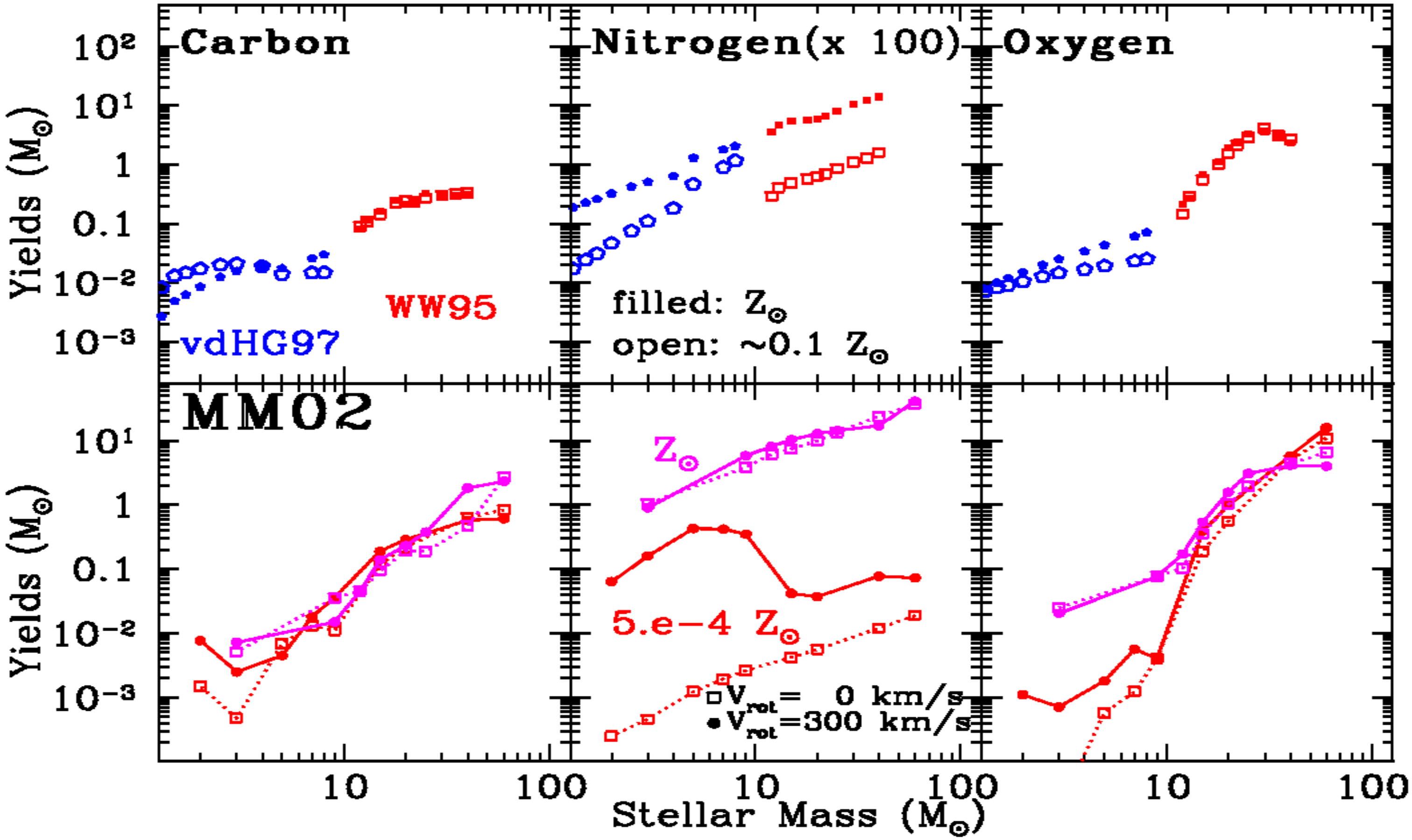
neither the absolute yields
(i.e. whether a star of
given mass is important
producer of an isotope)

nor the nature of the process
(i.e. primary or secondary)

can be known with certainty



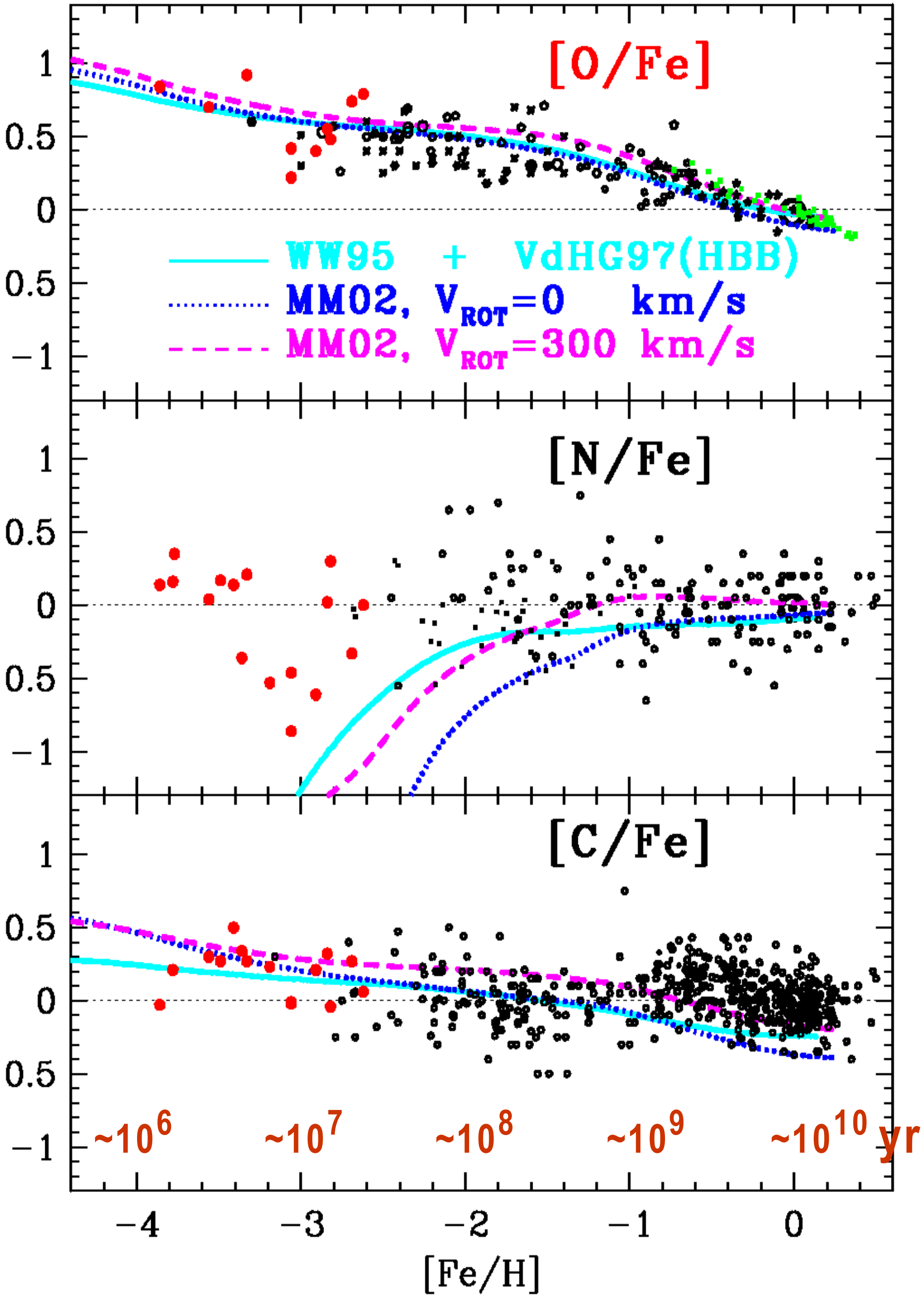
Yields of CNO elements



Nitrogen Production

Non Rotating:
- Massive stars (τ~10^7 years): Secondary
- Intermediate Mass (τ~10^8 years): Primary (HBB)
- Low Mass stars (τ~10^9 years): Secondary

Rotating Stars:
- Massive stars (τ~10^7 years): Still Secondary
- Intermediate and Low Mass ($\tau \geq 10^8$ years): ~Primary



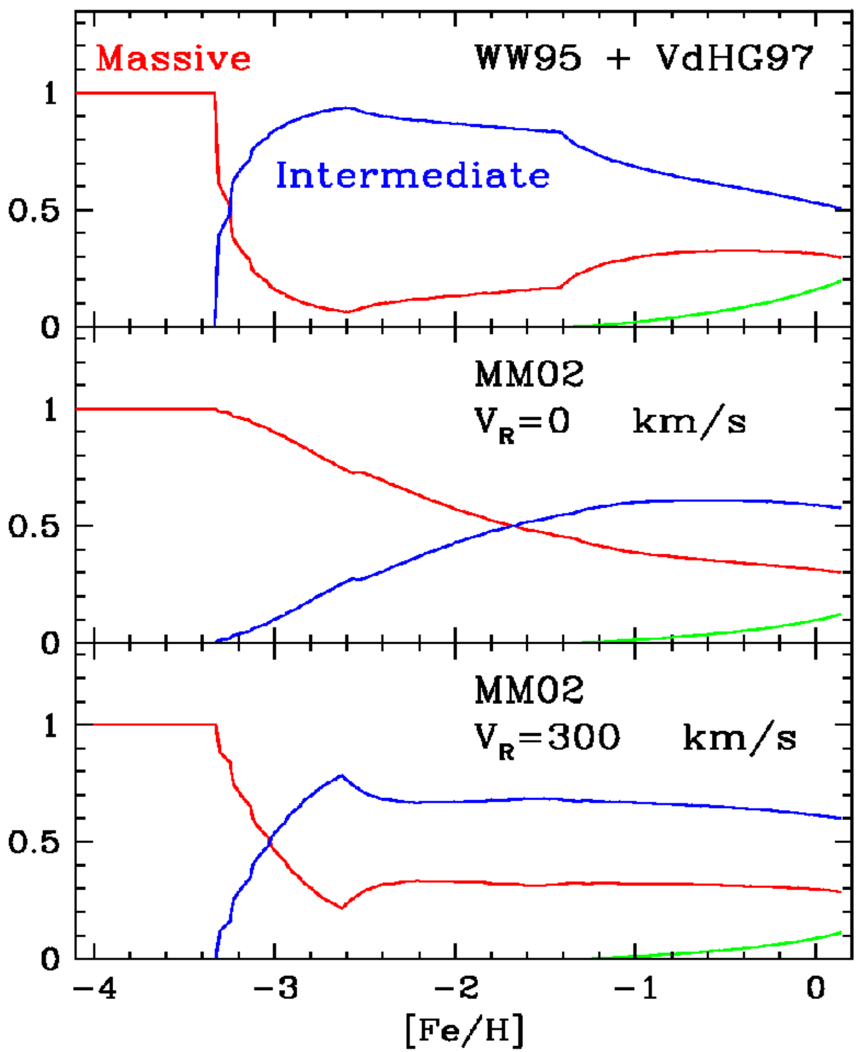
Primary N production from IMS
at late times ~matches
Fe production from SNIa
[N/Fe] ~ 0
Not exactly the case for C…

Stellar rotation has
similar effect on
yields of nitrogen
(mostly from
Intermediate mass stars)
as **Hot Bottom Burning**

Difficult to explain
earliest primary Nitrogen
unless extremely
high rotation velocity assumed,
~800 km/s (**Maeder and Meynet 2005**)

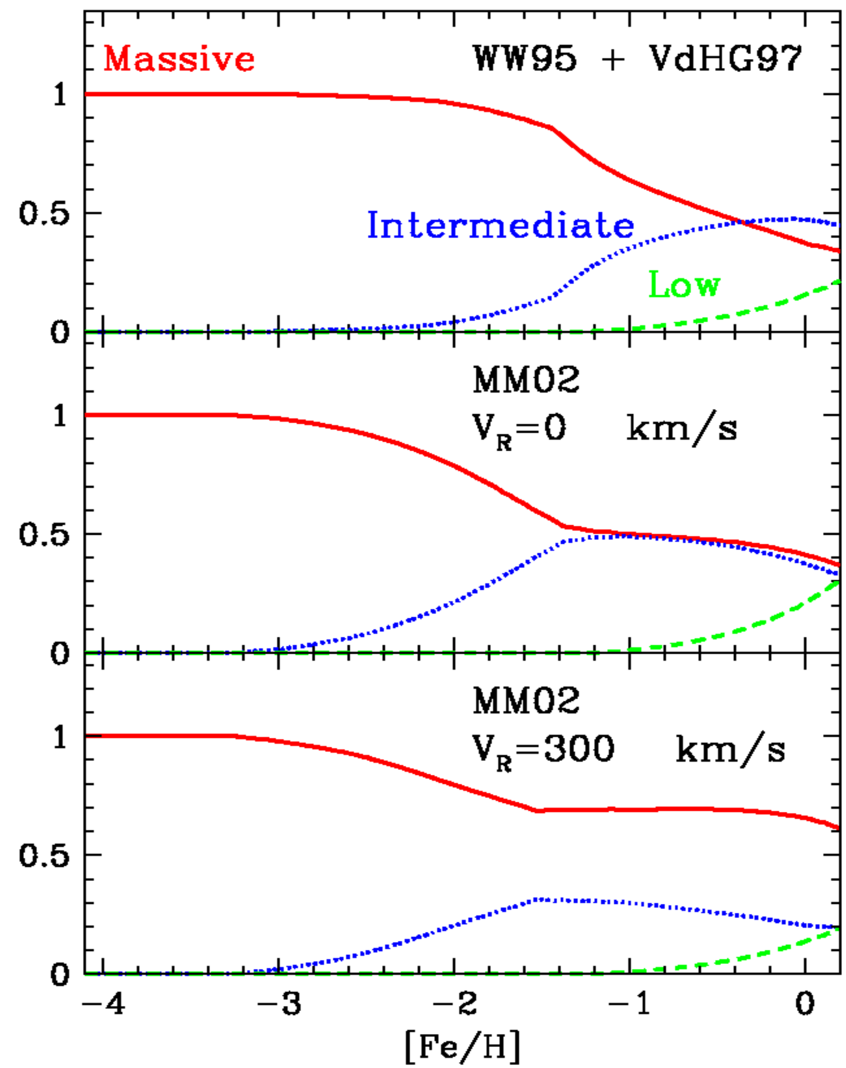
However: **timescales**
at low [Fe/H] are **uncertain**…
IF comparable to the time required
to reach [Fe/H]=-4, then IMS OK !

Fractional contribution
to N-14 production



Intermediate mas stars dominate
late production of N-14

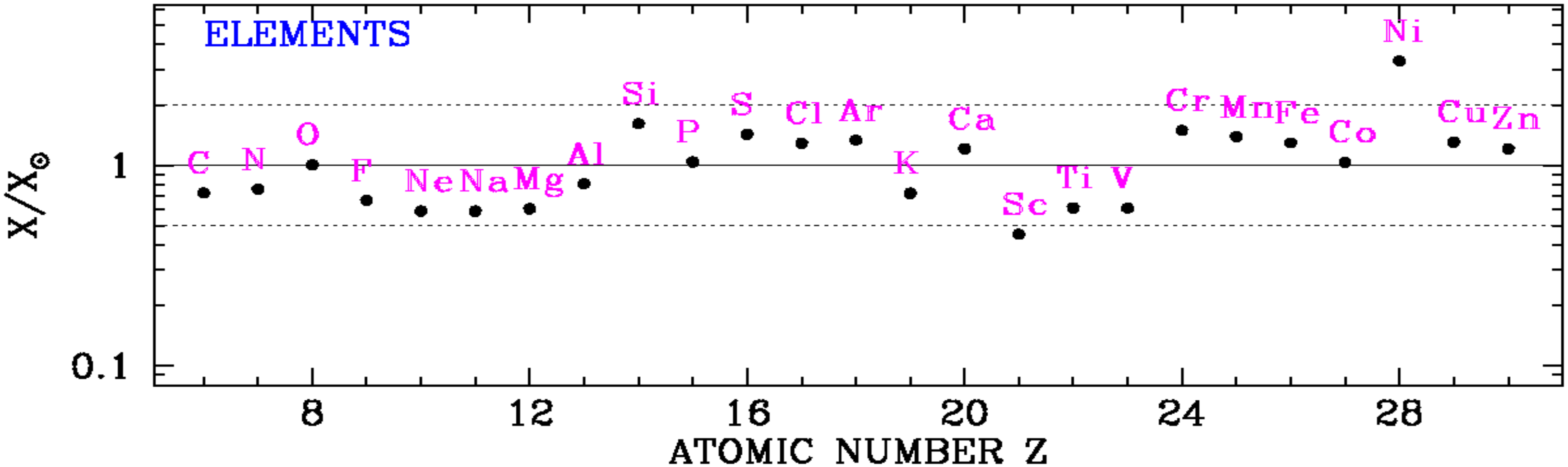
Fractional contribution
to C-12 production

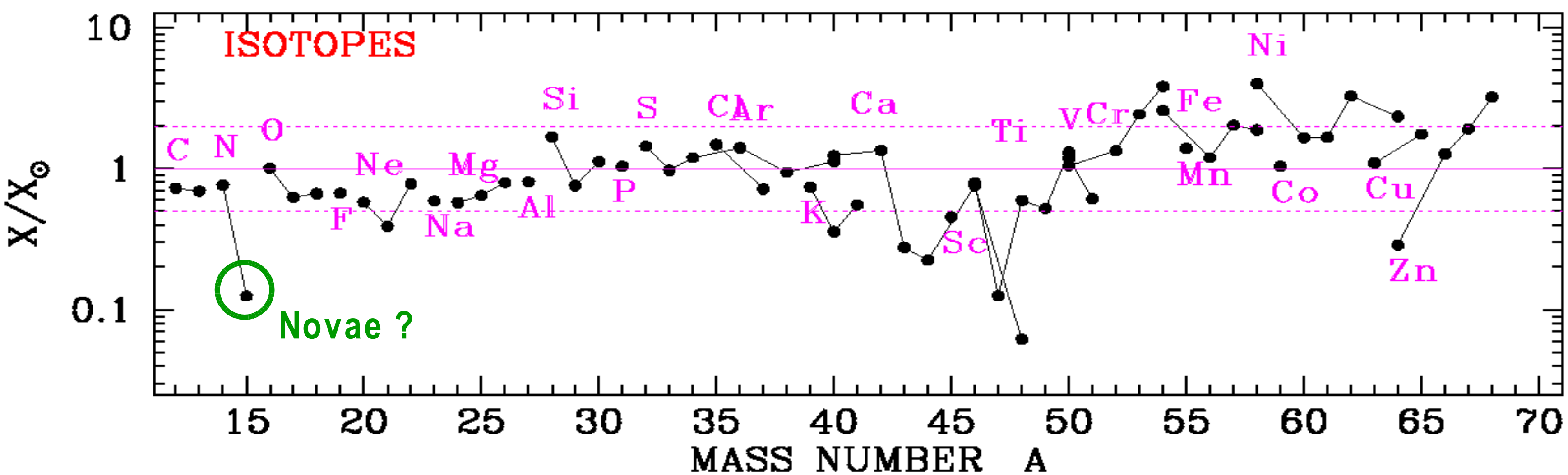


Rotating massive stars MAY
dominate the late production of C-12

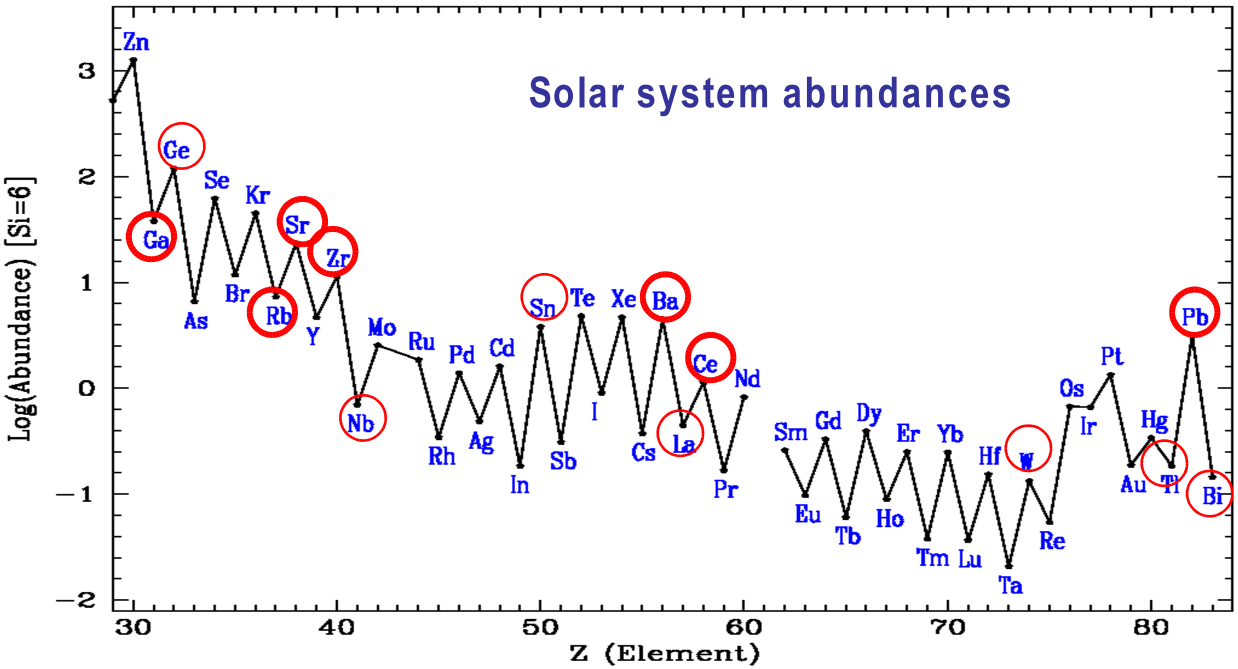
Abundances at Solar system formation

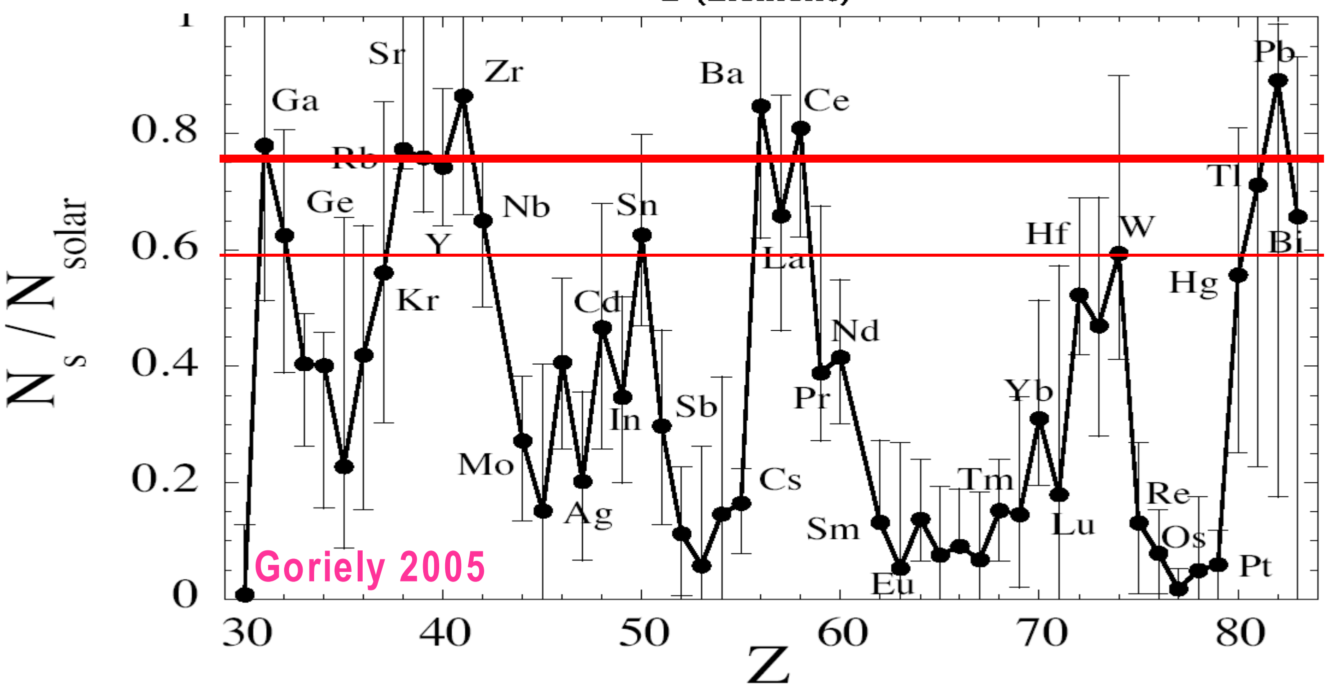
(Massive stars: Woosley+Weaver 1995;
Intermediate mass stars: van den Hoek+Gronewegen 1997;
SNIa: Iwamoto et al. 2000)





The heavier than Fe-peak nuclei





They are produced by neutron captures, on long or short timescales (s- and r- process)

Most heavy elements have a mixed origin (s- and r- process)

The solar abundances of a handful of elements are dominated by the s-process

(Ga, Sr, Y, Zr, Ba, Ce, Pb)

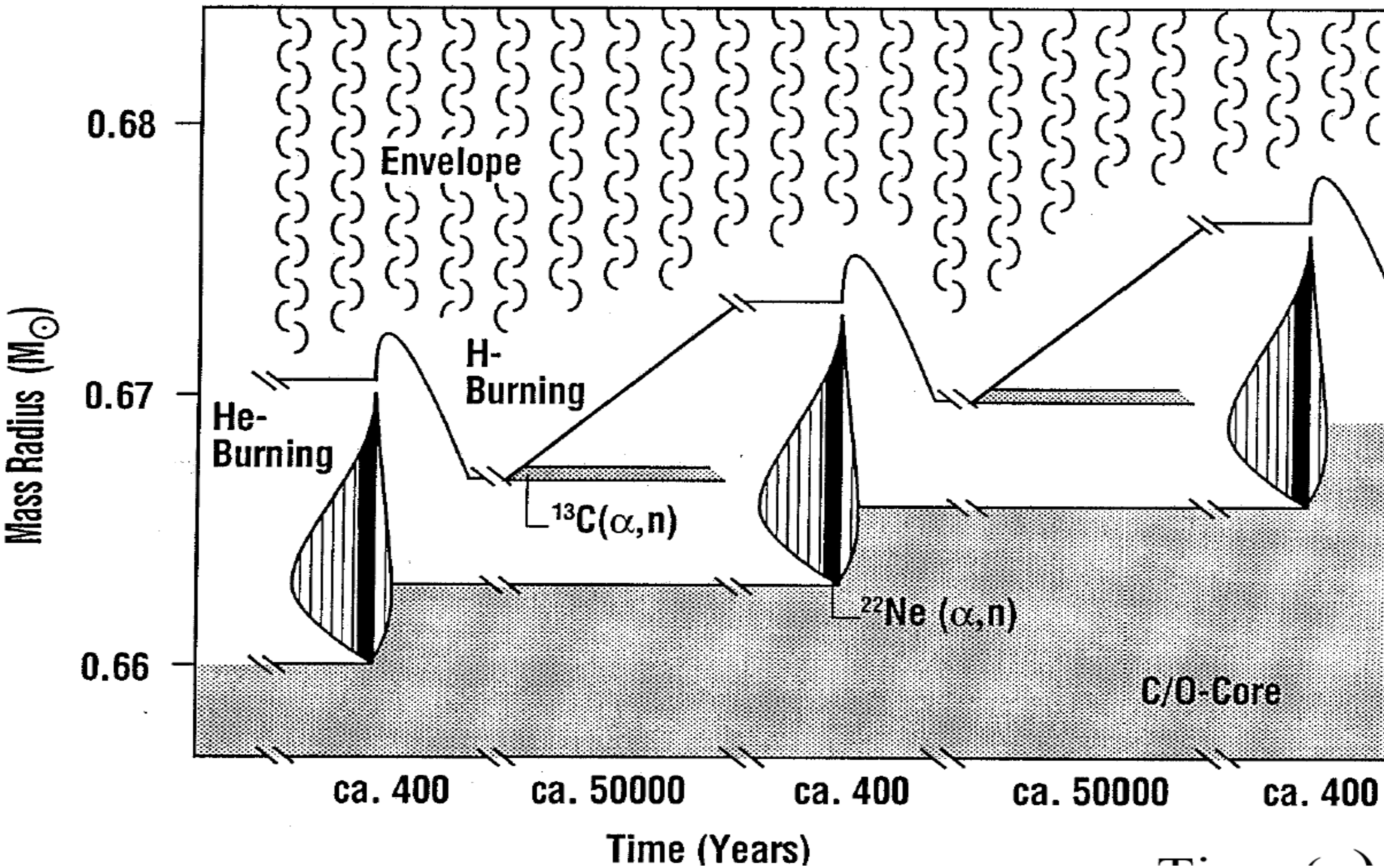
S-elements up to Sr are synthesized in the He-burning cores of massive stars, from neutrons released through **Ne22(α,n)Mg25** (Weak s- component)

The others, in AGB stars

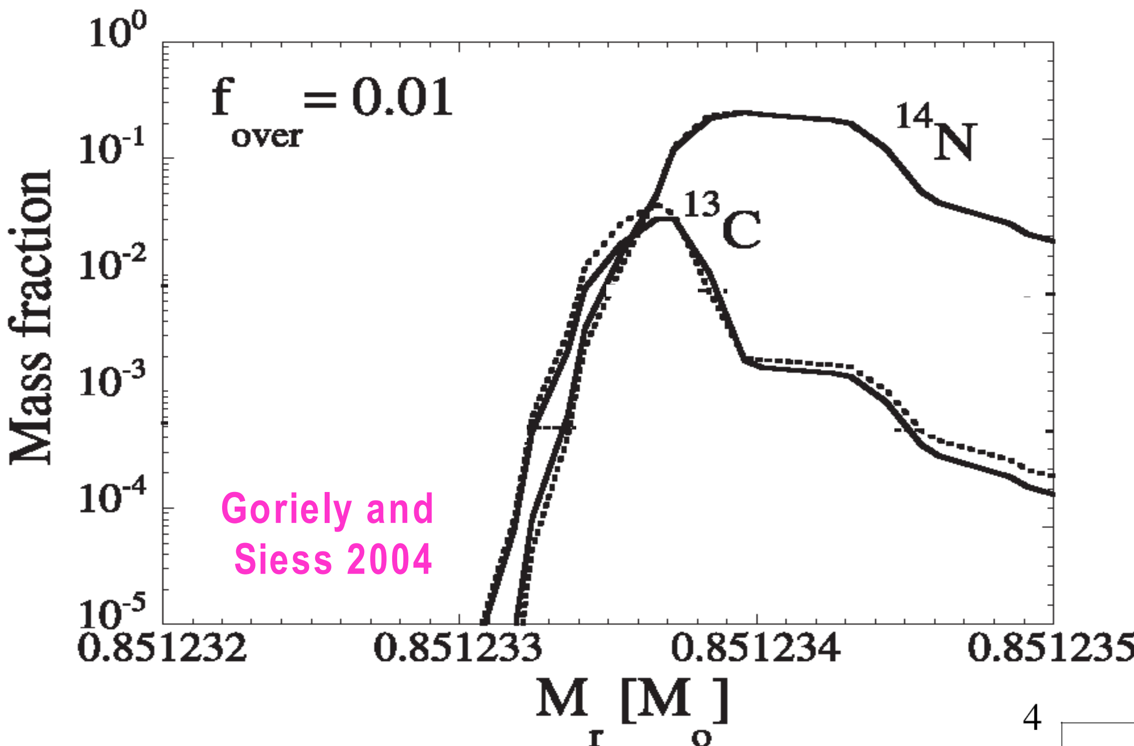
S- process in Low Mass (<2 M) thermally pulsing AGB stars: neutrons from

Radiative burning of C-13 (low neutron densities, for Main s-component) and

convective burning of Ne-22 (higher neutron densities, for some branching points)



No consistent model for the formation of the C13 "pocket"

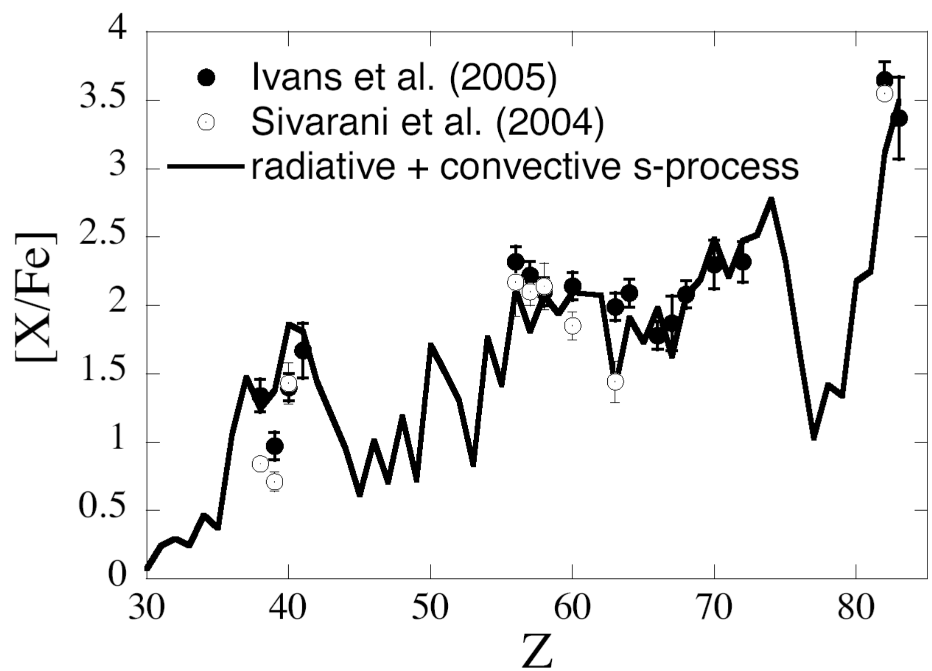


C13 created either "by hand" or
by C12(p,γ)N13(β)C13

Protons must be introduced
from the envelope, in
He-zones (rich in C12), but HOW ?

Convective overshoot ?
Rotational mixing ?
Gravity waves ?

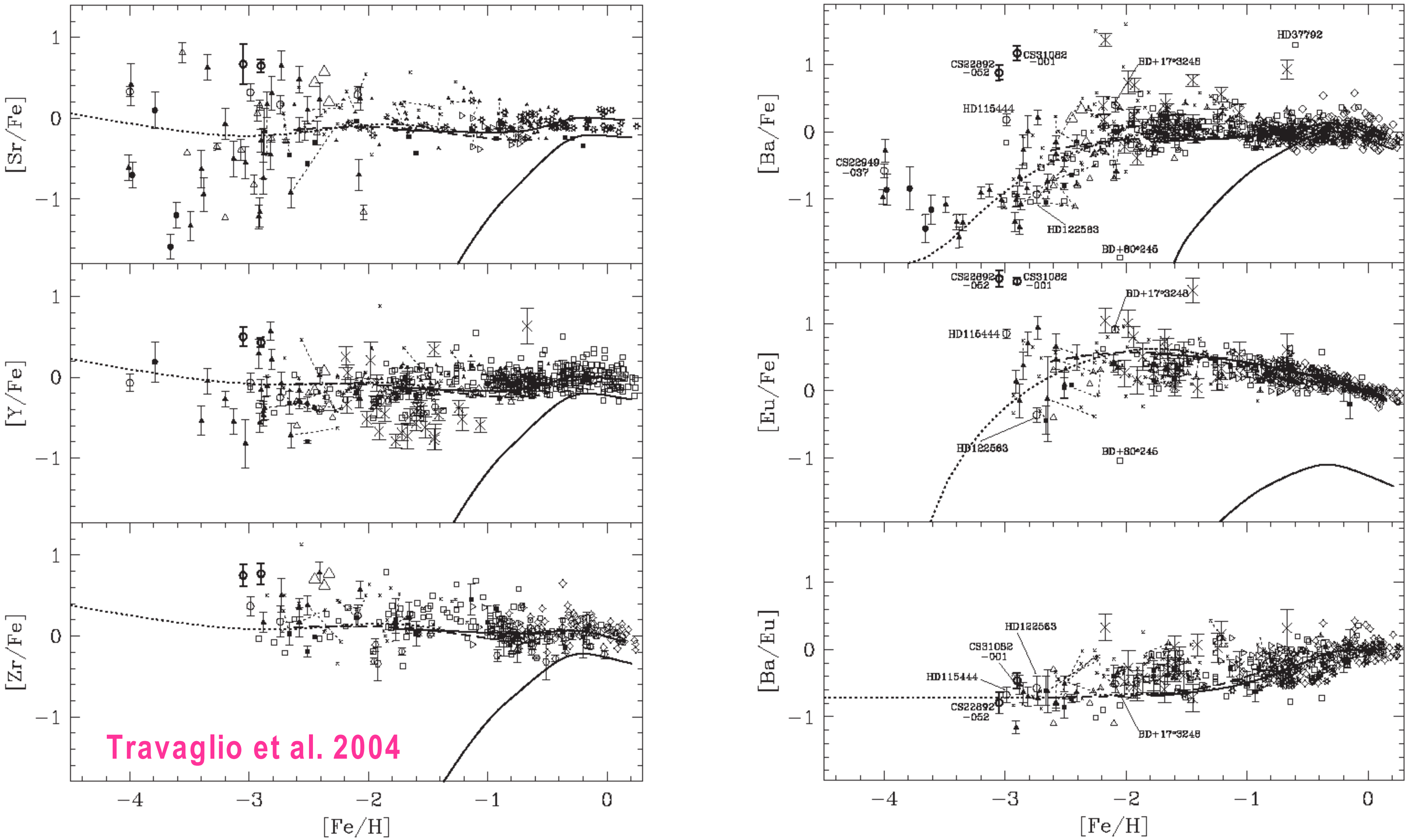
Parametrized models
of the s-process
in that site
reproduce succesfully
several observables



s-PROCESS FRACTIONAL CONTRIBUTIONS AT $t = t_\odot$ WITH RESPECT TO SOLAR SYSTEM ABUNDANCES

Travaglio et al. 2004

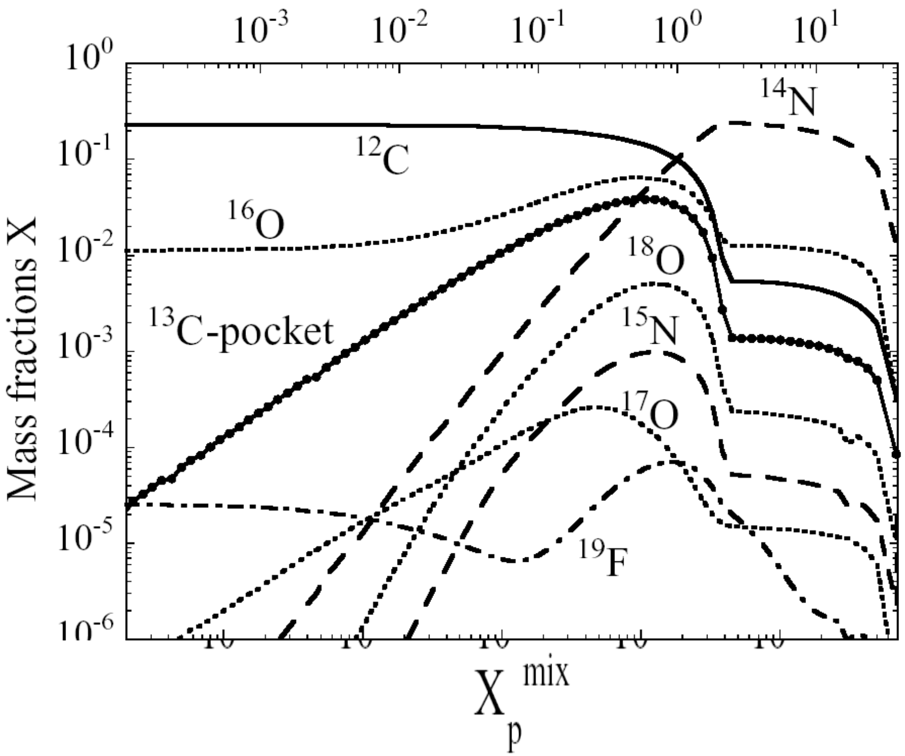
	Solar[a]	Main-s[b] (%)	Main-s[c] (%)	Strong-s[d] (%)	GCE[e] (IMS) (%)	GCE[e] (LMS+IMS) (%)
^{134}Ba	1.09E-01	98	158		6	93
^{135}Ba	2.96E-01	26	27		2	26
^{136}Ba	3.53E-01	102	137	0.3	6	96
^{137}Ba	5.04E-01	65	73		13	91
^{138}Ba	3.22E00	86	118	0.4	3	86
Ba		**81**	**92**			**80**
^{139}La	4.46E-01	62	83		2	63
La		**62**	**83**			**63**
^{140}Ce	1.00E00	84	97	0.6	2	79
^{142}Ce	1.26E-01	22	9		4	47
Ce		**77**	**87**			**74**
^{141}Pr	1.67E-01	49	56		1	47
Pr		**49**	**56**			**47**
^{142}Nd	2.25E-01	92	112	0.4	1	82
^{143}Nd	1.00E-01	32	37		1	32
^{144}Nd	1.97E-01	51	55		2	52
^{145}Nd	6.87E-02	27	32		1	28
^{146}Nd	1.42E-01	64	64		1	66
^{148}Nd	4.77E-01	19	8		1	19
Nd		**56**	**59**			**53**
^{147}Sm	3.99E-02	21	22		1	21
^{148}Sm	2.92E-02	97	102		1	99
^{149}Sm	3.56E-02	12	13		0	12
^{150}Sm	1.91E-02	100	100		3	100
^{152}Sm	6.89E-02	23	22		1	24
^{154}Sm	5.86E-02	1	0.5		0	69
Sm		**29**	**30**			**30**
^{151}Eu	4.65E-02	6	9		0	6
^{153}Eu	5.08E-02	5	6		0	5
Eu		**6**	**7**			**6**
^{204}Pb	6.11E-02	94	79	2	3	93
^{206}Pb	5.93E-01	58	31	2	2	62
^{207}Pb	6.44E-01	64	29	3	2	79
^{208}Pb	1.83E00	34	10	56	1	90
Pb		**46**	**19**			**91**
^{209}Bi	1.44E-01	5	3	5.5	1	22
Bi		**5**	**3**			**22**



If low mass stars (<2 M) are indeed at the origin of the s-process, how to explain the early appearance of the s-elements ?

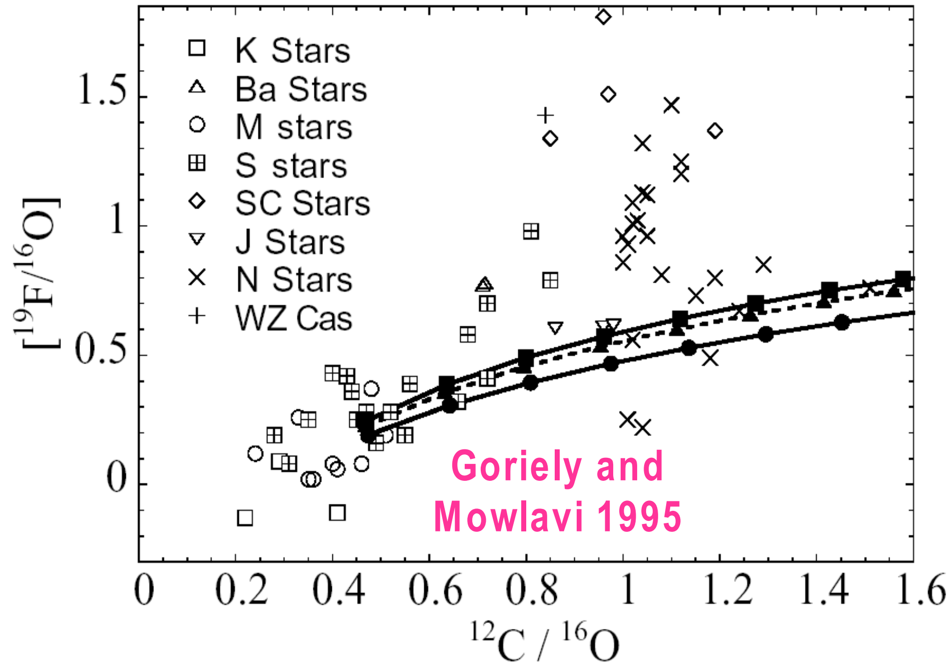
Production of Fluorine-19 in AGB stars

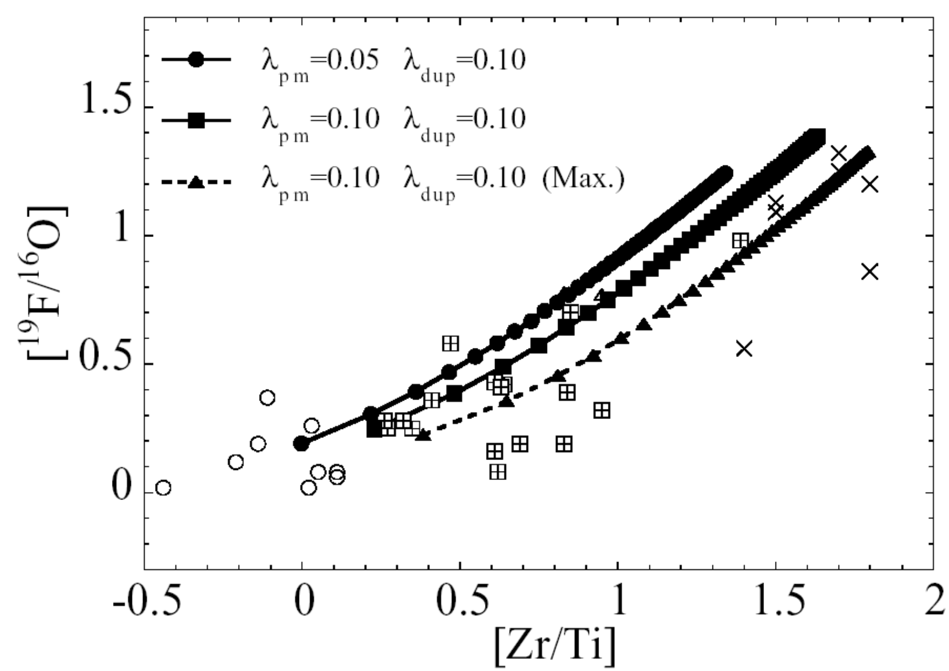
Direct consequence of mixing protons in regions enriched with He-burning products



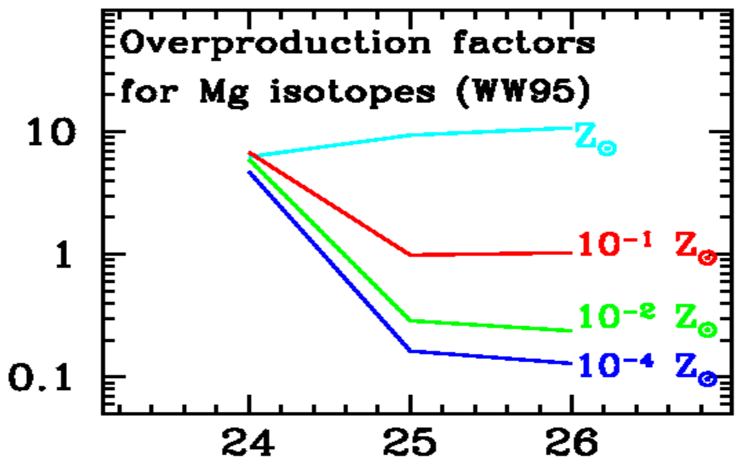
F-19 **is** observed in AGB star surfaces

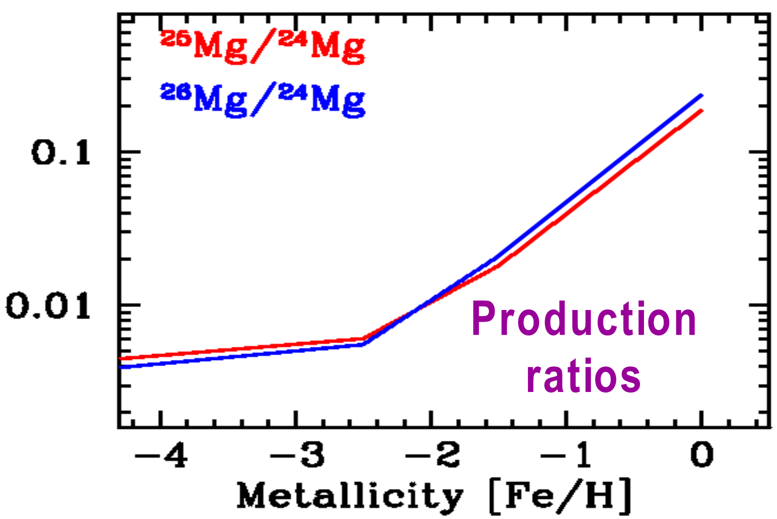
But there are other potential sources (WR stars, ν-nucleosynthesis in SNII)

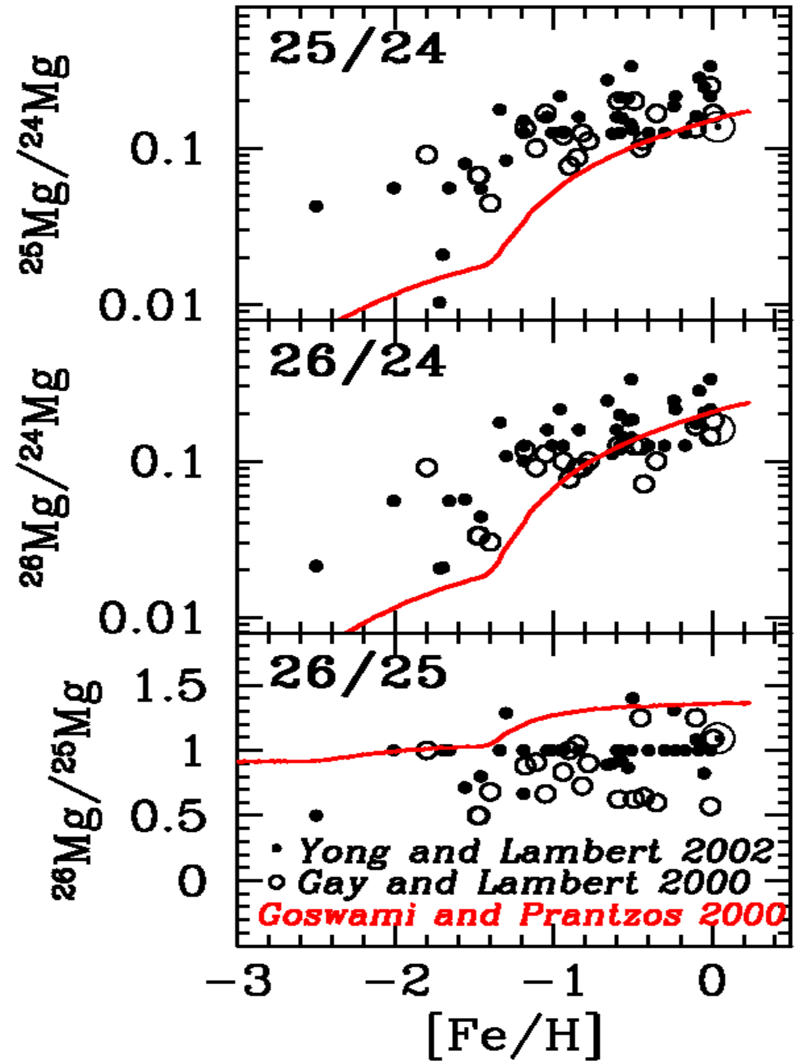


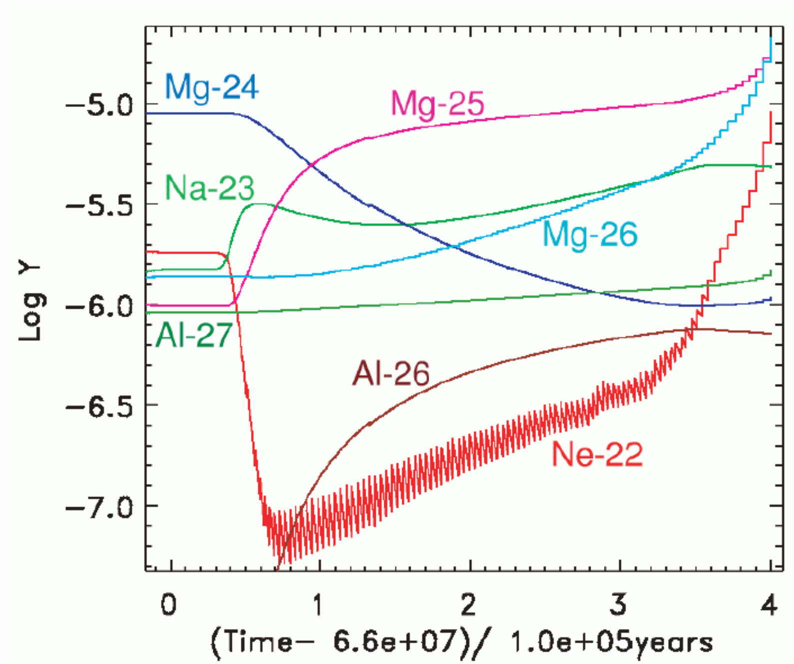


The Mg isotopic abundances

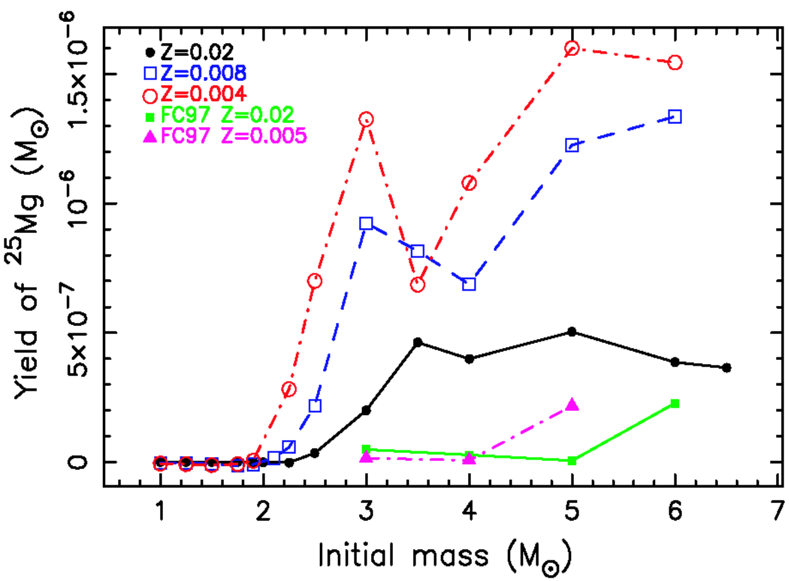


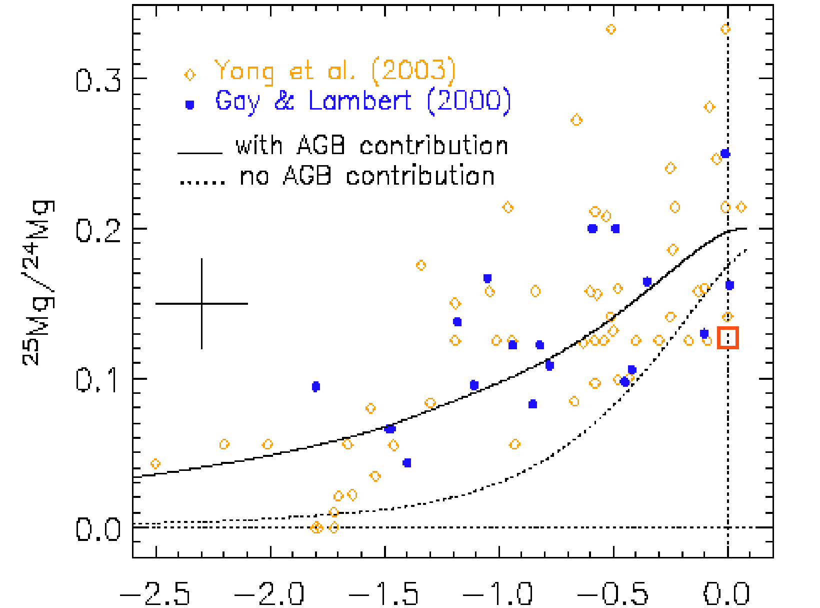


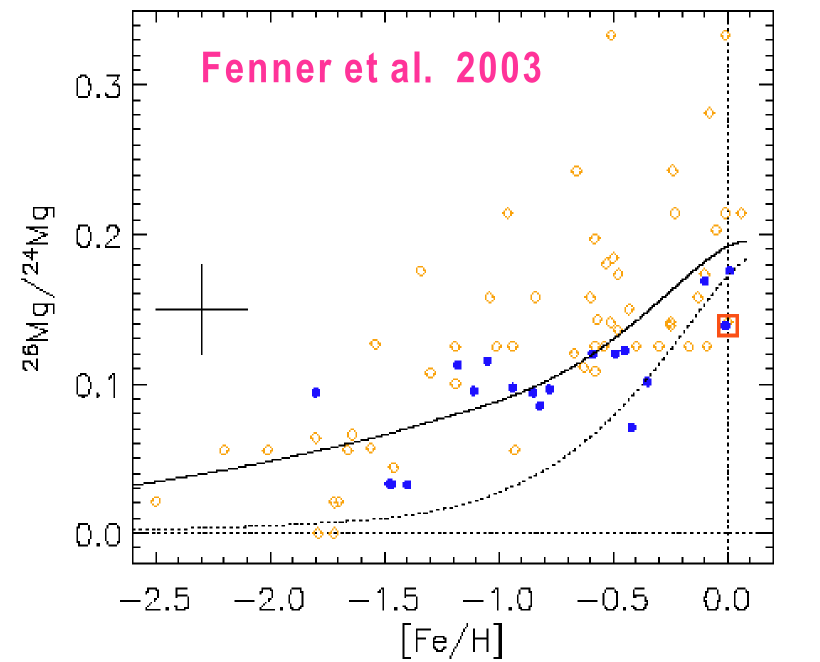




Karakas and Lattanzio 2003







Fenner et al. 2003

CONCLUSIONS

Do we really **need** LIMS in Galactic chemical evolution ?

CERTAINLY !

To destroy D

and - most of - He3, which they themselves produce
(BUT... a "small"observational problem here...)

and to produce *s- elements*
(BUT... can they produce them as early as observed ?)

QUITE PROBABLY

To produce 2/3 of solar N, as well as primary N
(BUT... can they produce it as early as observed in oldest halo stars ?)

POSSIBLY...

To produce late Li7 (BUT... how exactly they do it ?)

and – part of – He4, C12, C13, O17, F19, Mg isotopes...

AND... they are certainly doing things in BINARIES