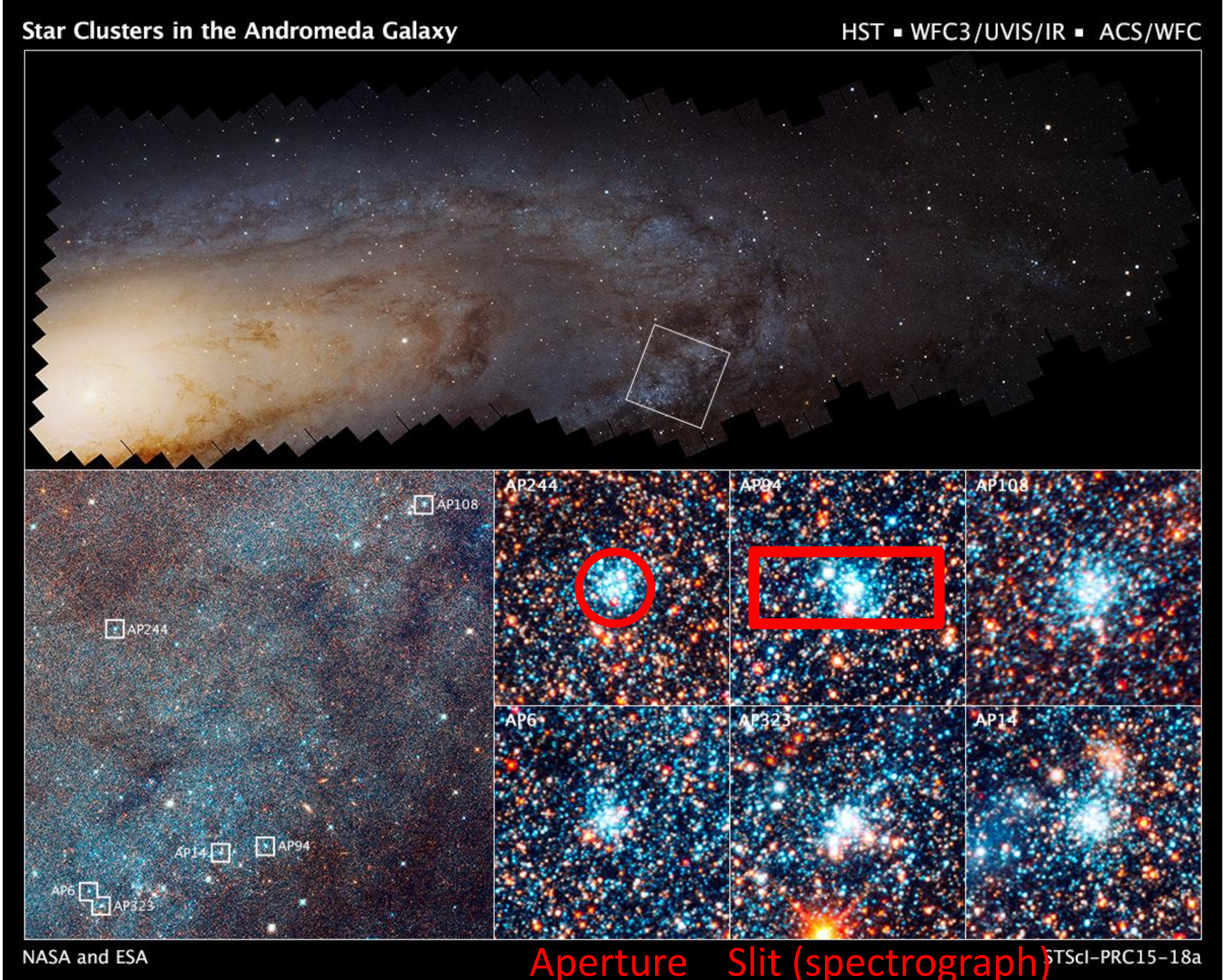
Integrated properties

- Integrated colors and spectra
- Especially interesting for distant and extragalactic star clusters
- “Think small”
- Pleiades: 2^{o}
- No new analysis with Gaia data, for example


Star Clusters in the Andromeda Galaxy
HST ▪ WFC3/UVIS/IR ▪ ACS/WFC
AP108
AP244
AP14
AP94
AP6
AP323
AP244
AP94
AP108
AP6
AP323
AP14
NASA and ESA
STScI-PRC15-18a
Aperture
Slit (spectrograph)

1’

Integrated Colors

As for distant Galaxies, we are able to observe integrated colors ***I(m)*** of star clusters. We are mainly able to estimate the age and total mass.

Techniques:

- "Aperture photometry" for distant star clusters

Aperture

- Sum up colors of members for resolved star clusters

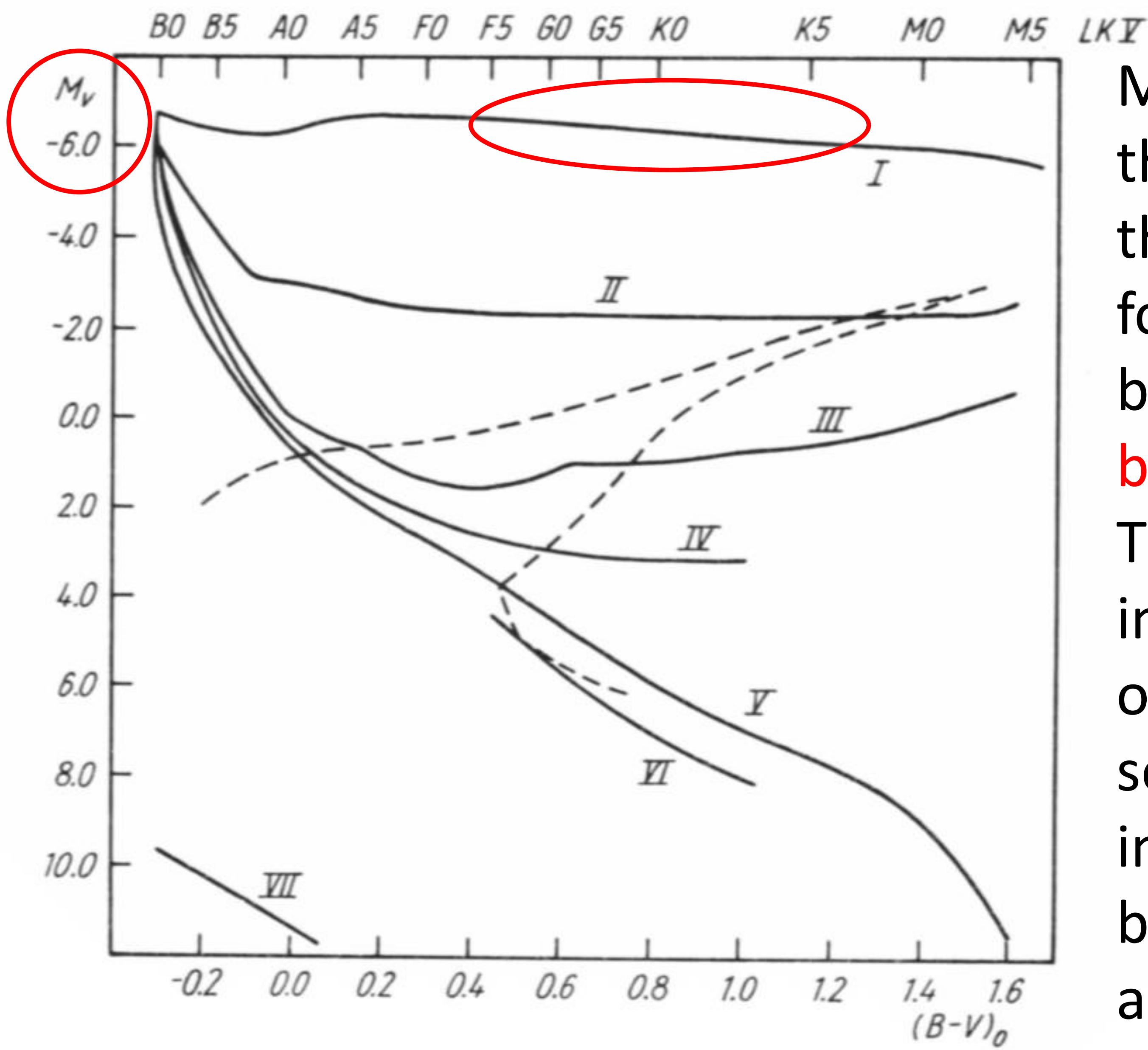
$$I(m) = -2.5 \ \log \left[\sum_i (10^{-0.4 m_i}) \right]$$

Starting point are the dereddened colors and absolute magnitudes. For the dereddening, here are the relations from Lata et al. (2002, A&A, 388, 158) for the Johnson-Cousins UBVRI system:

$$E(U-B) = 0.72E(B-V) + 0.05E(B-V)^2$$
$$E(U-V) = 1.72E(B-V)$$
$$E(V-R) = 0.60E(B-V)$$
$$E(V-I) = 1.25E(B-V)$$

For the integrated colors we get:

$$I(B-V) = I(B) - I(V)$$
$$I(U-B) = I(U) - I(B)$$
$$I(V-R) = I(V) - I(R)$$
$$I(V-I) = I(V) - I(I)$$



Most important is the knowledge of the membership for giants because of their brightness.

The incompleteness of the lower main sequence is not important because of low absolute magnitudes.

Lata et al., 2002, A&A, 388, 158

Clearly defined upper and lower mass limits

“Standard lines” for total masses from isochrones and population synthesis codes

González Delgado et al., 2005, MNRAS, 357, 945

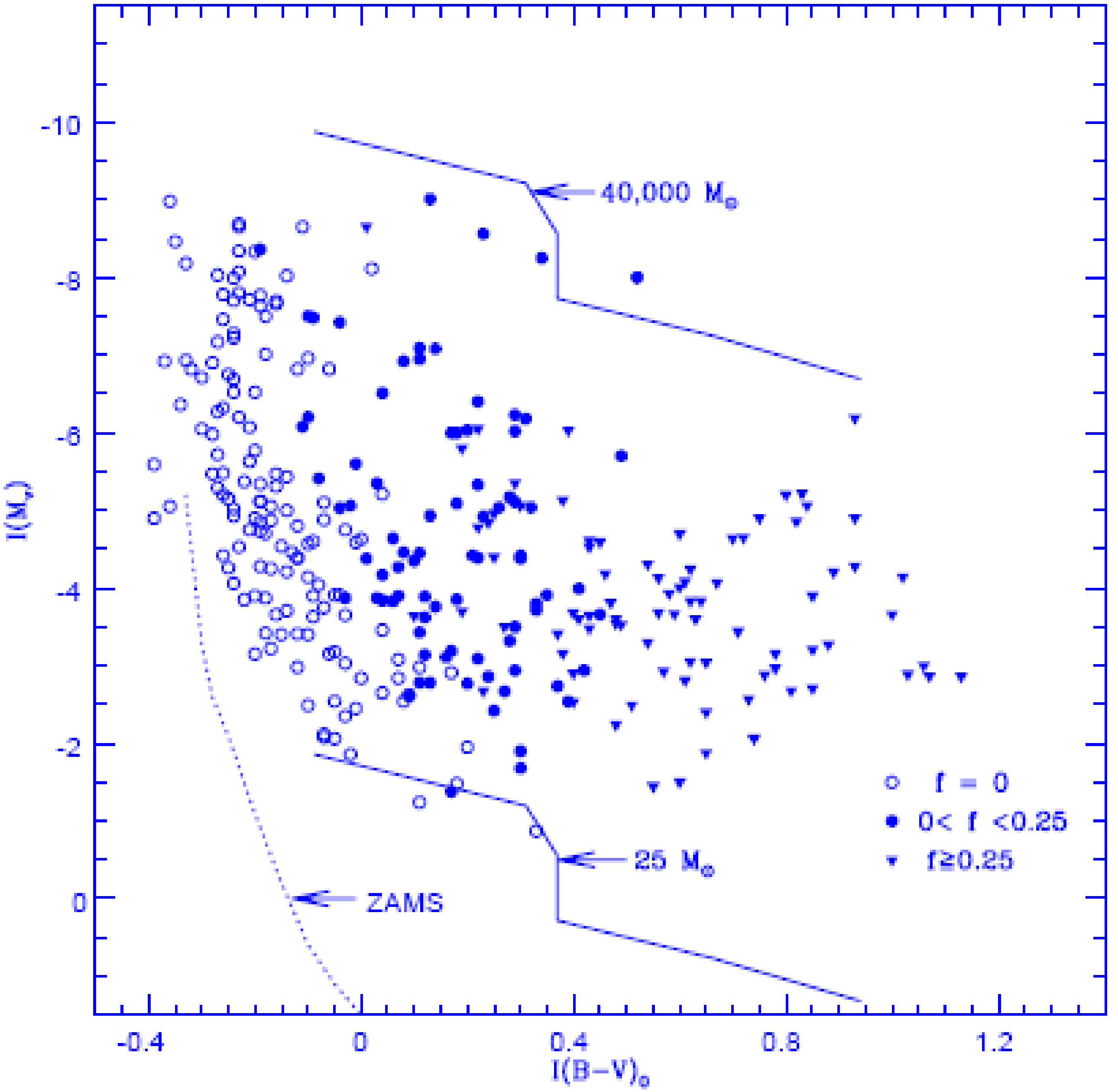


Fig. 2. The $I(M_V)$, $I(B-V)_0$ diagram. f is the fraction of red giants/supergiants in the open clusters.

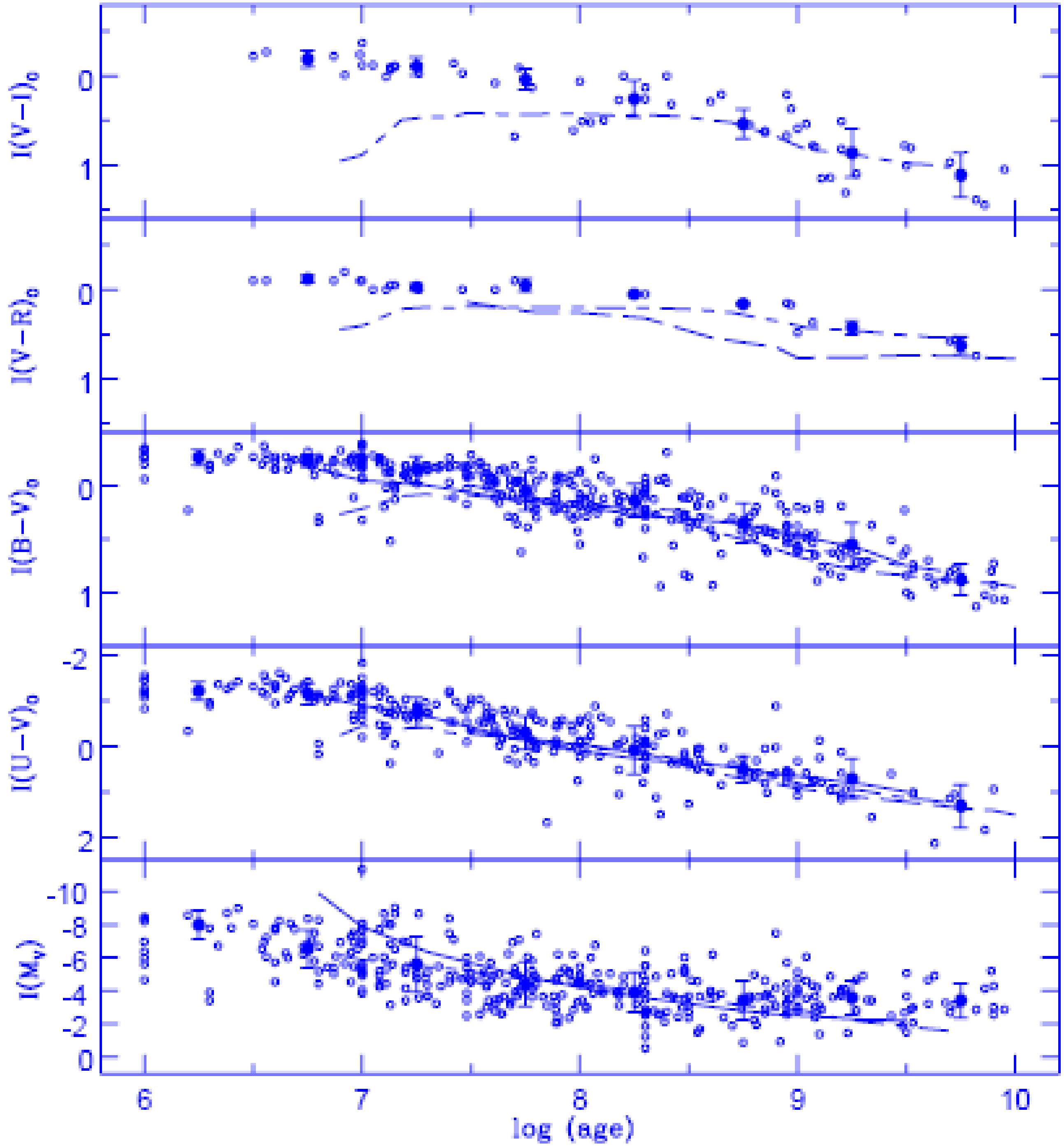
Lata et al., 2002, A&A, 388, 158

Relations for 352 galactic open clusters

The age and reddening were taken from the literature

Errors given by Lata et al. (2002):

$\sigma I(M_V) < 0.5$ mag
$\sigma I(colors) < 0.2$ mag



Results from Lata et al. (2002, A&A, 388, 158), important are the errors for the determination of the uncertainties in log t:

$$I(M_V) = (1.20 \pm 0.08)(\log\ t) + (-14.12 \pm 0.66)$$

with $\chi^2 = 2.017$

$$I(U-V)_0 = (0.74 \pm 0.03)(\log\ t) + (-6.07 \pm 0.23)$$

with $\chi^2 = 0.171$

$$I(B-V)_0 = (0.31 \pm 0.01)(\log\ t) + (-2.36 \pm 0.09)$$

with $\chi^2 = 0.037$

$$I(V-R)_0 = (0.22 \pm 0.02)(\log\ t) + (-1.65 \pm 0.17)$$

with $\chi^2 = 0.011$

$$I(V-I)_0 = (0.44 \pm 0.03)(\log\ t) + (-3.25 \pm 0.25)$$

with $\chi^2 = 0.048$

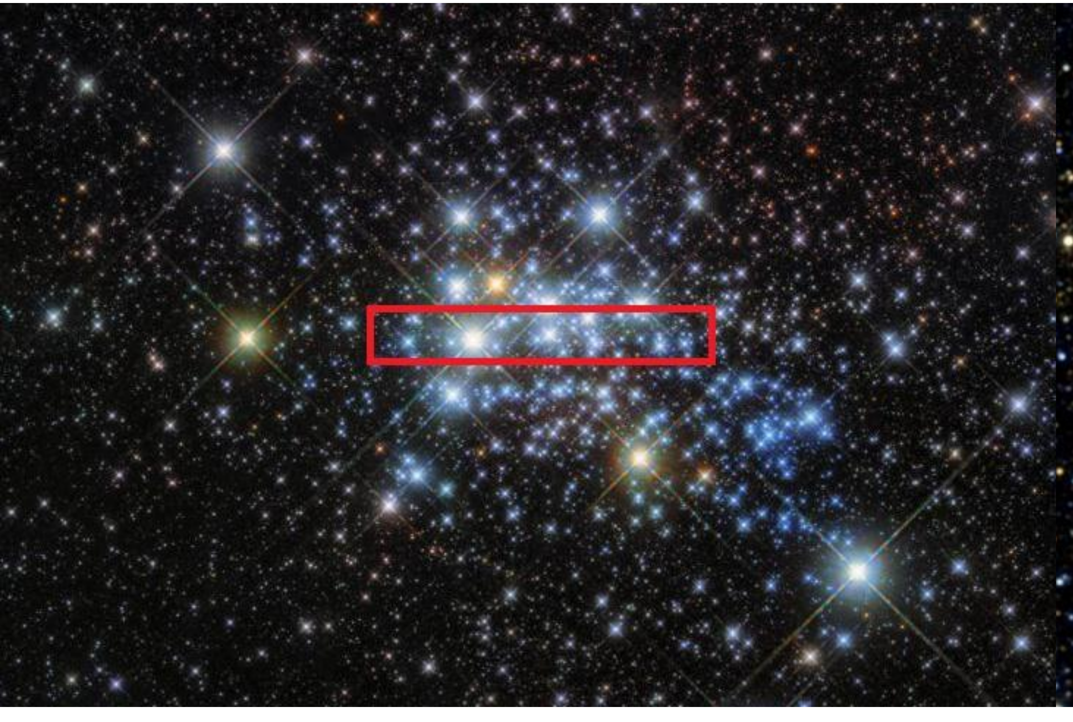
where t is the age (in years) of the cluster.

Integrated spectra of Star Clusters

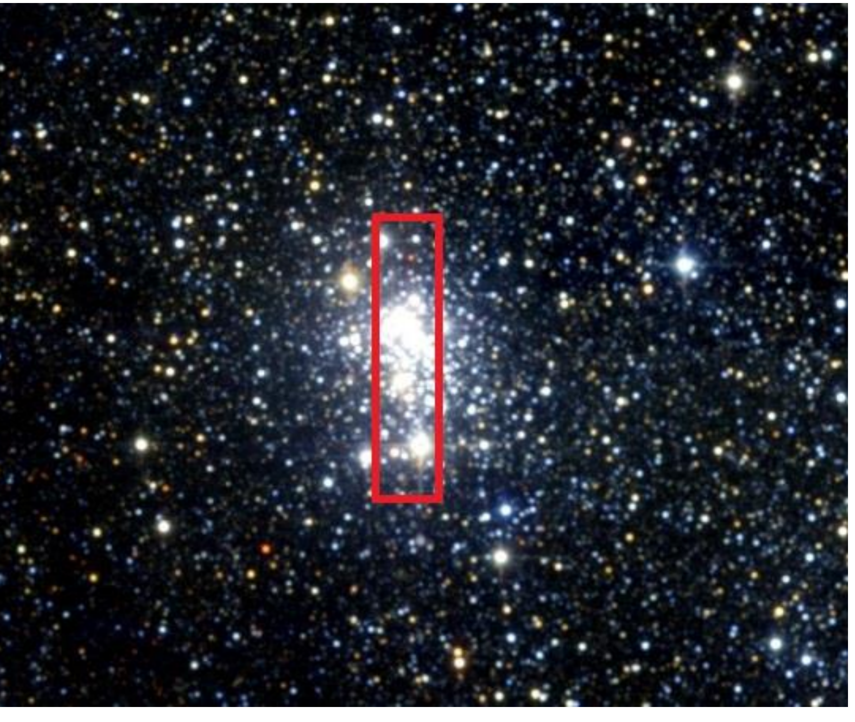
- Idea: clusters of different ages have different stellar content
- Example: older clusters (age > 100 Myr) will not have any very hot (O and B) type stars any more as members because they have evolved (e.g. Supernova)
- Technique: slit spectrum over cluster => integrated spectrum of all members
- Assumption: slit covers a representative sample for the cluster

Integrated spectra of Star Clusters

Slit of spectrograph



This will ***not*** work



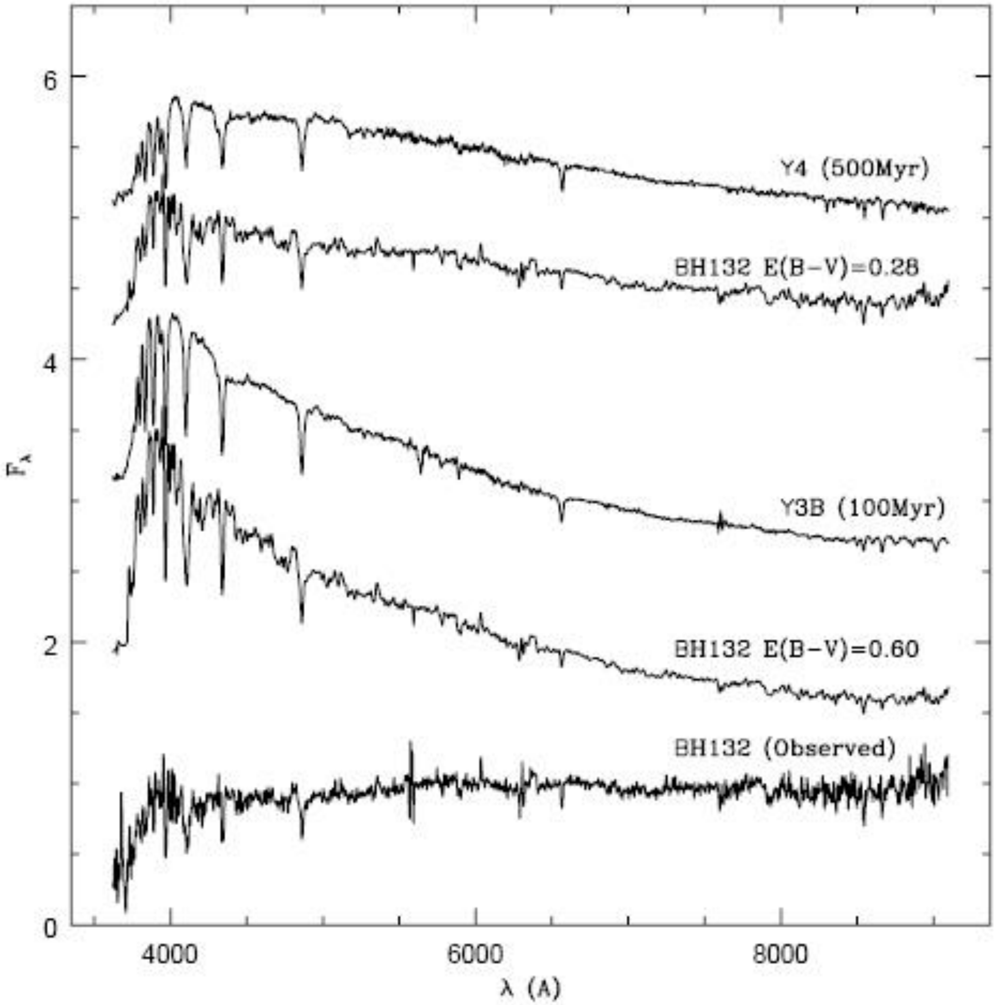
This will work

Integrated spectra of Star Clusters

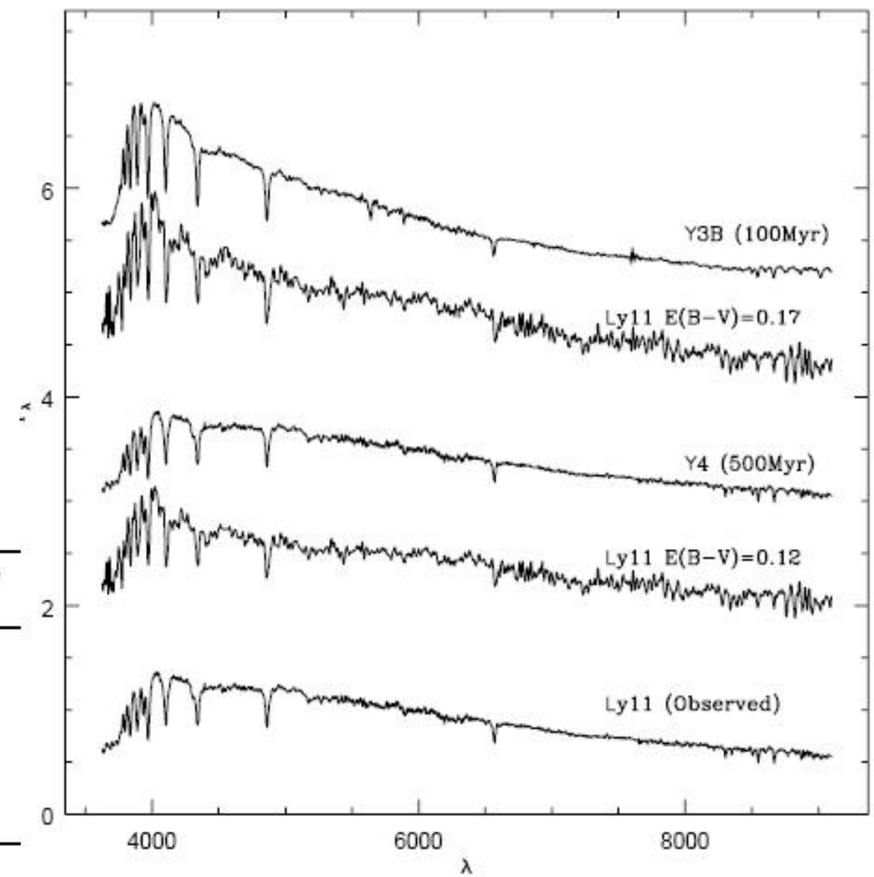
- How to get a standard library?
  1. Use isochrones together with the Initial Mass Function (IMF)
  2. Let the cluster evolve
  3. Calculate an integrated spectrum of „what‘s left“ in the cluster taking into account the luminosities of stars
  4. Do this for a wide variety of ages and metallicities (Z)
- Library for Globular clusters: https://www.noao.edu/ggclib/

Ahumada et al., 2000, A&AS, 141, 79

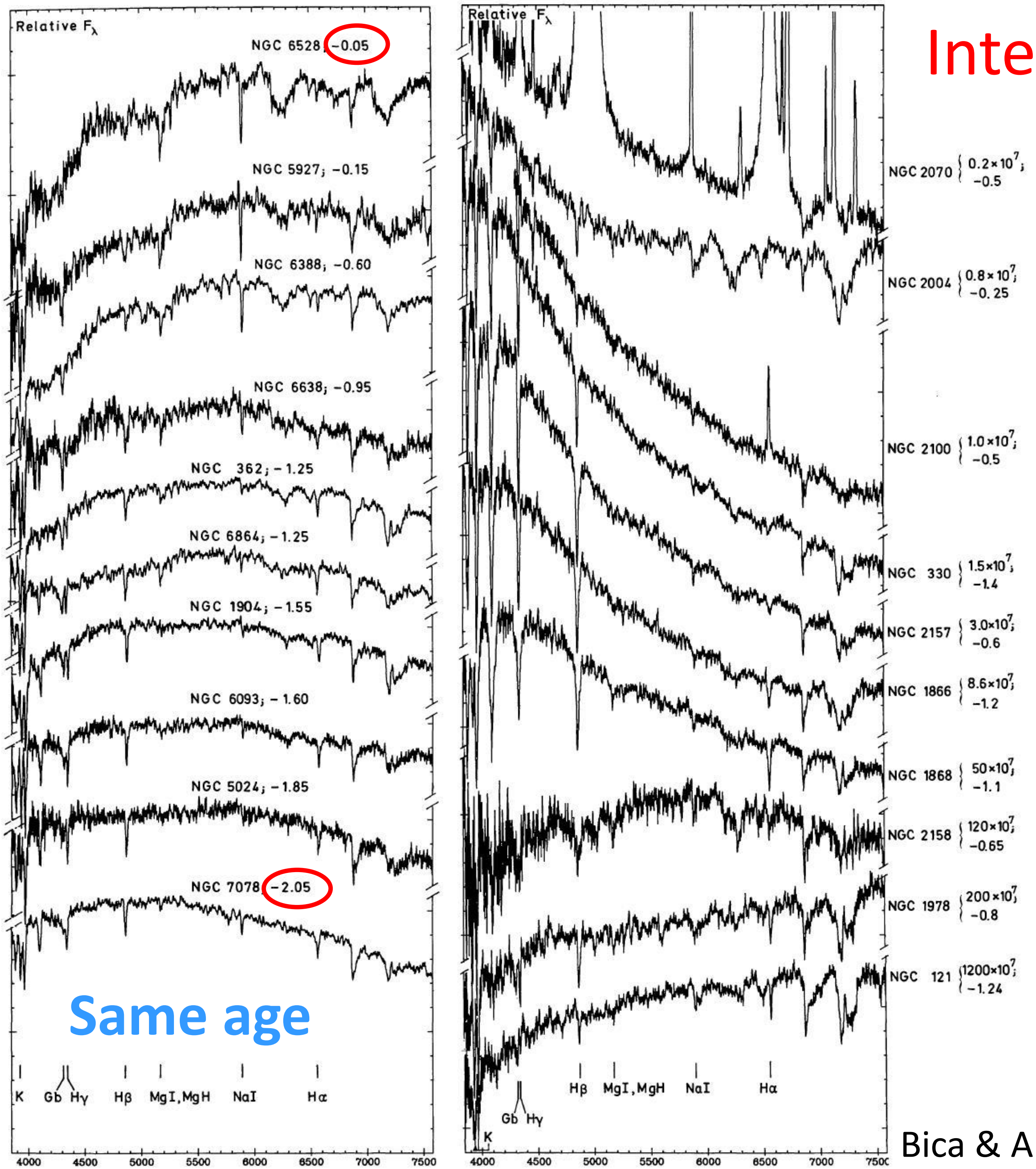
Here the assumption of the metallicity (Z) is solar



Cluster	$E(B-V)$	Age (Balmer) (Myr)	Age (template match) (Myr)	Adopted age (Myr)
Ruprecht 144	0.32 ± 0.02	200	100	150 ± 50
Melotte 105	0.31 ± 0.02	300	100	200 ± 100
BH 132	0.60 ± 0.05	200	100	150 ± 50
Hogg 15[a]	1.05 ± 0.05	30	3−6	5 ± 2
Pismis 21	1.50 ± 0.03	110	50	80 ± 30
Lyngå 11	0.12 ± 0.03	400	500	450 ± 50
BH 217	0.80 ± 0.03	20	50	35 ± 15



Integrated spectra

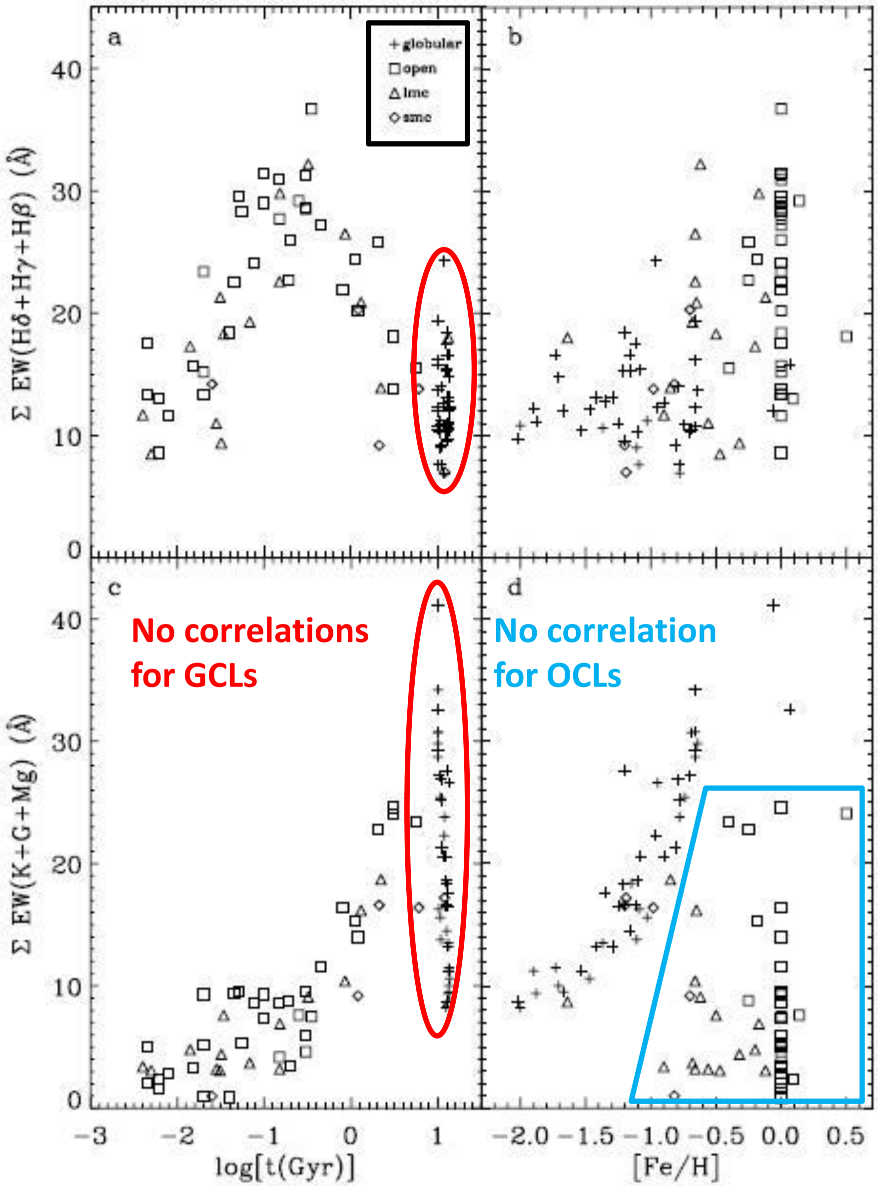


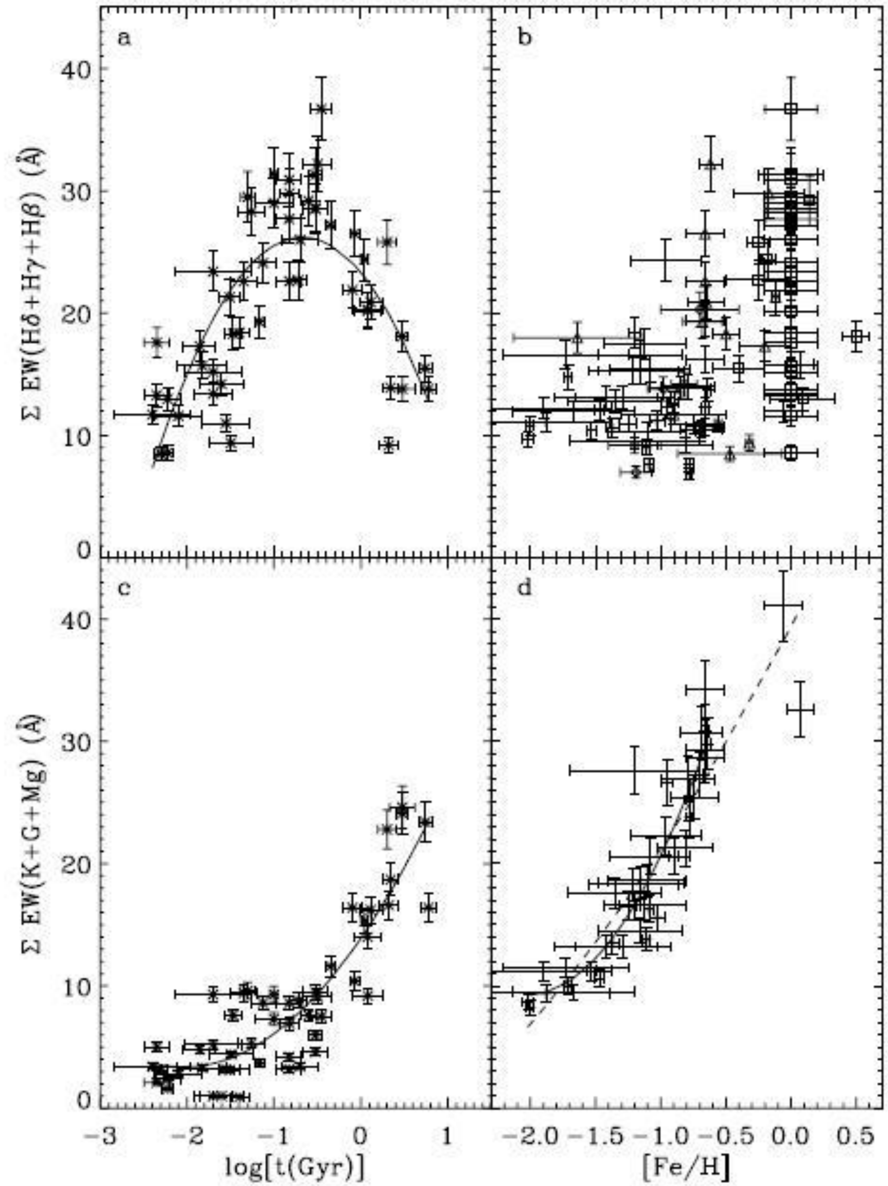
Z

Same age

Age

Bica & Alloin, 1986, A&A, 162, 21





Measured equivalent widths of lines versus age and metallicity

Santos & Piatti, 2004, A&A, 428, 79