Element Diffusion and Accretion in Metal Poor Stars

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Element Diffusion in Stars

Basics of stellar physics : two kinds of processes in competition

- « microscopic processes » (atomic diffusion)
- « macroscopic processes » (mixing, mass loss, accretion)

Importance of precise microphysics for stellar structure and evolution

1) gravitational settling (many codes)
2) thermal diffusion (not as precise as others)
3) radiative accelerations (Montreal, Yale, Toulouse)
4) concentration gradients (mostly important in case of mac motions)

-Large data basis on atomic physics, in relation with opacity projects: OPAL , OP…

-Asteroseismic tests

Importance of diffusion for metal poor stars

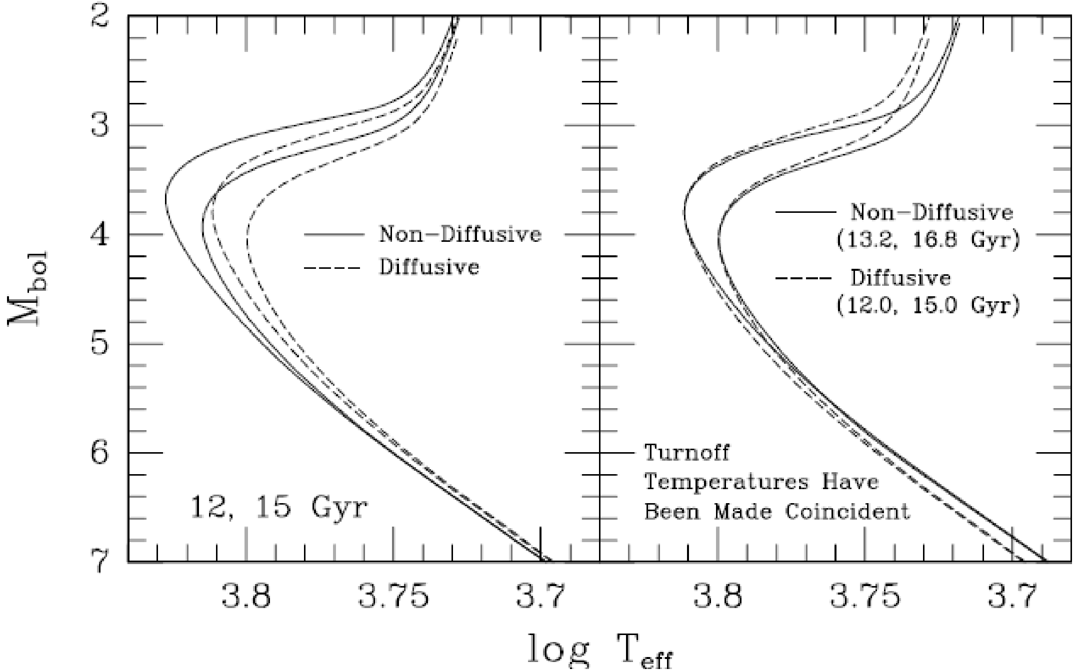
1) Ages (globular clusters)
2) Helium gradients
3) Lithium abundances
4) Detailed abundances of heavy elements

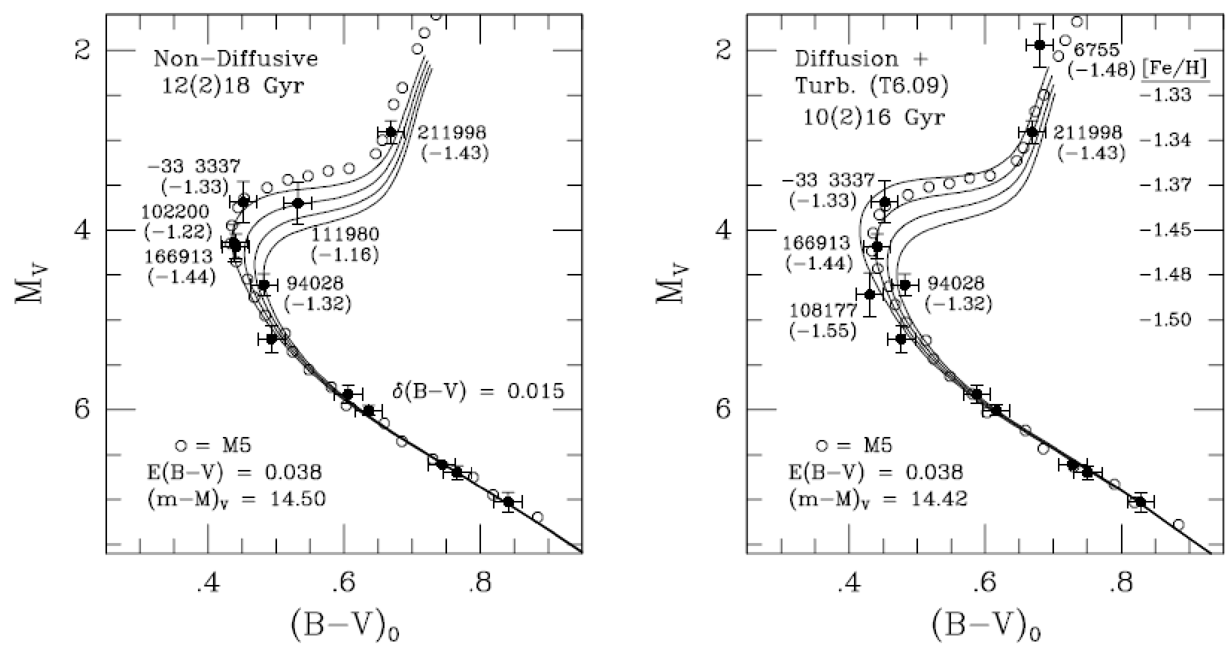
Consequences in case of accretion

Interaction with thermohaline convection (mu gradients)

Age of globular clusters

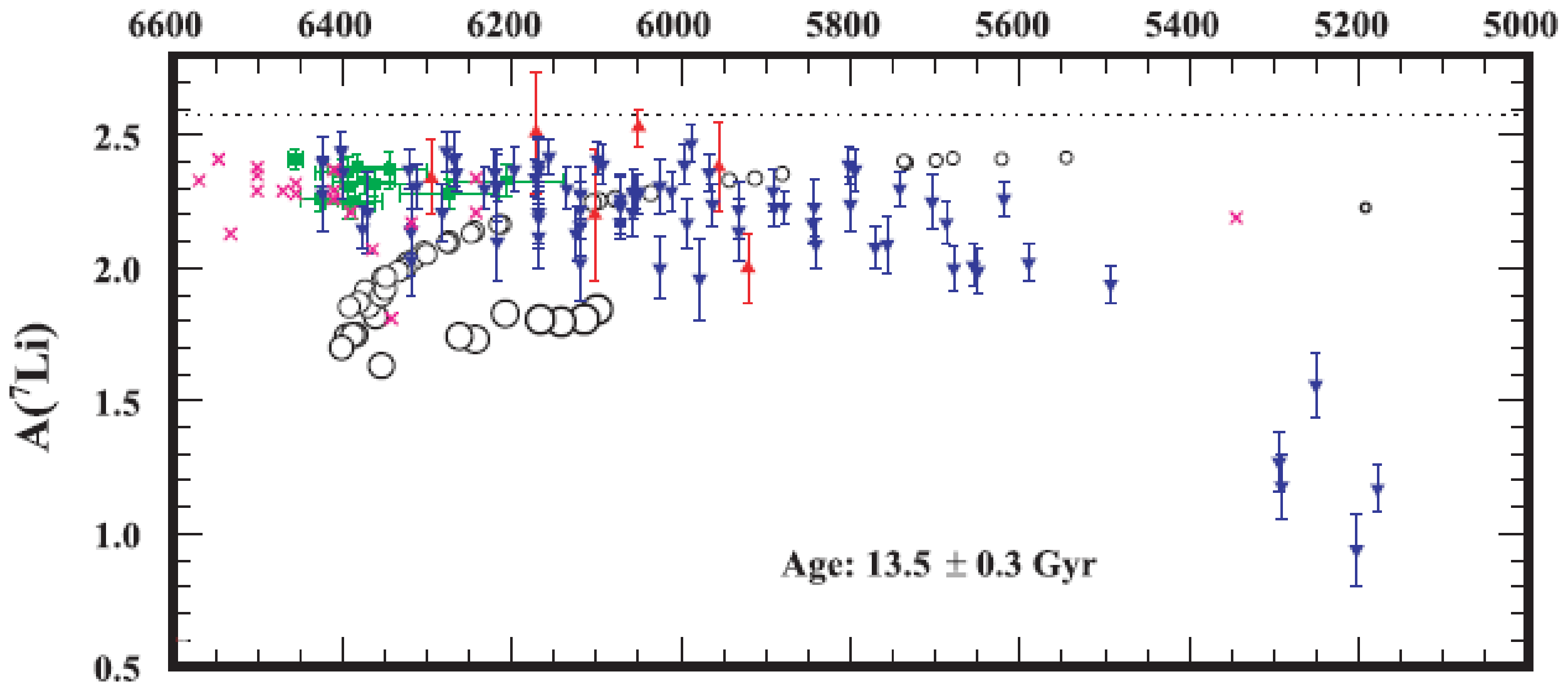
VanDenBerg et al. 2002



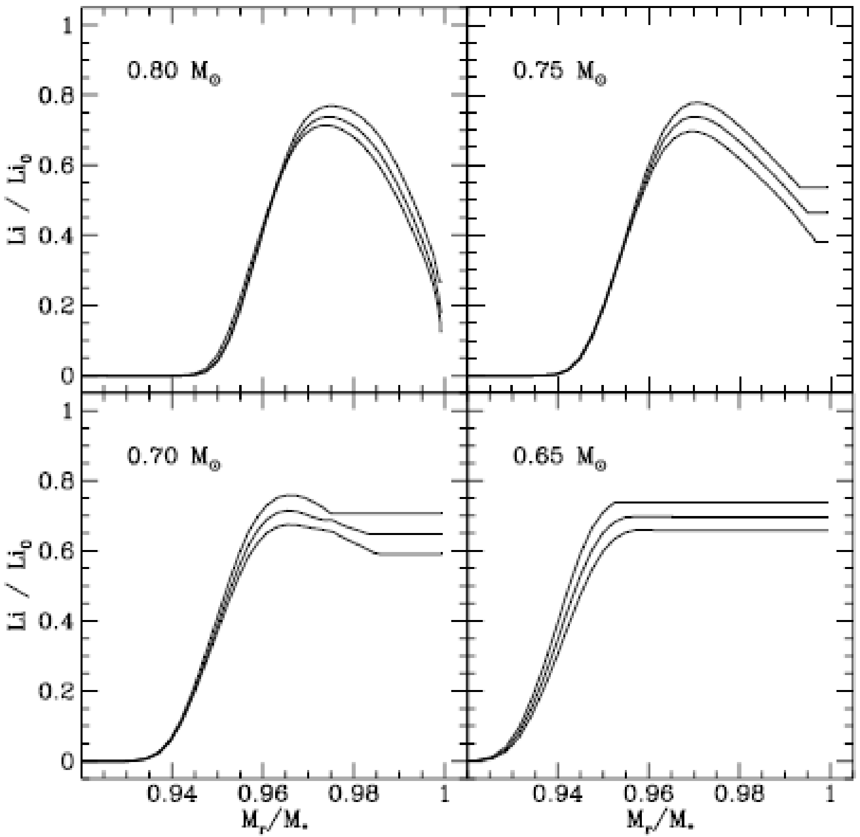


~ 10% reduction in age

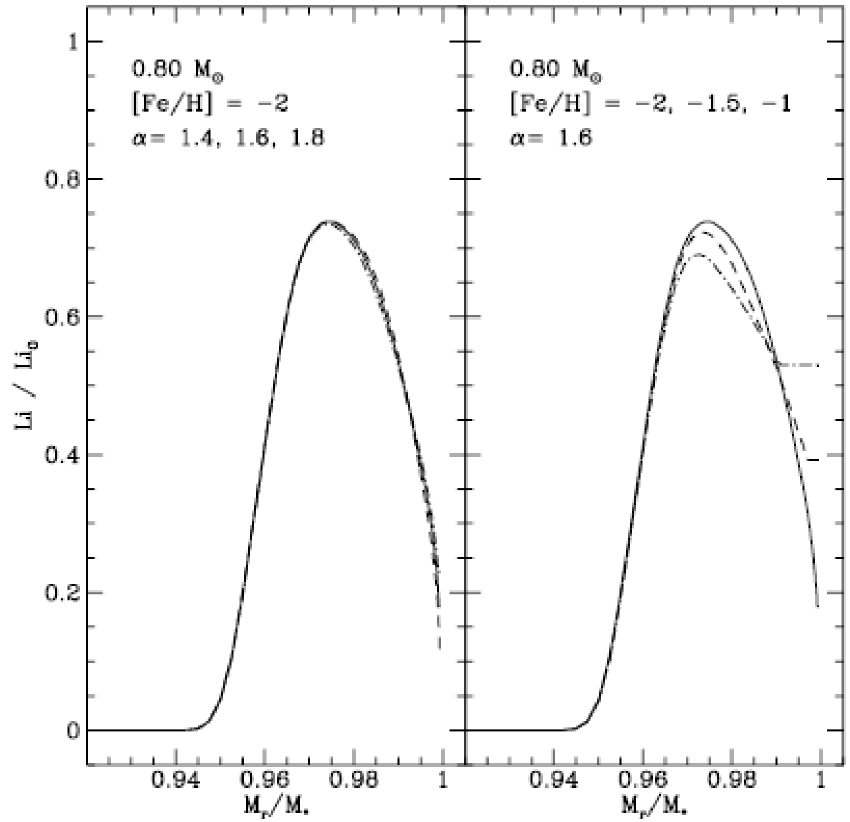
The lithium plateau



Richard, Michaud, Richer   2005



3 ages : 10, 12, 14 Gyr



left : α = 1.6 ——— right : [Fe/H] = -2
α = 1.4 - - - - [Fe/H] = -1.5
α = 1.8 —·— [Fe/H] = -1

Vauclair & Charbonnel 1998

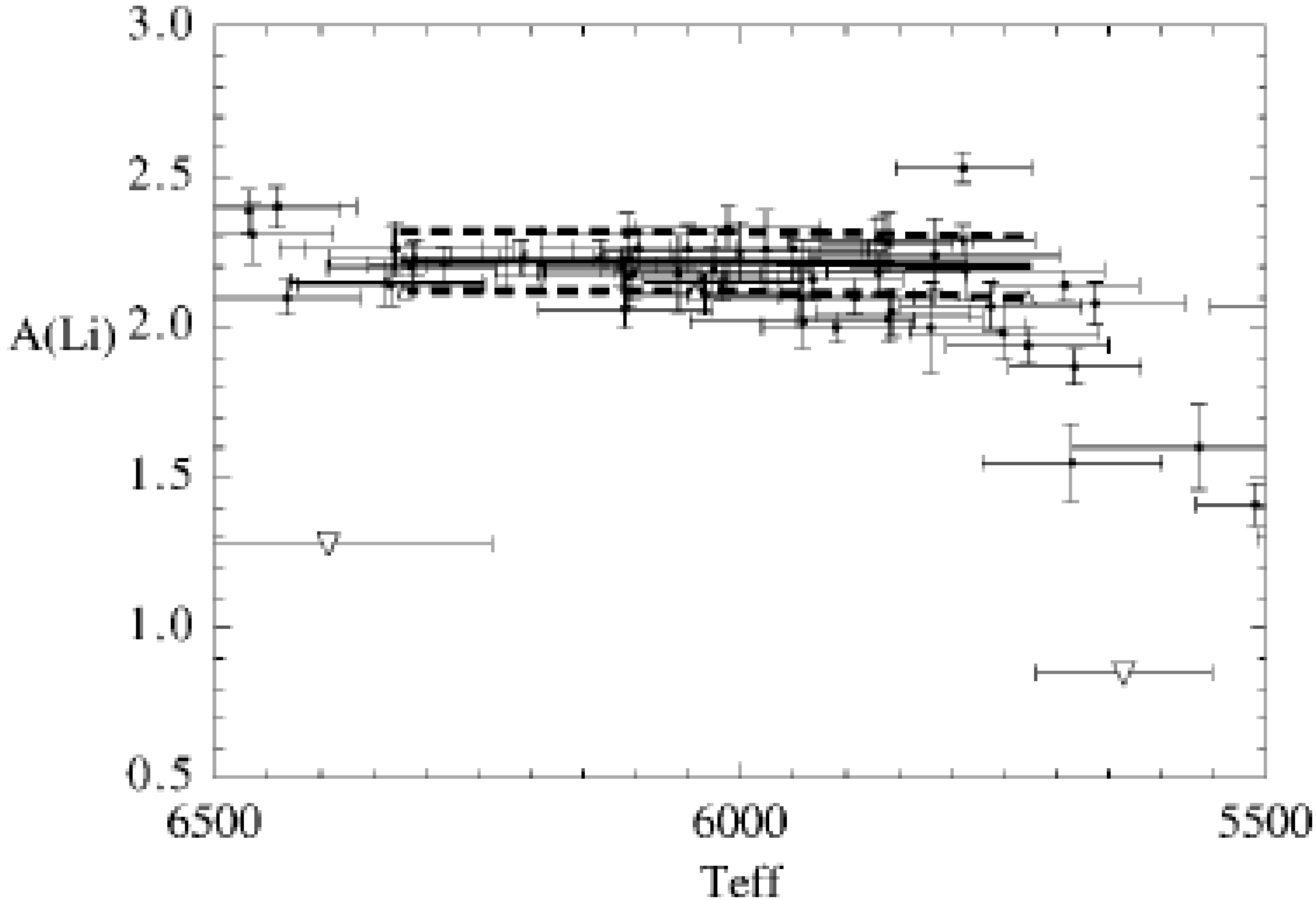
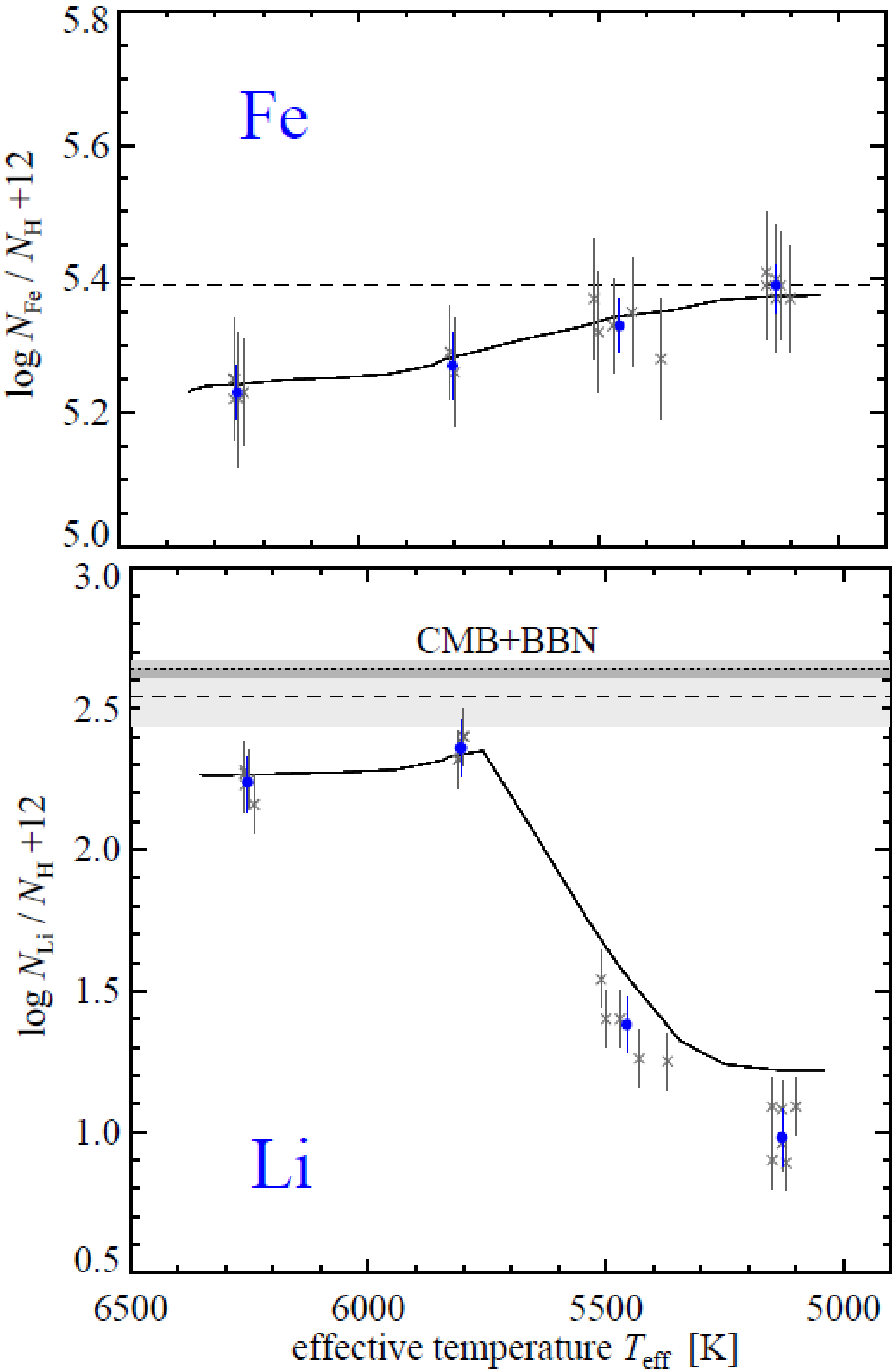


FIG. 3.—Comparisons between the theoretical results obtained after 12 Gyr and observations. The observational points and error bars are from BM97. The solid line shows the computed Li_{max} values; the dashed lines represent the uncertainties of ± 0.10 discussed in the text.



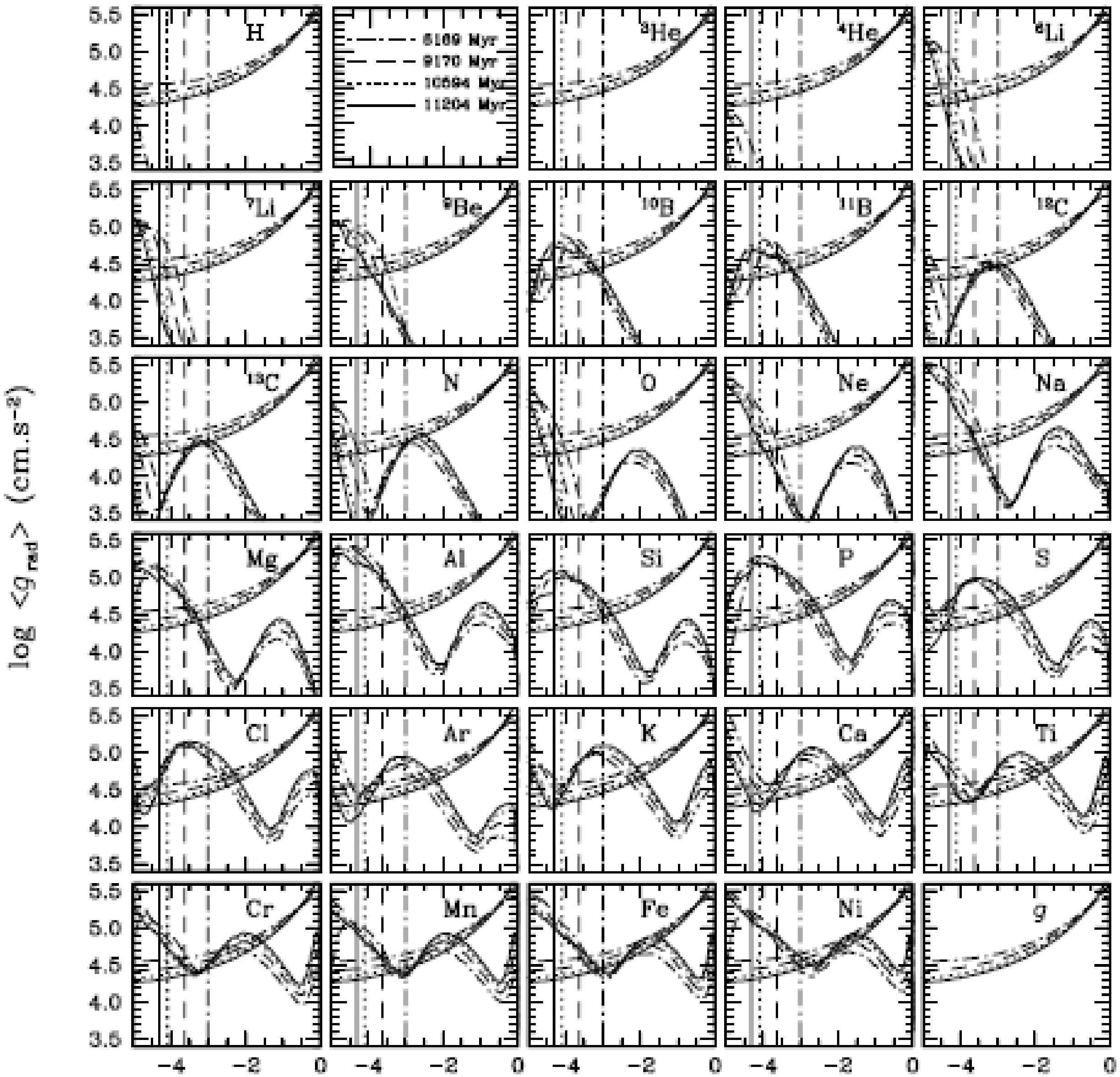
Korn, Gustafson, Richard et al., Nature 2006

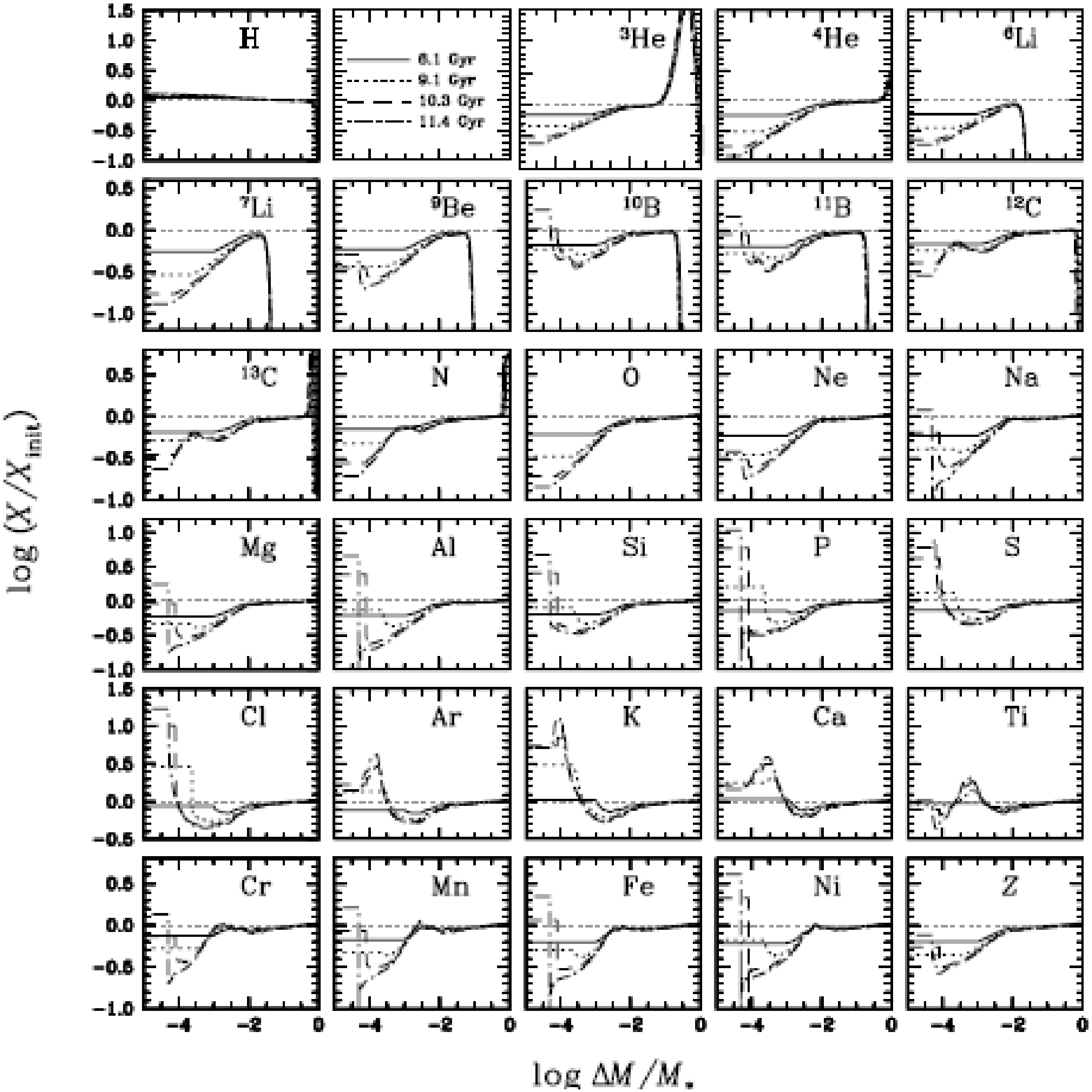
coordination lithium - iron

Radiative accelerations, full method

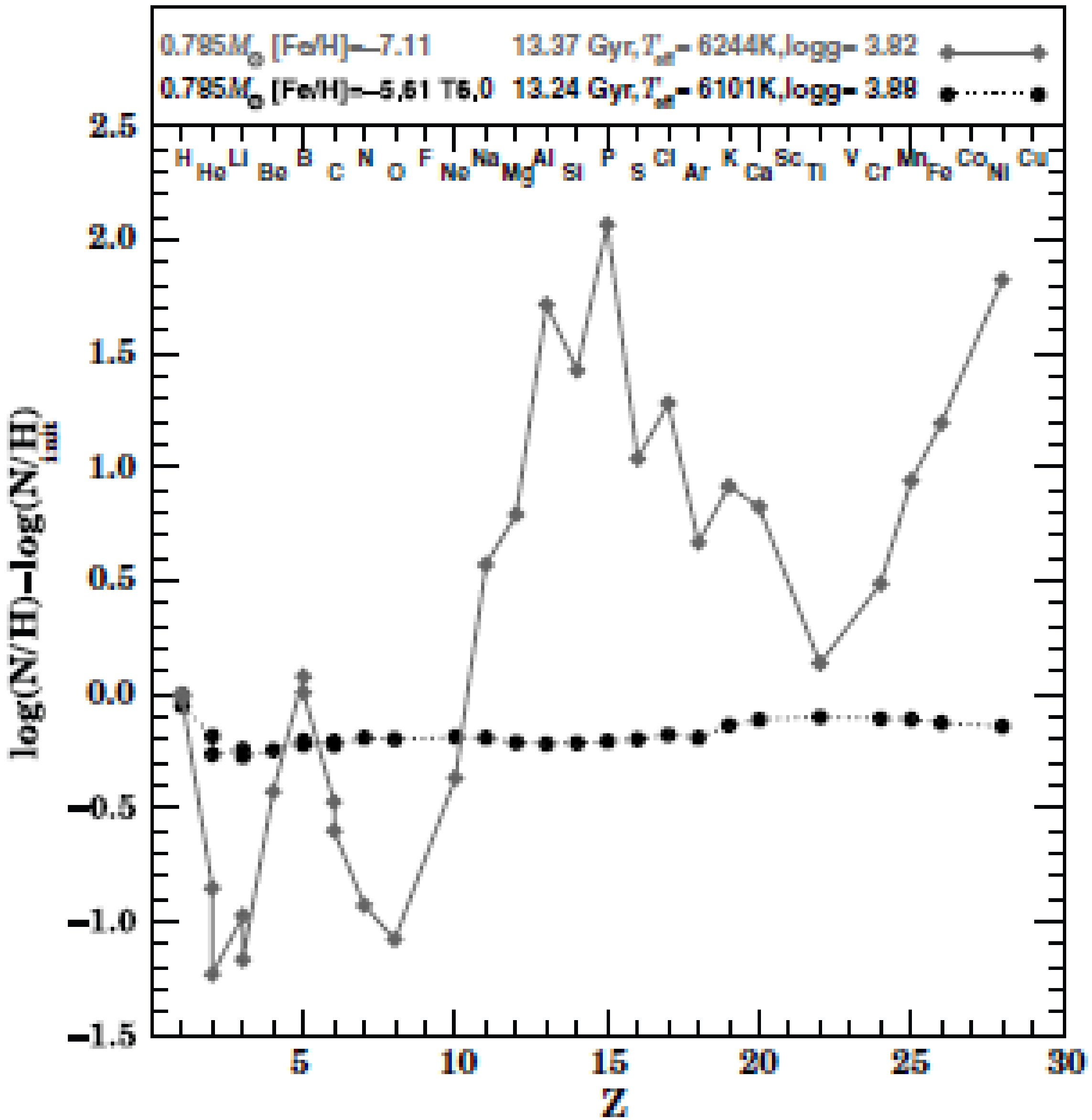
Richard et al 2002

using OPAL





H
8.1 Gyr
9.1 Gyr
10.3 Gyr
11.4 Gyr
^{3}He
^{4}He
^{6}Li
^{7}Li
^{9}Be
^{10}B
^{11}B
^{12}C
^{13}C
N
O
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Ti
Cr
Mn
Fe
Ni
Z
log $(X/X_{\rm init})$
log $\Delta M/M_*$

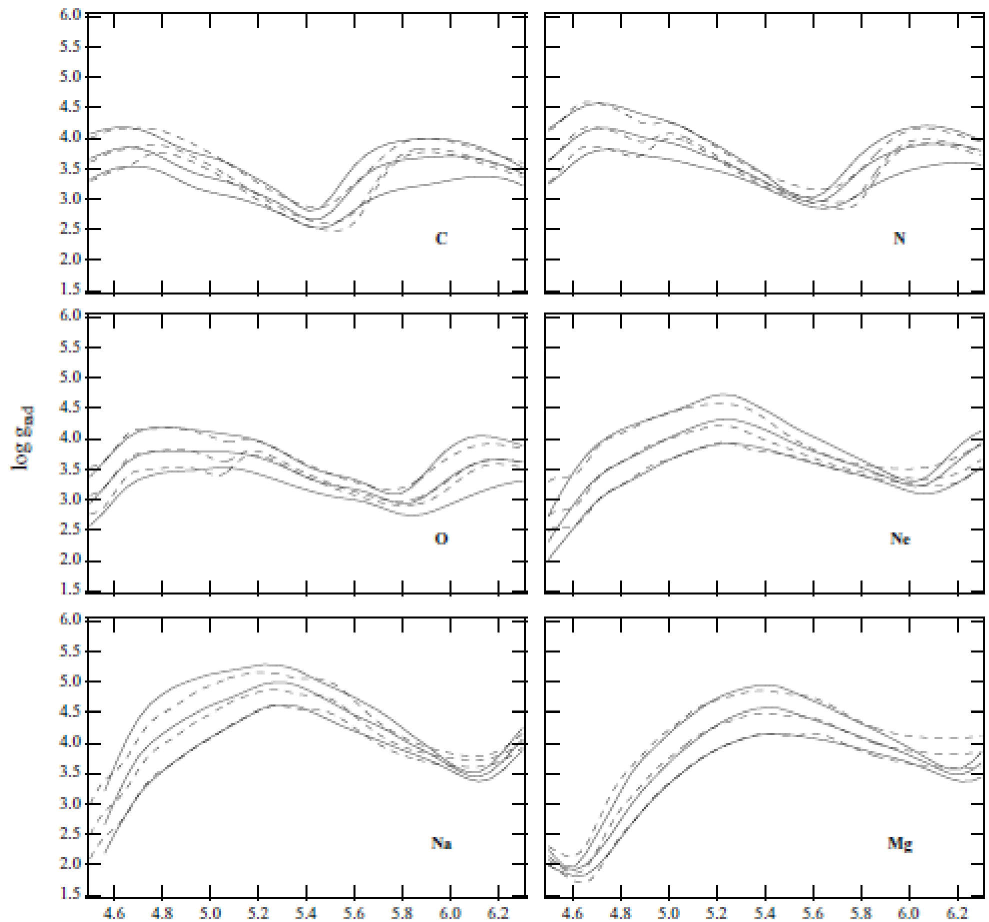


HE 1327-2326 [Fe/H] = -5 Korn et al. 2009

Radiative accelerations, SVP method

Leblanc & Alecian 2004

using OP



Comparison full method Seaton with approximate SVP method

Here: pop I ,
Te = 10000K, log g = - 4.3

Solid lines: Seaton
Dashed lines : SVP

thermohaline convection

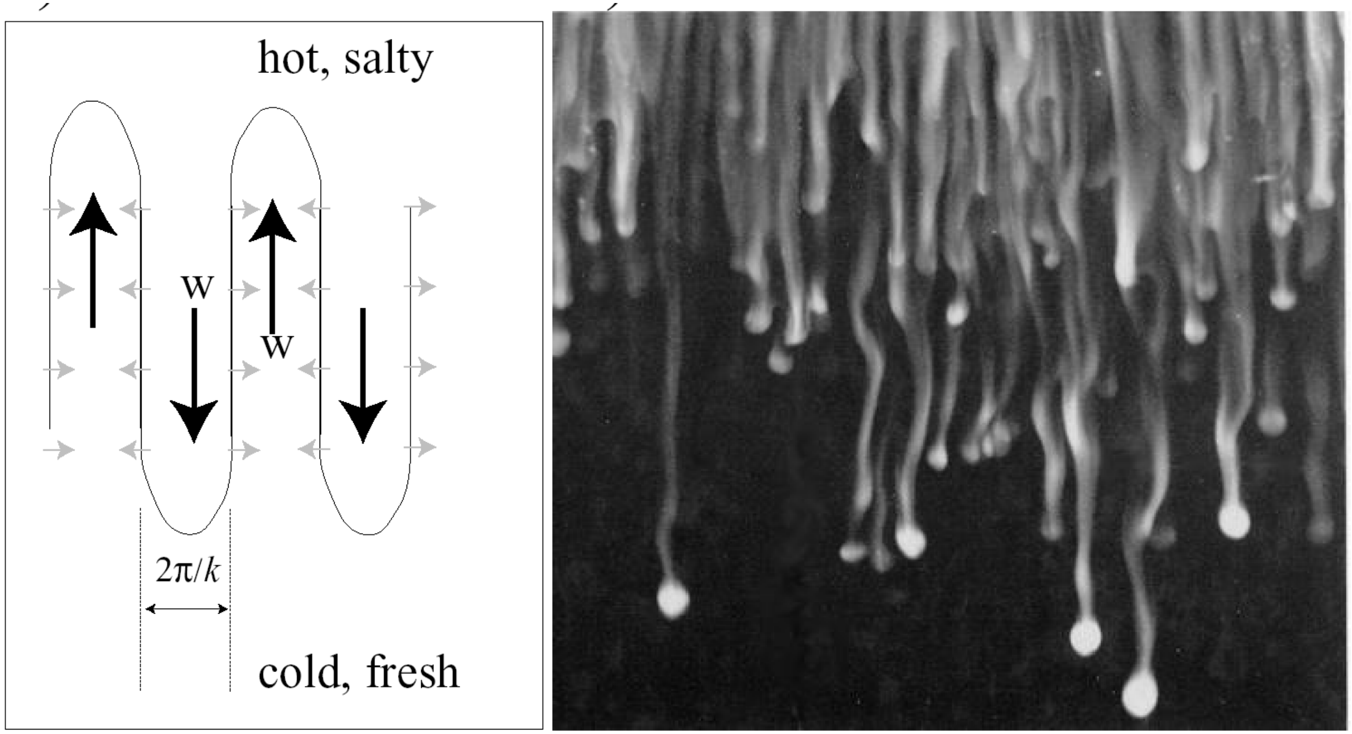


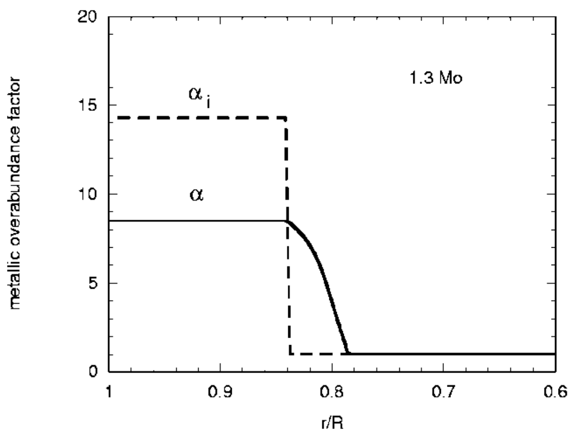
Figure 1.4: (a) A sketch of the salt finger instability. Heat flows rapidly down the temperature gradient (sketched by gray arrows) separating fingers, generating local density anomalies which drive vertical motion with velocity, w, and horizontal wavelength $2\pi/k$, where k is the horizontal wavenumber. (b) A laboratory photograph of salt fingers formed by hot salty water (containing fluorescene dye) overlying cold fresh water, photograph by J. Stewart Turner.

The stellar case

Thermohaline convection can occur in stars when a layer of large μ sits upon layers with smaller μ.

∇_{μ} = dlnμ/dlnP plays the role of the salinity gradient;

∇_{rad}- ∇ plays the role of the temperature gradient



Ledoux criterion : the medium is convectively unstable if : $\nabla_{crit} = \frac{\phi}{\delta}\nabla_{\mu} + \nabla_{ad} - \nabla < 0$

where $\phi = (\partial \ln \rho / \partial \ln \mu)$ and $\delta = (\partial \ln \rho / \partial \ln T)$

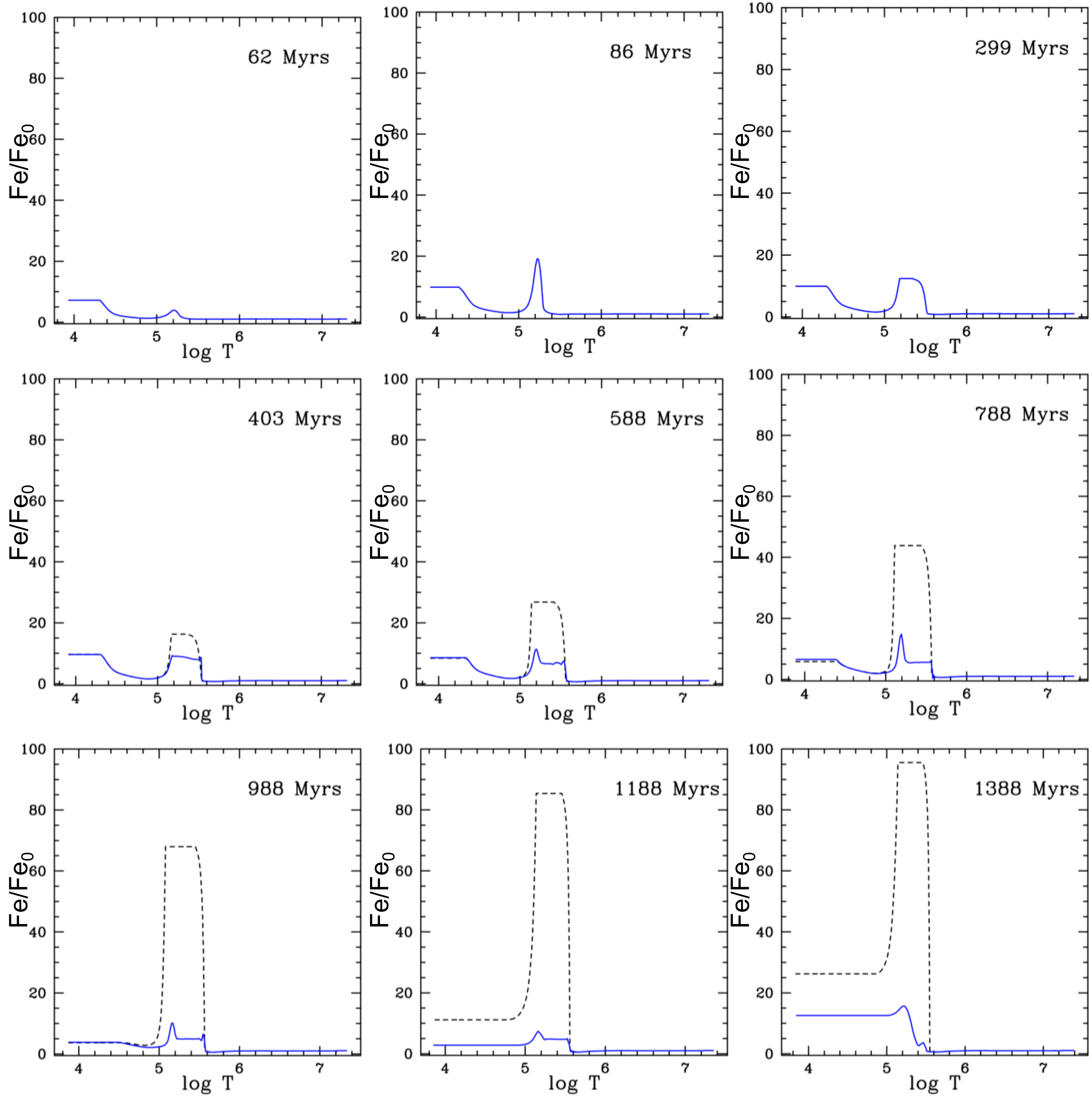
Thermohaline convection appears when : $\nabla_{crit} > 0$

This happens in particular when a metal poor star accretes metal rich matter
(and every time heavy matter sits upon lighter one, as for accumulation due to diffusion itself)

Théado, Vauclair, Alecian, Leblanc, 2009

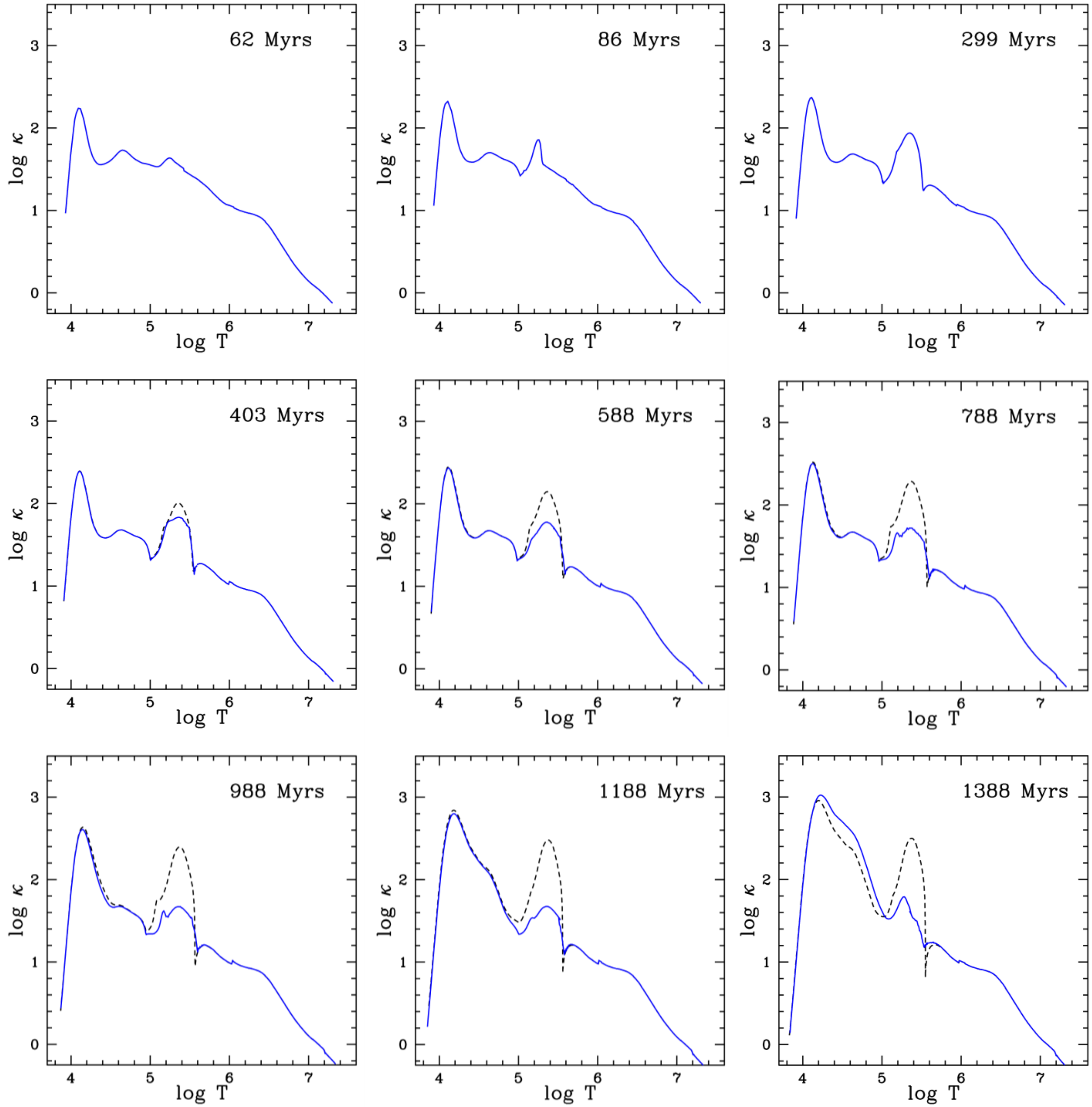
$1.7\ M_\odot$

Fe/Fe_0



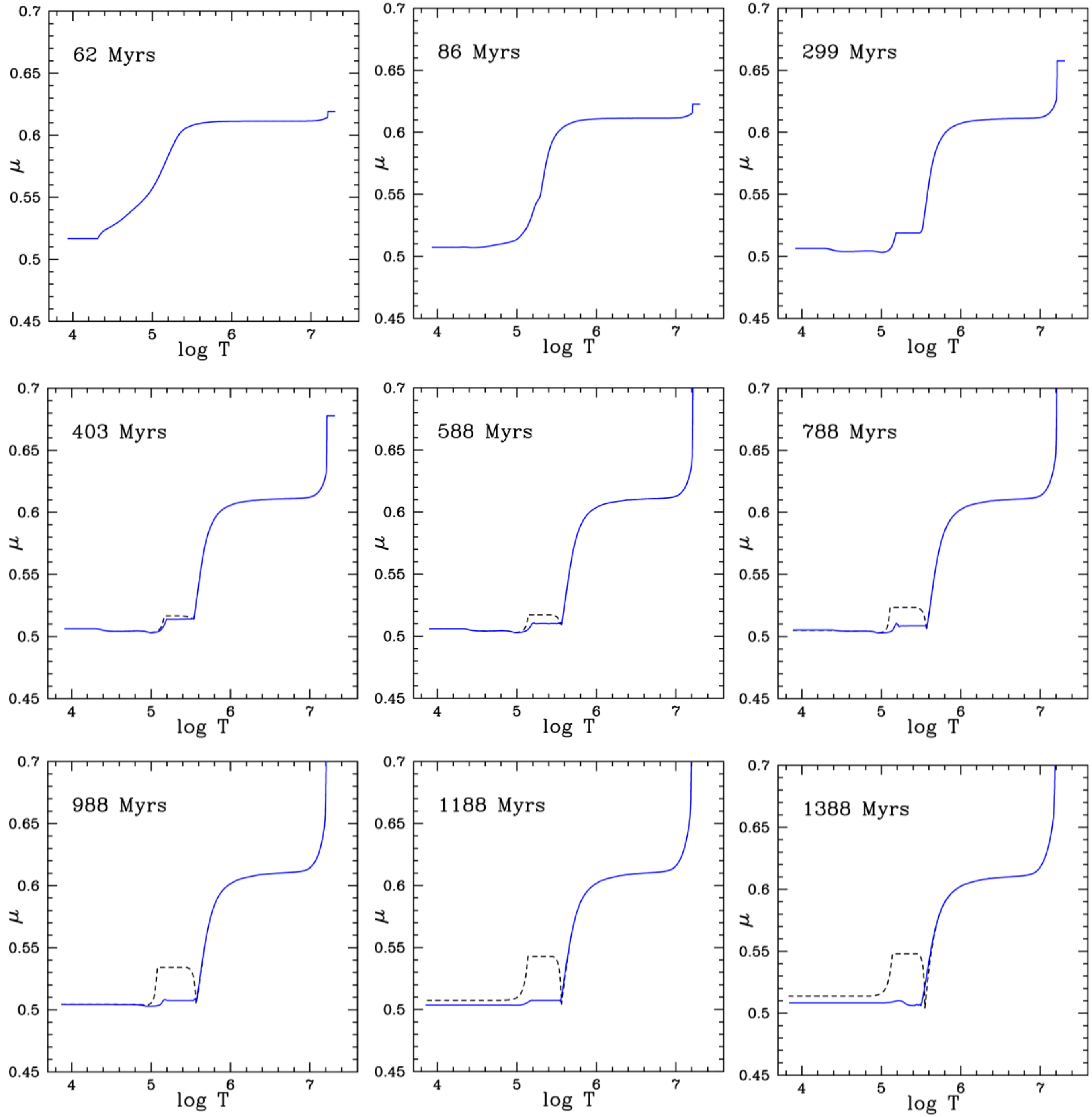
$1.7\ M_{\odot}$

Log κ



$1.7\ M_{\odot}$

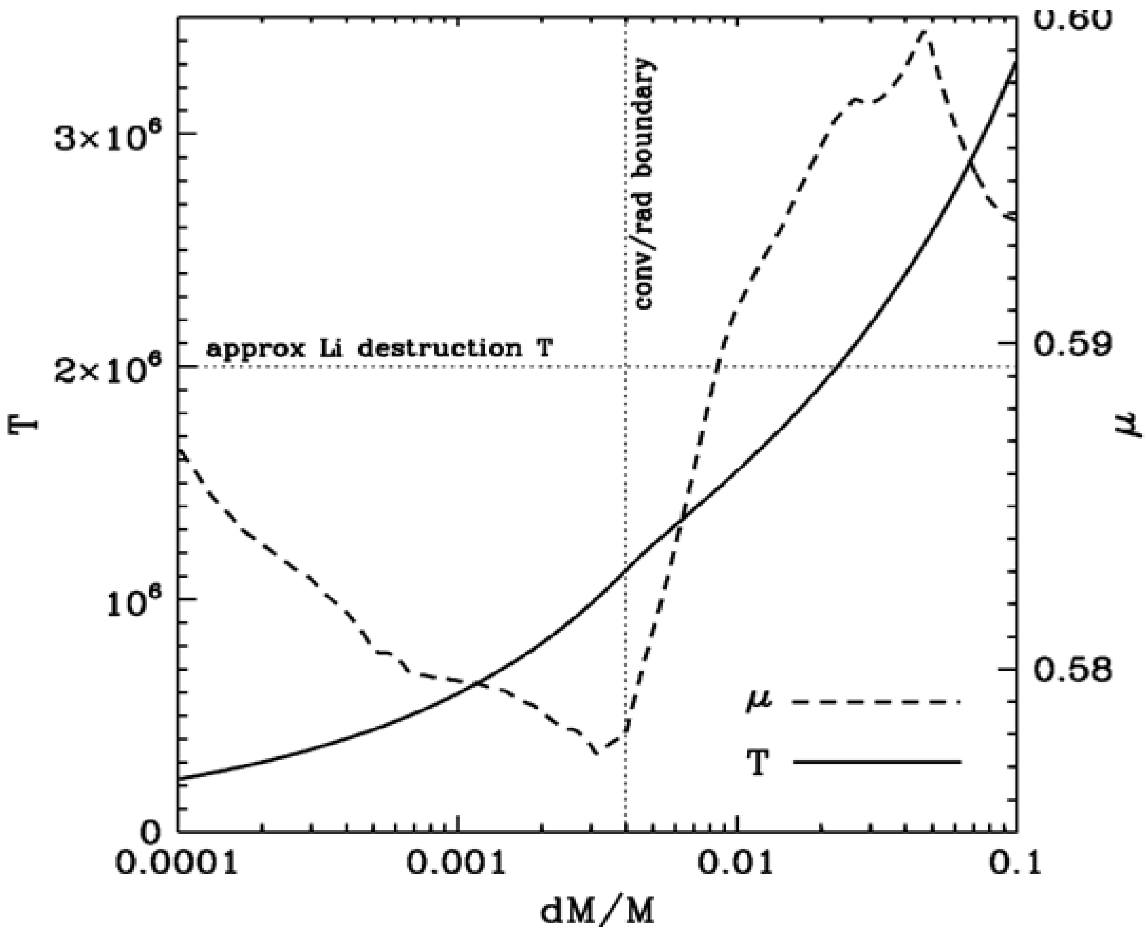
μ



62 Myrs
86 Myrs
299 Myrs
403 Myrs
588 Myrs
788 Myrs
988 Myrs
1188 Myrs
1388 Myrs
μ
log T

CS22964-161

A Metal-poor Double-lined Spectroscopic Binary with C, Li, and s-process Overabundances



Thompson et al. 2008

Conclusions:

- thermohaline convection should be taken into account

- difficult to handle (numerical simulations)

- can limit the accumulation of heavy elements in specific stellar layers (due to accretion, diffusion, mass loss, nuclear reactions)

- interact with other macroscopic motions, magnetic fields

- important: other effects leading to stabilizing mu-gradients, which allow thermohaline diffusion to take place.