The Metallicity Ladder in Resolved Stellar Populations
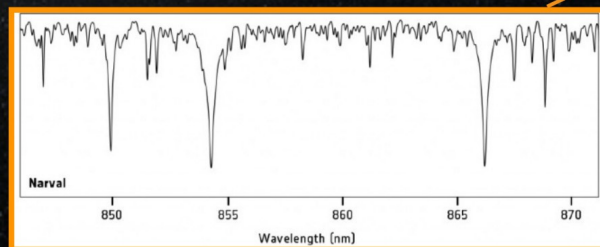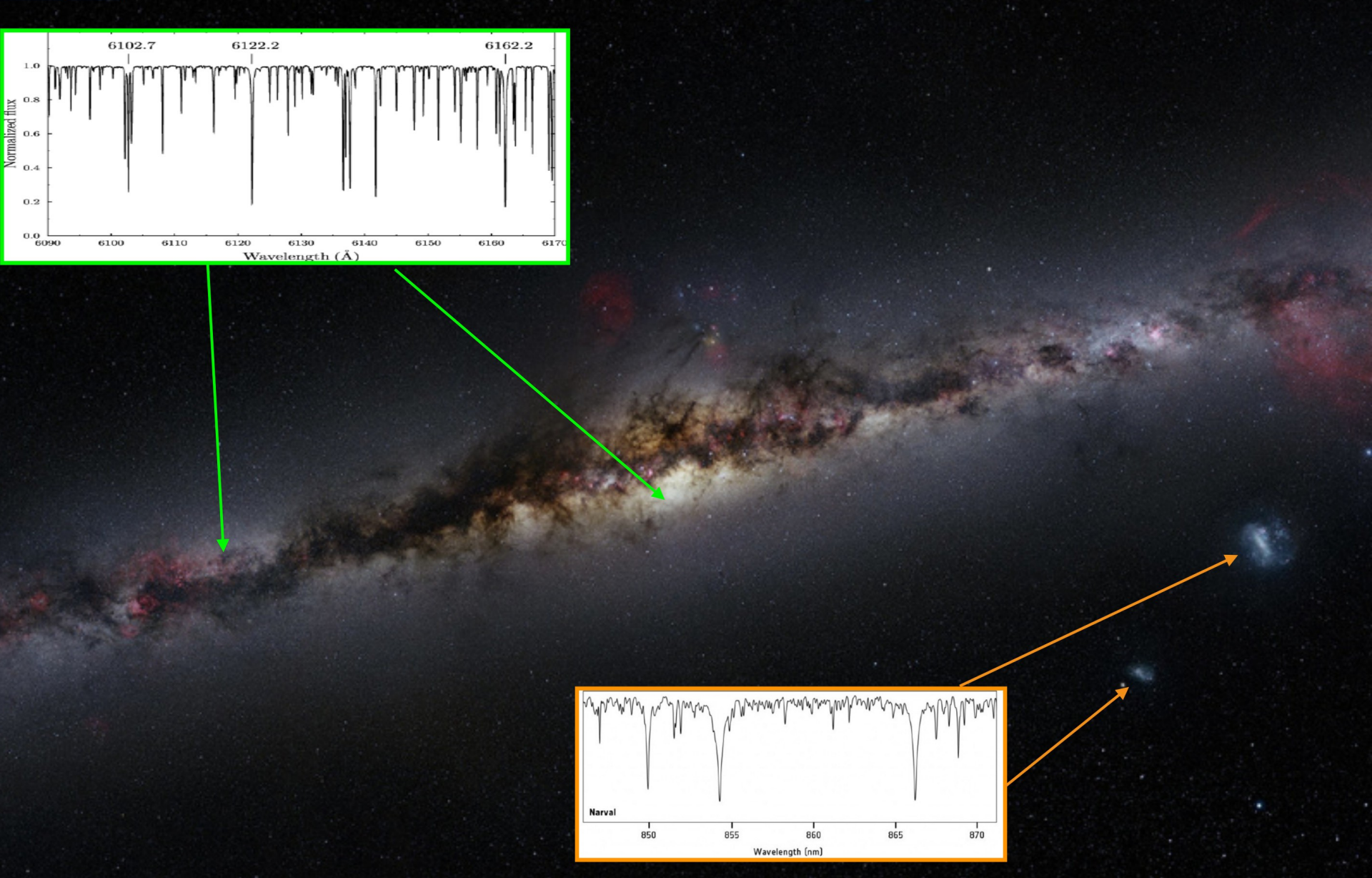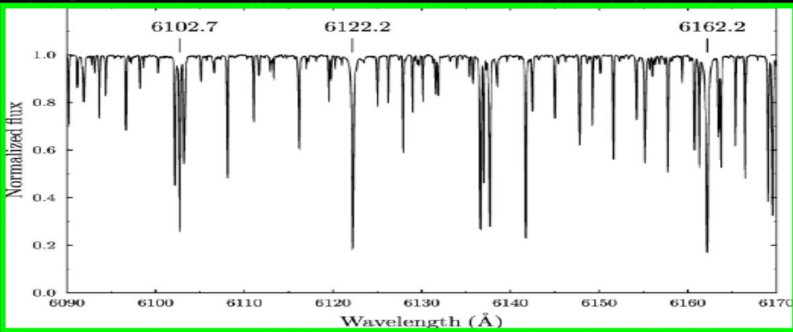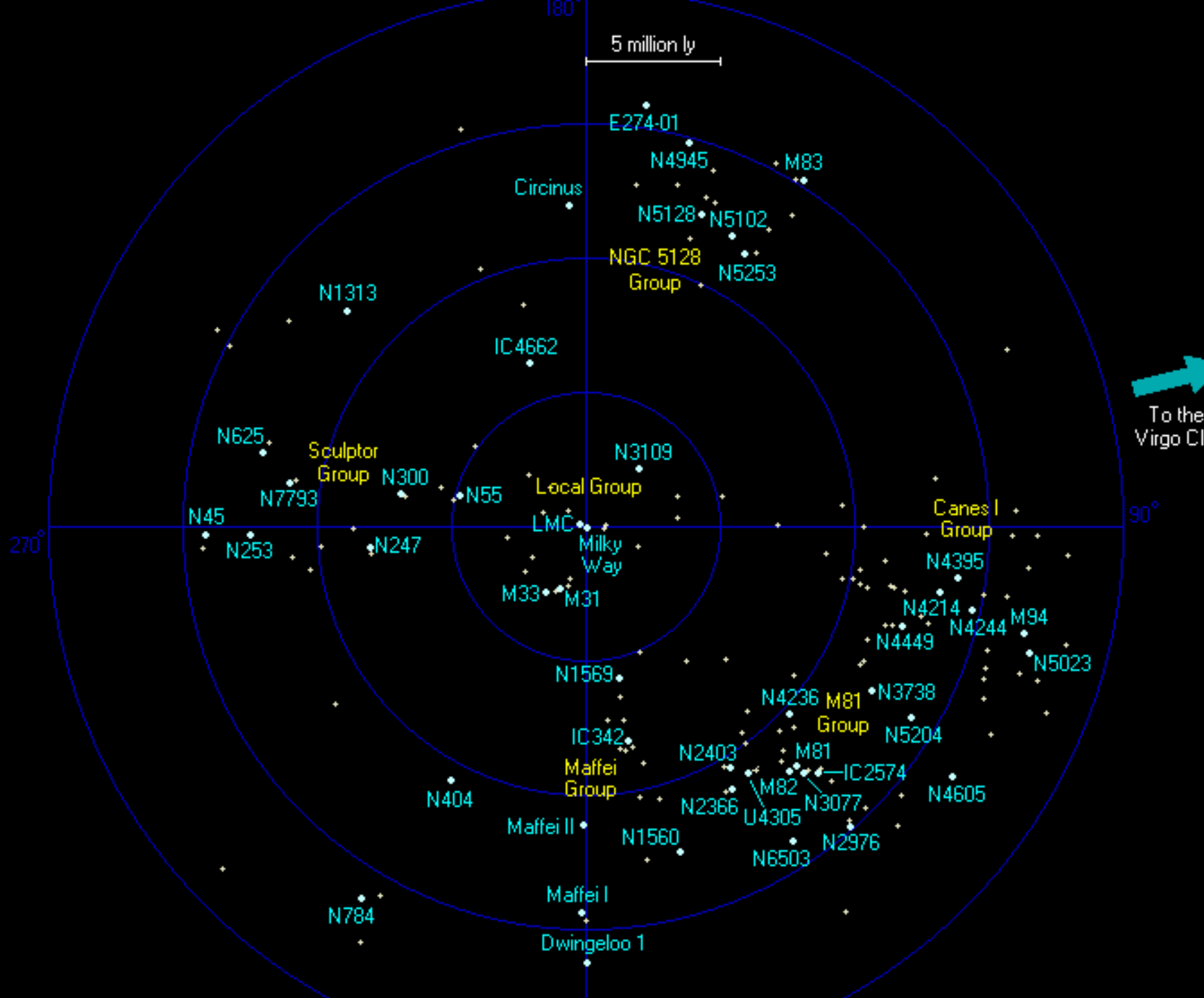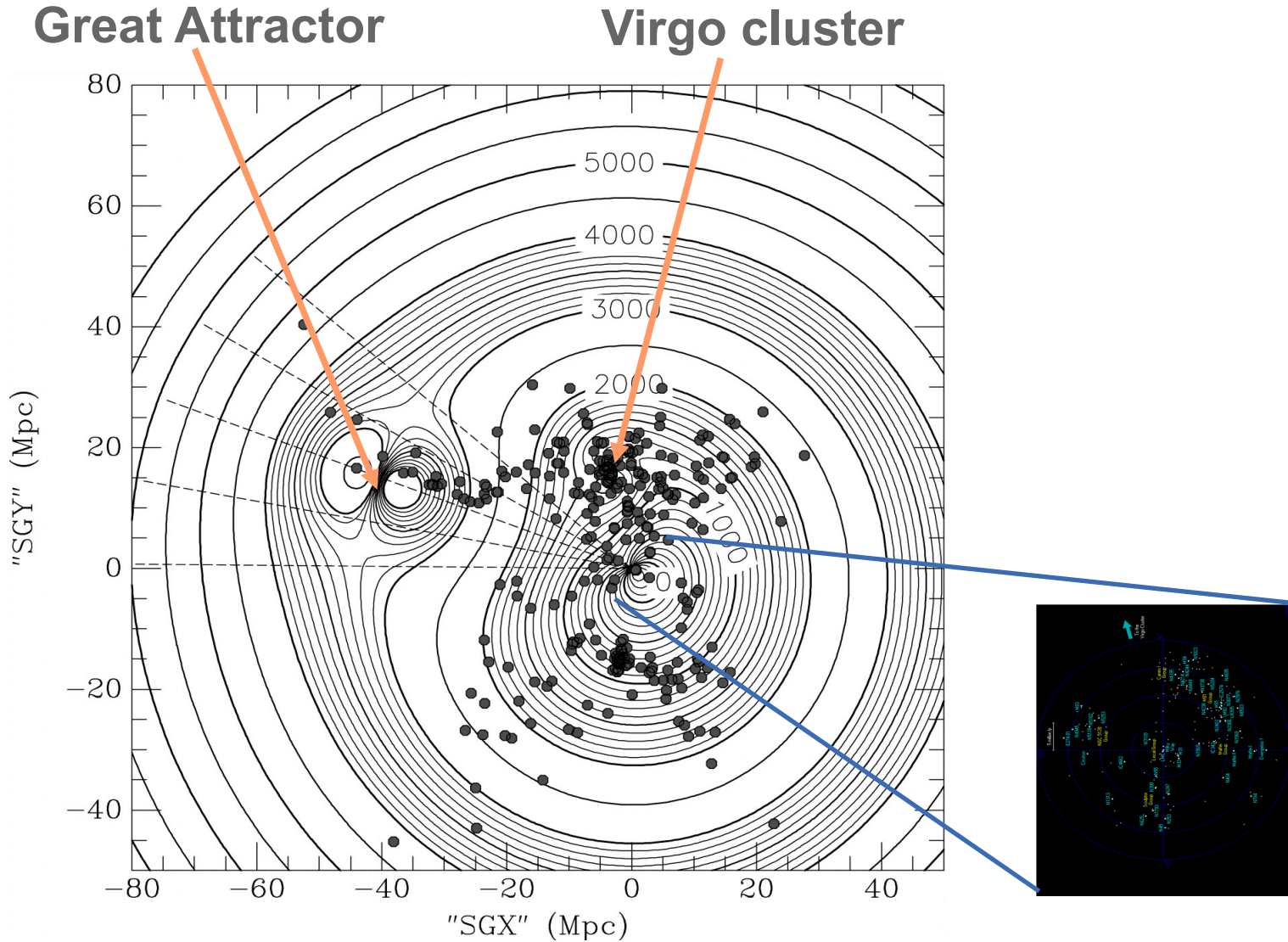
Tonry et al. (2002)

Manu

1. Abundances for a single star (atmosphere etc.)
2. MDF of a CSP

Ivo

3. Outside of MWG, high-rez very difficult/time consuming except the nearest satellites
4. So switch to methods using lower-rez > CaT
5. to be interpreted with closed/open boxes

The Calcium triplet method

- Low-resolution spectroscopy of RGB stars in the CaII triplet region

    - 2--4 AA FWHM

    - R ≈ 2000--3000

    - Calibrated vs. stars with high-rez abundances

Pal
1=C0325+794

discovered by Abell (1955) on POSS plates
14 kpc from Sun
19 kpc from the GC
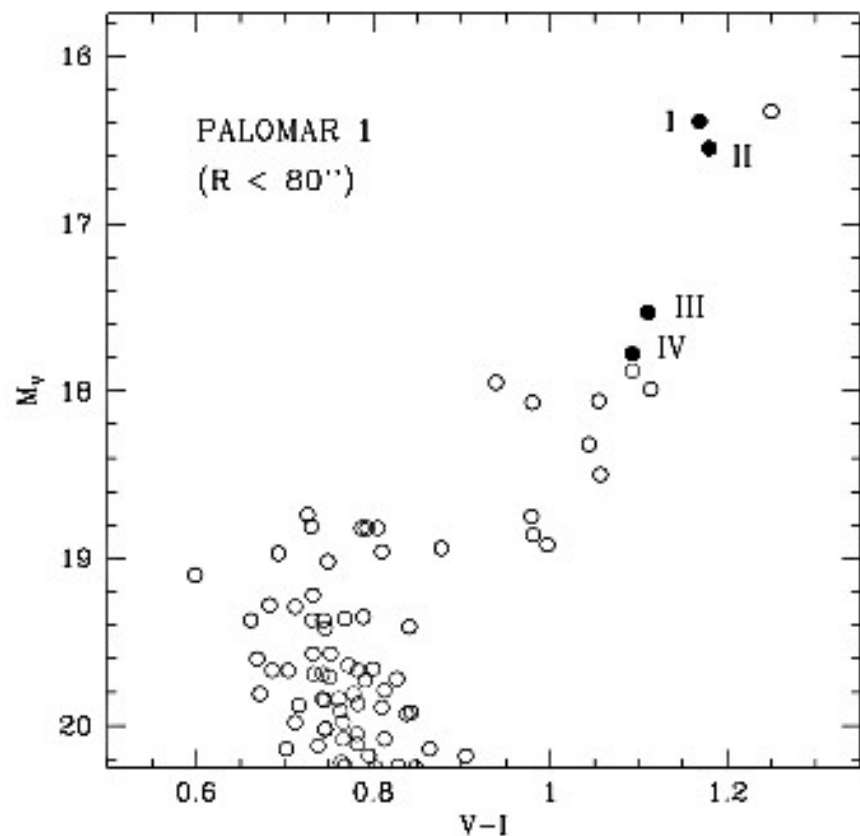4.5 kpc above plane

Mv =-2.5 ± 0.5,
M = 1300 ± 600 Msun

HST heritage

FIG. 1.—$V-I$ CMD of Pal 1. Only stars within the first 80″ are represented. The upper part of the mean sequence and the giant branch are clearly defined. Stars for which spectra have been obtained are identified by roman numerals.
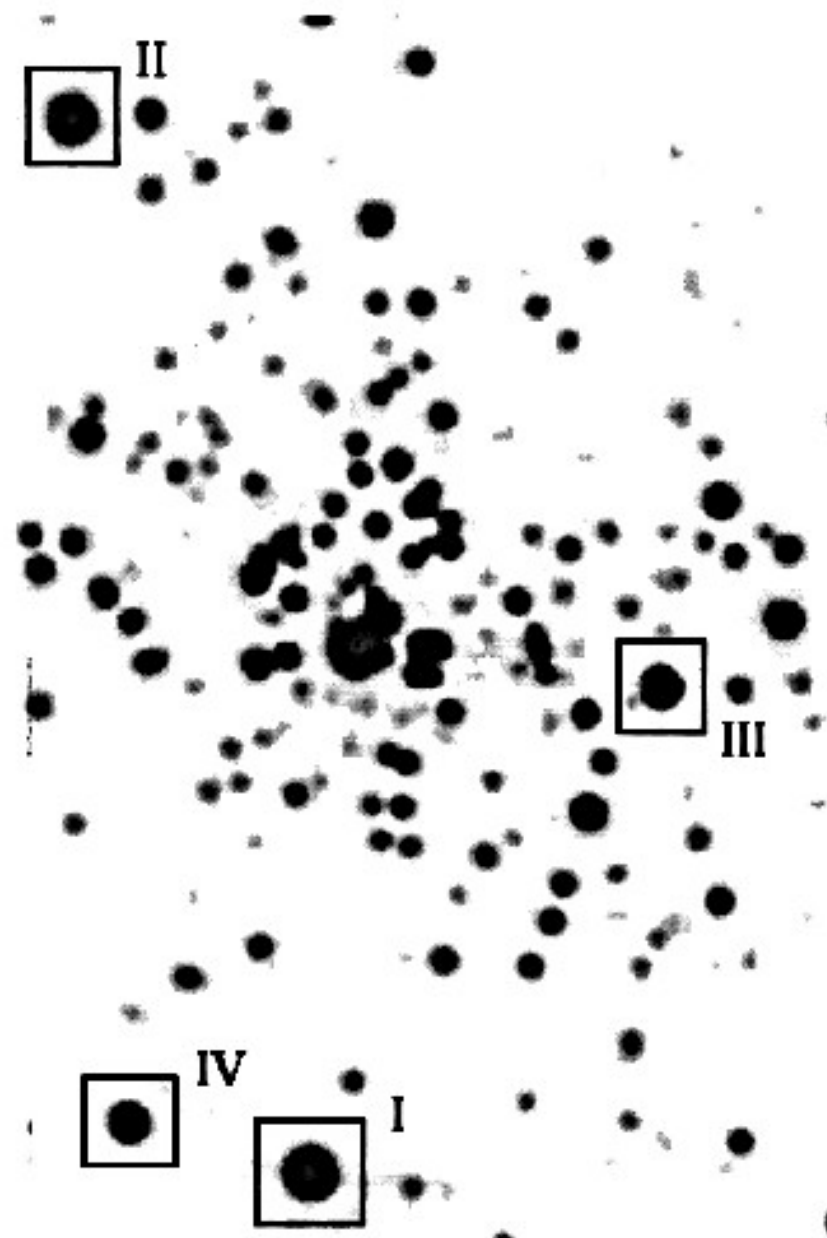

FIG. 2.—A 900 s I-band image of the central part of the cluster Pal 1 (1′.4 × 1′.5, north up, west left). The stars for which spectra have been obtained are marked.
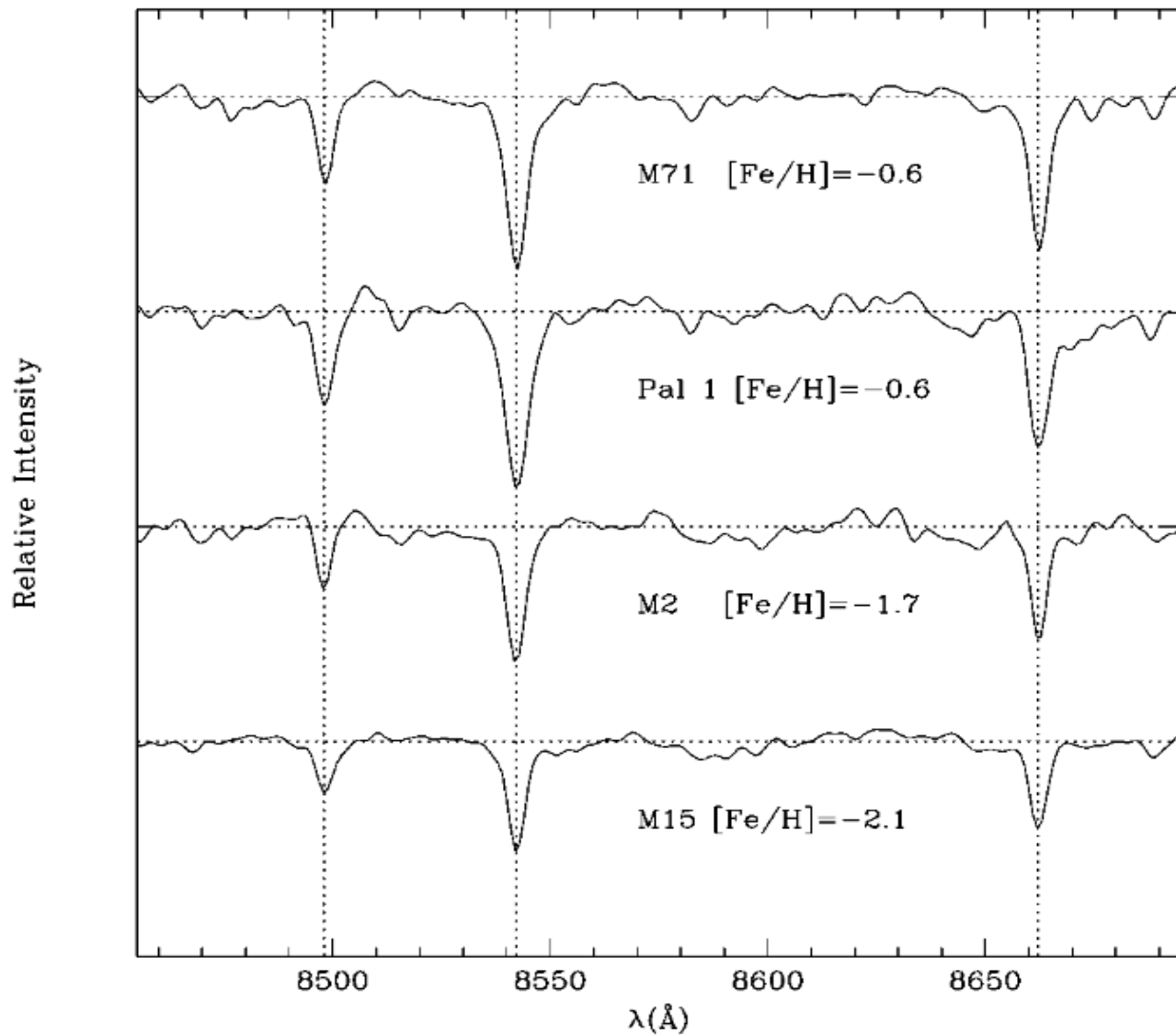
FIG. 3.—Sections of the spectra covering the Ca II triplet region for a single star of each observed cluster.
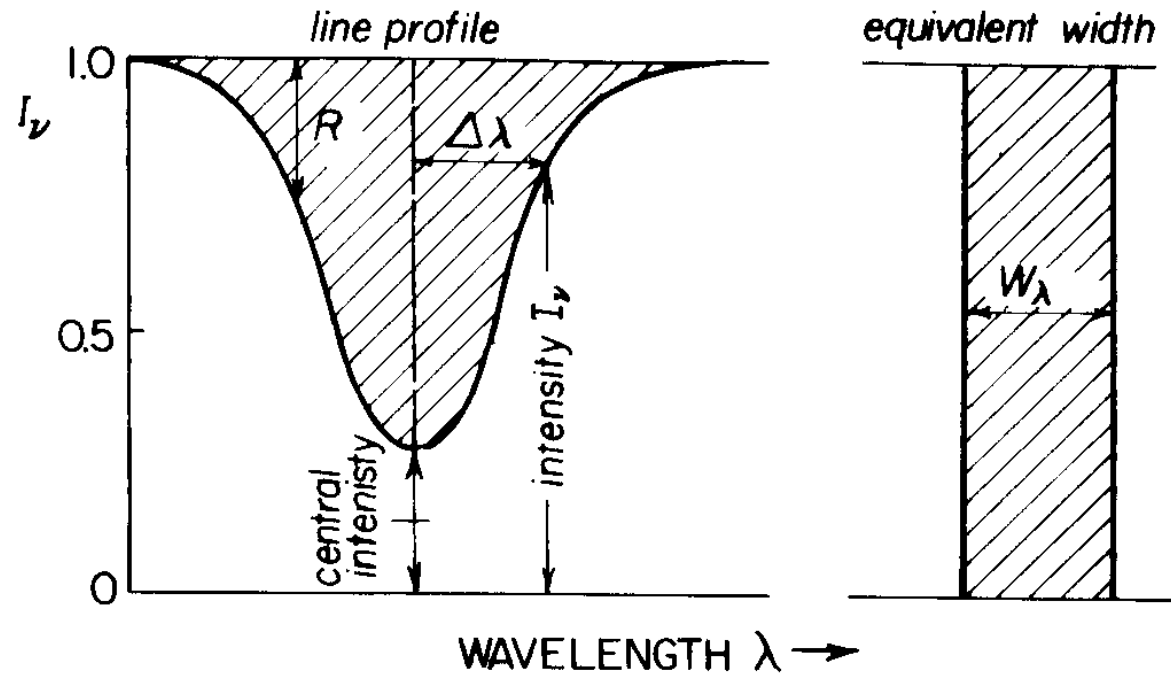
Definition of Equivalent Width

Fig. 3.4. Definition of equivalent width.

$$W_\lambda = \int R \, d\lambda$$

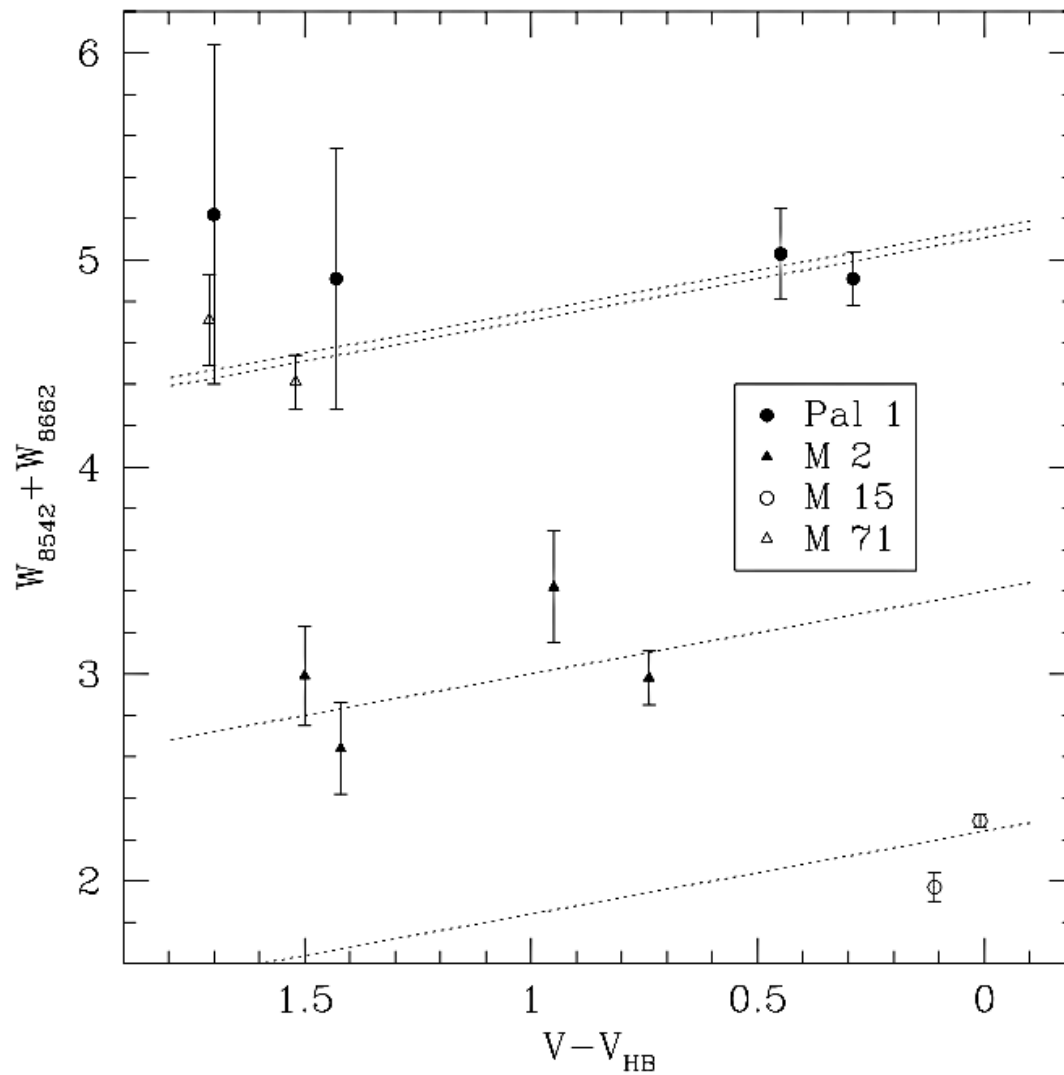This measure becomes independent from flux units (units are Angstrom)

FIG. 4.—Summed equivalent widths and their associated errors plotted vs. $V - V_{HB}$ for the cluster member stars (including stars III and IV of M2). Dotted lines reproduce the adopted best fit, as described in the text.
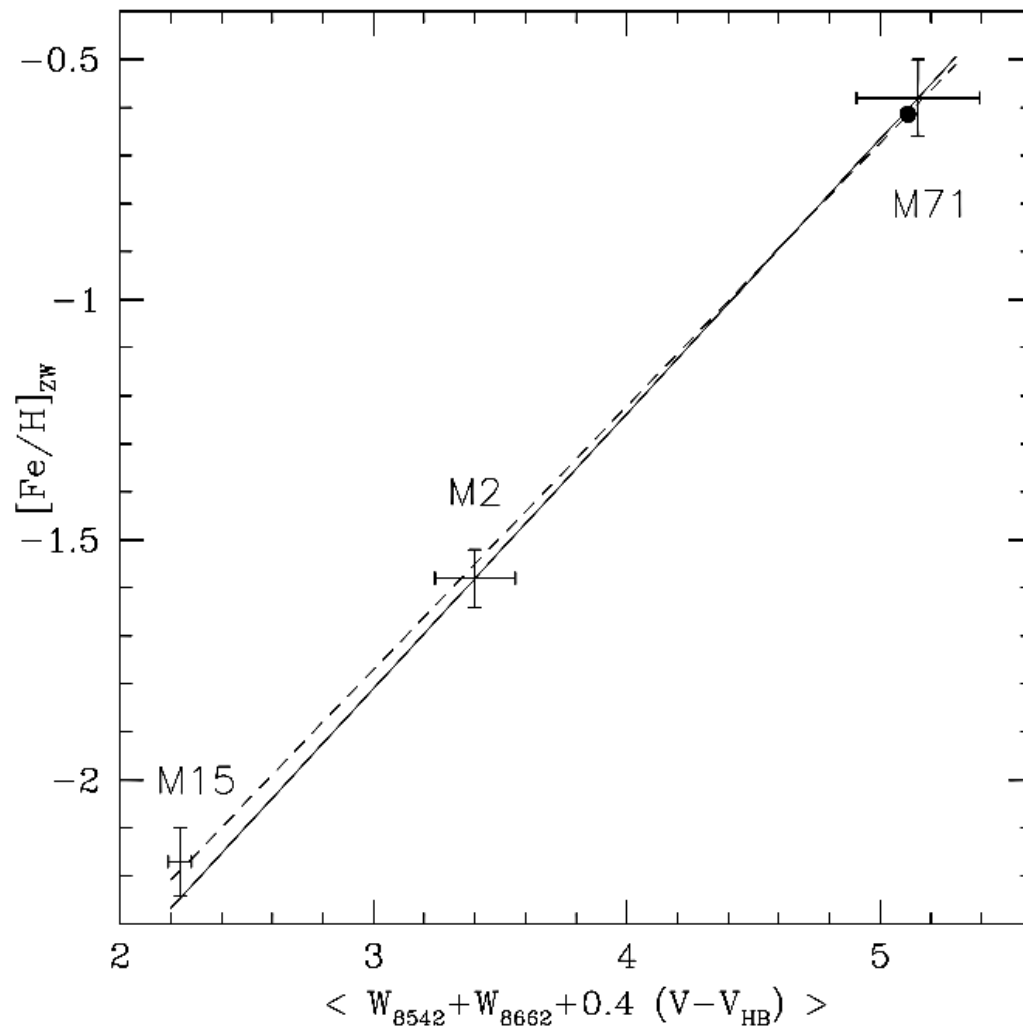
FIG. 5.—Abundance calibration for the Ca II line strengths. The reduced equivalent width W' is plotted against [Fe/H] on the Zinn & West (1984) scale for the three calibration clusters. The dashed line was fitted to the three calibration points by least squares, while the solid line was fitted to M2 and M71. Both lines represent the adopted calibration relations.
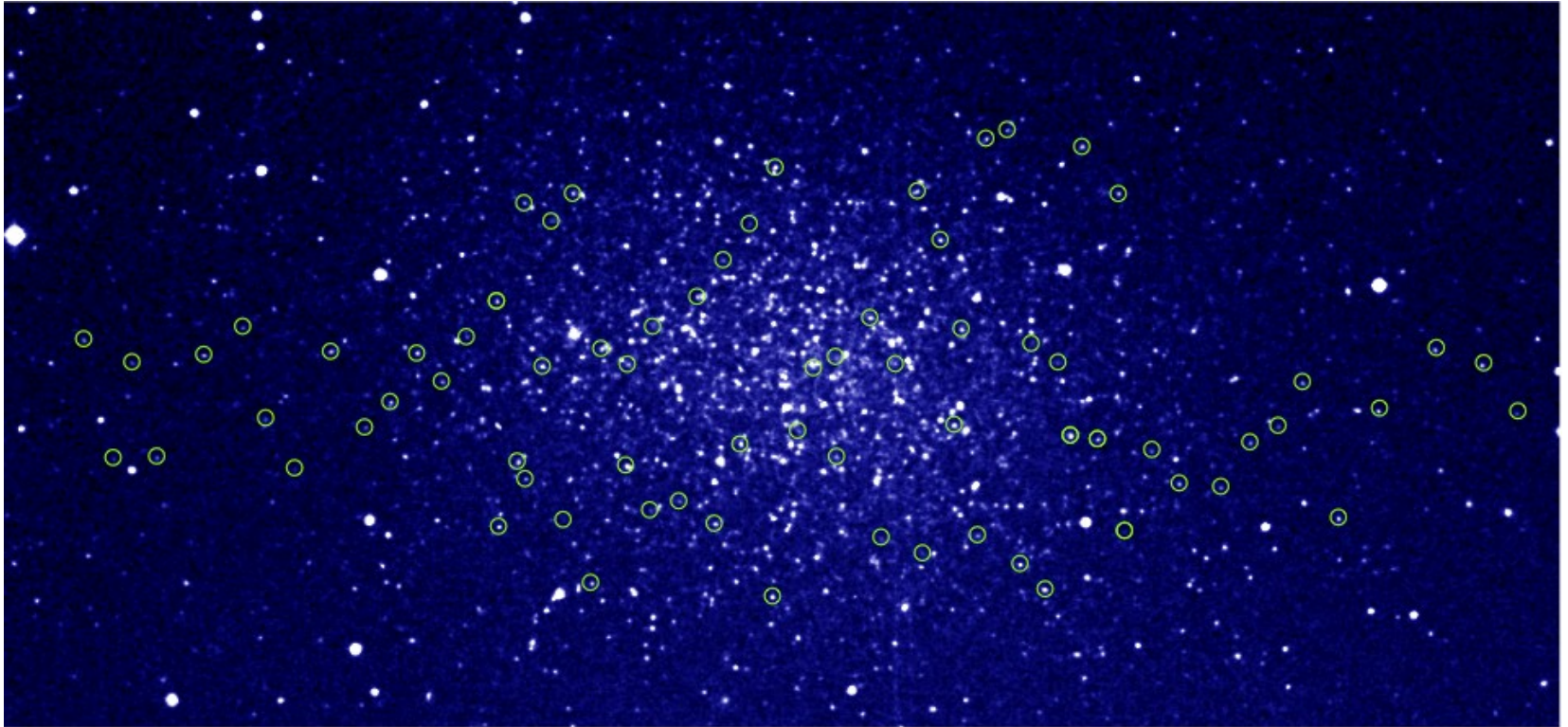
The Calcium triplet method

♦ Low-resolution spectroscopy of RGB stars in the CaII triplet region

♦ 2--4 AA FWHM
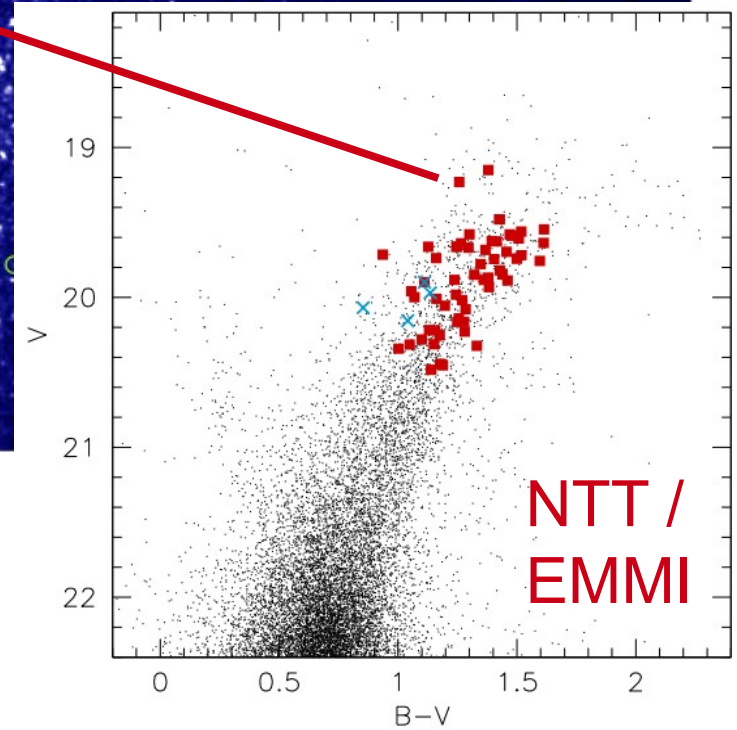
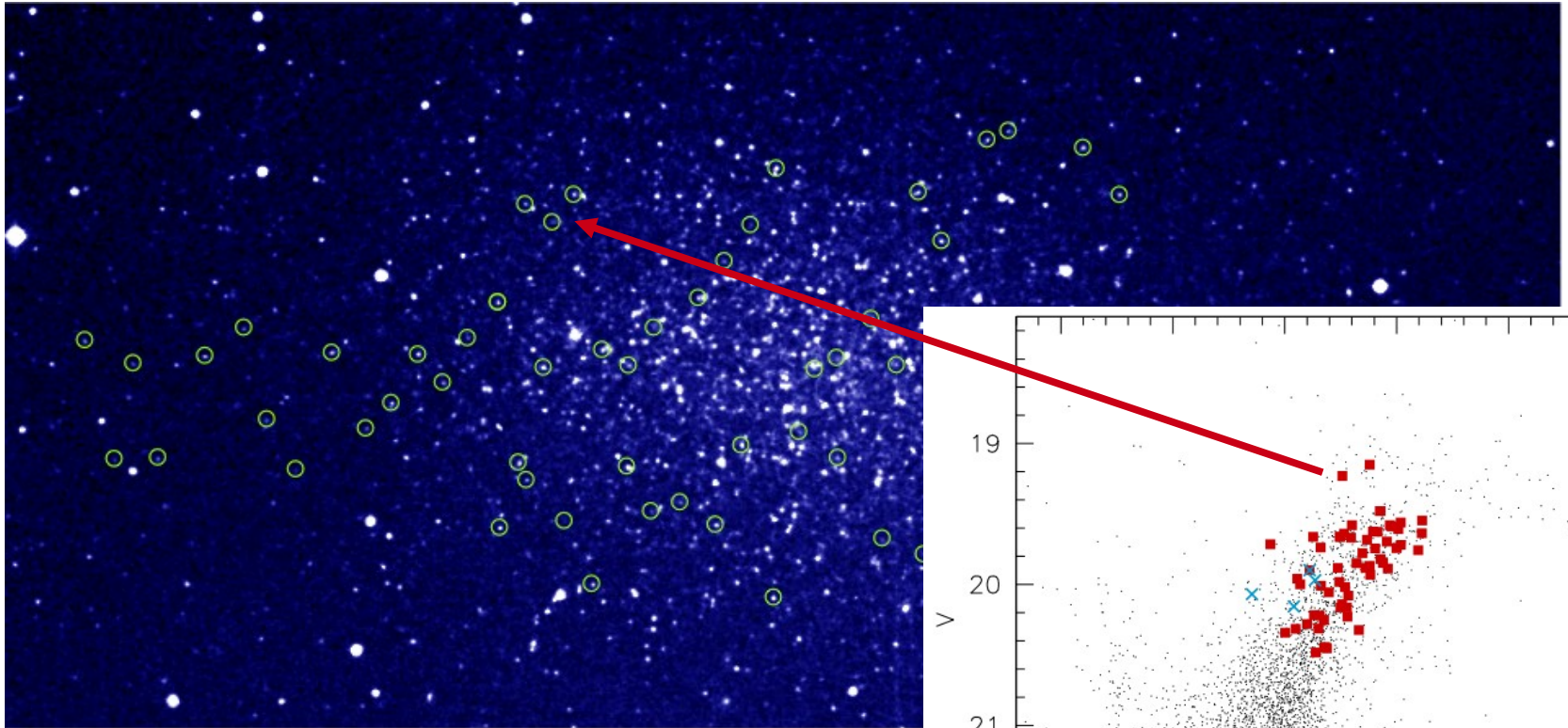♦ R ≈ 2000--3000
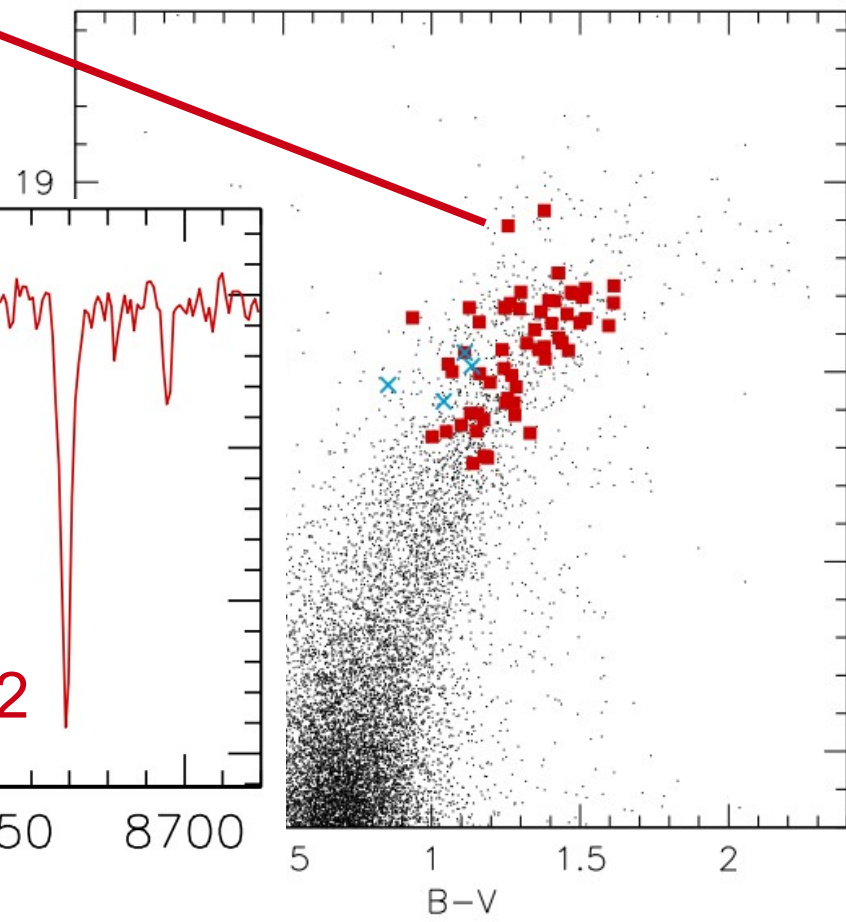
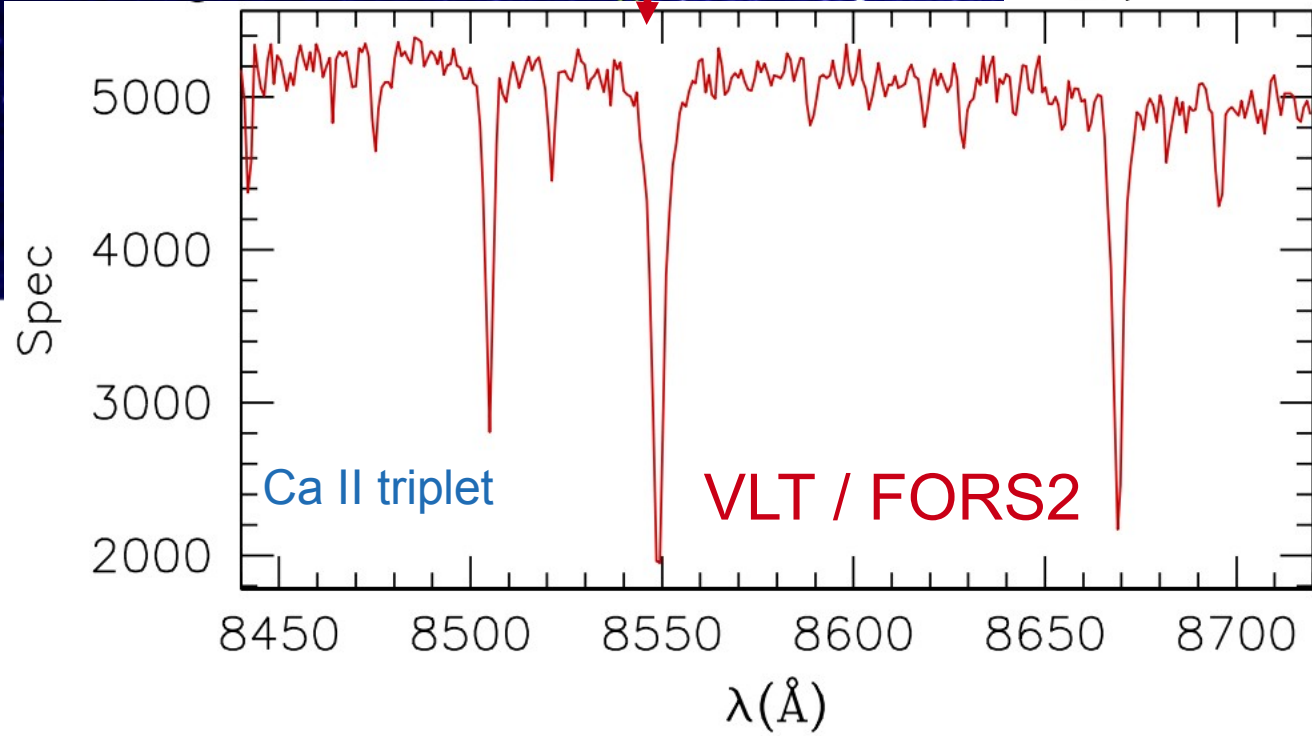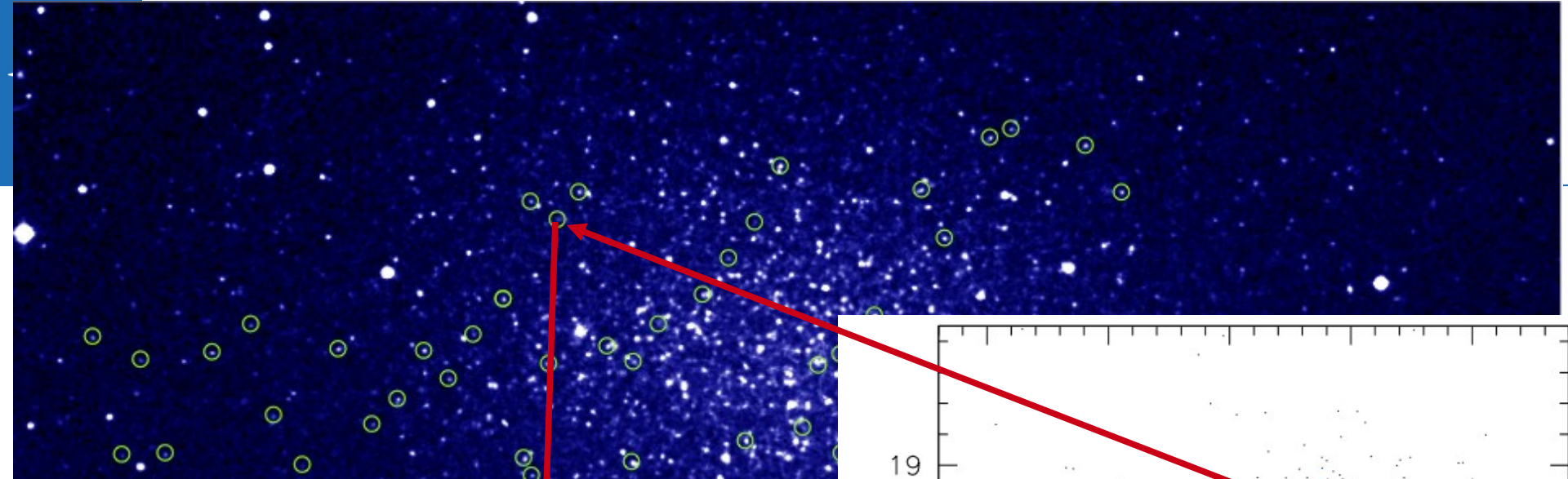♦ Start with example of simple population

The Calcium triplet method

- Low-resolution spectroscopy of RGB stars in the CaII triplet region

  - 2--4 AA FWHM

  - R ≈ 2000--3000

- Now try complex stellar population:
- ➢ Leo I dwarf spheroidal galaxy

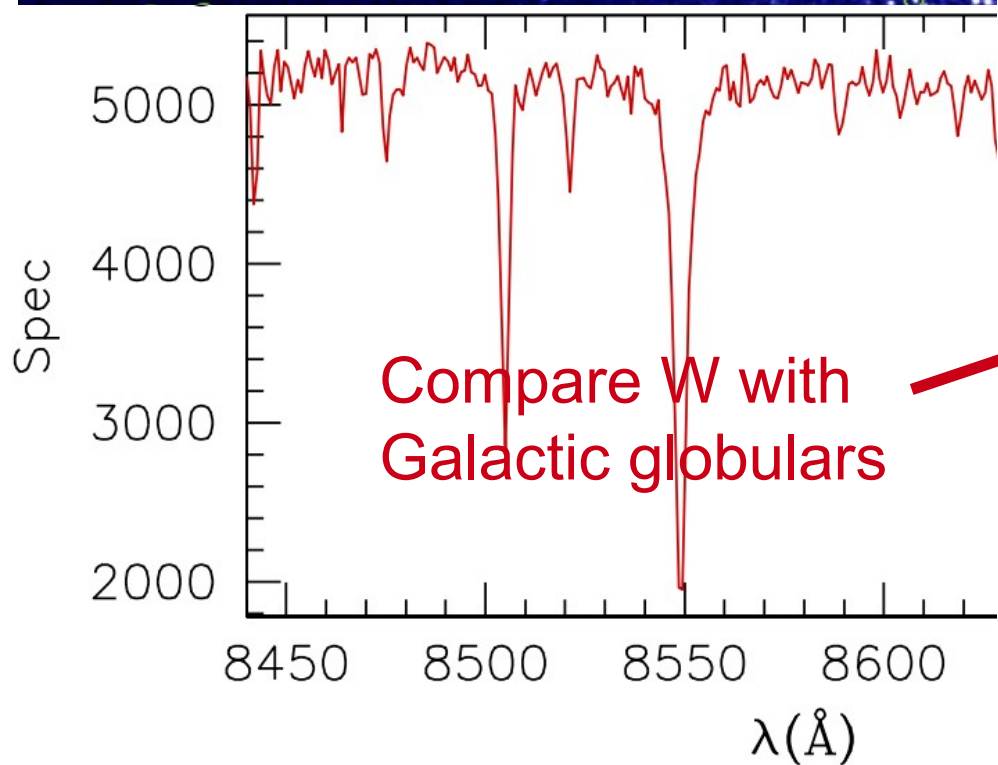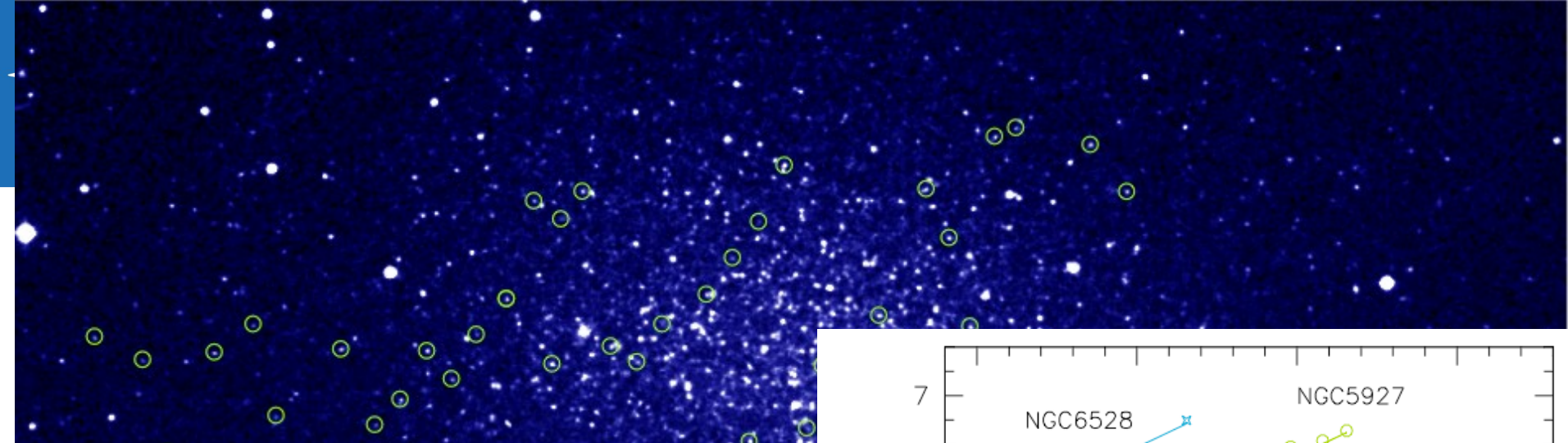# Leo I dwarf spheroidal galaxy

NTT /
EMMI

Ca II triplet

VLT / FORS2

Spec

5000

4000

3000

2000

8450   8500   8550   8600   8650   8700

$\lambda(\text{Å})$

19

5   1   1.5   2

B−V
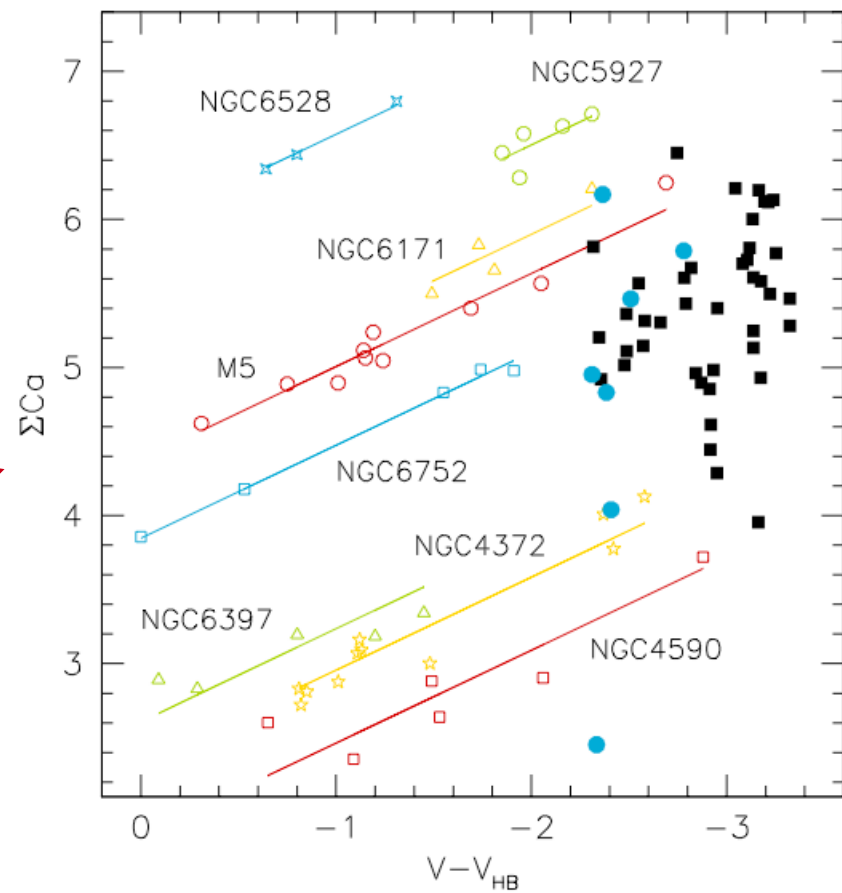
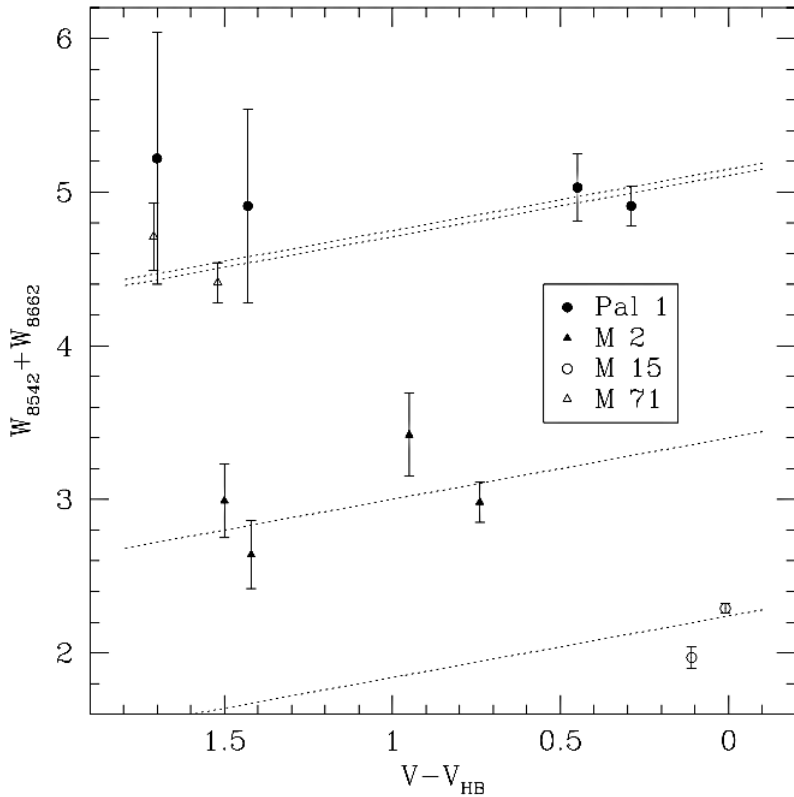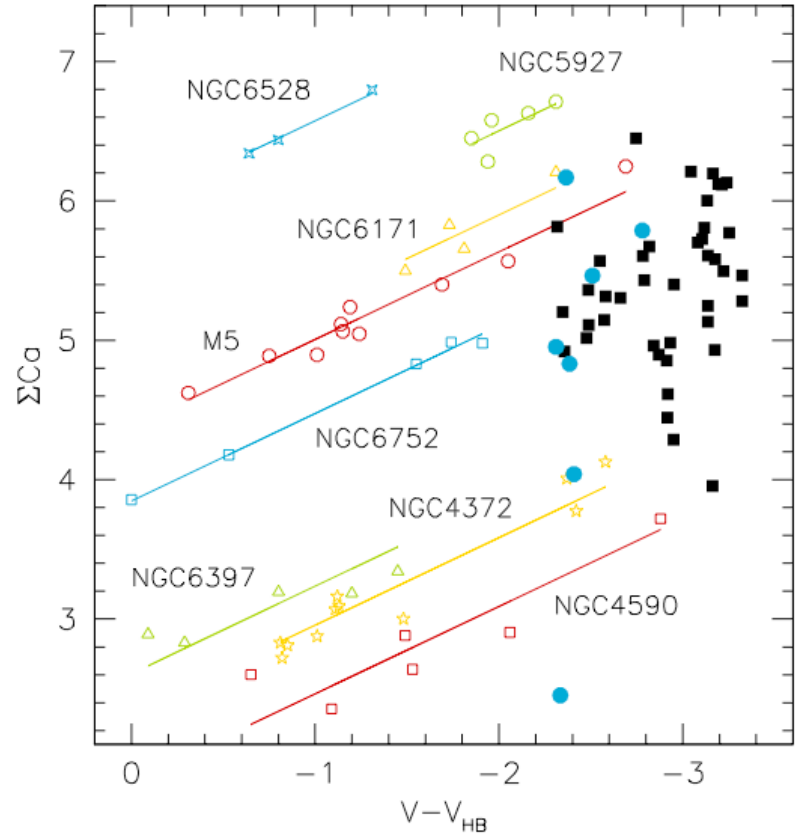Compare W with Galactic globulars

Simple vs. complex

FIG. 4.—Summed equivalent widths and their associated errors plotted vs. $V - V_{HB}$ for the cluster member stars (including stars III and IV of M2). Dotted lines reproduce the adopted best fit, as described in the text.
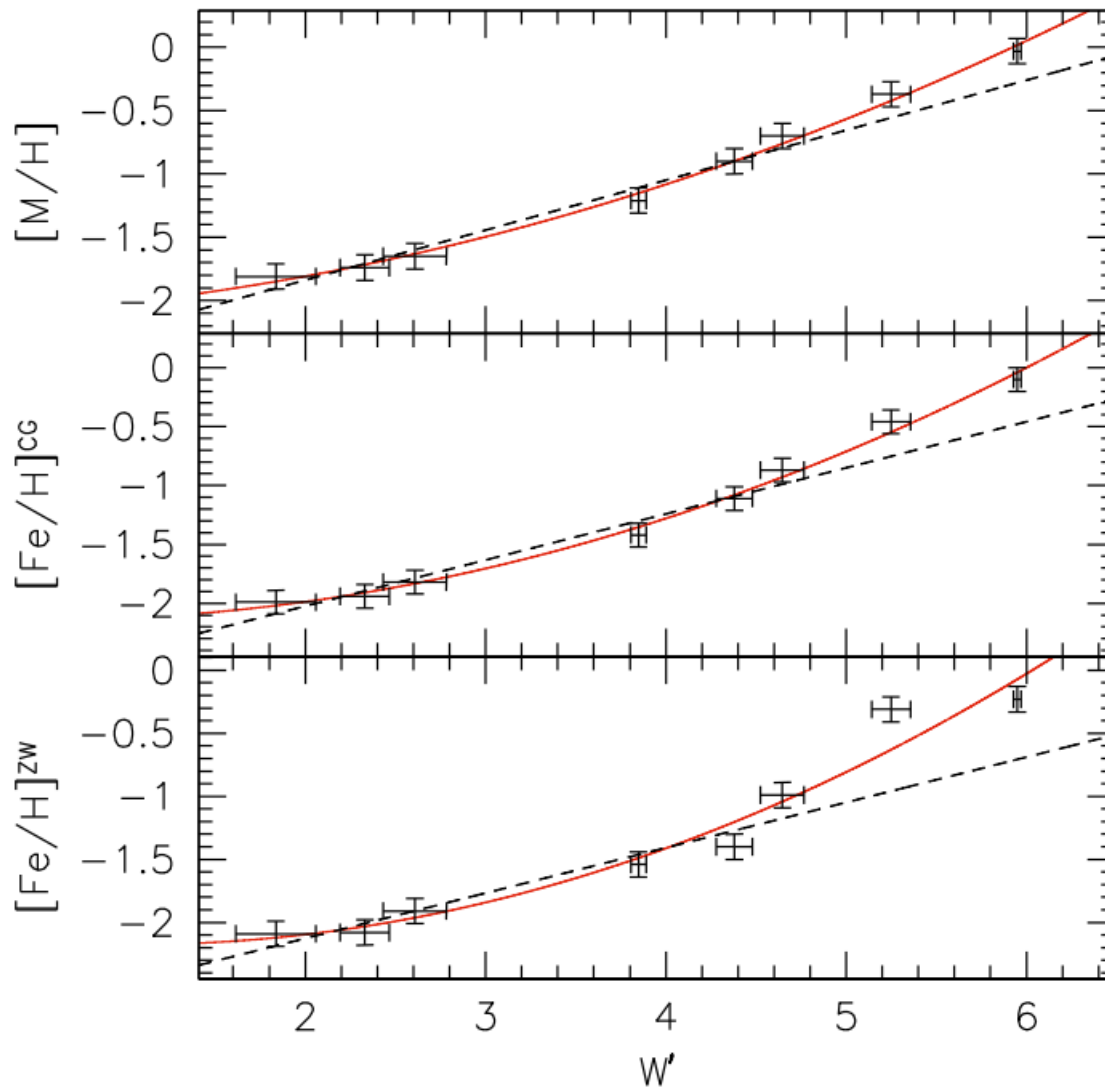
Fig. 7. The metallicity of the reference globular clusters against the reduced *EW* of CaT lines, for three adopted metallicity scales. The *solid* lines are quadratic fits, while the *dashed* straight lines are linear fits obtained for clusters with [Fe/H] < −0.6.
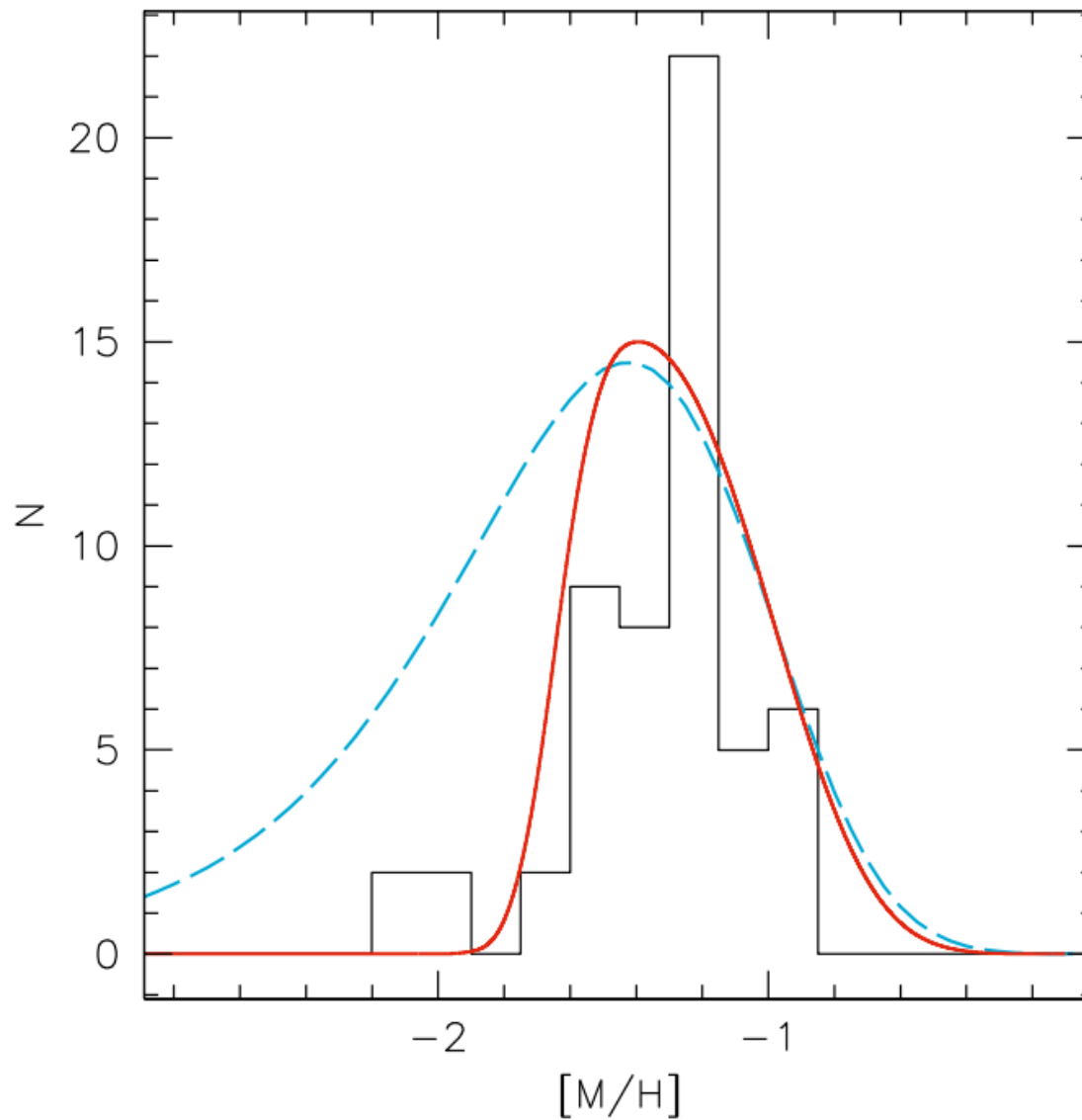
Fig. 9. The MDF of Leo I RGB stars on the [M/H] metallicity scale, compared with a simple model with a low effective yield (*dashed line*) and a model with a prompt initial enrichment (*solid line*).
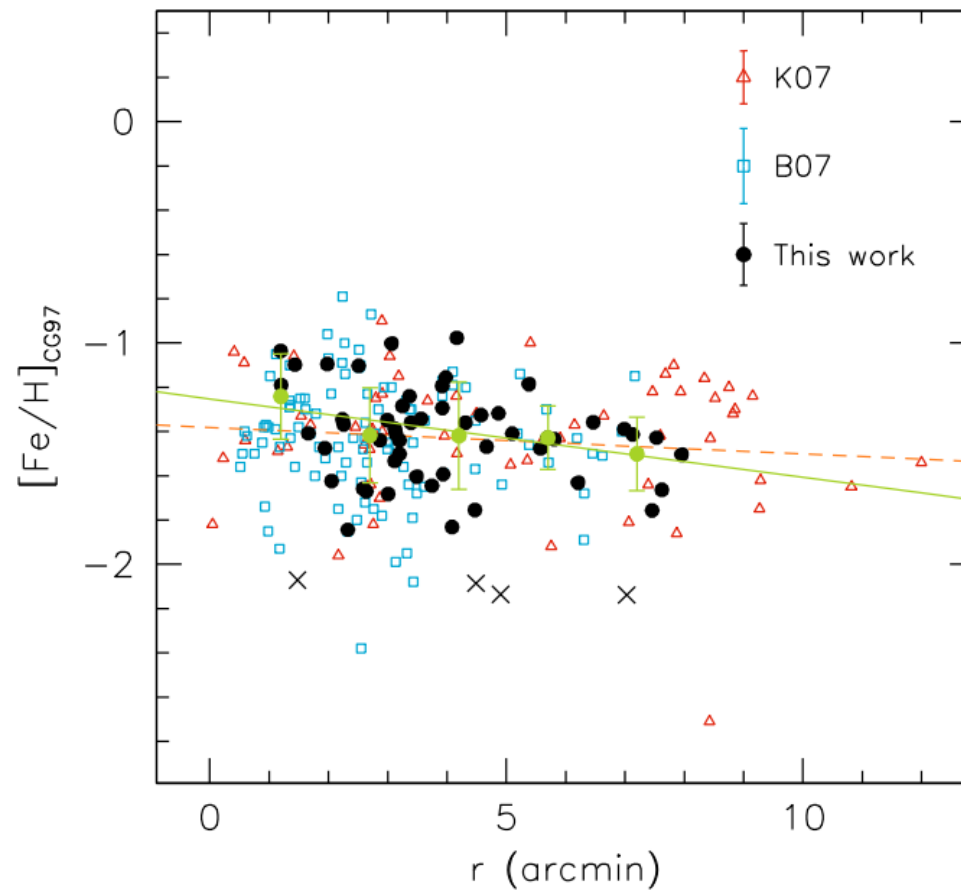
Fig. 10. Metallicities of Leo I stars on the [Fe/H] scale of CG97, plotted against the elliptical radius (see text). *Filled dots*: data in this paper; *open squares*: data from Bosler et al. (2007); *open triangles*: Koch et al. (2007b); *circles with error bars*: our data, binned in 1'.5 bins. The error bars of the binned data represent the abundance scatter (1σ) in each bin. The *crosses* are the 4 metal-poor stars in our sample. The typical errors of each study are shown in the upper right corner of the plot. The *solid line* is a fit to our (binned) data, while the *dashed line* represents a fit to all available spectroscopic data.
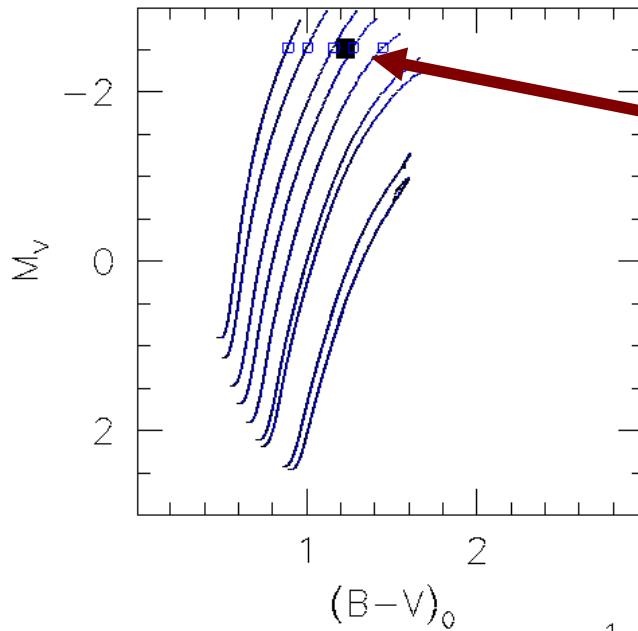
With:

- color
- luminosity
- metallicity

+ some isochrone interpolation
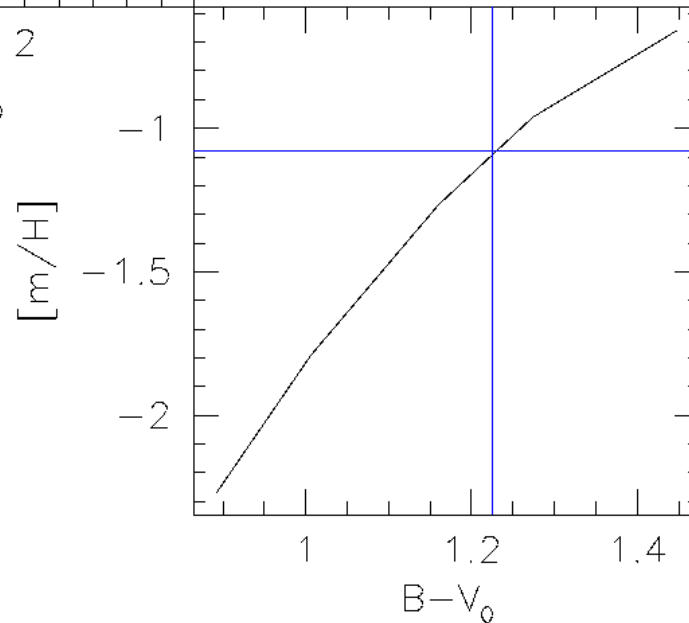   machinery by Ivo...
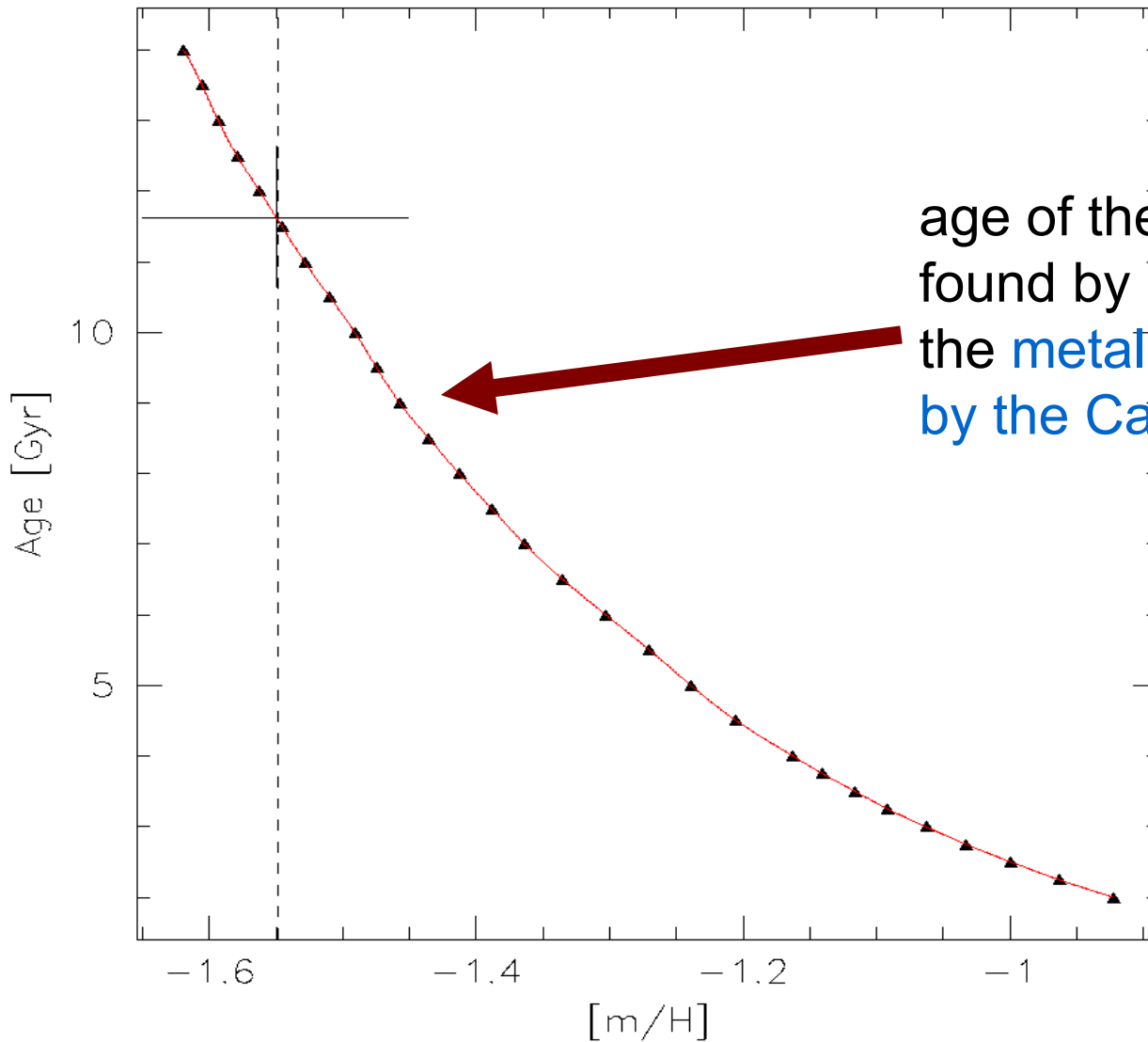
=> age of each star

Find isochrone's color
of RGB
at luminosity of each
star

Metallicity-color relation
interpolated by a cubic
spline

=> compute metallicity at
     stars' color

Then change age and repeat => age vs. [m/H]

age of the star can be found by using the metallicity yielded by the CaT method
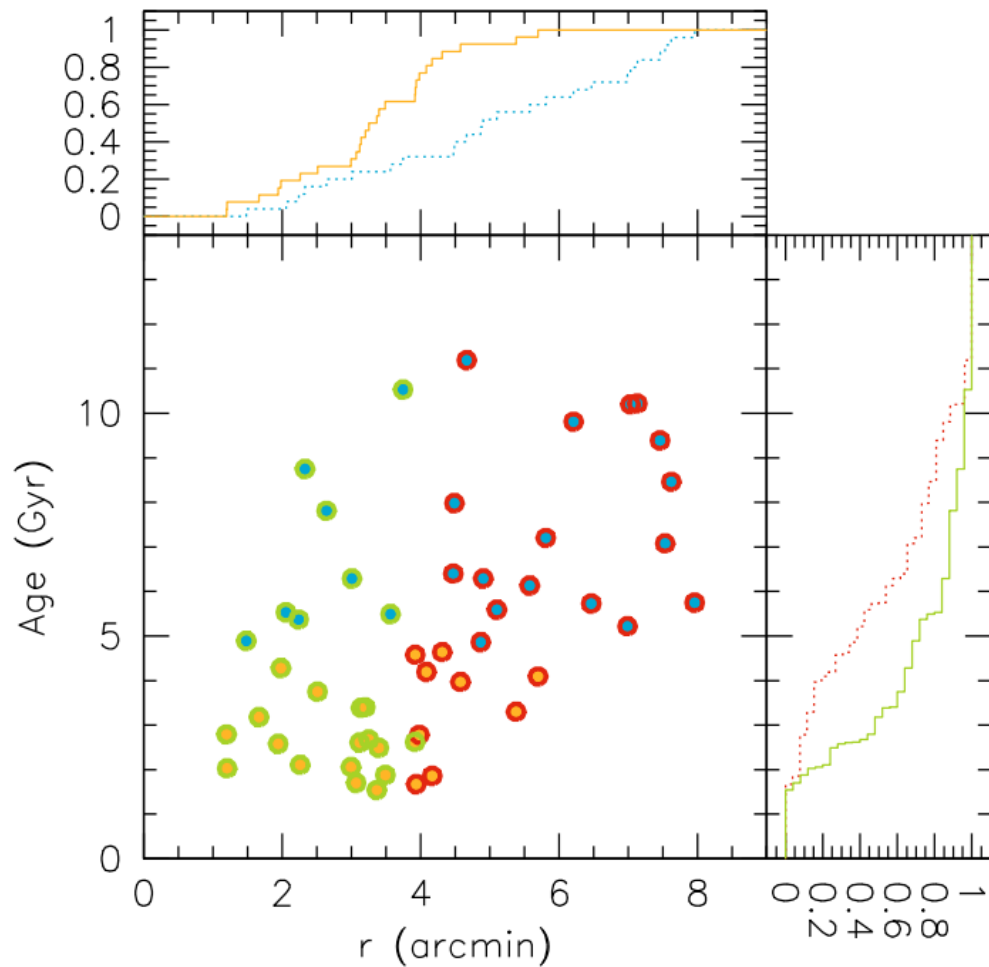
Fig. 12. Ages of the Leo I stars in our sample as a function of the elliptical radius (*central panel*). The *upper panel* shows the cumulative radial distributions of stars with ages smaller and larger (dotted line) than 4.6 Gyr. The cumulative age distributions of stars in the inner ($r < 3\rlap{.}'9$) and outer ($r > 3\rlap{.}'9$, dotted line) region are shown in the *right panel* (the different age and radial intervals are colour-coded in the electronic version of the journal). Younger stars appear to be more concentrated towards the centre of Leo I.
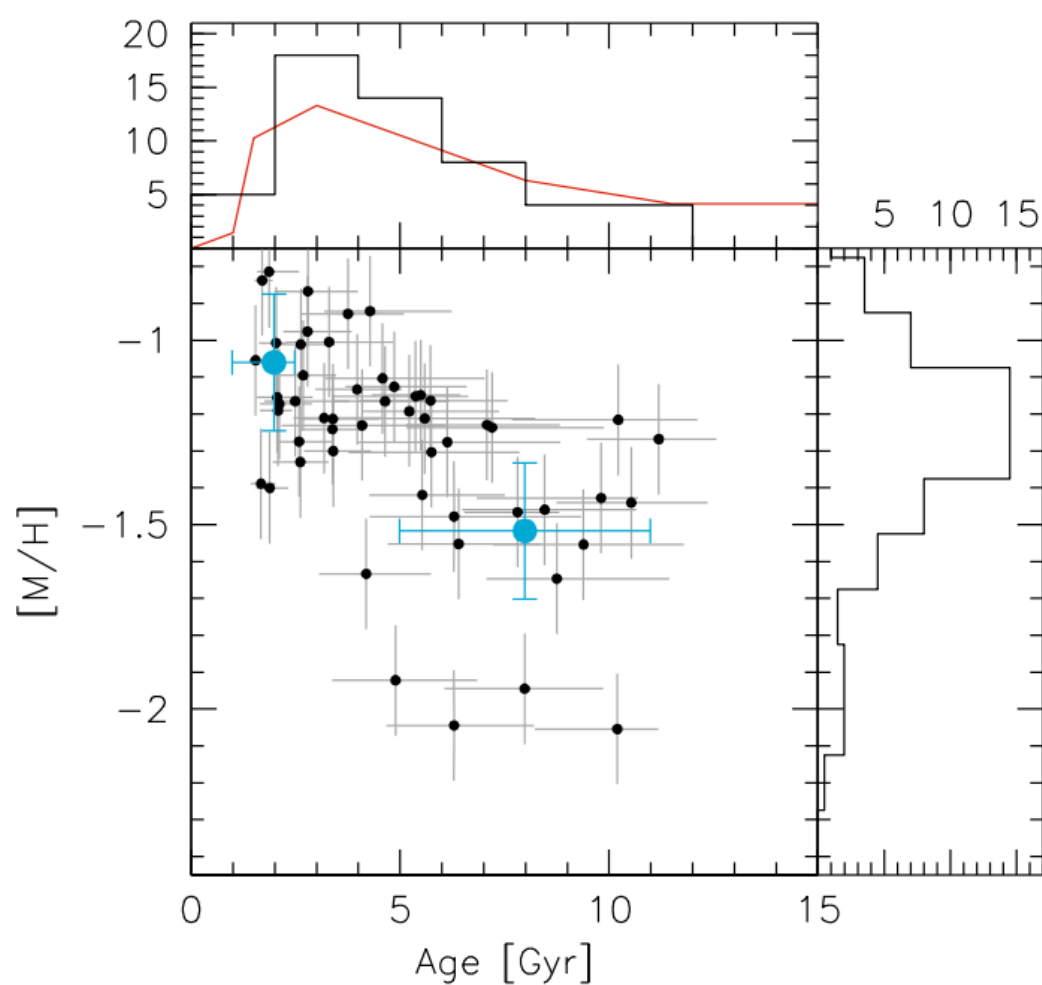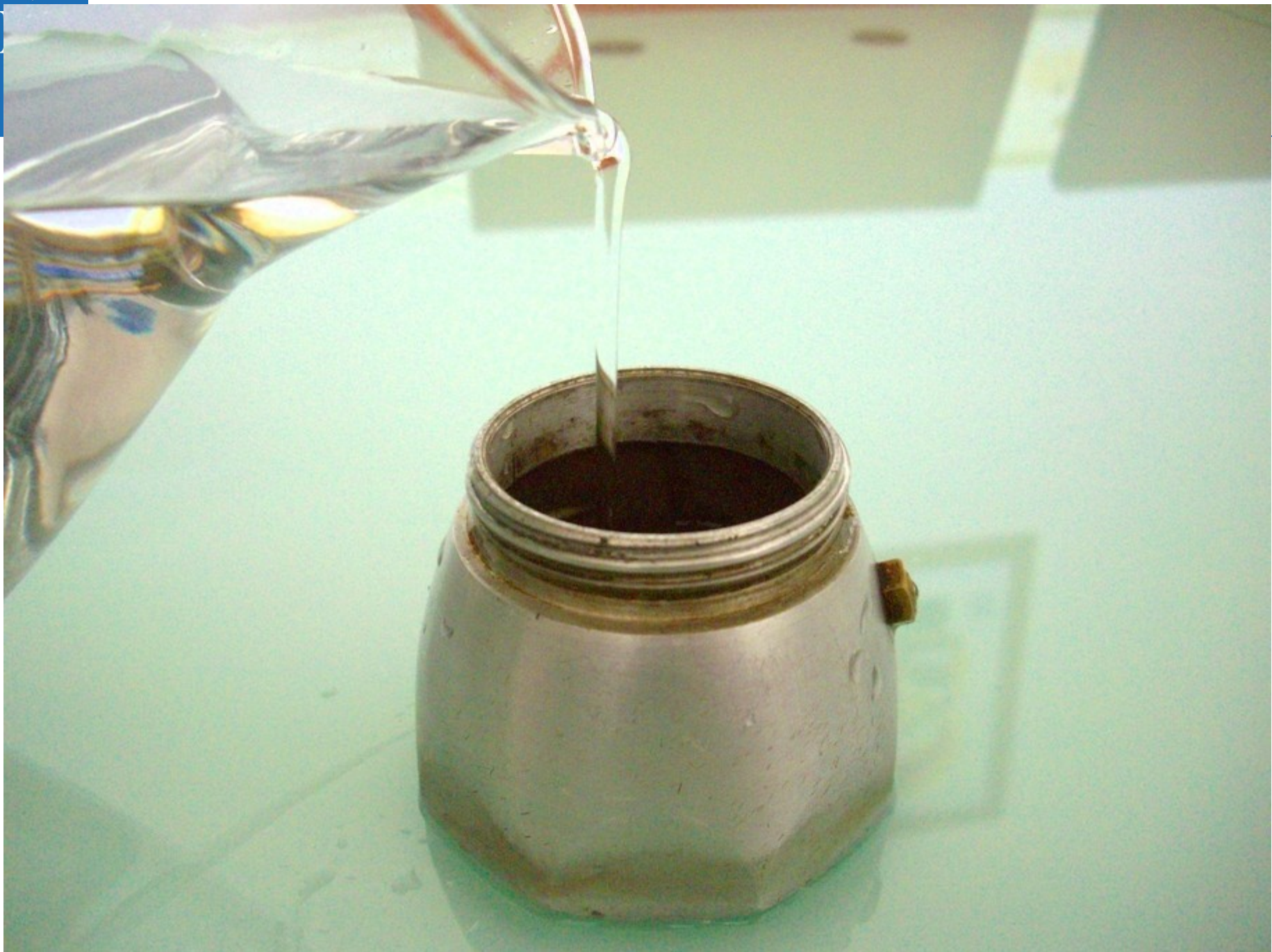
Fig. 11. The age-metallicity relation of Leo I RGB stars in our sample, on the [M/H] scale. The error bars in age represent the first and third quartile of the confidence intervals obtained through Monte Carlo realisations (see text for details). For the metallicity errors the representative value discussed in Sect. 4.3 is adopted. Also shown are the metallicities from high-resolution spectroscopy of two Leo I RGB stars from Tolstoy et al. (2003) (*big filled circles*). The side histograms are the marginal distributions in metallicity and age. The *solid line* in *the top panel* represents the SFH derived by Dolphin (2002) from HST photometry, normalised to the total number of stars in our sample.
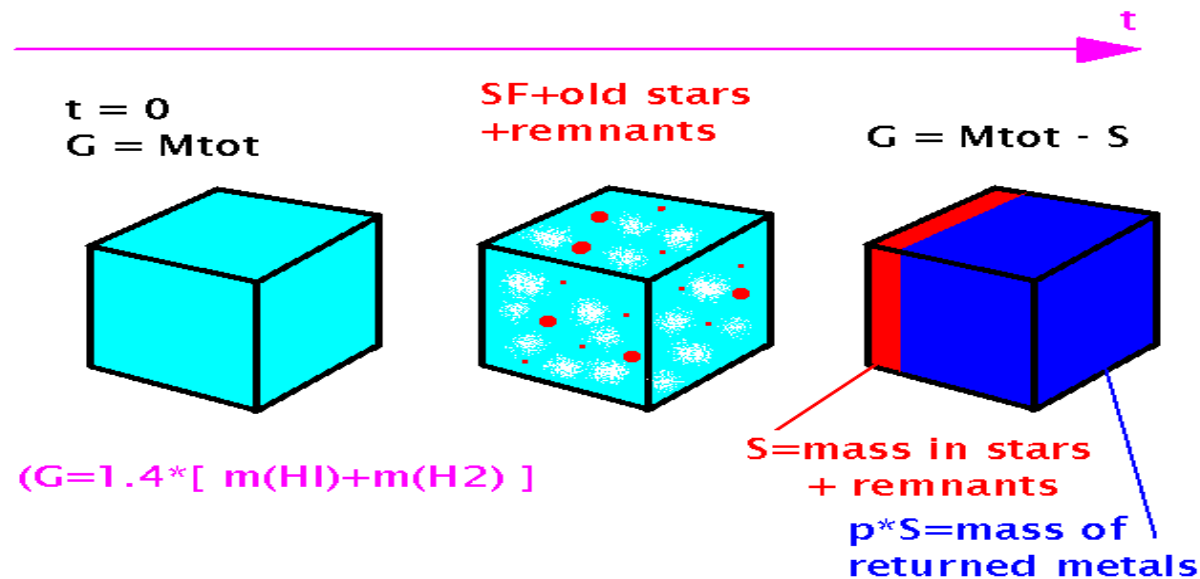
The closed box model

The "simple model" of GCE

t = 0
G = Mtot

SF+old stars +remnants

G = Mtot - S

(G=1.4*[m(HI)+m(H2)])

S=mass in stars + remnants

p*S=mass of returned metals

Isolated system
Perfect mixing
IMF = const
Nucleosynthetic yields p$_i$ = const

Instantaneous recycling (e.g. Oxygen)
"real" models => relax one or more
hypothesis (e.g. Delayed formation for N)

$$p_i = \frac{\int_{m(t)}^{m_U} m\, q_i(m)\, \phi(m)\, dm}{S}$$

Yield per stellar mass

IMF

Basic equations

$$Z = \frac{M_Z}{G} = \frac{pS}{G}$$

$$Z + dZ = \frac{M_Z + p\,dS}{G}$$

$$Z + dZ = Z + p\frac{dS}{G}$$

$$dZ = p\frac{-d(M_{\text{tot}} - S)}{G}$$

$$dZ = -p\frac{dG}{G}$$

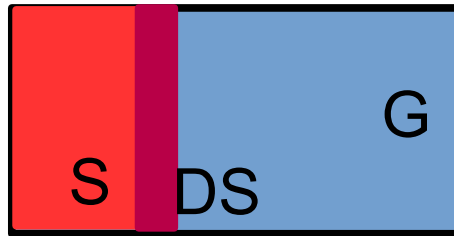$$Z_1 - Z_0 = -p\ln\frac{G_1}{G_0}$$

$$Z = -p\ln\frac{1}{\mu}$$

$$[\ Z_0 = 0;\ Z_1 = Z$$

$$G_0 = M_{\text{tot}};\ G_1 = G$$

$$\mu = \frac{G}{M_{\text{tot}}}\ ]$$

Mtot = G+S => dG = -dS

Metallicity of
ISM

Metallicity of
stars

$$dZ = p\frac{dS}{G}$$

$$\frac{dS}{dZ} = \frac{1}{p}\,G$$

$$\overline{m}\,\frac{dN}{dZ} = \frac{1}{p}\,G$$

$$\overline{m}\,\frac{dN}{dZ} = \frac{1}{p}\,M_{\text{tot}}\,e^{-Z/p}$$

$$\frac{dN}{dZ} = \frac{M_{\text{tot}}}{\overline{m}}\,\frac{1}{p}\,e^{-Z/p}$$

Mtot = M* + Mgas = constant

$$Z = p \ln \frac{1}{\mu}$$

μ=Mgas/Mtot

$$\frac{dN}{dZ} = \frac{M_{tot}}{m} \frac{1}{p} e^{-Z/p}$$

Leo I, Gullieuszik et al. 2009
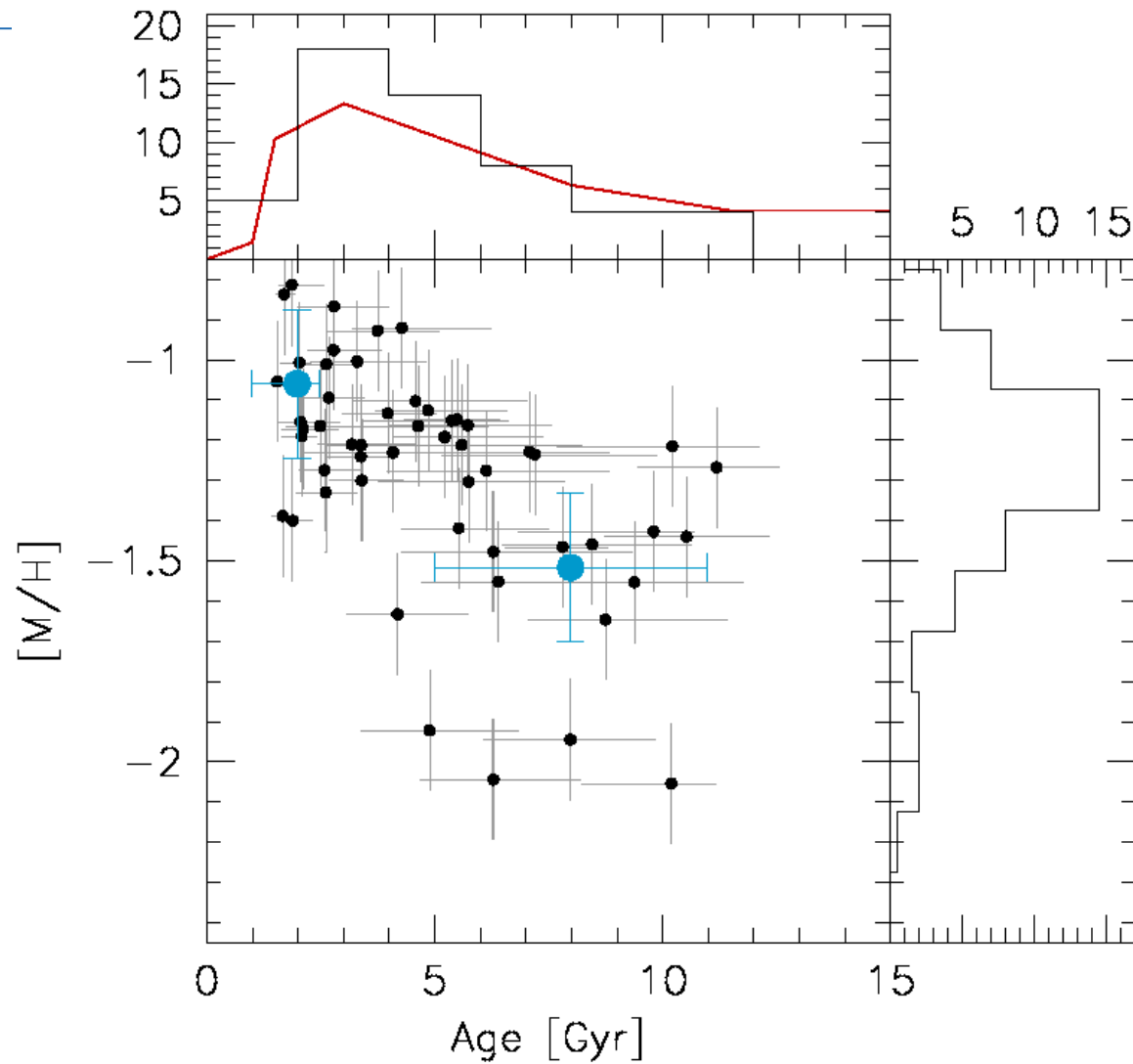
log(Z/Zo)

t

log(Z/Zo)

d μ/d t = 0.2

p=Zsun/2

t

AUX
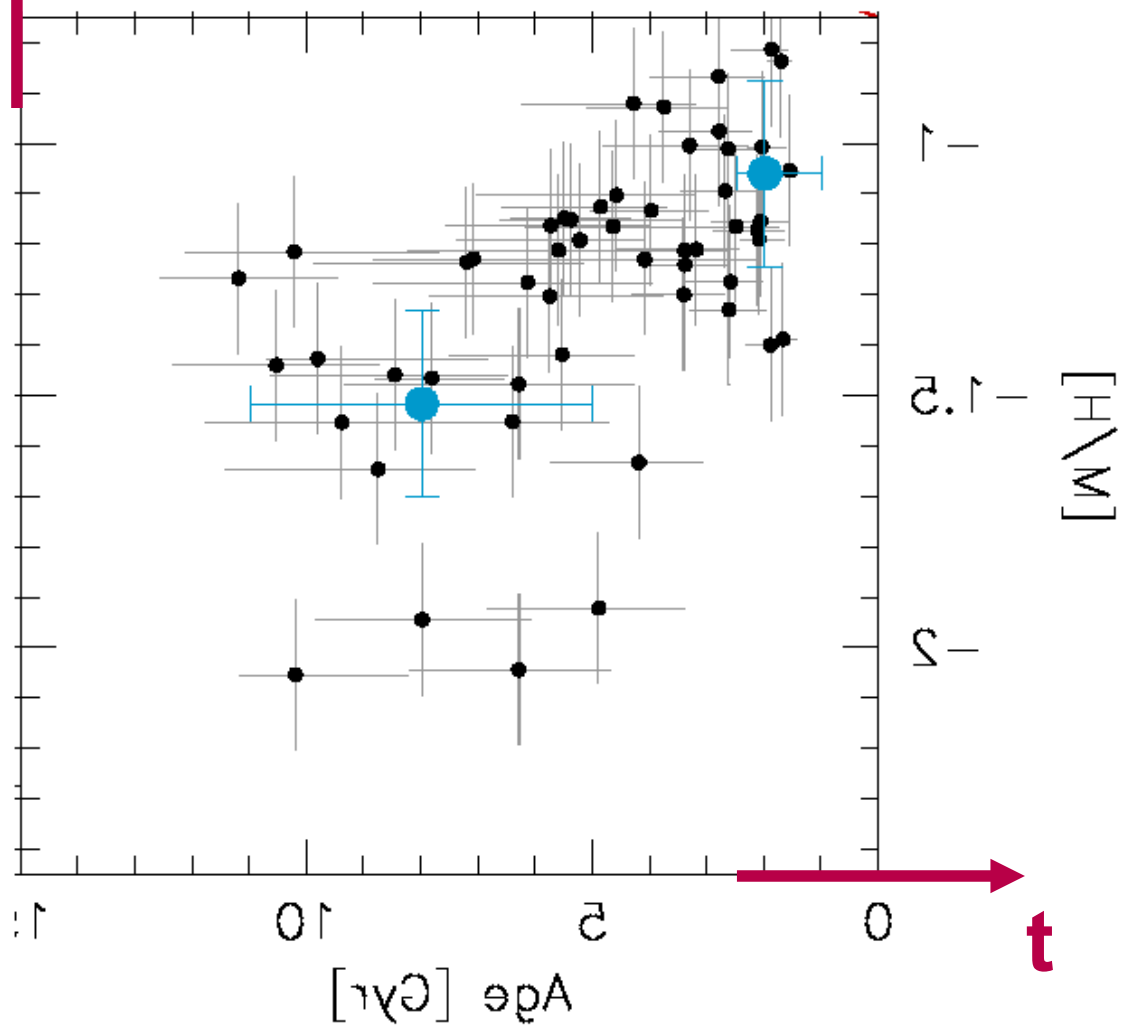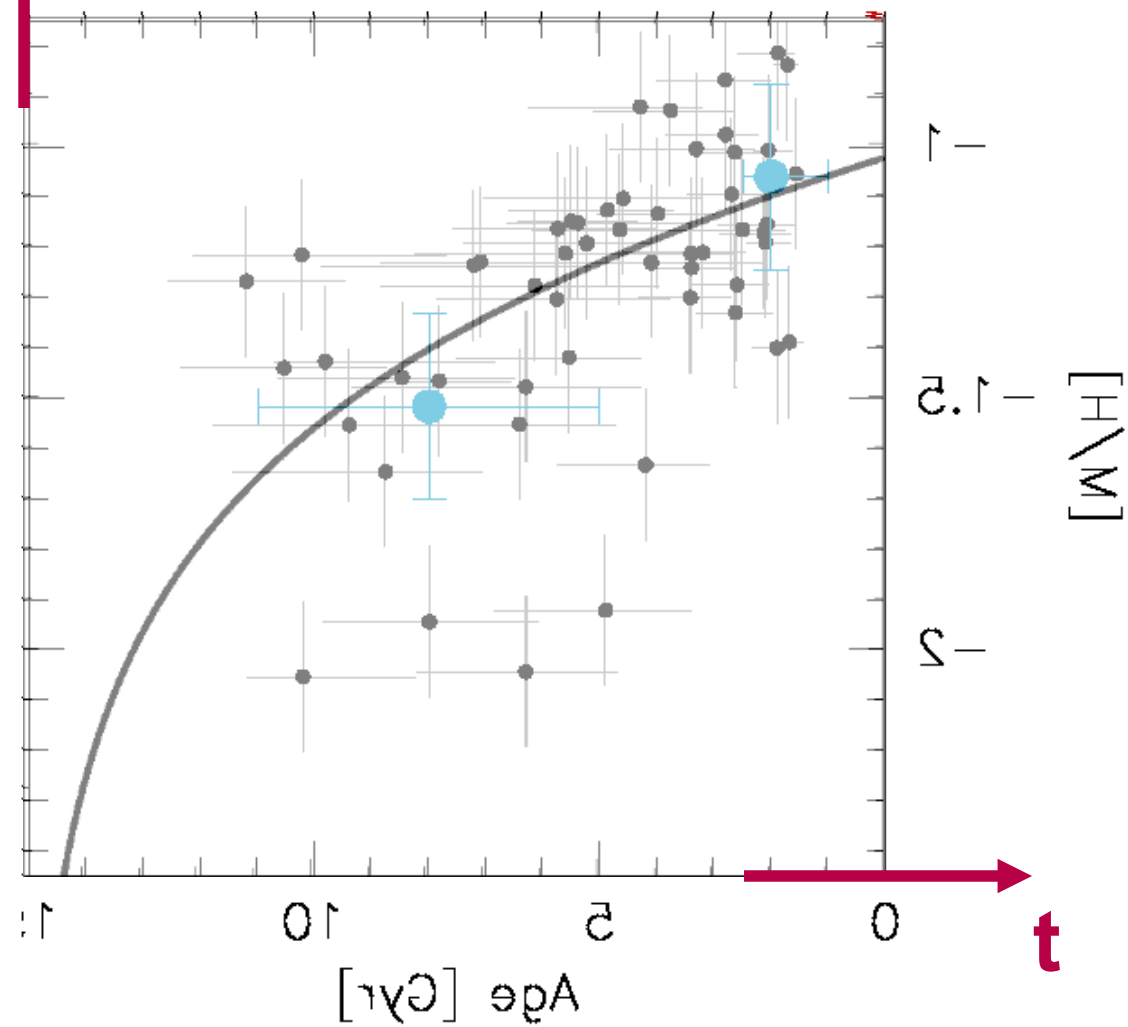
How to get metallicities of resolved stellar populations, from the basics to methods for distant objects.
Or from detailed abundances of small samples to coarse abundances of large samples.
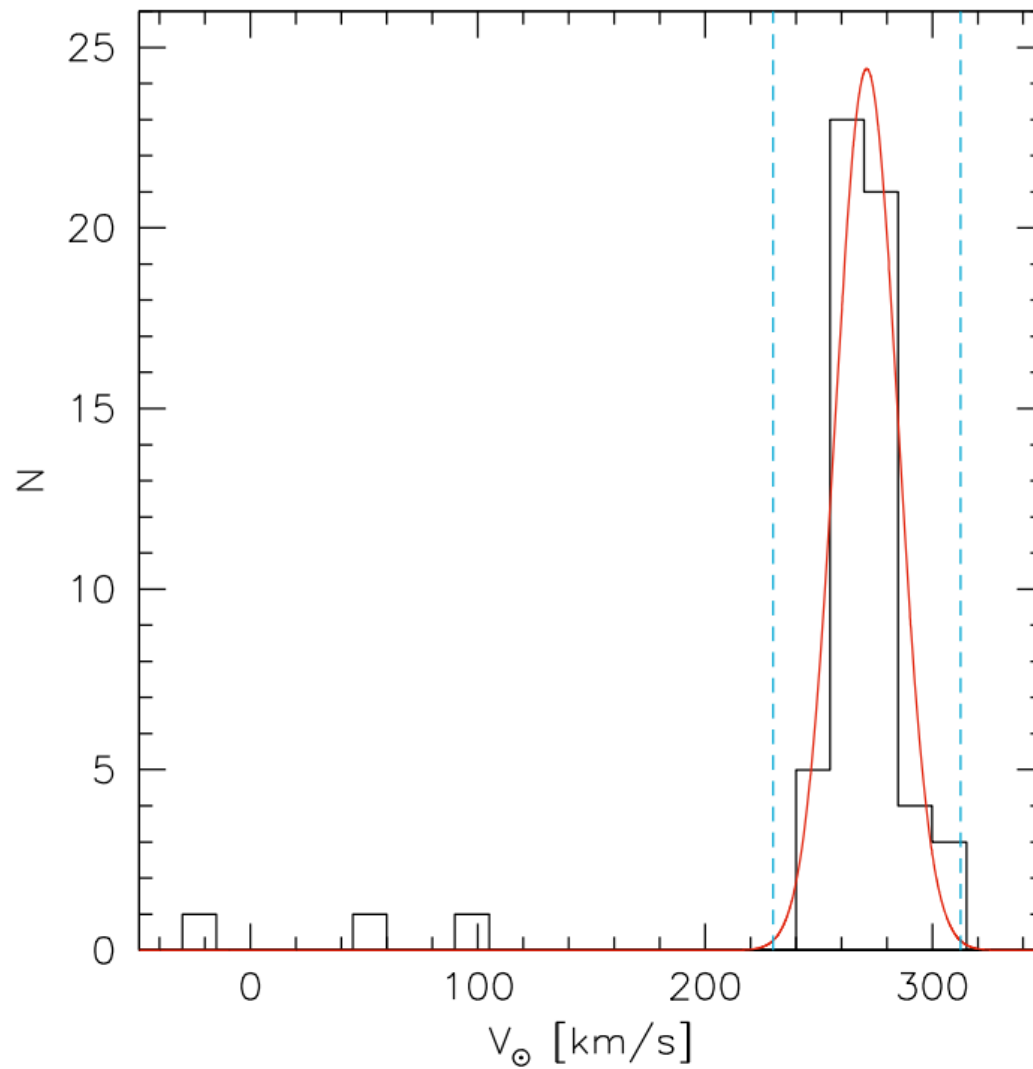
What is it?
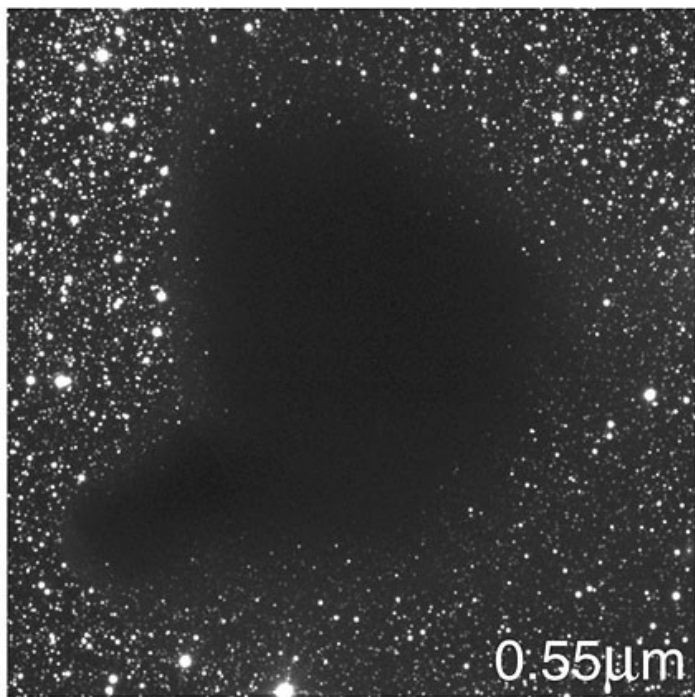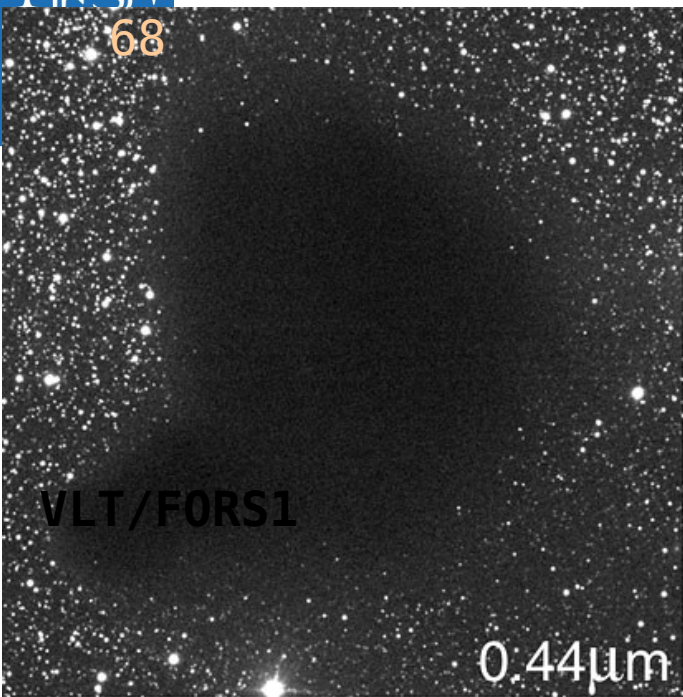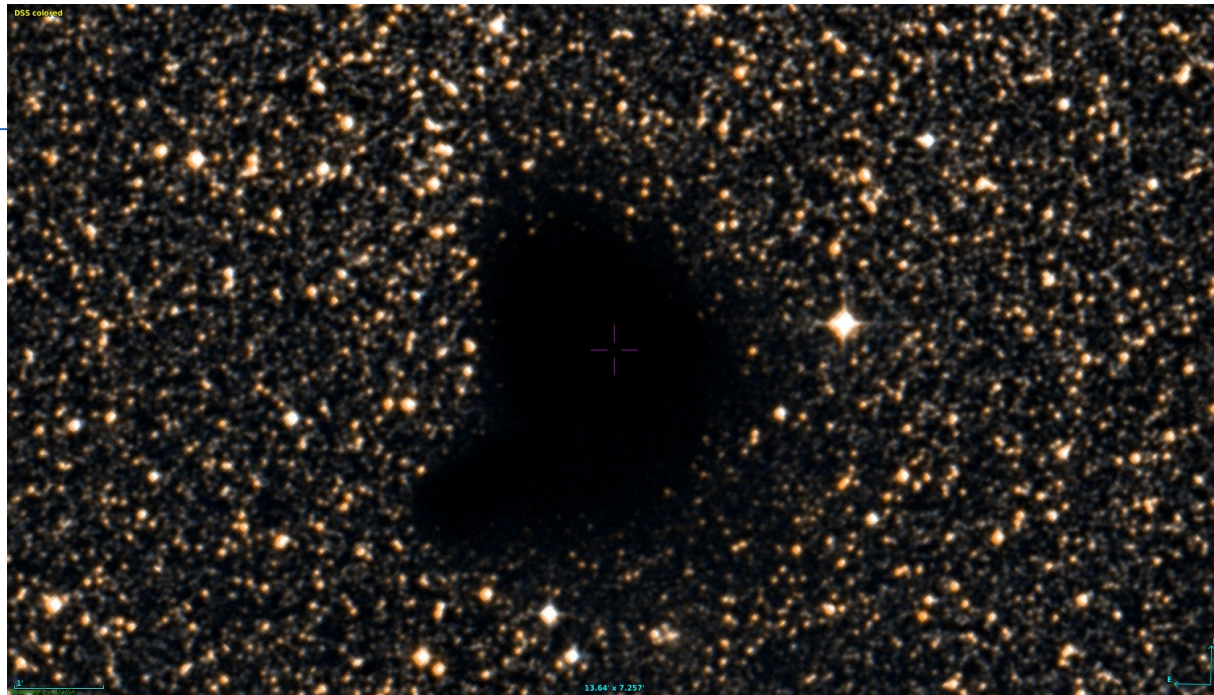Our lectures in this context

Fig. 4. Heliocentric radial velocities of stars in the Leo I field. The distribution is fitted with a Gaussian centred at 271 km s^{-1} and with dispersion 13.7 km s^{-1}. The vertical dashed lines represents the 3σ limits used to select members of Leo I.

Extension to NIR bands:

=> it does not matter how you compute <W'>!

VLT/FORS1
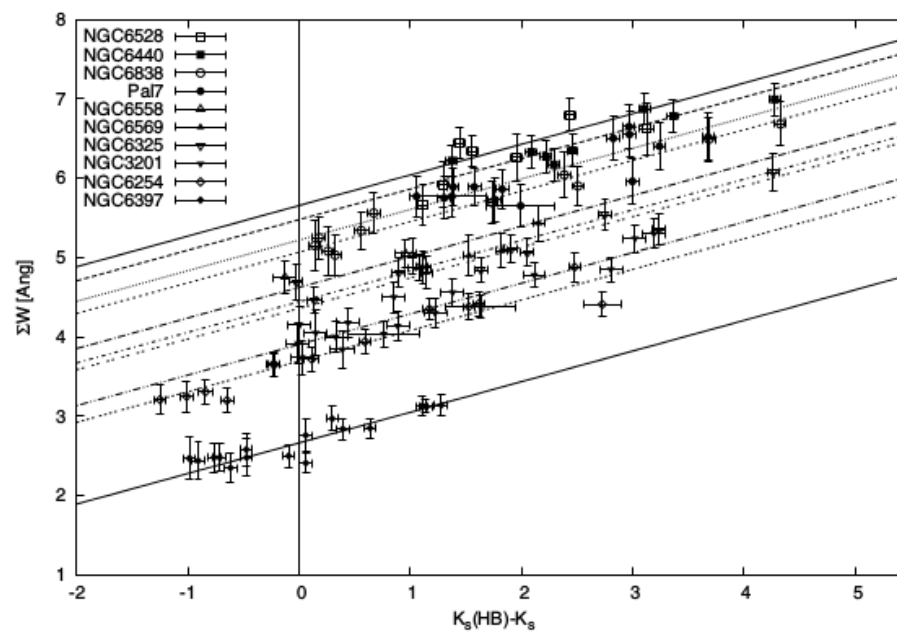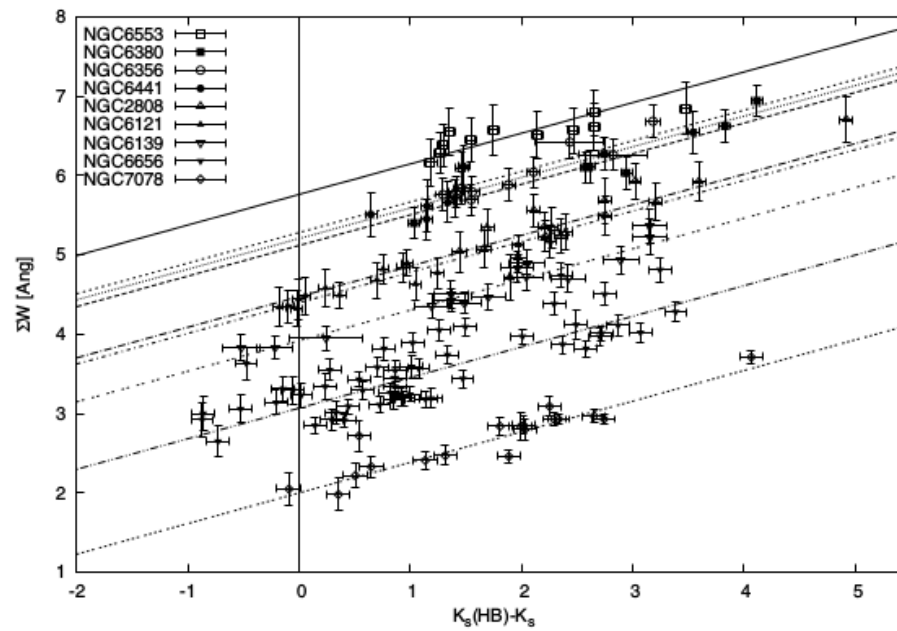
0.44μm

0.55μm

**NTT/SOFI
K-band**
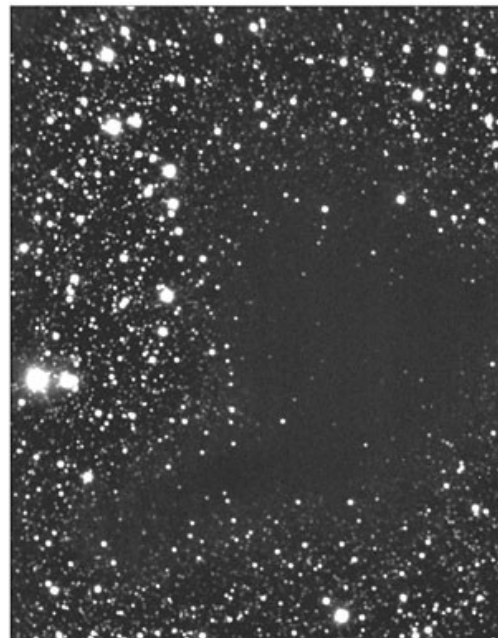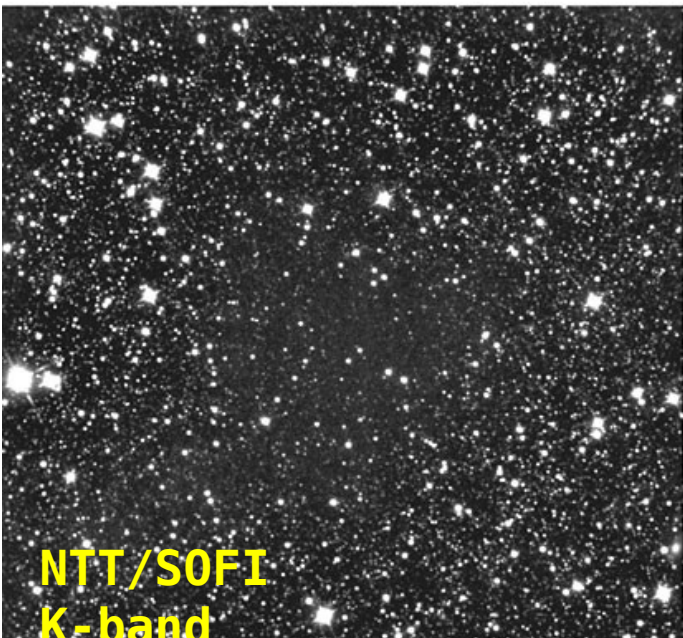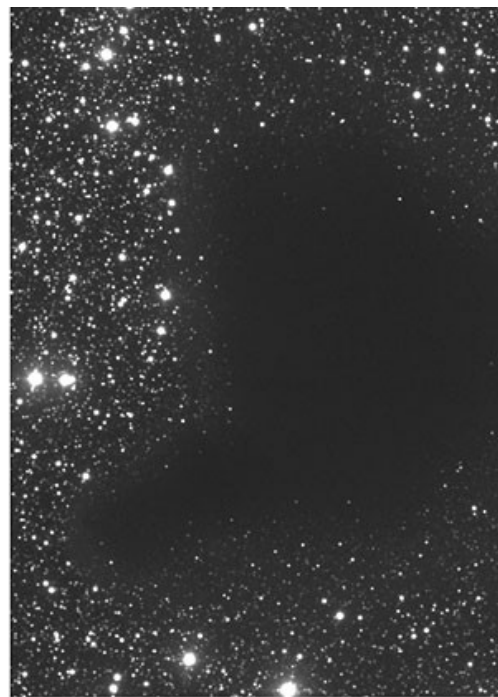
Fig. 3. Summed Ca II line strength $\sum W_{S12}$ plotted against magnitude difference from the red clump $K_s(\text{HB}) - K_s$ for the selected clusters.
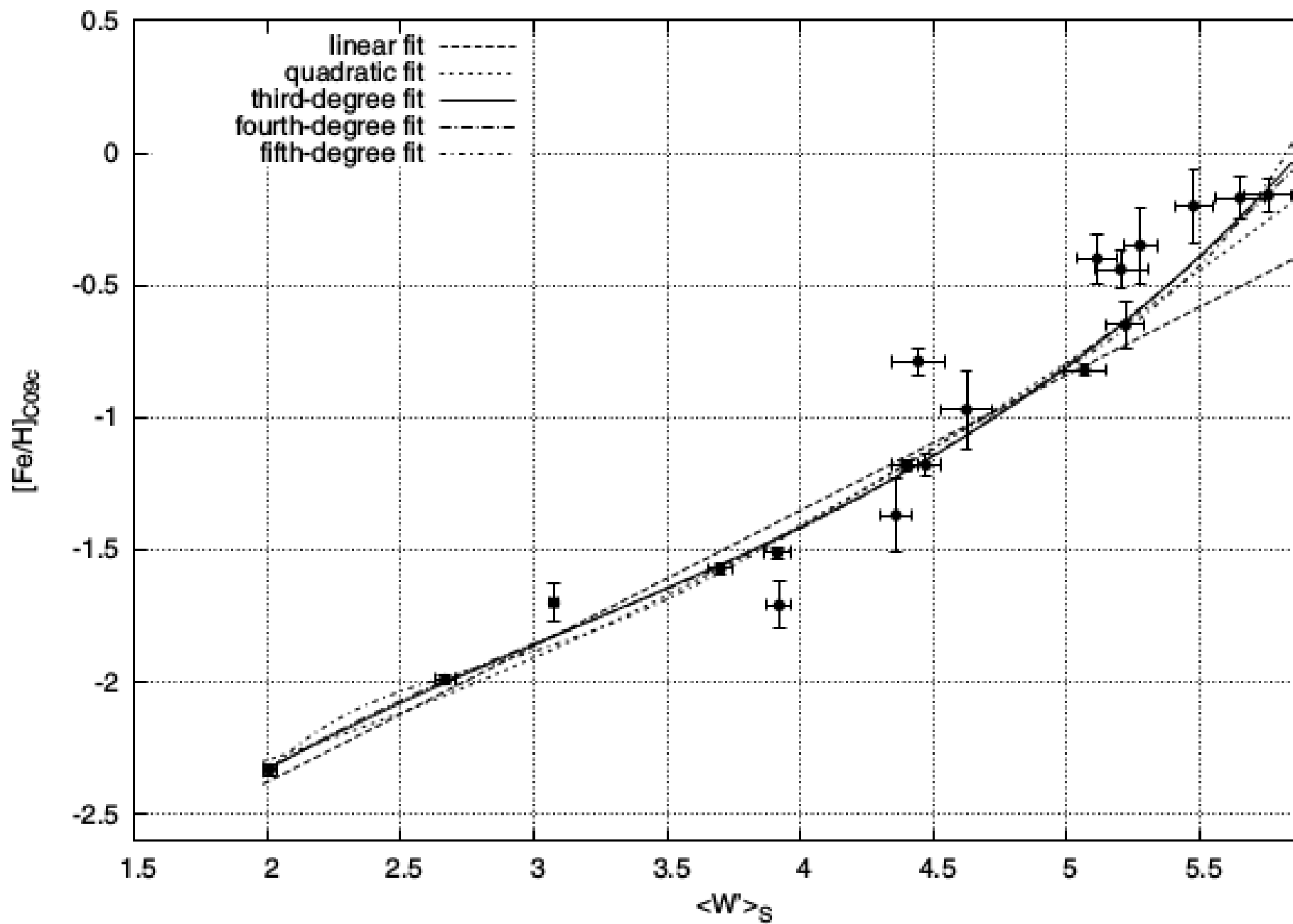
Fig. 5 Calibration relations between [Fe/H] on the scale of correc
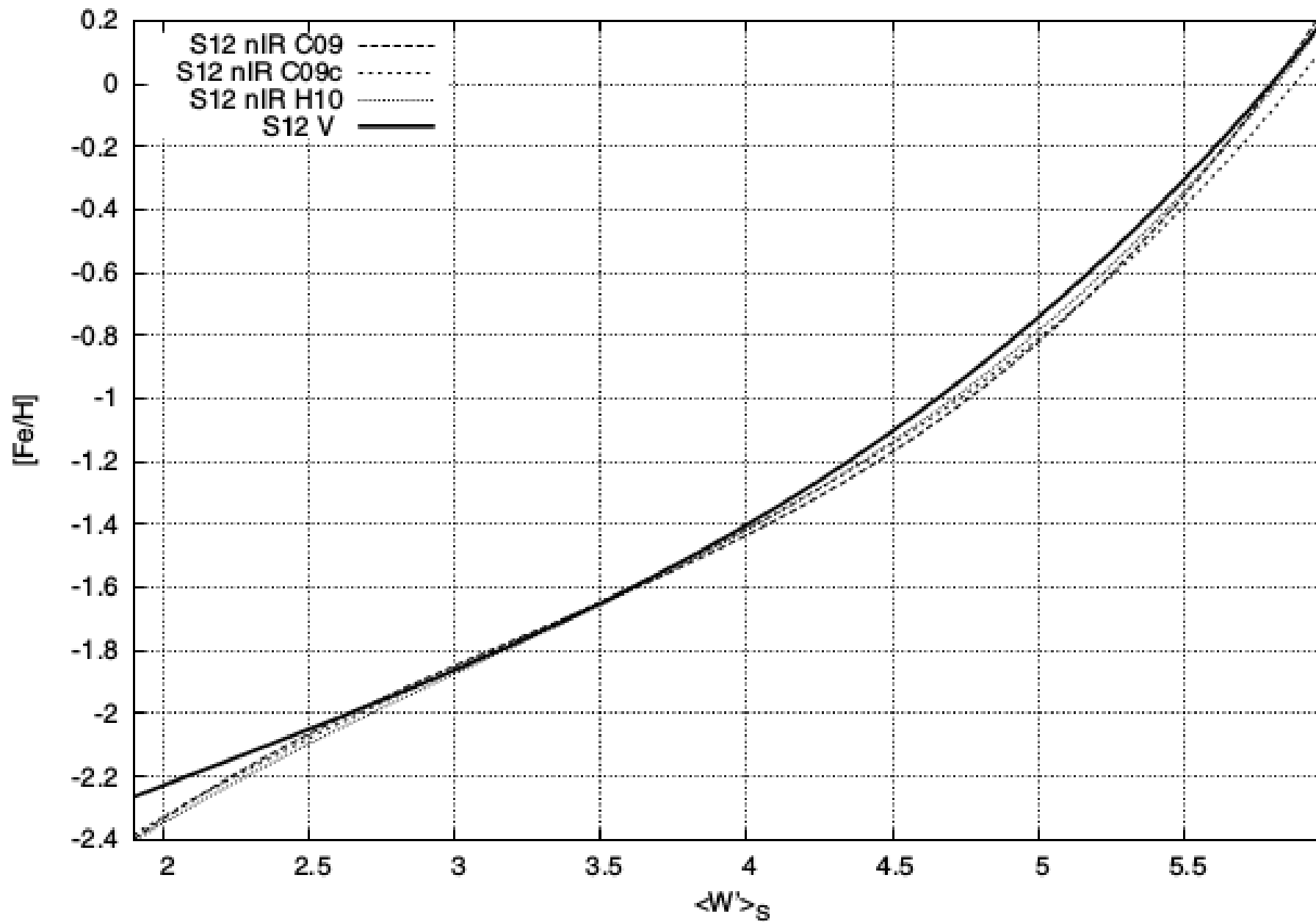
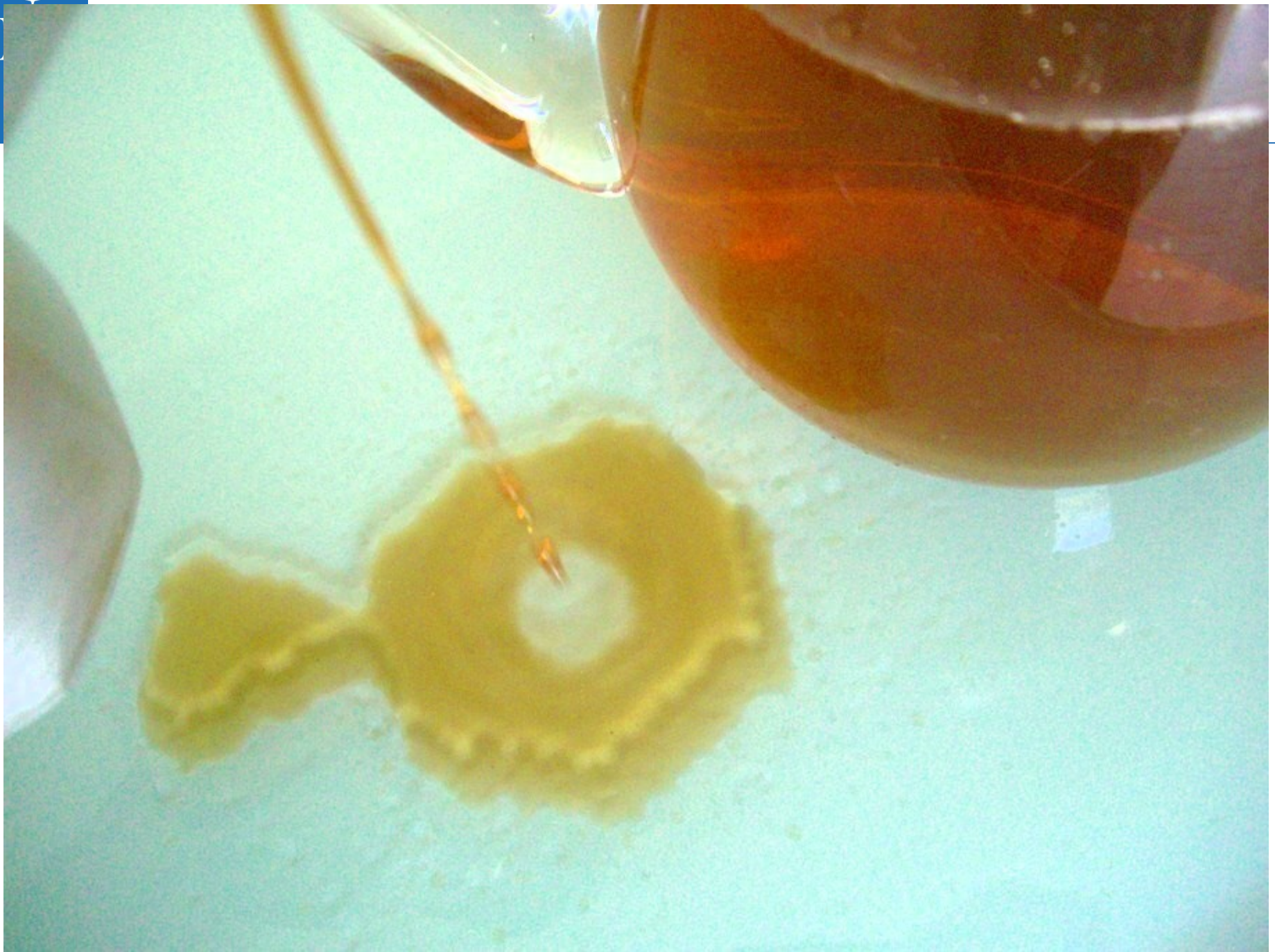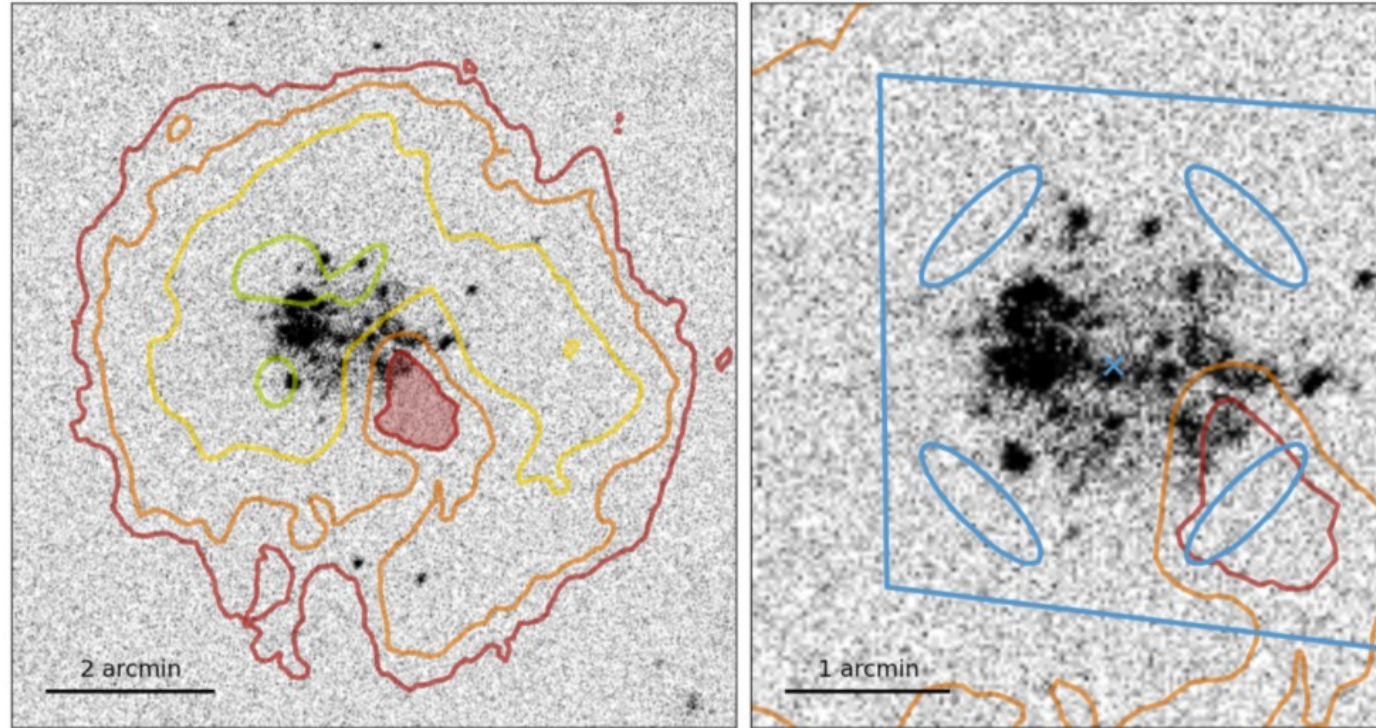**Fig. 7.** Comparison of the cubic calibration relations [Fe/H] vs. N

Fig. 5. GALEX far-ultraviolet image of SagDIG upon which HI contours are overplotted. The 3 highest density HI clump the inner, open (green) contours, while the HI hole is highlighte a shaded region. The *right panel* displays a closer view on the body of SagDIG highlighting (i) the quadrangle HST/ACS fie view; (ii) the SagDIG derived center (see text) marked by a c and (iii) the 4 equidistant elliptical regions; used to extract and com the stellar populations in the HI hole and the surrounding compa
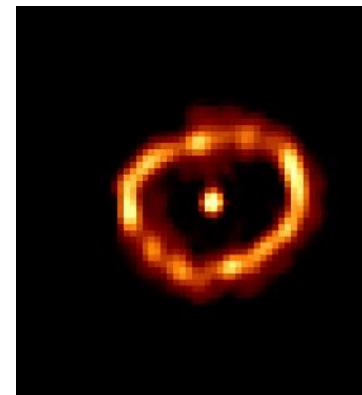
proto-planetary nebula
"rotten egg nebula"
HST/WFPC2
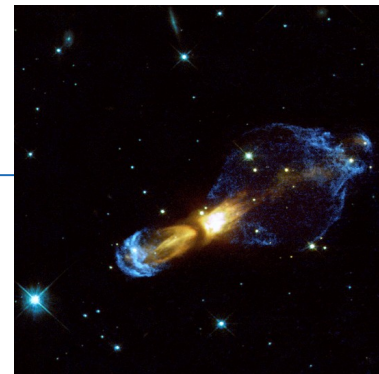
Nova Cygni 1992
Credit: NASA, ESA,
HST, F. Paresce,
R. Jedrzejewski
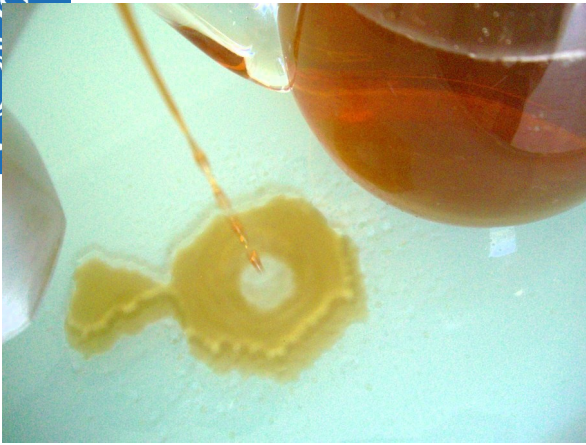(STScI)

Wolf-Rayet
stars
e.g., Eta
Carinae

SN Type II   SN
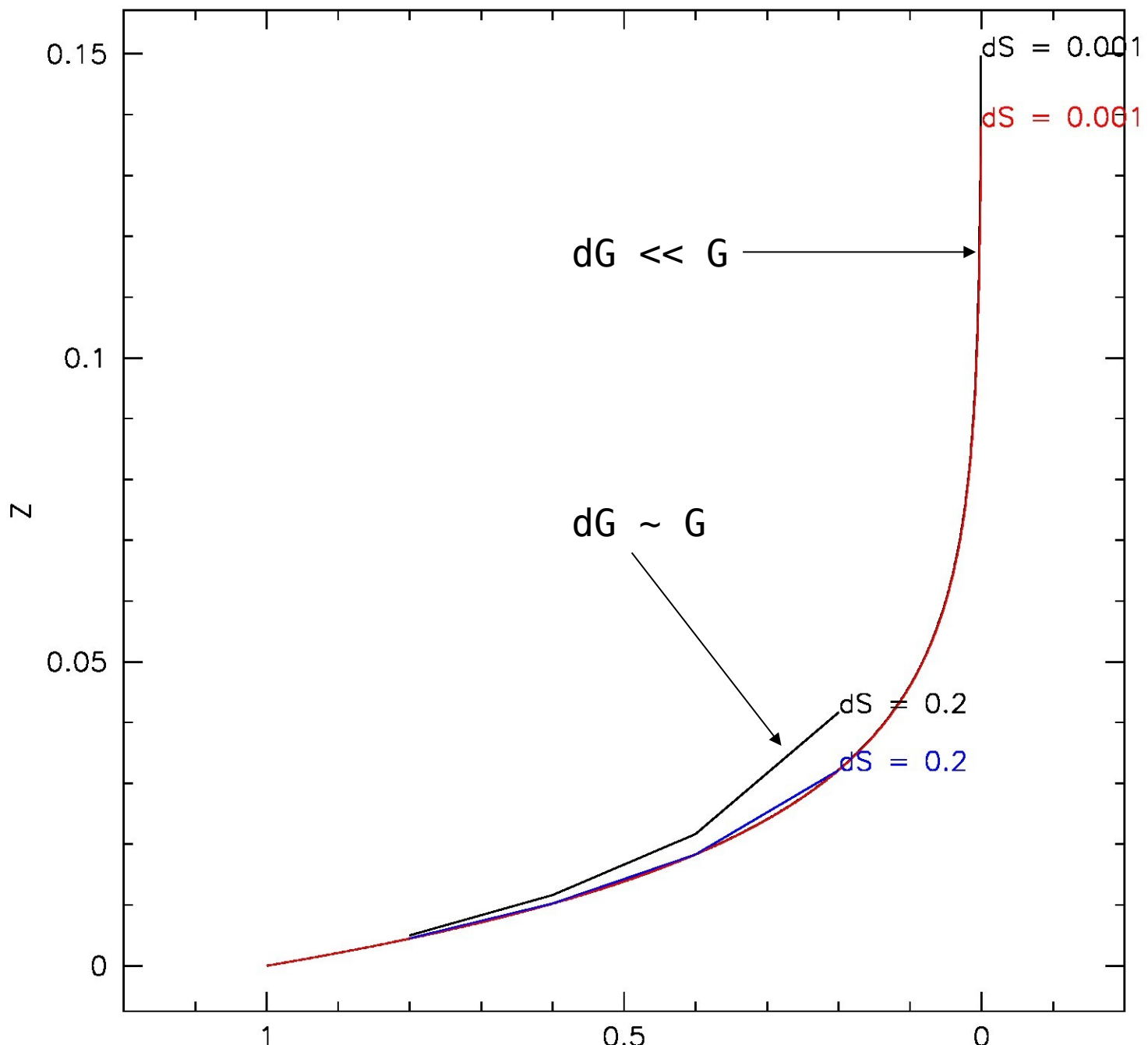Type Ia

M82: winds from a starburst galaxy

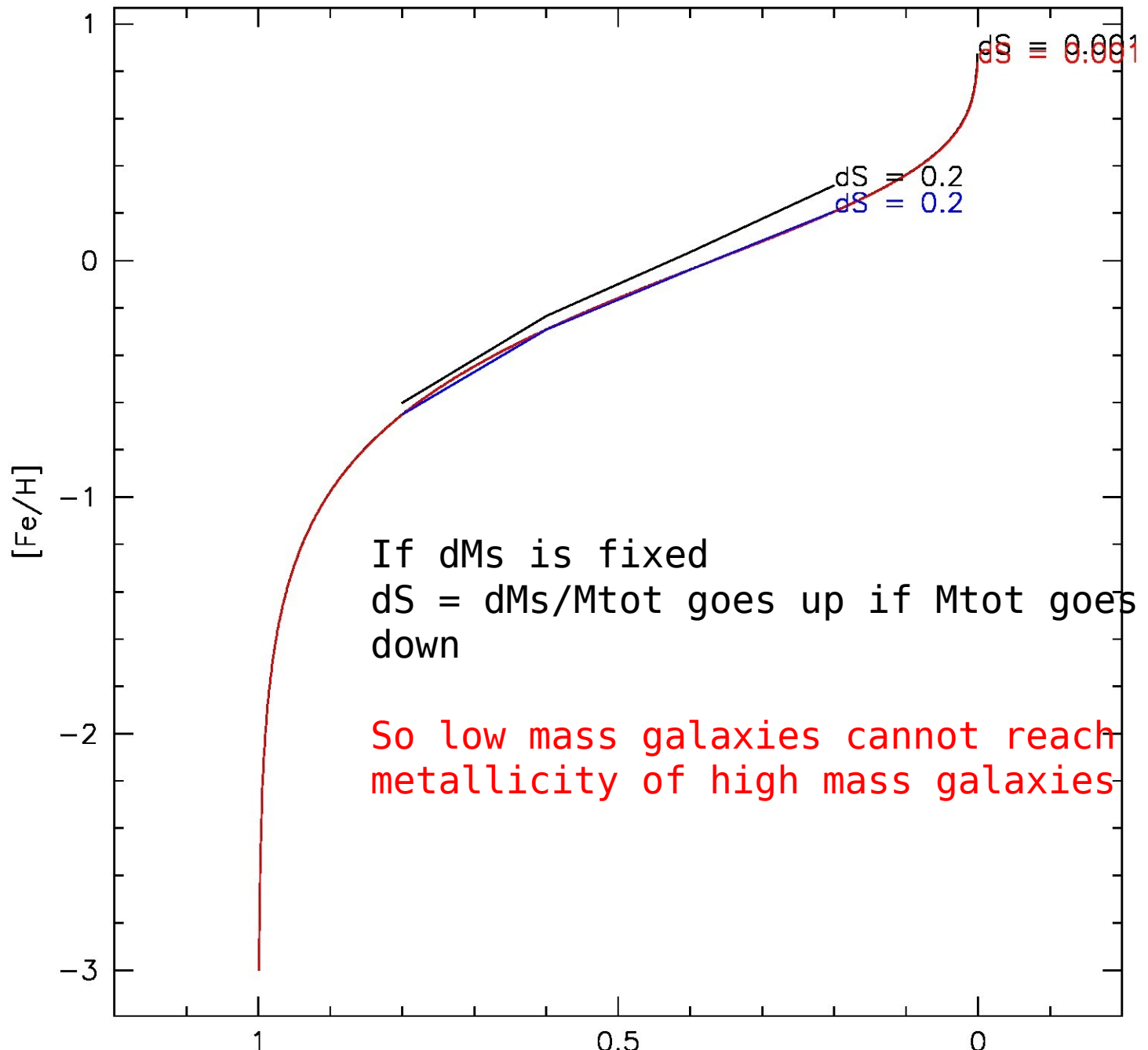Better if gas-rich dwarf galaxy, like

fixed

alpha-elements

p = 0.02

dS = 0.001

dS = 0.001

dG << G

dG ~ G

dS = 0.2

dS = 0.2

p = 0.02

[Fe/H]

dS = 0.001

dS = 0.2
dS = 0.2

If dMs is fixed
dS = dMs/Mtot goes up if Mtot goes
down

So low mass galaxies cannot reach
metallicity of high mass galaxies

Fornax dSph; Pont et al. (2004)
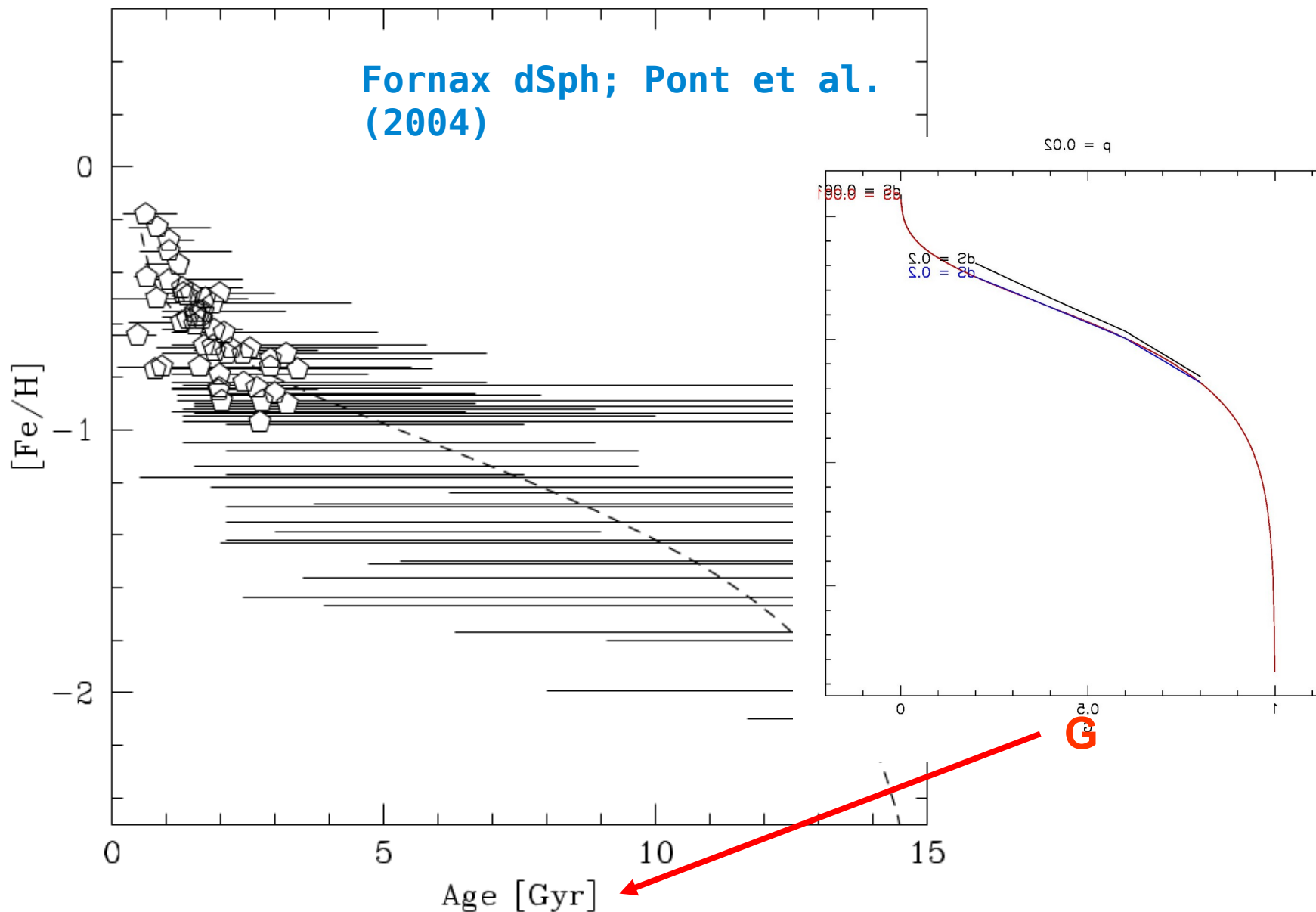
G

Assume G(t)

Age

FIG. 11.—AMR of our sample. Ages derived by comparison with stellar evolution models of Girardi et al. (2000). The horizontal bars are the 95% age confidence intervals for each star. The most likely age is indicated by a