# Integrated Colors

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

Techniques:
1. "Aperture photometry" for distant star clusters
2. 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:

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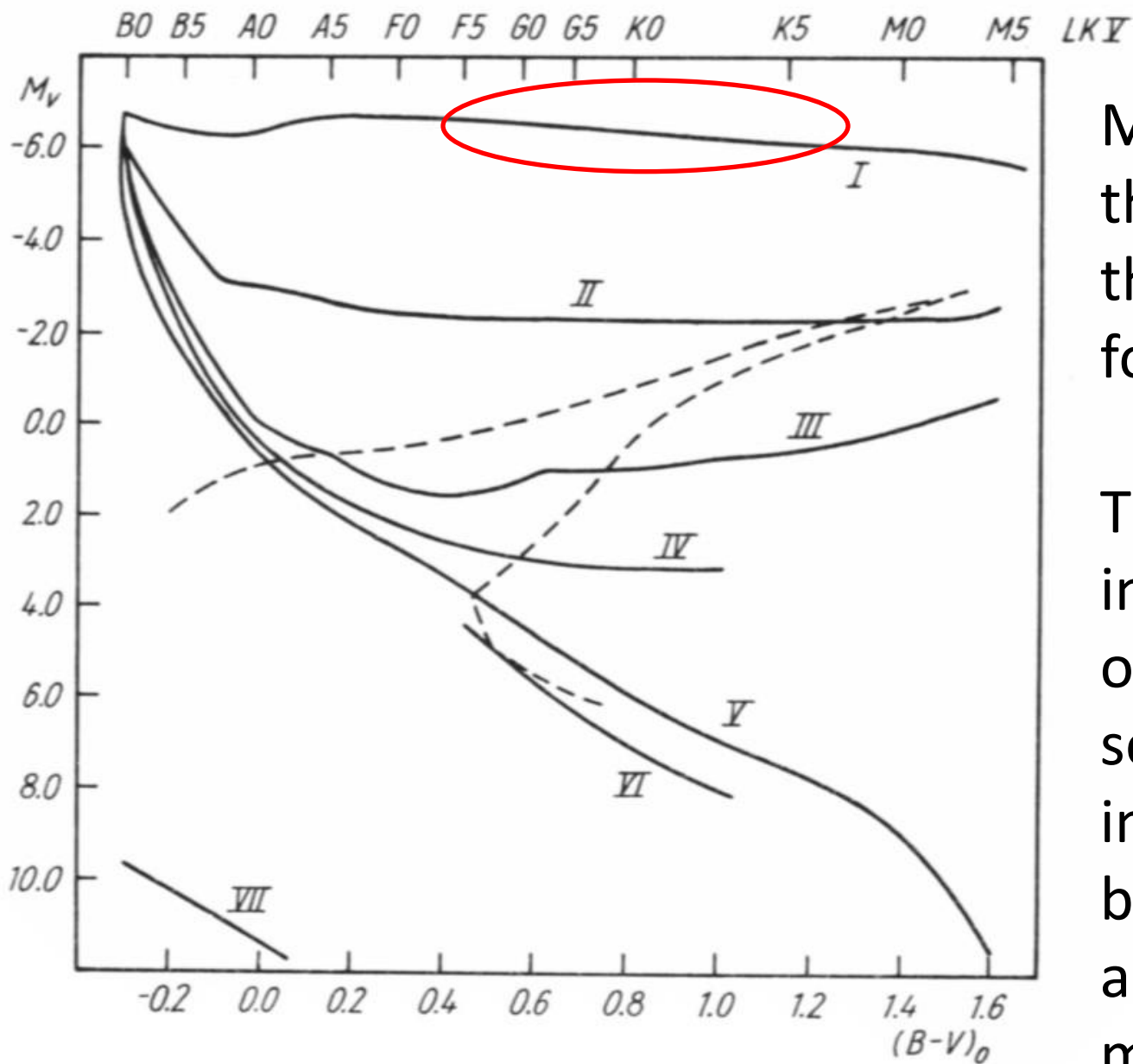$$E(V - I) = 1.25E(B - V)$$

For the integrated colors we get:

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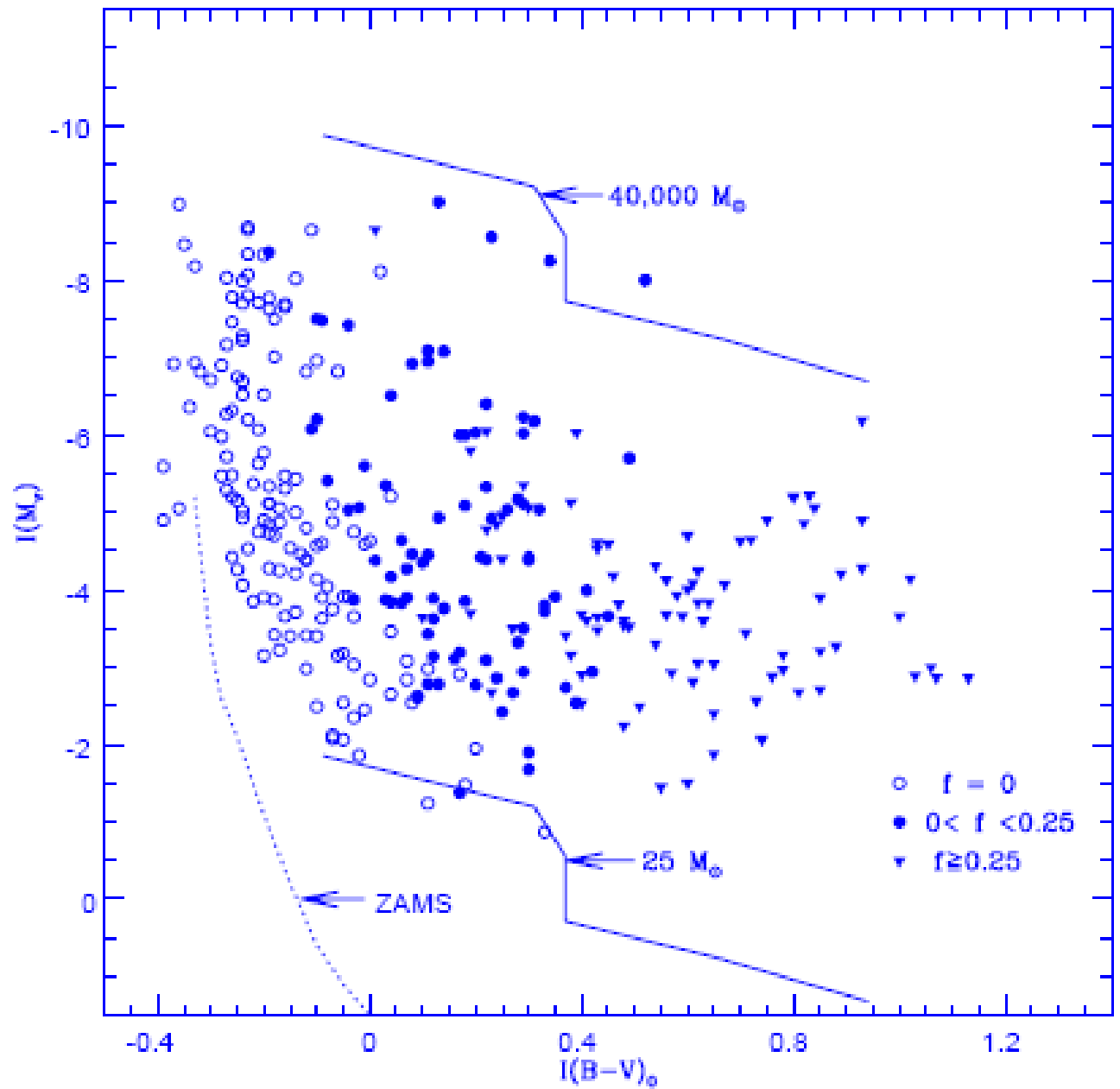$$I(V - R) = I(V) - I(R)$$
$$I(V - I) = I(V) - I(I)$$

Most important is the knowledge of the membership for giants

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

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



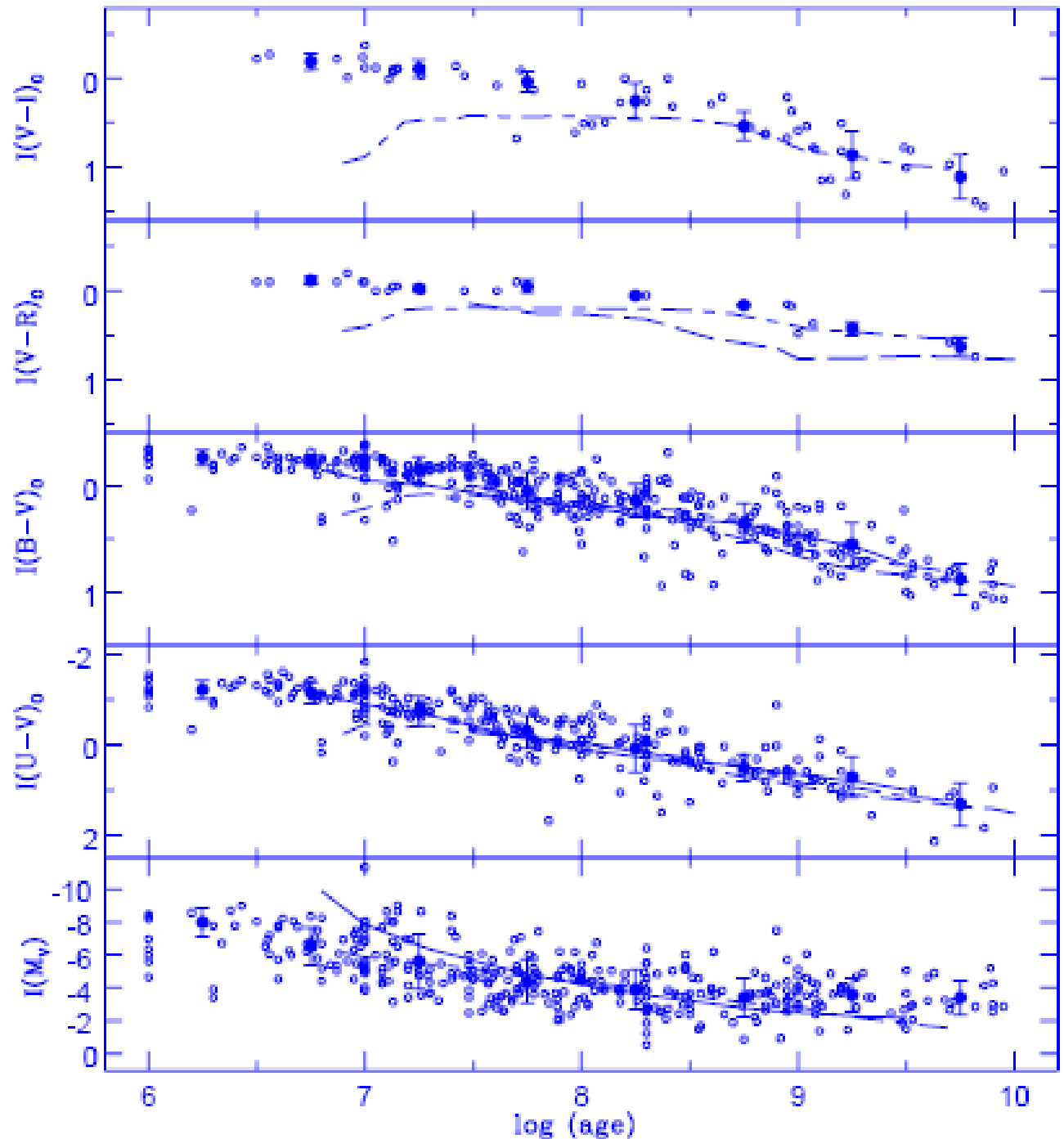**Fig. 2.** The $I(M_V)$, $I(B-V)_0$ diagram. $f$ is the fraction of red giants/supergiants in the open clusters.

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: old clusters (log t > 100 Myr) will not have any very hot (O and B) type stars any more as members because they have evolved

- Technique: slit spectrum over cluster => integrated spectrum of all members

- Assumption: slit covers a representative sample for the cluster

# Integrated spectra of Star Clusters

- How to get a standard library?
  1. Use isochrones together with IMF
  2. Let the cluster evolve
  3. Calculate an integrated spectrum of „what's left" in the cluster taking into account the luminosity of a star.
  4. Do this for a wide variety of ages and metallicities
- Library for Globular clusters: https://www.noao.edu/ggclib/

Ahumada et al., 2000, A&AS, 141, 79
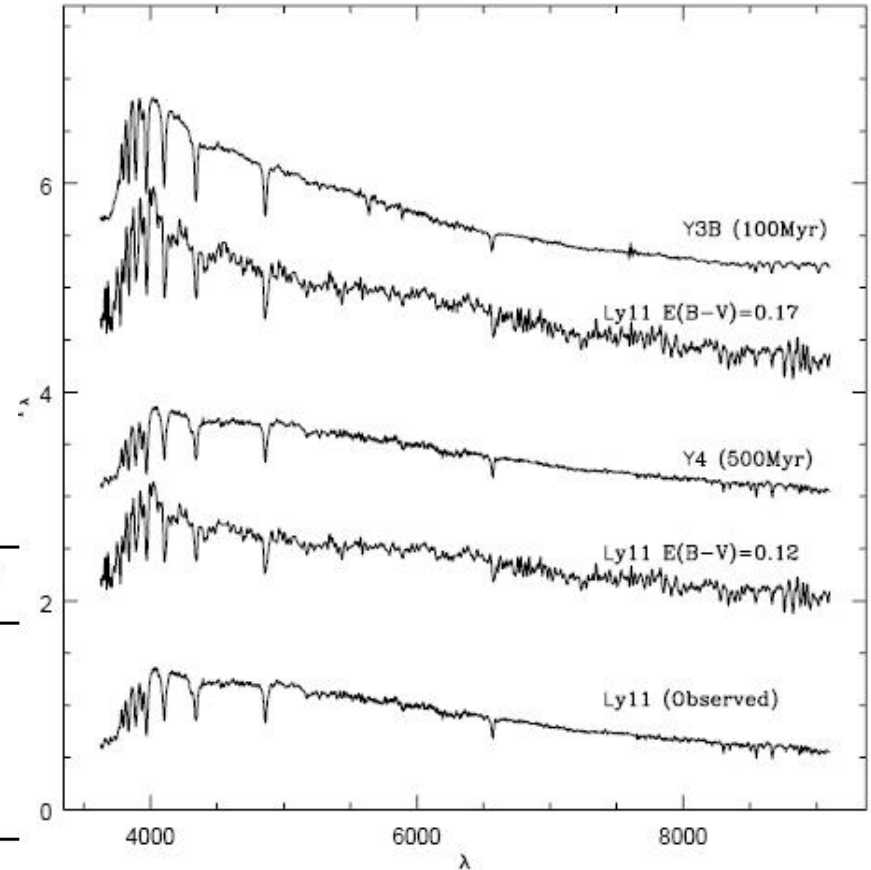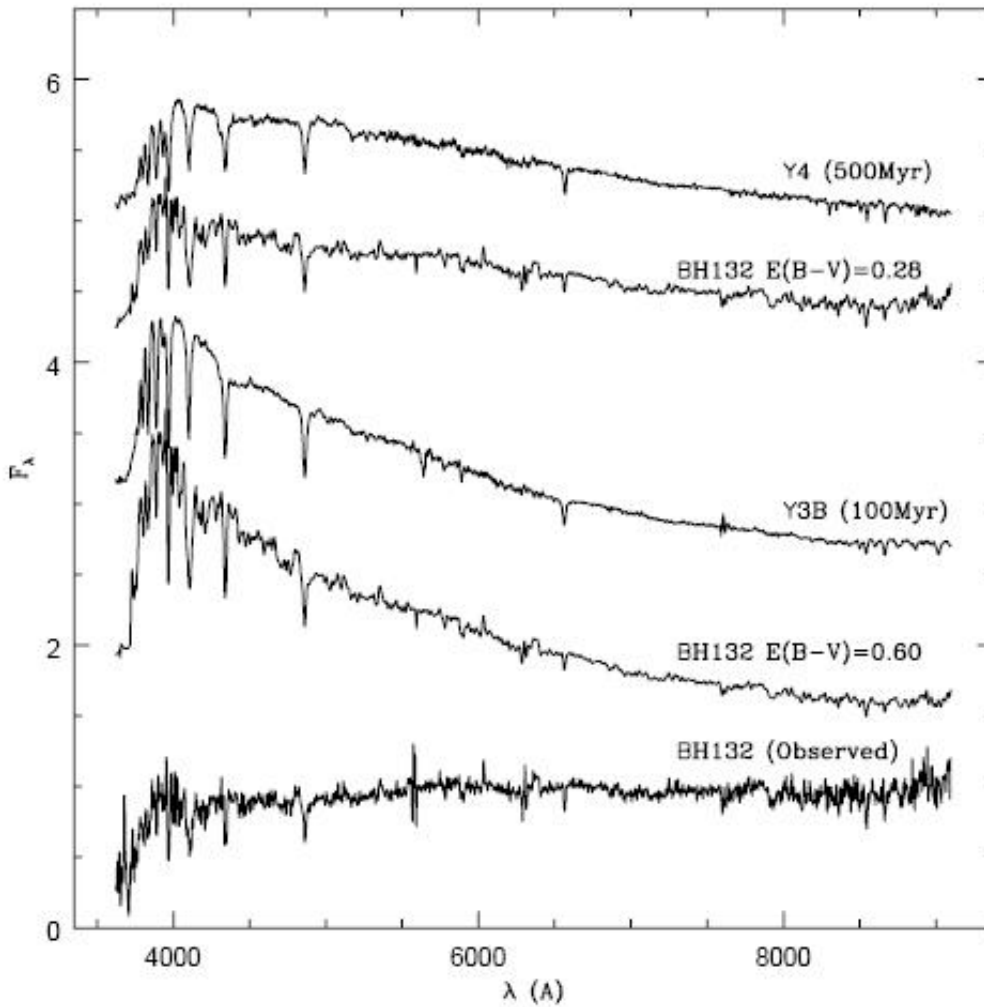
| Cluster | $E(B-V)$ | Age (Balmer) (Myr) | Age (template match) (Myr) | Adopted age (Myr) |
|---|---|---|---|---|
| Ruprecht 144 | $0.32 \pm 0.02$ | 200 | 100 | $150 \pm 50$ |
| Melotte 105 | $0.31 \pm 0.02$ | 300 | 100 | $200 \pm 100$ |
| BH 132 | $0.60 \pm 0.05$ | 200 | 100 | $150 \pm 50$ |
| Hogg 15[a] | $1.05 \pm 0.05$ | 30 | 3–6 | $5 \pm 2$ |
| Pismis 21 | $1.50 \pm 0.03$ | 110 | 50 | $80 \pm 30$ |
| Lyngå 11 | $0.12 \pm 0.03$ | 400 | 500 | $450 \pm 50$ |
| BH 217 | $0.80 \pm 0.03$ | 20 | 50 | $35 \pm 15$ |

Integrated spectra

Z

Age

Same age

Left panel (top to bottom):
NGC 6528; -0.05
NGC 5927; -0.15
NGC 6388; -0.60
NGC 6638; -0.95
NGC 362; -1.25
NGC 6864; -1.25
NGC 1904; -1.55
NGC 6093; -1.60
NGC 5024; -1.85
NGC 7078; -2.05

Right panel (top to bottom):
NGC 2070 { $0.2 \times 10^7$; -0.5 }
NGC 2004 { $0.8 \times 10^7$; -0.25 }
NGC 2100 { $1.0 \times 10^7$; -0.5 }
NGC 330 { $1.5 \times 10^7$; -1.4 }
NGC 2157 { $3.0 \times 10^7$; -0.6 }
NGC 1866 { $8.6 \times 10^7$; -1.2 }
NGC 1868 { $50 \times 10^7$; -1.1 }
NGC 2158 { $120 \times 10^7$; -0.65 }
NGC 1978 { $200 \times 10^7$; -0.8 }
NGC 121 { $1200 \times 10^7$; -1.24 }

Spectral features: K, Gb Hγ, Hβ, MgI, MgH, NaI, Hα

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

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