[Fe/H] AND [α/Fe] IN GLOBULAR CLUSTERS STARS IN A HOMOGENEOUS SCALE

SEARCH FOR MULTIPLE POPULATIONS

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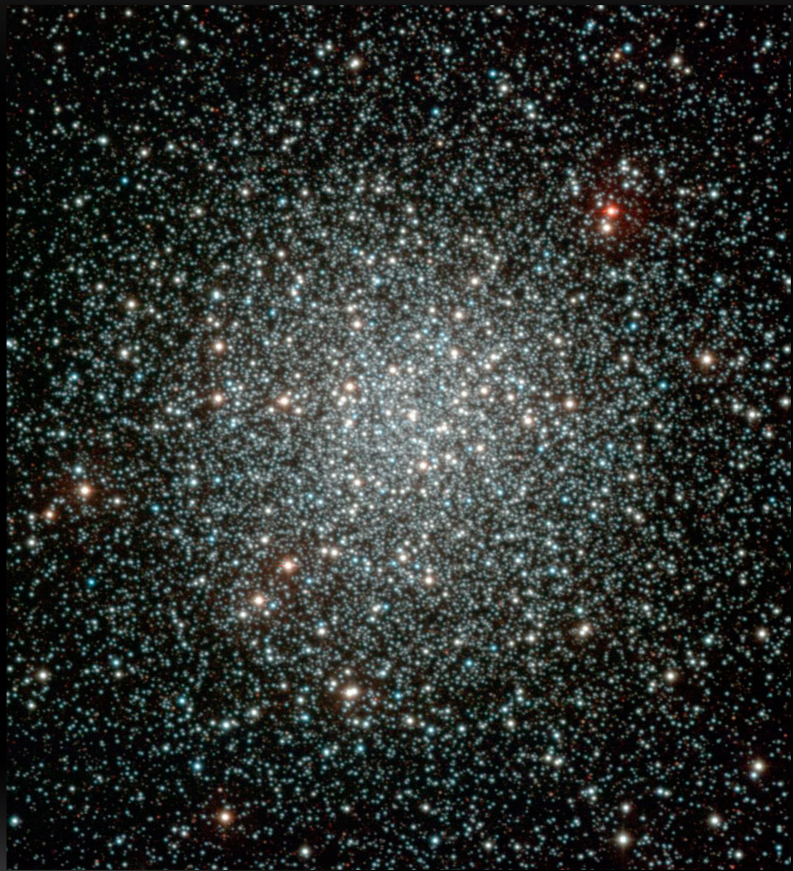
Why to study globular clusters in the Milky Way?

MOTIVATION

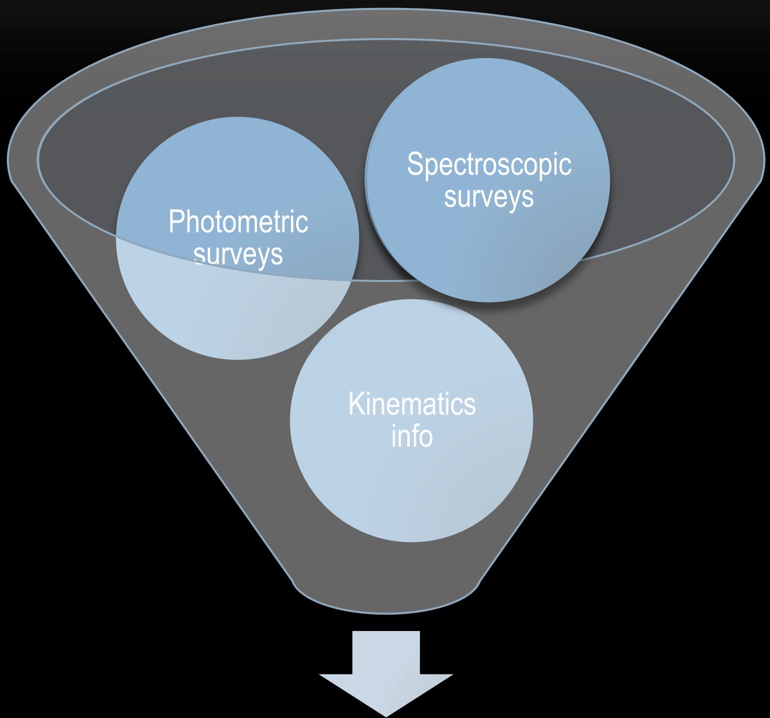
MOTIVATION

Globular Clusters tell us about:

- Star formation history of the host galaxy;
- Galaxy formation scenarios;
- Chemical evolution of the host galaxy;
- Dynamical evolution and interactions;
- Etc etc



MOTIVATION



Knowledge from GCs

MOTIVATION

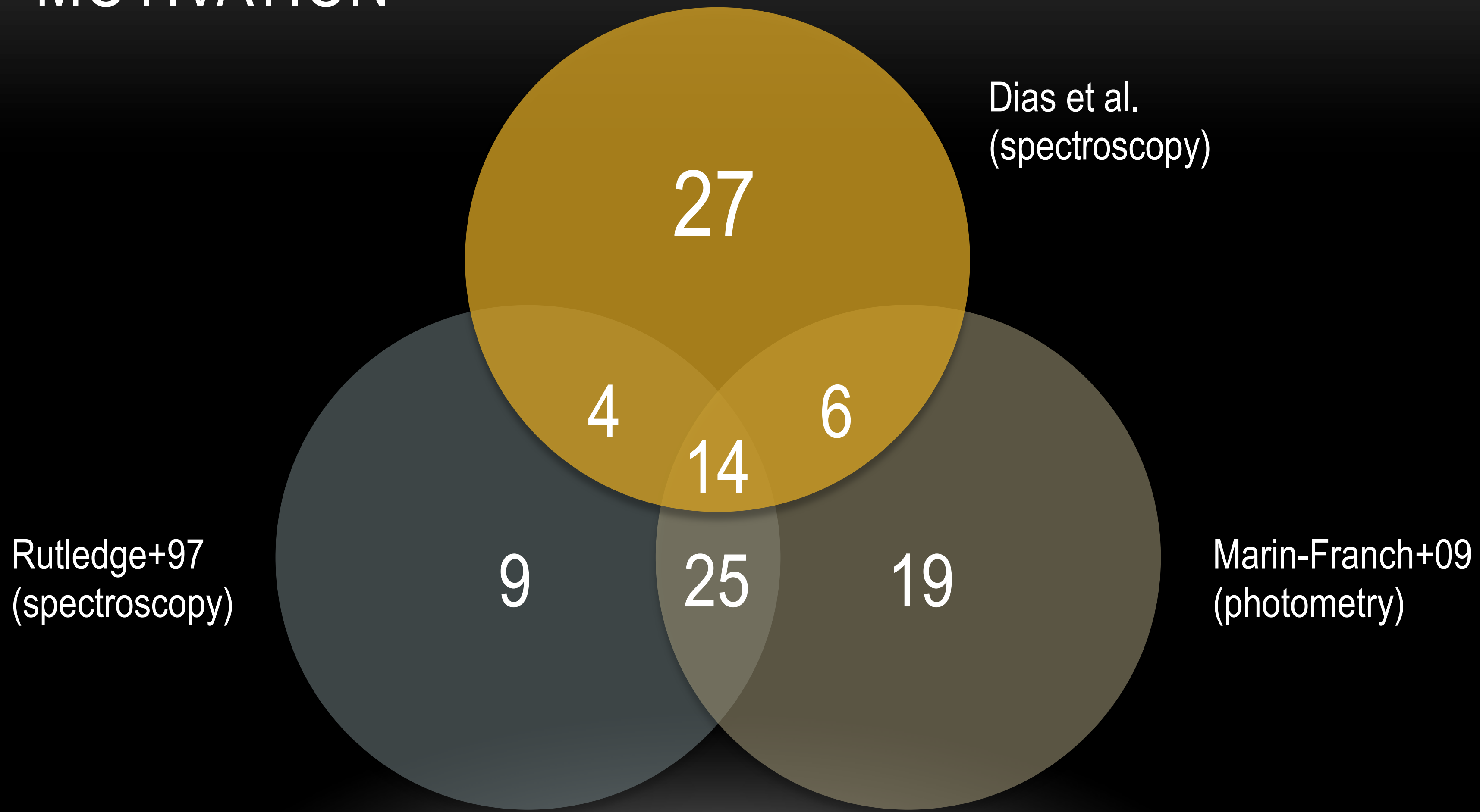
Rutledge+97
(spectroscopy)

52

MOTIVATION


Rutledge+97
(spectroscopy)
13
39
25
Marin-Franch+09
(photometry)

MOTIVATION

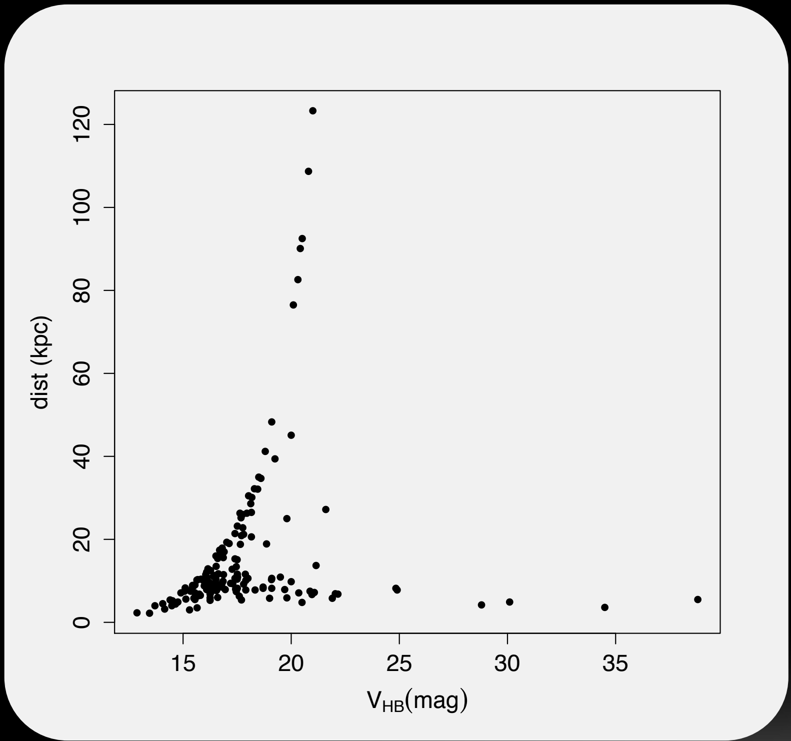

Dias et al.
(spectroscopy)
27
4
6
14
Rutledge+97
(spectroscopy)
9
25
19
Marin-Franch+09
(photometry)

How did we selected the clusters?

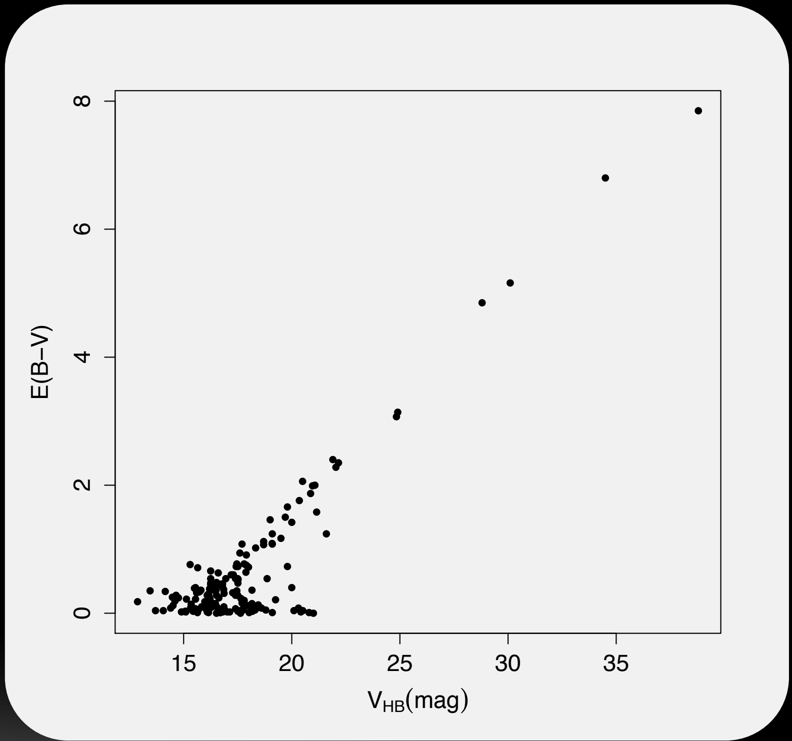
THE SAMPLE

THE SAMPLE

Distances – Harris catalog

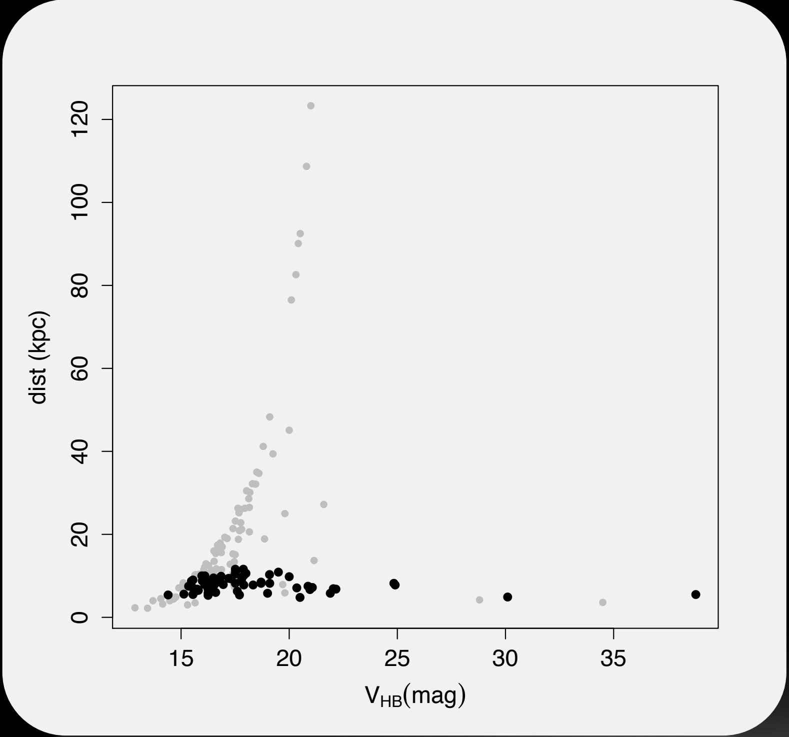


Reddening – Harris catalog

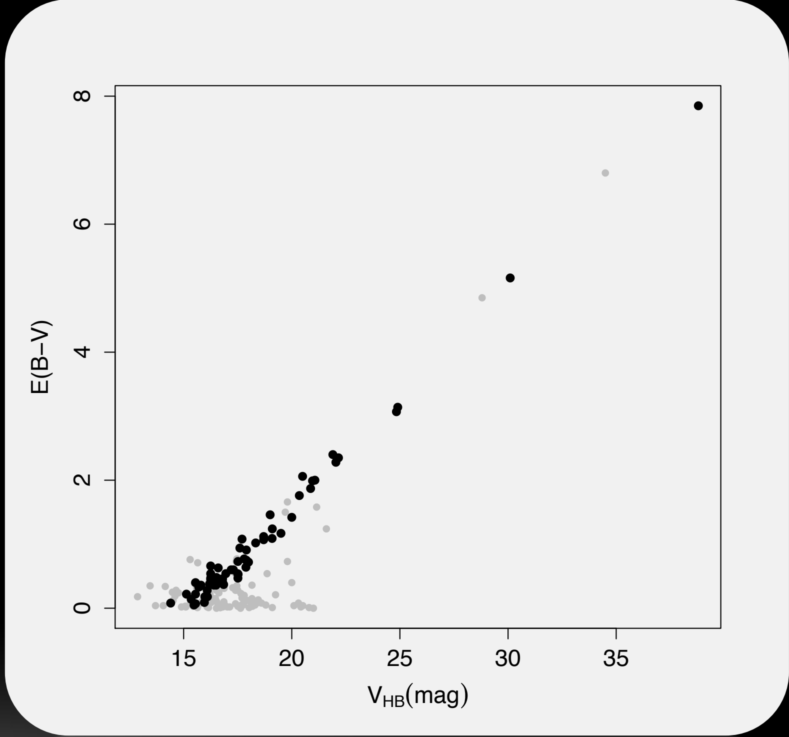


THE SAMPLE

Distances – Harris catalog: BULGE

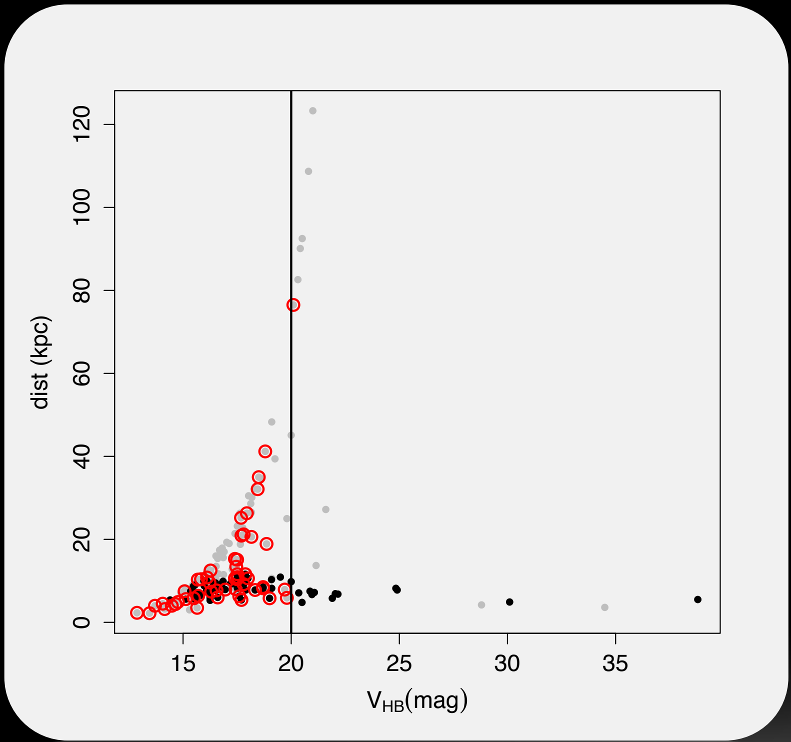


Reddening – Harris catalog: BULGE

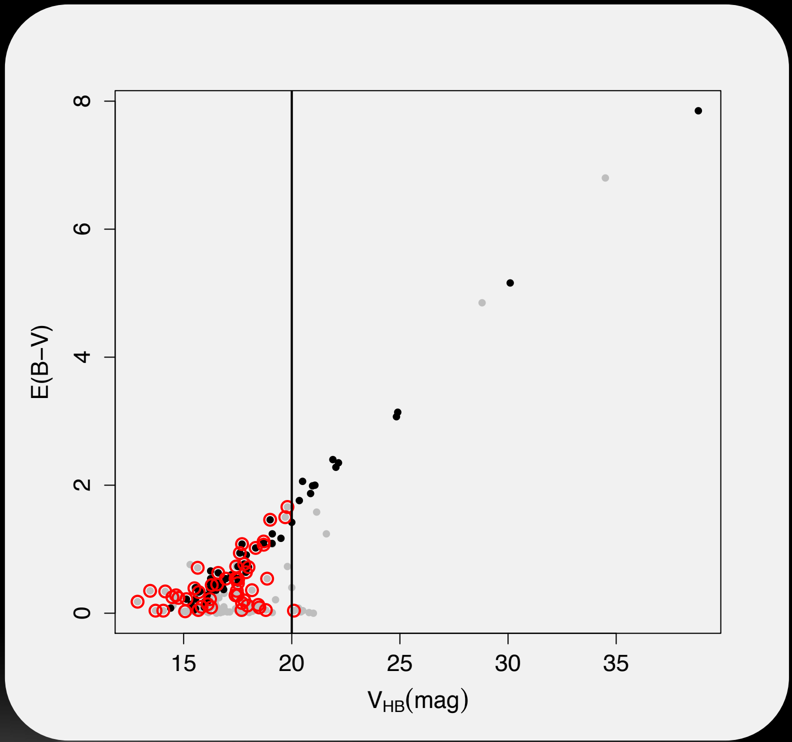


THE SAMPLE – SELECTED CLUSTERS

Distances – Harris catalog

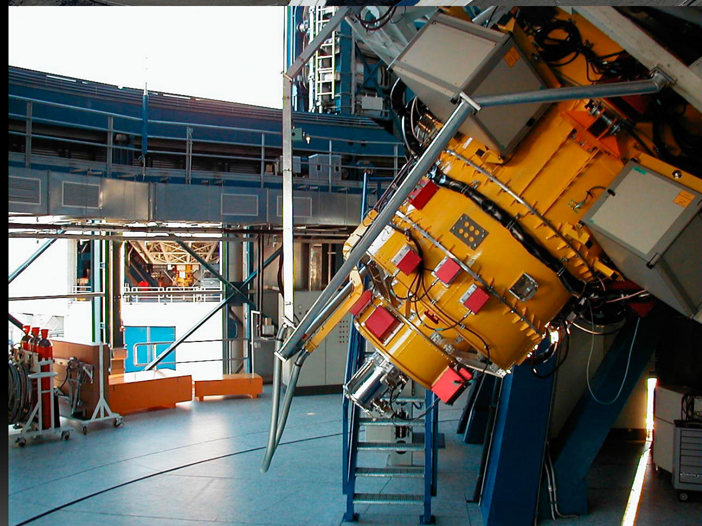


Reddening – Harris catalog



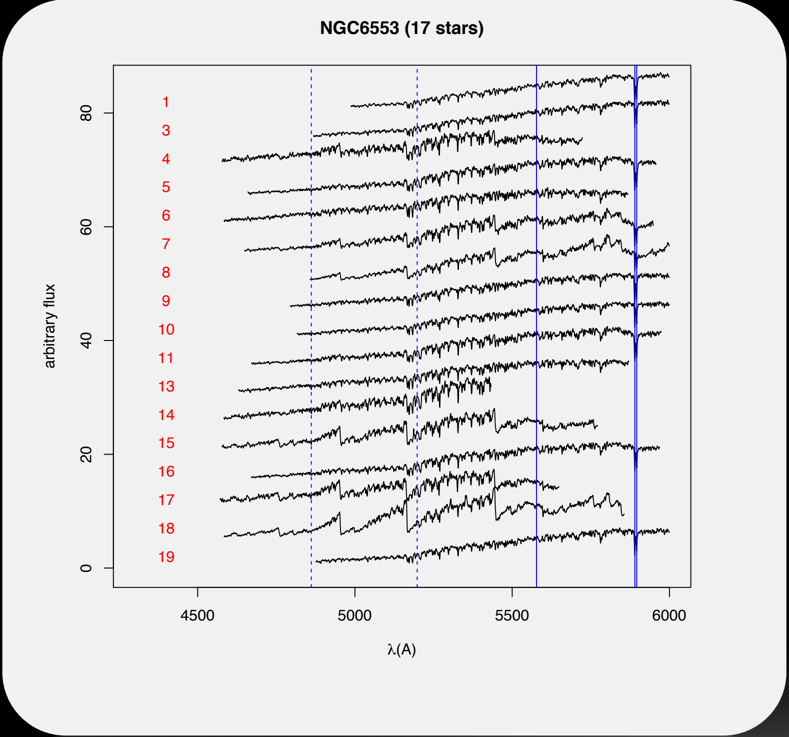
OBSERVATIONS

- 51 clusters @ FORS2/VLT - ESO:
  - 2001, 2002, 2003, 2006, 2012
- Wavelength range: 4800 – 5600 A
- Resolution: R ~ 2000
- RGB stars
- ~20 stars per cluster

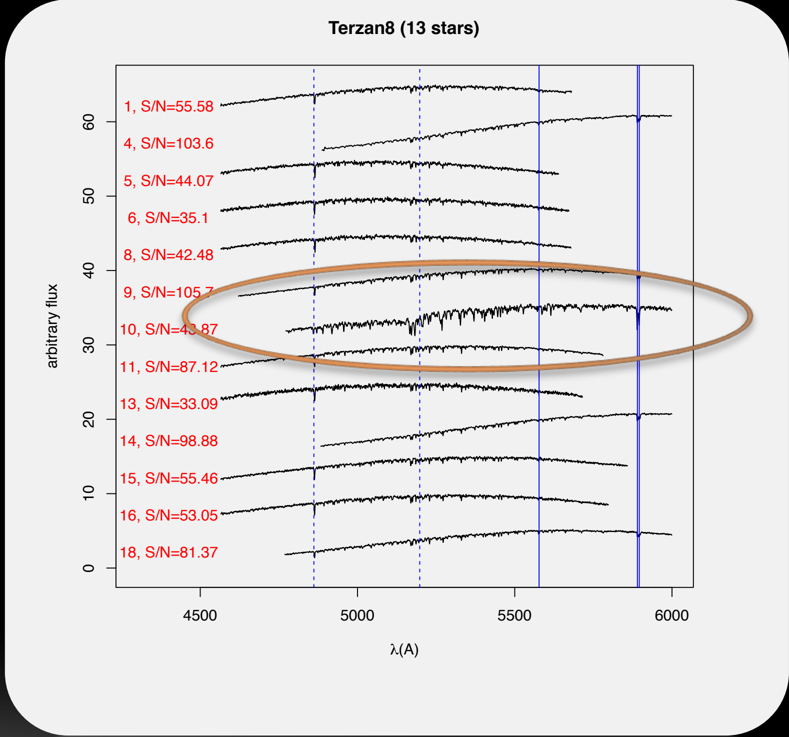


OBSERVATIONS

Metal-rich @ Bulge



Metal-poor @ Halo



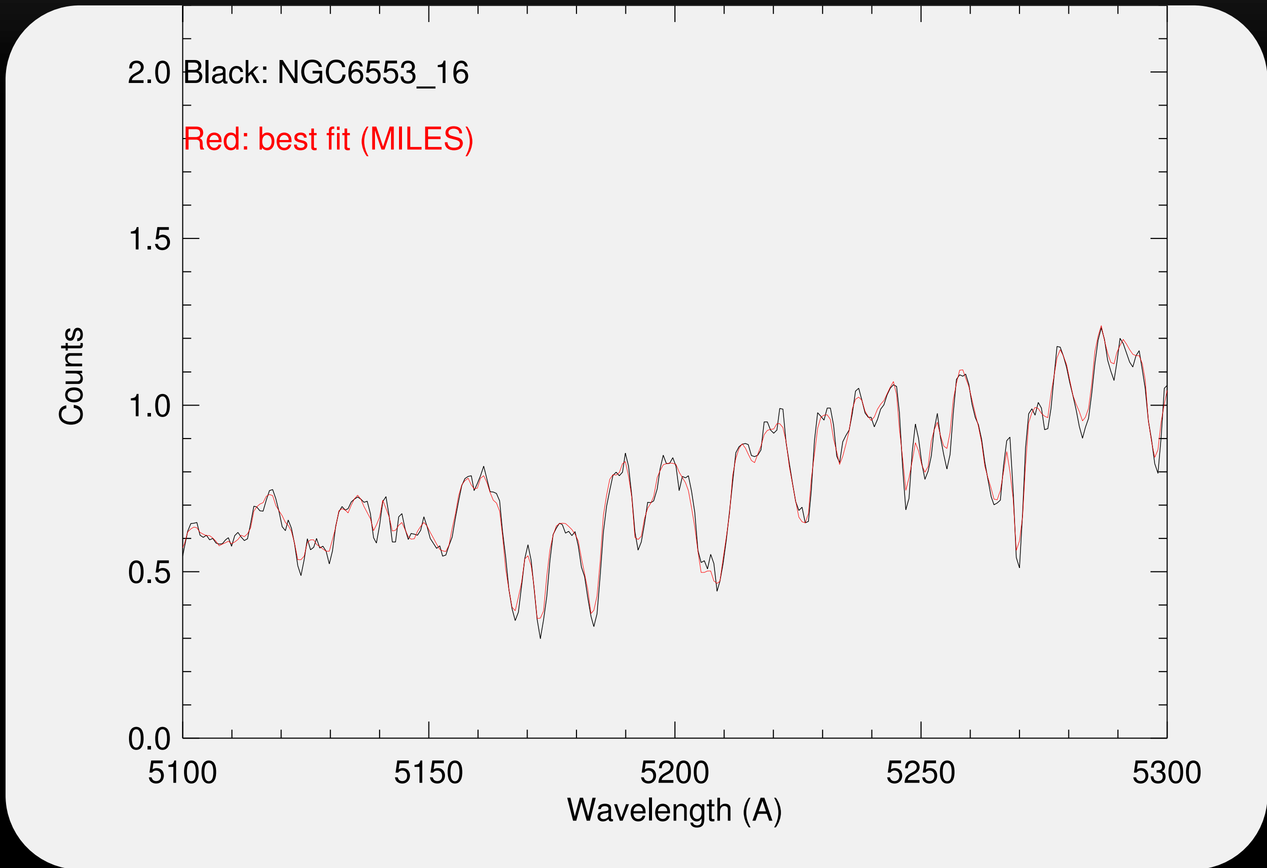
Using full spectrum fitting to derive T_{eff}, log(g), [Fe/H], [Mg/Fe]

METHOD

FULL SPECTRUM FITTING

- ETOILE code, by D. Katz (2001, 2011)
- Observed or synthetic stellar library: MILES, Coelho+05, …
- Pixel-by-pixel fitting ➔ χ^2 of the fit to each library spectrum
- Results on T_{eff}, log(g), [Fe/H], [Mg/Fe] ➔ weighted average of the library spectra param.
- Degeneracy T_{eff} - [Fe/H] ➔ color-T_{eff} relation

FULL SPECTRUM FITTING – NGC6553

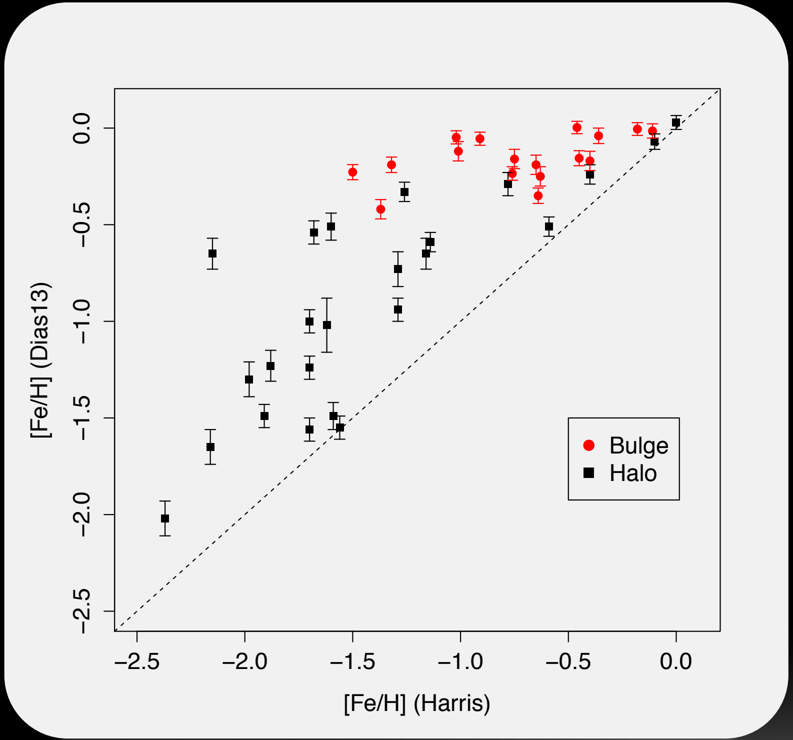


What can we extract from low-resolution spectroscopy?

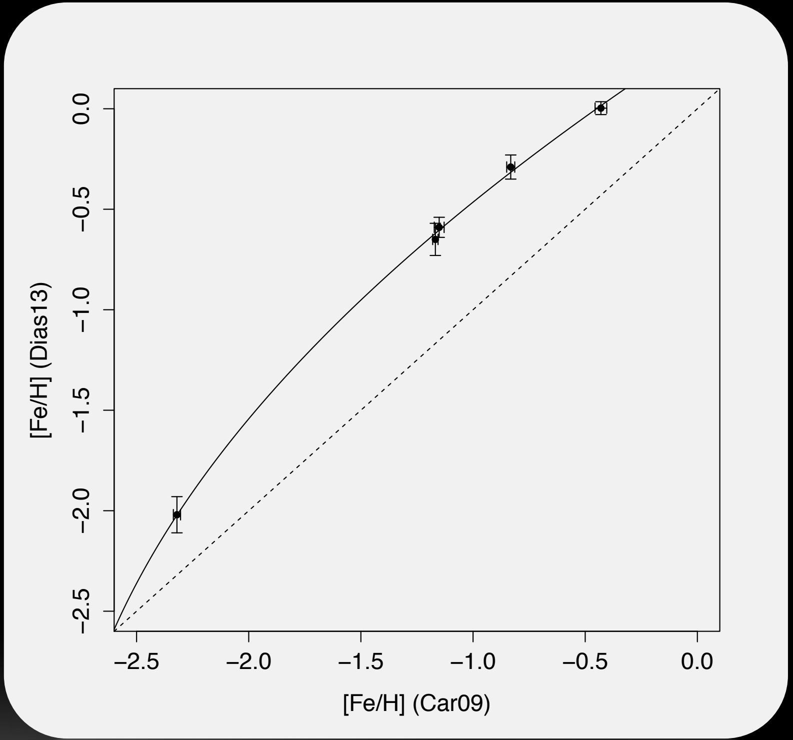
RESULTS

[Fe/H] – LITERATURE: SCALING TO CARRETTA+09

Unscaled metallicities

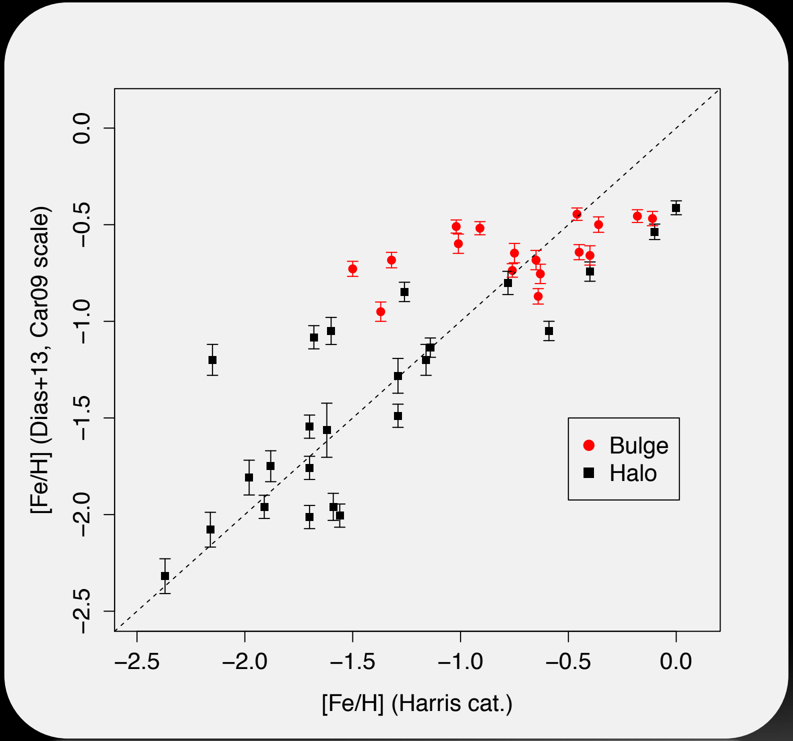


Carretta+09 – UVES results

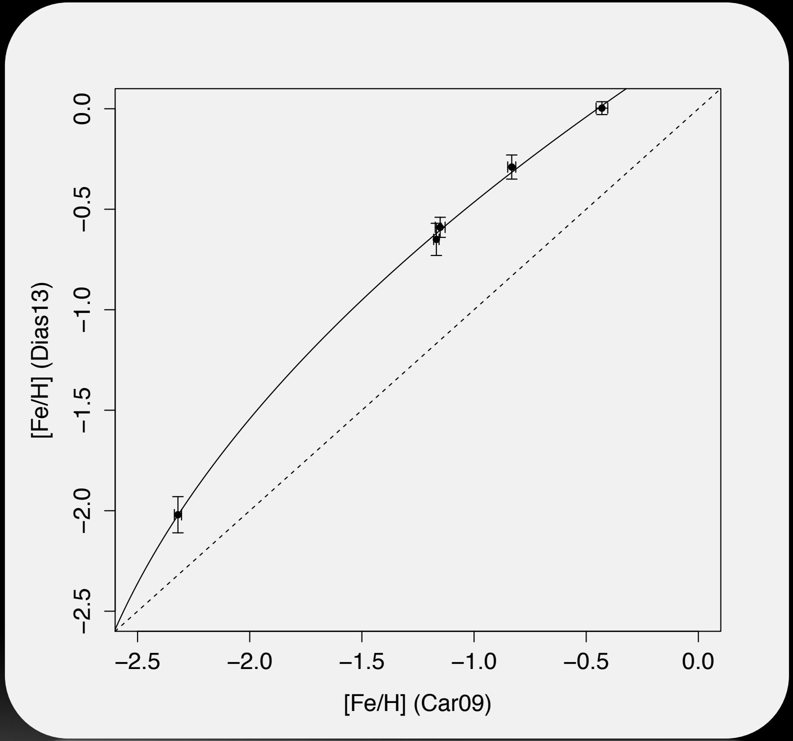


[Fe/H] – LITERATURE: SCALING TO CARRETTA+09

Metallicities scaled to Carretta+09

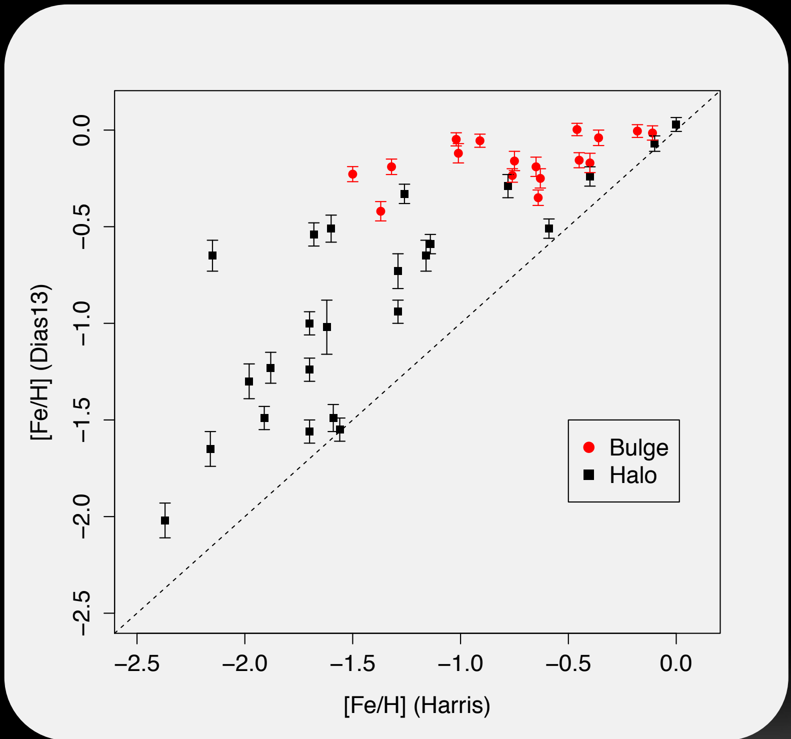


Carretta+09 – UVES results



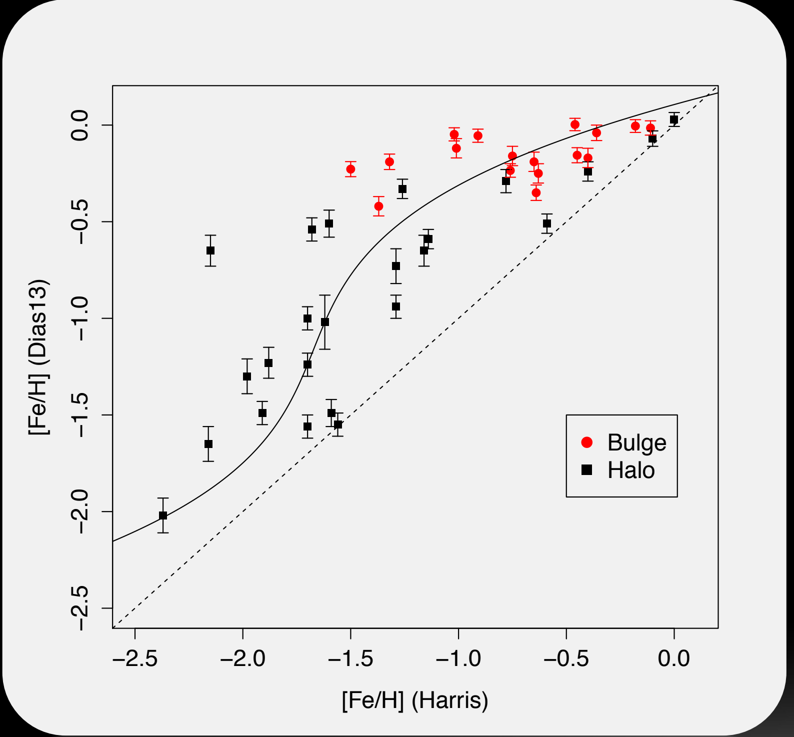
[Fe/H] – LITERATURE: SCALING TO HARRIS10

Unscaled metallicities

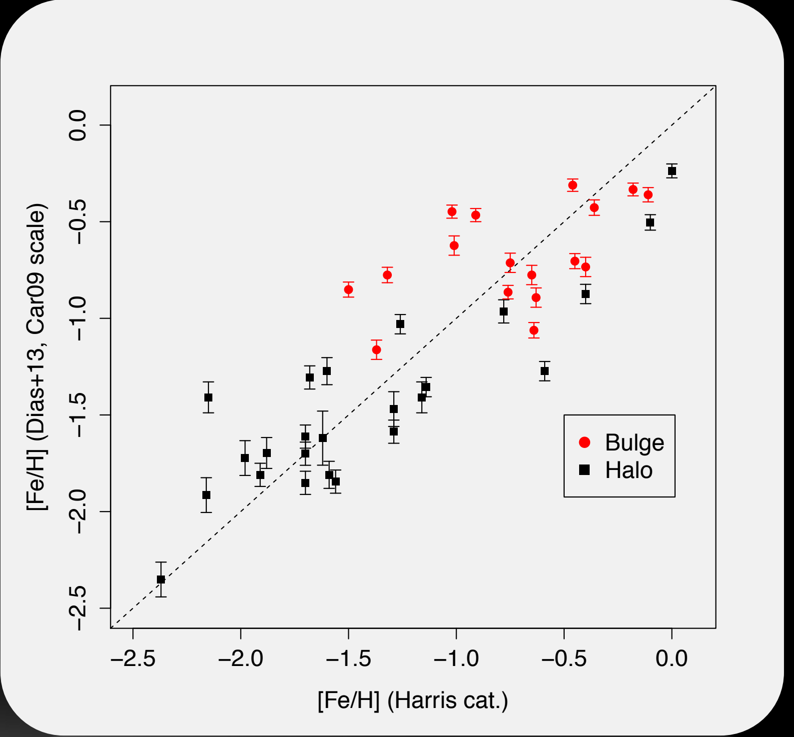


[Fe/H] – LITERATURE: SCALING TO HARRIS10

Unscaled metallicities

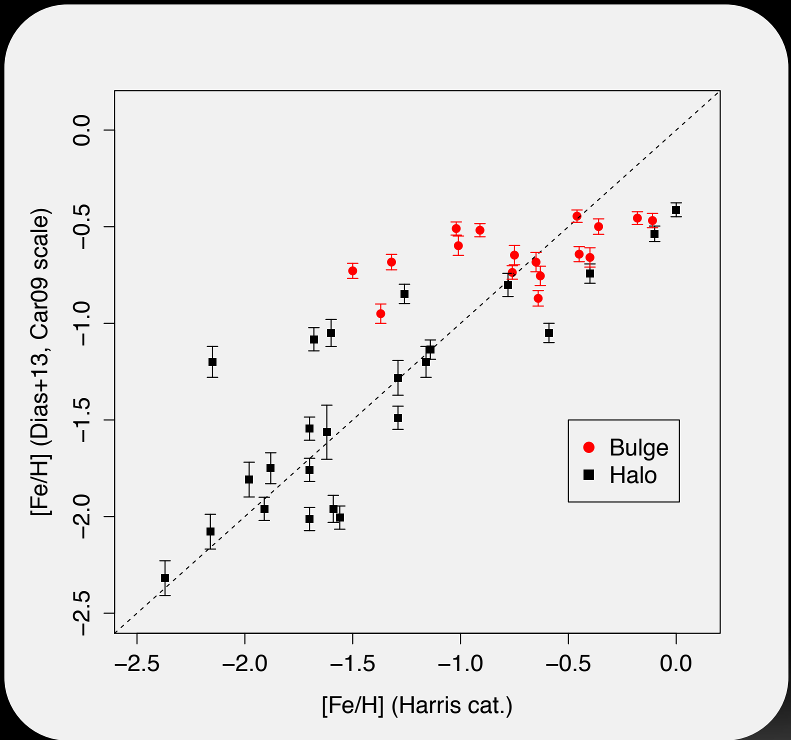


Scaled by Harris catalog (updated)

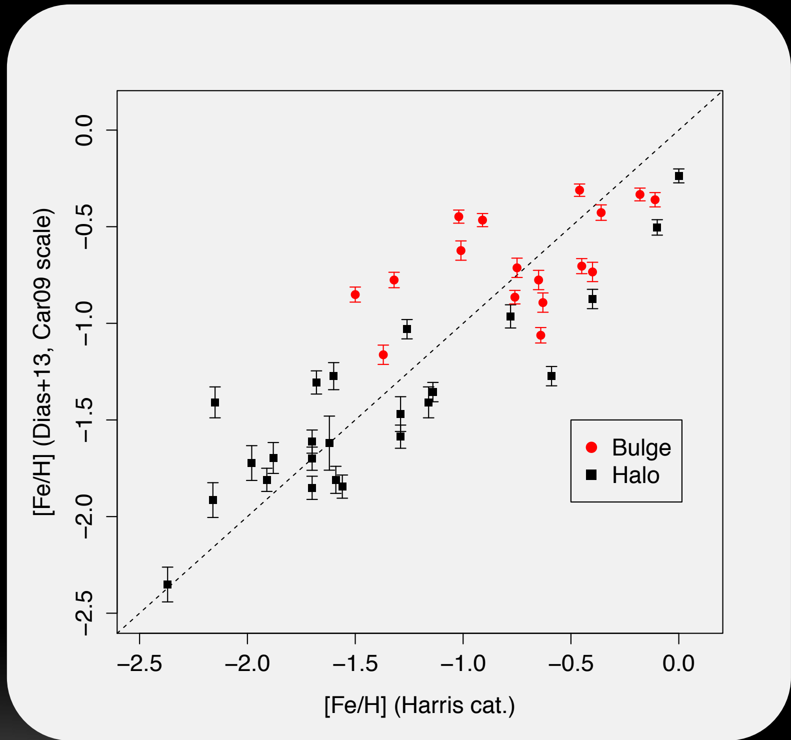


[Fe/H] – LITERATURE: COMPARING SCALES

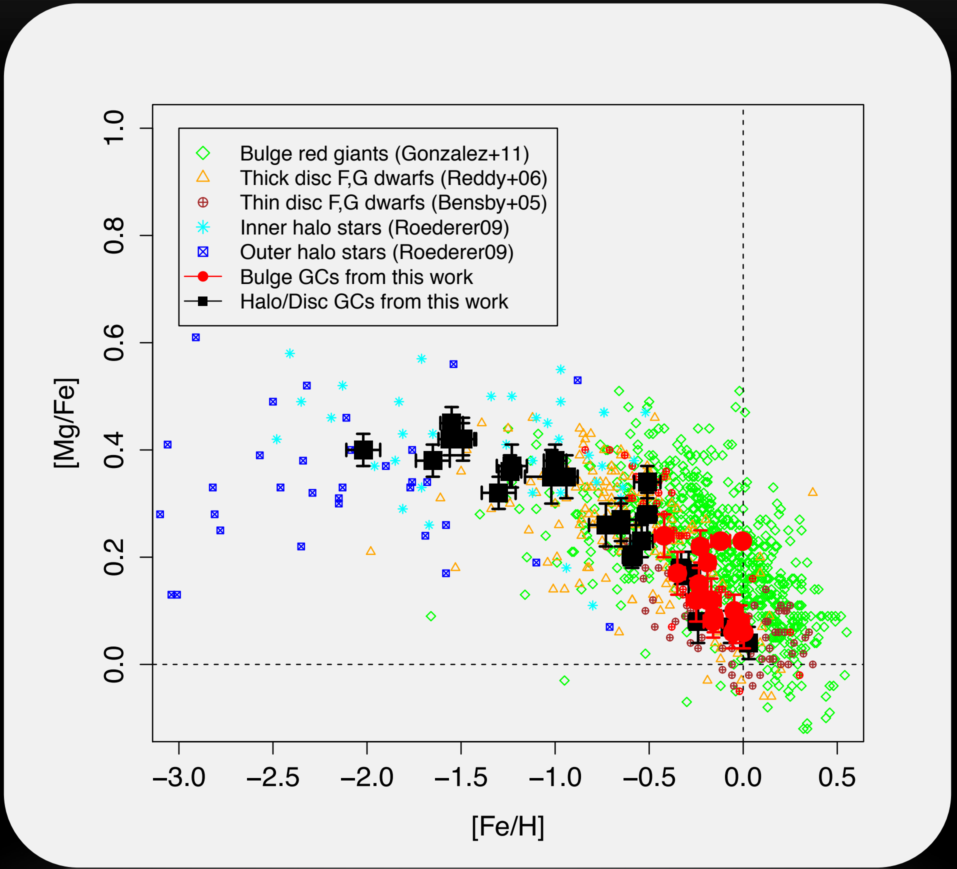
Metallicities scaled to Carretta+09



Scaled by Harris catalog (updated)



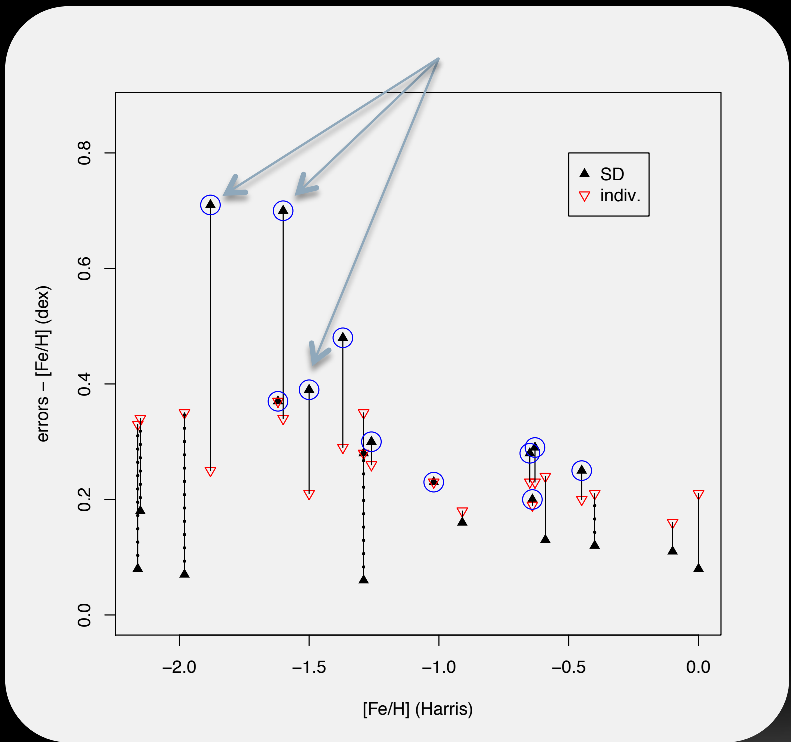
[Mg/Fe] vs. [Fe/H]



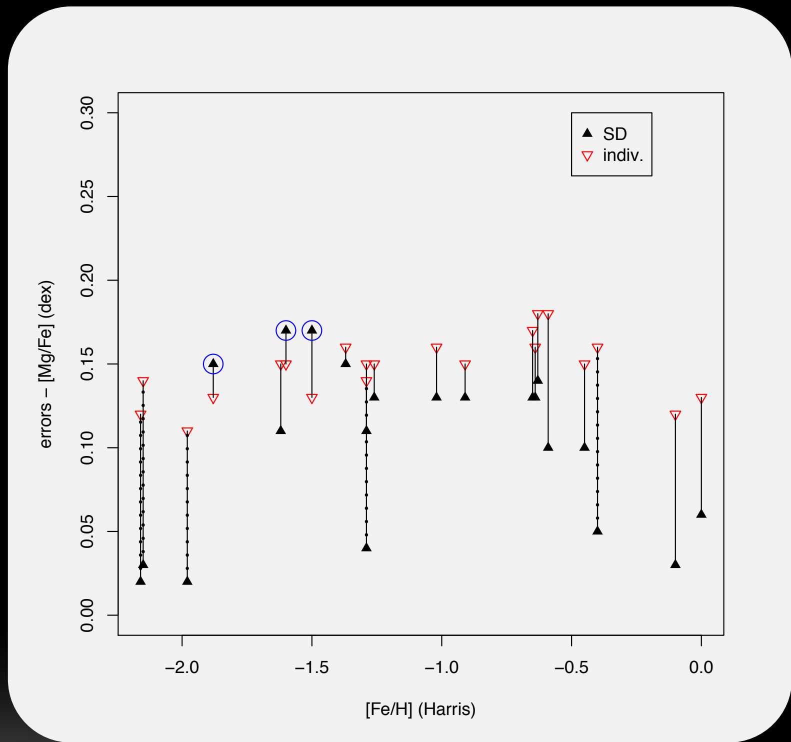
Bulge red giants (Gonzalez+11)
Thick disc F,G dwarfs (Reddy+06)
Thin disc F,G dwarfs (Bensby+05)
Inner halo stars (Roederer09)
Outer halo stars (Roederer09)
Bulge GCs from this work
Halo/Disc GCs from this work
[Mg/Fe]
0.0
0.2
0.4
0.6
0.8
1.0
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
[Fe/H]

[Mg/Fe] + [Fe/H]: MULTIPLE POPULATIONS?

Errors in [Fe/H]



Errors in [Mg/Fe]



CONCLUSIONS

- Homogeneous abundances studies are quite important!!
- This work provides:
  - Membership selection of RGB stars in BULGE clusters
  - Homogeneous [Fe/H] and [Mg/Fe]
  - Candidates to host multiple populations
  - Powerful technique to be applied in extragalactic star cluster systems

THANK YOU!

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Self-consistent physical parameters for 5 intermediate-age SMC stellar clusters from CMD modelling

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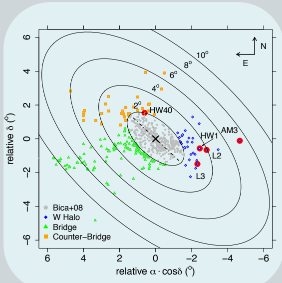
Motivation

- ✓ Small Magellanic Cloud (SMC) has a complex star formation history and evolution due to strong tidal interactions with Large Cloud and Milky Way (e.g. Diaz+12);
- ✓ Field and cluster stars have similar star formation history (Piatti+05,12);
- ✓ Star clusters in SMC are useful tools to determine ages and metallicities for each SMC region;
- ✓ There is a spread in metallicities for clusters with ages ~4-10 Gyr, around the Pagel+98 chemical evolution model (Parisi+09, Piatti+11);
- ✓ Stellar counterparts of the tidal gas structures may be characterized by age/metallicity gradients, however out to a>2º, no gradient was found to date (Piatti12).

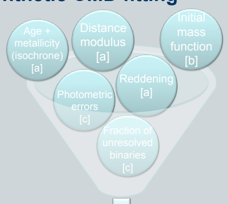
Goals

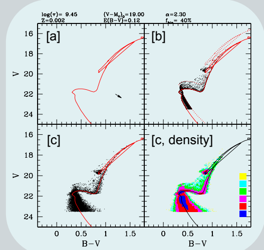
- ✓ To determine age, metallicity, and distance in a self-consistent way for the SMC clusters: AM3, Lindsay2, Lindsay 3, HW1, HW40;
- ✓ To relate the cluster properties and 3D distribution to chemical evolution models and tidal gas structures;
- ✓ To observe clusters in the outer regions of the Small Cloud;
- ✓ To classify 3 groups of clusters in outer regions.



⌘BD is a PhD student jointly at University of Sao Paulo - Brazil (Prof. Dr. Beatriz Barbuy), and ESO - Chile (Dr. Ivo Saviane).

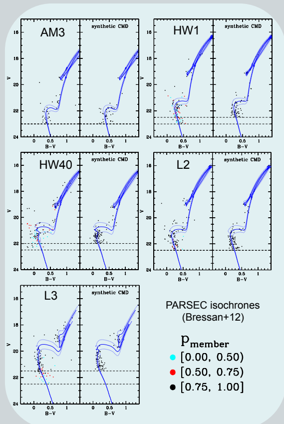
Synthetic CMD fitting



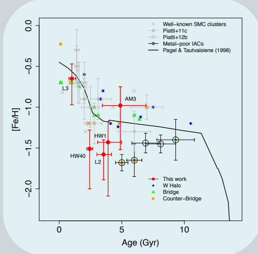


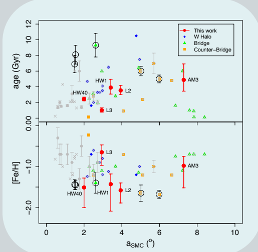
- ✓ A grid of ~9000 synthetic CMDs is made for different values of age, metallicity, distance, and reddening;
- ✓ One observed CMD is compared with the entire grid in order to find the best fit, with the maximum likelihood.

Best fits



Discussion & conclusions





- ✓ L2 and HW1 are studied for the first time in this work: they are physically close and have similar age (~4.0 Gyr) and metallicity ([Fe/H] ~ -1.5 dex);
- ✓ Results on AM3, L3, HW40 = literature;
- ✓ Results follow Pagel+98 model, with some dispersion for intermediate-age clusters;
- ✓ To analyse gradients in the outer regions of SMC, it is useful to separe these clusters in groups, as showed above;
- ✓ 4 clusters are in the West Halo region, that need more homogeneous studies to check for age and metallicity gradients.

References

❖ Bica et al. 2008, MNRAS, 389, 678
❖ Bressan et al. 2012, MNRAS, 427, 127
❖ Dias et al. 2013 (about to submit to A&A)
❖ Diaz & Bekki 2012, ApJ, 750, 36
❖ Parisi et al. 2009, AJ, 138, 517
❖ Piatti et al. 2005, MNRAS, 358, 1215
❖ Piatti 2011, MNRAS, 418, 69
❖ Piatti 2012, MNRAS, 422, 1109

More info:

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50 Years of Wide Field Studies in the Southern Hemisphere: Resolved Stellar Populations in the Galactic Bulge and the Magellanic Clouds.
La Serena, Chile. May 6-10, 2013.

SAMPLE OF VISIBLE SPECTRA

ID	Other names	$R_\odot$ (kpc)	E(B-V)	V_{HB} (mag)	[Fe/H]	# of stars	Bulge or Halo/Disc
Brighter RGB stars - 22 globular clusters (possible to observe with high resolution)							
NGC6397[c,d]		2.3	0.18	12.87	-2.02	24	H/D
NGC6121[d]	M4	2.2	0.35	13.45	-1.16	15	H/D
NGC6752[a]		4.0	0.04	13.70	-1.54	9	H/D
NGC104[a]	47Tuc	4.5	0.04	14.06	-0.72	16	H/D
NGC6656[d]	M22	3.2	0.34	14.15	-1.70	56	H/D
NGC6838[d]	M71	4.0	0.25	14.48	-0.78	13	H/D
NGC6254[d]	M10	4.4	0.28	14.65	-1.56	19	H/D
NGC3201[d]		4.9	0.24	14.76	-1.59	16	H/D
NGC5904[c]	M5	7.5	0.03	15.07	-1.29	9	H/D
NGC6352[e]		5.6	0.22	15.13	-0.64	14	B
NGC4372[c]		5.8	0.39	15.50	-2.17	11	H/D
NGC6366[e]		3.5	0.71	15.65	-0.59	17	H/D
NGC4590[b]	M68	10.3	0.05	15.68	-2.23	9	H/D
NGC6171[b]	M107	6.4	0.33	15.70	-1.02	4	B
NGC7078[d]	M15	10.4	0.10	15.83	-2.37	16	H/D
NGC2298[a]		10.8	0.14	16.11	-1.92	7	H/D
NGC2808[d]		9.6	0.22	16.22	-1.14	19	H/D
NGC5897[b]		12.5	0.09	16.27	-1.90	8	H/D
NGC6558[d]		7.4	0.44	16.30	-1.32	19	B
NGC5927[b]		7.7	0.45	16.55	-0.49	5	H/D
NGC6553[d]		6.0	0.63	16.60	-0.18	18	B
NGC6528[c,d]		7.9	0.54	16.95	-0.11	26	B
Fainter RGB stars - 29 globular clusters (distant and/or highly reddened)							
NGC5946[e]		{10.6}	{0.54}	17.40	-1.29	15	H/D
NGC6284[e]		{15.3}	0.28	17.40	-1.26	17	H/D
Lynga7[d]	BH184	8.0	{0.73}	17.43	-1.01	15	B
Pal11[e]		{13.4}	0.35	17.46	-0.40	12	H/D
NGC6316[e]		{10.4}	{0.54}	17.50	-0.45	16	B
NGC6356[d]		{15.1}	0.28	17.50	-0.40	18	H/D
NGC6441[d]		{11.6}	{0.47}	17.51	-0.46	19	B
NGC6569[d]		{10.9}	{0.53}	17.52	-0.76	18	B
Djorg2[e]	ESO456-SC38	6.3	{0.94}	17.60	-0.65	15	B
NGC5634[e]		{25.2}	0.05	17.68	-1.88	9	H/D
IC1276[d]	Pal7	5.4	{1.08}	17.70	-0.75	17	B
NGC6864[e]	M75	{20.9}	0.16	17.70	-1.29	12	H/D
NGC6355[e]		9.2	{0.77}	17.80	-1.37	16	B
Rup106[d]		{21.2}	0.20	17.80	-1.68	15	H/D
NGC6453[e]		{11.6}	{0.64}	17.88	-1.50	16	B
Terzan8[e]		{26.3}	0.12	17.95	-2.16	13	H/D
NGC6401[e]		10.6	{0.72}	18.00	-1.02	18	B
NGC6426[e]		{20.6}	0.36	18.16	-2.15	11	H/D
NGC6539[e]		7.8	{1.02}	18.33	-0.63	15	B
NGC5824[d]		{32.1}	0.13	18.45	-1.91	18	H/D
NGC5694[e]		{35.0}	0.09	18.50	-1.98	11	H/D
HP1[d]	BH229	8.2	{1.12}	18.70	-1.00	35	B
NGC6440[d]		8.5	{1.07}	18.70	-0.36	19	B
NGC7006[d]		{41.2}	0.05	18.80	-1.52	28	H/D
BH176[e]		{18.9}	0.54	18.86	0.00	15	H/D
Pal6[e]		5.8	{1.46}	19.00	-0.91	17	B
NGC6749[e]		7.9	{1.50}	19.70	-1.60	17	H/D
Pal10[e]		5.9	{1.66}	19.80	-0.10	13	H/D
Pal14[e]	AvdB	{76.5}	0.04	20.10	-1.62	7	H/D

COLOR – TEMPERATURE: NGC2808