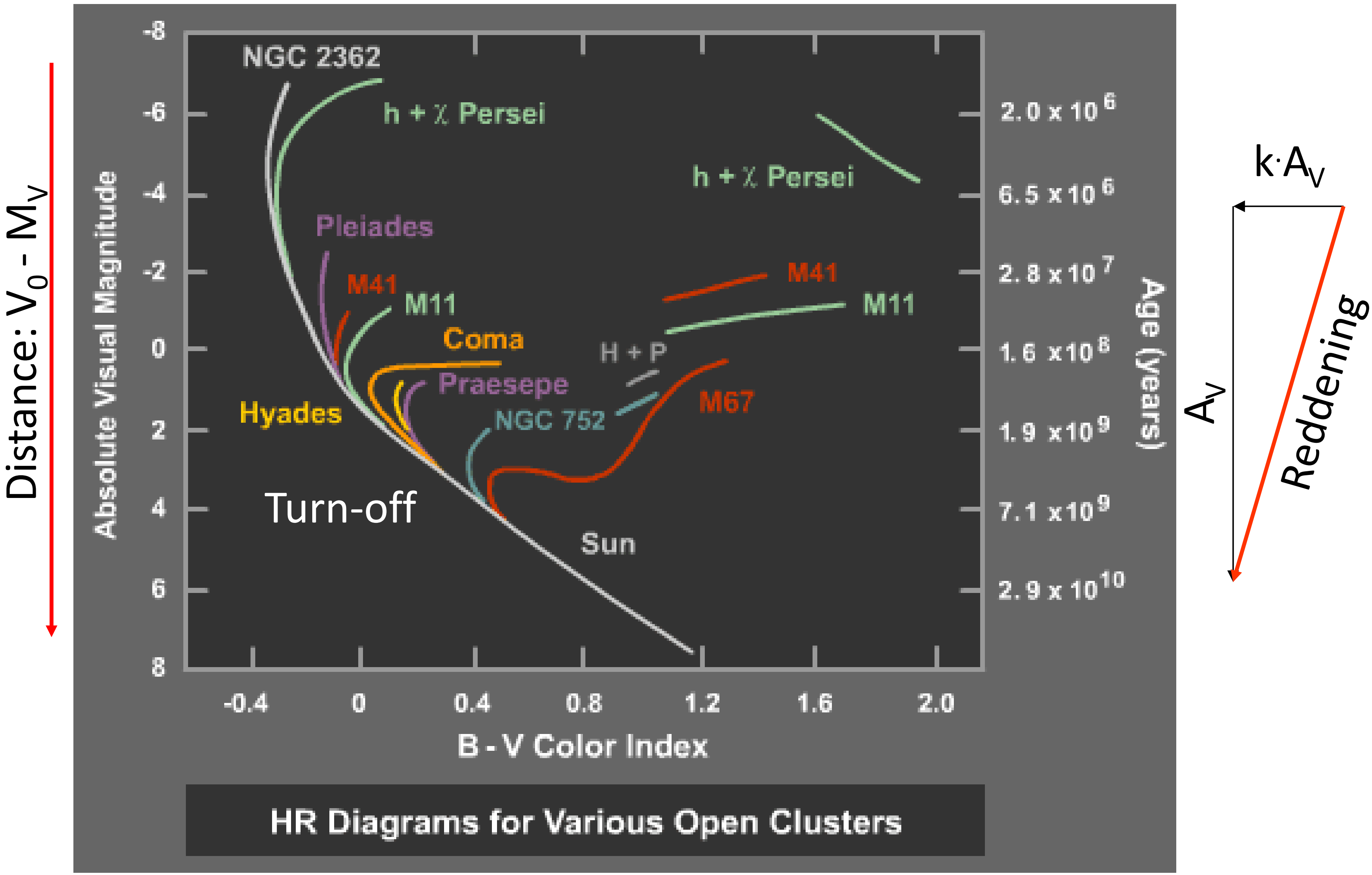
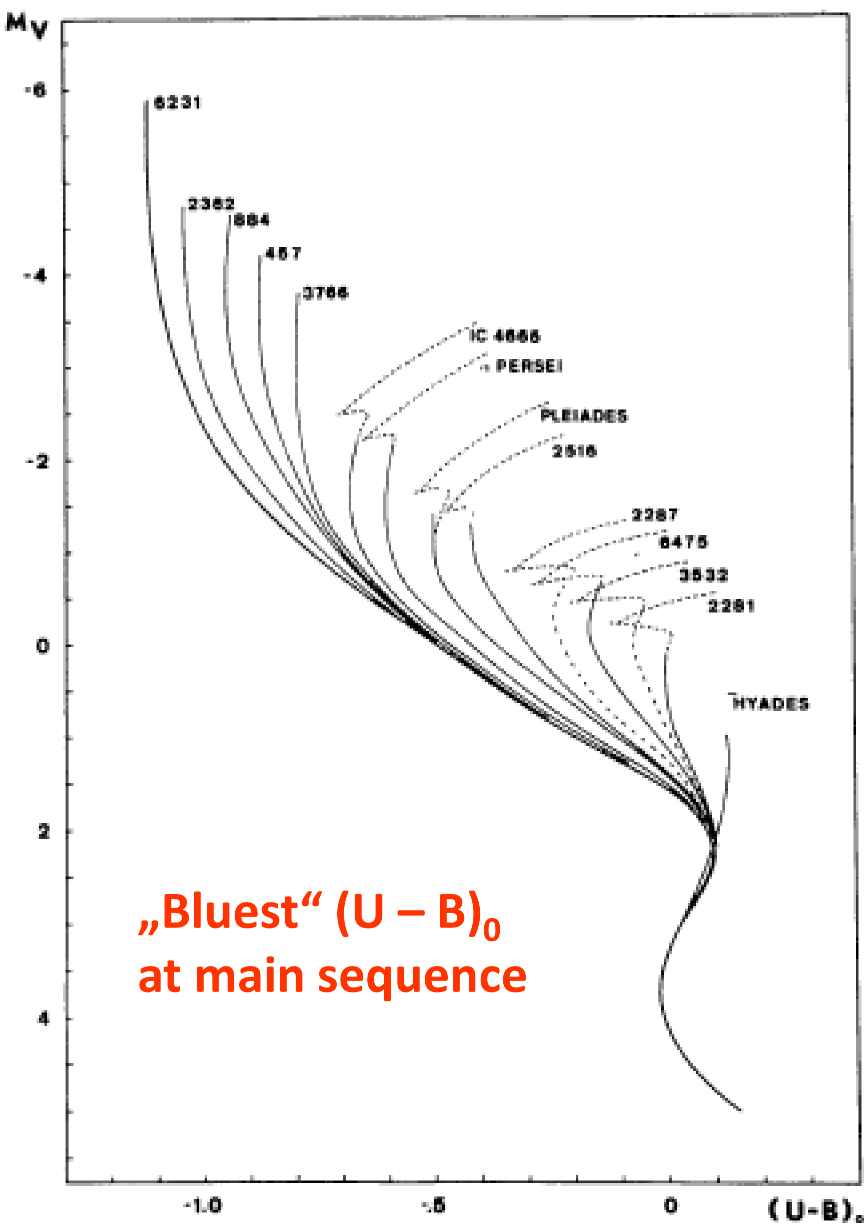


Distance: $V_0 - M_V$
Absolute Visual Magnitude
NGC 2362
h + χ Persei
h + χ Persei
Pleiades
M41
M11
M41
M11
Coma
H + P
Praesepe
Hyades
NGC 752
M67
Turn-off
Sun
-8
-6
-4
-2
0
2
4
6
8
-0.4
0
0.4
0.8
1.2
1.6
2.0
B - V Color Index
2.0 x 10^6
6.5 x 10^6
2.8 x 10^7
1.6 x 10^8
1.9 x 10^9
7.1 x 10^9
2.9 x 10^10
Age (years)
$k \cdot A_V$
A_V
Reddening
HR Diagrams for Various Open Clusters

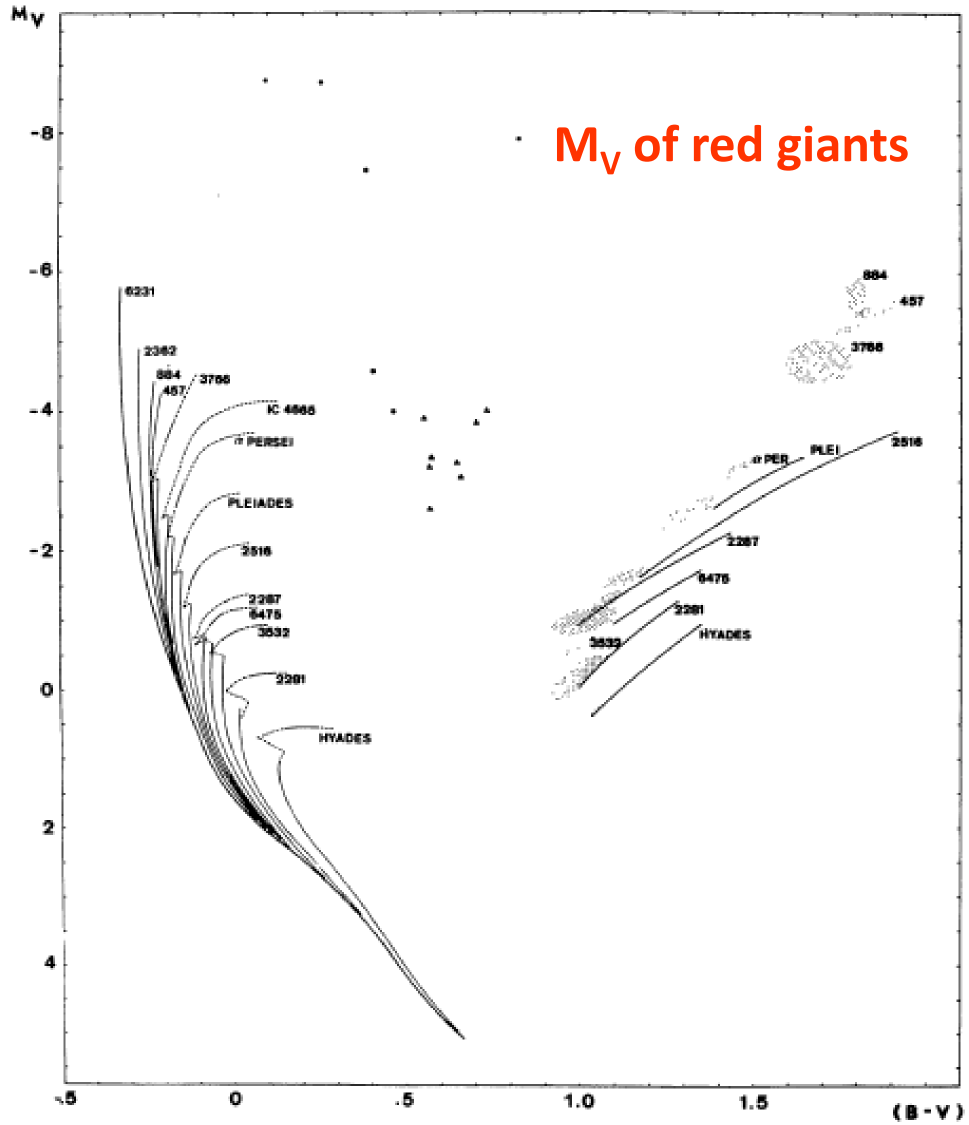
Turn off point

- Where is the turn-off point located?
  - Color/temperature
  - Absolute/apparent magnitude/luminosity
- Direct correlation with the age
- Difficult to define for young star clusters
- First, classical method, just „to look“ at color-magnitude-diagram

Mermilliod, 1981, A&A, 97, 235: no newer paper available!



„Bluest“ $(U-B)_0$ at main sequence



M_V of red giants

Dereddened indices

Mermilliod, 1981, A&A, 97, 235

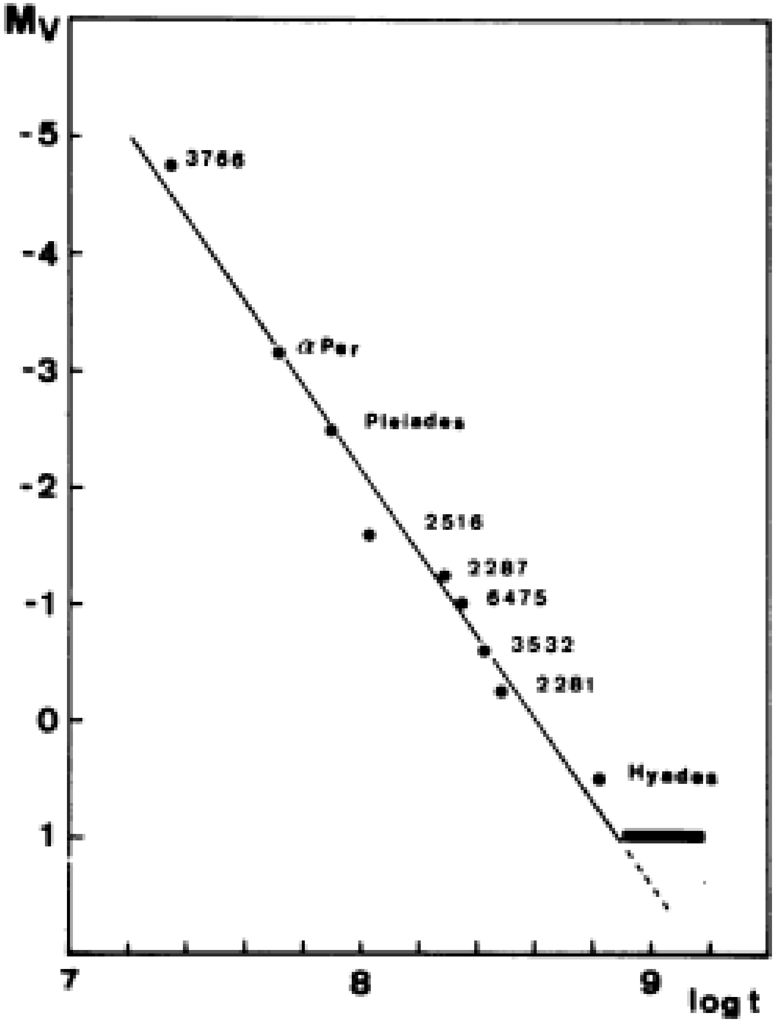


Fig. 7. Relation between the mean absolute magnitude of the red giant concentrations and log t. The darkened area at M_V=+1. indicates the position of the clump in old clusters.

A correlation has been established between the mean absolute magnitude of the red giant concentrations and ages (Fig. 7). A straight line has been fitted by eye, which gives the following relation:

$$\log t = 0.280\, M_V + 8.610$$

No direct error estimation possible

Possible to use for star clusters between 20 Myr and 800 Myr

Mermilliod, 1981, A&A, 97, 235

Very precise method

Possible to use between for star clusters between 20 Myr and 300 Myr

$(U-B)_0$ for cooler stars = older ages is almost **constant**

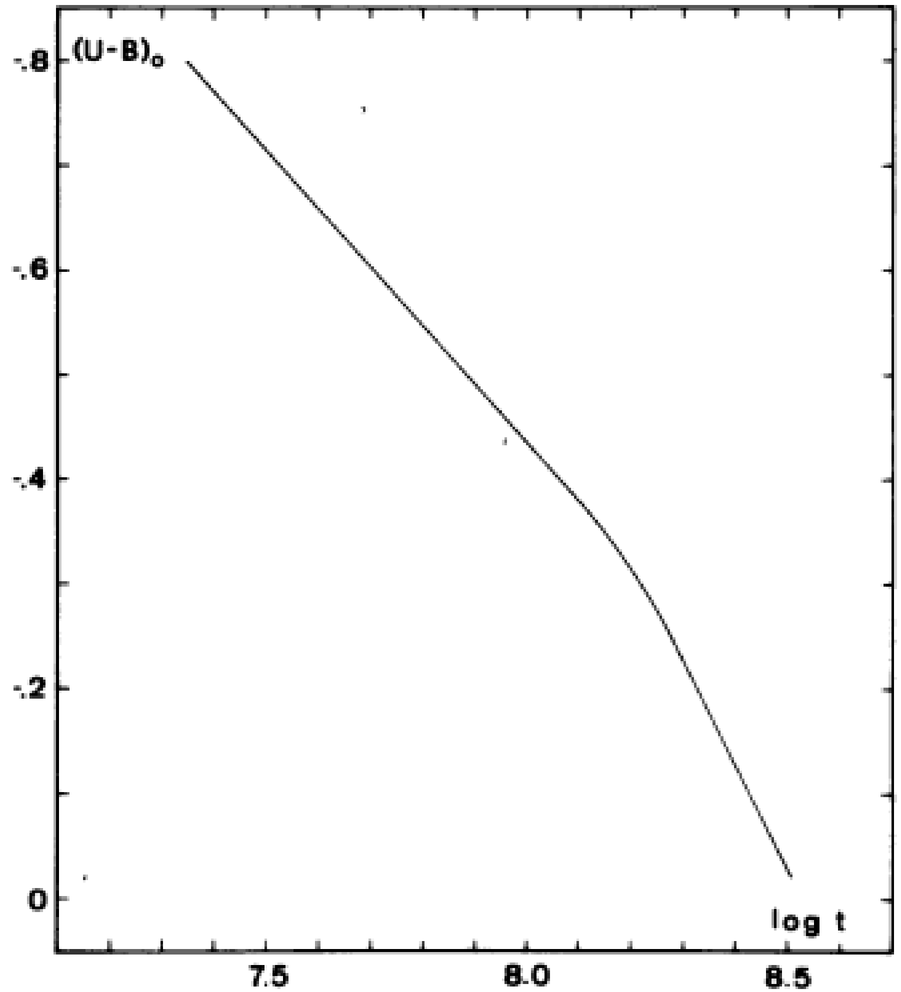
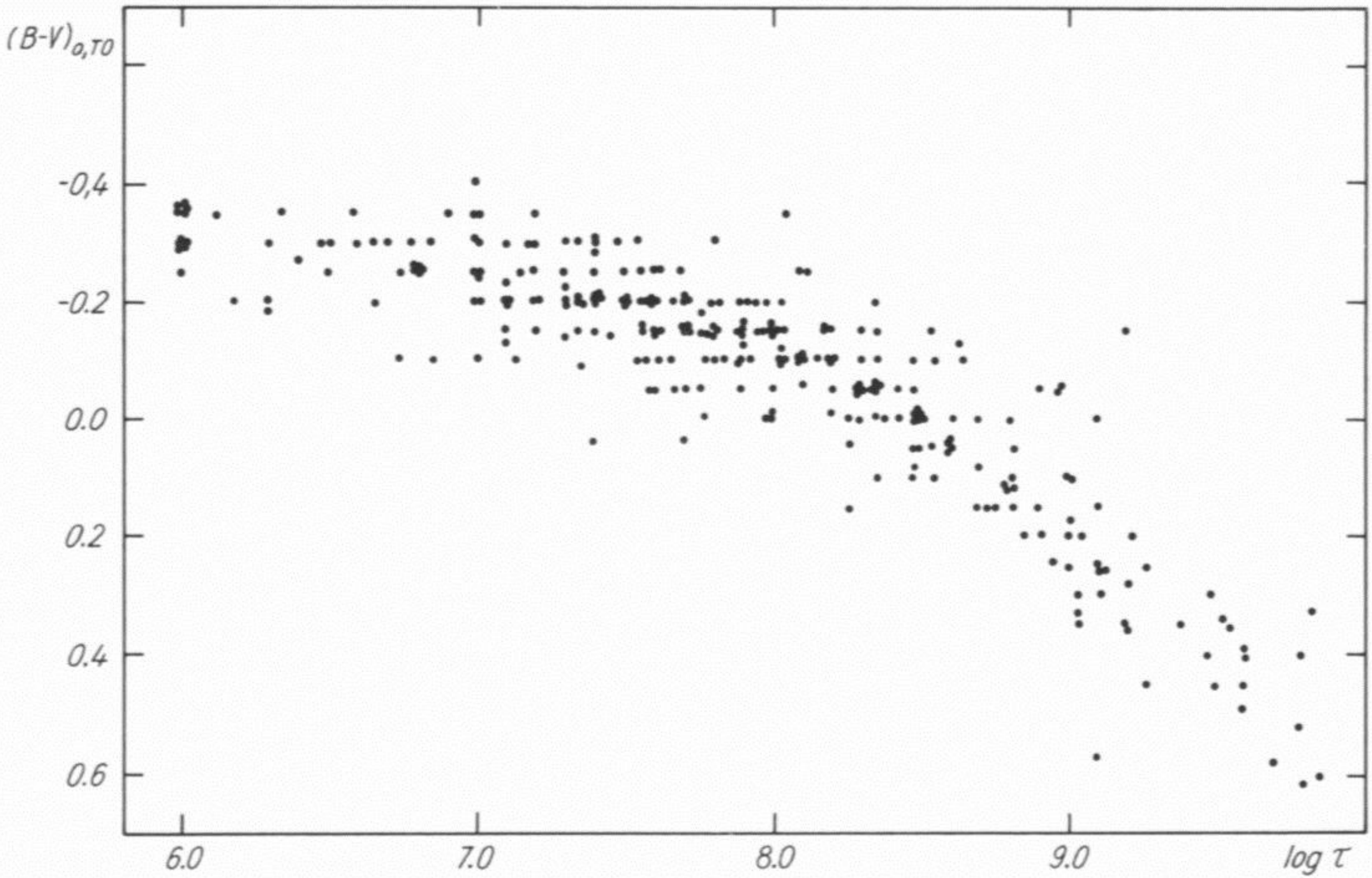


Fig. 6. Calibration of the bluest $(U-B)_0$ on the main sequence in terms of age ($\log t$)

$$-.80 \leq (U-B)_0 < -.35 \quad \log t = 1.795(U-B)_0 + 8.785$$
$$-.28 \leq (U-B)_0 < .00 \quad \log t = 0.813(U-B)_0 + 8.487$$



Not very accurate but still useful, never done for 2MASS and NIR

Calculation of Isochrones

The calculation of theoretical isochrone (= lines of equal age) is done with stellar atmospheres

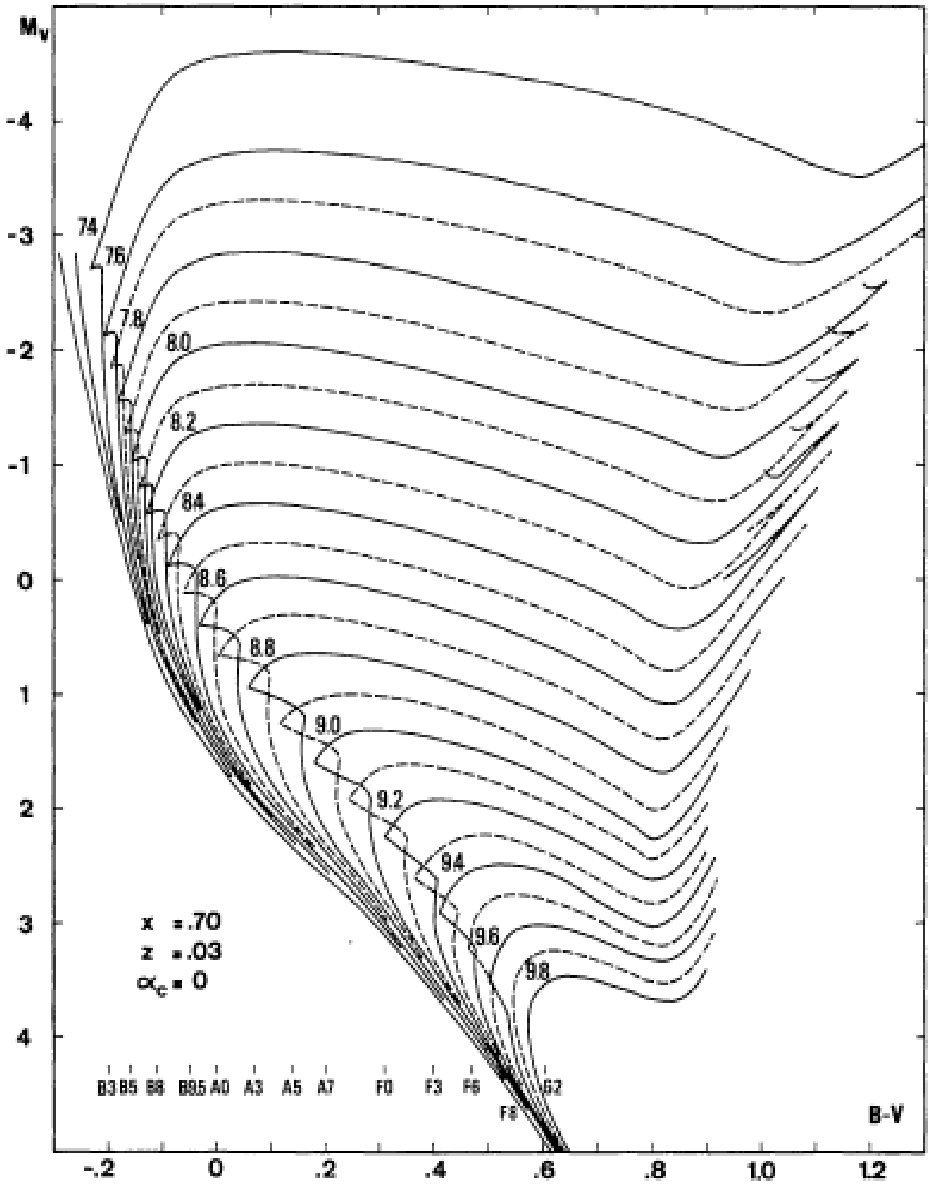
Free parameter : Metallicity [X, Y, Z]

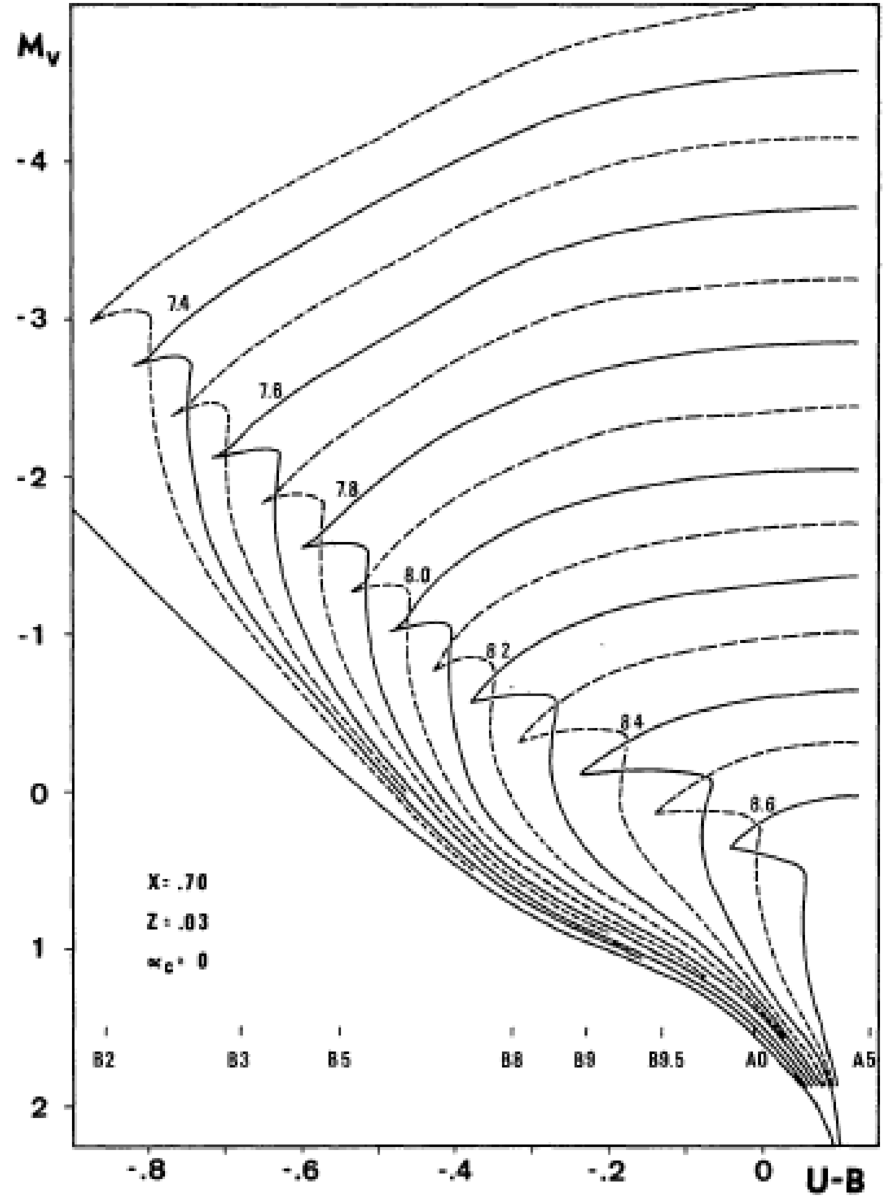
1. Zero Age Main Sequence $[T_{\mathrm{eff}}, L]_0$
2. Chemical and gravitational evolution
3. $[T_{\mathrm{eff}}, L](t)$
4. Adequate stellar atmosphere = **PHYSICS**
5. Absolute fluxes
6. Folding with filter curves
7. Colors, absolute magnitudes and so on

Which astrophysical “parameters“ are important?

- Equations of state
- Opacities
- Model of convection
- Rotation
- Mass loss
- Magnetic field
- Core Overshooting
- Abundance of helium
- …

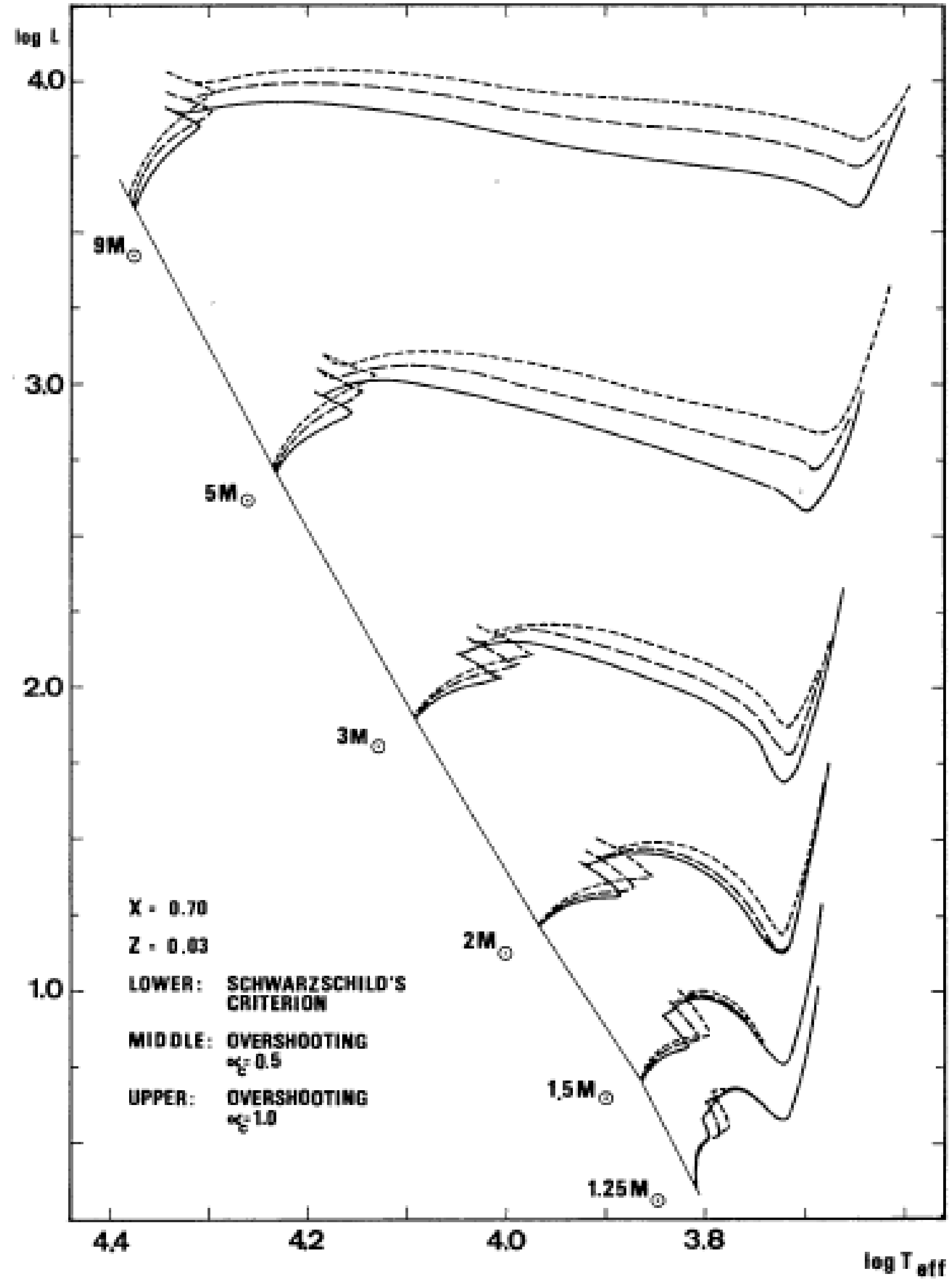
Maeder & Mermilliod, 1981, A&A, 93, 136





Maeder & Mermilliod, 1981, A&A, 93, 136

Different treatment of convection

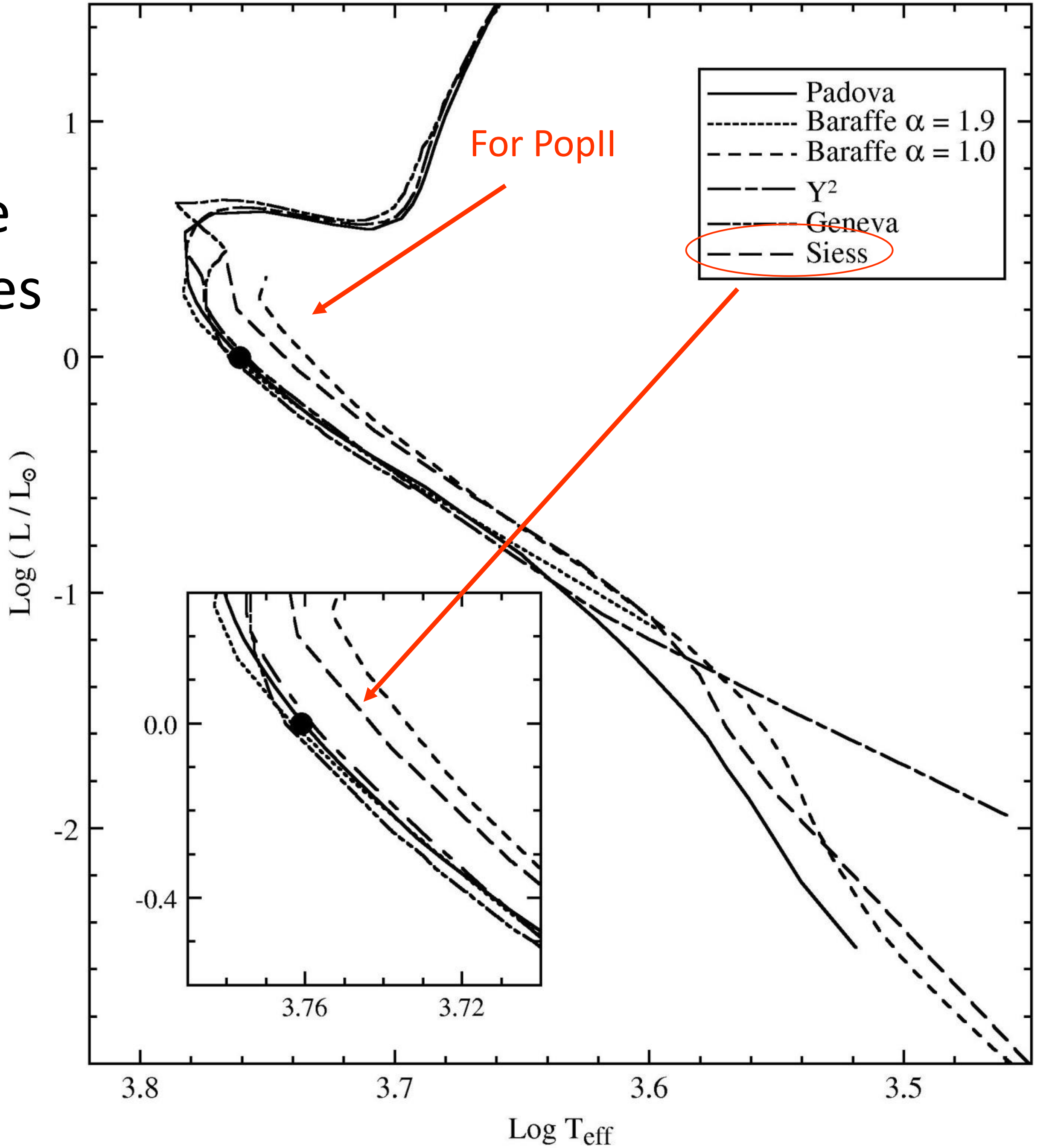


A comparison of isochrone sets

- Grocholski & Sarajedini (2003, MNRAS, 345, 1015) compared the following isochrones:
  1. “Padova”: Girardi et al., 2002, A&A, 391, 195
  2. Baraffe: Baraffe et al., 1998, A&A, 337, 403
  3. “Geneva”: Lejeune & Schaerer, 2001, A&A, 366, 538
  4. Y^2: Yi et al., 2001, ApJS, 136, 417
  5. Siess: Siess et al., 2000, A&A, 358, 593

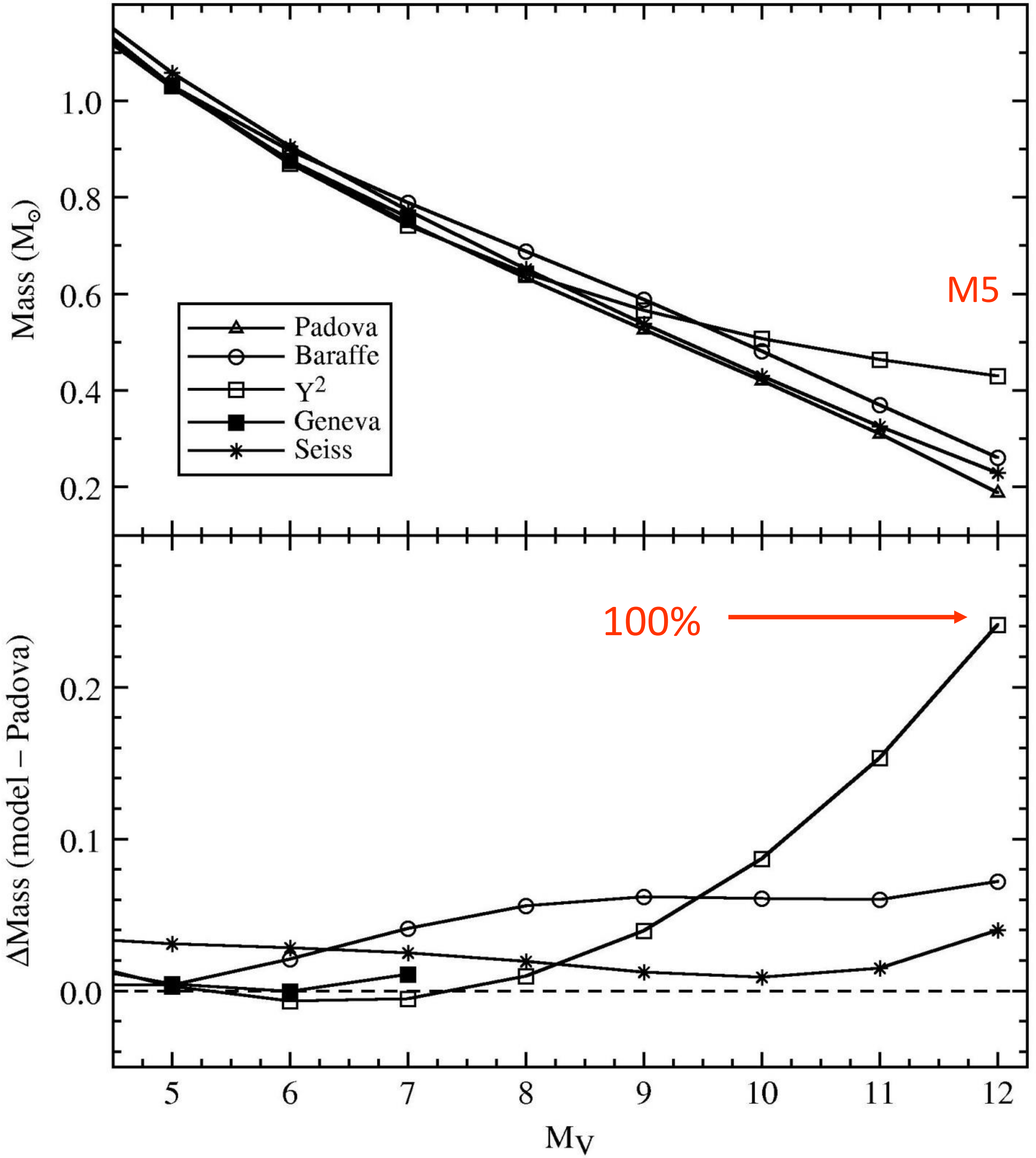
The location of the Sun with isochrones of 5 Gyr

Isochrones by Siess et al. (1997) seem "to have a problem"



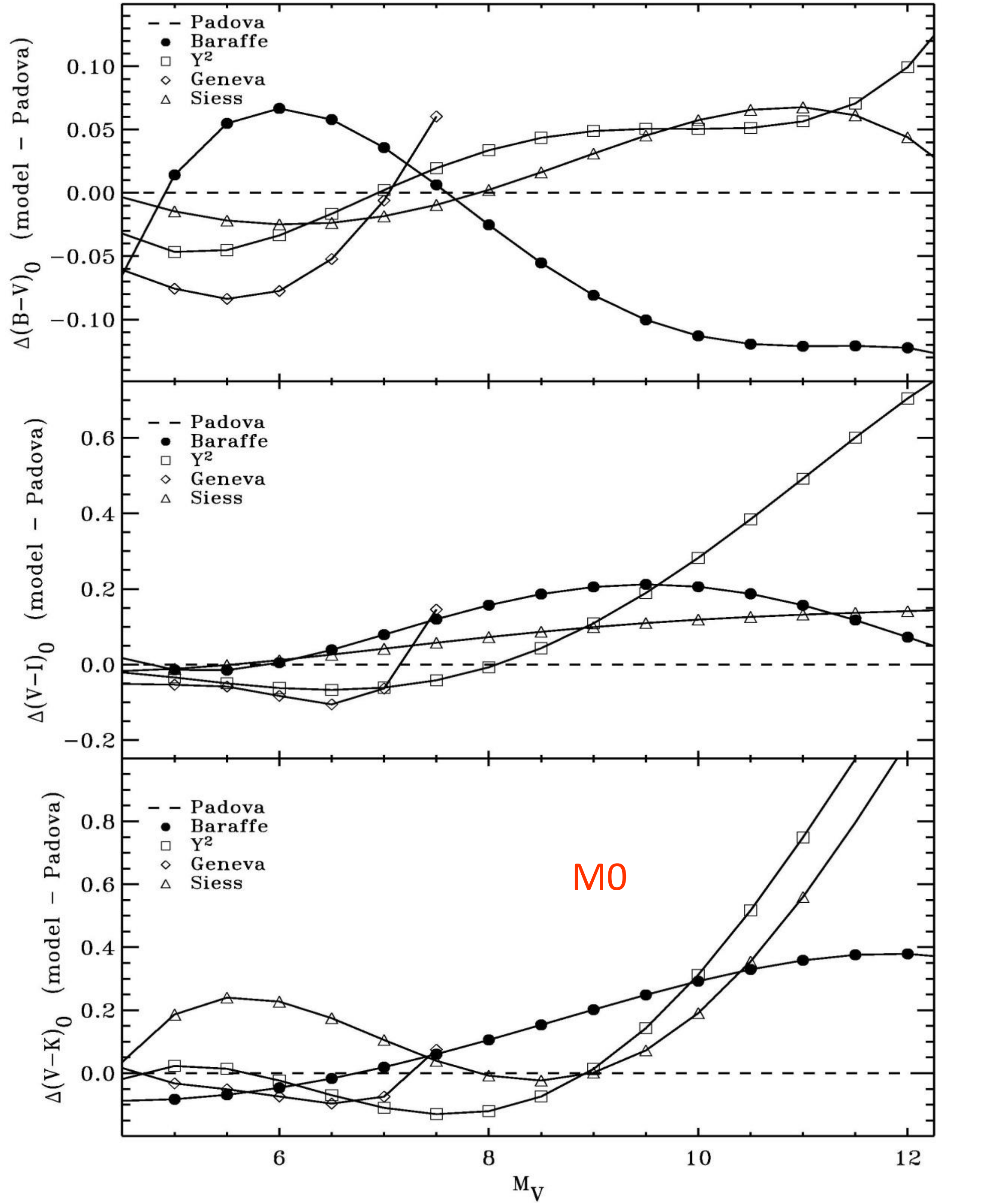
Comparison of different masses for a constant M_V

Zero line is the isochrone of the Padova group



Comparison of different color indices for a constant M_V

Zero line is the isochrone of the Padova group



Name	Available photometry	Log age	$E(B-V)$	[Fe/H]
M35 (NGC 2168)	$UBV\,RI\,JHK_S$	8.17	0.19	−0.160
M37 (NGC 2099)	$\ldots BV \ldots JHK_S$	8.73	0.27	0.089
NGC 1817	$\ldots BV\,RI\,JHK_S$	8.80	0.26	−0.268
NGC 2477	$UBV \ldots IJHK_S$	9.04	0.23	0.019
NGC 2420	$\ldots BV\,RI\,JHK_S$	9.24	0.05	−0.266
M67 (NGC 2682)	$UBV\,RI\,JHK_S$	9.60	0.04	0.000

Used Photometry

Parameters from the literature

Cluster	Padova	Baraffe	Geneva	Y^2	Siess	Twarog et al.
M35 (NGC 2168)	10.16	10.41	9.81	9.91	9.96	10.30
M37 (NGC 2099)	11.55	11.40	11.50	11.35	11.75	11.55
NGC 1817	12.10	12.30	11.90	11.85	12.00	12.15
NGC 2477	11.55	11.60	11.30	11.15	11.45	11.55
NGC 2420	12.12	12.45	11.95	11.90	12.07	12.10
M67 (NGC 2682)	9.80	9.80	9.60	9.45	9.65	9.80

log t, E(B-V) and [Fe/H] fixed, only Distance modulus determined

Value from the literature

Cluster	Padova	Baraffe	Geneva	Y^2	Siess	Twarog et al.
M35 (NGC 2168)	10.16	10.41	9.81	9.91	9.96	10.30
M37 (NGC 2099)	11.55	11.40	11.50	11.35	11.75	11.55
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NGC 2477	11.55	11.60	11.30	11.15	11.45	11.55
NGC 2420	12.12	12.45	11.95	11.90	12.07	12.10
M67 (NGC 2682)	9.80	9.80	9.60	9.45	9.65	9.80

Transformation in distances [pc]

- M35: 1148 [916,1208]; -20% +5%
- M37: 2042 [1905,2239]; -7% +10%
- NGC 1817: 2692 [2344,2884]; -13% +7%
- NGC 2477: 2042 [1698,2089]; -17% +2%
- NGC 2420: 2630 [2399,3090]; -9% +17%
- M67: 912 [776,912]; -15% +0%
- Mean values: -13(5)% +7(6)%, for one free parameter!

Cluster	Padova	Baraffe	Geneva	Y^2	Siess	Twarog et al.
M35 (NGC 2168)	10.16	10.41	9.81	9.91	9.96	10.30
M37 (NGC 2099)	11.55	11.40	11.50	11.35	11.75	11.55
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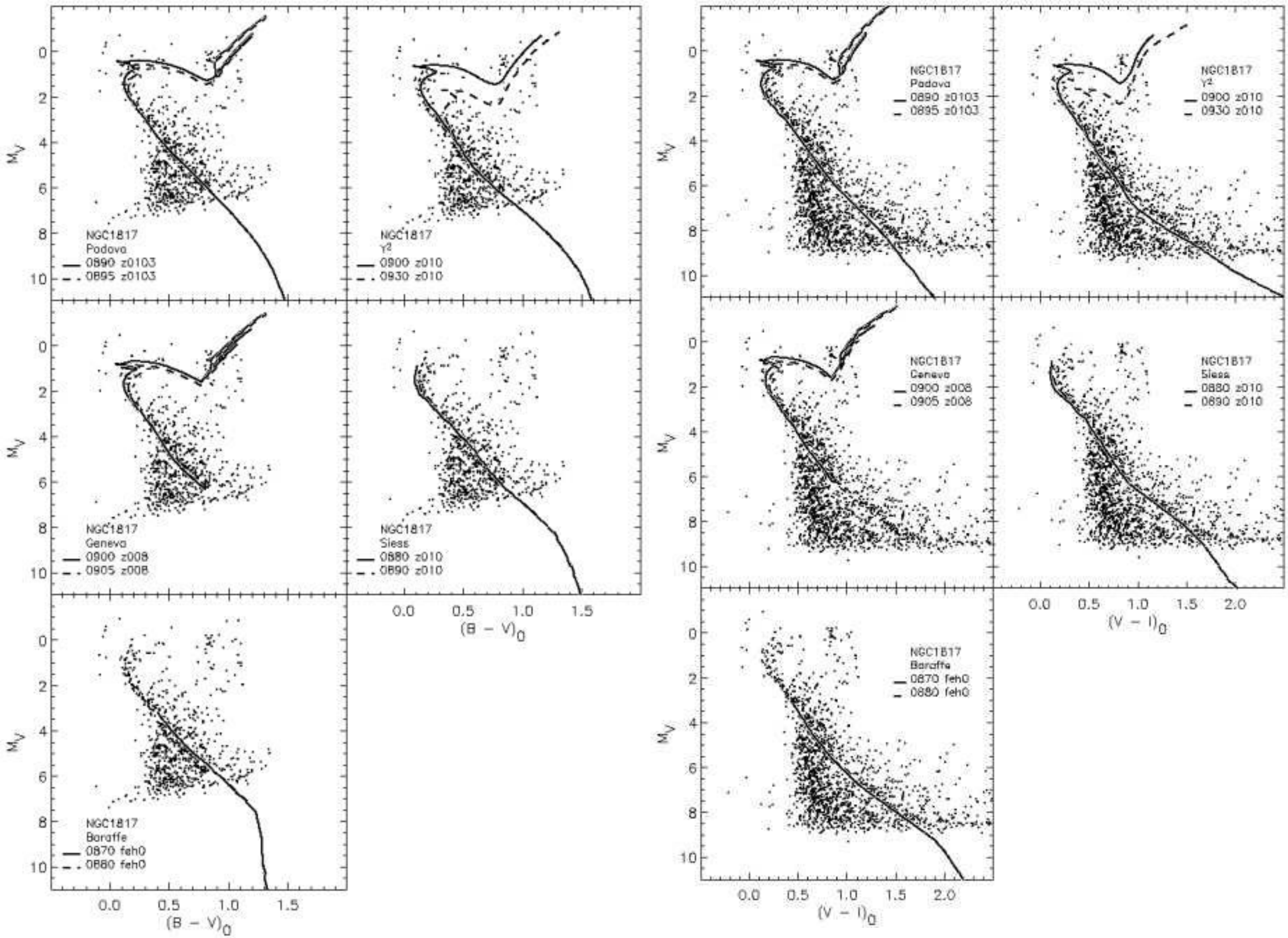
NGC 2420	12.12	12.45	11.95	11.90	12.07	12.10
M67 (NGC 2682)	9.80	9.80	9.60	9.45	9.65	9.80

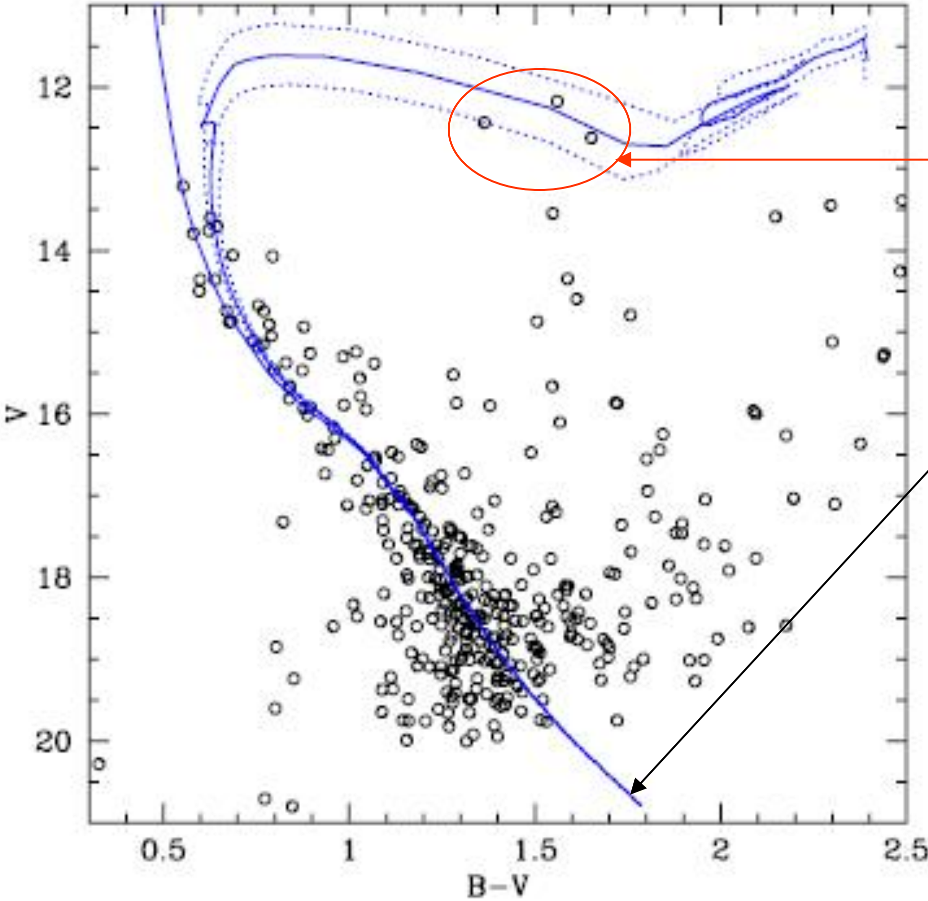
In a statistical point-of-view: significant

For a given reddening, metallicity and age, the isochrones by Baraffe et al. yield significantly brighter and Yi et al. significantly fainter absolute magnitudes .

In addition, the isochrones by Siess et al. do not reproduce the location of the Sun correctly.

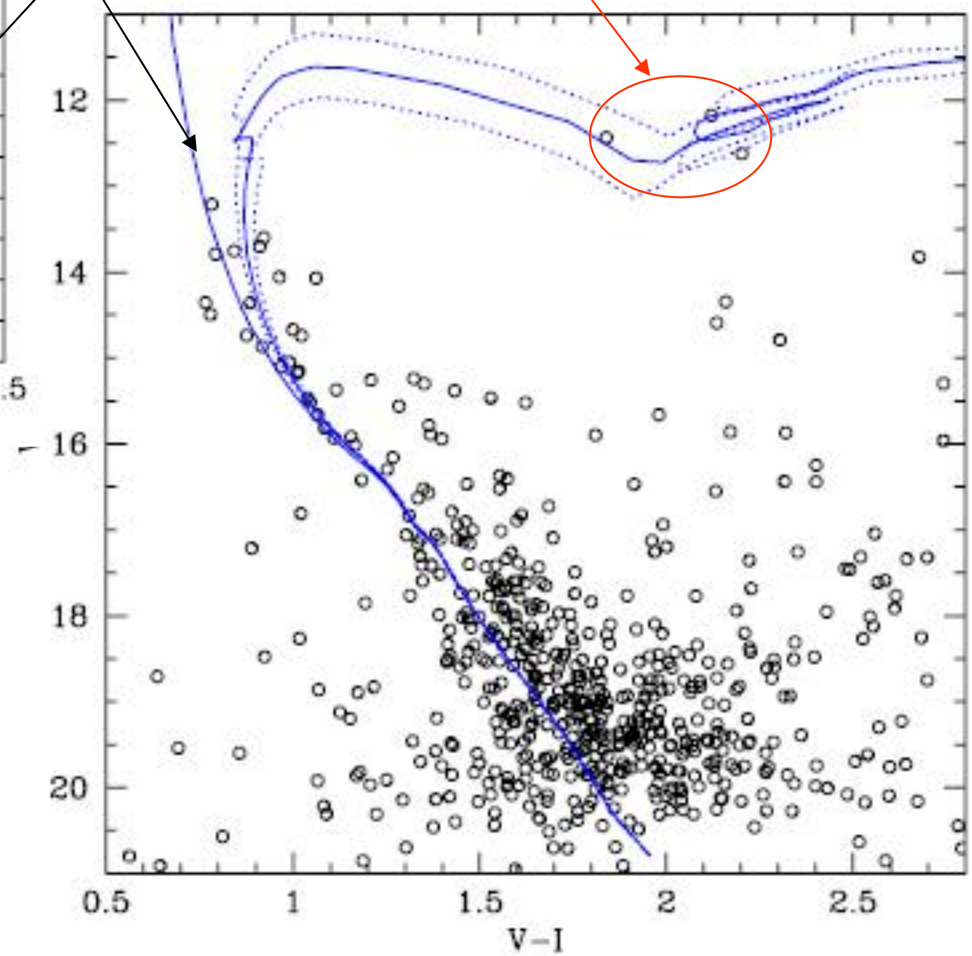


Grocholski & Sarajedini, 2003, MNRAS, 345, 1015



Age determination ONLY based on these three stars

log t = **7.0**



Isochrones for [Z] = 0.040 and log t = 8.0, 8.1 und 8.2

Result: $t = 130^{+40}_{-30}$ Myr

E(B-V) = 0.75(5) mag

$V - M_V = 14.00(25)$ mag

Automatic Methods

Jorgensen & Lindegren, 2005, A&A, 436, 127

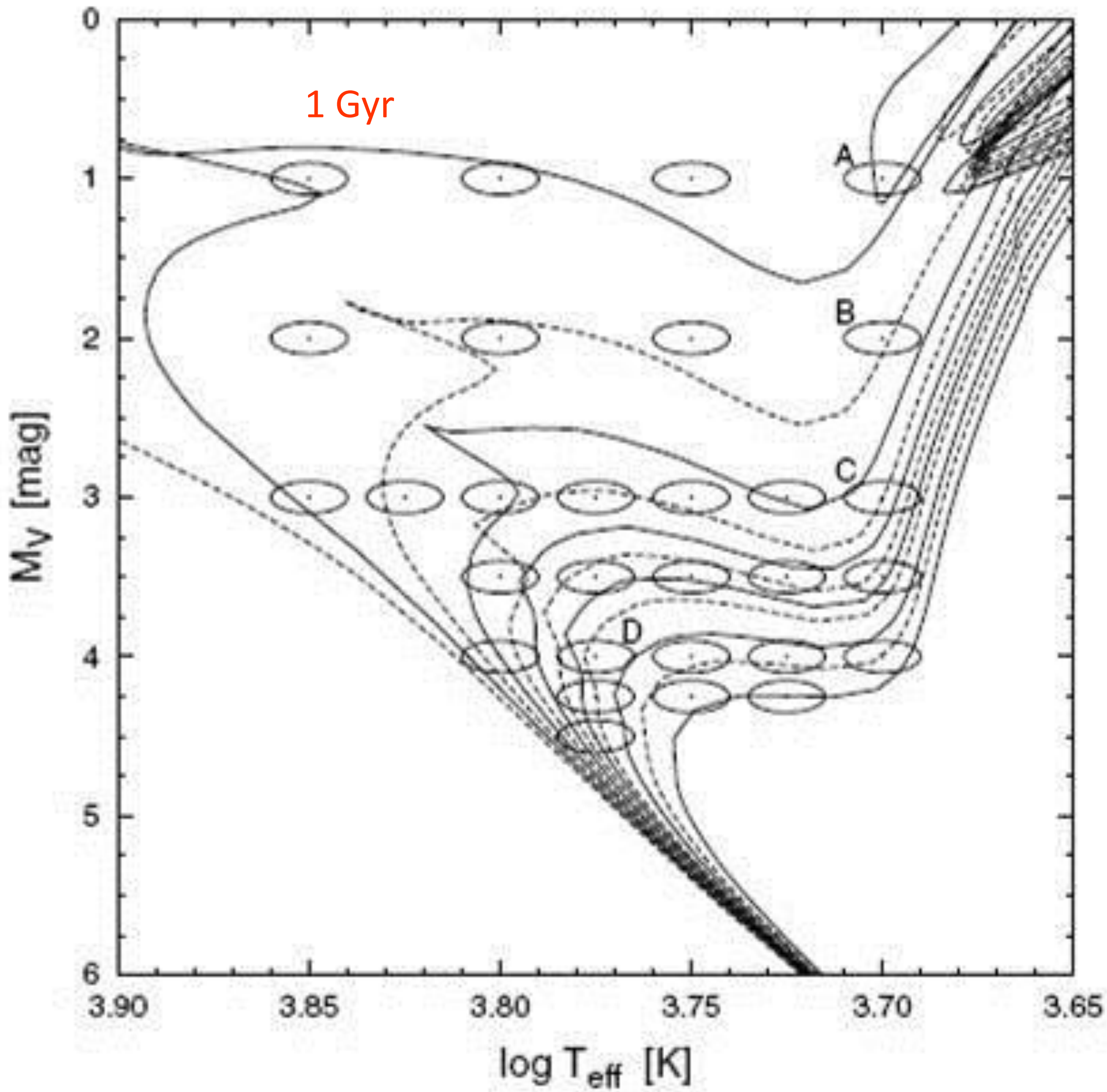
Definition of different „important“ areas (Box) in the CMD. Do this allocation as you like.

Turn-off point, location of the red giant clump, and so on.

Count the number of stars in each box.

Warning: you always „lose“ stars because of discrete boxes.

Only for t > 300 Myr



Other methods

- An et al., 2007, ApJ, 655, 233
- Buckner & Froebrich, 2013, MNRAS, 436, 1465
- Fernandes et al., 2012, A&A, 541, A95
- Frayn & Gilmore, 2003, MNRAS, 339, 887
- Kharchenko et al., 2005, A&A, 438, 1136
- Monteiro et al., 2010, A&A, 516, A2
- Oliveira et al., 2013, A&A, 557, A14
- Pinsonneault et al., 2003, ApJ, 598, 588