Cumulative theoretical uncertainties in Lithium Depletion Boundary Age

Emanuele Tognelli[1,2]

Pier Giorgio Prada Moroni[2,3]

Scilla Degl'Innocenti[2,3]

(1) University of Roma Tor Vergata, (2) INFN Pisa, (3) University of Pisa

Chemical and dynamical evolution of the Milky Way and Local Group galaxies - Sesto 2015

Introduction (1)

Lithium Depletion Boundary:
Alternative method to assign an age to young clusters (20-300 Myr)

(9 clusters, see e.g. reviews of Jeffries 2006, Soderblom et al 2013)

Lithium depletion:

- ^{7}Li **destroyed** during the PMS ($T_c > 2.5\times10^6$ K) for stellar mass **$M > 0.06 M_{sun}$**

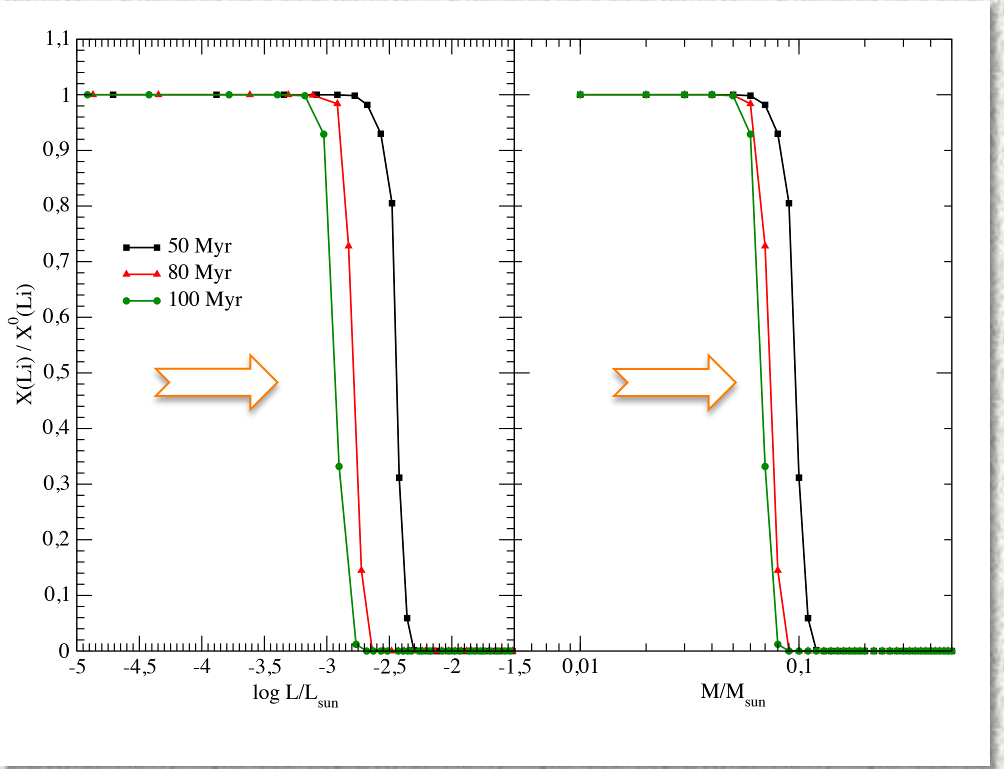
- **Completely destroyed** in fully convective stars: **$0.06 M_{sun} < M < 0.5\ M_{sun}$**

- Destruction timescale (τ_{ldb}) depends on T_c: **$T_c = T_c(M)$**

- τ_{ldb} decreases with the stellar mass: strongly dependent on **M**

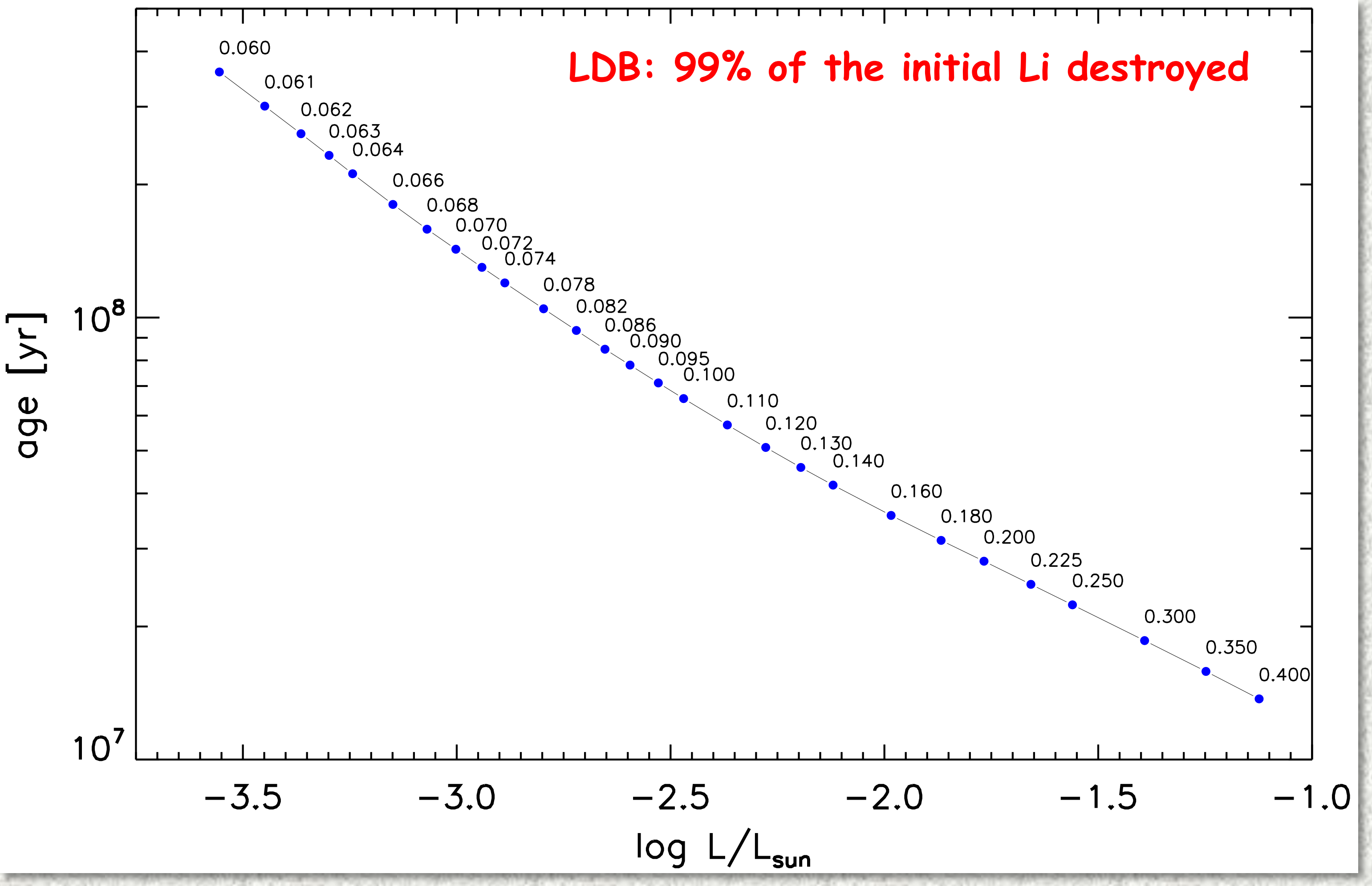
Lithium depletion boundary (LDB):

In a cluster: the faintest object with ≈ 0 surface ^{7}Li abundance



Age inferred by comparing the **observed** and **theoretically** computed **LDB luminosity**. Uncertainty on the models propagates into a final age uncertainty (Bildsten et al. 1997, Burke et al. 2004)

LDB age-luminosity



Stellar Models (1)

PROSECCO: **Pisa stellar evolutionary code**
(Degl'Innocenti et al. 2008)

Updated input physics
(Tognelli et al. 2012, Dell'Omodarme et al. 2012, Tognelli et al. 2014)

Detailed atmospheric models: PHOENIX atmospheric code
(Brott & Haushildt 2005)

Equation of state: extension to the brown dwarf regime
(Saumon, Chabrier & VanHorn 1995)

Updated nuclear cross sections for light elements (deuterium, lithium, beryllium, and boron)

Recently updated solar metals abundances (Asplund et al. 2009)

Uncertainty analysis
Input physics and initial chemical composition

$$LDB = LDB(\{p_l\}, \{x_k\})$$

$\{p_l\}$ = **input physics quantity** (i.e. opacity, cross section, mixing lenght…)

$\{x_k\}$ = **element abundance**

- **Independent variation** of each quantity.
  Individual uncertainty source.

  input physics: $LDB = LDB(p_j \pm \Delta p_j, \{p_{l\neq j}\}, \{x_k\})$

  chemical composition: $LDB = LDB(\{p_l\}, x_j \pm \Delta x_j, \{x_{k\neq i}\})$

- **Cumulative error stripe.**
  Simultaneous variation of all the analysed quantities at the same time.

Individual Uncertainty source (1)

Input Physics

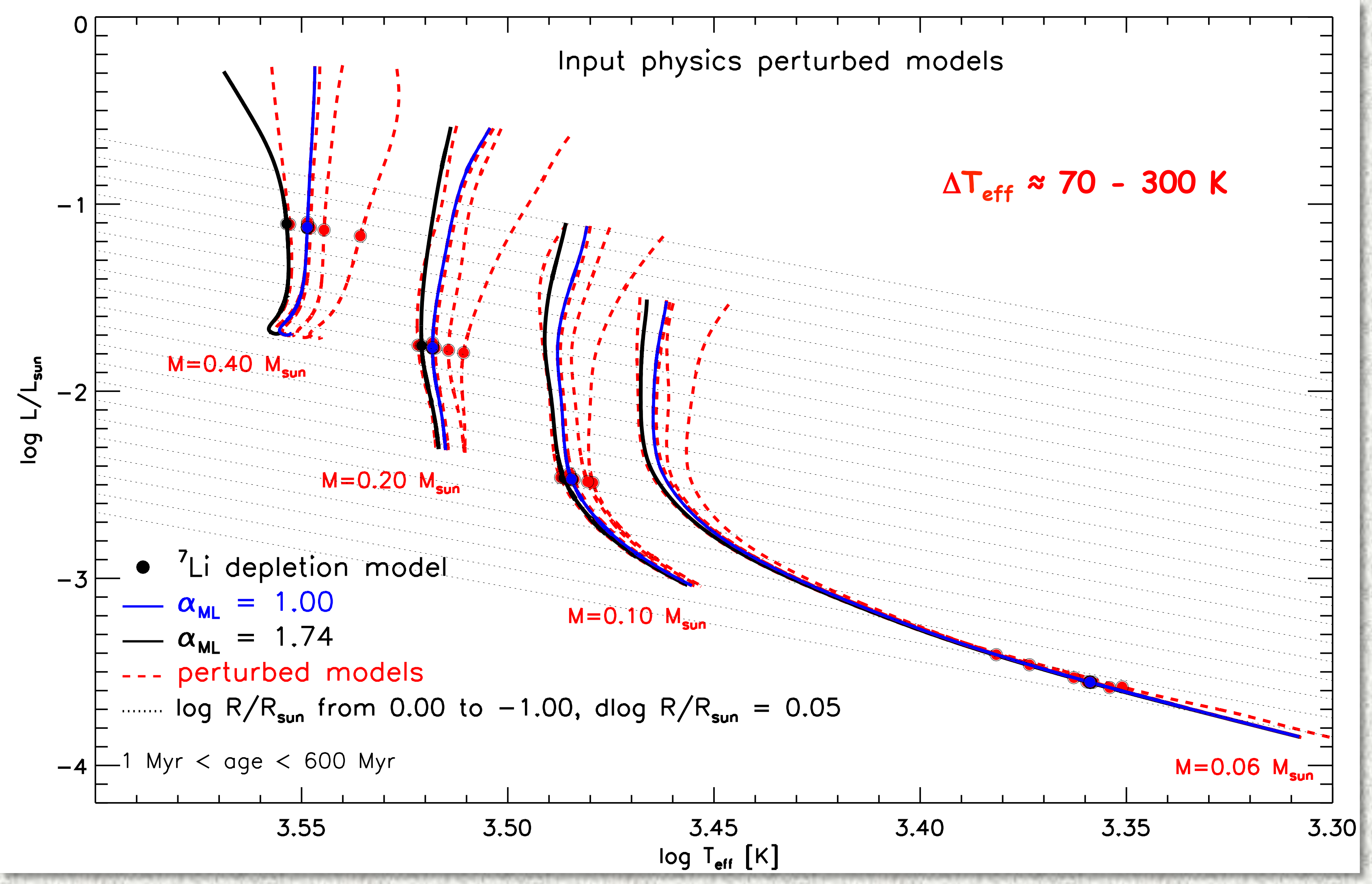
Table 3. Input physics varied in the computation of perturbed stellar models and their assumed uncertainty or range of variation. The flag "yes" specifies the quantities taken into account in the cumulative uncertainty calculation (see Sect. 5).

quantity	Individual Error Analysis
^{2}H(p,γ)^{3}He reaction rate	$\pm 3\%$
^{2}H(^{2}H,n)^{3}He reaction rate	$\pm 5\%$
^{2}H(^{2}H,p)^{3}H reaction rate	$\pm 5\%$
^{7}Li(p,α)α reaction rate	$\pm 10\%$
electron screening(p+^{7}Li) $^{(a)}$	$+50\%$, $+100\%$
BCs $^{(b)}$	BH05, AHF11, KS66
$\tau_{\rm ph}$ $^{(a)}$	2/3, 100
EOS $^{(b)}$	OPAL06, FreeEOS08, SCVH95
$\overline{\kappa}_{\rm rad}$	$\pm 5\%$

Uncertainty estimation not available...(future?!)

Individual Uncertainty source (2)

Input Physics



Individual Uncertainty source (3)

Chemical Composition

(analysed for the first time)

Table 4. Chemical composition parameters varied in the computation of perturbed stellar models and their assumed uncertainty. The flag "yes" in the last column specifies the quantities taken into account in the cumulative uncertainty calculation (see Sect. 5).

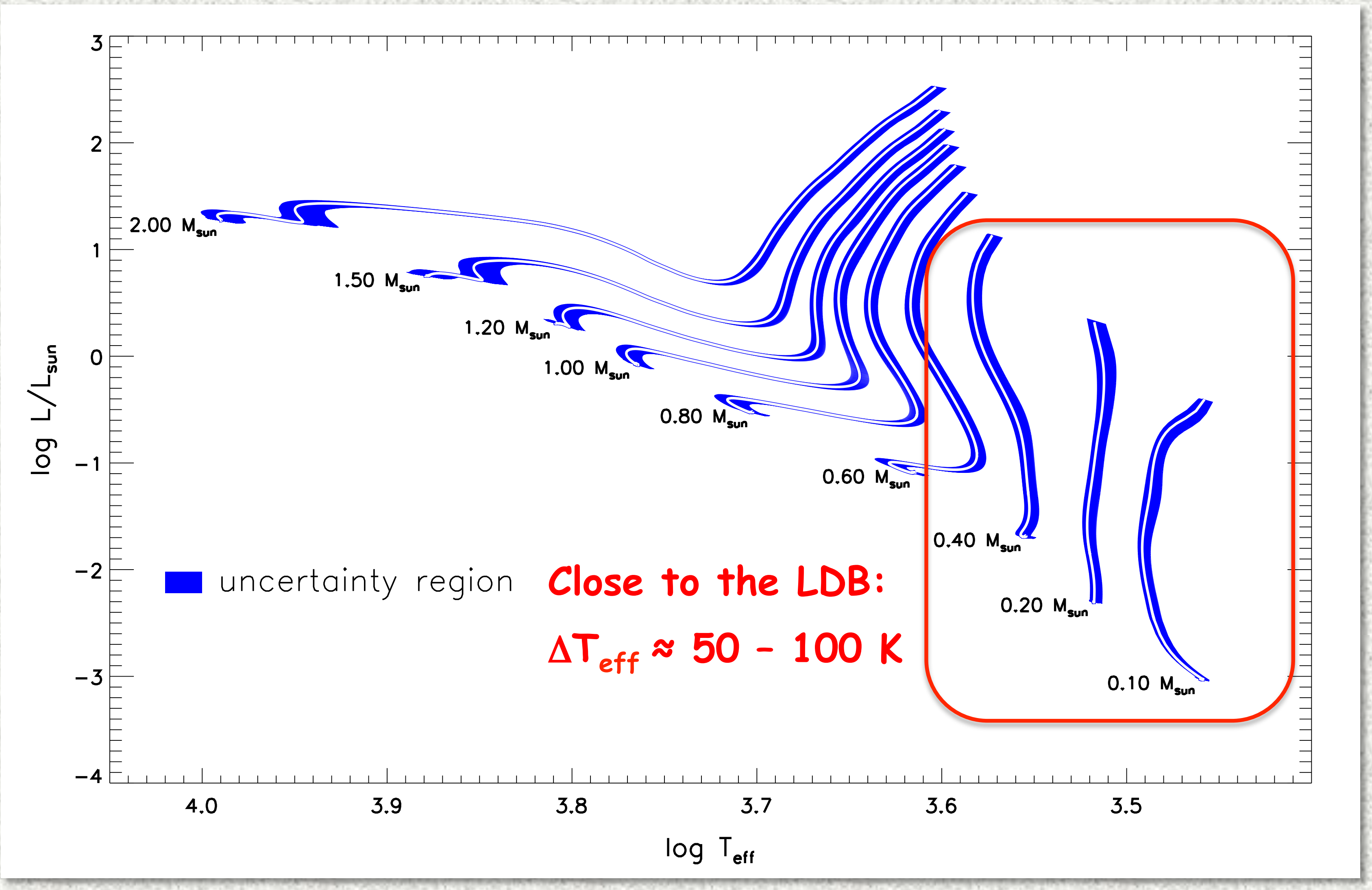
quantity	Individual Error Analysis
[Fe/H]	± 0.1dex
$\Delta Y/\Delta Z$	± 1
$(Z/X)_\odot$	$\pm 15\%$
X_d	$\pm 1 \times 10^{-5}$

$$Y = Y_\mathrm{P} + \frac{\Delta Y}{\Delta Z} Z$$

$$Z = \frac{(1 - Y_\mathrm{P})(Z/X)_\odot}{10^{-[\mathrm{Fe/H}]} + (1 + \Delta Y/\Delta Z)(Z/X)_\odot}$$

(see e.g. Gennaro et al. 2010)

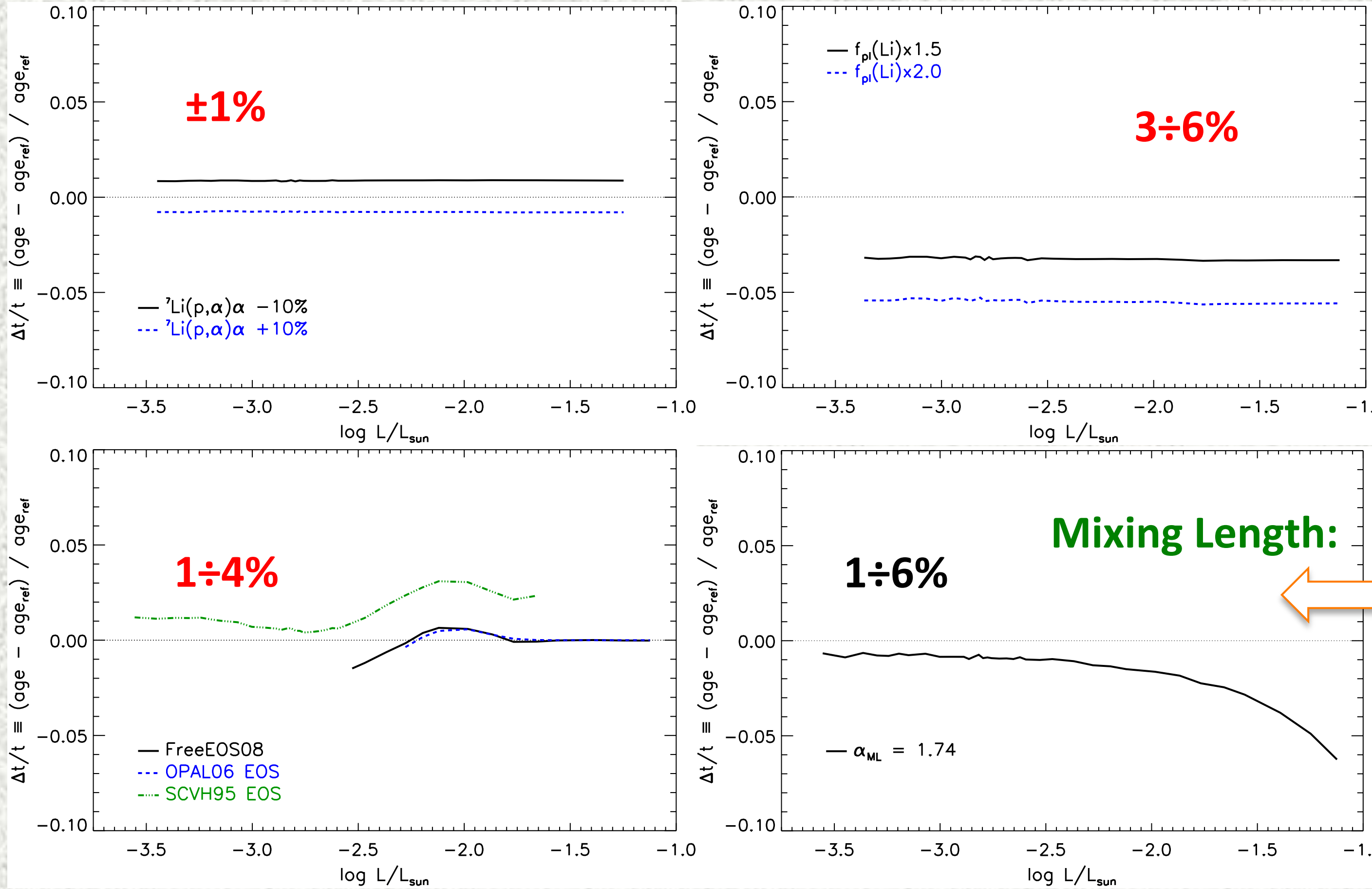
Individual Uncertainty source (4)



Individual Uncertainty source: INPUT PHYSICS (5)

Reaction Rate:

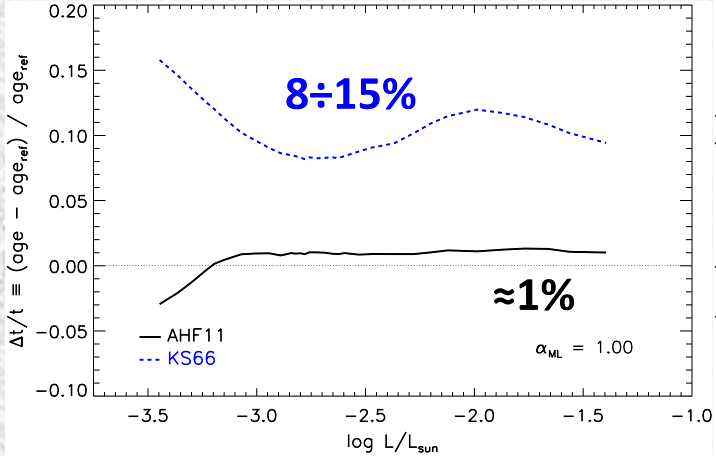
EOS:

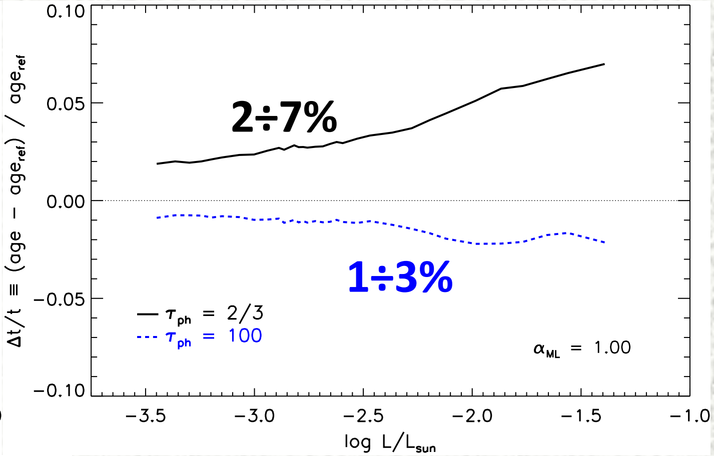


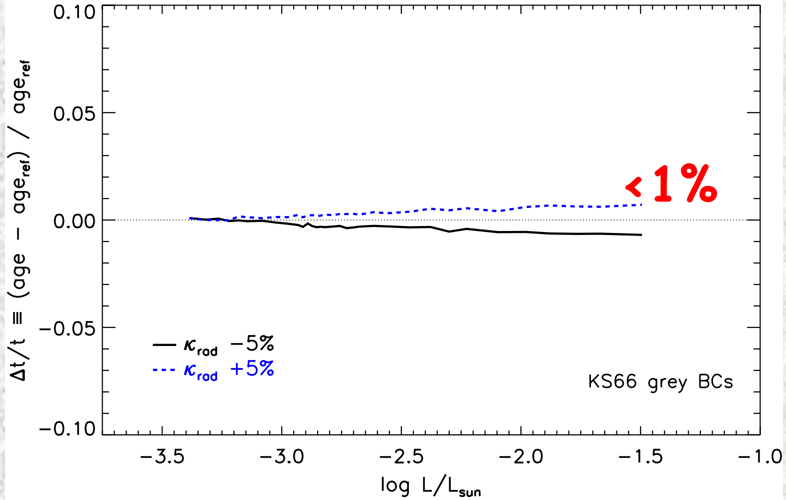
$T_c \propto M/R$,
$R = R(t)$

Individual Uncertainty source: INPUT PHYSICS (6)

Surface Boundary Conditions:







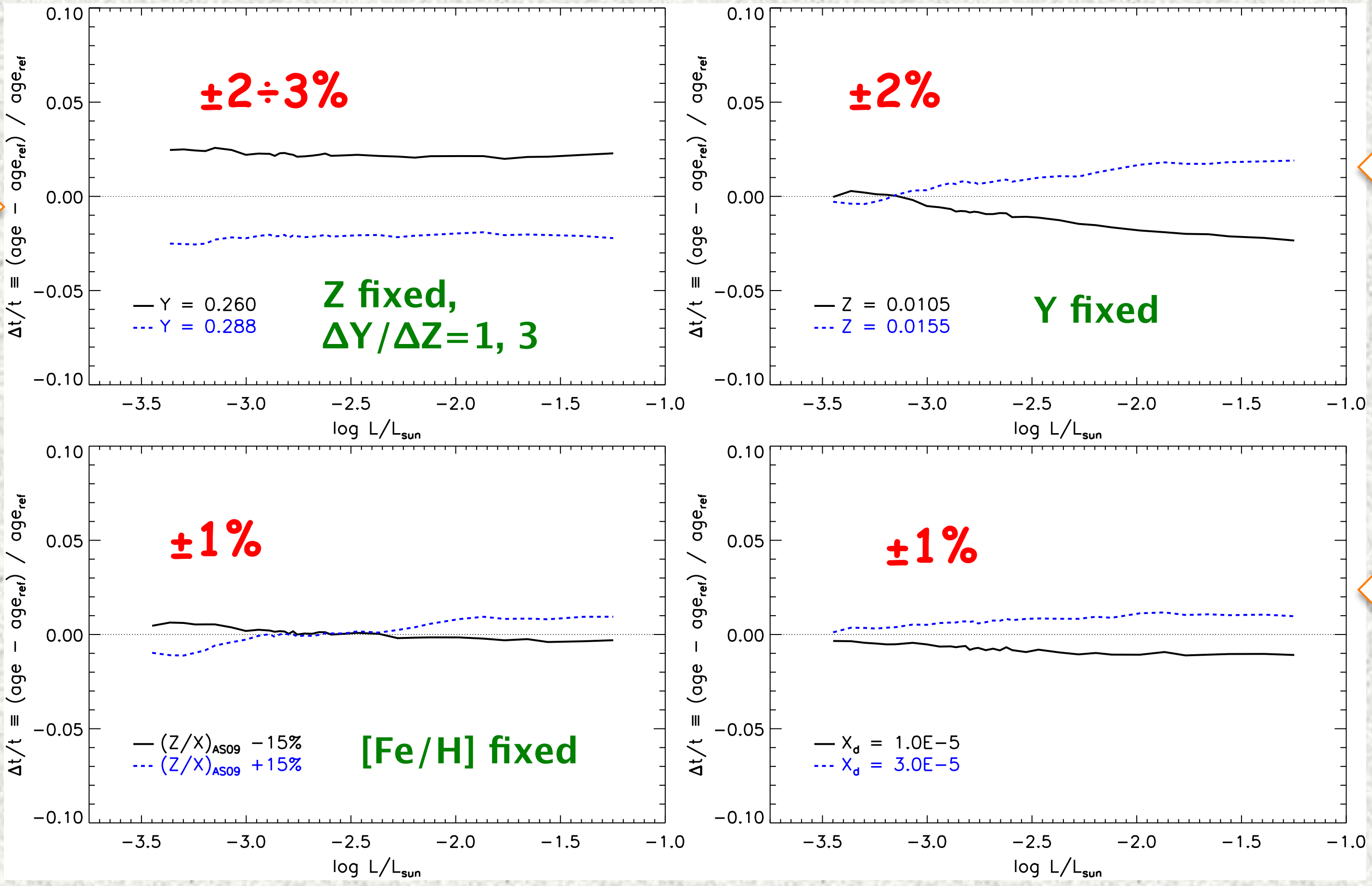
Opacity variation in the atmosphere (outer boundary conditions)

Individual Uncertainty source: CHEMICAL COMPOSITION (8)

Helium:

Metallicity:

Deuterium:



$$Y = Y_{\rm P} + \frac{\Delta Y}{\Delta Z} Z$$

$$Z = \frac{(1 - Y_{\rm P})(Z/X)_{\odot}}{10^{-[{\rm Fe/H}]} + (1 + \Delta Y/\Delta Z)(Z/X)_{\odot}}$$

Reference values:
Y=0.274, Z=0.013

Cumulative Error Stripe (1)

Input physics and chemical composition quantities/parameters can vary at the same time

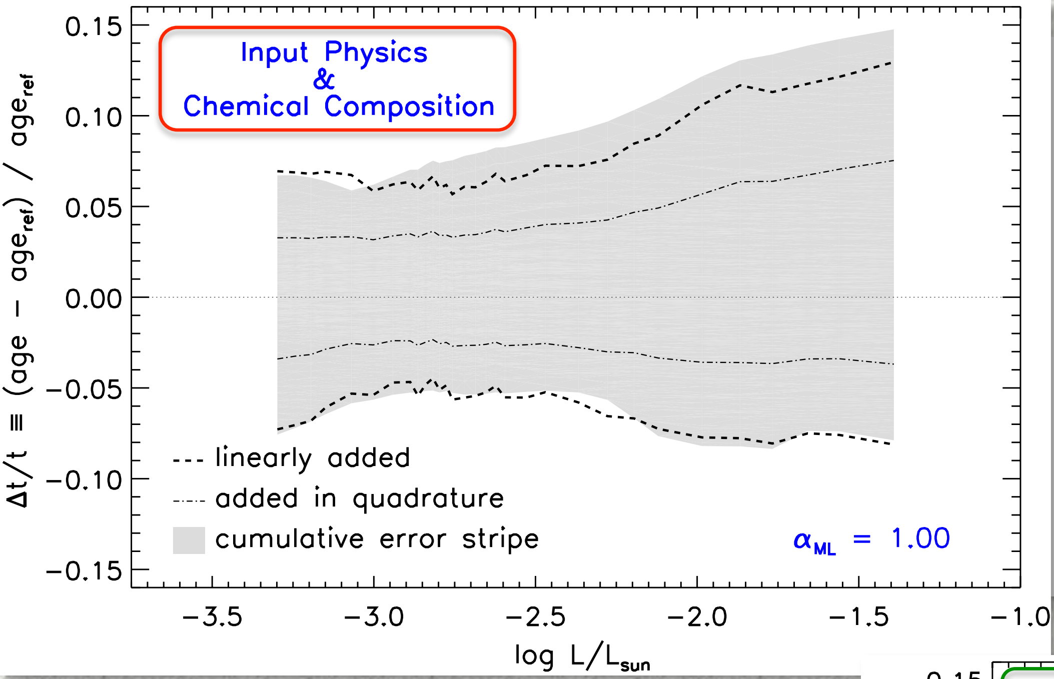
$$LDB = LDB(\{p_l\}, \{x_k\})$$

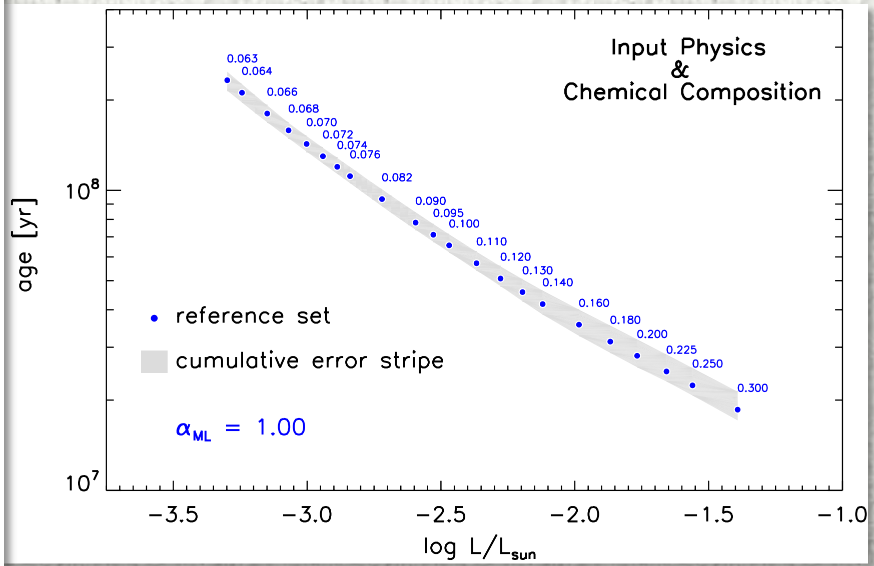
Input physics	Chemical composition
$p_j \Rightarrow \begin{cases} p_j + \Delta p_j \\ p_j \\ p_j - \Delta p_j \end{cases}$	$x_k \Rightarrow \begin{cases} x_k + \Delta x_k \\ x_k \\ x_k - \Delta x_k \end{cases}$

To obtain the error stripe we computed all the possible permutations of the perturbed $\{p_j\}$ and $\{x_k\}$

For a total of ≈ 400 sets of models!

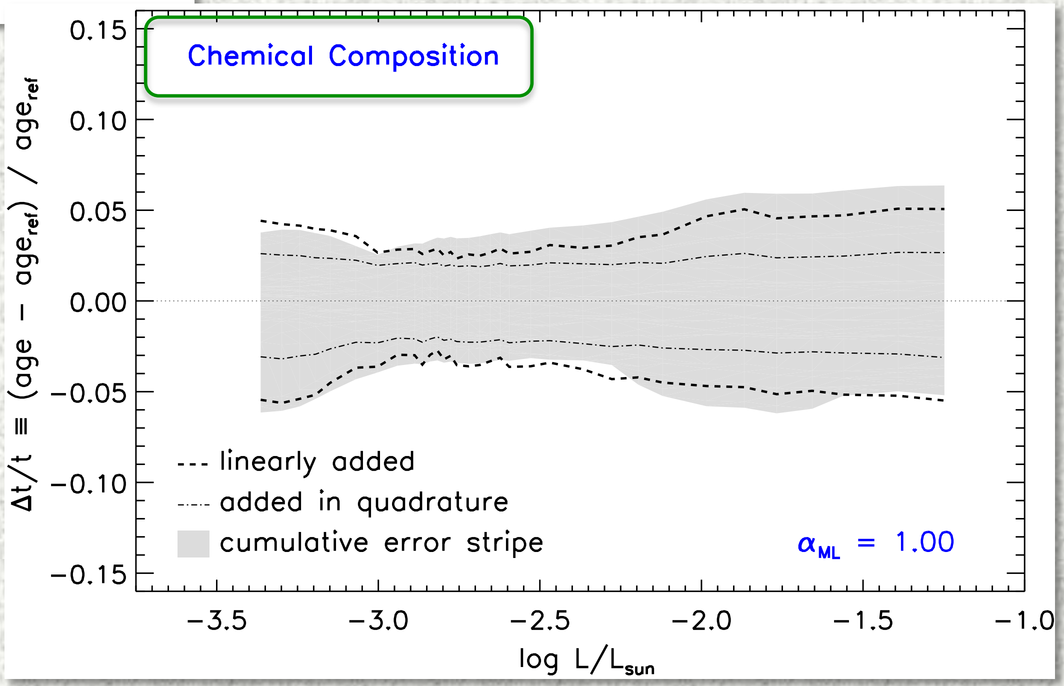
Cumulative Error Stripe (2)



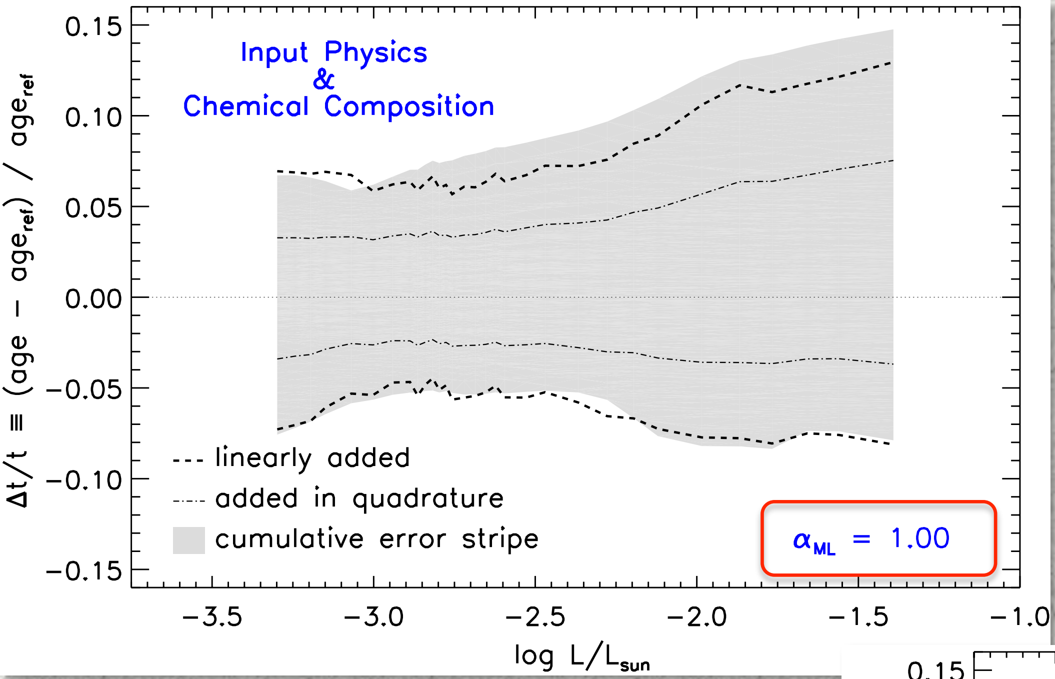


Error stripe: from 5% up to 15%

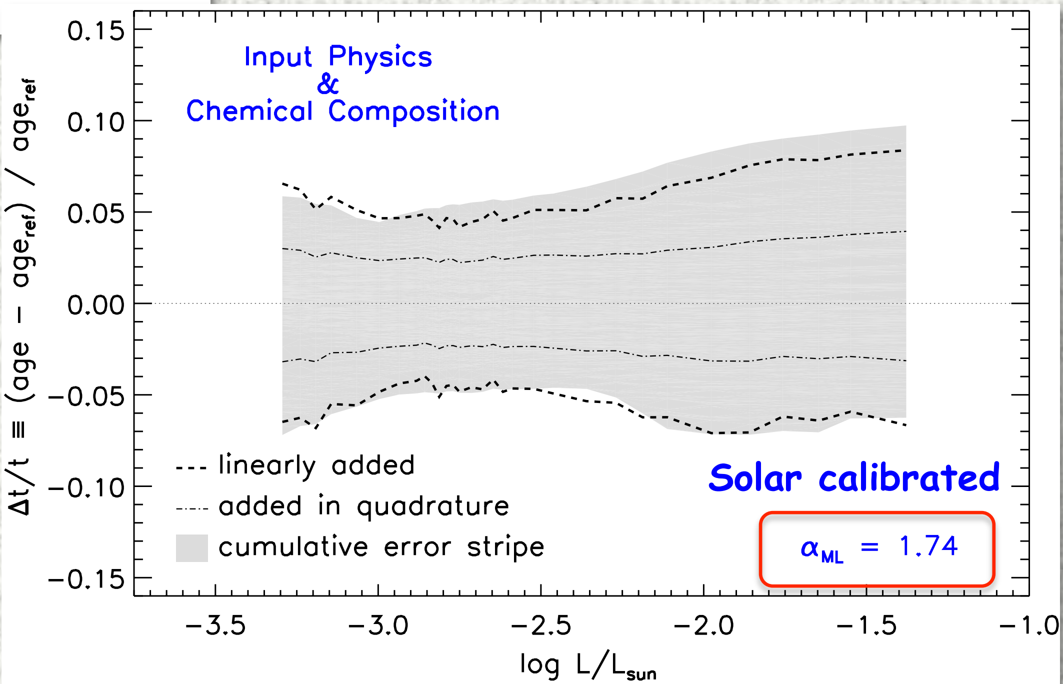
Chemical composition:
40% of the total error budget



Cumulative Error Stripe (3)



Effect of the Mixing Length parameter



Summary

- Analysis of the main uncertainty sources affecting theoretical LDB age determination

- Individual uncertainty sources: input physics and chemical composition

- For the first time cumulative error stripe: simultaneous variation of the input physics and chemical composition quantities/parameter

- Error stripe: 40% of the total error budget due to the uncertainty on the initial chemical composition

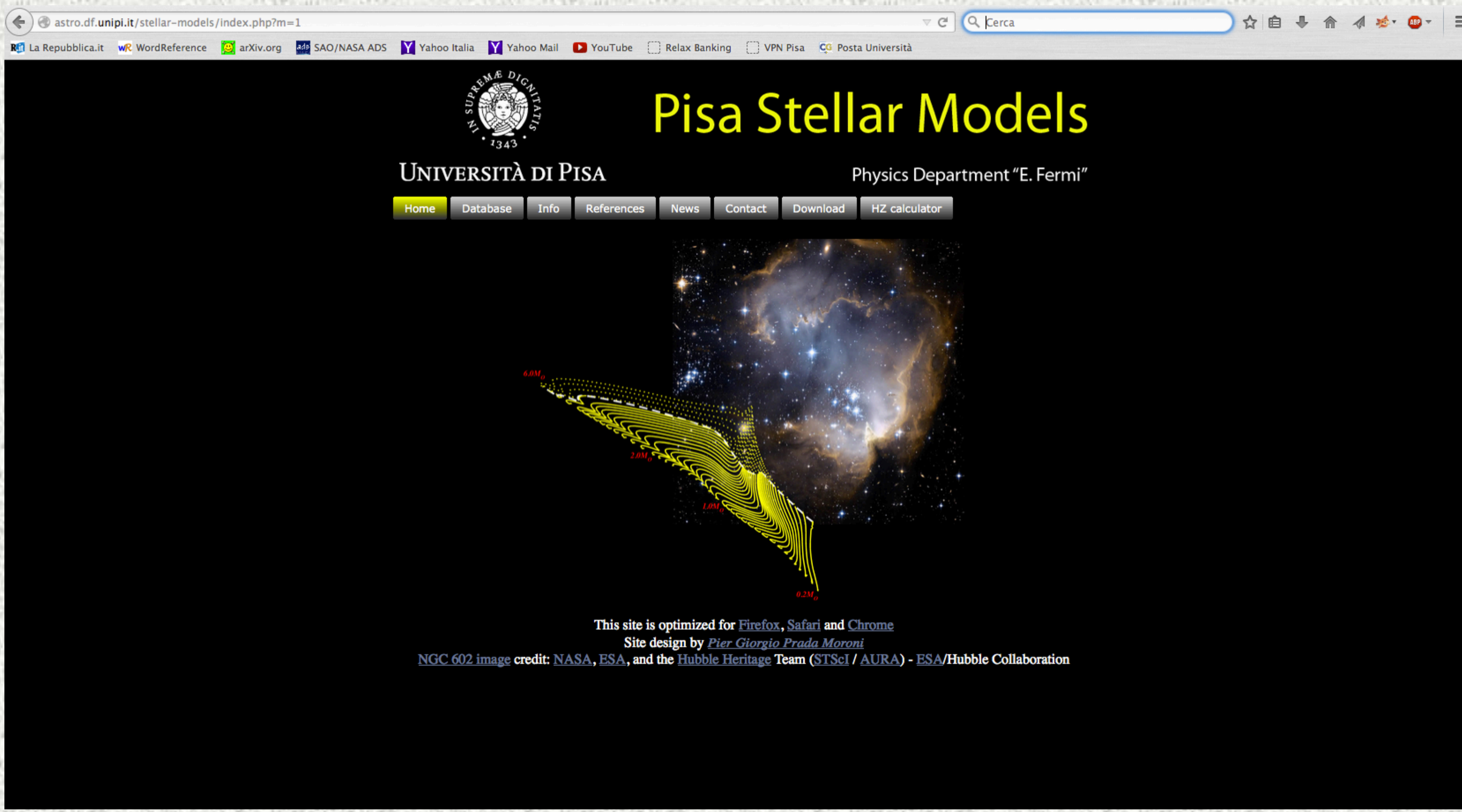
- Cumulative Error Stripe well reproduced by linealy adding the uncertainty due to individual variation

- Age uncertainty: from 5-8% (100 Myr) to 8-15% (20 Myr)

- Future: additional uncertainty sources (rotation, magnetic fields, accretion…)

Pisa Pre-Main Sequence and Low Mass Stars Database

http://astro.df.unipi.it/stellar-models/



Pre-Main Sequence: isochrones (1-100 Myr) and tracks (0.2 - 6.0 M_{sun})

Low Mass Stars: isochrones (8-15 Gyr) and tracks (0.3-1.1 Msun)

"[…] after all it's been written in the stars […]"

John Lennon, Woman, Double Fantasy, 1980

…The End!!!!