Revisiting the helium abundance from multiple MSs in Globular Clusters

Luca Casagrande
Max Planck Institute for Astrophysics

Laura Portinari
Tuorla Observatory

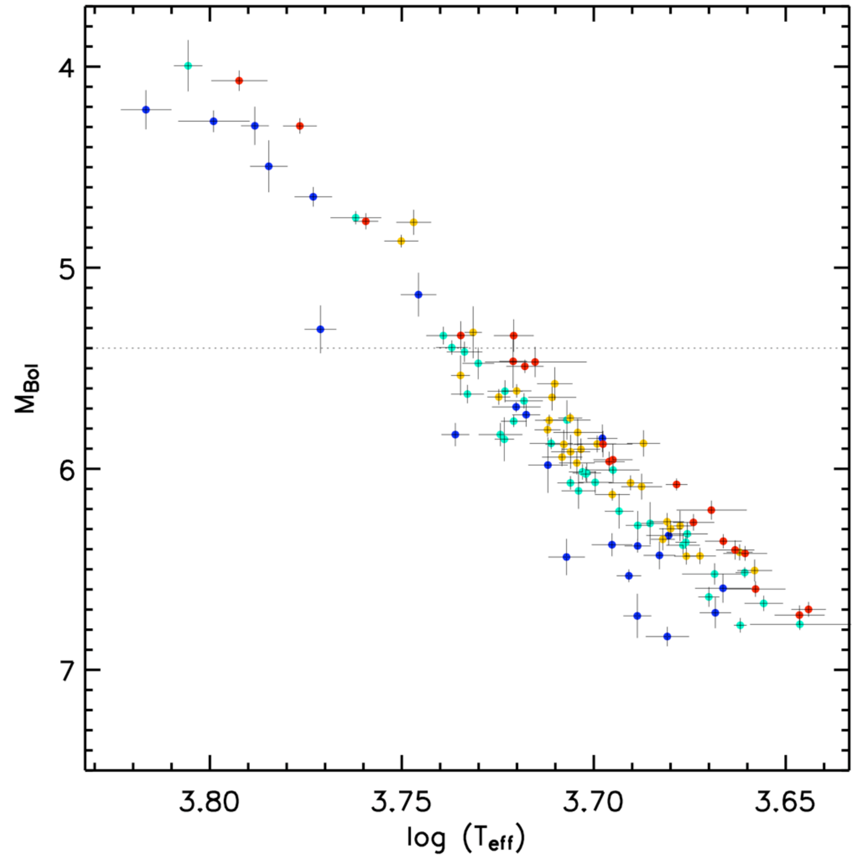
Revisiting the helium abundance from multiple MSs in Globular Clusters ?

Insights from nearby stars

Luca Casagrande
Max Planck Institute
for Astrophysics

Laura Portinari
Tuorla Observatory

✓ Fundamental stellar parameters (T_{eff}, F_{bol}) : *empirical / reliable determination (IRFM)*



•L. Casagrande; I. Ramírez; M. Asplund (MPA)
•J.Meléndez (CAUP)
•M. Bessell (ANU)

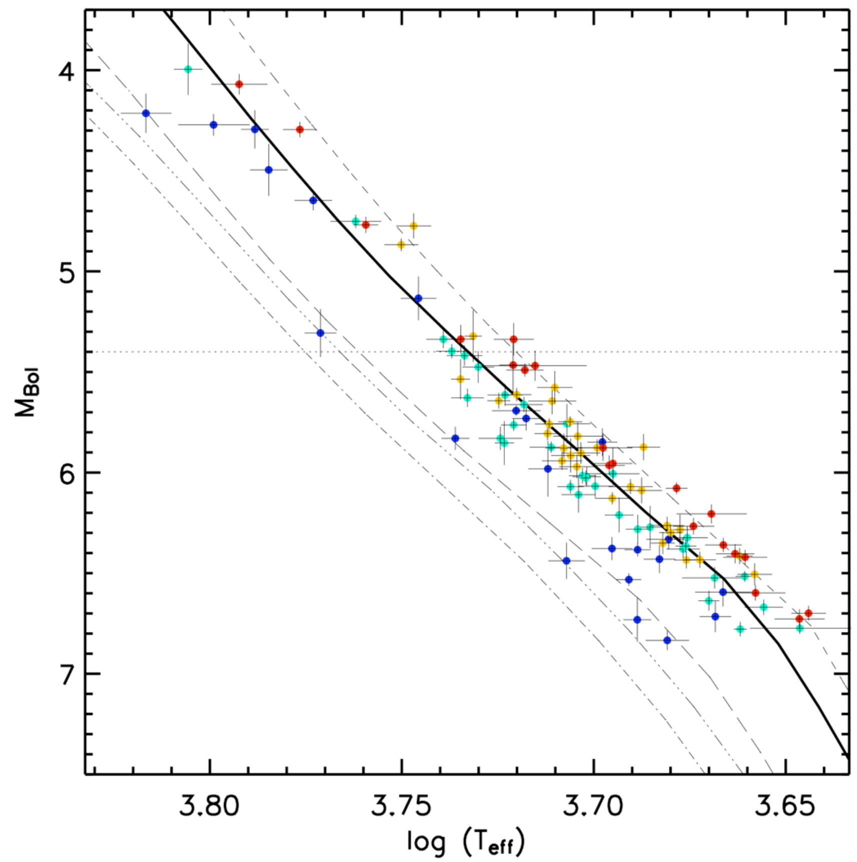
✓ Comparison with stellar models (directly T_{eff}-F_{bol} plane) : *pitfalls*

✓ Implication for multiple MSs in Globular Clusters : *downward revision of Y ?*

•L. Portinari & C. Flynn (Tuorla/Turku)
•L. Girardi (Padova)

✓ Fundamental stellar parameters (T_{eff}, F_{bol}) :

empirical / reliable determination (IRFM)



•L. Casagrande; I. Ramírez;
M. Asplund (MPA)
•J.Meléndez (CAUP)
•M. Bessell (ANU)

✓ Comparison with stellar models (directly T_{eff}-F_{bol} plane) :

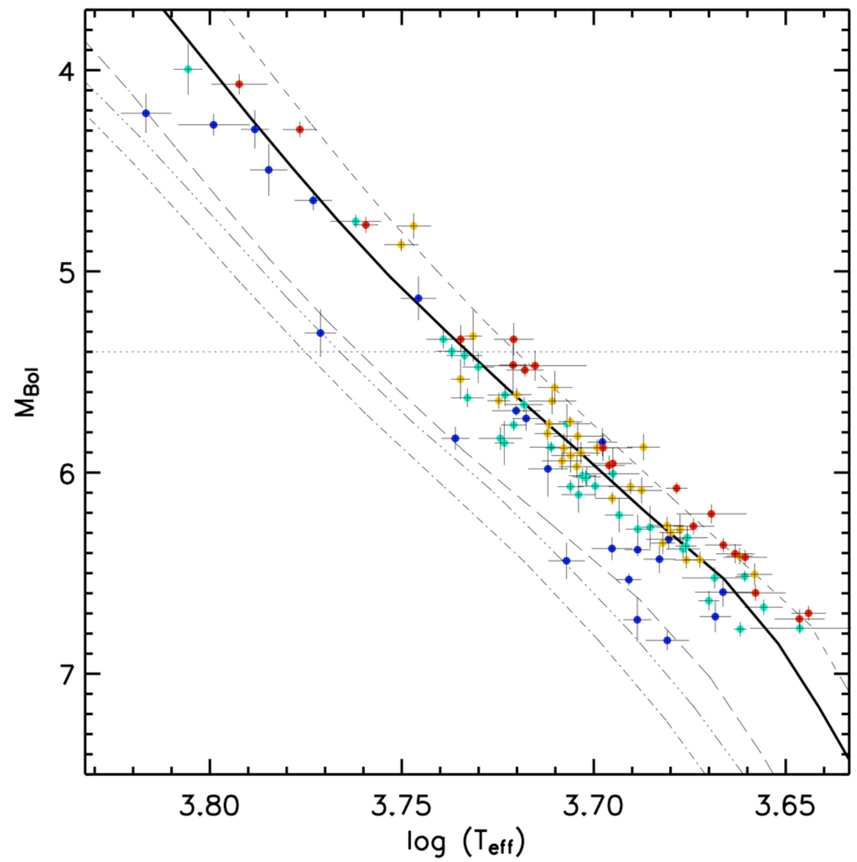
pitfalls

✓ Implication for multiple MSs in Globular Clusters :

downward revision of Y ?

•L. Portinari & C. Flynn (Tuorla/Turku)
•L. Girardi (Padova)

✓ Fundamental stellar parameters (T_{eff}, F_{bol}) :
empirical / reliable determination (IRFM)



•L. Casagrande; I. Ramírez; M. Asplund (MPA)
•J.Meléndez (CAUP)
•M. Bessell (ANU)

✓ Comparison with stellar models (directly T_{eff}-F_{bol} plane) :
pitfalls

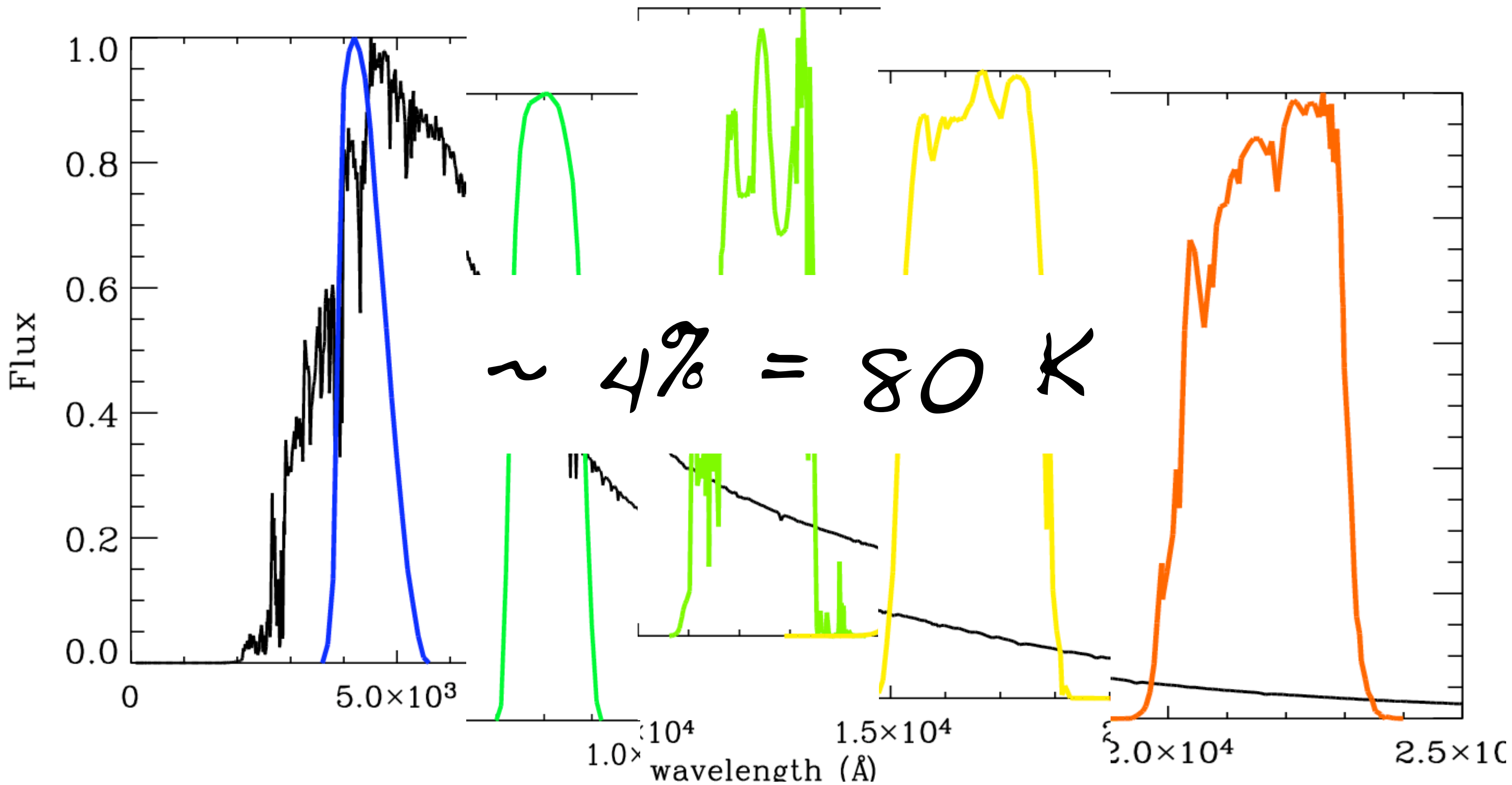
✓ Implication for multiple MSs in Globular Clusters :
downward revision of Y ?

•L. Portinari & C. Flynn (Tuorla/Turku)
•L. Girardi (Padova)

InfraRed Flux Method

Blackwell et al. (1977,1978,1979)

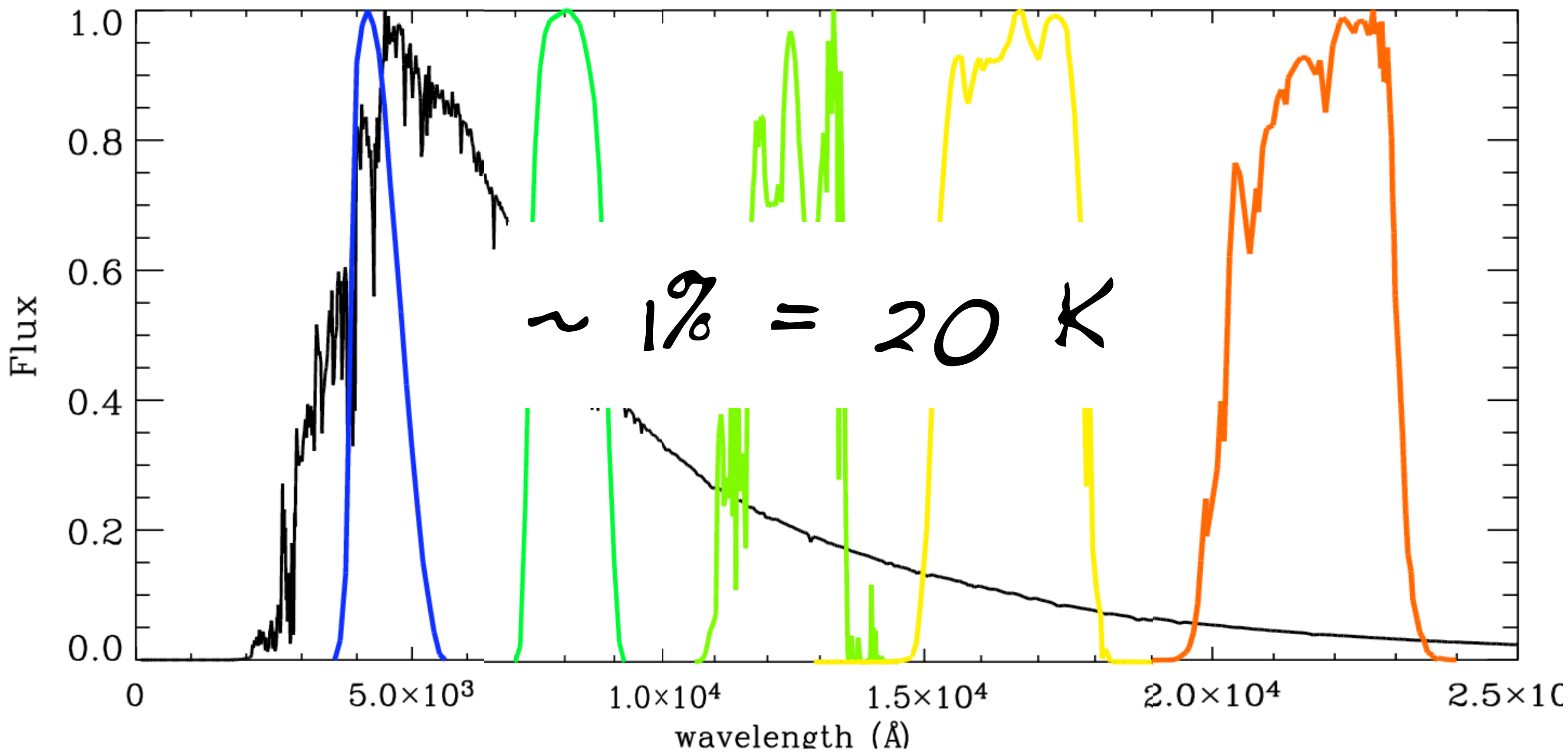
$$\frac{\mathcal{F}_{Bol}(\mathrm{Earth})}{\mathcal{F}_{\mathrm{IR}}(\mathrm{Earth})} = \frac{\sigma T_{\mathrm{eff}}^4}{\mathcal{F}_{\mathrm{IR}}(\mathrm{model})}$$



InfraRed Flux Method

Blackwell et al. (1977,1978,1979)

$$\frac{\mathcal{F}_{Bol}(\mathrm{Earth})}{\mathcal{F}_{\mathrm{IR}}(\mathrm{Earth})} = \frac{\sigma T_{\mathrm{eff}}^4}{\mathcal{F}_{\mathrm{IR}}(\mathrm{model})}$$



Casagrande, Portinari & Flynn (2006)

Casagrande, Ramírez, Meléndez, Bessell, Asplund (submitted) →

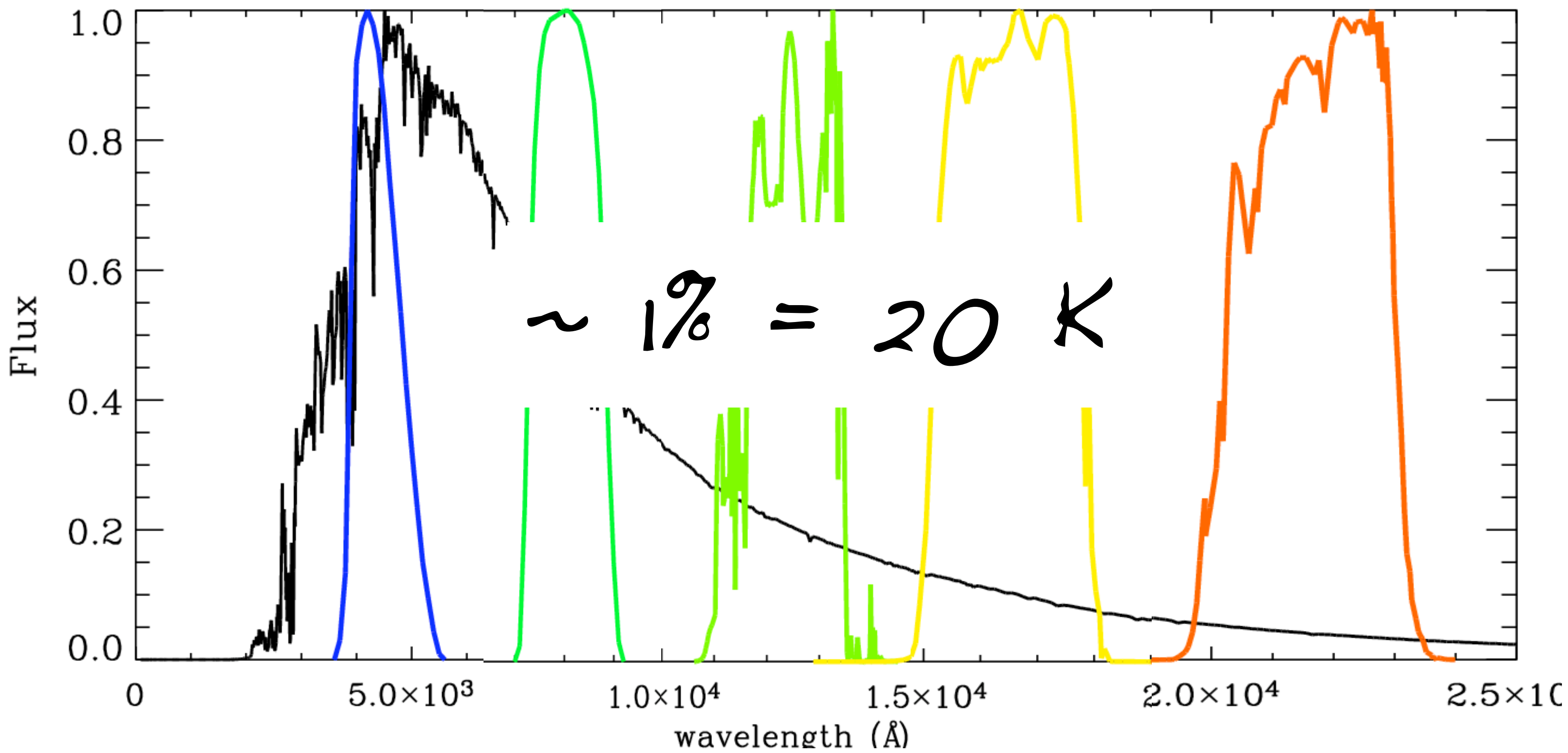
✓ HST absolute flux (*Bohlin 2007*)

✓ Solar Twins (*Meléndez et al. 2009*)

InfraRed Flux Method

Blackwell et al. (1977,1978,1979)

$$\frac{\mathcal{F}_{Bol}(\mathrm{Earth})}{\mathcal{F}_{\mathrm{IR}}(\mathrm{Earth})} = \frac{\sigma T_{\mathrm{eff}}^4}{\mathcal{F}_{\mathrm{IR}}(\mathrm{model})}$$



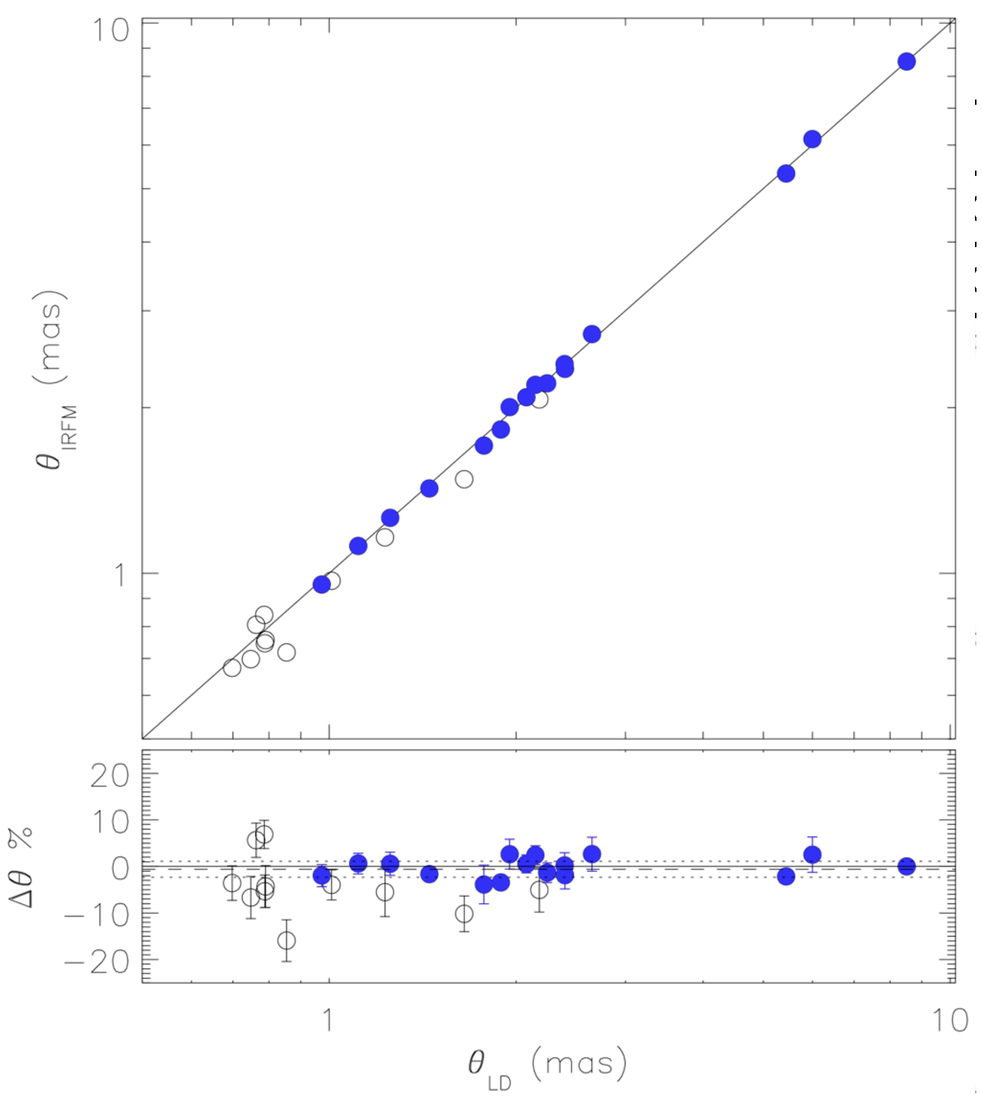
Casagrande, Portinari & Flynn (2006)

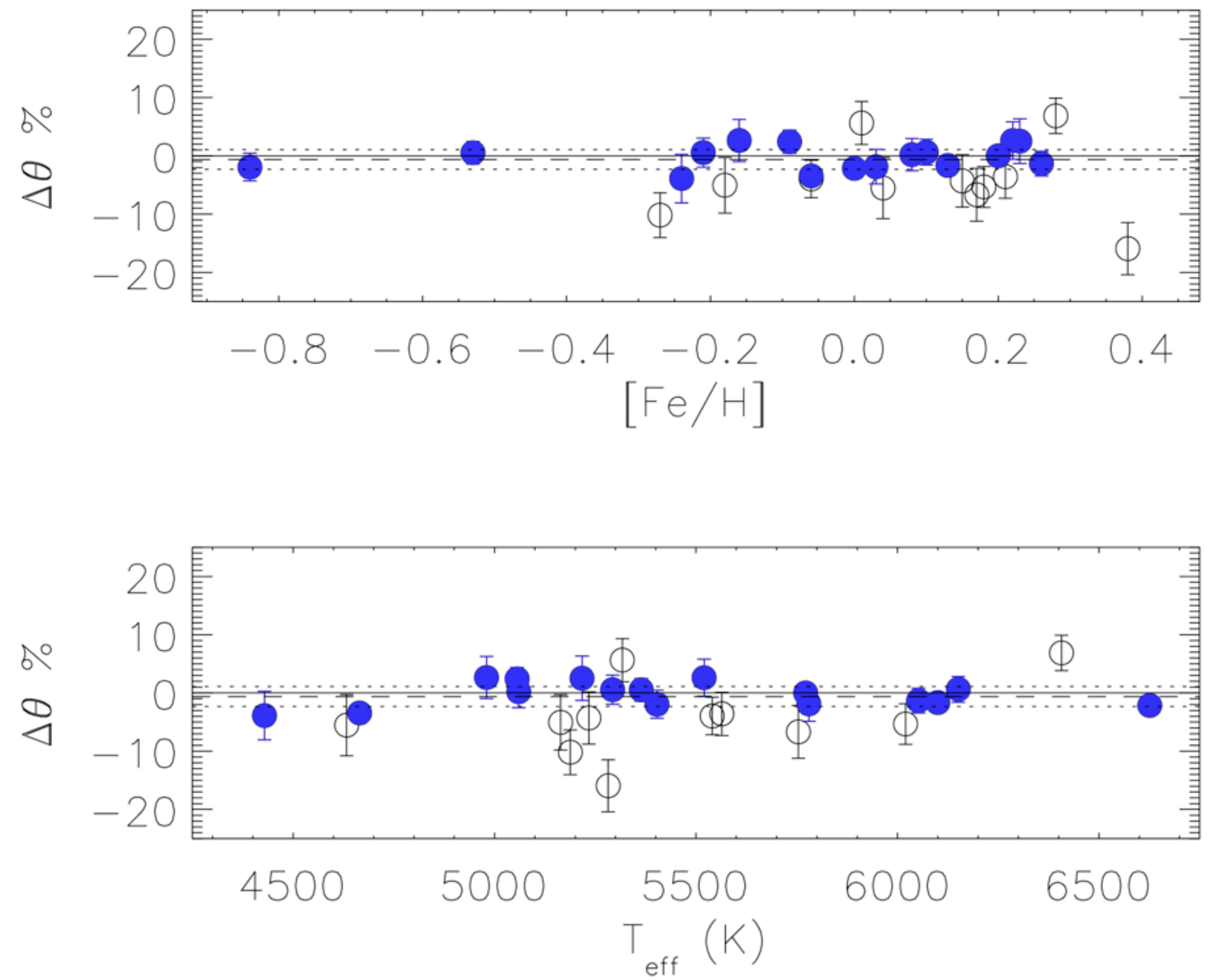
Casagrande, Ramírez, Meléndez, Bessell, Asplund (submitted) →

✓ HST absolute flux (*Bohlin 2007*)

✓ Solar Twins (*Meléndez et al. 2009*)

Absolutely calibrated $T_{\rm eff}$ scale

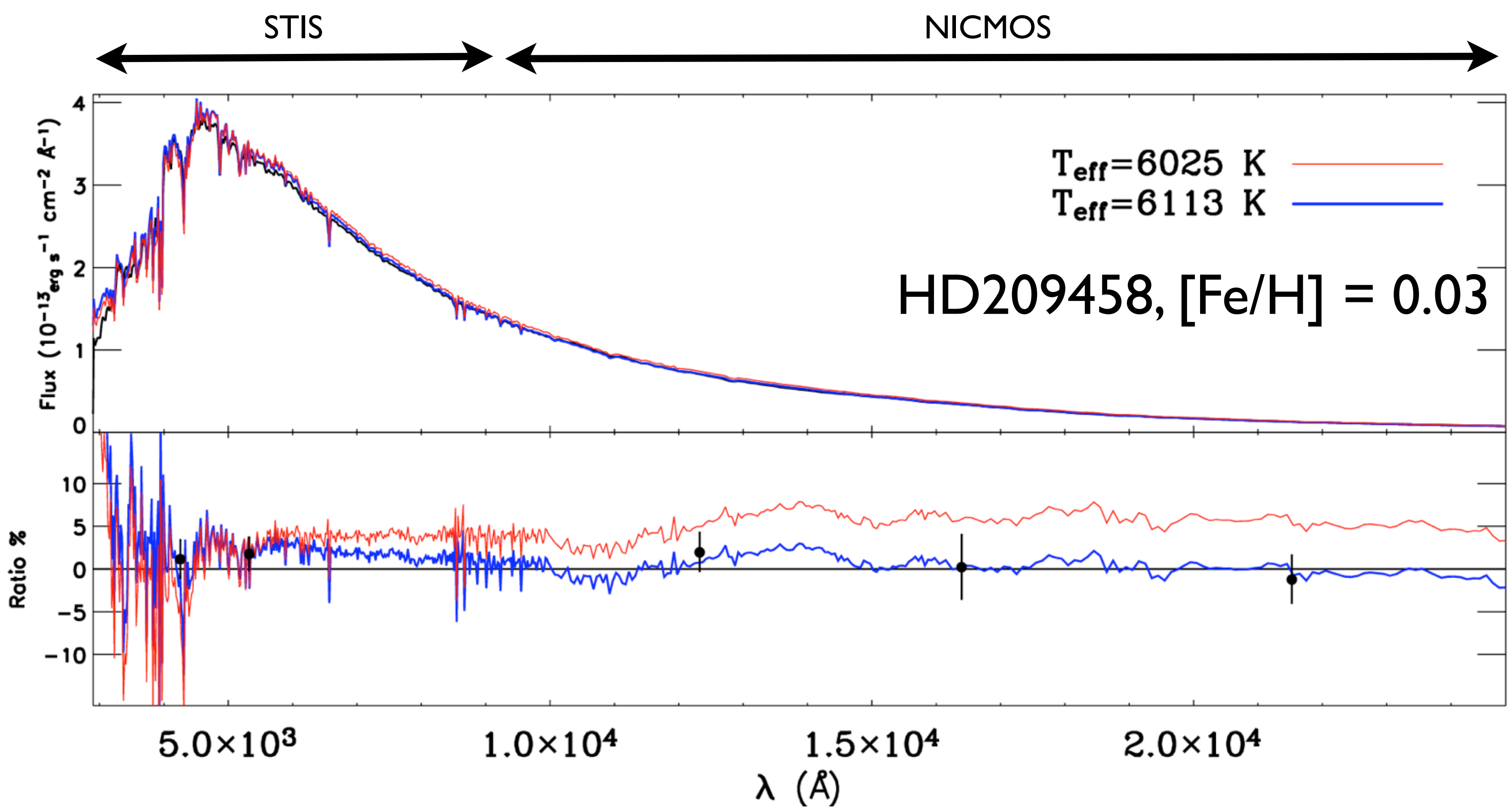


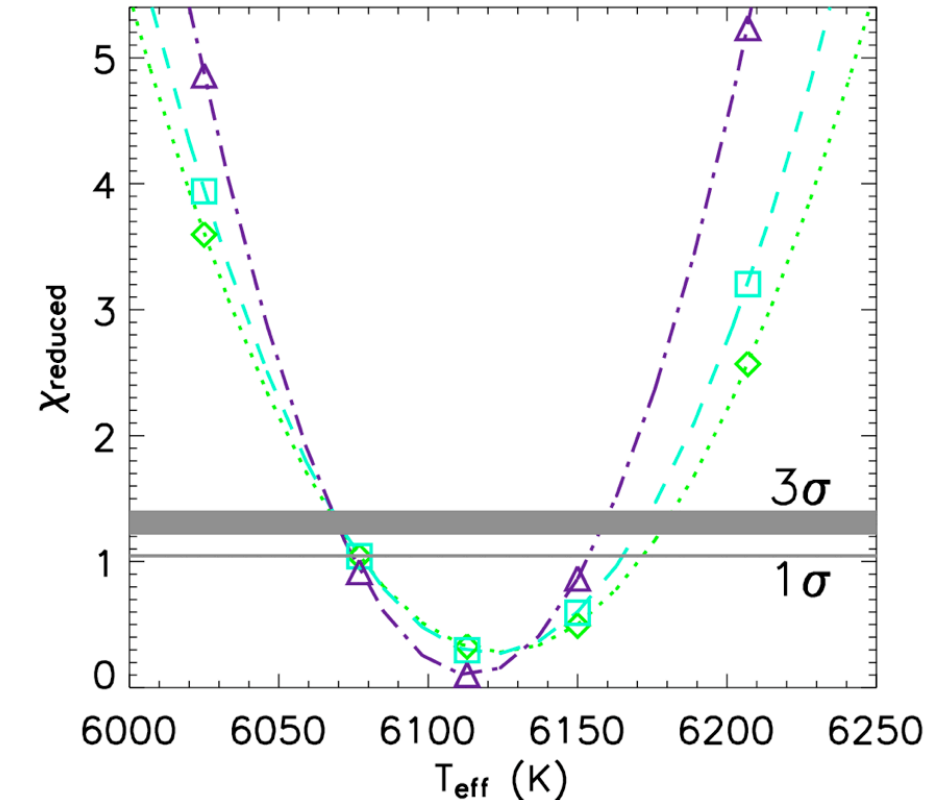


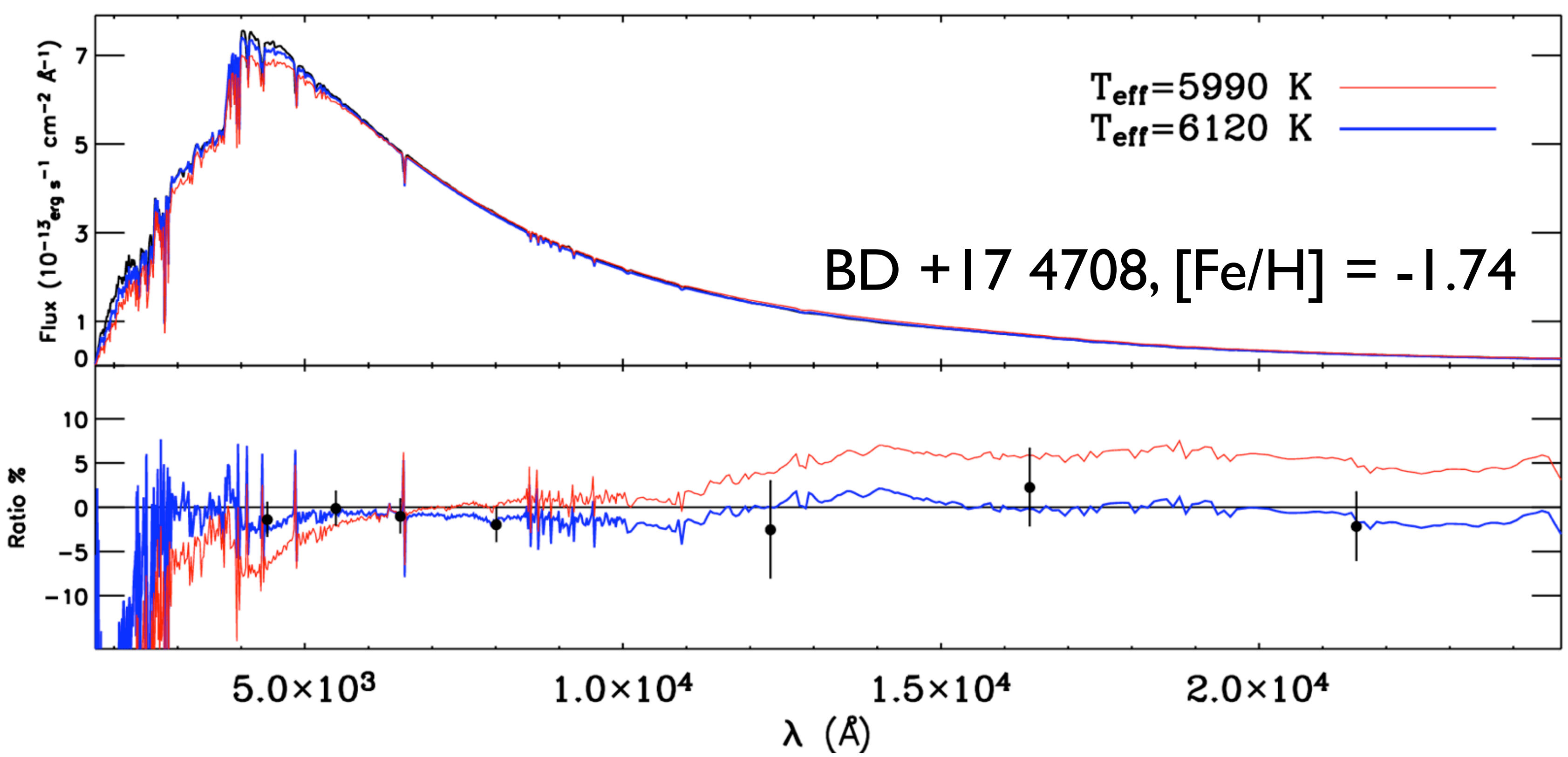
$$\Delta\theta = -0.6 \pm 1.7\% \longrightarrow \Delta T_{\rm eff} = 18 \pm 50{\rm K}$$

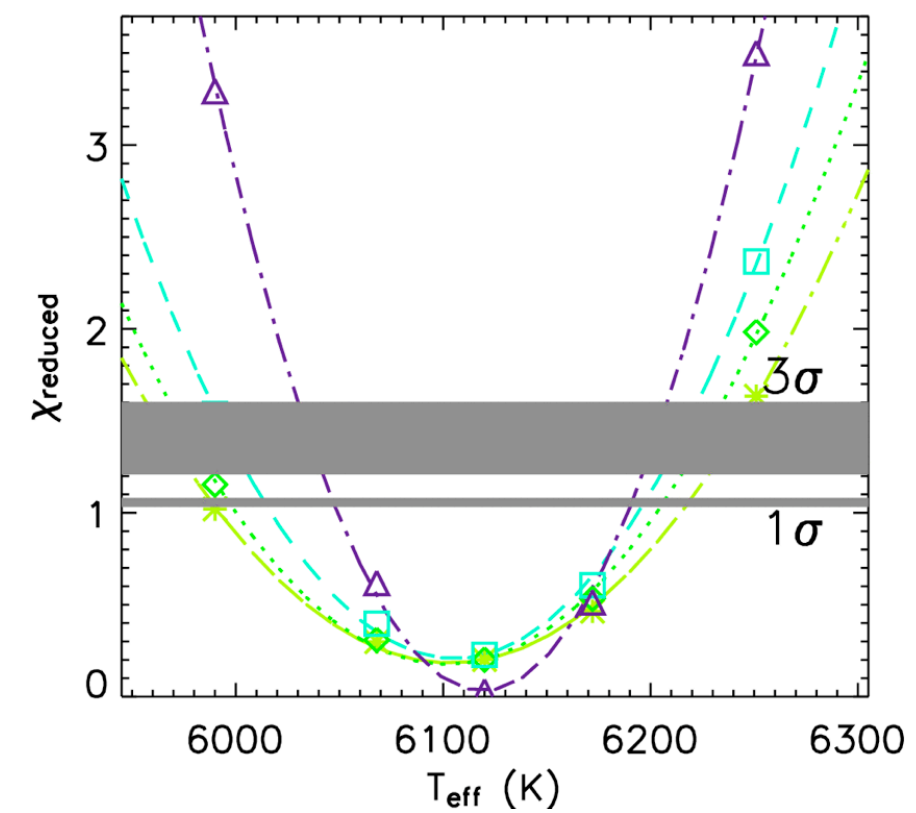
Casagrande, Ramírez, Meléndez, Bessell, Asplund (submitted)

HST Spectro-photometry



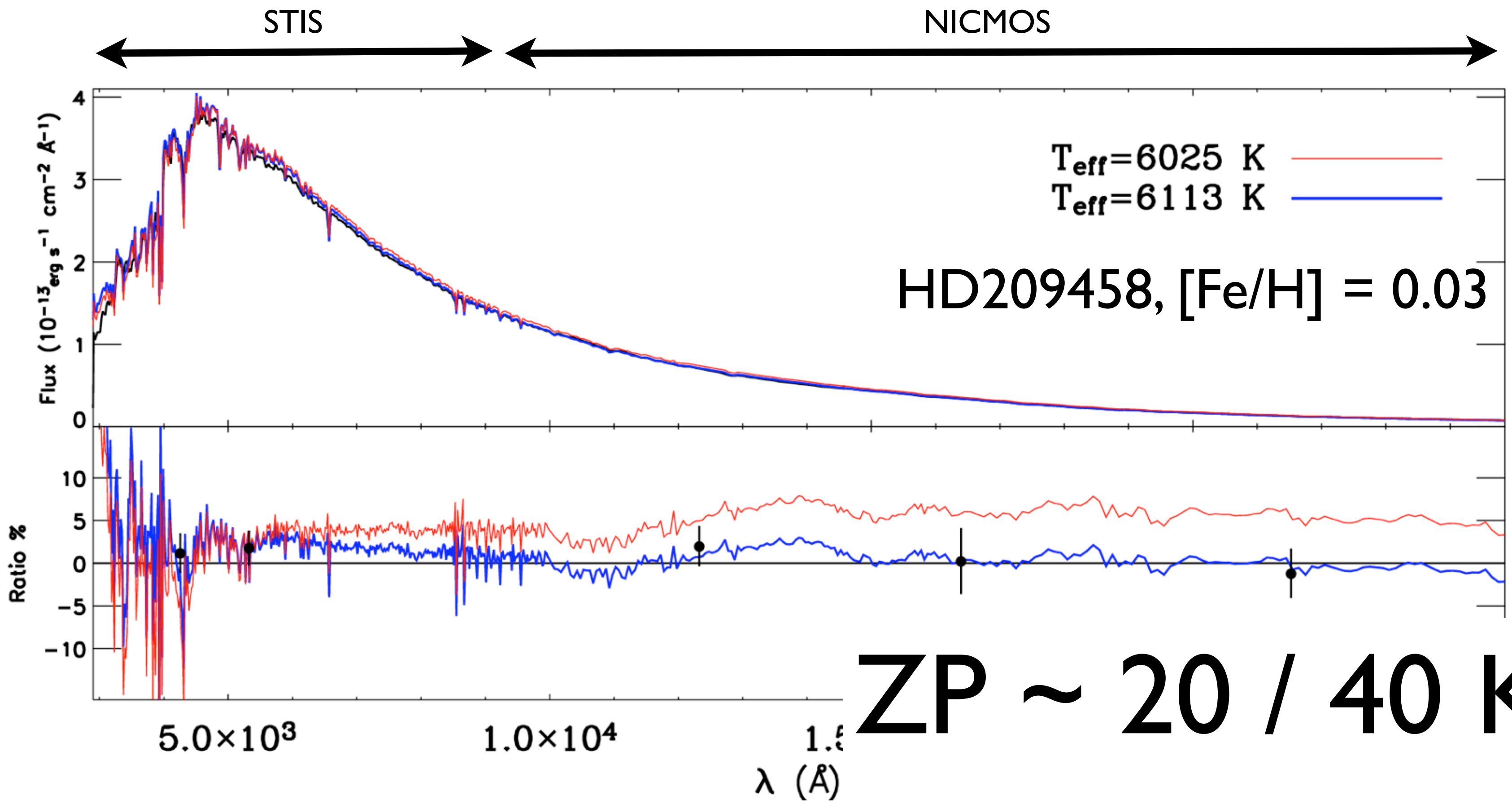




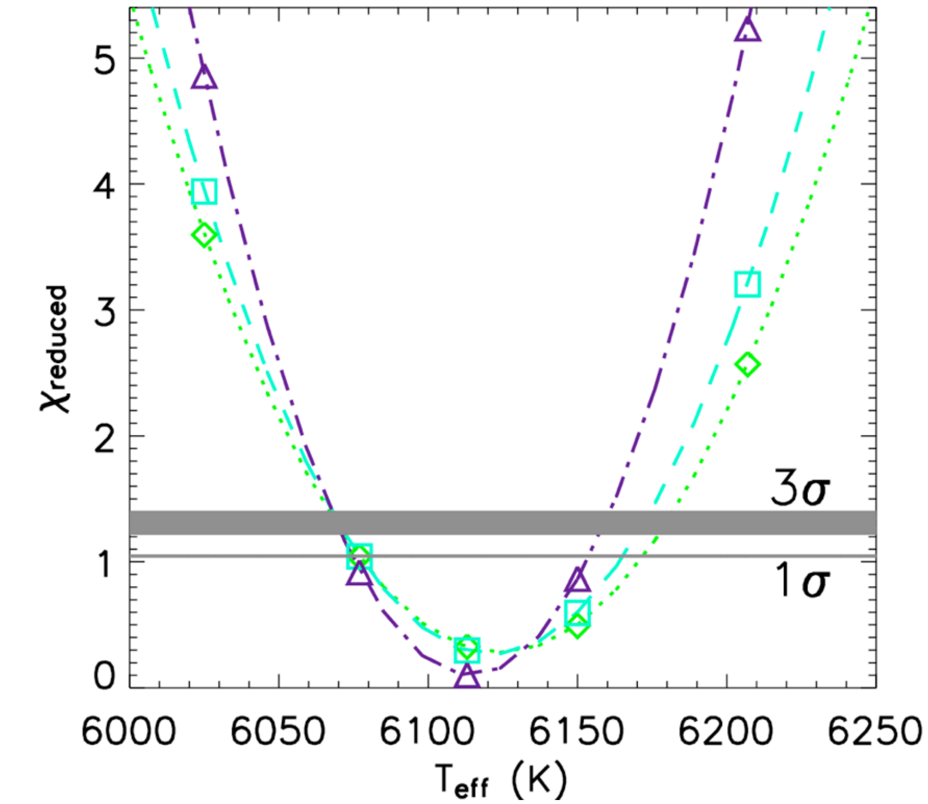


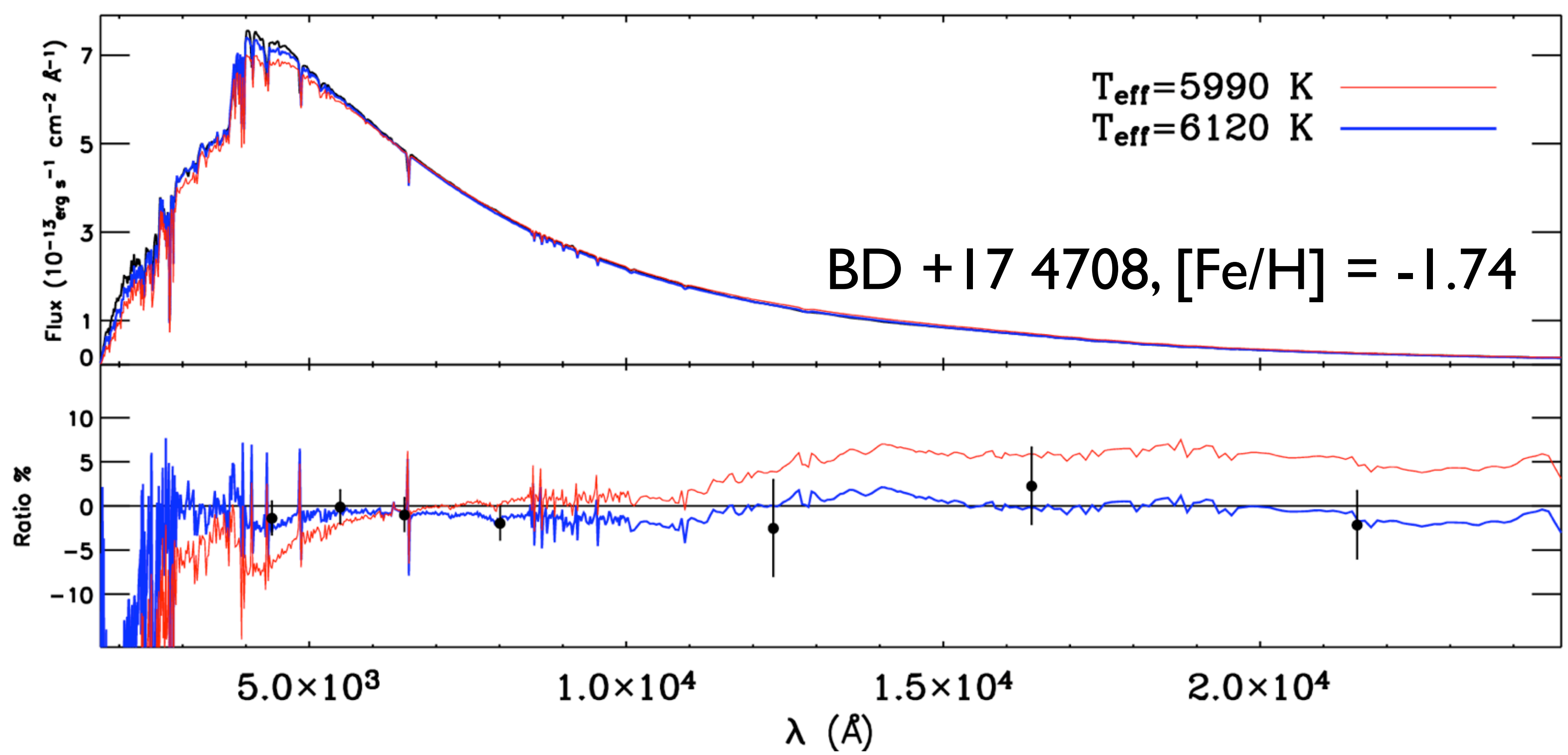
Casagrande, Ramírez, Meléndez, Bessell, Asplund (submitted)

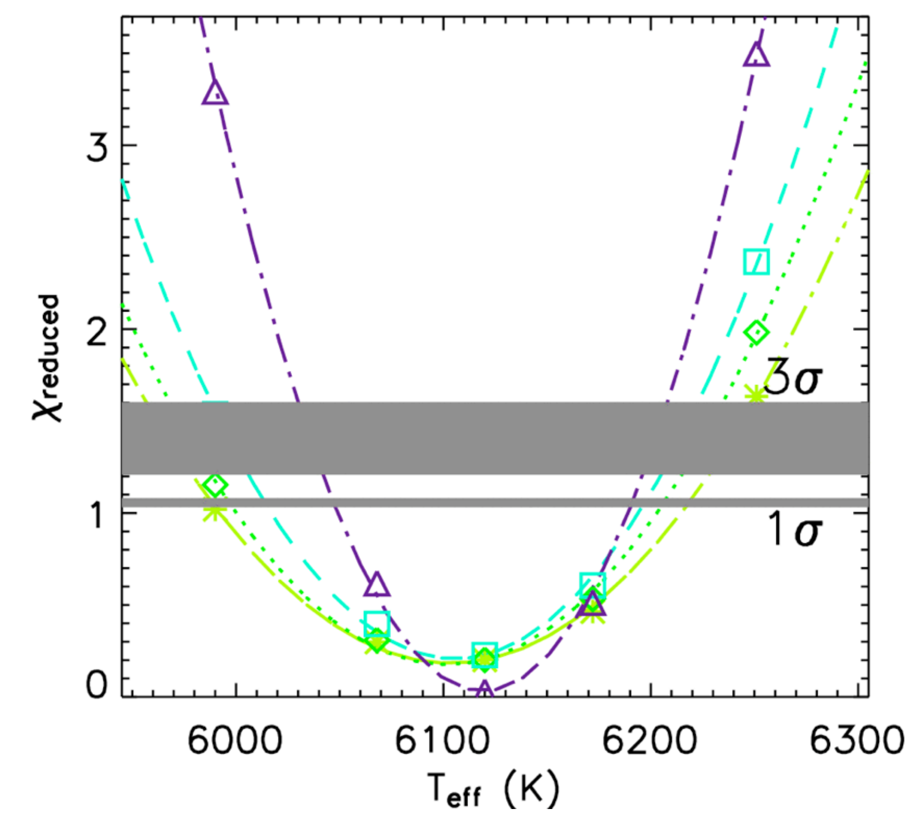
HST Spectro-photometry



ZP ~ 20 / 40 K



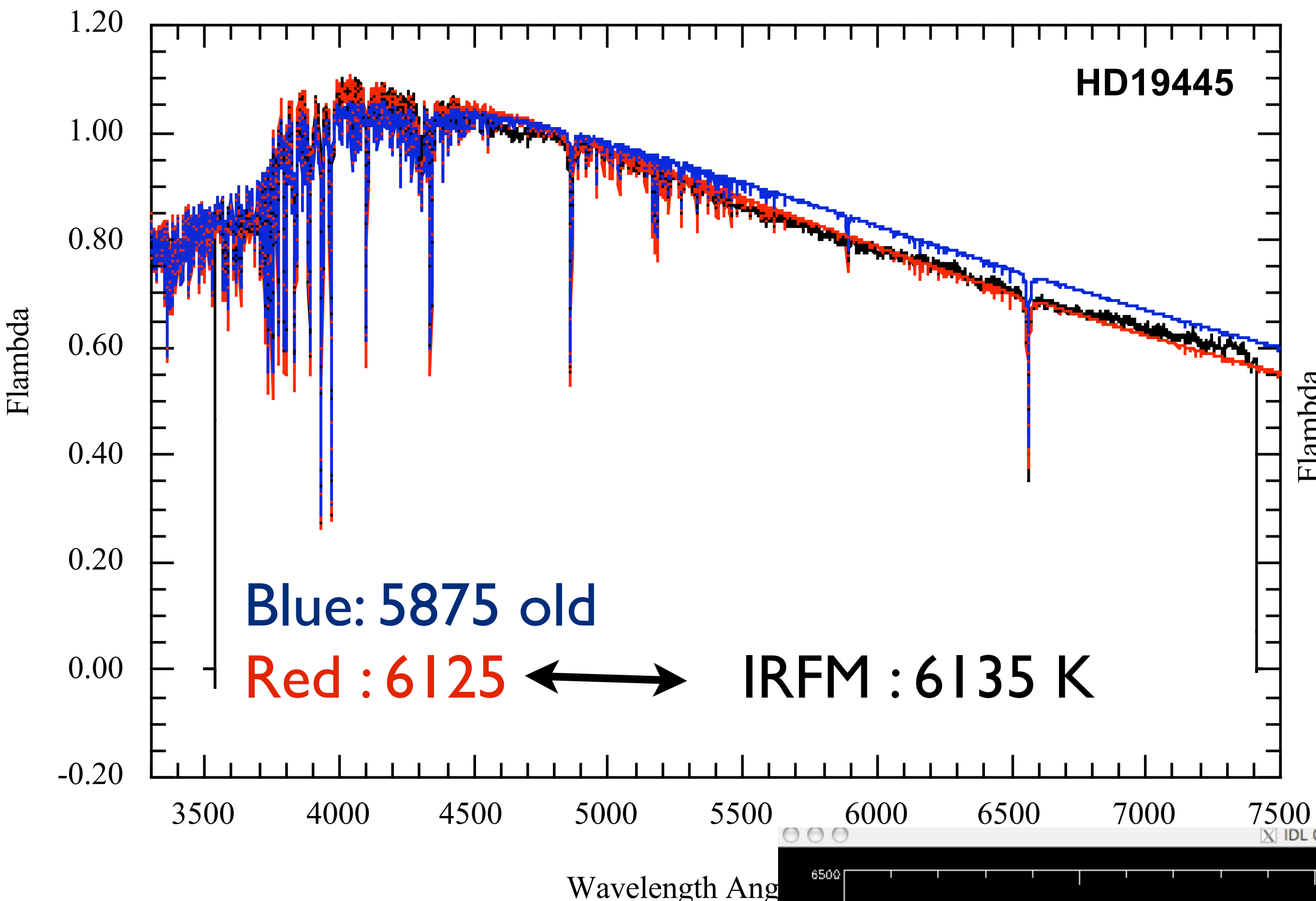


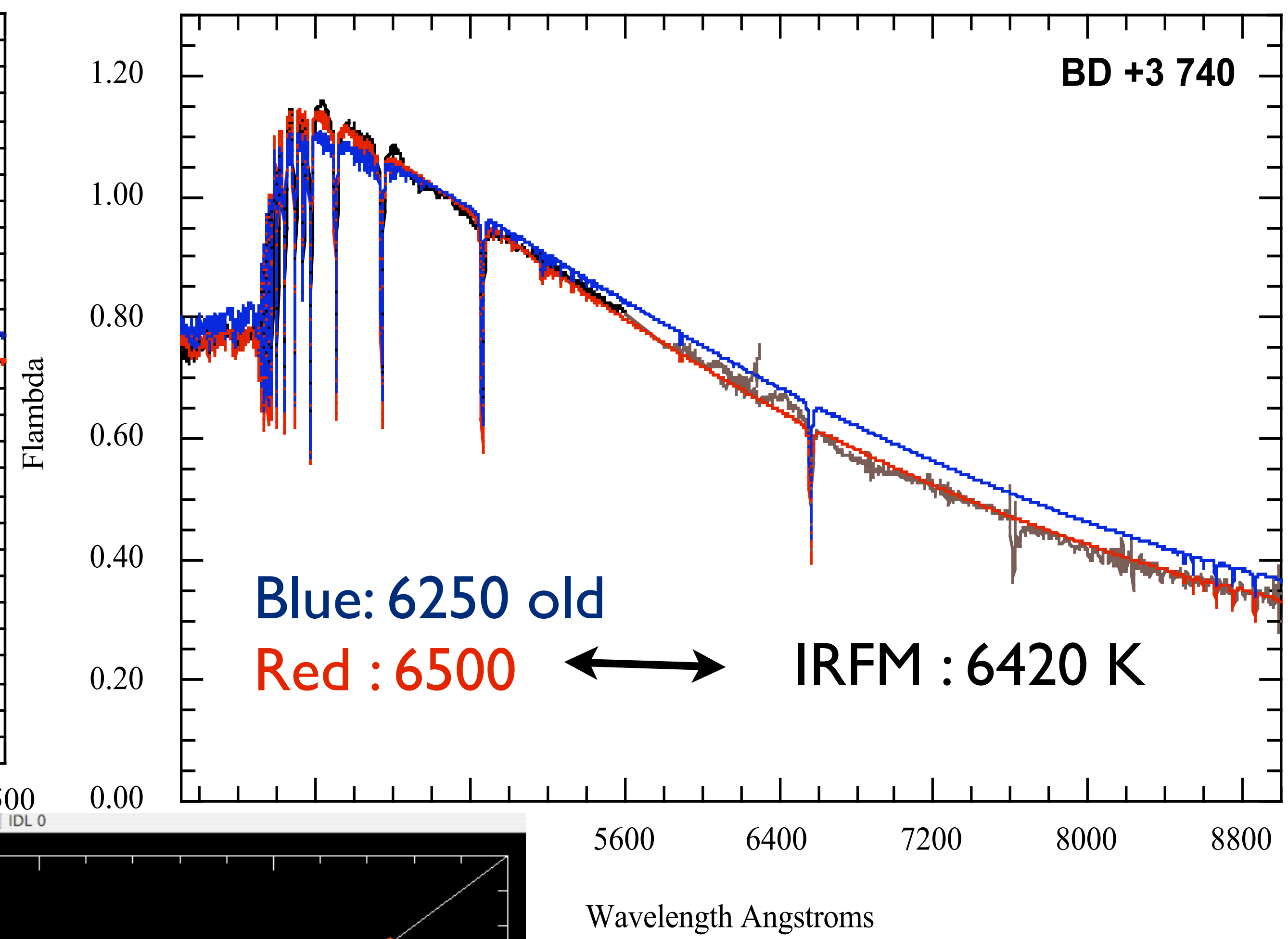


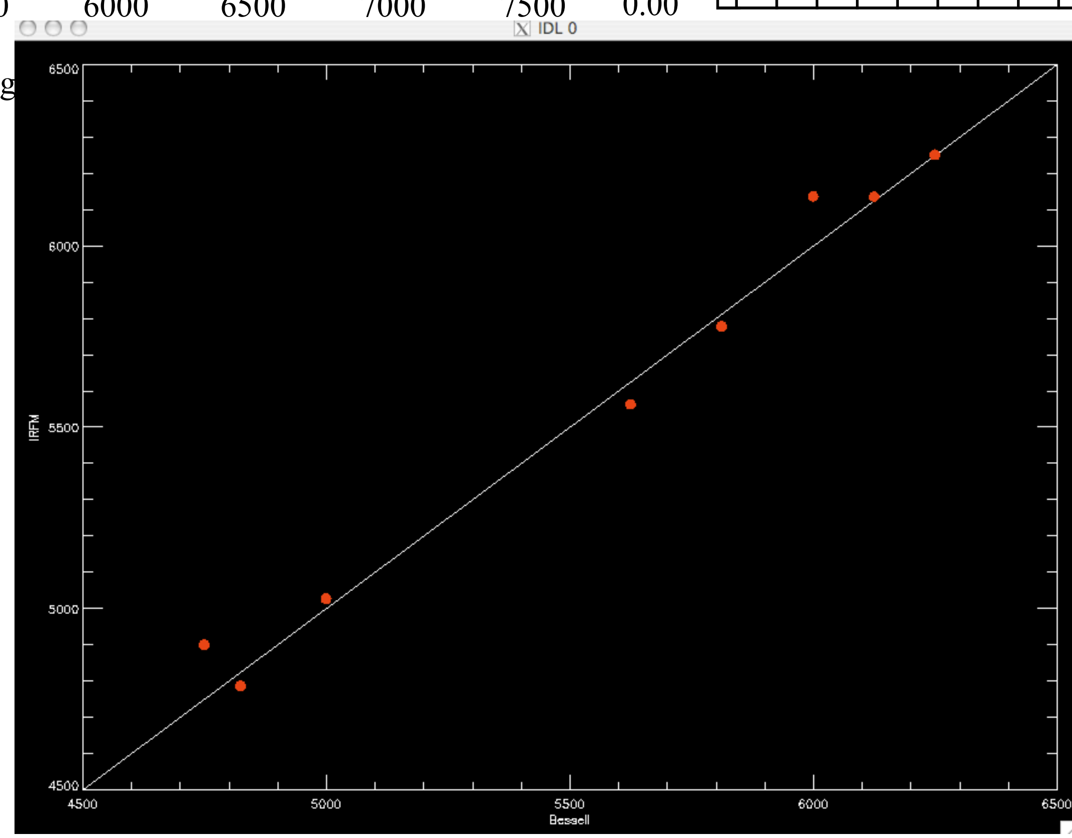
Casagrande, Ramírez, Meléndez, Bessell, Asplund (submitted)

More Spectro-photometry

M. Bessell (private comm.)



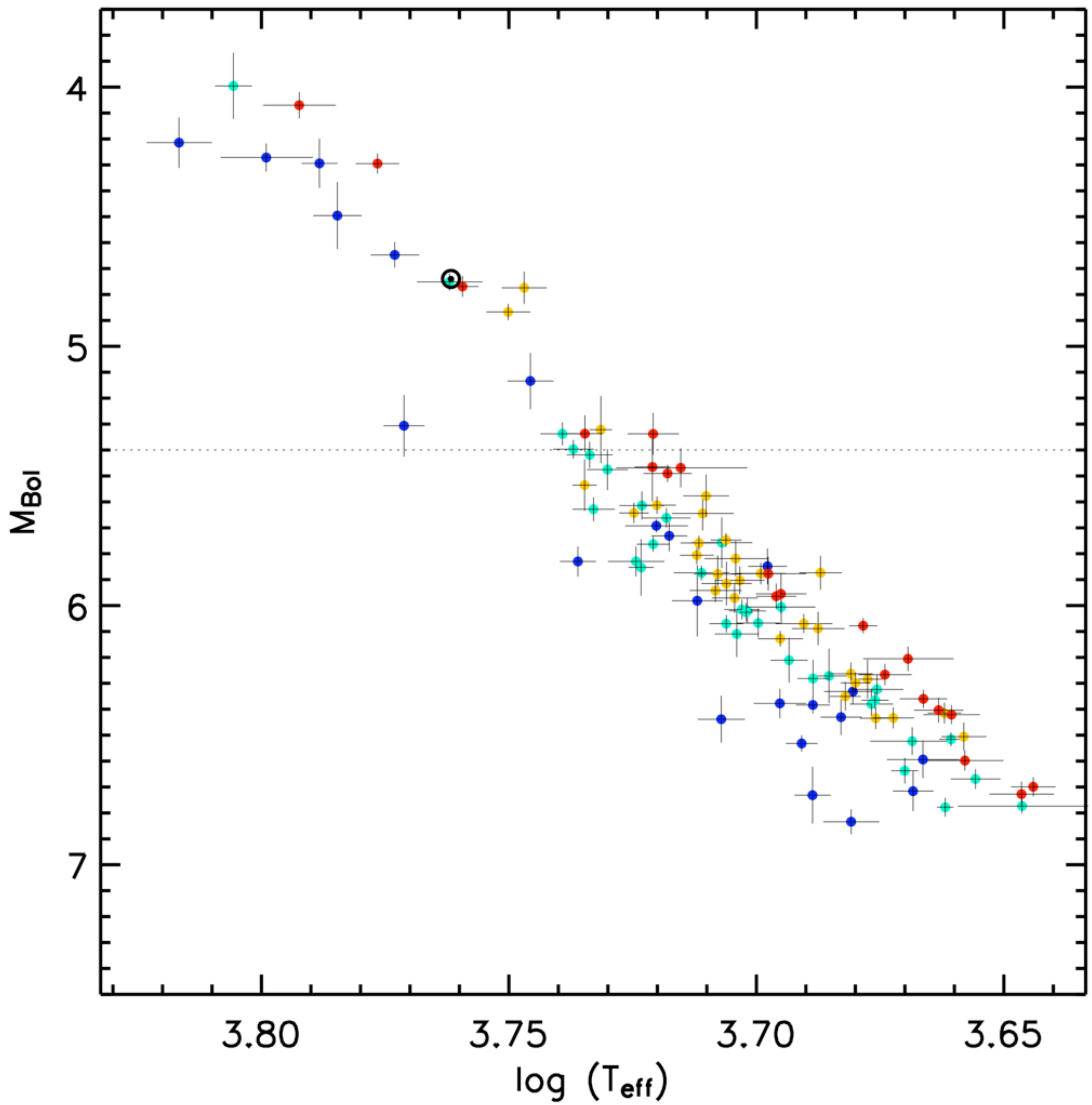




- Melendez's talk : Spite plateau

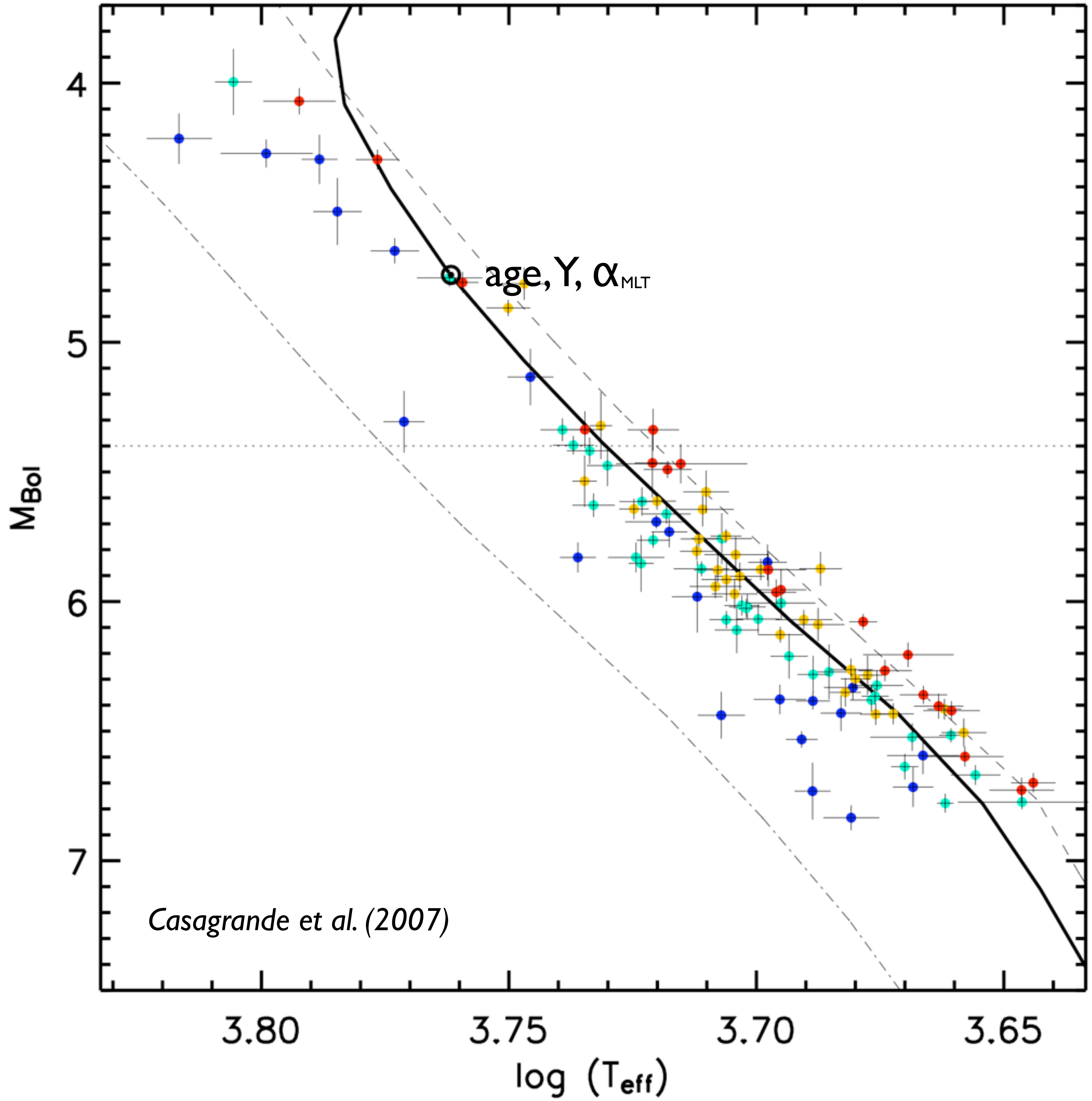
- Friday, 12:05 - 12.50, Discussion D

Broadening low MS



Effect of helium more prominent in theoretical HRD (*Castellani et al. 1999*)

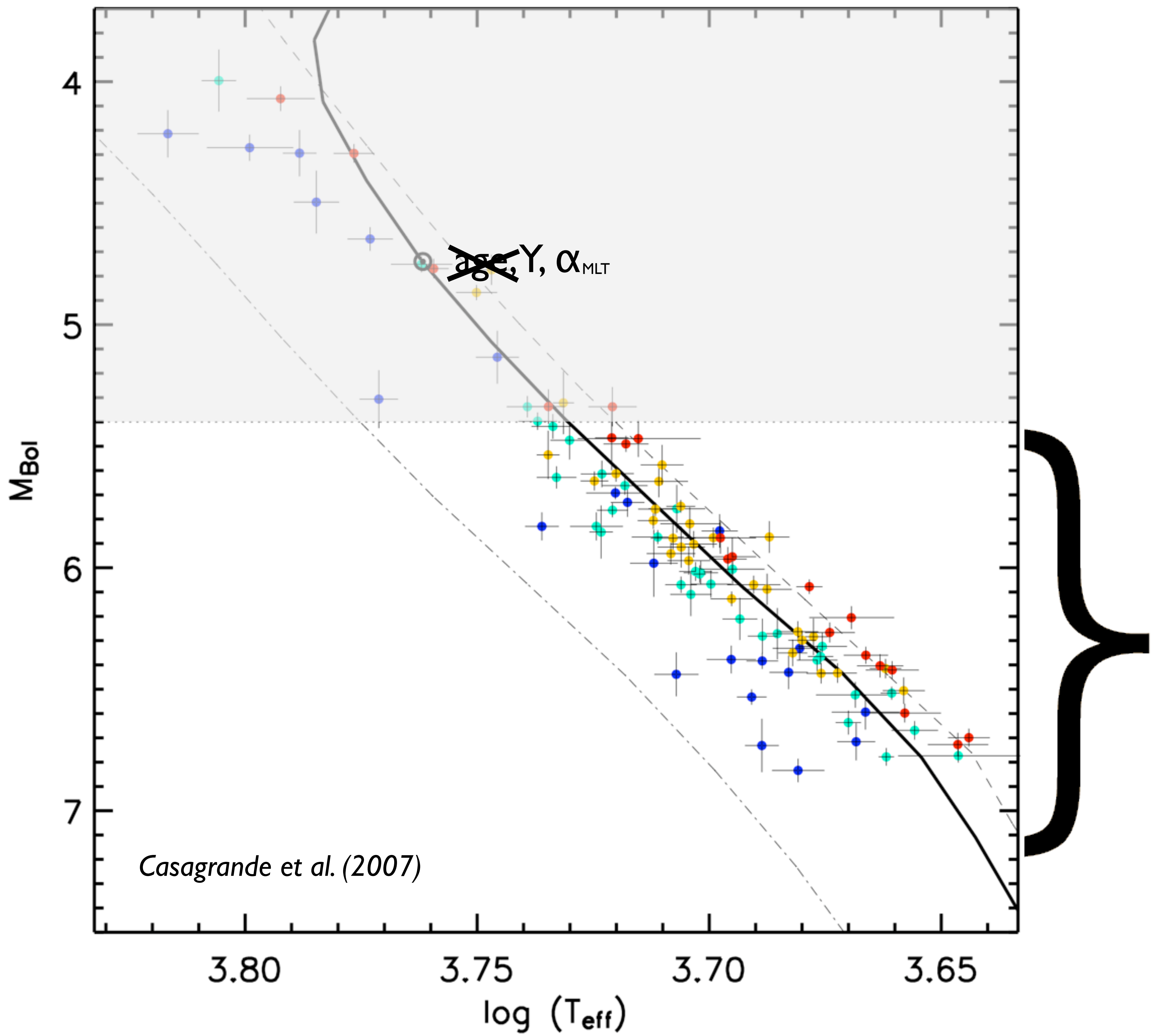
Broadening low MS



Effect of helium more prominent in theoretical HRD (*Castellani et al. 1999*)

Extended grid in Y,Z (Padova isochrones, *Bertelli et al. 2008*)

Broadening low MS



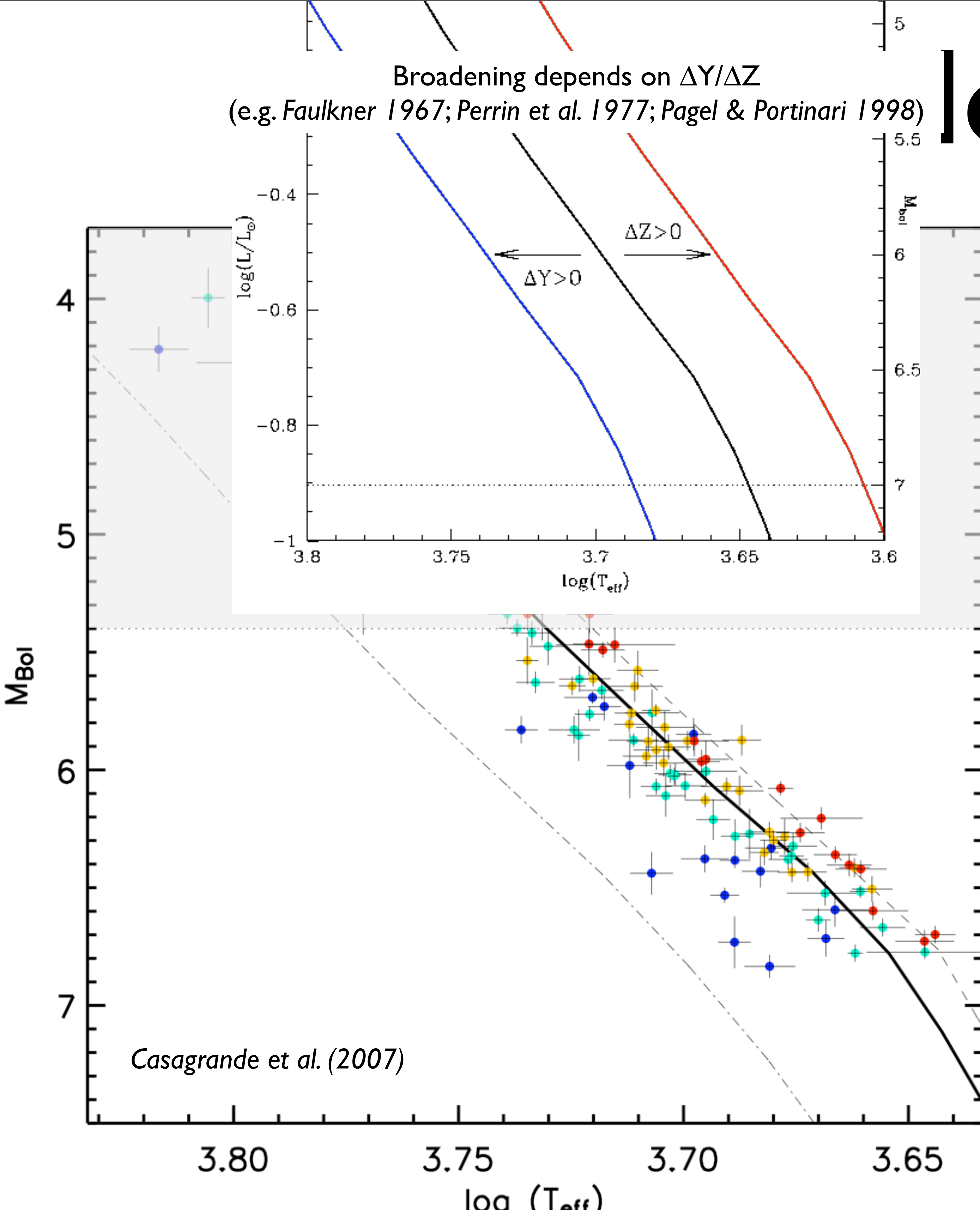
Effect of helium more prominent in theoretical HRD (*Castellani et al. 1999*)

Extended grid in Y,Z (Padova isochrones, *Bertelli et al. 2008*)

- 86 stars
- spectroscopic -1.8 < [Fe/H] < 0.34
- T_{eff}, M_{Bol} from IRFM
- Parallaxes better 6%

low MS

Broadening depends on ΔY/ΔZ
(e.g. *Faulkner 1967; Perrin et al. 1977; Pagel & Portinari 1998*)

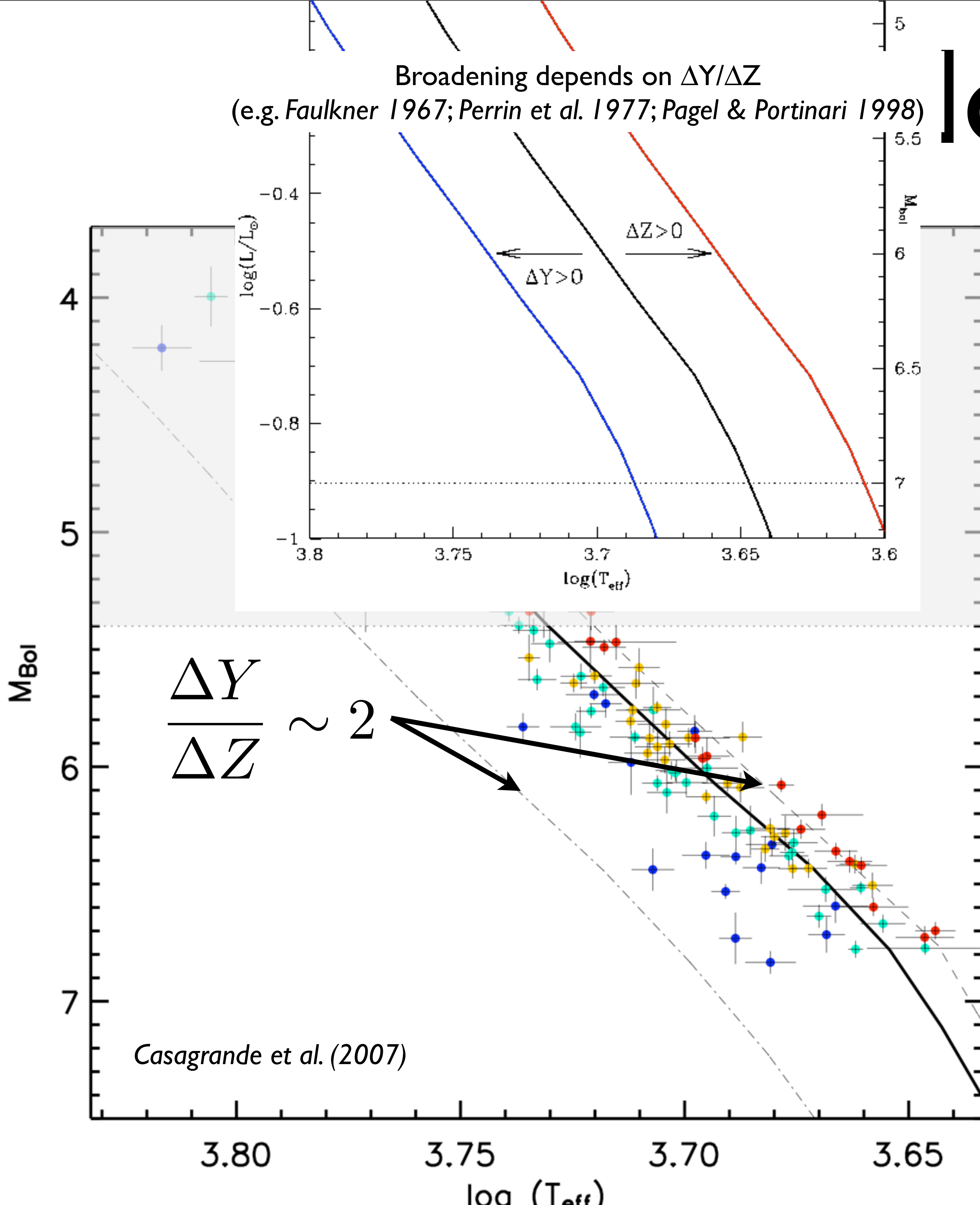


Effect of helium more prominent in theoretical HRD (*Castellani et al. 1999*)

Extended grid in Y,Z (Padova isochrones, *Bertelli et al. 2008*)

- 86 stars
- spectroscopic -1.8 < [Fe/H] < 0.34
- T_{eff}, M_{Bol} from IRFM
- Parallaxes better 6%

low MS

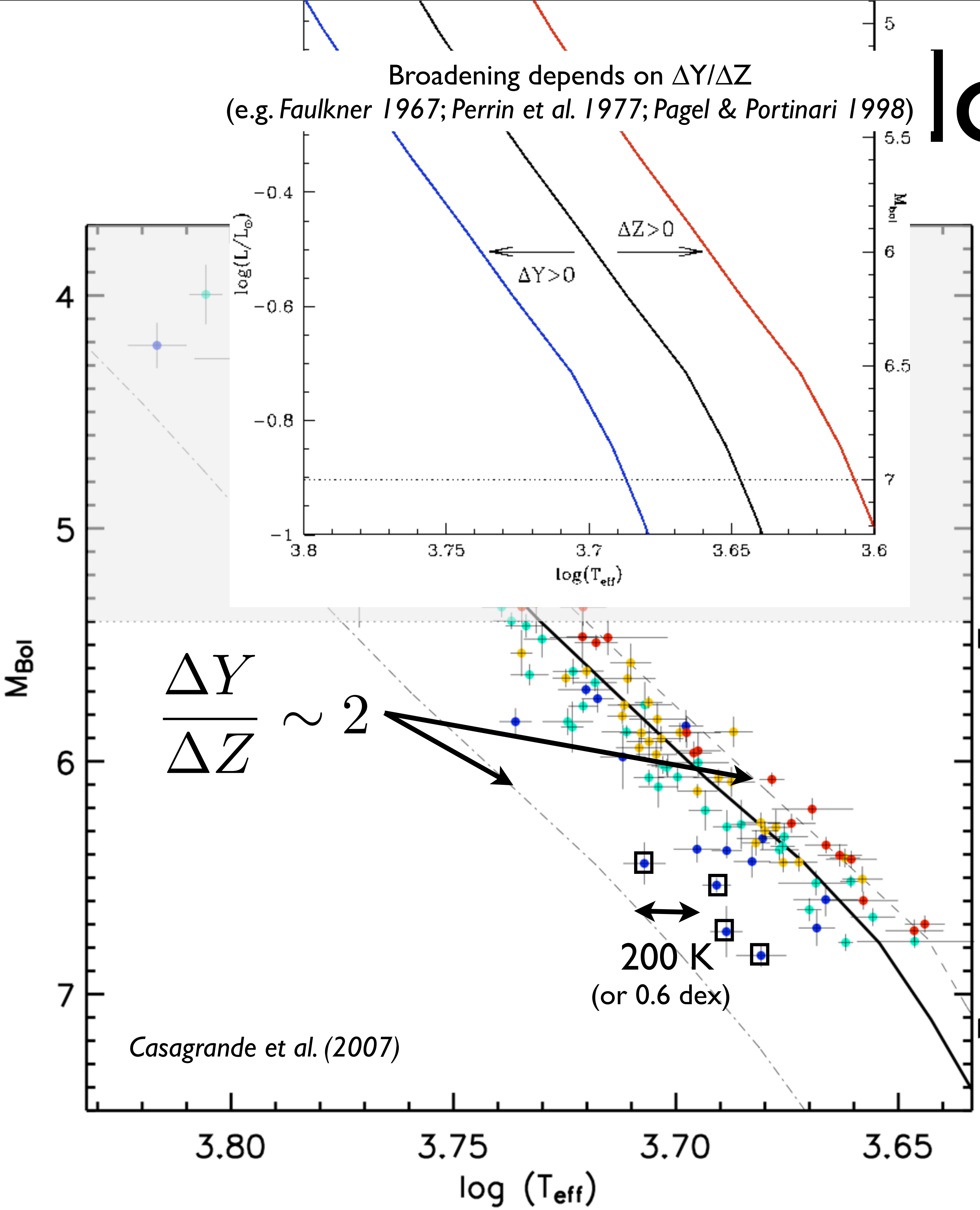


Effect of helium more prominent in theoretical HRD (*Castellani et al. 1999*)

Extended grid in Y,Z (Padova isochrones, *Bertelli et al. 2008*)

- 86 stars
- spectroscopic -1.8 < [Fe/H] < 0.34
- T_{eff}, M_{Bol} from IRFM
- Parallaxes better 6%

...low MS

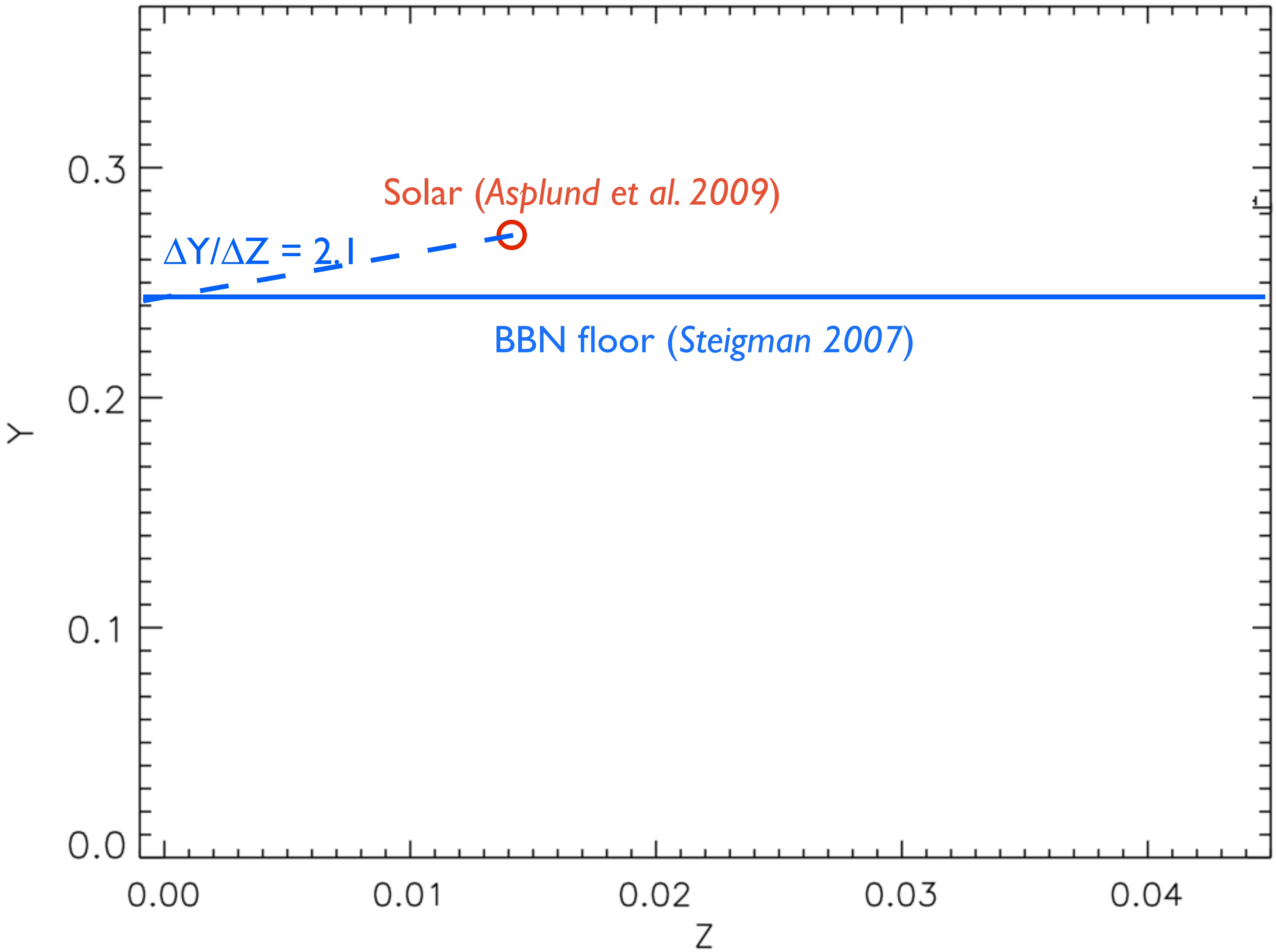


Effect of helium more prominent in theoretical HRD (*Castellani et al. 1999*)

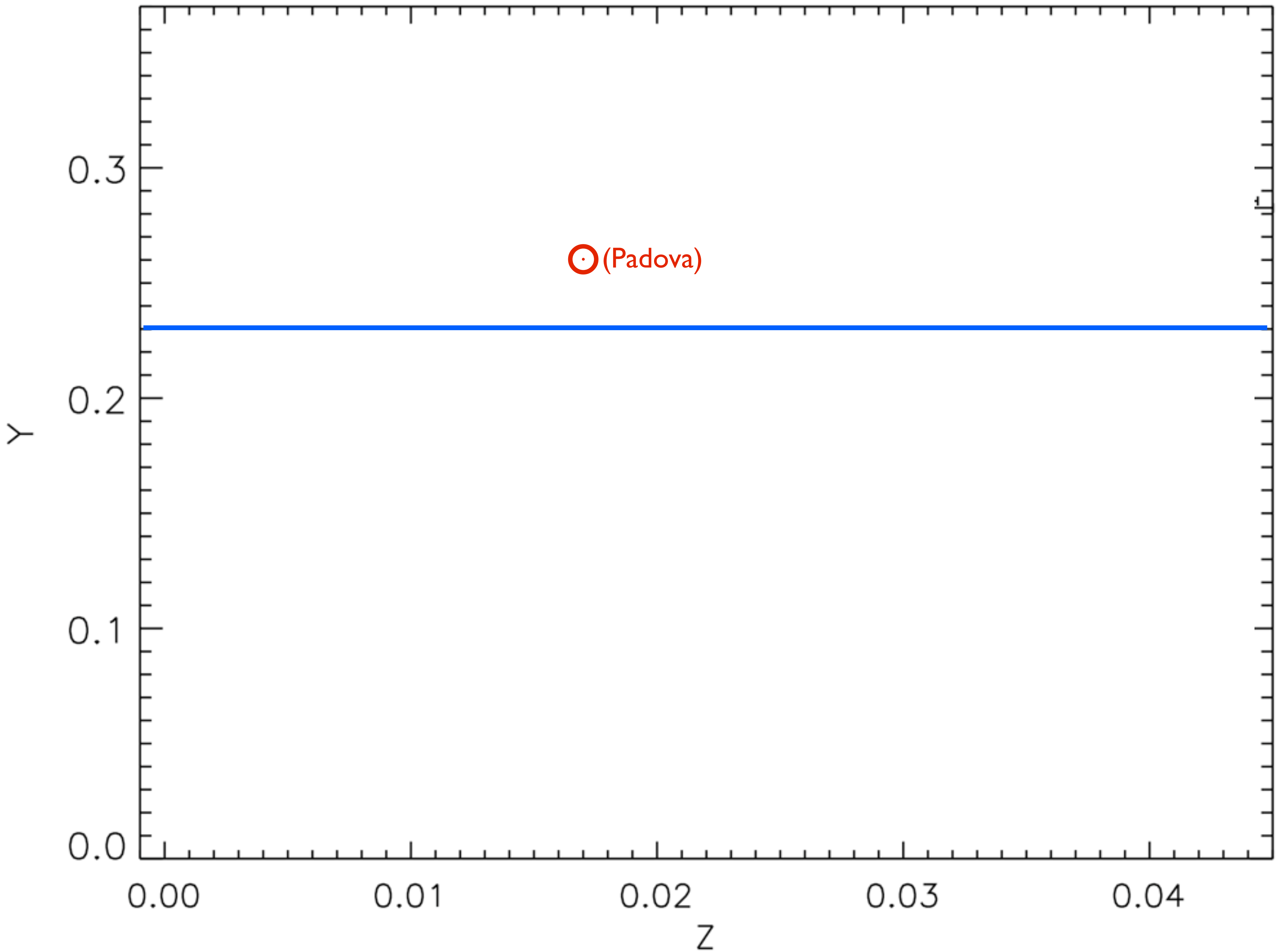
Extended grid in Y,Z (Padova isochrones, *Bertelli et al. 2008*)

- 86 stars
- spectroscopic -1.8 < [Fe/H] < 0.34
- T_{eff}, M_{Bol} from IRFM
- Parallaxes better 6%

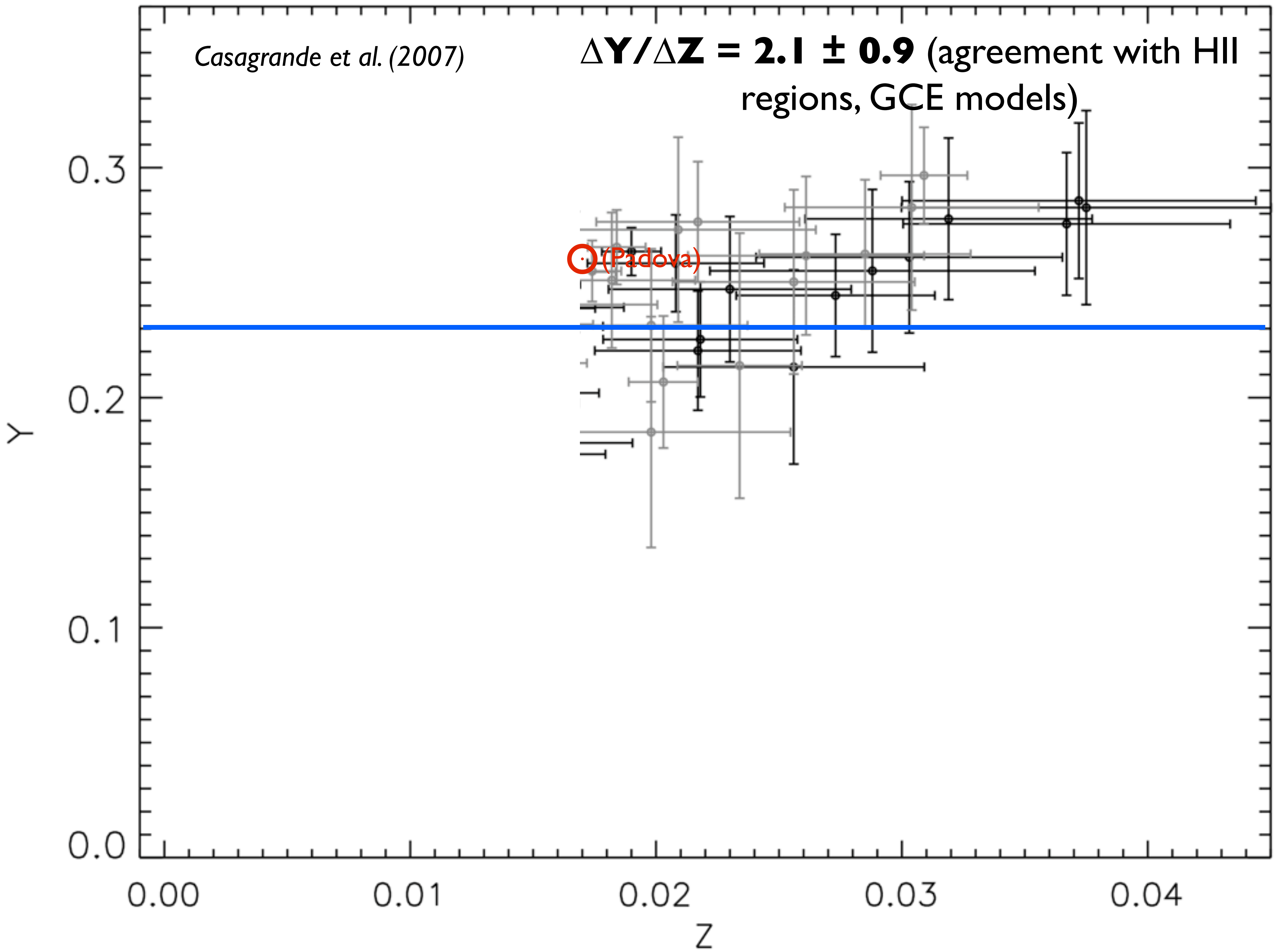
Y in nearby stars



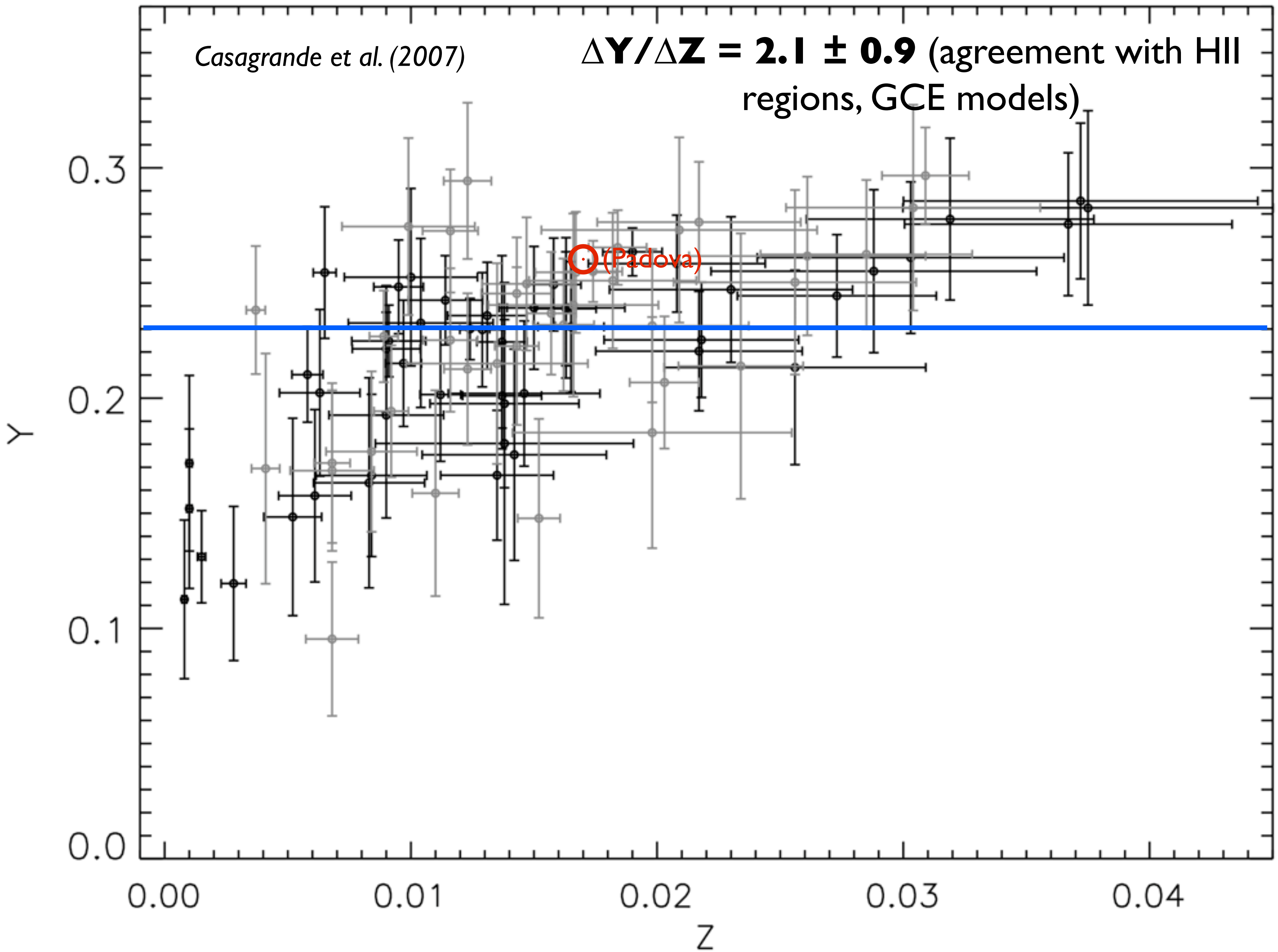
Y in nearby stars



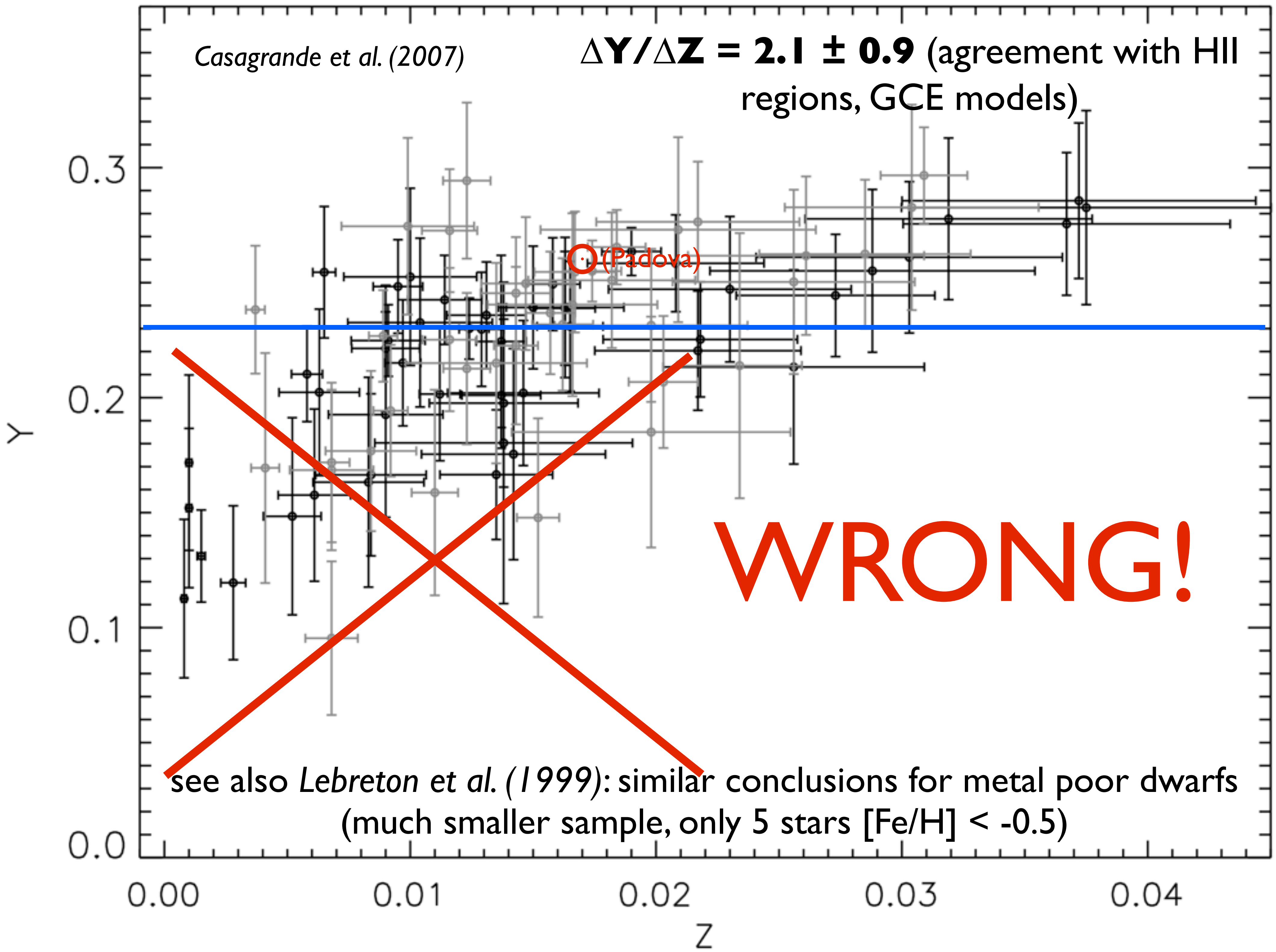
Y in nearby stars



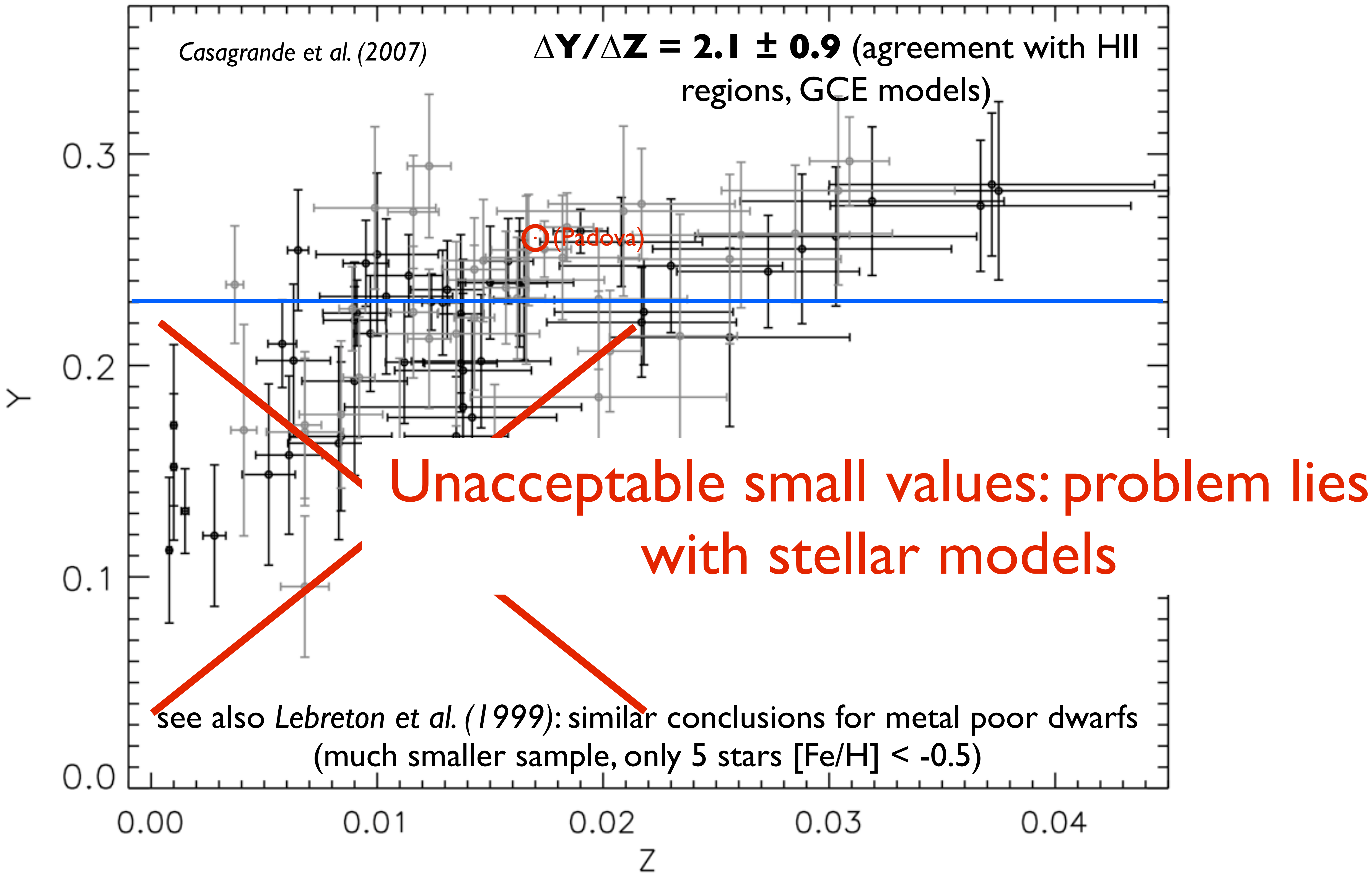
Y in nearby stars

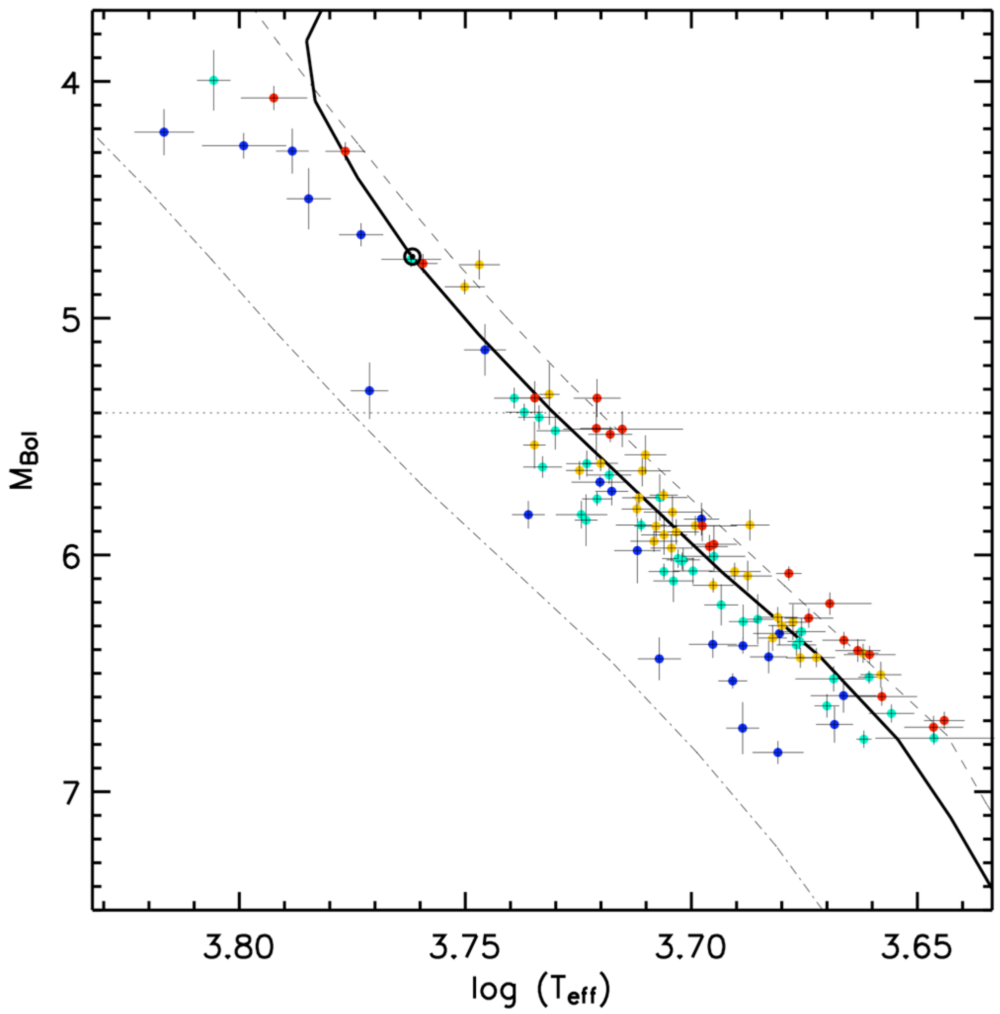


Y in nearby stars

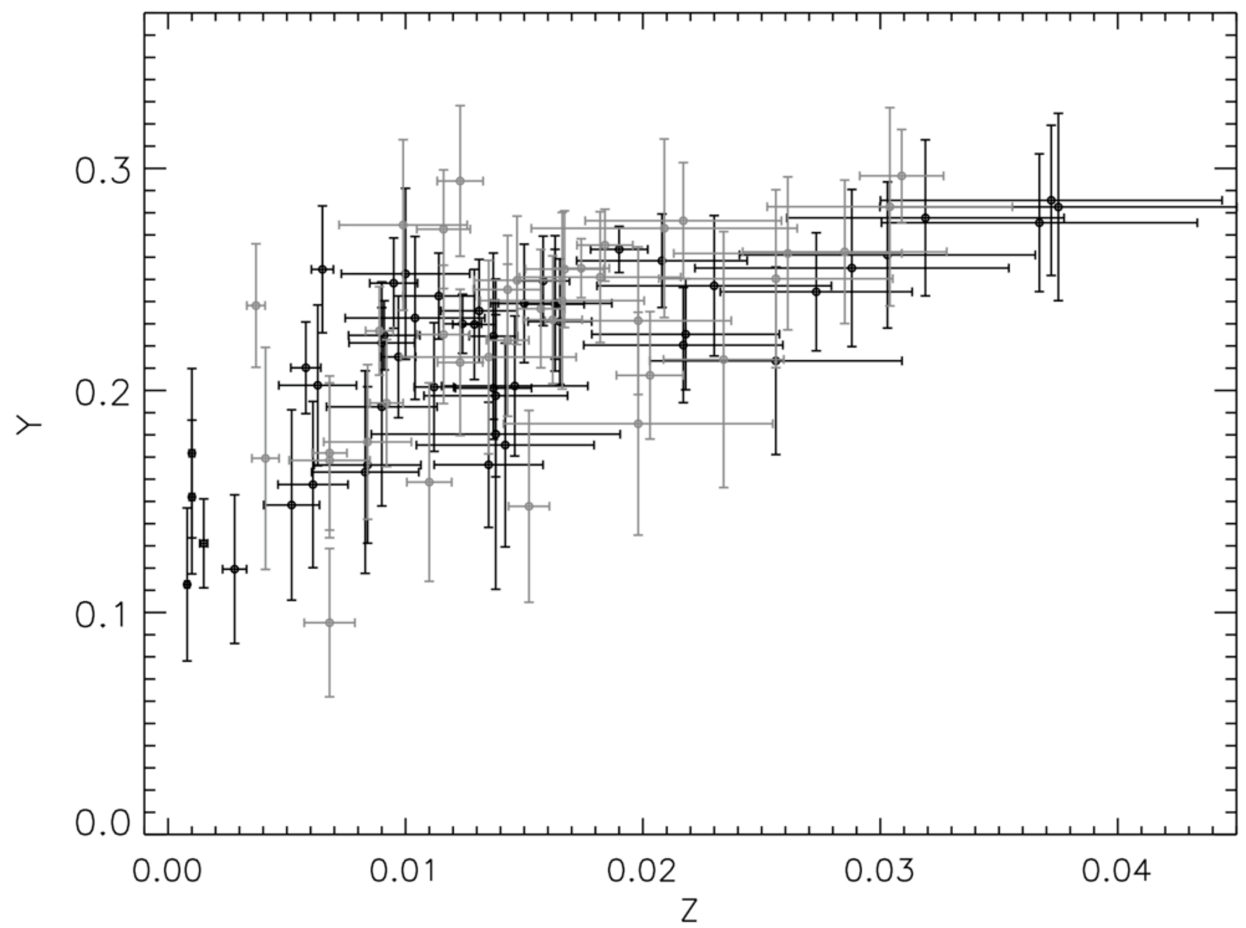


Y in nearby stars

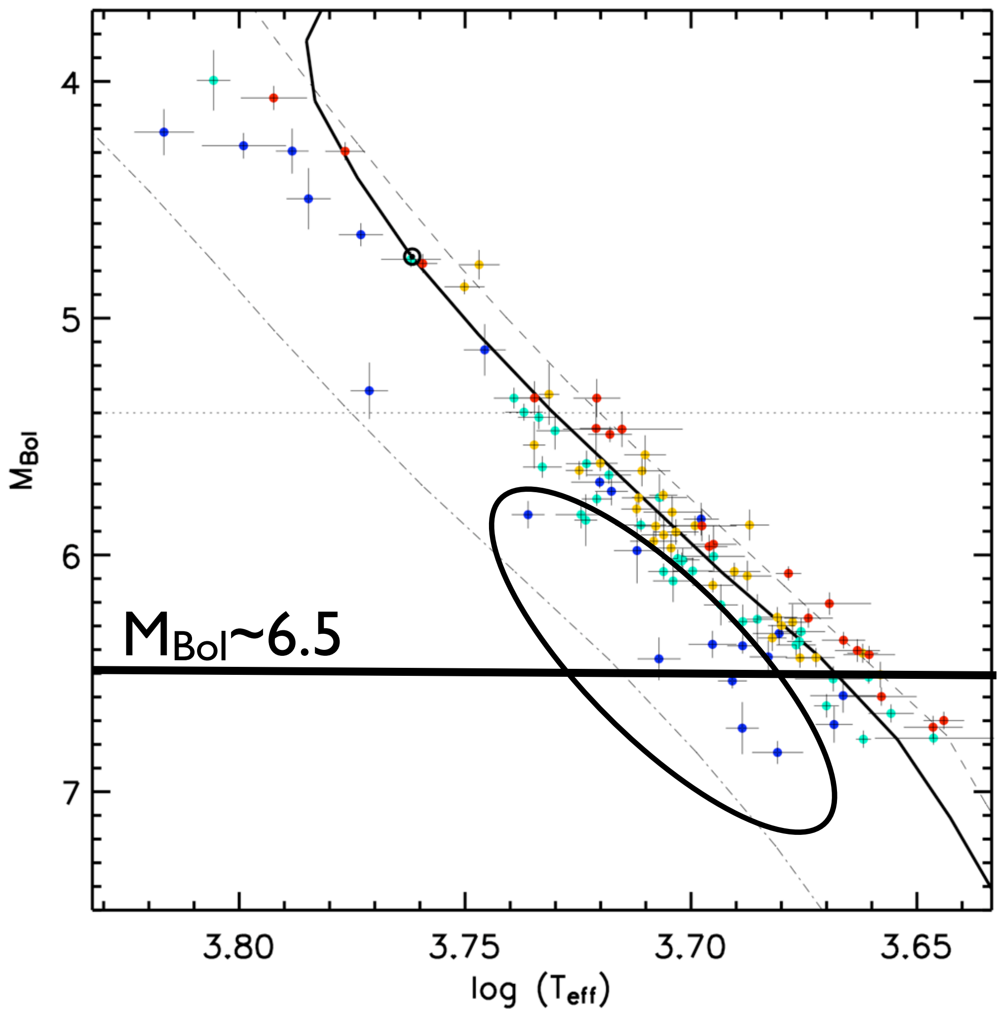


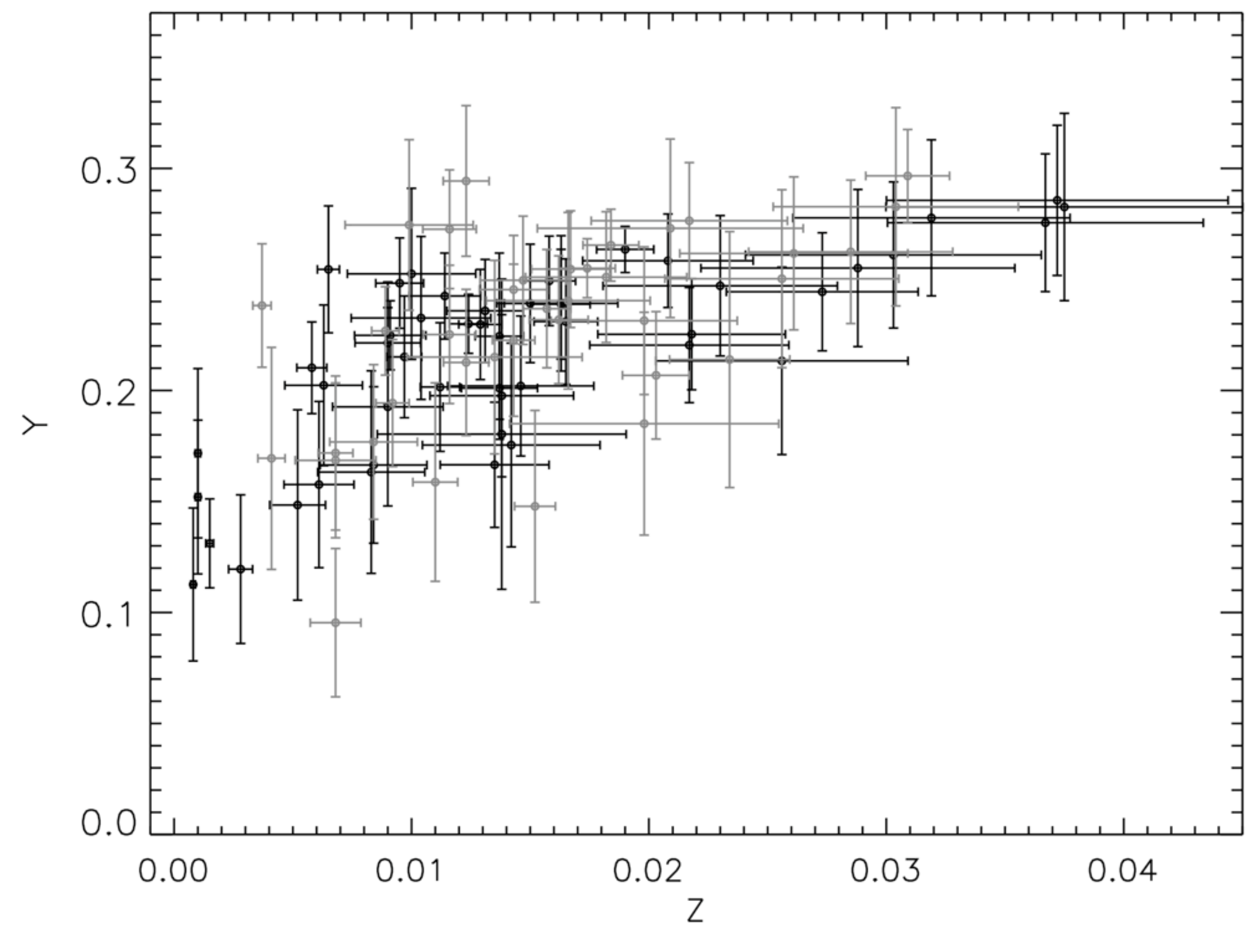


M_Bol
4
5
6
7
3.80
3.75
3.70
3.65
log (T_eff)

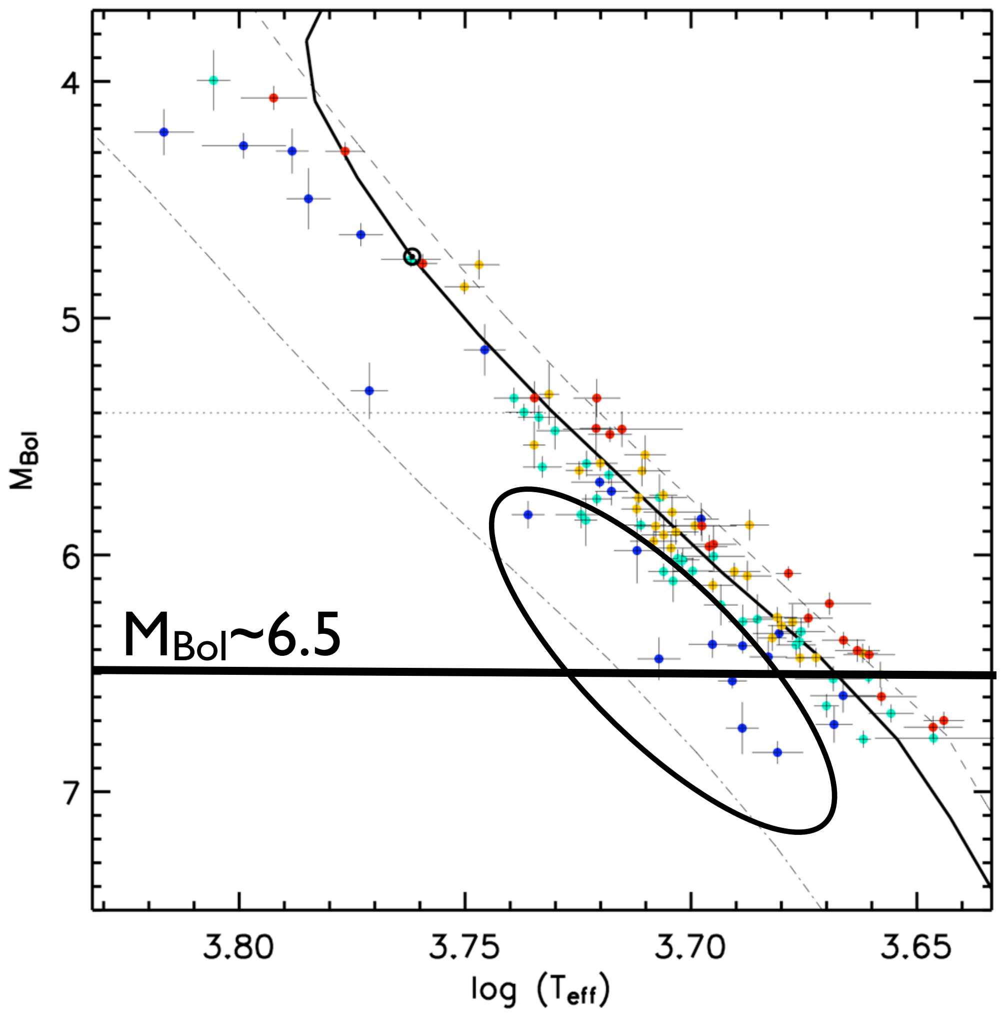


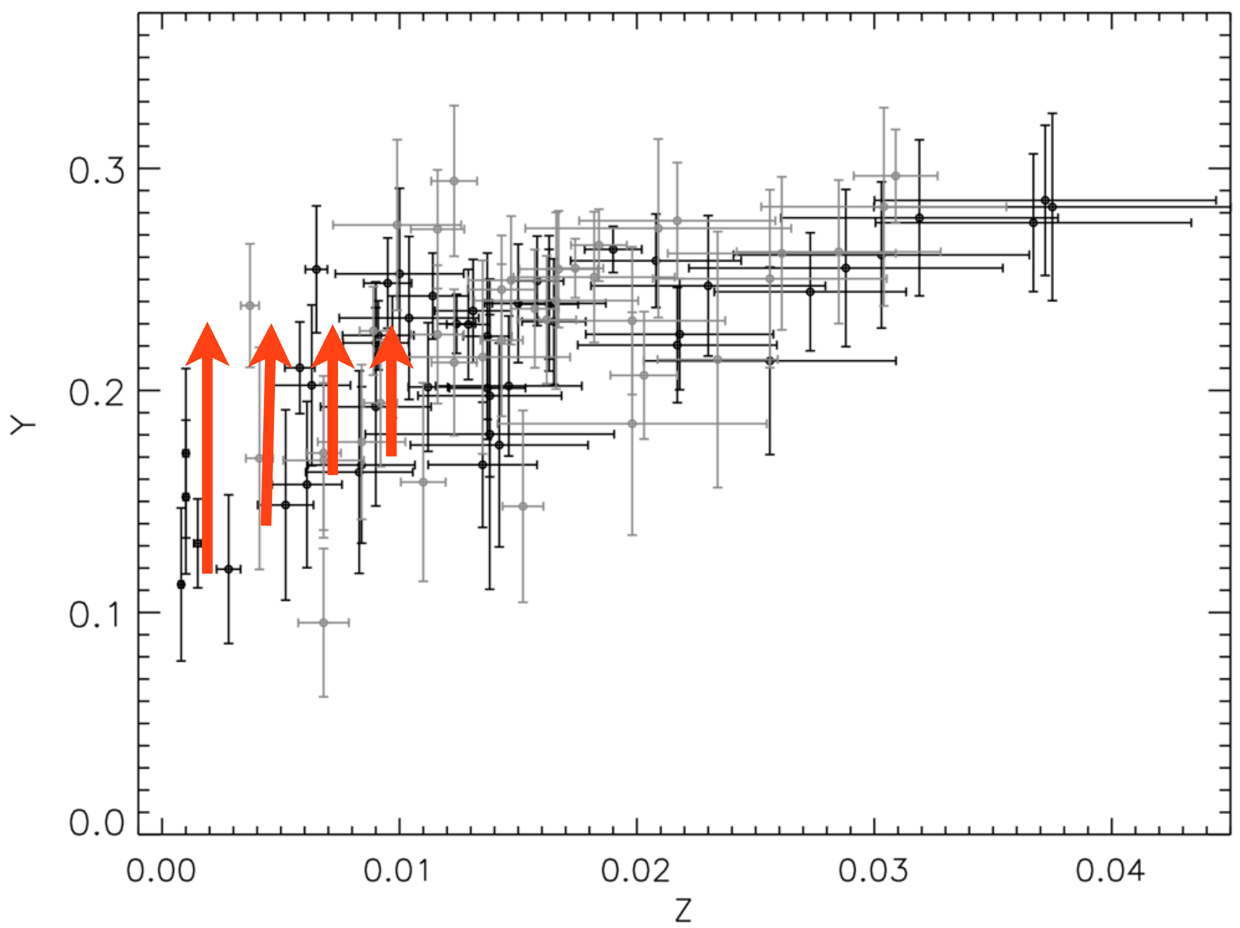
Y
0.0
0.1
0.2
0.3
0.00
0.01
0.02
0.03
0.04
Z





- Is the broadening predicted by the models at low Z reliable ?





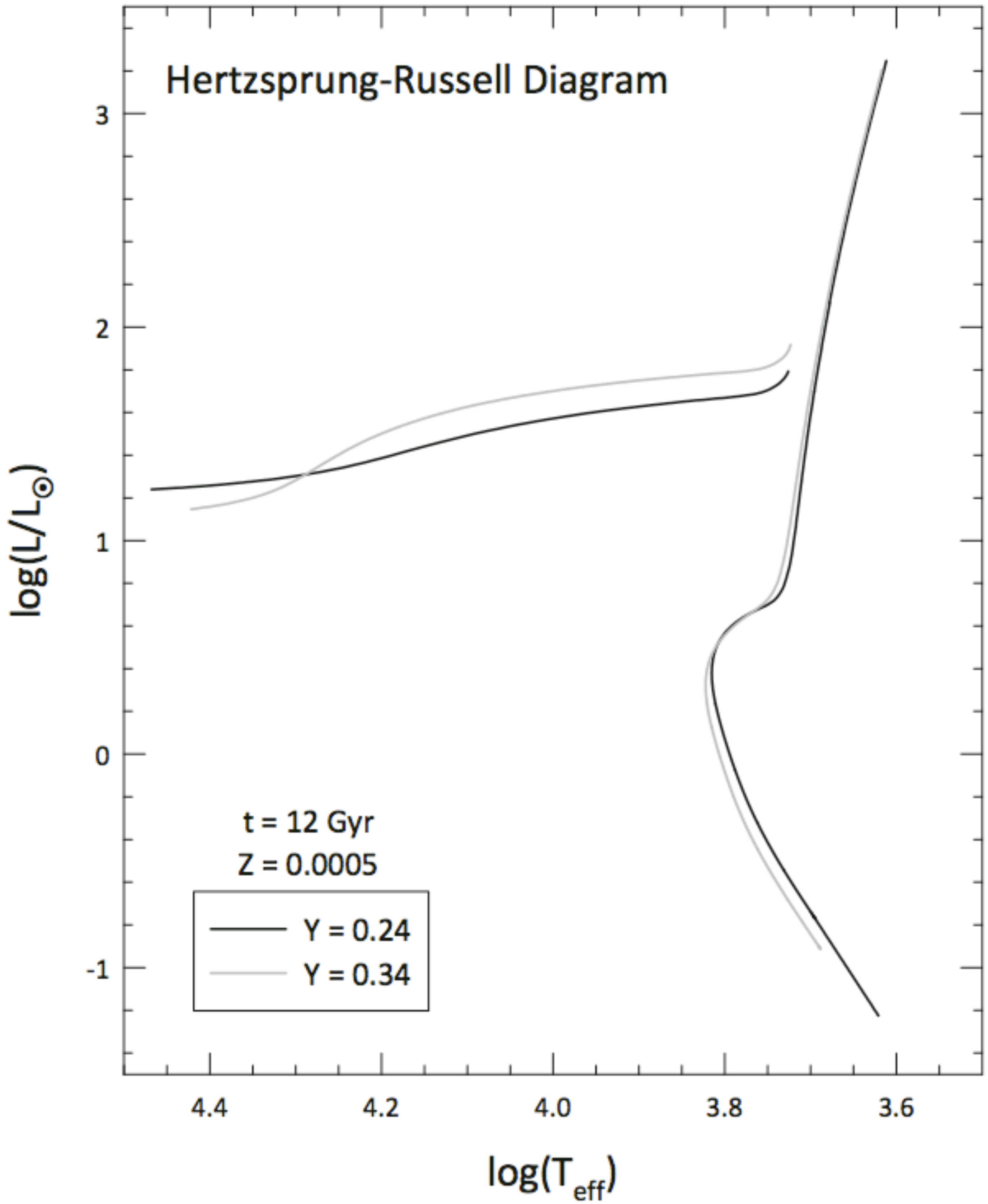
•Is the broadening predicted by the models at low Z reliable ?

•Reproducing the observed broadening with orthodox Y abundances : implications for multiple MSs in GCs ? Alias: *if observed broadening is narrower, is then 'easier' to invert the MS?*

An empirical approach... (Portinari, Casagrande & Flynn, to be submitted)

Multiple populations in GCs

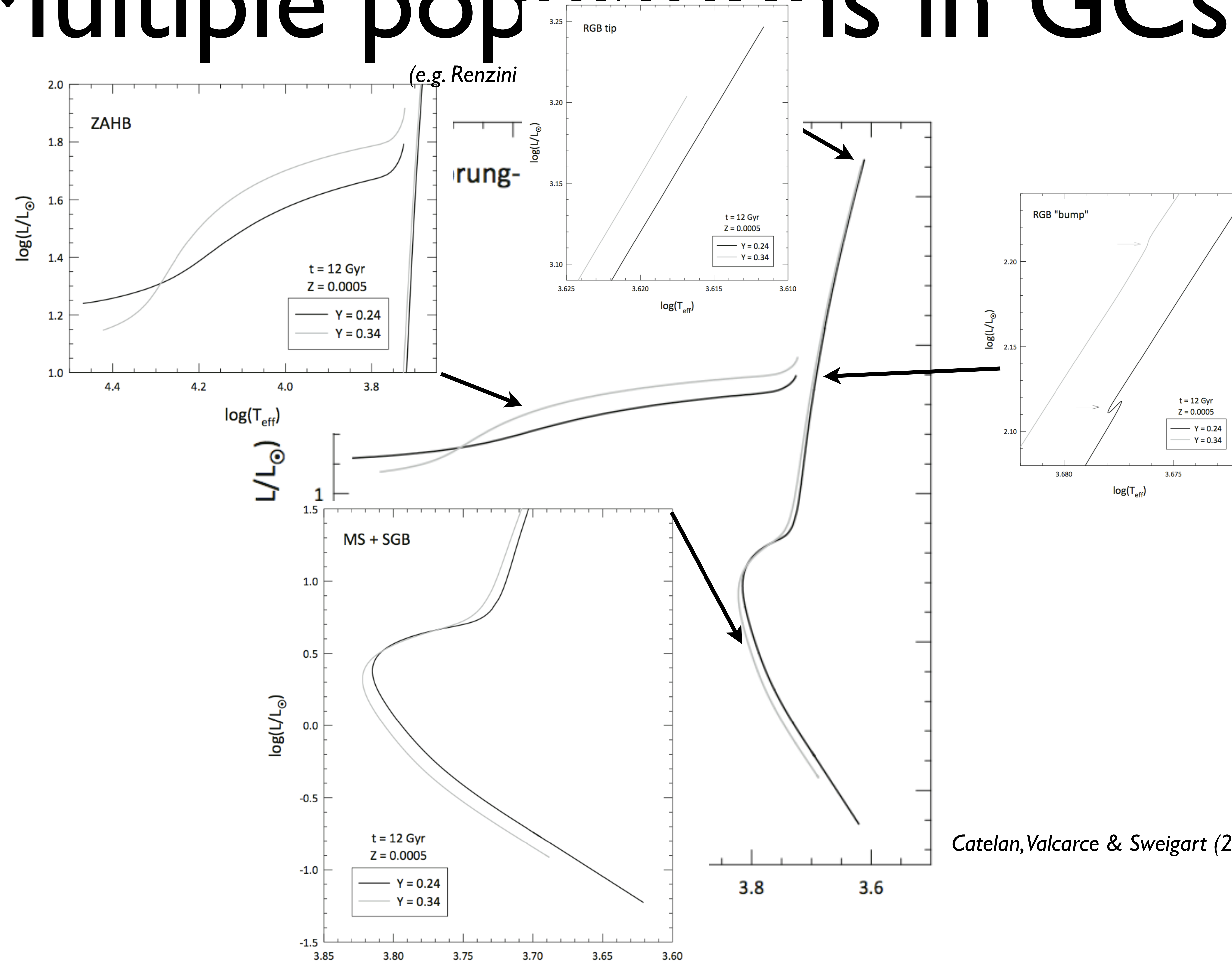
(e.g. Renzini 2008; Piotto 2009; Yi 2009)



Catelan, Valcarce & Sweigart (2009)

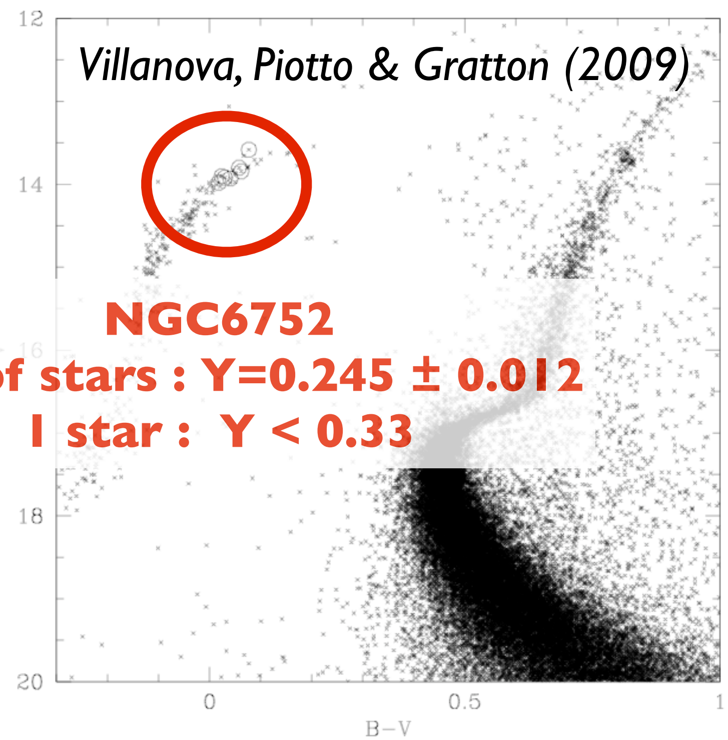
Multiple populations in GCs

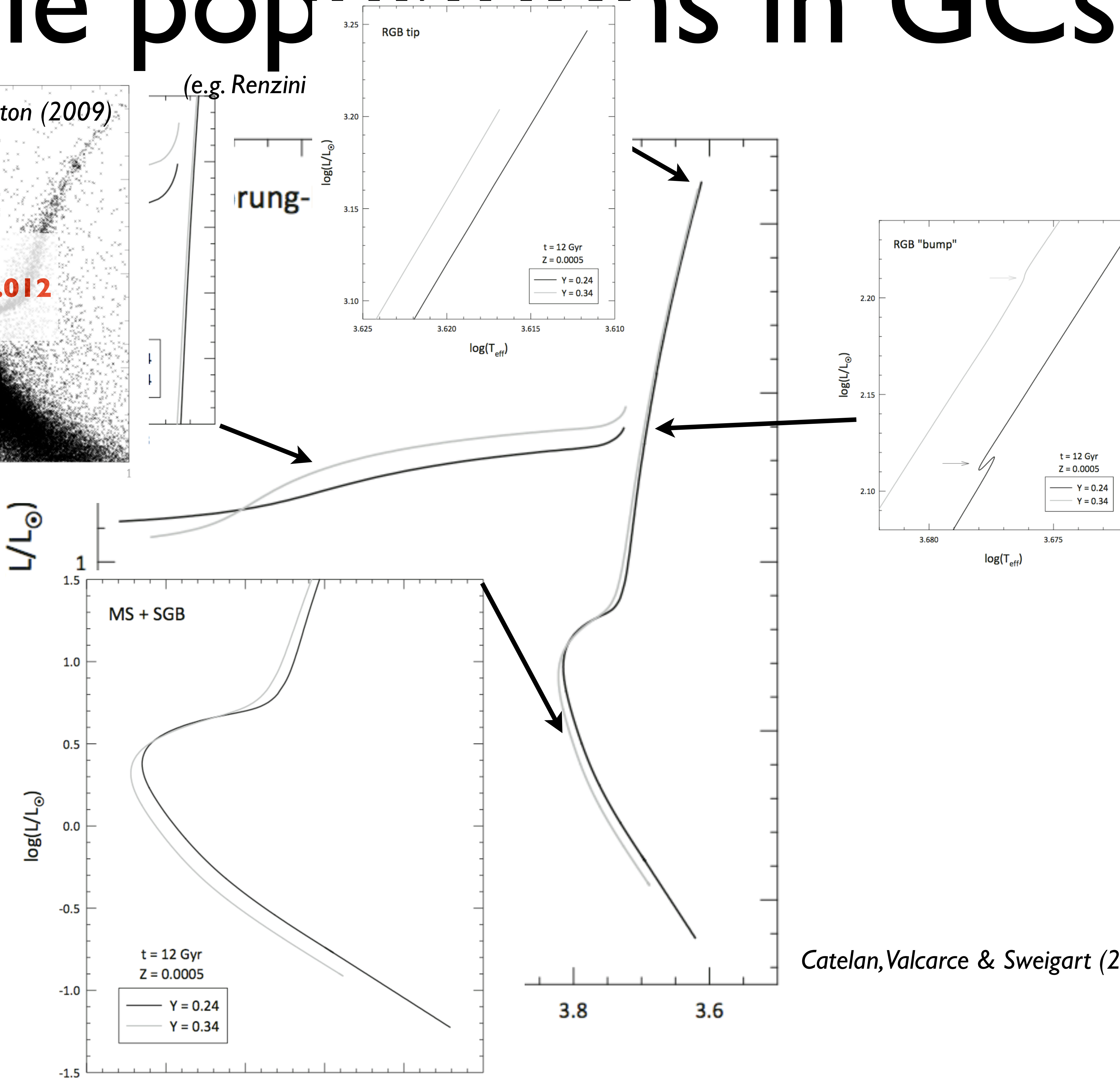
(e.g. Renzini



Catelan, Valcarce & Sweigart (2009)

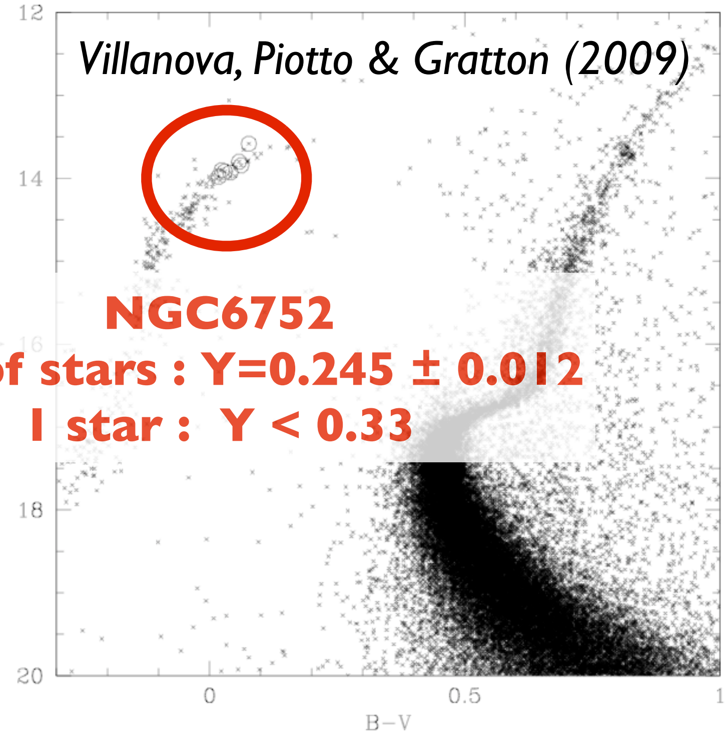
Multiple populations in GCs





Catelan, Valcarce & Sweigart (2009)

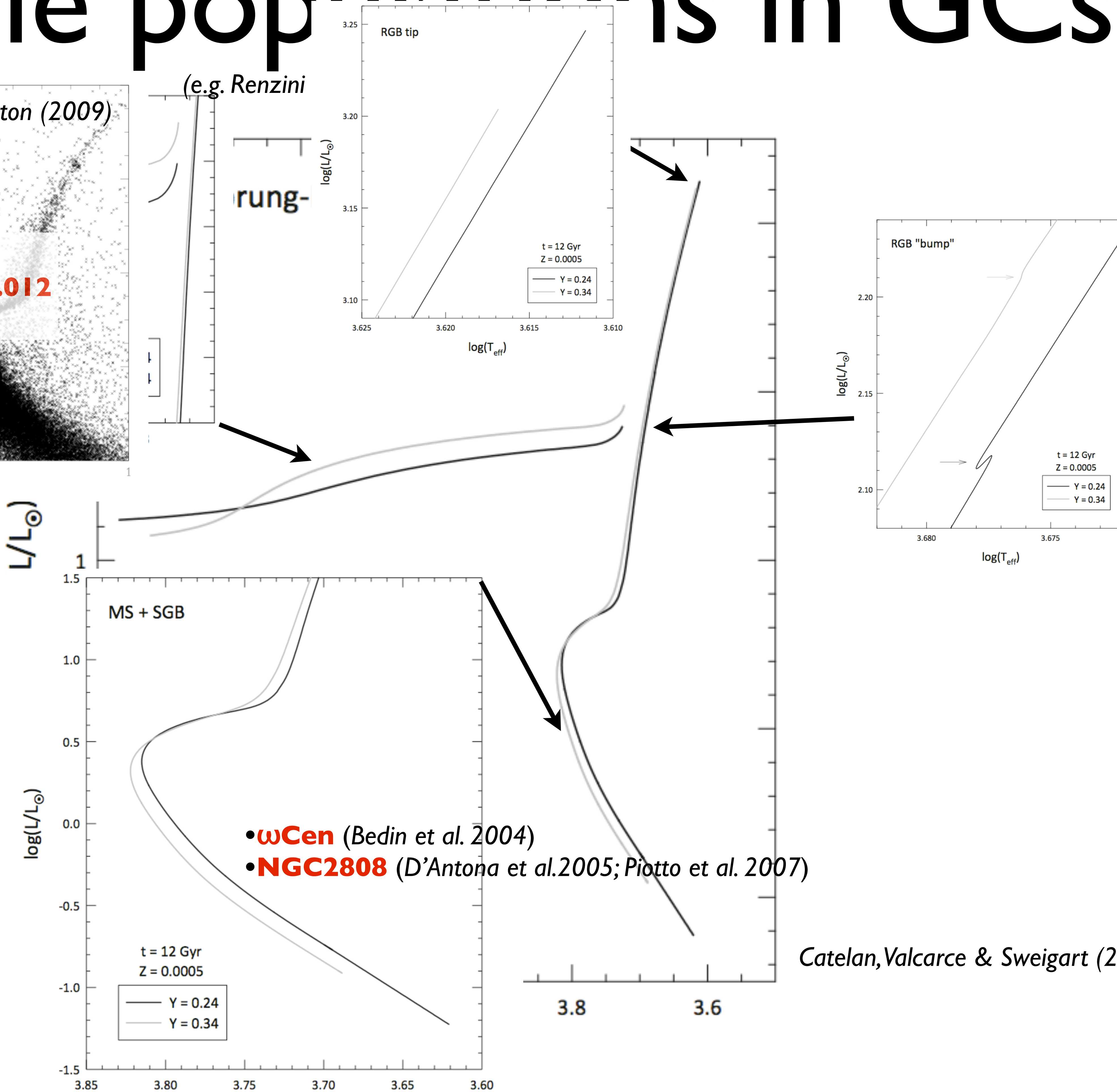
Multiple populations in GCs



NGC6752

bulk of stars : Y=0.245 ± 0.012

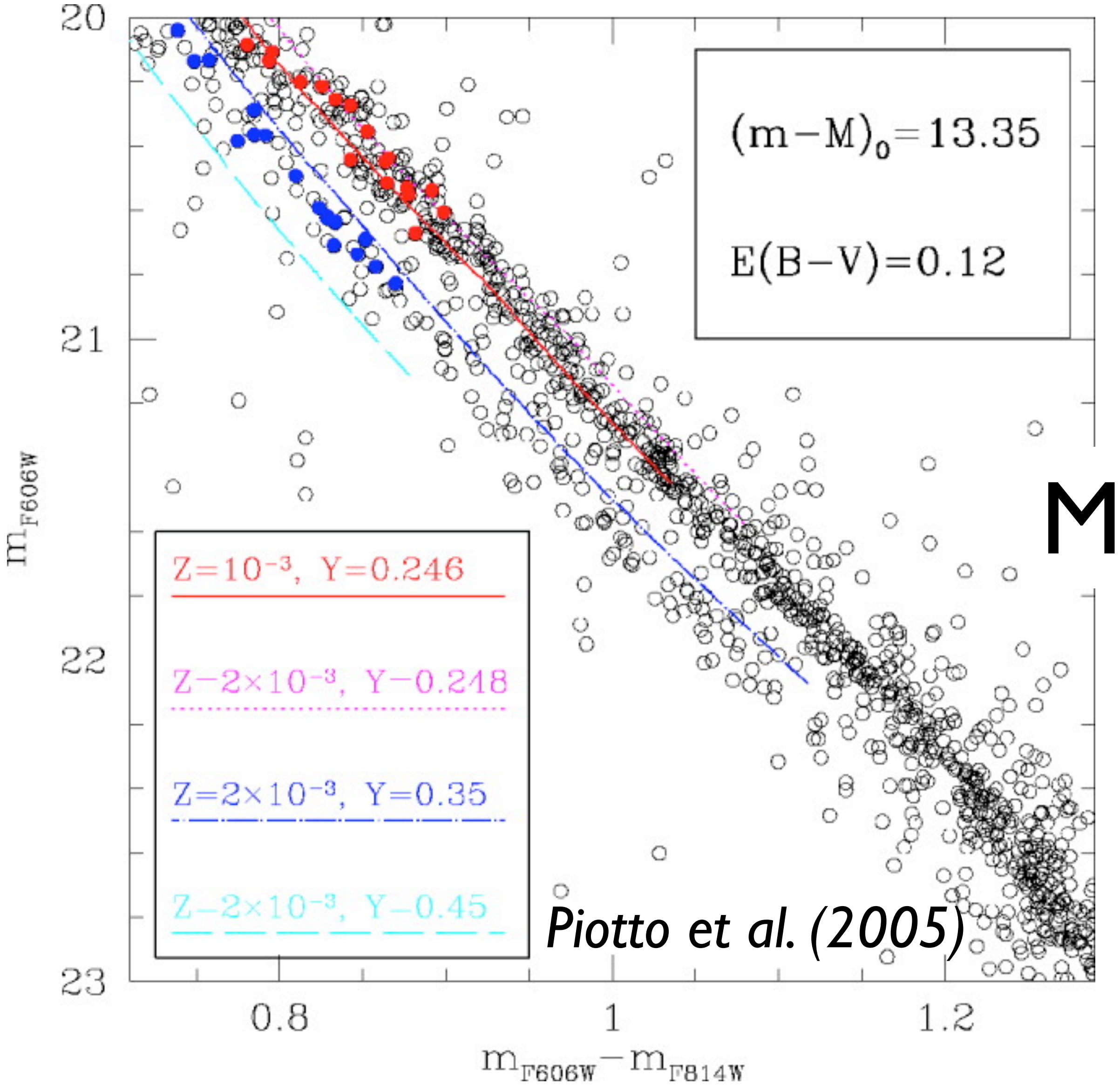
1 star : Y < 0.33



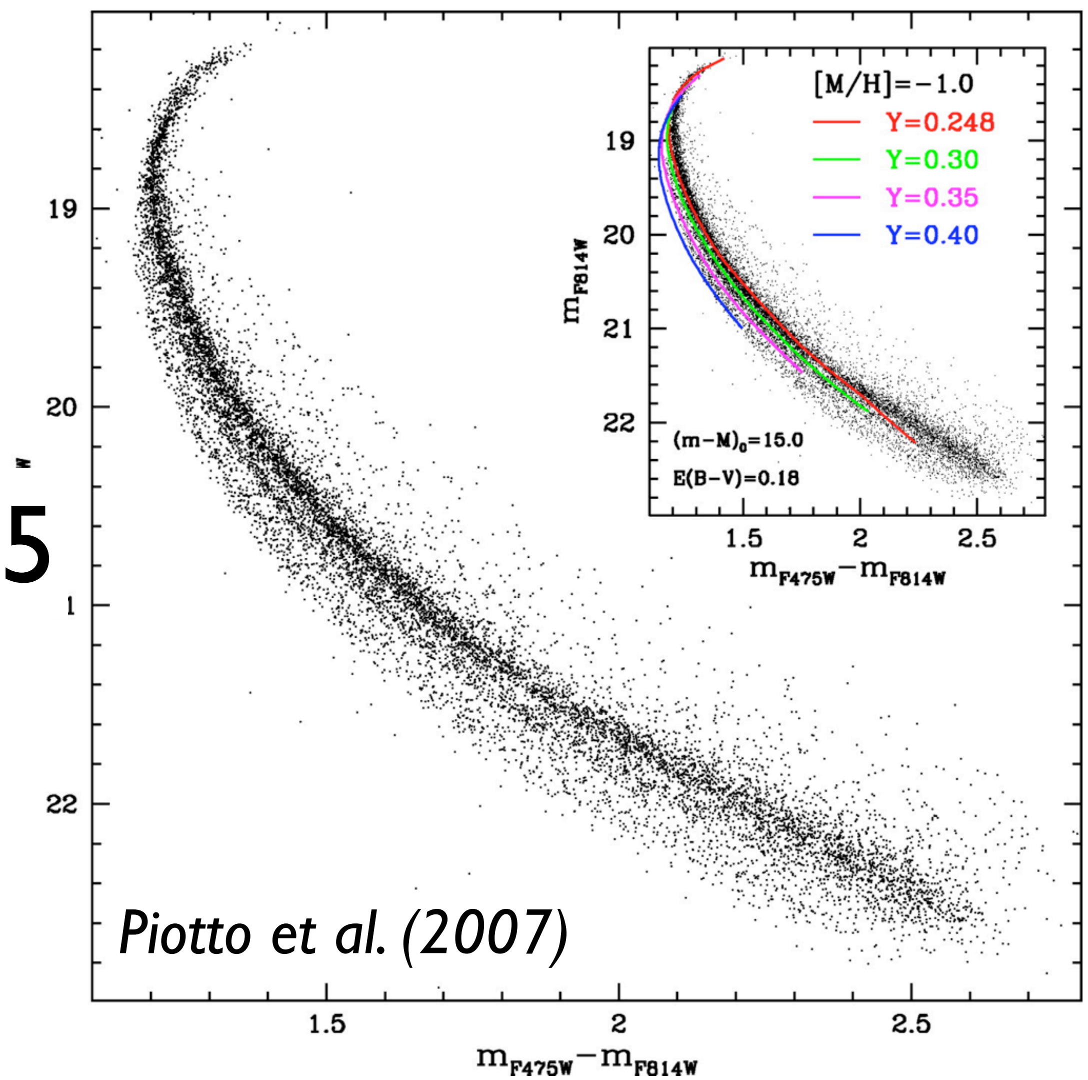
- **ωCen** (*Bedin et al. 2004*)
- **NGC2808** (*D'Antona et al.2005; Piotto et al. 2007*)

Catelan, Valcarce & Sweigart (2009)

MS: ωCen / NGC2808



M_{Bol} ~ 6.5



rMS: [Fe/H]=-1.6 Y_{rMS}~0.25

bMS: [Fe/H]=-1.3 Y_{bMS}~0.40

↓

ΔY ~ 0.15

(*also Norris 2004; Sollima et al. 2007*)

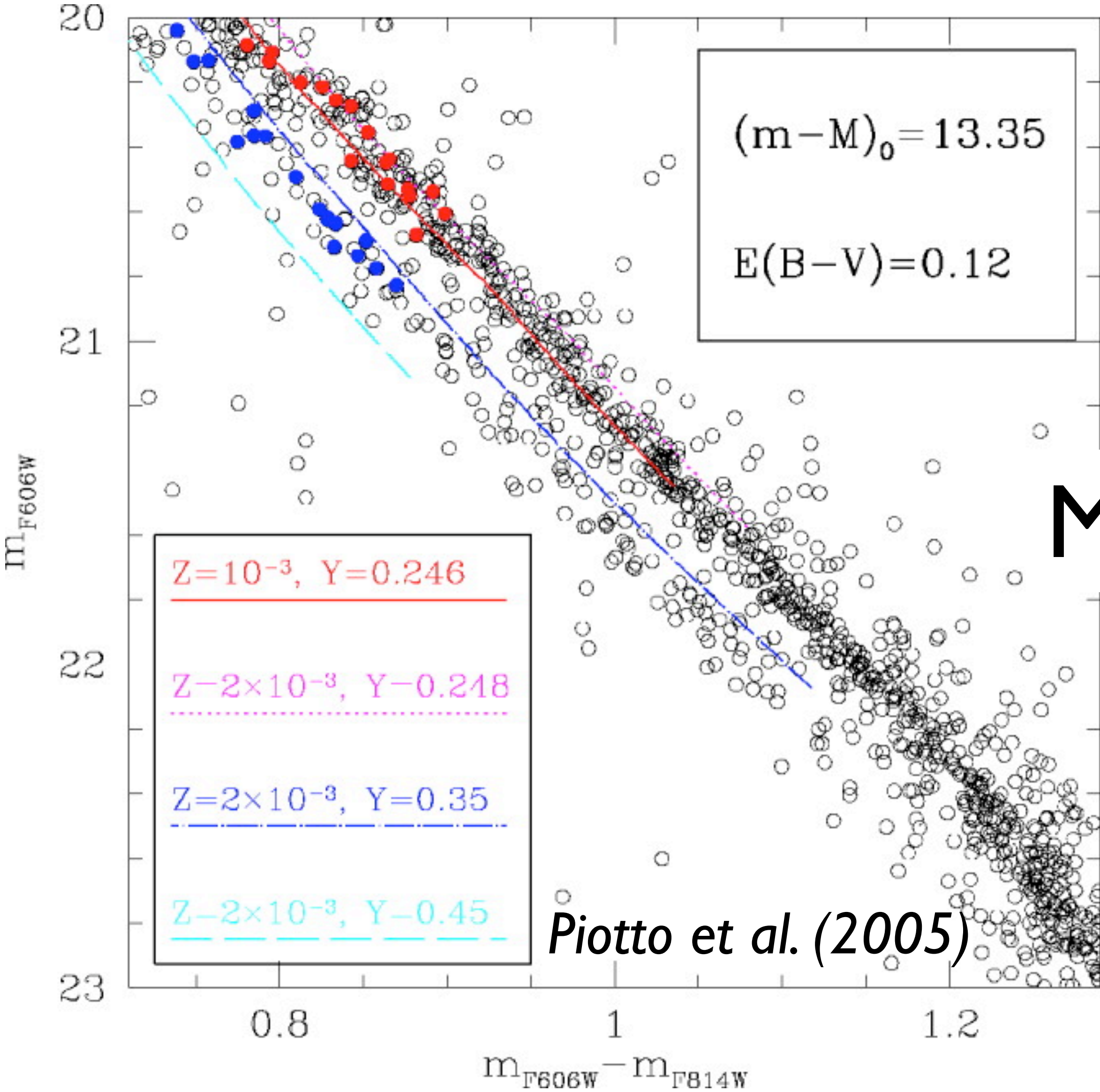
[Fe/H]=-1.1 ± 0.03

rMS: Y_{rMS} = 0.248

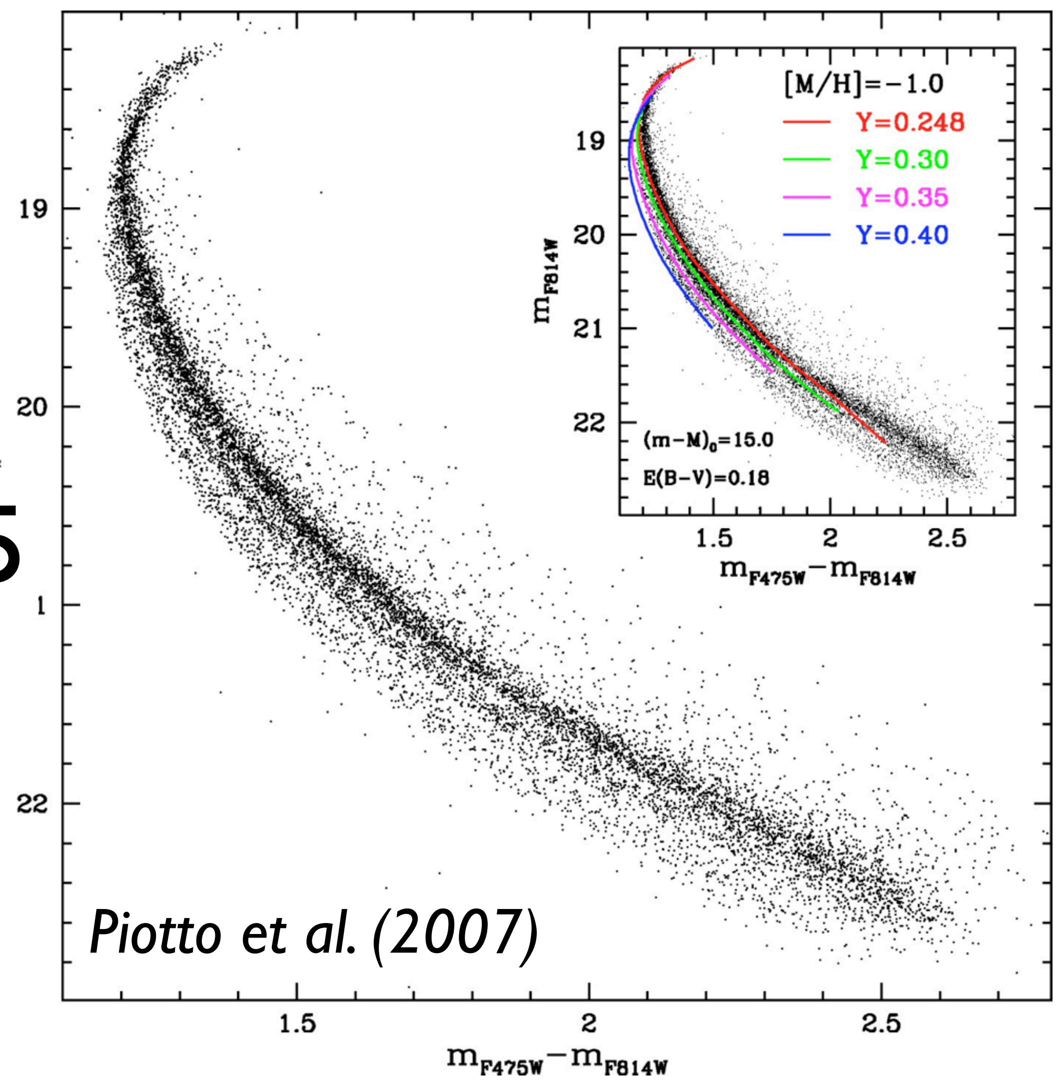
mMS: Y_{mMS} ~ 0.30 (ΔY=0.05)

bMS: Y_{bMS} ~ 0.37 (ΔY=0.12)

MS: ωCen / NGC2808



M_{Bol} ~ 6.5



Huge helium enhancement difficult to explain for stellar nucleosynthesis and chemical evolution models (e.g. *Prantzos & Charbonnel 2006; Maeder & Meynet 2006; Decressin et al. 2007a,b; Romano et al. 2007, 2009; Renzini 2008; Yi 2009*)

MS broadening: homology relations

•They provide a *simple analytical tool* to study the broadening of the MS (straightforward to apply on field dwarfs & GCs) → *it suits to be empirically calibrated*

MS broadening: homology relations

•They provide a *simple analytical tool* to study the broadening of the MS (straightforward to apply on field dwarfs & GCs) → *it suits to be empirically calibrated*

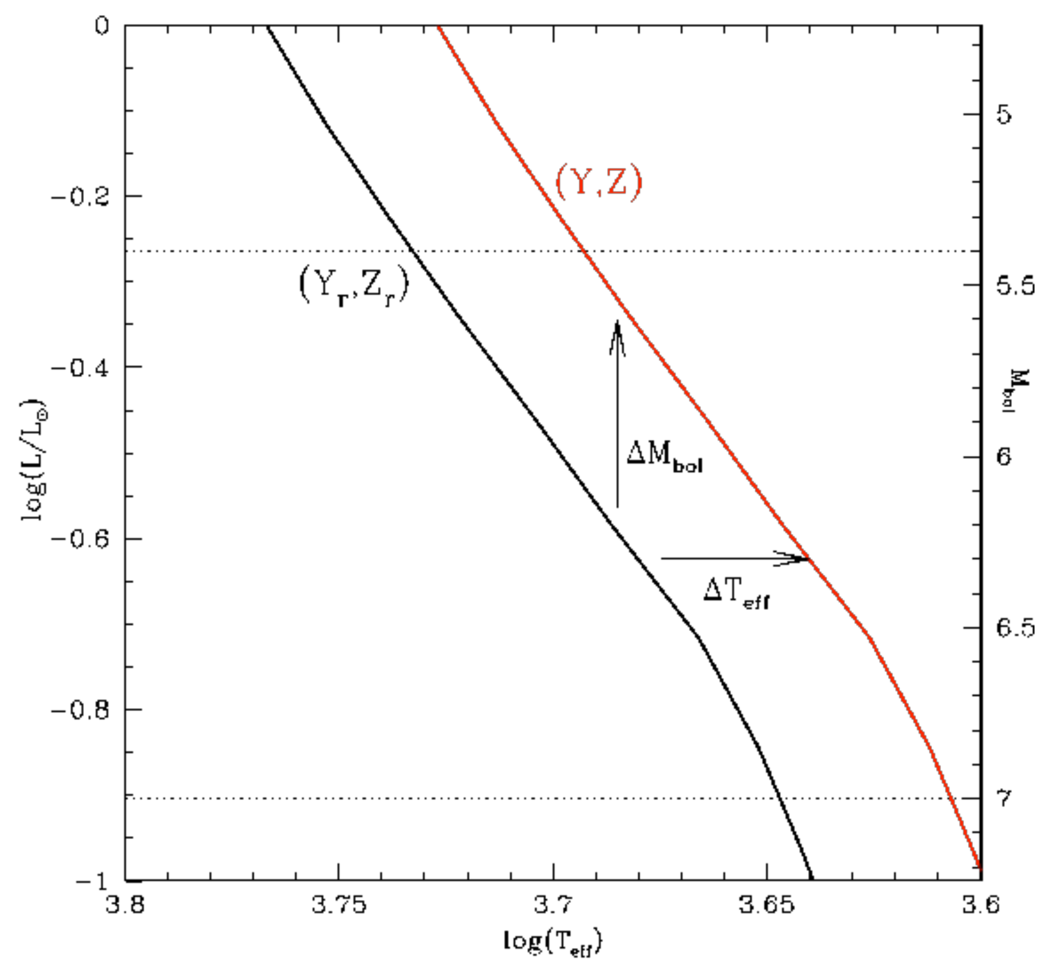
•Given the location of a reference ZAMS with composition (Y_r, Z_r), homology relations predict where a second ZAMS of composition (Y, Z) is located with respect to the first

$$\delta = 1 + \frac{\Delta Y}{\Delta Z}$$

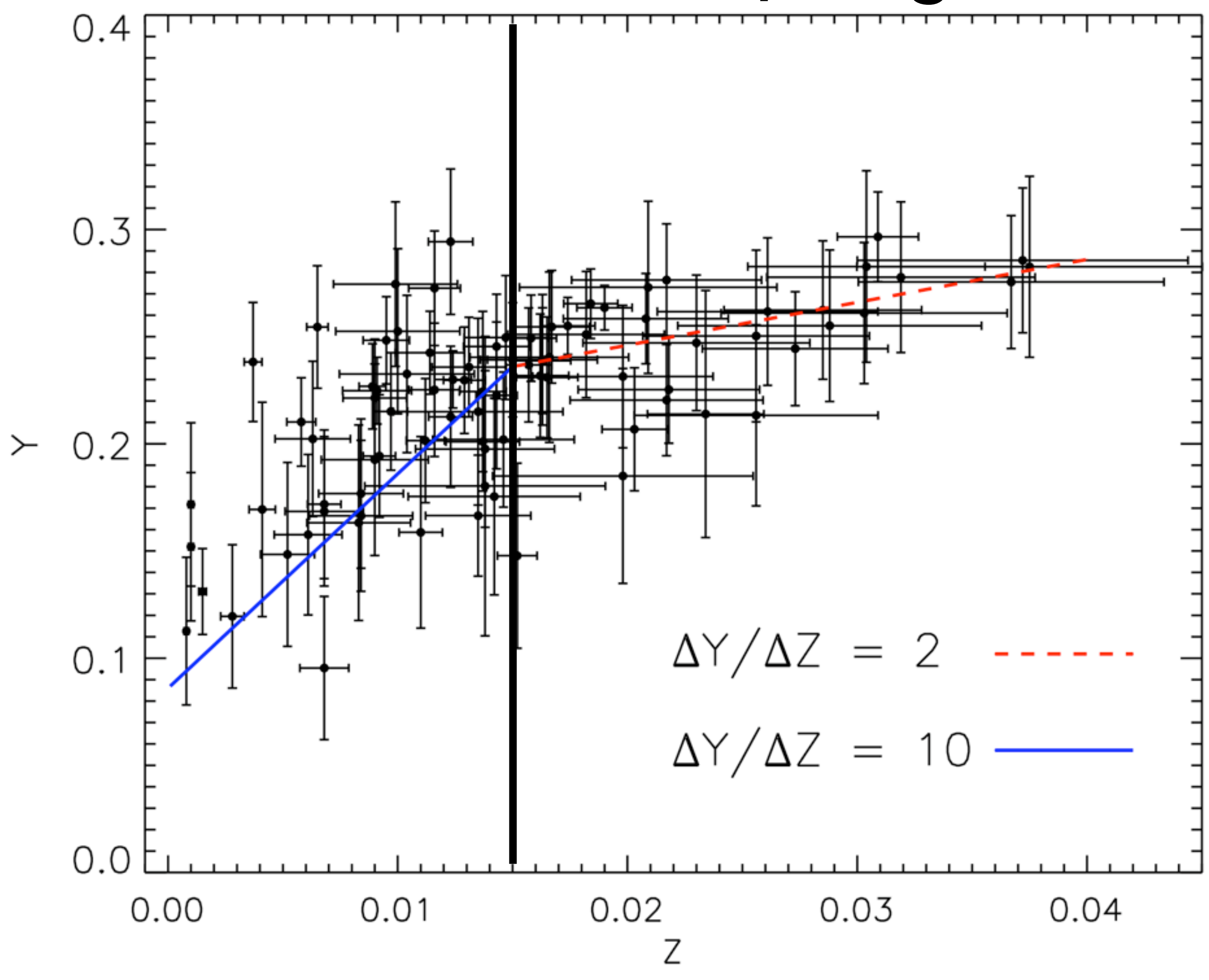
$$\Delta \log T_{\rm eff} = -P_1 \log\left[1 - \frac{\delta}{(0.6+X_r)}(Z - Z_r)\right] - P_2 \log\left(\frac{P_3 Z + 1}{P_3 Z_r + 1}\right)$$

$$P_1 = 0.50 \pm 0.03$$
$$P_2 = 0.064 \pm 0.005$$
$$P_3 = 670 \pm 200$$

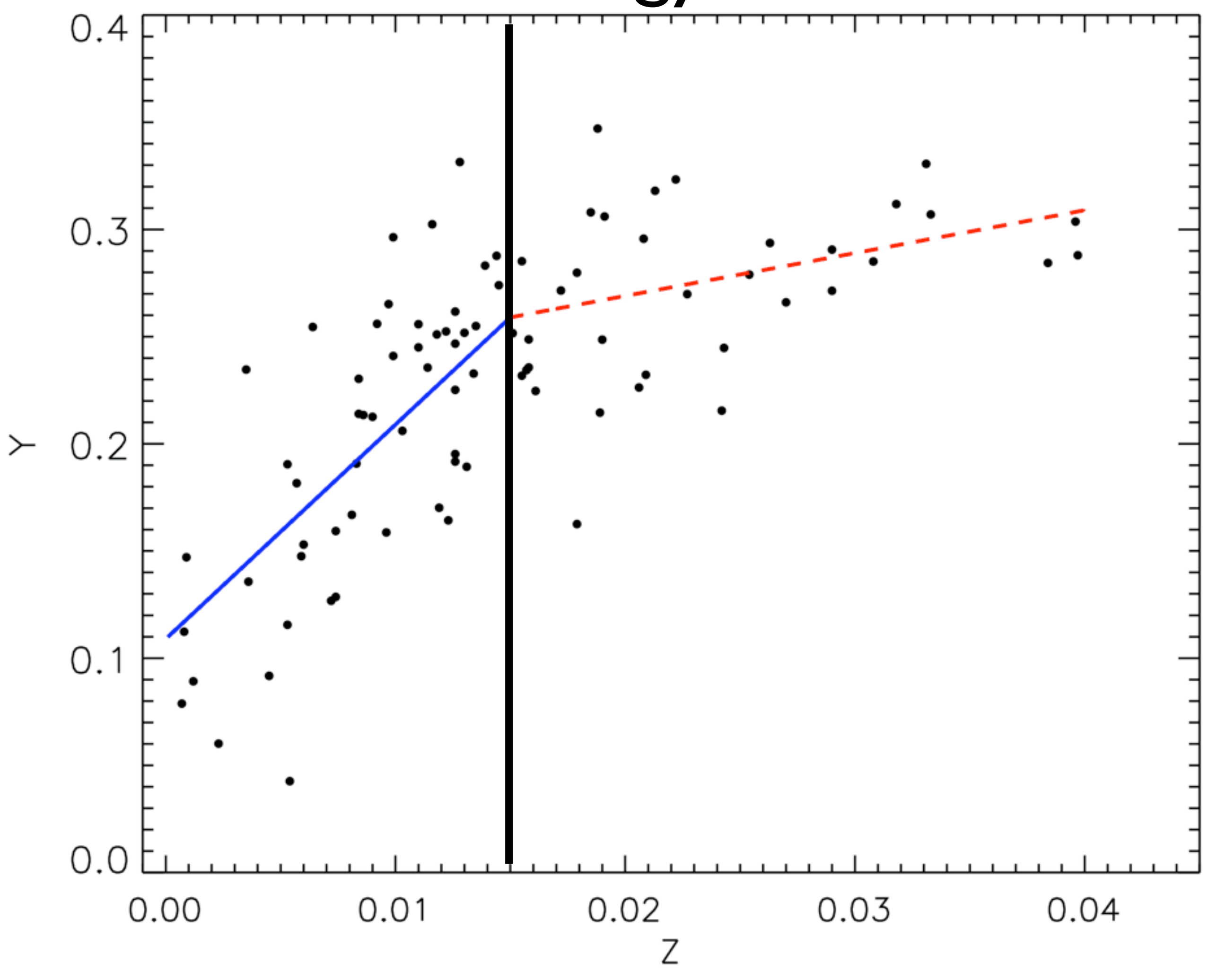
homology relations calibrated on isochrones (Padova)



isochrone fitting



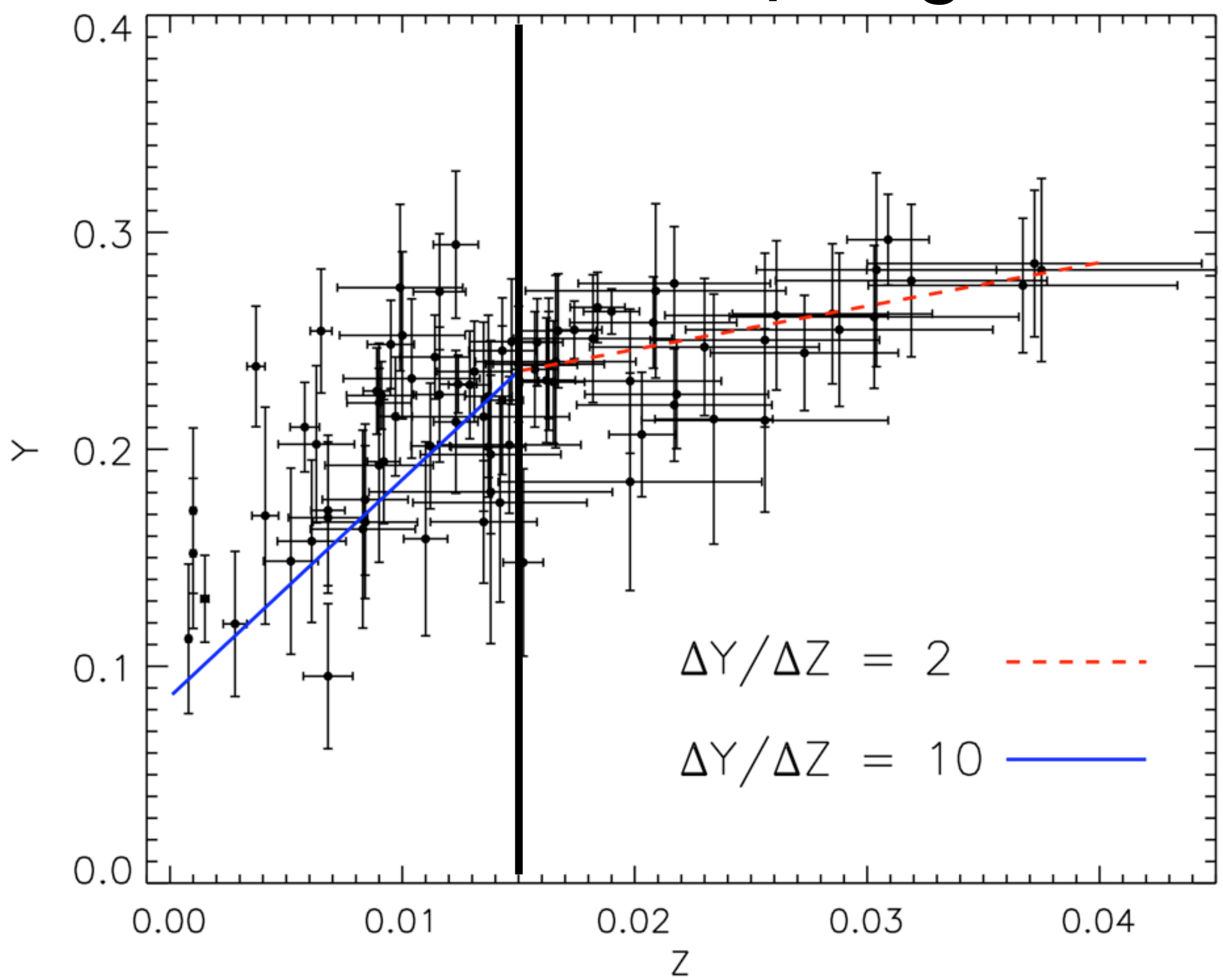
homology relations



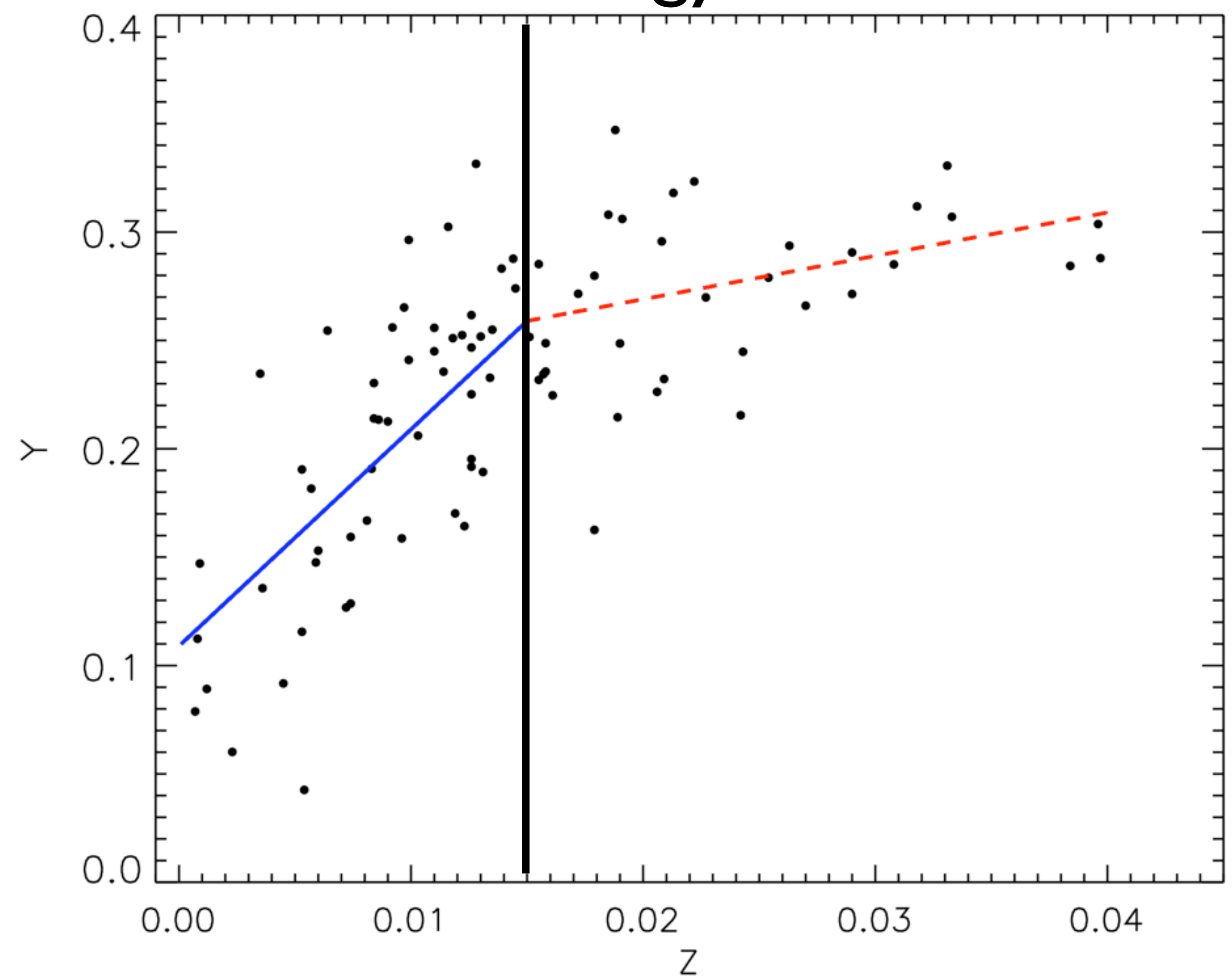
- Homology relations describe very well the behavior of theoretical isochrones as function of ΔY and $\Delta Y/\Delta Z$

- For our sample of local stars, homology relations return a similar Y(Z) plot as isochrones

isochrone fitting

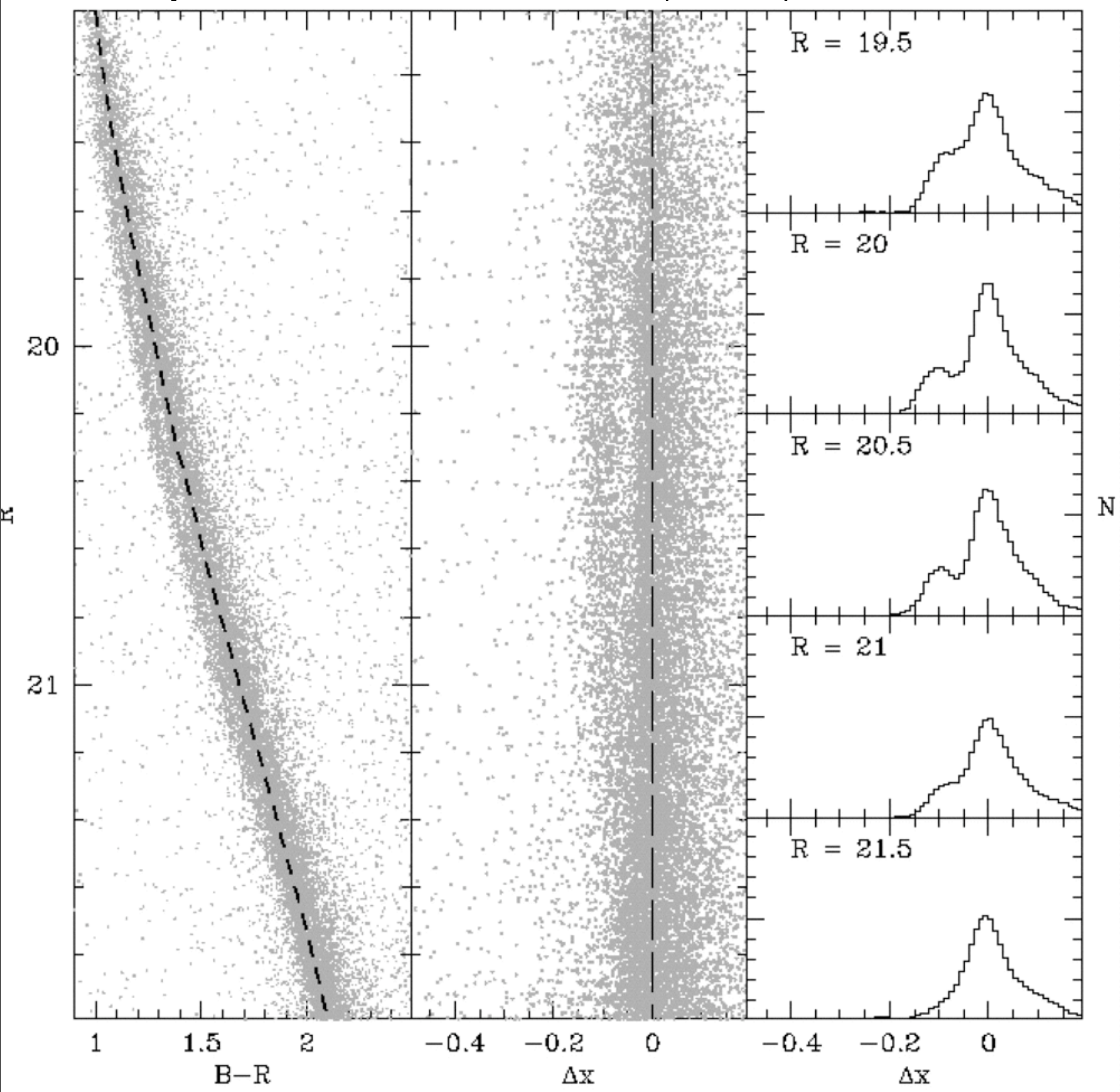


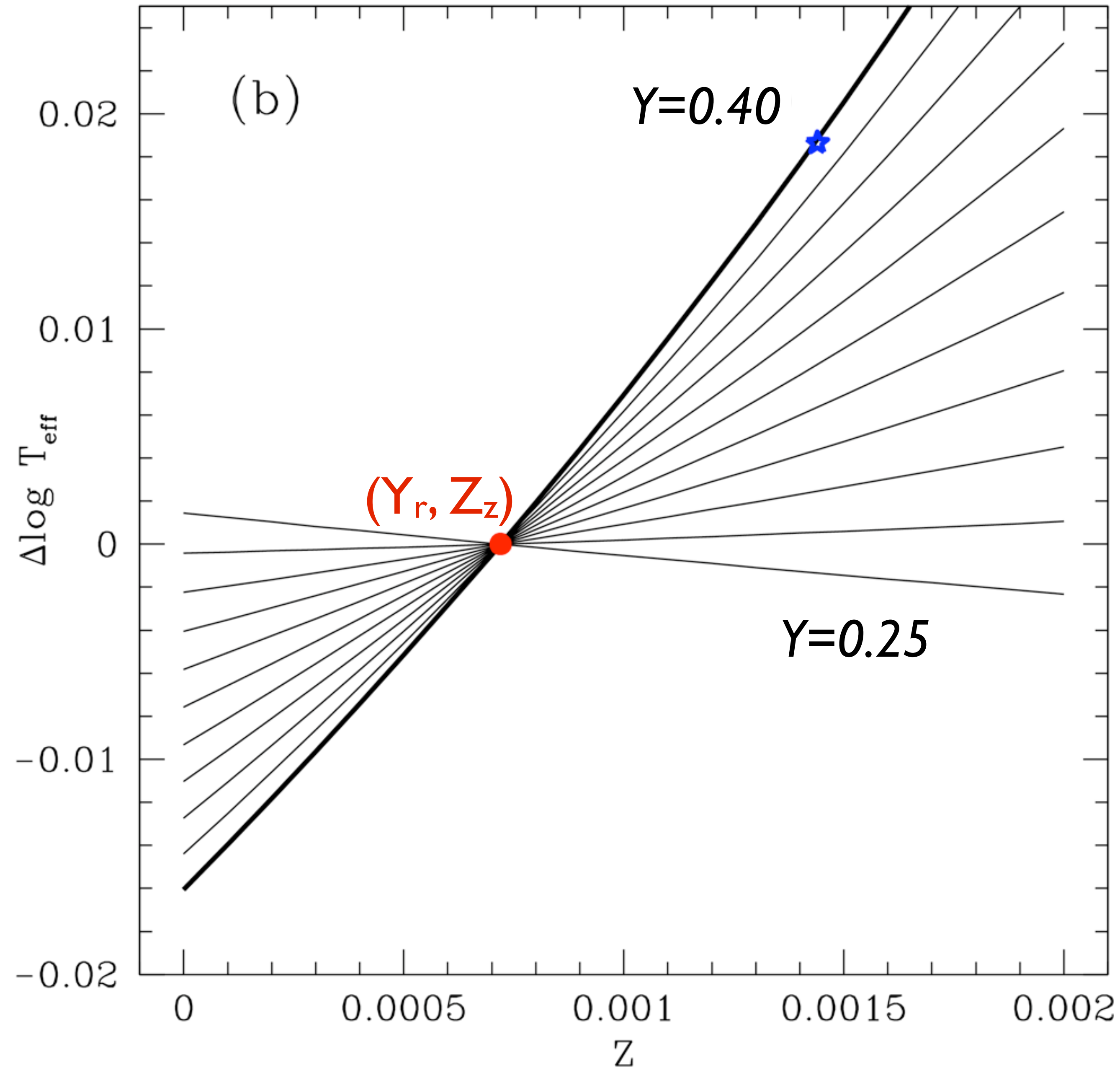
homology relations



Homology relations: ωCen

Deep FORS1, *Sollima et al. (2007)*





Maximum MS split @ R=20.5 (M_R~M_{Bol}=6.5)

(B-R) = 1.2, Δ(B-R) = 0.1 ⇒ ΔlogT_{eff}=0.0185

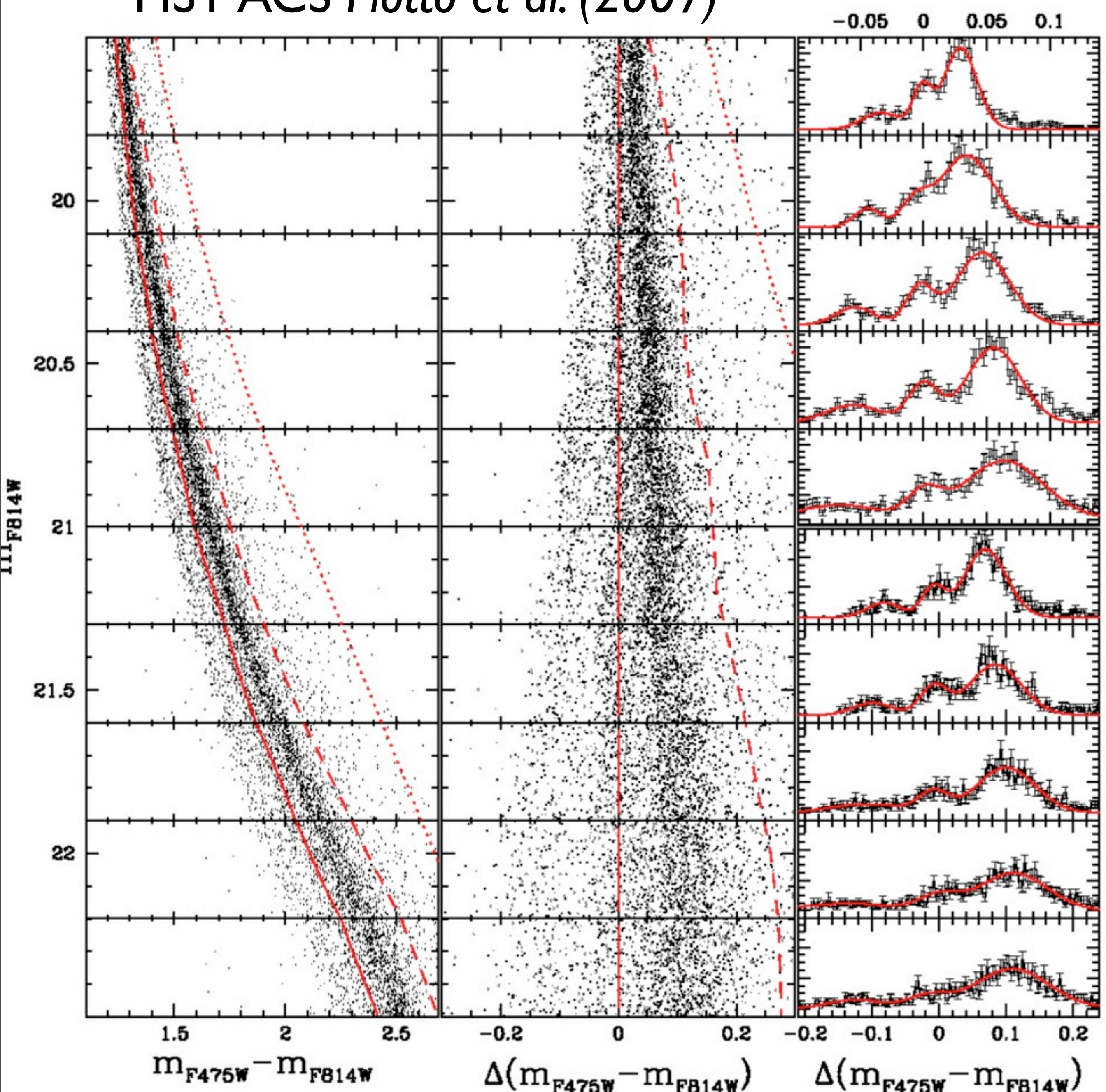
If **Y_{rMS} = 0.25** ⇒ **Y_{bMS} = 0.40**

perfect agreement with isochrone analysis

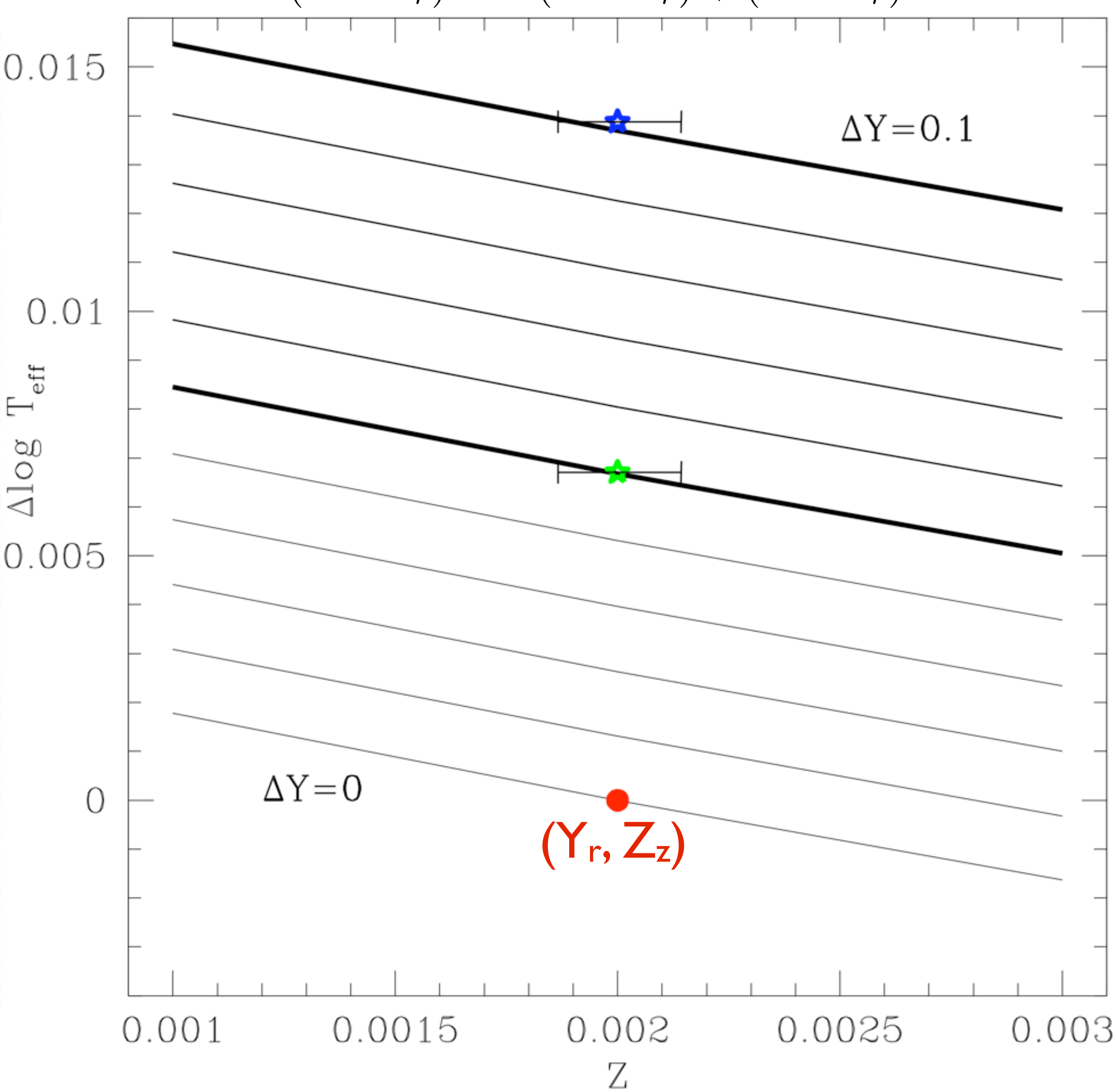
(Norris 2004; Piotto et al. 2005; Sollima et al. 2007)

Homology relations: NGC2808

HST ACS *Piotto et al. (2007)*



$\delta(Z-Z_r) \longrightarrow (Y-Y_r)+(Z-Z_r)$



Maximum MS split @ M814W=21.1 (M_{Bol}=6.8)

(F475W-F814W) = 1.72 ⇒ $\Delta \log T_{eff}$ = 0.007

Y_{rMS}=0.25 ⇒ Y_{mMS}=0.30 ⇒ Y_{bMS}=0.35

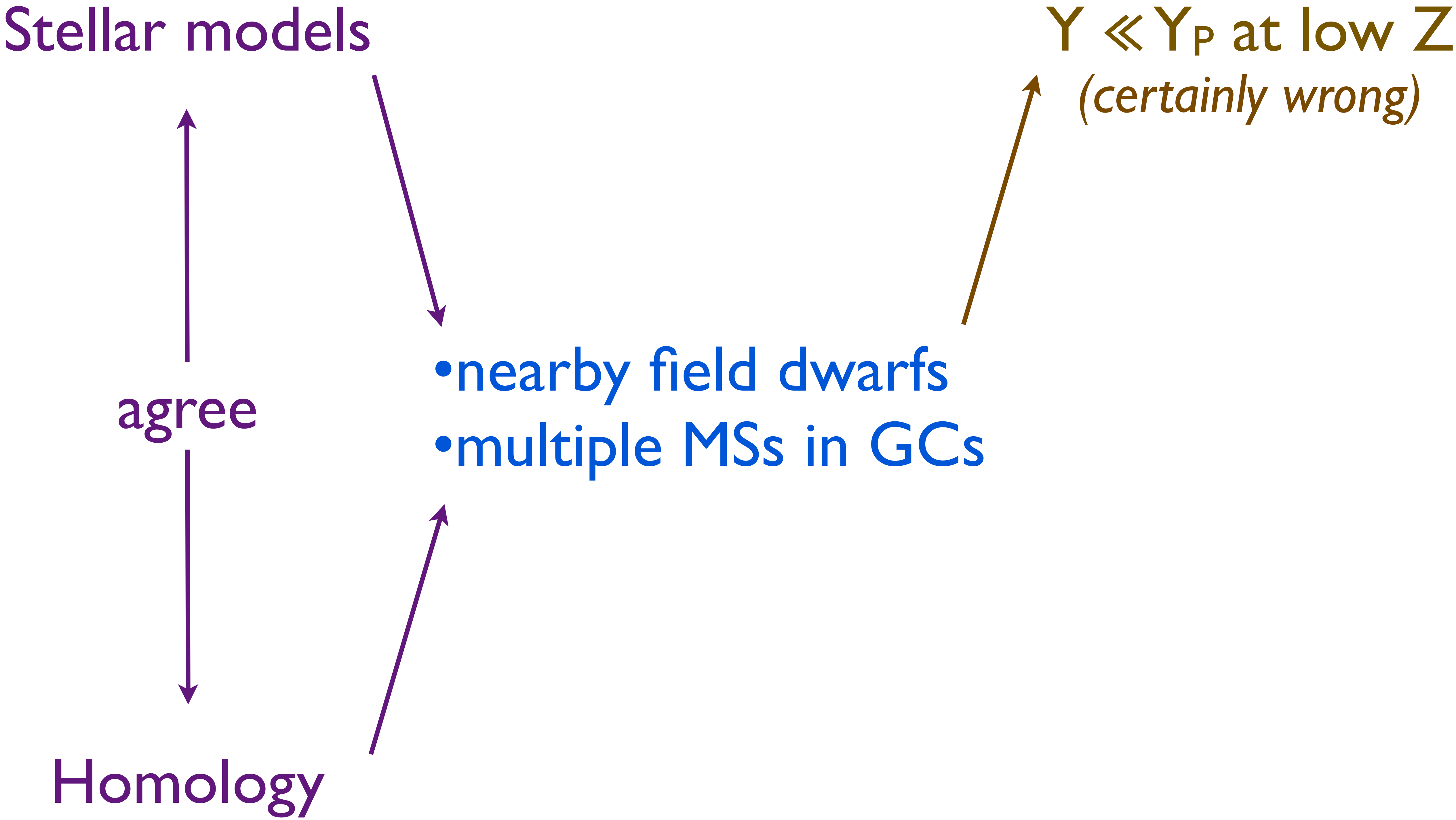
(excellent agreement with isochrone analysis
Y_{rMS} = 0.25 ⇒ Y_{mMS}=0.30 ⇒ Y_{bMS}=0.37 *Piotto et al. 2007*)

Stellar models

agree

Homology

- nearby field dwarfs
- multiple MSs in GCs



Stellar models
agree
Homology
•nearby field dwarfs
•multiple MSs in GCs
$Y \ll Y_P$ at low Z
(certainly wrong)

Stellar models

agree

Homology

- nearby field dwarfs
- multiple MSs in GCs

$Y \ll Y_P$ at low Z

(certainly wrong)

extremely Y rich sub-population

(possible revision ??)

Stellar models

agree

Homology

•nearby field dwarfs
•multiple MSs in GCs

$Y \ll Y_P$ at low Z

(certainly wrong)

both stemming from model inaccuracies?

extremely Y rich sub-population

(possible revision ??)

Homology relations: empirical calibration

- We define empirical homology relations, calibrated to fulfill BBN constraint at low Z (⇒ ΔY/ΔZ = 2)
- We will use them to reassess the multiple MSs in GCs

- molecular weight (50%)
- nuclear energy generation (40%)
- opacity (10%)

$$\Delta \log T_{\rm eff} = -P_1 \log\left[1 - \frac{\delta}{(0.6+X_r)}(Z - Z_r)\right] - P_2 \log\left(\frac{P_3 Z+1}{P_3 Z_r+1}\right)$$

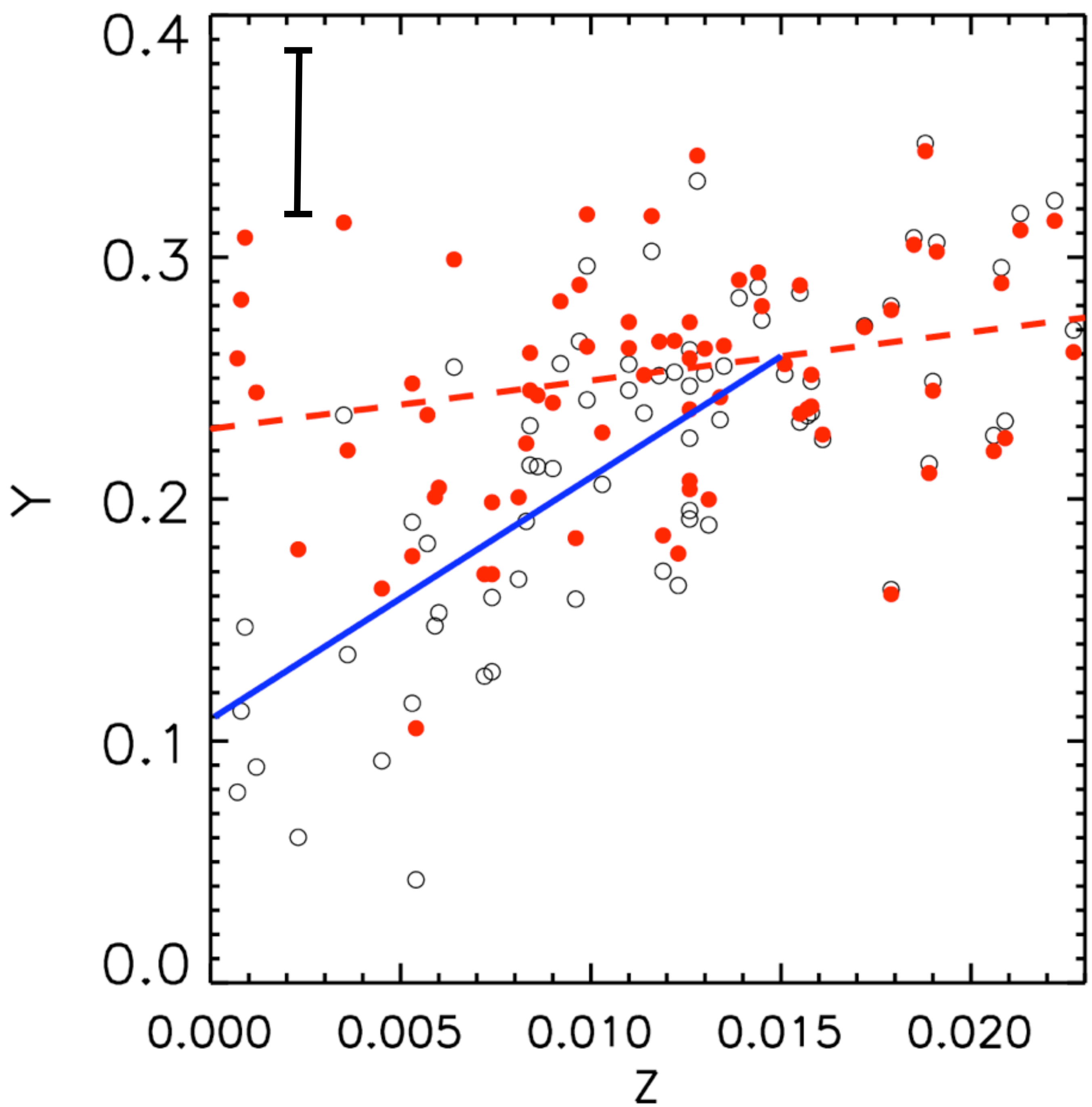
1st term: include the global dependence on ΔY

2nd term: (opacity) depends only on Z

2^{nd} term:

$$\Delta \log T_{\rm eff} = -0.50 \log \left[1 - \frac{\delta}{(0.6+X_r)}(Z - Z_r)\right] -0.064 \log \left(\frac{670Z+1}{670Z_r+1}\right)$$

$$\Delta \log T_{\rm eff} = -0.50 \log \left[1 - \frac{\delta}{(0.6+X_r)}(Z - Z_r)\right] -0.064 \log \left(\frac{150Z+1}{150Z_r+1}\right)$$



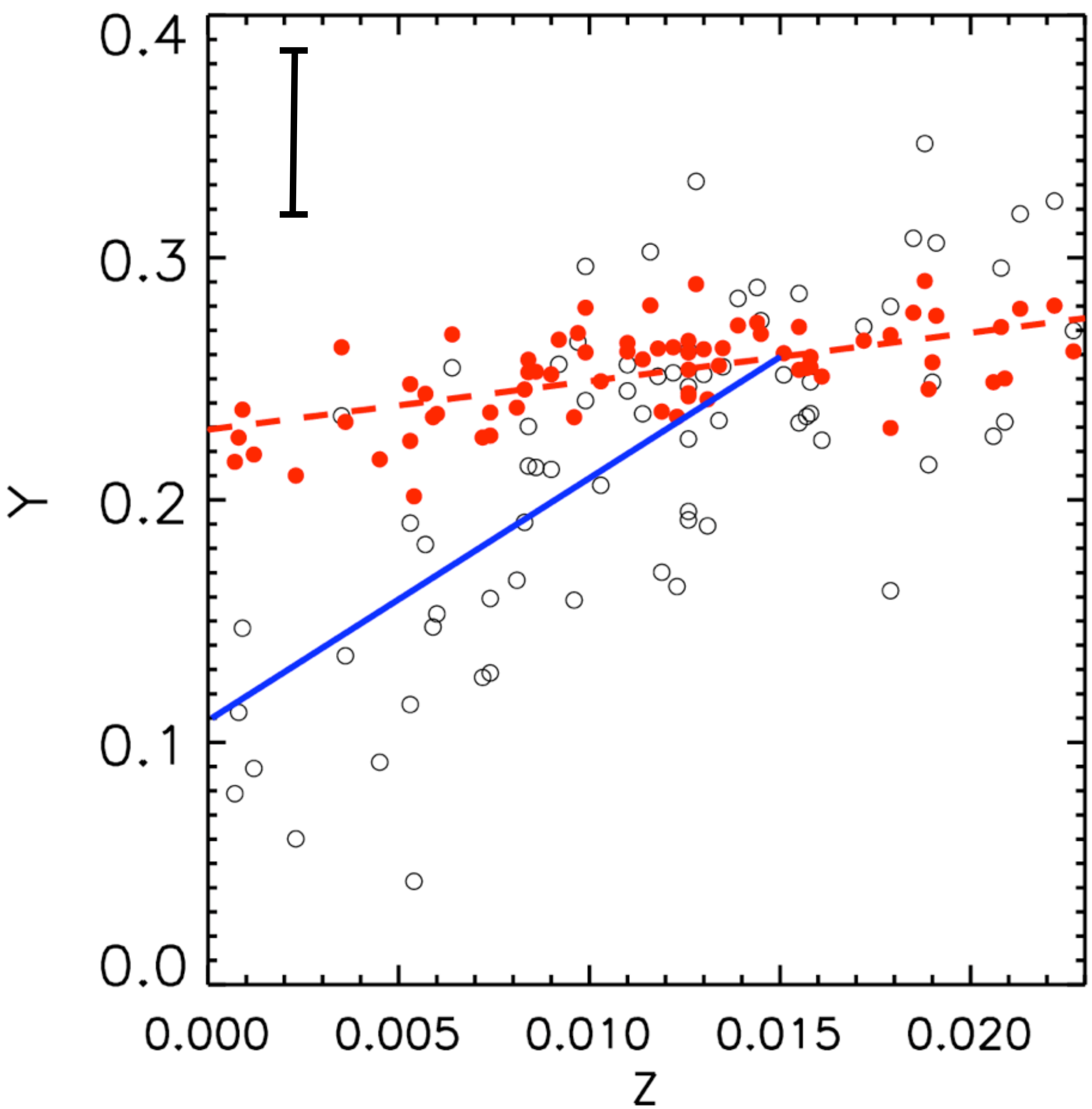
no effect on the GC multiple MS, since in GC the metallicity difference is minimal or vanishing

Huge scatter: problem with Y_P resolved on average, but considerable fraction of stars still below BBN

Ist term:

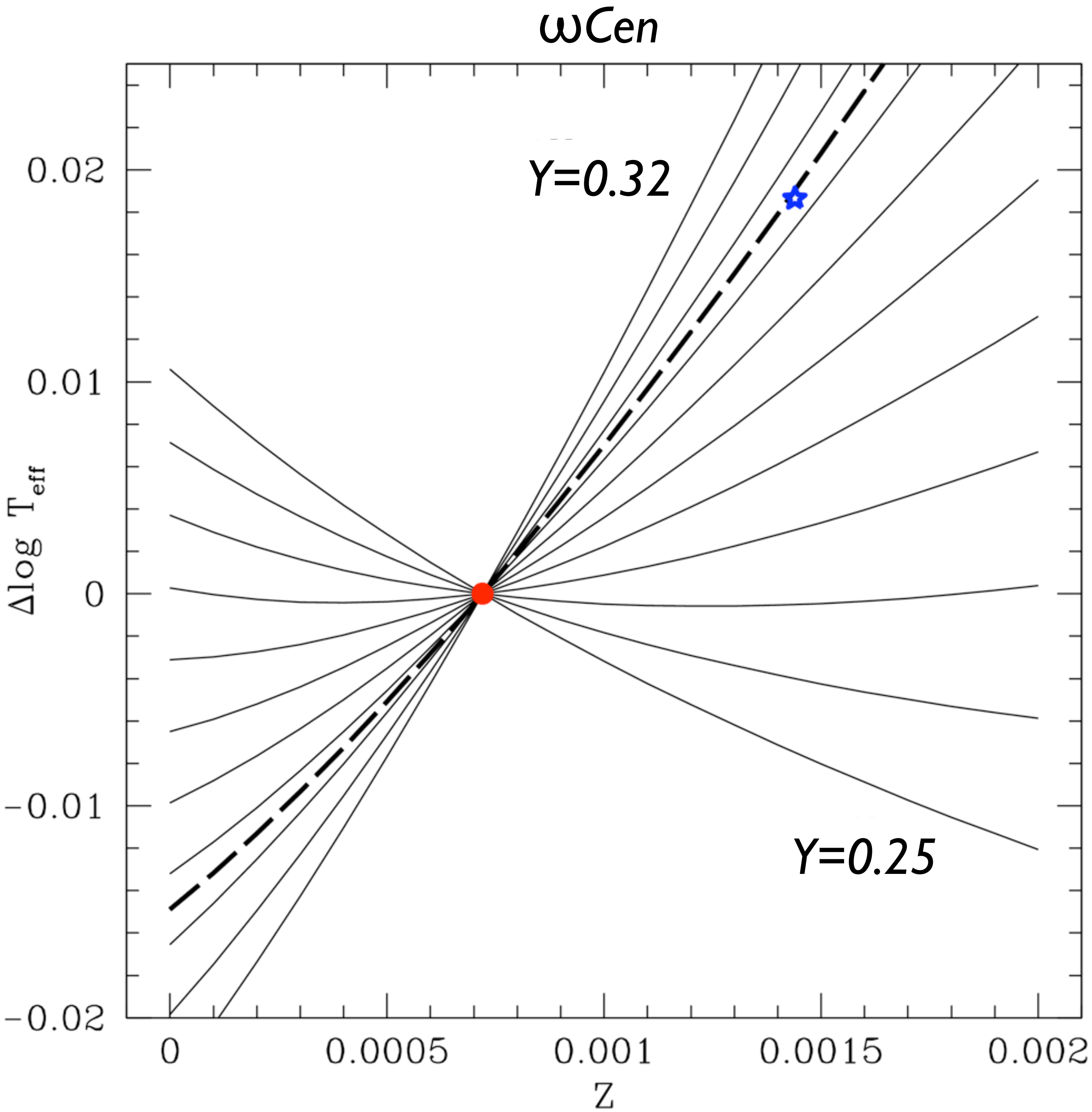
$$\Delta \log T_{\rm eff} = -0.50 \log \left[1 - \frac{\delta}{(0.6+X_r)}(Z - Z_r)\right] - 0.064 \log \left(\frac{670Z+1}{670Z_r+1}\right)$$

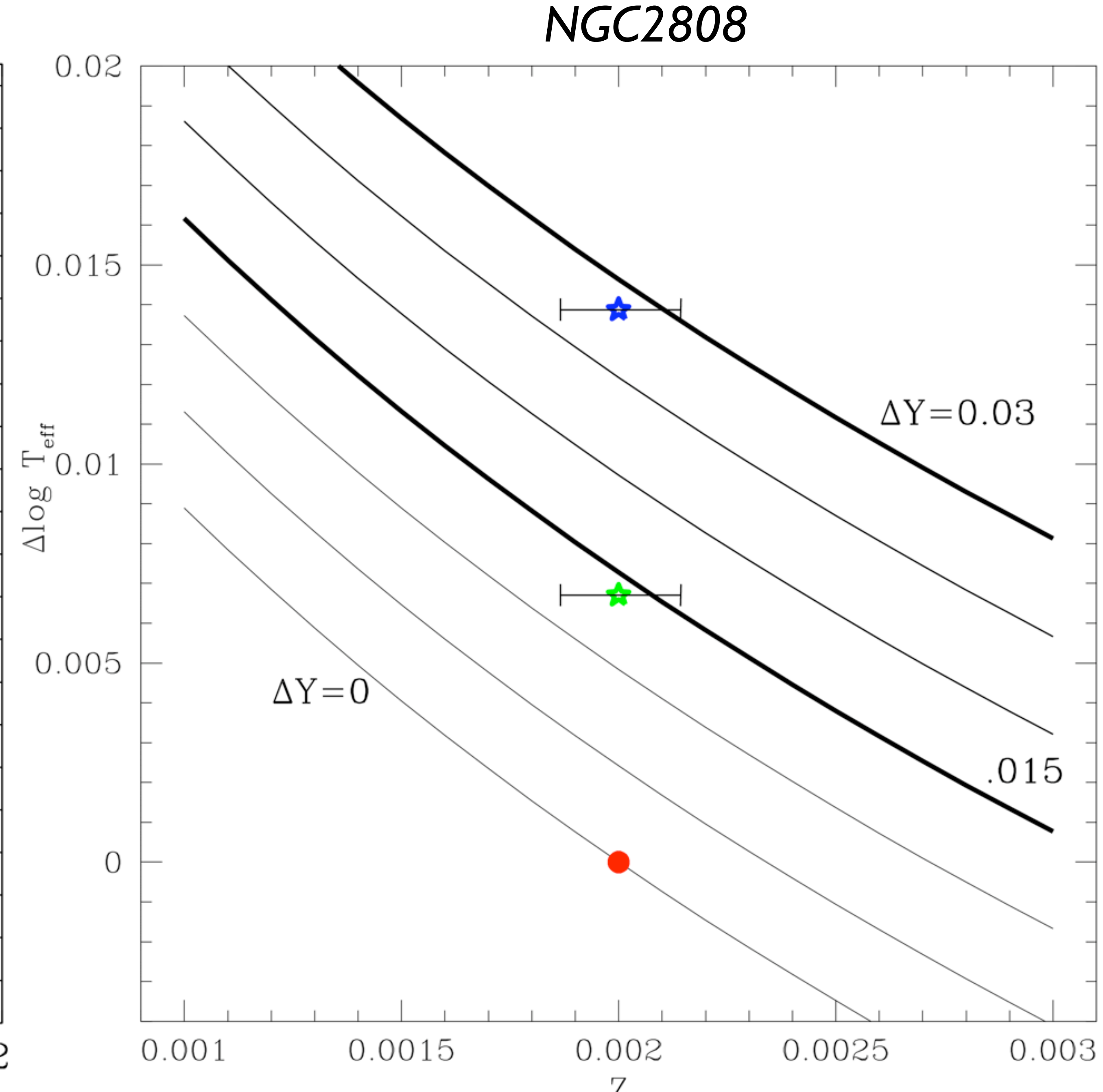
$$\Delta \log T_{\rm eff} = -1.5 \log \left[1 - \frac{\delta}{(0.6+X_r)}(Z - Z_r)\right] - 0.064 \log \left(\frac{670Z+1}{670Z_r+1}\right)$$



It is the preferred solution in terms of agreement with BBN

Consequences for Globular Clusters





If $Y_{rMS} = 0.25 \Rightarrow Y_{bMS} =$ 0.30-0.32

$Y_{rMS}=0.25 \Rightarrow$

$Y_{mMS}=0.26/0.27 \Rightarrow$

$Y_{bMS}=0.28/0.29$

Revision for Globular Clusters ?

- **Compelling** evidence for Y enhancement...

- **but intriguing** problems for low MS, low Z models!

- Our approach (homology) is just "toy model".

- Go into the physics of stellar models (Y dependence more than Z): worth exploring.

Conclusions

- T_{eff} scale : precise & accurate, now.

- Low MS stellar models at low Z predict unacceptably low $Y \ll Y_P$.

- Our exercise highlights the possible connection with the puzzle of extreme helium enrichment in some GCs.

- If the fault lies in the response of stellar models to the helium fraction, the extreme helium population in GCs could be far less rich ($Y = 0.30/0.32$ vs $Y = 0.40$).