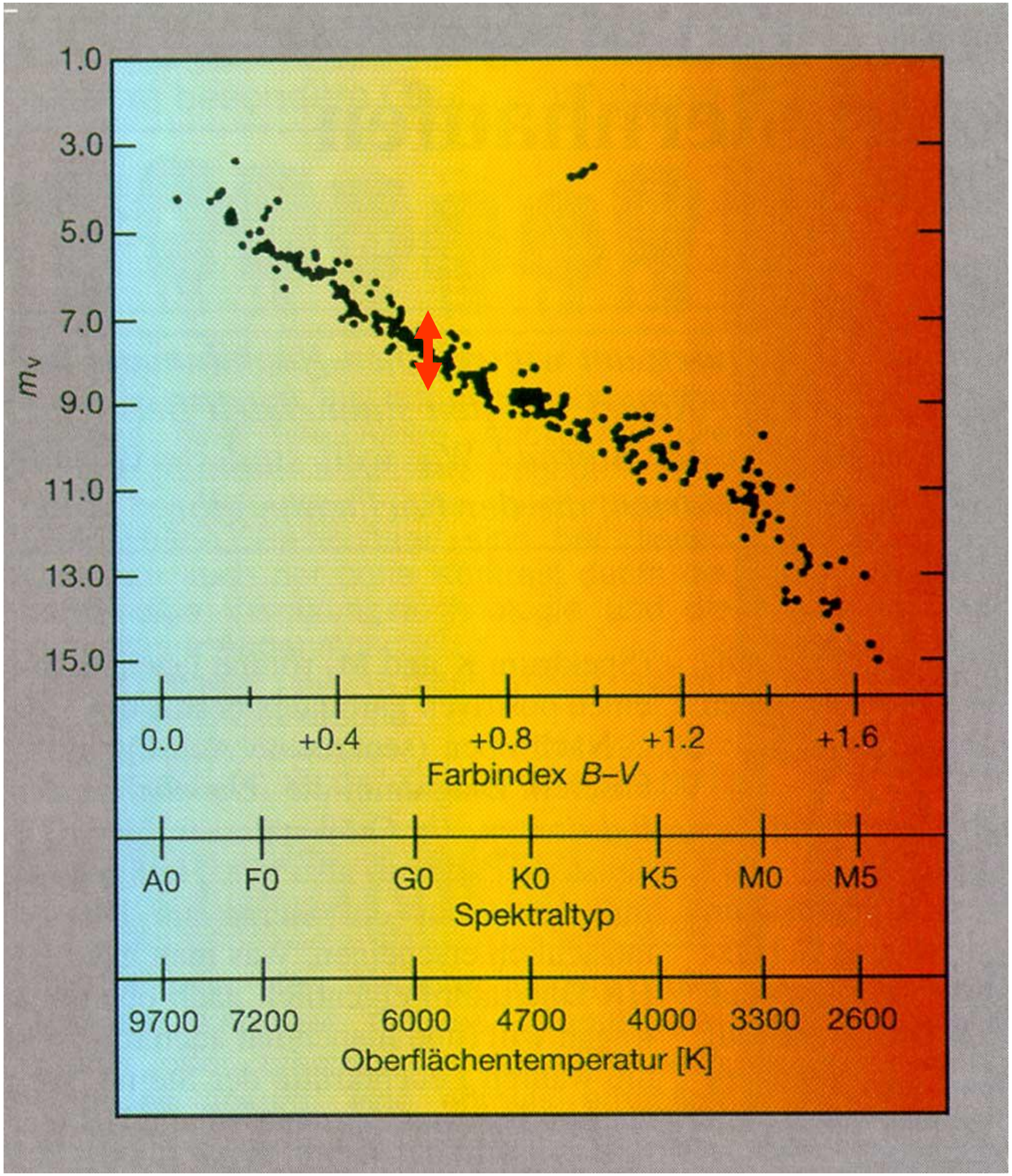


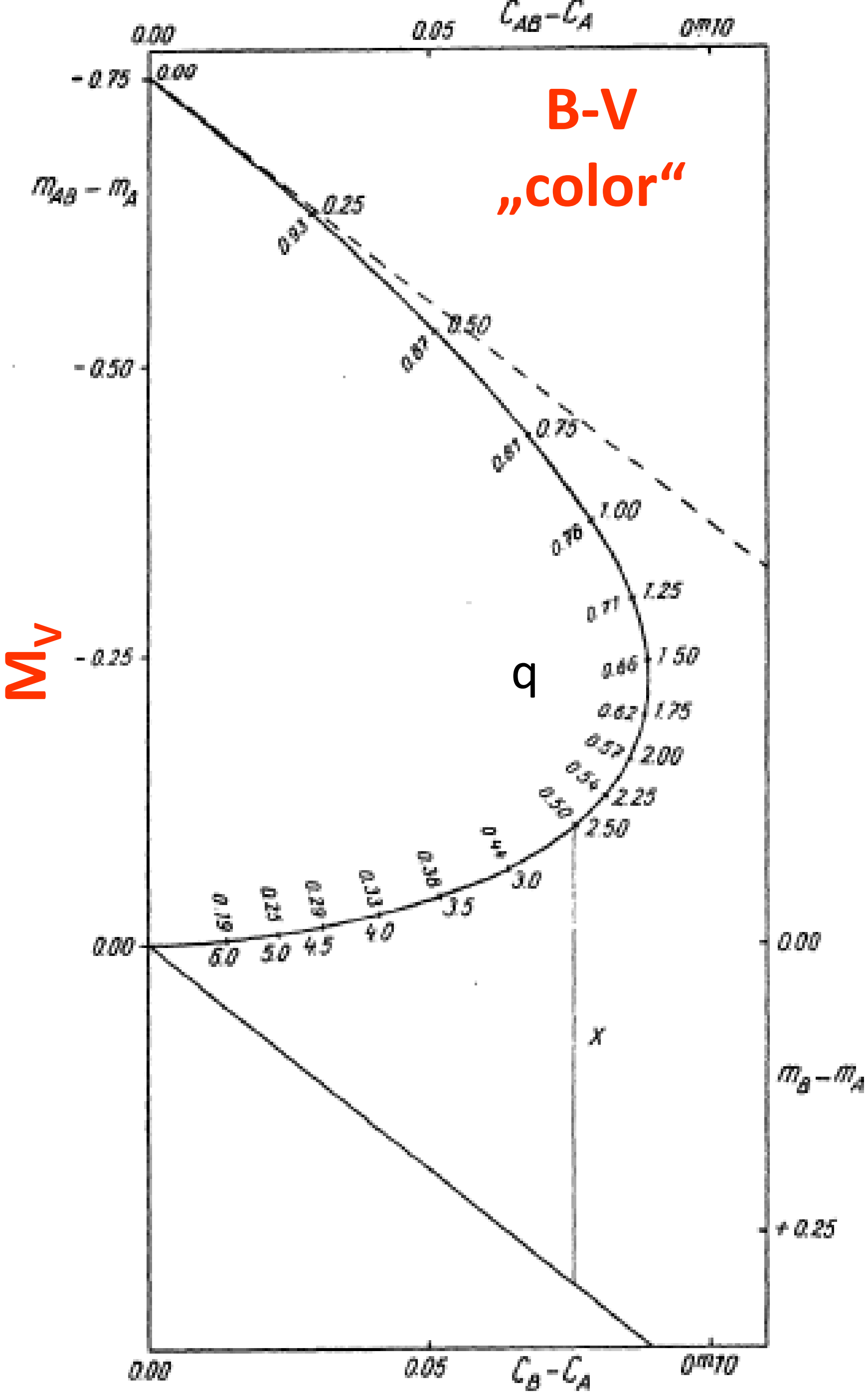
Hyades

log t = 8.90
d = 45 pc
[Fe/H] = +0.17 dex

Width of Main Sequence about 1.8 mag in M_V

NO
Observational error

What are the reasons?



Vertical distance from the main sequence

$$x = a(C_{AB} - C_A) + V_A - V_{AB}$$

Absolute magnitude:

$$M_V = -2.5 \log (L_1 + L_2)$$

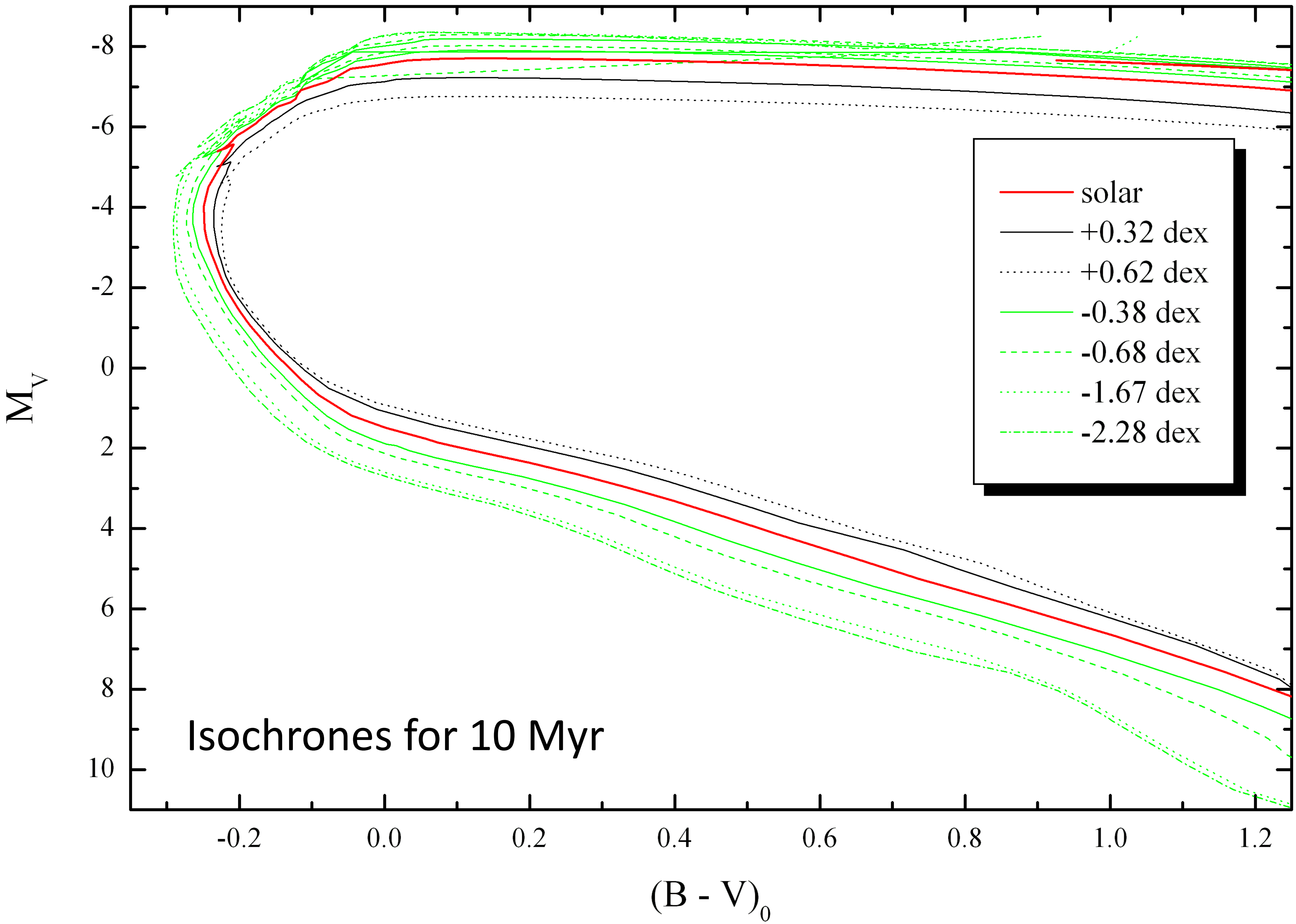
Maximum at $L_1 = L_2$ =>

$$M_V = -0.753 \text{ mag}$$

The maximal width of the main sequence due to binary systems is 0.753 mag

Haffner & Heckmann, 1937, VeGeo, 55, 77

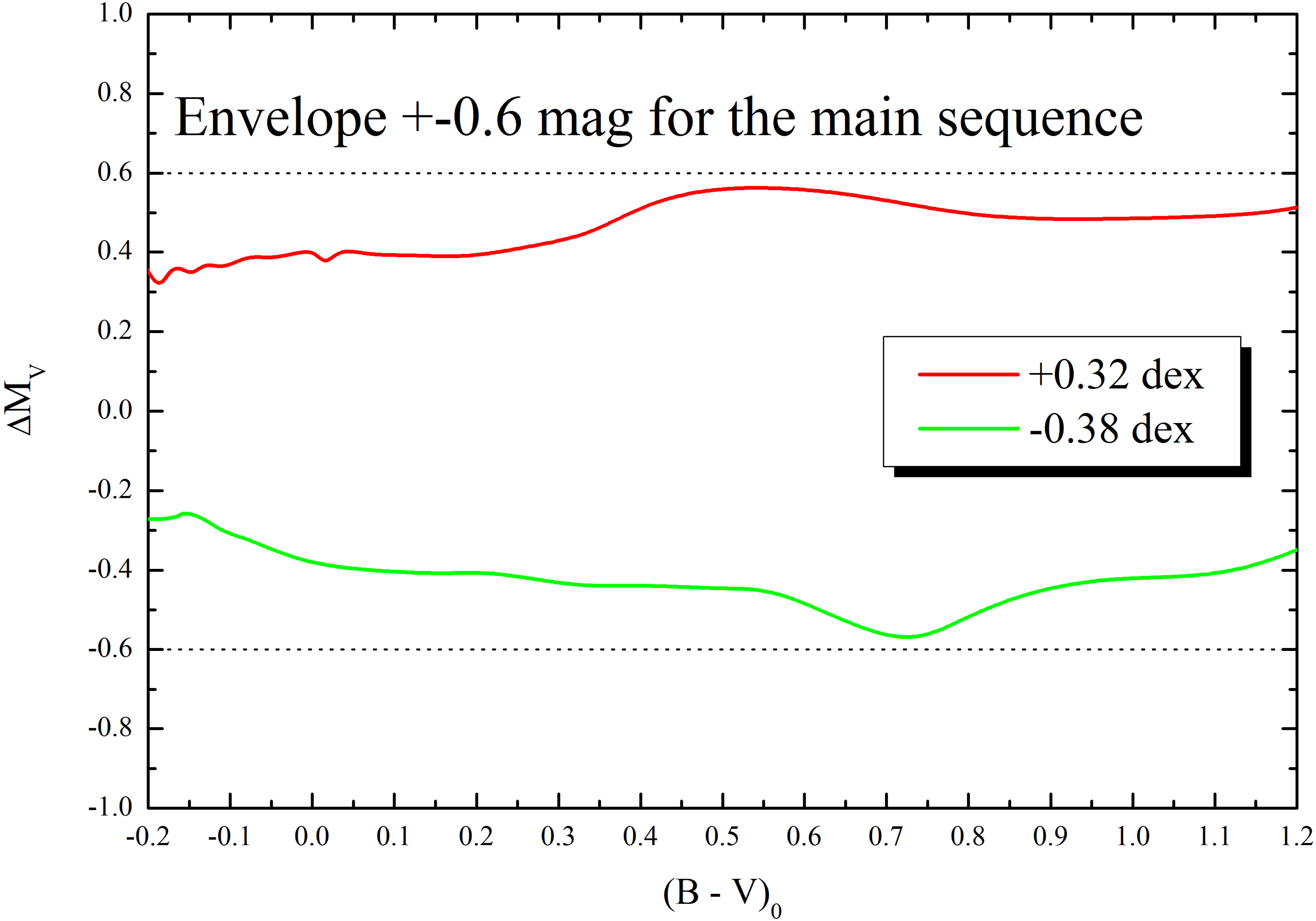
Metallicity => different opacity



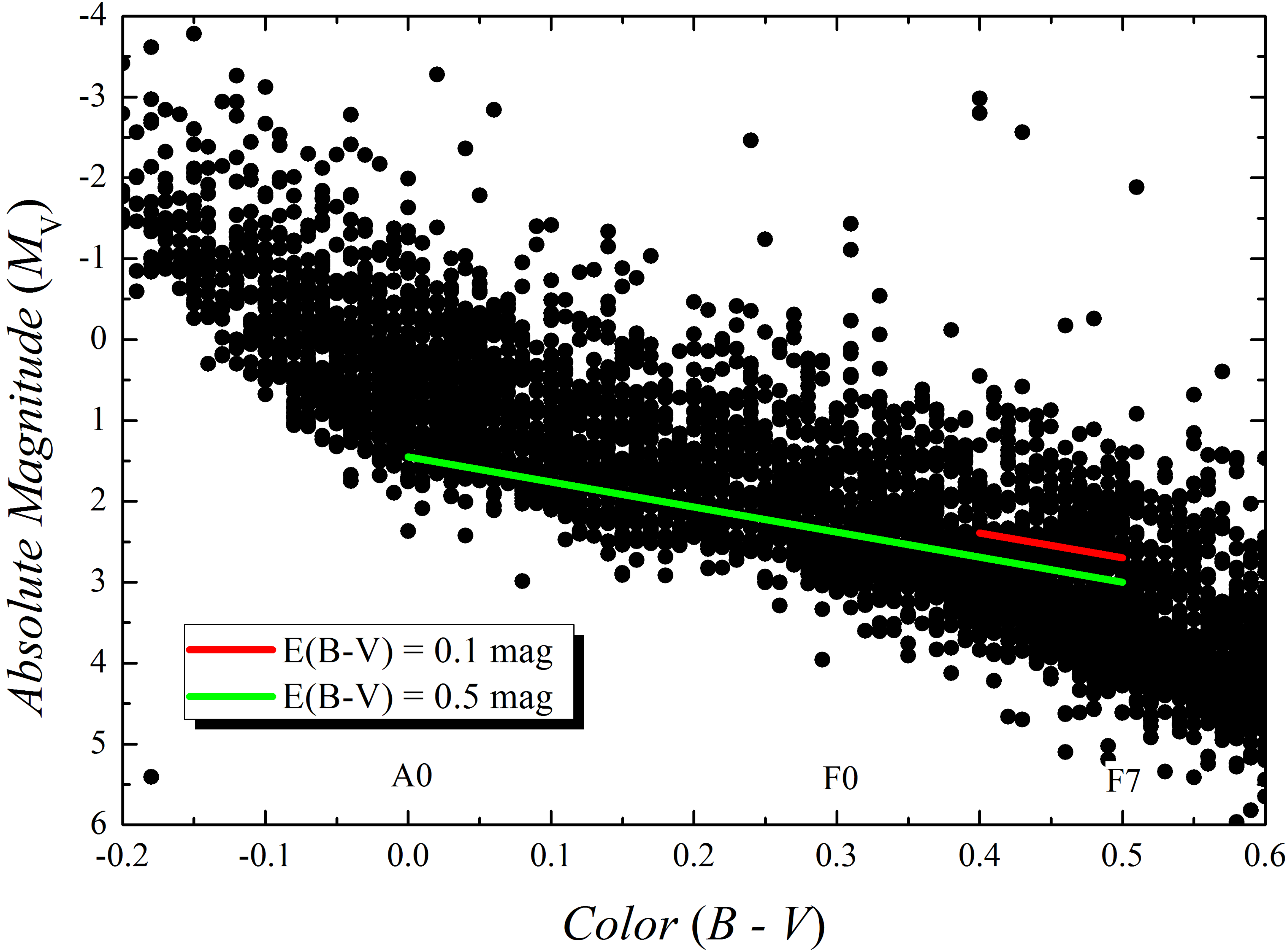
Praesepe: Fossati et al., 2008, A&A, 483, 891

At.N.	Element	HD 72846	HD 73345	HD 73450	HD 73574	HD 74028	HD 74050	HD 74587	HD 74718	Solar Abundances
		"Normal" A–type stars								
3	Li	< −8.08(–; 1)	< −8.33(–; 1)	< −8.70(–; 1)	< −8.38(–; 1)			< −8.41(–; 1)	< −8.26(–; 1)	−10.99
6	C	−3.58(–; 1)	−3.44(12; 3)	−3.27(–; 1)	−3.36(18; 2)	−3.39(08; 2)	−3.52(–; 1)	−3.49(01; 2)	−3.51(04; 2)	−3.65
8	O	−3.18(–; 1)	−3.22(01; 2)				−3.70(–; 1)	−3.30(–; 1)		−3.38
11	Na	−5.44(01; 2)	−5.37(01; 2)	−6.28(–; 1)	−5.57(02; 2)	−5.98(–; 1)	−5.64(13; 2)	−5.61(02; 2)	−5.70(14; 2)	−5.87
12	Mg	−4.18(08; 3)	−4.18(02; 3)	−5.02(18; 2)	−4.37(04; 3)	−4.86(08; 3)	−4.22(05; 4)	−4.56(08; 3)	−4.52(01; 2)	−4.51
14	Si	−4.62(16; 2)	−4.67(–; 1)	−4.13(–; 1)	−4.19(–; 1)	−4.17(–; 1)	−4.37(–; 1)	−4.16(–; 1)	−4.25(–; 1)	−4.53
16	S	−4.71(04; 2)	−4.44(03; 4)	−4.35(–; 1)	−4.61(02; 2)	−4.26(01; 2)		−4.50(04; 2)	−4.28(11; 2)	−4.90
20	Ca	−5.17(–; 1)	−5.39(09; 6)	−5.95(06; 4)	−5.86(16; 5)	−5.37(16; 2)	−6.13(06; 2)	−5.49(15; 6)	−5.68(02; 3)	−5.73
21	Sc	−8.88(–; 1)	−8.63(07; 3)	−8.57(14; 3)	−8.89(02; 3)	−8.35(–; 1)	−8.96(27; 3)	−8.56(–; 1)	−8.69(14; 2)	−8.99
22	Ti	−6.88(03; 5)	−6.95(06; 6)	−7.30(11; 5)	−6.98(09; 5)	−6.78(–; 1)	−7.08(15; 5)	−6.83(16; 3)	−6.93(10; 5)	−7.14
24	Cr	−6.23(06; 3)	−6.22(08; 2)	−6.56(08; 3)	−6.19(16; 3)	−6.23(12; 4)	−6.48(10; 3)	−6.05(13; 4)	−6.44(20; 5)	−6.40
25	Mn		−6.37(–; 1)	−6.88(–; 1)	−6.52(02; 2)	−6.77(–; 1)	−6.61(–; 1)	−6.62(04; 2)	−6.71(–; 1)	−6.65
26	Fe	−4.55(18; 42)	−4.33(11; 61)	−4.62(09; 15)	−4.49(10; 30)	−4.50(09; 18)	−4.44(13; 16)	−4.28(10; 33)	−4.61(11; 26)	−4.59
28	Ni	−5.70(18; 2)	−5.58(11; 4)	−5.82(16; 2)	−5.62(08; 4)	−5.93(14; 3)	−5.60(15; 3)	−5.84(–; 1)	−5.68(02; 3)	−5.81
39	Y	−9.75(–; 1)	−9.46(–; 1)	−9.83(–; 1)	−9.20(–; 1)	−9.56(–; 1)	−9.26(–; 1)	−9.13(–; 1)	−9.10(–; 1)	−9.83
56	Ba	−9.48(–; 1)	−9.30(06; 2)	−9.50(02; 2)	−8.98(04; 2)	−9.65(–; 1)	−9.52(01; 2)	−8.96(25; 2)	−9.15(–; 1)	−9.87
	$T_{\rm eff}$	8045	7993	7270	7662	7750	7872	7500	7600	
	$\log g$	3.50	3.96	4.20	4.00	4.50	3.66	4.20	4.00	
	$\upsilon_{\rm mic}$	2.5	2.6	2.7	2.6	2.6	2.6	2.7	2.7	
	$\upsilon \sin i$	119	85	138	102	150	188	90	155	

Fe: -4.28 to -4.62dex; 0.34 dex



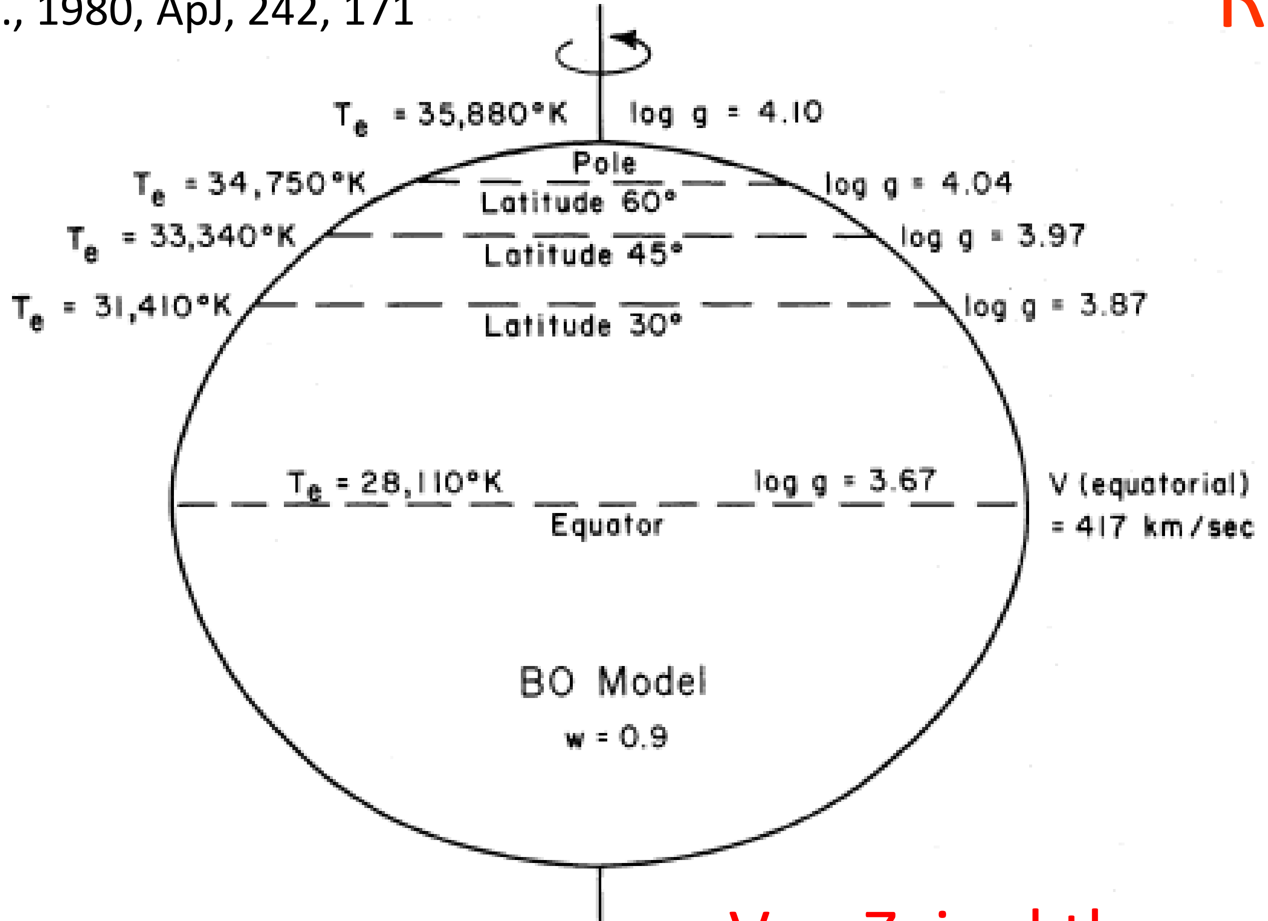
Envelope +-0.6 mag for the main sequence
+0.32 dex
-0.38 dex
ΔM_V
(B - V)_0
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2



-4
-3
-2
-1
0
1
2
3
4
5
6
Absolute Magnitude (M_V)
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Color (B - V)
A0
F0
F7
E(B-V) = 0.1 mag
E(B-V) = 0.5 mag

Slettebak et al., 1980, ApJ, 242, 171

Rotation

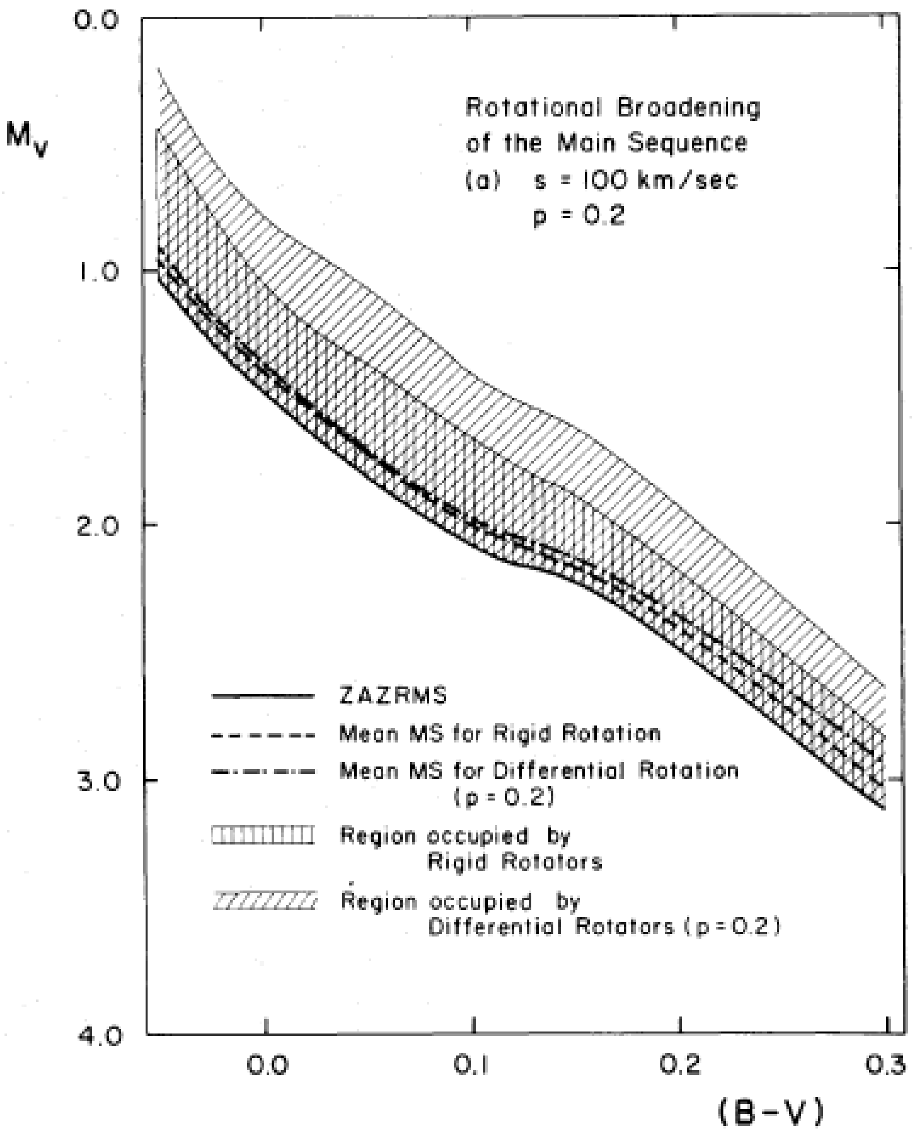


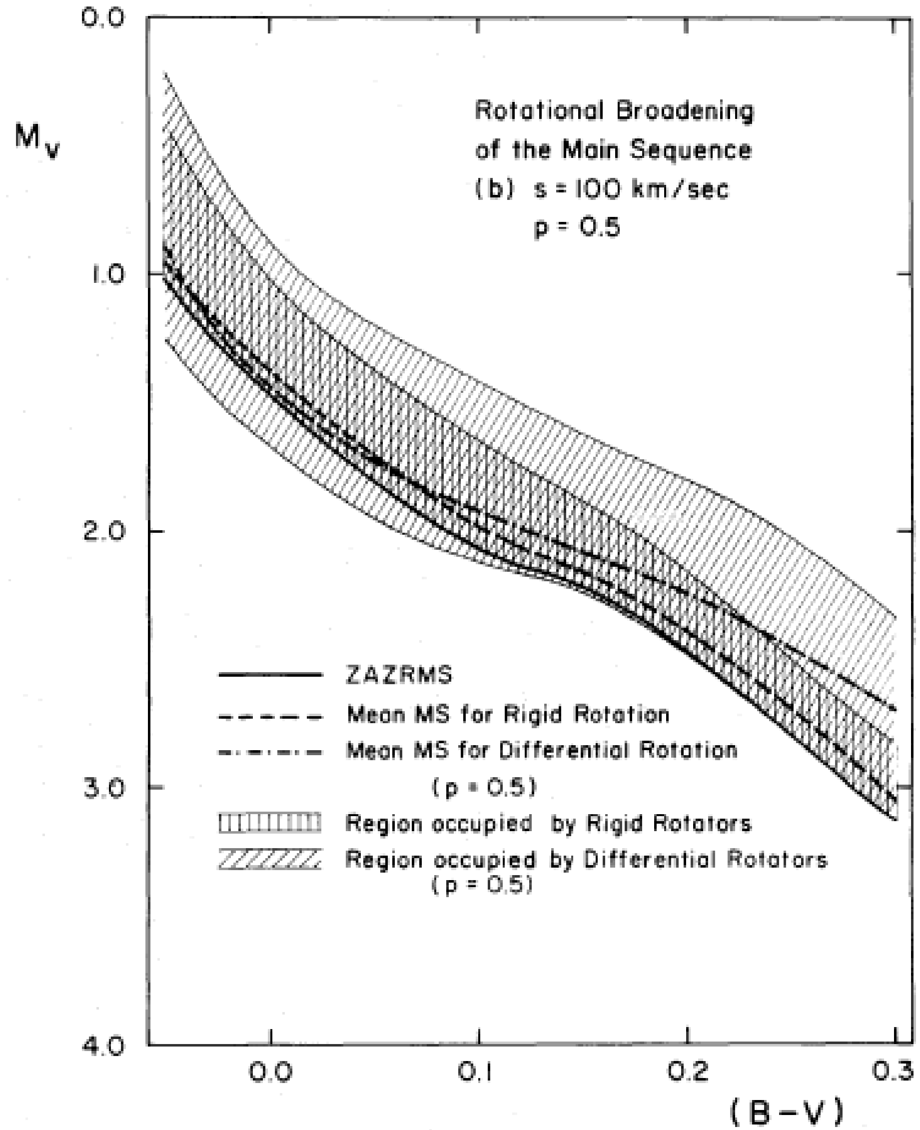
Von Zeipel theorem (1924, MNRAS, 84, 665)

Energy generation rate $$\epsilon = (\mathrm{const})\left(1 - \frac{\omega^2}{2\pi G\rho}\right)$$

From the rotational velocity => ε => T_{eff} and L (log g)

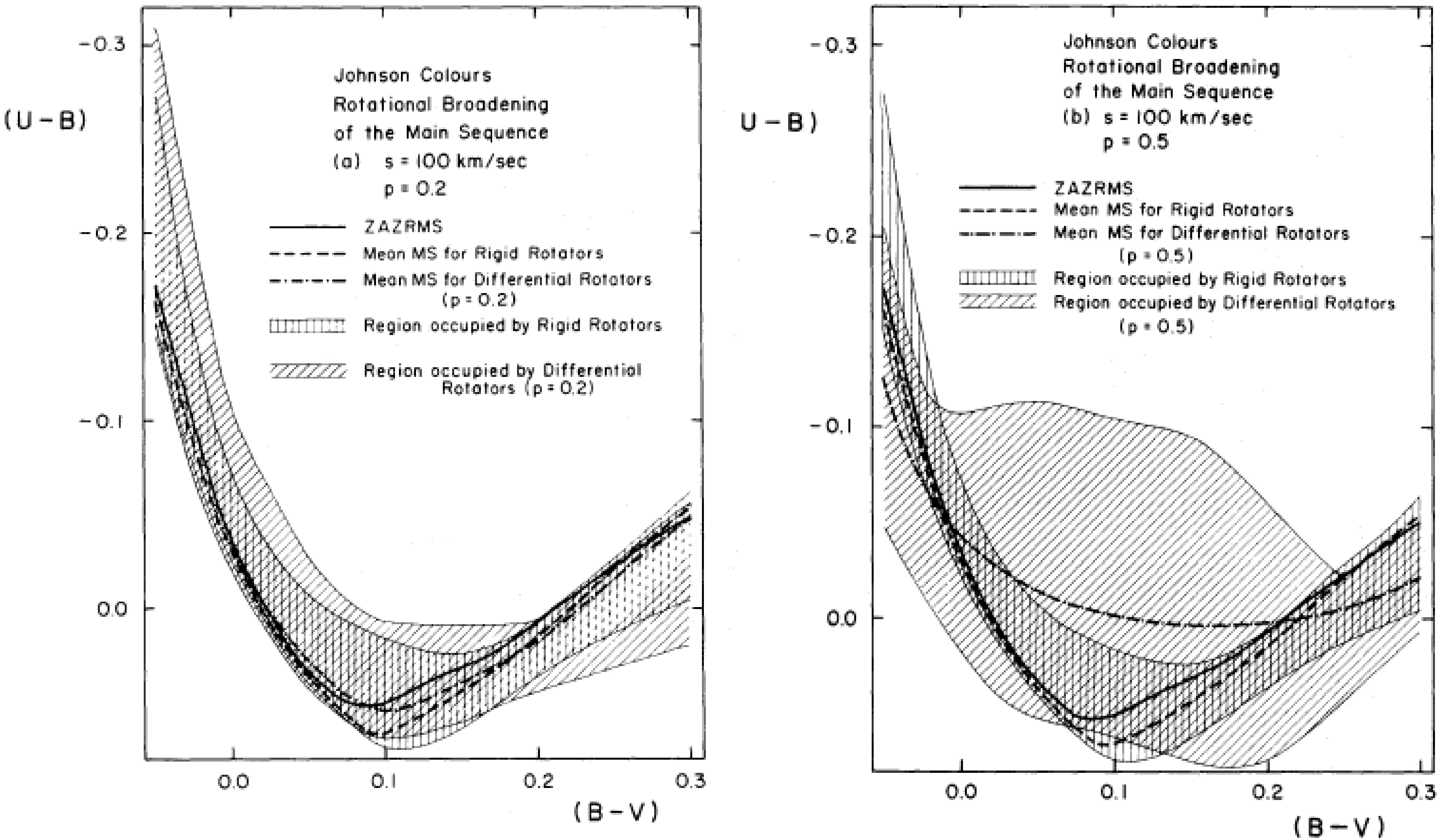
Collins & Smith, 1985, MNRAS, 213, 519





p … Degree of differential rotation

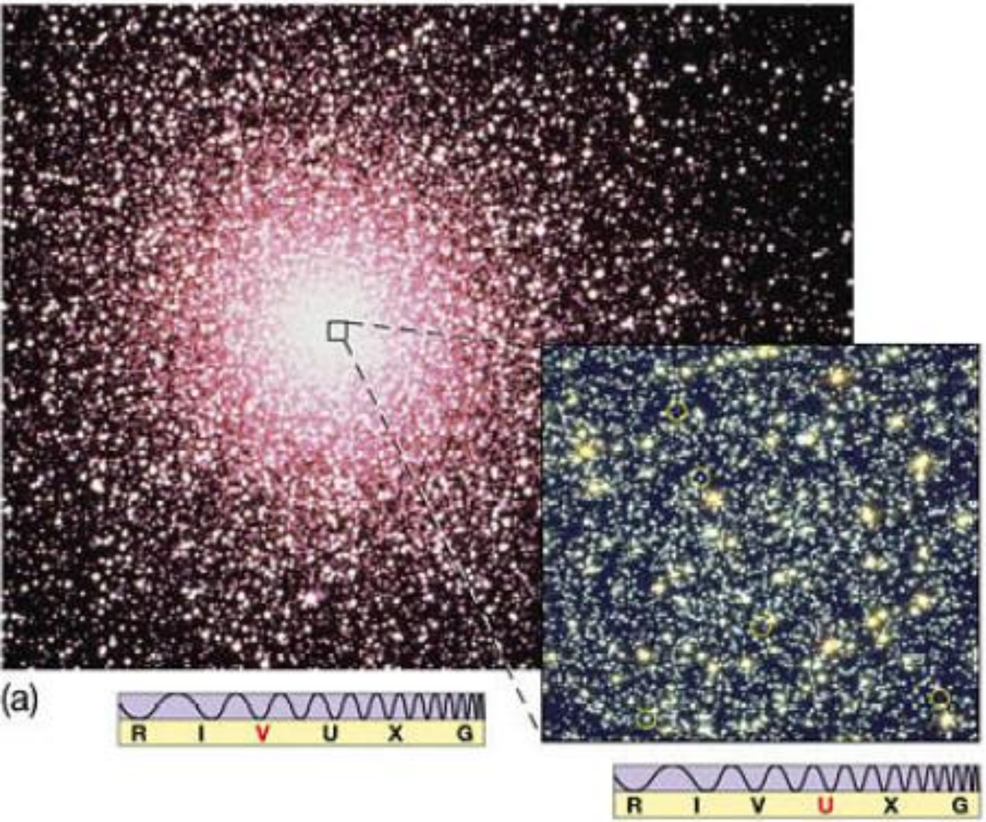
Collins & Smith, 1985, MNRAS, 213, 519

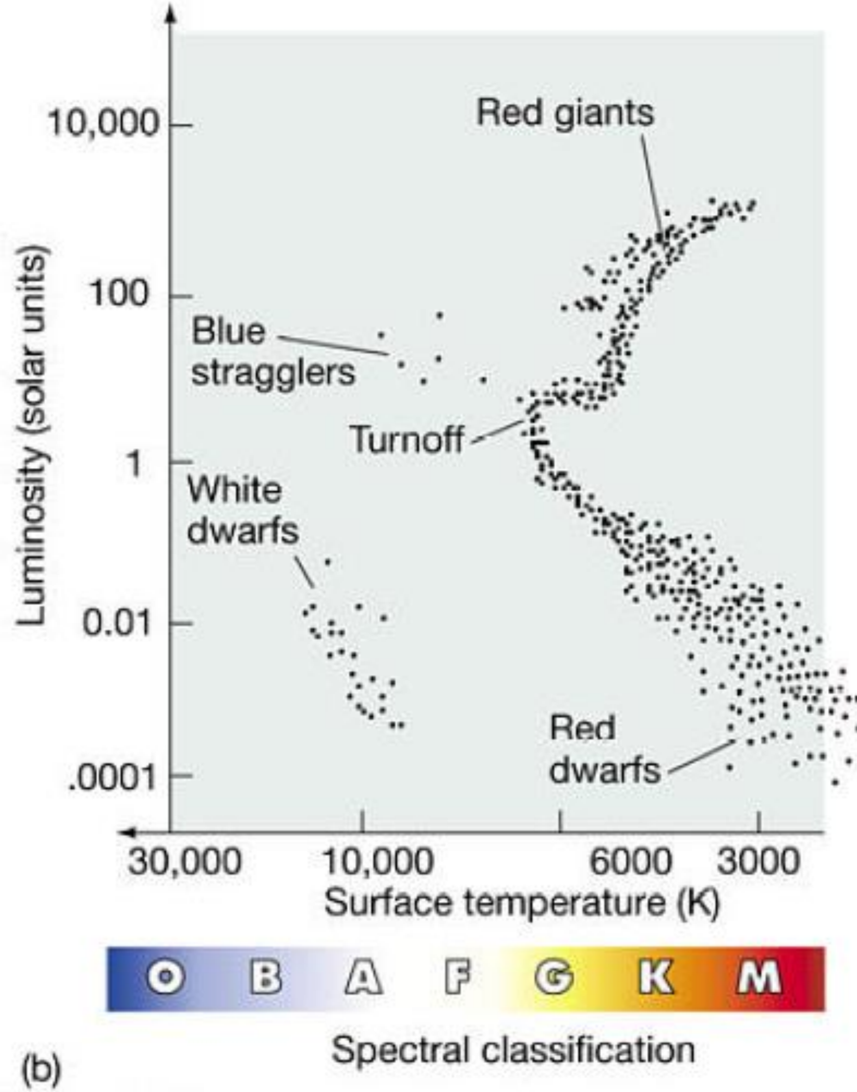


Conclusions – Width of the Main Sequence

- Differential reddening: $k \cdot \Delta E(B-V)$
- Spectroscopic Binaries: 0.753 mag
- Metallicity: up to 1.2 mag for M_V, but only 0.2 mag for (U – B) versus (B – V)
- Rotation: 1 mag for M_V, 0.2 (?) mag for (U – B) versus (B – V)

47 Tuc





NGC 104: d = 4500 pc, D = 31‘, [Fe/H] = -0.76 dex, t = 12 Gyr,

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Definition - Radii

- **Core Radius**: Distance at which the apparent surface luminosity has dropped by half
- **Half-Light Radius**: Distance from the core within which half the total luminosity from the cluster is received
- **Half-Mass Radius**: The radius from the core that contains half the total mass
- **Tidal Radius**: Distance from the center at which the external gravitation of the galaxy has more influence over the stars in the cluster than does the cluster itself

Density – Profile (King Profile)

- Heuristic description of the density law of star clusters (open and globular) by Ivan King (1962, AJ, 67, 471):

$$f = f_1[(1/r - 1/r_t)^2]$$

f … Stars per square unit or surface density; f_1 … Constant; r_t … Radius f(r) = 0

- General formula:

$$f = k\left\{\frac{1}{[1+(r/r_c)^2]^{\frac{1}{2}}} - \frac{1}{[1+(r_t/r_c)^2]^{\frac{1}{2}}}\right\}^2$$

k … Constant; r_c … core radius

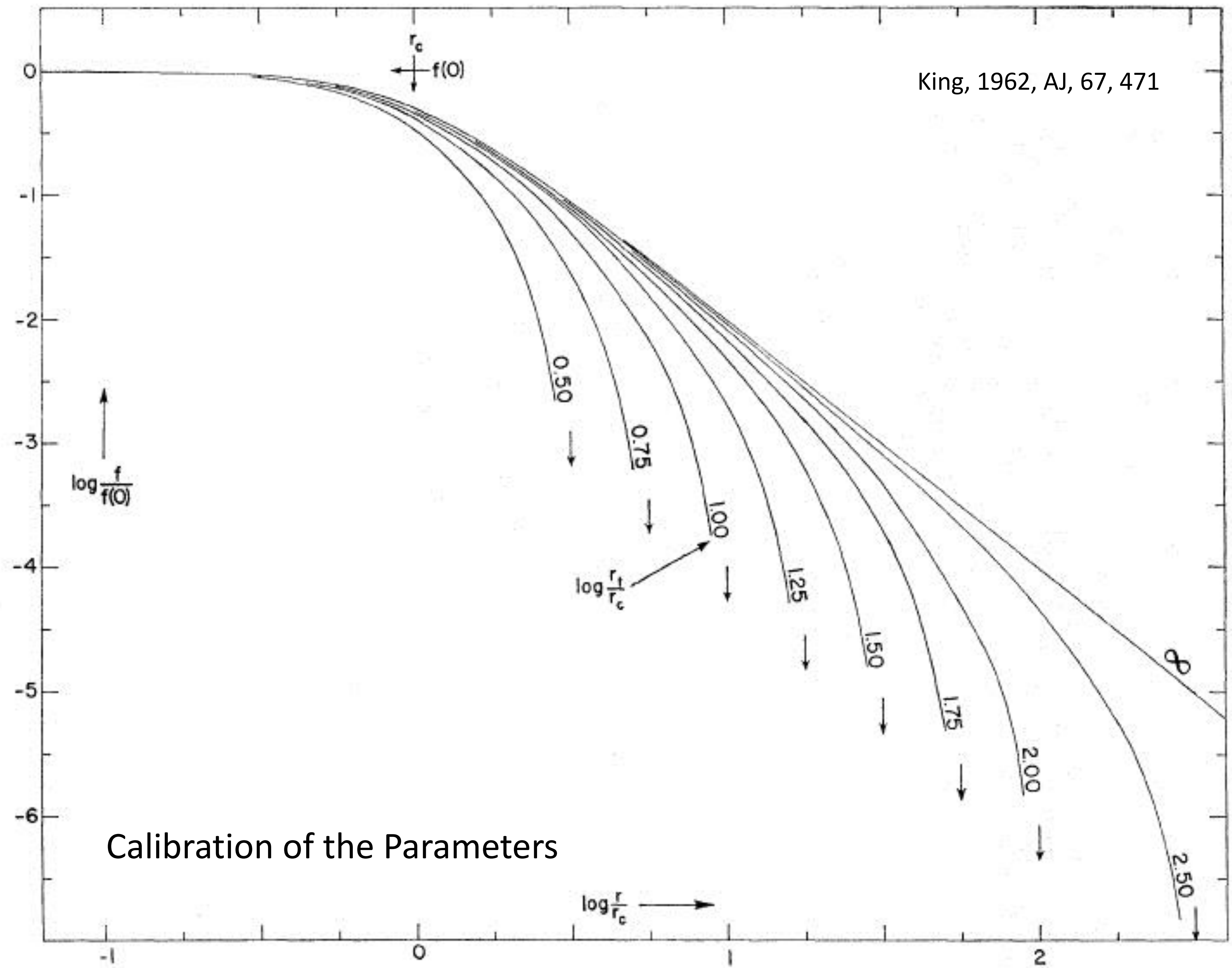
Density – Profile (King Profile)

- Typical Globular Cluster:
  1. $r_t/r_c \sim 30$
  2. Unit for k is V = 10 mag per square arc minute
- The parameters r_t and r_c can be treated within numerical simulations and can be converted into an „astrophysical quantity“, for example:

$$r_t = R(M/2M_g)^{\frac{1}{3}}$$

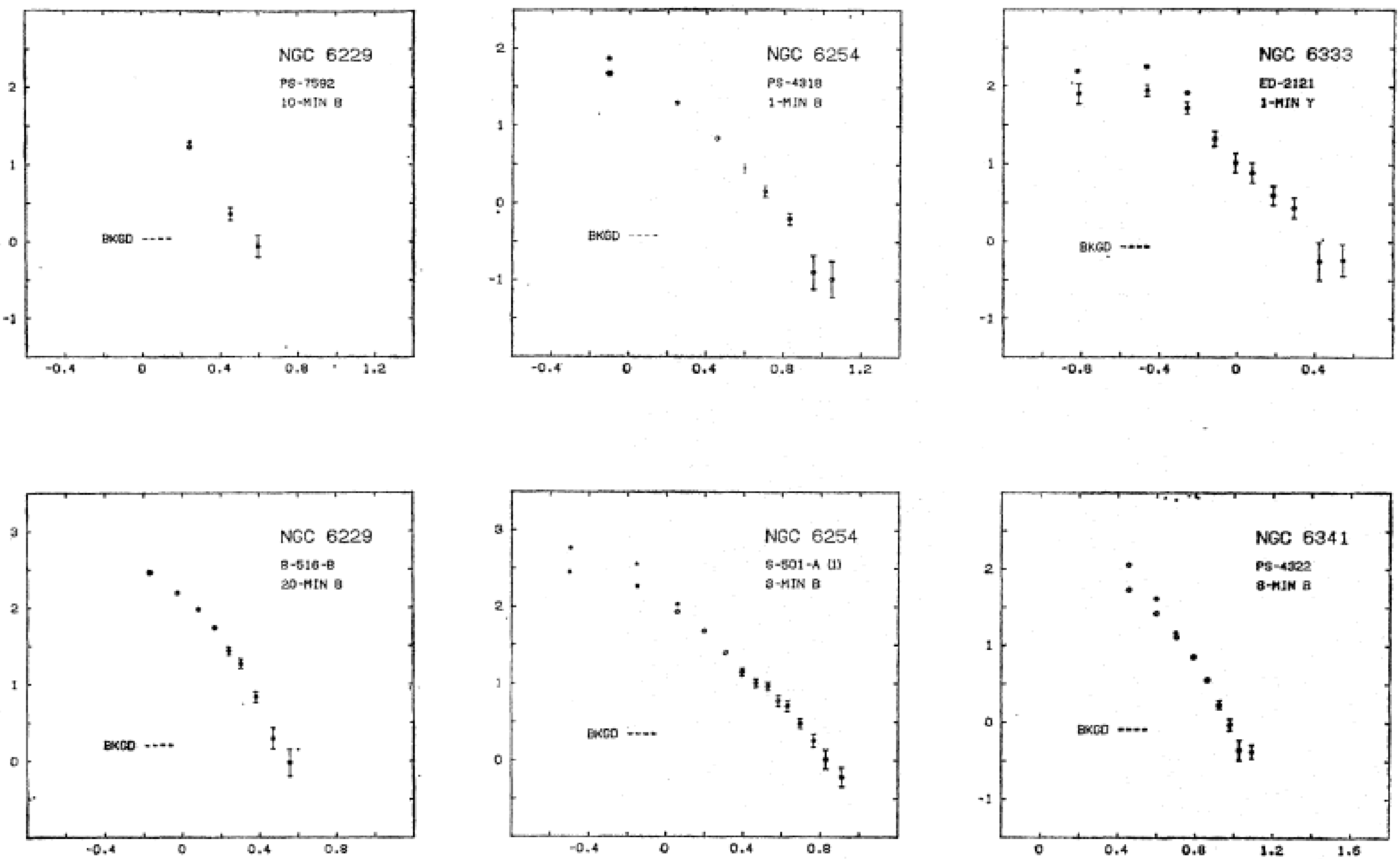
R … Distance from the galactic center; M … Mass of the Globular Cluster; M_g … Mass of the Milky Way

King, 1962, AJ, 67, 471

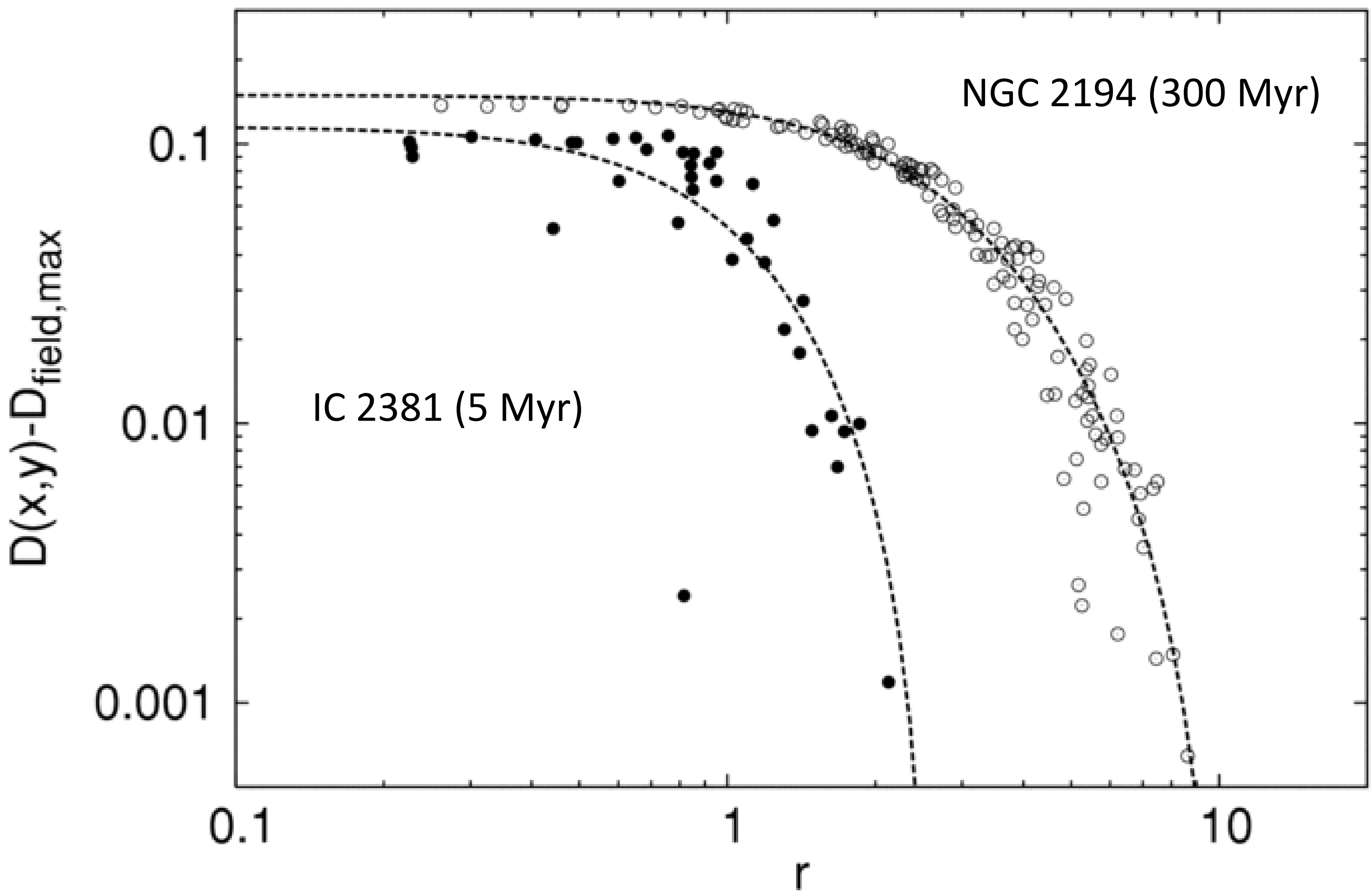


Calibration of the Parameters

King et al., 1968, AJ, 73, 456



Sánchez & Alfaro, 2005, ApJ, 696, 2086



Also works for open clusters

Ellipticity

Goodwin, 1997, MNRAS, 286, L39

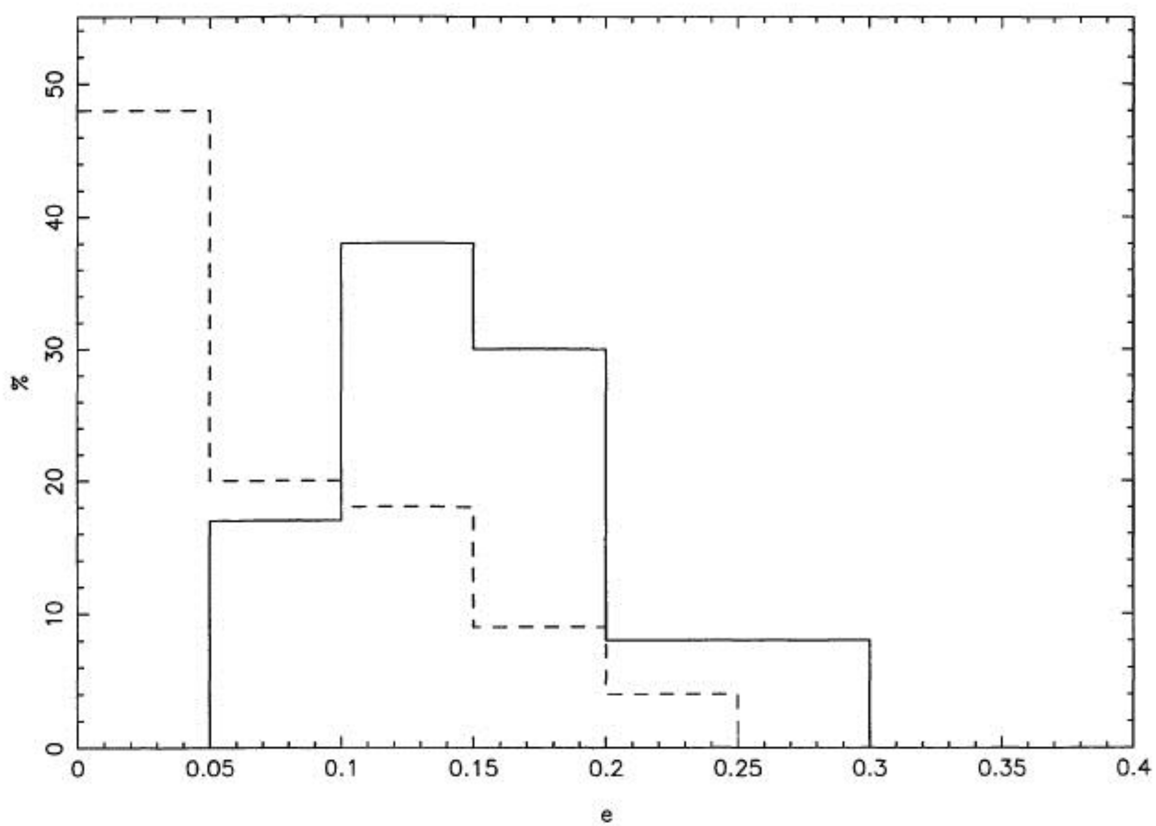
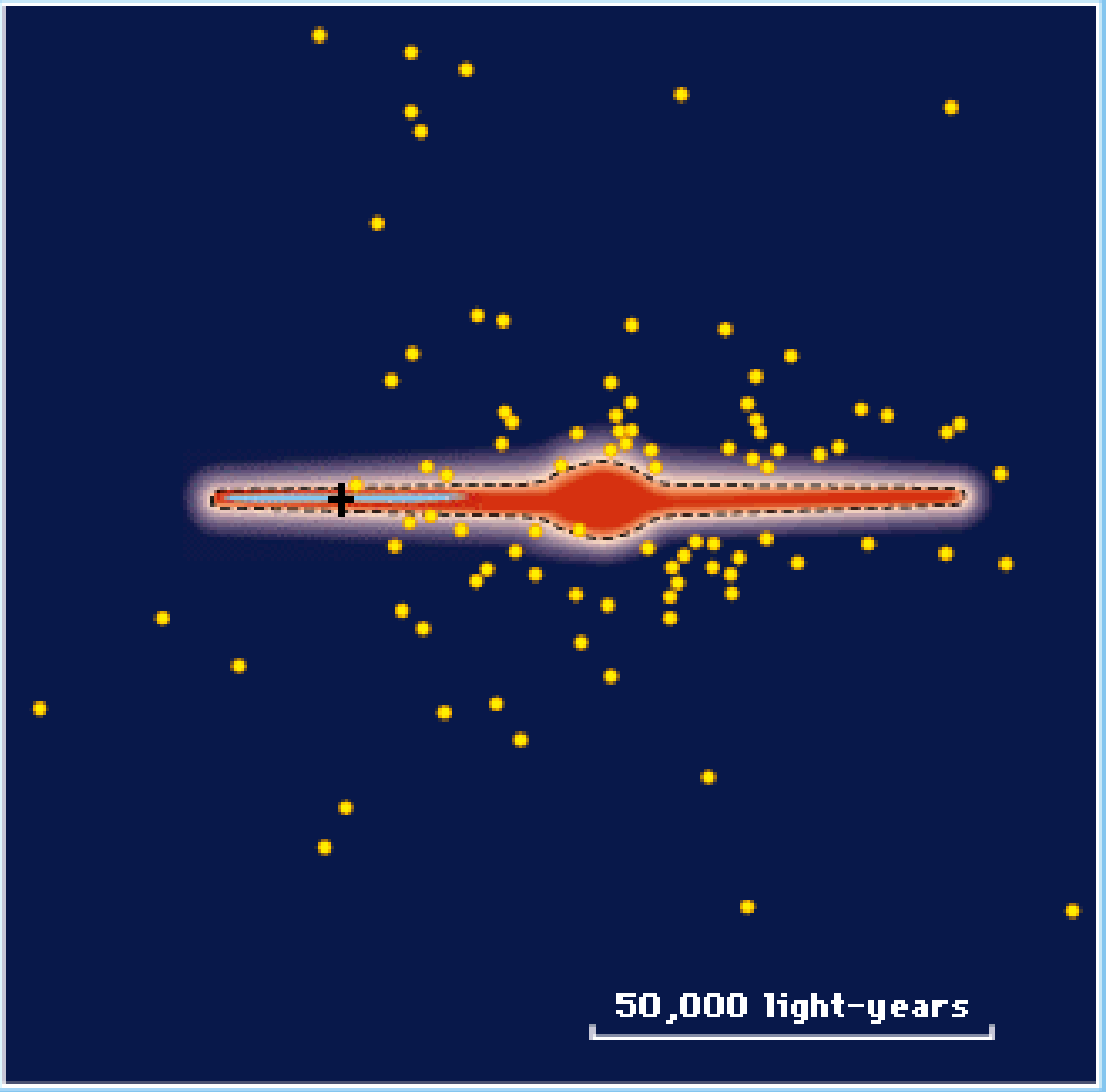


Figure 1. The ellipticity distributions of globular clusters in the LMC (full line) and the Galaxy (dashed line) from data in White & Shawl (1987) and Kontizas et al. (1989).



Dotted line indicates probable outline of the galaxy, a flattened lens-shaped system formed by the stars, as seen edgewise from outside. Eccentric position of the Sun is shown by a cross. Some of the known open star clusters are scattered among the stars in shaded region. Small circles represent globular clusters.

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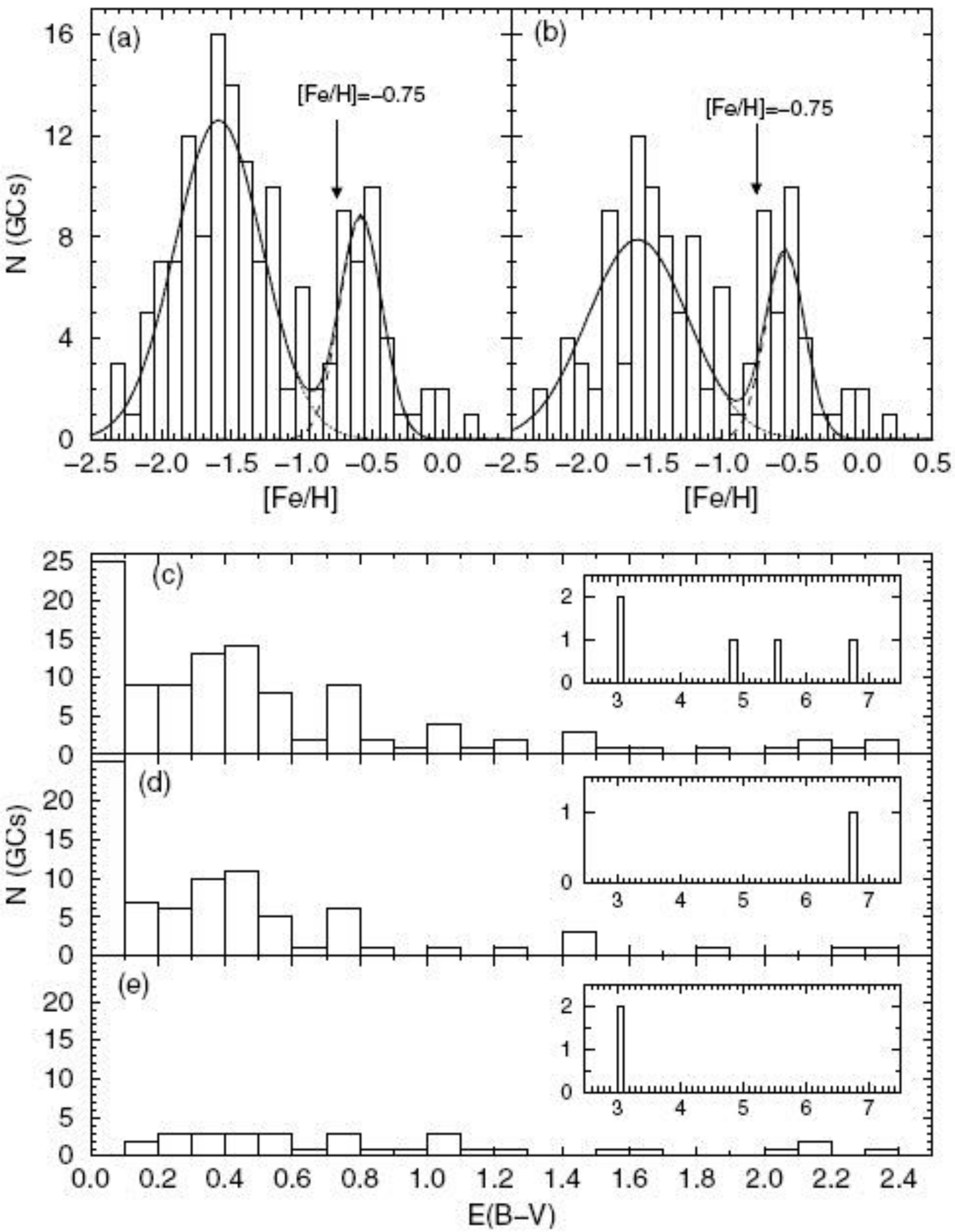
Two „external Populations“

- Halopopulation:
  - Spherical around the center of the Milky Way
  - Very extended (Halo)
  - $-2.5 < [Fe/H] < -1$ dex
  - $10 <$ Age < 15 Gyr
- Diskpopulation (Bulge):
  - More concentrated around the center of the Milky Way
  - $-0.7 < [Fe/H] < +0.5$ dex
  - Age about 10 Gyr
- Continuous transition!



Bica et al., 2006, A&A, 450, 105

153 Globulars

Two Populations

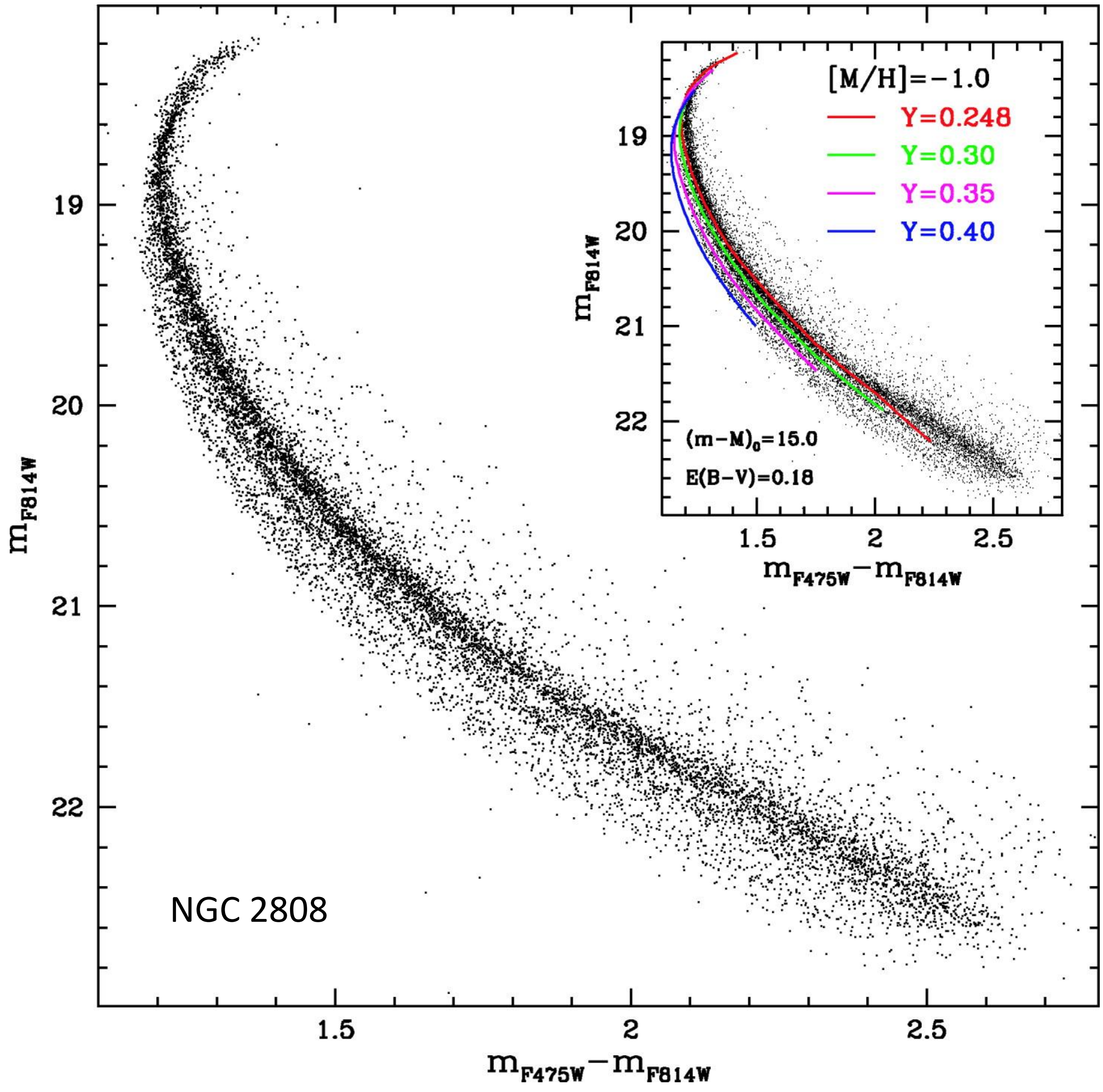
Reddening

Although the large distance, no reddening, Halo

New Globulars with large reddening and large distance detected

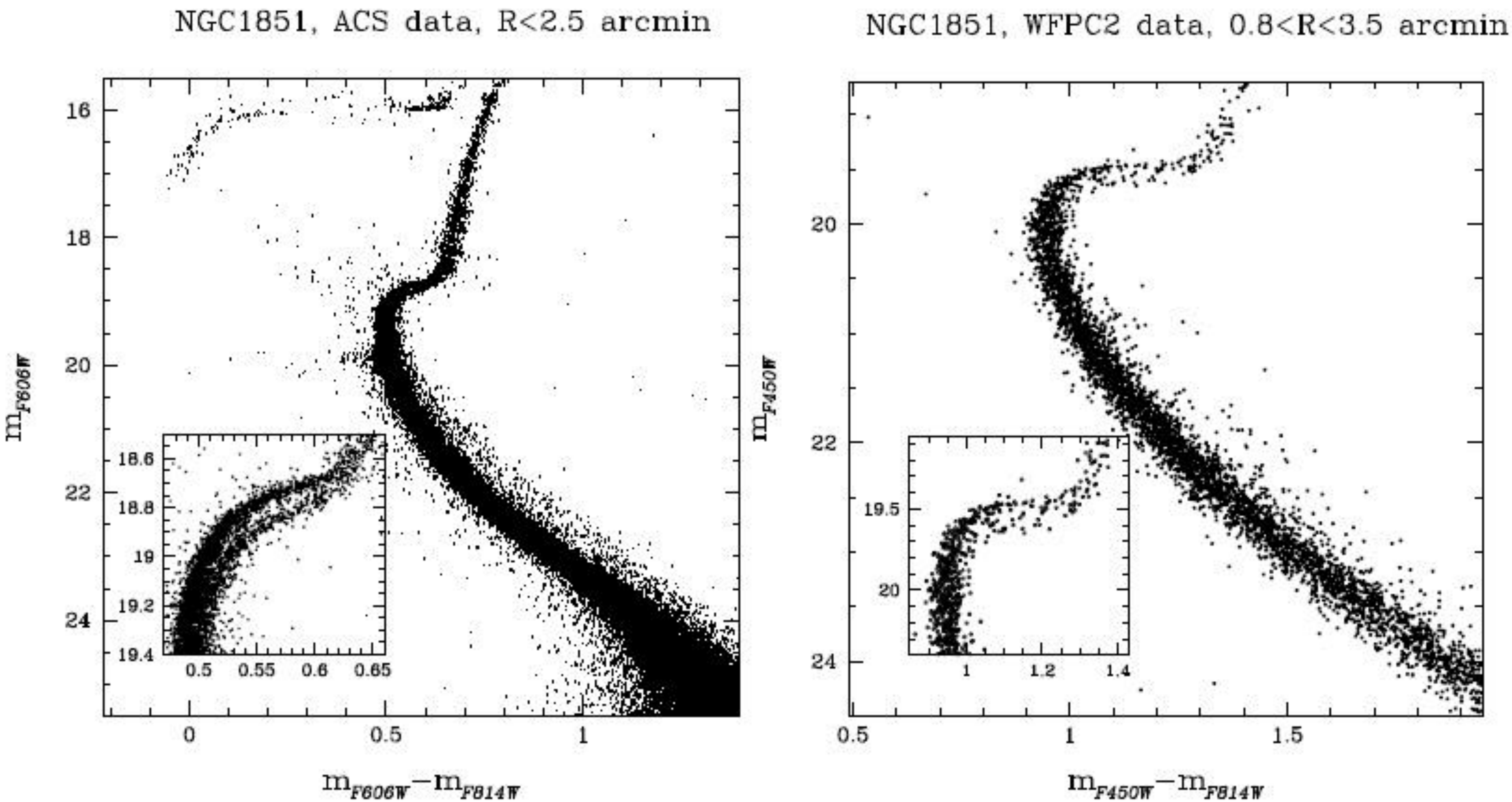
Multiple „ internal Populations“

- Multiple Main, AGB and HB Sequences within one Globular were found
- Not for all Globulars although same observational quality
- No clear morphology detected yet
- Also indications for the oldest OCLs
- Project SUMO: http://www.iac.es/proyecto/sumo/index.html



Piotto et al., 2007, ApJ, 661, L53

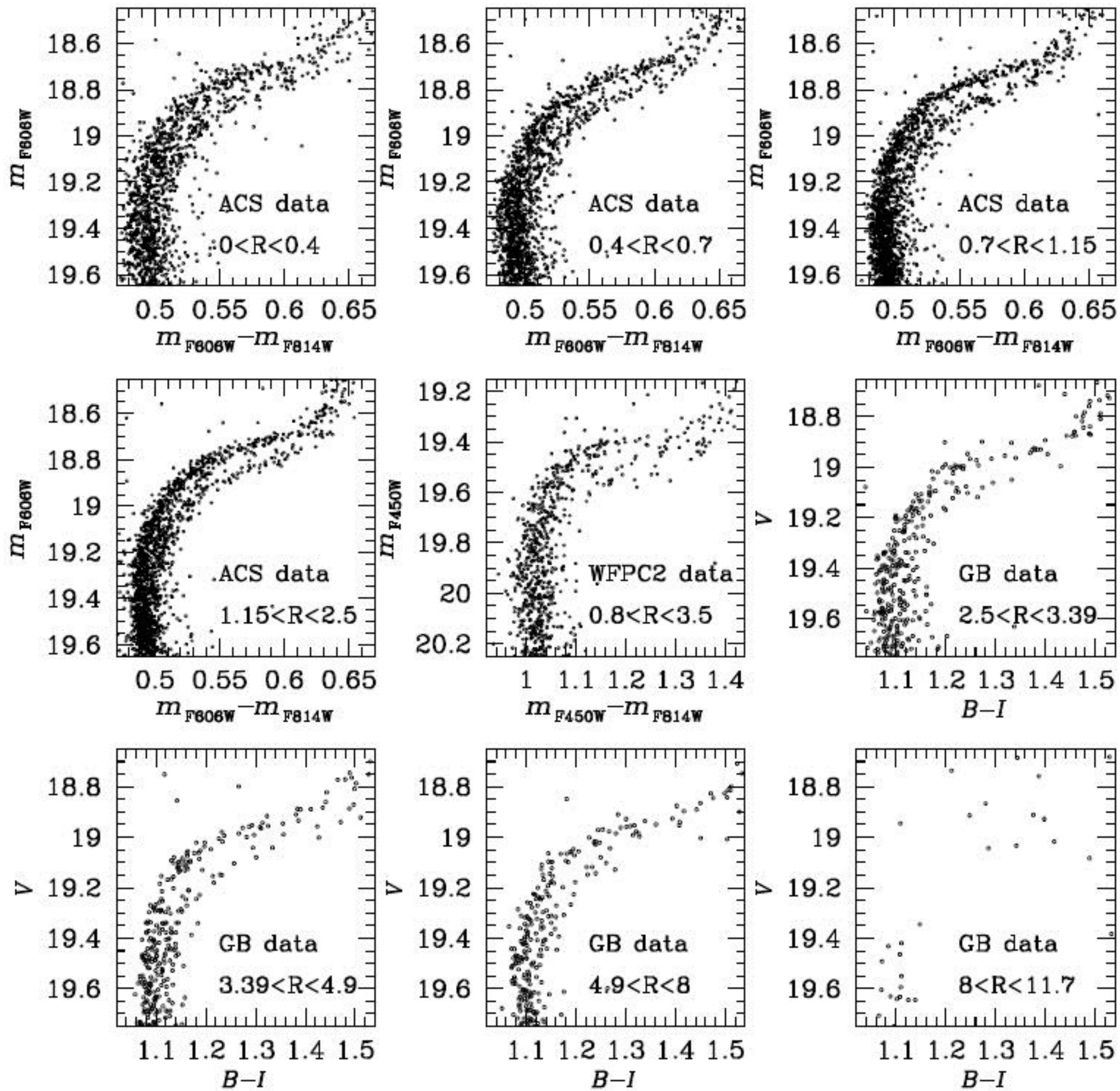
Different He content can explain the multiple MS

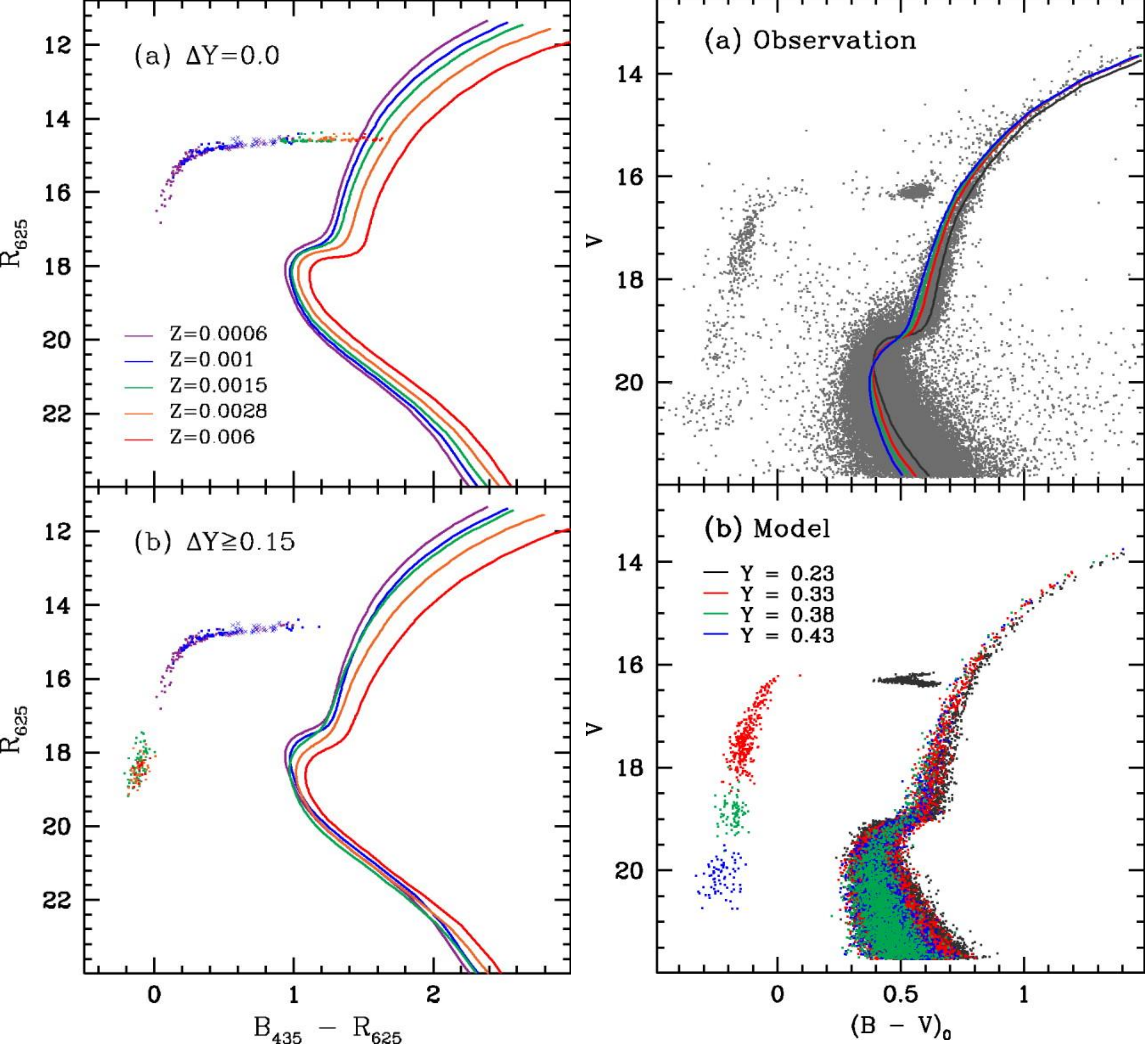


Double sub-giant branch but no double Main Sequence

Milone et al., 2009, A&A, 503, 755

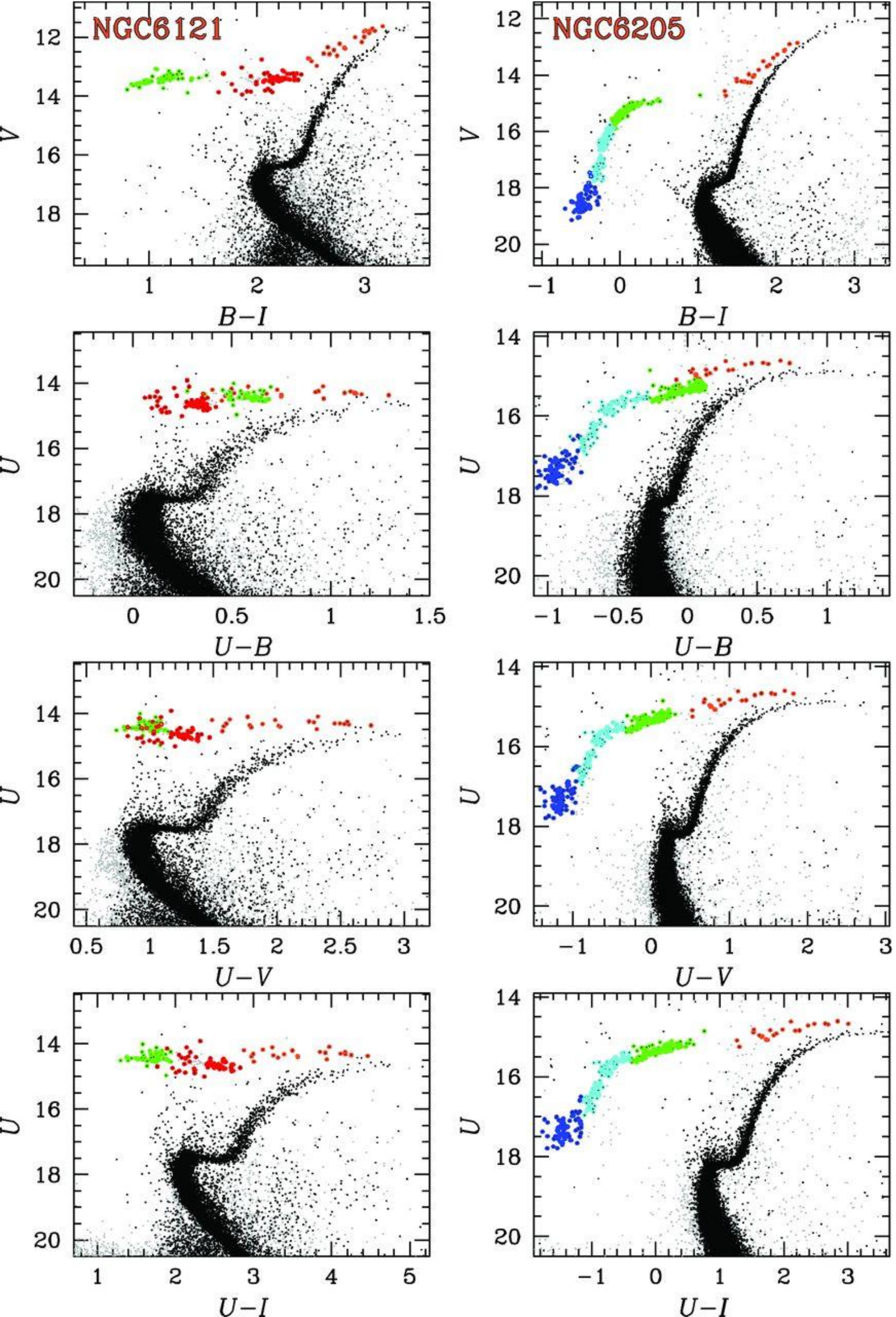
No “location” effect





Lee et al., 2005, ApJ, 621, L57

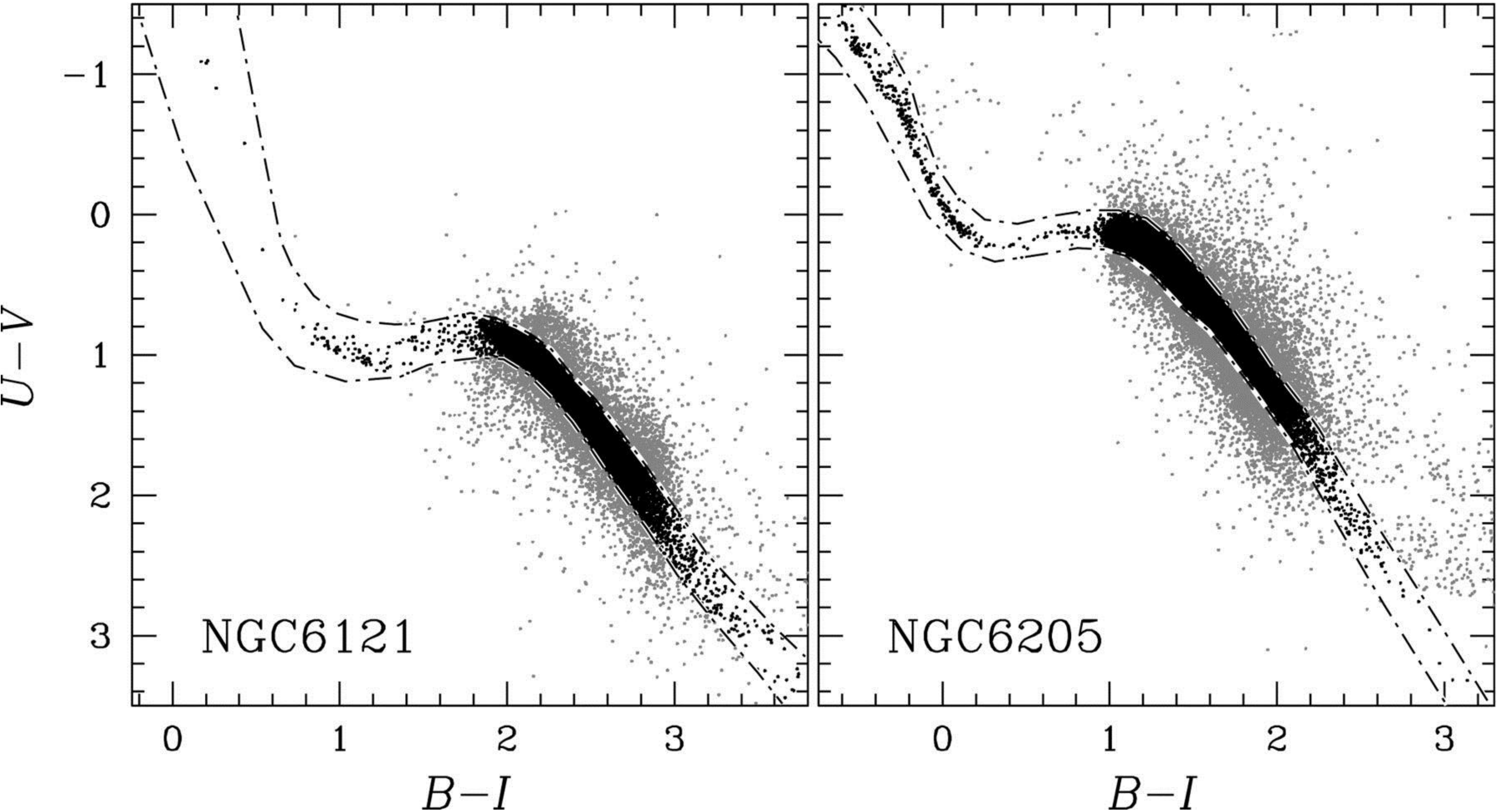
ω Centauri



SUMO (SUrvey of Multiple pOpulations in Globular Clusters)

Monelli et al., 2013, MNRAS, 431, 2126 (first paper)

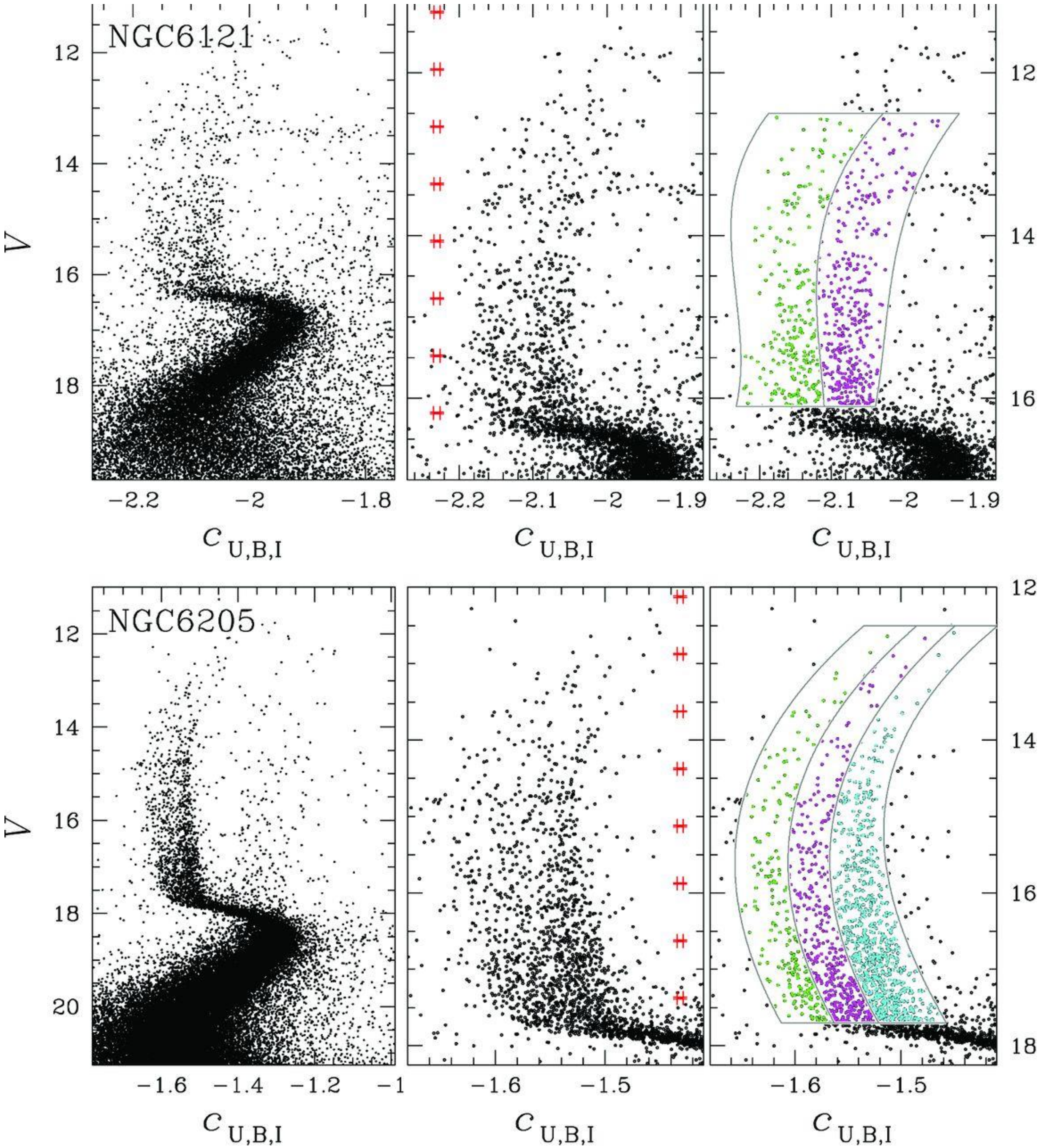
Cluster	RA	Dec.	*U*	*B*	*V*	*I*
NGC 104 [47 Tuc]	00 24 05.67	−72 04 52.6	21	106	115	103
NGC 288	00 52 45.24	−26 34 57.4	9	63	100	68
NGC 362	01 03 14.26	−70 50 55.6	11	140	162	151
NGC 2808	09 12 03.10	−64 51 48.6	48	652	545	203
NGC 3201	10 17 36.82	−46 24 44.9	13	4	4	4
NGC 4590 [M 68]	12 39 27.98	−26 44 38.6	14	48	48	35
NGC 5904 [M 5]	15 18 33.22	+02 04 51.7	28	75	132	127
NGC 6093 [M 80]	16 17 02.41	−22 58 33.9	21	25	45	22
NGC 6121 [M 4]	16 23 35.22	−26 31 32.7	12	1026	1425	41
NGC 6205 [M 13]	16 41 41.24	+36 27 35.5	20	58	54	67
NGC 6218 [M 12]	16 47 14.18	−01 56 54.7	46	196	212	166
NGC 6254 [M 10]	16 57 09.05	−04 06 01.1	17	18	27	29
NGC 6366	17 27 44.24	−05 04 47.5	8	9	30	18
NGC 6397	17 40 42.09	−53 40 27.6	11	42	36	28
NGC 6541	18 08 02.36	−43 42 53.6	12	33	36	23
NGC 6681 [M 70]	18 43 12.76	−32 17 31.6	13	28	48	38
NGC 6712	18 53 04.30	−08 42 22.0	35	38	49	–
NGC 6752	19 10 52.11	−59 59 04.4	35	84	1176	28
NGC 6809 [M 55]	19 39 59.71	−30 57 53.1	12	40	40	36
NGC 6934	20 34 11.37	+07 24 16.1	15	38	42	39
NGC 6981 [M 72]	20 53 27.70	−12 32 14.3	6	241	277	218
NGC 7078 [M 15]	21 29 58.33	+12 10 01.2	31	277	271	196
NGC 7099 [M 30]	21 40 22.12	−23 10 47.5	9	38	48	20



Reddening determination also works for these indices, not only for (U-B) versus (B-V)

Monelli et al., 2013, MNRAS, 431, 2126

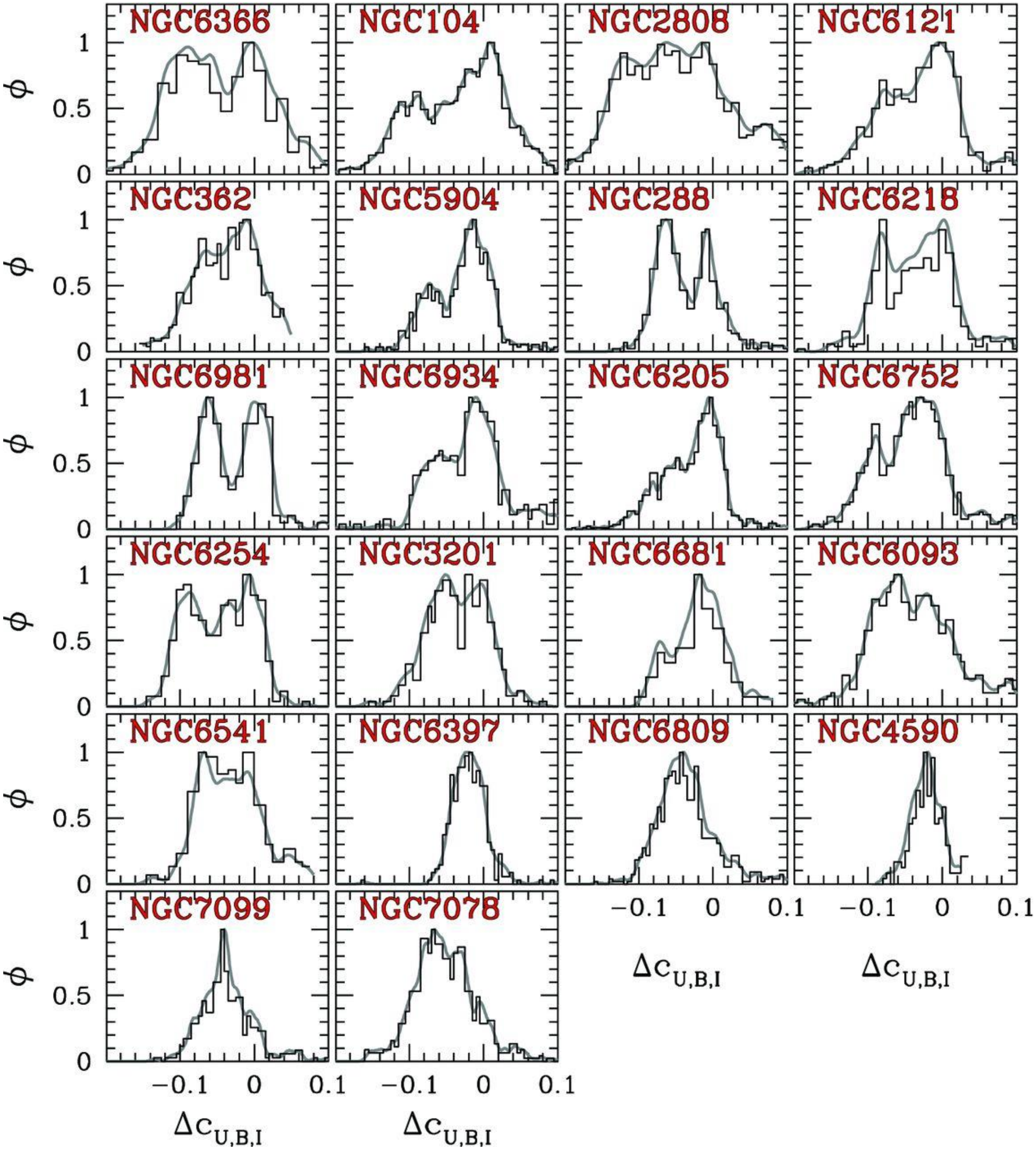
Red Giant Branch



$C_{U,B,I} = (U-B) - (B-I)$

Monelli et al., 2013, MNRAS, 431, 2126

Individual populations



Monelli et al., 2013, MNRAS, 431, 2126