Horizontal Branch A- and B-type Stars in Globular Clusters

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Globular Clusters

- some 10 000 to more than 1 000 000 stars with
  - same age
  - same distance and reddening
  - same initial chemical composition
- best approximation of physicist's laboratory
- large distances $\Rightarrow$ faint stars
- high densities $\Rightarrow$ crowding

The Discovery of the Horizontal Branch

ten Bruggencate (1927) used data from Shapley (1915) to plot apparent brightness versus colour index

- ⋆ first colour-magnitude diagram
- ⋆ description of red giant branch (RGB) and a horizontal branch (HB) departing from the RGB and extending over a wide colour range

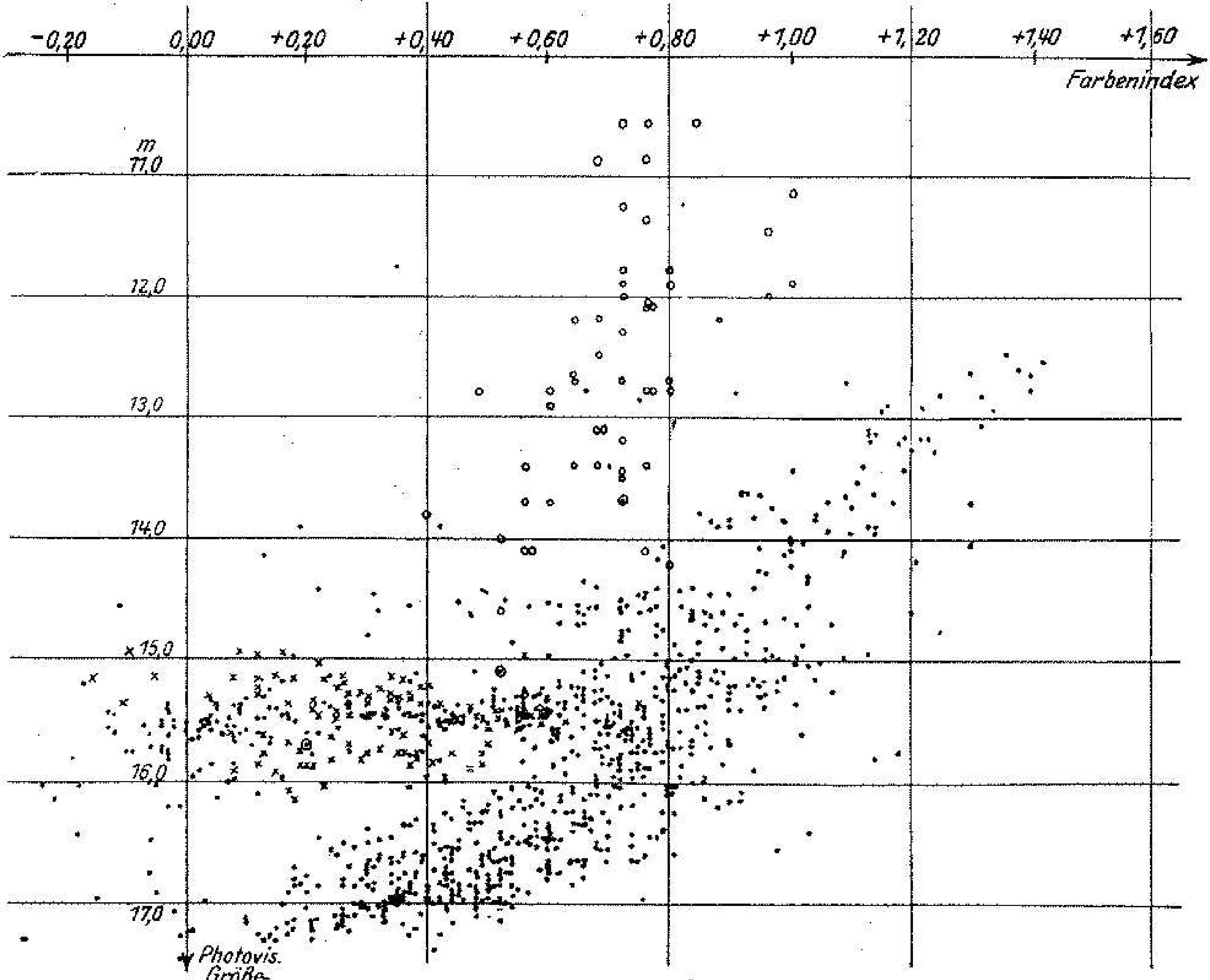
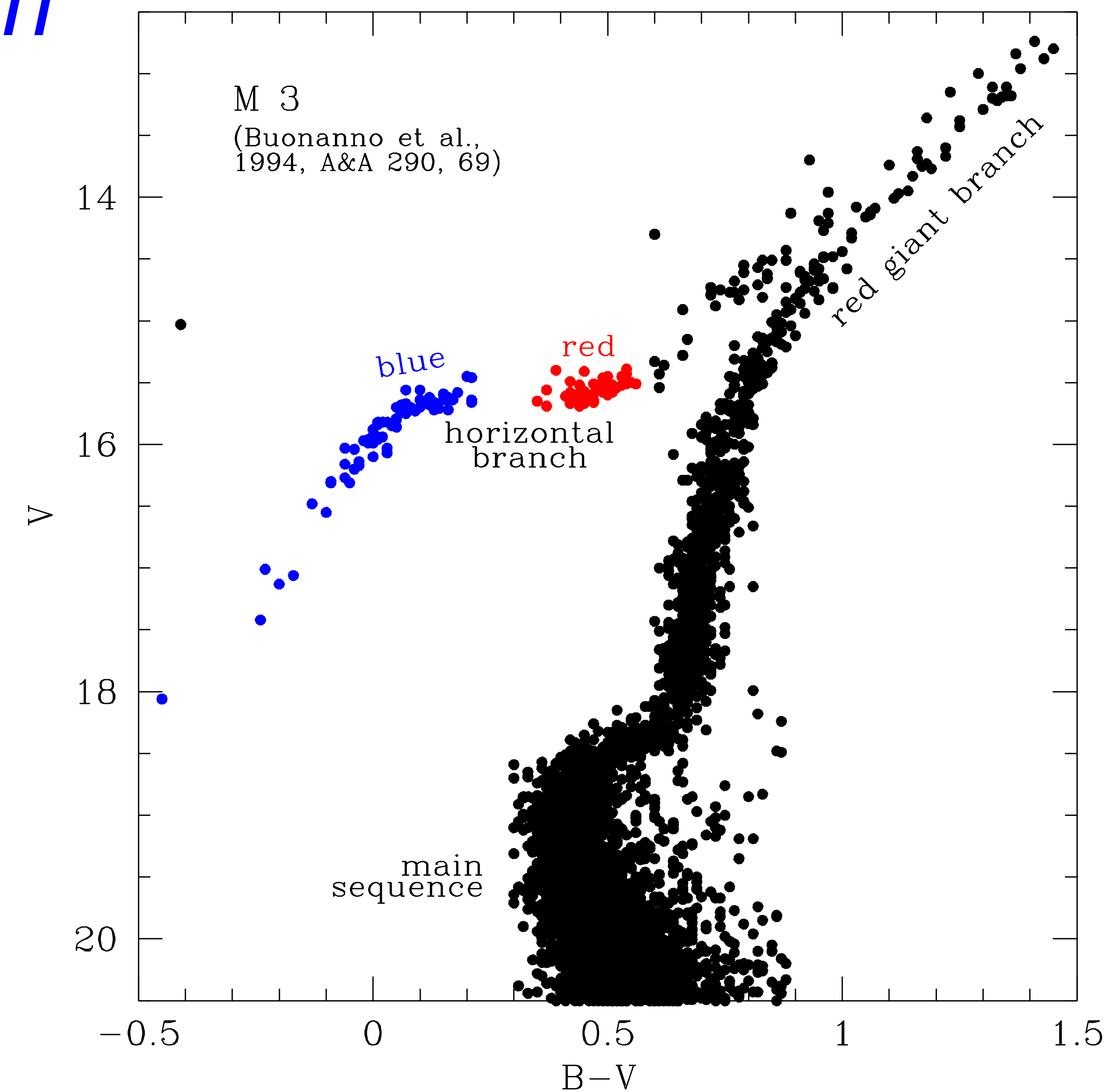


Abb. 21. Farbenhelligkeitsdiagramm des Kugelhaufens Messier 3.

Modern Colour-Magnitude Diagram



How to become a Horizontal Branch Star

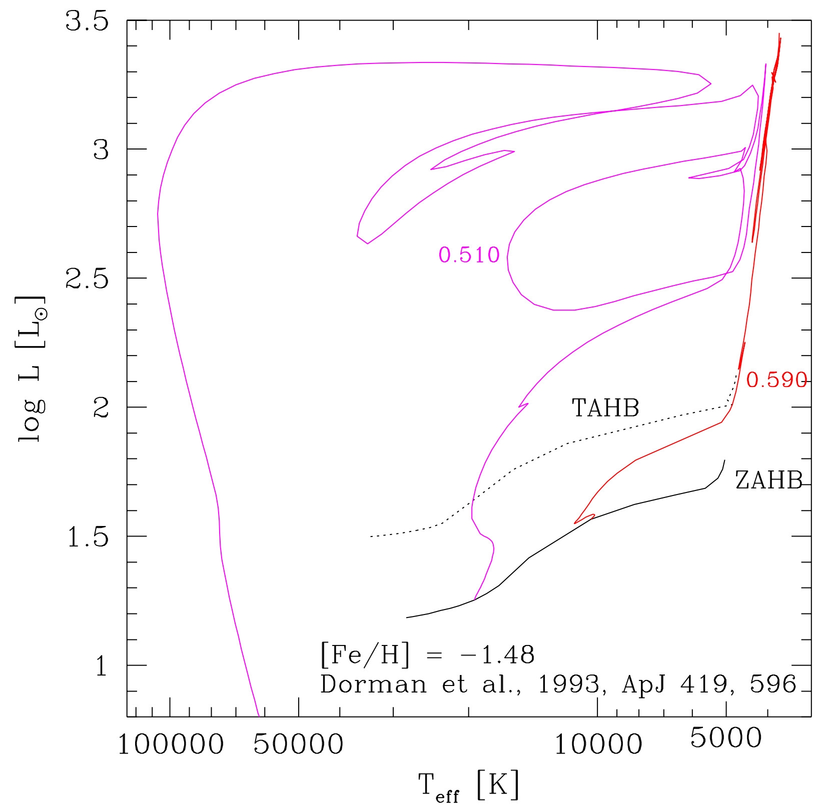
- ⋆ Hoyle & Schwarzschild (1955): HB stars are post-RGB stars with helium core burning
- ⋆ Sandage & Wallerstein (1960): HB becomes bluer with decreasing metallicity
- ⋆ Faulkner (1966): first zero-age HB models that become bluer with decreasing metallicity
  - ⋆ no mass loss assumed
  - ⋆ high helium abundance $Y = 0.35$ required

Mass Loss appears on the Stage (Iben & Rood, 1970)

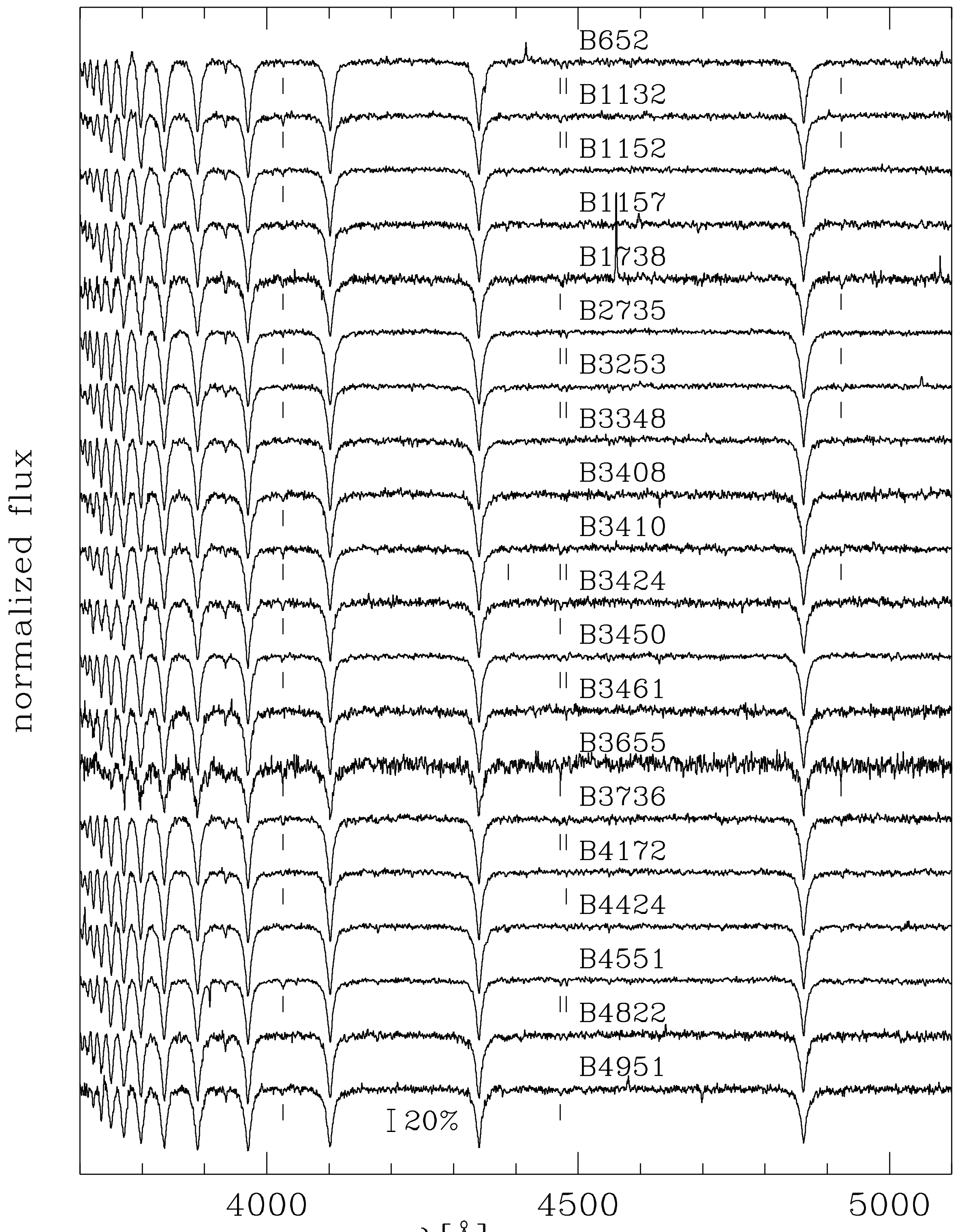
"In fact for the values of Y and Z most favored (Y $\geq$ 0.25 $\rightarrow$ 0.28, Z = $10^{-3} \rightarrow 10^{-4}$), individual tracks are the stubbiest. We can account for the observed spread in color along the horizontal branch by accepting that there is also a spread in stellar mass along this branch...It is somewhat sobering to realize that this conclusion comes near the end of an investigation that has for several years relied heavily on aesthetic arguments against mass loss ..."

Horizontal Branch Stars

- ⋆ helium burning core of about 0.5 $M_\odot$
- ⋆ hydrogen envelope of more than 0.02 $M_\odot$
- ⋆ hydrogen shell burning
- ⋆ evolve to the Asymptotic Giant Branch (AGB)



- ⋆ temperatures increases with decreasing metallicity and/or envelope mass



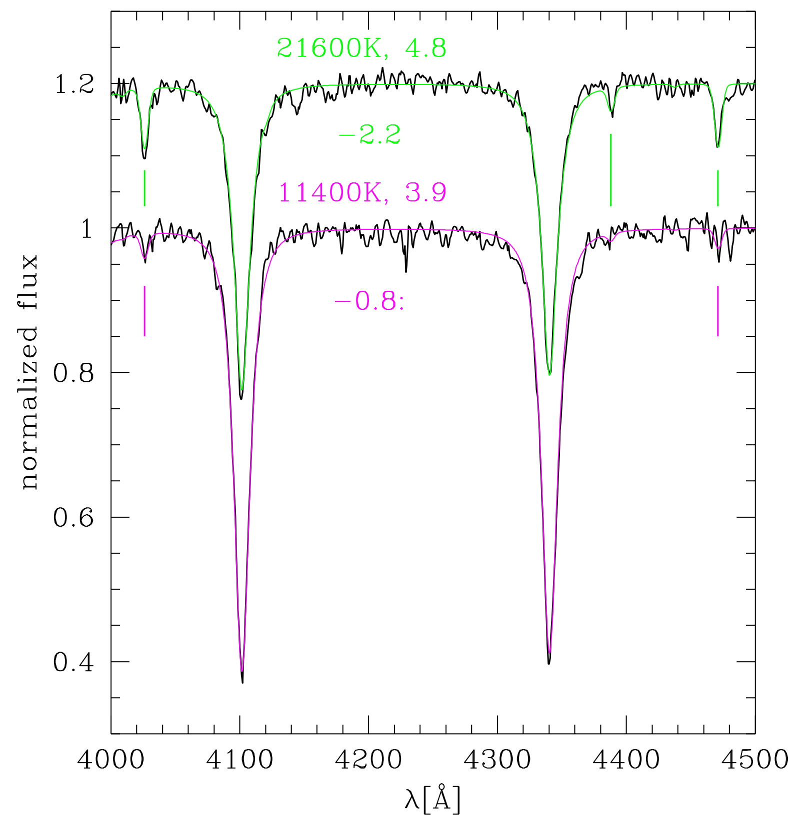
Blue Horizontal Branch Stars

- ⋆ strong H lines
- ⋆ weak He lines

Method

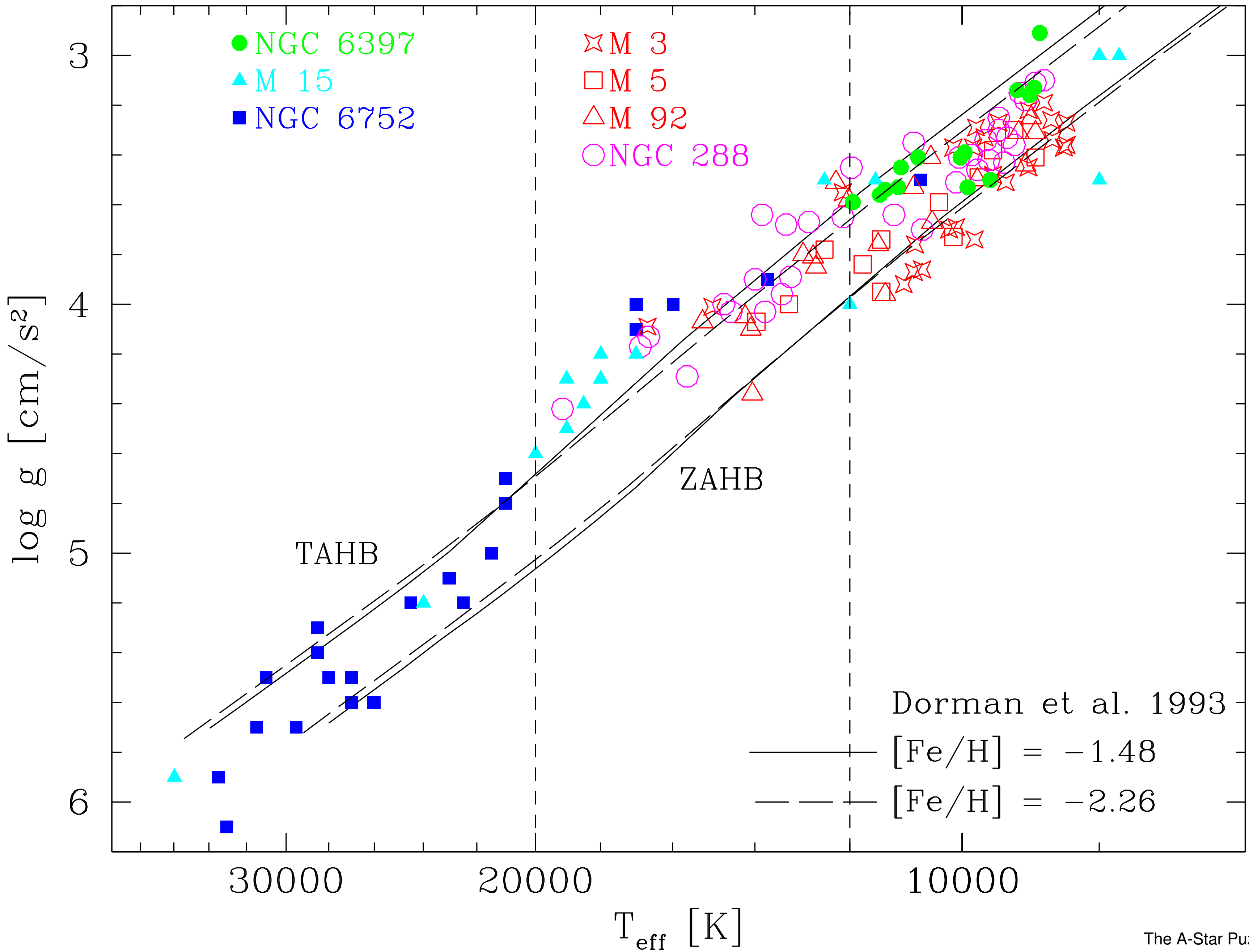
Analysis of
medium resolution spectra

- ⋆ fit of Balmer line profiles
  - ⇒ temperature
  - ⇒ surface gravity
- ⋆ and helium lines
  - ⇒ helium abundance

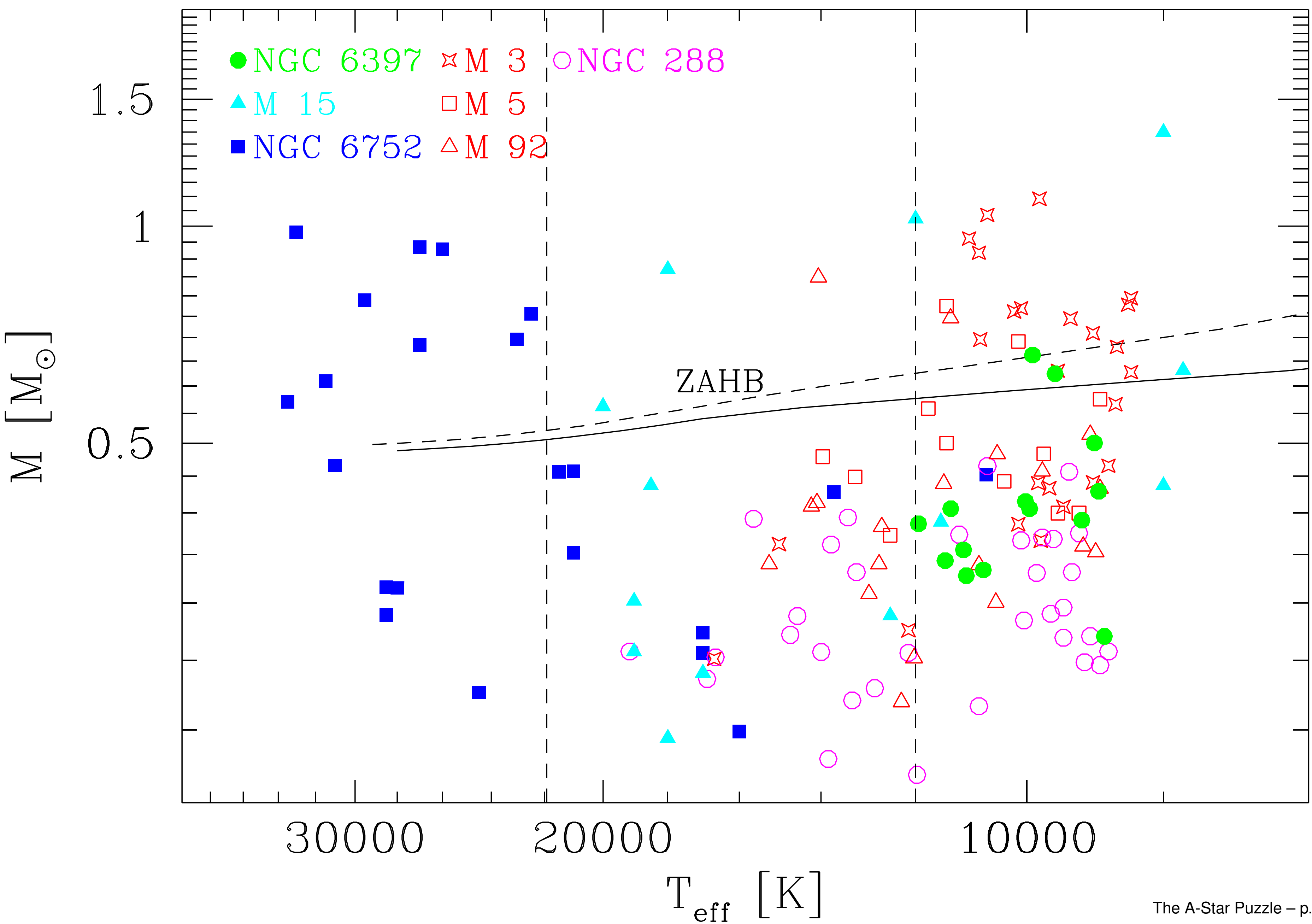


Temperatures and Gravities

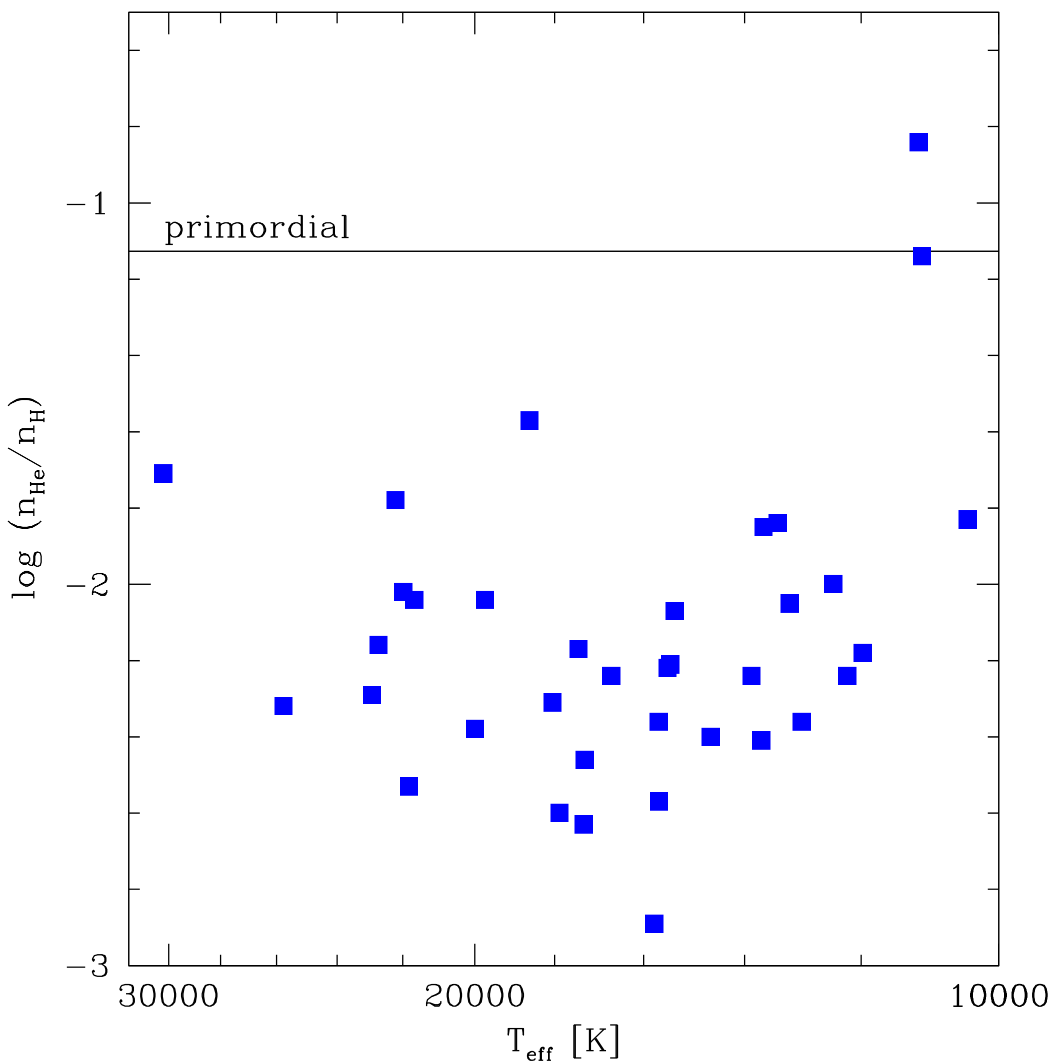
(Crocker et al. 1988, de Boer et al. 1995, Moehler et al. 1995, 1997)



Masses *(Moehler et al. 1997)*

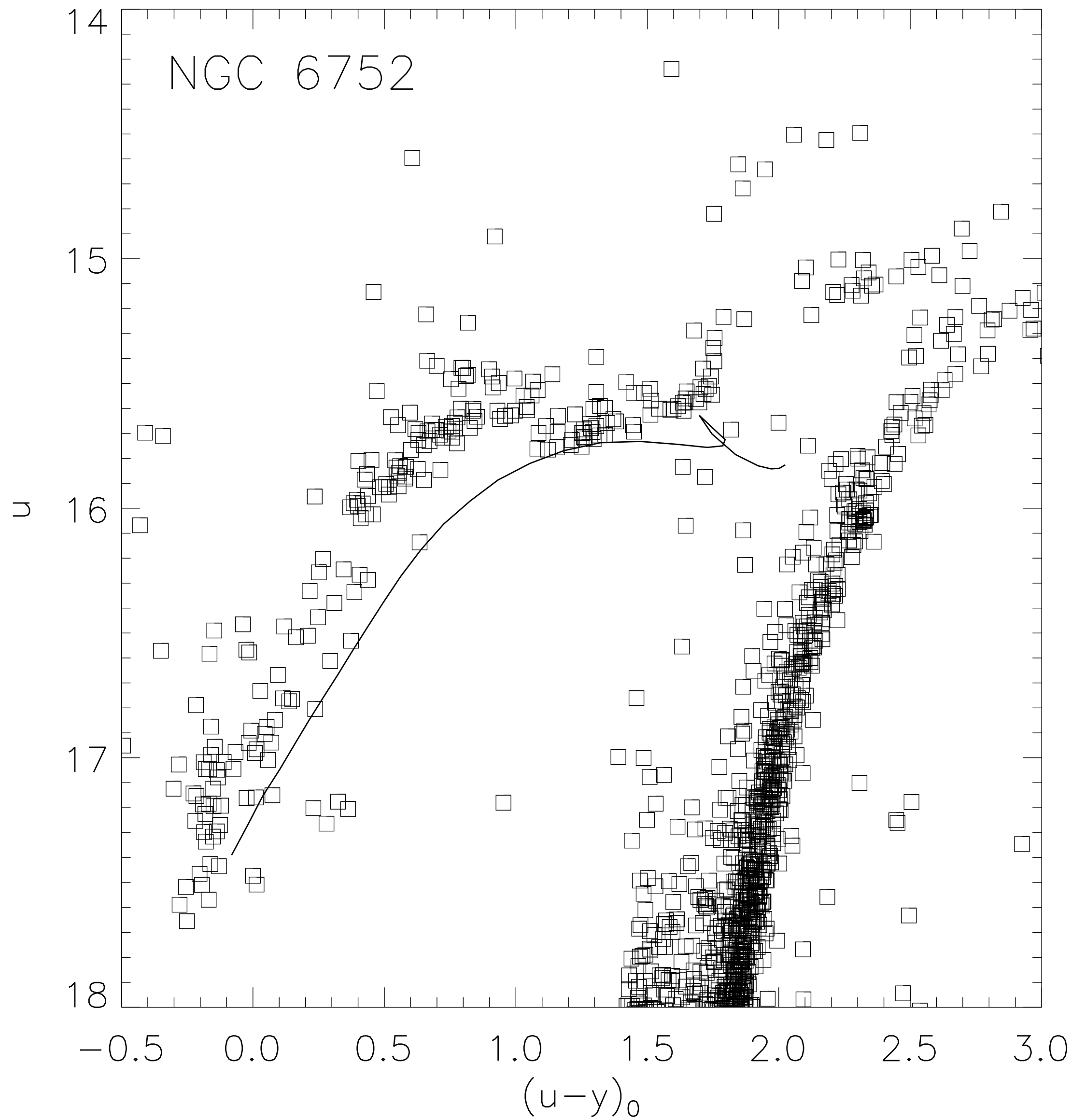


Helium Abundances *(Moehler et al. 2000)*



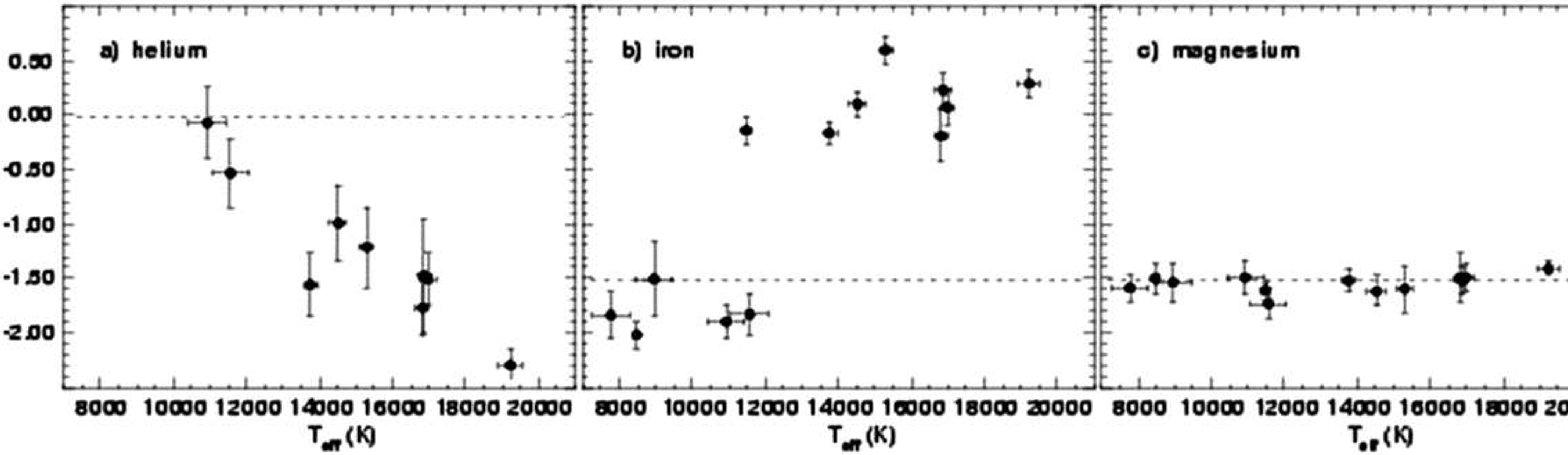
u-jump

Grundahl et al. (1999): observed in all globular clusters with sufficient photometry

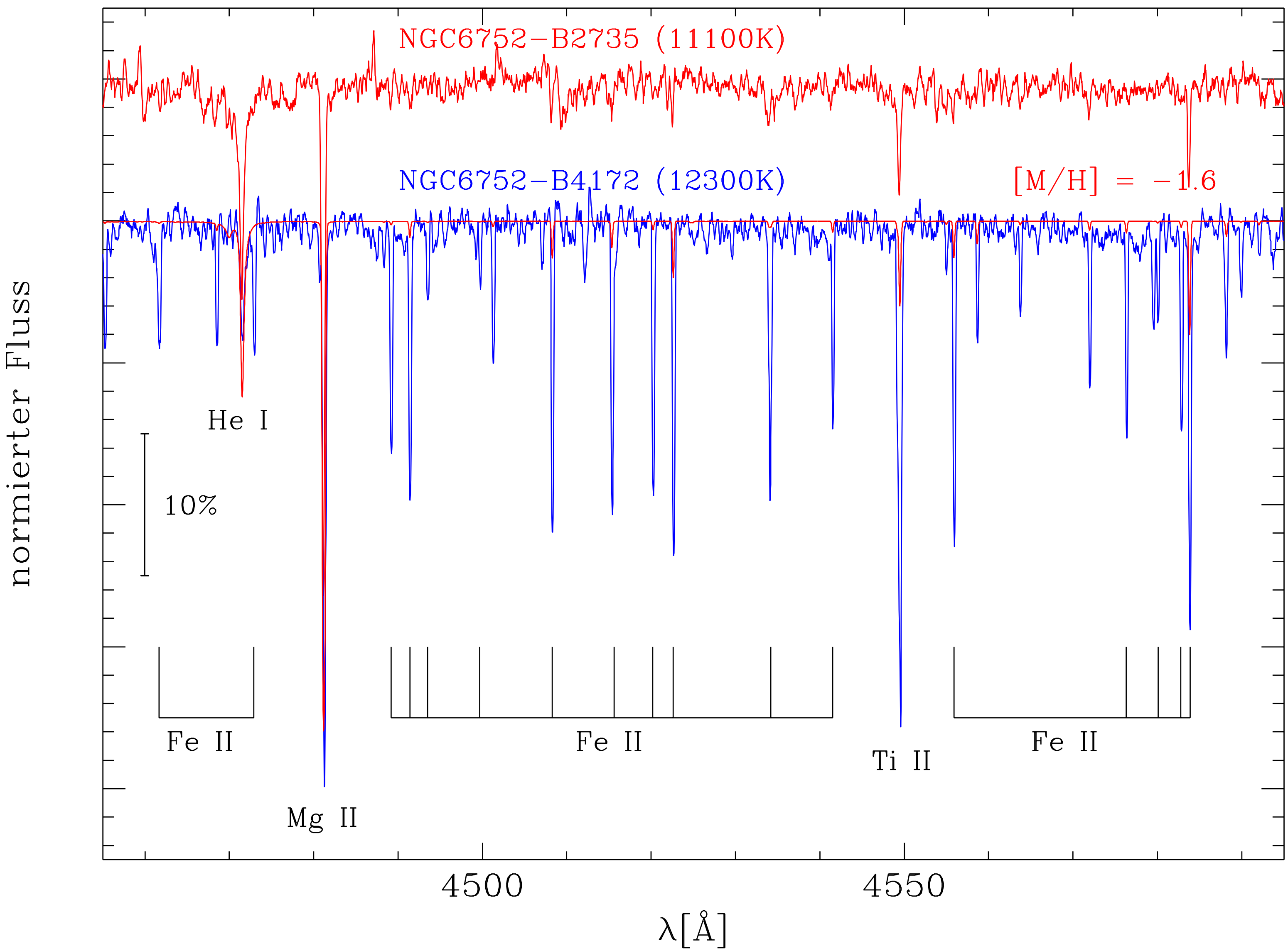


Iron Levitation

Behr et al. (1999, M13)



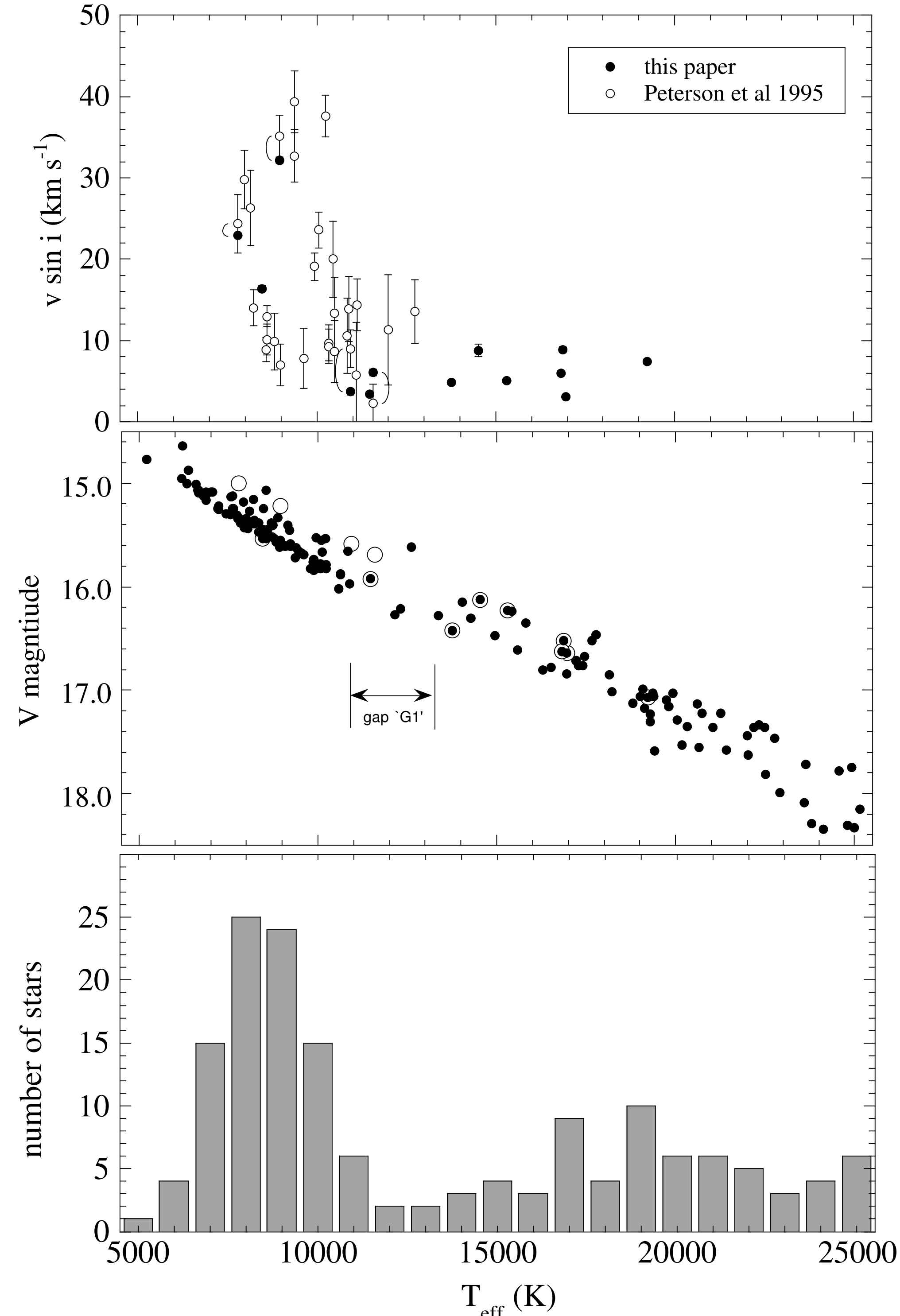
Iron enrichment



Rotation

Behr et al. (2000, M13):

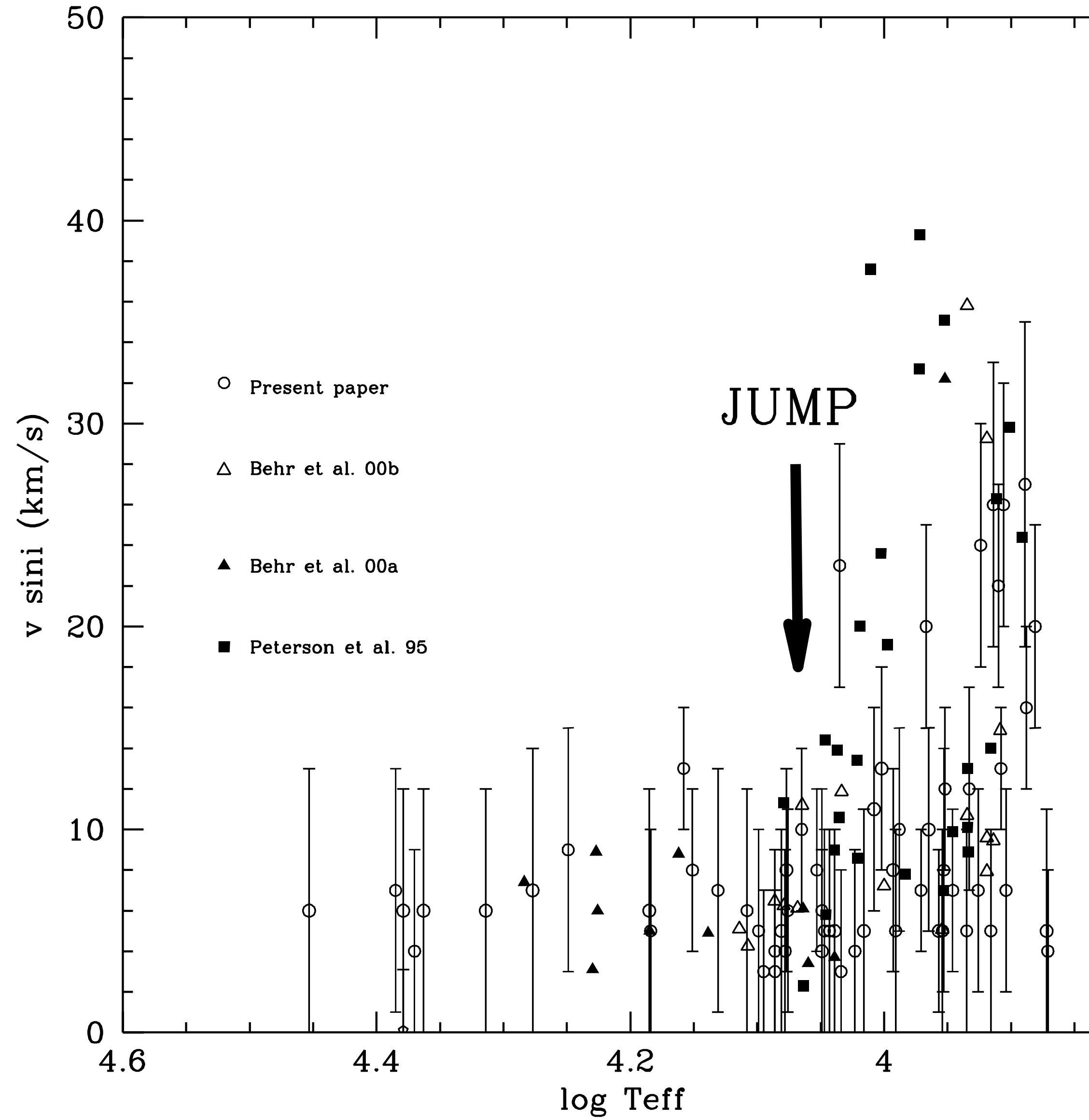
- ⋆ no fast rotators above ca. 12,000 K
- ⋆ small number of fast rotators below ca. 12,000 K



Rotation

Recio-Blanco et al. (2004)

- ⋆ no fast rotators above ca. 12,000 K in M13 and M15
- ⋆ no fast rotators at all in NGC2808 and M80

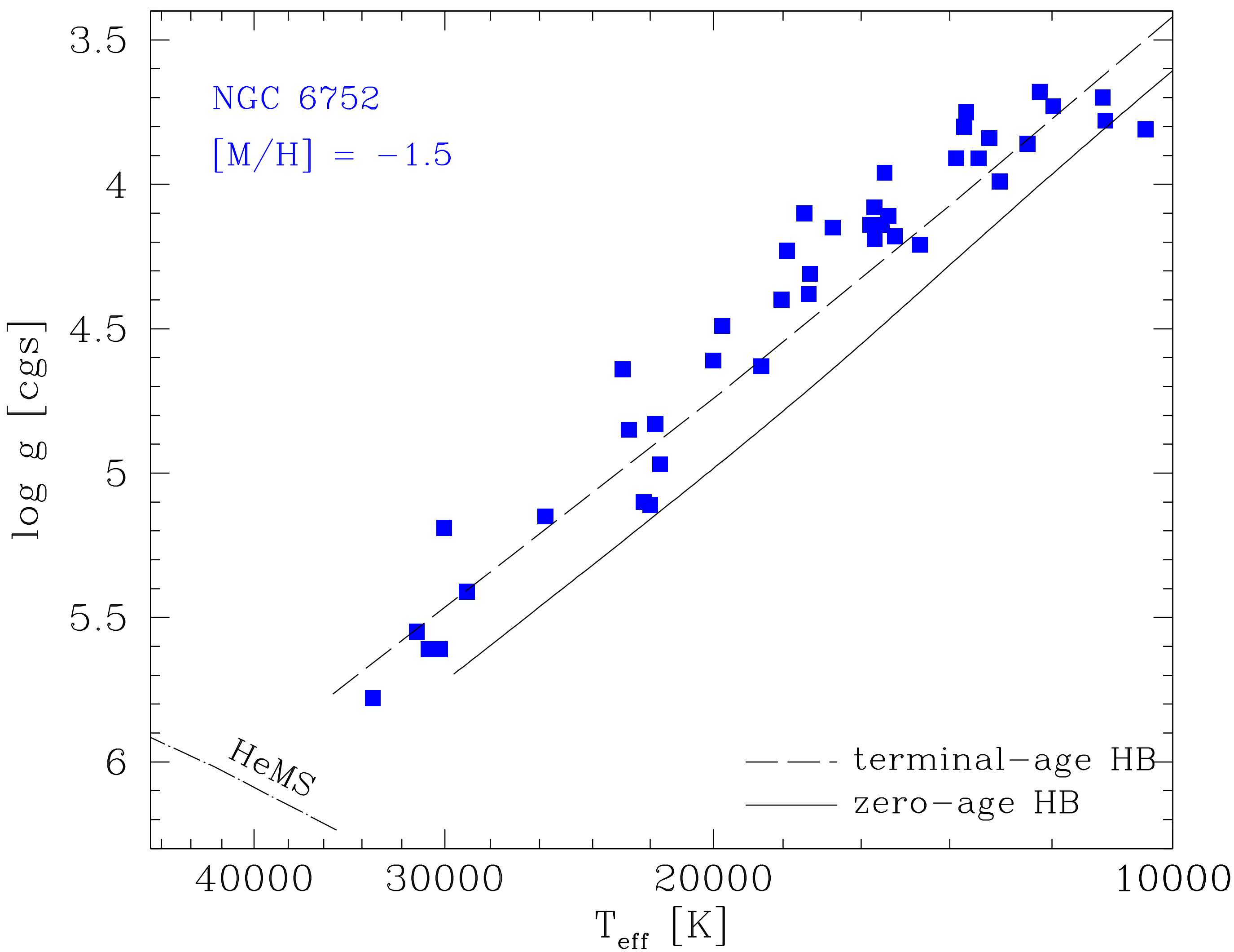


Diffusion

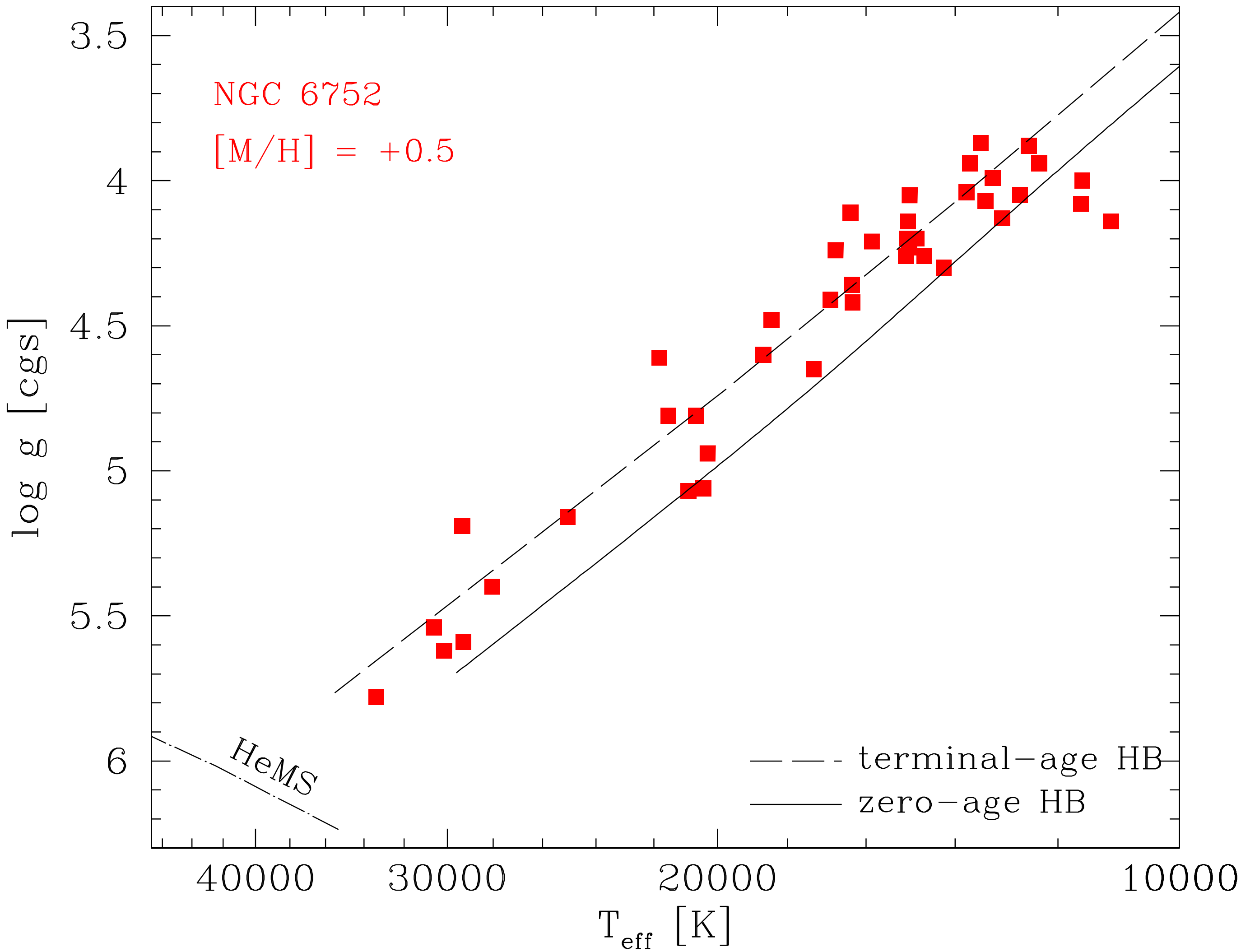
diffusion = gravitational settling + radiative levitation

- $\star$ change of metallicity in the stellar atmosphere
- $\star$ different temperature stratification
  - $\Rightarrow$ flux distribution
  - $\Rightarrow$ Balmer jumps
  - $\Rightarrow$ Balmer line profiles

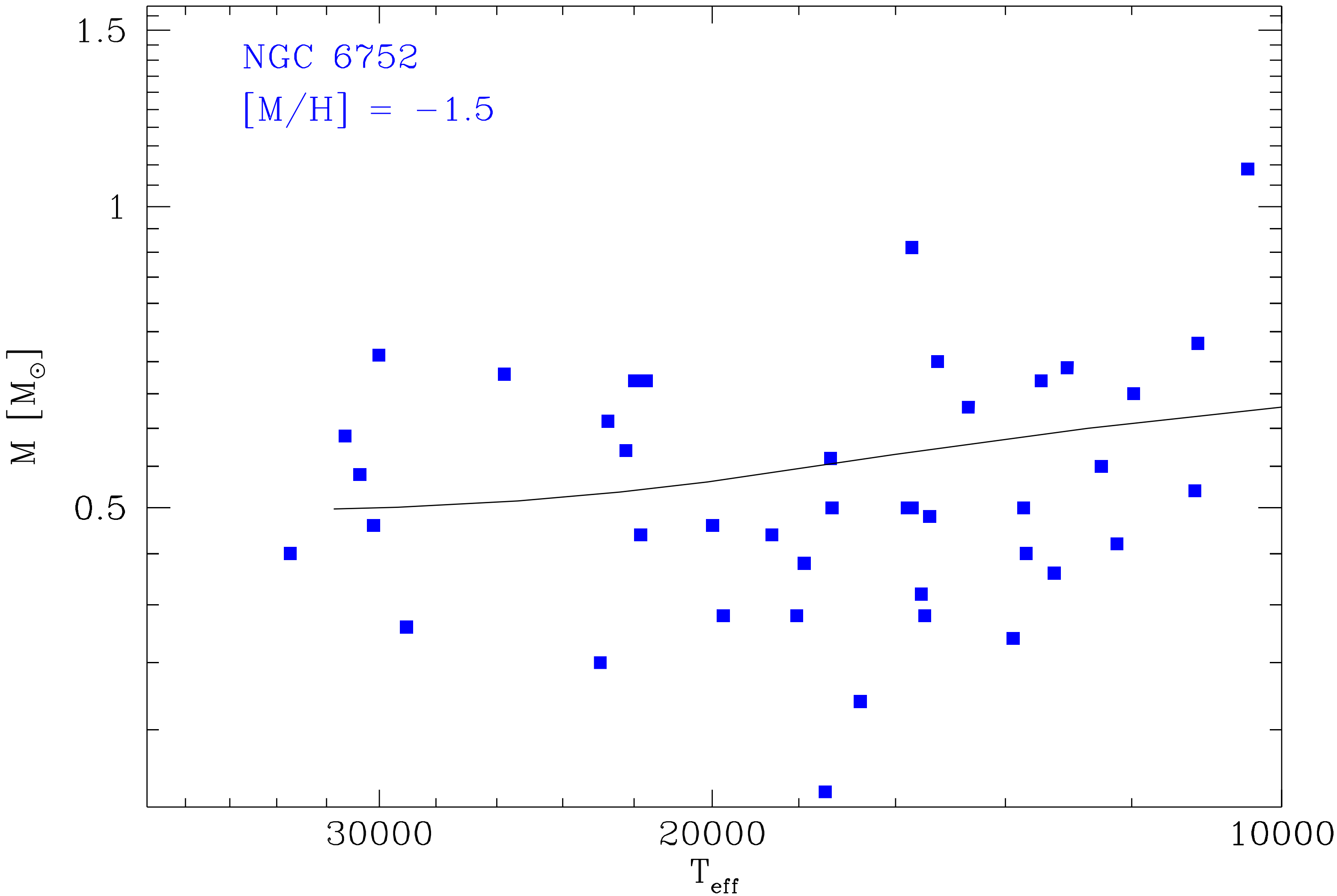
Metal-poor model atmospheres



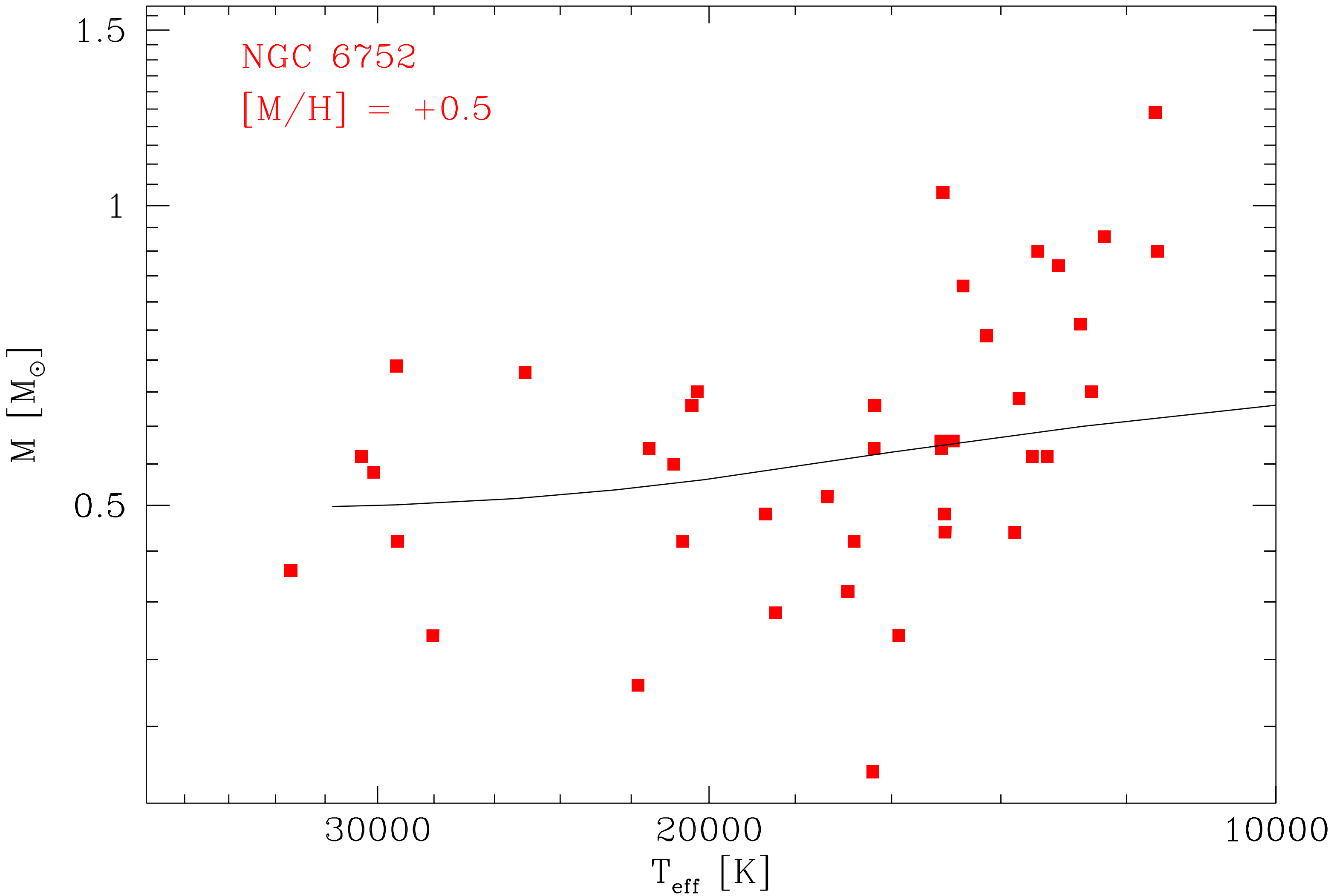
Metal-rich model atmospheres



Metal-poor model atmospheres



Metal-rich model atmospheres



Non-solar abundance ratios

$[X/H] = \log \frac{n_X}{n_H} - \log \frac{n_{X,\odot}}{n_{H,\odot}}$

Element	$<$11000 K		11500 K		15000 K		17000 K	
	[X/H]	n	[X/H]	n	[X/H]	n	[X/H]	n
Mg	-1.5	1	-1.2	1	-0.9	1	-0.9	1
Si	-1.2	4	< -3	4	$+0.3$	12	-0.3	8
P			$+1.2$	4	$+2.0$	19		
Mn					$+1.5$	4		
Ti			$+0.4$	20				
Fe	-1.8	6	$+0.6$	119	$+0.8$	60	$+0.5$	23
Y			$+2.0$	4				

Hot Horizontal Branch Stars

- $\star$ diffusion important for hot horizontal branch stars
  - $\Rightarrow$ non-solar abundance ratios
  - $\Rightarrow$ abundances from UV spectra of old stellar populations $\neq$ original abundances
- $\star$ analysis with metal-rich model atmospheres
  - $\Rightarrow$ mostly consistent with canonical evolution
  - $\Rightarrow$ remaining inconsistencies due to non-solar abundance ratios?
- $\star$ origin of fast rotators below 11,000 K unclear

Who is "we" (besides me)?

- ⋆ Allen V. Sweigart, Wayne B. Landsman (Goddard Space Flight Center)
- ⋆ Uli Heber (Bamberg)