The Pisa pre-MS tracks and isochrones

A rich database covering a large range of Z, Y, mass and age values

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Pisa pre-MS models: database

Table 4. Summary of the models available in the database.

	$X_D = 4.0 \cdot 10^{-5}$						$X_D = 2.0 \cdot 10^{-5}$		
	$\alpha = 1.68$			$\alpha = 1.2, 1.9$			$\alpha = 1.68$		
$Y_p =$	0.230	0.248		0.230	0.248		0.230	0.248	
$\Delta Y/\Delta Z =$	2	2	5	2	2	5	2	2	5
Z: $2.0 \cdot 10^{-4}$	0.230	0.248	0.250	0.230	0.248	0.250			
$1.0 \cdot 10^{-3}$	0.232	0.251	0.254	0.232	0.251	0.254			
$2.0 \cdot 10^{-3}$	0.234	0.253	0.259	0.234	0.253	0.259			
$3.0 \cdot 10^{-3}$	0.236	0.254	0.263	0.236	0.254	0.263			
$4.0 \cdot 10^{-3}$	0.238	0.256	0.269	0.238	0.256	0.269			
$5.0 \cdot 10^{-3}$	0.240	0.258	0.273	0.240	0.258	0.273			
$6.0 \cdot 10^{-3}$	0.242	0.260	0.279	0.242	0.260	0.279			
$7.0 \cdot 10^{-3}$	0.244	0.262	0.283	0.244	0.262	0.283			
$8.0 \cdot 10^{-3}$	0.246	0.265	0.289	0.246	0.265	0.289	0.246	0.265	0.289
$1.0 \cdot 10^{-2}$	0.250	0.268	0.299	0.250	0.268	0.299	0.250	0.268	0.299
$1.25 \cdot 10^{-2}$								0.274	
$1.5 \cdot 10^{-2}$	0.260	0.278	0.323	0.260	0.278	0.323	0.260	0.278	0.323
$1.75 \cdot 10^{-2}$								0.284	
$2.0 \cdot 10^{-2}$	0.270	0.288	0.349	0.270	0.288	0.349	0.270	0.288	0.349
$2.25 \cdot 10^{-2}$								0.298	
$3.0 \cdot 10^{-2}$	0.290	0.308	0.398	0.290	0.308	0.398	0.290	0.308	0.398

Pisa pre-MS models: database

- **43** stellar mass values 0.2-7 M_o for α: 1.68, 1.9
- **26** stellar mass values 0.2-2 M_o for α: 1.2
- **1** set with solar composition (Z=0.0137 Y=0.2529)

more than 4000 stellar tracks

- Pre-MS isochrones **1-100 Myr** for each set

Pisa pre-MS models: database

- The database is available at the url:

http://astro.df.unipi.it/stellar_models/

Tognelli, Prada Moroni, Degl'Innocenti 2010

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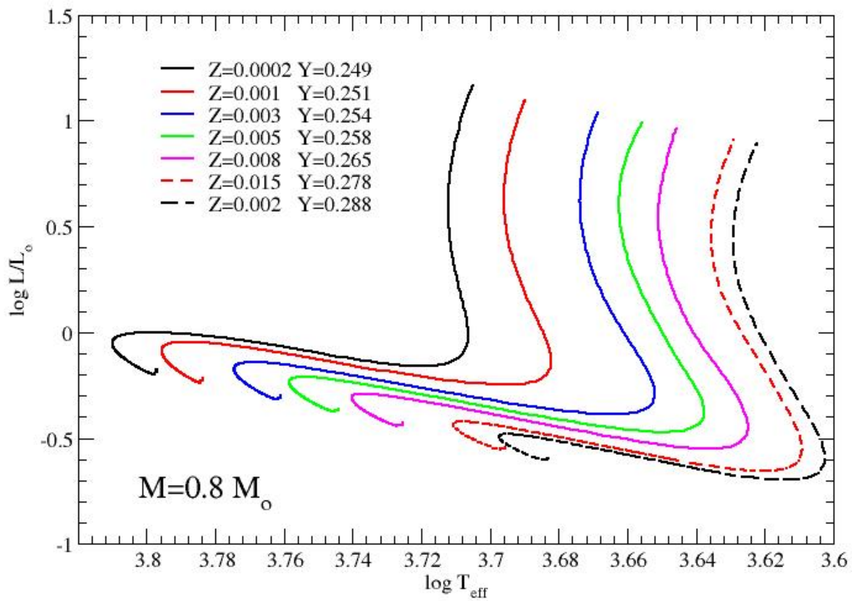
Dependence on Z and Y

- The location in the HR diagram of pre-MS tracks ***strongly*** depends on chemical composition, mainly on ***Z***

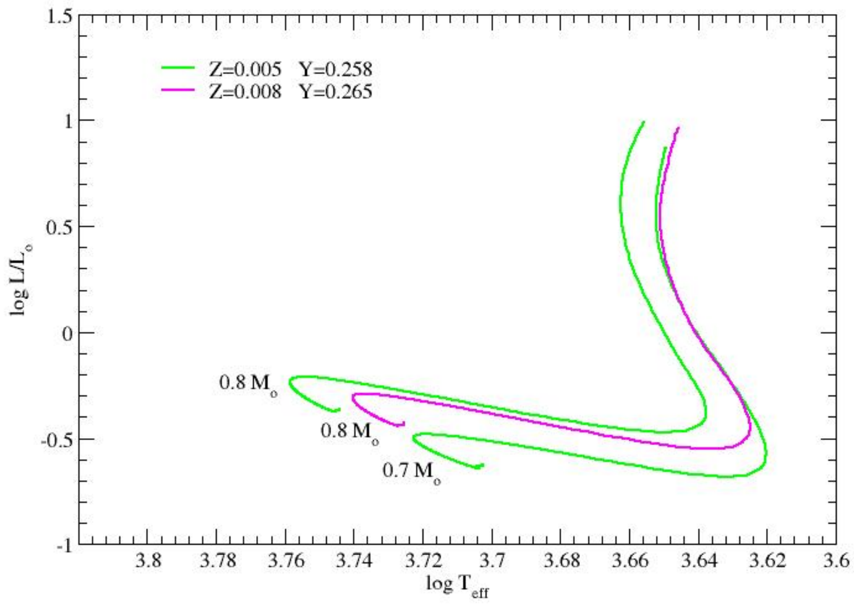


Dependence on Z and Y

- **Δ[Fe/H]=0.2** dex leads to a shift in T_{eff} of **≈100K**

ΔM=0.1 M_o

Δt≈70 %



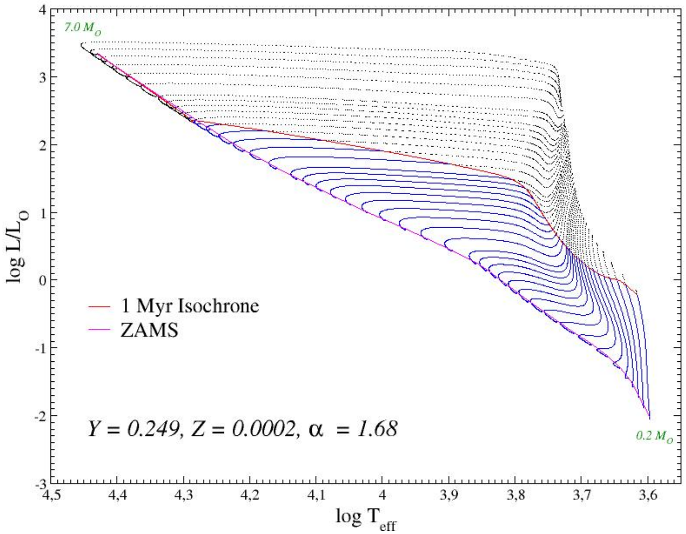
Dependence on Z and Y

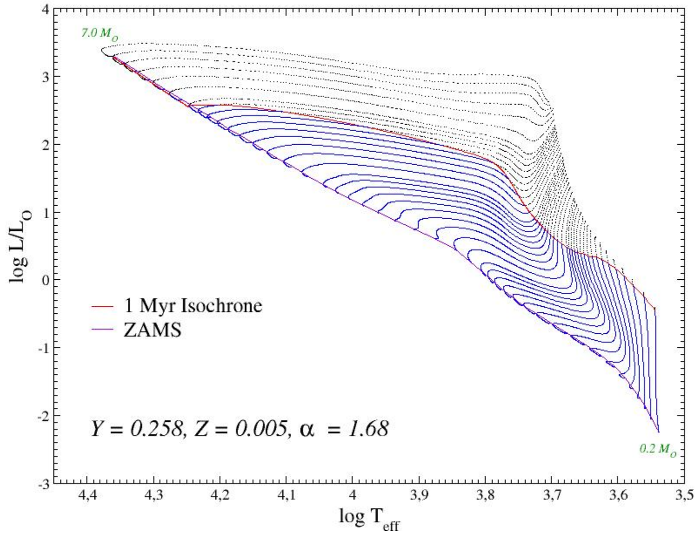
- When comparing data with theoretical pre-MS tracks, one must use models with the ***same*** metallicity of the observed stars

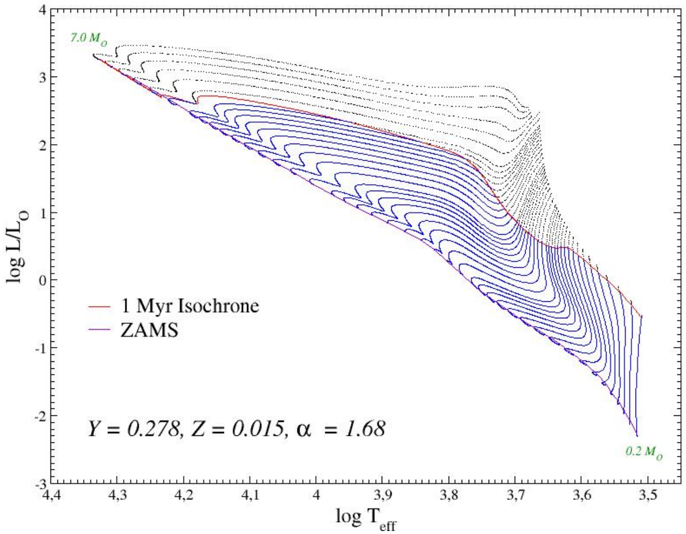
- An ***error in [Fe/H]*** translates in a shift in T_{eff} and hence in an error in the ***inferred mass and age***

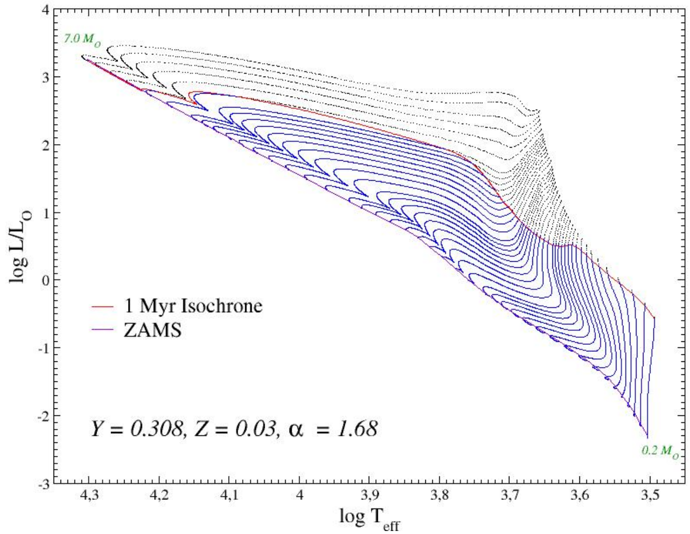
- This is the reason why we provide a database of models with a very fine grid of Z and Y

Pisa pre-MS models: tracks

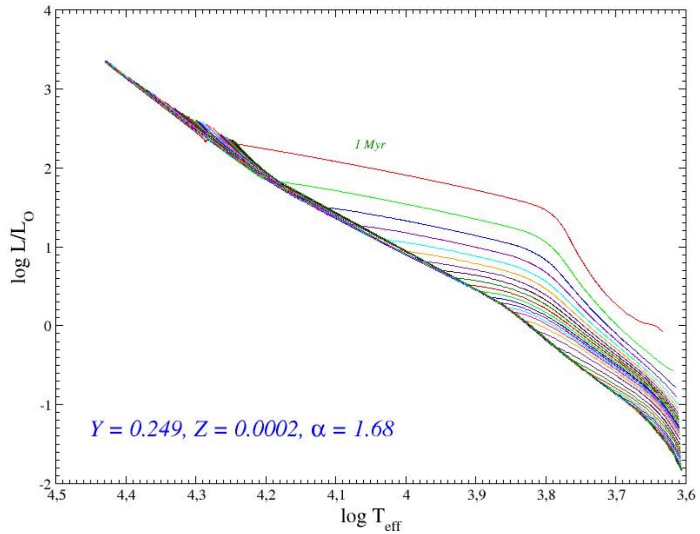


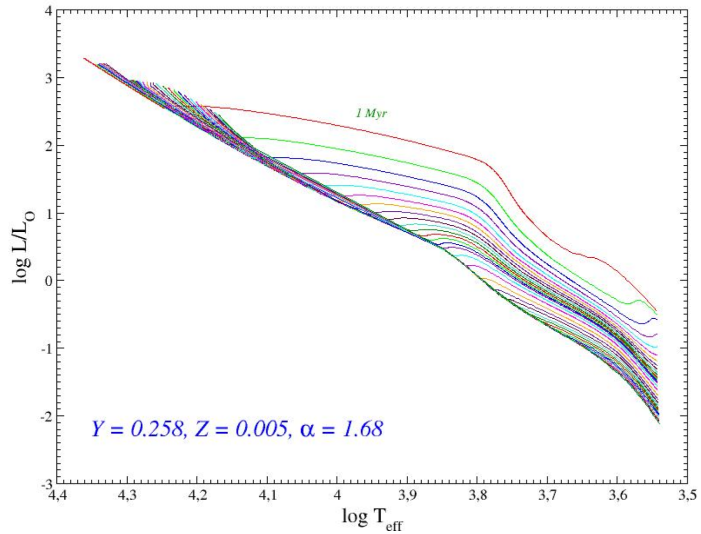


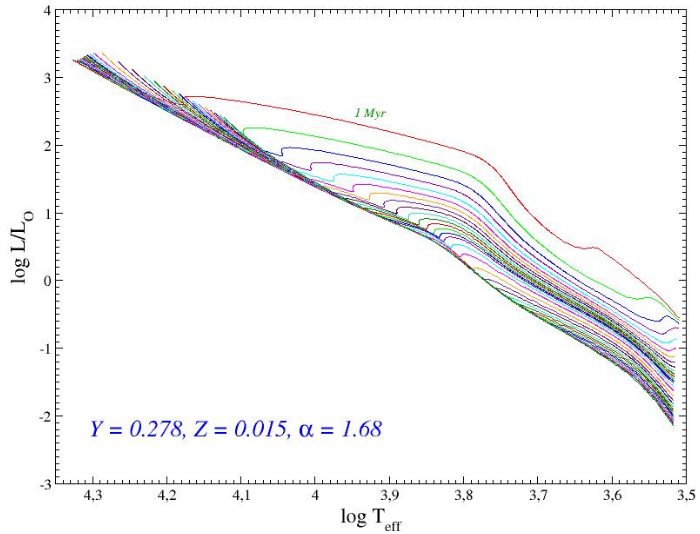


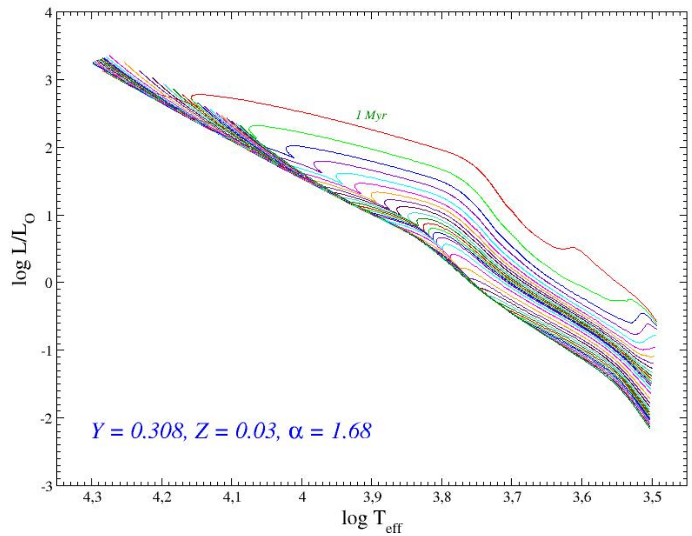


Pisa pre-MS models: isochrones









FRANEC code

- FRANEC evolutionary code *(Chieffi & Straniero 1989, Ciacio et al. 1997, Prada Moroni & Straniero 2002, Degl'Innocenti et al. 2008, Valle et al. 2009)*

- A full-evolutionary Henyey code able to follow the evolution of stars from the pre-MS to the WD phase

Pisa Models: input physics

- theoretical stellar models are as accurate and reliable as the input physics adopted in the computation

- the most updated physical ingredients available in the literature

Pisa Models: EOS

- **EOS** plays a crucial role, in particular in the convective regions of low mass stars, which are almost adiabatic
- $\boldsymbol{T_{eff}}$ and ***R*** of low-mass stars are determined by the adiabatic gradient, i.e. EOS
- **OPAL EOS**, release **2006** *(Rogers et al. 1996, Rogers & Nayfonov 2002)*
- **FreeEOS**, release **2008** *(Irwin 2004)*

Pisa Models: opacity

- Log T(K) > 4.2: **OPAL**, release 2006 *(Iglesias & Rogers 1996)*

- Log T(K) < 4.2: **Ferguson et al. (2005)**

- The location in the HR diagram of low-mass stars depends strongly on the molecular radiative opacity

Pisa Models: boundary conditions

- ***P***$(\tau_{ph}, T_{eff}, g, [Fe/H])$ and ***T***$(\tau_{ph}, T_{eff}, g, [Fe/H])$ at τ_{ph} provided by detailed, ***non-grey*** **atmospheric models** which solve the full radiative transport equation

- $\tau_{ph} = 10$

Pisa Models: boundary conditions

We adopt the model atmospheres by:

- **3000 K < T_{eff} < 10000 K**: Brott & Hauschildt (2005)

- **10000 K< T_{eff}< 50000 K**: Castelli & Kurucz (2003)

Pisa Models: convection

- Mixing length theory *(Bohm-Vitense 1968)*, in which the average convective efficiency depends on

$$l = \alpha \, H_p$$

α is a ***free*** parameter to be calibrated with observations

- The usual approach is the ***solar calibration***

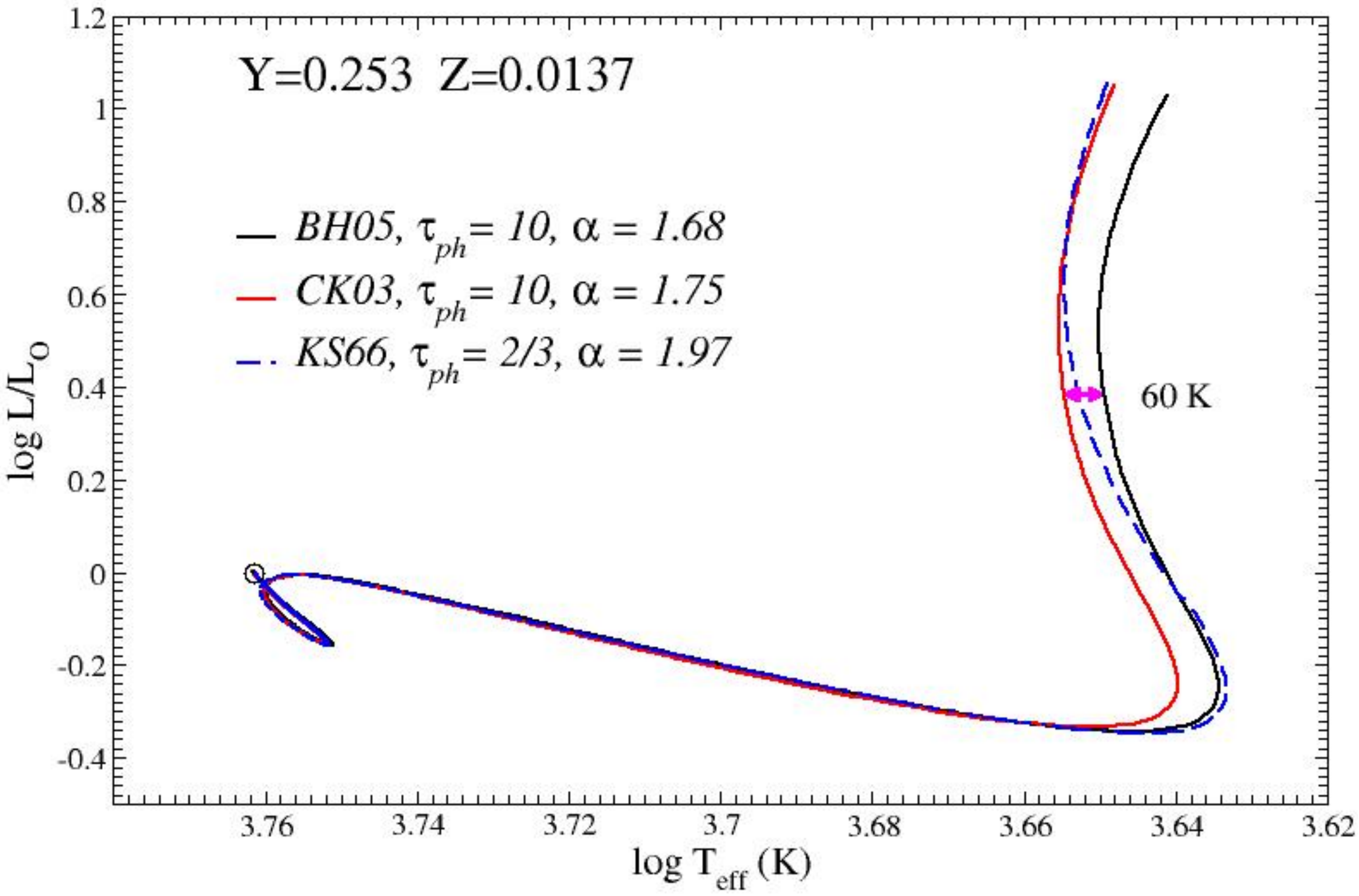
α= 1.68

Pisa Models: MLT calibration

- The "***solar calibration***" does not rely on a physical argument, since there is no reason to expect that the efficiency of convection is the same for stars of different masses and in different evolutionary stages *(D'Antona & Mazzitelli 1994, 1998, Montalban et al. 2004)*

- It is possible to obtain ***many*** solar models with significantly ***different*** pre-MS locations and shapes

Pisa Solar Model

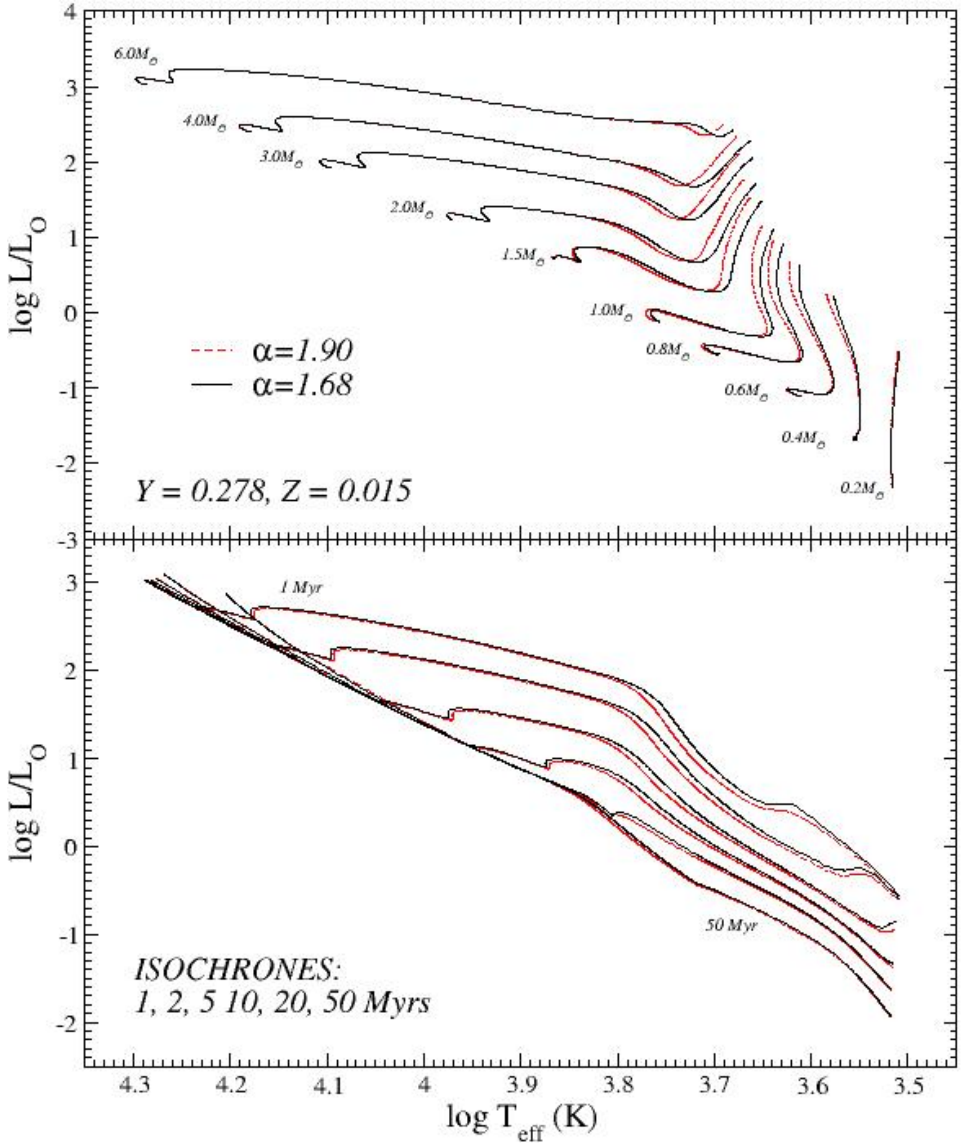


Pisa Models: MLT calibration

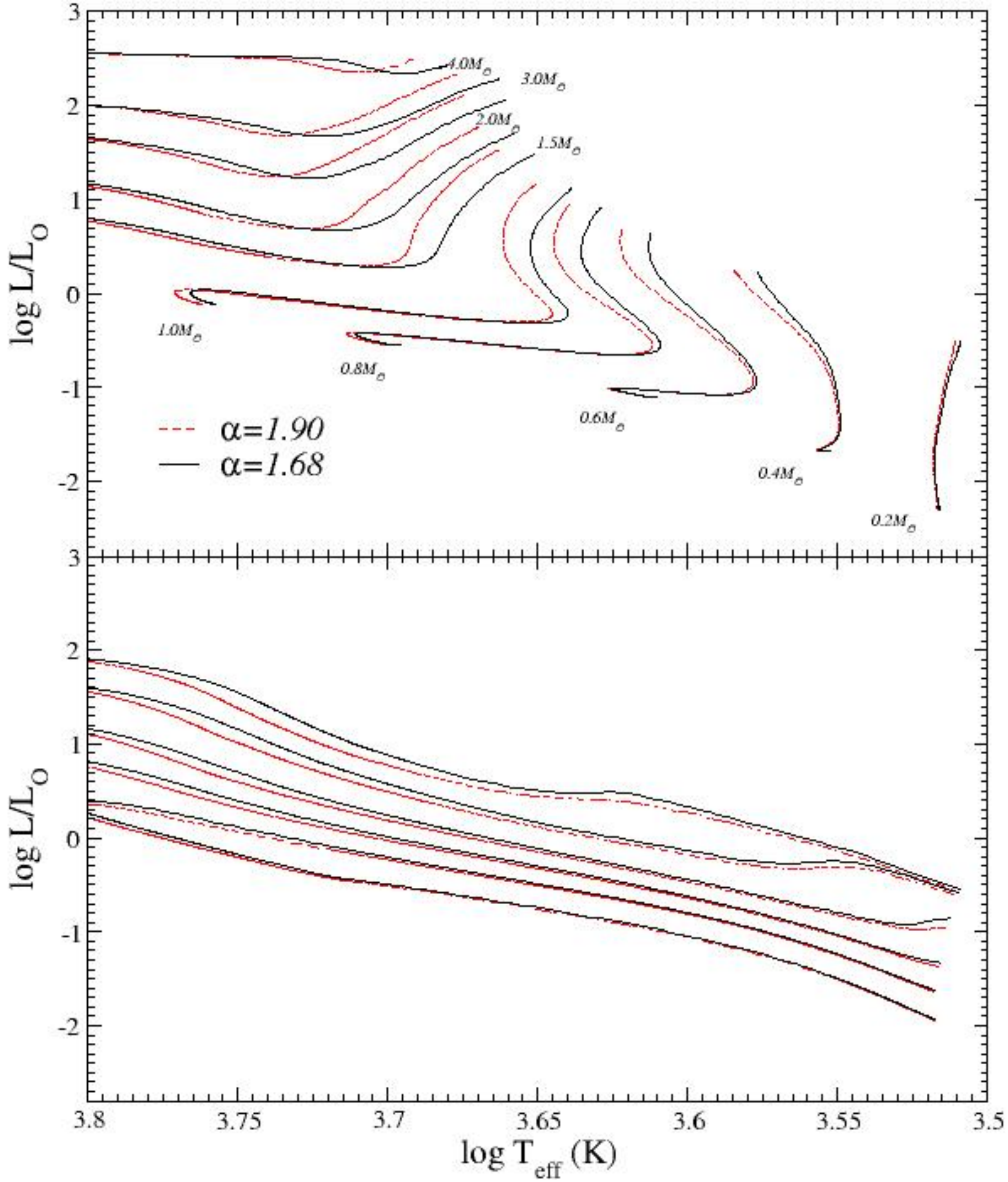
- At present, the value of α represents a source of uncertainty

- We computed models for 3 values of α: **1.2**, **1.68** (solar) and **1.9**

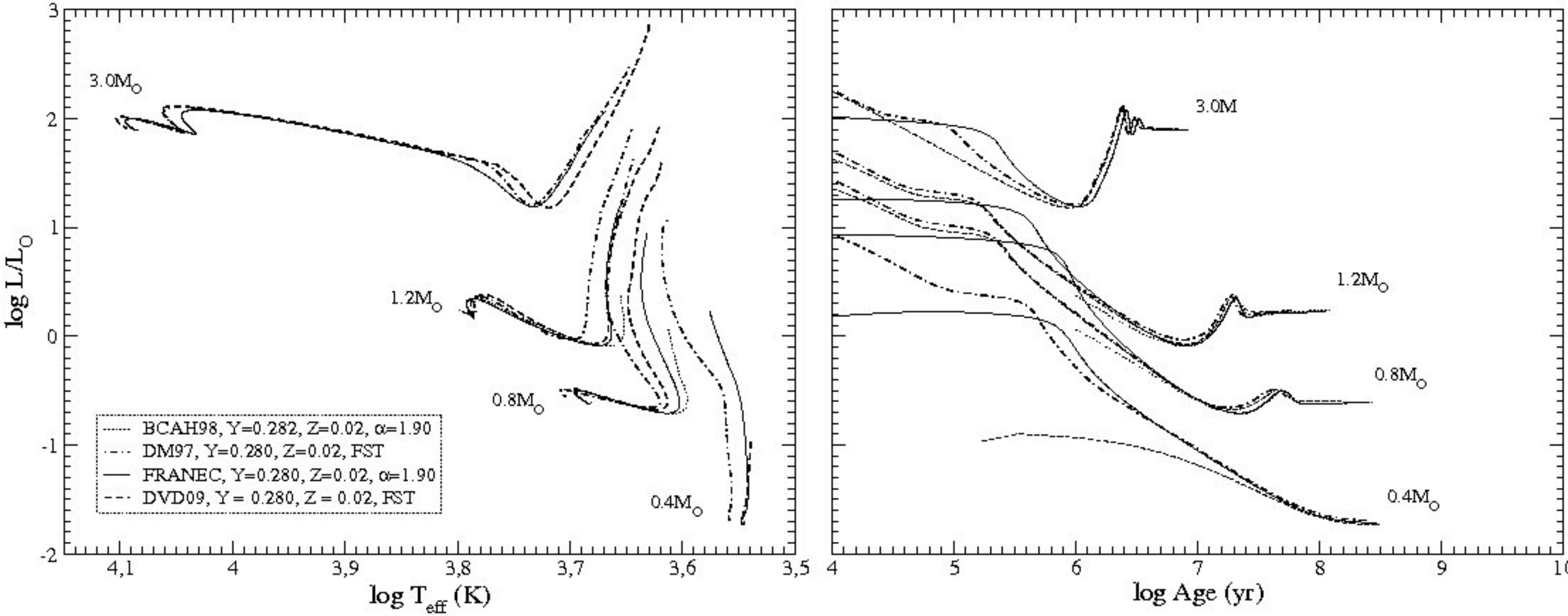
Pisa Models: convection



Pisa Models: convection



Comparison with other authors



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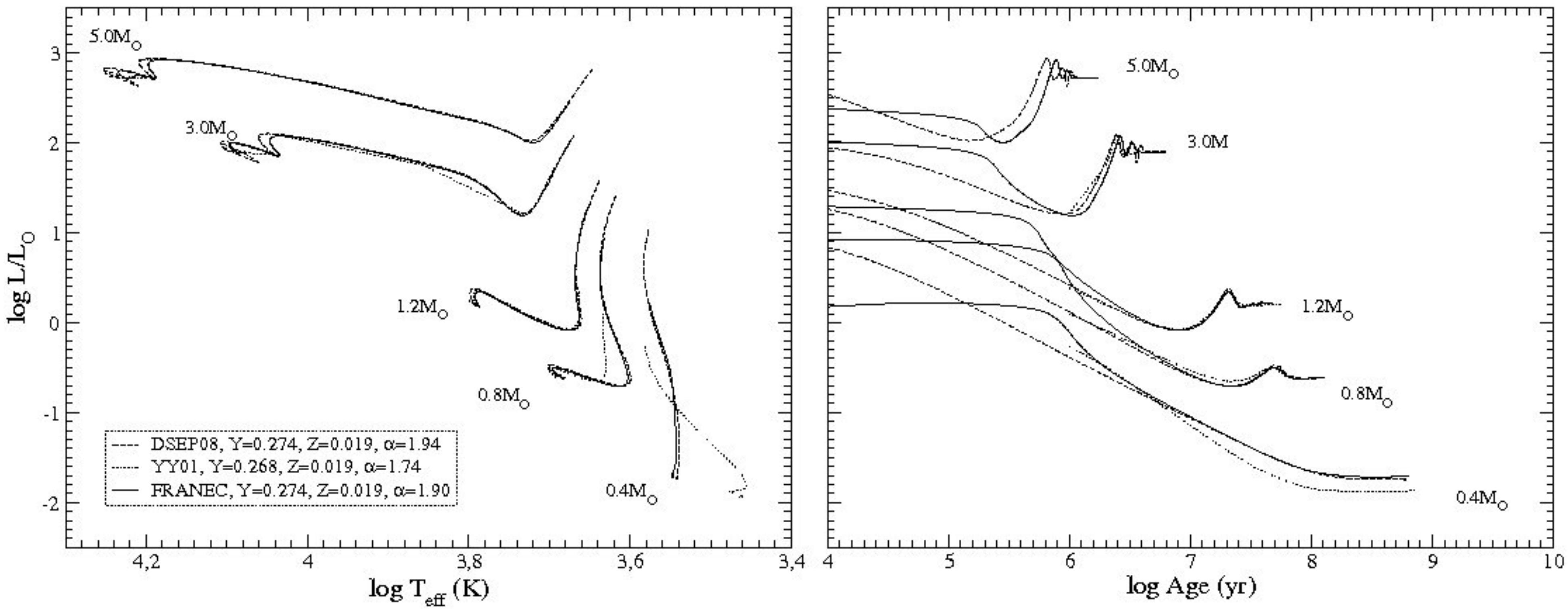

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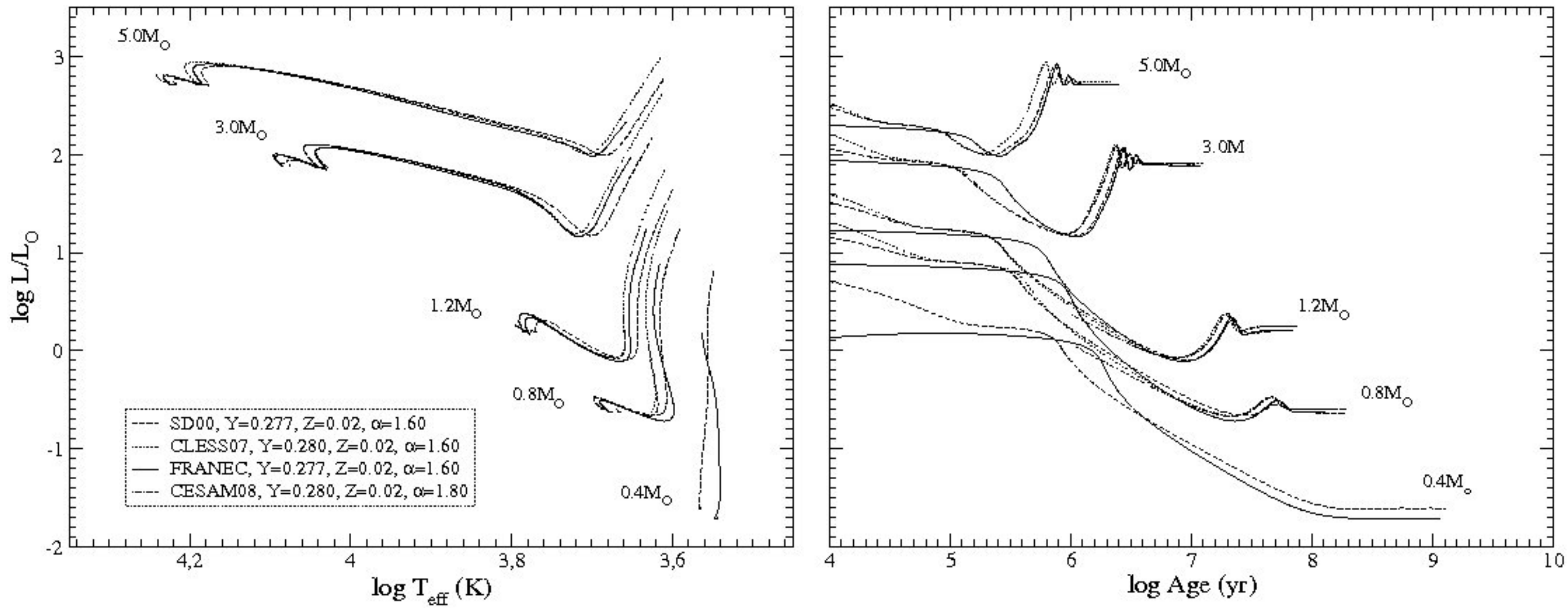

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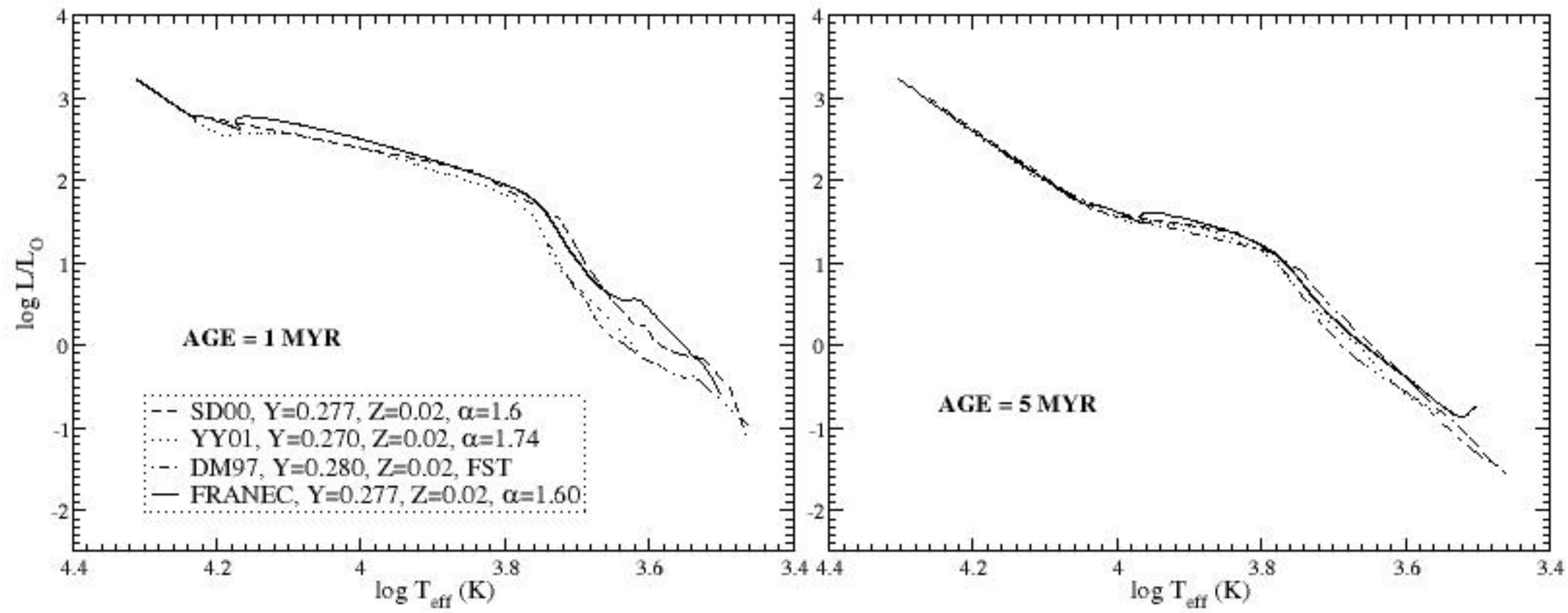

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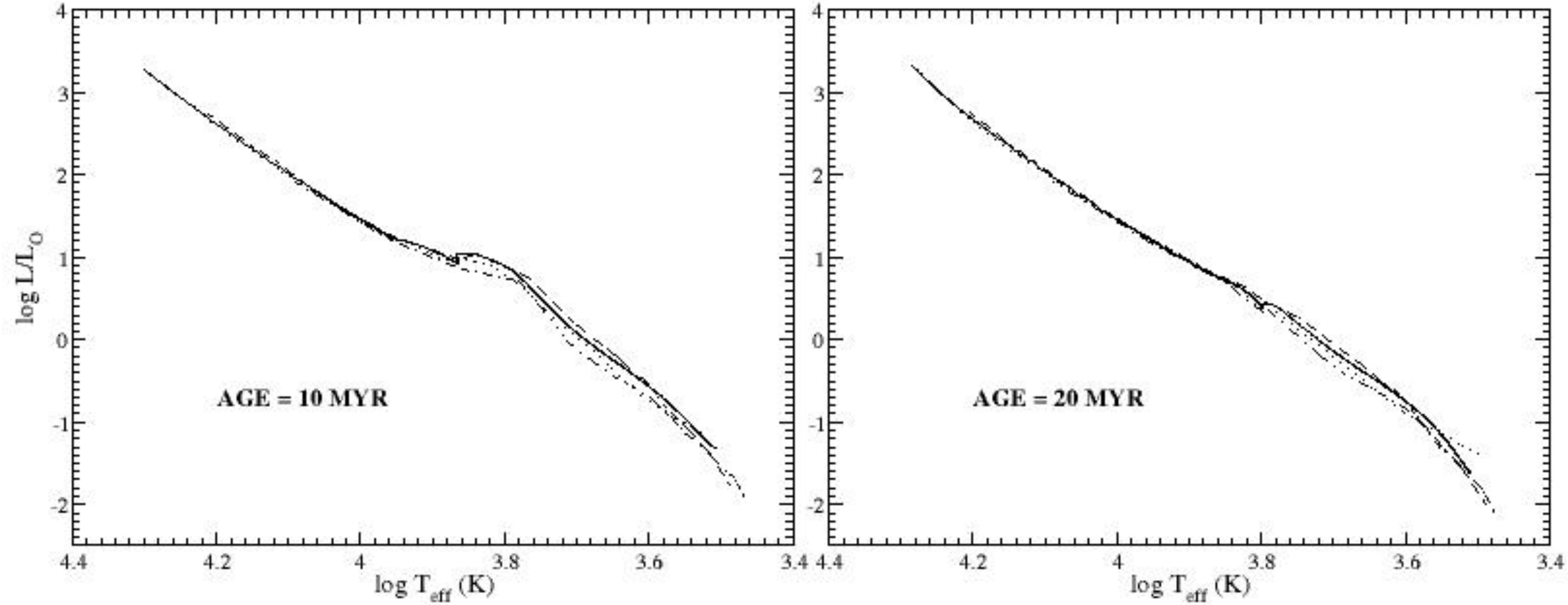

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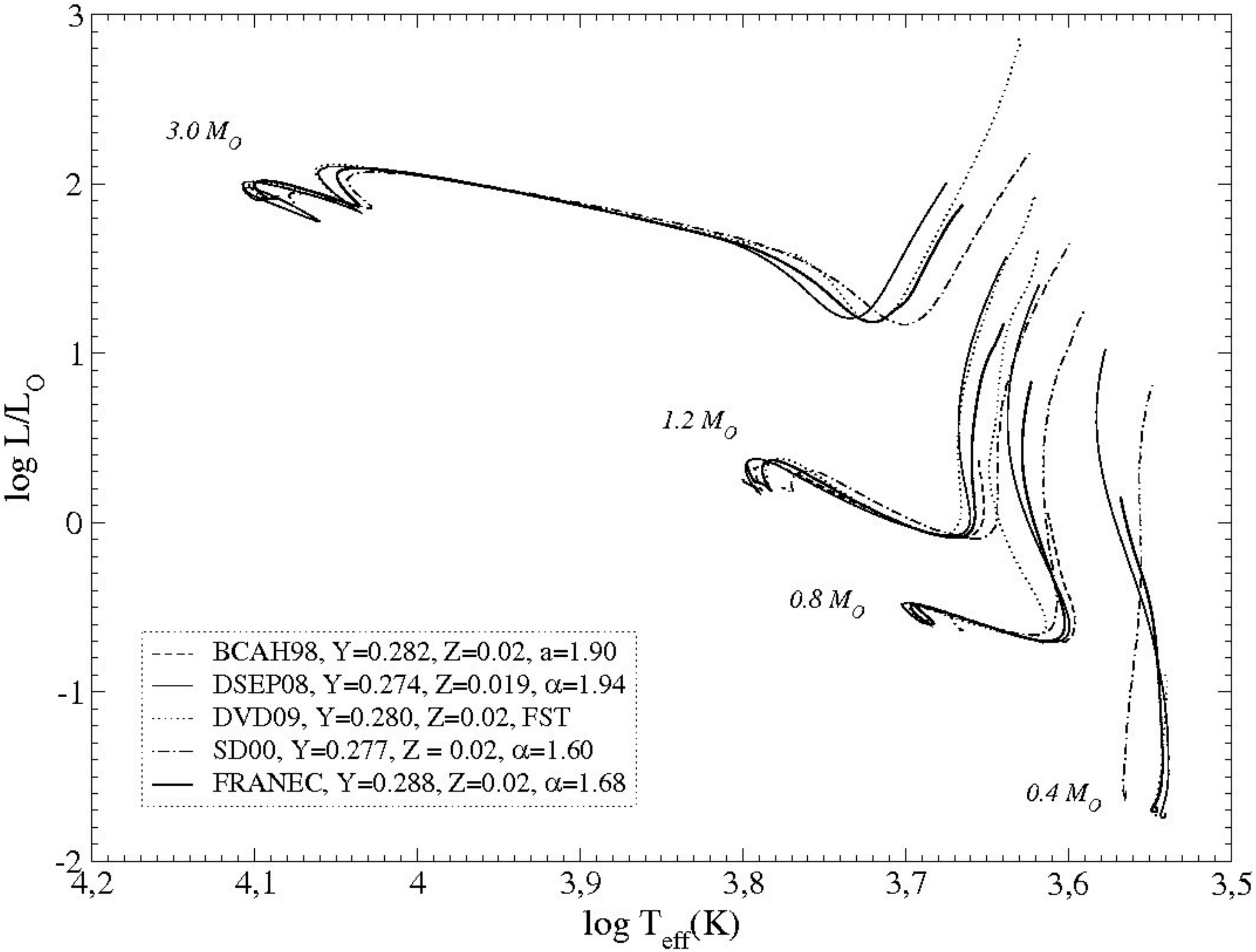
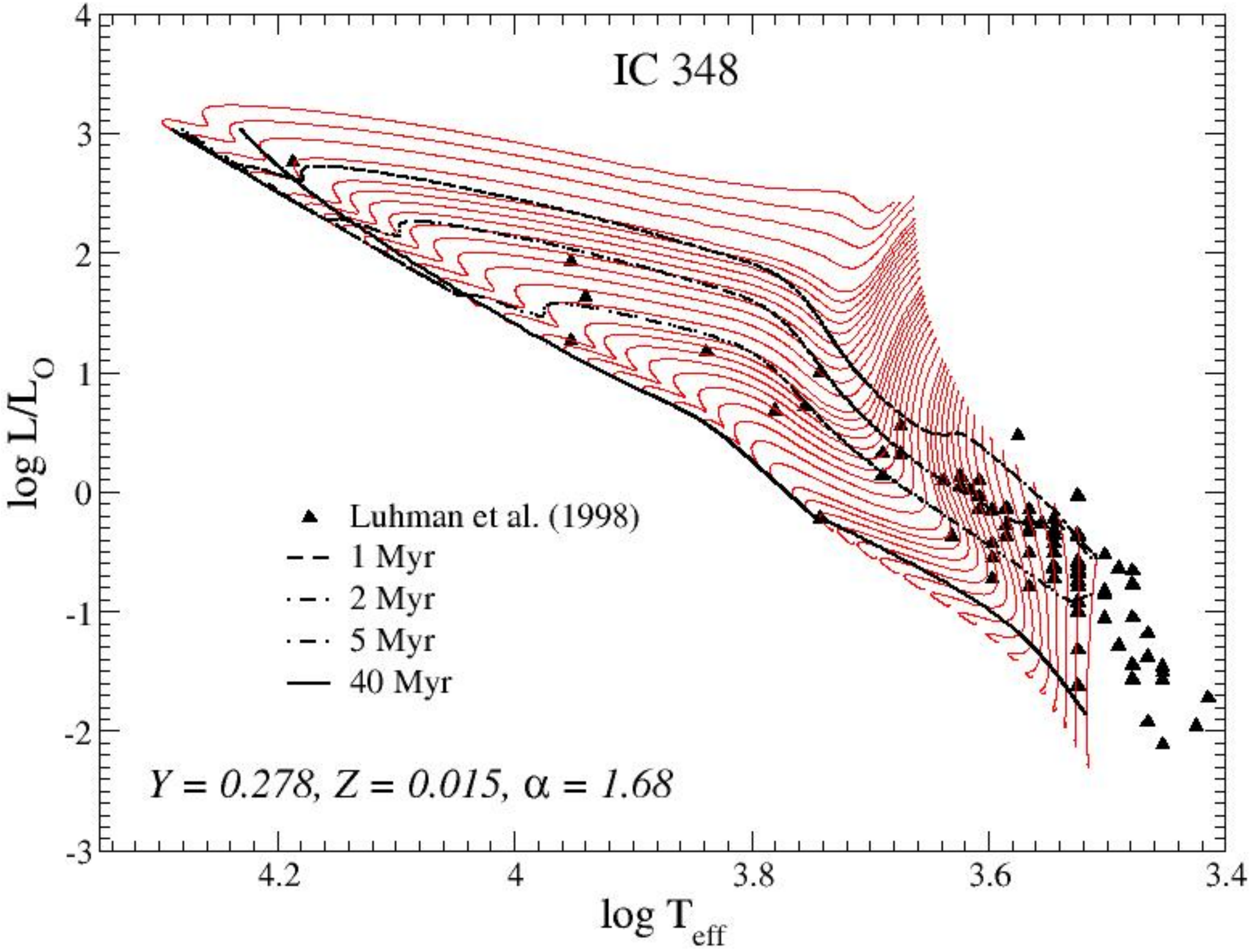
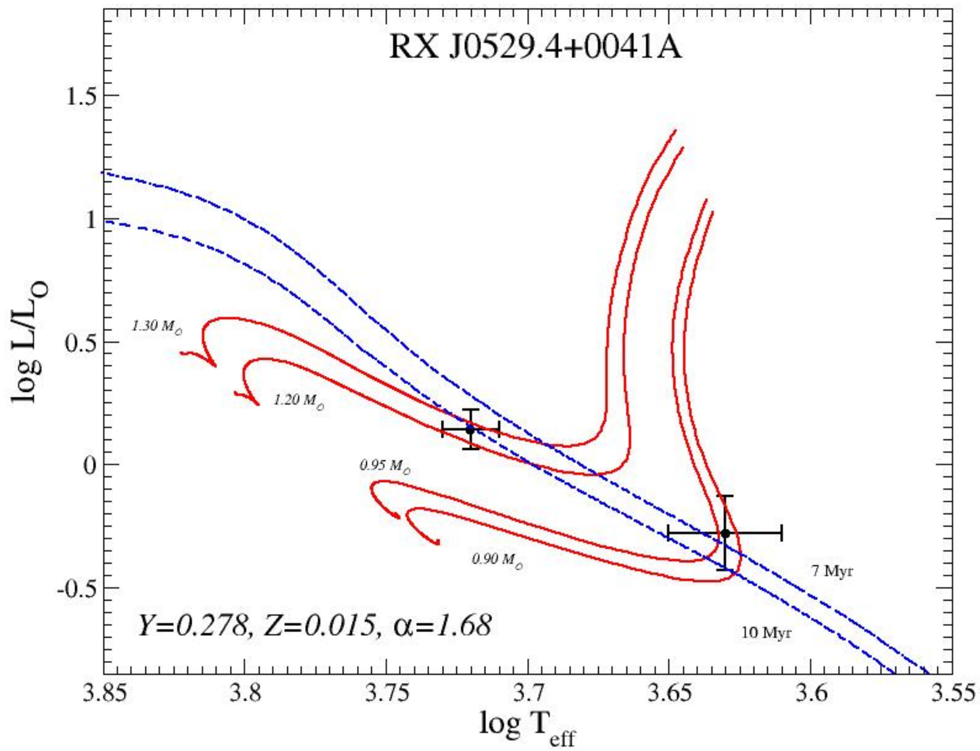


Comparison with data



Comparison with data



- Covino et al. 2004
- $M_1 = 1.27 \pm 0.01\ M_o$
- $M_2 = 0.93 \pm 0.01\ M_o$

See e.g. poster by ***Gennaro et al.***

Pisa pre-MS models: database

- The database is available at the url:

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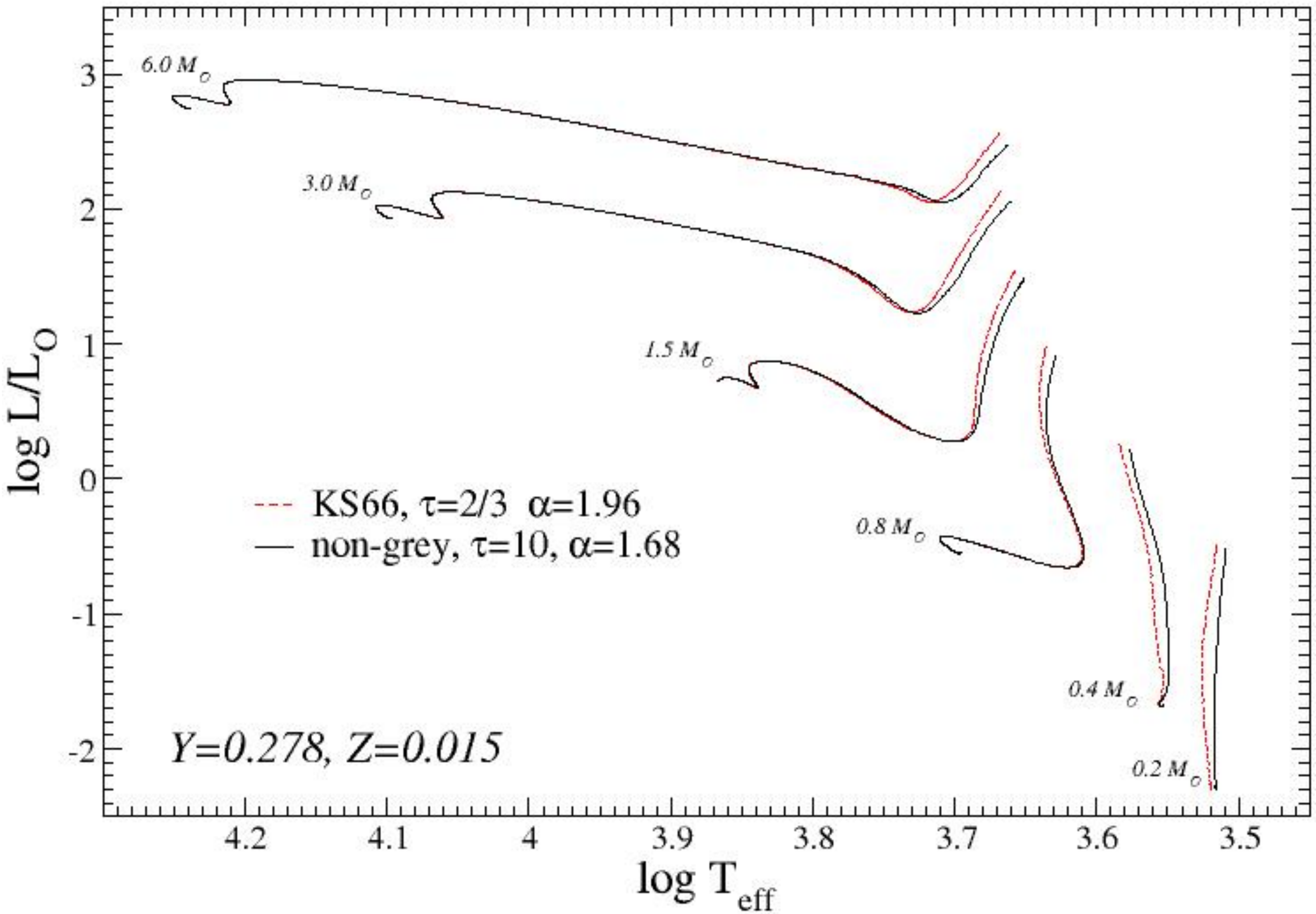
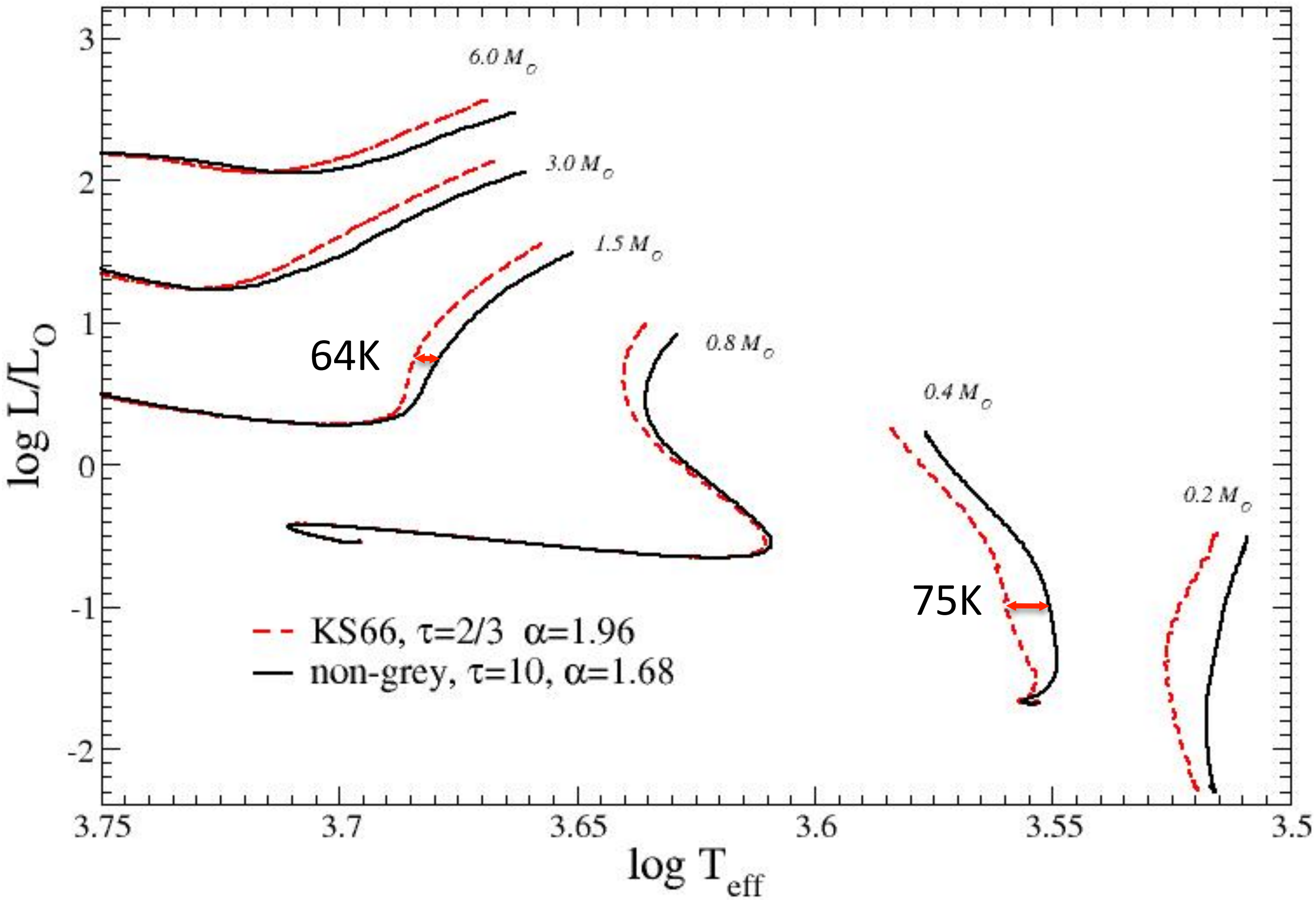
(Astronomy & Astrophysics, submitted)

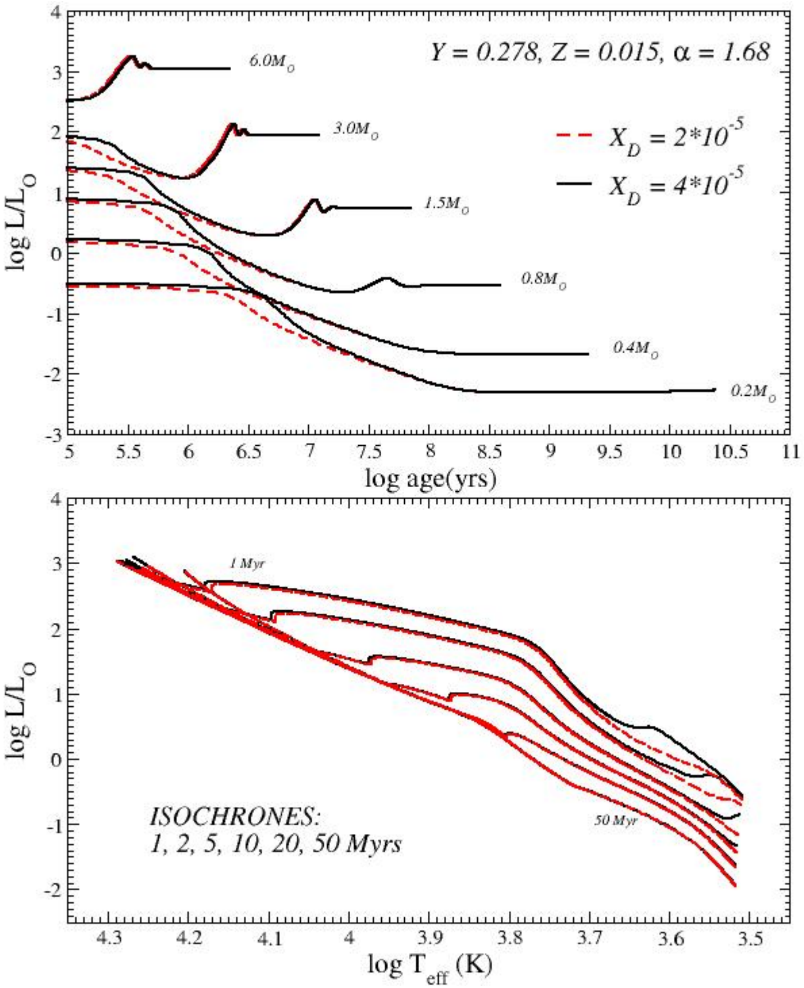
Pisa Models: solar calibration



Pisa Models: solar calibration



Pisa Models: D-burning



- The value of X_D affects only the very early evolution
- After a few Myr the isochrones converge
- X_D= 4x10^{-5} for all stars
- X_D= 2x10^{-5} for Z>0.007

Pisa Models: D-burning

- **Cosmological** D abundance:

$$3.8 \times 10^{-5} \leq X_D \leq 4.5 \times 10^{-5}$$

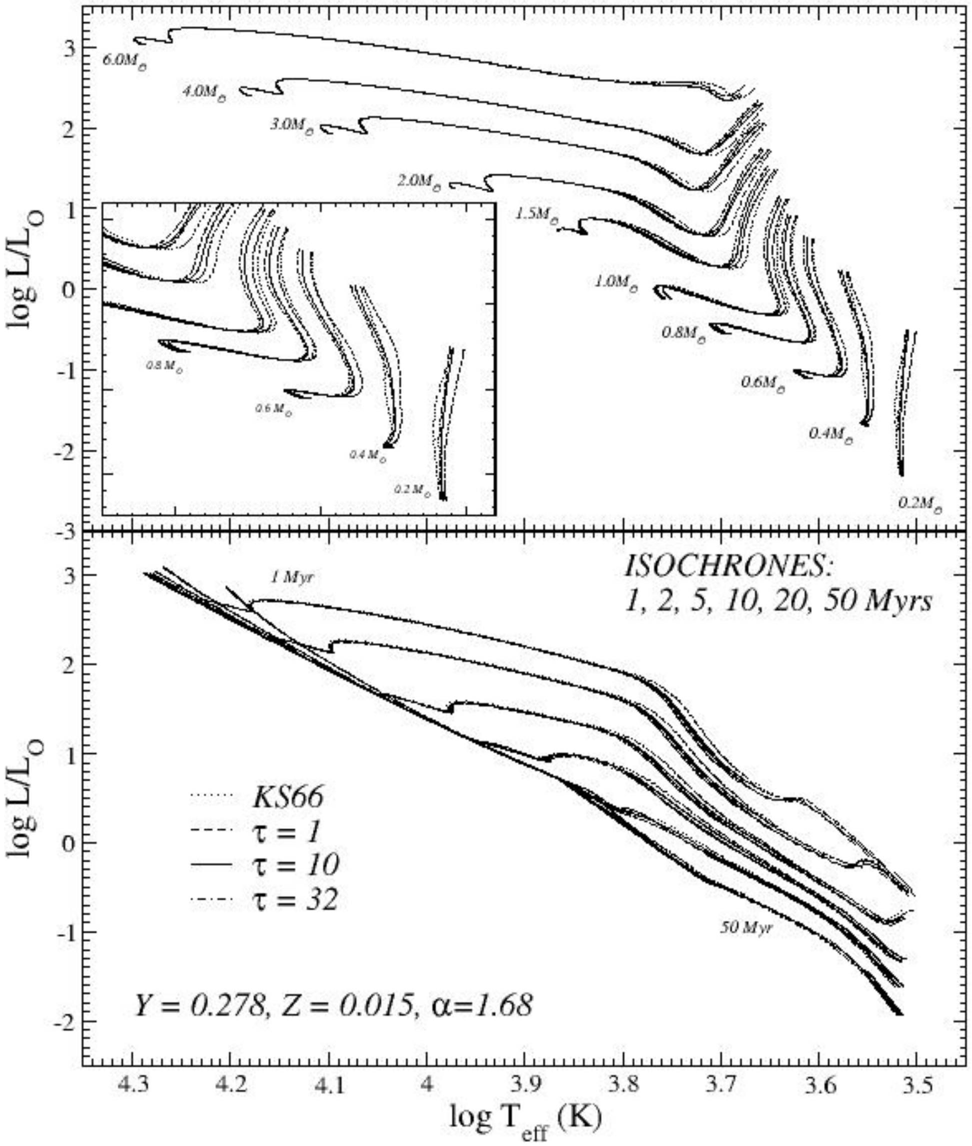
(Cyburt et al. 2004, Steigman et al. 2007, Pettini et al. 2008)

- As stellar generations follow each other, D is ***astrated***, since stars are net destroyers of D
- ***Solar neighbourhood*** D abundance:

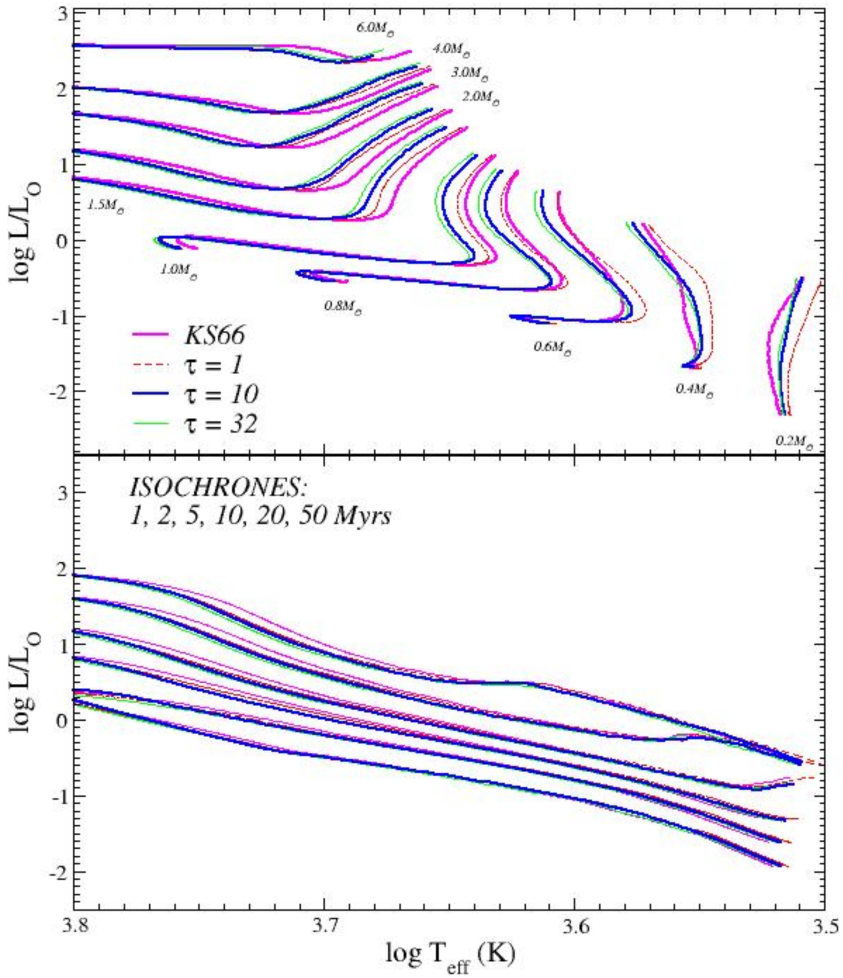
$$X_D \approx 2.5\text{-}3 \times 10^{-5}$$

(Geiss & Gloeckler 1998, Vidal-Madjar et al. 1998, Linsky 1998, Linsky et al. 2007, Steigman et al. 2007)

Pisa Models: boundary conditions



Pisa Models: boundary conditions



- Grey BCs provide **hotter** traks for very low-mass stars.
- For M> 1.2 M_o the ZAMS models are independent of BCs, since convection remains below the photospere and molecules are stable only in the outermost layers.

Pisa Solar Model

	Y_{ini}	Z_{ini}	Y_{sup}	Z_{sup}	α	R_{cz}
KS66	0.2532	0.0137	0.2222	0.0126	1.97	0.7294
CK03	0.2532	0.0137	0.2222	0.0126	1.75	0.7295
BH05	0.2533	0.0137	0.2221	0.0126	1.68	0.7295

Other standard solar models

	Y_{ini}	Z_{ini}	Y_{sup}	Z_{sup}	α	R_{cz}
BS05	0.2614	0.0140	0.2300	0.0125	1.96	0.7289
GZ06	0.2570	0.0135	0.2273	0.0124	1.99	0.7306
S09	0.2593	0.0139	0.2292	0.0126	2.10	0.7280

Pisa Models: nuclear network

- The current version of FRANEC follows the burning of 26 elements
- Initial abundances of ^{3}He, ^{6}Li, ^{7}Li, ^{9}Be, ^{11}Be from Geiss & Gloeckler (1998)
- Nuclear cross section from NACRE *(Angulo et al. 1999)*
- $^{14}N(p,\gamma)^{15}O$ from LUNA *(Marta et al. 2008)*

Comparison with other authors

Table 3. Summary of the main physical inputs adopted by the codes selected for the comparison with the present results.

Code:	EOS	Radiative Opacity	Boundary Conditions
BCAH98	Saumon, Chabrier & VanHorn 1995 (SCVH95)	OPAL96; Alexander & Ferguson (1994)	non-grey Hauschildt et al. (1999)
CESAM08	OPAL05	OPAL96; Alexander & Ferguson (1994)	grey atmosphere
CLES07	OPAL01	OPAL96; Alexander & Ferguson (1994)	grey atmosphere
DM97	OPAL96; MHD88	OPAL93; Alexander & Ferguson (1994)	grey atmosphere
DSEP08	Chaboyer & Kim (1995); Irwin (2004)	OPAL96; Feguson et al. (2005)	non-grey Hauschildt et al. (1999); Castelli & Kurucz (2003)
DVD09	OPAL05; SCVH95	OPAL96; Feguson et al. (2005)	non-grey Heiter et al. (2002); Allard & Hauschildt (1997)
SD00	Pols et al. (1995)	OPAL96; Alexander & Ferguson (1994)	non-grey
YY01	OPAL96; Chaboyer & Kim (1995)	OPAL96; Alexander & Ferguson (1994)	grey atmosphere

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Pisa pre-MS models: database

- **16** values of metallicity, $Z=0.0002 - 0.03$
- **3** values of the initial Y for each Z

$$Y = Y_p + \frac{\Delta Y}{\Delta Z} Z$$

- **2** values of Y_p: 0.230 and 0.248
- **2** values of $\Delta Y/\Delta Z$: 2 and 5
- **2** values of the initial X_D for $Z>0.007$
- **3** values of α: 1.2, 1.68, 1.9

Pisa Models: initial conditions

- ***Not realistic*** since it neglects the protostellar phase

- However, once the main accretion phase is finished, the evolution should ***quickly converge*** to that of standard hydrostatic models *(Stahler 1983, Palla & Stahler 1999)*.

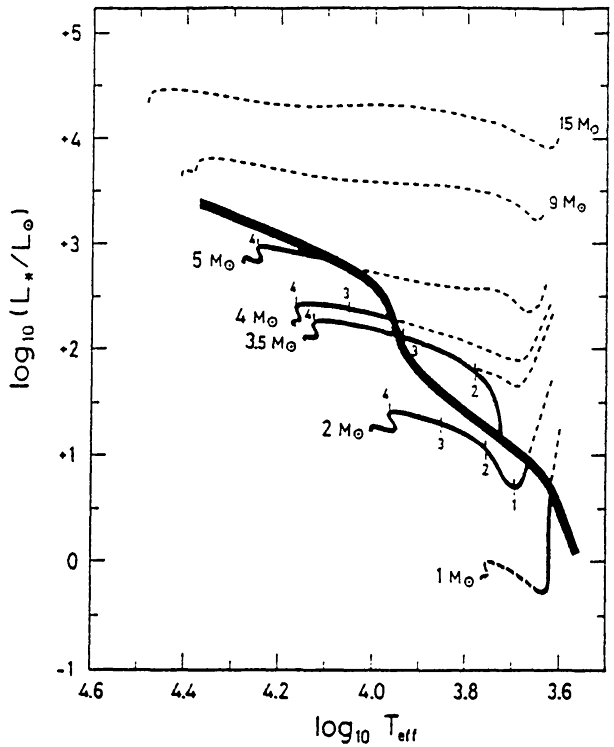

Fig. 1. PMS evolutionary tracks for stars of mass 1 $M_\odot \leq M_* \leq 5$ $M_\odot$ (*solid lines*). Evolutionary lifetimes are marked on each curve. The *heavy solid line* represents the "birthline". For comparison, the *dashed lines* give the standard tracks as computed by Iben (1965).

Palla & Stahler 1993

Pisa Models: initial conditions