

The Bologna Open Clusters Chemical Evolution project (in short: BOCCE)

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The BOCCE project: the team

In collaboration with:

Eugenio Carretta, Michele Cignoni, Monica Tosi (INAF-OA Bologna)
Raffaele Gratton, Enrico Held (INAF-OA Padova)
Gloria Andreuzzi, Luca Di Fabrizio (INAF-Fundación Galilei)
Jason Kalirai (UCO-Lick)
Gianni Marconi (ESO)

(and a few students: F. DeLuise, M.Manduchi, P. Carusillo, V. D'Orazi)

more info at www.bo.astro.it/~angela/bocce.html

The BOCCE project : outline of the talk

- ❖ Brief introduction on Open Clusters
- ❖ Presentation of our project
(& similar ones)
- ❖ Photometric part of BOCCE
(with a few interesting clusters)
- ❖ Spectroscopic part of BOCCE
(with the two most metal-rich clusters)
- ❖ Summary

The BOCCE project: generalities (1)

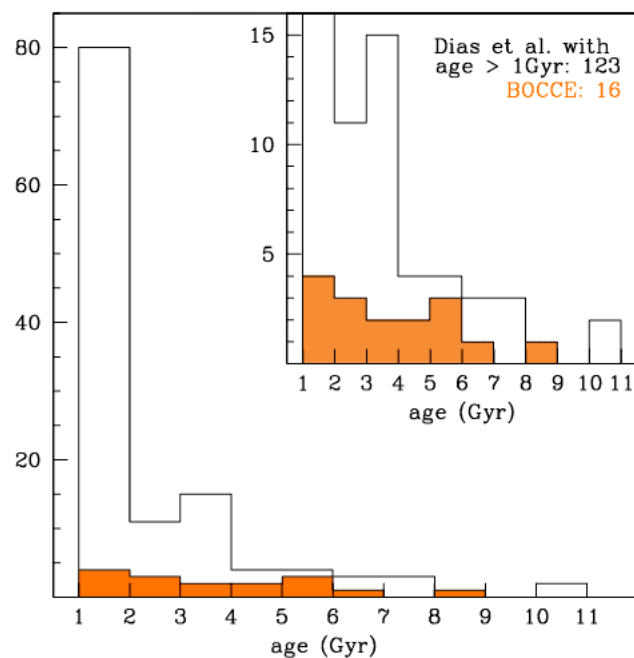
Why Open Clusters ?

- the MW disk
(seen at “all” disk positions, ages and metallicities)
- chemical evolution
(metallicity distribution: gradient(s) ?)
- stellar models
(at low-intermediate mass)
- as a bridge between GCs and field

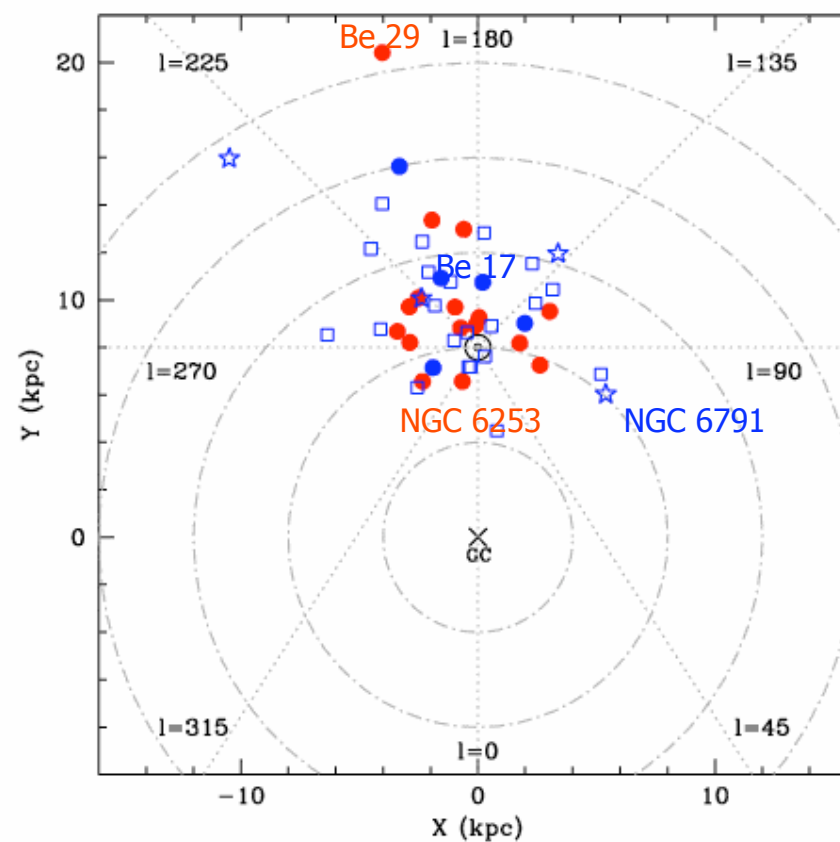
To study the history of the disk we need to concentrate on OLD clusters

The BOCCE project: generalities (2)

How many OLD Ocs ?



The BOCCE clusters :



The BOCCE project: generalities (3)

We are conducting a systematic and homogeneous study of a large and significant sample of Galactic Ocs using:

- PHOTOMETRY $\Rightarrow$ age, distance, reddening (& metallicity)
- LOW-RES SPECTROSCOPY $\Rightarrow$ RV (membership)
- HIGH-RES SPECTROSCOPY $\Rightarrow$ detailed abundances

We have obtained large amounts of data, and further analysis is on-going

(or will use archive data and data obtained in other collaborations, e.g. S. Randich & P. Sestito)

The BOCCE project: we are not alone in the Universe

(Mostly) photometry:

- Dias et al. (2002) : the catalogue of OCs (www.astro.iag.usp.br/~wilton)
- Bonatto, Bica, & Ortolani : many Ocs (&GCs), often new
- Claria', Piatti, Ahumada, et al. : photometry
- Janes, Phelps, Friel, et al. : photometry + RVs & abu from low-res
- Kaluzny et al. : photometry, & variables
- Pandey, Sagar, et al. : photometry
- Twarog & Anthony-Twarog : photometry, Stromgren
- Carraro, Costa, Baume, Moitinho, et al. : photometry of many Ocs
- WIYN collaboration : few clusters, well studied (www.astro.ufl.edu/~ata/wocs)
- Mermilliod et al. : RVs + WEBDA
- Paunzen et al. : peculiar stars + WEBDA (www.univie.ac.at/webda/)
- Maciejwsky & Niedzielsky : recently 42 Ocs (www.astro.uni.torun.pl/~gm/OCS/)
- San Pedro Martir OC survey : 300 Ocs

...

The BOCCE project: we are not alone in the Universe

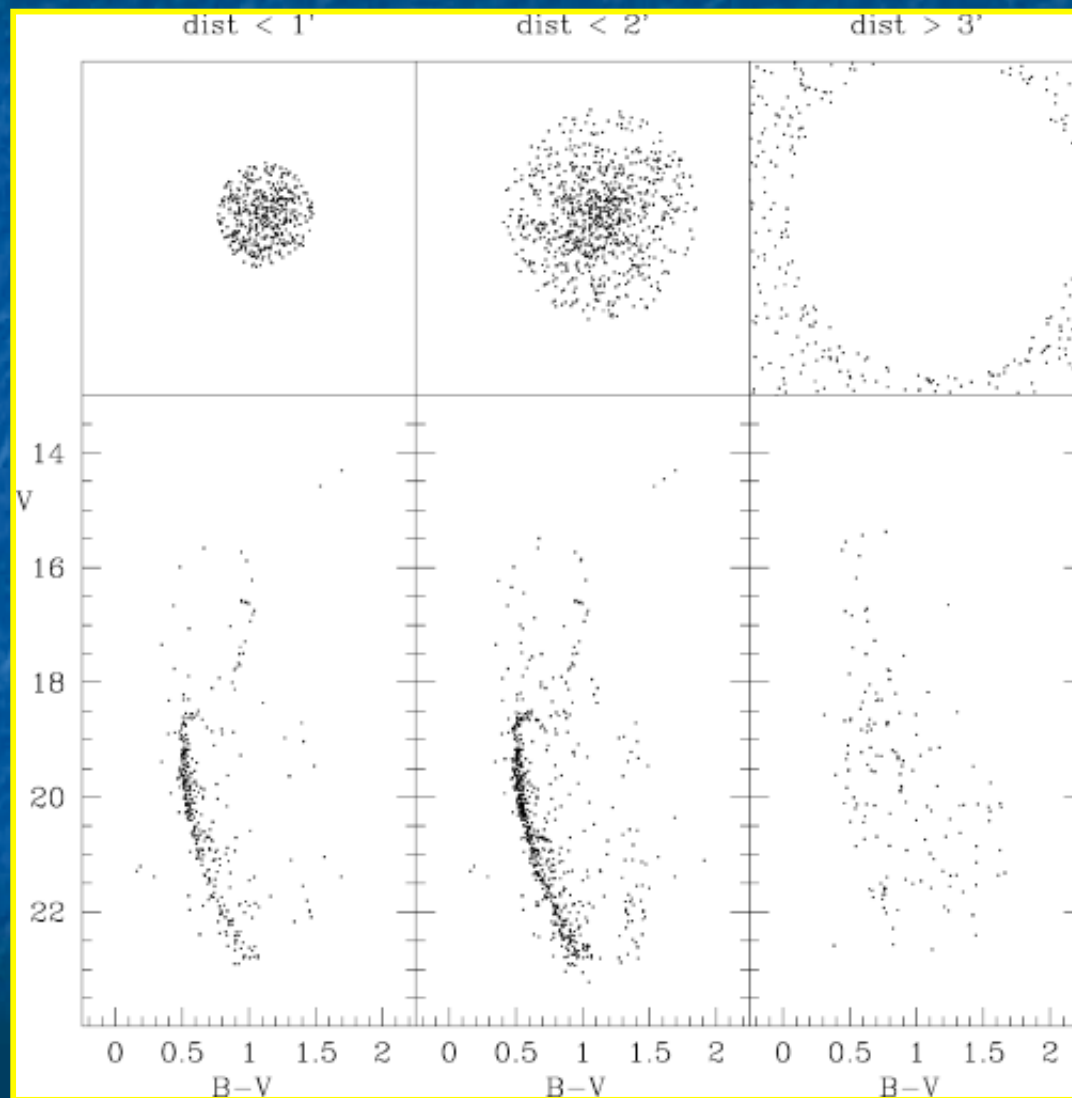
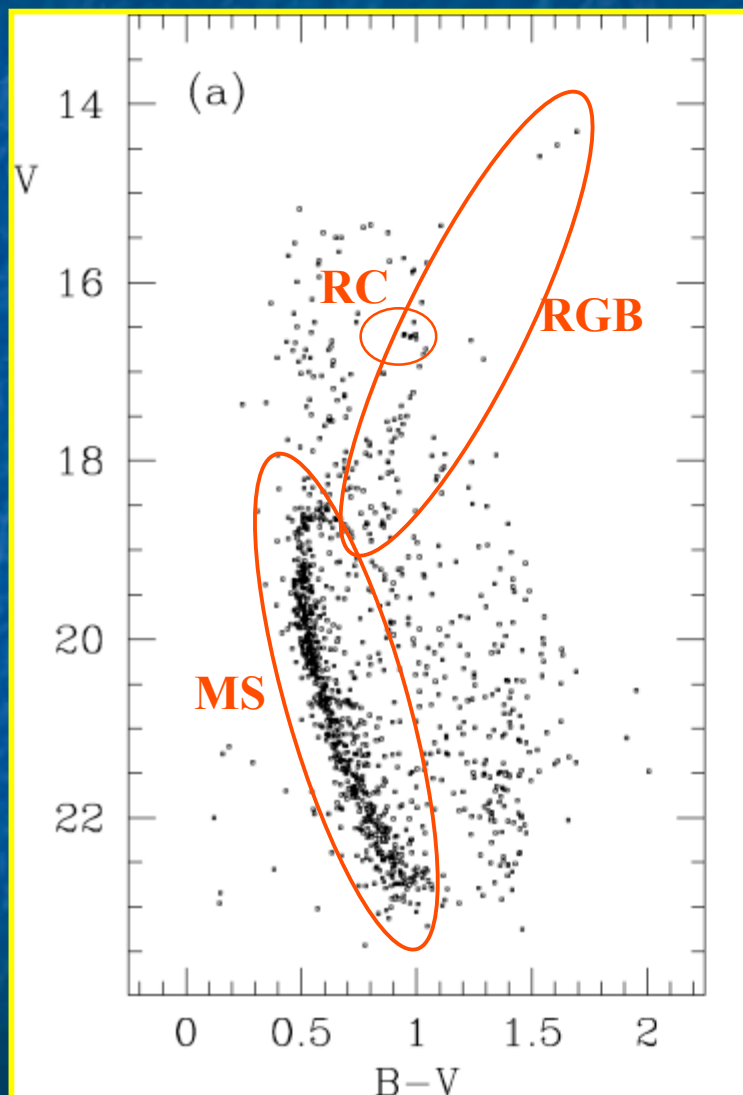
High-res spectroscopy:

- “Li people” : too many to cite them
- Friel et al. : Cr 261, Be 17, NGC 6939, IC 4756, NGC 7142
- Yong et al. : Be 20, Be 21, Be 29, Be 31, NGC 2141
- Carraro et al. : Be 29, Sau A, Be 22, Be 66, Be 25, Be 73, Be 75, Rup 4, Rup 7
- Sestito et al. : NGC 2324, NGC 2660, NGC 2477, NGC 3960, Be 32 (+ Be 20, Be 29, Mel 66, Cr 261, To 2)

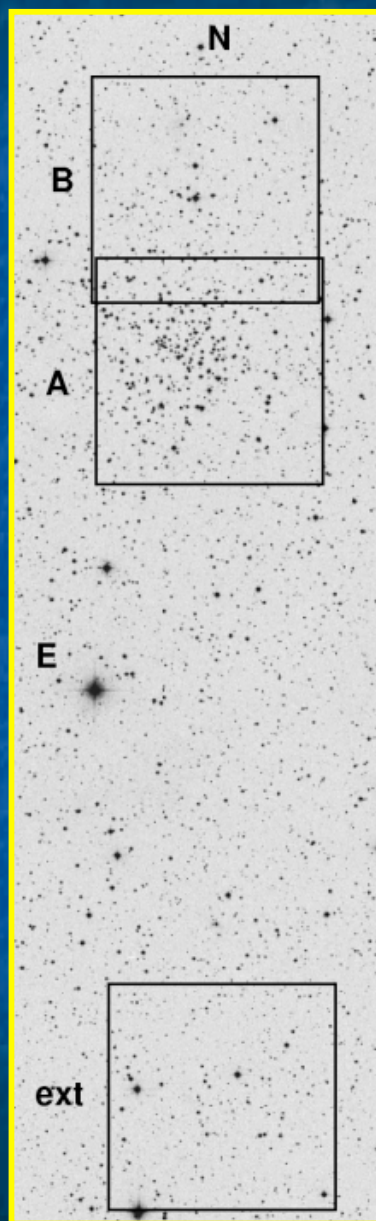
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The BOCCE project: photometry (1a)

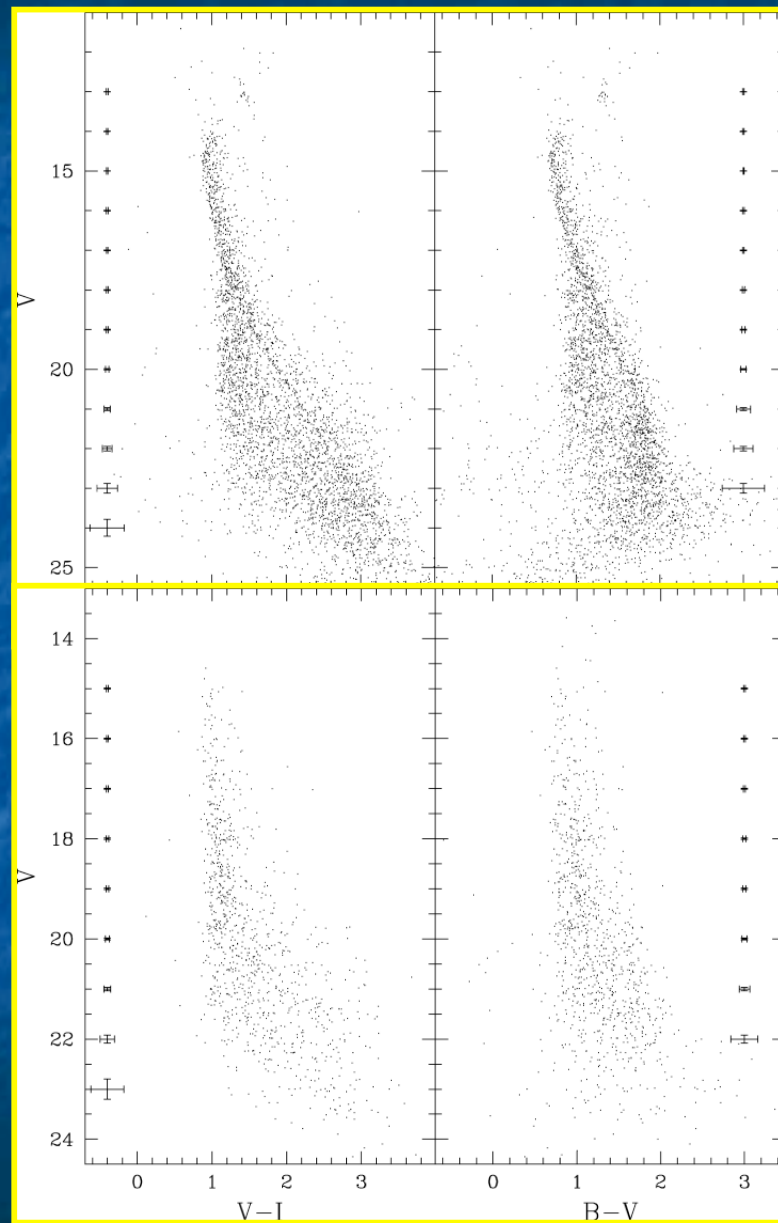
Be 29 : CMD (total & radial)



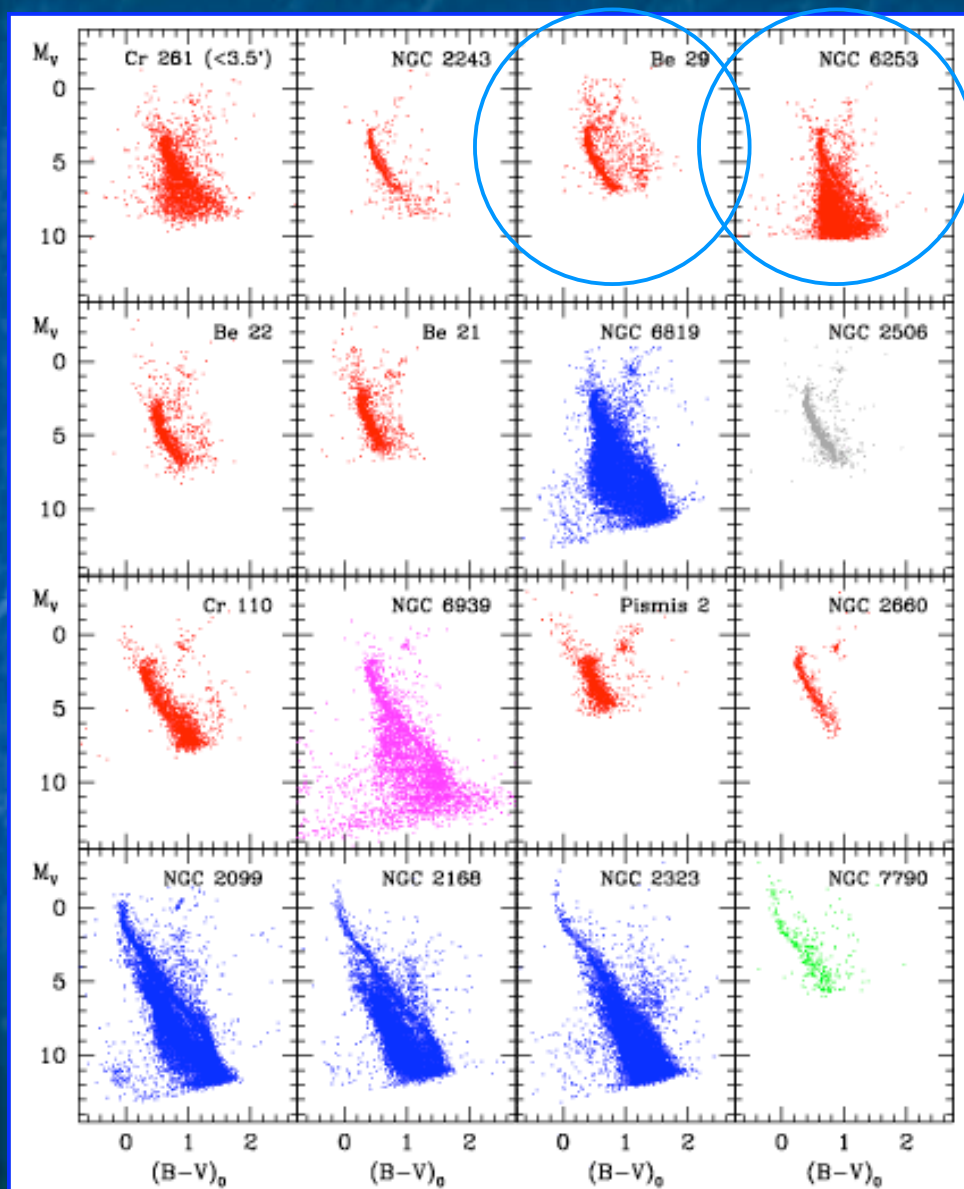
The BOCCE project: photometry (1b)



NGC 6939:
Fields centered
on the cluster
and a control,
external field



The BOCCE project: photometry (2)



CMDs to derive
age, distance,
reddening, and
metallicity
by means of
synthetic CMDs

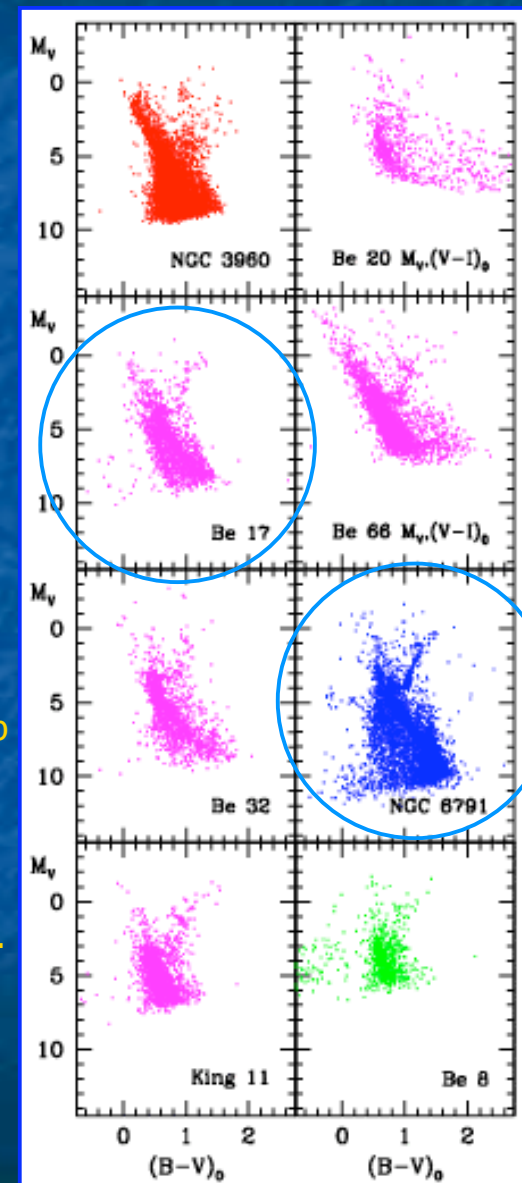
BOCCE (16 Ocs):
Bragaglia & Tosi 2006



NGC 3960, Be17:
Bragaglia et al. 2006a,b
Be 32, King 11:
Tosi et al. 2007

Be 20, Be 66:
Andreuzzi et al. , subm.

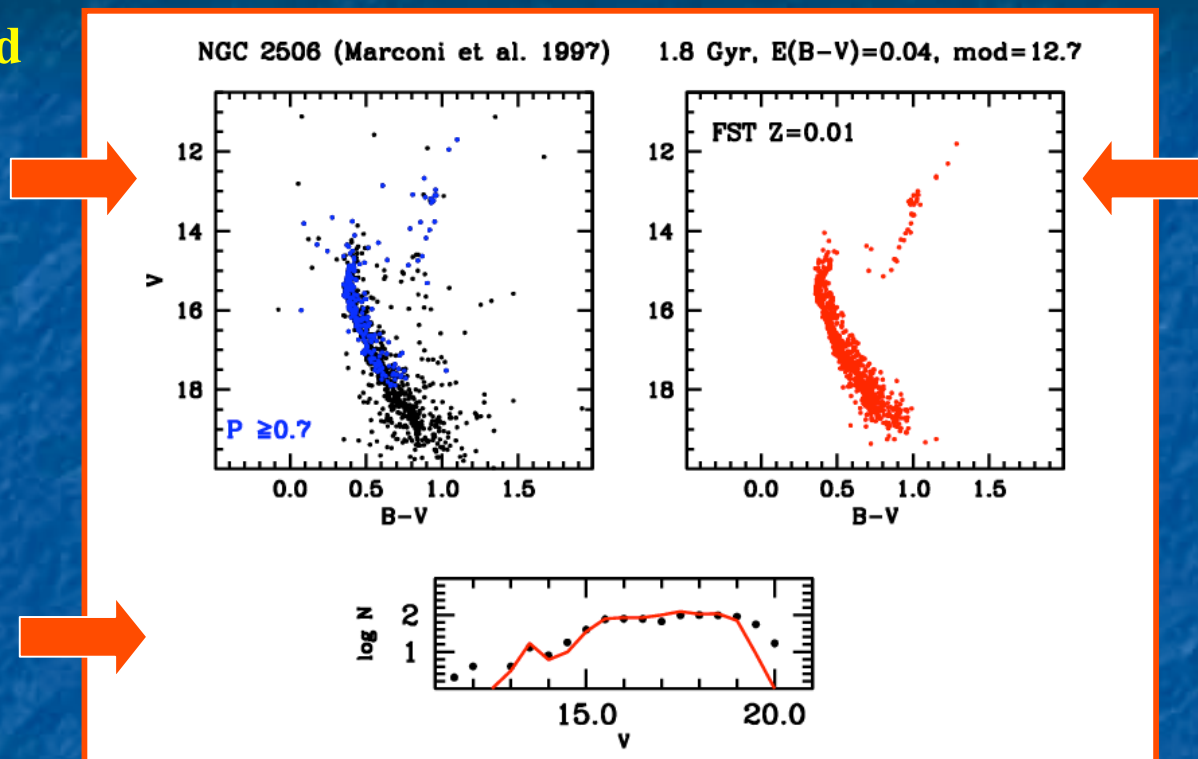
& work in progress on
NGC 6791, etc



The BOCCE project: photometry (3)

Observed

Synthetic



Synthetic CMDs generated via random extraction from stellar evolutionary tracks
 + conversion theo/obs (L , $T_{\text{eff}} \Rightarrow \text{mag, col}$)
 + photometric errors & binaries
 + completeness

Tracks used homogeneously:

- **FRANEC** (Dominguez, Chieffi, Limongi, Straniero 1999) : no overshooting
- **Padova** (Bressan, Bertelli, Chiosi, Fagotto 1993, 1994) : classical overshooting
- **FST** (Ventura, Zeppieri, Mazzitelli, D'Antona 1998) : Canuto-Mazzitelli oversh./no oversh.

The BOCCE project: photometry (4)

Properties of all clusters on the same scale
⇒ **the Galaxy**

Cluster	l	b	(m-M) ₀	E(B-V)	Z	age (Gyr)
NGC 7790	116.59	-1.01	12.65	0.54	0.020	0.10
NGC 2323	221.67	-1.33	10.20	0.22	0.020	0.12
NGC 2168	186.59	2.22	9.80	0.20	0.008	0.18
NGC 2099	177.64	3.09	10.50	0.36	0.008	0.43
NGC 2660	265.93	-3.01	12.30	0.40	0.020	0.95
Pismis 2	258.85	-3.34	12.70	1.29	0.020	1.10
NGC 6939	95.90	+12.30	11.30	0.34	0.020	1.30
Cr 110	209.65	-1.98	11.45	0.57	0.004	1.70
NGC 2506	230.56	+9.94	12.60	0.00	0.020	1.70
NGC 6819	73.98	+8.48	12.20	0.12	0.020	2.00
Be 21	186.84	-2.51	13.50	0.78	0.004	2.20
Be 22	199.90	-8.08	13.80	0.64	0.020	2.40
NGC 6253	335.46	-6.25	11.00	0.23	0.050	3.00
Be 29	197.98	8.03	15.60	0.12	0.004	3.70
NGC 2243	239.48	-18.01	12.74	0.08	0.004	4.80
Cr 261	301.68	-5.53	12.20	0.30	0.020	6.00
NGC 3960	294.37	+6.18	11.60	0.29	0.020	0.90
King 11	117.16	+6.48	11.75	1.04	0.010	4.25
Be 32	207.95	+4.40	12.60	0.12	0.008	5.20
Be 20	203.48	-17.37	14.70	0.13	0.008	5.80
Be 17	175.65	-3.65	12.20	0.62	0.008	8.50

Properties of all clusters with different tracks
⇒ **evolutionary models**

TABLE 3
AGE, DISTANCE MODULUS AND REDDENING FROM DIFFERENT STELLAR MODELS

Cluster	age (Gyr)			(m-M) ₀			E(B-V)		
	BBC	FRA	FST	BBC	FRA	FST	BBC	FRA	FST
Cr 261	9.00	5.00	6.00	12.0	12.2	12.2	0.25	0.29	0.30
NGC 2243	4.00	3.20	2.90	12.8	12.8	13.1	0.06	0.08	0.04
Be 29	3.70	2.30	3.50	15.6	15.8	15.8	0.13	0.15	0.10
NGC 6253	3.00	3.00	3.20	11.0	10.8	10.9	0.23	0.33	0.32
Be 22	2.40	2.10	2.50	13.8	14.0	13.9	0.64	0.65	0.65
Be 21	2.20	2.50	2.50	13.5	13.6	13.5	0.78	0.74	0.74
NGC 6819	2.00	1.80	2.30	12.2	12.0	12.0	0.12	0.15	0.10
NGC 2506	1.70	1.60	1.80	12.6	12.6	12.7	0.00	0.07	0.04
Cr 110	1.70	1.20	1.50	11.5	11.7	11.5	0.57	0.52	0.56
NGC 6939	1.30	1.00	1.30	11.3	11.3	11.4	0.34	0.38	0.36
Pismis 2	1.10	1.10	1.20	12.7	12.5	12.7	1.29	1.29	1.29
NGC 2660	0.95	0.75	1.10	12.3	12.3	12.1	0.40	0.42	0.37
NGC 3960	0.90	0.60	0.80	11.7	11.6	11.5	0.27	0.31	0.30
NGC 2099	0.43	0.59	0.52	10.5	10.5	10.4	0.34	0.16	0.36
NGC 2168	0.18	0.11	0.20	9.80	9.80	9.60	0.20	0.22	0.20
NGC 2323	0.12	0.11	0.13	10.2	10.0	10.0	0.22	0.22	0.22
NGC 7790	0.10	0.05	0.10	12.7	12.7	12.7	0.54	0.54	0.54

The BOCCE project: interesting clusters (a)

Be 29: the farthest one ?

age=3.5 – 3.7 Gyr

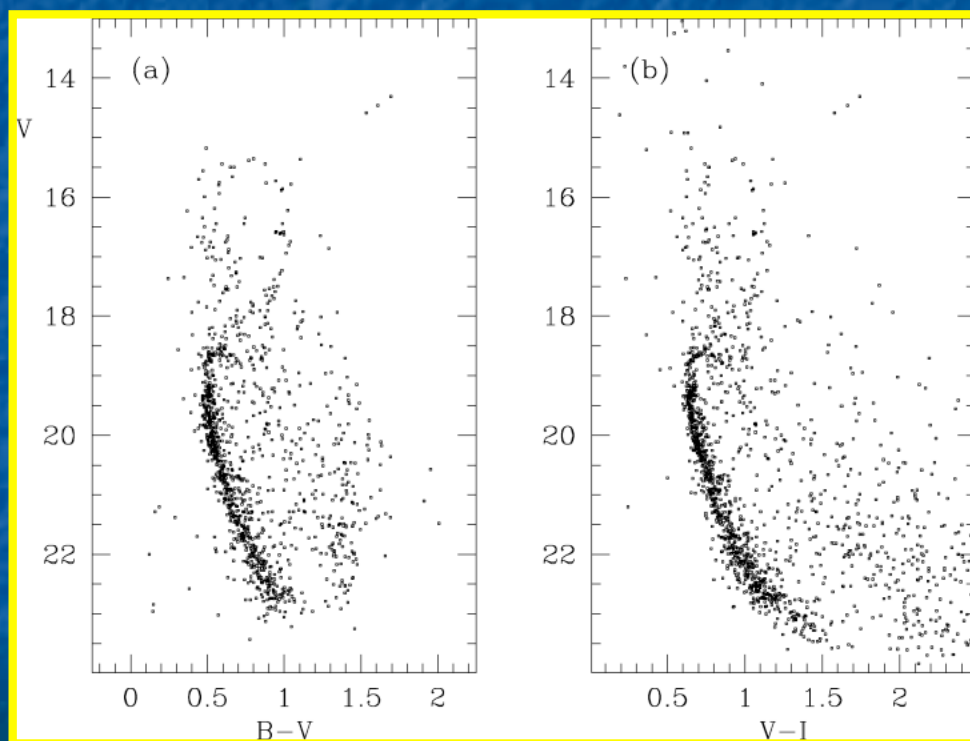
$(m-M)_0 = 15.6 - 15.8$

$E(B-V)=0.10 - 0.15$

$Z = 0.004$ (i.e., $[Fe/H] \approx -0.7$)

$R_{gc} = 21$ kpc

(Tosi et al. 2004)



$[Fe/H] = -0.44$ (Carraro et al. 2004)

$= -0.54$ (Yong et al. 2005)

$= -0.30$ (Sestito et al. 2007)

Be 17: the oldest one ?

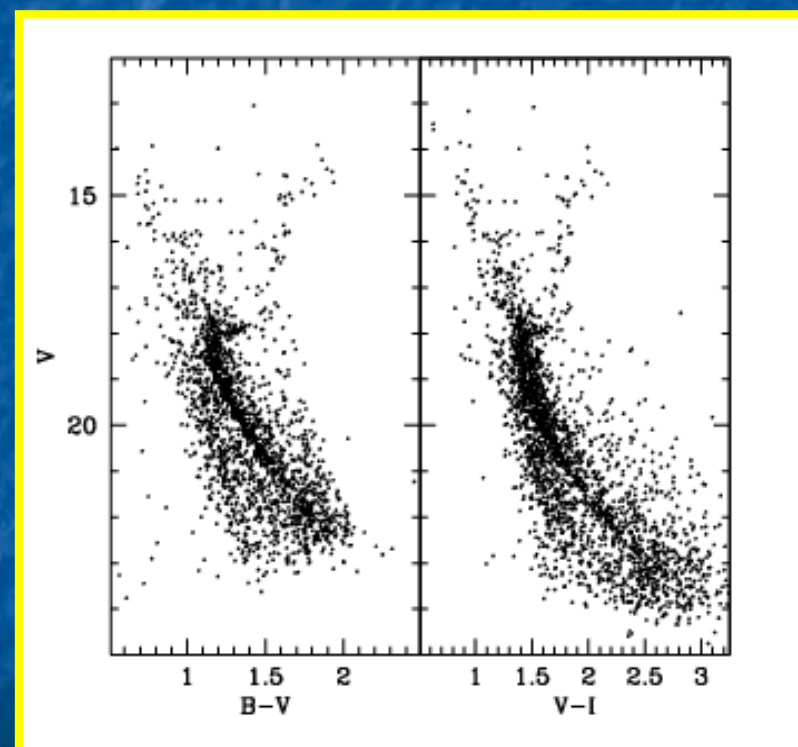
age=8.5 – 9 Gyr

$(m-M)_0 = 12.2$

$E(B-V)=0.60 - 0.62$

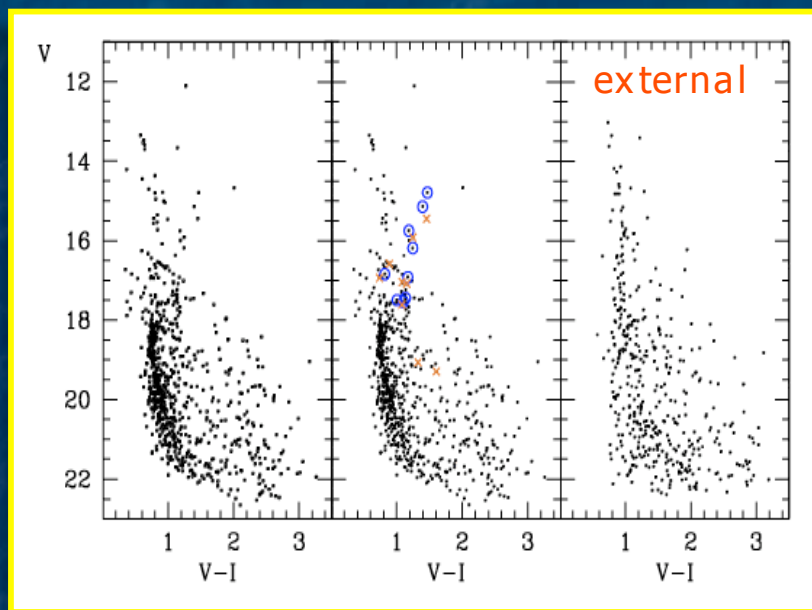
$Z = 0.008 - 0.01$ (i.e., $[Fe/H] \approx -0.3$)

(Bragaglia et al. 2006)



$[Fe/H] = -0.10$ (Friel et al. 2005)

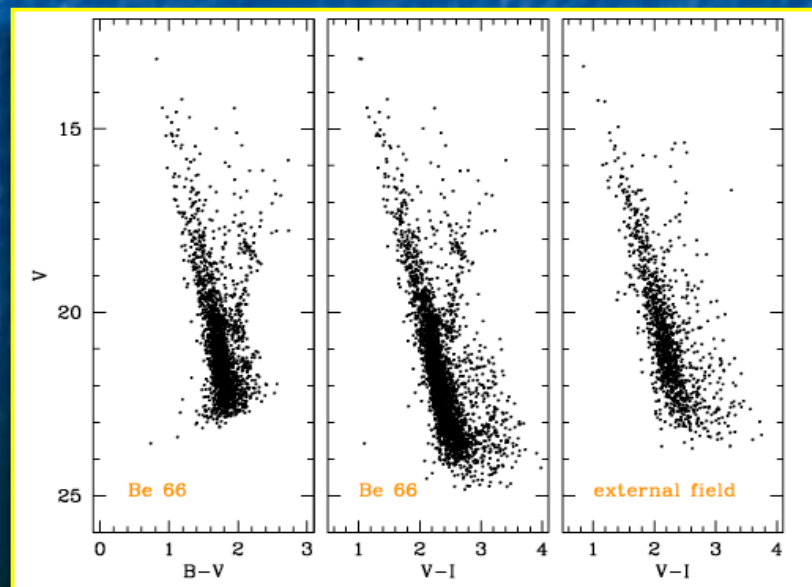
The BOCCE project: interesting clusters (b)



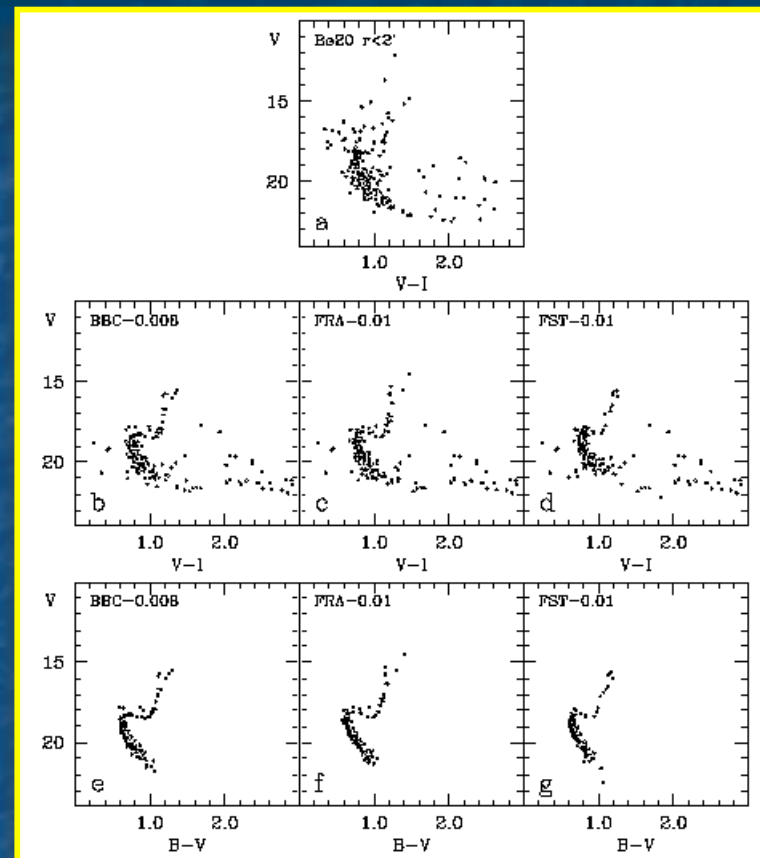
Be 20:

Observed

Synthetic



Be 66



Andreuzzi, Bragaglia, Tosi (MNRAS, to be subm.) :

Be20 age=5.8 Gyr $(m-M)_0=14.7$ $E(B-V)=0.13$

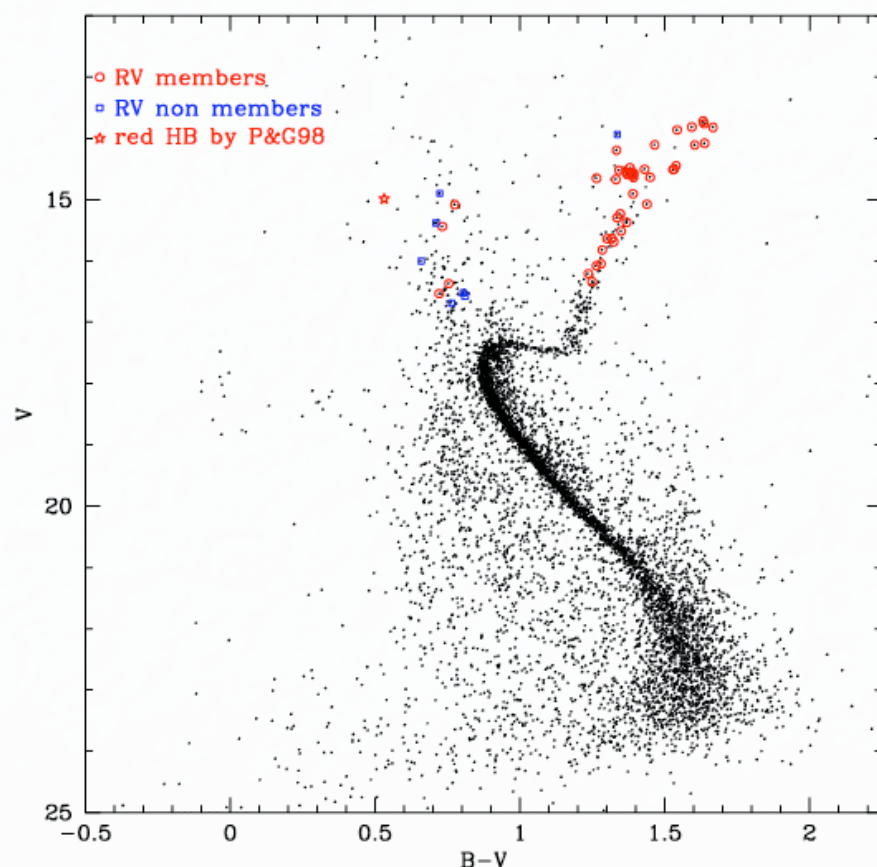
$Z=0.008$ $R_{gc} \approx 16$ kpc

Be66 age=3.0 Gyr $(m-M)_0=13.3$ $E(B-V)=1.20-1.24$

$Z=0.006$

The BOCCE project: NGC 6791

NGC 6791: the oldest one ? and the most metal-rich one ?
(perhaps, but see Be 17 for age and NGC 6253 for metallicity)



RVs from:
Scott et al. 1995
Geisler 1998
Peterson&Green 1998
Carraro et al. 2006
Origlia et al. 2006
Gratton et al. 2006

We need (new) homogenous tracks
at high Z :

Padova are in prep/in press ($Z=0.05, 0.07$)
FRANEC: Pisa version ($Z=0.04, 0.05$)
FST: Ventura ($Z=0.04, 0.05$)

Observed CMD: Kalirai et al. 2007, in press - Synthetic CMDs: work in progress

The BOCCE project: RV & membership

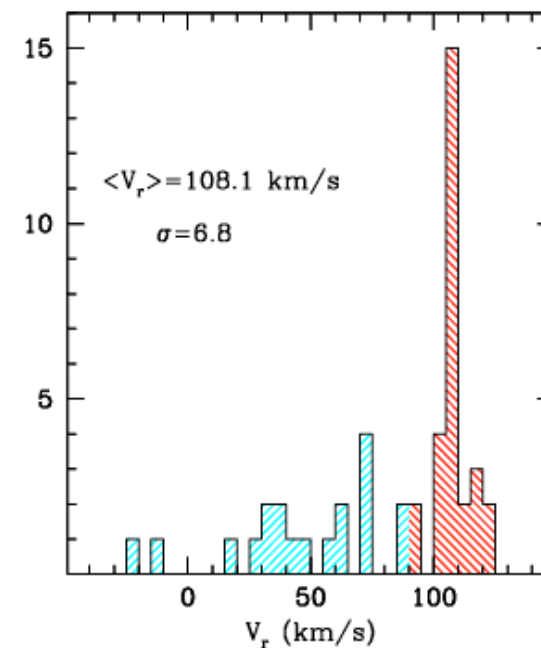
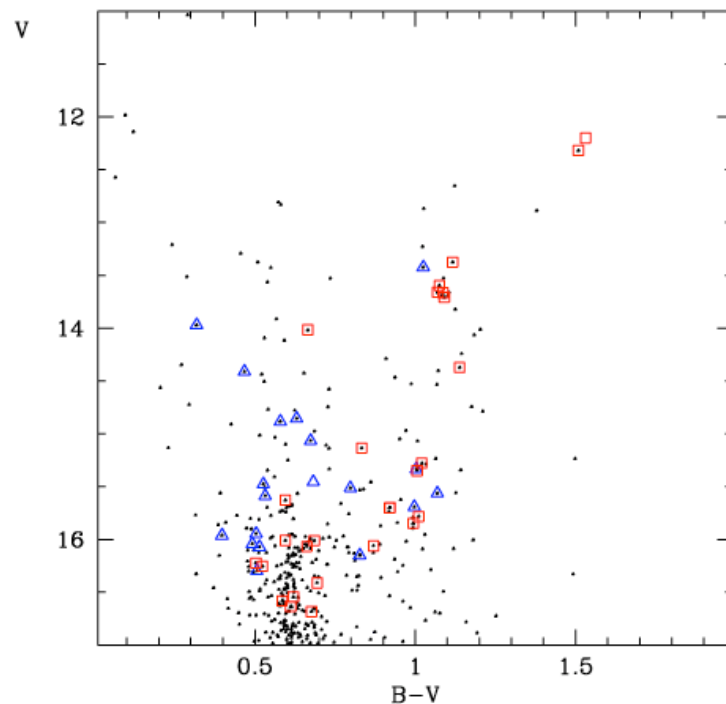
MOS@TNG : 20-100 stars per cluster, for RV (precision ~ 5 km/s)

Be 29 - Bragaglia et al. 2005 : 20 stars, 12 members, $\langle RV \rangle = 28$ (rms=5) km/s

Be 32 - D'Orazi et al. 2006 : 48 stars, 31 members, $\langle RV \rangle = 108$ (rms=7) km/s

Be 17 - in prep. : ~ 100 stars (from RGB-tip to MSTO)

Berkeley 32 (LRS@TNG)



The BOCCE project: high-res spectroscopy (1)

High-res spectra of Red Clump stars (3-6 per cluster) using SARG@TNG, FEROS, UVES :

NGC 6819: Bragaglia et al. 2001

NGC 2506, IC4651, NGC 6134; Cr 261: Carretta et al. 2004, 2005

NGC 3960: Bragaglia et al. 2006

NGC 6791: Gratton et al 2006

NGC 6253, NGC 6791: Carretta et al. 2007

We will complete with data from archives and from a companion program :

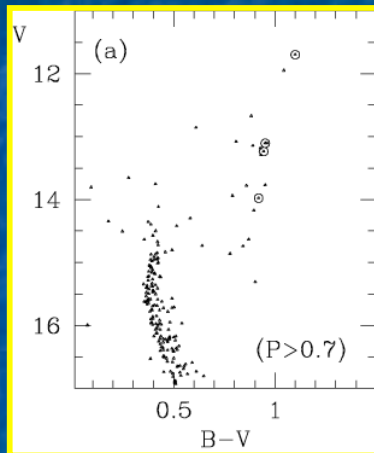
Sestito et al. 2006, 2007, in prep.; Bragaglia et al. 2007: these are part of the ITAL-FLAMES GTO project (PI R. Pallavicini) with 1 further OC, and a GO project (PI S. Randich) with 7 additional OCs, among them the distant ones Be20 and Be29.

We maintain the most homogeneous procedure :

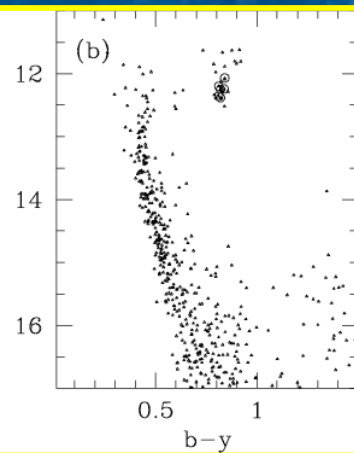
We adopt the same line lists, the same gf 's, model atmospheres, solar reference values, way to measure EW's, synthesis, kind of stars

The BOCCE project: high-res spectroscopy (2)

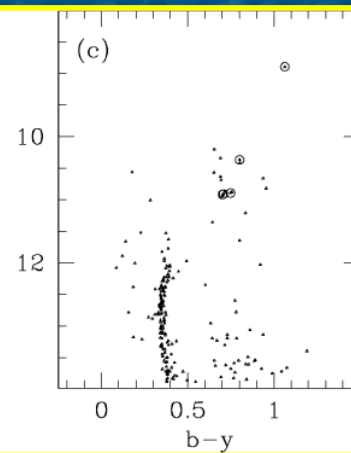
NGC 2506



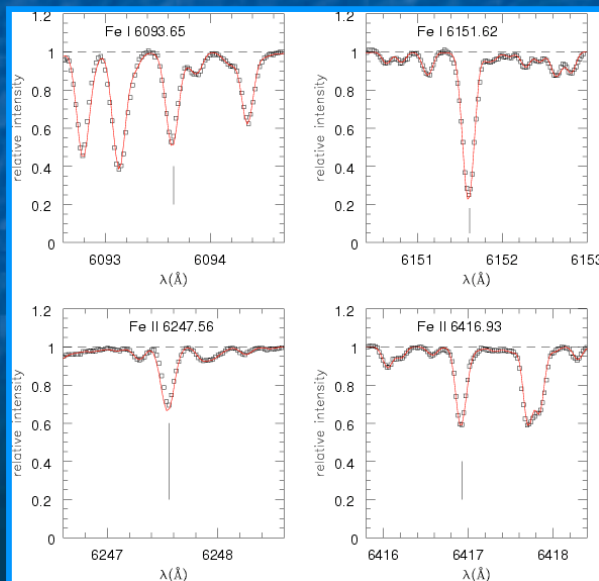
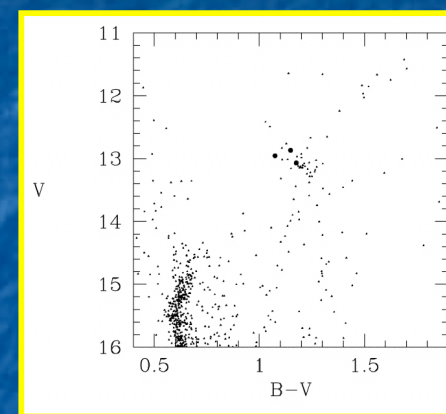
NGC 6134



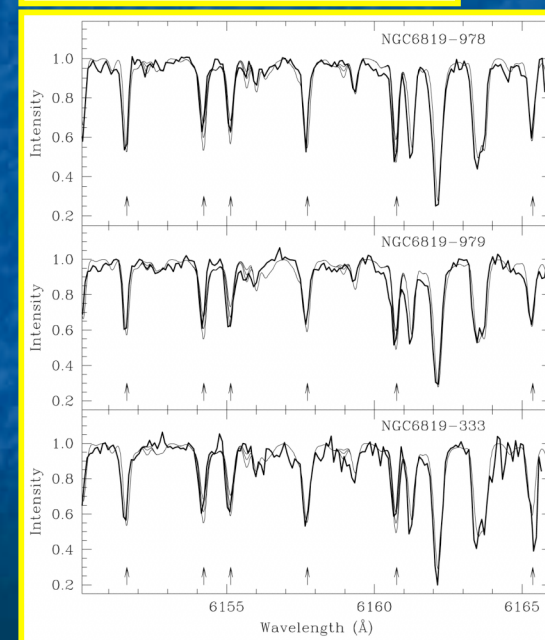
IC 4651



NGC 6819



Observed and synthetic spectrum of the field metal-rich giant HR3627 (observed at $R=140000$, S/N VERY high, with SARG@TNG)

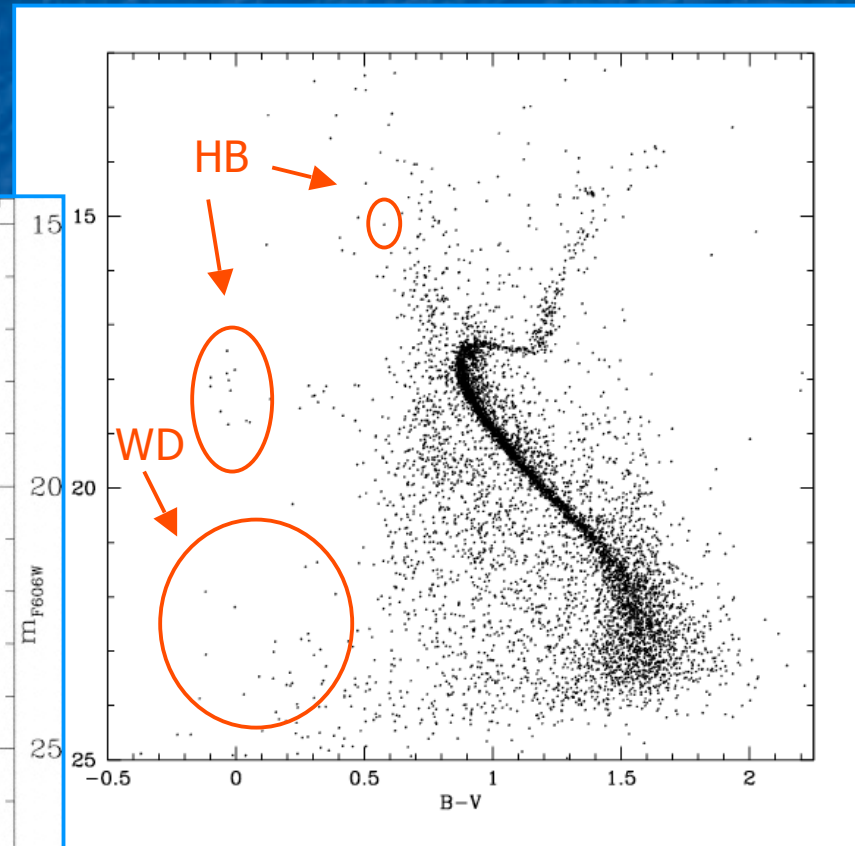
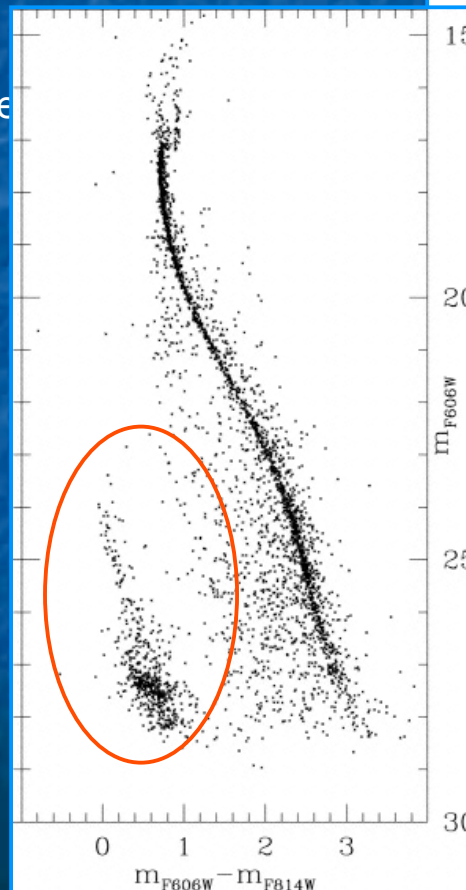


The BOCCE project: NGC 6253 & NGC 6791

NGC 6253: age=3 Gyr, $Z=0.05$, $(m-M)_0=11.0$,
 $E(B-V)=0.23$, $R_{gc}=6.60$ kpc

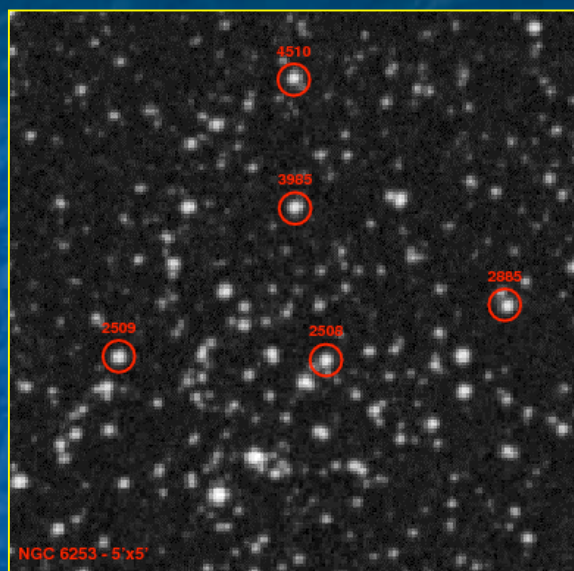
NGC 6791: age=9 Gyr, very metal-rich,
 $R_{gc}=8$ kpc

- oldest open cluster ?
 (Be 17, 8.5 Gyr, Bragaglia et al. 2008)
- highest $[Fe/H]$?
 (but see NGC 6253)
- blue HB
 (Kaluzny & Udalski 1992)
- He-core WDs
 (Kalirai et al. 2007)
- orbit: R_{gc} varies a lot
 (Bedin et al. 2006)

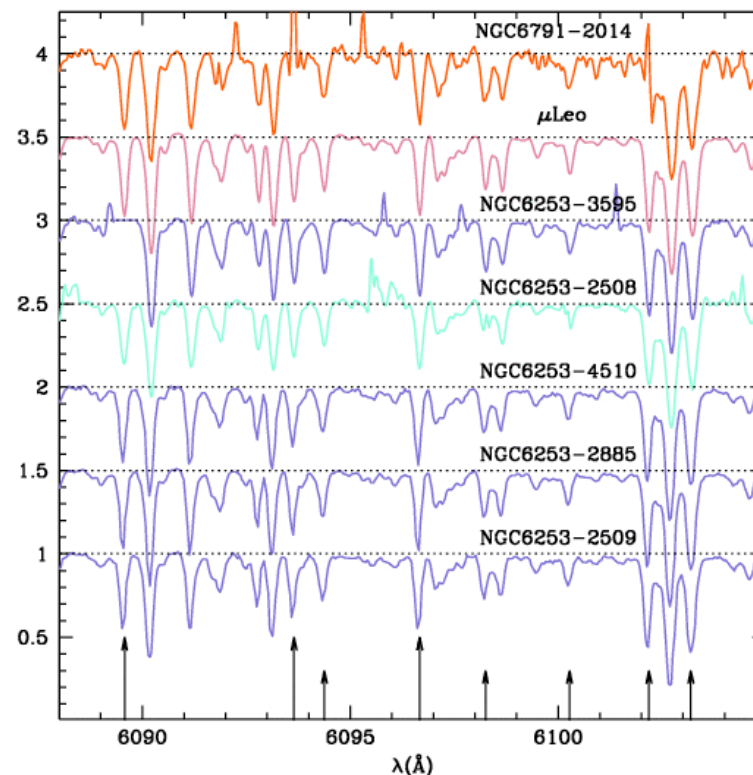
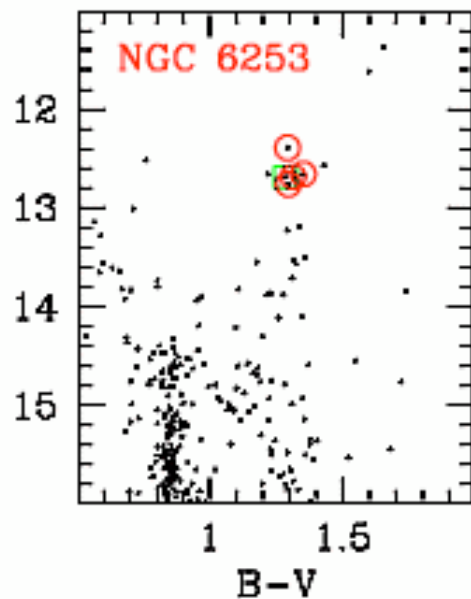
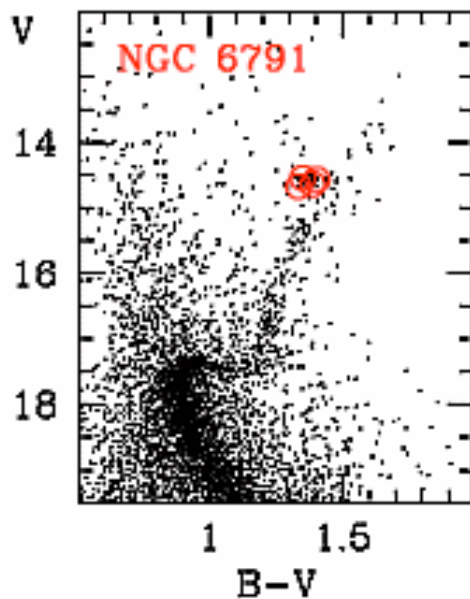


↑ Kalirai et al. 2007, CFHT V, B-V
 ← King et al. 2005, ACS-HST, "V,V-I"

The BOCCE project : NGC 6253 & NGC 6791



NGC6253



NGC 6253: FEROS@1.5m + UVES@VLT
NGC 6791: SARG@TNG

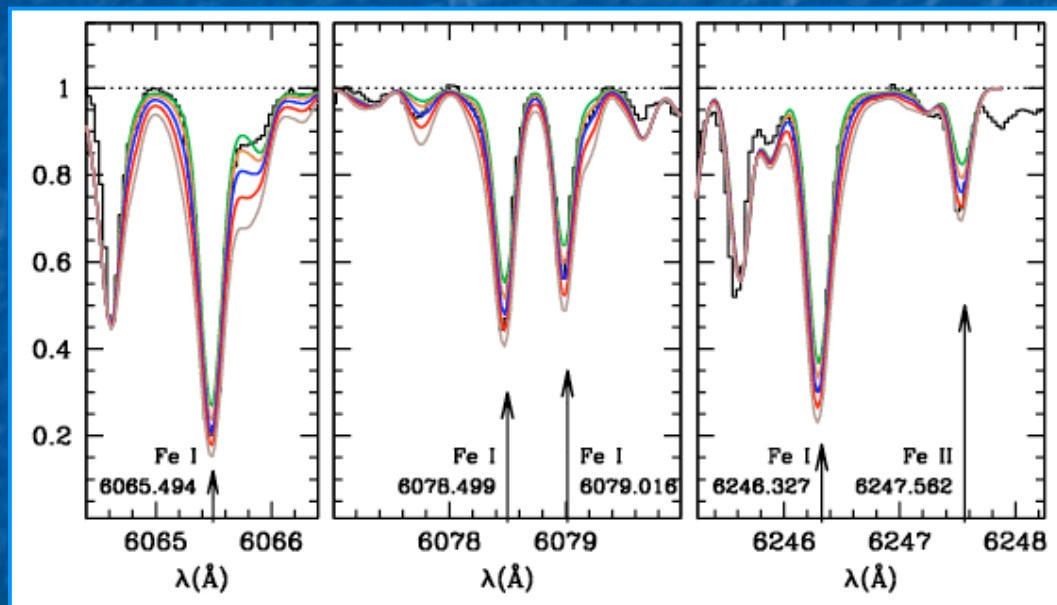
The BOCCE project : NGC 6253 & NGC 6791

We use a list of 50 FeI and 10 FeII lines for synthesis.

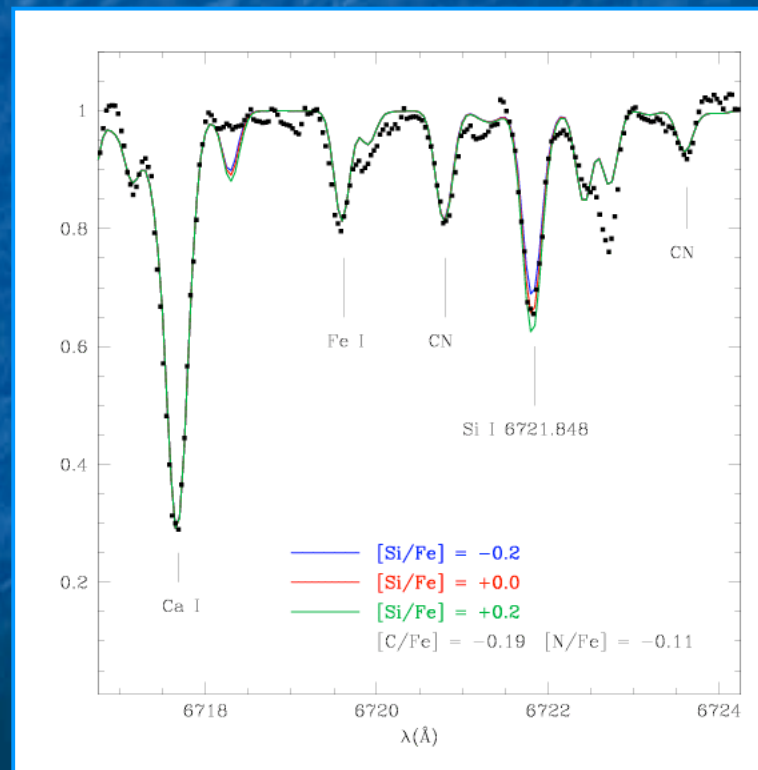
Line lists tested on the very high S/N ($S/N=400$) and resolution ($R=140000$) SARG spectrum of a metal-rich giant star, HR3627

a) Example of synthesis of 4 FeI and 1 FeII lines for star NG6253-2885, with $[Fe/H]=0.0$ to $+0.8$

25-30 FeI, 6 FeII lines used in total



b) Several other elements syntetized (C, N, O, Na, Mg, Al, Si, Ca, Sc II, Ti I, Mn, Ni, Ba II, Eu II)



The BOCCE project : NGC 6253 & NGC 6791

Carretta, Bragaglia, Gratton
2007, A&A, 473, 129

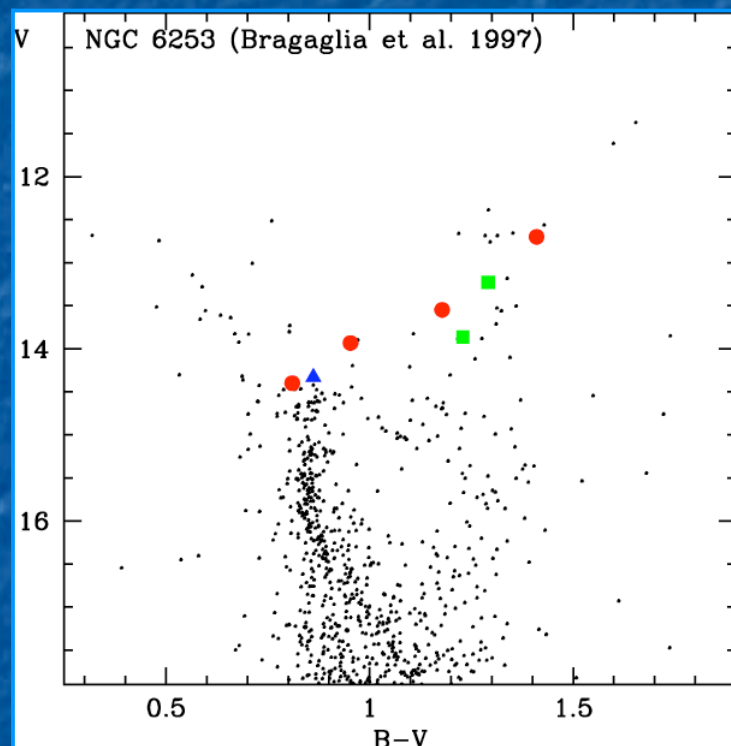
ID	Teff K	log g	v_t km s ⁻¹	Nr	[Fe/H]	rms
NGC 6253						
2509	4518	2.45	1.18	26	+0.45	0.11
2885	4438	2.39	1.19	26	+0.47	0.14
4510	4492	2.47	1.18	26	+0.42	0.12
2508	4536	2.47	1.18			
3595	4568	2.37	1.19	27	+0.48	0.09
NGC 6791						
2014	4463	2.30	1.05	26	+0.40	0.12
3009	4473	2.33	1.05	29	+0.56	0.14
3019	4468	2.35	1.05	28	+0.45	0.11
SE49	4512	2.32	1.05	28	+0.47	0.18

element	NGC 6253		NGC 6791		μ Leo
	mean	rms	mean	rms	
[Fe/H]	+0.46	0.03	+0.47	0.07	+0.46
[C/Fe]	-0.14	0.04	-0.23	0.11	-0.13
[N/Fe]	-0.14	0.03	-0.26		+0.32
[O/Fe]	-0.18	0.06	-0.31	0.08	-0.13
[Na/Fe]	+0.21	0.02	+0.13	0.21	+0.56
[Mg/Fe]	+0.01	0.03	+0.20	0.05	-0.07
[Al/Fe]	-0.08	0.12	-0.21	0.09	+0.30
[Si/Fe]	+0.09	0.06	-0.01	0.10	+0.08
[Ca/Fe]	-0.02	0.12	-0.15	0.08	-0.12
[Sc/Fe]	-0.06	0.01	-0.13	0.07	-0.06
[Ti/Fe]	-0.19:		+0.03	0.09	-0.05
[Mn/Fe]	+0.04	0.07	+0.08	0.07	-0.08
[Ni/Fe]	-0.05	0.00	-0.07	0.07	+0.06
[Ba/Fe]	+0.16	0.04	+0.28	0.12	
[Eu/Fe]	+0.03	0.00	-0.17	0.00	

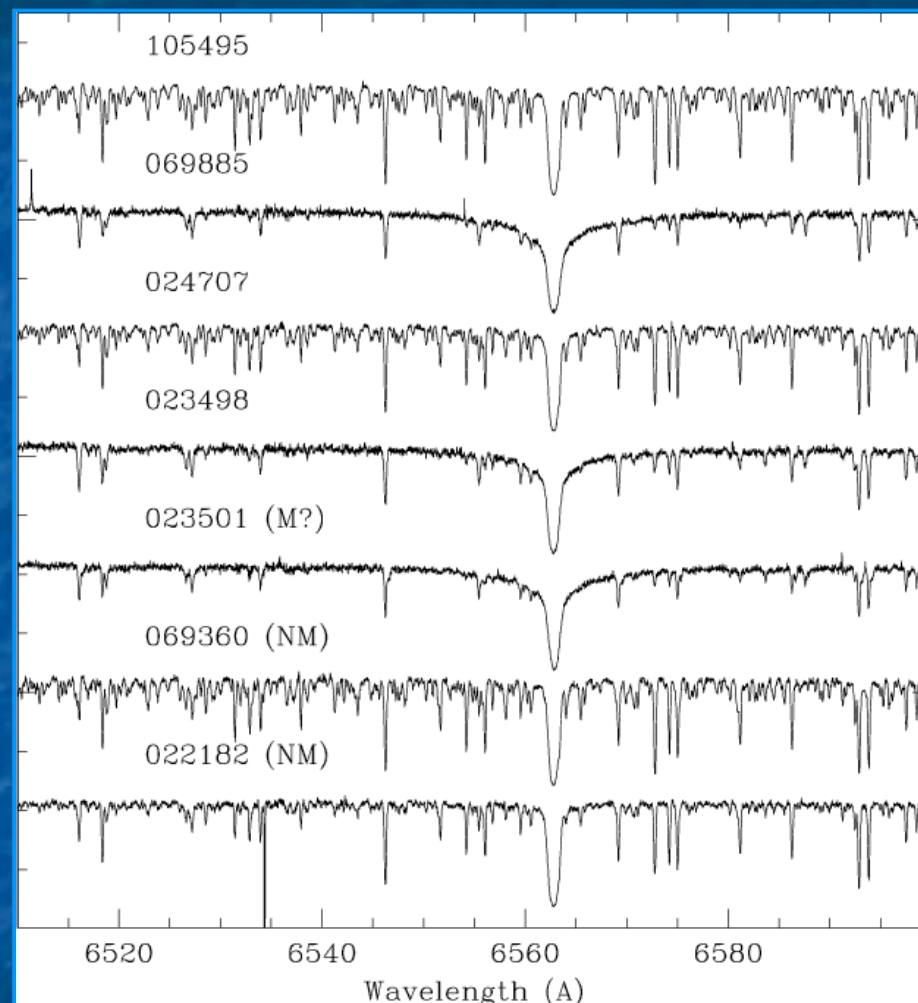
Atmospheric parameters from photometry:
Teff from V-K and Alonso et al. 1999
logg from distance and mass
 v_t from relation with logg (Carretta et al. 2004)

Other works: NGC 6253

NGC 6253



$[\text{Fe}/\text{H}] = +0.36$, $\text{rms}=0.07$
(without NM, clump)
 $+0.39$ (including clump)



FLAMES-UVES spectra

Sestito, Randich, Bragaglia 2007, A&A, 465, 185

Other works: NGC 6791

NGC 6791

Element	Present work	PG98	C+06	O+06
[Fe/H]	+0.47	+0.4	+0.39	+0.35
[C/Fe]	-0.23	+0.0		-0.35
[N/Fe]	-0.26	+0.5		
[O/Fe]	-0.31	+0.0		-0.07
[Na/Fe]	+0.13	+0.4		
[Mg/Fe]	+0.20	+0.2		-0.03
[Al/Fe]	-0.21	+0.0	-0.15	+0.05
[Si/Fe]	-0.01	+0.2	+0.02	+0.02
[Ca/Fe]	-0.15	+0.0	-0.03	+0.05
[Sc/Fe]	-0.13	+0.0		
[Ti/Fe]	+0.03	+0.0	-0.02	+0.03
[Ni/Fe]	-0.07	+0.0	-0.01	
[Ba/Fe]	+0.28	+0.0	-0.13	
[Eu/Fe]	-0.17	+0.1		

PG98 = Peterson & Green 1998
C+06 = Carraro et al. 2006
O+06 = Origlia et al. 2006

Peterson & Green 1998,
ApJ, 532, L39:
1 HB star

Gratton, Bragaglia, Carretta, Tosi 2006,
ApJ, 642, 462:
4 red clump stars

Carraro, Villanova, Demarque,
McSwain, Piotto, Bedin 2006,
ApJ 643, 1151:
10 RGB/clump stars with Hydra

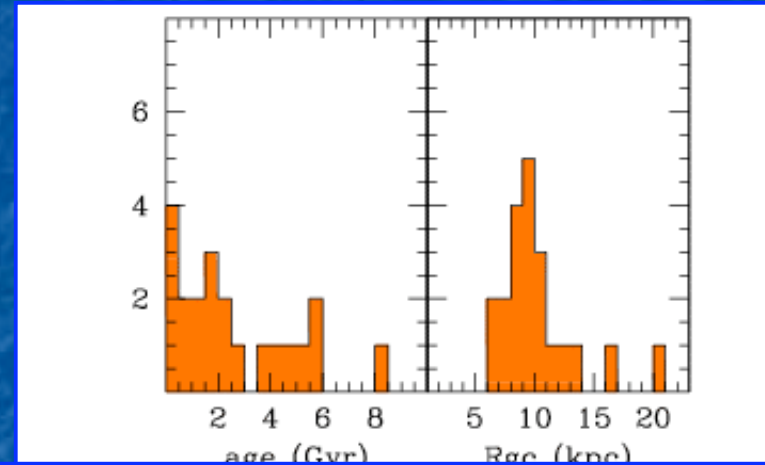
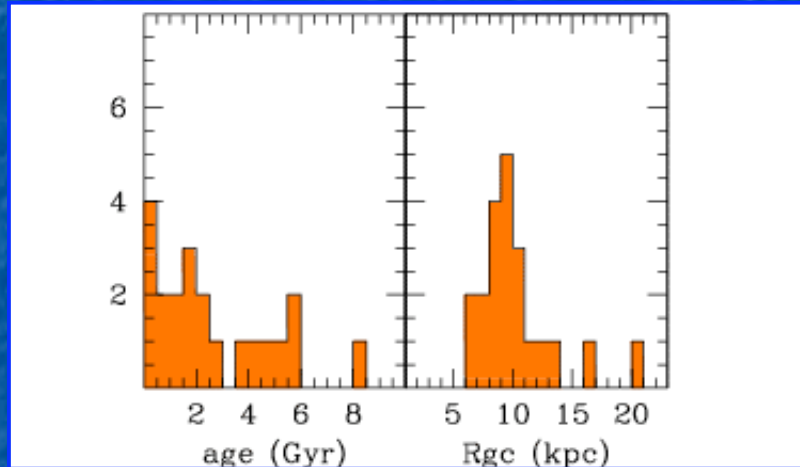
Origlia, Valenti, Rich, Ferraro 2006,
ApJ, 646, 499:
6 RGB-tip stars with NIRSPEC

The BOCCE project: high-res spectroscopy

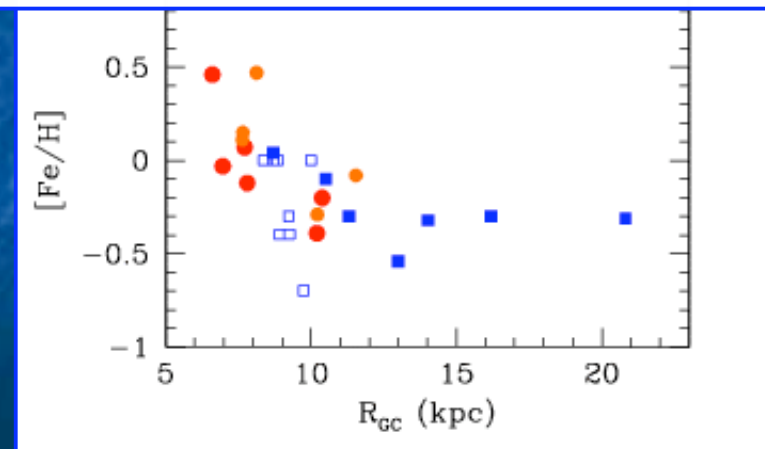
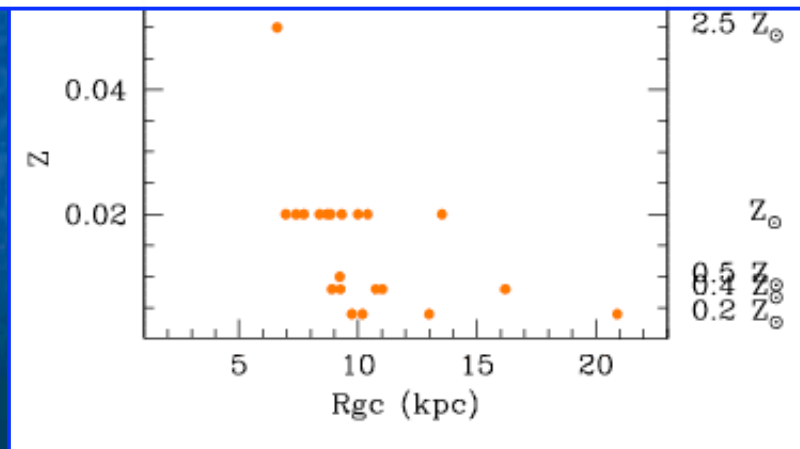
Cluster	age (Gyr)	Nr. stars	Spectrograph	[Fe/H]	Reference
Cr 261	6	6	FEROS	-0.03	Carretta et al. 2005
NGC 6819	2	3	SARG	+0.07	Bragaglia et al. 2001
NGC 2506	1.5	4	FEROS	-0.20	Carretta et al. 2004
NGC 3960	0.9	3	FEROS	-0.12	Bragaglia et al. 2006
NGC 6134	-	6	FEROS/UVES	+0.15	Carretta et al. 2004
IC 4651	-	5	FEROS	+0.11	Carretta et al. 2004
NGC 6791	-	4	SARG	+0.47	Gratton et al. 2006, Carretta et al. 2007
NGC 6253	3	4	FEROS/UVES	+0.45	Carretta et al. 2007
NGC 2204	-	3	UVES		in preparation
NGC 6939	1.3	3	SARG		in progress
Be 17	8.5	3	SARG		in progress
Mel 71	-	2	FEROS		in progress
IC 4756	-	3	FEROS		in progress
NGC 752	-	5	SARG		in progress
Be 32	5.2	9	UVES/FLAMES	-0.29	Sestito et al. 2006, Bragaglia et al. 2007
NGC 2660	0.95	5	UVES/FLAMES	+0.04	Sestito et al. 2006, Bragaglia et al. 2007
Be 29	3.7	6	UVES/FLAMES		in progress
Be 20	5.8	2	UVES/FLAMES		in progress
To 2	-	6	UVES/FLAMES		in progress
Mel 66	-	5	UVES/FLAMES		in progress
NGC 2477	-	6	UVES/FLAMES	+0.07	Sestito et al. 2006, Bragaglia et al. 2007
NGC 2324	-	7	UVES/FLAMES	-0.17	Sestito et al. 2006, Bragaglia et al. 2007

The BOCCE project: radial metallicity gradient (?)

Is there a radial metallicity gradient ?
(and see e.g. young stars, PNe, etc)



GOAL: complete homogeneity, i.e.= all properties derived in BOCCE



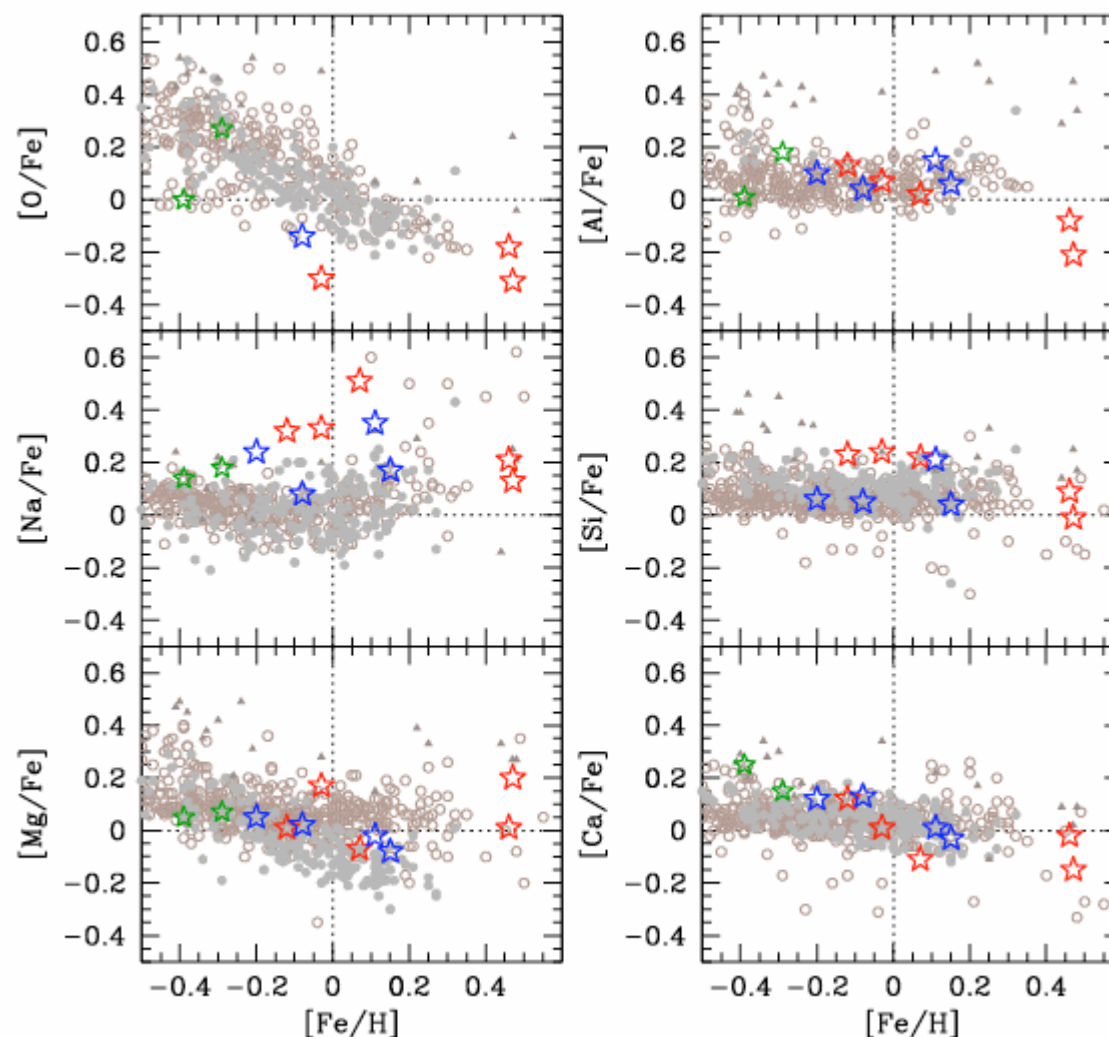
The BOCCE project & the Galactic disk (1)

Are OCs really
representative of the
general population of the
Galactic disk?

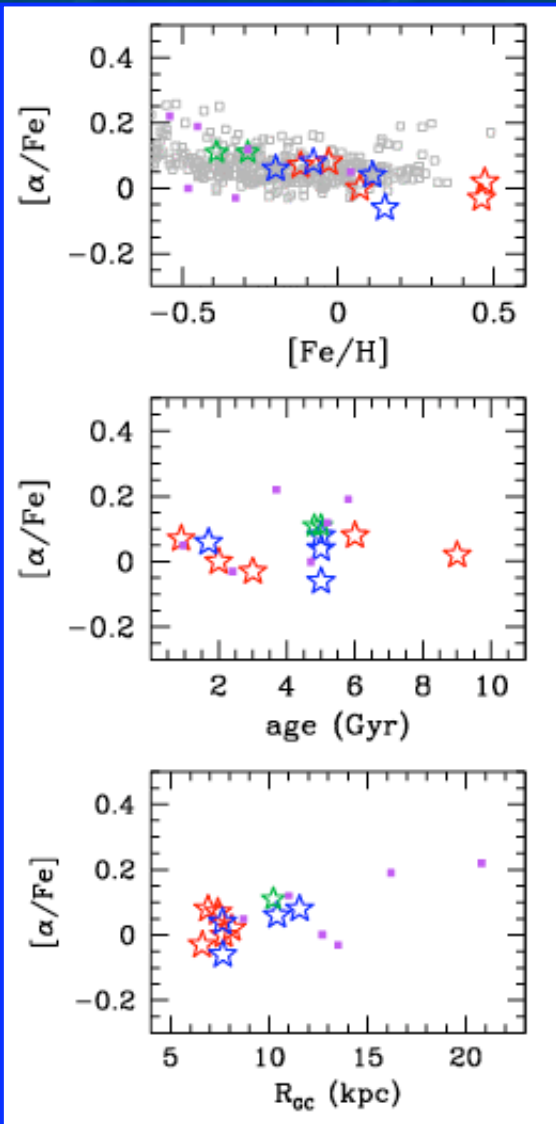
Stars: BOCCE clusters

Field data from:

Soubiran et al. 2005 (dwarfs)
Castro et al. 1997 (dwarfs)
Pompeia et al. 2003 (dwarfs)
Mishenina et al. 2006 (giants)
Fulbright et al. 2007 (bulge)



The BOCCE project & the Galactic disk (3)



$[\alpha/\text{Fe}]$: like thin disk field stars

$[\alpha/\text{Fe}]$: no trend with age

$[\alpha/\text{Fe}]$: trend with R_{gc} ?

(Sestito et al., in preparation & Carraro et al. 2007: no)

The BOCCE project: a summary

- ❖ We try to be as **homogeneous** as possible (internal consistency, systematics)
- ❖ We build a sample to test **stellar evolutionary models** at different masses (ages) and metallicities
- ❖ We derive **[Fe/H], α -el., Fe-group el., s-process el., CNO** for a **large sample** of old OCs for which we also measure **distance, age, reddening**
- ❖ Abundances are on **same scale** of GCs and field stars (comparison between galactic populations)
- ❖ OCs appear to **trace** reasonably **well** disk abundances

Wait for more OCs to come ...