Lithium factories in the Galaxy

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Genève, 9-13/11/2009
IAU Symposium 268 “Light elements in the Universe”

We need sites for Lithium production

Although Lithium is very fragile, its galactic abundance increases from logN(Li)~2.3 at the surface of Population II stars to logN(Li)~3.3 or more in pop. I →

even if Lithium is hidden in the atmospheres of pop.II, and its true primordial abundance is ~2.7, a galactic production by ~0.7dex is necessary

Summary

◊ The Cameron-Fowler (1971) mechanism for Lithium production

◊ Novae

◊ Massive AGBs (and super-AGBs)

◊ A short note on lithium and multiple populations in Globular Clusters

The Cameron-Fowler model

◊ Li produced by the chain

$$^{3}He(\alpha,\gamma)^{7}Be(e^{-},\nu)^{7}Li$$

in a convective hot region, so that ^{7}Be is transported to cooler regions before it turns into Li. Convective mixing brings Li back to the hot region where it can be burned, but it temporarily survives in the envelope and in the atmosphere. Production of Li is linked to the ^{3}He abundance in the region (remnant of incomplete p-p chain) and lasts until there is ^{3}He

Possible sites of nucleosynthesis

◊ **Nova outbursts** $T_{outburst} \sim 15 \times 10^7$ K

explosive nucleosynthesis: a hydrodynamical process

Arnould & Nørgaard 1975: ^{7}Li production proportional to ^{3}He abundance
Starrfield et al. 1978: at 150MK the Cameron-Fowler mechanism acts. Fast ejection of the ^{7}Be rich nova shell leads to ^{7}Li production

$$[Li / H] \approx 200 \times X_{3i} / X_{3sun}$$

D'Antona & Matteucci 1991 use this proportionality for a model of galactic chemical evolution (see later) →… BUT…

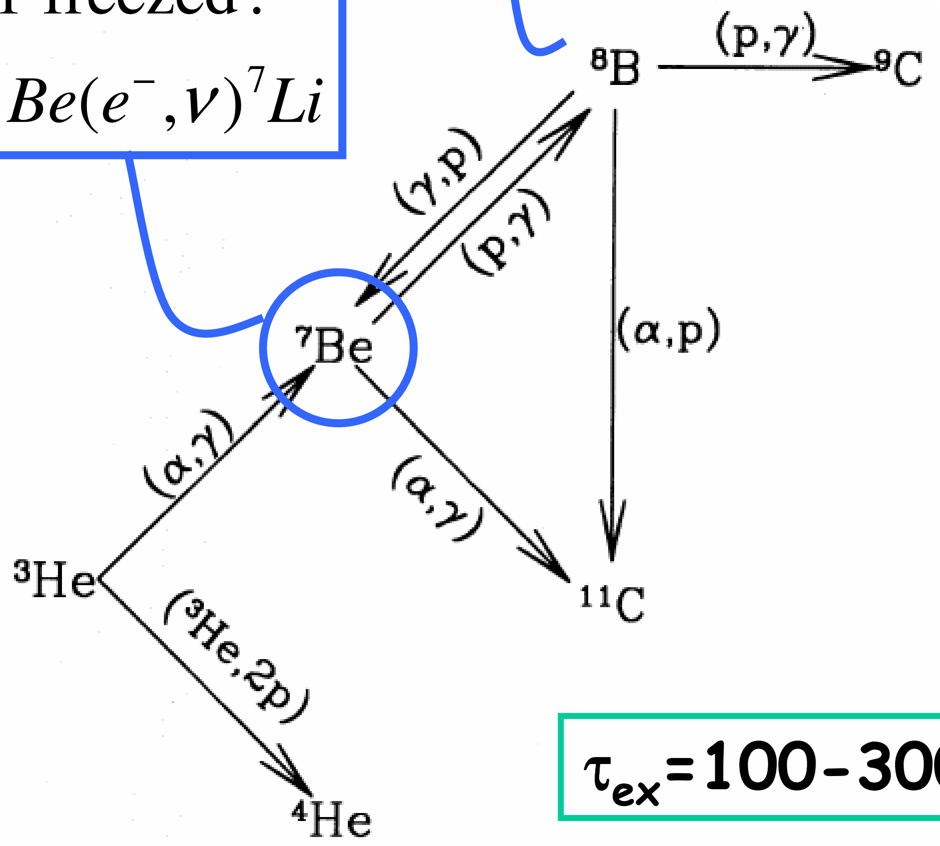
revised nova production

Boffin et al. 1993: one-zone models

$$^{8}B(\beta^{+},\nu)^{8}Be^{*} \rightarrow 2\,^{4}He$$

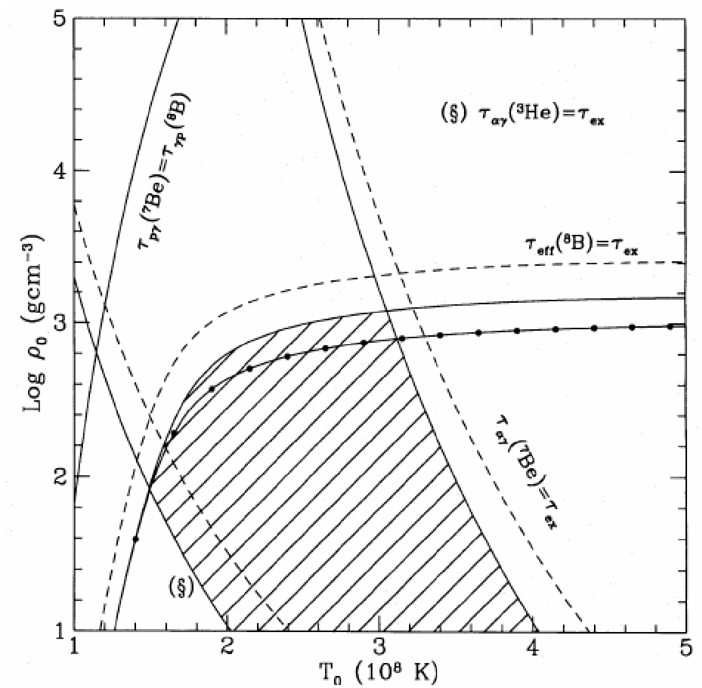
if freezed:

$$^{7}Be(e^{-},\nu)^{7}Li$$



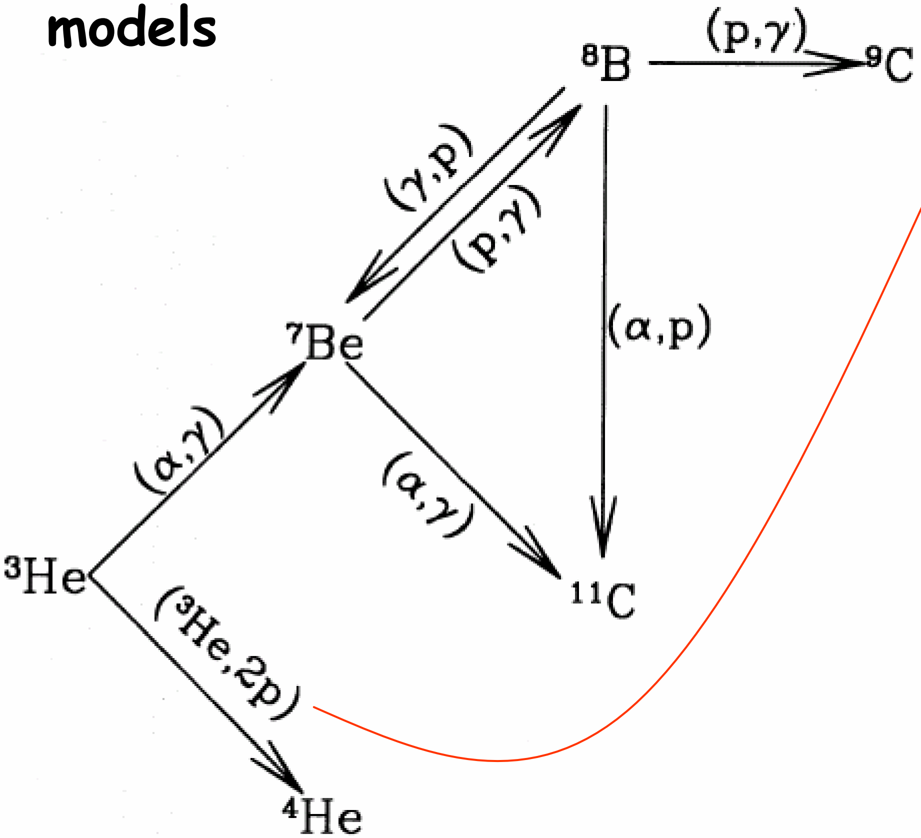
1) neglect of this reaction in S1978 → it gives a constraint on the upper density at outburst

τ_{ex}=100-300s



revised nova production

Boffin et al. 1993: one-zone models



2) this reaction is competitive! and its importance increases with X_{3He} squared. In the end they find:

$$\frac{X(^{7}\mathrm{Li})}{X_0(^{7}\mathrm{Li})} = 1 + 1.5 \log \frac{X(^{3}\mathrm{He})}{X_{\odot}(^{3}\mathrm{He})}$$

where $X_0(^{7}Li)$ is the lithium production when the solar He3 abundance is adopted

→ this is the key change for the DM2001 chemical evolution results

…but the efficiency of mixing by convection has to be checked

revised again nova production

Hernanz, José, Coc & Isern 1996 - José & Hernanz 1998

implicit hydro-code with a full reaction network, able to treat both the hydrostatic accretion phase and the explosion stage

two cases: CO core of 1 and 1.15Msun or
ONe core of 1.15 and 1.25Msun

the results depend on the core composition: CO cores have a shorter accretion phase, so that He3 is not destroyed efficiently and more Be7 is produced. Overproduction is found

^{7}Li YIELDS AND EJECTED MASSES FOR SOME NOVA MODELS

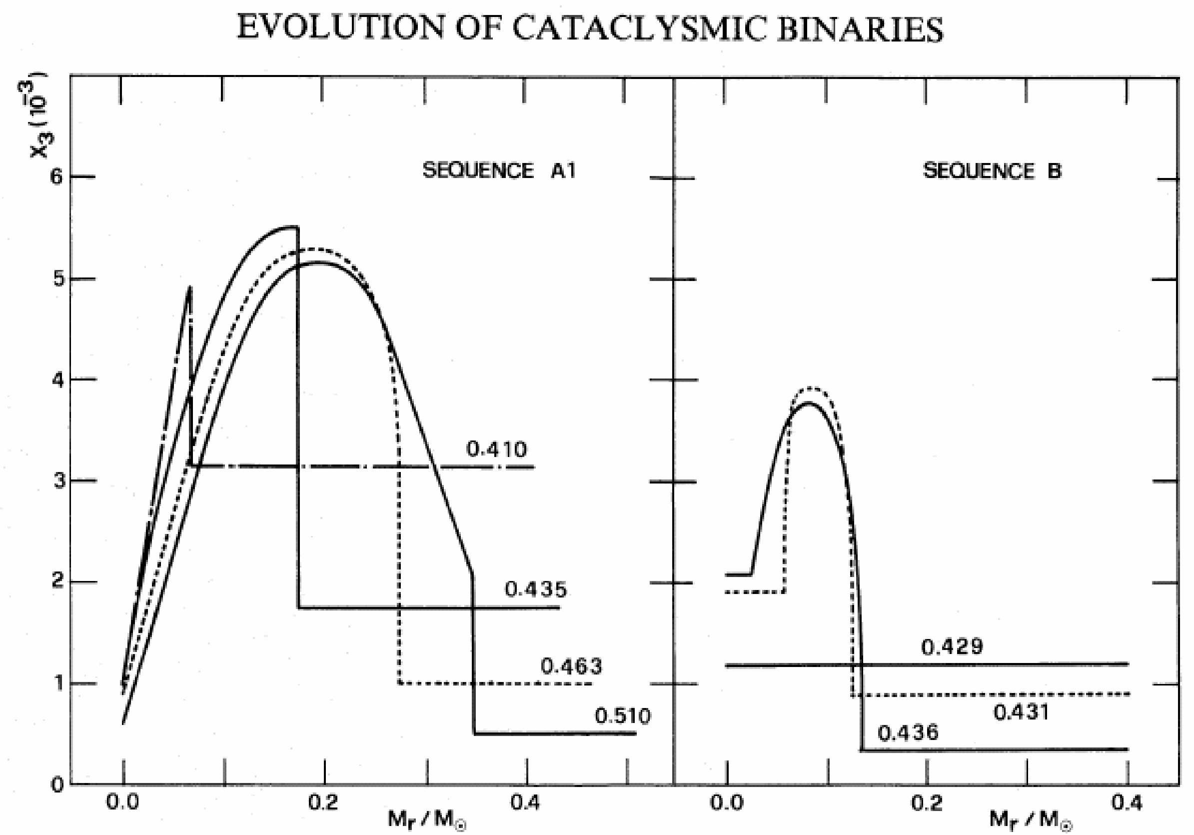
Composition	M_{wd} ($M_\odot$)	$\dot{M}$ ($M_\odot$ yr^{-1})	$\bar{X}$ (^{7}Li)	$\frac{N(^7\mathrm{Li/H})}{N(^7\mathrm{Li/H})_\odot}$	M^{ej}_{tot} ($M_\odot$)	$M^{ej}_{^7\mathrm{Li}}$ ($M_\odot$)
CO.............	1.0	2×10^{-10}	3.1×10^{-6}	742	2.3×10^{-5}	7.1×10^{-11}
CO.............	1.15	2×10^{-10}	8.2×10^{-6}	1952	1.3×10^{-5}	1.1×10^{-10}
ONe	1.15	2×10^{-10}	6.0×10^{-7}	143	1.9×10^{-5}	1.1×10^{-11}
ONe	1.25	2×10^{-10}	6.5×10^{-7}	155	1.8×10^{-5}	1.2×10^{-11}
ONe	1.25	2×10^{-8}	7.9×10^{-7}	187	8.3×10^{-6}	6.7×10^{-12}

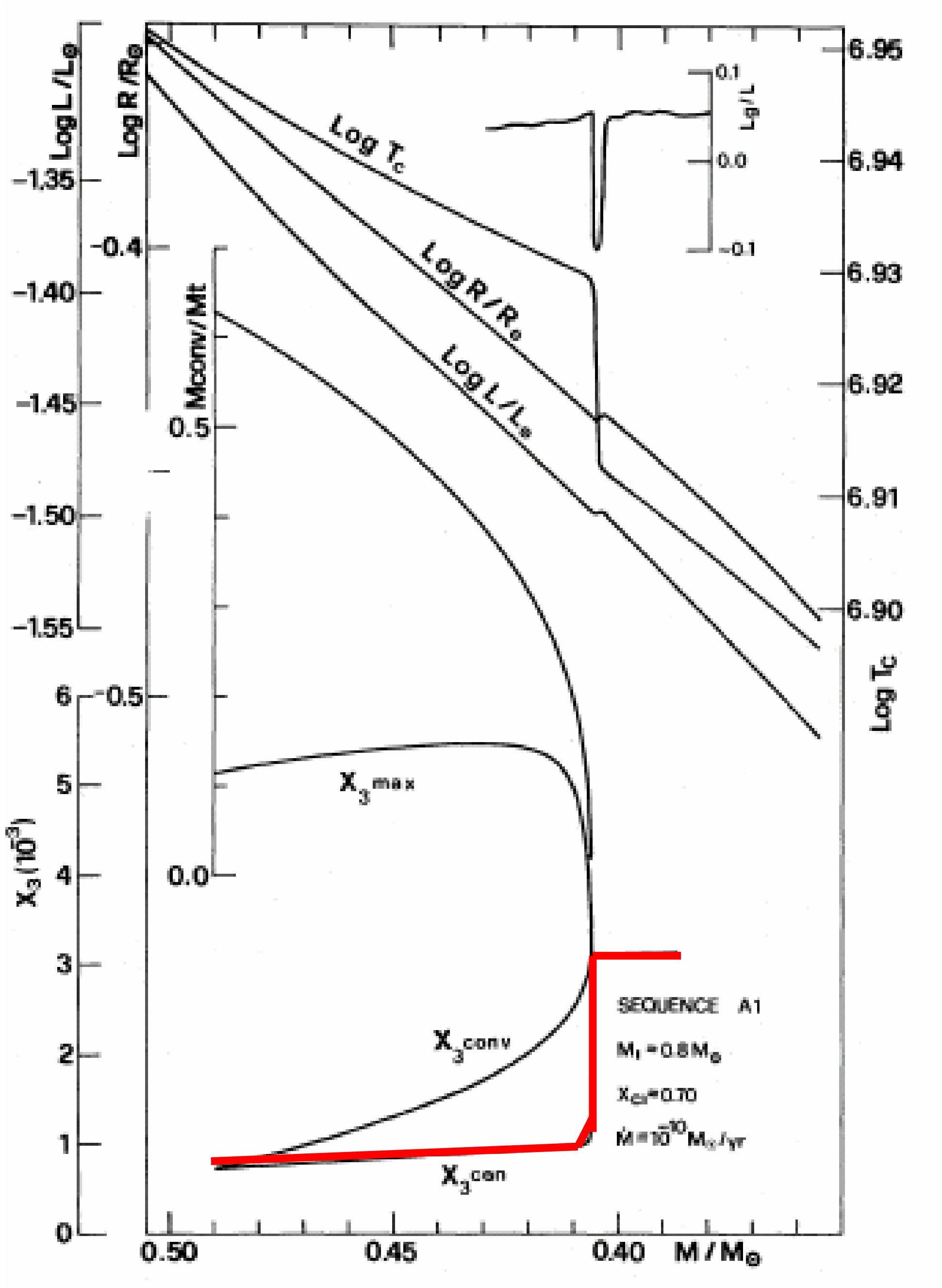
The donor stars of novae…

…are low mass stars losing mass at rates

$$10^{-10} < \dot{M} / Msun < 10^{-9}$$

thus their secular evolution lasts from 1Gyr to a Hubble time… and ^{3}He due to partial p-p burning accumulates in the envelope and is convected to the surface





D'Antona & Mazzitelli 1982

see also
Iben & Tutukov 1984
McDermott & Taam 1989

================================

D'Antona & Matteucci 1991 linked the Li7 production by novae to the He3 donor abundance, and this latter is linked to the <u>'delay time'</u> between the formation of the white dwarf and the beginning of the mass transfer and nova stage. This is why their Li- nova production was so efficient on a LONG galactic timescale!

The Li production in nova explosion modeling has stopped in 1998

it would be good to check the lithium production in 3D hydro simulations, especially if the problem of galactic lithium production is still with us

Is it possible that the initial ^3He in the donor envelope plays a more important role?

Possible sites of nucleosynthesis

◊ **Very luminous AGB stars** → $T_{HBB} > 4 \times 10^7$ K

a hydrostatic, slow process:

the bottom of the convective envelope reaches the H-shell burning region and nuclear reaction products are transported to the surface by convection

Iben 1973,
Sackman, Smith & Despain 1974,
Scalo, Despain & Ulrich 1975 → hot bottom convective envelopes → Hot Bottom Burning (HBB)

Hot Bottom Burning : Li, C and O

$^{3}He + {}^{4}He \rightarrow {}^{7}Be \rightarrow {}^{7}Li$
(Cameron & Fowler 1971)

$T > 4 \times 10^{7}$ K

In these same envelopes, Carbon also burns, so that the Carbon star features disappear

$^{12}C \rightarrow {}^{14}N$

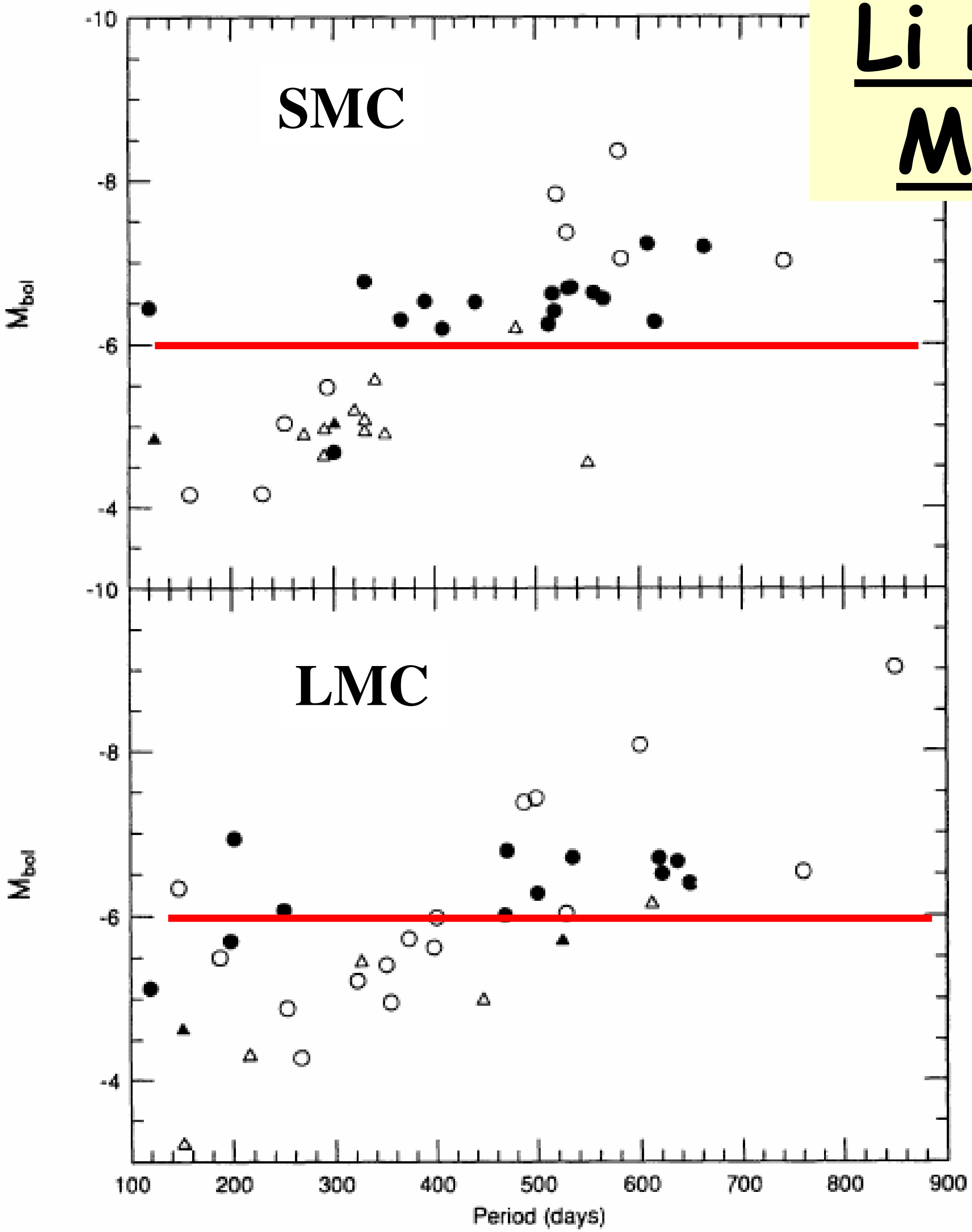
$T > 6.5 \times 10^{7}$ K

A third possible processing occurs at even larger T: H- burning through the ON cycle (this may occur in the low metallicity massive AGBs and is possibly at the basis of the self-enrichment process in GCs):

$^{16}O \rightarrow {}^{14}N$

$T > 8 \times 10^{7}$ K

Li rich AGBs in the Magellanic Clouds

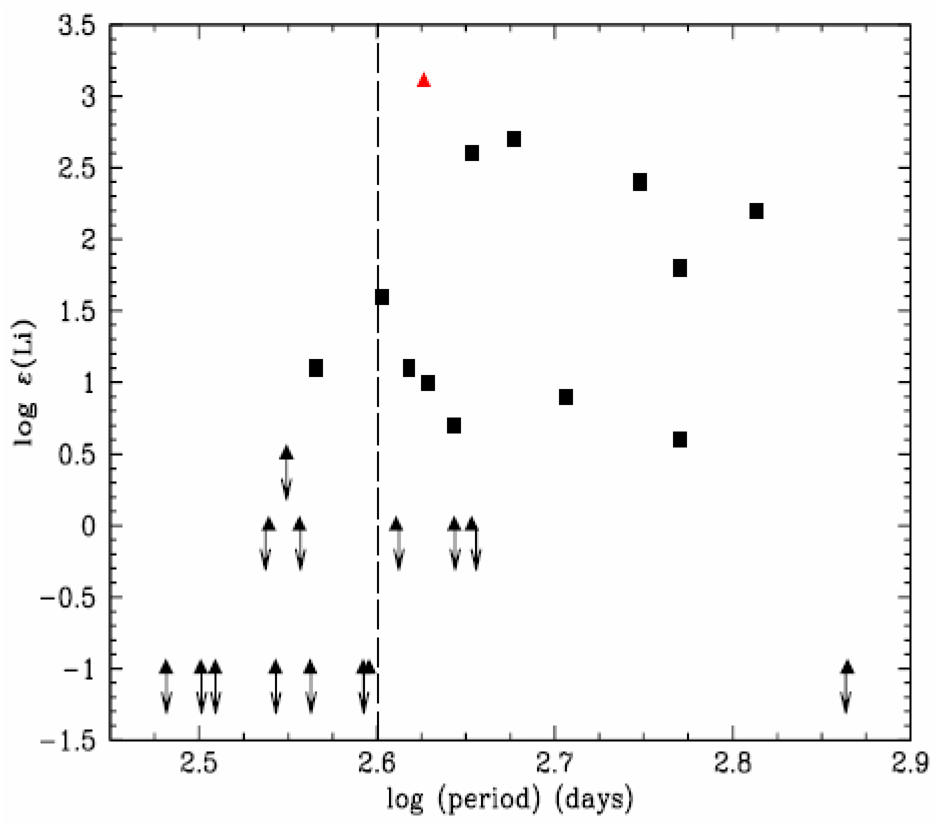


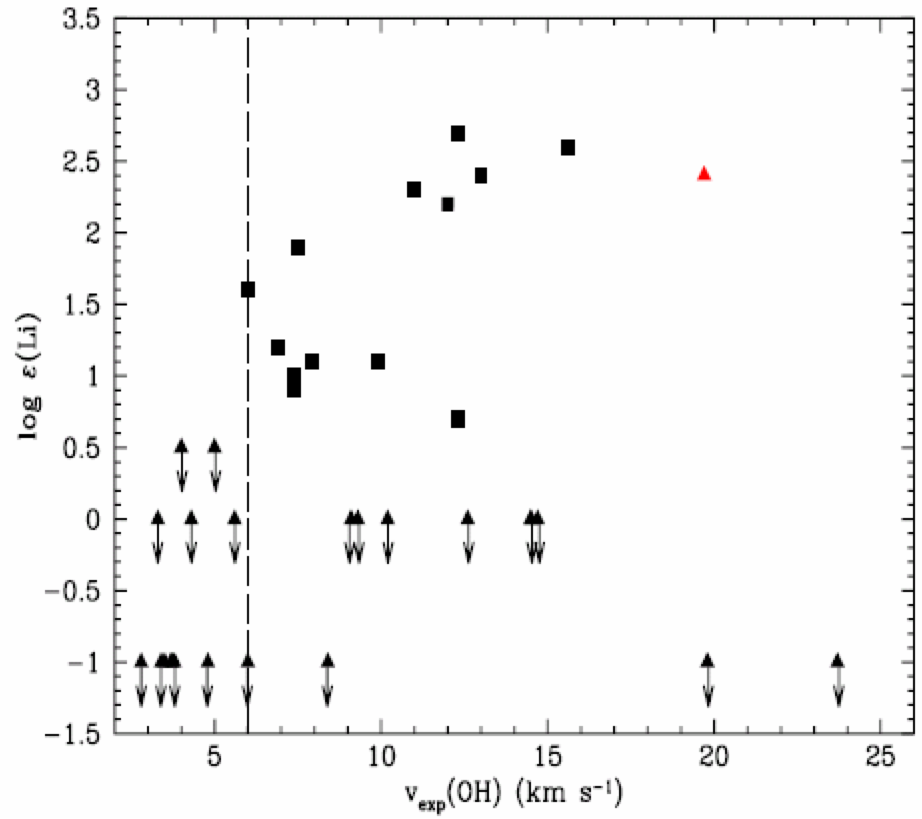
Smith & Lambert 1989, 1990. Figure from Smith, Plez & Lambert 1995

At Mbol<-6:
C-stars are no longer present;
practically ALL M-stars show Li7.

This is imputed to the process of 'Hot Bottom Burning',

Li rich AGBs in the Galaxy



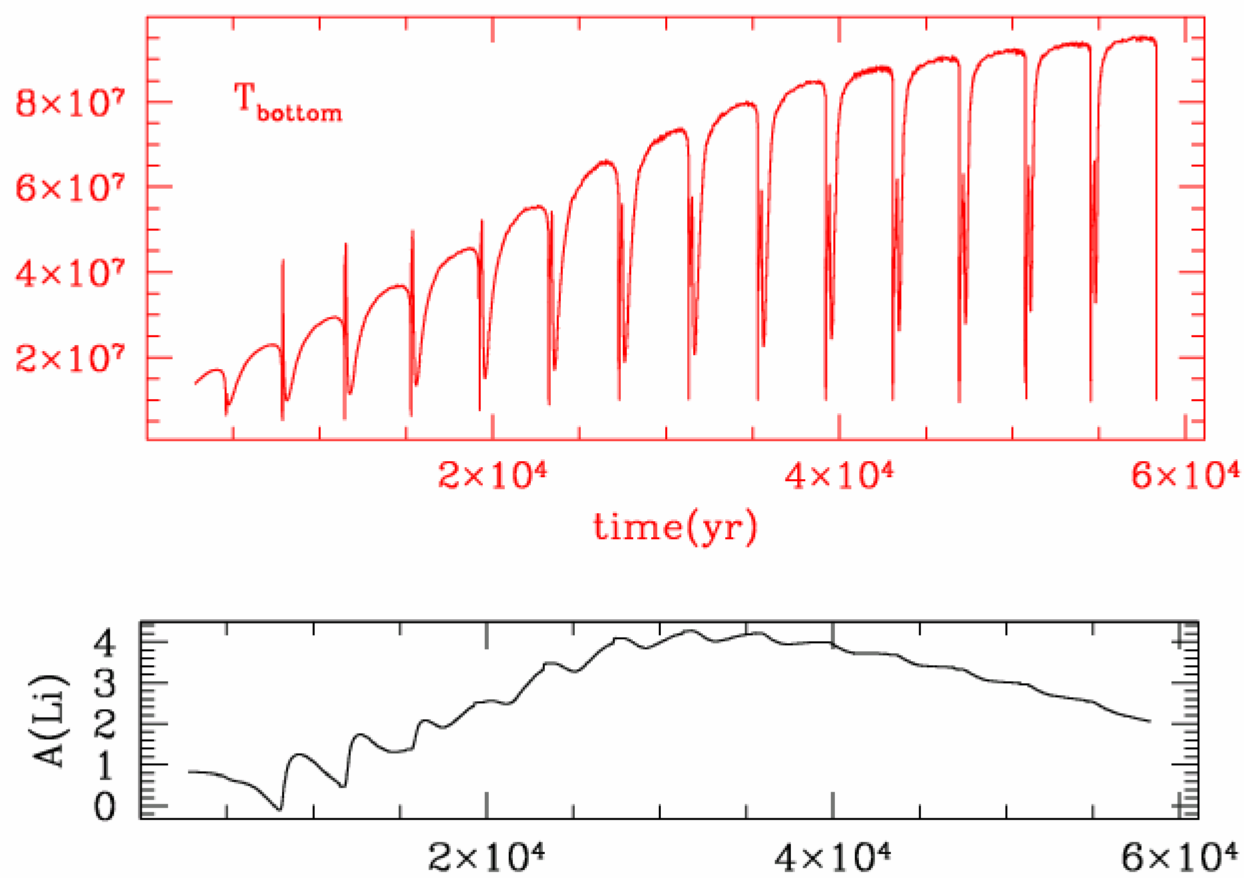


García Hernandez et al. 2006: examining a large sample of massive Galactic O-rich AGB stars show that the most massive of these objects [those having high expansion velocity derived from the OH maser emission, and the longer periods of variability (P>400days)] have high Lithium.

Modelling Li rich AGBs

we need...

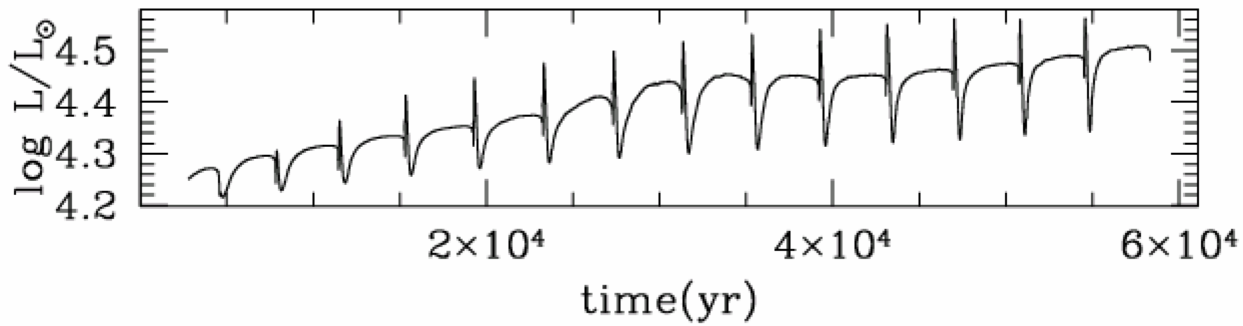
...COUPLING OF
NON-INSTANTANEOUS MIXING WITH THE NUCLEAR REACTION NETWORK MUST BE EMPLOYED



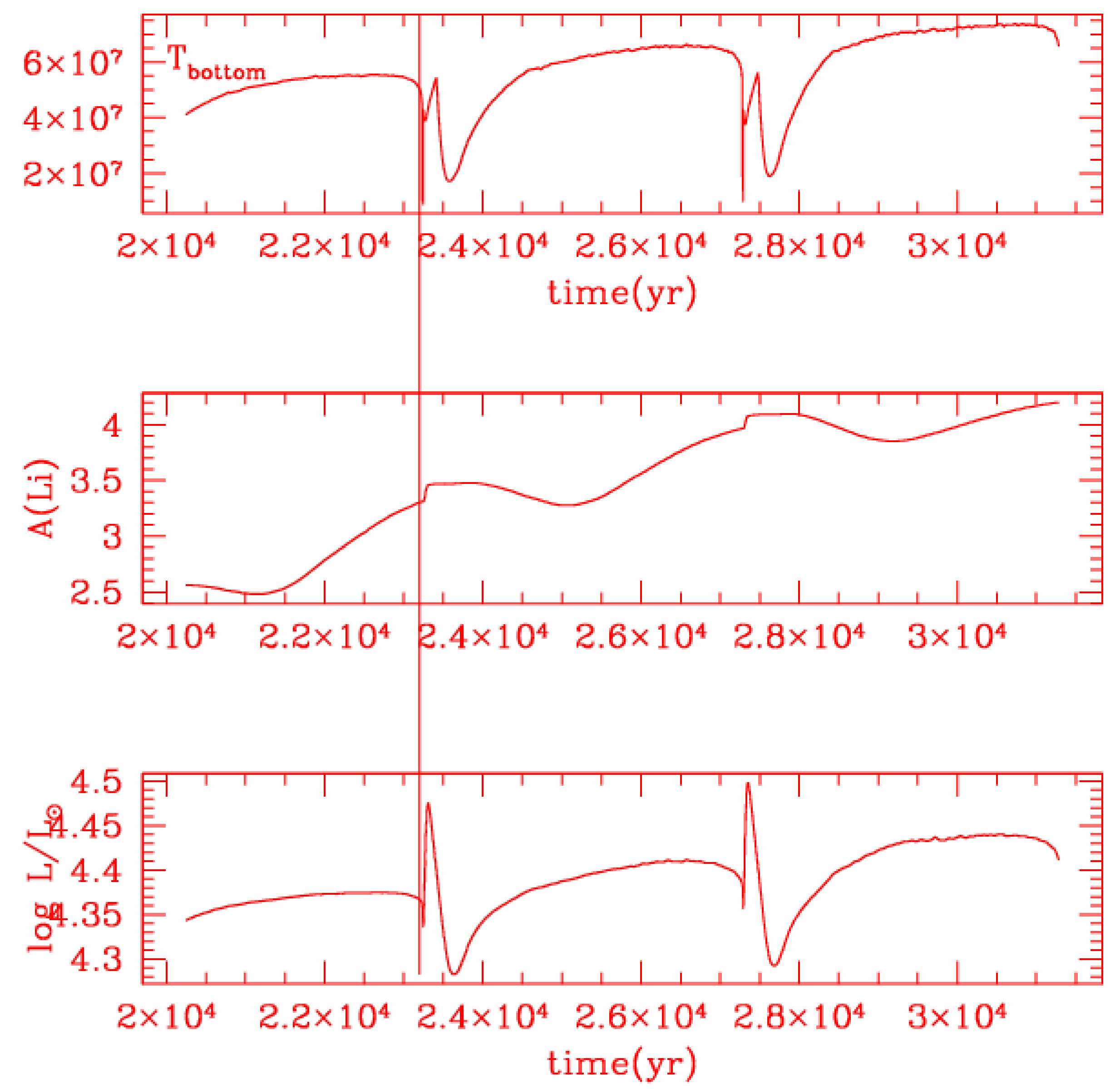
lifetime of the Li-rich phase is dictated by the available 3He

and by the HBB temperature

5Msun Z=0.001



during the TP, the Li production stops, and part of the Li is burned, until new production begins when T_{bottom} increases enough again



Modelling Li rich AGBs

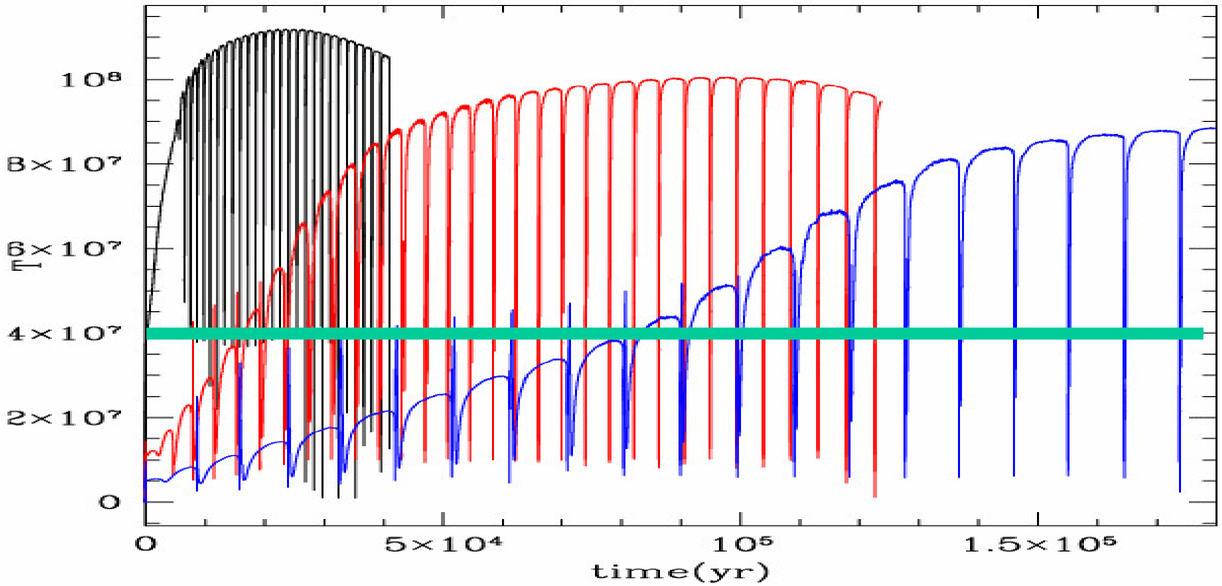
Lithium production and destruction depend on

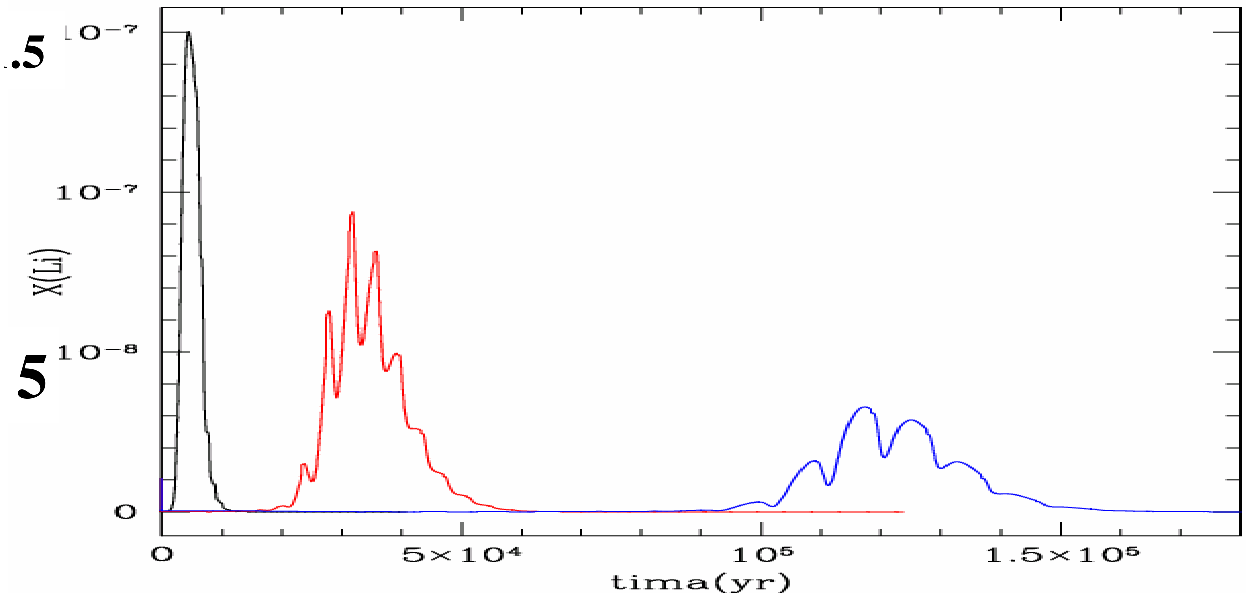
1) Initial mass (or better CORE MASS): it must be large enough to get HBB

2) CHEMICAL INPUTS (metallicity – envelope opacity) fixed mass → higher opacity or Z → lower T_{bce} → lower HBB

3) and on the physical inputs → mainly CONVECTION
high convection efficiency → higher T_{bce} → higher HBB

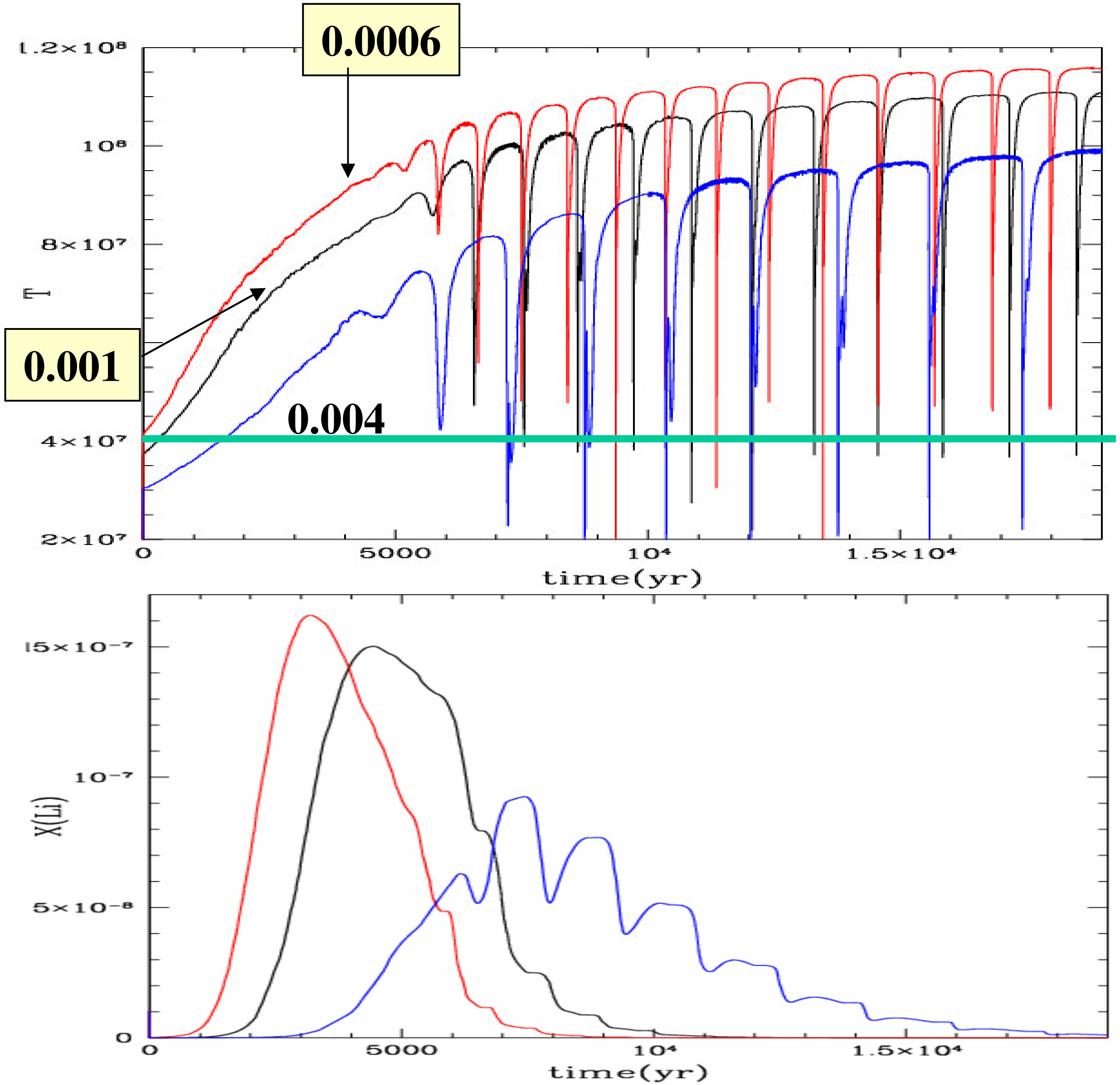
Mass dependence at Z=0.001





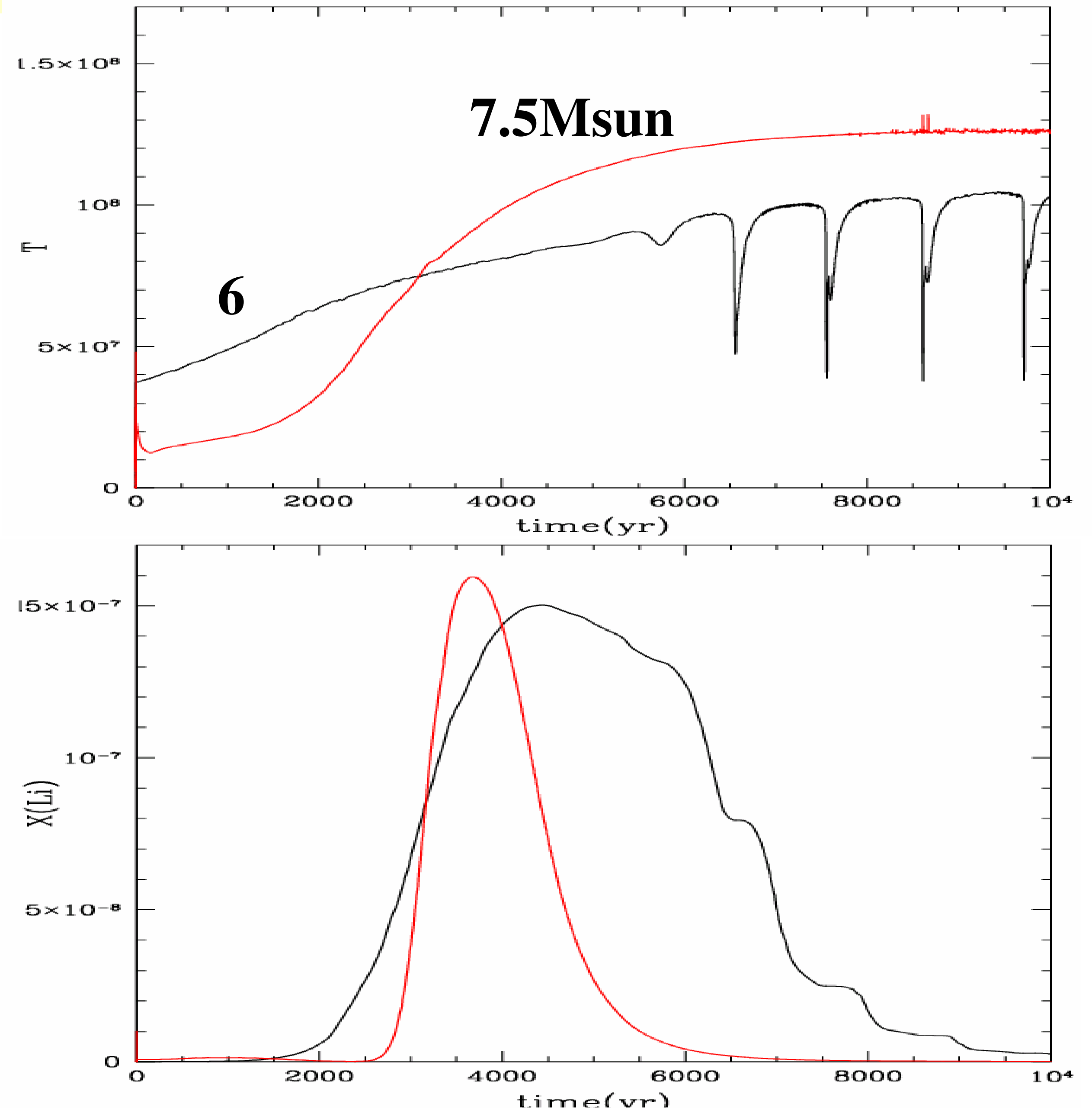
higher M → larger T_bottom → stronger and faster Li production

Metallicity dependence at M=6Msun



higher Z → smaller T_bottom → smaller and slower Li production

And what happens for super-AGBs?



super-AGBs produce a lot of Lithium at once!

But production does not mean yield!

two ingredients are important:
how much Li is made,
and how long it lasts →
so that mass loss can recycle it in the i.s.m.

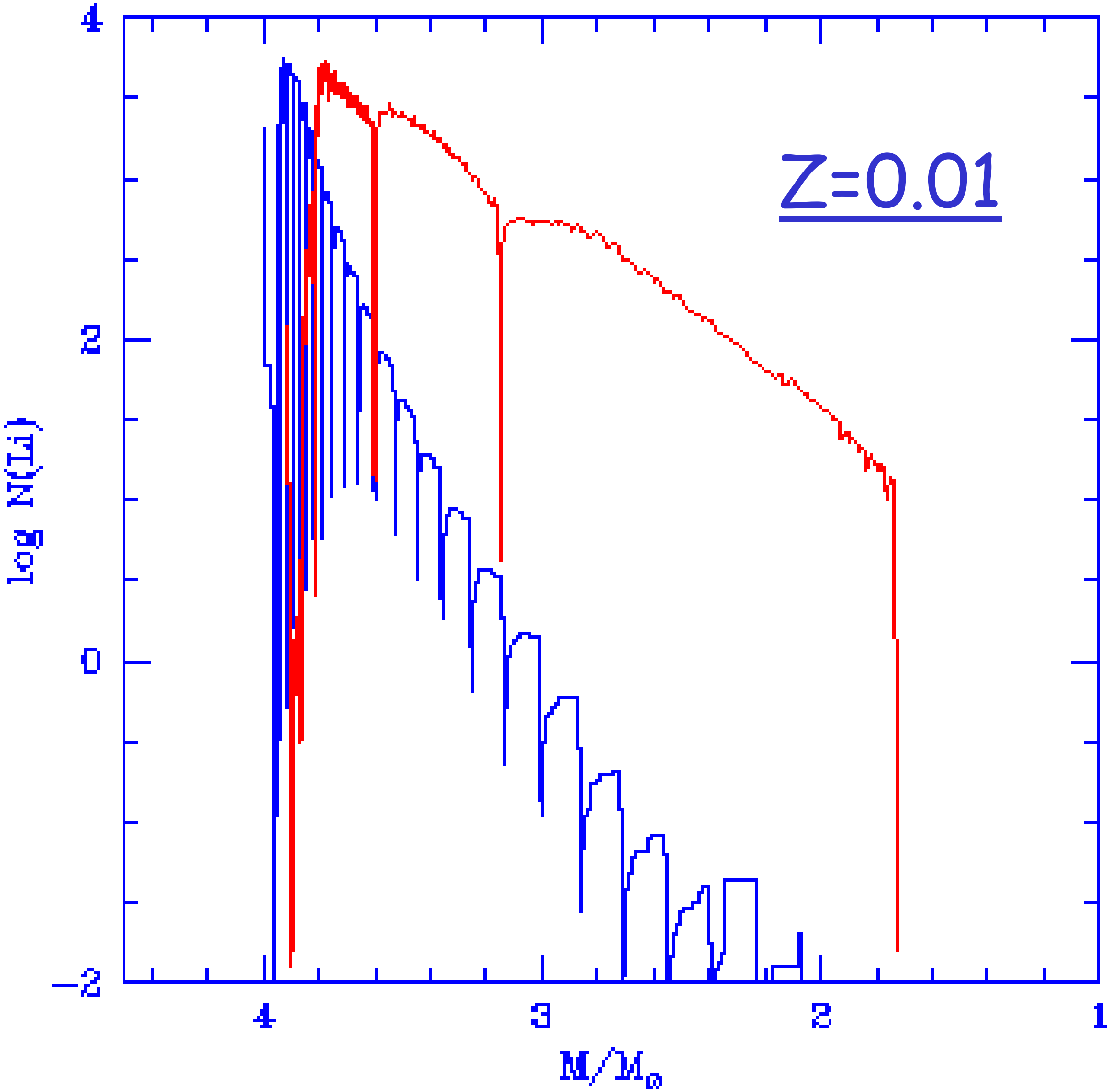
AND mass loss is another big unknown parameter (both absolute values and dependence on the luminosity)

Modelling Li rich AGBs

The Lithium yield from these stars depends on another not well known physical input → MASS LOSS

fixed mass and chemistry → higher mass loss rate during the phase of lithium production → larger yield

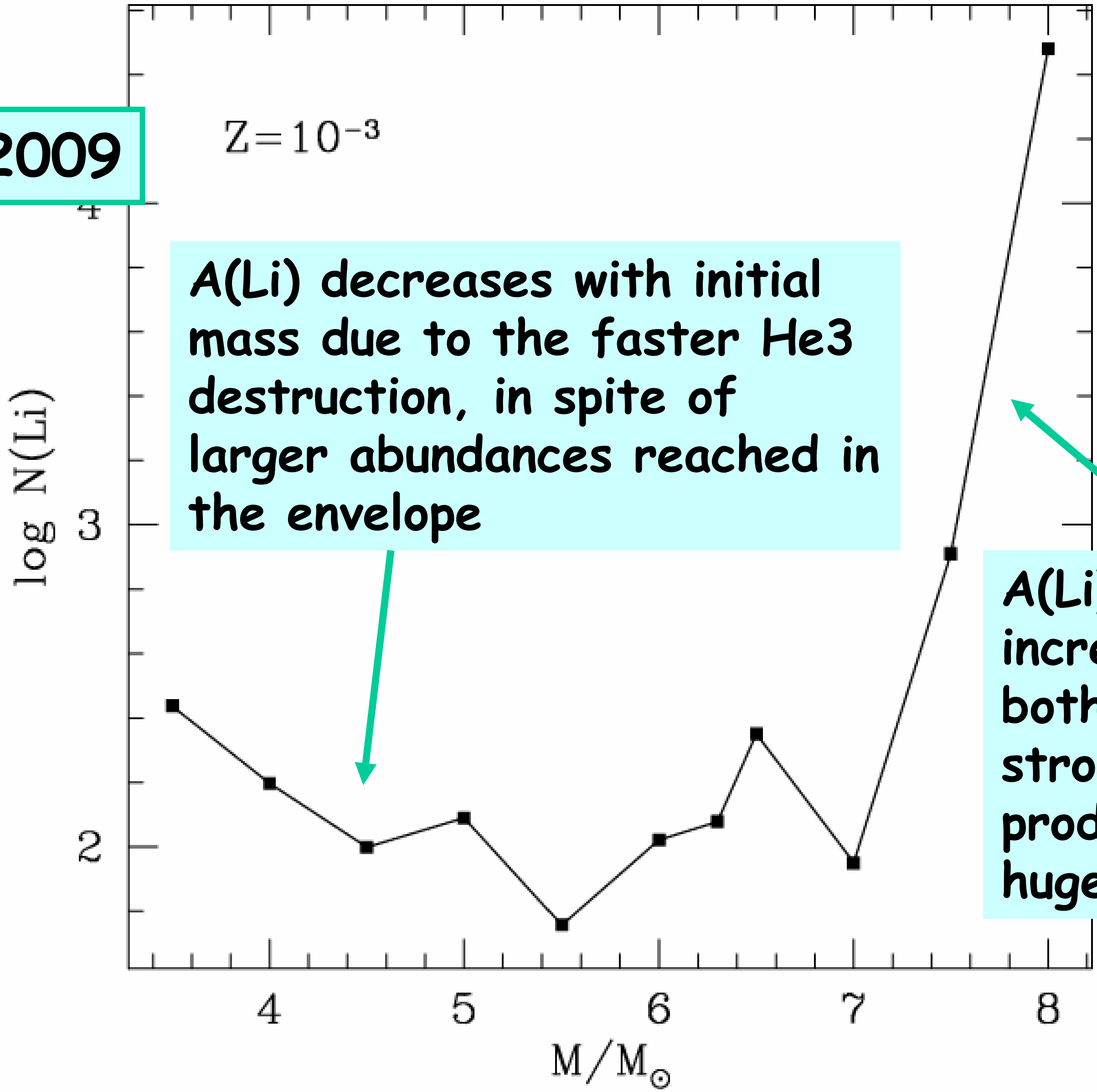
The mass loss rate influence on the lithium yield



Ventura et al. 2002
A&A 339,215

Abundance in the ejecta for Z=0.001

Ventura 2009



A(Li) decreases with initial mass due to the faster He3 destruction, in spite of larger abundances reached in the envelope

A(Li) re-increases due both to the stronger production and huge mass loss

bootstrapping

the larger the mass → the higher is Li during the production phase
the shorter the duration of the Li rich phase → the smaller is the Lithium yield

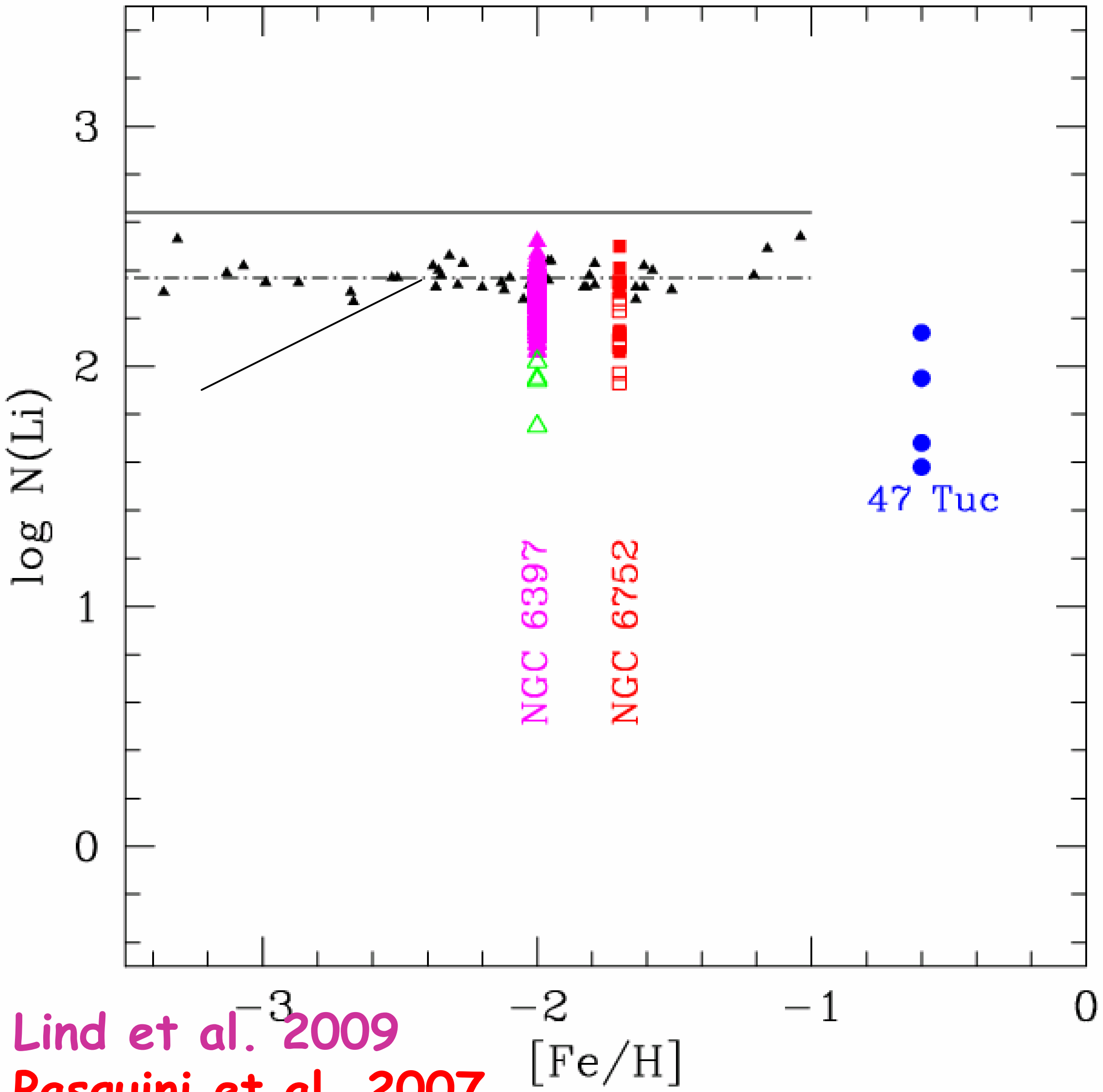
high Z (lower T_HBB) → longer duration of the Li production phase
high core mass →high L → huge mass loss rates →

We expect that the Li yield is positively correlated with Z and with the core mass → super AGBs of close to solar metallicity are possible great producers??? → possible consequences for galactic Li production, stay tuned for Francesca Matteucci's talk

Lithium (and AGBs) in Globular Clusters

◊ Globular Clusters so far examined contain two stellar generations: a "normal" (similar to halo stars) First Generation (FG) and a Second Generation (SG) showing the sign of hot CNO processing, Ne-Na cycle and sometimes Mg-Al cycle. The SG contains at least 50% of the cluster stars (Carretta et al. 2009a,b)

◊ Lithium is an important signature!



Lind et al. 2009

Pasquini et al. 2007

Bonifacio et al. 2007 → see also Valentina D'Orazio poster

Melendez & Ramirez (old) data for halo dwarfs of different Z: the Li plateau extends for

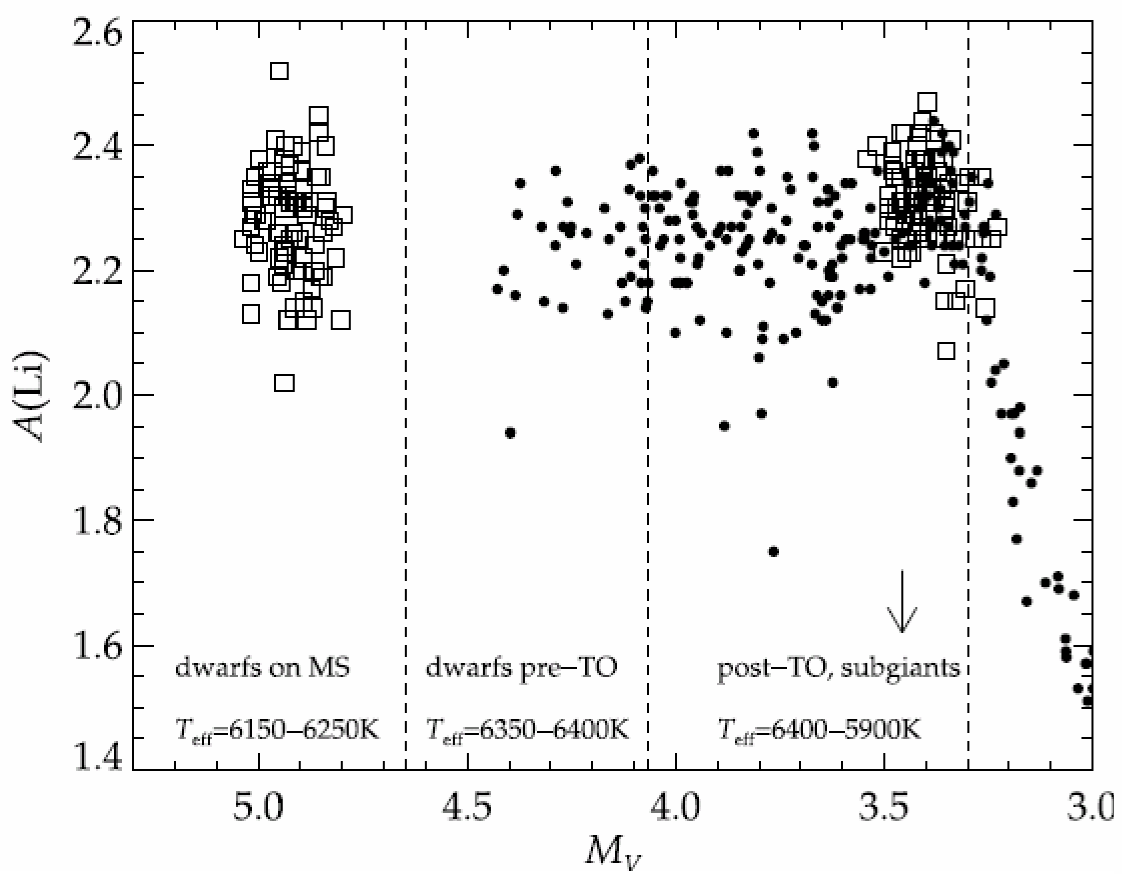
-3<[Fe/H]<-1

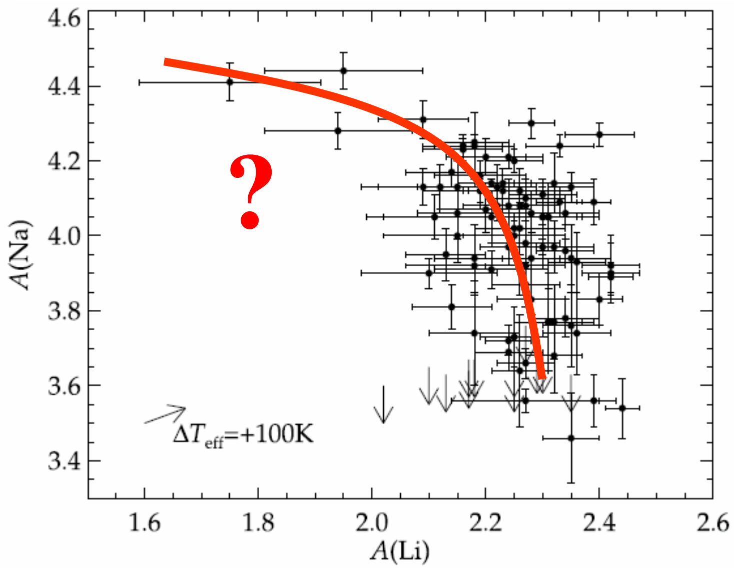
(slope for Fe/H<-2.5 not included)

BUT GC dwarfs seem to have a larger dispersion: <u>is it due to the presence of SG stars?</u>

Lind et al. 2009

NGC 6397





NGC 6397:very small spread, possibly within the errors, apart from 3 SG stars:is there a Na-Li anticorrelation?

an anticorrelation seems to be present in NGC 6752 and -possibly- 47Tuc→ DILUTION between pristine matter and hot-CNO processed matter

The SG is formed from matter processed in FG fast rotating massive stars or by HBB in the massive AGBs of the FG

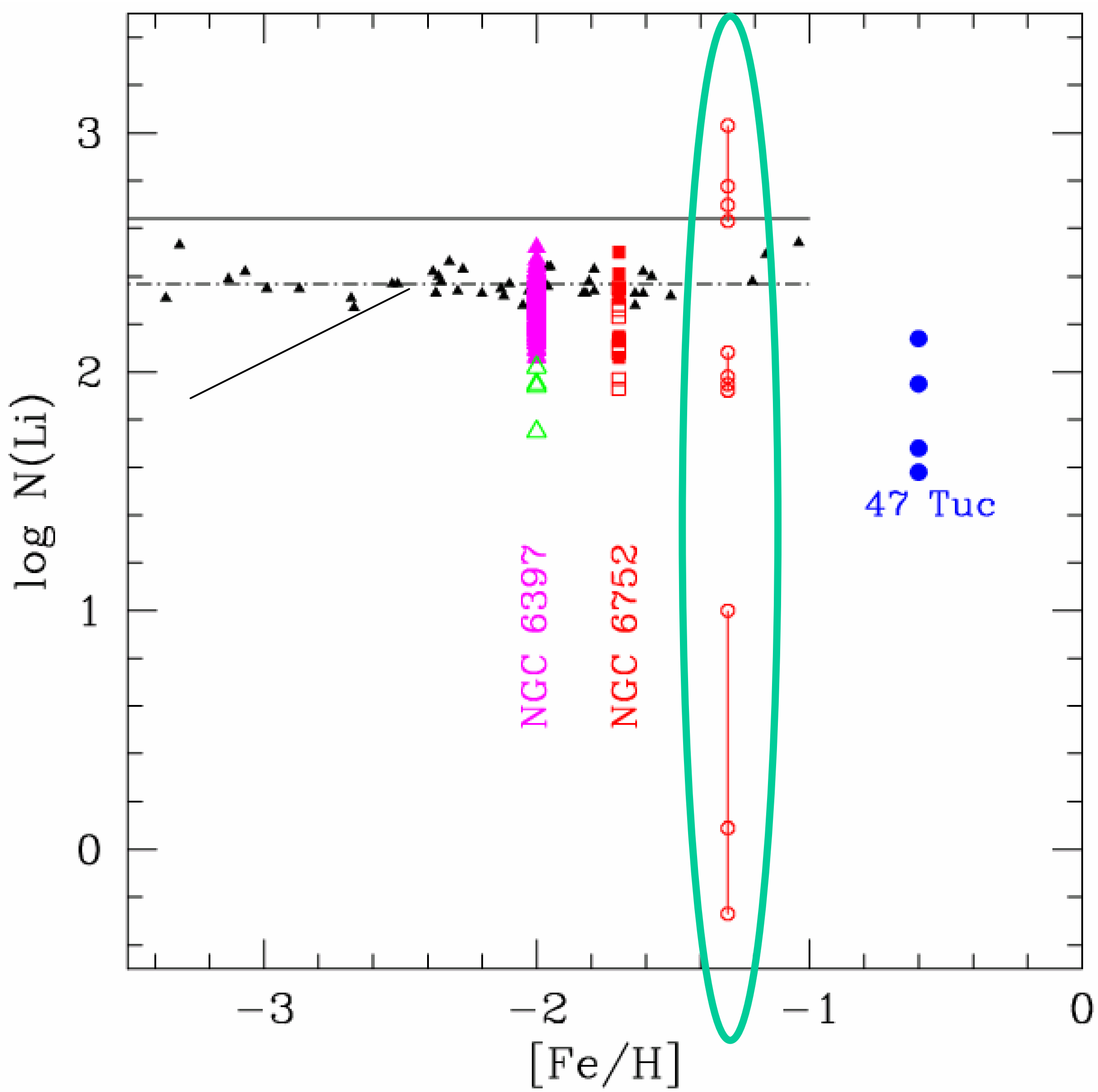
BUT

-massive stars destroy lithium

-AGB stars produce lithium, by the same process which produces the hot CNO cycled material

The observations should (might?) be able to let us choose among the two cases, based on the lithium abundance in the second generation stars

The yields in AGBs depend on Mdot!



here we see the role of mass loss at $Z=10^{-3}$

Center: 'standard' Mdot

Upper models: Mdot*2

Lower: Mdot from Vassiliadis & Wood

SUMMARY

◊ Novae are Lithium factories, but their Li production is (unfortunately) not proportional to the He3 in the donor and they are probably not the key element for Galactic Li evolution

◊ Massive AGBs are important producers, but their contribution in Li is very model dependent

◊ Super-AGBs of metallicity already close to solar may be important producers (further modeling needed)

◊ Lithium may be a useful key for the understanding of multiple populations in globulars