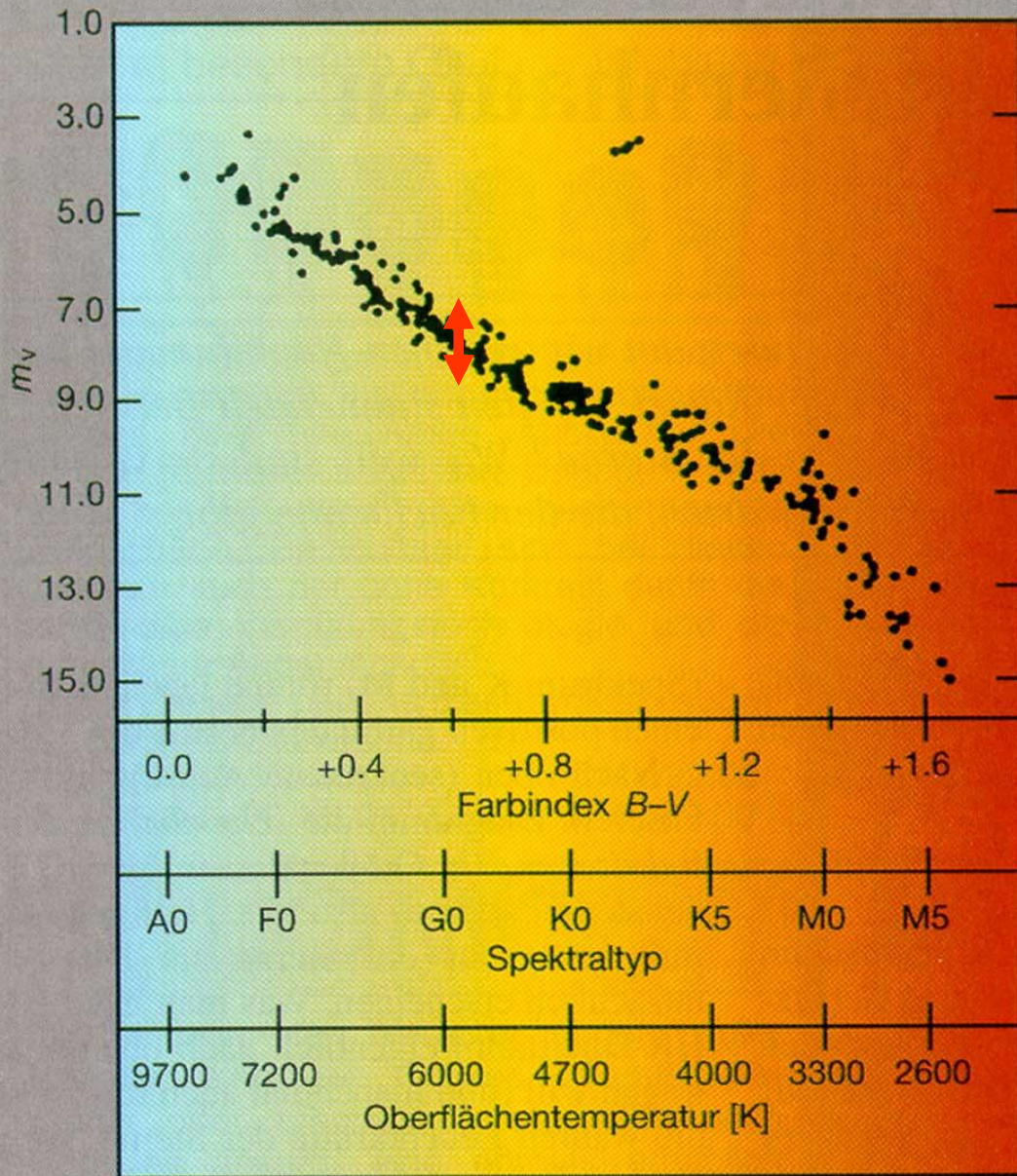


Hyades

$\log t = 8.90$

$d = 45 \text{ pc}$

$[\text{Fe}/\text{H}] = +0.17 \text{ dex}$

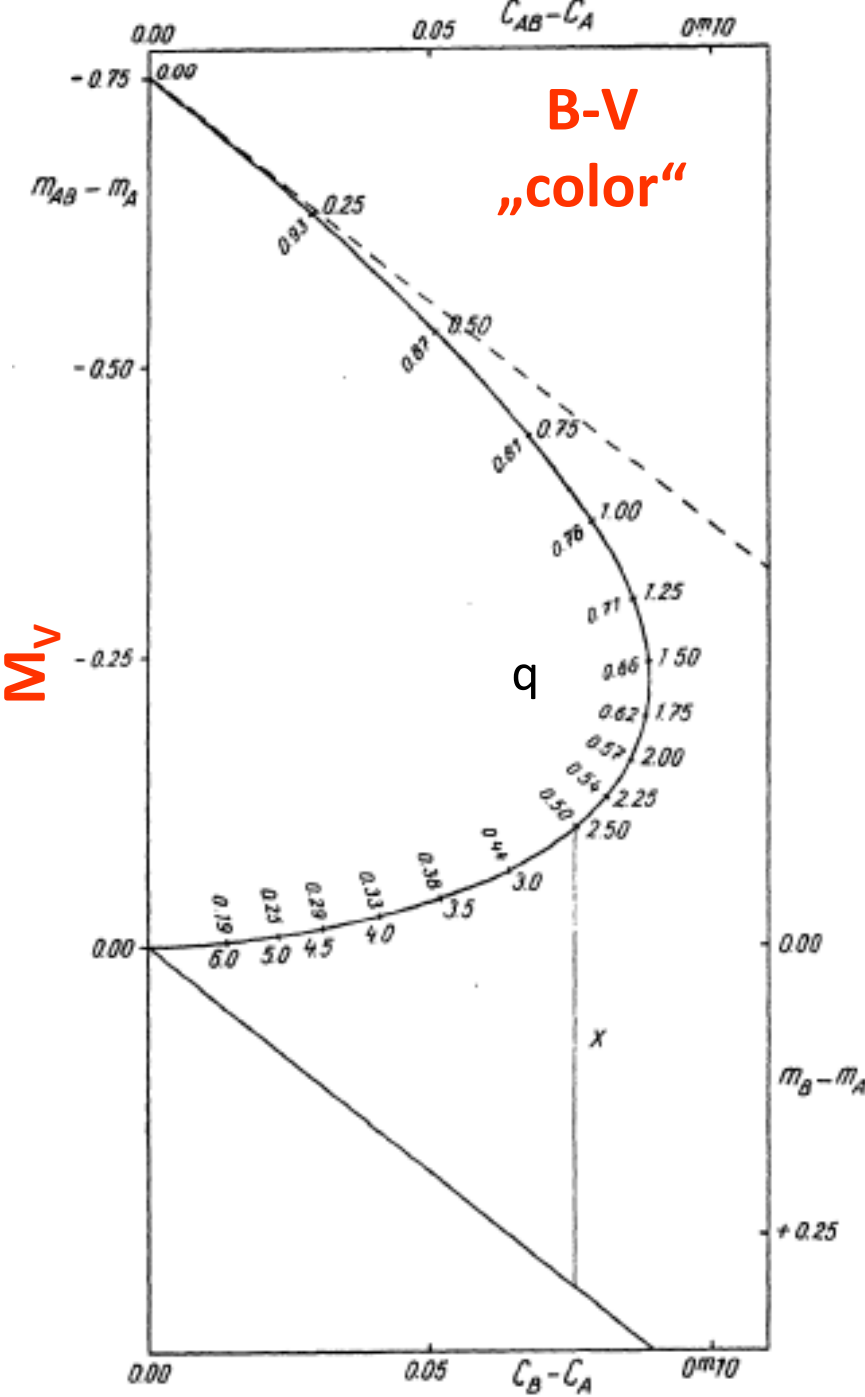


↕ Width of Main Sequence
about 1.8 mag in M_V

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 $L_1 = L_2 \Rightarrow$

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

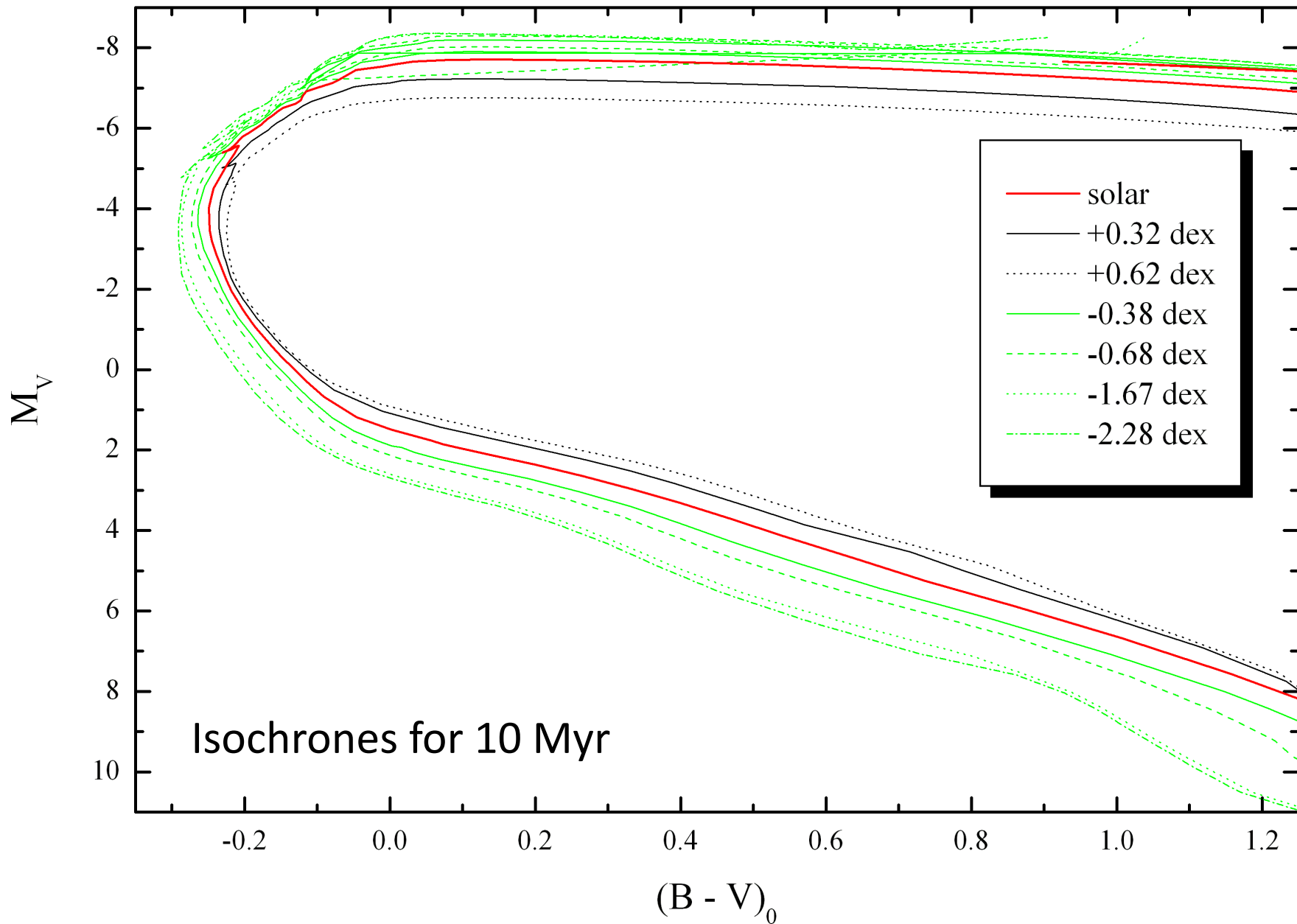
The maximal width of the main sequence due to binary systems is 0.753 mag

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

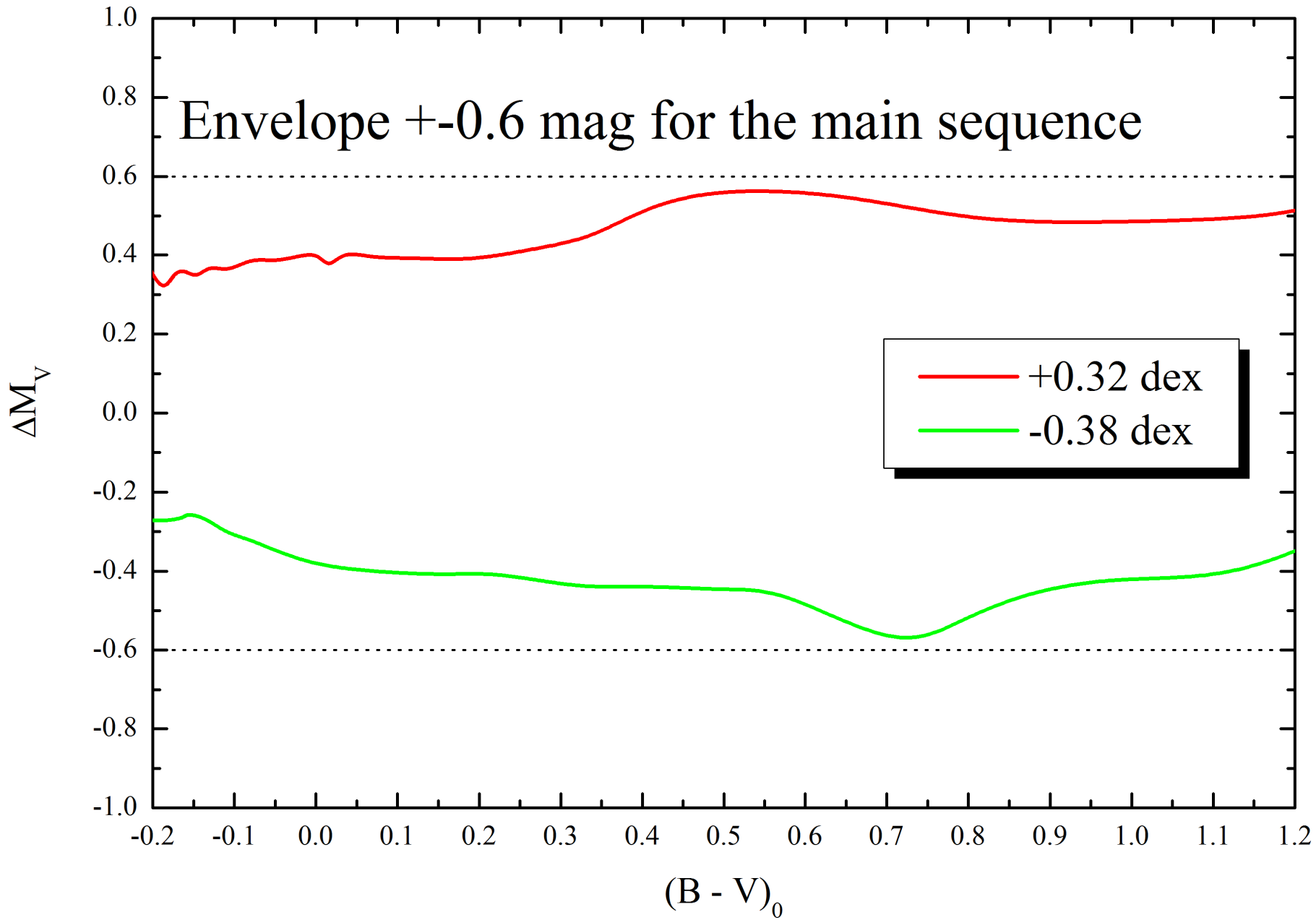
At.N.	Element	"Normal" A-type stars								Solar Abundances
		HD 72846	HD 73345	HD 73450	HD 73574	HD 74028	HD 74050	HD 74587	HD 74718	
3	Li	< -8.08(-; 1)	< -8.33(-; 1)	< -8.70(-; 1)	< -8.38(-; 1)			< -8.41(-; 1)	< -8.26(-; 1)	-10.99
6	C	-3.58(-; 1)	-3.44(12; 3)	-3.27(-; 1)	-3.36(18; 2)	-3.39(08; 2)	-3.52(-; 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_{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	
	ν_{mic}	2.5	2.6	2.7	2.6	2.6	2.6	2.7	2.7	
	$\nu \sin i$	119	85	138	102	150	188	90	155	

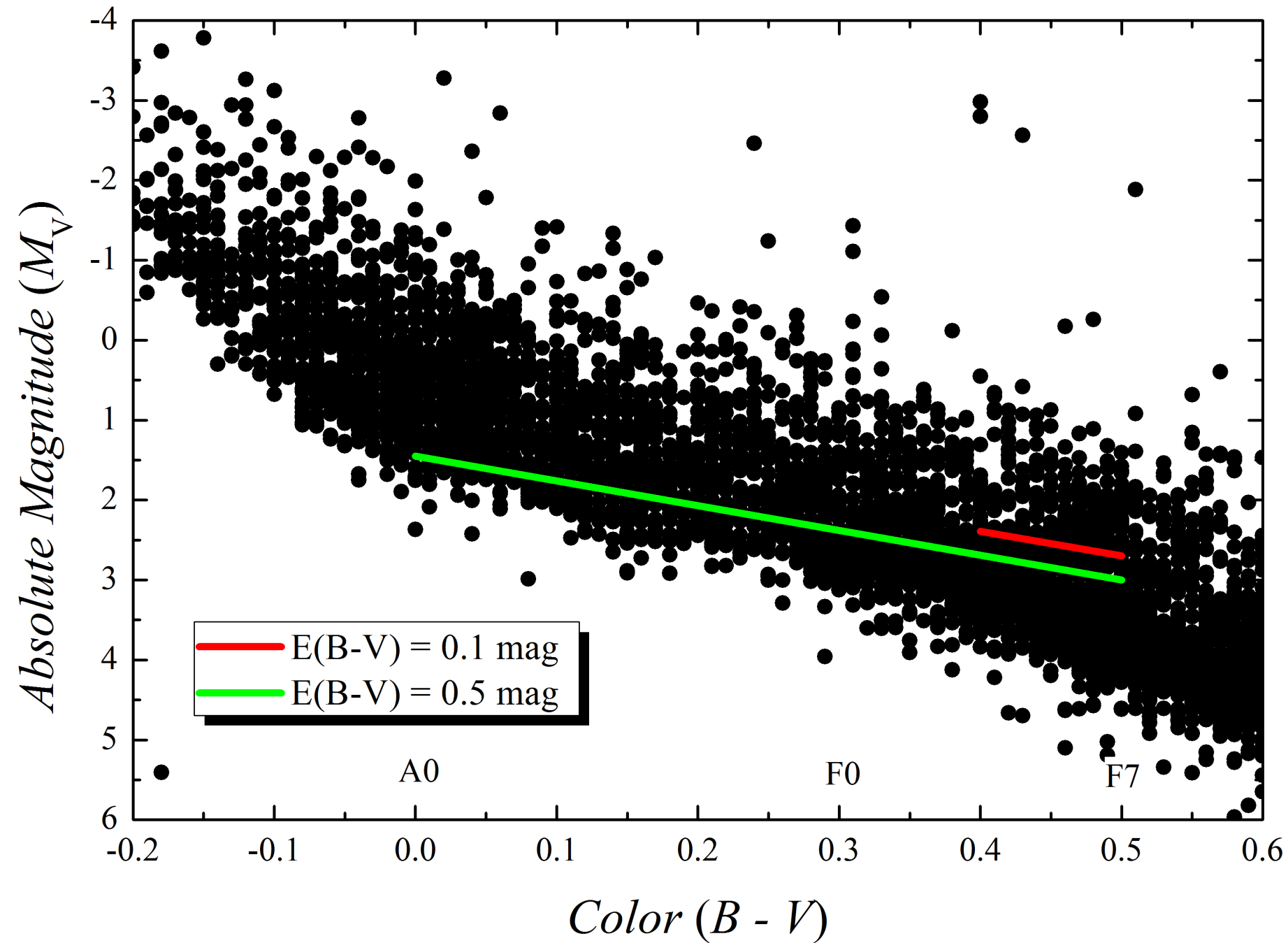
Fe: -4.28 to -4.62dex; 0.34 dex

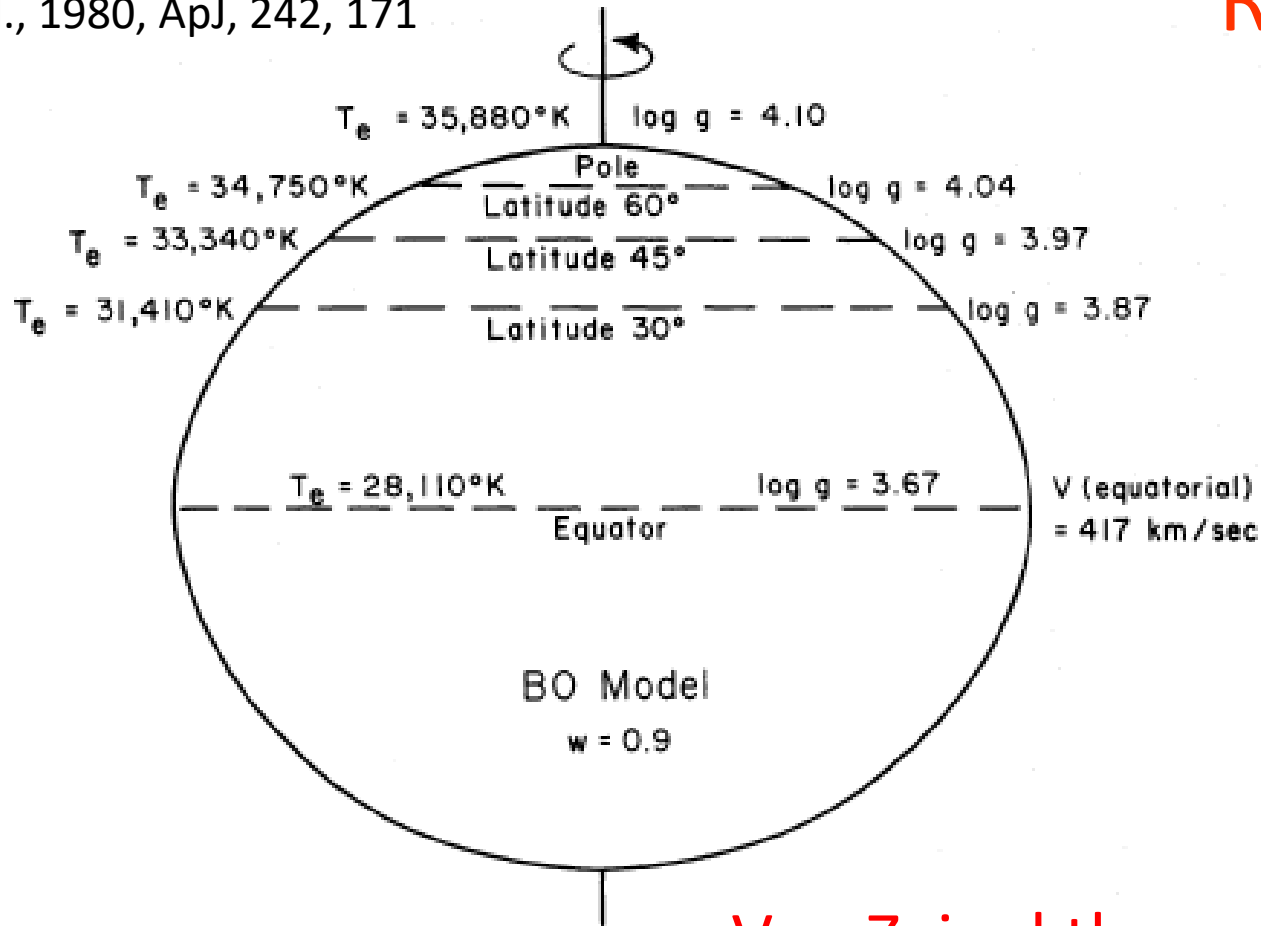
Metallicity => different opacity



Envelope ± 0.6 mag for the main sequence







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

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

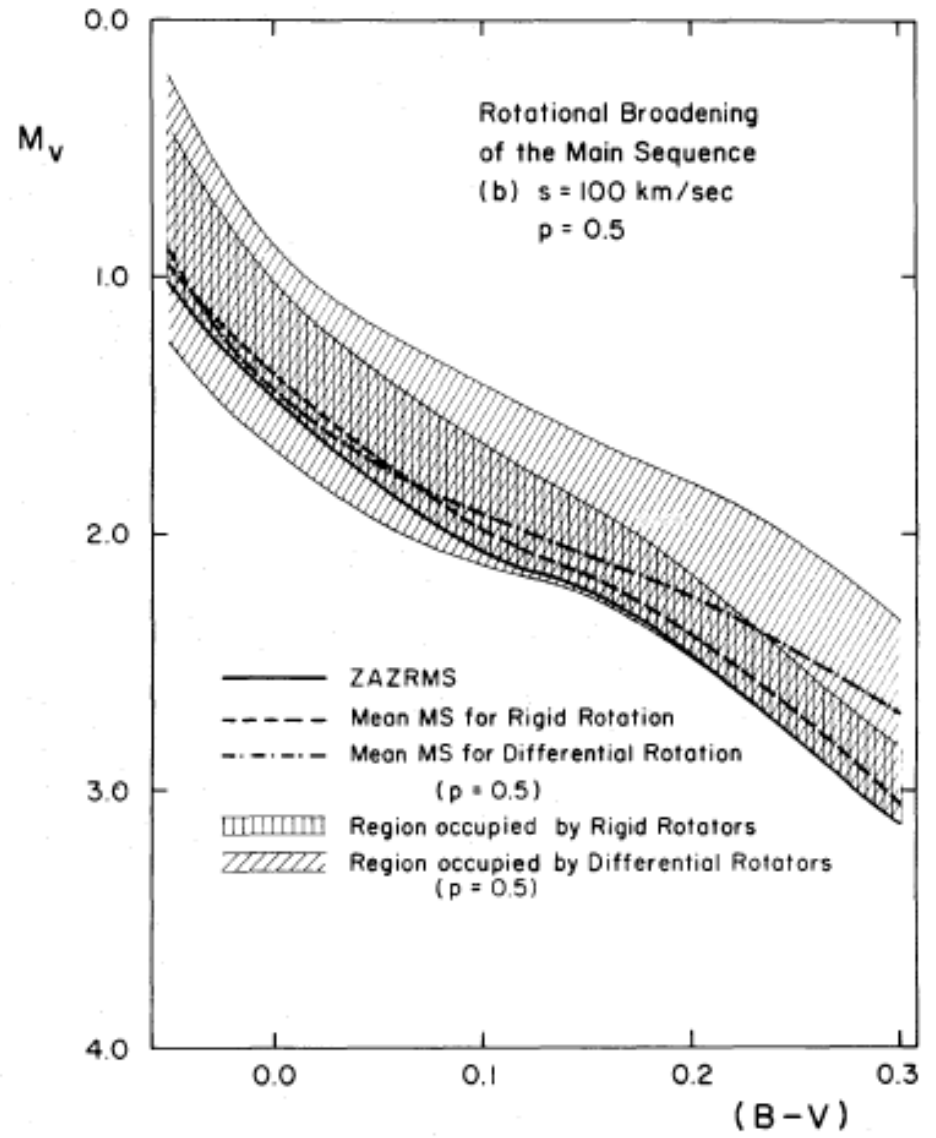
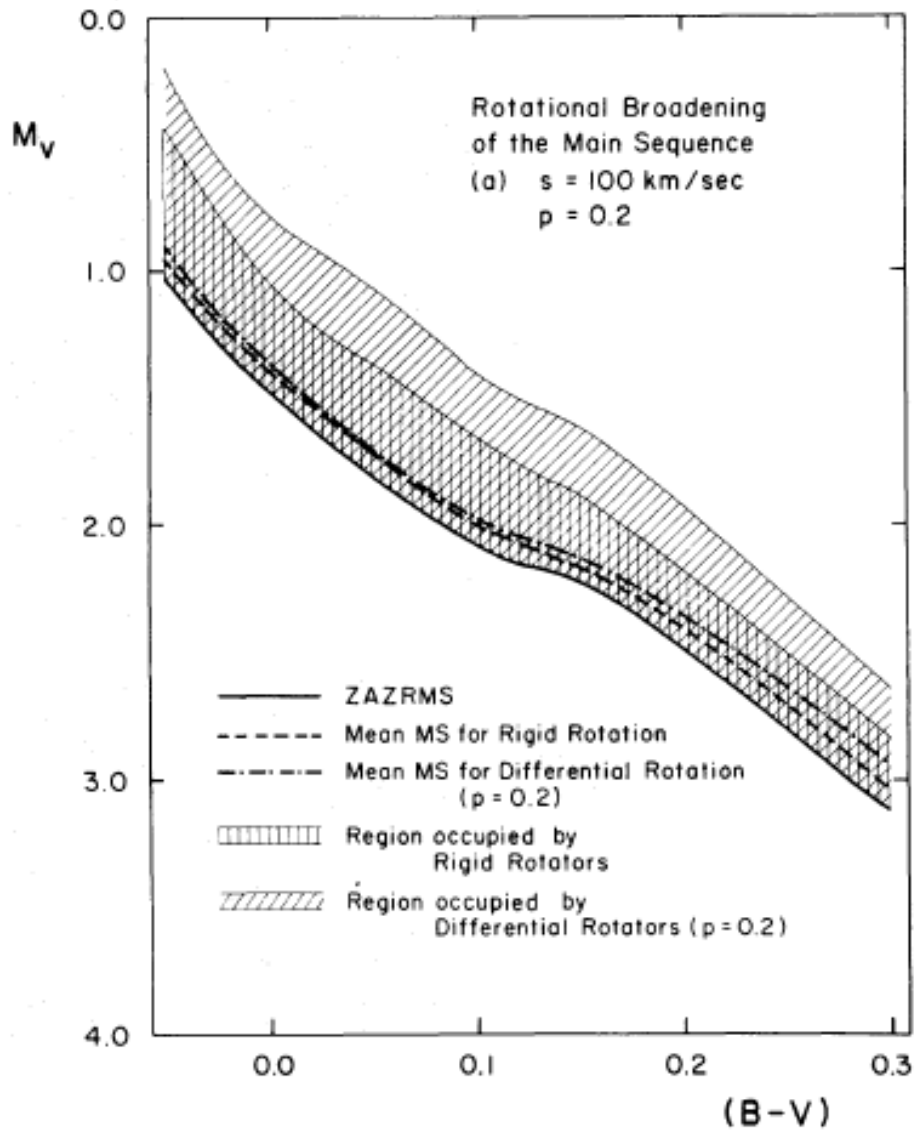
From the rotational velocity $\Rightarrow \epsilon \Rightarrow T_{\text{eff}}$ and L ($\log g$)

Vega

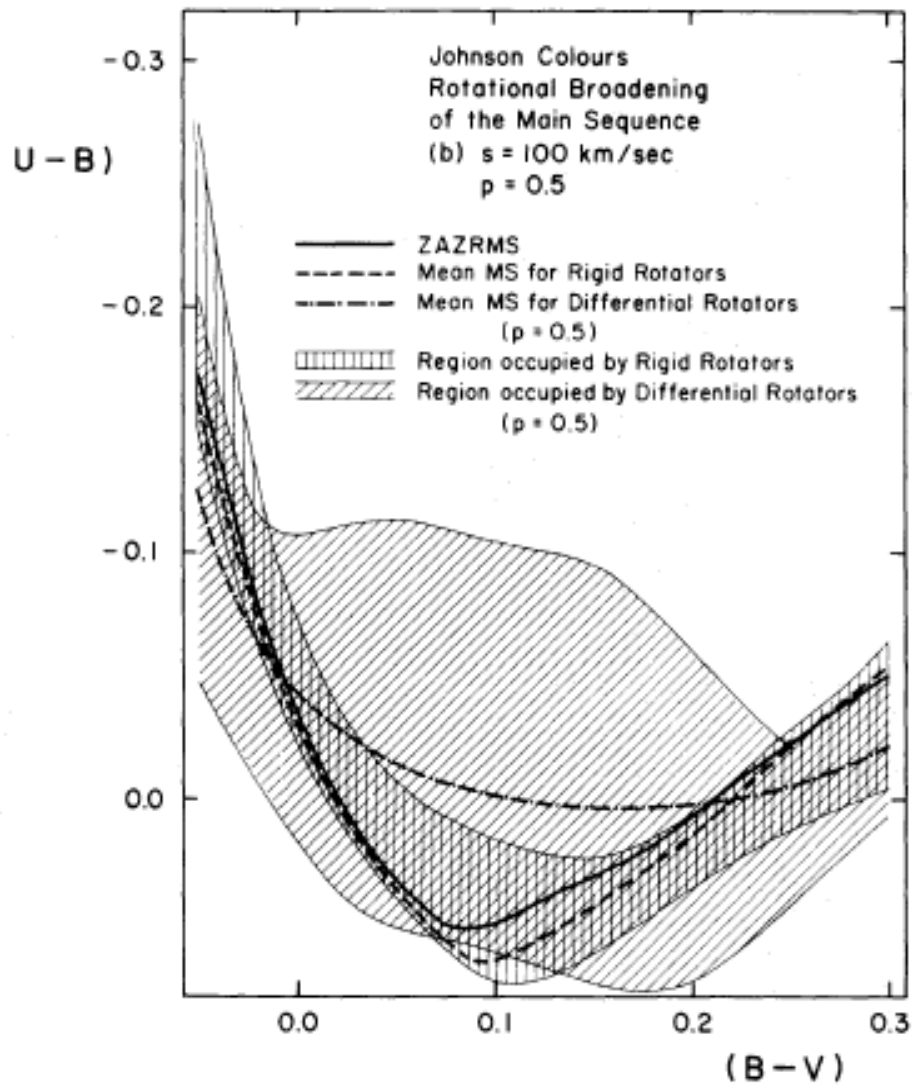
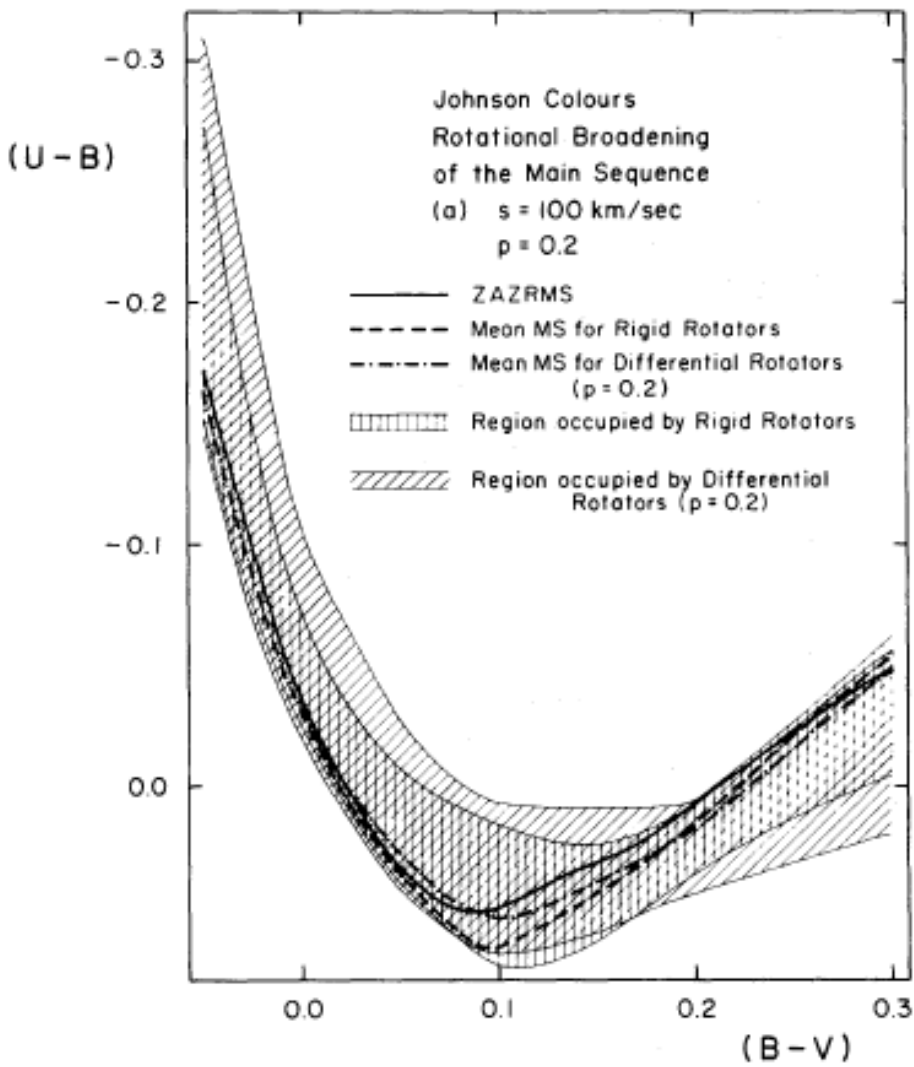
Table 7

A Summary of Physical Parameters for the Pole-on Model

Parameter	Value
Equatorial radius (R_{\odot})	2.75 ± 0.01
Polar radius (R_{\odot})	2.40 ± 0.02
Polar effective temperature (K)	10000 ± 30
Pole-to-equator T_{eff} difference (K)	1410
Mean effective temperature (K)	9560 ± 30
Luminosity (L_{\odot})	44 ± 2
Mass (M_{\odot})	2.4 ± 0.1
Polar surface gravity (cgs, dex)	4.04 ± 0.01
Pole-to-equator $\log g$ difference (cgs, dex)	0.26
Mean surface gravity (cgs, dex)	3.95 ± 0.01
Projected rotational velocity (km s^{-1})	20.8 ± 0.2
Inclination of rotation axis (degrees)	5.7 ± 0.1
Equatorial rotational velocity (km s^{-1})	211 ± 4
Fraction of breakup velocity (km s^{-1})	$0.81 \pm .02$



p ... Degree of differential rotation

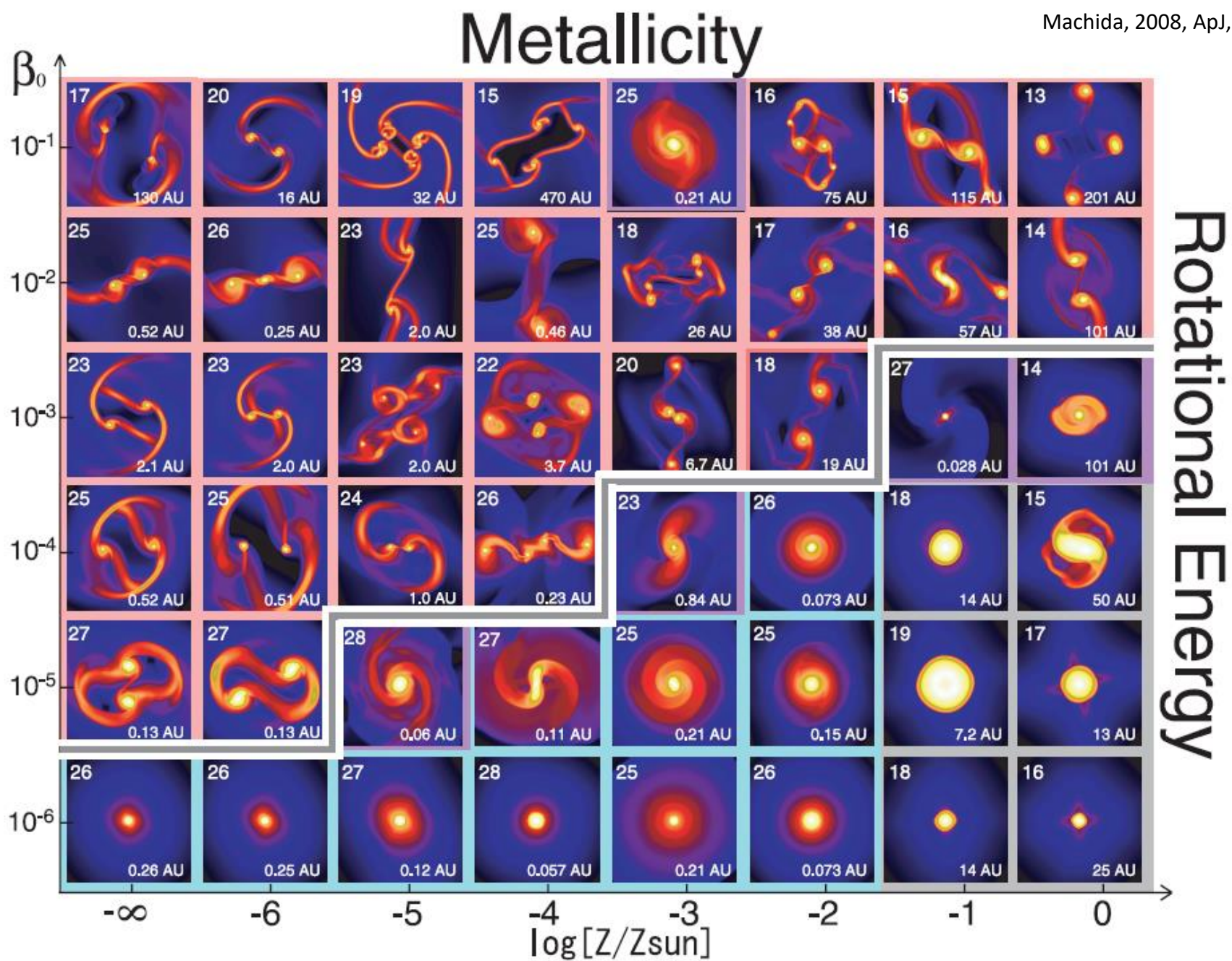


Conclusions – Width of the Main Sequence

- **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 $(B - V)$

Binary fraction

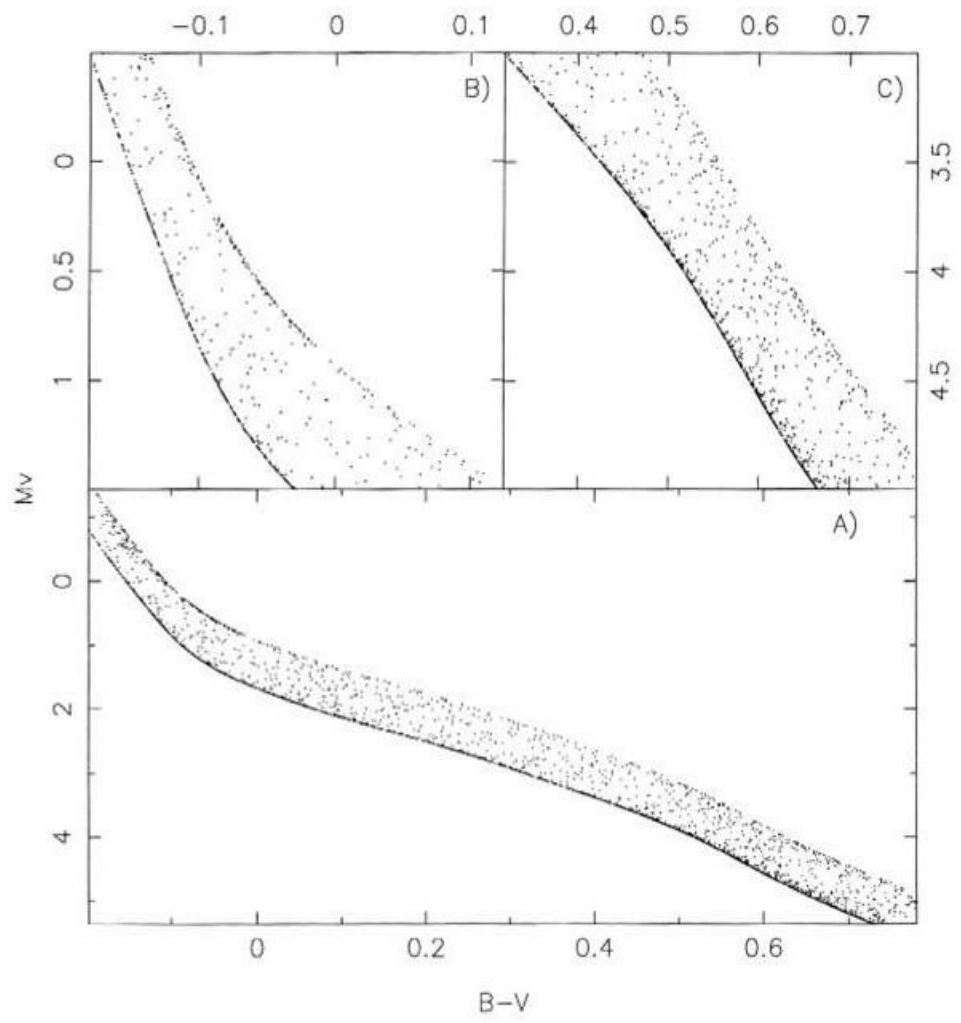
- Important for the formation and evolution of star clusters
- Critical parameter for the IMF
- Needed for N-body numerical simulations
- Observations are biased in many respects
- Many different types of binary systems



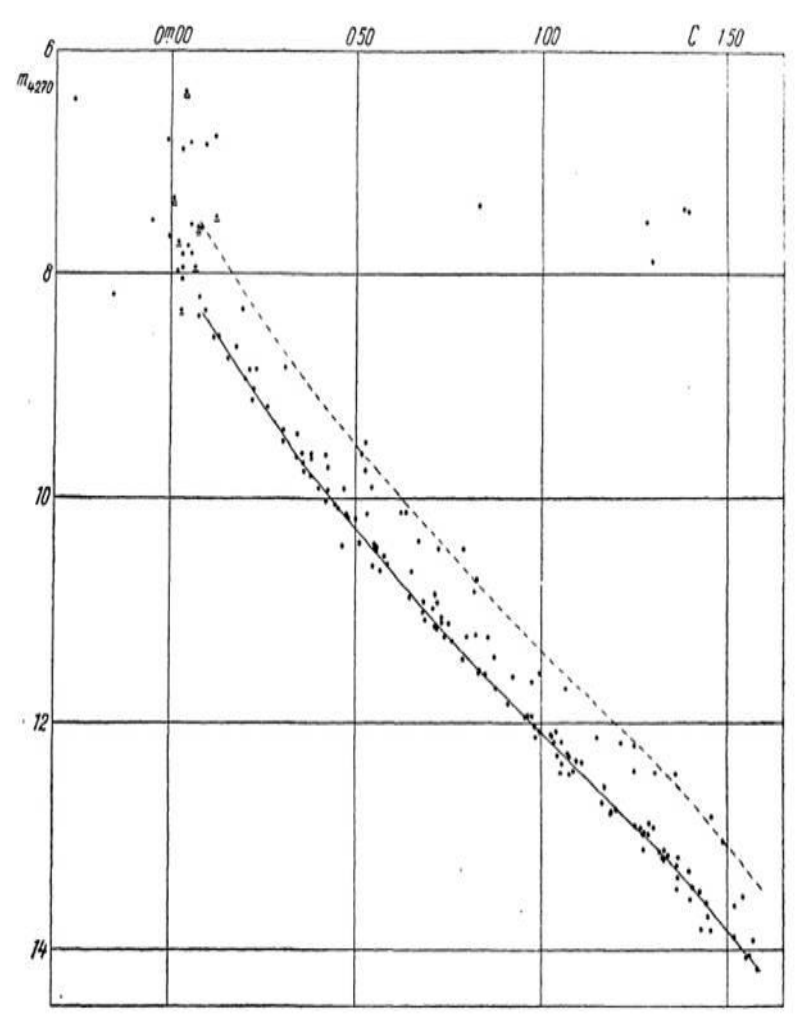
Lower metallicities seem to favour binary formation

How to observe the binary fraction?

- Photometric observations of star clusters
 1. “Cluster main sequence”
 2. Eclipsing binaries
 3. Positions (astrometric binaries)
- Spectroscopic observations
 1. Radial velocity variability
 2. Direct detection in spectrum (SB2)



Simulation with randomly distributed mass ratios



Observations of Praesepe with known binary systems

Observed binaries with the Gaia DR2

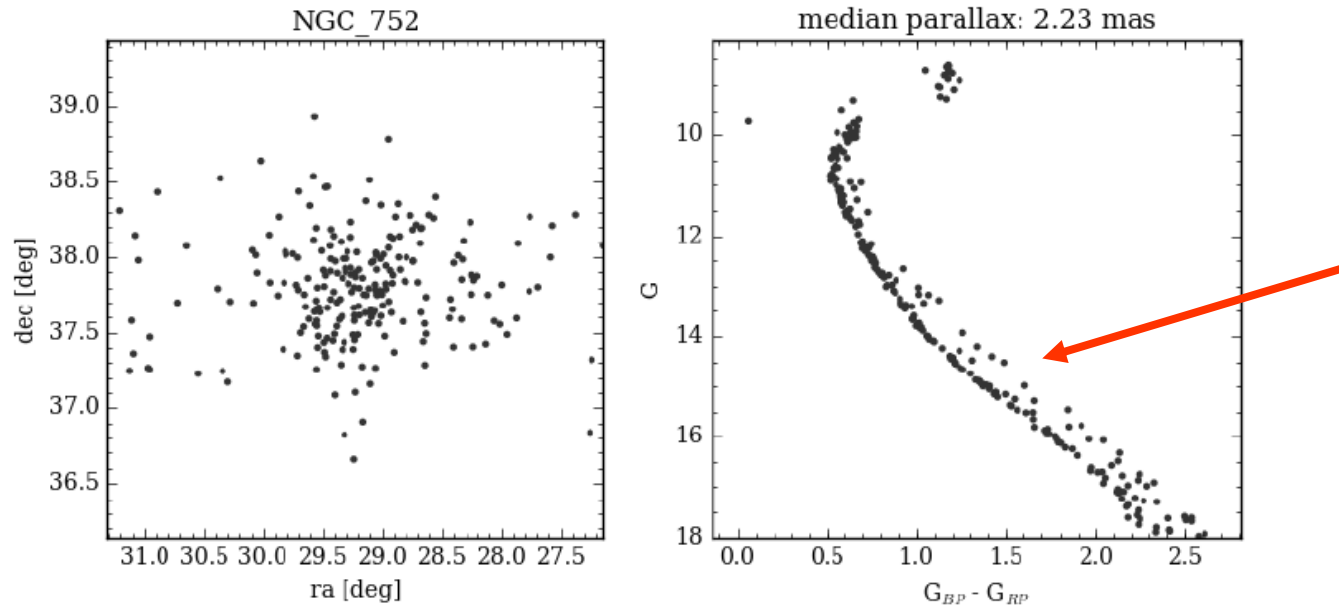


Fig. A.11. Left: distribution of the probable members of NGC 752. Right: colour-magnitude diagram of the probable members.

Observed binaries with the Gaia DR2

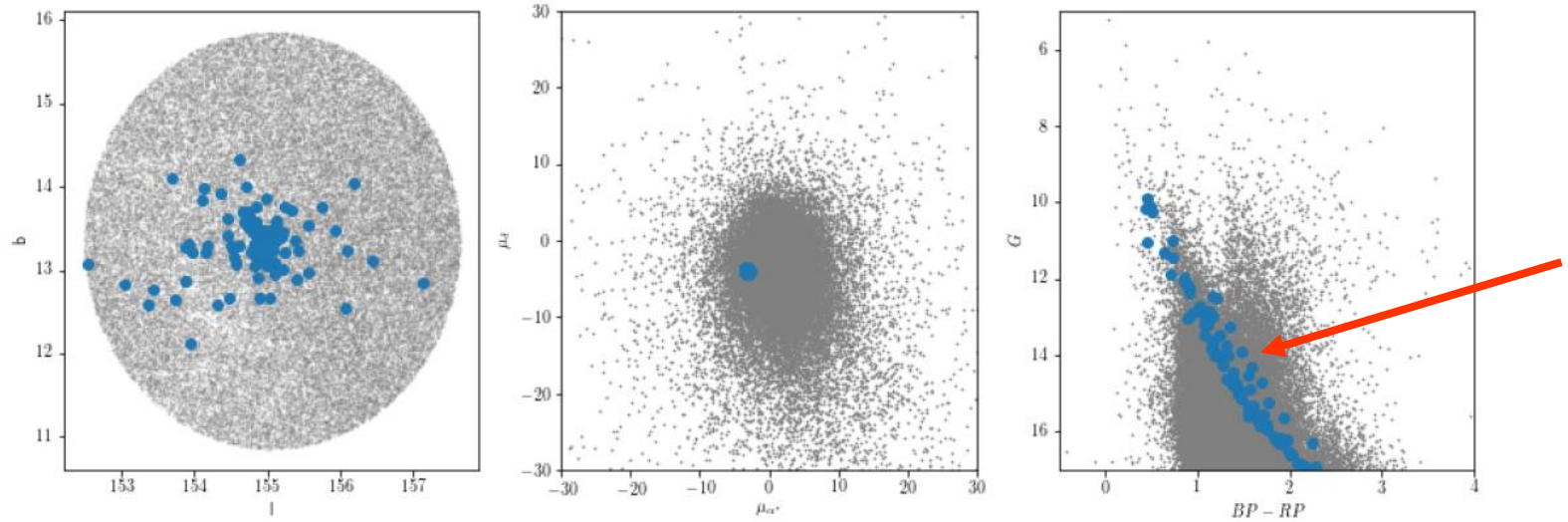
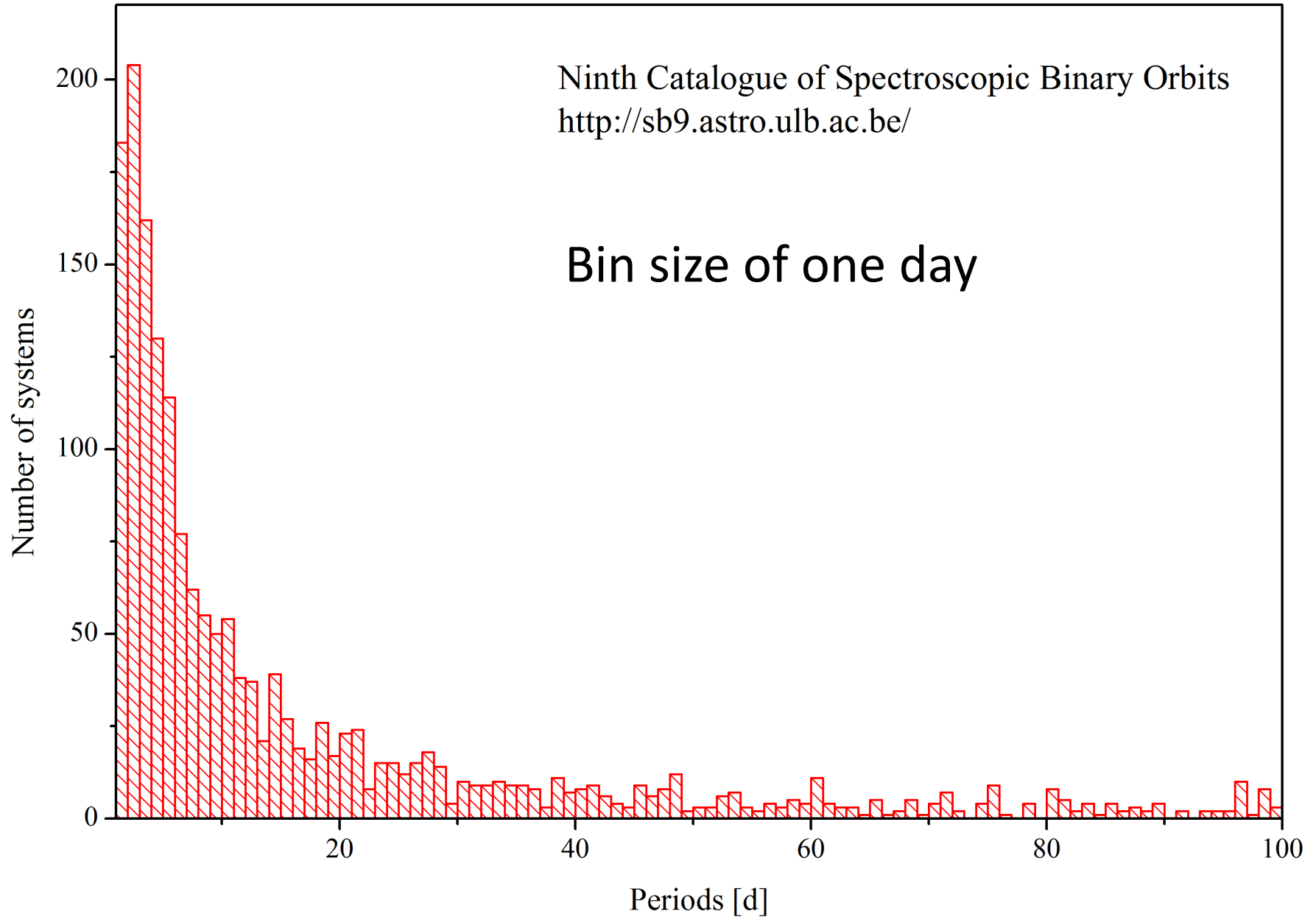


Fig. A.8: Member stars (blue) together with field stars (grey) for UBC8 in (l, b) (left) and in proper motion space (middle). The Color-Magnitude Diagram shows the sequence of the identified members (outlining an empirical isochrone) (right).

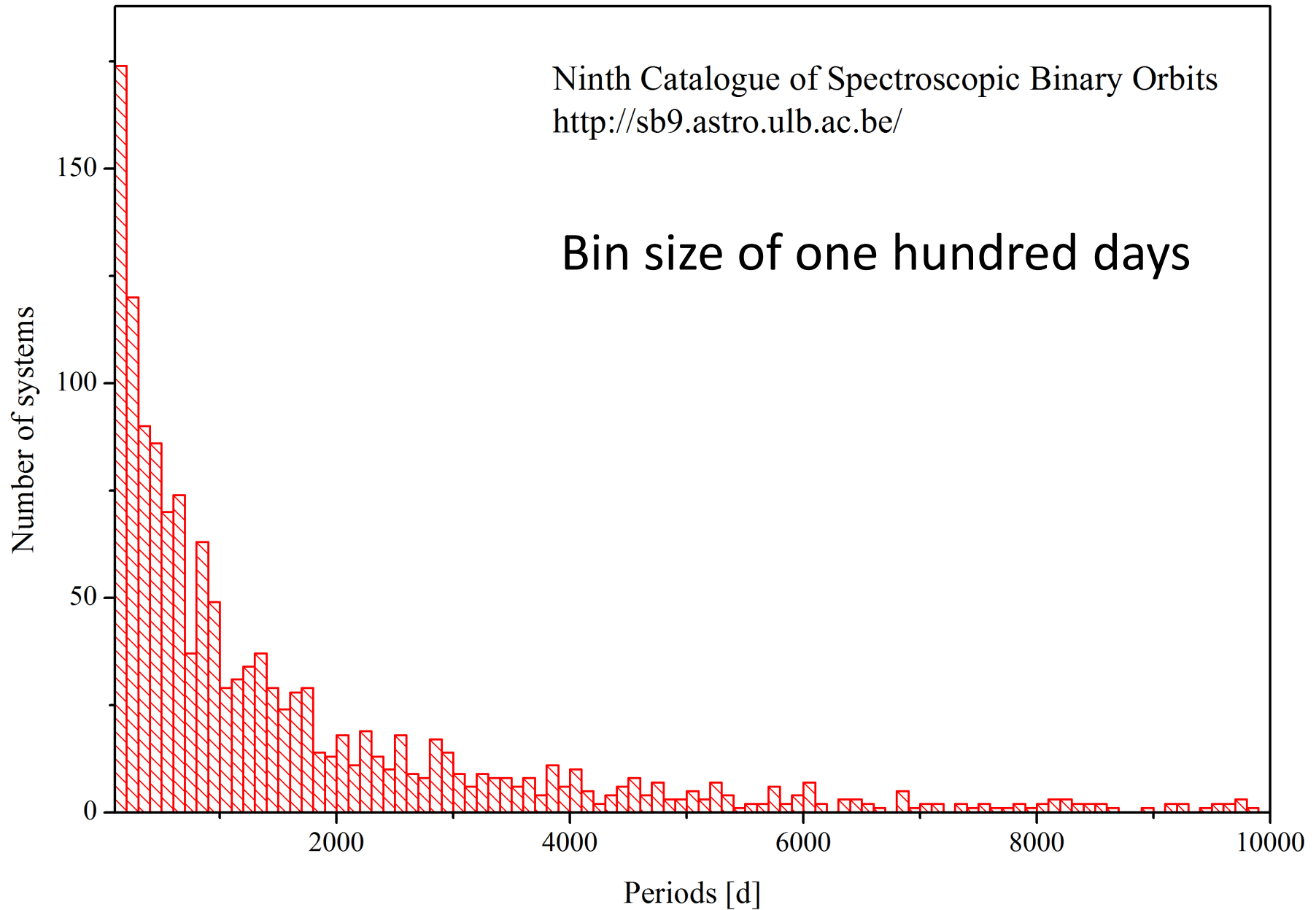
Ninth Catalogue of Spectroscopic Binary Orbits
<http://sb9.astro.ulb.ac.be/>

Bin size of one day



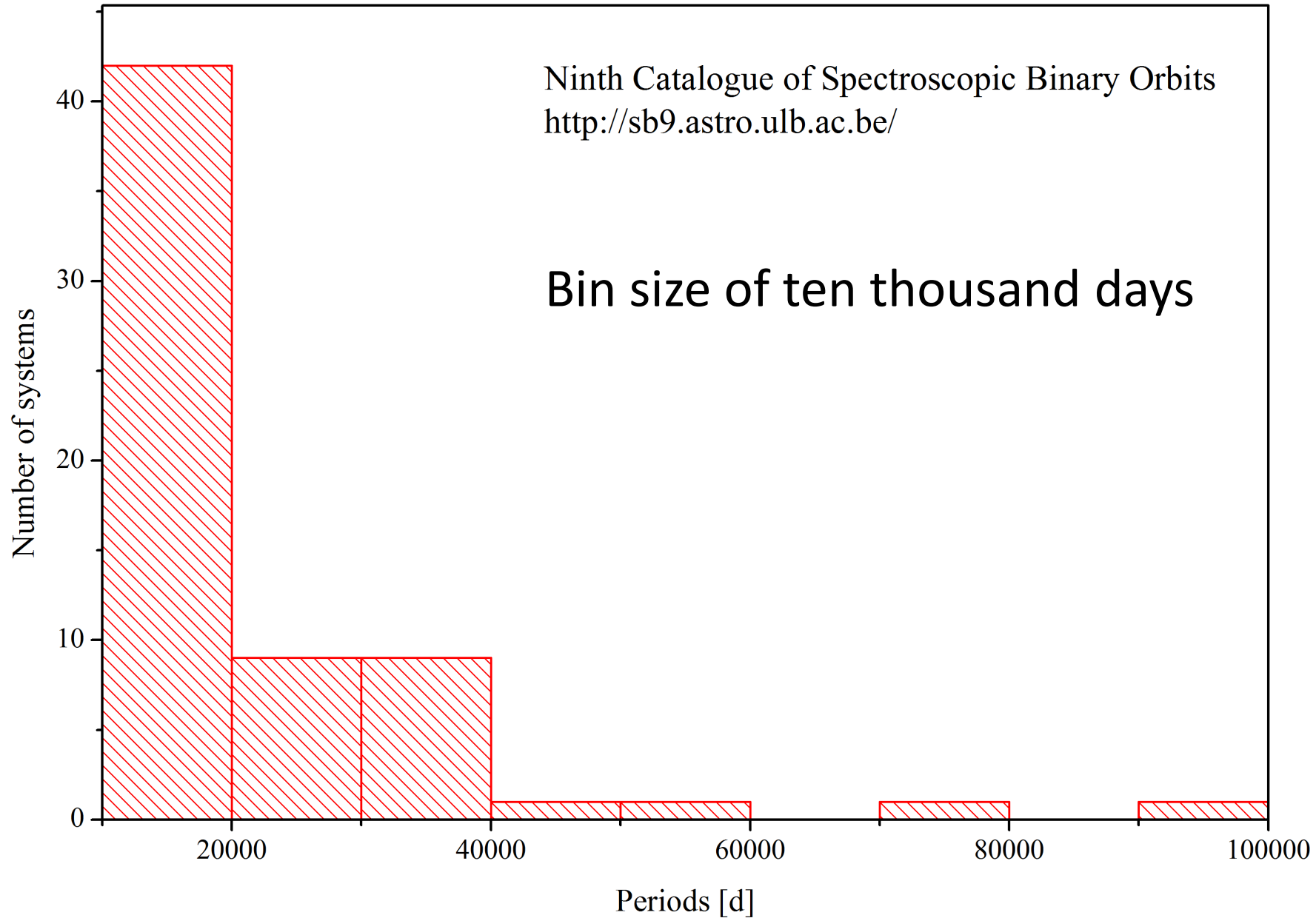
Ninth Catalogue of Spectroscopic Binary Orbits
<http://sb9.astro.ulb.ac.be/>

Bin size of one hundred days



Ninth Catalogue of Spectroscopic Binary Orbits
<http://sb9.astro.ulb.ac.be/>

Bin size of ten thousand days



Results for open clusters

- Sollima et al., 2010, MNRAS, 401, 577
 - NGC 188 (9.63): 21 – 58%
 - NGC 2204 (9.20): 12 – 36%
 - NGC 2243 (9.58): 34 – 70%
 - NGC 2420 (9.08): 17 – 51%
 - NGC 2516 (8.52): 25 – 66%
- Sana et al., 2009, MNRAS, 400, 1479
 - NGC 6611 (6.50): 44 – 67%
- Sana et al., 2008, MNRAS, 386, 447
 - NGC 6231 (6.50): 63% - ?
- Bica & Bonatto, 2005, A&A, 431, 943
 - IC 4651 (9.26): 50 +- 11%
 - NGC 2287 (8.20): 48 +- 45%
 - NGC 2447 (8.60): 21 +- 9%
 - NGC 2548 (8.56): 48 +- 23%
 - NGC 2682 (9.51): 39 +- 16%
 - NGC 3680 (9.20): 25 +- 5%
 - NGC 5822 (9.00): 16 +- 8%
 - NGC 6208 (9.11): 54 +- 30%
 - NGC 6694 (7.85): 18 +- 12%
- Sandhu et al., 2003, A&A, 408, 515
 - NGC 2099 (8.60): ~30%
 - King 5 (9.00): ~30%
 - King 7 (8.80): ~20%

	f		Globular clusters
NGC 288	0.15 ± 0.05 >0.06	M3	
NGC 362	0.21 ± 0.06		0.14 ± 0.08
NGC 2808		M4	$0.23^{+0.34}_{-0.23}$
NGC 3201		M15	~ 0.07
NGC 4590	>0.09	M22	
NGC 5053	>0.08	M30	
NGC 5466	>0.08	M55	>0.06
NGC 5897	>0.07	M71	$0.22^{+0.26}_{-0.12}$
NGC 6101	>0.09	M92	
NGC 6362	>0.06	Arp 2	>0.08
NGC 6397	<0.07	Terzan 7	>0.21
NGC 6723	>0.06	Palmoar 12	>0.18
NGC 6752	0.27 ± 0.12	Palmoar 13	0.30 ± 0.04
NGC 6792		47 Tucane	0.14 ± 0.04
NGC 6981	>0.10		