New Twists along the Horizontal Branches in Globular Clusters

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Who is “we” (besides me)?

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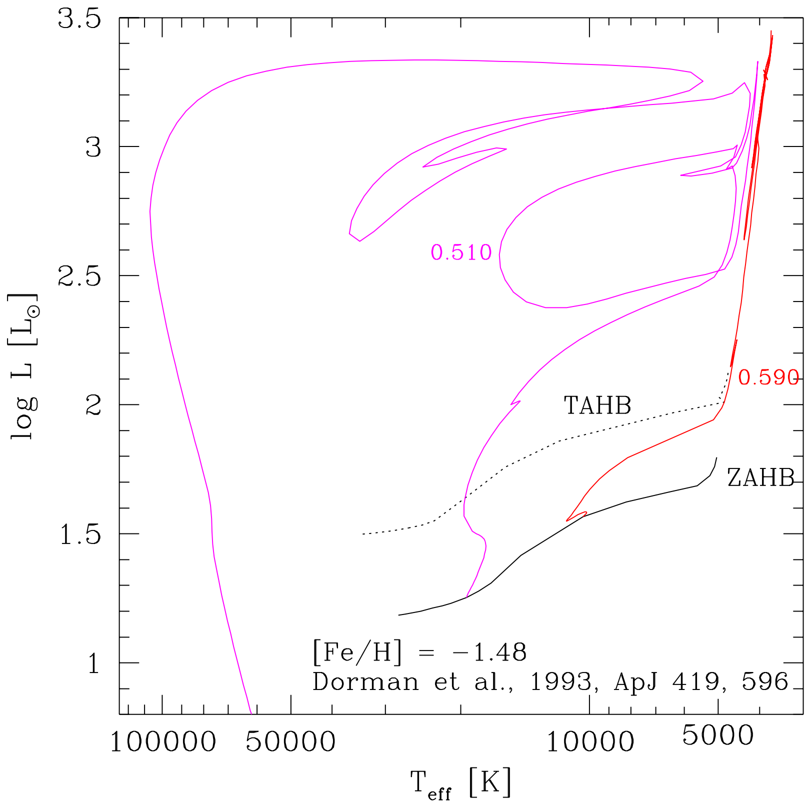
- ⋆ Stefan Dreizler (Tübingen)
- ⋆ Thierry Lanz (Baltimore)
- ⋆ Giuseppe Bono (Rome)
- ⋆ Matteo Monelli (Trieste)
- ⋆ Mario Nonino (La Laguna)

Overview

- ⋆ Horizontal Branch Stars
- ⋆ NGC 6388
- ⋆ ω Cen

Horizontal Branch Stars

- ⋆ helium burning core of about 0.5 $M_\odot$
- ⋆ hydrogen envelope of more than 0.02 $M_\odot$
- ⋆ hydrogen shell burning
- ⋆ temperature increases with decreasing metallicity and/or envelope mass



Blue Tails

- ⋆ increasing bolometric correction with increasing temperature
- ⋆ decreasing temperature sensitivity of optical colours with increasing temperature
- ⋆ horizontal branch $\longrightarrow$ blue tail
- ⋆ hottest stars at faint end

1st Parameter

distribution of stars along the horizontal branch ("horizontal branch morphology") depends on metallicity, i.e. metal-rich globular clusters like NGC 6388 should have only red horizontal branch stars

NGC6388: Problems and Possible Solutions

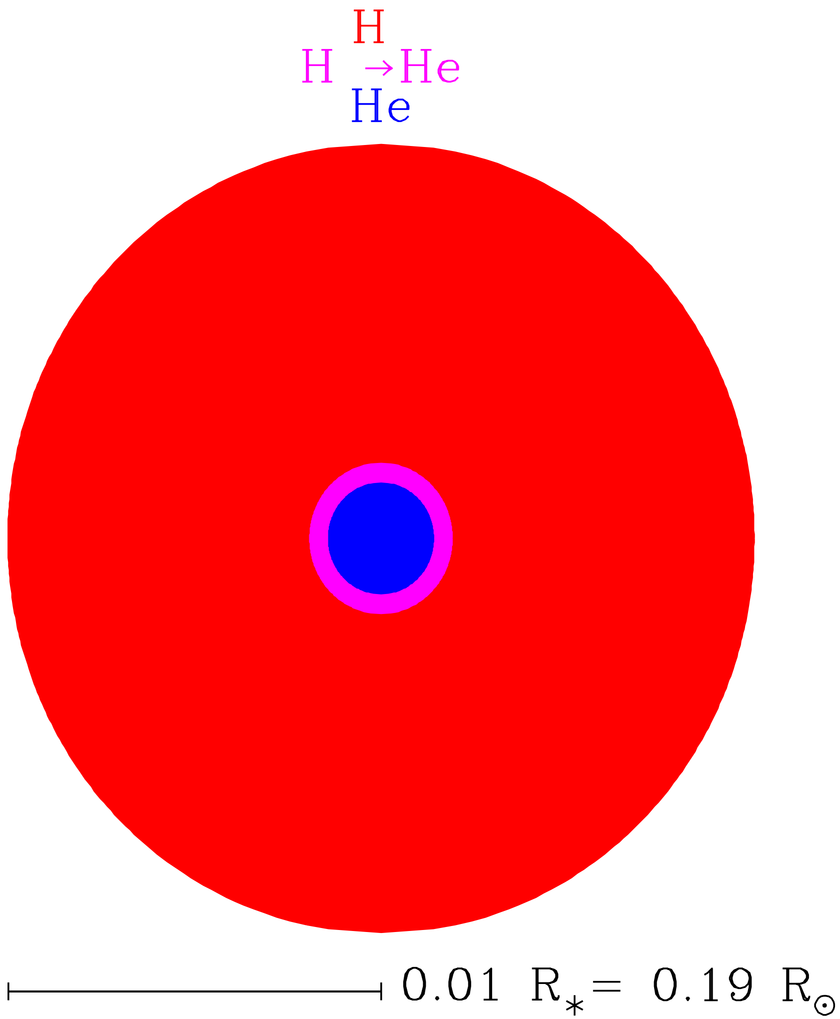
Problems (Rich et al. 1997):

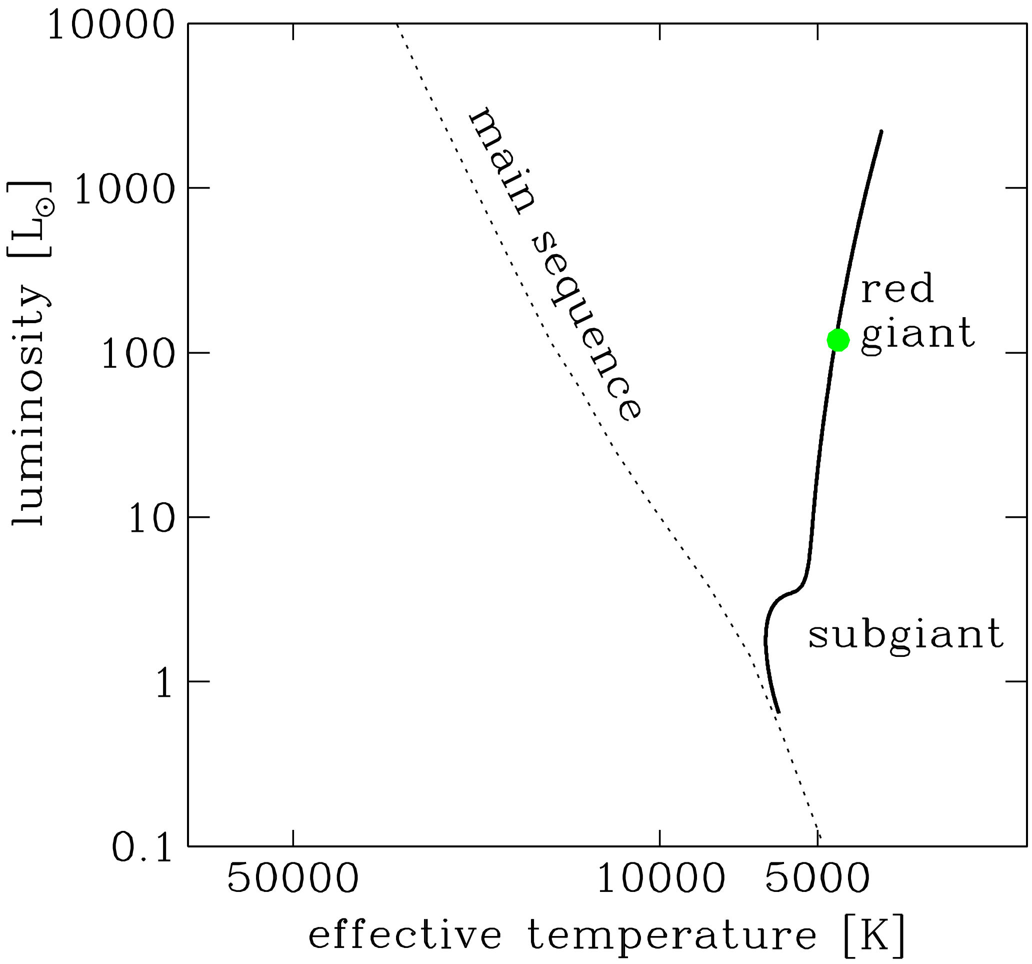
- ⋆ 15% of horizontal branch stars are blue
- ⋆ brightness increases with increasing temperature

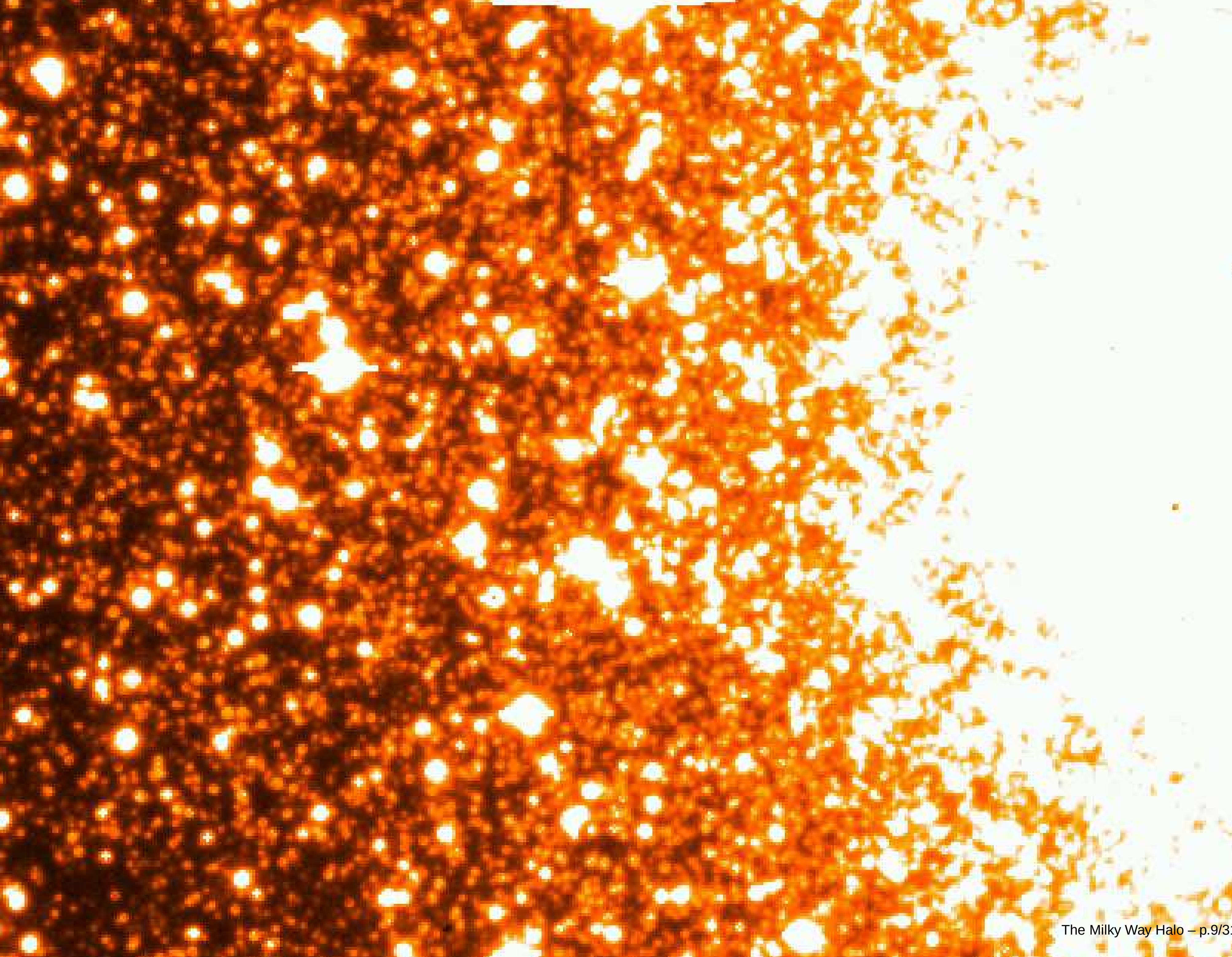
Possible solutions have to explain both effects

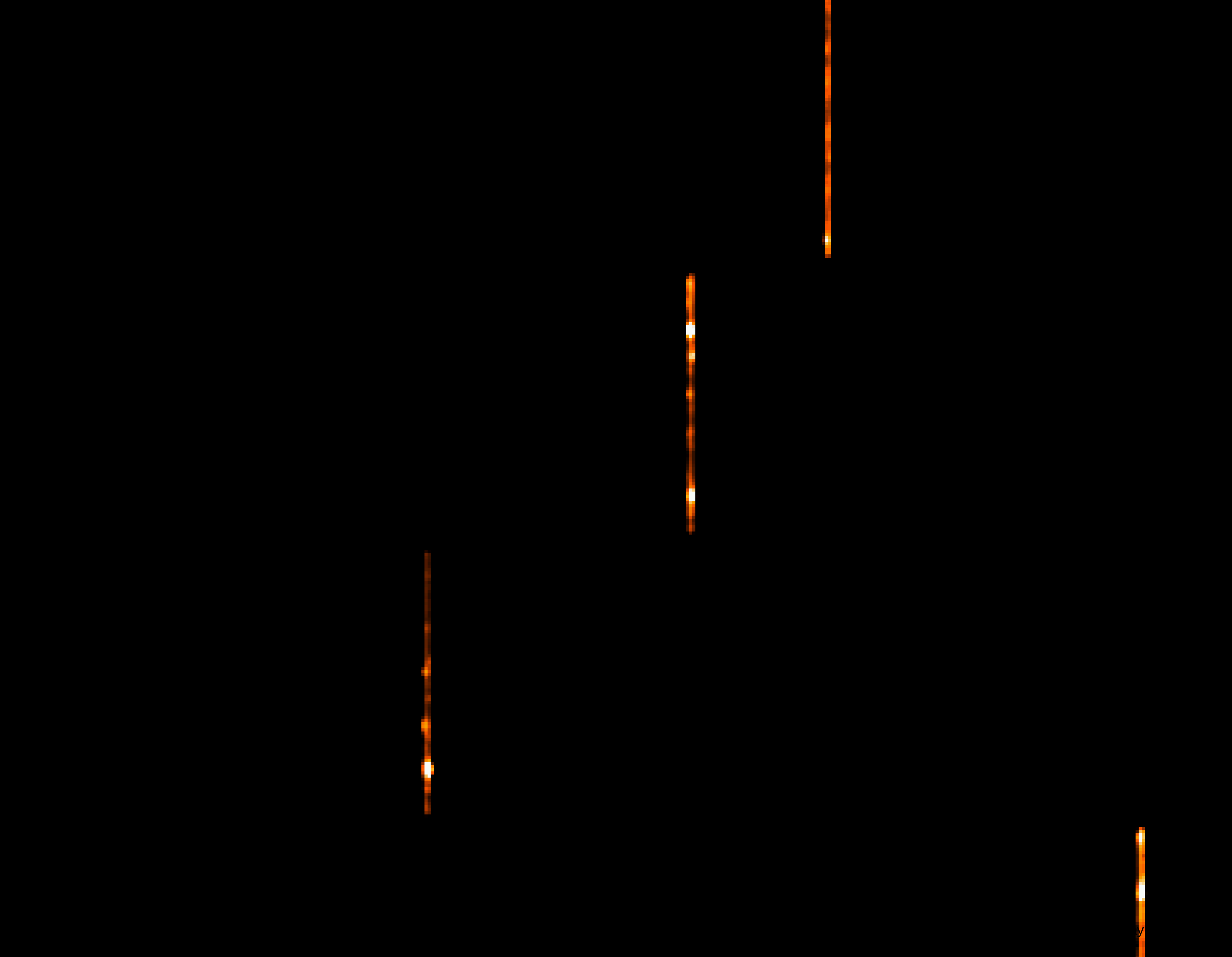
- ⋆ (several ones ruled out by now)
- ⋆ Helium Pollution (D'Antona et al. 2005)
  increased energy production ⇒ higher luminosity, lower log g
  increased mass loss ⇒ higher temperatures

Evolution of Low-Mass Stars

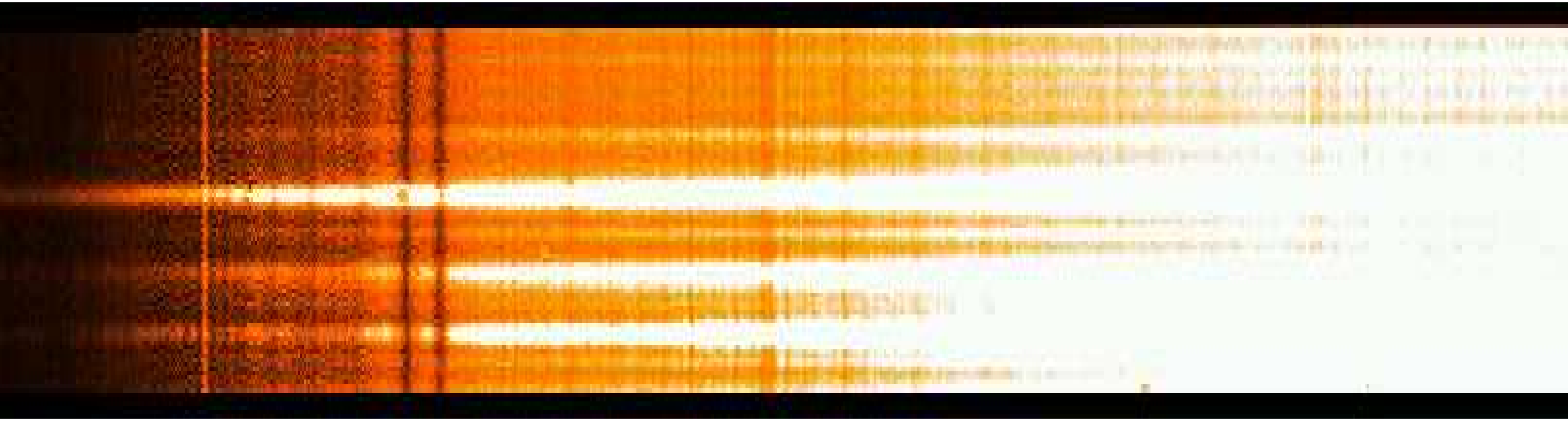


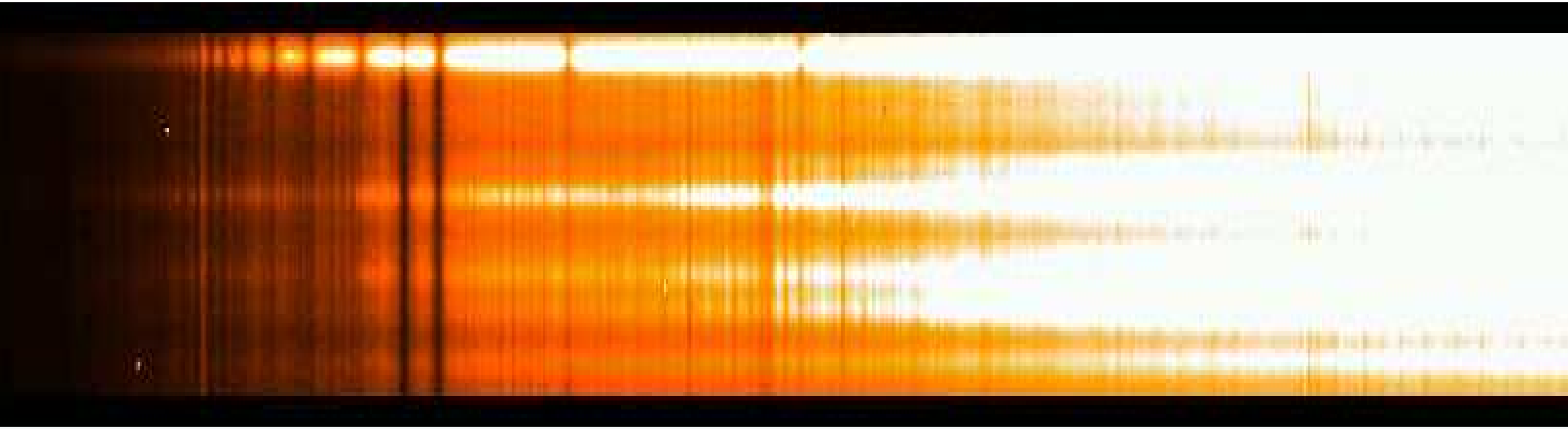




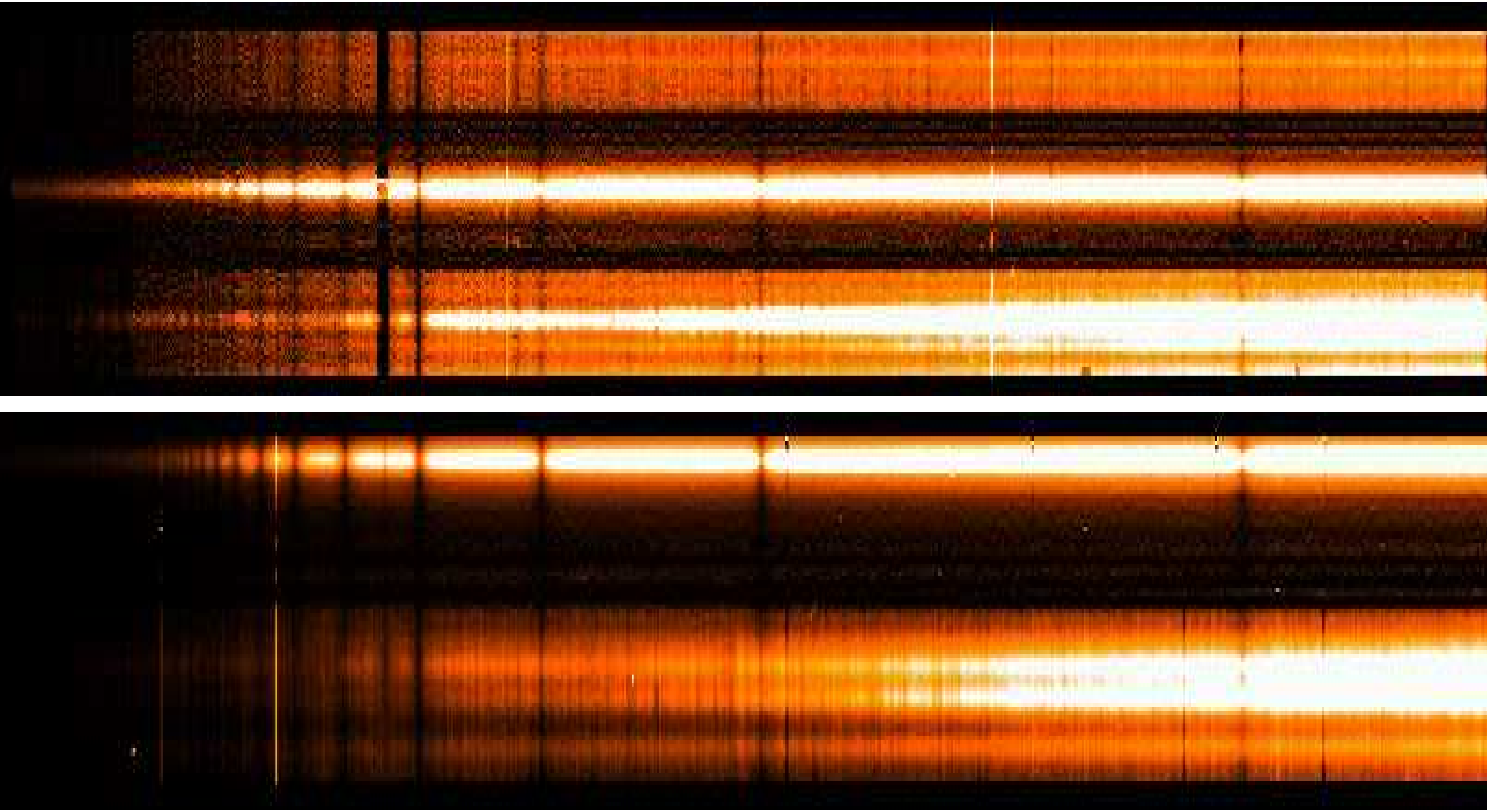


Spectra

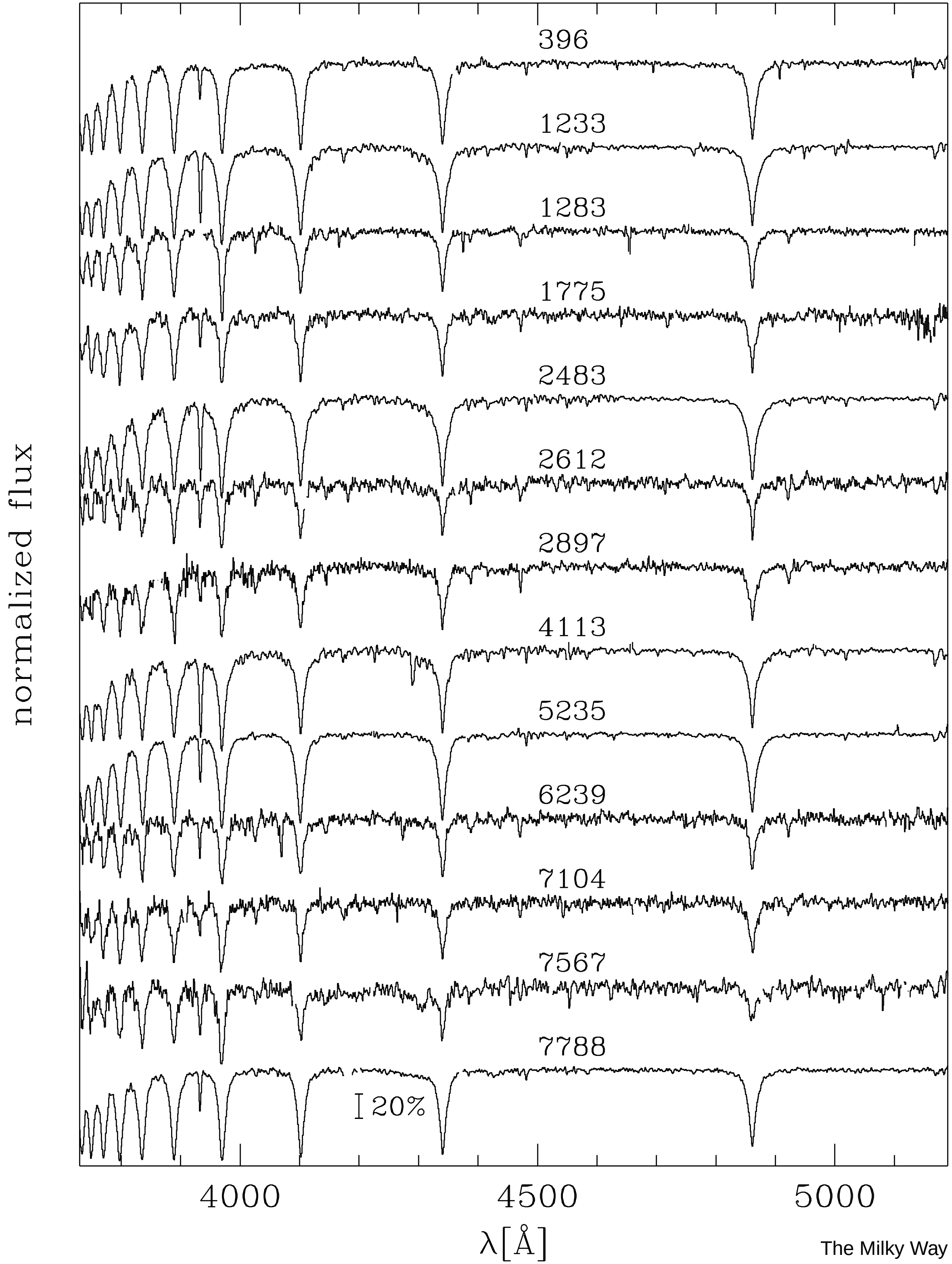




Sky-Corrected Spectra



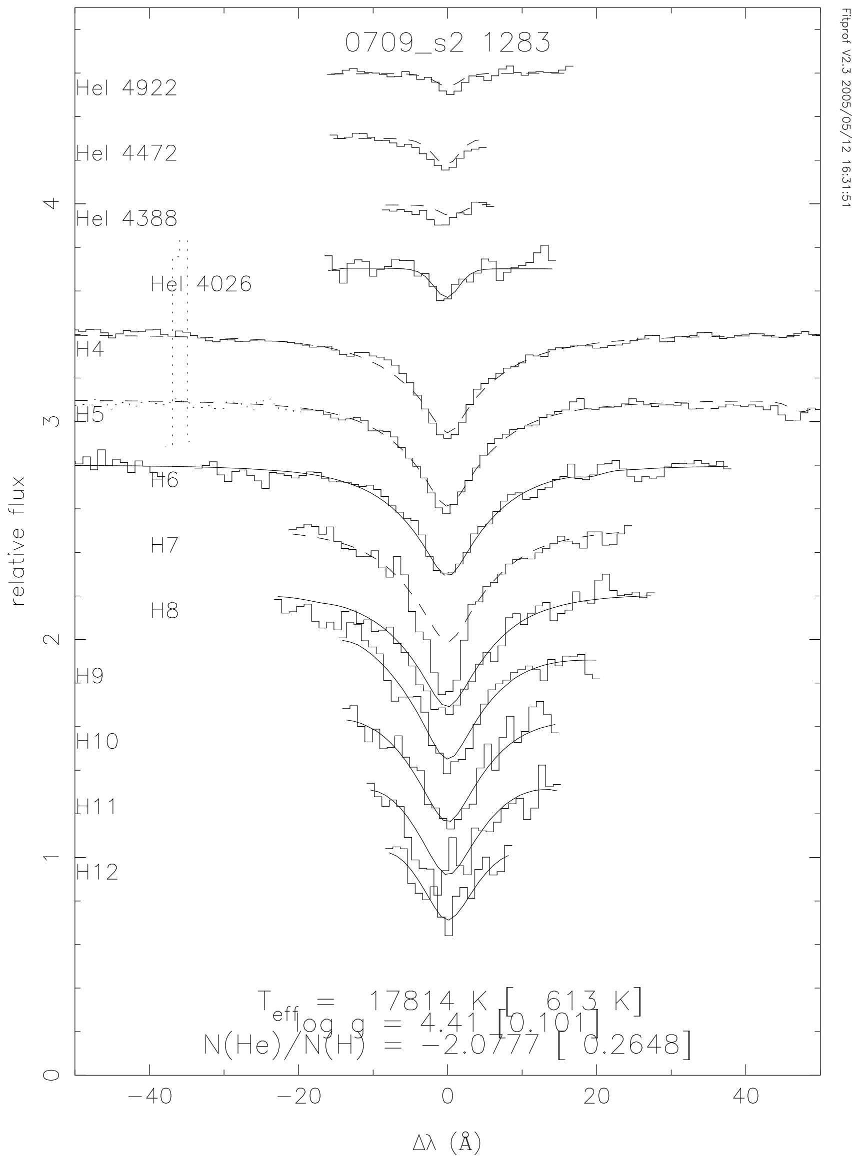
Spectra


396
1233
1283
1775
2483
2612
2897
4113
5235
6239
7104
7567
7788
20%
normalized flux
4000
4500
5000
λ[Å]

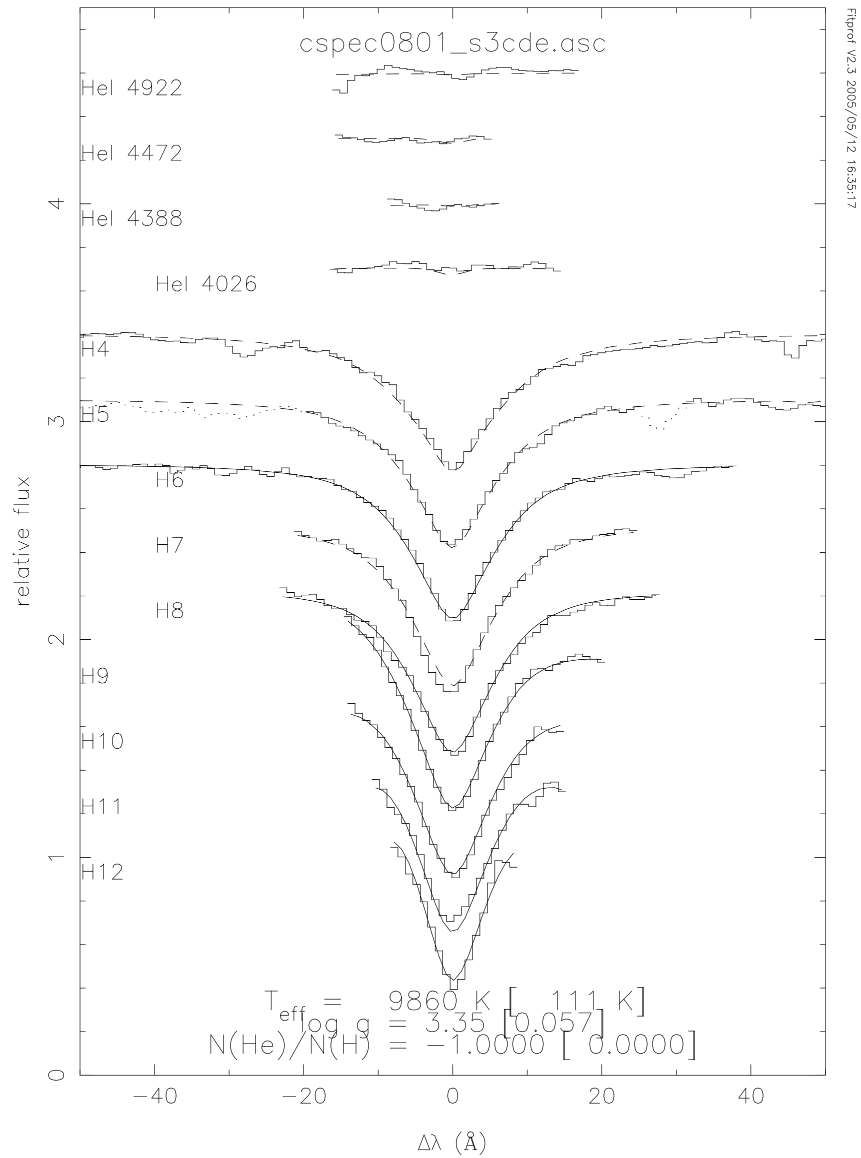
FORS Analysis

- $\star$ T_{eff}, $\log g$ and helium abundance from fit to Balmer and helium lines
- $\star$ model atmospheres for [M/H] = -0.5 for cool stars and for [M/H] = $+0.5$ for hot stars
- $\star$ mass estimates from cluster distance

Fits

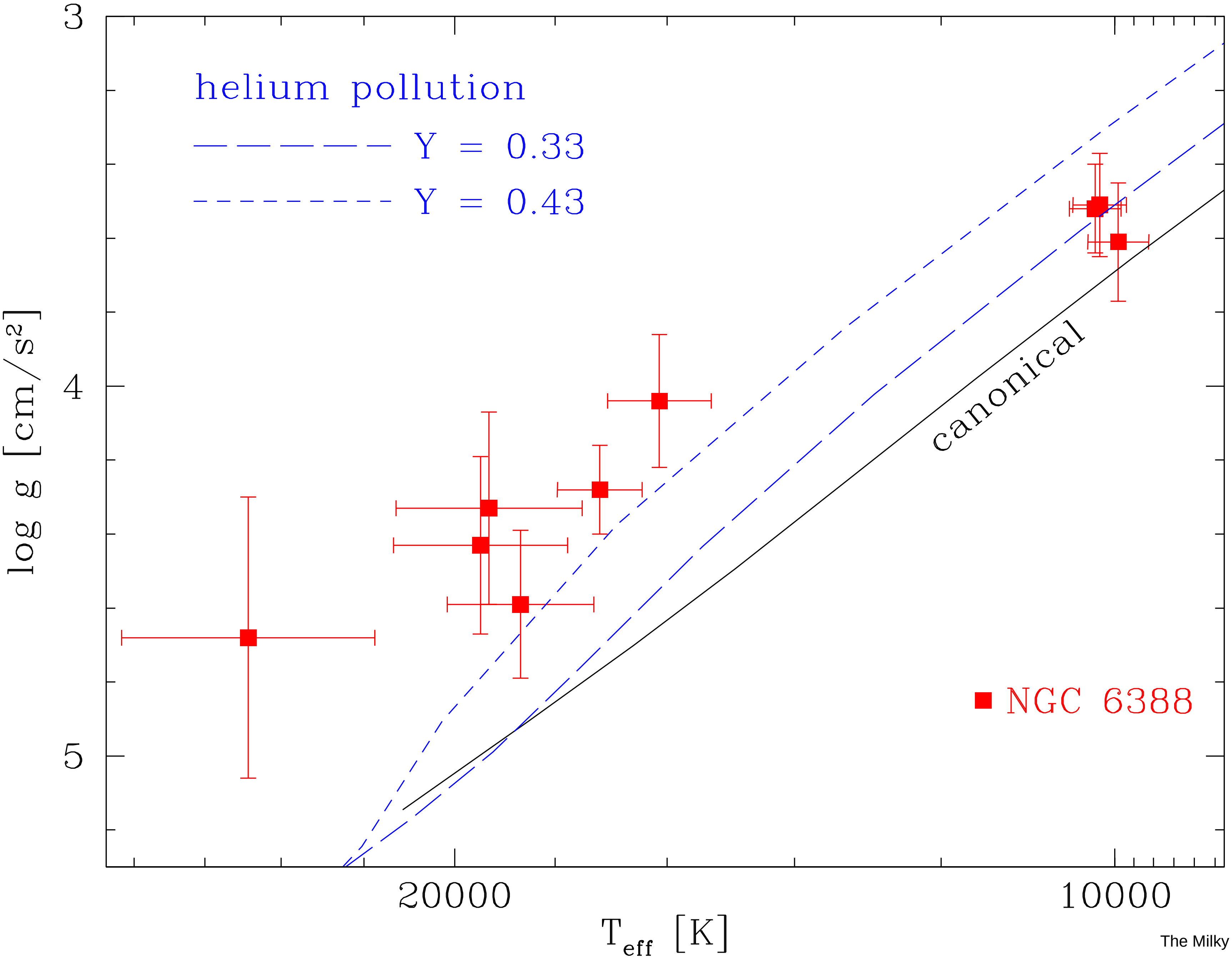


0709_s2 1283
HeI 4922
HeI 4472
HeI 4388
HeI 4026
H4
H5
H6
H7
H8
H9
H10
H11
H12
relative flux
Δλ (Å)
Teff = 17814 K [613 K]
log g = 4.41 [0.101]
N(He)/N(H) = −2.0777 [0.2648]
Fitprof V2.3 2005/05/12 16:31:51



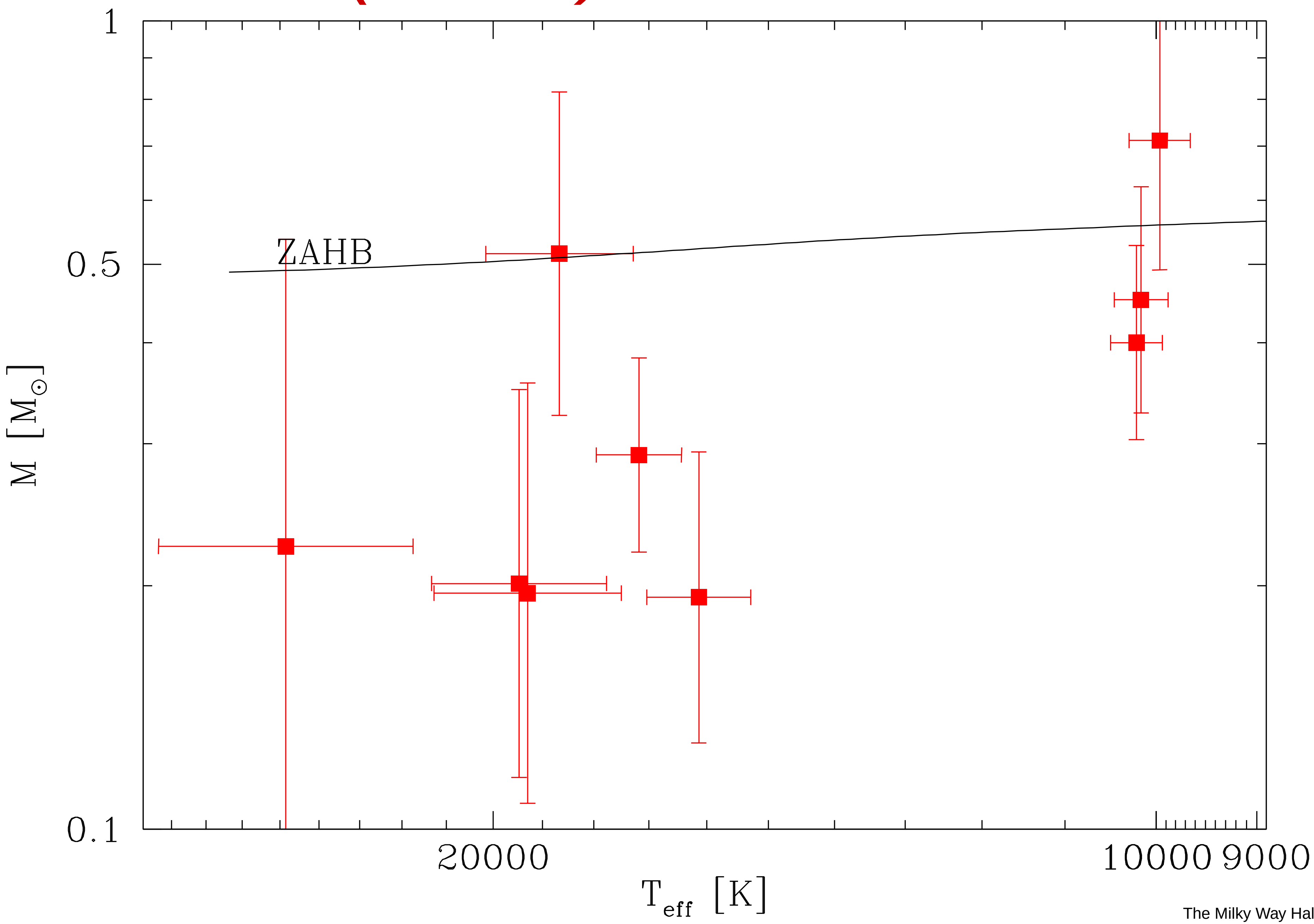
cspec0801_s3cde.asc
HeI 4922
HeI 4472
HeI 4388
HeI 4026
H4
H5
H6
H7
H8
H9
H10
H11
H12
relative flux
Δλ (Å)
Teff = 9860 K [111 K]
log g = 3.35 [0.057]
N(He)/N(H) = −1.0000 [0.0000]
Fitprof V2.3 2005/05/12 16:35:17

Results



helium pollution
Y = 0.33
Y = 0.43
canonical
NGC 6388
3
4
5
log g [cm/s²]
20000
10000
T_eff [K]

Results (cont'd)



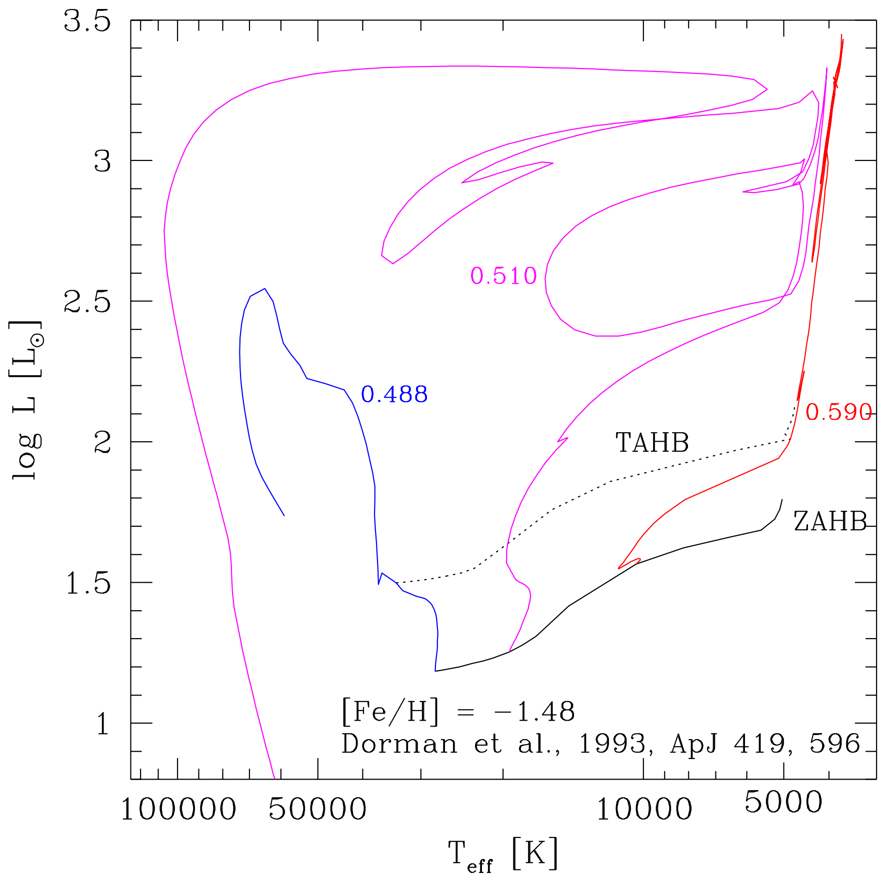
Conclusions - I

- ⋆ HB stars around 10 000 K support helium enrichment scenario
- ⋆ analysis of hotter stars yield low gravities and low masses
  ⇒ problems with data reduction
  ⇒ importance of consistency checks

(for details see Moehler & Sweigart, 2006, A&A 455, 943)

Extreme HB

- ⋆ hydrogen envelope of less than 0.02 $M_\odot$
- ⋆ no hydrogen shell burning
- ⋆ evolve directly to white dwarfs

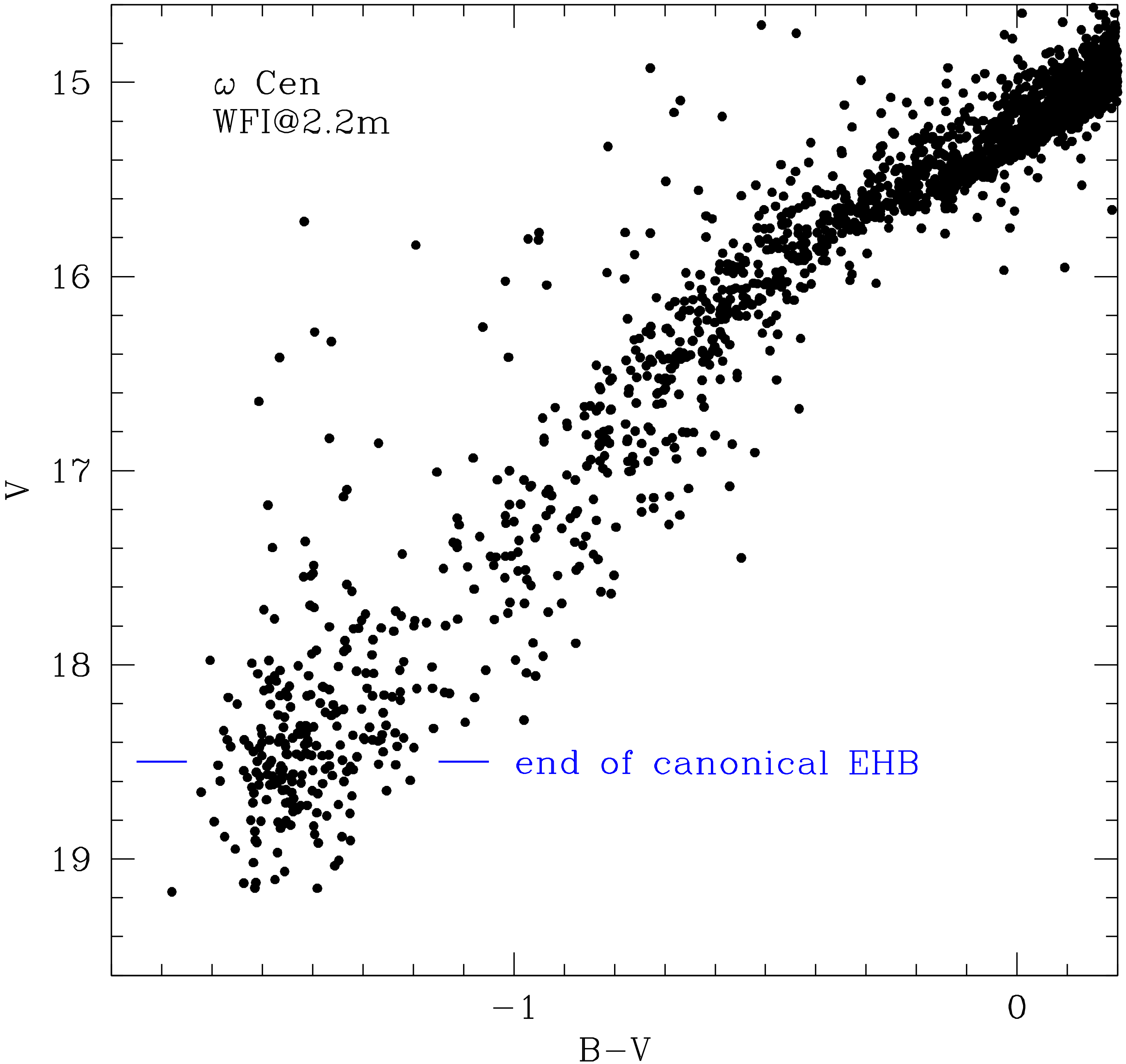


- ⋆ probable sources of UV excess in elliptical galaxies

Blue Hook Stars *(D'Cruz et al. 2000)*

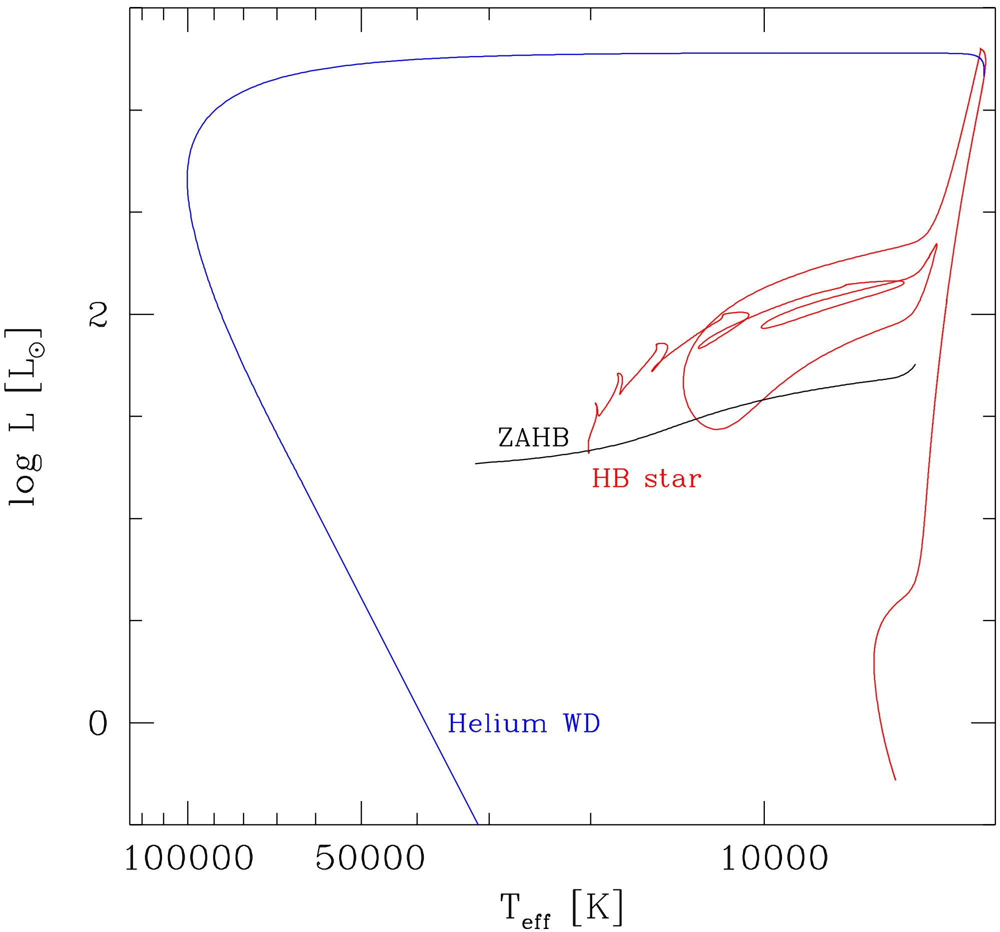
- ⋆ visually faintest stars are too hot
- ⋆ lie up to $0\overset{m}{.}7$ below zero-age HB (ZAHB) in UV-visual colour-magnitude diagram
  $\Rightarrow$"blue hook"

Blue Hook Stars (cont'd)



Blue Hook Stars (cont'd)

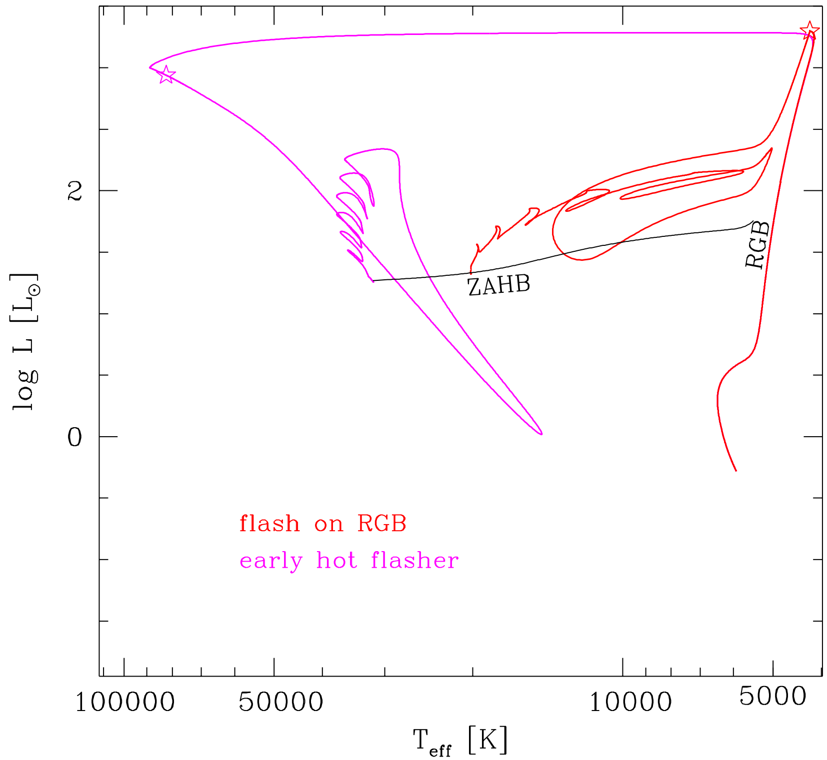
- ⋆ hotter than hottest canonical EHB stars
- ⋆ higher mass loss on RGB required
- ⋆ higher mass loss than hottest EHB star
  - ⇒ no helium flash on RGB
  - ⇒ star becomes helium white dwarf



Delayed Helium Flash

Castellani & Castellani (1993): He flash at high temperature after star leaves red giant branch (RGB) $\Rightarrow$ hot flasher

D'Cruz et al. (1996); Brown et al. (2001): flash at top of white dwarf cooling curve
$\Rightarrow$ early hot flasher

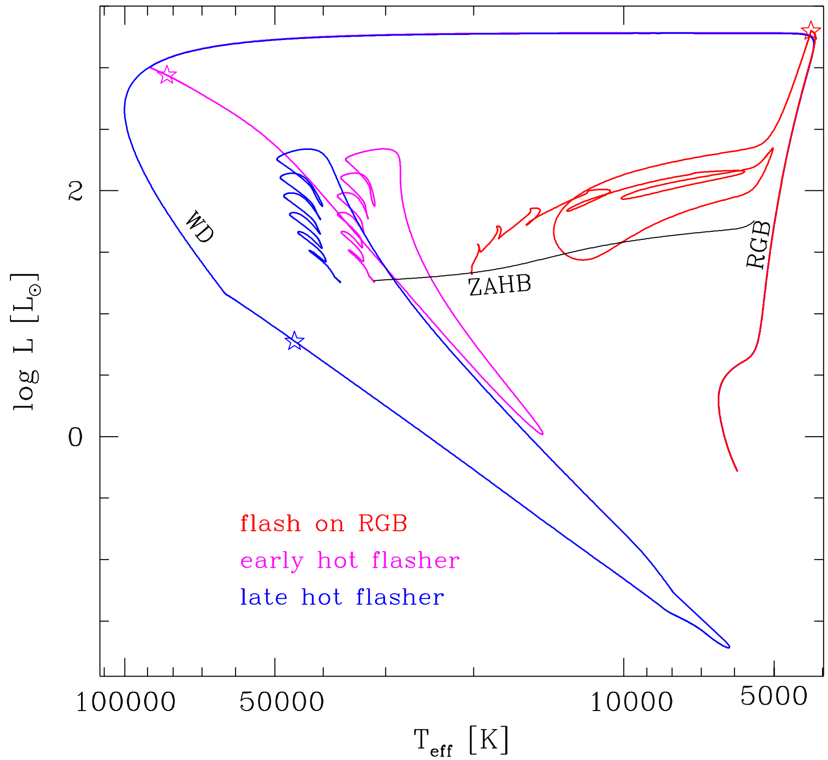


- $\star$ $T_{eff} \leq$ 30,000 K – 35,000 K
- $\star$ surface composition: H-rich, He-poor
- $\star$ clump of stars in ω Cen above hot end of ZAHB

Delayed Helium Flash (cont'd)

Brown et al. (2001): flash on white dwarf cooling curve
⇒ late hot flasher

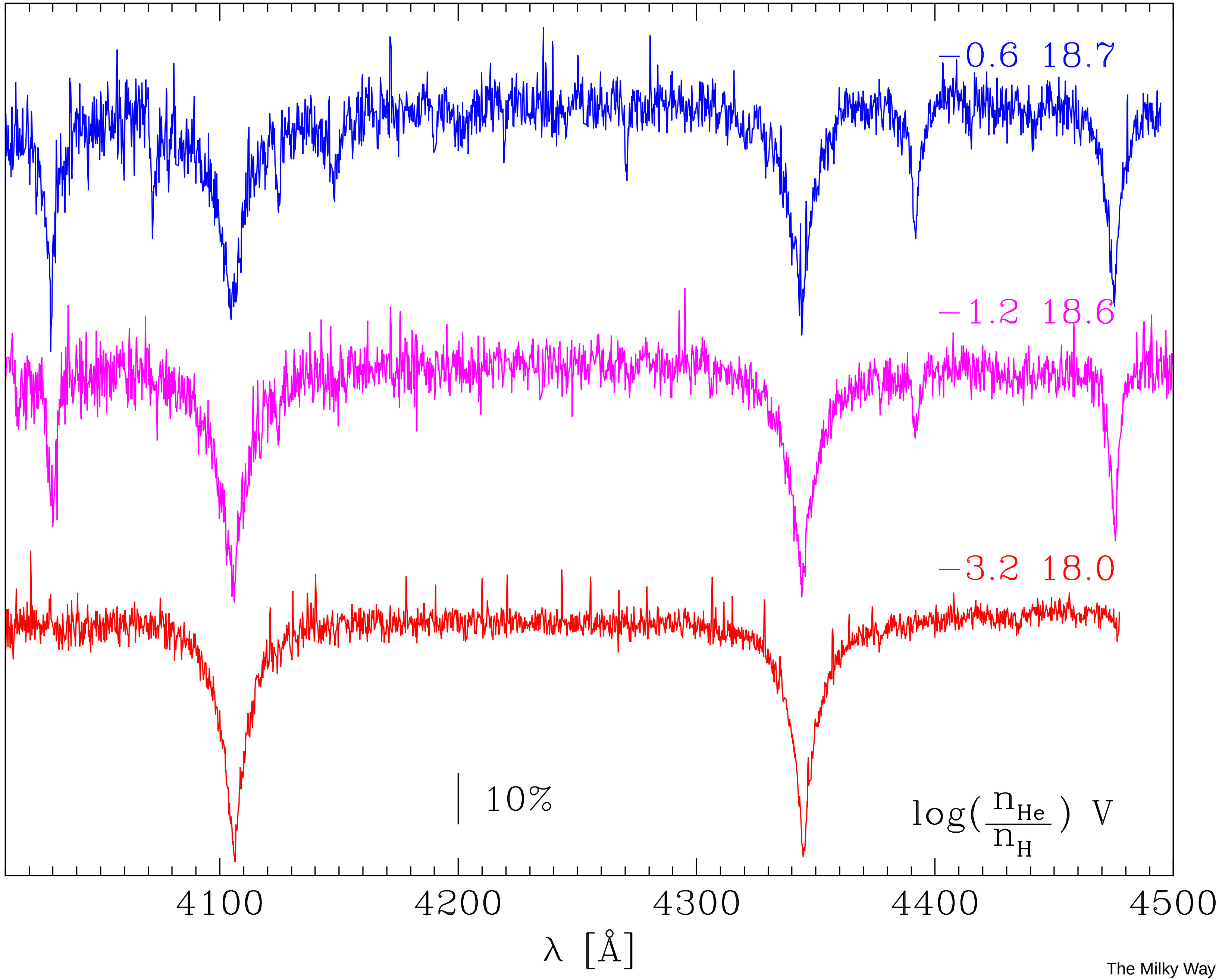
- ⋆ flash convection zone penetrates hydrogen envelope
  - ⋆ H mixed to the core
  - ⋆ He and C mixed outward into envelope
  - ⋆ T_{eff} ≈35,000 K
  - ⋆ surface composition: He/C-rich ⇒ reduces UV flux
  - ⋆ "blue hook"?



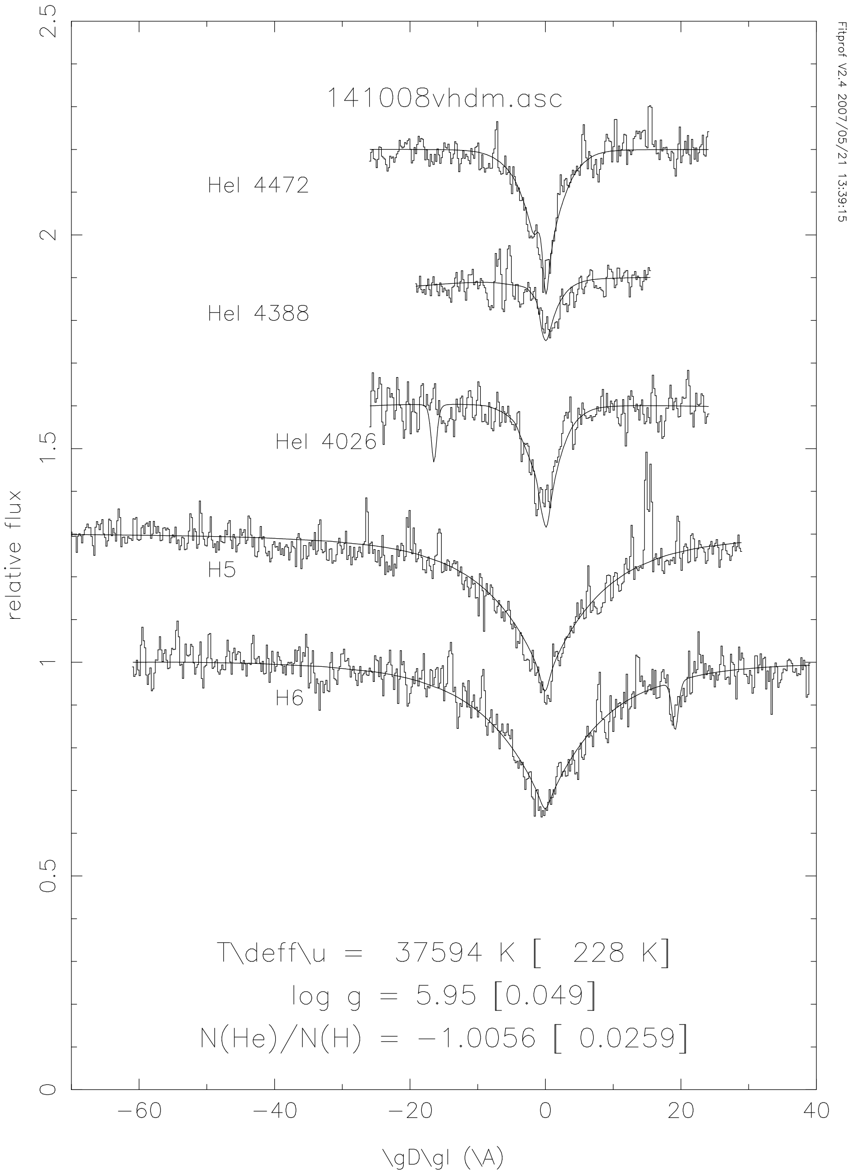
Spectroscopic Studies

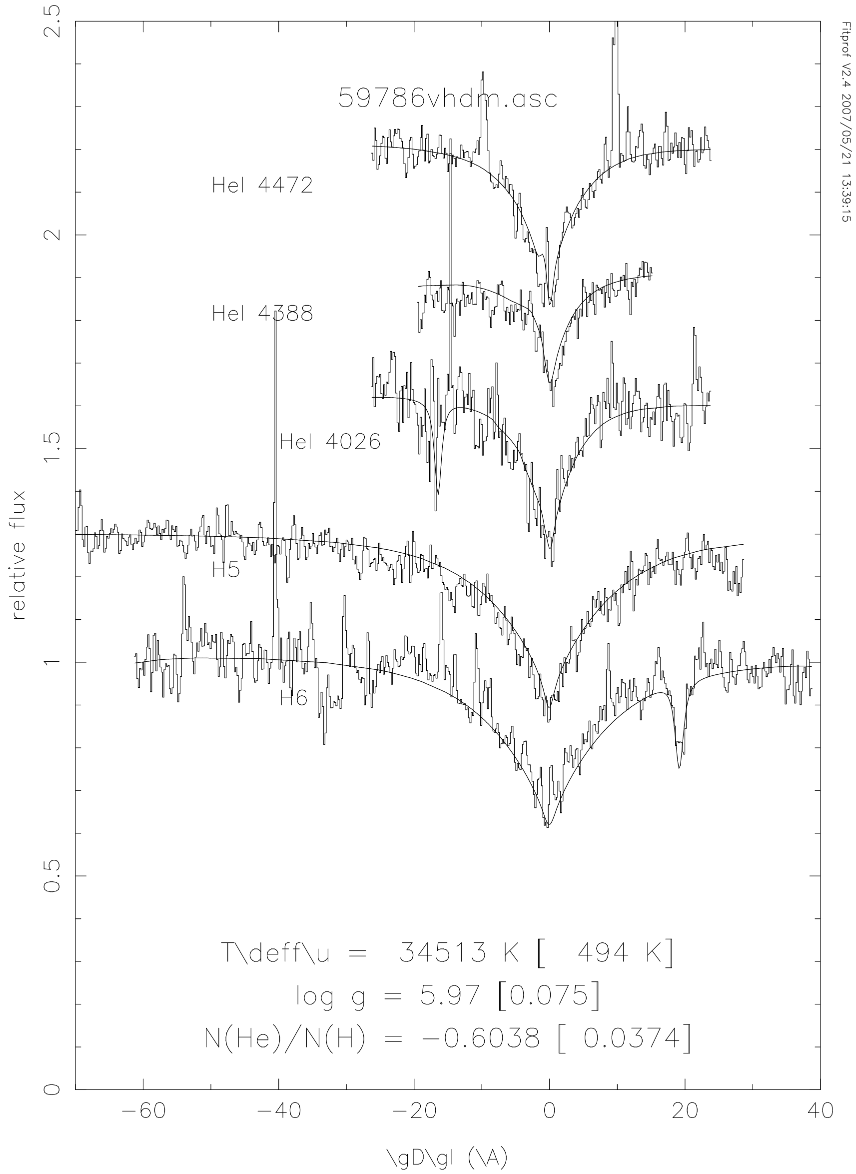
- ⋆ blue hook stars are more helium-rich than “normal” EHB stars
- ⋆ but not dominated by helium
- ⋆ abundances of C and N unclear
- ⋆ few stars
- ⋆ FLAMES observations
  - ⋆ medium resolution spectra of some 50 blue hook candidate stars
  - ⋆ analysis as described for NGC 6388

Spectra

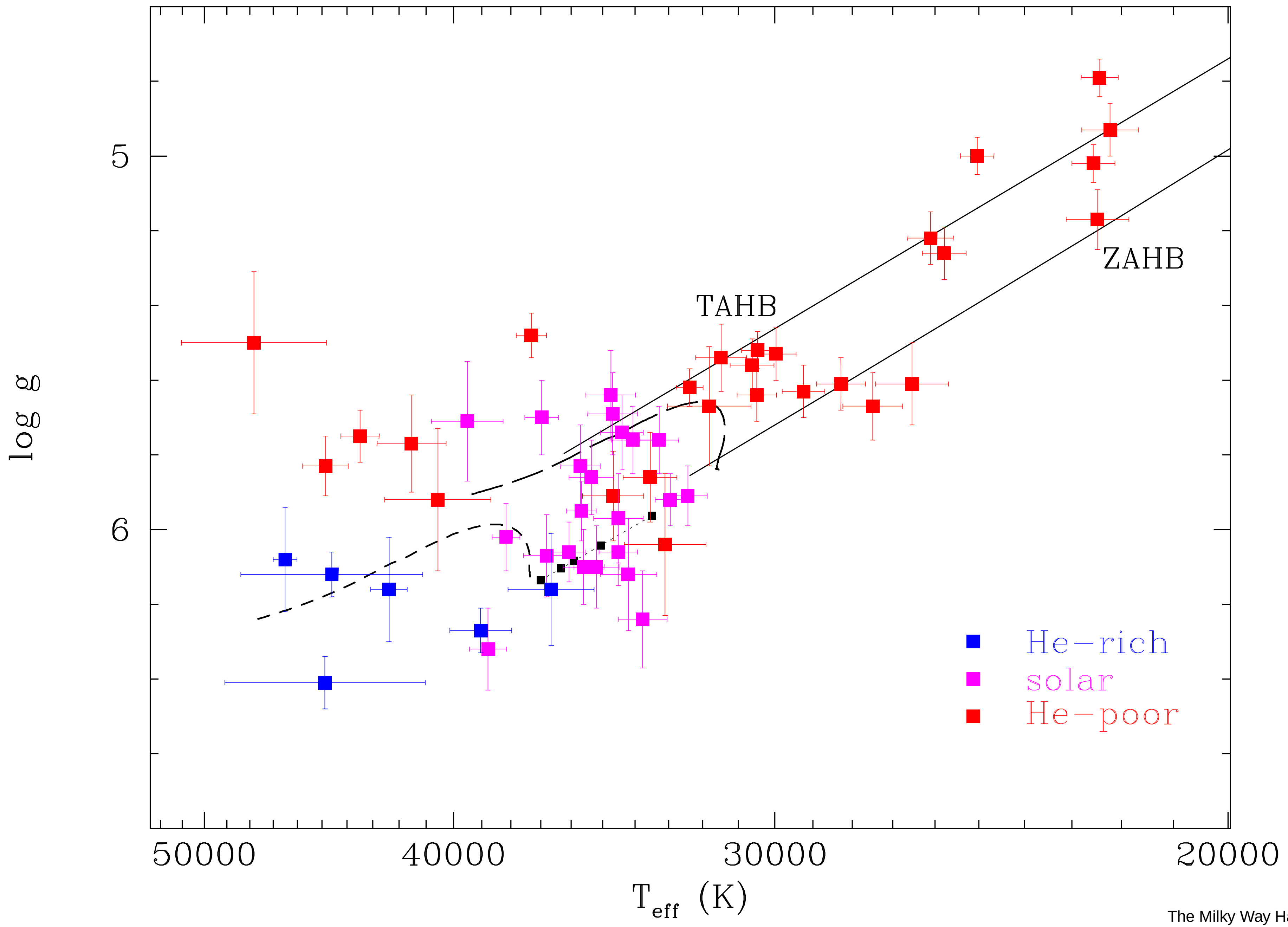


Fits


141008vhdm.asc
HeI 4472
HeI 4388
HeI 4026
H5
H6
relative flux
\gD\gl (\A)
T\deff\u = 37594 K [228 K]
log g = 5.95 [0.049]
N(He)/N(H) = −1.0056 [0.0259]
Fitprof V2.4 2007/05/21 13:39:15

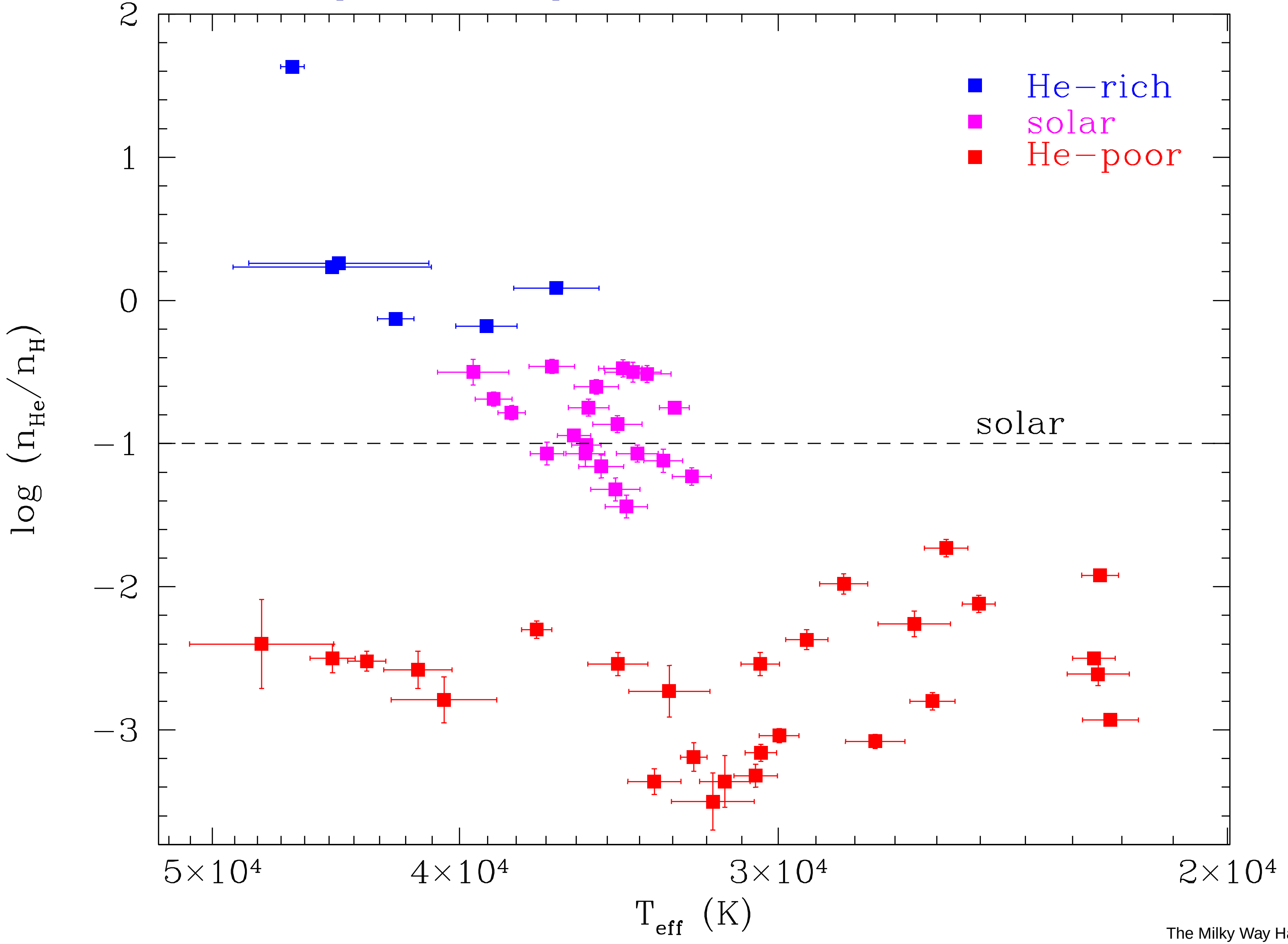

59786vhdm.asc
HeI 4472
HeI 4388
HeI 4026
H5
H6
relative flux
\gD\gl (\A)
T\deff\u = 34513 K [494 K]
log g = 5.97 [0.075]
N(He)/N(H) = −0.6038 [0.0374]
Fitprof V2.4 2007/05/21 13:39:15

Results



log g
5
6
TAHB
ZAHB
He−rich
solar
He−poor
50000
40000
30000
20000
T_{eff} (K)

Results (cont'd)



Conclusions - II

- ⋆ blue hook stars are more helium-rich than canonical EHB stars
- ⋆ most blue hook stars have helium abundances between 0.4 solar and 4 solar
- ⋆ the helium-rich blue hook stars have carbon abundances of up to 3% by mass (more than a factor of 300 above cluster abundance)
- ⋆ the role of diffusion is at the moment very unclear

References

- ★ Brown T.M., Sweigart A.V., Lanz T., Landsman W.B., Hubeny I., 2001, ApJ 562, 368
- ★ Castellani M., Castellani V., 1993, ApJ 407, 649
- ★ D'Antona F., Bellazzini M., Caloi V., Fusi Pecci F., Galetti S., Rood R.T., 2005, ApJ 631, 868
- ★ D'Cruz N.L., Dorman B., Rood R.T., 1996, ApJ 466, 359
- ★ D'Cruz N.L., O'Connell R.W., Rood R.T., 2000, ApJ 530, 352
- ★ Rich R.M., Sosin C., Djorgovski S.G., et al., 1997, ApJ 484, L25