# AGE DATING COMBINING STELLAR MODELS, SPECTROSCOPY AND ASTEROSEISMOLOGY.

## CHALLENGES FOR STELLAR EVOLUTION CALCULATIONS

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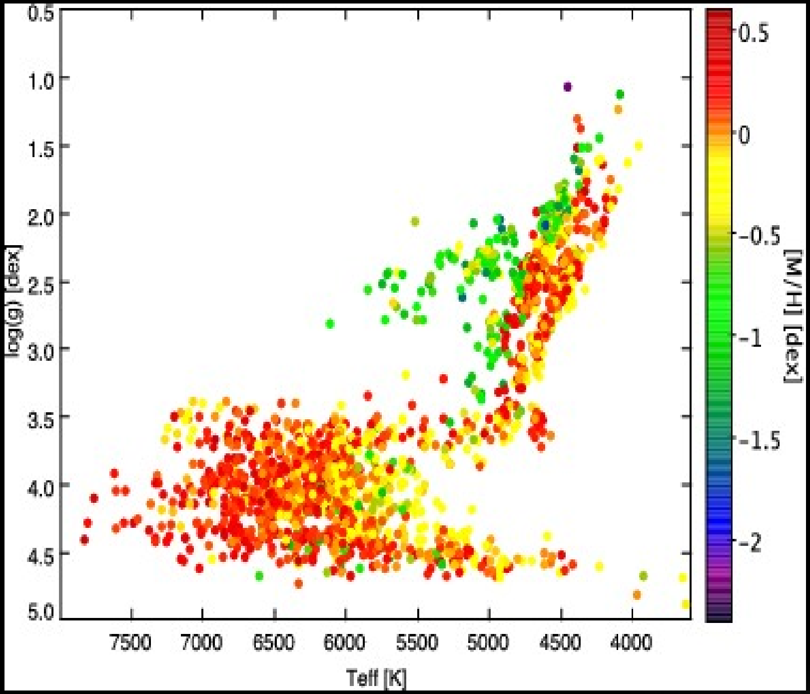
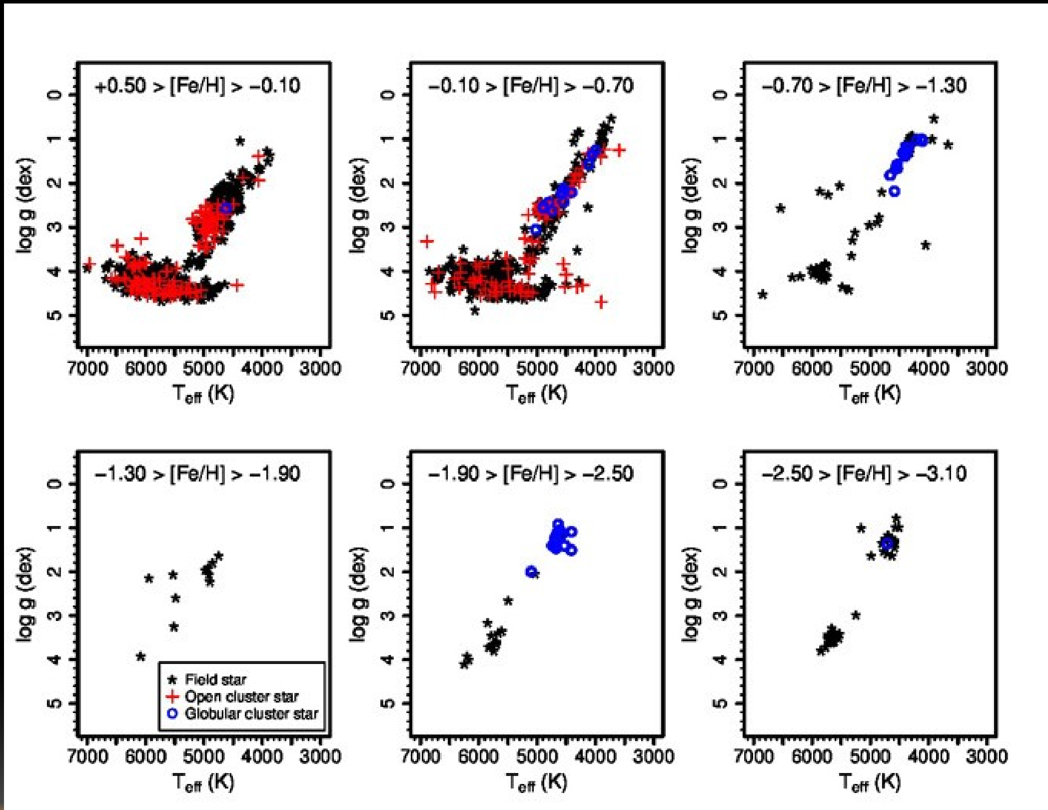
# Disk (Corot) field stars

Gazzano et al. (2013)




GAIA-ESO survey



# TWO MAJOR SOURCES OF UNCERTAINTY FOR AGE DETERMINATIONS OF FIELD LOW MASS STARS

**ATOMIC DIFFUSION**

**SUPERADIABATIC CONVECTION/BOUNDARY CONDITIONS**

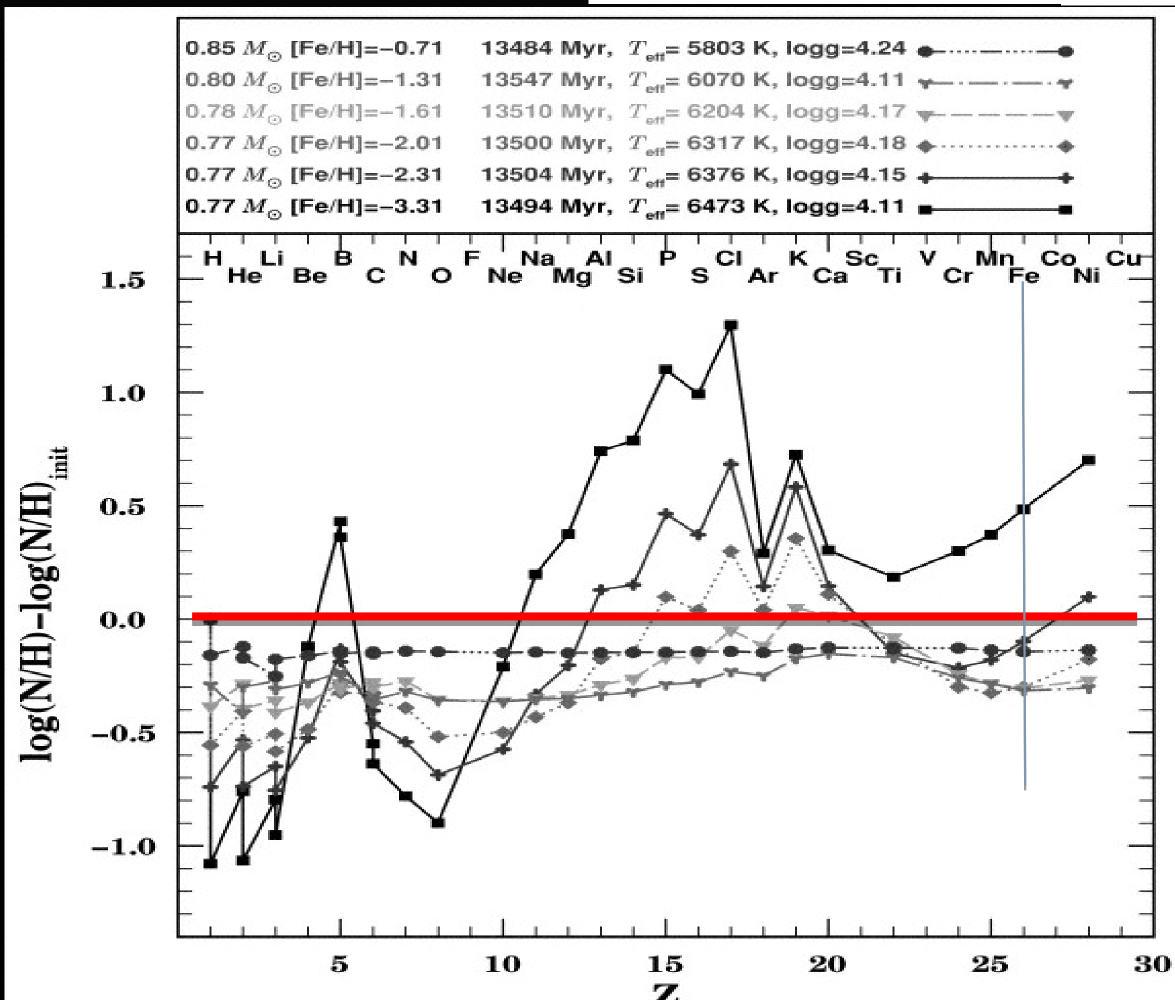
# ATOMIC DIFFUSION AND RADIATIVE LEVITATION

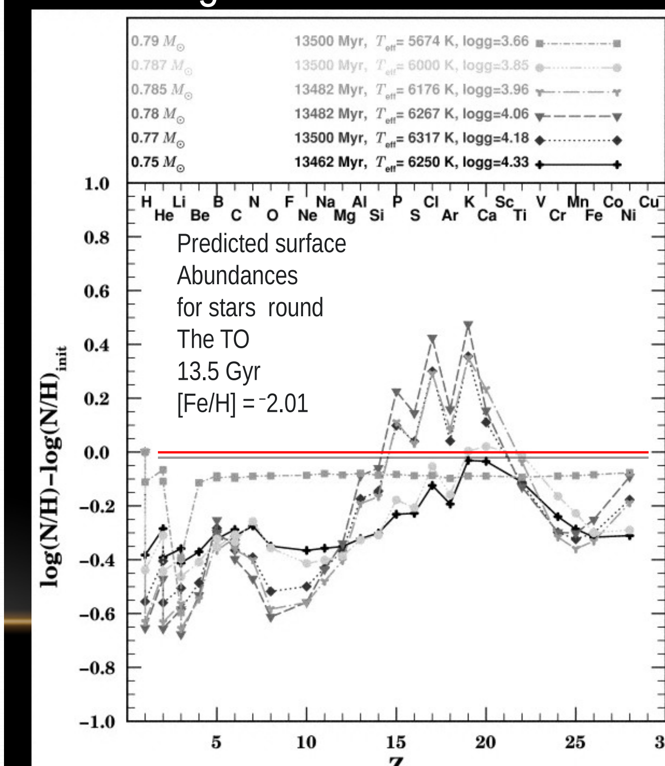
timescales → $\tau \approx K \quad M_{CZ}/(M\, T_{CZ}^{\;3/2})$

Richard et al. (2002)

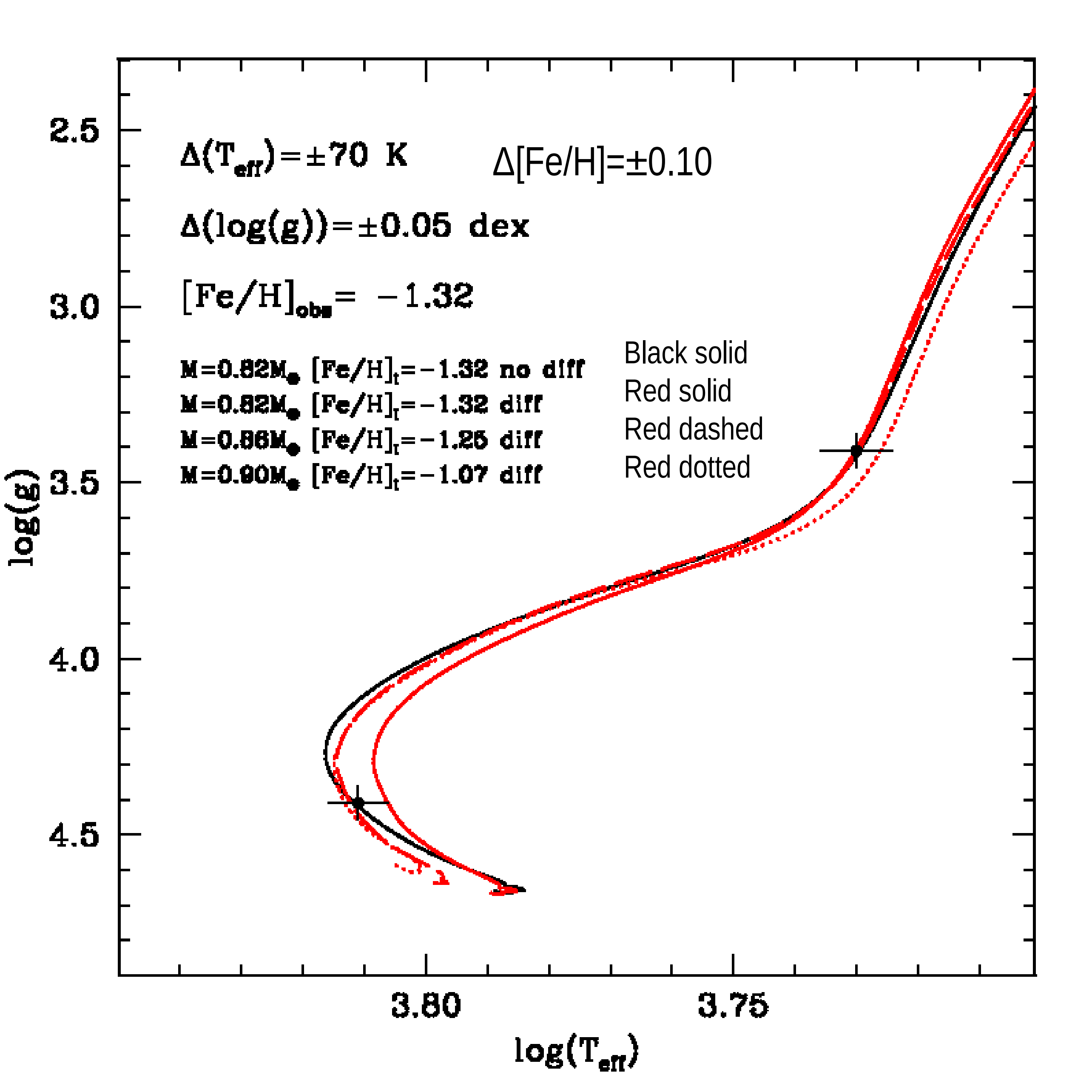
$$v_D = D_{ip} \left[ -\frac{\partial \ln c_i}{\partial r} \right] + D_{ip} \left[ \frac{A_i m_p}{kT} (g_{\text{rad},i} - g) + \frac{Z_i m_p g}{2kT} + k_T \frac{\partial \ln T}{\partial r} \right]$$

Diffusion velocity of a given element

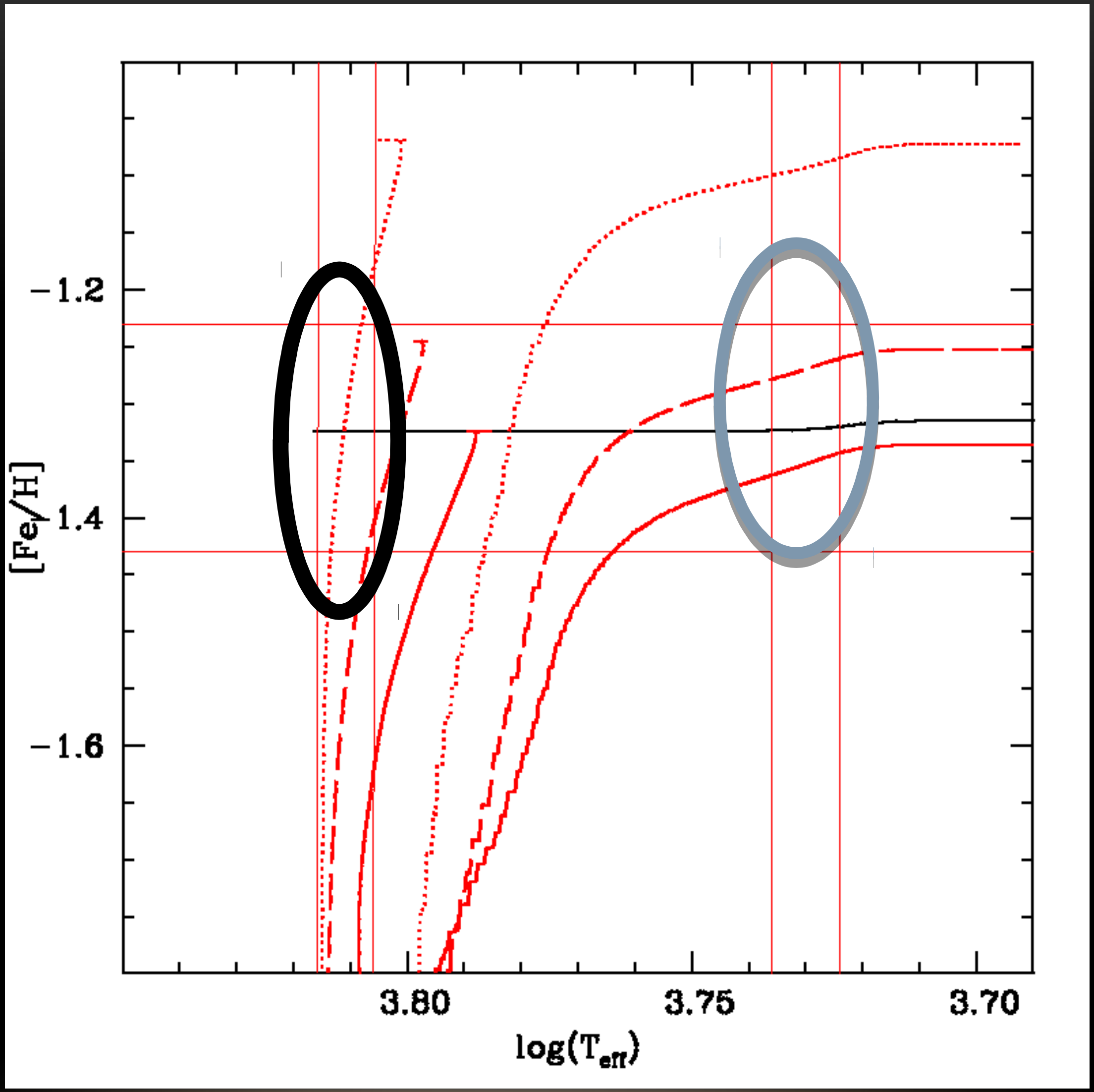


# ATOMIC DIFFUSION AND AGE OF FIELD STARS

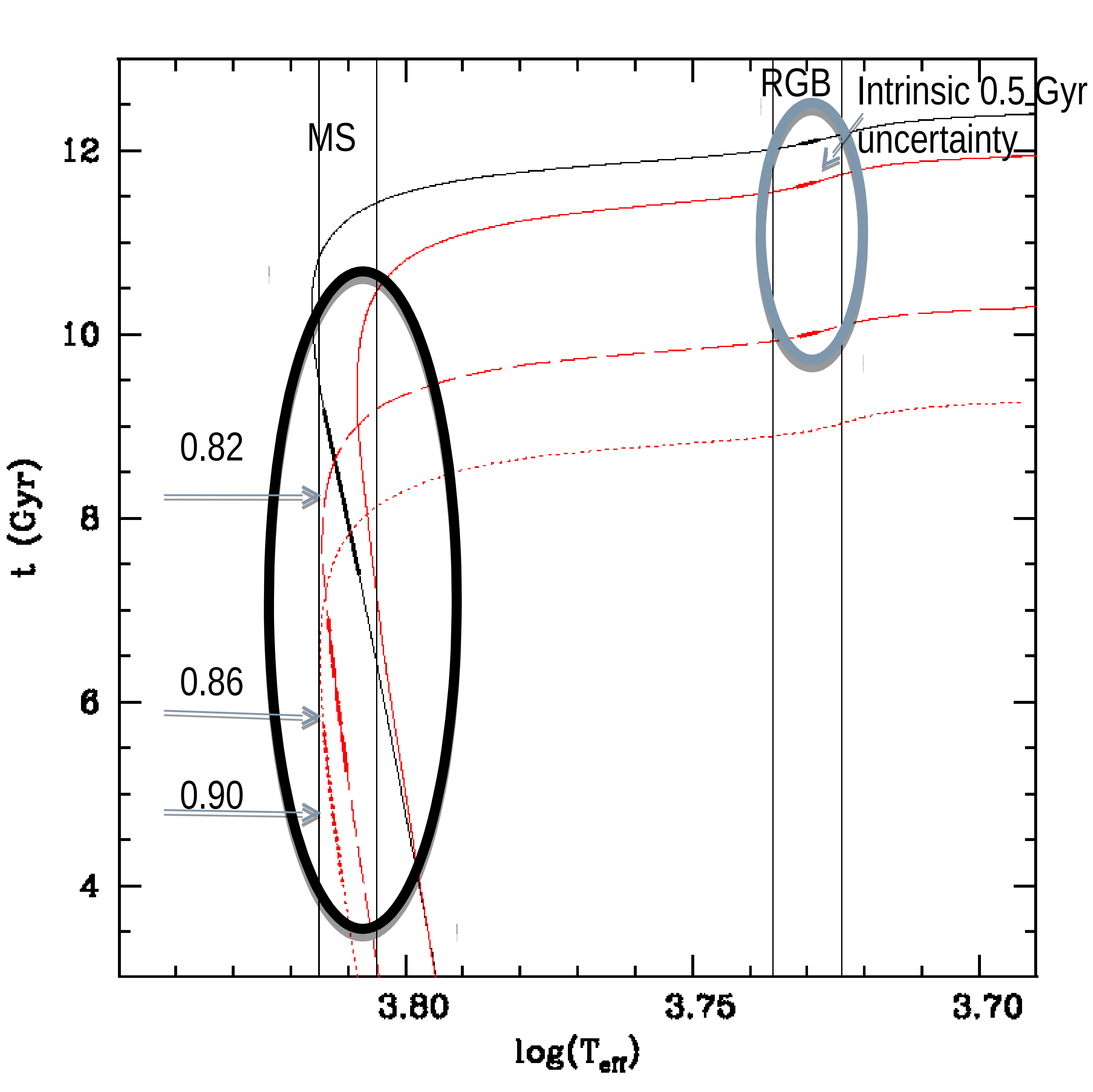


## Evolution of surface [Fe/H]

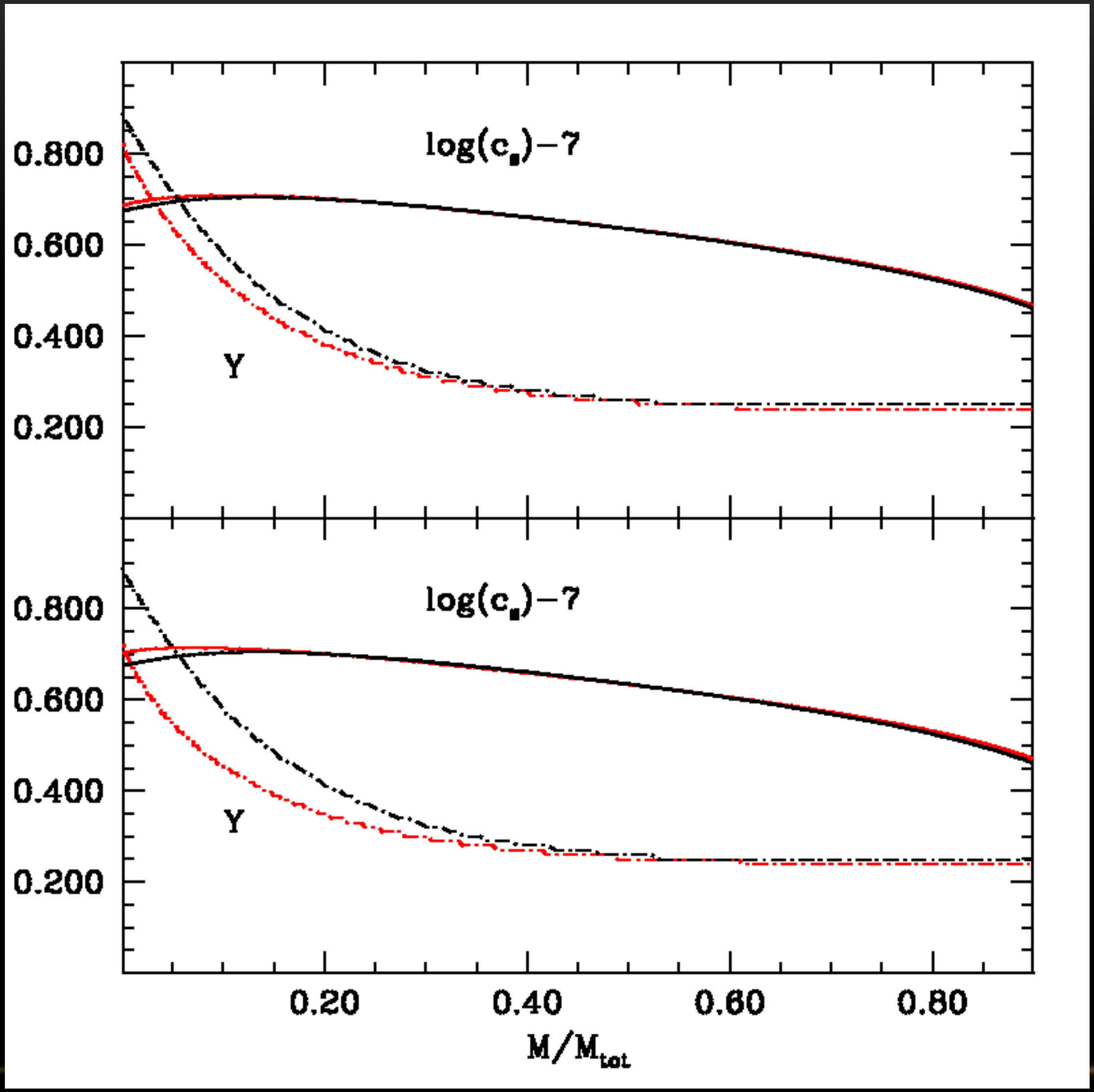


# AGE BIAS

We need to know the mass with a precision better than ~5% to have an age bias below ~2.5 Gyr on the MS and RGB



How capable is the ratio of small to large separations $r_{02}$ to break this degeneracy?



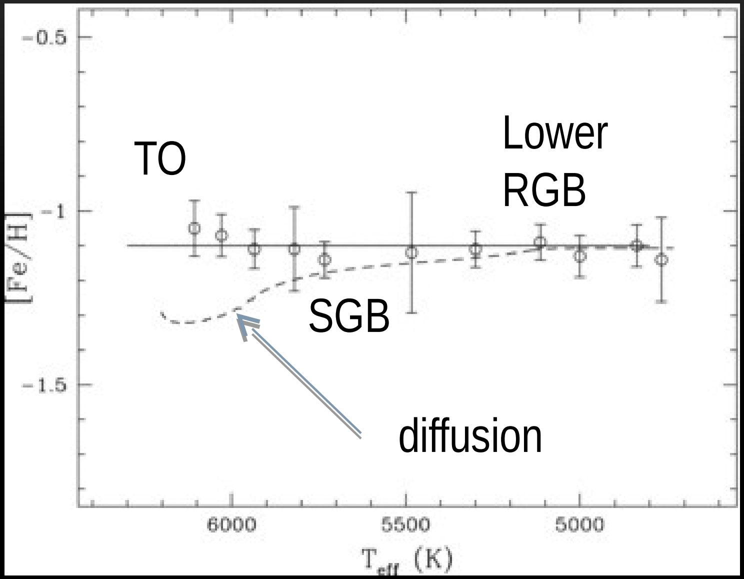

0.86M☉ [Fe/H]$_i$=−1.25

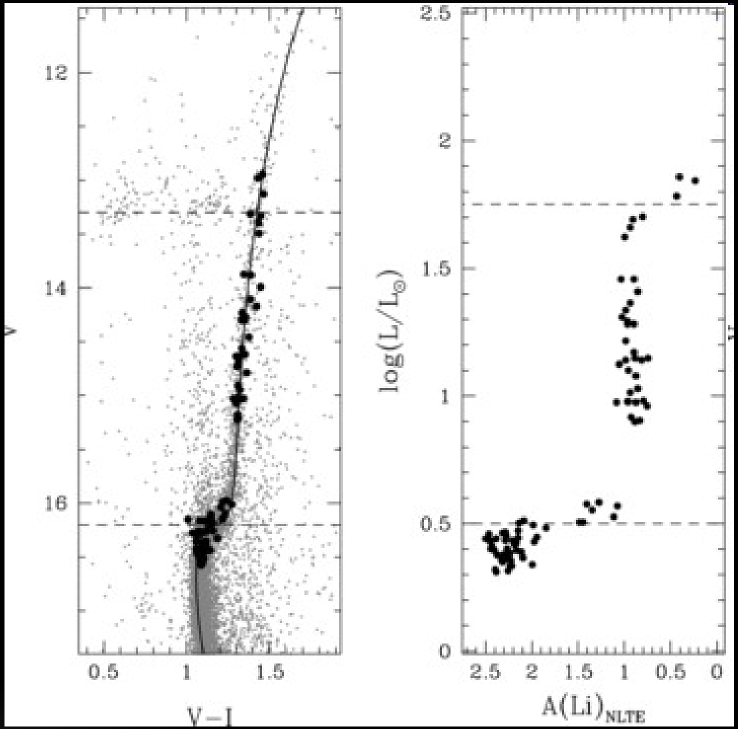
0.82 M☉ [Fe/H]$_i$=−1.32

0.9 M☉ [Fe/H]$_i$=−1.07

0.82 M☉ [Fe/H]$_i$=−1.32

# BUT….. HANG ON A MOMENT………IS DIFFUSION EFFICIENT?



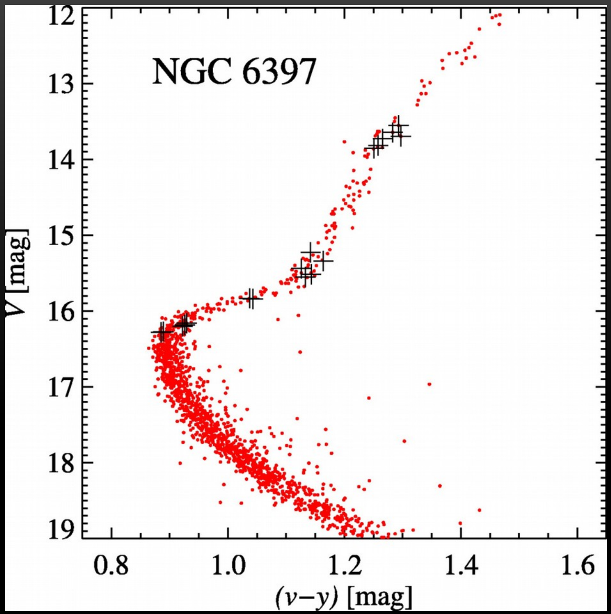



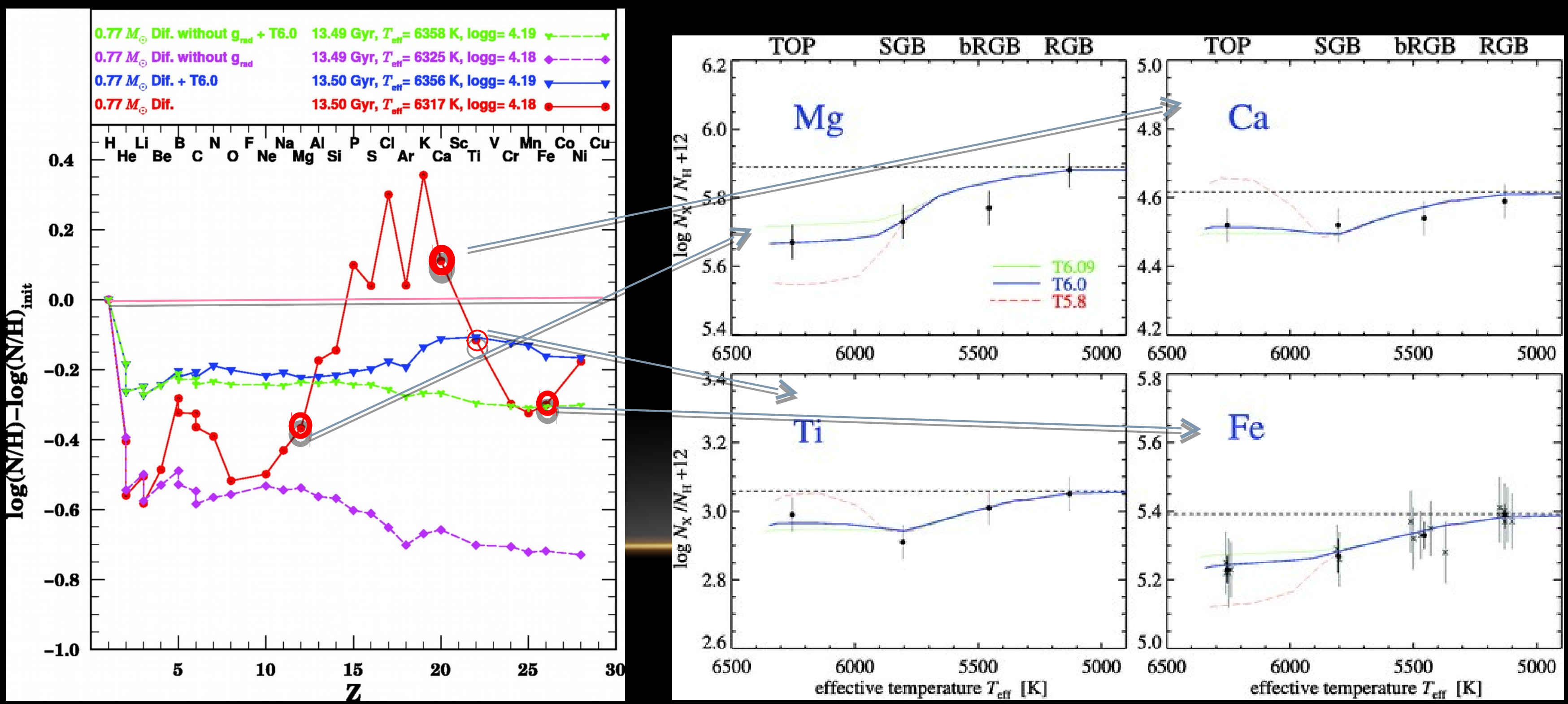

M4 ([Fe/H]~ −1.2)

Mucciarelli et al. (2011)

NGC 6397 ([Fe/H]~ −2.0)

Korn et al. (2007)

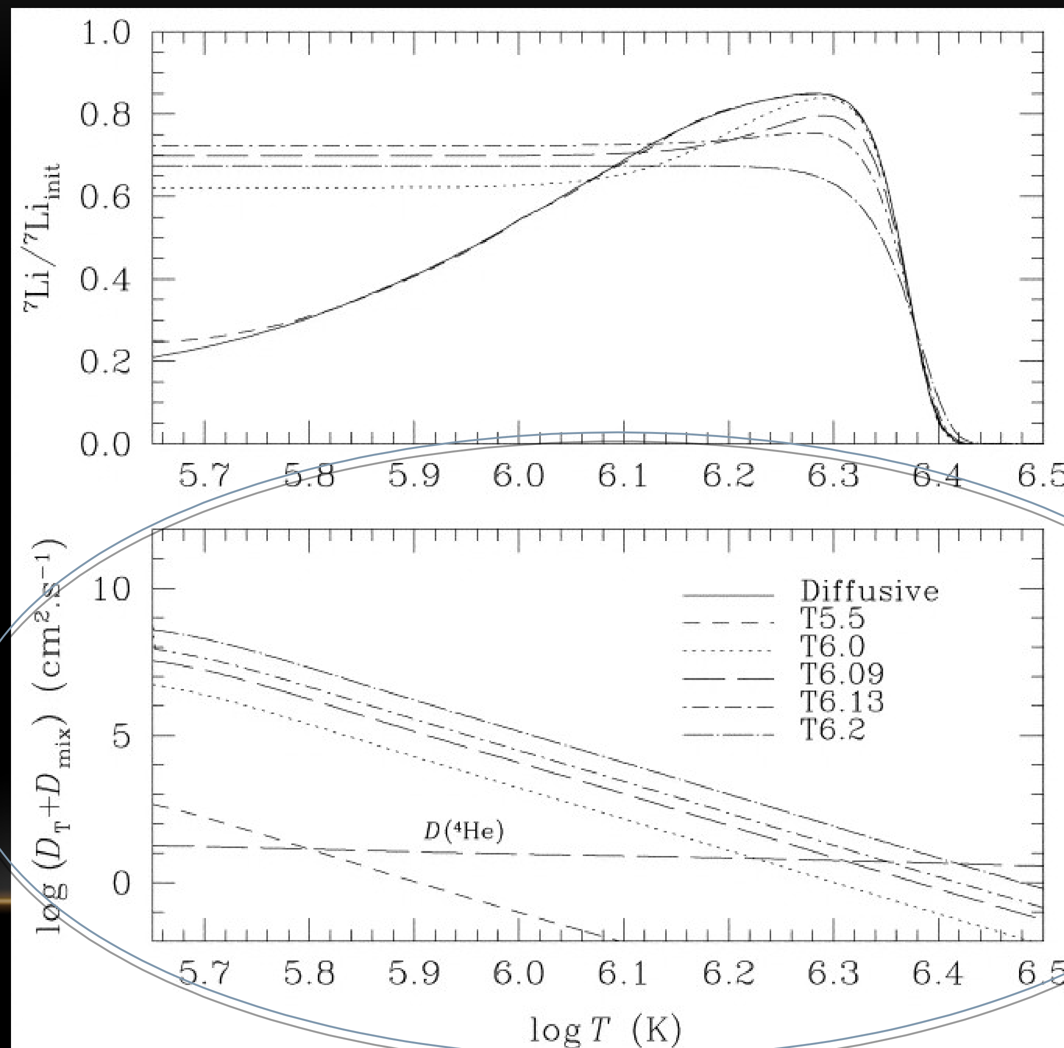


$$v_D = (D_{ip} + D_T)\left[-\frac{\partial \ln c_i}{\partial r}\right] + D_{ip}\left[\frac{A_i m_p}{kT}(g_{\mathrm{rad},i} - g) + \frac{Z_i m_p g}{2kT} + k_T \frac{\partial \ln T}{\partial r}\right]$$

$$D_T = 400\, D_{\mathrm{He}}(T_0)\left[\frac{\rho}{\rho(T_0)}\right]^{-3}.$$

$0.8\ M_{\odot}$

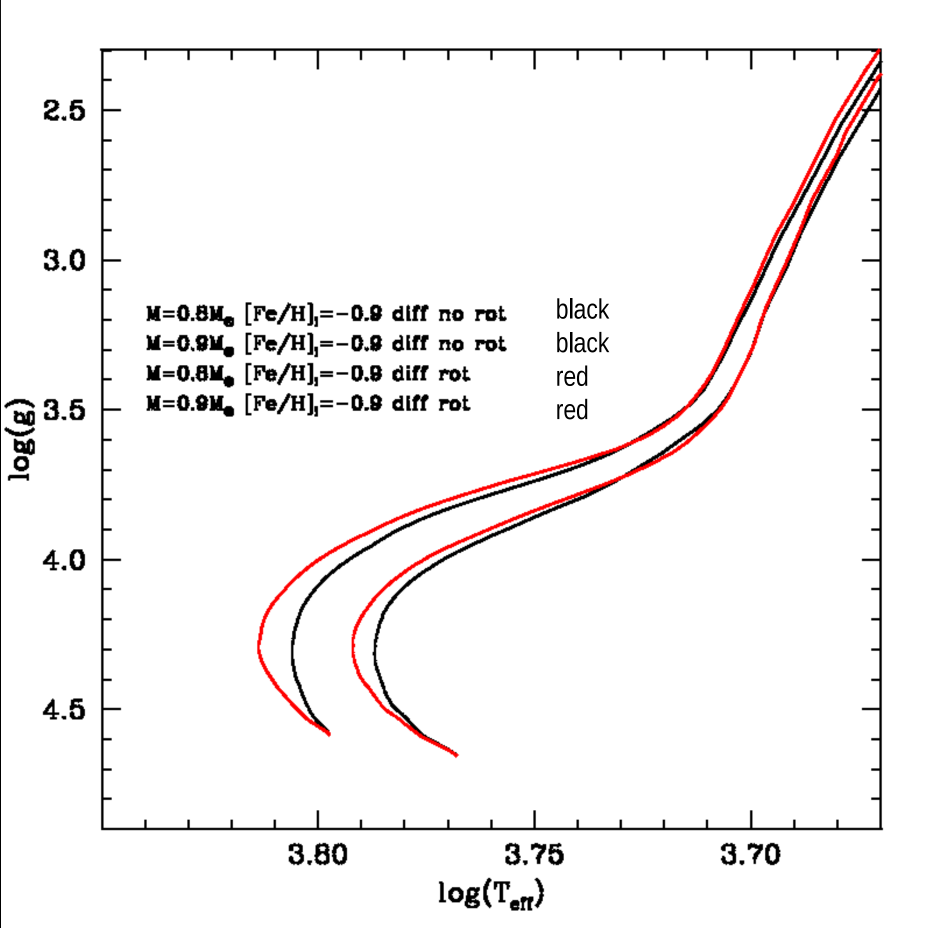


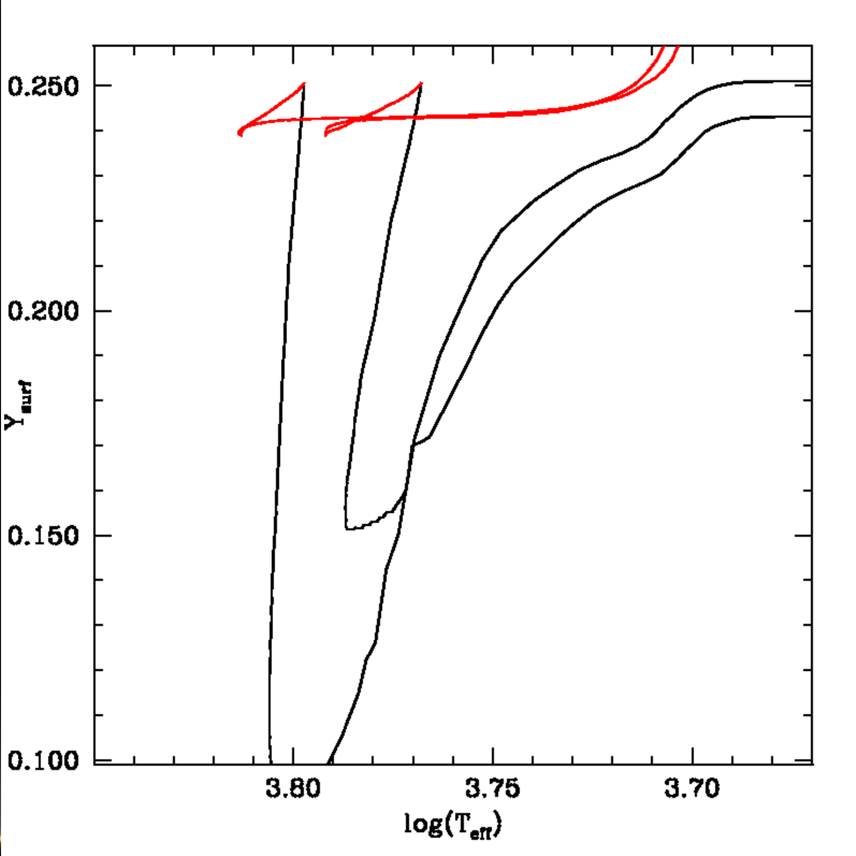

Inhibition of atomic diffusion by a counteracting diffusive process

Richard et al. (2002)

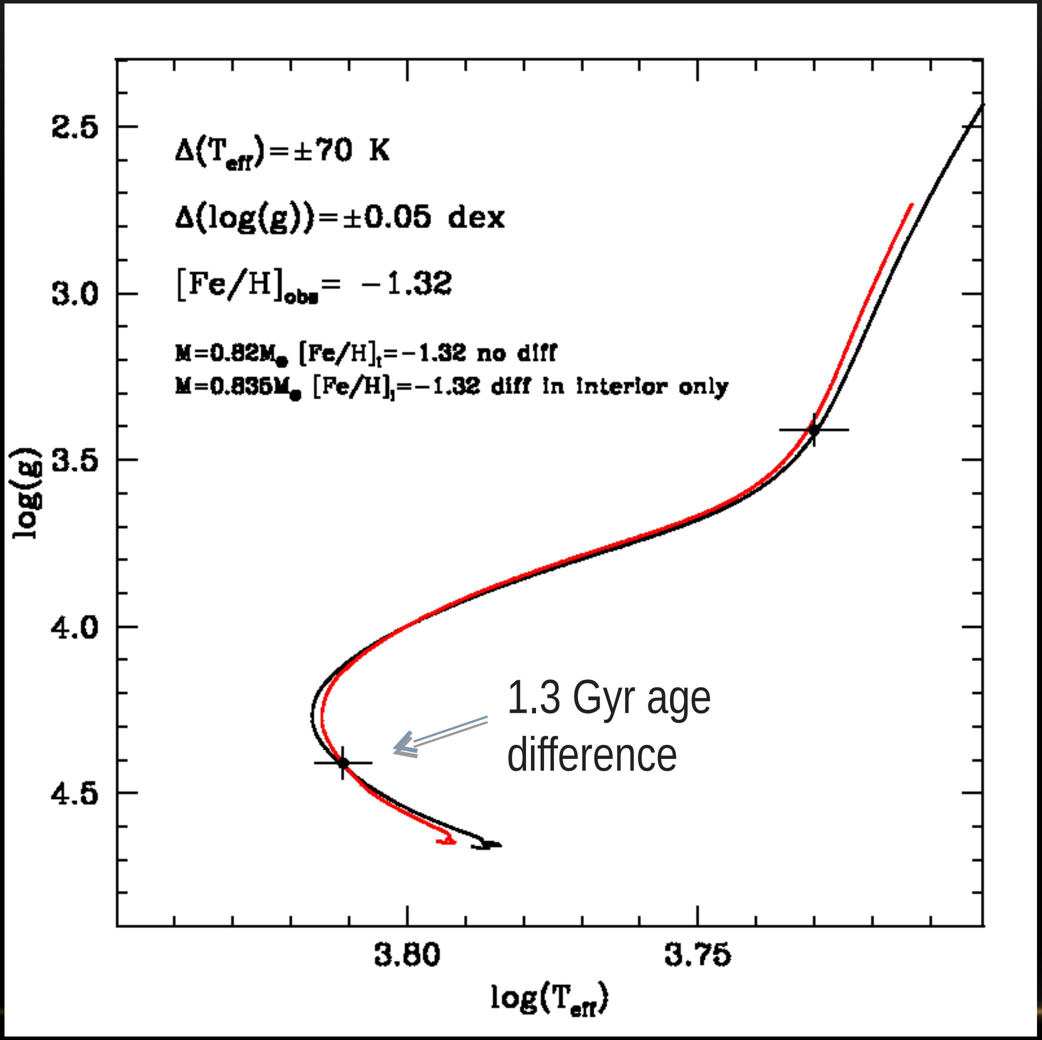
Rotation inhibits atomic diffusion from surface and also increases evolutionary timescales (rotational mixing counteracts the development of chemical gradients)

Georgy et al. (2013)



# Zero-order test with atomic diffusion inhibited from envelopes

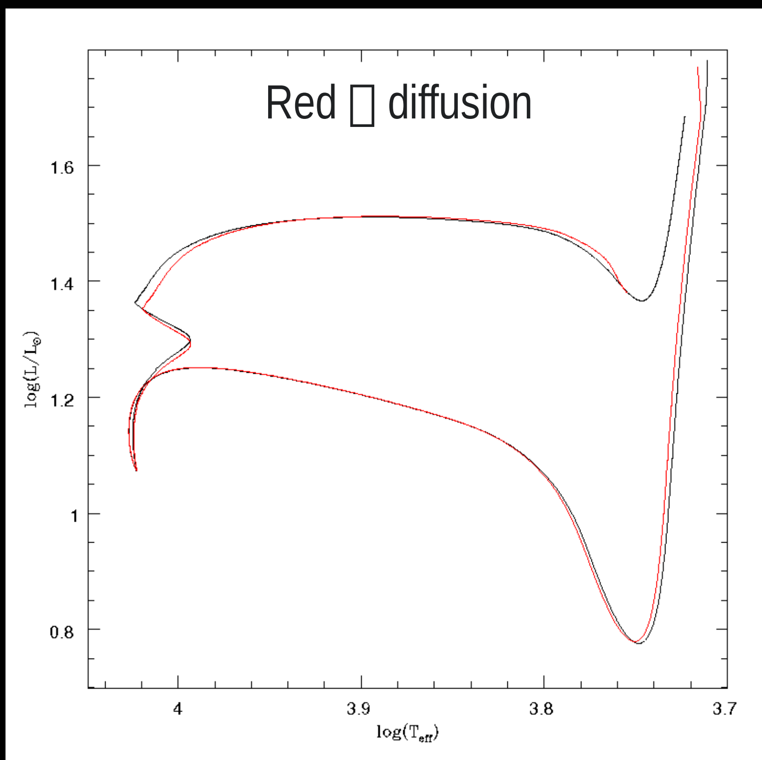


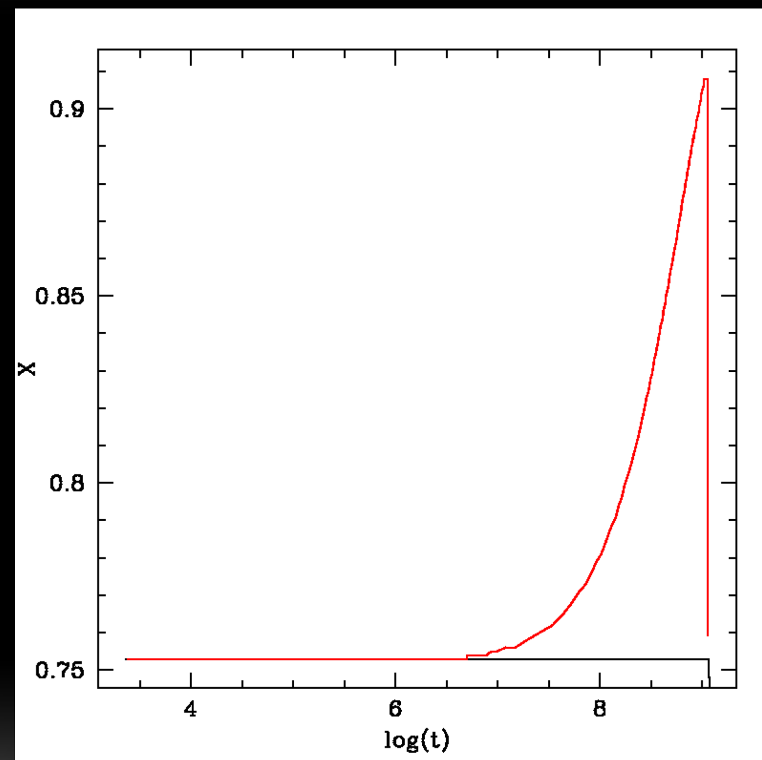
Is diffusion inefficient above 1.0-1.2 $M_{\odot}$?

2% difference of MS lifetime

[Fe/H] decreases by 0.3 dex at the TO

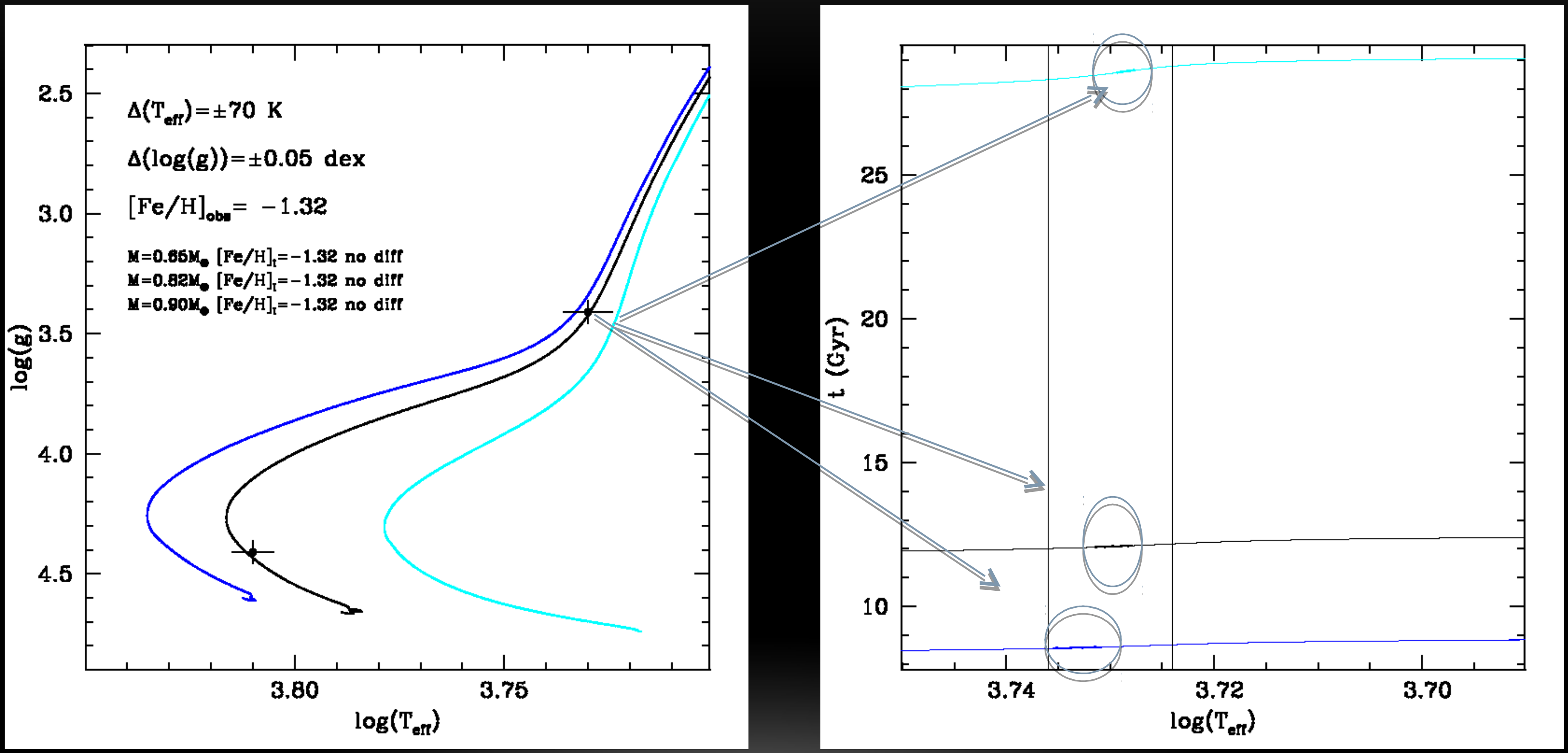
$1.6M_{\odot}$ $[Fe/H]_i=-1.32$



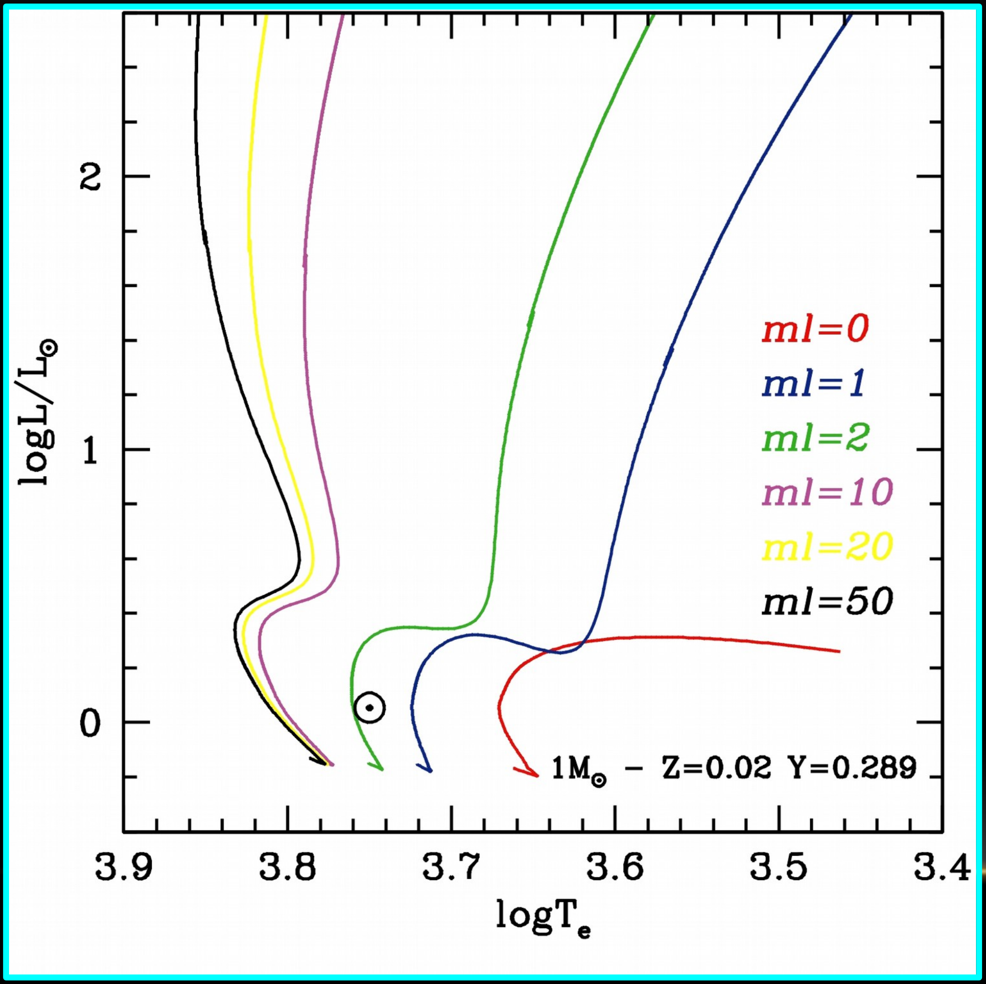
Knowledge of the mass for RGB stars (e.g. from asteroseismology) is crucial for age dating, irrespective of uncertainties of stellar evolution calculations.

We need precision in the order of 3% to keep the error on RGB ages around 10% (in the low mass star regime)



# MIXING LENGTH

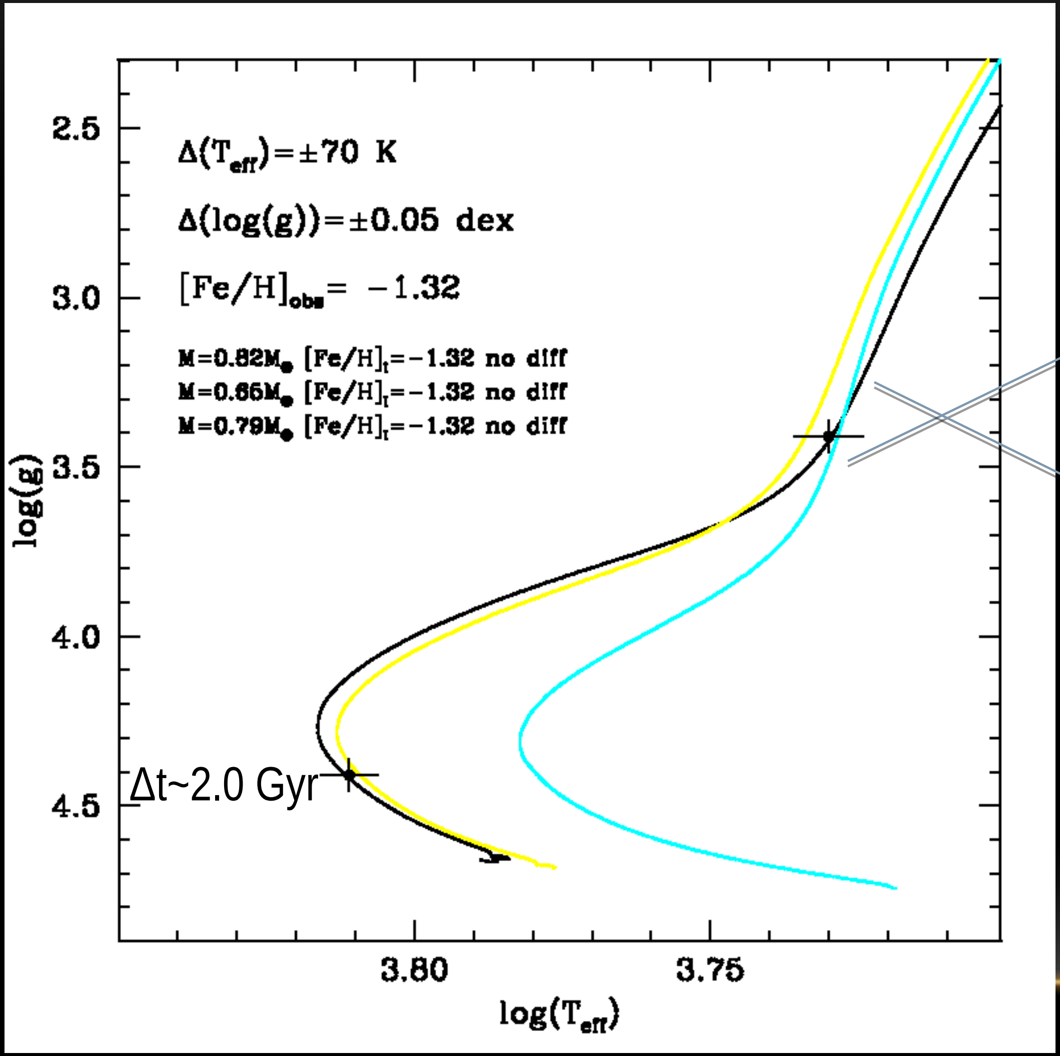
The value of α affects the effective temperature of stars with convective envelopes

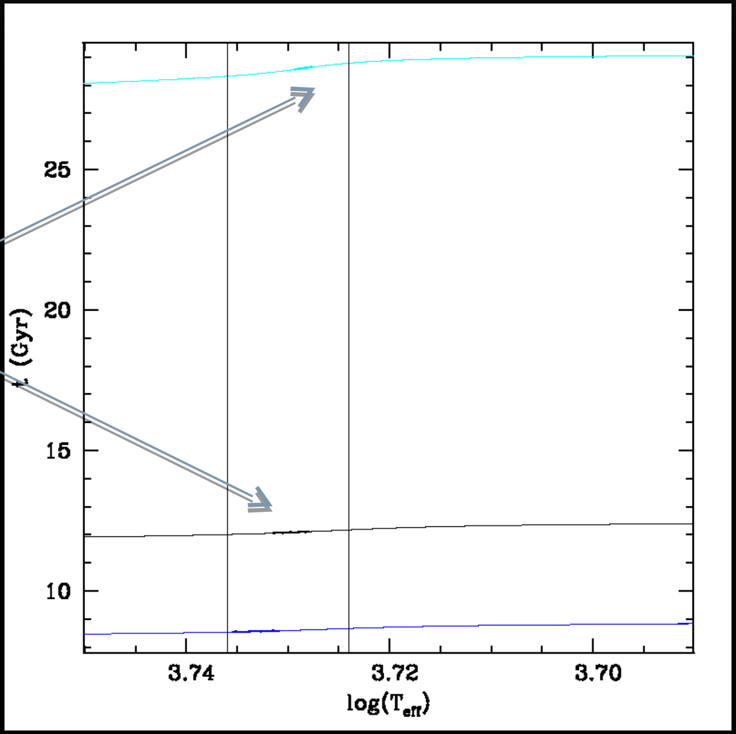



The'canonical' calibration is based on matching the solar radius with a theoretical solar models (Gough & Weiss 1976)

We should always keep in mind that there is a priori no reason why α should stay constant within a stellar envelope, and when considering stars of different masses and/or at different evolutionary stages

Increase Δα=+0.2 (BaSTI models)



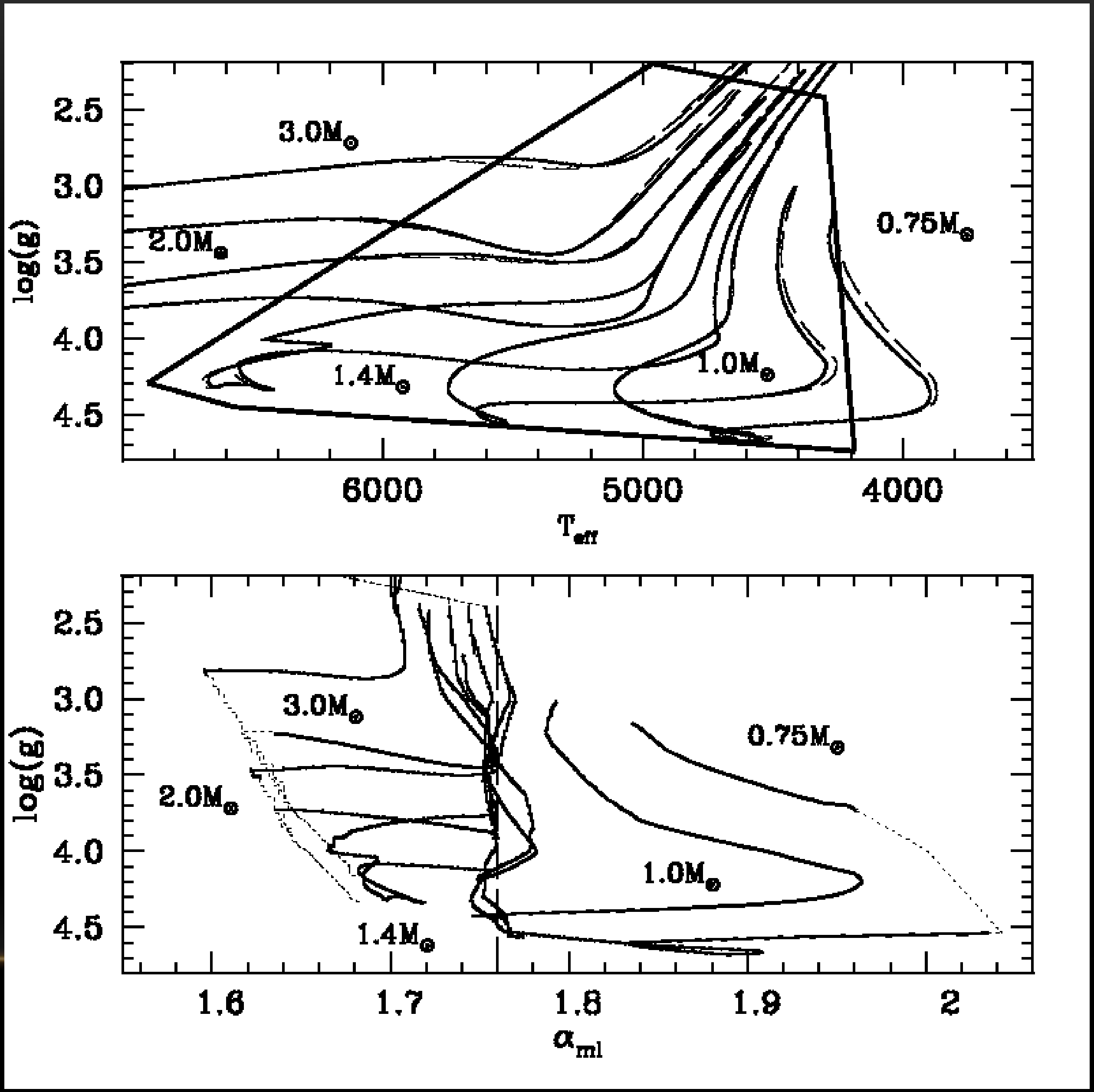
Does α really vary?
How much?
Are stellar models affected?

3D radiation hydrodynamics calibration (mixing length and boundary conditions) by Trampedach et al. (2014)

Solar metallicity only

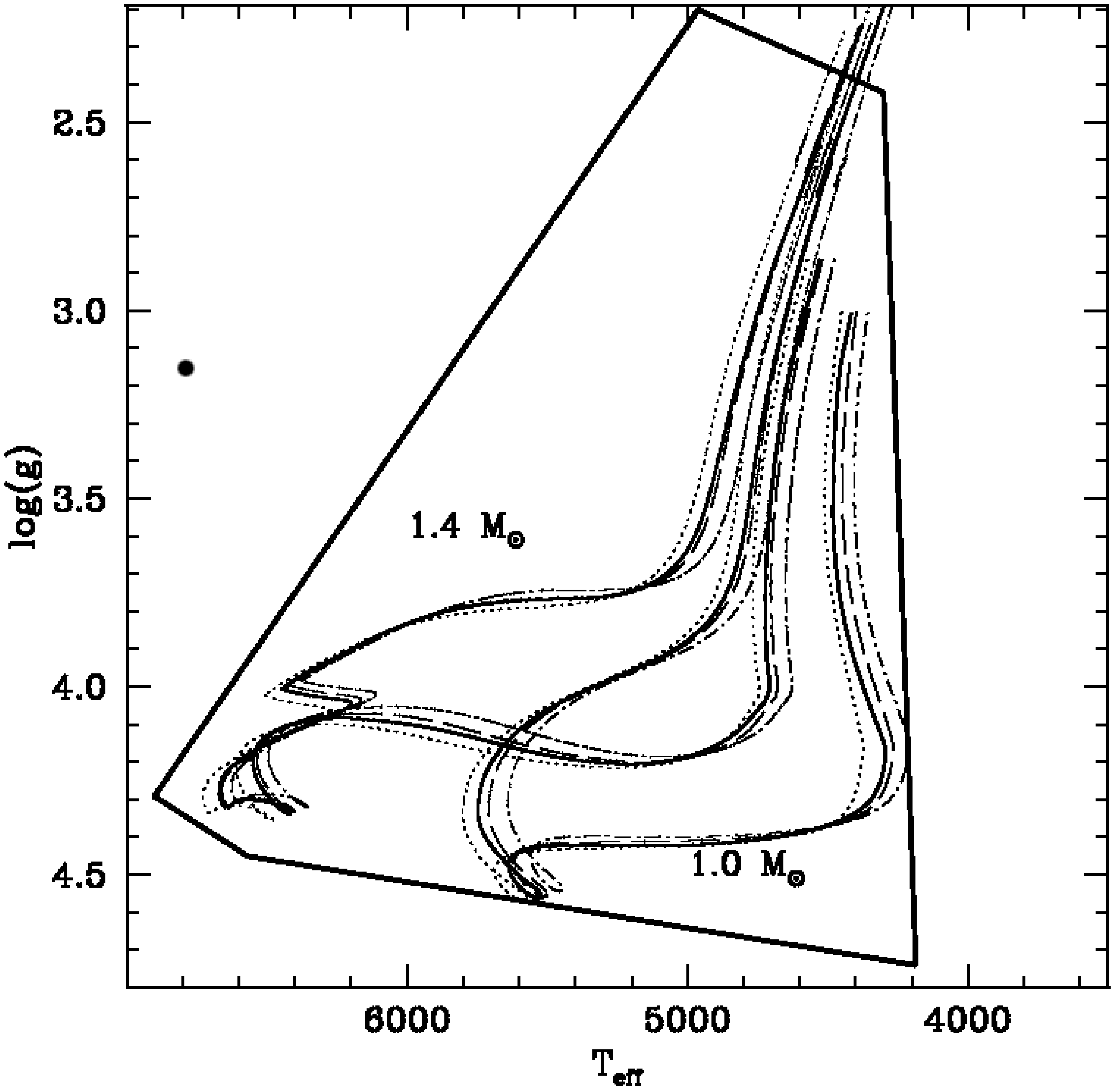
At most just 30-50 K difference between solar and variable α calibration

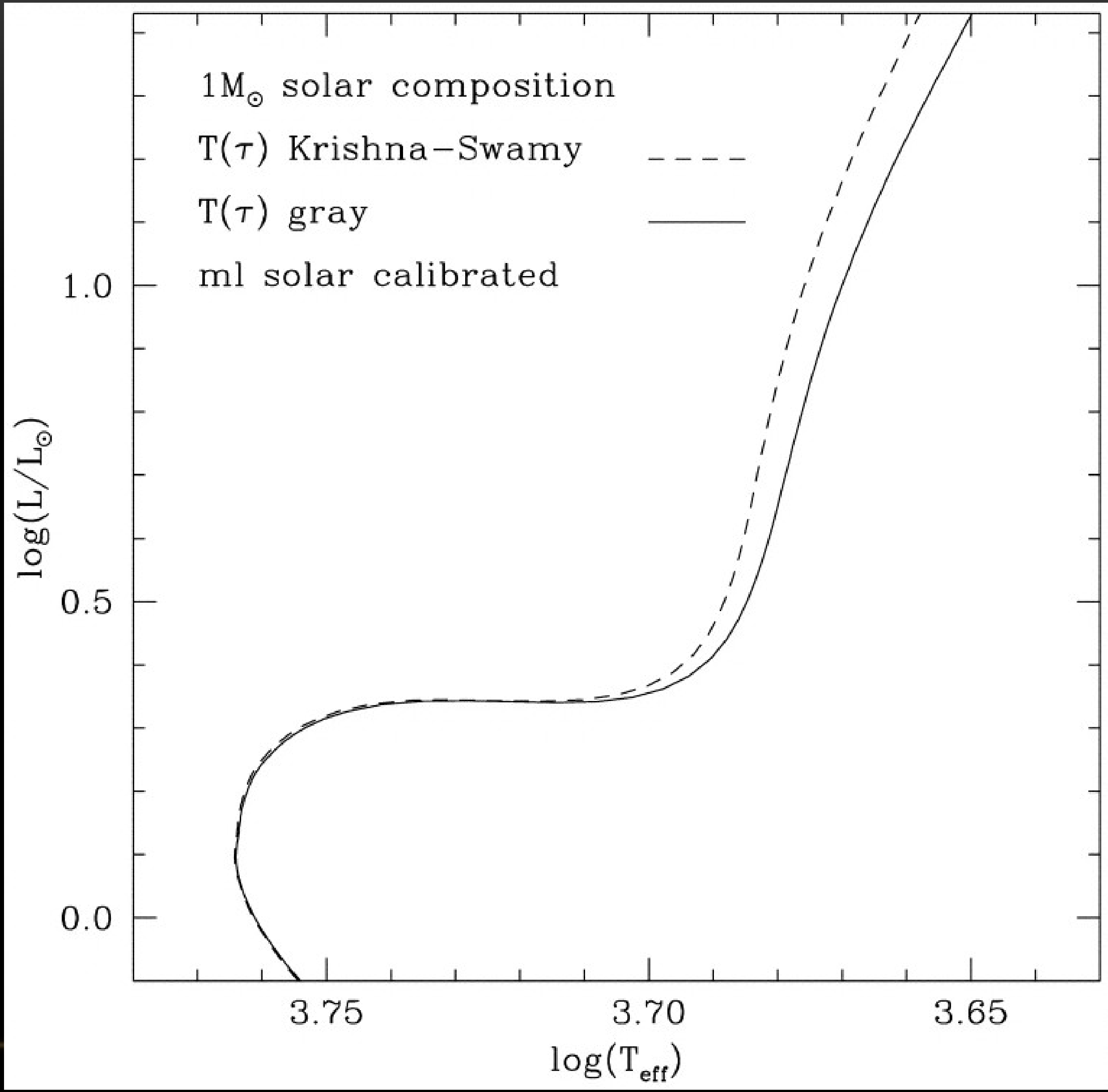
Salaris & Cassisi (2015)



## Effect of boundary conditions

Eddington
Hydro
Vernazza et al.
Krishna-Swamy





$1M_\odot$ solar composition
$T(\tau)$ Krishna–Swamy
$T(\tau)$ gray
ml solar calibrated
1.0
0.5
0.0
$\log(L/L_\odot)$
3.75
3.70
3.65
$\log(T_{eff})$

# CONCLUSIONS

The uncertain efficiency of diffusion in low mass stars may cause age uncertainties (for field objects) up to several 10s %, especially for MS stars close to the TO, when $T_{eff}$-g diagrams are employed

Accurate mass estimates (better than 5%) and the use of diagnostics of the interior chemical stratification can mitigate this problem and at the same time constrain the efficiency of diffusion in field stars

Combined uncertainties of superadiabatic convection and surface boundary condition treatments can have potentially a major impact on age estimates. Recent 3D radiation hydrodynamics simulation of atmospheres and envelopes provide variable mixing length calibrations that however do not modify substantially tracks calculated with solar mixing length (at least at solar metallicity).

The role of the boundary conditions seems to be more crucial than the variation of $\alpha$