

**OLD OPEN CLUSTERS  
AS TRACERS OF GALACTIC  
CHEMICAL EVOLUTION:  
the BOCCE project**

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## Why are Open Clusters important ?

- We see and measure them accurately in the whole disk
  - They are tracers of the disk and of its evolution
- The old OCs define the first epoch of formation in the disk
  - ~~Information on how the Milky Way formed~~
- They trace chemical abundances in the disk (up to 10 Gyr)
  - Information on the chemical evolution of the disk
- They are “laboratories” for stellar models/theory
  - Test of low and intermediate mass models

# Bologna Open Cluster Chemical Evolution

Poorly studied and exploited up to now :

**About 1200 in catalogues (e.g. Lynga, Mermilliod, Dias et al.)**

**Some hundreds studied (somehow)**

**About 100 have recent CCD studies**

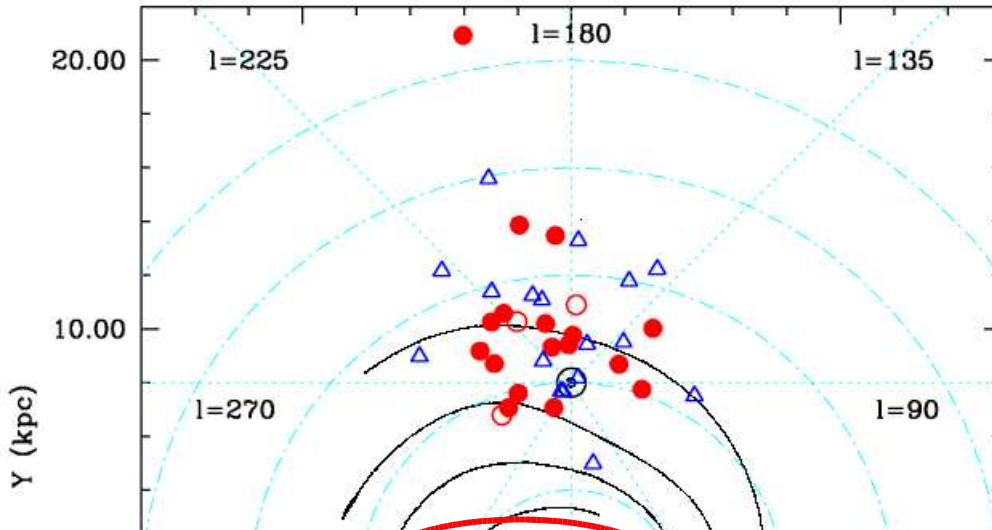
Number of OLD OCs known/studied has increased (about 80)

**We are building a sample LARGE AND HOMOGENEOUSLY ANALYZED of open clusters to accurately determine structure and evolution of the Galactic disk**

Photometric data & synthetic CMD technique:  
**age, distance, reddening (and metallicity)**

High-res spectra & fine abundance analysis:  
**elemental abundances**

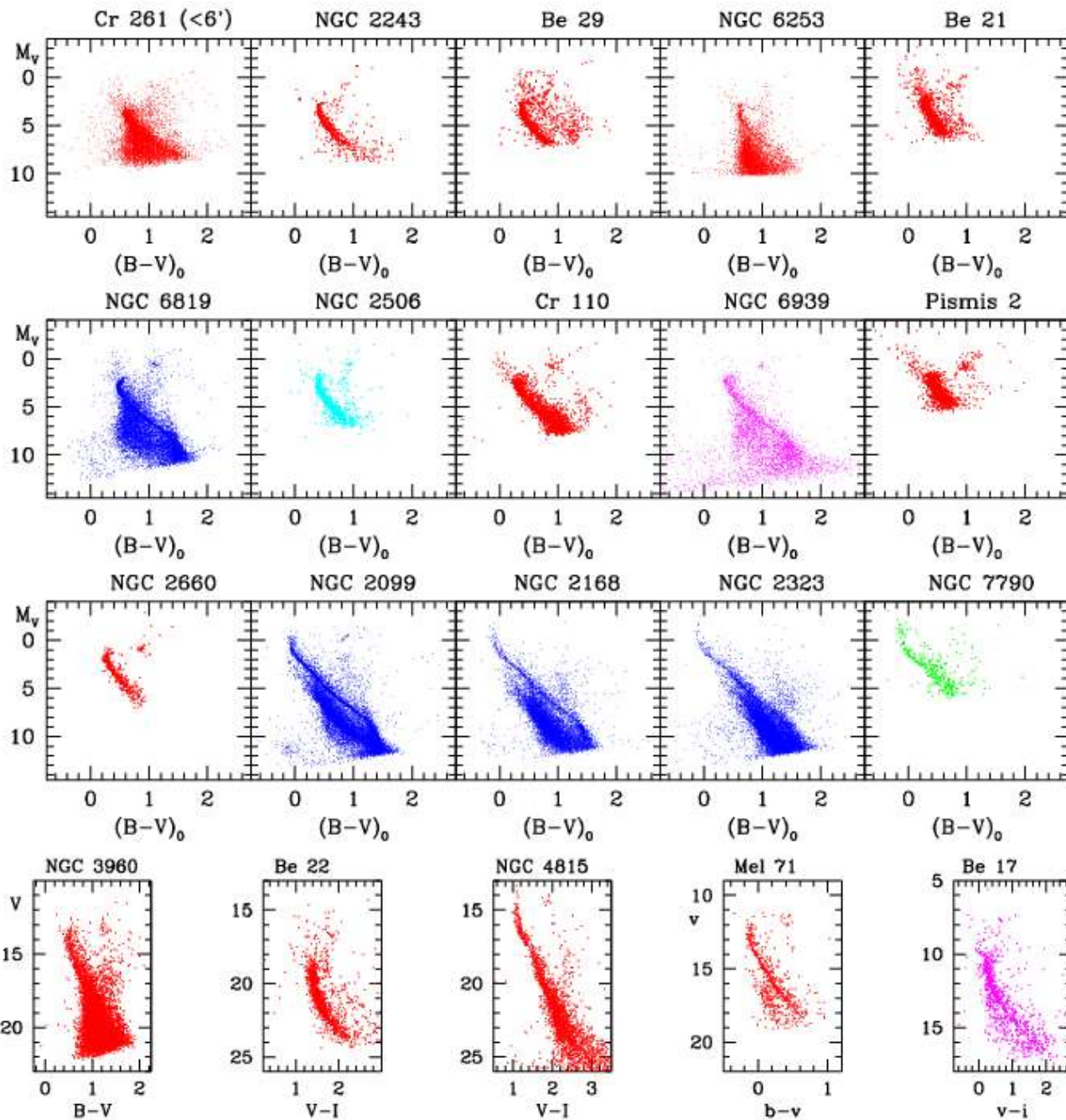
# Photometry: The BOCCE sample



**BOCCE = Bologna Open Clusters  
Chemical Evolution**

|          |              |          |          |
|----------|--------------|----------|----------|
| Cr 261   | <b>Be 29</b> | To 2     | NGC 6603 |
| NGC 2243 | NGC 6819     | NGC 2849 | IC 1311  |
| NGC 6253 | NGC 2099     | NGC 1193 | Be 66    |
| Be 21    | NGC 2168     | Be 20    | King 11  |
| NGC 2506 | NGC 2323     | Be 32    | Be 19    |
| Pismis 2 | Be 22        | IC 361   | NGC 6134 |
| NGC 2660 | NGC 3960     | IC 4756  | IC 4651  |
| Cr 110   | <b>Be 17</b> | NGC 2204 |          |
| NGC 7790 | Mel 71       | Tr 5     |          |
| NGC 6939 | NGC 4815     | NGC 2477 |          |

**Danish 1.5m  
NTT 3.5m  
VLT 8m  
Dutch 0.9m  
Loiano 1.5m  
TNG 3.5m  
CFHT 4m**

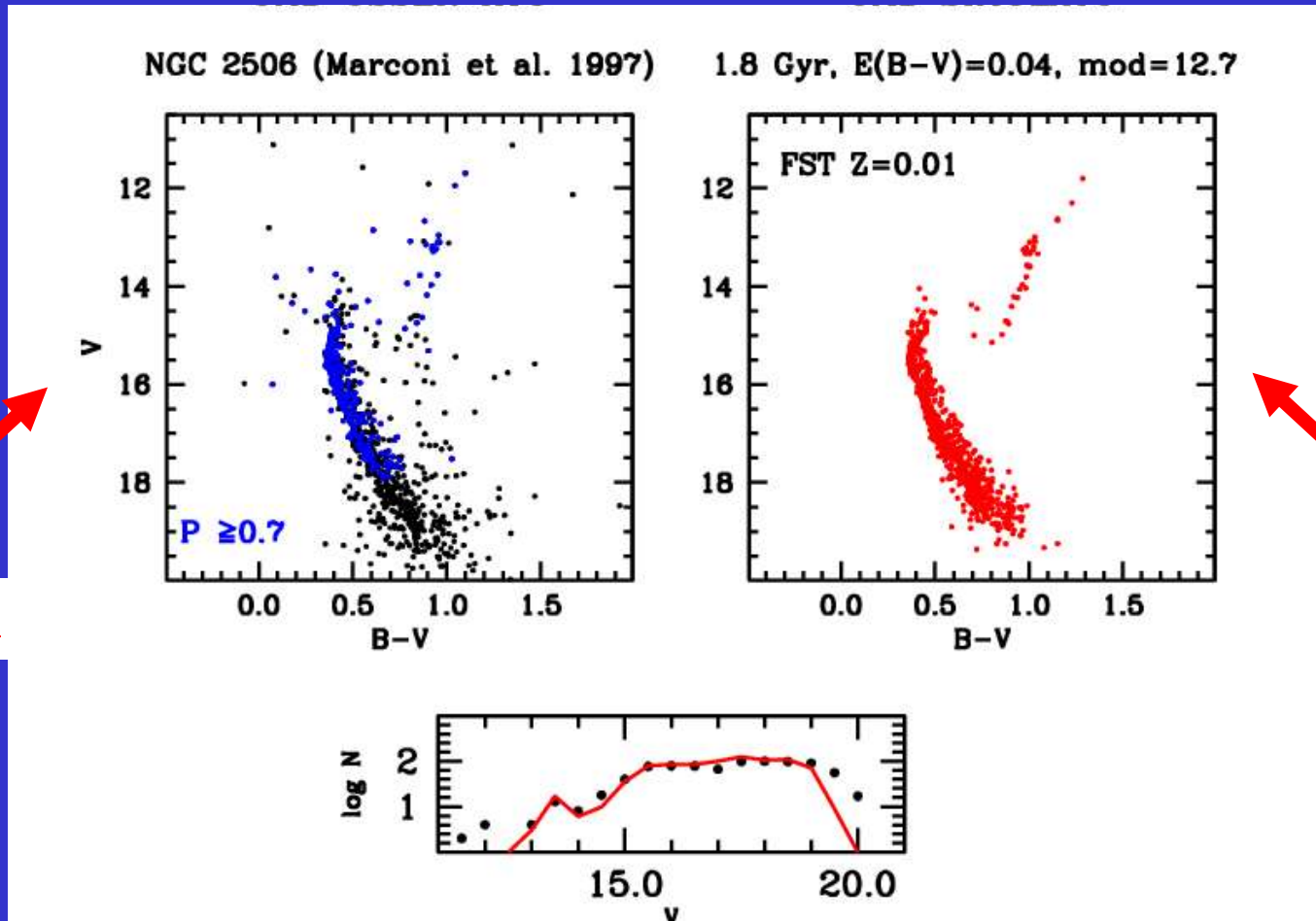


ESO tels.  
 CFHT  
 Loiano  
 CTIO  
 TNG

published

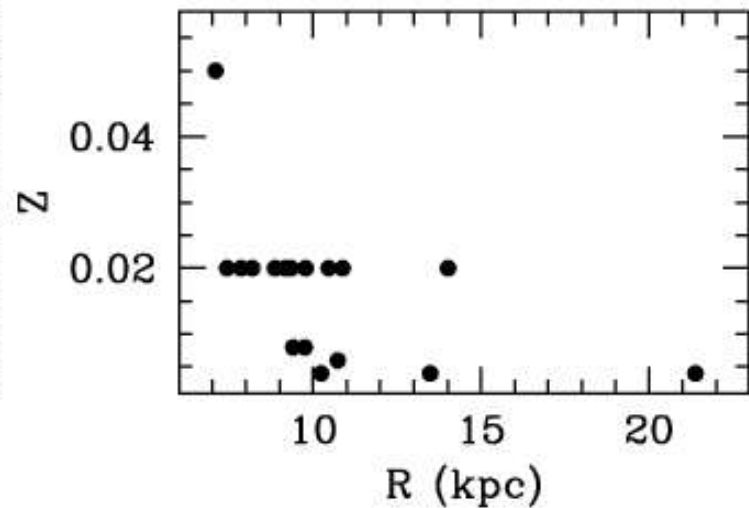
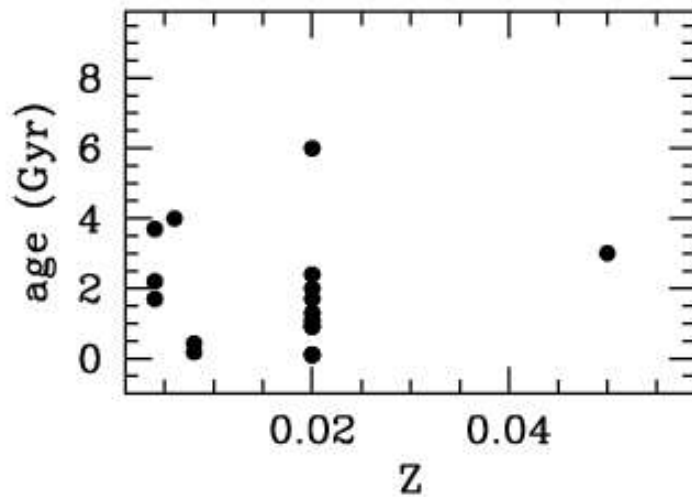
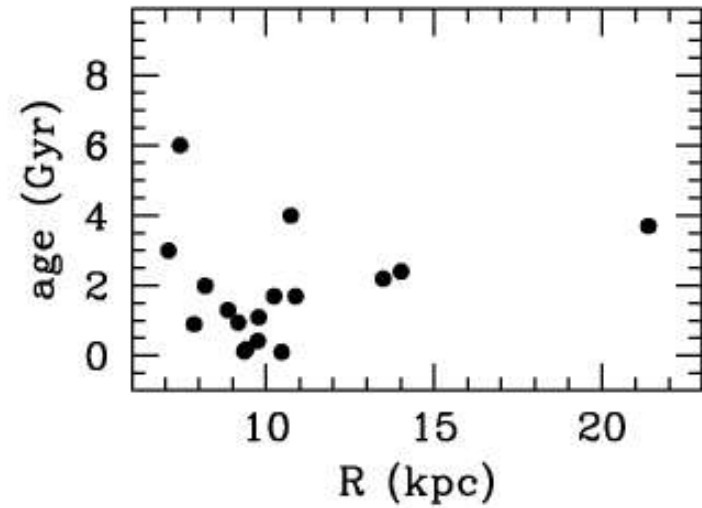
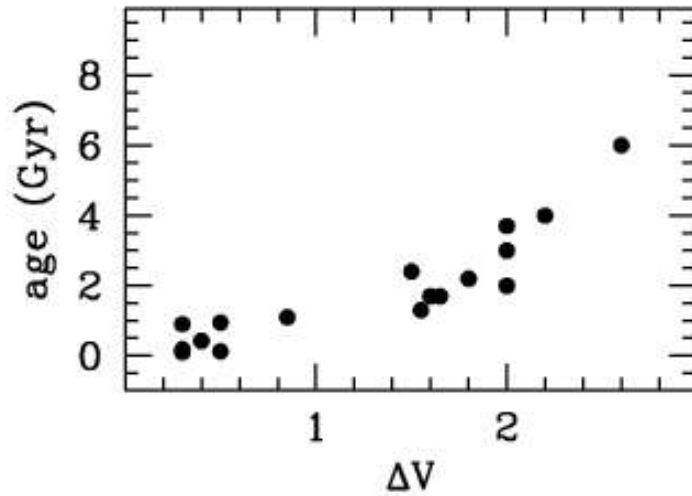
in progress

# Age, distance, reddening, metallicity : synthetic CMD technique



Evolutionary tracks used: FRANEC (1997), Padova (1994), FST (1998+)

# Results based on the first 17 clusters



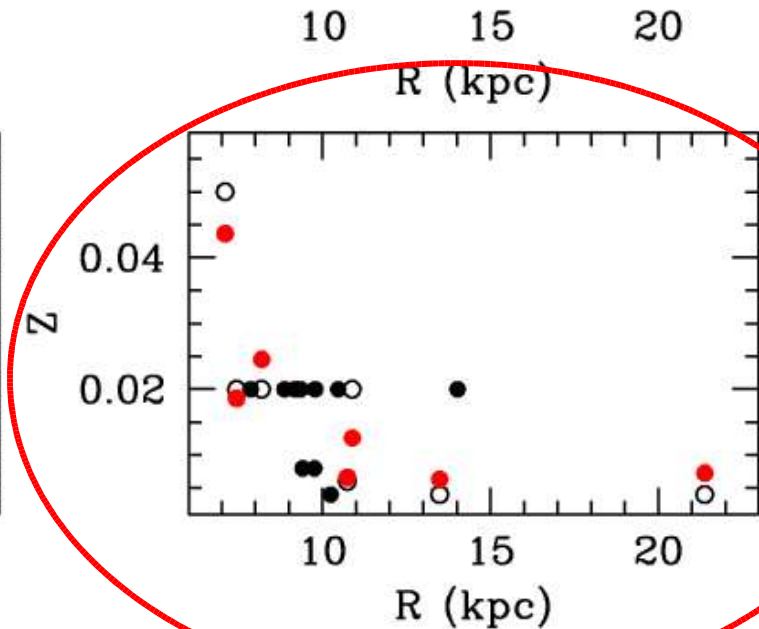
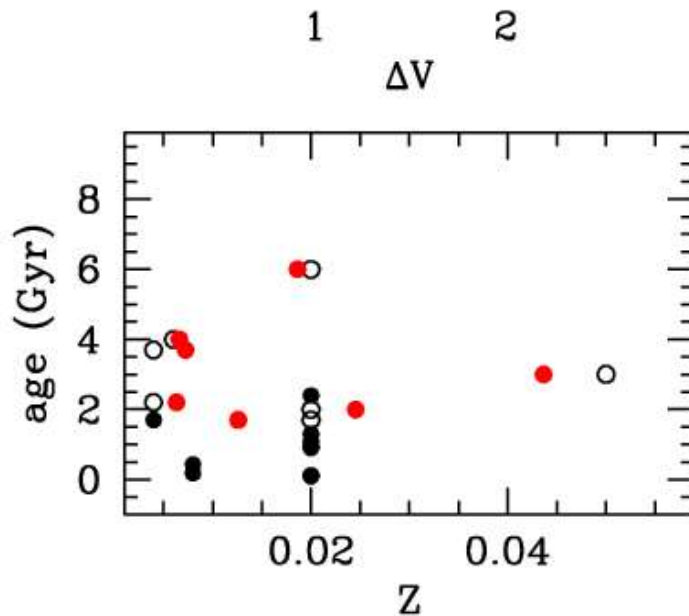
# Results based on the first 17 clusters

## Our group

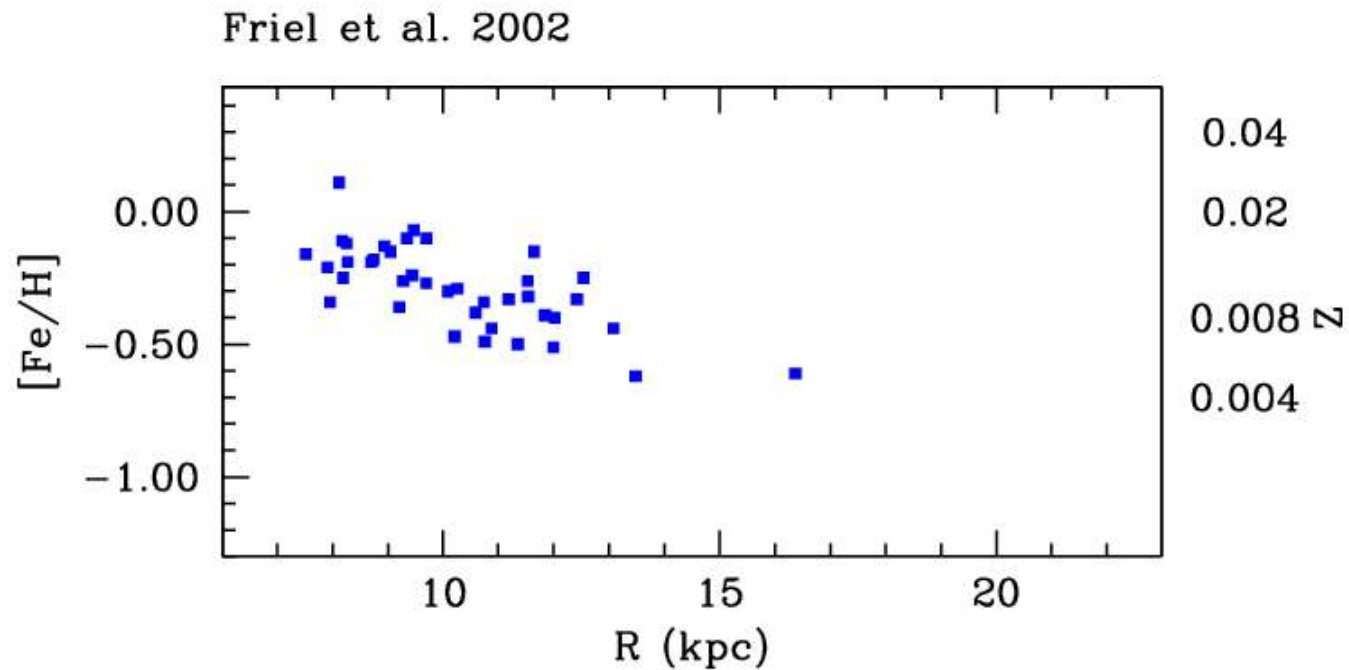
NGC2243: Gratton & Contarini 1994  
NGC6253: Carretta et al. 2000  
NGC6819: Bragaglia et al. 2001  
NGC2506: Carretta et al. 2004  
Cr 261: Carretta et al., in preparation

## Others

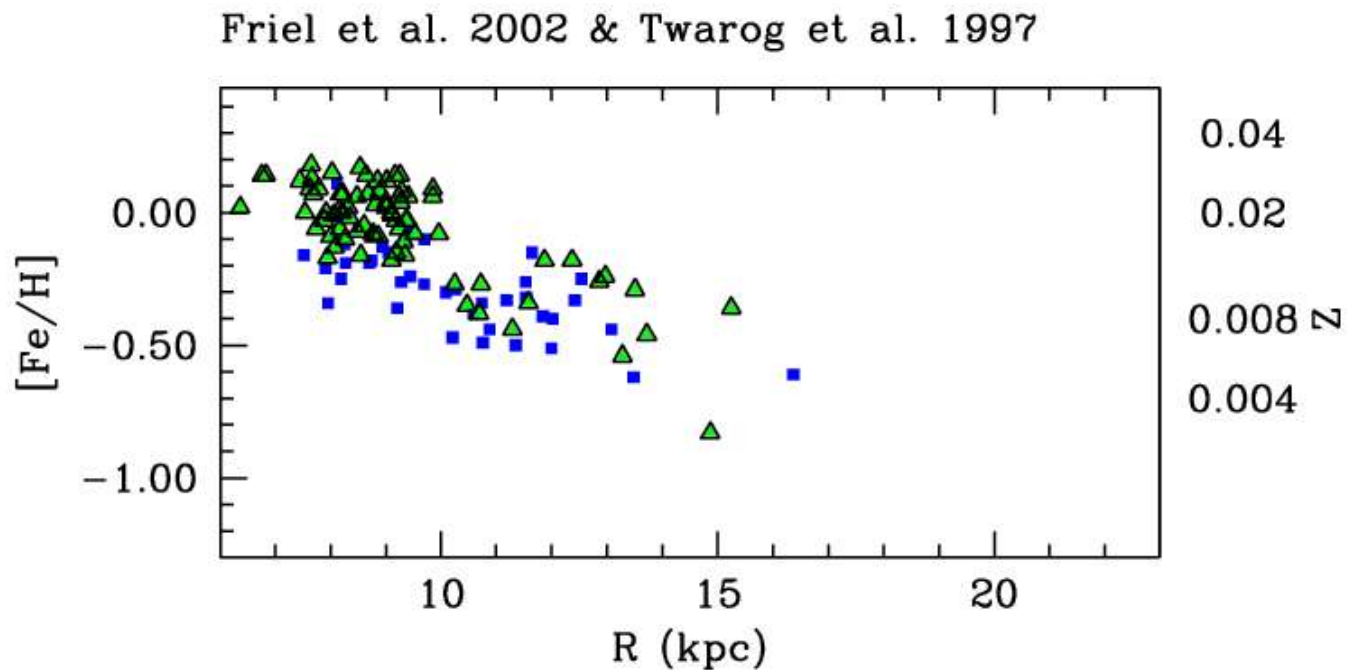
Be 21: Hill Pasquini 1999  
Be 29: Carraro et al. 2004



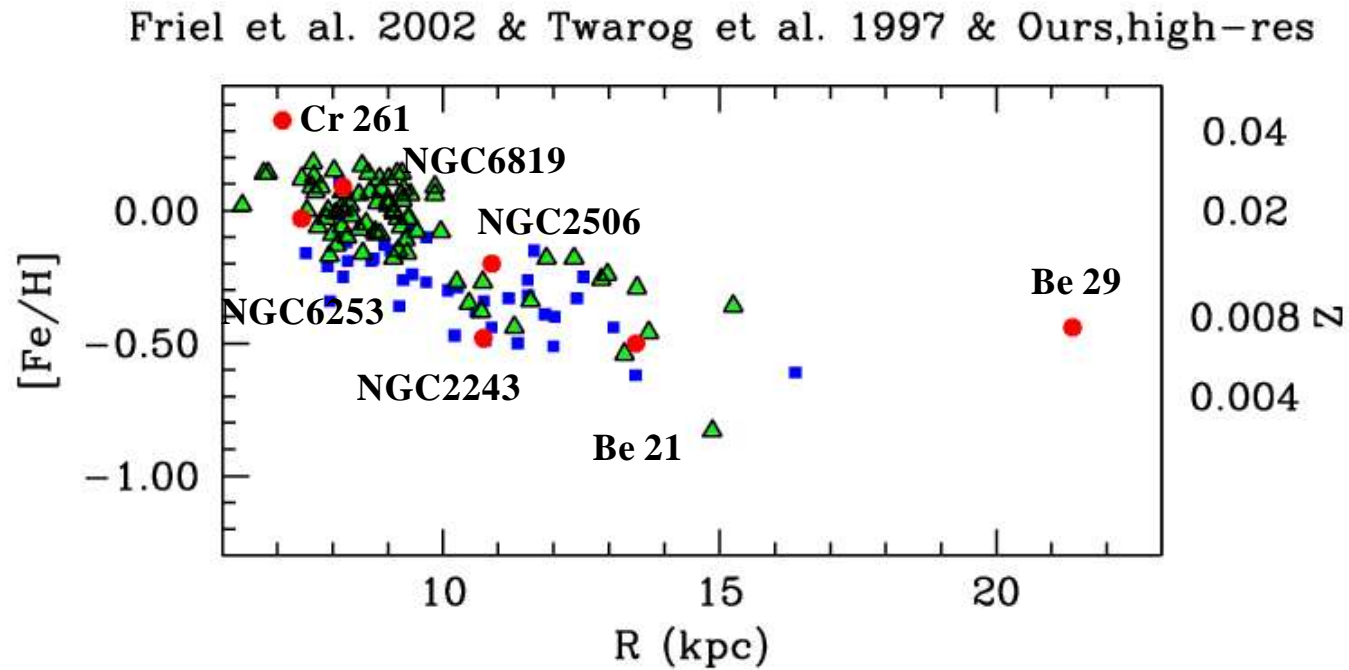
# Radial metallicity distribution



# Radial metallicity distribution

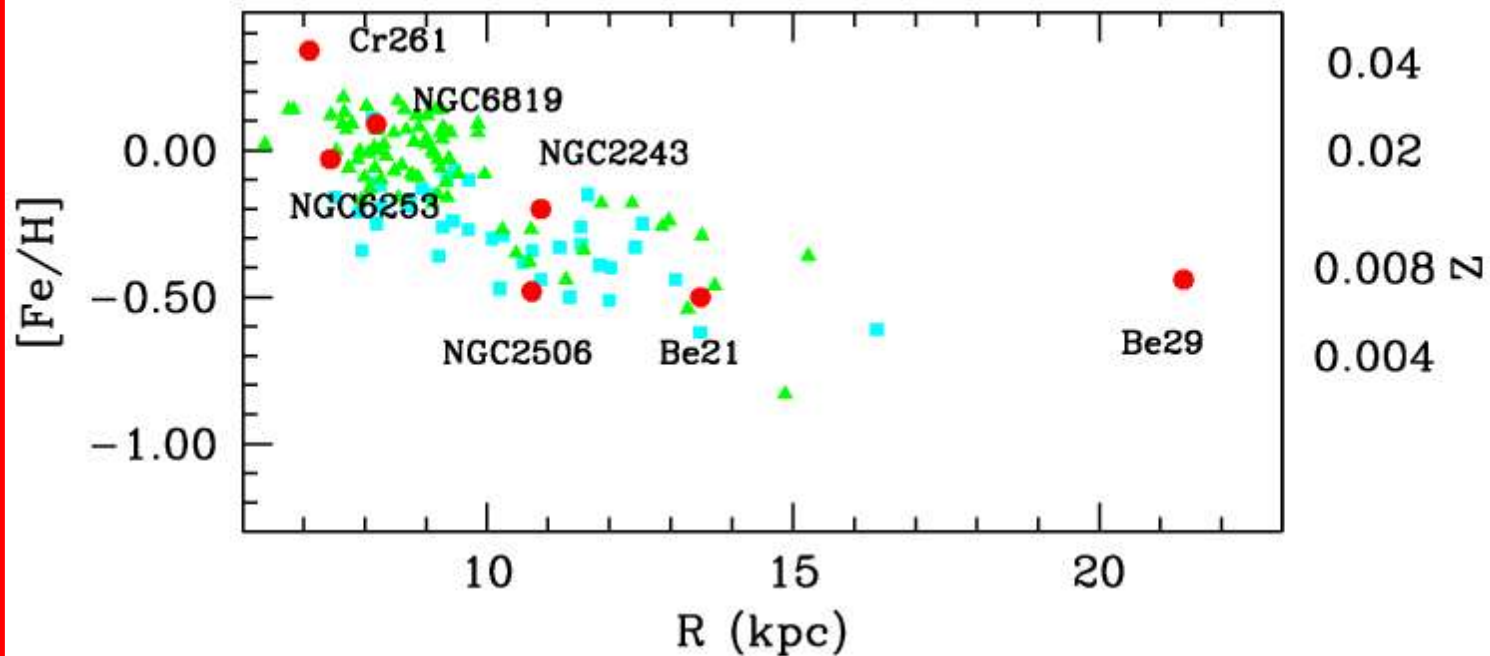


# Radial metallicity distribution



# Radial metallicity distribution

Friel et al. 2002 & Twarog et al. 1997 & Ours, high-res



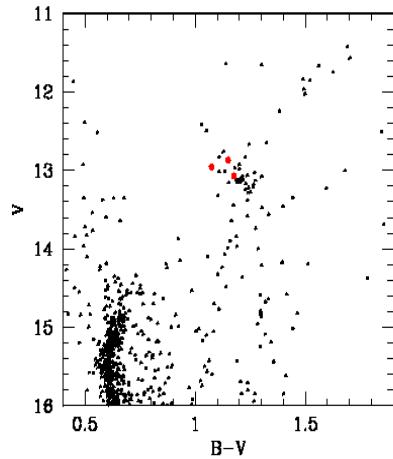
## First conclusions from the photometric sample

- **32 OCs presently in our sample, 1/2 finished**
- **Precise and homogeneous distance, reddening, age (metallicity)**
- **Test stellar evolutionary models (Geneva, Padova, FRANEC, FFT): moderate overshooting seems better**
- **Photometric abundances: gradient with  $R_{gc}$  (?), age dispersion at any  $R_{gc}$  and  $Z$ , qualitatively consistent with standard models of chemical evolution**

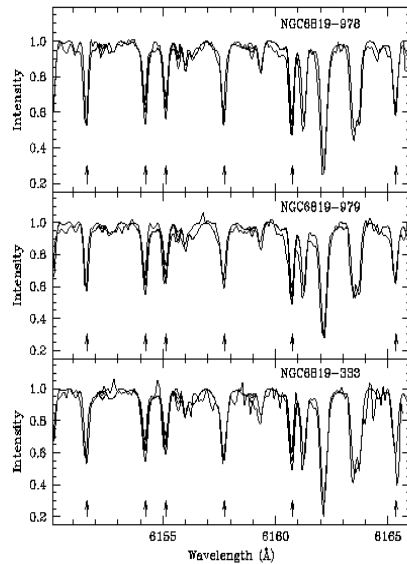
**Need reliable abundances (i.e. high-res spectroscopy)**

# High-res spectra & metallicity

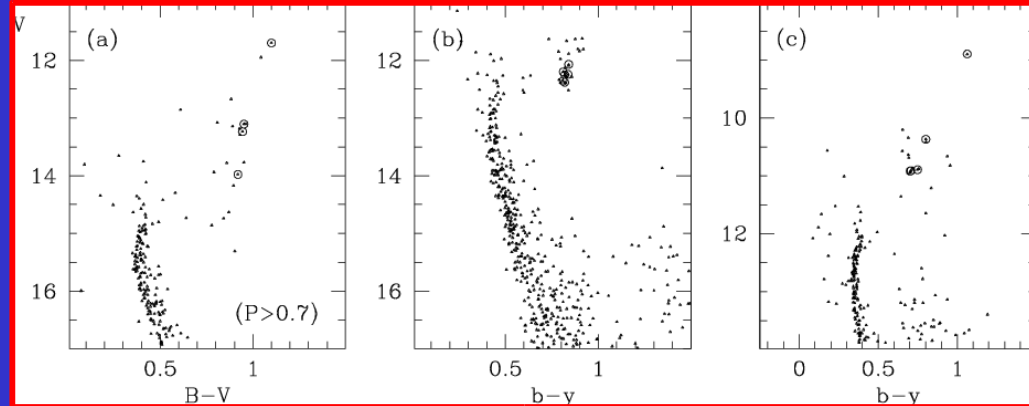
NGC 6819



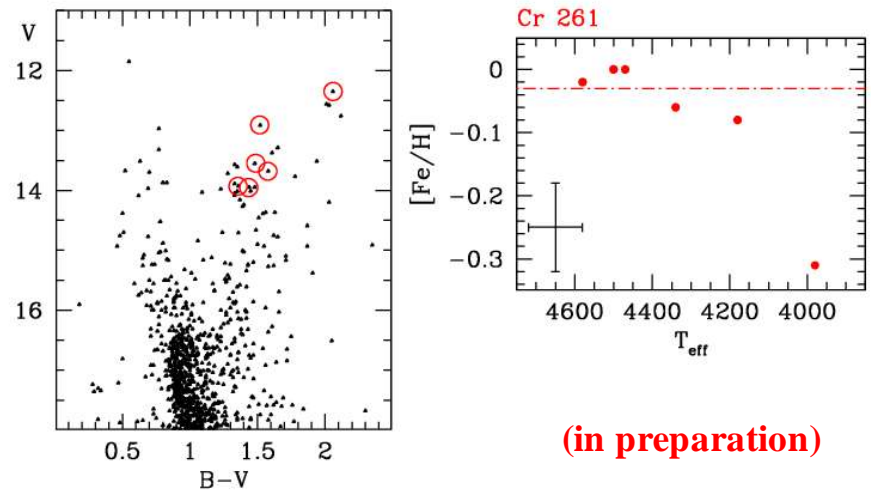
SARG analysis :  $[Fe/H]=+0.09 \pm 0.03$  (Bragaglia et al. 2001)



NGC 2506 NGC 6134 IC 4651 (Carretta et al.2004)

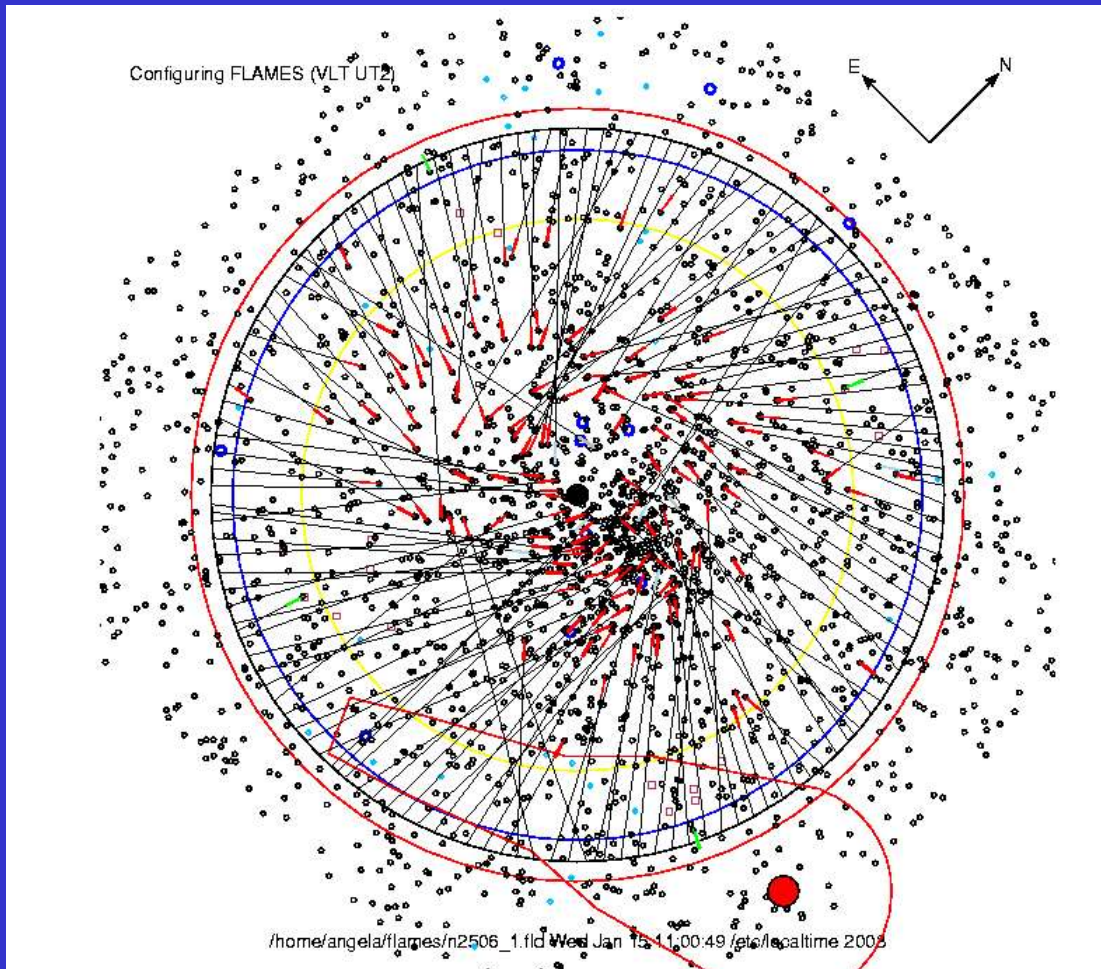


Cr 261



(in preparation)

# FLAMES @ VLT

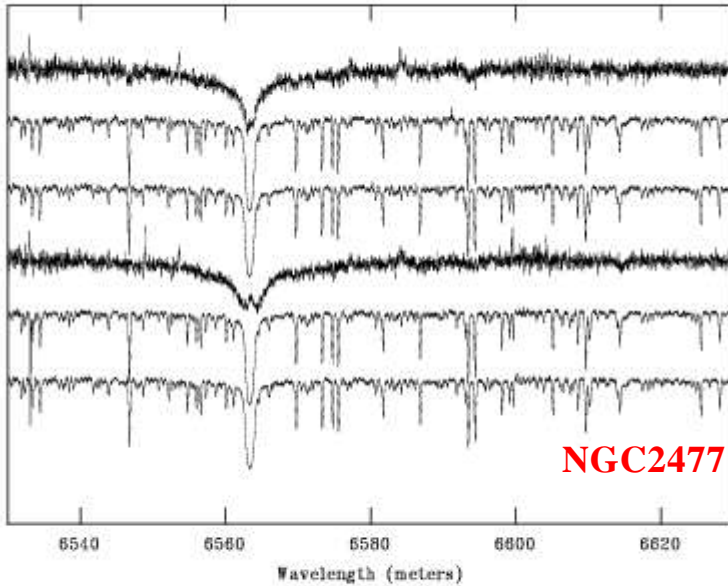


**Old:**  
**Cr 261**  
**NGC 2506**  
**Mel 66**

**GTO (Ital-FLAMES: Oss. Bologna, Cagliari, Palermo, Trieste)**

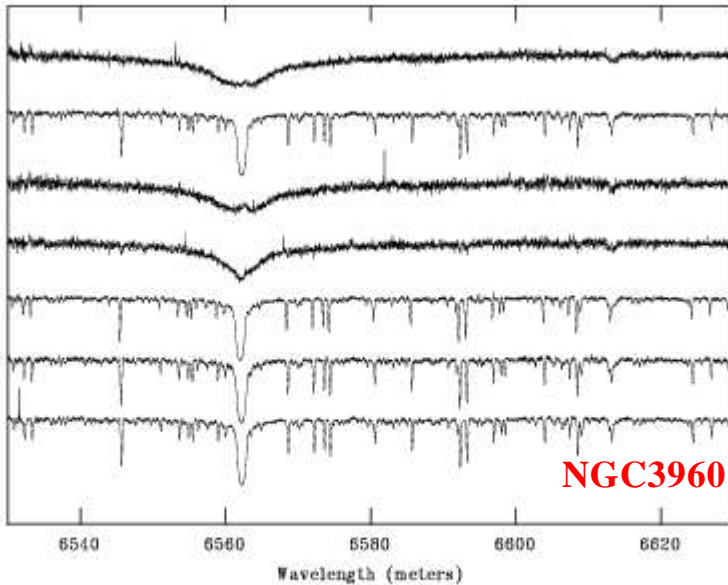
# FLAMES @ VLT

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Separation step = 0.06040157

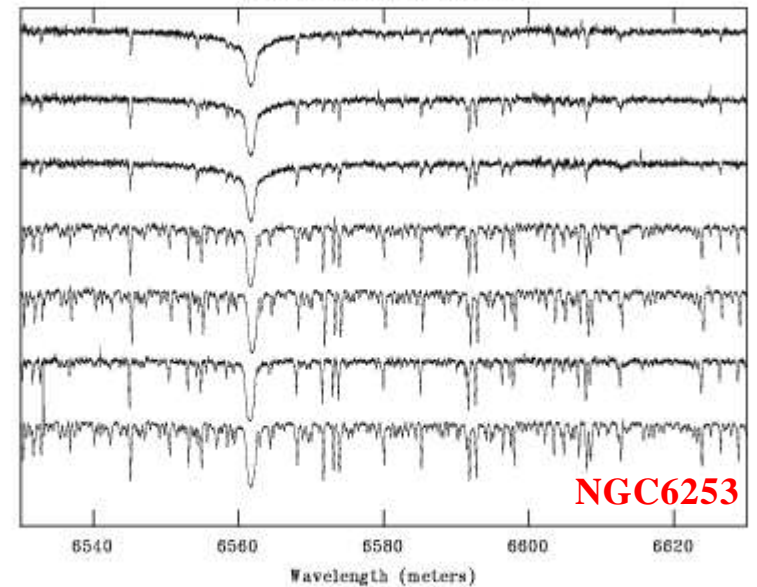


P73 (old):  
NGC 2477  
NGC 6253  
NGC 3960

NOAO/IRAF V2.12.1-EXPORT angela@pallino.bo.astro.it Fri 16:36:44 03-Sep  
Separation step = 0.09250565



NOAO/IRAF V2.12.1-EXPORT angela@pallino.bo.astro.it Fri 16:29:27 03-Sep  
Separation step = 0.09325381



GO

## First conclusions from the spectroscopic sample

- **NGC 6819** ( $[\text{Fe}/\text{H}] = +0.09$ ), **NGC 2506** ( $[\text{Fe}/\text{H}] = -0.20$ )  
**IC 4651** ( $[\text{Fe}/\text{H}] = +0.11$ ), **NGC 6134** ( $[\text{Fe}/\text{H}] = +0.13$ ),  
**Cr 261** ( $[\text{Fe}/\text{H}] \cong \text{solar}$ )  
qualitatively conform to the radial abundance gradient
- **We'll have  $[\text{Fe}/\text{H}]$ ,  $\alpha$  elements, precise and homogenous for 23 old OCs (9 new determinations) to compare with  $\approx 20$**
- **Metallicity for open clusters on same scale of globular clusters and field stars**

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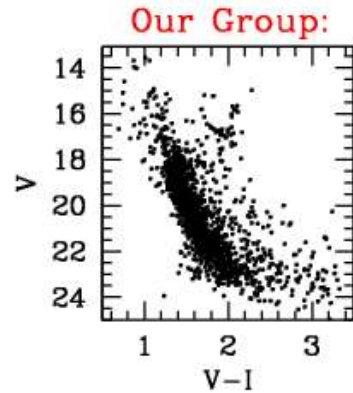
**Thank you**

\*\*\*\*\*

# High-res spectra : present & future

| Cluster  | Age<br>(Gyr) | $R_{GC}$<br>(kpc) | $E(B-V)$      | [Fe/H]<br>photom./spectr. | Notes                 |
|----------|--------------|-------------------|---------------|---------------------------|-----------------------|
| NGC 2506 | 1.7          | 10.50             | $\simeq 0.05$ | -0.2                      | FEROS FLAMES.GTO      |
| Cr 261   | 6.0          | 6.00              | $\simeq 0.20$ | $\sim 0.0$                | FEROS FLAMES.GTO      |
| IC 4651  | 2.5          | 7.65              | 0.09          | +0.11                     | FEROS                 |
| NGC 6134 | 0.7          | 7.10              | 0.263         | +0.13                     | FEROS UVES.           |
| Mel 71   | 1.0          | 10.46             | 0.11          | -0.30                     | FEROS                 |
| NGC 3960 | 0.8          | 7.96              | 0.30          | -0.34                     | FEROS FLAMES.P73      |
| IC 4756  | 0.9          | 8.19              | 0.19          | -0.22                     | FEROS                 |
| NGC 6253 | 3.0          | 7.00              | $\simeq 0.20$ | +0.36                     | FEROS UVES FLAMES.P73 |
| NGC 2204 | 1.6          | 11.84             | 0.09          | -0.58                     | UVES                  |
| NGC 6819 | 2.2          | 8.18              | 0.10          | +0.09                     | SARG                  |
| NGC 6939 | 2.2          | 8.70              | 0.32          | -0.14                     | SARG                  |
| Be 32    | 7.2          | 11.30             | 0.16          | -0.58                     | SARG                  |
| NGC 6791 | 10.0         | 9.50              | 0.12          | +0.40                     | SARG                  |
| Be 17    | 9.0          | 10.89             | 0.70          | -0.29                     | SARG                  |
| NGC 752  | 1.4          | 8.75              | 0.03          | -0.16                     | SARG                  |
| Hyades   | 0.6          | 8.55              | 0.01          | +0.13                     | SARG                  |
| NGC 2477 | 1.0          | 8.9               | 0.28          | -0.13                     | FLAMES.P73            |
| Mel 66   | 2.8          | 0.4               | 0.14          | -0.35                     | FLAMES.GTO            |
| Be 29    | 3.5          | 22                | 0.12          | -0.5                      | FLAMES.P74            |
| Be 20    | 4.9          | 16.4              | 0.14          | -0.60                     | FLAMES.P74            |
| To 2     | 2.5          | 13.1              | 0.30          | -0.44                     | FLAMES.P74            |
| NGC 2324 | 0.9          | 11.6              | 0.20          | -0.15                     | FLAMES.P74            |
| NGC 2141 | 2.5          | 12.6              | 0.40          | -0.26                     | FLAMES.P74            |

There is room  
for improvement

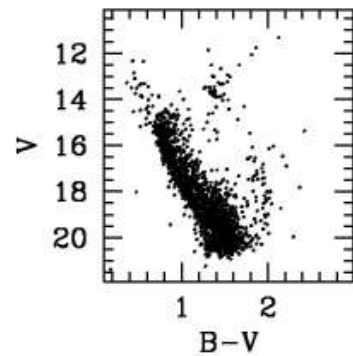
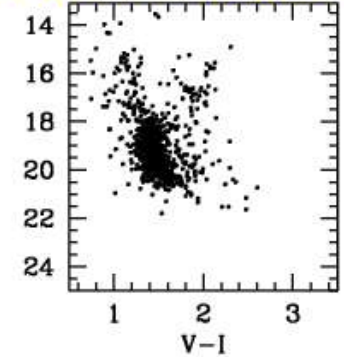


Berkeley 21

Tosi et al. (1998)

Janes et al. (1994)

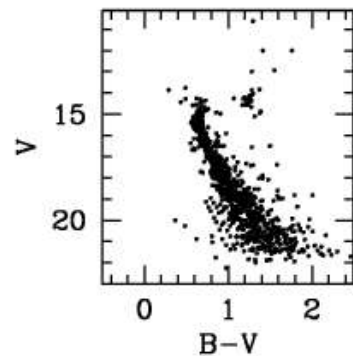
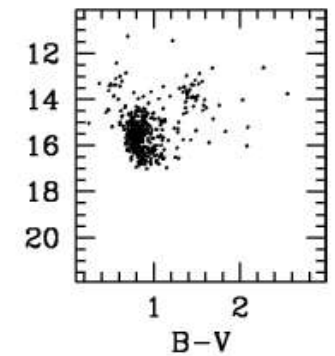
Best CMD in literature:



Cr 110

Bragaglia & Tosi (2003)

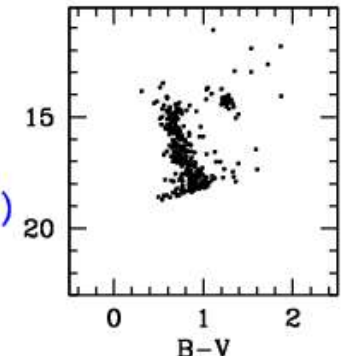
Dawson & Ianna (1998)



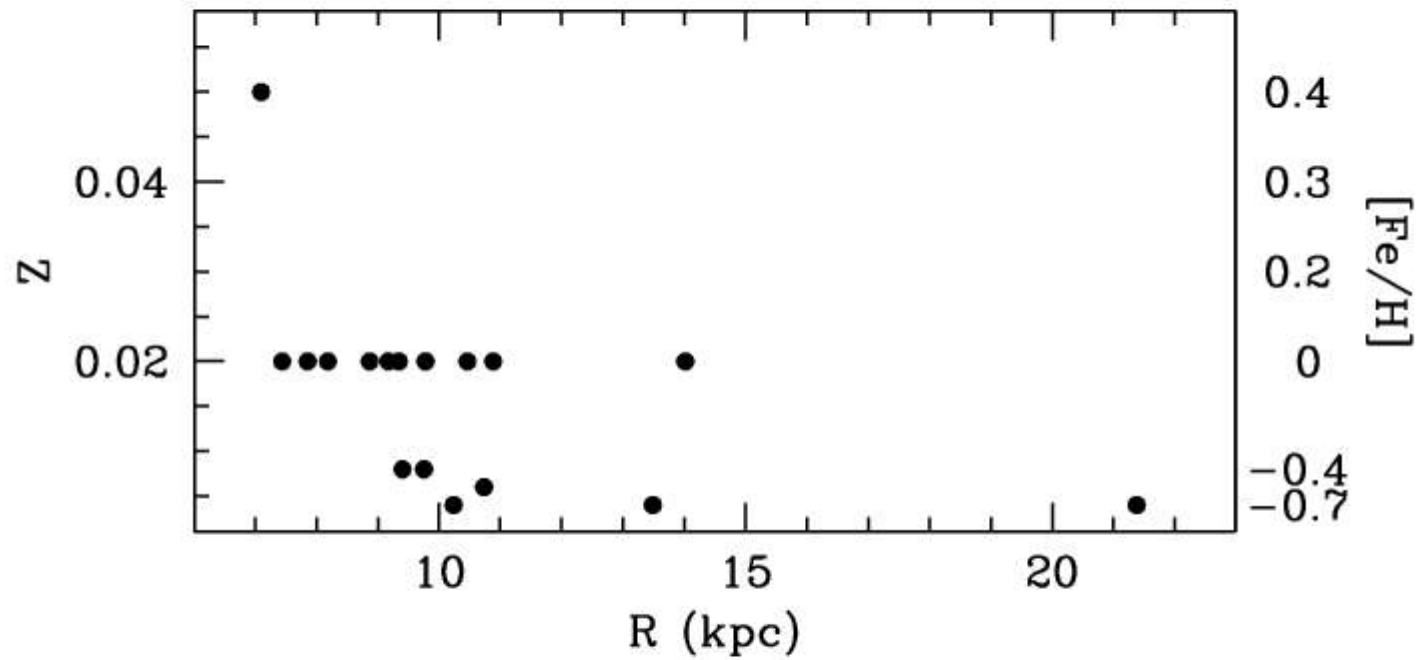
NGC 2660

Sandrelli et al. (1999)

Hartwick & Hesser (1973)



# Radial metallicity distribution



# Radial metallicity distribution

NGC2243: Gratton & Contarini 1994

NGC6253: Carretta et al. 2000

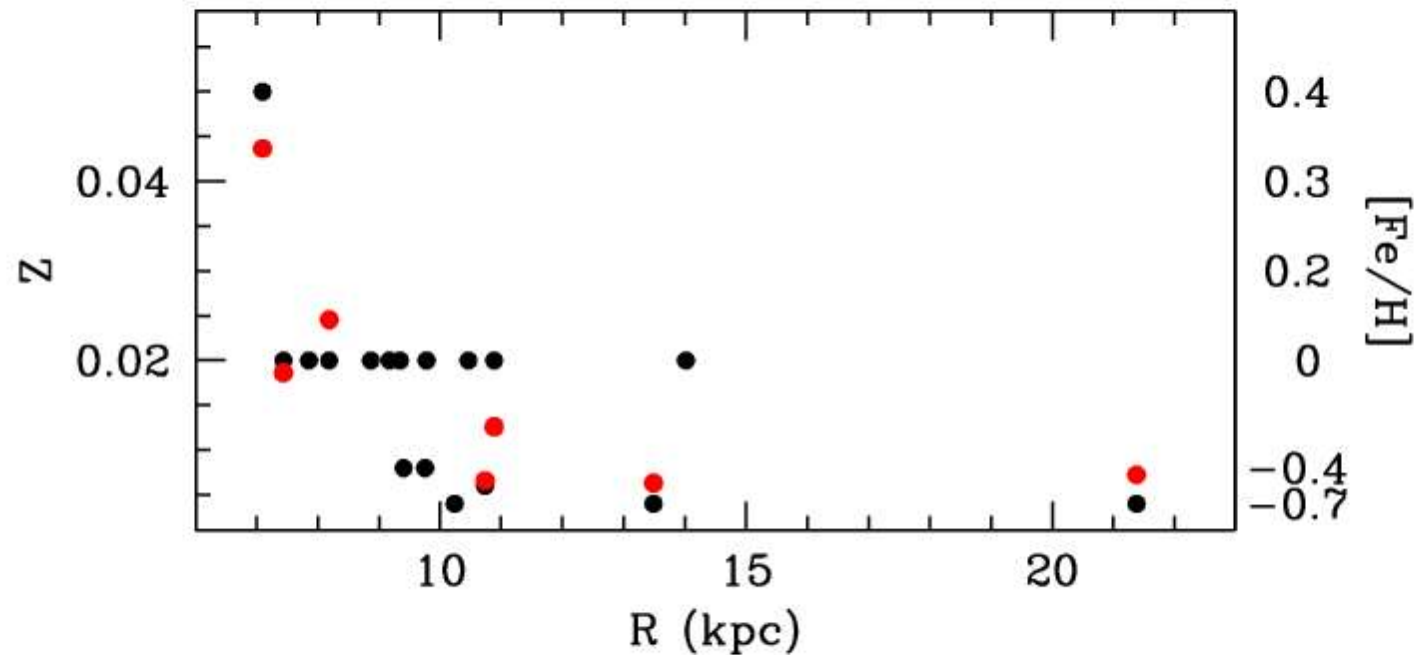
NGC6819: Bragaglia et al. 2001

NGC2506: Carretta et al. 2004

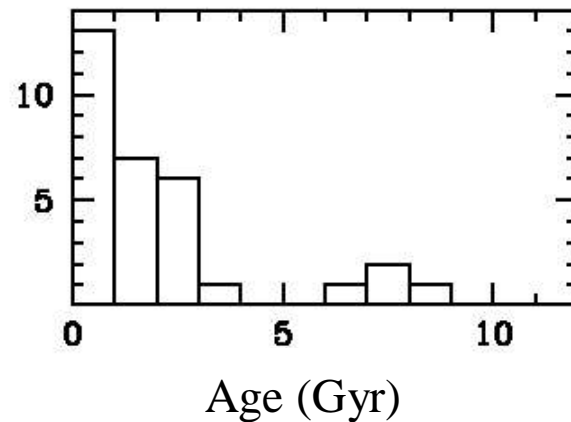
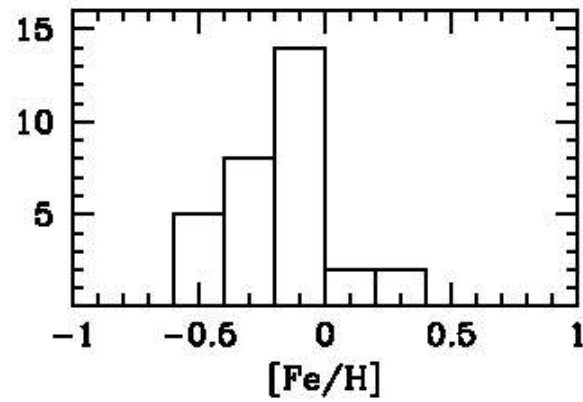
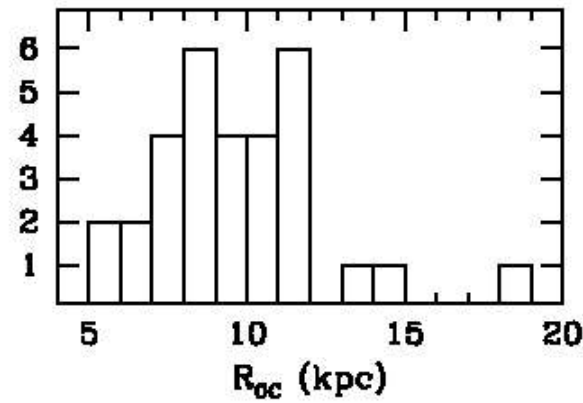
Cr 261: Carretta et al. in preparation

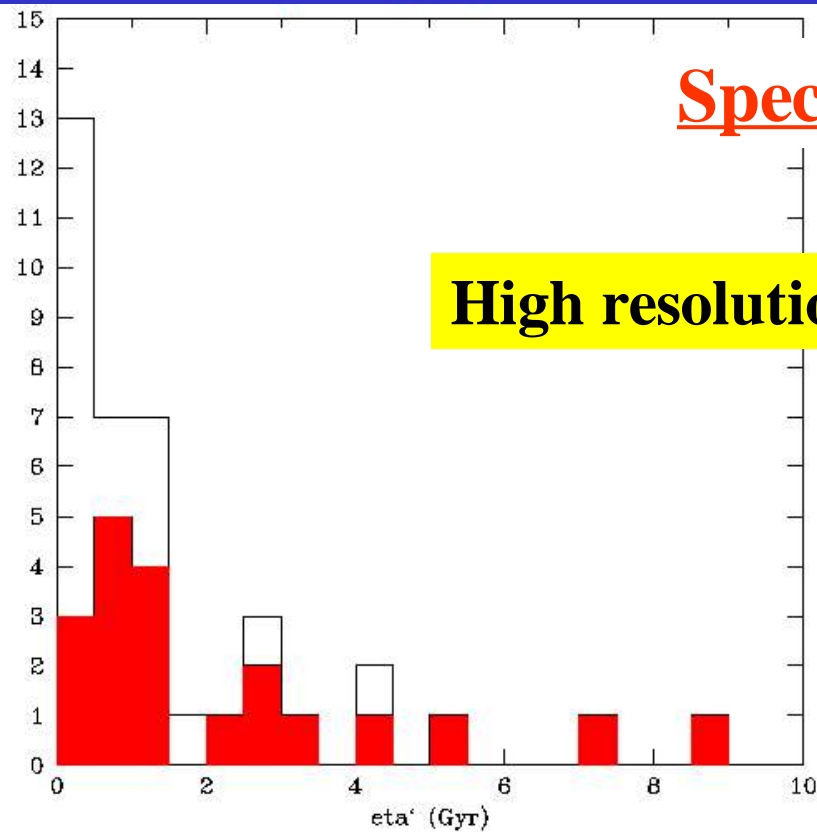
Be 21: Hill & Pasquini 1999

Be 29: Carraro et al. 2004



# Distribution of OC' s in our sample (in $R_{gc}$ , $[Fe/H]$ , age)





## Spectroscopy

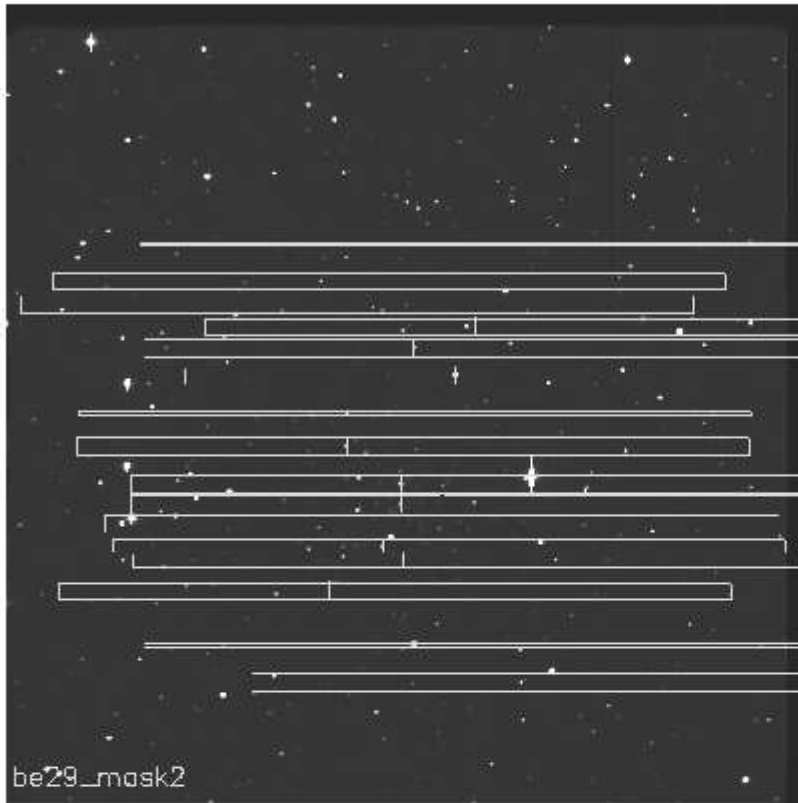
**High resolution required!**

**FEROS @1.5m ESO**  
**EMMI @NTT**  
**UVES @VLT**  
**SARG @TNG**  
 +  
**FLAMES @VLT**

- **27 OCs with [Fe/H] from high-res**
- **Our group will add at least 11 new (+9 in common)**
- **HOMOGENEOUS METALLICITIES FOR 20**  
**(Bragaglia, Carretta, Gratton, Tosi)**

# Membership ?

## Radial velocities



# MOS @ TNG : Be 29

(Bragaglia, Di Fabrizio, Held, Marconi, Tosi)

